Vector Meson Production in CLAS

Elton Smith, Jlab
and the CLAS Collaboration

Generalized Parton Distributions and Hard Exclusive Processes
Institute for Nuclear Theory Workshop
June 23 – 27, 2003

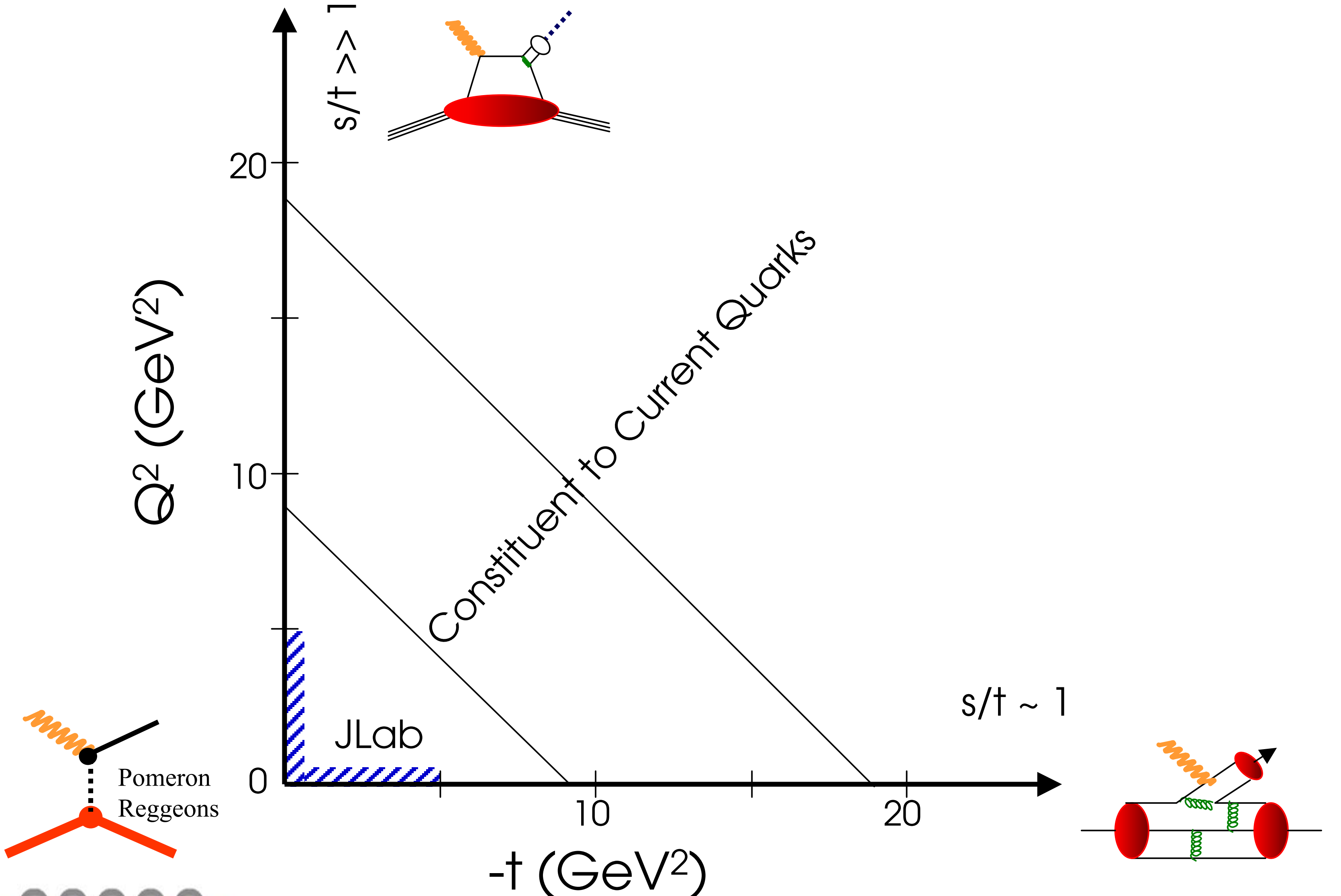
Outline

- Summary of ϕ, ρ and ω photoproduction data at high-t
- Results of electroproduction of ρ and ϕ mesons at 4.2 GeV
- Signal extraction and quality of data for electroproduction of ω and ϕ mesons at 5.75 GeV

Note: Analysis is proceeding on other channels

- DVCS
- π^0 and η
- Single spin asymmetries for γ, π^0, etc

Exclusive reactions

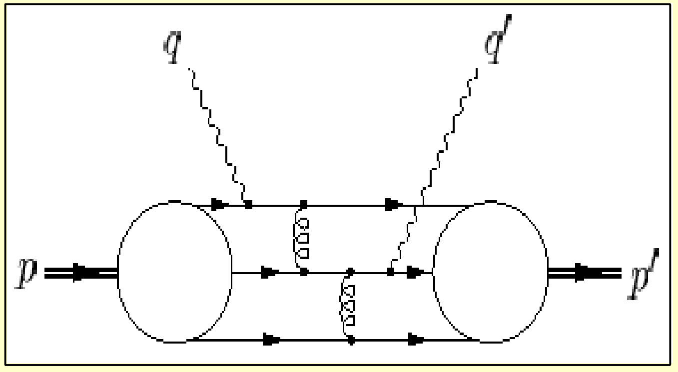


(Laget)

High t

Leading twist factorization

G. Lepage and S. Brodsky
Phys.Rev. D22 (1980) 2157



- **All partons are involved**
- **Hard scattering amplitude**
- **Soft physics encoded in**

Distribution Amplitudes

- Large p_T inclusive hadronic scattering
- Exclusive hadronic two-body reactions
- Wide Angle Meson photoproduction
- Wide Angle Compton Scattering

Dimensional Counting rules

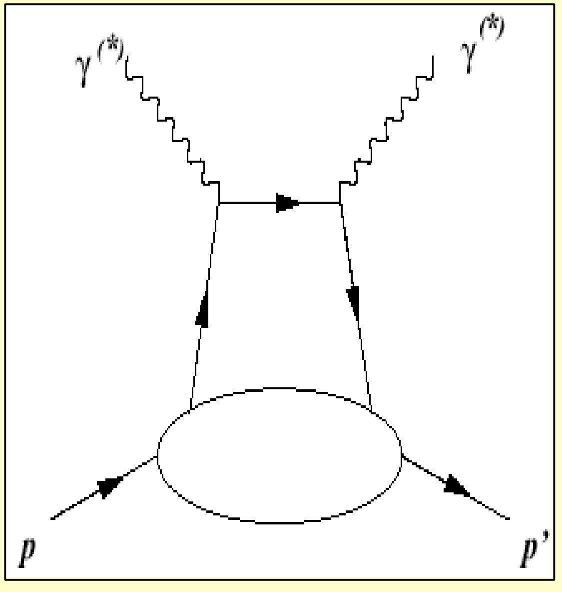
S.Brodsky G.Farrar
Phys.Rev.Lett. 31 (1973) 1153
Phys.Rev. D11 (1975) 1303

$-t \to \infty$
t/s **fixed**

$ds/dt(ab \to ab) \sim 1/s^{(n-2)}\ f_{ab}(t/s)$

High Q^2

Hand bag factorization



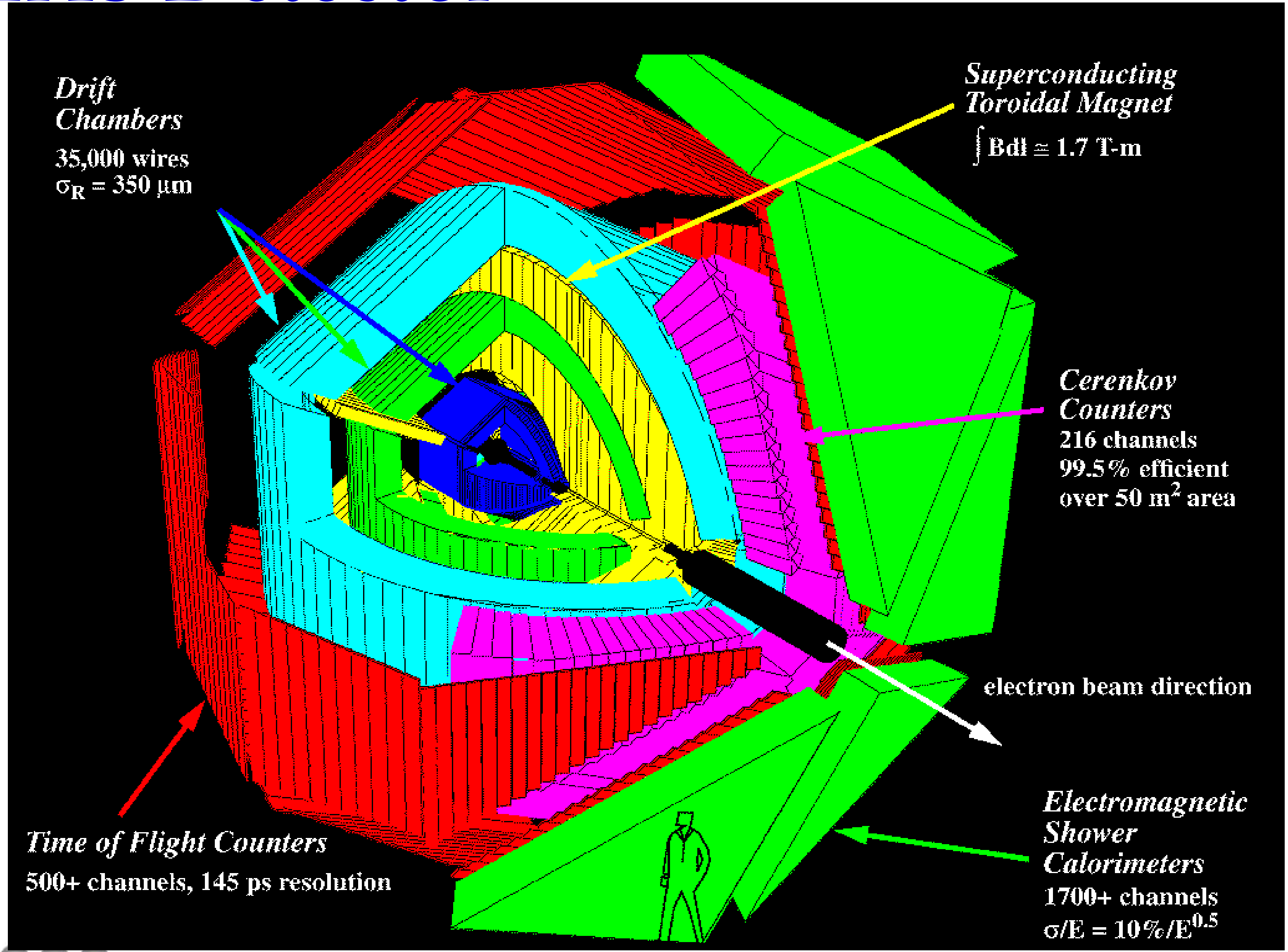
- **Only 1 active parton**
- **Hard scattering amplitude**
- **Soft physics encoded in**

Generalized Parton Distributions

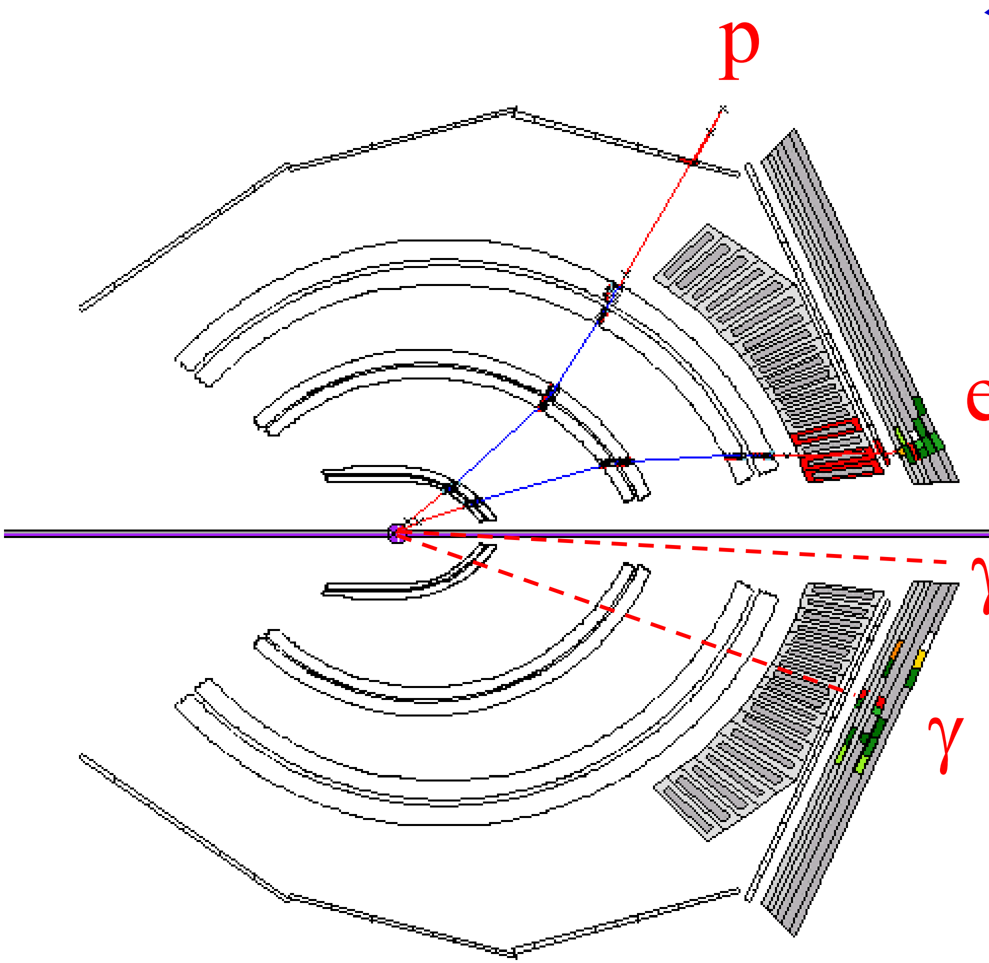
X.Ji Phys.Rev. D55 (1997) 7114
A.Radyushkin Phys.Rev. D56 (1997) 5524

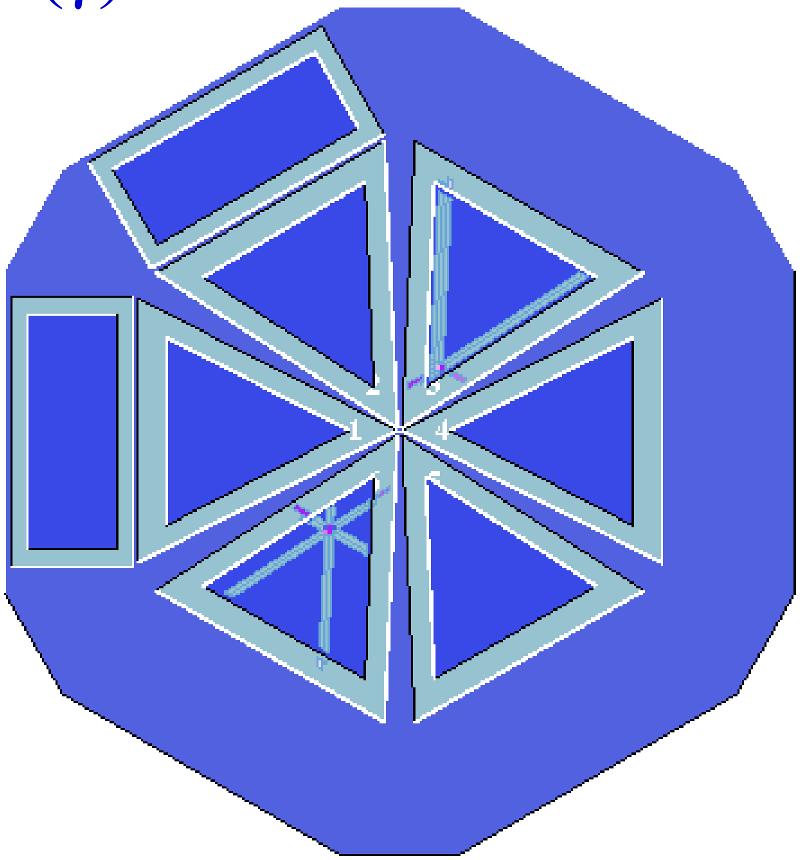
- Deeply Virtual Compton Scattering
- Deeply Virtual Meson Production
- Wide Angle Compton Scattering
- Wide Angle Meson Photoproduction

