High Statistics Search for Pentaquarks with Hyper*CP*

Michael J. Longo

University of Michigan

For the Hyper*CP* collaboration

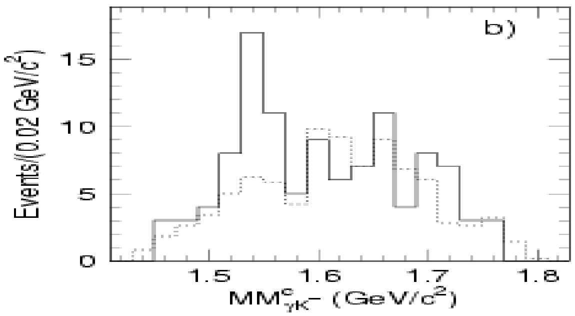
QNP 2004

Outline

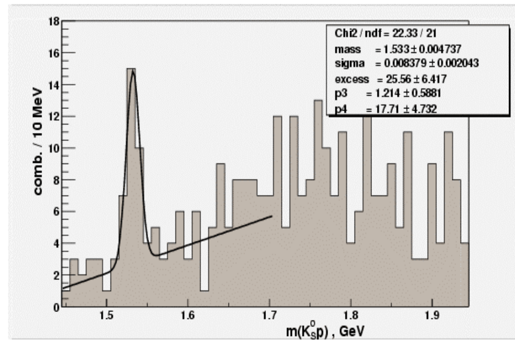
- Introduction
- E871/Hyper*CP* experiment
- Pentaquark search technique [mainly $\boldsymbol{\theta}^{+}$(1.54)]
- How (not) to make bumps
- Comments and conclusions

"Typical" Data from sightings

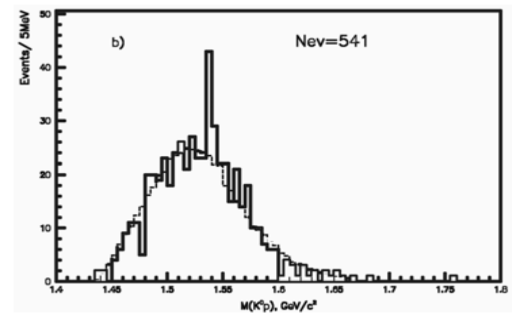
LEPS@SPring8



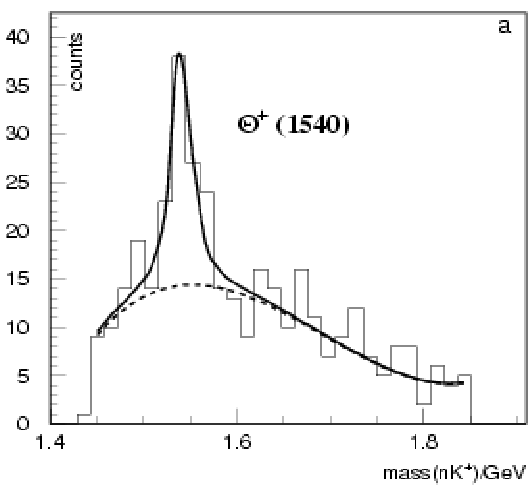
ITEP



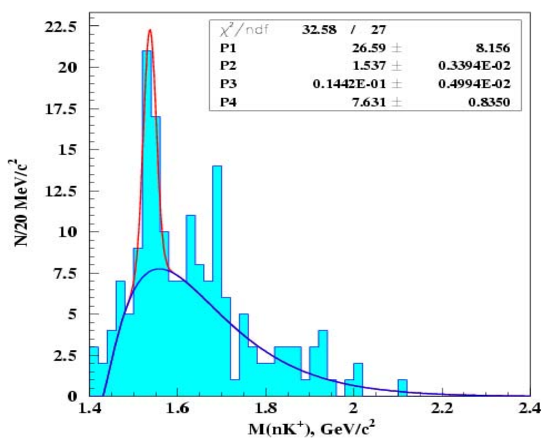
DIANA@ITEP



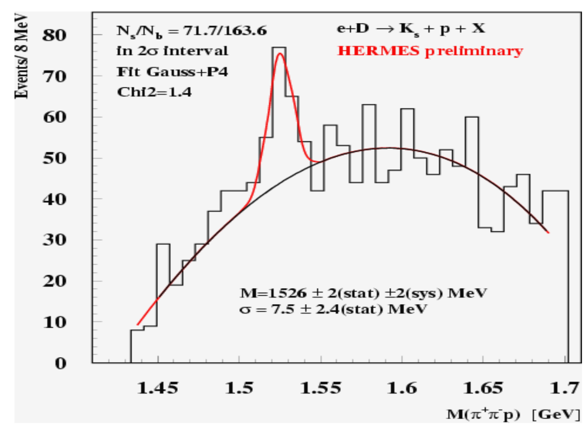
SAPHIR @ ELSA



CLAS@JLAB



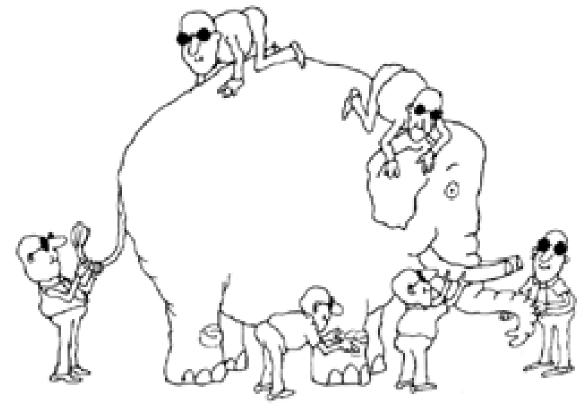
HERMES@DESY



Summary of Positive Results (from HERMES, Airapetian *et al.*)

Experiment	Θ^+ Mass (MeV)	Γ (MeV)
LEPS/SPring-8	: $1540 \pm 10 \pm 5$	: <25
DIANA	: $1539 \pm 2 \pm$ few	: <9
CLAS(d)	: $1542 \pm 2 \pm 5$	: <21
SAPHIR	: $1540 \pm 4 \pm 2$	: <25
ITEP(ν)	: 1533 ± 5	: <20
CLAS(p)	: $1555 \pm 1 \pm 10$	: $<26 \pm 7$
HERMES	: $1528 \pm 2.6 \pm 2.1$	: $19 \pm 5 \pm 2$
ITEP(p)	: $1526 \pm 3 \pm 3$	: <24
ZEUS	: 1527 ± 3	: $<10 \pm 2$

Note discrepancies in masses.



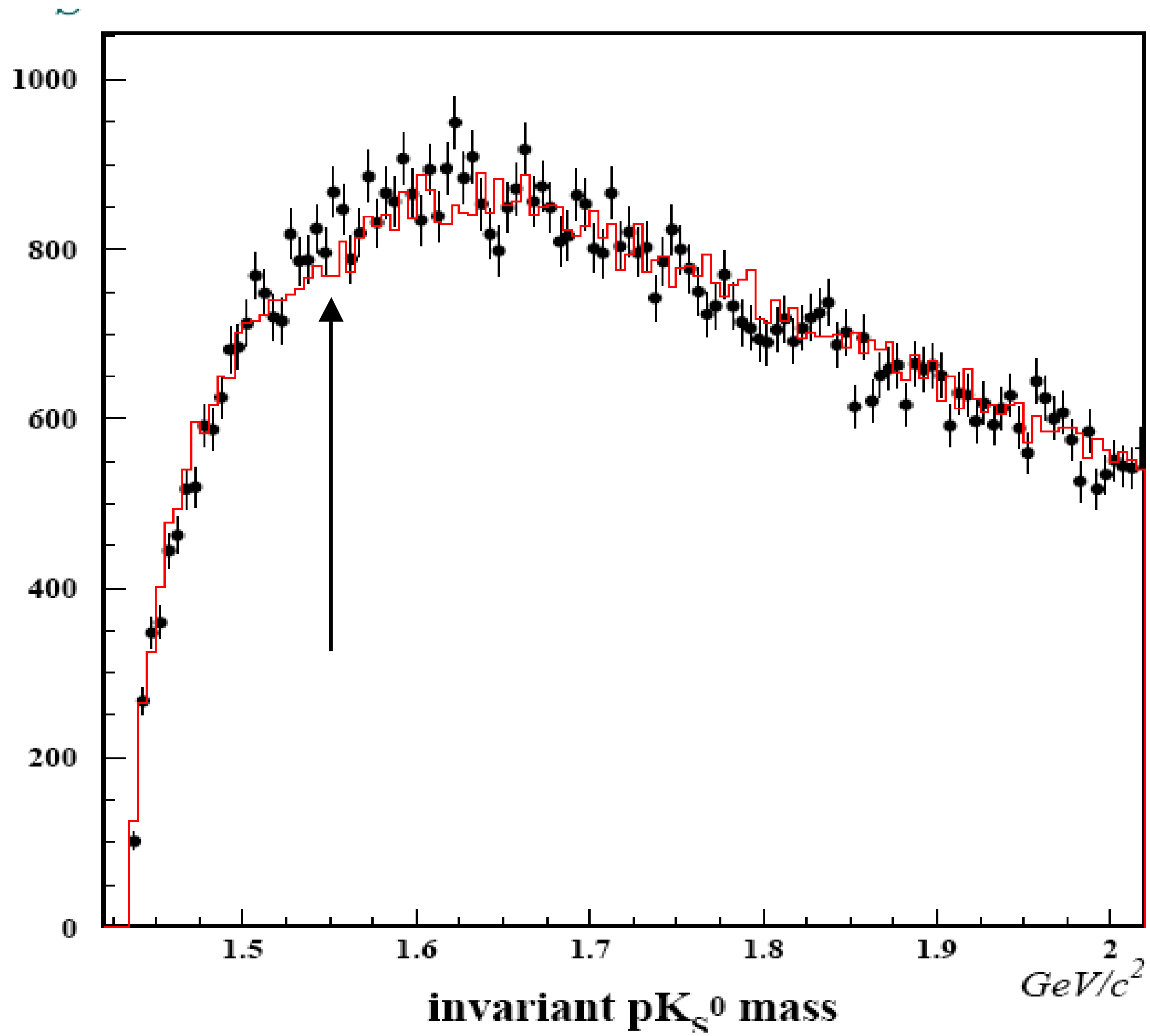
The discrepancies in mass are quite serious. It's hard to believe all experiments are looking at the same beast.

Negative Results

- HERA-B [PentaQuark Forum, DESY, 25 Nov. 2003] "No evidence for narrow pentaquark states" with 3.4 x 10^6 K_s and 2 x 10^4 Ξ^-.
- CDF [www-cdf.fnal.gov/physics/new/bottom/040428.blessed-theta/] No evidence for narrow K^0, p in either min. bias or large p_T data set.
- BES Collaboration [hep-ex/0402012] Upper limits ~10^{-5} for branching ratio of $J/\Psi \to \theta\bar{\theta}$.
- ALEPH, OPAL, PHENIX, DELPHI, NA49, unpublished (next 5 slides)
- STAR [S. Salur, nucl-ex/0403009], $\sqrt{s} = 200$ pp collisions, <~25 among ~5000 K^0, p
- Dozens of experiments over past 50 years [Particle Data Book]

Note that negative results are much less likely to be published– but they can't hide from Google!

New Results on the Θ_s from ALEPH

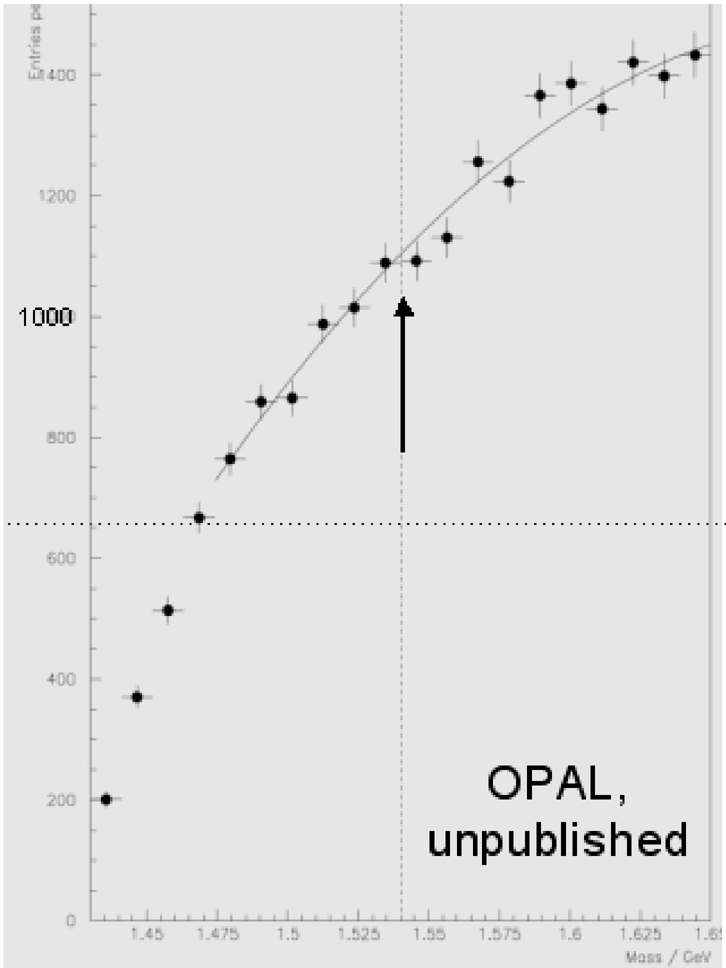


More unpublished non-sightings

ALEPH

Nothing fundamentally different seen in e+e

www.saske.sk/UEF/OSF/DIS/talks/plenary/milstead.ppt

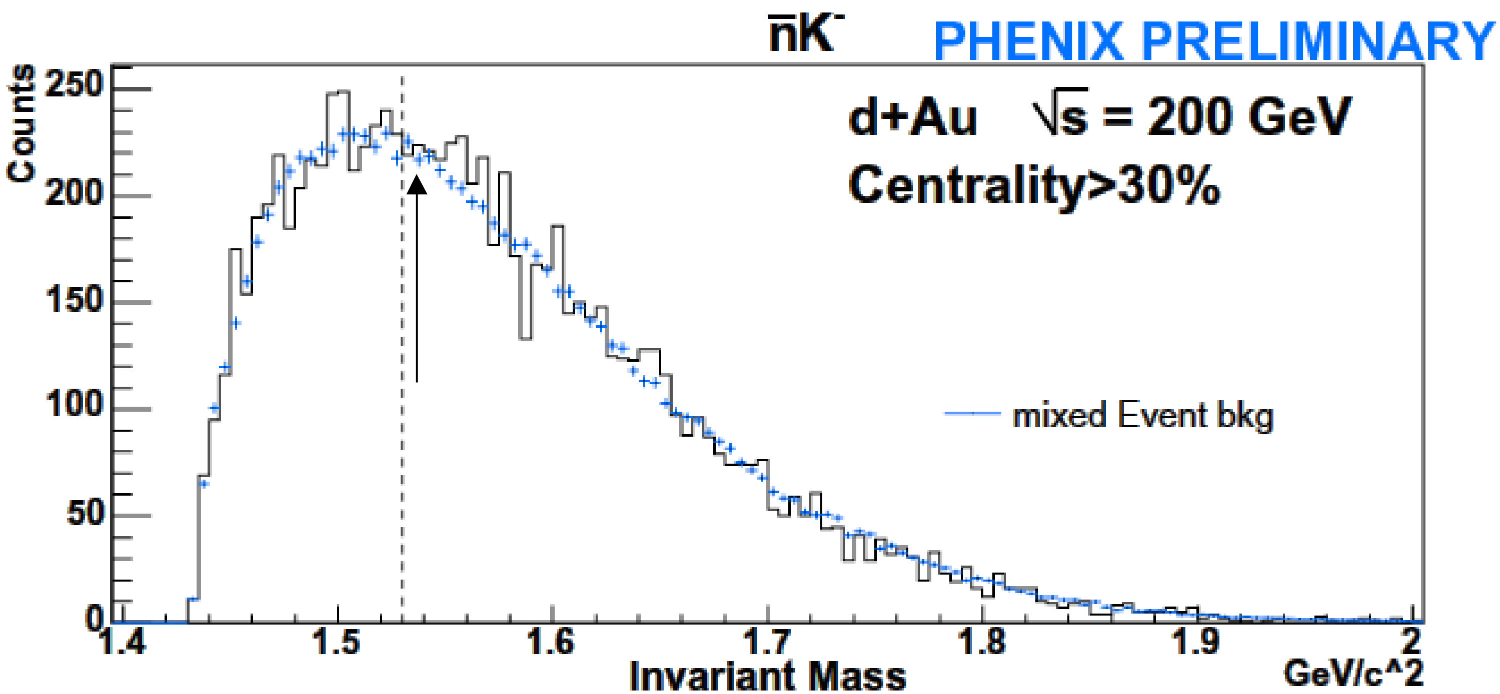


- Nothing to be seen
- But then, of course, people want more cuts, e.g.
  - Demand a K^+/K^- in events with K^0_s $\bar{p}/p$ combinations
  - Tighter dE/dx selections
  - Cuts on candidate momentum
- To ensure avoidance of topiary, I did this "blind"
  - I made 24 mass plots with different, anonymous, cuts, and invited my colleagues to find a peak
  - All agreed there was nothing
- But still people want work on this … I'm leaving it to Delphi

