JÜLICH
FORSCHUNGSZENTRUM

Hyperon Spectroscopy with $\overline{\text{P}}$ANDA

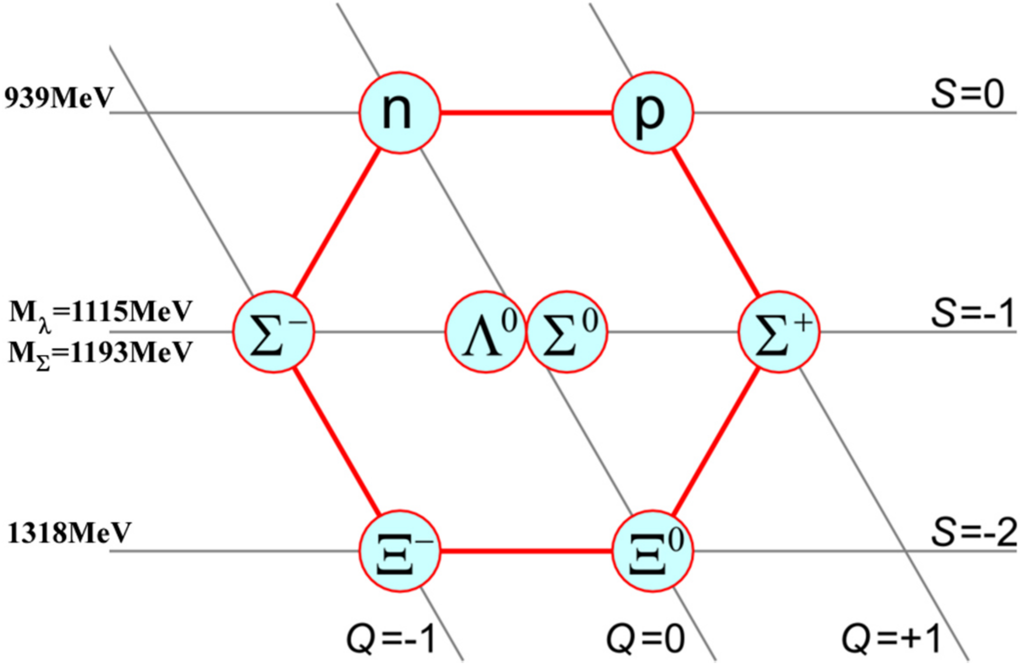
Sep 13, 2016 | Albrecht Gillitzer, IKP Forschungszentrum Jülich

Young Scientist Convent, LVIII PANDA Meeting, Mainz, September 2016

Outline

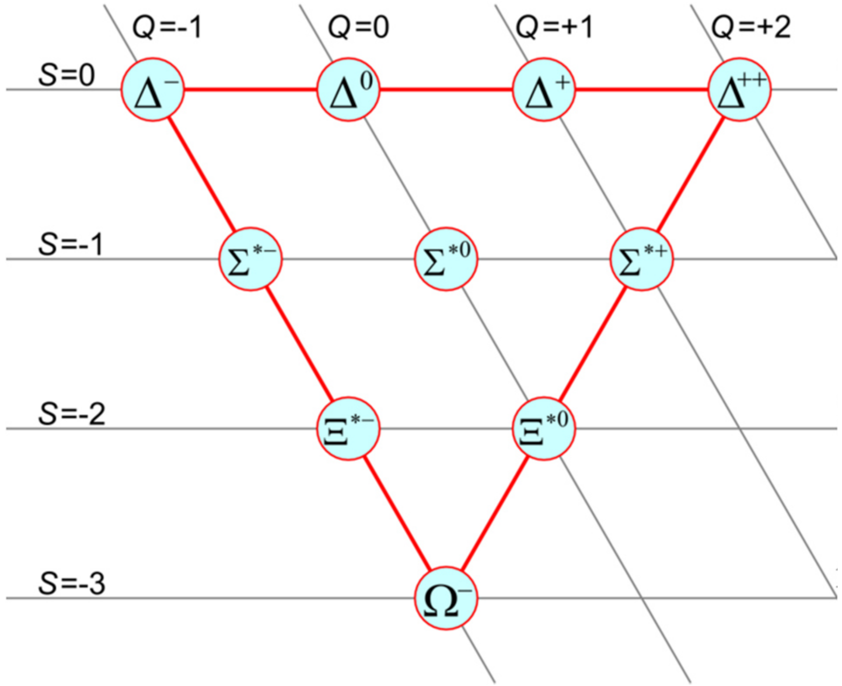
- How to understand baryonic excitation spectra?
- What is the present status in baryon spectroscopy?
- What can we do with PANDA?
- What are the challenges and requirements?

Ground States of Light Baryons: $SU(3)_F$ Symmetry



$J^P = 1/2^+$ ↑↓↑

baryon octet



$J^P = 3/2^+$ ↑↑↑

baryon decuplet

- Gell-Mann 1961: „The Eightfold Way“, SU(3) symmetry
- Gell-Mann, Zweig 1964: 3 „quarks“ as constituents

Need for Color

Baryon decuplet

$$|\Delta^{++}\rangle = |u_\uparrow u_\uparrow u_\uparrow\rangle \quad |\Delta^{+}\rangle = |u_\uparrow u_\uparrow d_\uparrow\rangle \quad |\Delta^{0}\rangle = |u_\uparrow d_\uparrow d_\uparrow\rangle \quad |\Delta^{-}\rangle = |d_\uparrow d_\uparrow d_\uparrow\rangle$$

$$|\Sigma^{*+}\rangle = |u_\uparrow u_\uparrow s_\uparrow\rangle \quad |\Sigma^{*0}\rangle = |u_\uparrow d_\uparrow s_\uparrow\rangle \quad |\Sigma^{*-}\rangle = |d_\uparrow d_\uparrow s_\uparrow\rangle$$

$$|\Xi^{*0}\rangle = |u_\uparrow s_\uparrow s_\uparrow\rangle \quad |\Xi^{*-}\rangle = |d_\uparrow s_\uparrow s_\uparrow\rangle$$

$$|\Omega^{-}\rangle = |s_\uparrow s_\uparrow s_\uparrow\rangle$$

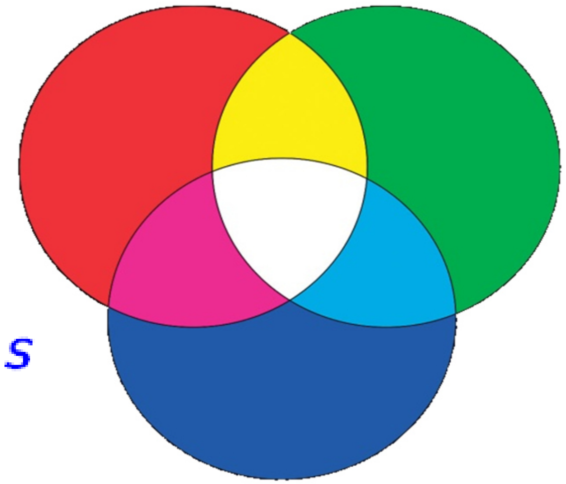
three identical fermions in Δ^{++}, Δ^{-}, Ω^{-} :

$\rightarrow$ problem with Pauli principle

H. Fritzsch, M. Gell-Mann, H. Leutwyler, Phys. Lett. B47 (1973) 365:

„Advantages of the Color Octet Gluon Picture“

$d, d, d, \quad u, u, u, \quad s, s, s$



$\Psi = \phi_{\text{color}}\, \xi_{\text{space}}\, \zeta_{\text{flavor}}\, \chi_{\text{spin}}$

color charge of hadrons is zero: ϕ_{color} always antisymmetric

Combining Spin, Flavor & Orbital Angular Momentum

flavor only: $SU(3)_F$

$$\mathbf{3} \otimes \mathbf{3} \otimes \mathbf{3} = \mathbf{10}_S \oplus \mathbf{8}_M \oplus \mathbf{8}_M \oplus \mathbf{1}_A$$

with *S*, *M*, *A* symmetric, mixed symmetry and antisymmetric in flavor (and spin) part under exchange of any 2 quarks

combine flavor & spin: $SU(6)_{f,s}$: 6 basic states: d↑, d↓, u↑, u↓, s↑, s↓

$$\mathbf{6} \otimes \mathbf{6} \otimes \mathbf{6} = \mathbf{56}_S \oplus \mathbf{70}_M \oplus \mathbf{70}_M \oplus \mathbf{20}_A$$

decomposed as:

$$\mathbf{56} = {}^4\mathbf{10} \oplus {}^2\mathbf{8}, \quad \mathbf{70} = {}^2\mathbf{10} \oplus {}^4\mathbf{8} \oplus {}^2\mathbf{8} \oplus {}^2\mathbf{1}, \quad \mathbf{20} = {}^2\mathbf{8} \oplus {}^4\mathbf{1}$$

superscript: (2*S*+1) spin multiplicity

SU(6) × *O*(3)

classification of baryons by
$J^P \ (D, L_N^P) \ S$

J^P: total baryon spin, parity
D: *SU*(6) multiplet
L: total quark orbital angular momentum
N: # quanta of excitation
S: total quark spin

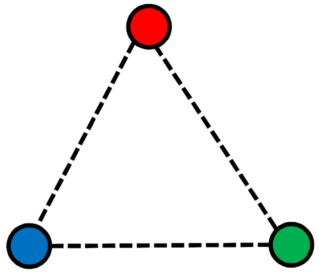
note: baryons with same J^P can mix!

assignment partially uncertain

J^P	(D, L_N^P)	S	Octet members				Singlets
$1/2^+$	$(56,0_0^+)$	1/2	$N(939)$	$\Lambda(1116)$	$\Sigma(1193)$	$\Xi(1318)$	
$1/2^+$	$(56,0_2^+)$	1/2	$N(1440)$	$\Lambda(1600)$	$\Sigma(1660)$	$\Xi(?)$	
$1/2^-$	$(70,1_1^-)$	1/2	$N(1535)$	$\Lambda(1670)$	$\Sigma(1620)$	$\Xi(?)$	$\Lambda(1405)$
$3/2^-$	$(70,1_1^-)$	1/2	$N(1520)$	$\Lambda(1690)$	$\Sigma(1670)$	$\Xi(1820)$	$\Lambda(1520)$
$1/2^-$	$(70,1_1^-)$	3/2	$N(1650)$	$\Lambda(1800)$	$\Sigma(1750)$	$\Xi(?)$	
$3/2^-$	$(70,1_1^-)$	3/2	$N(1700)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	
$5/2^-$	$(70,1_1^-)$	3/2	$N(1675)$	$\Lambda(1830)$	$\Sigma(1775)$	$\Xi(?)$	
$1/2^+$	$(70,0_2^+)$	1/2	$N(1710)$	$\Lambda(1810)$	$\Sigma(1880)$	$\Xi(?)$	$\Lambda(?)$
$3/2^+$	$(56,2_2^+)$	1/2	$N(1720)$	$\Lambda(1890)$	$\Sigma(?)$	$\Xi(?)$	
$5/2^+$	$(56,2_2^+)$	1/2	$N(1680)$	$\Lambda(1820)$	$\Sigma(1915)$	$\Xi(2030)$	
$7/2^-$	$(70,3_3^-)$	1/2	$N(2190)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	$\Lambda(2100)$
$9/2^-$	$(70,3_3^-)$	3/2	$N(2250)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	
$9/2^+$	$(56,4_4^+)$	1/2	$N(2220)$	$\Lambda(2350)$	$\Sigma(?)$	$\Xi(?)$	
			Decuplet members				
$3/2^+$	$(56,0_0^+)$	3/2	$\Delta(1232)$	$\Sigma(1385)$	$\Xi(1530)$	$\Omega(1672)$	
$3/2^+$	$(56,0_2^+)$	3/2	$\Delta(1600)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	
$1/2^-$	$(70,1_1^-)$	1/2	$\Delta(1620)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	
$3/2^-$	$(70,1_1^-)$	1/2	$\Delta(1700)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	
$5/2^+$	$(56,2_2^+)$	3/2	$\Delta(1905)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	
$7/2^+$	$(56,2_2^+)$	3/2	$\Delta(1950)$	$\Sigma(2030)$	$\Xi(?)$	$\Omega(?)$	
$11/2^+$	$(56,4_4^+)$	3/2	$\Delta(2420)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	

source: PDG 2008

Non-Relativistic Constituent Quark Model



(N.Isgur, G. Karl, PLB 72 (1977) 109)

