

Five-quark components in baryons

Bing-Song Zou

Institute of High Energy Physics, CAS, Beijing

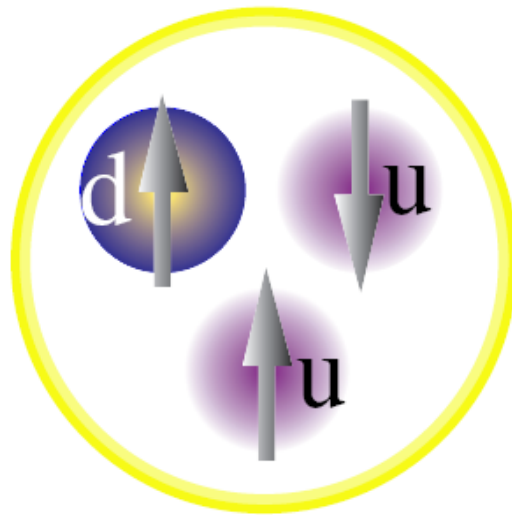
Outline:

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

1. 5-quark components in the proton

Classical picture of the proton

Constituent Quarks



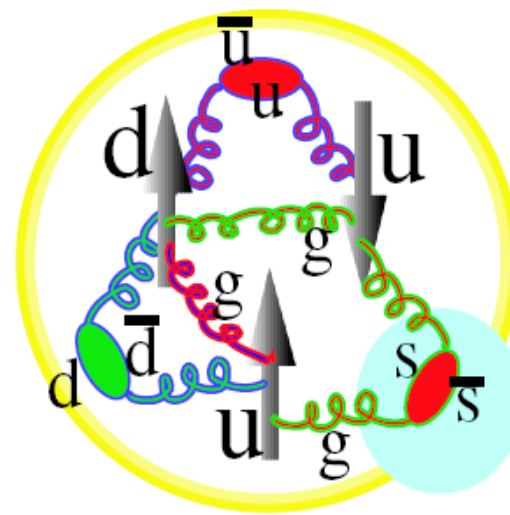
($Q^2 = 0 \text{ GeV}^2$)

baryon octet

masses, magn. momenta

1964-1974

Parton Distributions



($Q^2 > 1 \text{ GeV}^2$)

structure functions

momentum, spin

$$\bar{u}(x) = \bar{d}(x), \quad \bar{s}(x) = s(x)$$

1974-1992

Flavor asymmetry of light quarks in the nucleon sea

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

$$\rightarrow \quad \bar{d} - \bar{u} \sim 0.12 \quad \text{for a proton}$$

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

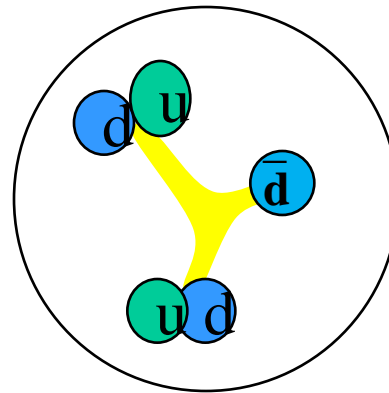
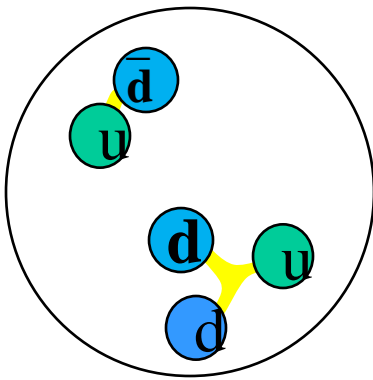
Two major theoretical schemes for $\bar{d} - \bar{u} \sim 0.12$

Meson cloud picture: Thomas, Speth, Weise, Oset, Brodsky, Ma, ...

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

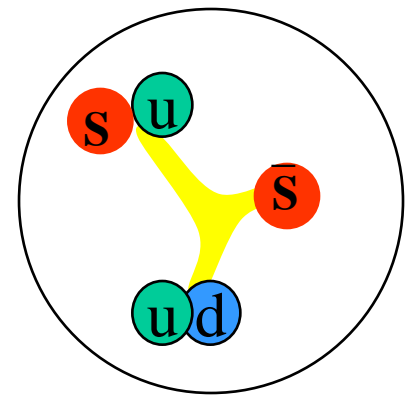
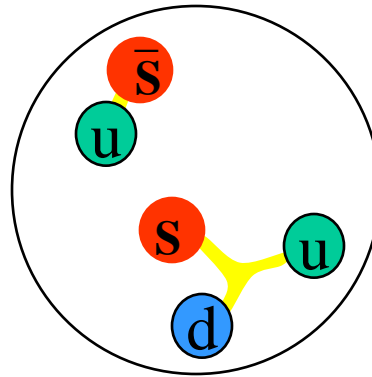
Penta-quark picture: Riska, Zou, Zhu, ...

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



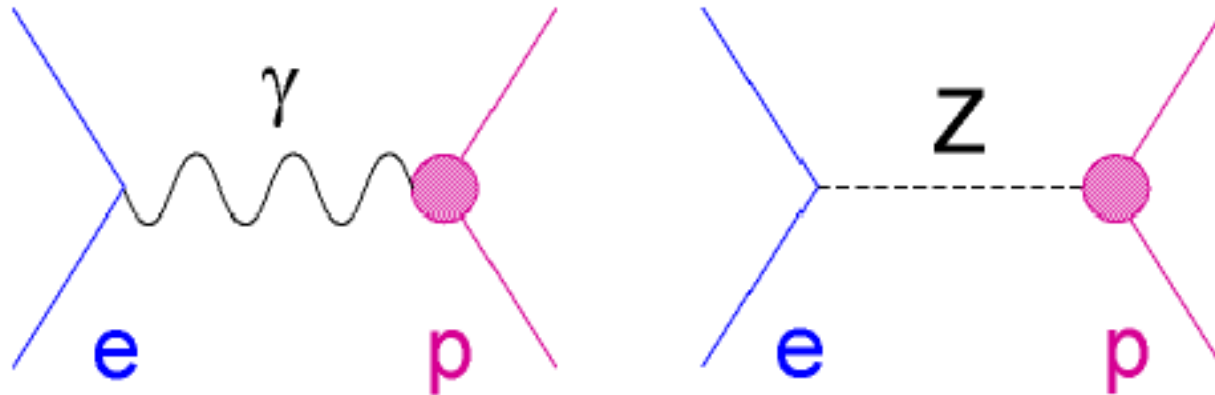
Predictions for \bar{s} / s asymmetry from two schemes :

