Five-quark components and breathing mode for baryons

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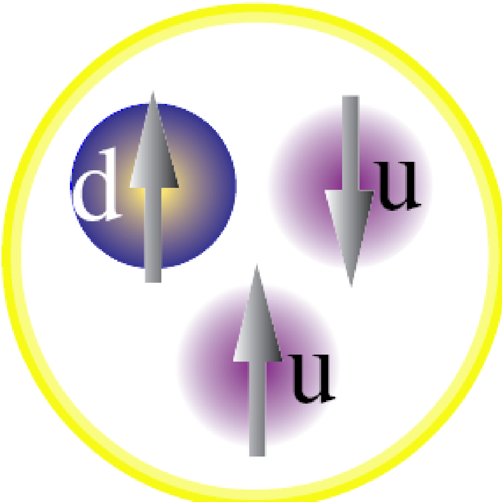
Outline:

- Introduction -- 5-quark components in the proton
- New scheme for N*(1535) and its$1/2^-$ nonet partners
  with large 5-quark components and breathing mode
- Evidence for the predicted $\Sigma^*(1/2^-)$
- Extension to hidden charm and beauty
- Conclusion

1. Introduction: 5-quark components in the proton

Classical picture of the proton

Constituent Quarks



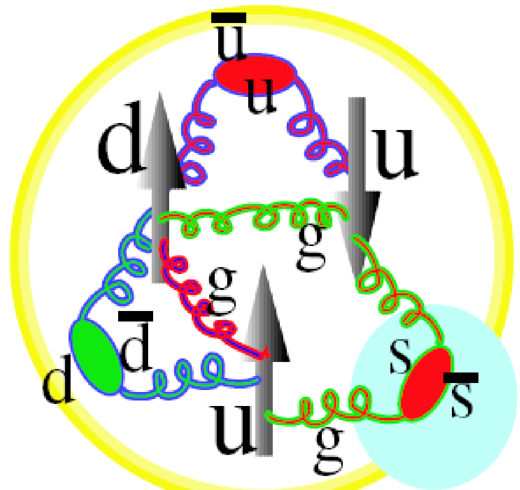
($Q^2 = 0$ GeV^2)

baryon octet

masses,magn. momenta

1964-1974

Parton Distributions



($Q^2 > 1$ GeV^2)

structure functions

momentum, spin

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

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

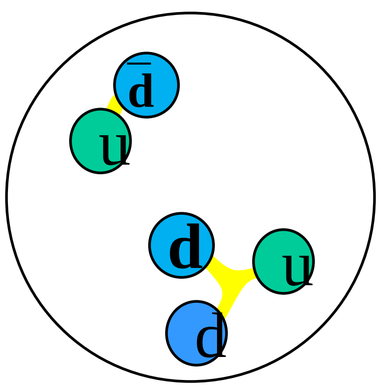
Two major theoretical schemes for $\bar{d} - \bar{u} \sim 0.12$

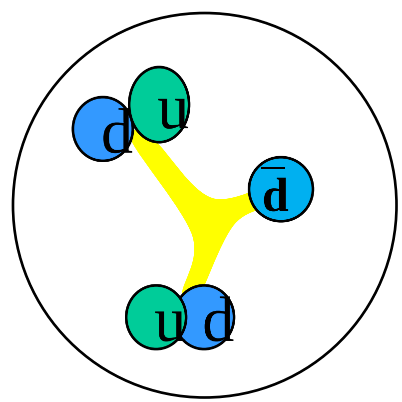
Meson cloud picture: Thomas, Speth, Henley, Meissner, Miller, Weise, Oset, Brodsky, Ma, …

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

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

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





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

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

$$1 \quad : \quad 1$$

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

$$+\ 0.084\ (uudgg) + \ldots \qquad \bar{d} - \bar{u} \sim 0.124$$

$(uud+ng)$ 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) hω

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

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

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

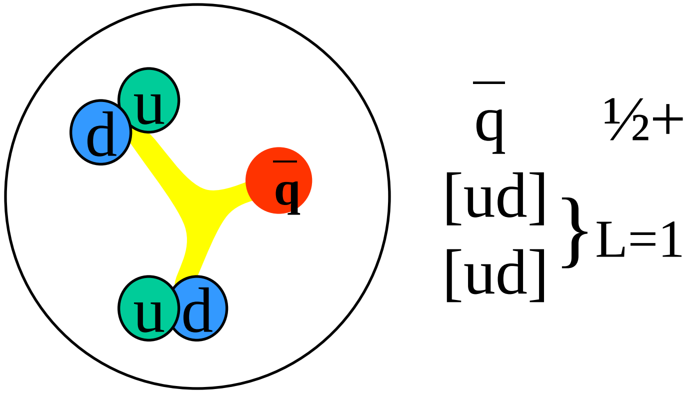
$\gamma p \to p\eta'$ & $pp \to pp\eta'$ → large $g_{N^*N\eta'}$

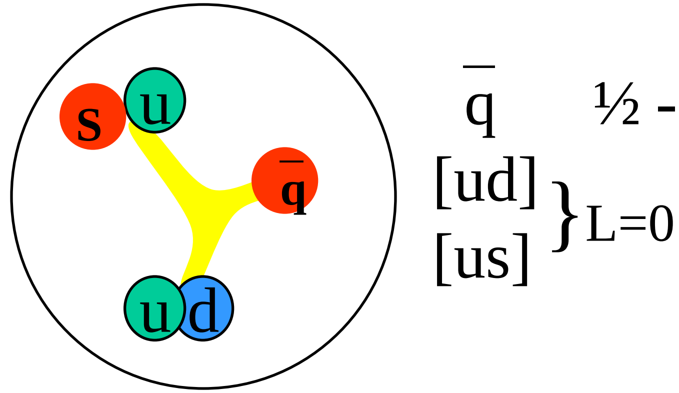
M.Dugger et al., PRL96 (2006) 062001; Cao&Lee, PRC78(2008) 035207

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

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

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





Zhang et al, hep-ph/0403210

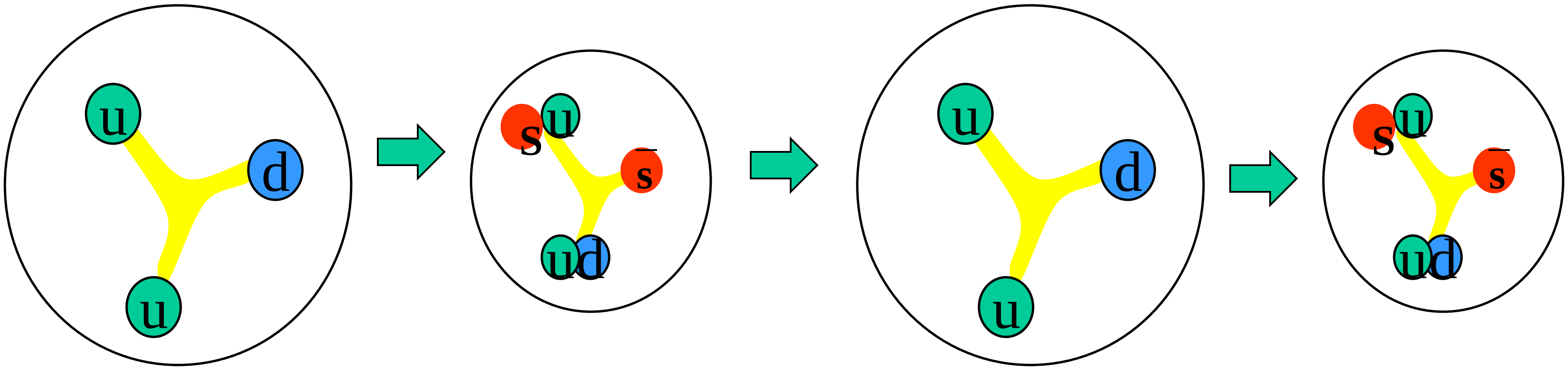
N*(1535) ~ uud (L=1) + ε [ud][us] $\bar{s}$ + …

