BACKGROUND SUBSTRACTION IN P.V. EXPERIMENTS

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Background substraction in PV experiments

Introduction and Motivation

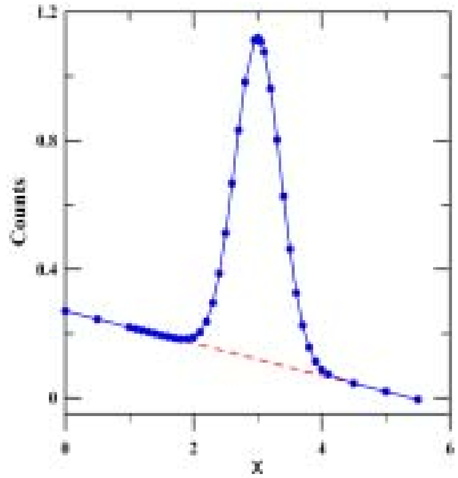
It is well known that the asymmetry in P.V experiments due to the exchange of the Z_0 boson is small ($\approx 10^{-6} - 10^{-5}$). Much care has to be taken in the measurement of such a small quantity. Since a few years, impressive improvements in technical aspects have been achieved and some of them have been or will be presented in this workshop. Whithout such improvements, the extraction of the physical quantity would be obtained with too large systematics errors and so meaningless.

In any experiment, simulation of all the processes which populate the "good" events as well as some "background" events, is a good tool to be sure that the experiment and in particular the experimental set-up is under control.

Simulation of very small effects is not an easy task for many reasons:

- The accuracy of the simulation depends strongly on the statistics and standard methods, which are time consuming, may become unefficient.
- Some of the physical effects, which are usually considered as small and therefore are neglected, may contribute.
- It is necessary to improve the description of some processes which are usually treated only in an approximate way.
- Accurate models and data needed do not exist.

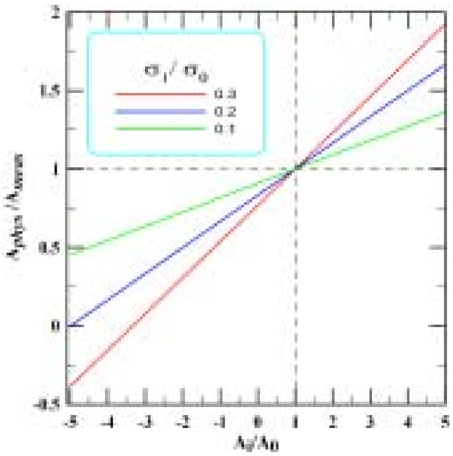
$$\text{Basic formula : } A_{\text{Phys}} = A_{\text{meas.}} \frac{1 + \sum A_i/A_0 \quad \sigma_i/\sigma_0}{1 + \sum \sigma_i/\sigma_0}$$



σ_0, A_0 Physical Xsection and Asym.

σ_i, A_i Background Xsection and Asym.

- The experimental set-up has to be designed to reduce the ratio σ_i/σ_0 and thus to minimize the systematic errors.
- The change in the sign of the ratio A_i/A_0 could be dramatic



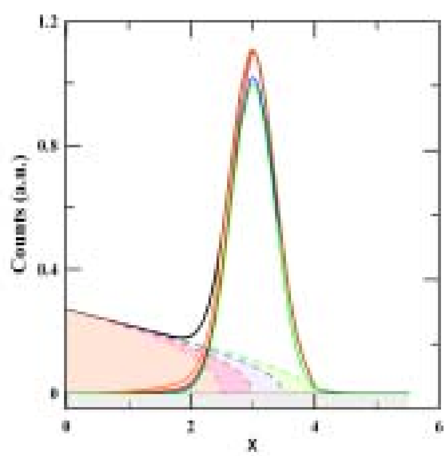
A_i/A_0	$A_{Phys}/A_{meas.}$
-3.	0.63
-2.	0.73
-1.	0.82
0.	0.91
1.	1.00
2.	1.09
3.	1.18

In principle, it is possible to experimentally study the background but the statistical precision could be poor as compared to the elastic peak.

It is possible to interpolate left and right sides if:

- Both Xsection and and Asymmetry have a "continuous" behaviour.

In some cases, it is possibe only to extrapolate the background and the experimental study of the background becomes less efficient.



MONTE CARLO (MC) simulations are supposed to be a powerful tool to understand both the elastic observables and the background features. At least it gives some complementary informations to measurement.

Monte-Carlo: One-to-One correspondance between uniform random number $\eta \in]0,1[$ and physical law.

This method is powerful if the physical laws under consideration are well known. MC results are accurate if we are able to generate a large number of events.

- One dimension:

$$\eta = \frac{\mathcal{N}}{\mathcal{D}} \qquad \mathcal{N} = \int_{x_{min}}^{x} f(x')\ dx' \qquad \mathcal{D} = \int_{x_{min}}^{x_{max}} f(x')\ dx'$$

- Two dimensions:

$$\eta_1 = \frac{\mathcal{N}_1}{\mathcal{D}_1}$$

$$\mathcal{N}_1 = \int_{x_{1min}}^{x_1} f_1(x_1')\ dx_1' \qquad \mathcal{D}_1 = \int_{x_{1min}}^{x_{1max}} f_1(x_1')\ dx_1'$$

$$f_1(x_1) = \int_{x_{2min}(x_1)}^{x_2} f(x_1, x_2')\ dx_2'$$

$$\eta_2 = \frac{\mathcal{N}_2}{\mathcal{D}_2}$$

$$\mathcal{N}_2 = \int_{x_{2min}(x_1)}^{x_2} f(x_1, x_2')\ dx_2' \qquad \mathcal{D}_2 = \int_{x_{2min}(x_1)}^{x_{2max}(x_1)} f(x_1, x_2)\ dx_2$$

♣ Using the definition of the Monte Carlo method is time consuming (you need to invert the expression in the numerator to get the physical quantity.)

♣ To increase the efficiency of the M.C method:

1) Introduction of weights
2) Calculate the Xsections we are interested in.