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

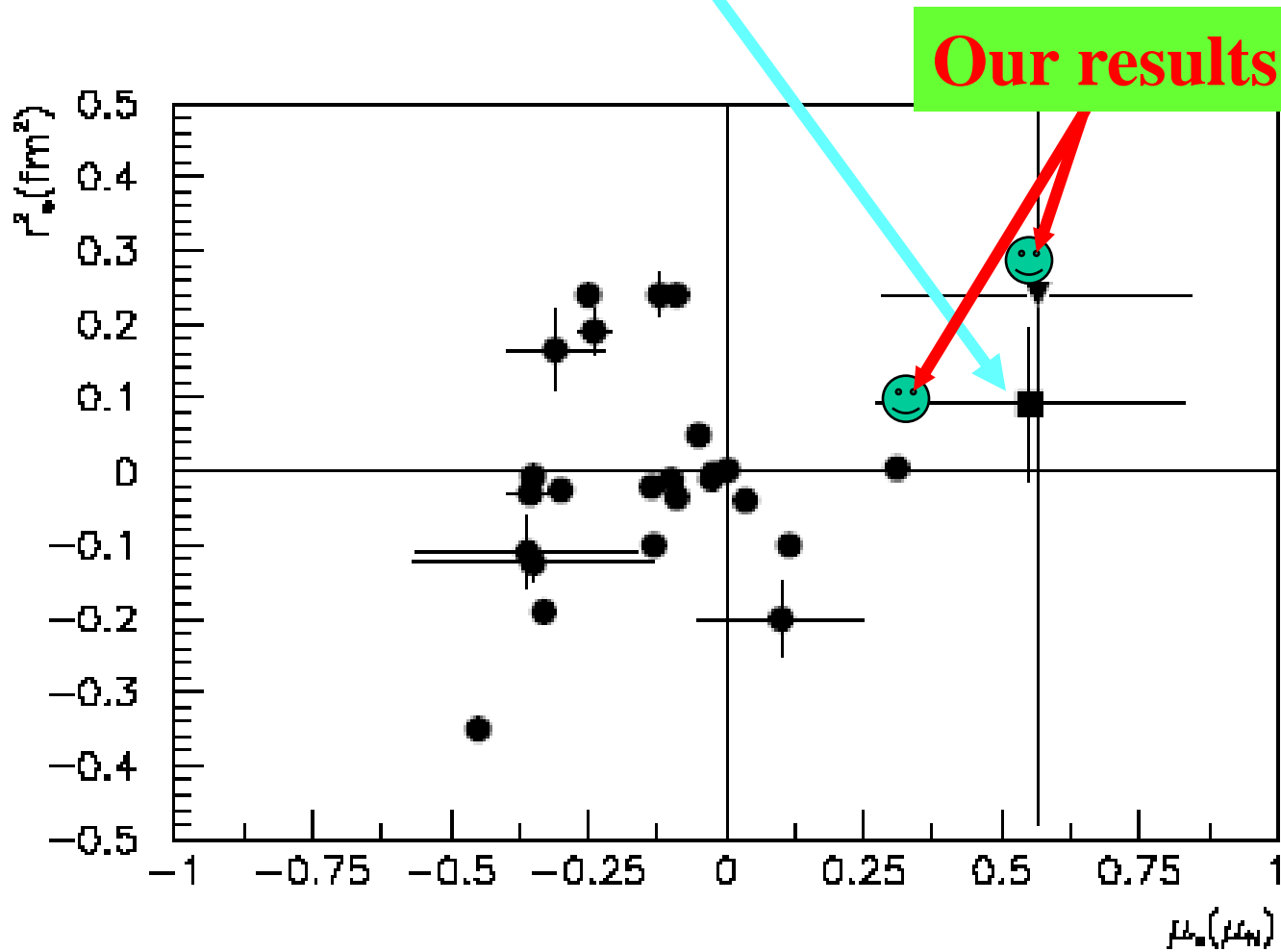
HAPPEX/CEBAF, Phys.Rev.Lett. 96 (2006) 022003

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 $\rightarrow \mu_s \sim 0$

With $\sim 25\%$ $\bar{q}qqqq$ 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

**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**

$uud (L=1) 1/2^- \sim N^*(1535)$ **should be the lowest**

$uud (n=1) 1/2^+ \sim N^*(1440)$

$uds (L=1) 1/2^- \sim \Lambda^*(1405)$

harmonic oscillator ($2n + L + 3/2$) $\hbar\omega$

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

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

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

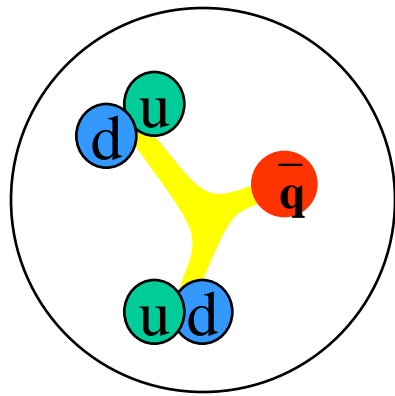
$\gamma p \rightarrow p\eta' \text{ \& } pp \rightarrow pp\eta' \rightarrow$ **large $g_{N^*N\eta'}$**

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

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

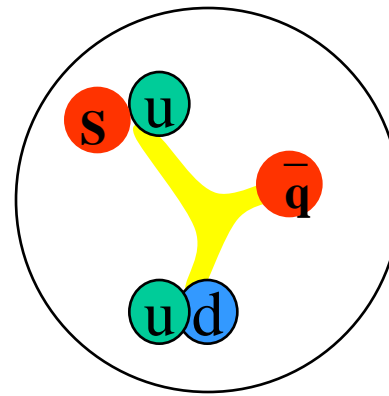
Xie, Zou & Chiang, PRC77(2008)015206; Cao, Xie, Zou & Xu, PRC80(2009)025203

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



$$\bar{q} \quad 1/2^+$$

$$\left. \begin{array}{l} [ud] \\ [ud] \end{array} \right\} L=1$$



$$\bar{q} \quad 1/2^-$$

$$\left. \begin{array}{l} [ud] \\ [us] \end{array} \right\} L=0$$

Zhang et al, hep-ph/0403210

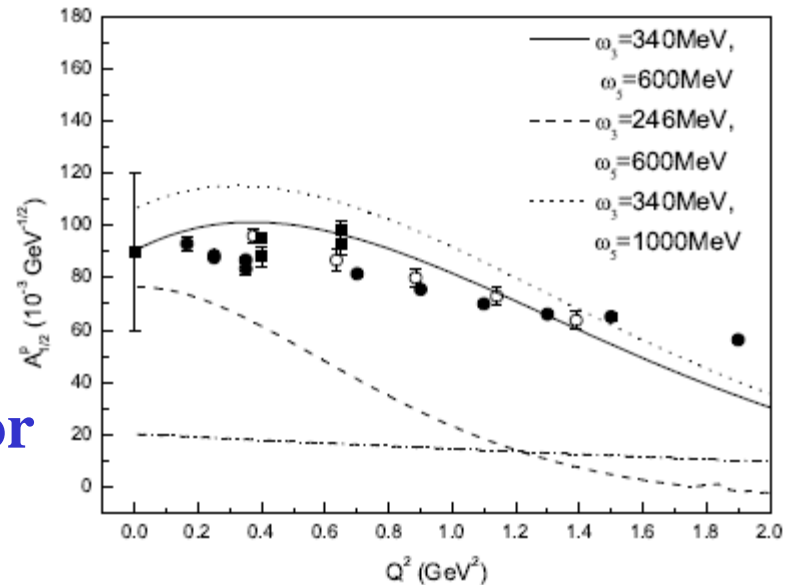
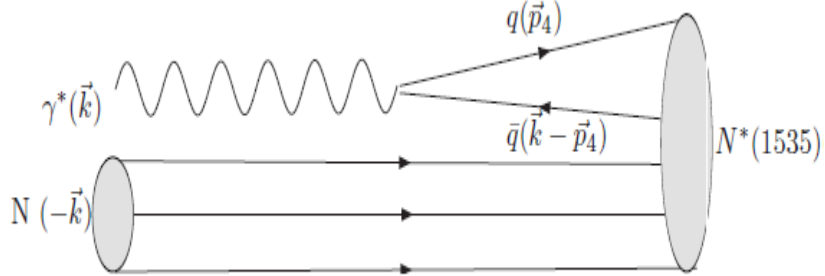
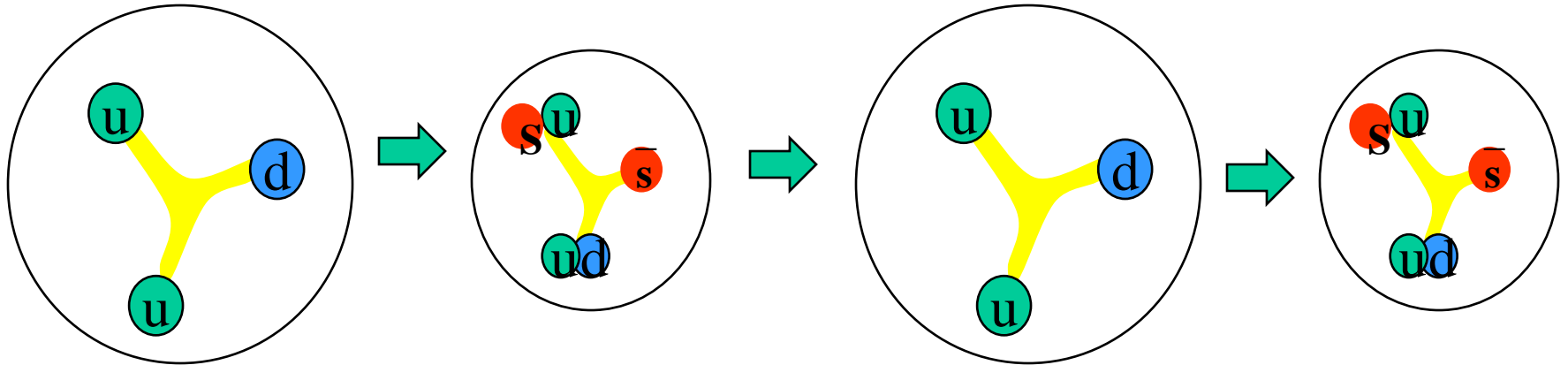
$$N^*(1535) \sim uud (L=1) + \varepsilon [ud][us] \bar{s} + \dots$$

