Scaling phenomenology of meson photoproduction in new CLAS G11A results from CMU

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OUTLINE

1. INTRODUCTION AND OVERVIEW
2. SCALING: REGGE
3. SCALING: FIXED-ANGLE
4. PWA: INTERPOLATING TRAJECTORIES
5. SUMMARY

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INTRODUCTION

- CLAS G11A experiment – unpolarized photoproduction on ℓH_2 target, two-prong trigger, mostly runs with electron beam energy 4.019 GeV.
- Missing baryon resonance problem – look at non-$N\pi$ channels.
- CMU is analysing several of these channels – $p\omega$ (M. Williams), $p\eta$, $p\eta'$ (M. Williams, Zeb Krahn), including strangeness production – $K^+\Lambda$ (M. McCracken), $K^+\Sigma^0$ (B. Dey).
- Differential cross sections and polarizations – $\sqrt{s}$ from threshold till ~ 2.85 GeV in 10 MeV wide bins. Wide angular coverage – $-0.95 \leq \cos\theta_{CM}^{meson} \leq 0.95$
- $p\omega$ PWA already done and nearing publication. PWA on other channels is in progress. Final goal – do a coupled channel analysis!
- Status of my $K^+\Sigma^0$ analysis – $d\sigma/dt$ and P_Σ measurements are in collaboration Analysis Review review stage.
- I've shown these measurement results in previous talks, so, I'll focus on some of the new *physics* results that are beginning to emerge.

UNIVERSALITY IN HIGH $\sqrt{s}$ BEHAVIOR

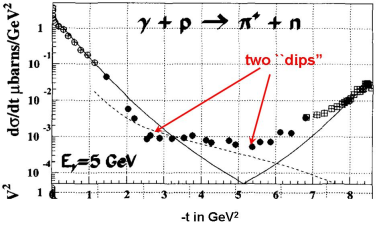
$\gamma p \rightarrow K^+\Sigma^0$

- Recap: at the June Users' Group meeting, I showed that for $\gamma p \rightarrow K^+\Sigma^0$, $d\sigma/dt$-vs-t shows a "dip" structure above $\sqrt{s} \approx 2.2$ GeV.

- Furthermore, at even higher energies, the "dip" separates into *two* separate "dips".

UNIVERSALITY IN HIGH $\sqrt{s}$ BEHAVIOR

- Similar behavior can be seen in the other pseudoscalar mesons too (in varying degrees/kinematics).



SLAC data

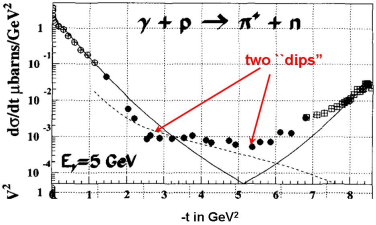
Anderson *et al*, PRD 14 (1976) 649

(plot: Guidal *et al*, Nucl. Phys. A 627 (1997) 645-678)

UNIVERSALITY IN HIGH $\sqrt{s}$ BEHAVIOR

- Similar behavior can be seen in the other pseudoscalar mesons too (in varying degrees/kinematics).

$\gamma p \to p + \eta'$



SLAC data

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- *Away from the resonance region*, there seems to be a universality in the features for exclusive $\gamma p \to \mathrm{PS} + \mathrm{B}$ (PS = π, K, η, η'; B = baryon)

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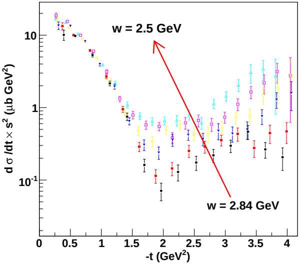
SCALING PART I: REGGE REGION

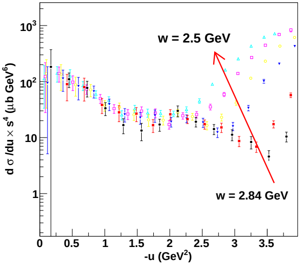
- Let's start by looking at large $\sqrt{s}$, $|t| \rightarrow 0$ (forward-angle) and $|u| \rightarrow 0$ (backward-angle). This's the "Regge region".
- Regge scaling: $d\sigma/dx \sim s^{2\alpha(x)-2}$, where $x = u, t$ and $\alpha(x) = \alpha_0 + \alpha_1 x$ is the Regge trajectory for the particular exchange.
- Note: most previous high energy world data at are at $|t| \rightarrow 0$. *The new CLAS results are unique in having a wide angular coverage.*
- We want to cover all three regions: forward-, mid- and backward-angles. This's important because we want to tie them all together finally.

