ρ^0 Production at E665

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E665 Diffractive ρ

$$0.1 < Q^2 < 10\ \mathrm{GeV}^2$$

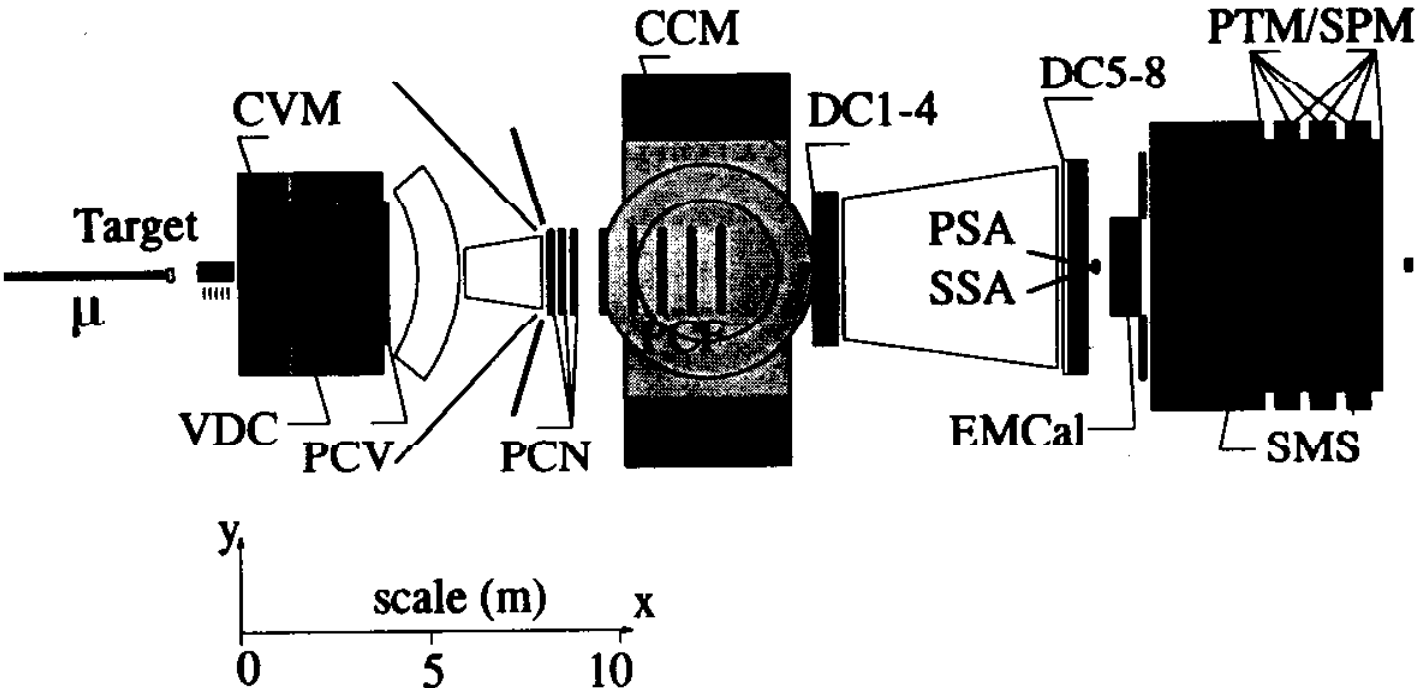
- Mass Distributions

- Cross Sections:
  transition from real to virtual photon.
  W dependence

- t' distributions - does the ρ shrink?

- angular distributions -
  s-channel helicity conservation?
  Transition from transverse to longitudinal polarizations.

Fermilab Experiment E665
Muon-Nucleon Scattering



500 GeV Muons

1m Liquid H2 and D2 Targets

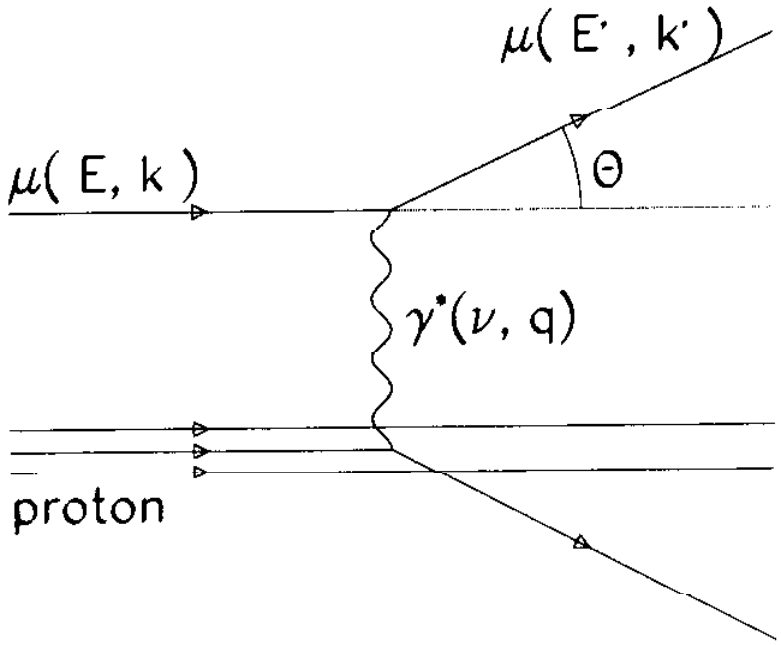
~150 Layers of Tracking

2 Open Dipole Magnets

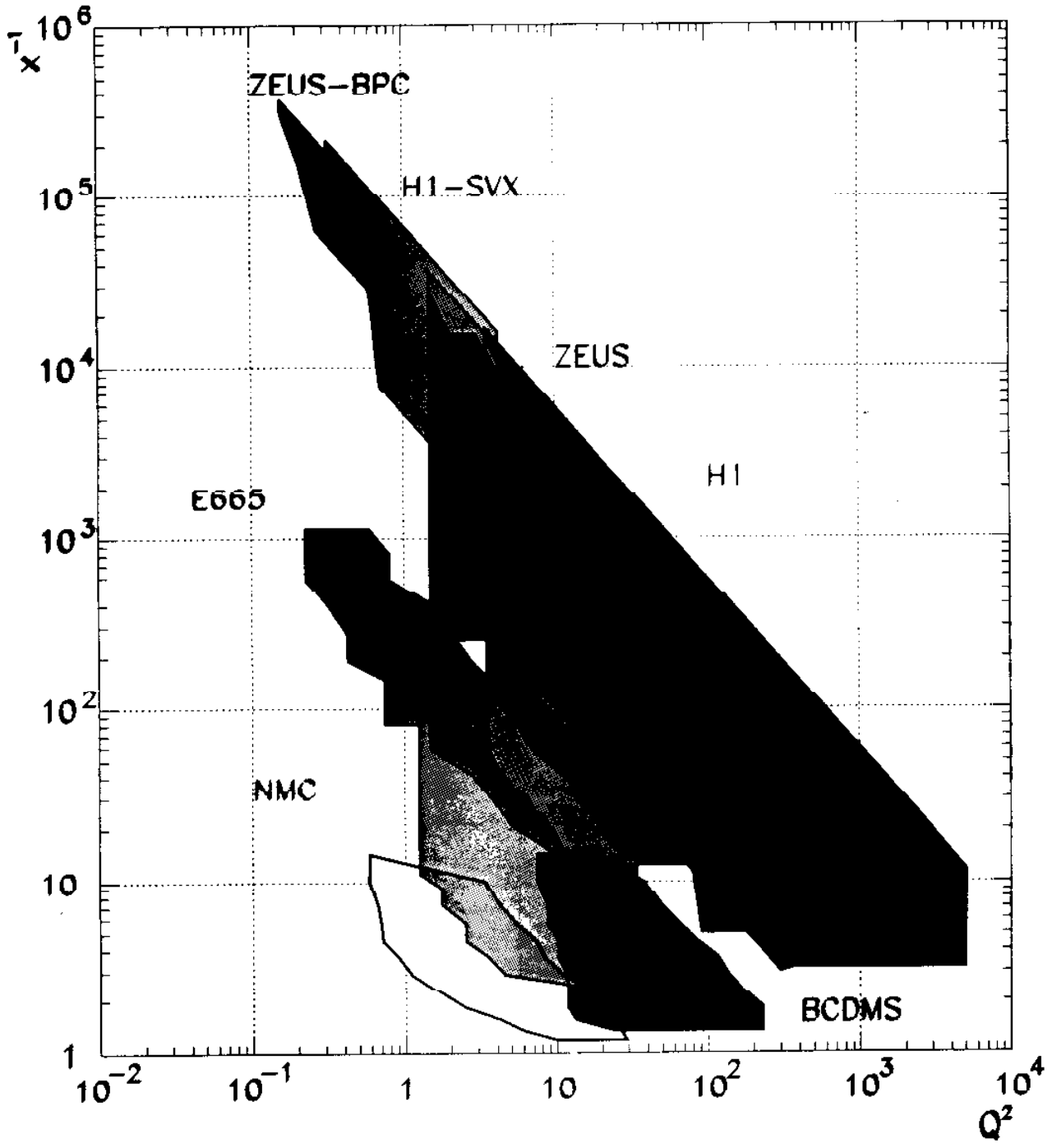
Electromagnetic Calorimeter

Hadron Absorber/Muon Tagger

Definition of kinematic variables

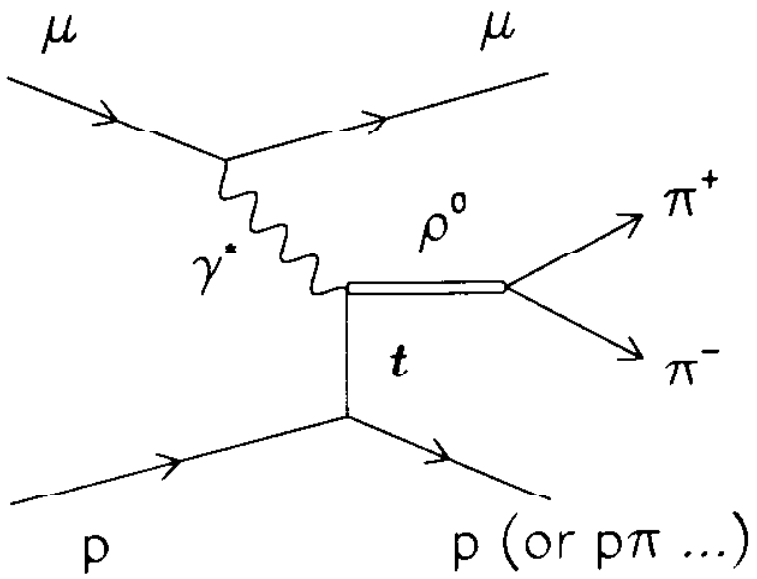


$Q^2 = -(k - k')^2$	negative 4-momentum transfer squared
θ	μ scattering angle in lab
$\nu = E - E'$	leptonic energy transfer in lab
$W^2 = M^2 + 2M\nu - Q^2$	hadronic cm energy squared
$x_{Bj} = Q^2/2M\nu$	Bjorken scaling variable
$y = \nu/E$	fractional leptonic energy transfer in lab
M	proton mass


