Light/Strange/Charm Hadron Measurements in ep Collisions as a Baseline for Heavy-Ion Physics

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on behalf of
H1 and ZEUS Collaborations

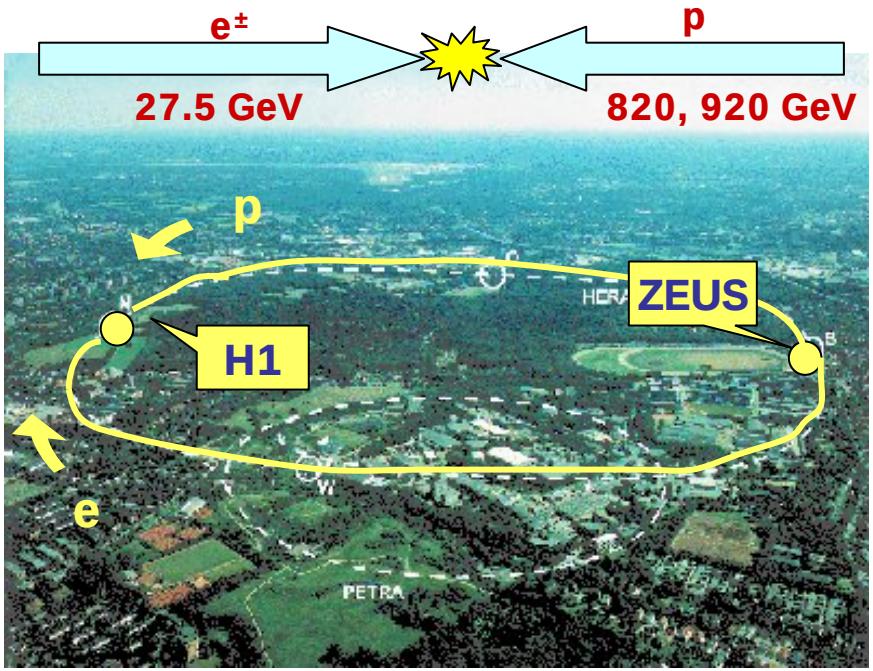
- Inclusive non-diffractive photoproduction of $\rho(770)^0$, $K^*(892)^0$ and $\phi(1020)$ mesons
- K^0_s and Λ at low Q^2 in DIS
- Inclusive $K^{*\pm}$ production at low Q^2 in DIS

H1

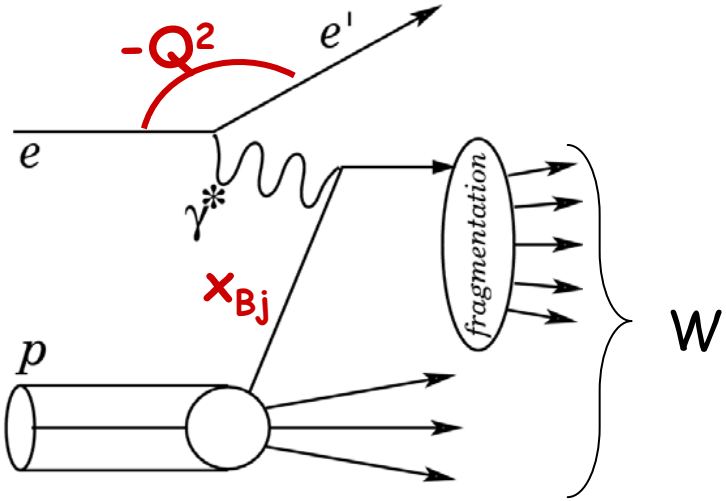
- Inclusive $K^0_s K^0_s$ resonance production
- Production of excited charm and charm-strange mesons

ZEUS

The HERA Collider



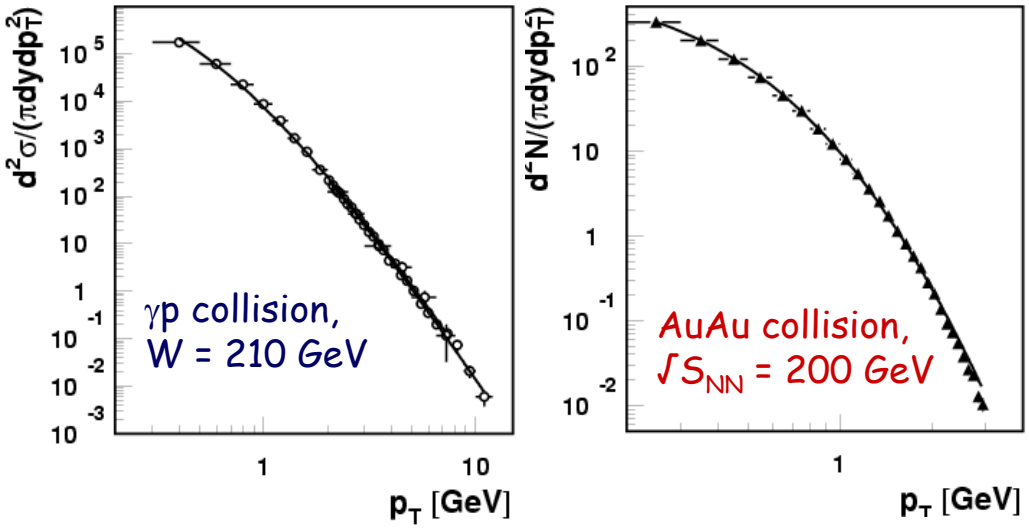
H1 and ZEUS:
- 92 - 07 years
- Lumi ~ 0.5 fb^{-1} (each exper.)

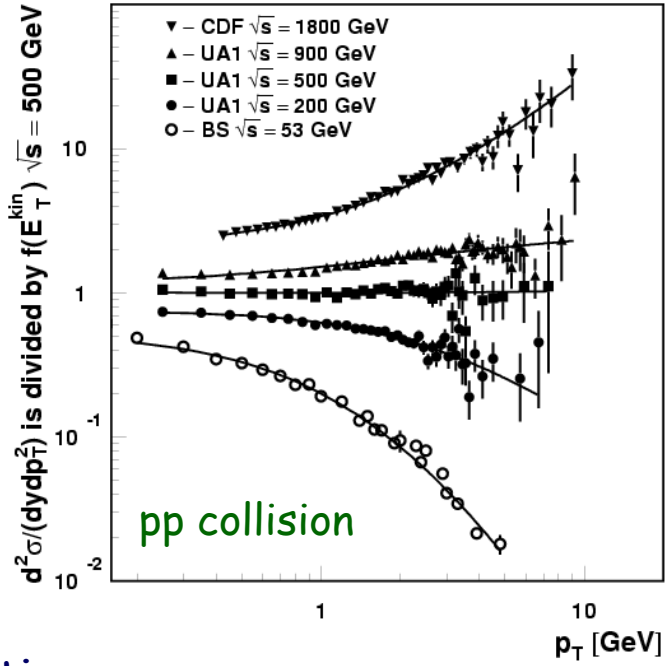


ep kinematics:

energy c.m.: $\sqrt{s}$ = 300-320 GeV
hadronic energy: $W = m(\gamma^* p)$
photon virtuality : Q^2
two regions: $Q^2 \approx 0$ GeV² — photoproduction
$Q^2 > 1$ GeV² — electroproduction (DIS)

Charged Particle Production





- Inclusive charged spectrum in γp, pp and AuAu collision could be describe by power law distribution:

$$f(E_T^{kin}) = \frac{A}{(E_{T_0} + E_T^{kin})^n} = \begin{cases} \dfrac{A}{(E_T^{kin})^n}, & E_T^{kin} >> E_{T_0} \\ \sim \exp(-E_T^{kin}/T), & E_T^{kin} < E_{T_0}, \quad T = E_{T_0}/n \end{cases}$$

