

Hyperon Spectroscopy

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LEPS2 Workshop
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Photoproduction

1. **No Isospin Selection Λ/Σ**
 2. **Polarized Beam \rightarrow Spin/Parity**
 3. **Baryon Spectroscopy @ Resonance Energy**
- **Hyperon Resonances**
 $\Lambda(1405)$, $\Sigma(1480)$, Ξ^*
 - **Exotic Baryons**

$\Lambda(1405) S_{01}$

$$I(J^P) = 0(\frac{1}{2}^-)$$

Mass $m = 1406 \pm 4$ MeV

Full width $\Gamma = 50.0 \pm 2.0$ MeV

Below $\bar{K}N$ threshold

| $\Lambda(1405)$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------|--------------------------------|-------------|
| $\Sigma \pi$ | 100 % | 152 |

$\Sigma(1385) P_{13}$

$$I(J^P) = 1(\frac{3}{2}^+)$$

$\Sigma(1385)^+$ mass $m = 1382.8 \pm 0.4$ MeV ($S = 2.0$)

$\Sigma(1385)^0$ mass $m = 1383.7 \pm 1.0$ MeV ($S = 1.4$)

$\Sigma(1385)^-$ mass $m = 1387.2 \pm 0.5$ MeV ($S = 2.2$)

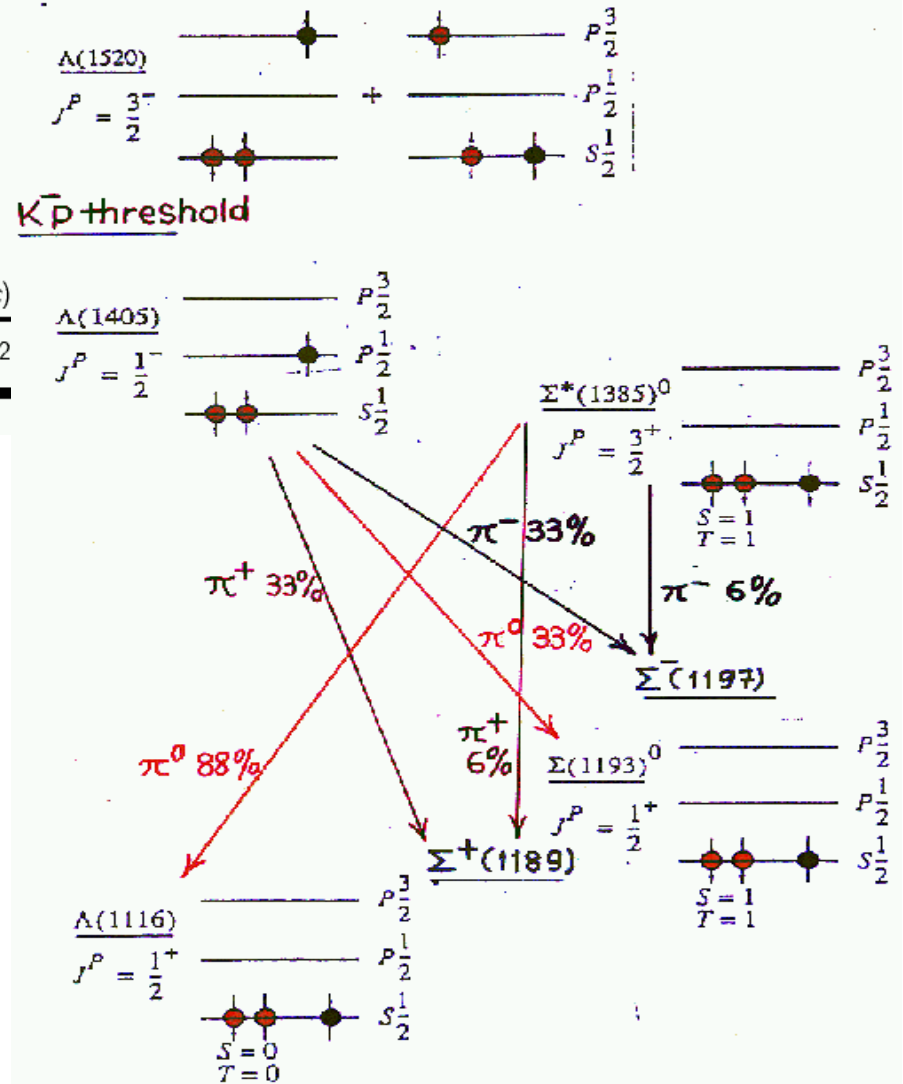
$\Sigma(1385)^+$ full width $\Gamma = 35.8 \pm 0.8$ MeV

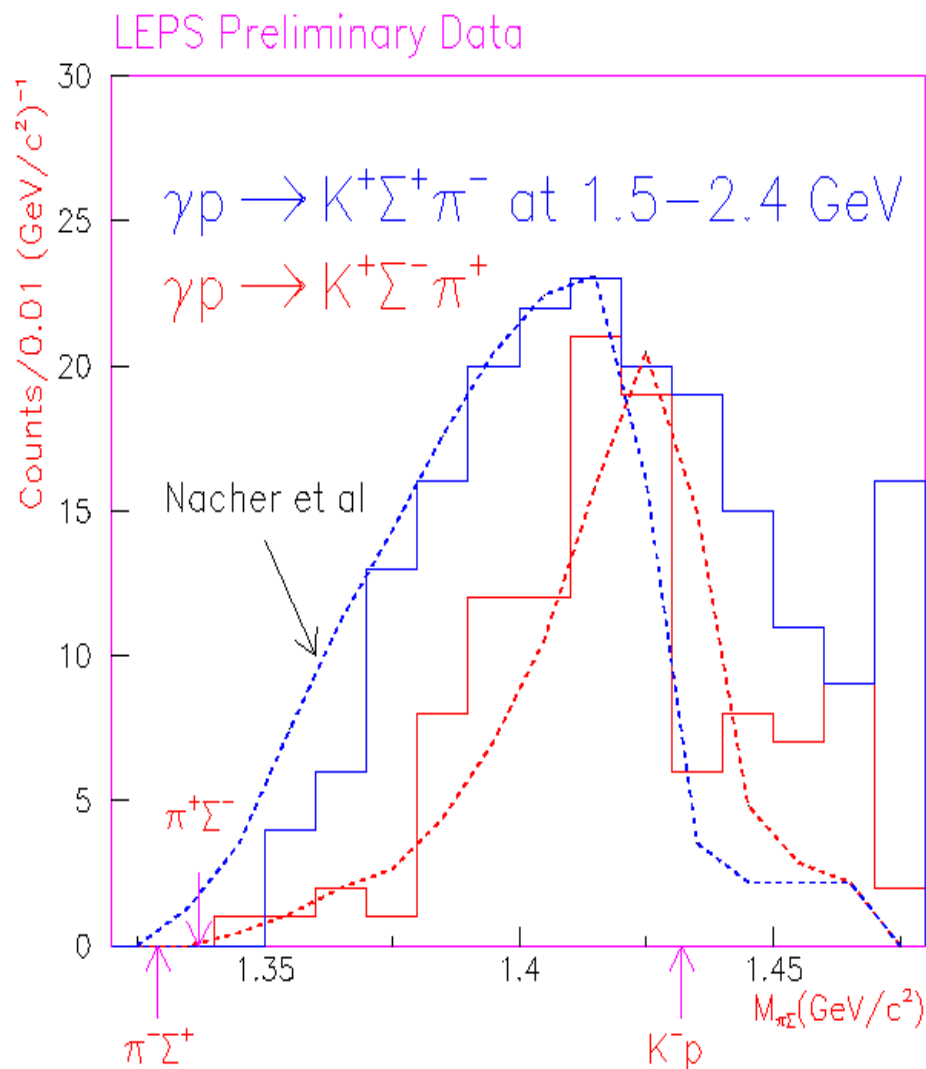
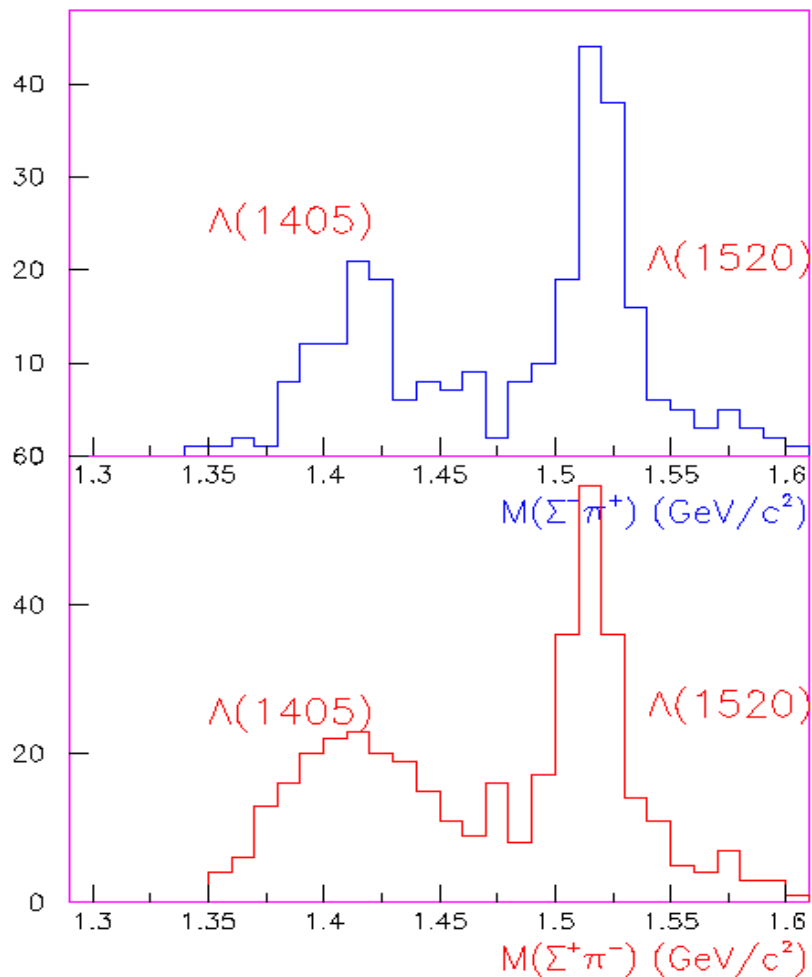
$\Sigma(1385)^0$ full width $\Gamma = 36 \pm 5$ MeV