x^{-1}
10^6
10^5
10^4
10^3
10^2
10
1
ZEUS–BPC
H1–SVX
ZEUS
H1
E665
NMC
BCDMS
10^{-2}
10^{-1}
1
10
10^2
10^3
10^4
Q^2

Reaction studied : $\mu\, p \rightarrow \mu\, p\, \rho^0$

$\hookrightarrow \pi^+\, \pi^-$



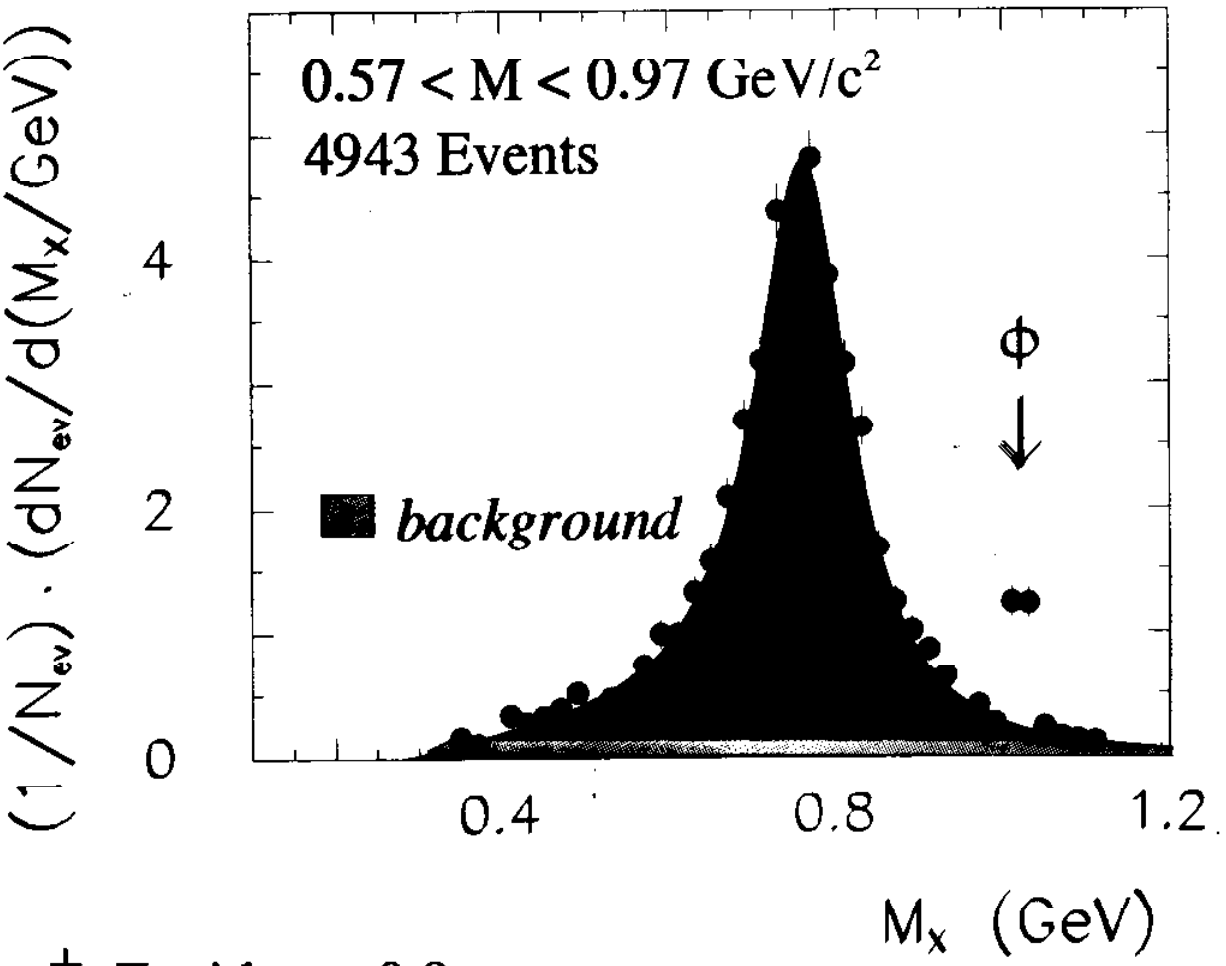
Beam μ, scattered μ and π^+, π^- are measured
Recoil p or dissociation products of p are not observed
However, t is measured with good resolution

Selection of candidates for $\mu\, p \rightarrow \mu\, p\, \rho^0$:

- Two hadrons of opposite charge
- $t' = t - t_{min} < 1\ GeV^2$
- Fraction z of γ^* energy carried by $\pi^+\pi^- > 0.9$
- $\pi^+\pi^-$ mass between 0.57 GeV and 0.97 GeV

