Wolfgang Eyrich, Universität Erlangen-Nürnberg, Trento, Feb. 10th, 2004

Search for Pentaquark States in the COSY-TOF Experiment

Motivation

Experiment

Results

$pp \rightarrow \Sigma^{+}K^{0}p$

$pp \rightarrow \Lambda K^{+}p$

Future plans

$pn \rightarrow \Lambda K^{0}p$

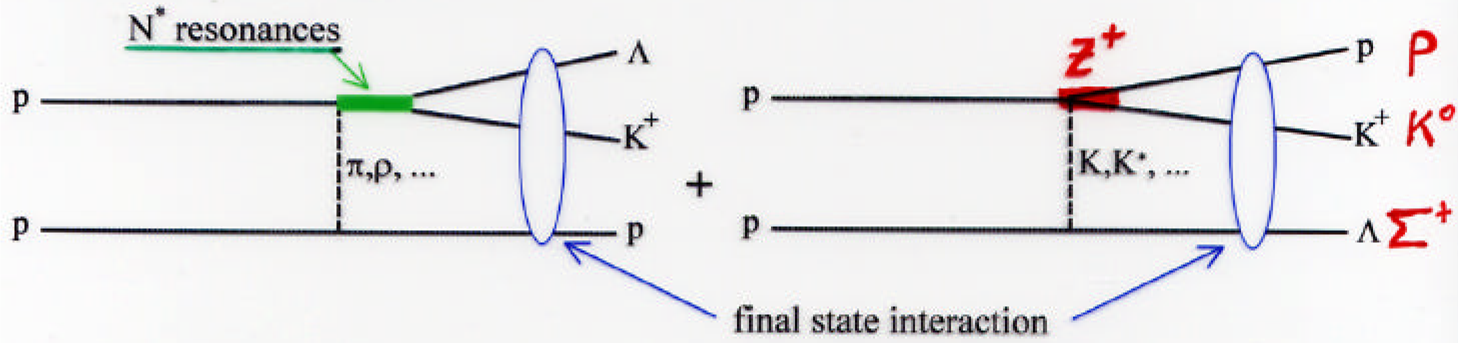
$\vec{p}\vec{p} \rightarrow \Sigma^{+}K^{0}p$

Summary

Strangene$\bar{s}$s production at COSY-TOF: $pp \rightarrow KYN$

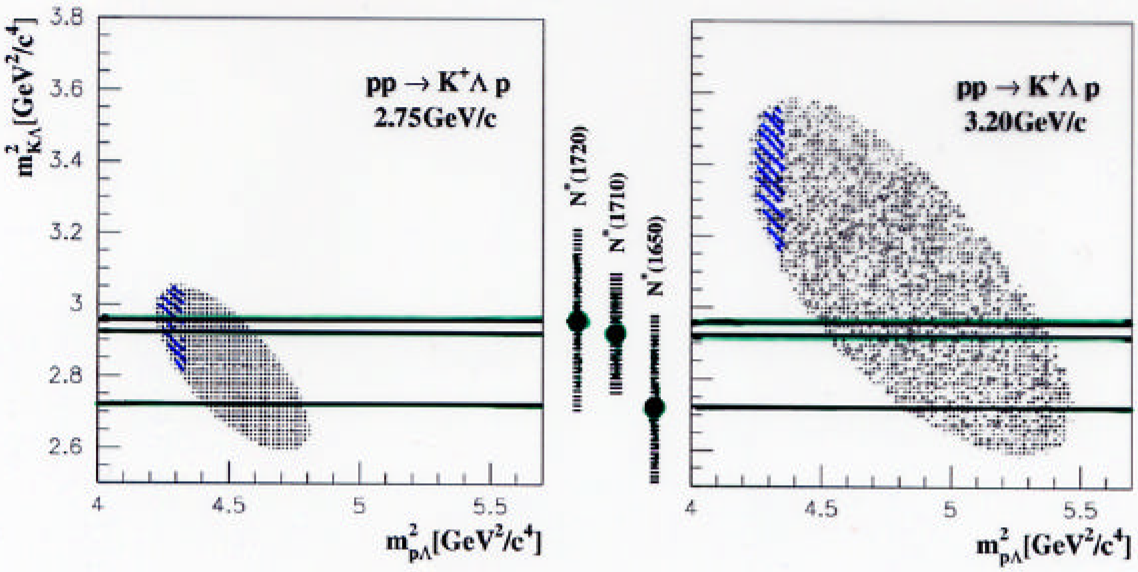
Information: dynamics + structure → degrees of freedom

Meson Exchange Model



Experiment:

- exclusive observables
  - polarization: Hyperon-polarization, polarized beam
- full phase-space → Dalitz Plots



- threshold region → only few partial waves

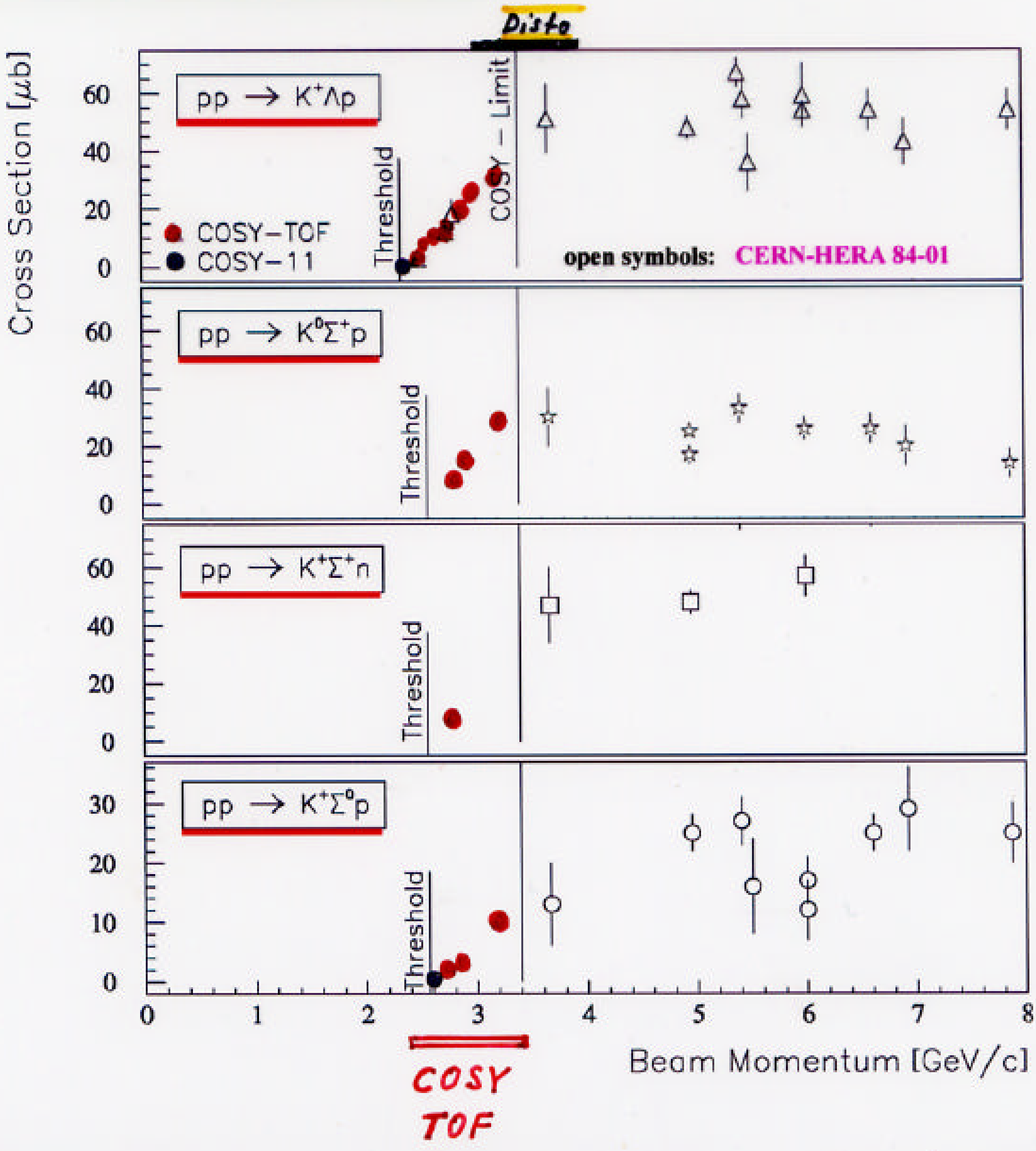
Comparison:

- different reaction channels : $Y = \Lambda, \Sigma^{o}, \Sigma^{+}, (\Sigma^{-})$
- different hadronic surroundings
  - ⇒ data from $\gamma p \rightarrow K^{+}\Lambda$ *ELSA, CEBAF*

Strangeness production at COSY

	Reaction	$\sqrt{s}$ [GeV]	p(Thresh.) [GeV/c]	E_{kin}(Thresh.) [GeV]
	$pp \to K^+\Lambda p$	2.548	2.339	1.582
	$pp \to K^+\Sigma^+ n$	2.622	2.560	1.789
	$pp \to K^+\Sigma^0 p$	2.624	2.566	1.793
	$pp \to K^0\Sigma^+ p$	2.625	2.569	1.796
Test	$p\binom{n}{p} \to K^+\Lambda np$	2.549	2.338	1.583
	$p\binom{n}{p} \to K^0\Lambda pp$ ⋮	2.552	2.347	1.590

Data on hyperon production



8 momenta: 2.5 – 3.3 GeV/c + 2 polarized

Exotic Anti-Decuplet of Baryons: Prediction from Chiral Solitons

H. Weigel, H. Walliser and others

Dmitri Diakonov[◇*], **Victor Petrov**[◇] **and Maxim Polyakov**[◇†] [1],

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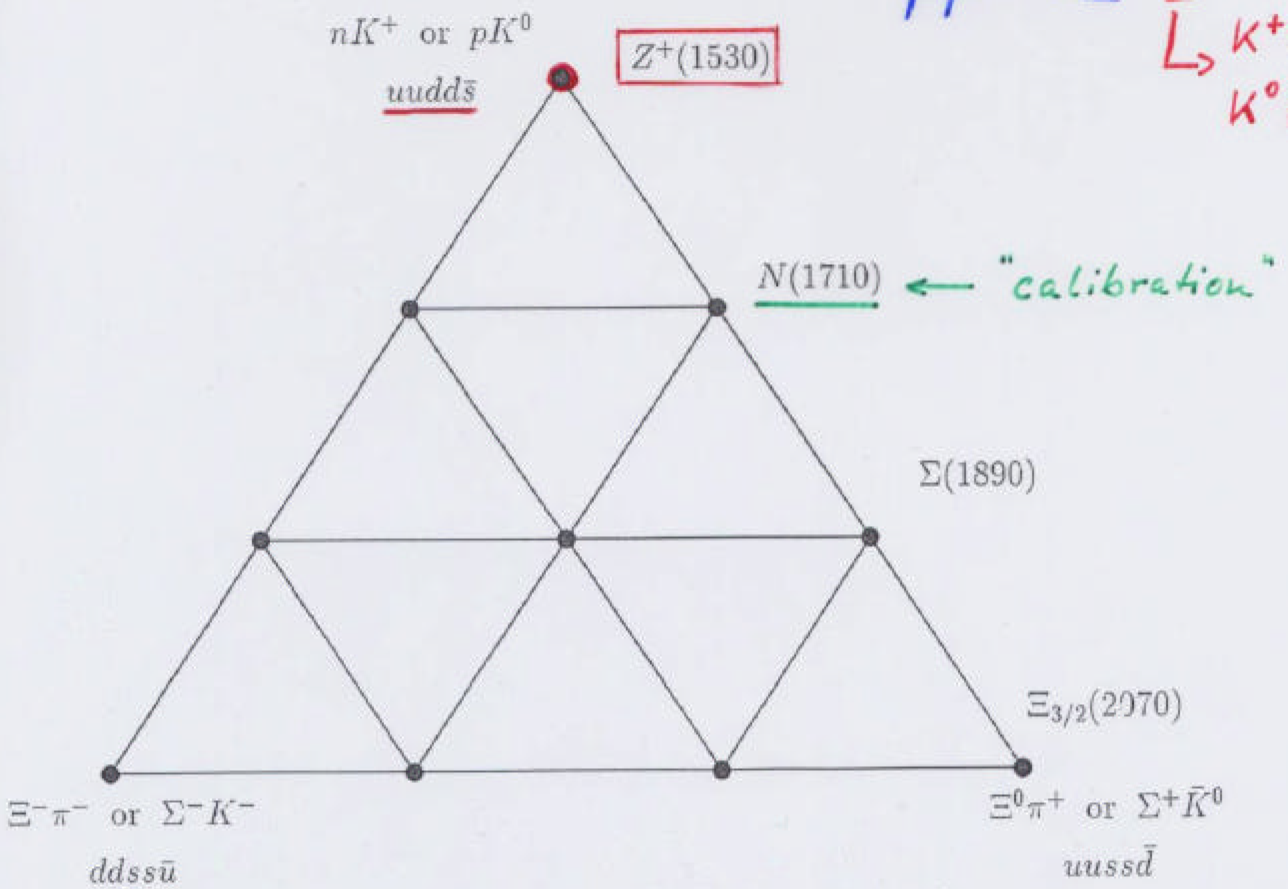
[*]*NORDITA, Blegdamsvej 17, 2100 Copenhagen, Denmark*
[†]*Inst. für Theor. Physik II, Ruhr-Universität Bochum, D-44780 Bochum, Germany*

Abstract

We predict an exotic Z^+ baryon (having spin 1/2, isospin 0 and strangeness +1) with a relatively low mass of about 1530 MeV and total width of less than 15 MeV. It seems that this region of masses has avoided thorough searches in the past.

$pp \rightarrow \Sigma^+ Z^+$
$\quad \hookrightarrow K^+ n$
$\qquad K^0 p$



$\leftrightarrow$ H. Weigel : $\Gamma \approx 100$ MeV !

Table 5. Predictions for masses and total widths of the members of the anti-decuplet and possible candidates for these states

	T	Y	Mass in MeV	Width in MeV	Possible candidate
Z^+	0	2	1530	15	—
$N_{\overline{10}}$	1/2	1	1710 (input)	~ 40	$N(1710)P_{11}$
$\Sigma_{\overline{10}}$	1	0	1890	~ 70	$\Sigma(1880)P_{11}$
$\Xi_{3/2}$	3/2	-1	2070	> 140	$\Xi(2030)$?

- Nucleon–nucleon collisions
  $pn \to \Lambda Z^+ \to \Lambda K^+ n$ or $\Lambda K^0 p$, $p_{lab} > 2.60$ GeV/c
  $pp \to \Sigma^+ Z^+ \to \Sigma^+ K^+ n$ or $\Sigma^+ K^0 p$, $p_{lab} > 2.8$ GeV/c
- Photon-nucleon collisions
  $\gamma p \to \bar{K}^0 Z^+ \to \bar{K}^0 K^+ n$ or $\bar{K}^0 K^0 p$, $p_{lab} > 1.7$ GeV/c
  $\gamma n \to K^- Z^+ \to K^- K^+ n$ or $K^- K^0 p$, $p_{lab} > 1.7$ GeV/c
- Pion-nucleon collisions
  $\pi^- p \to K^- Z^+ \to K^- K^+ n$ or $K^- K^0 p$ $p_{lab} > 1.7$ GeV/c
  $\pi^+ n \to \bar{K}^0 Z^+ \to \bar{K}^0 K^+ n$ or $\bar{K}^0 K^0 p$, $p_{lab} > 1.7$ GeV/c.

Subject: Re: Z+
Date: Mon, 13 Oct 1997 08:22:29 WET0WET DST
From: Wolfgang.Eyrich@Physik.Uni-Erlangen.de
To: eyrich@Physik.Uni-Erlangen.de
CC: eyrich@Physik.Uni-Erlangen.de

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Return-Path: <maximp@hadron.tp2.ruhr-uni-bochum.de>
Received: from hadron.tp2.ruhr-uni-bochum.de by merlin.physik.uni-erlangen.de
          (MX V4.2 AXP) with SMTP; Wed, 08 Oct 1997 17:12:45 WET0WET DST
Received: by hadron.tp2.ruhr-uni-bochum.de (AIX 3.2/UCB 5.64/4.03) id AA20637;
          Wed, 8 Oct 1997 17:12:18 +0200
From: maximp@hadron.tp2.ruhr-uni-bochum.de (Maxim Polyakov)
Message-ID: <9710081512.AA20637@hadron.tp2.ruhr-uni-bochum.de>
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To: Wolfgang.Eyrich@Physik.Uni-Erlangen.de
Date: Wed, 8 Oct 1997 17:12:18 +0200 (DFT)
In-Reply-To: <009B6F09.265A8612.926@Physik.Uni-Erlangen.de> from
    "Wolfgang.Eyrich@Physik.Uni-Erlangen.de" at Jul 8, 97 09:24:07 am
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MIME-Version: 1.0
Content-Type: text/plain; charset=US-ASCII
Content-Transfer-Encoding: 7bit
Content-Length: 684
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Dear Wolfgang,

probably you heard in Vancouver that Jim Napolitano
from Troy (USA) analyses old SLAC data on K+p-->piKN
to search for exotic Z+. Now they put upper limit on
production cross section at the level of 10 microbarn,
which is still higher of our theoretical estimates
about 1 microbarn. Now I started again to think about
possibility to search for Z+ in other reactions, like
you do at Juelich. Also I have a lot of questions about
kaon beams in general.

Would it be possible to meet each other ? I am still
in Bochum, unfortunately I do not have around experts
in experiments. It would be extremely beneficial for
me to have a discussion with you.