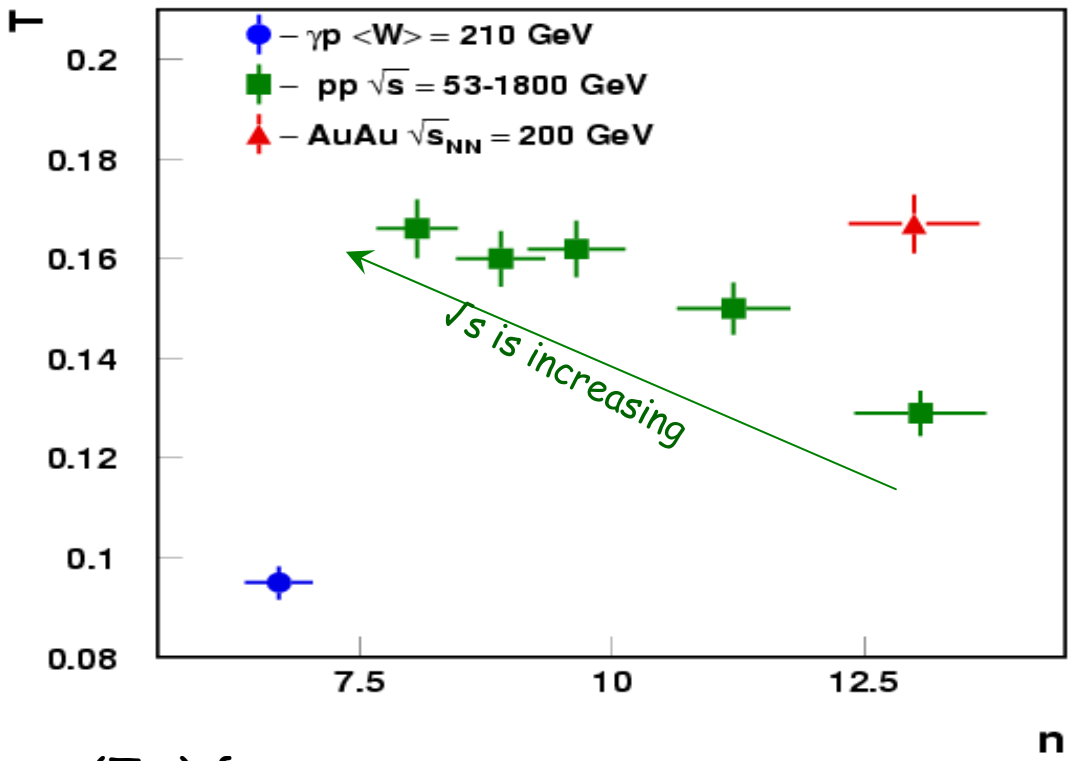
pQCD

Boltzmann distribution

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

Comparison with simpler systems (γp, pp) gives more understanding for heavy ion collision

Charged Particle Production

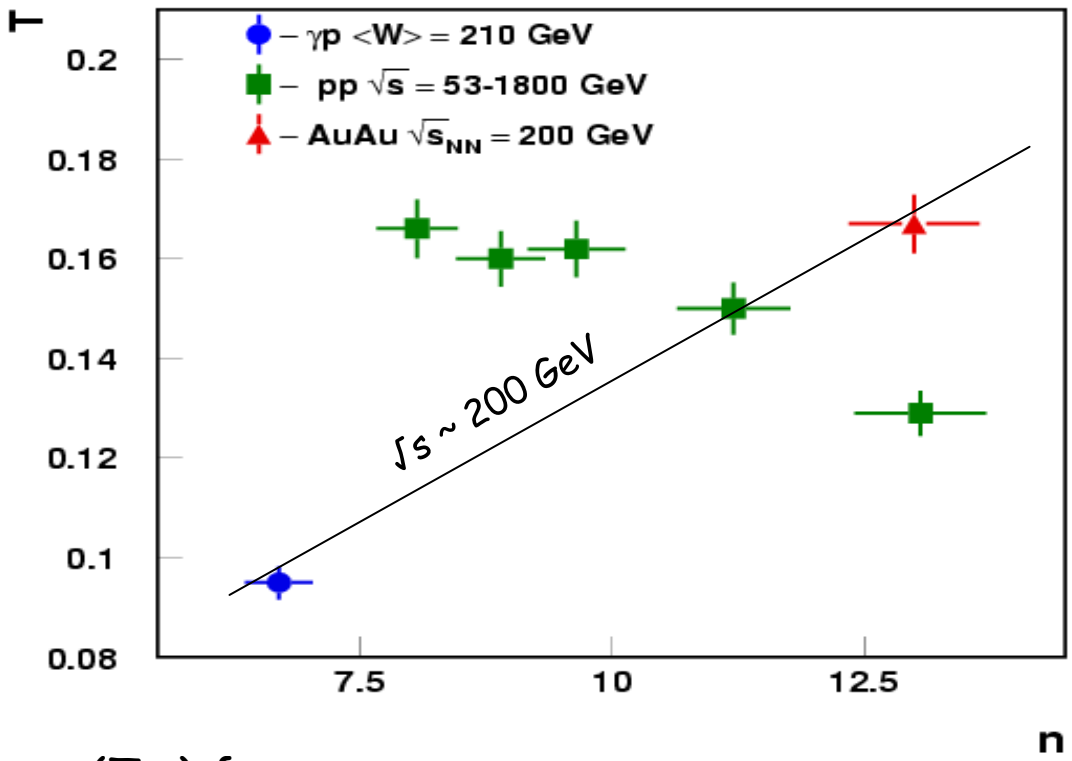


(T,n) frame:

- stability island in pp spectrum

Comparison with simpler systems (γp, pp) gives more understanding for heavy ion collision

Charged Particle Production



(T,n) frame:

- stability island in pp spectrum
- linear dependents for γp, pp and AuAu at the same energy $\sqrt{s} \sim 200$ GeV
- other regularities …

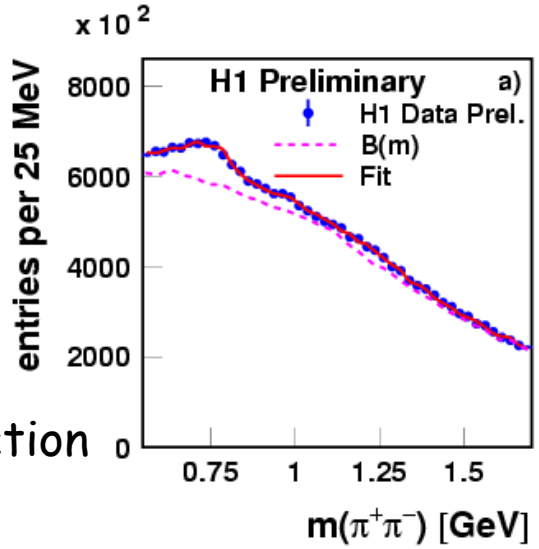
Comparison with simpler systems (γp, pp) gives more understanding for heavy ion collision

