Five-quark components in excited baryons

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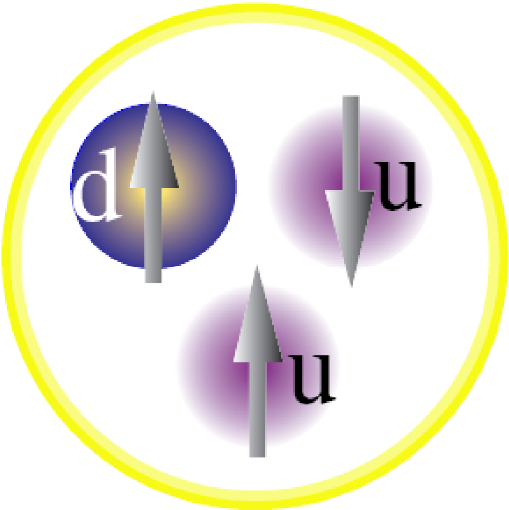
Outline:

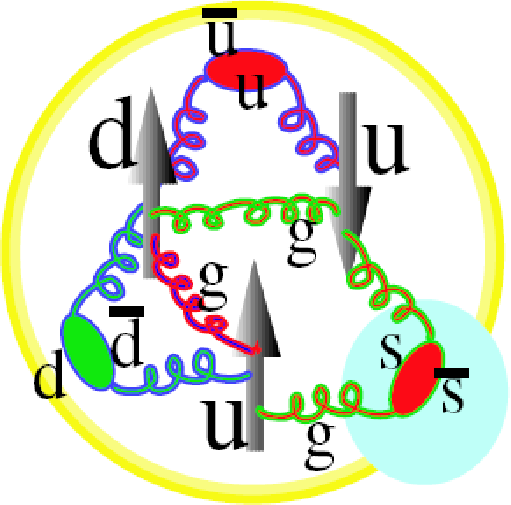
- Introduction -- 5-quark components in the proton
- New scheme for N*(1535) and its1/2$^-$ nonet partners with large 5-quark components
- Evidence for the predicted Σ*(1/2$^-$)
- 5-quark components in other baryons
- 4-quark components in mesons
- Conclusion

1. Introduction: 5-quark components in the proton

Classical picture of the proton

Constituent Quarks	Parton Distributions





($Q^2 = 0$ GeV^2)	($Q^2 > 1$ GeV^2)
baryon octet	structure functions
masses,magn. momenta	momentum, spin
	$\bar{u}(x) = \bar{d}(x)$, $\bar{s}(x) = s(x)$
1964-1974	**1974–1992**

Flavor asymmetry of light quarks in the nucleon sea

Deep Inelastic Scattering (DIS) + Drell-Yan (DY) process

→ $\bar{d} - \bar{u} \sim 0.12$ for a proton

Garvey&Peng, Prog. Part. Nucl. Phys.47, 203 (2001)

Table 1. Values of the integral $\int_0^1 [\bar{d}(x) - \bar{u}(x)]dx$ determined from the DIS, semi-inclusive DIS, and Drell-Yan experiments.

Experiment	$\langle Q^2 \rangle$ (GeV^2/c^2)	$\int_0^1 [\bar{d}(x) - \bar{u}(x)]dx$
NMC/DIS	4.0	0.147 ± 0.039
HERMES/SIDIS	2.3	0.16 ± 0.03
FNAL E866/DY	54.0	0.118 ± 0.012

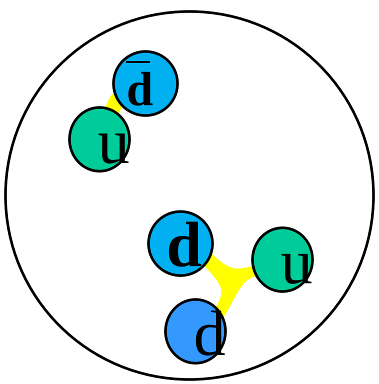
Two major theoretical schemes for $\bar{d} - \bar{u} \sim 0.12$

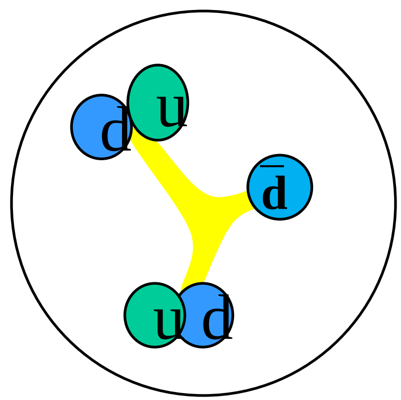
Meson cloud picture: Thomas, Speth, Henley, Meissner, Miller, Weise, Oset, Brodsky, Ma, …

$$| p > \sim | uud > + \varepsilon_1 | n (udd) \pi^+ (\bar{d}u) >$$
$$+ \varepsilon_2 | \Delta^{++} (uuu) \pi^- (\bar{u}d) > + \varepsilon' | \Lambda (uds) K^+ (\bar{s}u) > \ldots$$

Penta-quark picture : Riska, Zou, Zhu, …

$$| p > \sim | uud > + \varepsilon_1 | [ud][ud] \bar{d} > + \varepsilon' | [ud][us] \bar{s} > + \ldots$$





Detailed balance model : Zhang, Ma, Zou, Yang, Alberg, Henley

$$uud \Leftrightarrow uudg \quad \begin{cases} uudd\bar{d} & 1/2 \\ uudu\bar{u} & 1/3 \end{cases} \quad \cdots\cdots\cdots\cdots$$

1 : 1

$$p = 0.168\ (uud) + 0.168\ (uudg) + 0.084\ (uudd\bar{d}) + 0.056\ (uudu\bar{u}) + 0.084\ (uudgg) + \ldots$$

$$\bar{d} - \bar{u} \sim 0.124$$

$(uud+ng)$ 50% $(uudd\bar{d}+ng)$ 22.4% $(uudu\bar{u}+ng)$ 15.0%

With ~25% $\bar{q}qqqq$ components in the proton, the "spin crisis" and single spin asymmetry may also be naturally explained.

An-Riska-Zou, PRC73 (2006) 035207; F.X.Wei, B.S.Zou, hep-ph/0807.2324

$$\Delta_u = 0.85 \pm 0.17$$

$$\Delta_d = -(0.33 \sim 0.56)$$

$$\Delta_u = \frac{4}{3}|A_{3q}|^2$$

$$\Delta_d = -\frac{1}{3}(1 - P_{s\bar{s}})$$

$$\Delta L_q = \frac{4}{3}(P_{d\bar{d}} + P_{s\bar{s}})$$

We must go beyond the simple 3q models,

meson cloud vs penta-quark not settled yet.

2. New scheme for N*(1535) and its $1/2^-$ nonet partners

- **Mass order reverse problem for the lowest excited baryons**

  uud (L=1) ½ - ~ N*(1535) **should be the lowest**

  uud (n=1) ½ + ~ N*(1440)

  uds (L=1) ½ - ~ Λ*(1405)

  harmonic oscillator (2n + L + 3/2) ħω

- **Strange decays of N*(1535) :** **PDG → large $g_{N^*N\eta}$**

  $J/\psi \to \bar{p}N^* \to \bar{p}\,(K\Lambda)$ / $\bar{p}\,(p\eta)$ → large $g_{N^*K\Lambda}$

  Liu&Zou, PRL96 (2006) 042002; Geng,Oset,Zou&Doring, PRC79 (2009) 025203

  $\gamma p \to p\eta'$ & $pp \to pp\eta'$ → large $g_{N^*N\eta'}$

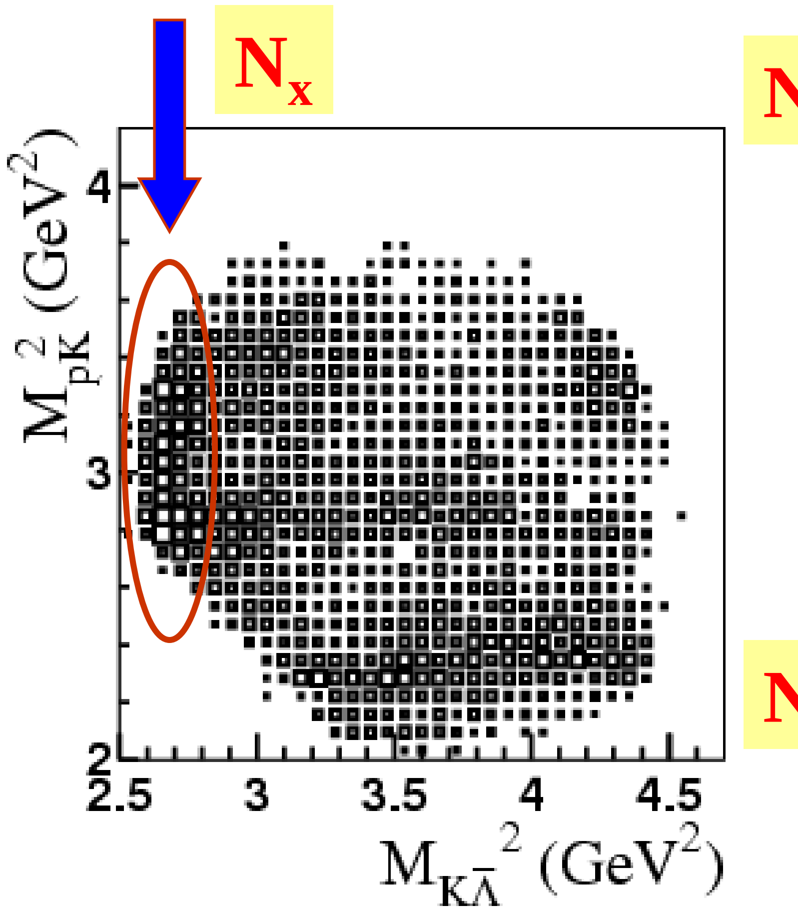
  M.Dugger et al., PRL96 (2006) 062001; Cao&Lee, PRC78(2008) 035207