$\Rightarrow$ 4943 events

E665 ρ^0 data on Hydrogen



$\pi^+\pi^-$ with $z > 0.9$

$E_\mu \sim 470$ GeV

$0.0001 < x < 0.6$

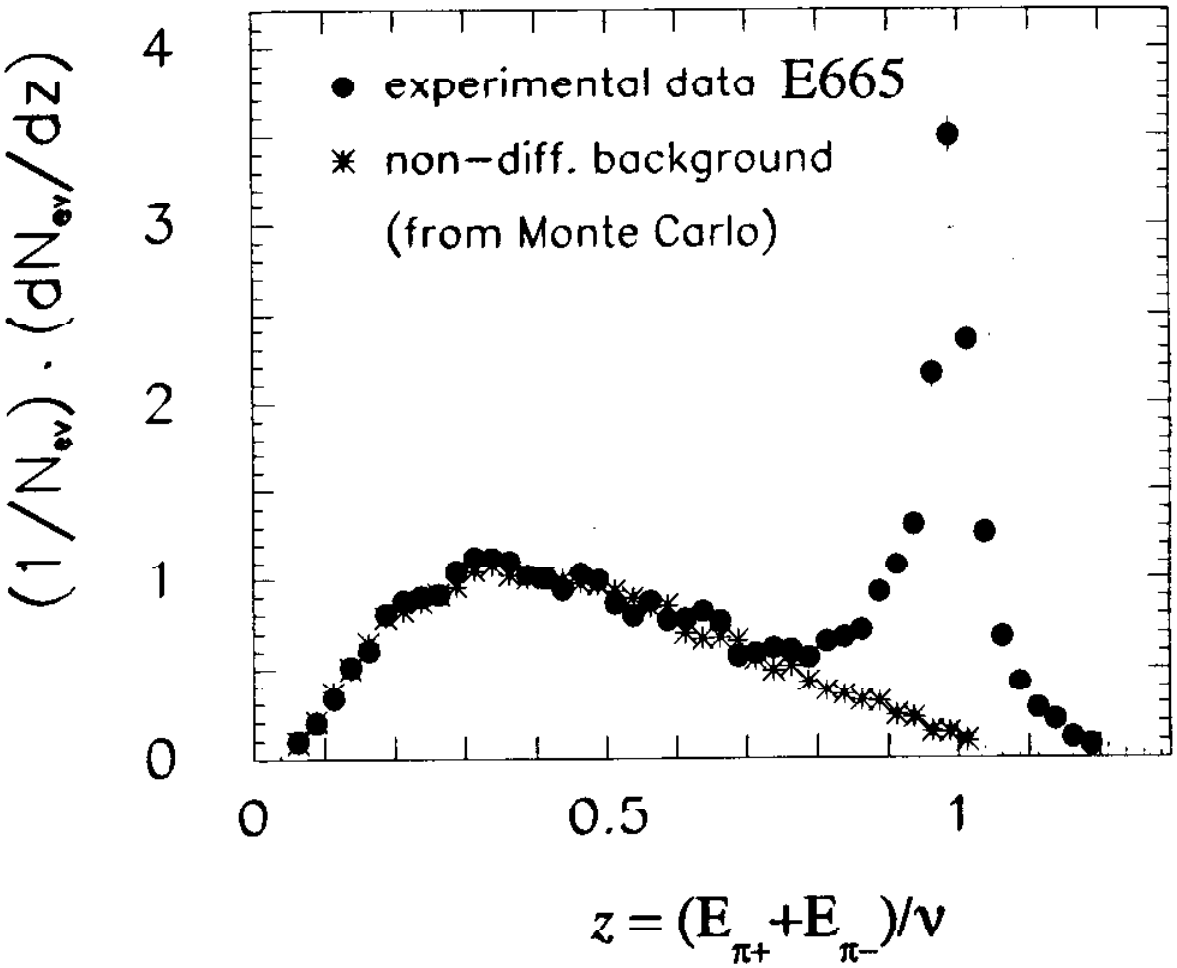
$0.15 < Q^2 < 20$ GeV^2

$0.05 < y < 0.8$

$20 < \nu < 420$ GeV

No large EM cluster

Elasticity of $\pi^+\pi^-$ Events

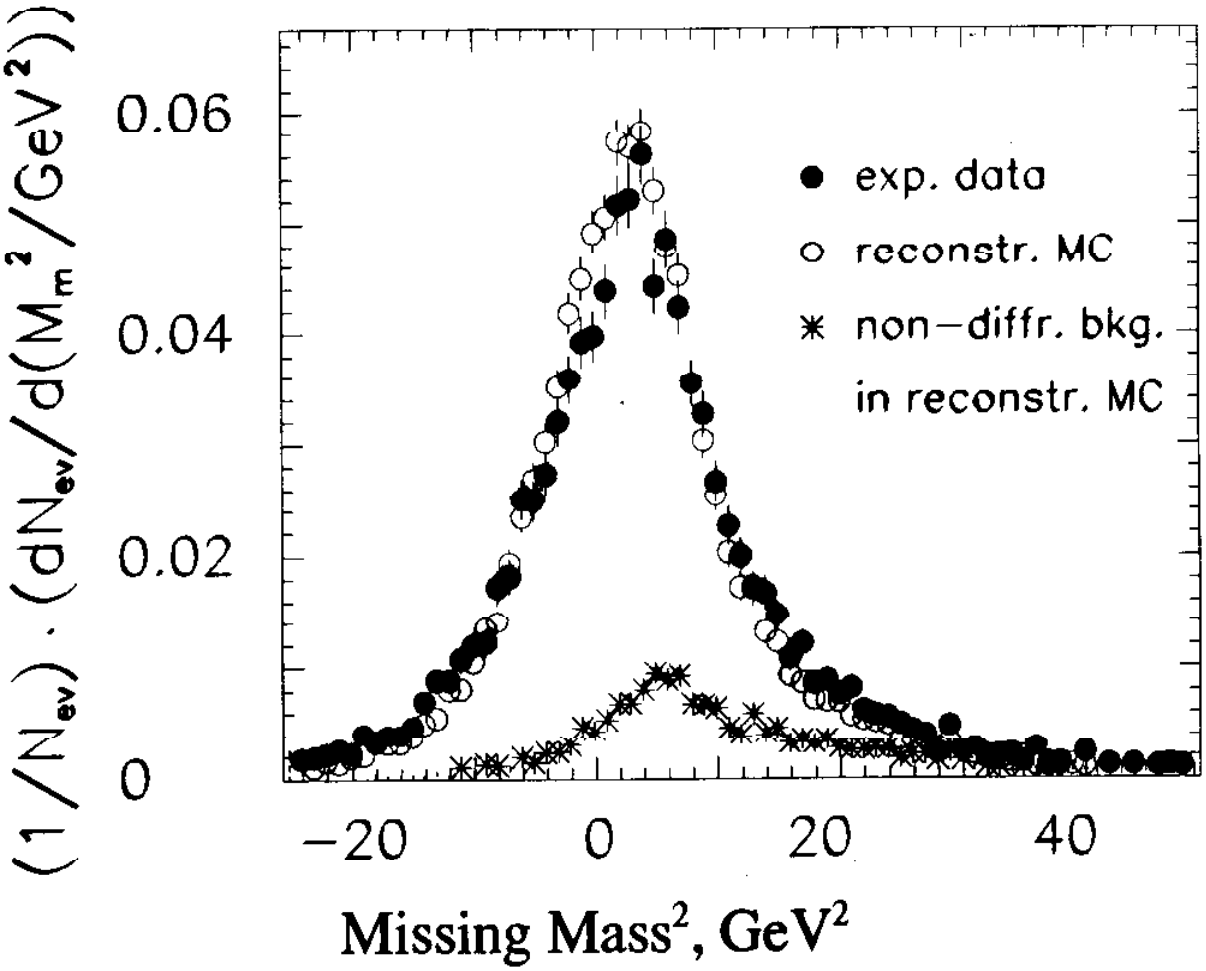


Monte Carlo : Inelastic = LUND
+ Single and Double diffraction
+ Radiative Corrections (GAMRAD)
+ Full GEANT detector simulation

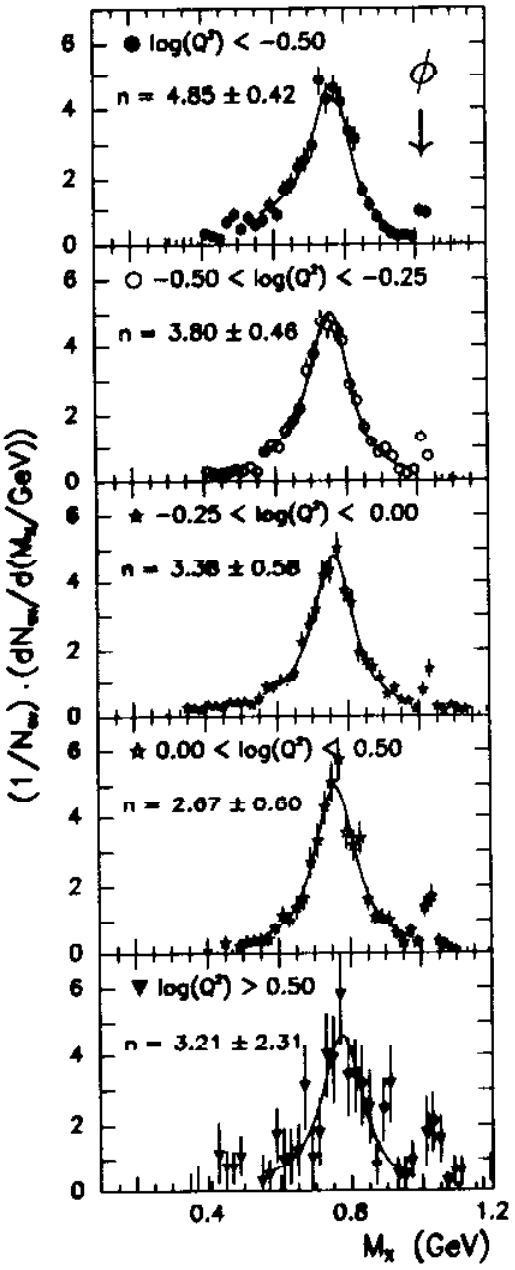
Backgrounds from Proton dissociation

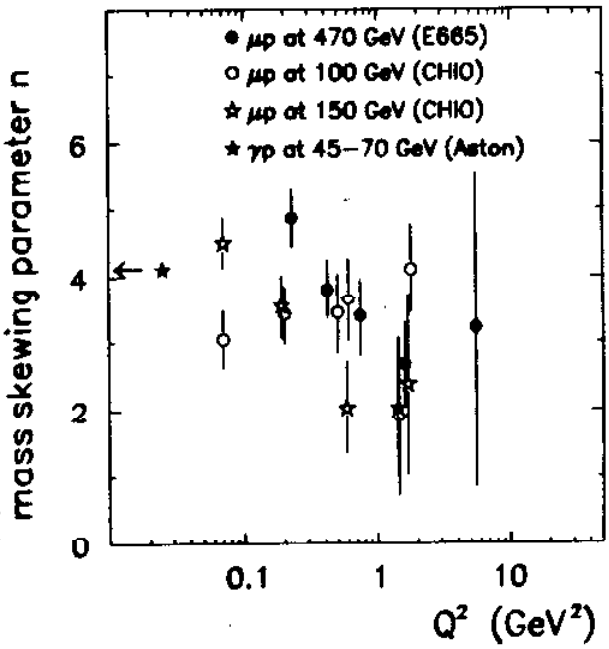
E665 cannot detect the proton and does not have missing mass resolution to distinguish double diffraction (DD) in which the proton breaks up from single diffraction (SD) in which it remains intact..

We assume DD/(SD + DD) = 20 +/− 10% and correct for DD contamination.



h^+h^- mass distribution for different Q^2 regions

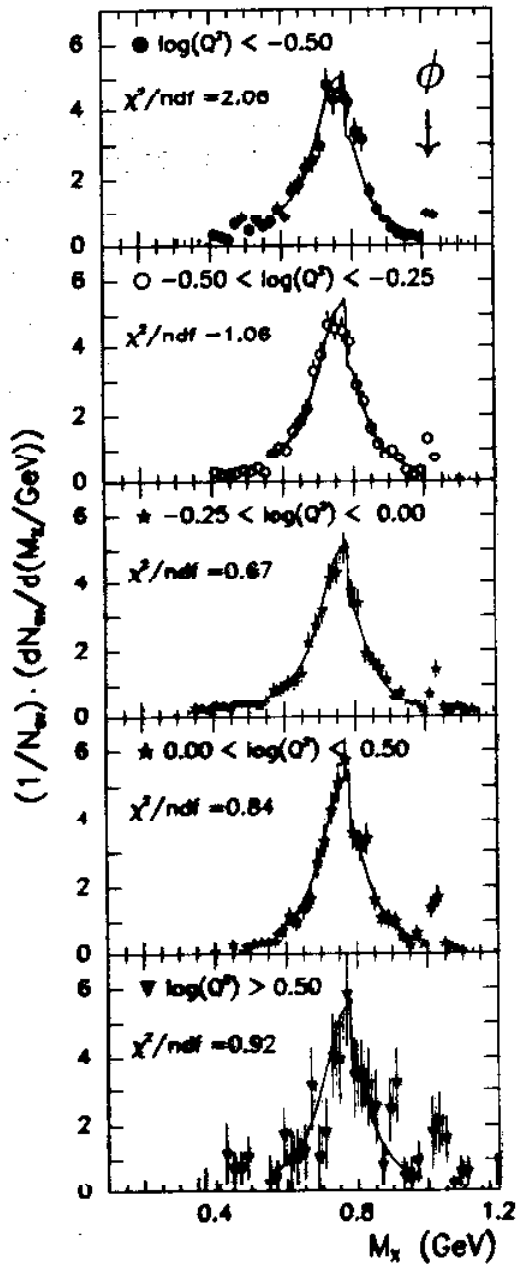




Solid curves : fit of relativistic P-wave Breit-Wigner with mass skewing factor $(M_\rho/M_{\pi\pi})^n$

