Caucasian-German School and Workshop on Hadron Physics

Tbilisi, Georgia, August 30th – September 4th

Search for the Pentaquark Θ^+ state

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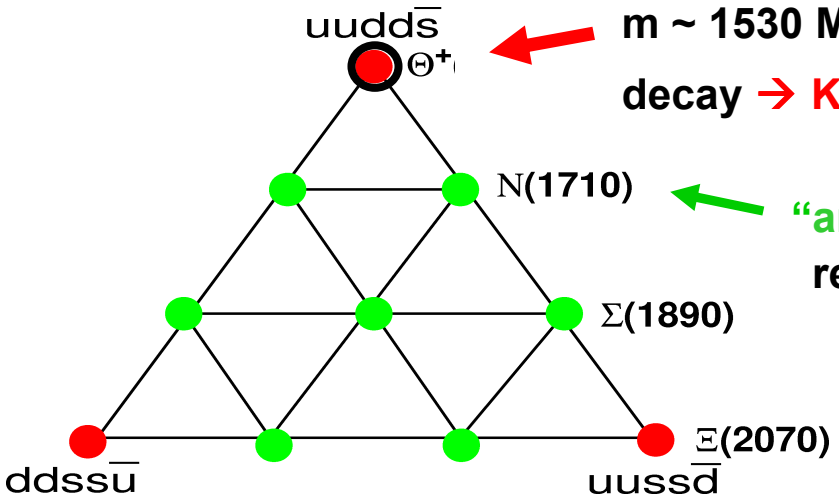
- Introduction
- Evidence for the Θ^+
- Evidence from COSY-TOF
- Summary
- Future plans

Motivation

Chiral soliton model → antidecuplet including exotic states

D. Diakonov, V. Petrov, and M. Polyakov, Z. Phys. A 359 (1997) 305



m ~ 1530 MeV, Γ ~ 15 MeV !, S = + 1, $J^p = ½^+$

decay → $K^0p + K^+n$

"anchor" → mass spacing

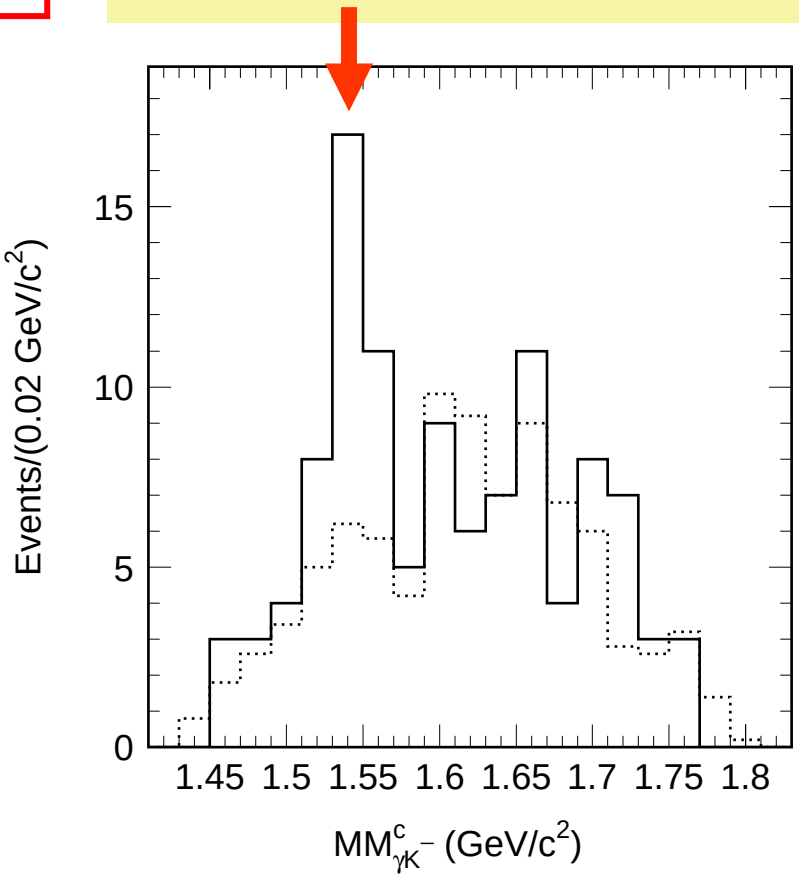
related width: Γ ~ 50 MeV

Numerous calculations in various models:

different masses and widths, splitting, mixing → **many questions!**

LEPS

First evidence on Θ^+ $\gamma n \rightarrow K^+ K^- n$ on Carbon



Peak at $M = 1.54 \pm 0.01$ GeV
Γ < 25 MeV
significance 4.6σ

too optimistic !

Fermi motion

complicated correction

Background

estimated by a fit in the mass region above 1.59 GeV.

Assumption

- **is from non-resonant K^+K^- production on neutron**
- **is identical to non-resonant K^+K^- production on proton**

Phys.Rev.Lett. 91 (2003) 012002

hep-ex/0301020

DIANA

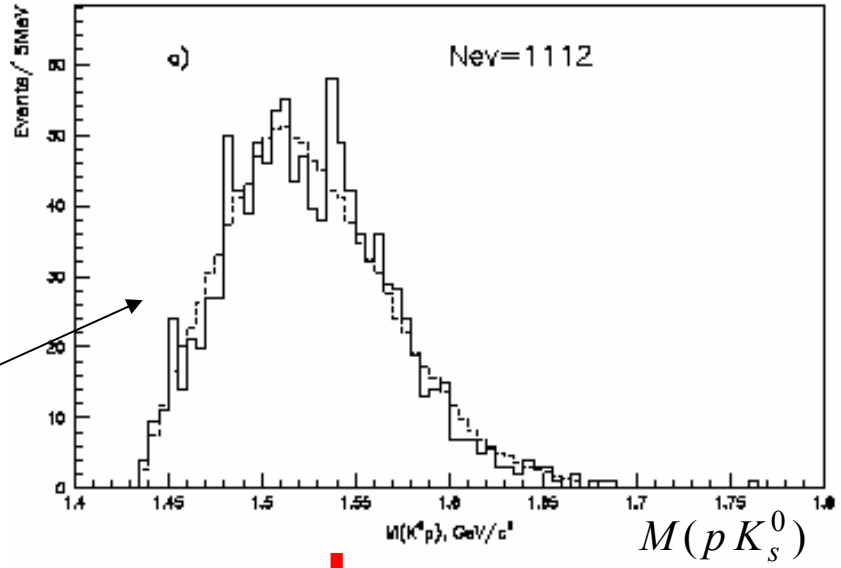
at ITEP: **K Xe → Xe' p K^0_s** p_{beam} = 850 MeV

Reanalyzed

Bubble chamber data

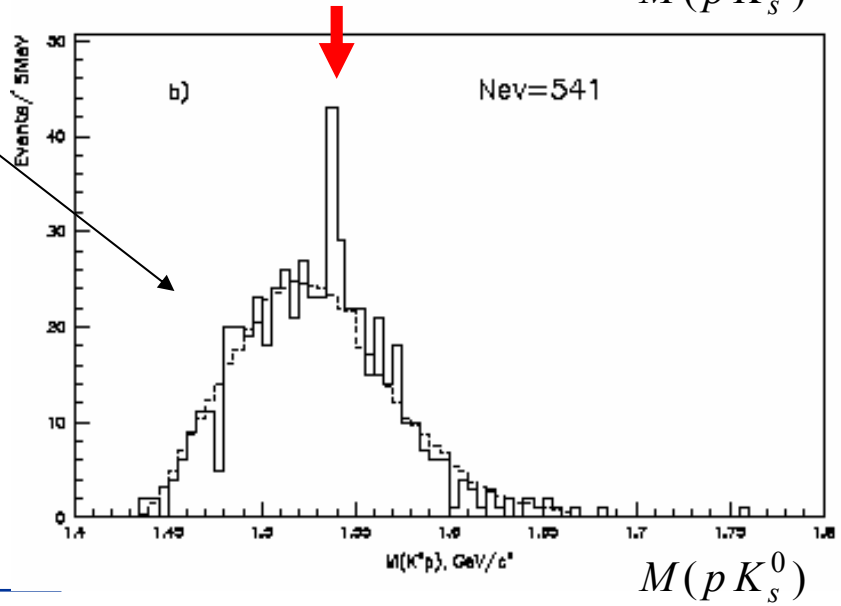
from 1986

all events



events with cuts on

p- and k- angles

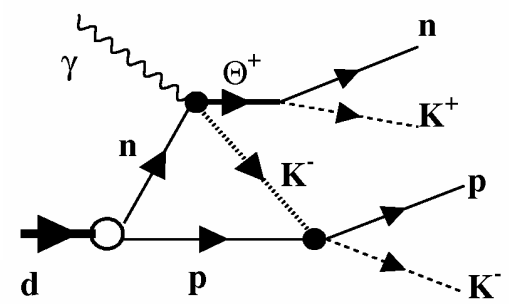


M = 1539 ± 2 MeV
Γ < 9 MeV !
significance 4.4σ

Phys. Atom. Nucl.66 (2003) 1715

CLAS

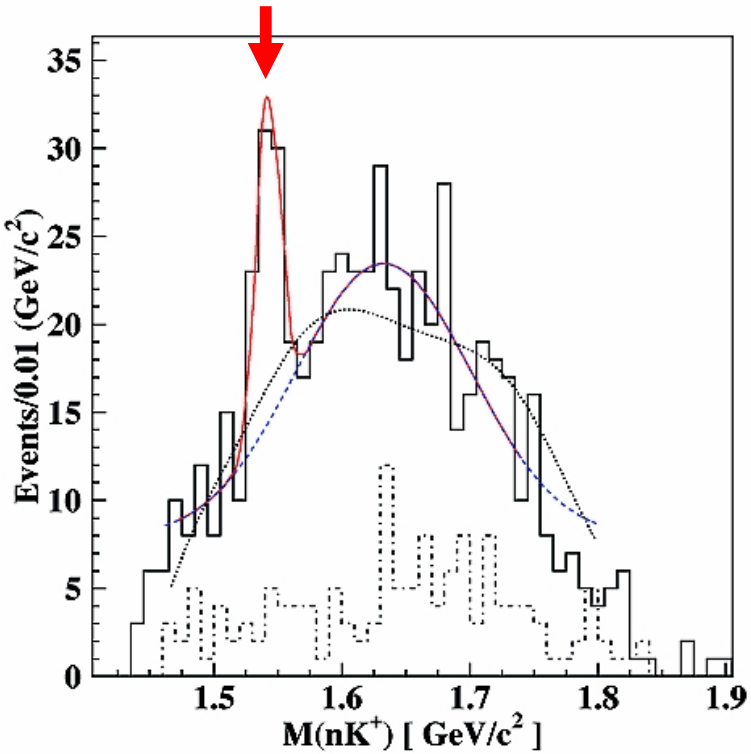
at JLAB: γd Reactions $1.5 < E_\gamma < 3.1$ GeV



Requires FSI – both nucleons involved

No Fermi motion correction necessary

Exclusive measurement



Remove events with IM(K^+K^-)→ φ(1020) by IM > 1.07 GeV

Remove events with IM(pK^-)→ Λ(1520)

n momentum cut: p(n) > 80 MeV/c

→ neutron not spectator

K^+ momentum cut: p(K+) < 1.0 GeV/c

Peak at 1542 ± 5 MeV
Γ~ 21 MeV/c
significance 5.2 ± 0.6σ

hep-ex/0307018, PRL 91(2003) 252001

CLAS

at JLAB: γp Reactions $E_\gamma = 3 - 5.25$ GeV

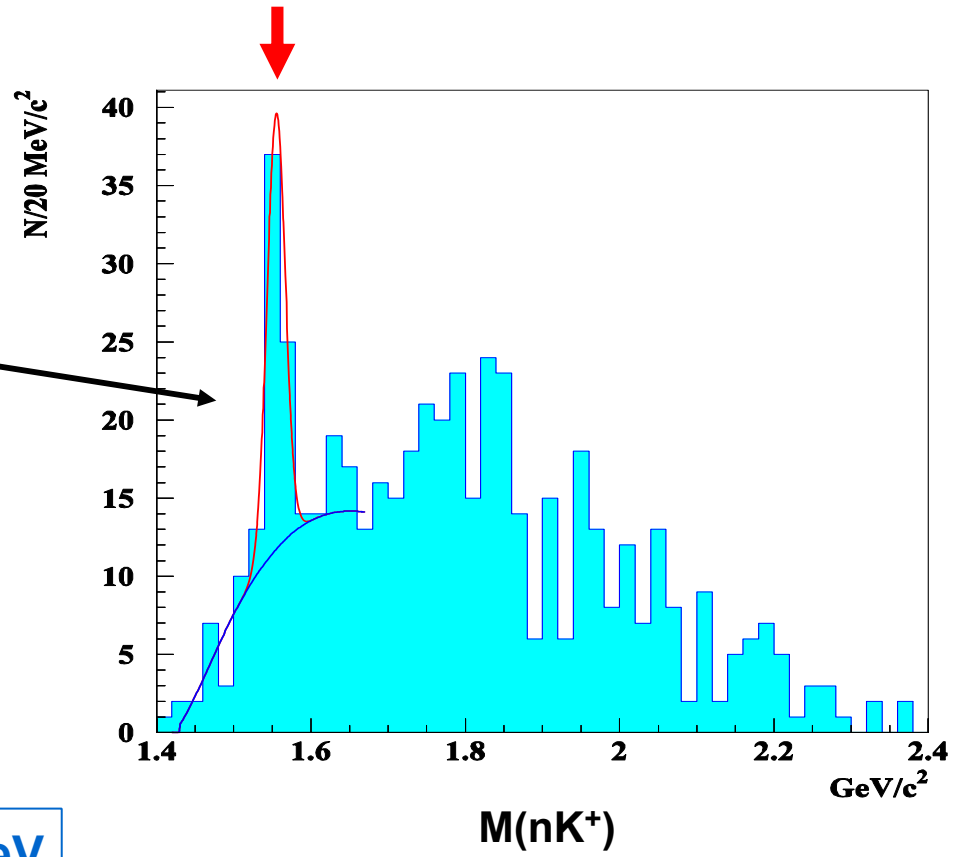
$\gamma\ p \rightarrow \pi^+ K^- K^+ n$

M(nK^+) - spectrum:

Cuts: $\cos\theta^*(\pi^+) > 0.8$

$\cos\theta^*(K^+) < 0.6$

(Without cuts:
Only small signal on
a large background)



Peak at M = 1555 ± 1 ± 10 MeV
Γ < 26 MeV
significance =7.8σ

hep-ex/0311046, PRL 92(2004) 032001

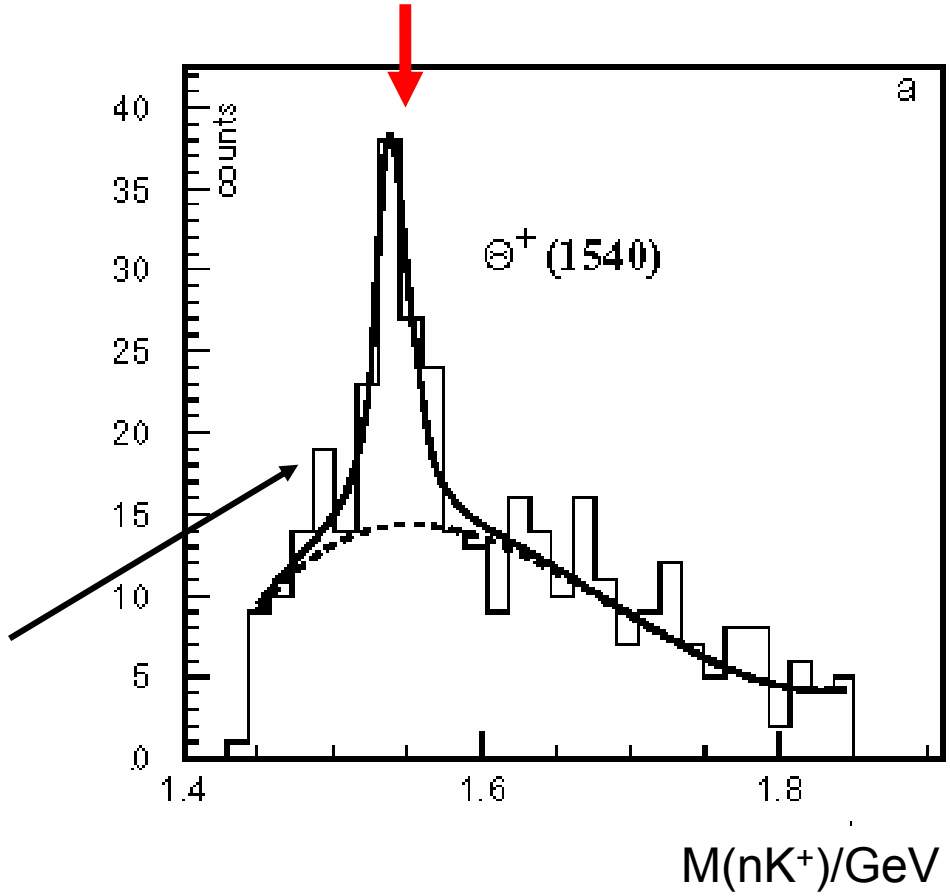
SAPHIR

at ELSA: γp Reactions $E_\gamma = 3$ - 5.25 GeV

Saphir detector:
had full coverage
in forward direction

Series of kinematical fits applied to suppress Background

M(nK⁺) - spectrum:
Cut: cosθ*(K^o_s) > 0.5



M = 1540 ± 4 ± 2 MeV
Γ < 25 MeV
significance 4.8σ

Phys. Lett. B 572 (2003) 127

SVD-2

at ITEP: $p\,A \rightarrow X + p\,K^0_S$ $\quad p_{beam} = 70$ GeV/c

Active target:

Si-detector + lead foil Sandwich

Selection of events:

with multiplicity < 6

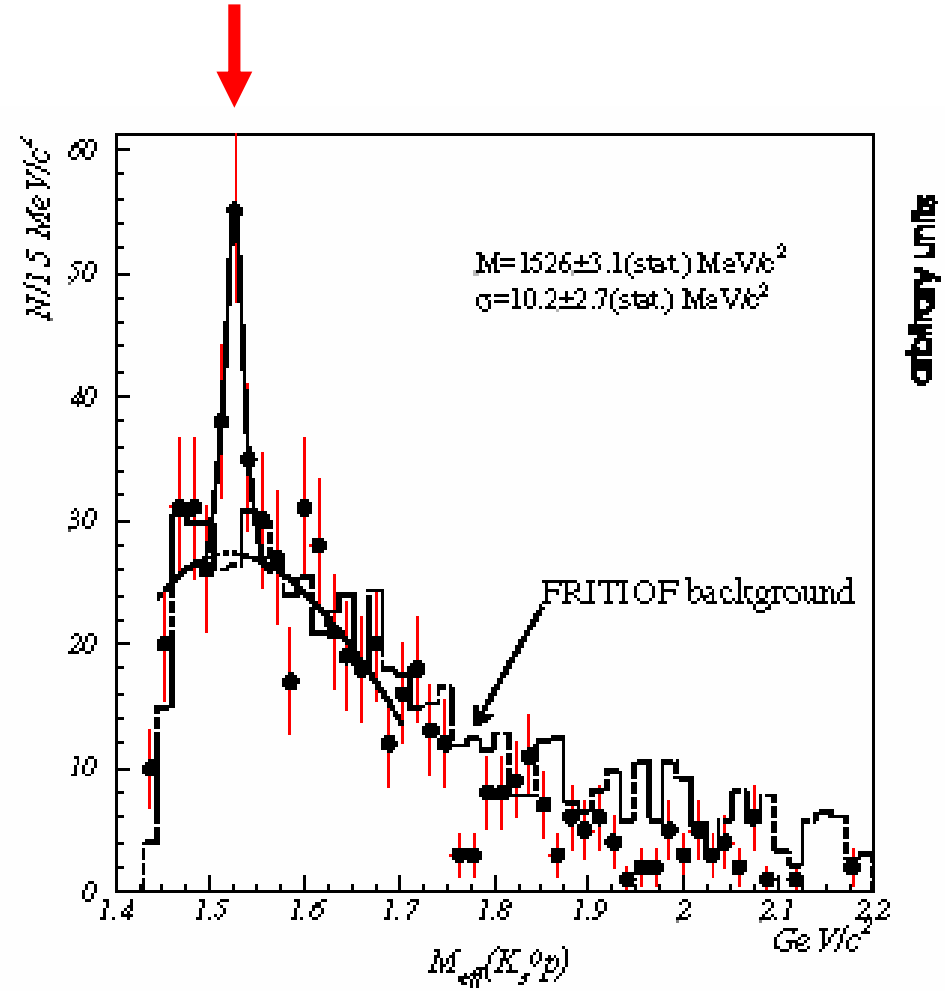
→ reduction of combinatorical background

$M = 1526 \pm 3 \pm 3$ MeV

$\Gamma < 24$ MeV

significance 5.6σ

hep-ex/0401024



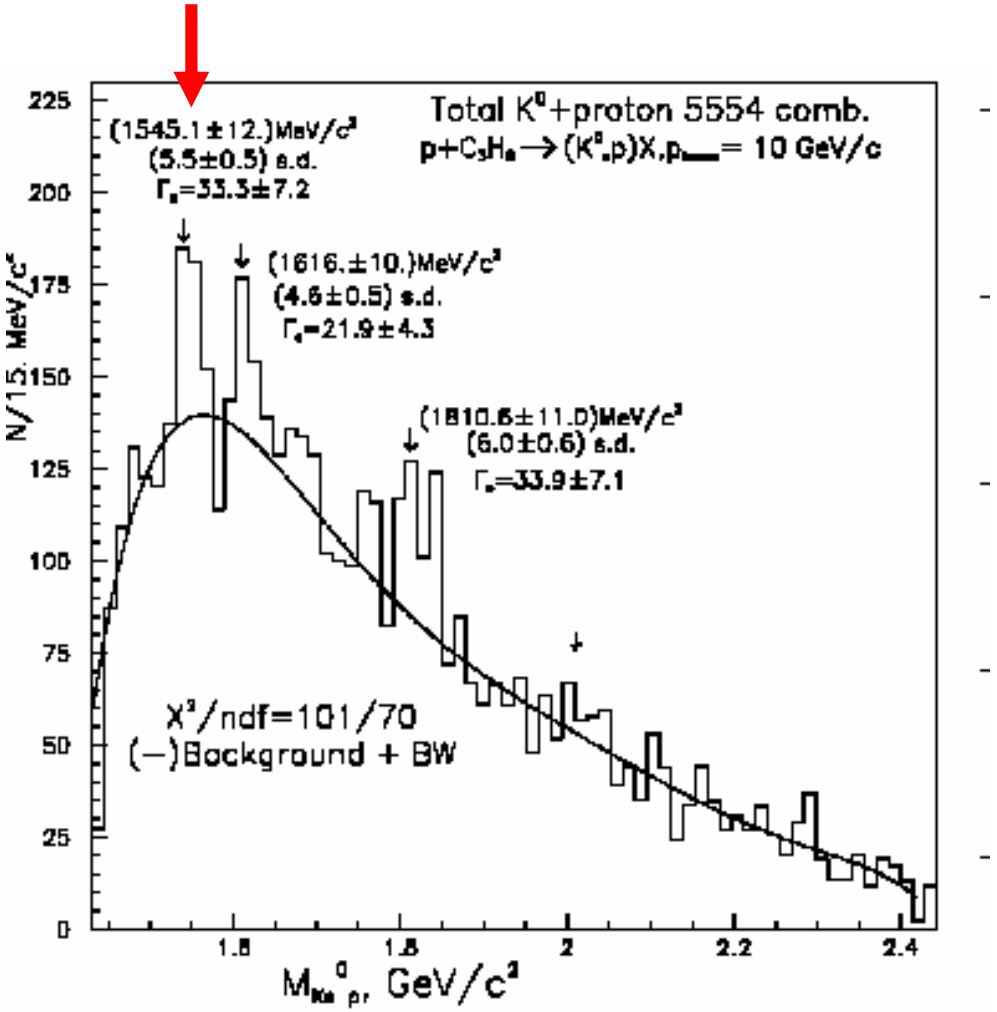
Yerevan

$p + A \rightarrow X + p K^0_S$ $\quad p_{beam} = 10$ GeV/c

C_3H_8 – target

Bubble chamber

Events selected:
Protons with small
or large momentum
to maximize peak



M = 1545 ± 12 MeV
Γ < 35 MeV
significance 5.5σ

hep-ex/0403044

HERMES

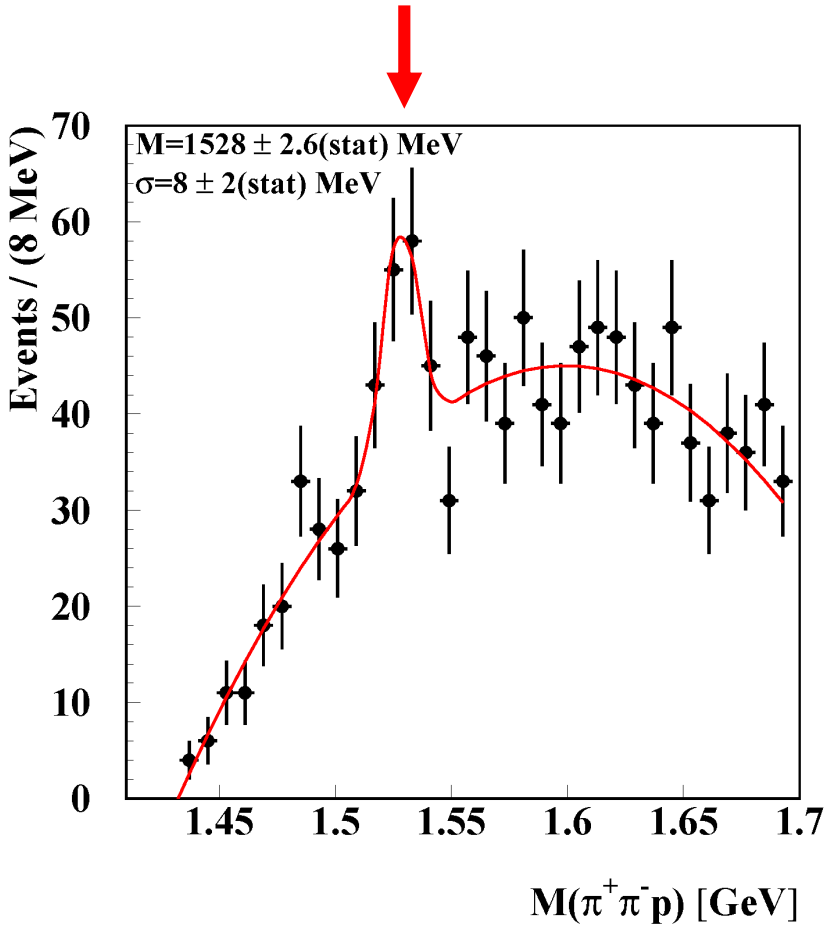
HERA at DESY: $e^+ + D \rightarrow X + p K^0_S$ E_{e+} = 28GeV