$\Sigma(1385)^-$ full width $\Gamma = 39.4 \pm 2.1$ MeV ($S = 1.7$)

Below $\bar{K}N$ threshold

| $\Sigma(1385)$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|----------------------------|--------------------------------|-------------|
| $\Lambda \pi$ | 88 ± 2 % | 208 |
| $\Sigma \pi$ | 12 ± 2 % | 127 |





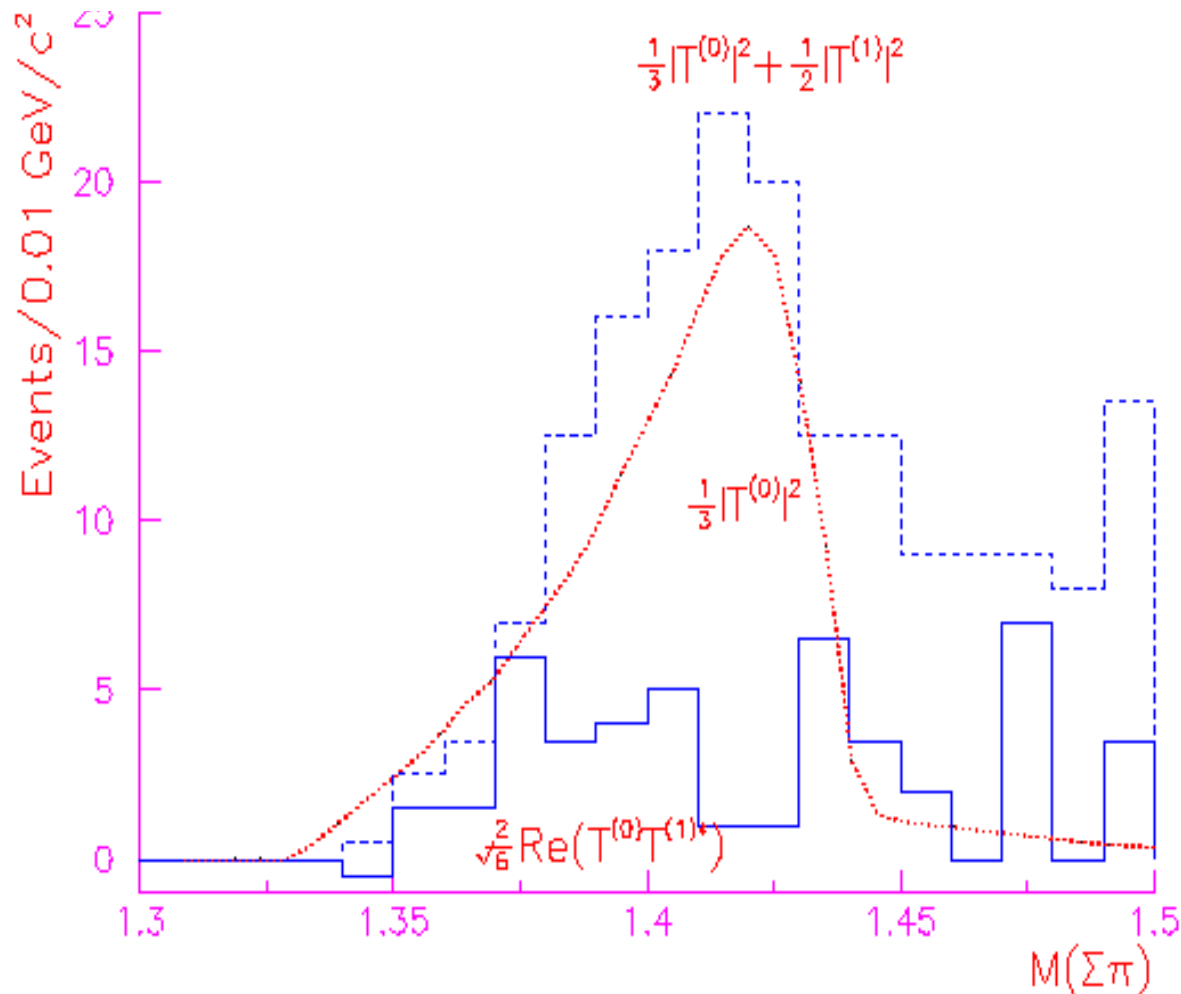
L(1405)

S(1480)

X Resonances

Exotics

$$\frac{d\sigma(\pi^\pm\Sigma^\mp)}{dM_I} \propto \frac{1}{3}|T^{(0)}|^2 + \frac{1}{2}|T^{(1)}|^2 \pm \frac{2}{\sqrt{6}}\text{Re}(T^{(0)}T^{(1)*})$$



L(1405)

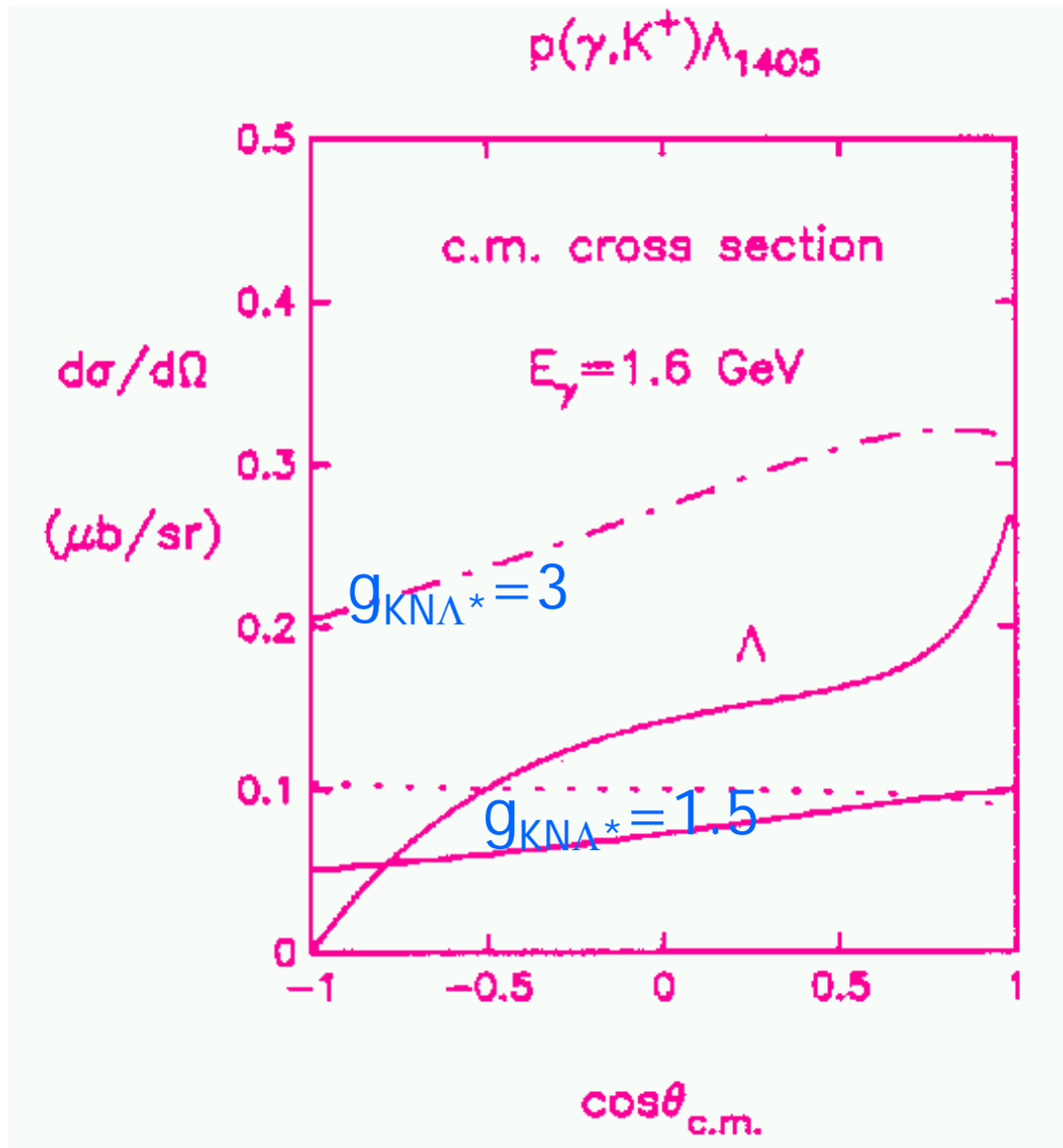
S(1480)