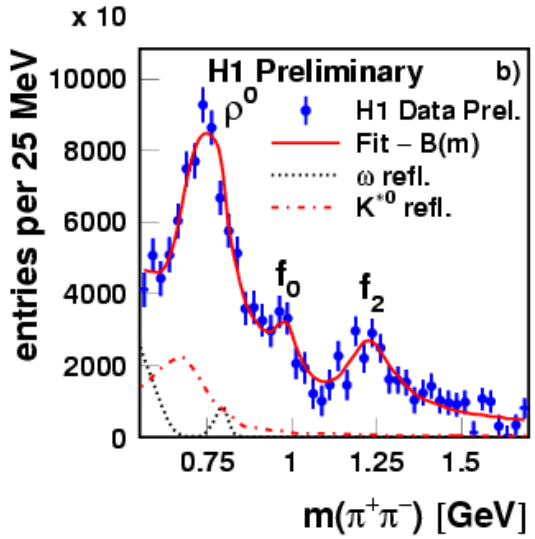
Inclusive Photoproduction ρ^0, K* and ϕ

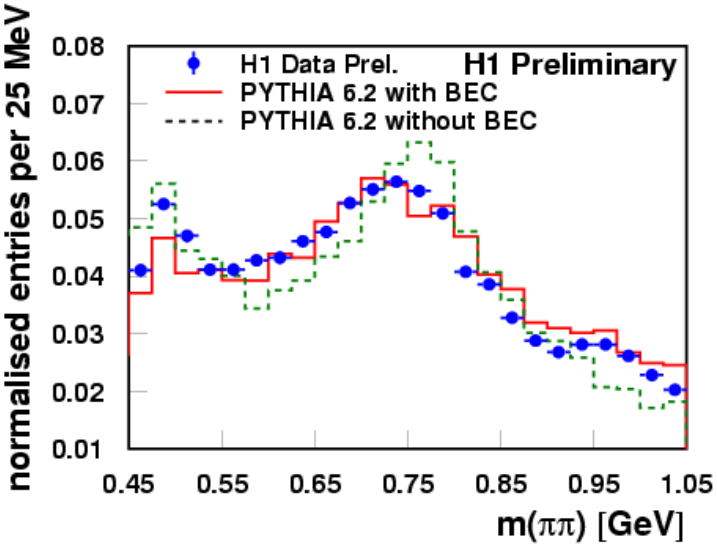
Photoproduction ($Q^2 \sim 0$)
2000 year $\langle W \rangle \approx 210$ GeV
Lumi = 36.5 pb^{-1}
$|y_{lab}| < 1$, $0.5 < p_T < 7$ GeV

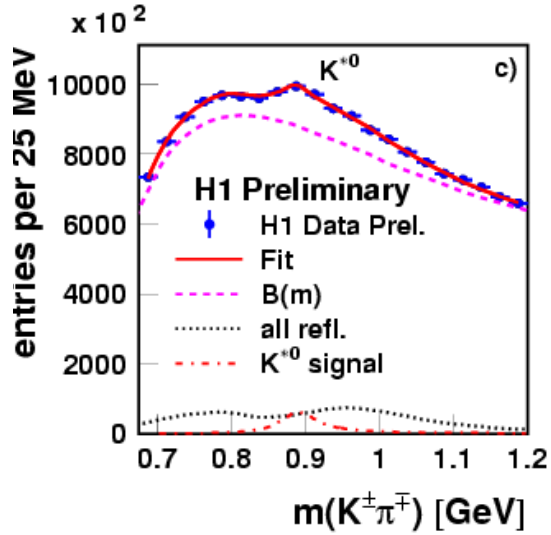
Fit:
modified rel. BW + BG + Reflection

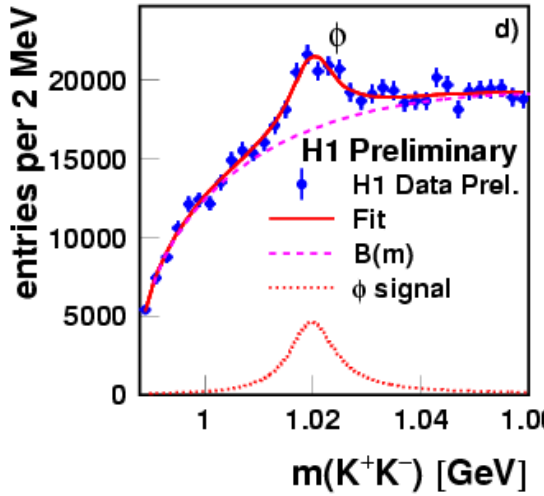
$m(\pi^+\pi^-) - m(\pi^\pm\pi^\pm)$





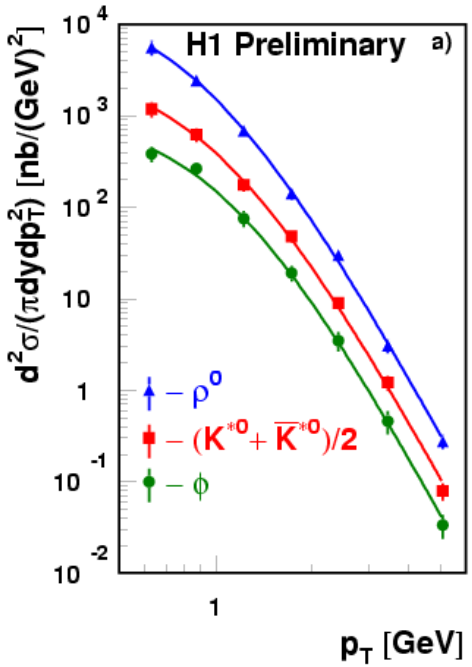


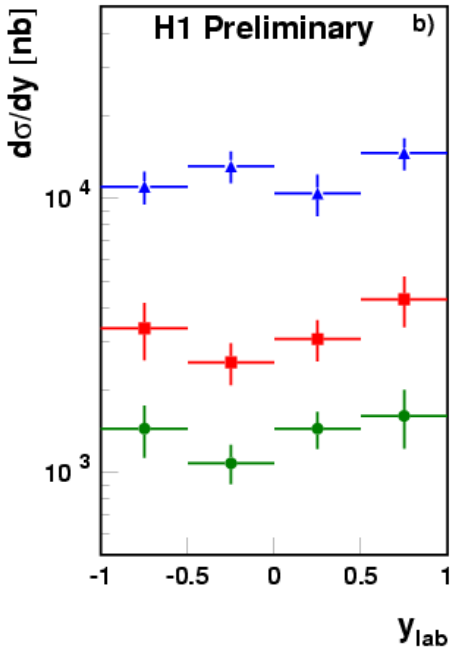




A modification of ρ^0 produced in γp collisions is described by taking into account Bose-Einstein correlations in Monte Carlo

ρ^0, K* and ϕ: cross section, comparison with RHIC



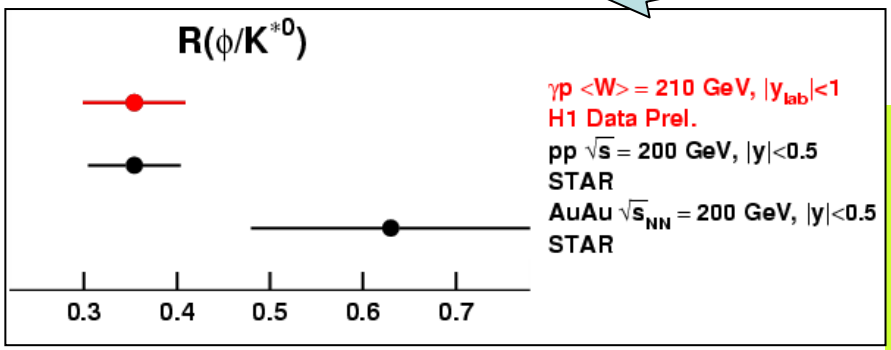


$$f(E_T^{kin}) = \frac{A}{(E_{T_0} + E_T^{kin})^n},$$

$$A = \underbrace{\left\langle \frac{d\sigma}{dy} \right\rangle_{|y_{lab}|<1}} \frac{(n-1)(n-2)(E_{T_0})^{n-1}}{2\pi(E_{T_0} + (n-2)m_0)}$$

$\langle d\sigma/dy \rangle_{|y_{lab}|<1}$ is extrapolated cross section in all p_T range

Calculate ratios R of mesons cross section using this extrapolation



- The ratio $R(\phi/K^*)$ measured in γp is in agreement with pp results and below that for AuAu measured at about the same collision energy at RHIC.
- More precise DATA are need from AuAu measurements.

