Reaction dynamics in the effective Lagrangian method

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Narrow Nucleon Resonance, Edinburg

Introduction

Exotic structure of baryon resonances

qq and/or $q\bar{q}$ correlations

Production reactions

We define the standard mechanism

(1) $K\Lambda(1520)$: Energy & Angular dependence

Beam & Decay asymmetry

(2) $K\Lambda_{gs}$: Beam asymmetry, Meson cloud

(3) ϕ: Energy & Angular dependence

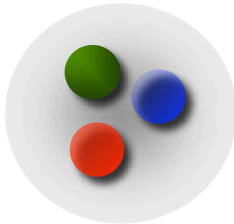
(4) $K\Lambda(1405)$: Energy dependence

Introduction

- Constituent quark model

  Successful for *ground states*

  $q\bar{q}$ and qqq of *independent particles*



Introduction

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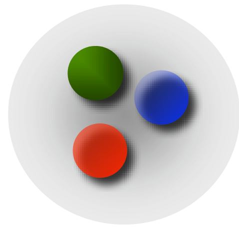

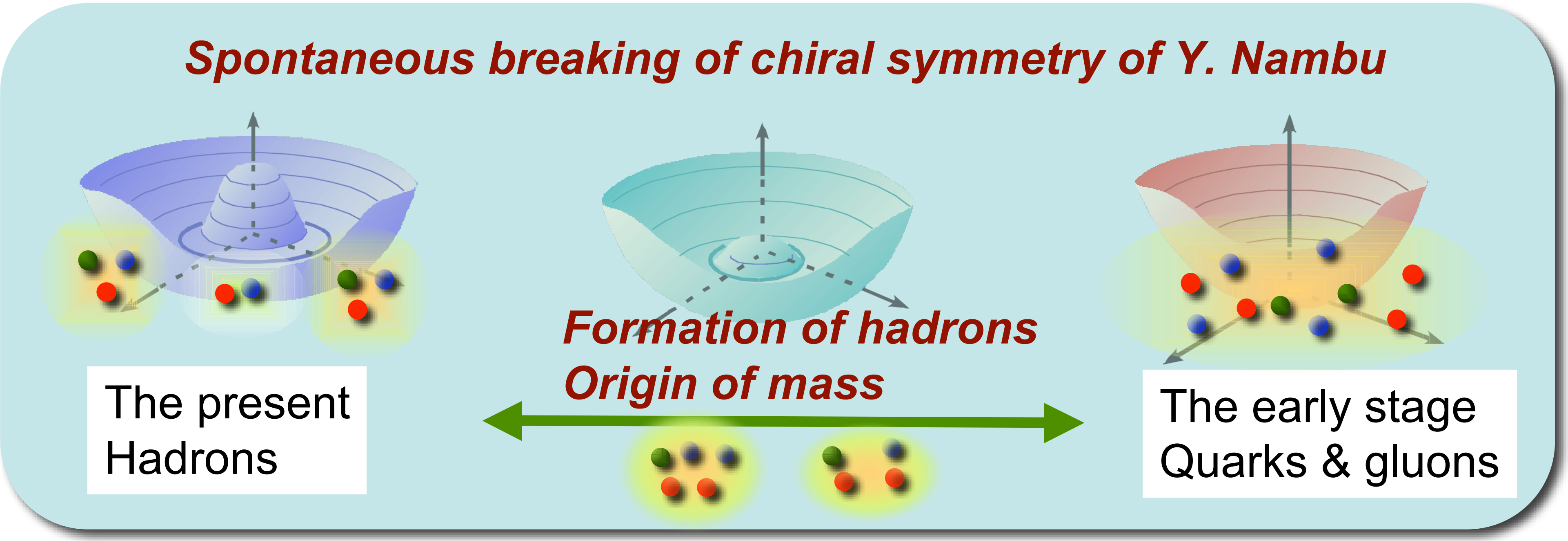

Observation of exotic hadron resonances

Θ^+, N*(1670), Λ(1405), …, X(3872), Z^+(4430), etc

Pentaquarks ***Hadronic molecule*** ***Tetraquarks***

Key question:
What multiquark configurations are possible?

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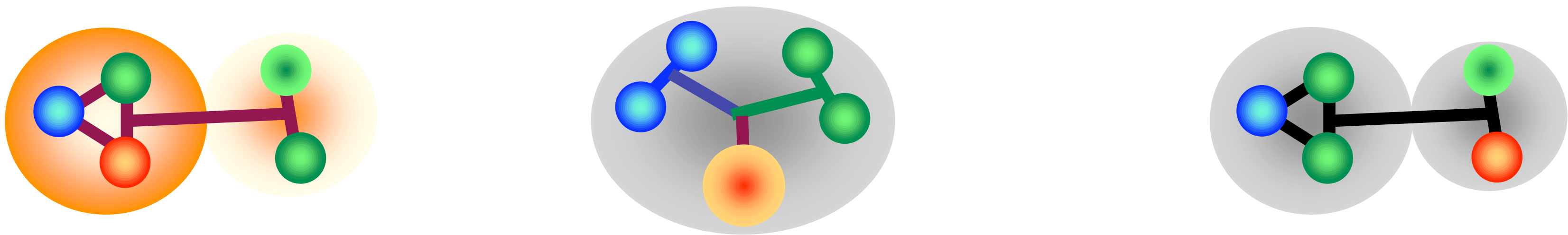
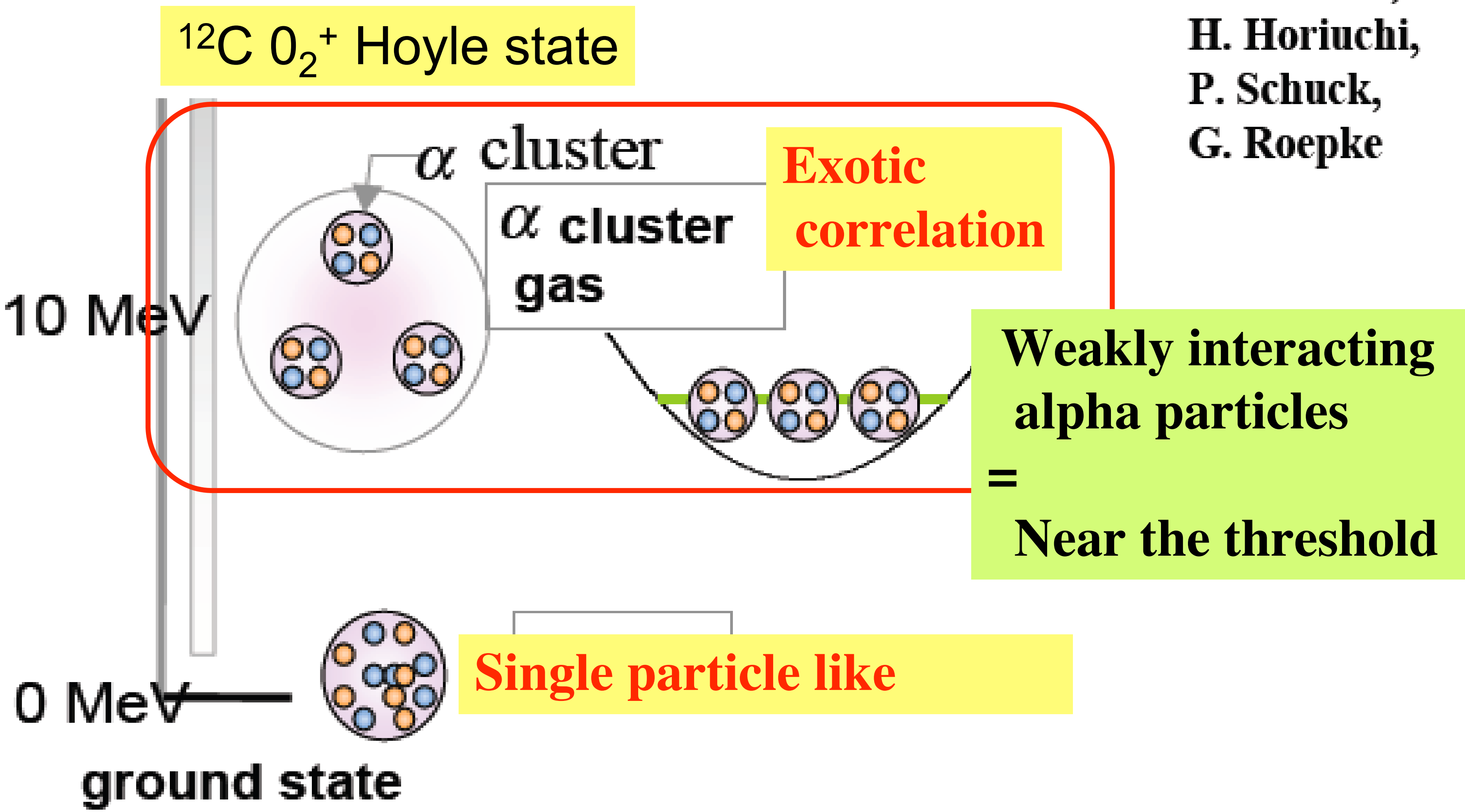


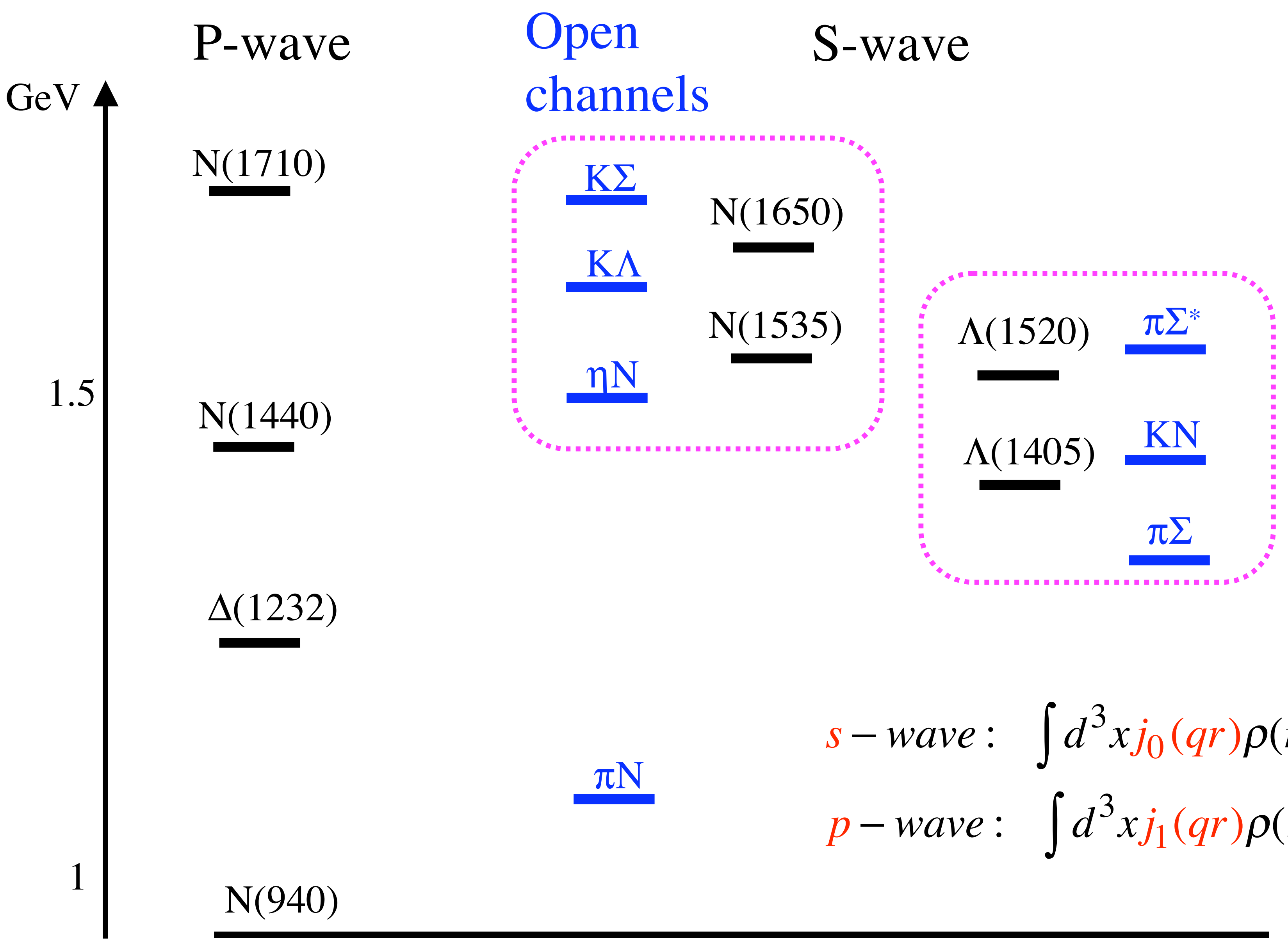
Triquark *Diquark* *Meson-baryon*

Colored correlation *Colorless correlation*

Example in Nuclear Physics

Y. Funaki,
A. Tohsaki,
H. Horiuchi,
P. Schuck,
G. Roepke





$$s - wave: \int d^3x\, j_0(qr)\rho(r)$$

$$p - wave: \int d^3x\, j_1(qr)\rho(r)$$

How can we test/observe such configurations ?

