Mayor Surprises in $\pi^0\pi^0$ Production by π^- and K^- at Intermediate Energies

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$$f_0(600) \equiv \sigma \qquad I, J^{PC} = 0^+, 0^{++}$$

$$m = 400 - 1200 \text{ MeV}$$

$$\Gamma = 600 - 1000 \text{ MeV}$$

$$f_0 \rightarrow \pi\,\pi \ (\sim 100\%)$$

$f_0(600)$ and $\pi(135)$ are chiral partners

		$I(\pi^0\pi^0)$	$I(\pi^+\pi^-)$
1	$\pi^- p \rightarrow \pi^0\pi^0 n$	0, 2	0,1,2
2	$\gamma\, p \rightarrow \pi^0\pi^0 p$	0, 2	0,1,2
3	$K^- p \rightarrow \pi^0\pi^0 \Lambda$	0	0,1
4	$K^- p \rightarrow \pi^0\pi^0 \Sigma^0$	0,2	0,1,2

$$\frac{d^5\sigma\,(K^- p \rightarrow \pi^0\pi^0\Lambda)}{d(m_{\pi\pi}^2)\; d(m_{\pi\Lambda}^2)\; d\phi\; d\theta\; ds}$$

Since $\pi^0\pi^0\Lambda \rightarrow (\pi^0\pi^0)\,(\pi^0 n) \rightarrow 6\gamma n$

need a multiphoton spectrometer:

The Crystal Ball Detector

Isobar Model for $K^- p \to \pi^0 \pi^0 \Lambda$

1. $K^- p \to \Lambda^*$
2a. $\Lambda^* \to f_0 \Lambda$ $\quad f_0 \to \pi^0 \pi^0$
2b. $\Lambda^* \to \pi^0 \Sigma^0(1385)$ $\quad \Sigma \to \pi^0 \Lambda$

Dalitz plot is an event-density plot of a 3-body final state reaction.

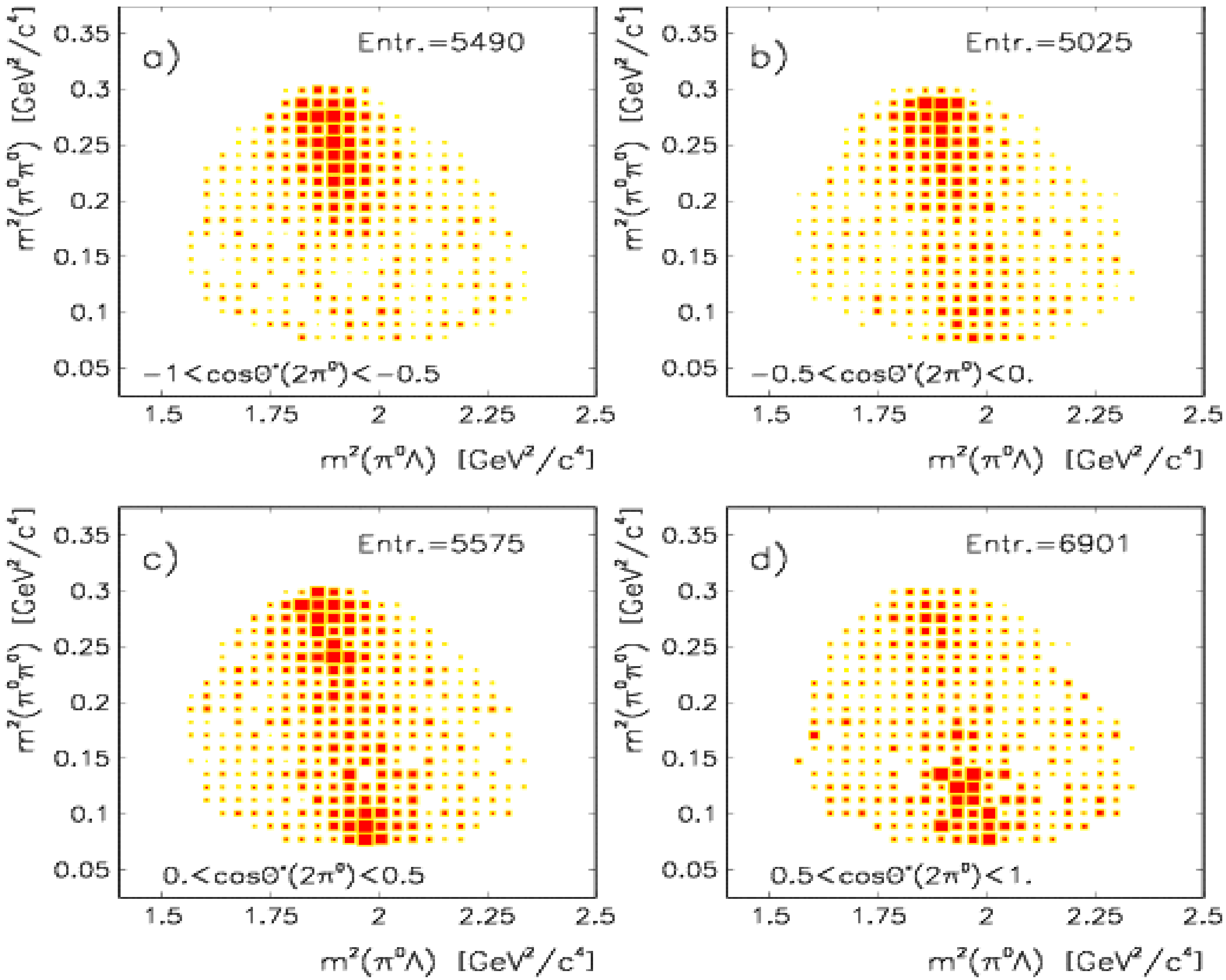
Axes: $m^2(\pi^0 \pi^0)$ and $m^2(\pi^0 \Lambda)$

Property: area is proportional to invariant phase space.