Ansatz:

spin-independent + spin-dependent part: $$H = H_{\mathrm{si}} + H_{\mathrm{sd}}$$

$$H_{\mathrm{si}} = \sum_i \left(m_i + \frac{p_i^2}{2m_i} \right) + \sum_{i<j} \left(\frac{1}{2} b r_{ij} + c - \frac{2\alpha_s}{3 r_{ij}} \right)$$

split into harmonic part + anharmonic perturbation

$$H_{\mathrm{si}} = \sum_i \left(m_i + \frac{p_i^2}{2m_i} \right) + \sum_{i<j} \left(\frac{1}{2} k r_{ij}^2 + U(r_{ij}) \right) \equiv H_0 + \sum_{i<j} U(r_{ij})$$ with

$$U(r_{ij}) = \frac{1}{2} b r_{ij} + c - \frac{2\alpha_s}{3 r_{ij}} - \frac{1}{2} k r_{ij}^2$$

Non-Relativistic Constituent Quark Model

⇒ exactly solvable for H_0 , for simplicity $S = 0$ & $S = -3$: $m_1 = m_2 = m_3 \equiv m$

change of variables: ⇒

$$\vec{R} = \frac{m_1\vec{r}_1 + m_2\vec{r}_2 + m_3\vec{r}_3}{m_1 + m_2 + m_3} \qquad \vec{\rho} = \frac{1}{\sqrt{2}}(\vec{r}_1 - \vec{r}_2) \qquad \vec{\lambda} = \frac{1}{\sqrt{6}}(\vec{r}_1 + \vec{r}_2 - 2\vec{r}_3)$$

correspondingly: $\vec{P}, \vec{p}_\rho, \vec{p}_\lambda$ with $M = 3m$ ⇒

$$H_0 = \frac{P^2}{2M} + \left(\frac{p_\rho^2}{2m} + \frac{3}{2}k\rho^2\right) + \left(\frac{p_\lambda^2}{2m} + \frac{3}{2}k\lambda^2\right)$$

$$\Psi_{LM}^\sigma = \psi_{LM}^\sigma \frac{\alpha^3}{\pi^{3/2}} \exp\left(-\frac{1}{2}\alpha^2\left(\rho^2 + \lambda^2\right)\right)$$

$$\varepsilon_N = \left(N + \frac{3}{2}\right)\omega \qquad \omega \equiv (3k/m)^{1/2}$$

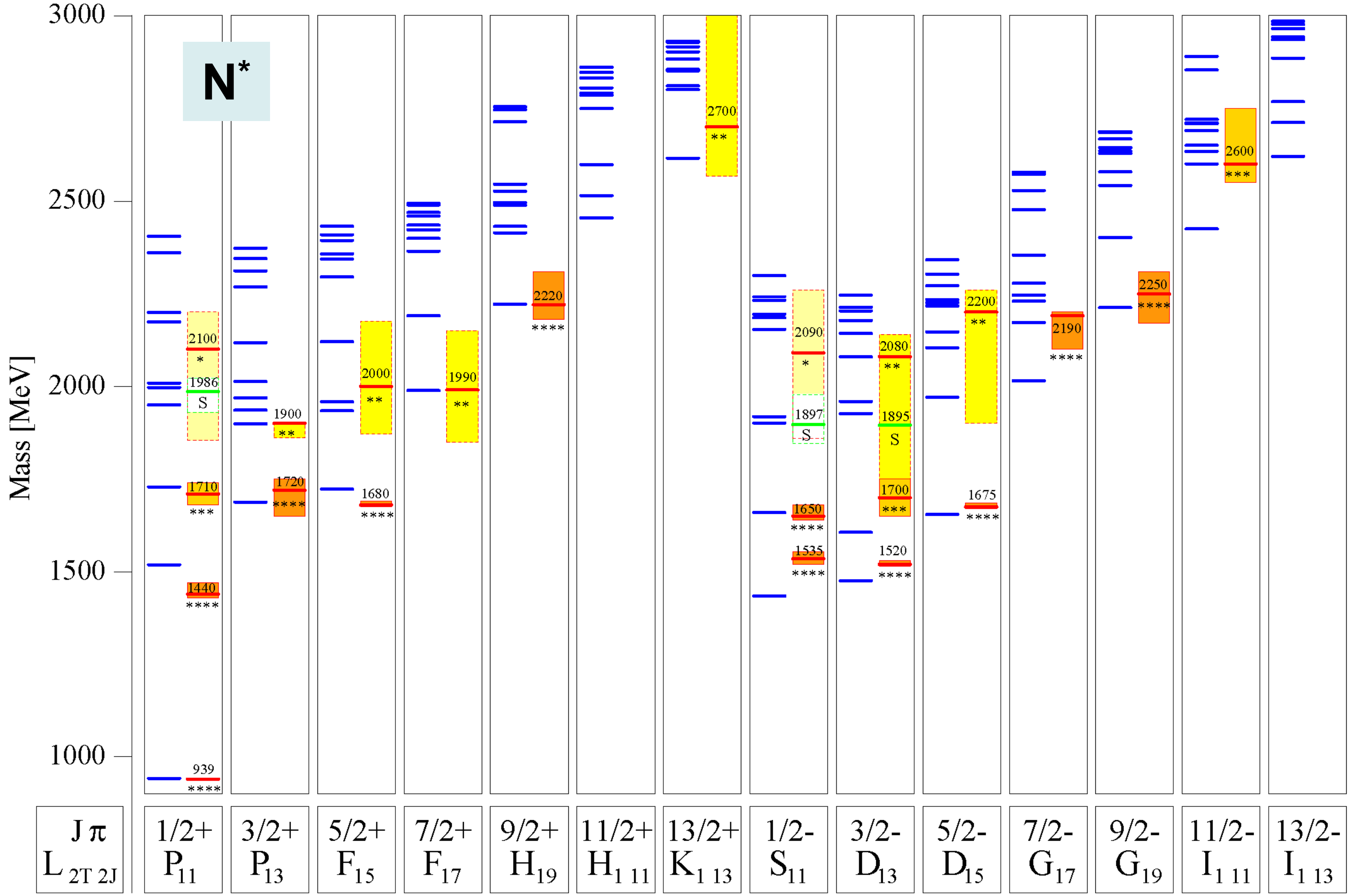
⇒ 2 degenerate oscillators

σ denotes the symmetry w.r.t. exchange of two quarks

equidistant energy levels:

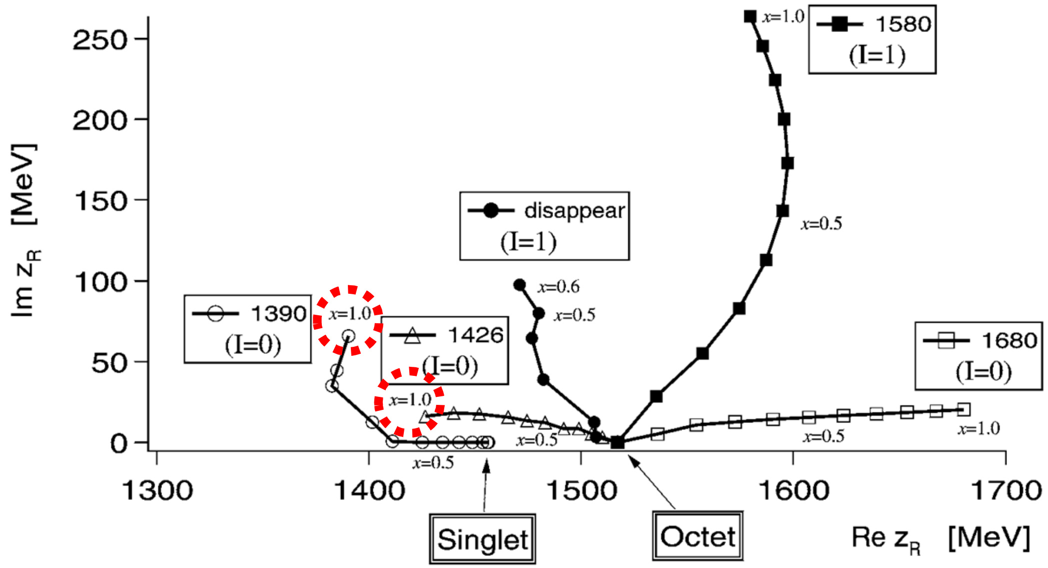
remember: $N = 2(n - 1) + l$

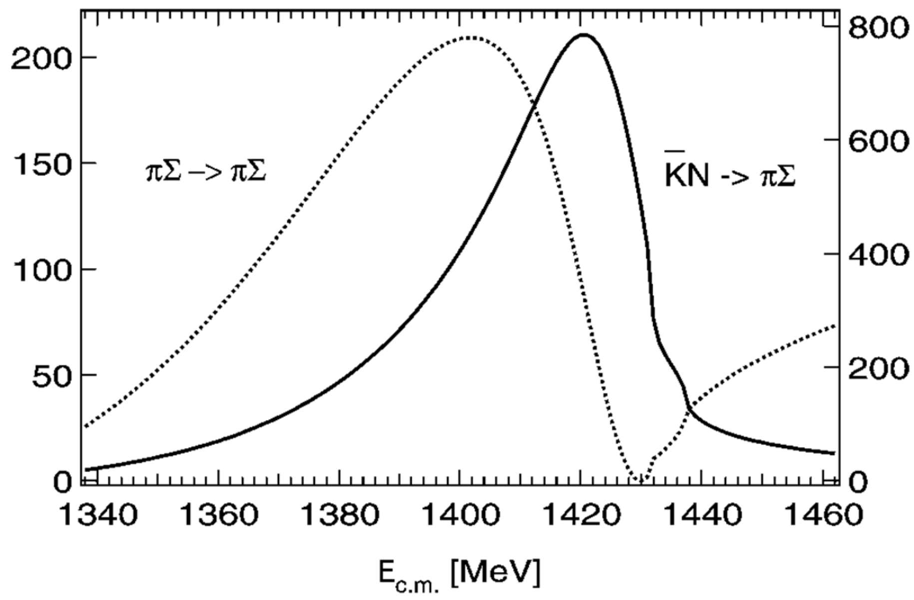
Modern Quark Models



U. Löring *et al.*, Eur. Phys. J. A10 (2001) 395

Dynamical Generation of Resonances

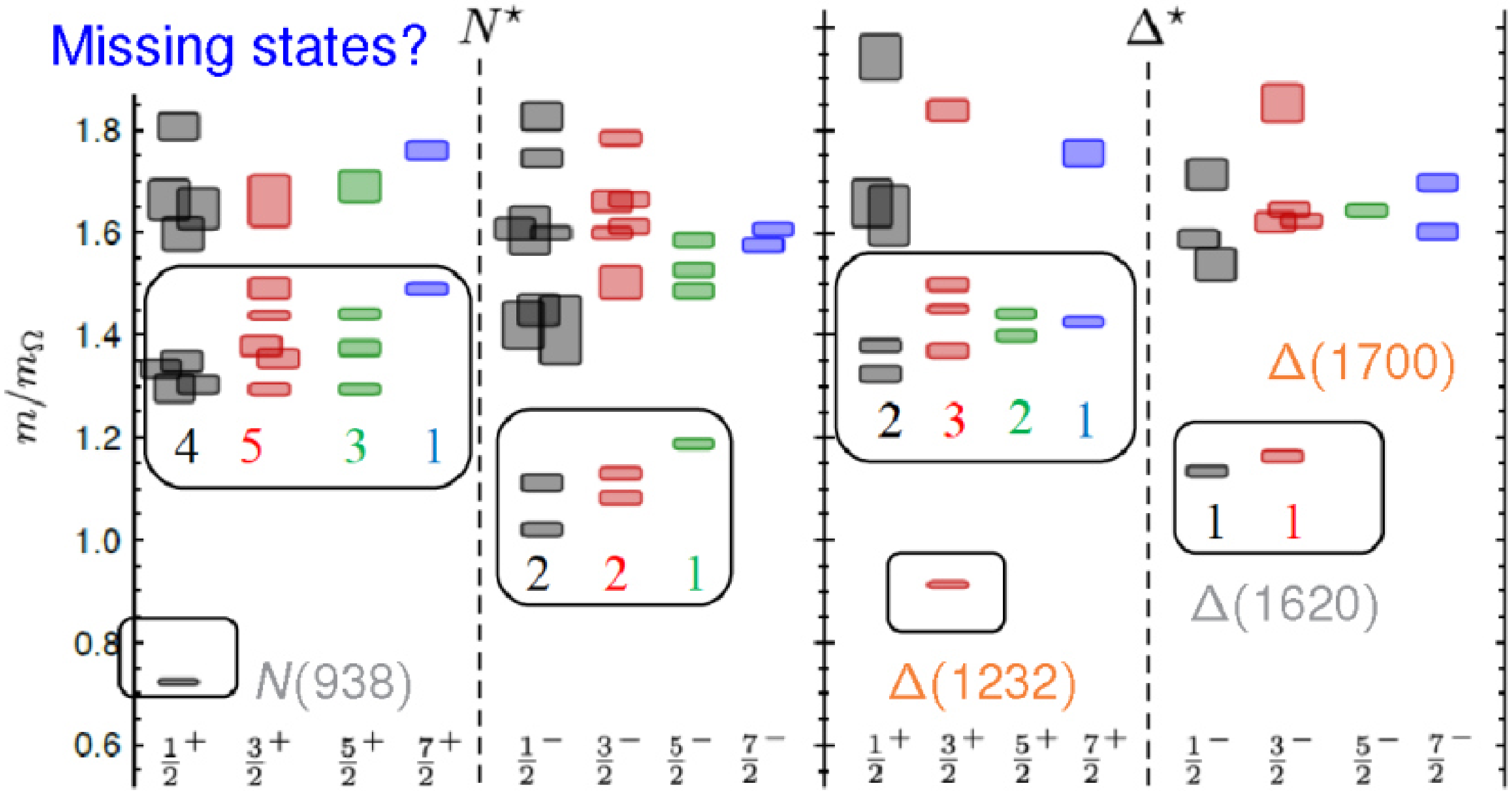




- example: Λ(1405)
- meson octet ⊗ baryon octet in S = -1, Q = 0
- coupled channel analysis:
- $K^-p, \overline{K}^0 n, \pi^0\Lambda, \pi^0\Sigma^0, \pi^+\Sigma^-, \pi^-\Sigma^+, \eta\Lambda, \eta\Sigma^0, K^0\Xi^0, K^+\Xi^-$

D. Jido *et al.*, Nucl. Phys. A725 (2003) 181

Lattice QCD



$m_\pi = 396\ \mathrm{MeV}$

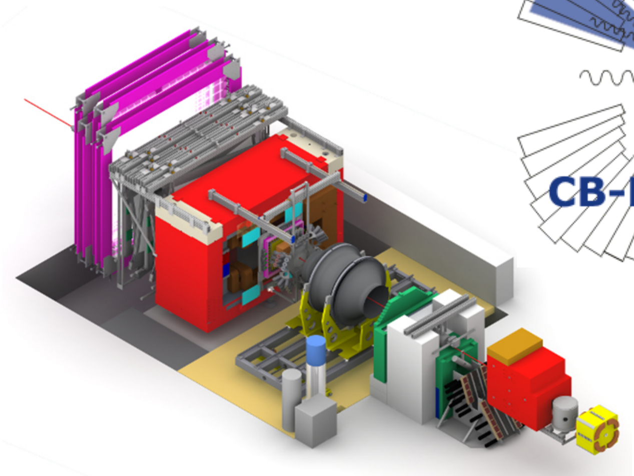
exhibits features of SU(6)×O(3) symmetry

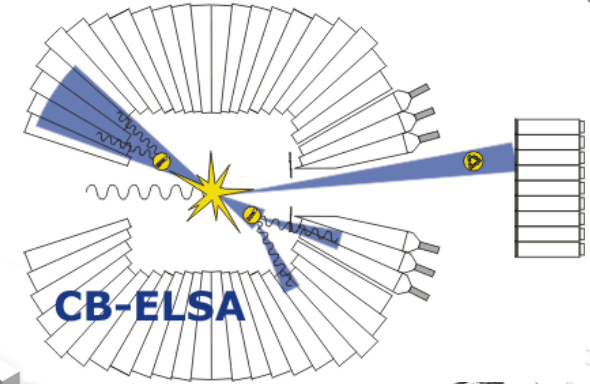
level count consistent with quark model

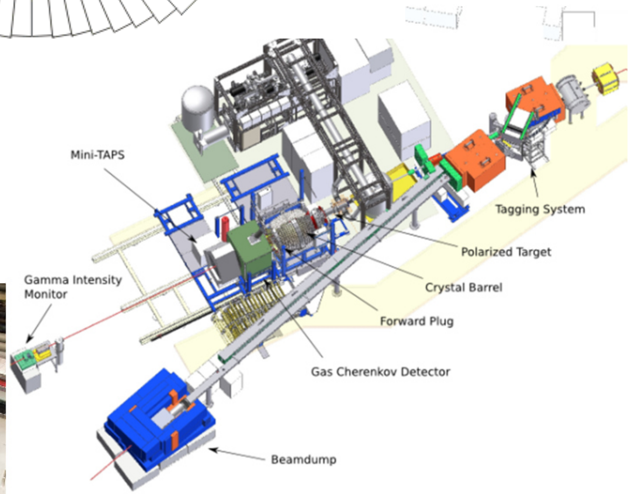
R.G. Edwards *et al.*, Phys. Rev. D 84 (2011) 074508

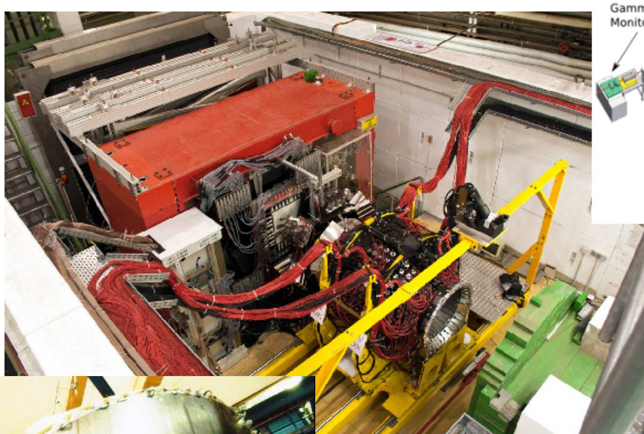
Experimental Activities

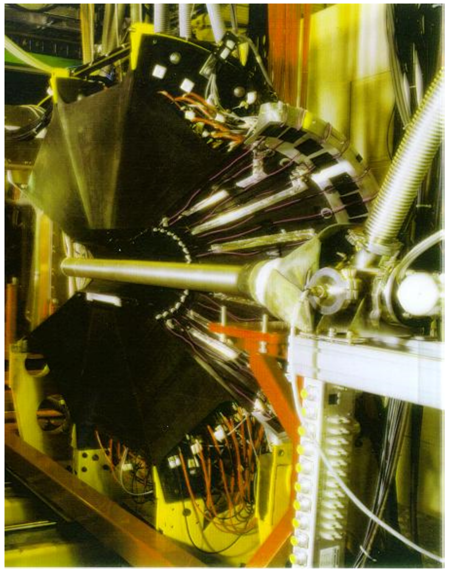
- Early studies: π induced reactions: πN → πN, ππN, KΛ, KΣ, …
- Modern studies: Baryon Spectroscopy with in photo-induced reactions

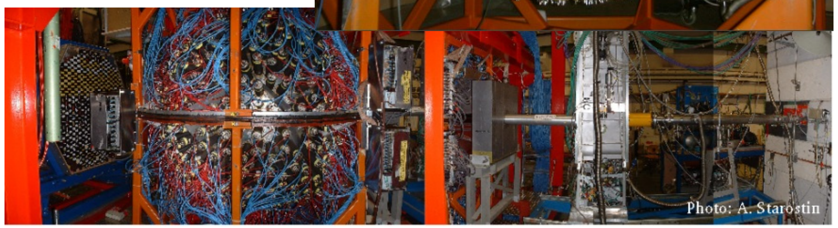












Achievements in N* Spectroscopy

$\boxed{N(1875)\frac{3}{2}^-}$ or $N(1875)D_{13}$

$N(1875)\frac{3}{2}^-$ pole parameters (MeV)			
$M_{\rm pole}$	1860±25	$\Gamma_{\rm pole}$	200±20
Elastic pole residue	2.5±1.0	Phase	not defined
$2\,{\rm Res}_{\pi N\to\Lambda K}/\Gamma$	1.5±0.5%	Phase	not defined
$2\,{\rm Res}_{\pi N\to\Sigma K}/\Gamma$	4±2%	Phase	not defined
$2\,{\rm Res}_{\pi N\to N\sigma}/\Gamma$	8±3%	Phase	−(170±65)°
$A^{1/2}$ (GeV$^{-\frac{1}{2}}$)	0.018±0.008	Phase	−(100±60)°
$A^{3/2}$ (GeV$^{-\frac{1}{2}}$)	0.010±0.004	Phase	(180±30)°