↓

Need more understanding of reaction dynamics

Production reactions

(1) $K\Lambda(1520)$

Energy dependence, Angular dependence

Beam asymmetry, Decay asymmetry

(2) $K\Lambda_{\mathbf{gs}}$

Beam asymmetry, Meson cloud

(3) ϕ

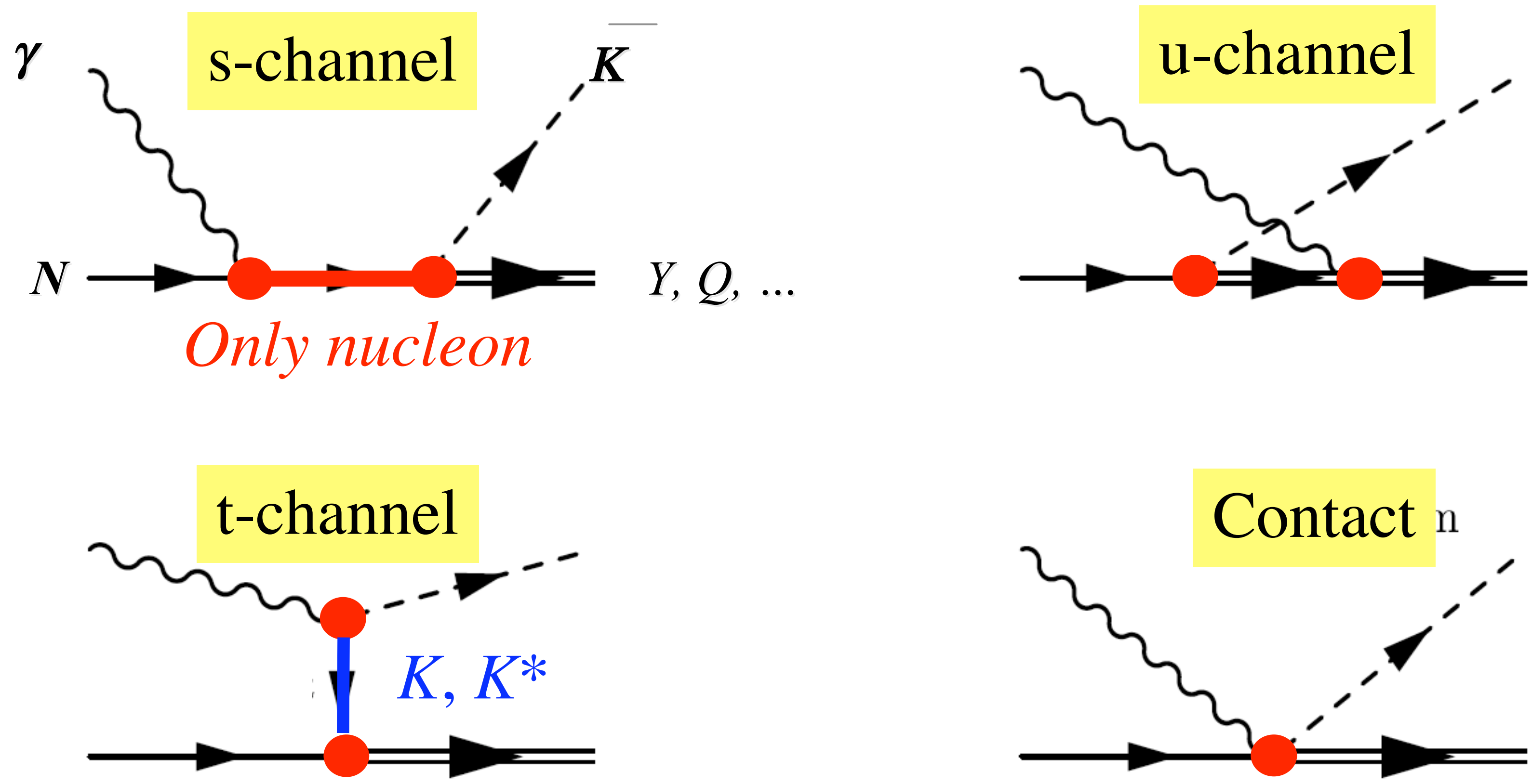
Energy dependence, Angular dependence

(4) $K\Lambda(1405)$

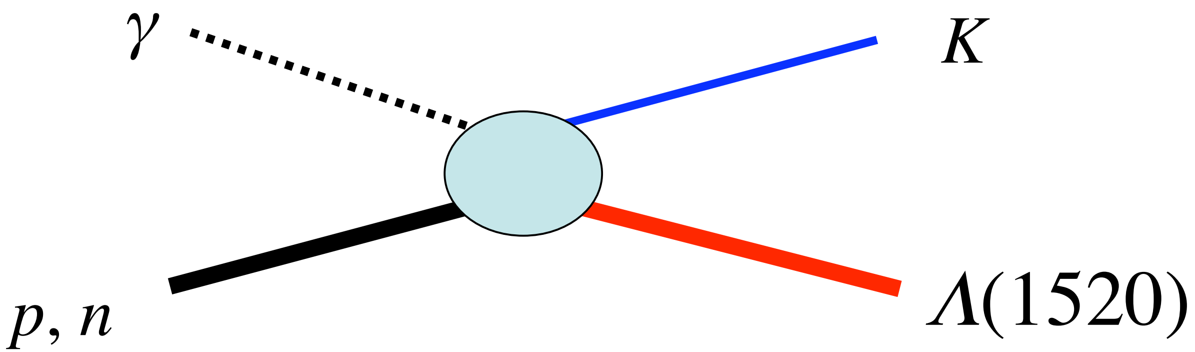
Energy dependence

Effective Lagrangian method
- Photoproductions -

Minimal diagrams



(1) Λ(1520)



Nam, Hosaka, Kim, PRD71, 114012 (2005)
e–Print: **hep-ph/0503149**

Also Karliner & Lipkin: e–Print: **hep-ph/0506084**

LEPS Data Muramatsu et al, 0904.2034[nucl-ex], to appear PRL

Lagirangians

$$\mathcal{L}_{\gamma NN} = -e\bar{N}\left(\gamma_\mu + i\frac{\kappa_N}{2M_N}\sigma_{\mu\nu}k_1^\nu\right)A^\mu N + \text{h.c.}, \qquad \mathcal{L}_{\gamma KK} = ie\{(\partial^\mu K^\dagger)K - (\partial^\mu K)K^\dagger\}A_\mu,$$

$$\mathcal{L}_{\gamma\Lambda^*\Lambda^*} = -\bar{\Lambda}^{*\mu}\left[\left(-F_1 \not{A} g_{\mu\nu} + F_3 \not{A}\frac{k_{1\mu}k_{1\nu}}{2M_{\Lambda^*}^2}\right) - \frac{\not{k}_1\not{A}}{2M_{\Lambda^*}}\left(-F_2 g_{\mu\nu} + F_4\frac{k_{1\mu}k_{1\nu}}{2M_{\Lambda^*}^2}\right)\right]\Lambda^{*\nu} + \text{h.c.},$$

$$\mathcal{L}_{\gamma KK^*} = g_{\gamma KK^*}\epsilon_{\mu\nu\sigma\rho}(\partial^\mu A^\nu)(\partial^\sigma K)K^{*\rho} + \text{h.c.}, \qquad \mathcal{L}_{KN\Lambda^*} = \frac{g_{KN\Lambda^*}}{M_K}\bar{\Lambda}^{*\mu}\Theta_{\mu\nu}(A,Z)(\partial^\nu K)\gamma_5 N + \text{h.c.},$$

$$\mathcal{L}_{K^*N\Lambda^*} = -\frac{ig_{K^*N\Lambda^*}}{M_{K^*}}\bar{\Lambda}^{*\mu}\gamma^\nu(\partial_\mu K_\nu^* - \partial_\nu K_\mu^*)N + \text{h.c.}, \qquad \mathcal{L}_{\gamma KN\Lambda^*} = -i\frac{eg_{KN\Lambda^*}}{M_K}\bar{\Lambda}^{*\mu}A_\mu K\gamma_5 N + \text{h.c.},$$

Lagirangians

$$\mathcal{L}_{\gamma NN} = -e\bar{N}\left(\gamma_\mu + i\frac{\kappa_N}{2M_N}\sigma_{\mu\nu}k_1^\nu\right)A^\mu N + \text{h.c.}, \qquad \mathcal{L}_{\gamma KK} = ie\{(\partial^\mu K^\dagger)K - (\partial^\mu K)K^\dagger\}A_\mu,$$

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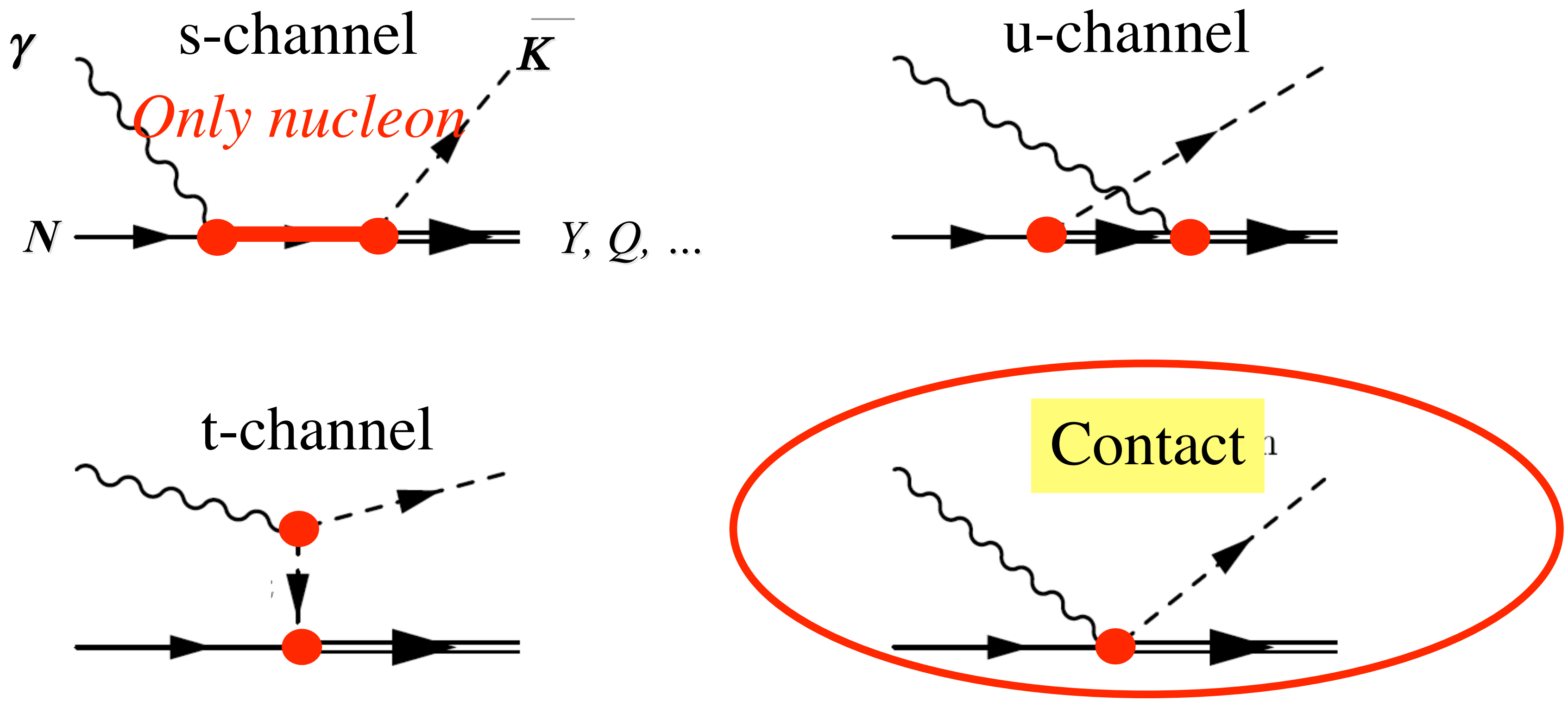
- Known couplings
- K*NΛ coupling is not known but not very important
- Ignore γΛ*Λ* couplings, $F_{1\sim4}$

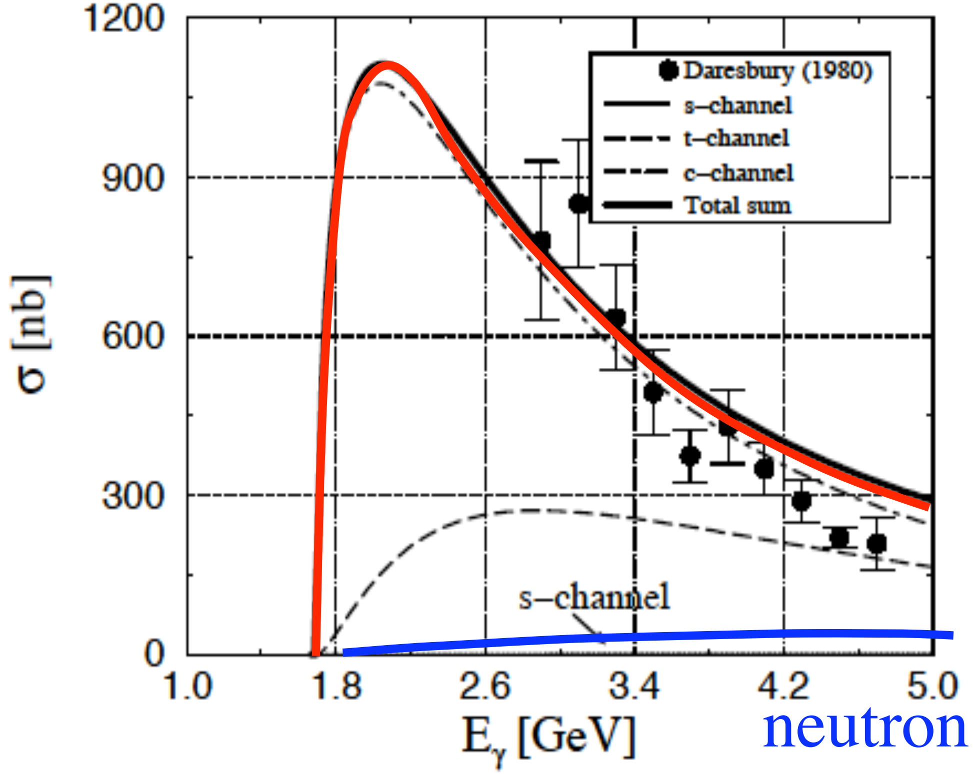
Minimal diagrams



Contact term dominance
cf: Kroll-Ruderman Theorem

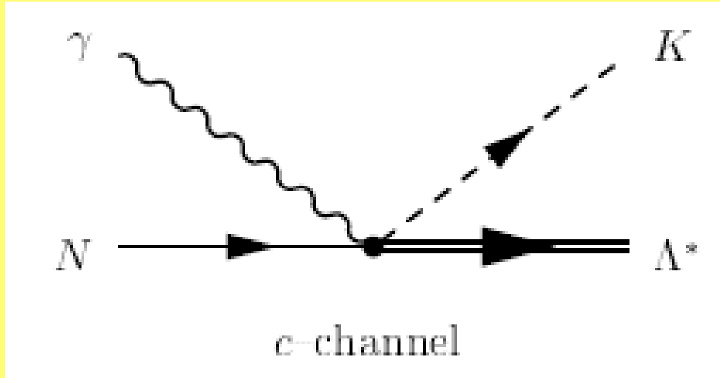
Total σ

Data: D.P. Baber et al,
Z. Phys. C7, 17 (1980)



Λ = 700 MeV

Contact term dominance



σ(p) >> σ(n)