Examples of weights:

Example 1: $a \; + \; b \; \longrightarrow \; 1 \; + \; 2$

$$\eta_\theta = \frac{\theta_1 - \theta_{1min}}{[\Delta\theta_1]} \qquad \eta_\phi = \frac{\phi_1 - \phi_{1min}}{[\Delta\phi_1]}$$

$$W = \frac{\mathcal{L}}{N_T} \, [\Delta\theta_1] \, [\Delta\phi_1] \, \frac{d^2\sigma}{d\Omega_1} \, \sin(\theta_1)$$

$\mathcal{L}$: Luminosity

N_T: Number of random events

$[\Delta\theta_1]$: Angular range for $\theta_1 = \theta_{1max} - \theta_{1min}$

$[\Delta\phi_1]$: Angular range for $\phi_1 = \phi_{1max}(\theta_1) - \phi_{1min}(\theta_1)$

Example 2: $a + b \longrightarrow 1 + 2 + 3$

$$\eta_\theta = \frac{\theta_1 - \theta_{1min}}{[\Delta\theta_1]} \qquad \eta_\phi = \frac{\phi_1 - \phi_{1min}}{[\Delta\phi_1]}$$

$$\eta_E = \frac{E_1 - E_{1min}(\theta_1)}{[\Delta E_1]}$$

$$W = \frac{\mathcal{L}}{N_T} [\Delta\theta_1] [\Delta\phi_1] [\Delta E_1] \frac{d^3\sigma}{d\Omega_1 \, dE_1} \sin(\theta_1)$$

$\mathcal{L}$: Luminosity

N_T: Number of random events

$[\Delta\theta_1]$: Angular range for $\theta_1 = \theta_{1max} - \theta_{1min}$

$[\Delta\phi_1]$: Angular range for $\phi_1 = \phi_{1max}(\theta_1) - \phi_{1min}(\theta_1)$

$[\Delta E_1]$: Energy range for $E_1 = E_{1max}(\theta_1) - E_{1min}(\theta_1)$

The two methods are equivalent if the weights are introduced correctly (M. Morlet)

In the following part of the talk, I will concentrate on specific examples extracted from PVA4 and G0 experiments.

PVA4

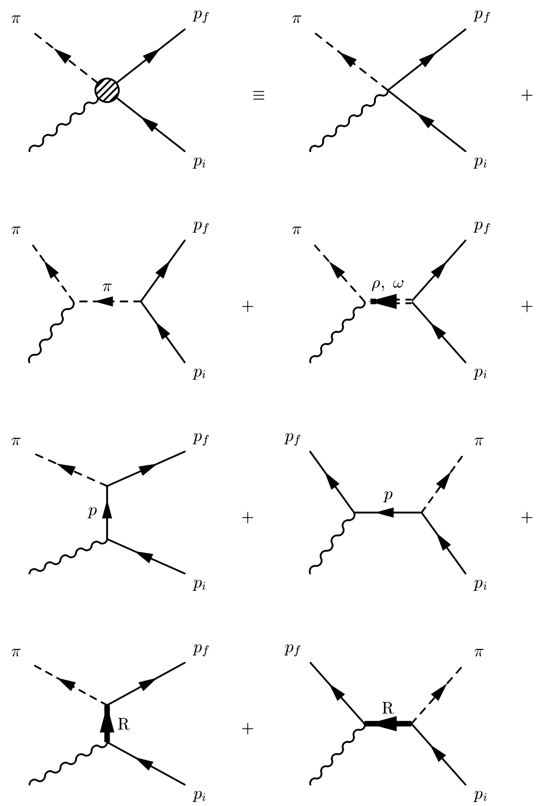
Contribution of the ineleastic electrons to the spectrum:

$$e \ + \ p \ \longrightarrow \ e' + \ p' \ + \ \pi^0$$

$$e \ + \ p \ \longrightarrow \ e' + \ n' \ + \ \pi^+$$

When the incident energy is $\leq$ 1GeV, calculations based on effective Lagrangians are in good agreement with data.
$\Longrightarrow$ reliable simulations of the background.

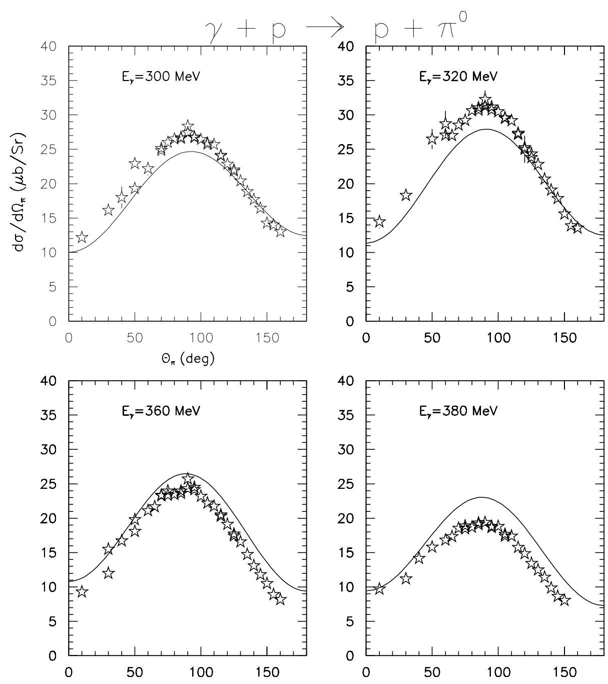
$$\frac{d^3\sigma}{d\Omega_{e'} \ dE_{e'}} = \int \frac{d^3\sigma}{d\Omega_{e'} \ dE_{e'} \ d\overline{\Omega}_\pi} \ d\overline{\Omega}_\pi$$

