Multi-quark components in hadrons

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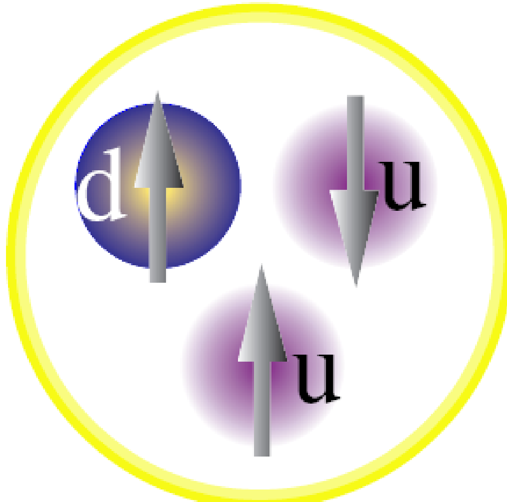
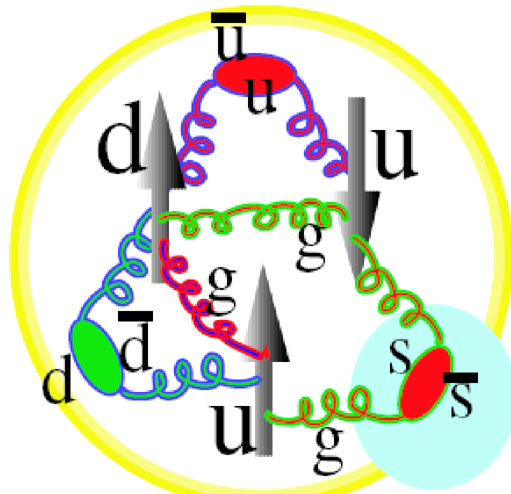
Outline:

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

1. 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)

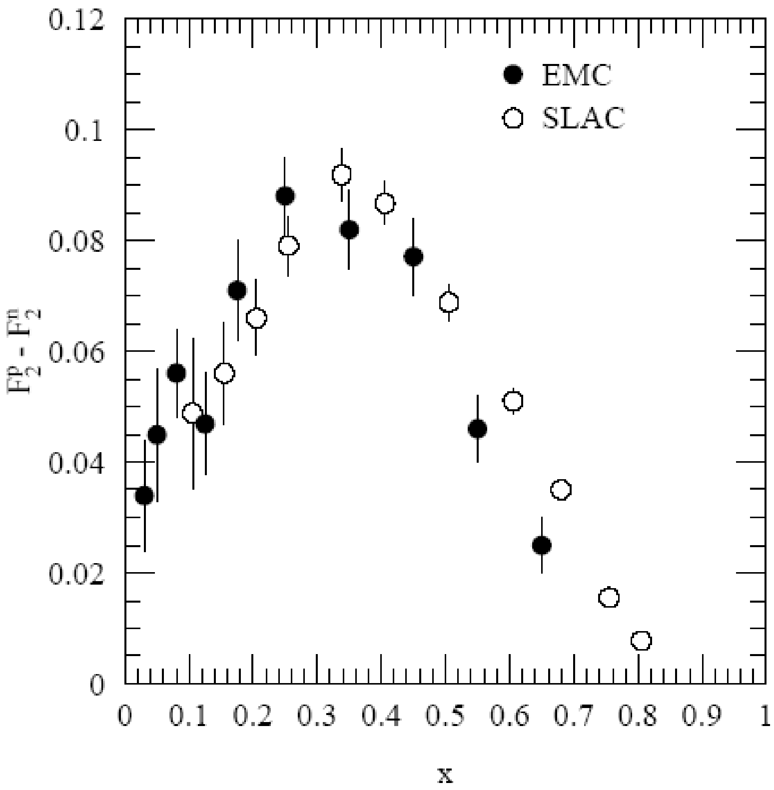
Table 1. Values of the integral $\int_0^1 [\bar{d}(x) - \bar{u}(x)]dx$ determined from the DIS, semi-inclusive DIS, and Drell-Yan experiments.

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

DIS Gottfried Sum Rule : assuming $\bar{d} = \bar{u}$

$$I_2^p - I_2^n = \int_0^1 [F_2^p(x,Q^2) - F_2^n(x,Q^2)]/x \; dx = \sum_i [(Q_i^p)^2 - (Q_i^n)^2] = 1/3.$$

$$\int_0^1 [F_2^p(x,Q^2) - F_2^n(x,Q^2)]/x \; dx = \frac{1}{3} + \frac{2}{3}\int_0^1 [\bar{u}(x,Q^2) - \bar{d}(x,Q^2)]dx.$$



$$\sigma_{DY}(p+d)/2\sigma_{DY}(p+p) \simeq (1+\bar{d}(x_2)/\bar{u}(x_2))/2.$$

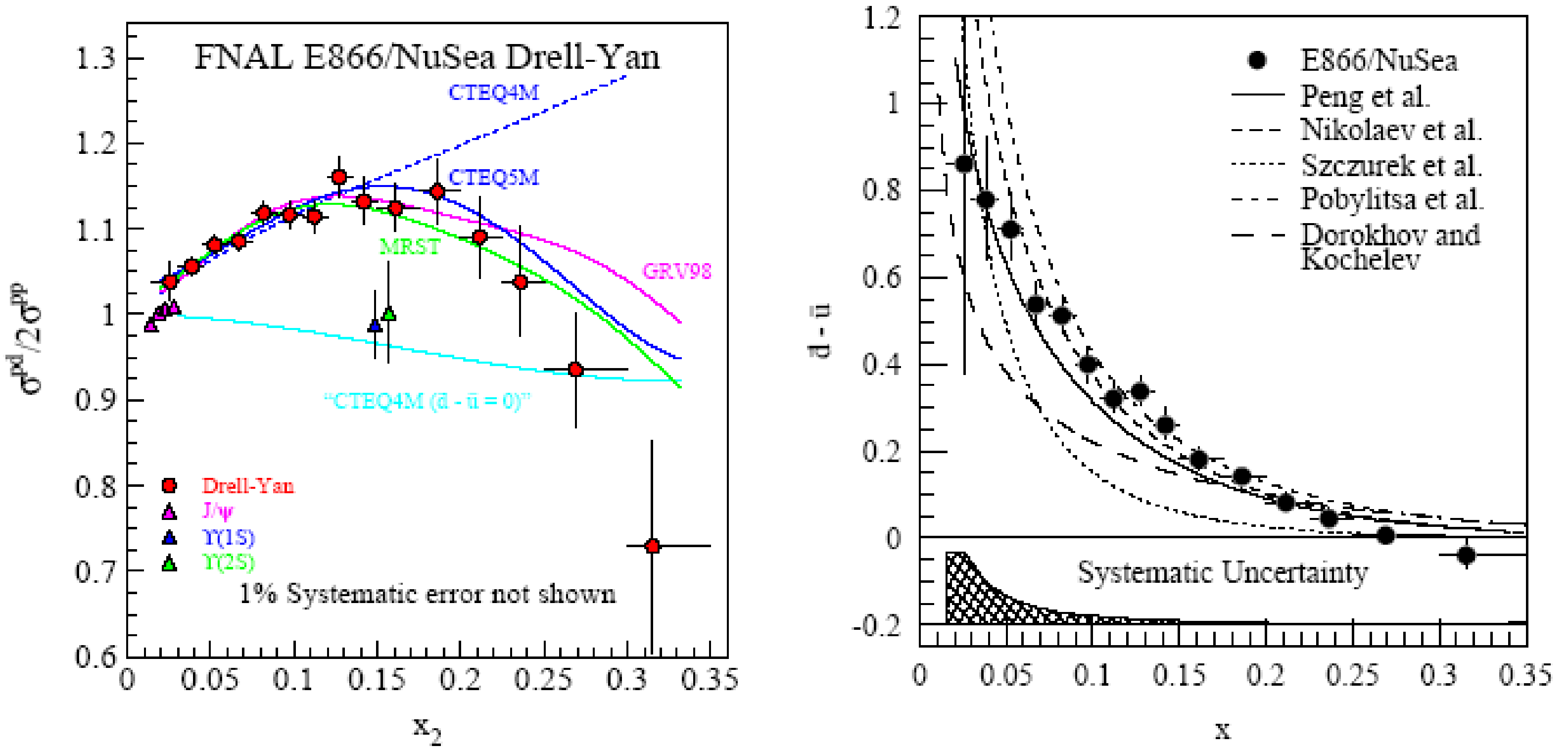
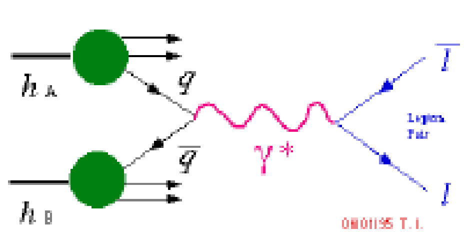


FIGURE 1. Left panel: Cross section ratios of $p+d$ over $2(p+p)$ for Drell-Yan, J/Ψ, and Υ production from FNAL E866. Right panel: Comparison of E866 $\bar{d}-\bar{u}$ data with calculations from various models [2].

