Particle Production at HERA

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on behalf of
the ZEUS and H1 Collaborations

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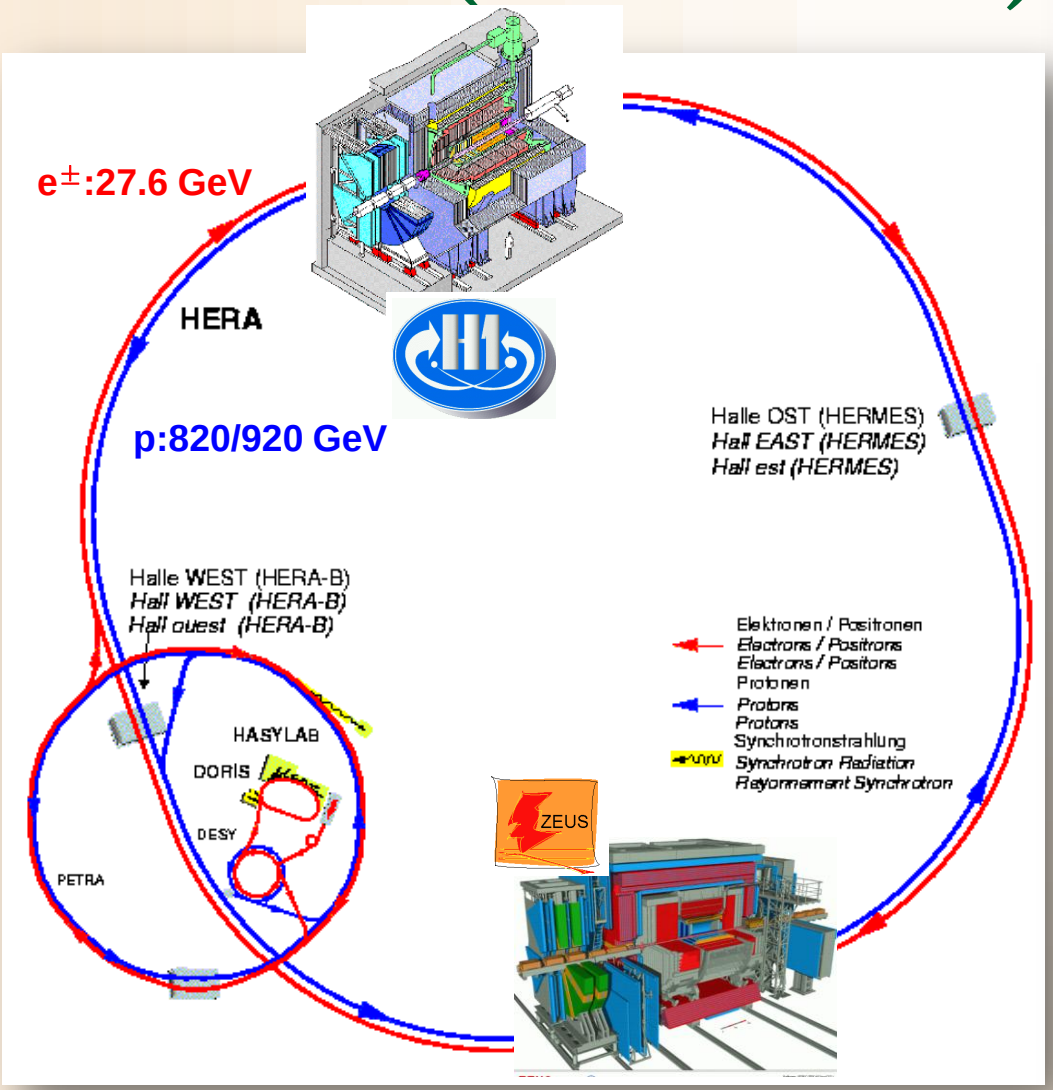
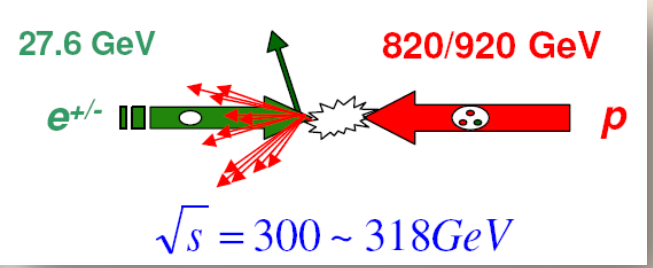
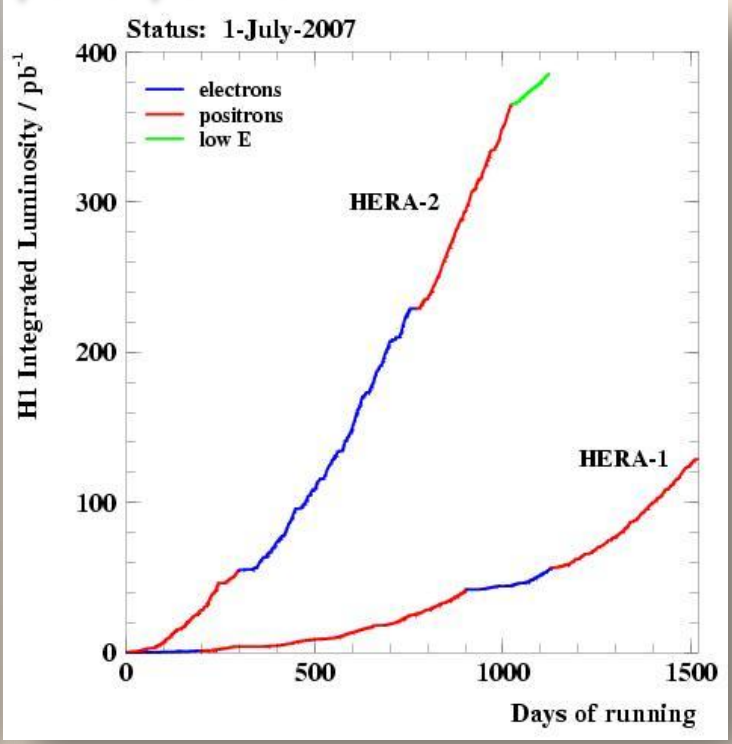
Lake Louise Winter Institute, February 15-21, 2009

HERA (1992 – 2007)



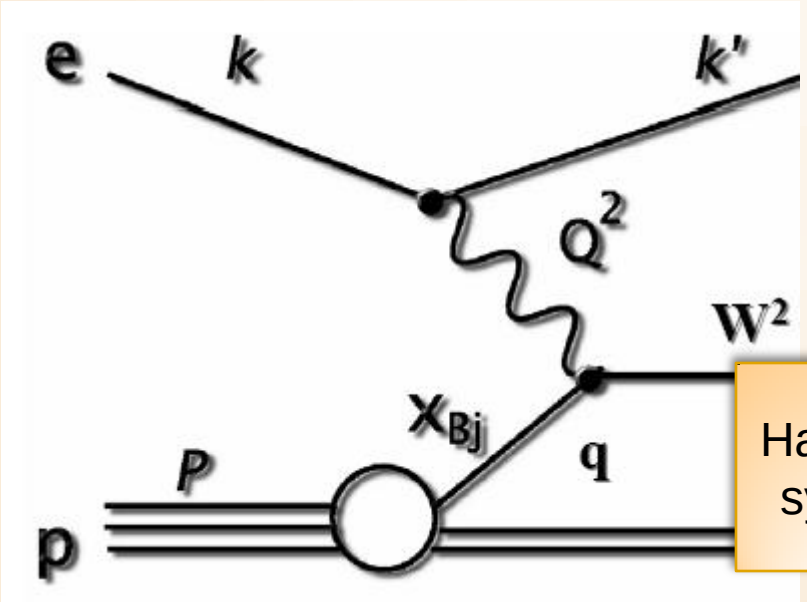


Integrated luminosity: 0.5 fb^{-1} per experiment



HERA Kinematics

The momentum transferred: $\mathbf{Q^2} = -\mathbf{q}^2 = -(\mathbf{k} - \mathbf{k'})^2$
The center of mass energy: $\mathbf{s} = (\mathbf{k} + \mathbf{p})^2$
Mass of the total hadronic system: $\mathbf{w^2} = (\mathbf{q} + \mathbf{p})^2$