CLAS Detector



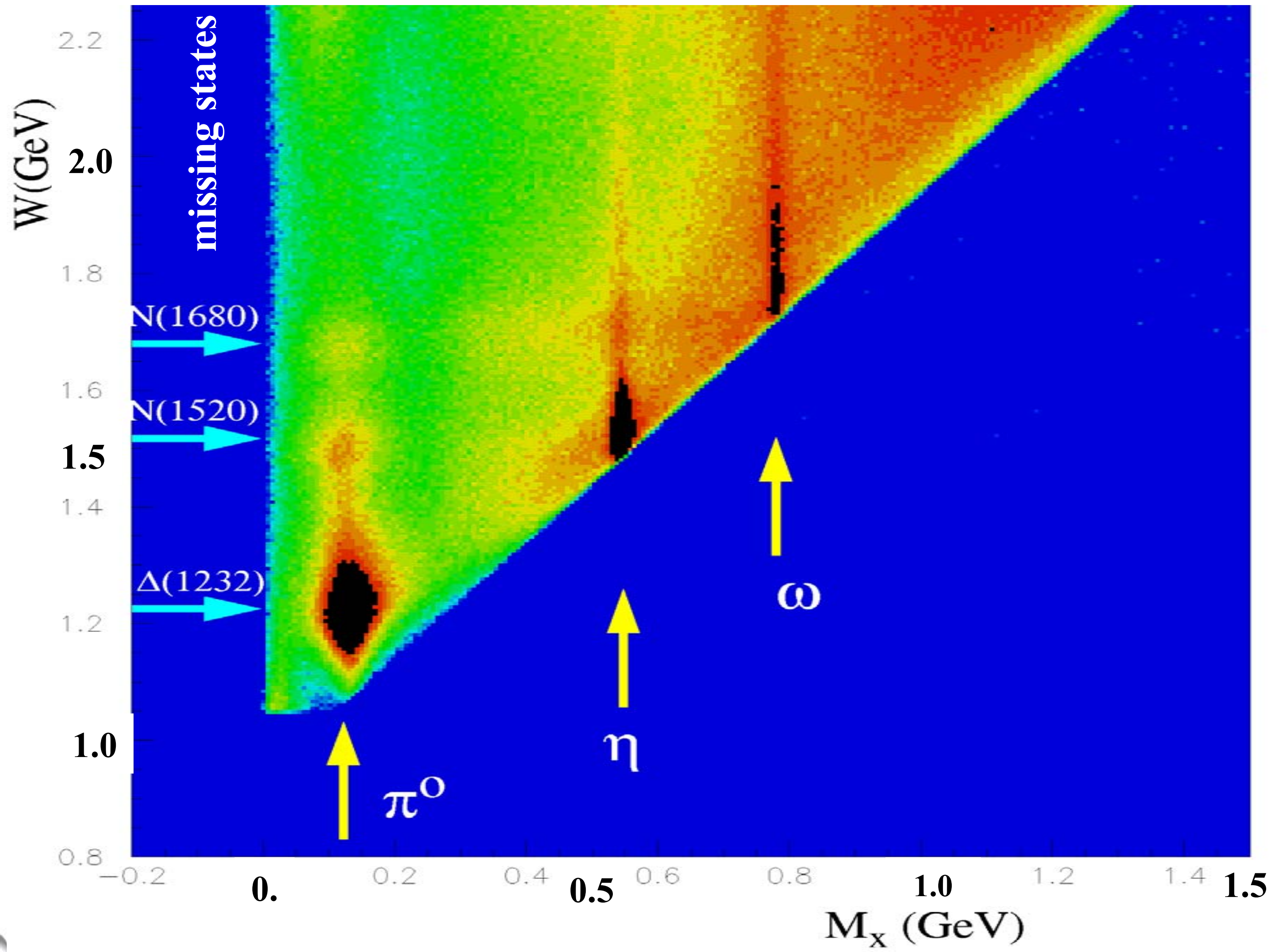
Example: $ep \to ep\pi^0 \searrow \gamma\ (\gamma)$



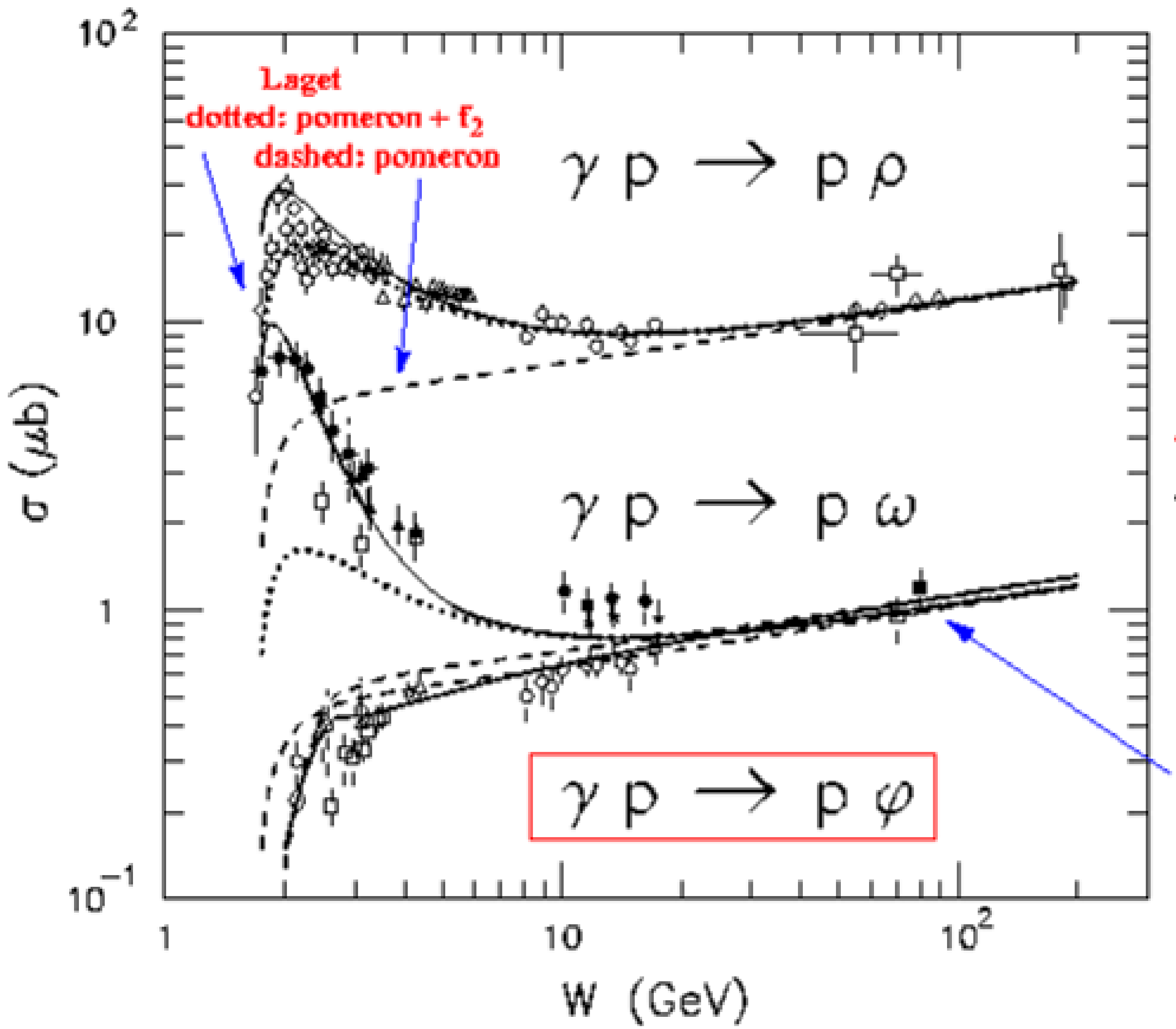


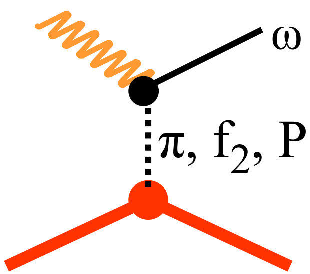
CLAS Detector MC

Coverage for ep → e'pX, E=4 GeV

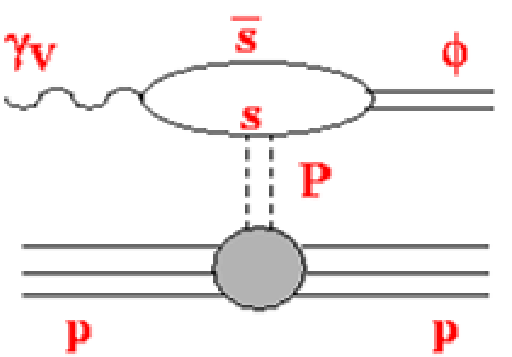


Photoproduction Cross Sections





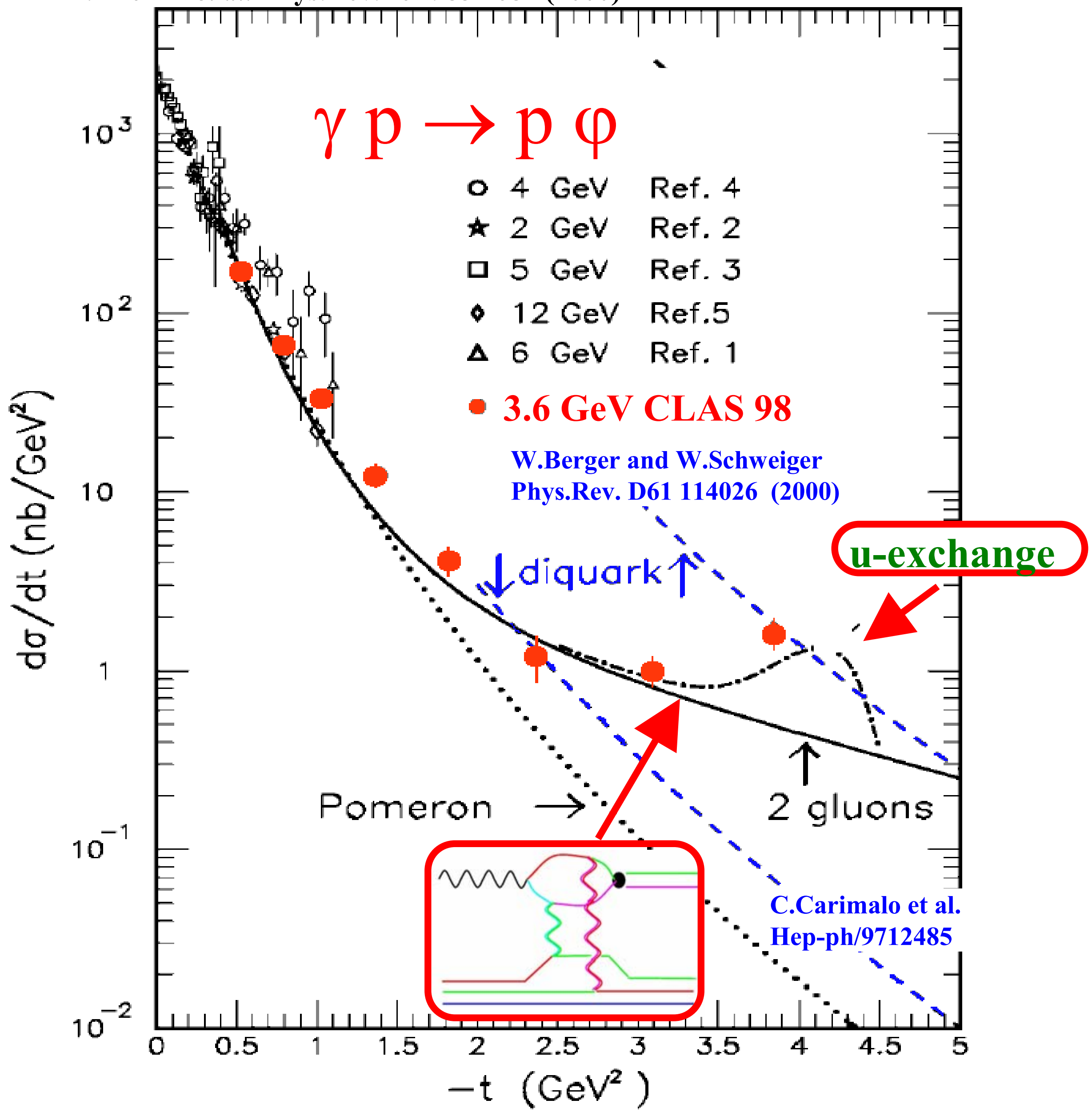
φ production



pomeron exchange dominates the cross section at all energies.

dσ/dt
ϕ mesons

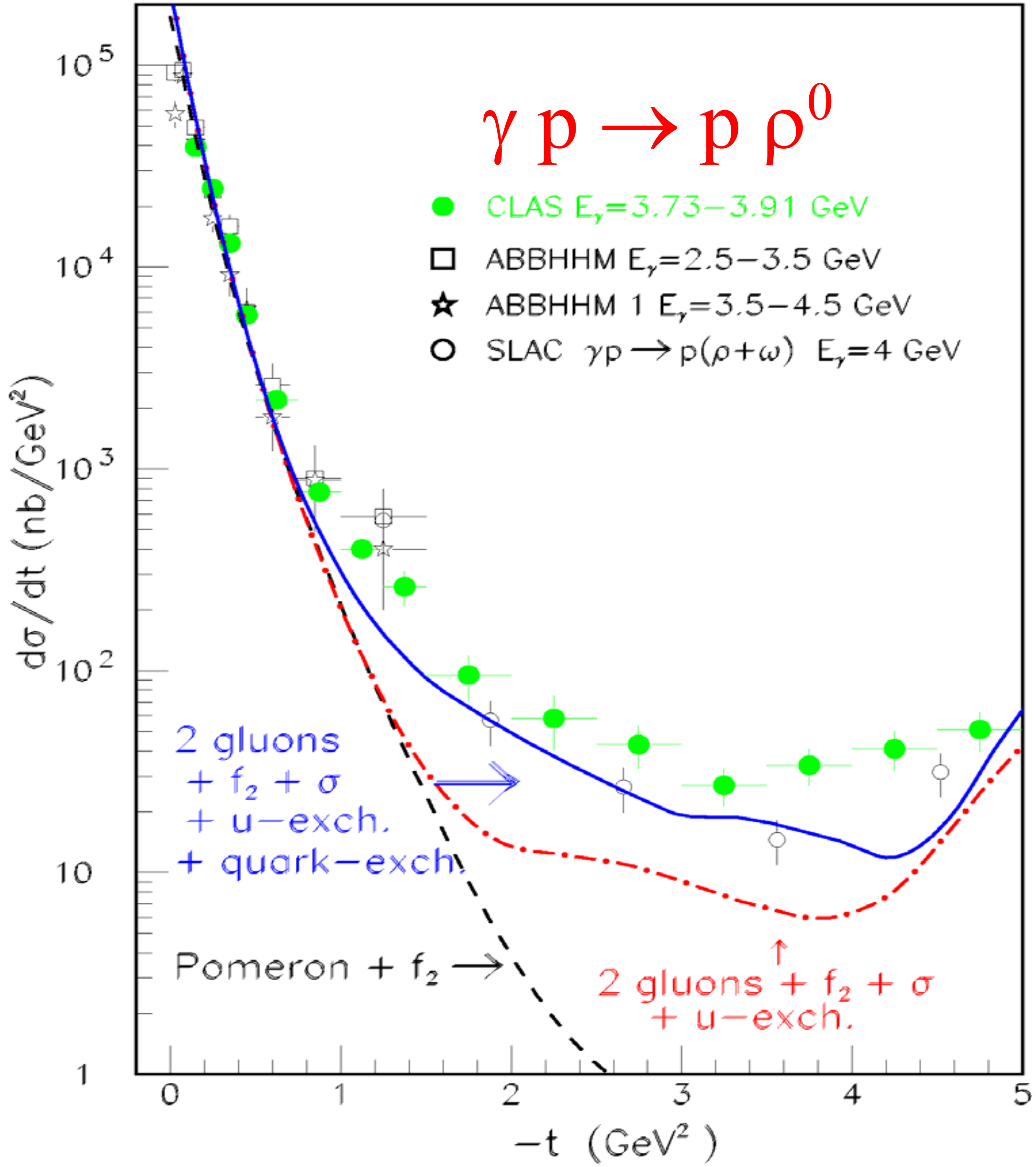
E.Anciant *et al.* Phys.Rev.Lett. 85 4682 (2000)



dσ/dt
ρ^0 mesons

- The same 2-gluons coupling used in Φ photo-production
- ($f_2 + \sigma$) exchange at low momentum transfer
- quark-exchange parametrized through 'Saturated Regge Trajectories'
- quark-exchange dominates at large *-t*

M.Battaglieri *et al.* *Phys. Rev. Lett.* *87 172002 (2001)*



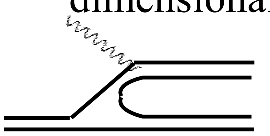
dσ/dt

ω mesons

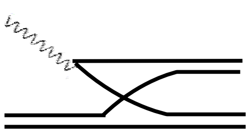
- The same model used in Φ and ρ photo-production
- Full model = 2 gluons + correlations + π–exch. + f_2-exchange + u-exchange
- No pQCD calculations available