f_0 gives a uniform horizontal band

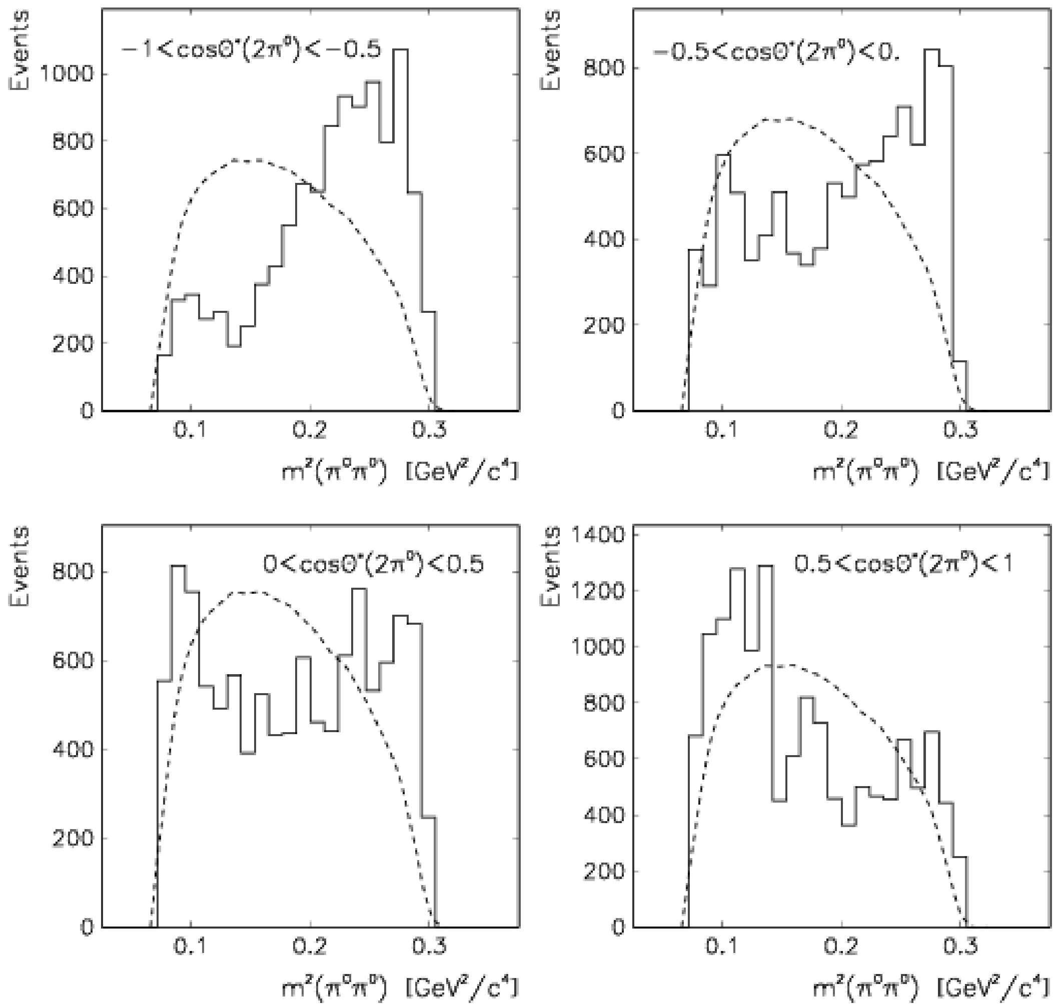
$\Sigma^0(1385)$ gives a non-uniform vertical band

$p_{K^-} = 714$ MeV/c $\quad K^- p \to \pi^0 \pi^0 \Lambda$



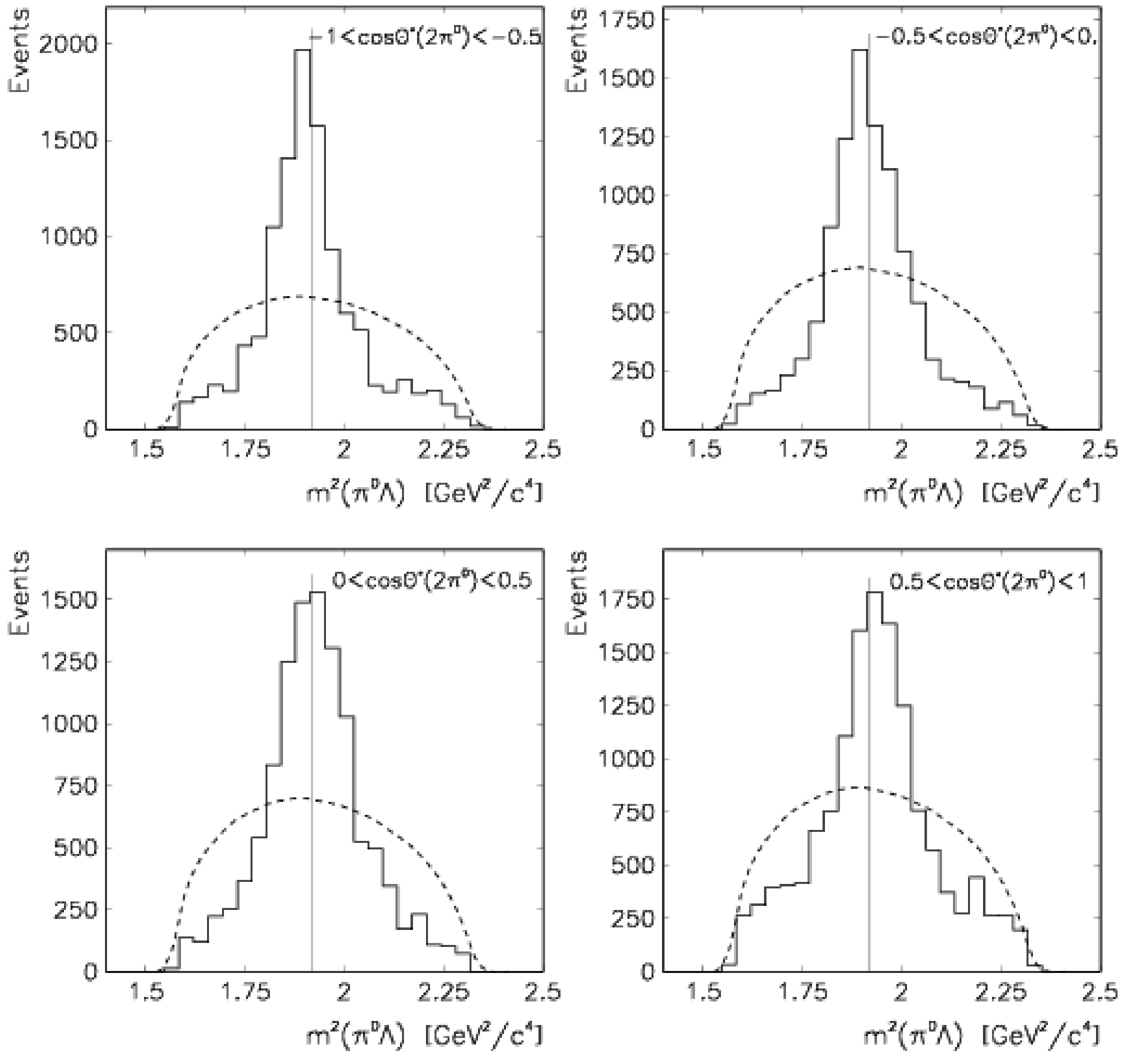
Dependence of Dalitz plot on $\cos\theta_{\pi\pi}$

