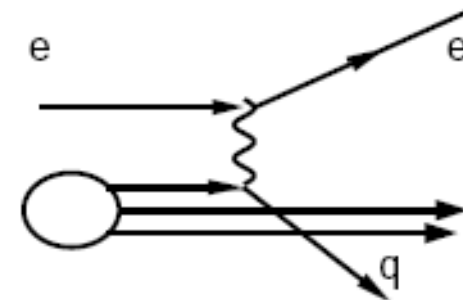
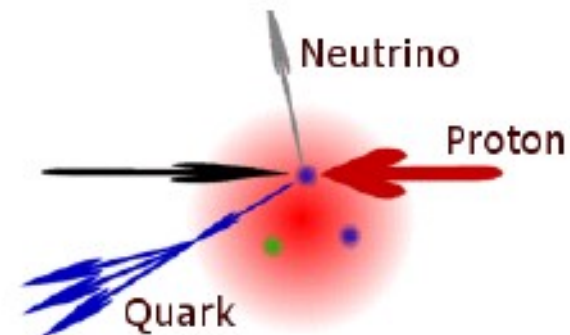
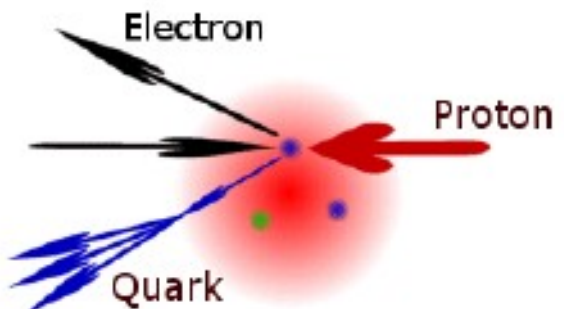


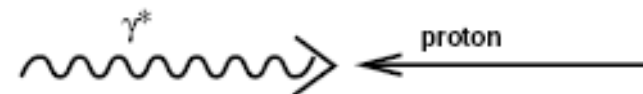
Produkcja hadronów w zderzeniach e-p przy energiach akceleratora HERA

Teresa Tymieniecka, Zakład cząstek,

E-mail: teresa@fuw.edu.pl



Przy energiach 300 GeV w ep CMS

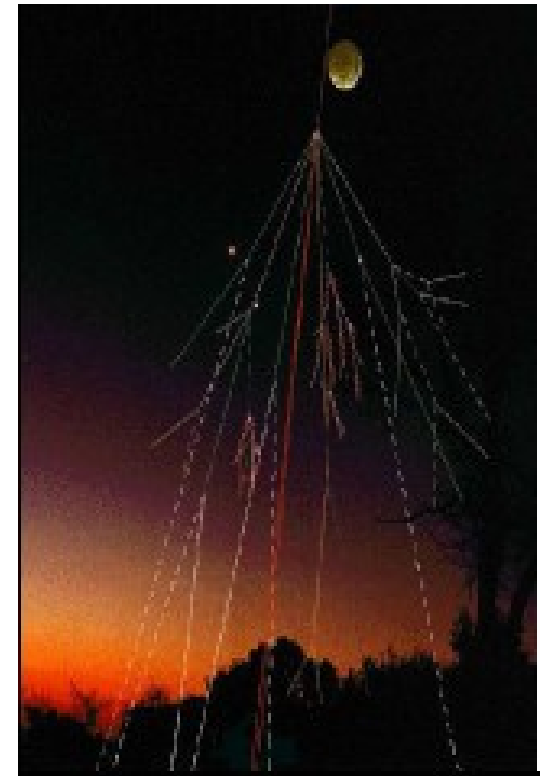


Najważniejsze problemy fizyki cząstek

- Pochodzenie masy (cząstka Higgsa)
- Ciemna materia i ciemna energia
- Łamanie symetrii kombinowanej CP
- Promieni kosmicznych o najwyższych energiach
- Dodatkowe wymiary
- Oscylacje neutrin
- Supersymetria



Fizyka jest czarno-biała



Zagadnienia omawiane

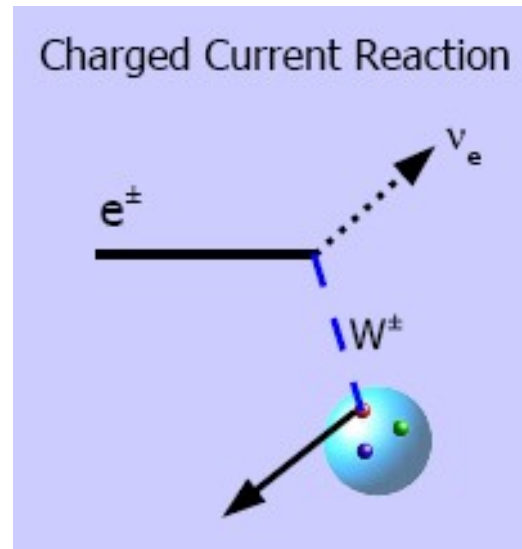
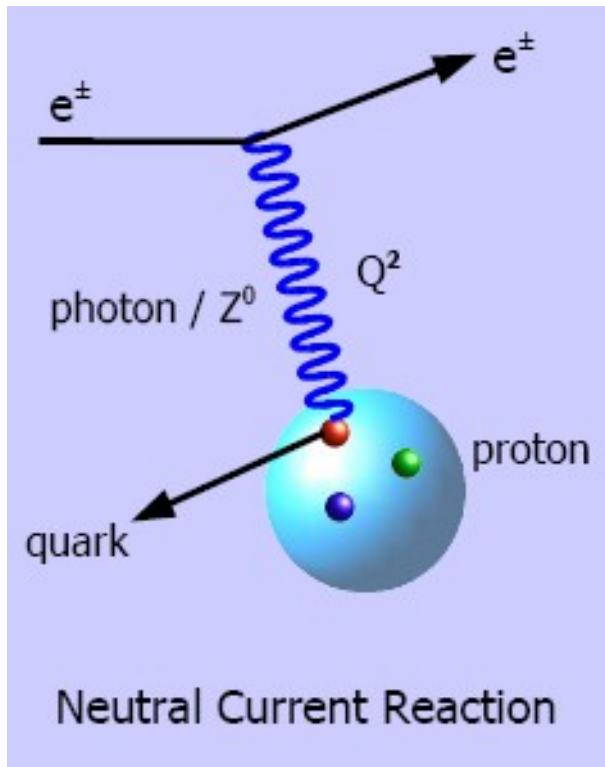
- Akcelerator HERA
- Funkcje struktury nukleonu F_2 , F_3 , F_L
- Przekrój czynny foton-proton
- Biegająca stała sprzężenia α_s

- Funkcje fragmentacji
 różnice między anihilacją e^+e^- i rozpraszaniem ep
- Asymetria azymutalna (*T-odd effect*)
- Produkcja (anty)deuteronu, mezonów gluonowych, pentakwarków
- Oddziaływania wielokrotne

- Przyszłość
 - promienie kosmiczne (chwilowo w eksperymencie ZEUS)
 - zawartość ciężkich kwarków w protonie

Produkcja hadronu h

$$\frac{d\sigma}{du} \sim f_{\gamma/e}() \cdot f_{j/p}() \cdot d\sigma_{\gamma j \rightarrow q,g} \cdot D_{q,g \rightarrow h}(, u)$$

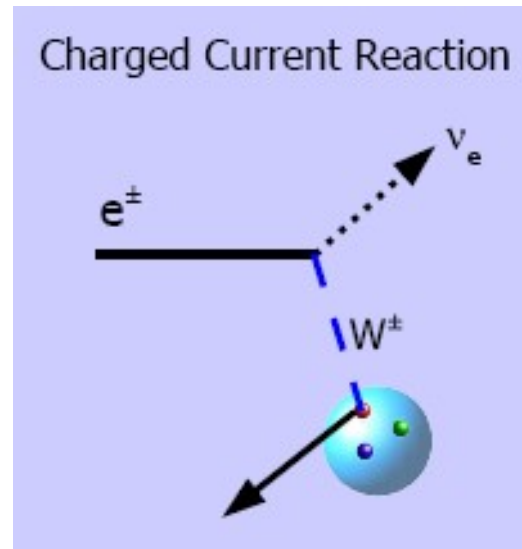
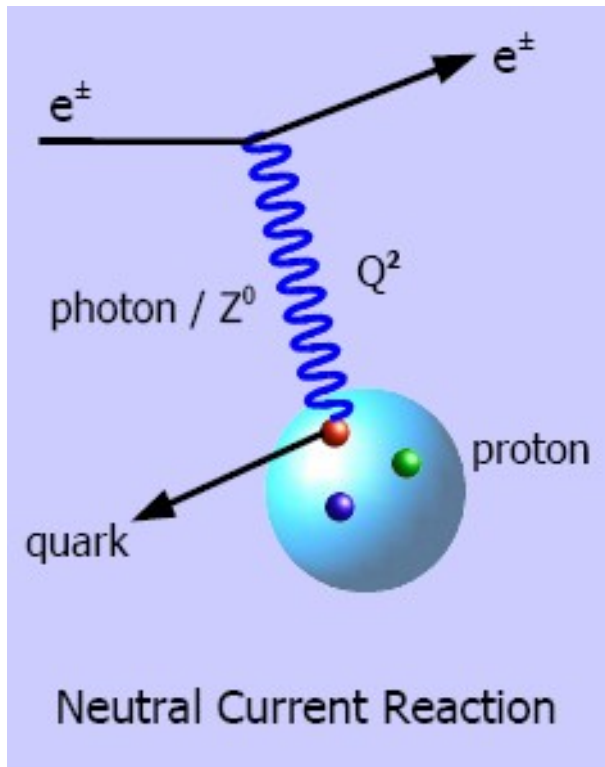


Produkcja hadronu h

$$\frac{d\sigma}{du} \sim f_{\gamma/e}() \cdot f_{j/p}() \cdot d\sigma_{\gamma j \rightarrow q,g} \cdot D_{q,g \rightarrow h}(, u)$$

Wyemitowanie γ

Znalezienie partonu j w protonie

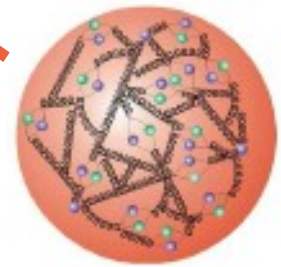
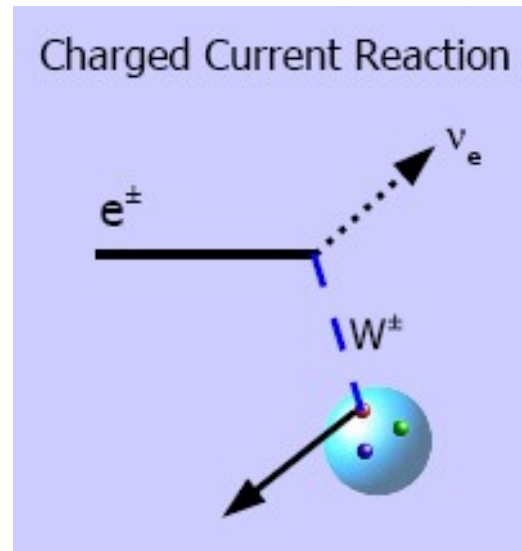
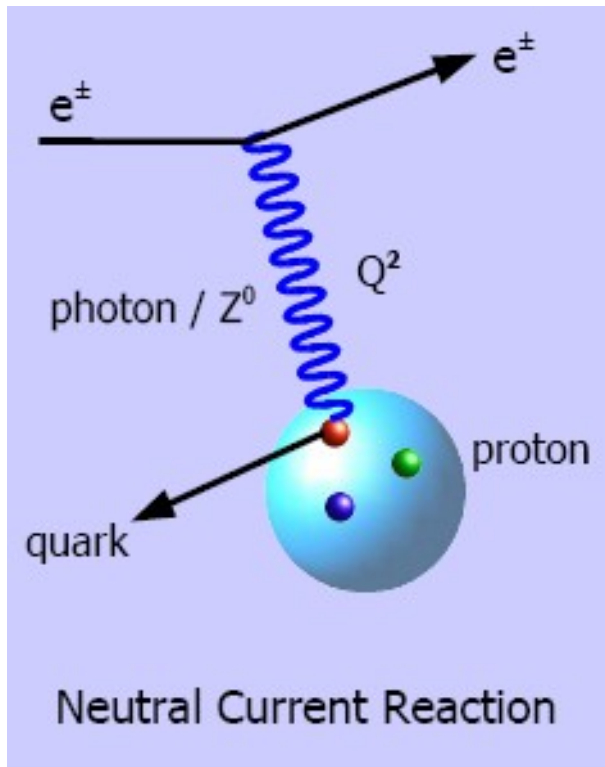


Produkcja hadronu h

$$\frac{d\sigma}{du} \sim f_{\gamma/e}() \cdot f_{j/p}() \cdot d\sigma_{\gamma j \rightarrow q,g} \cdot D_{q,g \rightarrow h}(, u)$$

Wyemitowanie γ

Znalezienie partonu j w protonie



H.Fritzsch, Kwarki walencyjne jako kwasi cząstki
Eur.Phys.J.C44(2005)59

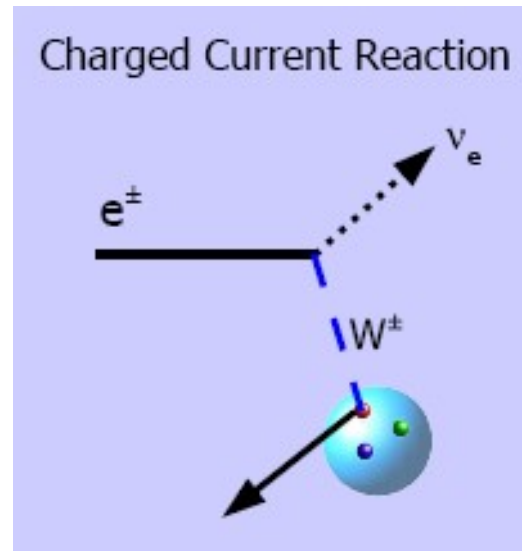
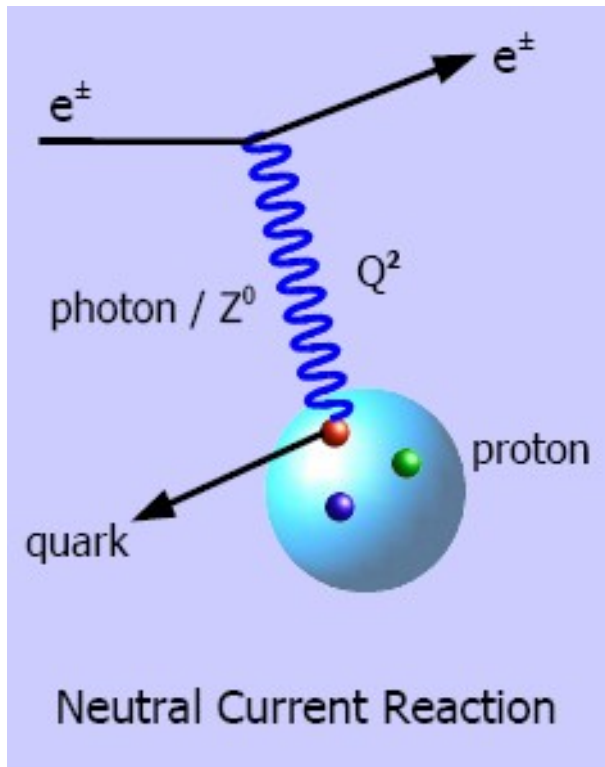
Produkcja hadronu h

$$\frac{d\sigma}{du} \sim f_{\gamma/e}() \cdot f_{j/p}() \cdot d\sigma_{\gamma j \rightarrow q,g} \cdot D_{q,g \rightarrow h}(, u)$$

Wyemitowanie γ

Znalezienie partonu j w protonie

Partonowe przekroje czynne (z teorii QCD)



Produkcja hadronu h

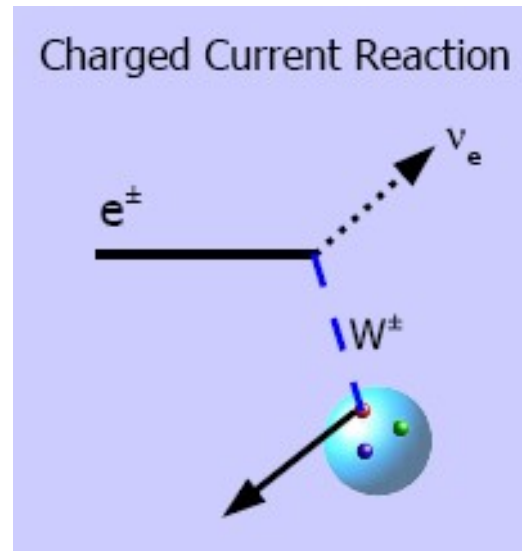
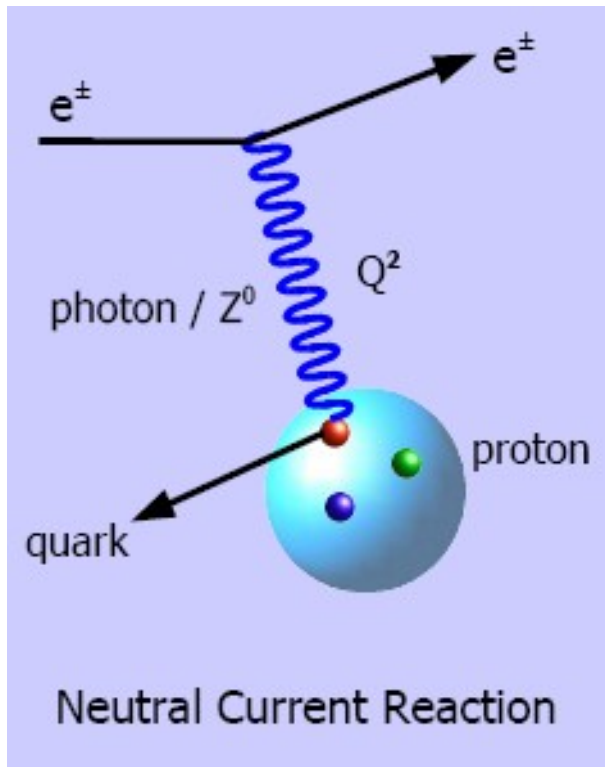
$$\frac{d\sigma}{du} \sim f_{\gamma/e}() \cdot f_{j/p}() \cdot d\sigma_{\gamma j \rightarrow q,g} \cdot D_{q,g \rightarrow h}(, u)$$

Wyemitowanie γ

Znalezienie partonu j w protonie

Partonowe przekroje czynne (z teorii QCD)

