

*Hyperon Production,  $\Lambda$  Polarization and the Pentaquark  
 $\Theta^+$  at COSY-TOF*

*M. Wagner  
for the COSY-TOF collaboration*

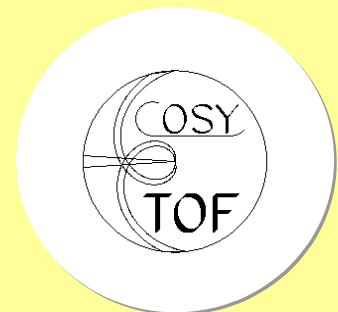
**Physikalisches Institut, Universität Erlangen-Nürnberg, Germany**

**Present adress:**

**Dept. of Physics, Kyoto University, Japan**

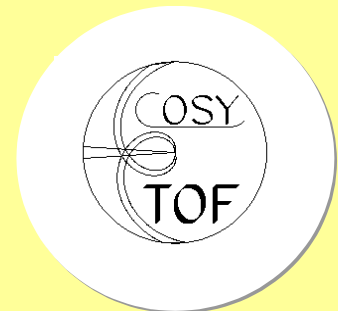
**Brookhaven National Laboratory – RBRC – Bldg. 510A - Upton, NY 11973-5000 – USA**

**\* supported by the German BMBF and Forschungszentrum Jülich**



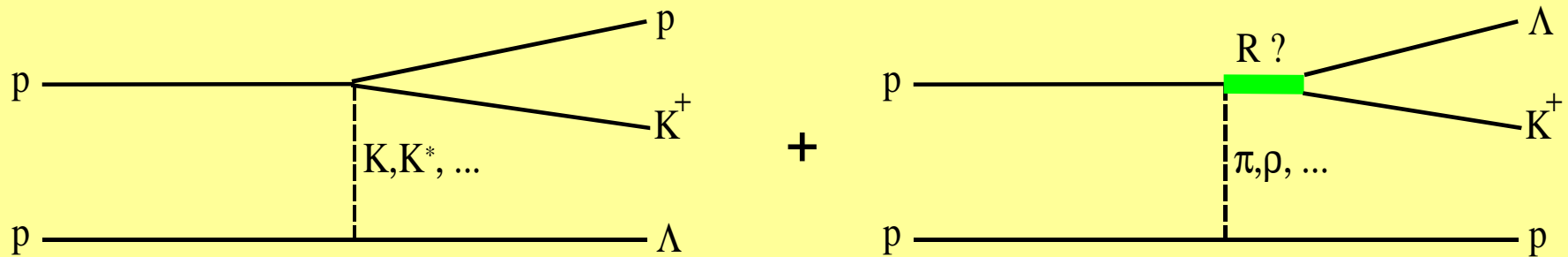
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- Strangeness Production at Threshold region in NN induced Reactions – Overview
- The Experiment COSY-TOF
- Measurement Principles of the Channel  $pp \rightarrow pK^+\Lambda$
- Results (Total Cross Sections,  $N^*$ , Polarization)
- Measurement Principles of the Channel  $pp \rightarrow pK^0\Sigma^+$
- Results (Total Cross Sections, Model Fits, ...)
- Pentaquarks at COSY-TOF
- Summary and Outlook



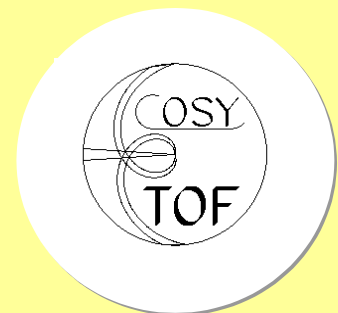
# Strangeness Production at Threshold Region in NN Induced Reactions - Overview

## Meson Exchange Model



**Initial** and **final** state interaction

+  
coupled-channel-effects (CUSP)

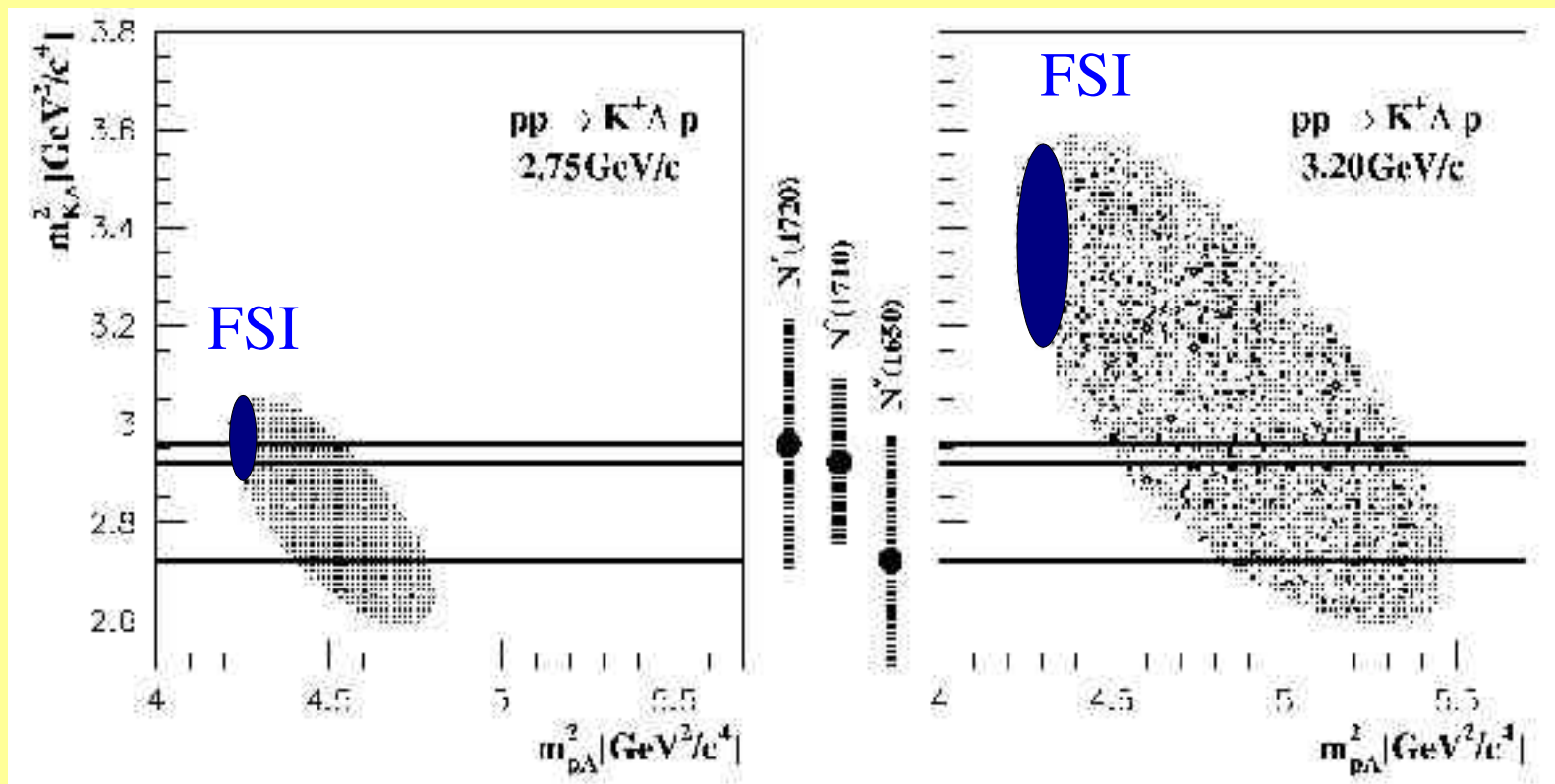


# Strangeness Production at Threshold Region in NN Induced Reactions - Overview

## EXPERIMENT:

Exclusive observables: hyperon polarization, beam polarization

Full phase space coverage → Dalitz analysis (FSI  $\Leftrightarrow$  Resonances)



# Strangeness Production at Threshold Region in NN Induced Reactions - Overview

Threshold region  $\Rightarrow$  only few partial waves!

Hyperon production in  $NN \rightarrow NKY$ :

Comparison with:

other reaction channels:

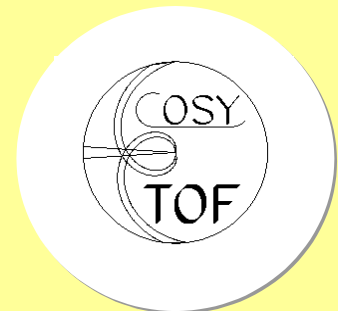
$$Y = \Lambda, \Sigma^+, \Sigma^0, \Sigma^-$$

other hadronic environments:

$$\gamma p \rightarrow K^+ \Lambda \text{ (ELSA, CEBAF)}$$

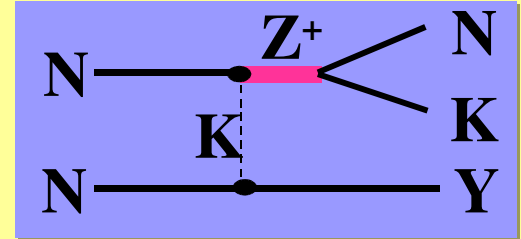
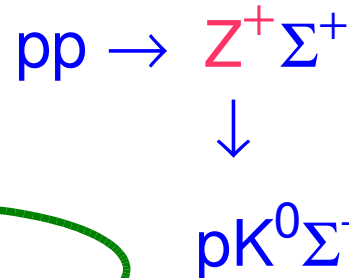
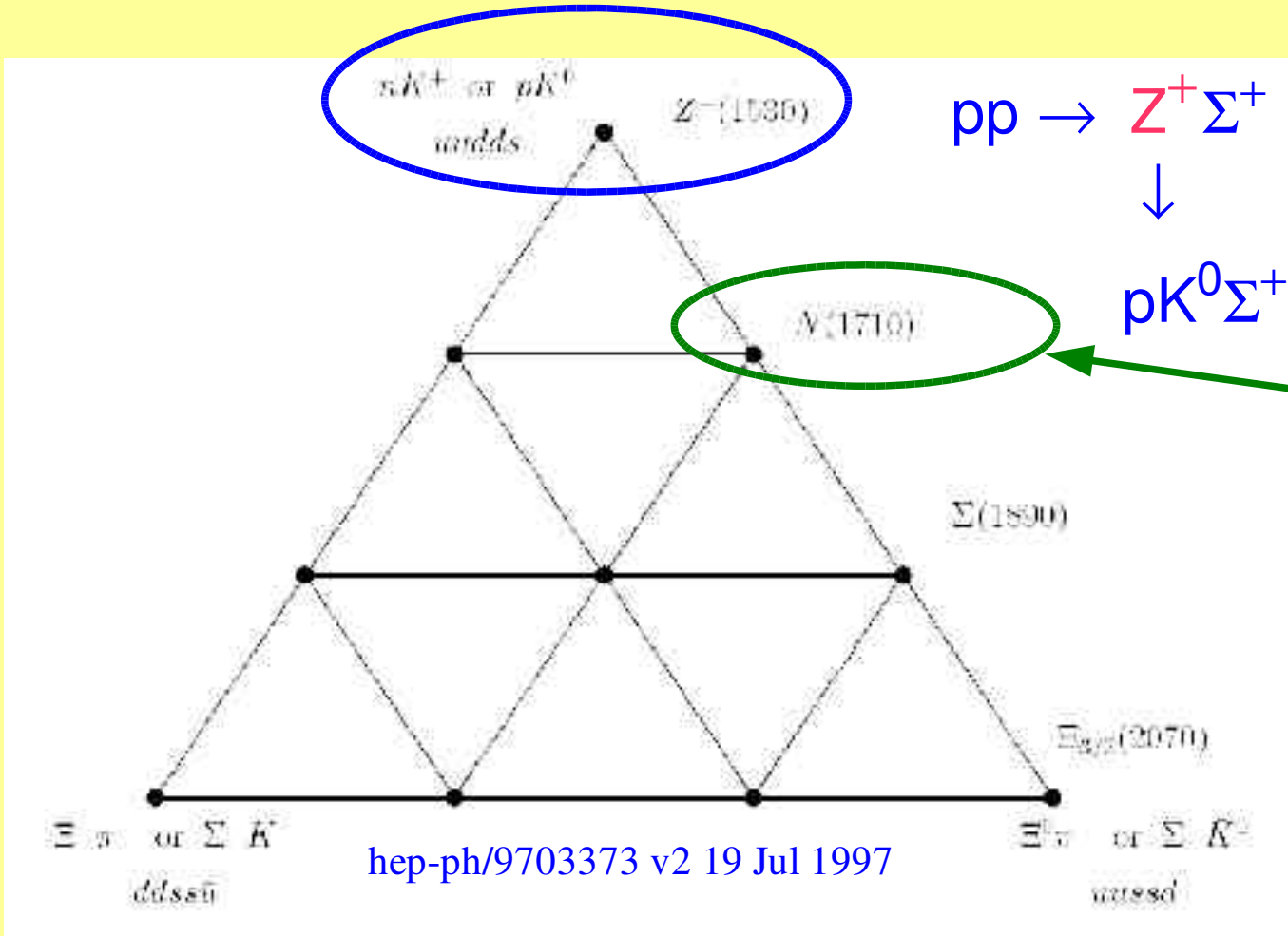
simple regime as **input** for reactions in nuclear collisions:

medium effects (e.g.  $K^+/K^-$  ratio at GSI)



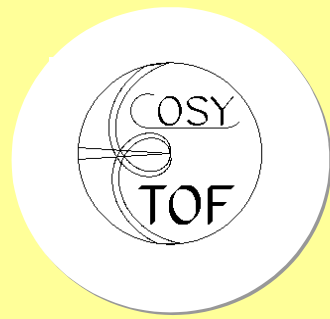
# Strangeness Production at Threshold Region in NN Induced Reactions - Overview

Chiral soliton model → predicts exotic states







Exotic states located at the corners of the anti-decuplet triangle  $N^*(1710)$  „anchor“

lightest member:  
 $Z^+ (\Theta^+) 1530 \text{ MeV}$   
 $\Gamma < 30 \text{ MeV}$   
 R. Jaffe: hep-ph/0401187

