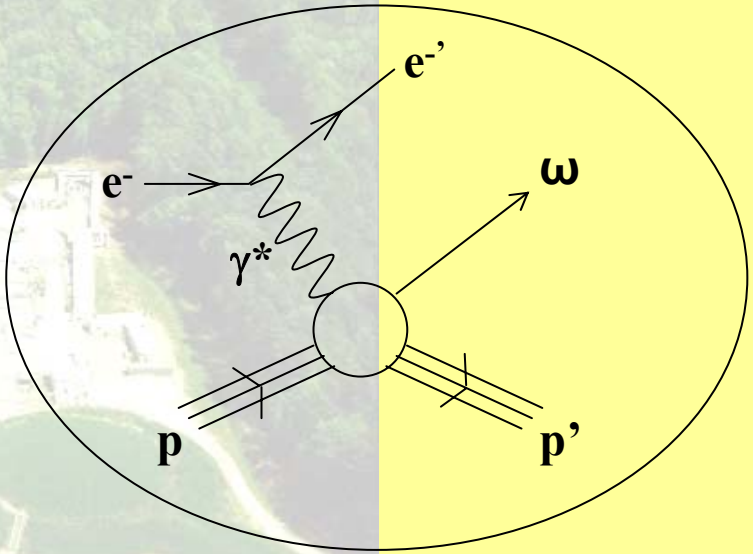
Deeply Virtual ω Production

Ludyvine Morand
CEA/SPhN group
CLAS collaboration

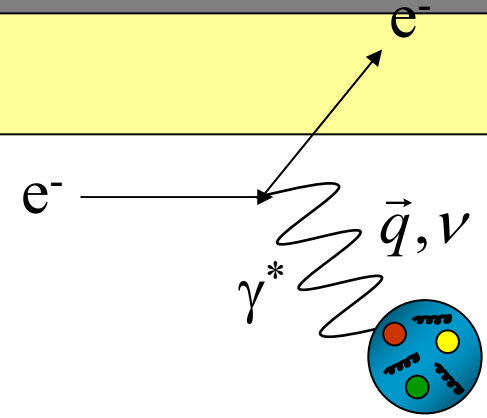
- **Motivations**
- **Experiment**
- **Analysis**
- **What do we learn?**



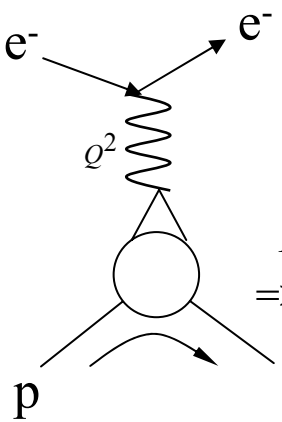
Users' Group Workshop and Annual Meeting
June 16-18, 2004

Motivations

High Q^2 reactions give access to internal dynamics of the nucleon



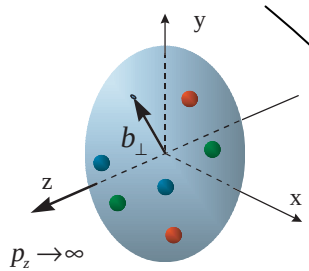
Exclusive elastic reactions

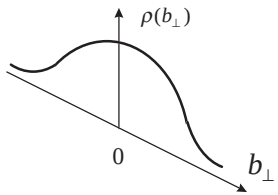


$$Q^2 = -t$$

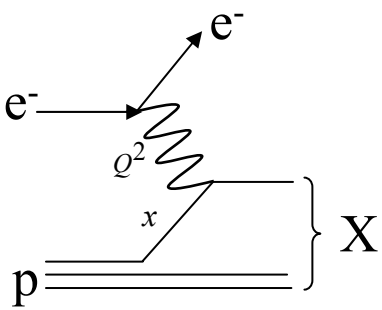
Form Factors

=> transverse position

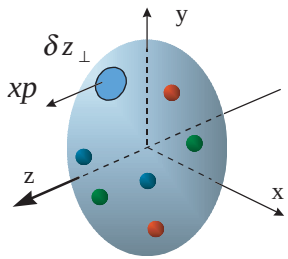




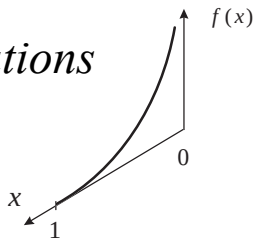
Deep inclusive reactions



$$x = x_B$$



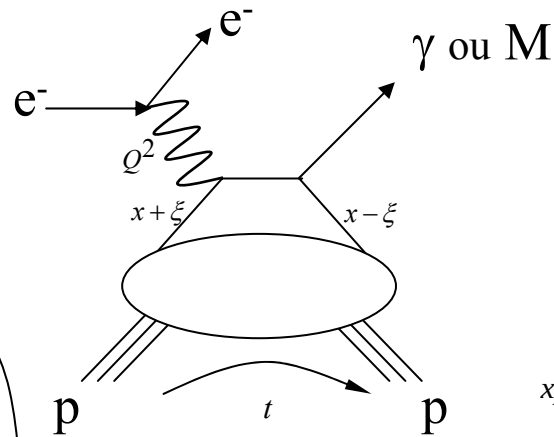
Parton Distributions



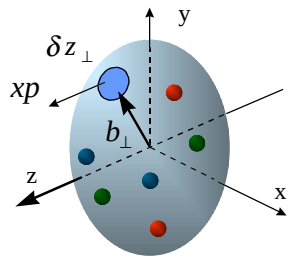
⇒ longitudinal momentum fraction

⇒ quarks contribution to nucleon spin

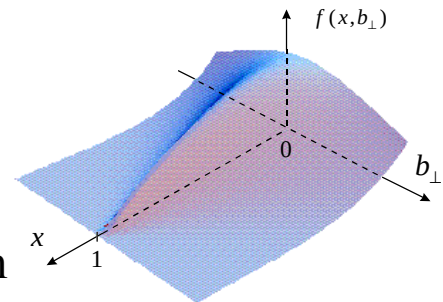
Deep exclusive reactions



$$x,\ t,\ \xi$$



Generalized Parton Distributions (GPDs)



⇒ correlations !

⇒ quark angular momentum

GPD formalism for vector mesons

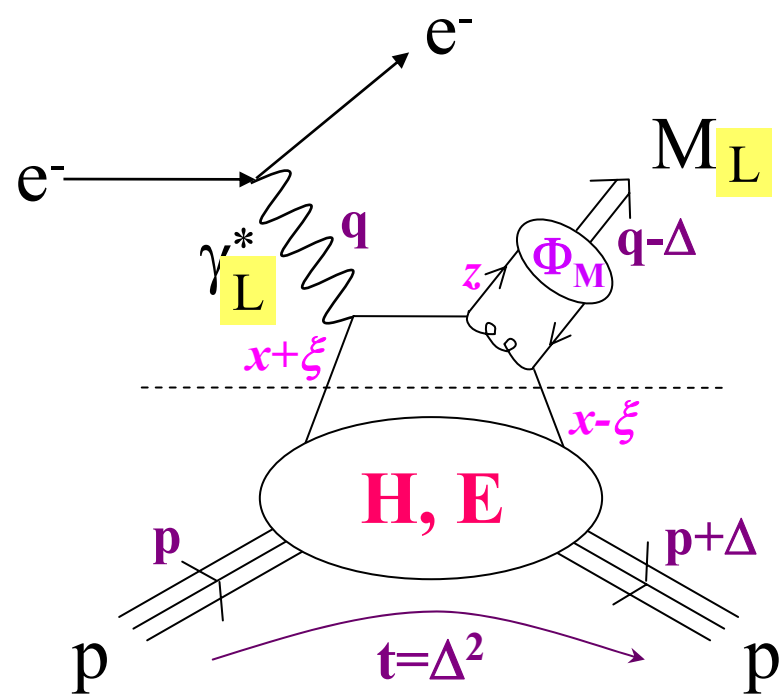
$= \rho^0, \omega, \phi$

Bjorken regime:

$Q^2 \longrightarrow \infty$

$\nu \longrightarrow \infty$

x_B finite



t small

$\gamma^*_L \rightarrow M_L$

FACTORIZATION

Collins et al.

Amplitude:

$$A_L = \left(\int_0^1 dz \frac{\Phi_M(z)}{z} \right) \frac{1}{Q} \int_{-1}^{+1} dx \left\{ \left[\frac{1}{x-\xi+i\varepsilon} + \frac{1}{x+\xi-i\varepsilon} \right] (aH+bE)(x,\xi,t) \right\}$$

Cross section:

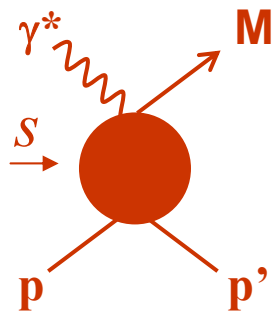
$$\sigma_L\left(\gamma^*_L p \rightarrow p M_L\right) = \Gamma \left| A_L \right|^2 \propto \frac{1}{Q^6}$$

Scaling law

Experiment goals

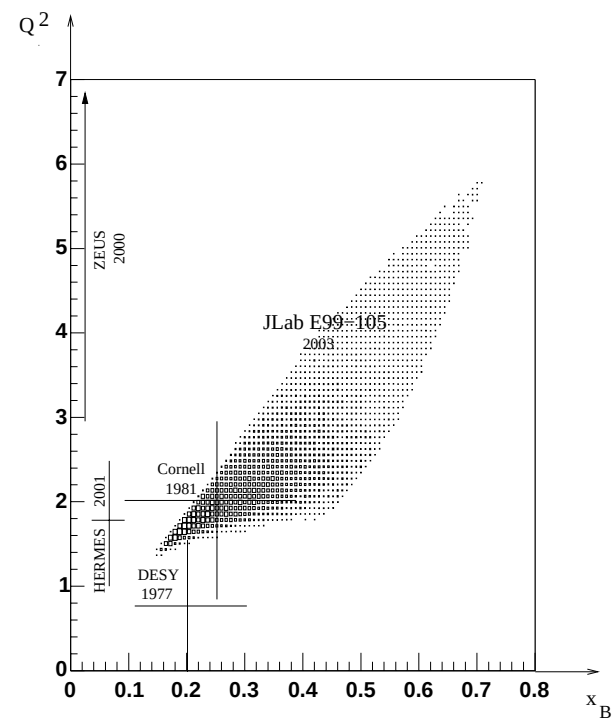
Test of the validity domain of GPD formalism for the ω meson case

- ✓ Determine if the processus is measurable
- ✓ Check if there is *s*-channel helicity conservation (SCHC)
- ✓ Extract $\sigma_L(\gamma^*_L p \rightarrow p M_L)$ and test scaling law in $1/Q^6$
- ✓ Determine if the processus is dominant



Need to study all channels to make a flavor separation of GPDs

Mesons	GPD combinaisons
ρ^0	2u+d
ω	2u-d
ϕ	s



ρ^0, ω, ϕ meson ?