Funkcje fragmentacji $q,g \rightarrow h$

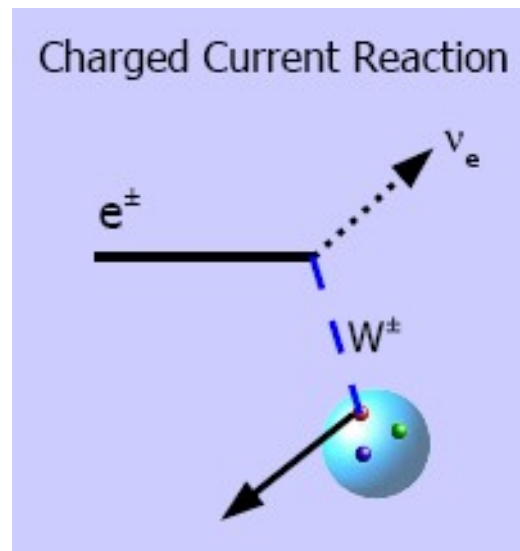
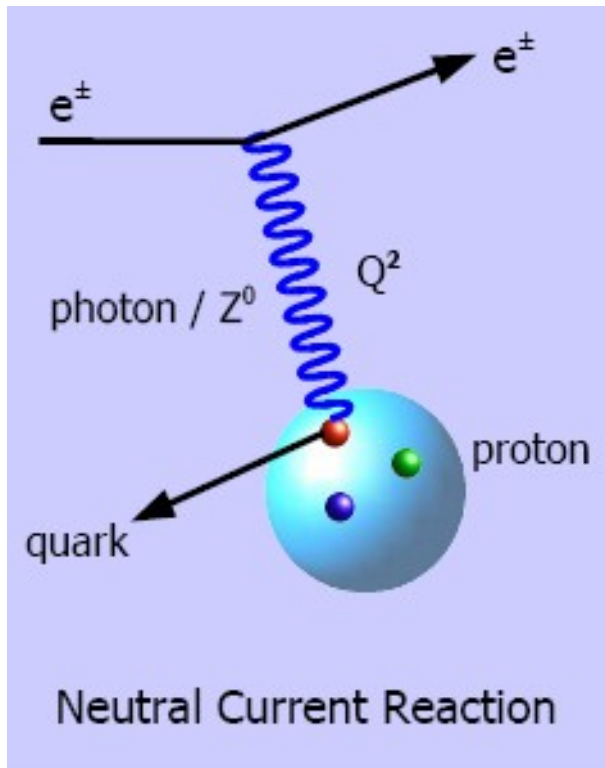


$f_{j/p}()$, $D_{q,g \rightarrow h}$ uniwersalne dla e^+e^- , $e p$, $p p$, πp

Produkcja hadronów h

$$\frac{d\sigma}{du} \sim f_{\gamma(Z^0)/e}() \cdot f_{i/\gamma}() \cdot f_{j/p}() \cdot d\sigma_{ij \rightarrow q,g} \cdot D_{q,g \rightarrow h}(, u)$$

Strukturę fotonu



Z teorii

QED $f_{\gamma(Z^0)/e}()$

QCD $d\sigma_{ij \rightarrow q,g}$

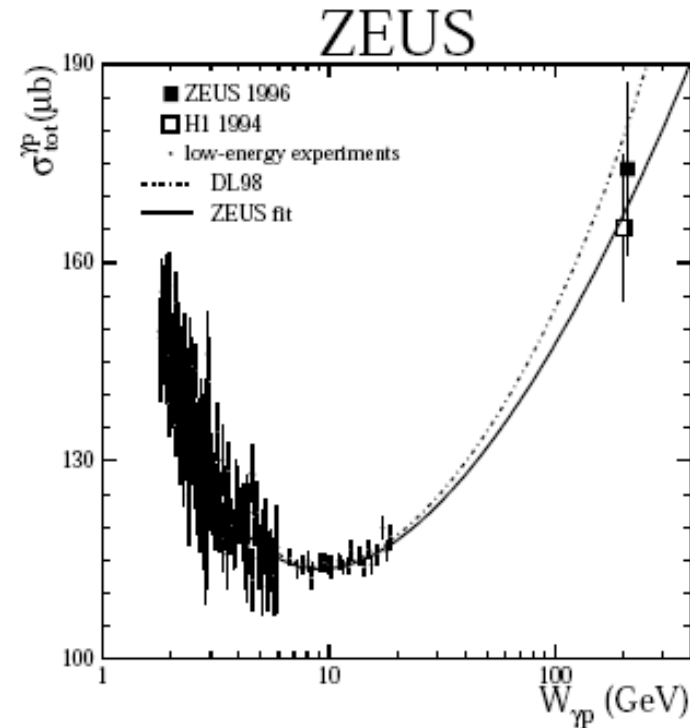
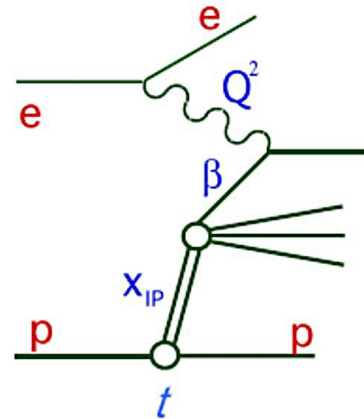


Z doświadczenia:
f.struktury i f.fragmentacji

Najważniejsze działy fizyki ep

- **Fotoprodukcja**

- **Dyfrakcja**

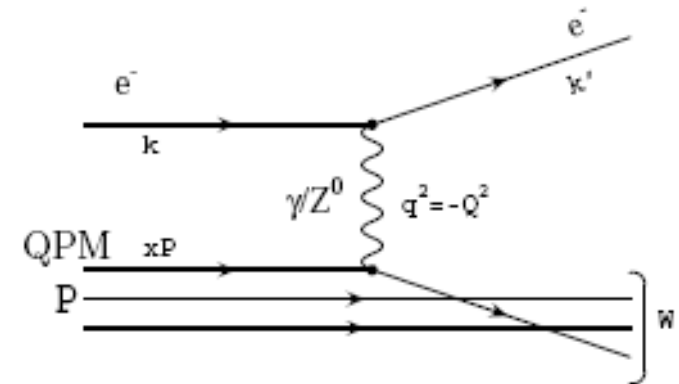


- **Głęboko nieelastyczne rozpraszanie**

$$\frac{d^2\sigma(e^\pm p)}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4} \left[Y_+ F_2^{L,R}(x, Q^2) - y^2 F_L^{L,R}(x, Q^2) \pm Y_- x F_3^{L,R}(x, Q^2) \right]$$



F_2, F_L, F_3

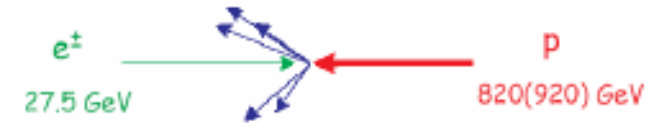


Akcelerator HERA w DESY w Hamburgu

(Narzędzie)



HERA - the world's only ep collider



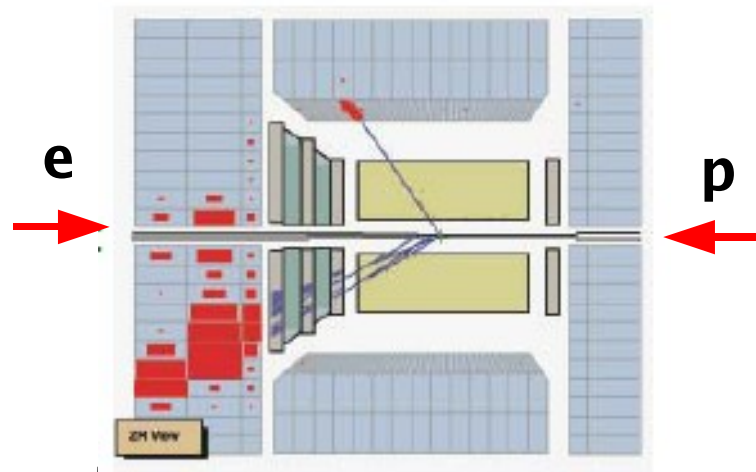
equivalent to 50 TeV fixed target

Brak polaryzacji wiązki e

1992 – 1995	$e^-(e^+)$	$E_p=820$ GeV	$\int L \approx 13$ pb ⁻¹
1996 – 1997	e^+		$\int L \approx 45$ pb ⁻¹
1998 – 2000	$e^-(e^+)$	$E_p=920$ GeV	$\int L \approx 95$ pb ⁻¹

Polaryzacji podłużna wiązki e

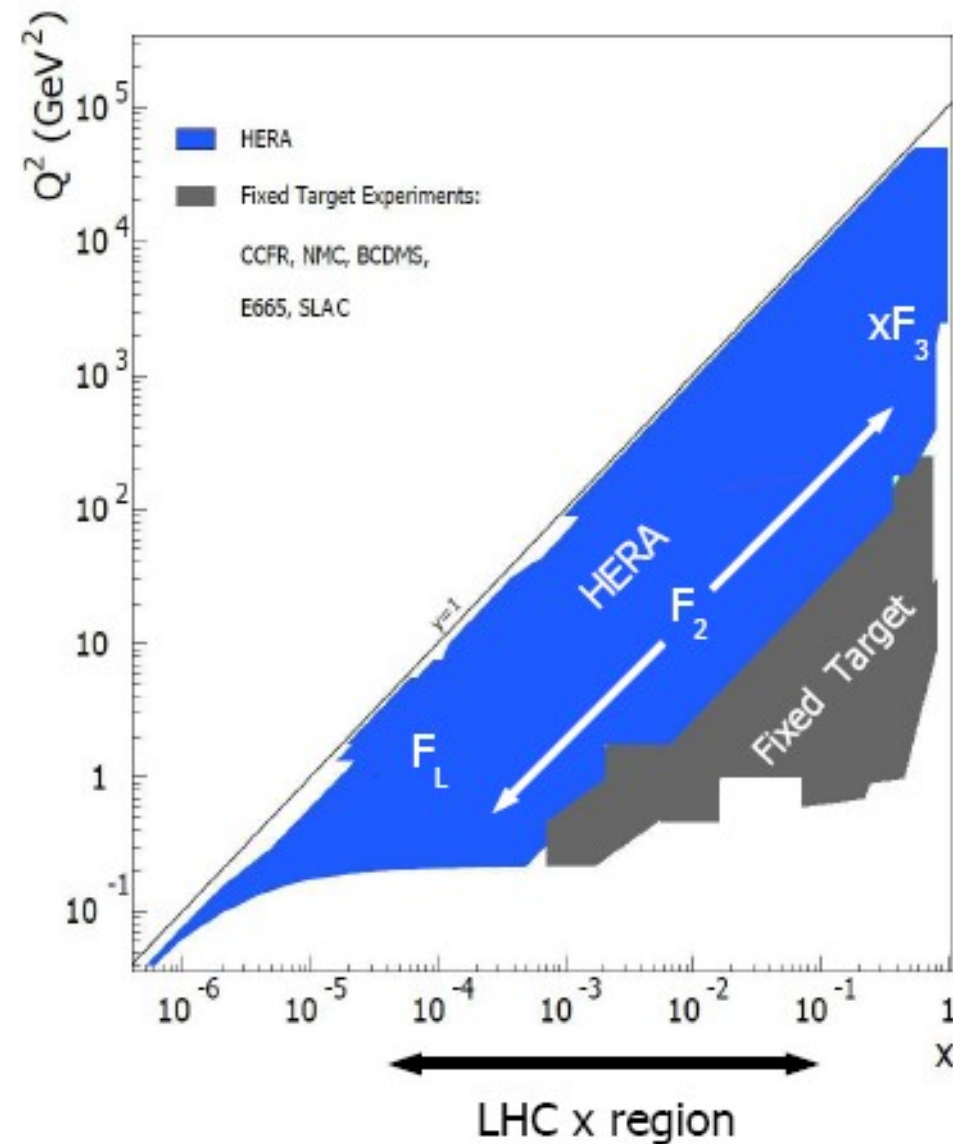
2003 – 2007	$e^-(e^+)$	$E_p=920$ GeV	$\int L \approx 406$ pb ⁻¹
2007	e^+	$E_p=550$ GeV	$\int L \approx 13$ pb ⁻¹
2007	e^+	$E_p=675$ GeV	$\int L \approx 8$ pb ⁻¹



W latach 1995 – 2000 w detektorze ZEUS
brak detektora wierzchołka

Struktura protonu

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



$$\tilde{F}_2 \propto \sum (xq_i + x\bar{q}_i)$$

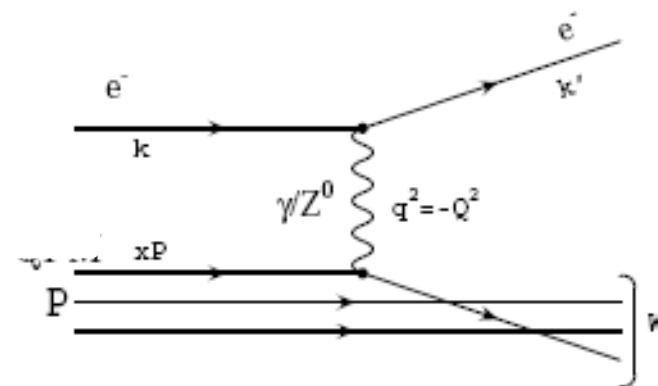
$$x\tilde{F}_3 \propto \sum (xq_i - x\bar{q}_i)$$

$$\tilde{F}_L \propto \alpha_s \cdot xg(x, Q^2)$$

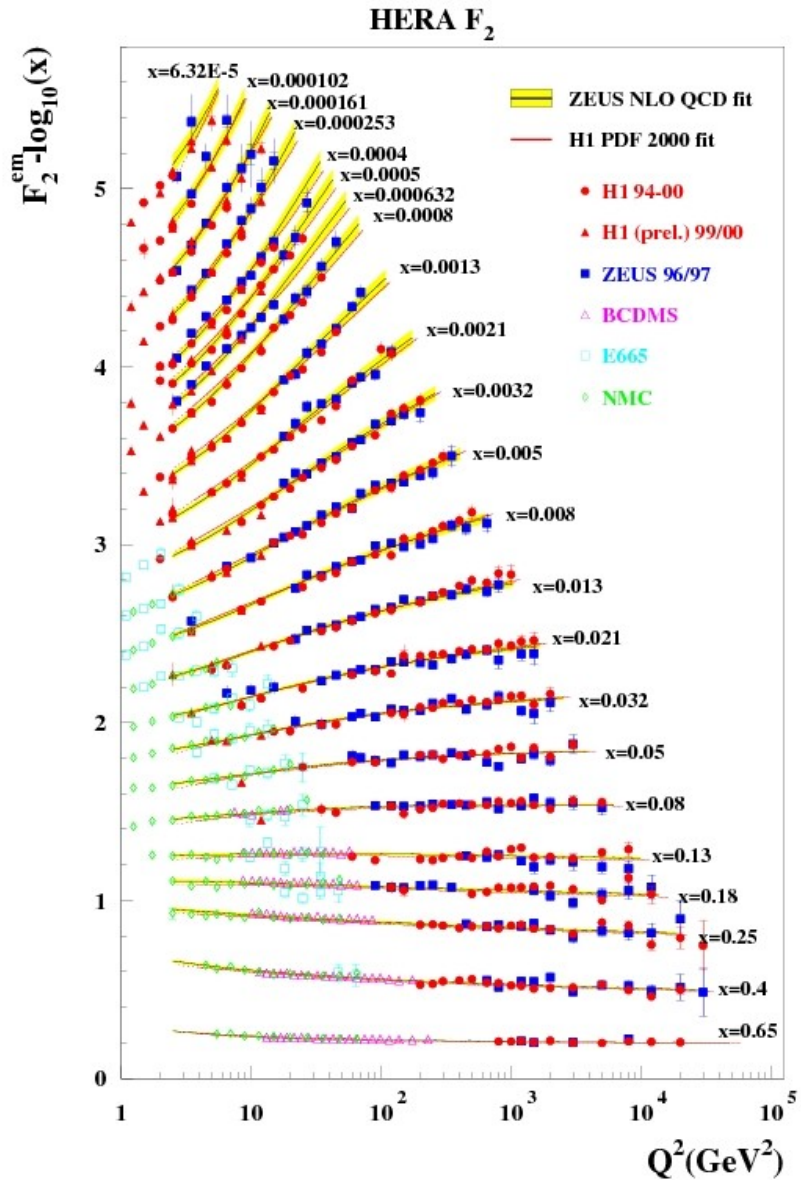
Główny wkład

gdy $Q^2 \sim M_Z$

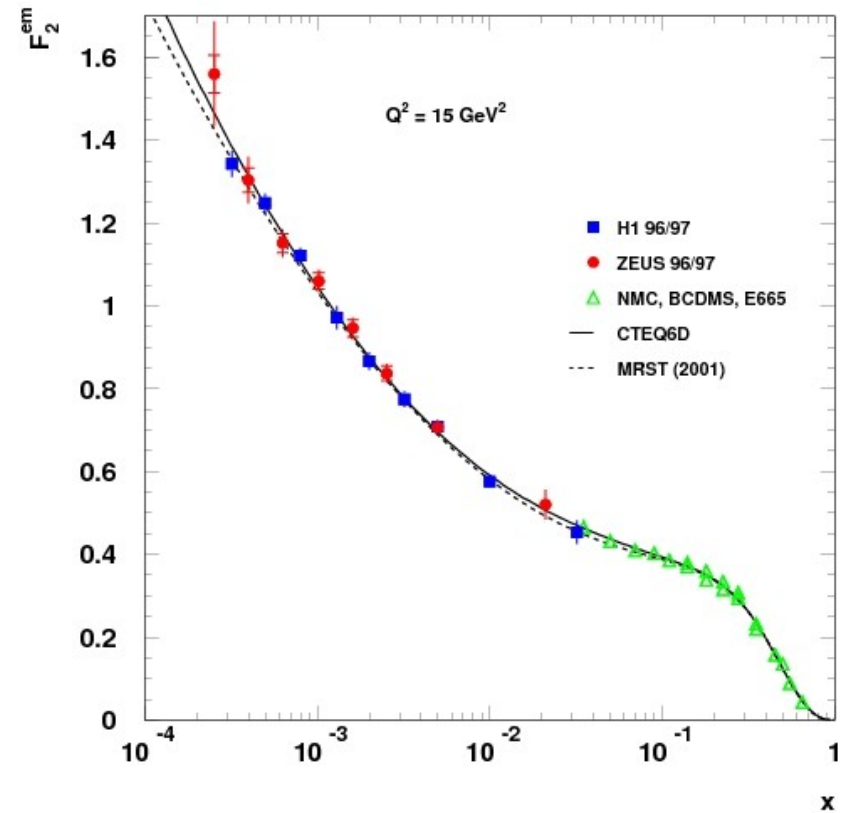
dla dużych y
czyli W



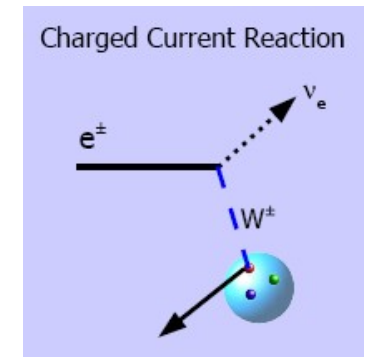
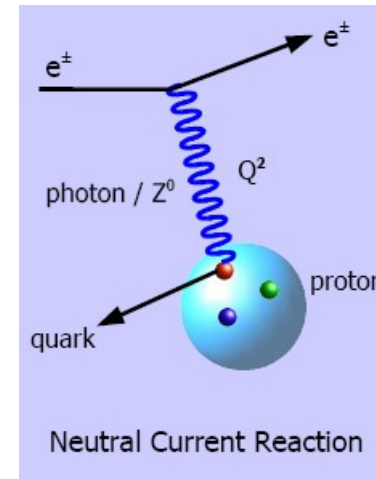
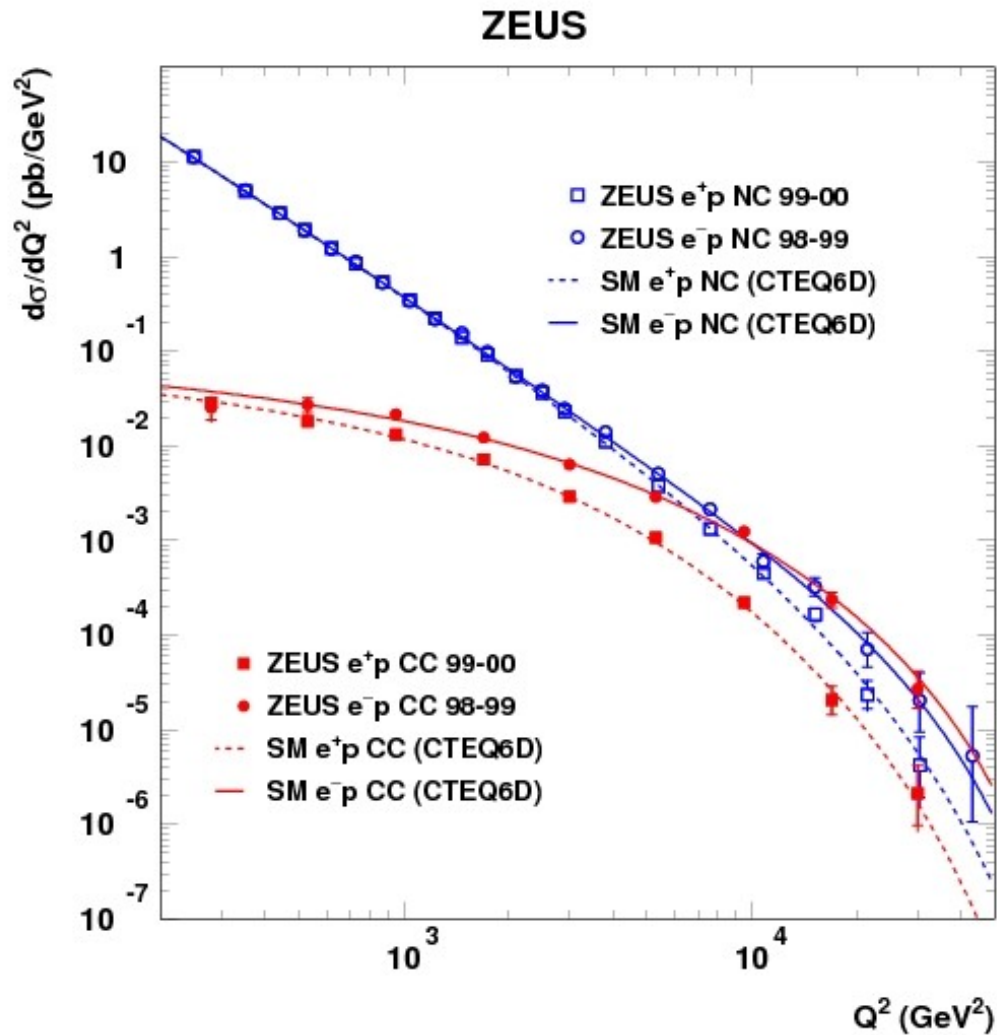
Struktura protonu $F_2(Q^2, x)$