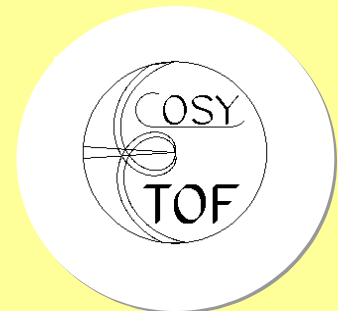


# Strangeness Production at Threshold Region in NN Induced Reactions - Overview

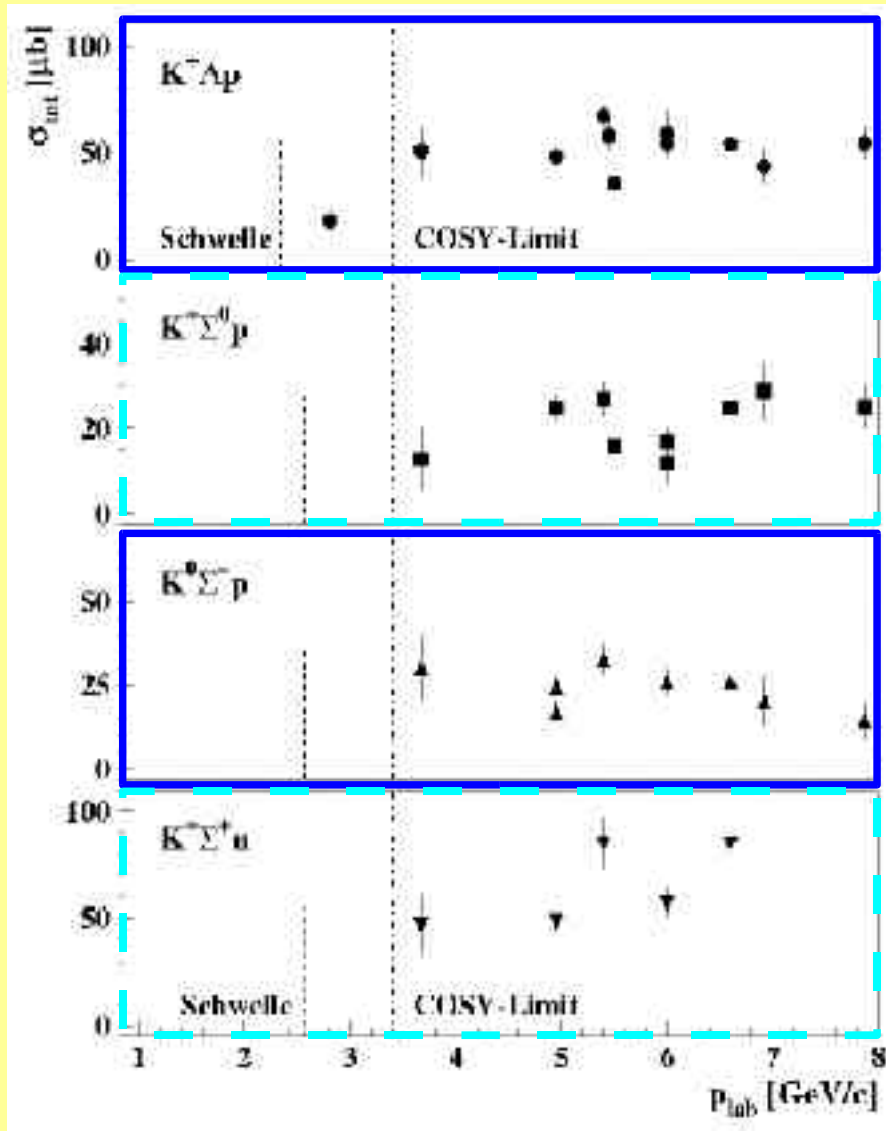
## Strangeness Production at COSY-TOF:

		$\sqrt{s}$ [GeV]	p (thresh) [GeV/c]
	$pp \rightarrow pK^+ \Lambda$	2.548	2.339
	$pp \rightarrow K^+ \Sigma^+ n$	2.622	2.560
	$pp \rightarrow K^+ \Sigma^0 p$	2.624	2.566
	$pp \rightarrow K^0 \Sigma^+ p$	2.625	2.569
	$p n \rightarrow K^+ \Lambda n$	2.549	2.338
	$p n \rightarrow K^+ \Lambda n p$		
	$p n \rightarrow K^0 \Lambda p p$	2.552	2.347
	$p n \rightarrow K^+ \Sigma^- p p$		

TEST



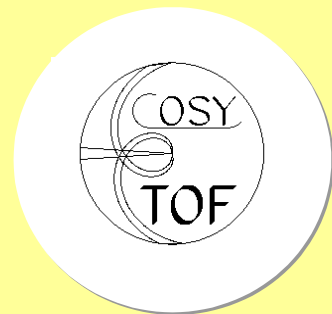
# Strangeness Production at Threshold Region in NN Induced Reactions - Overview



Data situation for pp reactions before COSY:

almost no data in threshold region

Threshold data:  
few partial waves





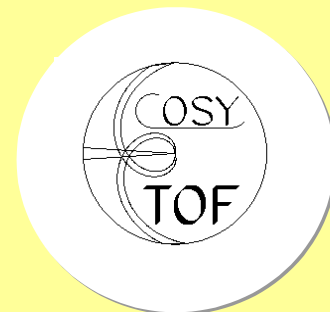
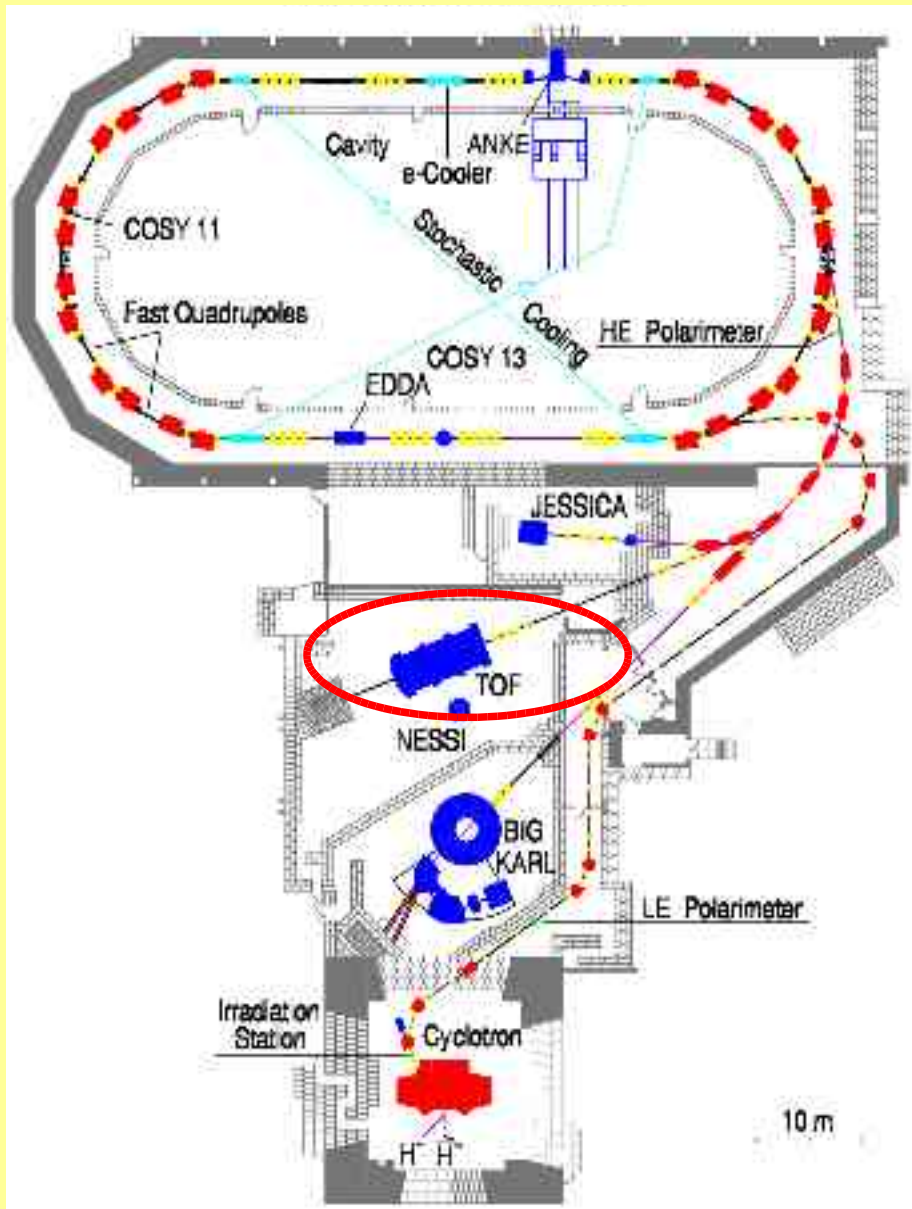
## The COSY Facility

Cooler Synchrotron Jülich:

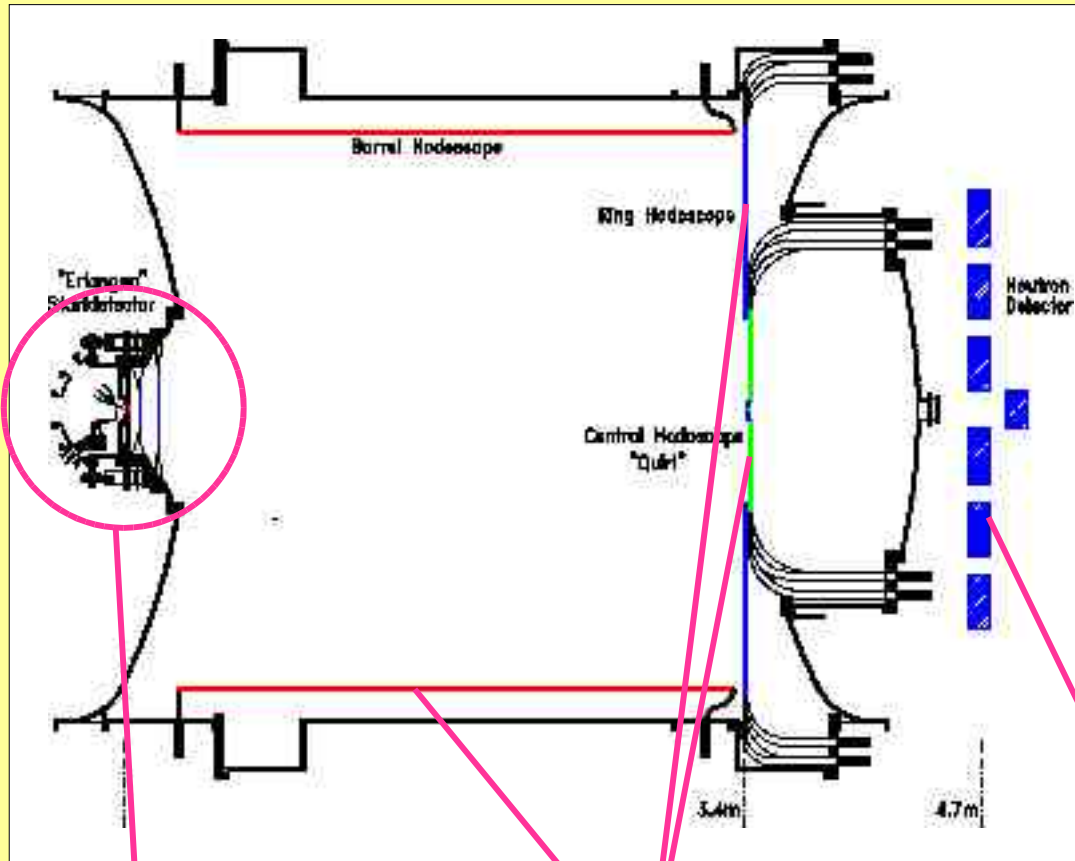
180 m circumference

Phase space cooling (electron and stochastic)

Max. beam momentum:  
3.6 GeV/c



# The TOF Experiment



**Erlangen start detector system optimized for vertex reconstruction**

**stop detector system**

- TOF-information
- track information
- $4\pi$ -coverage

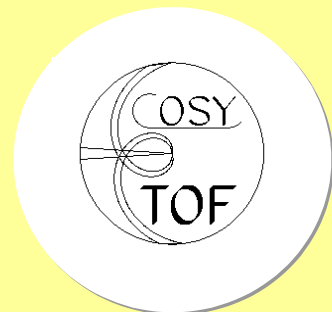
**neutron detector**  
 $pp \rightarrow nK^+\Sigma^+$