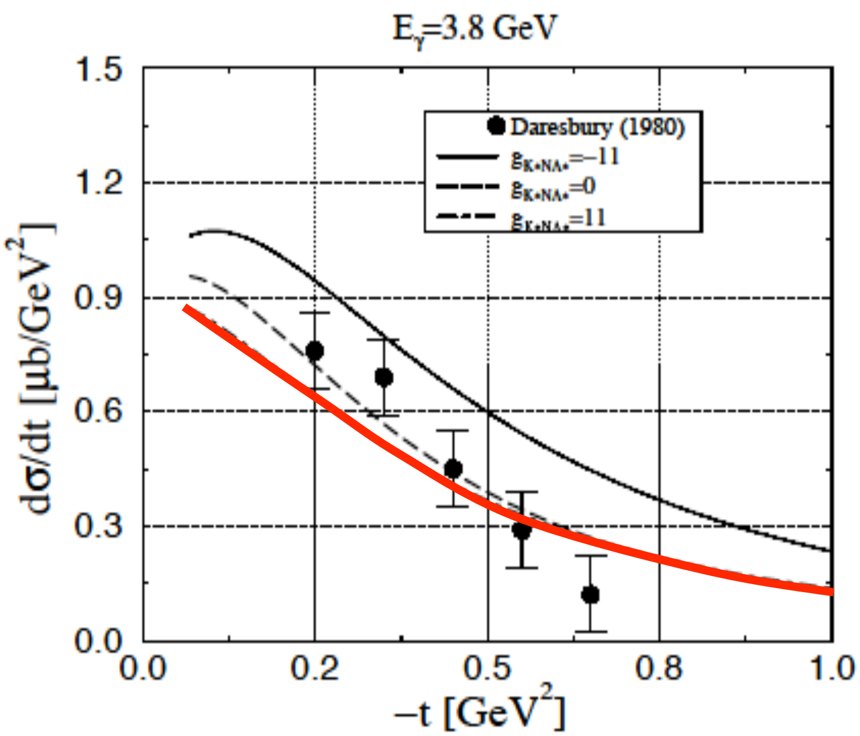
(σ(p) << σ(n), Θ)

Consistent with the new data by Muramatsu et al 0904.2034[nucl-ex]

t/θ dependence

Forward peak

Data: D.P. Baber et al,
Z. Phys. C7, 17 (1980)



Muramatsu et al
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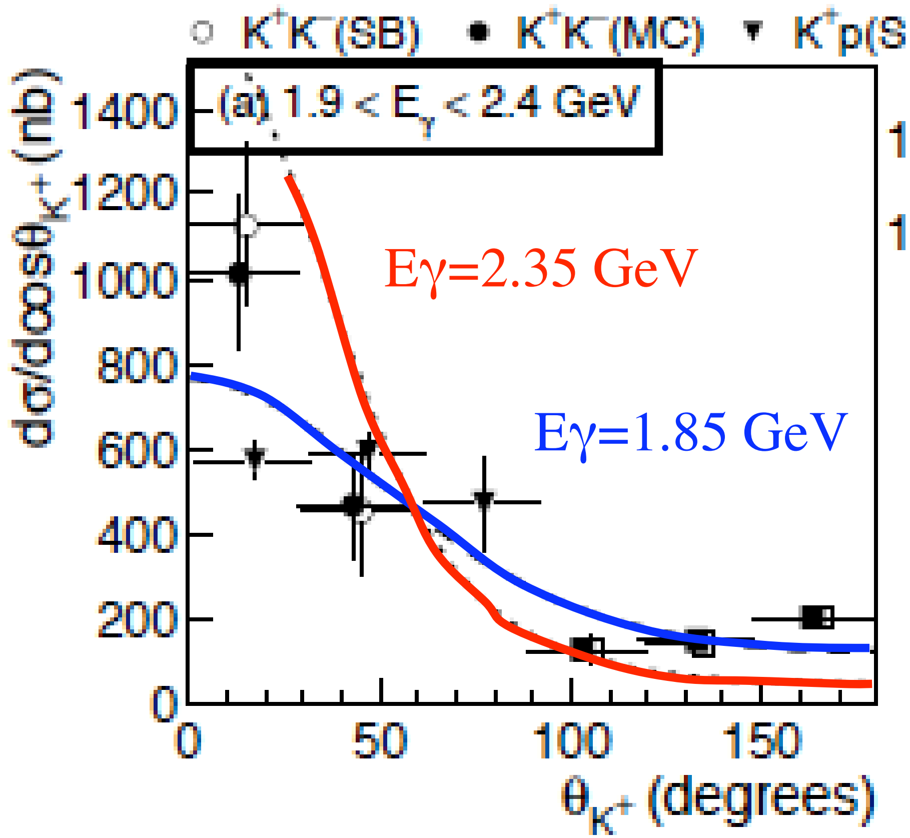
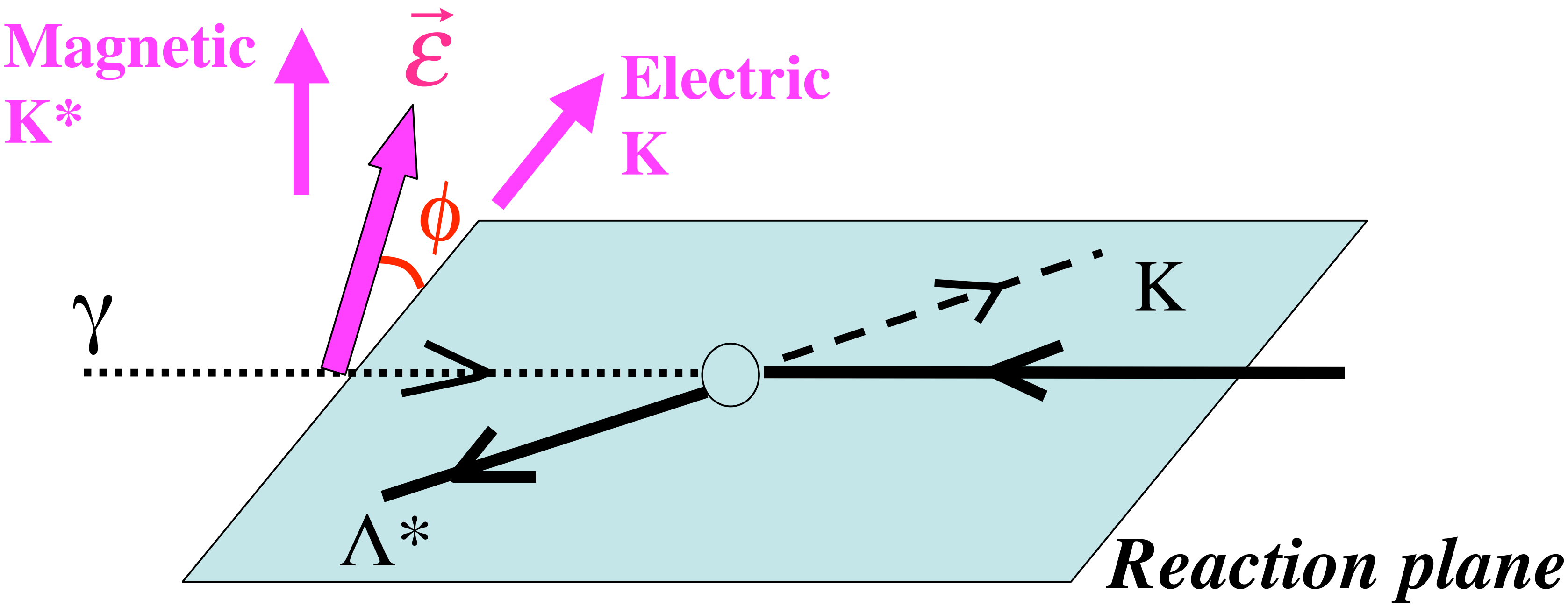
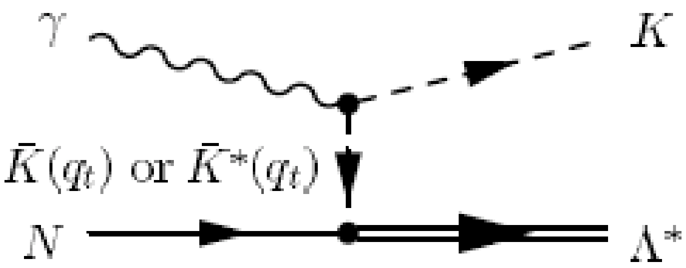


Beam asymmetry

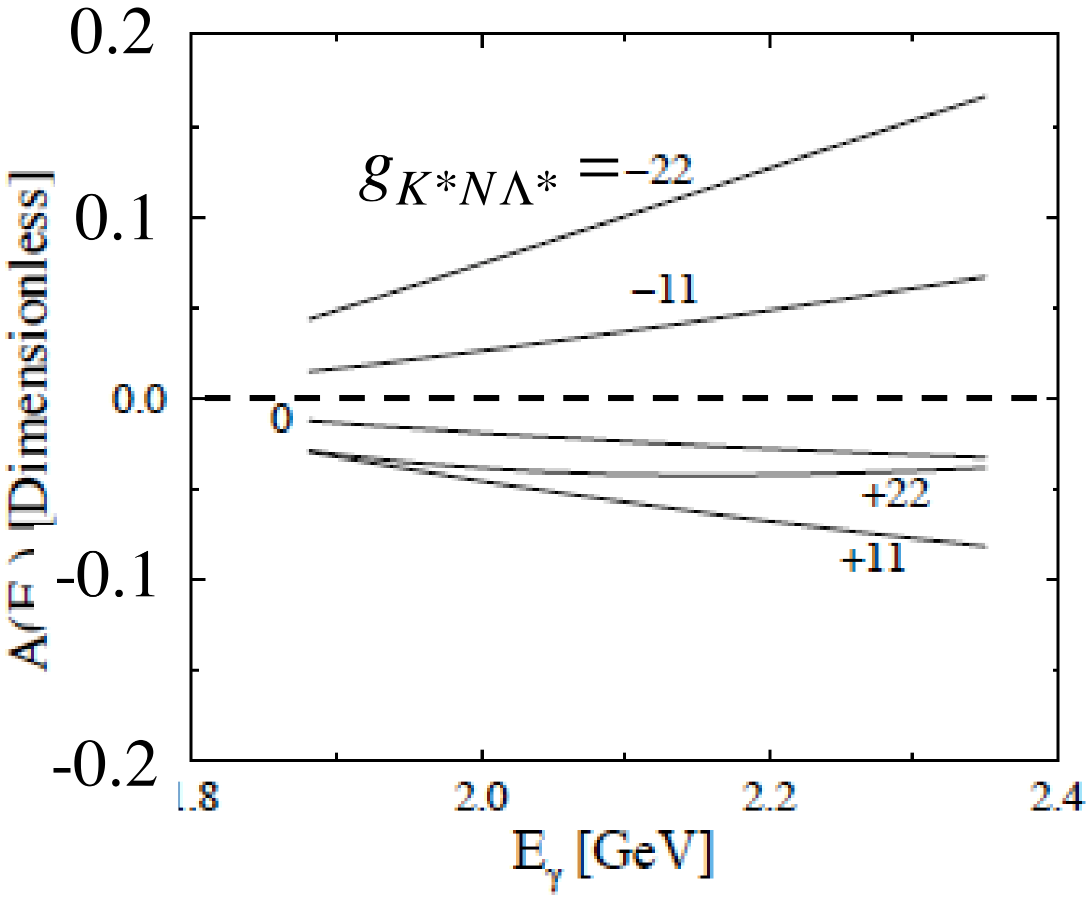




Electric	$P=(-1)^J$	K-exch
Magnetic	$P=(-1)^{J+1}$	K^*-exch

$$\sigma(\phi) \Rightarrow \Sigma = \frac{\sigma(90^\circ) - \sigma(0^\circ)}{\sigma(90^\circ) + \sigma(0^\circ)}$$