$$N^*(1440) \sim uud (n=1) + \xi [ud][ud] \bar{d} + \dots$$

$$\Lambda^*(1405) \sim uds (L=1) + \varepsilon [ud][su] \bar{u} + \dots$$

$N^*(1535)$: $[ud][us] \bar{s} \rightarrow$ larger coupling to $N\eta$, $N\eta'$, $N\phi$ & $K\Lambda$, weaker to $N\pi$ & $K\Sigma$, 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:

$$\Lambda^* \quad [us][ds] \bar{s} \quad \sim \quad 1575 \text{ MeV}$$

$$\Sigma^* \quad [us][du] \bar{d} \quad \sim \quad 1360 \text{ MeV}$$

$$\Xi^* \quad [us][ds] \bar{u} \quad \sim \quad 1520 \text{ MeV}$$

Prediction of other unquenched models:

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

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

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

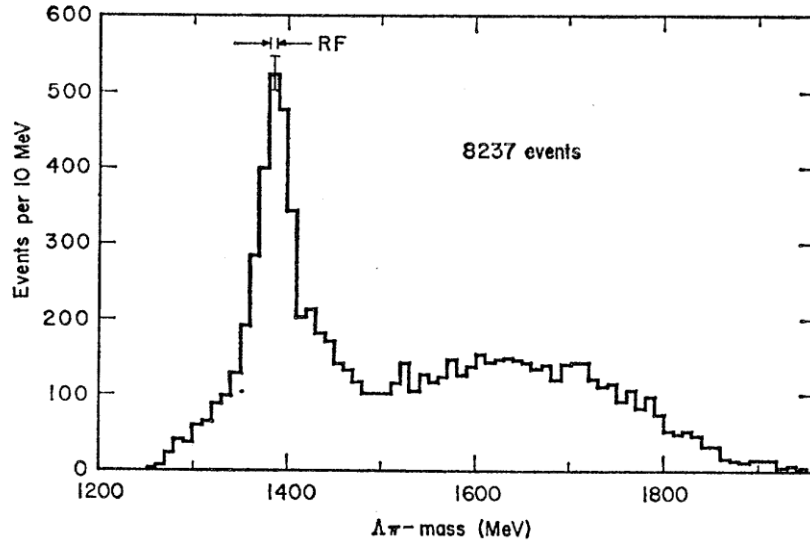
broad non-resonant $\Sigma^*(1/2^-)$ structure

Jido-Oset et al , NPA725(2003)181

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

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

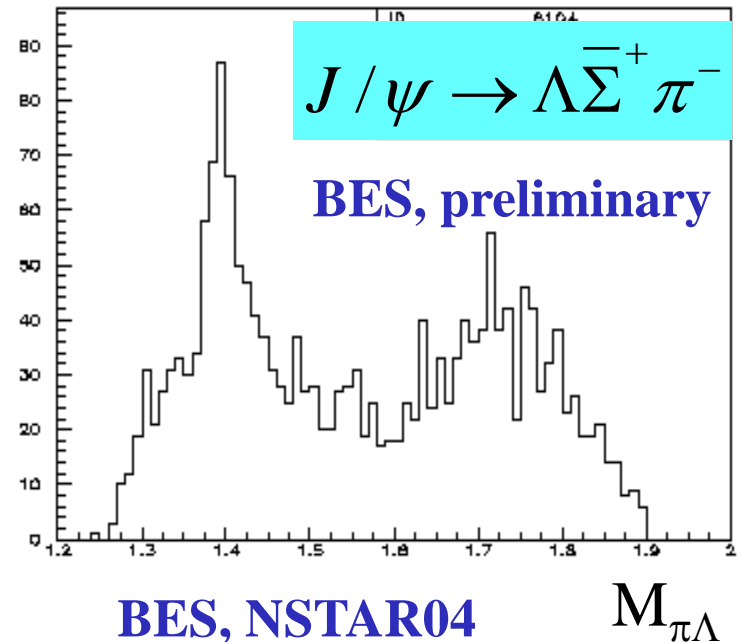
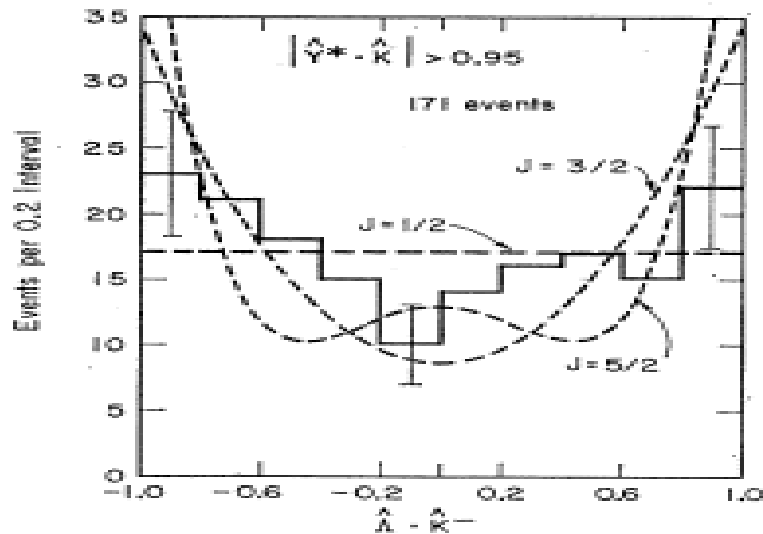
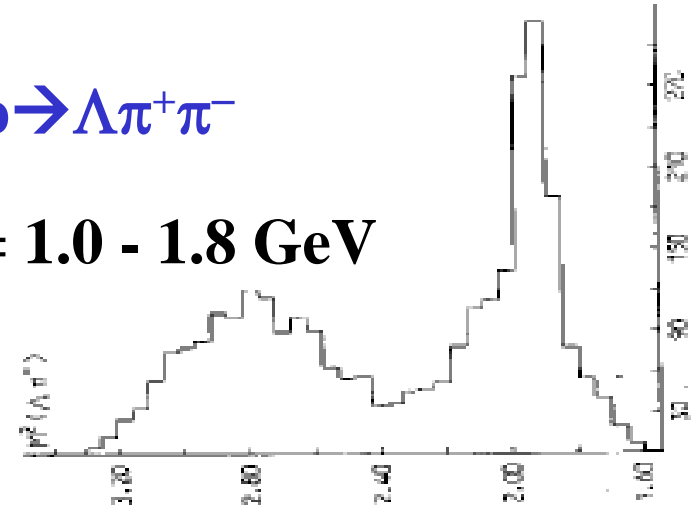
Huwe, PR181(1969)1824

