Evidence for a new $Y^*(1475)$ hyperon in pp collisions at ANKE

2.83 GeV $pp \rightarrow pK^+Y$

$Y = \Lambda_{1116}$, Σ_{1193}, $\Sigma(1385)$, $\Lambda(1405)$, $Y^*(1475)$, $\Lambda(1520)$

- excess energy:

  424 MeV, 348 MeV, 155 MeV, 135 MeV, 65 MeV, 20 MeV

- kinematical limit: mass=1540 MeV/c^2

"Multichannel analysis of the reaction $K^-p \to K^0\pi^-p$ at 4.2 GeV/c"

J.J.Engelen et al., Nucl. Phys. B167 (1980) 61

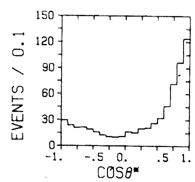


Fig. 3. Distribution of the cosine of the production angle of $\Sigma(1765)$, after iteration 1.

4. The iterative procedure

4.1. Iteration 2

As a result of iteration 1 with the input described in subsect. 3.2 the channels are separated only approximately. We will not illustrate this statement in detail here, but rather turn to the next iteration.

Iteration 2 uses as input improved t' dependences for the $(K\pi)$ partial waves. These t' dependences, covering the full t' range, can be determined on the output of iteration 1. For the $(p\pi)$ channels we also determine t' dependences now. [For the $(p\pi)$ channels the four-momentum transfer squared from initial to final K is used. See sect. 5 for the full distribution function of the $(p\pi)$ system.]

For channel vii, $\Sigma^+(1765)$, we observe evidence for both forward (K^* exchange) and backward (Δ^{++} exchange) production, as is illustrated by the $\cos\Theta^*$ (Θ^* is the c.m. production angle of the $(p\bar{K}^0)$ system) distribution of fig. 3. Hence we will describe the production characteristics of channel vii in terms of $\cos\Theta^*$.

As the most striking result after iteration 1 it appears necessary to introduce a new channel:

$$K^-p \to \pi^-\Sigma^+(1480) \qquad \text{to be called channel viii}\,.$$

Evidence for this channel is deduced from the $M(p\bar{K}^0)$ distribution of channel iiib, the $2^+1 - K^*(1420)$ partial wave. This $M(p\bar{K}^0)$ distribution is reproduced in fig. 4, where a distinct peak at a mass of about 1.5 GeV can be observed. Iteration 2 will take this channel into account, with a Breit–Wigner mass dependence, central value 1480 MeV and width 80 MeV. This width has been estimated from the data of fig. 4. Using this width (as a working hypothesis) we obtained satisfactory results (see also subsect. 5.3), but on our value of 80 MeV we should allow for an error of about 20 MeV.

As a result of iteration 2 the peak in the $M(p\bar{K}^0)$ distribution of channel iiib has indeed vanished (dotted histogram in fig. 4). The output of iteration 2 shows as

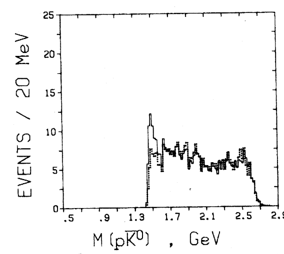


Fig. 4. $M(p\bar{K}^0)$ distribution for the $2^+1-(K\pi)$ channel after iteration 1 (full histogram) and 2 (dotted histogram).

another striking result a considerable change in the $\cos\theta_{p\pi}$, the cosine of the polar angle in the $(p\pi^-)$ Gottfried–Jackson frame, distribution of the $(p\pi)$ channels. These distributions showed strong peaking for $\cos\theta_{p\pi} \approx 1$. These peaks have disappeared after iteration 2. Our interpretation of this observation is, that due to the better t' dependences [both for $(K\pi)$ and $(p\pi)$ channels] used in iteration 2, a better separation of channels has been achieved. A contamination of the $(p\pi)$ channels by the $(K\pi)$ channels is indeed expected at $\cos\theta_{p\pi} \approx 1$, when the outgoing proton goes approximately in the same direction as the incoming one. For channel vii we observe a similar change in $\cos\theta_{pK}$ [now in the (pK^0) Gottfried–Jackson frame] in going from iteration 1 to iteration 2. These effects are illustrated in figs. 5a–d, where the full histograms are the results of iteration 1 and the dotted ones of iteration 2.

4.2. Iteration 3: study of the $(p\pi^-)$ system

The asymmetric shape of the $\cos\theta_{p\pi}$ distributions of the $(p\pi)$ samples (figs. 5a–c) shows that our samples of channels iv, v and vi do not correspond to pure resonances. A more detailed understanding of the $(p\pi)$ system can be obtained from a spin-parity analysis. The distribution function for the $(p\pi)$ system is written:

$$f_{p\pi} = \sum_{\substack{J_1J_2 \\ M_1M_2\lambda\eta}} \rho^{J_1J_2}_{M_1M_2\eta}\, \mathrm{BW}^{J_1}(M)\,\mathrm{BW}^{J_2}(M)^*\, F^{J_1}_{M_1}(t')\, F^{J_2}_{M_2}(t') \times A^{J_1}_{M_1\lambda\eta}(\theta,\phi)\, A^{J_2}_{M_2\lambda\eta}(\theta,\phi)^*\,, \qquad (12)$$

with $\theta \equiv \theta_{p\pi}$ and $\phi = \phi_{p\pi}$ the polar and azimuthal angles of the proton in the $(p\pi)$ Gottfried–Jackson frame, M the $(p\pi^-)$ effective mass, and t' as defined above. The

Status (PDG 2004)

- reasonable information:
  $Y=\Lambda_{1116}, \Sigma_{1193}, \Sigma(1385), \Lambda(1520)$
- question about $\Lambda(1405)$ nature
- $\Sigma(1480)$ Bumps omitted from Summary Table:
  - status * with unknown quantum numbers
  - estimated mass of 1480 MeV/c^2 from 120 events
    (1480, 1485±10, 1479±10, 1465±15)
  - width: no estimated value → Γ_{av}= 45 MeV/c^2
    (80±20, 40±20, 31±15, 30±20)
  - decay modes: $N\bar{K}$, $\Lambda\pi$, $\Sigma\pi$

$\Gamma(\Sigma\pi)/\Gamma(\Lambda\pi)=0.82 \pm 0.51$, $\Gamma(N\bar{K})/\Gamma(\Lambda\pi)=0.72 \pm 0.50$, $\Gamma(N\bar{K})/\Gamma_{total}$=small

Properties of strange baryons

	mass (MeV/c^2)	FWHM (MeV/c^2)
Λ_{1116}	1115.683±0.006	(2.50±0.02)·10^{-12}
Σ_{1192}	1192.642±0.024	0.0089±0.0009
$\Sigma(1385)$	1383.7±1.0	36±5
$\Lambda(1405)$	1406 ±4	50 ±2
$\Sigma(1480)$	1480	30 ÷ 80
$\Lambda(1520)$	1519.5 ±1.0	15.6 ±1.0

Production of Y*(1475)

$pp \rightarrow pK^{+}Y^{*}(1475) \rightarrow \mathbf{pK^{+}N\bar{K}}$

$\rightarrow \mathbf{pK^{+}\pi^{0}\Lambda} \rightarrow pK^{+}\pi^{0}\pi^{-}p$

$\rightarrow \mathbf{pK^{+}\pi\Sigma}$

$\rightarrow pK^{+}\pi^{+}\Sigma^{-} \rightarrow pK^{+}\pi^{+}\pi^{-}n$

$\rightarrow pK^{+}\pi^{-}\Sigma^{+} \rightarrow pK^{+}\pi^{-}\pi^{+}n$

$\rightarrow pK^{+}\pi^{0}\Sigma^{0} \rightarrow pK^{+}\pi^{0}\Lambda\gamma \rightarrow pK^{+}\pi^{0}\pi^{-}p\,\gamma$ (CGC≡0 for **Σ)**