Beam asymmetry



Quark model

$g_{K^*N\Lambda^*} \sim 10$

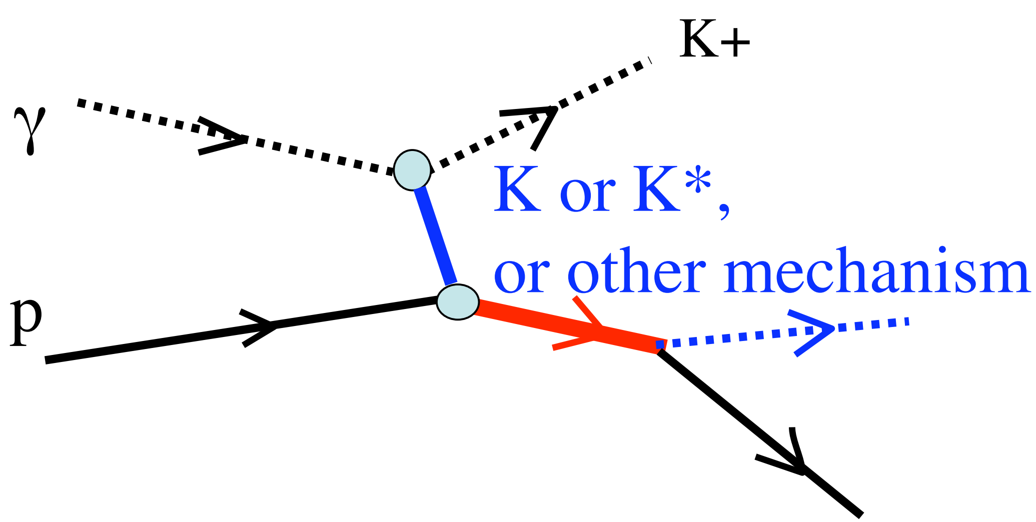
Chiral unitary

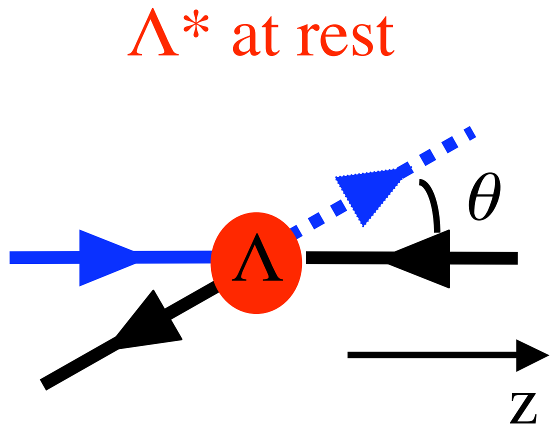
$g_{K^*N\Lambda^*} \sim 1.5$

−0.01±0.07

Muramatsu et al

Decay asymmetry





If $h(\Lambda^*) = 1/2$: $\cos^2\theta + \frac{1}{3}$

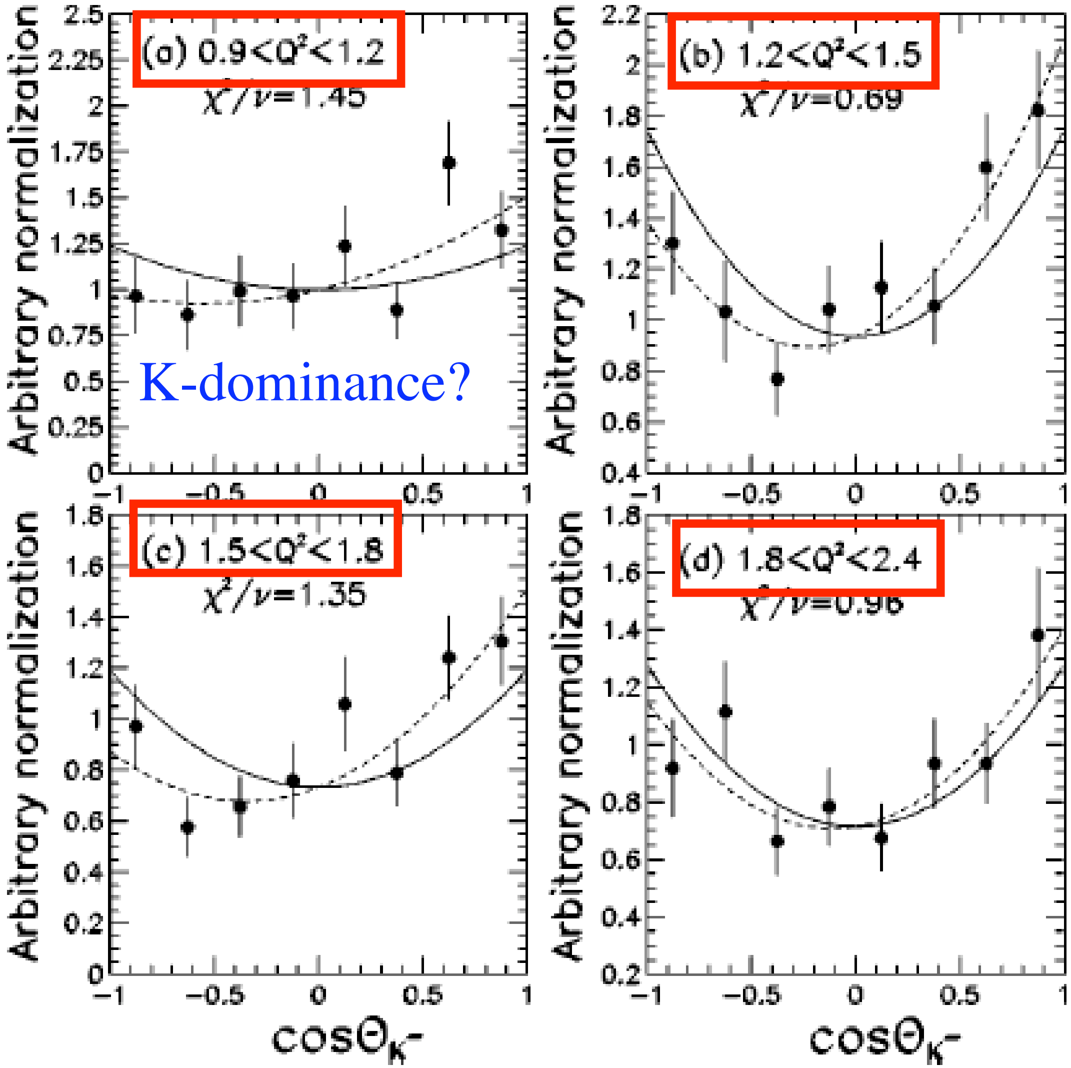
If $h(\Lambda^*) = 3/2$: $\sin^2\theta$

K-exch: $\cos^2\theta + \frac{1}{3}$

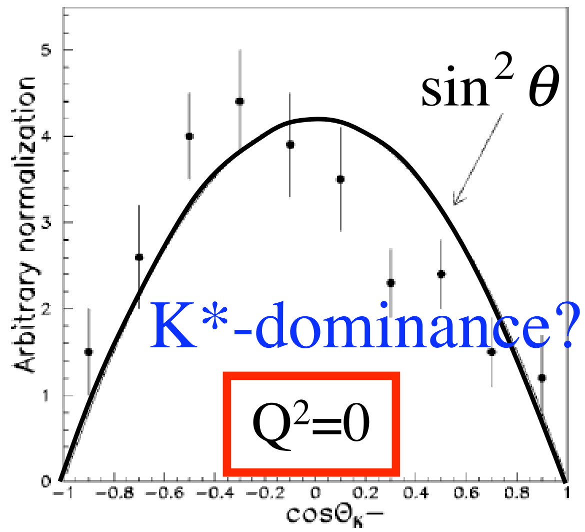
K*-exch: $\frac{2}{3}\sin^2\theta + \frac{4}{9}$

Contact: const

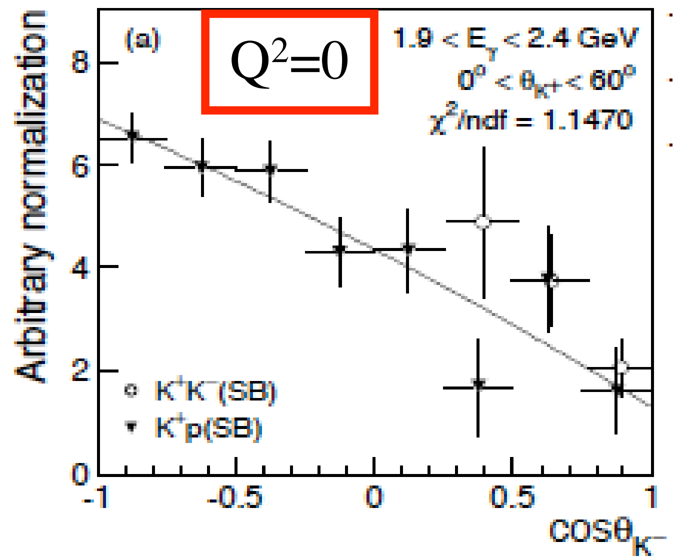
S. P. Barrow et al@JLab
PRC64, 044601 (2001)



D. Barber et al.,
Z. Phys. C7, 17 (1980)



Muramatsu et al
0904.2034[nucl-ex]



The contact term
has weak θ-dependence

Λ(1520) photoproduction

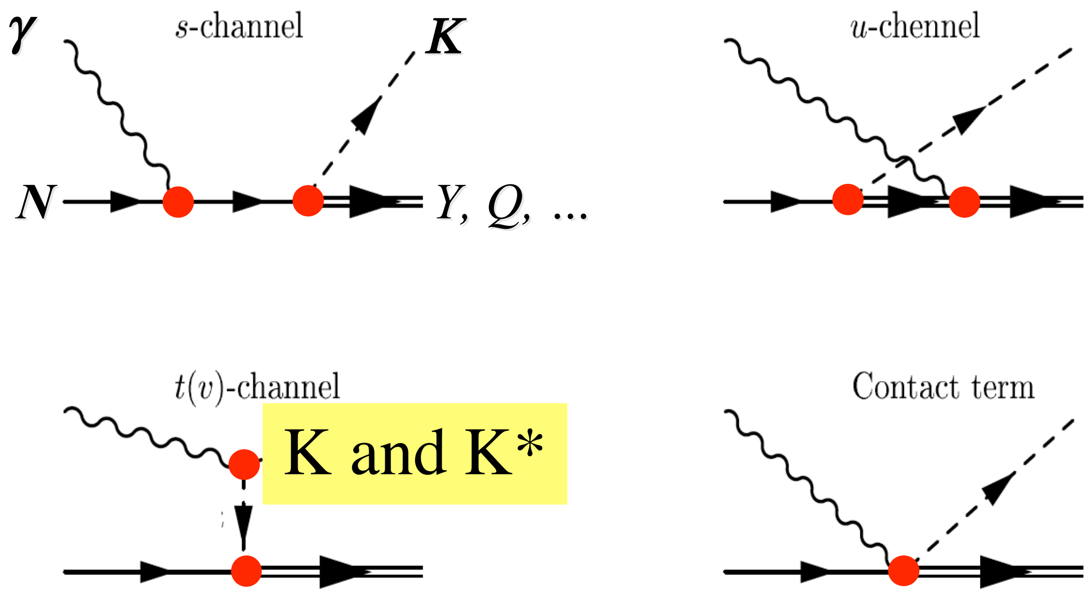
- A simple Lagrangian method implies the contact term dominance
- Proton σ is larger than neutron σ
- Angular dependence, beam asymmetry, decay asymmetry seems consistent with the contact term dominance

(2) KΛ-production for meson cloud

virtual $q\bar{q}$

Ozaki-Nagahiro-Hosaka
Phys.Lett.B665:178-181,2008.

Standard processes



AND

(2) KΛ-production for meson cloud

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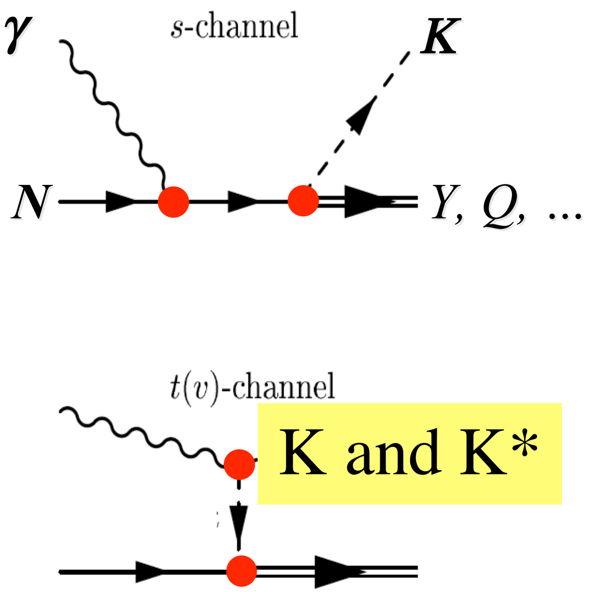
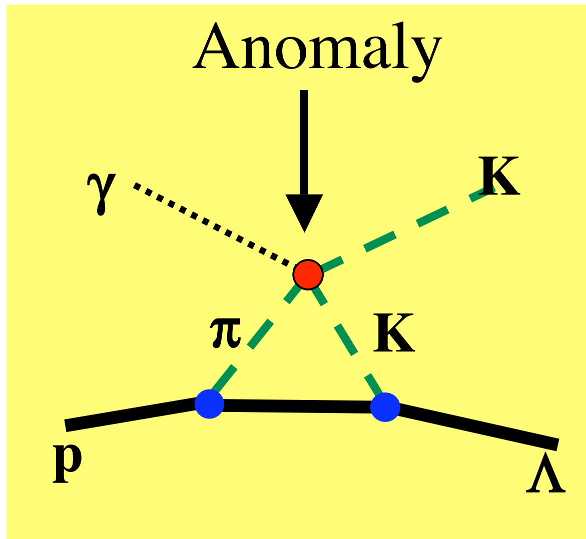
Ozaki-Nagahiro-Hosaka
Phys.Lett.B665:178-181,2008.

Standard processes



+



Too large K* coupling?

	Phenomenological*
$g_{KN\Lambda}$	-13.46
$g_{KN\Sigma}$	4.25
$g^V_{K^*N\Lambda}$	-25.21
$g^T_{K^*N\Lambda}$	33.13
$g^V_{K^*N\Sigma}$	-15.33
$g^T_{K^*N\Sigma}$	-29.67

* Bennhold et al., NPA695 (2001) 237
Also discussed by Guidal et al. NPA627 (1997) 645

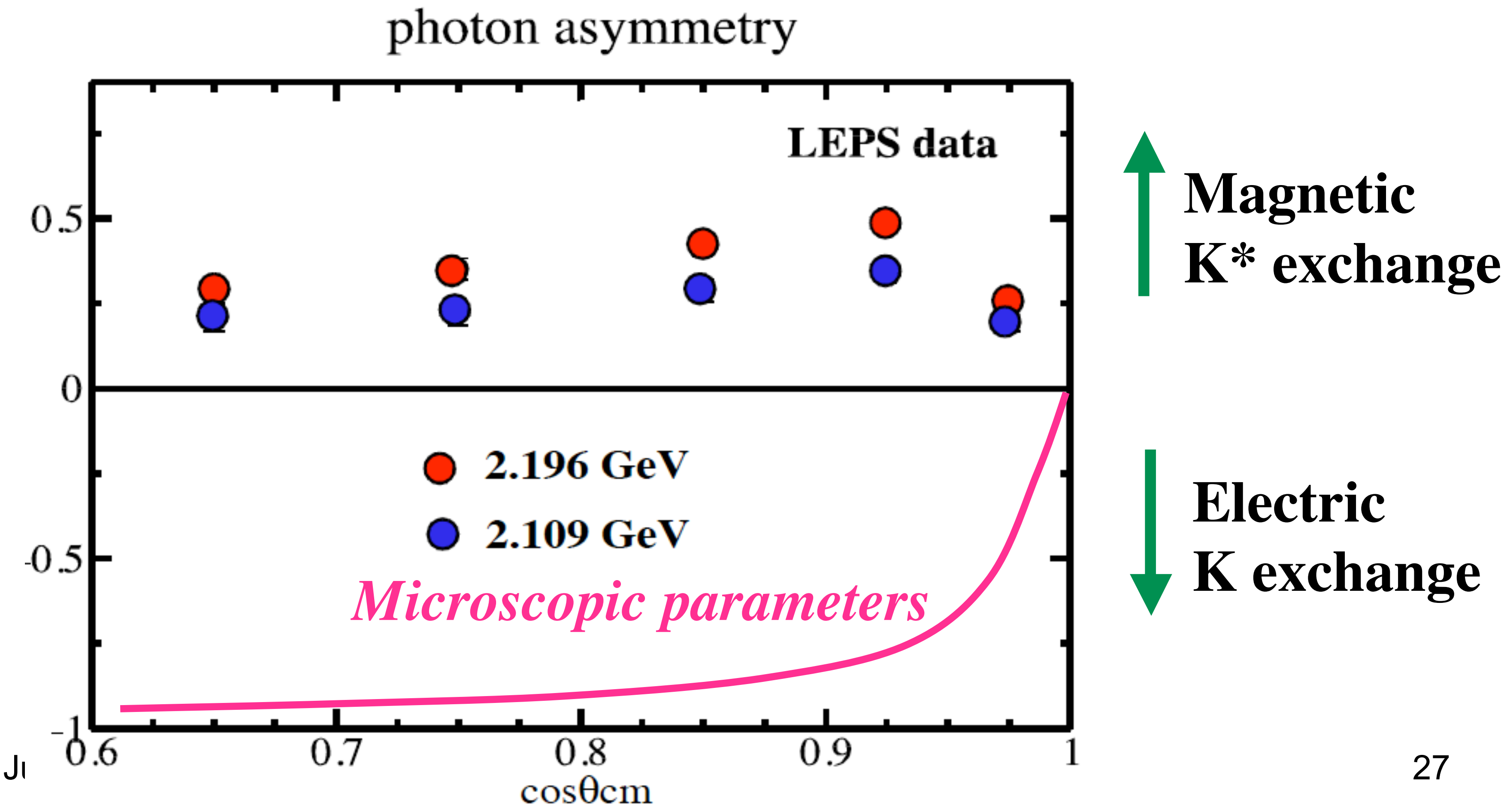
Too large K* coupling?