$N(1875)\frac{3}{2}^-$ Breit-Wigner parameters (MeV)			
$M_{\rm BW}$	1880±20	$\Gamma_{\rm BW}$	200±25
Br($N\pi$)	3±2%	Br($N\eta$)	5±2%
Br(ΛK)	4±2%	Br(ΣK)	15±8%
Br($N\sigma$)	60±12%		
$A^{1/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	0.018±0.010	$A^{3/2}_{BW}$ (GeV$^{-\frac{1}{2}}$)	−0.009±0.005

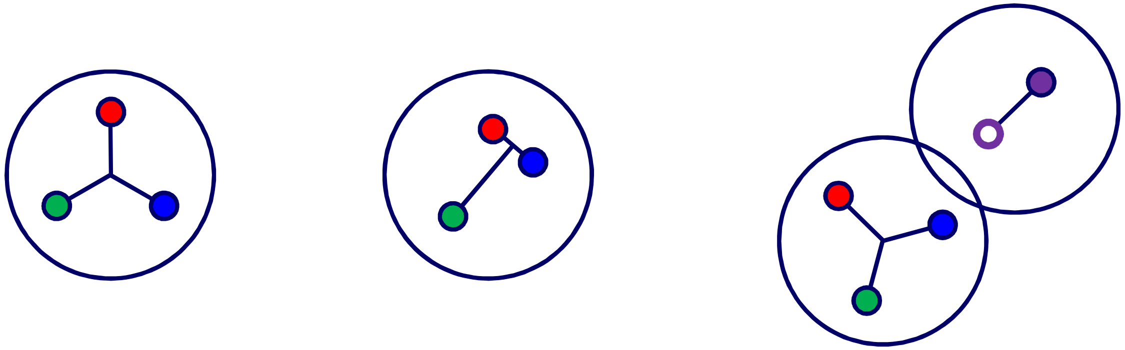
	All	πN	γN	$N\eta$	ΛK	ΣK	$\Delta\pi$	$N\sigma$
$N(1875)\frac{3}{2}^-$	⋆⋆⋆	⋆	⋆⋆⋆		⋆⋆⋆	⋆⋆		⋆⋆⋆

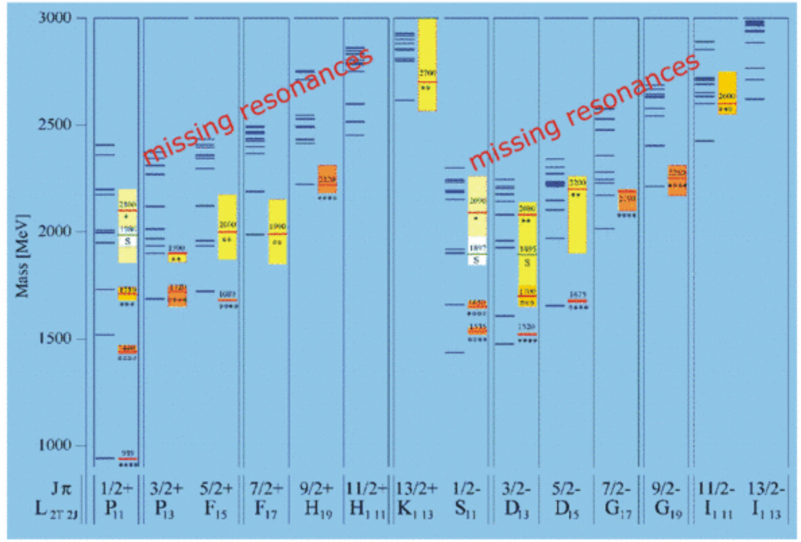
BnGa PWA:
A.V. Anisovich *et al.*, EPJA 48 (2012) 15

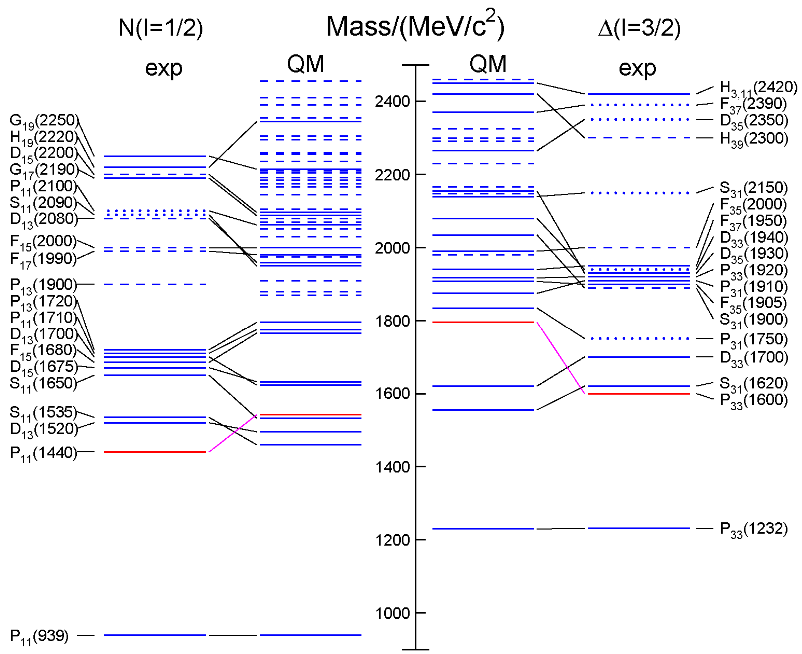
N^*	J^P $(L_{2I,2J})$	2010	2014
N(1440)	$1/2^+$ (P_{11})	* * **	* * **
N(1520)	$3/2^-$ (D_{13})	* * **	* * **
N(1535)	$1/2^-$ (S_{11})	* * **	* * **
N(1650)	$1/2^-$ (S_{11})	* * **	* * **
N(1675)	$5/2^-$ (D_{15})	* * **	* * **
N(1680)	$5/2^+$ (F_{15})	* * **	* * **
N(1685)			*
N(1700)	$3/2^-$ (D_{13})	* * *	* * *
N(1710)	$1/2^+$ (P_{11})	* * *	* * *
N(1720)	$3/2^+$ (P_{13})	* * **	* * **
N(1860)	$5/2^+$		**
N(1875)	$3/2^-$		* * *
N(1880)	$1/2^+$		**
N(1895)	$1/2^-$		**
N(1900)	$3/2^+$ (P_{13})	**	* * *
N(1990)	$7/2^+$ (F_{17})	**	**
N(2000)	$5/2^+$ (F_{15})	**	**
~~N(2080)~~	D_{13}	**	
~~N(2090)~~	S_{11}	*	
N(2040)	$3/2^+$		*
N(2060)	$5/2^-$		**
N(2100)	$1/2^+$ (P_{11})	*	*
N(2120)	$3/2^-$		**
N(2190)	$7/2^-$ (G_{17})	* * **	* * **
~~N(2200)~~	D_{15}	**	
N(2220)	$9/2^+$ (H_{19})	* * **	* * **

Open Questions

- Missing resonances
- Wrong masses, wrong sequence
- Relevant degrees of freedom?
  - 3-quark?
  - quark-diquark?
  - meson-baryon dynamics





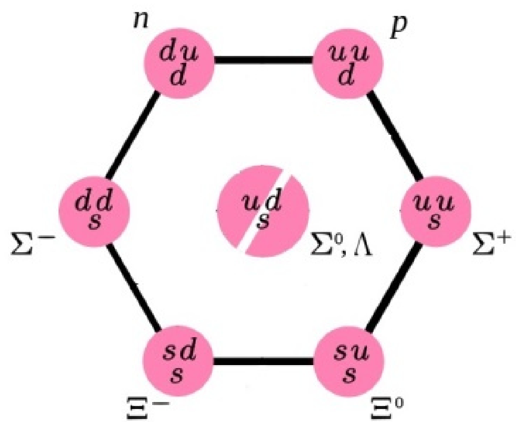


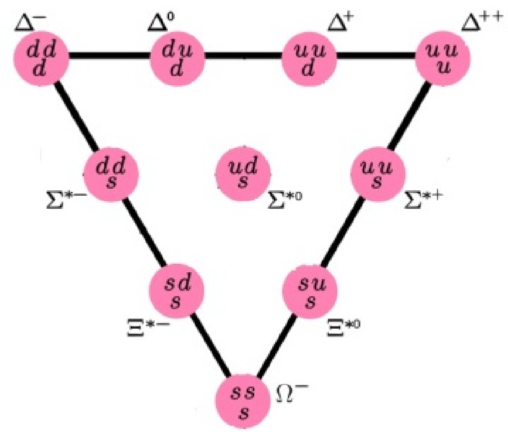
from RPP 2014 / QM: S. Capstick, W. Roberts

Strange Partners

- Approximate SU(3) flavor symmetry
- N* & Δ states have partners in the strange sector
- focus on Ξ and Ω
  - Ξ: as many states as N* & Δ together (1)
  - Ω: as many states as Δ
- scrutinize our understanding of the baryon excitation pattern

(1) in case of SU(3) symmetry !





Status of Ξ^* Resonances: RPP 2014

Chin. Phys. C 38 (2014) 090001

Ξ(1820):

Teodoro78 favors *J* = 3/2, but cannot make a parity discrimination. Biagi 87c is consistent with *J* = 3/2 and favors negative parity for this *J* value.

Table 1. The status of the Ξ resonances. Only those with an overall status of *** or **** are included in the Baryon Summary Table.

Particle	J^P	Overall status	Status as seen in — $\Xi\pi$	ΛK	ΣK	$\Xi(1530)\pi$	Other channels
Ξ(1318)	1/2+ ?	****					Decays weakly
Ξ(1530)	3/2+	****	****				
Ξ(1620)		*	*				
Ξ(1690)		***		***	**		
Ξ(1820)	3/2− ?	***	**	***	**	**	
Ξ(1950)		***	**	**		*	
Ξ(2030)		***		**	***		
Ξ(2120)		*		*			
Ξ(2250)		**					3-body decays
Ξ(2370)		**					3-body decays
Ξ(2500)		*		*	*		3-body decays

****	Existence is certain, and properties are at least fairly well explored.
***	Existence ranges from very likely to certain, but further confirmation is desirable and/or quantum numbers, branching fractions, *etc.* are not well determined.
**	Evidence of existence is only fair.
*	Evidence of existence is poor.