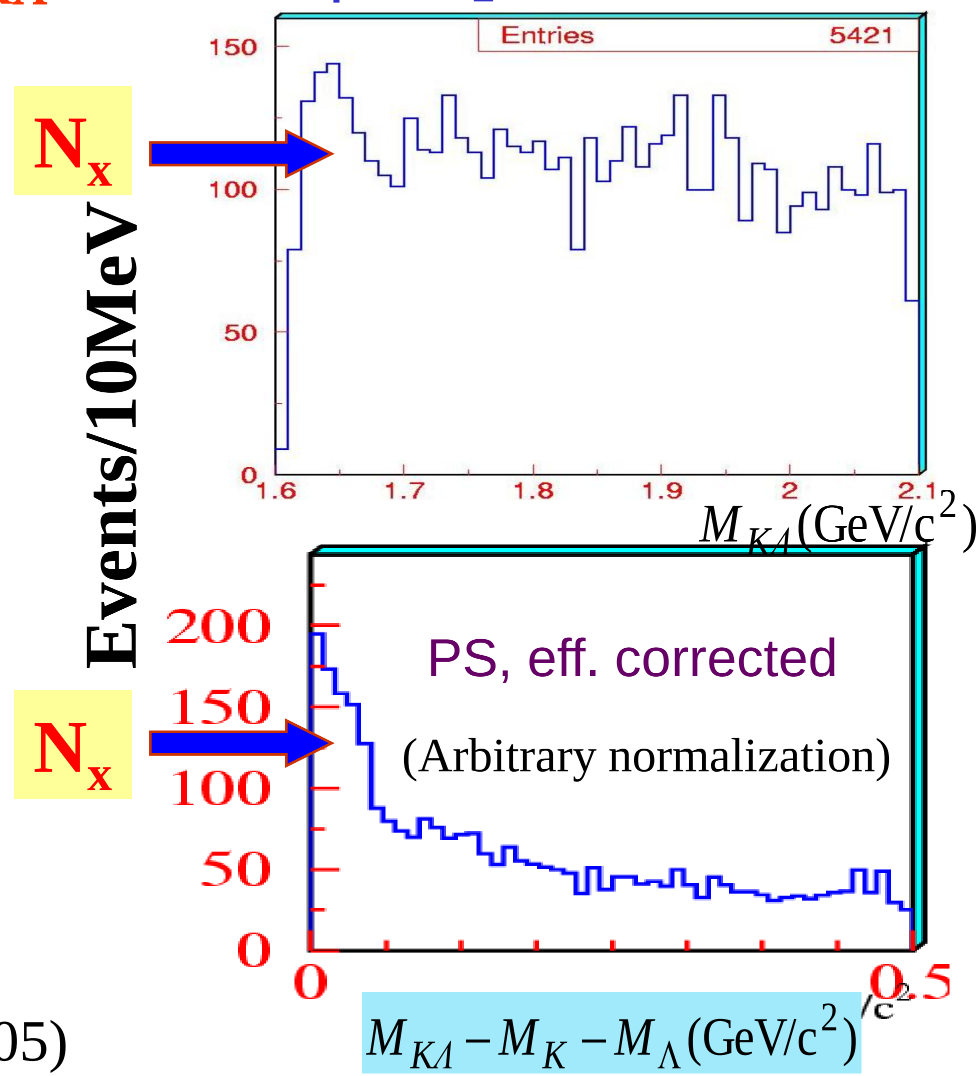
  $\pi^- p \to n\phi$ & $pp \to pp\phi$ & $pn \to d\phi$ → large $g_{N^*N\phi}$

  Xie, Zou & Chiang, PRC77(2008)015206; Cao, Xie, Zou & Xu, PRC80(2009)025203

Strange properties of N*(1535)

Evidence for large $g_{N^*K\Lambda}$ from $J/\psi \rightarrow p\, K^- \bar{\Lambda}$ + c.c.





BES, Int. J. Mod. Phys. A20 (2005)

a) Assuming N_x to be purely N*(1535) :

B.C. Liu, B.S. Zou, PRL96 (2006) 042002; PRL98 (2007) 039102

From relative branching ratios of

$J/\psi \rightarrow p\ \bar{N}^* \rightarrow p\ (K^-\ \bar{\Lambda})\ /\ p\ (\ \bar{p}\eta)$

$g_{N^*K\Lambda} / g_{N^*p\eta} / g_{N^*N\pi} \sim 2 : 2 : 1$

b) N_x as dynamical generated with unitary chiral theory:

N*(1535) + non-resonant part

L.S.Geng, E.Oset, B.S. Zou, M.Doring, PRC79 (2009) 025203

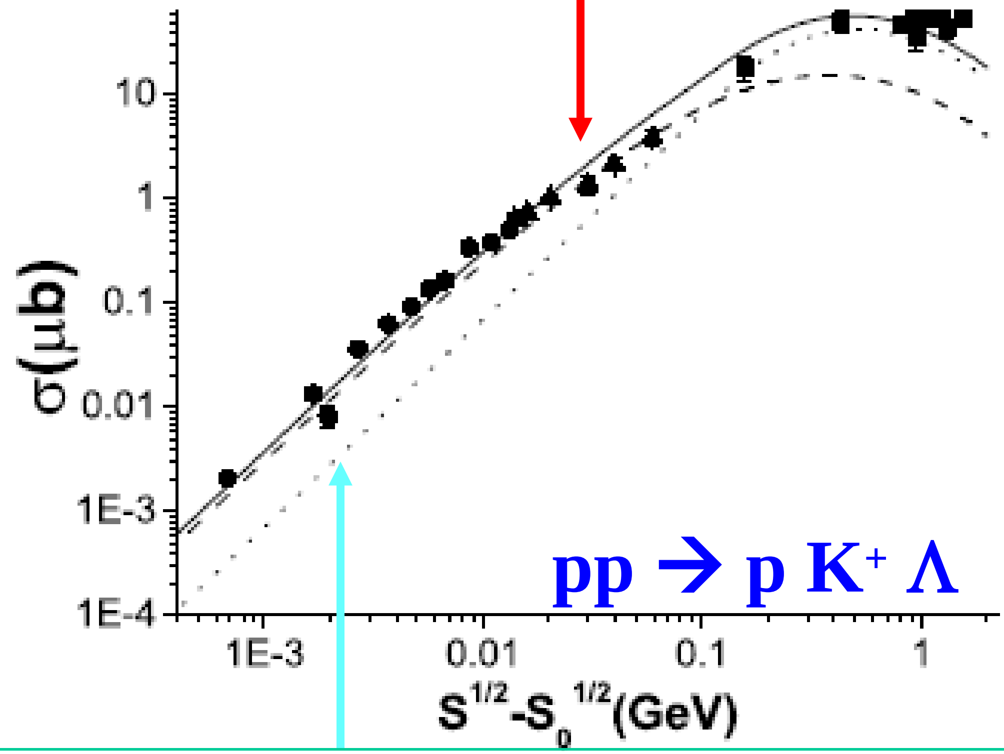
$g_{N^*K\Lambda} / g_{N^*p\eta} / g_{N^*N\pi} \sim 1.2 : 2 : 1$

Phenomenology : Large $g_{N^*K\Lambda} \rightarrow$ large $s\bar{s}$ in N*(1535)

$\bar{s}$[su][ud] or $K\Lambda$-$K\Sigma$ state

Evidence for large $g_{N^*K\Lambda}$ from $pp \to p K^+ \Lambda$

Total cross section and theoretical results with N*(1535), N*(1650), N*(1710), N*(1720)
B.C.Liu, B.S.Zou, Phys. Rev. Lett. 96 (2006) 042002

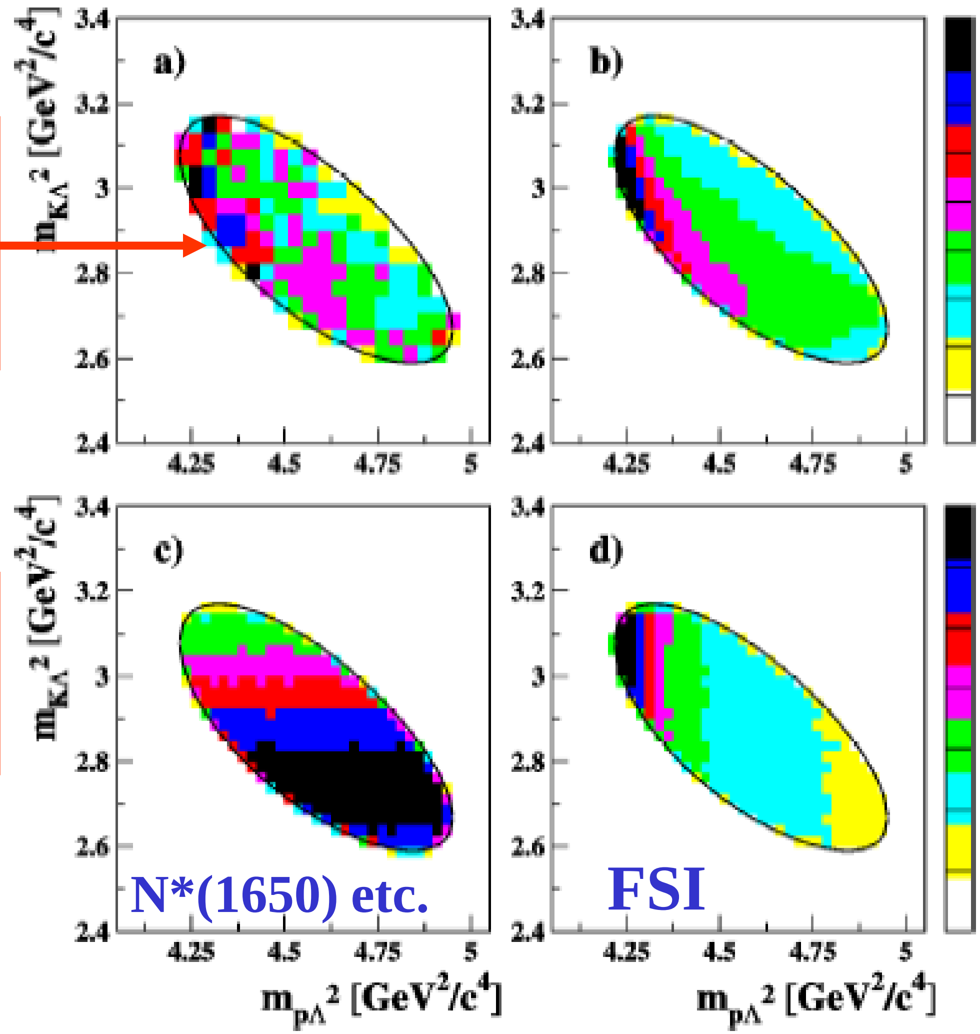


Tsushima,Sibirtsev,Thomas, PRC59 (1999) 369, without including N*(1535)

