K_{Long} beam experiment in JLAB and search for pentaquark states in the meson photoproduction reactions

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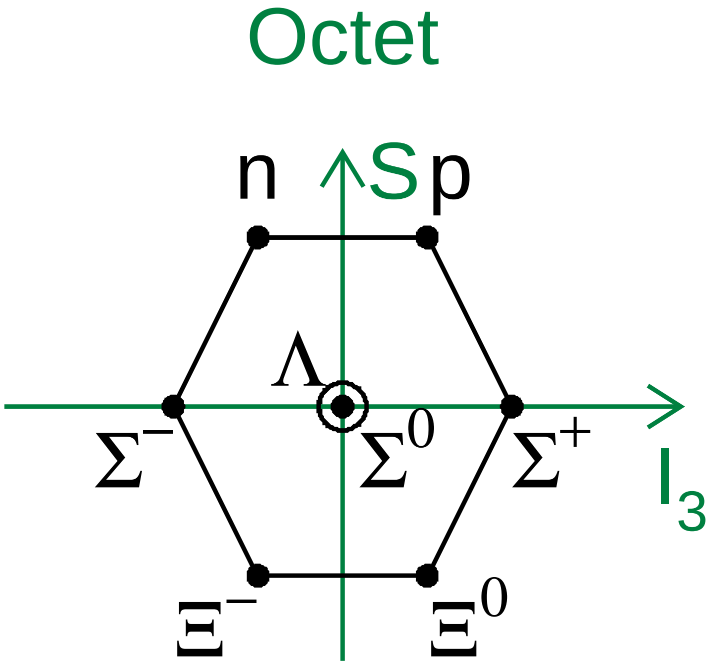
K_{Long} beam motivation

1. Search for the missing Σ-hyperons
2. Search for the pentaquark states predicted by the chiral soliton model (Dyakonov, Petrov, Polyakov).

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



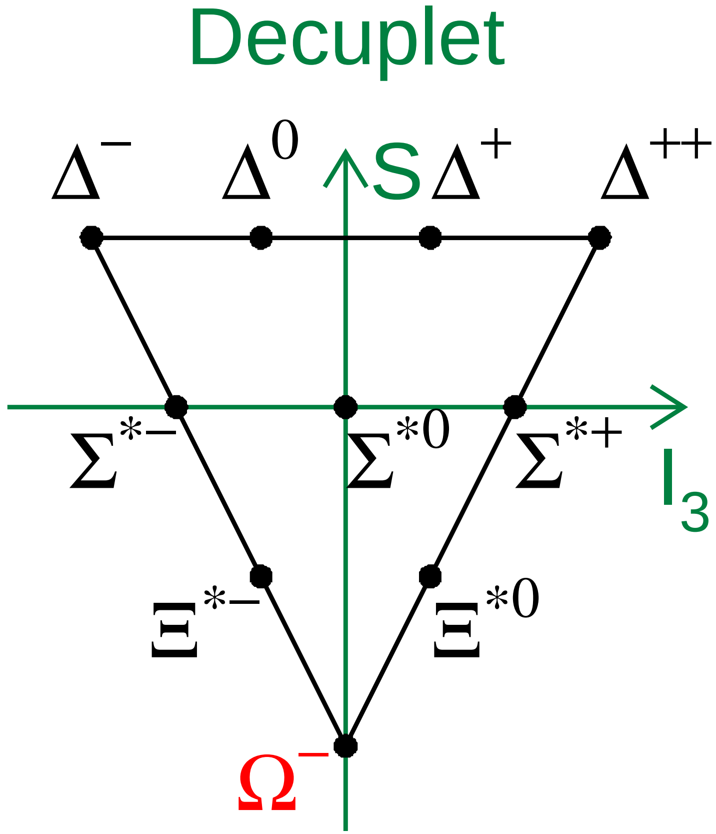


Table 1: Λ-hyperons used in the first fit of the data.

		J^P	Status	Mass	Width
singlet	$\Lambda(1405)$	$1/2^-$	****	$1405^{+1.3}_{-1.0}$	50.5 ± 2.0
$N(1535)$	$\Lambda(1670)$	$1/2^-$	****	$1660 - 1680$	$25 - 50$
$N(1650)$	$\Lambda(1800)$	$1/2^-$	***	$1720 - 1850$	$200 - 400$
singlet	$\Lambda(1520)$	$3/2^-$	****	1519.5 ± 1.0	15.6 ± 1.0
$N(1520)$	$\Lambda(1690)$	$3/2^-$	****	$1685 - 1695$	$50 - 70$
$N(1675)$	$\Lambda(1830)$	$5/2^-$	****	$1810 - 1830$	$60 - 110$
$N(2190)$	$\Lambda(2100)$	$7/2^-$	****	$2090 - 2110$	$100 - 250$
$N(1440)$	$\Lambda(1600)$	$1/2^+$	***	$1560 - 1700$	$50 - 250$
$N(1710)$	$\Lambda(1810)$	$1/2^+$	***	$1750 - 1850$	$50 - 250$
$N(1700)$	$\Lambda(1890)$	$3/2^+$	****	$1850 - 1910$	$60 - 200$
$N(1680)$	$\Lambda(1820)$	$5/2^+$	****	$1815 - 1825$	$70 - 90$
$N(2060)$	$\Lambda(2110)$	$5/2^+$	***	$2090 - 2140$	$150 - 250$

Table 2: Σ-Hyperons used in the first fit of the data.

		J^P	Status	Mass	Width
$N(1440)$	$\Sigma(1660)$	$1/2^+$	***	$1630 - 1690$	$40 - 200$
$\Delta(1230)$	$\Sigma(1385)$	$3/2^+$	****	1382.80 ± 0.35	36.0 ± 0.7
$N(1680), \Delta(1905)$	$\Sigma(1915)$	$5/2^+$	****	$1900 - 1935$	$80 - 160$
$N(1990), \Delta(1950)$	$\Sigma(2030)$	$7/2^+$	****	$2025 - 2040$	$150 - 200$
$N(1520)$	$\Sigma(1670)$	$3/2^-$	****	$1665 - 1685$	$40 - 80$
$N(1535), \Delta(1620), N(1650)$	$\Sigma(1750)$	$1/2^-$	***	$1730 - 1800$	$60 - 160$
$N(1675)$	$\Sigma(1775)$	$5/2^-$	****	$1770 - 1780$	$105 - 135$
$N(1700), \Delta(1700)$	$\Sigma(1940)$	$3/2^-$	***	$1900 - 1950$	$150 - 300$

Many Σ states are missing.

The πN (KN) interaction. Three measurements are needed to fix quantum numbers

$$A_{\pi N} = \omega^* \left[G(s,t) + H(s,t) i(\vec{\sigma}\vec{n}) \right] \omega' \qquad \vec{n}_j = \varepsilon_{\mu\nu j} \frac{q_\mu k_\nu}{|\vec{k}||\vec{q}|} .$$

$$G(s,t) = \sum_L \left[(L+1) F_L^+(s) + L F_L^-(s) \right] P_L(z) ,$$

$$H(s,t) = \sum_L \left[F_L^+(s) - F_L^-(s) \right] P'_L(z) .$$

Differential cross section in c.m.s. of the reaction

$$|A|^2 = \frac{1}{2} \mathrm{Tr} \left[A^*_{\pi N} A_{\pi N} \right] = |G(s,t)|^2 + |H(s,t)|^2 (1 - z^2)$$

the recoil asymmetry:

$$P = \frac{\mathrm{Tr} \left[A^*_{\pi N} \sigma_2 A_{\pi N} \right]}{2|A|^2 \cos\phi} = \sin\Theta \frac{2Im \left(H^*(s,t) G(s,t) \right)}{|A|^2} .$$

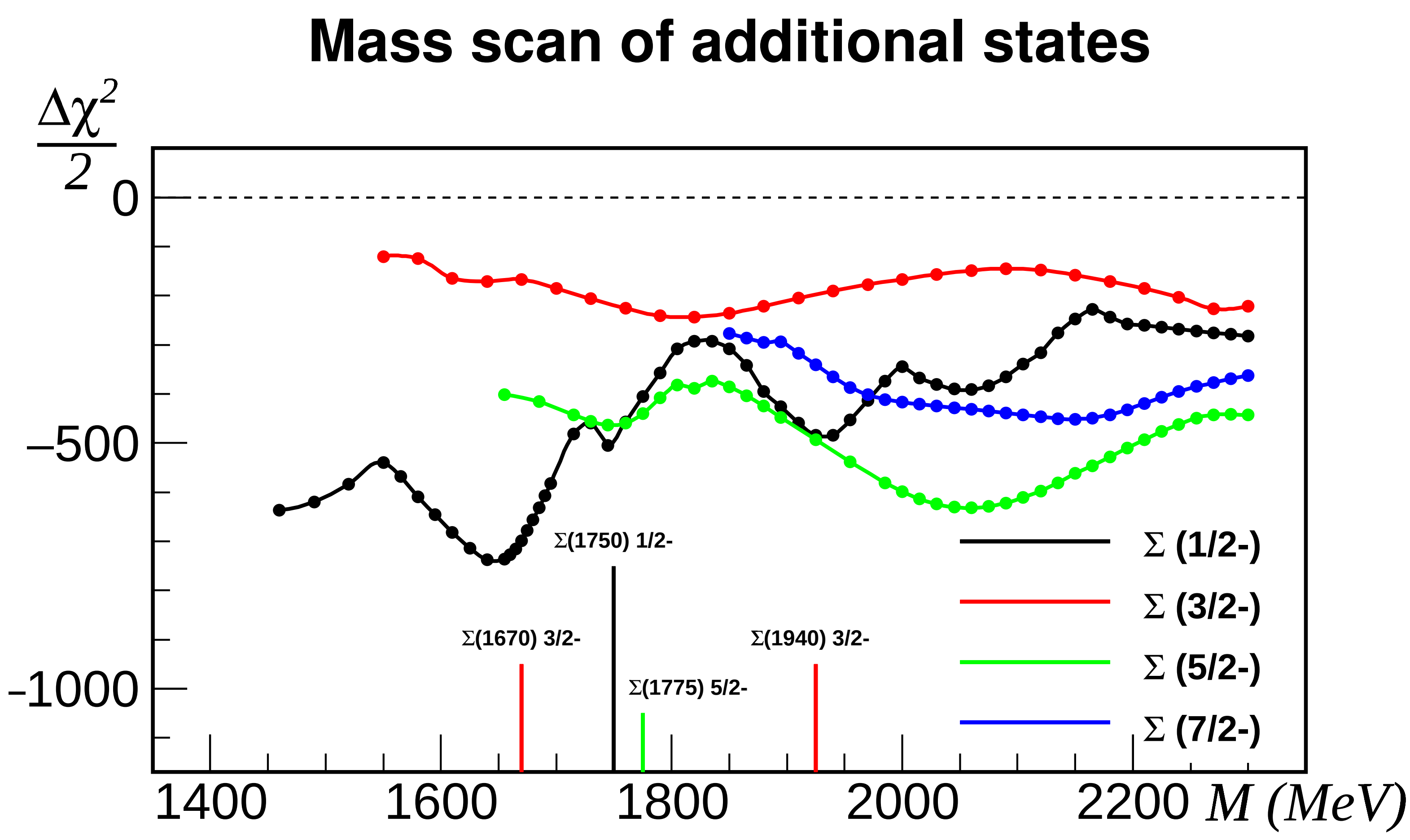
and the rotation parameter.

Kaon beam motivation

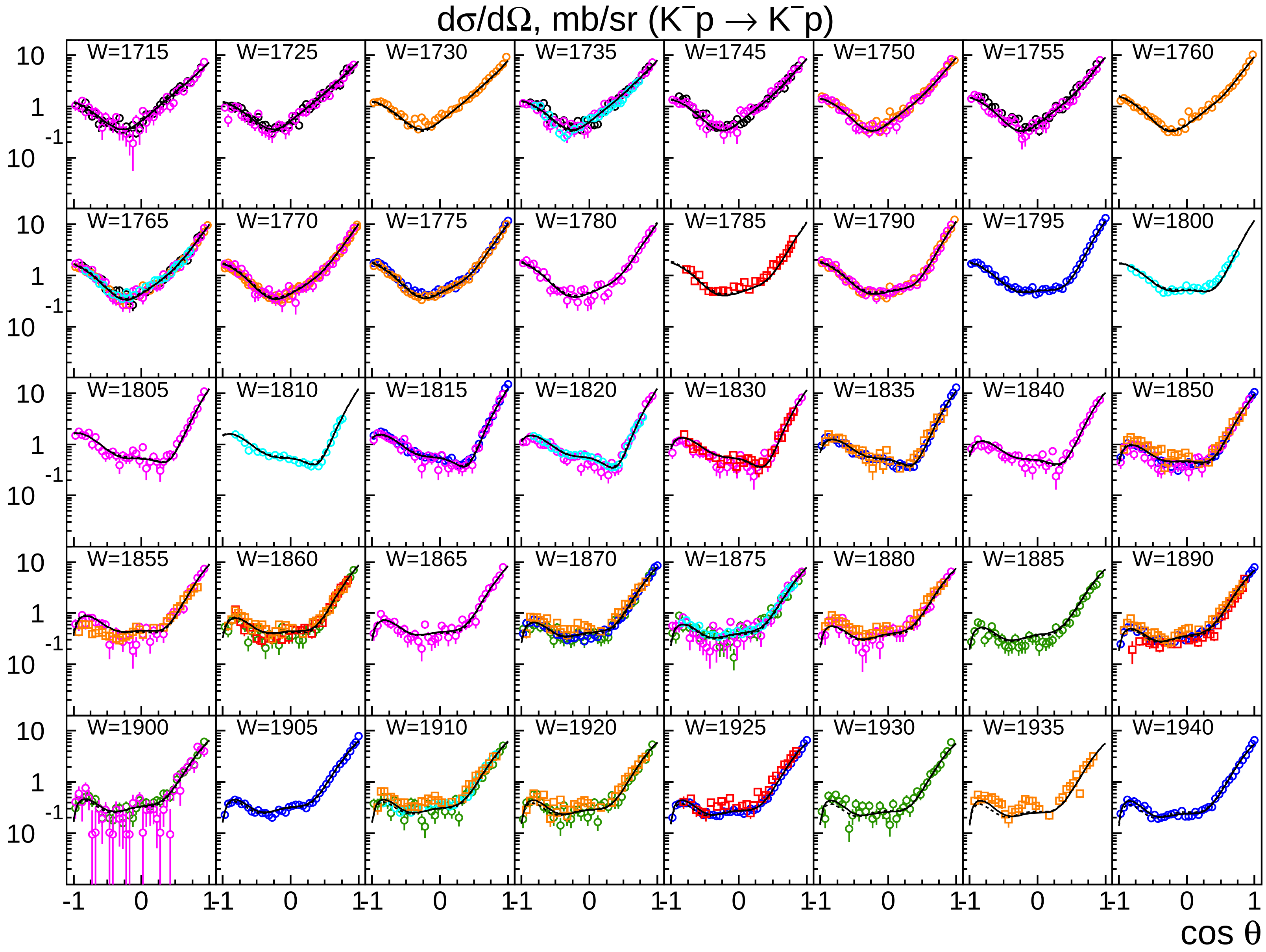
There is a hope to observe the baryon multiplets and therefore to confirm the states observed in the Nucleon and Delta sector.

Table 3: List of reactions used in the partial wave analysis.

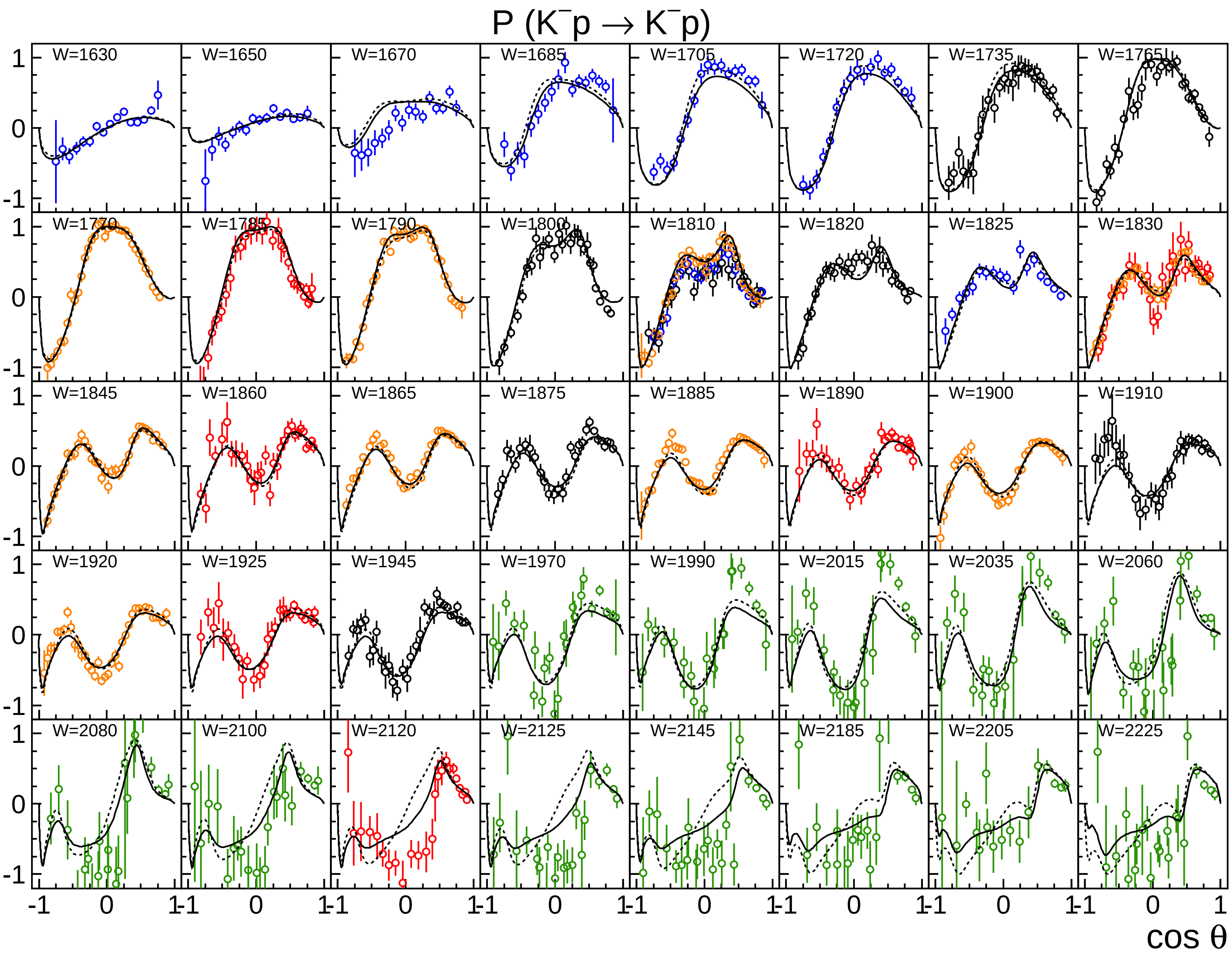
$K^- p \to K^0 n$	$K^- p \to K^- p$	$K^- p \to \omega\Lambda$
$K^- p \to \pi^0\Lambda$	$K^- p \to \eta\Lambda$	$K^- p \to \pi^+\Sigma^-$
$K^- p \to \pi^0\Sigma^0$	$K^- p \to \pi^-\Sigma^+$	$K^- p \to \pi^0\pi^0\Lambda$
$K^- p \to K^+\Xi^-$	$K^- p \to K^0\Xi^0$	$K^- p \to \pi^0\pi^0\Sigma^0$