SU(6) x O(3) Classification

RPP 2014: Chin. Phys. C 38 (2014) 090001

„Assignments for …
Ξ(1820) and Ξ(2030), are merely educated guesses.“

Ξ(1690), Ξ(1950): ?

T. Melde *et al.*, PRD 77 (2008) 114002

decuplet: no Ξ*, no Ω*

"… nothing of significance on Ξ resonances has been added since our 1988 edition."

J^P	$(D, L^P_N)\ S$	Octet members				Singlets
$1/2^+$	$(56,0^+_0)$ 1/2	$N(939)$	$\Lambda(1116)$	$\Sigma(1193)$	$\Xi(1318)$	
$1/2^+$	$(56,0^+_2)$ 1/2	$N(1440)$	$\Lambda(1600)$	$\Sigma(1660)$	$\Xi(1690)^\dagger$	
$1/2^-$	$(70,1^-_1)$ 1/2	$N(1535)$	$\Lambda(1670)$	$\Sigma(1620)$ $\Sigma(1560)^\dagger$	$\Xi(?)$	$\Lambda(1405)$
$3/2^-$	$(70,1^-_1)$ 1/2	$N(1520)$	$\Lambda(1690)$	$\Sigma(1670)$	$\Xi(1820)$	$\Lambda(1520)$
$1/2^-$	$(70,1^-_1)$ 3/2	$N(1650)$	$\Lambda(1800)$	$\Sigma(1750)$ $\Sigma(1620)^\dagger$	$\Xi(?)$	
$3/2^-$	$(70,1^-_1)$ 3/2	$N(1700)$	$\Lambda(?)$	$\Sigma(1940)^\dagger$	$\Xi(?)$	
$5/2^-$	$(70,1^-_1)$ 3/2	$N(1675)$	$\Lambda(1830)$	$\Sigma(1775)$	$\Xi(1950)^\dagger$	
$1/2^+$	$(70,0^+_2)$ 1/2	$N(1710)$	$\Lambda(1810)$	$\Sigma(1880)$	$\Xi(?)$	$\Lambda(1810)^\dagger$
$3/2^+$	$(56,2^+_2)$ 1/2	$N(1720)$	$\Lambda(1890)$	$\Sigma(?)$	$\Xi(?)$	
$5/2^+$	$(56,2^+_2)$ 1/2	$N(1680)$	$\Lambda(1820)$	$\Sigma(1915)$	$\Xi(2030)$	
$7/2^-$	$(70,3^-_3)$ 1/2	$N(2190)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	$\Lambda(2100)$
$9/2^-$	$(70,3^-_3)$ 3/2	$N(2250)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	
$9/2^+$	$(56,4^+_4)$ 1/2	$N(2220)$	$\Lambda(2350)$	$\Sigma(?)$	$\Xi(?)$	

J^P	$(D, L^P_N)\ S$	Decuplet members			
$3/2^+$	$(56,0^+_0)$ 3/2	$\Delta(1232)$	$\Sigma(1385)$	$\Xi(1530)$	$\Omega(1672)$
$3/2^+$	$(56,0^+_2)$ 3/2	$\Delta(1600)$	$\Sigma(1690)^\dagger$	$\Xi(?)$	$\Omega(?)$
$1/2^-$	$(70,1^-_1)$ 1/2	$\Delta(1620)$	$\Sigma(1750)^\dagger$	$\Xi(?)$	$\Omega(?)$
$3/2^-$	$(70,1^-_1)$ 1/2	$\Delta(1700)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$
$5/2^+$	$(56,2^+_2)$ 3/2	$\Delta(1905)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$
$7/2^+$	$(56,2^+_2)$ 3/2	$\Delta(1950)$	$\Sigma(2030)$	$\Xi(?)$	$\Omega(?)$
$11/2^+$	$(56,4^+_4)$ 3/2	$\Delta(2420)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$

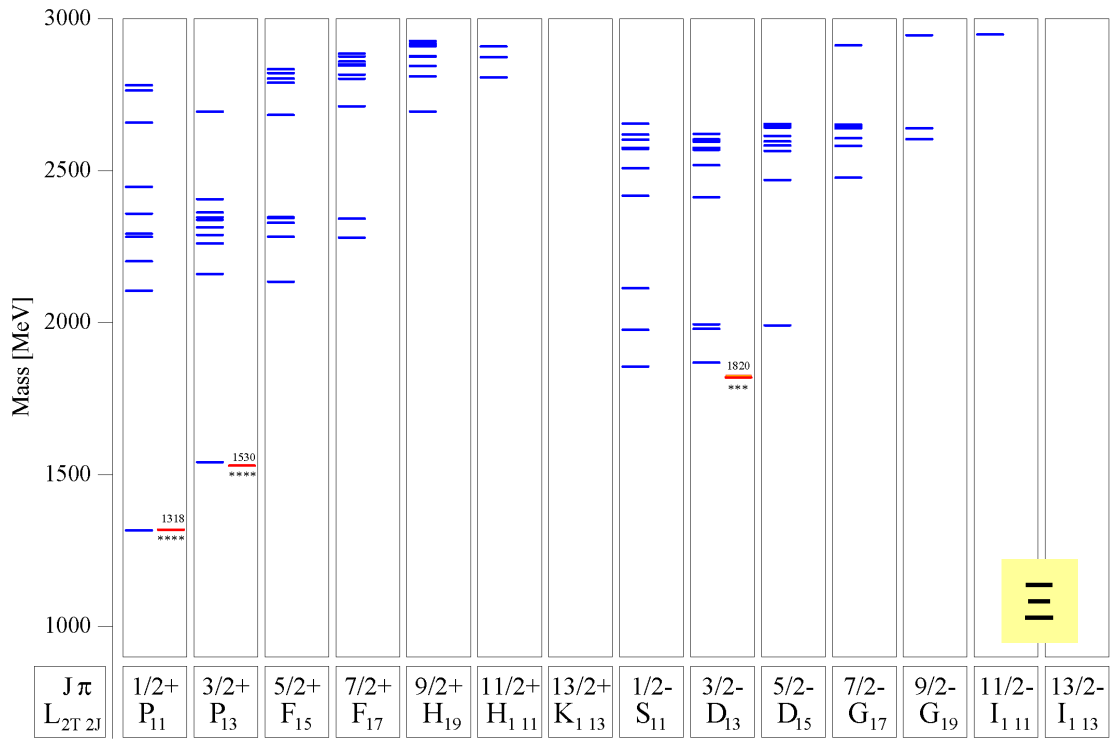
Quark Model for Ξ & Ω

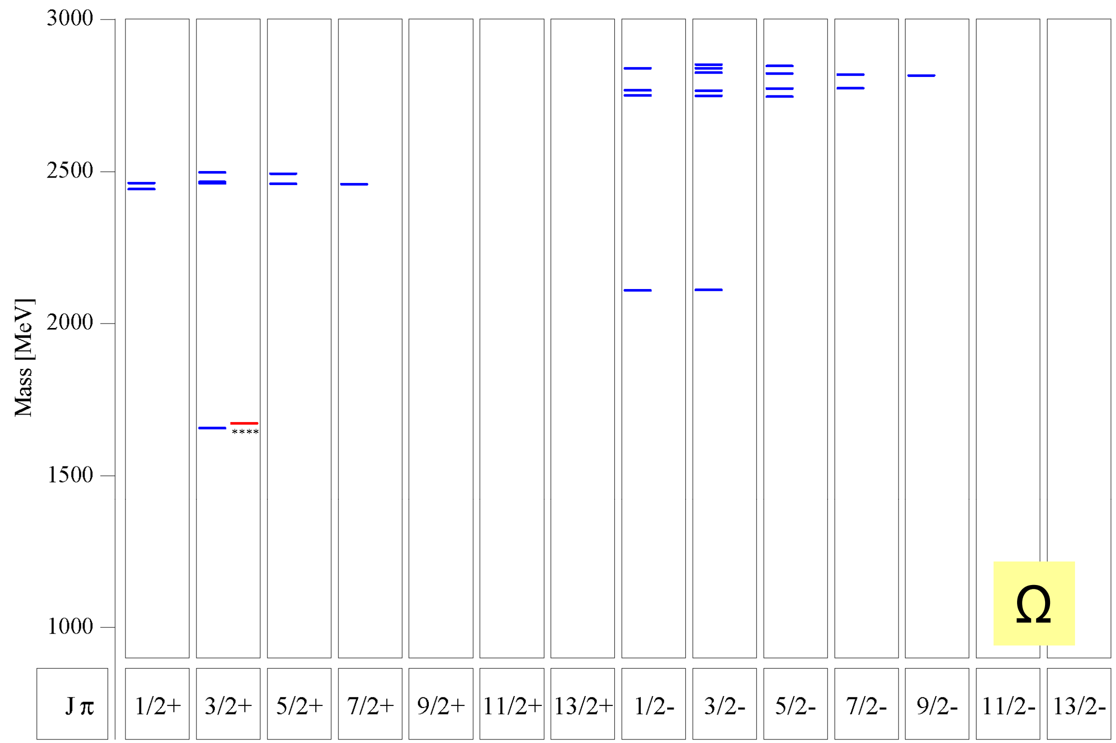
Ξ:

- many states predicted below 3 GeV
- compare $1/2^+$ and $1/2^-$ excitation

Ω:

- several states predicted between 2 GeV and 3 GeV
- compare $3/2^+$ and $3/2^-$ excitation