	Phenomenological*	Microscopic**
$g_{KN\Lambda}$	-13.46	-12.65
$g_{KN\Sigma}$	4.25	5.92
$g^V_{K^*N\Lambda}$	-25.21	-5.63
$g^T_{K^*N\Lambda}$	33.13	-18.34
$g^V_{K^*N\Sigma}$	-15.33	-3.25
$g^T_{K^*N\Sigma}$	-29.67	7.86

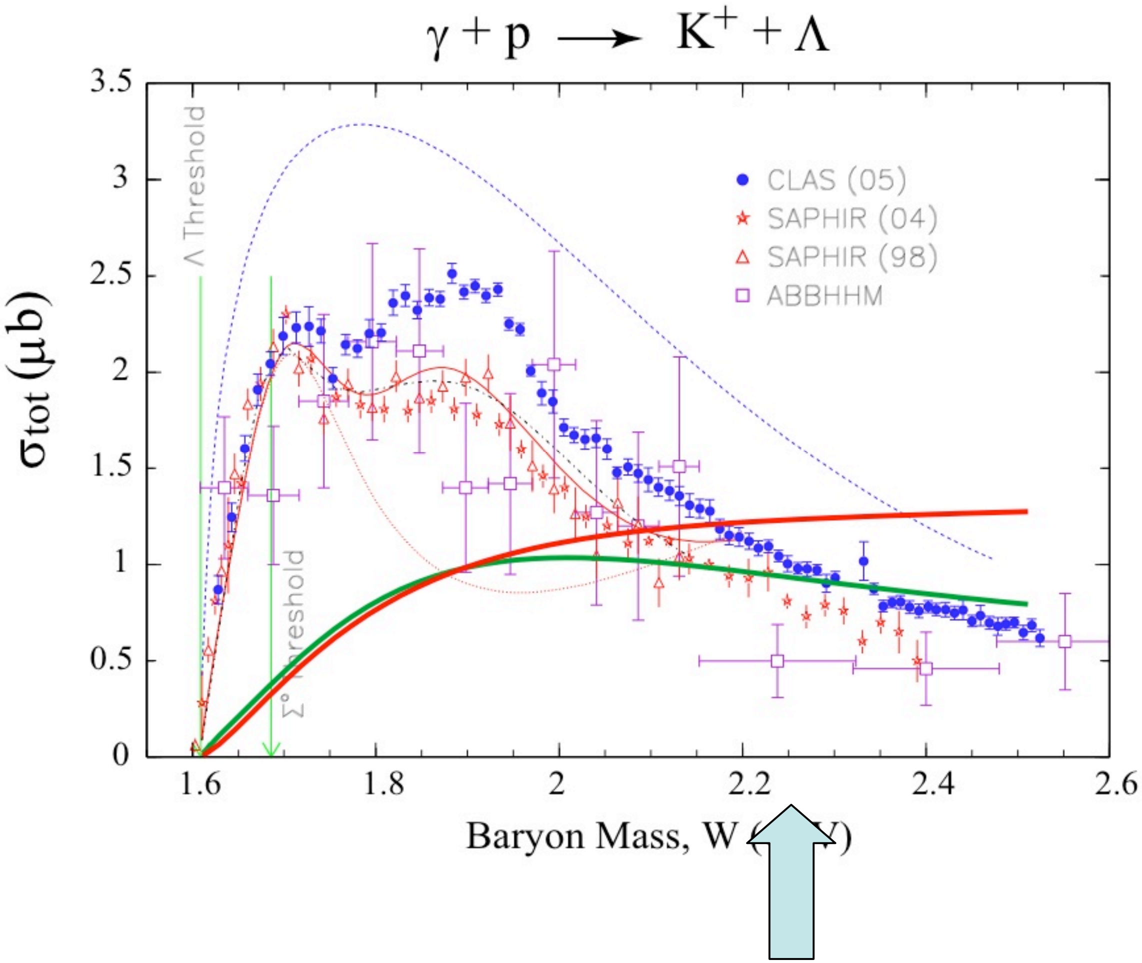
* Bennhold et al., NPA695 (2001) 237
Also discussed by Guidal et al. NPA627 (1997) 645
** Reuber et al (Bonn), NPA 570 (1994) 543

Beam asymmetry

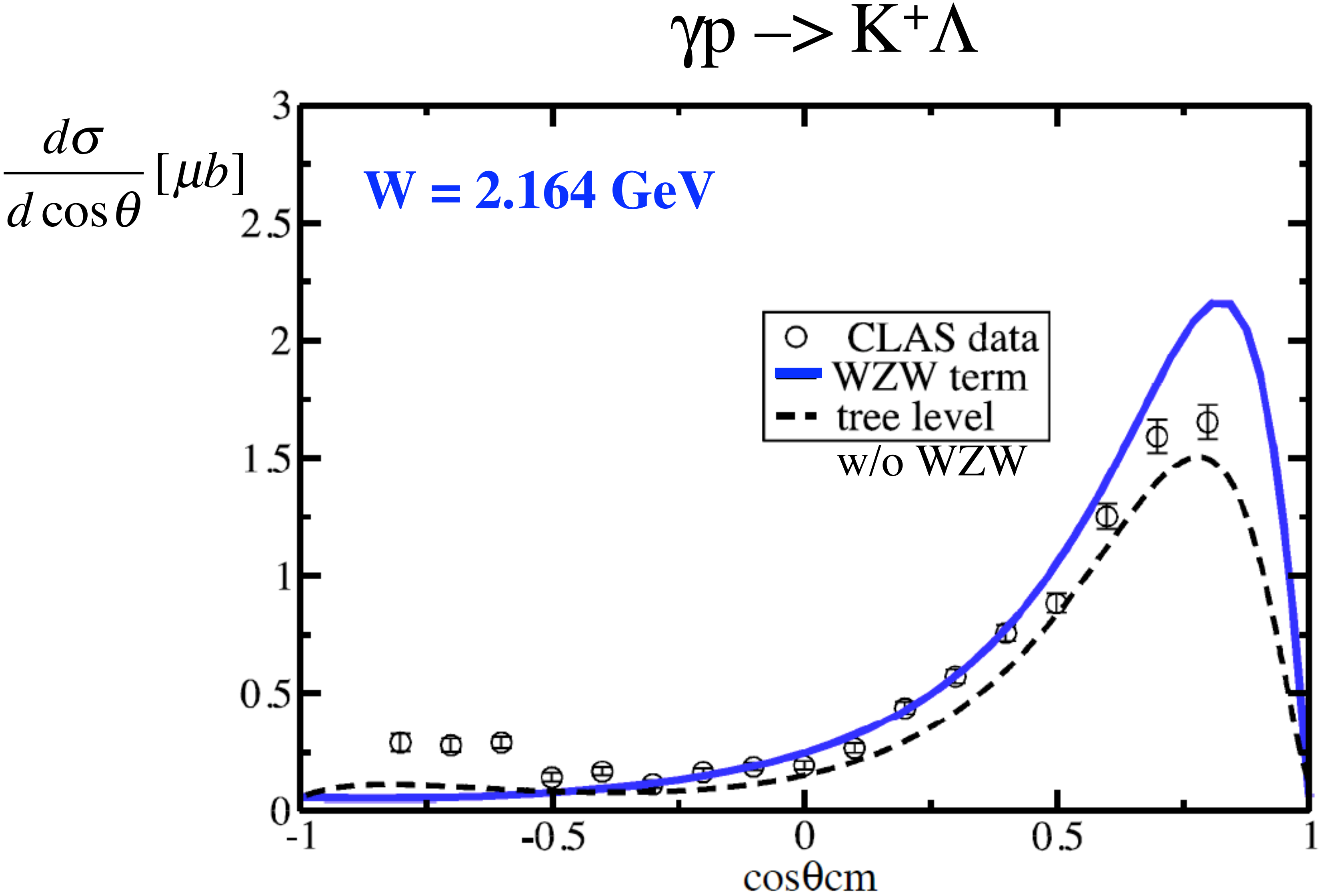
$\gamma p \to K^- \Lambda$ LEPS data, Sumihama et al. PRC73,035214 (2006)



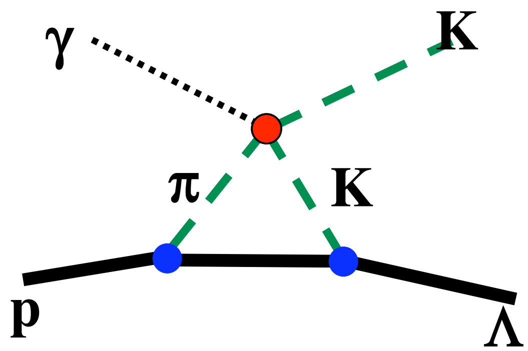
Where to study



Angular dependence



By adding



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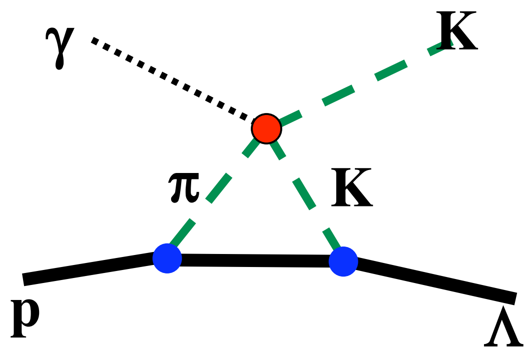
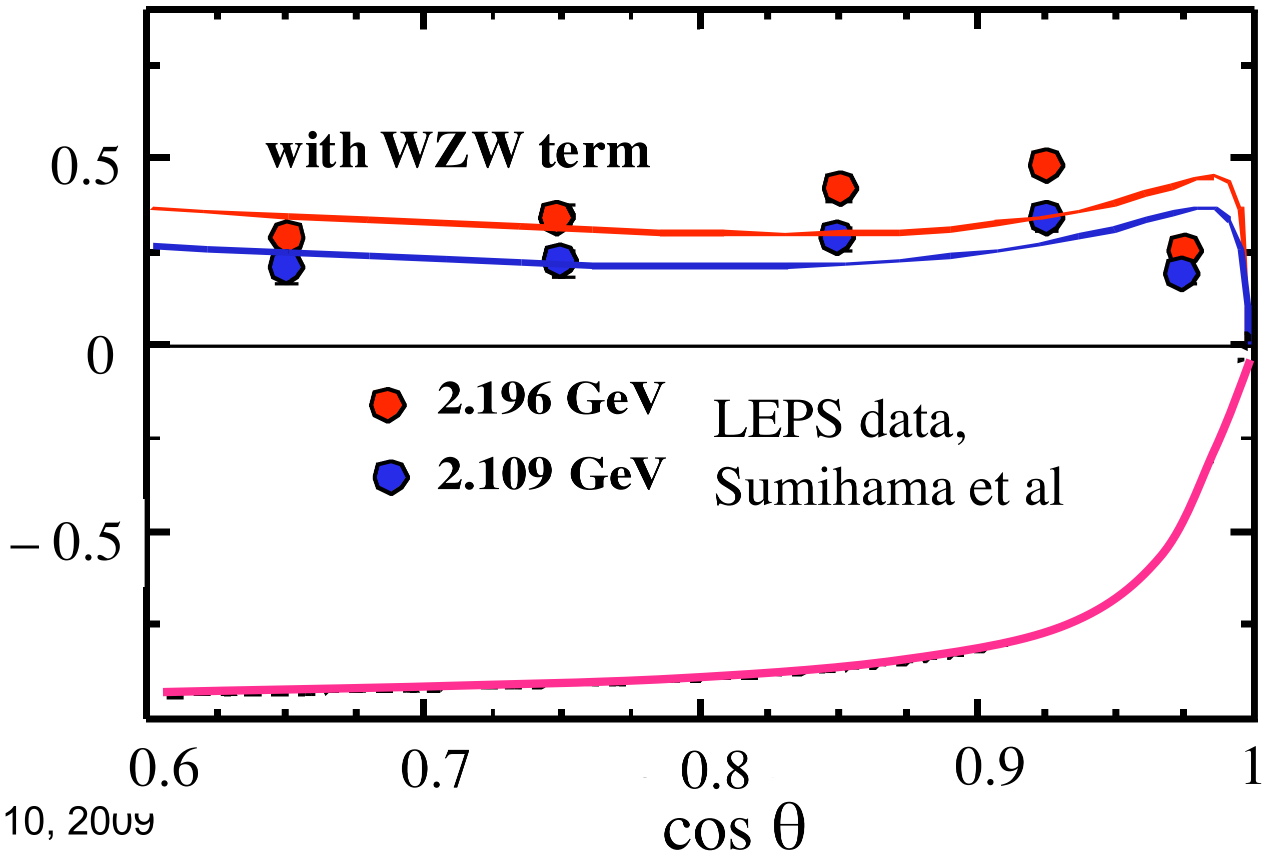


LEPS data, Sumihama et al. , PRC73,035214 (2006)



