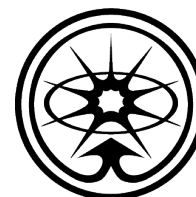




# Light Mesons in Photoproduction



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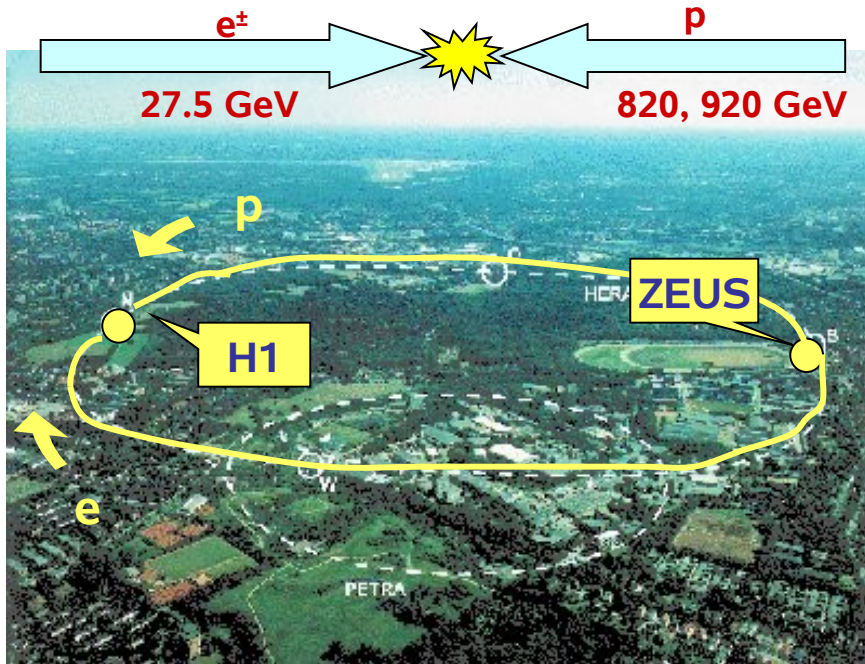


on behalf of  
H1 Collaboration

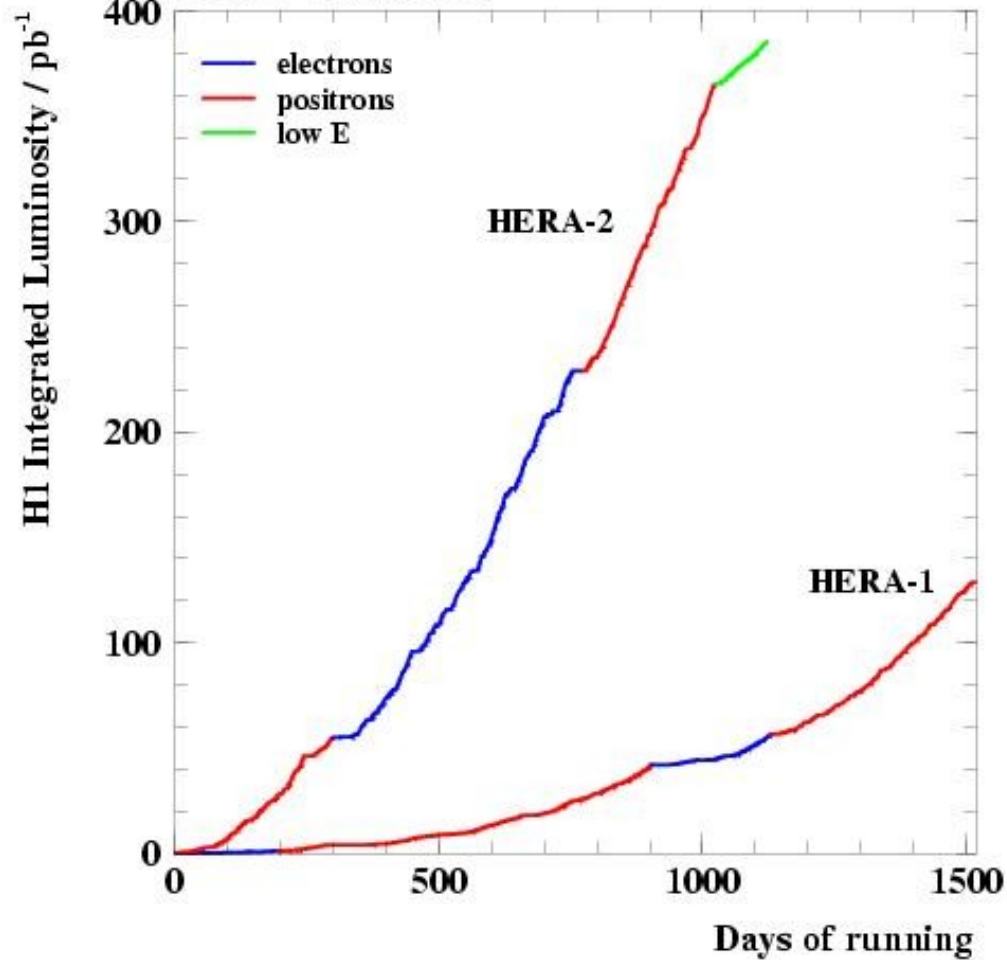
H1 Collab., Phys. Lett. B **673** (2009) 119-126

- Introduction
- Cross section measurements:  $\rho^0$ ,  $K^{*0}(892)$ ,  $\phi(1020)$  *meson*
- Comparison with models
- Comparison with RHIC results