The Drell-Yan Process



$$\bar{d}/\bar{u} > 1$$

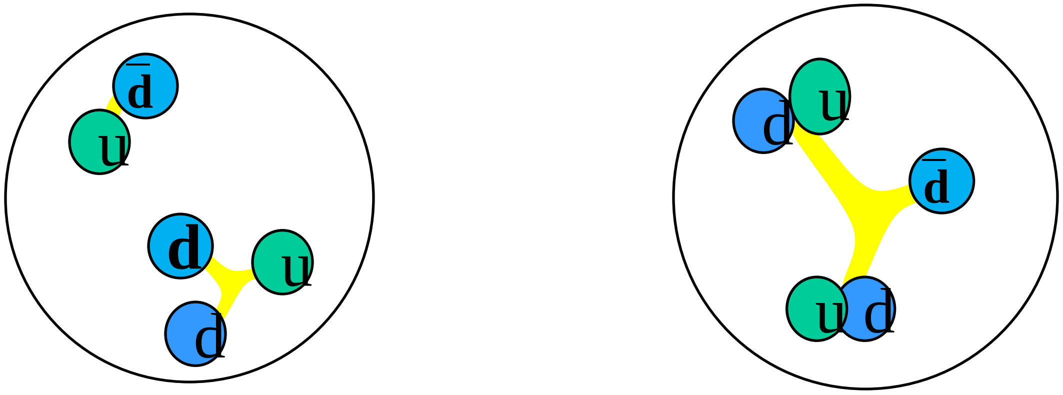
Two major theoretical schemes for $\bar{d} - \bar{u} \sim 0.12$

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

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

1 : 1

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

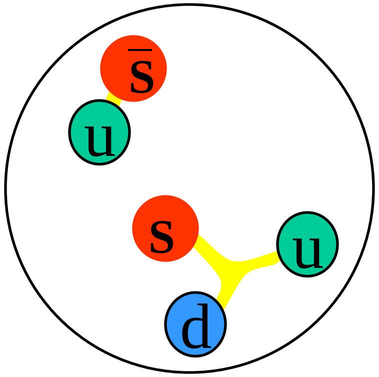
$$+\,0.084\,(uudgg) + \ldots$$

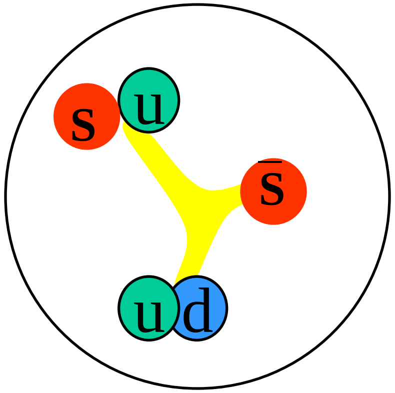
$$\bar{d} - \bar{u} \sim 0.124$$

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

Predictions for $\bar{s}$ / s asymmetry from two schemes :

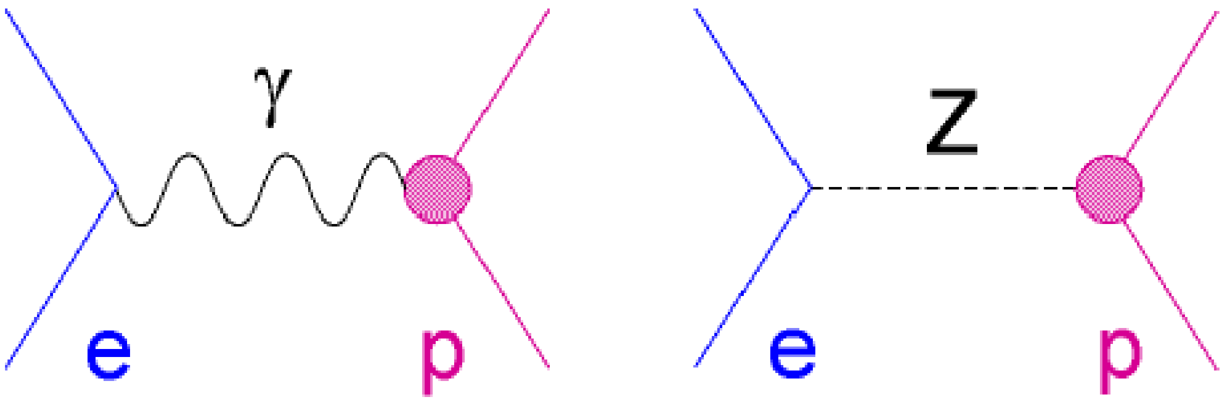
	meson cloud	penta-quark
strange spin Δs :	< 0	< 0
magnetic moment μ_s :	< 0	> 0
strange radium r_s :	< 0	> 0





Expt: $\Delta s = -0.05 \sim -0.1$ D. de Florian et al., PRD71 (2005) 094018

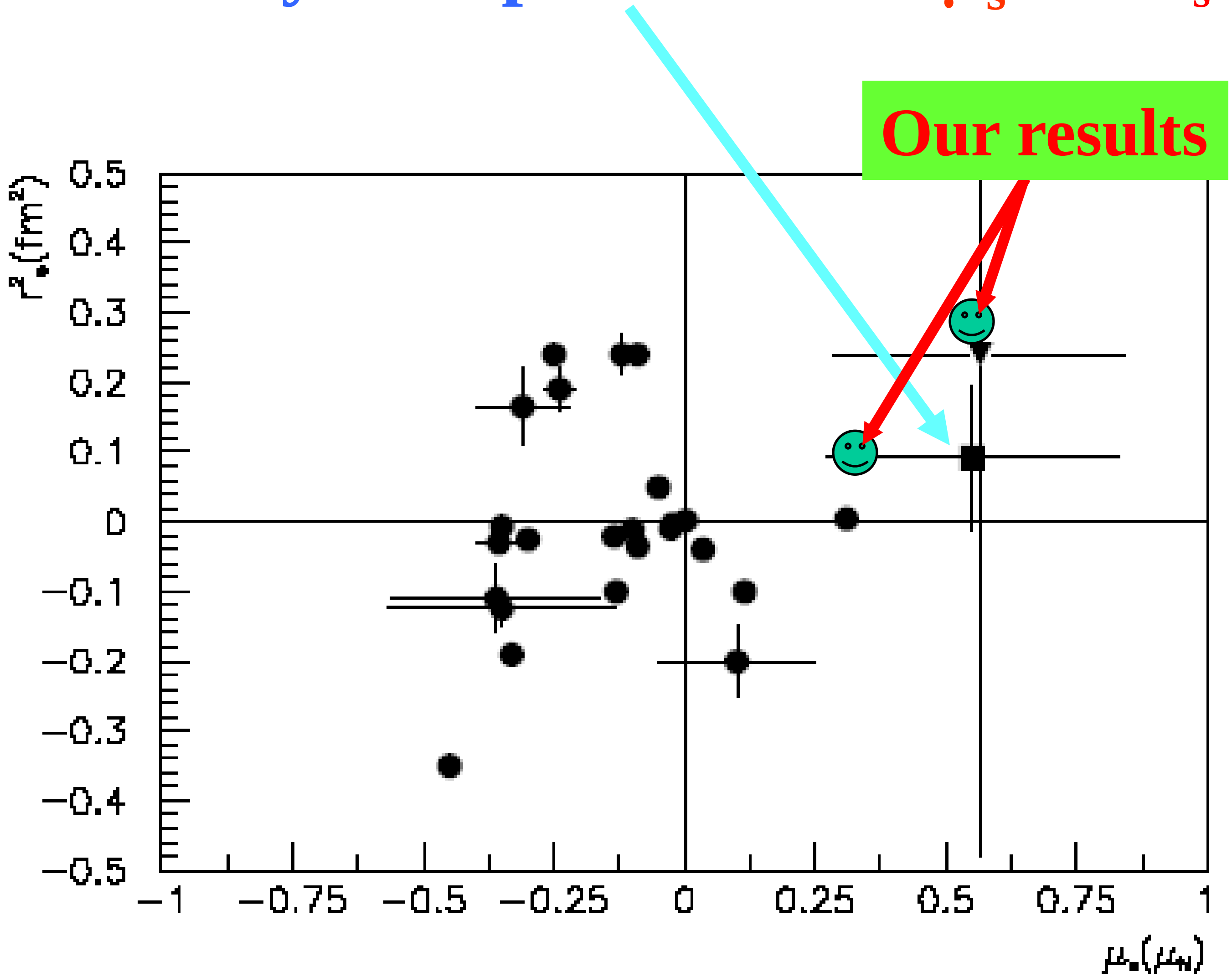
The strange magnetic moment μ_s and radii r_s from parity violating electron scattering



G0,HAPPEX/CEBAF, SAMPLE/MIT-Bates, A4/MAMI

HAPPEX/CEBAF, Phys.Rev.Lett. 96 (2006) 022003
G0/CEBAF, Phys.Rev.Lett. 95 (2005) 092001
A4/MAMI, Phys.Rev.Lett. 94 (2005) 152001
SAMPLE/MIT-Bates: Phys.Lett.B583 (2004) 79

Theory vs experiment for μ_s and r_s



Zou&Riska, PRL95(2005)072001; Riska&Zou, PLB636 (2006) 265
An-Riska-Zou, PRC73 (2006) 035207

Experiment extraction of μ_s and r_s wrong?

R.Young et al., PRL97 (2006) 102002 → $\mu_s \sim 0$
S.Baunack et al.(A4), PRL102(2009)151803

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) hω

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

J/ψ → $\bar{p}$N* → $\bar{p}$ (KΛ) / $\bar{p}$ (pη) → large $g_{N^*K\Lambda}$

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

γp → pη' & pp→ppη' → large $g_{N^*N\eta'}$

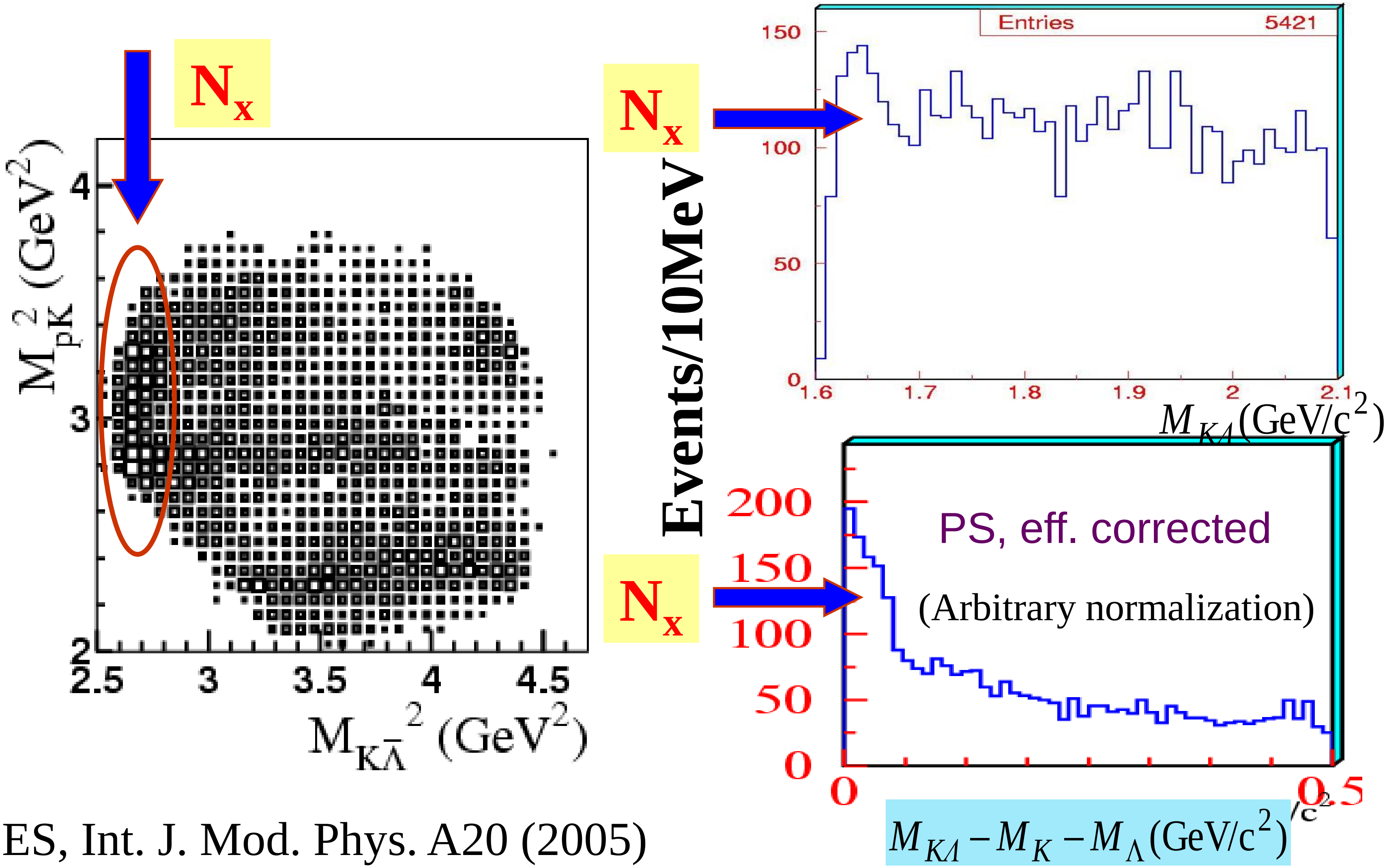
M.Dugger et al., PRL96 (2006) 062001; Cao&Lee, PRC78(2008) 035207