Quark exchange

Power low behavior according dimensional counting



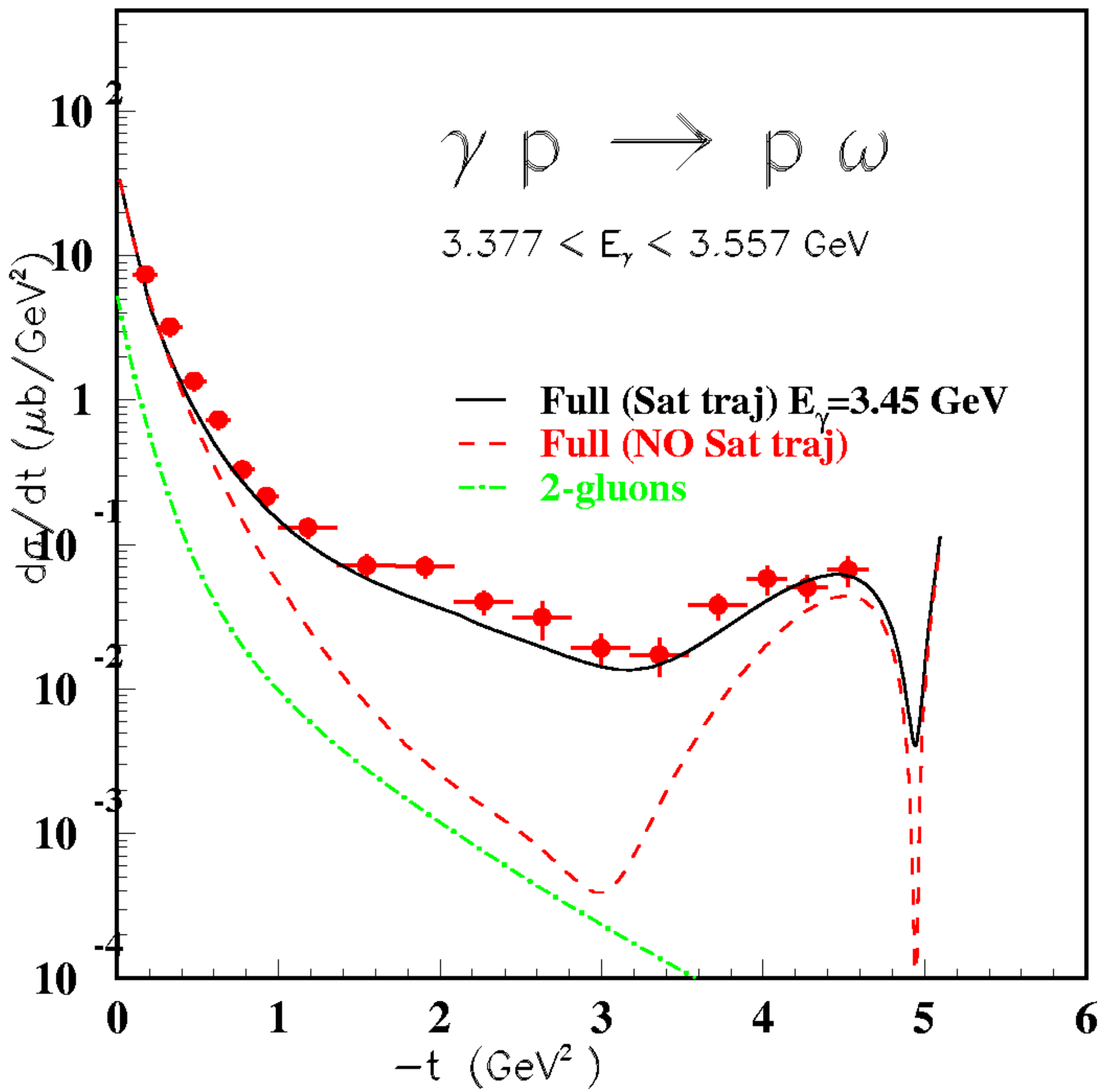
Should scale as s^{-7}



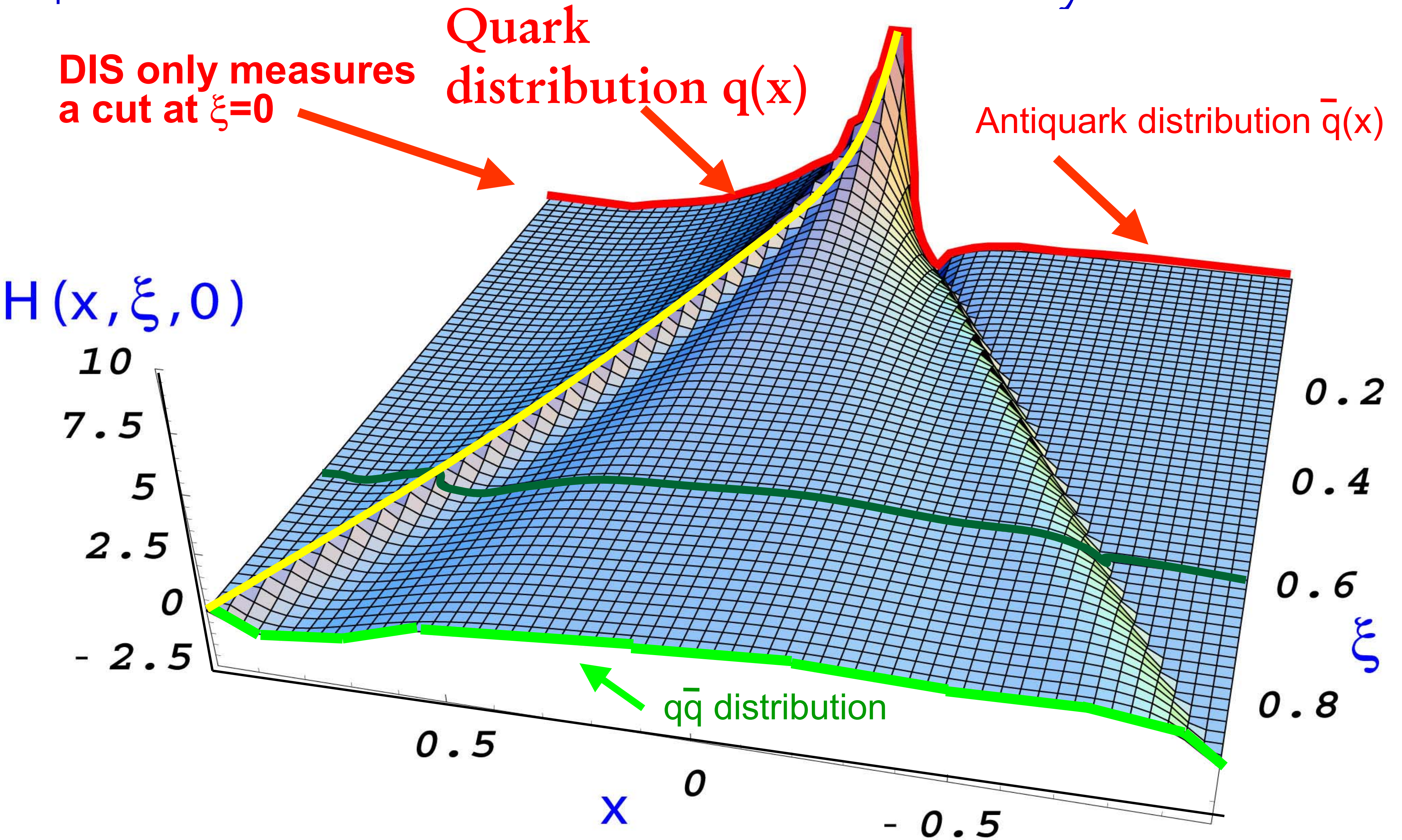
Should scale as s^{-8}

B = –7.9±0.3

M.Battaglieri *et al. Phys. Rev. Lett. 90 022002-1 (2003)*



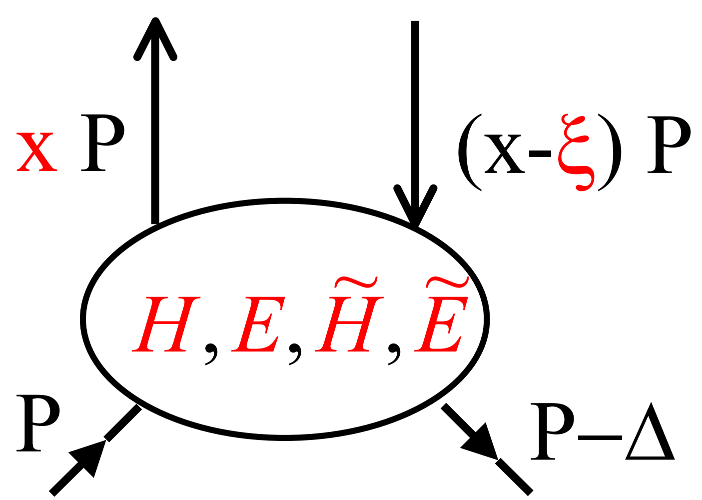
GPDs Contain Information beyond



Limiting Cases for GPDs

Ordinary Parton Distributions $(\Delta, t, \xi \rightarrow 0)$

$H_0(x,0) = q(x)$ *unpolarized* $\widetilde{H}_0(x,0) = \Delta q(x)$ *polarized*



$\xi = \frac{\Delta \cdot z}{P \cdot z}$ $t = \Delta^2$

Nucleon Form Factors (Sum Rules)

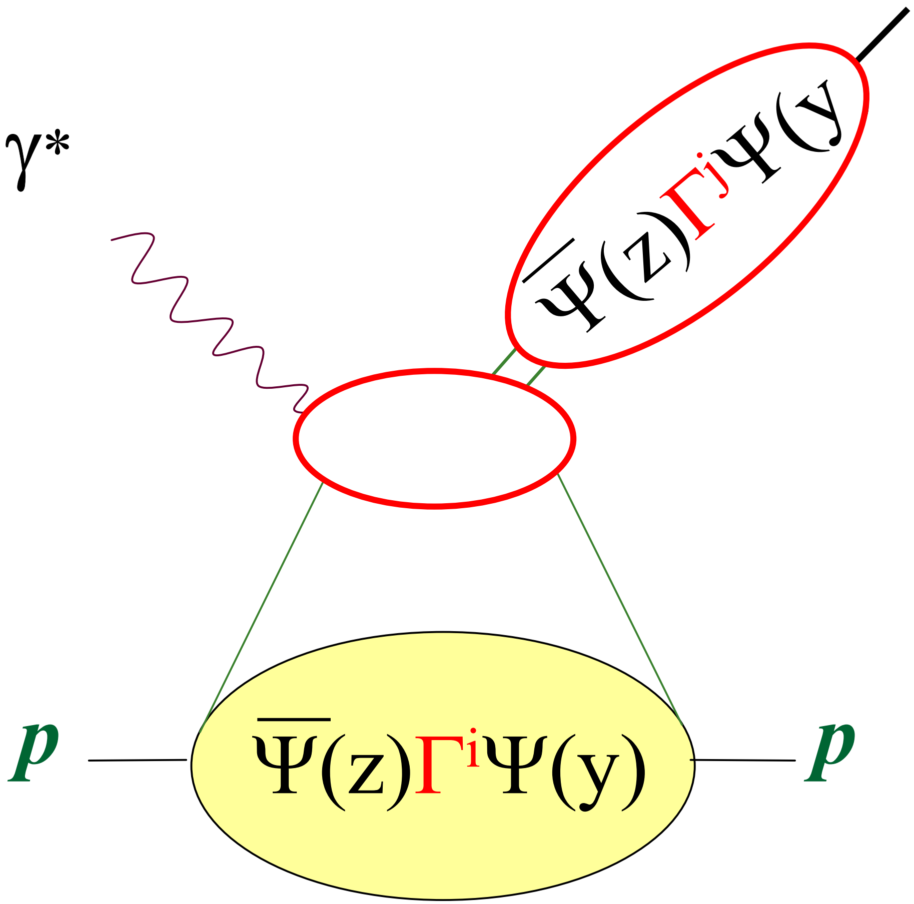
$\int H_\xi(x,t)dx = F_1(t)$ Dirac

$\int \widetilde{H}_\xi(x,t)dx = g_A(t)$ Axial vector

$\int E_\xi(x,t)dx = F_2(t)$ Pauli

$\int \widetilde{E}_\xi(x,t)dx = h_A(t)$ Pseudoscalar

Meson Production as a Filter



Use quantum numbers of meson to select appropriate combinations of parton distributions in nucleon.

Pseudoscalers (polarized)

- π^0: $\Delta u_v - \frac{1}{2}\,\Delta d_v$
- η : $\Delta u_v - \frac{1}{2}\,\Delta d_v + 2\Delta s_v$

Vector Mesons (unpolarized)

- $\rho_L{}^0$: $u + \bar{u} + \frac{1}{2}\,(d + \bar{d})$; g
- $\omega_L{}^0$: $u + \bar{u} - \frac{1}{2}\,(d + \bar{d})$; g
- $\phi_L{}^0$: $s + \bar{s}$; g

Program to determine GPD's

$$ep \rightarrow ep\rho^0 \longrightarrow H^2, E^2$$

$$\square \quad \pi^+\pi^-$$

$$en\pi^+ \longrightarrow \widetilde{H}^2, \widetilde{E}^2$$

$$e\;\;p\gamma \longrightarrow H^2, E^2, \widetilde{H}^2, \widetilde{E}^2$$

$$\vec{e}p \rightarrow ep\gamma \longrightarrow H, E, \widetilde{H}$$

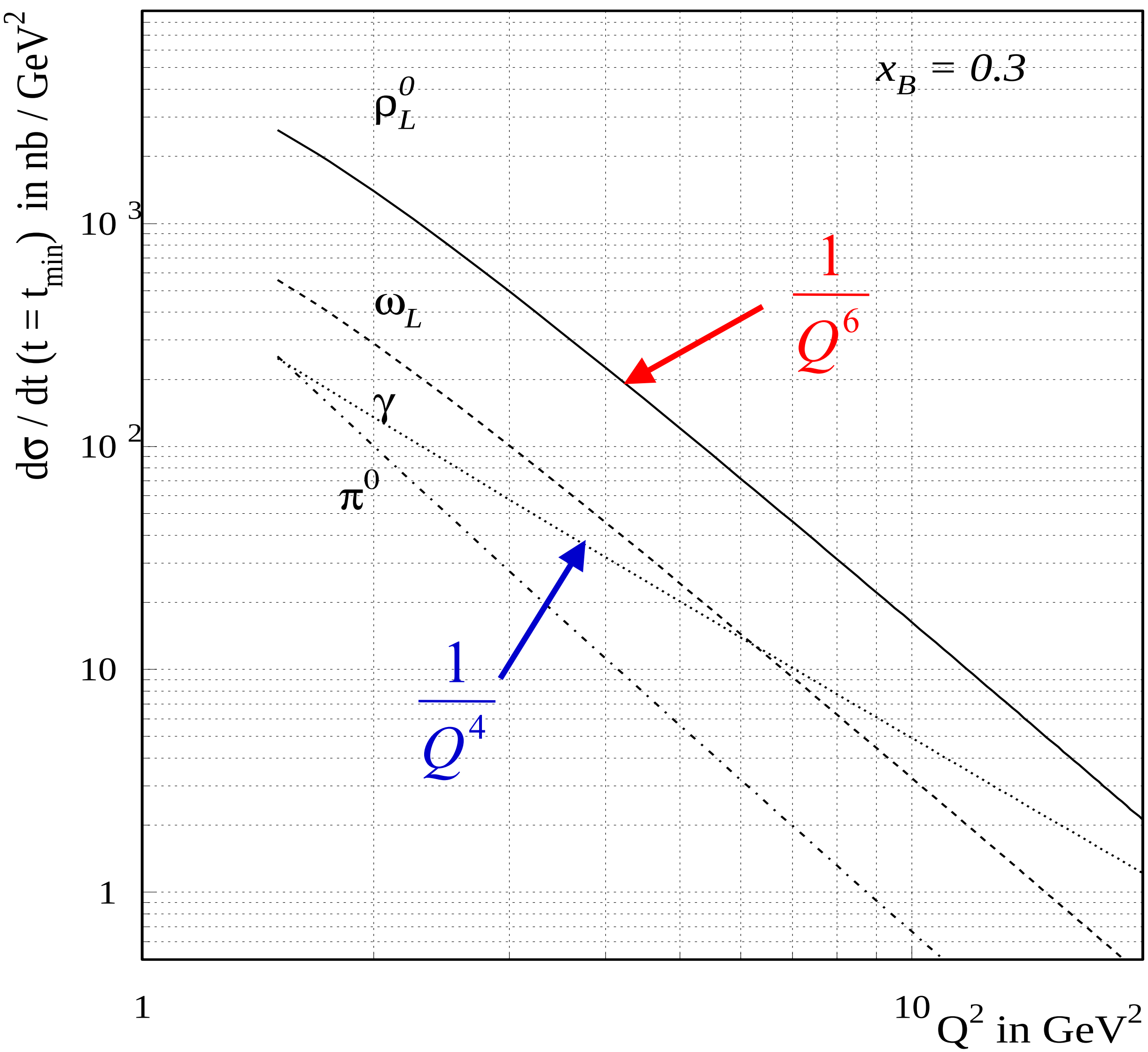
$$e\vec{p} \rightarrow en\pi^+ \longrightarrow \widetilde{H} * \widetilde{E}$$