All the best, Maxim

Baryon Excitation in $K^{\pm}p$ Reactions

J. Napolitano, J. Cummings, and M. Witkowski

Department of Physics, Rensselaer Polytechnic Institute, Troy, NY 12180

MENU 97,

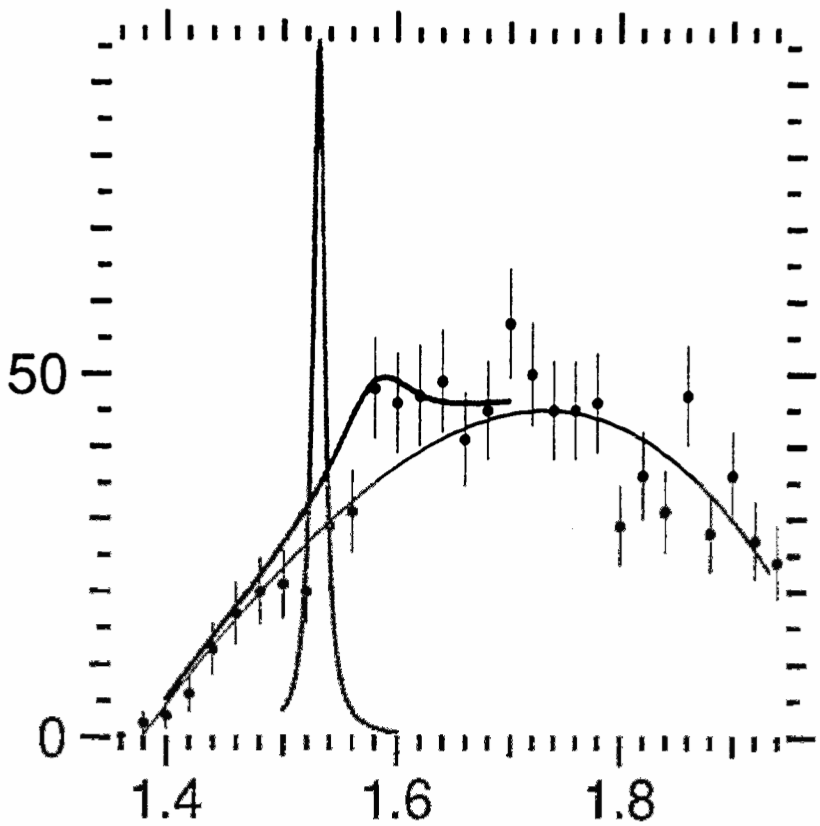
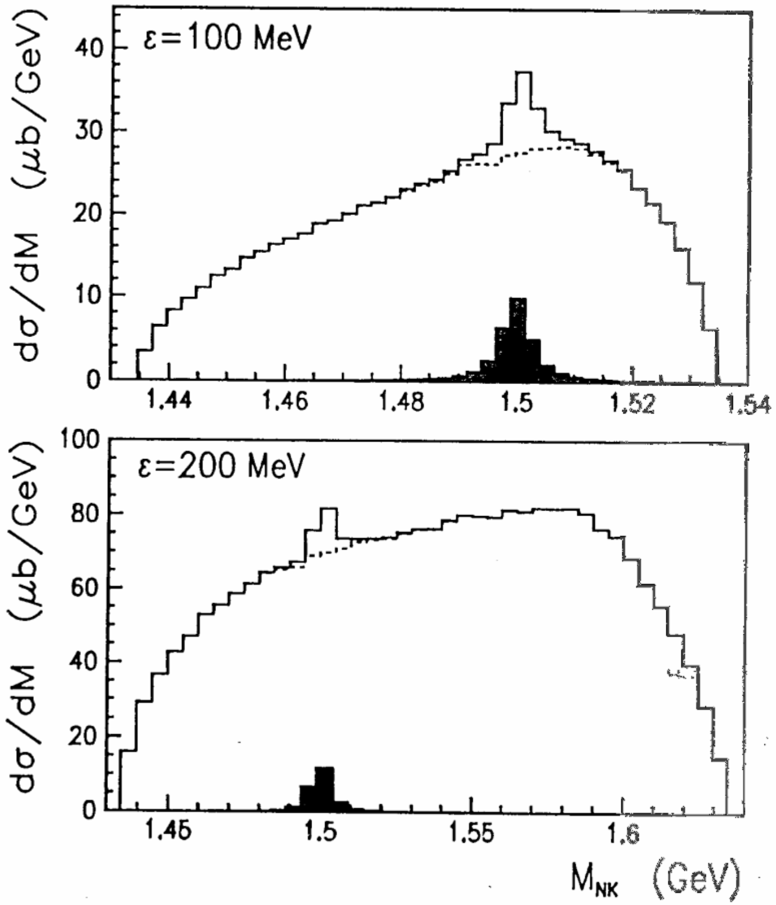


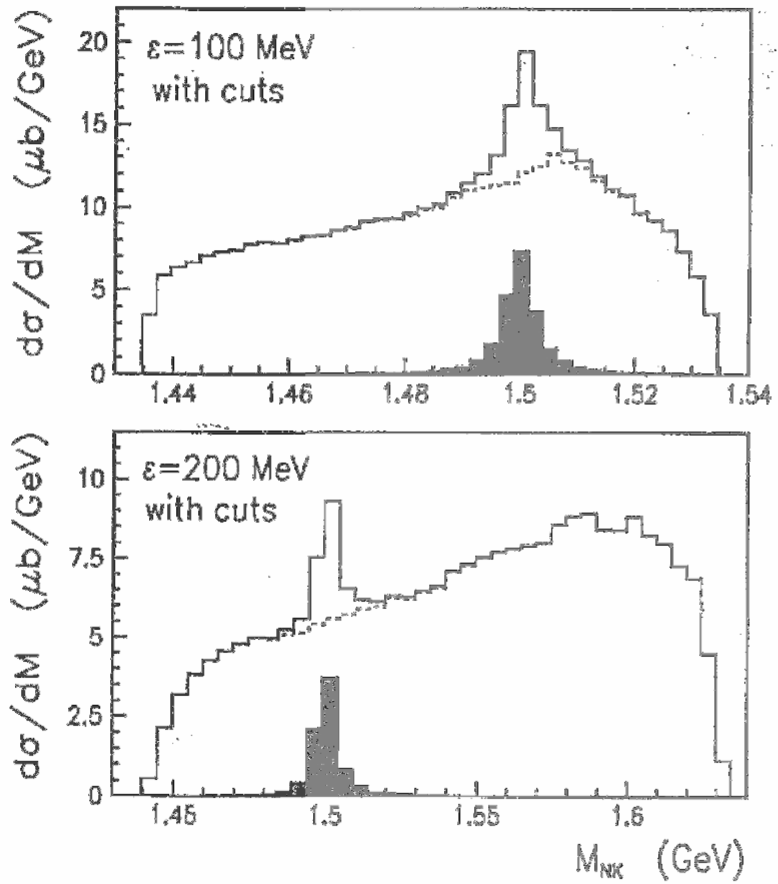
Figure. 5. Distribution of K^+n mass in the reaction $K^+p \rightarrow \pi^+_{\text{FAST}}K^+n$. The curves show the expected distributions based on the mass, width, and cross sections for Z^+=baryon production and decay in this reaction. See the text for details.

M.Polyakov, A.Sibirtsev et al.

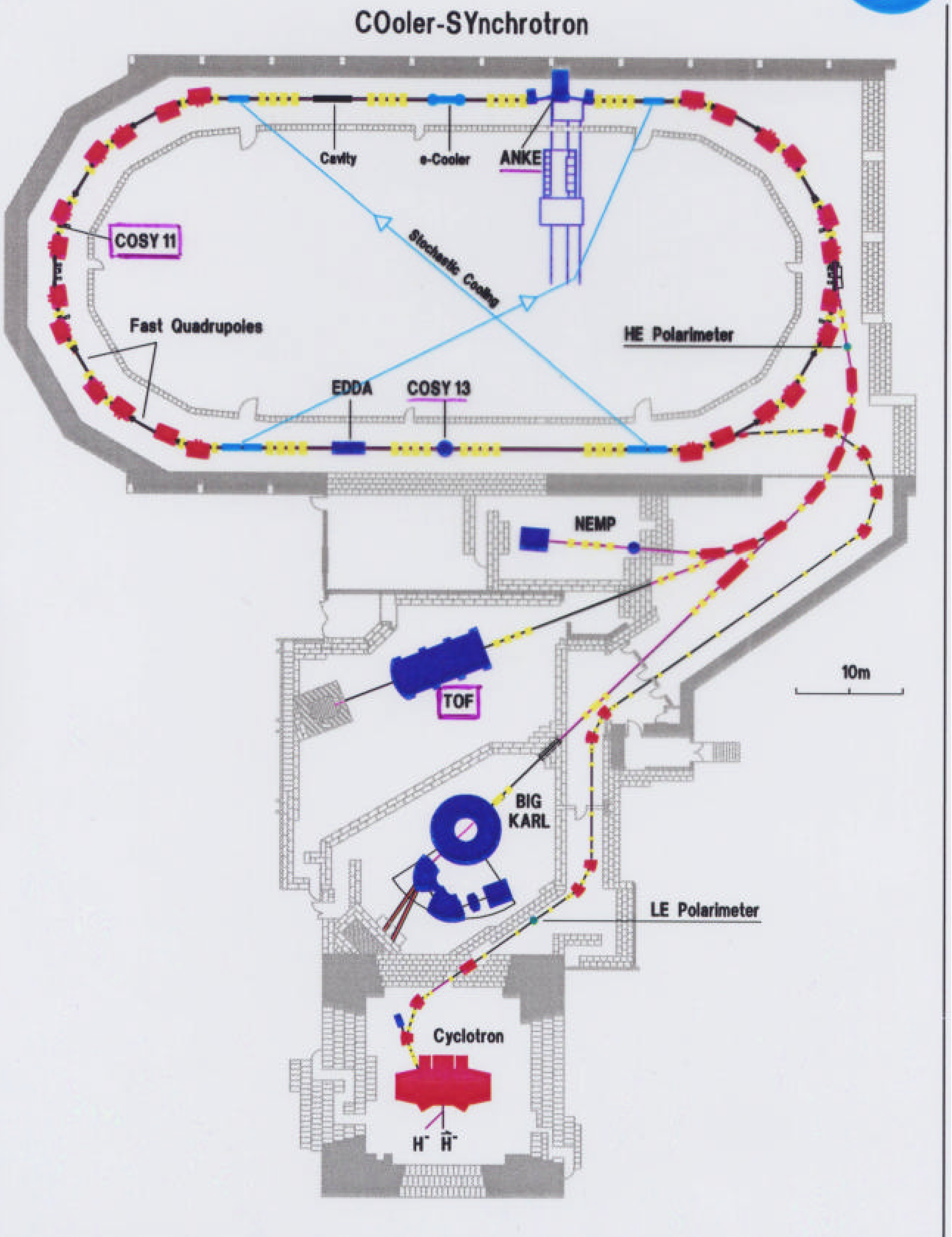
$pp \to n\Sigma^+K^+$

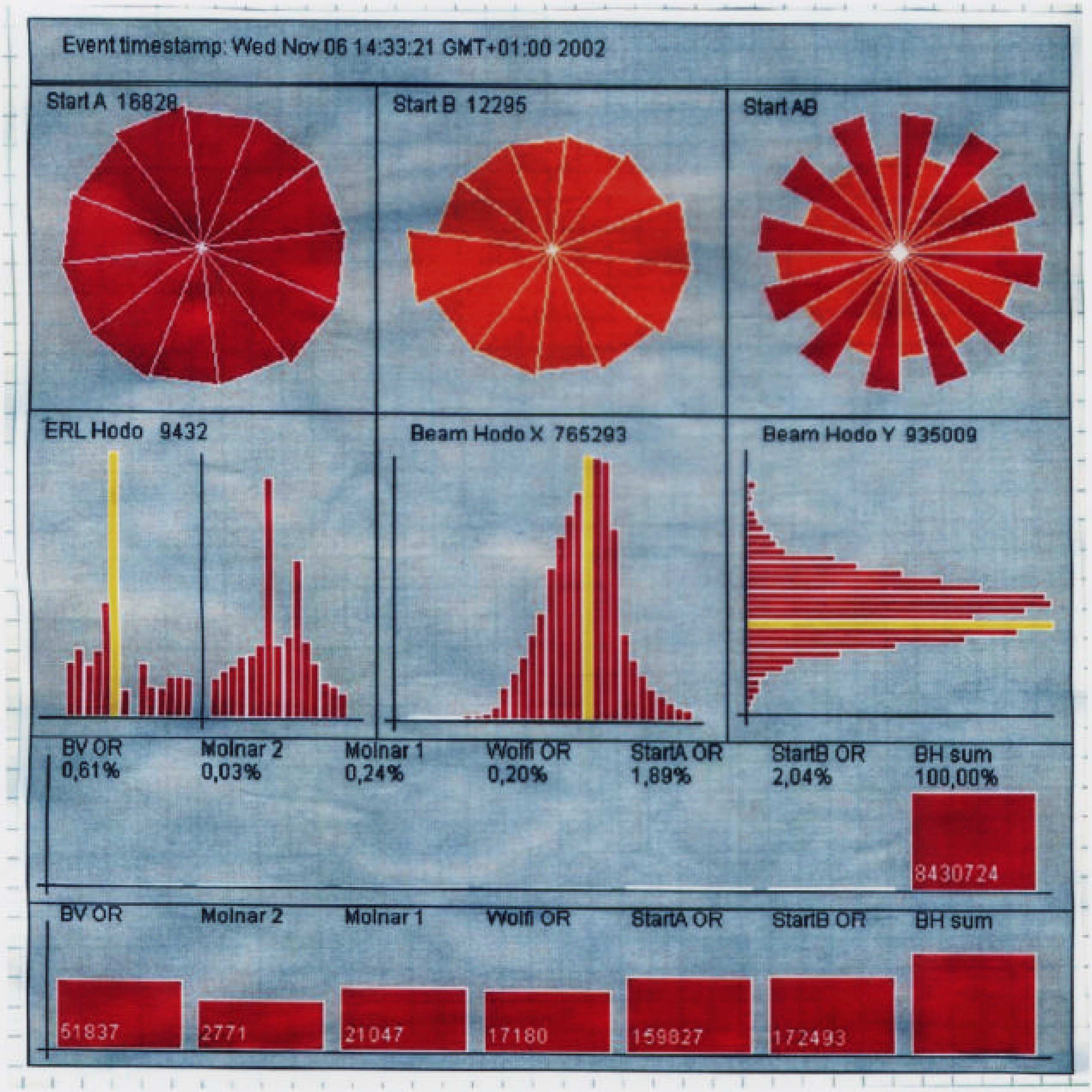


$pp \to n\Sigma^+K^+$



Forschungszentrum Jülich

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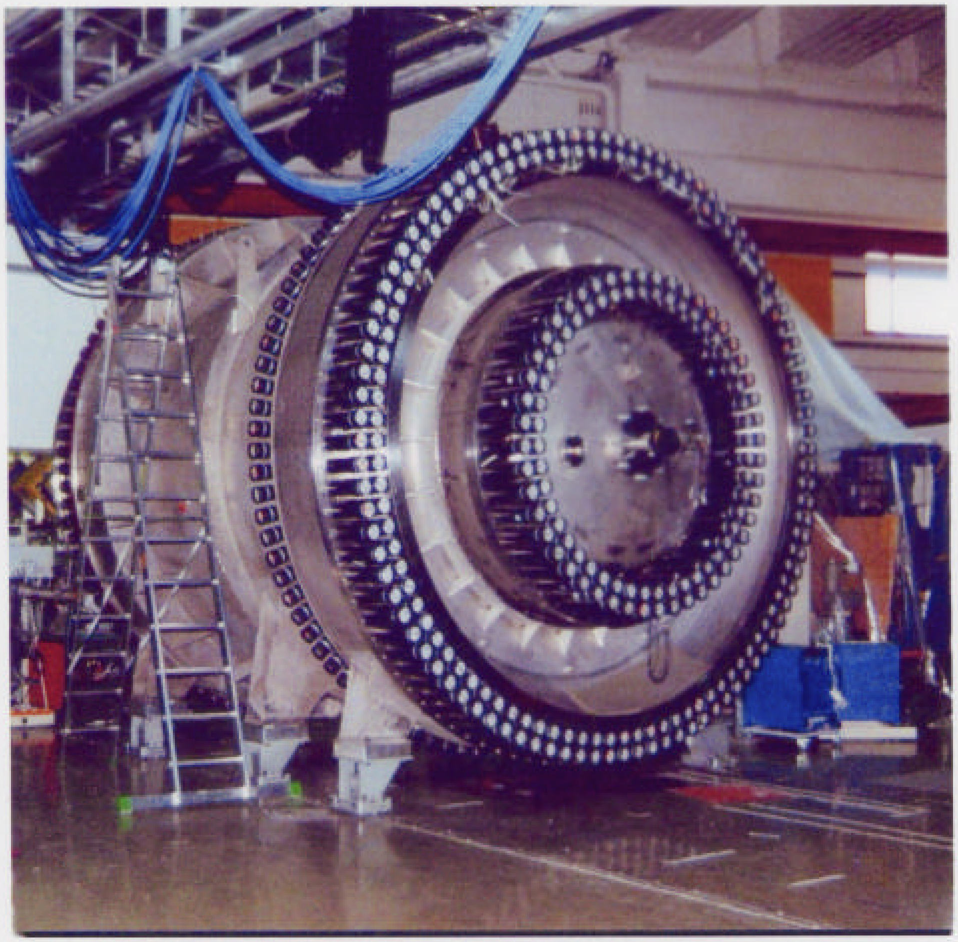
Start B 12295
Start AB
ERL Hodo 9432
Beam Hodo X 765293
Beam Hodo Y 935009
BV OR
0,61%
Molnar 2
0,03%
Molnar 1
0,24%
Wolfi OR
0,20%
StartA OR
1,89%
StartB OR
2,04%
BH sum
100,00%
8430724
BV OR
Molnar 2
Molnar 1
Wolfi OR
StartA OR
StartB OR
BH sum
51837
2771
21047
17180
159827
172493