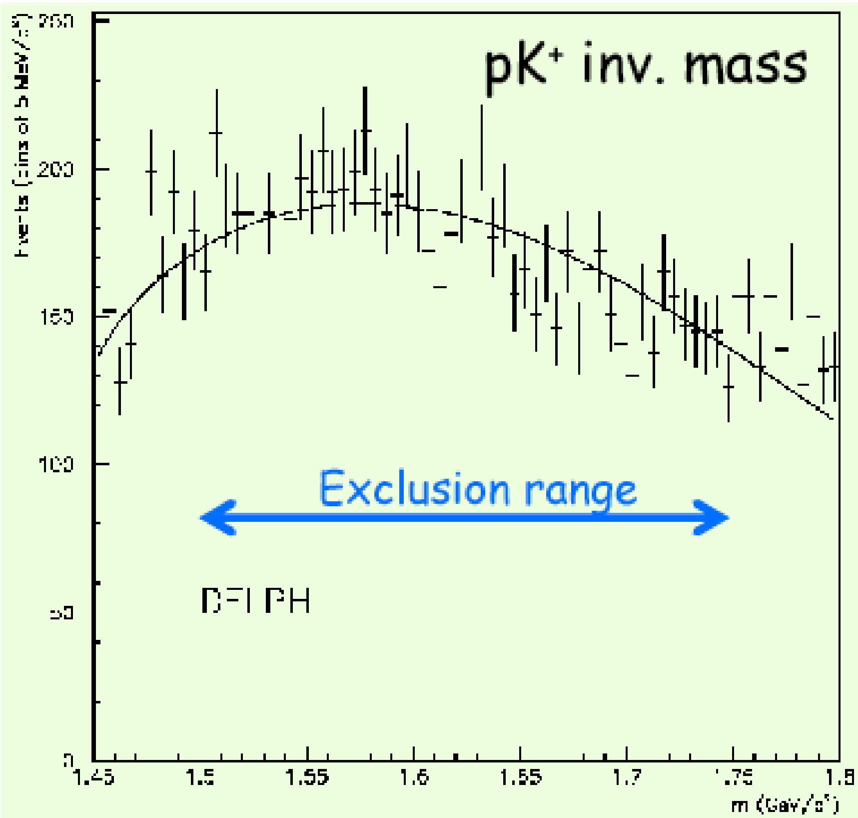
21 June 2002 George Lafferty 5

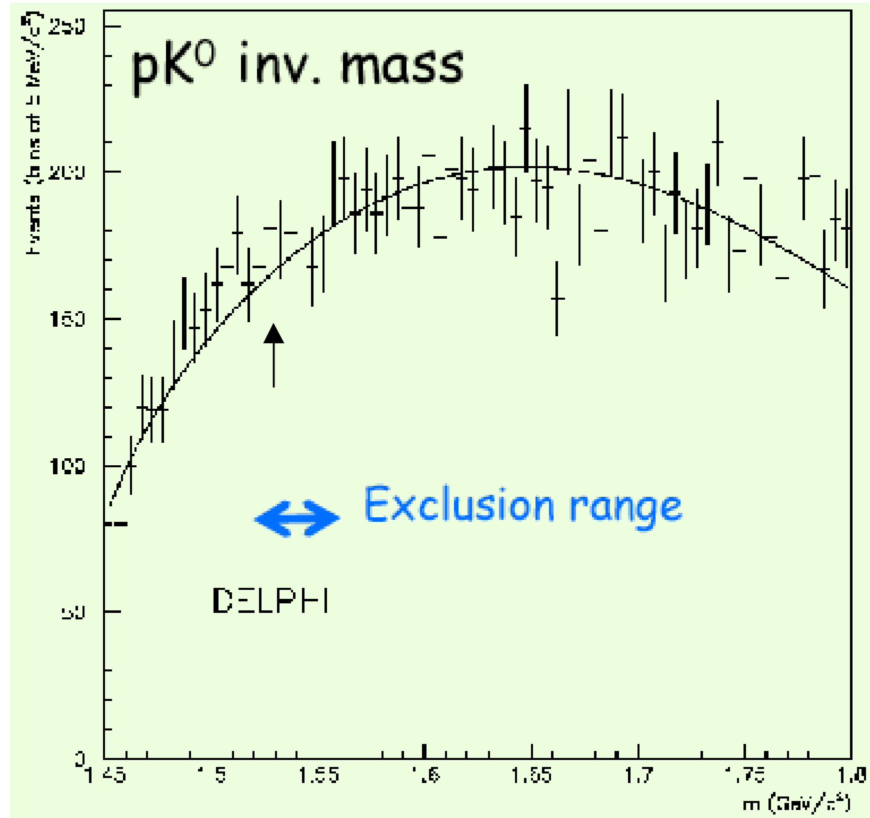
George Lafferty, www.hep.man.ac.uk/u/gdl/xmas.ppt

C. Pinkenburg, nucl-ex/0404001, (after timing correction…)



DELPHI

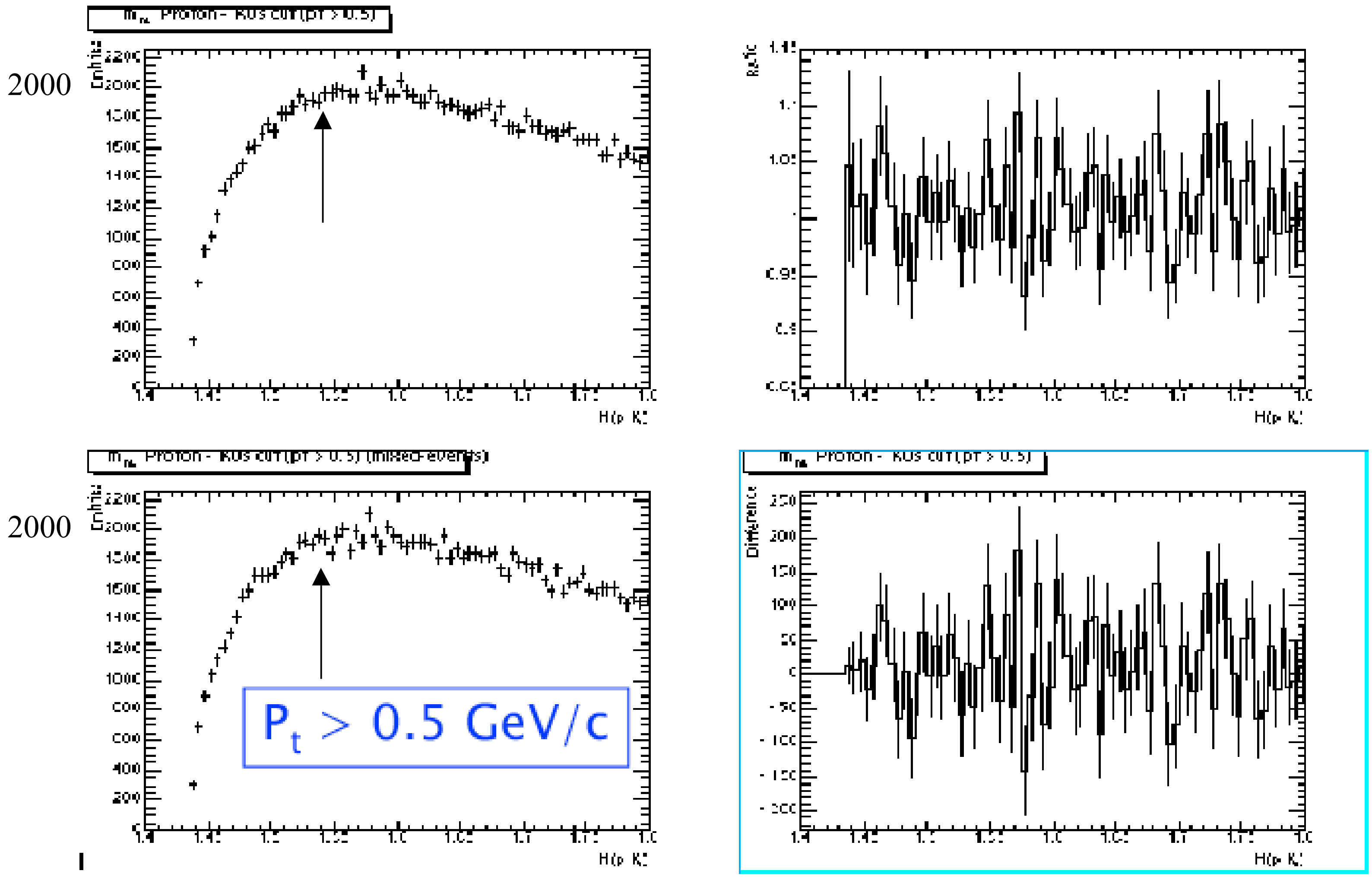




Nothing → multiplicity limits

$\langle N(\Theta^{++}) \rangle < 0.006$ $\langle N(\Theta^{+}) \rangle < 0.015$

$\theta^+ \rightarrow p + K^0$ in central Pb+Pb NA49/Blume



Cahn & Trilling

A width of 1 MeV is quite uncommon for a hadronic decay. For comparison we consider the $\Lambda(1520)$, which decays by d wave to $\bar{K}N$ with a partial width of 7.2 MeV. If the $\Theta(1540)^+$ decays via p wave, it might be expected to be somewhat broader than the $\Lambda(1520)$. Instead it is evidently much narrower.

It is not possible to make quantitative statements of the same sort using the photoproduction data reported by CLAS [3,4] or SAPHIR [5]. However, qualitatively, the very small apparent width suggests that nonresonant production cross sections should be quite small, while the data of these experiments seem to show quite visible effects.

The value for the width inferred from the DIANA and the limits derived from the charge-exchange and total-cross-section measurements in deuterium are not inconsistent. However, they point to such a narrow width that, if the $\Theta(1540)^+$ truly exists, it is exotic dynamically as well as in its quantum numbers.

See also, Sibirtsev *et al*., hep-ph/0405099; Nussinov, hep-ph/0307357; R.A. Arndt *et al*., nucl-th/0311030; Haidenbauer & Krein,Phys.Rev. C68, 05221(2003)

A width <1 MeV is unprecedented for a hadronic decay, and very hard to explain.

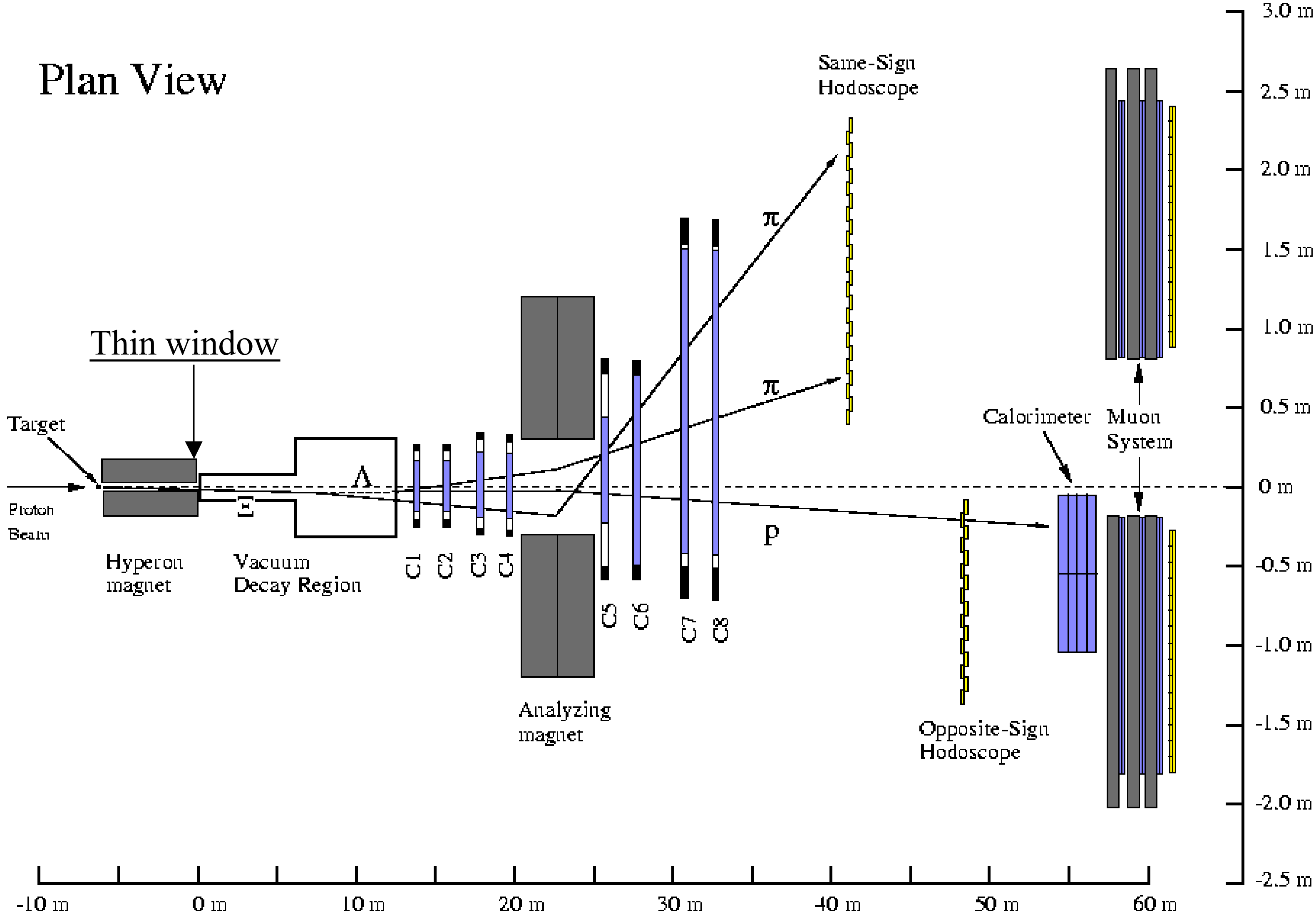
It also appears to be inconsistent with the width measured by HERMES.

From an experimental point of view, the narrow width puts a premium on good experimental mass resolution. – If the signal/background ratio is ~1 with a 10 MeV mass resolution, It will be ~10 with a 1 MeV mass resolution (!)

FNAL E871/HyperCP Experiment

- Designed for studying CP violation in the hyperon decay sequence, $\Xi \to \Lambda\pi$, $\Lambda \to p\pi$.
- 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.

E871/HyperCP Spectrometer



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.