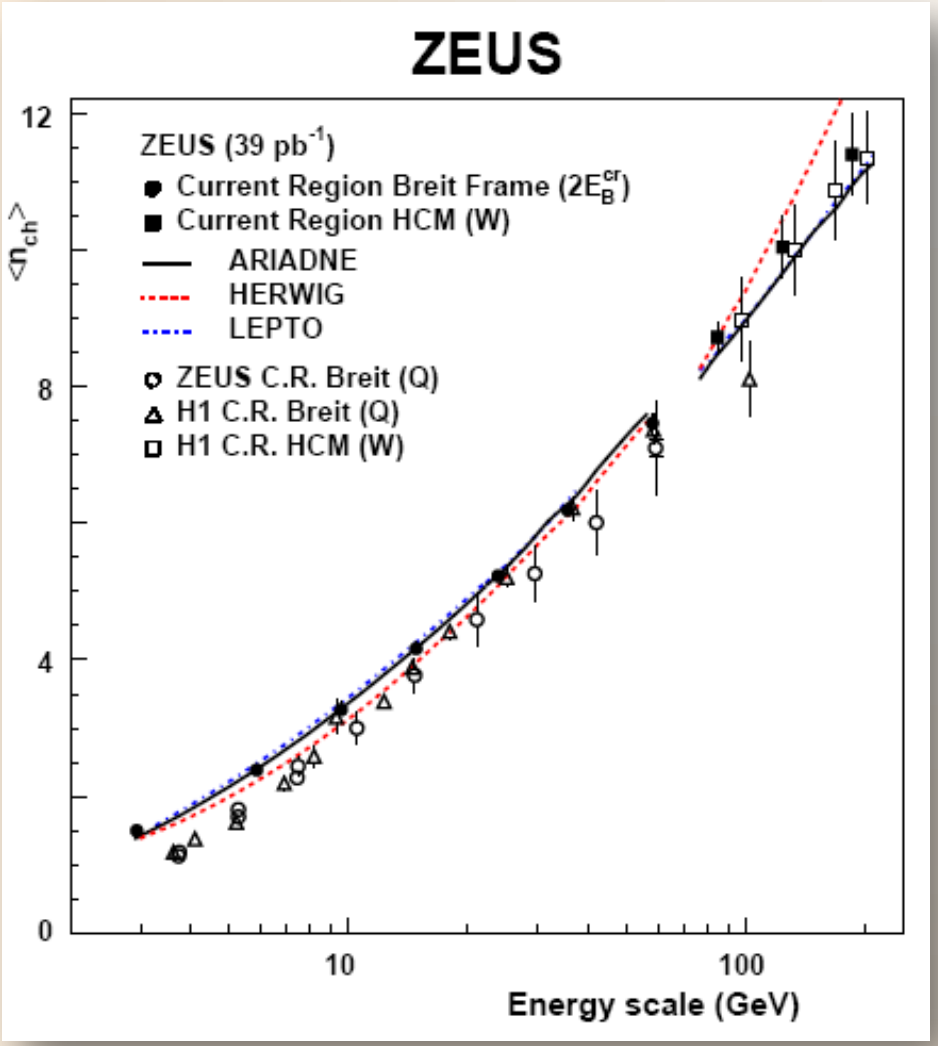
Hadronic system

The talk covers

- Charged multiplicity
- Strangeness production
- ρ^0, K^{*0}, Φ production
- $K^0_s K^0_s$ resonances

$Q^2 \approx 0$ GeV^2: Photoproduction (γp)
$Q^2 > 1$ GeV^2: Deep Inelastic Scattering (DIS)

Energy dependence of the charged multiplicity in DIS



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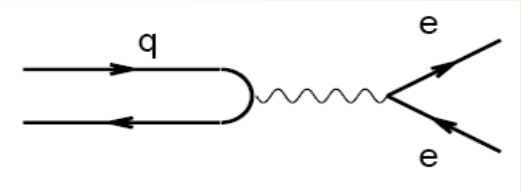
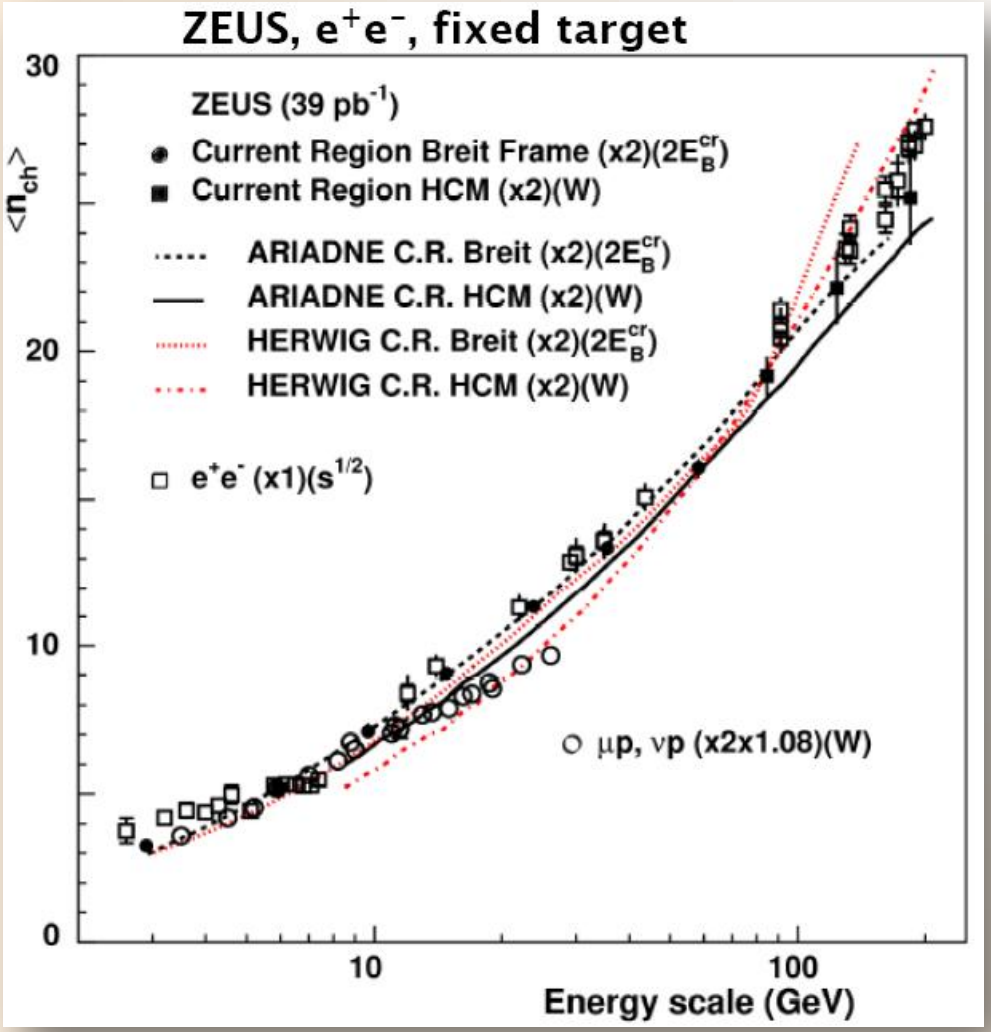