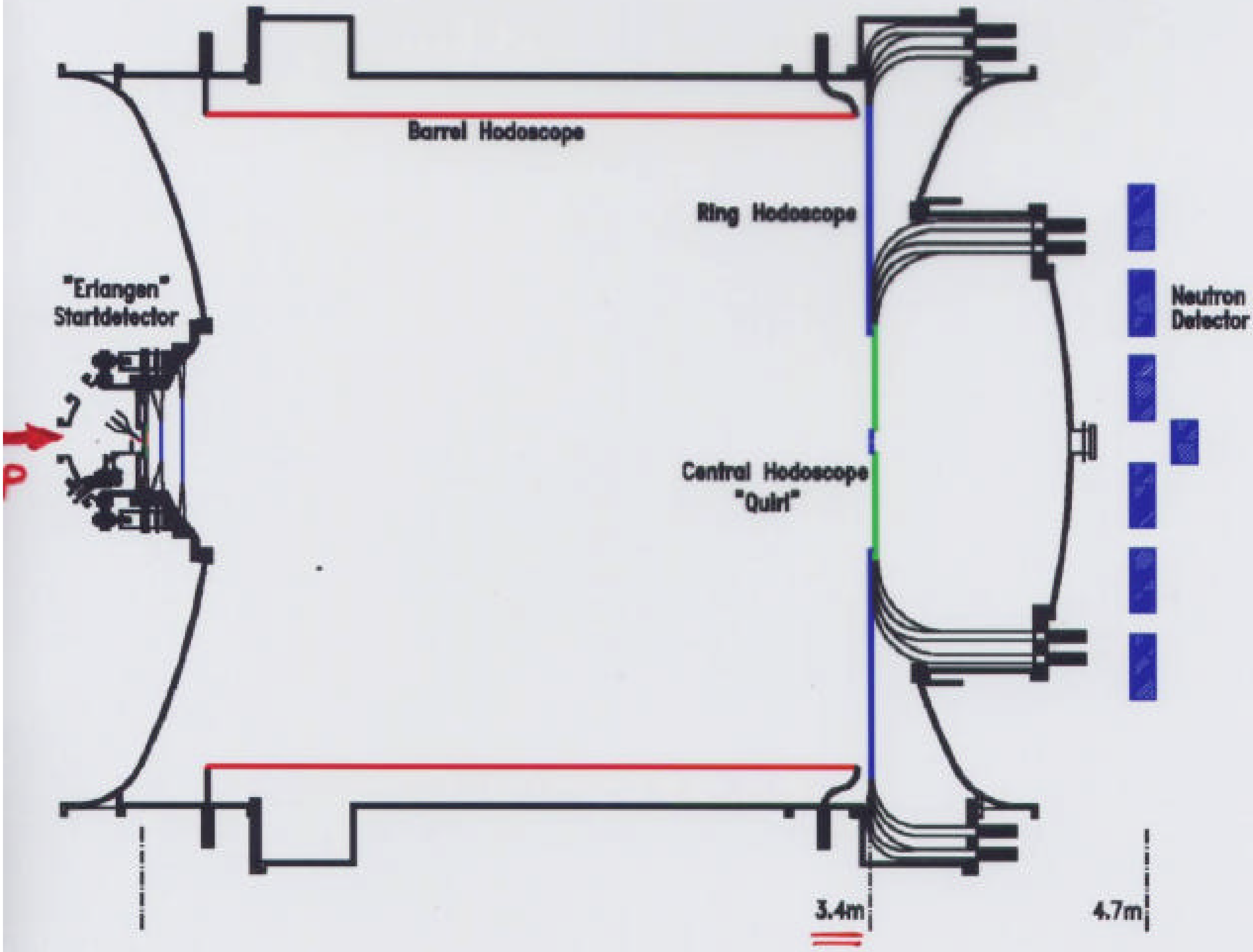
COSY Time of Flight Spectrometer



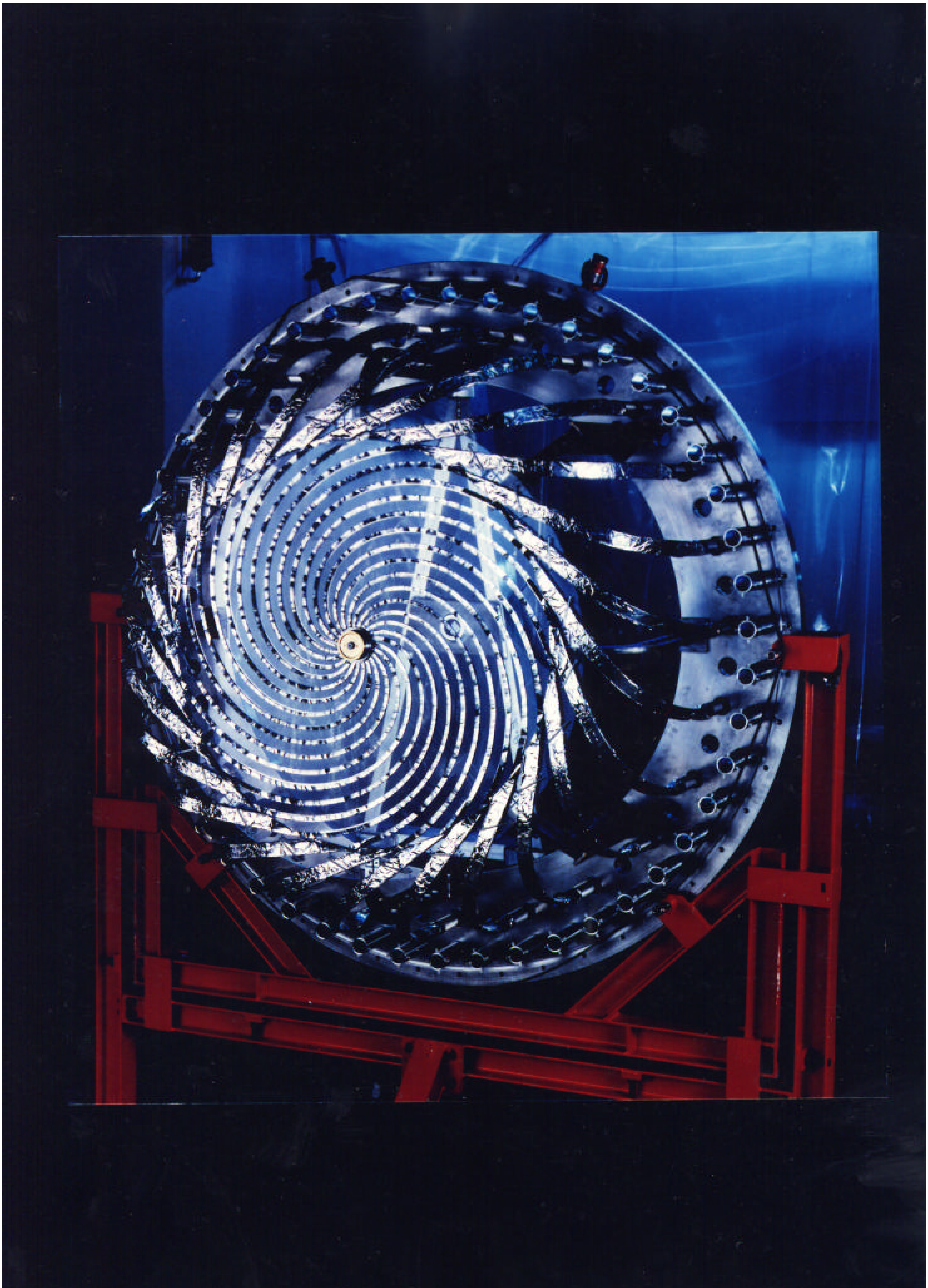
Set up with one barrel

Set up with two barrels

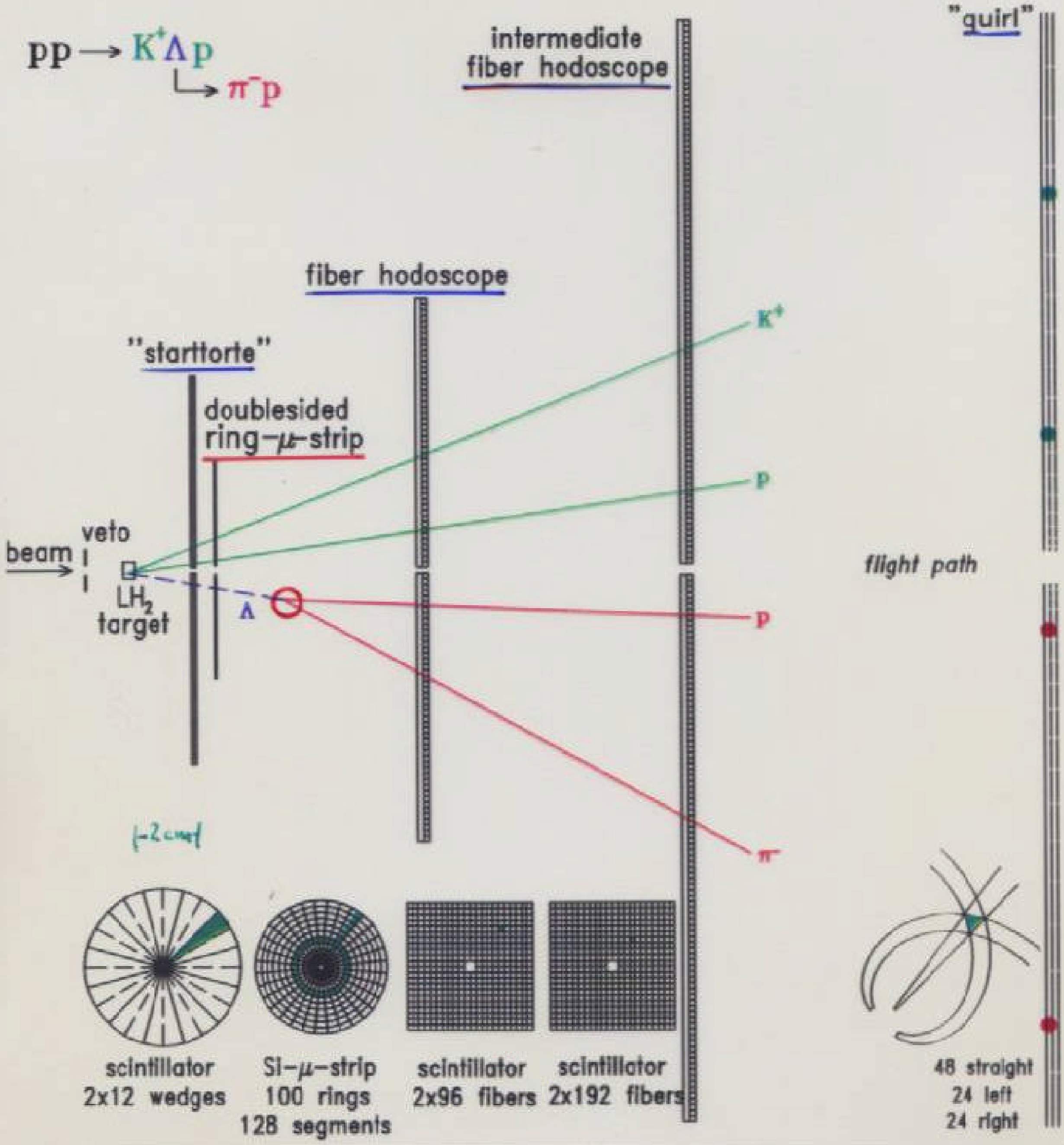
COSY-TOF Detector Setup 2000



- large angle (non-magnetic) spectrometer
- modular vacuum vessel
- miniaturized target
- startdetector systems (2π, η/η', Bremsstrahlung, Hyperon)
- stopdetector system (Central-, Ring- and Barrel-Hodoscopes)
- neutron wall
- central calorimeter

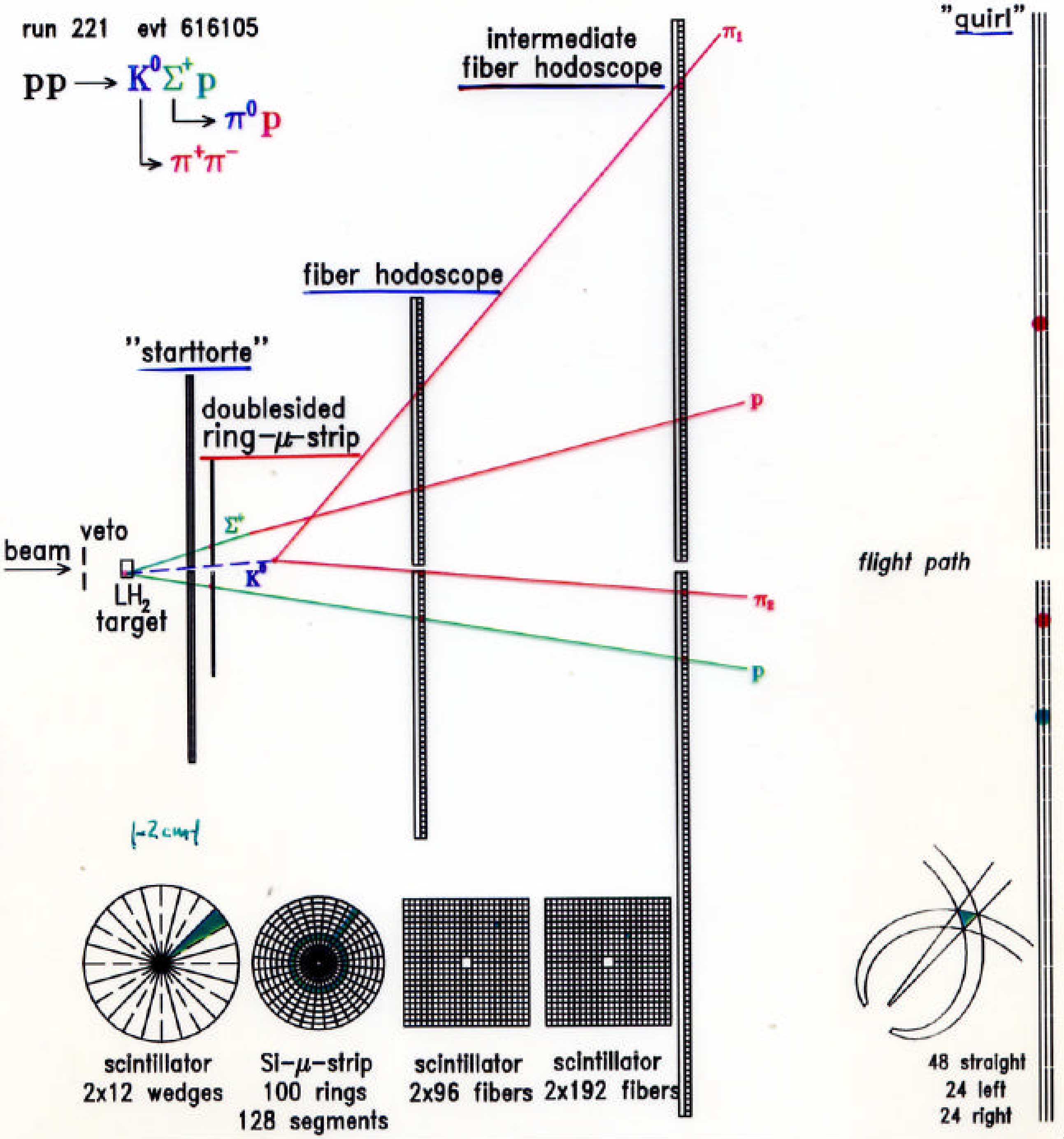


Scheme of '98 setup



- start detector optimized for track and vertex reconstruction
- complete geometric reconstruction
- additional information drafted from ToF and dE/dx
- trigger: charged multipilcity $2 \rightarrow 4$

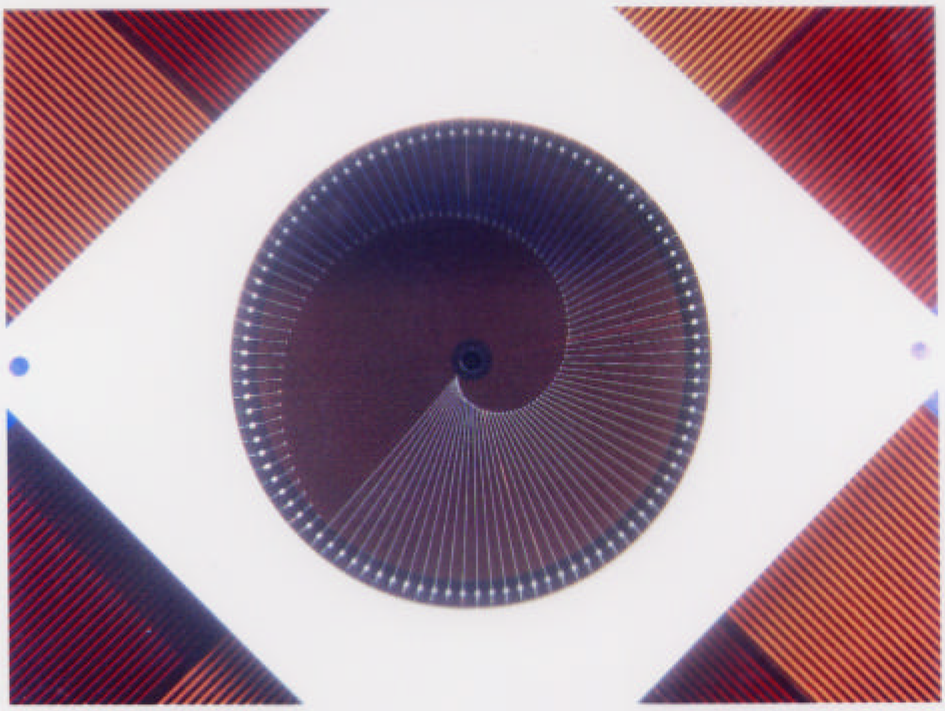
Scheme of '98 setup



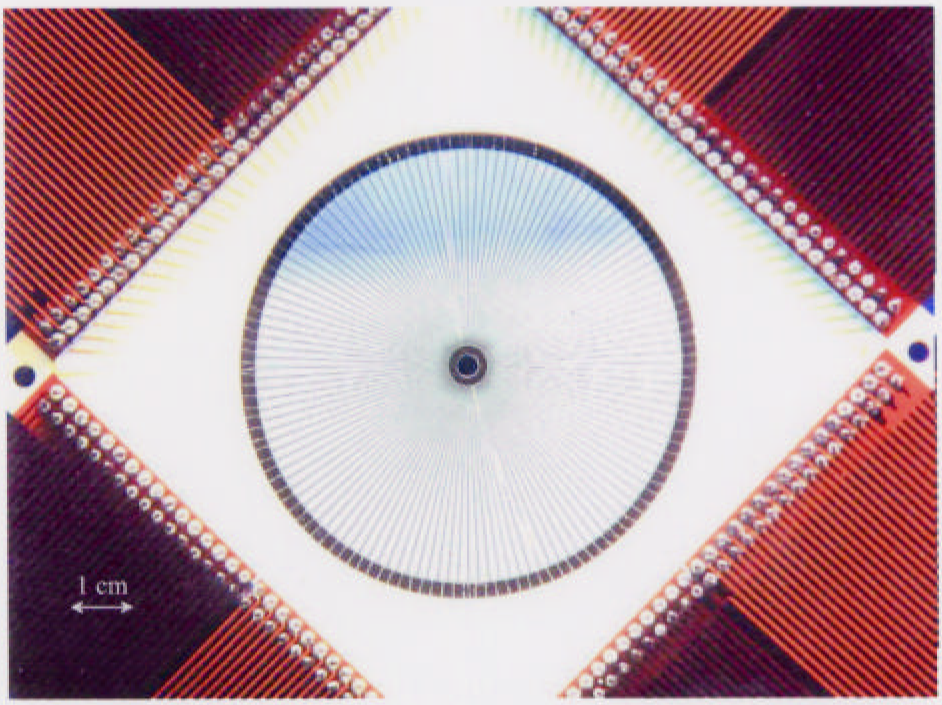
- start detector optimized for track and vertex reconstruction
- complete geometric reconstruction
- additional information drafted from ToF and dE/dx
- trigger: charged multipilcity 2 → 4