Pentaquark Search Technique

- Look mainly for $\theta(1.54\,\text{GeV}) \rightarrow p + K^0$ with $K_s^0 \rightarrow \pi^+ + \pi^-$ produced in thin windows (~5 x 10^{-4} interaction lengths) at upstream end of vacuum decay region.

- Note that, except for muons, we have no particle identification. However, K_s^0 can be identified by reconstructing (π^+,π^-) mass, and proton usually carries off largest fraction of the momentum.

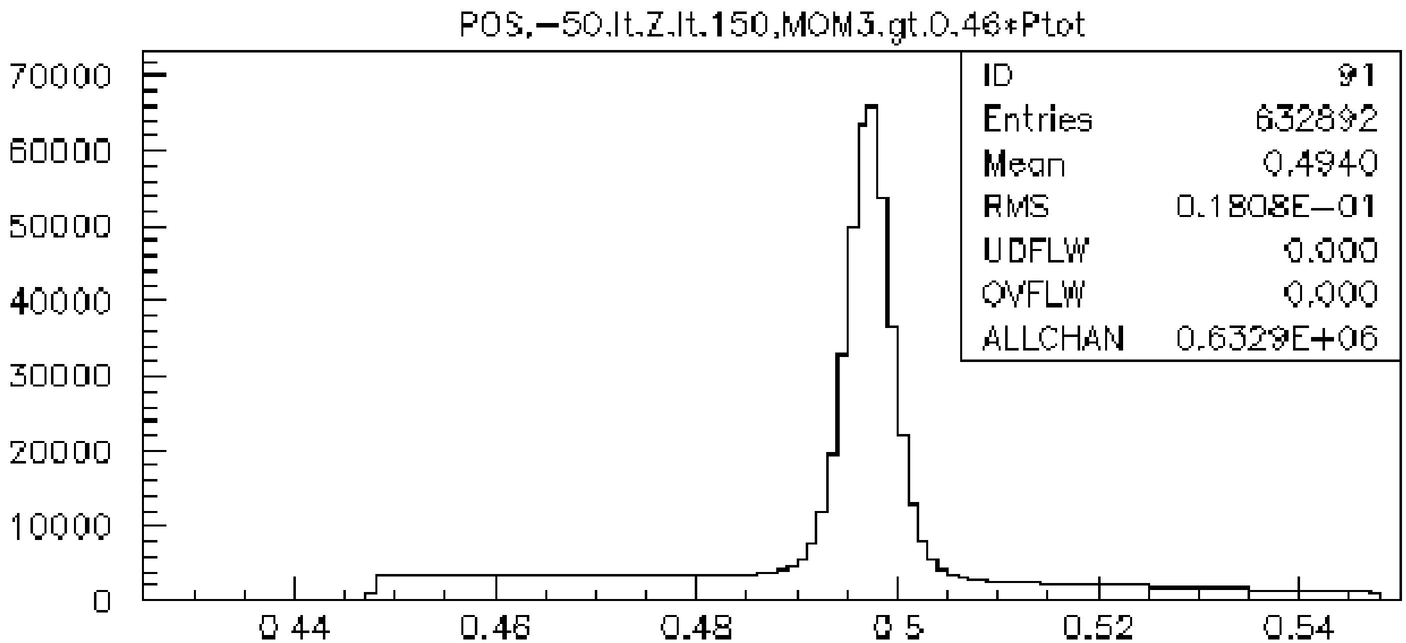
- Note that trigger used for pentaquark search was prescaled by a factor of 100, so only 1% of potential candidates were recorded.

- Our mass resolution is < 2 MeV/c^2, much better than that for most experiments that observed pentaquarks.

Summary of Cuts Applied to Events

- Vertex from region near thin windows. (Produced in window)
- Two-pion mass between 0.490 and 0.505 GeV/c^2. (Good K^0_s)
- Total momentum vector should not extrapolate back to production target. (Not from target)
- Total momentum vector should not extrapolate back to edge of defining collimator. (Not from collimator edge)
- Proton momentum >0.50 P_{tot}. (Proton carries off most of momentum)
- Cuts to remove "ghost tracks" (Remove events with duplicated tracks)

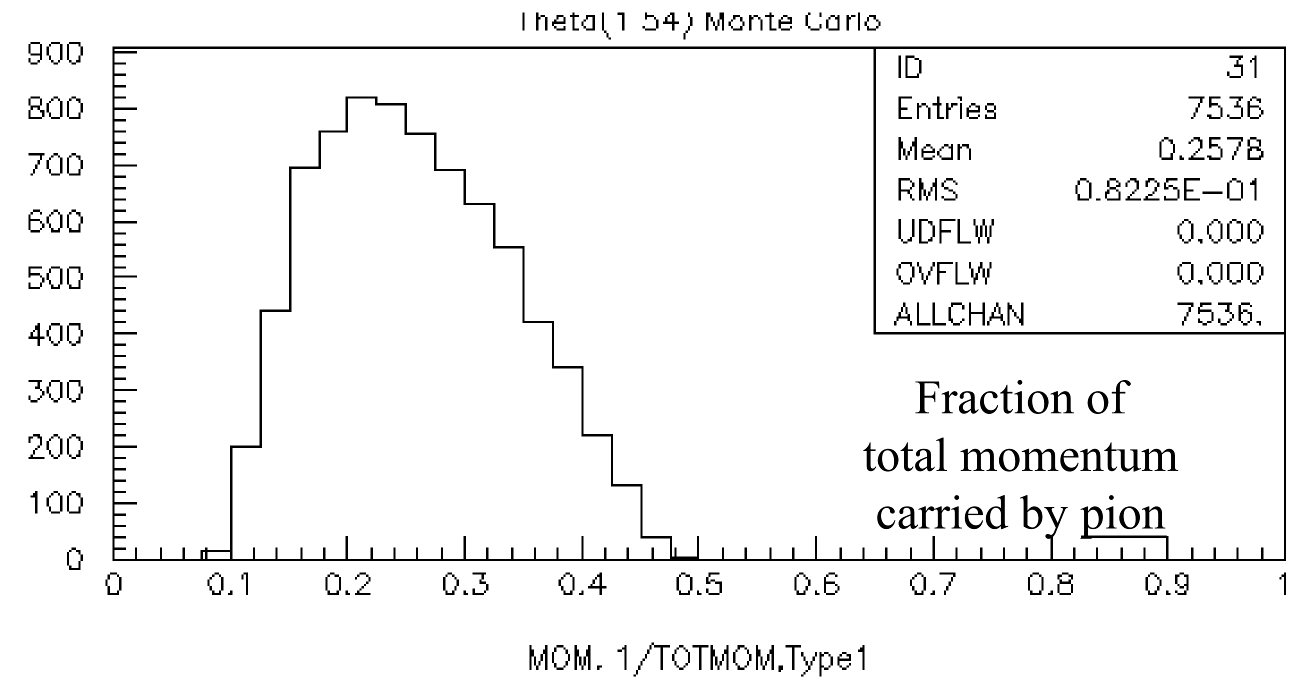
2-pion reconstructed mass for θ^+ candidates

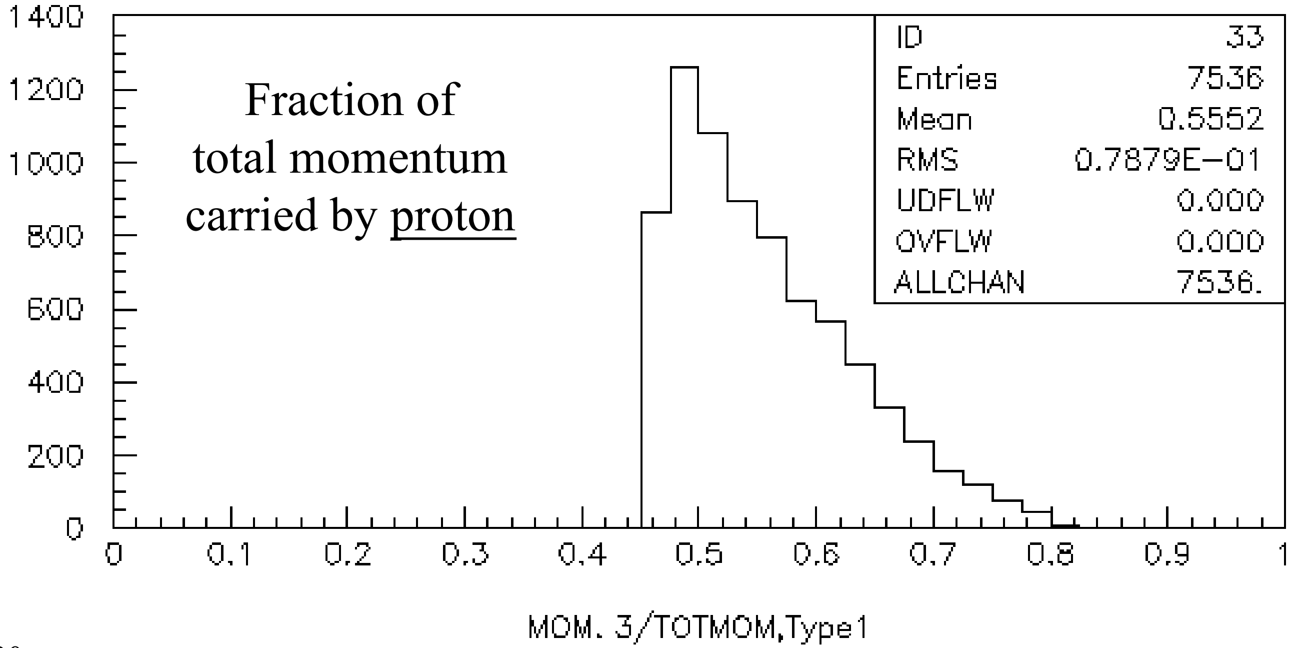


π^+,π^- mass (GeV)

~400,000 clean K_s^0

19

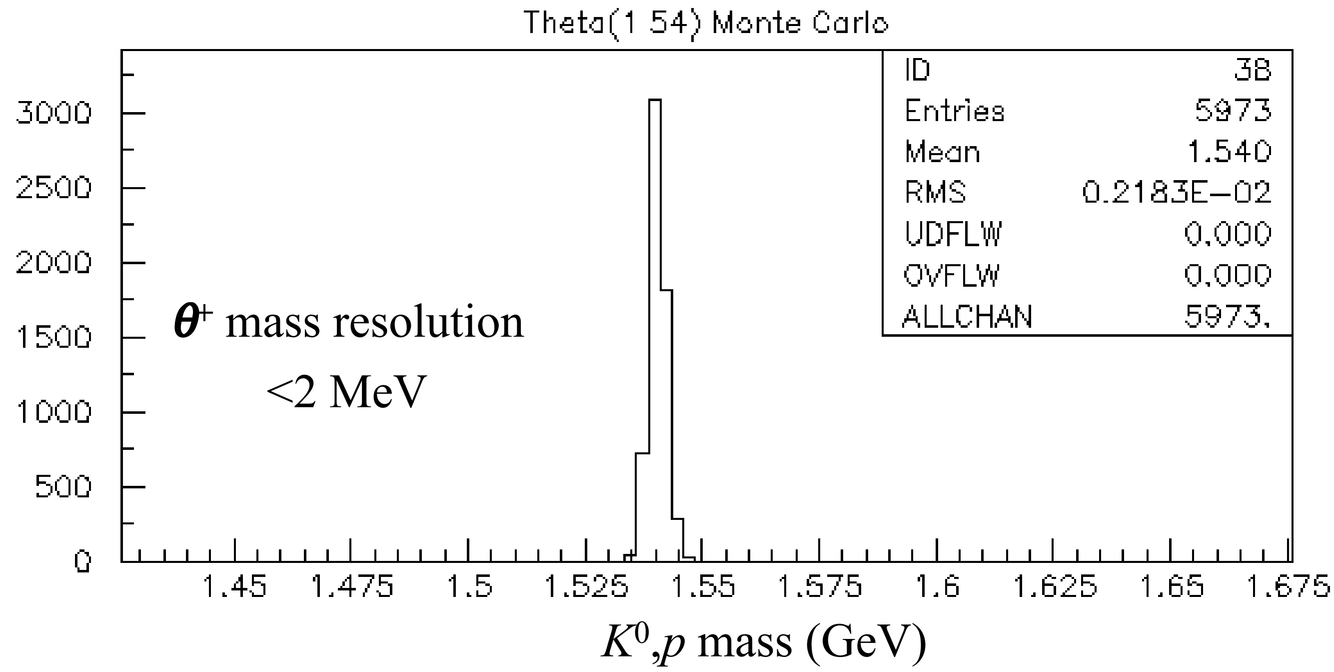




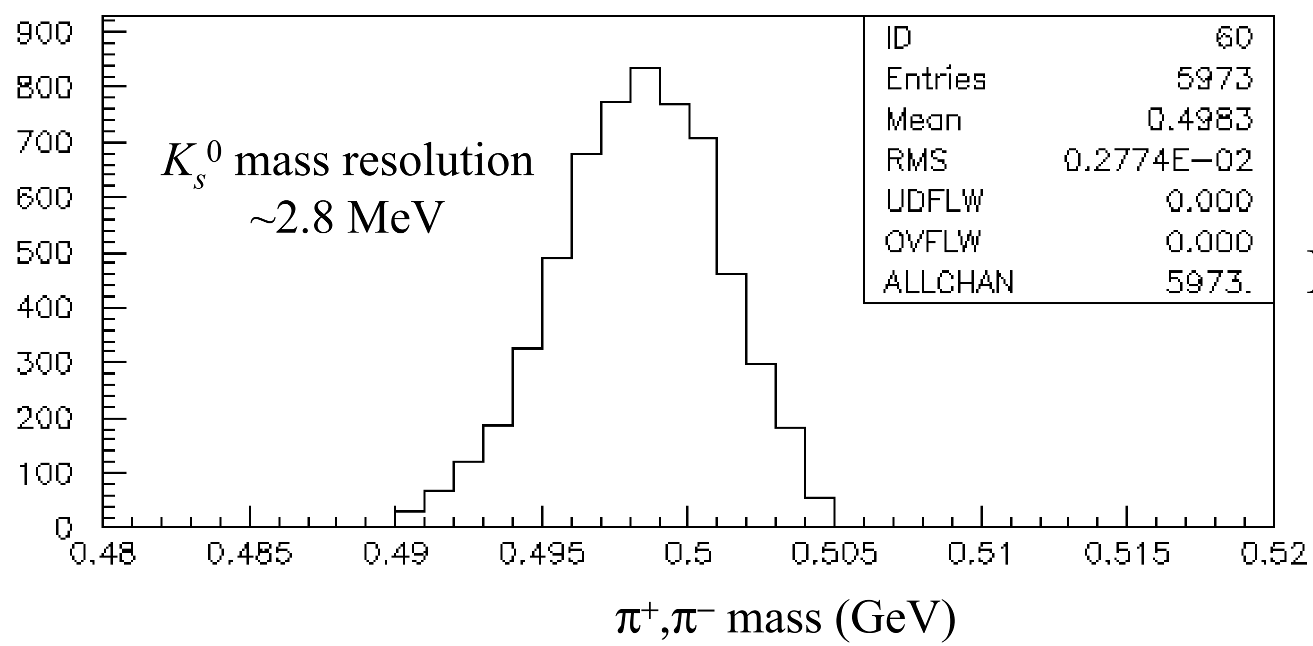
θ^+ Monte Carlo: Proton momentum >> pions'