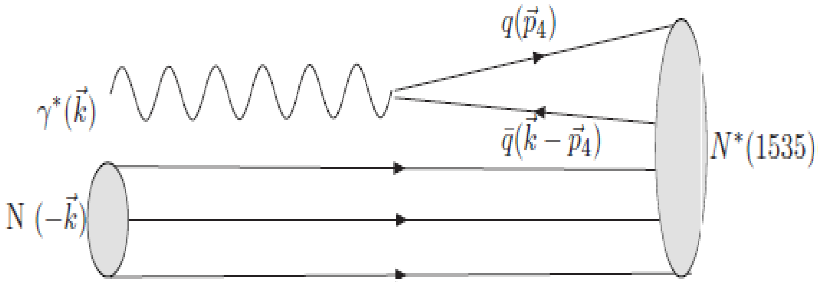
N*(1440) ~ uud (n=1) + ξ [ud][ud] $\bar{d}$ + …

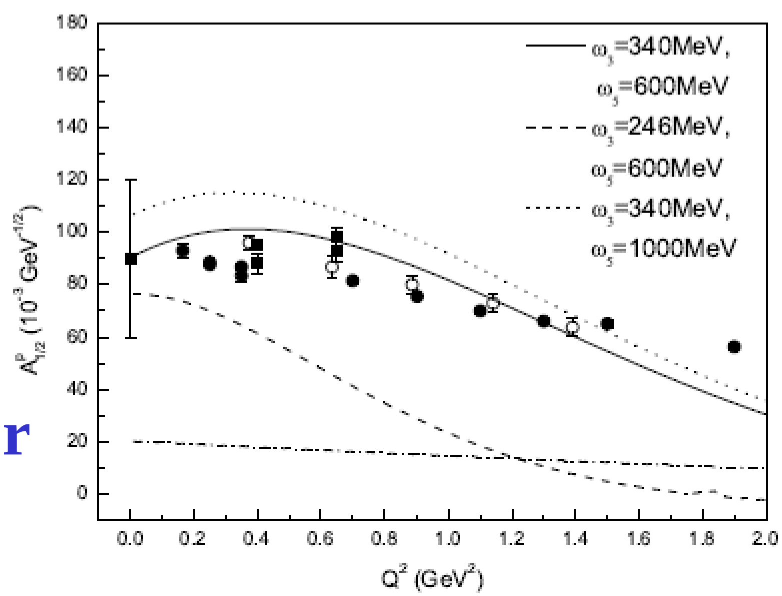
Λ*(1405) ~ uds (L=1) + ε [ud][su] $\bar{u}$ + …

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)





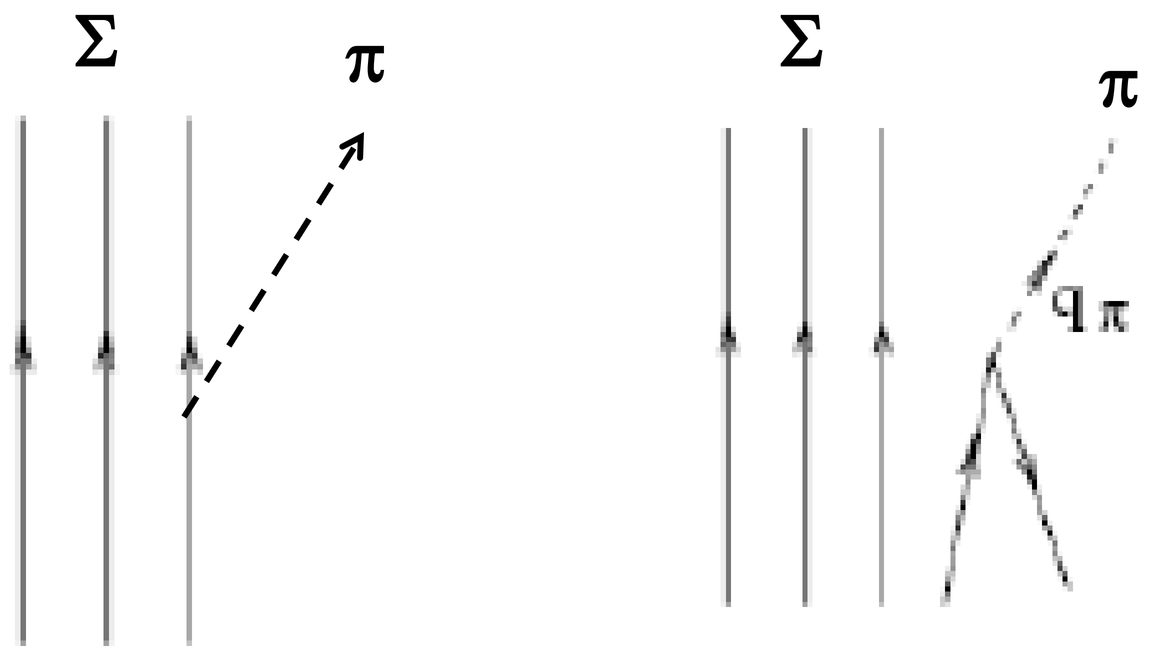


Important role for N* EM form factor

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

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

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

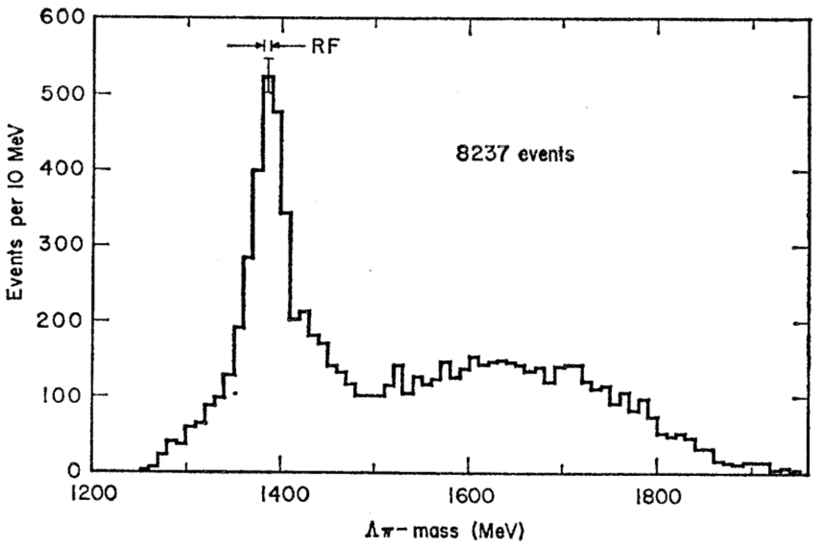
broad non-resonant $\Sigma^*(1/2^-)$ structure