X Resonances

Exotics

Williams et al, PRC 43 (1991)452

$d\sigma/d\Omega$ is sensitive
to the strong coupling
constant $g_{K\Lambda(1405)}$



L(1405)

S(1480)

X Resonances

Exotics

Hyperon production in pp collisions with ANKE at COSY

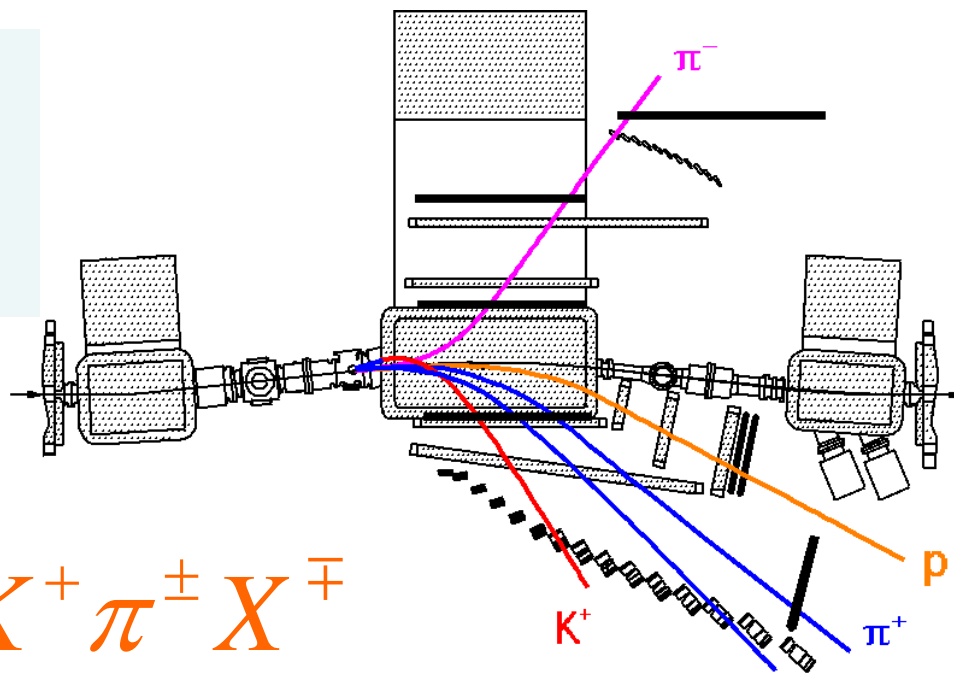
e.g. $\Sigma(1480)$

1-star “bump” in PDG

ZEUS: an indication in the $K^0 p$ invariant mass

Crystal Ball: not observed in $K^- p \rightarrow \pi^0 \pi^0 \Lambda$

- 3.65 GeV/c proton beam
- three-particle coincidences ($pK + \pi^\pm$)



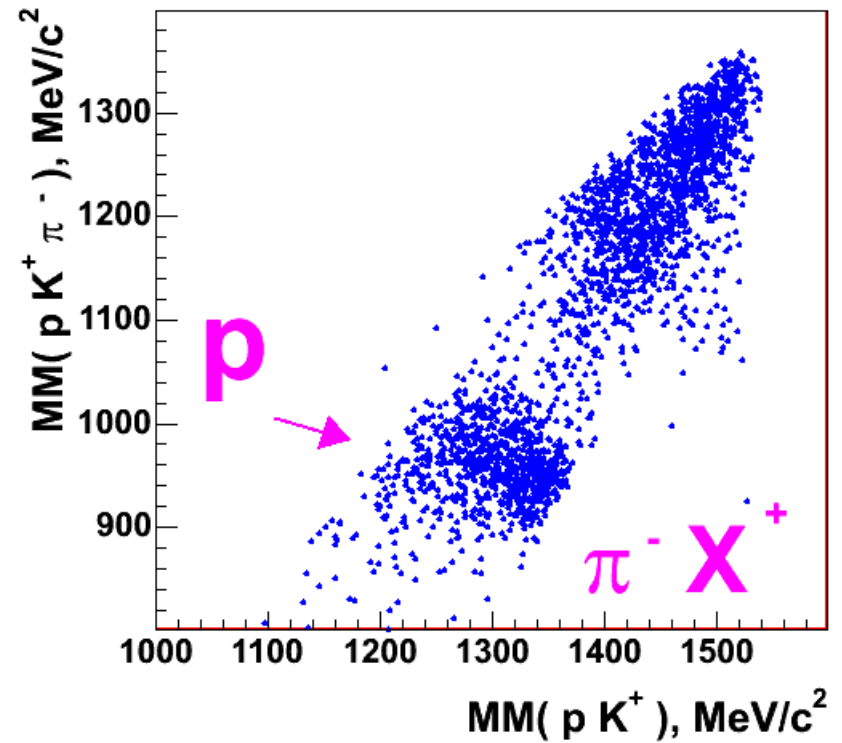
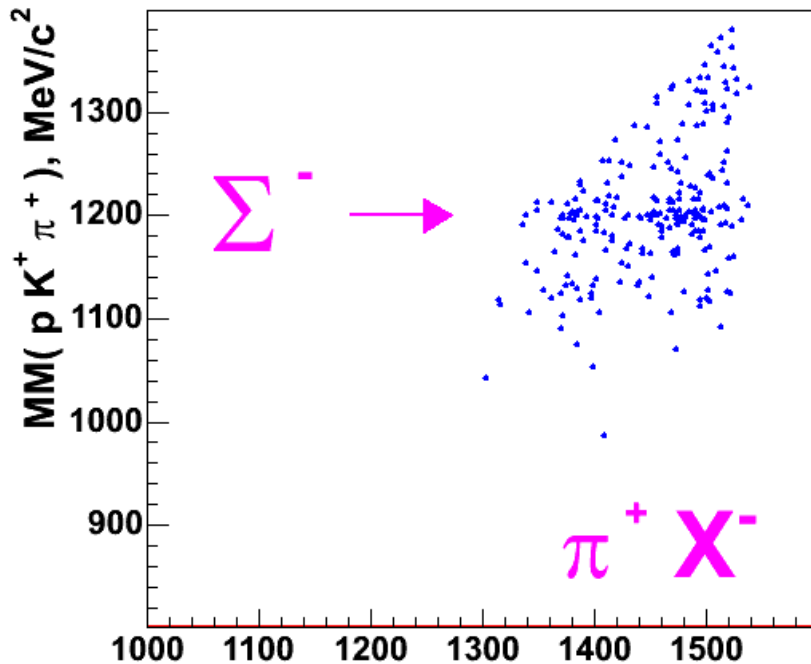
L(1405)

S(1480)