$p_{K^-} = 714$ MeV/c $K^- p \rightarrow \pi^0 \pi^0 \Lambda$

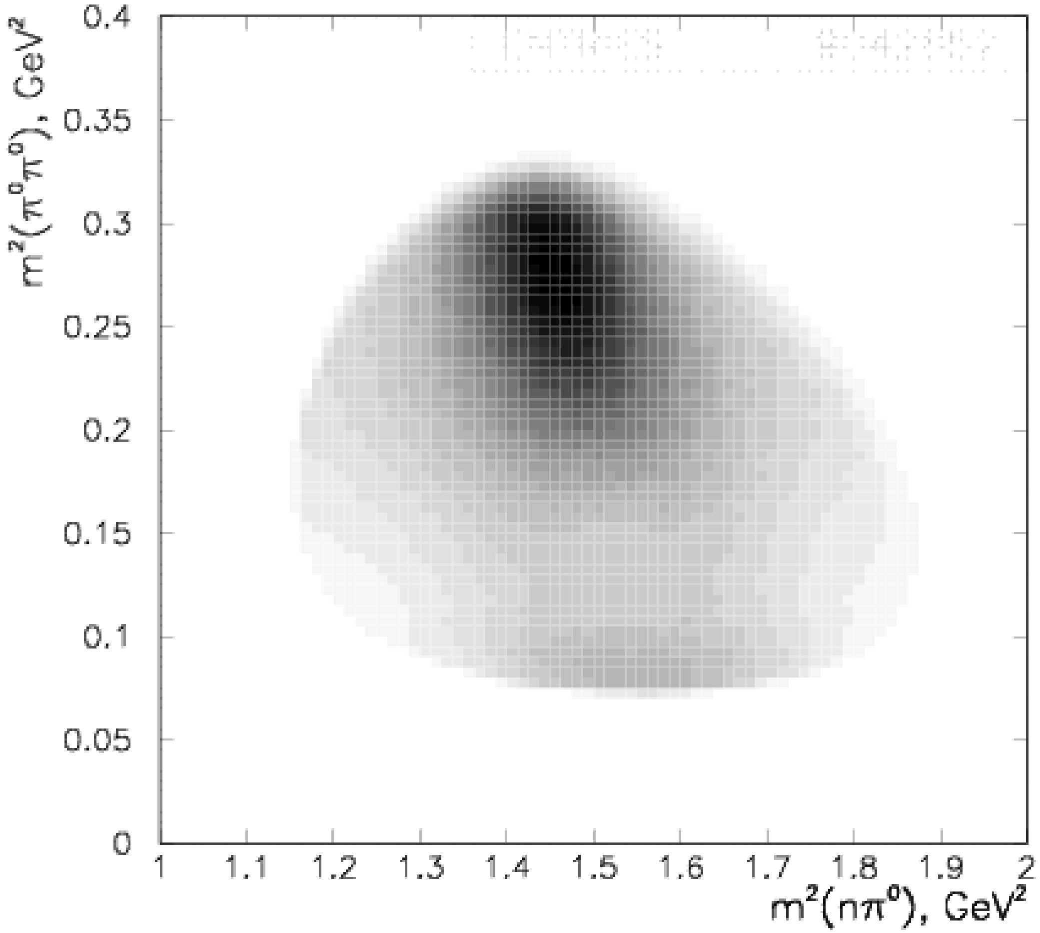


Dependence of $m_{\pi\pi}^2$ on $\cos\theta_{\pi\pi}$

$p_{K^-} = 714$ MeV/c $\quad K^-p \rightarrow \pi^0\pi^0\,\Lambda$