π^-p → nϕ & pp → ppϕ & pn → dϕ → 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

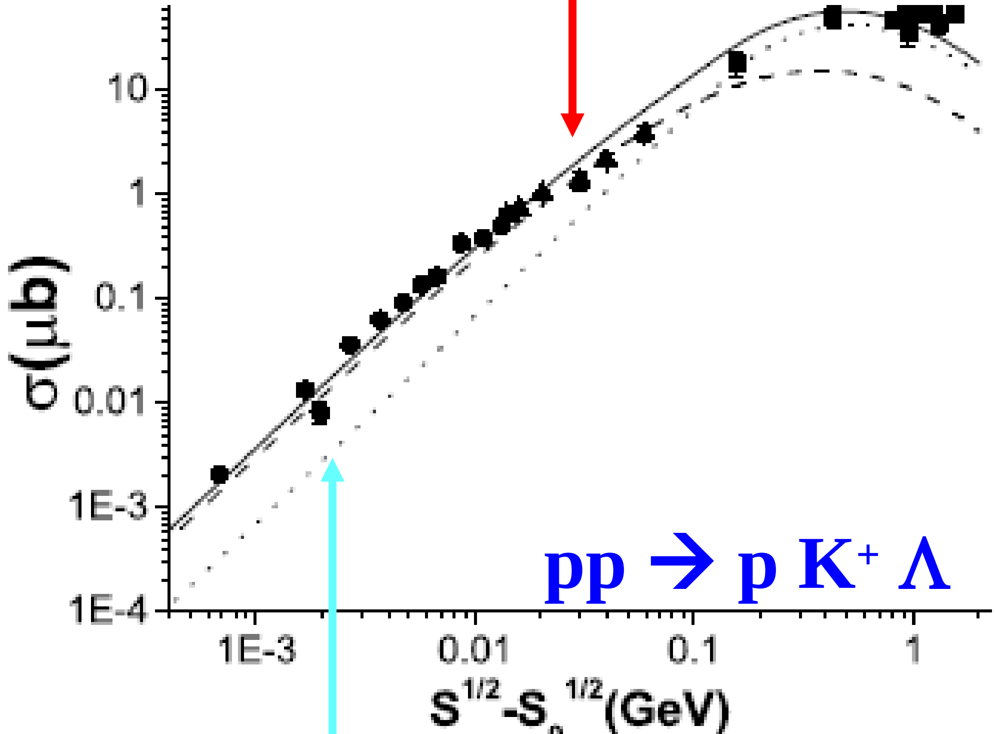
$$g_{N^*K\Lambda} / g_{N^*p\eta} / g_{N^*N\pi} \sim 1.2 : 2 : 1$$

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

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

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

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

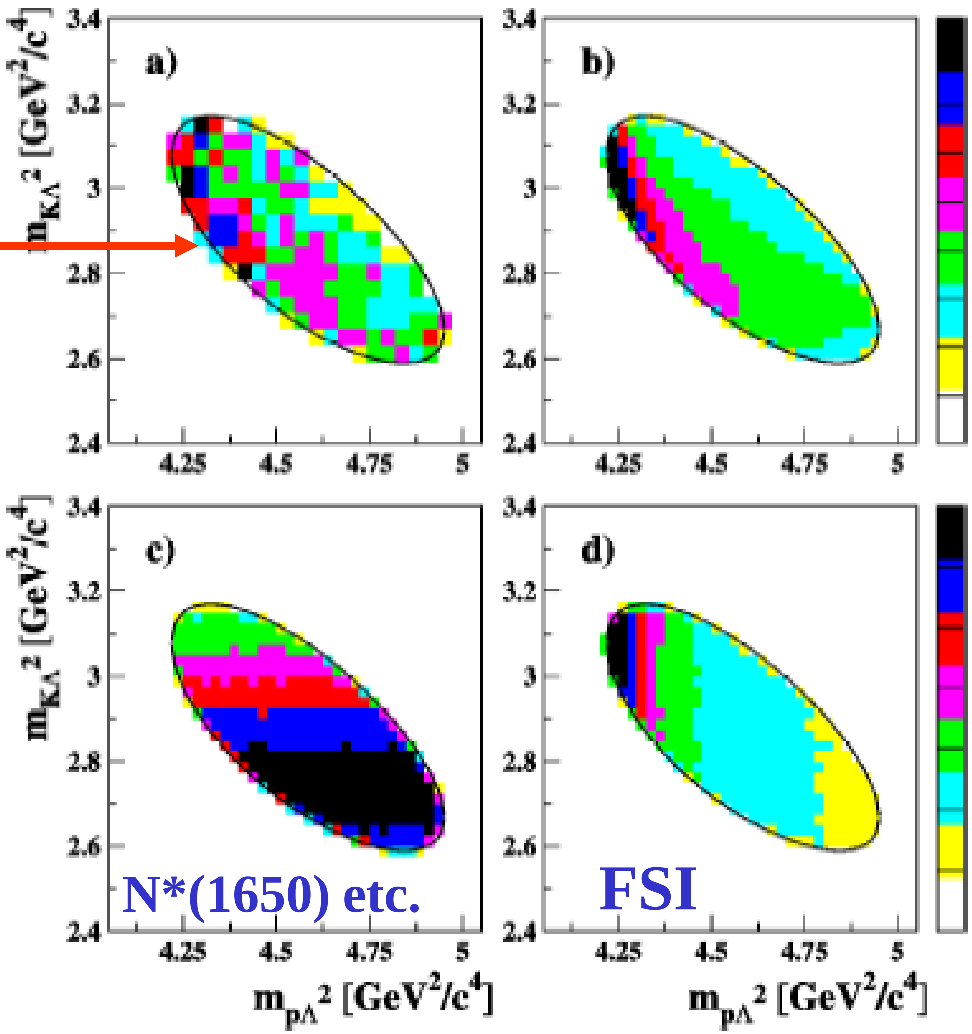


Tsushima,Sibirtsev,Thomas, PRC59 (1999) 369, without including N*(1535)

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

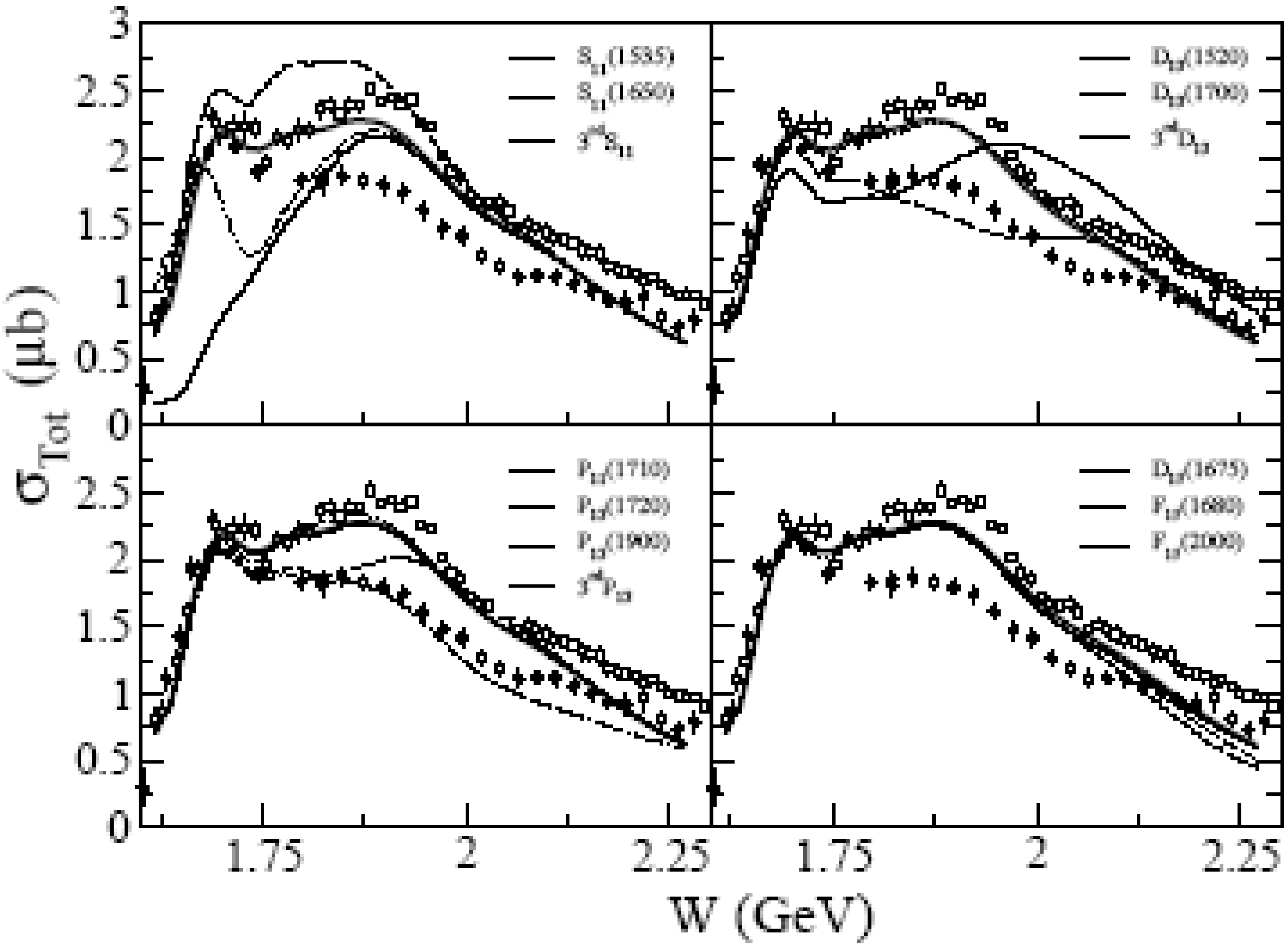
B.C.Liu & B.S.Zou, Phys. Rev. Lett. 98 (2007) 039102 (reply)
A.Sibirtsev et al., Phys. Rev. Lett. 98 (2007) 039101 (comment)