- Breit Frame
  Current region → e^+e^-
  Target region → pp
  e^+e^-: $s^{1/2} = 2E_{beam}$
  ep(BF): Q or $2E^{cr}_B$
  ep(HCM): W

- Mean multiplicity distributions compared show better agreement with theoretical predictions by using $2E^{cr}_B$ of the Breit Frame instead of Q

- Out of three Monte Carlo simulations ARIADNE gives the best description of the data

Energy dependence of the charged multiplicity



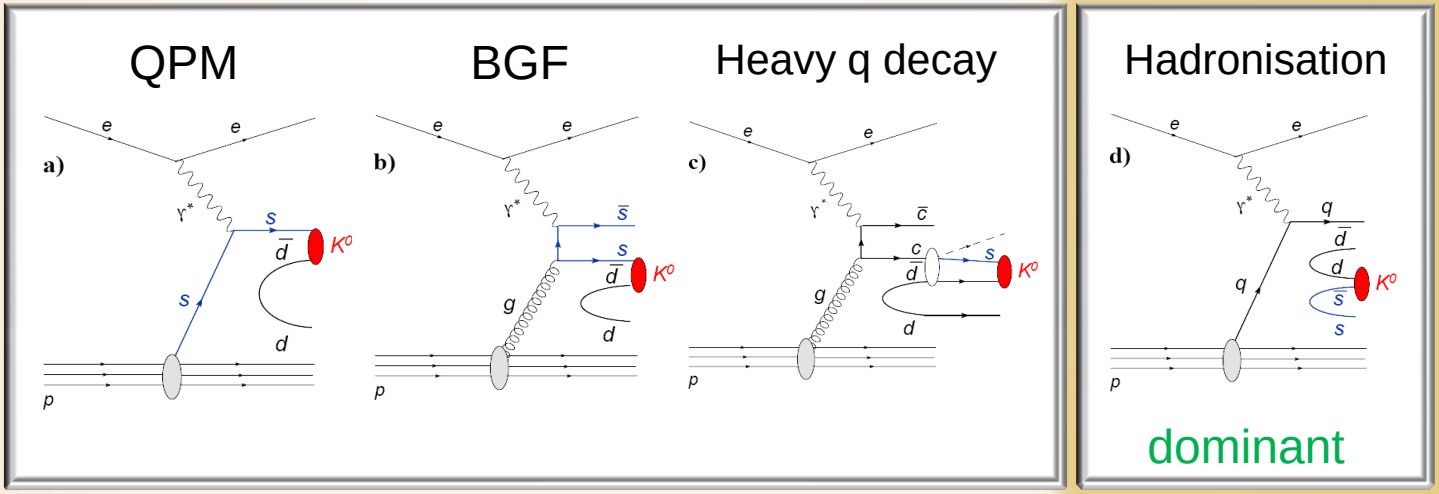
- Data and Monte Carlo predictions are in agreement
- The energy dependences are similar in the current region of the Breit and HCM frames, and comparable to e^+e^- results.
- Universality of mean charged multiplicity dependence with energy scale

Strangeness production at low Q^2 in DIS

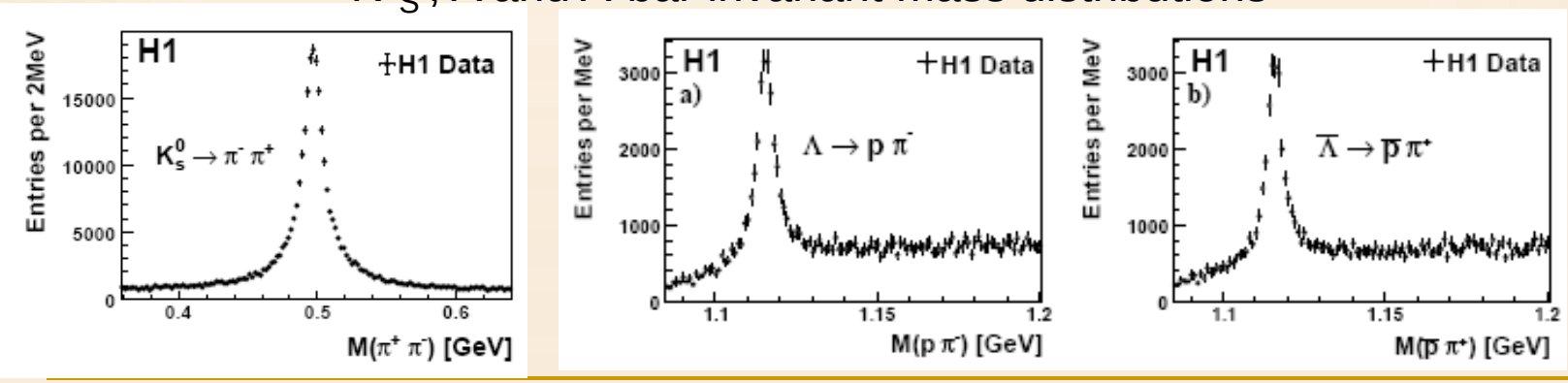
$2 < Q^2 < 100$ GeV^2 $\mathcal{L} = 49.9$ pb^{-1}