Dependence of $m_{\pi\Lambda}^2$ on $\cos\theta_{\pi\pi}$

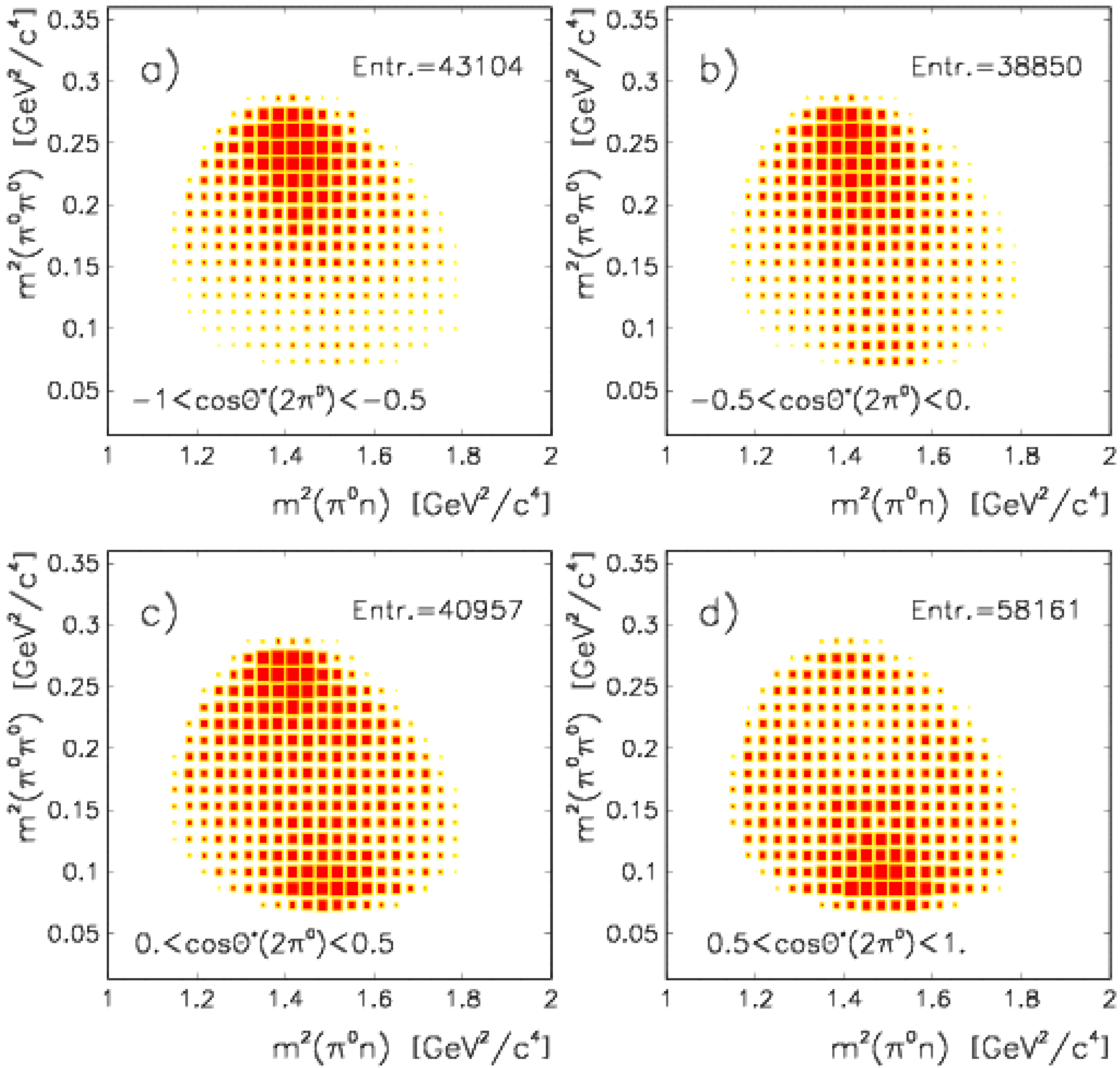


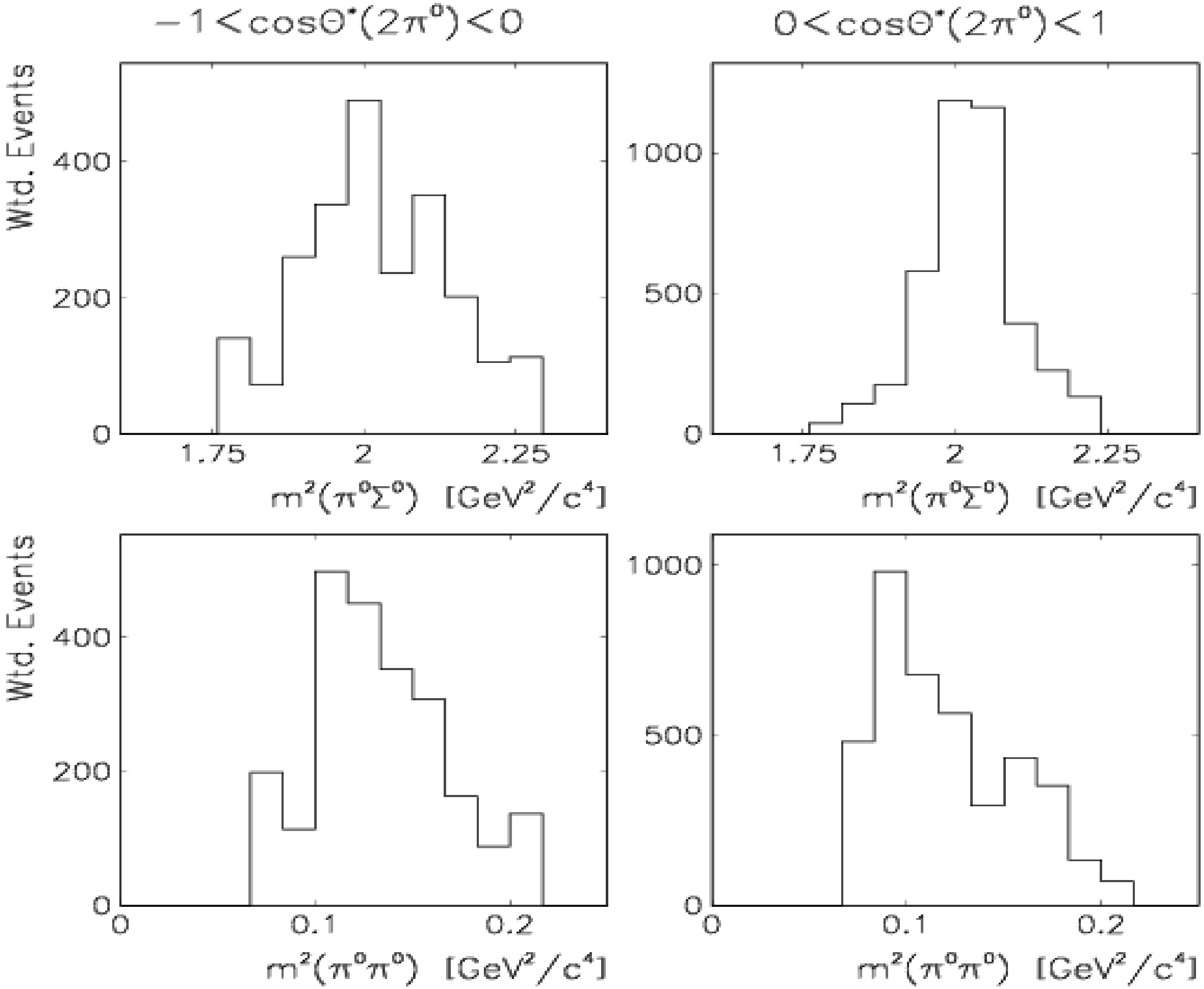
$$\pi^- p \rightarrow \pi^0 \pi^0 n$$

$p_\pi = 717$ MeV/c $\quad \Delta p = 24$