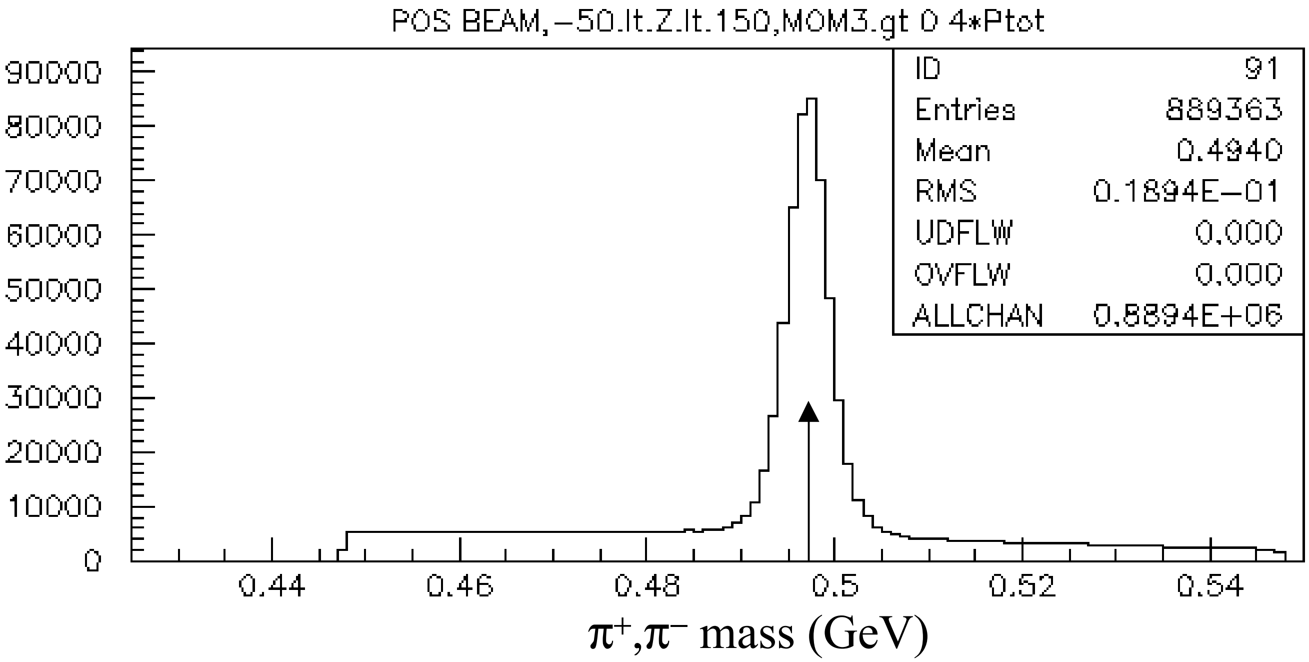
θ^+(1.54) Monte Carlo

Reconstructed K_s^0, p mass



Reconstructed π^+,π^- mass

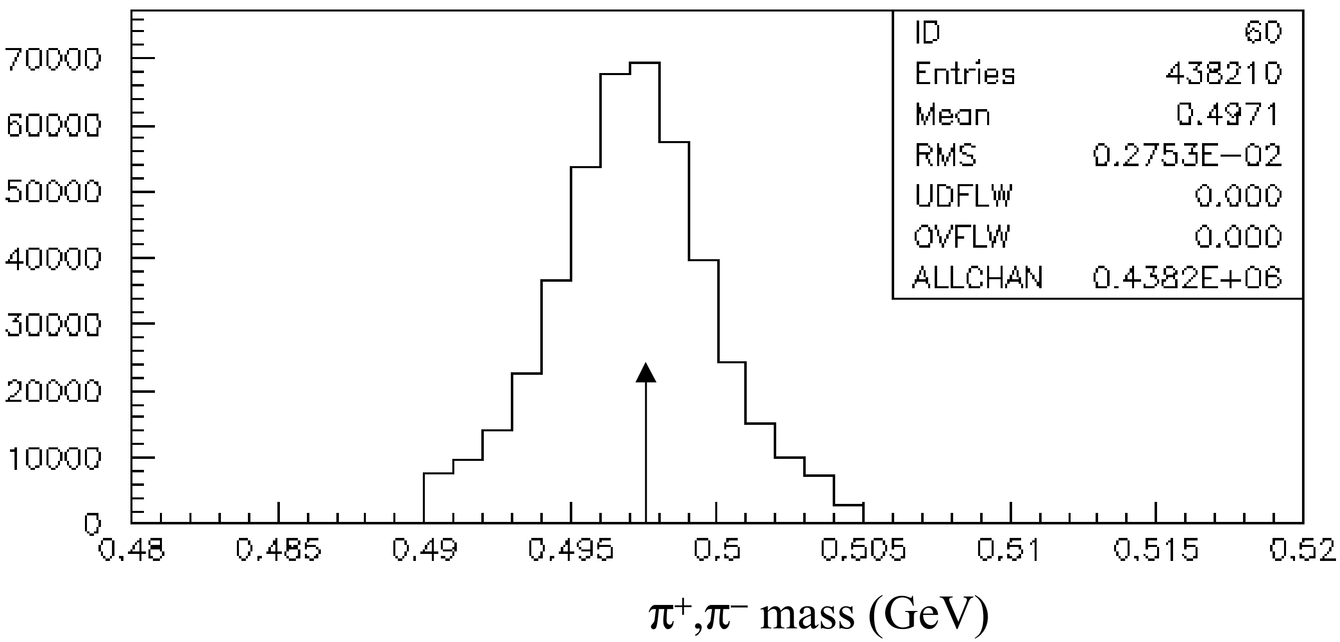




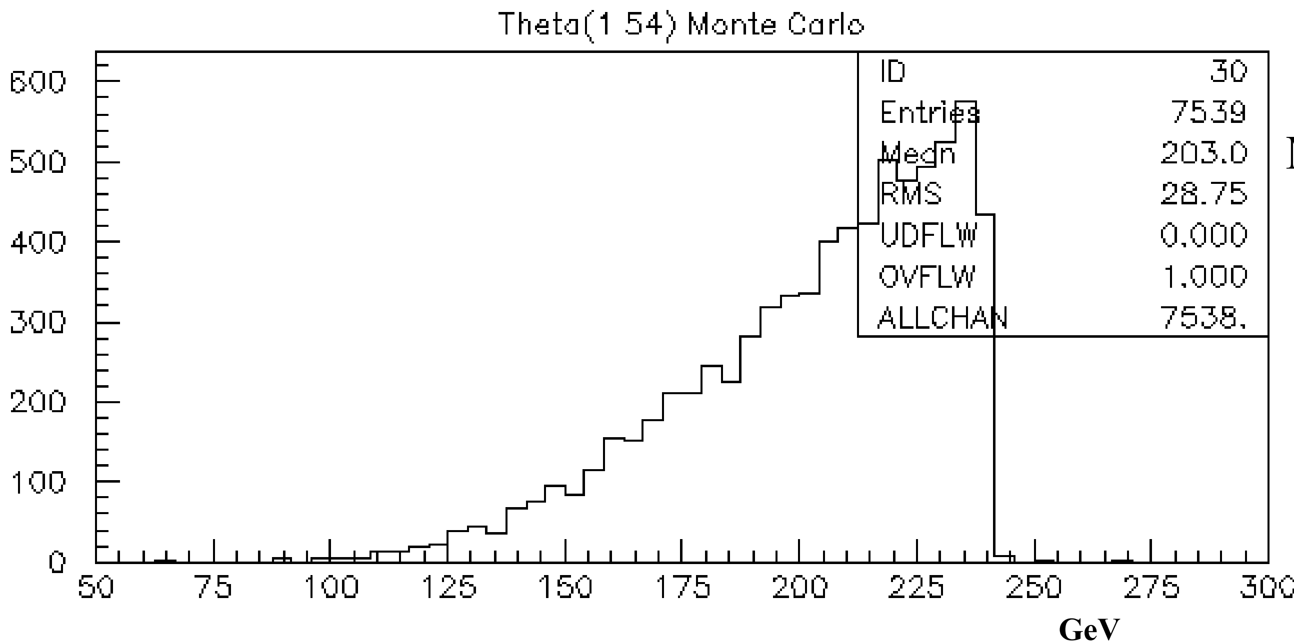
Reconstructed π^+,π^- mass

Data –

***K*^{0} peak**

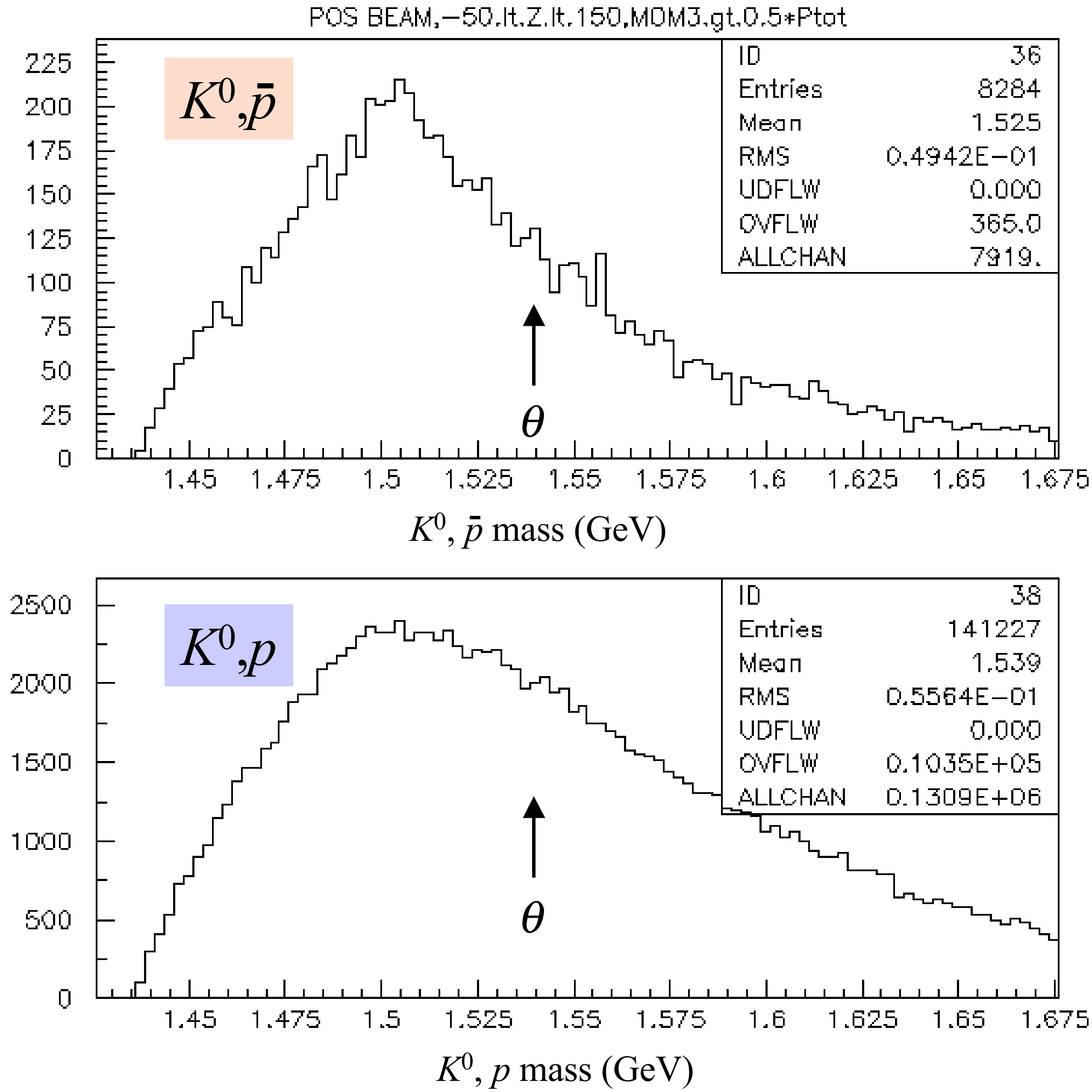


Reconstructed π^+,π^- mass, after cuts, θ^+ candidates



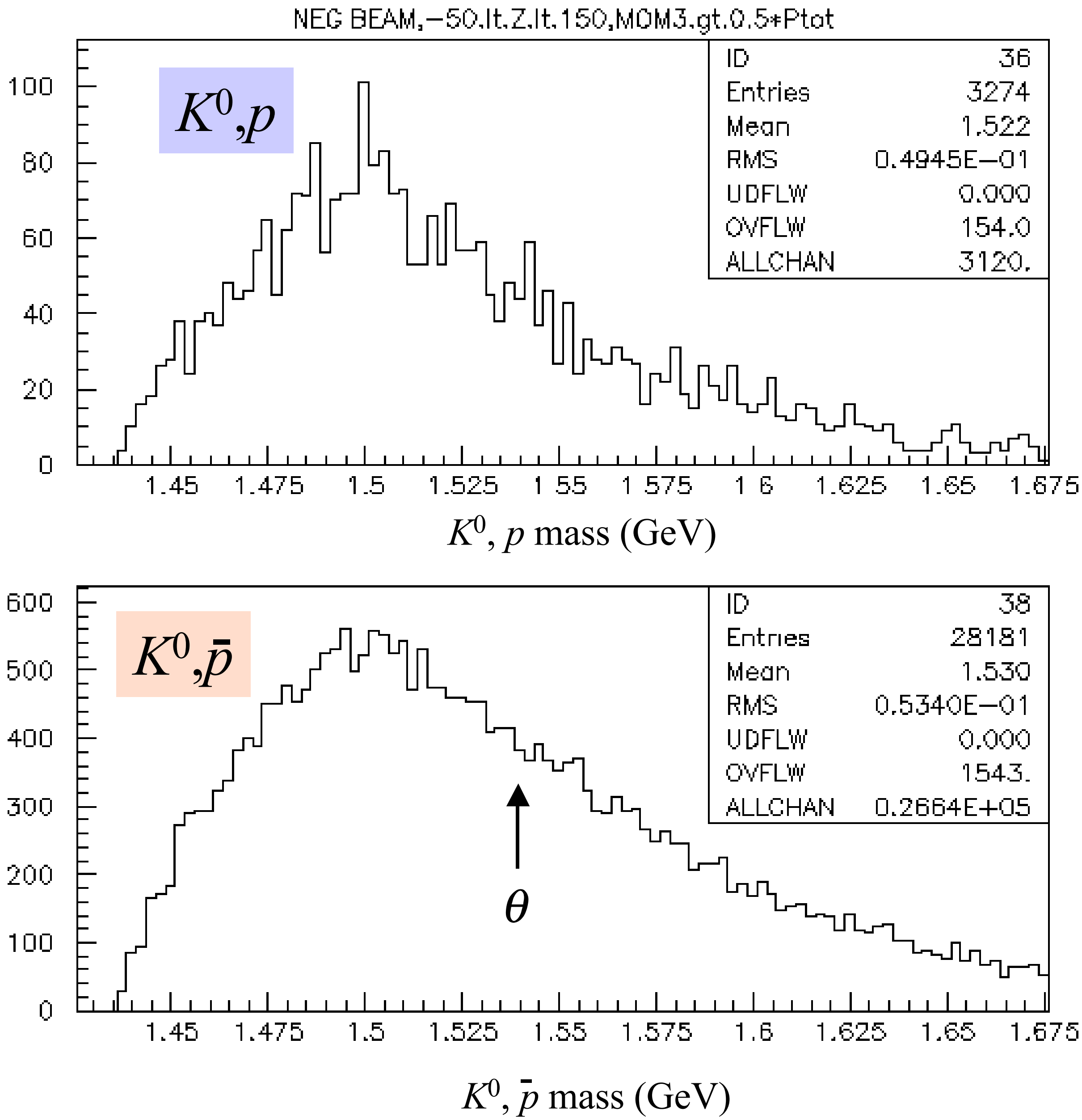
Momentum dist. accepted events starting with flat distribution