→ $\sigma_{\rho 0} > \sigma_\omega >> \sigma_\phi$

→ ρ^0 meson study already done at 4.2 GeV

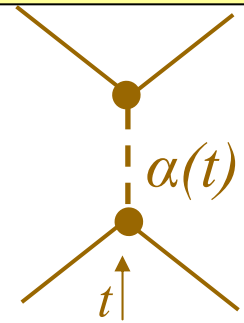
→ Very little existing data for ω meson

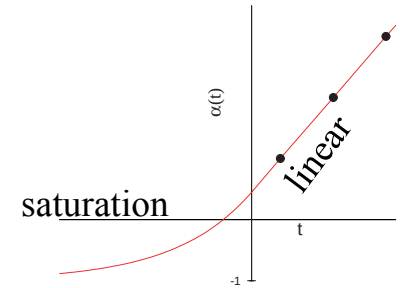
→ Pion exchange role not known at high Q^2

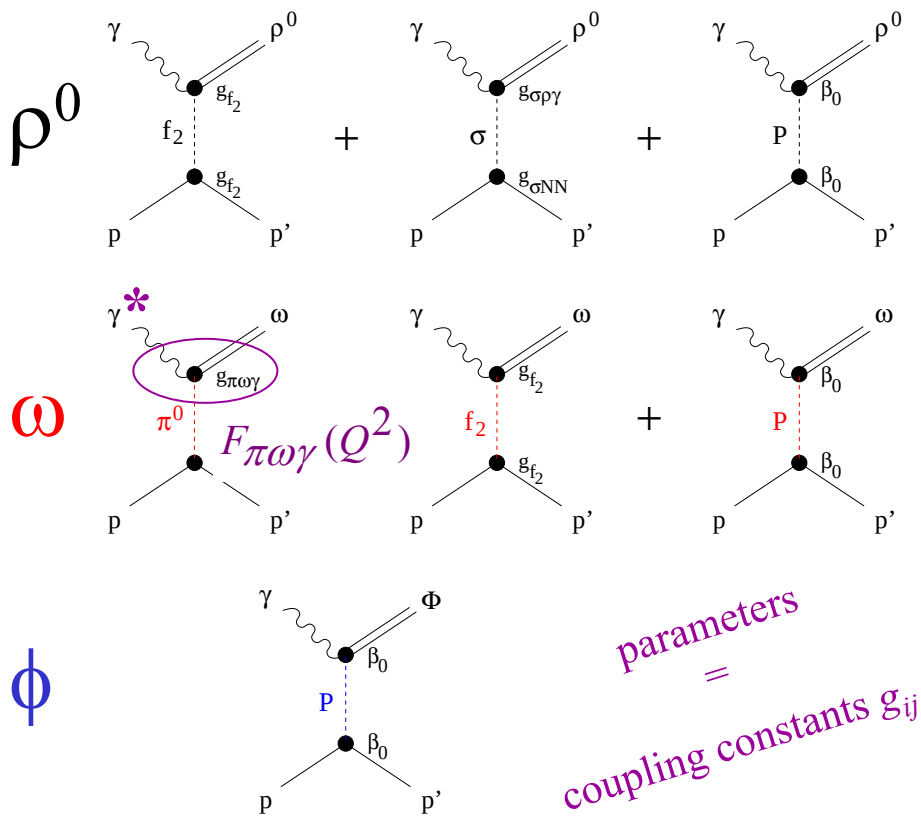
JML* model based on Regge theory

* *Jean-Marc Laget et al.*

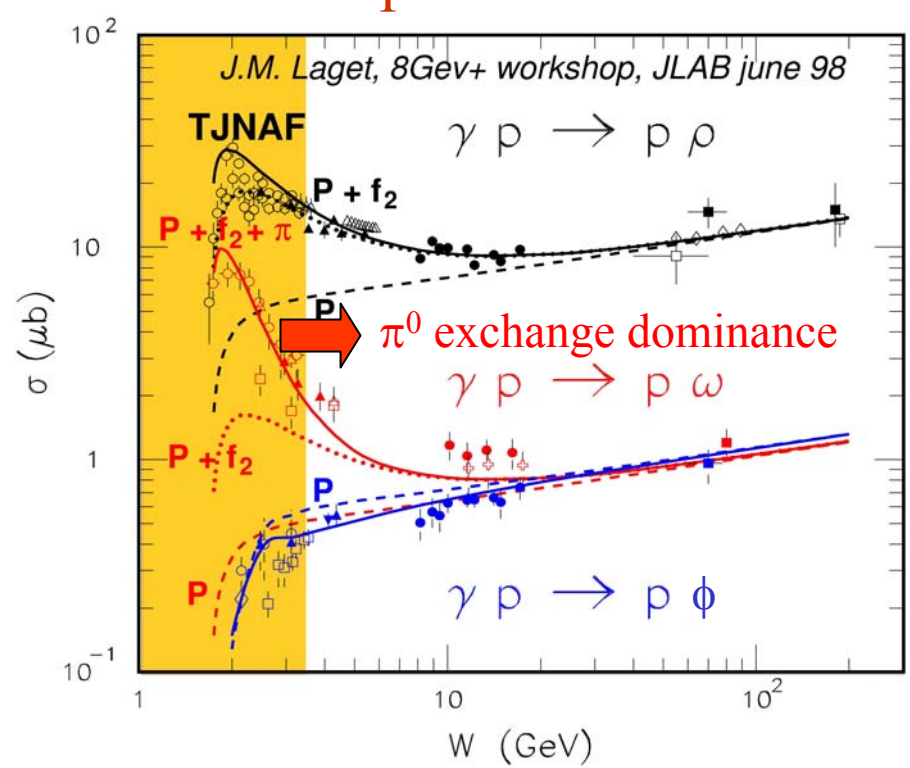
Regge trajectories exchange in *t* channel







Photoproduction case



Extension to electroproduction case

→ add a parameter = electromagnetic form factor

$$F_{\pi\omega\gamma}(Q^2) = \frac{1}{1+Q^2/\Lambda_\pi^2}$$

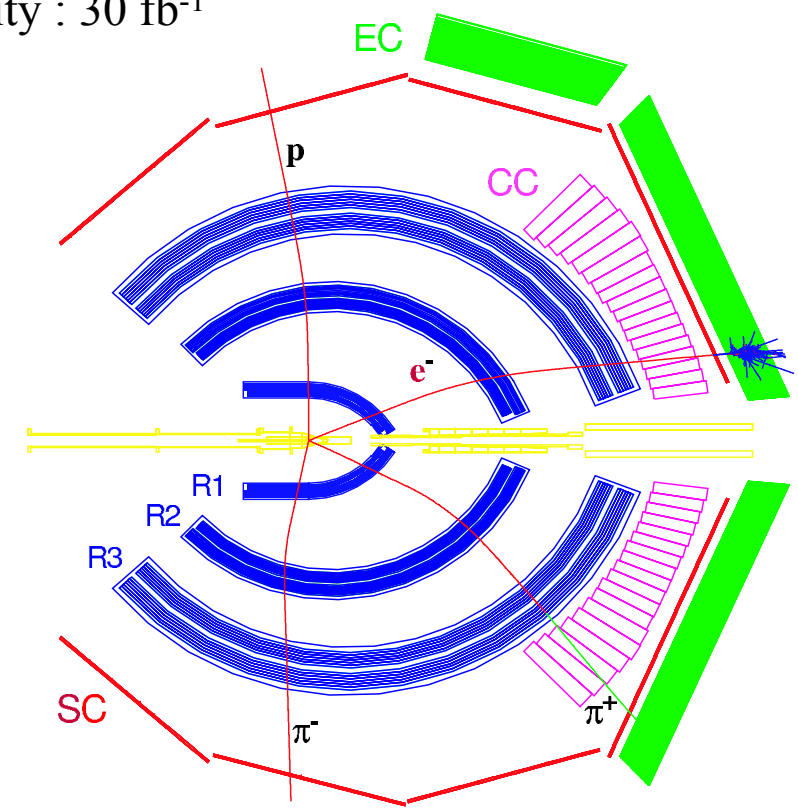
Experiment

CLAS e1-6 run

- **October 2001 – January 2002**
- Electron beam : E = 5.75 GeV, I = 7 nA
- 1.25 billions events
- 11 terabytes of data on tape
- Integrated luminosity : 30 fb^{-1}

$$e^- p \rightarrow e^- p \omega$$

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



First part of data analysis

Extraction of cross sections (study of $e^-p\pi^+X$ final state)

$$\sigma_{e^- p \to e^- p\omega} \propto \frac{n_{e^- p \to e^- p\omega + background} - n_{background}}{L_{\text{int}}}, \quad n = \frac{N}{eff}$$

- Particule identification
- **ω channel identification**
- **Determination of CLAS efficiency in 4D**
- **Background subtraction**
- Normalization