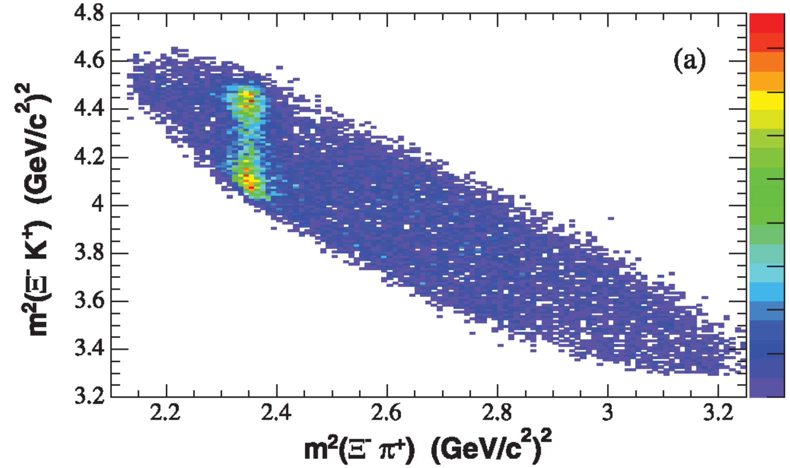


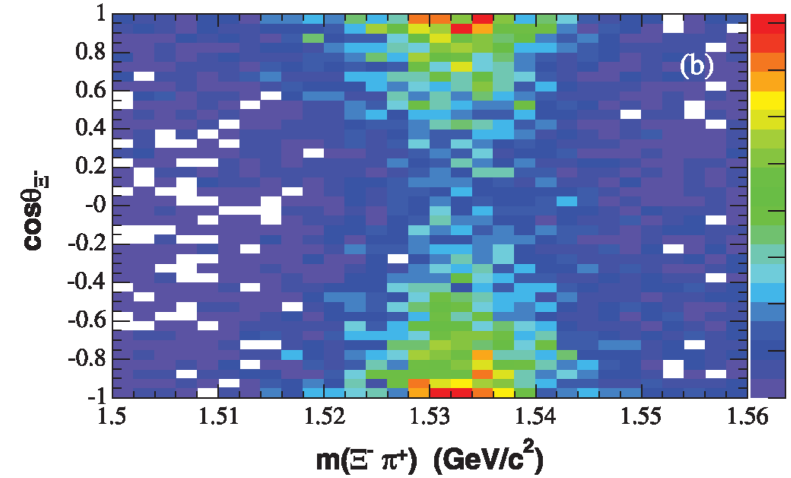
U. Löring *et al.*, EPJA 10 (2001) 447

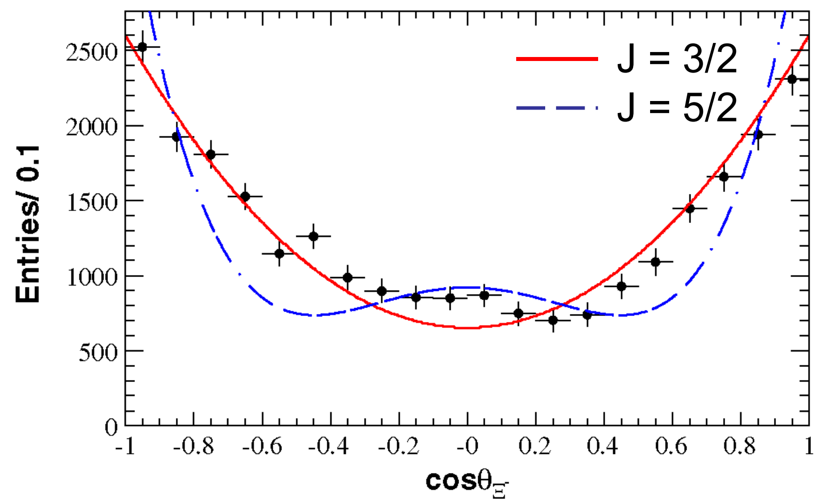
s.a.: M. Pervin, W. Roberts, PRC 77 (2008) 025202

Data on Ξ^* States: $\Xi(1530)$

- The only reasonably well studied Ξ resonance:
- $\Xi(1530)$ - decuplet g.s. $J^P = 3/2^+$
- $\Gamma = 9\ldots10$ MeV *Compare to Δ!!*
- decay: ~100% $\Xi\pi$
- BaBar measured the $\Xi(1530)^0$ spin $J = 3/2$ in $\Lambda_c^+ \rightarrow \Xi^- \pi^+ K^+$
- favor $J^P = 1/2^-$ for $\Xi(1690)$







BaBar: B. Aubert *et al.*, PRD 78 (2008) 034008

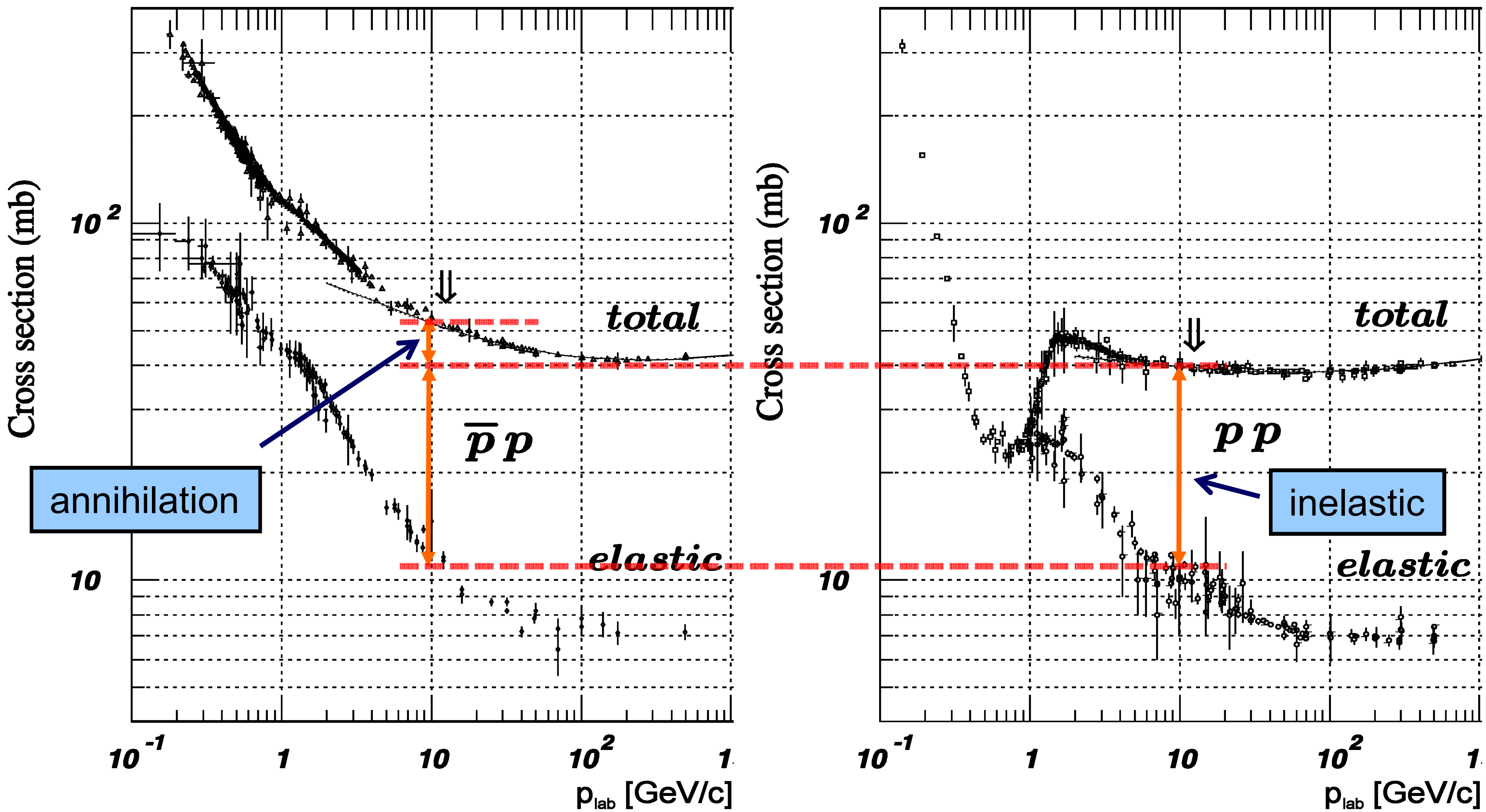
A Little Bit of $\overline{\text{P}}$ANDA History

Original Focus: Charmonium States, Hybrids and Glueballs

see „FAIR“ CDR, Nov 2001, PANDA TPR, Feb 2005

- Charmonium
- Gluonic Excitations
- Charm in Nuclei
- Hypernuclei and -atoms
- Further options (open charm, nucleon structure and form factors, CP violation)

Composition of the $\bar{p}p$ cross section



inelastic part:

$\sigma_{non\text{-}ann} / \sigma_{ann}$: ~ 0.1 (p = 1.5 GeV/c), ~ 1 (p = 5 GeV/c), ~3 (p = 15 GeV/c)

$\bar{\text{P}}$ANDA is a Factory for (Excited) Hyperons !

hyperon-antihyperon cross sections:

- $\sigma(\bar{p}p \rightarrow \bar{\Lambda}\Lambda, \bar{\Lambda}\Sigma, \bar{\Sigma}\Sigma) \cong 10 \ldots 100\ \mu\text{b}$ measured
- $\sigma(\bar{p}p \rightarrow \bar{\Xi}\Xi) \cong 2\ \mu\text{b}$ measured
- $\sigma(\bar{p}p \rightarrow \bar{\Omega}\Omega) \cong 2 \ldots 100\ \text{nb}$ predicted

➢ *production* rates at full luminosity $2 \cdot 10^{32}\ \text{s}^{-1}\text{cm}^{-2}$:

- up to $1.7 \cdot 10^{9}$ Λ per day, ~(1 - 5)$\cdot 10^{8}$ Σ per day (charge state dep.)
- up to $3.5 \cdot 10^{7}$ Ξ per day
- maybe $5 \cdot 10^{5}$ Ω per day (using σ = 30 nb)

- at comparative energy above threshold, we expect the same order of magnitude for excited states

Hirschegg 2007: The structure and dynamics of hadrons

Int. Workshop XXXV on Gross Properties of Nuclei and Nuclear Excitations

Hirschegg, Kleinwalsertal, Austria, January 14 - 20, 2007

Baryon Spectroscopy at PANDA

Albrecht Gillitzer, Institut für Kernphysik, Forschungszentrum Jülich

1. Why to study baryon excitations in $\bar{p}p$ collisions?
2. Relevant reaction channels
3. First simulation results
4. Implications for the PANDA design

Most Promising: Study Ξ Resonances

- very little known ←→ rather high cross section
- find missing resonances
- determine branching to various decay modes:
  $\Xi\pi,\ \Xi\pi^+\pi^-,\ \Xi\pi^0\pi^0,\ \Lambda K^-,\ \Sigma\bar{K},\ \Xi\eta,\ \Xi\eta\pi,\ \Xi\eta',\ \Xi\omega,\ \Xi\phi, \ldots$
- determine J^P quantum numbers if possible

