Measurement of Double-Polarization Observables in $\vec{\gamma}\,\vec{\mathrm{p}} \rightarrow \mathrm{p}\,\pi^+\pi^-$

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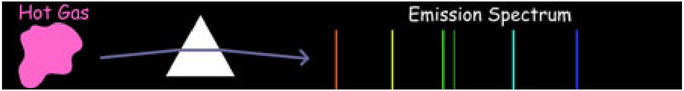
Meeting of PAC 29, 1/12/2005

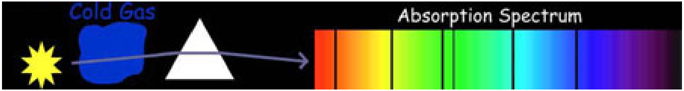
Outline

Outline

Spectroscopy

Atomic spectra allow access to QED



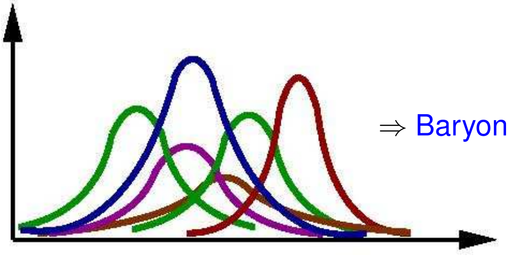


- Discrete spectrum of absorption and emission lines

$\Rightarrow$ Does excitation spectrum of nucleon provide access to QCD ?

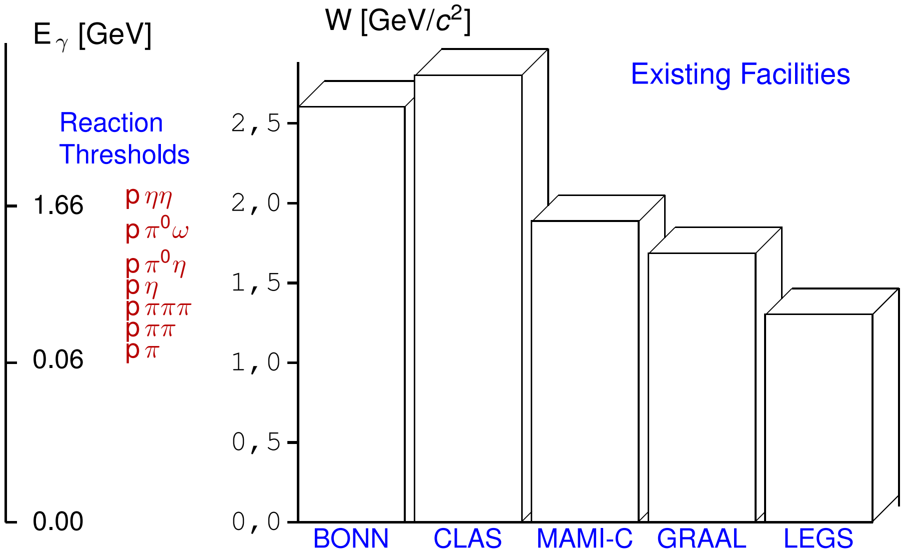
The Challenges in Baryon Spectroscopy

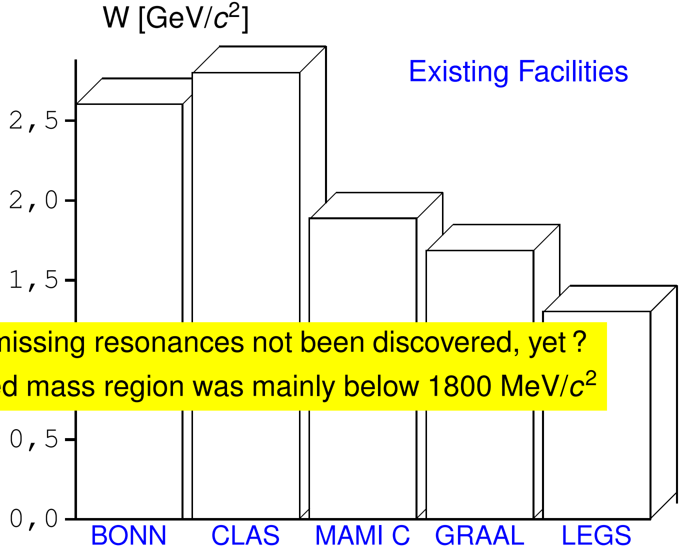
Unfortunately, N^* spectral lines look more like