- *K meson decays with π^{+} and π^{-}*

Production of Y*(1475)

$pp \rightarrow pK^+Y^*(1475) \rightarrow \mathbf{pK^+N\bar{K}}$

$\rightarrow \mathbf{pK^+\pi^0\Lambda} \rightarrow pK^+\pi^0\pi^-p$

$\rightarrow \mathbf{pK^+\pi\Sigma}$

$\rightarrow pK^+\pi^+\Sigma^- \rightarrow pK^+\pi^+\pi^-n \Rightarrow MM(pK^+\pi^+)=M(\Sigma_{1197})$

$\rightarrow pK^+\pi^-\Sigma^+ \rightarrow pK^+\pi^-\pi^+n$

$\rightarrow pK^+\pi^0\Sigma^0 \rightarrow pK^+\pi^0\Lambda\gamma \rightarrow pK^+\pi^0\pi^- p\,\gamma$ (CGC≡0 for **Σ)**

- *K meson decays with π^+ and π^-*

Experiment

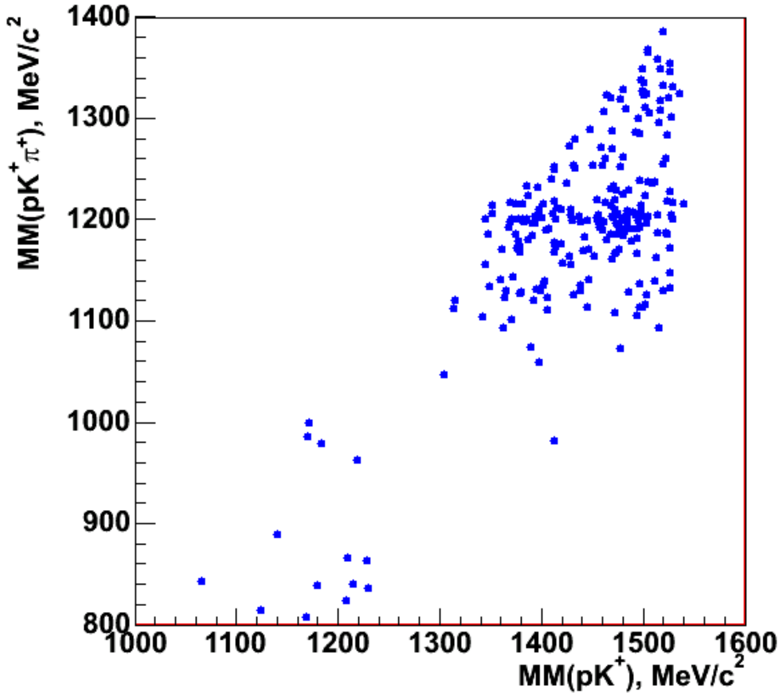
- by-product from the a_0 production experiment in February 2002
- 2.83 GeV protons on H_2 cluster-jet target
- triple coincidences: $pK^+\pi^+$ and $pK^+\pi^-$
- event selection with delayed veto
  - 442 events of $pK^+\pi^+$
  - 10624 events of $pK^+\pi^-$

- *K^+ in positive detector (Te)*
- *p in forward detector*
- *π^+ in positive detector (Te and SW)*
- *π^- negative detector*
  - *only part of negative scintillators used*

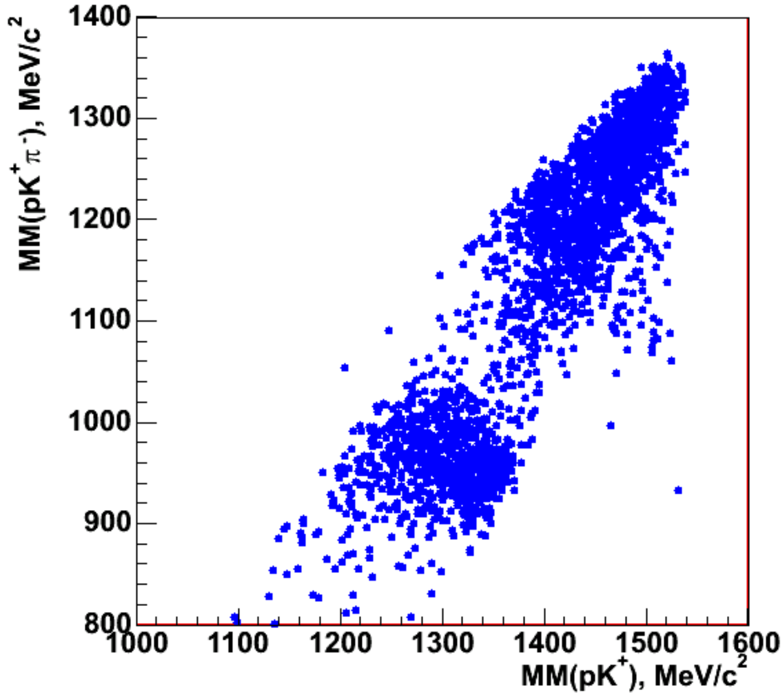
	ACCEPTANCE	
	horizontal	vertical
K^+	$-10° \div 15°$	$\pm 6°$
proton	$-5° \div 15°$ for π^+	$\pm 4°$
	$-8° \div 12°$ for π^-	
π^+ / π^-	$\pm 15°$	$\pm 6°$

MM(pK$^+\pi$) vs MM(pK$^+$)

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

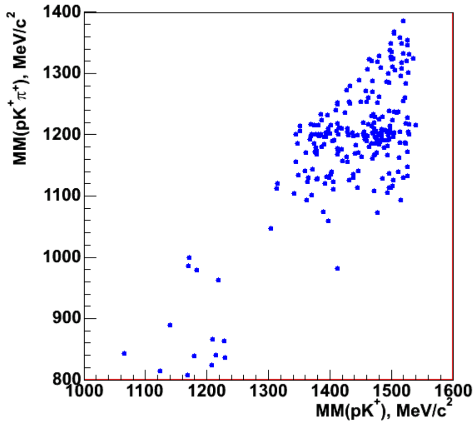


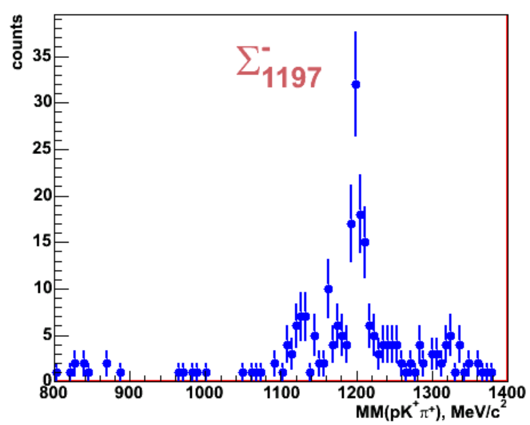
2.83 GeV pp $\rightarrow$ pK$^+\pi^-$X$^+$



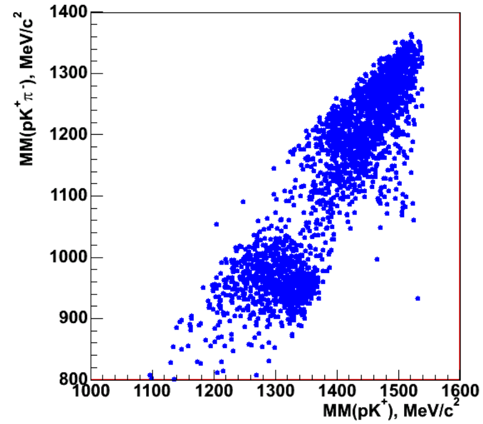
MM(pK$^+\pi$)

