# Inclusive Photoproduction of $\rho^\circ$, $K^{*\circ}$ and $\varphi$ Mesons at HERA

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on behalf of
H1 Collaboration

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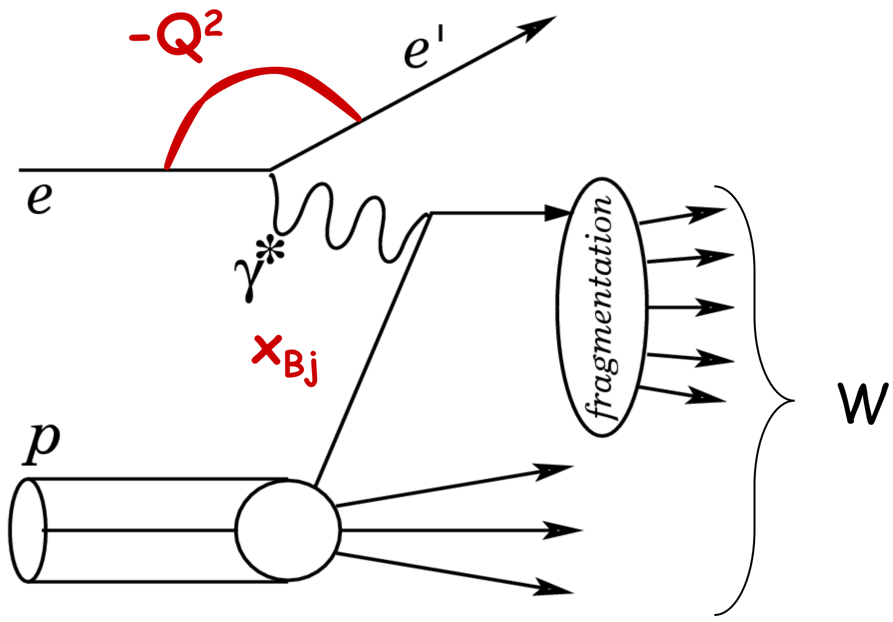
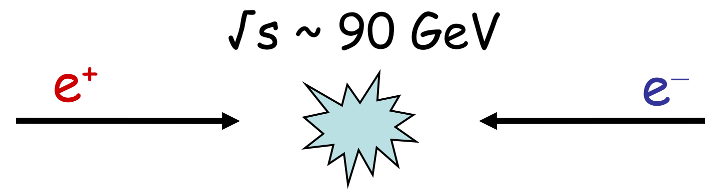
# ep kinematics




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

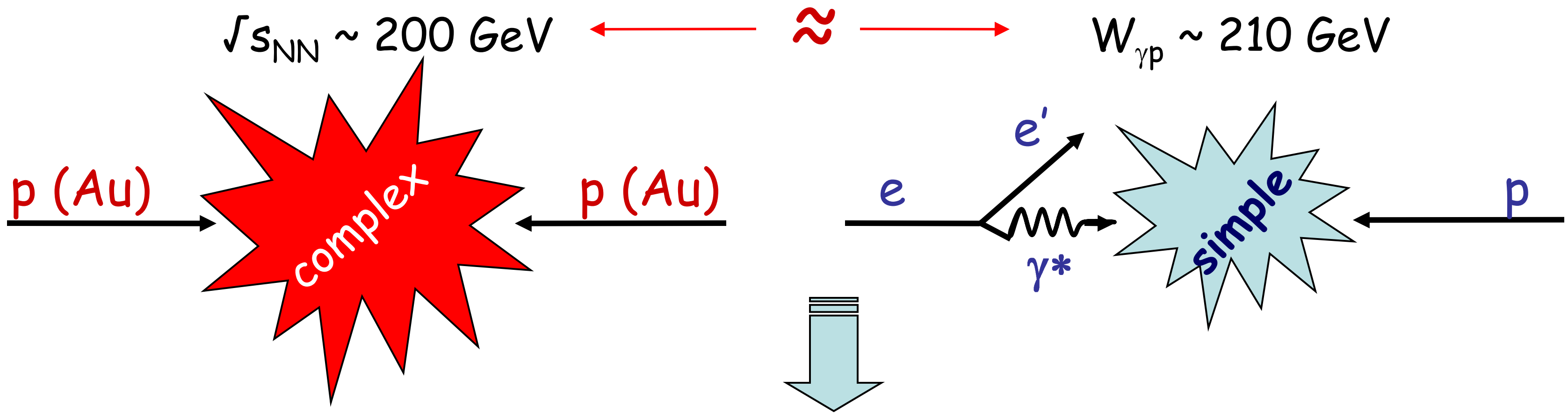
# Motivation

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




- RHIC:
- H1:

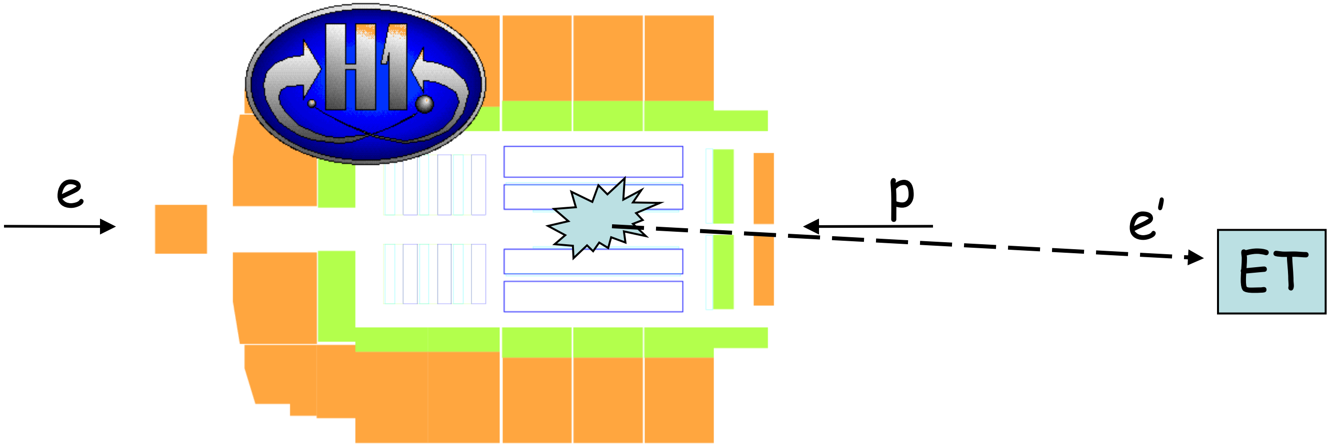
inclusive $\rho(770)^0$, $K^*(892)^0$ and $\varphi(1020)$