-Time-Of-Flight-Spectrometer

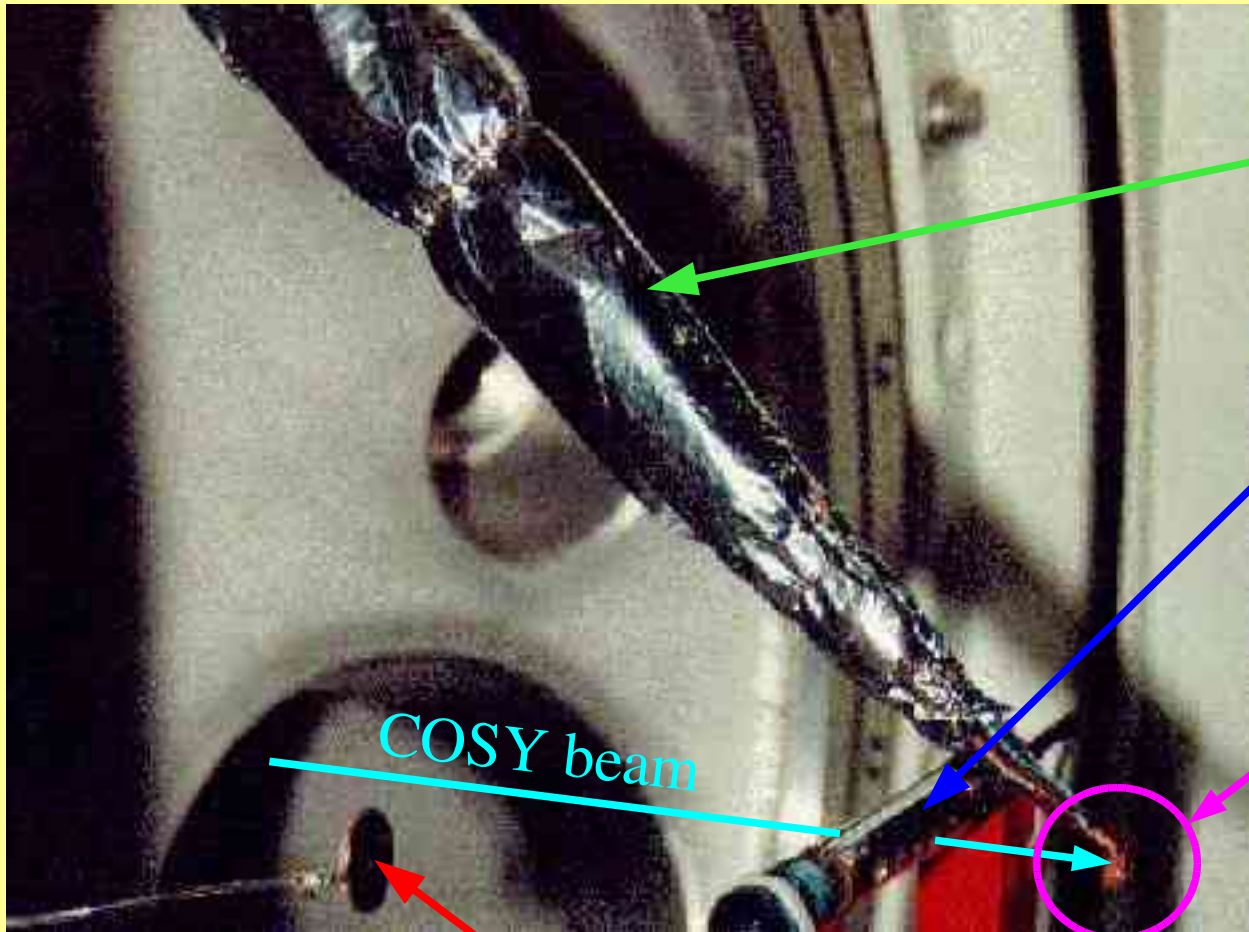
-external experiment

-modular concept

-very tiny  $\text{LH}_2$  target



# The LH<sub>2</sub> Target



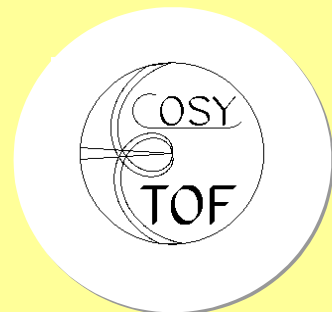
Cooling system  
for H<sub>2</sub>

Veto detector

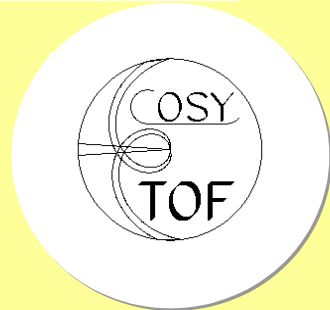
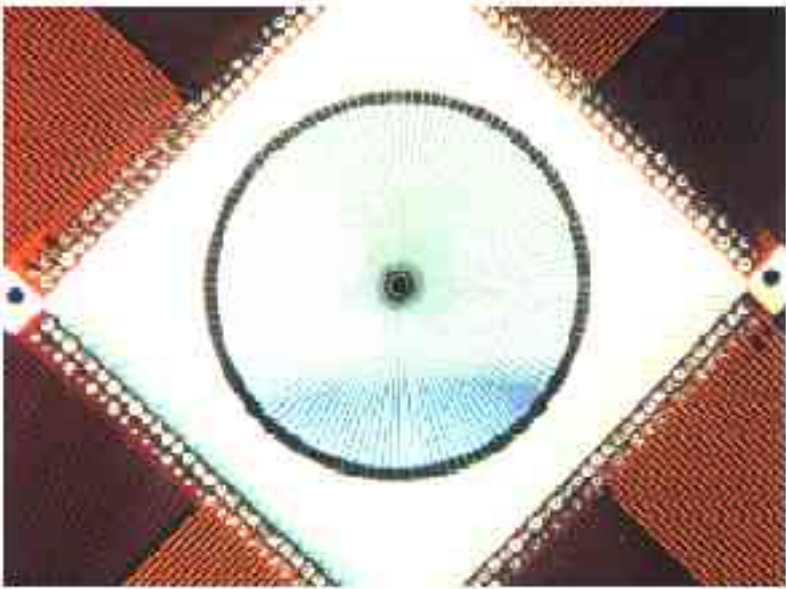
Target cell  
4mm length  
6mm Ø  
4 μm mylar windows

COSY beam

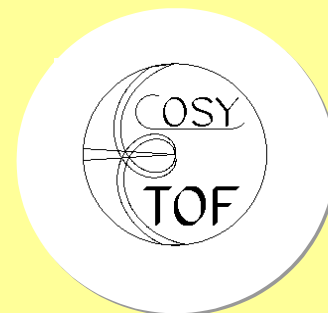
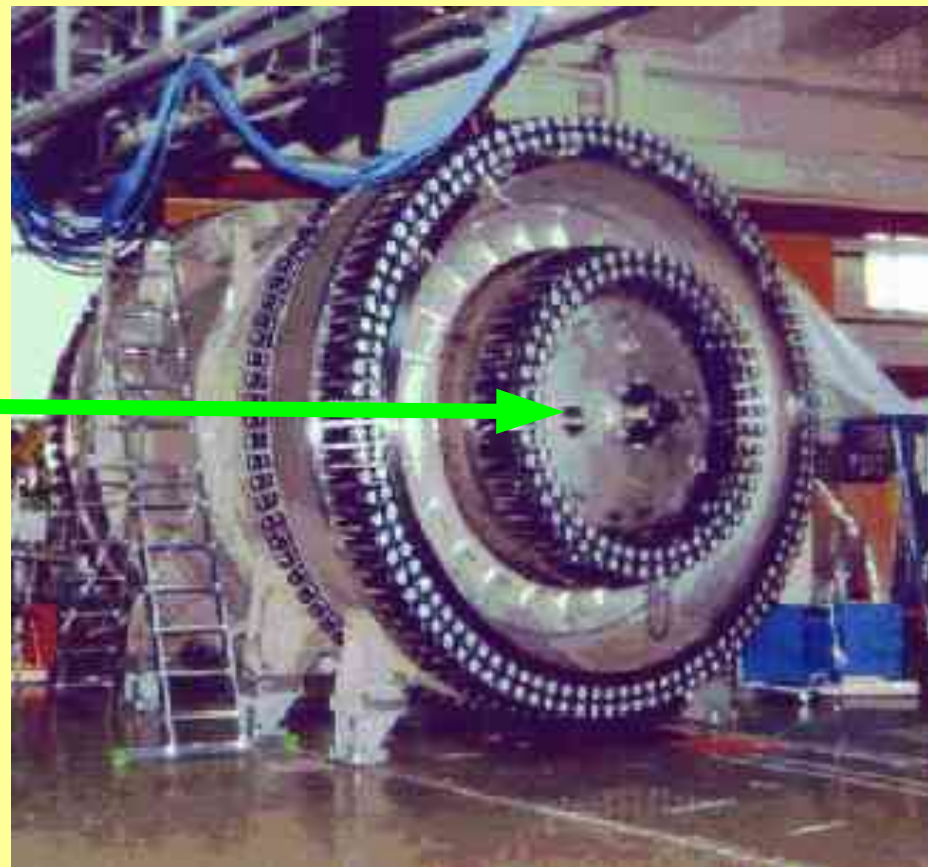
Ruby cristal for rough beam sudies



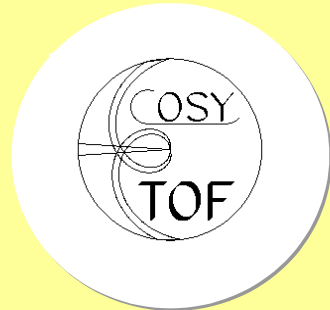
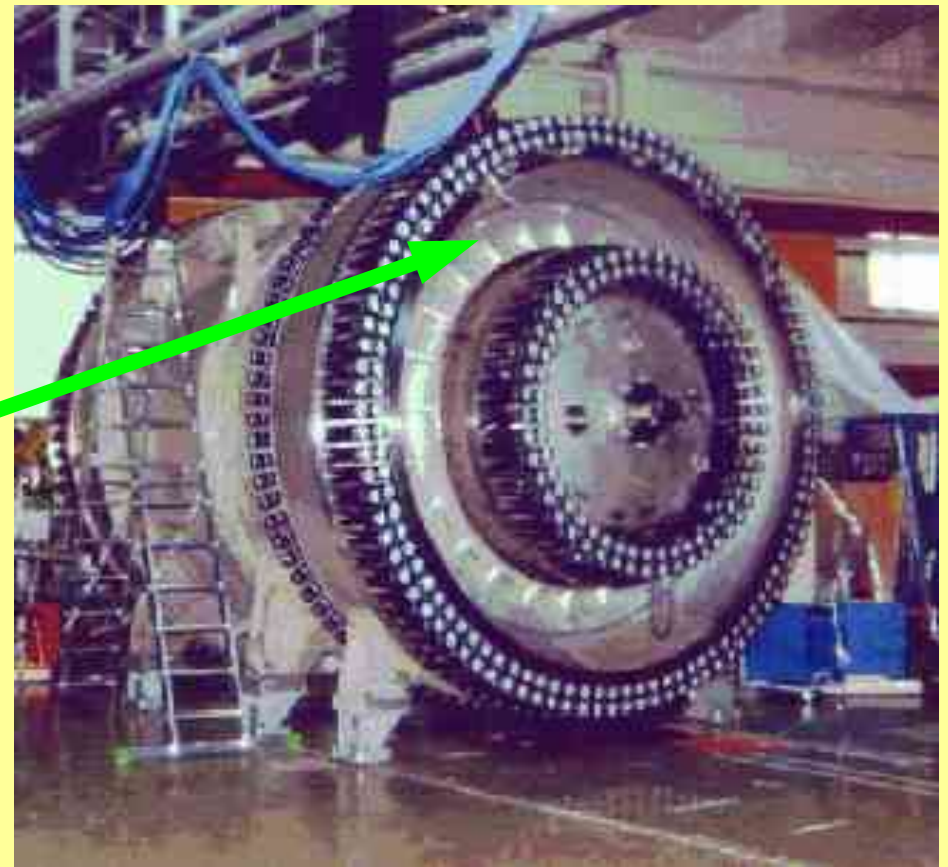
## The „Erlangen Start Detector“



# The Stop Detector System

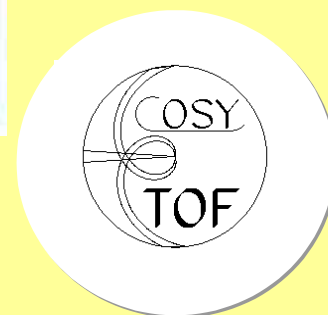


# The Stop Detector System



# Hyperon Measurement Program @ COSY-TOF

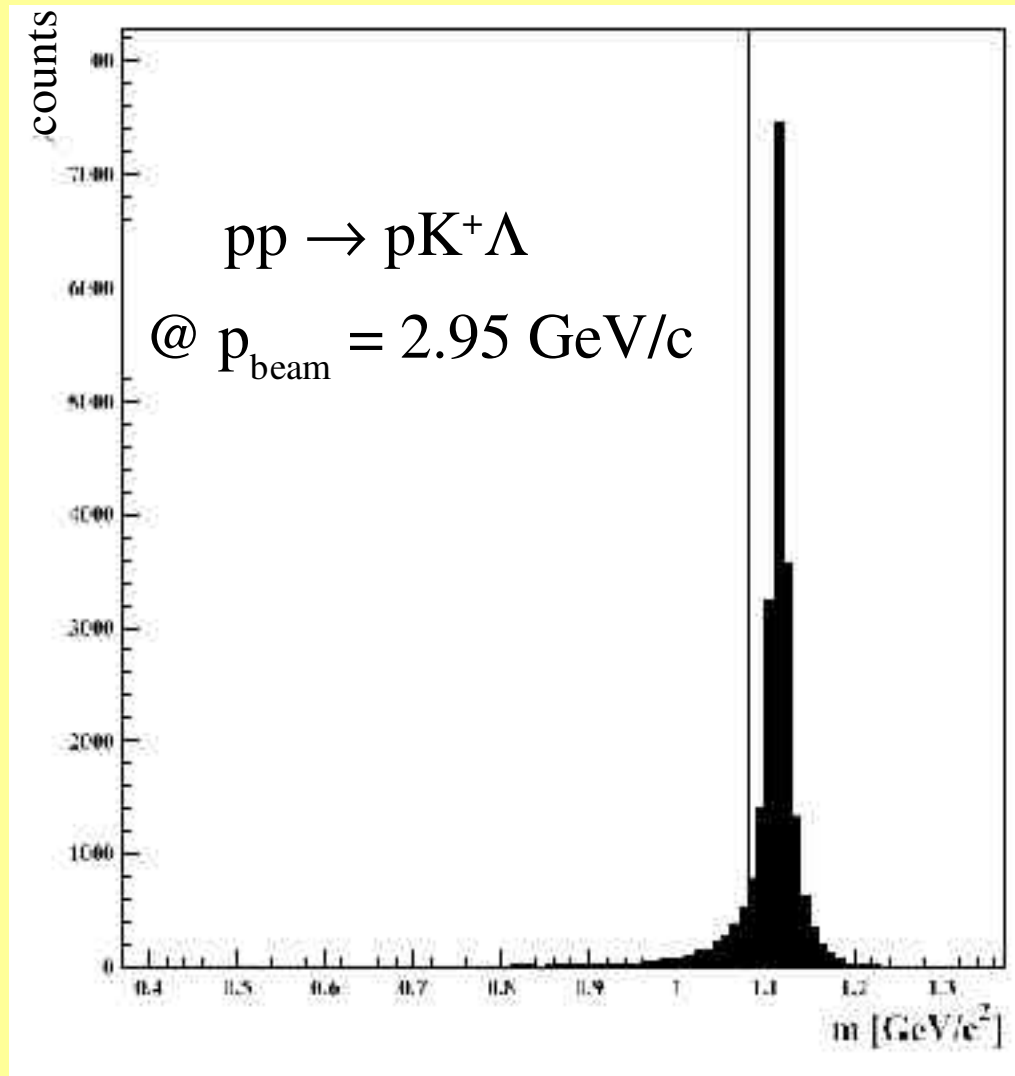
Reaction	Momentum [GeV/c]	Run
$pp \rightarrow K^+ \Lambda p$	2.50 / 2.75	1996
	2.59 / 2.68 / 2.85	1998
	2.95 / 3.20 / 3.30	2000 / 2002
$pp \rightarrow K^+ \Sigma^0 p$	2.85 / 2.95 / 3.20	1998 / 2000
$pp \rightarrow K^0 \Sigma^+ p$	2.85 / 2.95 / 3.20	1998 / 2000
$pp \rightarrow K^+ \Sigma^+ n$	2.85 / 2.95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