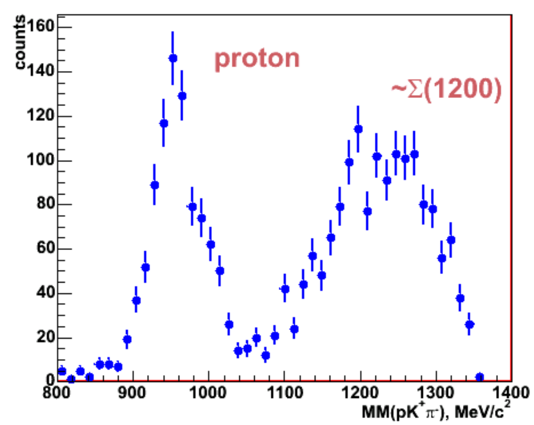
2.83 GeV pp $\rightarrow$ pK$^+\pi^+$X$^-$





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

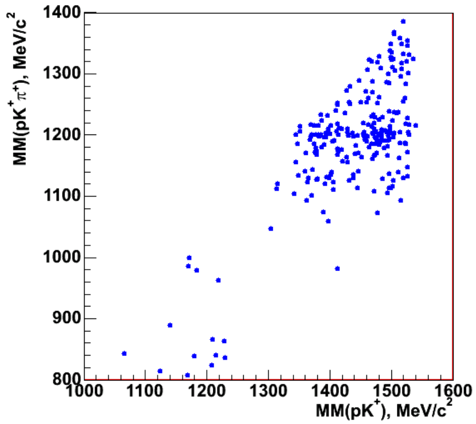


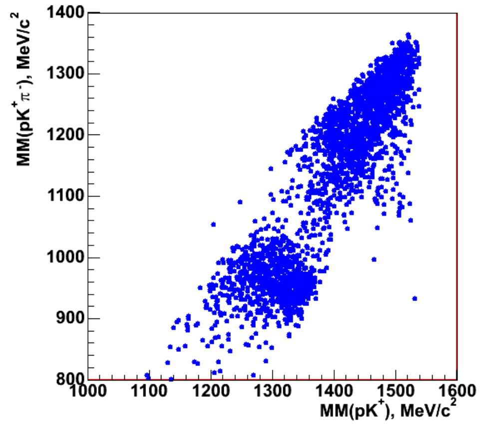


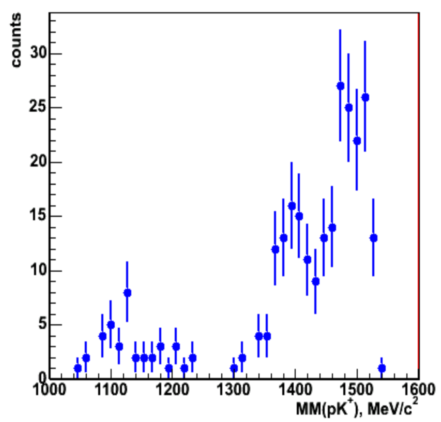
MM(pK^+)

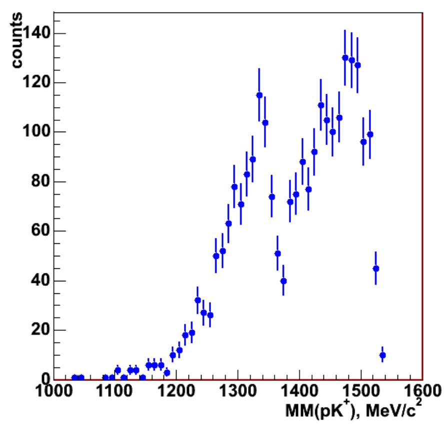
2.83 GeV pp $\rightarrow pK^+\pi^+X^-$

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

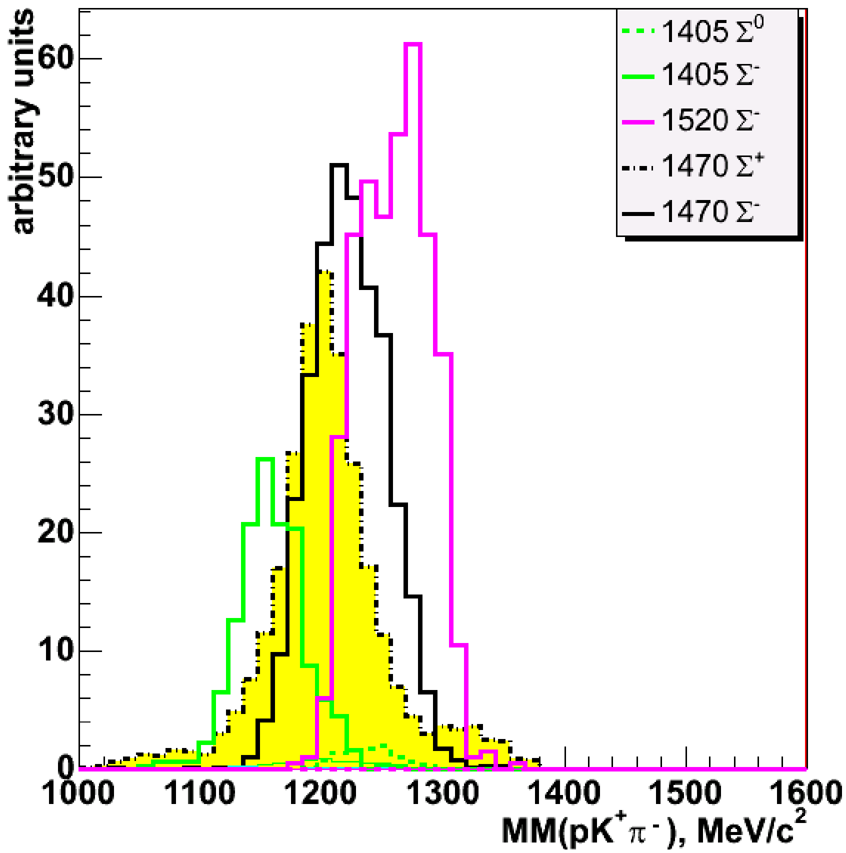






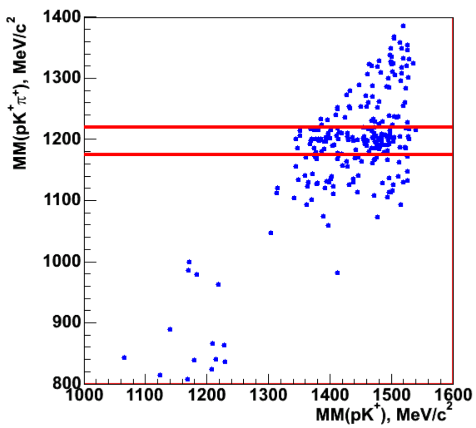


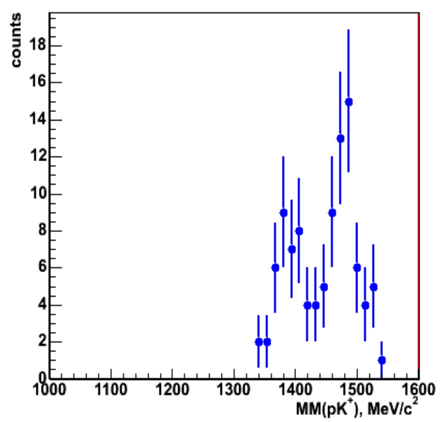
More details: $pp \to pK^+\pi^-\Sigma^+ \to pK^+\pi^-\pi^+n$