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

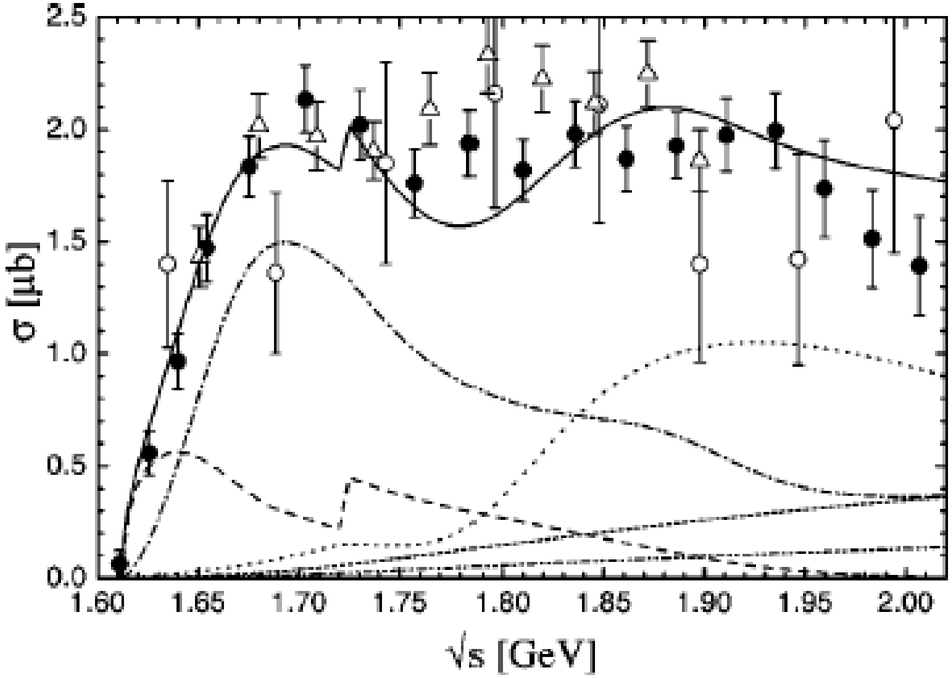


Both FSI & N*(1535) are needed !

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



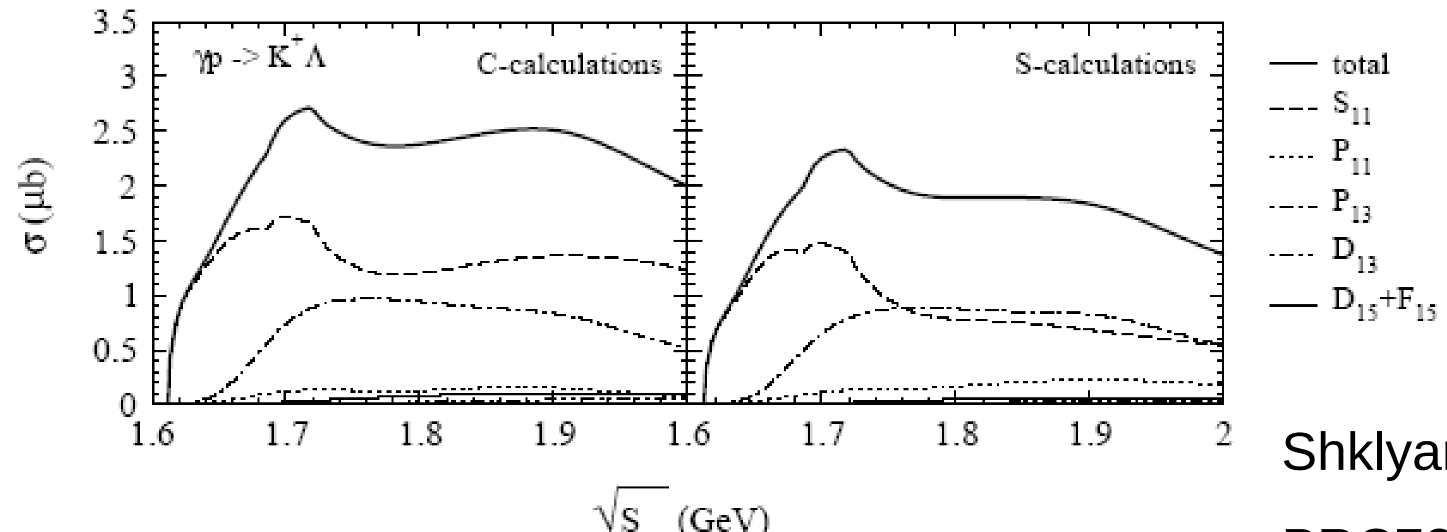
B. Julia-Diaz, B. Saghai, T.-S.H. Lee, F. Tabakin, Phys. Rev. C **73**, 055204 (2006)



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 $pp \to p K^+\Lambda$ / $pp \to p K^+\Sigma^0$

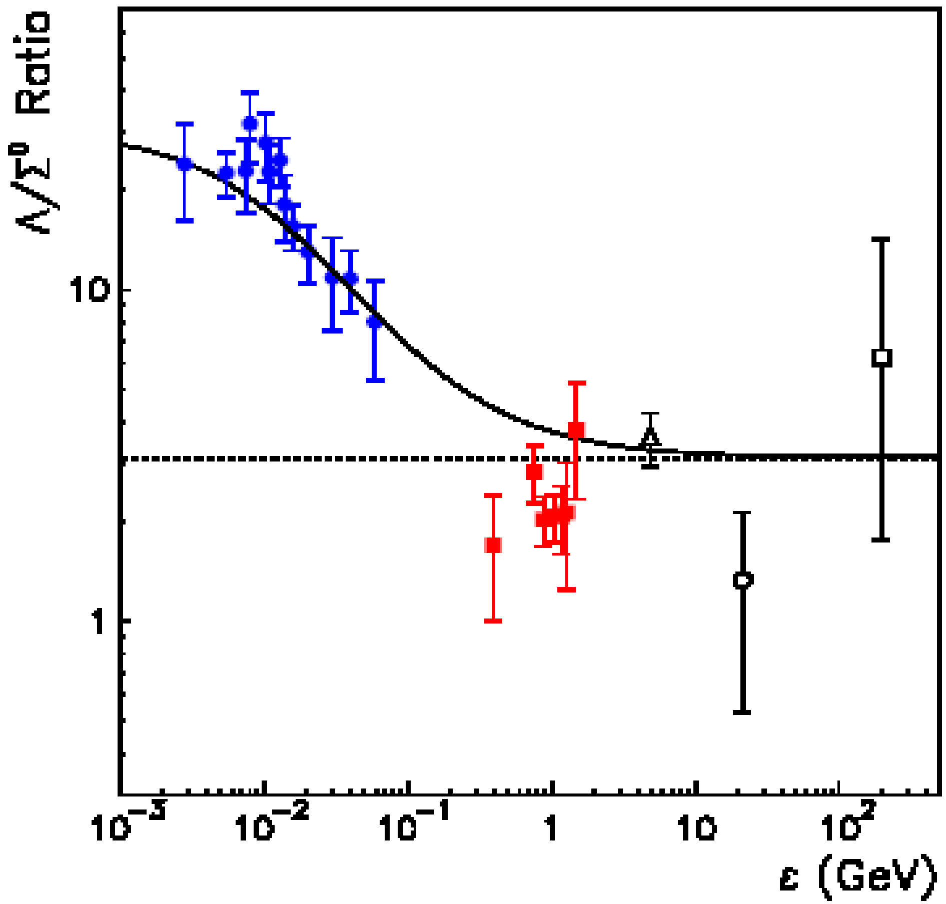


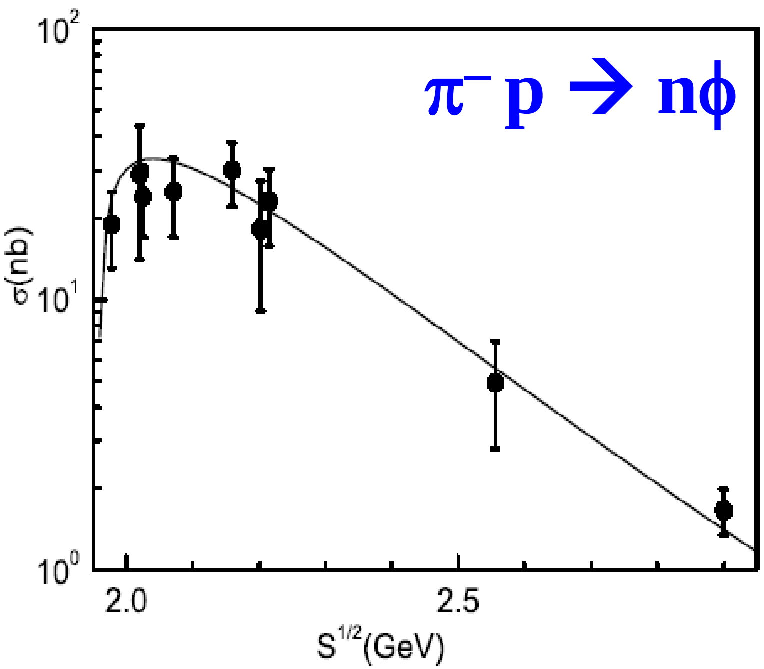
Fig. 3. The Λ/Σ^0 cross-section ratio as a function of the excess energy ϵ. The solid circles show the ratio obtained for the $pp \to K^+\Lambda p$ and $pp \to K^+\Sigma^0 p$ reactions at COSY [2]. Solid