n decreases as Q^2 increases

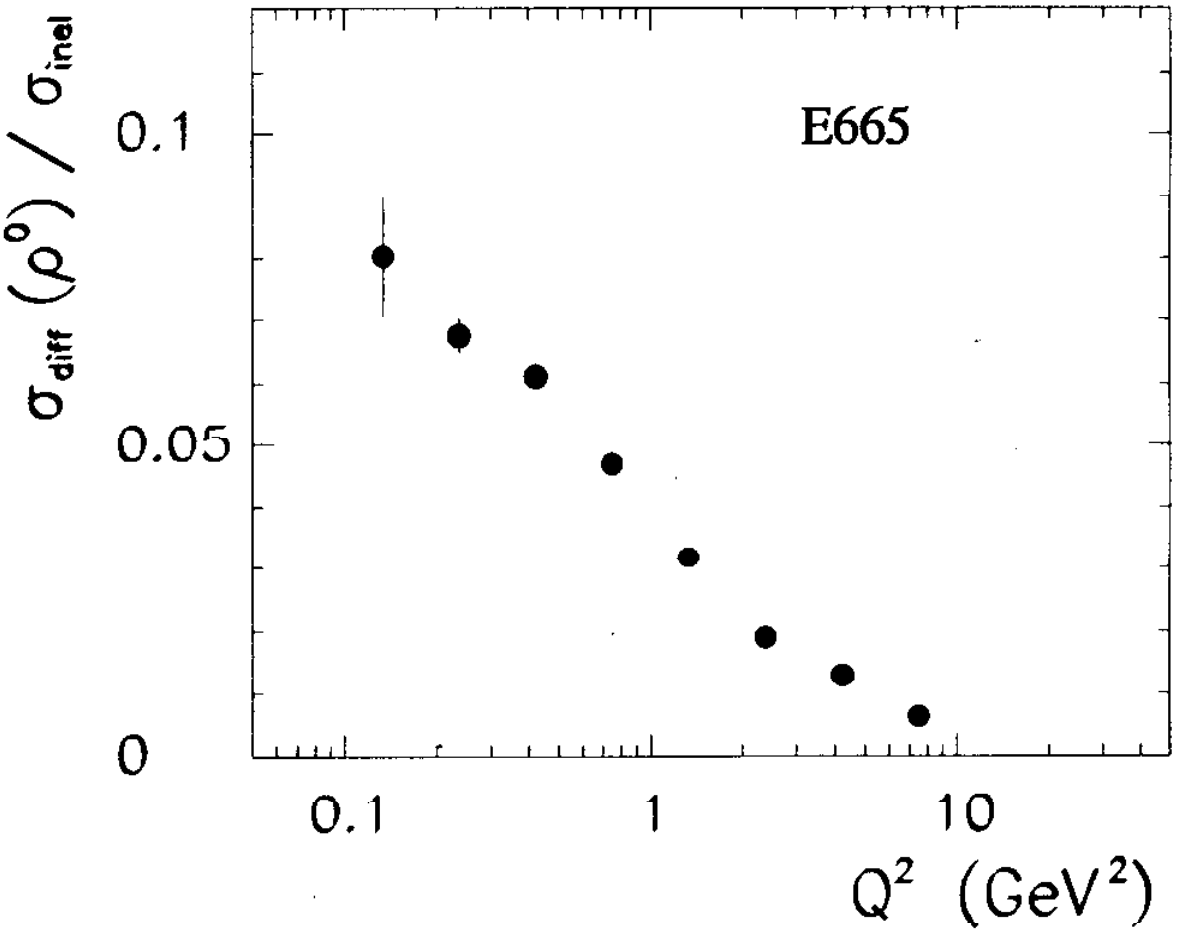
h^+h^- mass distribution for different Q^2 regions



Solid curves : prediction
by Niesler, Piller, Weise,
Phys.Lett. B389 (1996) 157

- In VDM, shape (asymmetry) of $\pi\pi$ mass spectrum and of e.m. form factor $F_\pi(M^2_{\pi\pi})$ of pion are related
- Q^2 dependence of asymmetry is caused by factor $[M^2_{\pi\pi}/(Q^2 + M^2_{\pi\pi})]^2$ in expression for cross section.

Diffractive ρ production as a fraction of the inelastic cross section.

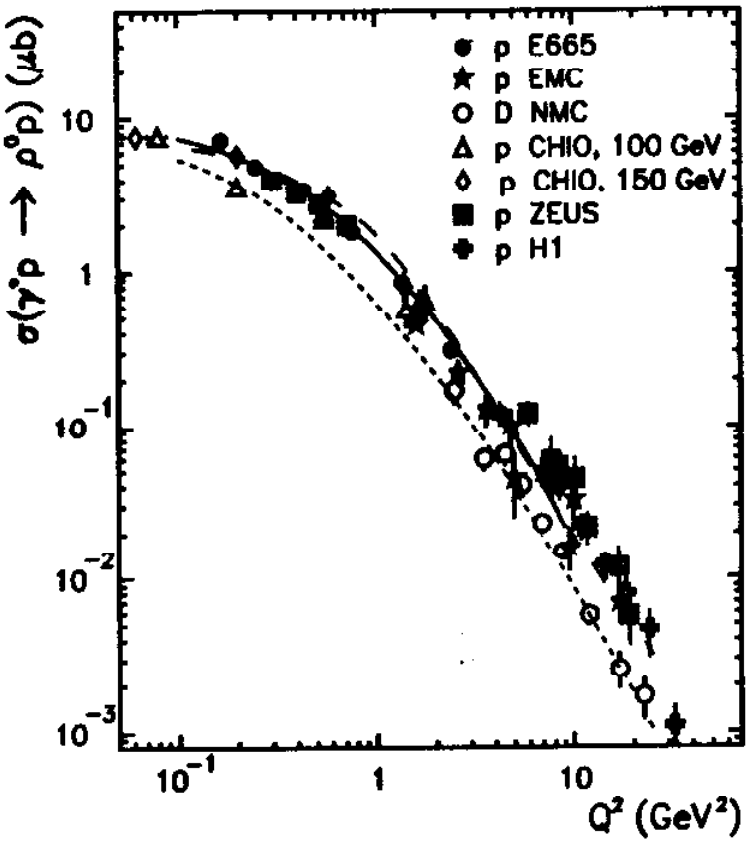


Measure this, use F^2(E665) to find σ(μp ->μρp)

Hand convention σ(μp) -> σ(γ*p)

ε, the photon flux polarization factor is 0.6-0.99

$$\sigma(\gamma^* p \rightarrow \rho^0 p) = \frac{1}{\Gamma_T} \cdot \frac{d\sigma(\mu p \rightarrow \mu p \rho^0)}{d\nu dQ^2}$$
$$= \sigma_T + \epsilon \cdot \sigma_L \quad \text{versus} \quad Q^2$$



Solid curve : fit of $\sigma = \sigma_0 \cdot \left(\frac{M_\rho^2}{Q^2+M_\rho^2}\right)^m \cdot [1 + \epsilon R(Q^2)]$

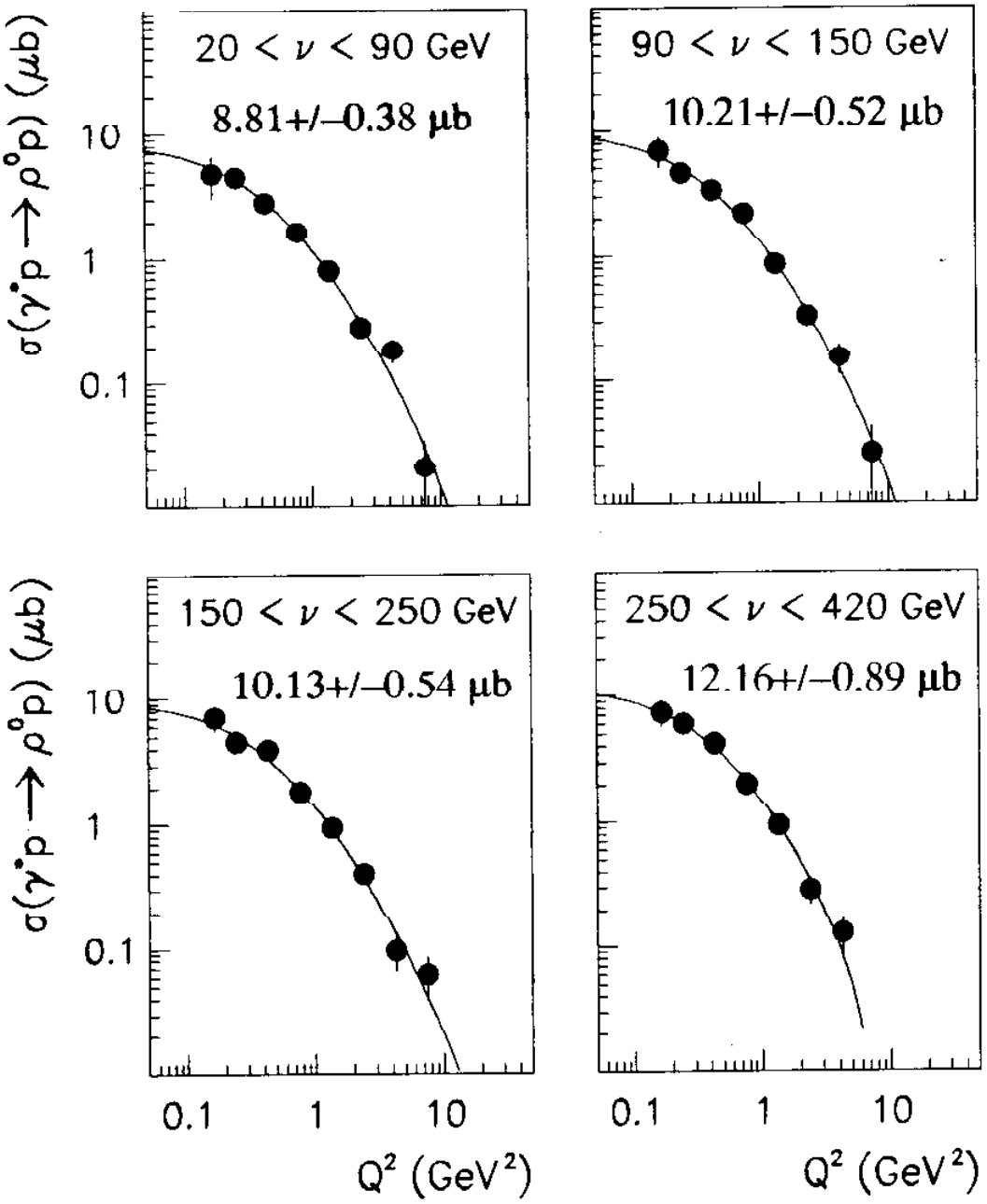
$\Rightarrow \sigma_0 = (10.23 \pm 0.56)\ \mu b \qquad m = 2.51 \pm 0.07$