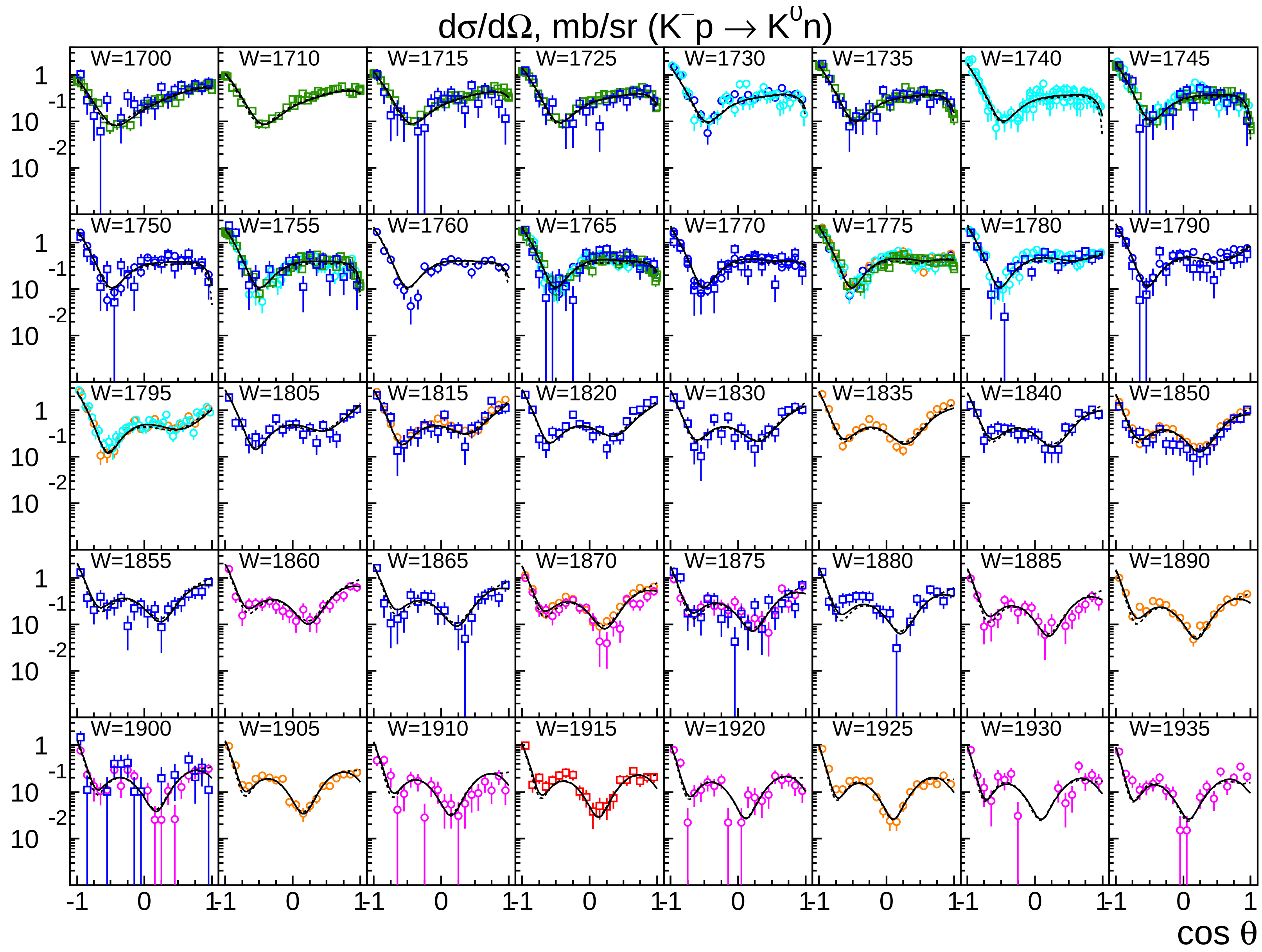
Mass scan of additional states
Δχ²/2
0
–500
-1000
1400
1600
1800
2000
2200
M (MeV)
Σ(1750) 1/2-
Σ(1670) 3/2-
Σ(1940) 3/2-
Σ(1775) 5/2-
Σ (1/2-)
Σ (3/2-)
Σ (5/2-)
Σ (7/2-)



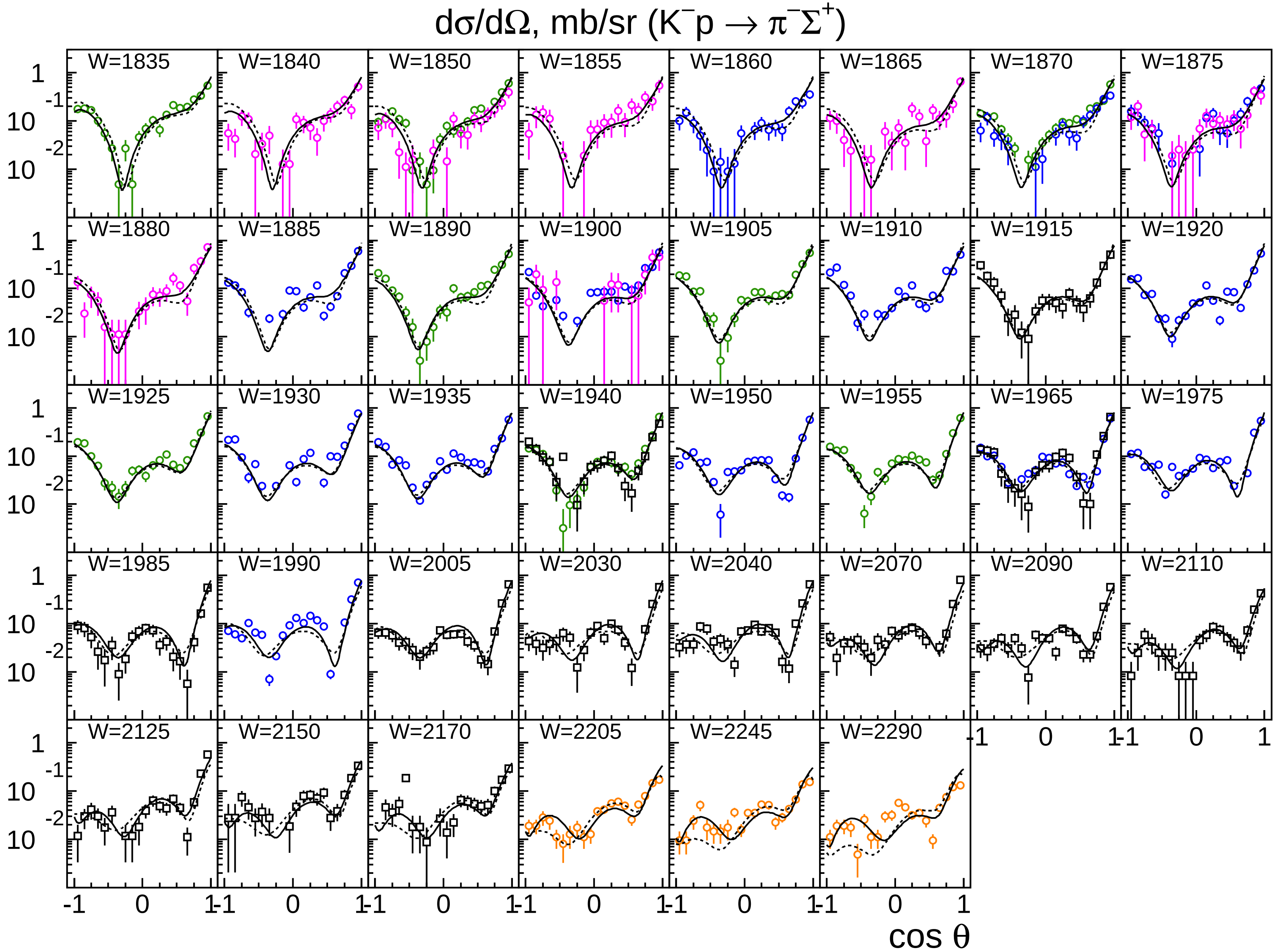
dσ/dΩ, mb/sr (K⁻p → K⁻p)
W=1715
W=1725
W=1730
W=1735
W=1745
W=1750
W=1755
W=1760
W=1765
W=1770
W=1775
W=1780
W=1785
W=1790
W=1795
W=1800
W=1805
W=1810
W=1815
W=1820
W=1830
W=1835
W=1840
W=1850
W=1855
W=1860
W=1865
W=1870
W=1875
W=1880
W=1885
W=1890
W=1900
W=1905
W=1910
W=1920
W=1925
W=1930
W=1935
W=1940
10
1
10^-1
-1
0
1
cos θ



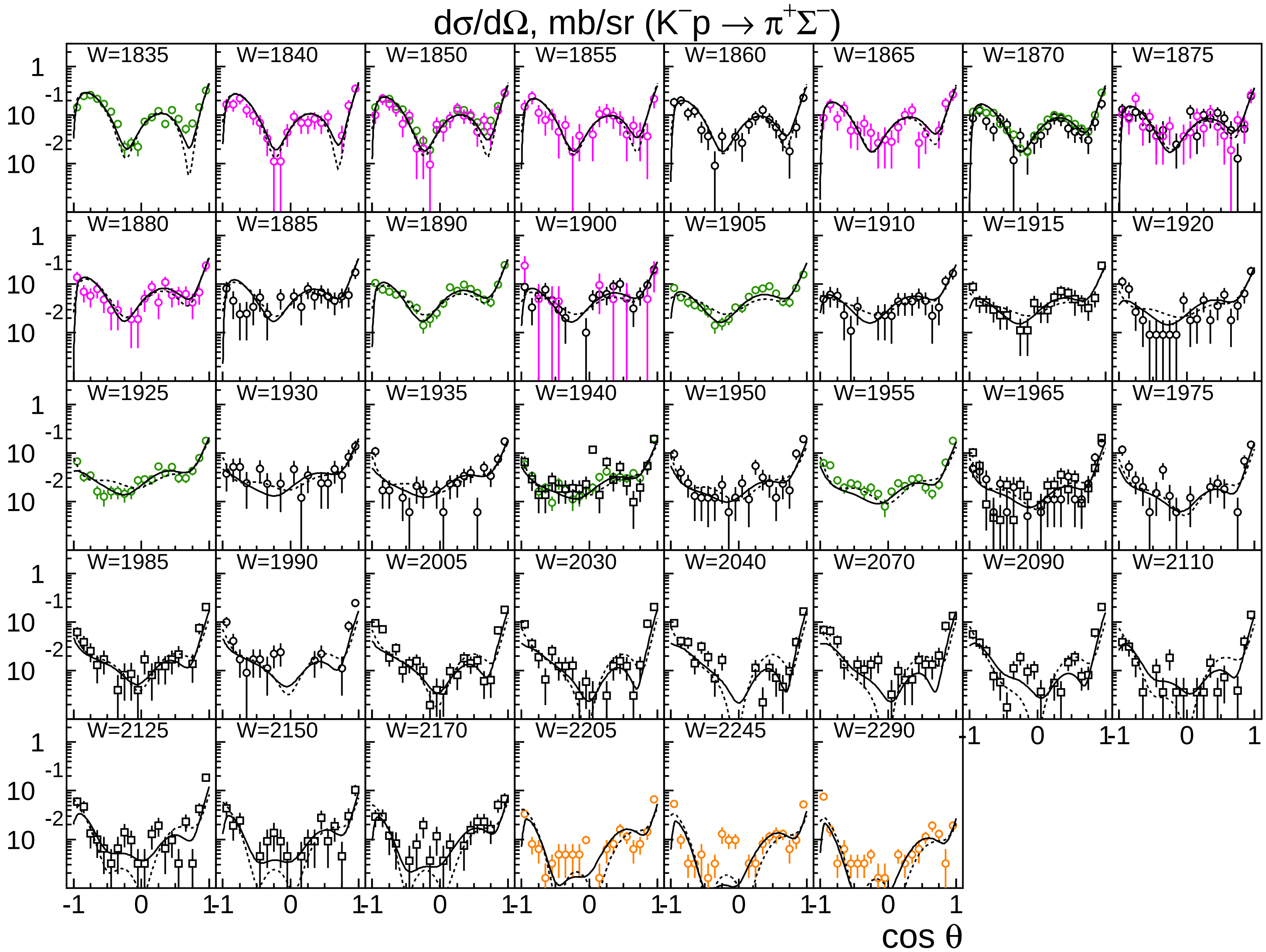
P (K⁻p → K⁻p)
W=1630
W=1650
W=1670
W=1685
W=1705
W=1720
W=1735
W=1765
W=1770
W=1785
W=1790
W=1800
W=1810
W=1820
W=1825
W=1830
W=1845
W=1860
W=1865
W=1875
W=1885
W=1890
W=1900
W=1910
W=1920
W=1925
W=1945
W=1970
W=1990
W=2015
W=2035
W=2060
W=2080
W=2100
W=2120
W=2125
W=2145
W=2185
W=2205
W=2225
cos θ



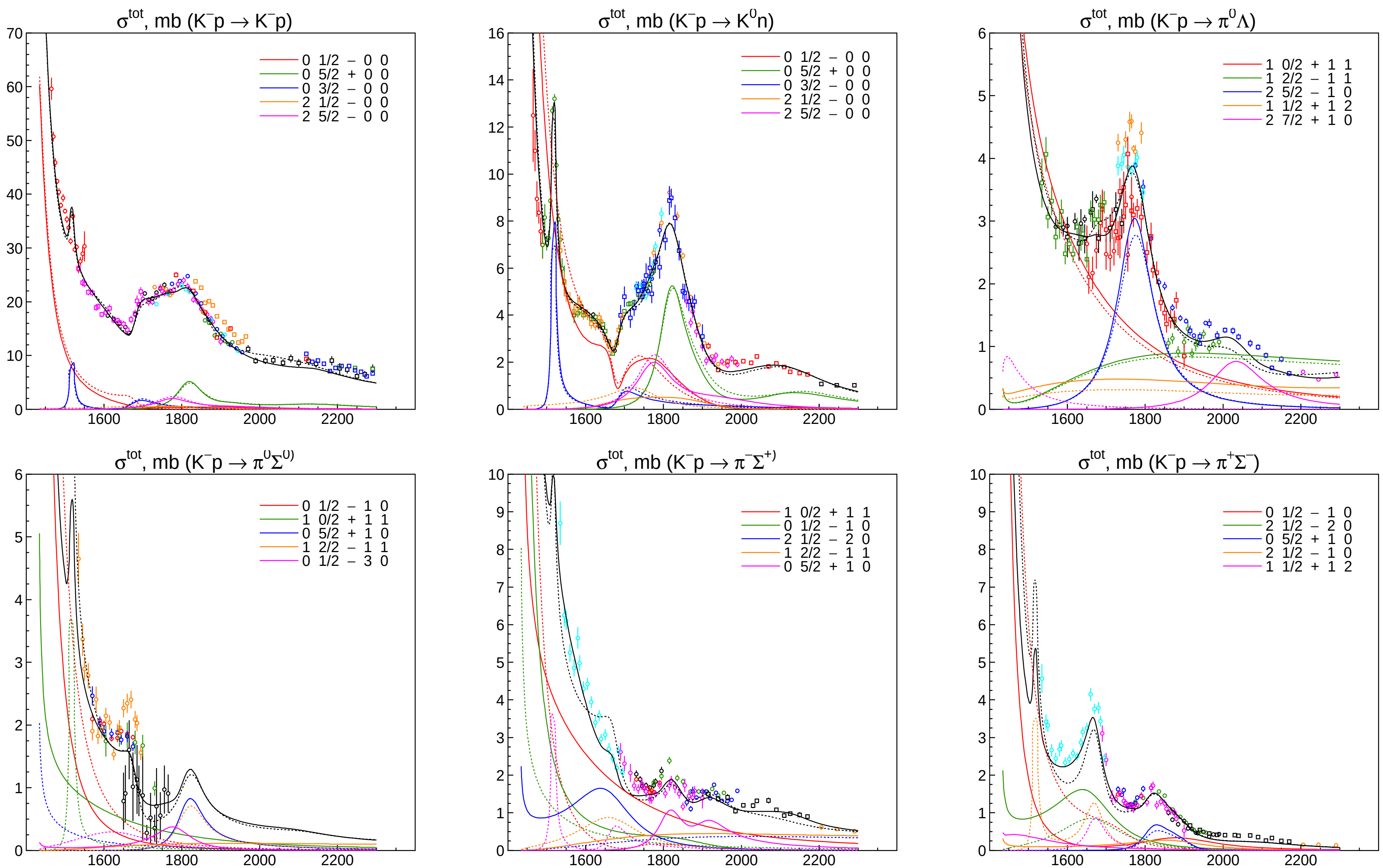
dσ/dΩ, mb/sr (K⁻p → K⁰n)
W=1700
W=1710
W=1715
W=1725
W=1730
W=1735
W=1740
W=1745
W=1750
W=1755
W=1760
W=1765
W=1770
W=1775
W=1780
W=1790
W=1795
W=1805
W=1815
W=1820
W=1830
W=1835
W=1840
W=1850
W=1855
W=1860
W=1865
W=1870
W=1875
W=1880
W=1885
W=1890
W=1900
W=1905
W=1910
W=1915
W=1920
W=1925
W=1930
W=1935
cos θ



dσ/dΩ, mb/sr (K⁻p → π⁻Σ⁺)
W=1835
W=1840
W=1850
W=1855
W=1860
W=1865
W=1870
W=1875
W=1880
W=1885
W=1890
W=1900
W=1905
W=1910
W=1915
W=1920
W=1925
W=1930
W=1935
W=1940
W=1950
W=1955
W=1965
W=1975
W=1985
W=1990
W=2005
W=2030
W=2040
W=2070
W=2090
W=2110
W=2125
W=2150
W=2170
W=2205
W=2245
W=2290
cos θ


dσ/dΩ, mb/sr (K⁻p → π⁺Σ⁻)
W=1835
W=1840
W=1850
W=1855
W=1860
W=1865
W=1870
W=1875
W=1880
W=1885
W=1890
W=1900
W=1905
W=1910
W=1915
W=1920
W=1925
W=1930
W=1935
W=1940
W=1950
W=1955
W=1965
W=1975
W=1985
W=1990
W=2005
W=2030
W=2040
W=2070
W=2090
W=2110
W=2125
W=2150
W=2170
W=2205
W=2245
W=2290
cos θ

Analysis of the Kp collision reactions (Preliminary) (M.Matveev)