DESY-08-095
Submitted to *Eur.Phys.J.* **C**

Strange hadron production mechanism

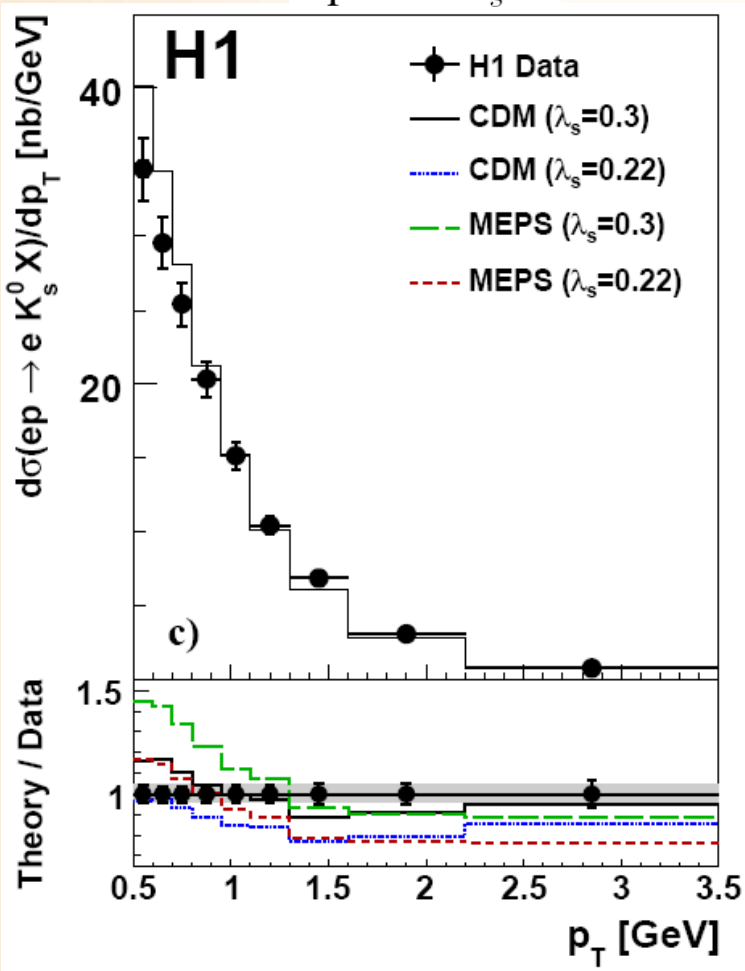


K^0_S , Λ and Λ-bar invariant mass distributions

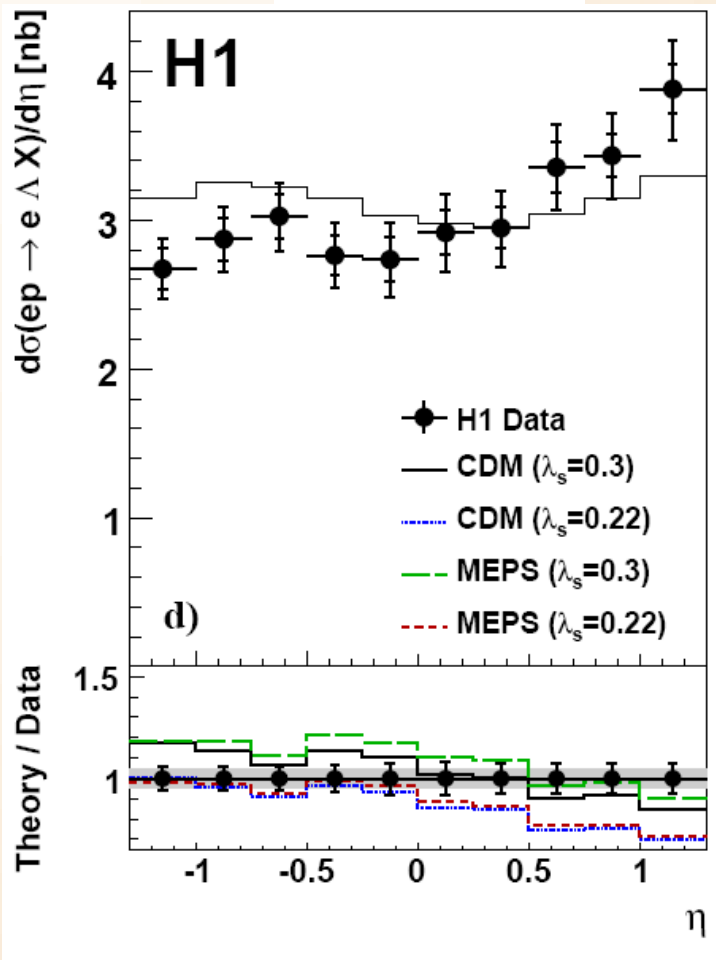


Strangeness production at low Q^2 in DIS

$e\,p \rightarrow e\,K^0_s\,X$



$e\,p \rightarrow e\,\Lambda\,X$



$\lambda_s = P_s/P_q$

- The measured total cross sections and their ratios are in general agreement with the predictions based on DJANGOH. Some small discrepancies still exist.
- The Λ – Λ-bar asymmetry is also measured and found to be consistent with zero.

Inclusive photoproduction of ϱ^0,K^{*0} and Φ mesons

γp <W>=210 GeV

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Accepted by *Phys.Lett.* **B**