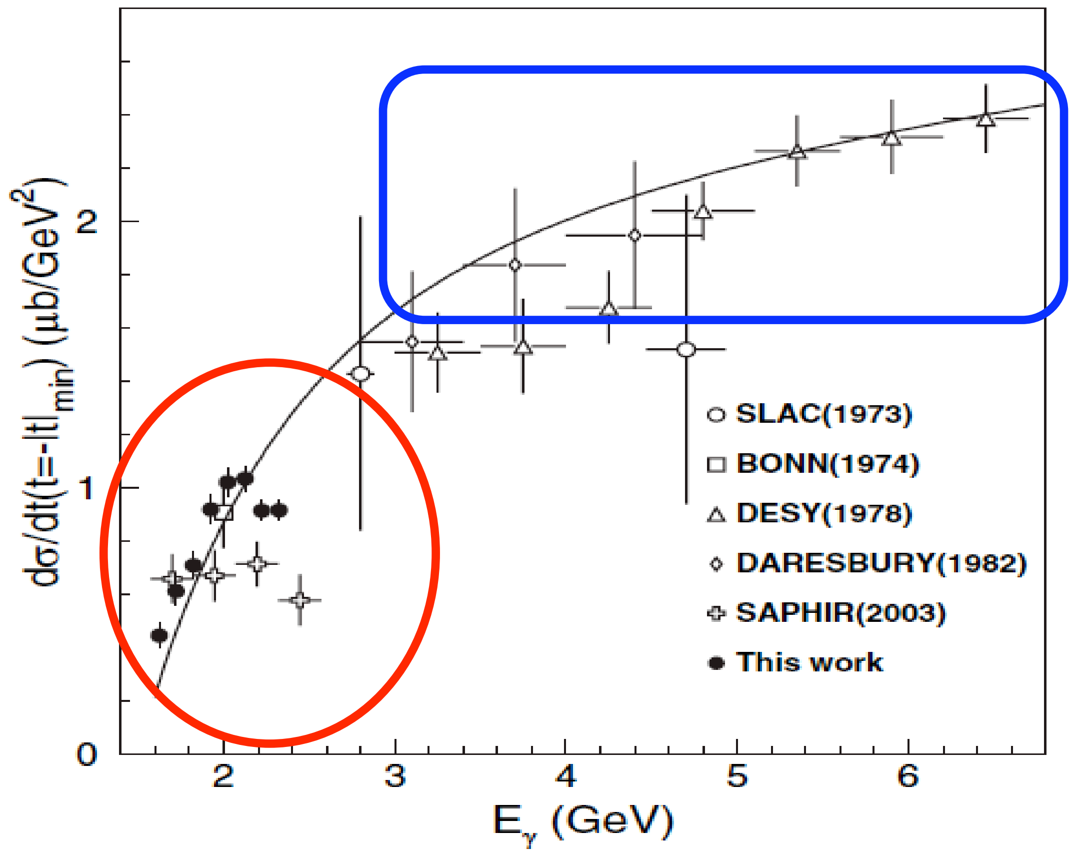
The puzzle of the large K* coupling has been solved

Magnetic strength is provided by the QCD anomaly

Meson cloud is important

(3) ϕ production

γ N -> ϕ N

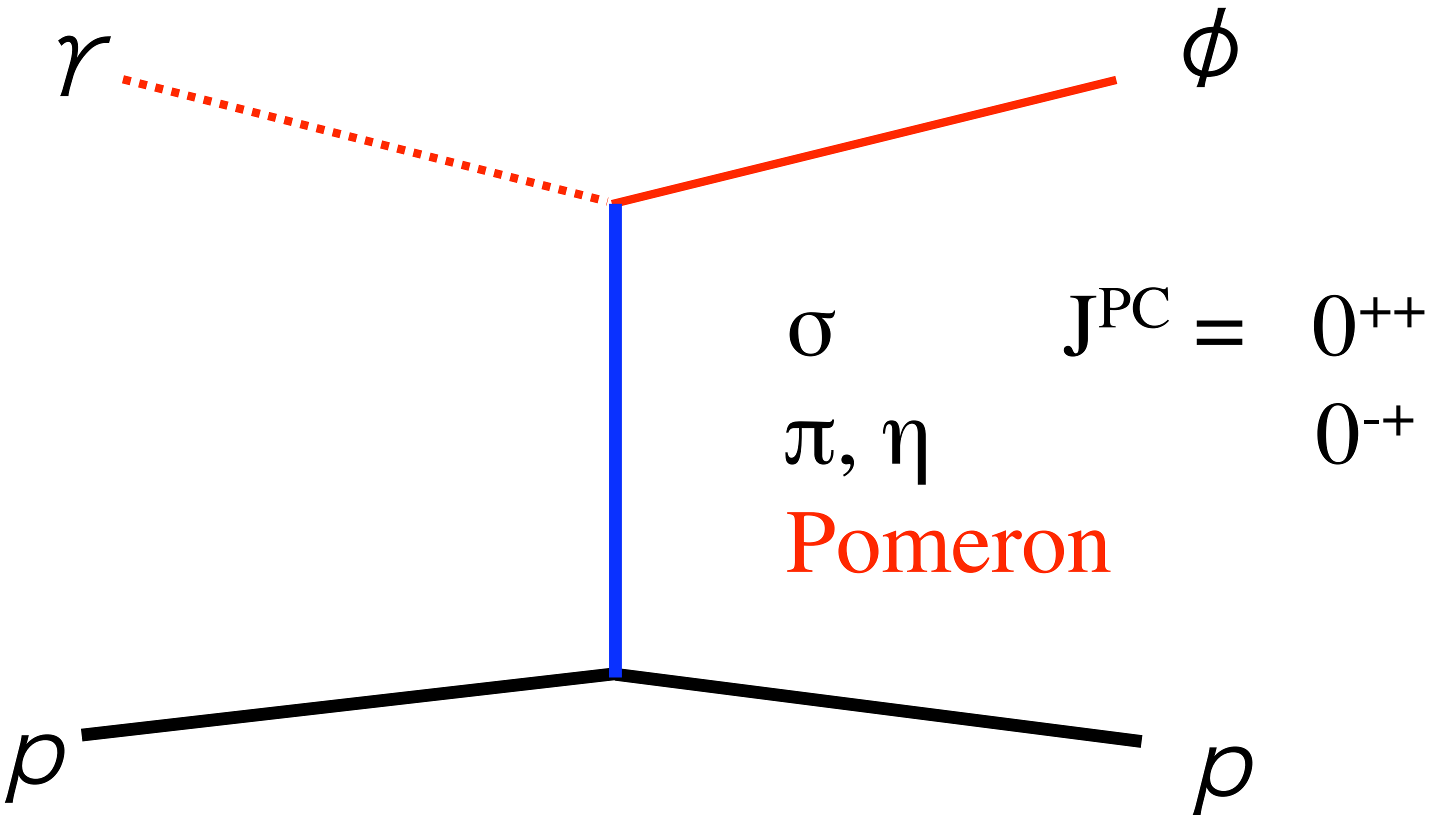


Increase as *E*

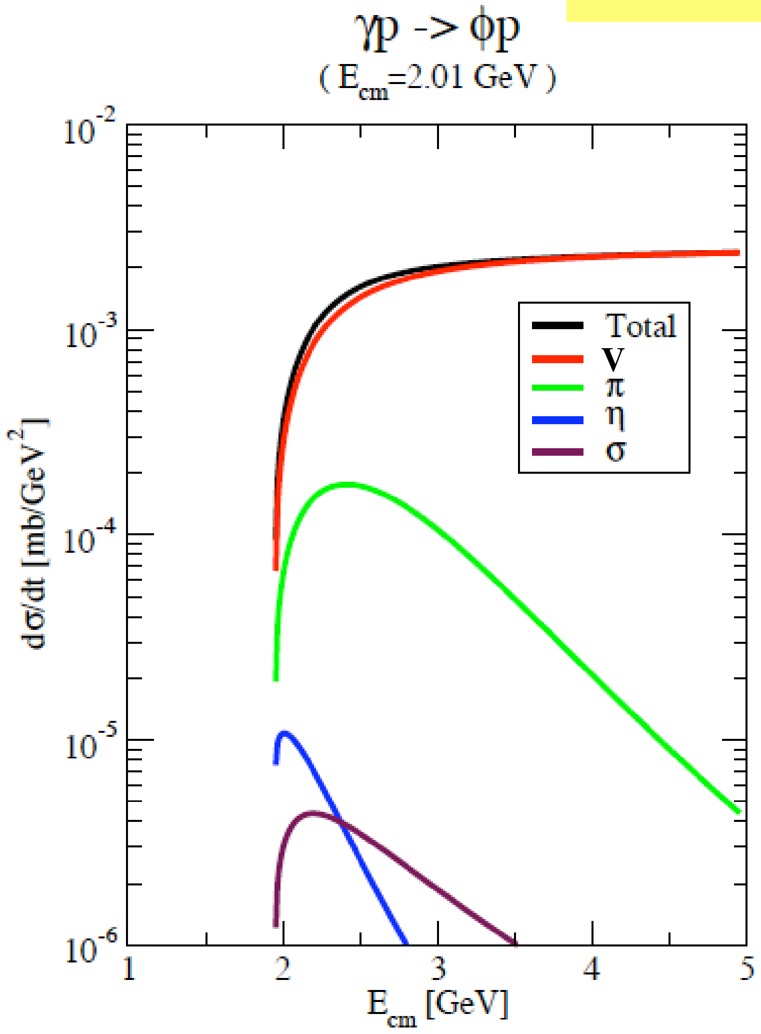
Bump at 2 GeV
or
Dip at 2.2 GeV

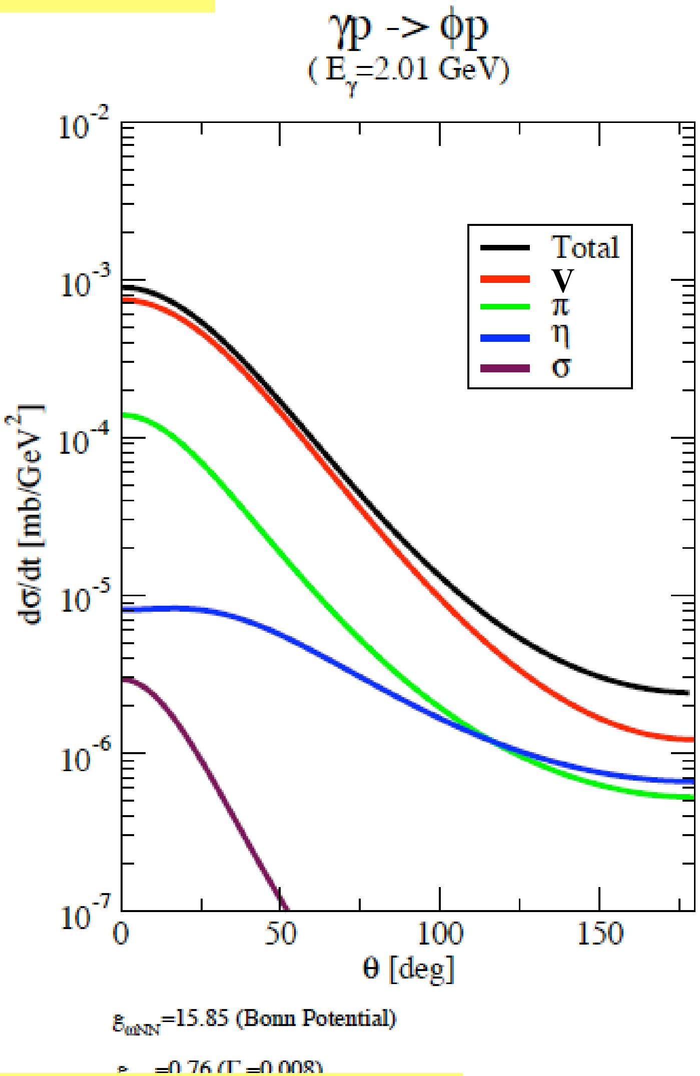
Mibe et al
PRL95,182001
(2005)

Pomeron and Meson exchanges



Exchange of $J^{PC} = 1^{-+}$





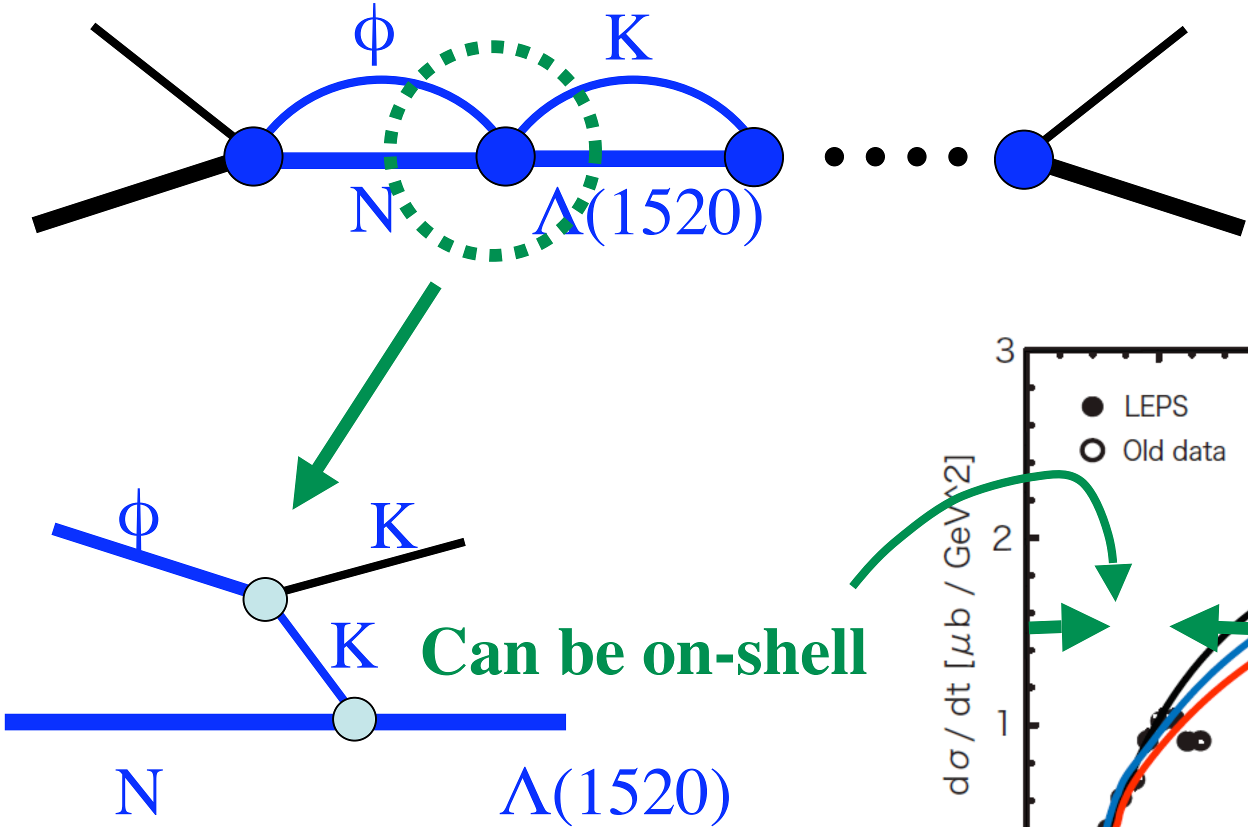
- Increasing as energy is increased
- Forward peak