		ANL-Osaca	Bn-Ga	Model A	Model B	Bn-Ga
$K^-p \to K^-p$	$d\sigma/d\Omega$	**3962**	**5170**	**3.07**	**2.98**	**1.80**
	P	**510**	**1180**	**2.04**	**2.08**	**1.41**
$K^-p \to \bar{K}^0 n$	$d\sigma/d\Omega$	**2950**	**3445**	**2.67**	**2.75**	**1.55**
$K^-p \to \pi^-\Sigma^+$	$d\sigma/d\Omega$	**1792**	**2455**	**3.37**	**3.49**	**1.45**
	P	**418**	**593**	**1.30**	**1.28**	**2.09**
$K^-p \to \pi^0\Sigma^0$	$d\sigma/d\Omega$	**580**	**691**	**3.68**	**3.50**	**1.96**
	P	**196**	**124**	**6.39**	**5.80**	**2.41**
$K^-p \to \pi^+\Sigma^-$	$d\sigma/d\Omega$	**1786**	**2082**	**2.56**	**2.18**	**1.59**
$K^-p \to \pi^0\Lambda$	$d\sigma/d\Omega$	**2178**	**2478**	**2.59**	**3.71**	**1.66**
	P	**693**	**892**	**1.41**	**1.73**	**1.25**
$K^-p \to \eta\Lambda$	$d\sigma/d\Omega$	**160**	**160**	**2.69**	**2.03**	**1.50**
$K^-p \to K^0\Xi^0$	$d\sigma/d\Omega$	**33**	**67**	**1.24**	**1.61**	**0.89**
$K^-p \to K^+\Xi^-$	$d\sigma/d\Omega$	**92**	**193**	**2.05**	**1.74**	**1.31**
$K^-p \to \Lambda\omega$	$d\sigma/d\Omega$	**–**	**300**	**—**	**—**	**1.03**
$K^-p \to \Lambda\omega$	$\rho_{00}, \rho_{10}, \rho_{1-1}$	**–**	**158**	**—**	**—**	**1.30**

Table 4: Σ-Hyperons Observed states

J^P		Known state	New state	Mass
$1/2^+$	$N(1440)$	$\Sigma(1660)$		
$3/2^+$	$\Delta(1230)$	$\Sigma(1385)$		
$5/2^+$	$N(1680), \Delta(1905)$	$\Sigma(1915)$	????	
$7/2^+$	$N(1990), \Delta(1950)$	$\Sigma(2030)$	????	
$3/2^-$	$N(1520)$	$\Sigma(1670)$		
$1/2^-$	$N(1535), \Delta(1620), N(1650)$	$\Sigma(1750)$	$\Sigma(1620)$	1680 ± 8
			$\Sigma(1900)$	1936 ± 10
$5/2^-$	$N(1675)$	$\Sigma(1775)$		
$3/2^-$	$N(1700), \Delta(1700)$	$\Sigma(1940)$	$\Sigma(1860)$	1856 ± 10
$1/2^-$	$N(1895)$		$\Sigma(2120)$	2158 ± 25

Let us consider the decay of the isospin 0 and isospin 1 states into K^-p and K^0n

$$
\begin{aligned}
|A(K^-p)|^2 &= \left(A_1\frac{1}{\sqrt{2}} + A_0\frac{1}{\sqrt{2}}\right)^2 = \frac{1}{2}\left(|A_1|^2 + |A_0|^2 + 2Re(A_1A_0^*)\right) \\
|A(K^0n)|^2 &= \left(A_1\frac{1}{\sqrt{2}} - A_0\frac{1}{\sqrt{2}}\right)^2 = \frac{1}{2}\left(|A_1|^2 + |A_0|^2 - 2Re(A_1A_0^*)\right)
\end{aligned}
$$

$$
A_{KN} = \omega^*\left[G(s,t) + H(s,t)i(\vec{\sigma}\vec{n})\right]\omega' \qquad \vec{n}_j = \varepsilon_{\mu\nu j}\frac{q_\mu k_\nu}{|\vec{k}||\vec{q}|} \, .
$$

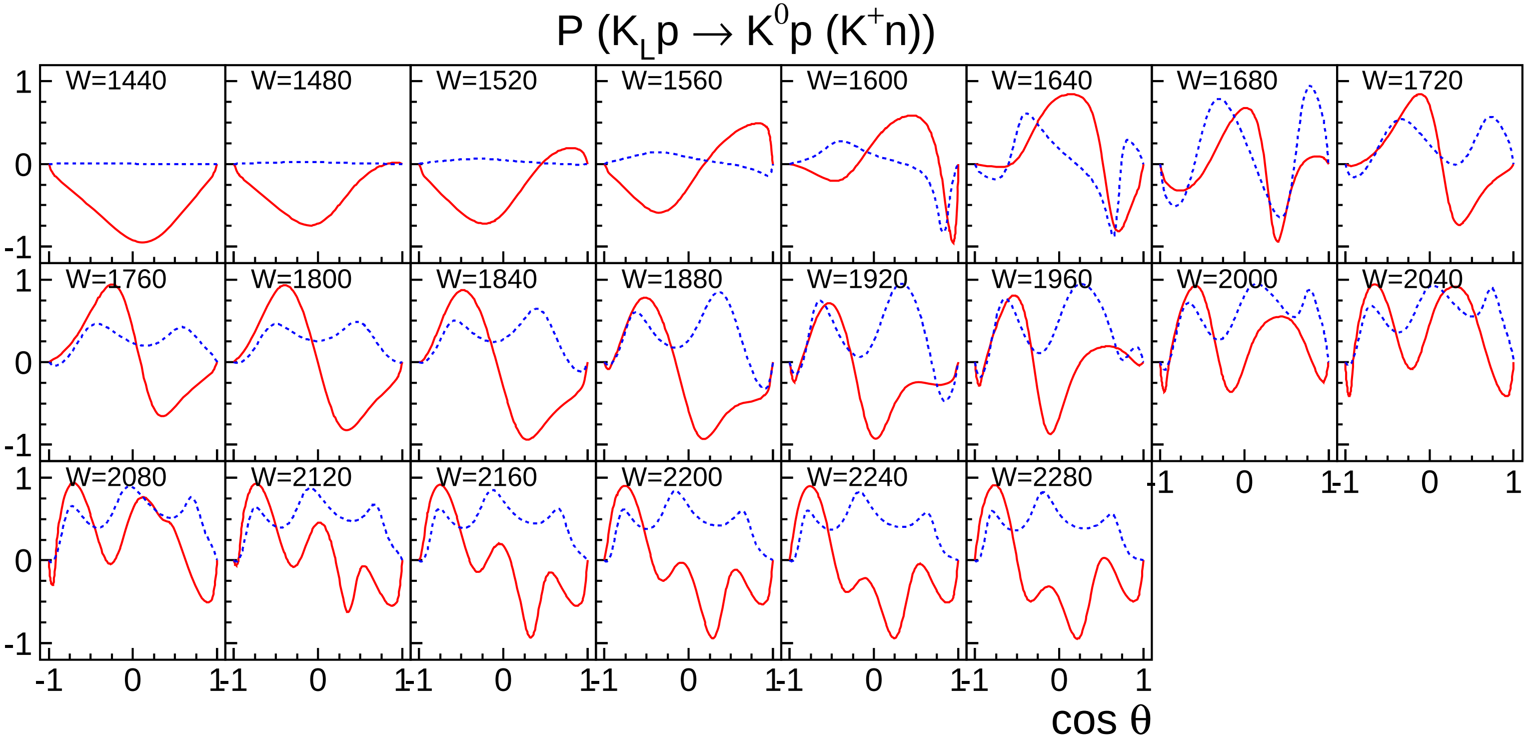
Differential cross section in c.m.s. of the reaction

$$
|A|^2 = \frac{1}{2}\mathrm{Tr}\left[A^*_{\pi N}A_{\pi N}\right] = |G(s,t)|^2 + |H(s,t)|^2(1-z^2)
$$

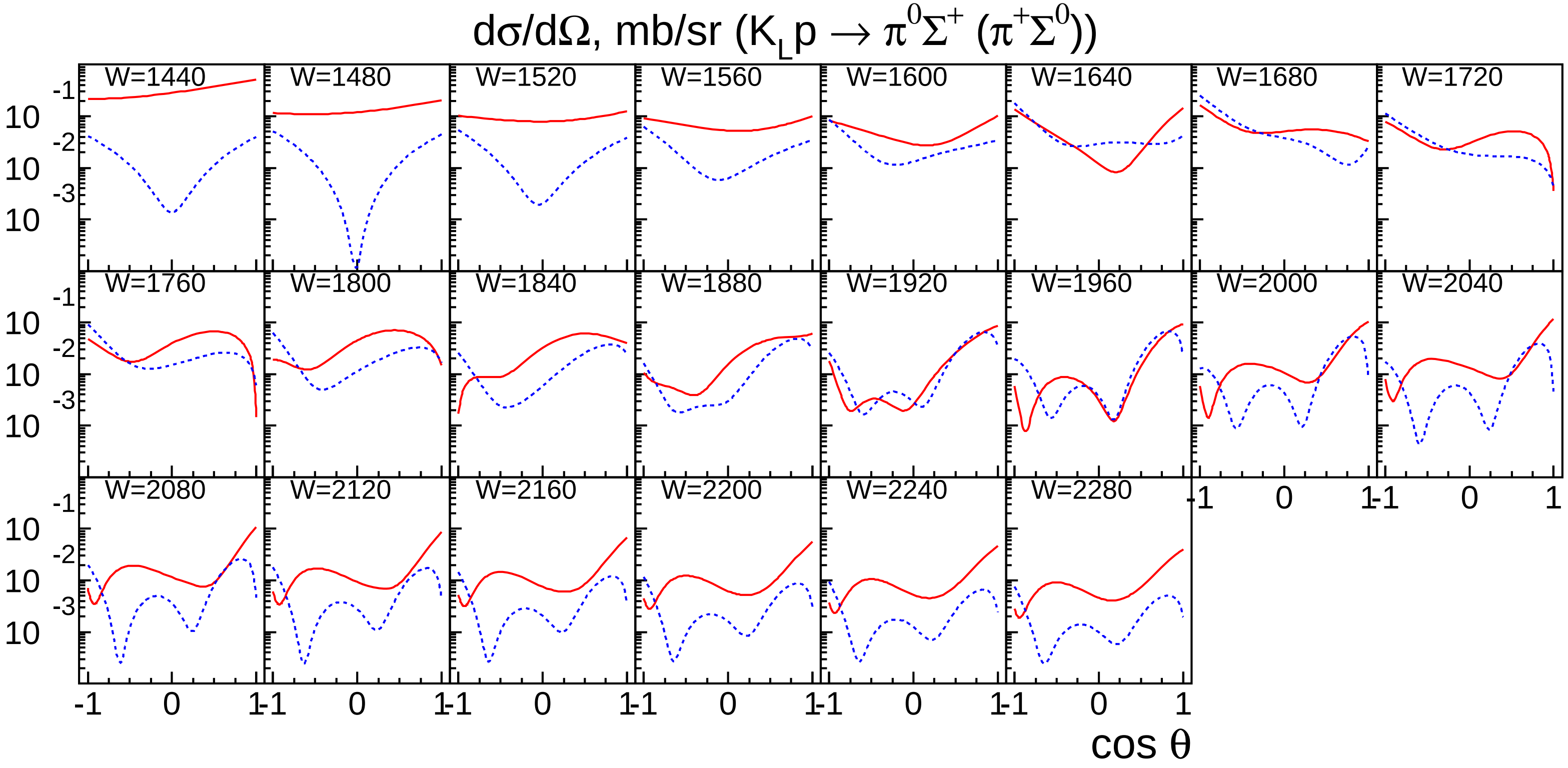
the recoil asymmetry:

$$
P = \frac{\mathrm{Tr}\left[A^*_{\pi N}\sigma_2 A_{\pi N}\right]}{2|A|^2\cos\phi} = \sin\Theta\frac{2Im\left(H^*(s,t)G(s,t)\right)}{|A|^2} \, .
$$

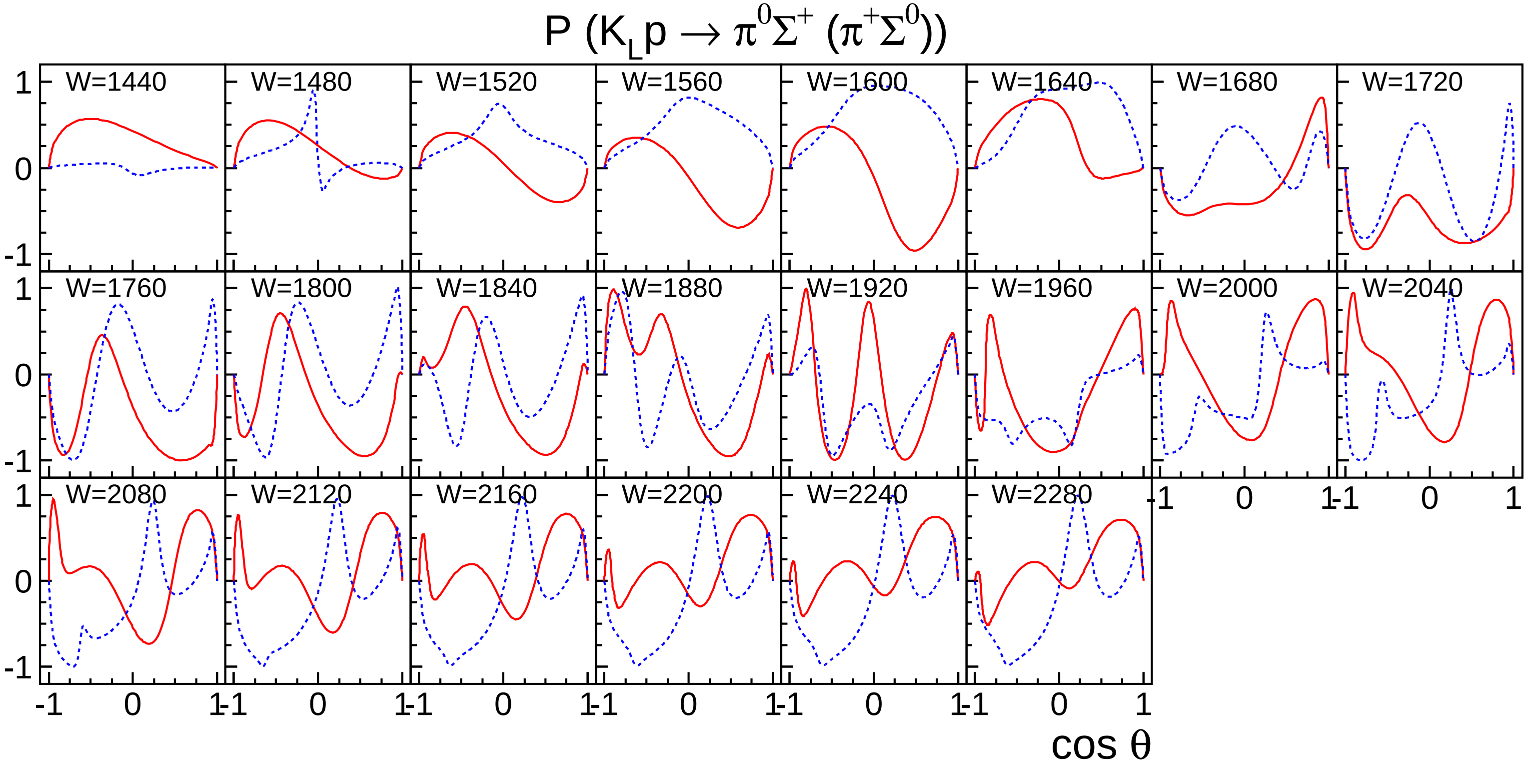
Prediction for the recoil asymmetry $K_L p \to K^0 p (K^+ n)$



Prediction for $\frac{d\sigma}{d\Omega}(K_L p \to \pi^0\Sigma^+(\pi^+\Sigma^0))$



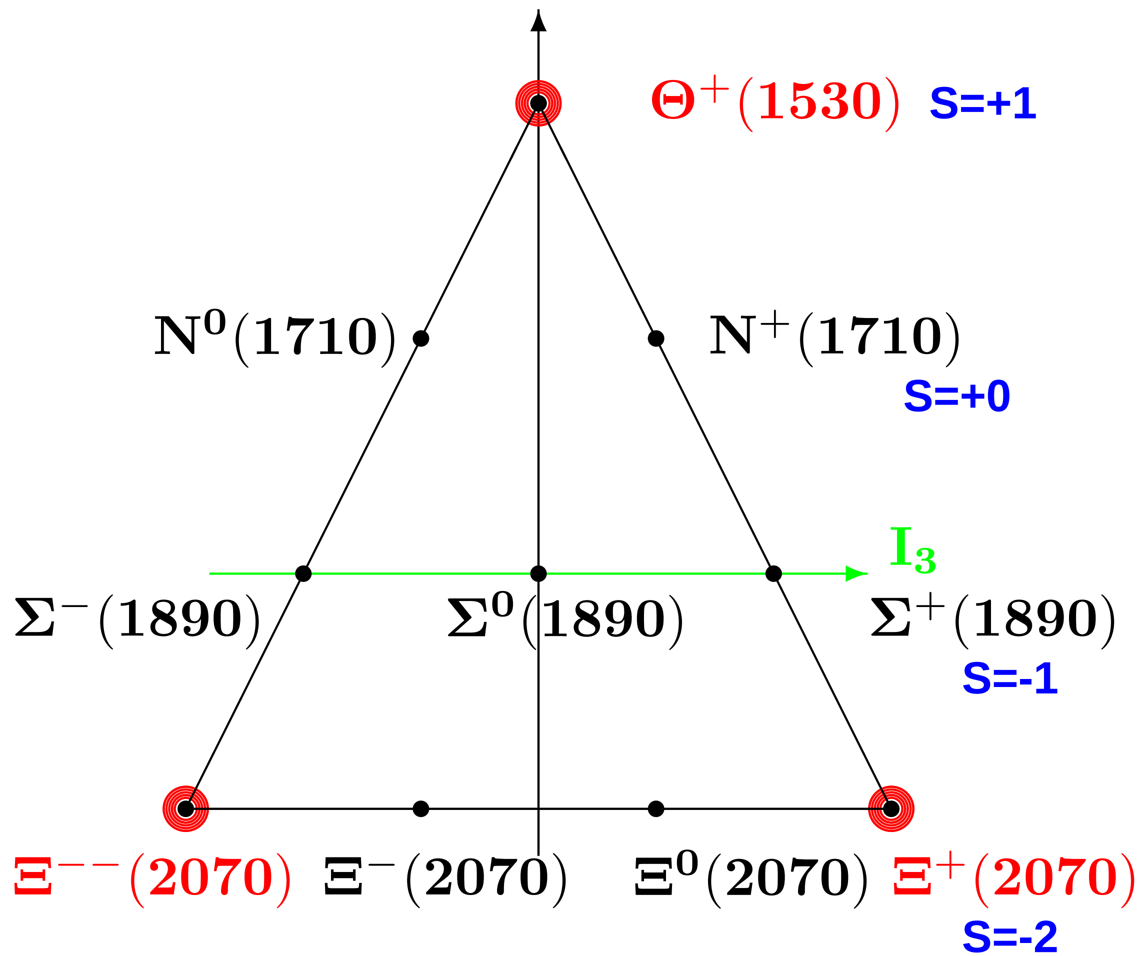
Prediction for the recoil asymmetry $K_L p \to \pi^0\Sigma^+(\pi^+\Sigma^0)$



The chiral soliton model (Дьяконов, Петров, Поляков) predicts the existence of an antidecuplet:

1	$\mathrm{uud}\mathrm{d}\bar{\mathrm{s}}$
4/3	$\mathrm{uud}(1/\sqrt{3}\mathrm{d}\bar{\mathrm{d}} + \sqrt{2/3}\mathrm{s}\bar{\mathrm{s}})$
5/3	$\mathrm{uus}(1\sqrt{3}\mathrm{s}\bar{\mathrm{s}} + \sqrt{2/3}\mathrm{d}\bar{\mathrm{d}})$
2	$\mathrm{uuss}\bar{\mathrm{d}}$