$$\rho(770)^0 \rightarrow \pi^+\pi^-$$

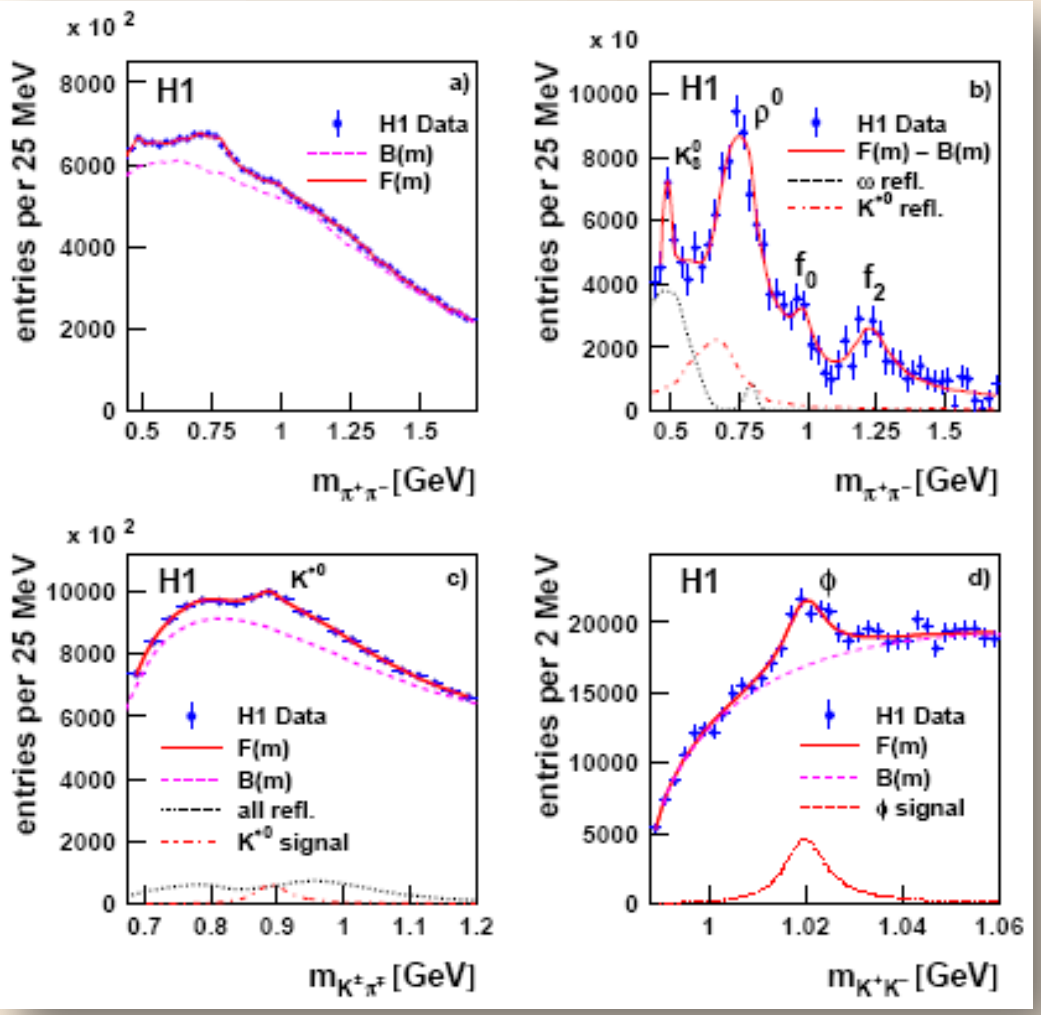
$$K^*(892)^0 \rightarrow K^+\pi^-$$

$$\overline{K}^*(892)^0 \rightarrow K^-\pi^+$$

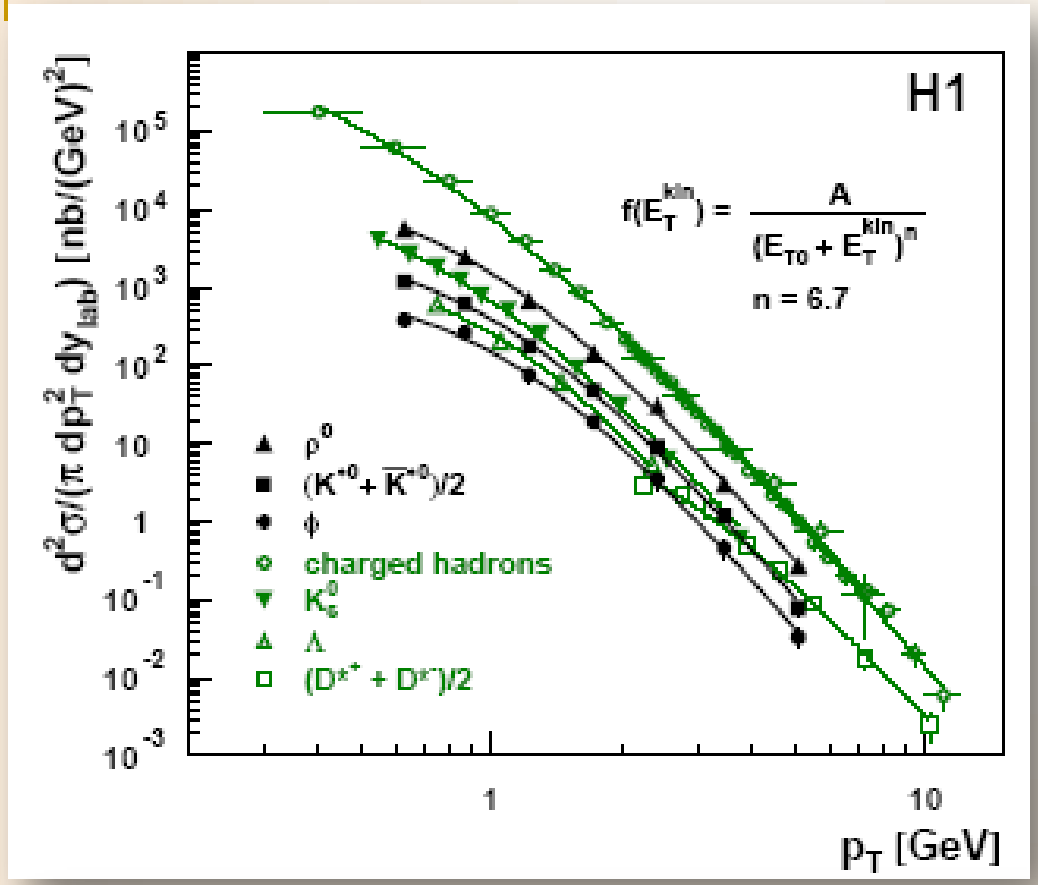
$$\phi(1020) \rightarrow K^+K^-$$

Pion kaon separation: using dE/dx and requiring P_T < 1.5 GeV

Invariant mass spectrum fitted with background, reflections and signals.



Inclusive photoproduction of ϱ^0,K^{*0} and Φ mesons



Transverse kinetic energy:

$$E_T^{kin} = \sqrt{m_0^2 + p_T^2} - m_0$$

The exponential behaviour follows from a thermodynamic model of hadroproduction, in which E_{T0} plays the role of the temperature of hadronisation.

Experiment	Measurement	$R(\phi/K^{*0})$
H1	γp, $\langle W \rangle = 210$ GeV, $\lvert y_{lab} \rvert < 1$	0.354 ± 0.060
STAR	pp, $\sqrt{s} = 200$ GeV, $\lvert y \rvert < 0.5$	0.35 ± 0.05
	Au-Au, $\sqrt{s_{NN}} = 200$ GeV, $\lvert y \rvert < 0.5$	0.63 ± 0.15

The cross section ratios are compared to other experiments

Inclusive $K^0_s K^0_s$ resonance production in ep

Phys.Rev.Lett. 101:112003,2008

Motivations

- The Standard Model allows for the existence of color singlet gluonballs.
- The $K^0_s K^0_s$ system is expected to couple to scalar and tensor glueballs:

$K^0_S K^0_S$ **bound states** $\Rightarrow J^{PC}$: 0^{++} **(scalar)**; 2^{++} **(tensor) . . .**

- Lattice QCD predicts that the lightest glueball has $J^{PC} = 0^{++}$ and lies in the mass range 1730 $\pm$ 100 MeV

DATA sample:

- ZEUS data: $\mathcal{L} \approx 0.5$ fb^{-1}
- The data sample is dominated by 90% photoproduction, while 10% is Deep Inelastic Scattering

Inclusive $K^0_s K^0_s$ resonance production in ep

	Coherent States Properties based on SU(3)		
Coherent 2^+ states	$f_2(1270)$	$a_2(1320)$	$f_2(1525)$
Isospin I =	0	1	0
Quark Content	$(u\bar{u}+d\bar{d})/\sqrt{2}$	$(u\bar{u}-d\bar{d})/\sqrt{2}$	$s\bar{s}$
Charge Factor	$(\frac{2}{3}\times\frac{2}{3}+\frac{1}{3}\times\frac{1}{3})\frac{1}{2}$	$(\frac{2}{3}\times\frac{2}{3}-\frac{1}{3}\times\frac{1}{3})\frac{1}{2}$	$\frac{1}{3}\times\frac{1}{3}$
Amplitude ratio	5 BW	-3 BW	2 BW