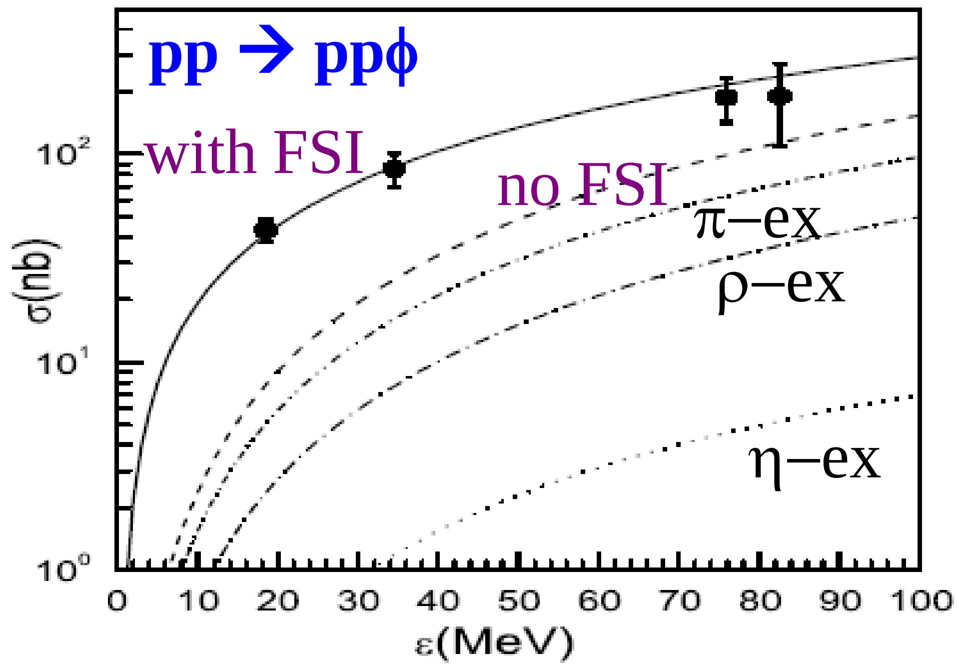
A.Sibirtsev et al., EPJA29 (2006) 363

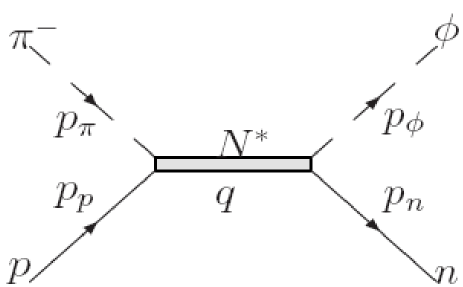
[2] P.Kowina et al., EPJA22 (2004) 293

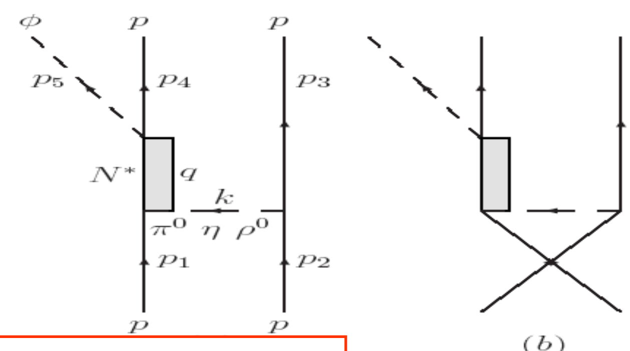
Evidence for large $g_{N^*N\phi}$ from $\pi^- p \to n\phi$, $pp \to pp\phi$ & $pn \to d\phi$

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



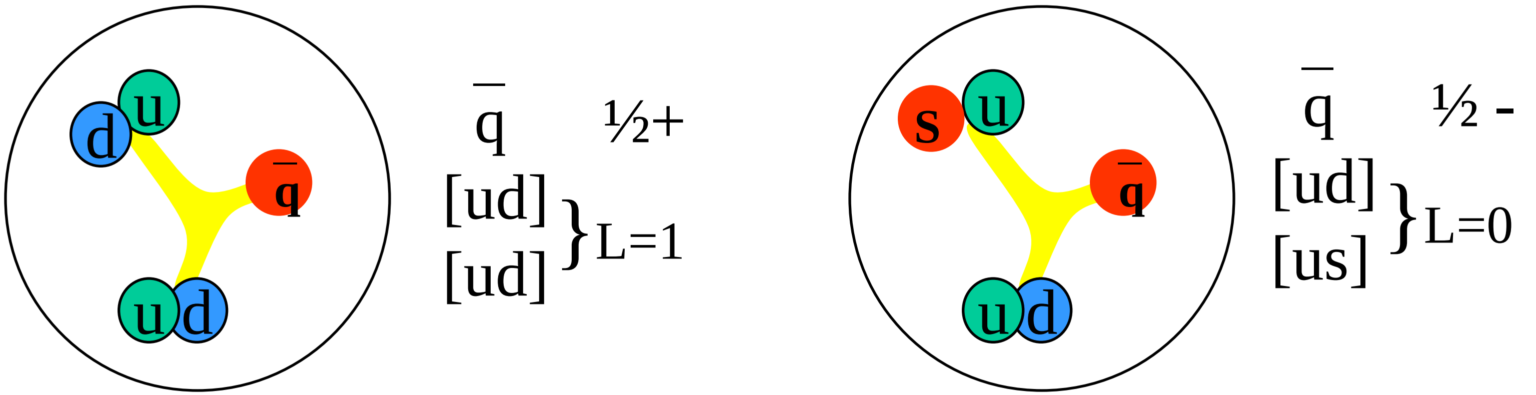






Evasion of OZI rule by N*(1535) !

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



Zhang et al, hep-ph/0403210

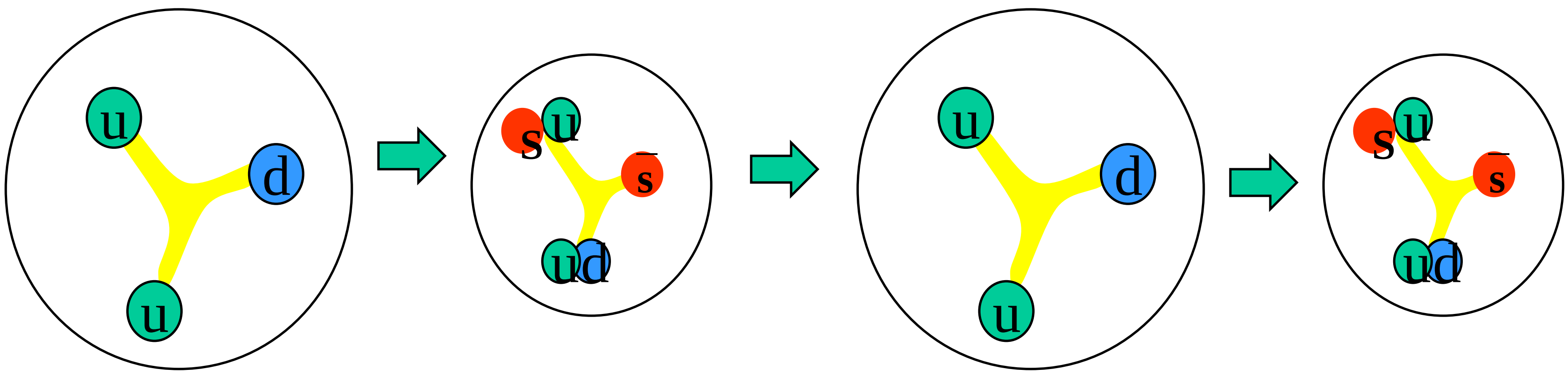
N*(1535) ~ uud (L=1) + ε [ud][us] $\bar{s}$ + …

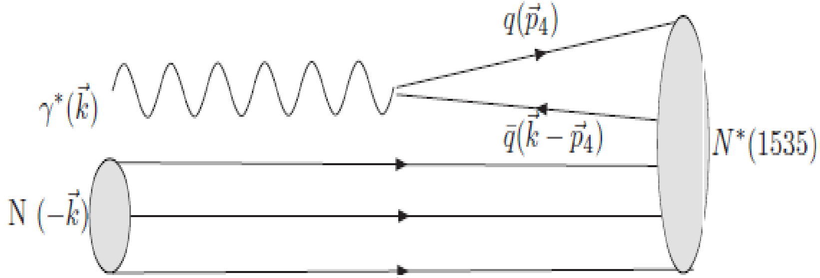
N*(1440) ~ uud (n=1) + ξ [ud][ud] $\bar{d}$ + …

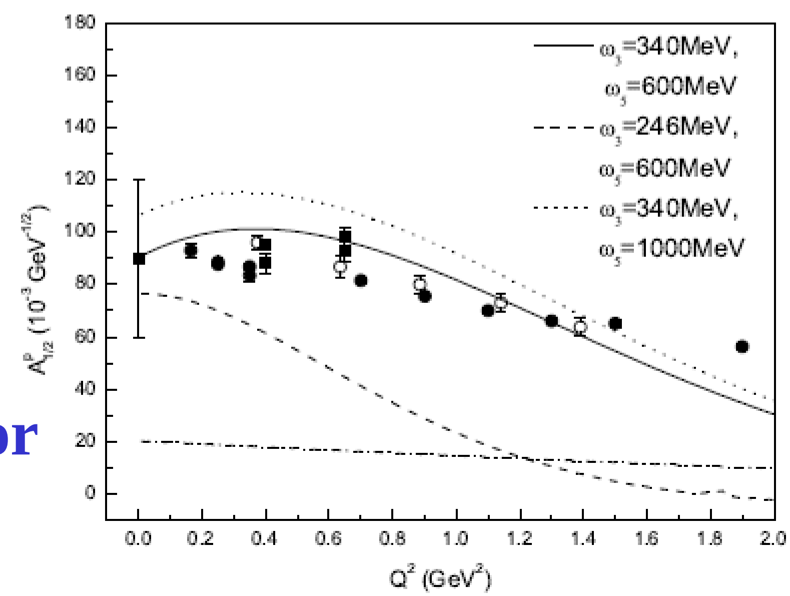
Λ*(1405) ~ uds (L=1) + ε [ud][su] $\bar{u}$ + …

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

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

Σ*($1/2^-$) ~ Λ*($1/2^-$)