X Resonances

Exotics

$$pp \rightarrow pK^+ \pi^\pm X^\mp$$



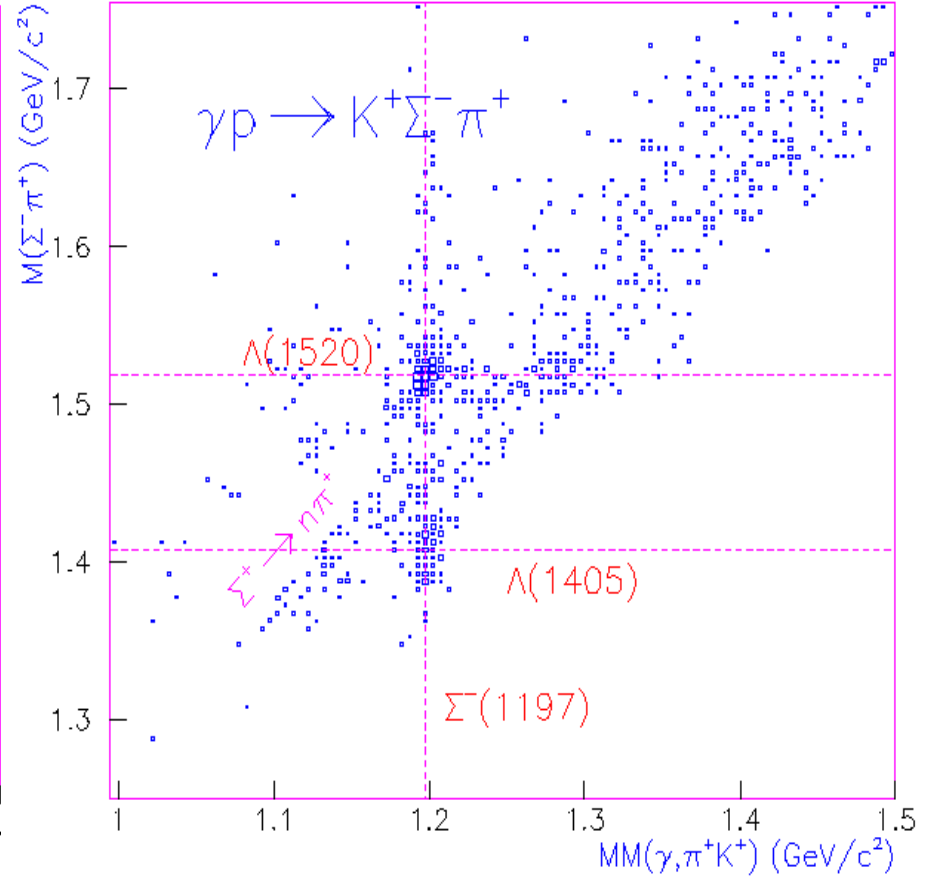
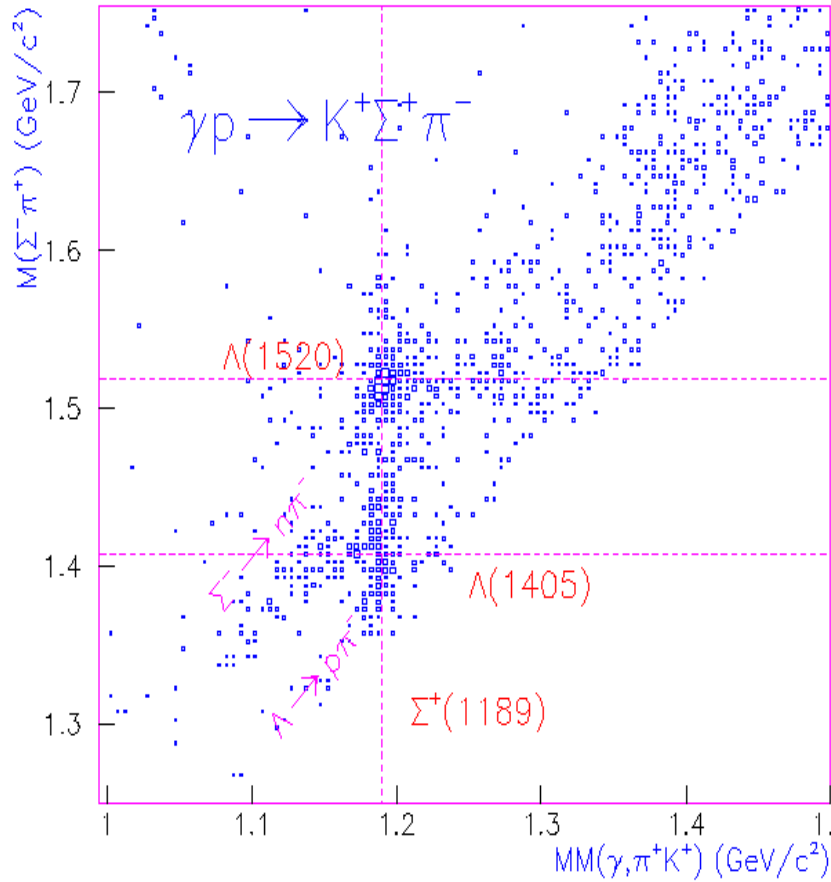
L(1405)

S(1480)

X Resonances

Exotics

$p(\gamma, K^+ \pi)$ Reactions



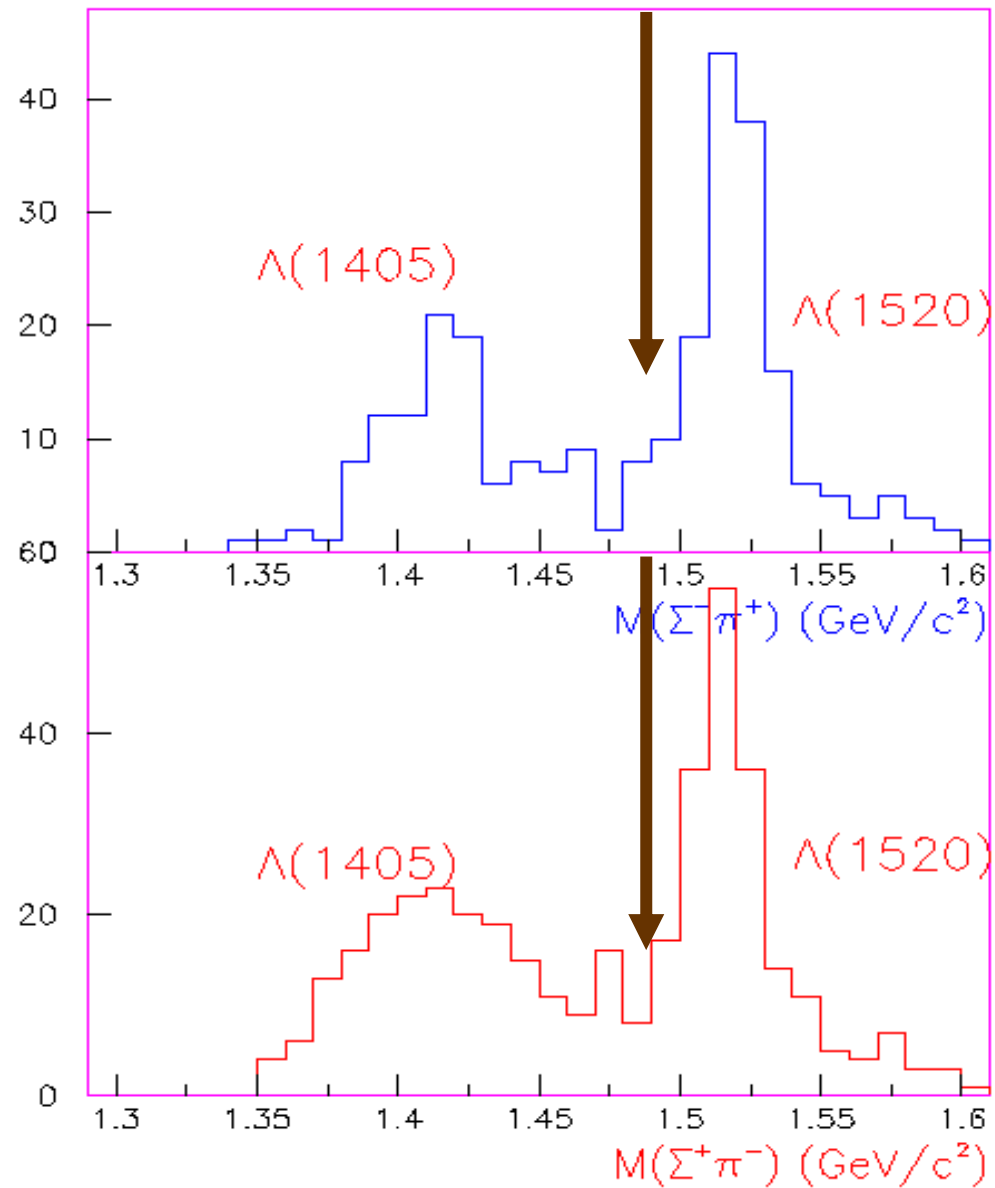
L(1405)

S(1480)

X Resonances

Exotics

$$\rho(\gamma, K+\pi)$$



L(1405)

S(1480)