REGGE SCALING: BOTH u AND t CHANNELS

$$\gamma p \to K^+\Sigma^0$$



$|t| \to 0 \sim s^2$ scaling



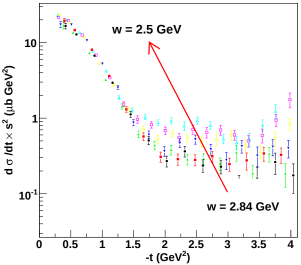
$|u| \to 0 \sim s^4$ scaling

- Scaling powers different because exchange trajectories are different.
- Note: with multiple trajectories (at the amplitude level), expect only an “effective” scaling power for the differential cross-sections.

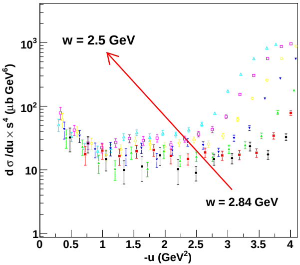
REGGE SCALING: MORE EXAMPLES

$\gamma p \rightarrow K^+\Lambda$

(from Mike McCracken's CMU thesis)



$\boxed{|t| \rightarrow 0 \sim s^2 \text{ scaling}}$



$\boxed{|u| \rightarrow 0 \sim s^4 \text{ scaling}}$

- Note: we don't *quite* go to the $|t| \rightarrow 0$ or $|u| \rightarrow 0$ limits (the extreme forward/backward angles).
- The *onset* of the Regge behavior is also channel dependent.

REGGE SCALING: THE "POWERS"

- Guidal *et al* and later, Bradford and co-workers noted that for the hyperons, if the exchanges trajectories are K^+ and $K^*(892)$, then $\alpha(t)_{K^+} + \alpha(t)_{K^*(892)} \sim 0$ near $t \sim 0$.
- If $\alpha_{eff} \sim 0$ then the scaling power $-2(\alpha - 1) \sim 2$. This could explain the power law behavior.
- For the u-channel case, the exchanges are Λ/Σ. What are the Regge trajectories?

$$\alpha(u)_\Lambda \sim -0.6 + 0.9u$$
$$\alpha(u)_\Sigma \sim -0.8 + 0.9u$$

- u-channel: $t \to u$, physical region: $u < 0$
- At $|u| \to 0$:

$$(2\alpha - 2)_\Lambda \approx -3.2$$
$$(2\alpha - 2)_\Sigma \approx -3.6$$

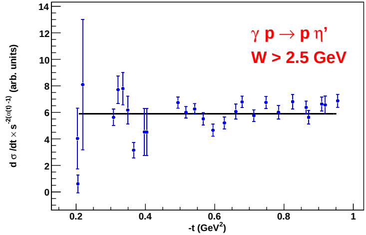
- It is thus *conceivable* that the scaling power $-(2\alpha - 2)$ be > 2.

REGGE SCALING: ONE LAST EXAMPLE

$$\gamma p \longrightarrow p\eta'$$

(Zeb Krahn's CMU thesis)

- t-channel Regge exchanges are the ω/ρ trajectories: $\alpha(t)_{\omega/\rho} \approx 0.5 + 0.9t$.
- Plot $\frac{d\sigma}{dt} \times s^{-2(\alpha(t)-1)}$ keeping the full t dependence. Include only points with $\sqrt{s} > 2.5$ GeV and $|t| \leq 1$ GeV^2



- After scaling, the differential cross-sections approximately line up.