FSI vs N*(1535) contribution in pp → p K⁺ Λ

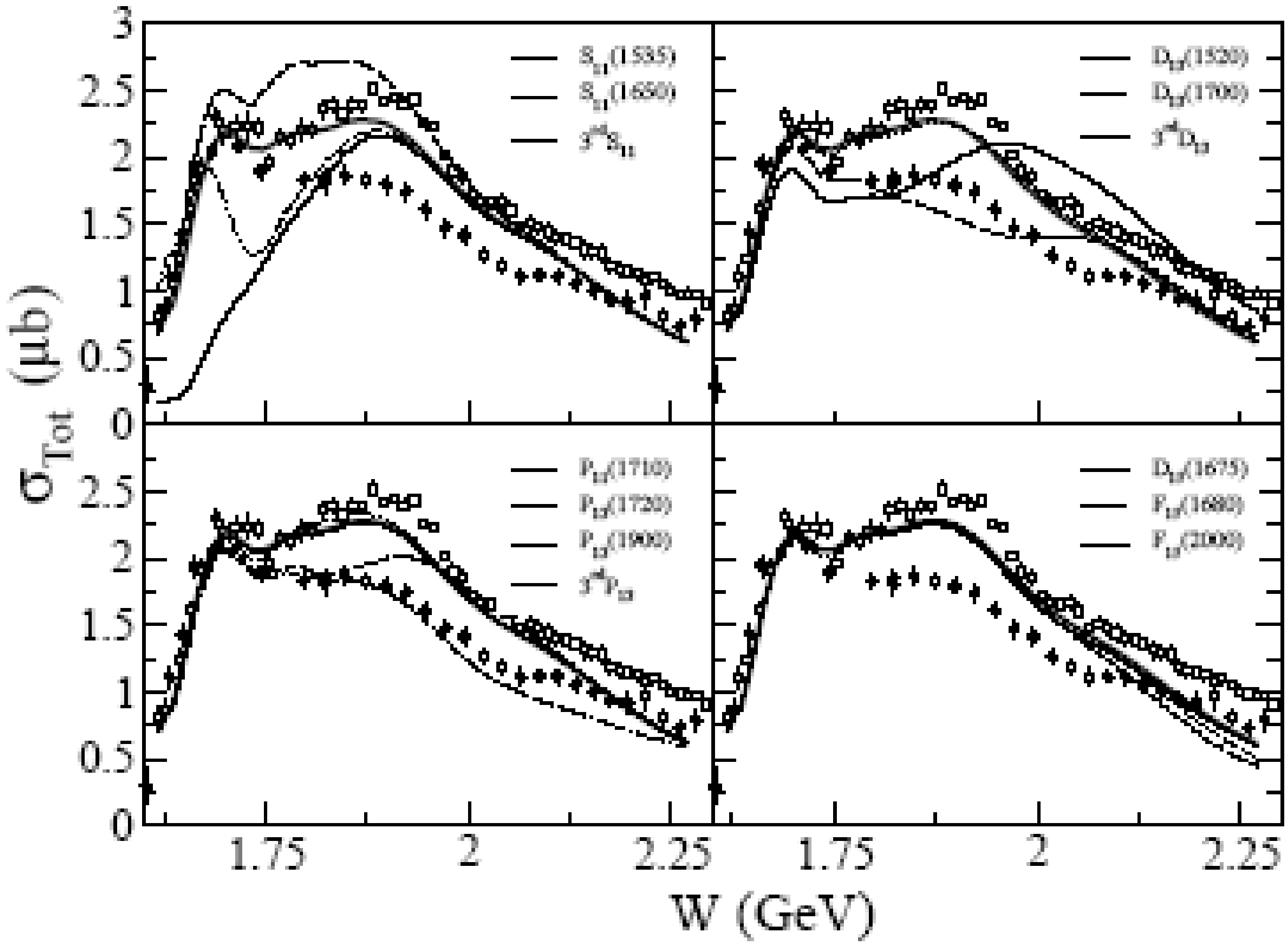
B.C.Liu & B.S.Zou, Phys. Rev. Lett. 98 (2007) 039102 (reply)
A.Sibirtsev et al., Phys. Rev. Lett. 98 (2007) 039101 (comment)

COSY-TOF data
S. Abdel-Samad *et al.*,
Phys.Lett.B632:27(2006)

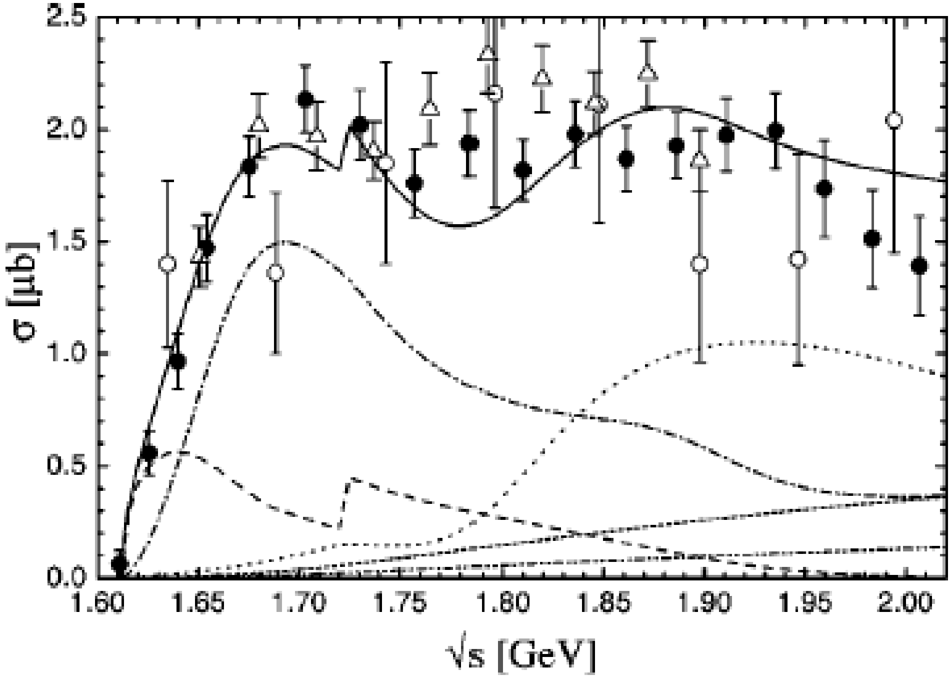


Both FSI & N*(1535) are needed !

Evidence for large $g_{N^*K\Lambda}$ from $\gamma\, p \rightarrow K^+ \Lambda$



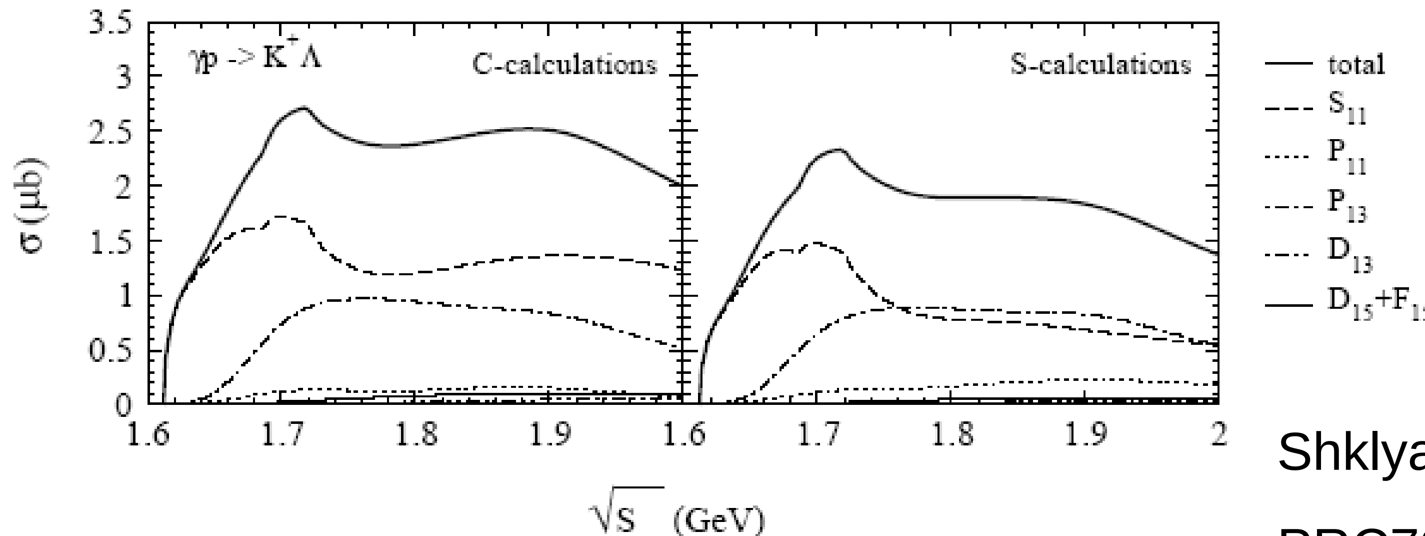
B. Julia-Diaz, B. Saghai, T.-S.H. Lee, F. Tabakin, Phys. Rev. C **73**, 055204 (2006)



G.Penner&U.Mosel,
PRC66 (2002) 055212

Partial wave decomposition
For the fit to SAPHIR92-94
Data

Dashed line : 1/2 -
Dot-dashed line : 3/2+



Shklyar,Lenske&Mosel,

PRC72 (2005) 015210

Evidence for small $g_{N^*K\Sigma}$ from $pp \rightarrow p K^+\Lambda$ / $pp \rightarrow p K^+\Sigma^0$