$\Rightarrow$ Baryons are broad and overlapping

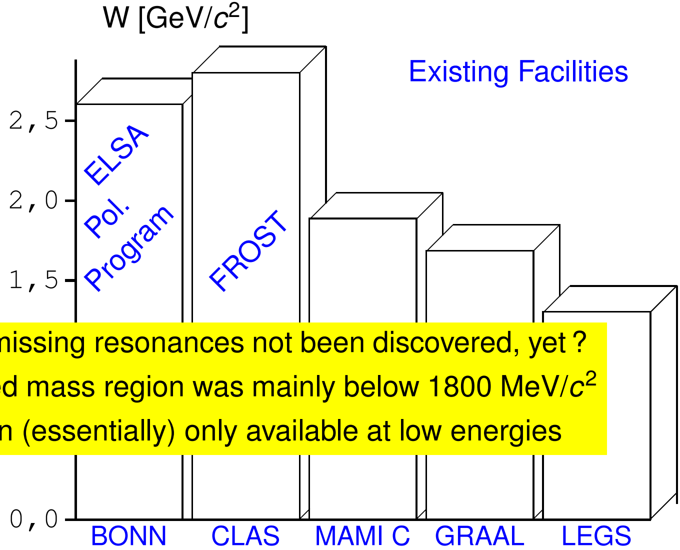
- Rescattering Effects
  $\Rightarrow$ Require Coupled-Channel Analysis
  (need to measure as many final states as possible)
- Polarization (need complete experiments)


E $_\gamma$ [GeV]
Reaction Thresholds
1.66
0.06
0.00
p $\eta\eta$
p $\pi^0\omega$
p $\pi^0\eta$
p η
p $\pi\pi\pi$
p $\pi\pi$
p π
W [GeV/c^2]
Existing Facilities
2,5
2,0
1,5
1,0
0,5
0,0
BONN
CLAS
MAMI-C
GRAAL
LEGS



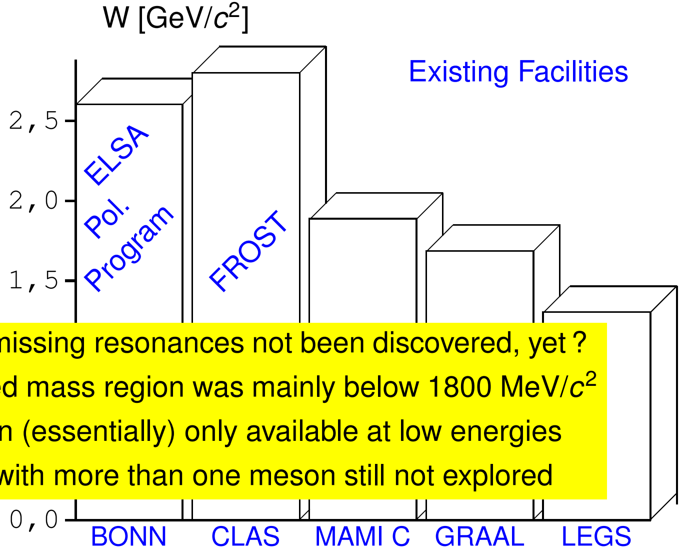
Why have the missing resonances not been discovered, yet ?

- Investigated mass region was mainly below 1800 MeV/c^2



Why have the missing resonances not been discovered, yet ?

- Investigated mass region was mainly below 1800 MeV/c^2
- Polarization (essentially) only available at low energies



Why have the missing resonances not been discovered, yet ?

- Investigated mass region was mainly below 1800 MeV/c^2
- Polarization (essentially) only available at low energies
- Channels with more than one meson still not explored

Great Chance ...