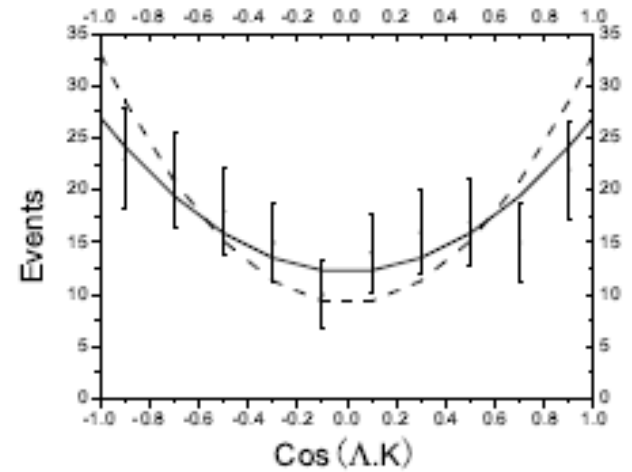
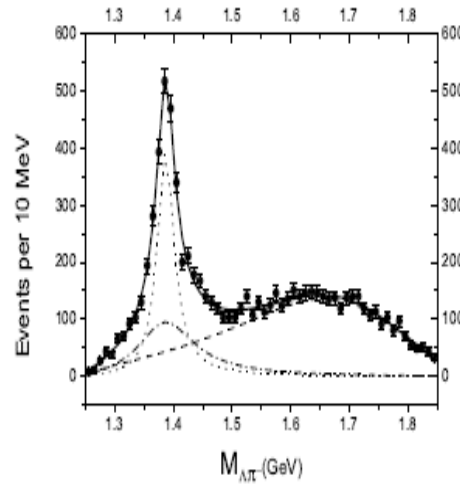
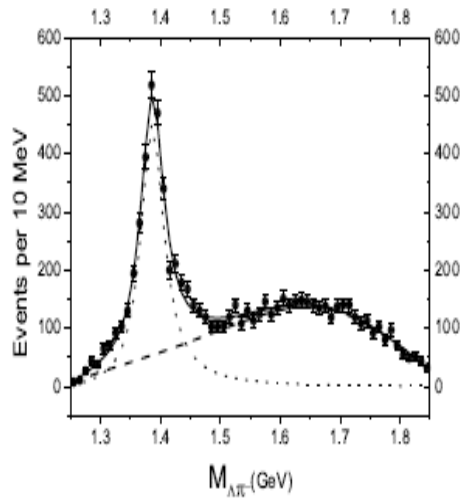


Cameron et al., NPB143(1978)189

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

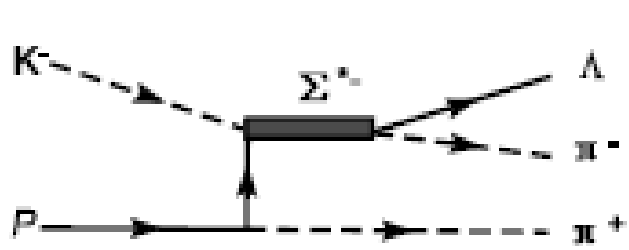
$P_K = 1.0 - 1.8 \text{ GeV}$



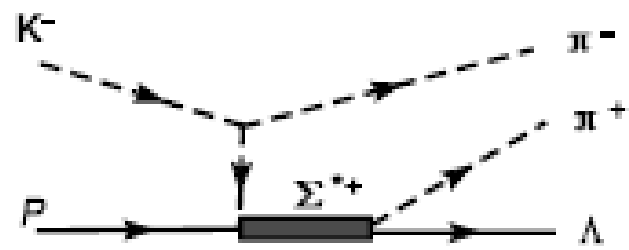


	$M_{\Sigma^*(3/2)}$	$\Gamma_{\Sigma^*(3/2)}$	$M_{\Sigma^*(1/2)}$	$\Gamma_{\Sigma^*(1/2)}$	χ^2/ndf (Fig.1)	χ^2/ndf (Fig.2)
Fit1	1385.3 ± 0.7	46.9 ± 2.5			68.5/54	10.1/9
Fit2	$1386.1^{+1.1}_{-0.9}$	$34.9^{+5.1}_{-4.9}$	$1381.3^{+4.9}_{-8.3}$	$118.6^{+55.2}_{-35.1}$	58.0/51	3.2/9

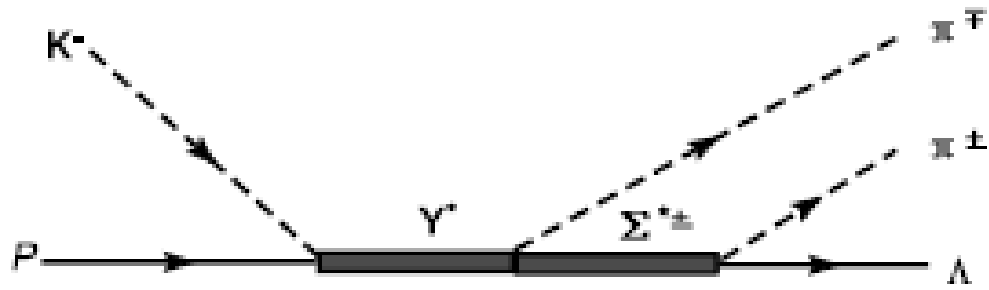
J.J.Wu, S.Dulat, B.S.Zou, PRD80 (2009) 017503



(a)



(b)