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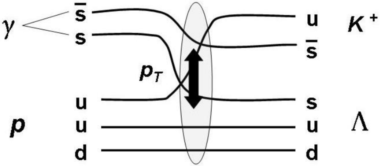
SCALING PART II: FIXED-ANGLE REGION

- Look at large s *and* large $-t$ or $-u$, with constant t/s or u/s.
- In the high energy limit, $t/s \sim (1 - \cos\theta)$, so $\cos\theta \approx$ fixed. Take $\theta \sim 90^\circ$.
- Simplified picture: transfer momentum $p_T \sim \sqrt{|t|}$ sets the time scale: $\tau \sim 1/p_T$.



- Large p_T means constituents have very little time to interact. Hard scattering at the parton level (fixed-angle region)
- Small p_T means constituents have time to form intermediate bound states. Regge poles are exchanged (Regge region)
- Intermediate region? – interpolating trajectories.

FIXED-ANGLE SCALING LAWS

- Brodsky and Farrar (PRL 31 (1973), 1153): for exclusive scattering at $s \to \infty$, t/s fixed,

$$\boxed{(d\sigma/dt)_{AB\to CD} \sim s^{2-n} f(t/s)}$$

- n is the total number of elementary fields participating in the hard scattering process.

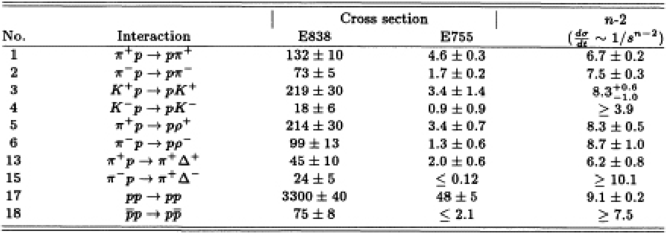
- Note: a photon counts a single parton. However if it participates as VMD-like $\gamma \to q\bar{q}$, then it counts as 2 partons.

- So the prediction is: $d\sigma/dt_{\gamma p \to \pi p} \sim s^{-7}$. The same law should apply to the other pseudoscalar mesons ηp, $\eta' p$, $K^+\Lambda$, $K^+\Sigma^0$, and even the vector meson ωp.

- Again, under the VMD picture this should change to s^{-8}. *So in general, something between -7 and -8 is predicted.*

PREVIOUS EXPERIMENTS

- BNL experiment **Comparison of 20 exclusive reactions at large t**, White *et al*, PRD 49 (1994), 58

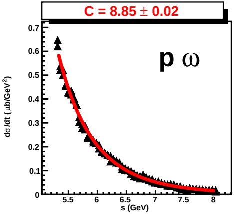


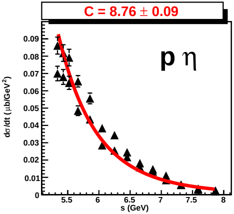
		Cross section		n-2
No.	Interaction	E838	E755	($\frac{d\sigma}{dt} \sim 1/s^{n-2}$)
1	$\pi^+ p \to p\pi^+$	132 ± 10	4.6 ± 0.3	6.7 ± 0.2
2	$\pi^- p \to p\pi^-$	73 ± 5	1.7 ± 0.2	7.5 ± 0.3
3	$K^+ p \to pK^+$	219 ± 30	3.4 ± 1.4	$8.3^{+0.6}_{-1.0}$
4	$K^- p \to pK^-$	18 ± 6	0.9 ± 0.9	≥ 3.9
5	$\pi^+ p \to p\rho^+$	214 ± 30	3.4 ± 0.7	8.3 ± 0.5
6	$\pi^- p \to p\rho^-$	99 ± 13	1.3 ± 0.6	8.7 ± 1.0
13	$\pi^+ p \to \pi^+ \Delta^+$	45 ± 10	2.0 ± 0.6	6.2 ± 0.8
15	$\pi^- p \to \pi^+ \Delta^-$	24 ± 5	≤ 0.12	≥ 10.1
17	$pp \to pp$	3300 ± 40	48 ± 5	9.1 ± 0.2
18	$\bar{p}p \to p\bar{p}$	75 ± 8	≤ 2.1	≥ 7.5

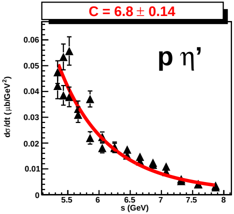
More or less good agreement with theory.