Doublesided Si-Microstrip Detector

- $r_{min} = 3.1$ mm, $r_{max} = 32$ mm, $d_{Cristal} = 500$ µm
- front: 100 concentric rings

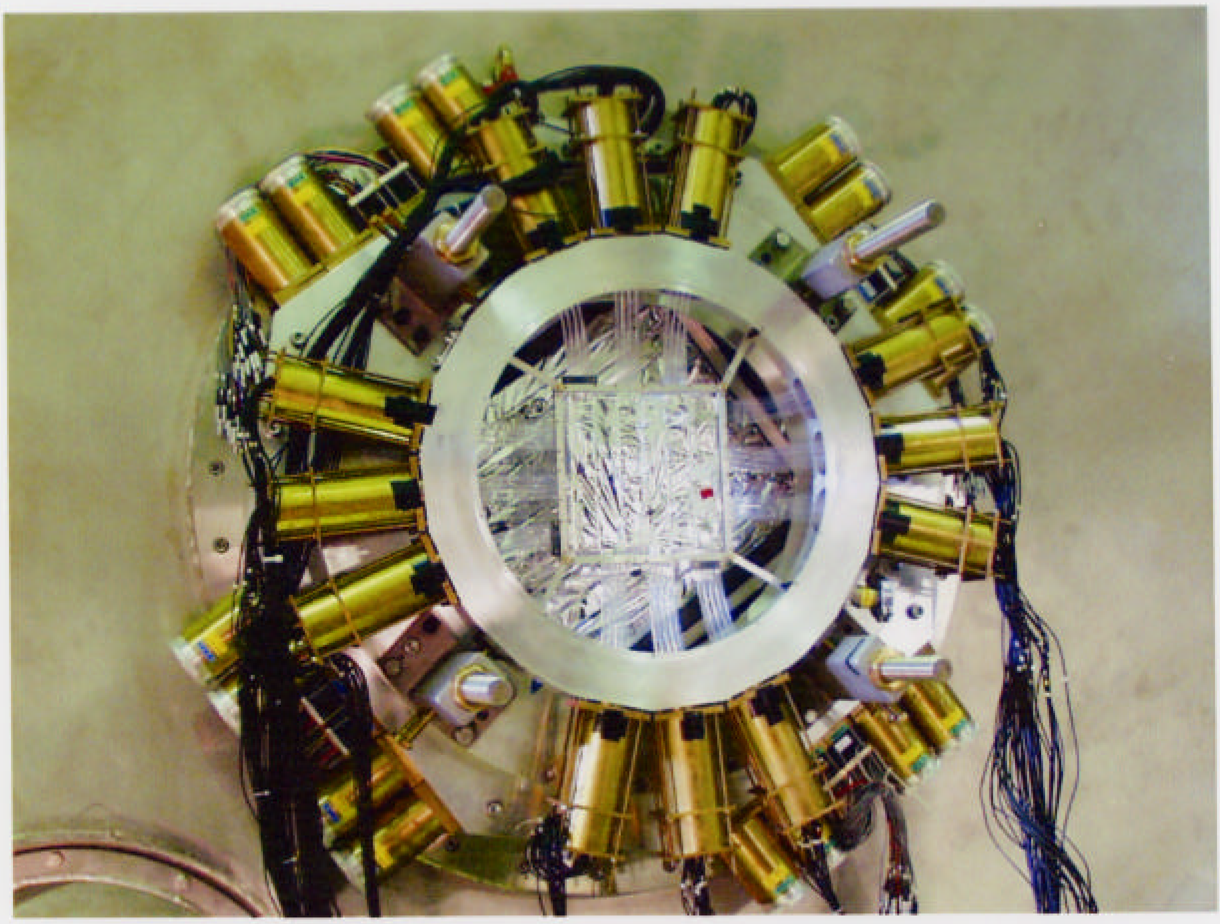


- back: 128 segments



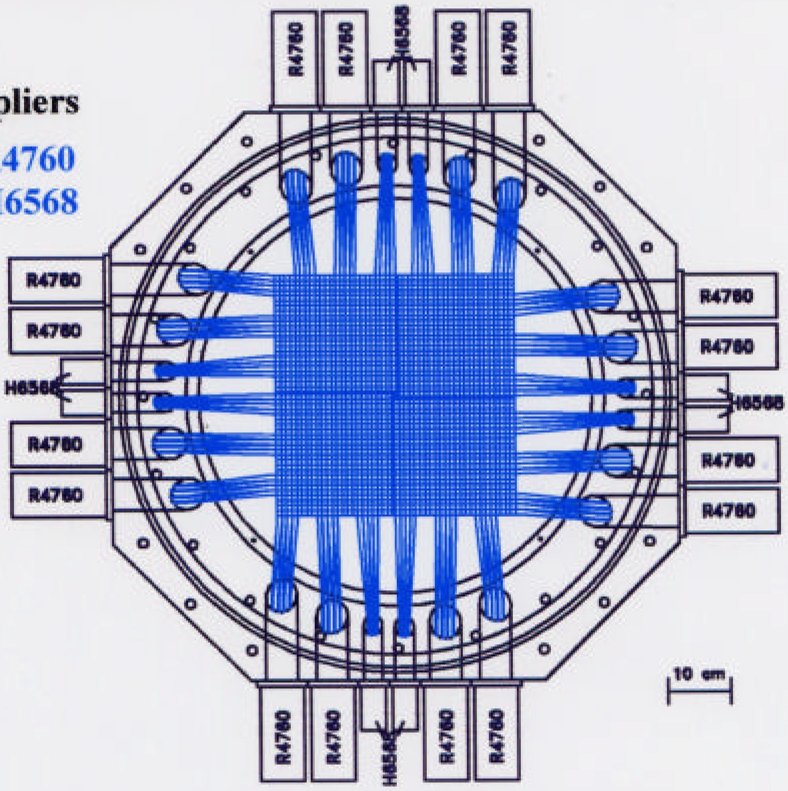
Scintillating Fiber Hodoscopes

- 2×96 fibers (x,y), 2×192 fibers (u,v)
- Bicron BCF12 ($2{\times}2$ mm^2, single cladding)



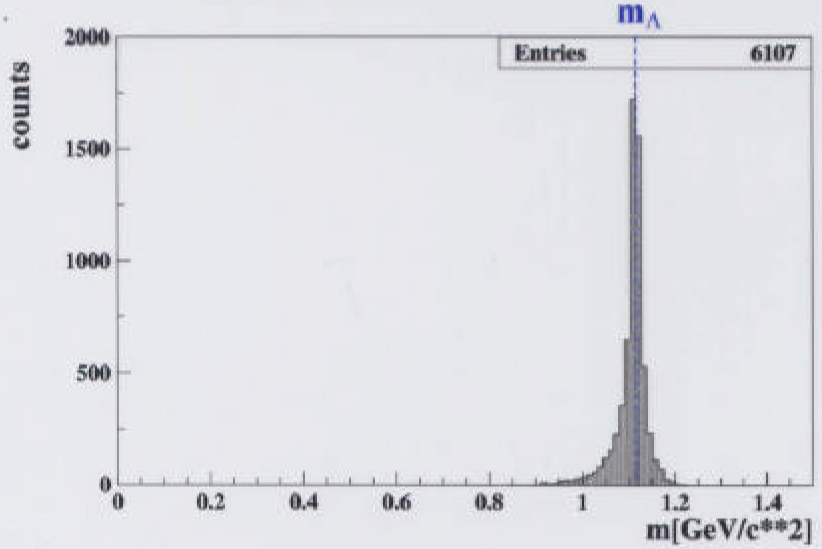
- 16-fold Photomultipliers

  Hamamatsu R4760
  H6568



Reconstruction of Λ-Hyperons

mass reconstruction



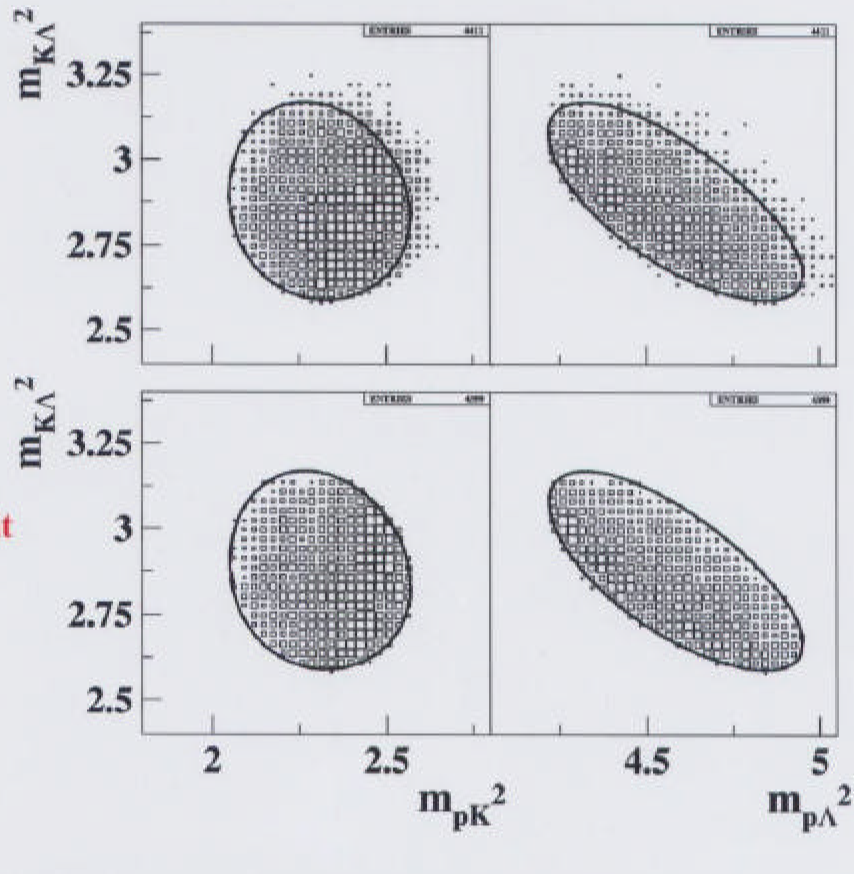
$pp \rightarrow K^+ \Lambda p$

@ 2.85 GeV/c

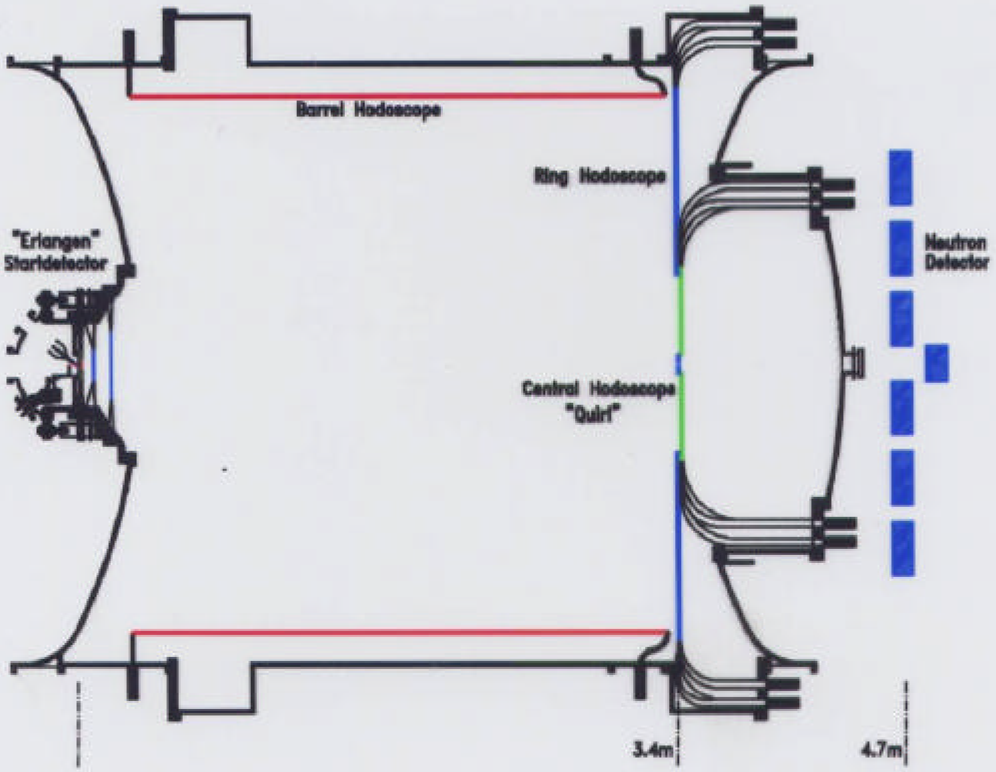
Dalitz plot

geometric

+ kinematic fit



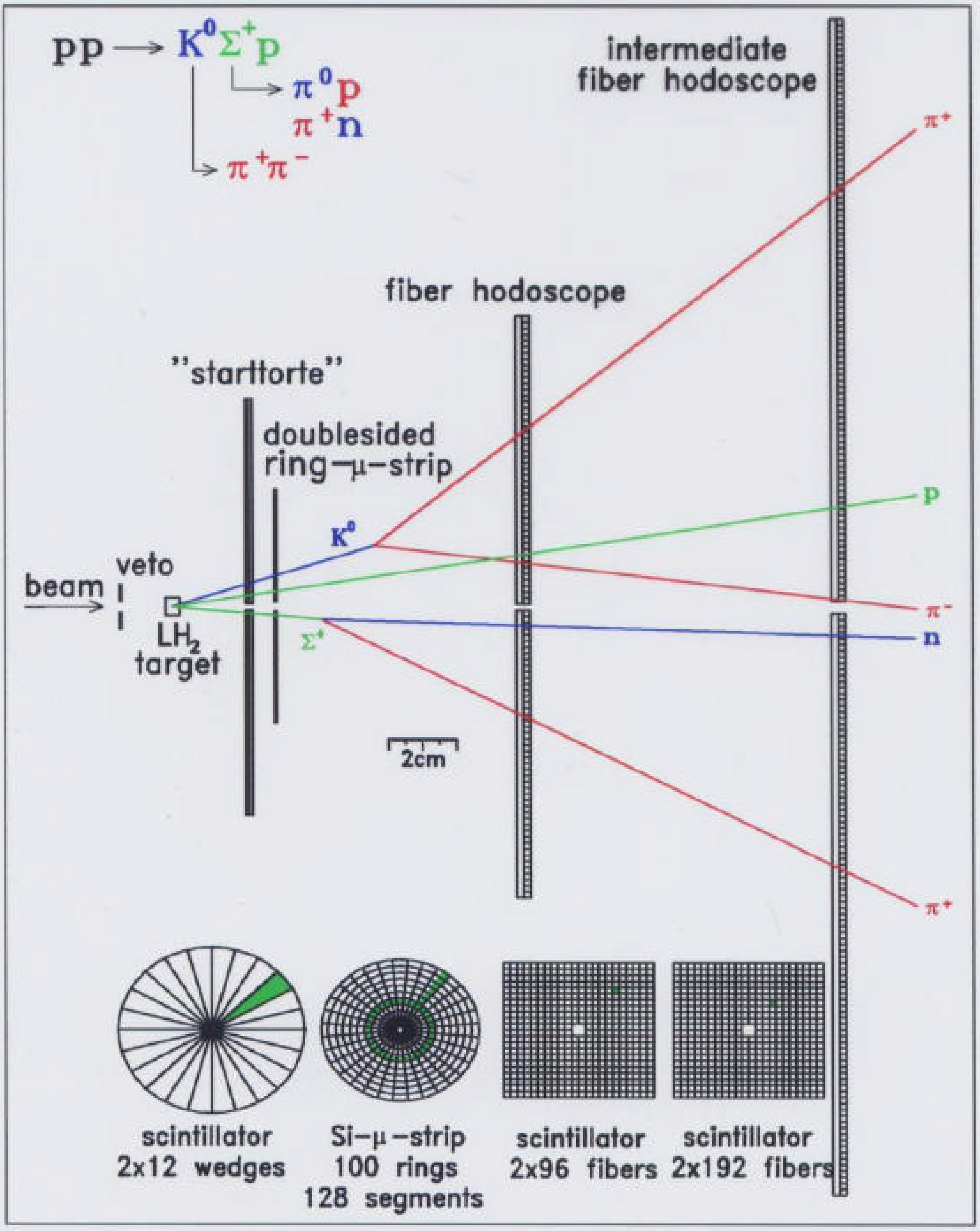
TOF setup 2000 and measured beam momenta