Jido-Oset et al , NPA725(2003)181

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

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

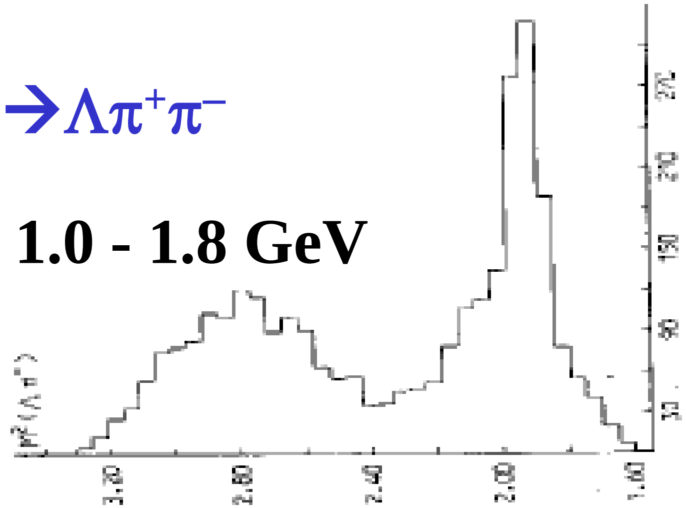
Huwe, PR181(1969)1824

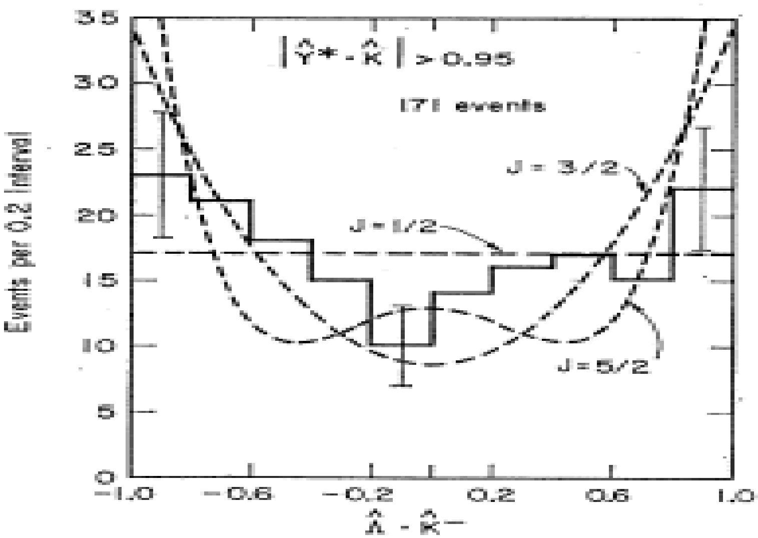


Cameron et al., NPB143(1978)189

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

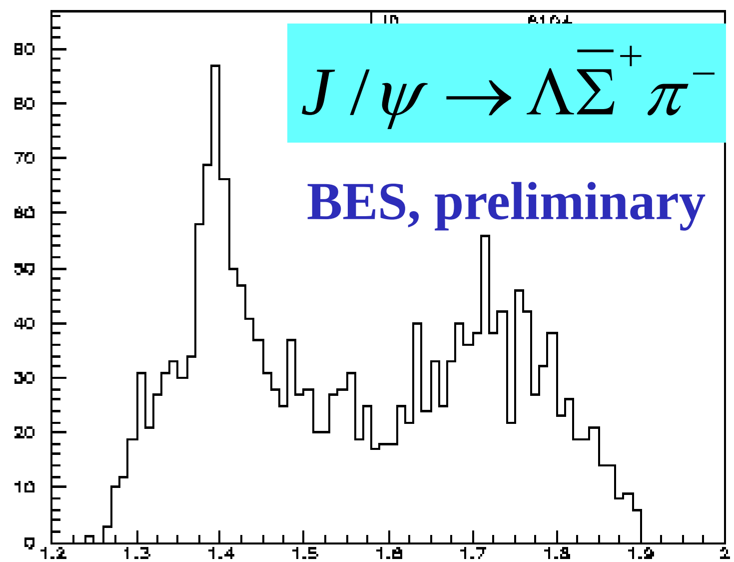
P_K = 1.0 - 1.8 GeV





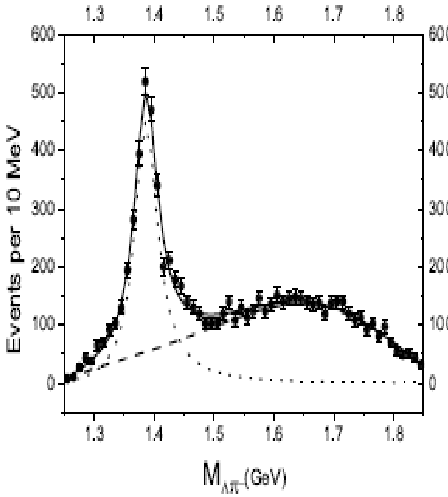
$$J/\psi \rightarrow \Lambda \bar{\Sigma}^+ \pi^-$$

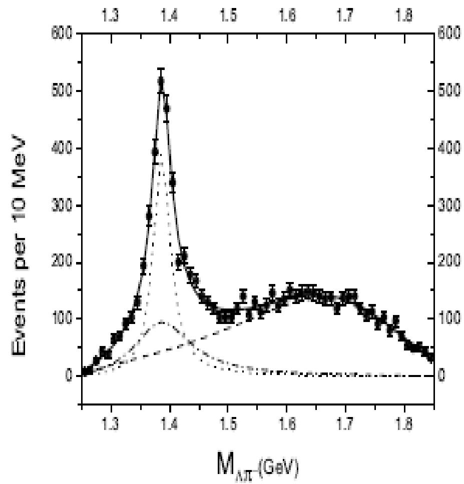
BES, preliminary

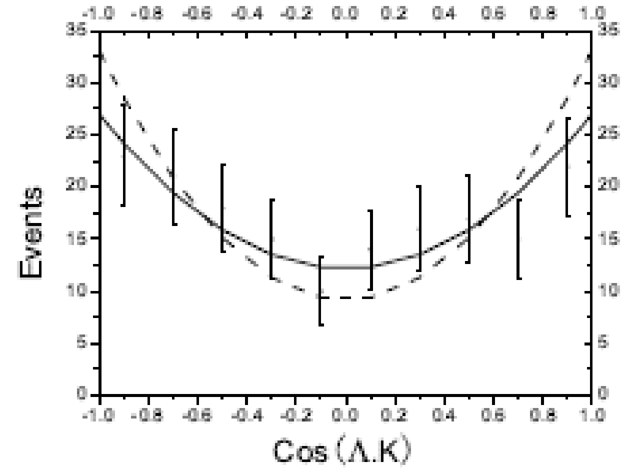


BES, NSTAR04

$M_{\pi\Lambda}$







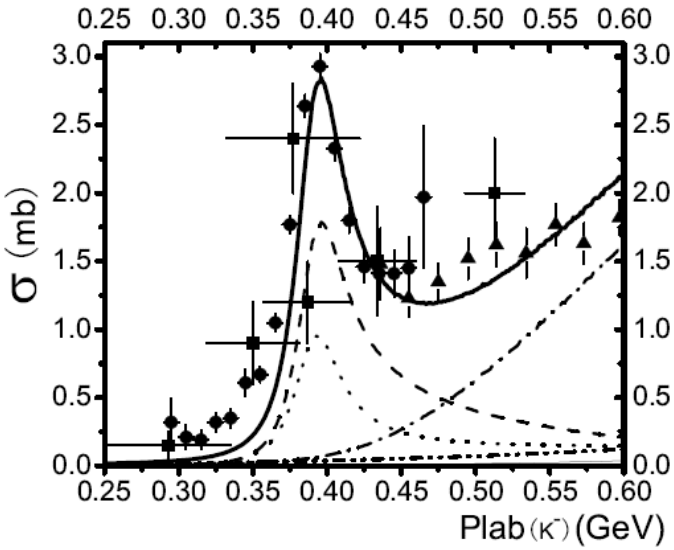
	$M_{\Sigma^*(3/2)}$	$\Gamma_{\Sigma^*(3/2)}$	$M_{\Sigma^*(1/2)}$	$\Gamma_{\Sigma^*(1/2)}$	χ^2/ndf(Fig.1)	χ^2/ndf(Fig.2)
Fit1	1385.3 ± 0.7	46.9 ± 2.5			$68.5/54$	$10.1/9$
Fit2	$1386.1^{+1.1}_{-0.9}$	$34.9^{+5.1}_{-4.9}$	$1381.3^{+4.9}_{-8.3}$	$118.6^{+55.2}_{-35.1}$	$58.0/51$	$3.2/9$