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

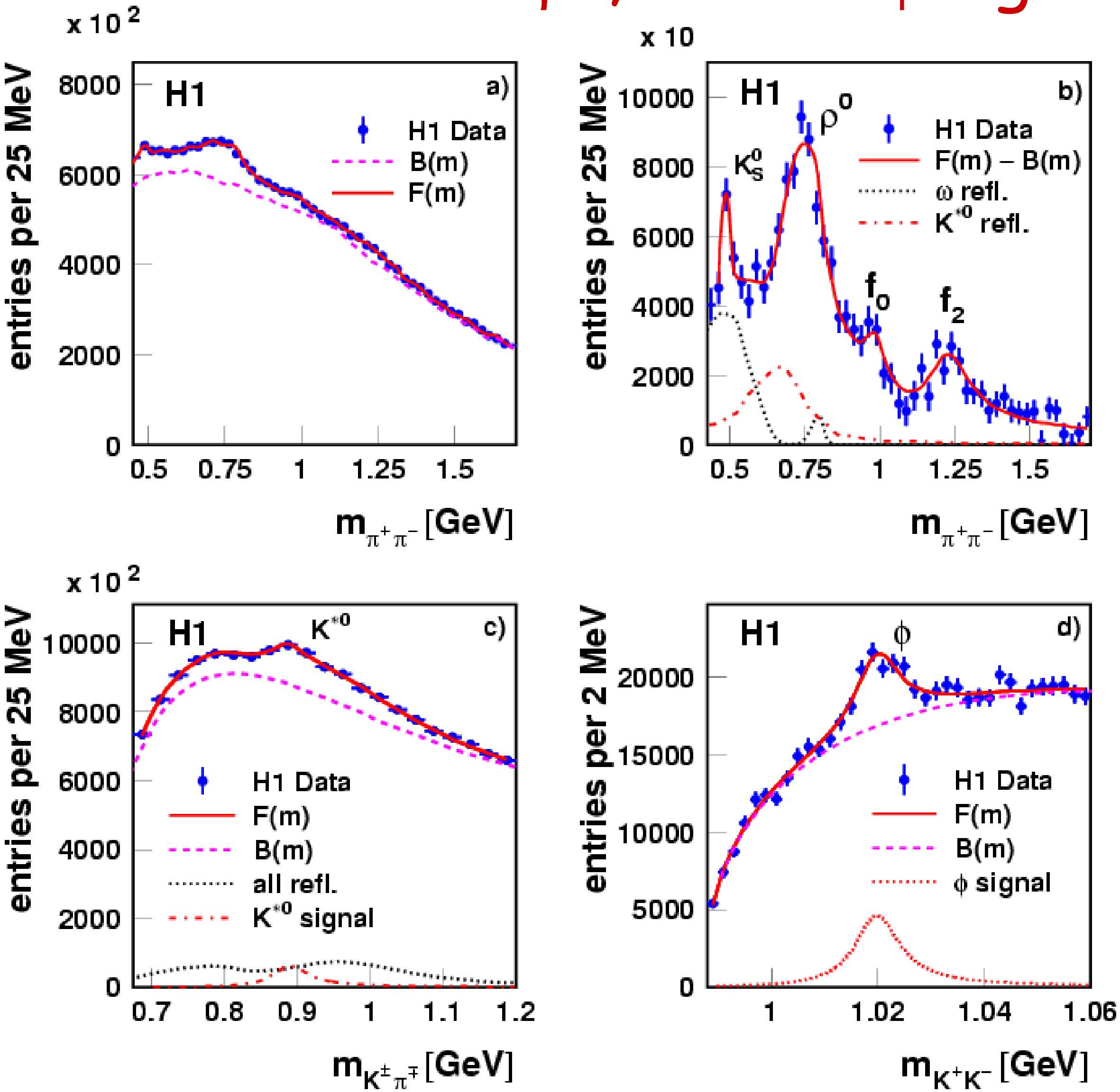



Main selection criteria for event:

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

$\rho^0 \to \pi^+\pi^-$ $\qquad$ $K^{*0} \to K\pi$ $\qquad$ $\phi \to K^+K^-$

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




Fit function:

$F(m) = S(m) + R(m) + B(m)$

Signal

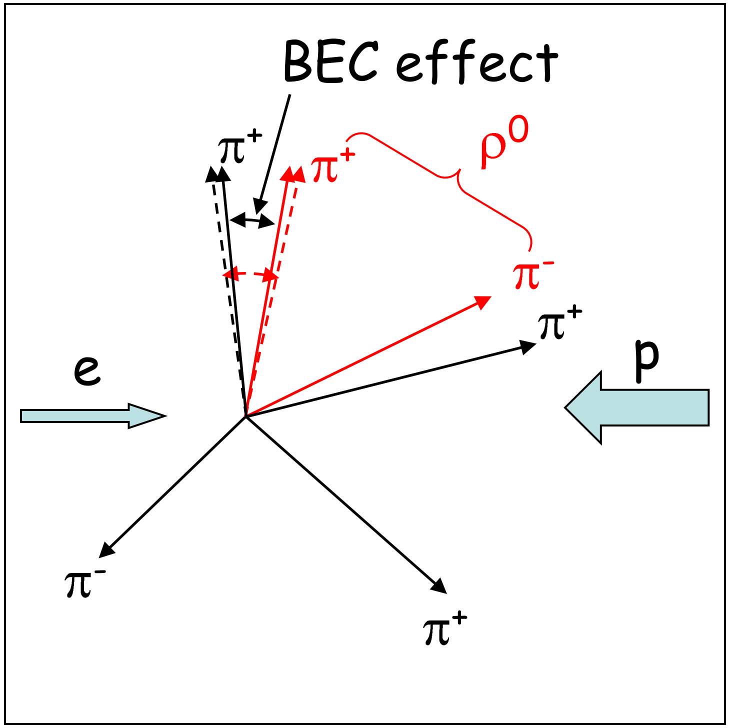
Reflection

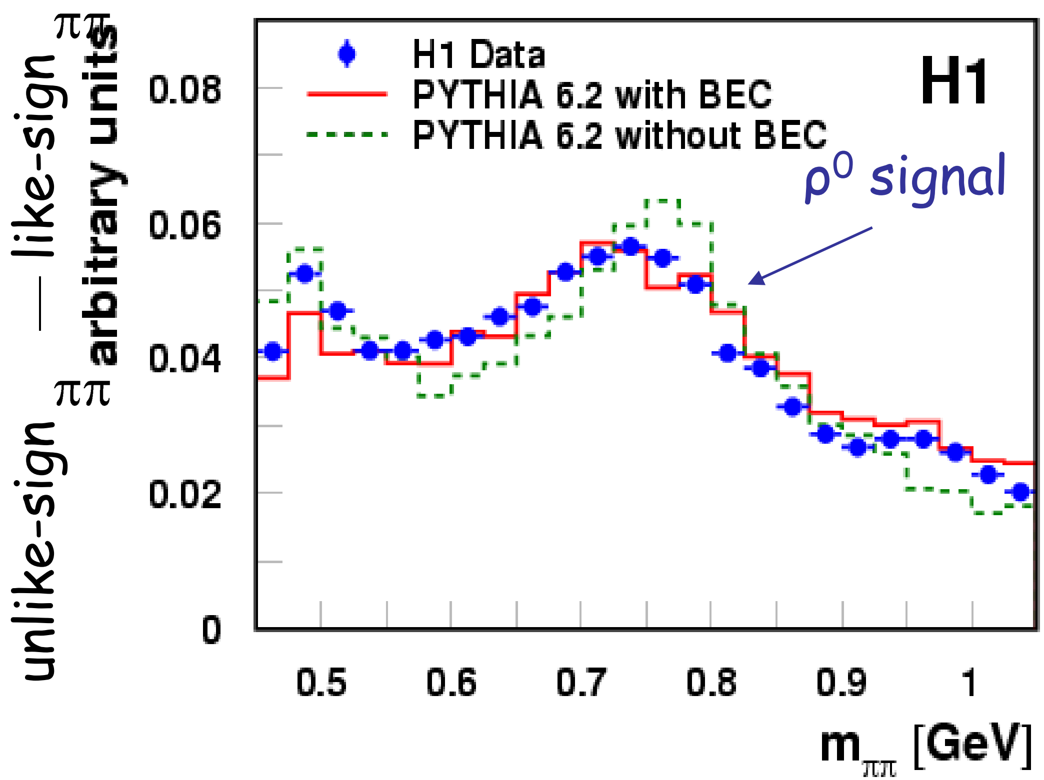
Comb. background

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

# Bose-Einstein Correlations (BEC)

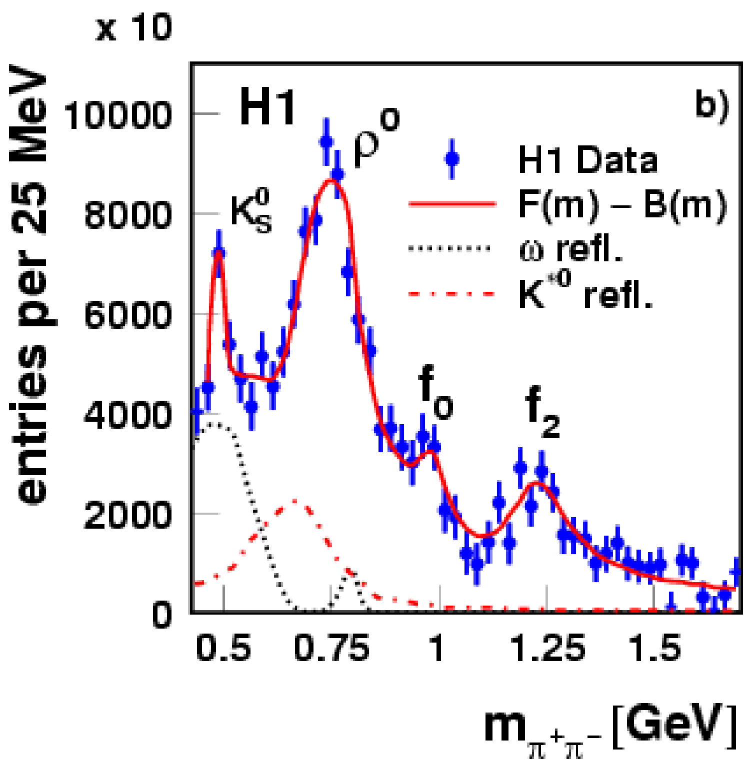
distortion of $\rho^0$ mass spectrum due to BEC