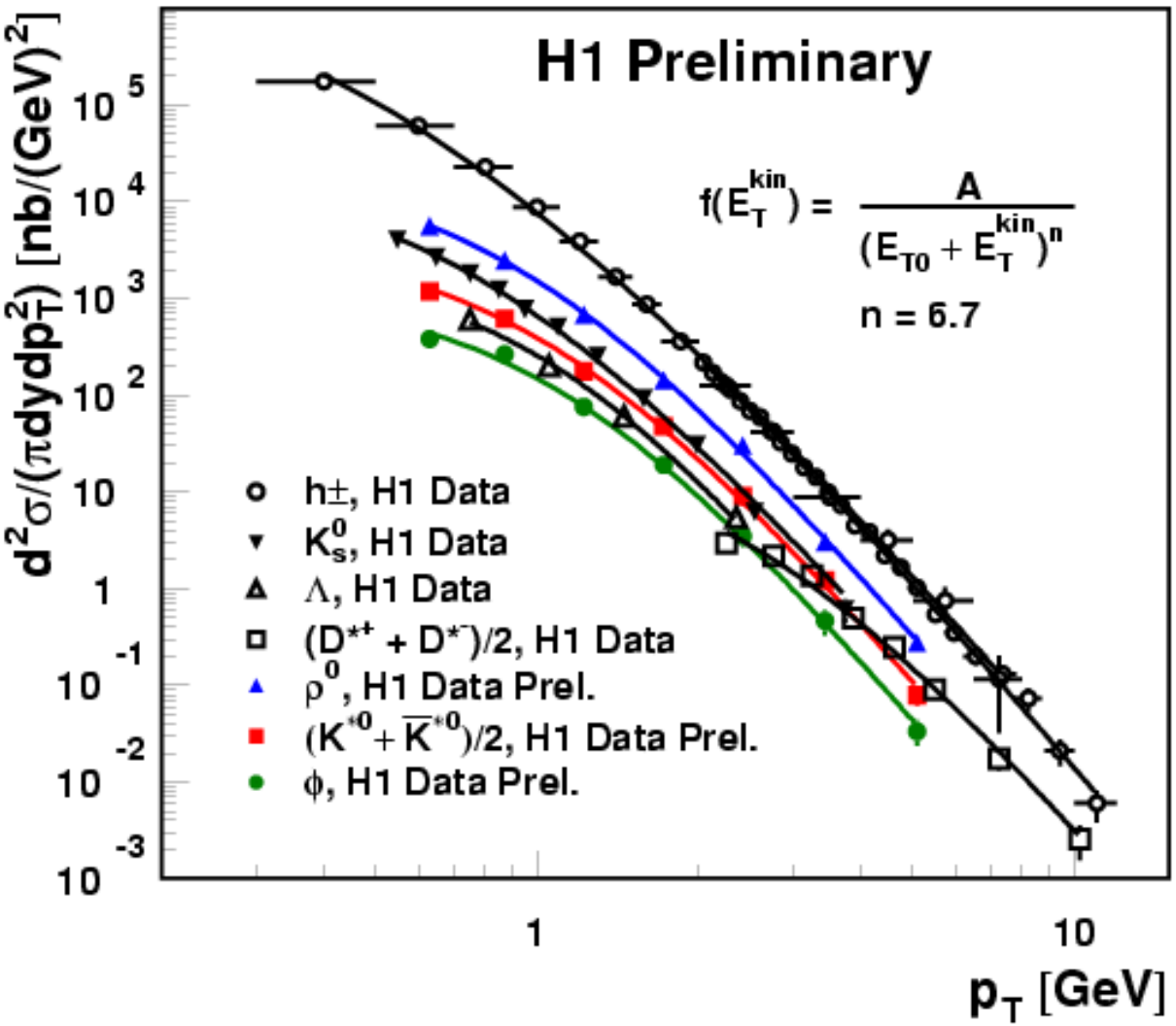
ρ^0, K* and ϕ: cross section fit parameters

H1 Preliminary

	ρ^0	$(K^{*0} + \overline{K}^{*0})/2$	ϕ
$<d\sigma/dy>_{\|y\|<1}$ [nb]	23600 ± 2400	5220 ± 560	1850 ± 210
T [GeV]	0.151 ± 0.006	0.166 ± 0.008	0.170 ± 0.009
T^{PYTHIA} [GeV]	0.136	0.140	0.149
$<E_T>$ [GeV]	1.062 ± 0.014	1.205 ± 0.017	1.333 ± 0.020
$<E_T^{kin}>$ [GeV]	0.287 ± 0.014	0.313 ± 0.017	0.315 ± 0.020
$<p_T>$ [GeV]	0.726 ± 0.021	0.811 ± 0.025	0.860 ± 0.032
$<p_T>_{pp}$ [GeV]	0.616 ± 0.062	0.81 ± 0.14	0.82 ± 0.03
$<p_T>_{AuAu}$ [GeV]	0.83 ± 0.10	1.08 ± 0.14	0.97 ± 0.02

- ρ^0, K* and ϕ are produced with about the same value of the average $<E_T^{kin}>$
- n is described by PYTHIA6.2 (pQCD) while T is not (non pQCD)
- $<p_T>$ in H1 is in agreement with RHIC pp and is lower then RHIC AuAu