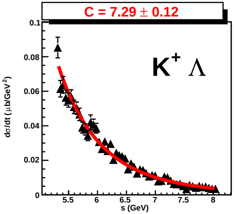
- CLAS experiment: ω photoproduction at large p_T, Battaglieri, PRL 90 (2003), 022002. Found power law behavior s^{-C} with $C \approx 7.2 \pm 0.8$

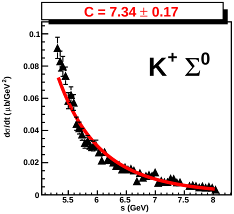
NEW CLAS *G11A* RESULTS











Fixed angle scaling: $\theta = 90^{\circ}$

Fit fn: $f(s) = A\,s^{-C}$

CLAS g11a data

- Note the high precision for $p\omega$!
- Interesting that the Λ and Σ^0 results look similar and very close to the predicted s^{-7}.

NEW CLAS $G11A$ RESULTS: FEATURES

- It is interesting that fixed-angle scaling is visible in the new CLAS data for all the mesons, and lies around the predicted scaling behavior.
- The $p\eta$ and $p\eta'$ cases are limited by statistics, but still "point towards" a scaling behavior.
- For hard scattering, it seems that $K^+\Lambda$ and $K^+\Sigma^0$ behaves very similarly and well within the scaling-law prediction. Does the singlet/triplet structure of the (ud) diquark not matter here?
- Excellent statistics for $p\omega$ and the fit looks very good. The experimental power law approaches s^{-9} however, which's different from the prediction. So why is the vector meson different?

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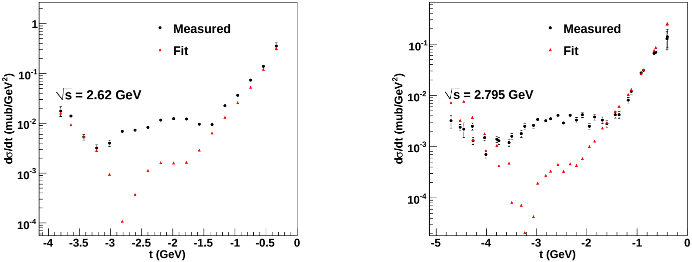
PWA FITS

- "Scaling region" is high s ($\sqrt{s} > 2.5$ GeV). But, our main goal is to look for missing resonances (lower $\sqrt{s}$).
- However, to fix the "background processes" (non-resonant u- and t-channel exchanges), we look at the high $\sqrt{s}$ region where there's presumably very little resonance contribution.

- Regge based approach has been quite successful to explain the high energy data.
- Chief attraction: simplicity and few parameters (no form-factors are involved).
- Theoretical difficuilties: replaces the Feynman propagators by a Regge propagator computed at the "first materialization" m_1.
- Assumption: m_1^2 not "too far" from the *physical region* (u, $t < 0$). Okay for $m_{K^+}^2 \approx 0.25$, but a stretch for m_p^2, $m_\Lambda^2 \approx 1$ (u-channel exchanges).

$p\eta'$ FITS

- Trial fit run over 2.6 GeV$\leq \sqrt{s} \leq$2.84 GeV.
- "Reggized" ρ (t-channel) + p (u-channel) trajectories – "rotating" or "constant" phase. Used "rotating" versions here (arbitary choice).
- A scale factor for each trajectory – 2 fit parameters (note simplicity!). 10 iterations per fit.



- Forward and backward angles are being fit quite well.
- Obviously, mid-angle regions are not being described very well.