$$\tilde{F}_2 \propto \sum (xq_i + x\bar{q}_i)$$

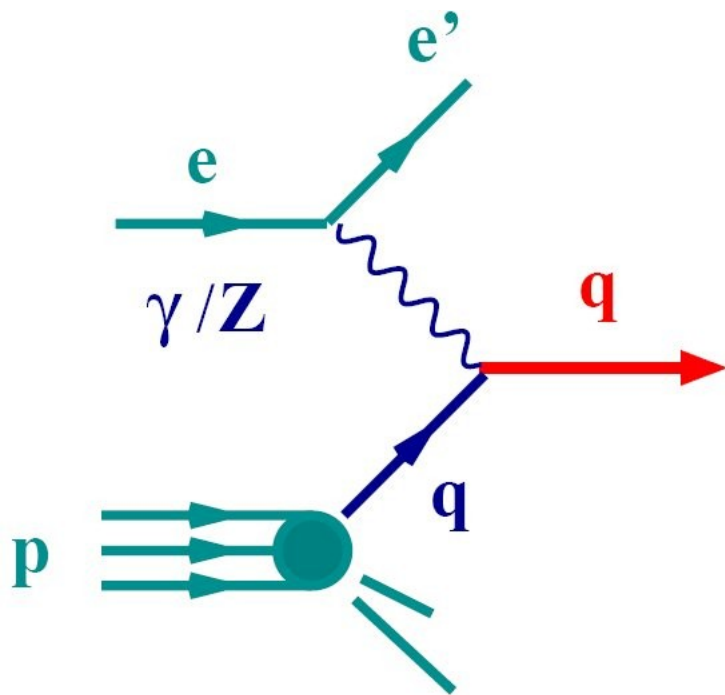


Struktura protonu F_3

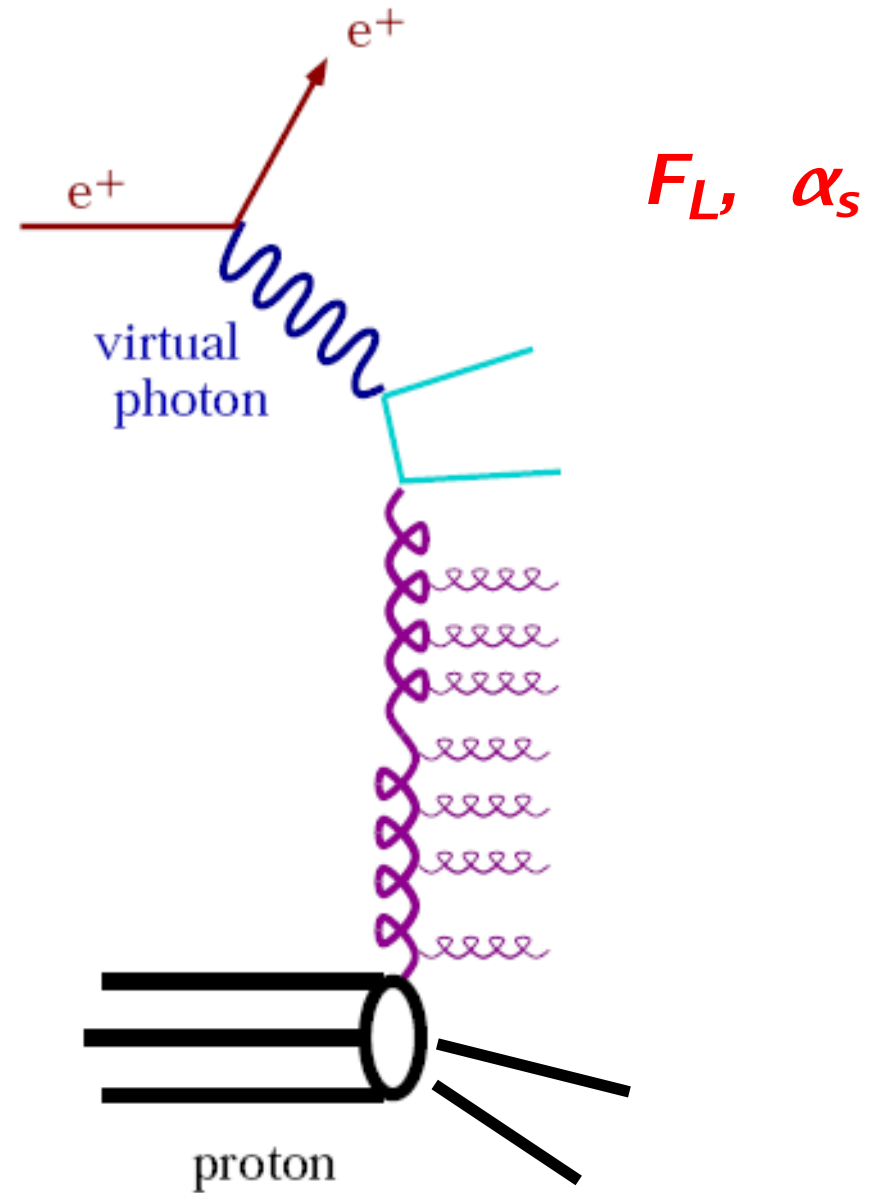


$$xF_3^{\tilde{}} \propto \sum (xq_i - x\bar{q}_i)$$

Produkcja inkluzywana hadronów

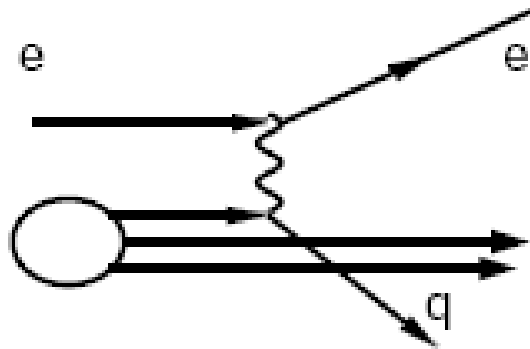


F_2, F_3

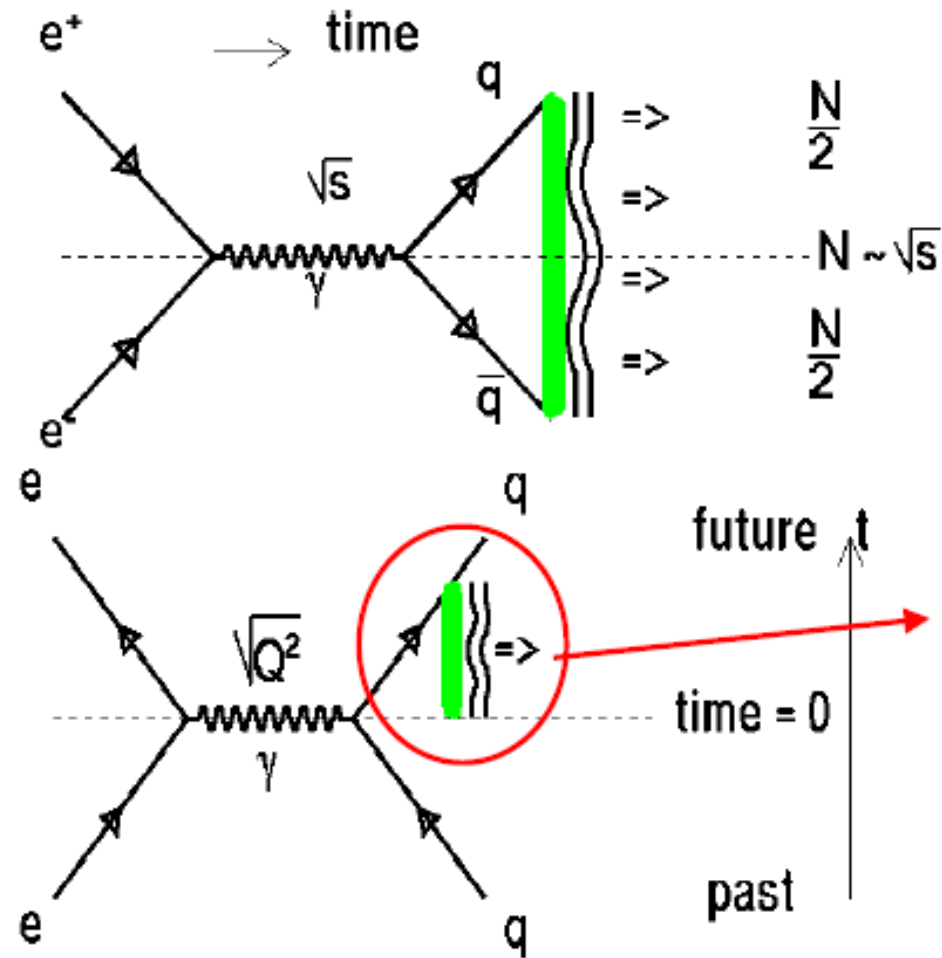


Porównanie ep i e⁺e⁻

ep

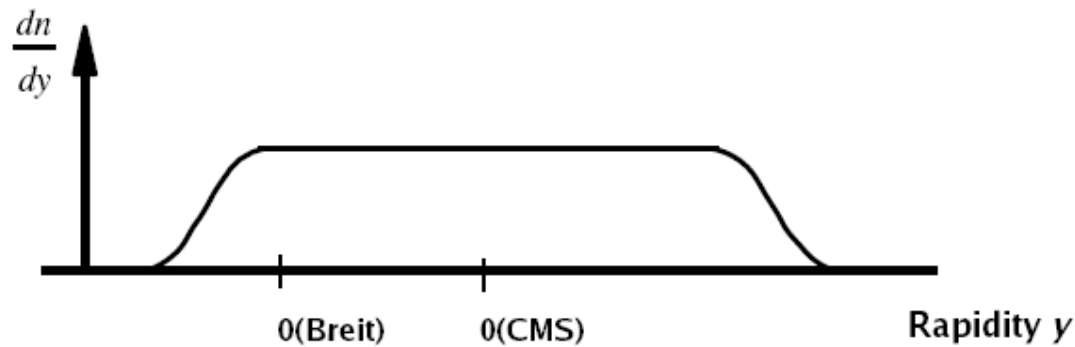
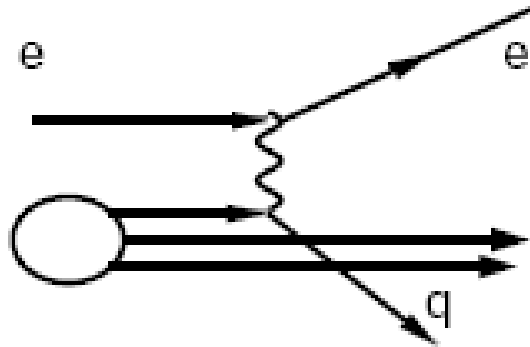


e⁺e⁻

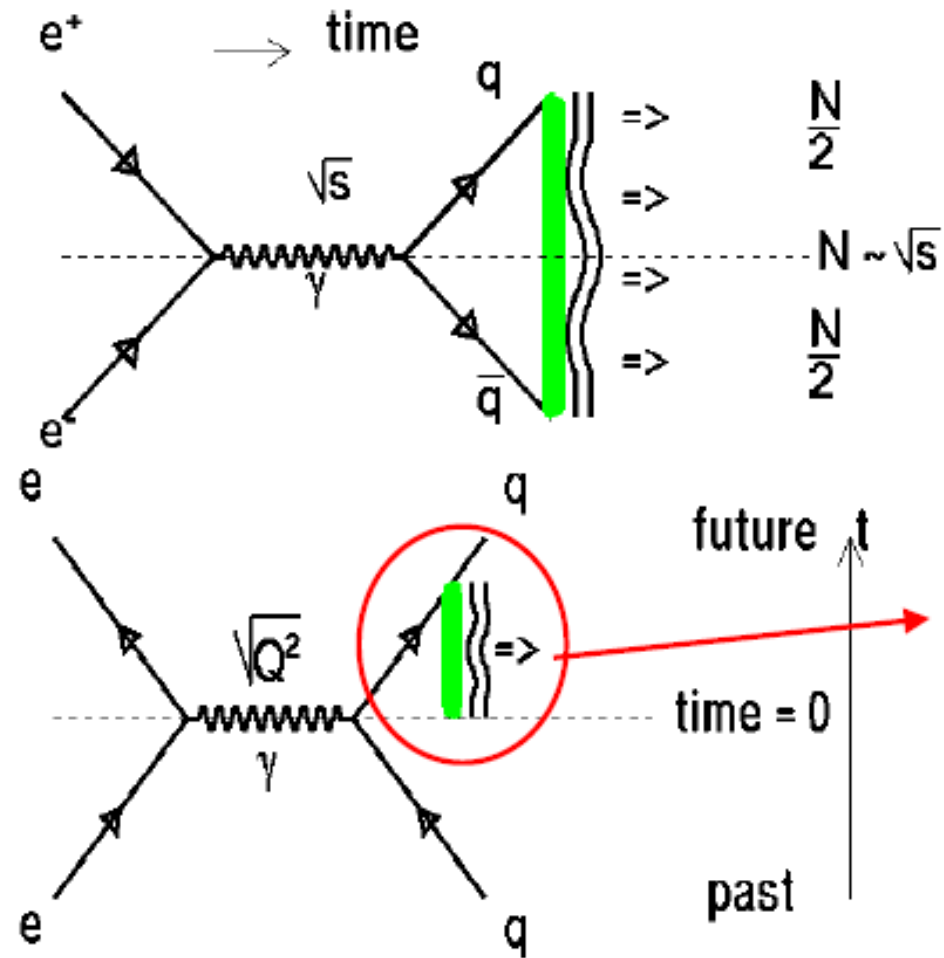


Porównanie ep i e⁺e⁻

ep

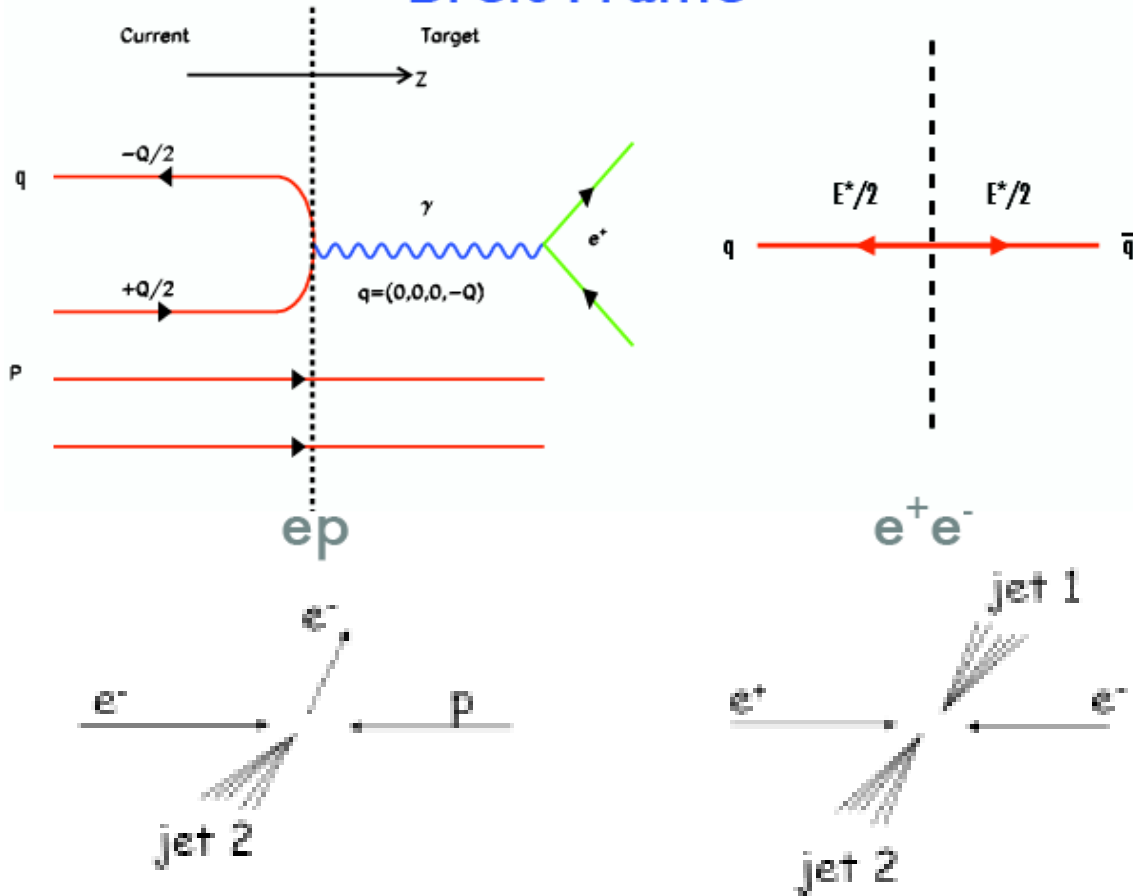


e⁺e⁻

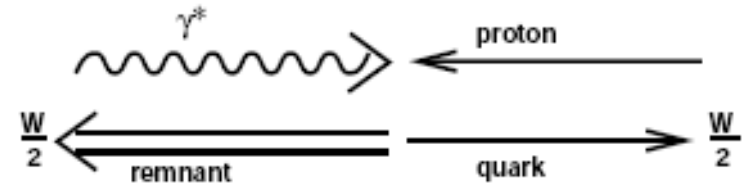


Reference frames

Breit Frame

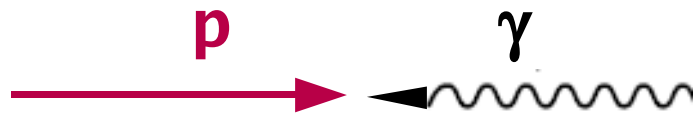


Hadronic Centre of Mass or CMS γp



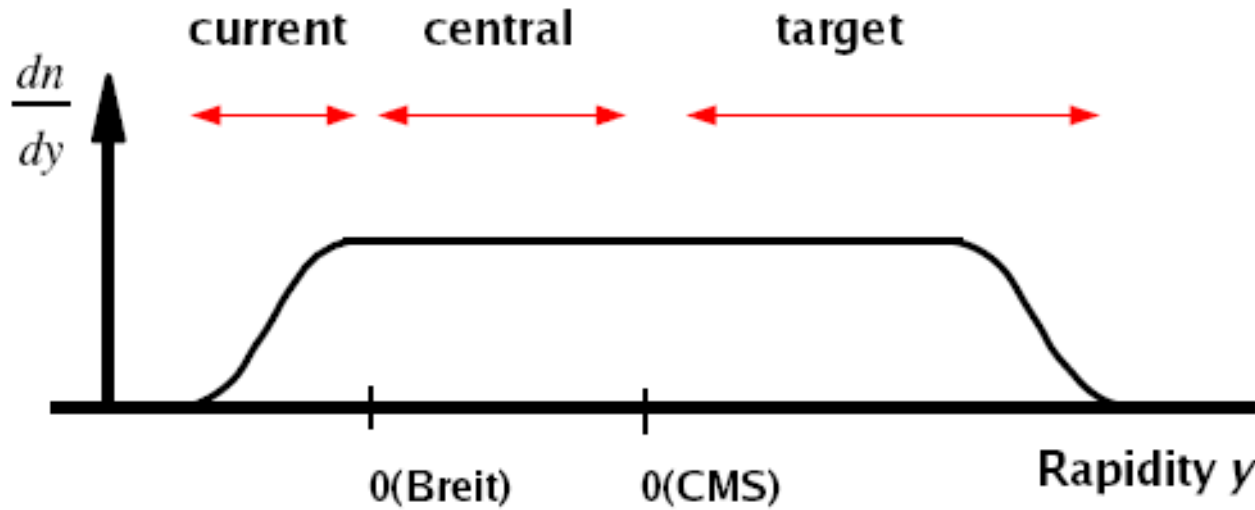
Photon virtuality, Q , is related to momentum of scattered quark.