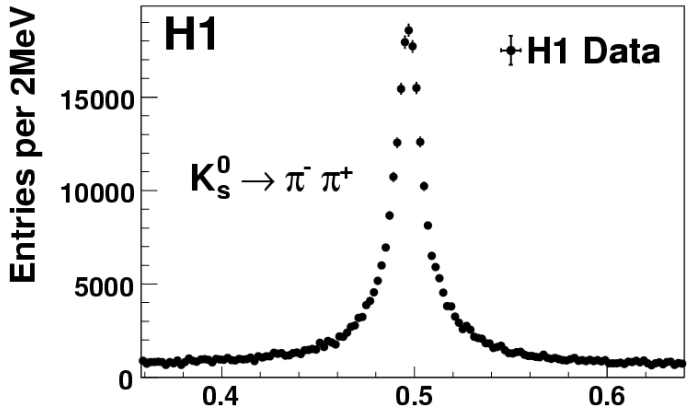
ρ^0, K* and ϕ: cross section

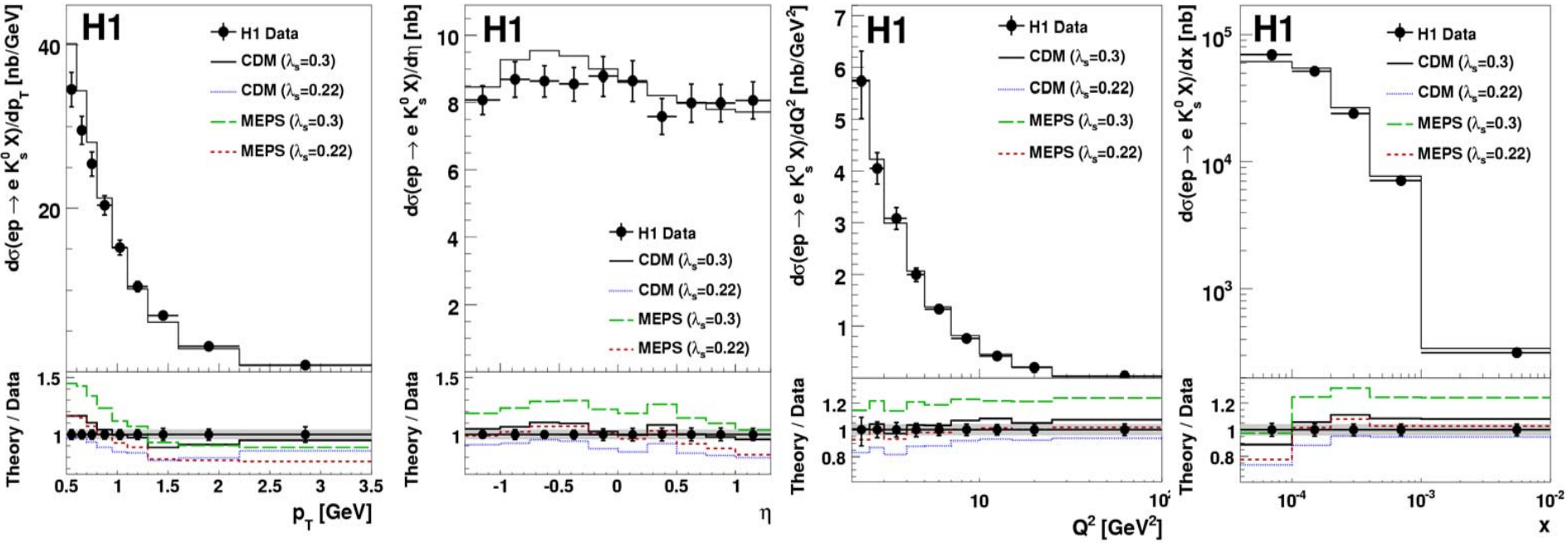


- All inclusive photoproduction cross sections measured at H1 is described by power law distribution with fixed n = 6.7 calculated from h±

K^0_s signal

DIS ($2 < Q^2 < 100\ GeV^2$)
HERA I
Lumi = 49.9 pb^{-1}
$|\eta| < 1.3,\ 0.5 < p_T < 3.5\ GeV$
Fit: 2 Gaussian functions + BG

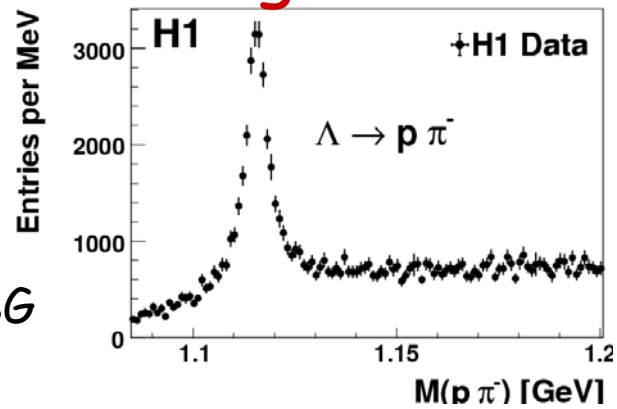


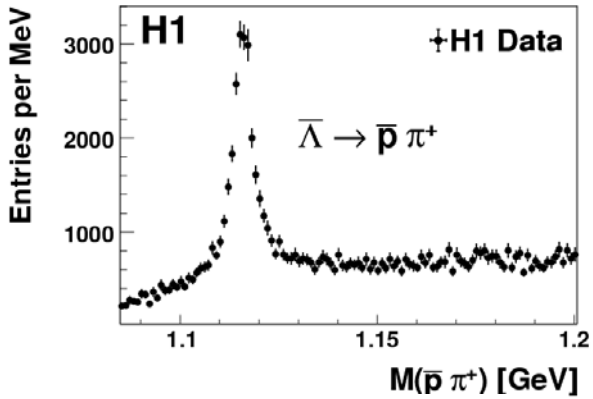


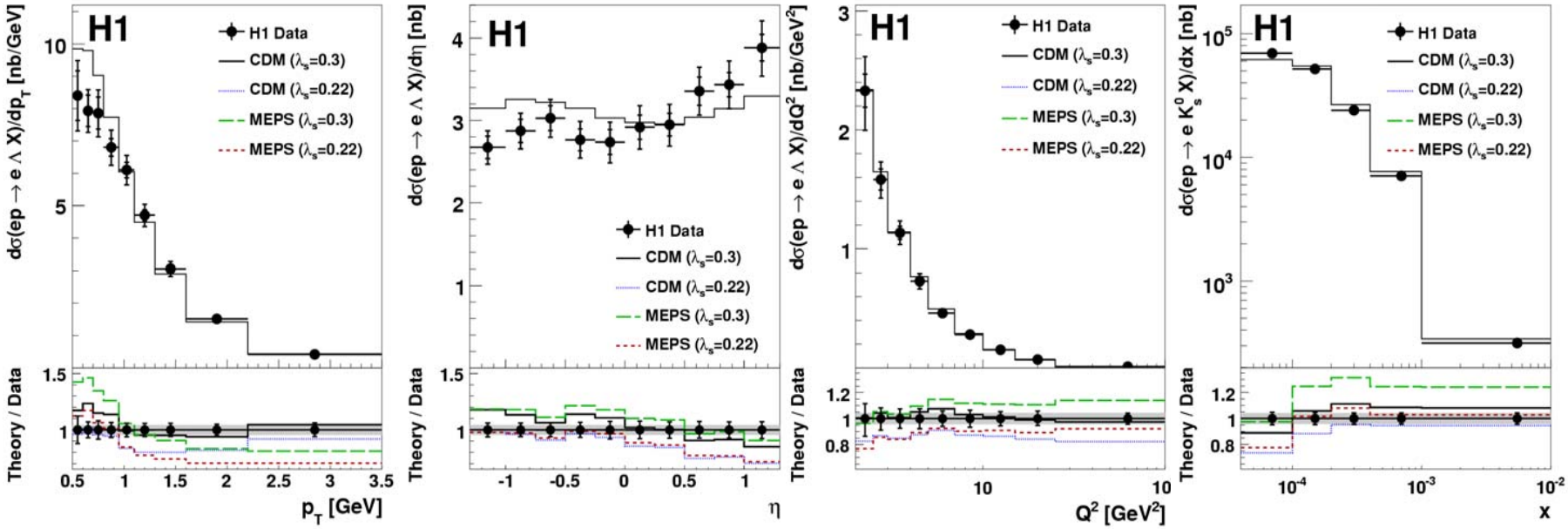
- Overall features of the Data are reproduced by the ARIADNE CDM with $\lambda_s = 0.3$ and MEPS with $\lambda_s = 0.22$
- Predictions fail to describe the details in low p_T, low x and large η

Λ signal

DIS ($2 < Q^2 < 100\ GeV^2$)
HERA I
Lumi = 49.9 pb^{-1}
$|\eta| < 1.3,\ 0.5 < p_T < 3.5\ GeV$
Fit: 2 Gaussian functions + BG