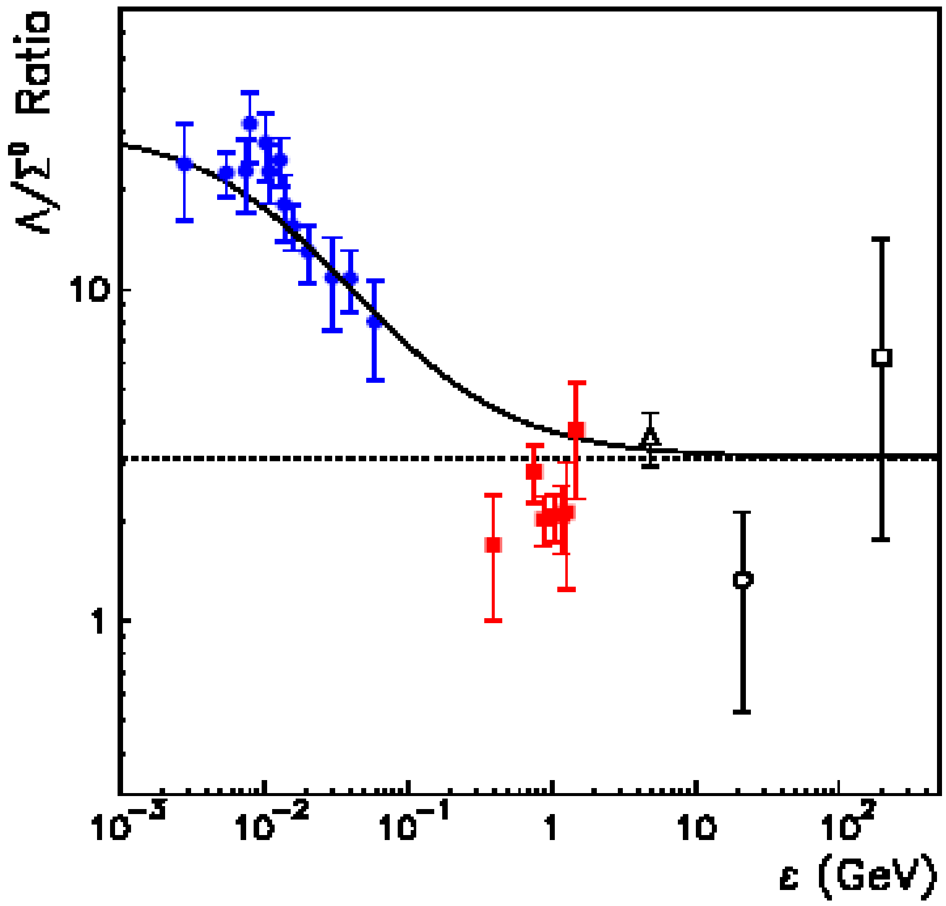


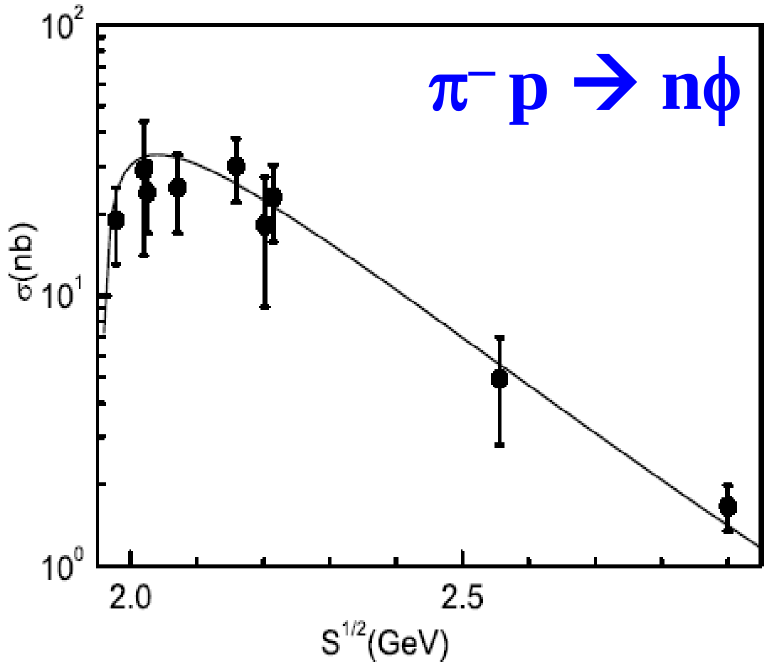
Fig. 3. The Λ/Σ^0 cross-section ratio as a function of the excess energy ϵ. The solid circles show the ratio obtained for the $pp \rightarrow K^+\Lambda p$ and $pp \rightarrow K^+\Sigma^0 p$ reactions at COSY [2]. Solid

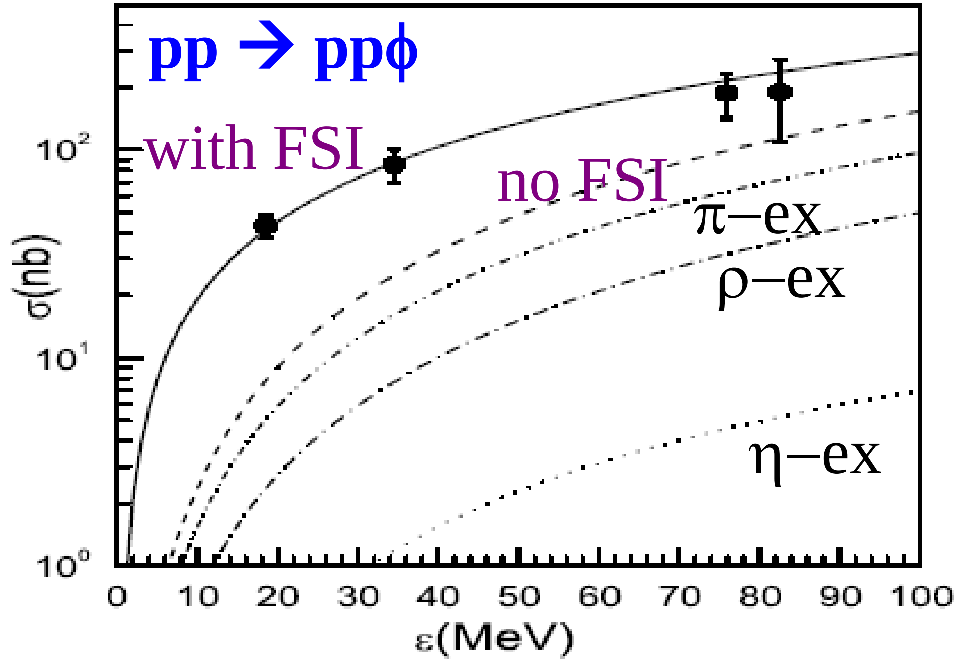
A.Sibirtsev et al., EPJA29 (2006) 363

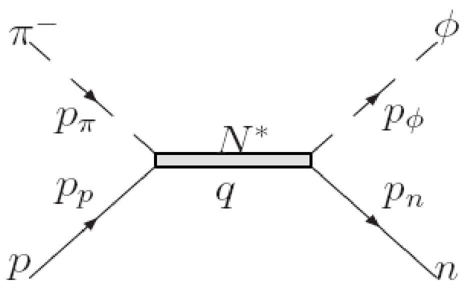
[2] P.Kowina et al., EPJA22 (2004) 293

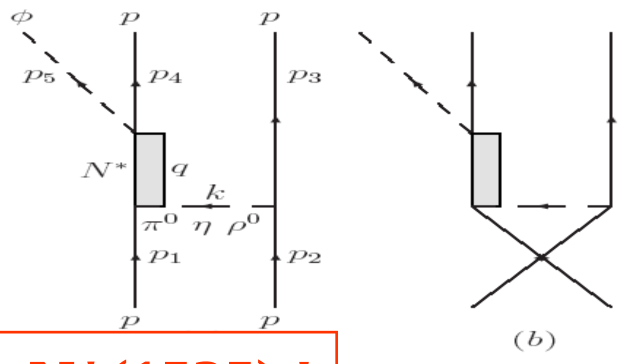
Evidence for large $g_{N^*N\phi}$ from $\pi^- p \to n\phi$, $pp \to pp\phi$ & $pn \to d\phi$

Xie, Zou & Chiang, PRC77(2008)015206; Cao, Xie, Zou &Xu, PRC80(2009)025203



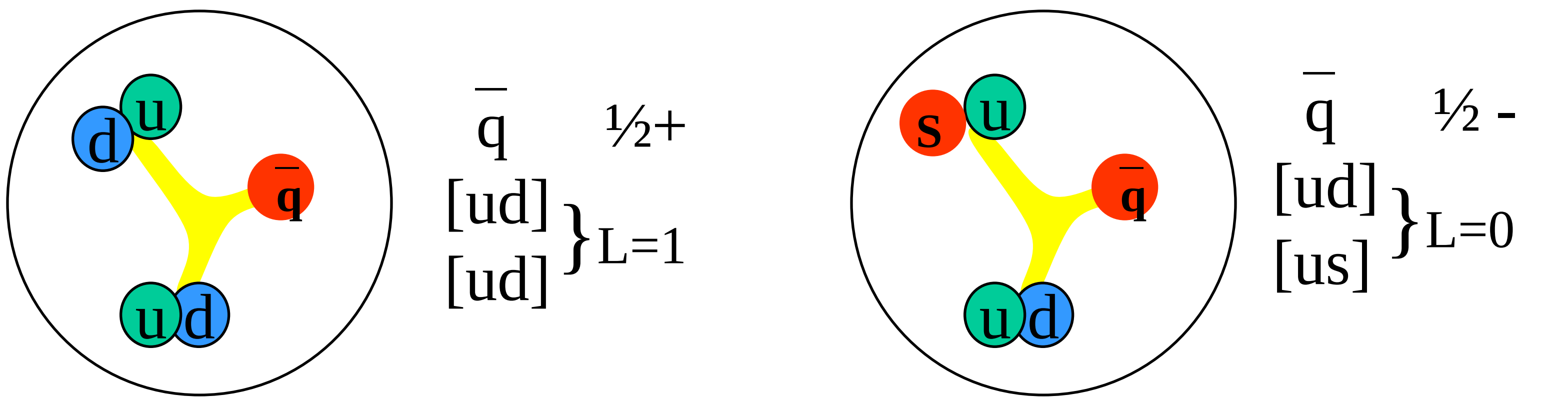






Evasion of OZI rule by N*(1535) !

New Scheme for N*(1535) and its 1/2⁻ nonet partners



Zhang et al, hep-ph/0403210

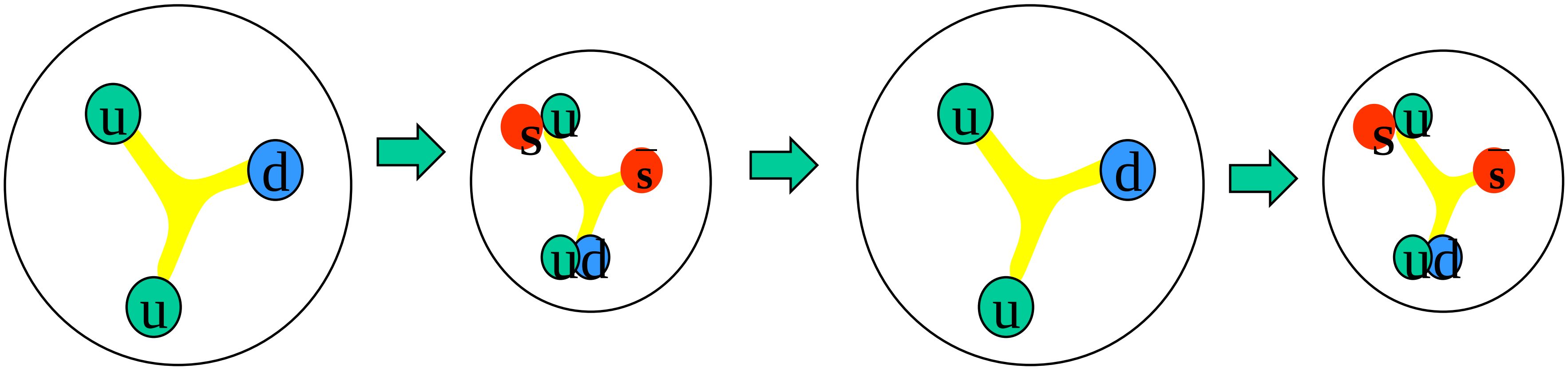
N*(1535) ~ uud (L=1) + ε [ud][us] $\bar{s}$ + …

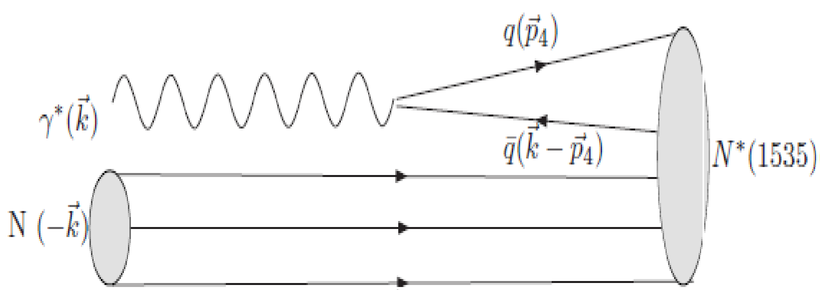
N*(1440) ~ uud (n=1) + ξ [ud][ud] $\bar{d}$ + …