Identification of channel through missing mass

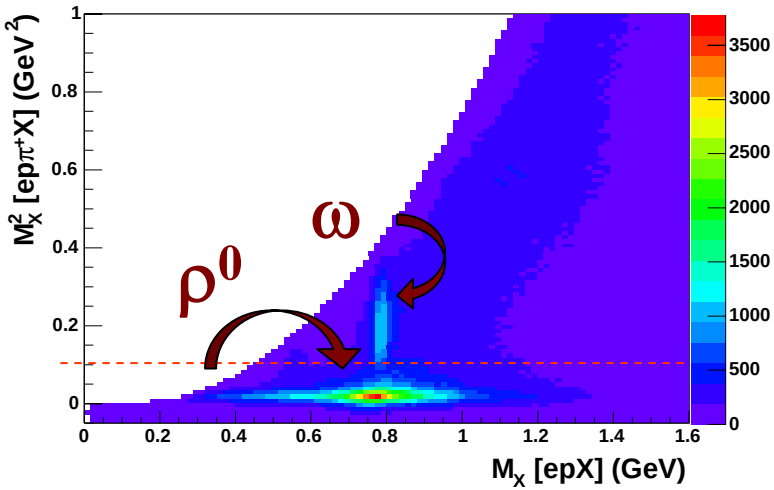
$e^- p \rightarrow e^- p \omega$

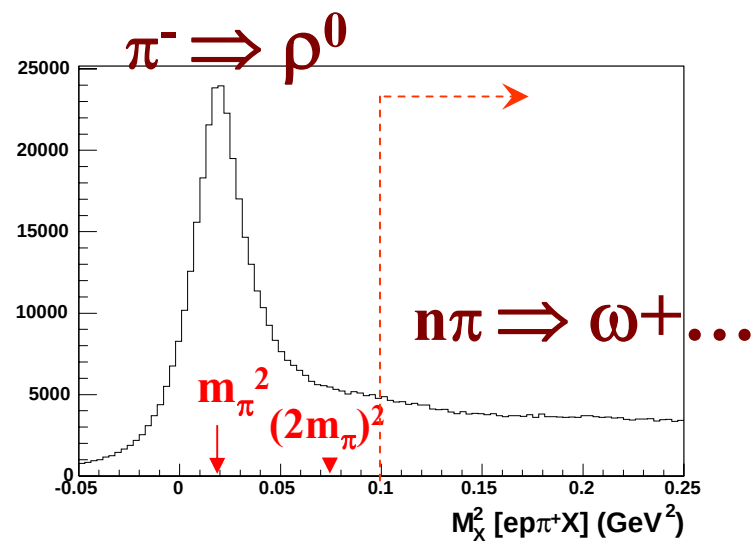
$\omega \rightarrow \pi^+ \pi^- \pi^0$

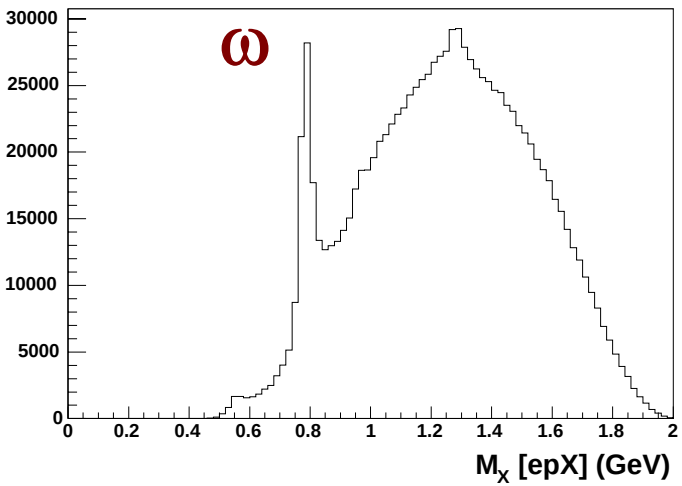
Separation of :

$\omega \rightarrow \pi^+ \pi^- \pi^0$ (M = 783 MeV, Γ = 8 MeV)

$\rho^0 \rightarrow \pi^+ \pi^-$ (M = 770 MeV, Γ = 151 MeV)







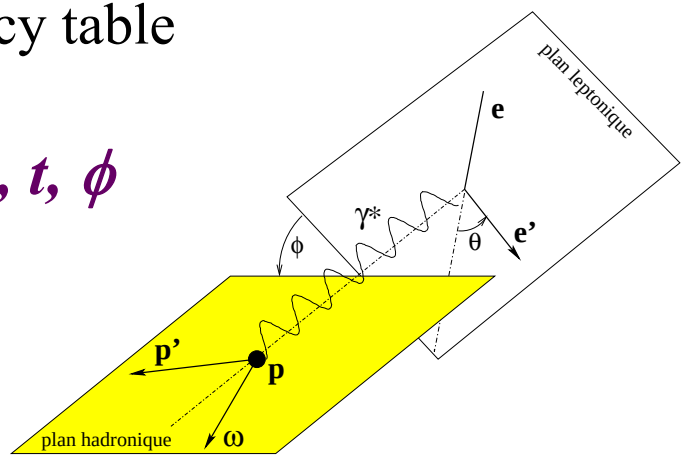
Determination of CLAS efficiency in 4D

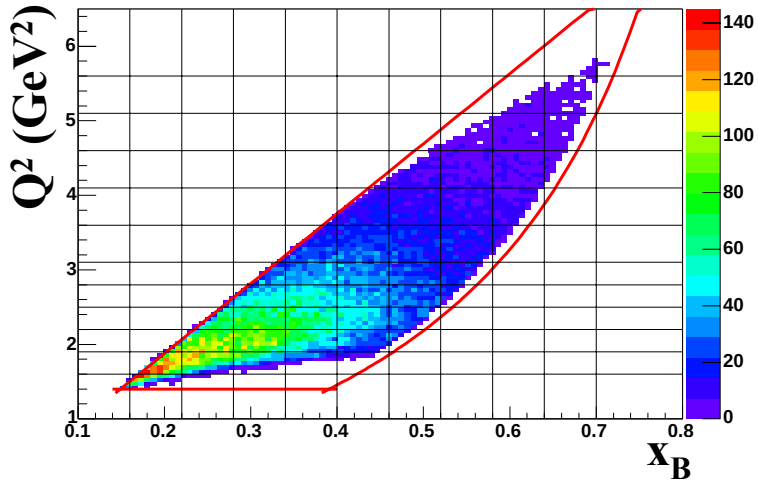
through simulation

28 millions events
20 days

4 kinematical variables
=> 4D efficiency table

Q^2, x_B, t, ϕ





Event Generator → *Ngen* → CLAS Simulator → Analysis Code → *Nacc* →

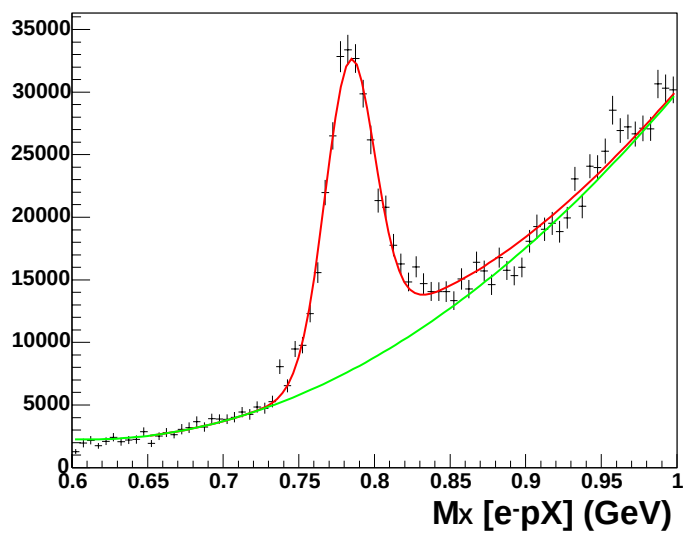
For each 4D bin : *eff* = *Nacc/Ngen* *eff* ~ 2.5%

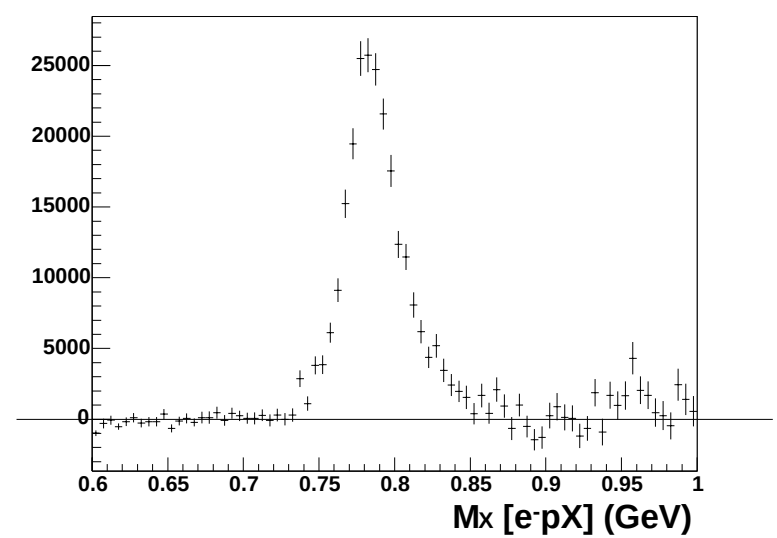
Background subtraction

→ Event weighting : $w=1/eff(Q^2,x_B,t,\phi)$

→ Fit of $M_X[e^-pX]$ with :

y(m)	=	Skewed Gaussian	+	Pol2
		(peak + radiative tail)		(background)