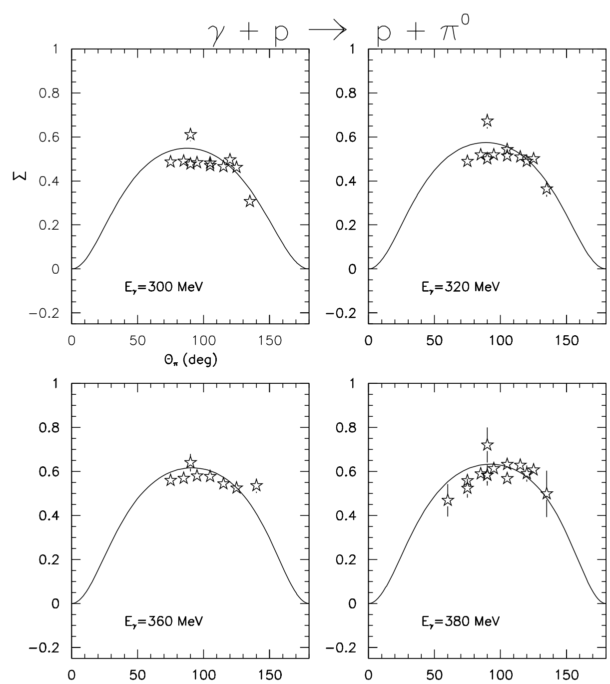


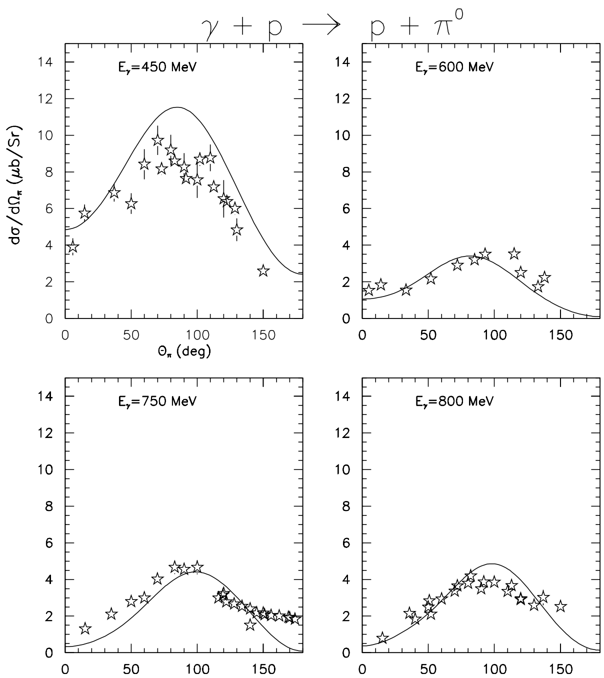
Resonances: $\boldsymbol{P_{33}}$**(1232),** $\boldsymbol{P_{11}}$**(1440),** $\boldsymbol{D_{13}}$**(1520) and** $\boldsymbol{S_{11}}$**(1535)**

Two observables have been calculated to test our generator of events in photo-production of pions: the Cross-section and the photon asymmetry defined as:

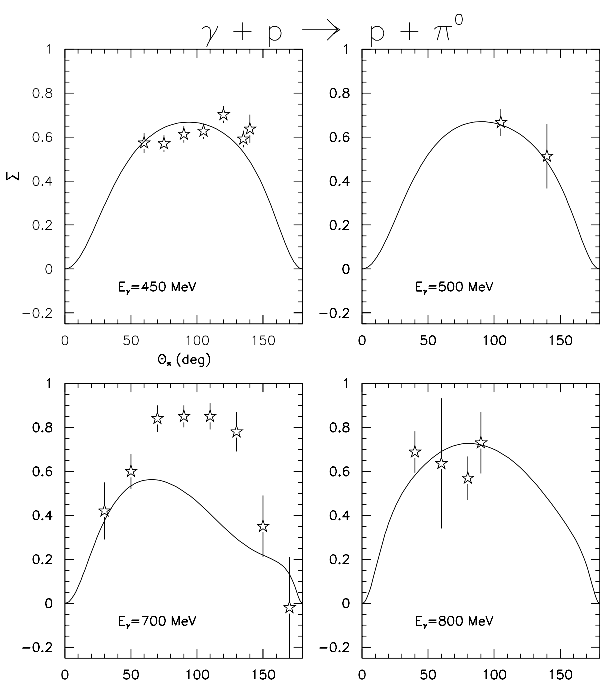
$$\boldsymbol{\Sigma = \frac{\sigma_\perp - \sigma_\parallel}{\sigma_\perp + \sigma_\parallel}} \; .$$


$\gamma + p \longrightarrow p + \pi^0$
$d\sigma/d\Omega_\pi$ (μb/Sr)
Θ_π (deg)
E_γ=300 MeV
E_γ=320 MeV
E_γ=360 MeV
E_γ=380 MeV

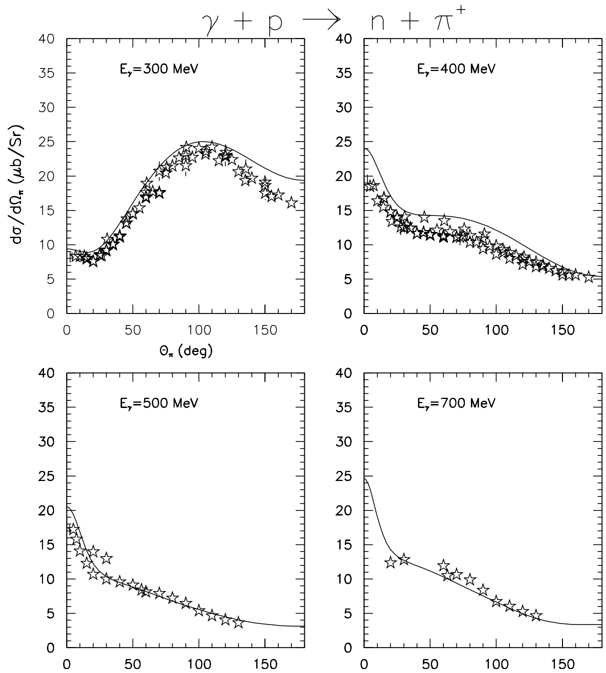

$\gamma + p \longrightarrow p + \pi^0$
Σ
Θ_π (deg)
E_γ=300 MeV
E_γ=320 MeV
E_γ=360 MeV
E_γ=380 MeV



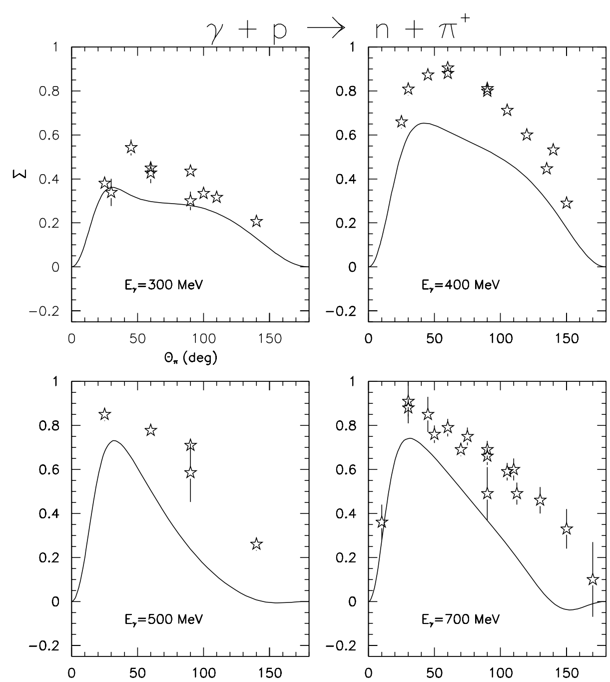
$\gamma + p \longrightarrow p + \pi^0$
E_γ=450 MeV
E_γ=600 MeV
E_γ=750 MeV
E_γ=800 MeV
$d\sigma/d\Omega_\pi$ (μb/Sr)
Θ_π (deg)