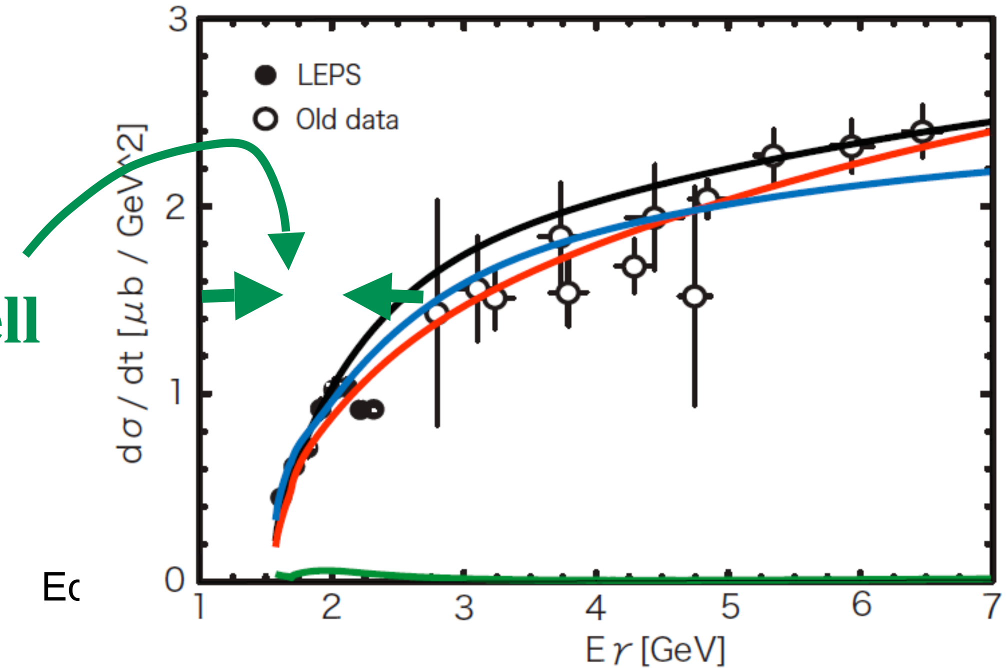
Coupled channels for the bump?

The importance was also emphasized by Shklyar for N*(1670)

γN --> ϕN, $K\Lambda(1520)$, ($K\Lambda$, $K\Sigma$) --> ϕN

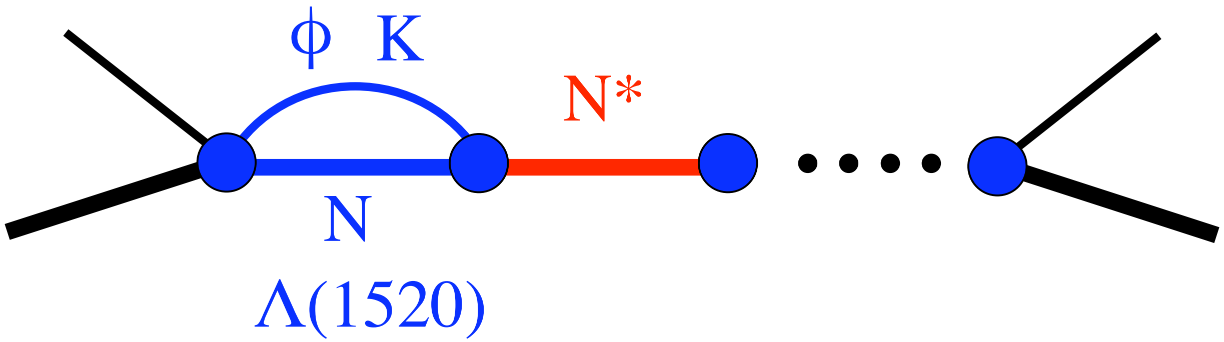
Ozaki-Nagahiro-Hosaka-Scholten





Resonance?

Titov, Lee, PRC, 065205 (2003)



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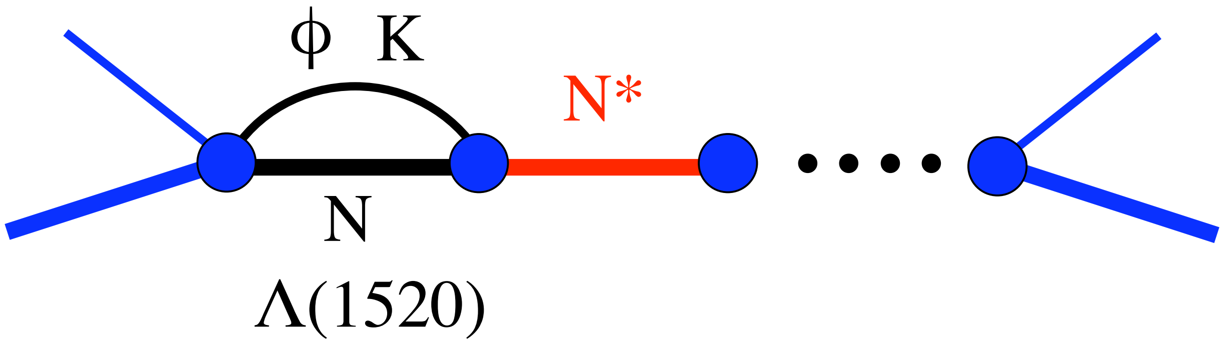

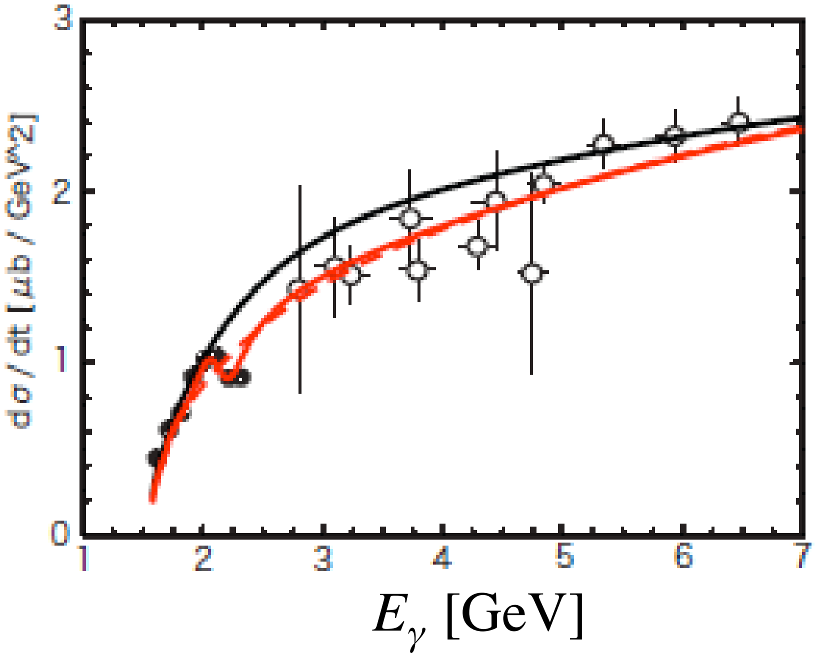

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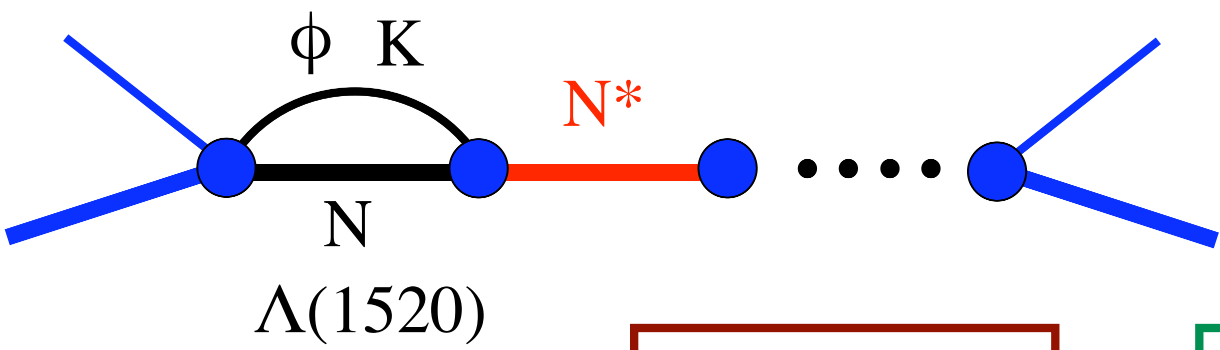
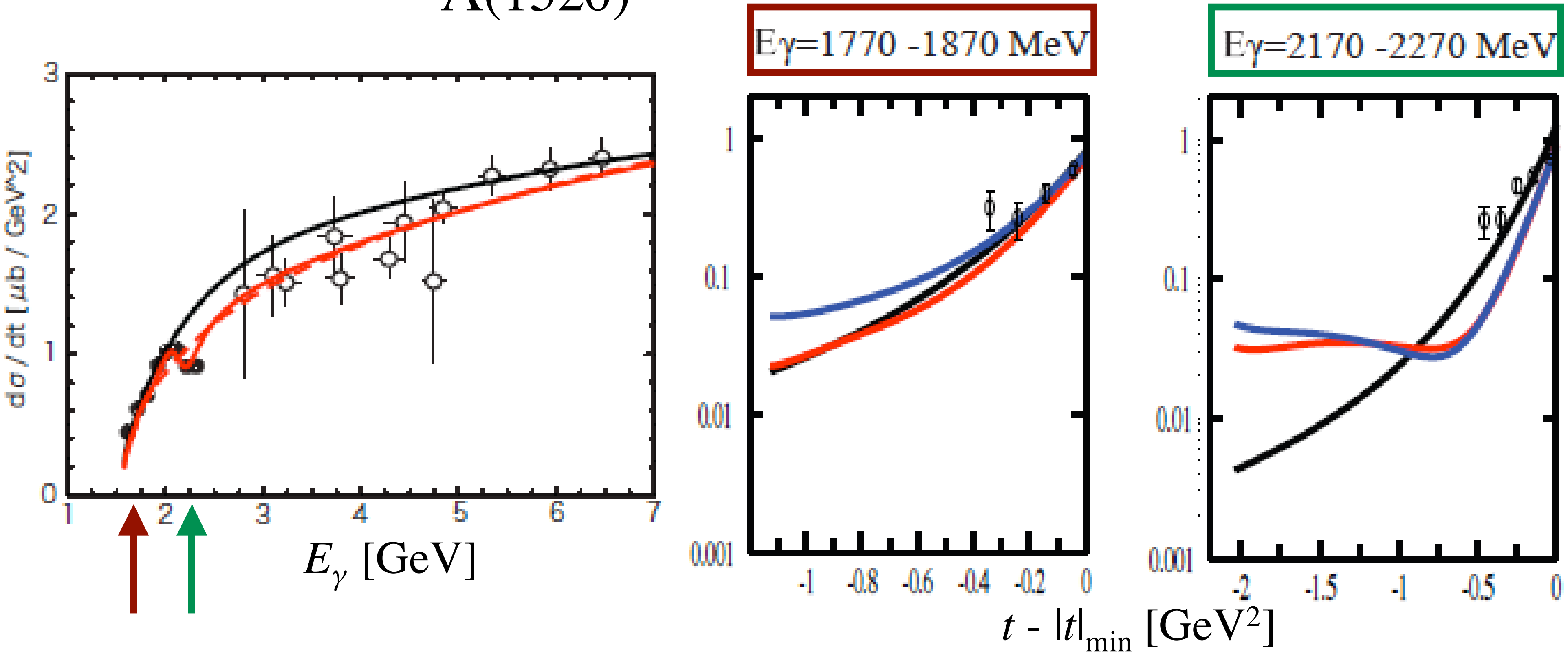