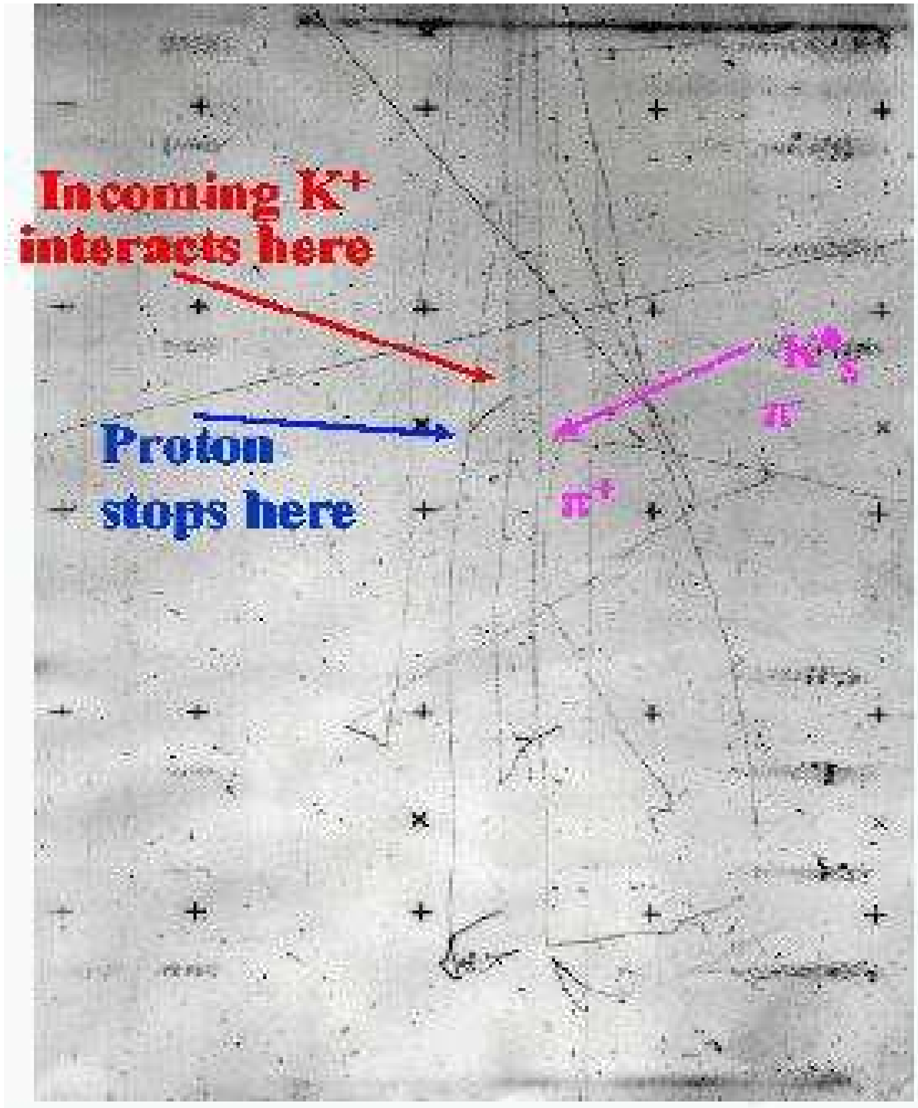
Antidecuplet



DIANA/ITEP:

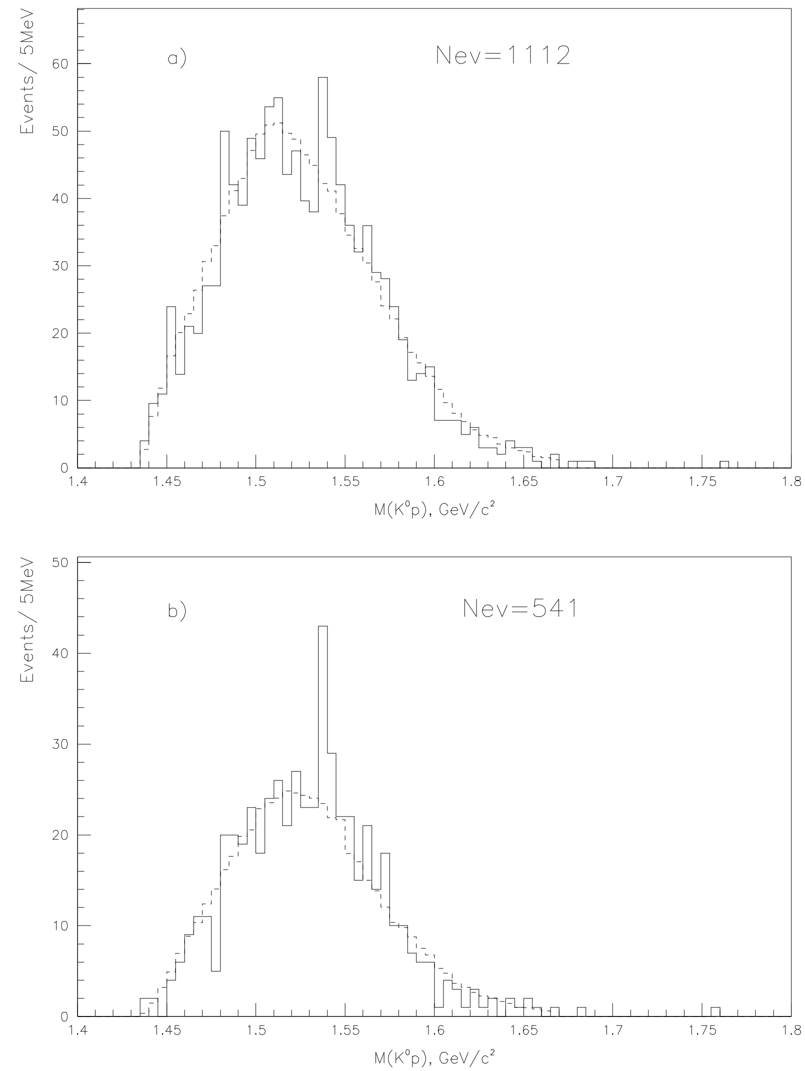
Charge exchange expt.

- $K^+ n \rightarrow \mathbf{\Theta^+(1540)} \rightarrow pK^0_s$
- **’quasifree’ in Xe bubble chamber**
- $K^+ Xe \rightarrow Xe' pK^0_s$
- K^+ **momentum from range in Xe**



- **Stereo photos taken and evaluated**
- **secondary vertex $K^0_s \to \pi^+\pi^-$**
- **and a proton track**
- **Particle ID and momentum from track (density and range)**
- **41,000 K^+ tracked**
- **73 seen Θ^+ 300 produced ('two-body' cut, nK^+)**

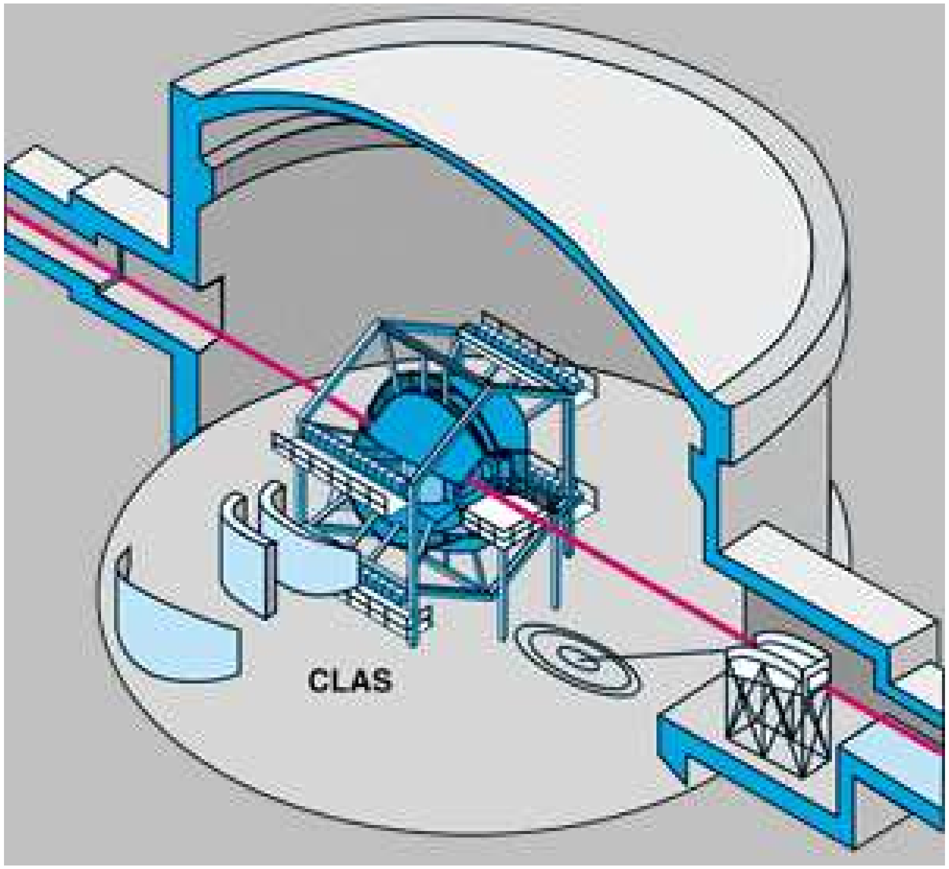
The width of the Θ^+ is < 9 MeV



pK^0_s invariant mass for all protons (top) and loose 'two-body' cut

CLAS/Jlab:

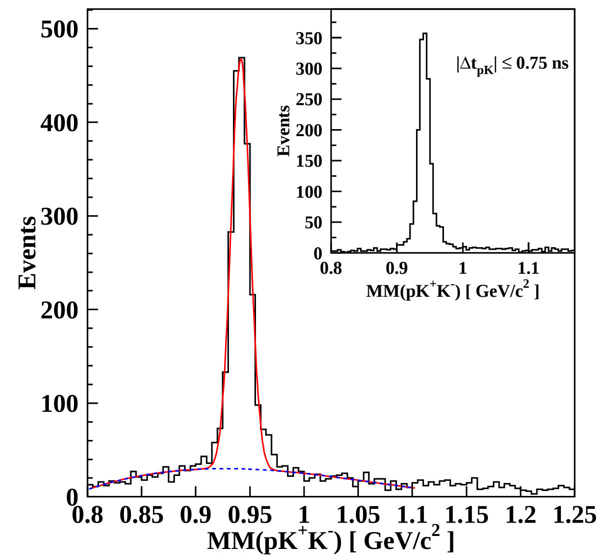
- **Torus magnet with 6 superconducting coils**
- **Liquid H_2/D_2 target, trigger counters**
- **Drift chambers with 35,000 cells**
- **TOF system**
- **Electromagnetic Pb/sci sandwich calorimeter**
- **Gas Cerenkov counters, e/π separation**

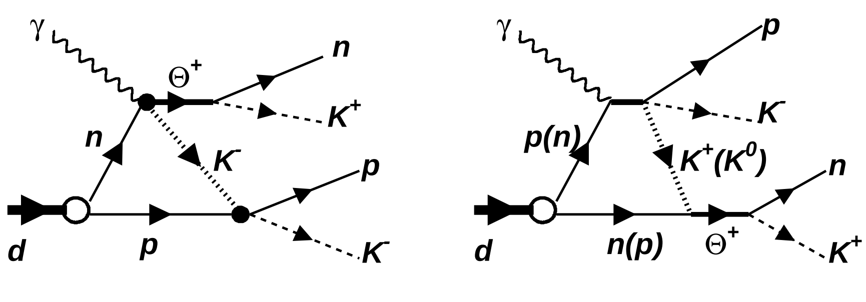


Study of the reaction

$$\gamma d \rightarrow pnK^+K^-$$

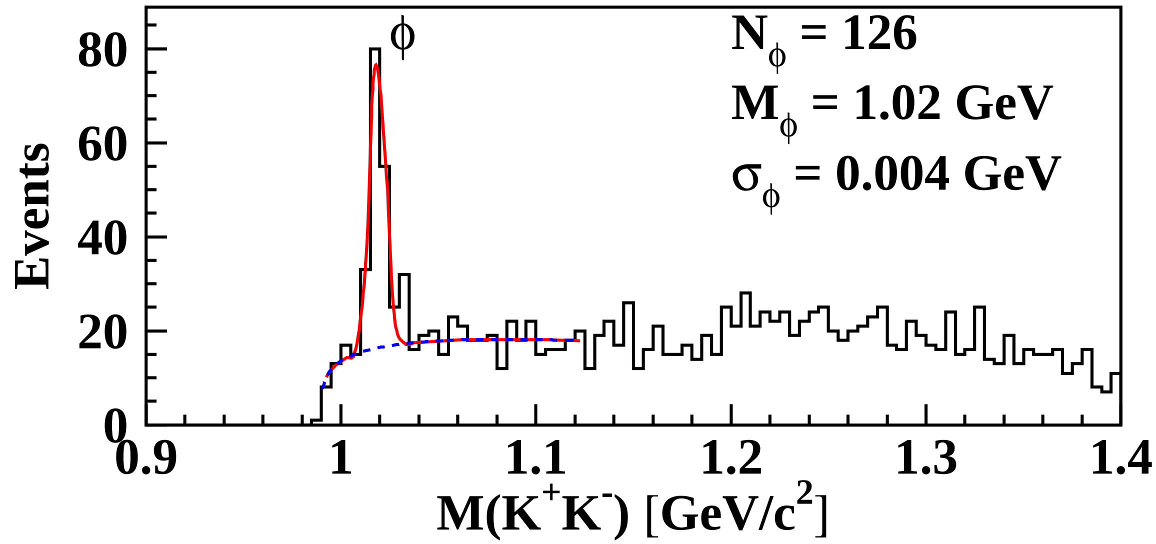
1. **Detected:** K^+, K^-, p, **hence "no spectator" nucleon**
2. **TOF for particle identification**
3. **Missing mass calculated and neutron reconstructed**
4. **Proposed reaction mechanisms:**



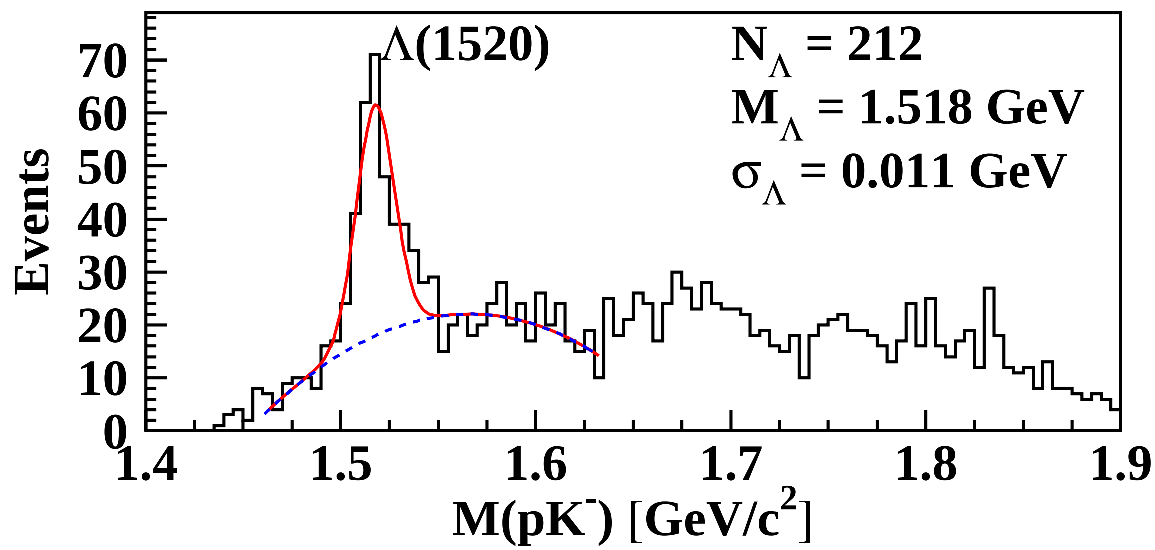


a) b)

The K^+K^- invariant mass

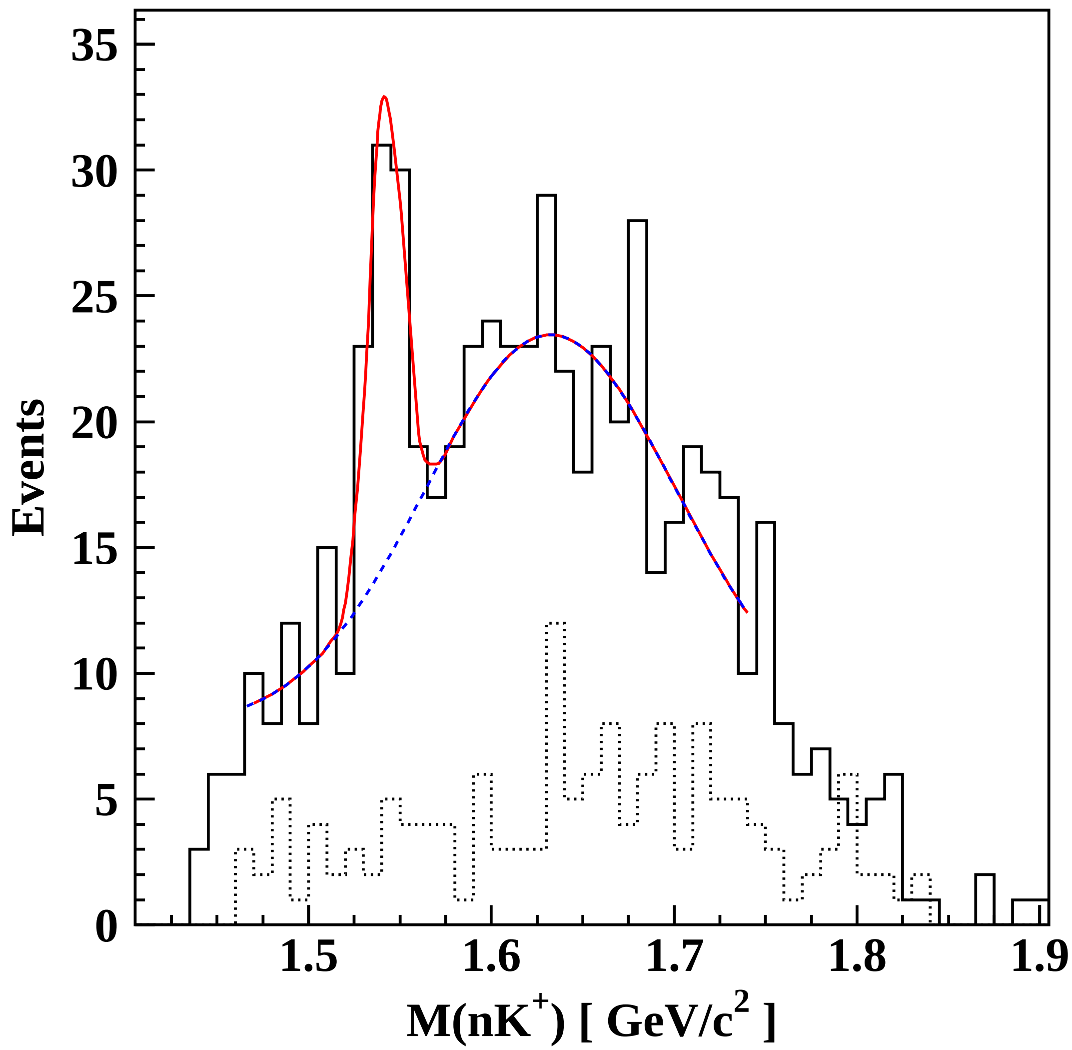


The pK^- invariant mass



The nK^+ invariant mass

$\mathbf{M_{\Theta^+}}$	=	1542$\pm$ 5 MeV
$\mathbf{\Gamma_{\Theta^+}}$	$\leq$	21 MeV
Decay:		$\mathbf{nK^+}$
Yield:		212 $\mathbf{\Lambda(1520)}$,
		43 $\mathbf{\Theta^+}$