X Resonances

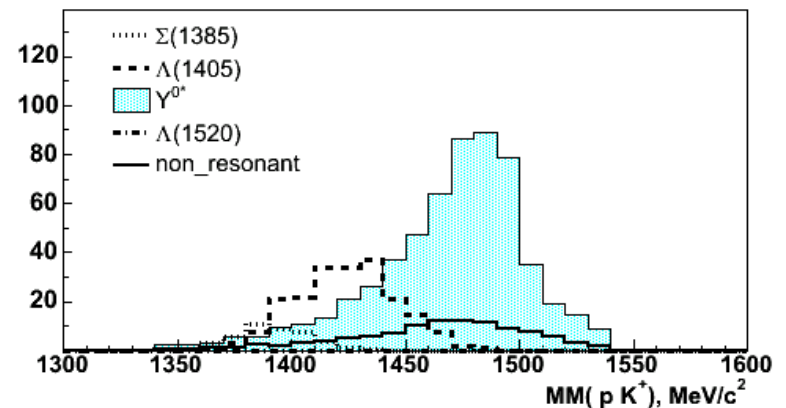
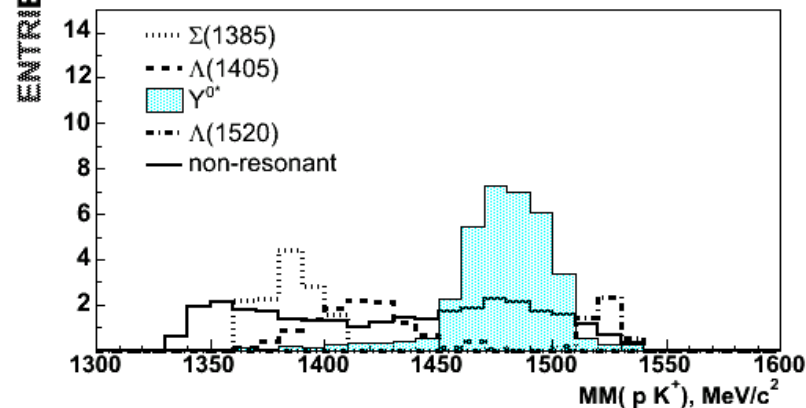
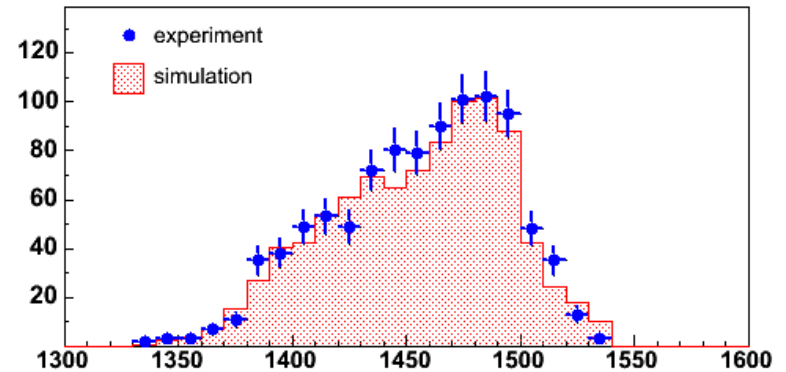
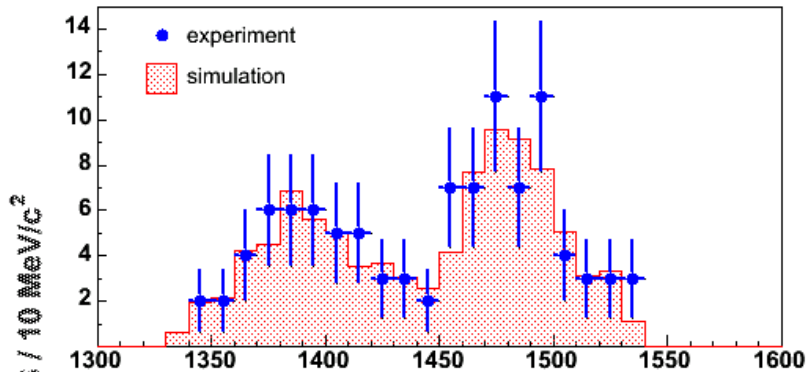
Exotics

COSY ANKE RESULTS

Y^{0*} : $M=1480 \text{ MeV}/c^2$, $\Gamma=60 \text{ MeV}/c^2$

$pp \rightarrow pK^+ \pi^+ X^-$

$pp \rightarrow pK^+ \pi^- X^+$



L(1405)

S(1480)

X Resonances

Exotics

- Υ^{0*} observed in pp collisions
in two final states: $\Upsilon^{0*} \rightarrow \pi^+ X^-$ and $\Upsilon^{0*} \rightarrow \pi^- X^+$
- Υ^{0*} mass: $(1480 \pm 15) \text{ MeV}/c^2$
- Υ^{0*} width: $(60 \pm 15) \text{ MeV}/c^2$
- cross section of a few hundred nanobarns
consistent for both final states
- statistical significance at the 4.8σ level
- Υ^{0*} non-3 quark candidate ?

$$3 \times 3 \times 3 = 10 + 8 + 8a + 1$$

$$= (\Delta^*, \Sigma^*, \Xi^*, \Omega^*) + (N^*, \Sigma^*, \Lambda^*, \Xi^*) + (N^*, \Sigma^*, \Lambda^*, \Xi^*) + \Lambda^*$$

$$\rightarrow N^* : \Delta^* : \Lambda^* : \Sigma^* : \Xi^* : \Omega^* = 2 : 1 : 3 : 3 : 3 : 1 \quad (\# \text{ of } N^* = 14)$$

| Resonance | Δ^* | Λ^* | Σ^* | Ξ^* | Ω^* |
|------------|------------|-------------|------------|---------|------------|
| Expected # | 7 | 21 | 21 | 21 | 7 |
| Observed # | 10 | 14 | 10 | 6 | 2 |

- **Hyperon Resonances**

➔ **5 GeV photon beam for 2.3 GeV Ξ^* Production**

Ξ^* Resonance Study

TABLE I: The status of the Ξ resonances.

| Particle | $L_{2I,2L}$ | Status | $\Xi\pi$ | ΛK | ΣK | $\Xi(1530)\pi$ | Others |
|-------------|-------------|--------|----------|-------------|------------|----------------|--------|
| $\Xi(1318)$ | P_{11} | **** | | | | | weakly |
| $\Xi(1530)$ | P_{13} | **** | **** | | | | |
| $\Xi(1620)$ | | * | * | | | | |
| $\Xi(1690)$ | | *** | | *** | ** | | |
| $\Xi(1820)$ | D_{13} | *** | ** | *** | ** | ** | |
| $\Xi(1950)$ | | *** | ** | ** | | * | |
| $\Xi(2030)$ | | *** | | ** | *** | | |
| $\Xi(2120)$ | | * | | | | | |
| $\Xi(2250)$ | | ** | | | | | 3-body |
| $\Xi(2370)$ | | ** | | | | | 3-body |
| $\Xi(2500)$ | | * | | * | * | | 3-body |

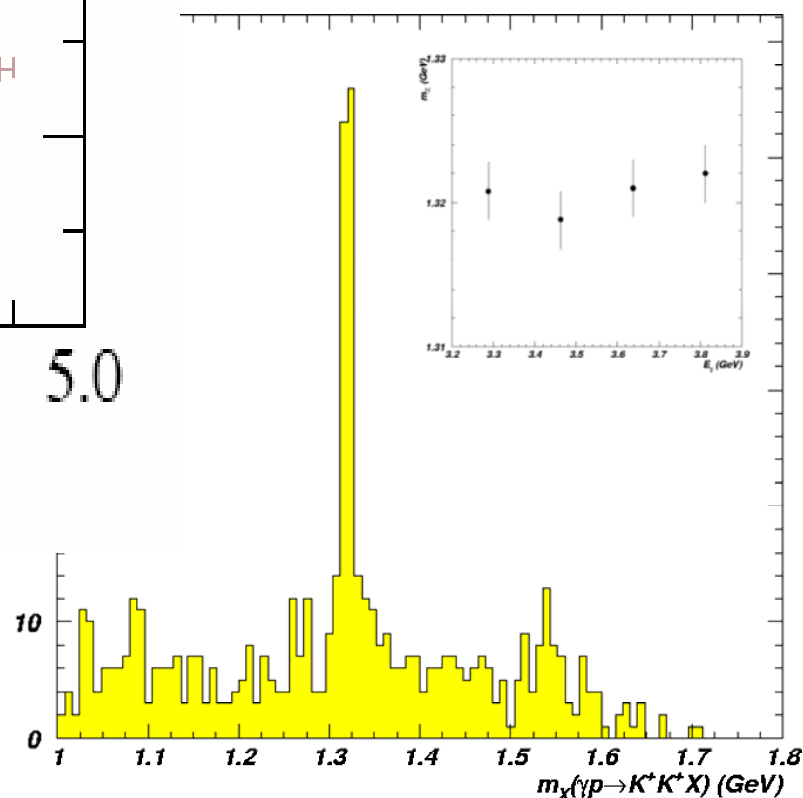
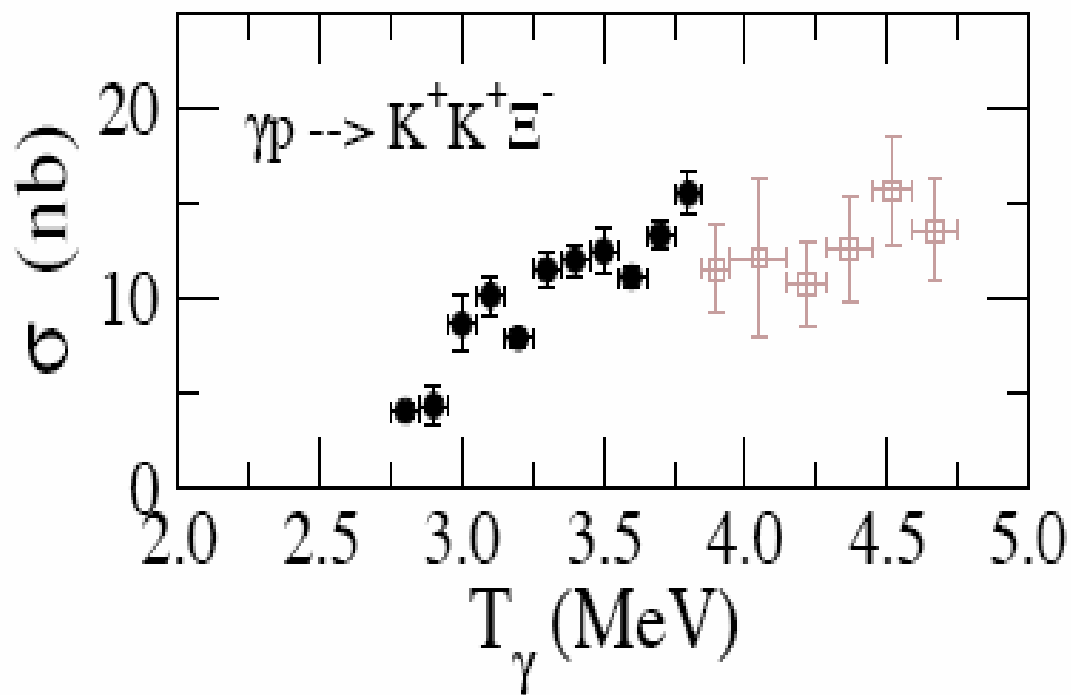
TABLE II: Threshold momenta and production cross-sections for Ξ resonances in $K^- p$ reaction