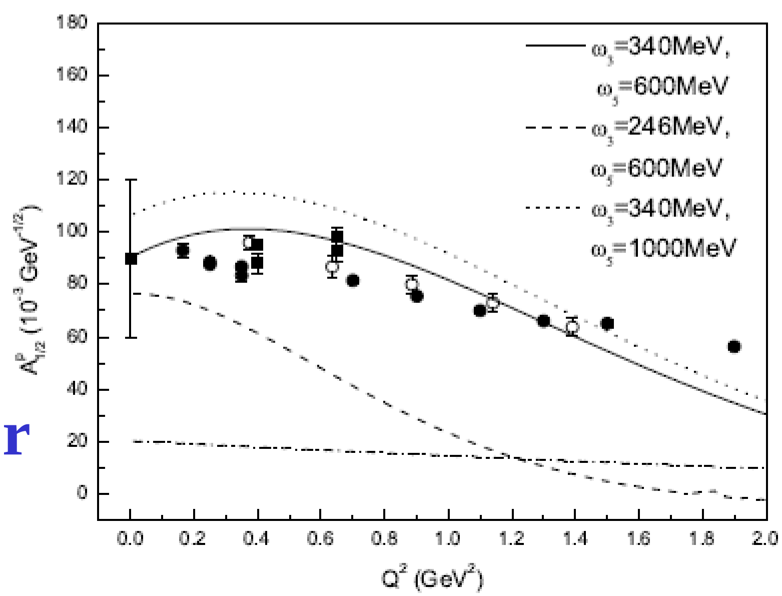
Λ*(1405) ~ uds (L=1) + ε [ud][su] $\bar{u}$ + …

N*(1535): [ud][us] $\bar{s}$ → larger coupling to Nη, Nη', Nϕ & KΛ, weaker to Nπ & KΣ, and heavier !

The breathing mode for the N*(1535)





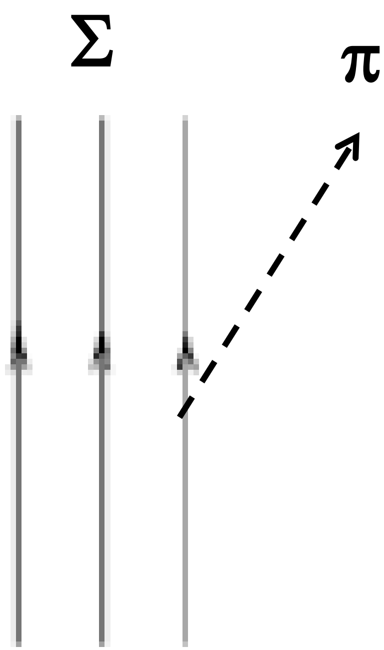


Important role for N* EM form factor

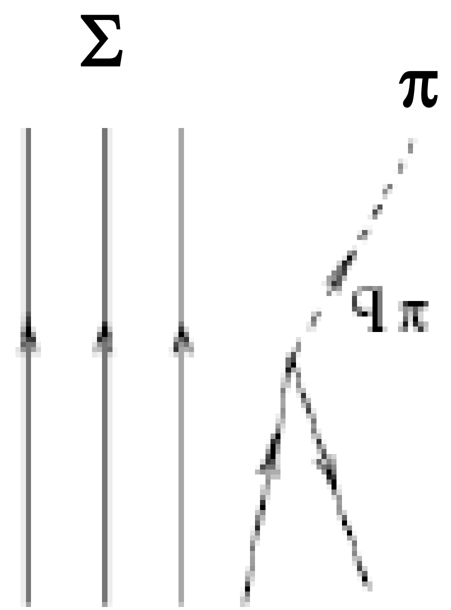
An & Zou, EPJA39(2009)195

50% 5q components in Λ*(1405)
to reproduce Γ(Λ*→Σπ) = 50 MeV

An, Saghai,Yuan,He, PRC81(2010)045203



Λ*(1405)



Λ*(1405)

The new scheme for the $1/2^-$ nonet predicts:

Λ^* [us][ds] $\bar{s}$ ~ 1575 MeV

Σ^* [us][du] $\bar{d}$ ~ 1360 MeV

Ξ^* [us][ds] $\bar{u}$ ~ 1520 MeV

Prediction of other unquenched models:

(1) 5-quark model   Helminen & Riska, NPA699(2002)624

$\Sigma^*(1/2^-) \sim \Lambda^*(1/2^-)$

(2) K Λ-KΣ dynamics   Weise, Oset et al.

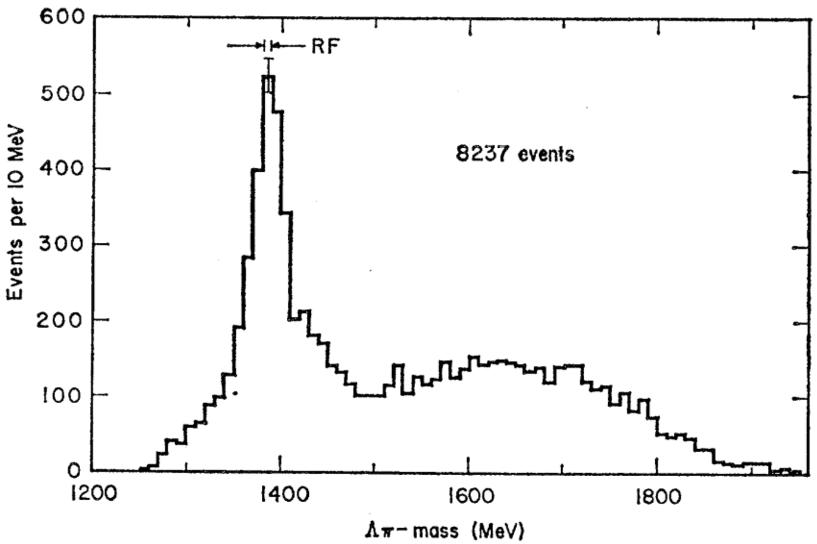
broad non-resonant $\Sigma^*(1/2^-)$ structure

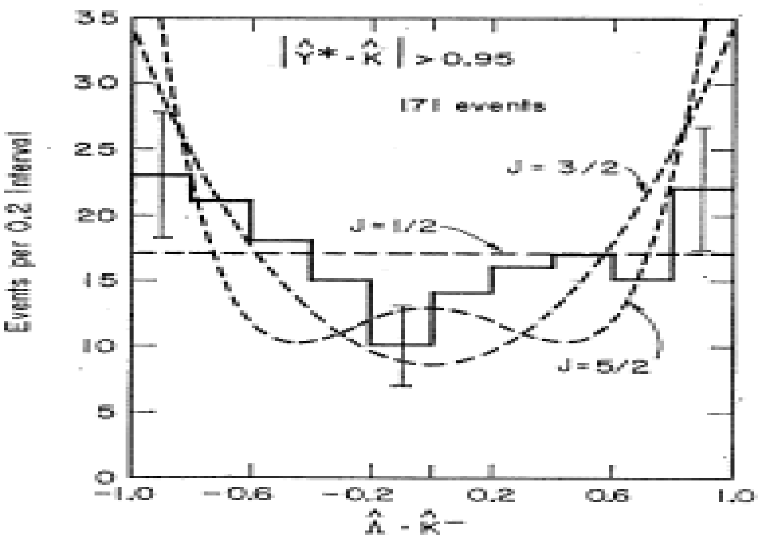
Jido-Oset et al , NPA725(2003)181

Important to look for the $\Sigma^*(1/2^-)$ around 1380 MeV !