# The HERA Collider



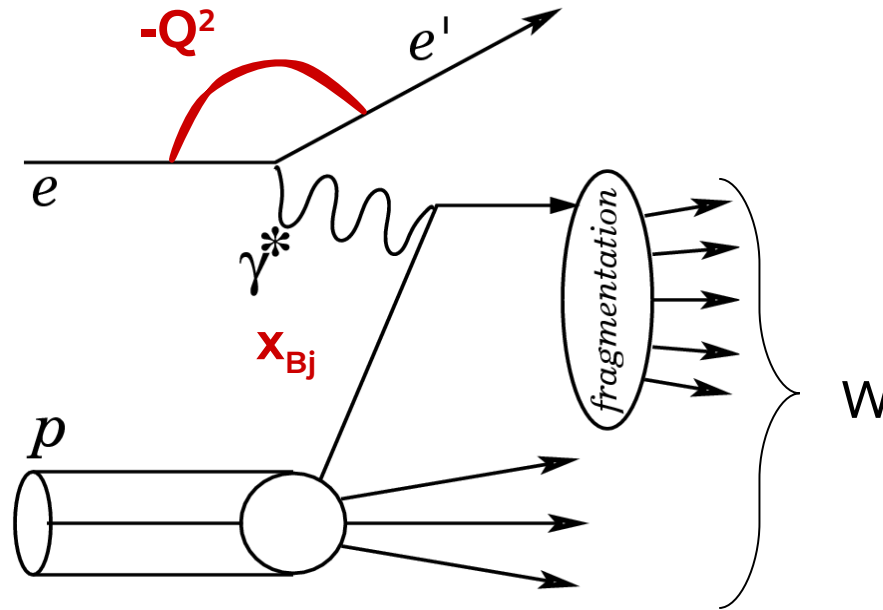
Status: 1-July-2007



H1 and ZEUS:

- 92 - 07 years
- Lumi  $\sim 0.5 \text{ fb}^{-1}$  (each exper.)

# ep kinematics



energy c.m.:  $\sqrt{s} = 300\text{-}320 \text{ GeV}$

hadronic energy:  $W = m(\gamma^*p)$

photon virtuality :  $Q^2$

two regions:  $Q^2 \approx 0 \text{ GeV}^2$  — photoproduction

$Q^2 > 1 \text{ GeV}^2$  — electroproduction (DIS)

# Motivation

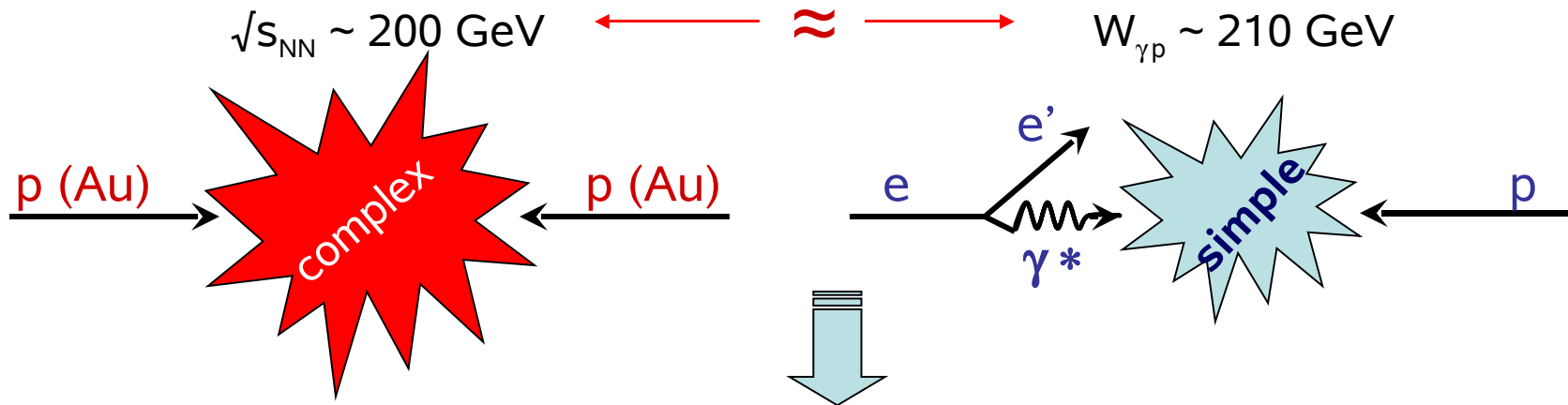
- $e^+e^-$  collisions at LEP:  
distortion of  $\rho^0$  line shape and shift  
towards lower masses was observed



- RHIC:

inclusive  $\rho(770)^0$ ,  $K^*(892)^0$  and  $\phi(1020)$

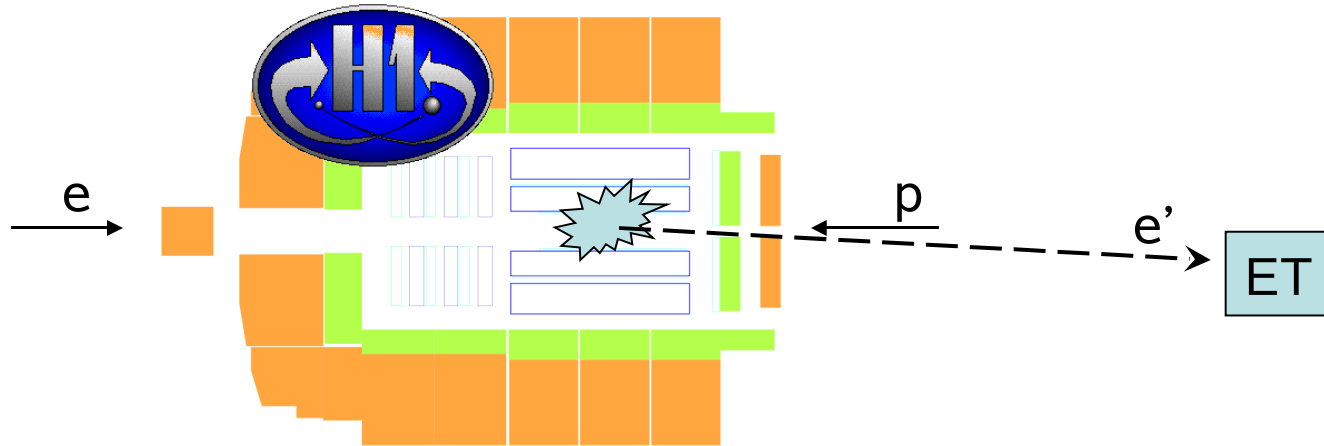
- H1:



give a unique opportunity to make comparison of RHIC results  
with simpler interaction system (HERA)

$\rho^0$ ,  $K^{*0}(892)$ ,  $\phi(1020)$  measurements at HERA help to study hadronisation

# Selection



Main selection criteria for event:

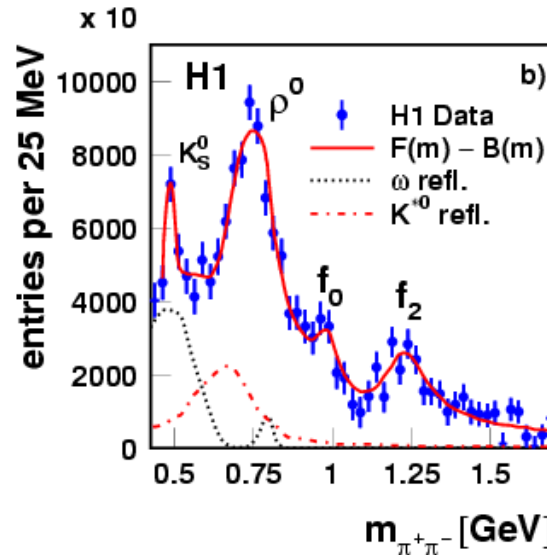
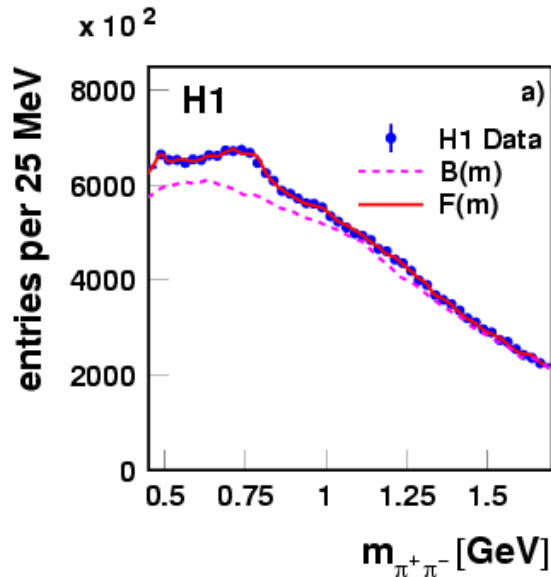
- H1 data 2000 with  $L = 36.5 \text{ pb}^{-1}$
- Photoproduction  $Q^2 < 0.01 \text{ GeV}^2$  with  $e'$  in ET (electron tagger)
- $174 < W < 256 \text{ GeV} \Rightarrow \langle W \rangle = 210 \text{ GeV}$
- Trigger requires at least 3 tracks in the Central Tracker with  $p_T > 0.4 \text{ GeV}$

$$\rho^0 \rightarrow \pi^+\pi^-$$

$$K^{*0} \rightarrow K\pi$$

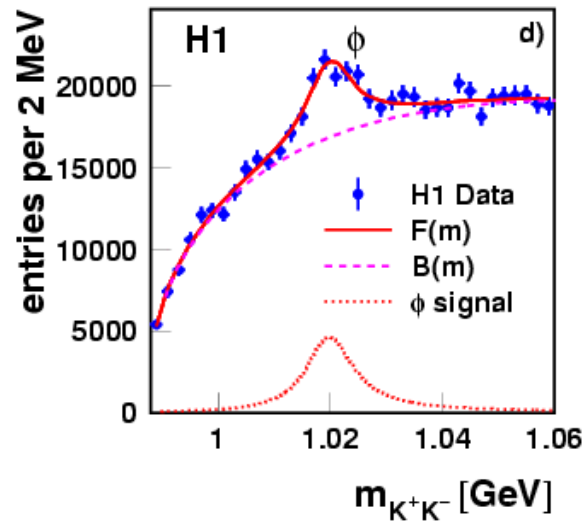
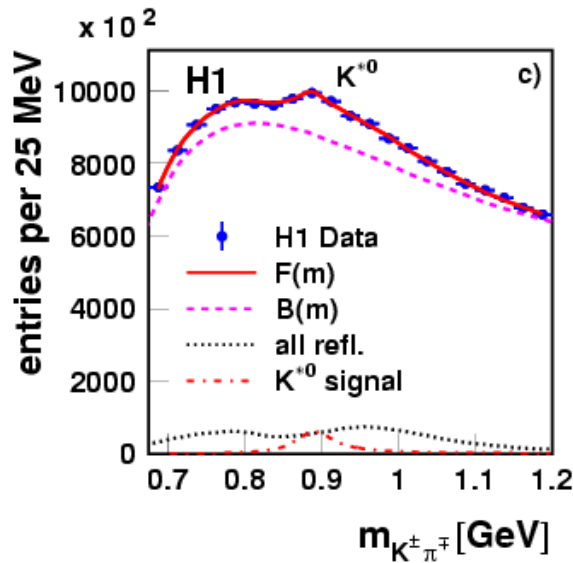
$$\phi \rightarrow K^+K^-$$