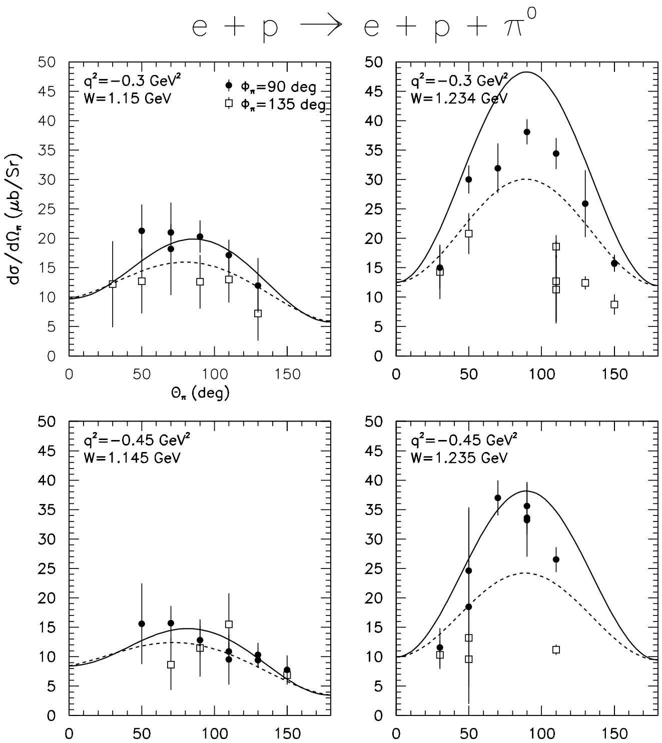
$\gamma + p \longrightarrow p + \pi^0$
Σ
E_γ=450 MeV
E_γ=500 MeV
E_γ=700 MeV
E_γ=800 MeV
Θ_π (deg)



$\gamma + p \longrightarrow n + \pi^+$
E_γ=300 MeV
E_γ=400 MeV
E_γ=500 MeV
E_γ=700 MeV
$d\sigma/d\Omega_\pi$ (μb/Sr)
Θ_π (deg)



$\gamma + p \longrightarrow n + \pi^+$
E_γ=300 MeV
E_γ=400 MeV
E_γ=500 MeV
E_γ=700 MeV
Σ
Θ_π (deg)



e + p → e + p + π⁰
q²=−0.3 GeV²
W=1.15 GeV
Φπ=90 deg
Φπ=135 deg
q²=−0.3 GeV²
W=1.234 GeV
q²=−0.45 GeV²
W=1.145 GeV
q²=−0.45 GeV²
W=1.235 GeV
dσ/dΩπ (μb/Sr)
Θπ (deg)

Contribution of the γ's coming from the π^0 decay

$$e + p \longrightarrow e' + p' + \pi^0 \longrightarrow e' + p' + 2\gamma$$

Impossible to disentangle electrons and photons in the detector.

- **Standard method**:

  a) 3 random numbers ($\longrightarrow \theta_{e'}, \phi_{e'}, E_{e'}$)

  Effective Lagrangien + <u>all</u> <u>Resonances</u> $\longrightarrow \dfrac{d^3\sigma(h_e)}{d\Omega_{e'}\ dE_{e'}\ d\overline{\Omega}_{\pi^0}}$

  b) $\pi^0 \longrightarrow 2\gamma$

  Lorentz boost + π^0 decay + ...

$\longrightarrow$ - One incident energy : 600 hours CPU

$\Longrightarrow$ - Impossible to take into account the external radiative corrections,...

$\Longrightarrow$ - Photon Asymmetry ??

- **Calculation of the interesting Xsection:**

  Lagrangien for $\pi^0 \longrightarrow 2\gamma$ is known

$$\frac{d^3\sigma}{d\Omega_\gamma\ dE_\gamma} = \int \frac{d^3\sigma(h_e)}{d\Omega_{\pi^0}\ dE_{\pi^0}} \frac{m_\pi^2}{4\pi} \frac{1}{E_{\pi^0} - p_{\pi^0}\vec{u}_{\pi^0}\cdot\vec{u}_\gamma}\ \delta\Big(\frac{m_\pi^2}{E_{\pi^0} - p_{\pi^0}\vec{u}_{\pi^0}\cdot\vec{u}_\gamma} - E_\gamma\Big)\ d\Omega_{\pi^0}\ dE_{\pi^0}$$

$$\frac{d^3\sigma(h_e)}{d\Omega_{\pi^0}\ dE_{\pi^0}} = \int \frac{d^5\sigma(h_e)}{d\Omega_{\pi^0}\ dE_{\pi^0}\ d\Omega_{e'}}\ d\Omega_{e'} = \int \frac{d^5\sigma(h_e)}{d\Omega_{e'}\ dE_{e'}\ d\overline{\Omega}_{\pi^0}}\ \mathrm{J_{ac}}\ \ d\Omega_{e'}$$

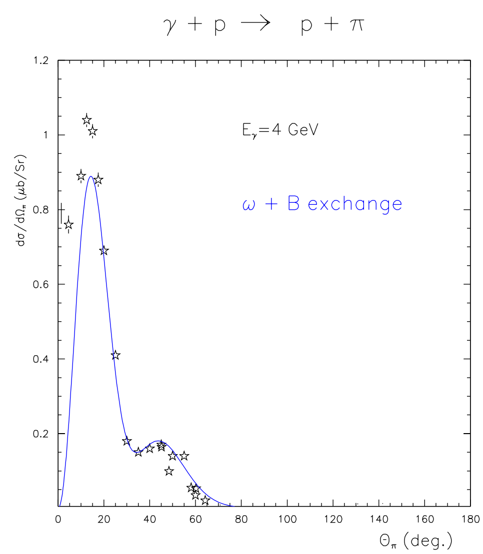
◇ **Electro-production and inclusive xsection of π or proton:**
integration over the electron angles has to be performed:
We have to replace the usual Flux Factor Γ which is divergent when $\theta_{e'} \longrightarrow 0$ and $m_e = 0$ with $\overline{\Gamma}$

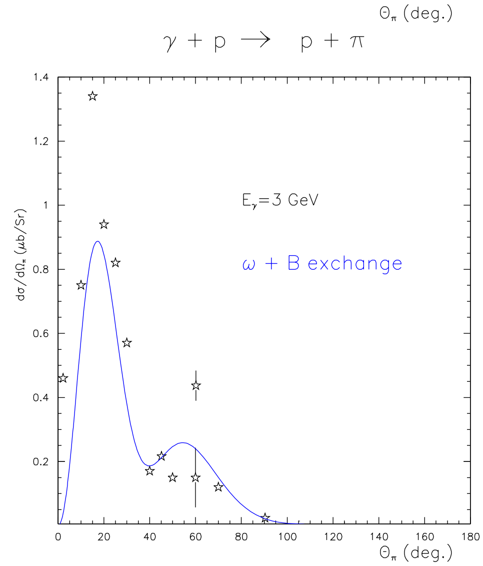
$$\Gamma \;=\; \frac{\alpha}{2\pi^2}\frac{E'_e}{E_e}\frac{E_\gamma}{Q^2}\frac{1}{1-\varepsilon}\;,\longrightarrow \overline{\Gamma} = \frac{\alpha}{8\pi^2}\frac{|\vec{p'}_e|}{|\vec{p}_e|}E_\gamma F_{virt}$$