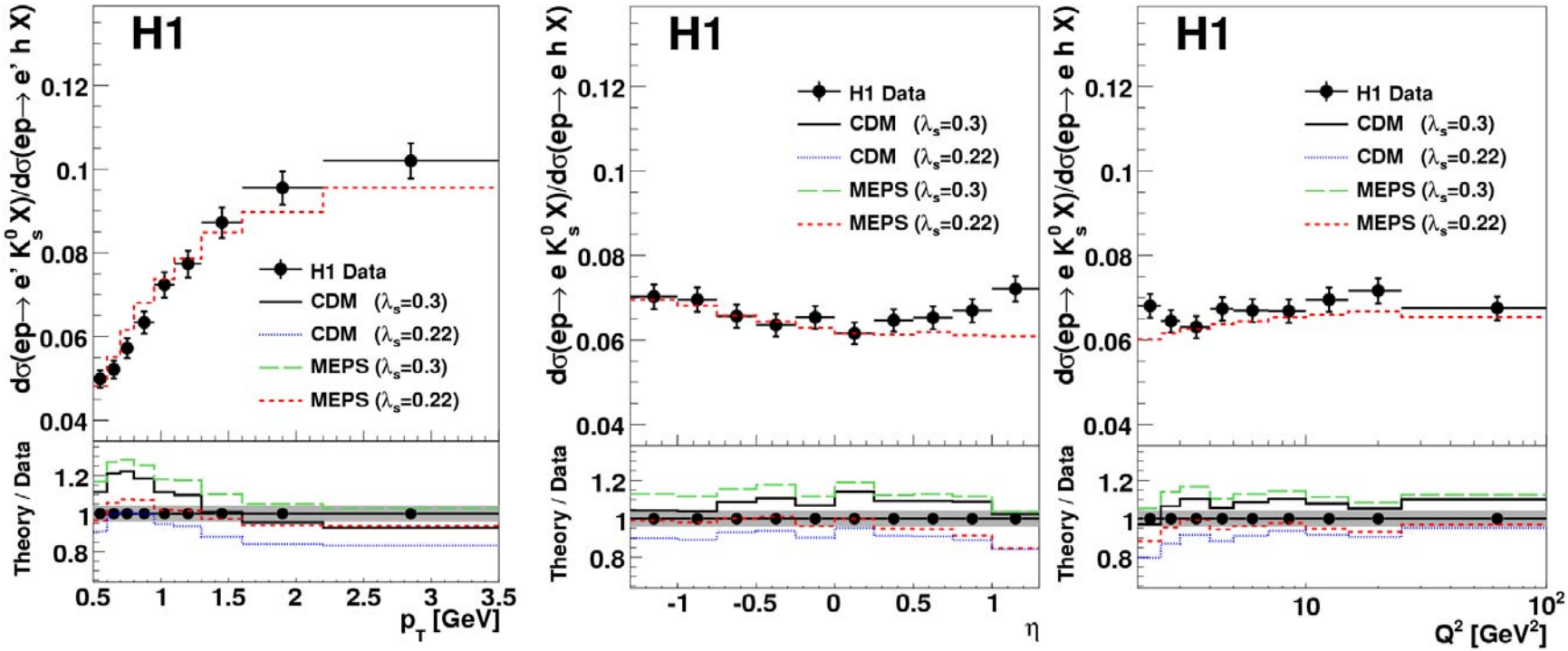






- Overall features of the Data are reproduced by the ARIADNE CDM with $\lambda_s = 0.3$ and MEPS with $\lambda_s = 0.22$
- Predictions fail to describe the details in low p_T, low x and large η
- No asymmetry in the Λ and $\overline{\Lambda}$ is found within errors

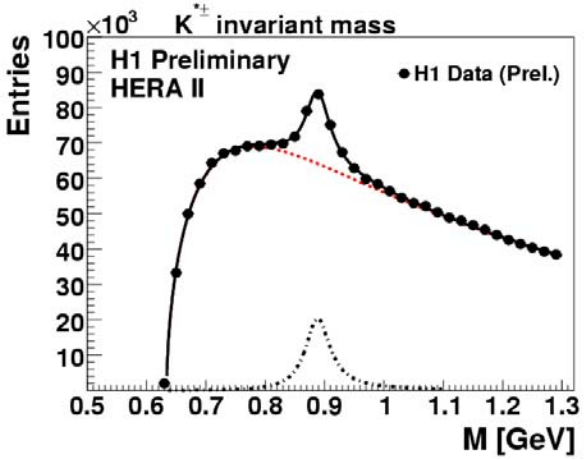
K^0_s to Light Hadrons

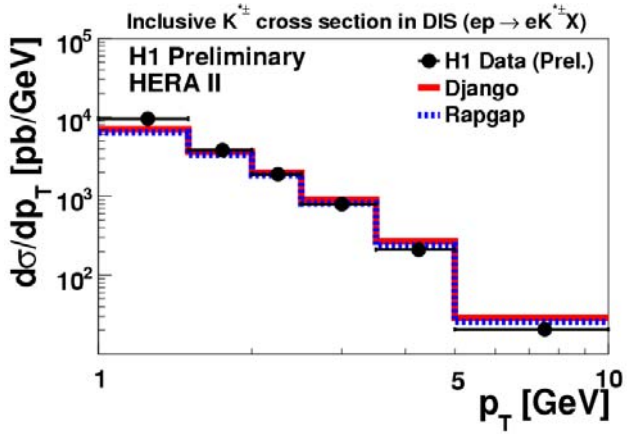


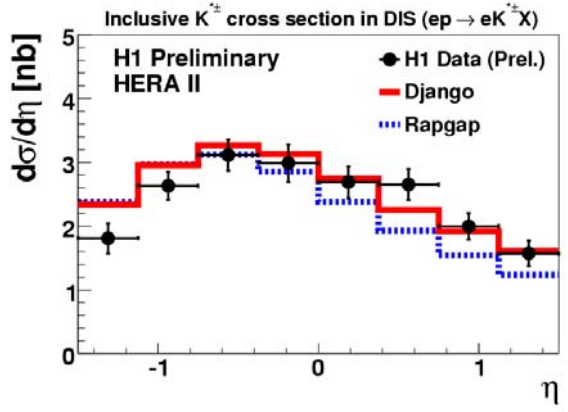
- K^0_s/hadrons is overall described by CDM and MEPS with λ_s = 0.22
- K^0_s and Λ is better described by CDM with λ_s = 0.3

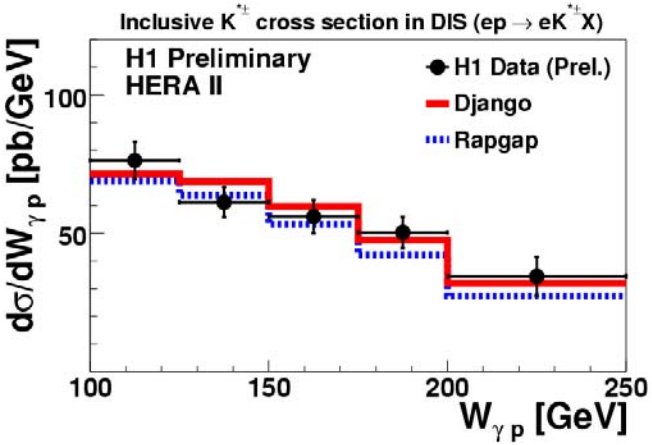
$K^{*\pm} \to K^0_s \pi^\pm$ signal

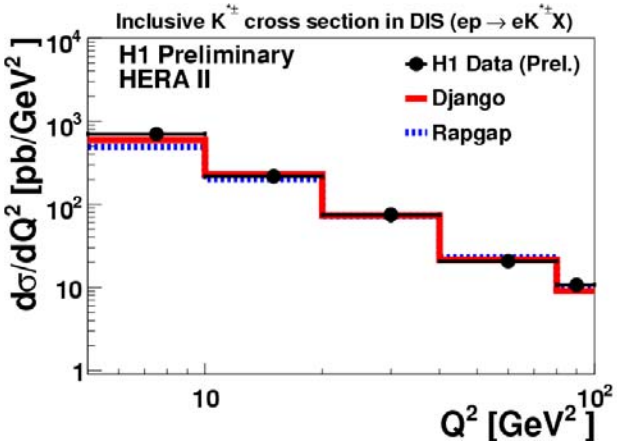
DIS: $5 < Q^2 < 100\ GeV^2$ HERA II: Lumi = $302\ pb^{-1}$ $p_T(K^*) > 1\ GeV$, $|\eta(K^*)| < 1.5$