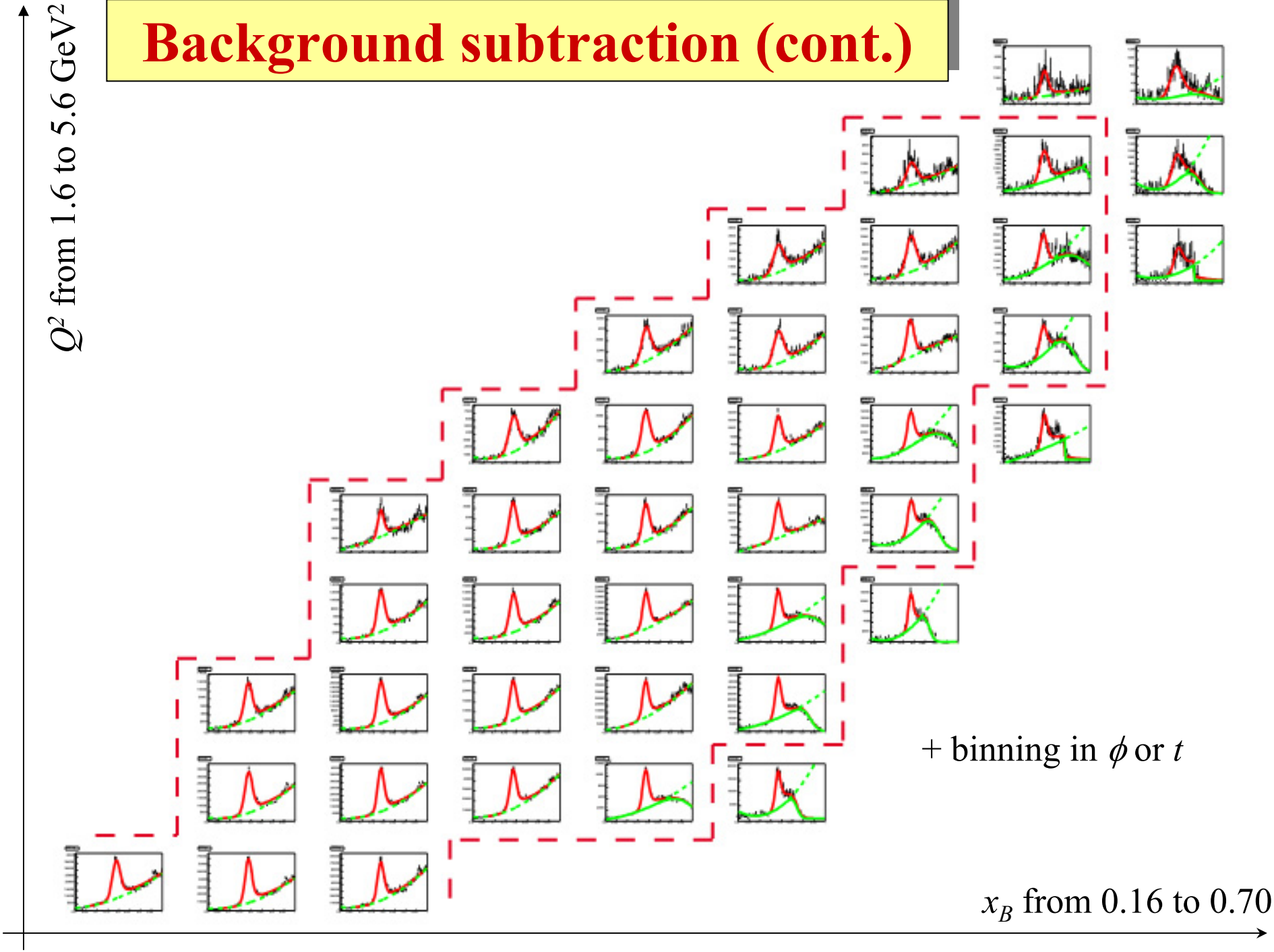




→ Subtraction of Pol2.

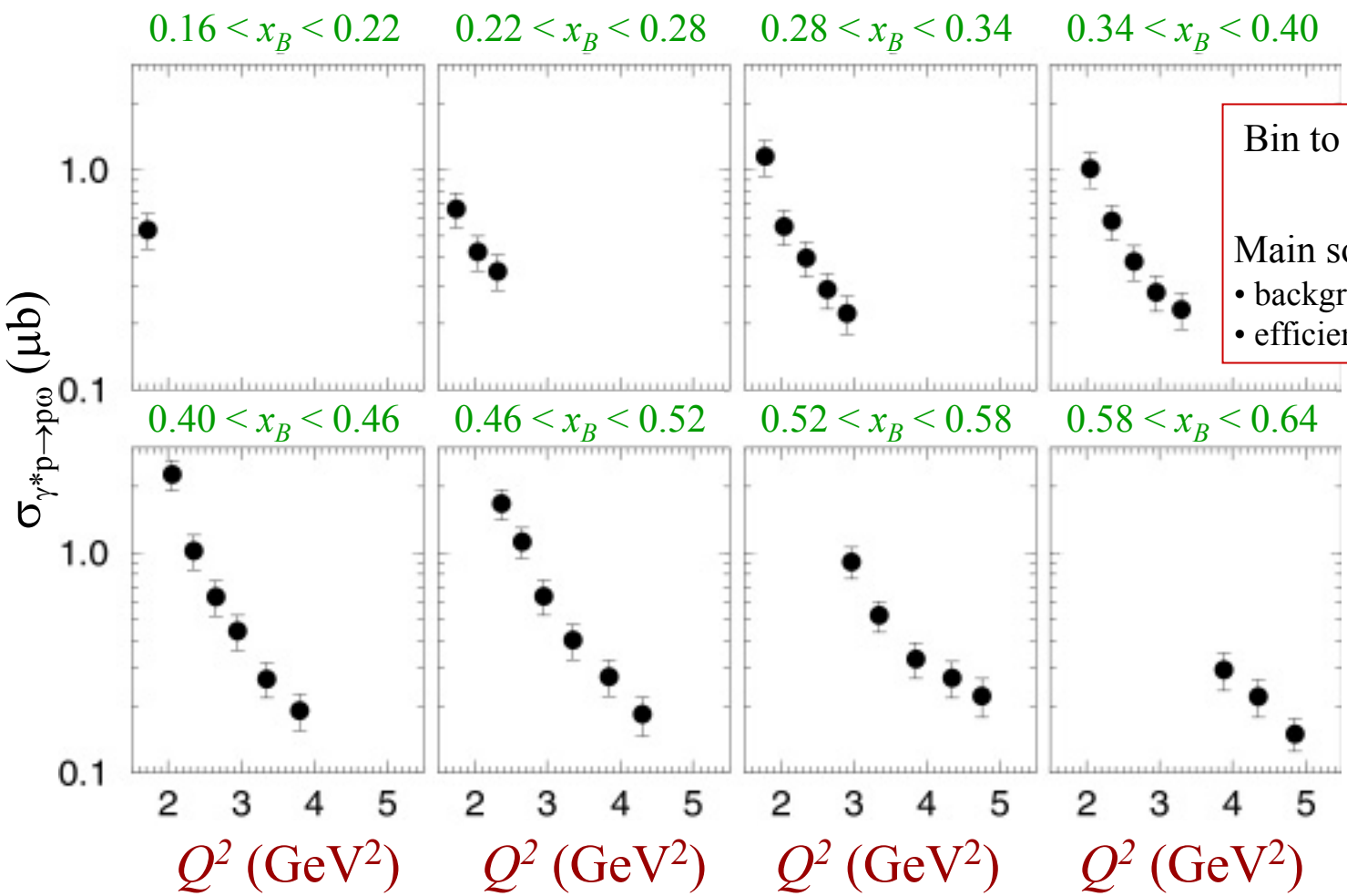
→ Integration of event number between 720 and 850 MeV.

Background subtraction (cont.)



Extraction of $\sigma_{\gamma^* p \to p\omega}$

$$\sigma_{\gamma^* p \to p\omega}(Q^2, x_B) = \frac{1}{\Gamma_V(Q^2, x_B)} \frac{1}{BR_{\omega \to \pi^+\pi^-\pi^0}} \frac{n_\omega(Q^2, x_B)}{L_{\text{int}} \Delta Q^2 \Delta x_B} \times \frac{1}{eff_{CC} eff_{EC} eff_w} \times F_{rad}$$

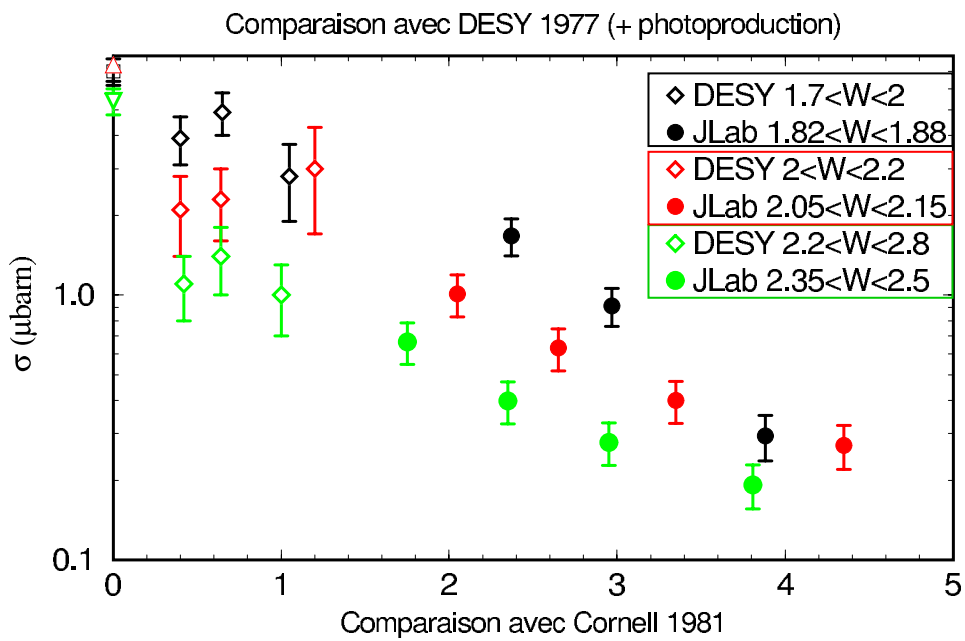


Bin to bin syst. errors included = 15-18%

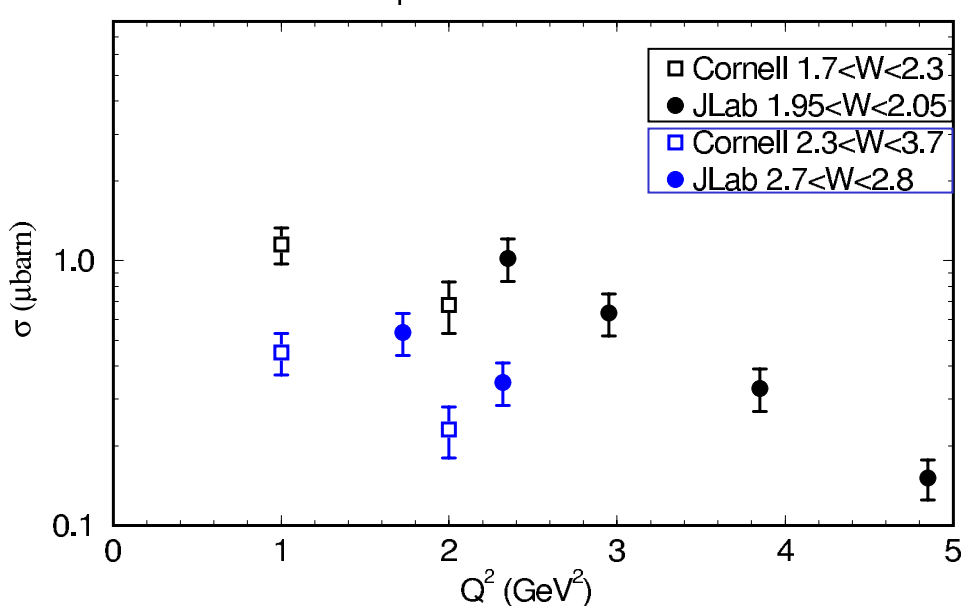
Main sources :