3. Evidence for the predicted $\Sigma^*(1/2^-)$

Huwe, PR181(1969)1824

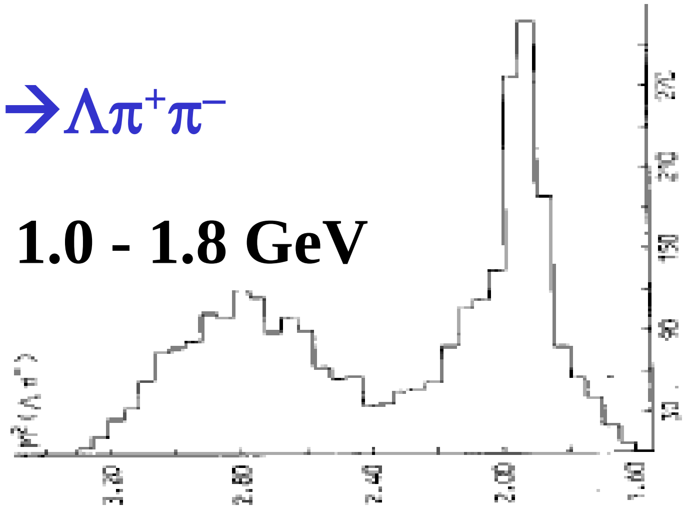


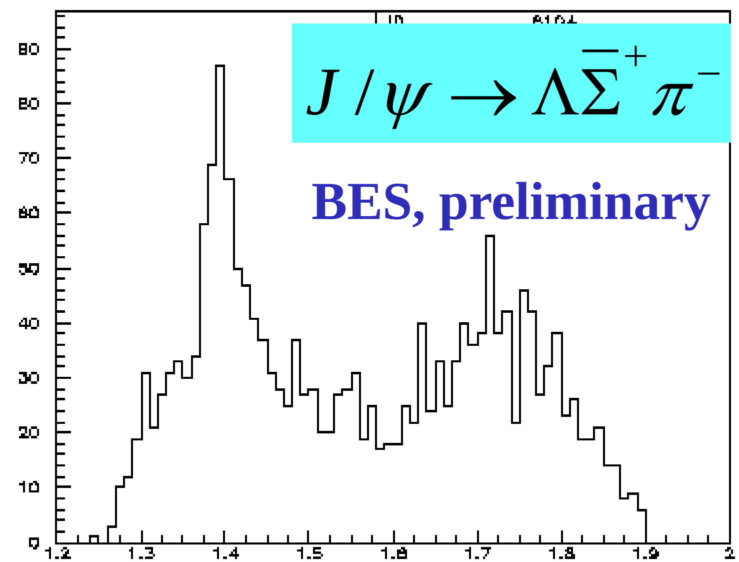


Cameron et al., NPB143(1978)189

$K^- p \rightarrow \Lambda\pi^+\pi^-$

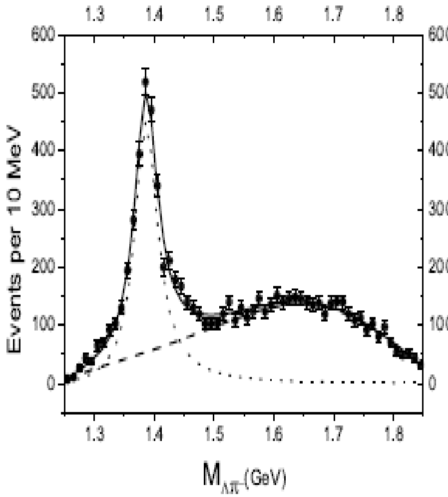
$P_K = 1.0 - 1.8$ GeV

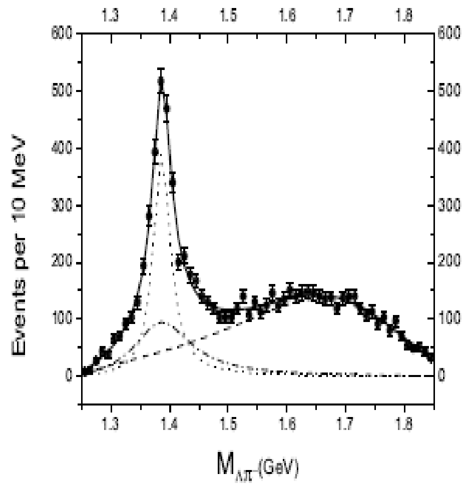


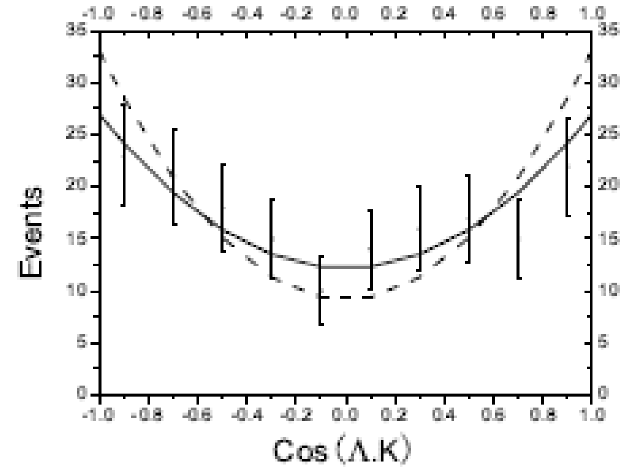


BES, NSTAR04

$M_{\pi\Lambda}$

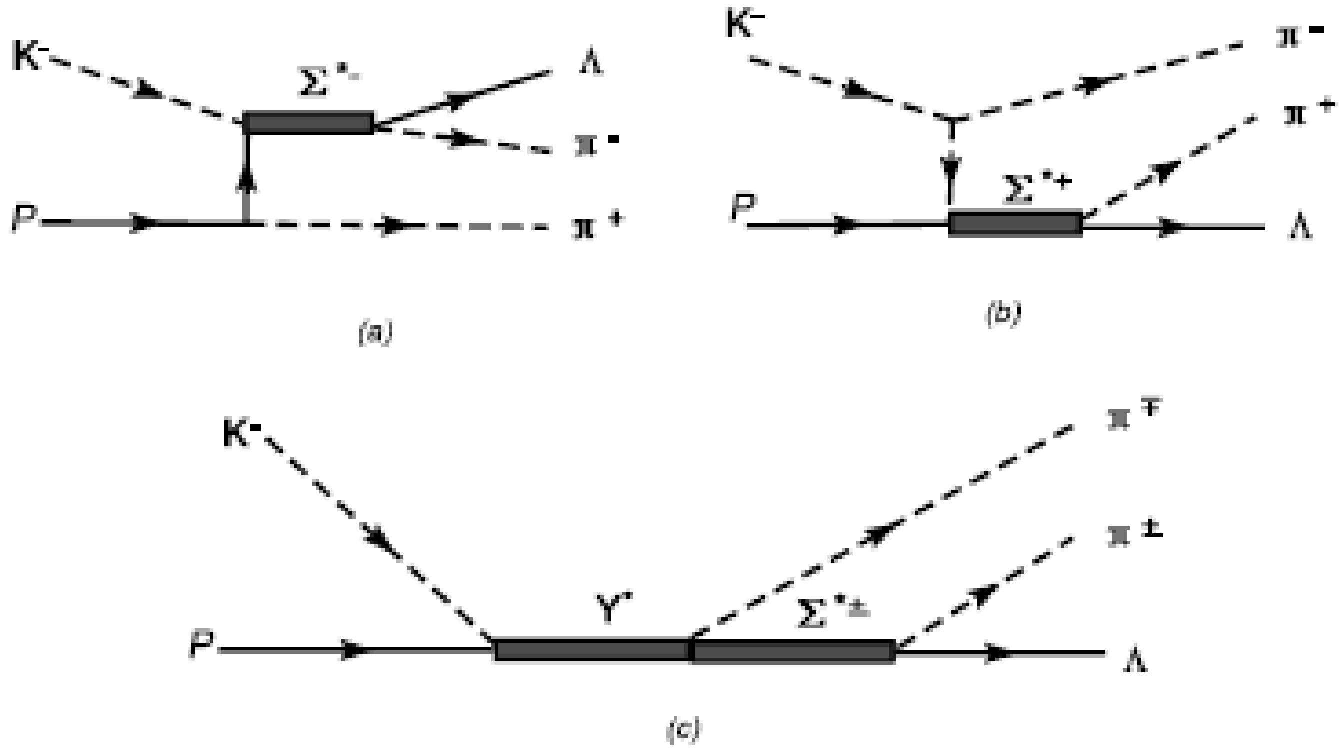






	$M_{\Sigma*(3/2)}$	$\Gamma_{\Sigma*(3/2)}$	$M_{\Sigma*(1/2)}$	$\Gamma_{\Sigma*(1/2)}$	χ^2/ndf(Fig.1)	χ^2/ndf(Fig.2)
Fit1	1385.3 ± 0.7	46.9 ± 2.5			$68.5/54$	$10.1/9$
Fit2	$1386.1^{+1.1}_{-0.9}$	$34.9^{+5.1}_{-4.9}$	$1381.3^{+4.9}_{-8.3}$	$118.6^{+55.2}_{-35.1}$	$58.0/51$	$3.2/9$

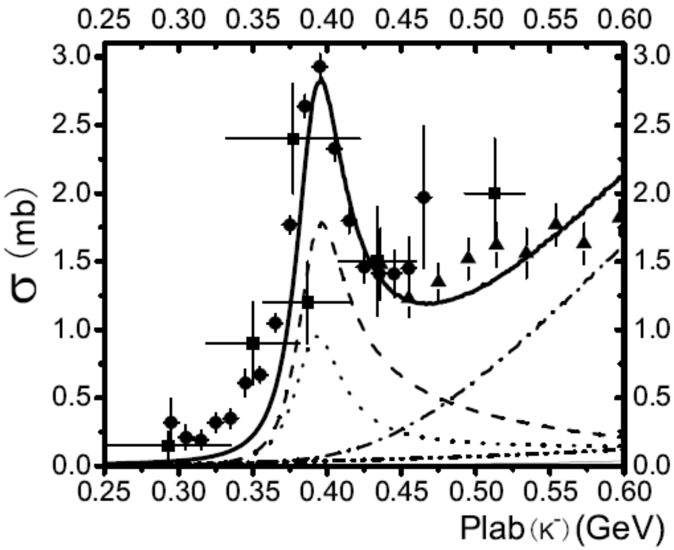
J.J.Wu, S.Dulat, B.S.Zou, PRD80 (2009) 017503

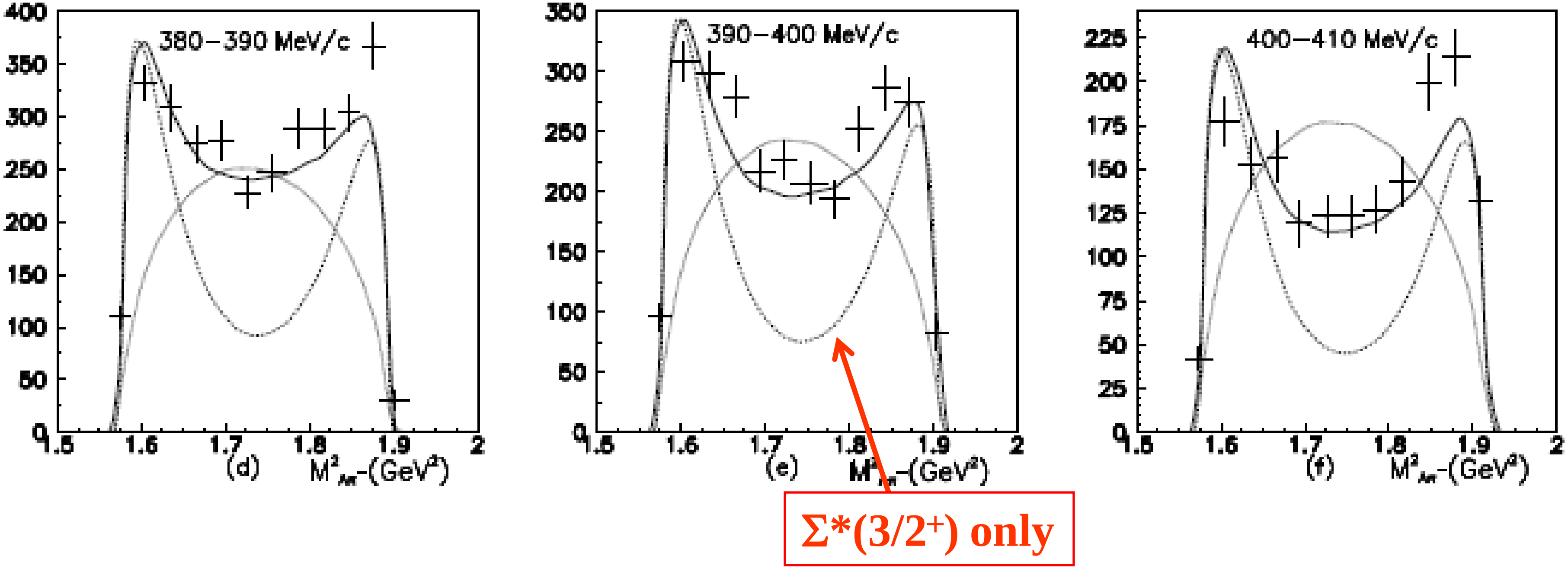

K-
Σ*-
Λ
π-
π+
P
(a)
K-
π-
π+
Σ*+
P
Λ
(b)
K-
π∓
π±
Y*
Σ*±
P
Λ
(c)