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

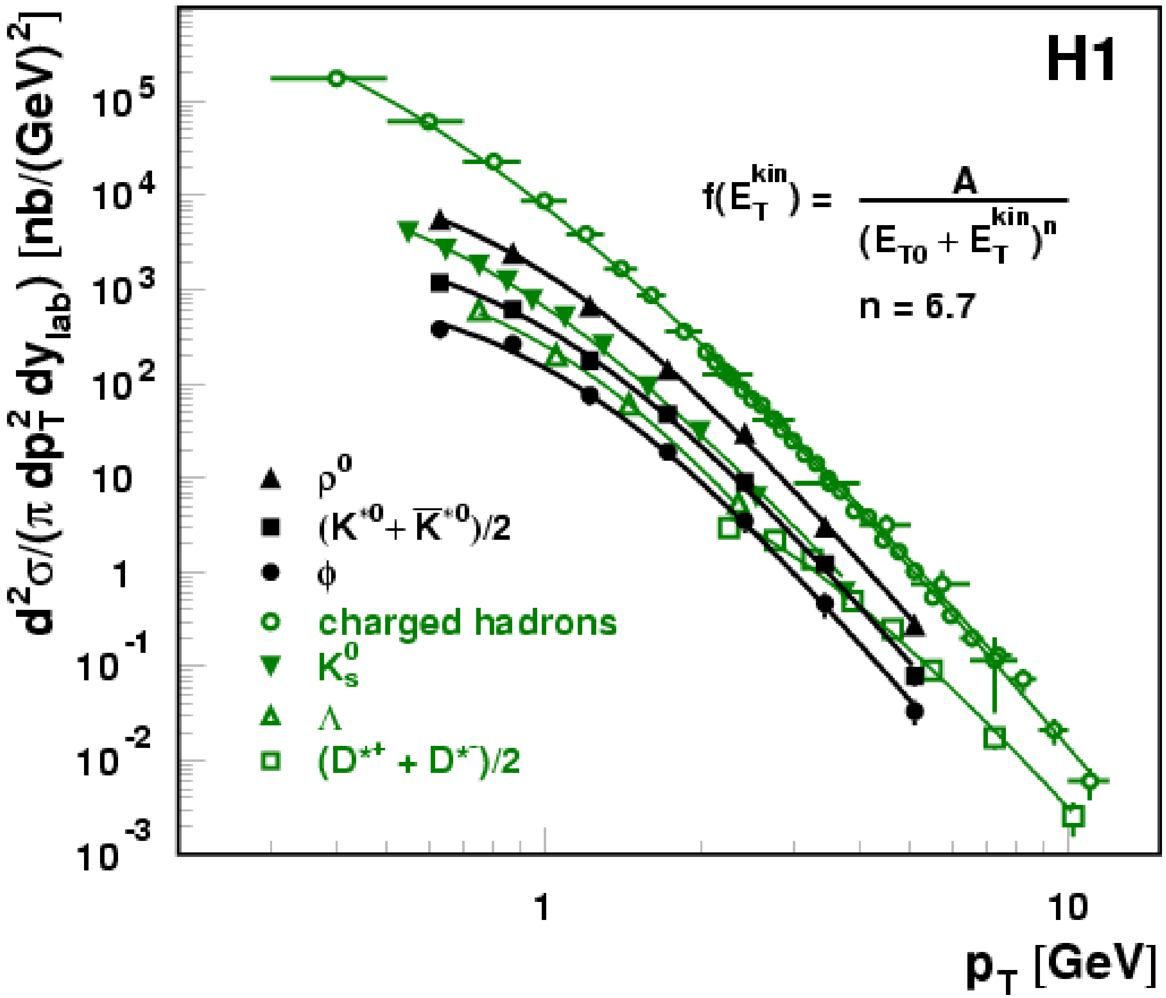
# $\rho^0$, K* and $\phi$: cross section measurement