# $\rho^0$ , $K^*$ and $\phi$ signal



Fit function:  
 $F(m) = S(m) + R(m) + B(m)$

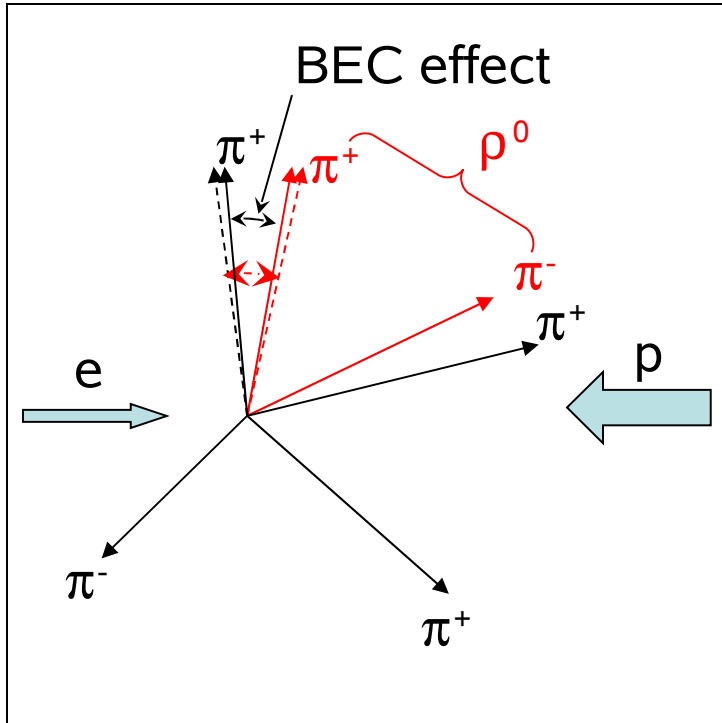
Signal  
 Reflection  
 Comb. background



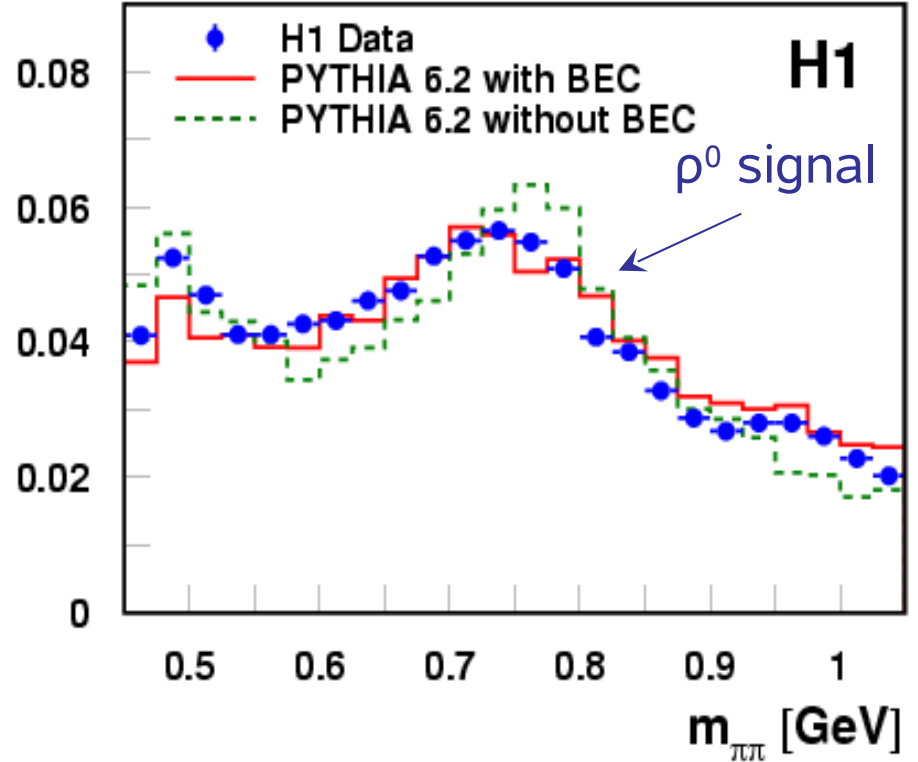
Clear signals of  $\rho^0$ ,  $K^*$  and  $\phi$  mesons are observed