The Double-Polarization Program (FROST) at JLab:

- E 02-112 $\Rightarrow$ *Photoproduction of Hyperons*
- E 03-105 $\Rightarrow$ π *Photoproduction*
  E 04-102
- E 05-012 $\Rightarrow$ η *Photoproduction*
- PR 06-013 $\Rightarrow$ $\pi^+\pi^-$ Photoproduction (same exp. setup)

The Double-Polarization Program at ELSA (Crystal Barrel Experiment):
(among many other proposals)

- ELSA 6/2005 $\Rightarrow$ $\pi^0\pi^0$ *Photoproduction*
- ELSA 7/2005 $\Rightarrow$ $\pi^0\eta$ *Photoproduction*

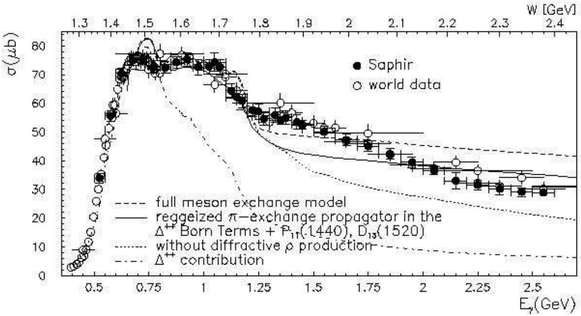
Outline

Motivation: Low-Energy Regime

- $P_{11}(1440)$ (*Roper Resonance*) $\rightarrow$ too low in mass ?
  - dynamically-generated resonance effect
  - state with a strong gluonic component
  - small (qqq)-component with a substantial contribution from the meson cloud

  $\Rightarrow$ Parameters depend strongly on data and analysis
- Contribution of $D_{13}(1520)$ to $\gamma\,p \;\rightarrow\; p\,\pi^+\,\pi^-$ cross section
  - Different interpretations of $\gamma\,p \;\rightarrow\; p\,\pi^+\,\pi^-$ total cross section data
    - Oset et al.: $D_{13}(1520) \rightarrow \Delta\pi$ dominant contribution
    - Laget et al.: $P_{11}(1440) \rightarrow p\sigma$ dominant
  - $D_{13}(1520) \rightarrow \Delta\pi$ in D-wave (PDG: 10–14 %) and S-wave (5–12 %) ?
- $P_{33}(1600)$ (*Roper Resonance* of Δ system) $\rightarrow$ too low in mass ?

Motivation: Medium-Energy Regime



$3^{\rm rd}$ resonance region

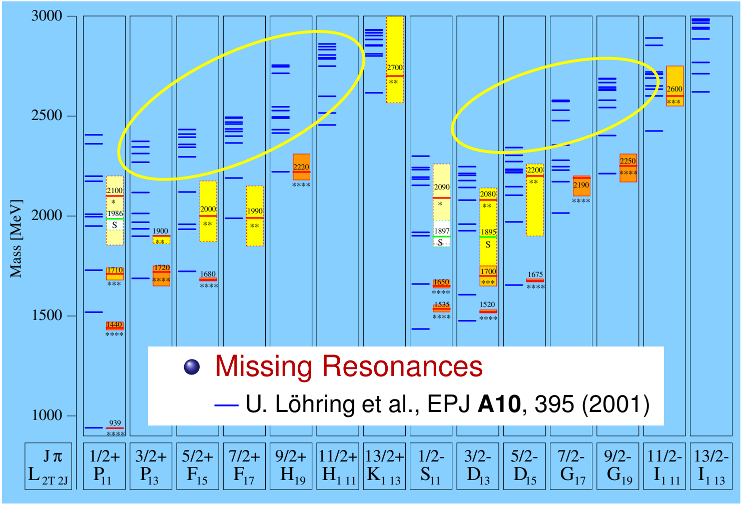
- $F_{15}(1680)$
- $D_{13}(1700)$
- $D_{33}(1700)$
- $P_{13}(1720)$

How to disentangle ?

Discrepancy of CLAS $P_{13}(1720)$ with PDG: two close-by P_{13} states ?