Dashed curve : Pichowsky et al., nucl-th/9612049

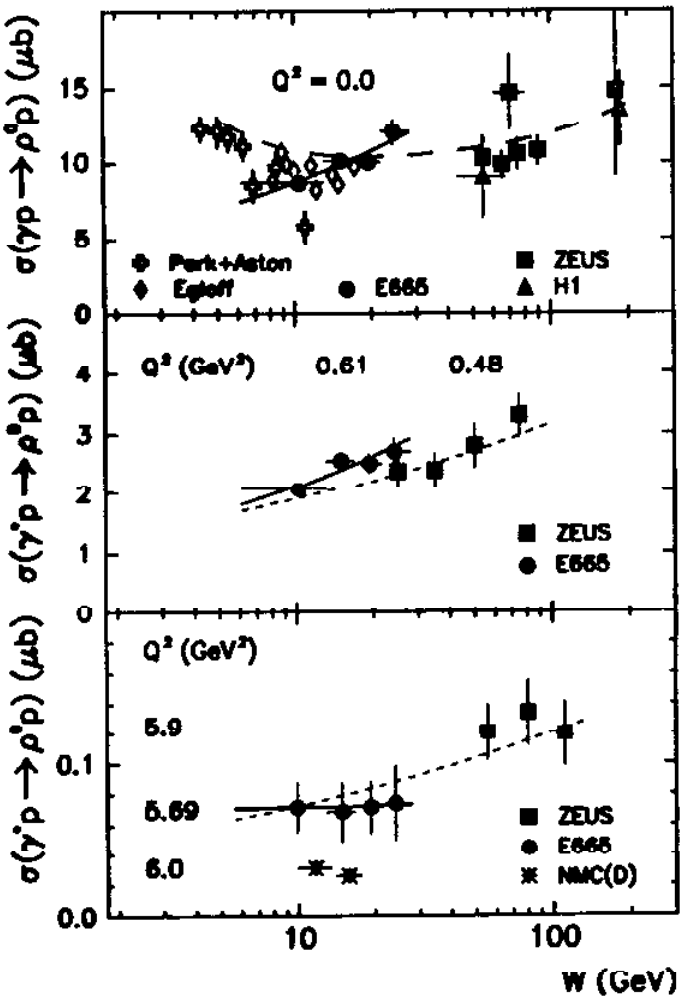
Dotted curve : Nemchik et al., hep-ph/9605231

ν Dependence of σ(γp->ρp)

Cross section as Q-> 0 shown in red
systematics errors are ~5%+13% acceptance
+ 8-15% due to double-diffraction assumptions



$\sigma(\gamma^* p \rightarrow \rho^0 p) = \sigma_T + \epsilon \cdot \sigma_L$ versus W
for different regions of Q^2



$\kappa = 0.31 \pm 0.20$

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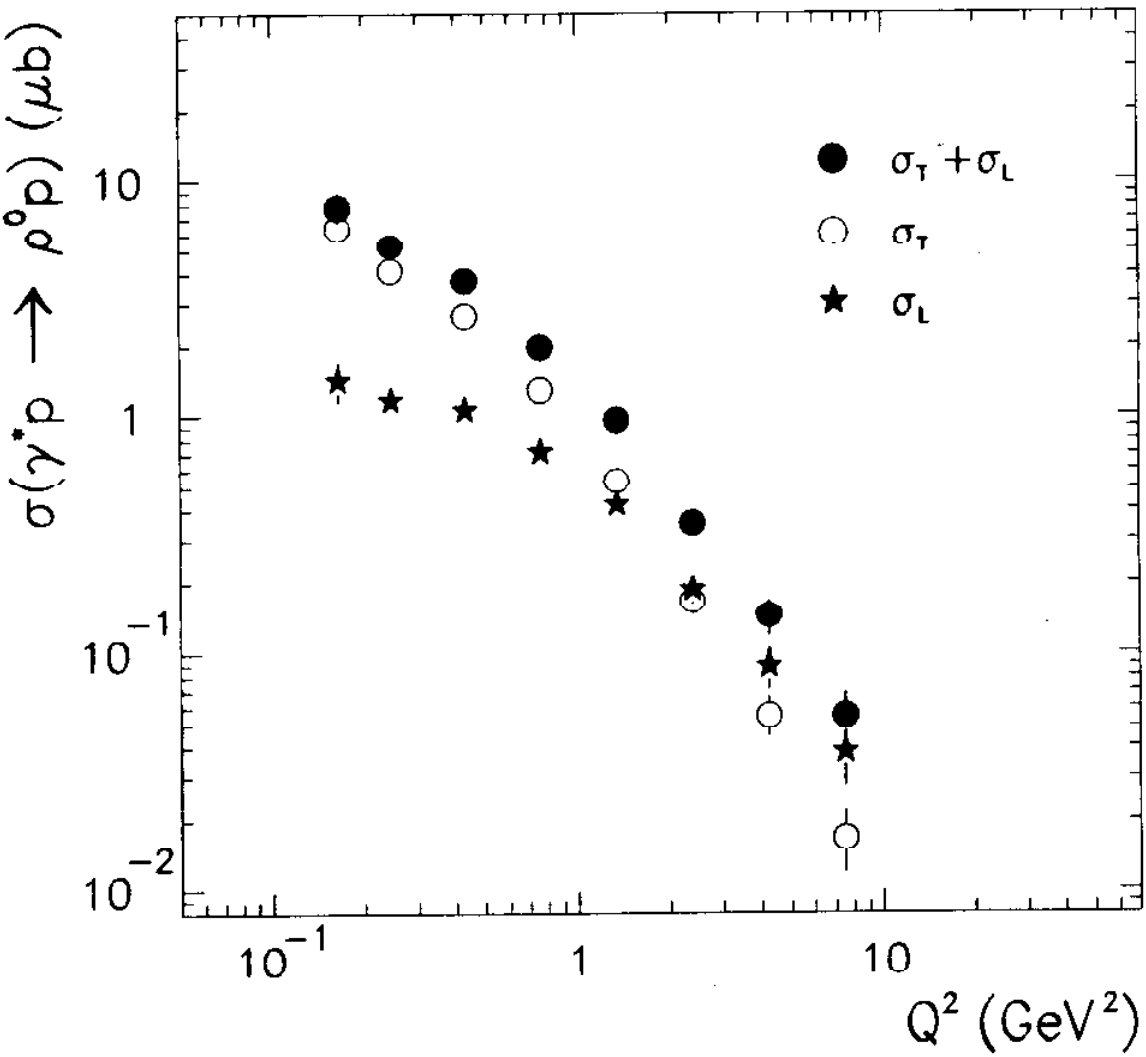
$\kappa = 0.02 \pm 0.75$

Dashed curve : Schuler and Sjöstrand, P.L. B300 (1993) 169; Nucl.Phys. B407 (1993) 539