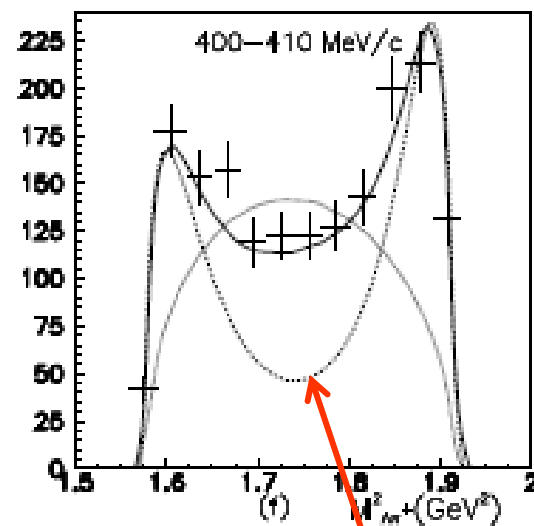
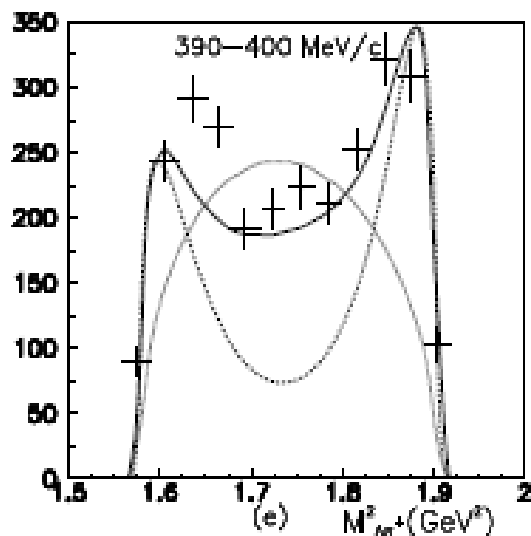
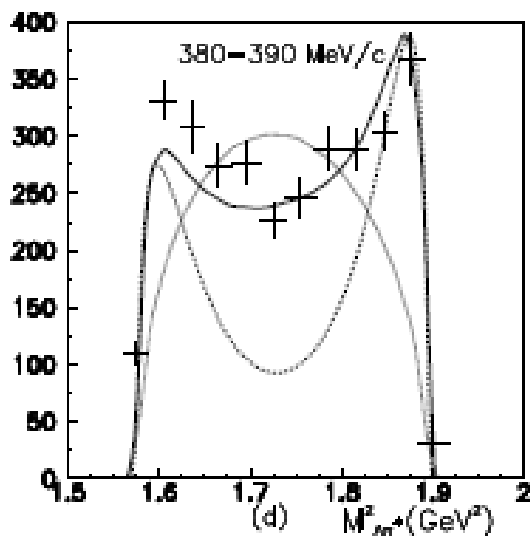
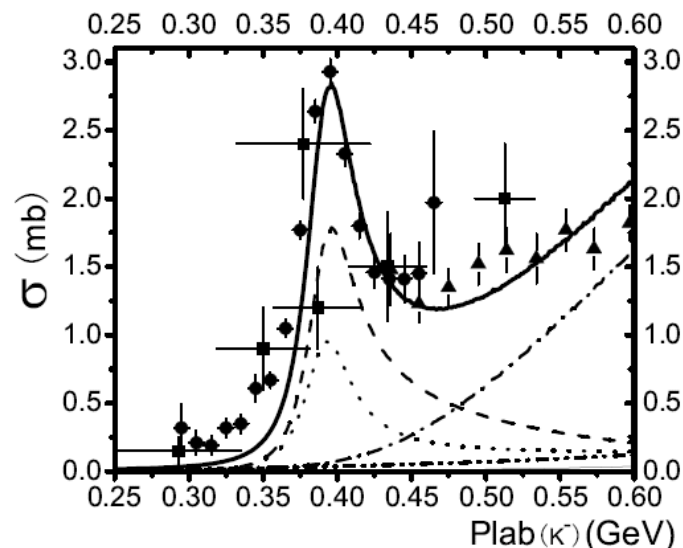


(c)

$$K^- p \rightarrow \Lambda^* \rightarrow \Sigma_{3/2}^{*-} \pi^+ \rightarrow \Lambda \pi^+ \pi^-$$

$$K^- p \rightarrow \Lambda^* \rightarrow \Sigma_{1/2}^{*-} \pi^+ \rightarrow \Lambda \pi^+ \pi^-$$

$$P_K \approx 0.4 \text{ GeV}$$



$\Sigma^*(3/2^+)$ only

J.J.Wu, S.Dulat, B.S.Zou, [arXiv:0909.1380](https://arxiv.org/abs/0909.1380) [hep-ph]