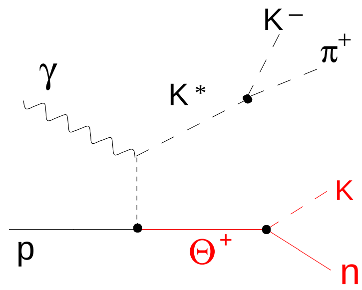


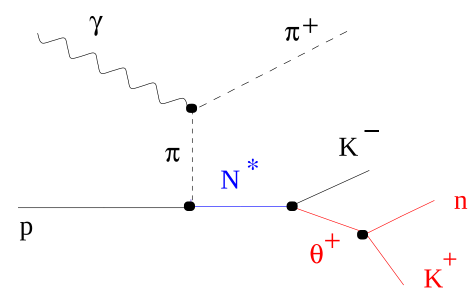
Study of the reaction

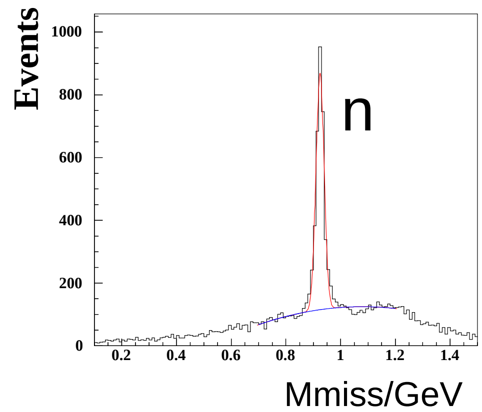
$$\gamma p \rightarrow nK^+K^-\pi^+$$

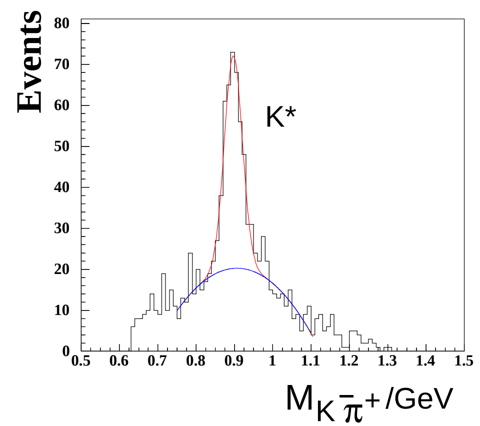
1. **Detected:** K^+, K^-, π^+
2. **TOF for particle identification**
3. **Missing neutron reconstructed from kinematics**

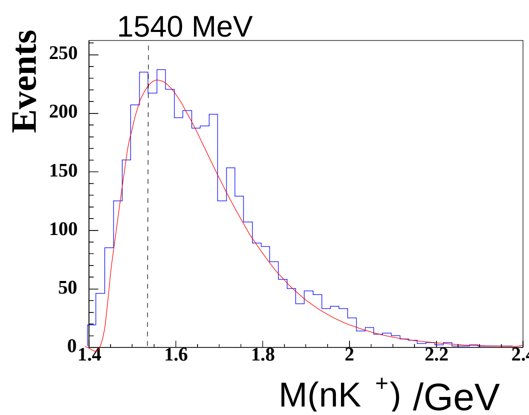
possible reaction mechanisms:





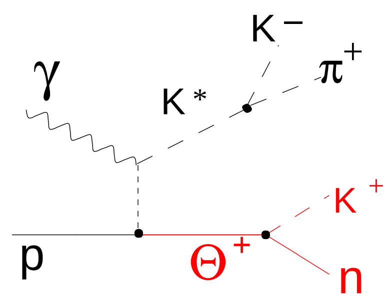


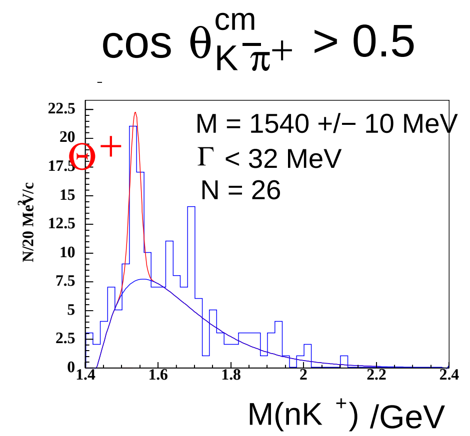




no signal without further cuts !

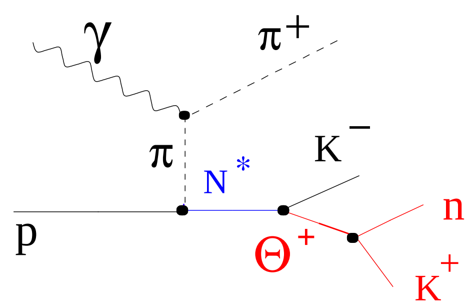
$\Theta^+(1540)$ seen after cut in angle $\Rightarrow$ 26 Θ^+

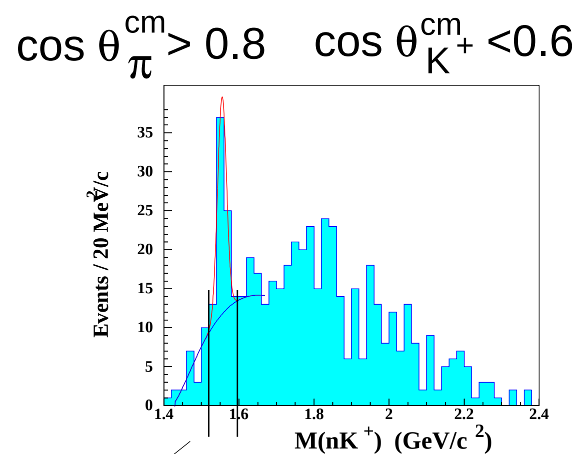




Does the $\Theta^+(1540)$ come from a N$^*(2400)$?

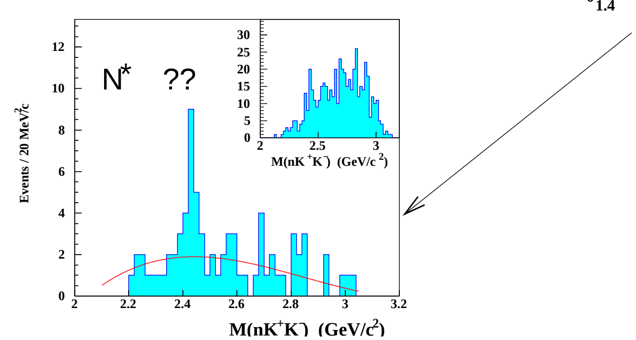
42 Θ^+



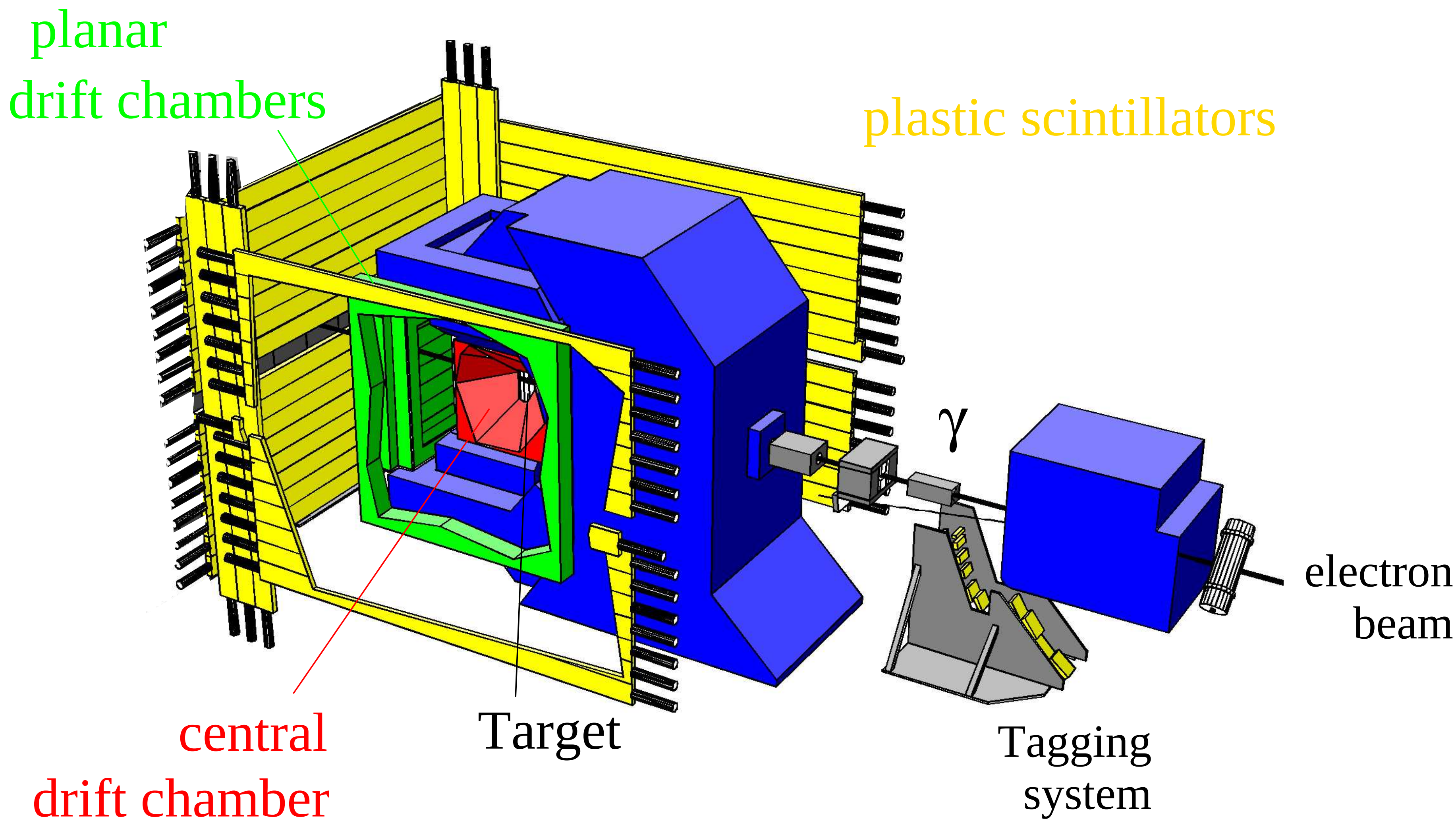


M =1555 +/− 20 MeV

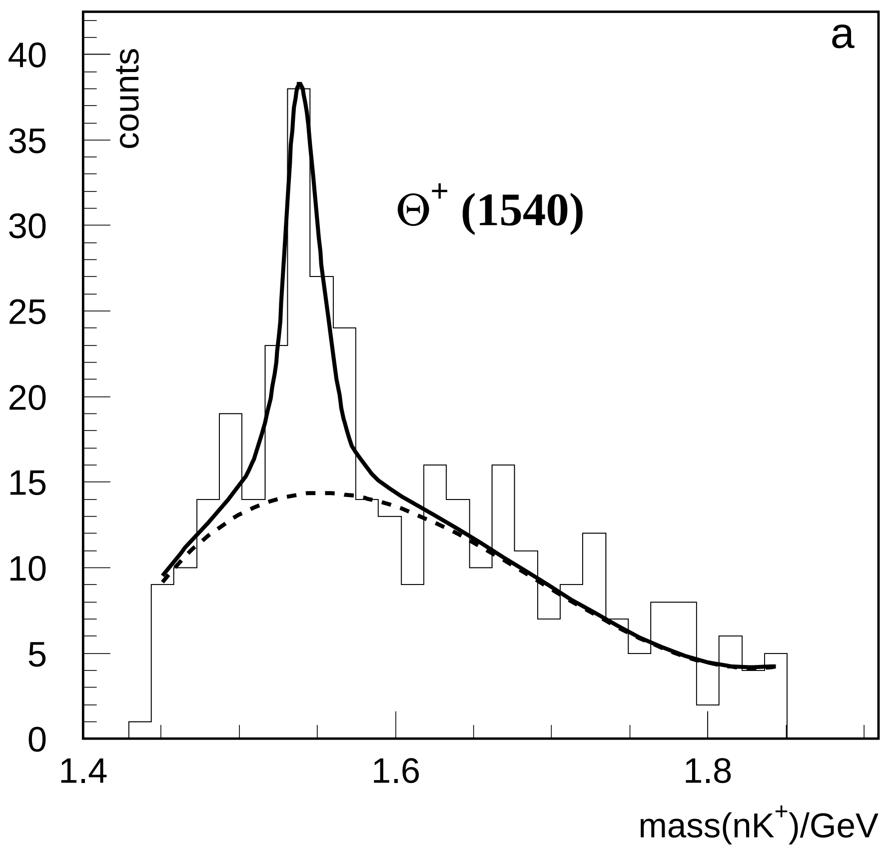
Γ < 26 MeV

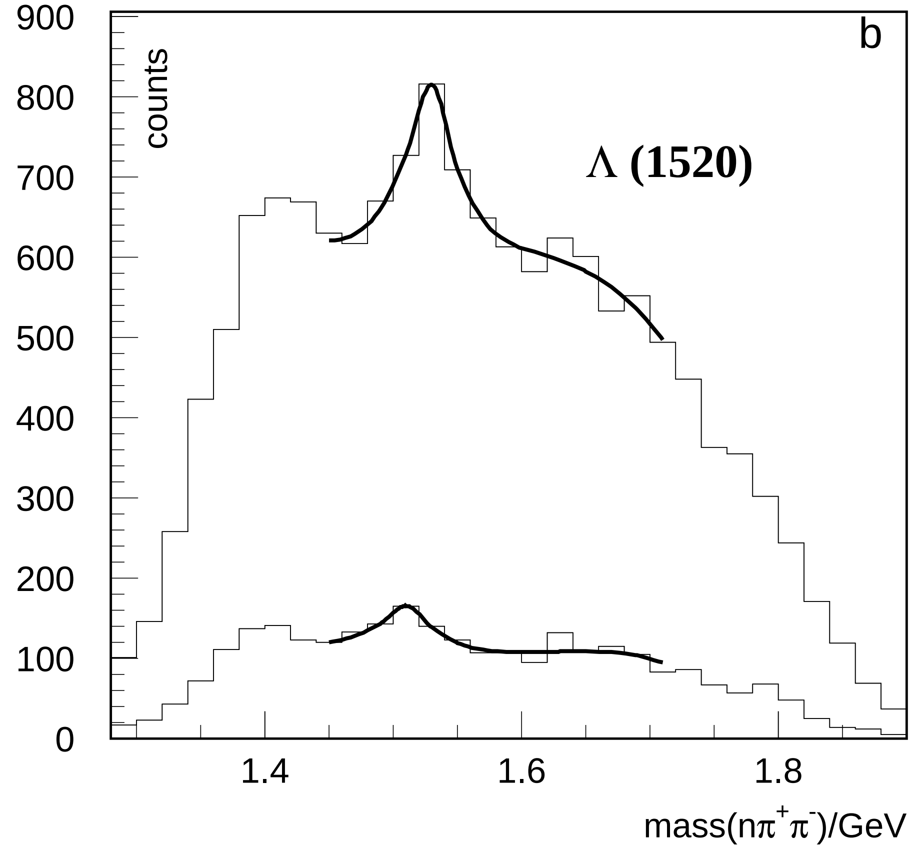


SAPHIR/ELSA:


planar
drift chambers
plastic scintillators
γ
electron
beam
central
drift chamber
Target
Tagging
system

γ p -> n K+Ks





$\mathbf{nK^+}$ **mass with** $\pi^+\pi^- = \mathbf{K^0_s}$

$\mathbf{nK^0_s}$ **mass with** $\pi^+\pi^- = \mathbf{K^0_s}$

Left: $\cos\vartheta_{K^0_s} > \mathbf{0.5}$

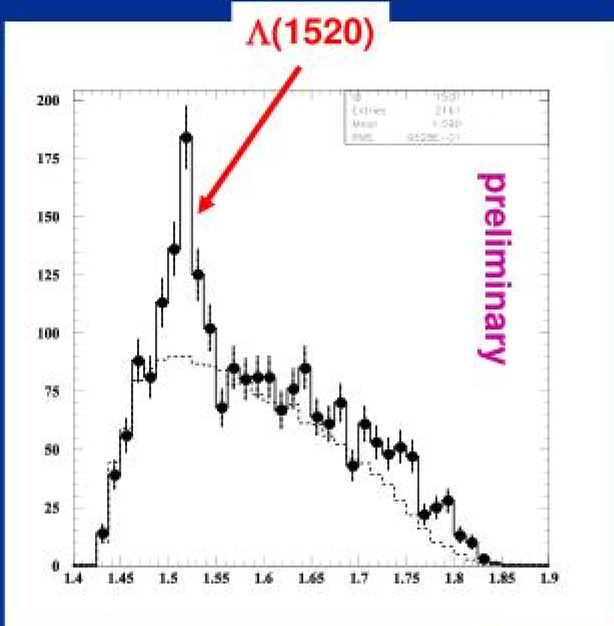
Right: with/without $\cos\vartheta_{K^0_s} > \mathbf{0.5}$

Old and New Signal from LEPS/SPring8

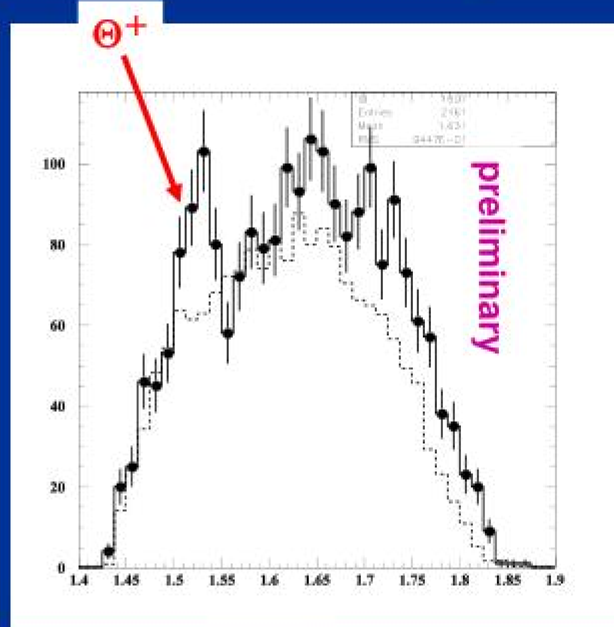
N. Muramatsu

$\gamma D \rightarrow K^{-}X$

- Mix K^{+}, K^{-}, γ from different events in LH_2 data.
- $\Lambda(1520)$ contribution was removed from the sample.