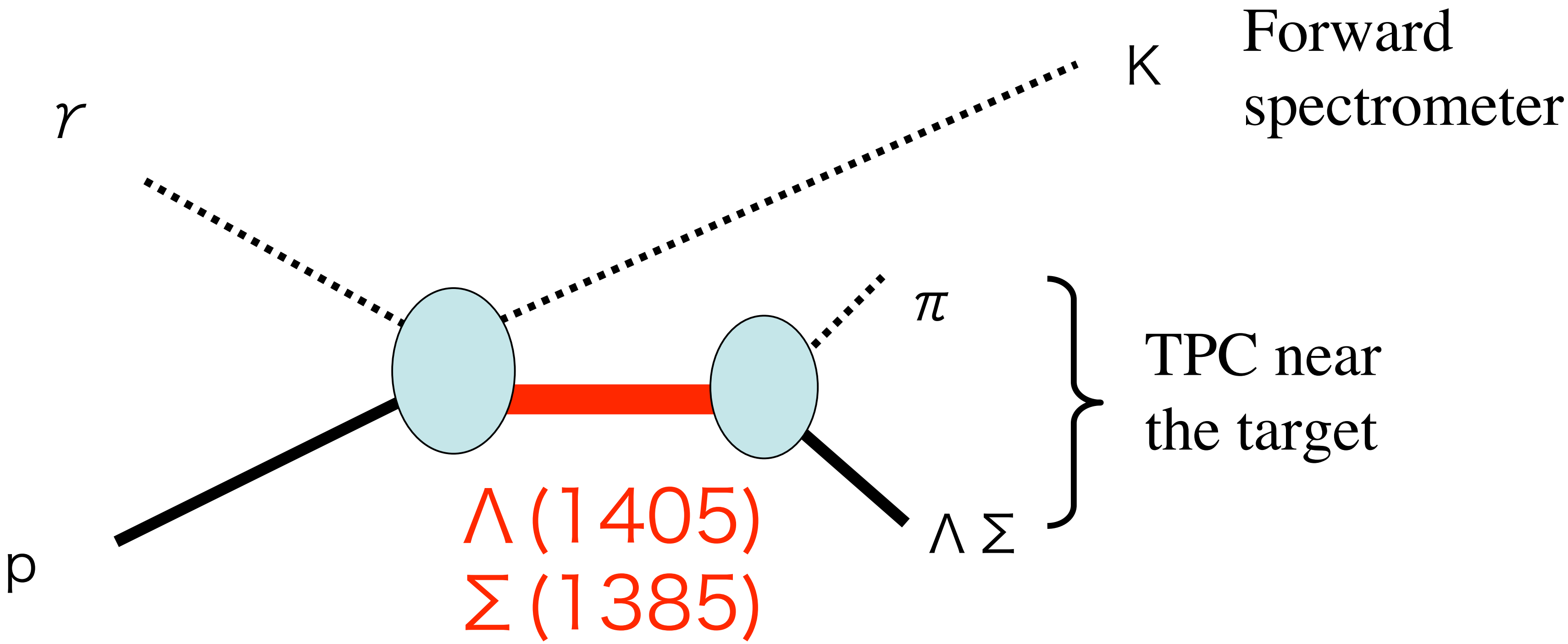
Φ production seems dominated by Pomeron

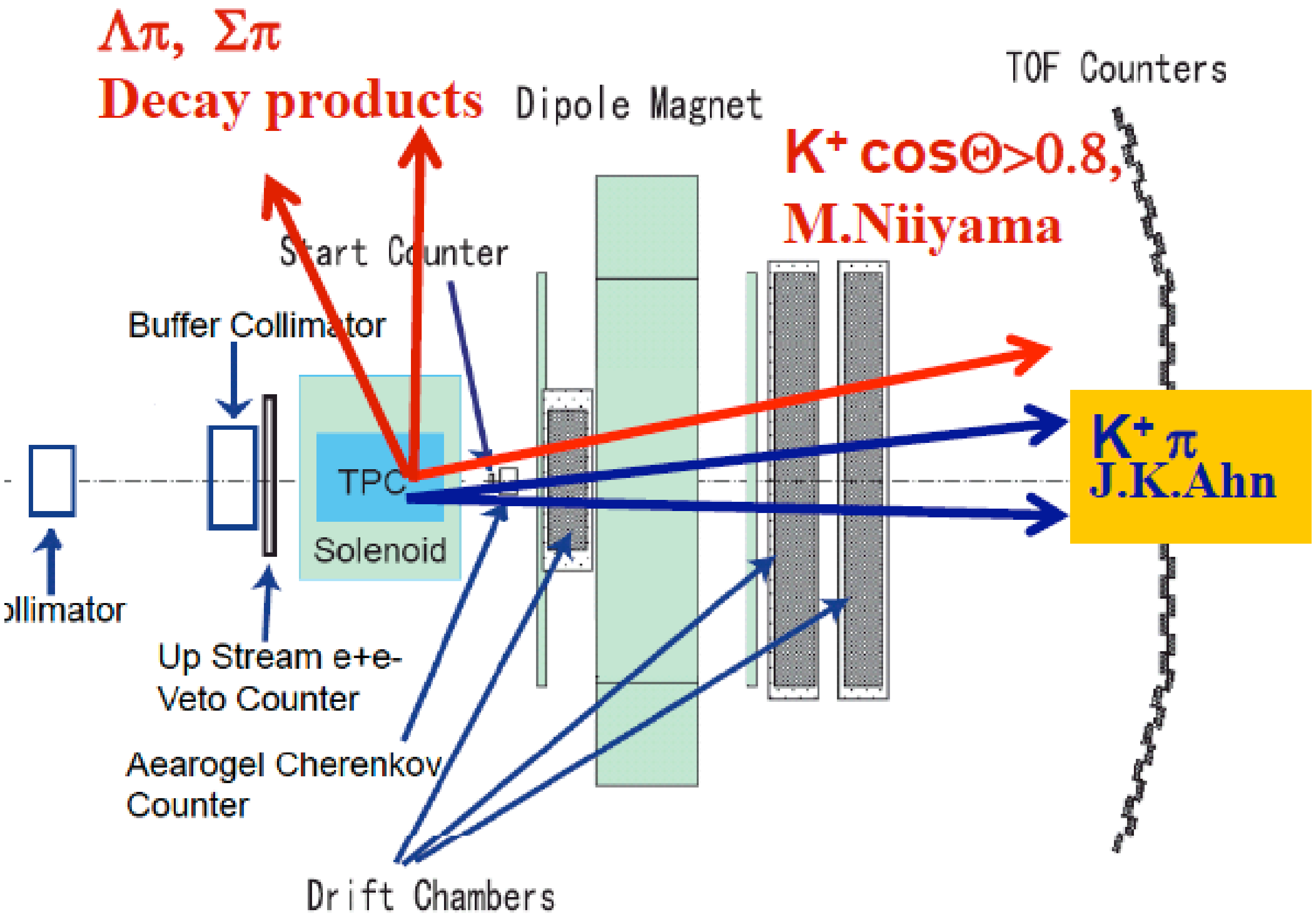
Coupled channel effects are not important

N* is a possible candidate
to explain the bump/dip near the threshold,

(4) Λ(1405)

Niiyama et al,
Phys.Rev.C78:035202,2008





Σ(1385) photoproduction

$$\gamma\, p \rightarrow K^{+}\, \Sigma(1385) \rightarrow K^{+}\Lambda\, \pi^{0} \rightarrow K^{+}\, p\pi^{-}\, \pi^{0}$$

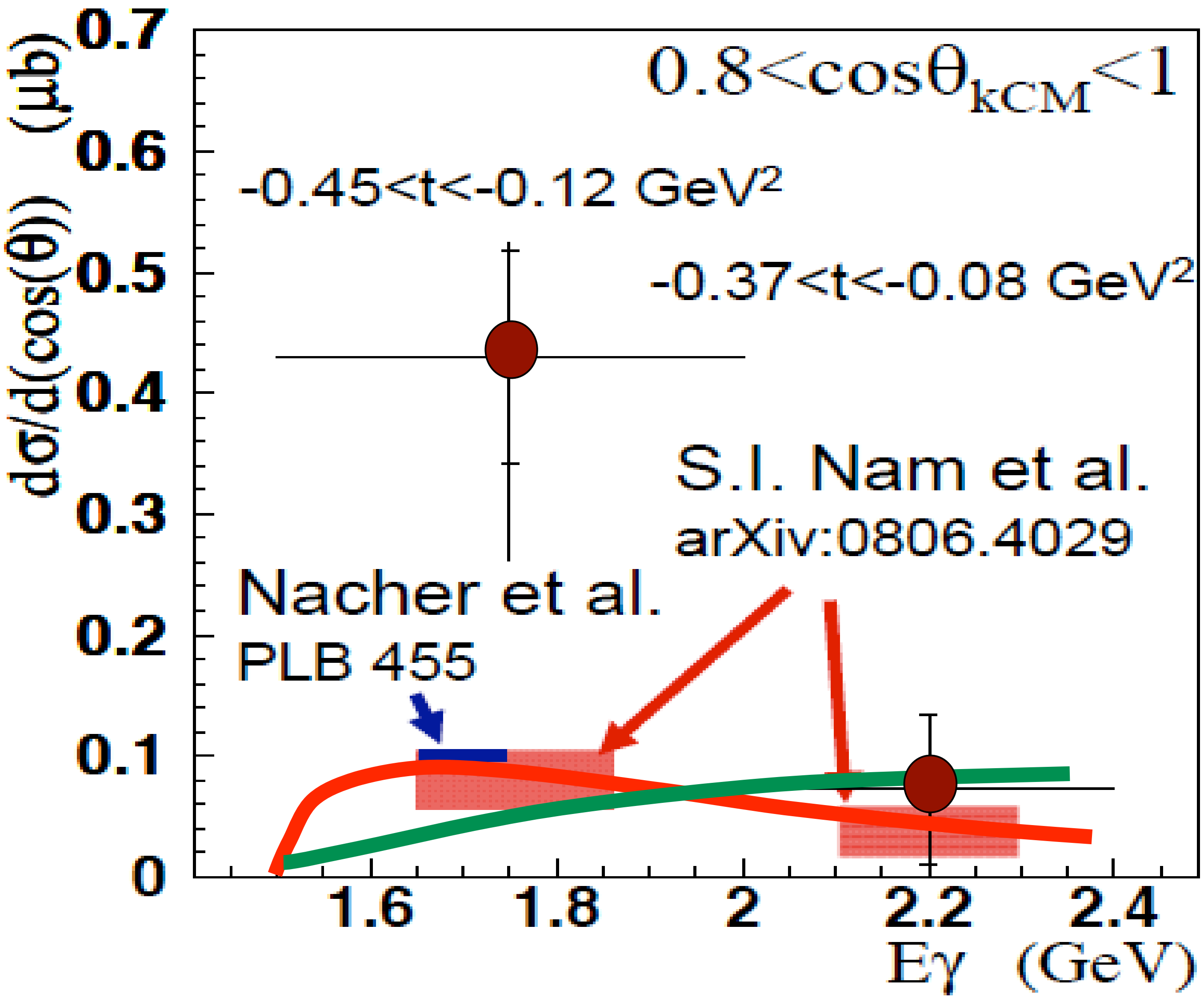
spectrometer (K^+) TPC ($p\pi^-$)

Λ(1405) production

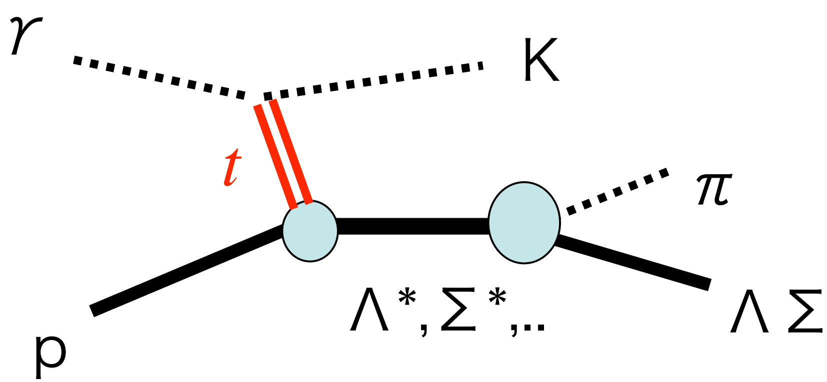
Spectrometer TPC

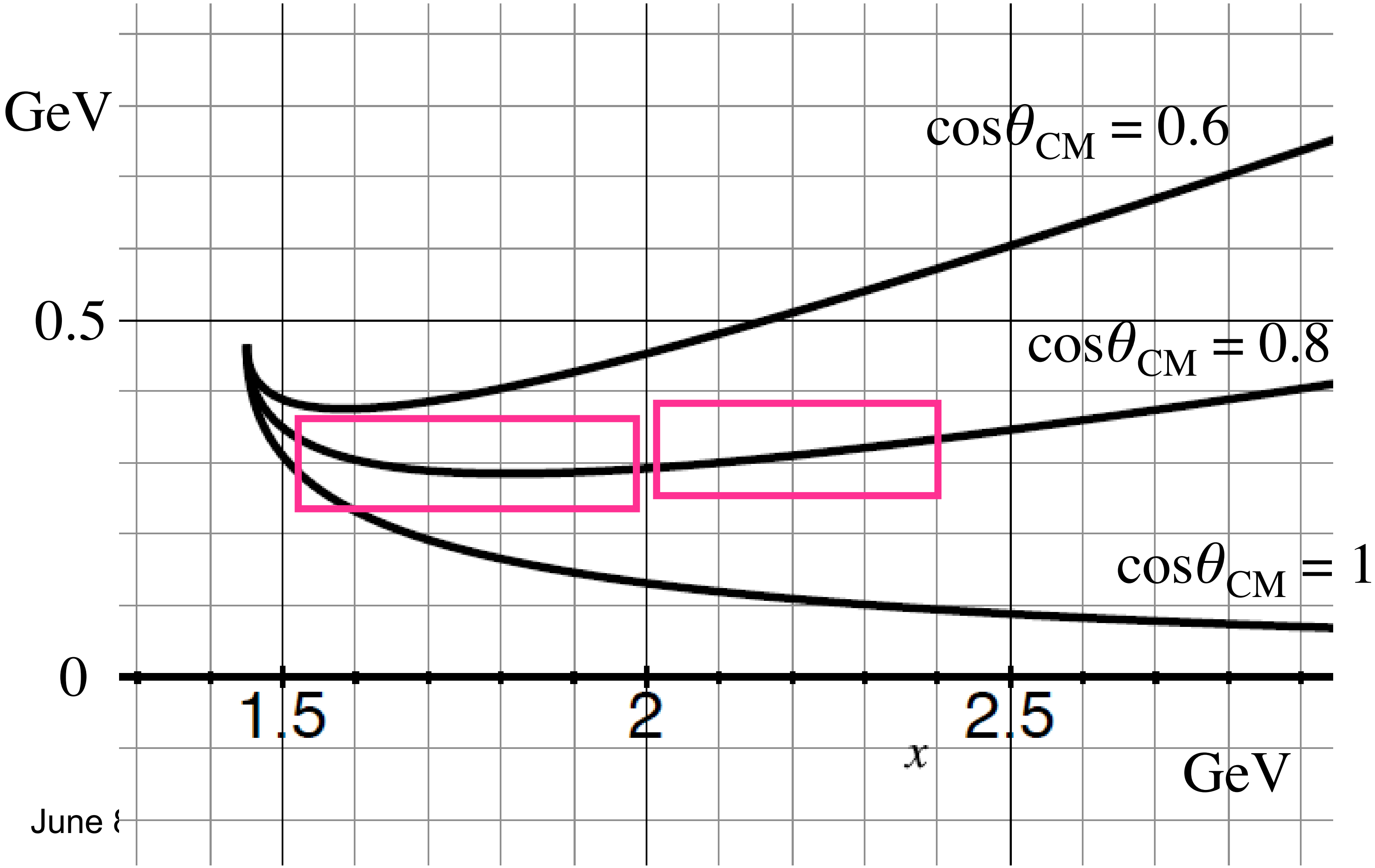
$$\gamma\, p \rightarrow K^{+}\, \Lambda(1405) \rightarrow K^{+}\Sigma^{\pm}\, \pi^{\mp} \rightarrow K^{+}\, \pi^{+}\, \pi^{-}\, n$$

Unexpected energy dependence



$|t|^{1/2}$ vs E_γ





Summary

- Exotics may have *correlations*

  $q\bar{q}$, qq, qqq

  Question; how are they realized and observed

  We are still on the way to the answer

- Λ(1520) can be explained by standard react. mechanism

  Structure information is in various coupling constants
- Role of QCD anomaly through meson cloud in KΛ prod.
- Coupled channels are not important for ϕ prod.

  Possible explanation by N^* ~ 2200 MeV
- Λ(1405) seems very unusual