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

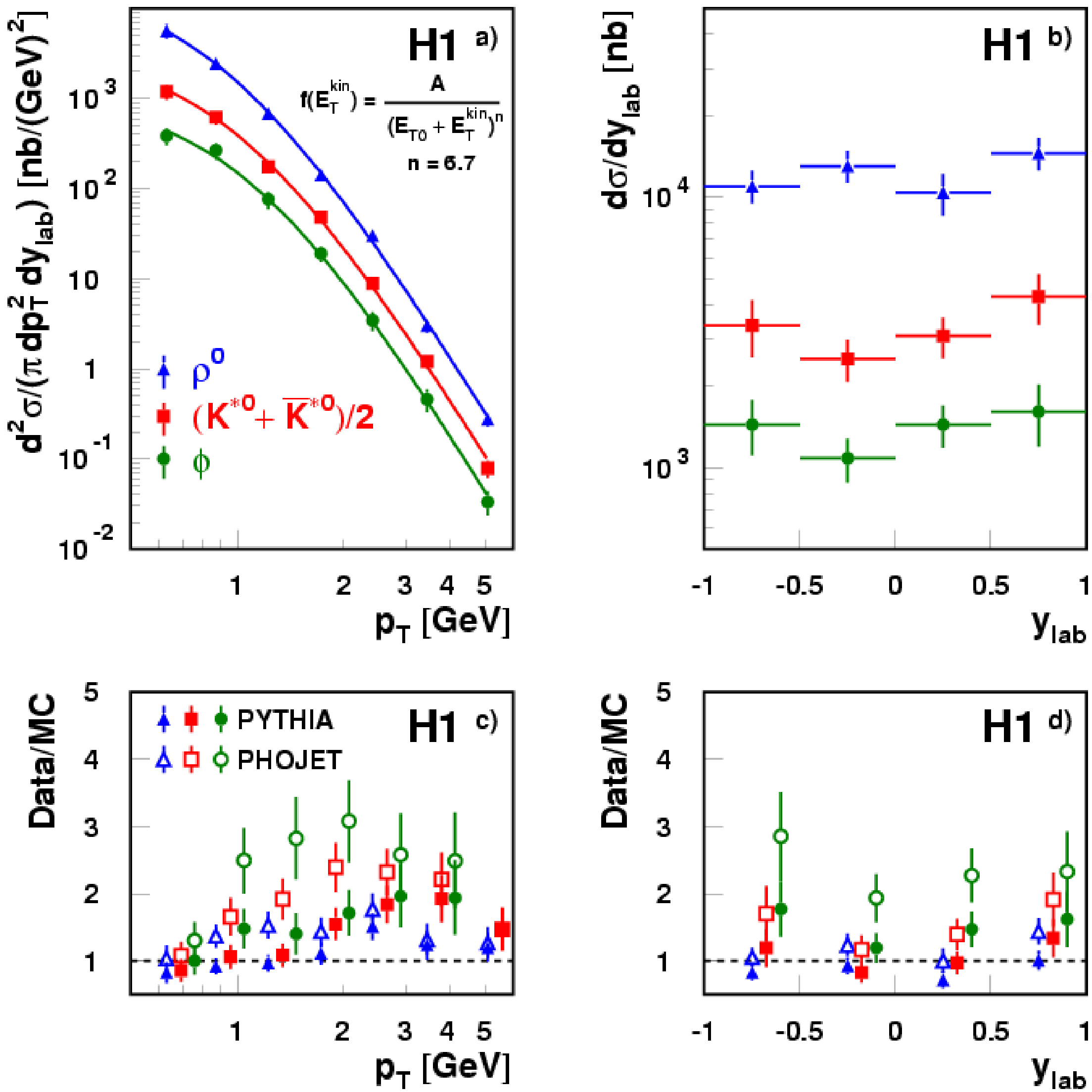
$$\sigma^{\gamma p}_{vis}(\gamma p \to \rho^0 X) = 25600 \pm 1800 \pm 2700\ \mathrm{nb}$$
$$\sigma^{\gamma p}_{vis}(\gamma p \to K^{*0} X) = 6260 \pm 350 \pm 860\ \mathrm{nb}$$
$$\sigma^{\gamma p}_{vis}(\gamma p \to \phi X) = 2400 \pm 180 \pm 340\ \mathrm{nb}$$

# 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

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




PHOJET10: Dual Parton Model

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

$$f(E_T^{kin}) = \frac{A}{(E_{T0}+E_T^{kin})^n} = \begin{cases} \dfrac{A}{(E_T^{kin})^n}, & E_T^{kin} > E_{T0} \\ \exp(-E_T^{kin}/T), & E_T^{kin} < E_{T0} \end{cases} \qquad T = E_{T_0}/n$$

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

pQCD

Thermodynamic model

$$A = \left\langle \frac{d\sigma}{dy} \right\rangle_{y_{lab}} \frac{(n-1)(n-2)E_{T0}^{n-1}}{2\pi(E_{T0}+(n-2)m_0)}$$

is extrapolated
cross section in all $p_T$ range

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

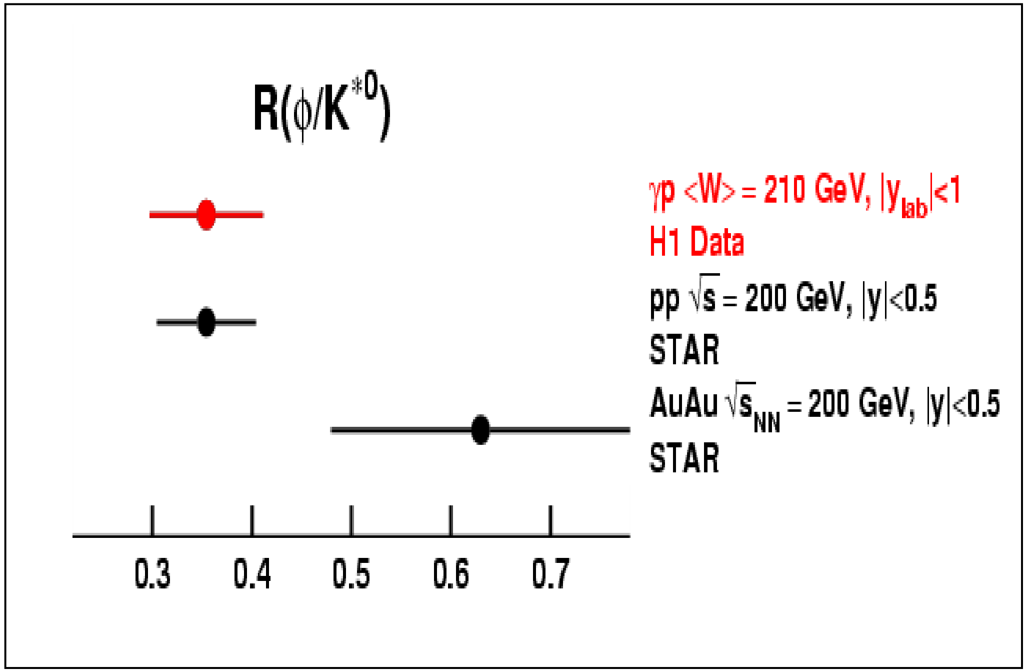
$$f(E_T^{kin}) = \frac{A}{(E_{T_0}+E_T^{kin})^n} \Rightarrow \langle E_T^{kin} \rangle$$