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

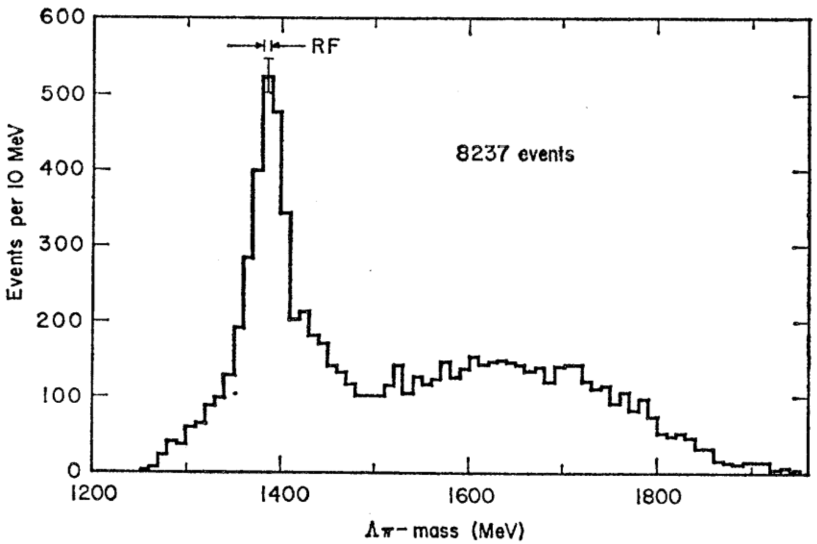
broad non-resonant Σ*($1/2^-$) structure

Jido-Oset et al , NPA725(2003)181

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

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

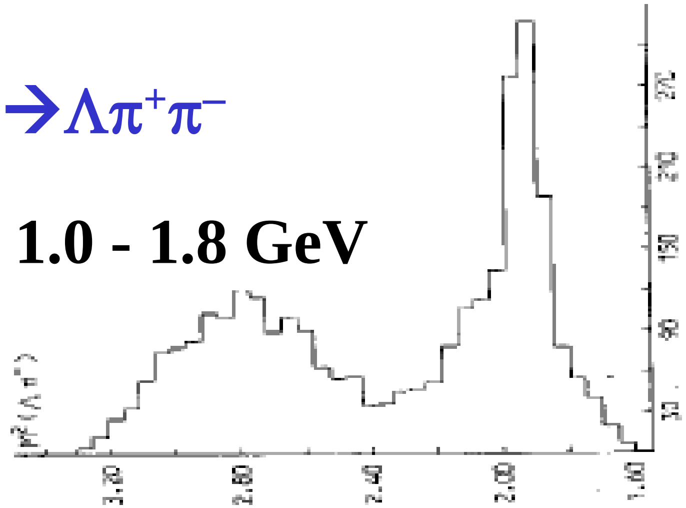
Huwe, PR181(1969)1824

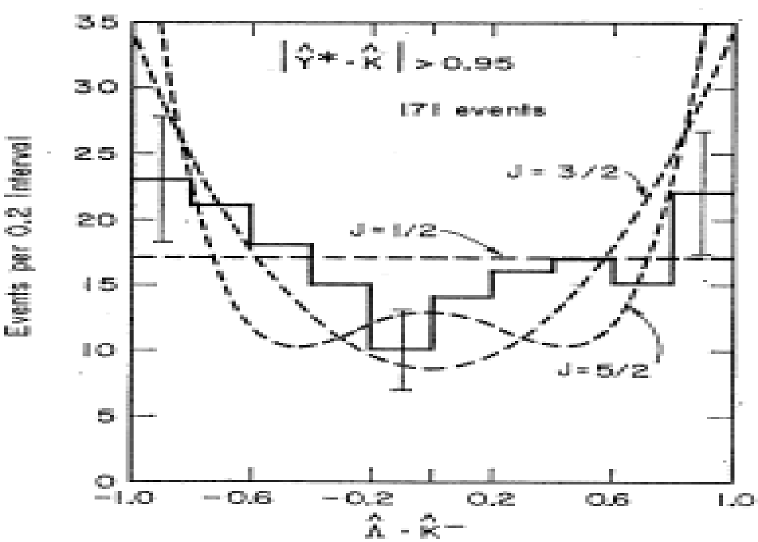


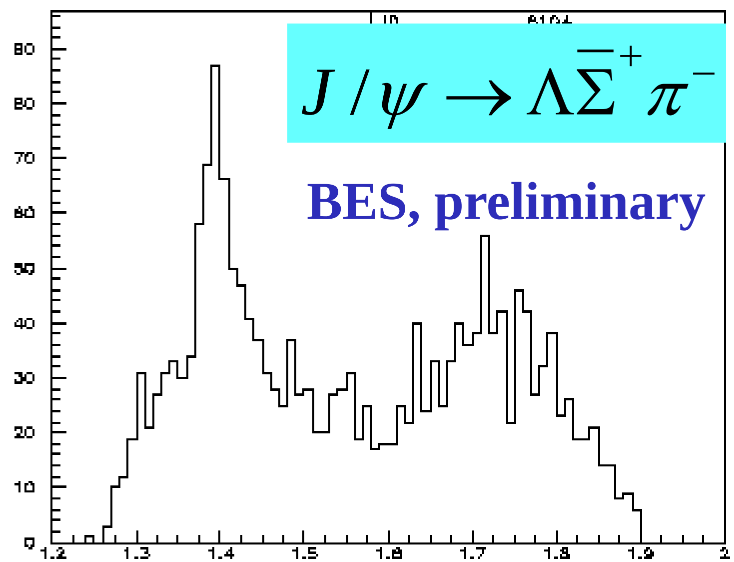
Cameron et al., NPB143(1978)189

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

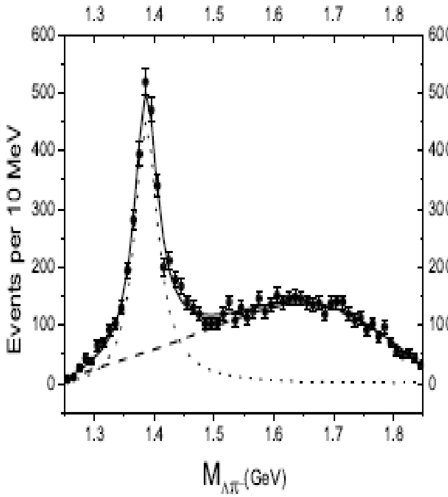
P_K = 1.0 - 1.8 GeV

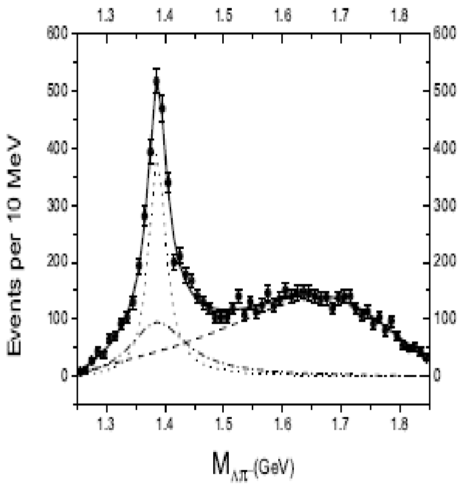


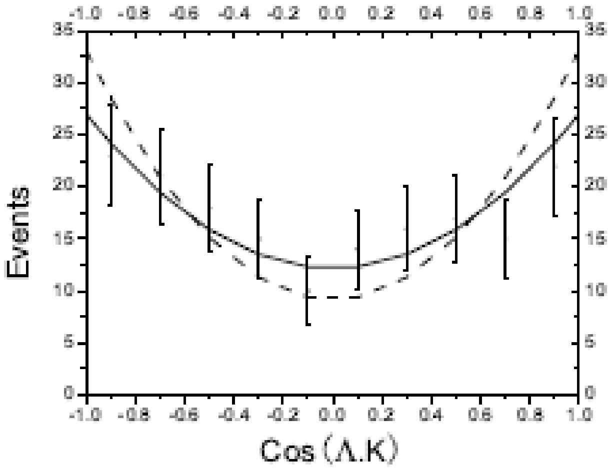




BES, NSTAR04

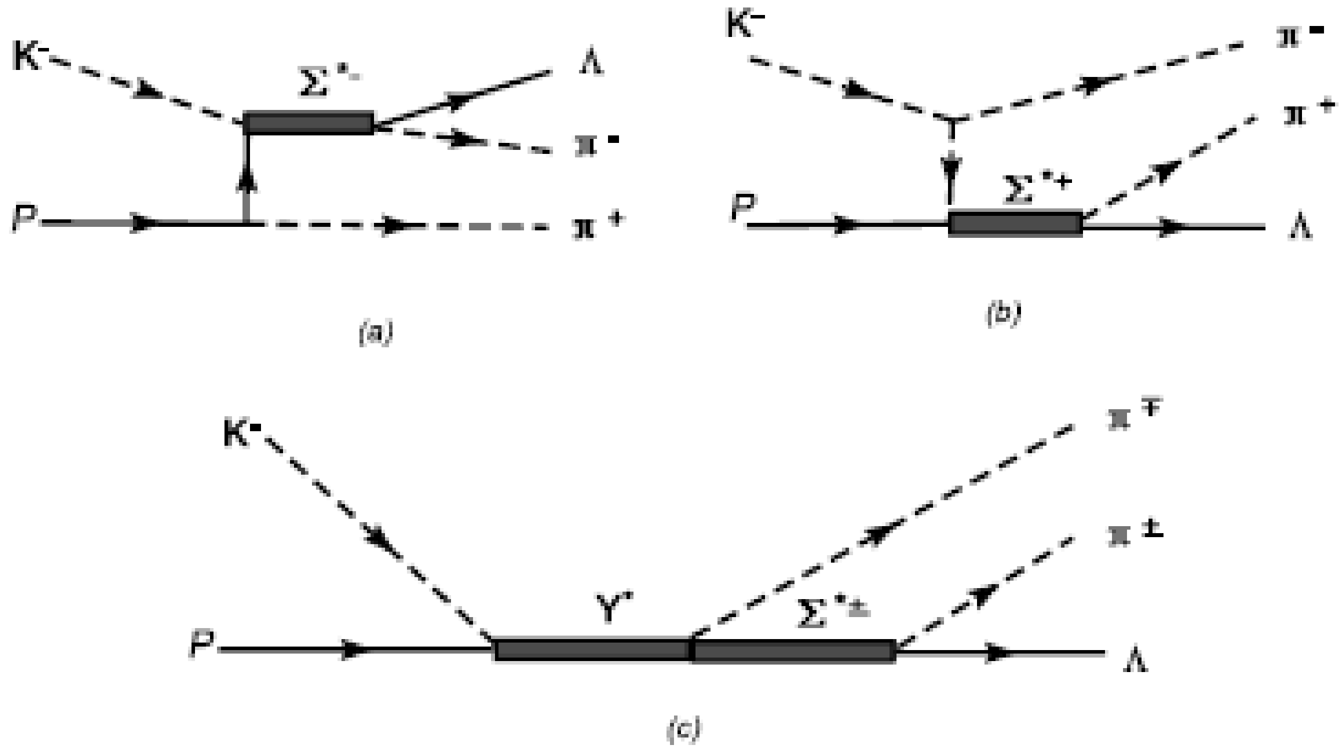






	$M_{\Sigma^*(3/2)}$	$\Gamma_{\Sigma^*(3/2)}$	$M_{\Sigma^*(1/2)}$	$\Gamma_{\Sigma^*(1/2)}$	χ^2/ndf(Fig.1)	χ^2/ndf(Fig.2)
Fit1	1385.3 ± 0.7	46.9 ± 2.5			$68.5/54$	$10.1/9$
Fit2	$1386.1^{+1.1}_{-0.9}$	$34.9^{+5.1}_{-4.9}$	$1381.3^{+4.9}_{-8.3}$	$118.6^{+55.2}_{-35.1}$	$58.0/51$	$3.2/9$