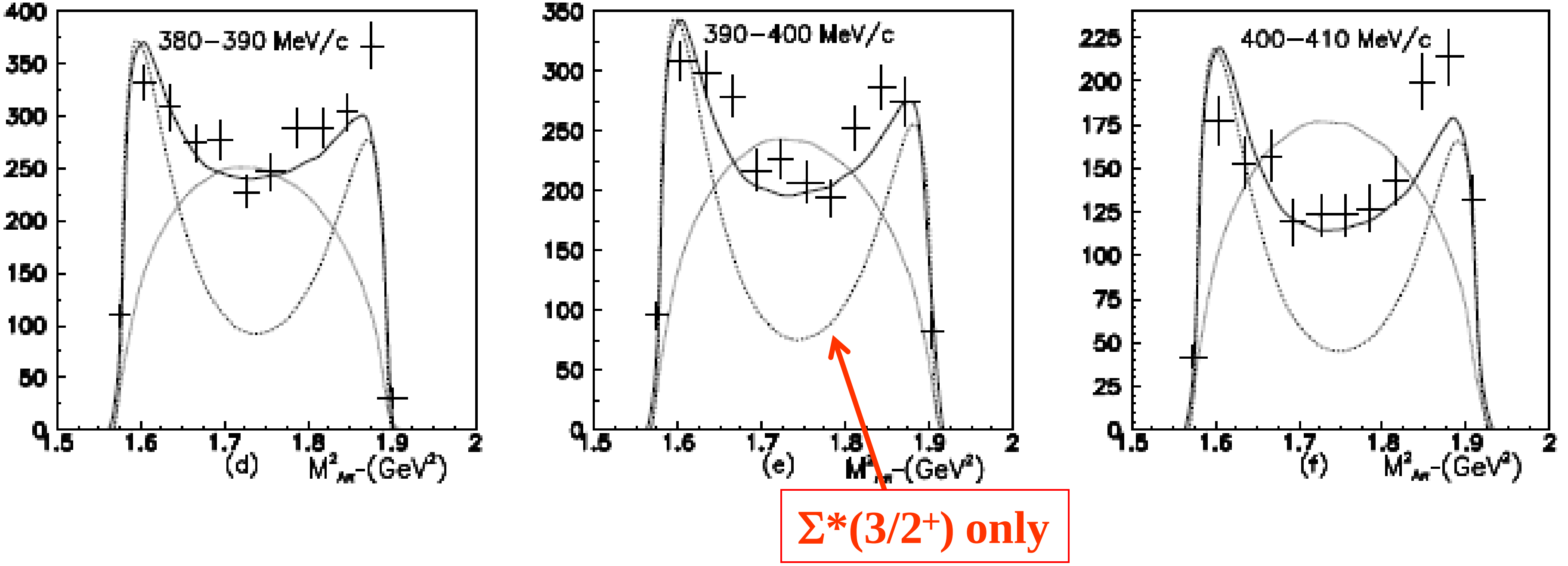
J.J.Wu, S.Dulat, B.S.Zou, PRD80 (2009) 017503

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

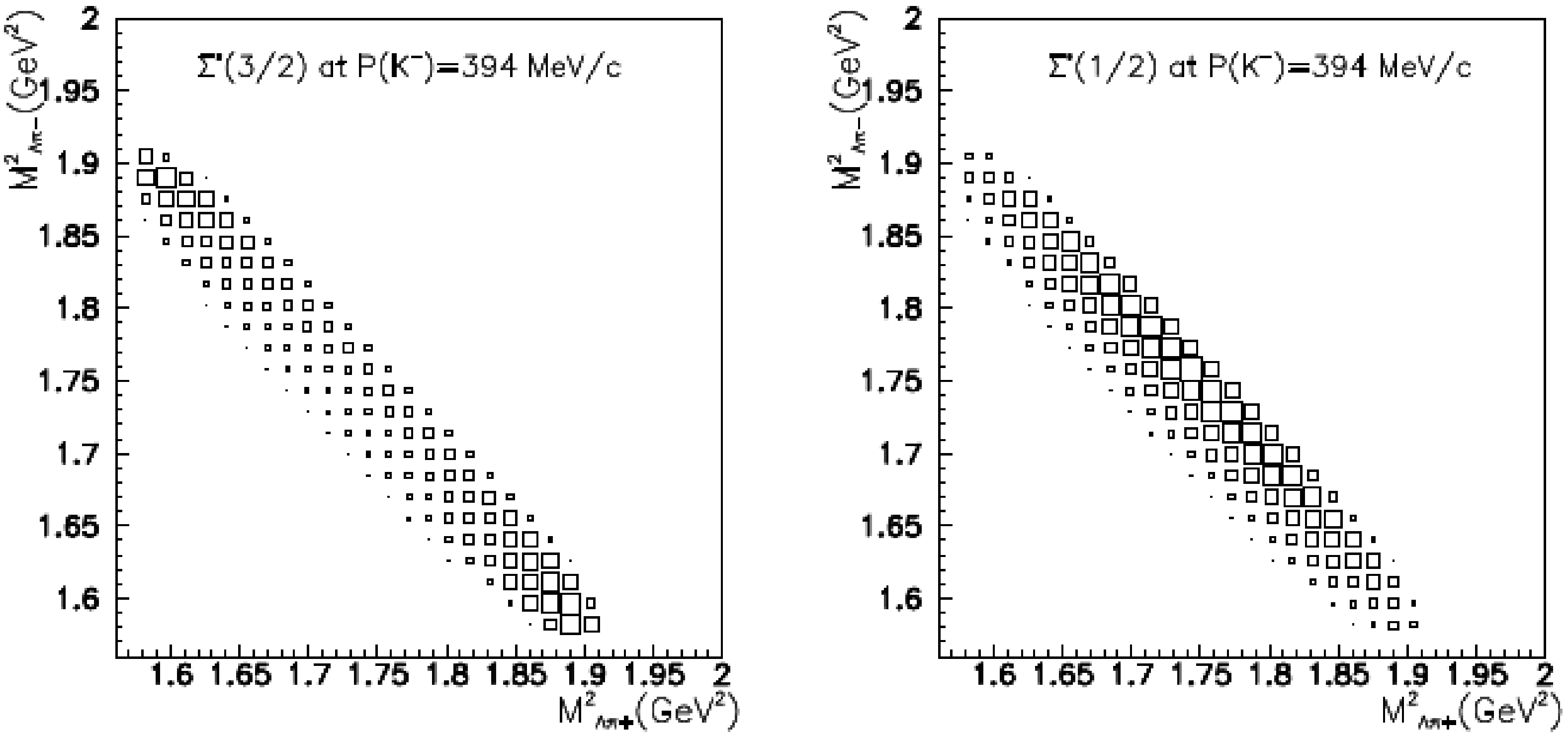
$$K^-p \to \Lambda^* \to \Sigma^{*-}_{1/2}\pi^+ \to \Lambda\pi^+\pi^-$$