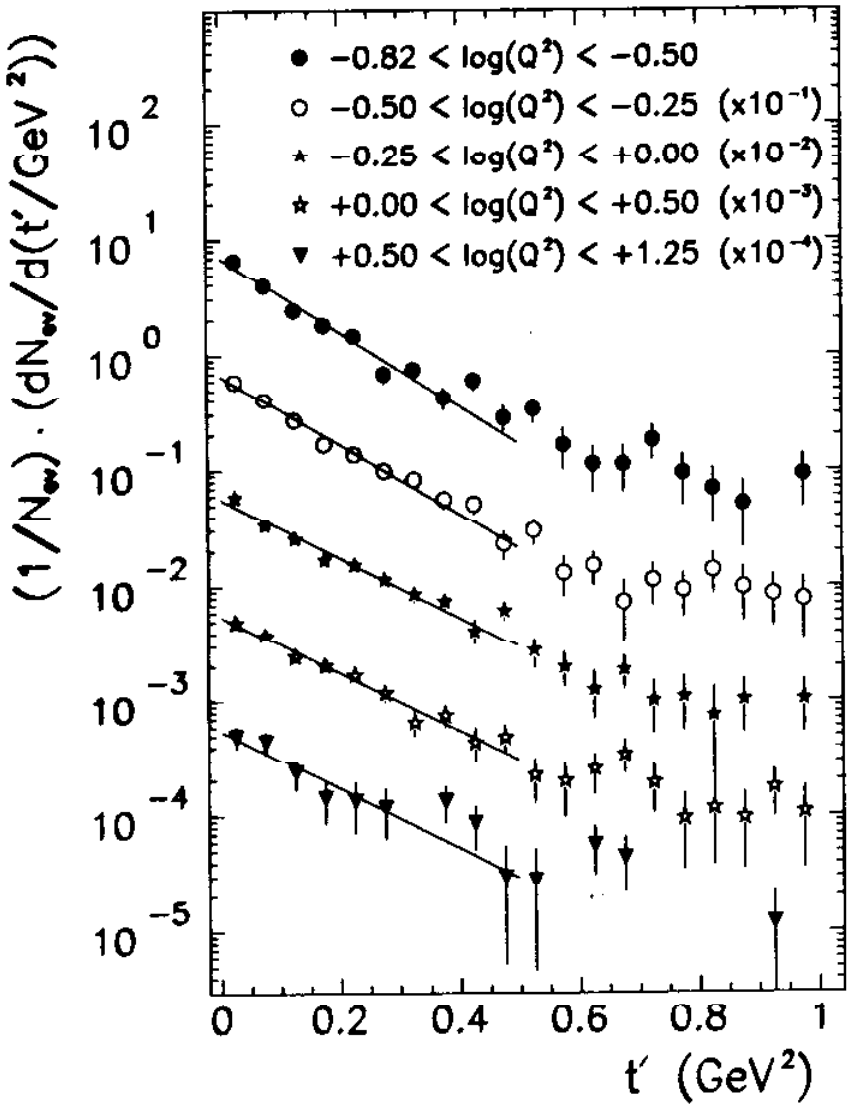
Dotted curve : $c \cdot (W/GeV)^{0.22}$

Solid curve : fits of $a \cdot (W/GeV)^{\kappa}$ to E665 data

Transverse and Longitudinal Cross Sections vs Q^2



t' $(= t - t_{min})$ distributions for different regions of Q^2



fits $a \cdot e^{-b\,t'}$

$b\,(GeV^{-2})$
8.3 ± 0.4
7.7 ± 0.4
6.5 ± 0.4
6.7 ± 0.5
6.0 ± 1.3

b decreases as Q^2 increases $\Rightarrow$

evidence for shrinkage of the effective $\gamma^* p$ interaction radius

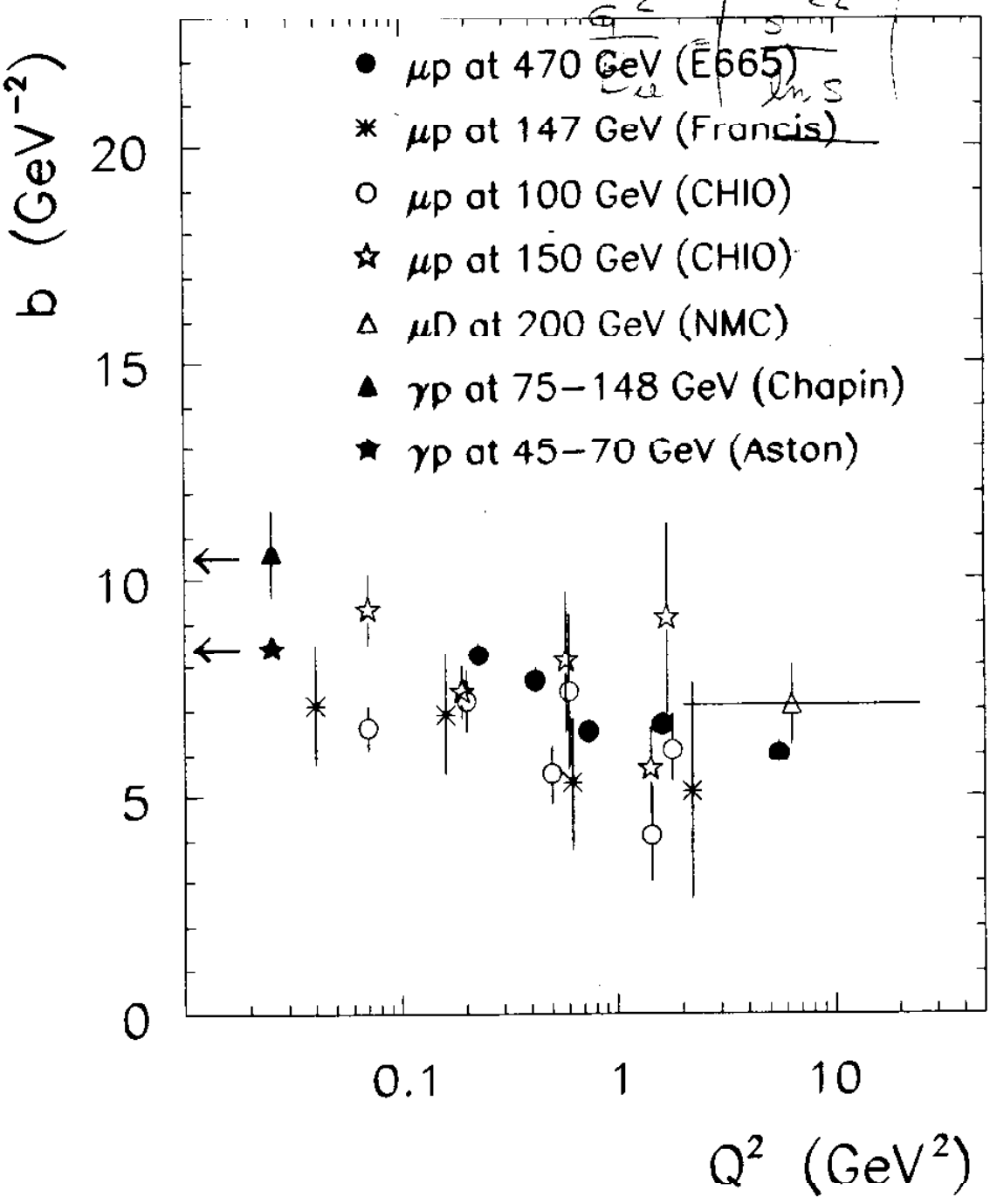
(decrease of transverse size of $q\overline{q}$ pair with increasing Q^2)

06/400

Sjostrand 1 VDM s dependence

Q^2 Dependence of t' slopes

$d\sigma/dt' = A\, e^{-bt'}$



W dependence of t slope b

Regge theory predicts

$$\frac{d\sigma}{dt} \sim (W^2)^{2\alpha(t)-2} \qquad \alpha(t) = \alpha_0 + \alpha' \cdot t$$

$$\Rightarrow \quad \Delta b = 4\alpha' \cdot \Delta lnW$$

Q^2 (GeV^2)	W (GeV)	b (GeV^{-2})	
$0.31 - 0.56$	$8 - 25$	$7.7 \pm 0.4 \pm 0.3$ $(t' < 0.5)$	E665
$0.25 - 0.85$	$50 - 90$	$9.3 \pm 0.7 \pm 0.8$ $(t < 0.4)$	ZEUS (BPC)

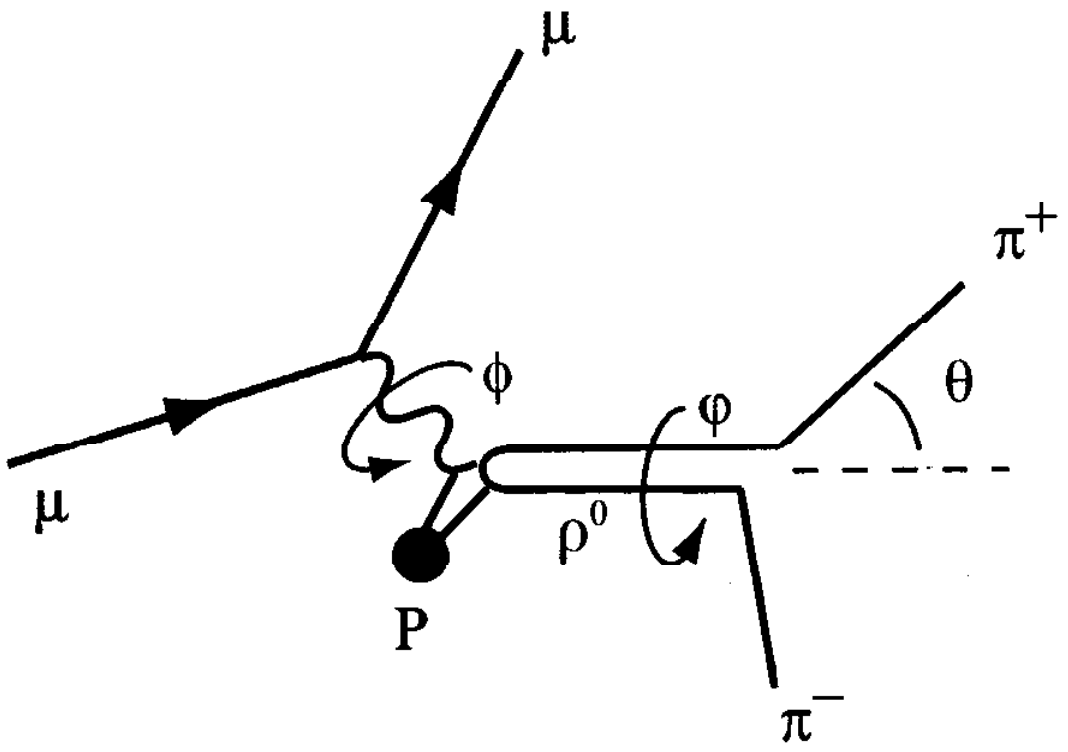
$\Rightarrow \quad \Delta lnW \sim 1.5$

$\Delta b = 1.6 \pm 0.8 \pm 0.8\ GeV^{-2}$ is consistent with a soft Pomeron : $\alpha' = 0.25\ GeV^{-2}$

Shrinkage of t distribution with increasing W is also seen

- in photoproduction — Aston, H1, ZEUS
- and at higher Q^2 $(8 < Q^2 < 50\ GeV^2)$ — H1

ρ^0 Decay Distributions



ϕ angle between muon and production planes

φ angle between production and decay planes

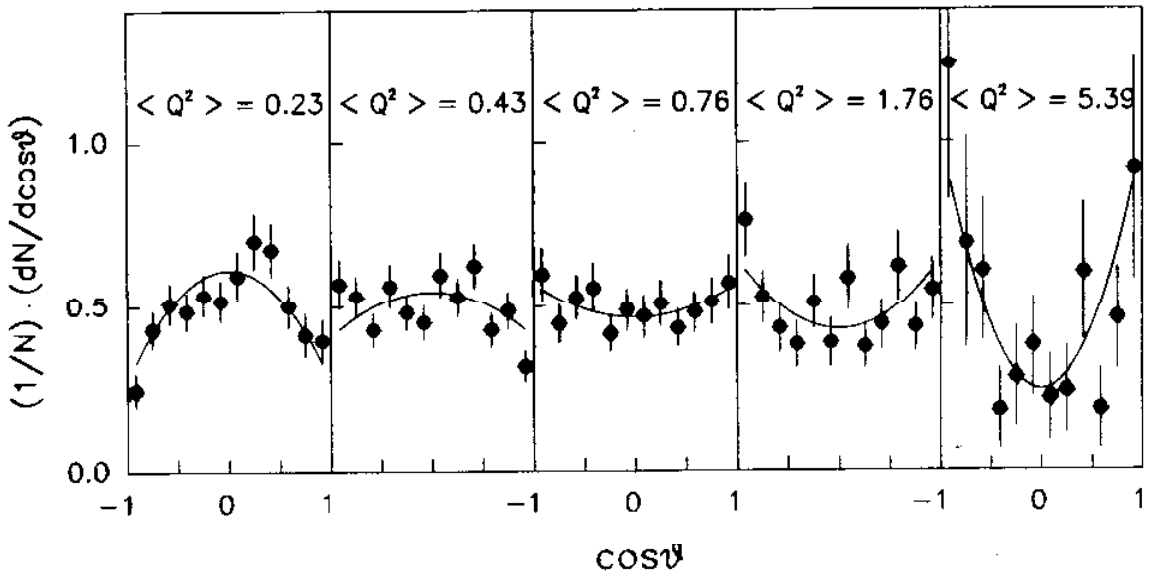
θ center-of-mass angle of π^+ relative to ρ^0.