Quasi-real Photoproduction

***Event selection*:**

maximizing K^0_S peak in $M(\pi^+\pi^-)$ spectrum

minimizing background in $M(\pi^+\pi^- p)$ spectrum

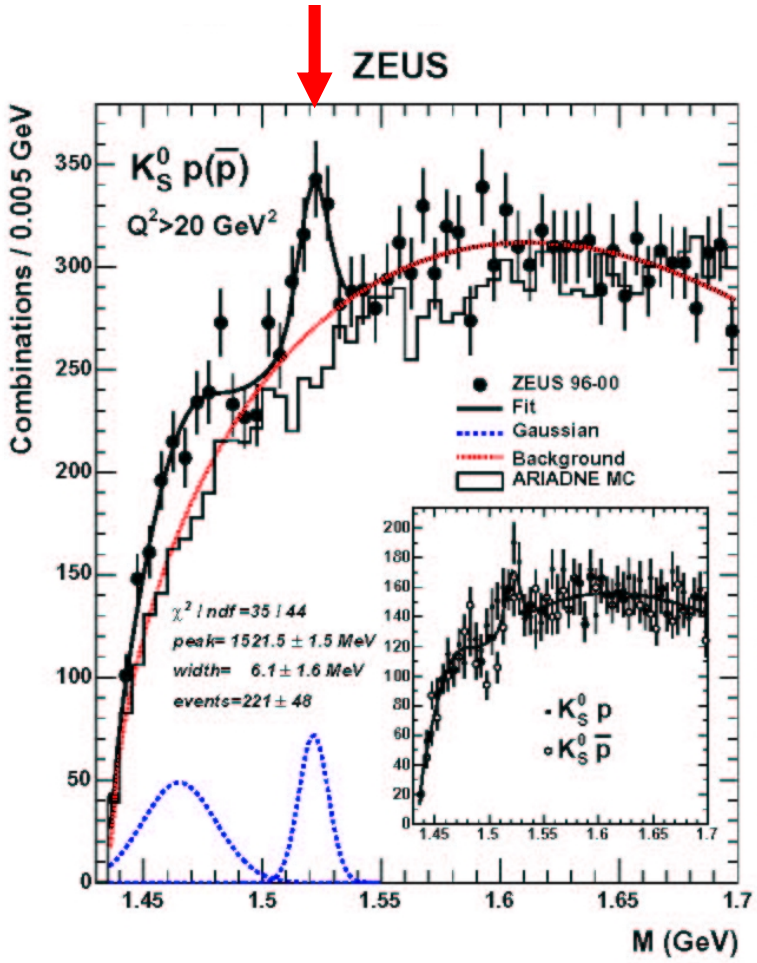


$M = 1528 \pm 4 \pm$ MeV
Γ < 19 MeV
significance ~ 4σ

hep-ex/0312044, Phys. Lett. B 585 (2004) 213

ZEUS

at HERA($\sqrt{s} \approx$ 300 GeV) **Search for $\Theta^+ \to K^0_S p$ in DIS**



$M(\Theta^+) = 1521.5 \pm 1.5(stat.)^{+2.8}_{-1.7}(syst.)$ **MeV**

$Width = 6.1 \pm 1.6(stat.)^{+2.0}_{-1.4}(syst.)$ **MeV**

above but compatible with resolution

221 ± 48 **events** ≈ 4.6 **s.d.**

Signal seen in both charges (inset)

$K^0_S\bar{p}$ **fit:** 96 ± 34 **(2.8 s.d.)**

If real - evidence for antipentaquark Θ^-

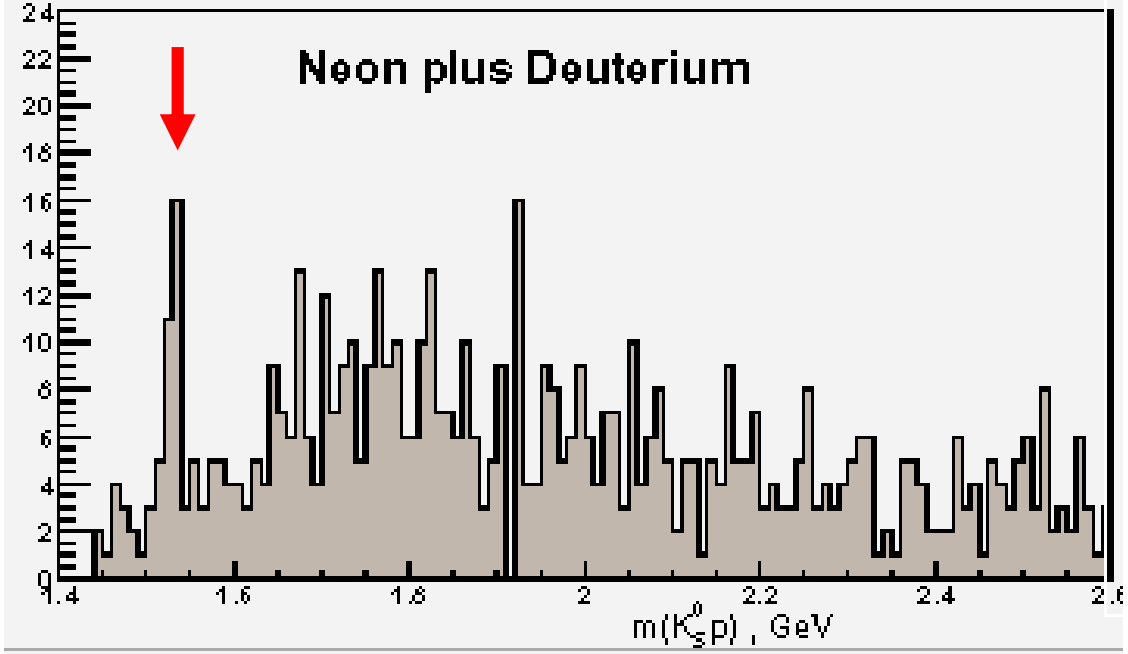
Phys. Lett. B 591 (2004) 7

Neutrino

CERN + Fermilab: $\nu + A \rightarrow X + p\, K^0_s$ $E_\nu \sim 100$ GeV

Reanalyzed data from bubble chamber Experiments

A = D + Ne



Peak at M = 1533 ± 5 MeV
Γ < 20 MeV
significance ≈ 4σ

hep-ex/0309042,

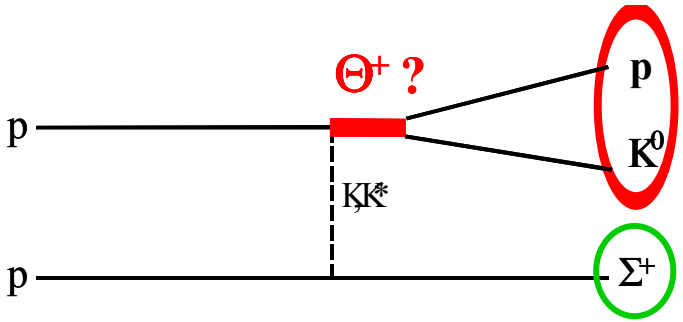
Search for Θ^+ at COSY-TOF

Strangeness production at COSY-TOF: pN → KYN

Information: dynamics + structure ⟶ degrees of freedom

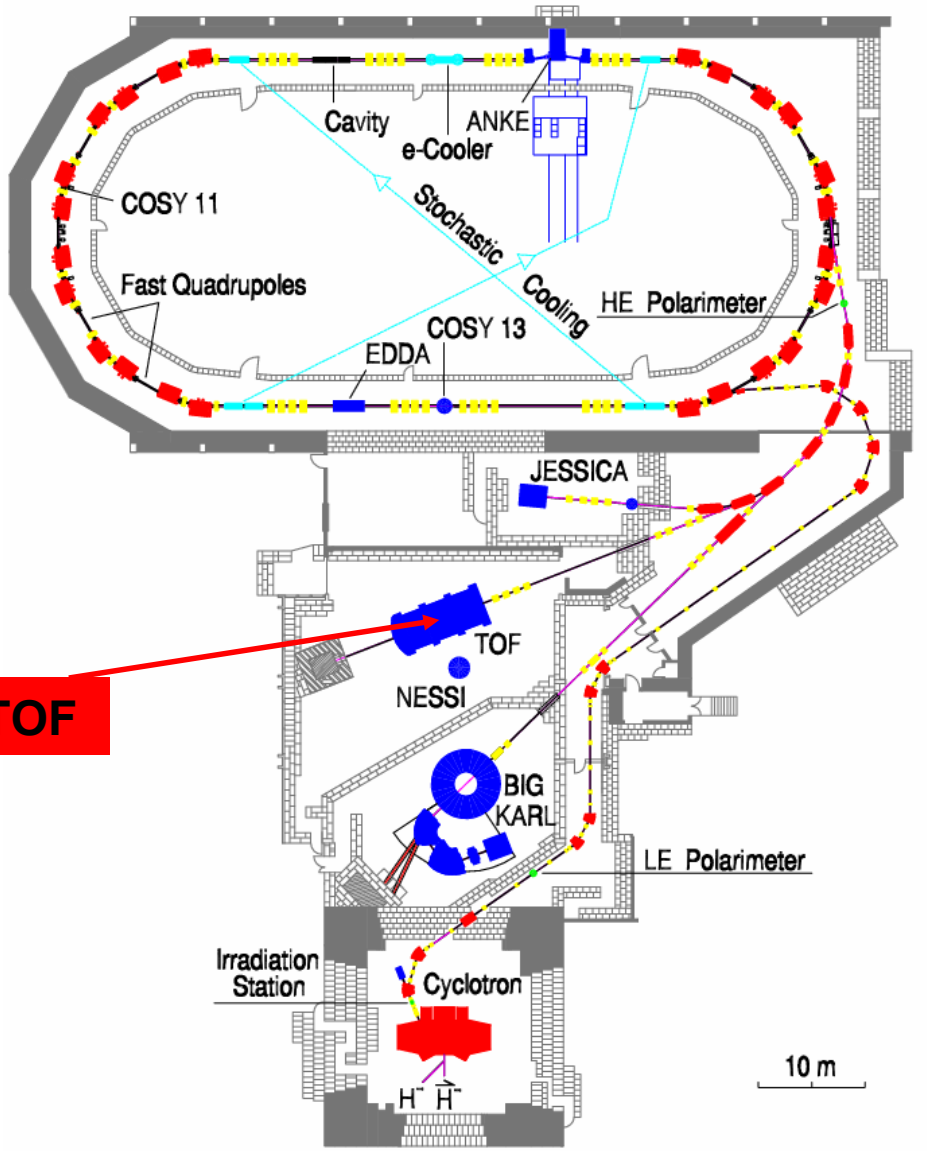
different reaction channels : N = p, n Y = Λ, Σ^0, Σ^+, Σ^-