Knowledge of particle rapidity is important for understanding of underlying processes and for comparison with e^+e^- or pp .

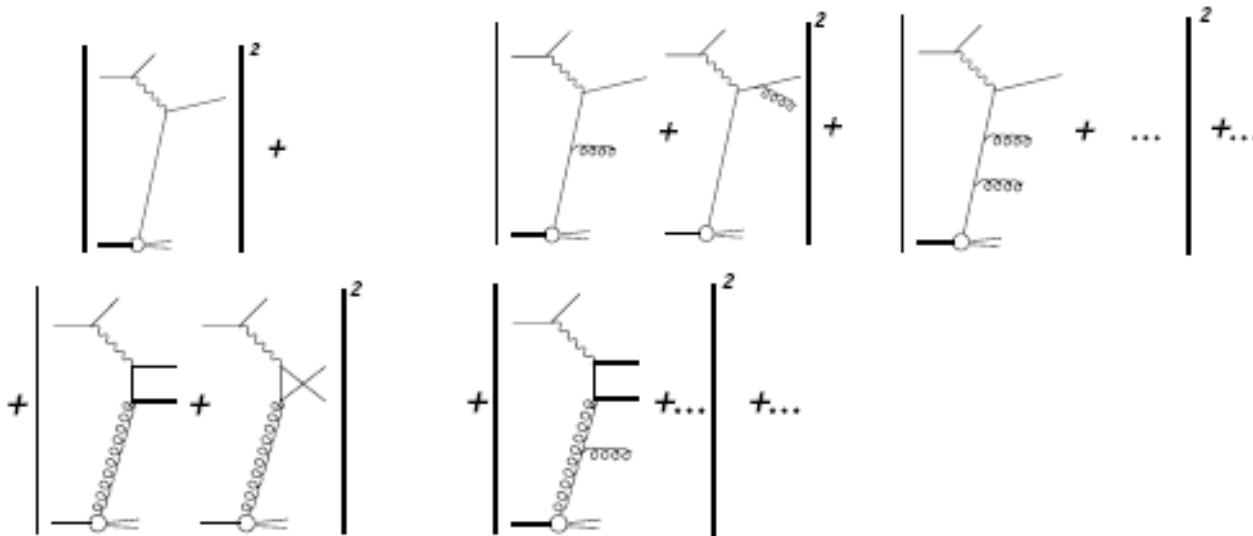


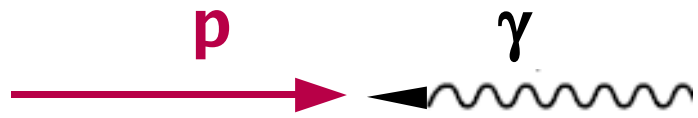
W zależności od *rapidity* (pospieszności, chyżości, ..itd) cechy wyprodukowanych hadronów są różne.

Similar to e^+e^-



$$y = \frac{1}{2} \ln \left(\frac{E + p_L}{E - p_L} \right)$$

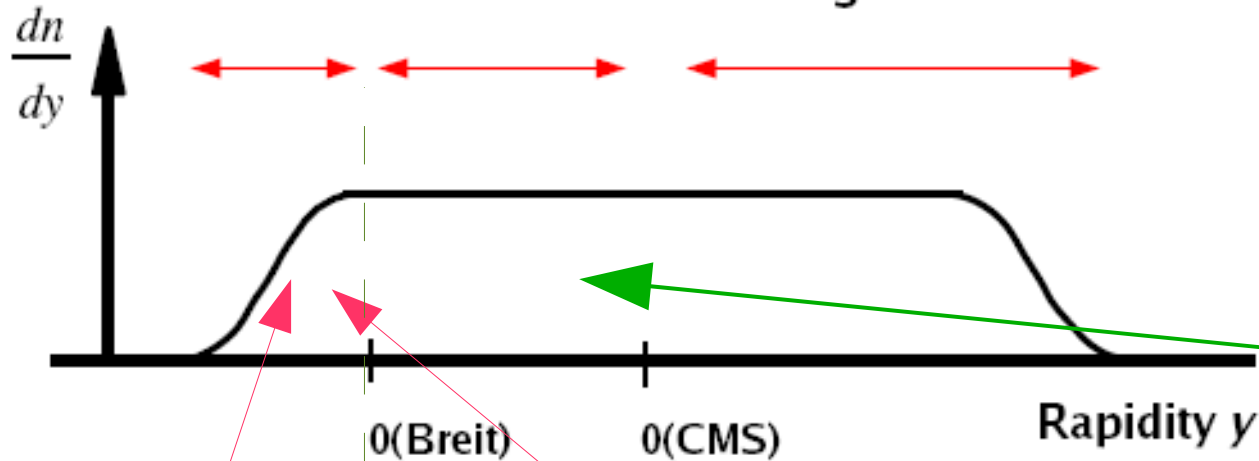




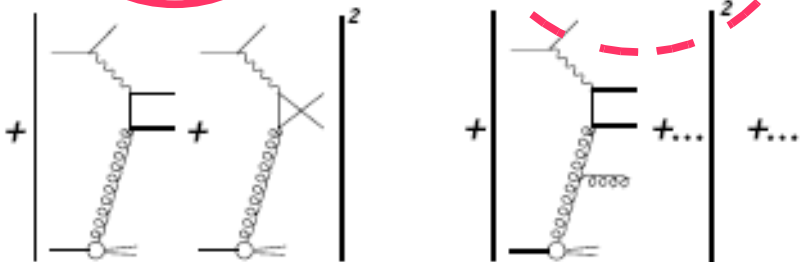
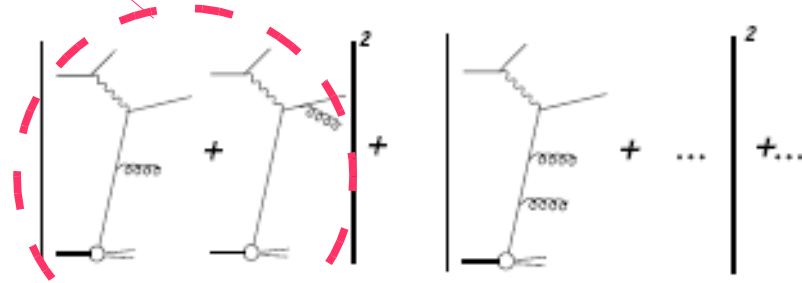
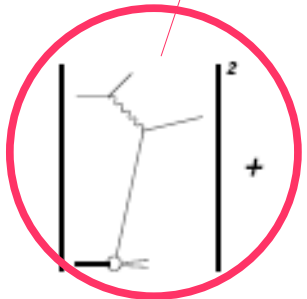
Rapidity określa cechy wyprodukowanych hadronów

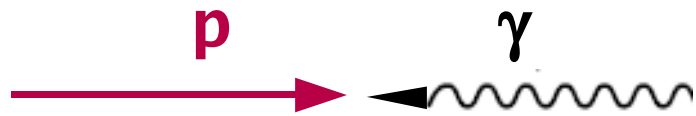
Similar to e^+e^-

$p p$



glueballs, pentaquaks



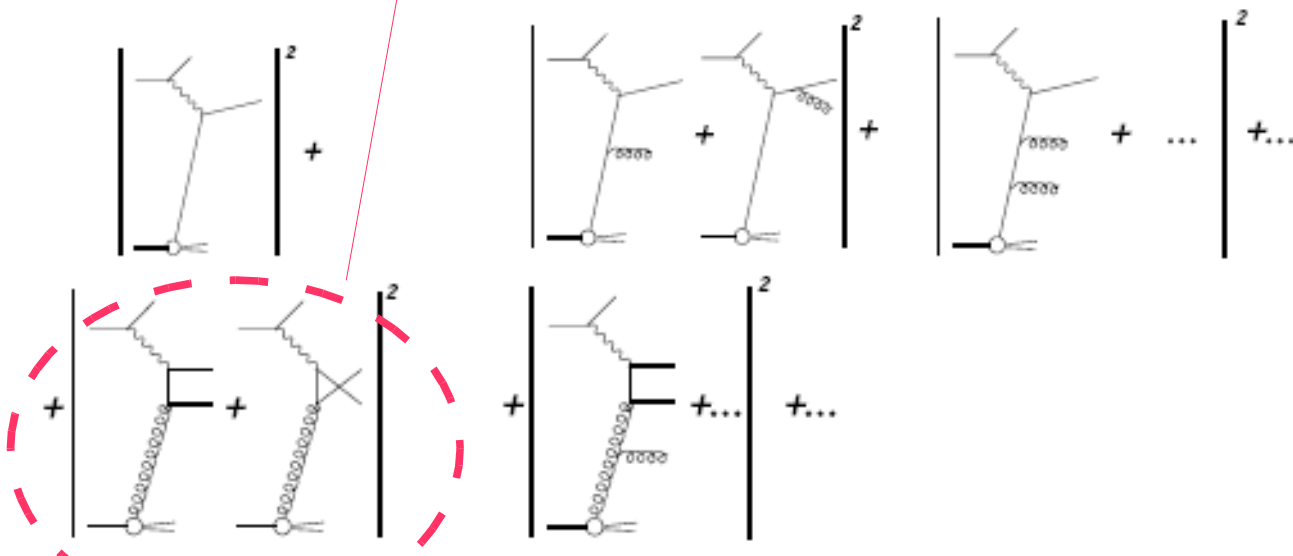
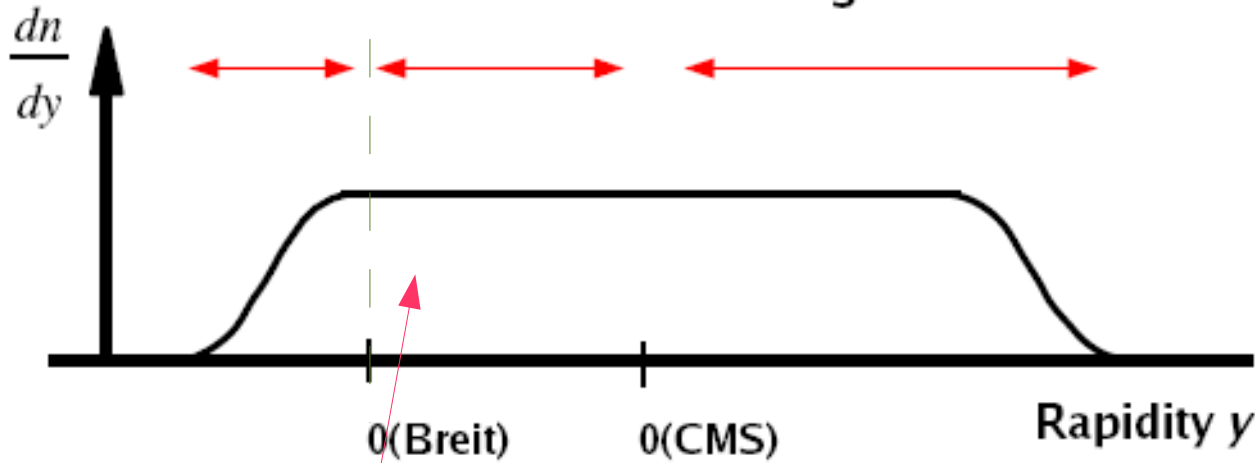


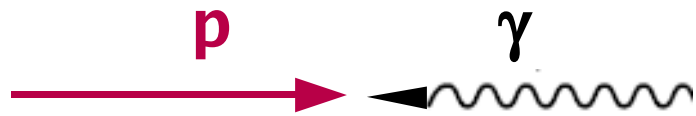
Rapidity określa cechy wyprodukowanych hadronów

Similar to e^+e^-

$p p$

current central target

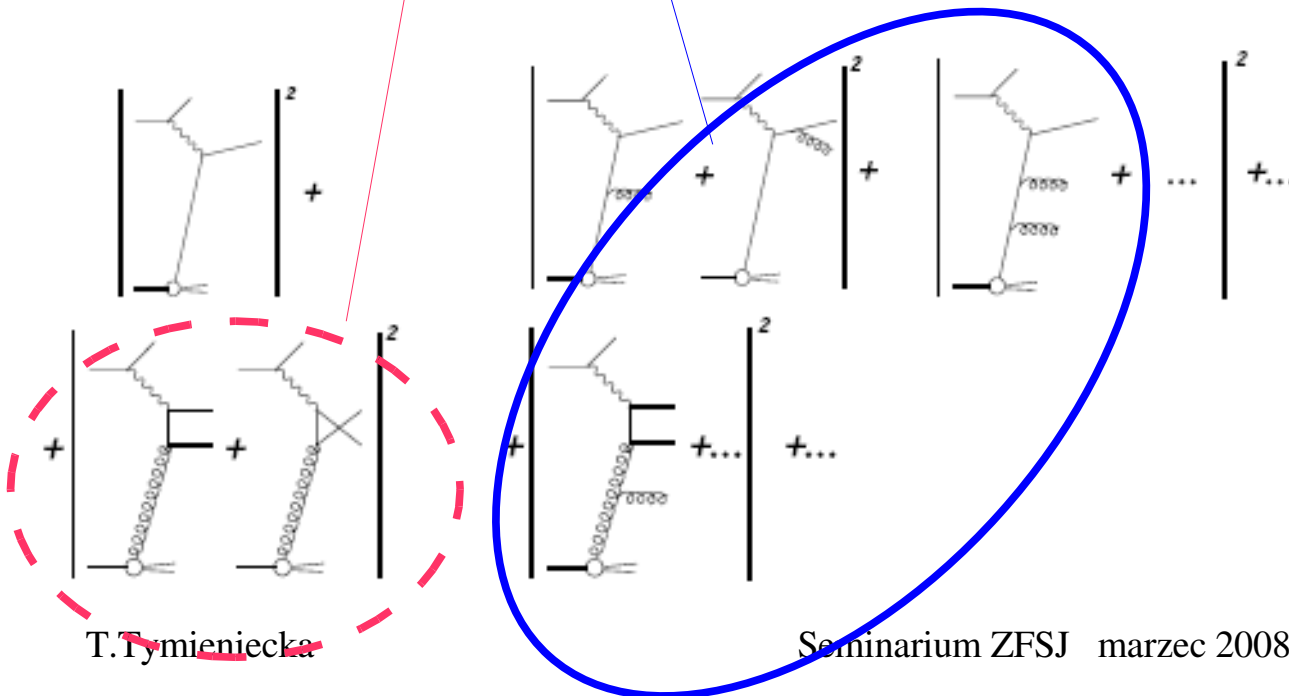
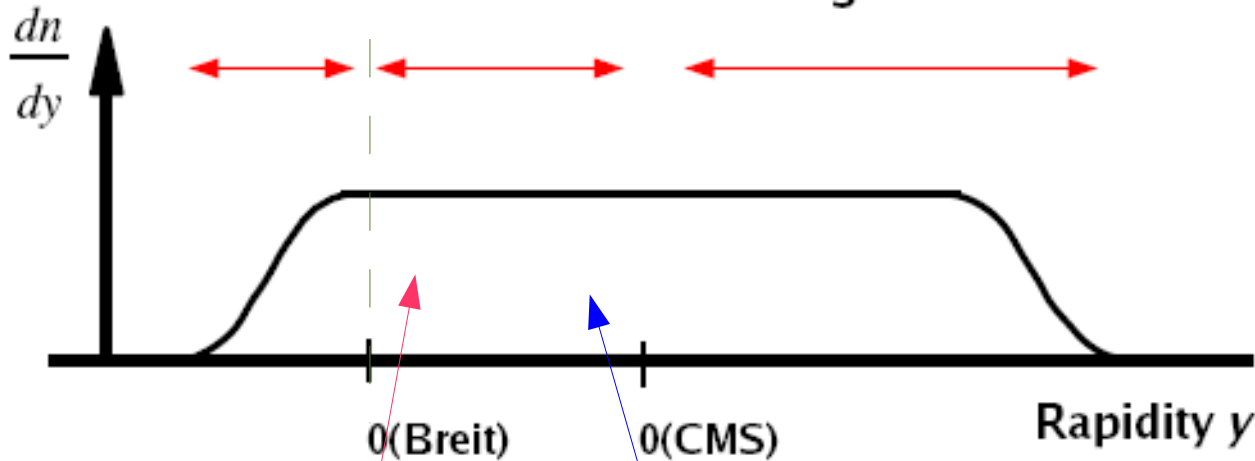