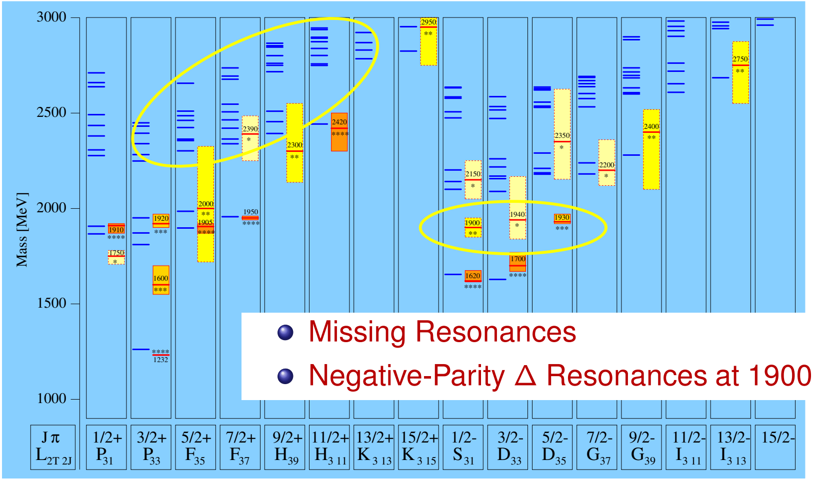
$\Rightarrow$ This would be in contradiction with quark models !

Motivation: High-Energy Regime $\longrightarrow$ N* Spectrum



- Missing Resonances
  — U. Löhring et al., EPJ **A10**, 395 (2001)

Motivation: High-Energy Regime $\longrightarrow \Delta^*$ Spectrum



- Missing Resonances
- Negative-Parity Δ Resonances at 1900 MeV/c^2

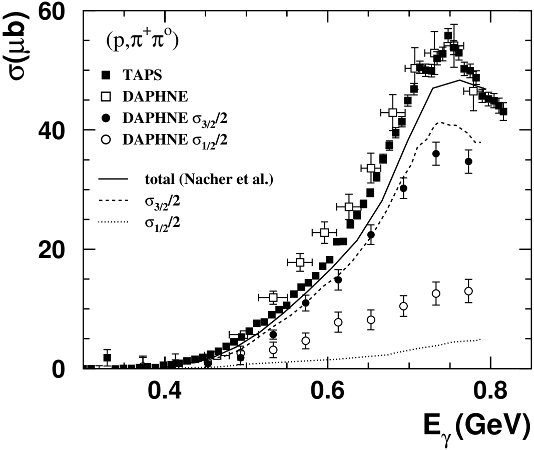
Motivation: High-Energy Regime

- Reactions with two or more mesons in the final state account for most of the cross section at W $\geq$ 2 GeV/c^2
- Large efforts at ELSA for neutral decay modes: $\pi^0\pi^0$, $\pi^0\eta$, etc.
  $\Rightarrow$ $\pi^+\pi^-$ at CLAS !
- There is certainly resonance production above 2 GeV/c^2
  But: resonances broad and overlapping $\Rightarrow$ Big Challenge

$\Rightarrow$ Ultimate goal: coupled-channel analysis including pol. constraints to nail down these resonances

Outline

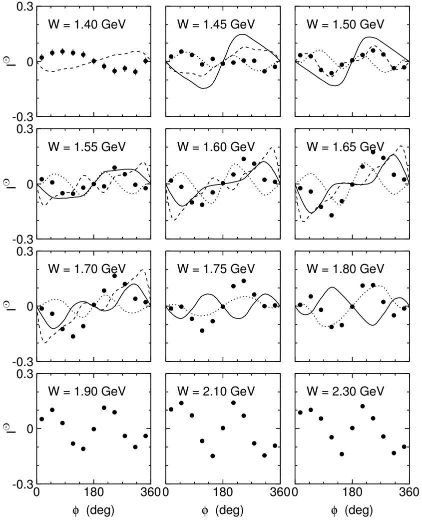
Helicity Dependence of the Reaction $\vec{\gamma}\,\vec{p} \rightarrow n\,\pi^0\pi^+$



GDH Collaboration (Mainz):

- Largest contribution from $\sigma = \frac{3}{2}$
- Nacher et al. underestimates $\sigma = \frac{1}{2}$

Beam Asymmetry $I^{\odot}$ in $\vec{\gamma}\,p \rightarrow p\,\pi^+\pi^-$



CLAS Measurements
(S. Strauch et al.)

and model calculations:

- Mokeev et al. (solid)
- Fix and Arenhövel (dashed)