$MM(pK^+)$

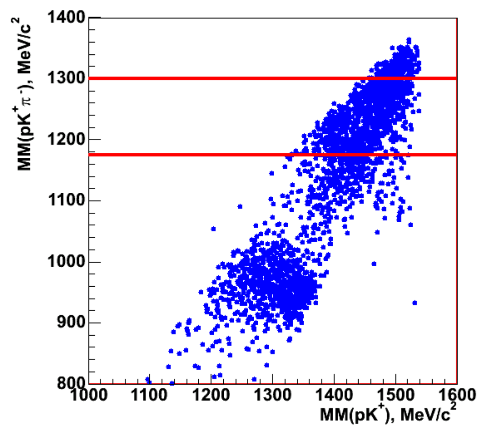
2.83 GeV $pp \rightarrow pK^+\pi^+X^-$

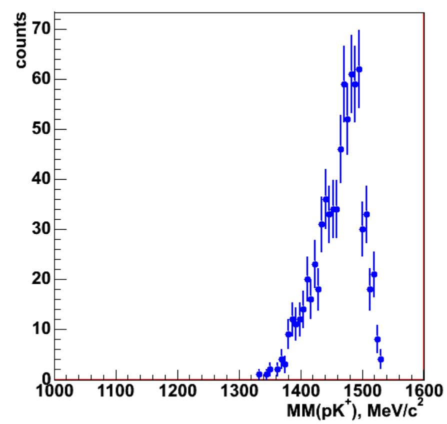




$MM(pK^+\pi^+)$~1200 MeV/c^2

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



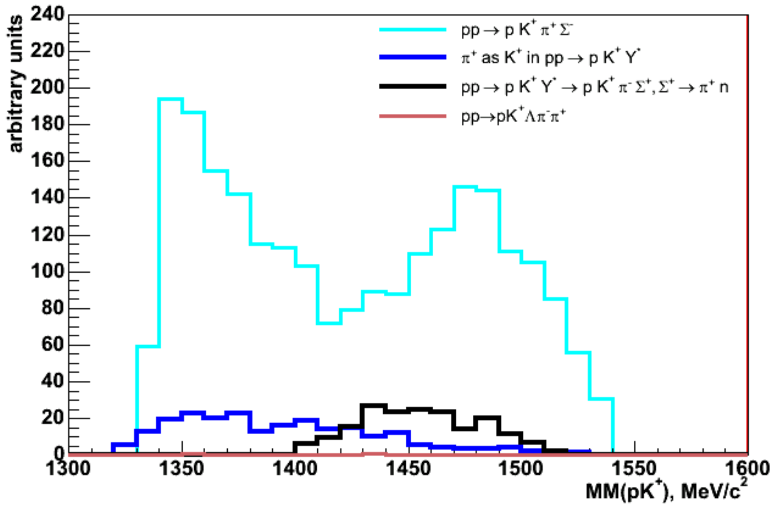


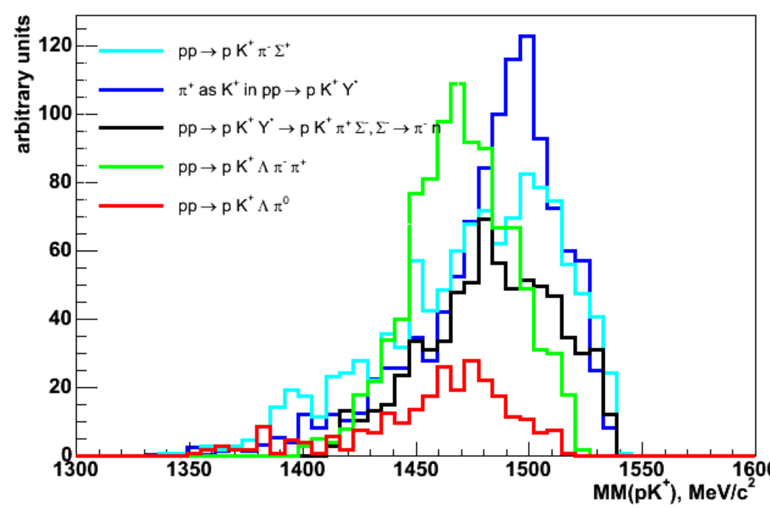
1175 < $MM(pK^+\pi^-)$ < 1300 MeV/c^2

Monte Carlo simulations of the reaction 2.83 GeV $pp \to pK^+Y$

- simulations for Y = $\Sigma(1385)$, $\Lambda(1405)$, Y*(1475), $\Lambda(1520)$
- GEANT3 only with phase space (GENBOD)
  - 65 MeV above the threshold for Y*(1475) production
  - possible deviations
    - FSI between pY*(1475) $\to$ small
    - K^+Y(1475) couples to N and Δ resonances $\to$ broad
- parameters in simulations
  - mass of Y*(1475)
  - width of Y*(1475)
- fitted relative contributions of four heavy hyperons and background

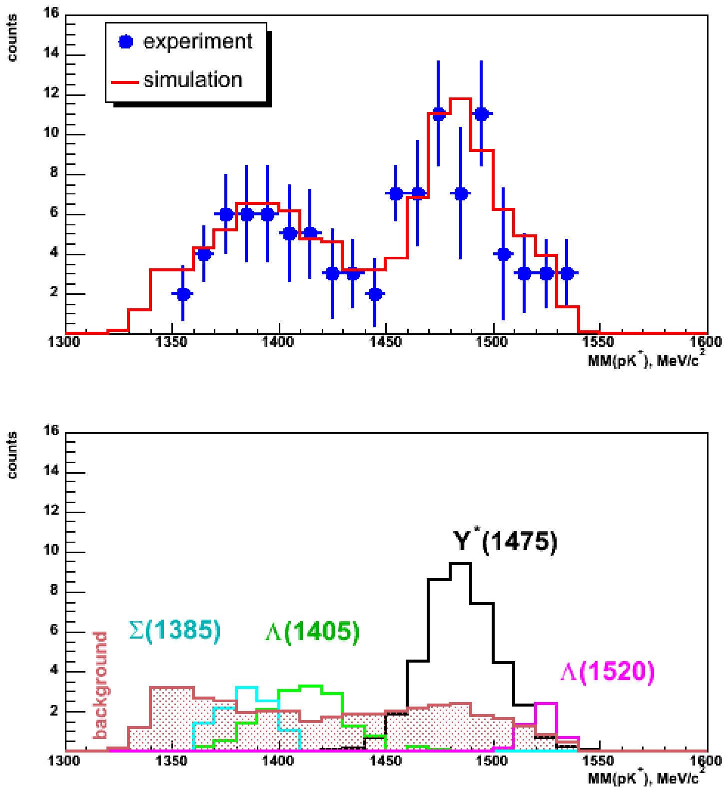
Background


arbitrary units
240
220
200
180
160
140
120
100
80
60
40
20
0
1300
1350
1400
1450
1500
1550
1600
MM(pK$^+$), MeV/c^2
pp → p K$^+$ π^+ Σ^-
π^+ as K$^+$ in pp → p K$^+$ Y*
pp → p K$^+$ Y* → p K$^+$ π^- Σ^+, Σ^+ → π^+ n
pp→pK$^+$$\Lambda\pi^-\pi^+$