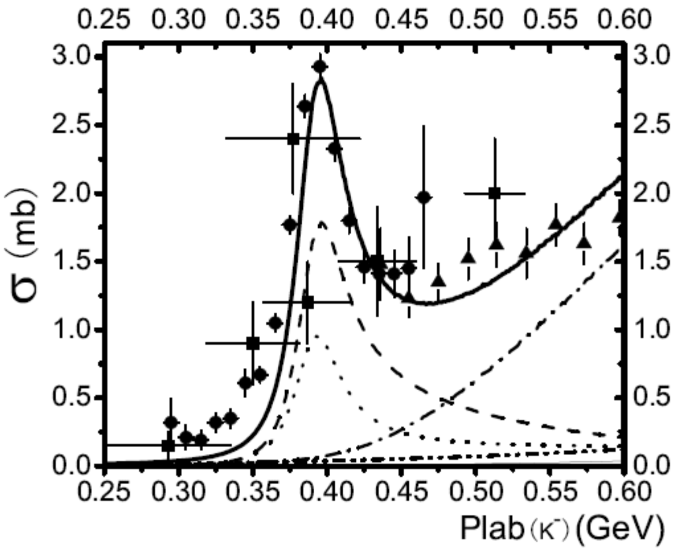
J.J.Wu, S.Dulat, B.S.Zou, PRD80 (2009) 017503

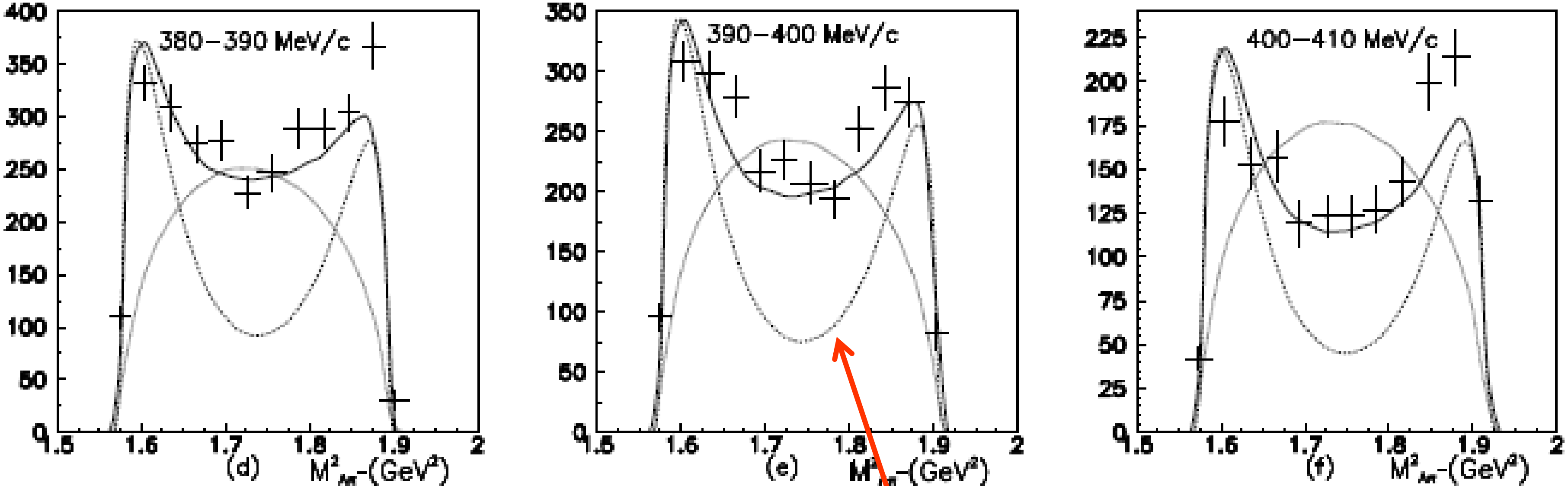

K⁻
Σ*⁻
Λ
π⁻
P
π⁺
(a)
K⁻
π⁻
π⁺
Σ*⁺
P
Λ
(b)
K⁻
π∓
π±
Y*
Σ*±
P
Λ
(c)

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

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

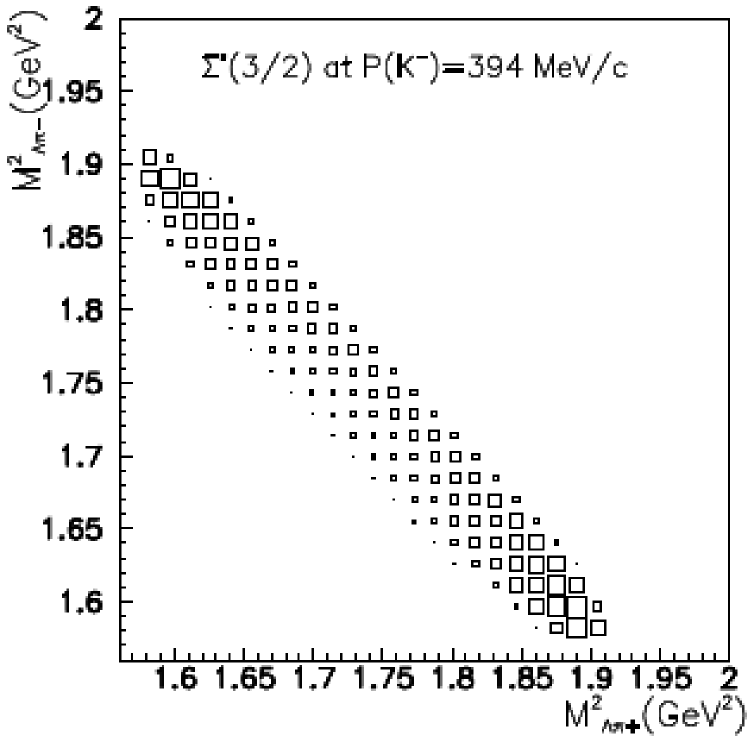
$P_K \approx 0.4$ GeV

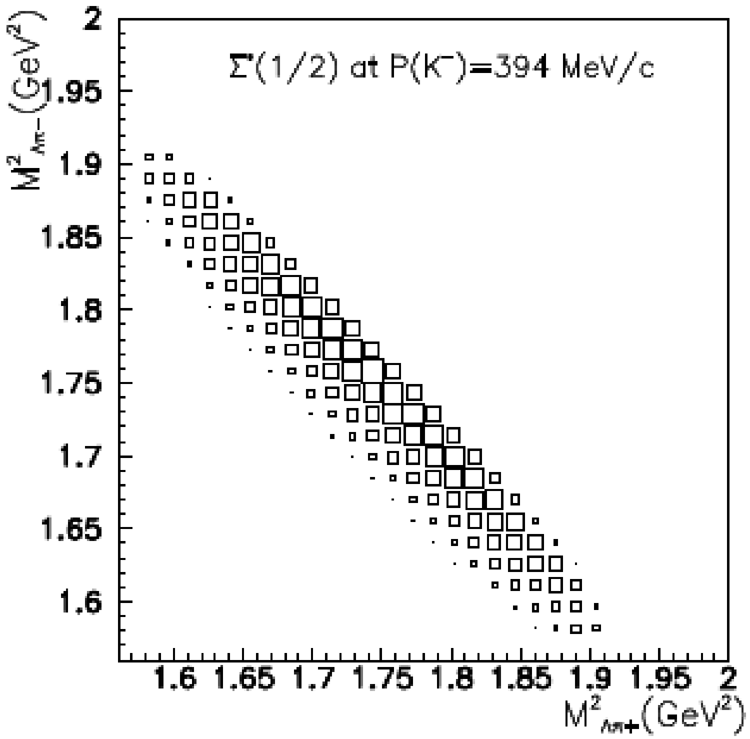




Σ*(3/2+) only

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





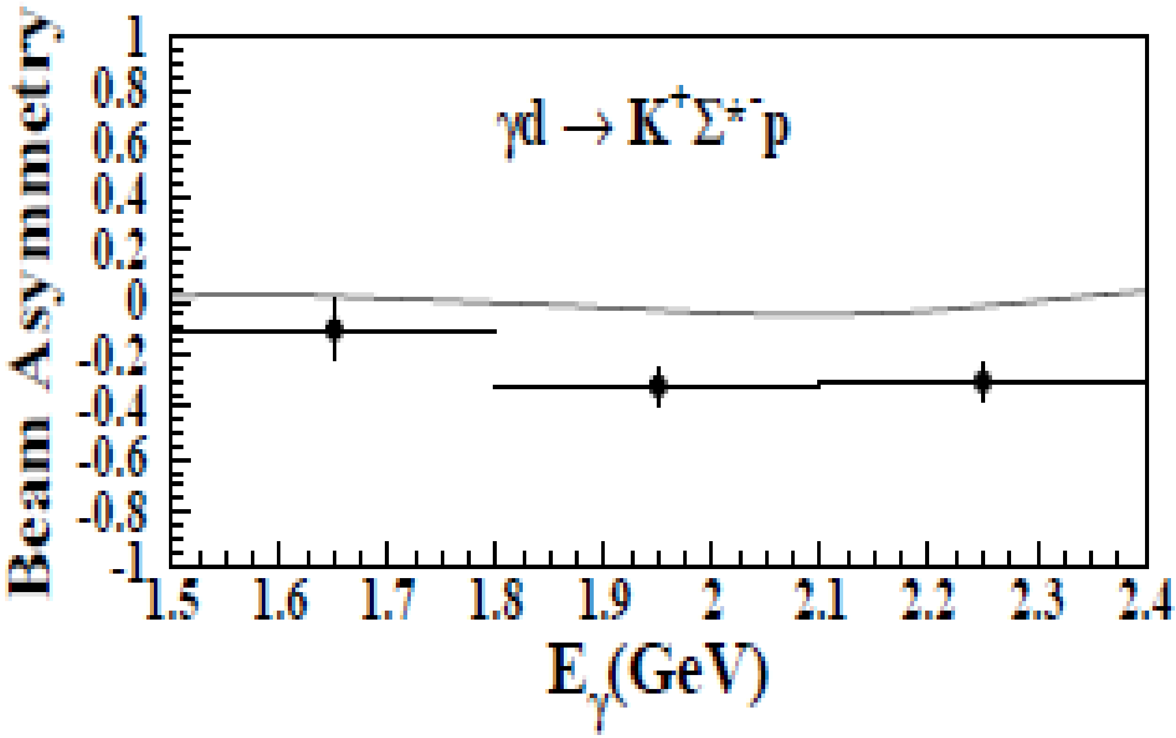
$\Sigma^*(3/2^+)$ & $\Sigma^*(1/2^-)$ → different Dalitz plots & mass spectra

Both are needed to reproduce the data !