Outline

Beam-Target Polarization Observables

$$\frac{d\sigma}{d\Omega} = \sigma_0 \{ 1 - \delta_l \, \Sigma \cos 2\phi + \Lambda_x (-\delta_l \, \mathbf{H} \sin 2\phi + \delta_\odot \, \mathbf{F}) - \Lambda_y (-\mathbf{T} + \delta_l \, \mathbf{P} \cos 2\phi) - \Lambda_z (-\delta_l \, \mathbf{G} \sin 2\phi + \delta_\odot \, \mathbf{E}) \}$$

$\Leftarrow$ Single-Meson Final States (7 Observables)

Two-Meson Final States $\Rightarrow$ (15 Observables)

$$I = I_0 \{ (1 + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}) + \delta_\odot (\mathbf{I}^\odot + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}^\odot) + \delta_l [\sin 2\beta (\mathbf{I}^s + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}^s) \cos 2\beta (\mathbf{I}^c + \vec{\Lambda}_i \cdot \vec{\mathbf{P}}^c)] \}$$

Circular Beam and Longitudinal Target Polarization

$$\frac{d\sigma}{d x_i} = \sigma_0 \{ (1 + \Lambda_z \cdot \mathbf{P_z}) + \delta_\odot (\mathbf{I}^\odot + \Lambda_z \cdot \mathbf{P_z^\odot})\}$$

$$(\rightarrow\Rightarrow - \leftarrow\Rightarrow) := \frac{d\sigma(\rightarrow\Rightarrow)}{d x_i} - \frac{d\sigma(\leftarrow\Rightarrow)}{d x_i} = 2 \cdot \sigma_0 \{\delta_\odot (\mathbf{I}^\odot + \Lambda_z \cdot \mathbf{P_z^\odot})\}$$

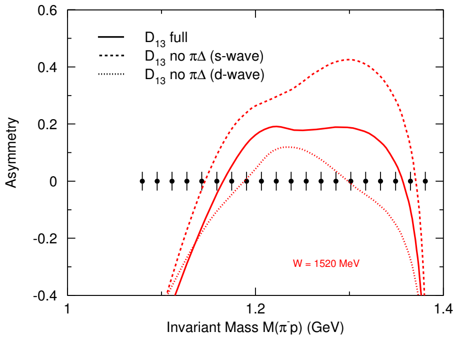
$$(\leftarrow\Leftarrow - \rightarrow\Leftarrow) := \frac{d\sigma(\leftarrow\Leftarrow)}{d x_i} - \frac{d\sigma(\rightarrow\Leftarrow)}{d x_i} = 2 \cdot \sigma_0 \{\delta_\odot (-\mathbf{I}^\odot + \Lambda_z \cdot \mathbf{P_z^\odot})\}$$

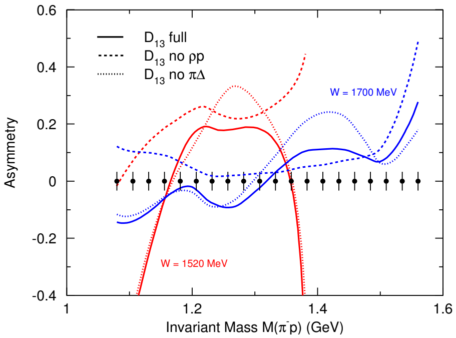
1) $(\rightarrow\Rightarrow - \leftarrow\Rightarrow) + (\leftarrow\Leftarrow - \rightarrow\Leftarrow) := \frac{d\sigma_{3/2}}{d x_i} - \frac{d\sigma_{1/2}}{d x_i} = 4 \cdot \sigma_0 \cdot \delta_\odot \cdot (\Lambda_z \cdot \mathbf{P_z^\odot})$

2) $(\leftarrow\Leftarrow - \leftarrow\Rightarrow) - (\rightarrow\Rightarrow - \rightarrow\Leftarrow) := -4 \cdot \sigma_0 \cdot (\Lambda_z \cdot \mathbf{P_z})$

Outline

Model Calculations of $P_z^{\odot}$ (known as E) by A. Fix





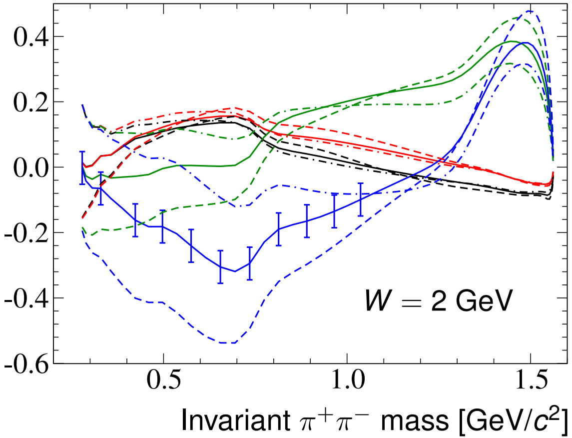
⇒ Can clearly distiguish between solutions if $\Delta A \leq 0.05$

⇒ Reality will be a mixture of S-/D-wave !

