Caucasian-German School and Workshop

in Nuclear Physics,

Spin in Hadron Physics

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Status & Future Plans for COSY-TOF*

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

Content

- Introduction
- The COSY-TOF experiment
- Physics at COSY-TOF
- Future physics at COSY-TOF
- Summary
- Outlook

Introduction

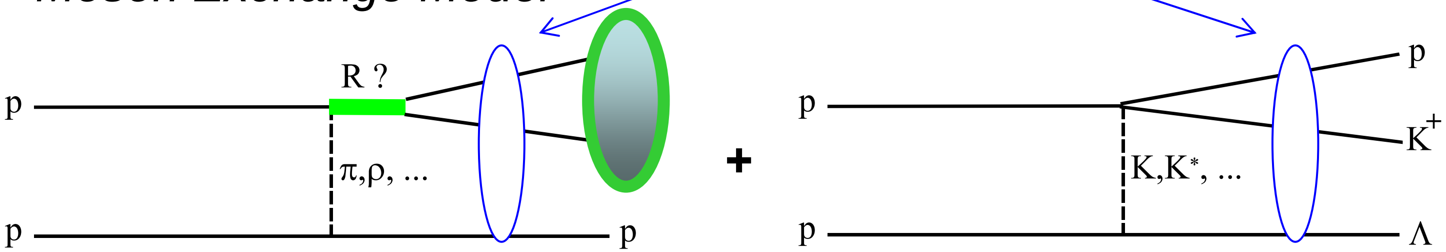
Information: **structure + dynamics** ⟶ **degrees of freedom**

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

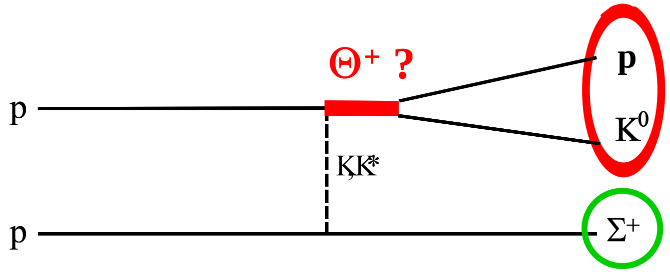
different reaction channels : N = p, n   Y = $\Lambda, \Sigma^0, \Sigma^+, \Sigma^-$