$MM^{C}(\gamma, K^{+})$ GeV/c^2



$MM^{C}(\gamma, K^{-})$ GeV/c^2

Θ^+: Comparison of different results

experiment	reaction	decay channel	mass (MeV)	statistical significance
Spring-8	$\gamma n \rightarrow K^-\Theta^+$	K^+n	1540 ± 10	5σ
DIANA	$K^+n \rightarrow K^-\Theta^+$	$K^0_S p$	1539 ± 2	4σ
SAPHIR	$\gamma p \rightarrow \overline{K^0_S}\Theta^+$	K^+n	1540 ± 6	5σ
CLAS	$\gamma n \rightarrow K^- p\Theta^+$	K^+n	1542 ± 5	5σ
CLAS	$\gamma p \rightarrow K^-\pi^+\Theta^+$	K^+n	1555 ± 10	8σ
CLAS	$\gamma p \rightarrow \overline{K^0_S}\Theta^+$	K^+n	1571 ± 10	
BC	$\nu A \rightarrow \Theta^+$ **X**	$K^0_S p$	1533 ± 5	7σ
HERMES	$ed \rightarrow \Theta^+$ **X**	$K^0_S p$	1526 ± 5	6σ

width determination limited by experimental resolution $\Gamma < 20 MeV$

The most worrying results from kaon (meson) beams

Total cross section:

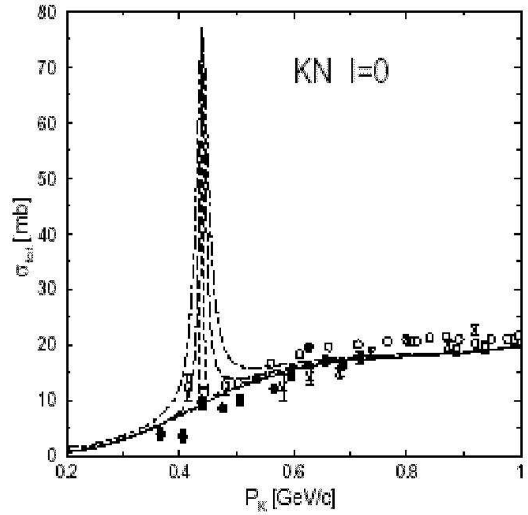
$$\sigma = \frac{4\pi}{k^2}\frac{(2J+1)0.389}{(2S_1+1)(2S_2+1)}B_{in}B_{out}$$

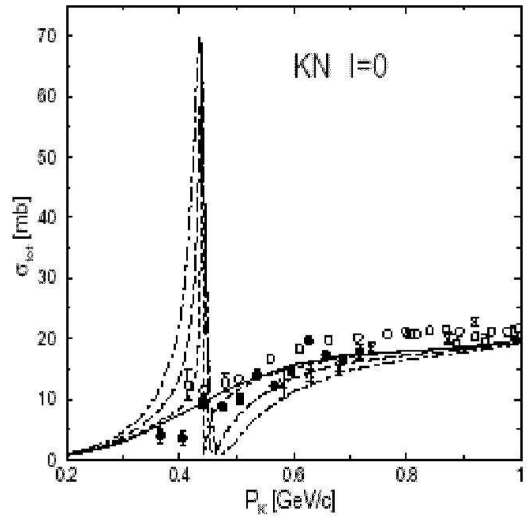
$$k^2 = \frac{(M^2-(m_p+m_K)^2)(M^2-(m_p-m_k)^2)}{4M^2}$$

$M = 1540$ **MeV** $\quad k^2 = 0.073$ **MeV**^{2}

If e.g. $B_{in} = B_{out} = 1$

$$\sigma = 70\ mb$$



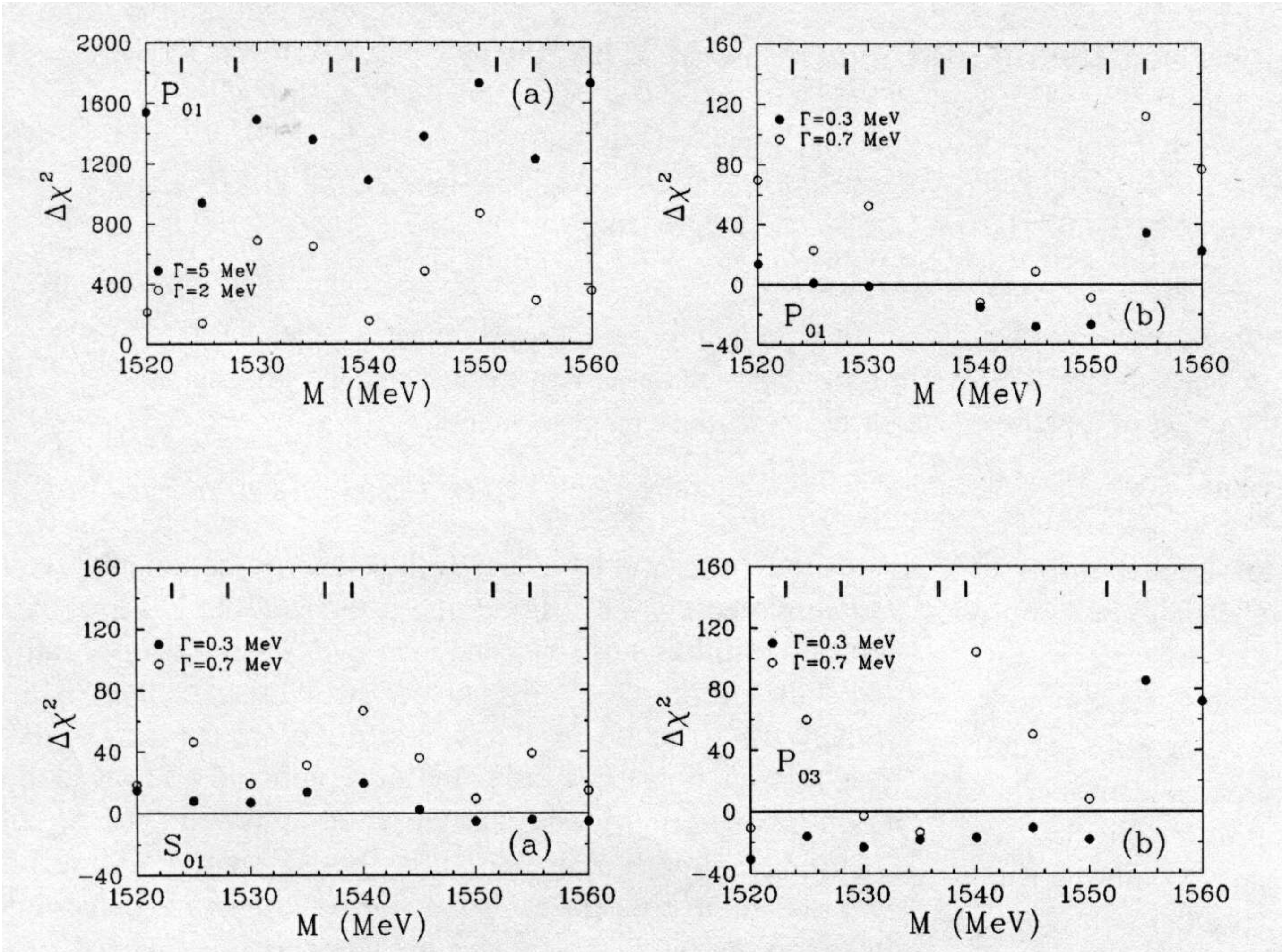


Study of K^+-nucleon scattering

R.A. Arndt, I.I. Strakovsky and R.L. Workman

Restrictions on width of Θ^+:

$\Gamma < 2\,MeV$



Combined analysis of Θ^+ production in Kaon induced experiments

J. Haidenbauer, S. Krewald, A. Sibirtsev, Ulf-G. Meissner

Reactions:

$$K^+ d \to K^0 + p + p$$

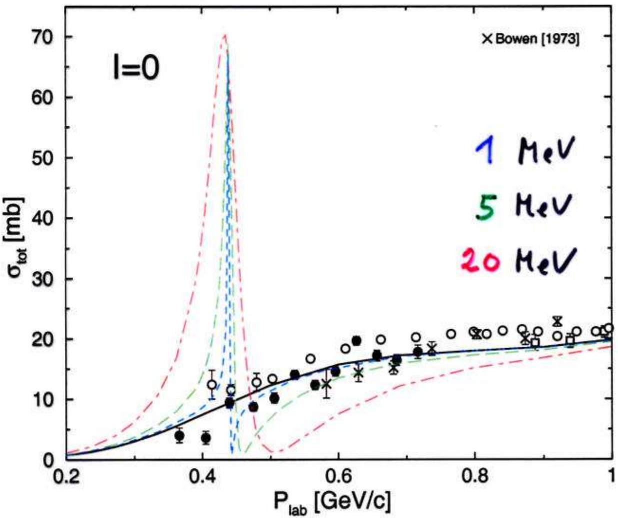
$$K^+ d \to K^+ + n + p$$

$$K^+ d \to K^+ d$$

$K_L\, p$**– scattering**

$\Gamma < 1$ **MeV** **even** $\Gamma < 0.8$ **MeV**

P_lab [GeV/c]



$$\sigma \propto \frac{1}{k^2} \sum_{\ell} \sin^2 \delta_{\ell}(k)$$

HyperCP from Fermilab

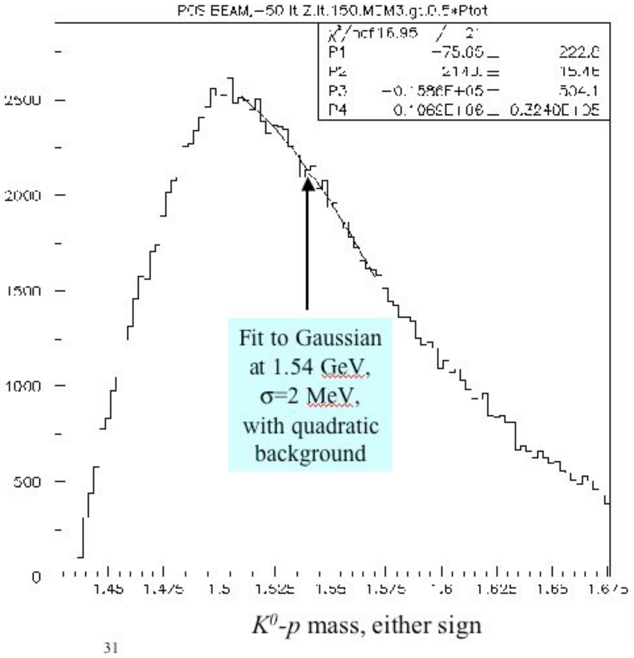
M. Longo

FNAL E871/HyperCP Experiment

- Designed for studying CP violation in the hyperon decay sequence, $\Xi \rightarrow \Lambda\pi$, $\Lambda \rightarrow p\pi$.
- Hyperon channel, fast chambers, simple trigger, high resolution spectrometer, fast DAQ
- Took data in 1997 and 1999
- Mixed beam with protons, pions, kaons, hyperons, with a broad momentum spread, ~120-250 GeV/c.

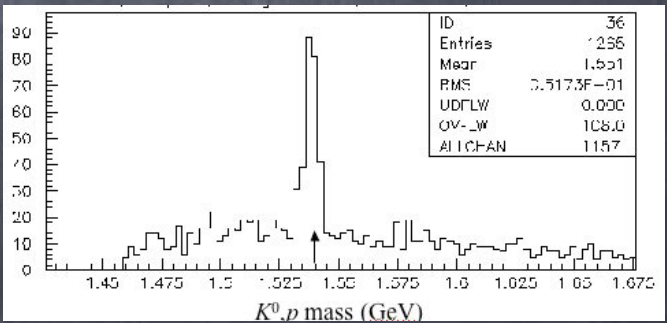
Data Summary

- 30,000 Exabyte tapes.
- Total data comprise ~120 terabytes, a volume of data greater than that in the Library of Congress.
- ~230 x 10^9 events on tape
- ~2.5 x 10^9 Ξ^- and $\overline{\Xi}^+$decays.
- 0.5 x 10^9 K decays
- 19 x 10^6 Ω^- and $\overline{\Omega}^+$ decays.
- Beam polarity changed by reversing magnets.
- ~50% of triggers came from titanium and kapton thin windows upstream of decay region, or from nearby material.

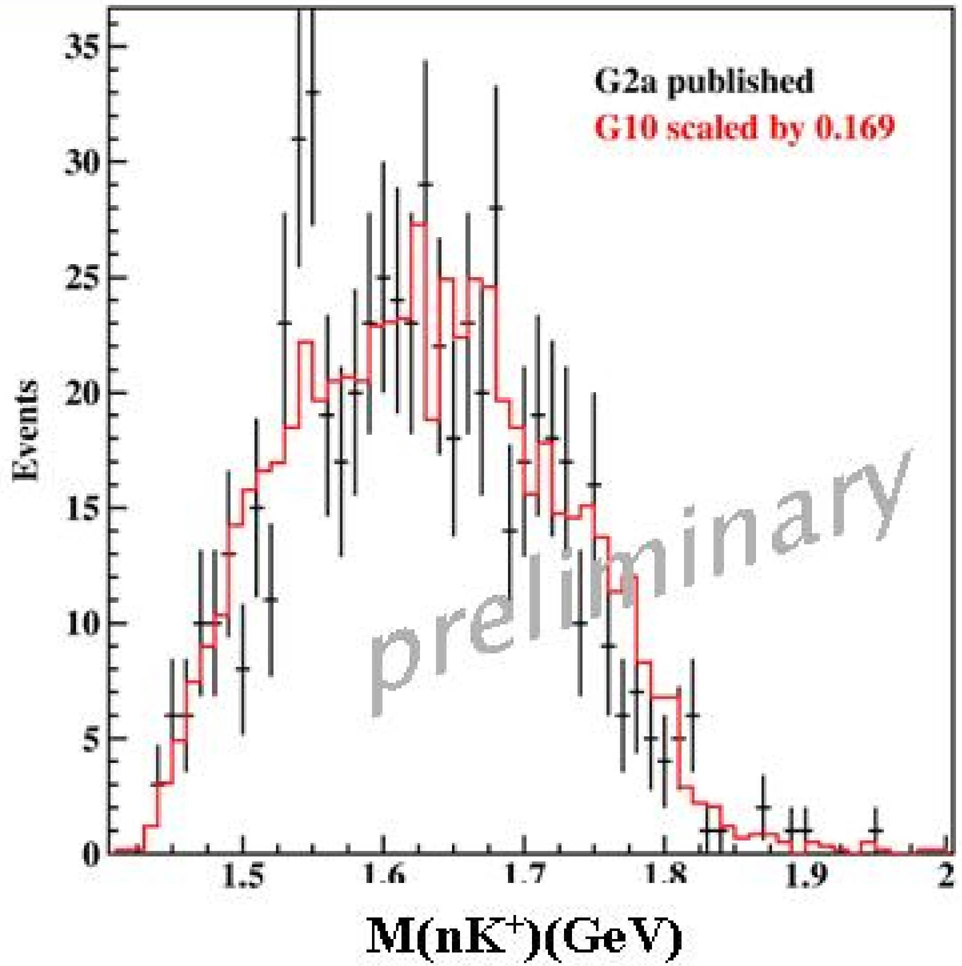


90% CL limit ~370 events out of 150000 K^0-p candidates. P1 is the amplitude of the gaussian.
Bins are 2 MeV

Ghost tracks with can produce a peak at 1.54 GeV



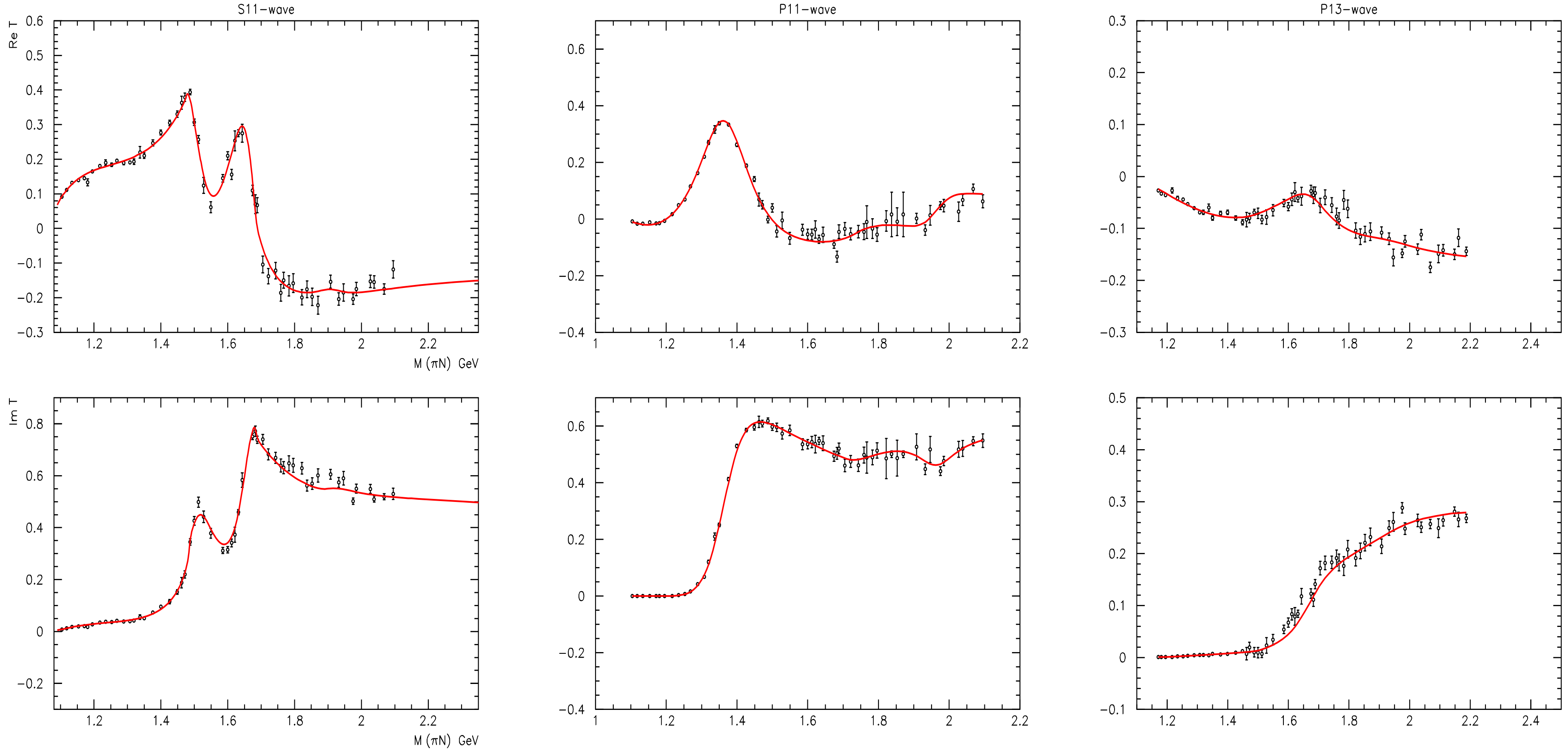
High Statistics CLAS(d) result



- ***Model-independent uppper limit 95% CL for Θ^+ is < 20nb.***
- ***With assumptions about the spectator, we can set a model-dependent upper limit to the cross section of < 4-5 nb.***

$N(1710)$ **and** $N(1680)$

$N\pi \rightarrow N\pi$ S_{11}, P_{11} and P_{13} waves



The πN (KN) interaction.