Search for exotic Θ^+ ⟷



- **exclusive observables**
- **full phase-space → Dalitz Plots**

COSY - Facility



TOF

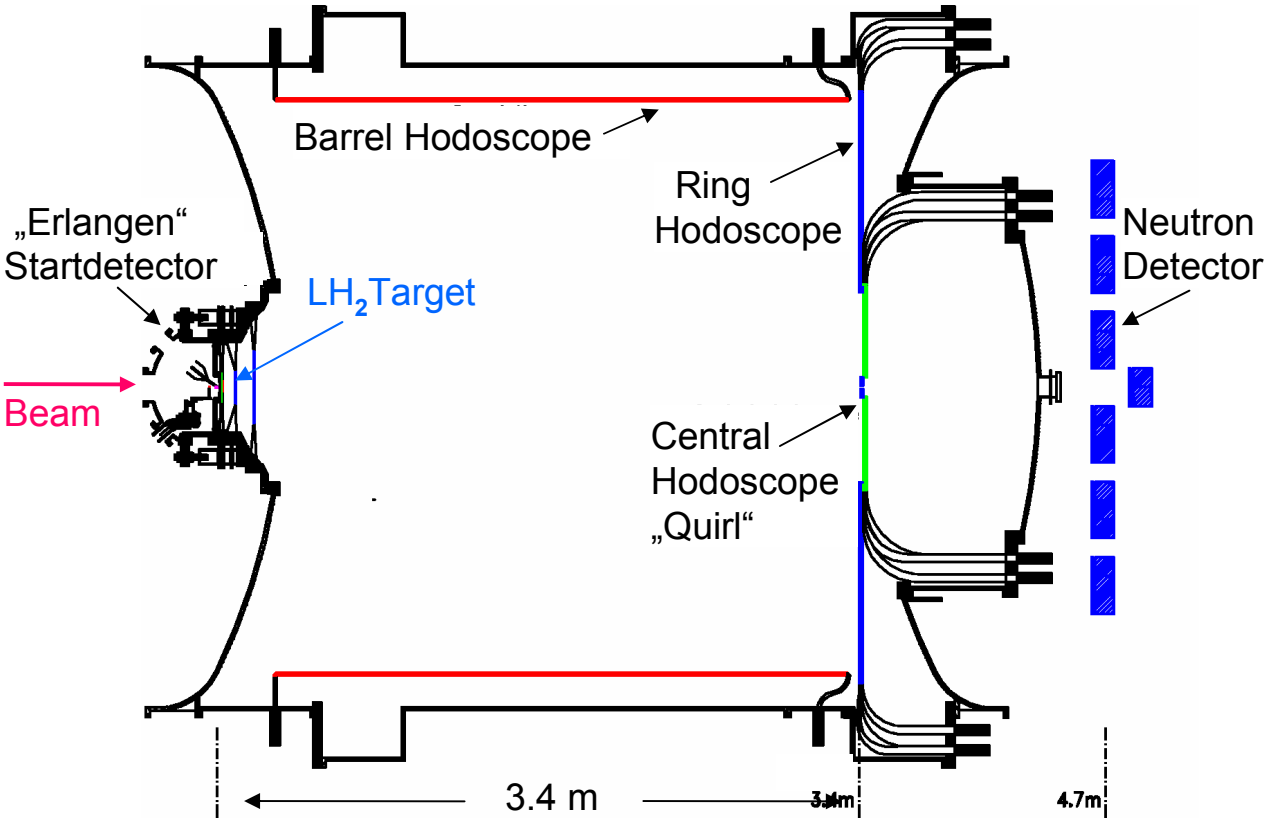
Cooler Synchrotron Jülich

Circumference: 180 m

Phase space cooling: electron and stochastic

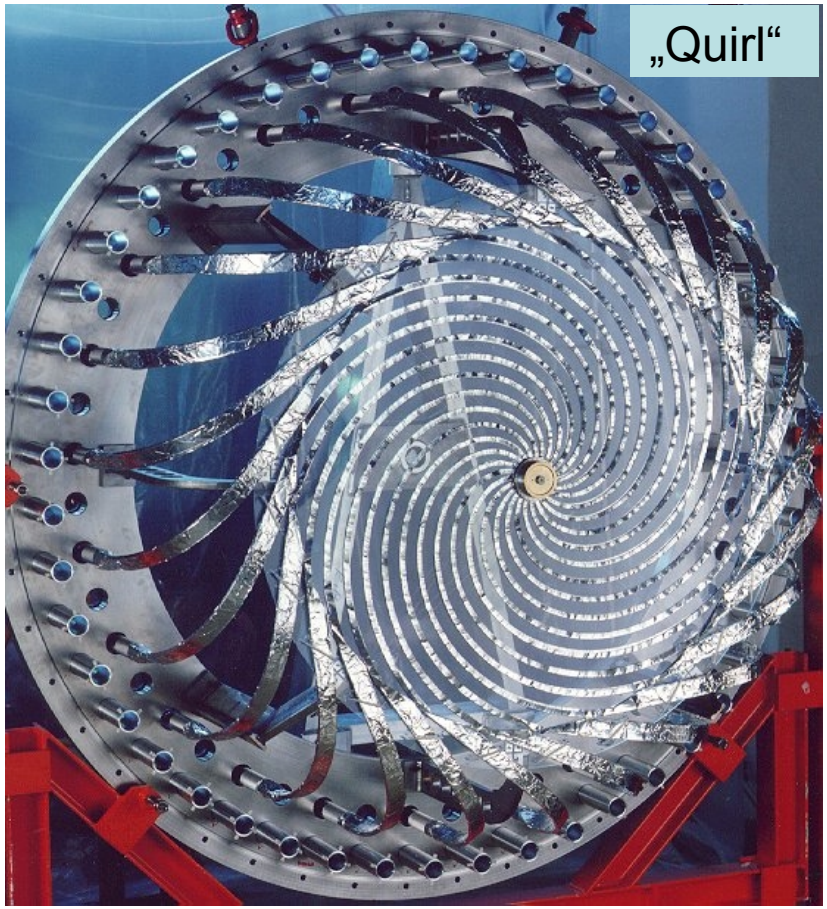
Beam momentum: maximum: 3.6 GeV/c

COSY - TOF

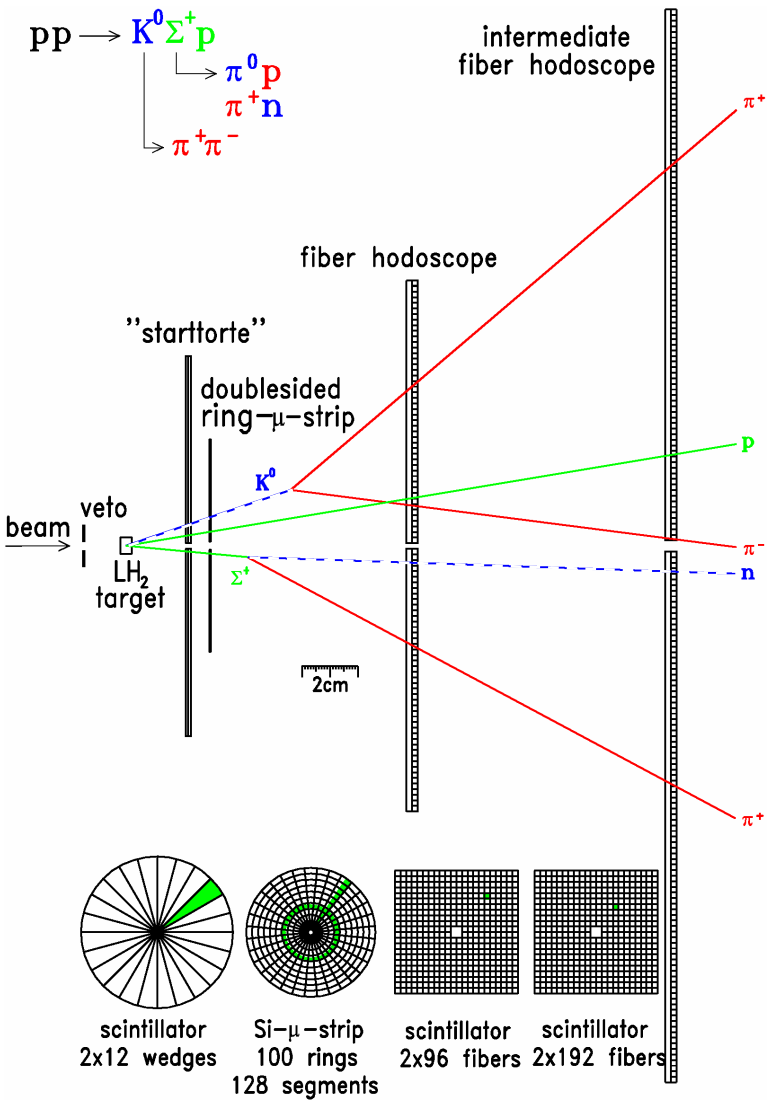


- large angle (non magnetic) spectrometer
- modular vacuum vessel
- tiny liquid hydrogen target
- startdetector system
- stopdetector system