⇒ Needs very small errors to distinguish between different contributions !

Model Calculations of $P_x^{\odot}$ by W. Roberts

$\phi = 0.0035$ rad (almost 0), $\phi = 0.56$ rad, $\phi = 2.09$ rad, $\phi = 3.04$ rad (almost π)



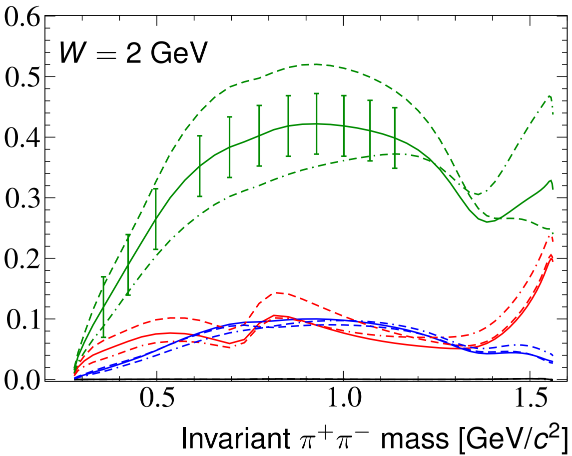
Circ. Beam → Trans. Target

- Solid Line
  Full Calculation
- Dashed Line
  $S_{11}(1900)$ Omitted
- Dashed-Dotted Line
  $P_{31}(1910)$ Omitted

$\Rightarrow$ goal: $\Delta P_z^c \leq 0.05$

Model Calculations of $P_y^{\odot}$ by W. Roberts

$\phi = 0.0035$ rad (almost 0), $\phi = 0.56$ rad, $\phi = 2.09$ rad, $\phi = 3.04$ rad (almost π)



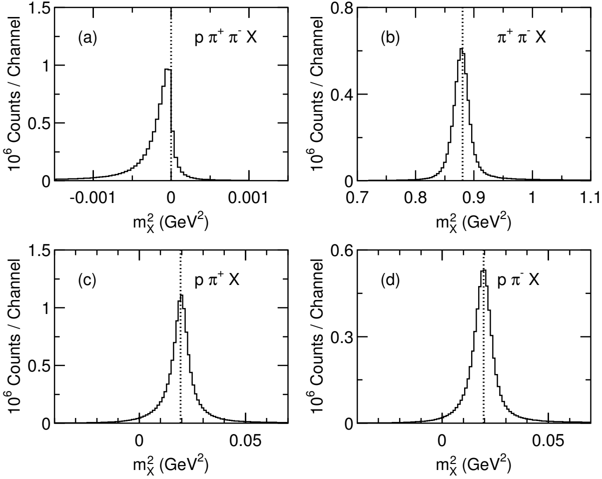
Circ. Beam → Trans. Target

- Solid Line
  Full Calculation
- Dashed Line
  $S_{11}(1900)$ Omitted
- Dashed-Dotted Line
  $P_{31}(1910)$ Omitted

$\Rightarrow$ goal: $\Delta P_z^c \leq 0.05$

Outline

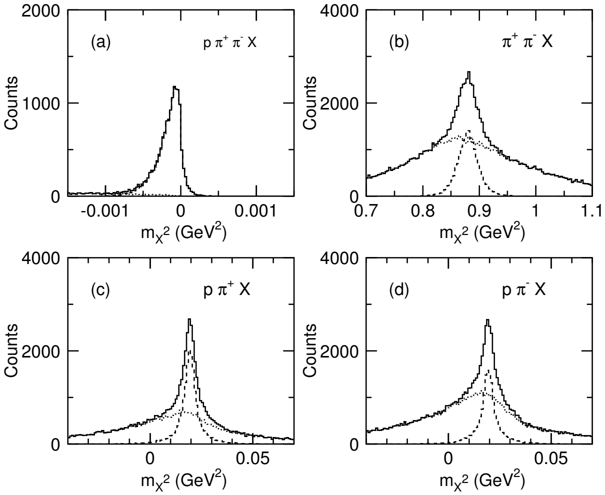
Background Estimate



g1c Data Set ($\vec{\gamma}\,p$)