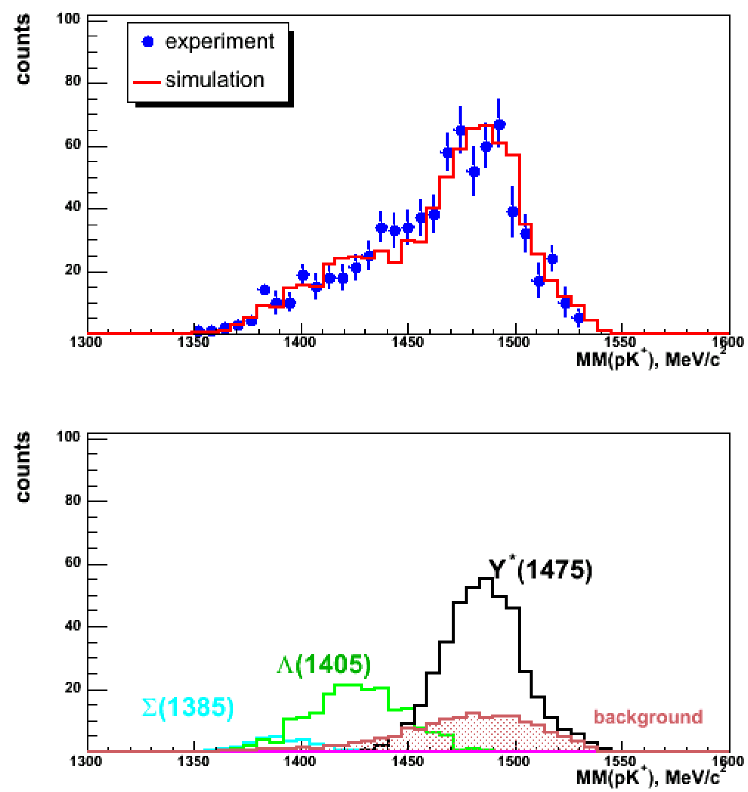

arbitrary units
120
100
80
60
40
20
0
1300
1350
1400
1450
1500
1550
1600
MM(pK$^+$), MeV/c^2
pp → p K$^+$ π^- Σ^+
π^+ as K$^+$ in pp → p K$^+$ Y*
pp → p K$^+$ Y* → p K$^+$ π^+ Σ^-, Σ^- → π^- n
pp → p K$^+$ Λ π^- π^+
pp → p K$^+$ Λ π^0

Experimental and simulated missing mass distributions

2.83 GeV pp → $pK^+\pi^+X^-$
Y*(1475): mass=1475 MeV/c^2, Γ=45 MeV/c^2



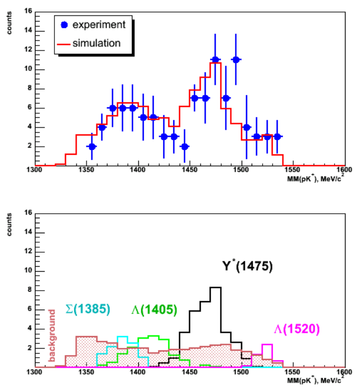
2.83 GeV pp → $pK^+\pi^-X^+$
Y*(1475): mass=1470 MeV/c^2, Γ=45 MeV/c^2



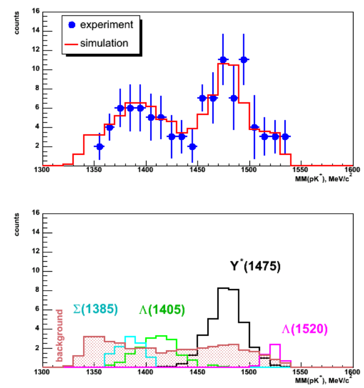
Experimental and simulated missing mass distributions

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

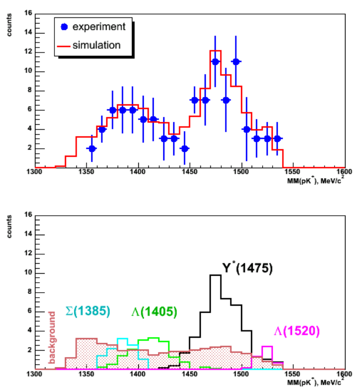
mass=1460 MeV/c^2, Γ=45 MeV/c^2



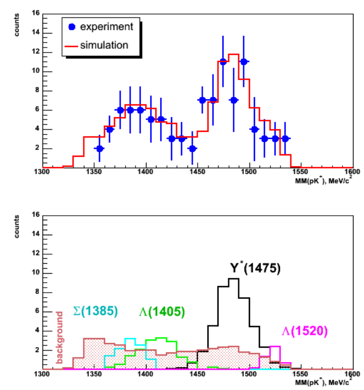
mass=1470 MeV/c^2, Γ=45 MeV/c^2



mass=1470 MeV/c^2, Γ=55 MeV/c^2



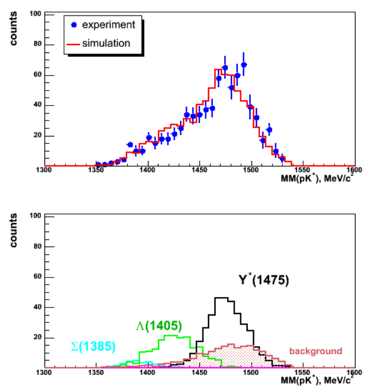
mass=1475 MeV/c^2, Γ=45 MeV/c^2



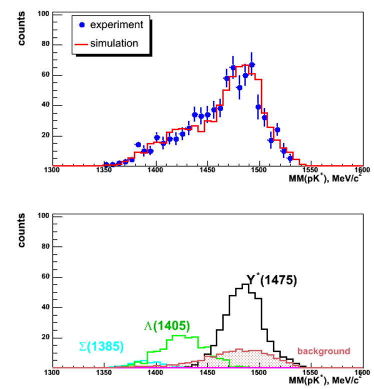
Experimental and simulated missing mass distributions