COSY-TOF - Stop Detector



The „Erlangen Start Detector“



delayed decays of K^0, Λ
→ charged multiplicity 2 → 4
→ trigger

vertex reconstruction

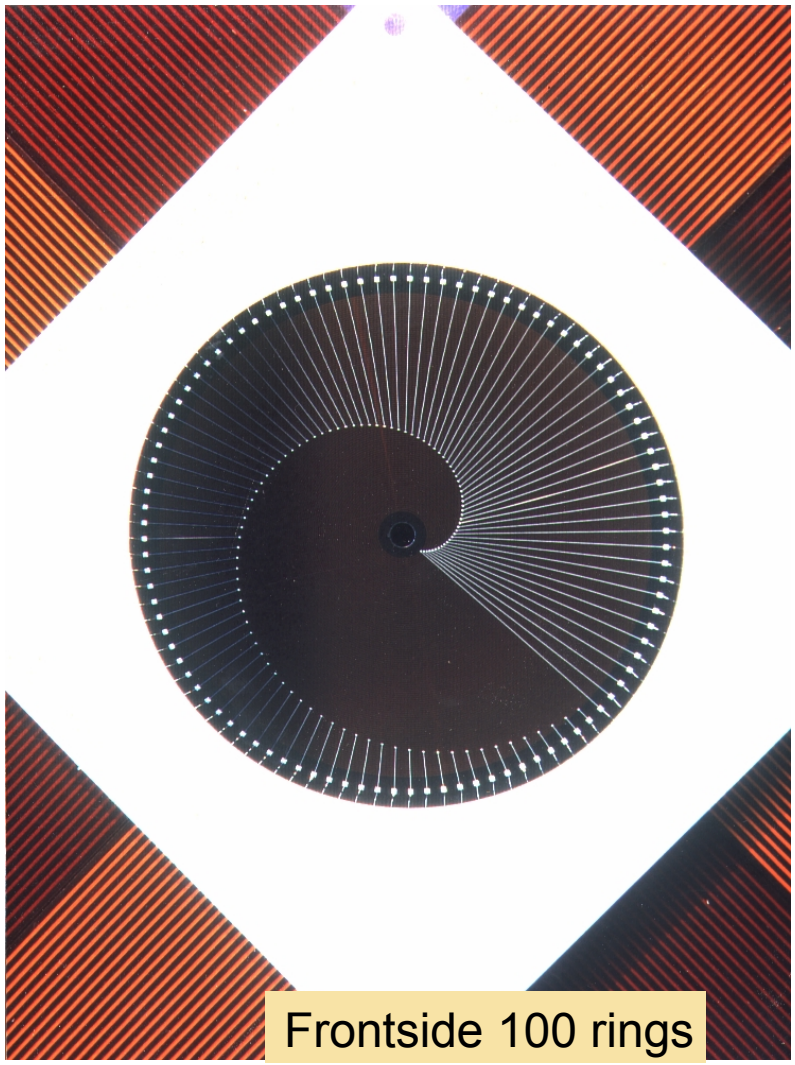
identification of K^0_s:
decay → „V“

identification of Σ^+:
decay → kink in track

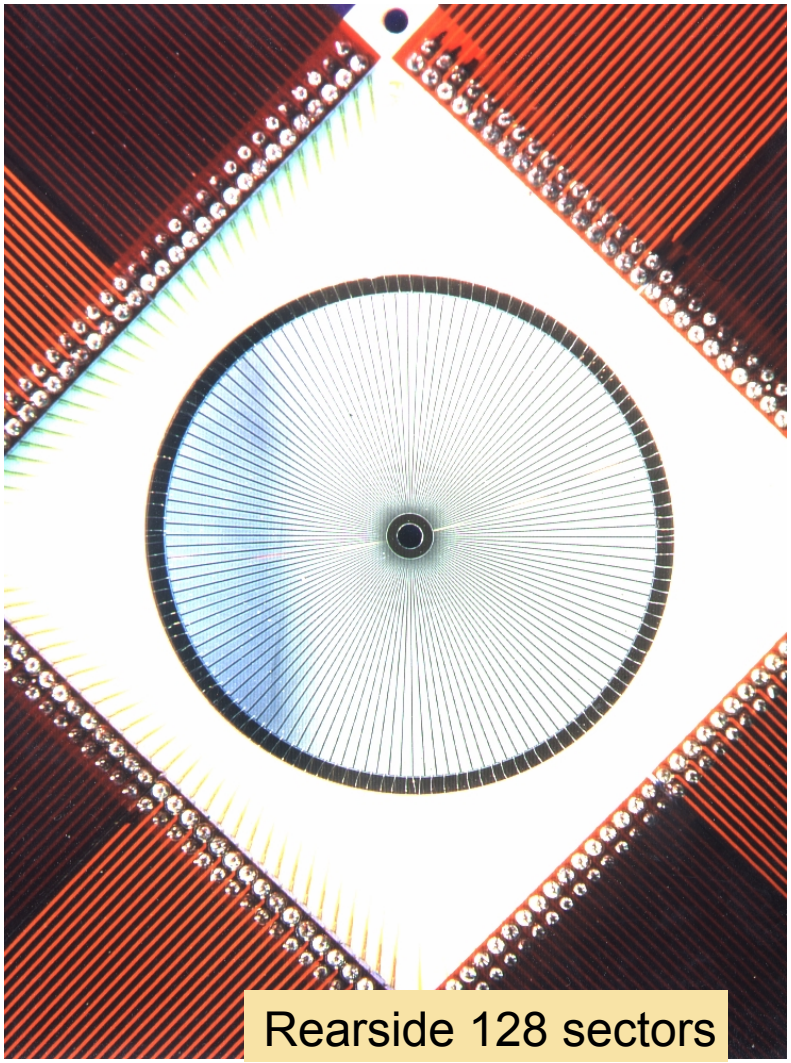
complete geometric reconstruction

„4π“ cover

„Erlangen Start Detector“: Ring microstrip detector

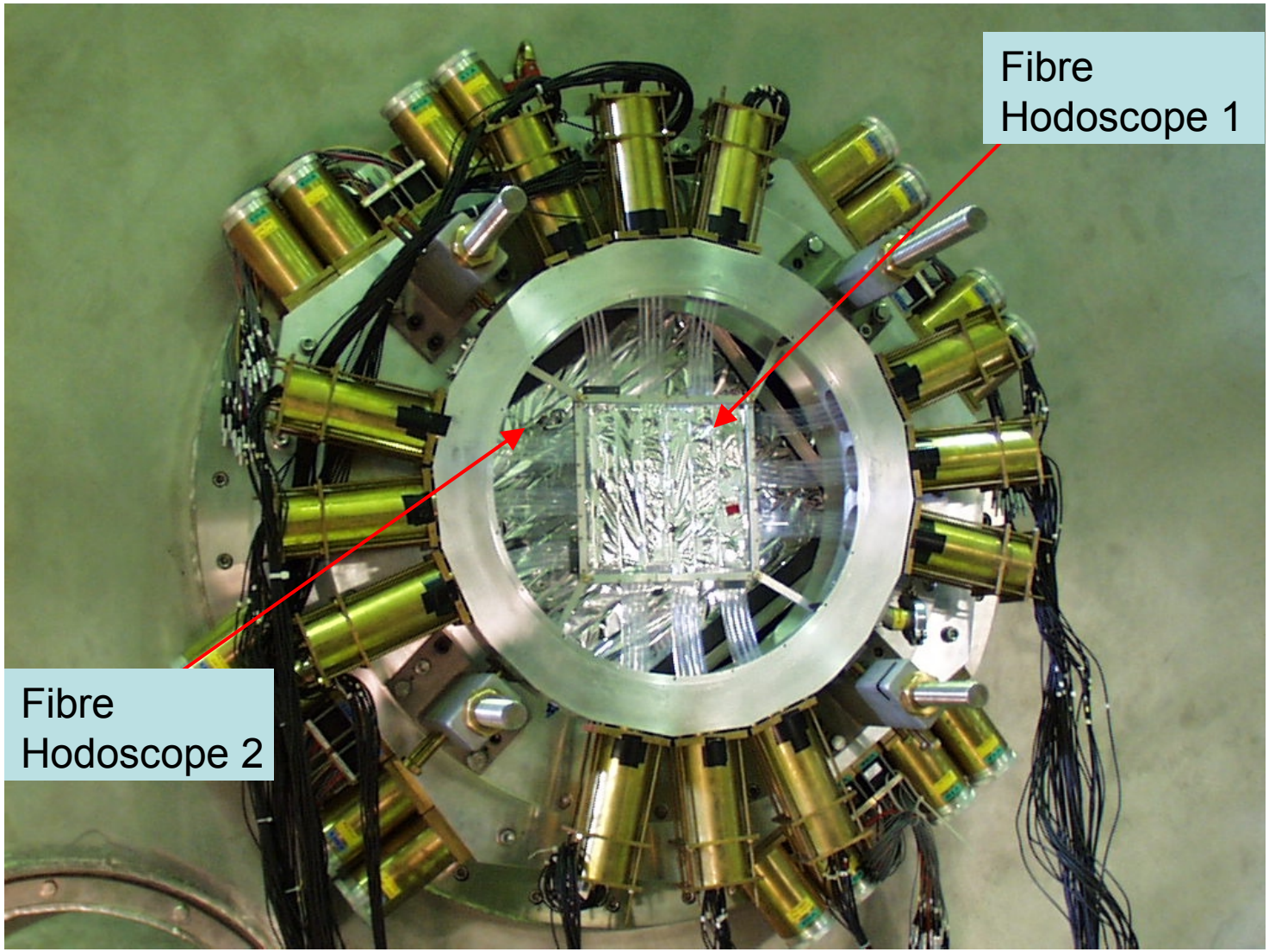


Frontside 100 rings



Rearside 128 sectors

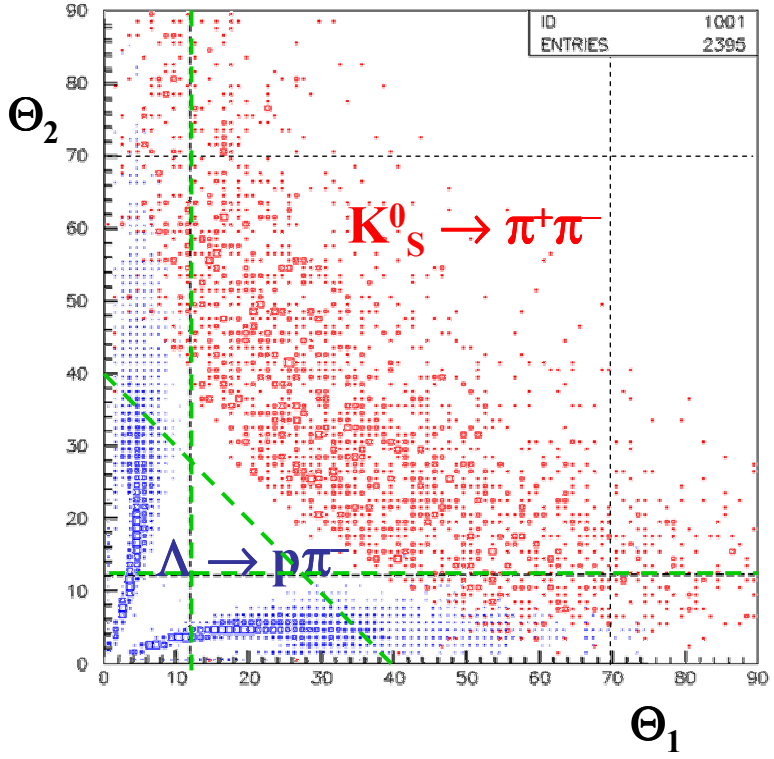
„Erlangen Start Detector“: Fibre Hodoscopes

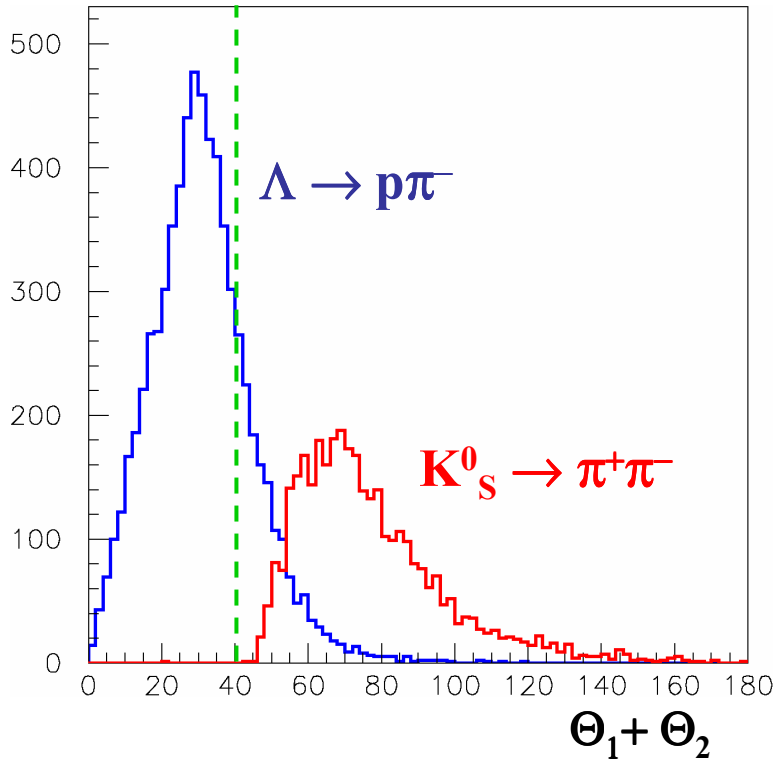


pp → Σ^+K^0p: background separation

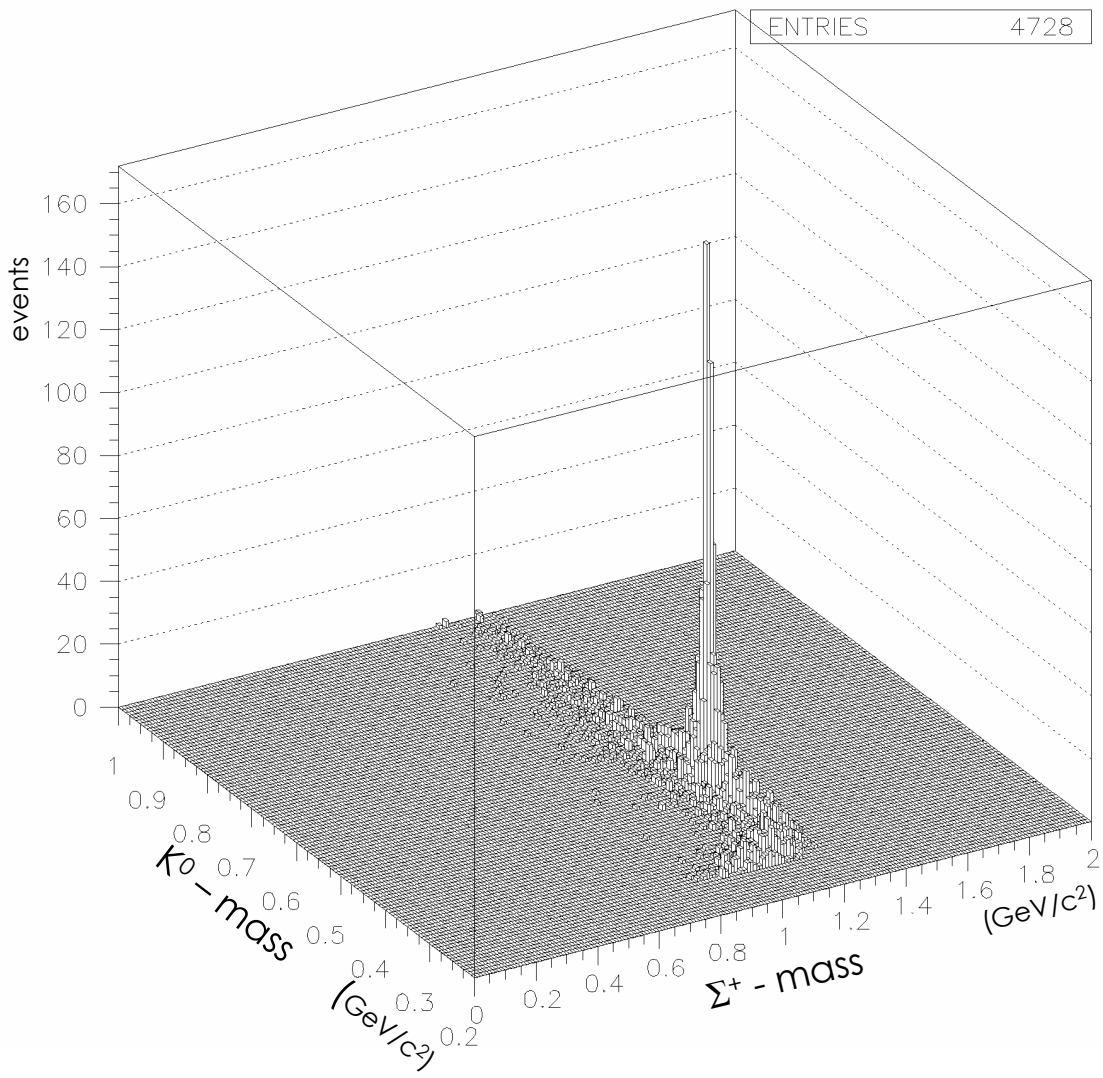
Separation of pp → $pK^0\Sigma^+$ from pp → $pK^+\Lambda$ and $pK^+\Sigma^0(\rightarrow \gamma\Lambda)$