$2 \times 7 \cdot 10^6$ events

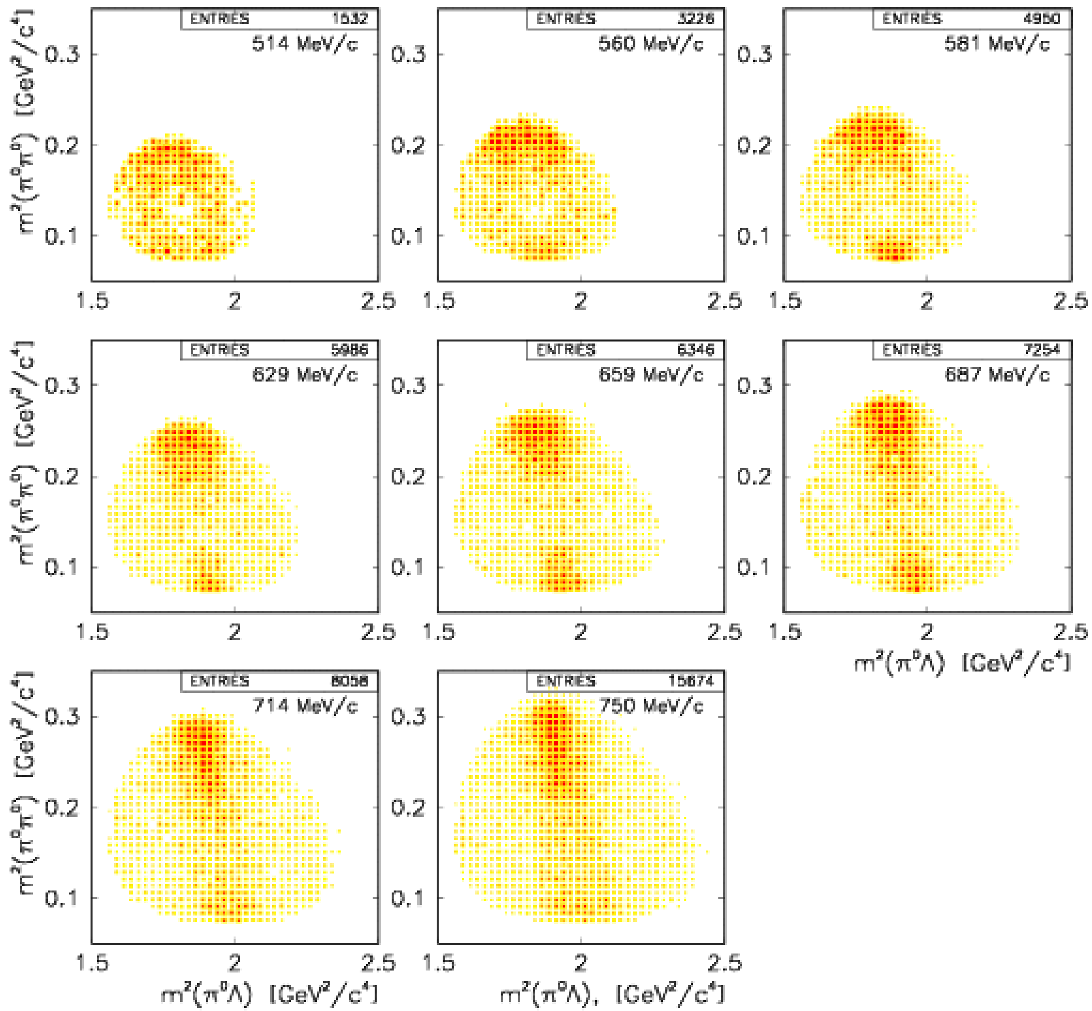
$\pi^- p \rightarrow \pi^0 \pi^0 n$ 656 MeV/c





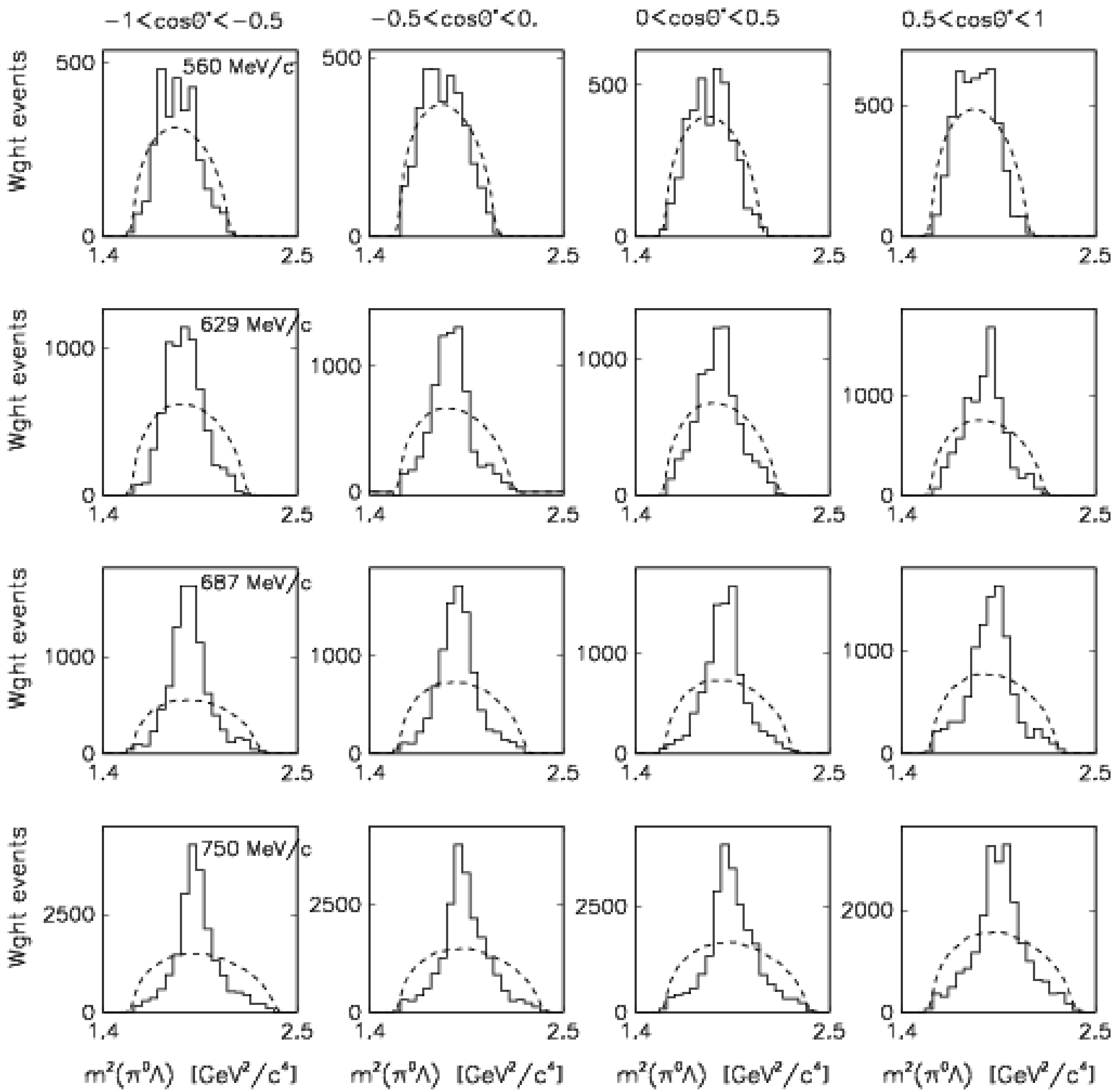
$K^- p \rightarrow \pi^0 \pi^0 \Sigma^0$