2.83 GeV pp $\rightarrow pK^{+}\pi^{-}X^{+}$

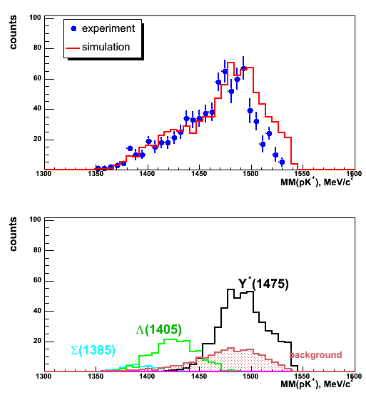
mass=1460 MeV/c^2, Γ=45 MeV/c^2



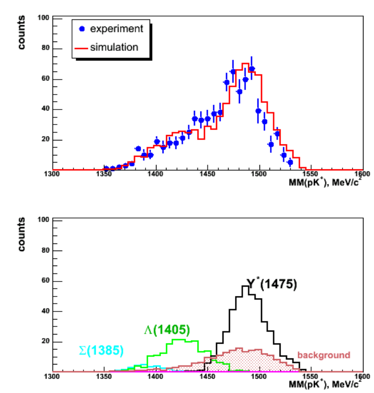
mass=1470 MeV/c^2, Γ=45 MeV/c^2



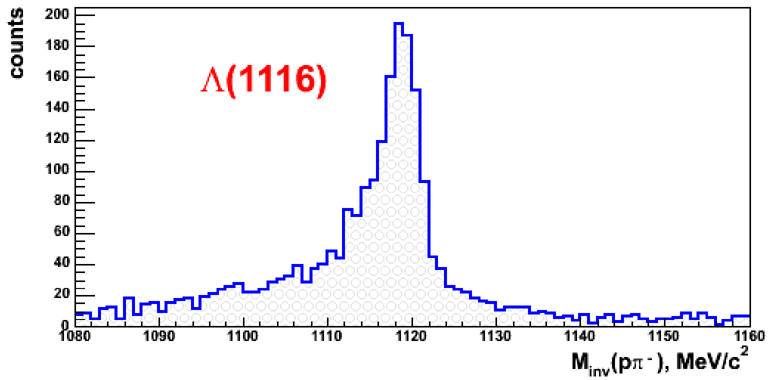
mass=1470 MeV/c^2, Γ=55 MeV/c^2

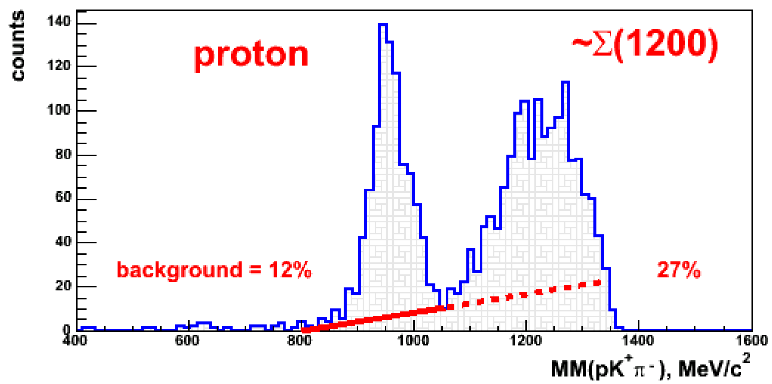


mass=1475 MeV/c^2, Γ=45 MeV/c^2



More details …

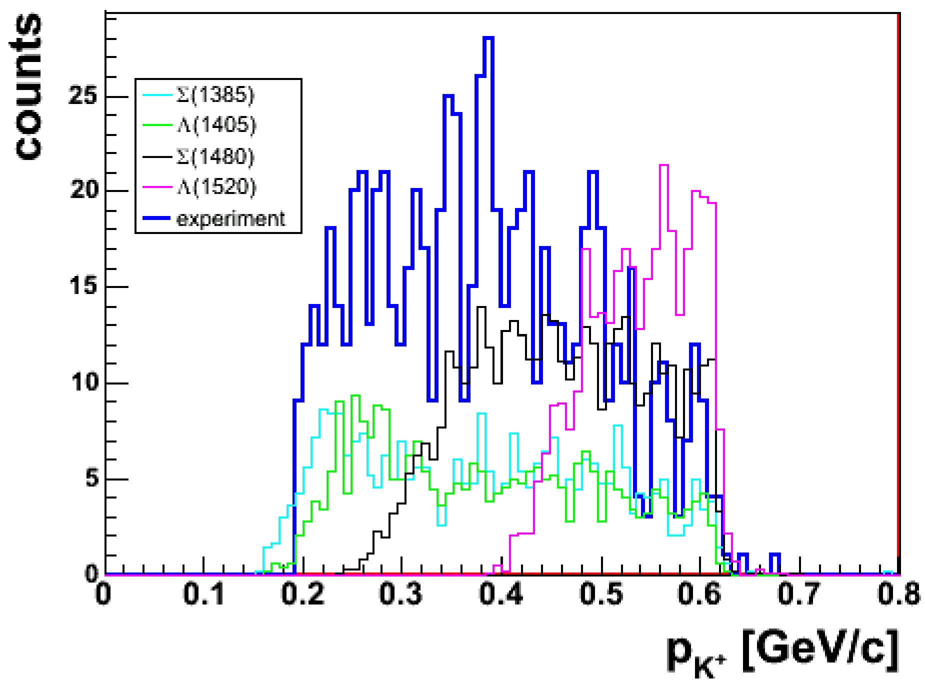




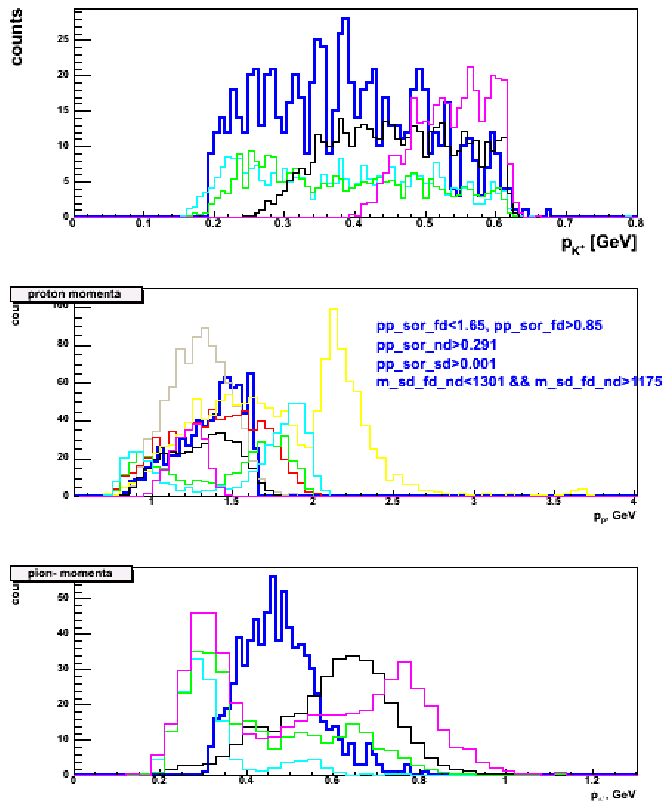
$\Delta M(\Lambda) \sim 3$ MeV/c^2

$\Delta M(\text{proton}) \sim 5$ MeV/c^2

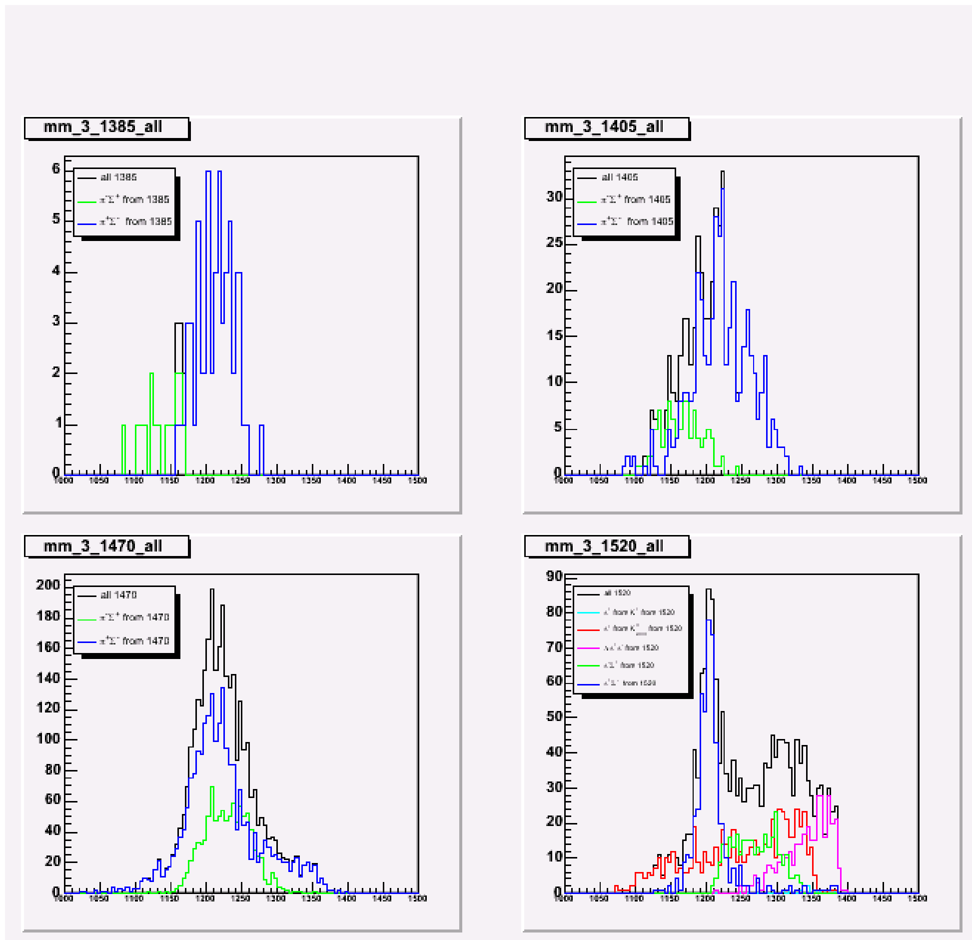
More details: K$^+$ momenta from 2.83 GeV $pp \to pK^+Y$