$\psi = \varphi - \phi$

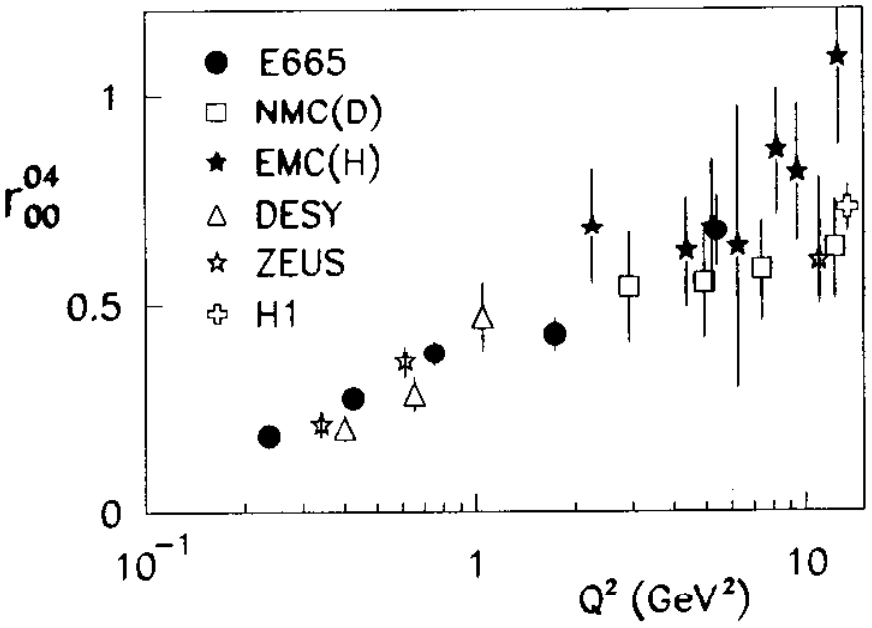
ρ^0 decay in the helicity frame :

quantization axis = direction of ρ^0 in $\gamma^* p$ cms

ϑ = angle between decay π^+ and quantization axis

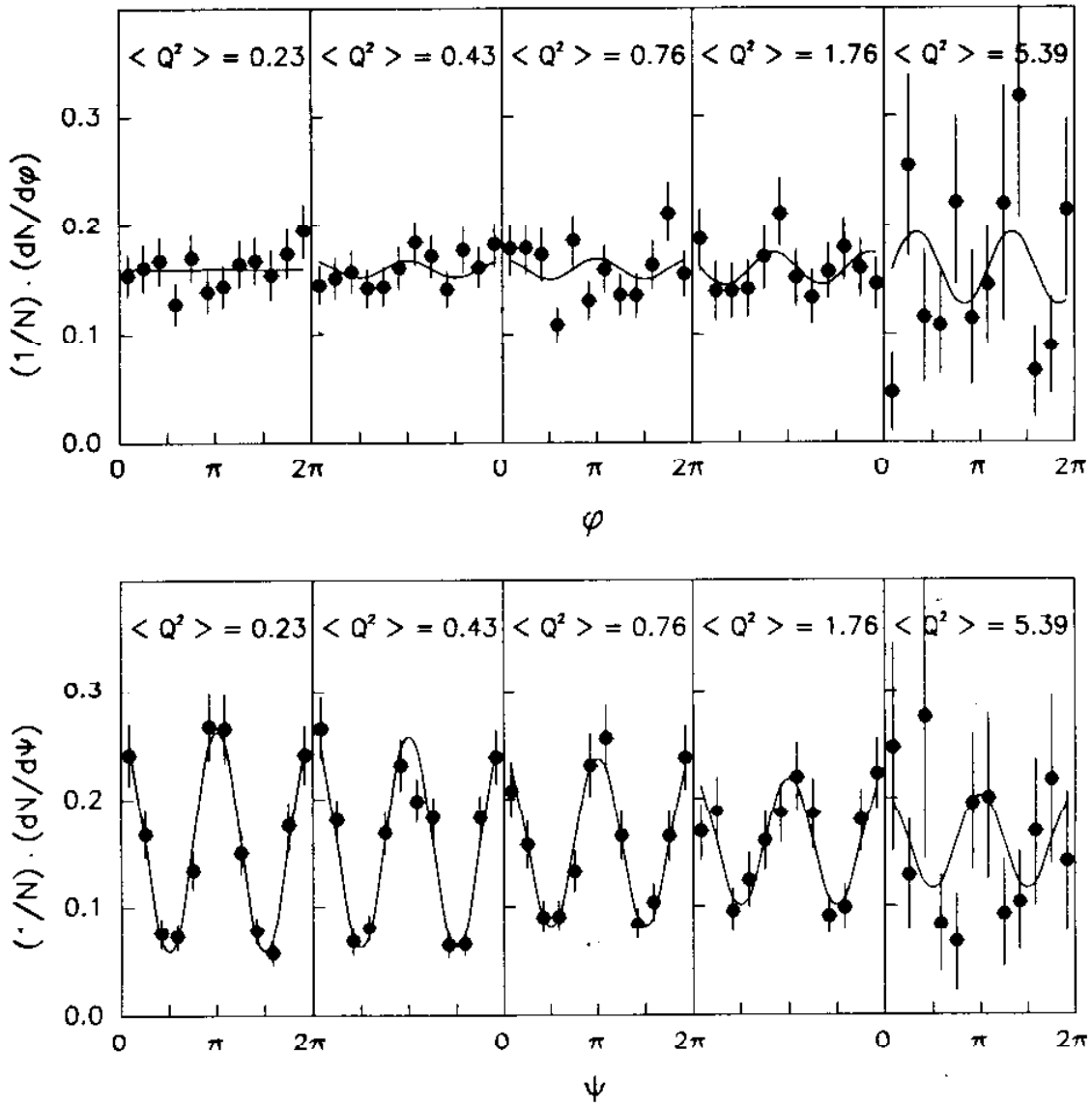


$$\frac{1}{N} \cdot \frac{dN}{dcos\vartheta} = \frac{3}{4} \cdot \left[1 - r_{00}^{04} + (3r_{00}^{04} - 1)\, cos^2\vartheta\right]$$



r_{00}^{04} is probability that ρ^0 has helicity 0 (longitudinal)

Azimuthal angular distributions :



φ = azimuthal angle (around quantization axis) of decay π^+ relative to $\boldsymbol{\rho^0}$ production plane

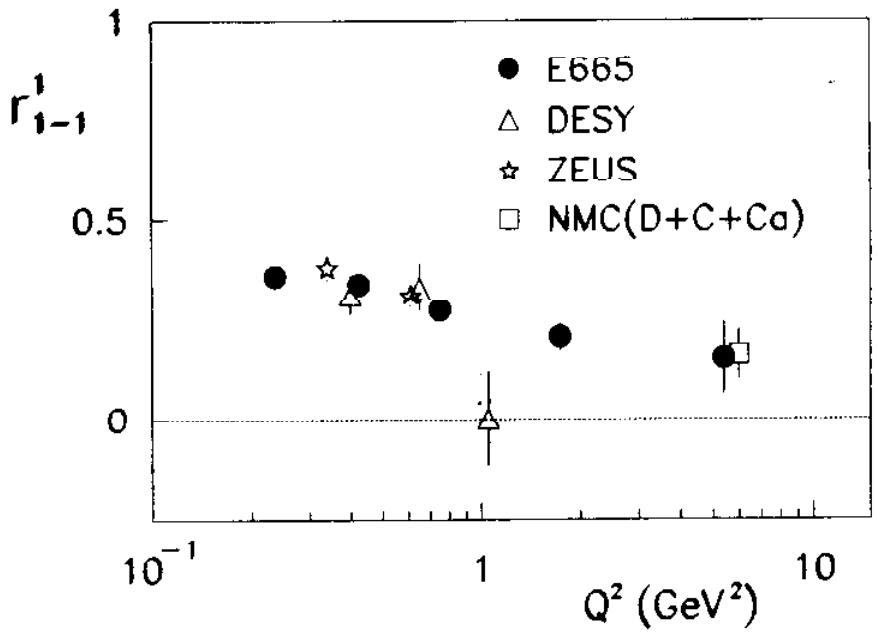
ϕ – angle (around virtual-photon direction) between $\boldsymbol{\rho^0}$ production plane and lepton plane (formed by the beam μ and the scattered μ)

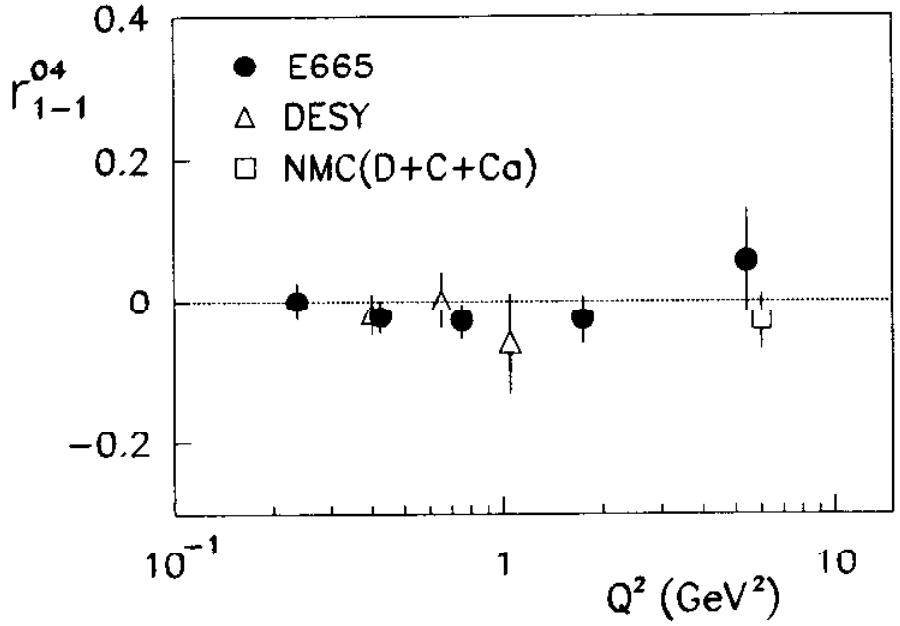
$\psi = \varphi - \phi$

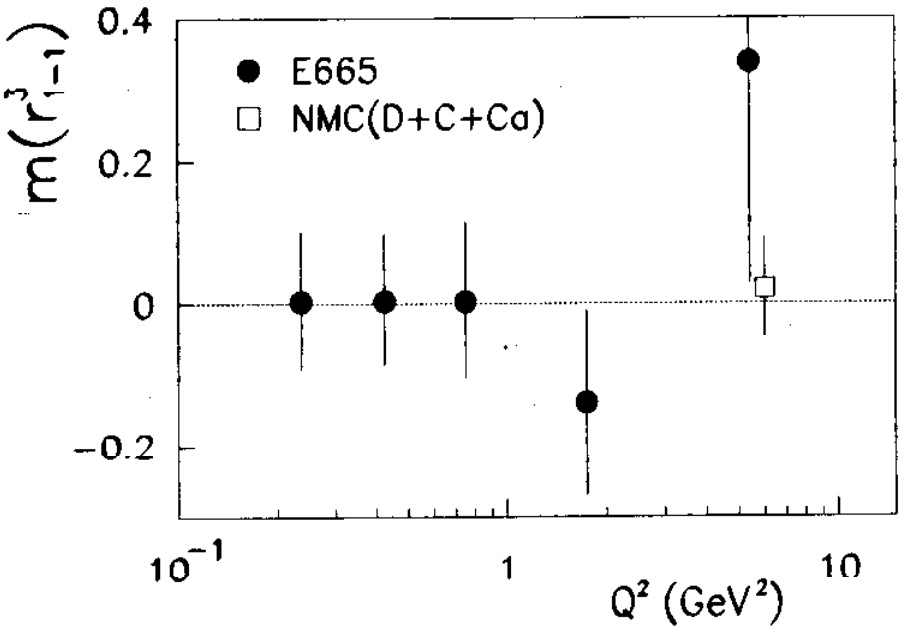
If helicity of virtual photon is retained by ρ^0
(s-channel helicity conservation SCHC)

$$\Rightarrow \quad r^{04}_{1-1} = r^{3}_{1-1} = 0$$

$$\frac{1}{N} \cdot \frac{dN}{d\psi} = \frac{1}{2\pi} \cdot \left[1 + 2\epsilon\, r^{1}_{1-1}\, cos2\psi\right]$$