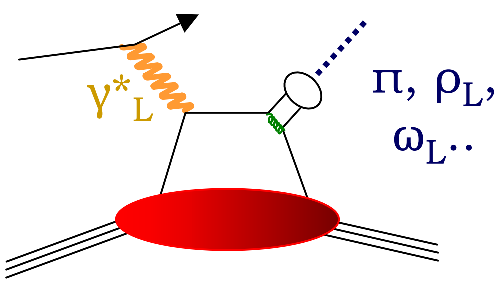
Other Channels

$\vec{e}\;p \rightarrow$ eN (η,π) e $\Delta\;\pi$ e Nω e (Λ,Σ) K

Q^2 dependence of $d\sigma/dt$

$\gamma^* + p \rightarrow M + p : (M = \rho^0_L, \omega_L, \Phi_L, \pi^0, \gamma)$





DVMP
(Meson production)

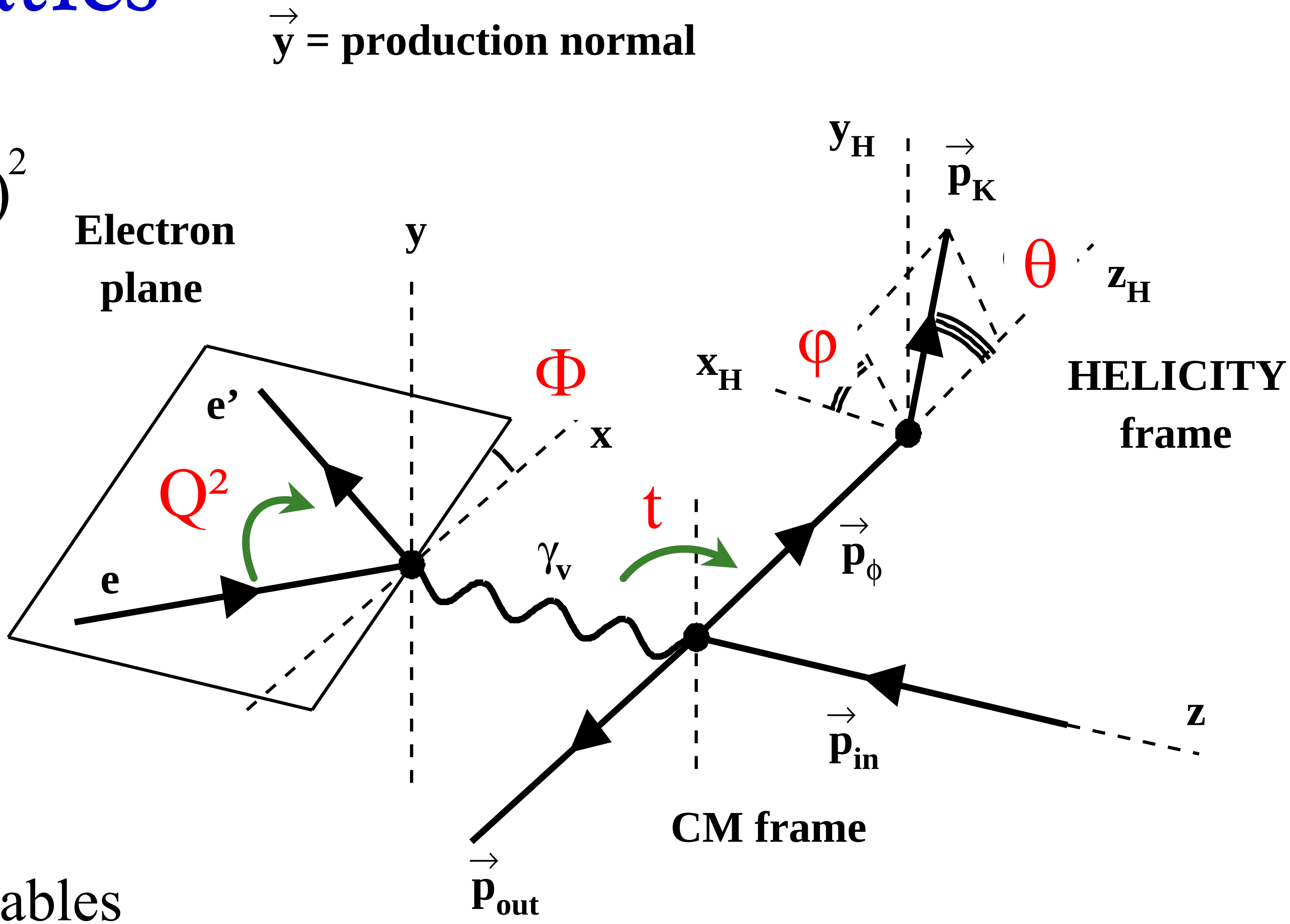
Kinematics

$$Q^2 = -(e - e')^2$$

$$x_B = \frac{Q^2}{2pq}$$

$$t = (p - p')^2$$

$$\Delta\tau = \frac{2\nu}{Q^2 + M_V^2}$$



Relevant variables

Q^2 x_B t M_{K+K-} θ_{K+H} ϕ_{K+H} Φ

ρ and ω signatures

Hadjidakis/IPN Orsay

The ρ and ω production

$E_\gamma > 2$ GeV — POMERON + f_2 + π exchange

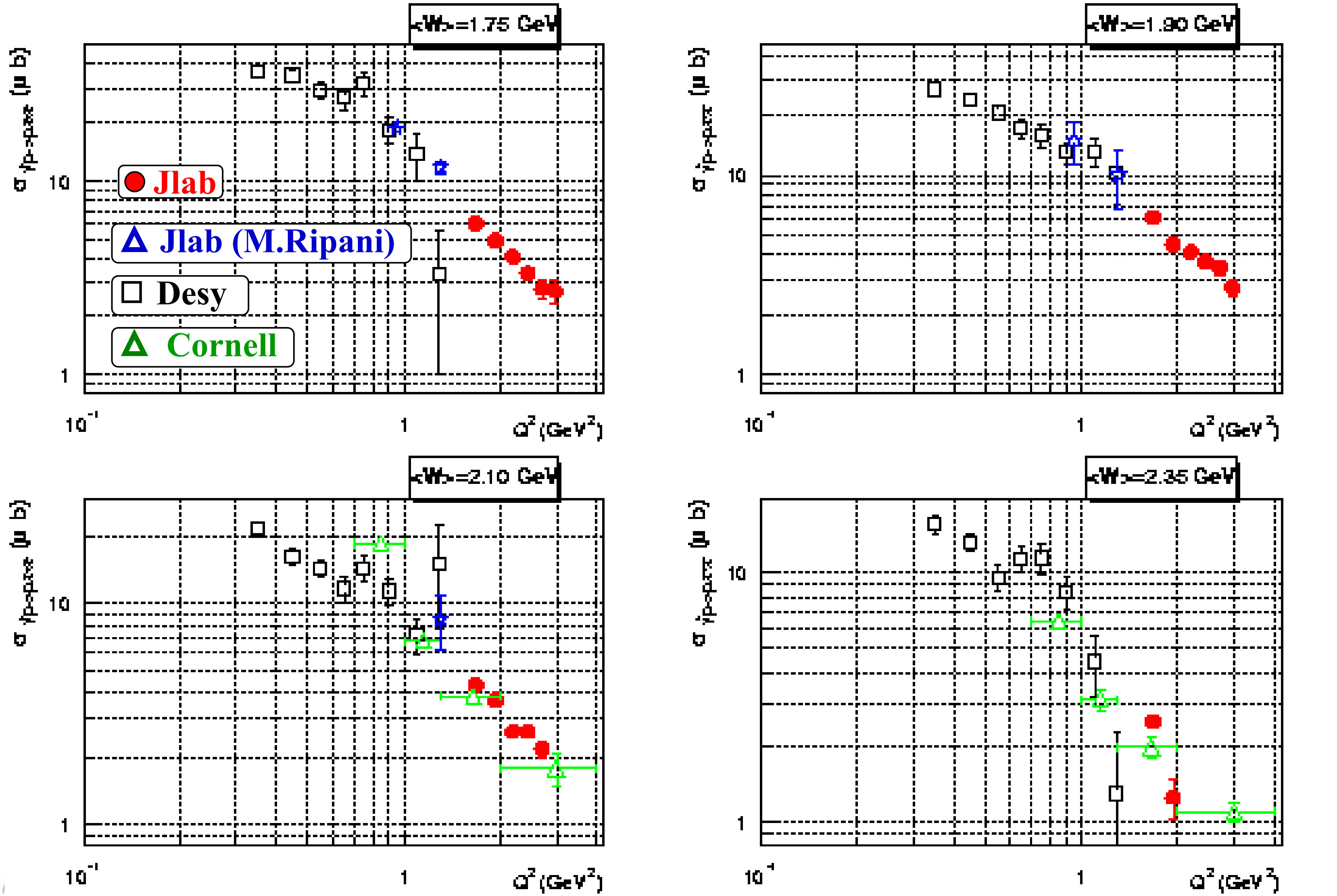
$-t > 1$ GeV^2/c^2 — Quark interchange mechanisms

Experimentally

- $\gamma + p \rightarrow p + \rho^0 \rightarrow p + \pi^+ + (\pi^-)$ has 3 charged part in final state
- Large $\sigma \sim 15$ μbarn @ E_γ 3-4 GeV
- Dominant in 2 pions production (~70% of $\sigma(\pi^+\pi^-)$ @ E_γ 3-4 GeV)

- $\gamma + p \rightarrow p + \omega \rightarrow p + \pi^+ + (\pi^- + \pi^0)$ 3 charged part in final state
- Sizeable $\sigma \sim 3$ μbarn @ E_γ 3-4 GeV
- Very small width (~ 8 MeV): good signal-noise ratio

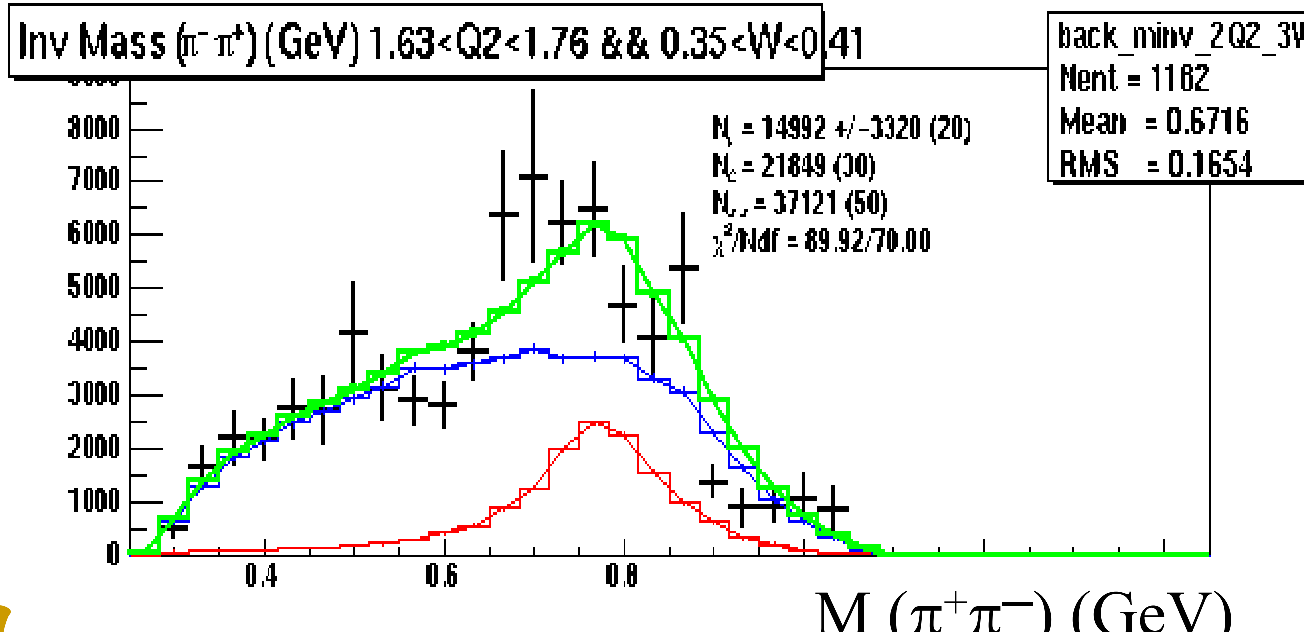
Q^2 dependence of $\gamma^* p \rightarrow p\pi^+\pi^-$ E=4.2 GeV