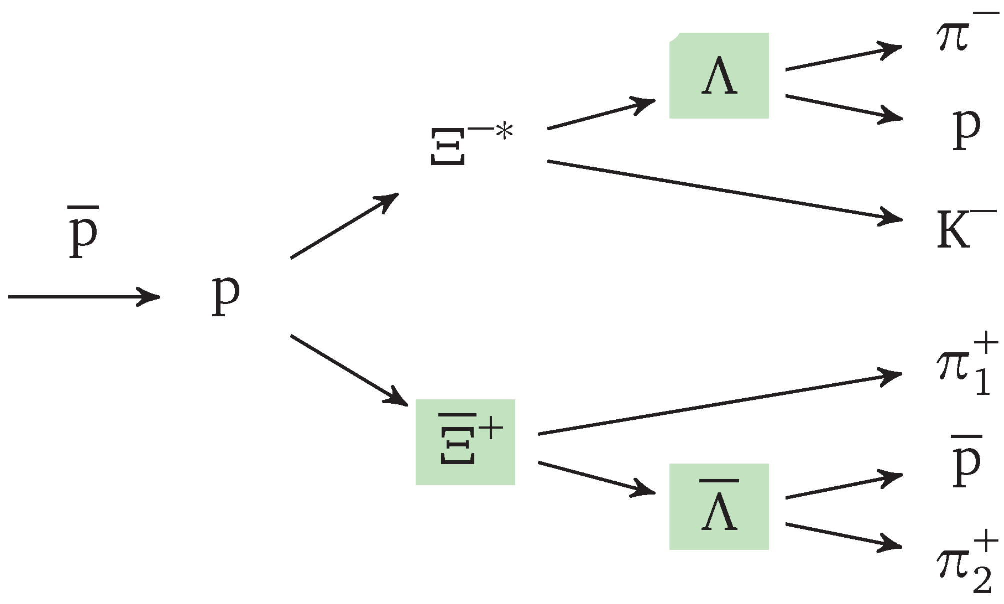
recent progress:
PAWIAN now includes baryons

see talk by Bertram Kopf

strategy:

select $\bar{p}$ momentum to produce a specific resonance close to threshold

Recent Simulation & Analysis

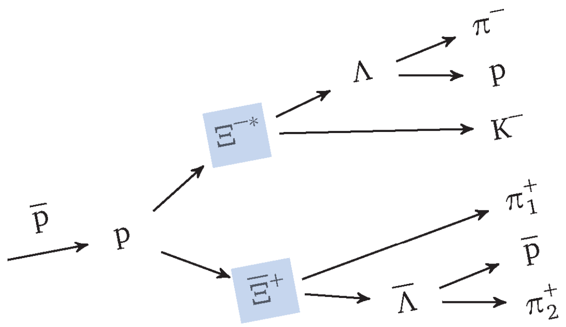


new MC simulations & analyses:

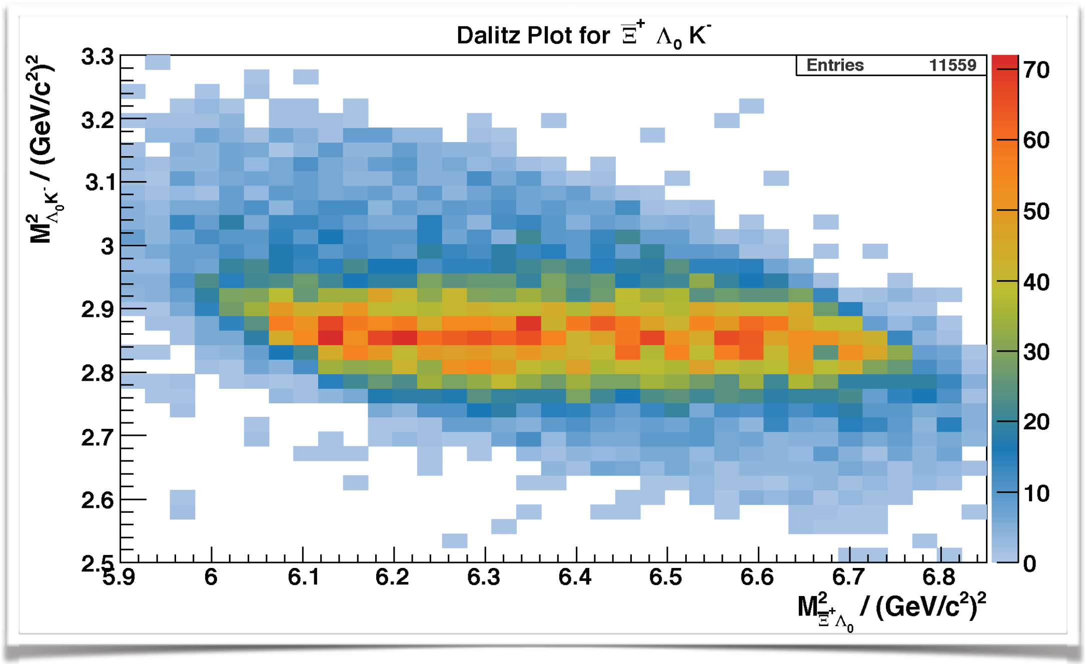
- André Zambanini, completed, PhD thesis U Bochum 2015
- 4.1 GeV/c $\bar{p}p \to \Xi(1690)^-\bar{\Xi}^+ \to K^-\Lambda\bar{\Xi}^+$
- ~$0.5 \cdot 10^6$ signal events, ~$50 \cdot 10^6$ DPM background events

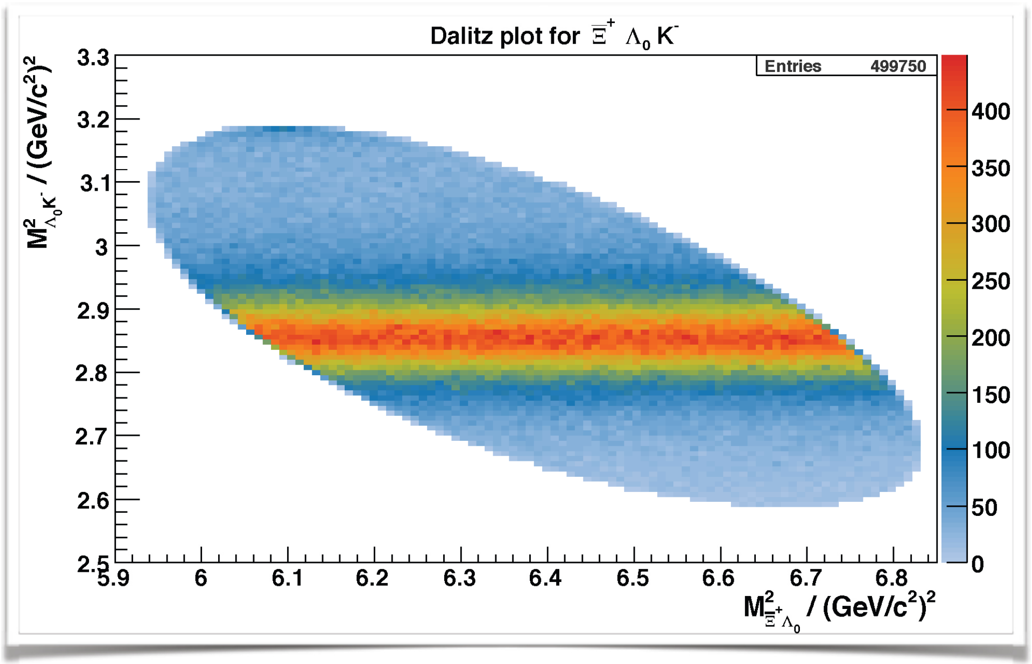
- Jennifer Pütz, PhD thesis fully devoted to Ξ spectroscopy
- 4.6 GeV/c $\bar{p}p \to \Xi(1820)^-\bar{\Xi}^+ \to K^-\Lambda\bar{\Xi}^+$ & c.c.
- $1.5 \cdot 10^6$ signal events, $15 \cdot 10^6$ DPM background events so far

$\Xi^+\Xi^-$ System — Dalitz-Plot



$\bar{\Xi}^+\Lambda K^-$ final state: $M^2(\Lambda K^-)$ vs. $M^2(\bar{\Xi}^+\Lambda)$





Reconstructed (bef. 4C kin. fit)

Simulation input

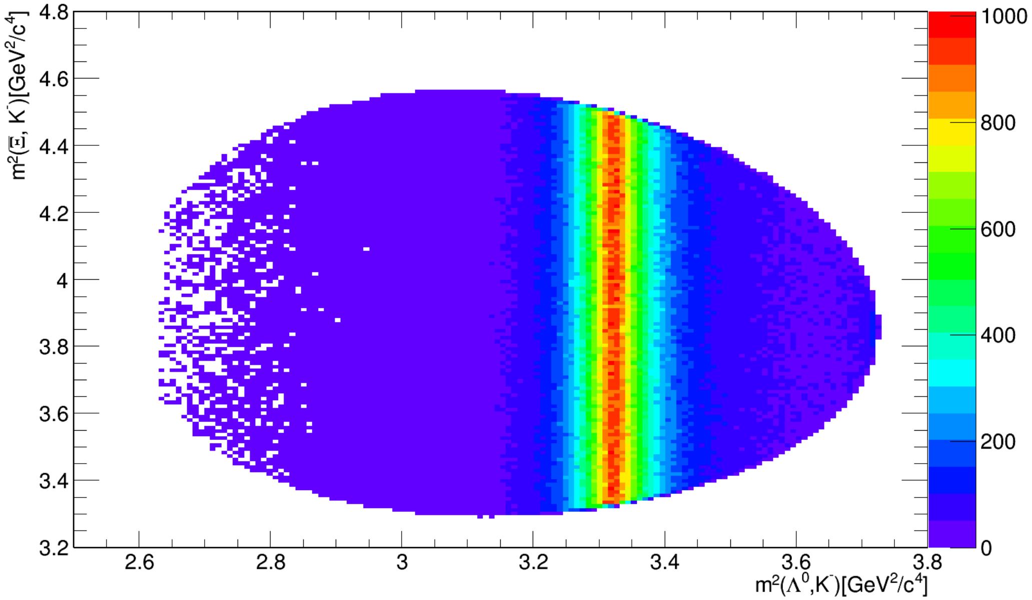
$\sigma_M(\bar{\Xi}^+) = 3.2$ MeV

$f_{rec} \sim 2.5\%$, $f_{bckg} \sim 0.2\cdot 10^{-7}$

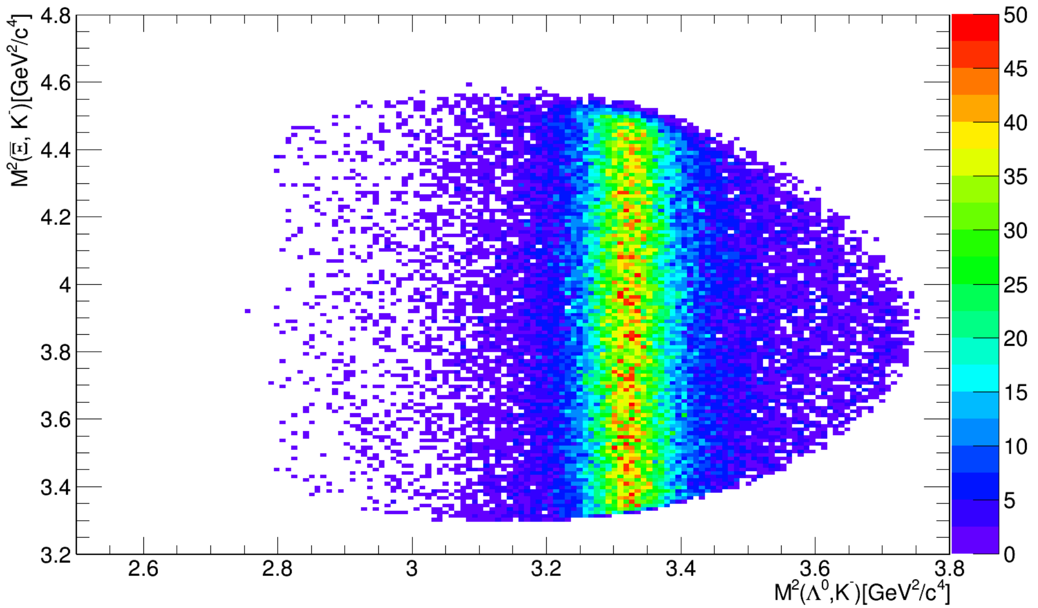
André Zambanini, Dissertation Univ. Bochum (2015)