$$K^- p \to \Lambda^* \to \Sigma^{*-}_{3/2}\pi^+ \to \Lambda\pi^+\pi^-$$

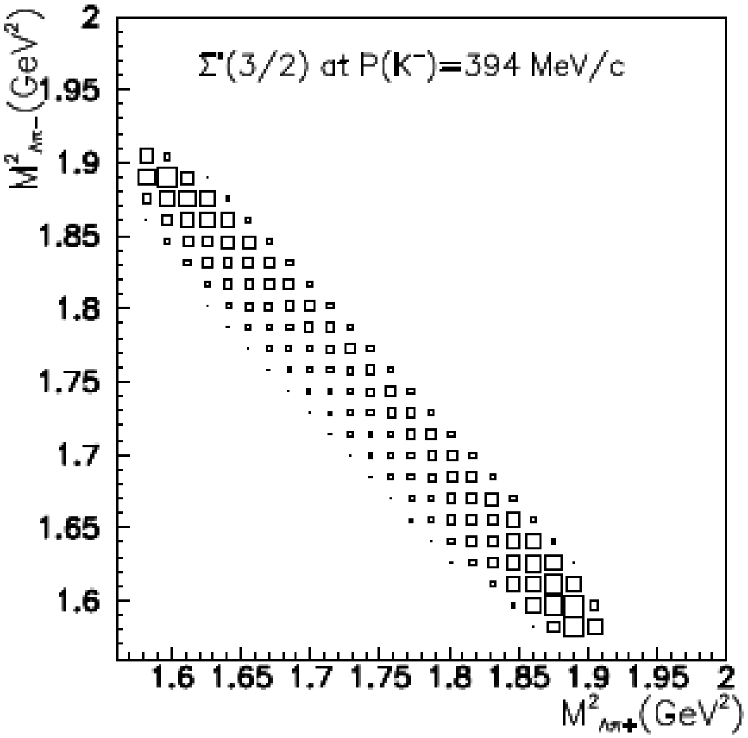
$$K^- p \to \Lambda^* \to \Sigma^{*-}_{1/2}\pi^+ \to \Lambda\pi^+\pi^-$$

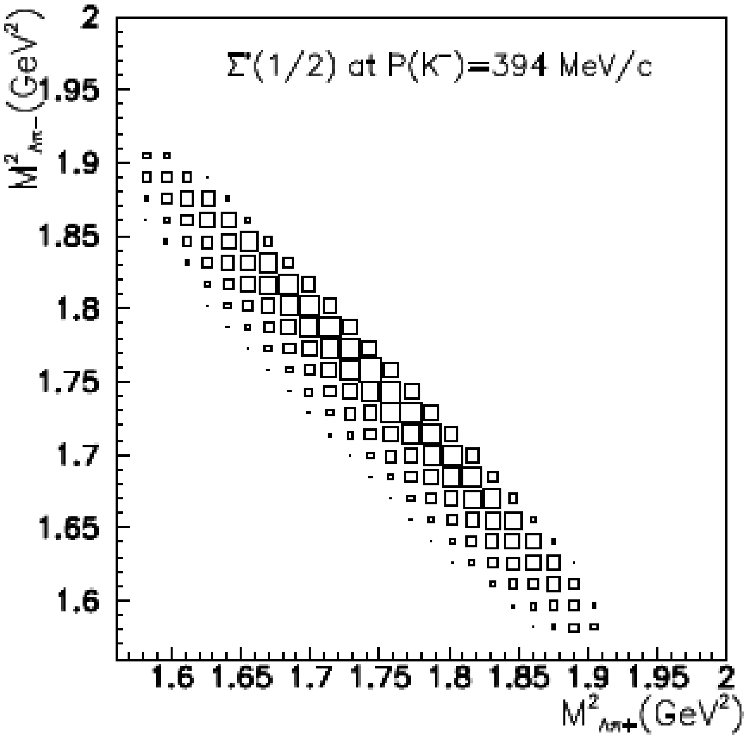
$P_K \approx 0.4$ GeV





J.J.Wu, S.Dulat, B.S.Zou, Phys. Rev. C81 (2010) 045210





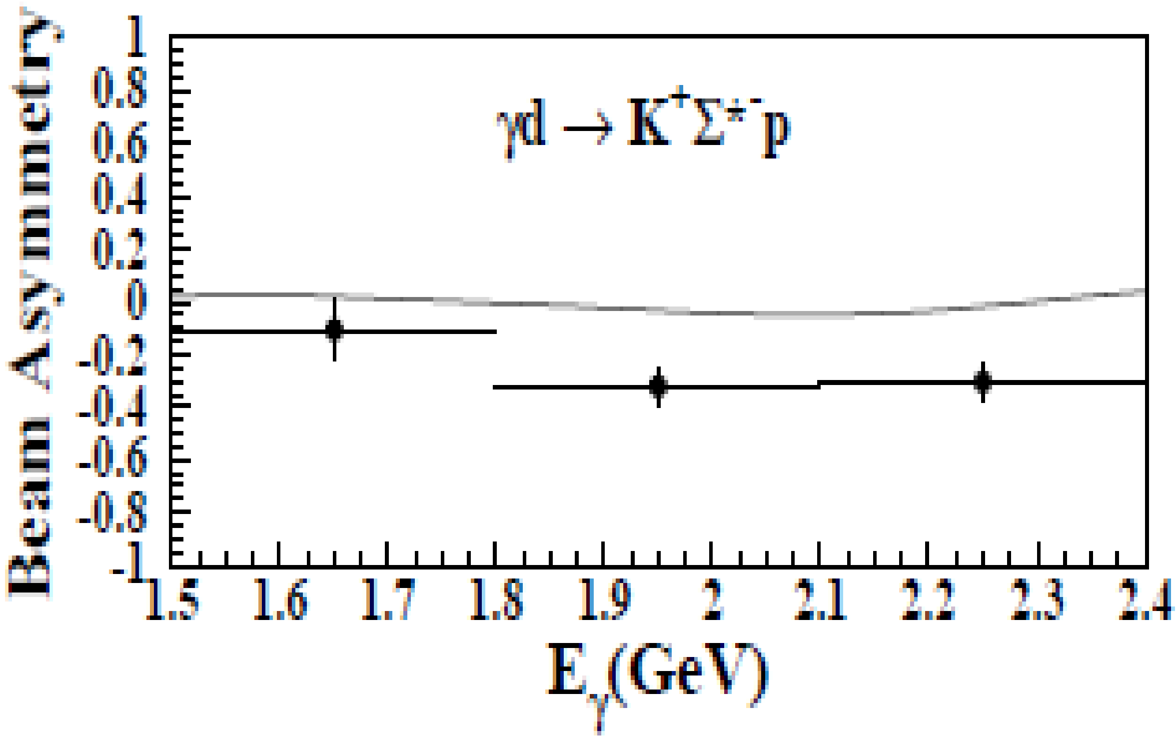
$\Sigma^*(3/2^+)$ & $\Sigma^*(1/2^-)$ → different Dalitz plots & mass spectra

Both are needed to reproduce the data !

Other evidence: failed to reproduce data with Σ∗(1385)

LEPS, PRL102(2009)012501

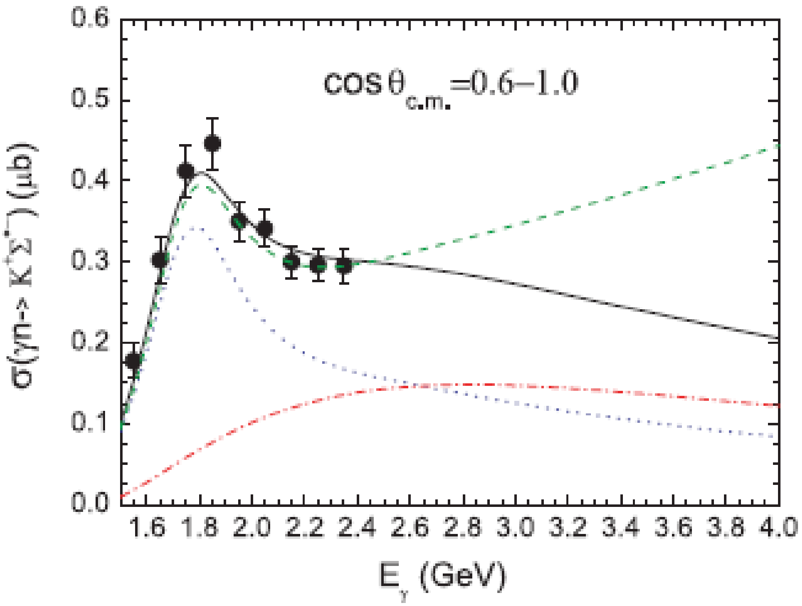
Y. Oh, C. M. Ko, and K. Nakayama, PRC77(2008) 045204

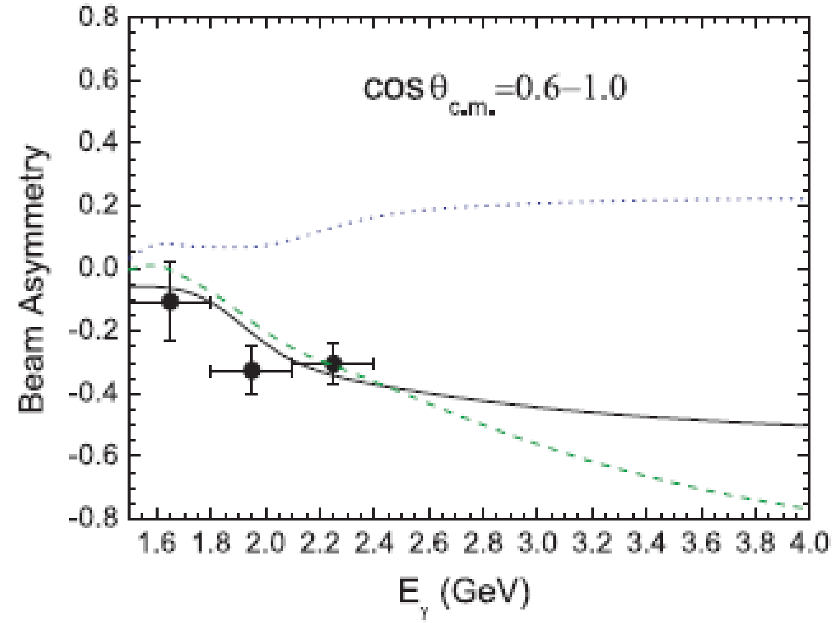


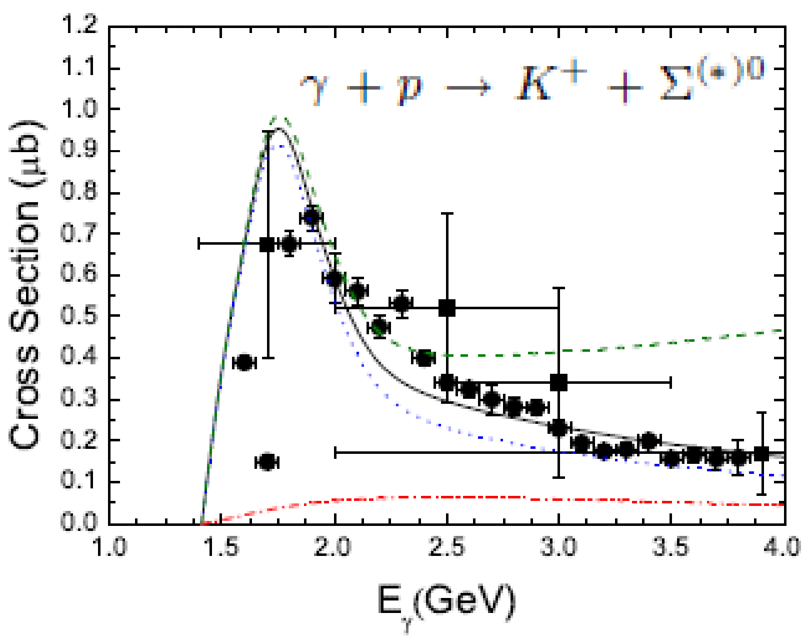
Something new ? Σ*(1/2⁻) ?