# Bose-Einstein Correlations (BEC)

distortion of  $\rho^0$  mass spectrum due to BEC

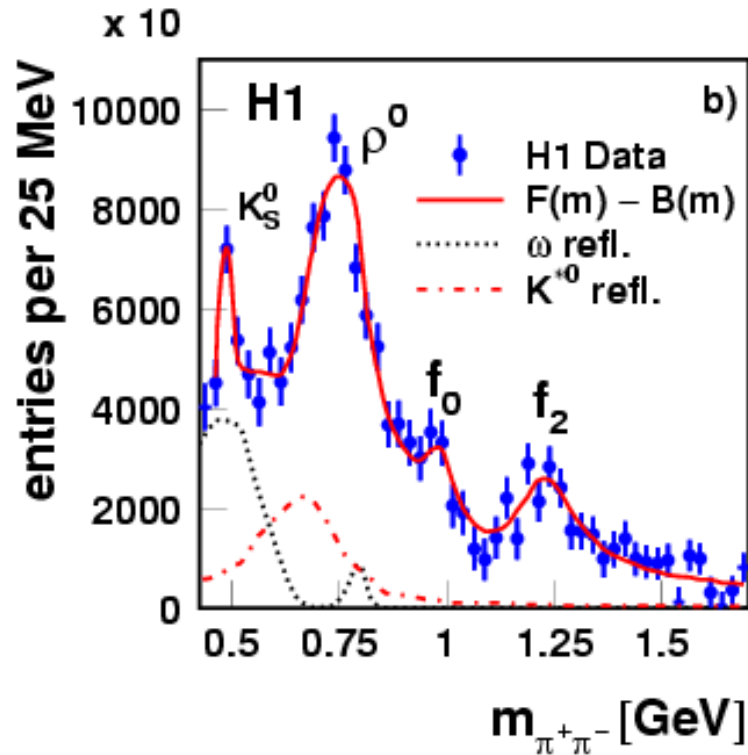


unlike-sign  $\pi\pi$  — like-sign  $\pi\pi$   
arbitrary units



A modification of  $\rho^0$  produced in  $\gamma p$  collisions is described by taking into account Bose-Einstein correlations in Monte Carlo

# $\rho^0$ , $K^*$ and $\phi$ : cross section measurement



$Q^2 < 0.01 \text{ GeV}^2$  &&  $174 < W < 256 \text{ GeV}$ ,  $p_T > 0.5 \text{ GeV}$  &&  $|y_{\text{lab}}| < 1$ :

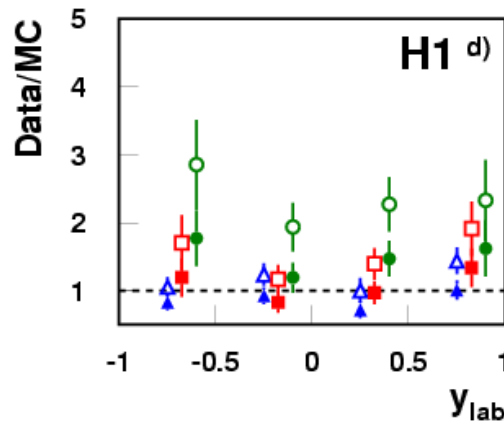
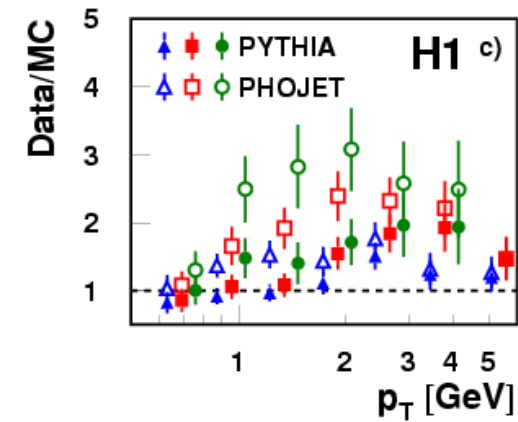
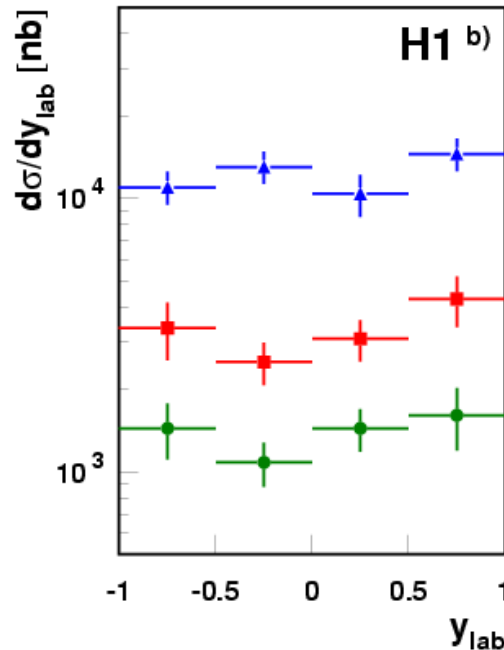
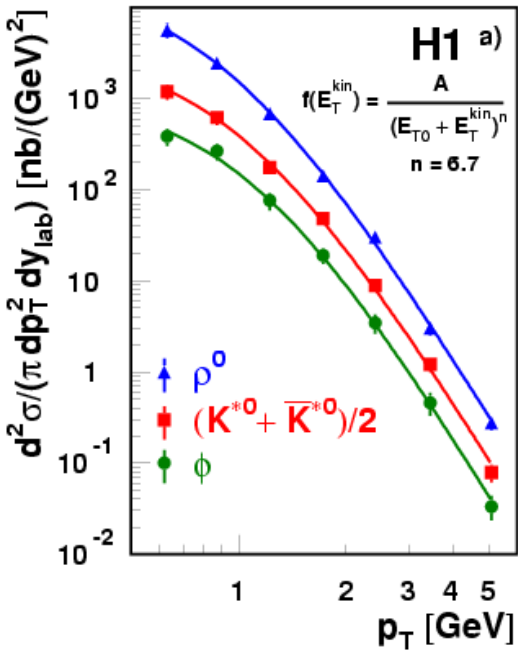
$$\sigma_{\text{vis}}^{\gamma p}(\gamma p \rightarrow \rho^0 X) = 25600 \pm 1800 \pm 2700 \text{ nb}$$

$$\sigma_{\text{vis}}^{\gamma p}(\gamma p \rightarrow K^{*0} X) = 6260 \pm 350 \pm 860 \text{ nb}$$

$$\sigma_{\text{vis}}^{\gamma p}(\gamma p \rightarrow \phi X) = 2400 \pm 180 \pm 340 \text{ nb}$$