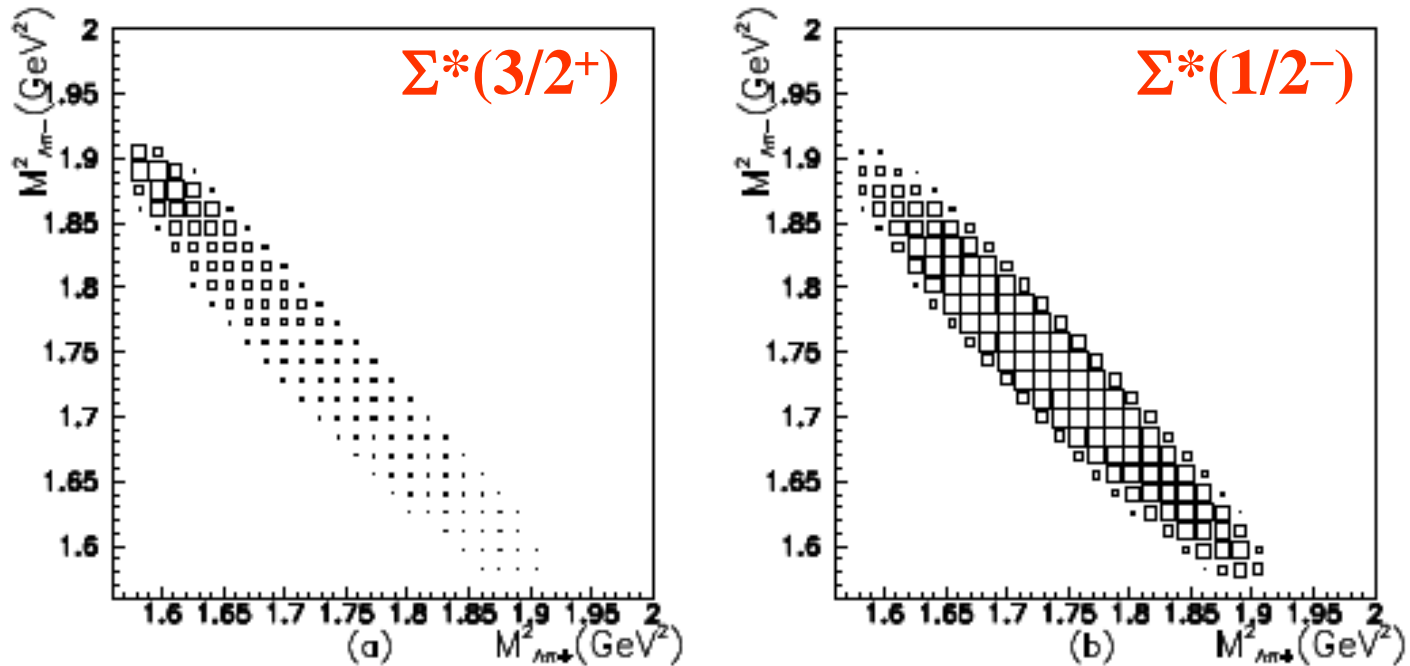


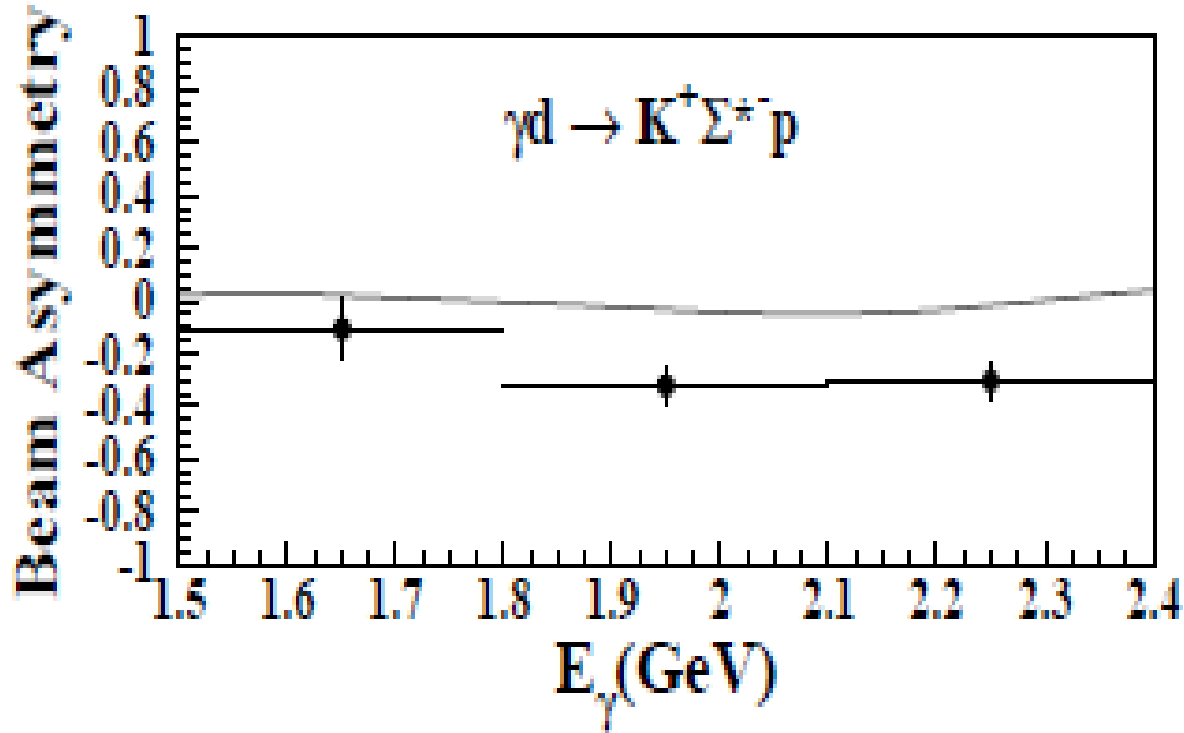
FIG. 7: Dalitz plots (a) and (b) corresponding to the reactions $K^-p \rightarrow \Lambda^* \rightarrow \Sigma_{3/2}^* \pi^+ \rightarrow \Lambda \pi^+ \pi^-$ and $K^-p \rightarrow \Lambda^* \rightarrow \Sigma_{1/2}^* \pi^+ \rightarrow \Lambda \pi^+ \pi^-$, respectively, at $P_{lab}(K^-) = 0.394$ GeV.

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

Both are needed to reproduce the data !

Other evidence: failed to reproduce data with $\Sigma^*(1385)$

LEPS, PRL102(2009)012501



Something new ? $\Sigma^*(1/2^-)$!

P.Gao, J.J.Wu, B.S.Zou, to be submitted

4. 5-quark components in other baryons

Δ^{++*} (1620) $1/2^-$ -- 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

\rightarrow	$\Delta^*(1620) 1/2^-$	ρN molecule ?	1705 MeV
	$\Sigma^*(1750) 1/2^-$	K^*N molecule ?	1820 MeV
	$\Xi^*(1950) 1/2^-?$	$K^*\Lambda$ molecule ?	2010 MeV
	$\Omega^*(2160) 1/2^-?$	$K^*\Xi$ molecule ?	2215 MeV

$1/2^-$ baryon decuplet $\sim V_8 B_8$ molecules ?

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

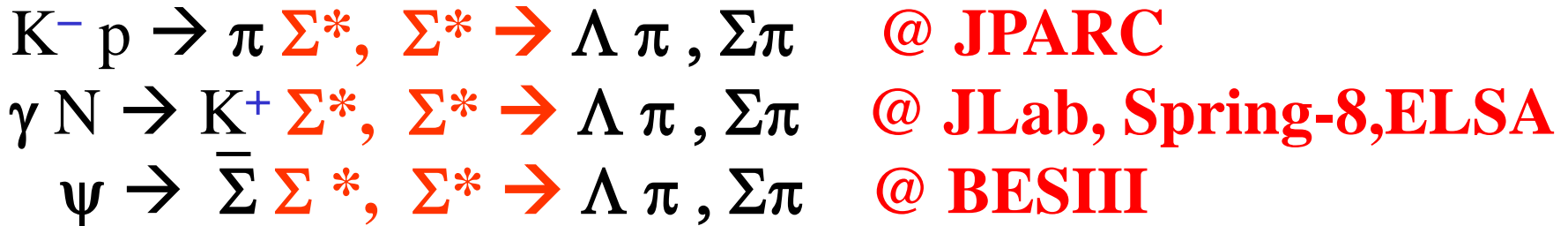
Li,Riska, NPA766(2006)172; Juli áD áz,Riska, NPA780(2006)175

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 $L=1$!**
 - $1/2^-$ baryon nonet $\sim \bar{q}q^2q^2$ state + ...**
 - $1/2^-$ baryon decuplet $\sim V_8B_8$ molecules + ...**
- 5-quark components are important for all baryons!**

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 :