Rapidity określa cechy wyprodukowanych hadronów

Similar to e^+e^-

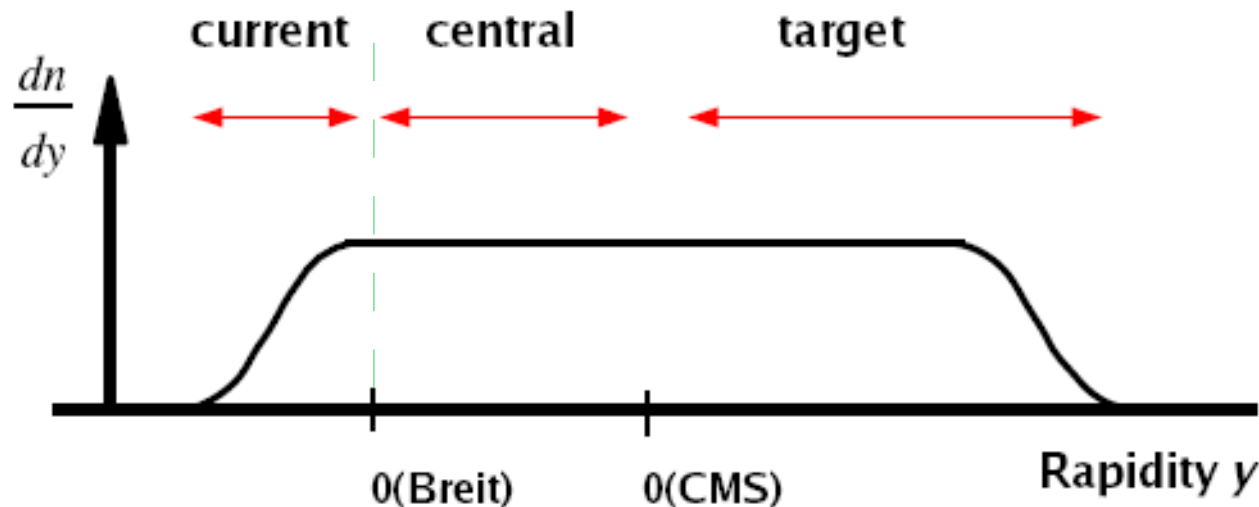
current central target





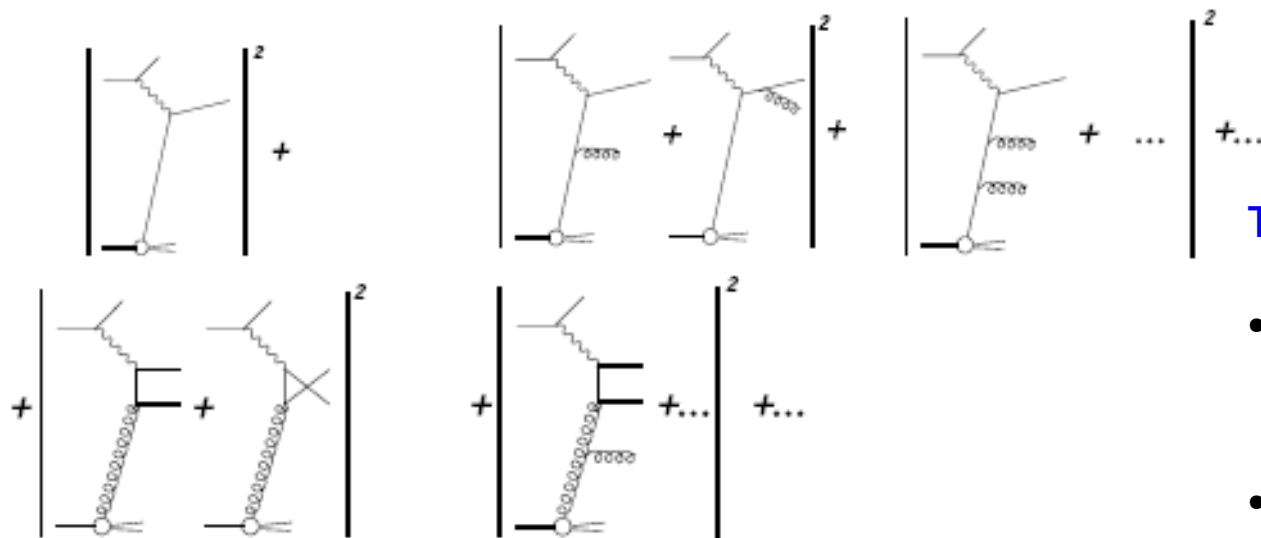
Rapidity określa cechy wyprodukowanych hadronów

Similar to e^+e^-



Cel badań:

- funkcje fragmentacji (scaled momenta)
- asymetrii azymutalnej (*T-odd effect*)
- produkcja hadronów (rozmiar źródła)



Two similar analyses on fragmentation:

- H1 Collaboration, DESY 07-065, Phys.Lett. (luminosity 44 pb^{-1})
- ZEUS Collaboration, (Preliminary) (luminosity 0.5 fb^{-1})

Fragmentation functions $D(z, Q^2)$

Hadron spectra in ep hard scattering

$$f(x, Q^2) \otimes \sigma(Q^2) \otimes D(z, Q^2)$$

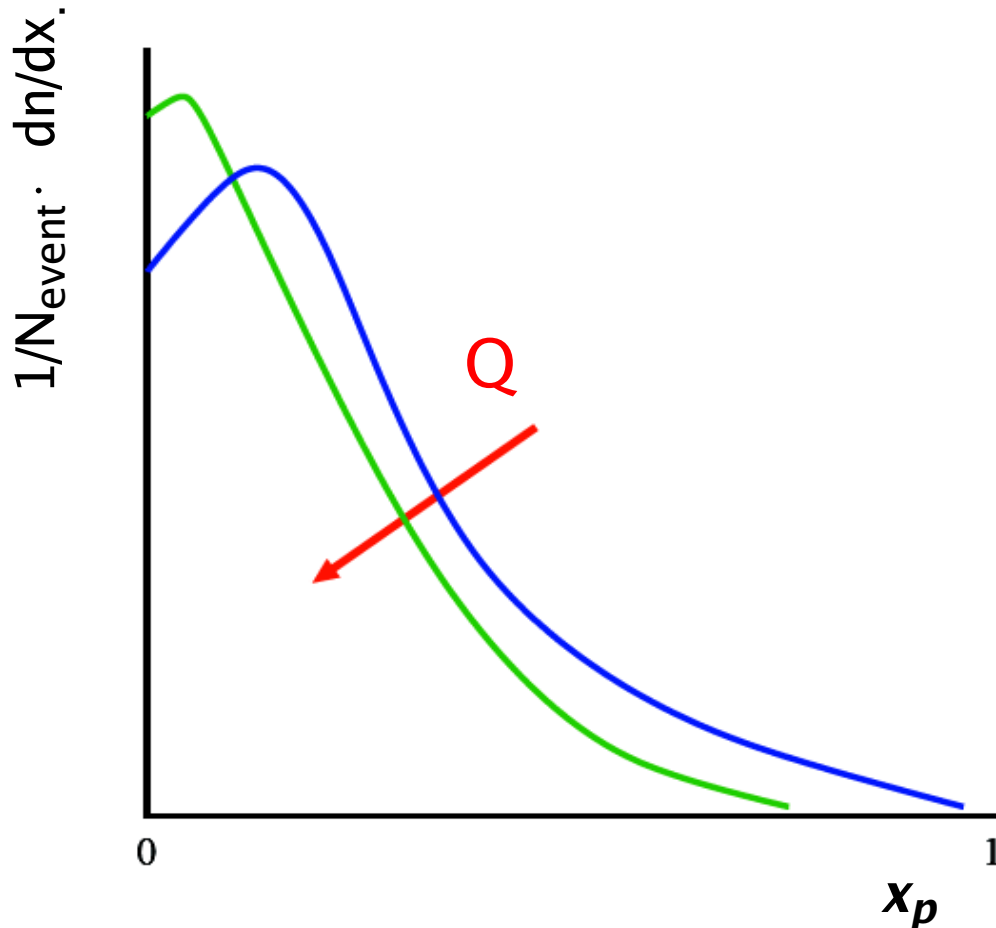
Parton density \nearrow \nwarrow parton cross section (NLO,..) \nwarrow probability for a parton to fragment into a hadron carrying a given fraction z of the parton energy

- Evolution of FF given by DGLAP
- FF are universal (from factorisation theorem)
- Scaling violation in the Q^2 evolution permits to determine α_s

Scaled momentum

$$x_p = \frac{(2 P_h)}{Q} = \frac{P_h}{E_{beam}}$$

For ep and e^+e^-

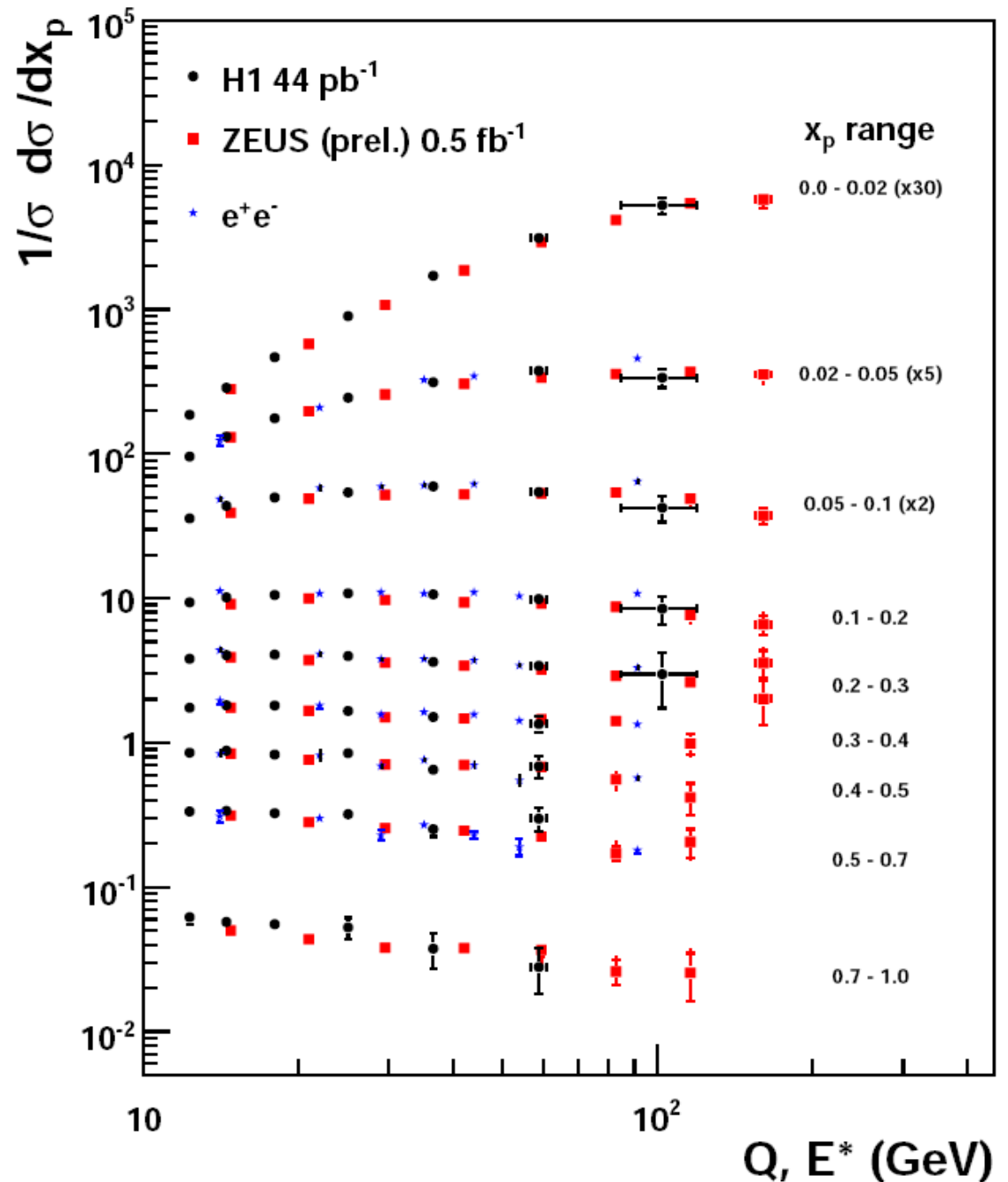


P_h – momentum of charged particles in current region of the Breit frame.

With Q increasing dn/dx_p is softer, i.e. more particles with smaller fraction of energy $Q/2$.

$\ln(1/x_p)$

Comparison ep with e^+e^-
 supports the concept of
 quark fragmentation
 universality.



Fragmentation functions (FF):

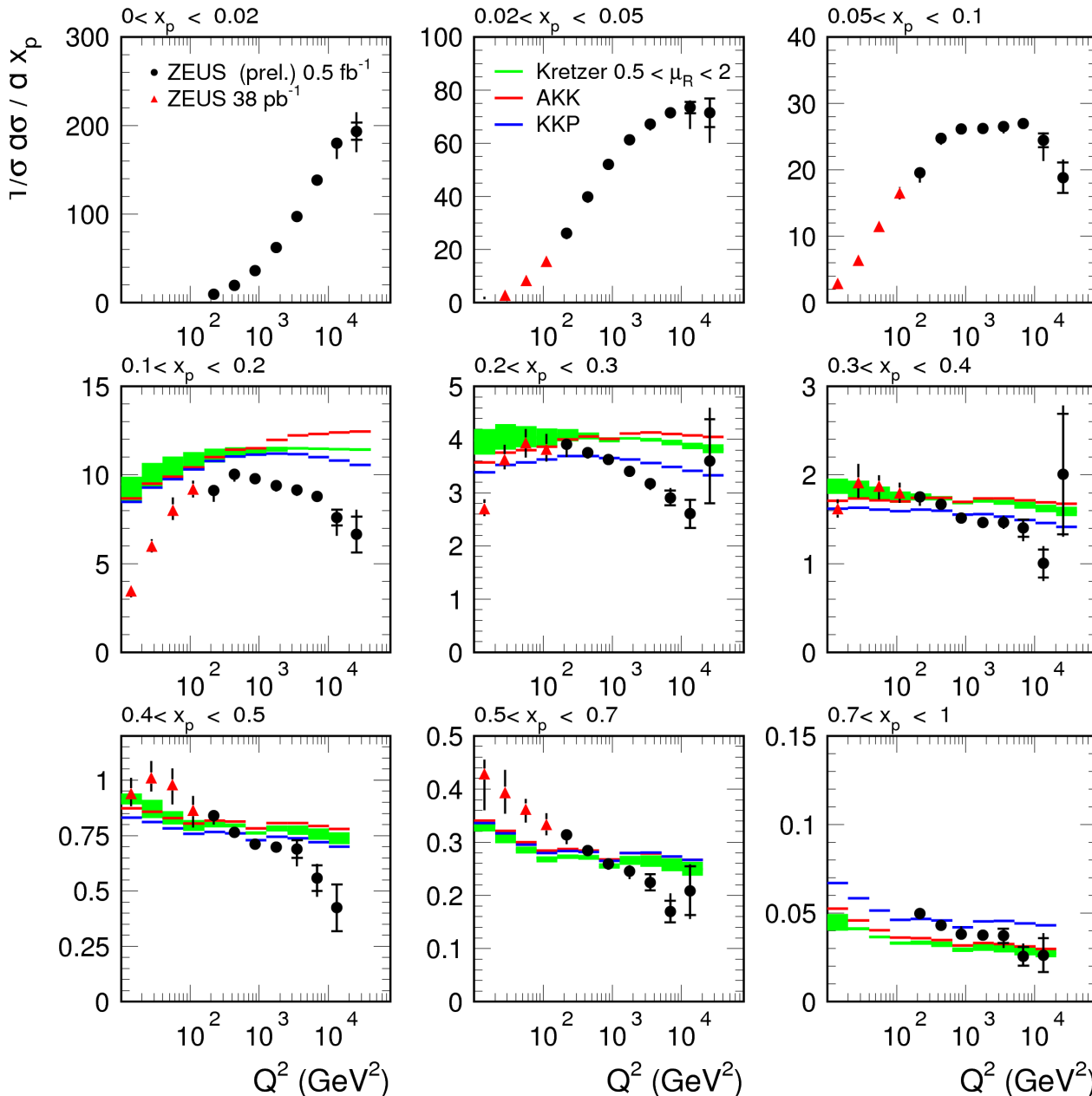
NLO QCD predictions implemented in CYCLOPS (PDF: CTEQ6M, $\Lambda_{\overline{\text{MS}}}^{(5)}=266$)

supported by S.Albino)

Full NLO matrix element + partonic FF proposed by:

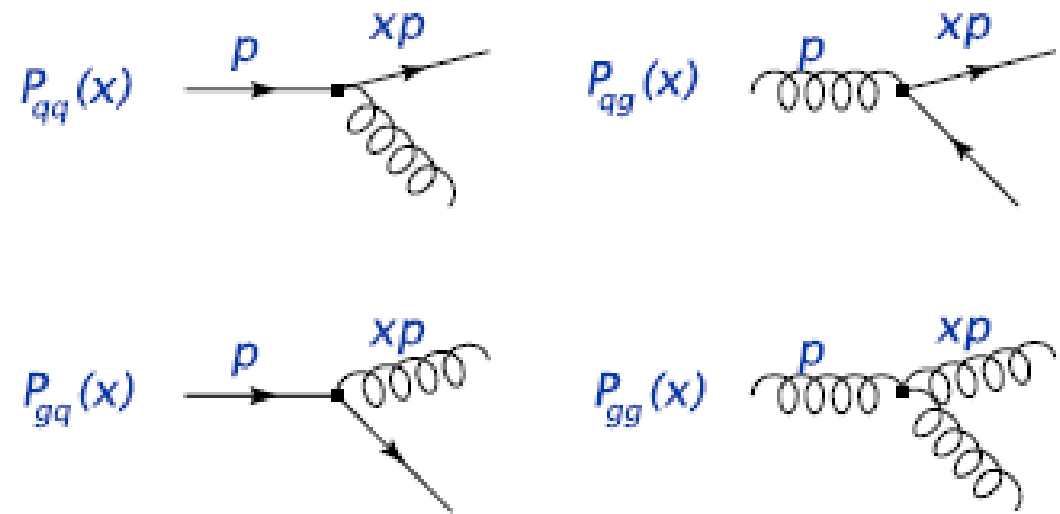
- **Kretzer** (2000) at Z^0 pole data ALEPH, SLD, low-en. TPC
- **KKP** (Kniehl, Kramer, Poetter) (2000) at Z^0 pole data ... + DELPHI, 3jet OPAL
- **AKK** (Albino, Kniehl, Kramer) (2005) update of KKP (d,s)

ZEUS



Funkcja rozgałęzień

- Feynman diagrams in leading order



- Evolution equations for parton distributions f_i
 - predictions from fits to reference processes (universality)

$$\frac{d}{d \ln \mu^2} f_i(x, \mu^2) = \sum_k \left[P_{ik}(\alpha_s(\mu^2)) \otimes f_k(\mu^2) \right] (x)$$

- Splitting functions P

$$P = \underbrace{\alpha_s P^{(0)} + \alpha_s^2 P^{(1)}}_{\text{NLO}} + \alpha_s^3 P^{(2)} + \dots$$

NLO: standard approximation (large uncertainties)

Splitting functions for a quarter of a century

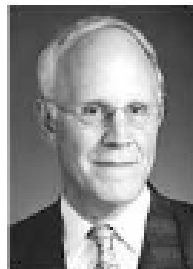
$$\begin{aligned}
 P_{aa}^{(0)}(x) &= C_F(2\rho_{qq}(x) + 3\delta(1-x)) \\
 P_{ab}^{(0)}(x) &= 0 \\
 P_{ba}^{(0)}(x) &= 2n_f\rho_{bb}(x) \\
 P_{bb}^{(0)}(x) &= 2C_F\rho_{bb}(x) \\
 P_{gg}^{(0)}(x) &= C_A\left(4\rho_{gg}(x) + \frac{11}{3}\delta(1-x)\right) - \frac{2}{3}n_f\delta(1-x)
 \end{aligned}$$

1973



The Nobel Prize in Physics 2004

"For the discovery of asymptotic freedom in the theory of the strong interaction"



David J. Gross



H. David Politzer



Frank Wilczek

$$\begin{aligned}
 P_{aa}^{(1)+}(x) &= 4C_A C_F \left(\rho_{qq}(x) \left[\frac{67}{18} - \zeta_2 + \frac{11}{6}H_0 + H_{0,0} \right] + \rho_{qq}(-x) \left[\zeta_2 + 2H_{-1,0} - H_{0,0} \right] \right. \\
 &\quad \left. + \frac{14}{3}(1-x) + \delta(1-x) \left[\frac{17}{24} + \frac{11}{3}\zeta_2 - 3\zeta_3 \right] \right) - 4C_F n_f \left(\rho_{qq}(x) \left[\frac{5}{9} + \frac{1}{3}H_0 \right] + \frac{2}{3}(1-x) \right. \\
 &\quad \left. + \delta(1-x) \left[\frac{1}{12} + \frac{2}{3}\zeta_2 \right] \right) + 4C_F^2 \left(2\rho_{qq}(x) \left[H_{1,0} - \frac{3}{4}H_0 + H_2 \right] - 2\rho_{qq}(-x) \left[\zeta_2 + 2H_{-1,0} \right. \right. \\
 &\quad \left. \left. - H_{0,0} \right] - (1-x) \left[1 - \frac{3}{2}H_1 \right] - H_0 - (1+x)H_{0,0} + \delta(1-x) \left[\frac{3}{8} - 3\zeta_2 + 6\zeta_3 \right] \right)
 \end{aligned}$$

$$\begin{aligned}
 P_{aa}^{(1)-}(x) &= P_{aa}^{(1)+}(x) + 16C_F \left(C_F - \frac{C_A}{2} \right) \left(\rho_{qq}(-x) \left[\zeta_2 + 2H_{-1,0} - H_{0,0} \right] - 2(1-x) \right. \\
 &\quad \left. - (1+x)H_1 \right)
 \end{aligned}$$

$$P_{ab}^{(1)}(x) = 4C_F n_f \left(\frac{20}{9} \frac{1}{x} - 2 + 6x - 4H_0 + x^2 \left[\frac{8}{3}H_1 - \frac{56}{9} \right] + (1+x) \left[5H_0 - 2H_{0,0} \right] \right)$$