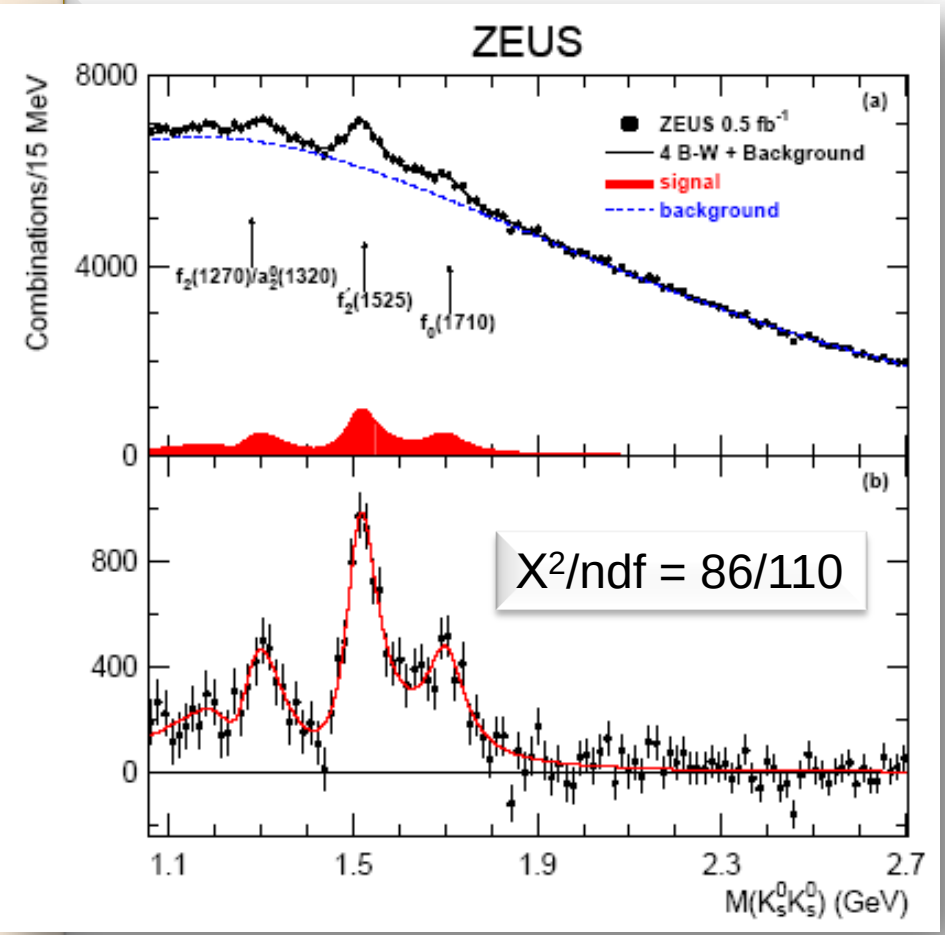
Function = a {5 * BW_f_2(1270) – 3 * BW_a_2(1320) + 2 * BW_f_2(1525)}^{2}
+ b {BW_f_0(1710)}^{2}
+ c Background U(M)

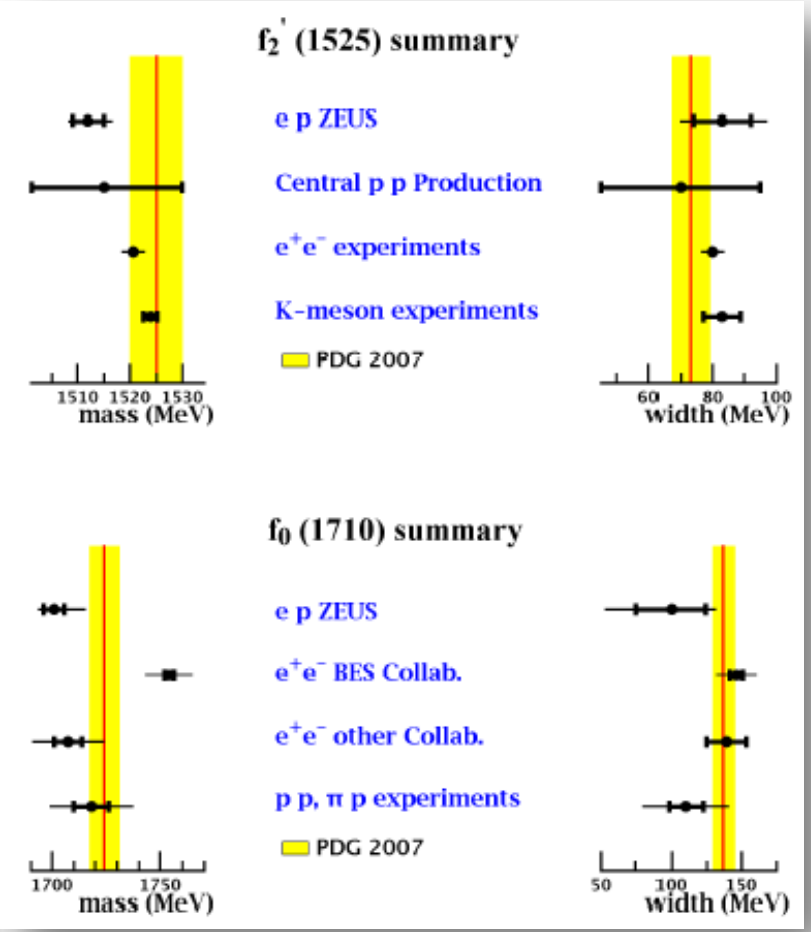
BW is a relativistic Breit Wigner amplitude:

$$F(M) = \frac{m\sqrt{\Gamma}}{m^2 - M^2 - im\Gamma}$$

Faiman, D. and Lipkin, H. J. and Rubinstein, H. R., Phys. Lett. **B59**, 269 (1975)

Inclusive $K^0_s K^0_s$ resonance production





- One of the best $f_0(1710)$ reported signals: 4058 $\pm$ 820 events ≈ 5 s.d.
- If $f_0(1710)$ is seen in $\gamma\gamma \to K^0_S K^0_S$ (TASSO,L3) it is unlikely to be pure glueball since photons can couple in the partonic level only to charged quarks

Outlook

- Many other analyses are published or ongoing
- HERA has a rich program on particle production, complementary to e^+e^- and pp

Backup slides

Energy dependence of the charged multiplicity in deep inelastic scattering at HERA

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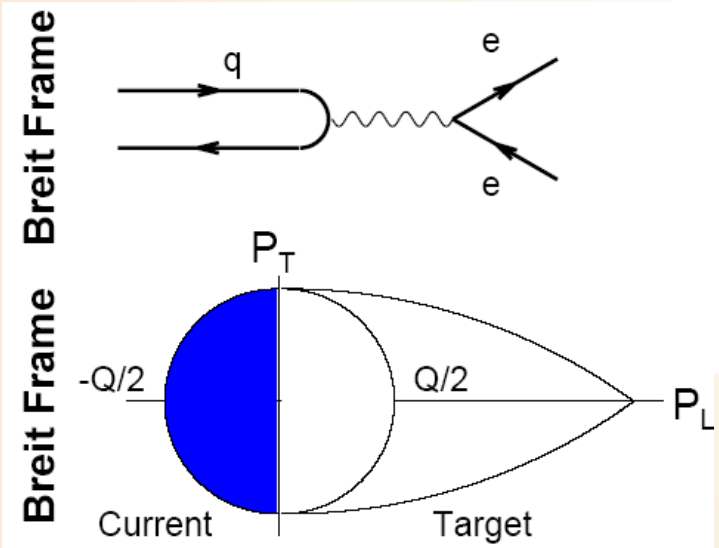
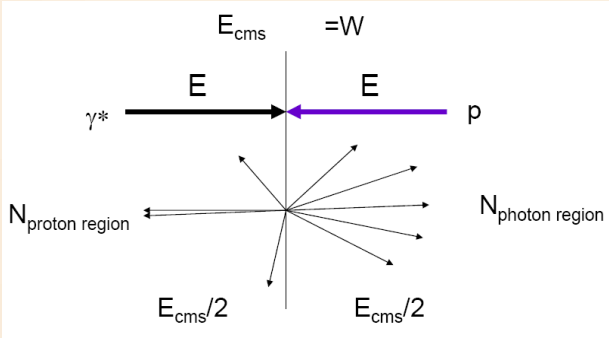
Reference frames in DIS event:



$P_L < 0$: current region
$P_L > 0$: target region

Current region is comparable to e+e-
Target region is comparable to pp collisions