θ^+(1.54) Monte Carlo



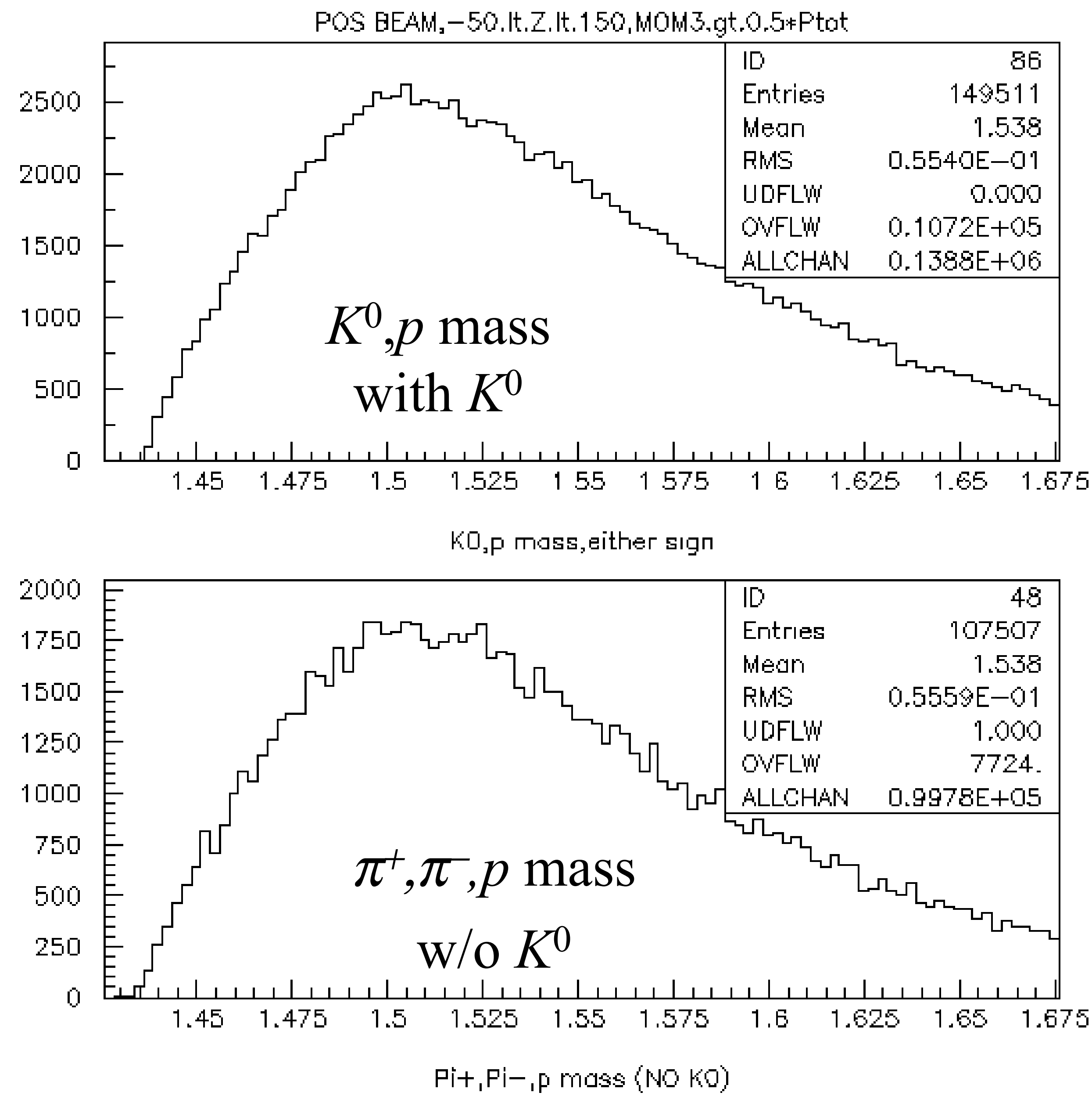
DATA

Reconstructed K^0,p mass, positive beam, events from thin window.



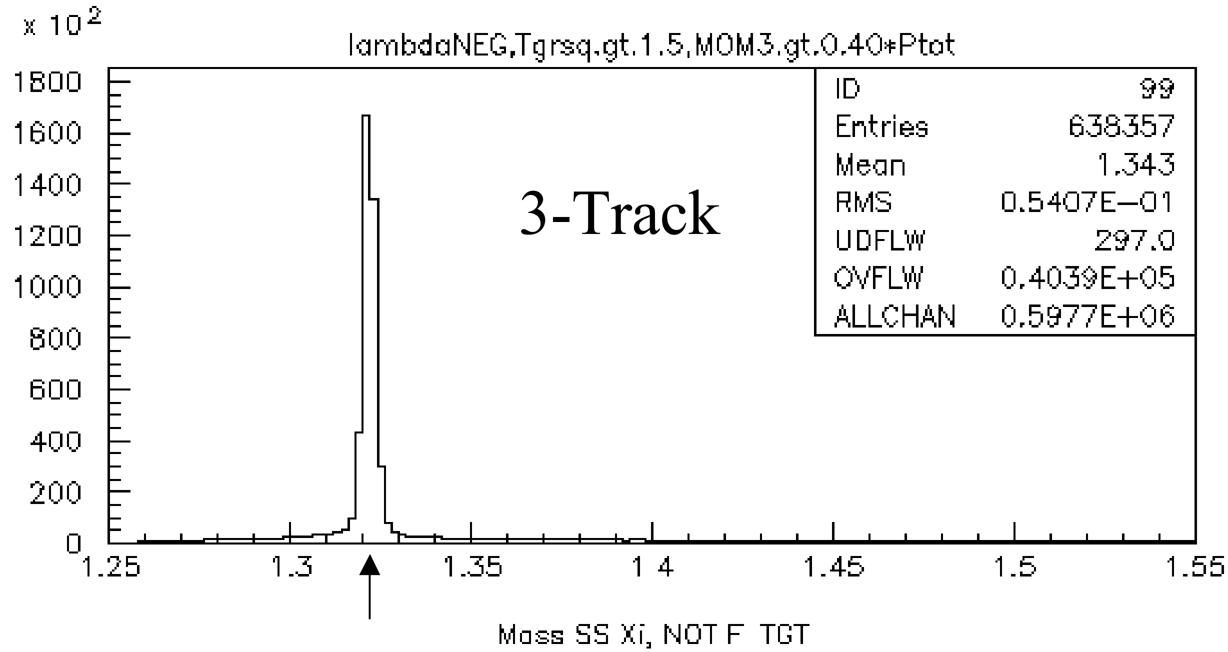
DATA

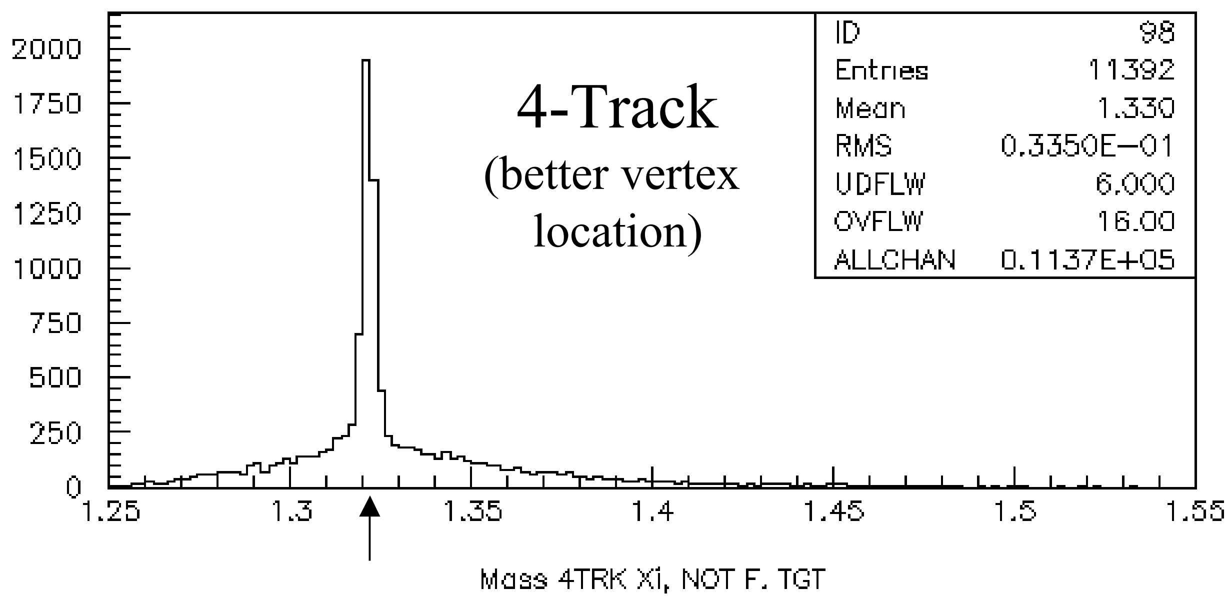
Same for negative beam



Compare mass spectrum of K^0,p events to that for π^+,π^-,p events (not K^0)

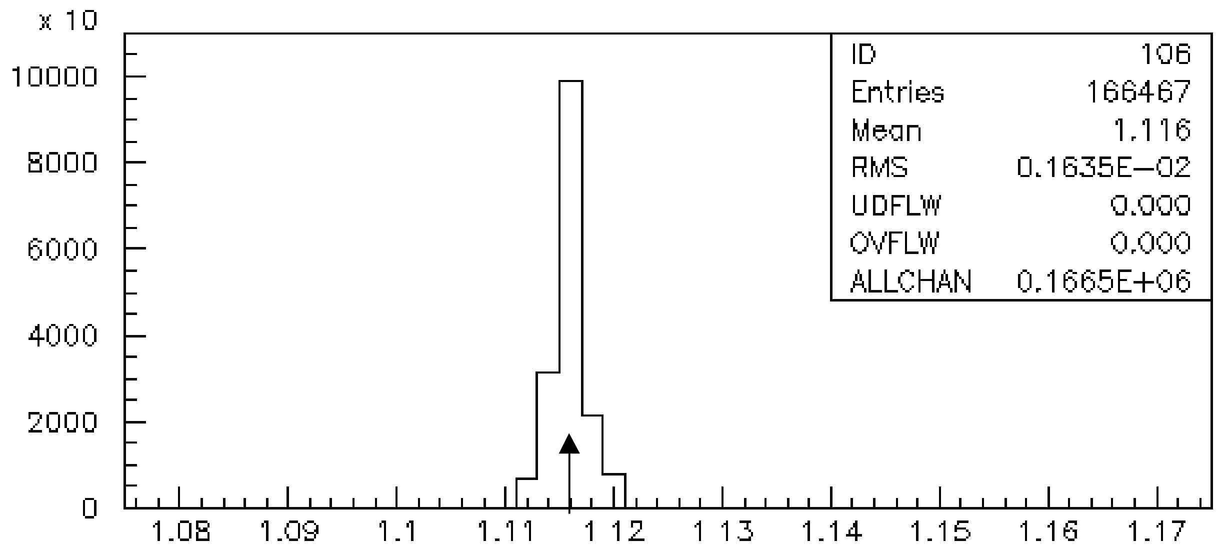
Nothing special about K^0,p events!





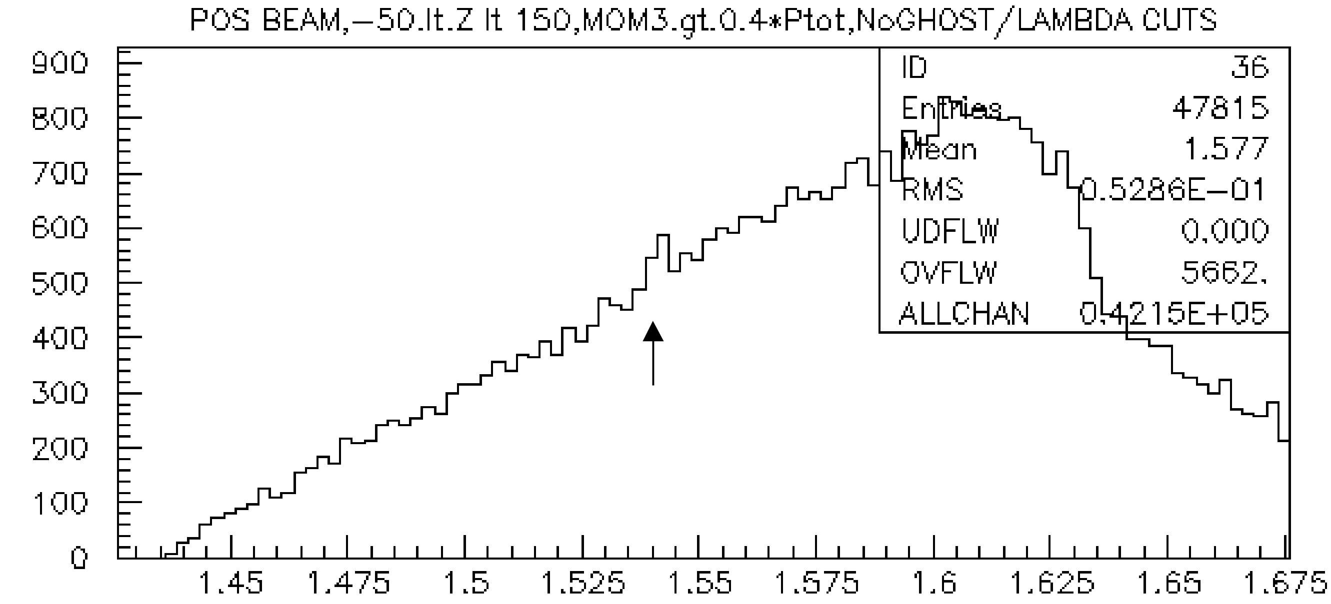
Ξ^- not pointing back to target $\rightarrow$ from thin window.

We see lots of Ξ^- from window.