ρ^0

E = 4.2 GeV

Background Subtraction

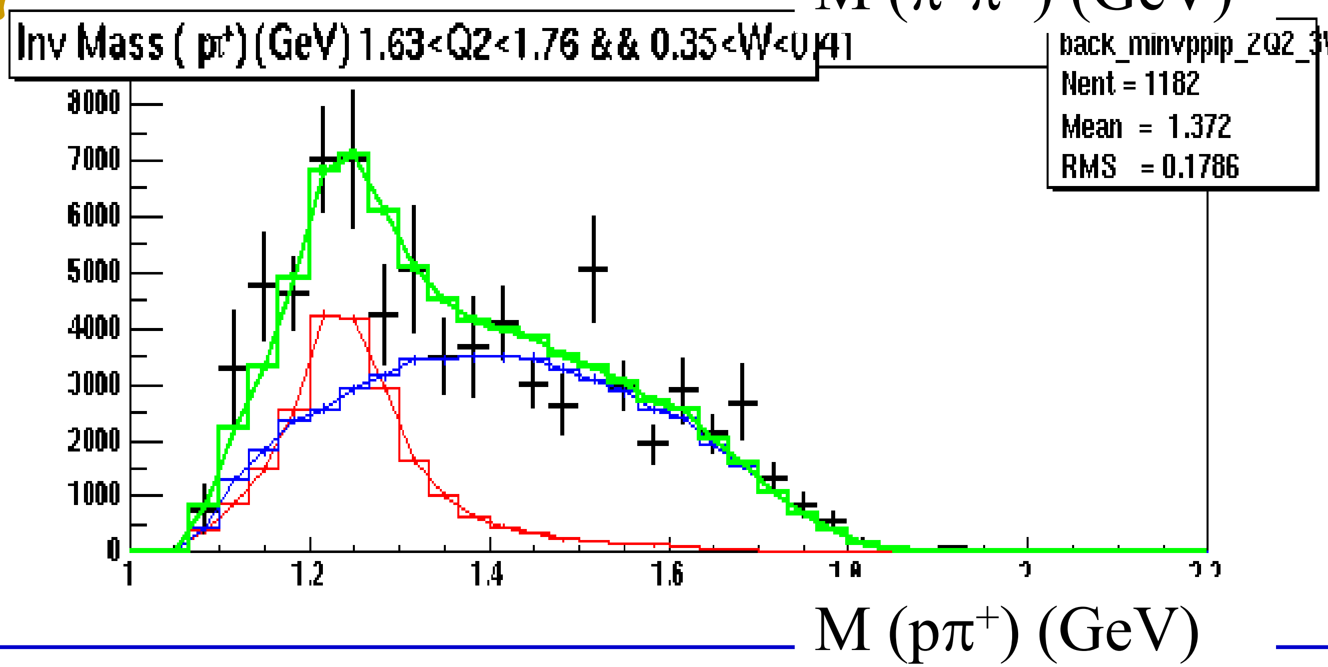


$ep\pi^+\pi^-$ Data

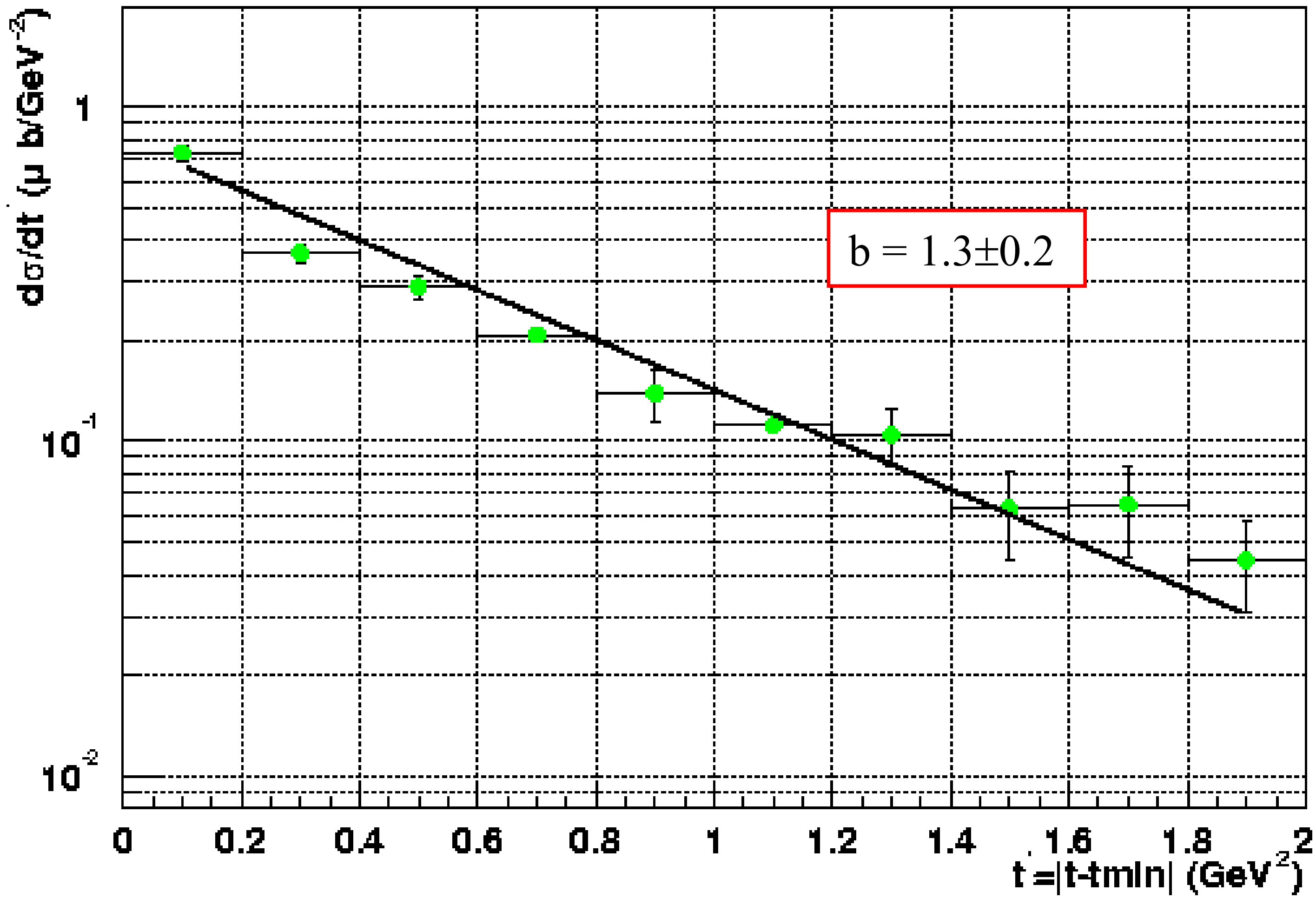
ρ signal

$\Delta^{++}\pi^-$

$p\pi^+\pi^-$ PS

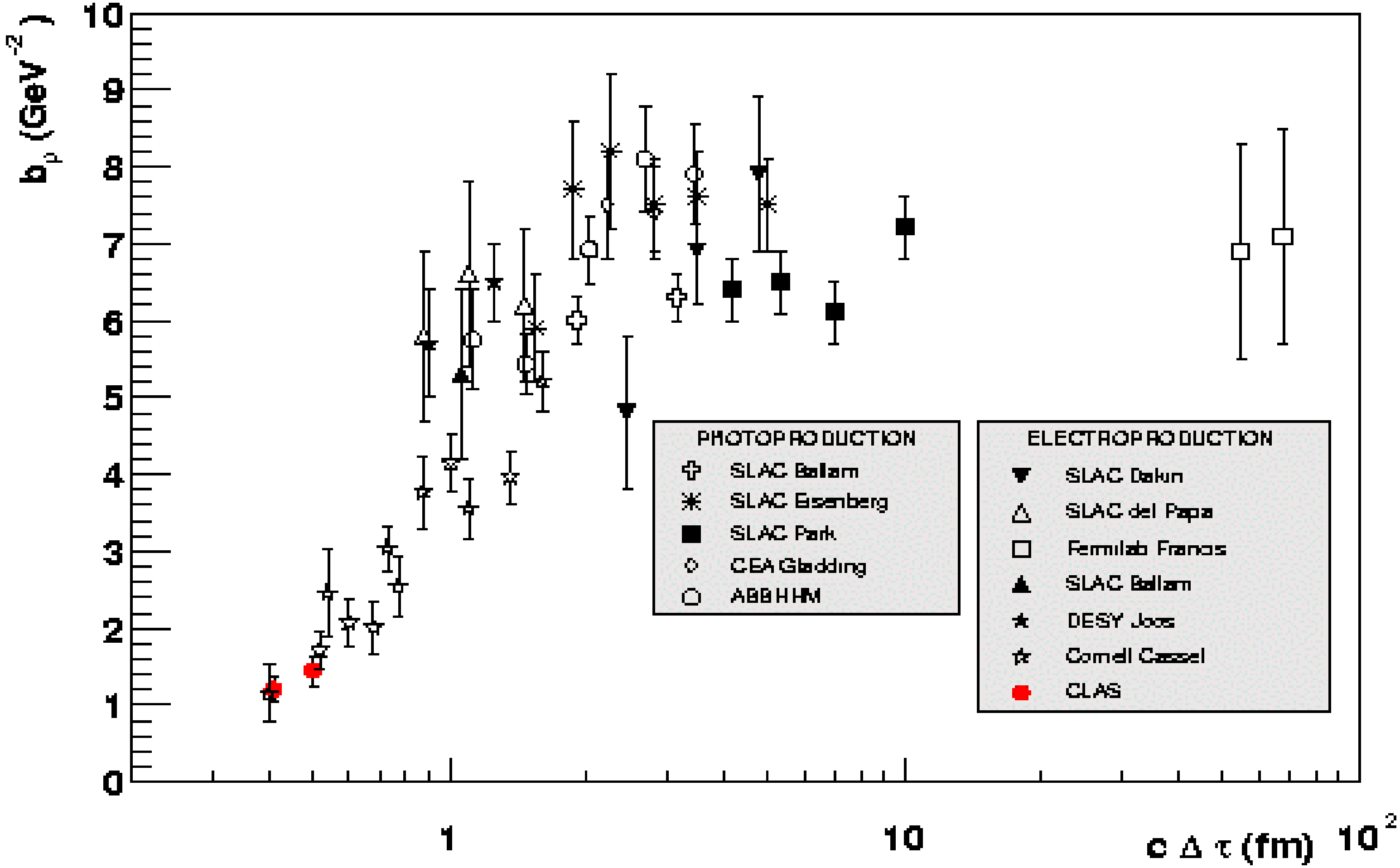


ρ^0 t-dependence



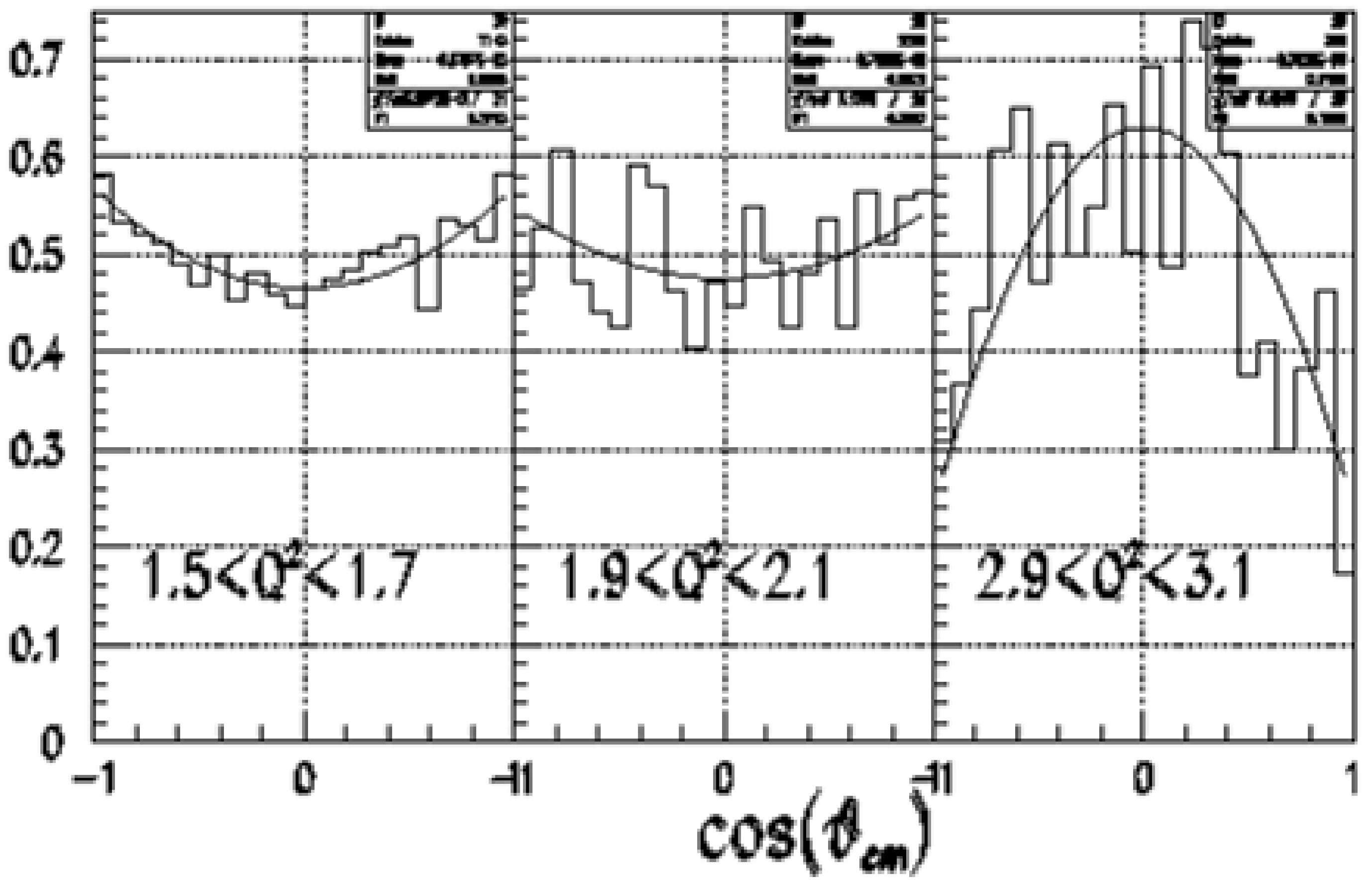
Impact parameter b_ρ for ρ production

bare γ dressed γ

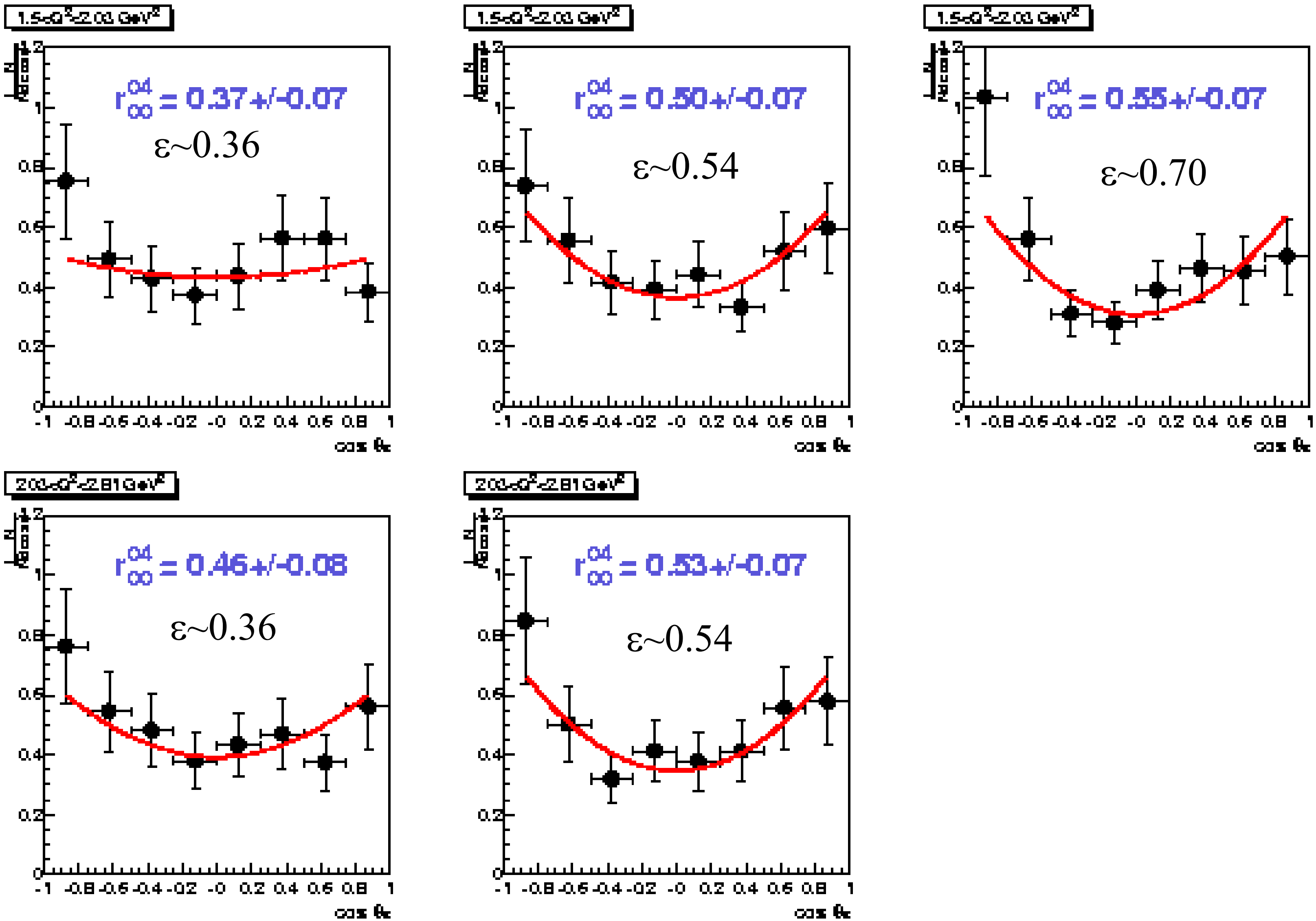


Decay distribution from MC

Decay Distribution: $\rho_L \dashrightarrow \pi^+\pi^-$ ~ $T \sin^2\theta_{cm} + 2 L \cos^2\theta_{cm}$

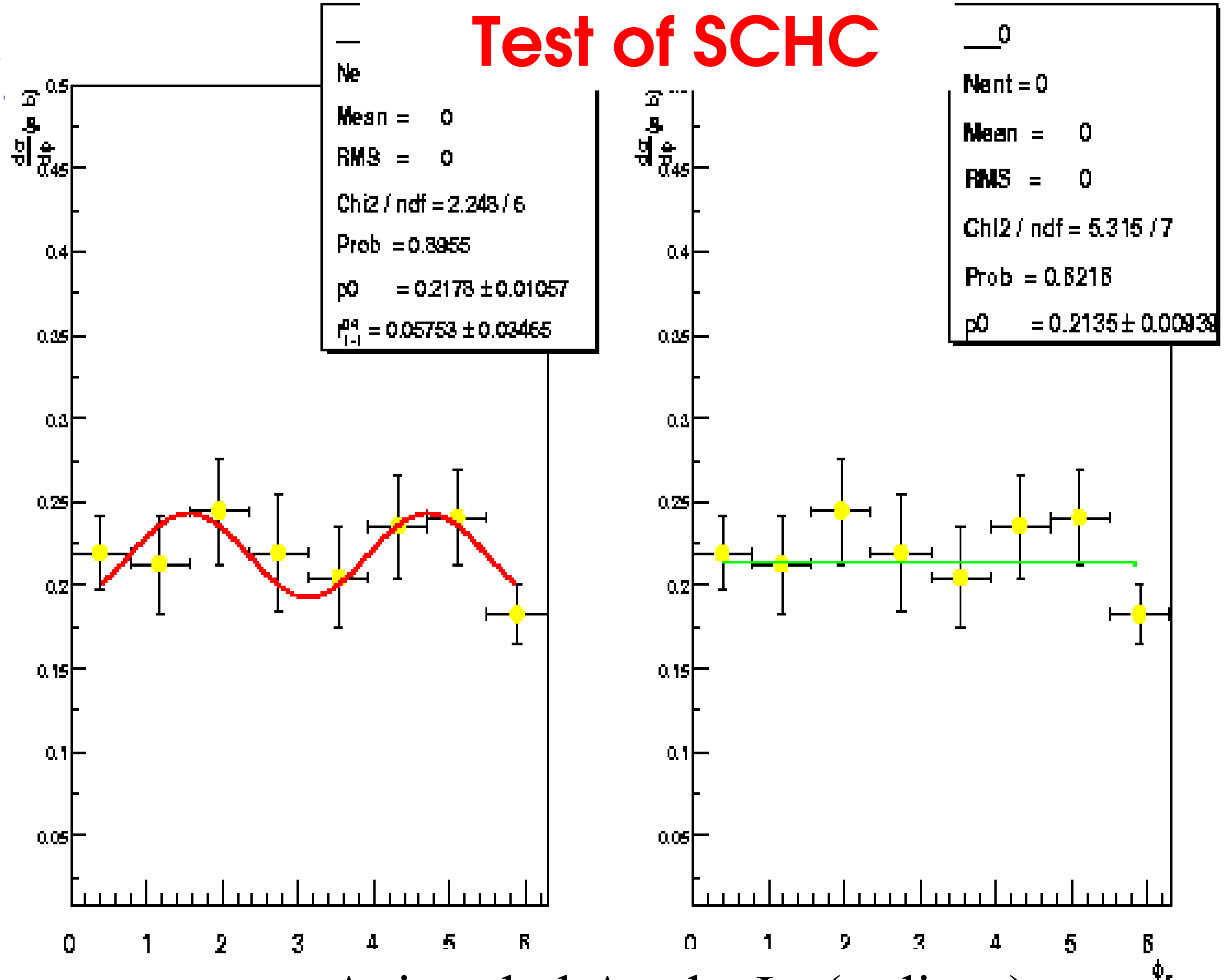


ρ^0 angular distribution



ρ^0 (flat) azimuthal angular distr.