$K^{-}p \rightarrow \pi^{0}\pi^{0}\Lambda$

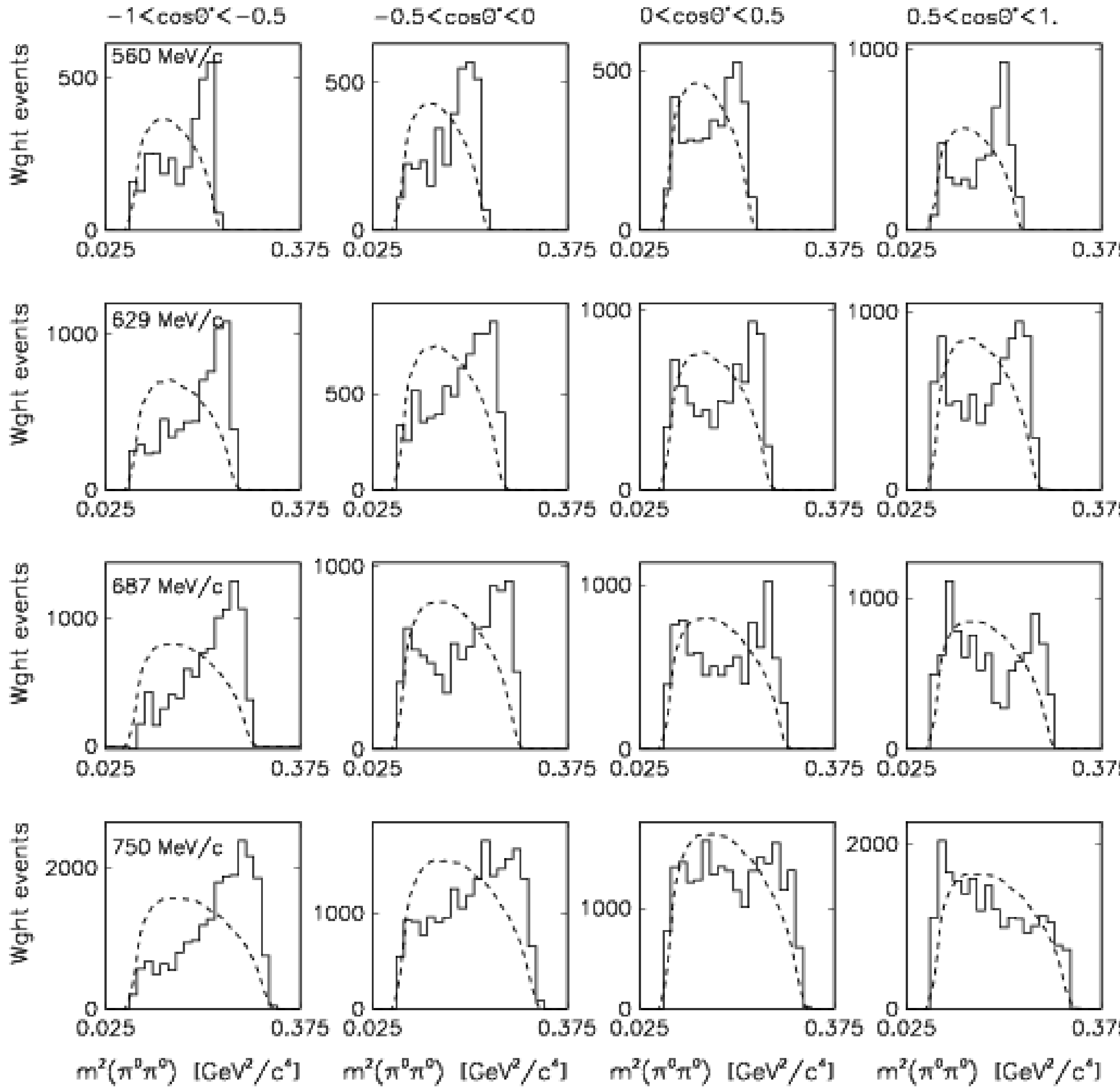


Dependence of Dalitz plot on beam momentum

$\pi^0\pi^0\Lambda$



$K^-p \to \pi^0\pi^0\Lambda$



Flavor Symmetry of QCD

$\pi^- p \to \eta n$	$K^- p \to \eta \Lambda$
1. sharp onset	**1.** sharp onset
2. $\sigma = (21 \pm 3) \mu b \times \tilde{p}_\eta$	**2.** $\sigma = (18 \pm 3) \mu b \times \tilde{p}_\eta$
3. $\sigma_{max} = (2.6 \pm 0.3) mb$	**3.** $\sigma_{max} = (1.4 \pm 0.2) mb$
4. bowl-shaped dσ	**4.** bowl-shaped dσ
5.	**5.** Λ-polarization < 0.1
6. $a_{\eta n}$ = large and attractive	**6.** $a_{\eta \Lambda}$ = large and attractive
7. BR($N^* \to \eta n$) = (30 – 55)% anomalously large	**7.** BR($\Lambda^* \to \eta \Lambda$) = (37 ± 7)% anomalously large
8. $N^* = N(1535)$ $\frac{1}{2}^-$	**8.** $\Lambda^* = \Lambda(1670)$ $\frac{1}{2}^-$

Interpretation

$$L_{QCD} = L_{glue} + L_{quark}$$

$$L_{QCD} = \overbrace{-\tfrac{1}{4}F_{\mu}F^{\mu}}^{L_{glue}} + \overbrace{\overline{\psi}_q D\psi_q - \overline{\psi}_q m_q \psi_q}^{L_{quark}}$$

$$= \overbrace{-\tfrac{1}{4}F_{\mu}F^{\mu} + \overline{\psi}_q D\psi_q}^{L_0} \overbrace{- \overline{\psi}_q m_q \psi_q}^{L_m}$$

$$= L_0 + L_m$$

g_s = strong coupling constant.
A_μ = gluon field.
ψ_q = quark field.