P_{beam} = 2.95 GeV/c Monte Carlo simulations





pp → $\Sigma^+ K^0 p$: reconstructed masses

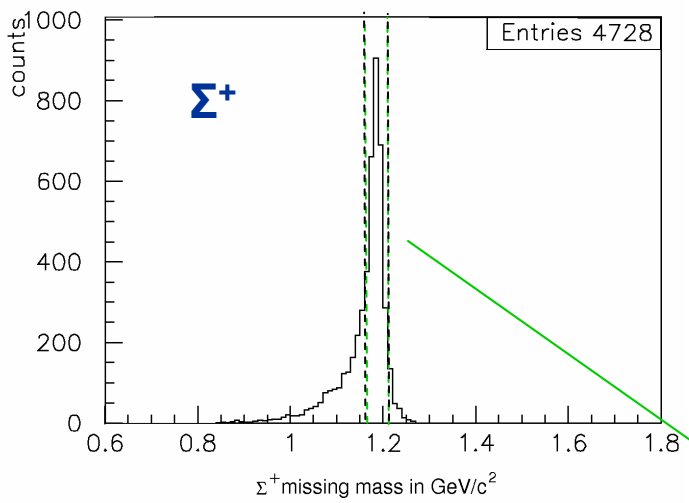


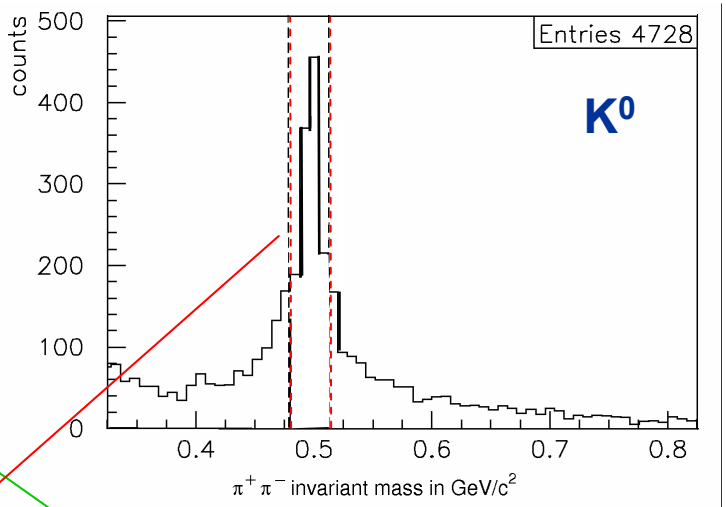
P_{beam} = 2.95 GeV/c

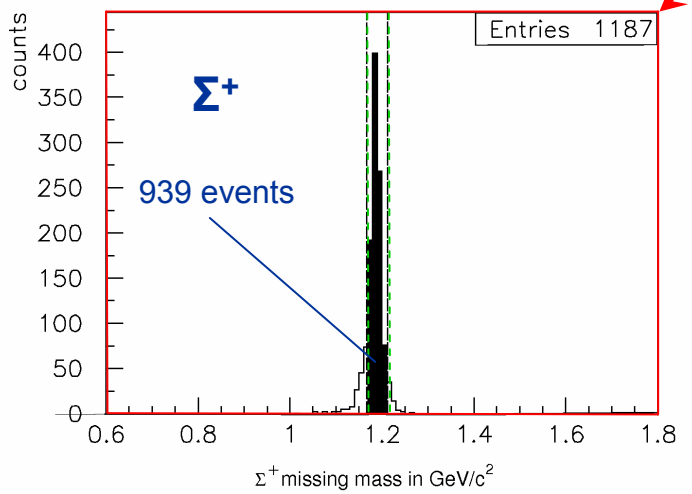
Runs 2000 + 2002

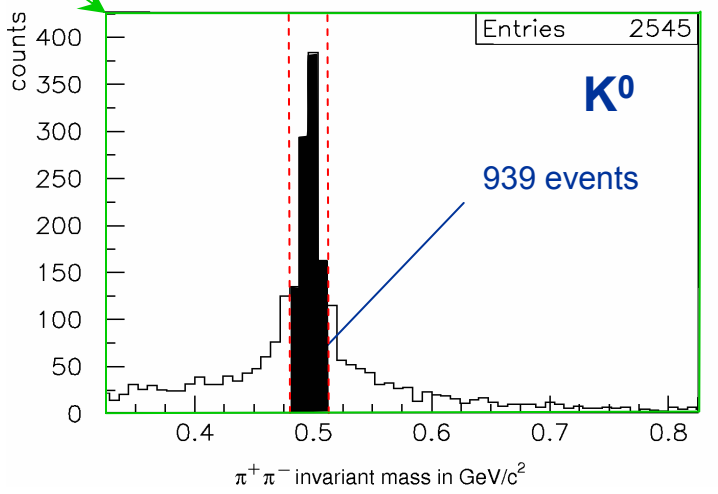
pp → $\Sigma^+ K^0 p$: cuts on masses

P_{beam} = 2.95 GeV/c **Run 2000 + Run 2002**



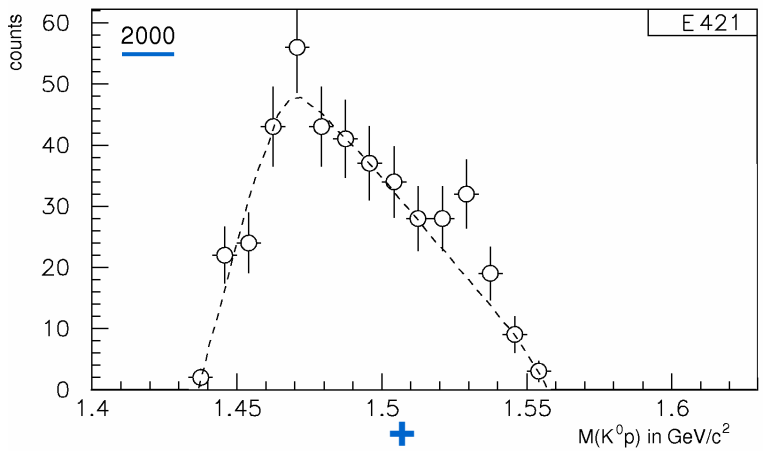






pp → Σ^+K^0p: K^0p mass spectra

P_{beam} = 2.95 GeV/c



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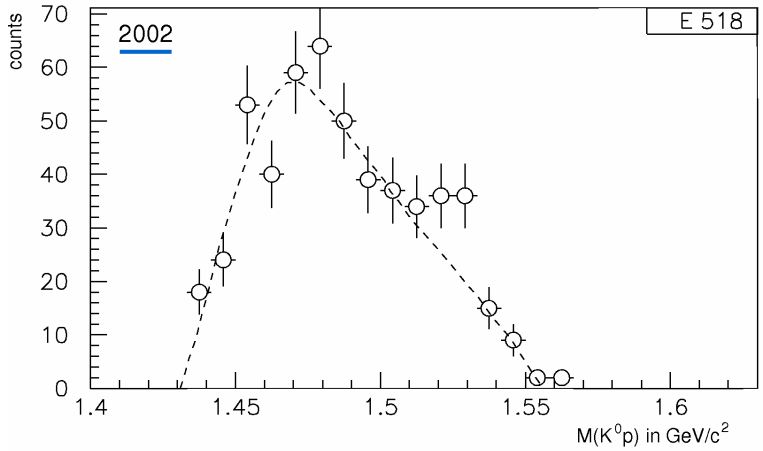

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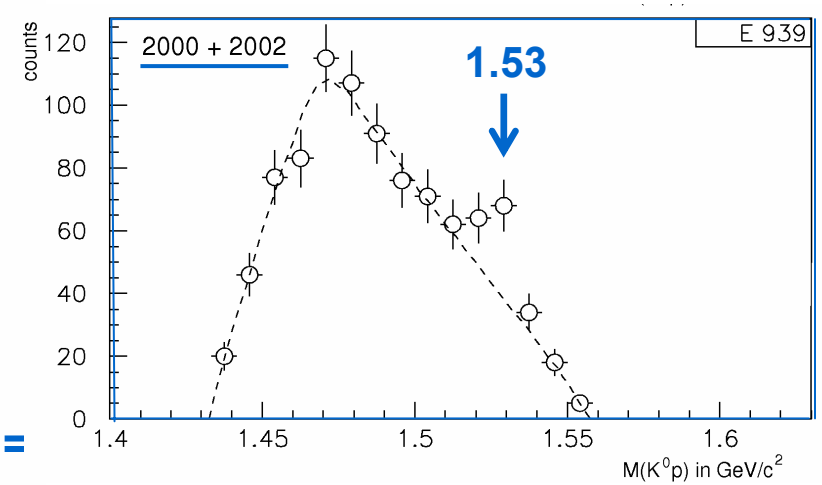


significance: 4 – 6 σ

(depending on method)

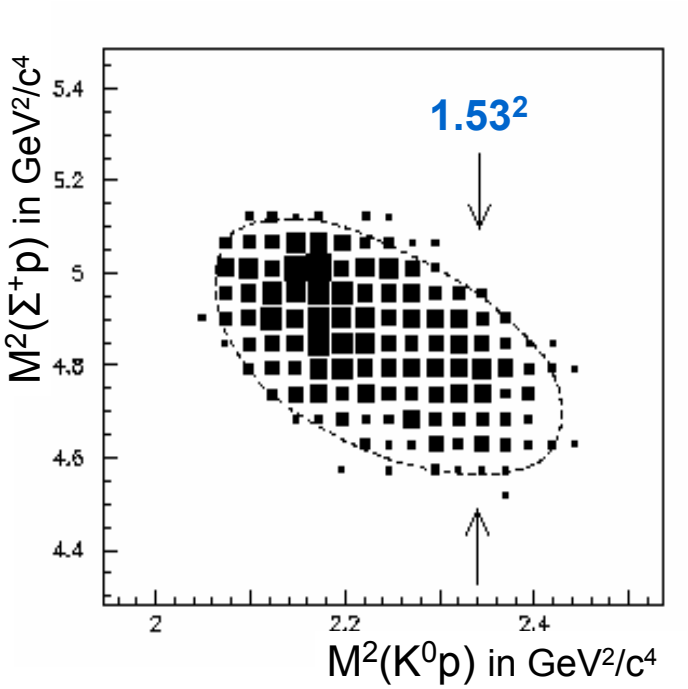
$NS / \sqrt{NB}$ $5.9\,\sigma$

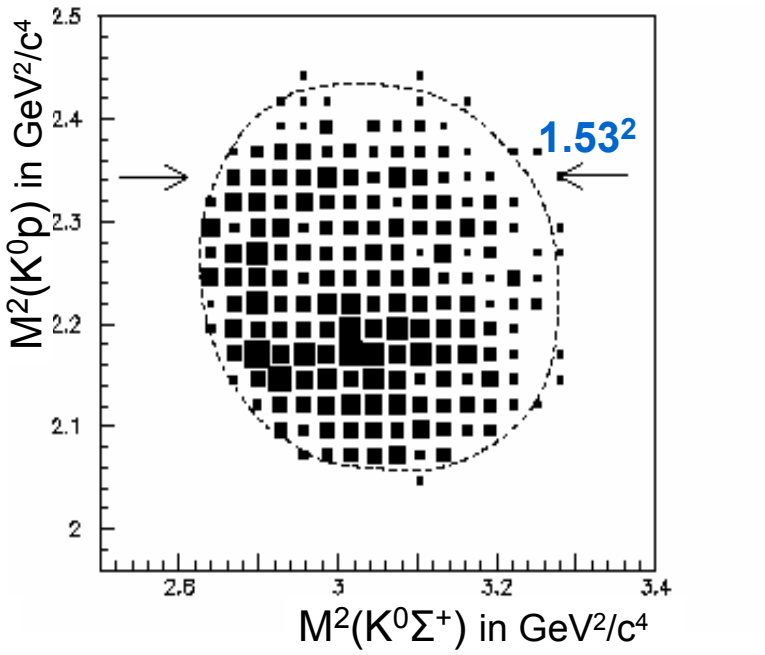
$NS / \sqrt{NS + NB}$ $4.7\,\sigma$

$NS / \sqrt{(NS + NB) + NB}$ $3.7\,\sigma$

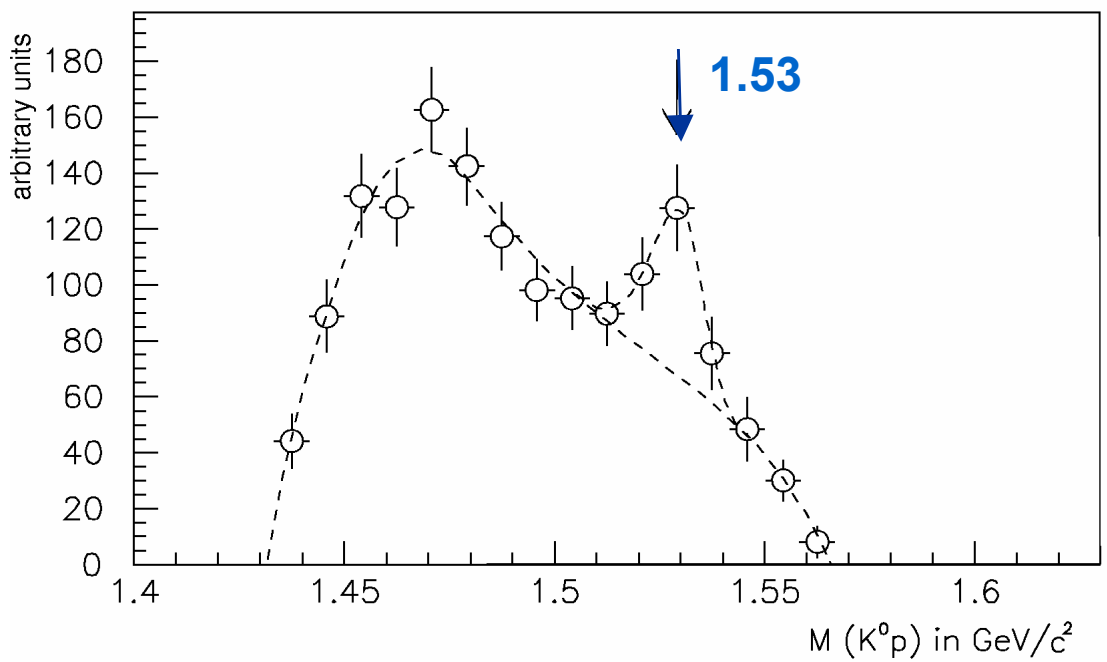
pp → Σ^+K^0p: Dalitz plots

P_{beam} = 2.95 GeV/c





pp → $\Sigma^+ K^0 p$: efficiency corrected $K^0 p$ spectrum

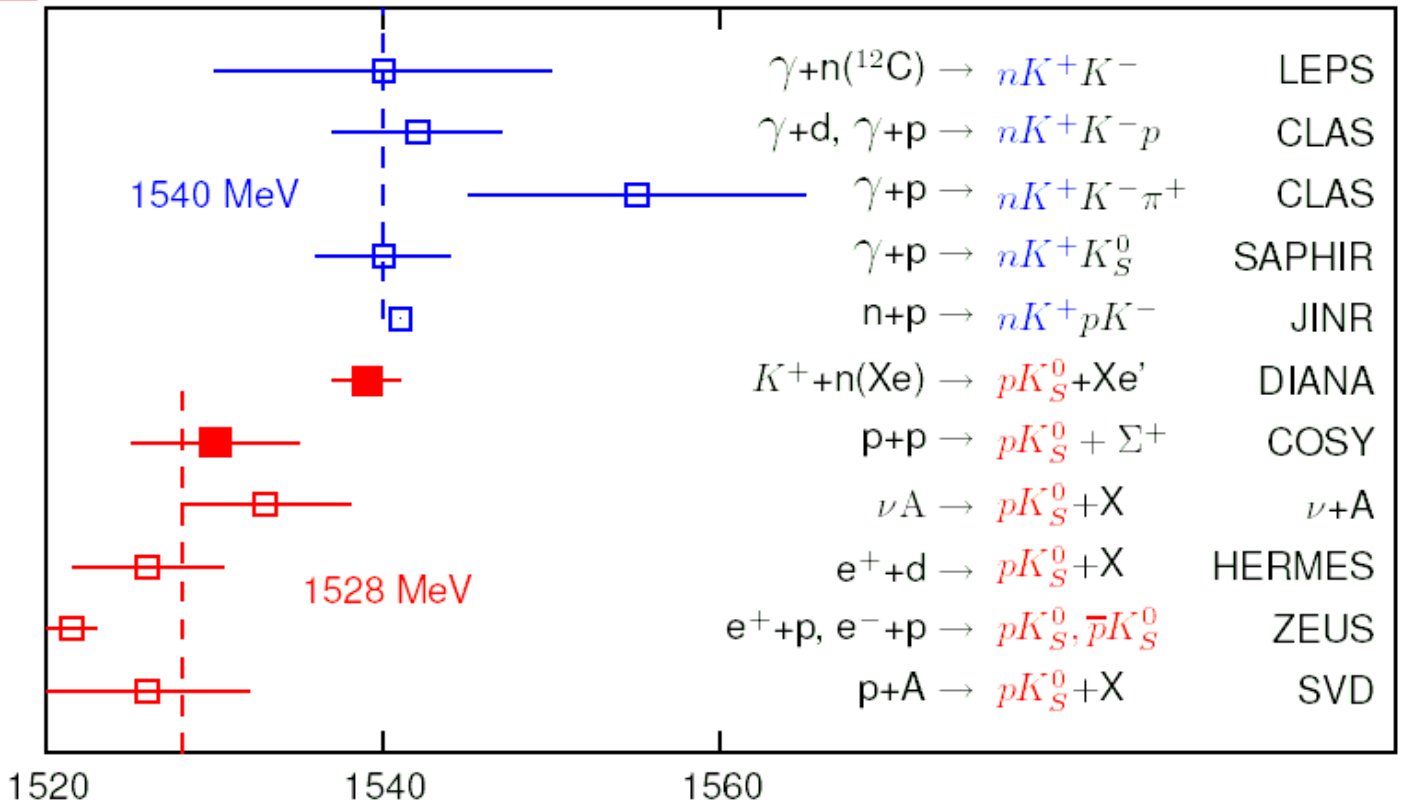


Mass 1530 ± 5 MeV/c²
Width ≤ 18 ± 4 MeV/c² (FWHM)
Strangeness S = + 1
Cross section: $0.4 \pm 0.1_{stat} \pm 0.1_{sys}$ μb

***hep-ex/0403011, Phys. Lett. B* 595 (2004), 127**

Summary

Positive results on Θ+



Negative results on Θ+

e+e- collider data: Belle, BaBar, ALEPH, DELPHI, etc.