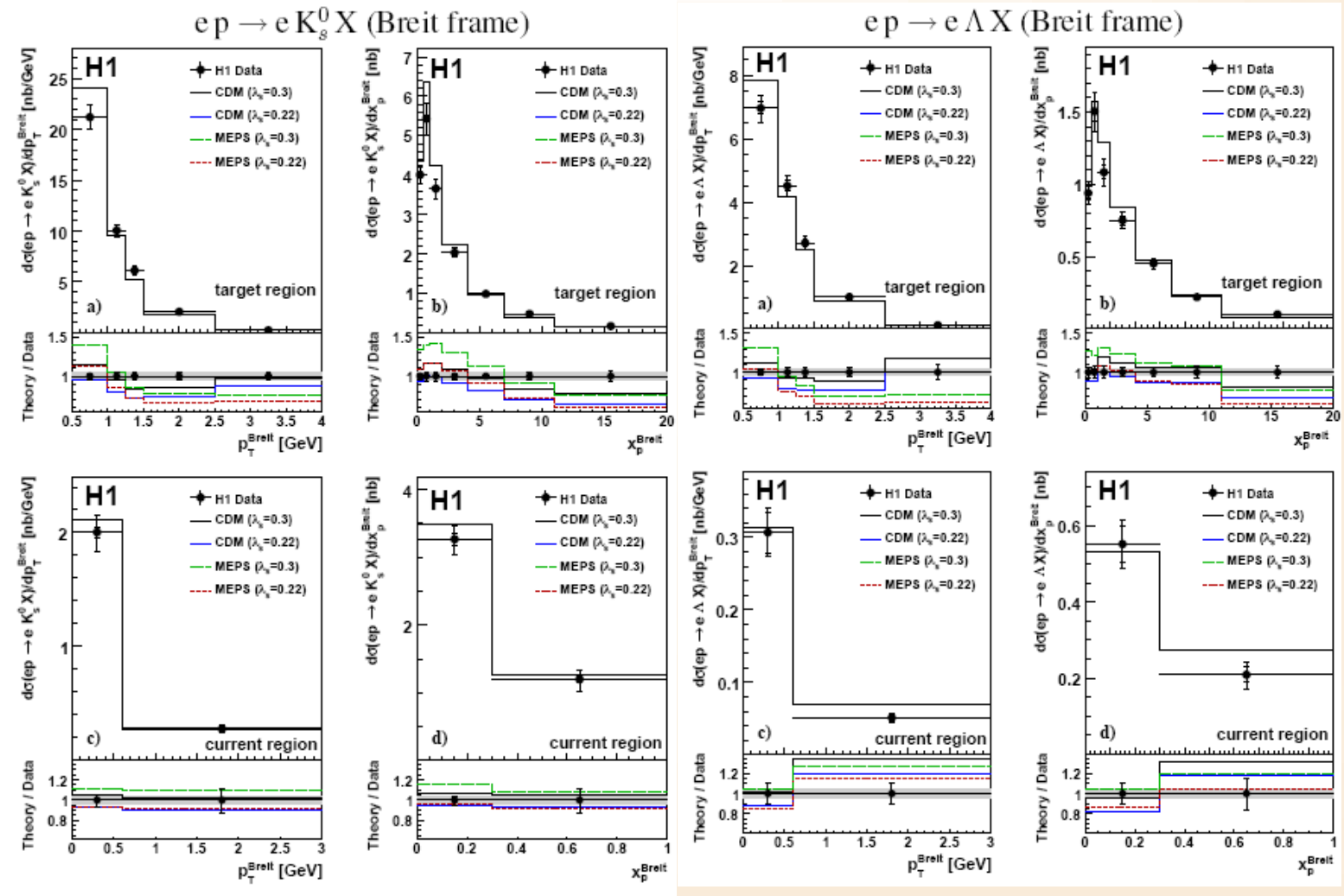
Hadronic center-of-mass



e^+e^-: $s^{1/2} = 2E_{beam}$
ep(Breit Frame): Q or E^{cr}_B
ep(HCM): W

Strangeness Production at low Q^2 in DIS

In Breit frame



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Inclusive $K^0_s K^0_s$ resonance production in ep collisions at HERA

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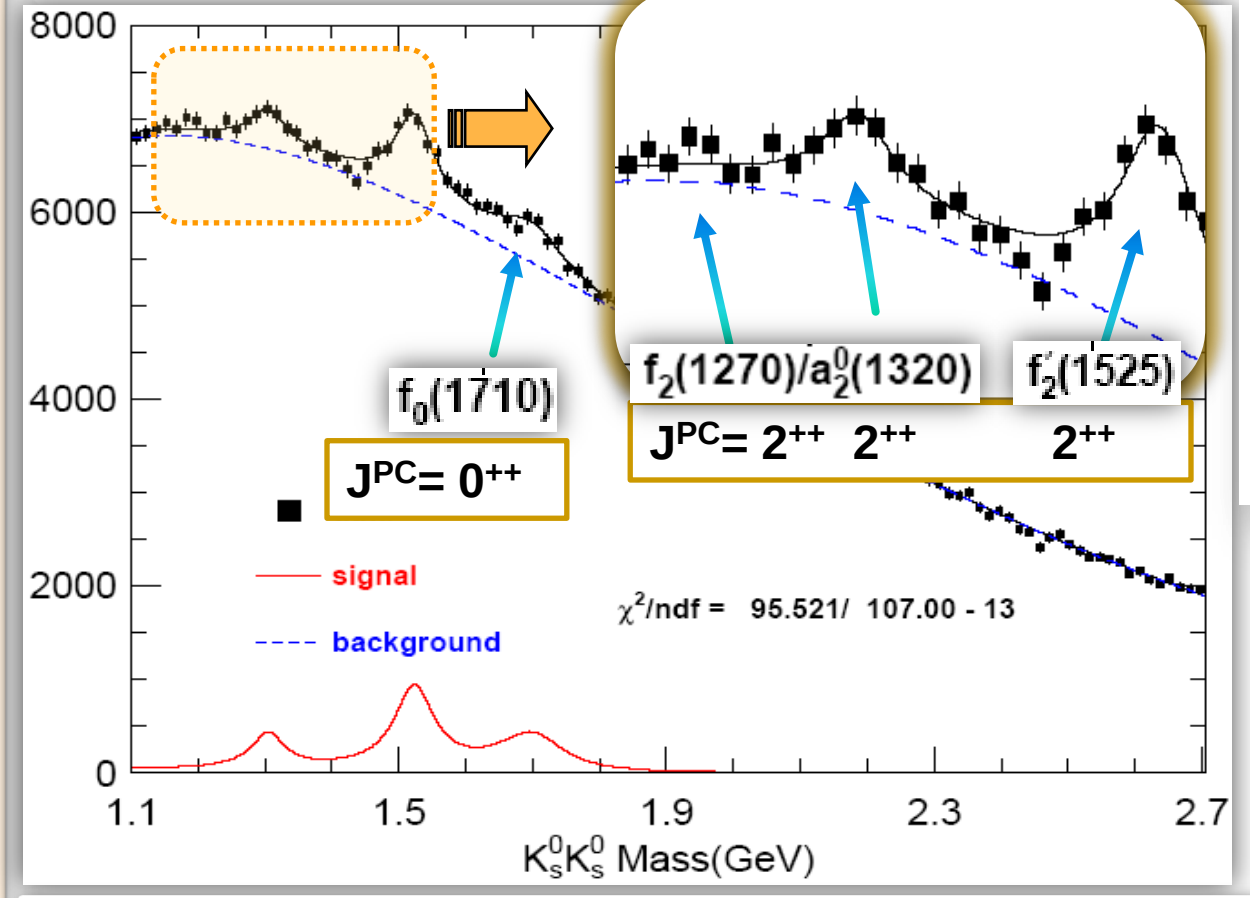
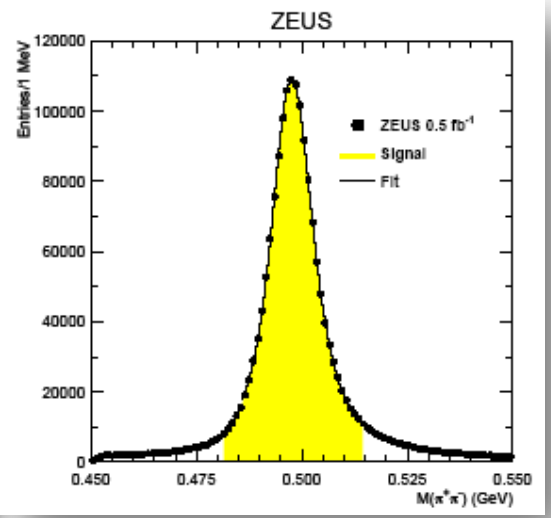