# $\rho^0$ , $K^*$ and $\phi$ : cross section



PHOJET10: DPM

PYTHIA6.2: LO QCD ME  
with a very low  $p_T$  cut-off  
and PS

- invariant differential cross section can be described by power law distribution
- within rapidity range, the meson production rates are constant as a function of rapidity, within errors
- PYTHIA and PHOJET models do not describe the shape of the measured  $p_T$  spectrum

# $\rho^0$ , $K^*$ and $\phi$ : power law distribution

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

pQCD

Thermodynamic model

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

$$A = \underbrace{\left\langle \frac{d\sigma}{dy_{lab}} \right\rangle_{|y_{lab}| < 1}}_{\text{is extrapolated cross section in all } p_T \text{ range}} \frac{(n-1)(n-2)(E_{T_0})^{n-1}}{2\pi(E_{T_0} + (n-2)m_0)}$$

is extrapolated  
cross section in all  $p_T$  range

# $\rho^0$ , $K^*$ and $\phi$ : cross section fit parameters

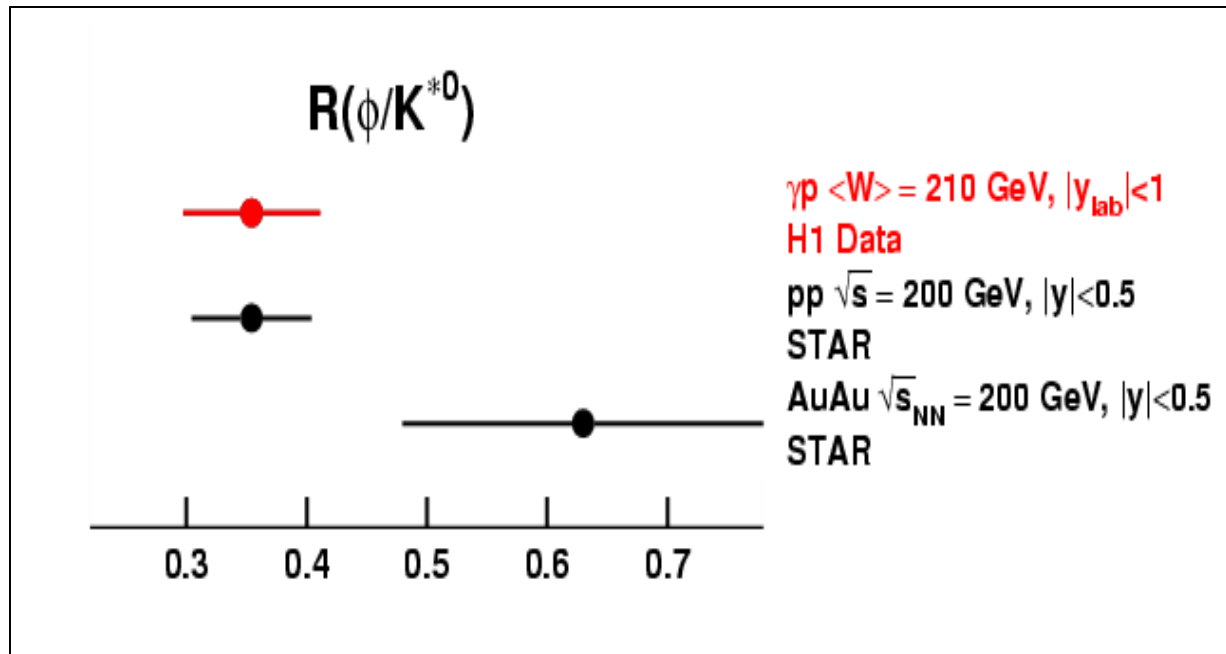
$$f(E_T^{kin}) = \frac{A}{(E_{T_0} + E_T^{kin})^n} \quad \longrightarrow \quad \langle E_T^{kin} \rangle$$

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

		$\rho^0$	$(K^{*0} + \bar{K}^{*0})/2$	$\phi$
$\gamma p$	$\langle d\sigma/dy_{lab} \rangle_{ y_{lab}  < 1}$ [nb]	$23600 \pm 2700$	$5220 \pm 600$	$1850 \pm 230$
	$E_{T_0}/n = T$ [GeV]	$0.151 \pm 0.011$	$0.166 \pm 0.012$	$0.170 \pm 0.012$
	$\langle E_T \rangle$ [GeV]	$1.062 \pm 0.018$	$1.205 \pm 0.020$	$1.333 \pm 0.022$
	$\langle E_T^{kin} \rangle$ [GeV]	$0.287 \pm 0.018$	$0.313 \pm 0.020$	$0.314 \pm 0.022$
	$\langle p_T \rangle$ [GeV]	$0.726 \pm 0.027$	$0.810 \pm 0.030$	$0.860 \pm 0.035$
$pp$	$\langle p_T \rangle_{pp}$ [GeV]	$0.616 \pm 0.062$	$0.81 \pm 0.14$	$0.82 \pm 0.03$
Au-Au	$\langle p_T \rangle_{AuAu}$ [GeV]	$0.83 \pm 0.10$	$1.08 \pm 0.14$	$0.97 \pm 0.02$