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

| | | $\rho^0$ | $(K^{*0}+\overline{K}^{*0})/2$ | $\phi$ |
|---|---|---|---|---|
| $\gamma p$ | $\langle d\sigma/dy_{lab}\rangle\vert_{\vert y_{lab}\vert<1}$ [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




| $dN/dy$ * 1000 | γp (H1) | pp(STAR) |
|---|---|---|
| $\rho^0$ | $236\pm30$ | $259\pm40$ |
| K* | $52\pm7$ | $51\pm7$ |
| $\phi$ | $18\pm3$ | $18\pm1$ |

Remarkable agreement between production rates in pp and photoproduction

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

# 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 $\langle E_T^{kin} \rangle$
  $\Rightarrow$ 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 $\varphi$ meson reconstructed efficiency

polarization

- $p_T > 0.5$ 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. |

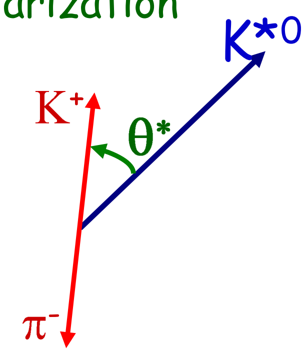
Extra cuts for mesons:

$K^{*0}$: 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



# Fit Procedure

$\rho^0 \to \pi^+\pi^-$ $K^{*0} \to K\pi$ $\phi \to K^+K^-$

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

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

rel. Breit-Wigner $BW(m) = Amm_0\Gamma(m)/[(m^2-m_0^2)^2 + m_0^2\Gamma^2(m)]$

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

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

reflection $R(m)$:

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

for $K^{*0}$ : $\rho^0 \to \pi^+\pi^-$, $\omega \to \pi^+\pi^-(\pi^0)$, $\phi \to K^+K^-$

and self-reflection $K^{*0} \to K\pi$

for $\phi$: —

combinatorial background $B(m)$:

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

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

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:

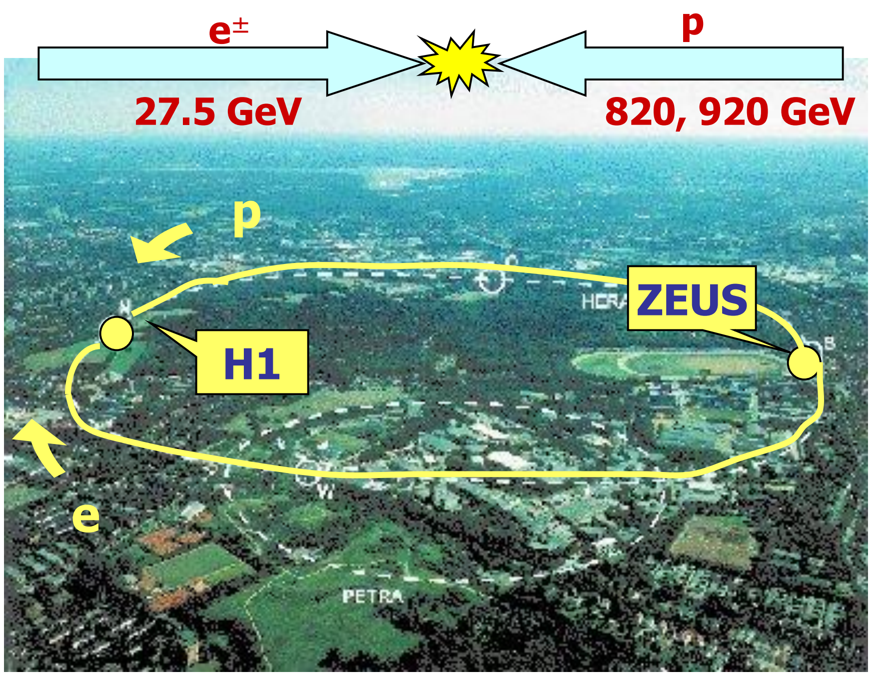
$$\frac{d\sigma^{\gamma p}}{dy_{lab}} = \frac{N}{\mathcal{L}\cdot BR\cdot\Phi_\gamma\cdot\epsilon\cdot\Delta y_{lab}}$$