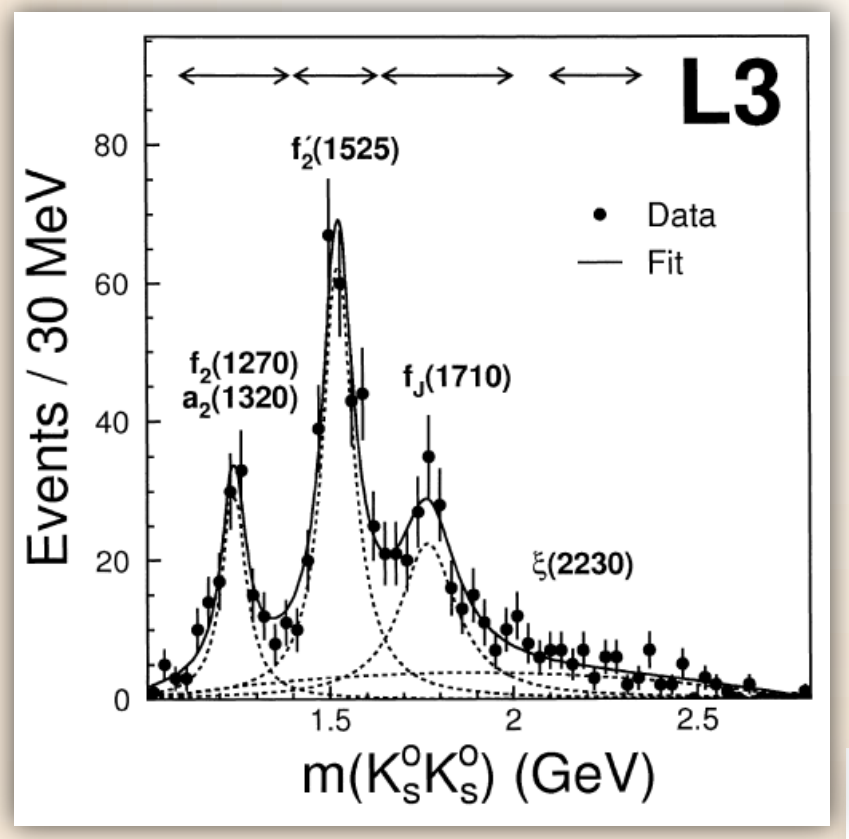
Full sample contains:

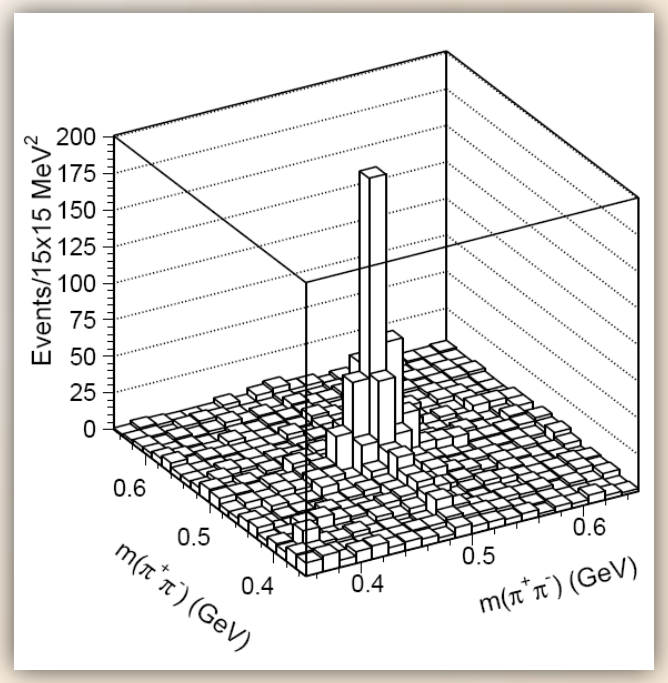
1300509 K^0_s → 672418 $K^0_s K^0_s$

Fit unable to describe the constructive and destructive interference between $f_2(1270)/a_2(1320)$ and $f_2(1525)$.

Inclusive $K^0_s K^0_s$ resonance production in ep collisions at HERA: Previous Publication

- **"K0sK0s Final State in two photon collisions and implications for glueballs" (L3)** Published in **Phys.Lett.B501:173-182,2001 (hep-ex/0010037)**





~4σ for $f_J(1710)$

	$f_2(1270)$-$a_2(1320)$	$f_2'(1525)$	$f_J(1750)$
Mass (MeV)	1239 ± 6	1523 ± 6	1767 ± 14
Width (MeV)	78 ± 19	100 ± 15	187 ± 60
Area	123 ± 22	331 ± 37	220 ± 55

Inclusive $K^0_s K^0_s$ resonance production in ep collisions at HERA

Fit	No interference		Interference		PDG 2007 Values	
χ^2/ndf	96/95		86/97			
in MeV	Mass	Width	Mass	Width	Mass	Width
$f_2(1270)$	1304 ± 6	61 ± 11	1268 ± 10	176 ± 17	1275.4 ± 1.1	$185.2^{+3.1}_{-2.5}$
$a_2^0(1320)$			1257 ± 9	114 ± 14	1318.3 ± 0.6	107 ± 5
$f_2'(1525)$	$1523 \pm 3^{+2}_{-8}$	$71 \pm 5^{+17}_{-2}$	$1512 \pm 3^{+1.4}_{-0.5}$	$83 \pm 9^{+5}_{-4}$	1525 ± 5	73^{+6}_{-5}
$f_0(1710)$	$1692 \pm 6^{+9}_{-3}$	$125 \pm 12^{+19}_{-32}$	$1701 \pm 5^{+9}_{-2}$	$100 \pm 24^{+7}_{-22}$	1724 ± 7	137 ± 8

Table 1: *The measured masses and widths for the $f_2(1270)$, $a_2^0(1320)$, $f_2'(1525)$ and $f_0(1710)$ states using $K_S^0 K_S^0$ decays as determined by one fit neglecting interference and another one with interference as predicted by SU(3) symmetry arguments included. Both statistical and systematic uncertainties are quoted. The systematic uncertainty for the $f_2(1270)/a_2^0(1320)$ peak is expected to be significant and it is not listed. Also quoted are the PDG values for comparison.*