Test of SCHC



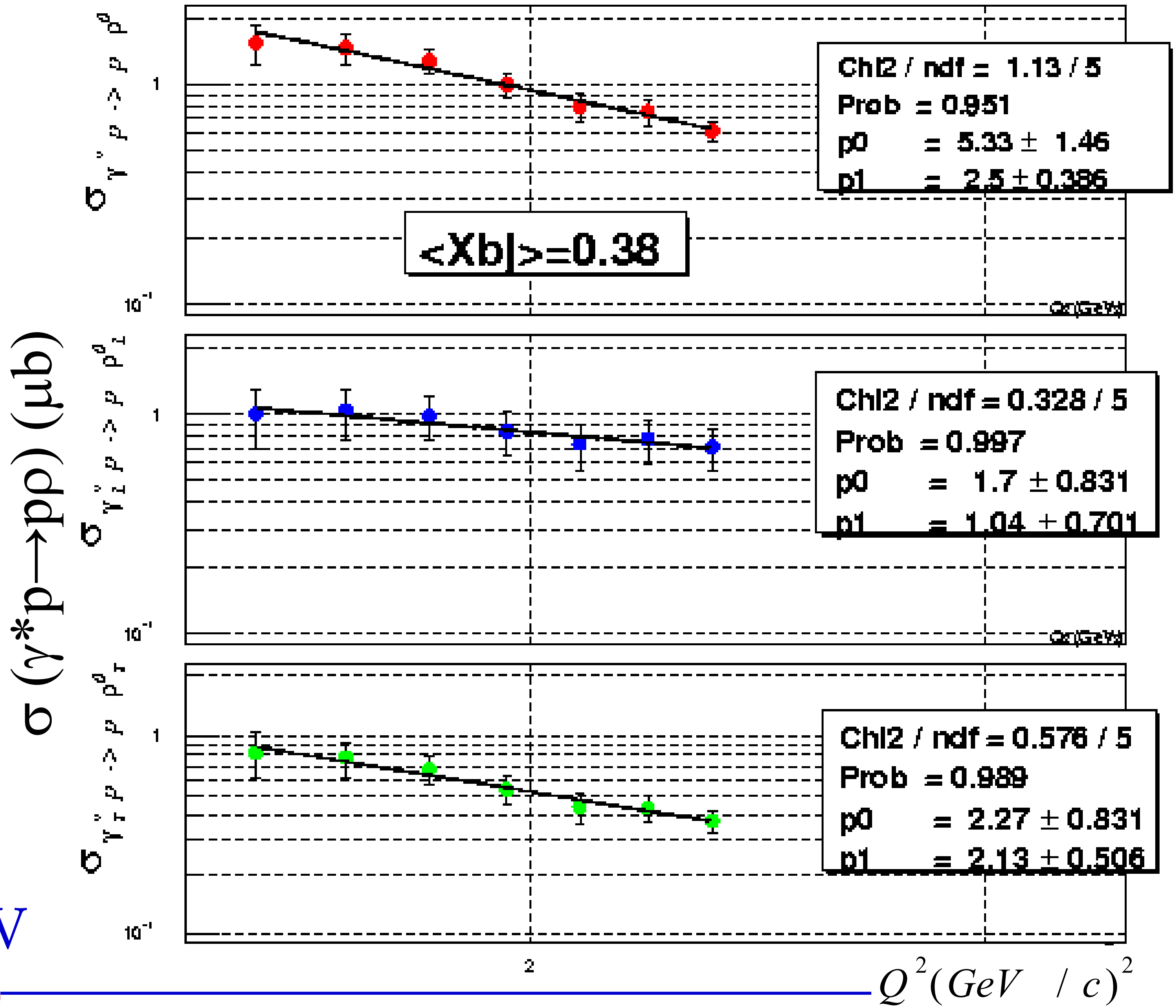
Azimuthal Angle Φ_π (radians)

ρ^0

σ_{tot}

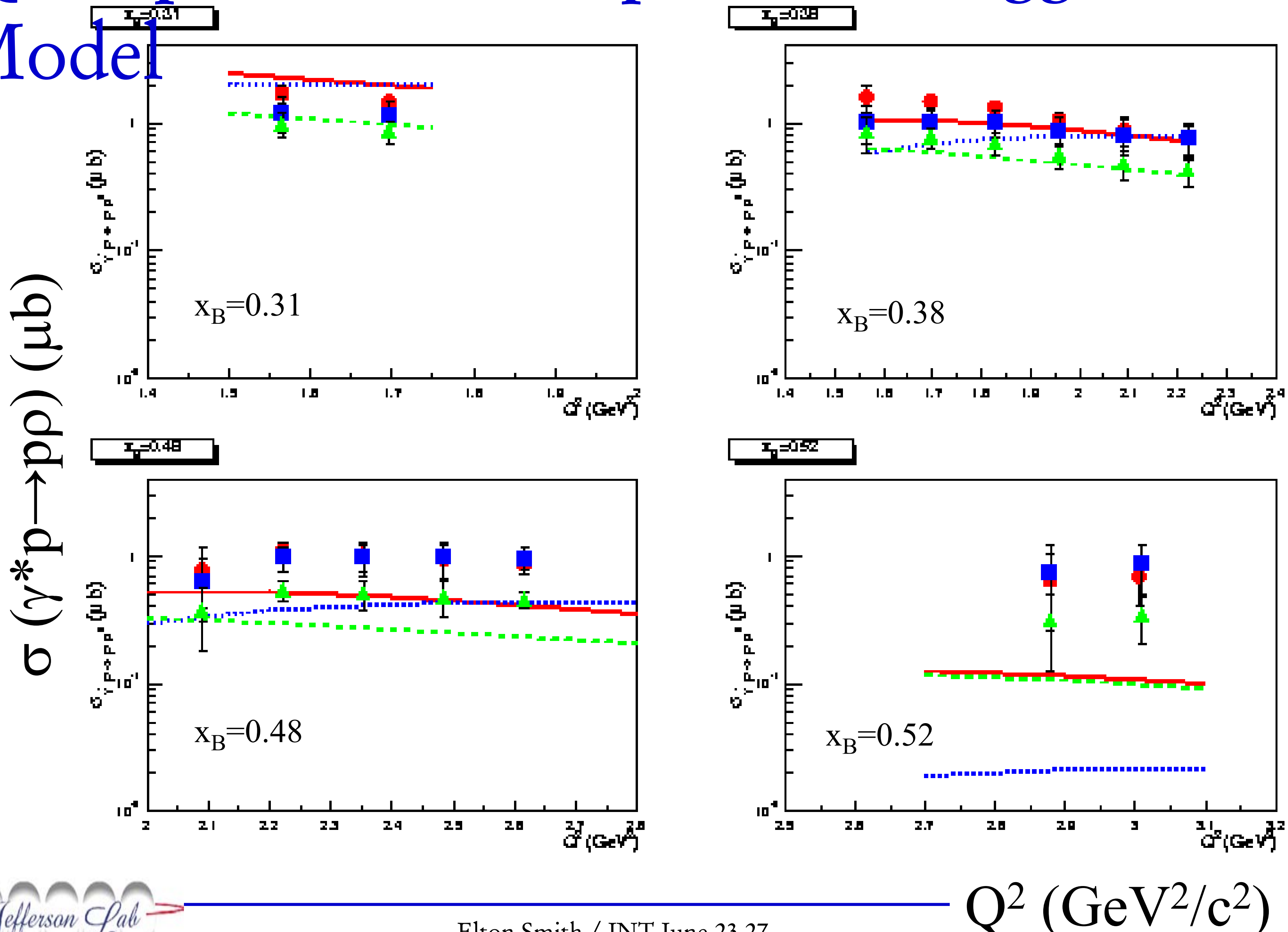
σ_L

σ_T

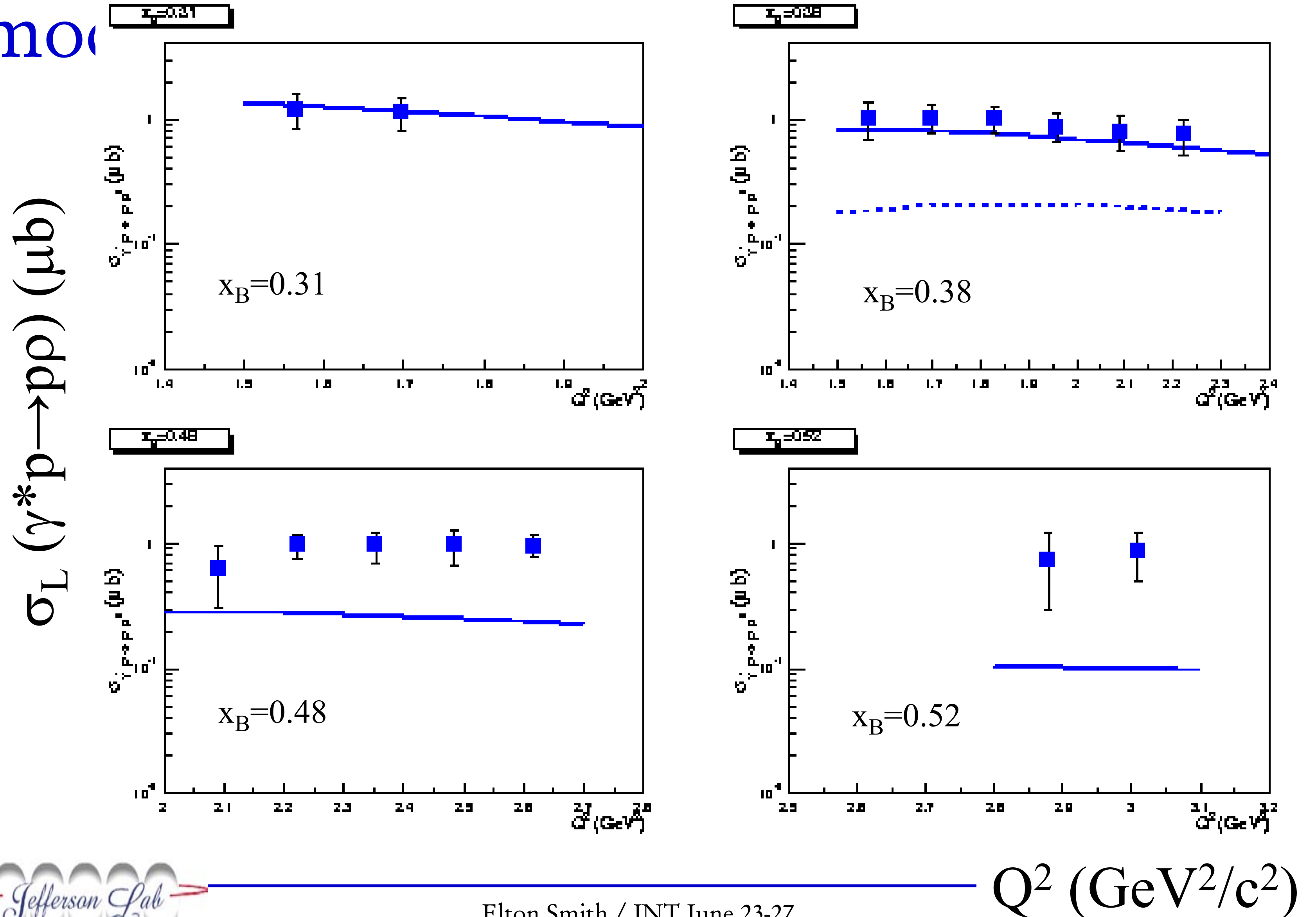


E = 4.2 GeV

Q2 dependence compared to Regge Model



Q2 dependence compared to GPD mo[del]



Conclusions from ρ analysis @ 4.2 GeV

- $d\sigma/dt \sim \exp(1.3\ \mathrm{GeV}^{-2}\ t)$ for $c\Delta\tau \sim 0.45$ fm
  - Exponent $B = 1.3\ \mathrm{GeV}^{-2} \sim 0.2$ fm
- Both Regge and GPD models fail to reproduce data at large x (low W)
- Regge model reproduces σ_T, but fails for σ_L
- GPD model (frozen α_s, no D-term, $b_{val}=5$, $b_{sea}=1$) adequately represents the data

ϕ meson signatures

The φ production

$E_\gamma > 2$ GeV — POMERON exchange

$-t > 1$ GeV^2/c^2
- POMERON nature
- Correlations between quarks

Experimentally

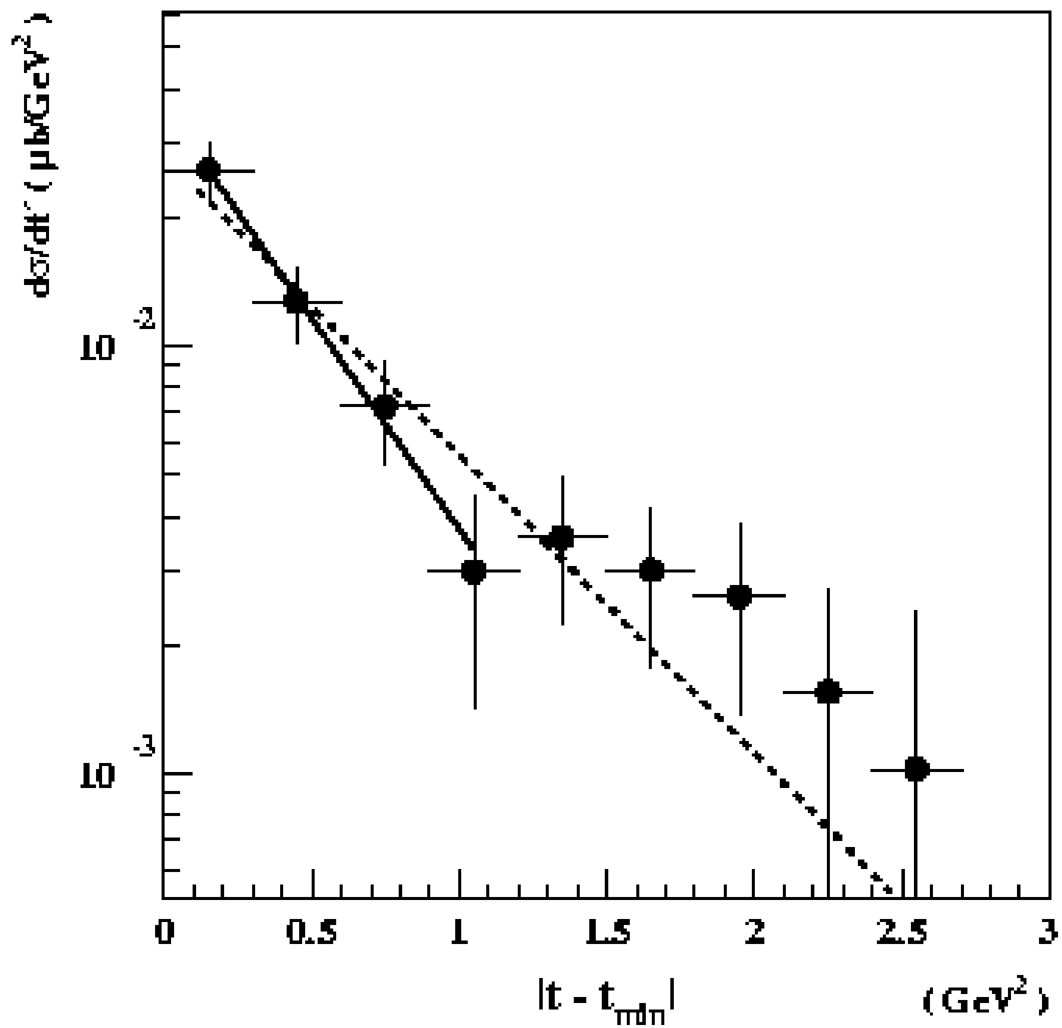
- $\gamma + p \rightarrow p + \varphi \rightarrow p + K^+ + (K^-)$ high b.r. (~50%) in 2 charged kaons
- Very small width (~ 4 MeV): good signal-noise ratio
- Not easy to measure due to the low σ and the kaons decay