Reaction	Momentum [GeV/c]	Run
$pp \to K^+\Lambda p$	2.50 / 2.75	1996
	2.59 / 2.68 / 2.85	1998
	2.95 / 3.20 / 3.30	2000 / 2002
$pp \to K^+\Sigma^0 p$	2.85 / 2.95 / 3.20	1998 / 2000
$pp \to K^0\Sigma^+ p$	2.85 / 2.95 / 3.20	1998 / 2000
$pp \to K^+\Sigma^+ n$	2.85 / 2.95 / 3.20	1998 / 2000
polarized beam: $pp \to KYN$	2.75 / 2.95	2002

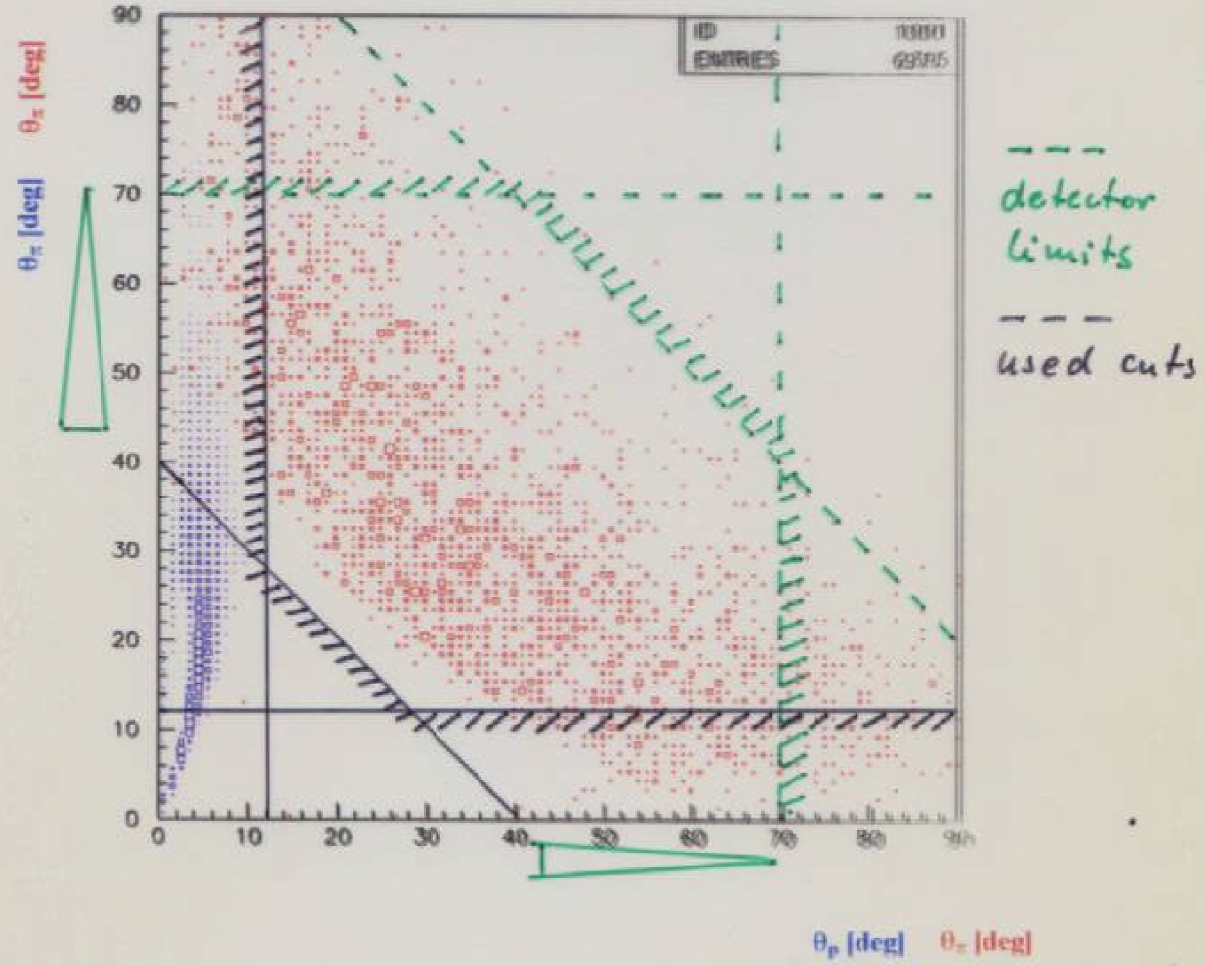
COSY-TOF:

Scheme of the "Erlangen start detector"



Decay kinematics

$\Lambda \rightarrow \pi^- p$ $\quad K^0_s \rightarrow \pi^+\pi^-$

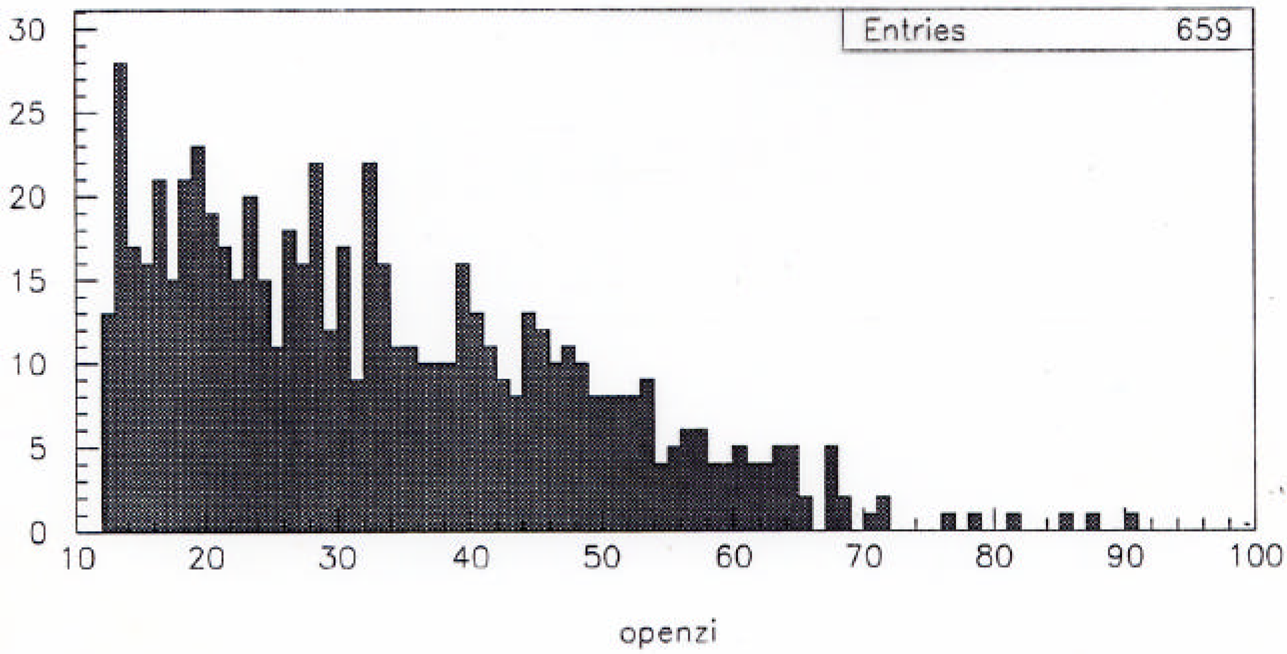


$pp \rightarrow \Sigma^+ K^0 p$ $\quad$ $p_{beam} = 2.95$ GeV/c

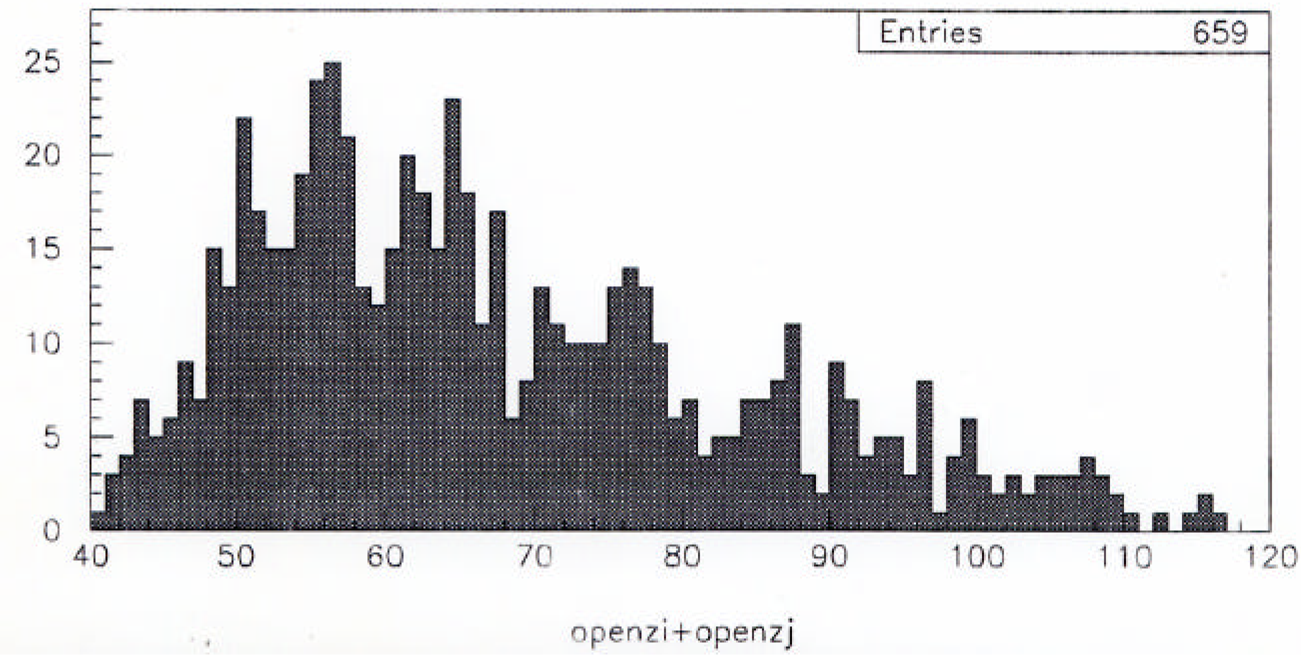
$\quad K^0 \rightarrow \pi^+\pi^-$

$\quad \Sigma^+ \rightarrow p\pi^0 / n\pi^+$ $\quad$ data 2002

N ($\Theta_{\pi 1/2}$)



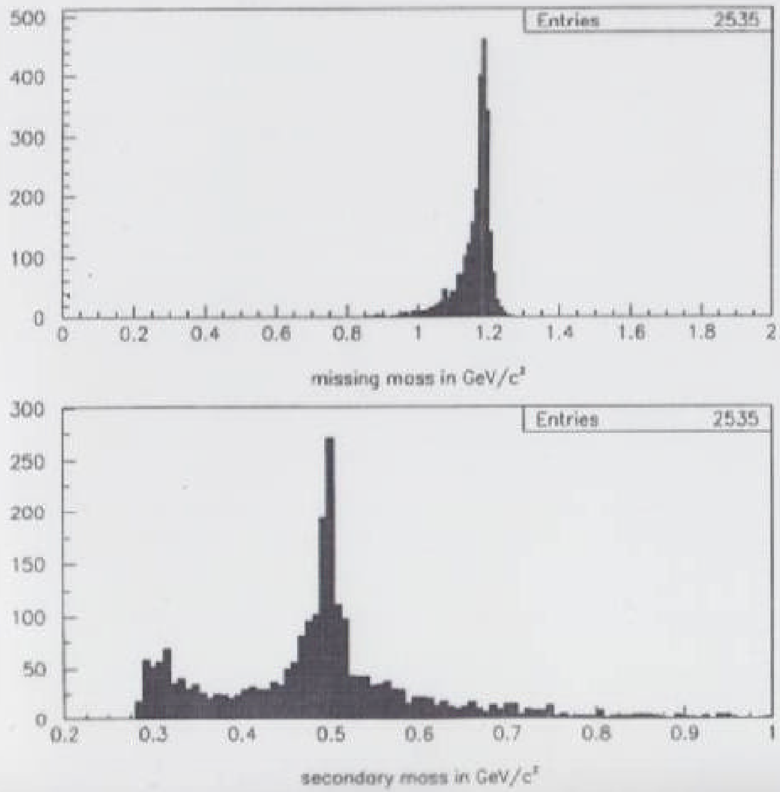
N ($\Theta_{\pi 1} + \Theta_{\pi 2}$)



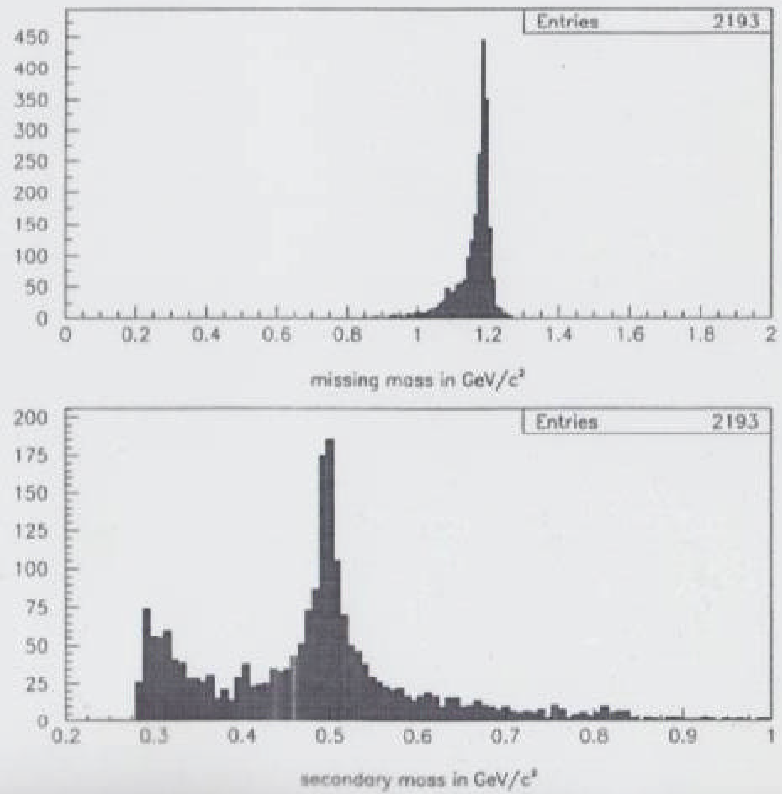
$pp \rightarrow \Sigma^+ K^0 p$ $p_{beam} = 2.95$ GeV/c

reconstructed mass of Σ^+ (above) and K^0_s (below)

data 2002

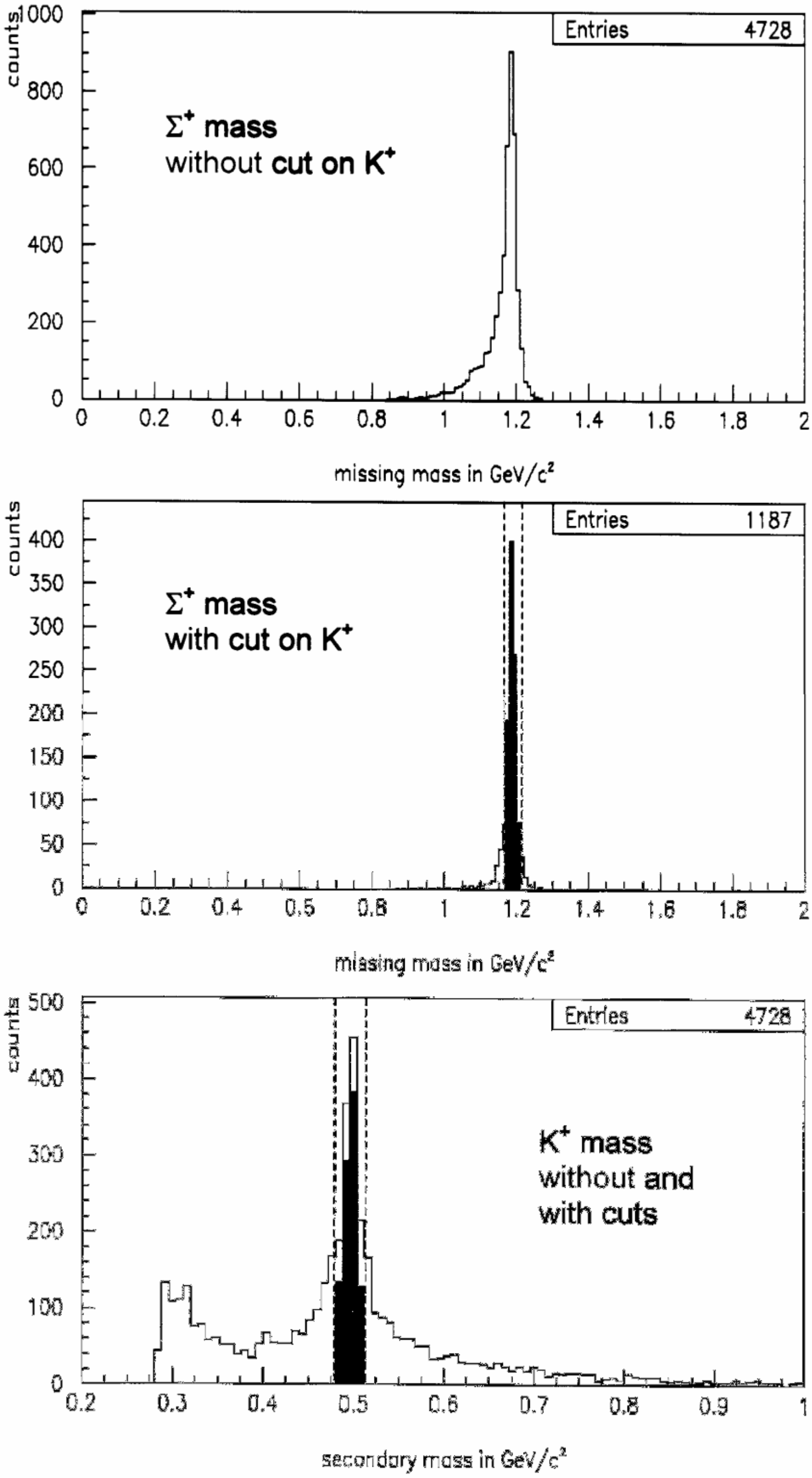


data 2000



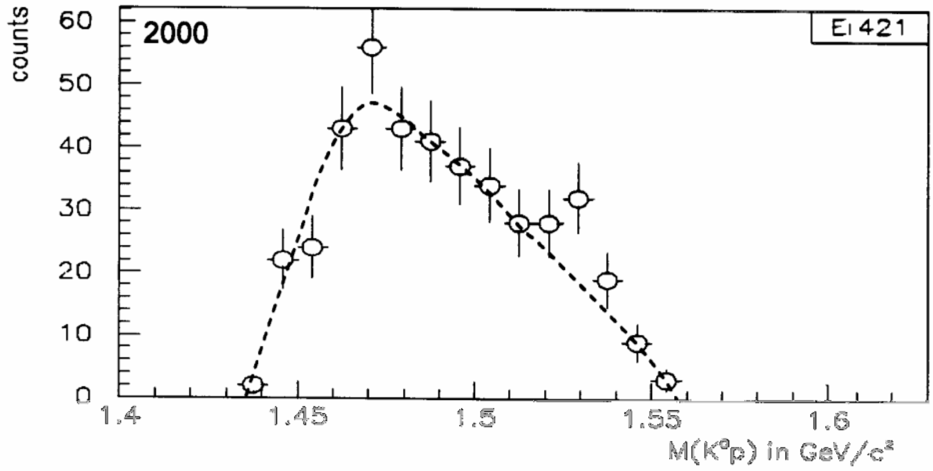
$pp \rightarrow \Sigma^+ K^0 p \quad p_{beam} = 2.95$ GeV/c