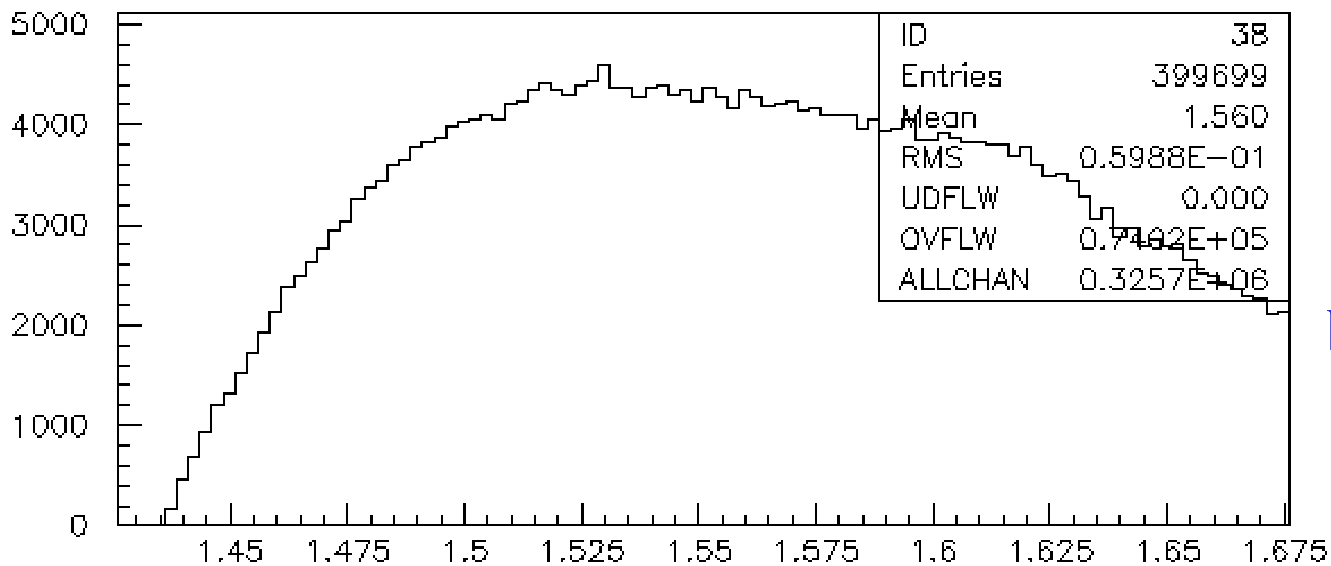


p,π^- mass (GeV), not from target

Lots of *Λ*'s
from thin window



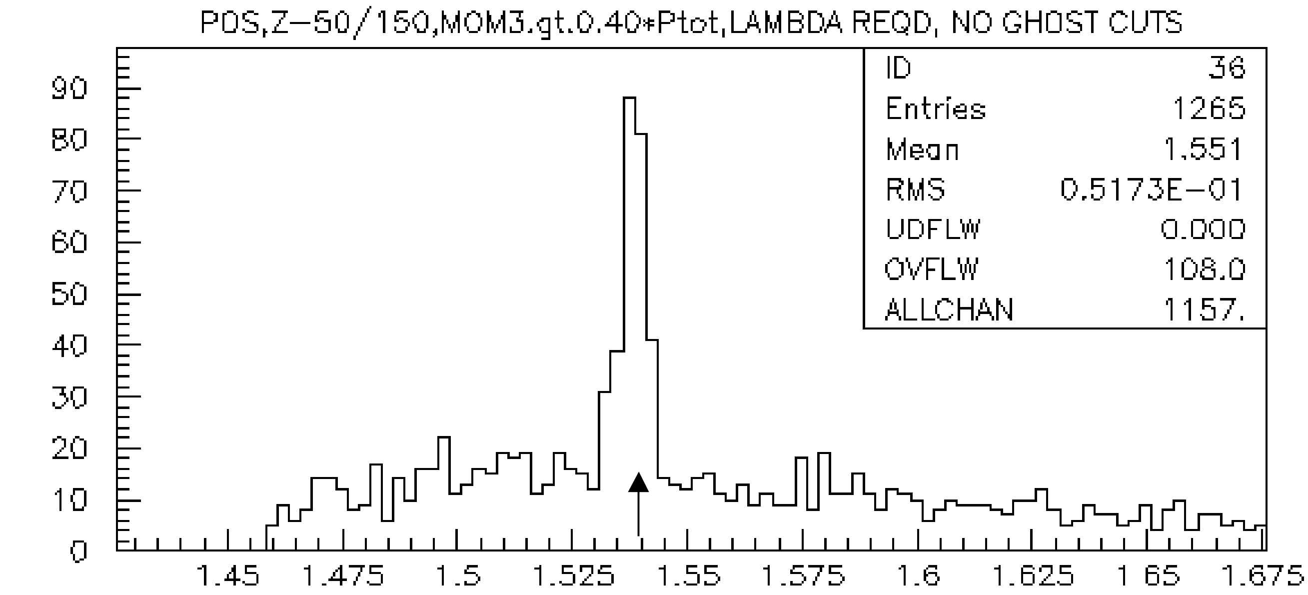
K^0,p mass (GeV)



$K^0,\bar{p}$ mass (GeV)

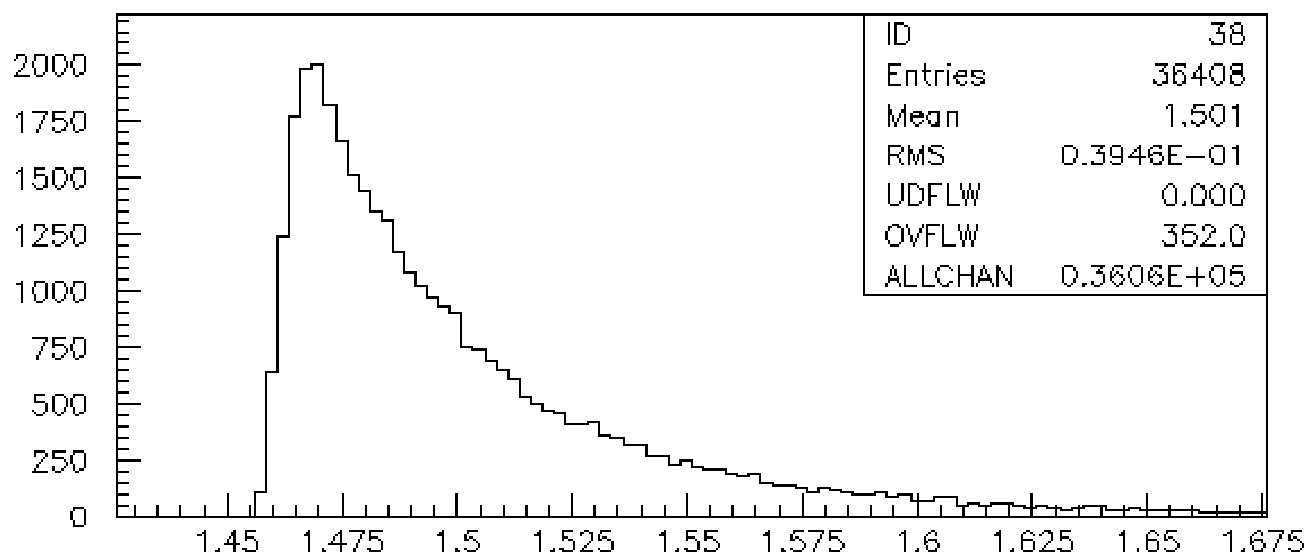
Data w/o "ghost" cuts: Ghosts can cause a peak near 1.54 GeV

"Ghosts" are near-duplicate tracks that occur in both electronic and bubble chamber experiments.



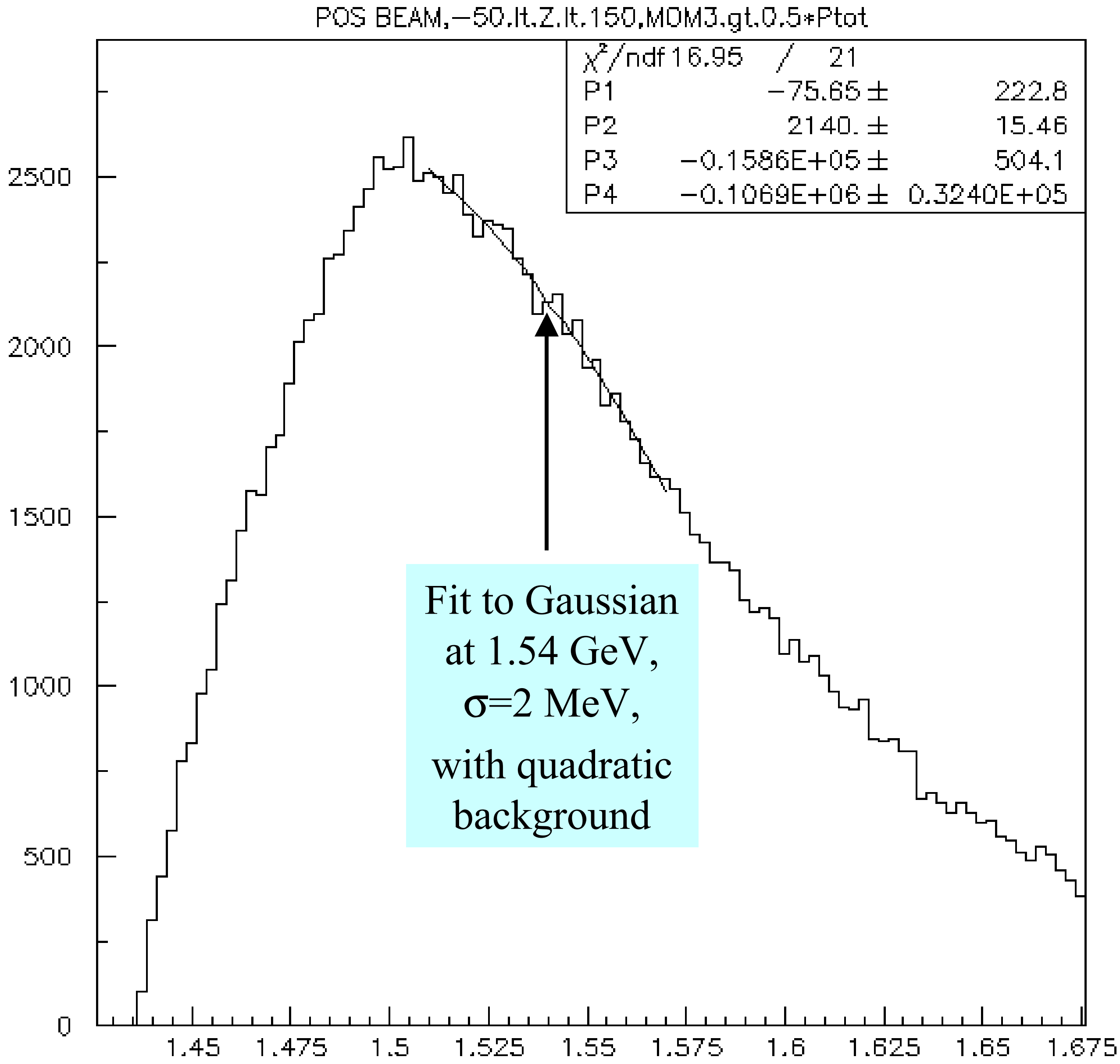
K^0,p mass (GeV)

Data w/o ghost cuts and a Λ required.



$K^0,\bar{p}$ mass (GeV)

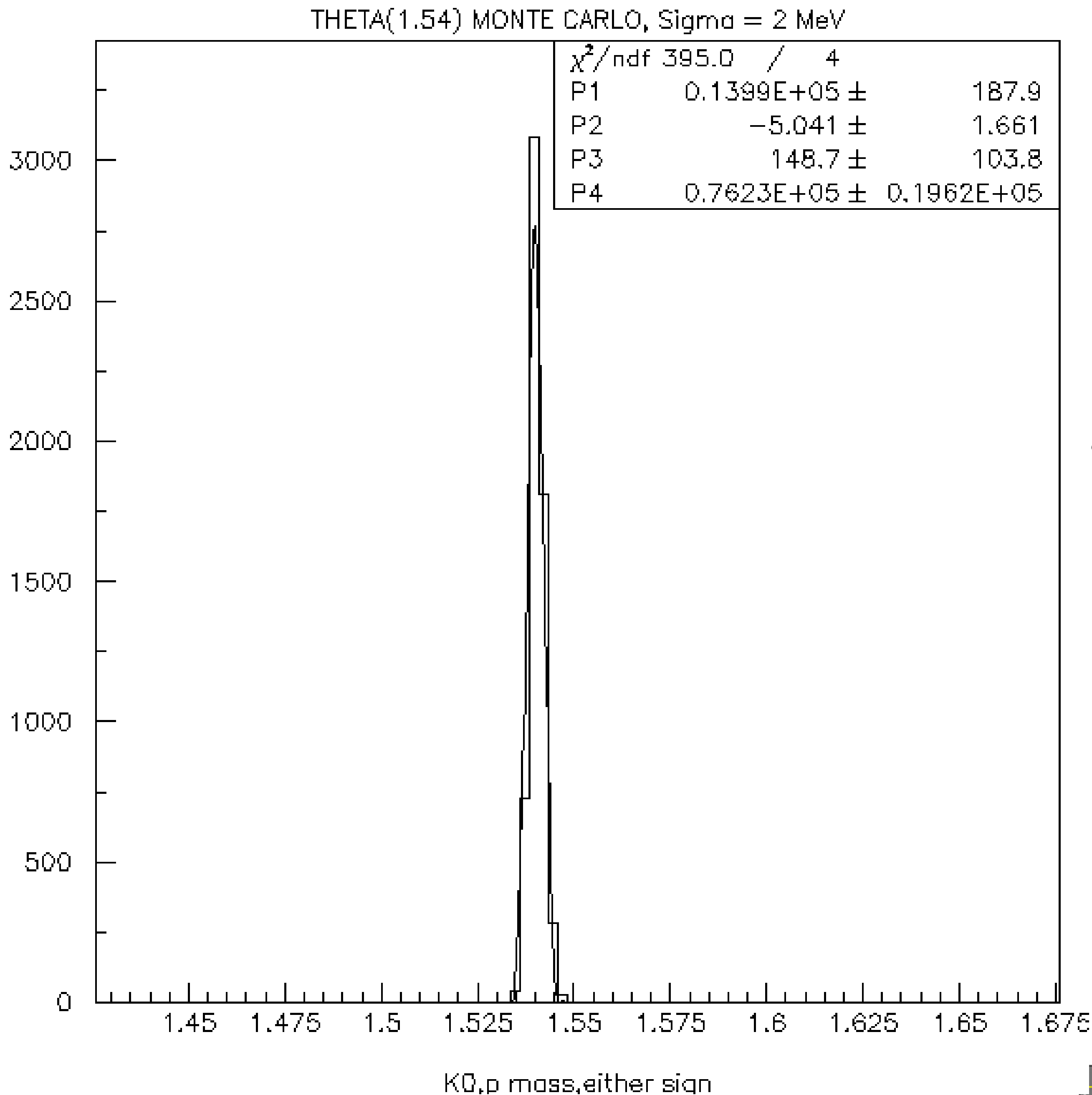
"Ghosts" plus a Λ can cause a peak near 1.54 GeV.