SATURATED REGGE TRAJECTORIES

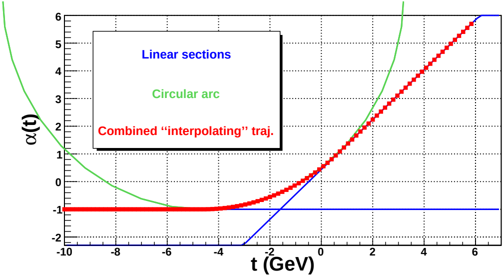
- We have seen earlier that the Regge region and fixed-angle region consists of very different *physics*. The only seeming connection is that both shows scaling, but scaling of completely different natures.
- Conventional Regge trajectories are linear while hard scattering scaling has a constant/flat exponent. In Regge language, the trajectories seem to get "saturated off" for large negative t or u.
- Following is from Brodsky *et al*, PRD 8 (1973), 4117:

  $-u$, $-t$, s all large with u/s and t/s fixed
  $\mathcal{A}_{AB\to CD} \sim sF_A(-s)F_C(u)F_D(t) \sim s^{1-A}(-u)^{-C}(-t)^{-D}$
  where the form-factors $F_M(x) \sim (-x)^{-M}$; $M = 1, 2$ for mesons and baryons resp.
  in *photoproduction*, $\mathcal{A} = \mathcal{A}_\mu k_T^\mu$ where $k_T \sim \sqrt{s}$. Propagator $\sim 1/t$, so $M = 1$.
- These reproduce the fixed-angle scaling laws. Next, cast them in the Regge form:
  $\mathcal{A} \sim \beta(t)(-u)^{\alpha(t)}$ OR $\mathcal{A} \sim \beta(u)(-t)^{\alpha(u)}$
- Then, in the Regge form, the "saturated" trajectories for $\gamma p \to \text{PScalar} + \text{Baryon}$:

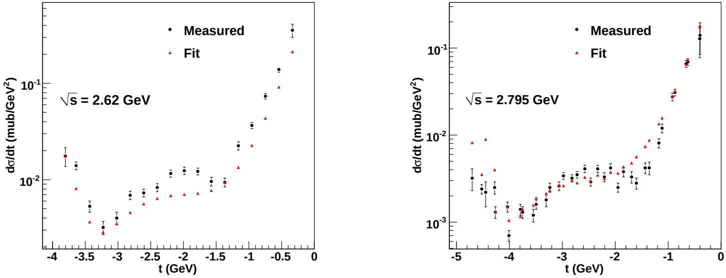
$$\boxed{\alpha(u)_{-u\to\infty} = -2, \qquad \alpha(t)_{-t\to\infty} = -1}$$

INTERPOLATING TRAJECTORIES

- Join the linear and flat saturated parts smoothly by an *interpolating trajectory*.
- Theoretical (analytic) expression was given by Sergeenko (Z. Phys. C 64 (1994), 315), but only for quarkonia. Guidal *at al* used the formula for ρ trajectory in their $\pi^+ n$ analysis.
- Try the simple but adhoc construction: join the two limits by an circular arc. Make the linear parts to be tangents to this circle.
- Shown below for the ω case:



REFIT $p\eta'$ USING INTERPOLTING TRAJECTORIES



- Marked improvement!
- Works best at higher $\sqrt{s}$ – just as expected.

REGGE FITS – OVERVIEW

- Overall, the Regge description seems like a very compact way of describing the data.
- Using interpolating trajectories, the high energy data can be fit quite well (*works for the other mesons as well*).
- The radius of the "arc" becomes as new fit variable now.
- Caveat: overcounting could occur from "duality", if we use resonances *and* the Reggeized background contributions, at the *intermediate* energies. So one needs to be careful.

OUTLINE

SUMMARY AND WORK IN PROGRESS

- We have found some very interesting *universal* features for exclusive pseudoscalar meson photoproduction. Given that spin-parity-wise they are equivalent, it is probably not too unexpected.

- We confirm fixed-angle scaling in these reactions, as predicted by Brodsky and co-workers.

- Saturating the Regge trajectories in a manner dictated by the fixed-angle behavior, we were able to fit the high energy data over almost the entire angular spectrum.

- The saturated Regge fits need to be further tuned and finalized. Also, they have to be compared with Feynman pole fits (with form factors).

- Our final goal is to do perform a coupled channel PWA using the K-matrix formalism on all these channels, to look for missing baryon resonances.