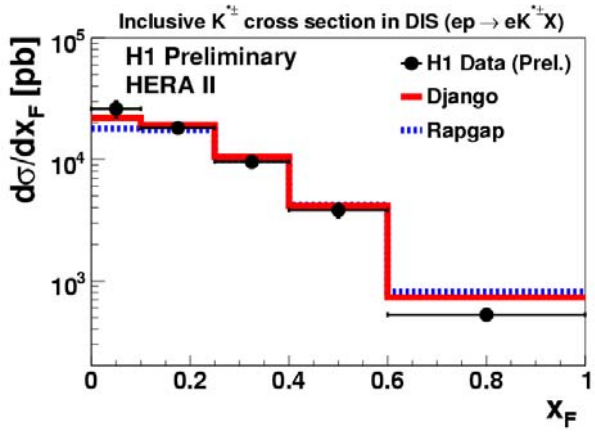








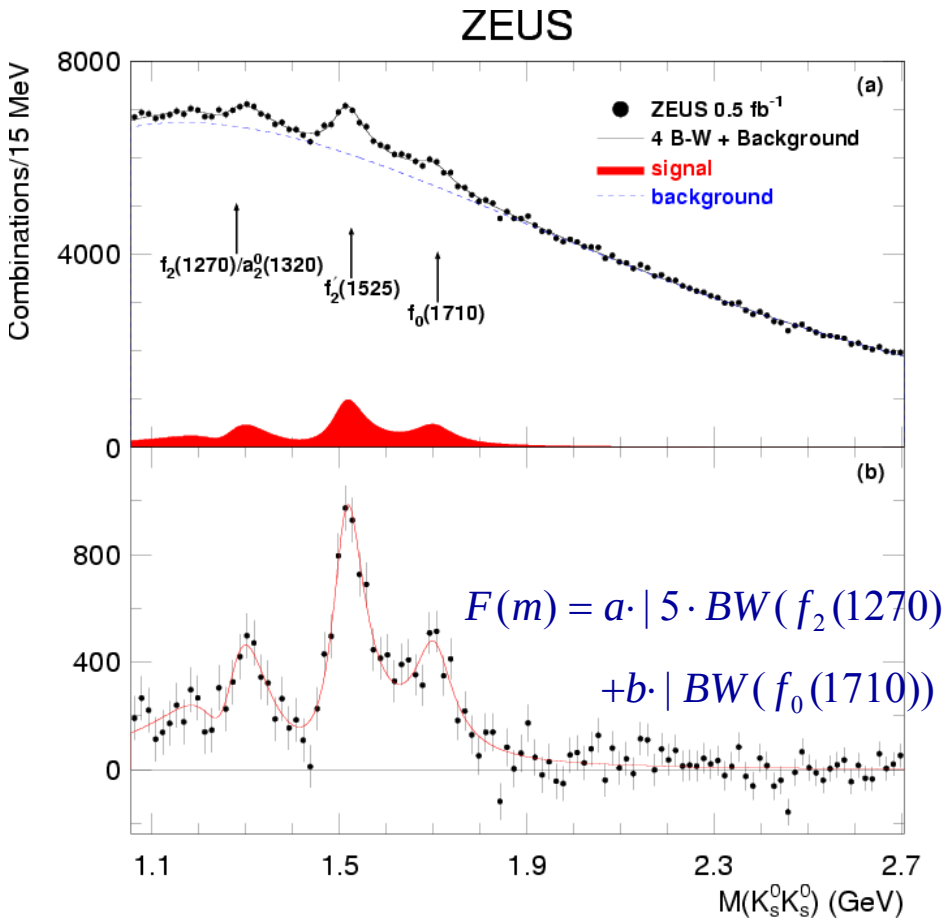




Django (CDM) and RAPGAP (MEPS) are in agreement with Data
Consistent with K^0_s and Λ Data

$K^0_s K^0_s$: Glueball Candidate

HERA I + HERA II Data, all Q^2 => selected 672418 $K^0_s K^0_s$ combinations

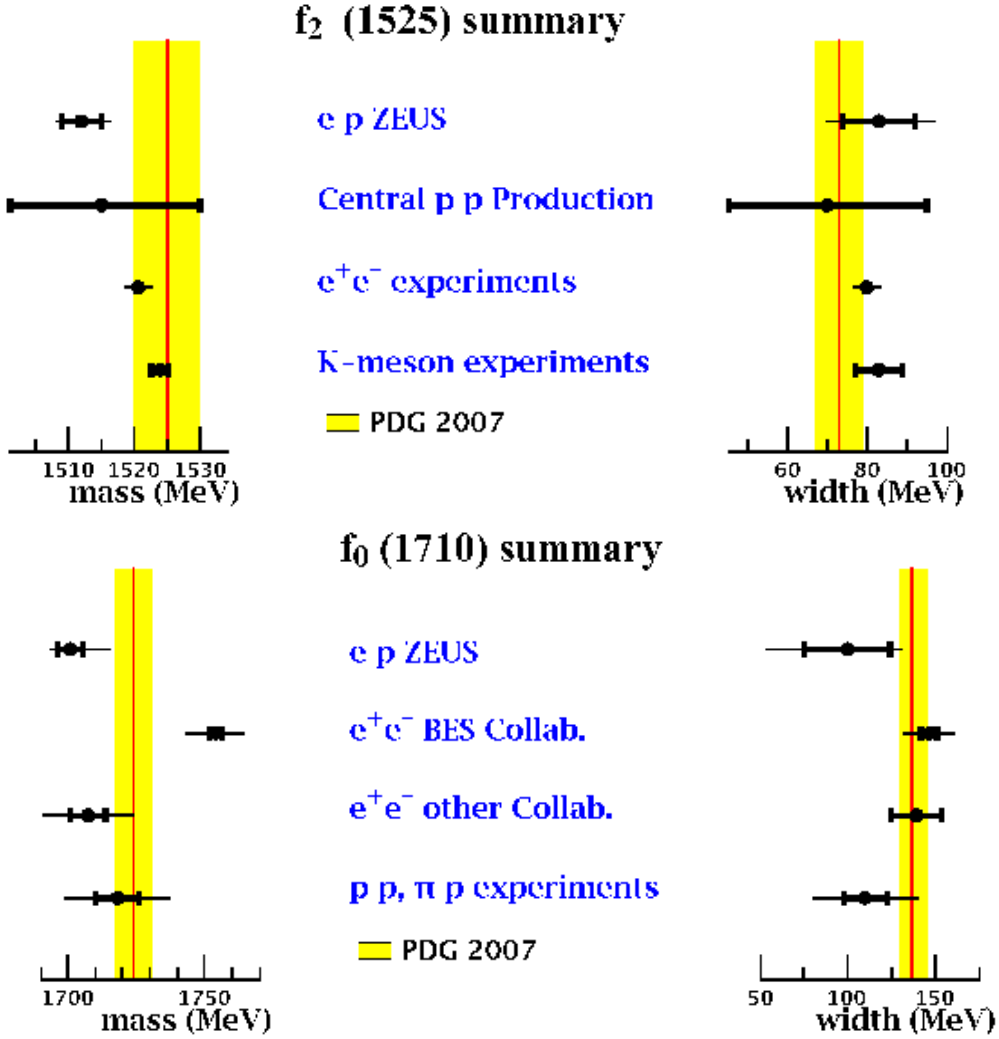


- the lightest glueball:
  $J^{PC} = 0^{++}$, M = 1550-1750 MeV
- fit:
  interference rel. BW + BG:

$$F(m) = a \cdot |\, 5 \cdot BW(f_2(1270) - 3 \cdot BW(a_2^0(1320)) + 2 \cdot BW(f_2'(1525))\,|^2 +$$
$$+ b \cdot |\, BW(f_0(1710))\,|^2 + BG$$

- $f_0(1710)$ is observed with 5 sigma effect
- this state is considered to be a glueball candidate