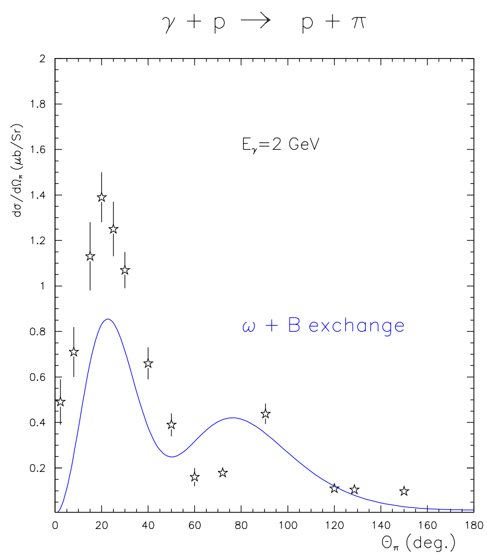
(S. Ong and J. VdW -Phys. Rev. C 63, 024614-)

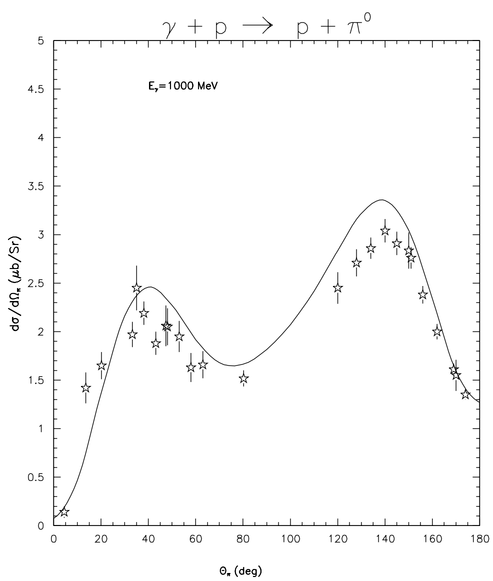
G0 Experiment Forward Angles

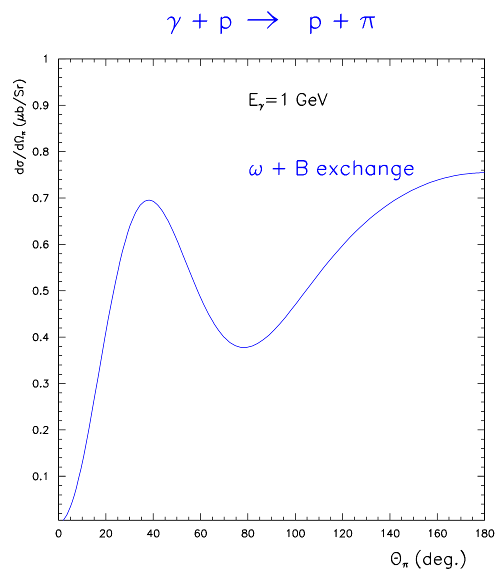
- Detection of the protons $\rightarrow$ $d^3\sigma/d\Omega_p\ dE_p$
- $E_e = 3$ GeV
- On the market: E.P.C. Code from LightBody and O'Connel (Extrapolation from high energy data) reliable ???
- Effective Lagrangian models not reliable (Energy too high)
- Regge Models not accurate enough






$\gamma + p \rightarrow p + \pi$
E_γ=2 GeV
ω + B exchange
$d\sigma/d\Omega_\pi$ (μb/Sr)
Θ_π (deg.)


$\gamma + p \rightarrow p + \pi^0$
E_γ=1000 MeV
$d\sigma/d\Omega_\pi$ (μb/Sr)
Θ_π (deg)


$\gamma + p \rightarrow p + \pi$
E_γ=1 GeV
ω + B exchange
$d\sigma/d\Omega_\pi$ (μb/Sr)
Θ_π (deg.)

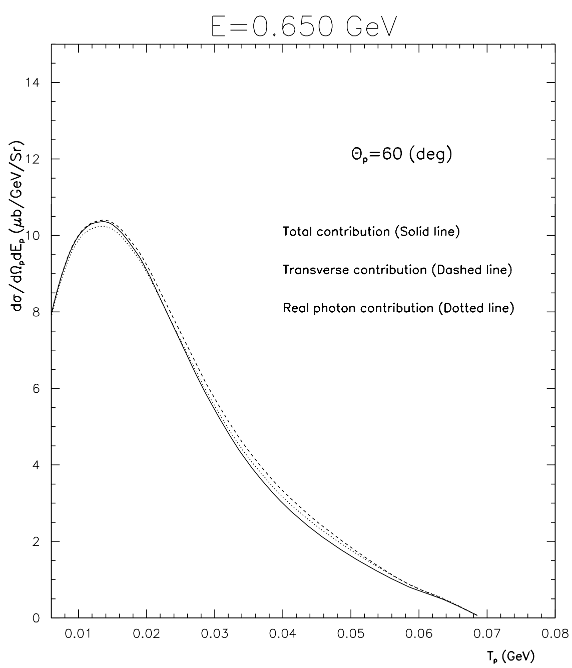
New generator of Inclusive Protons (Pions) deduced from photo-production data.

$$\frac{d^3\sigma}{d\Omega_p\ dE_p} = \int \frac{d^3\sigma}{d\Omega_p\ dE_p\ d\Omega_{e'}}\ d\Omega_{e'}$$

Basic idea: Because of the virtual photon propagator, the main contribution to this integral for the electro-production comes from the terms with $q^2 \approx 0$.

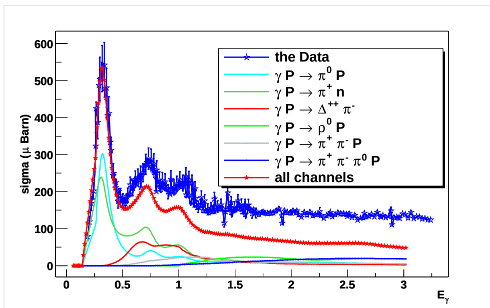
Validation of the model with $e + p \longrightarrow e' + p' + \pi^0$

- E_e= 0.650 GeV; Effective Lagrangien calculation reliable
- Three different calculations:
  - a) Photo-production "data"
  - b) Transverse contribution only
  - c) "exact" calculation

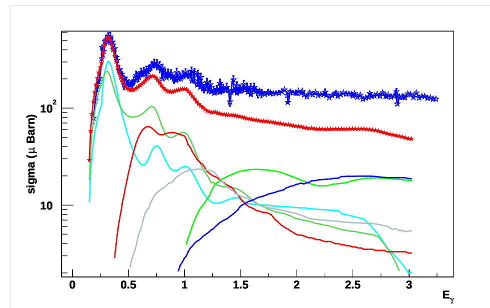


Experimental photo-production cross-sections given by the GRAAL (GRenoble Anneau Accelerateur Laser) generator of events between 0.150 GeV and 3 GeV.