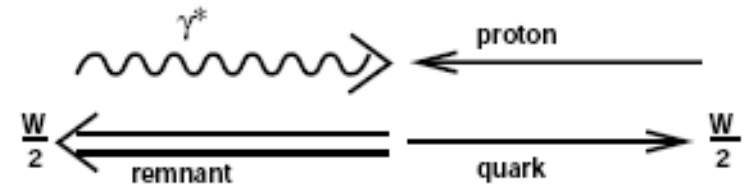
$$\begin{aligned}
 P_{ba}^{(1)}(x) &= 4C_A n_f \left(\frac{20}{9} \frac{1}{x} - 2 + 25x - 2\rho_{bb}(-x)H_{-1,0} - 2\rho_{bb}(x)H_{1,1} + x^2 \left[\frac{44}{3}H_1 - \frac{218}{9} \right] \right. \\
 &\quad \left. + 4(1-x) \left[H_{0,0} - 2H_0 + xH_1 \right] - 4\zeta_2 x - 6H_{0,0} + 9H_1 \right) + 4C_F n_f \left(2\rho_{bb}(x) \left[H_{1,0} + H_{1,1} + H_2 \right. \right. \\
 &\quad \left. \left. - \zeta_2 \right] + 4x^2 \left[H_0 + H_{0,0} + \frac{5}{2} \right] + 2(1-x) \left[H_0 + H_{0,0} - 2xH_1 + \frac{29}{4} \right] - \frac{15}{2} - H_{0,0} - \frac{1}{2}H_0 \right)
 \end{aligned}$$

$$\begin{aligned}
 P_{bb}^{(1)}(x) &= 4C_A C_F \left(\frac{1}{x} + 2\rho_{qq}(x) \left[H_{1,0} + H_{1,1} + H_2 - \frac{11}{6}H_1 \right] - x^2 \left[\frac{8}{3}H_0 - \frac{44}{9} \right] + 4\zeta_2 - 2 \right. \\
 &\quad \left. - 7H_0 + 2H_{0,0} - 2H_1 x + (1+x) \left[2H_{0,0} - 5H_1 + \frac{37}{9} \right] - 2\rho_{qq}(-x)H_{-1,0} \right) - 4C_F n_f \left(\frac{2}{3}x \right. \\
 &\quad \left. - \rho_{qq}(x) \left[\frac{2}{3}H_1 - \frac{10}{9} \right] \right) + 4C_F^2 \left(\rho_{qq}(x) \left[3H_1 - 2H_{1,1} \right] + (1+x) \left[H_{0,0} - \frac{7}{2} + \frac{7}{2}H_0 \right] - 3H_{0,0} \right. \\
 &\quad \left. + 1 - \frac{3}{2}H_0 + 2H_1 x \right)
 \end{aligned}$$

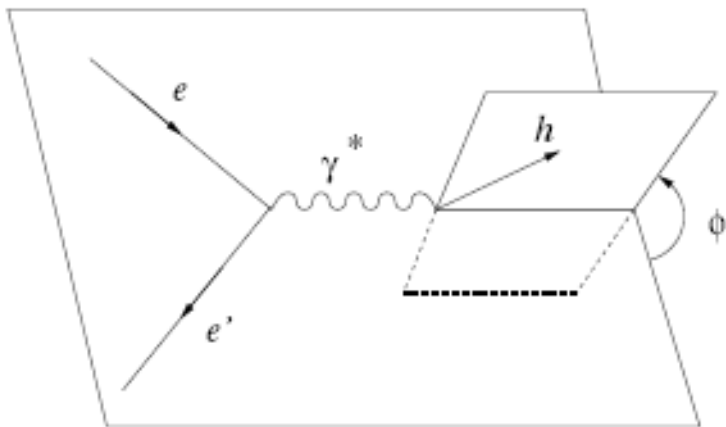
$$\begin{aligned}
 P_{gg}^{(1)}(x) &= 4C_A n_f \left(1-x - \frac{10}{9}\rho_{gg}(x) - \frac{13}{9} \left(\frac{1}{x} - x^2 \right) - \frac{2}{3}(1+x)H_0 - \frac{2}{3}\delta(1-x) \right) + 4C_A^2 \left(27 \right. \\
 &\quad \left. + (1+x) \left[\frac{11}{3}H_0 + 8H_{0,0} - \frac{27}{2} \right] + 2\rho_{gg}(-x) \left[H_{0,0} - 2H_{-1,0} - \zeta_2 \right] - \frac{67}{9} \left(\frac{1}{x} - x^2 \right) - 12H_1 \right. \\
 &\quad \left. - \frac{44}{3}x^2 H_1 + 2\rho_{gg}(x) \left[\frac{67}{18} - \zeta_2 + H_{0,0} + 2H_{1,0} + 2H_2 \right] + \delta(1-x) \left[\frac{8}{3} + 3\zeta_3 \right] \right) + 4C_F n_f \left(2H_0 \right. \\
 &\quad \left. + \frac{21}{3x} + \frac{10}{3}x^2 - 12 + (1+x) \left[4 - 5H_0 - 2H_{0,0} \right] - \frac{1}{2}\delta(1-x) \right) .
 \end{aligned}$$

1980

Asymetria azymutalna $e p \rightarrow e h X$ dla niespolaryzowanych wiązek



$$\frac{d\sigma}{d\phi} = A + B \cos \phi + C \cos 2\phi + D \sin \phi + E \sin 2\phi$$



$$\langle \cos \phi \rangle = \frac{B}{2A}$$

$$\langle \cos 2\phi \rangle = \frac{C}{2A}$$

$$\langle \sin \phi \rangle = \frac{D}{2A}$$

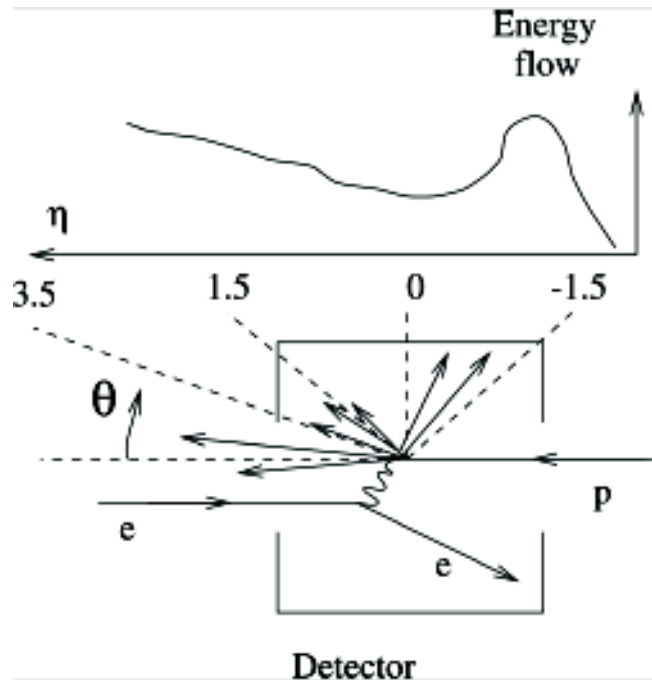
$$\langle \sin 2\phi \rangle = \frac{E}{2A}$$

$$0.01 < x < 0.1$$

$$100 < Q^2 < 8000 \text{ GeV}^2$$

Metoda:
przeptywu energii poprzecznej

Metoda przepływu energii



Azimuthal asymmetry comes from:

- ★ Two-body processes (BGF and QCDC)
- ★ Boson polarization
- ★ **Longitudinally polarized electron beam**
- ★ **Parity violating weak interactions**
- ★ **Final hadron polarization**
- ★ **Intrinsic parton momentum in the proton**
- ★ **Wymiana dwufotonowa**

$$\frac{d\sigma}{d\phi} = A + B \cos \phi + C \cos 2\phi + D \sin \phi + E \sin 2\phi$$



T-even




T-odd

$$\langle \sin \phi \rangle = \left\langle \frac{(\vec{k} \times \vec{k}') \cdot \vec{p}'_T}{|\vec{k} \times \vec{k}'| \cdot |\vec{p}'_T|} \right\rangle$$

Dane z e⁺p z lat 1996-7

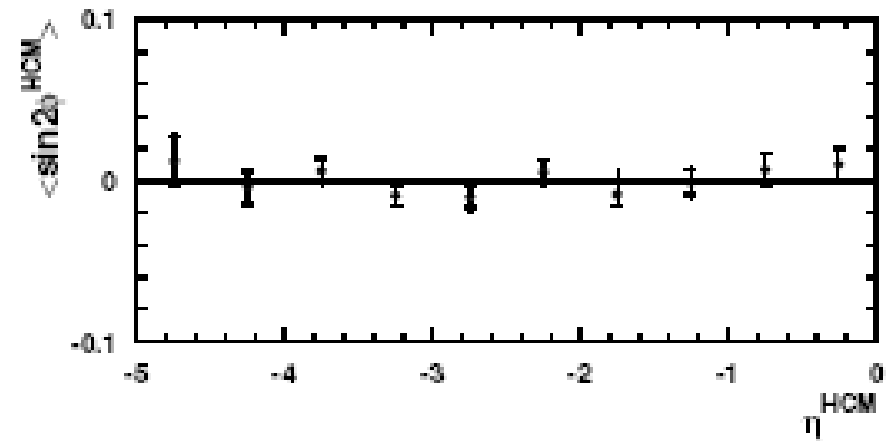
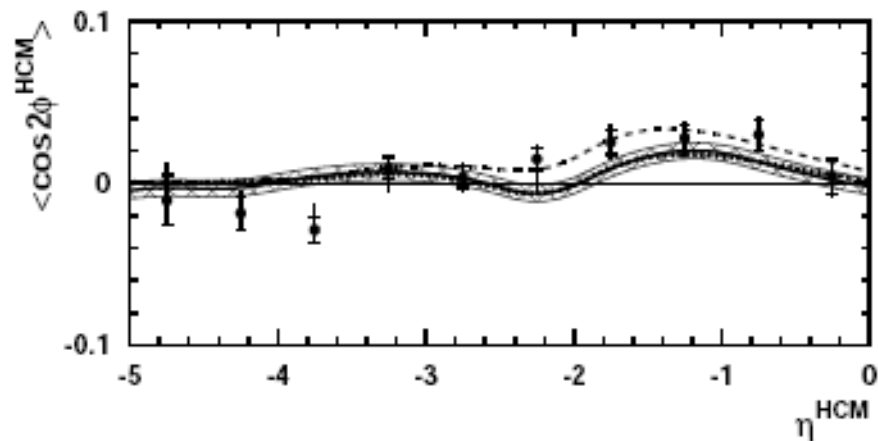
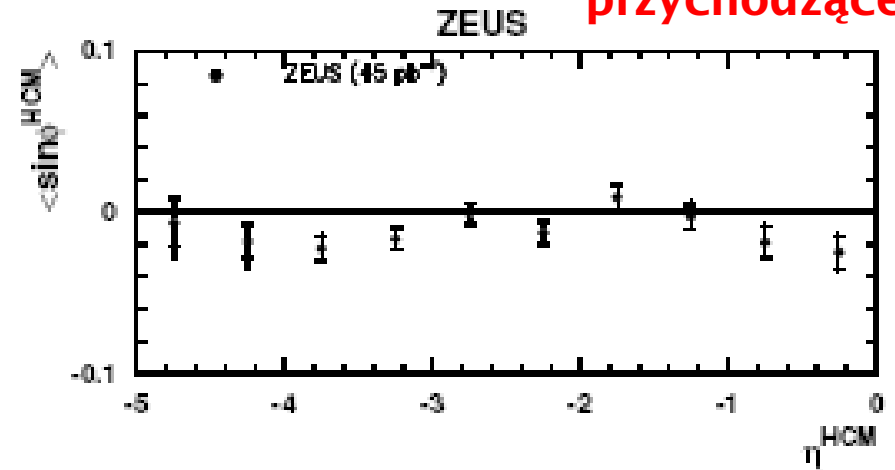
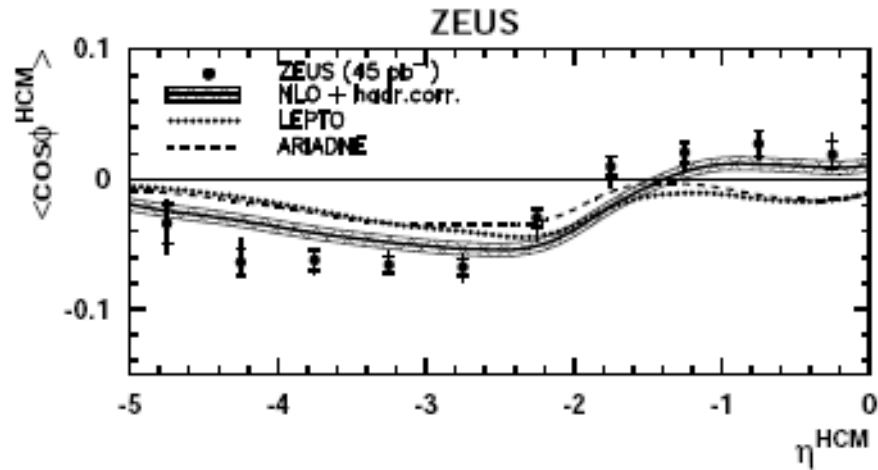
ZEUS Coll., Eur.Phys.J. C51(2007)289

Rozkłady azymutalne w $ep \rightarrow ehX$



rapidity

przychodzącego p

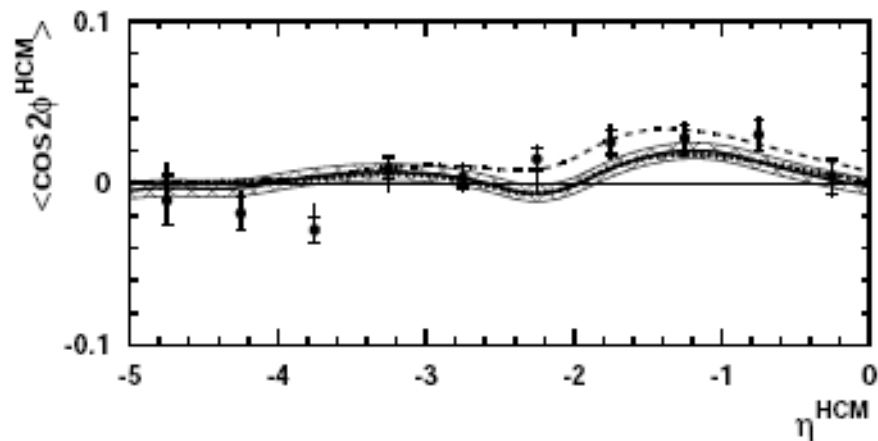
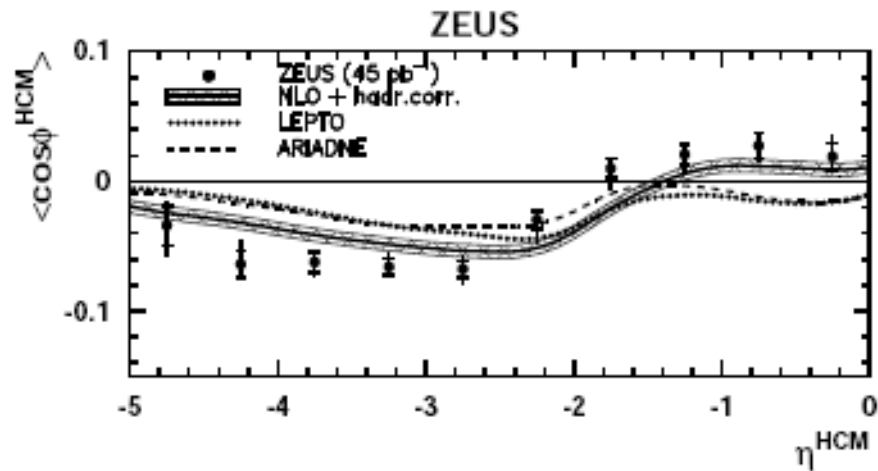


Oczekiwania:

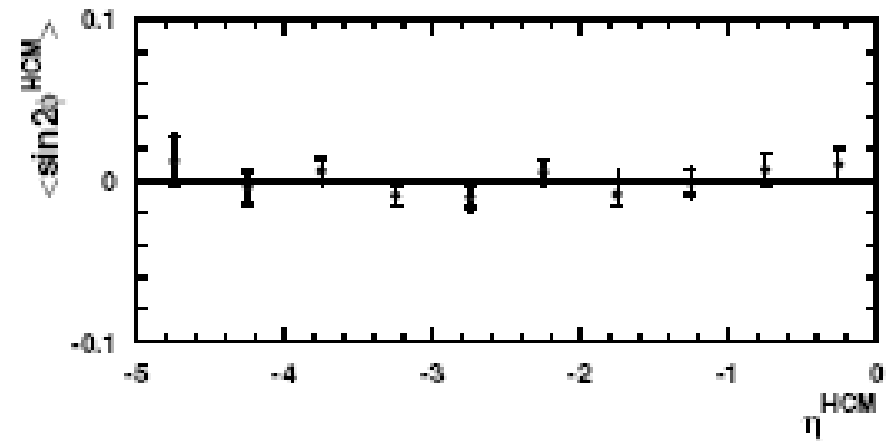
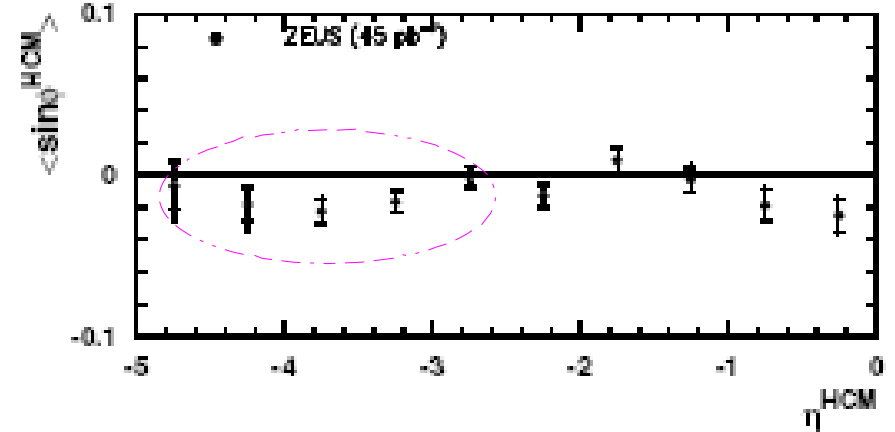
mierzalne małe

zero lub promile

Rozkłady azymutalne w $ep \rightarrow ehX$



Current Region

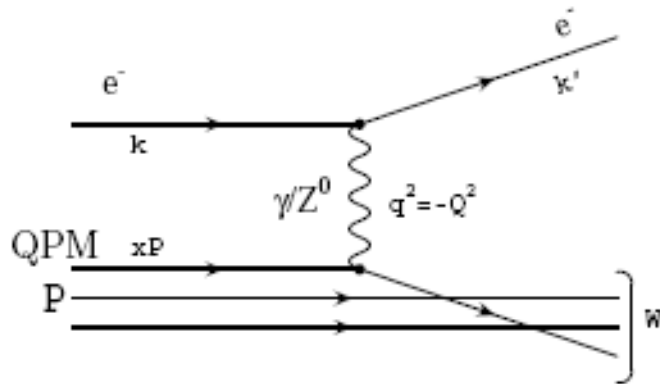


Oczekiwania:

mierzalne małe

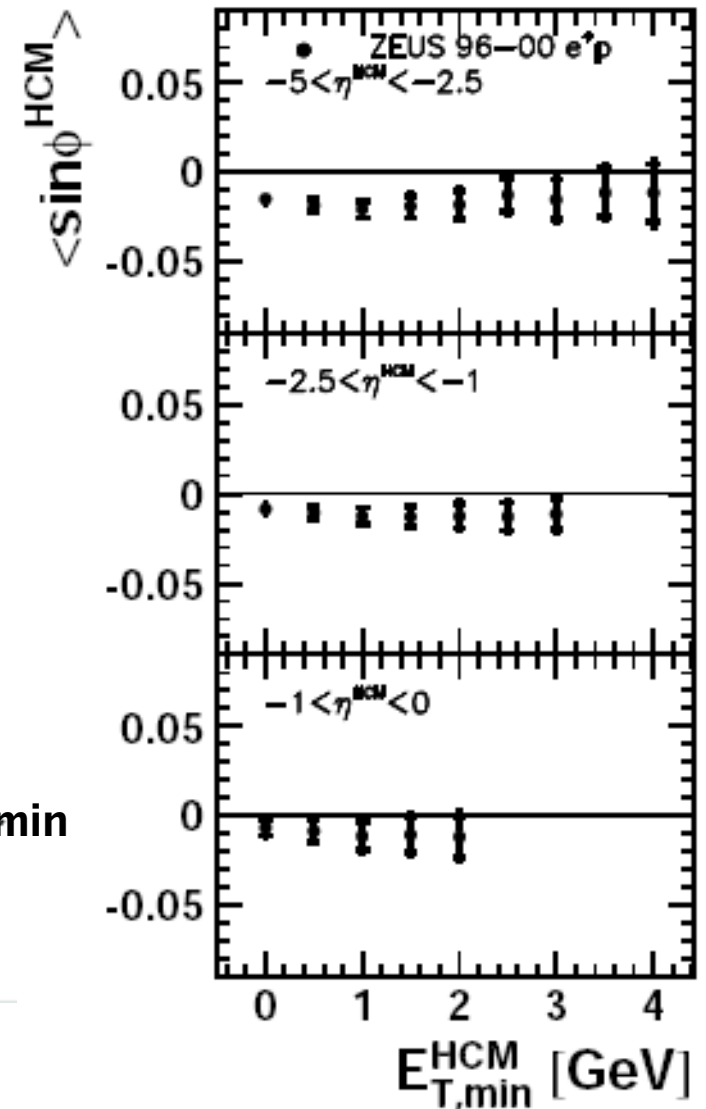
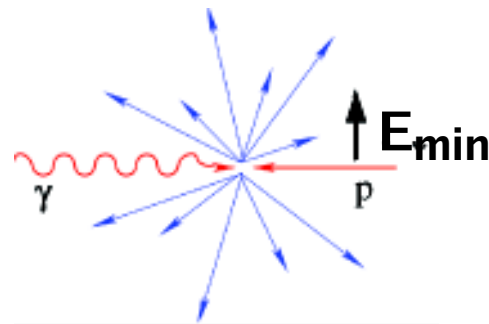
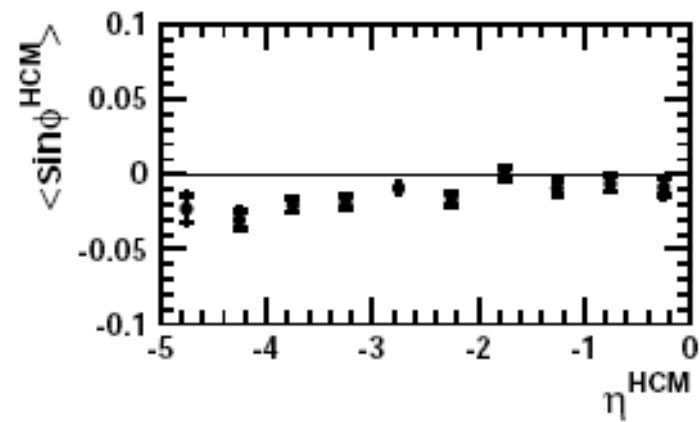
zero lub promile (T-odd)

T-odd effect

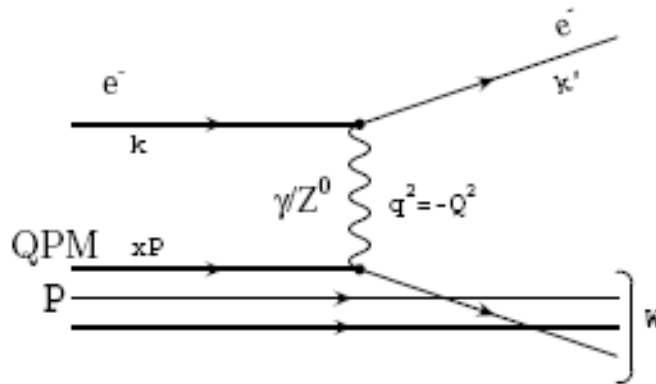


$$\langle \sin \phi \rangle = \left\langle \frac{(\vec{k} \times \vec{k}') \cdot \vec{p}'_T}{|\vec{k} \times \vec{k}'| \cdot |\vec{p}'_T|} \right\rangle$$

Dane 1996-2000

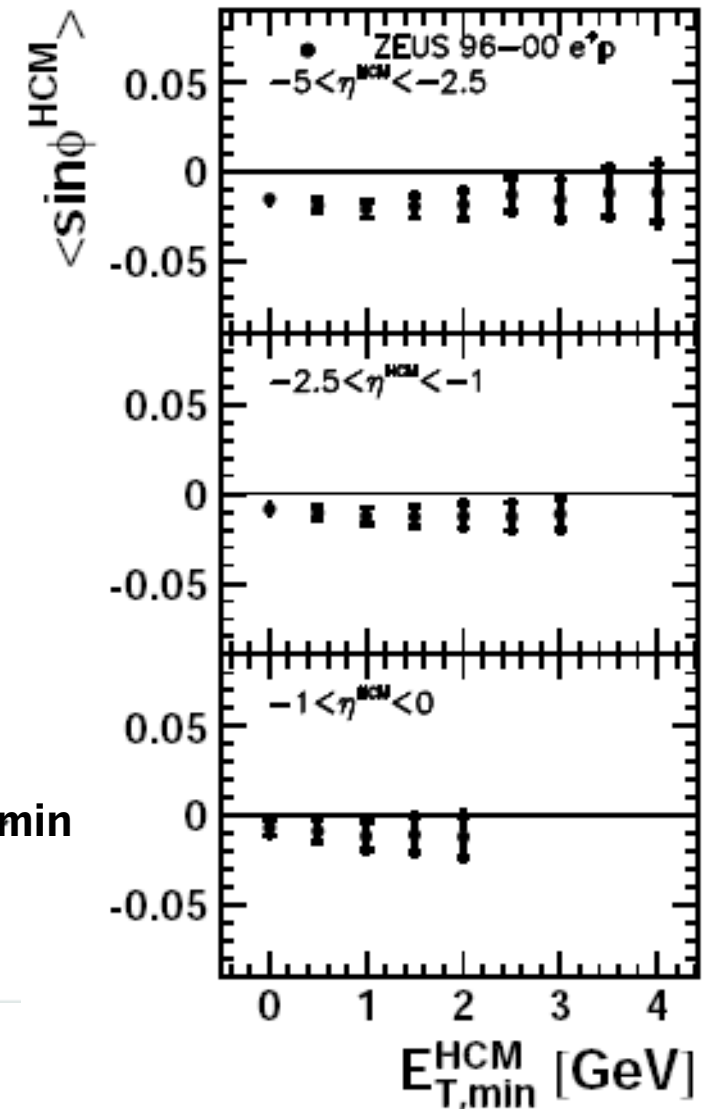
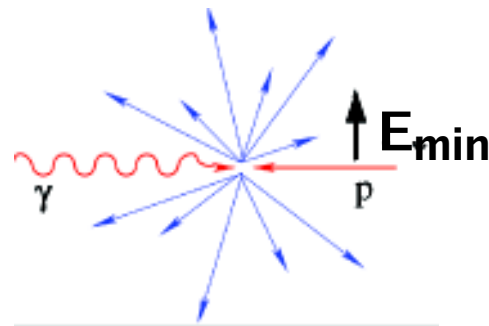
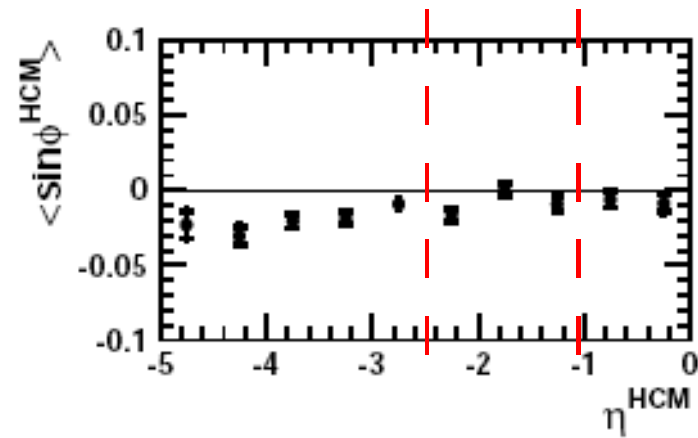


T-odd effect



$$\langle \sin \phi \rangle = \left\langle \frac{(\vec{k} \times \vec{k}') \cdot \vec{p}'_T}{|\vec{k} \times \vec{k}'| \cdot |\vec{p}'_T|} \right\rangle$$

Dane 1996-2000



Wiele publikacji teoretycznych, ale brak było pomiarów.

De Rujula, Kaplan, deRafael, NP. B35 (1971)365

Przewidywania, których doświadczenie nie potwierdza:

T-even \gg 10 * T-odd (tylko spolaryzowanych wiązek)

T-odd (NC) < T-odd (CC)

Wnioski:

potrzebne sugestie od teoretyków

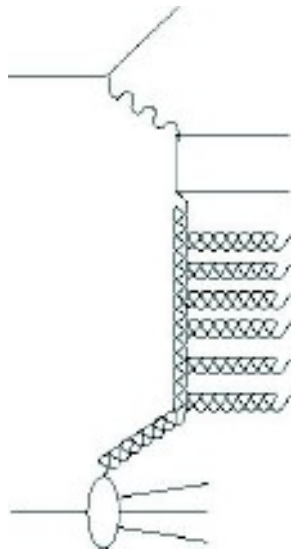
Produkcja ekskluzywana cząstek

Dlaczego ważne:

- przy modelowaniu procesów z oddziaływań wysokich energii
- przy testowaniu produkcji cząstek, w szcz. przekazu liczby barionowej

Omówimy:

- produkcje (anty)deuteronów, pentakwarków, mezonów gluonowych
- pomiar rozmiarów źródła emitującego cząstki



prądy podobny do e^+e^-

centralny

ZEUS Coll. DESY 07-070
H1 Coll. DESY 04-032
ZEUS Coll. DESY 07-063
ZEUS Coll. DESY 06-226

Deuteron and anti-deuteron

Bound state of two nucleons or multi-quark particle ?

In elementary collisions — overlap of wave function in the final state,

- Not included in the standard hadronisation model , i.e. JETSET type
- Anti-d was observed in e^+e^- by ARGUS, OPAL, ALEPH, CLEO
- Observation of anti-d in ep photoproduction (H1)
- **First measurement of d and \bar{d} in DIS (ZEUS)**
(high background— beam-gas, beam-wall, secondary interactions)

ZEUS Collaboration, DESY 07-070,
H1 Collaboration, DESY 04-032,

Deuteron and anti-deuteron

The **coalescence model** gives the cross section for formation of an object with A nucleons

$$\frac{E_A}{\sigma_{tot}} \frac{d^3\sigma_A}{d^3P_A} = B_A \left(\frac{E_N}{\sigma_{tot}} \frac{d^3\sigma_N}{d^3p_N} \right)^A \quad p_N = P_A/A \quad A = 2$$

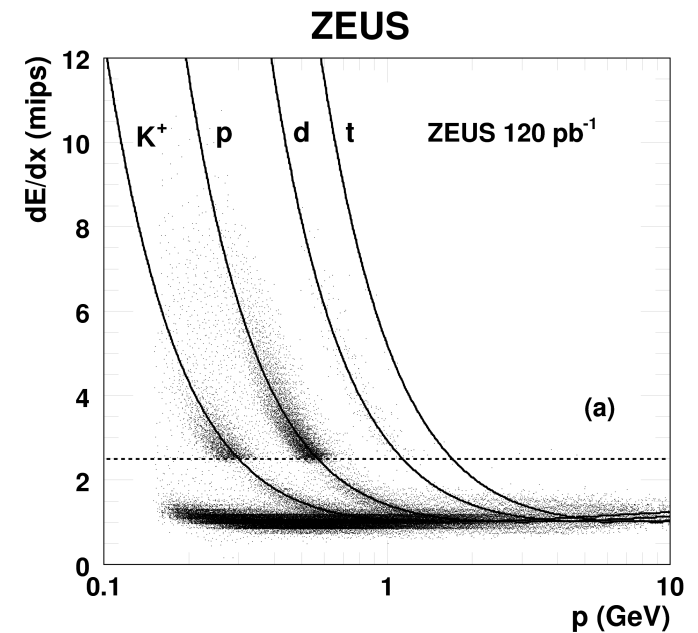
The coalescence parameter $B_2 \propto \frac{1}{V} \propto \frac{1}{R^3}$ where R – source radius

Selection criteria:

- 120 pb^{-1} (HERA I)
- $Q^2 > 1 \text{ GeV}$

Method of identification:

- dE/dx
- Distance of closest approach **DCA**



Number of events:

p $1.52 \cdot 10^5$

\bar{p} $1.62 \cdot 10^5$ ← tracking efficiency

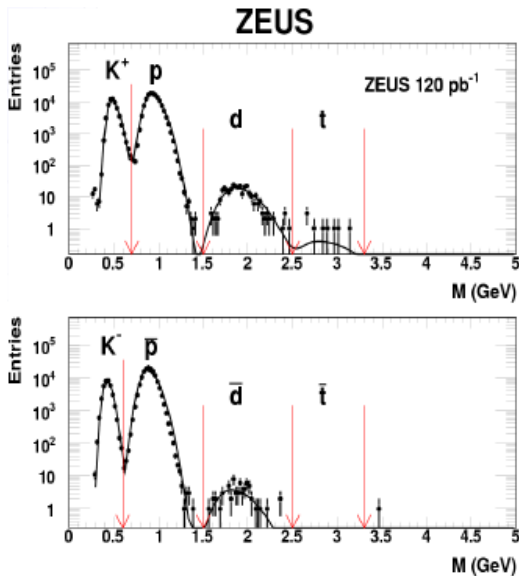
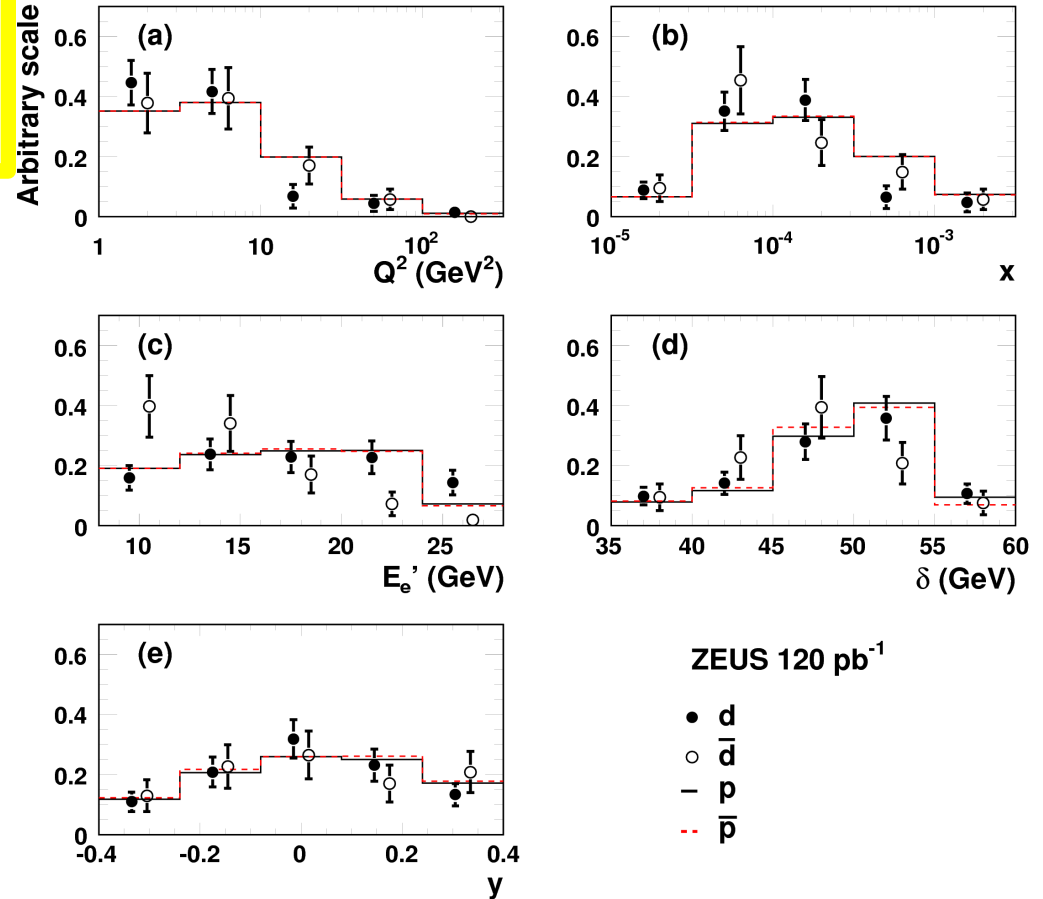
d 177 ± 17

\bar{d} 53 ± 7

No $d(\bar{d})$ is found in current region of Breit frame in agreement with low rate in e^+e^- .
 Only 2.5% of $p(\bar{p})$ is emitted in this region.

Deuteron yield is suppressed by a factor of ~ 1000 w.r.t. protons

ZEUS



$d(\bar{d})$ distributions are consistent with those for $p(\bar{p})$ except anti- d as function of scattered electron energy (E_e') (related to W .)