- background subtraction = 8 or 12%
- efficiency calculation = 8%

Comparison with previous data



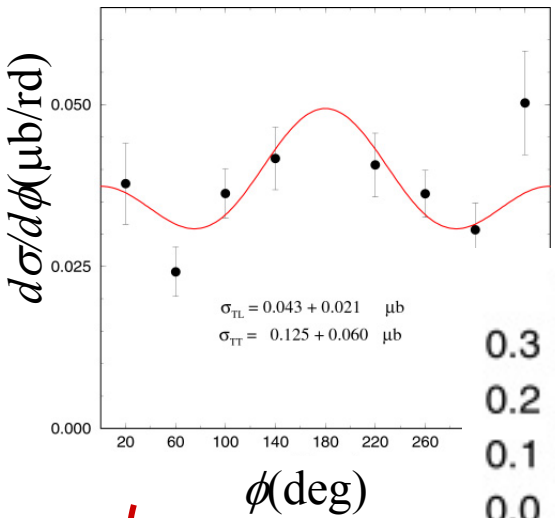
⇒ Compatibility
with DESY data (1977)



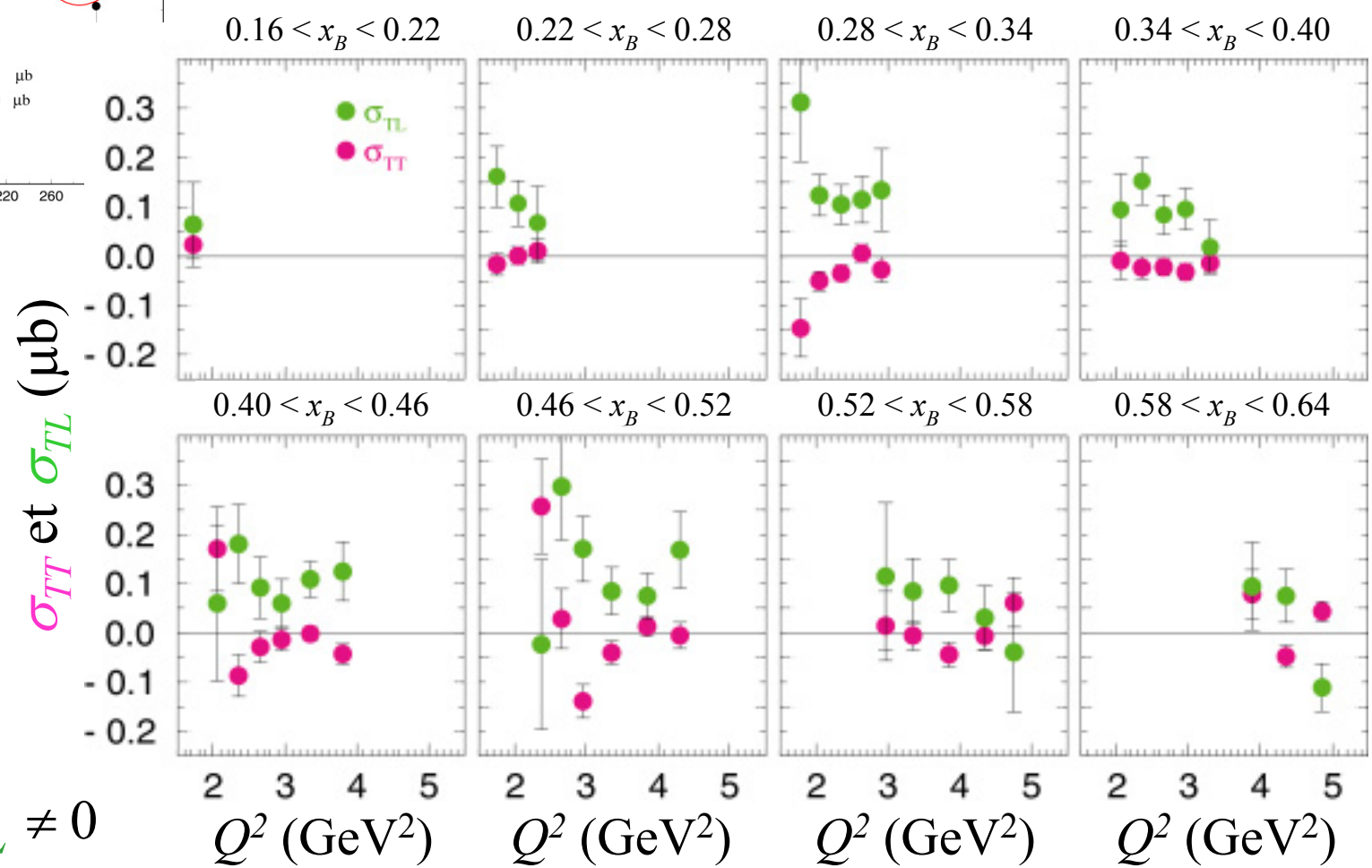
⇒ Disagreement
with Cornell data (1981)

Q^2 range
much extended with our data

Differential cross sections in ϕ



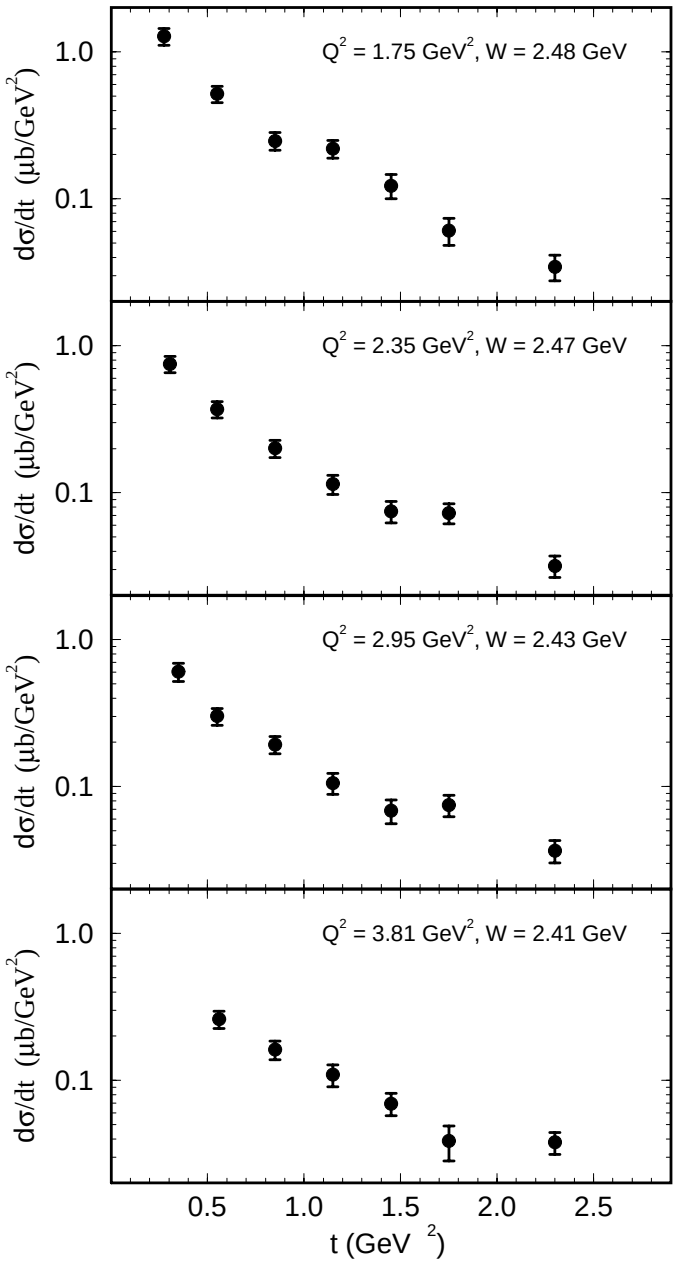
$$\frac{d\sigma_{\gamma^* p \to p\omega}}{d\phi} = \frac{1}{2\pi}\left(\sigma_T + \varepsilon\sigma_L + \varepsilon\cos 2\phi\,\sigma_{TT} + \sqrt{2\varepsilon(1+\varepsilon)}\cos\phi\,\sigma_{TL}\right)$$