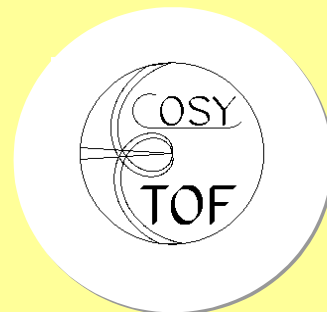


# Results on $pp \rightarrow pK^+\Lambda$



Momentum and energy  
conservation  
 $\rightarrow$  missing mass analysis

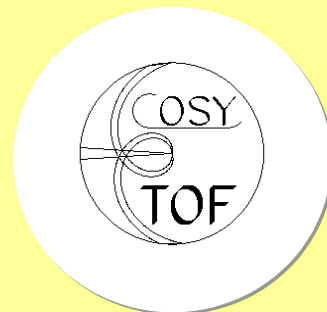
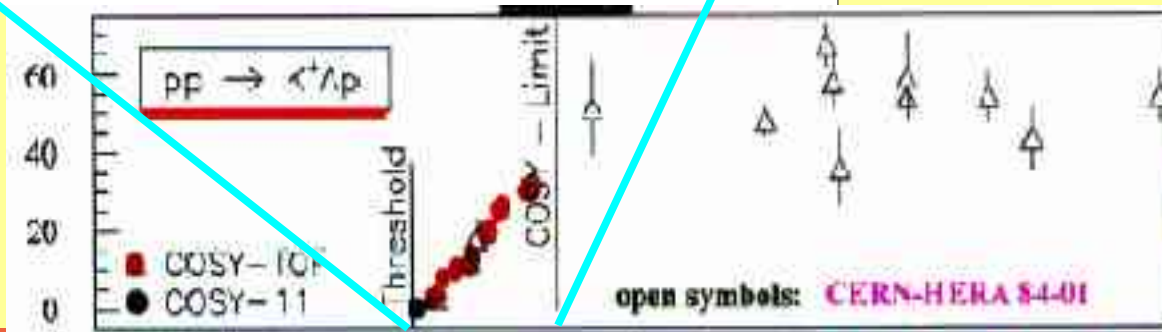
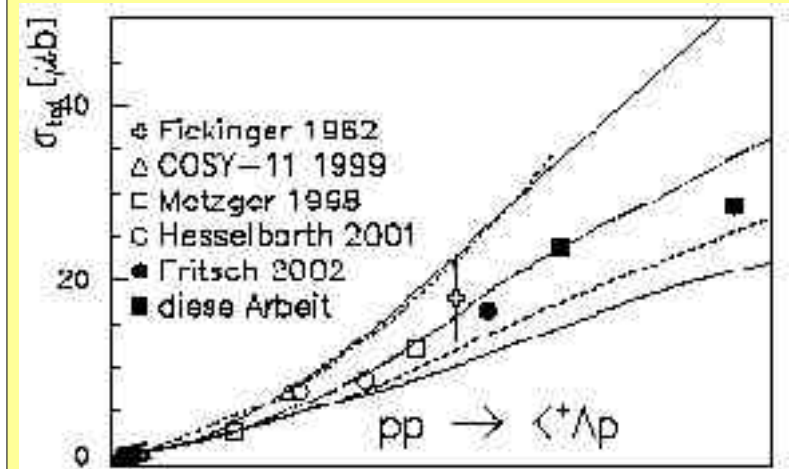
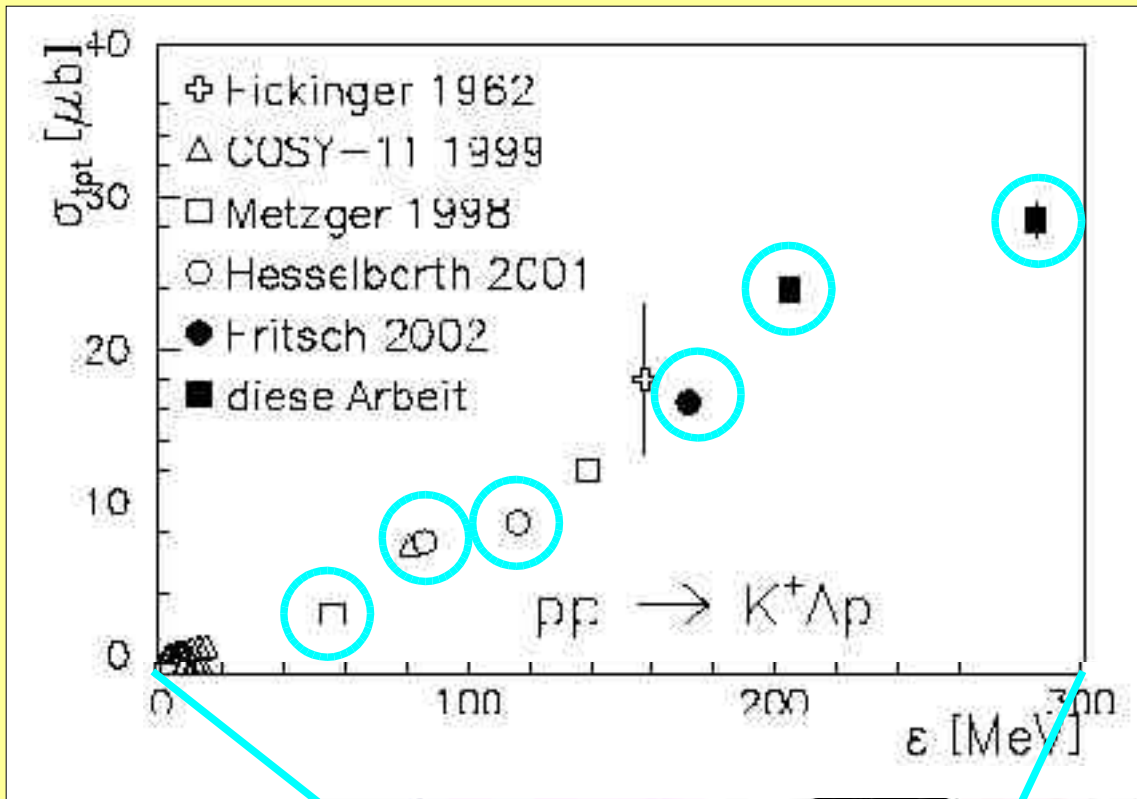
data sample quasi  
background free

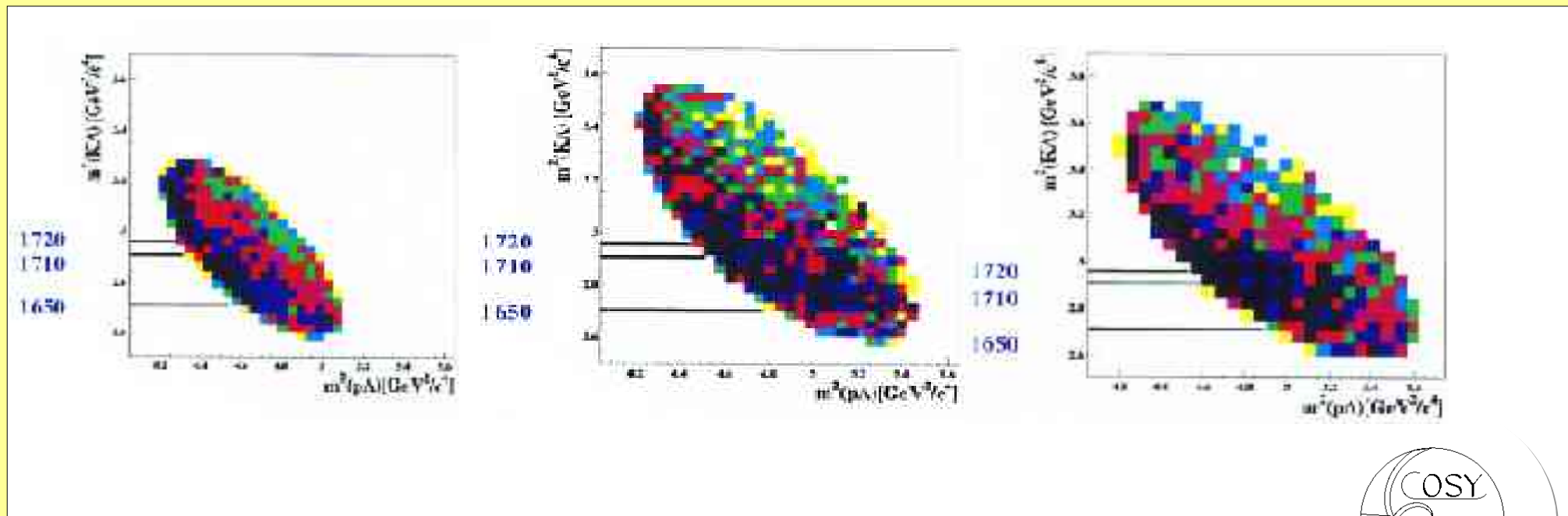
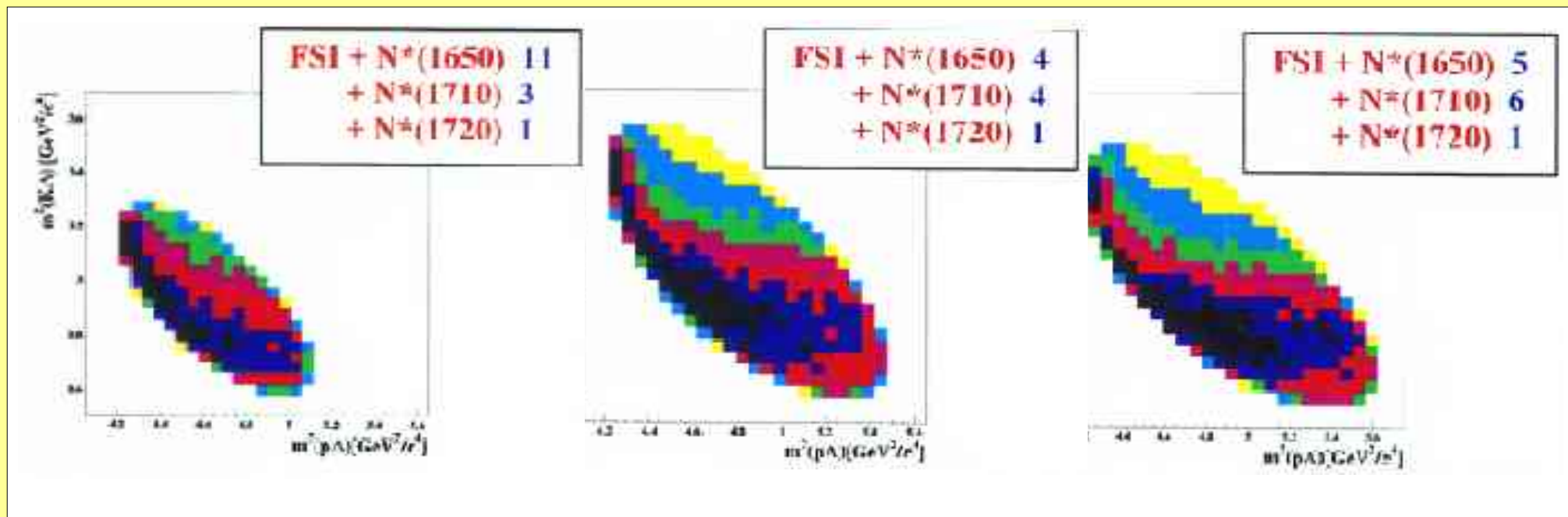