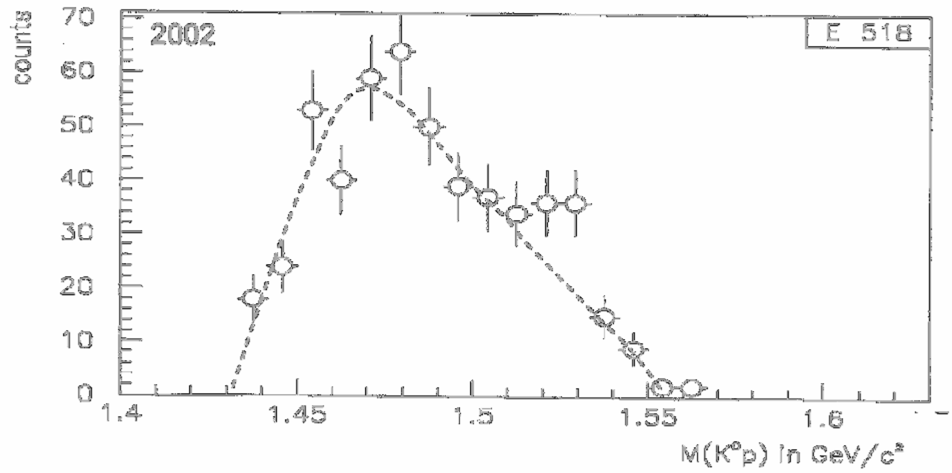
Cuts on reconstructed masses of Σ^+ and K^0

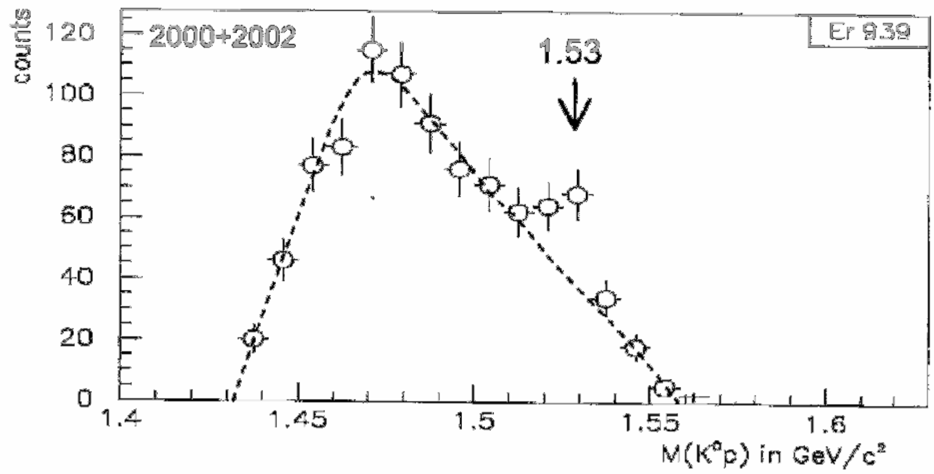


$pp \to \Sigma^+ K^0 p \quad p_{beam} = 2.95$ GeV/c

K^0p – invariant mass spectra



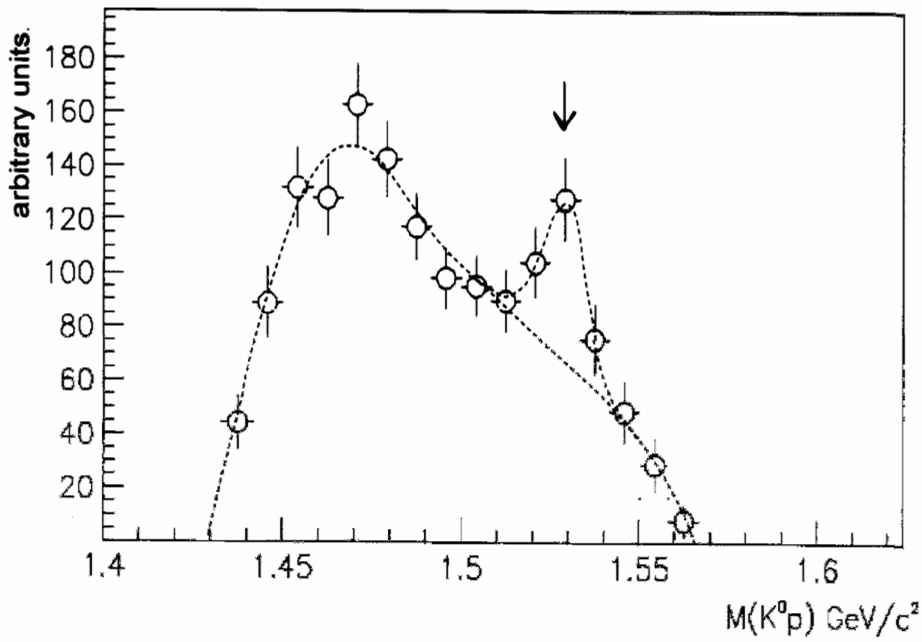




$pp \rightarrow \Sigma^+ K^0 p \quad p_{beam} = 2.95$ GeV/c

K^0p – invariant mass spectrum

efficiency corrected



preliminary

→ **Mass:** 1530 ± 5 MeV/c^2

Width: $\leq 22 \pm 4$ MeV/c^2 (FWHM)

Significance: $4 - 6\ \sigma$ (depending on method)

$(N_S/\sqrt{N_B} \quad \rightarrow 5.9\ \sigma)$

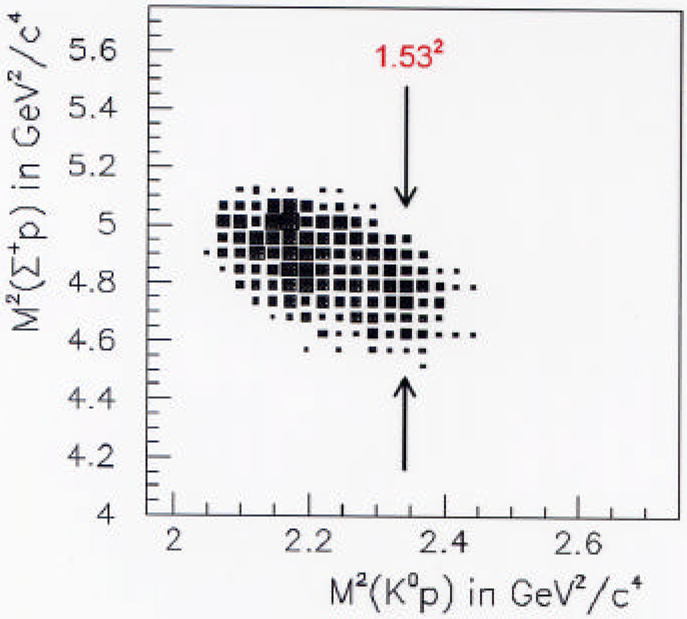
$(N_S/\sqrt{N_S+N_B} \quad \rightarrow 4.7\ \sigma)$

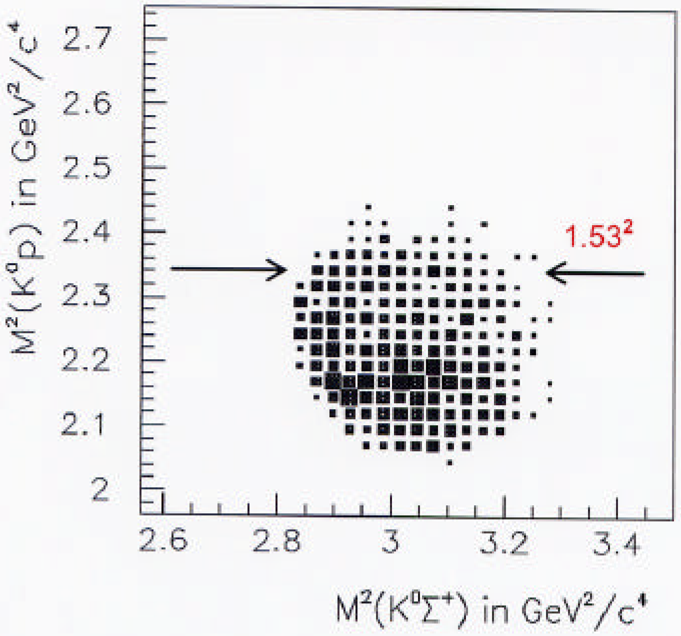
$(N_S/\sqrt{(N_S+N_B)+N_B} \quad \rightarrow 3.7\ \sigma)$

Cross section: $0.4 \pm 0.1_{stat.} \pm 0.1_{syst.}\ \mu b$

$pp \rightarrow \Sigma^+ K^0 p \quad p_{beam} = 2.95$ GeV/c

Dalitz Plots



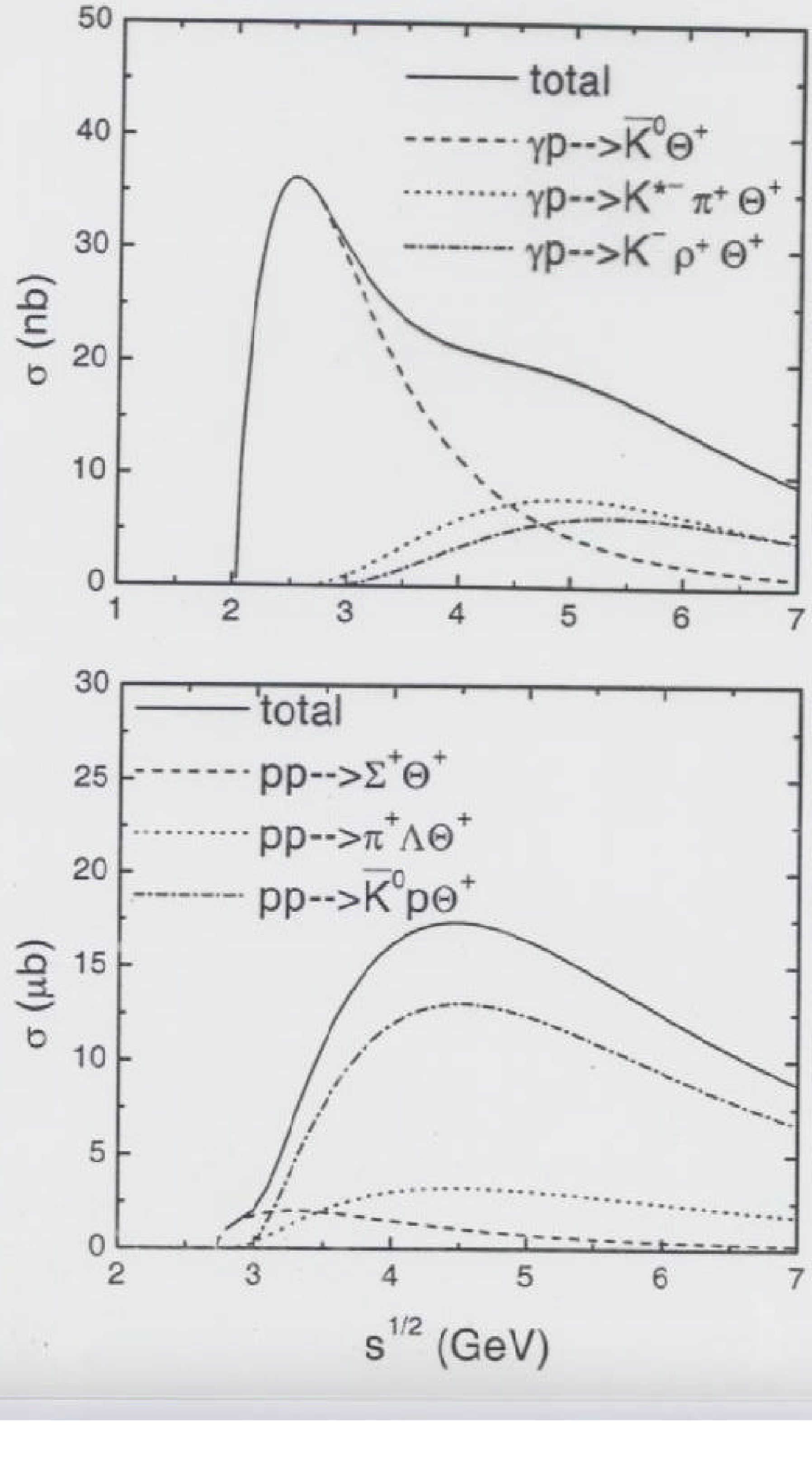


Cross sections for pentaquark baryon production from protons in reactions induced by hadrons and photons

W. Liu[1] and C. M. Ko[1]

[1]*Cyclotron Institute and Physics Department, Texas A&M University, College Station, Texas 77843-3366, USA*

(Dated: August 11, 2003)



Θ^+ search at COSY-TOF today and tomorrow

$\underline{pp} \rightarrow \Sigma^+ K^0 p$	++	$p_{beam} \geq 2.9$ GeV/c
$\rightarrow \Sigma^+ K^+ n$	?-	$p_{beam} \geq 2.9$ GeV/c
$\rightarrow \pi^+ \Lambda K^0 p$	+	$p_{beam} \geq 3.2$ GeV/c on tape
$\rightarrow \pi^+ \Lambda K^+ n$	?--	

$\underline{pn} \rightarrow \Lambda K^0 p$	++	$p_{beam} \geq 2.7$ GeV/c test pos.
$\Lambda K^+ n$	?-	

Related topic: width of N^* (1710)

$pp \rightarrow \Lambda K^+ p$	++	$p_{beam} \geq 2.9$ GeV/c on tape

Parity of Θ^+:

Polarized Beam + polarized target + plans (paper)

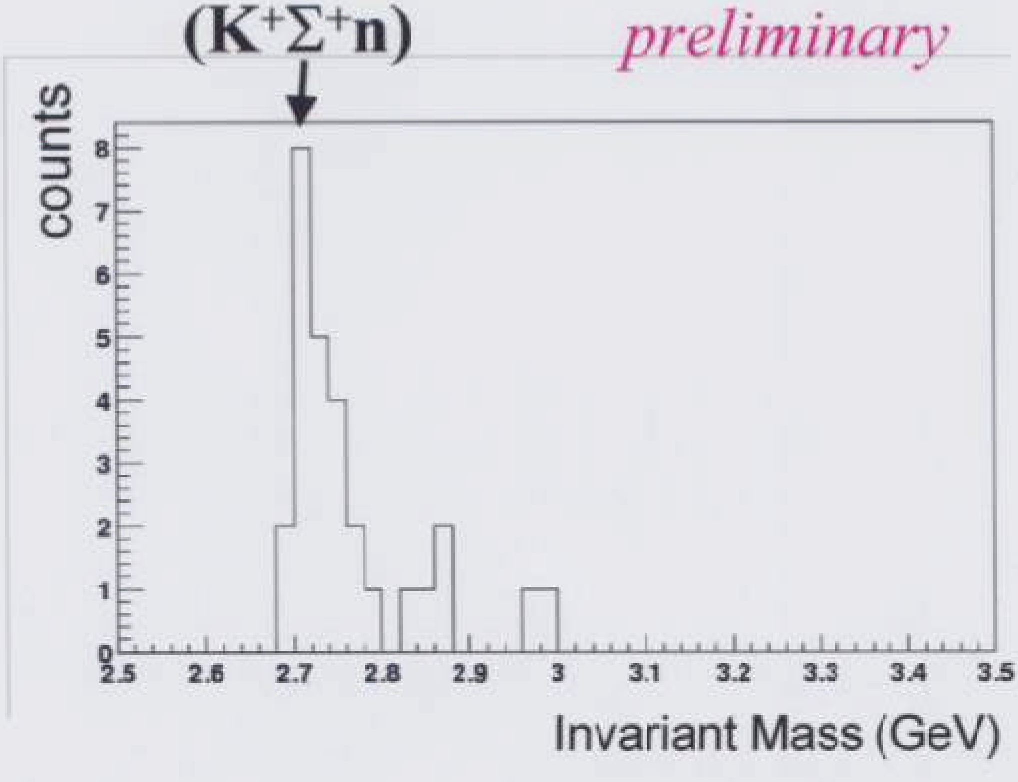
Σ^+ Production in the Reaction Channel $pp \rightarrow K^+\Sigma^+n$ at 2.85 GeV/c

low reconstruction efficiency (0,2 ‰)