ϕ t-distribution

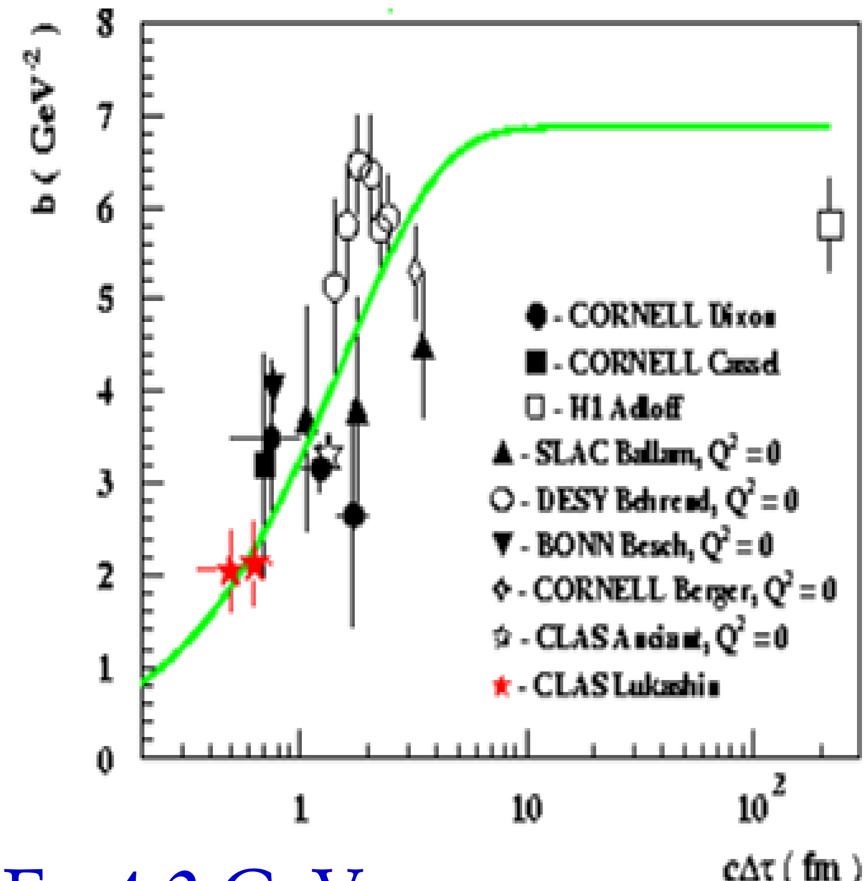
Lukashin et al. 2001

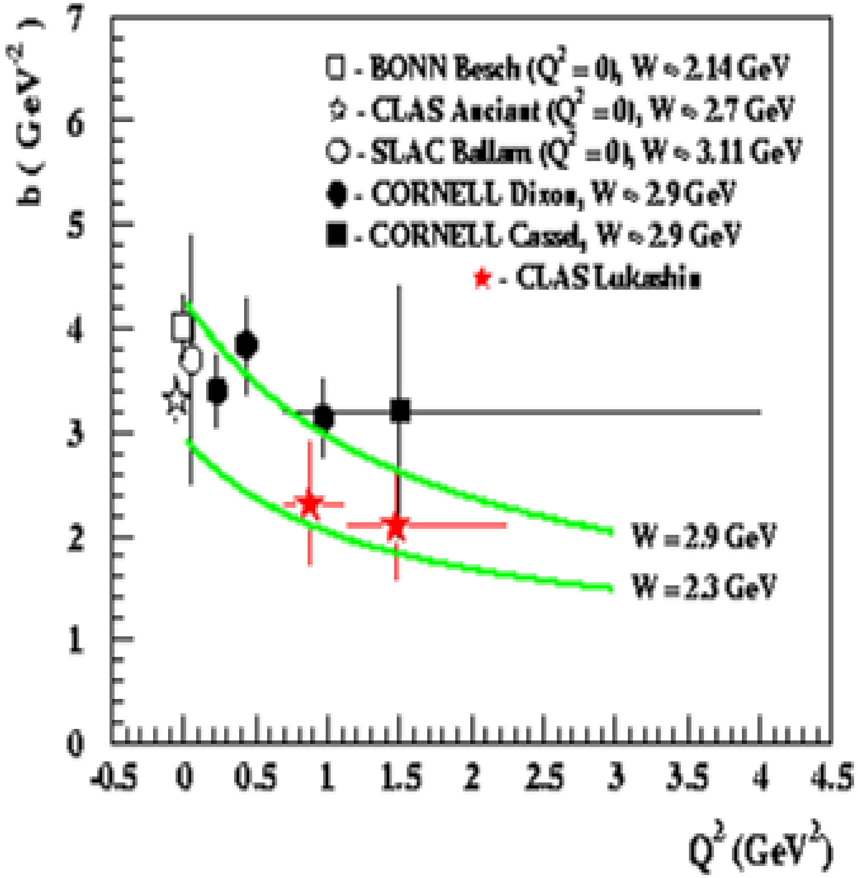
b_ϕ = 1.61±0.31 GeV^{-2}
(full range)

b_ϕ = 2.27±0.42 GeV^{-2}
(-t < 1.2 GeV^{-2})



ϕ production: Interaction region scales with fluctuation time $\Delta\tau \sim 1/\Delta E$



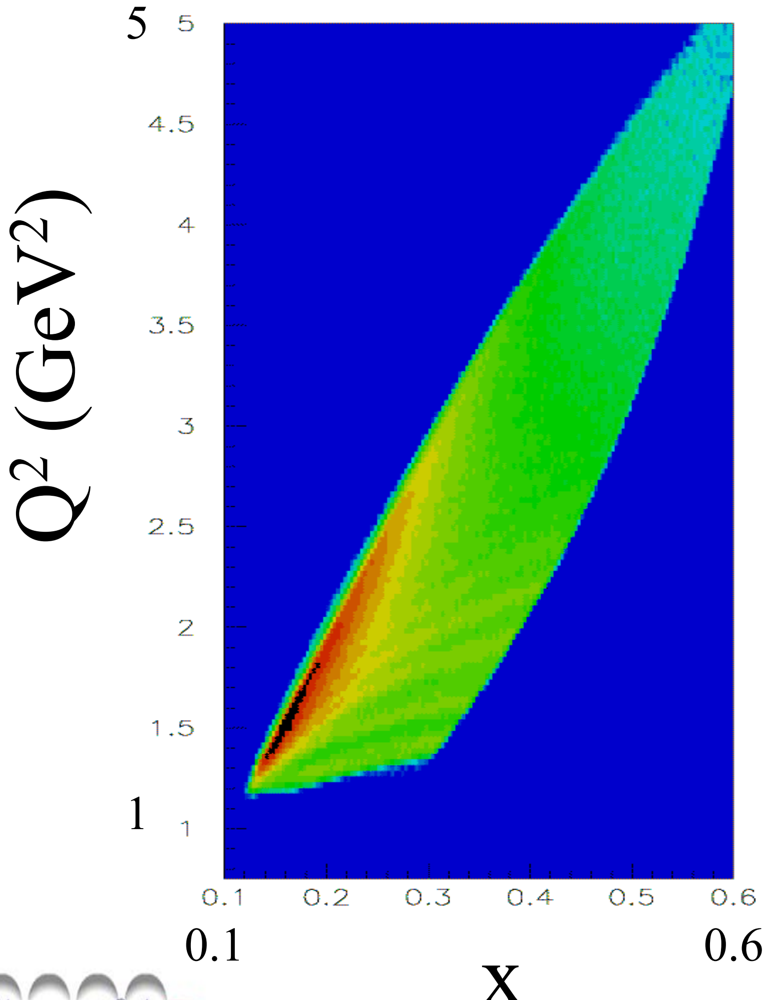


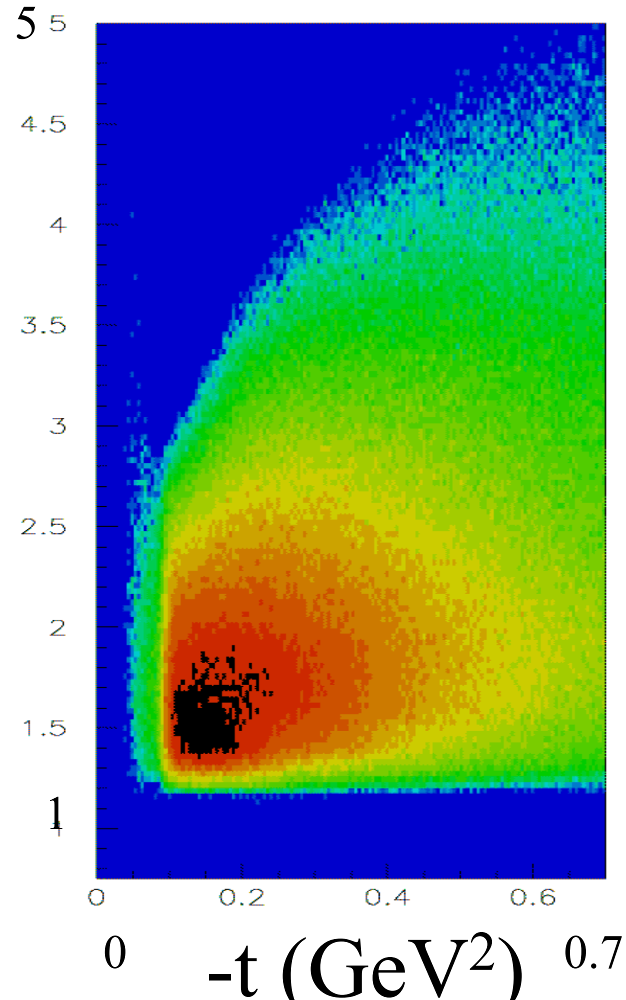
E = 4.2 GeV

CLAS Kinematical coverage in Q^2, t, x_B

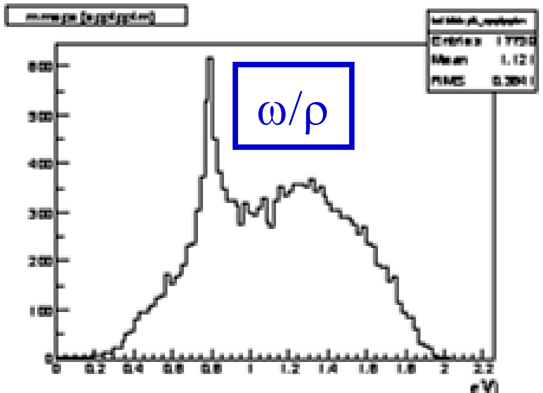
W > 2 and E = 5.75 GeV, ep→ epX, Beam Pol = 70%

Integrated Luminosity = 2.6×10^{40} cm^{-2}

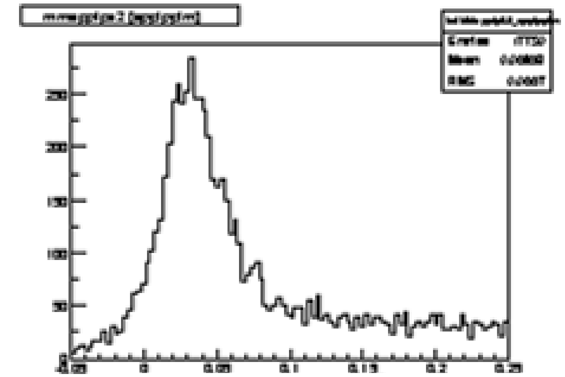




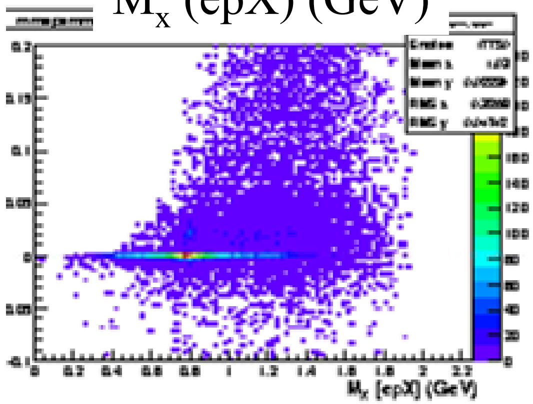
Selection of exclusive
ep → ep $\pi^+\pi^-(\pi^0)$ events
For angular analysis



M_x (epX) (GeV)

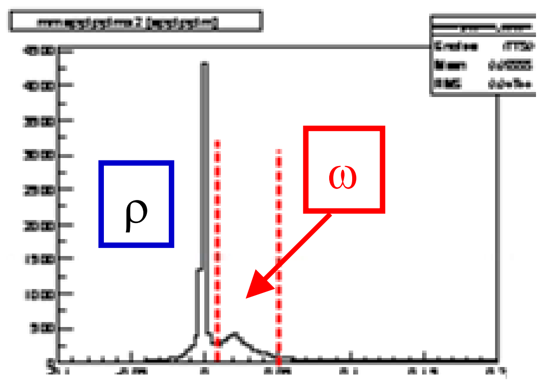


M_x^2 (epπ^+X) (GeV^2)

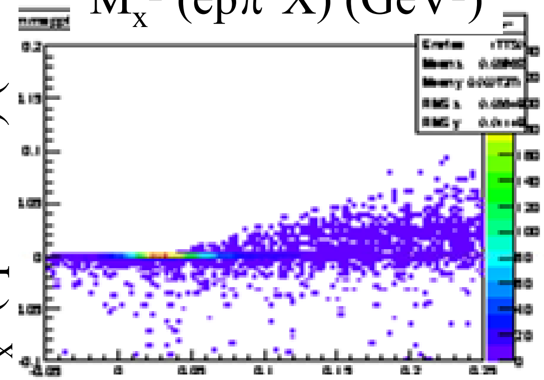


M_x^2 (ep$\pi^+\pi^-$X) (GeV^2)

M_x (epX) (GeV)

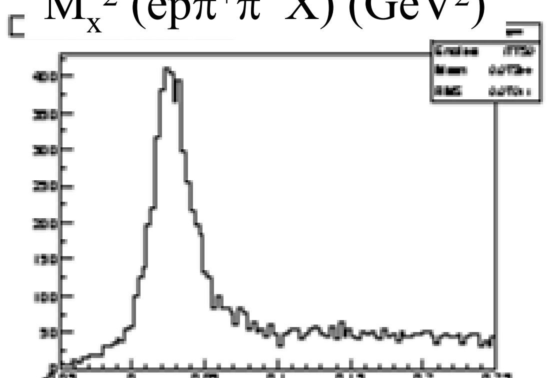


M_x^2 (ep$\pi^+\pi^-$X) (GeV^2)

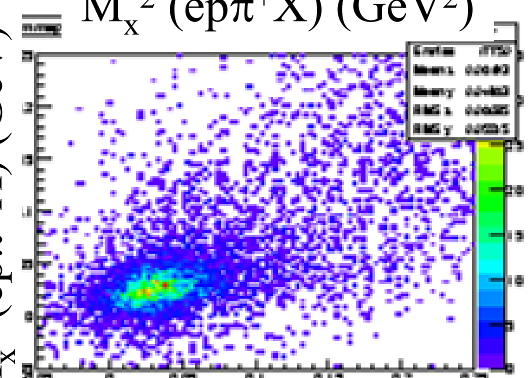


M_x^2 (ep$\pi^+\pi^-$X) (GeV^2)

M_x^2 (epπ^+X) (GeV^2)



M_x^2 (epπ^-X) (GeV^2)

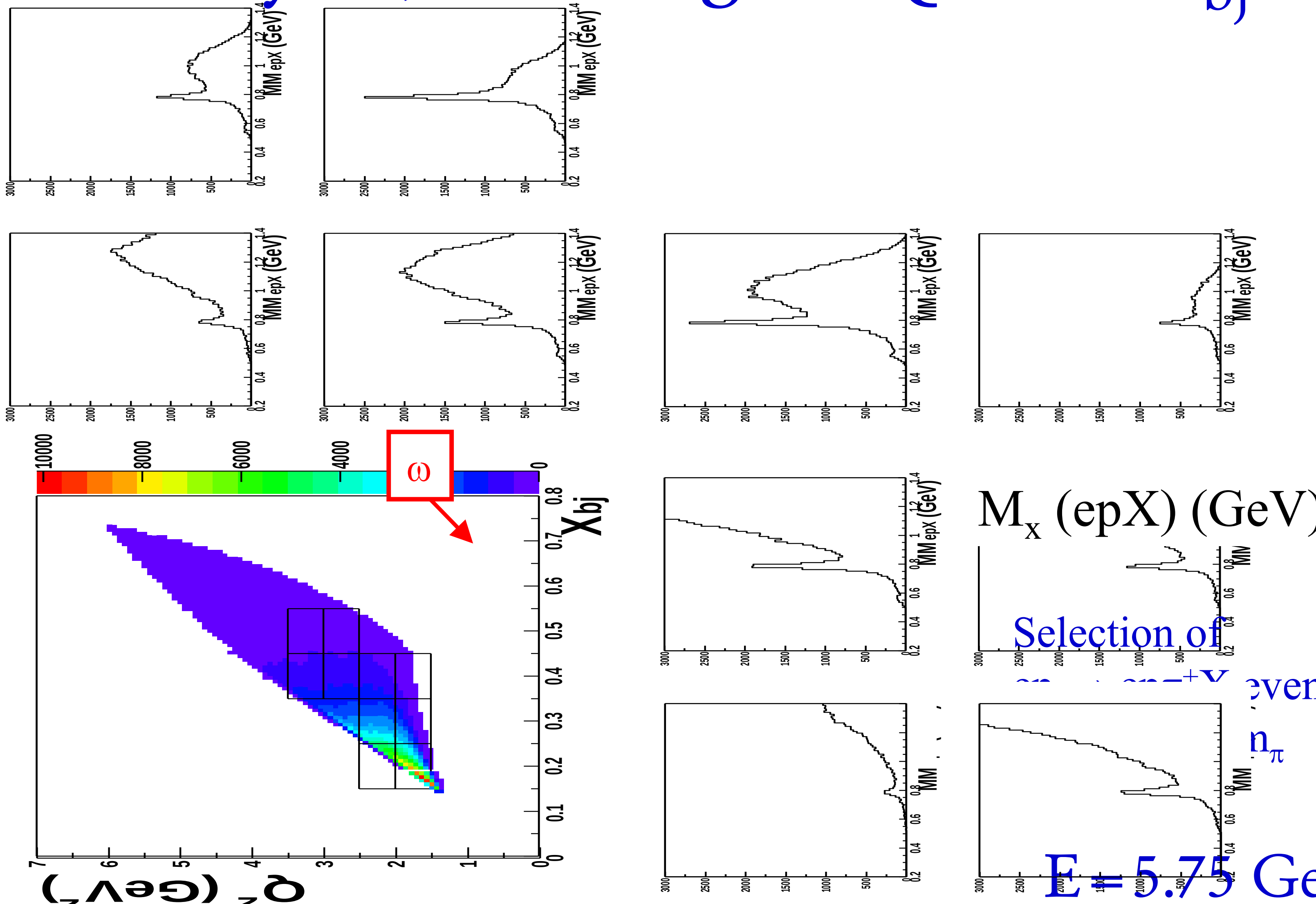


M_x^2 (epπ^-X) (GeV)