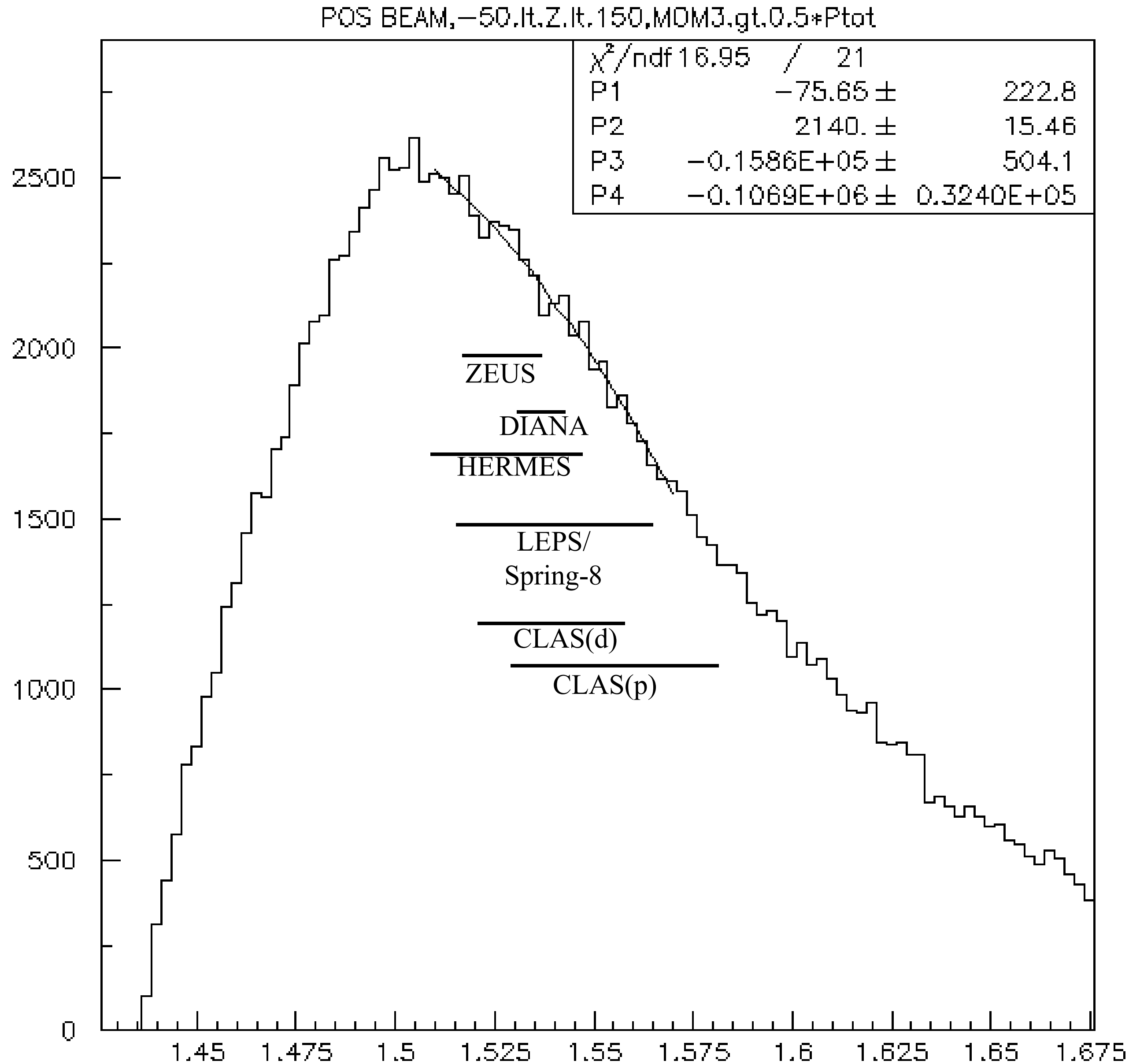
K^0-p mass, either sign

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

HyperCP Preliminary

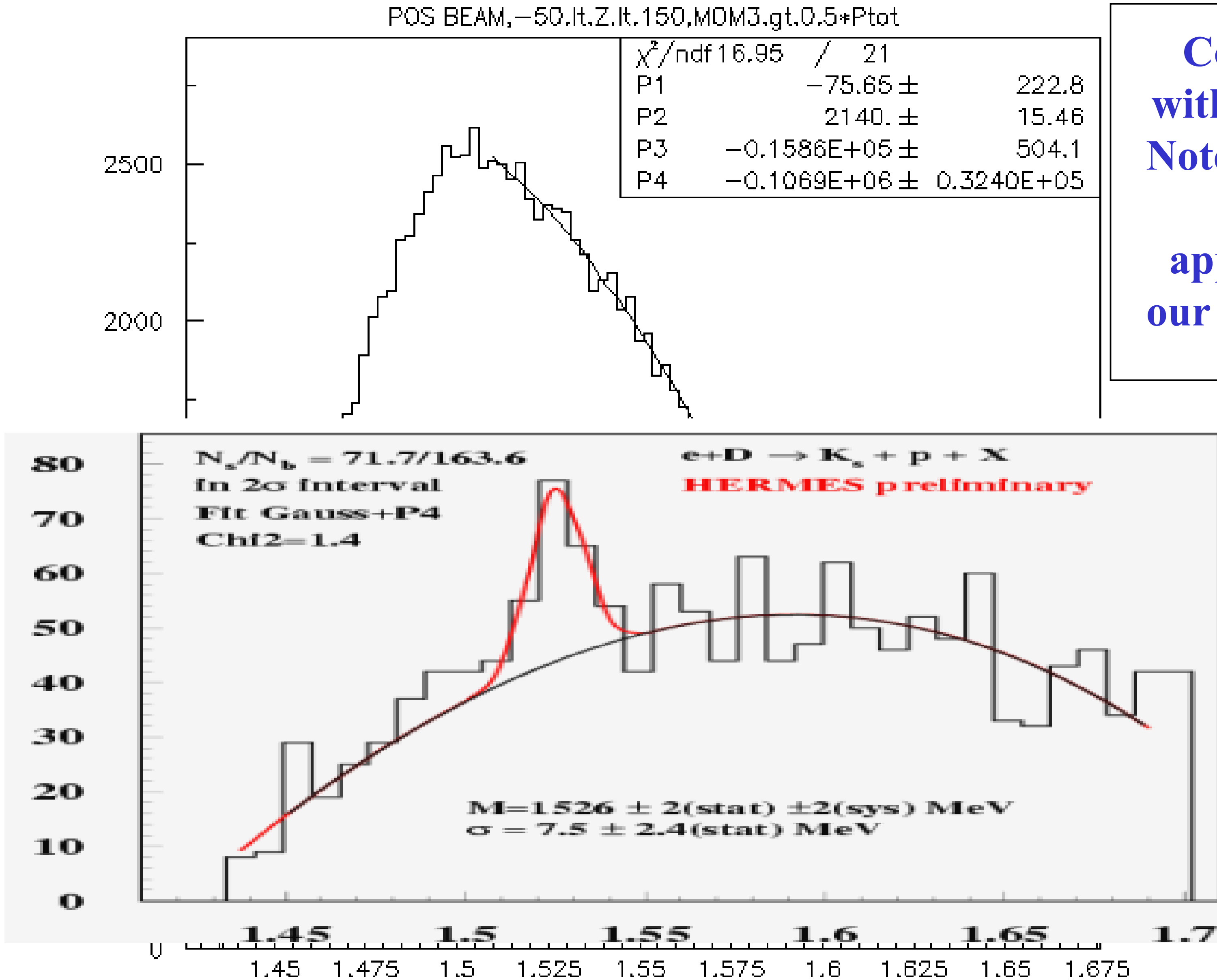


Same fit applied to θ^+(1.54) Monte Carlo



K^0-p mass, either sign

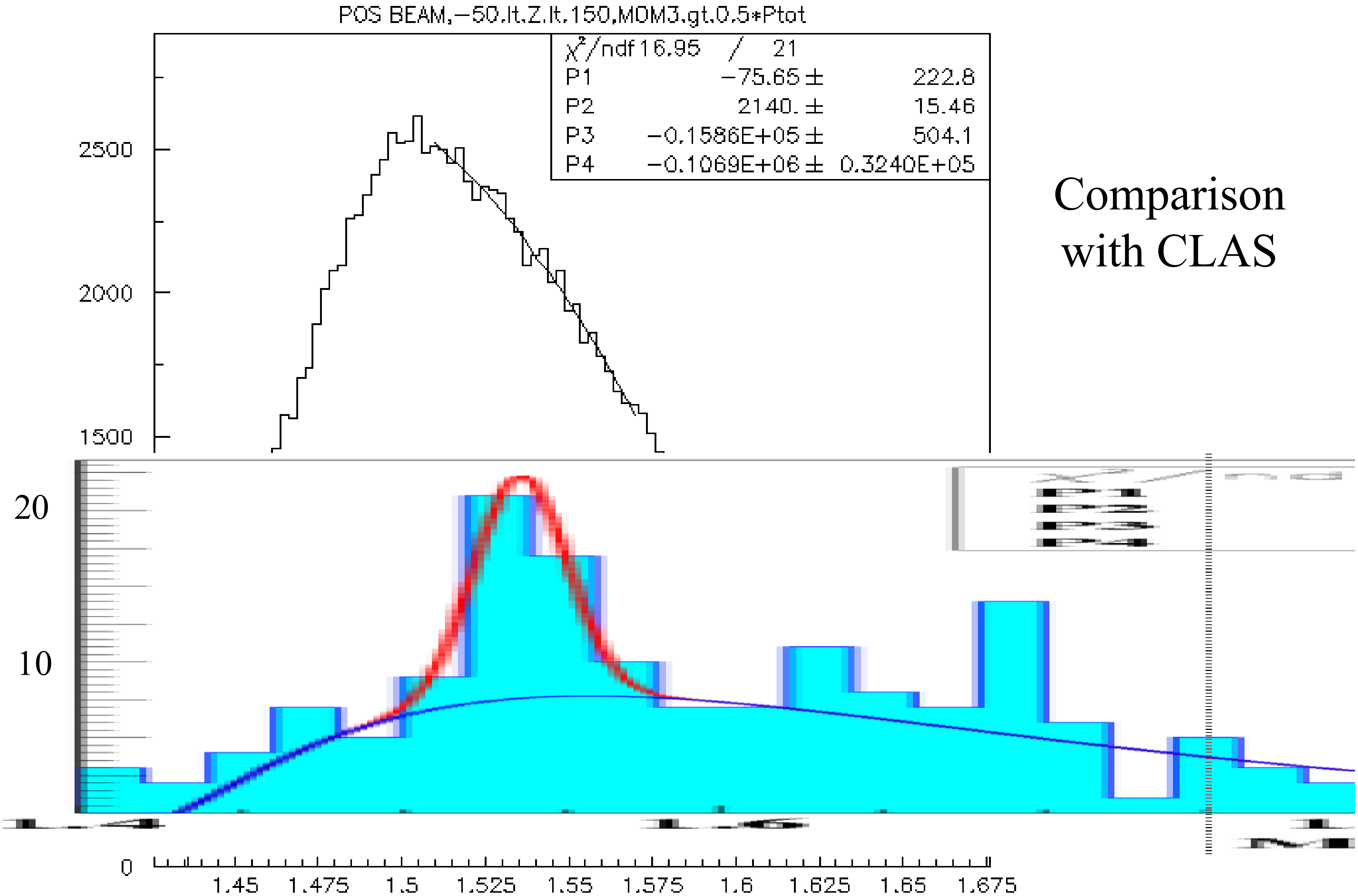
Horizontal bars indicate reported widths



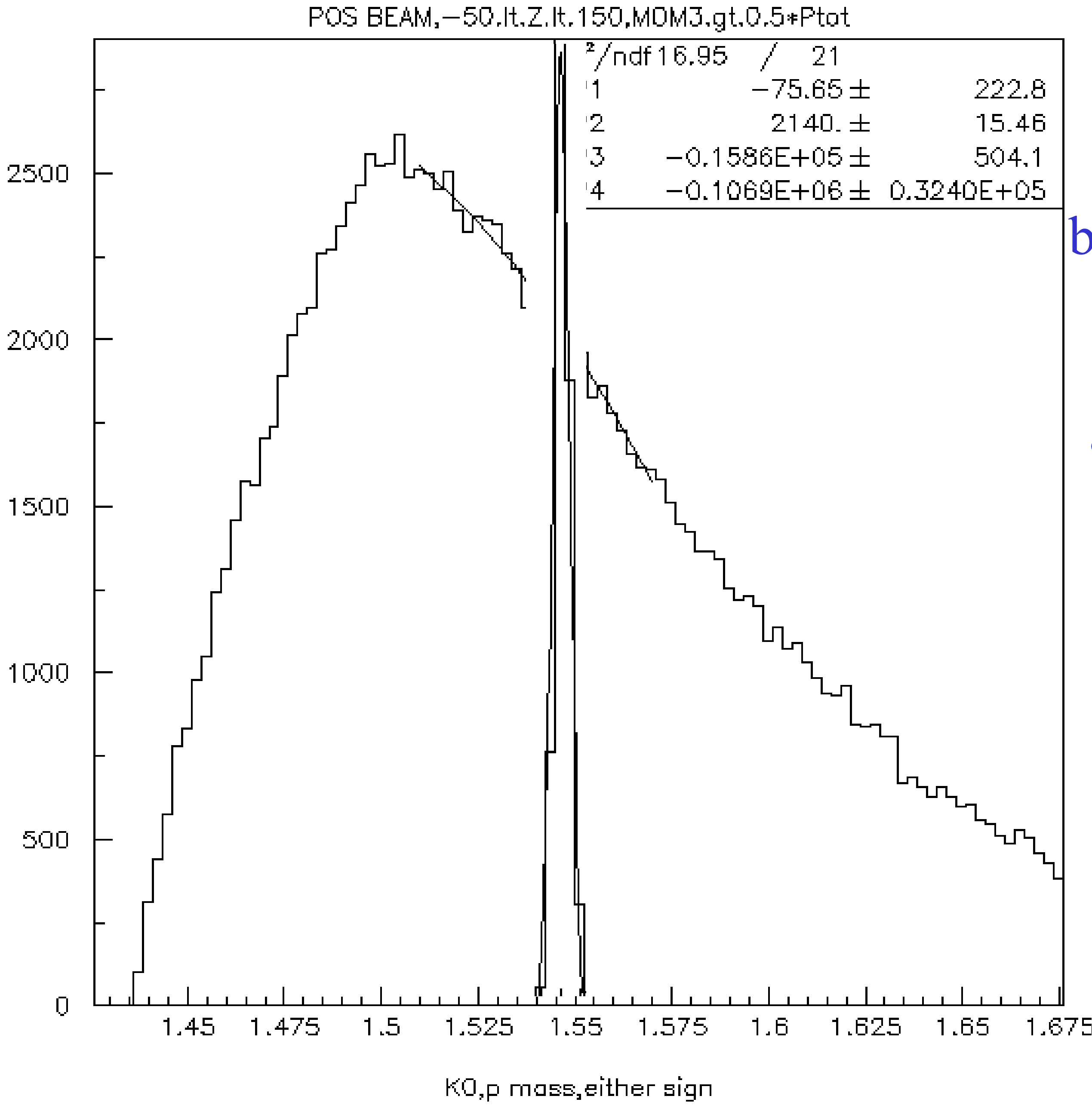
Comparison with HERMES. Note that signal should appear in 1 of our 2 MeV bins!

K^0-p mass, either sign

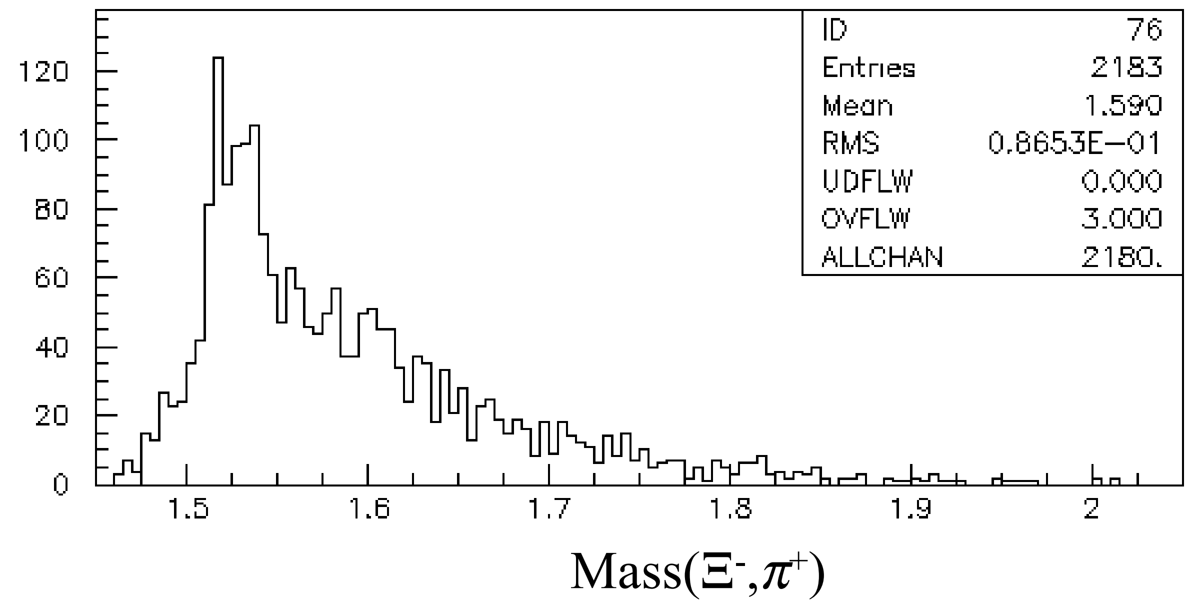
Comparison with CLAS



K^0-p mass, either sign



If our signal/ background were comparable to sightings and width were less than expt'l resolution, we should see a peak like this!



Our acceptance for Ξ^{--}(1.862) is too poor to make a useful limit.
We seem to see the Ξ^0 (1.53), but the width is suspiciously wide.
A broad peak near threshold is suggestive of the "Deck effect".