P.Gao, J.J.Wu, B.S.Zou, Phys. Rev. C 81 (2010) 055203

$$\gamma + n \rightarrow K^{+} + \Sigma^{(*)-}$$





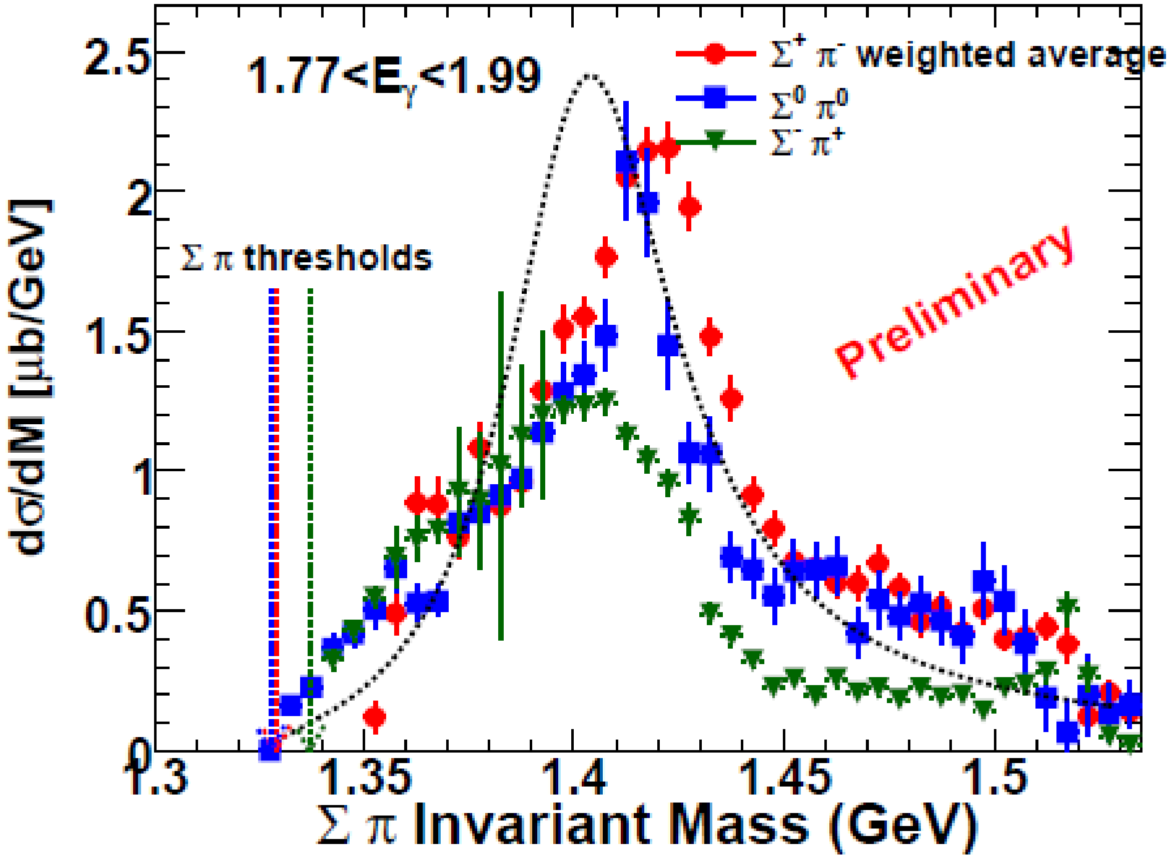


dot lines: $\Sigma^*(3/2^+)$ with h=1.00
dashed : $\Sigma^*(3/2^+)$ with h=1.11
solid: including $\Sigma^*(1/2^-)$

P.Gao, J.J.Wu, B.S.Zou,
Phys. Rev. C 81 (2010) 055203

$\gamma\, p \rightarrow K^{+} \pi\, \Sigma$

R.Schumacher, K.Moriya



J^P=1/2⁻   I=1 is needed besides Λ*(1405) !

$$\frac{d\sigma(\pi^{+}\Sigma^{-})}{dM_{I}} \propto \frac{1}{2}\left|T^{(1)}\right|^{2} + \frac{1}{3}\left|T^{(0)}\right|^{2} + \frac{2}{\sqrt{6}}\mathrm{Re}\left(T^{(0)}T^{(1)*}\right) + O\left(T^{(2)}\right)$$

$$\frac{d\sigma(\pi^{-}\Sigma^{+})}{dM_{I}} \propto \frac{1}{2}\left|T^{(1)}\right|^{2} + \frac{1}{3}\left|T^{(0)}\right|^{2} - \frac{2}{\sqrt{6}}\mathrm{Re}\left(T^{(0)}T^{(1)*}\right) + O\left(T^{(2)}\right)$$

$$\frac{d\sigma(\pi^{0}\Sigma^{0})}{dM_{I}} \propto \frac{1}{3}\left|T^{(0)}\right|^{2} + O\left(T^{(2)}\right)$$

J/ψ decay **branching ratio * 10^4**

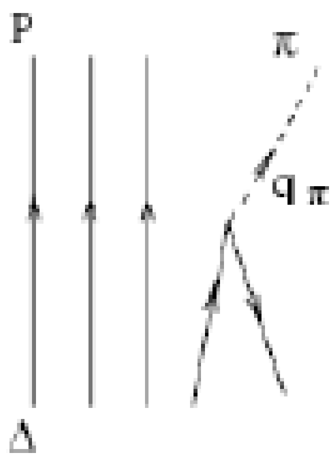
$\bar{p}\,\Delta(1232)^+$	3/2+	< 1	} SU(3) breaking
$\bar{\Sigma}^-\,\Sigma(1385)^+$		3.1 ± 0.5	
$\bar{\Xi}^+\,\Xi(1530)^-$		5.9 ± 1.5	
$\bar{p}\,N^*(1535)^+$	1/2-	10 ± 3	} SU(3) allowed
$\bar{\Sigma}^-\,\Sigma(1360)^+$		?	
$\bar{\Xi}^+\,\Xi(1520)^-$		?	

It is very important to check whether under the Σ(1385) and Ξ(1520) peaks there are $1/2^-$ components ?

4. 5-quark components in other baryons

$\bar{q}qqqq$ in Δ and N*(1440)

Li,Riska, NPA766(2006)172; Juliá-Díaz,Riska,NPA780(2006)175;



Δ^{++*} (1620) ½ $^{-}$ -- The lowest excited uuu state with L=1 in classical 3q models

$\pi^+ p \rightarrow \rho^+ p$ & $pp \rightarrow nK^+\Sigma^+ \rightarrow$ very large $g_{\Delta^* N\rho}$

J.J.Xie, B.S.Zou, PLB649 (2007) 405

→	**Δ*(1620) ½-**	**ρN molecule ?**	**1705 MeV**
	Σ*(1750) ½-	**K*N molecule ?**	**1820 MeV**
	Ξ*(1950) ½-?	**K*Λ molecule ?**	**2010 MeV**
	Ω*(2160) ½-?	**K*Ξ molecule ?**	**2215 MeV**

$1/2^-$ baryon decuplet ~ V_8B_8 molecules ?

5. 4-quark components in mesons

$\bar{q}q$ $^3S_1$ nonet

$\phi(1020)$ $\bar{s}s$

$K(892)$ $\bar{s}d$

$\omega(782)$ $\bar{u}u + \bar{d}d$
$\rho(770)$ $\bar{u}u - \bar{d}d$

$\bar{q}q$ $^3P_0$ or $\bar{q}^2q^2$ nonet ?

$a_0(980)$ $\bar{u}u - \bar{d}d$, $[\bar{u}\,\bar{s}][us]-[\bar{d}\,\bar{s}][ds]$
$f_0(980)$ $\bar{s}s$, $[\bar{u}\,\bar{s}][us]+[\bar{d}\,\bar{s}][ds]$

$\kappa(800)$ $\bar{s}d$, $[\bar{s}\,\bar{u}][ud]$

$f_0(600)$ $\bar{u}u + \bar{d}d$, $[\bar{u}\,\bar{d}][ud]$

$D^*_{s0}(2317) \sim \bar{s}c\ (L=1) + [\bar{q}\,\bar{s}][qc] + DK + \ldots$
$D^*_{s1}(2460) \sim \bar{s}c\ (L=1) + D^*K + \ldots$
$X(3872) \sim \bar{c}c\ (L=1) + [\bar{q}\,\bar{c}][qc] + D^*D + \ldots$

Conclusion I

- **Meson-cloud vs diquark cluster for $\bar{d} - \bar{u} \sim 0.12$**

- **Predictions for the strangeness in the proton:**

meson cloud : $\Delta s < 0$, $\mu_s < 0$, $r_s < 0$

diquark cluster : $\Delta s < 0$, $\mu_s > 0$, $r_s > 0$

- **$\bar{q}qqqq$ in S-state more favorable than qqq with L=1 !**
& $\bar{q}qqq$ in S-state more favorable than $\bar{q}q$ with L=1 !

$1/2^-$ baryon nonet $\sim$ $\bar{q}q^2q^2$ state + …

0^+ meson octet $\sim$ $\bar{q}^2q^2$ state + …

multiquark components are important for hadrons!

Conclusion II

- Quenched quark models and unquenched models give very distinctive predictions for $\Sigma^*(1/2^-)$;
- Possible existence of a $\Sigma^*(1/2^-)$ around 1380 MeV: evidence needs confirmation ;
  relevant to Kp, Kpp interactions or bound states
- It should be checked by forthcoming experiments :

$K^- p \rightarrow \pi \Sigma^*, \ \Sigma^* \rightarrow \Lambda \pi , \Sigma\pi$ @ JPARC

$\gamma N \rightarrow K^+ \Sigma^*, \ \Sigma^* \rightarrow \Lambda \pi , \Sigma\pi$ @ JLab, Spring-8,ELSA

$\psi \rightarrow \bar{\Sigma} \Sigma^*, \ \Sigma^* \rightarrow \Lambda \pi , \Sigma\pi$ @ BESIII