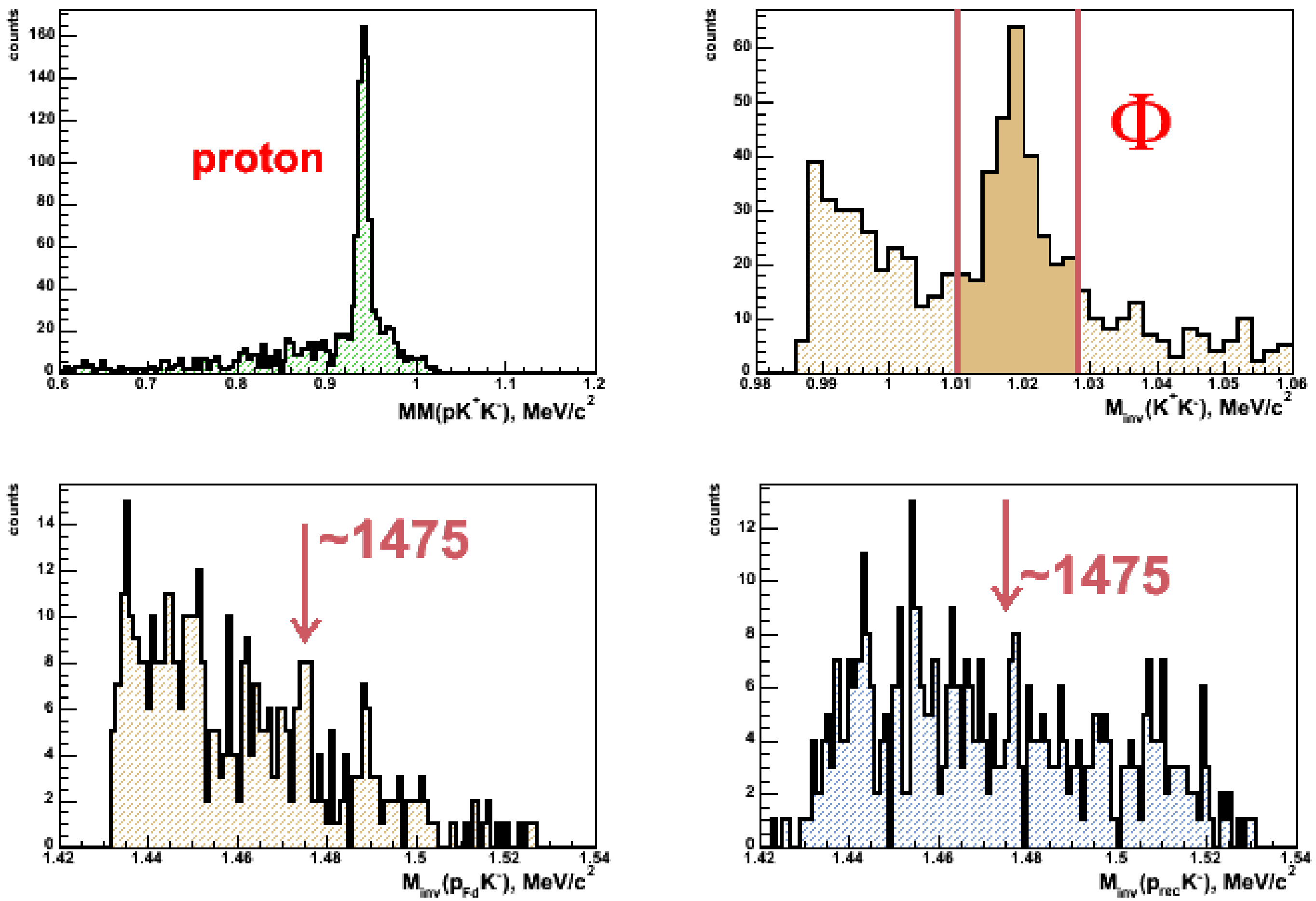
More details: K^+, p and π^- momenta from 2.83 GeV $pp \rightarrow pK^+Y$



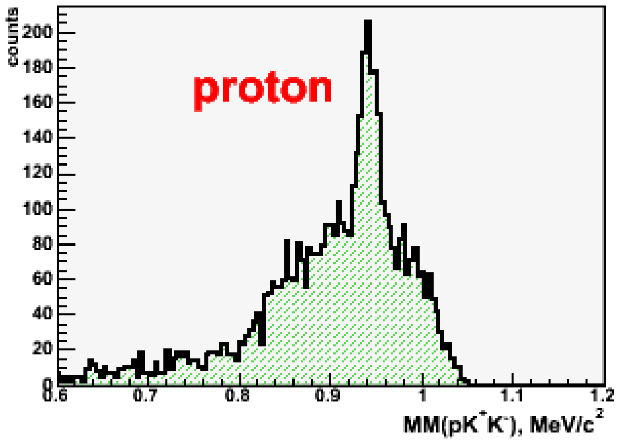
Decay modes

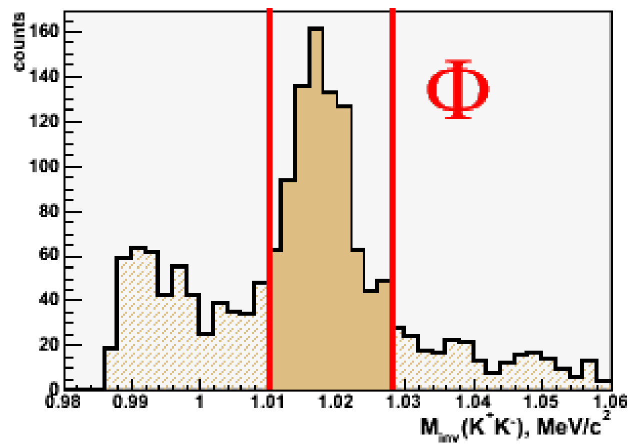

mm_3_1385_all
all 1385
from 1385
from 1385
mm_3_1405_all
all 1405
from 1405
from 1405
mm_3_1470_all
all 1470
from 1470
from 1470
mm_3_1520_all