- At least two particles detected
- Distributions essentially background free

Estimate of an Effective Dilution Factor



- **Solid Line**
  total number of events
- **Dashed Line**
  polarized hydrogen
- **Dotted Line**
  unpolarized nucleons

a) $D = 0.05$ b) $D = 0.27$

c) $D = 0.44$ d) $D = 0.29$

$\Rightarrow D_{\text{eff}} = 0.38$

Outline

Statistical Uncertainties of the Measurements

The asymmetry is given by $A_z^{\odot} = \dfrac{1}{D_{\text{eff}} \cdot \delta_{\odot} \cdot \Lambda_z} \dfrac{N_{\parallel} - N_{\perp}}{N_{\parallel} + N_{\perp}}$

and the statistical error by $\Delta A_z^{\odot}(\text{stat.}) \approx \dfrac{1}{D_{\text{eff}} \cdot \delta_{\odot} \cdot \Lambda_z} \dfrac{1}{\sqrt{N_{\parallel} + N_{\perp}}}$

The total number of counts required to reach a certain precision $\Delta A_z^{\odot}(\text{stat.})$:

$$\Rightarrow N_{\parallel} + N_{\perp} \approx \left(\frac{1}{D_{\text{eff}} \cdot \delta_{\odot} \cdot \Lambda_z \cdot \Delta A_z^{\odot}(\text{stat.})} \right)^2$$

and thus, the beam time needed to reach a certain statistical accuracy $\Delta A_z^{\odot}$:

$$T = \frac{1}{\dot{N}_{\gamma}(E)} \cdot \frac{1}{(\Delta A_z^{\odot})^2} \cdot \frac{1}{\sigma_{\text{unpol}}} \cdot \frac{1}{\rho_{\text{target}}^{\text{p}} \cdot \epsilon} \cdot \frac{D_{\text{eff}}^{-1}}{(\delta_{\odot} \cdot \Lambda_z)^2} \cdot N_{\text{bins}}$$

FROST Experiments

<table>
<tr><th></th><th></th><th colspan="11">Photon beam energy (GeV)</th><th colspan="3">(days)</th></tr>
<tr><th></th><th></th><th>0.4-0.6</th><th>0.6-0.8</th><th>0.8-1.0</th><th>1.0-1.2</th><th>1.2-1.4</th><th>1.4-1.6</th><th>1.6-1.8</th><th>1.8-2.0</th><th>2.0-2.2</th><th>2.2-2.4</th><th>2.4-2.6</th><th>Required</th><th>Request</th><th>Approval</th></tr>
<tr><td>Setting A lin/trans</td><td>E03-105</td><td></td><td>32</td><td>32</td><td>32</td><td>48</td><td>48</td><td>96</td><td>96</td><td></td><td></td><td></td><td>16</td><td>4</td><td>0</td></tr>
<tr><td></td><td>E05-012</td><td></td><td></td><td>98</td><td>134</td><td>134</td><td>134</td><td>134</td><td>134</td><td></td><td></td><td></td><td>32</td><td>27</td><td>27</td></tr>
<tr><td></td><td>E02-112</td><td></td><td></td><td></td><td>114</td><td>114</td><td>114</td><td>114</td><td>114</td><td>114</td><td>114</td><td>114</td><td>38</td><td>38</td><td>5</td></tr>
<tr><td></td><td>total</td><td></td><td>32</td><td>98</td><td>134</td><td>134</td><td>134</td><td>134</td><td>134</td><td>114</td><td>114</td><td>114</td><td>48</td><td></td><td>32</td></tr>
<tr><td>Setting B circ/trans</td><td>E03-105</td><td colspan="5">110</td><td colspan="3">145</td><td></td><td></td><td></td><td>11</td><td>11</td><td>10</td></tr>
<tr><td></td><td>E05-012</td><td></td><td></td><td colspan="3">100</td><td colspan="3">140</td><td></td><td></td><td></td><td>10</td><td>0</td><td>0</td></tr>
<tr><td></td><td>total</td><td colspan="5">110</td><td colspan="3">145</td><td></td><td></td><td></td><td>11</td><td></td><td>10</td></tr>
<tr><td>Setting C lin/long</td><td>E03-105</td><td></td><td>8</td><td>16</td><td>16</td><td>24</td><td>32</td><td>32</td><td>64</td><td></td><td></td><td></td><td>8</td><td>8</td><td>8</td></tr>
<tr><td></td><td>E05-012</td><td></td><td></td><td>48</td><td>48</td><td>60</td><td>60</td><td>72</td><td>144</td><td></td><td></td><td></td><td>18</td><td>10</td><td>10</td></tr>
<tr><td></td><td>total</td><td></td><td>8</td><td>48</td><td>48</td><td>60</td><td>60</td><td>72</td><td>144</td><td></td><td></td><td></td><td>18</td><td></td><td>18</td></tr>
<tr><td>Setting D circ/long</td><td>E04-102</td><td colspan="6">192</td><td colspan="5">168</td><td>15</td><td>19</td><td>9</td></tr>
<tr><td></td><td>E05-012</td><td></td><td></td><td colspan="4">100</td><td colspan="2">140</td><td></td><td></td><td></td><td>10</td><td>0</td><td>0</td></tr>
<tr><td></td><td>E02-112</td><td></td><td></td><td></td><td colspan="3">480</td><td colspan="5">480</td><td>40</td><td>40</td><td>15</td></tr>
<tr><td></td><td>total</td><td colspan="6">580</td><td colspan="5">480</td><td>44</td><td></td><td>24</td></tr>
</table>