$$A_{\pi N} = \omega^* \left[G(s,t) + H(s,t) i(\vec{\sigma}\vec{n})\right] \omega' \qquad \vec{n}_j = \varepsilon_{\mu\nu j} \frac{q_\mu k_\nu}{|\vec{k}||\vec{q}|} \,.$$

$$G(s,t) = \sum_L \big[(L+1)F_L^+(s) + LF_L^-(s)\big] P_L(z) \,,$$

$$H(s,t) = \sum_L \big[F_L^+(s) - F_L^-(s)\big] P_L'(z) \,.$$

Differential cross section in c.m.s. of the reaction

$$|A|^2 = \frac{1}{2} \mathrm{Tr}\,[A^*_{\pi N} A_{\pi N}] = |G(s,t)|^2 + |H(s,t)|^2 (1-z^2)$$

the recoil asymmetry:

$$P = \frac{\mathrm{Tr}\,[A^*_{\pi N} \sigma_2 A_{\pi N}]}{2|A|^2 \cos\phi} = \sin\Theta \frac{2Im\,(H^*(s,t)G(s,t))}{|A|^2} \,.$$

and the rotation parameter.

$$|A|^2 = |G(s,t)|^2 + |H(s,t)|^2(1-z^2) \qquad |A|^2 \frac{P}{\sin\Theta} = 2Im\left(H^*(s,t)G(s,t)\right) .$$

$$\underline{S_{1,1}}; \quad G = F_0^+; \quad H = 0; \quad |A|^2 = |F_0^+|^2 \tag{1}$$

$$\underline{P_{1,1}}; \quad G = F_1^- z; \quad H = -F_1^-; \quad |A|^2 = |F_1^-|^2 \tag{2}$$

$$\underline{P_{1,3}}; \quad G = 2F_1^+ z; \quad H = F_1^+; \quad |A|^2 = |F_1^+|^2(3z^2+1)$$

Both S_{11} and P_{11} distributions are flat. Recoil asymmetry is zero for single partial wave.

$$\underline{S_{1,1}+P_{1,1}}: \quad P\frac{|A|^2}{\sin\Theta} = -2Im(F_0^+ F_1^{-*}) \quad |A|^2 = |F_0^+|^2 + |F_1^-|^2 + 2zRe(F_0^{+*}F_1^-)$$

$$\underline{S_{1,1}+P_{1,3}}: \quad P\frac{|A|^2}{\sin\Theta} = 2Im(F_0^+ F_1^{+*}) \quad |A|^2 = |F_0^+|^2 + |F_1^+|^2(3z^2+1) + 4zRe(F_0^{+*}F_1^+)$$

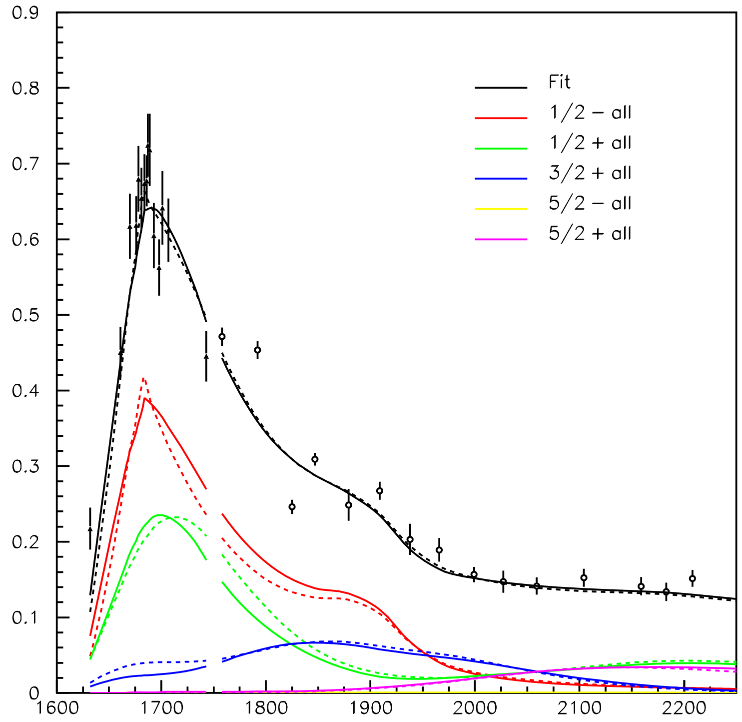
$$\underline{P_{1,1}+P_{1,3}}: \quad P\frac{|A|^2}{\sin\Theta} = 6zIm(F_1^{+*}F_1^-) \quad |A|^2 = |F_1^+ - F_1^-|^2 + z^2\left(3|F_1^+|^2 - 2Re(F_1^{+*}F_1^-)\right) .$$

S and P-waves can be extracted from the differential cross section and recoil asymmetry. For higher partial waves the rotation parameter is needed.

The fit of the the $\pi^- p \to K\Lambda$ reaction

Full experiment for $\pi N \to K\Lambda$: differential cross section, analyzing power, rotation parameter.

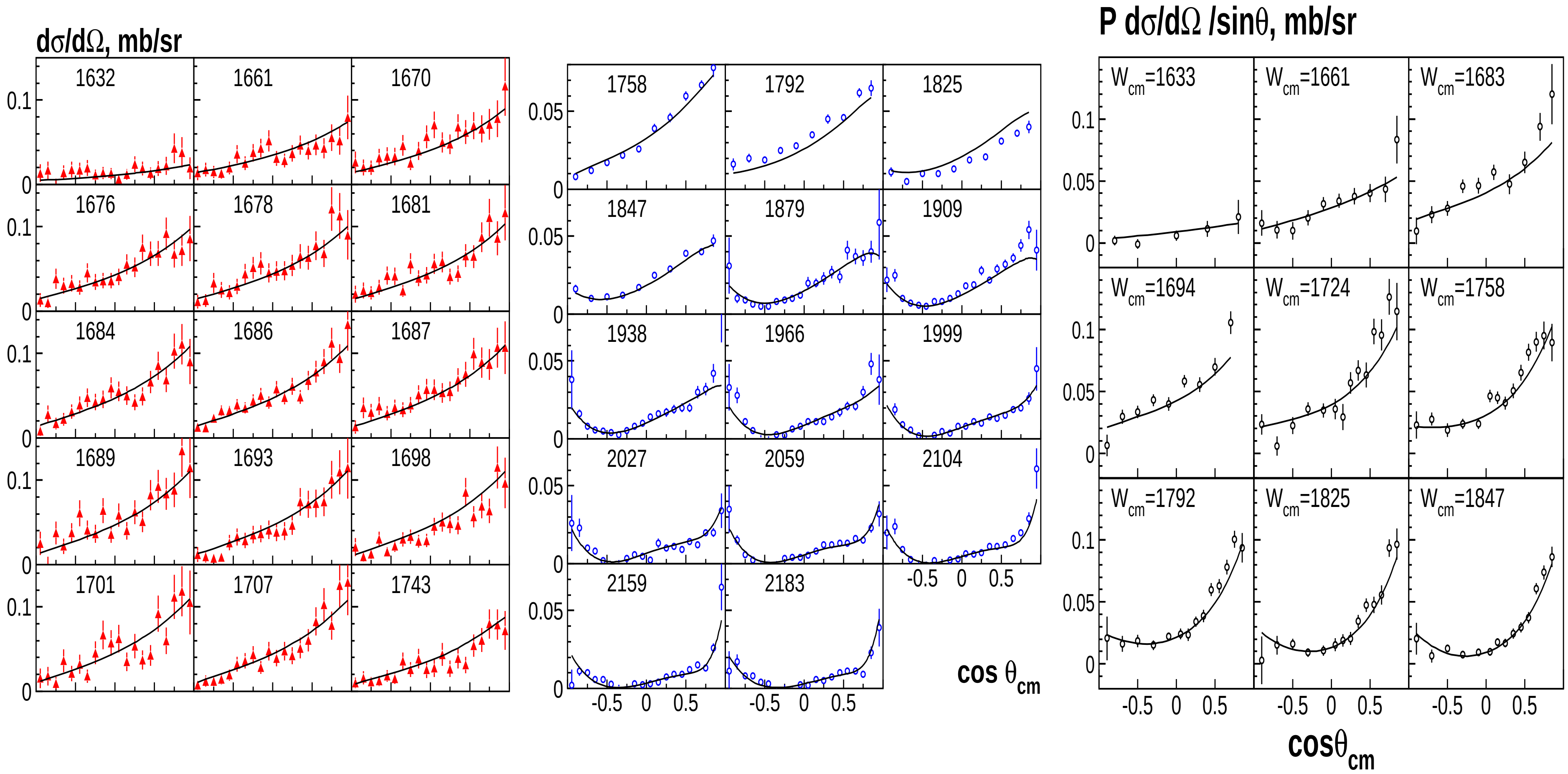
A clear evidence for resonances which are hardly seen (or not seen) in the elastic reactions: $N(1710)P_{11}$, $N(1900)P_{13}$,



The total cross section for the reaction $\pi^- p \to K^0\Lambda$ and contributions from leading partial waves.

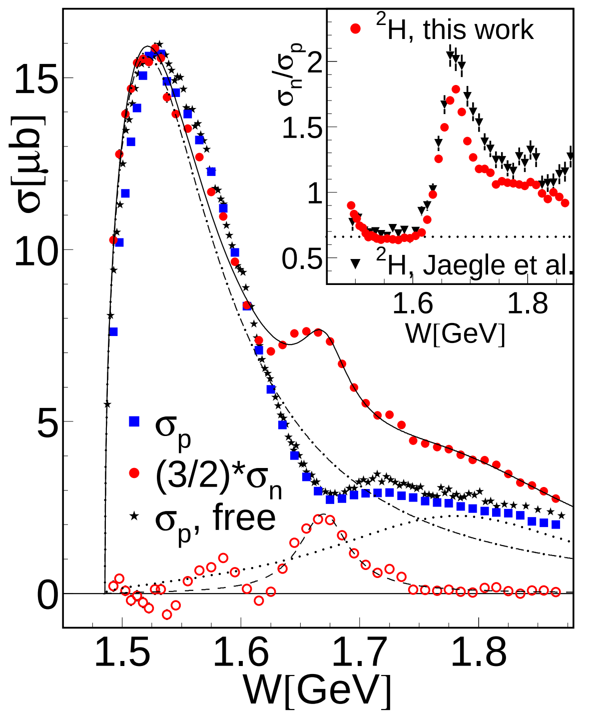
The fit of the the $\pi^- p \to K\Lambda$ reaction

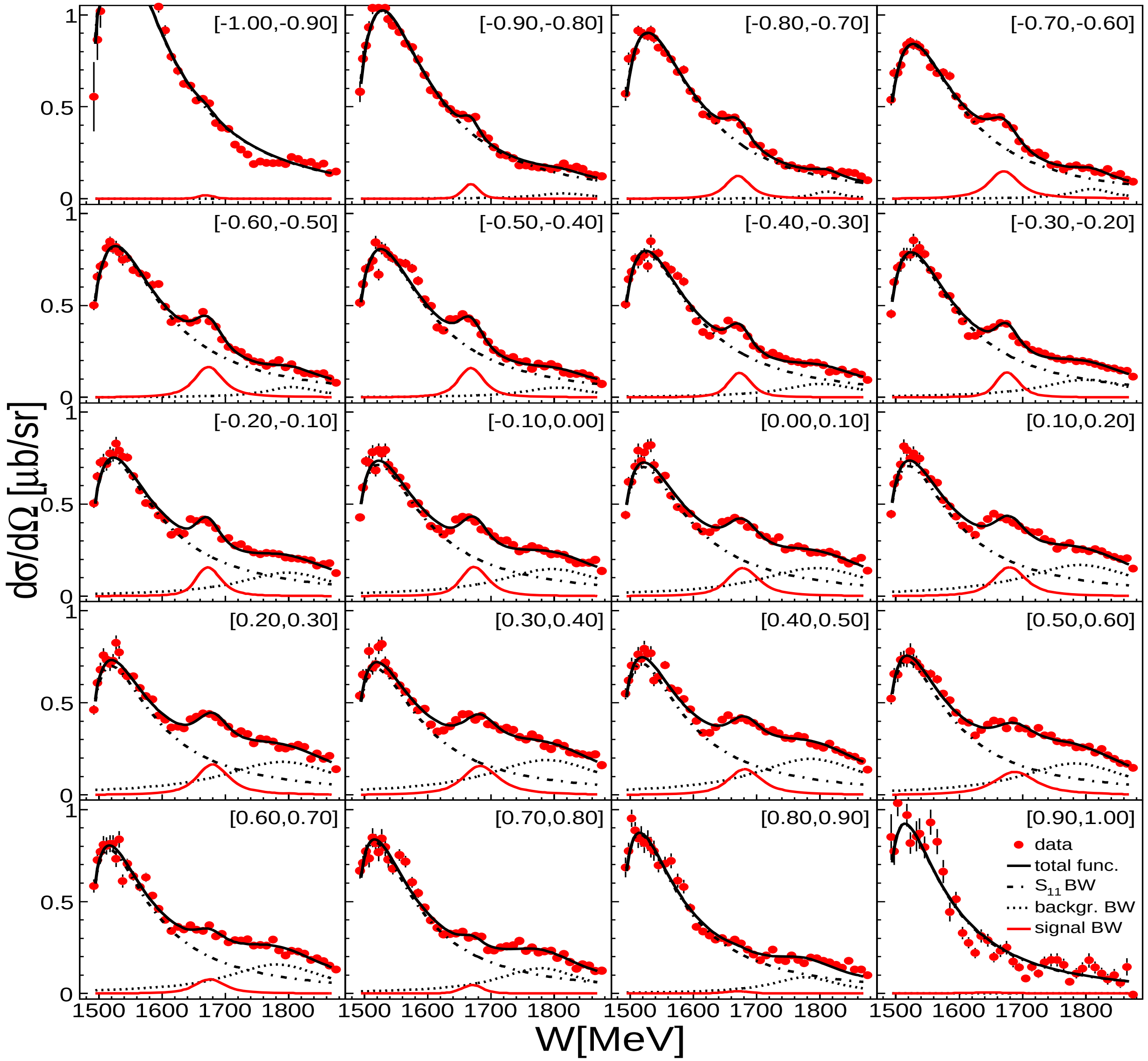
$N(1710): M = 1690 \pm 15$ **MeV,** $-2Im = 155 \pm 25$ **MeV**



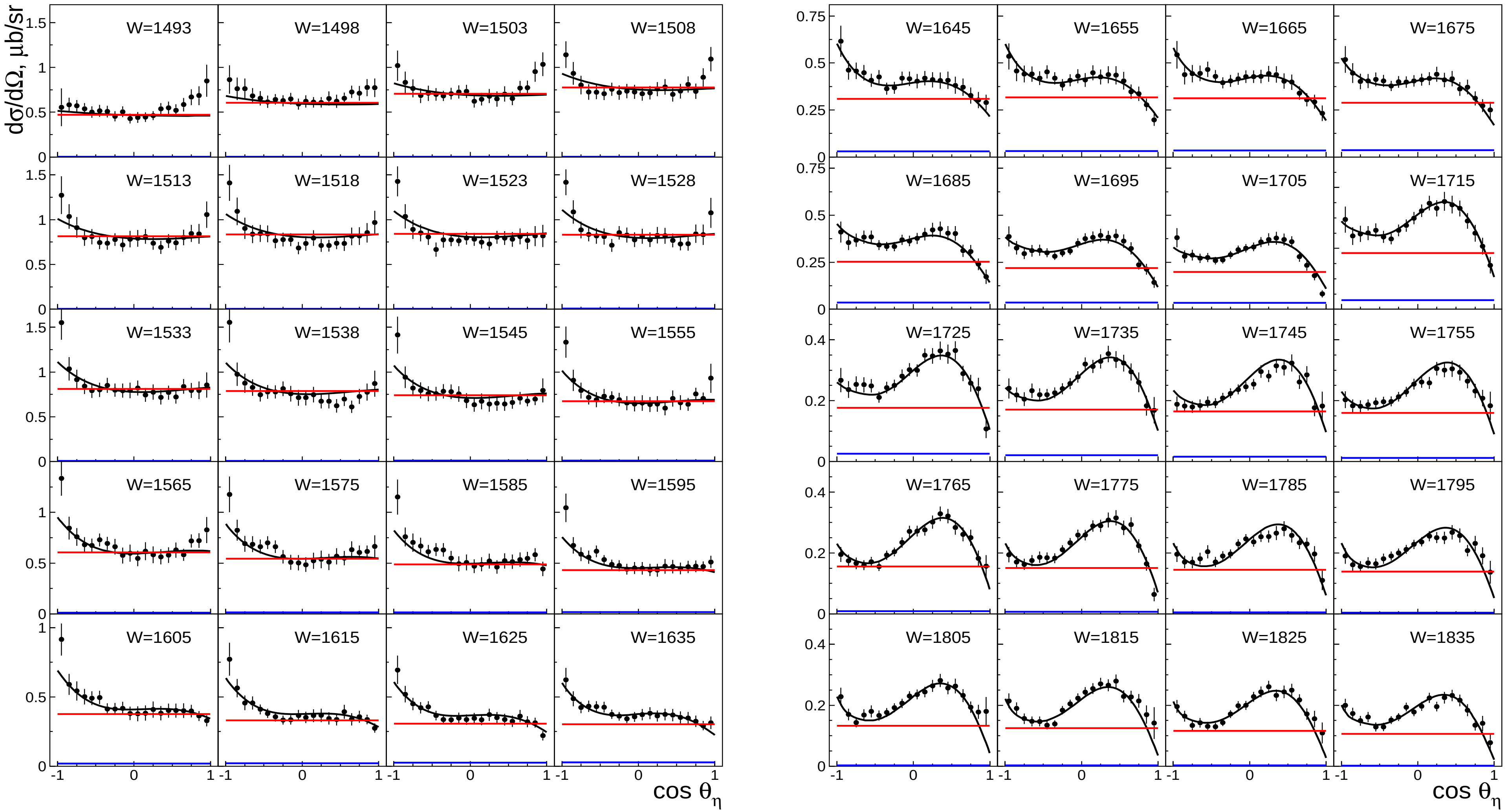
$\gamma p \rightarrow \eta p$ and $\gamma n \rightarrow \eta n$ data

Energy resolution of η: ΔW=10-42 MeV (W=1500-1850 MeV)