# Results on $pp \rightarrow pK^+\Lambda$

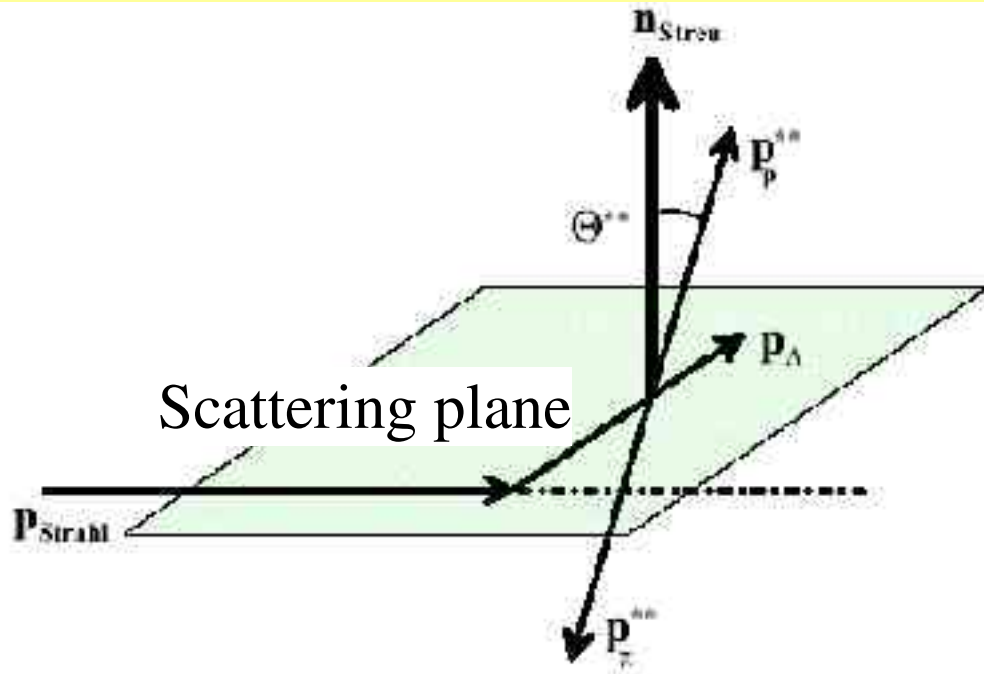
Total cross sections

○ TOF data

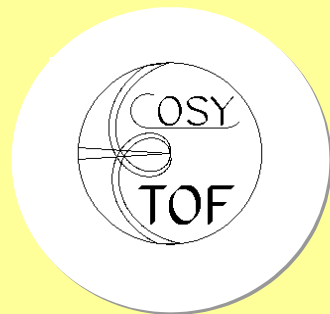


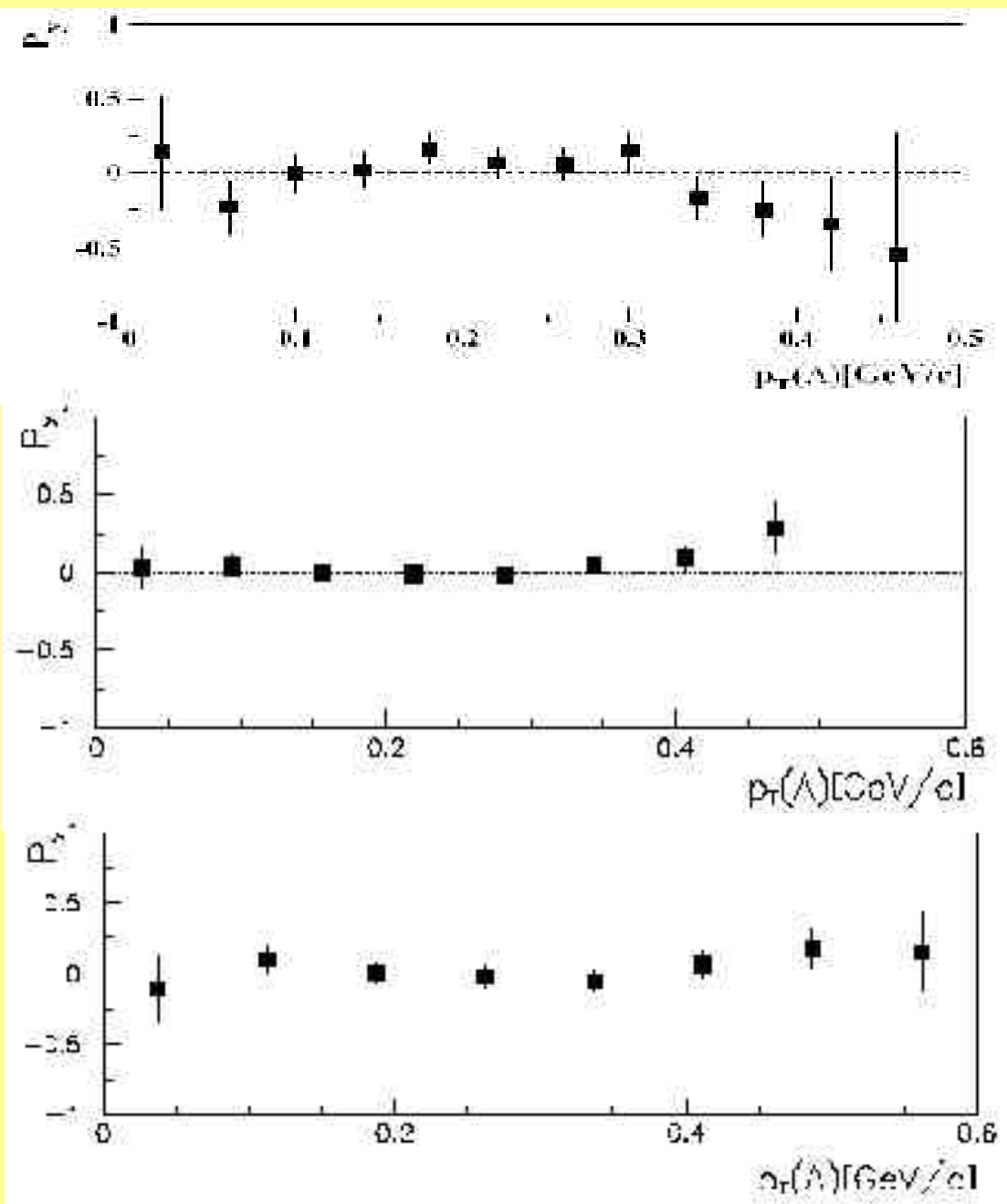


## $\Lambda$ polarization



$$\mathcal{P}_{\Lambda} = \frac{1}{\alpha} \times \frac{\sum_i \cos \Theta_i^{**}}{\sum_i \cos^2 \Theta_i^{**}}$$

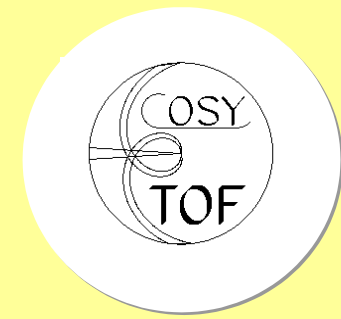


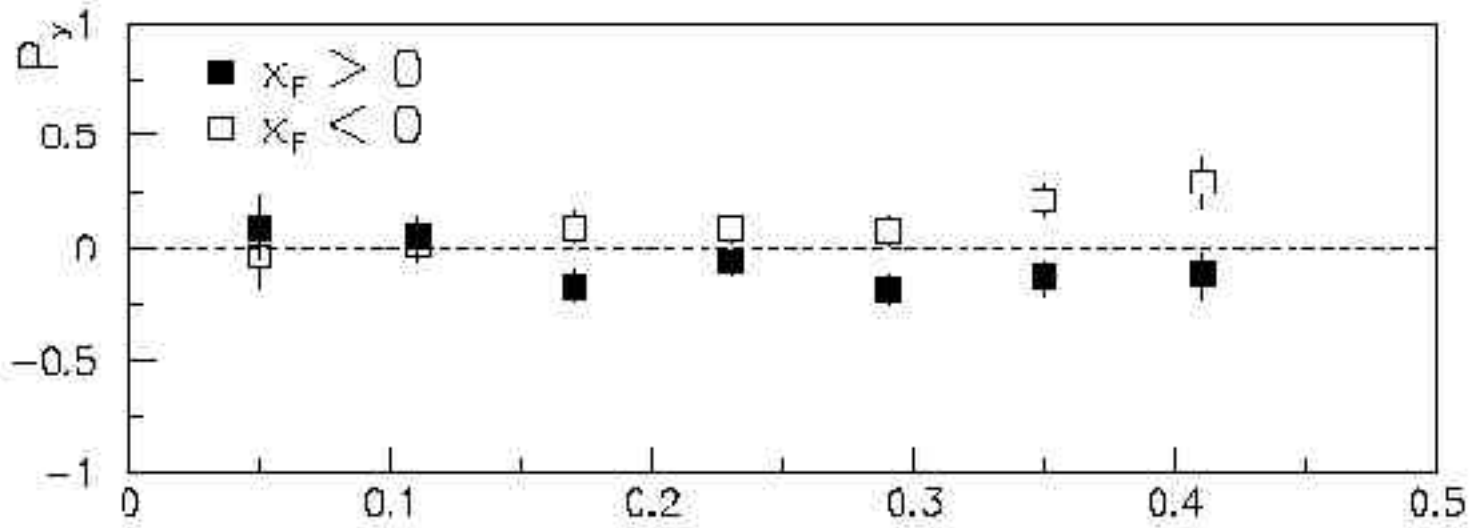


$p_{\text{beam}} = 2.85 \text{ GeV}/c$

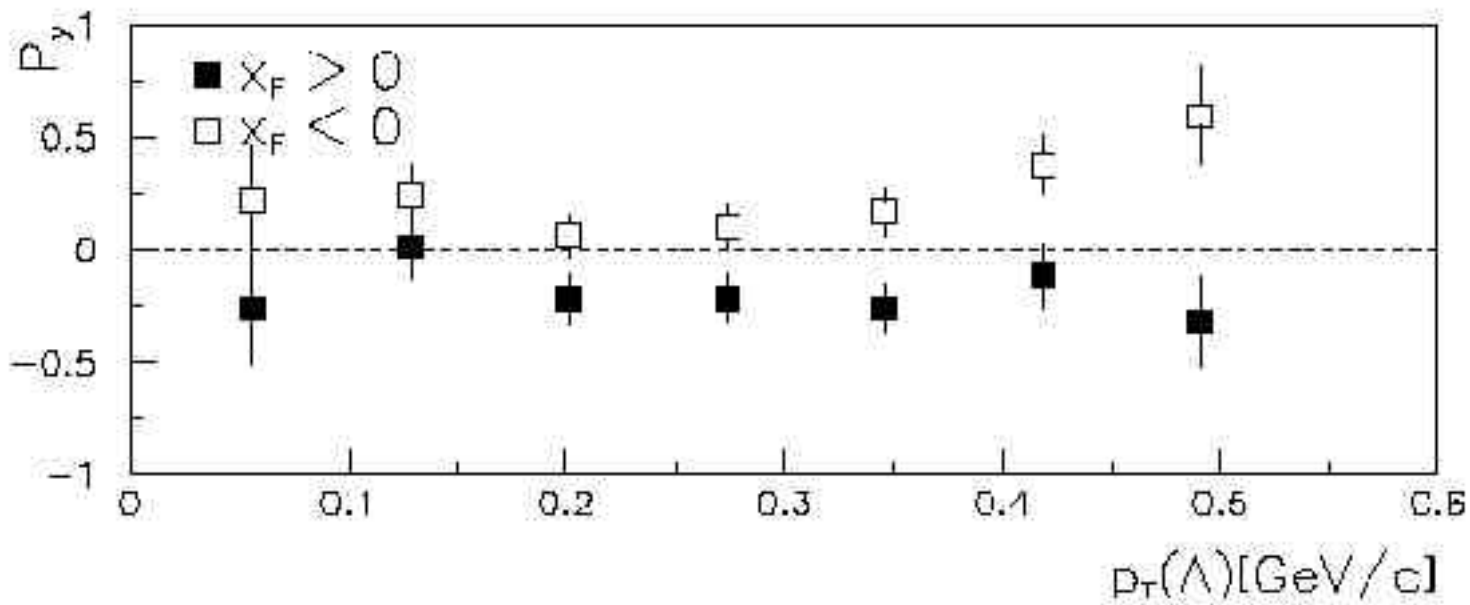
$2.95 \text{ GeV}/c$

$3.20 \text{ GeV}/c$

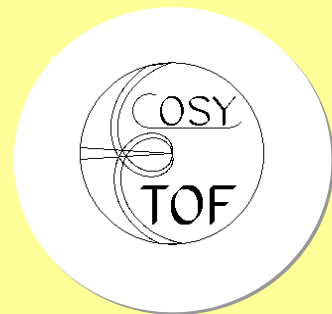




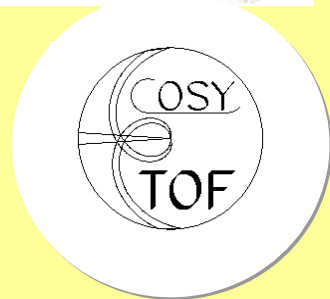
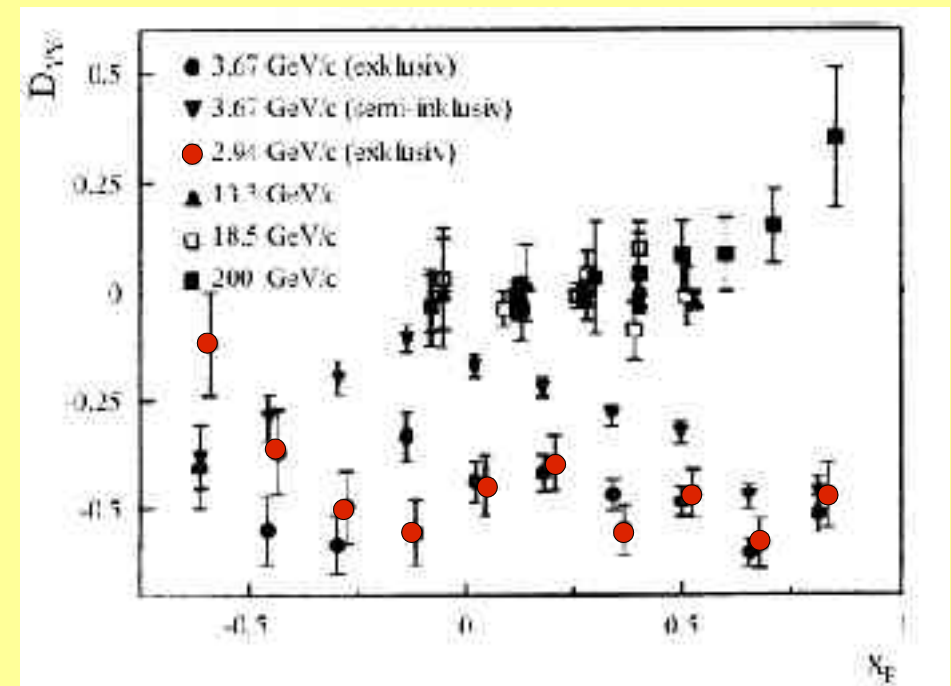
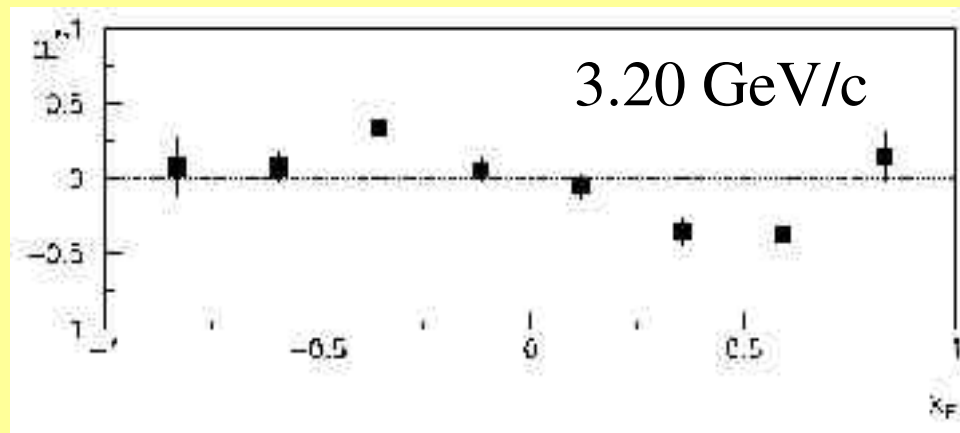
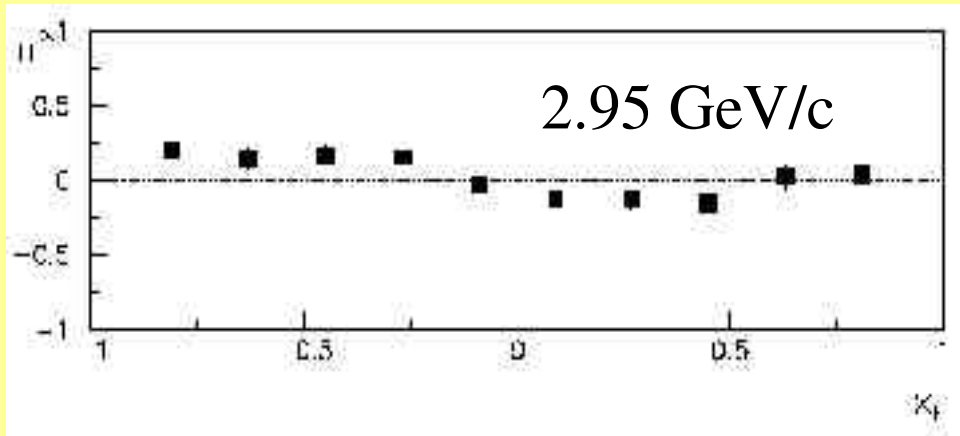
2.95 GeV/c