$L_{glue} = f(g_s, A_\mu)$
$L_{quark} = f(g_s, \psi_q, A_\mu, m_q)$
$L_0 = f(g_s, A_\mu, \psi_q)$
$L_m = f(\psi_q, m_q)$

L_0 embodies the universality of the strong interactions. It conserves isospin, charge symmetry, G-parity, and SU(3).

ALL FS breaking (IS, CS, and GP) is due to

$$L_m = \overline{\psi} m \psi$$

(disregarding electromagnetic interactions)

L_m allows the determination of
$m_d - m_u$ and $m_s - m_d$.

Prediction from isospin invariance:

$$\sigma(\pi^+ p) = \sigma(\pi^- n) \neq \sigma(\pi^+ n)$$

Expand to SU(3) for p~0.7GeV/c

A $\pi^- p \to N^* \to \pi^0 \Delta^0(1232) \to \pi^0 \pi^0 n$

B $K^- p \to \Lambda^* \to \pi^0 \Sigma^0(1385) \to \pi^0 \pi^0 \Lambda$

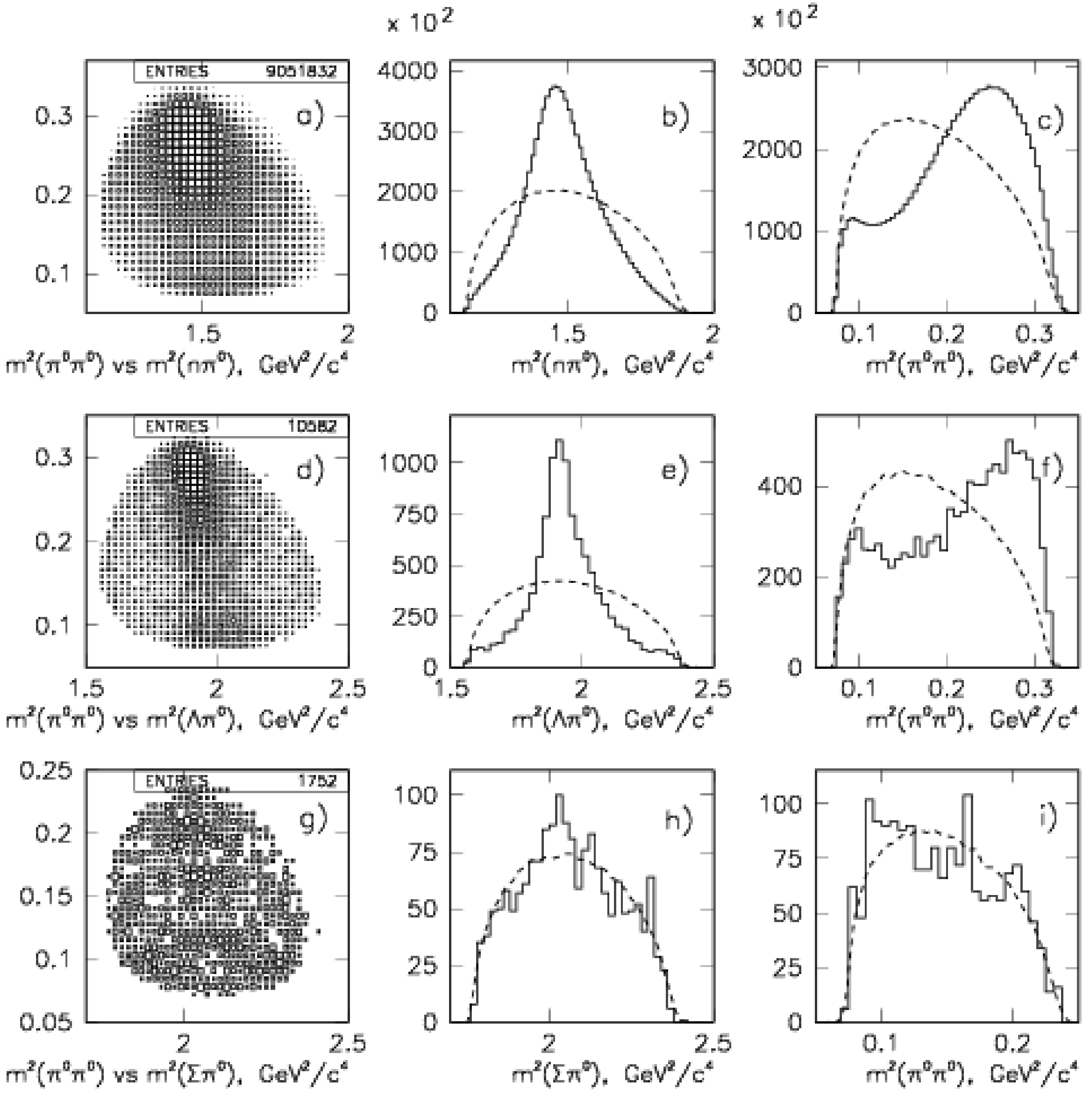
C $K^- p \to \Sigma^* \to \pi^0 \Lambda(1405) \to \pi^0 \pi^0 \Sigma^0$

D $\gamma p \to N^* \to \pi^0 \Delta^+(1232) \to \pi^0 \pi^0 p$

SU(3) Flavor Symmetry:

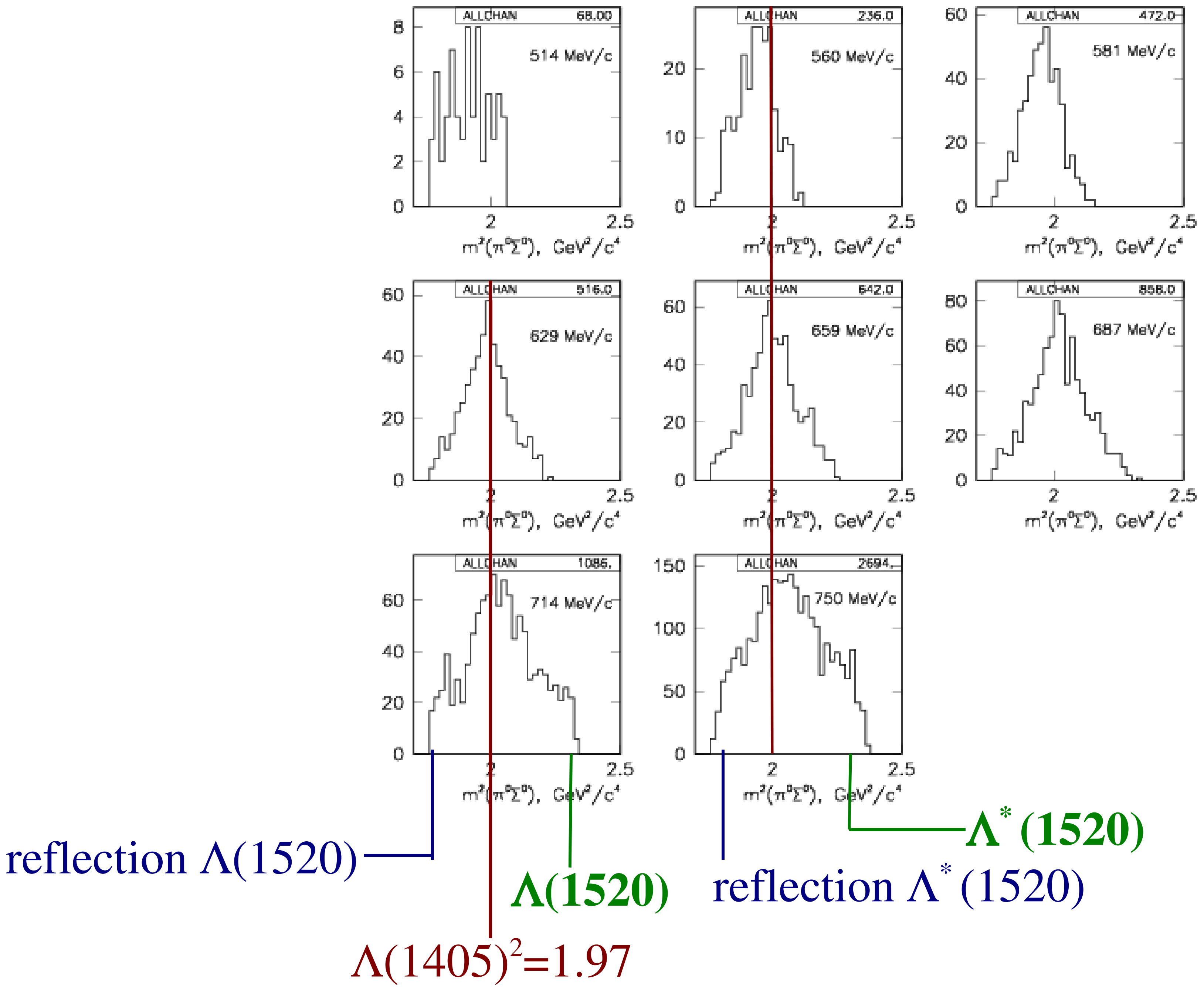
$$A \leftrightarrow B \not\leftrightarrow C \not\leftrightarrow D$$

	$\pi^0\pi^0 n$	$\pi^0\pi^0\Lambda$	$\pi^0\pi^0\Sigma^0$
σ_t(mb)	1.4	0.7	0.1
intermediate state	$\Delta(1232)\ (3/2)^+$	$\Sigma(1385)\ (3/2)^+$	$\Lambda(1405)\frac{1}{2}^-$
SU(3) class	decup	decup	singlet
$m^2(\pi\ B)$	one big, slim, peak		1 wide peak
shape	concave	concave	convex
cosθ	little	little	strong
$m^2(\pi^0\pi^0)$	two unequal peaks		one peak
shape	similar		different
cosθ	strong	strong	little
0.7	0.1 GeV^2	0.1	
0.3	0.15	0.15	
-0.3	0.23	0.23	
-0.7	0.21	0.21	
$\sqrt{s}$ dependence	similar		



ENTRIES 9051832
a)
m²(π⁰π⁰) vs m²(nπ⁰), GeV²/c⁴
x 10²
b)
m²(nπ⁰), GeV²/c⁴
x 10²
c)
m²(π⁰π⁰), GeV²/c⁴
ENTRIES 10582
d)
m²(π⁰π⁰) vs m²(Λπ⁰), GeV²/c⁴
e)
m²(Λπ⁰), GeV²/c⁴
f)
m²(π⁰π⁰), GeV²/c⁴
ENTRIES 1752
g)
m²(π⁰π⁰) vs m²(Σπ⁰), GeV²/c⁴
h)
m²(Σπ⁰), GeV²/c⁴
i)
m²(π⁰π⁰), GeV²/c⁴

$K^-p \to \pi^0\pi^0\Sigma^0$



Summary and Conclusions

1. $\pi^0\pi^0$ production by π^- and K^- in S_{11} and D_{13} region is dominated by baryonic-resonance intermediate state(s)

   $K^-p \to \pi^0\pi^0\Lambda$ by $\Sigma^*(1385)\ (3/2)^+$

   $K^-p \to \pi^0\pi^0\Sigma^0$ by $\Lambda^*(1405)\ ½^-$, $\Lambda^*(1520)\ (3/2)^-$

   $\pi^-p \to \pi^0\pi^0 n$ by $\Delta^*(1232)\ (3/2)^+$

   $\gamma p \to \pi^0\pi^0 p$ by $\Delta^*(1232)\ (3/2)^+$

2. There is no direct evidence for $f_0 \to \pi^0\pi^0$

   $\sigma_t < 10\%$

3. No evidence for a $\Sigma^*(1480) \to \pi^0\Lambda$ or any other light Σ^* besides the $\Sigma^*(1385)$

Summary and Conclusions

4. Dalitz plots depend strongly on $\theta_{\pi\pi}$.

Consequences:

a. need to measure full $d^5\sigma$

b. Existing σ_t need to be reevaluated (except CB)

c. Energy dependence of δ_0^0 for $\pi^0\pi^0$ scattering phase needs reevaluation

d. Expect more accurate mass and width for $\Sigma^*(1385)$ and $\Lambda^*(1405)$, in particular for $\Sigma^{+-0}(1385)$ mass splitting

e. mass and width of $f_0(600)$ still unclear

Summary and Conclusions

5. Occurance of phantom peaks in $m(\pi^0\pi^0)$ due to the dominance of strong intermediate state baryonic resonances.
6. New triumphs of broken SU(3) flavor symmetry: $d^5\sigma(K^-p \to \pi^0\pi^0\Lambda)$ has the same features as $d^5\sigma(\pi^-p \to \pi^0\pi^0 n)$ while $d^5\sigma(K^-p \to \pi^0\pi^0\Sigma^0)$ is quite different.

   Flavor symmetry provides a unique tool to search for exotic baryonic states (hybrids, MB bound states…)