$\bar{p}p \rightarrow \bar{\Xi}^+\Xi(1820)^- \rightarrow \bar{\Xi}^+\Lambda K^-$

$\bar{\Xi}^+\Lambda K^-$ final state: $M^2(\bar{\Xi}^+K^-)$ vs $M^2(\Lambda K^-)$



Generated



Reconstructed

$\sigma_M(\bar{\Xi}^+)$ = 4.0 MeV
f_{rec} = 2.1% (updated)
background suppression under study

Jenny Pütz, Talk at FAIRNESS 2016

Early Physics: Expected Rates for Strange Baryons

- initial phase: $L \cong 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ instead of $L \cong 2 \cdot 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- nevertheless the $\Xi\bar{\Xi}$ production rate will be $R_{\Xi\bar{\Xi}} \cong 10/s \cong 10^{6}/\mathrm{d}$
- for $\Omega\bar{\Omega}$ production we expect $R_{\Omega\bar{\Omega}} \cong 0.3/s \cong 3 \cdot 10^{4}/\mathrm{d}$
- for excited states the cross section should be of the same order of magnitude as for the ground state for given $\sqrt{s} - \sqrt{s_{\mathrm{thr}}}$
- the *detected* rate depends on the specific decay mode (branching & reconstruction efficiency)
- e.g. $\bar{p}p \to \bar{\Xi}^{+}\Xi^{*-} \to \bar{\Xi}^{+}\Xi^{-}\pi^{0} \to \bar{\Lambda}\pi^{+}\Lambda\pi^{-}\pi^{0} \to \bar{p}\pi^{+}\pi^{+}p\pi^{-}\pi^{-}\pi^{0}$
  assume $b = 0.5 \cdot 0.64^{2} = 0.2$ and $\epsilon = 5\%$ → $R_{det} \cong 10^{4}/\mathrm{d}$

Ξ^* / Ω^* Studies within the $\overline{\text{P}}$ANDA Physics Program

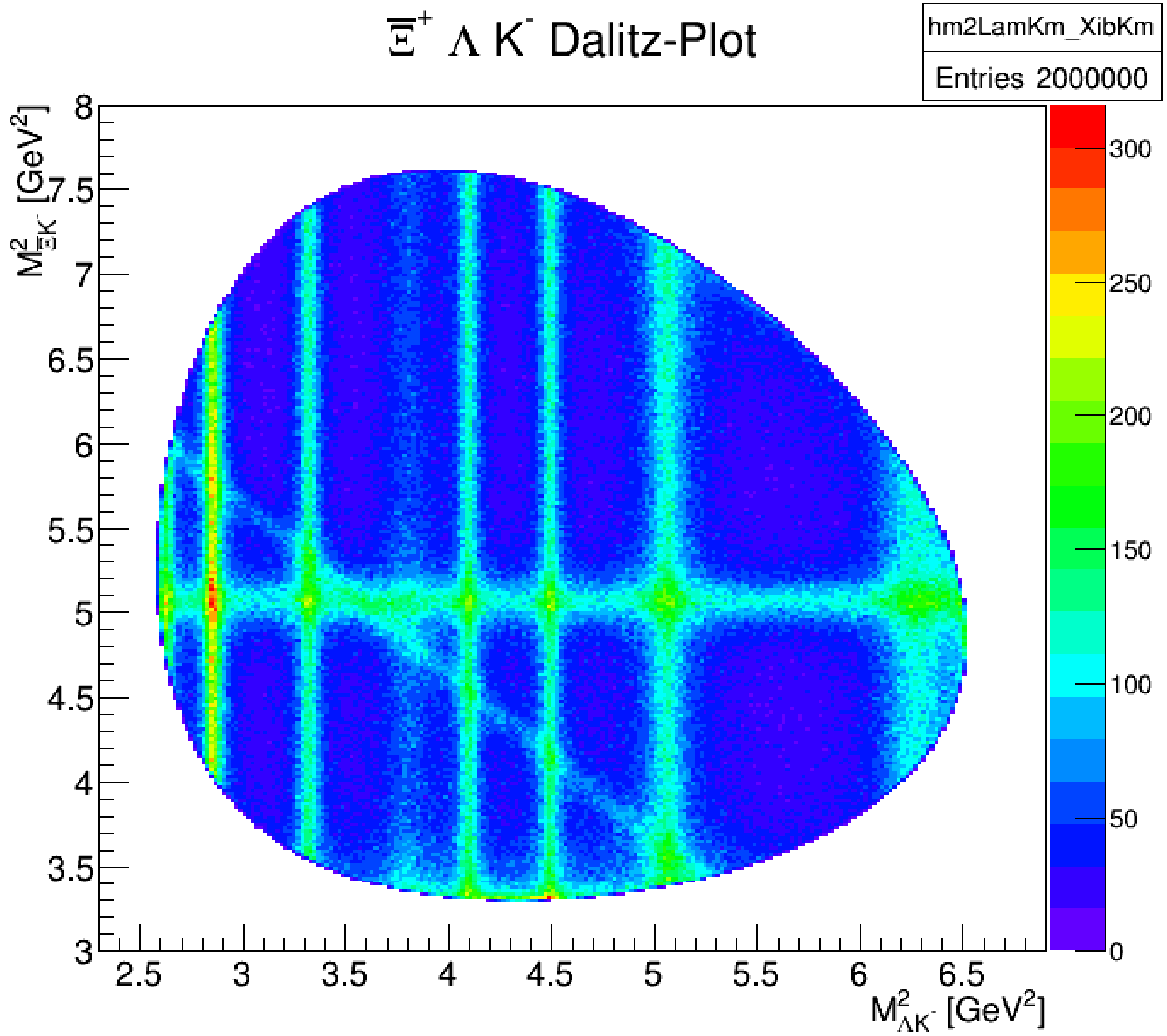
- good case for initial phase with lower L
- Λ & Σ spectroscopy can be done in parallel

- long runs to measure the X(3872) width in energy scan planned:
- parallel trigger for Ξ^* and Ω^*
- $p \approx 7.0$ GeV/c
- $M_{max}(\Xi^*) \approx 2.55$ GeV ($M_{max}(\Omega^*) \approx 2.20$ GeV)

- later: long runs for threshold scan of $D_s^{\pm} D_s(2317)^{\mp}$
- $p \approx 8.8$ GeV/c
- $M_{max}(\Omega^*) \approx 2.61$ GeV

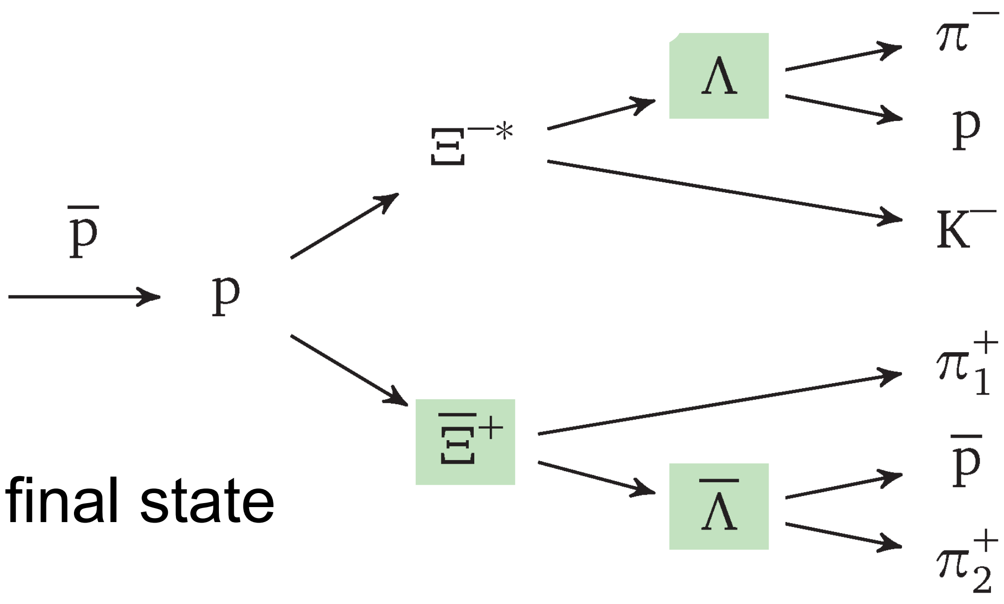
Ξ^* Production at p = 7.0 GeV/c (it will not look like this)

- EvtGen
- $\bar{p}p \rightarrow \bar{\Xi}^+\Xi^{*-} \rightarrow \bar{\Xi}^+\Lambda K^-$
- included all Ξ^* states in PDG above $\Lambda\bar{K}$ threshold
- typical width ~20 MeV
- decay: PHSP
- added $\bar{\Xi}^+\Lambda K^-$ cont., Λ^* & Σ^* states [(1)], $K(3100)$ [(2)]



(1) $\Sigma(2250)$ enhanced
(2) seen in $\bar{p}\Lambda$, $\bar{p}\Lambda\,\mathrm{n}\pi$ & c.c.

Challenges & Requirements



- Complex decay topology
  - Number of charged particles in final state
  - Displaced vertices
  - Charged → charged + neutral

➢ need

- ❖ Realistic pattern recognition for displaced tracks
- ✓ Vertex fitter for charged + neutral
- ✓ Decay tree fitter
- ❖ Realistic tracking for FTS

- Forward Boost ←→ PANDA Start Setup !

Implications for the PANDA design

still valid !

- $\bar{p}p \rightarrow \bar{Y}Y^* \rightarrow \bar{p}p$ + mesons:
  final state particles more forward than typically in annihilation reactions
- large fraction of particles emitted into region between FS and STT
  large fraction of Λ decay behind MVD
  $\Rightarrow$ improvement with additional tracking detectors (MVD disks, GEM)
- pions have low transverse momentum (< 250 MeV/c)
  $\Rightarrow$ dE/dx measurement in MVD and STT
  $\Rightarrow$ v / ToF measurement inside TS
- relevant decay channels with $K^{\pm}$
  $\Rightarrow$ K/π separation in all regions of phase space
- importance of Dalitz plot analysis
  $\Rightarrow$ avoid acceptance holes and discontinuities as much as possible

Conclusion

still valid !

- Spectroscopy of strange baryons with $\bar{p}p$ at PANDA looks promising
- First studies of specific channels relevant for Ξ^* and Ω^* production have been started; charmed baryons will follow
- Much more detailed studies required
- Implications for PANDA design already visible

Large fraction of $\bar{p}p$ cross section with baryon-antibaryon in final state

- Opportunity for PANDA to study interesting physics
- Deserves more attention !