$\sigma_{TT} \neq 0, \sigma_{TL} \neq 0$

=> First indication of helicity non conservation in *s*-channel

Differential cross sections in *t*



Large *t* range, up to 2.7 GeV$^{2.}$

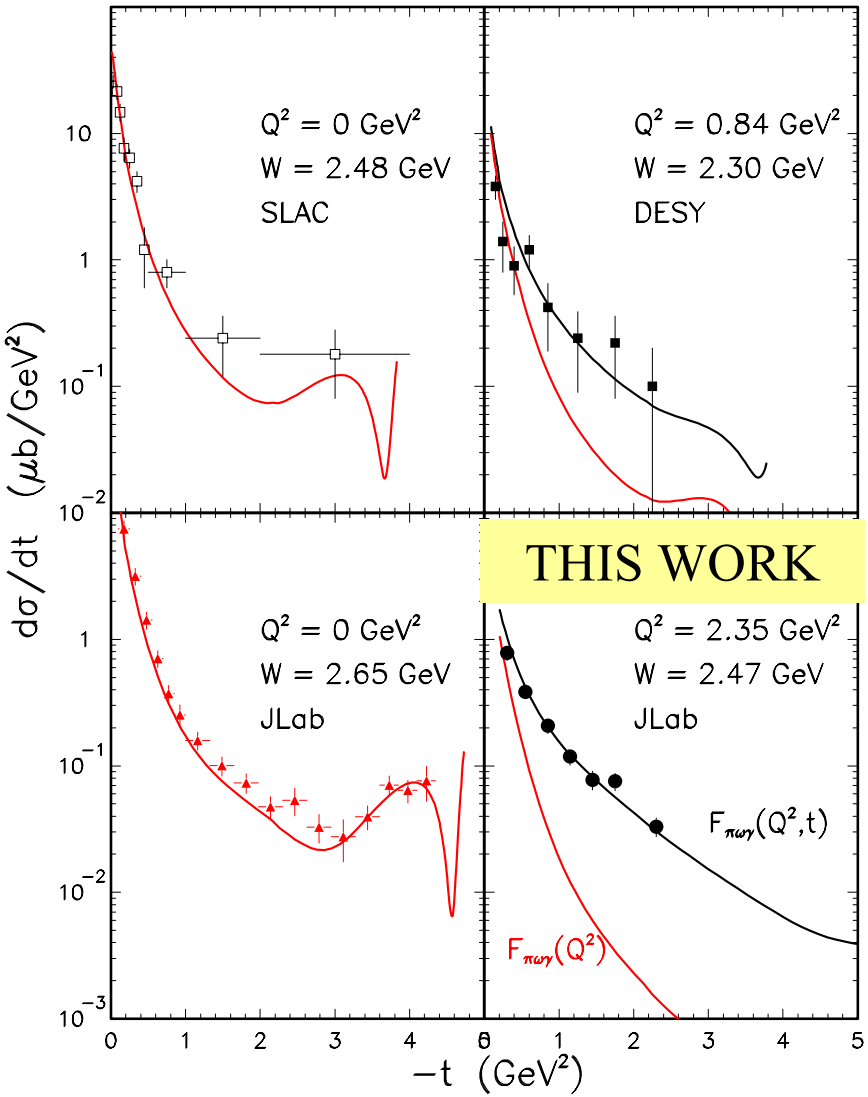
<u>Small *t* :</u>

diffractif regime ($d\sigma/dt \propto e^{bt}$)

<u>Large *t* :</u>

cross sections larger than anticipated

Comparison with JML model

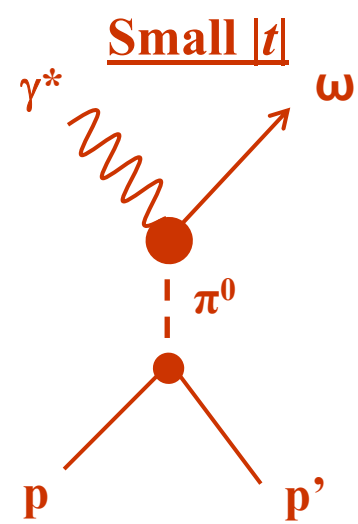


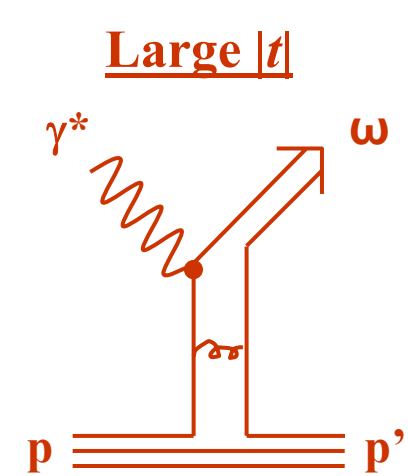
Model includes exchange of π^0, f_2, P

$$F_{\pi\omega\gamma}(Q^2) = \frac{1}{1+\frac{Q^2}{\Lambda_\pi^2}}$$

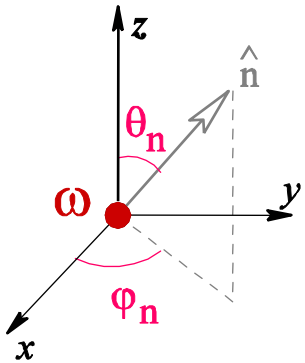
$$F_{\pi\omega\gamma}(Q^2,t) = \frac{1}{1+\frac{Q^2}{\Lambda_\pi^2(t)}}$$

$$\Lambda_\pi^2(t) = \Lambda_\pi^2\left(\frac{1+\alpha_\pi(0)}{1+\alpha_\pi(t)}\right)^2$$





Second part of data analysis

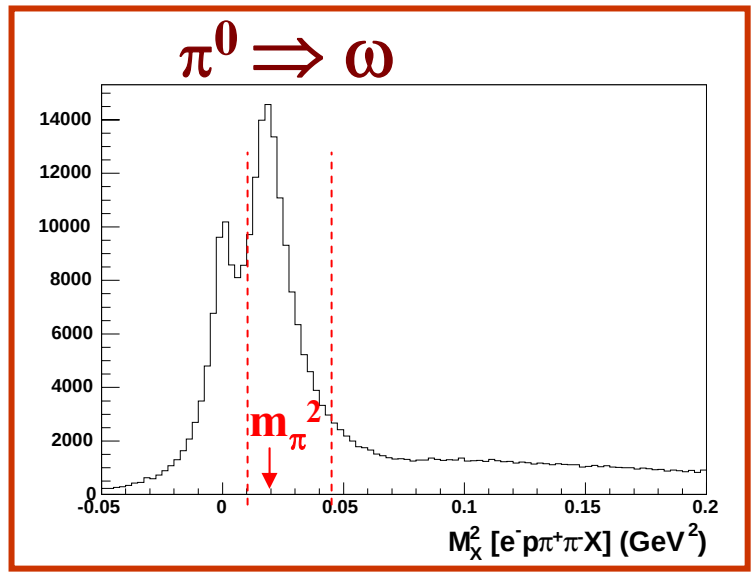


Angular distribution of ω decay products

(study of $e^-p\pi^+\pi^-X$ final state)

- Determination of ω polarization
- Test of *s*-channel helicity conservation (SCHC)

- ω channel identification
- Determination of CLAS efficiency in 6D
- Study of ω decay



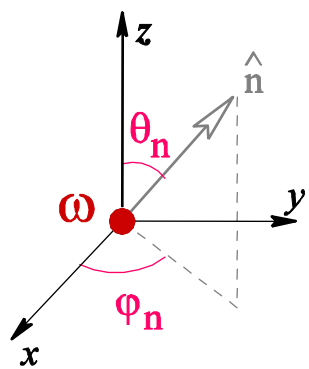
6D efficiency table

$Q^2, x_B, t, \phi, \theta_N, \varphi_N$

eff ~ 0.15%

Formalism for ω decay

Decay angular distribution :



$$\begin{cases} W\left(\cos\theta_N, \varphi_N, \phi\,;\, r_{ij}^{\beta}\right) \\ r_{ij}^{\beta} = f\left(\rho_{ij}^{\alpha}, \varepsilon, R\right) \end{cases}$$

α ↔ virtual photon polarization

i, j ↔ ω meson helicity

ρ_{ij}^{α} elements of ω spin density matrix

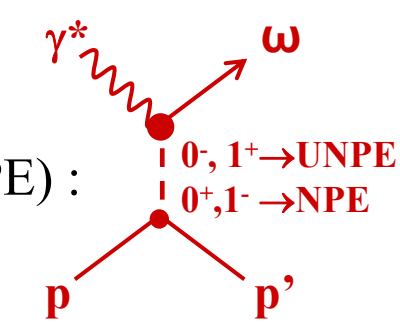
ε parameter of virtual photon polarization

$R = \sigma_L/\sigma_T$ (Rp : $\sigma = \sigma_T + \varepsilon\sigma_L$)

Deduce :

- ω polarization via $r_{ij}^{\beta}\left(\rho_{ij}^{\alpha}\right)$
- SCHC test : $r_{1-1}^{04} = 0$ (necessary condition)
- **If SCHC, then** $R = r_{00}^{04} \Big/ \varepsilon\left(1 - r_{00}^{04}\right) \Rightarrow$ **separation σ_L, σ_T**
- Test of hypothesis of natural parity exchange in the *t*-channel (NPE) :

$$1 - r_{00}^{04} + 2r_{1-1}^{04} - 2r_{11}^{1} - 2r_{1-1}^{1} = 0 \quad \text{(necessary condition)}$$