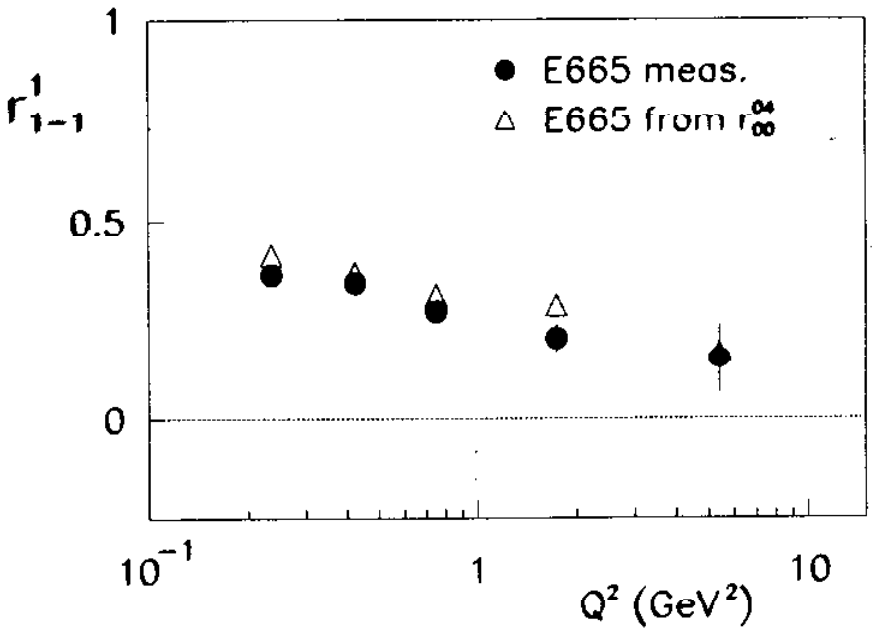


$$\frac{1}{N}\cdot\frac{dN}{d\varphi} =$$

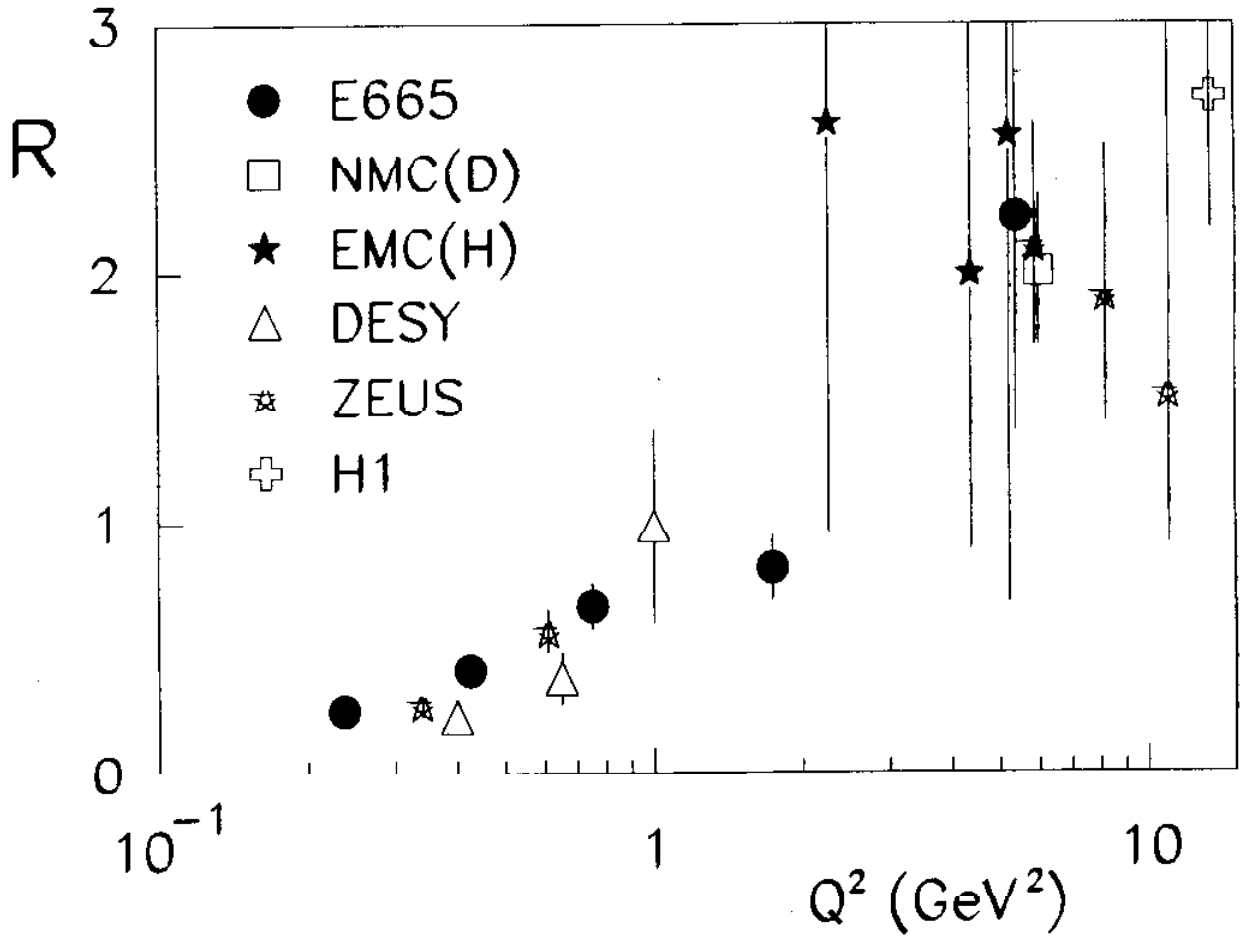
$$\frac{1}{2\pi}\cdot\left[1 - 2r^{04}_{1-1}\,cos2\varphi + 2P\sqrt{1-\epsilon^2}Im(r^3_{1-1})\,sin2\varphi\right]$$

s-channel helicity conservation (SCHC)
and natural-parity exchange in t channel $\Rightarrow$

$$r^1_{1-1} = \frac{1}{2} \cdot (1 - r^{04}_{00})$$



$R = \sigma_L/\sigma_T$ derived from r^{04}

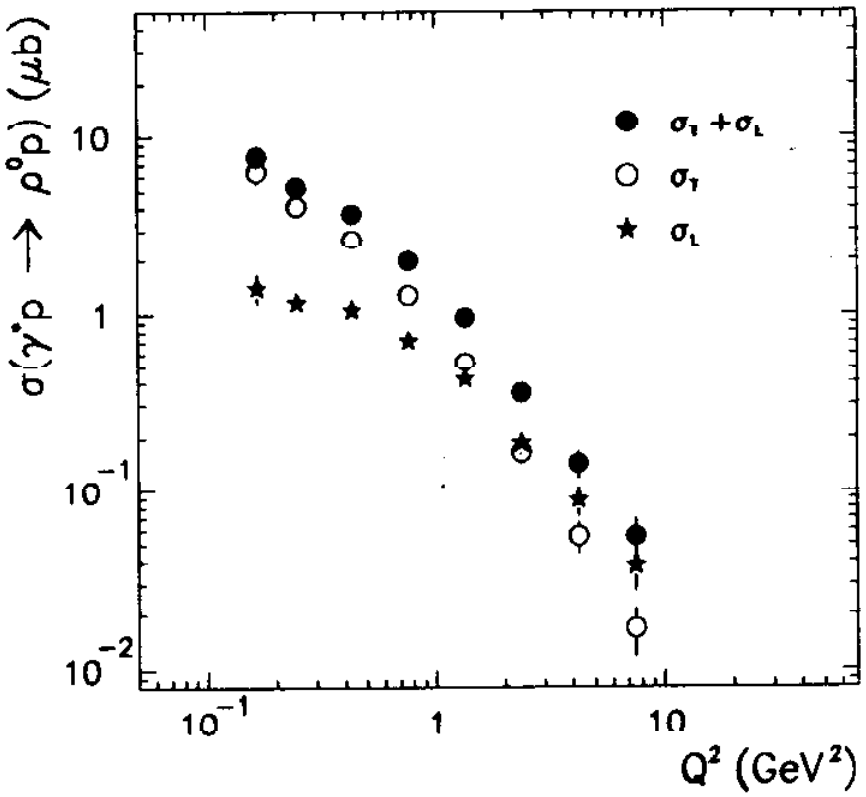


$$\gamma^* p \rightarrow \rho^0 p : \quad \sigma_T = \frac{\sigma}{1 + \epsilon R}$$

$$\sigma_L = \frac{\sigma R}{1 + \epsilon R}$$

$$\sigma_T + \sigma_L = \frac{\sigma(1 + R)}{1 + \epsilon R}$$

plotted versus Q^2



$< c > \cong 0.81$

$$R = \frac{\sigma_L}{\sigma_T} = (0.66 \pm 0.05) \cdot (Q^2)^{(0.61 \pm 0.09)}$$

(from E665 fit to angular distributions)

Conclusions

- Photo-production $\sigma(\gamma p \rightarrow \rho p) = 10.30 +/- 0.33$ μb and rises gently with W
- Mass distributions are skewed at low Q^2
- t' distributions flatten as Q^2 rises
- angular distributions are consistent with SCHC
- ρ polarization becomes longitudinal quickly as Q^2 rises