High-energy protons: HERA-B, E690, CDF, D0, HyperCP, etc.

Theorie

Summary by Carl E. Carlson, Particle Theory group

at pentaquark 04

Lots of theory work, from assorted starting points

- Lattice gauge theory and QCD sum rule workers presented a number of independent calculations. Majority finds the pentaquark, and finds it with negative parity. But may be safer to say parity and existence not settled.
- Chiral quark soliton models (still) predict existence of lightest pentaquarks in flavor $\overline{10}$ with mass in 1500 Mev range and positive parity.
- Quark model can accommodate either parity. Seems easier to explain narrowness of state if parity is positive. Available numerical estimates of positive/negative parity pentaquark widths are dramatically different.
- Possibility that Θ^+ is $NK\pi$ bound molecular bound state is intriguing and could render much of the other work moot.

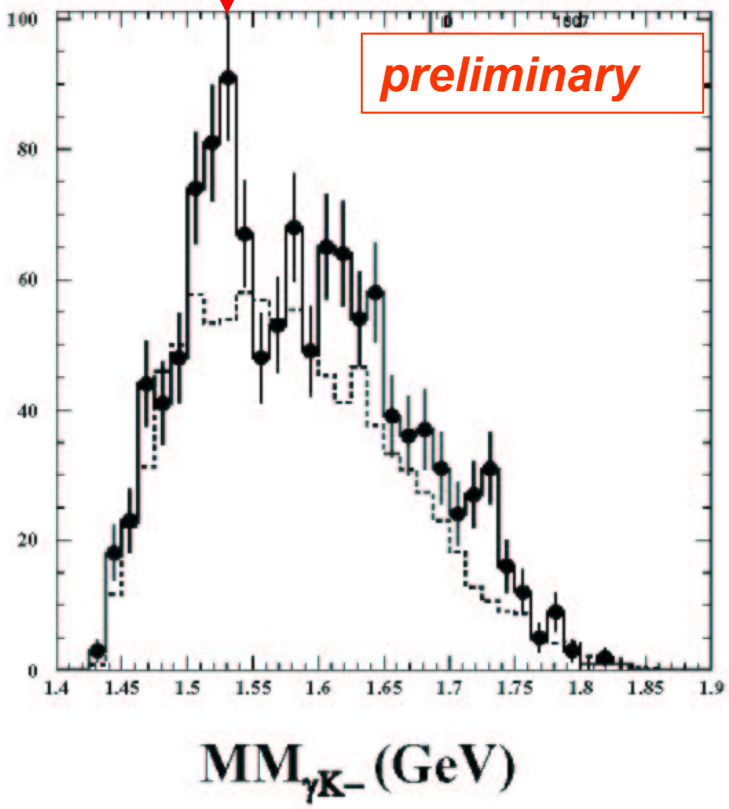
LEPS

New Results on LD2: Nakano et al. Pentaquark04

- Data taken from Oct. 2002 to Jun. 2003.

  LD2 target. ⟶ Less Fermi motion effect.

1.53 GeV !



- Background level around 1.53 GeV in 4 bins is ~220 events IF we take the mixed event BG method.
- The excess above the BG level is ~90 events.
- The peak position, width, significance strongly depends on the BG shape.

Future

Experimental Outlook

New results expected in the near future:

goal: confirmation → more insight

- CLAS high-statistics proton data (just done)
- HERMES: > double statistics (now running)
- KEK E559: $\pi^+ p \rightarrow K^-(\Theta^+)$ run in May 2005
- COSY-TOF:

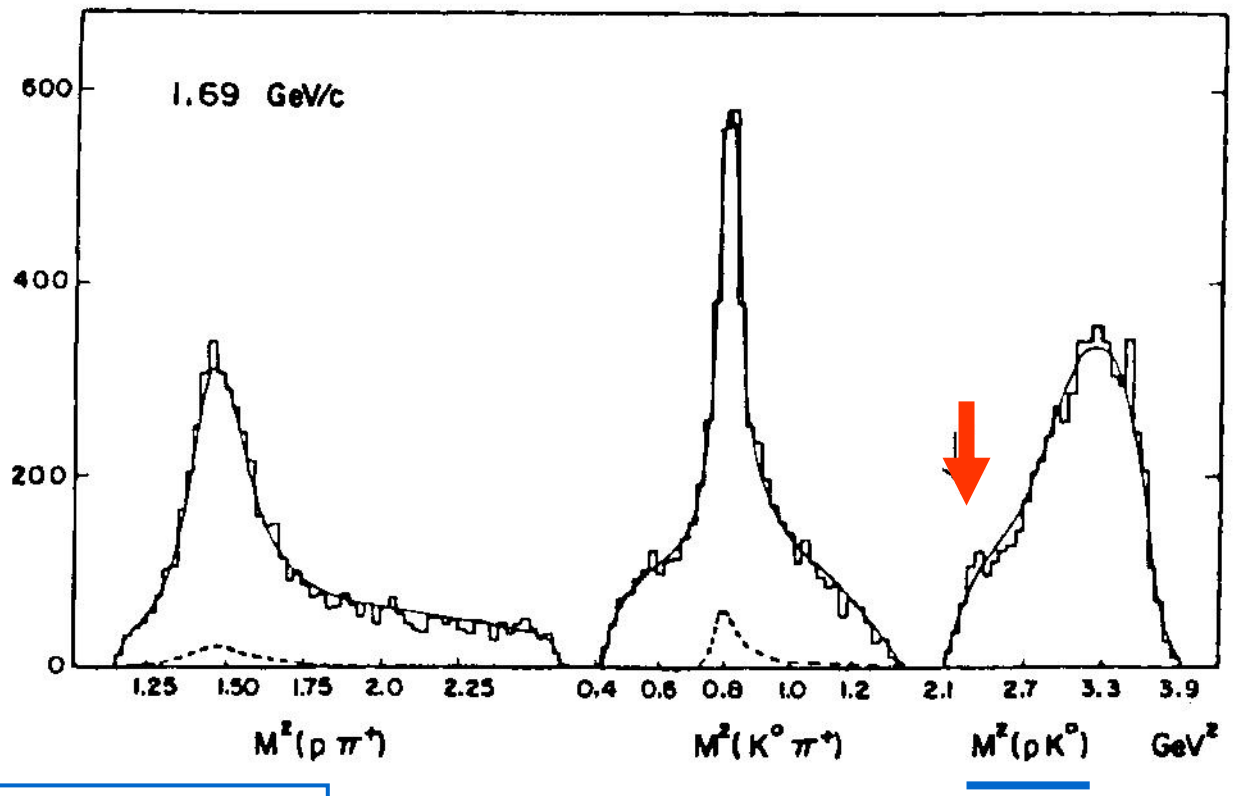
2004: $pp \rightarrow \Sigma^+ K^0 p$ factor of five more events → confirmation

2005: $pn \rightarrow \Lambda K^0 p$ using a LD_2 target, successful test in 2002
pol. beam + Λ-polarization → towards parity of Θ^+

2005: $pp \rightarrow \Sigma^+ K^0 p$ polarized beam + polarized target → Θ^+ parity

1973

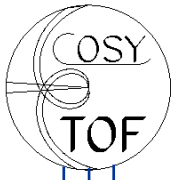
First hints: $K^+ p \rightarrow p K^0_s \pi^+$ $p_{beam} = 1.69$ GeV/c



M = 1.53 GeV
Peak ≈ 100 events

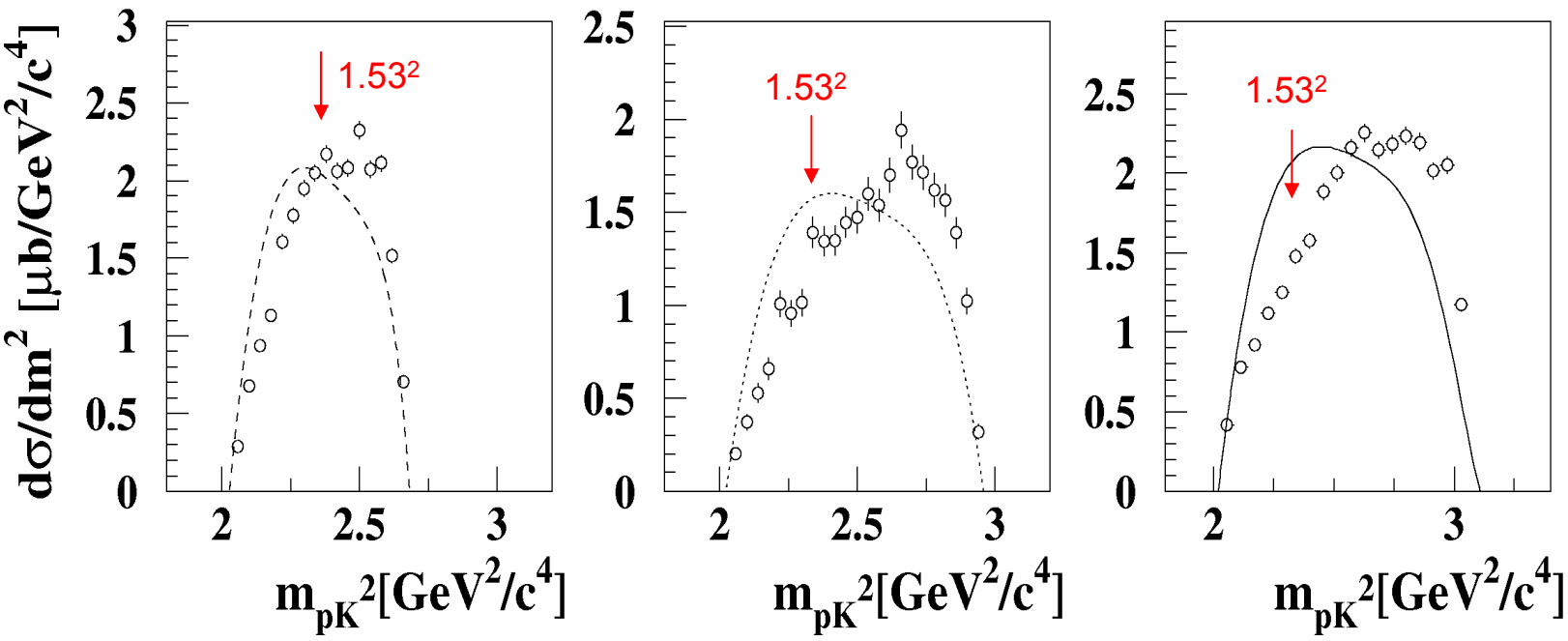
Nucl. Phys.B 99 (1975) 346

see also E. Klempt



$pp \rightarrow \Lambda K^+ p$: search for Θ^{++}

P_{beam} : 2.95 GeV/c 3.20 GeV/c 3.30 GeV/c



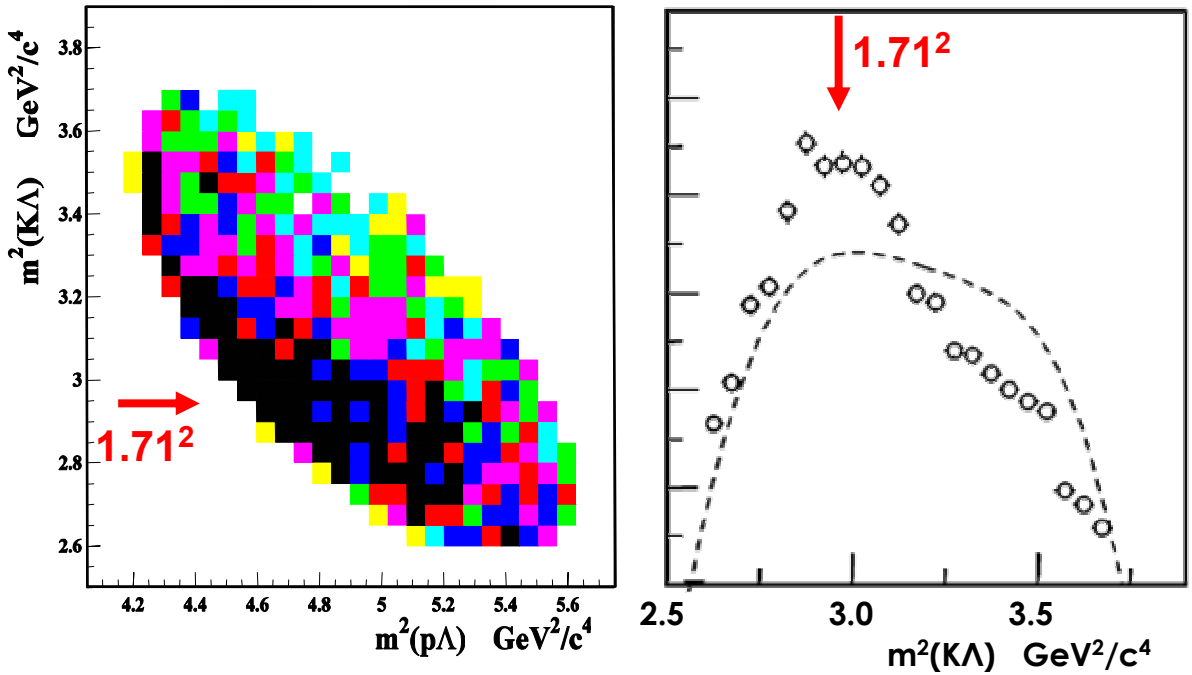
Preliminary: no evidence for Θ^{++} in pK^+ spectra