$P_K \approx 0.4$ GeV





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



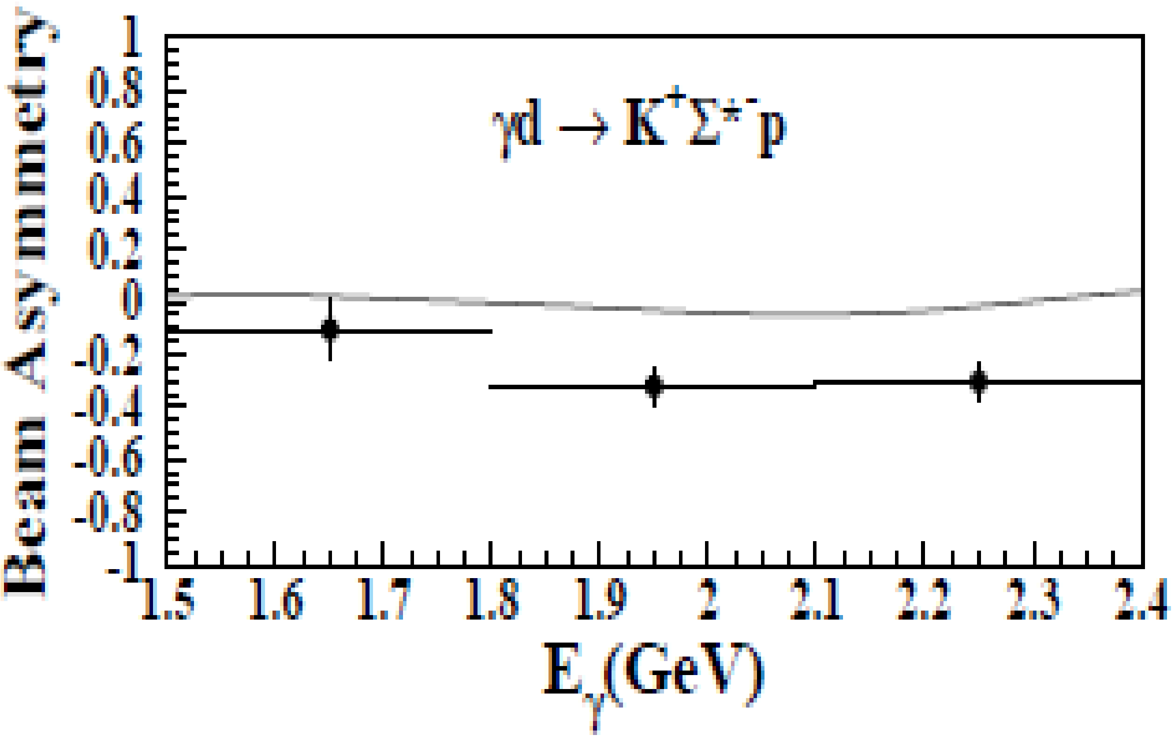
Σ*(3/2⁺) & Σ*(1/2⁻) → different Dalitz plots & mass spectra

Both are needed to reproduce the data !

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

LEPS, PRL102(2009)012501

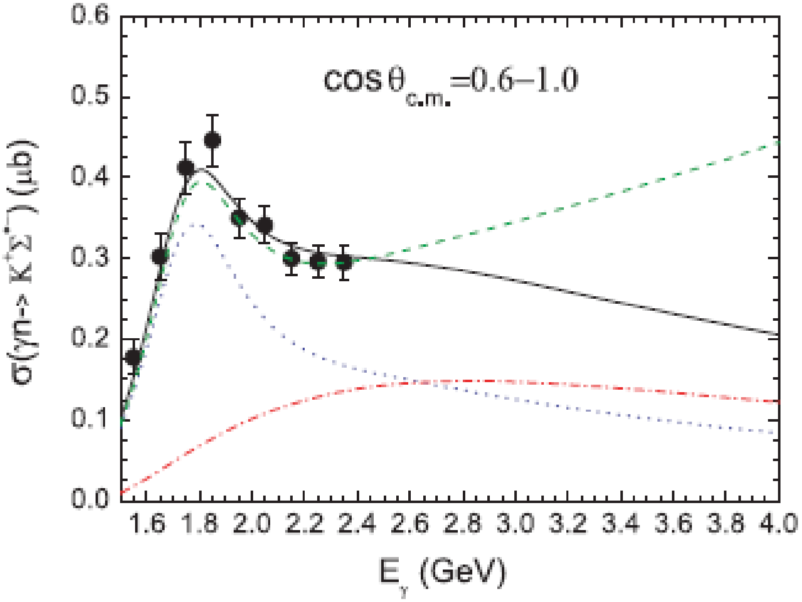
Y. Oh, C. M. Ko, and K. Nakayama, PRC77(2008) 045204