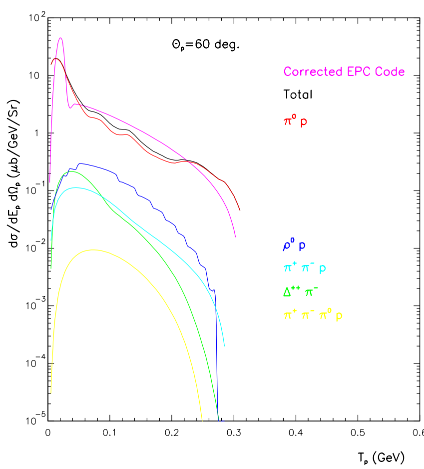
- **Angular distribution in a few channels.**
- **Total cross-sections in many channels.**

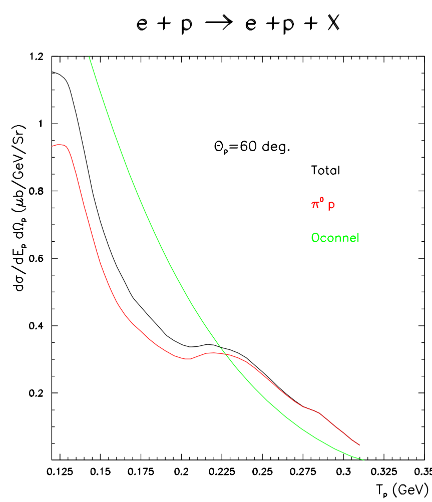


(a) I



(b) II

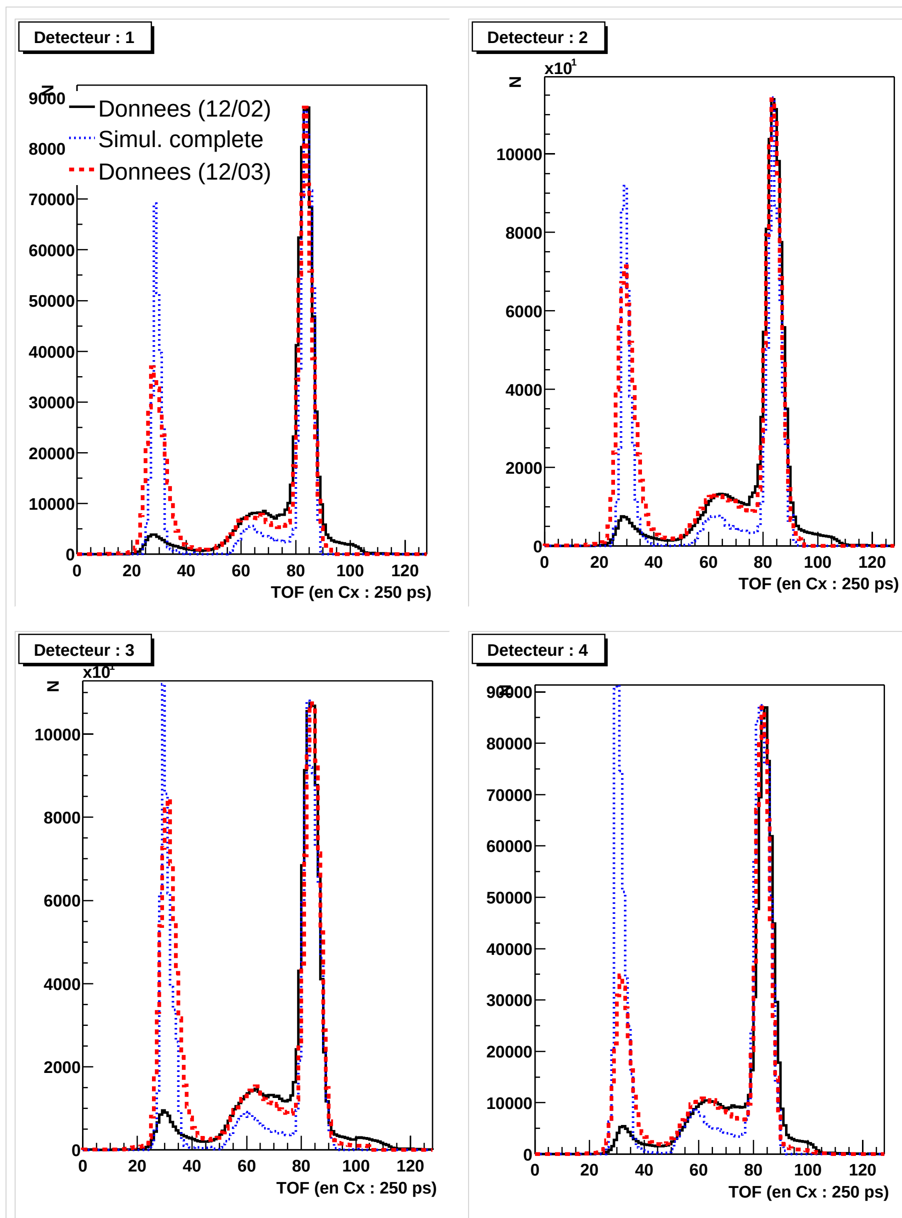


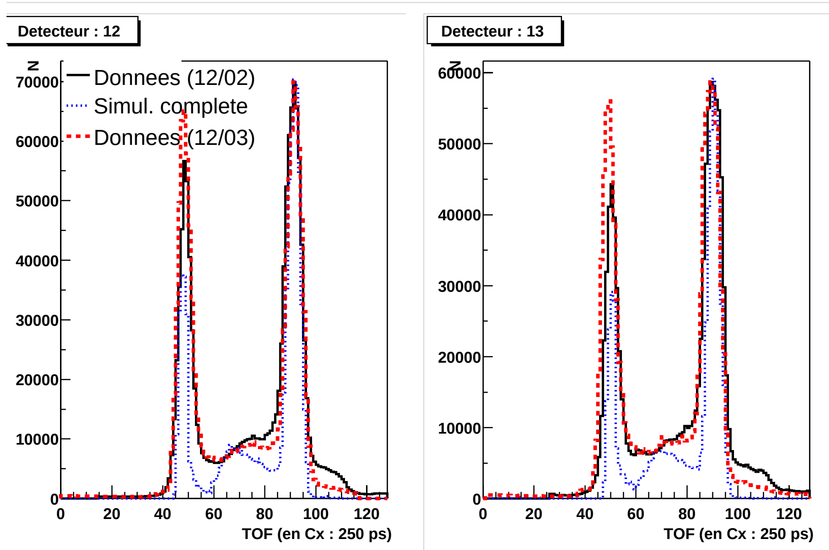


- **The differential cross-section for high energy protons is larger with our model as compared to EPC code.**
- **Beyond the resonances domain, the total cross-section is underestimated (by a factor ≈ 2 for the high energy photons).**
- **One pion production is the most important process.**
- **The inclusive cross-section due to the 2π, 3π is only derived through the total photo-production cross-section. (The angular distributions have never been measured)**