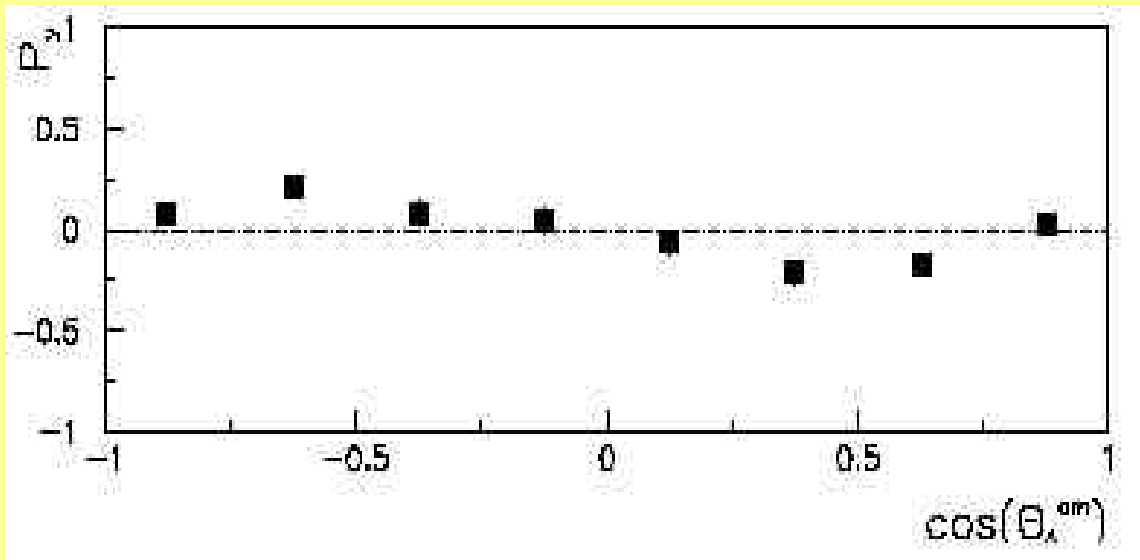


3.20 GeV/c

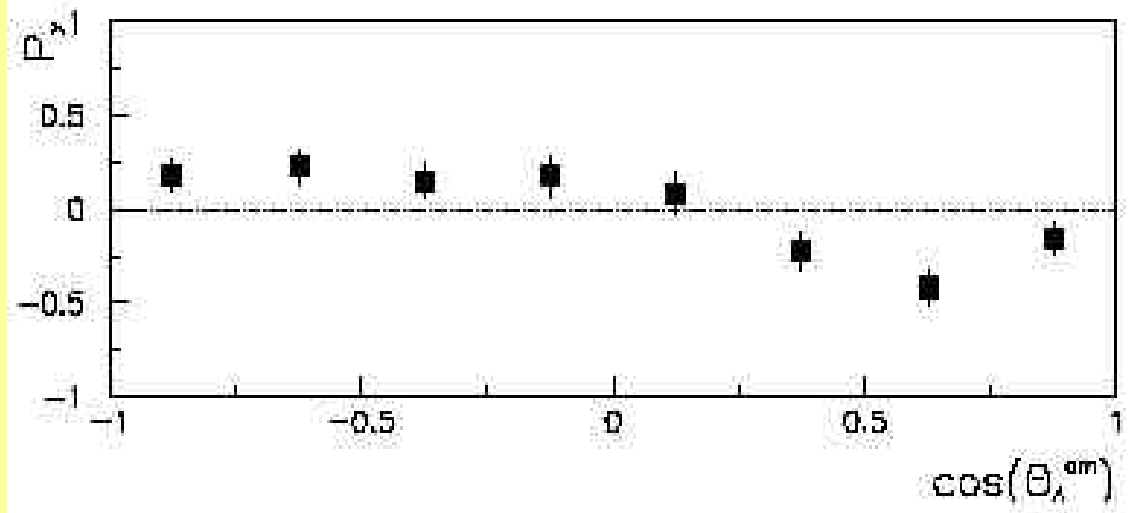


# Comparison with DISTO data @ 2.94 GeV/c

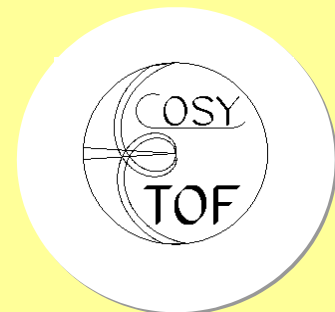




2.95 GeV/c

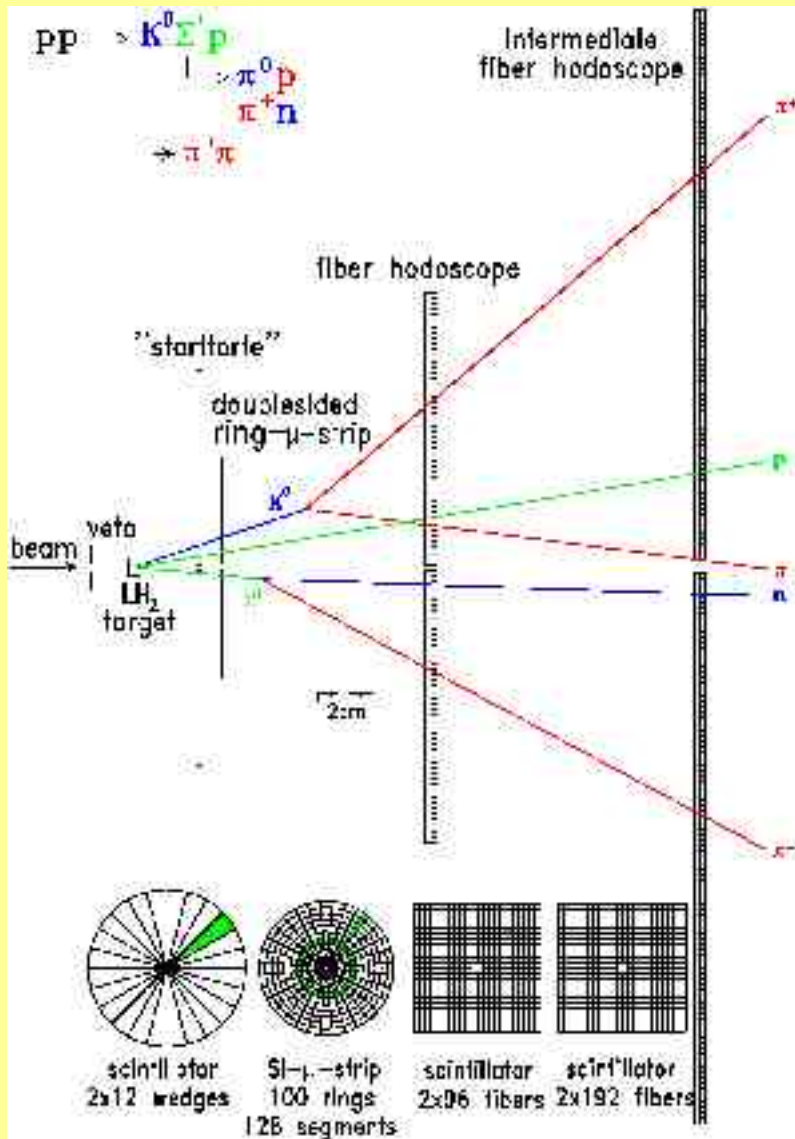


3.20 GeV/c





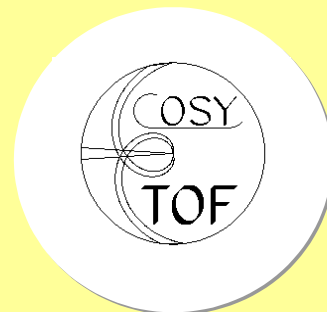
# The Measurement of the Reaction Channel $pp \rightarrow pK^0\Sigma^+$



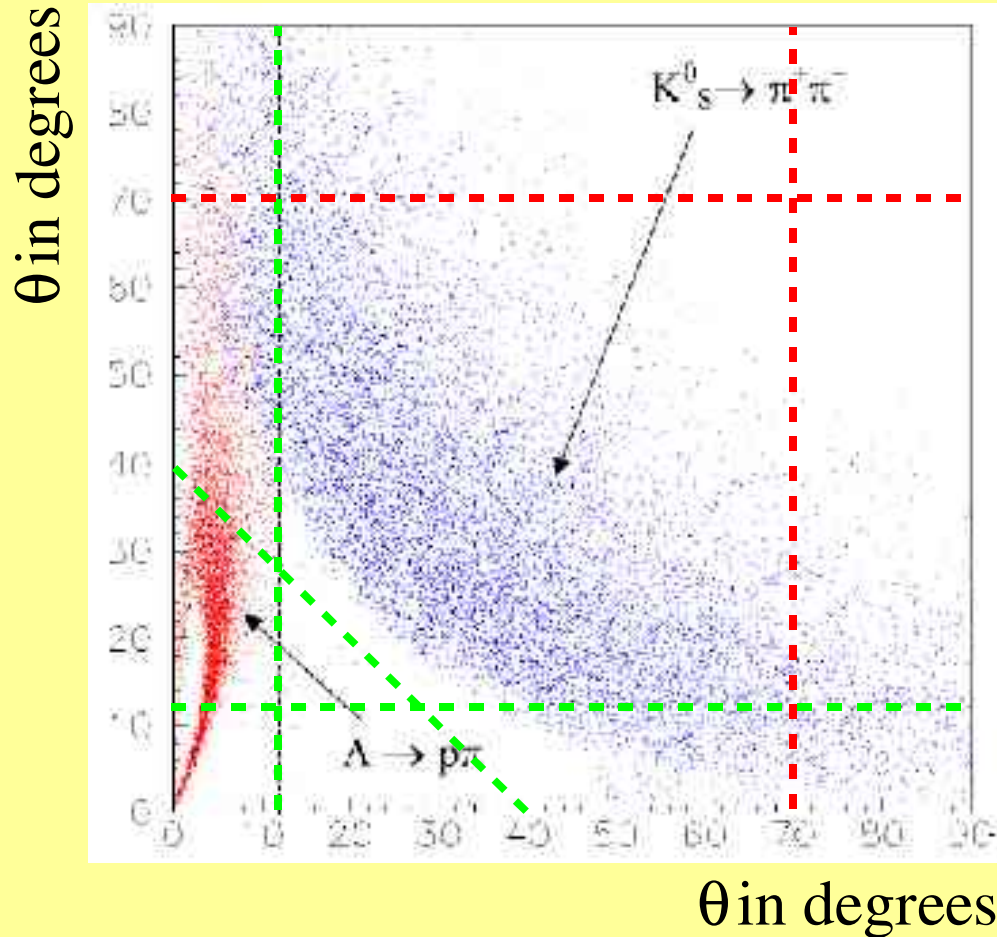
***Charged multiplicities***  
 **$2 \rightarrow 4$**

***$\Sigma^+$  with kink in primary track***

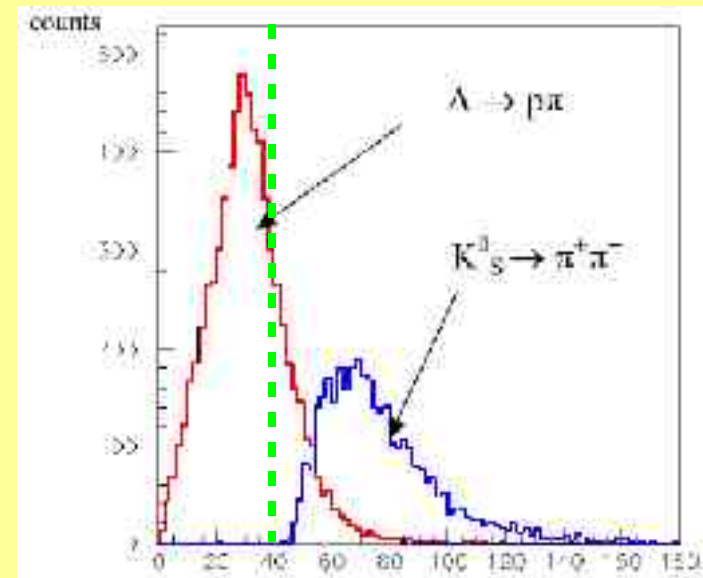
***identification of  $K^0_s$***



# The Measurement of the Reaction Channel $pp \rightarrow pK^0\Sigma^+$



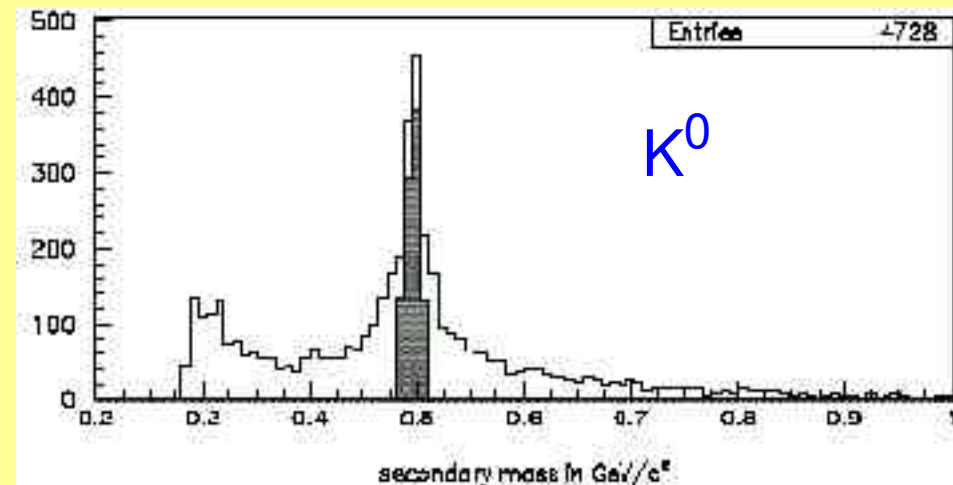
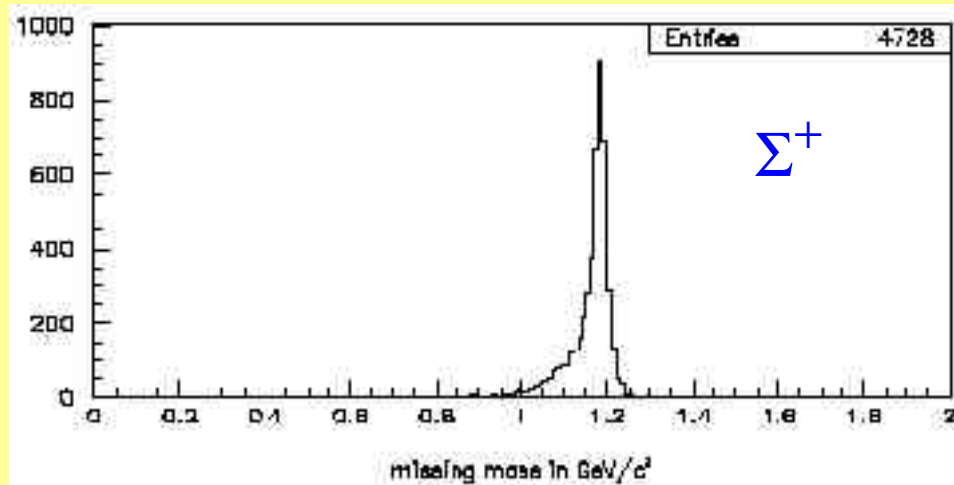
Separation of  $pp \rightarrow pK^0\Sigma^+$   
from background  $pp \rightarrow pK^+\Lambda$