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

LEPS, PRL102(2009)012501

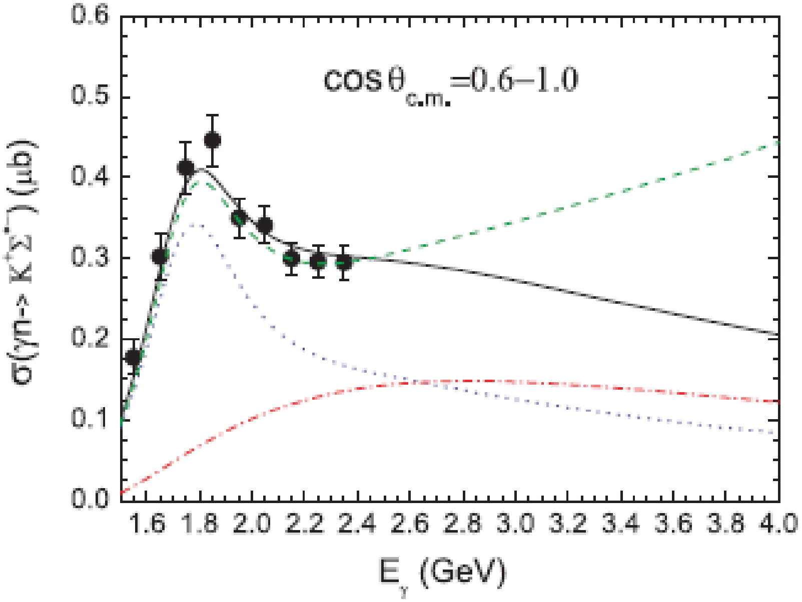
Y. Oh, C. M. Ko, and K. Nakayama, PRC77(2008) 045204

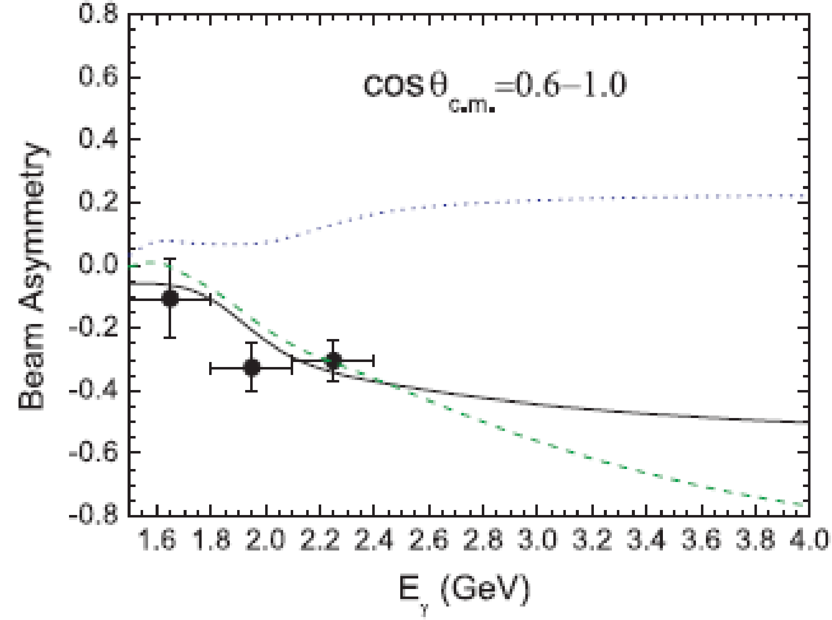


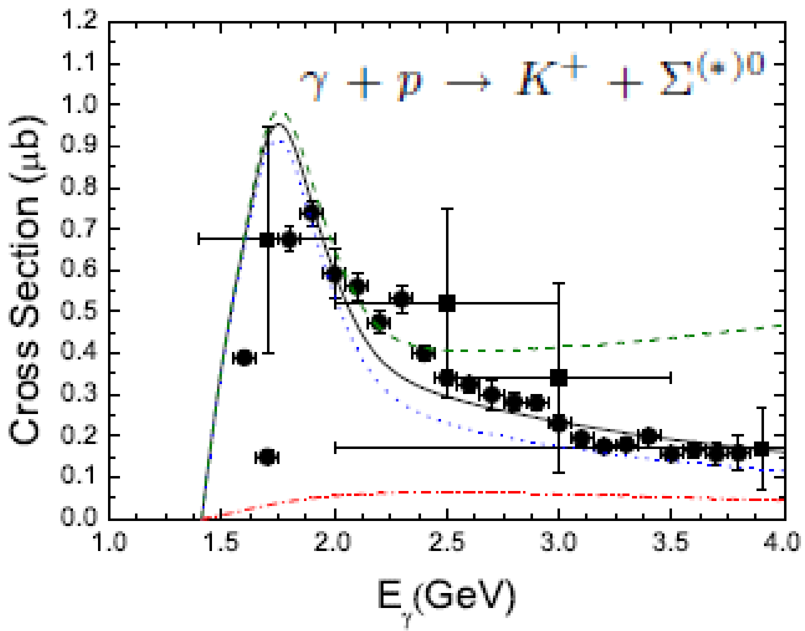
Something new ? Σ*(1/2⁻) ?

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

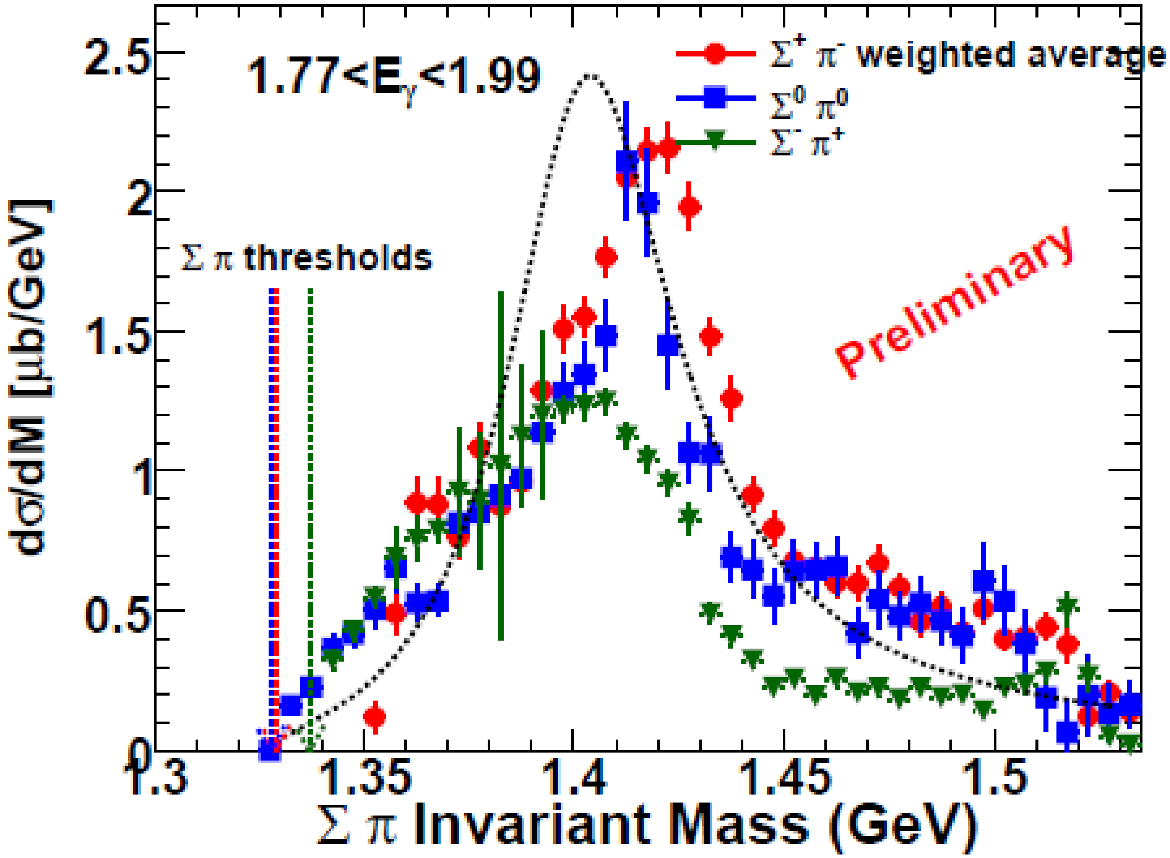
dashed : $\Sigma^*(3/2^+)$ with h=1.11

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 $\Sigma(1385)$ and $\Xi(1520)$ peaks there are $1/2^-$ components ?

4. 5-quark components in other baryons

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

→ $\Delta^*(1620)$ ½-	ρN molecule ?	1705 MeV
	$\Sigma^*(1750)$ ½-	K^*N molecule ?	1820 MeV
	$\Xi^*(1950)$ ½-?	$K^*\Lambda$ molecule ?	2010 MeV
	$\Omega^*(2160)$ ½-?	$K^*\Xi$ molecule ?	2215 MeV

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

Role of 5q in Δ and N*(1440) – see papers by Riska et al.

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

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 ~ $\bar{q}q^2q^2$ state + …

0^+ meson octet ~ $\bar{q}^2q^2$ 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**