| final state | p_{th} (GeV) | σ (μb) | simulation (μb) |
|----------------------------------|----------------|----------------------------|------------------------------|
| $\Xi^- \pi^+ \pi^- K^+$ | 1.666 | $13^a, 26^b, 3^e$ | 10 |
| $\Xi^{0*}(1530) \pi^- K^+$ | 1.834 | $11.6^b, 9^e$ | 10 |
| $\Xi^- \pi^+ \pi^- \pi^0 K^+$ | 1.989 | 25.4^d | 5 |
| $\Xi^{*-}(1530) \pi^+ \pi^- K^+$ | 2.184 | | 5 |
| $\Xi^{*-}(1820) K^+$ | 2.206 | $4^a, 2.5^b$ | 3 |
| $\Xi^- \pi^+ K^{0*}(892)$ | 2.309 | $10.5^b, 4^d$ | 10 |
| $\Xi^{0*}(1530) K^{0*}(892)$ | 2.494 | $7^c, 6.5^e$ | 5 |
| $\Xi^{*-}(1950) K^+$ | 2.536 | 0.8^b | 0.5 |
| $\Xi^{--}(1860) \pi^+ K^+$ | 2.668 | | 0.0(0.5) |

^{a)} at 2.87 GeV/c[16], ^{b)} at 4.2 GeV/c[13], ^{c)} at 3.95 GeV[17],
^{d)} at 6.5 GeV[18], ^{e)} at 3 GeV[19]

$$\gamma p \rightarrow K^+ K^+ \Xi^-$$

L. Guo & D. P. Weygand, for CLAS collab.



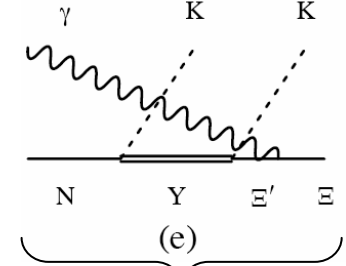
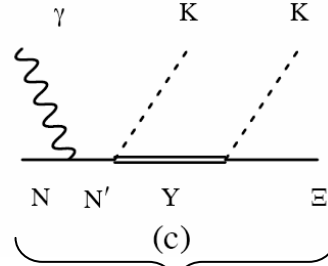
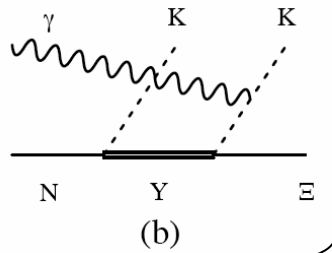
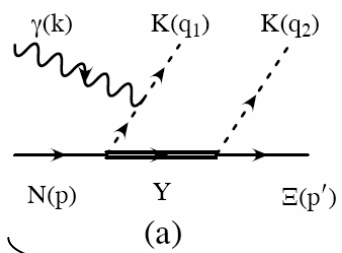
L(1405)

S(1480)

X Resonances

Exotics

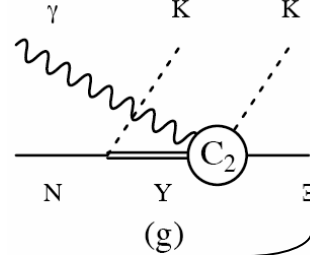
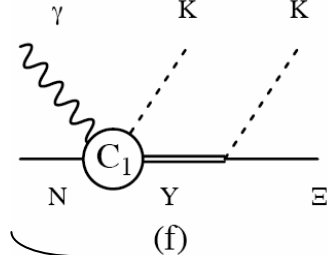
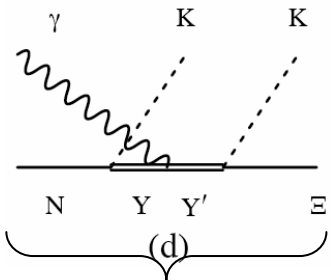
$\gamma N \rightarrow K K \Xi$ (model):



K-exchange

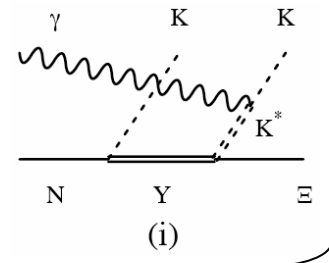
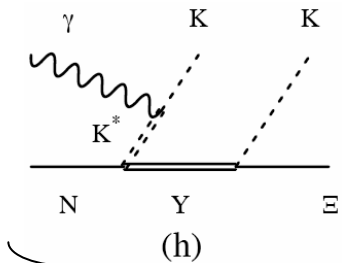
N/N'

\Xi/\Xi'



contact current

Y = Y' resonance current
Y \neq Y' radiative decay



K*-exchange

+ ($K_1(q_1) \leftrightarrow K_2(q_2)$)

L(1405)

S(1480)

X Resonances

Exotics

Compiled Ξ^* Data

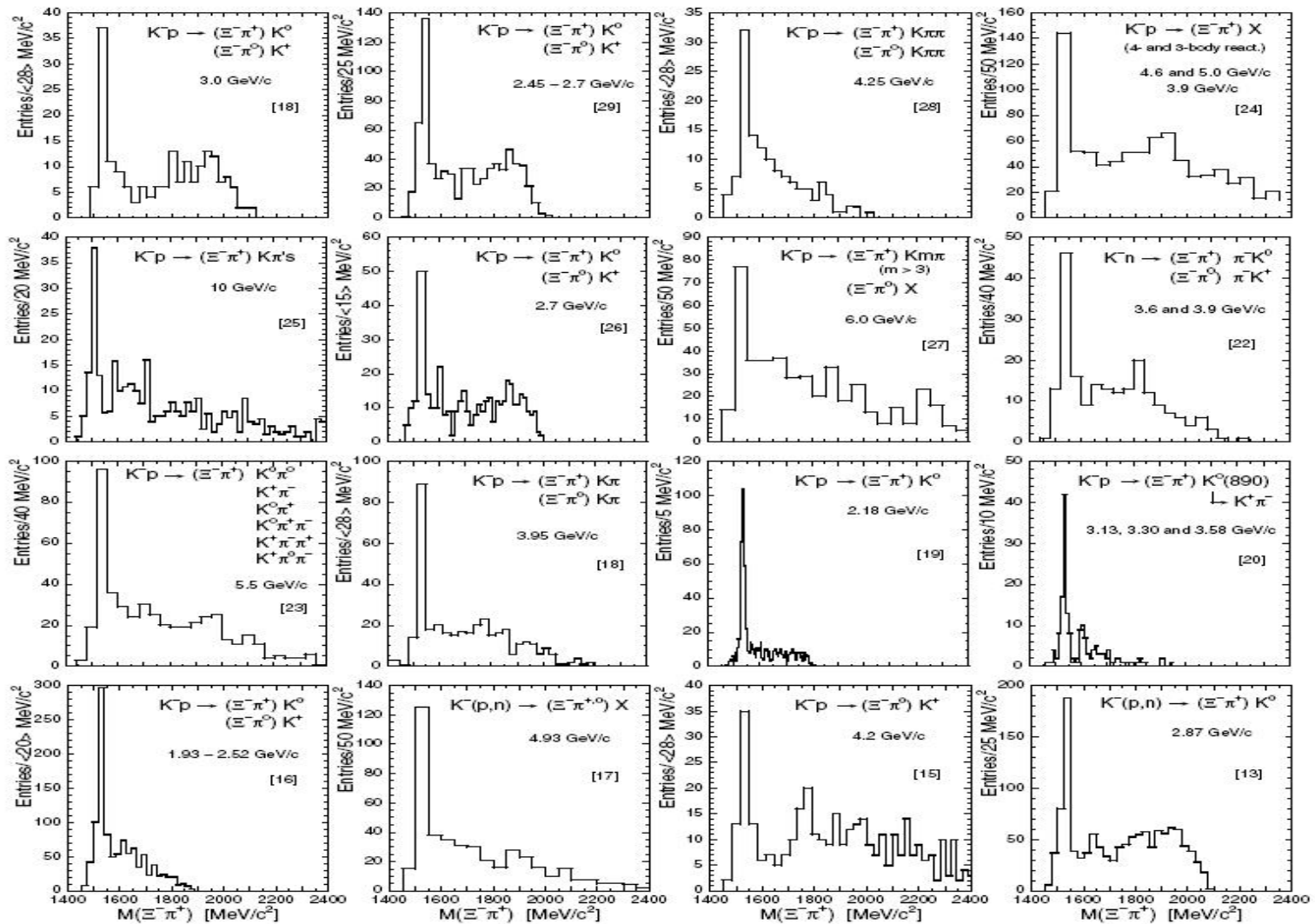


Fig. 1. Compilation of data on $\Xi^- \pi^+$ -spectroscopy

L(1405)