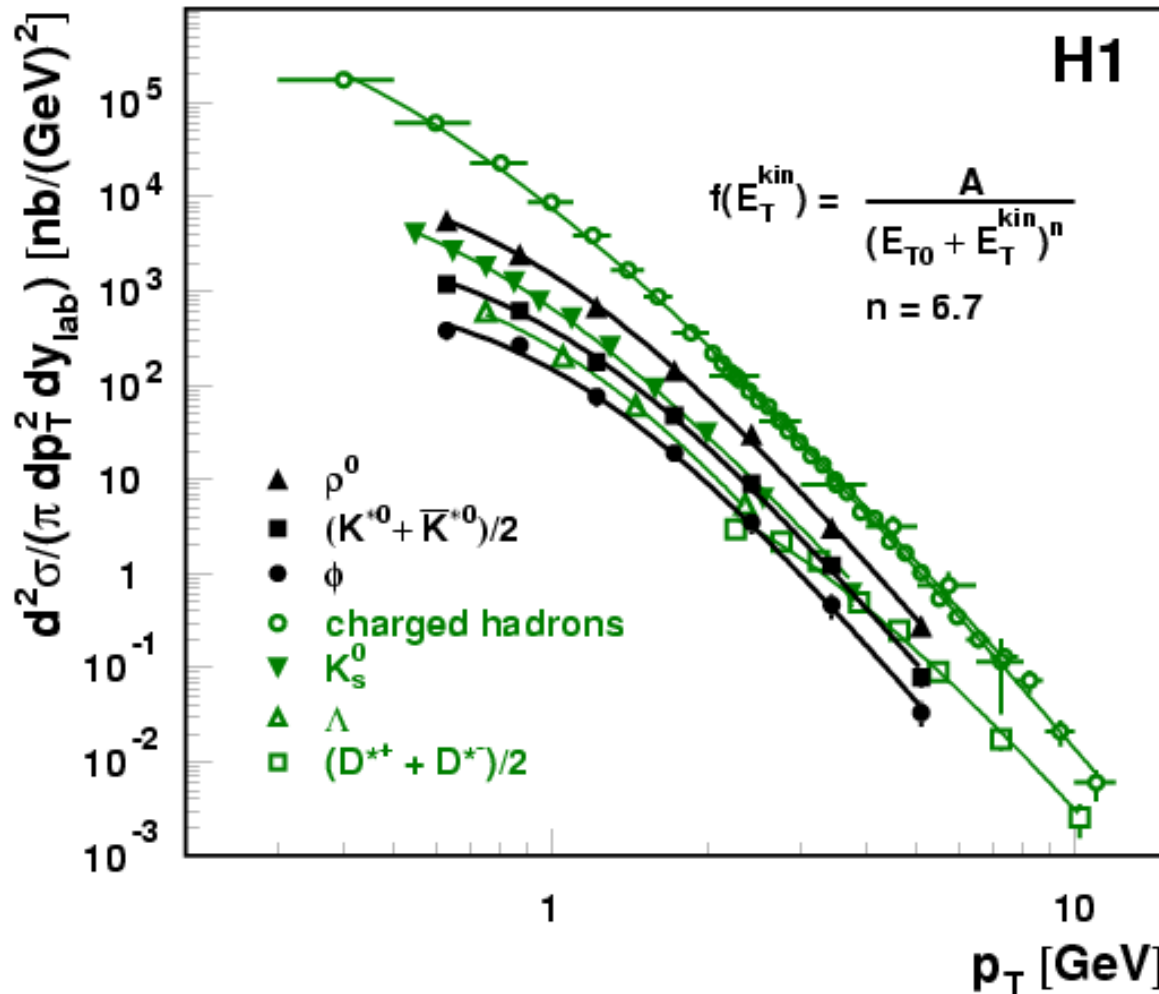
- $\rho^0$ ,  $K^*$  and  $\phi$  are produced with about the same value of the average  $\langle E_T^{kin} \rangle$   
 $\Rightarrow$  supports a thermodynamic picture of hadronic interactions
- $n$  is described by Monte Carlo while  $T$  is not (non pQCD)
- $\langle p_T \rangle$  in H1 is in agreement with RHIC  $pp$  and is lower than RHIC AuAu

# $\rho^0$ , $K^*$ and $\phi$ : comparison with RHIC



The ratio of the production cross-sections  $R(\phi/K^*)$  measured in  $\gamma p$  is in agreement with  $pp$  results and below that for  $AuAu$  measured at about the same collision energy at RHIC

# Hadron photoproduction at H1



All inclusive photoproduction cross sections measured at H1 are described by power law distribution with the same  $n = 6.7$  calculated from charged hadrons

# Summary

Light  $\rho(770)^0$ ,  $K^*(892)^0$  and  $\phi(1020)$  mesons photoproduction at HERA:

- first measurement in photoproduction at HERA
- the description of the  $\rho^0$  shape of the meson is improved by taking Bose-Einstein correlations into account
- $p_T$ -spectra are described by power law distribution
- $\rho^0$ ,  $K^*$  and  $\phi$  are produced with about the same value of  $\langle E_T^{\text{kin}} \rangle$   
 $\Rightarrow$  support a thermodynamic picture of hadronic interactions
- comparison with RHIC results
  - The ratio of the production cross-sections  $R(\phi/K^*)$  measured in  $\gamma p$  is in agreement with  $pp$  results at about the same collision energy at RHIC
  - Some tendency for  $\phi$  meson production to be more abundant in Au-Au collisions is observed
- universality in  $p_T$ -spectra of hadrons at H1 is observed