J/ψ decay

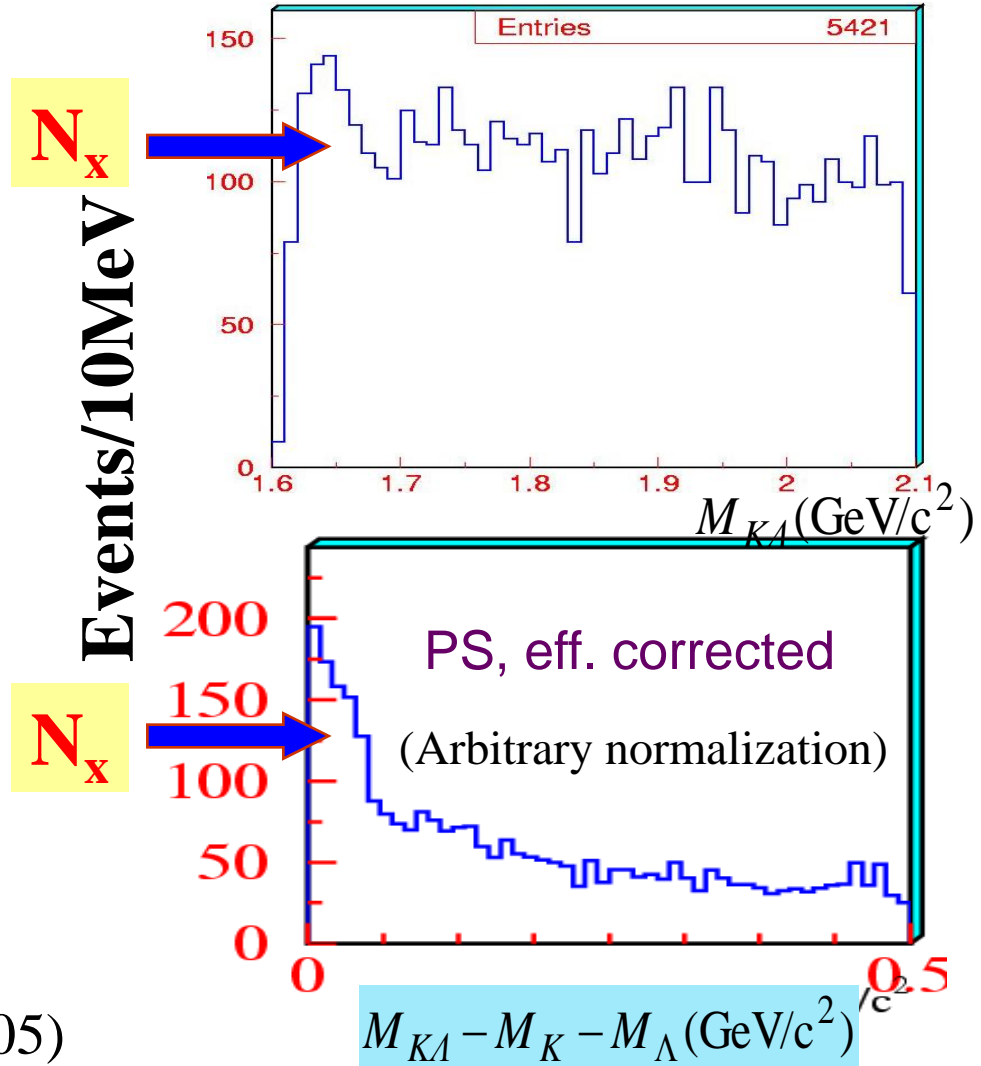
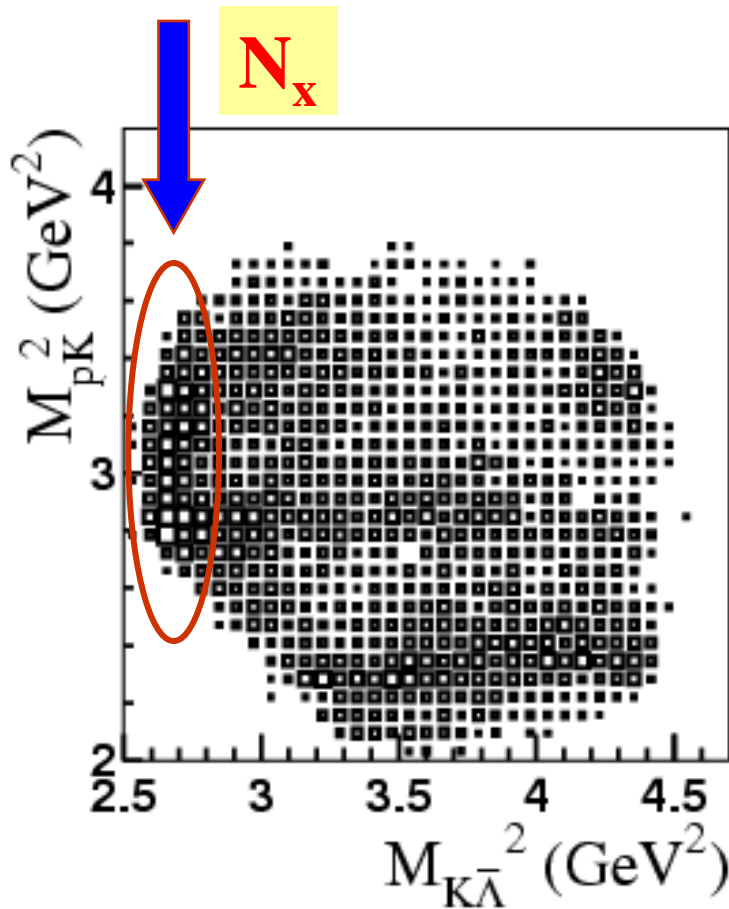
branching ratio * 10⁴

$\bar{p} \Delta(1232)^+$	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 ?

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

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

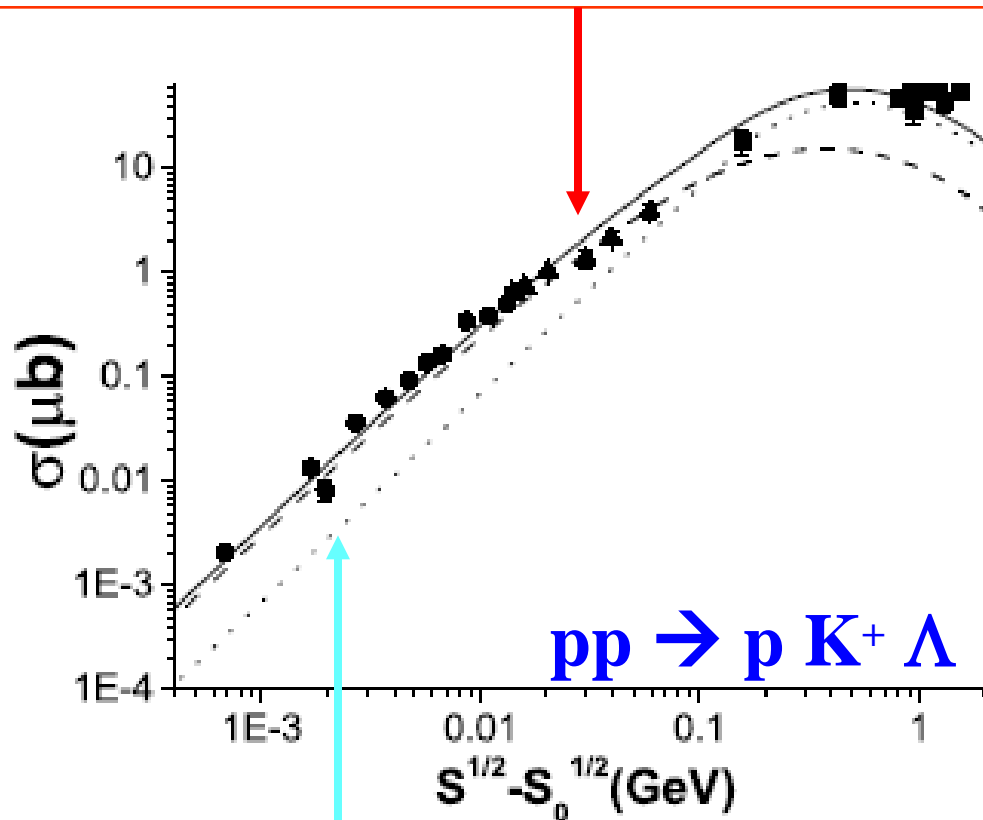
Phenomenology : Large $g_{N^*K\Lambda} \rightarrow$ large $\bar{s}s$ in $N^*(1535)$

$\bar{s}[su][ud]$ 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 $pp \rightarrow p K^+ \Lambda$