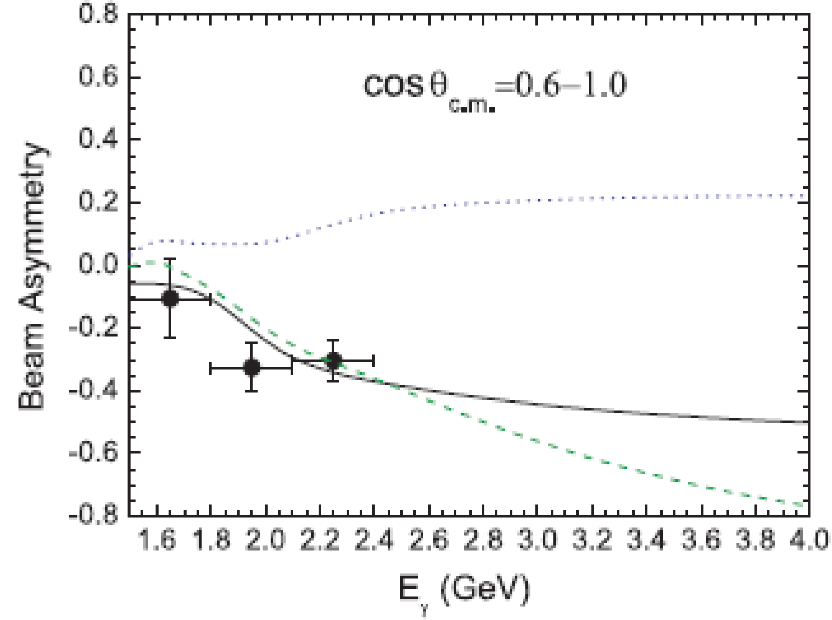


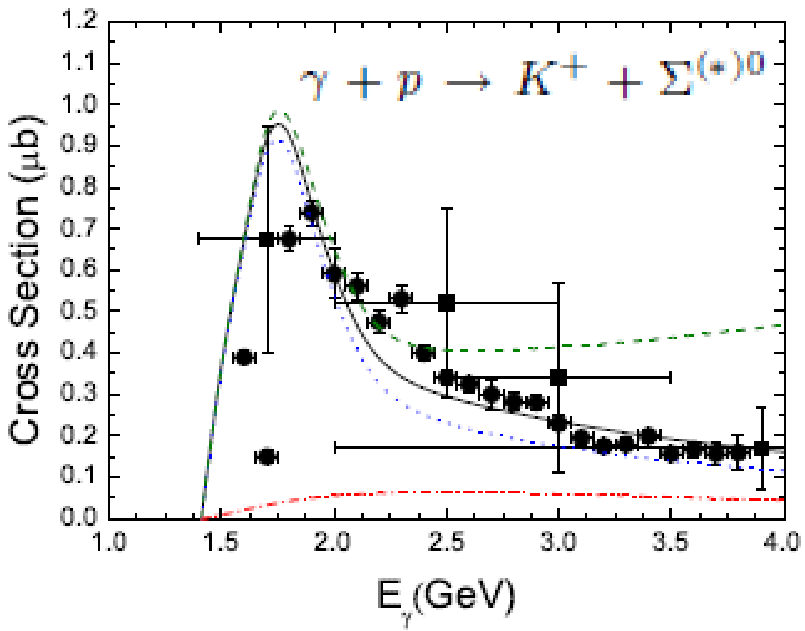
Something new ? **Σ*(1/2⁻) ?**

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

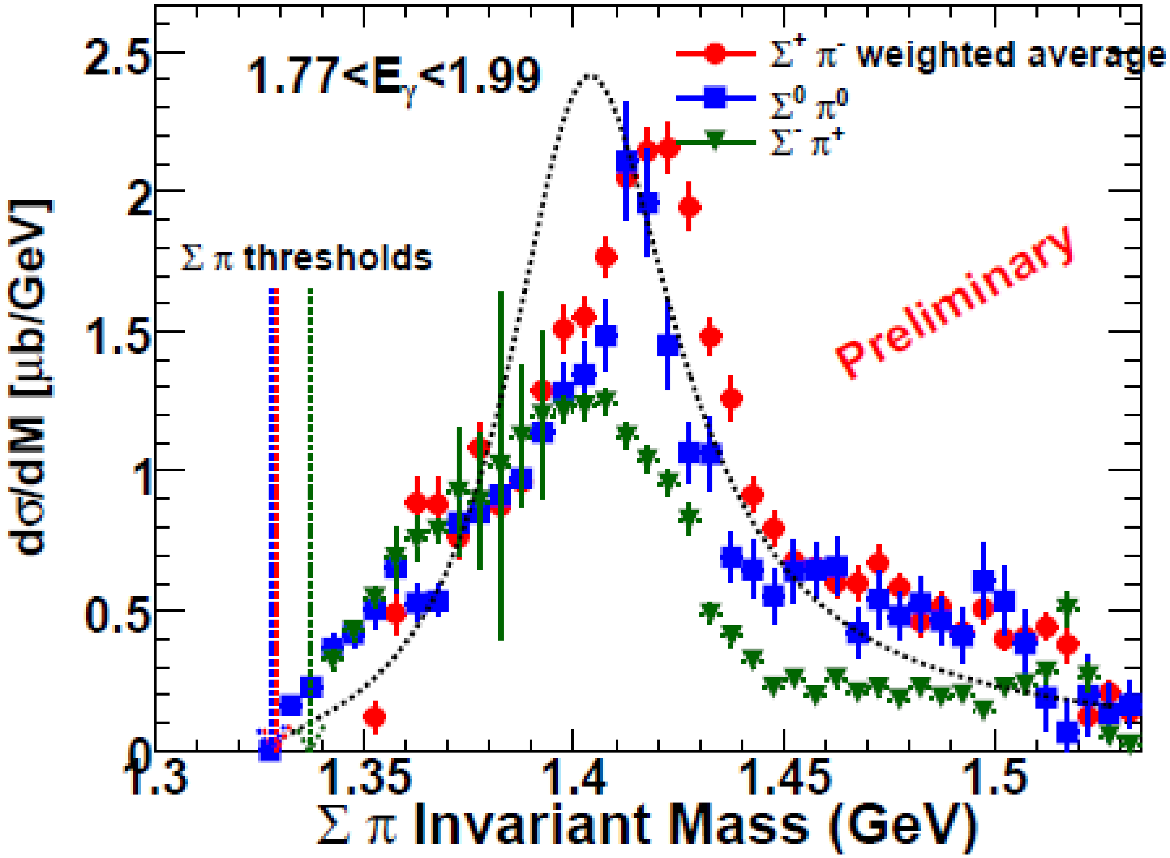
dashed : $\Sigma^*(3/2^+)$ with h=1.11

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

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

4. Extension to hidden charm and beauty

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 ?

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

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

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

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

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

$D^*_{s1}(2460) \sim \bar{s}c\ (L=1) + D^*K + \ldots$

$X(3872) \sim \bar{c}c\ (L=1) + [\bar{q}\,\bar{c}][qc] + D^*D + \ldots$

Many other proposed dynamically generated states

Problem:

None of them can be clearly distinguished from qqq or $\bar{q}q$ due to tunable ingredients and possible large mixing of various configurations

Solution: **Extension to hidden charm and beauty for baryons**

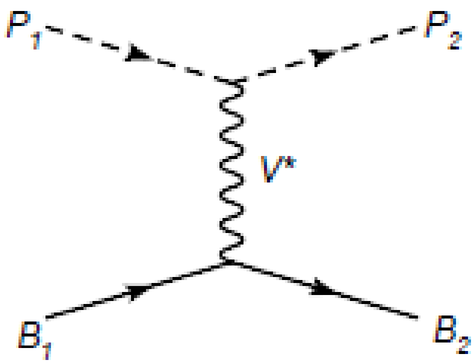
N*(1535) $\bar{s}suud$

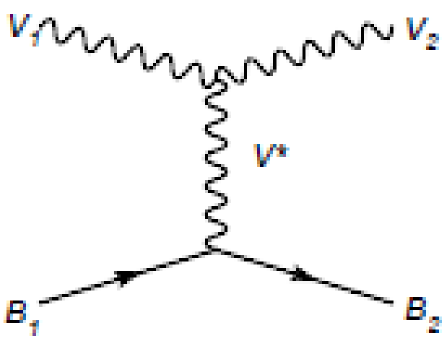
N*(4260) $\bar{c}cuud$ J.J.Wu, R.Molina, E.Oset, B.S.Zou. arXiv:1007.0573[nucl-th]

N*(11050) $\bar{b}buud$ J.J.Wu, B.S.Zou. to be submitted.

$K\Sigma$, Kp → $\bar{D}\Sigma_c$, $\bar{D}_s\Lambda_c$ → $B\Sigma_b$, $B_s\Lambda_b$ bound states

J.J.Wu, R.Molina, E.Oset, B.S.Zou. arXiv:1007.0573[nucl-th]





$$\mathcal{L}_{VVV} = ig\langle V^\mu [V^\nu, \partial_\mu V_\nu]\rangle$$

$$\mathcal{L}_{PPV} = -ig\langle V^\mu [P, \partial_\mu P]\rangle$$

$$\mathcal{L}_{BBV} = g(\langle \bar{B}\gamma_\mu [V^\mu, B]\rangle + \langle \bar{B}\gamma_\mu B\rangle\langle V^\mu\rangle)$$

$$V_{ab(P_1 B_1 \to P_2 B_2)} = \frac{C_{ab}}{4f^2}(E_{P_1} + E_{P_2}),$$

$$V_{ab(V_1 B_1 \to V_2 B_2)} = \frac{C_{ab}}{4f^2}(E_{V_1} + E_{V_2})\vec{\epsilon}_1 \cdot \vec{\epsilon}_2,$$

$$T = [1 - VG]^{-1} V$$

$$T_{ab} = \frac{g_a g_b}{\sqrt{s} - z_R}$$

	(I,S)	z_R (MeV)	g_a		
N*	$(1/2,0)$		$\bar{D}\Sigma_c$	$\bar{D}\Lambda_c^+$	
		4269	2.85	0	
Λ*	$(0,-1)$		$\bar{D}_s\Lambda_c^+$	$\bar{D}\Xi_c$	$\bar{D}\Xi_c'$
		4213	1.37	3.25	0
		4403	0	0	2.64

TABLE III: Pole positions z_R and coupling constants g_a for the states from $PB \to PB$.