- analysis cuts
- detector limits

$\theta$  in degrees

# Summarized Histogramms – Mass Cuts

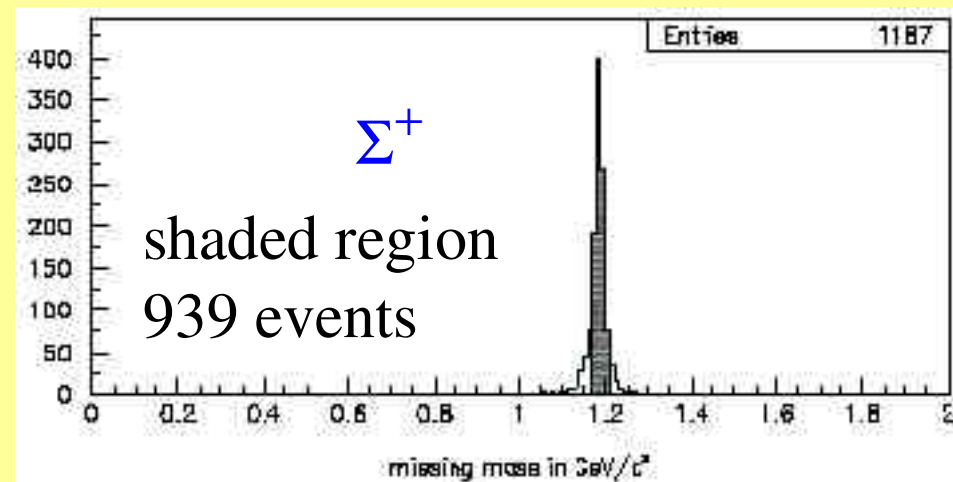


Jan. 2000

+

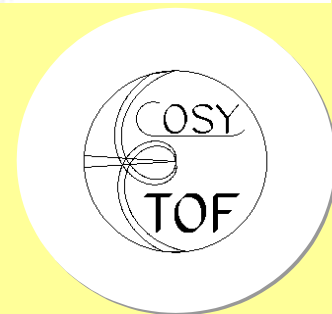
Oct. 2002

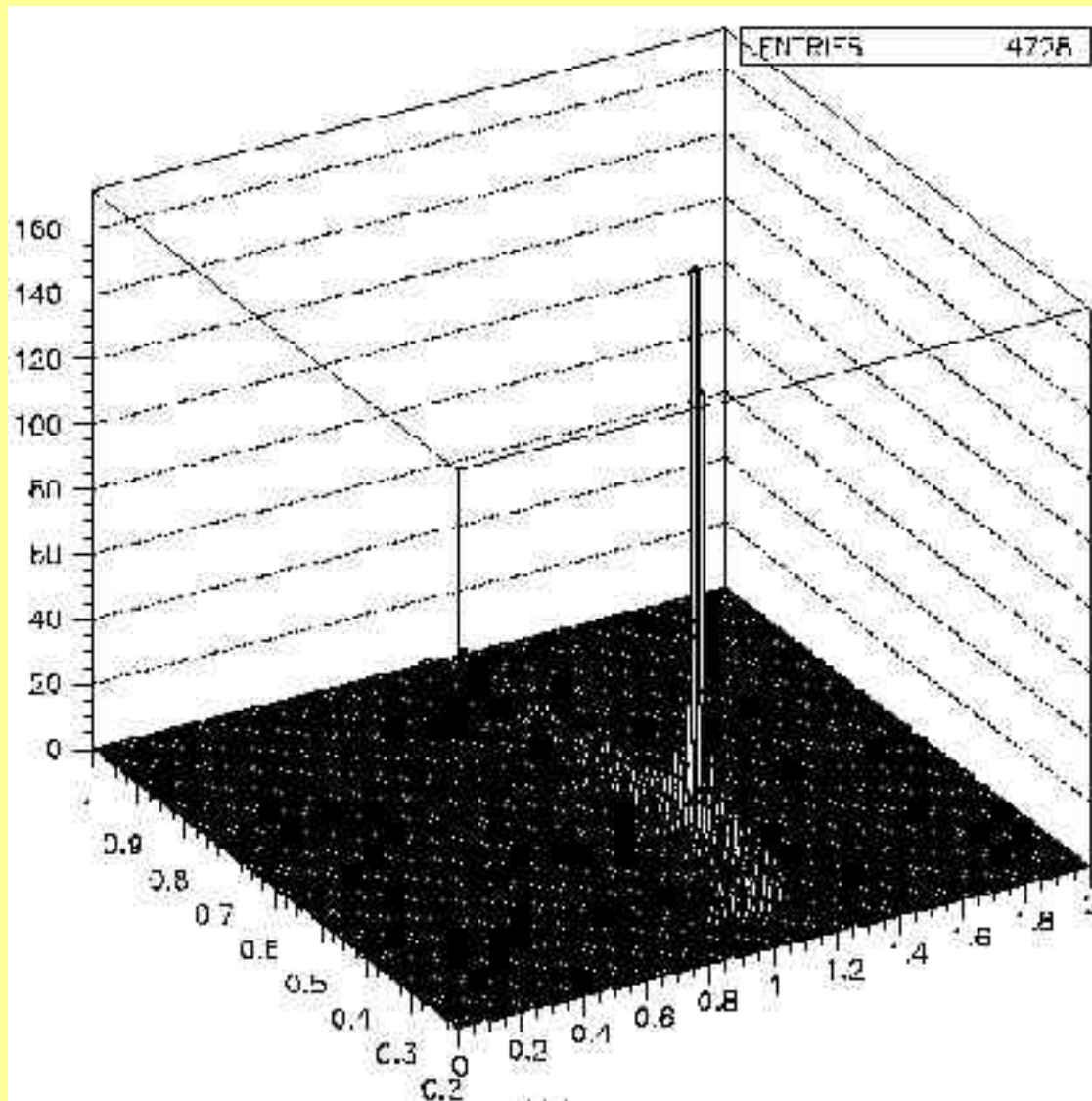
$$p_{\text{beam}} = 2.95 \text{ GeV}/c$$



COSY-TOF collaboration

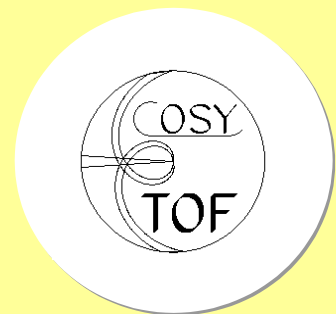
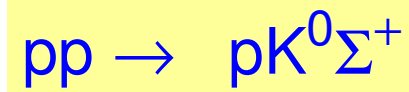
hep-ex/0403011 accepted for Phys. Lett. B





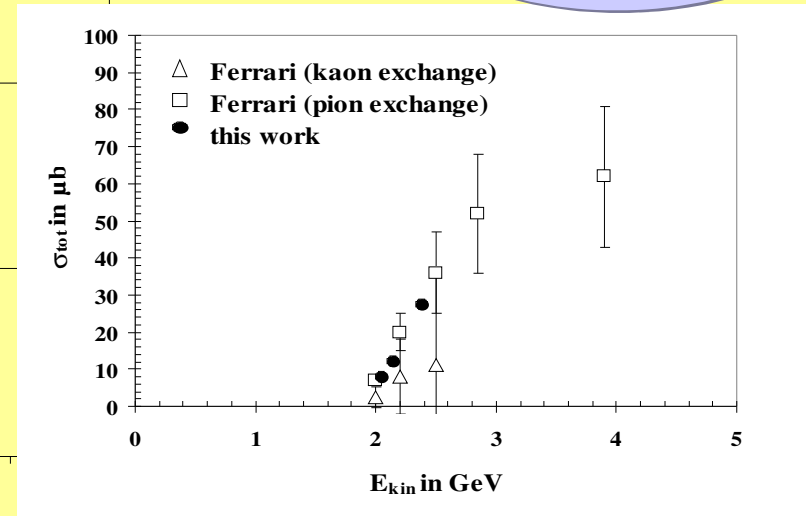
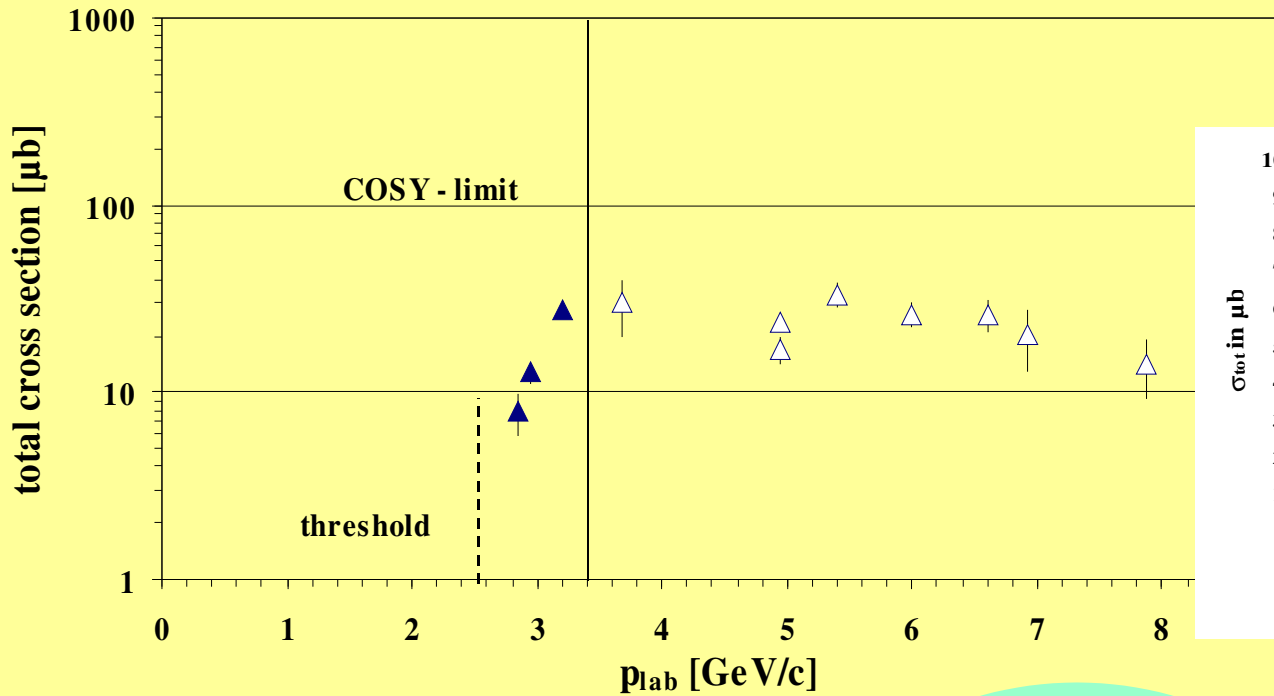
Reconstructed masses  
well correlated

$$p_{\text{beam}} = 2.95 \text{ GeV}/c$$



# $\sigma_{tot} pp \rightarrow K^0 \Sigma p$

E. Ferrari, Phys. Rev.  
Vol.120, No.3, 1960



$p_{Lab} = 2,85 \text{ GeV}/c$

( $\epsilon=93 \text{ MeV}$ ):

$\sigma_{tot} = 7,8 \mu\text{b}$

$\pm 1,6 \mu\text{b}$

$p_{Lab} = 2,95 \text{ GeV}/c$

( $\epsilon=126 \text{ MeV}$ ):

$\sigma_{tot} = 12,7 \mu\text{b}$

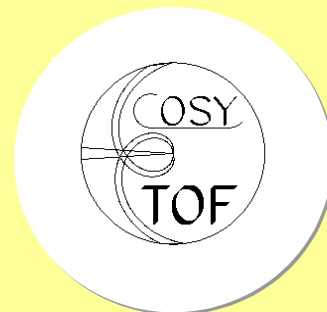
$\pm 1,3 \mu\text{b}$

$p_{Lab} = 3,2 \text{ GeV}/c$

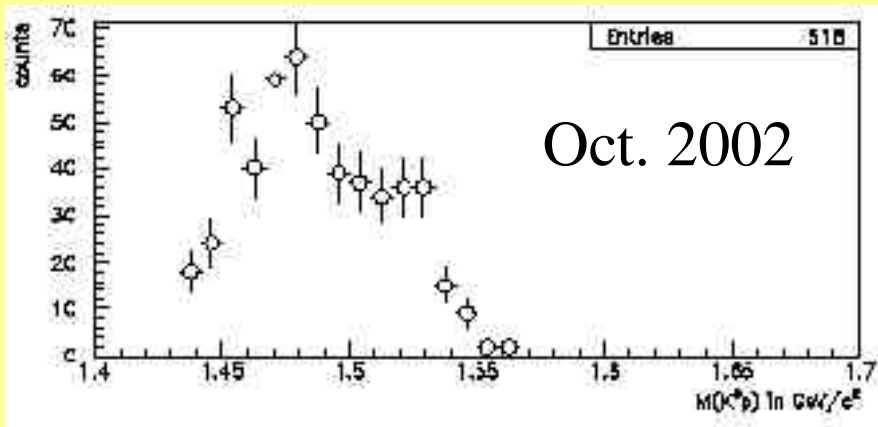
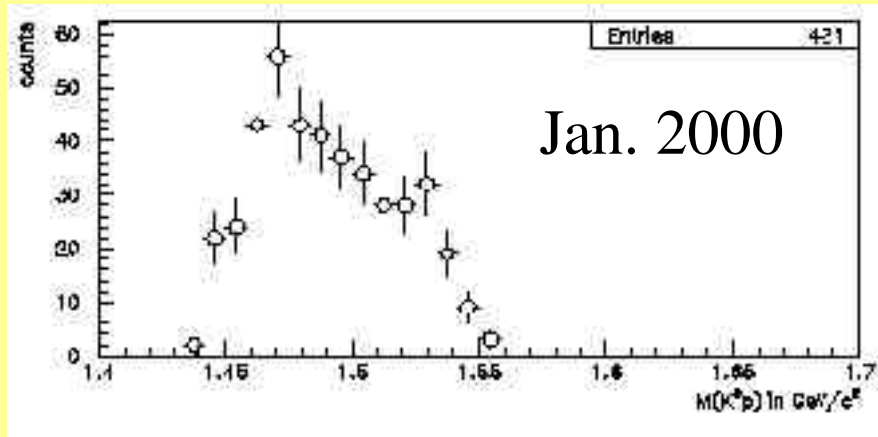
( $\epsilon=206 \text{ MeV}$ ):