M_x^2 (epπ^+X) (GeV^2)

E = 5.75 GeV

ω analysis, binning in Q^2 and x_{bj}

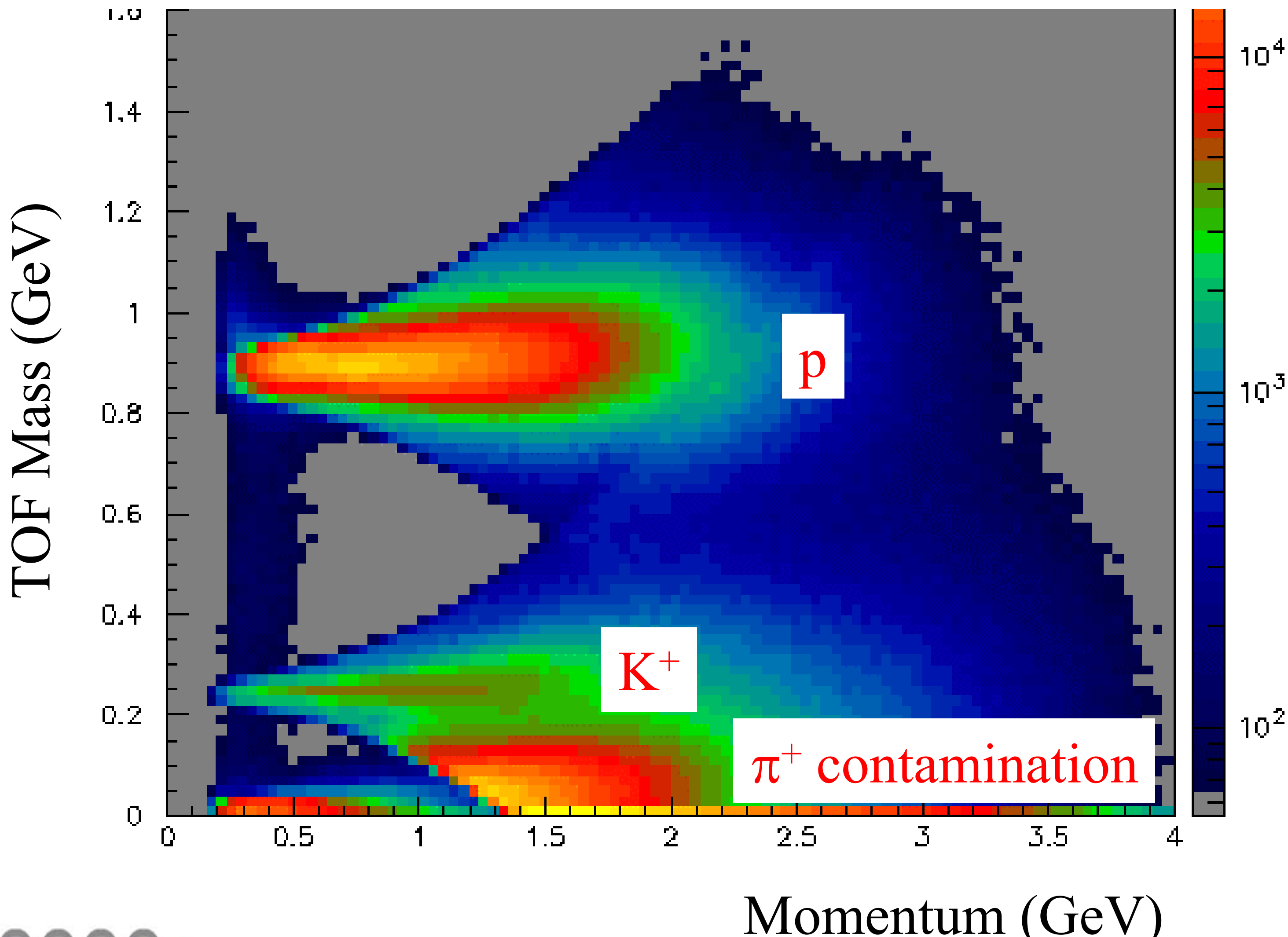


M_x (epX) (GeV)

Selection of ... events

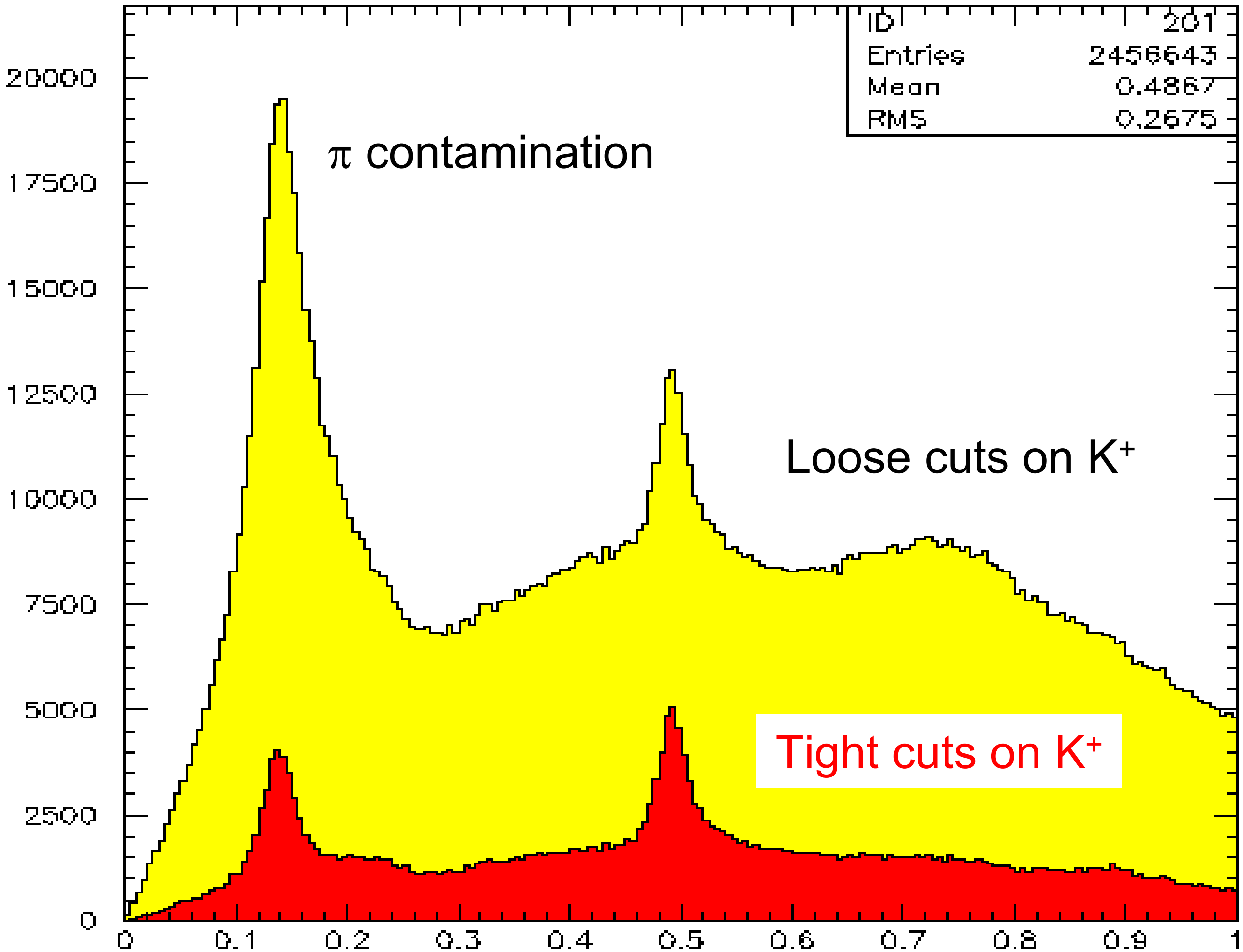
E = 5.75 GeV

Particle identification for K^+ skim



Santoro / Jlab, VPI

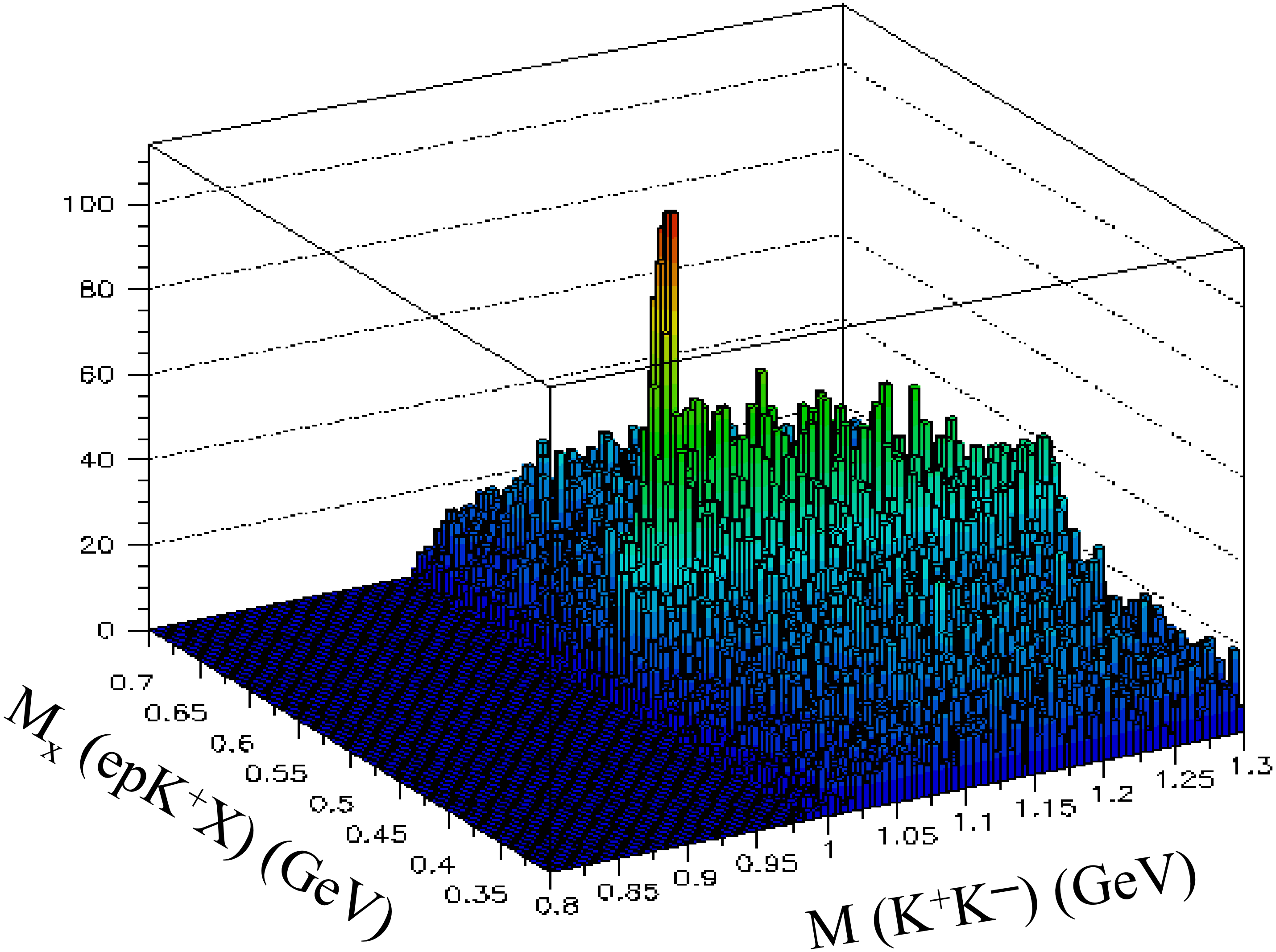
K⁻ selection



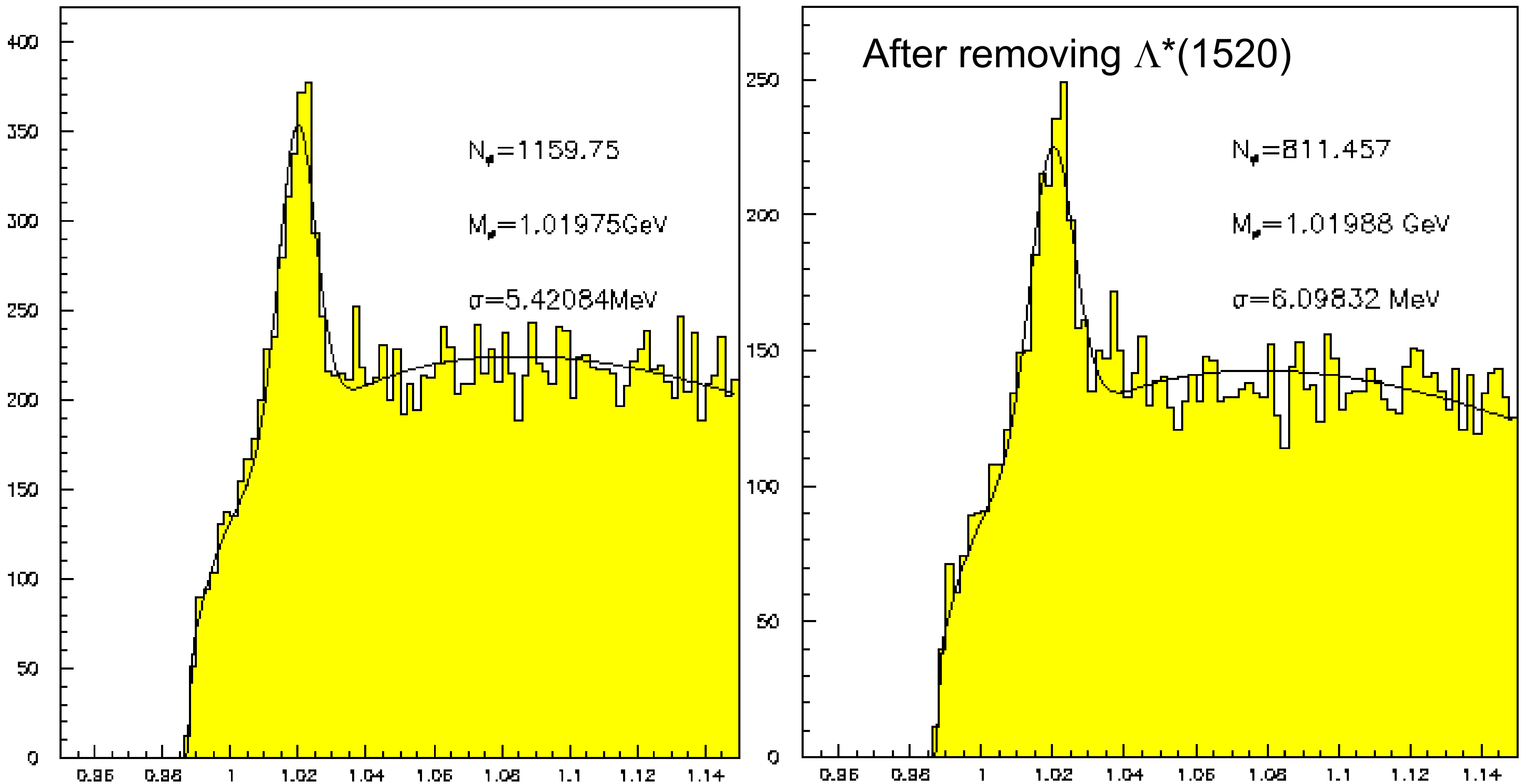
M_x (epK$^+$X) (GeV)

ϕ peak

E = 5.75 GeV



ϕ yields



M (K^+K^-) (GeV) M (K^+K^-) (GeV)

Summary of 5.75 data set

- Clear and clean signals for both ω and ϕ
  - Limited angular analysis will be possible for both
- Analysis of ρ signal will follow in parallel with analysis for ω production
- These data will challenge theorists to develop a consistent picture for their description