S(1480)

X Resonances

Exotics

MM for $p(K^-, K^+)X$ @3GeV/c

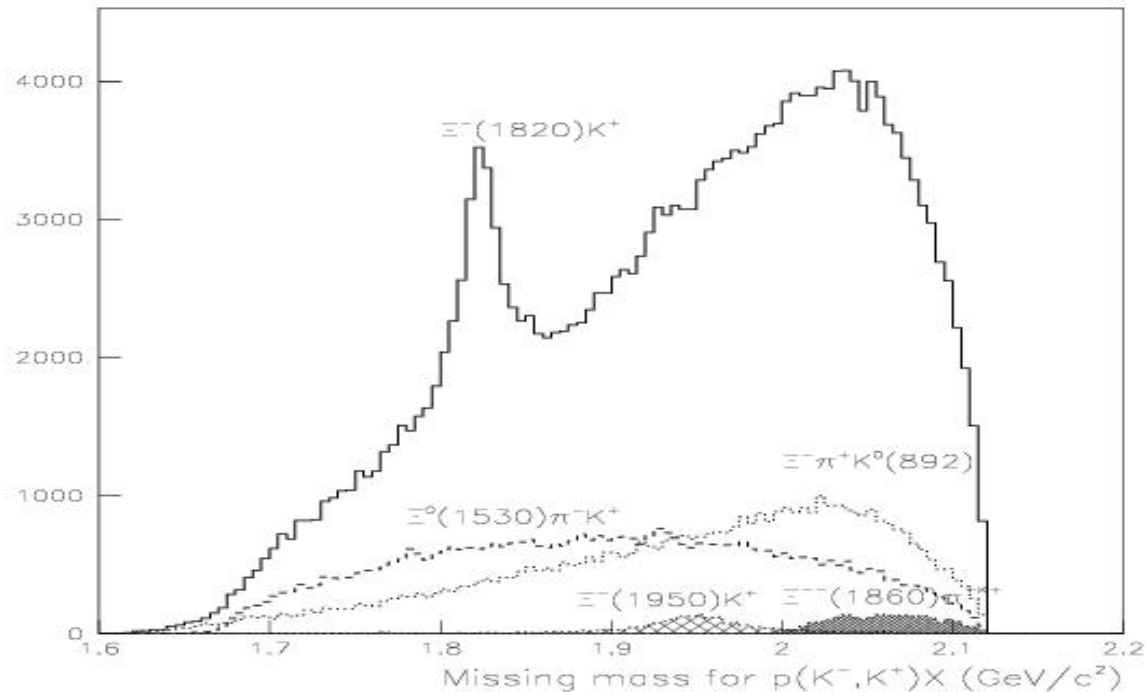
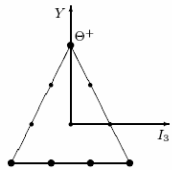


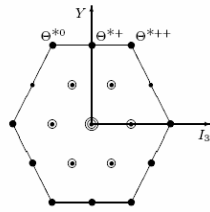
FIG. 3: Missing mass distributions for $p(K^-, K^+)X$ reaction. A sharp peak is attributed to a $\Xi^-(1820)$ production. Contributions from $\Xi^0(1530)$ and $K^0(892)$ channels are represented as dashed and dotted lines, respectively. $\Xi^-(1950)$ production contributes to a little bump structure around $1.95 \text{ GeV}/c^2$. An exotic $\Xi^{--}(1860)$ state is not included in a total missing-mass distribution, but shown to see kinematical region for $\Xi^{--}(1860)\pi^+$ production.

Pentaquarks @ J-PARC

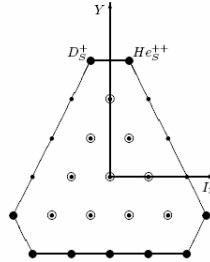
| | | | | |
|------------------------------------|------------------------------------|---------------------------|----------------------------------|-------------------------------------|
| $\pi^- p \rightarrow K^- \Theta^+$ | $K^+ p \rightarrow \pi^+ \Theta^+$ | $K^+ n \rightarrow K^+ n$ | $K^- n \rightarrow K^+ \Xi^{--}$ | $K^- p \rightarrow \pi^- K^0 \Xi^+$ |
| 2 GeV/c | 1 GeV/c | 0.5 GeV/c | 2.5 GeV/c | 2.5 GeV/c |
| K1.8 | K1.1 | K0.8 | High-p | High-p |



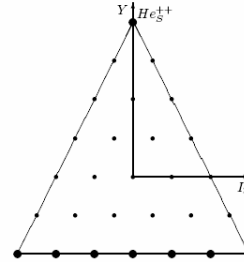
{10} J = 1/2



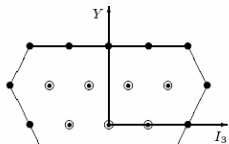
{27} J = 3/2; 1/2



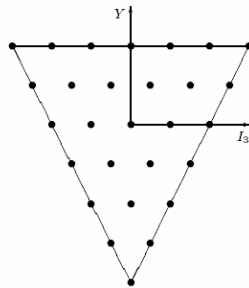
{35} B = 2



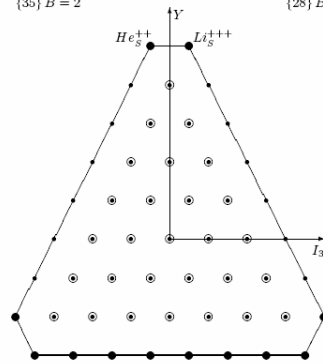
{28} B = 3



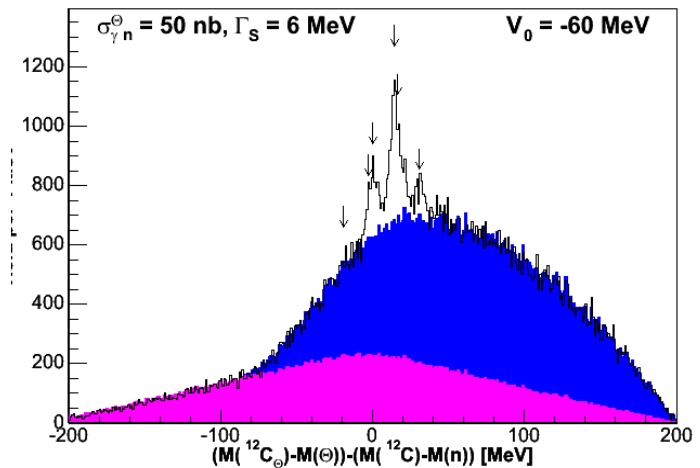
{35} J = 5/2; 3/2



{28} J = 5/2



{80} B = 4



Hyponuclei

J=1/2, 3/2, 5/2

B=2, 3, 4

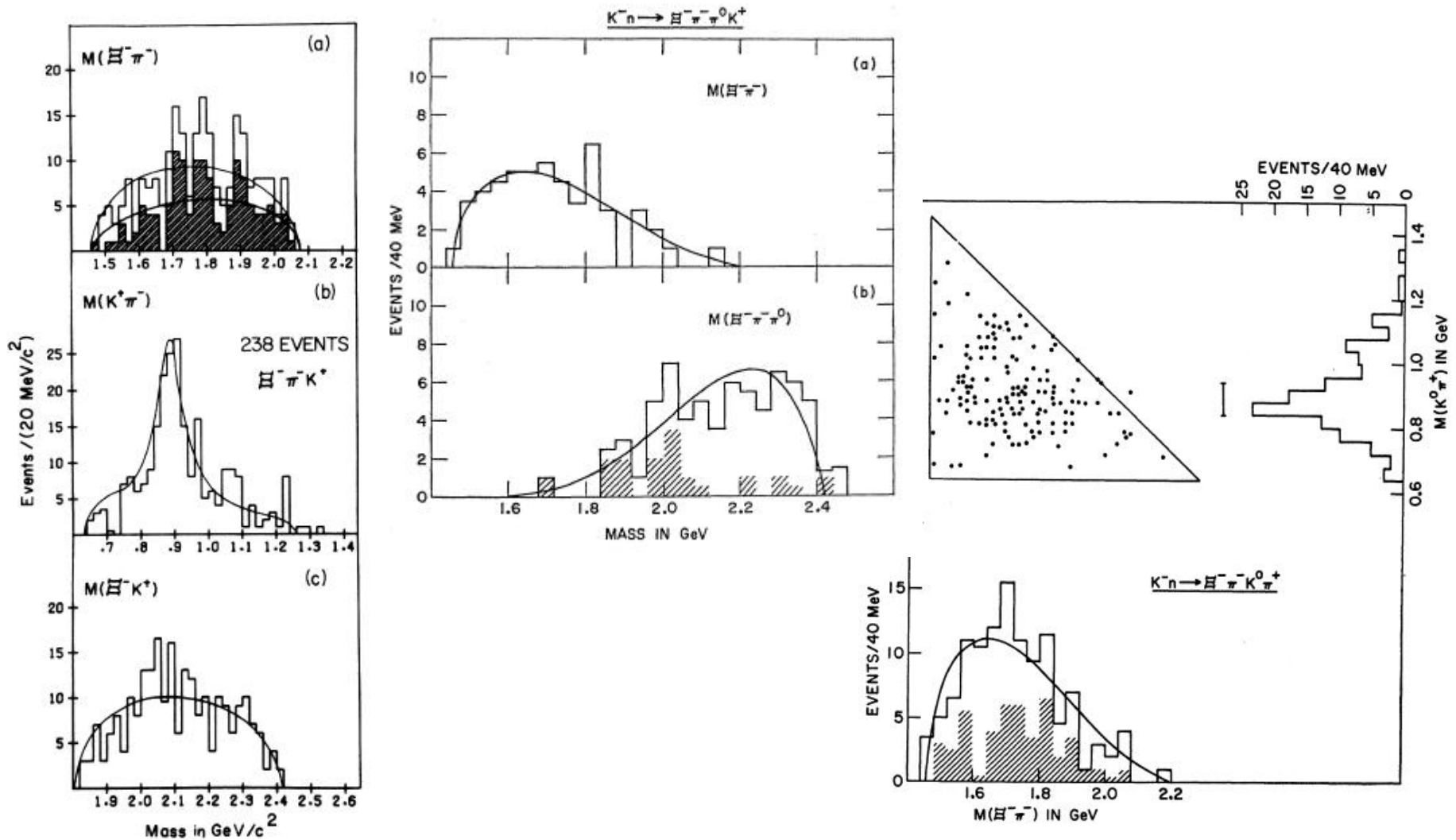
L(1405)