Comparison with G0 Forward angles - TOF spectra

- Electro-production + photo-production in LH2 target
- Aluminium windows totally ignored





CONCLUSIONS

- Simulations of TOF proton spectra are only in fair agreement and Monte-Carlo method gives a good ESTIMATION of the background.
- Renormalization of the cross-section for the high energy proton spectrum should be considered. (a factor 2 is missing in the total photo-production cross-section)
- The contribution of the windows is much more difficult to estimate.

Real Photon Contribution

As mentioned previously, the TOF proton spectrum includes, in addition to the electro-production, some contribution from the photo-production. This photo-production is due to the competition, in any material, between electro-production of the incoming electron beam and the real Bremsstrahlung photons.

The basic ingredients to calculate the photo-production contribution are:

- t: the thickness in unit of the radiation length of the material
- $t = density(g/cm^3) \times thickness(cm)/X_0$ (≈ 0.02 for LH_2 and $\ell = 20$ cm)
- $X_0 \equiv$ Radiation Length of the material (63.04 g/cm^2 for LH_2)
- $I_e(E_0, E, t)\ dE$: Probability of an electron initially with energy E_0 of being in the energy interval E, $E + dE$ after passing through a target of thickness t.
- $I_\gamma(E_0, E_\gamma, t)$: The number of photons in the energy E_γ, $E_\gamma + dE_\gamma$ after an electron, initially with an an energy E_0 has passed through a target of thicknesss t.

Boundary Conditions:

$$\begin{cases} I_\gamma(E_0, E_\gamma, t = 0) = 0 \\ I_e(E_0, E, t = 0) = \delta(E - E_0) \end{cases}$$

$$I_e(E_0, E, t) = \frac{(E_0 - E)^{bt}}{E_0^{bt}} \frac{\rho(E_0, E_0 - E)\ t}{\Gamma(1 + bt)} \qquad b \approx 4/3$$

$$\rho(E_0, E_0 - E) \approx \frac{1}{E_0 - E}\left(\frac{4}{3} - \frac{4}{3}\frac{E_0 - E}{E_0} + (\frac{E_0 - E}{E_0})^2\right)$$

Yung-Su Tsai Rview of Modern Physics, Vol 46, (1974) p.815

Y.S. Tsai and Van Whitis Phys. Rev. 149 (1966) p.1248

$$I_\gamma(E_0, E_\gamma, t) = \int_0^t \underbrace{\text{-}e^{-\mu(t-t')} dt'}_{\text{Att. Factor}} \int_{E_{min}}^{E_0} I_e(E_0, E, t')\ \rho(E, E_\gamma) dE$$

$\mu \approx 7/9,\ E_{min} \simeq E_\gamma$

$$\rho(E, E_\gamma) = \frac{N}{A} X_0 \underbrace{\frac{d\sigma_b}{dE_\gamma}(E, E_\gamma)}_{\text{Bremsstrahlung Xsection}}$$

$$\frac{d\sigma_b}{dE_\gamma}(E, E_\gamma) = \frac{A}{N X_0} \frac{1}{E_\gamma} \left(y^2 - \frac{4}{3} y + \frac{4}{3} \right) g(y) \qquad y = \frac{E_\gamma}{E}$$

Usual calculations:

- Complete screening case: $g(y) = 1$
- Moreover, with this approximation, Tsai and Van Whitis have derived an analytical expression:

$$[I_\gamma(E_0, E_\gamma, t)]_{approx} = \frac{1}{E_\gamma} \; \frac{(1 - \frac{E_\gamma}{E_0})^{\frac{4}{3}t} - e^{-\frac{7}{9}t}}{\frac{7}{9} + \frac{4}{3} \ln (1 - \frac{E_\gamma}{E_0})}$$

♣ Validity of the complete screening approximation:

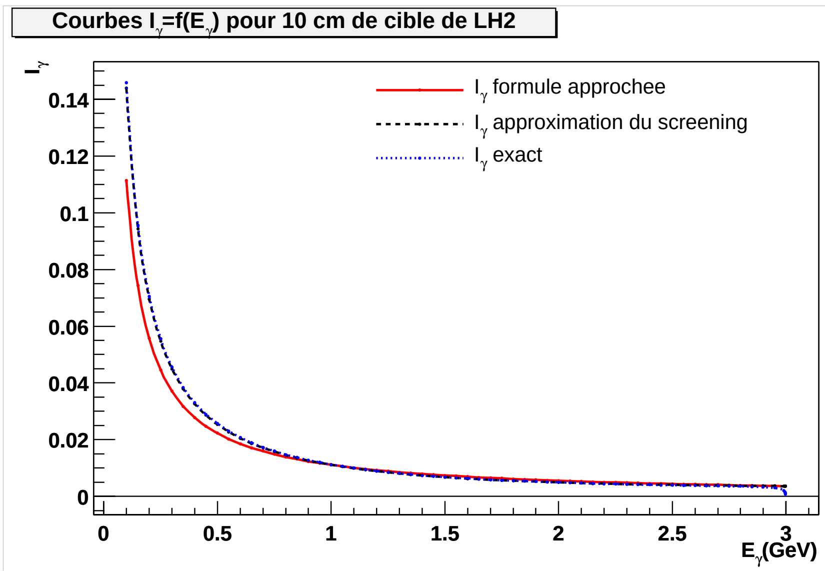
Y. Tsai: If one is not particularly concerned with the detailed shape at the high-energy tip of the bremsstrahlung spectrum, the complete screening case is a good approximation.