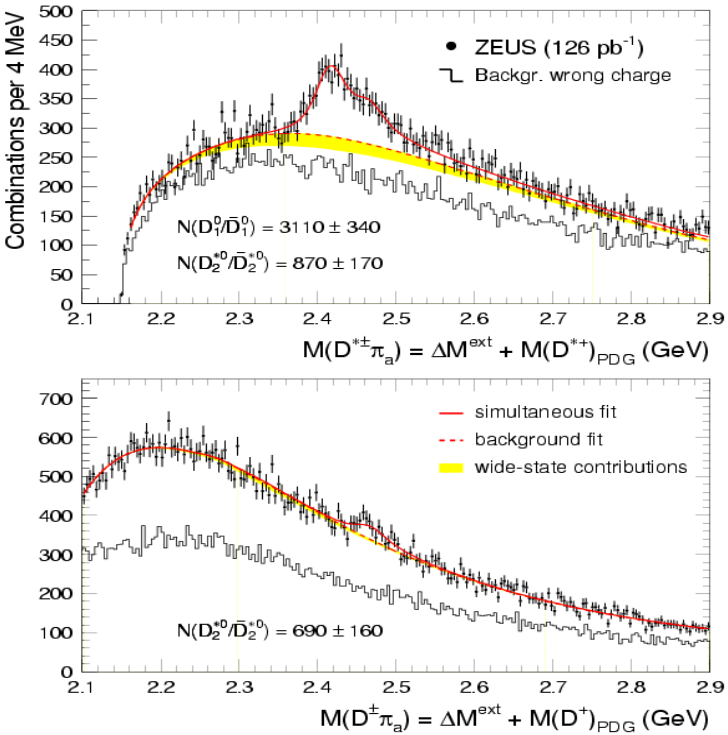
$K^0_s K^0_s$: Glueball Candidate



The measured masses of the $f'_2(1525)$ and $f_0(1710)$ states are somewhat below the world average, however, the width consistent with the PDG

Excited Charmed Mesons

The large charm production cross section at HERA provides possibility to study excited charm and charm-strange mesons



Orbitally excited P-wave mesons:

$D_1(2420)^0 \rightarrow D^{*+}\pi^-$

$D_2^*(2460)^0 \rightarrow D^{*+}\pi^-, D^+\pi^-$

Helicity measurements:

$h(D^0_1) = 5.9\ ^{+3.0}_{-1.7}(stat.)\ ^{+2.4}_{-1.0}$ (sys.) HQET: +3

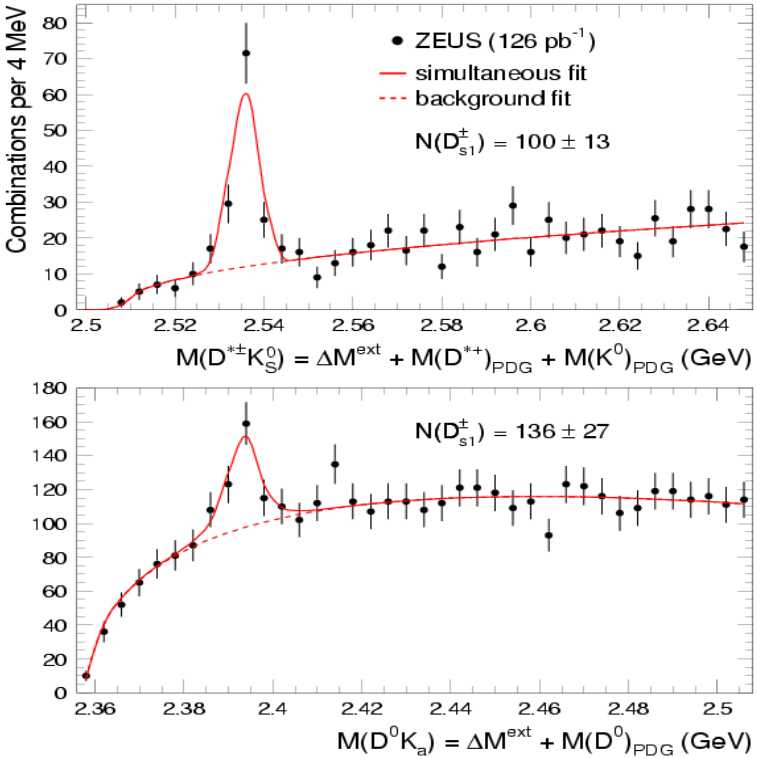
$f(c \rightarrow D^0_1) = 3.5 \pm 0.4\ ^{+0.4}_{-0.6}$ %

$f(c \rightarrow D^{*0}_2) = 3.8 \pm 0.7\ ^{+0.5}_{-0.6}$ %

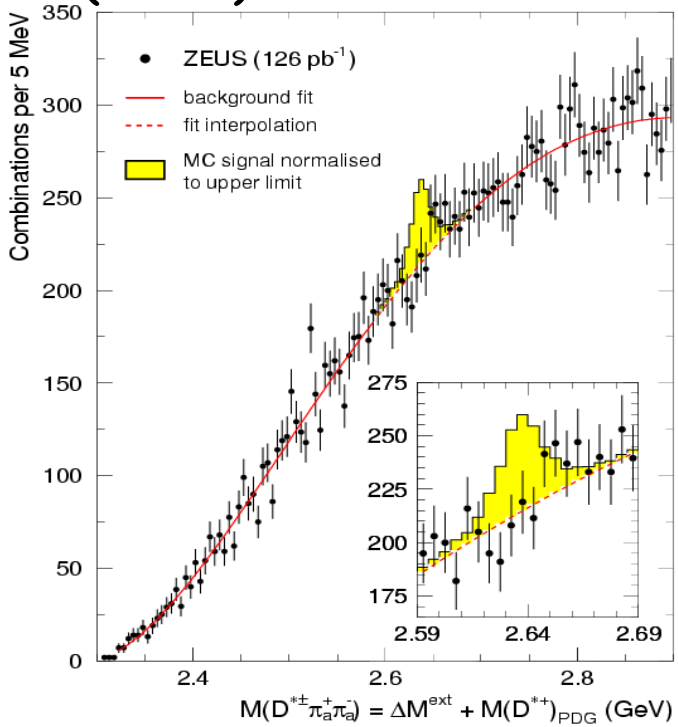
- D^0_1 consistent with pure D-wave h = +3
- Consistent with e^+e^- measurements

Excited Charmed Mesons

excited charm-strange meson
$D_{s1}(2536) \rightarrow D^{*+}K^0_S$, $D^{*0}K^+$



radially excited charm meson
$D^{*\prime}(2640)^+ \rightarrow D^{*+}\pi^+\pi^-$



best upper limit on
$f(c \rightarrow D^{*\prime}) \cdot Br(D^{*\prime} \rightarrow D^{*+}\pi^+\pi^-) < 0.4\%$ (95% C.L.)

Helicity measurements:
$h(D^+_{s1}) = -0.74^{+0.23}_{-0.17}$ (stat.) $^{+0.06}_{-0.05}$ (sys.) HQET: 0
$f(c \rightarrow D^0_1) = 1.1 \pm 0.2 \pm 0.1\%$

- D^0_1 inconsistent with pure S-wave h = 0
- $D^{*\prime}$ is not observed

Summary

- Light $\rho(770)^0$, $K^*(892)^0$ and $\phi(1020)$ mesons production:
  - first measurement in photoproduction at HERA
  - comparison with RHIC results
  - universality is observed

- Strange particle production:
  - K^0_s, Λ and $K^{*\pm}$ production was measured at DIS
  - CDM and MEPS describe overall features well

- Gluball candidate in $K^0_s K^0_s$:
  - clear evidence for $f'_2(1525)$ and $f_0(1710)$ states

- Charm production:
  - orbital exited D^0_1, D^{*0}_2 and D^+_{s1} are measured
  - radially excited $D^{*\prime +}$ is not observed