	Required	Request	Approval
E02-112	78	78	20
E03-105	27	23	18
E04-102	15	19	9
E05-012	70	37	37
			84

Beam Time Request

Setting	Energy [GeV]	$\sigma_{\rm tot}^{\rm p}$ [μb]	$\dot{N}_\gamma$ [MHz]	$N_{\rm bins}$	$\delta_\odot$ / δ_l	$\Lambda_{\rm tg}$	ΔA	T [h]
A								
B circ/trans	$E_{\rm e^-} = 3.1$	≈ 35	≈ 3	2000	0.82	0.85	0.05	100
C lin/long	$E_\gamma = 2.0$	≈ 40	≈ 5	2000	0.7	0.85	0.05	72
	$E_\gamma = 2.2$	≈ 35	≈ 5	2000	0.7	0.85	0.05	83
	$E_\gamma = 2.4$	≈ 35	≈ 5	2000	0.7	0.85	0.05	83
	$E_\gamma = 2.6$	≈ 35	≈ 5	2000	0.7	0.85	0.05	83
D circ/long	$E_{\rm e^-} = 3.1$	≈ 35	≈ 3	2000	0.82	0.85	0.05	100

Σ 27 d

Required beam time to study $\gamma p \to p\pi^+\pi^-$ at and above 2 GeV/c^2

Beam Time Request

Setting	Energy [GeV]	σ^{p}_{tot} [μb]	$\dot{N}_\gamma$ [MHz]	N_{bins}	$\delta_\odot$ / δ_l	Λ_{tg}	ΔA	T [h]
A								
B circ/trans	$E_{e^-} = 3.1$	$\approx$ 35	$\approx$ 3	2000	0.82	0.85	0.05	100
C lin/long	$E_\gamma = 2.0$	$\approx$ 40	$\approx$ 5	2000	0.7	0.85	0.05	72
	$E_\gamma = 2.2$	$\approx$ 35	$\approx$ 5	2000	0.7	0.85	0.05	83
	$E_\gamma = 2.4$	$\approx$ 35	$\approx$ 5	2000	0.7	0.85	0.05	83
	$E_\gamma = 2.6$	$\approx$ 35	$\approx$ 5	2000	0.7	0.85	0.05	83
D circ/long	$E_{e^-} = 3.1$	$\approx$ 35	$\approx$ 3	2000	0.82	0.85	0.05	100

PAC 29 Beam Time Request: 4 days for setting B

$\Rightarrow$ Will prove success of FROST and come back later ...