S(1480)

X Resonances

Exotics

Old $M(\Xi^- \pi^-)$ Data



L(1405)

S(1480)

X Resonances

Exotics

Simulated Ξ^{--} Production

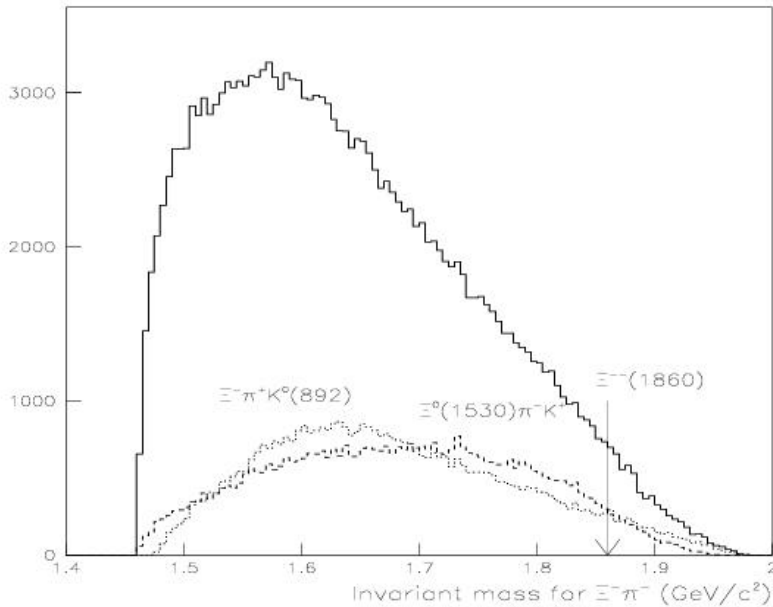


FIG. 5: Invariant mass spectrum for $\Xi^- \pi^-$ in $p(K^-, K^+)$ reactions at 3 GeV/c. It contains only contributions from $\Xi^- \pi^-$ production channels. A smooth distribution shows no accidental peak structure over a whole mass region. For an exotic $\Xi^{--}(1860)$ mass region main background processes are $K^0(892)$ and $\Xi^0(1530)$ production channels.

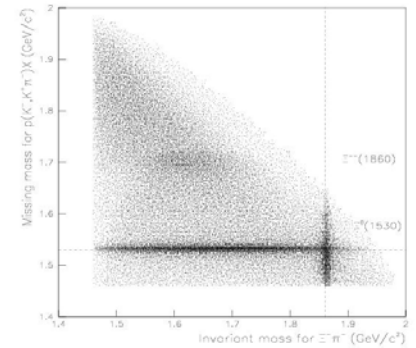


FIG. 6: Invariant mass spectrum for $\Xi^- \pi^-$ versus missing mass for $p(K^-, K^+ \pi^-)$ reactions at 3 GeV/c. A strong horizontal band for $\Xi^0(1530)$ production appears over a whole mass region. A vertical band for an exotic $\Xi^{--}(1860)$ production is added to show a kinematical region.

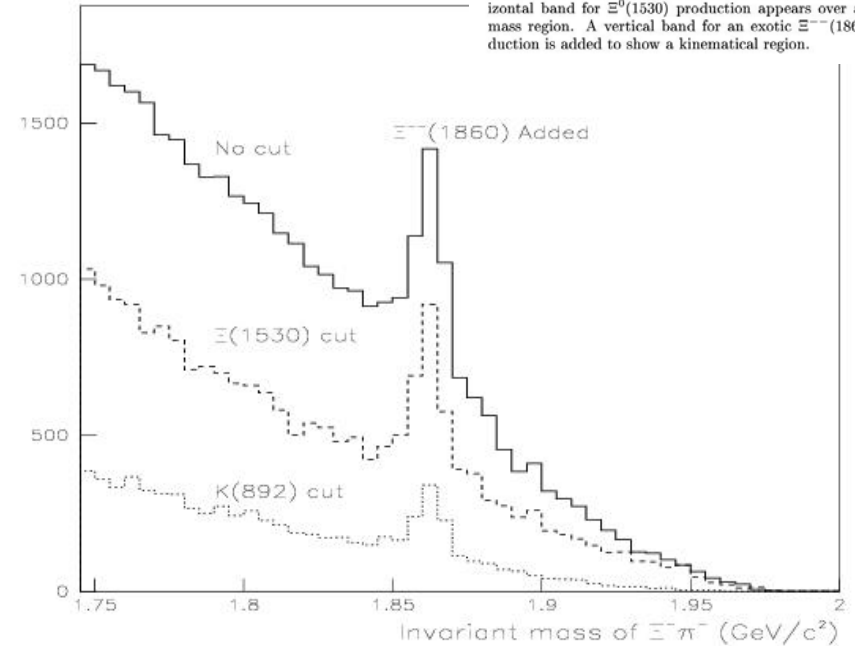


FIG. 8: Invariant mass spectrum of $\Xi^- \pi^-$ with added $\Xi^{--}(1860)$ events, assuming $\sigma(K^- p \rightarrow \Xi^- - \pi^+ K^+) = 0.5 \mu\text{b}$ at 3 GeV/c. Dashed and dotted lines denote the invariant mass spectra with $\Xi(1530)$ and $K(892)$ cuts, respectively.

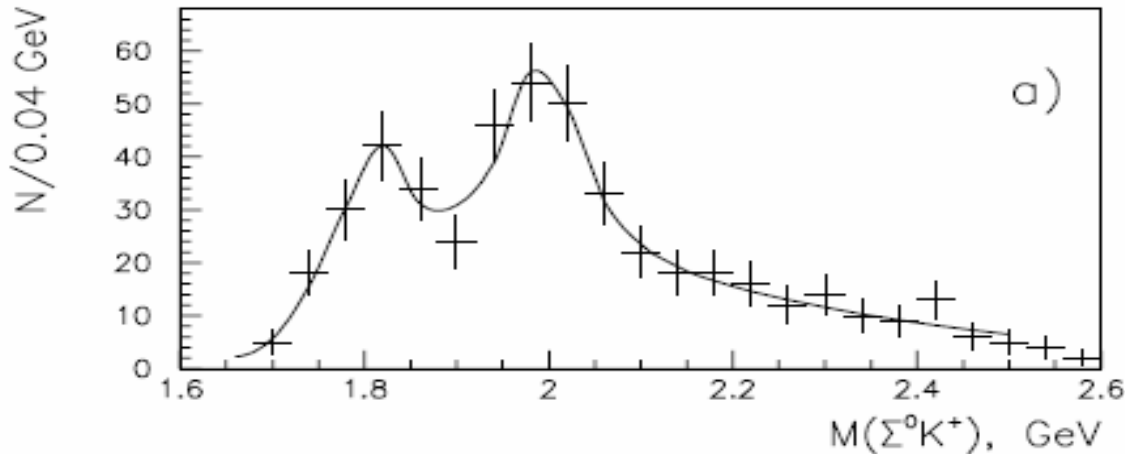
L(1405)

S(1480)

X Resonances

Exotics

X(2000) and $\Sigma(3170)$



- $pN \rightarrow X(2000)N \rightarrow \Sigma^0 K^+ N$ @ 70 GeV
- $uud\bar{s}\bar{s}$ pentaquark? SPHINX @ ITEP
- $K-p \rightarrow \Sigma(3170)\pi^- \rightarrow \Sigma K \bar{K} \pi \pi \pi^-$ @ 6.5, 8.25 GeV
- $uuss\bar{s}$ pentaquark? CERN and Argonne BC