Study of ω decay

① 1D projection method

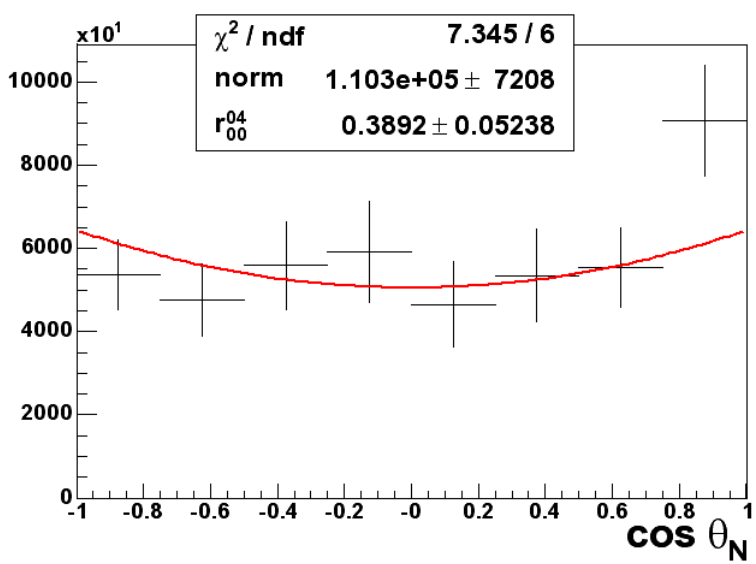
$$\int\int_{\varphi_N\,\phi}$$

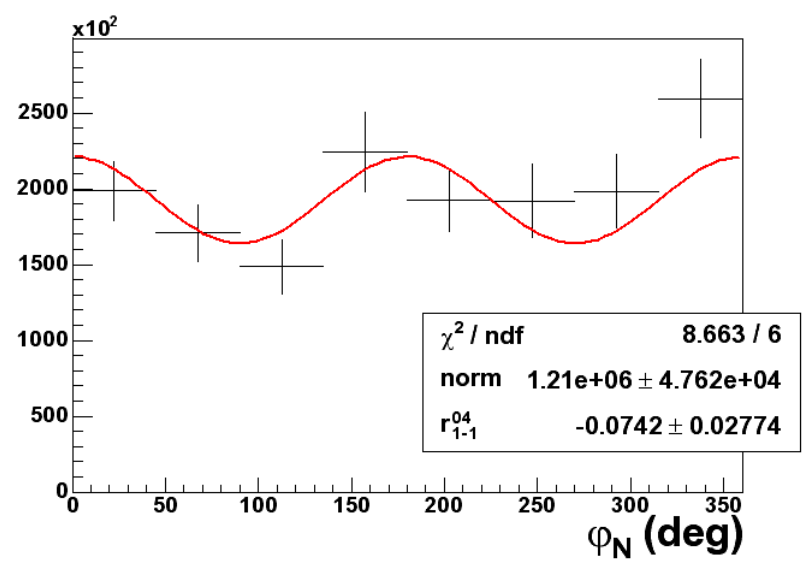
$$\begin{aligned}
W(\cos\theta_N,\varphi_N,\phi) = \frac{3}{4\pi}\Big[&\frac{1}{2}\left(1-r_{00}^{04}\right)+\frac{1}{2}\left(3r_{00}^{04}-1\right)\cos^2\theta_N \\
&-\sqrt{2}\,\mathrm{Re}\,r_{10}^{04}\sin 2\theta_N\cos\varphi_N - r_{1-1}^{04}\sin^2\theta_N\cos 2\varphi_N \\
&-\varepsilon\cos 2\phi\left(r_{11}^{1}\sin^2\theta_N + r_{00}^{1}\cos^2\theta_N - \sqrt{2}\,\mathrm{Re}\,r_{10}^{1}\sin 2\theta_N\cos\varphi_N - r_{1-1}^{1}\sin^2\theta_N\sin 2\varphi_N\right) \\
&-\varepsilon\sin 2\phi\left(\sqrt{2}\,\mathrm{Im}\,r_{10}^{2}\sin 2\theta_N\sin\varphi_N + \mathrm{Im}\,r_{1-1}^{2}\sin^2\theta_N\sin 2\varphi_N\right) \\
&+\sqrt{2\varepsilon(1+\varepsilon)}\cos\phi\left(r_{11}^{5}\sin^2\theta_N + r_{00}^{5}\cos^2\theta_N - \sqrt{2}\,\mathrm{Re}\,r_{10}^{5}\sin 2\theta_N\cos\varphi_N - r_{1-1}^{5}\sin^2\theta_N\cos 2\varphi_N\right) \\
&+\sqrt{2\varepsilon(1+\varepsilon)}\sin\phi\left(\sqrt{2}\,\mathrm{Im}\,r_{10}^{6}\sin 2\theta_N\sin\varphi_N + \mathrm{Im}\,r_{1-1}^{6}\sin^2\theta_N\sin 2\varphi_N\right)\Big]
\end{aligned}$$

$$\int\int_{\cos\theta_N\,\phi}$$

$$W(\cos\theta_N) = \frac{3}{4\pi}\left[\frac{1}{2}\left(1-r_{00}^{04}\right)+\frac{1}{2}\left(3r_{00}^{04}-1\right)\cos^2\theta_N\right]$$

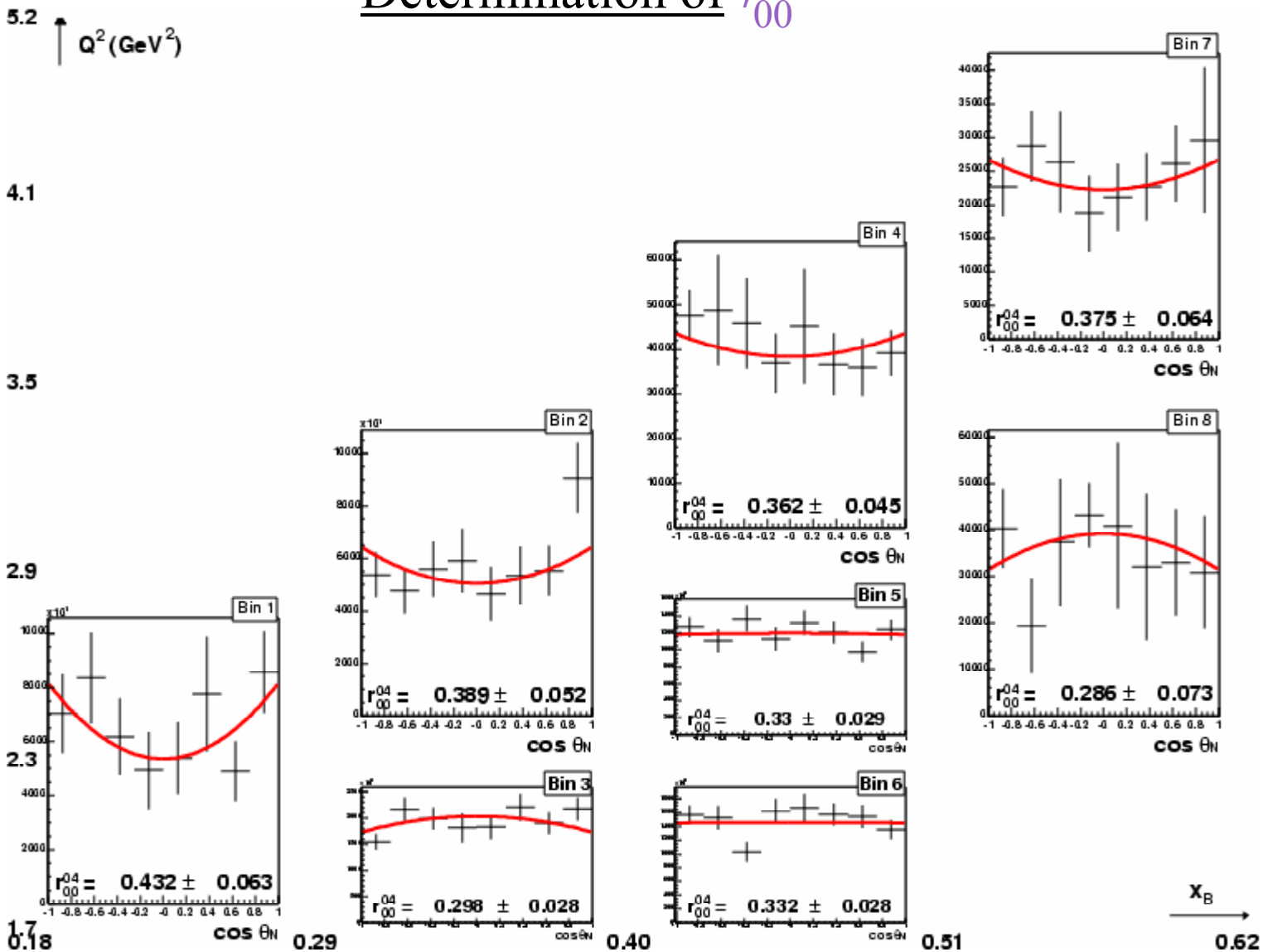
$$W(\varphi_N) = \frac{1}{2\pi}\left[1-2r_{1-1}^{04}\cos 2\varphi_N\right]$$





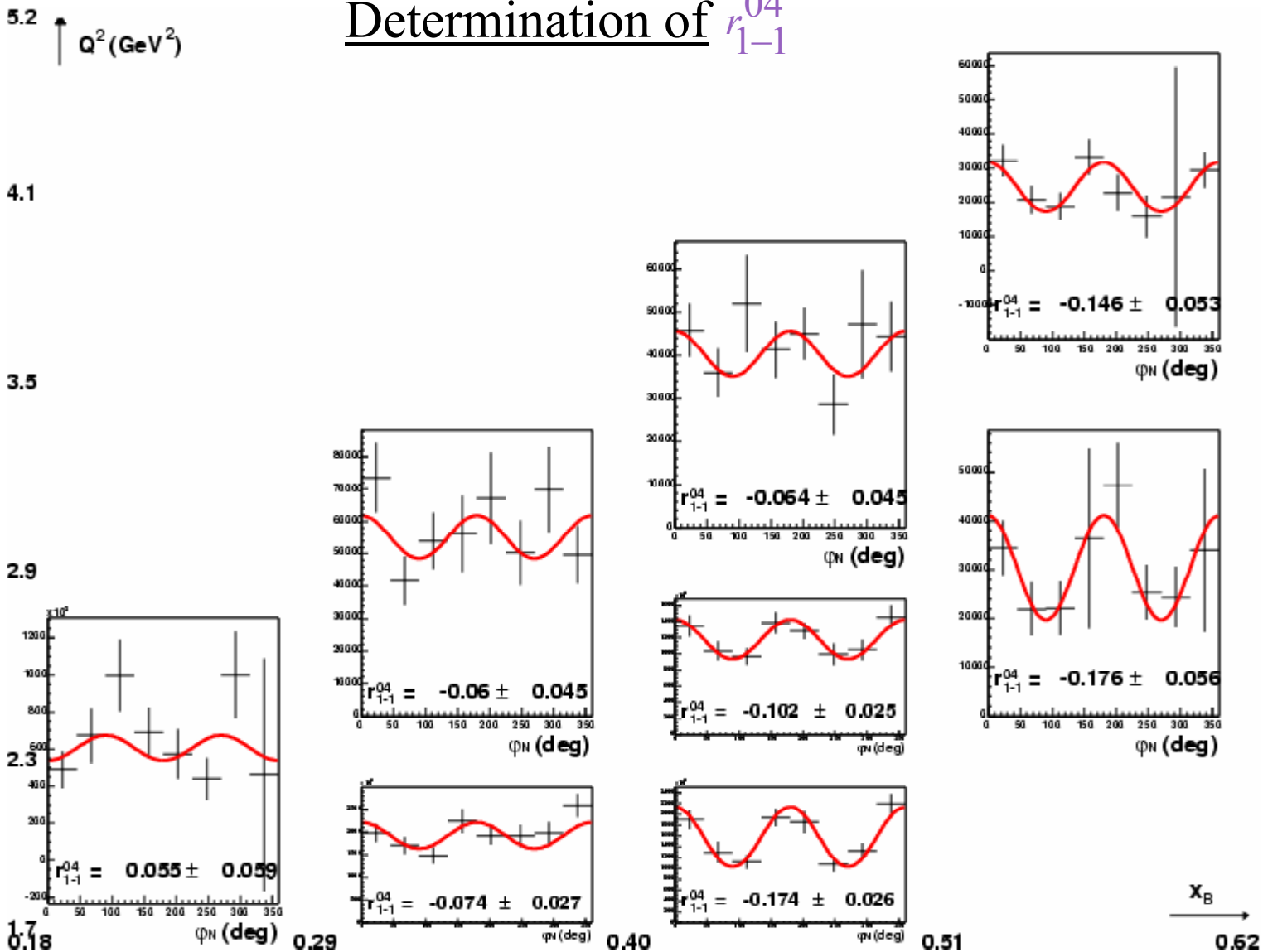
Study of ω decay (2)