⟶ ≈ 30 events

P.Schönmeier
TU-Dresden

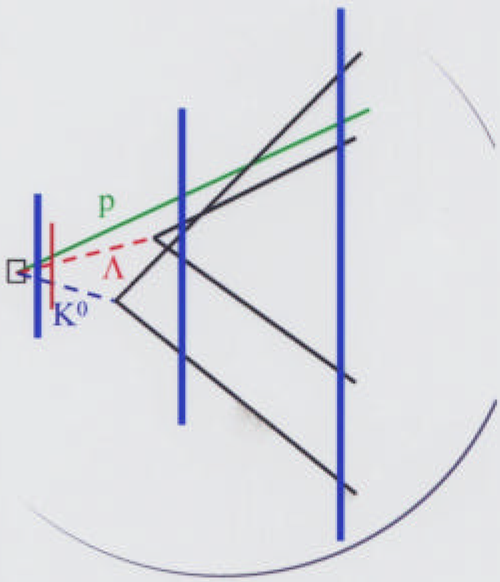
$\sigma_{tot} \approx$ **11 μb ± 2,4 μb**

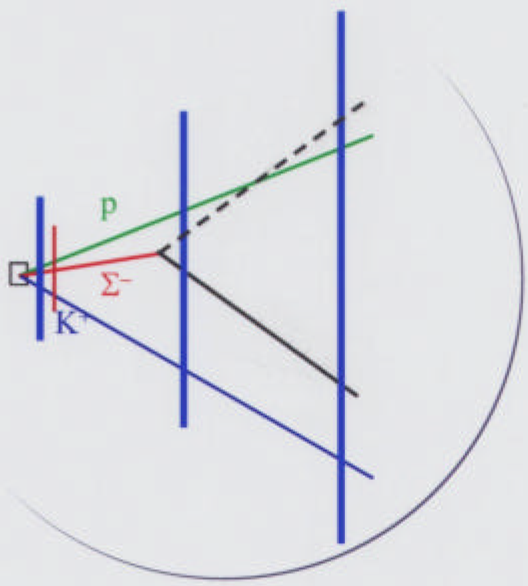


Hyperon production in quasi-free pn-reactions with D_2-target

Investigated reactions:

$pn \rightarrow pK^0\Lambda$ $\qquad$ $pn \rightarrow pK^+\Sigma^-$

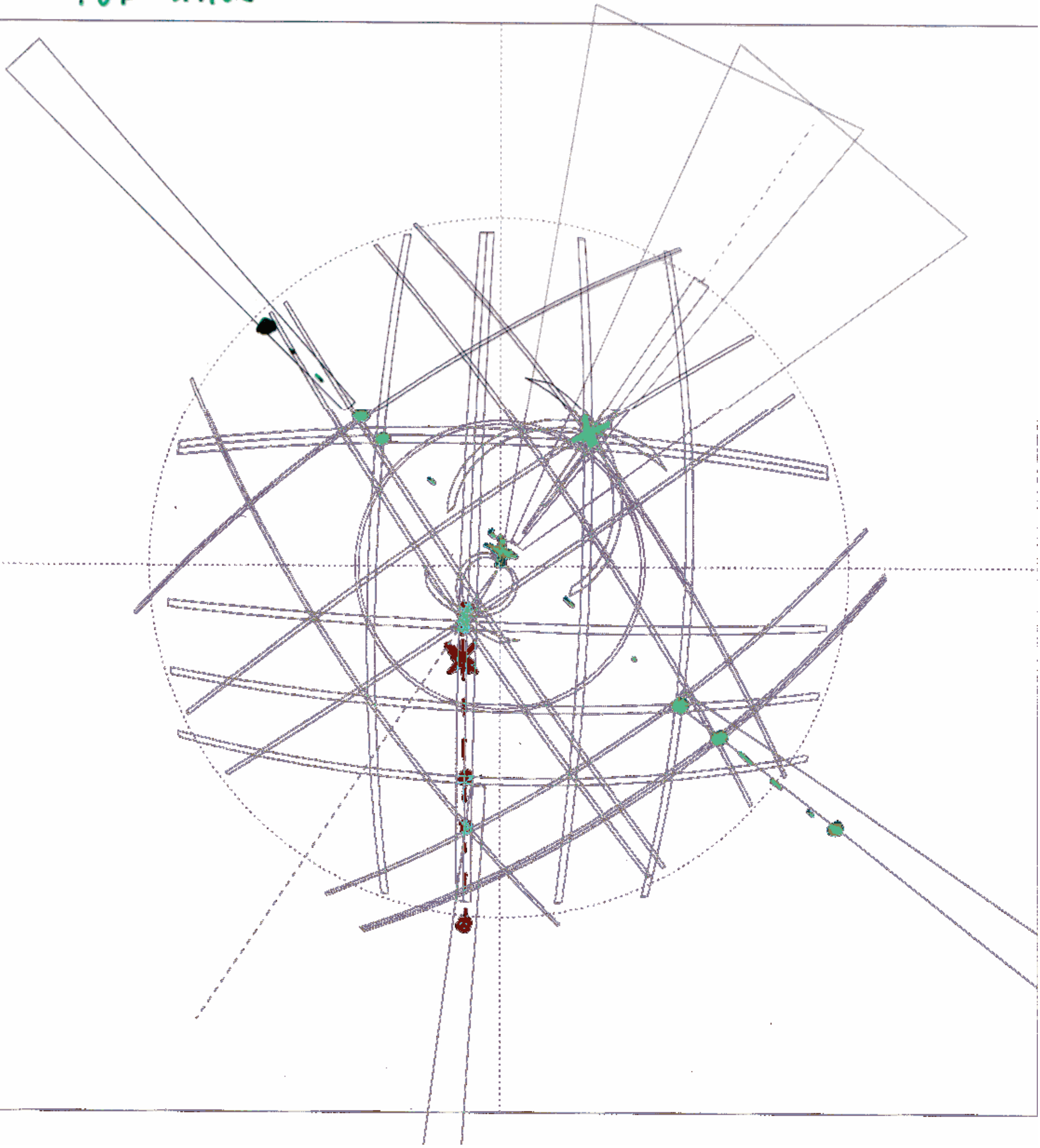




ALMSEPP 3.1
Run
Event 414

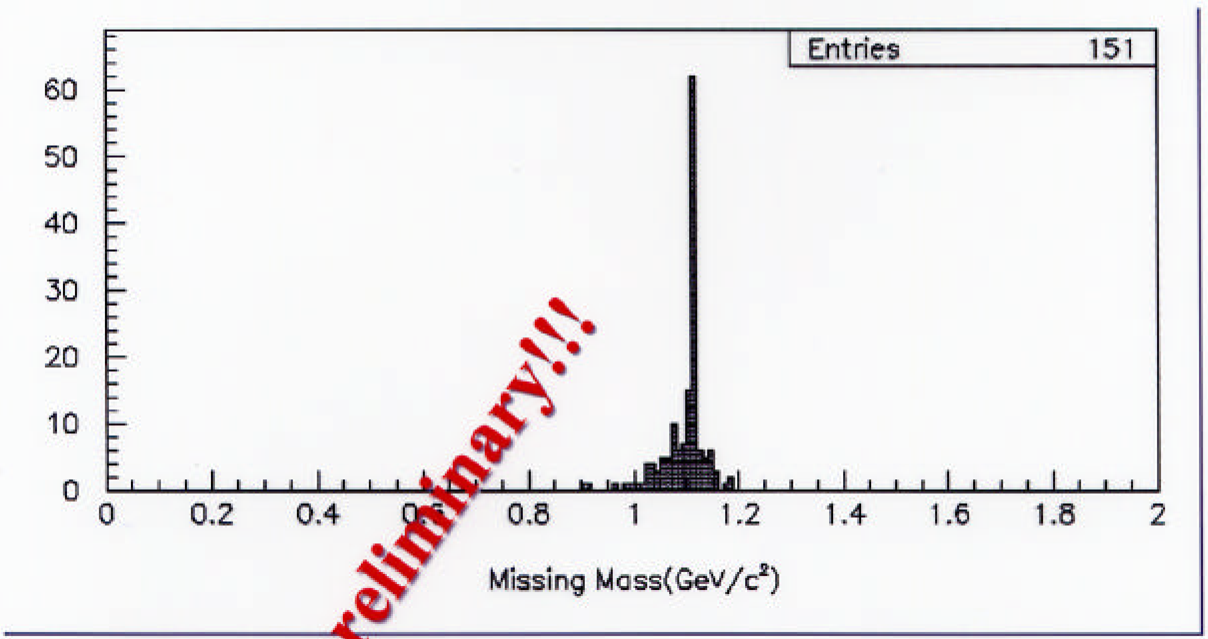
$pn \rightarrow pK^0\Lambda$

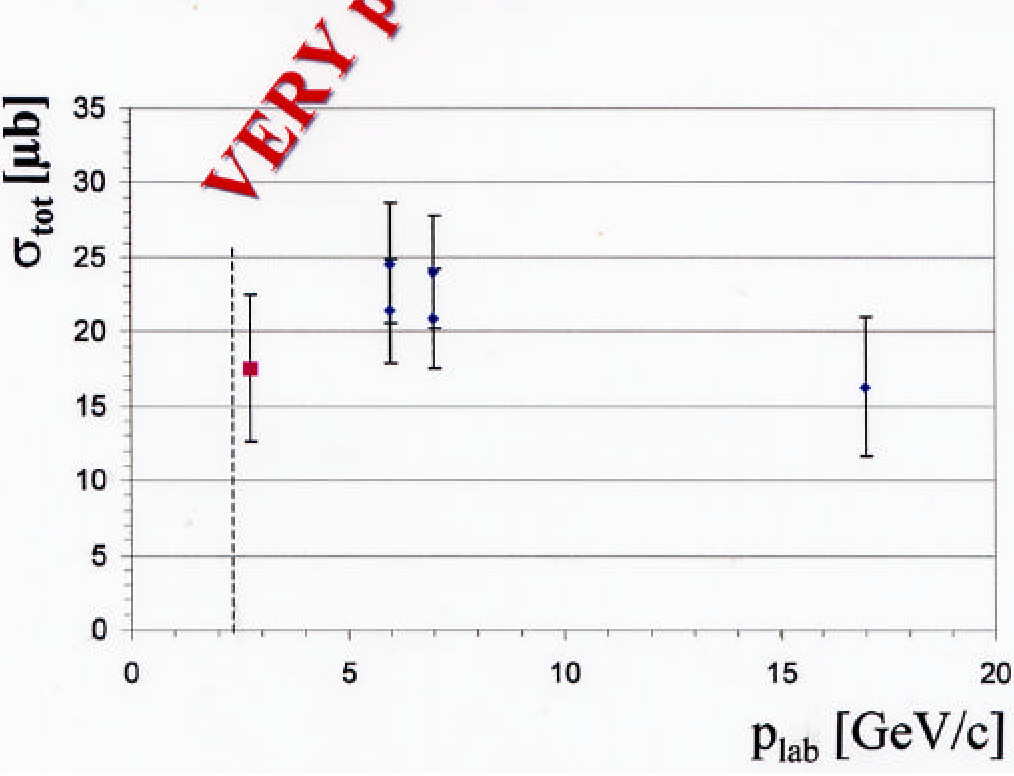
TOF 11/02



$pn \rightarrow pK^0\Lambda$

$p_{beam} = 2{,}75$ GeV/c





ε=134 MeV:
σ_{tot} = 17,5μb
± 5 μb

$N(1710)\ P_{11}$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ Status: ∗∗∗

Most of the results published before 1975 are now obsolete and have been omitted. They may be found in our 1982 edition, Physics Letters **111B** (1982).

The various partial-wave analyses do not agree very well.

$N(1710)$ MASS

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1680 to 1740 (≈ 1710) OUR ESTIMATE				
1717 ± 28	MANLEY	92	IPWA	$\pi N \rightarrow \pi N$ & $N\pi\pi$
1700 ± 50	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
$1723\pm\ 9$	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1706	CUTKOSKY	90	IPWA	$\pi N \rightarrow \pi N$
1692	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
1730	SAXON	80	DPWA	$\pi^- p \rightarrow \Lambda K^0$
1690	BAKER	79	DPWA	$\pi^- p \rightarrow n\eta$
1650 to 1680	BAKER	78	DPWA	$\pi^- p \rightarrow \Lambda K^0$
1721	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$
1625 ± 10	[1] BAKER	77	IPWA	$\pi^- p \rightarrow \Lambda K^0$
1650	[1] BAKER	77	DPWA	$\pi^- p \rightarrow \Lambda K^0$
1720	[2] LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$
1670	KNASEL	75	DPWA	$\pi^- p \rightarrow \Lambda K^0$
1710	[3] LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$

$N(1710)$ WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
50 to 250 (≈ 100) OUR ESTIMATE				
480 ± 230	MANLEY	92	IPWA	$\pi N \rightarrow \pi N$ & $N\pi\pi$
$93\pm\ 30$	CUTKOSKY	90	IPWA	$\pi N \rightarrow \pi N$
$90\pm\ 30$	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
$120\pm\ 15$	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
540	BELL	83	DPWA	$\pi^- p \rightarrow \Lambda K^0$
200	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
550	SAXON	80	DPWA	$\pi^- p \rightarrow \Lambda K^0$
97	BAKER	79	DPWA	$\pi^- p \rightarrow n\eta$
90 to 150	BAKER	78	DPWA	$\pi^- p \rightarrow \Lambda K^0$
167	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$
$160\pm\ 6$	[1] BAKER	77	IPWA	$\pi^- p \rightarrow \Lambda K^0$
95	[1] BAKER	77	DPWA	$\pi^- p \rightarrow \Lambda K^0$
120	[2] LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$
174	KNASEL	75	DPWA	$\pi^- p \rightarrow \Lambda K^0$
75	[3] LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$

$N(1710)$ DECAY MODES

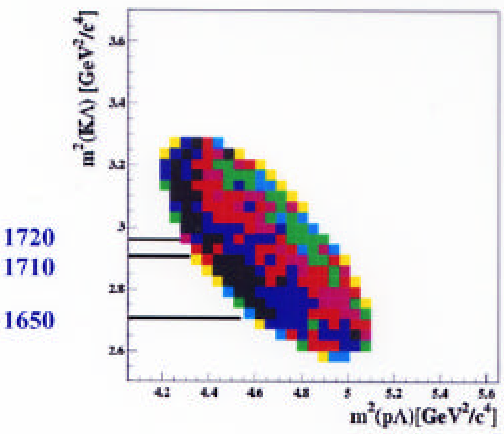
The following branching fractions are our estimates, not fits or averages.

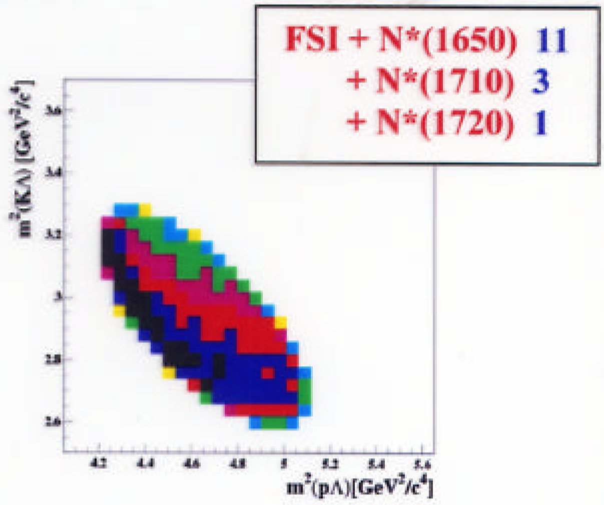
	Mode	Fraction (Γ_i/Γ)
Γ_1	$N\pi$	10–20 %
Γ_2	$N\eta$	
Γ_3	ΛK	5–25 %
Γ_4	ΣK	
Γ_5	$N\pi\pi$	40–90 %
Γ_6	$\Delta\pi$	15–40 %
Γ_7	$\Delta(1232)\pi$, P-wave	
Γ_8	$N\rho$	5–25 %
Γ_9	$N\rho$, S=1/2, P-wave	