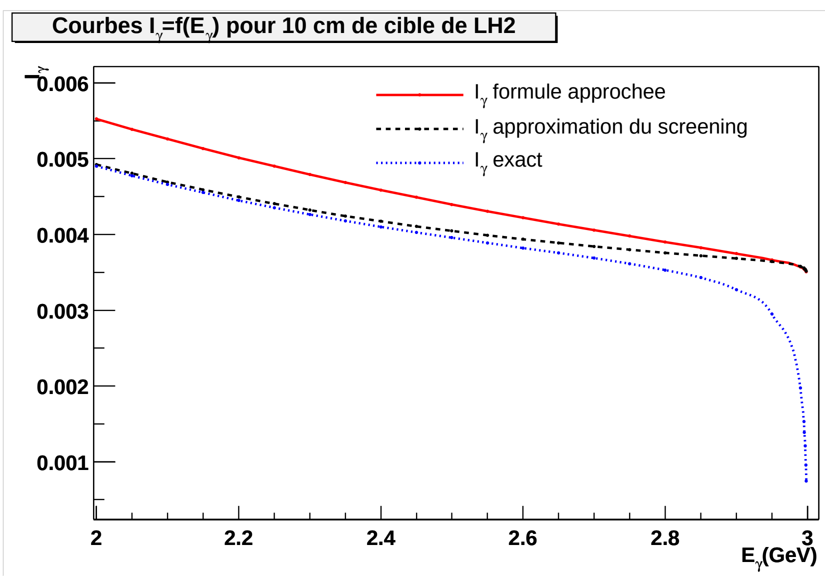
BUT the inelastic protons which are under the elastic peak are produced by the high-energy tip of the bremsstrahlung spectrum.

New calculations without the screening approximation.

- LH2 target
- Aluminium target in the Thomas-Fermi Molliere Model:

New expressions for $I_\gamma(E_0, E_\gamma, t)$ have been derived.





Solid Line **:** Analytical Expression

Dashed Line **:** Complete Screening Case

Dotted Line **:** No Complete Screening Approximation

Other Possible False Asymmetries

Other possible source of physical false asymmetries are due to the change of the polarization of the outgoing proton with the electron helicity.

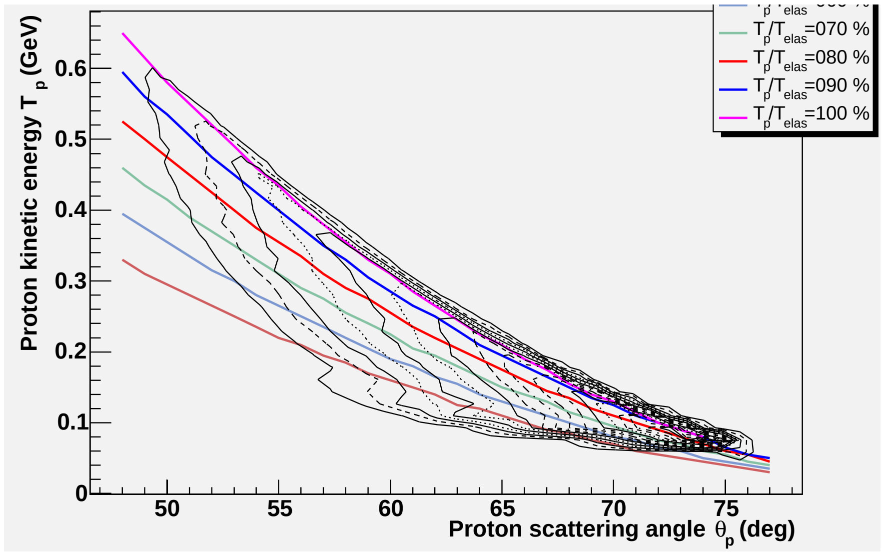
- If there is no material between the place where the reaction takes place and the detector, this polarization has no effect on the counting rate.

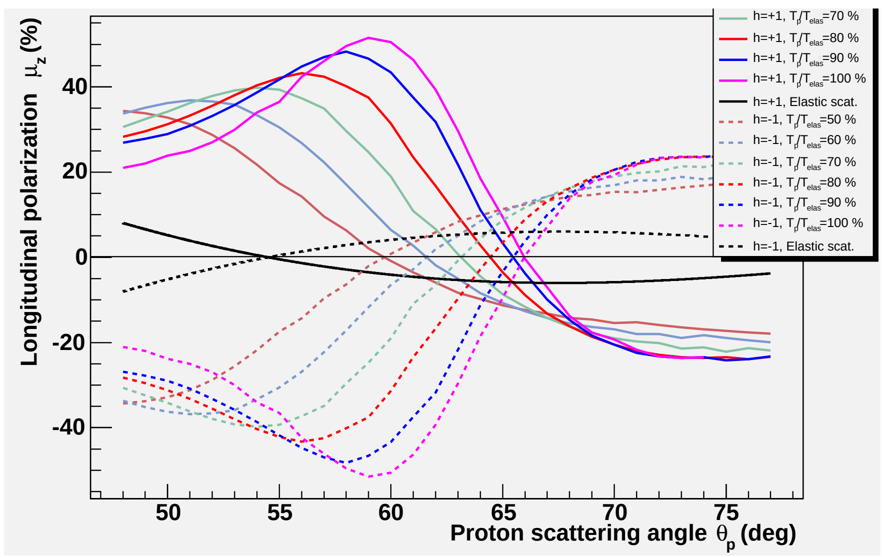
- As the outgoing proton passes some material (target, windows, collimators), this polarization may induce some false asymmetry. There is some possibility for this false asymmetry to be enhanced by some misalignement of the experimental set-up.

In the elastic case, reliable calculations of the polarization exist. The magnitude of the polarization depends on the scattering angle of the proton. Its value is small at large angle ($\approx$ 6% at 75 deg. and about 35 % at 50 deg.)

From symmetry relations and if we assume no misalignement, we end up with a polarization along the axis of the incident beam:

- The sign of this component changes with the helicity of the incoming electron
- For a definited value of the helicity, the absolute value of the component is small and does not change very much with the proton angle.
- For a definited value of the helicity, the sign of this component changes with the proton angle.





ESTIMATION of the polarization for the inelastic events has been performed within the framework of the Regge trajectories in the $\vec{e} + p \longrightarrow e + \vec{p} + \pi^0$ process.

- The same features as in the elastic case are observed but the magnitude of the component of the polarization is MUCH LARGER.
- In the TOF spectrum of inelastic protons, the false asymmetries of low Q^2 and large Q^2 have opposite signs.
- In the TOF spectrum of elastic protons, the false asymmetry should be smaller.

SUMMARY AND CONCLUSION

The backgrounds in the measured asymmetry play an important role in the extraction of the physical asymmetry. The physical asymmetry is affected by:

- A dilution factor
- An asymmetry ratio which may drastically change the physical asymmetry if the asymmetry due to this background is large and of opposite sign compared to the physical asymmetry.

It is possible to study the background properties experimentally but simulations are very important as a complementary tool.

In a few examples, it has been shown that standard methods have to be improved to simulate such small quantities. Moreover, it is necessary to check that the standard approximations may be used.

In some cases, because of a lack of data or reliable models, only estimations can be achieved.