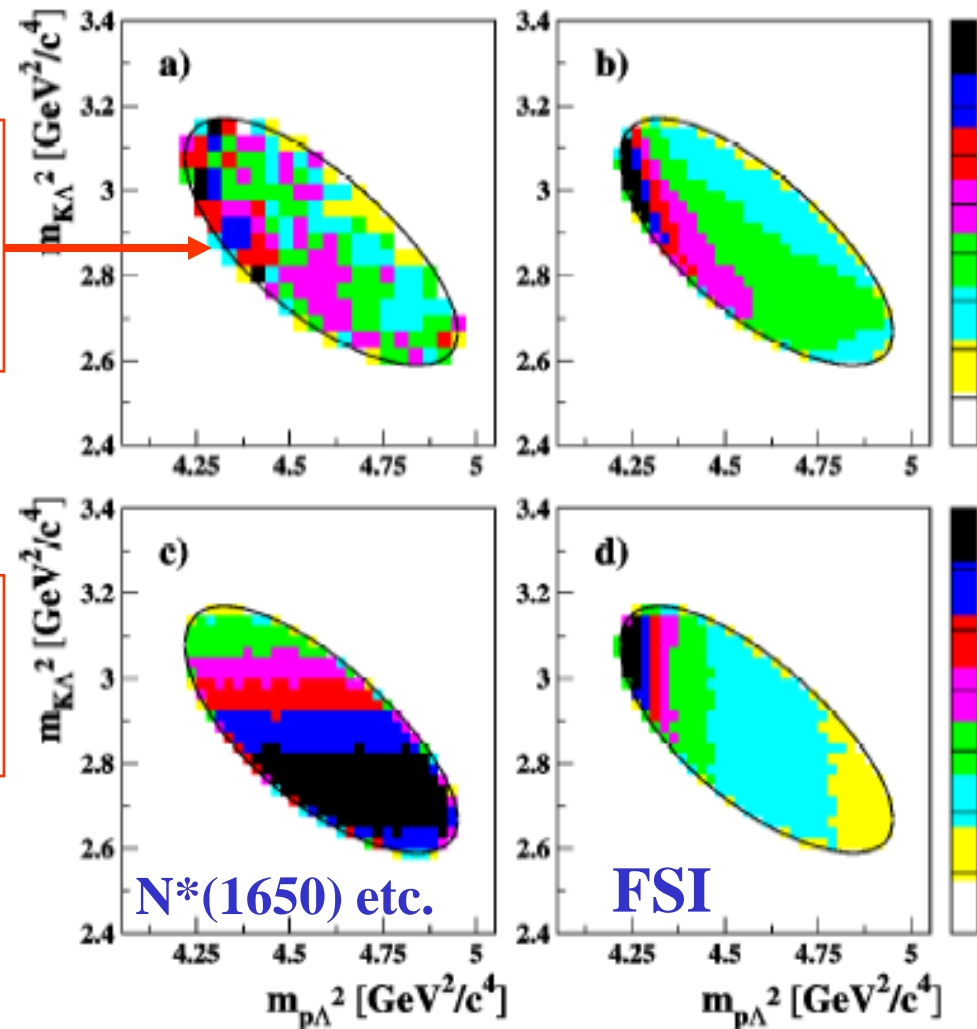
B.C.Liu & B.S.Zou, Phys. Rev. Lett. 98 (2007) 039102 (reply)

A.Sibirtsev et al., Phys. Rev. Lett. 98 (2007) 039101 (comment)

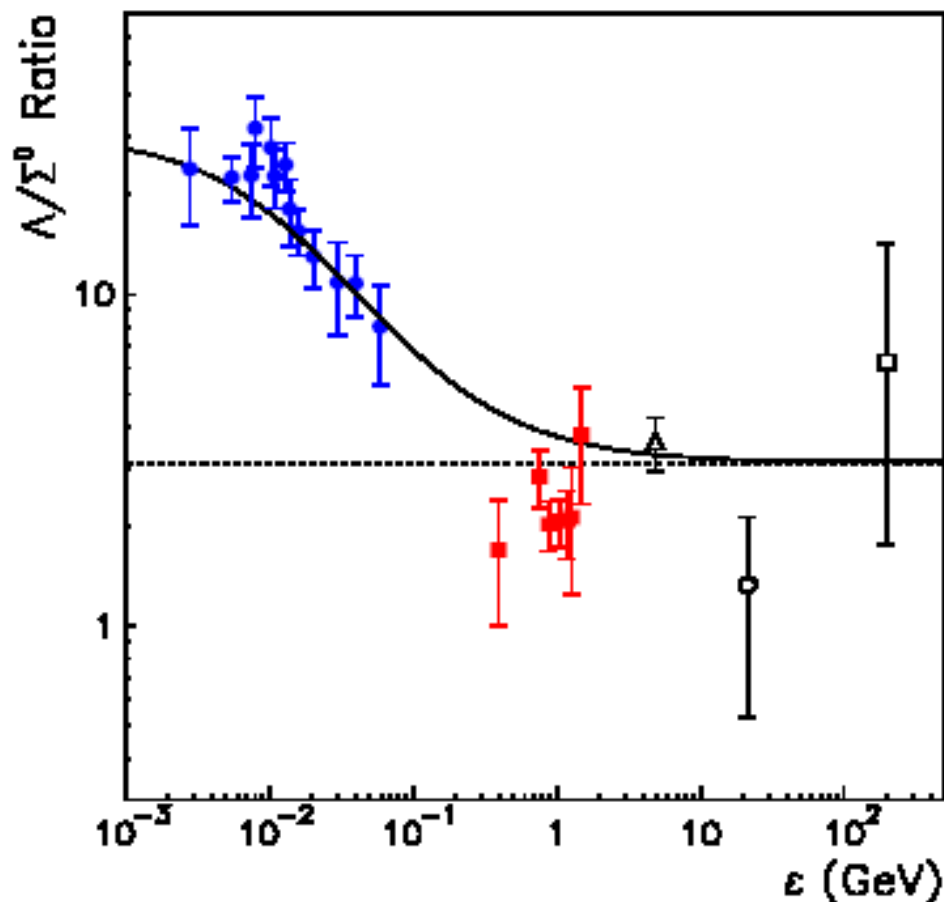
COSY-TOF data
S. Abdel-Samad *et al.*,
Phys.Lett.B632:27(2006)



**Both FSI & $N^*(1535)$
are needed !**



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



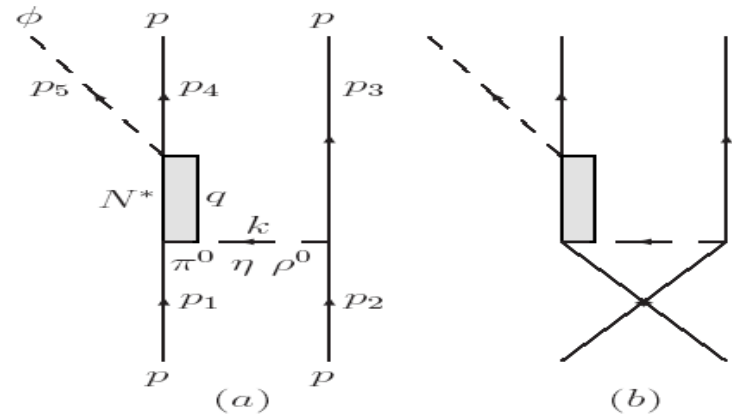
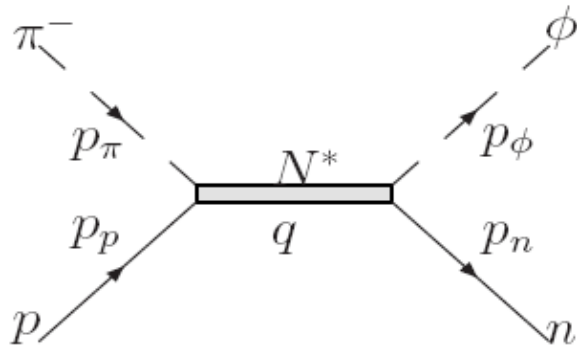
**A.Sibirtsev et al.,
EPJA29 (2006) 363**

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

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

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

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



Evasion of OZI rule by $N^*(1535)$!

Evidence for large $g_{N^*N\eta'}$ from $\gamma p \rightarrow p \eta'$, $pp \rightarrow pp\eta'$

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