Back up

# $\rho^0$ , $K^*$ and $\phi$ : visible kinematical range

All mesons are analyzed in following:

-  $|y| < 1$  in 7  $p_T$  bins:

1 bin	2 bin	3 bin	4 bin	5 bin	6 bin	7 bin
0.5-0.75	0.75-1.	1.-1.5	1.5-2.	2.-3.	3.-4.	4.-7. GeV

Extra cuts for mesons:

$K^{*0}$ : 1 bin: Kaon dE/dx ident. &&  $\cos\theta^* < 0$ ; 2-3 bin: Kaon dE/dx ident.

$\phi$ : 1-3 bin: Kaon dE/dx identification

bin  $p_T$ : 0.-0.25 GeV is excluded due to non description DATA and MC

bin  $p_T$ : 0.25-0.5 GeV is excluded due to big Background for  $K^{*0}$  and small  $\phi$  meson reconstructed efficiency

-  $p_T > 0.5$  GeV in 4  $y$  bins:

1 bin	2 bin	3 bin	4 bin
-1.: -0.5	-0.5-0.	0.-0.5	0.5-1.

Extra cuts for mesons:

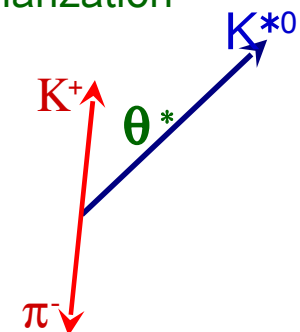
$K^{*0}$ : 1-4 bin: Kaon dE/dx ident. &&  $\cos\theta^* < 0$

$\phi$ : 1-4 bin: Kaon dE/dx identification

$y$  – rapidity of mesons

$p_T$  – transverse momentum of mesons

polarization





# Fit Procedure

$$\rho^0 \rightarrow \pi^+\pi^-$$

$$K^{*0} \rightarrow K\pi$$

$$\phi \rightarrow K^+K^-$$

Fit function:  $F(m) = S(m) + R(m) + B(m)$

Signal  $S(m)$  = convolution of  $BW(m)$  and  $res(m, m')$

rel. Breit-Wigner  $BW(m) = A m m_0 \Gamma(m) / [(m^2 - m_0^2)^2 + m_0^2 \Gamma^2(m)]$

$$\Gamma(m) = \Gamma_0 (q/q_0)^{2l+1} m_0 / m$$

resolution function  $res(m, m') = 1/[2p] \cdot \Gamma_{res} / [(m - m')^2 + (\Gamma_{res}/2)^2]$

reflection  $R(m)$ :

for  $\rho^0$ :  $K^{*0} \rightarrow K\pi$  and  $\omega \rightarrow \pi^+\pi^-(\pi^0)$

for  $K^{*0}$ :  $\rho^0 \rightarrow \pi^+\pi^-$ ,  $\omega \rightarrow \pi^+\pi^-(\pi^0)$ ,  $\phi \rightarrow K^+K^-$   
and self-reflection  $K^{*0} \rightarrow K\pi$

for  $\phi$ : —

combinatorial background  $B(m)$ :

for  $\rho^0$  and  $K^{*0}$ :

$$B(m) = \{M(\pi^\pm\pi^\pm) \text{ or } M(K^\pm\pi^\pm)\} \cdot \{\text{Pol}(2-3) \text{ or } (a_1 + a_2 \cdot x) \cdot \exp(-a_3 \cdot x - a_4 \cdot x^2)\}$$

$$\text{for } \phi: B(m) = b_1 \cdot (m^2 - 4m_K^2)^{b_2} \cdot \exp(-b_3 \cdot m)$$

# $\rho^0$ , $K^*$ and $\phi$ : cross section calculation

Invariant differential cross section:

$$\frac{1}{\pi} \frac{d^2 \sigma^{\gamma P}}{dp_T^2 dy_{lab}} = \frac{N}{\pi \cdot \mathcal{L} \cdot BR \cdot \Phi_\gamma \cdot \epsilon \cdot \Delta p_T^2 \cdot \Delta y_{lab}}$$

Differential cross section:

$$\frac{d\sigma^{\gamma P}}{dy_{lab}} = \frac{N}{\mathcal{L} \cdot BR \cdot \Phi_\gamma \cdot \epsilon \cdot \Delta y_{lab}}$$

$N$  – number of mesons from fit

$\Delta p_T^2$  and  $\Delta y_{lab}$  – bin widths

$\mathcal{L} = 36.5 \text{ pb}^{-1}$

$\Phi_\gamma = 0.0127$  – photon flux

$BR = 1.$  for  $\rho^0$ ,  $0.67$  for  $K^{*0}$  and  $0.49$  for  $\phi$

$\epsilon = \epsilon_{rec} \cdot A_{etag} \cdot A_3 \cdot \epsilon_{trig}$  – efficiency

reconstruction efficiency for the meson  $\epsilon_{rec}$  varies from 45% to 90%  
(using Monte Carlo)

positron tagger acceptance  $A_{etag} = 48.5\%$

trigger acceptance  $A_3$  varies from 50% to 95% (using Monte Carlo)

trigger efficiency  $\epsilon_{trig} \sim 90\%$  (using Monitor Triggers)