$\sigma_{tot} = 27,2 \mu\text{b}$

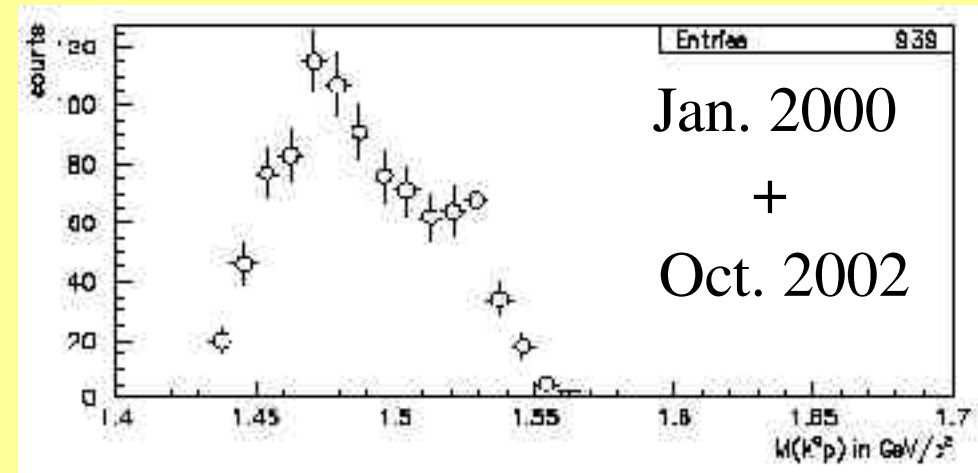
$\pm 2,5 \mu\text{b}$



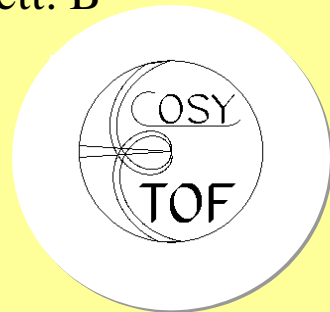
# Subsystem $K^0p$



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



COSY-TOF collaboration  
hep-ex/0403011 accepted for Phys. Lett. B



# K<sup>0</sup>p Invariant Mass Spectrum Efficiency Corrected



$p_{\text{beam}} = 2.95 \text{ GeV}/c$

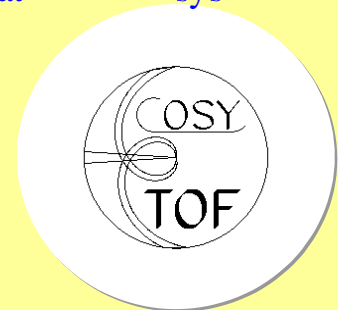
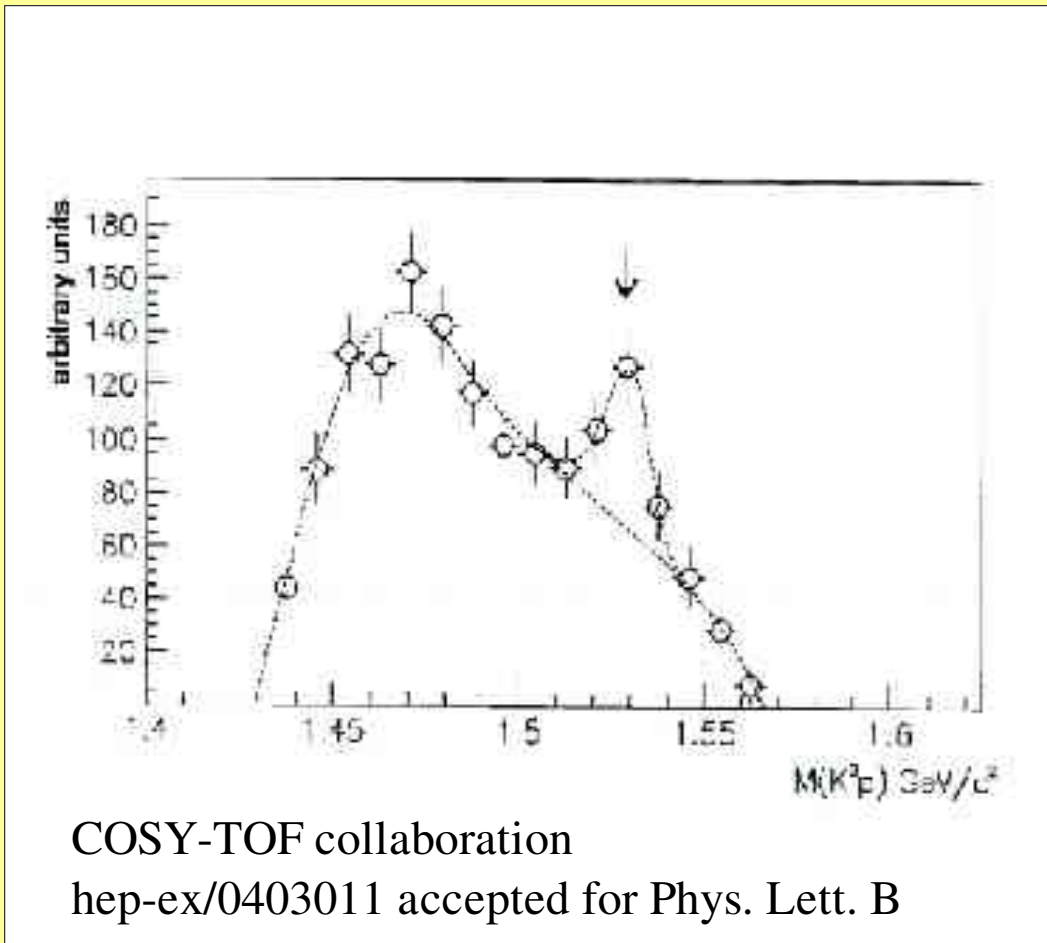
Mass  $1530 \pm 5 \text{ MeV}/c^2$   
 Width  $< 18 \text{ MeV}/c^2$  (FWHM)  
**significance: 4 – 6  $\sigma$**  (depending on method)

$N_S / \sqrt{N_B} \quad 5.9 \sigma$

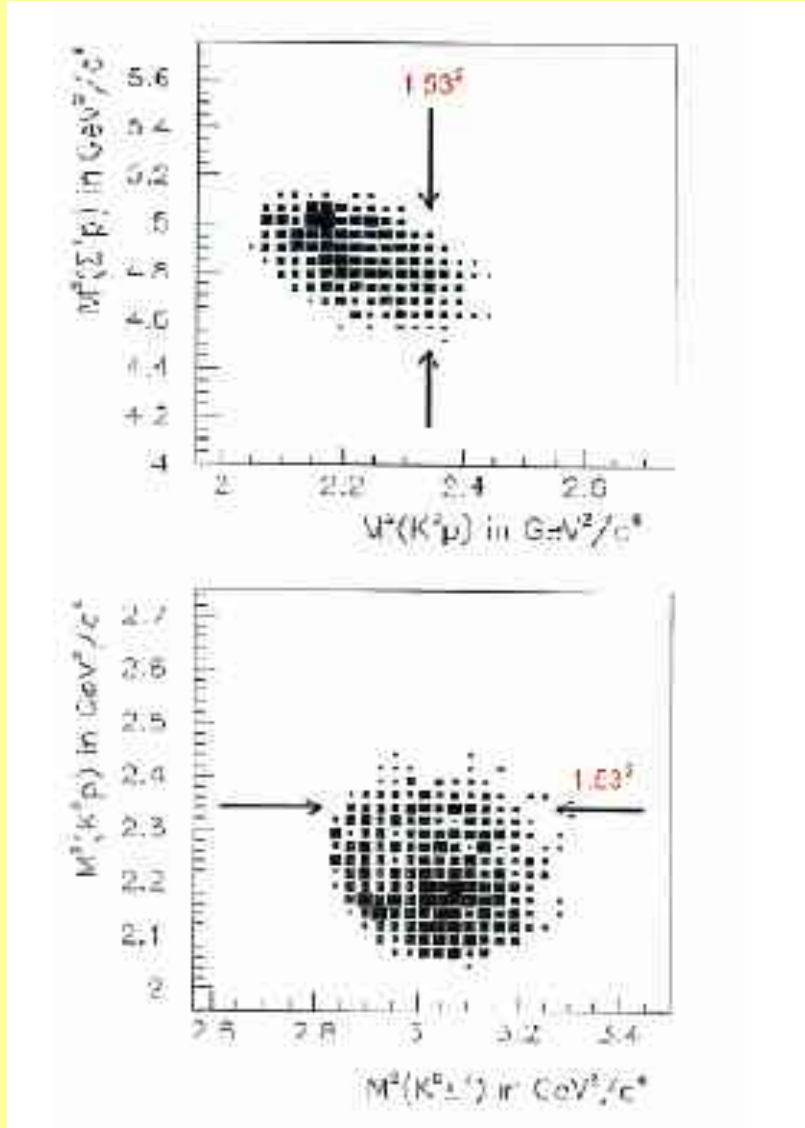
$N_S / \sqrt{N_S + N_B} \quad 4.7 \sigma$

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

**crosssection:  $0.4 \pm 0.1_{\text{stat}} \pm 0.1_{\text{sys}} \mu\text{b}$**

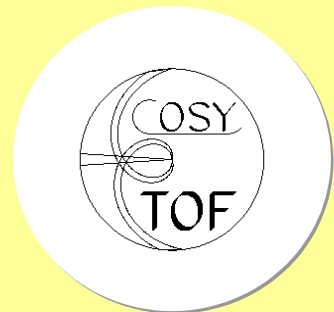


# Dalitz Distributions



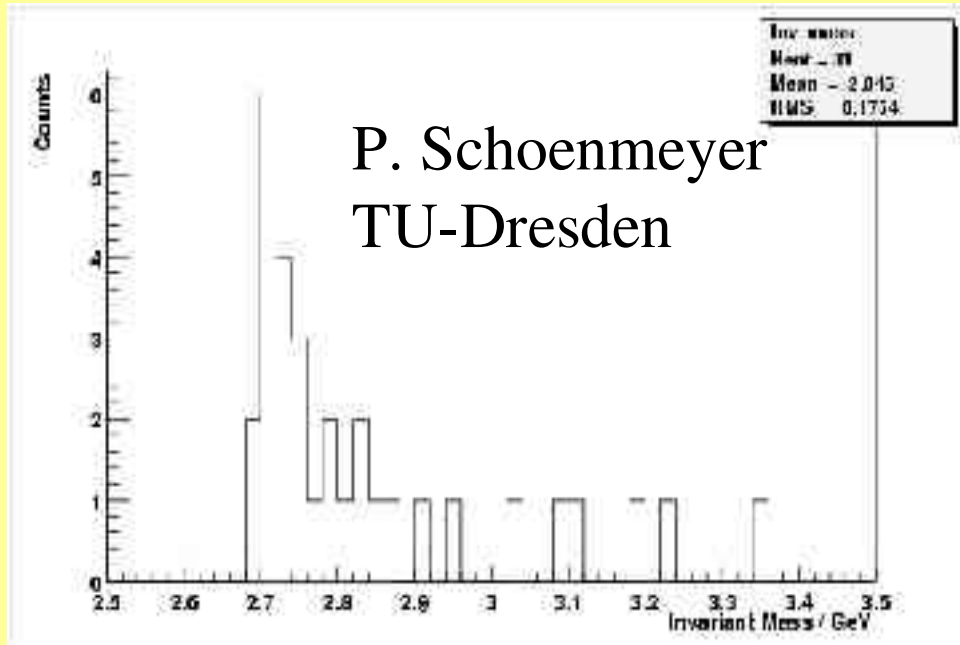
$$p_{\text{beam}} = 2.95 \text{ GeV}/c$$

COSY-TOF collaboration  
hep-ex/0403011 accepted for Phys. Lett. B





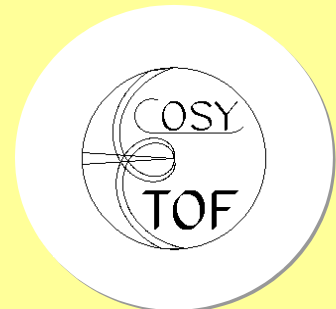
# Search for Pentaquarks in Other NN Induced Reaction Channels



$$p_{\text{beam}} = 2.85 \text{ GeV}/c$$

Search for possible isospin partners:  $pp \rightarrow \Sigma^- \theta^{+++}$   
 $\theta^{+++} \rightarrow \pi^+ \Delta^{++}$   
(weak decay)

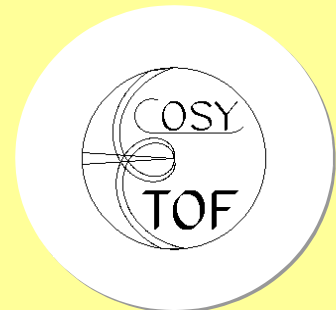
and  $pp \rightarrow \Lambda \Theta^{++} \rightarrow \Lambda p K^+$  (Capstick et. al.)



## Summary and Outlook

The reaction channel  $pp \rightarrow pK\Lambda$  has been measured exclusively in detail:

- total cross sections in threshold region
- $\Lambda$  polarization
- Reaction mechanism strongly  $N^*$  influenced
- Differential observables (not shown here)



## Summary and Outlook

### COSY-TOF

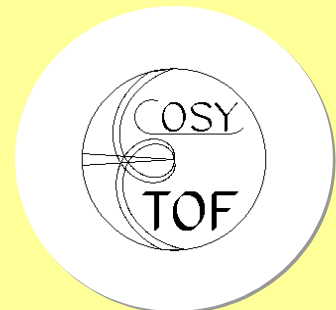
observed a **narrow resonance  $S=+1$**  in the  $K^0p$  invariant mass spectrum from the **exclusive measurement** of  $pp \rightarrow pK^0\Sigma^+$  at  $p_{\text{beam}} = 2.95 \text{ GeV}/c$ :

Mass  $1530 \pm 5 \text{ MeV}/c^2$

Width  $< 18 \text{ MeV}/c^2$  (FWHM)

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

**cross-section:  $0.4 \pm 0.1_{\text{stat}} \pm 0.1_{\text{sys}} \mu\text{b}$**



## Summary and Outlook

### In progress:

search for possible isospin partners  $\Theta^{++}$  and  $\Theta^{+++}$

### Future plans:

new measurement with LD2 target for pn induced reactions  
(pn  $\rightarrow$  pK<sup>0</sup> $\Lambda$ )

### Detector upgrade:

- (2004) third layer for fiber hodoscope
- (2005) additional tracker
- (2005) polarized target ( $\Theta^+$  parity)