	(I,S)	z_R (MeV)	g_a		
N*	$(1/2,0)$		$\bar{D}^*\Sigma_c$	$\bar{D}^*\Lambda_c^+$	
		4418	2.75	0	
Λ*	$(0,-1)$		$\bar{D}_s^*\Lambda_c^+$	$\bar{D}^*\Xi_c$	$\bar{D}^*\Xi_c'$
		4370	1.23	3.14	0
		4550	0	0	2.53

TABLE IV: Pole position and coupling constants for the bound states from $VB \to VB$.

	(I,S)	M	Γ			Γ_i			
N*	$(1/2,0)$			πN	ηN	$\eta' N$	$K\Sigma$		$\eta_c N$
		4261	56.9	3.8	8.1	3.9	17.0		23.4
Λ*	$(0,-1)$			$\bar{K}N$	$\pi\Sigma$	$\eta\Lambda$	$\eta'\Lambda$	$K\Xi$	$\eta_c\Lambda$
		4209	32.4	15.8	2.9	3.2	1.7	2.4	5.8
		4394	43.3	0	10.6	7.1	3.3	5.8	16.3

TABLE V: Mass (M), total width (Γ), and the partial decay width (Γ_i) for the states from $PB \to PB$, with units in MeV.

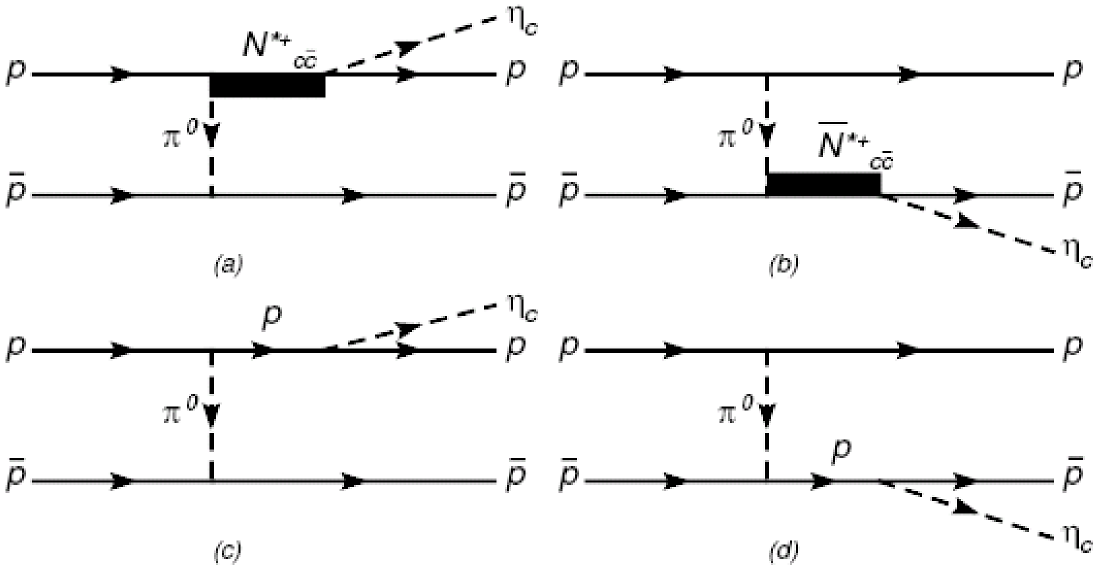
	(I,S)	M	Γ			Γ_i			
N*	$(1/2,0)$			ρN	ωN	$K^*\Sigma$			$J/\psi N$
		4412	47.3	3.2	10.4	13.7			19.2
Λ*	$(0,-1)$			$K^* N$	$\rho\Sigma$	$\omega\Lambda$	$\phi\Lambda$	$K^*\Xi$	$J/\psi\Lambda$
		4368	28.0	13.9	3.1	0.3	4.0	1.8	5.4
		4544	36.6	0	8.8	9.1	0	5.0	13.8

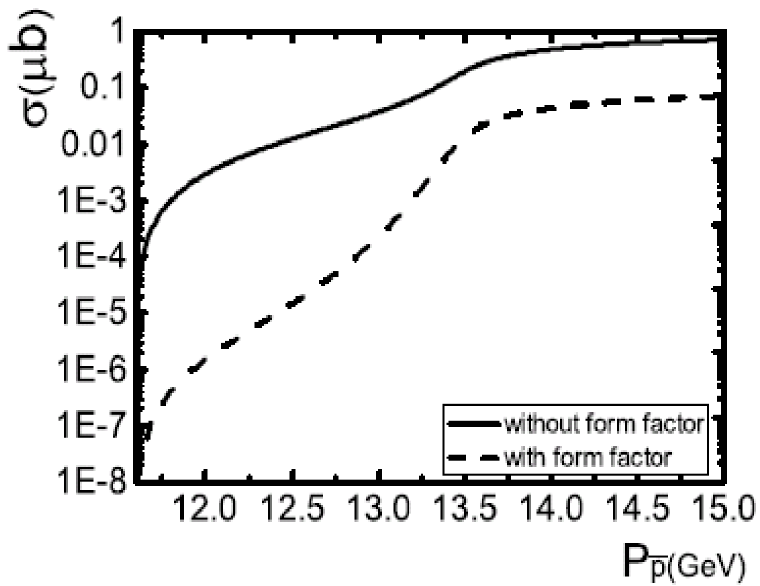
TABLE VI: Mass (M), total width (Γ), and the partial decay width (Γ_i) for the states from $VB \to VB$ with units in MeV.

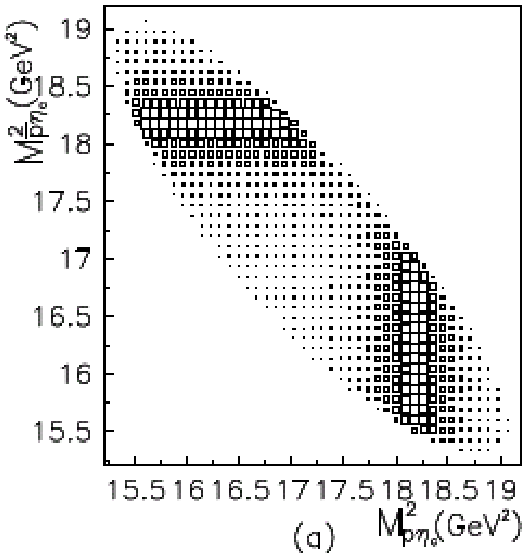
Super-heavy narrow N* and Λ* with hidden charm !