Number of events:

p $1.52 \cdot 10^5$

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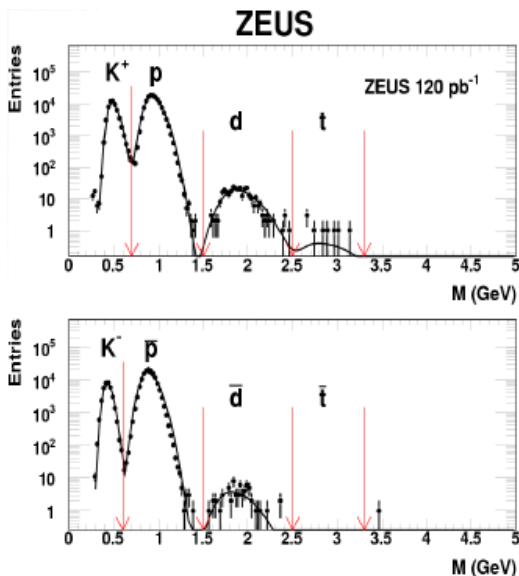
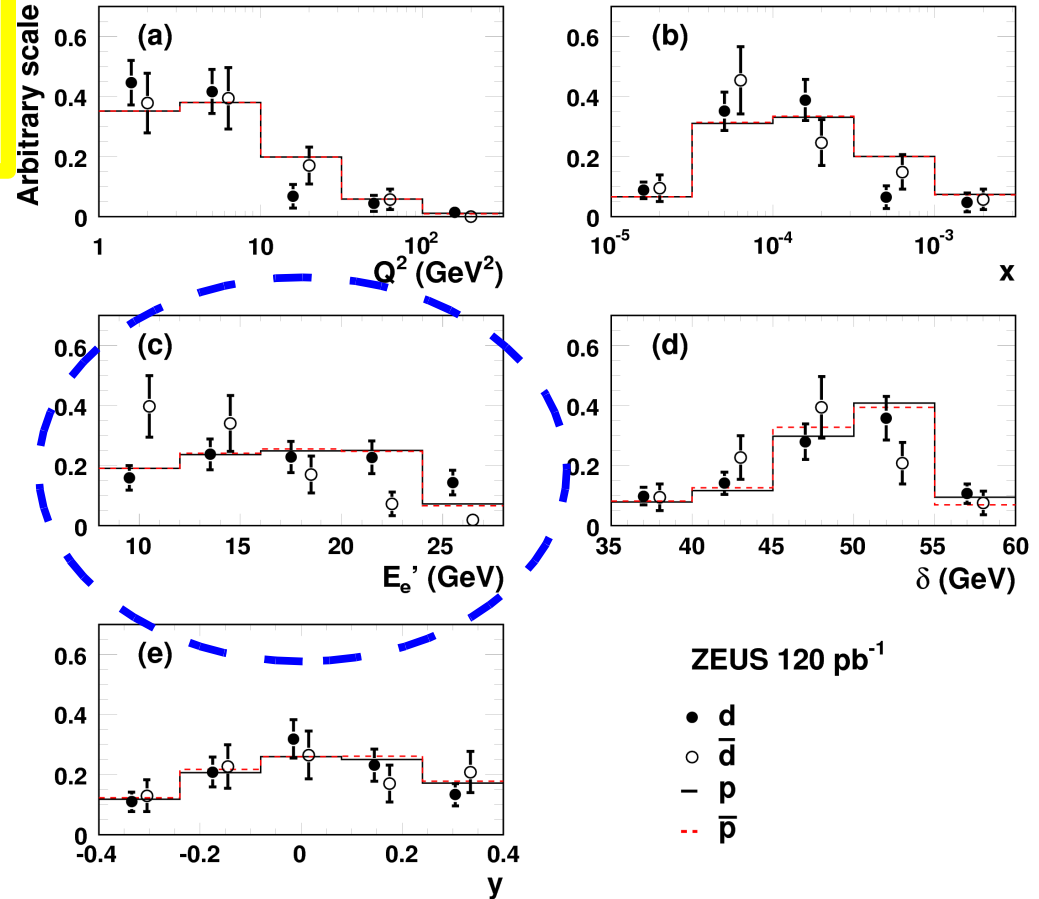
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ZEUS



$d(\bar{d})$ distributions are consistent with those for $p(\bar{p})$ except anti- d as function of scattered electron energy (E_e') (related to W .)

The coalescence parameter B_2

- larger for d than for anti-d
- similar for DIS and for photoproduction

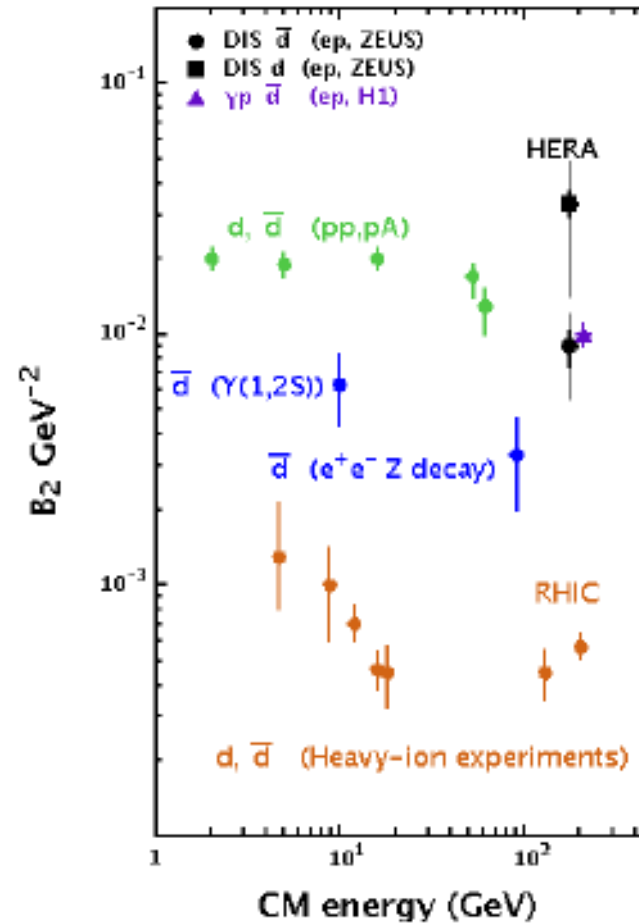
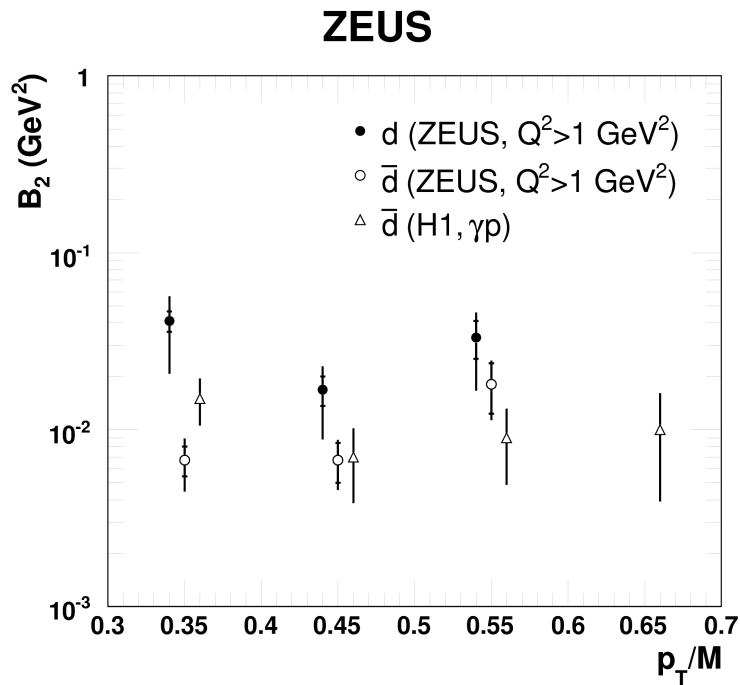
$$\frac{E_d}{\sigma_{tot}} \frac{d^3\sigma_d}{d^3P_d} = B_2 \left(\frac{E_p}{\sigma_{tot}} \frac{d^3\sigma_p}{d^3p_p} \right)^2$$

World data

Source radius
 $R^3 \sim 1/B_2$

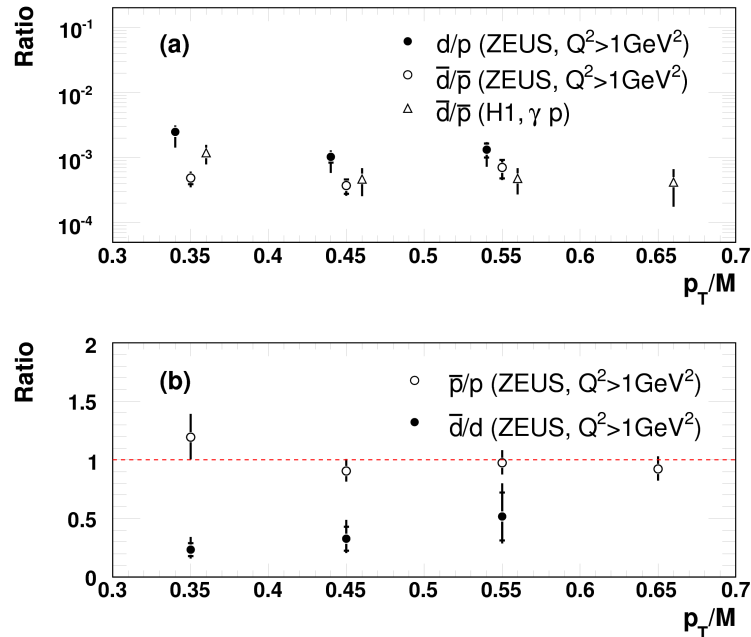
small

large



particle-to-particle yields

ZEUS



$$\bar{p}/p = 1$$

$$\bar{d}/d \neq 1$$

Summary:

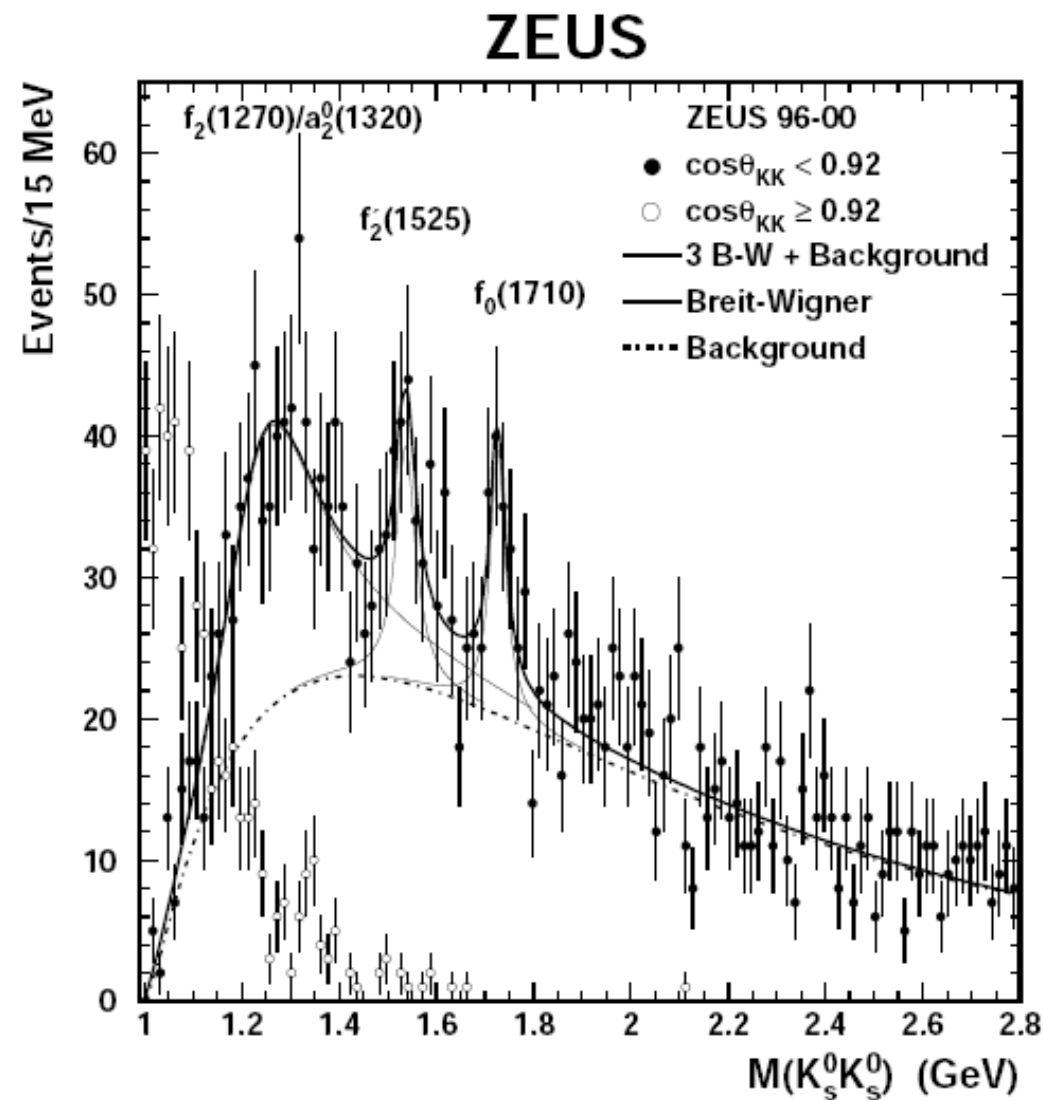
- first observation of d production, of anti-d in DIS,
- rate of anti-d is smaller than d,
- rate of p is consistent with anti-p, no chance to investigate small baryon-antibaryon asymmetry,

- if the coalescence model is used the source volume is different for d and anti-d, and different than in e^+e^- .

Mezony gluonowe (?)

Badano rozkłady $K_S^0 K_S^0$

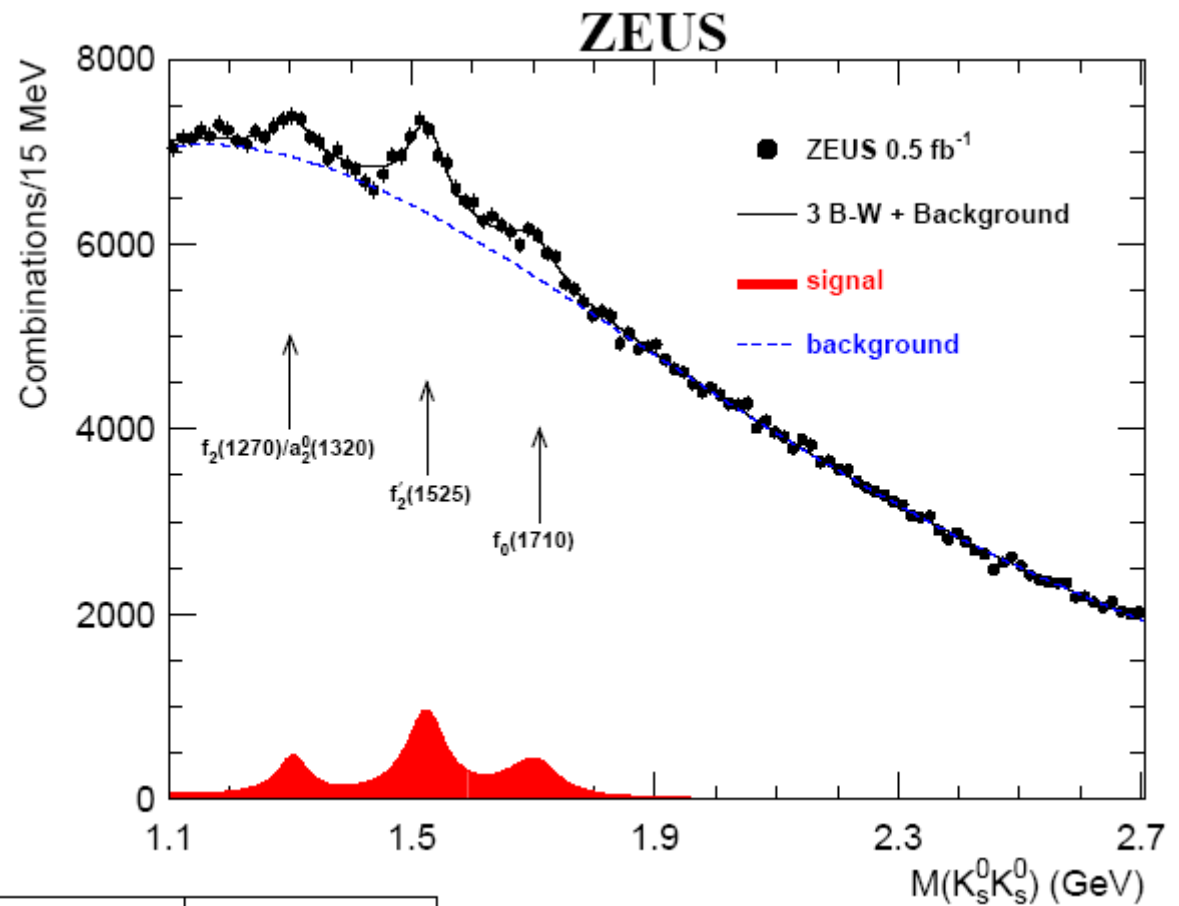
Wszyscy kandydaci z obszaru
centralnego w DIS



podobne wyniki dla fotoprodukcji,

Mezony gluonowe (?)

Badano rozkłady $K_s^0 K_s^0$ w fotoprodukcji

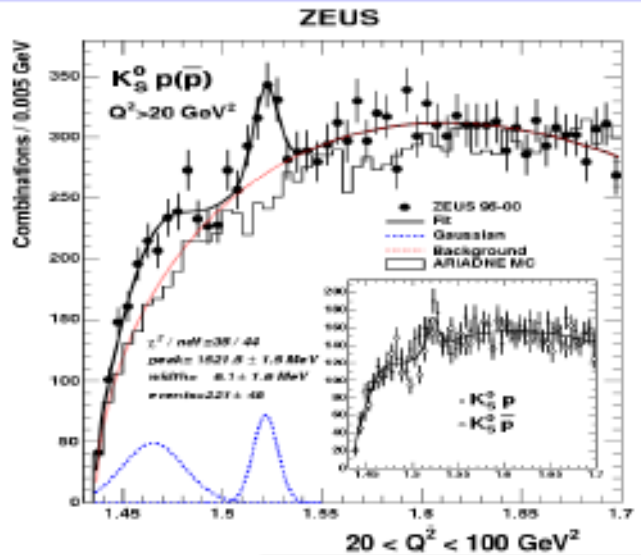


	$f_2(1270)/a_2^0(1320)$	$f_2'(1525)$	$f_0(1710)$
mass(MeV)	1304 ± 5	$1523 \pm 2^{+2}_{-8}$	$1695 \pm 6^{+8}_{-3}$
width(MeV)	---	$76 \pm 5^{+13}_{-7}$	$105 \pm 11^{+21}_{-35}$
Particle Data Group 2007 Values			
mass(MeV)	$1275.4 \pm 1.1/1318.3 \pm 0.6$	1525 ± 5	1724 ± 7
width(MeV)	$185.2^{+3.1}_{-2.5}/107 \pm 5$	73^{+6}_{-5}	137 ± 8

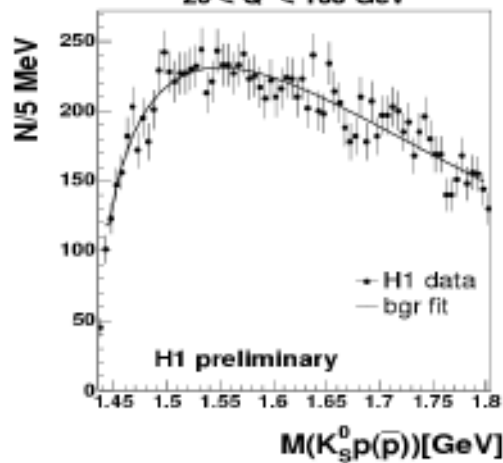
Table 1: Numbers extracted from the $K_s^0 K_s^0$ invariant mass fits and PDG values

Pentaquarks?

$K_s^0 p$ i $K_s^0 \bar{p}$



Masa $1521.5 \pm 1.5 \pm 2.8$ _{1.7} MeV



Podsumowanie

Pomiar z eksperymentów przy akceleratorze HERA wniosły istotny wkład do wiedzy o strukturze protonu i o produkcji hadronów

- **Rozkłady partonów znane z dokładnością do kilku procent,**
- **Pomiary inkluzywne hadronów:**
 - **funkcji fragmentacji**
 - **asymetria azymutalna i *T-odd effect***
- **Pomiary hadronów**
 - **produkcja (anty)deuteronu w oddziaływaniach elementarnych**
 - **produkcja nowych stanów:
pentakwarków i mezonów gluonowych (*glueballs*)**