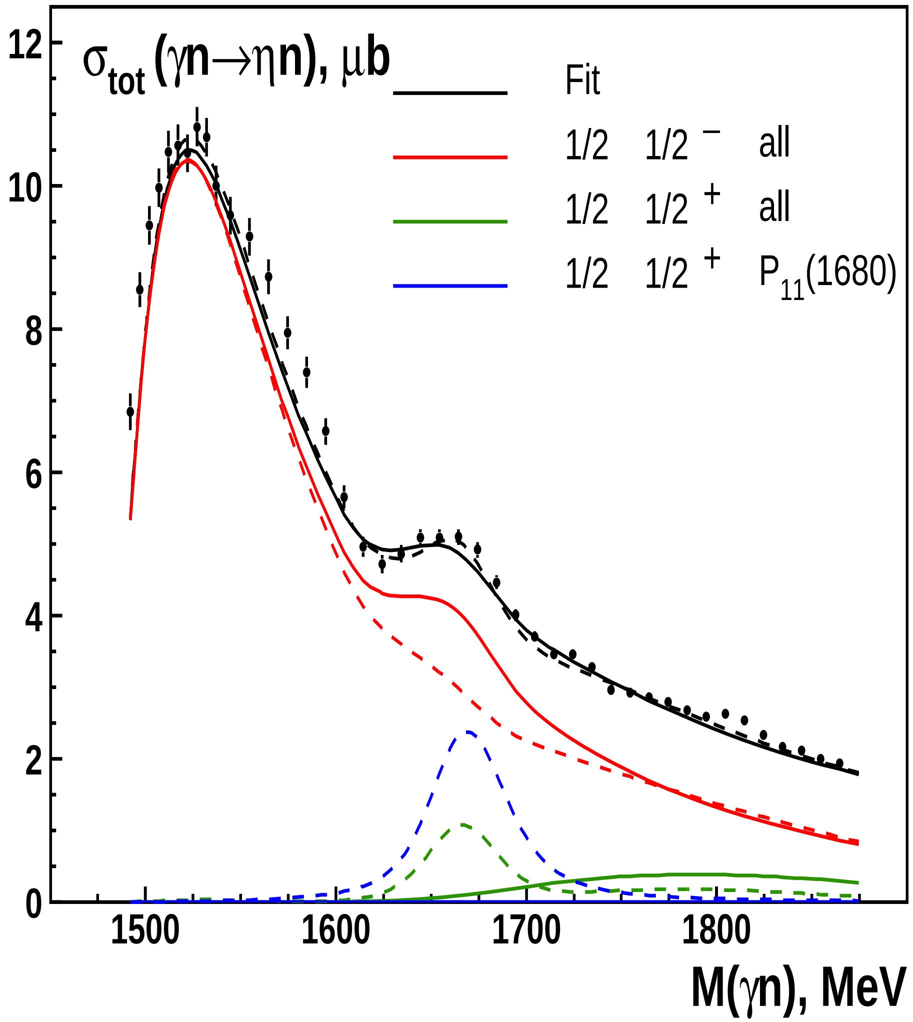




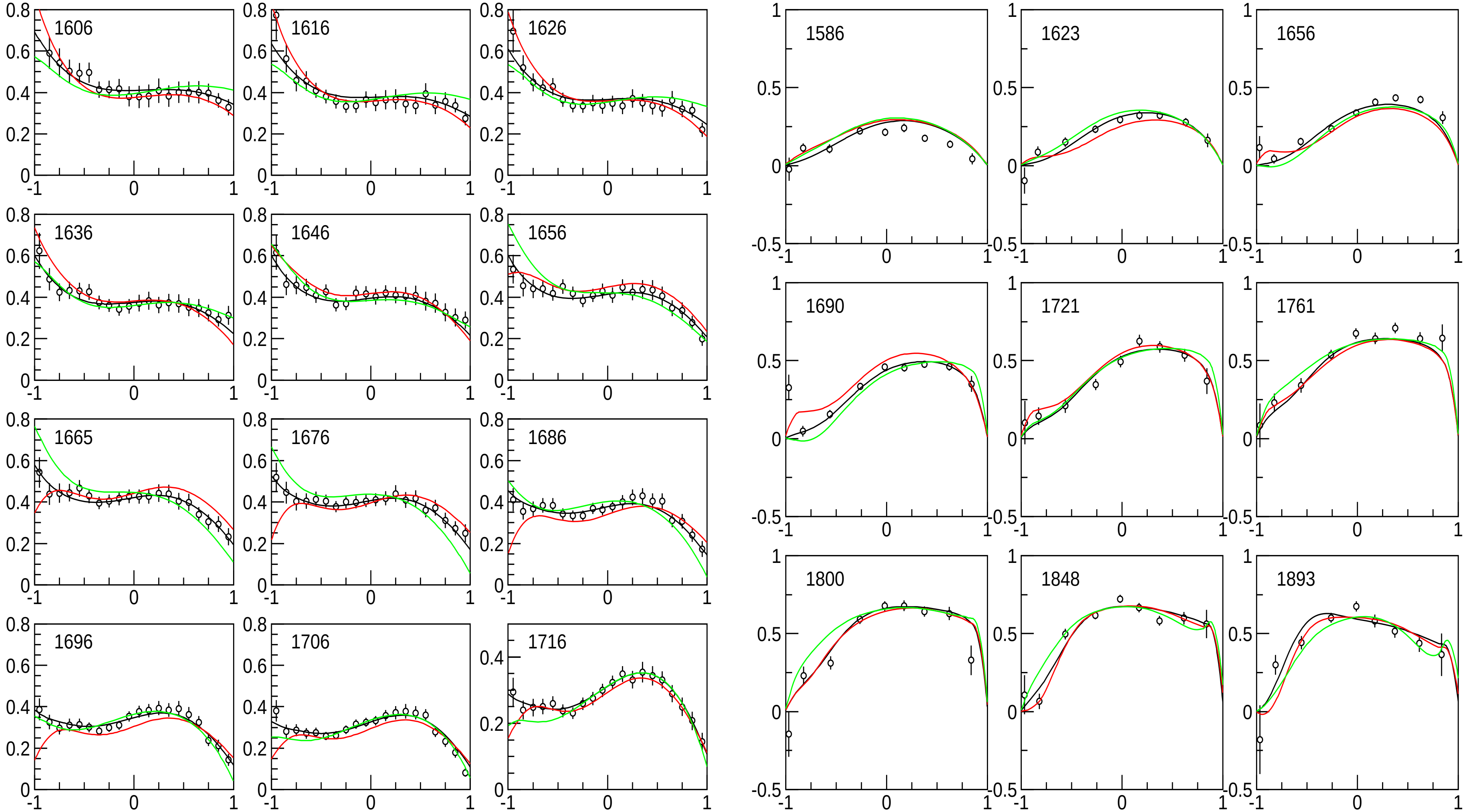
Solution with interference between S_{11} states



Solution with a narrow P_{11} state



The description of the differential cross section and GRAAL data is notably worse



Limit for the production of $P_{11}(1680)$**:** $|A^{\frac{1}{2}}|Br(\eta n) <$ **5 Gev**$^{-\frac{1}{2}}10^{-3}$

In c.m.s. of the reaction

$$A=\sum_i u(k_1)V^{*(i\pm)\mu}_{\alpha_1\dots\alpha_n}F^{\beta_1\dots\beta_n}_{\alpha_1\dots\alpha_n}N^{(\pm)}_{\beta_1\dots\beta_n}u(q_1)\varepsilon_\mu BW^{\pm}_L(s)=\omega^* J_\mu\varepsilon_\mu\omega'\ ,$$

$$J_\mu=i\mathcal{F}_1\sigma_\mu+\mathcal{F}_2(\vec\sigma\vec q)\frac{\varepsilon_{\mu ij}\sigma_i k_j}{|\vec k||\vec q|}+i\mathcal{F}_3\frac{(\vec\sigma\vec k)}{|\vec k||\vec q|}q_\mu+i\mathcal{F}_4\frac{(\vec\sigma\vec q)}{\vec q^2}q_\mu\ .$$

$$\mathcal{F}_1(z)=\sum_{L=0}^{\infty}[LM^+_L+E^+_L]P'_{L+1}(z)+[(L+1)M^-_L+E^-_L]P'_{L-1}(z)\ ,$$

$$\mathcal{F}_2(z)=\sum_{L=1}^{\infty}[(L+1)M^+_L+LM^-_L]P'_L(z)\ ,$$

$$\mathcal{F}_3(z)=\sum_{L=1}^{\infty}[E^+_L-M^+_L]P''_{L+1}(z)+[E^-_L+M^-_L]P''_{L-1}(z)\ ,$$

$$\mathcal{F}_4(z)=\sum_{L=2}^{\infty}[M^+_L-E^+_L-M^-_L-E^-_L]P''_L(z).$$

Differential cross section and polarization observables

$$\mathcal{I}(\theta) = |E_0^+|^2 + |M_1^-|^2 - 2z(\mathrm{Re}E_0^+\mathrm{Re}M_1^- + \mathrm{Im}E_0^+\mathrm{Im}M_1^-)$$

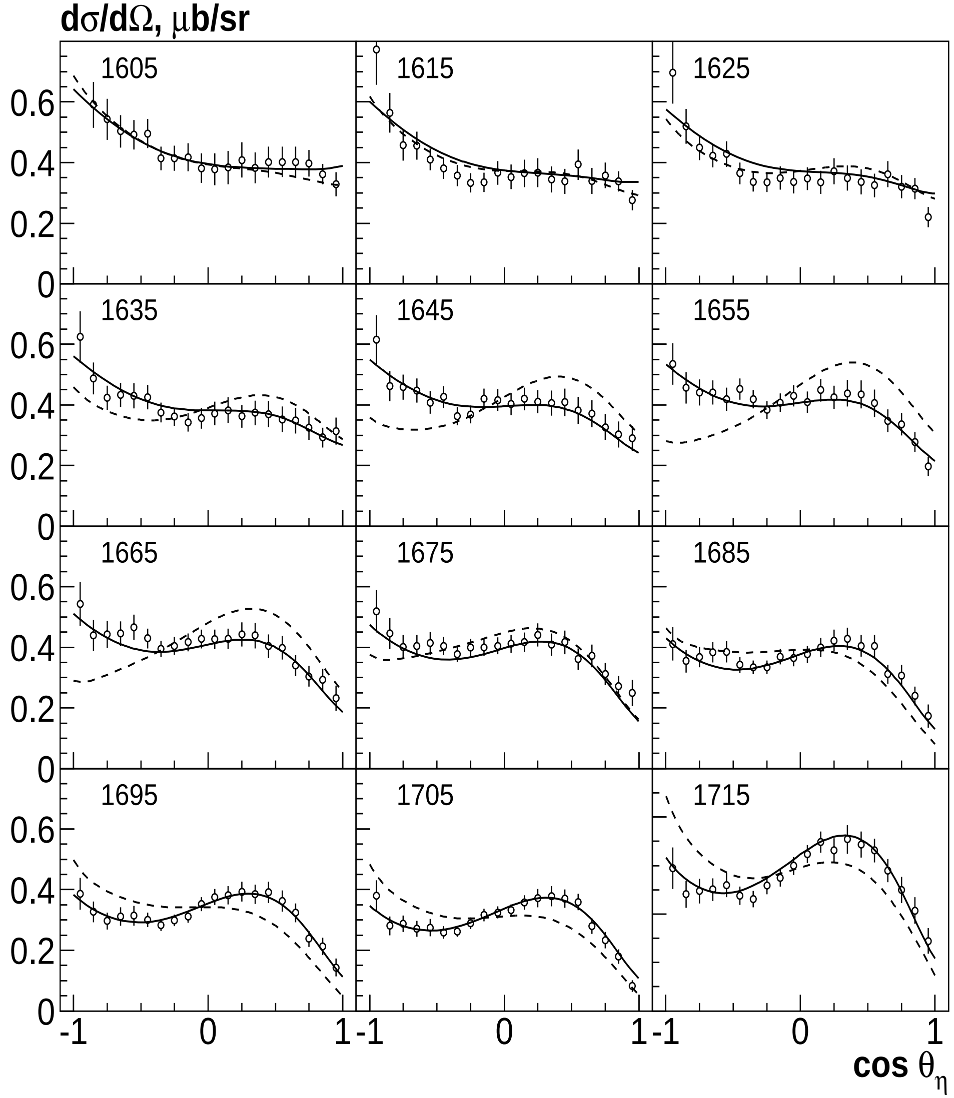
$$\Sigma\mathcal{I}(\theta) = \frac{3\sin^2\theta}{2}\,\mathrm{Re}\{-3|E_1^+|^2 + |M_1^+|^2 - 2M_1^{-*}(E_1^+ - M_1^+) + 2E_1^{+*}M_1^+\}$$

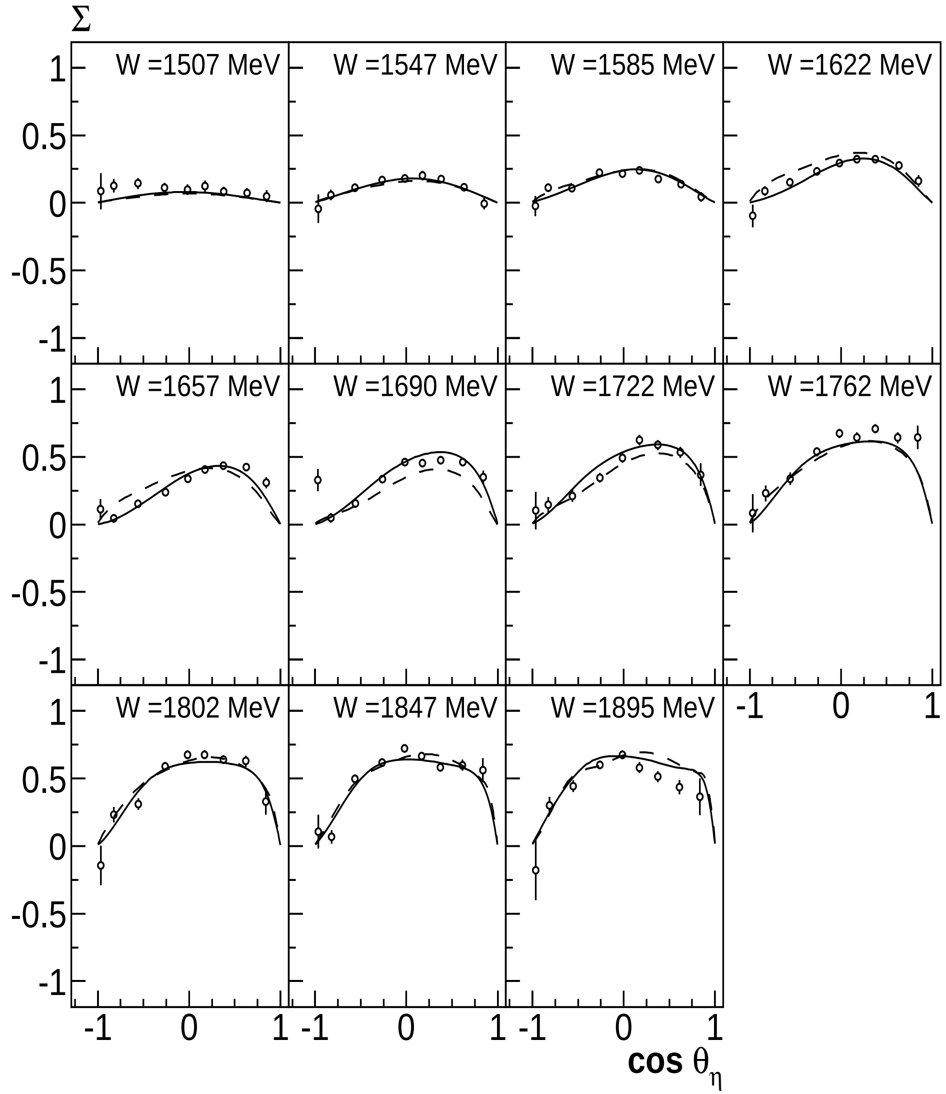
$$T\mathcal{I}(\theta) = 3\sin\theta\,\mathrm{Im}\{E_0^{+*}(E_1^+ - M_1^+) - z[M_1^{-*}(E_1^+ - M_1^+) - 4M_1^{+*}E_1^+]\}$$

$$P\mathcal{I}(\theta) = -2\sin\theta\{\mathrm{Re}E_0^+\mathrm{Im}M_1^- - \mathrm{Im}E_0^+\mathrm{Re}M_1^-\}$$

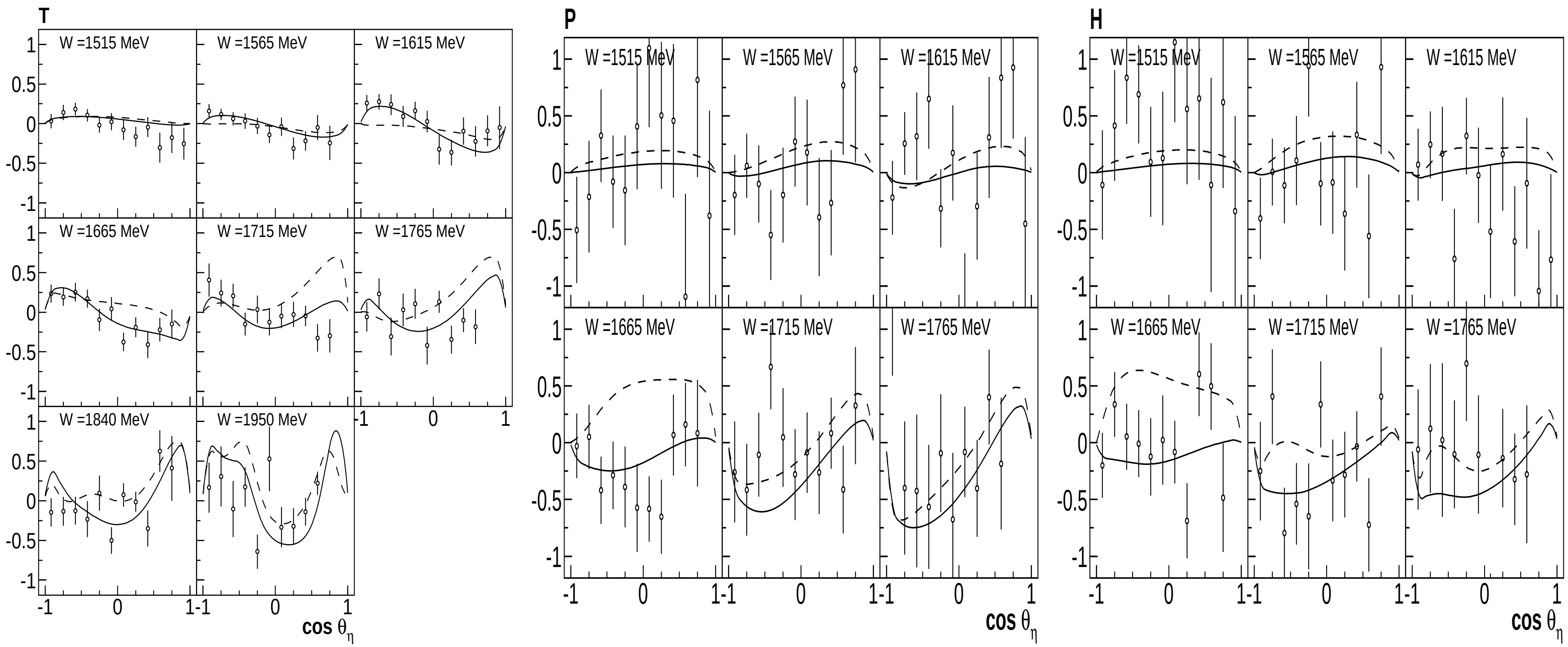
$$H\mathcal{I}(\theta) = -2\sin\theta\{\mathrm{Re}E_0^+\mathrm{Im}M_1^- - \mathrm{Im}E_0^+\mathrm{Re}M_1^-\}$$

The description of the differential cross section and beam asymmetry is notably worse





The description of the T, P, H observables



Summary

- The peak in the $\gamma n \to \eta n$ reaction is defined by the interference inside S-wave
- The K_{Long} beam experiment is the nice tool for the search of the Σ hyperon states
- The pentaquark $\Theta^+(1540)$ state (if it exists) should be a very narrow one, with width $\Gamma < 1$ MeV
- Its partner $N(1680)$ should also be a very narrow. But it is not clear where it should decay
- If we see a signal from $\Theta^+(1540)$ there is a chance to observe its Σ-partner