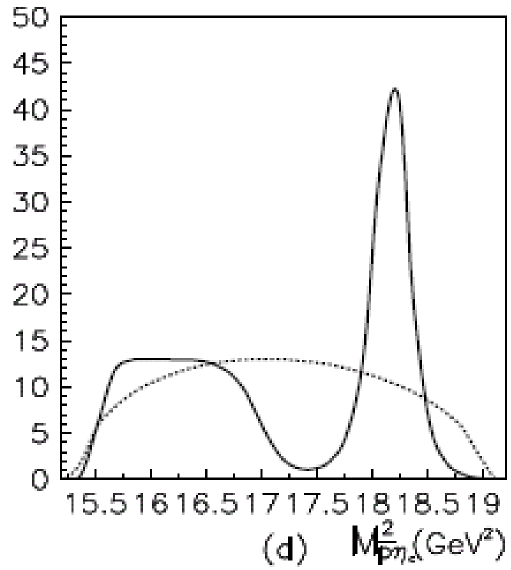
Definitely not qqq states !

Prediction for PANDA



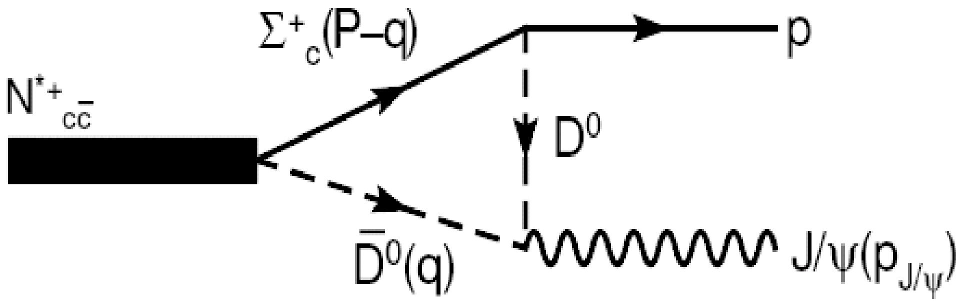






$\bar{p}p \rightarrow \bar{p}p\eta_c$

0.07 -- 0.7μb



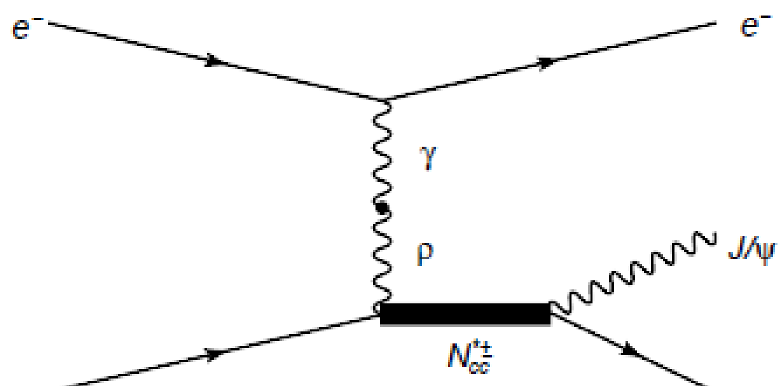
3 orders of magnitude smaller than N* → $p\eta_c$

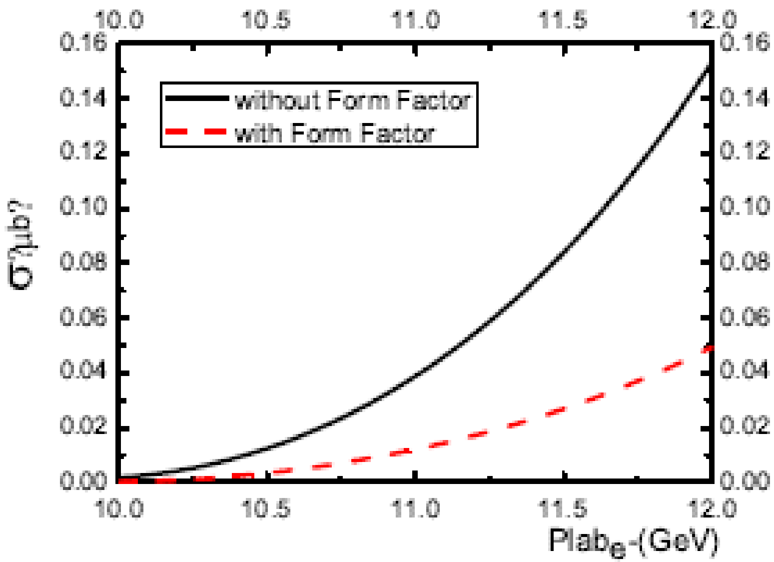
$\bar{p}p \rightarrow \bar{p}pJ/\psi$ ~ 0.03 nb

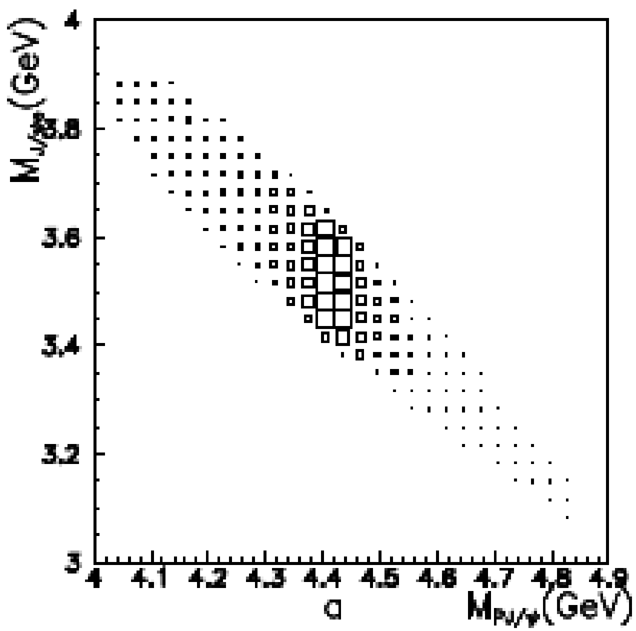
~ 250 events per day at PANDA/FAIR by $L=10^{31}\ cm^{-2}s^{-1}$

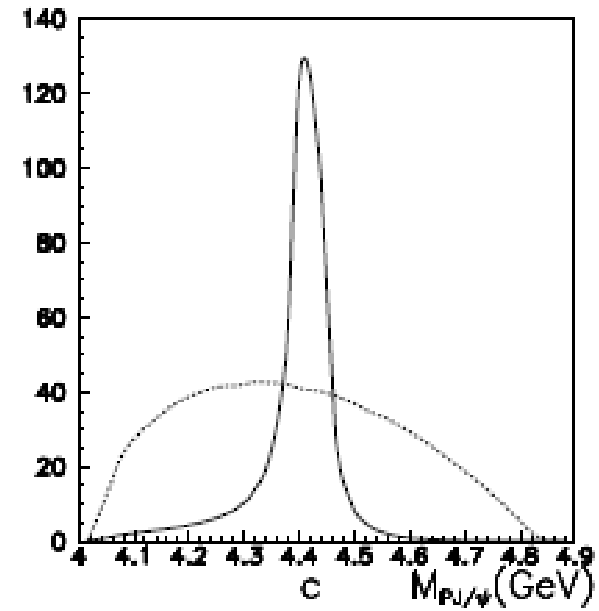
These Super-heavy narrow N* and Λ* can be found at PANDA !

Prediction for 12GeV@JLab









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 :**

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

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

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

Conclusion III

- **Super heavy narrow N* and Λ* are predicted to exist**
  $\bar{D}\Sigma_c$, $\bar{D}_s\Lambda_c$ → $B\Sigma_b$, $B_s\Lambda_b$ **bound states**
- **They are definitely not qqq baryons**
- **They can be looked for at 12GeV@Jlab and PANDA**
  maybe also at RHIC , EIC?