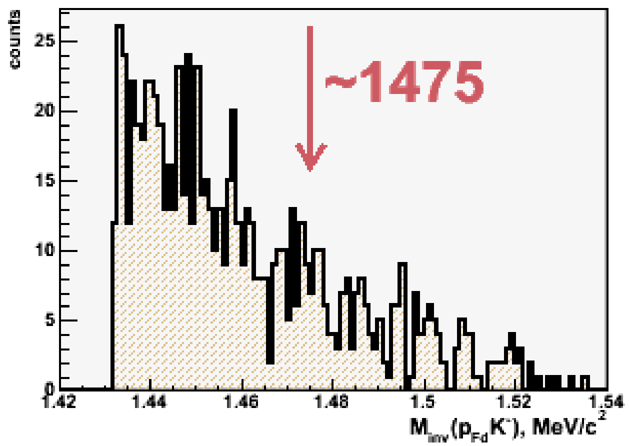
2.83 GeV pp→ppK$^+$K$^-$ from Y.Maeda



2.88 GeV $pp \rightarrow ppK^+K^-$ from Y.Maeda



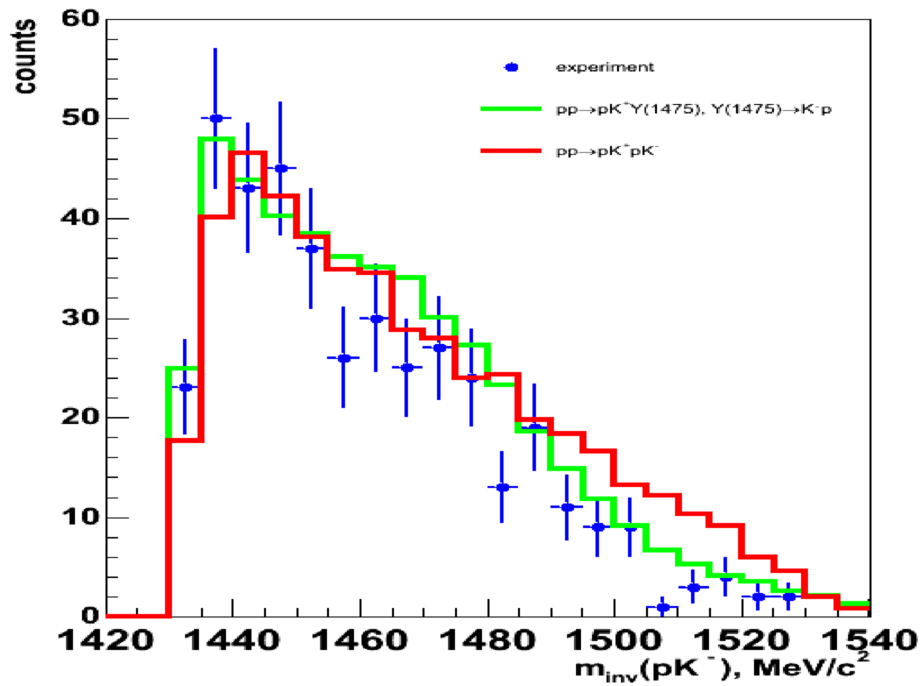




CH_2 target

Decay modes of Y*(1475)

$pp \to pK^+Y^*(1475) \to pK^+N\bar{K} \to p\,K^+\,p\,K^-$

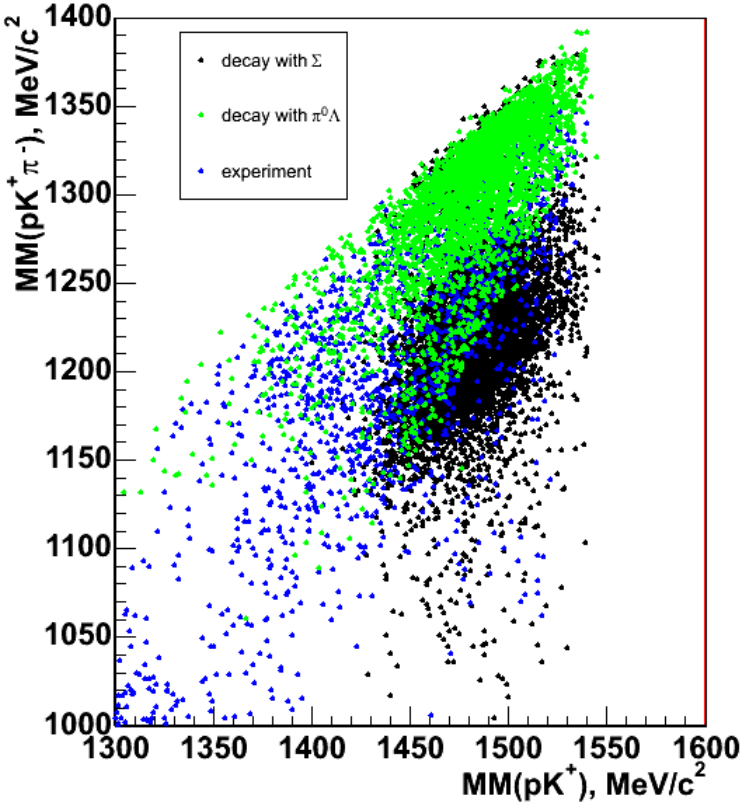


(data from Y.Maeda)

upper limit for $Y^*(1475) \to p\,K^+\,p\,K^-$?

Decay modes of Y*(1475)

$pp \rightarrow pK^+Y^*(1475) \rightarrow pK^+\pi^0\Lambda \rightarrow pK^+\pi^0\pi^-p$



Event number

	π^+	π^-
EXPERIMENT	100	967
MC $\Sigma(1385)$	20	32
MC $\Lambda(1405)$	22	170
MC $\Sigma(1480)$	52	692
MC $\Lambda(1520)$	6	73

Cross section

	$pp \longrightarrow pK^+\pi^+X^-$	$pp \longrightarrow pK^+\pi^-X^+$
counts	100 → *52 for Σ(1480)*	967 → *692 for Σ(1480)*
ε_{Pd} for K^+	0.9	0.9
ε_{Pd} for π^+ / ε_{Nd} for π^-	0.7	0.7
ε_{Fd} for protons	0.7	0.7
$\varepsilon_{delay\ veto}$	0.15	0.15
effective time (s)	419597	389773
luminosity integrated (pb^{-1})	4.0	3.7
luminosity average (s^{-1} cm^{-2})	$0.95(0.92 \div 0.98) \bullet 10^{31}$	
acceptance for Σ(1385)	0.000008	0.000285
acceptance for Λ(1405)	0.000077	0.000491
acceptance for Σ(1480)	0.000261	0.002220
acceptance for Λ(1520)	0.000845	0.006166

Cross section

	$pp \rightarrow pK^+\pi^+\Sigma^-$	$pp \rightarrow pK^+\pi^-X^+$
$\Sigma(1480)$ counts	52	692
ε_{Pd} for K^+	0.9	0.9
ε_{Pd} for π^+ / ε_{Nd} for π^-	0.7	0.7
ε_{Fd} for protons	0.7	0.7
$\varepsilon_{delay\ veto}$	0.15	0.15
effective time (s)	419597	389773
luminosity integrated (pb^{-1})	4.0	3.7
luminosity average (s^{-1} cm^{-2})	0.95 (0.92÷0.98) • 10^{31}	
acceptance (for $\Sigma(1480)$)	0.000261	0.002220
σ_{total}(nb)	**736**	**1045**

Cross section errors

- 10% for efficiencies of 3 detectors
- 10% for delayed veto
- 20% for luminosity

$\Rightarrow$ 0.9 • 0.9 • 0.9 • 0.9 • 0.8 $\rightarrow$ ***-52 %***

1.1 • 1.1 • 1.1 • 1.1 • 1.2 $\rightarrow$ ***+76 %***

Statistical error: π^+: ***14 %***

π^-: ***4 %***

$\Rightarrow$ for $pp \rightarrow pK^+Y$ with π^+: $(\mathbf{736} \pm 103_{stat}\ {}^{-383}_{+560})$ nb

for $pp \rightarrow pK^+Y$ with π^-: $(\mathbf{1045} \pm 39_{stat}\ {}^{-543}_{+794})$ nb

Cross section errors

- 10% for efficiencies of 3 detectors
- 10% for delayed veto
- 20% for luminosity

$\Rightarrow$ $0.9 \cdot 0.9 \cdot 0.9 \cdot 0.9 \cdot 0.8 \rightarrow$ ***-52 %***

$1.1 \cdot 1.1 \cdot 1.1 \cdot 1.1 \cdot 1.2 \rightarrow$ ***+76 %***

Statistical error: ***10 ÷ 20 %***

Summary

- Y*(1475) observed in charge symmetric final states
- mass: (1475 ± 15) MeV/c^2
- width: (45 ± 10) MeV/c^2
- $N\bar{K}$ decay mode not observed but an upper limit ?
- cross section for 2.83 GeV pp $\rightarrow$ $pK^+Y^*(1475)$: ~ 1μb