Determination of r_{00}^{04}



ω decay study (3)

Determination of r^{04}_{1-1}



$r^{04}_{1-1} \neq 0$ => other indication of non conservation of helicity in the *s*-channel

ω decay study (4)

② Method of moments :

$$r^{04}_{00} = \frac{5}{2}\left\langle \cos^2\theta_N \right\rangle - \frac{1}{2}$$

$$\mathrm{Re}\, r^{04}_{10} = -\frac{5}{4\sqrt{2}}\left\langle \sin 2\theta_N \cos\phi \right\rangle$$

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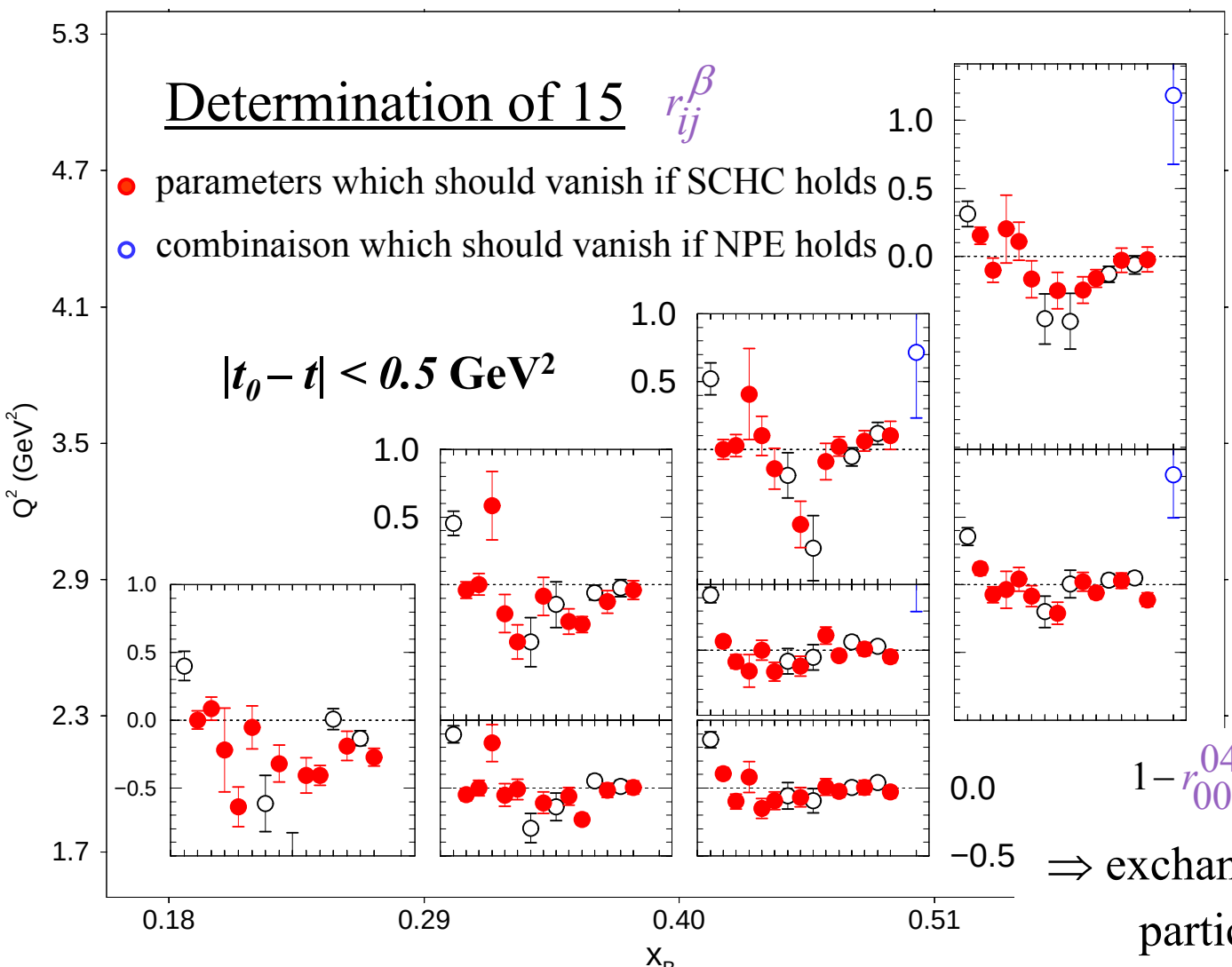
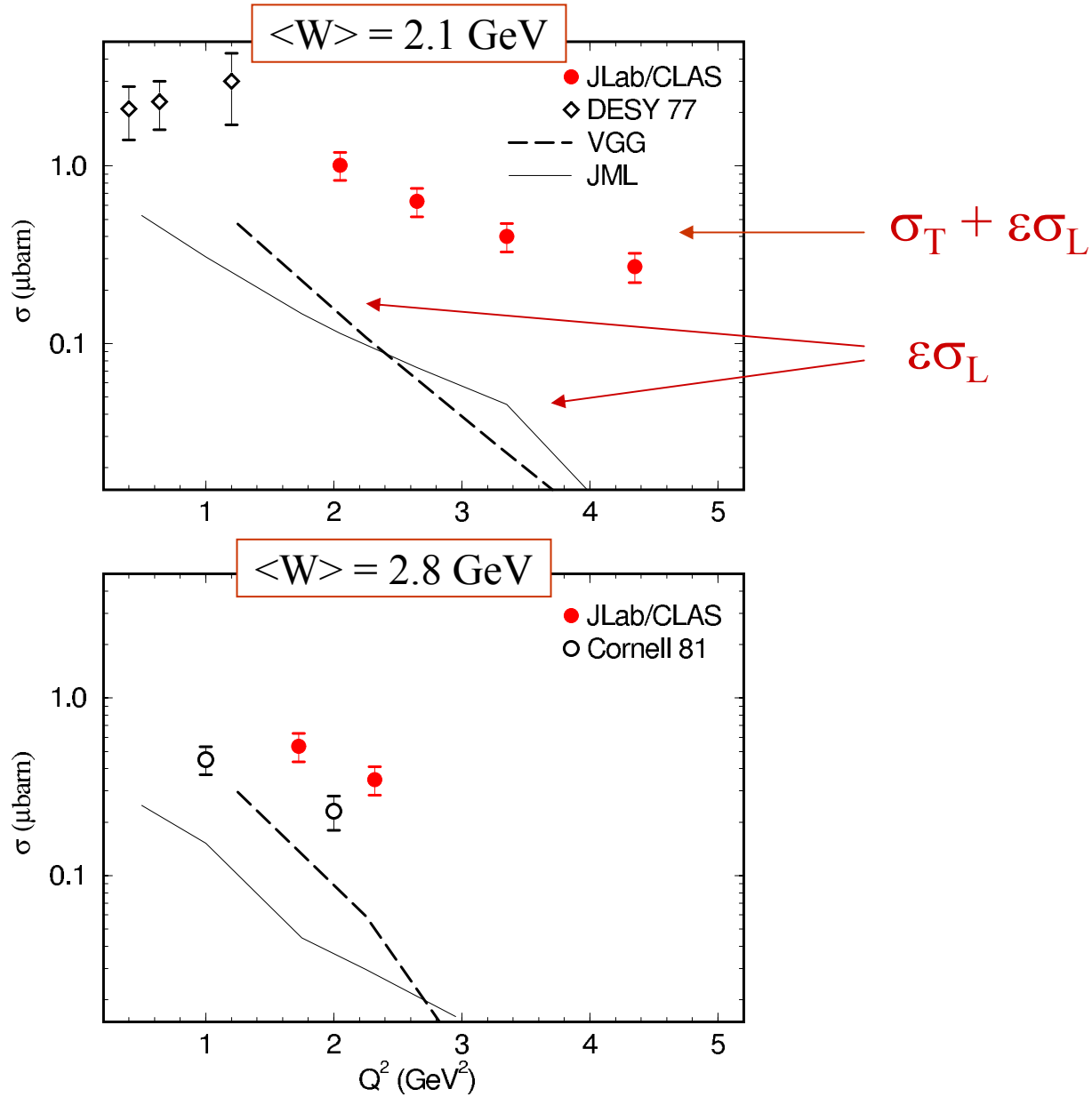


$$1 - r^{04}_{00} + 2r^{04}_{1-1} - 2r^{1}_{11} - 2r^{1}_{1-1} \neq 0$$

⇒ exchange of UNnatural parity particle in the *t*-channel

Contribution of $\varepsilon\sigma_L$ from VGG (GPDs) and JML (Regge) models

VGG model:
M. Vanderhaeghen,
P. Guichon,
M. Guidal



Conclusions and perspectives

- Precise measurements of the $e^- p \rightarrow e^- p \omega$ reaction at high Q^2 and over a wide range in t
- Exclusive reactions are measurable at high Q^2 (even with the current « modest » CEBAF energy)
- First significant analysis of ω decay in electroproduction

What do we learn ?

- Cross sections larger than anticipated at high t
- SCHC does not hold
- Evidence for unnatural parity exchange

  $\rightarrow \pi^0$ exchange very probable even at high Q^2

Comparison to models

- JML model (Regge) :

Good agreement when introducing a t dependence in the $\pi\omega\gamma$ form factor
→ suggests coupling to a « point » object at high t

- VGG model (GPDs) :

Direct comparison not possible since σ_L not measured
Nevertheless
→ handbag diagram contributes only about 1/5 of measured cross sections
→ no incompatibility
→ ω most challenging/difficult channel to access GPD

Perspectives

- Continue the comparison of our results with the JML model:

$$(\sigma_{TT},\ \sigma_{TL},\ r_{ij})$$

- Systematic study of other processes ($e^- p \rightarrow e^- p \rho^0, \phi, \gamma$)
  in view of an interpretation in terms of GPDs

Franck Sabatie & Valery Kubarovsky talks in Exclusive Reactions session

- Measurements feasible up to Q^2=8-9 GeV^2 with CEBAF@12 GeV