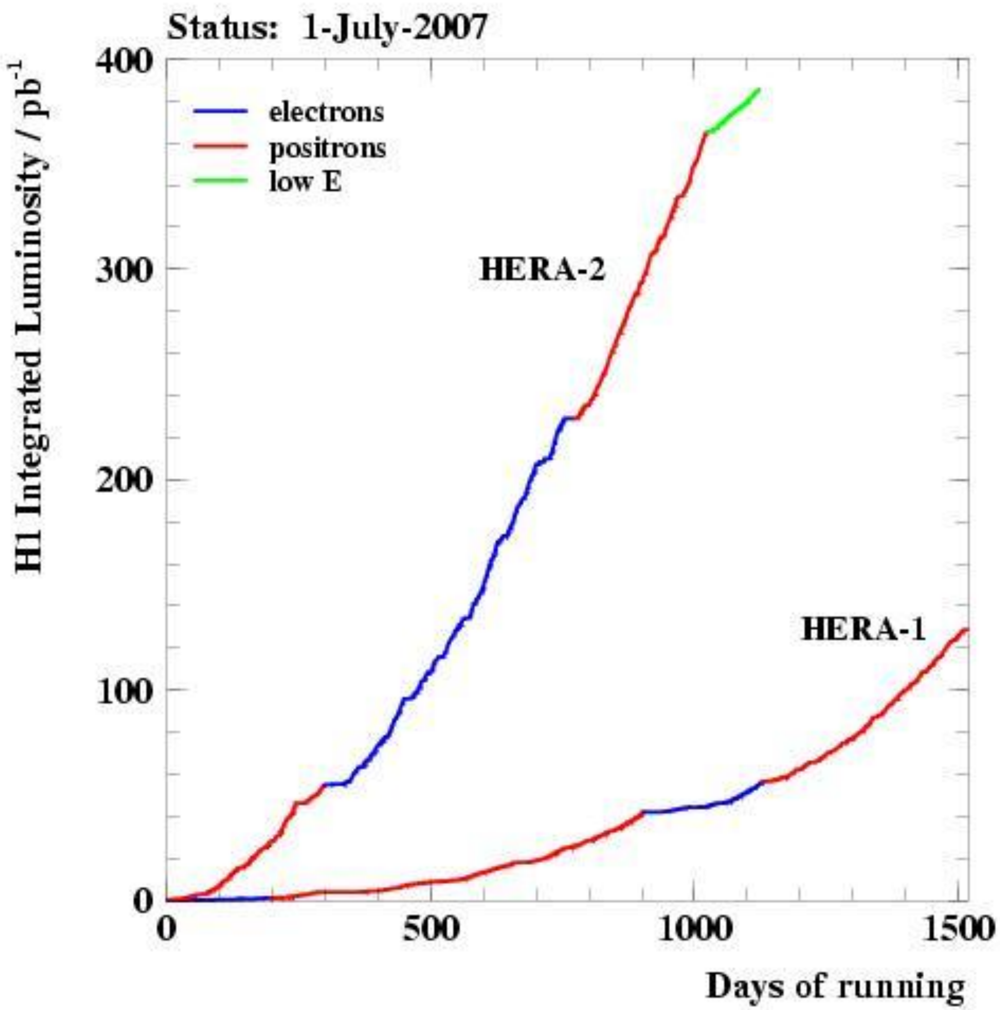
N – number of mesons from fit
$\Delta p_T^2$ and $\Delta y_{lab}$ – bin widths
$\mathcal{L}$ = 36.5 pb$^{-1}$
$\Phi_\gamma$ = 0.0127 – photon flux
BR = 1. for $\rho^0$, 0.67 for $K^{*0}$ and 0.49 for $\phi$

$\varepsilon = \varepsilon_{rec} \cdot \mathcal{A}_{etag} \cdot \mathcal{A}_3 \cdot \varepsilon_{trig}$ – efficiency

reconstruction efficiency for the meson $\varepsilon_{rec}$ varies from 45% to 90% (using Monte Carlo)
positron tagger acceptance $\mathcal{A}_{etag}$ = 48.5%
trigger acceptance $\mathcal{A}_3$ varies from 50% to 95% (using Monte Carlo)
trigger efficiency $\varepsilon_{trig}$ ~ 90% (using Monitor Triggers)

# The HERA Collider




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