KINEMATICAL INTERPRETATION OF THE FIRST π-p RESONANCE*

Robert T. Deck
University of Michigan, Ann Arbor, Michigan
(Received 12 June 1964)

It is the contention of this note that a similar dif-

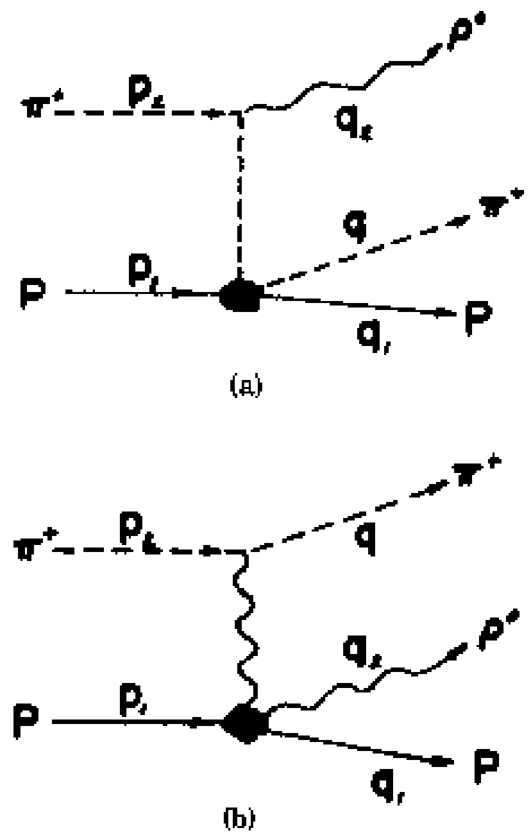


FIG. 1. Single-particle exchange diagrams giving rise to a kinematical peak in the π-ρ mass spectrum.

The "Deck Effect" –
A rather general kinematic mechanism for producing a (broad) peak near threshold.
[Robert Deck, Phys. Rev. Lett., August, 1964.]

Deck Effect, cont'd

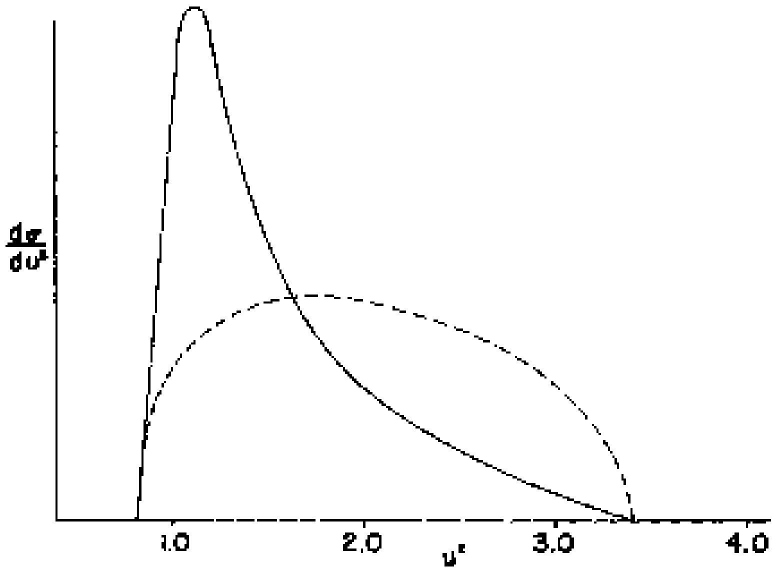


FIG. 2. Plot of the differential cross section obtained from the diagram of Fig. 1(a) as a function of the squared mass of the pi-rho system. The peak in the mass spectrum results from the assumption that the virtual exchanged pion is diffraction scattered from the nucleon. The dashed curve corresponds to phase space.

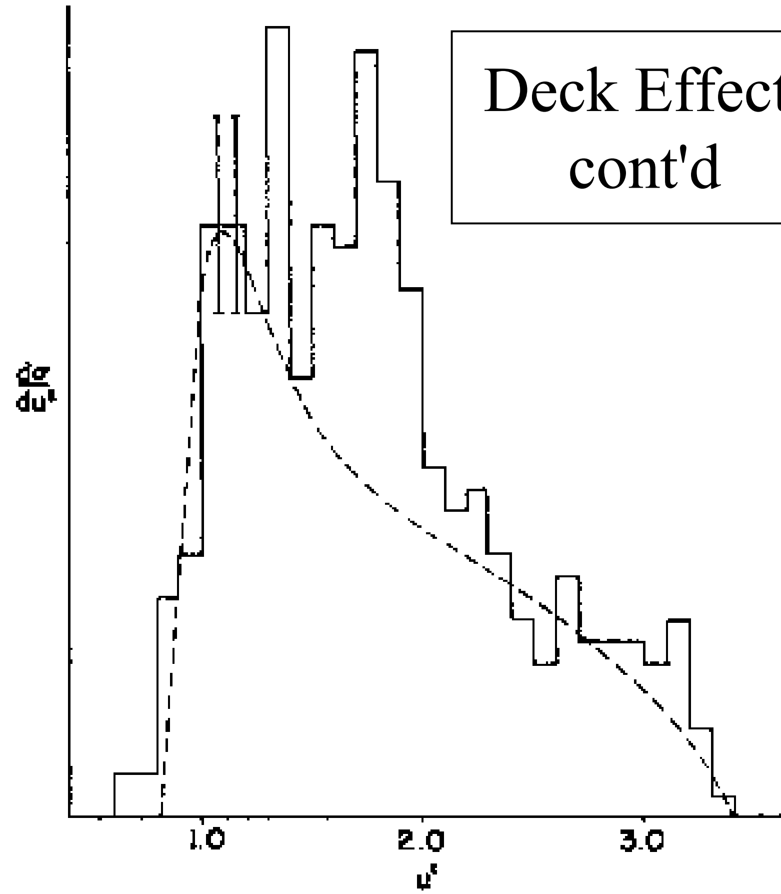
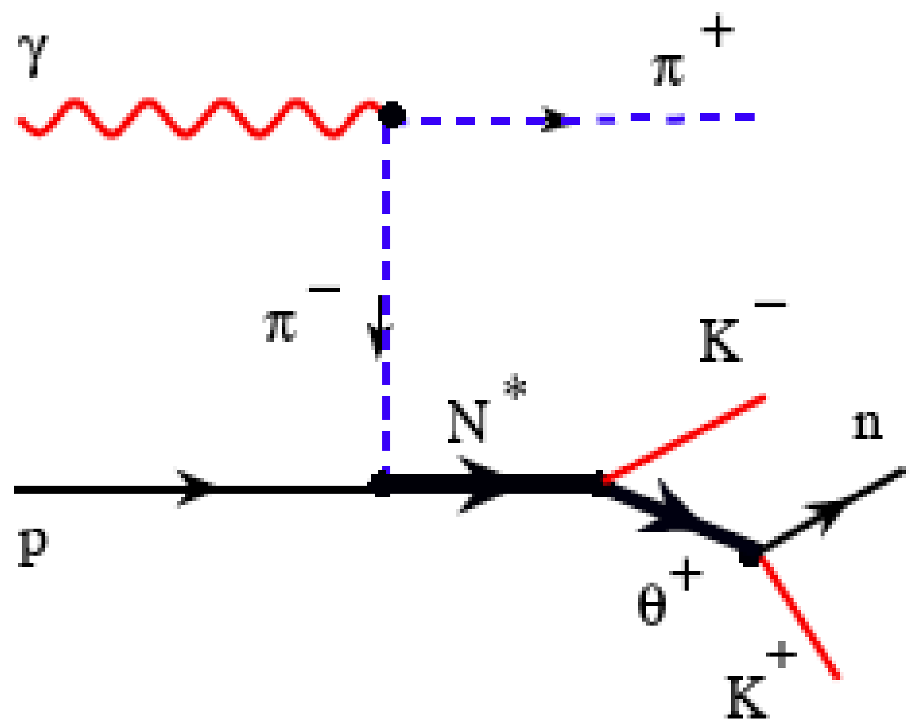


FIG. 3. Sketch of the data of reference 1 as a function of the squared mass of the pi-rho system. The dashed curve represents a fit to the data obtained by combining the present calculation with phase space so as to obtain reasonable agreement at the upper and lower extremes of the spectrum.

The histogram of Fig. 3 is a sketch of the data of reference 1 at the pion lab momentum cited above. Subsequent experiments[3] indicate that the broad peak in the data exhibited at low values of u^2 consists of two adjacent peaks at approximately $(1.08\ \text{BeV})^2$ and $(1.32\ \text{BeV})^2$. The magnitude of the observed total cross section reported in reference 1 is 0.86 mb.

The nature of the present calculation is such that a reliable value for the total cross section

the measured total cross section considerably exceeds this estimate it is likely that a π-ρ resonance does enhance the reaction. This conclu-



Decay of N^* is one possible diagram for θ^+ photoproduction. Diffractive production of N^*s by "pomeron" or pion exchange should produce lots of θ^+ from protons interacting in the thin window.

The production of θ^+ involves the rearrangement of quarks, just as in any other hadronic production process. A virtual nucleon or N^* produced diffractively from an incident proton can decay into a θ^+ and K^-

Quark Counting

Proton = *uud* $\qquad$ $\theta^+ = uudd\bar{s}$ $\qquad$ $\Xi^- = dss$

To make a Ξ^-, the proton must pick up 2 *s* quarks from the sea. To make a θ^+, the proton only needs to pick up a $d\bar{s}$. Thus naively one would expect the production of θ^+ would be considerably greater than Ξ^-. Yet we see no θ^+ and many 1000's of Ξ^- produced in the thin window**?????**

Comments & Conclusions

- Mixed beam and wide momentum spread so no reflections.
- High resolution spectrometer with mass resolution <2 MeV, comparable to estimated intrinsic width
- Many events so many checks and careful event selection.
- We see many thousands of K^0s and hyperons coming from
- the thin window, but < 370 $\theta^+(1.54)$ among 150,000 K^0,p candidates.
- The ratio of θ^+ to total K^0, p is <0.25% at 90% confidence level. This is compared to 2–8% for $\theta^+ \longrightarrow K^0, p$ sightings
- The production of the θ^+ would have to be exotic, as well as its dynamics, and quantum numbers!!

Some personal observations….

• Non-sightings, though mostly unpublished, now are beginning to outnumber the sightings.

• Generally the non-sightings have far more events than the sightings. This not only determines their statistical significance but also allows detailed checks on data.

• The statistical significance of a "bump" has to be adjusted for the number of histograms one looks at. [In my case many thousands!!]

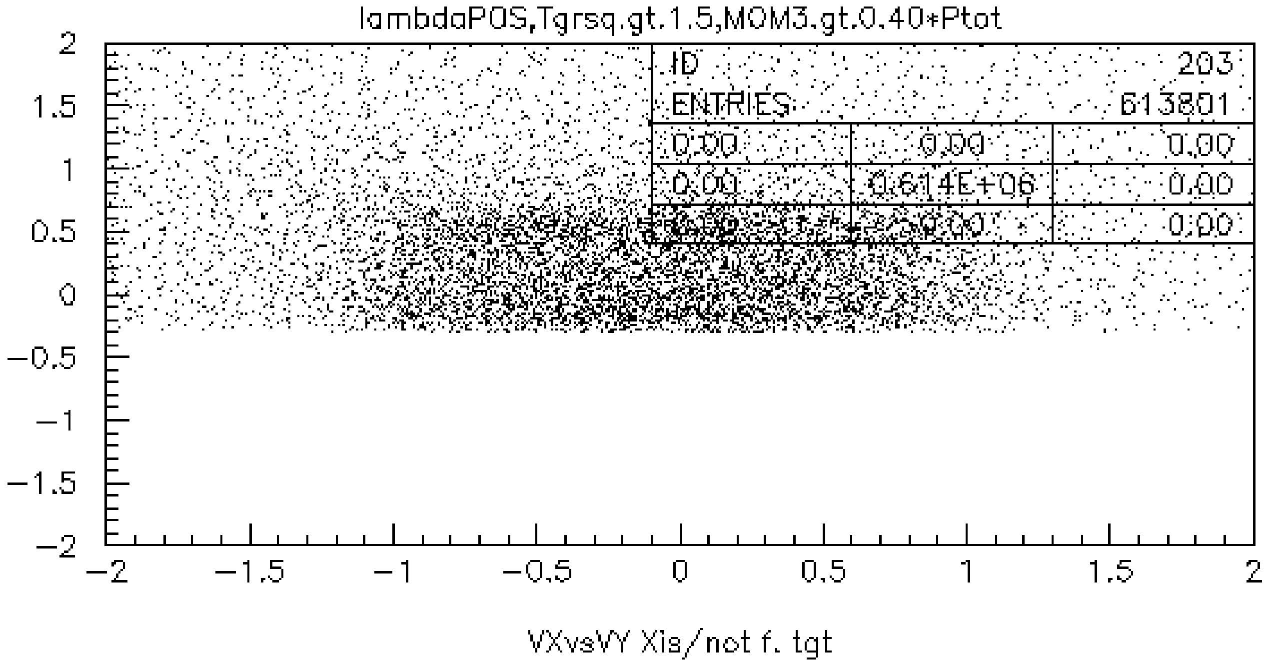
• In my experience, it's a lot easier to produce (fake) bumps, than it is not to find a real one.

• It would be extremely surprising if pentaquarks were only produced in certain processes at some energies. Usually all hadrons are produced with similar fractional probability in all processes well above threshold or off resonance, e.g., *p-p, π-p, K-p, e-p, γ-p, e-e, ν-p*, Z^0 decays, ψ decays, ….

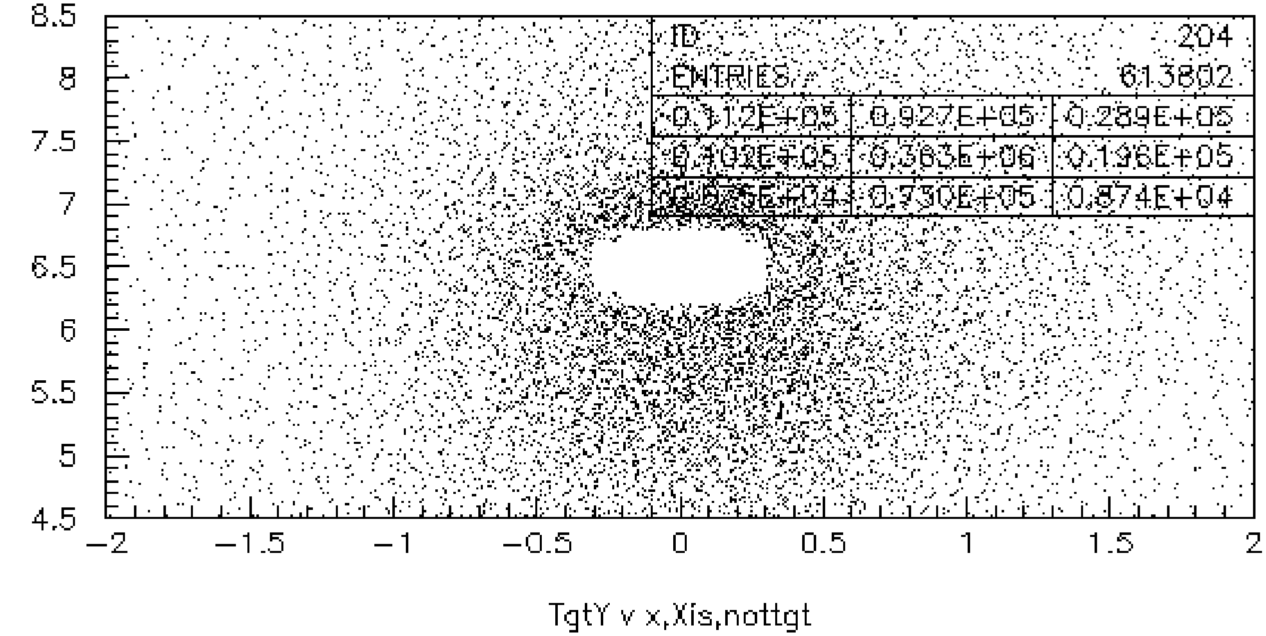
Recipe for Pentaquark Soup (MJL)

- Take a handful of events.
- Apply cuts according to taste.
- Bin carefully.
- Add a touch of Deck effect.
- Season with kinematic reflections and a few ghost tracks.
- Voila un bon pentaquark potage!

(Backup slides)



Vertex x,y distribution for K^0,p candidates



Target x,y distribution for K^0,p candidates