In progress: investigations of Dalitz plots

search for Θ^{+++} in $pp \rightarrow \Sigma^- \Theta^{+++}$

pp → ΛK⁺p: N* resonances

P_{beam} : 3.30 GeV/c



N*(1710) contributes strongly

Influence of pΛ-FSI

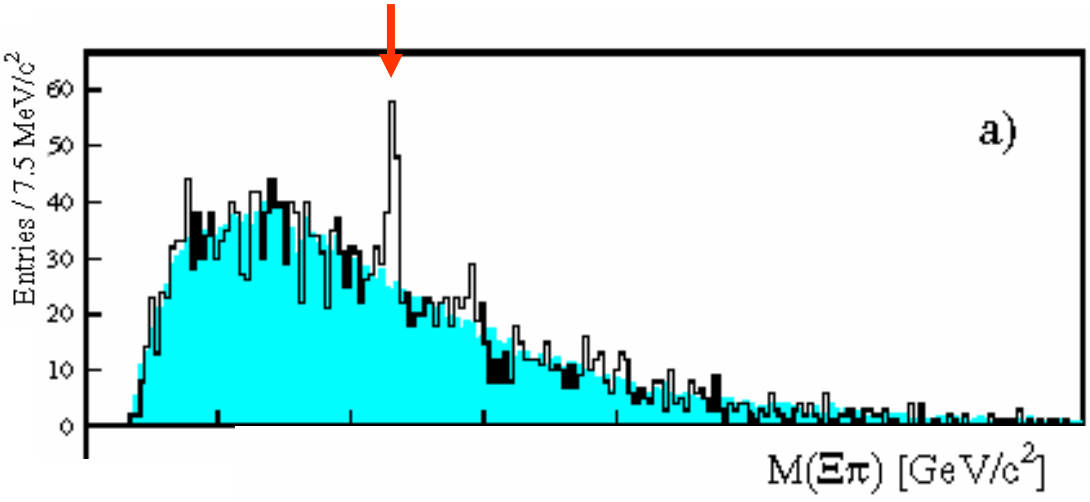
In progress: Investigation of Dalitz plots → **width**

Ξ^{--} ?

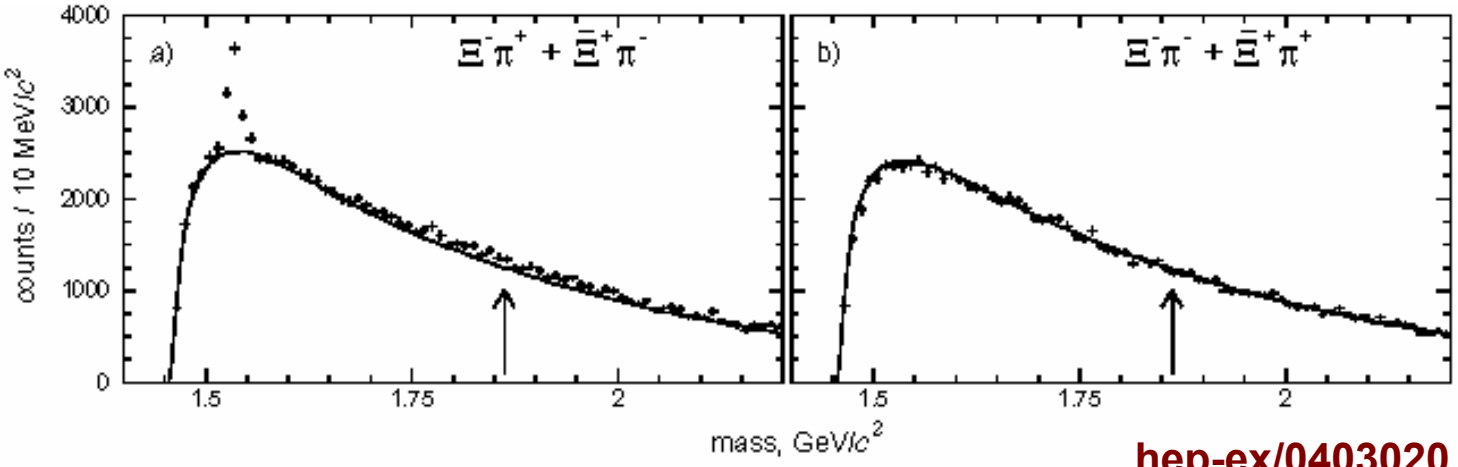
Evidence from NA49: $p\,p \rightarrow X + \Xi^- \pi^- + c.c.$ $(+ \Xi^- \pi^+ + c.c.)$

$M = 1862 \pm 2$ MeV
$\Gamma < 21$ MeV
significance = 4.6σ

hep-ex/0310014



No Evidence from HERA-B: search in $\Xi^- \pi^- + c.c.$



hep-ex/0403020

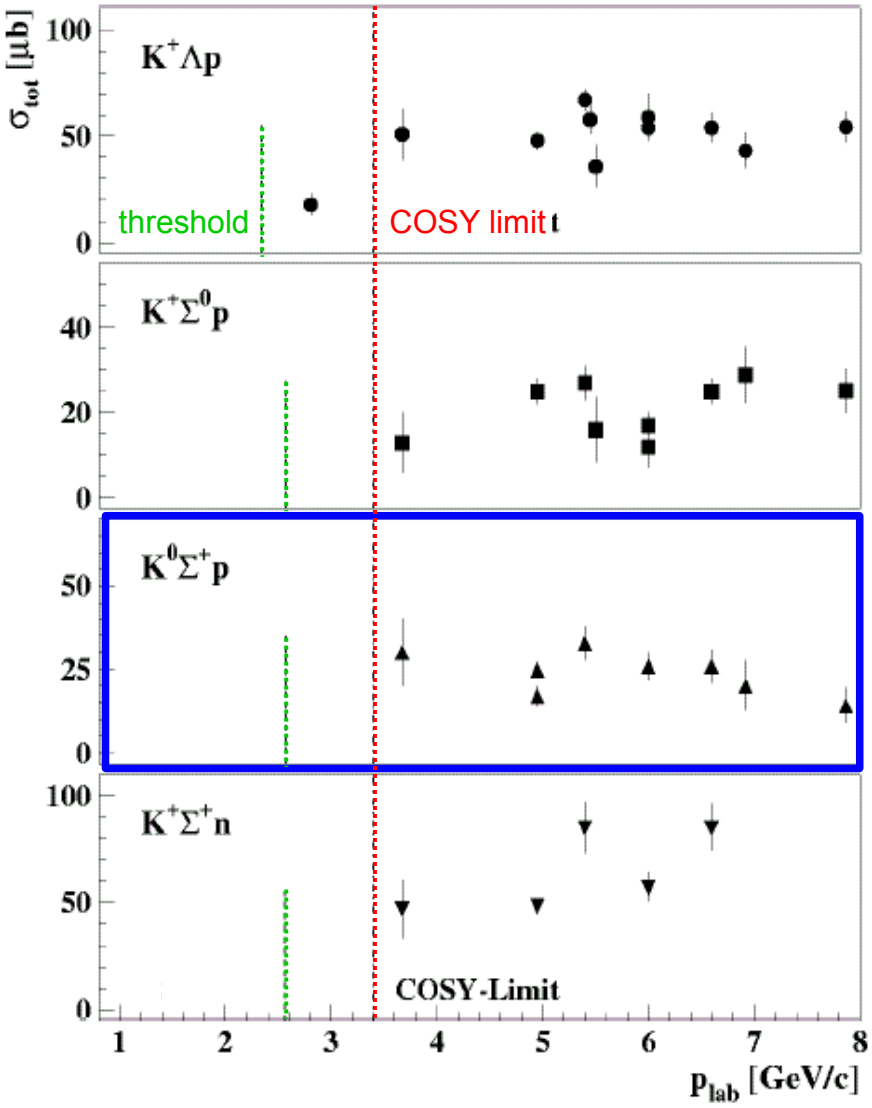
Summary

Significance recalculated

by E. Klempt: $\sigma = NS / \sqrt{(NS+NB)+NB}$

Mass (MeV)	Width (MeV)	N_{event}	Statist. signif.	Reaction	Experiment
$1540 \pm 10 \pm 5$	< 25	19 ± 2.8	$\sim 2.7\sigma$	$\gamma C \to C' K^+ K^-$	LEPS
$1539 \pm 2 \pm 2$	< 9	29	$\sim 3.0\sigma$	$\gamma p \to n K^+ K^0_s$	DIANA
$1542 \pm 2 \pm 5$	< 21	43	$\sim 3.5\sigma$	$\gamma d \to pn K^+ K^-$	CLAS
$1540 \pm 4(\pm 3)$	< 25	63 ± 13	4.8σ	$\gamma p \to n K^+ K^0_s$	SAPHIR
$1533 \pm 5(\pm 3)$	< 20	27	$\sim 4.0\sigma$	ν–induced	CERN, FNAL
$1555 \pm 1 \pm 10$	< 26	41	$\sim 4.0\sigma$	$\gamma p \to n K^+ K^- \pi^+$	CLAS
1528 ± 4	< 19	~ 60	$\sim 4\sigma$	γ^*–induced	HERMES
$1526 \pm 3 \pm 3$	< 24	50	3.5σ	p-p reaction	SVD-2
1530 ± 5	< 18		3.7σ	p-p reaction	COSY
1545 ± 12	< 35	~ 100	$\sim 4\sigma$	p-A reaction	YEREVAN
$1521.5 \pm 1.5^{+2.8}_{-1.7}$	< 6	221	4.6σ	Fragmentation	ZEUS

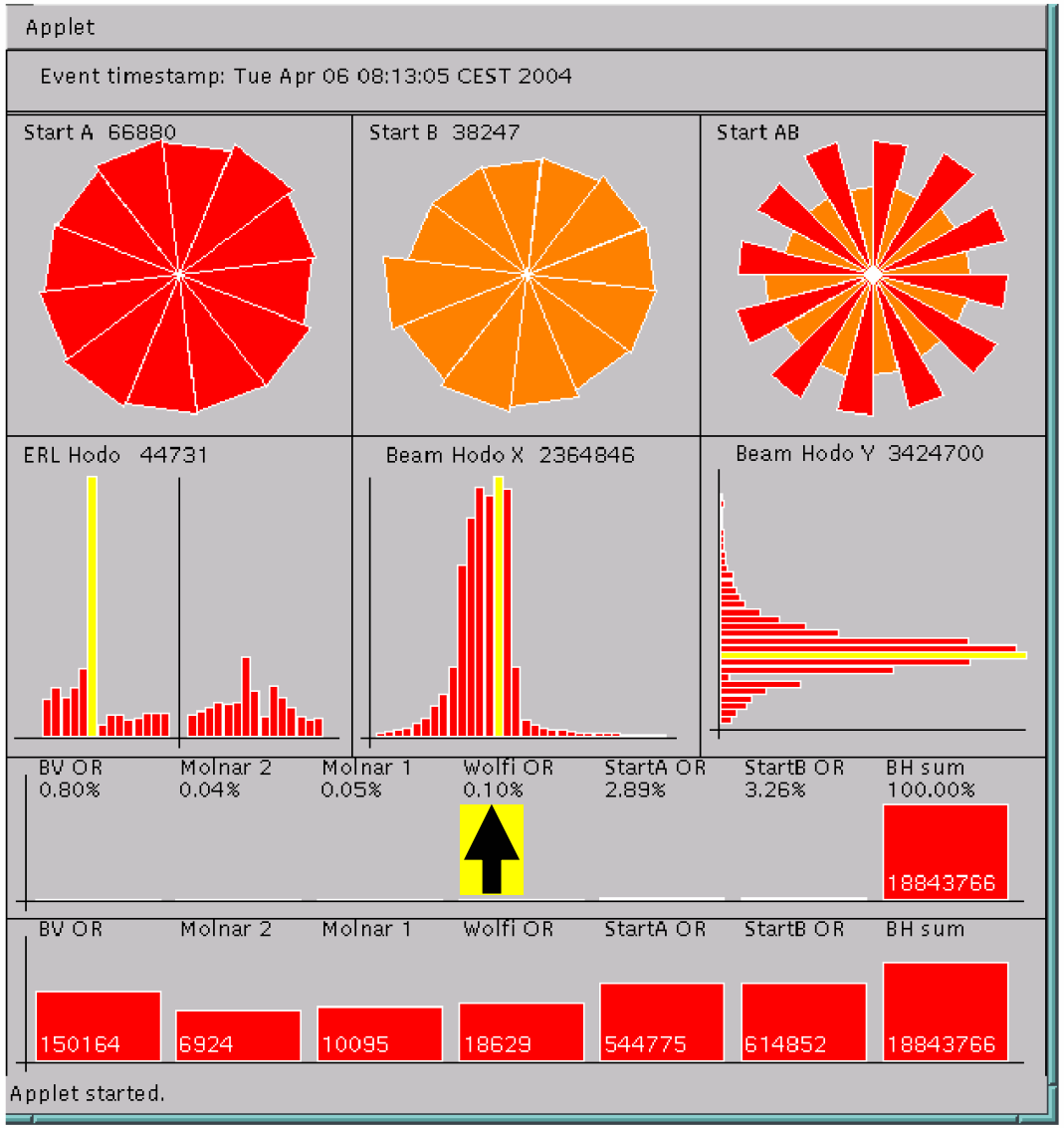
pp → KYN close to threshold



Strangeness production in pp → KYN reactions before COSY:

almost no data in threshold region

COSY - beam



Beam-Quality

Veto-detector

with 2 mm hole

0.1% intensity

Beam-Intensity

used

1 - 3 x 10^7 p/s

pp → $\Sigma^+ K^0 p$: reconstructed masses

P_{beam} = 2.95 GeV/c Run 2000 ↔ Run 2002