Dalitzplot Distribution

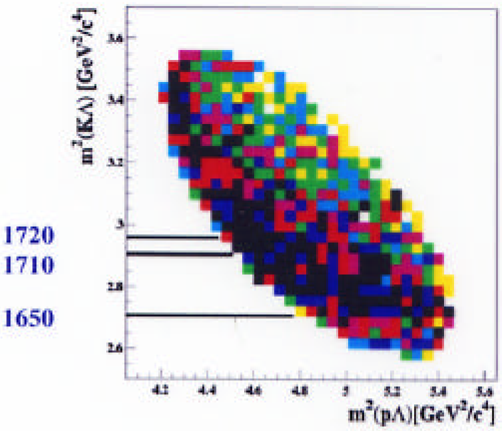
Data | **Model**

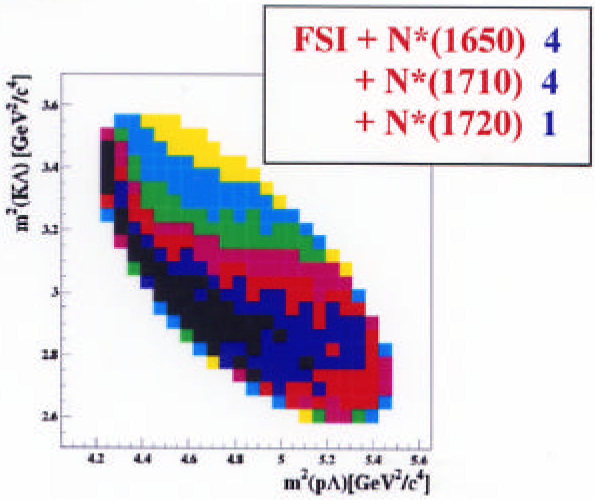
$K^+\Lambda p$ @ 2.95 GeV/c



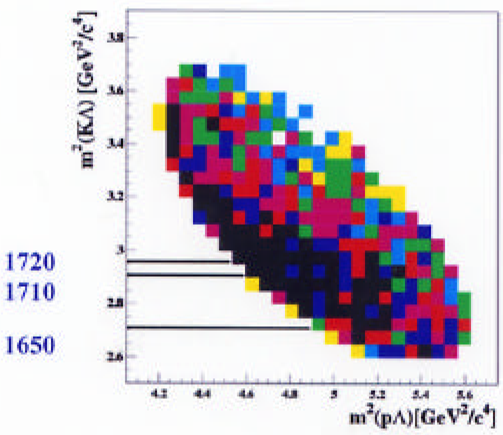


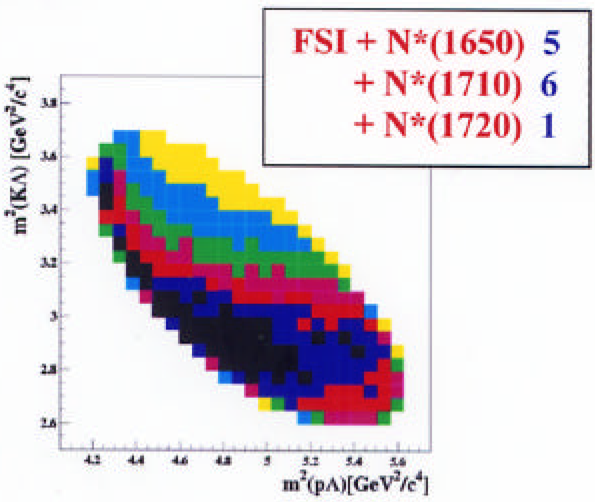
$K^+\Lambda p$ @ 3.20 GeV/c





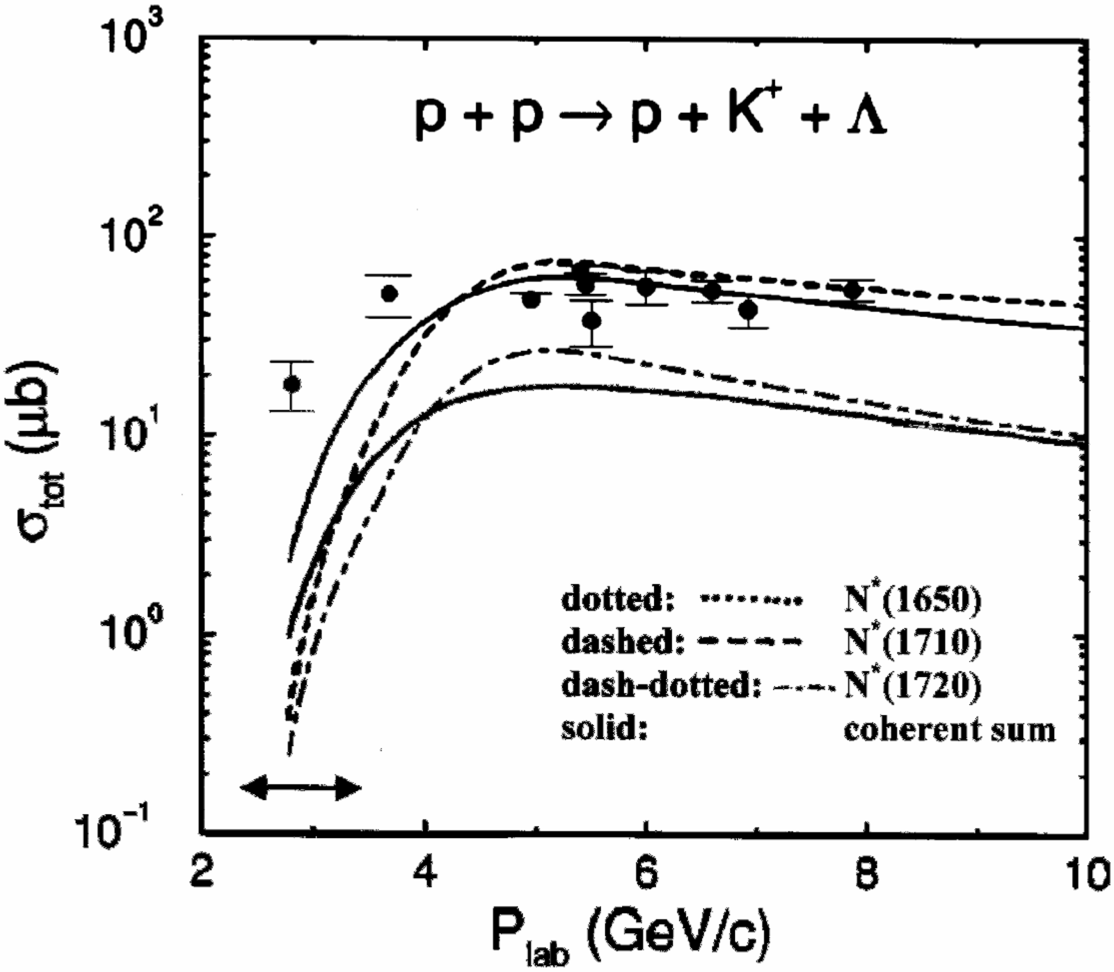
$K^+\Lambda p$ @ 3.30 GeV/c





Influence of N^*-Resonances on $pp \to K^+\Lambda p$

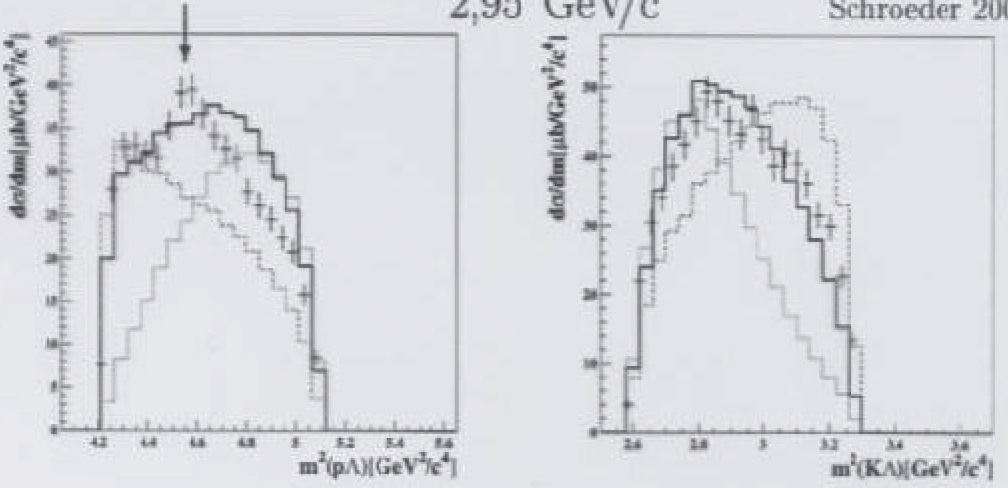
Calculations from R. Shyam, Phys. Rev. C 60 (1999)
R. Shyam, G. Penner and U. Mosel, Phys. Rev. C 63 (2001):



Projections of the Dalitzplots

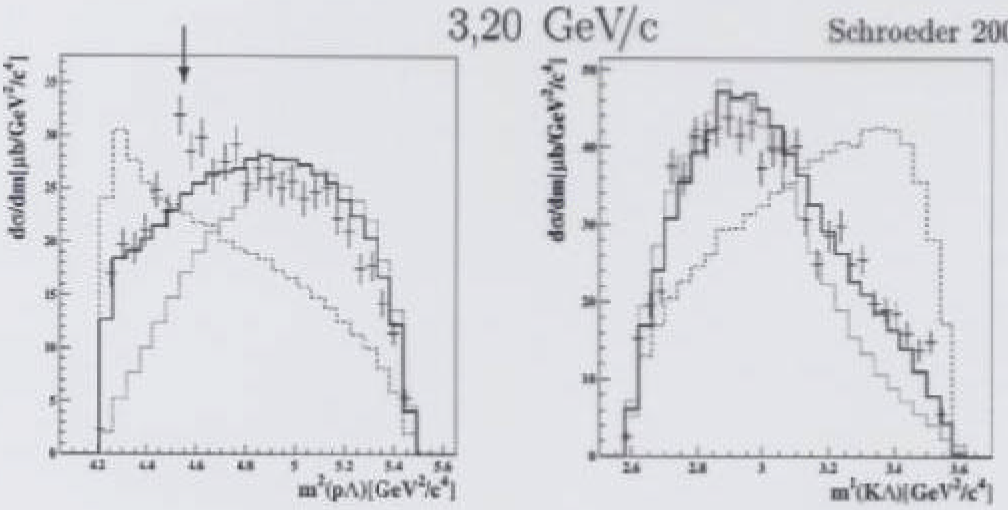
2,95 GeV/c

Schroeder 2003 preliminary



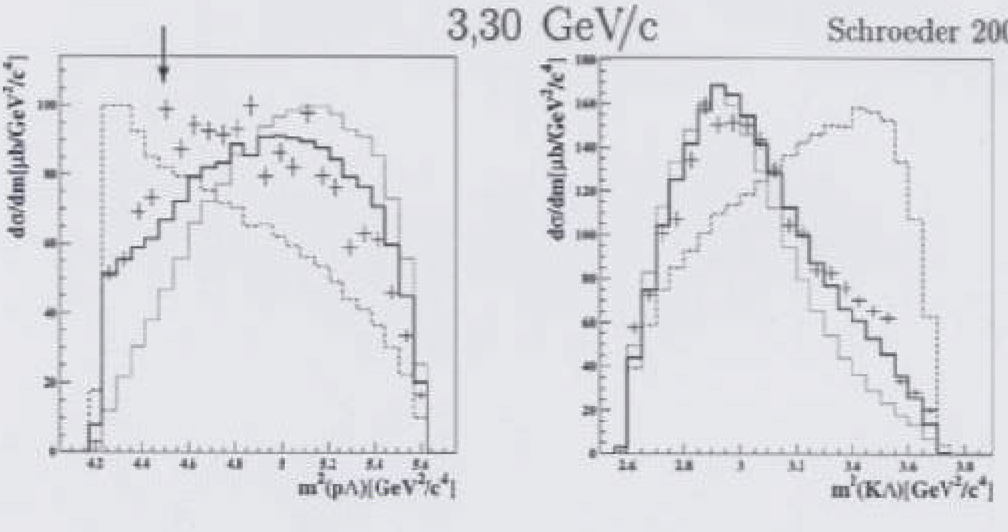
3,20 GeV/c

Schroeder 2003 preliminary



3,30 GeV/c

Schroeder 2003 preliminary



"More Exotics"

If Θ^+ is an isotensor state $\rightarrow$ search for the partners!

Θ^{++}

$pp \to \Lambda K^+ p$ ++ $p_{beam} \geq 2.7$ GeV/c   on tape

$\quad \to \pi^0 \Lambda K^+ p$?? $p_{beam} \geq 3.2$ GeV/c   on tape

Θ^{0}

$pn \to \Sigma^+ K^0 n$?? $p_{beam} \geq 2.9$ GeV/c

Θ^{+++}

$pp \to \Theta^{+++} \Sigma^-$ + $p_{beam} \geq 2.9$ GeV/c   on tape

$\Sigma^- \xrightarrow{\text{delayed}} \pi^- n$

$\Theta^{+++} \xrightarrow{\text{delayed}} p\, \pi^+ \pi^+$

$\quad \Delta^{++} \pi^+$

$\quad \Delta^{++} \to p\, \pi^+$

Interpretation of the Θ^+ as an isotensor pentaquark with weakly decaying partners

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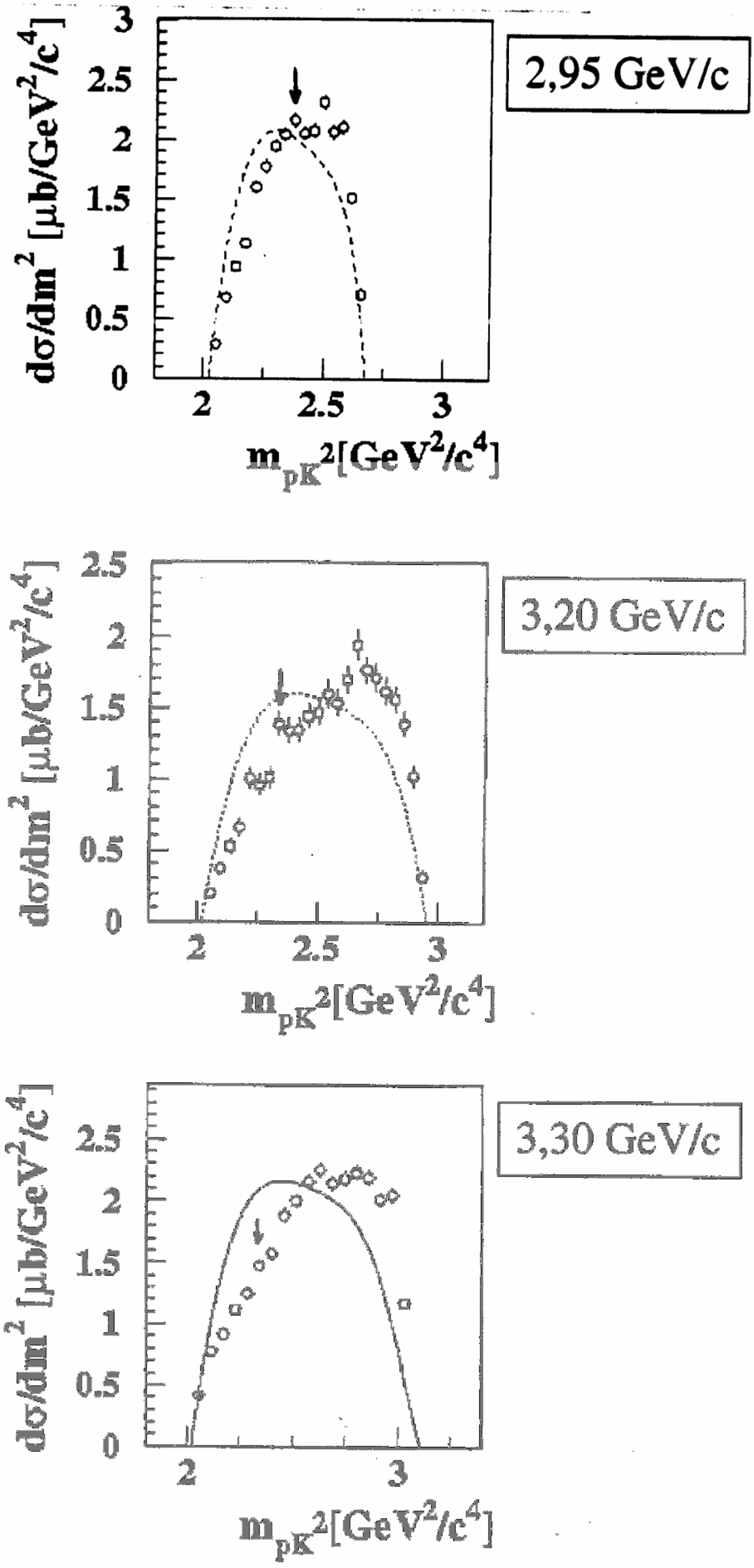
State	Quarks	I_z	Decay modes
Θ^-	$dddd\bar{s}$	-2	
Θ^0	$uddd\bar{s}$	-1	nK^0
Θ^+	$uudd\bar{s}$	0	nK^+, pK^0
Θ^{++}	$uuud\bar{s}$	1	pK^+
Θ^{+++}	$uuuu\bar{s}$	2	

Table 1: Quark content, I_z, and strong decay modes of Θ states.

State	Decay mode		Pairs	State	Decay mode		Pairs
Θ^{+++}	$p\pi^+l^+\nu_l$	A	1	Θ^-	$n\pi^-$	E	0
	$p\pi^+\pi^+$	A	1		$n\pi^-\pi^0$	E	1
	$p\pi^+\pi^0l^+\nu_l$	P	1		$n\pi^-\pi^-l^+\nu_l$	P	1
	$\Delta^{++}l^+\nu_l$	A	0		$\Delta^-\pi^0$	E	0
	$\Delta^{++}\pi^+$	A	0		$\Delta^-\pi^-l^+\nu_l$	P	0
	$\Delta^{++}\pi^0l^+\nu_l$	P	0		$\Delta^-f_0(600)$	E	0

pp → $K^+\Lambda p$ projection on the pK^+ subsystem



Summary

COSY-TOF

observed a narrow resonance with S = +1

in the K^0p invariant mass spectrum

from the exclusive measured reaction $pp \rightarrow \Sigma^+K^0p$

at p_{beam} = 2.95 GeV/c

preliminary

Mass: 1530 ± 5 MeV/c^2

Width: $\leq 22 \pm 4$ MeV/c^2 (FWHM)

Significance: $4 - 6\ \sigma$ (depending on method)

Cross section: $0.4 \pm 0.1_{stat.} \pm 0.1_{syst.}$ μb

In Progress:

Investigation of the N^* (1710)

Search for possible isospin partners

Future plans at COSY-TOF

Proposal in March for pn $\rightarrow \Lambda K^0 p \rightarrow$ run in 2004

Upgrade of the detector:

1. step (2004): third layer for fibre hodoscope
2. step (2005): additional tracker (straws)
3. step (200?): polarized target
   $\rightarrow$ parity of Θ^+

Kollaboration

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