Meson Exchange Model

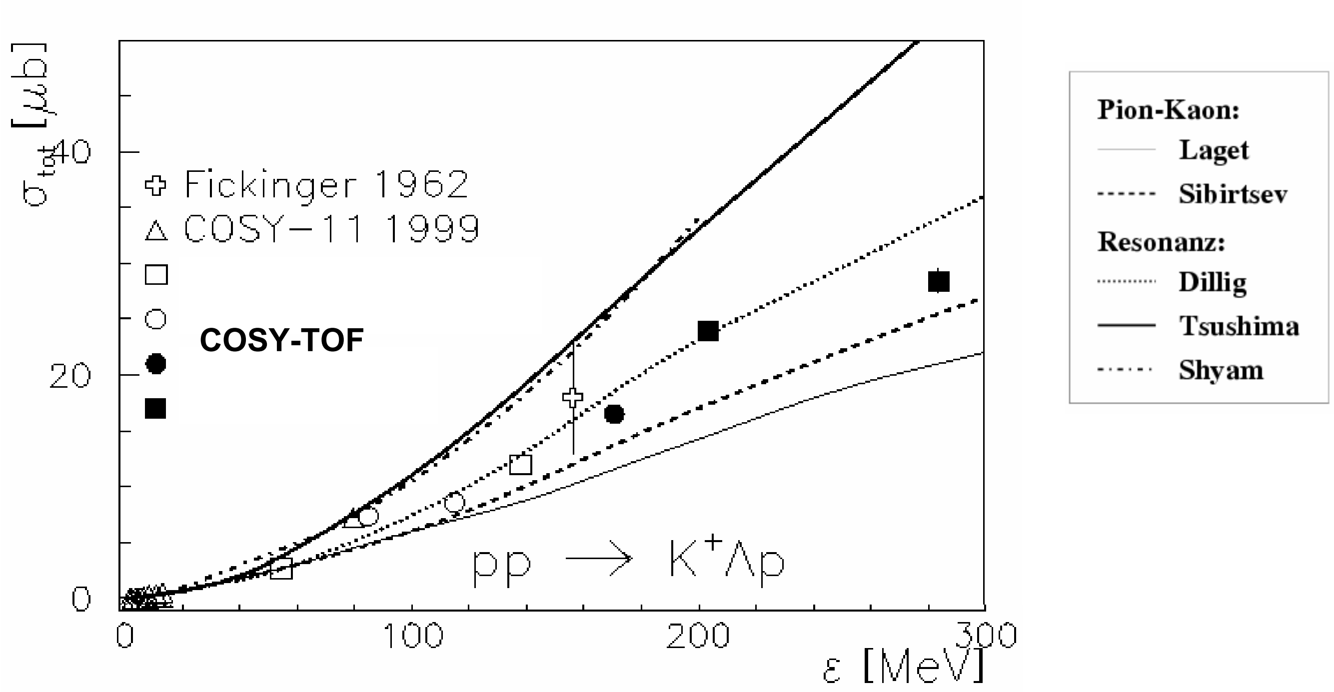
pΛ final state interaction



Search for exotic Θ^+ ⟷



Comparison of the calculations



No discrimination between models !!

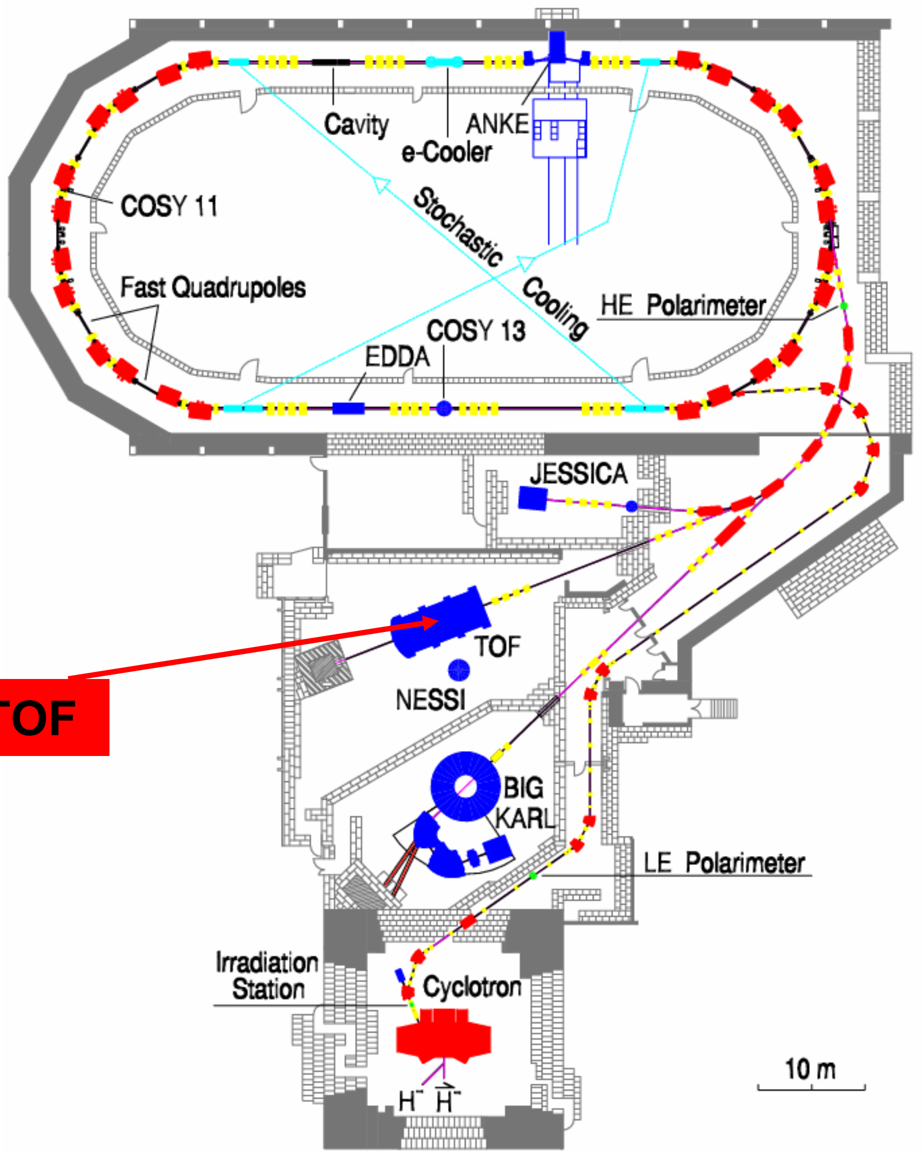
↳ **differential observables**

↳ **COSY-TOF** ↳ **Dalitz plot**

Strangeness̄ production at COSY-TOF

- exclusive observables
- threshold region → only few partial waves, no Y*
- full phase space → Dalitz Plots
- polarization: Λ-polarization, polarized beam, (polarized target)

COSY - Facility



TOF

Cooler Synchrotron Jülich

Circumference: 180 m

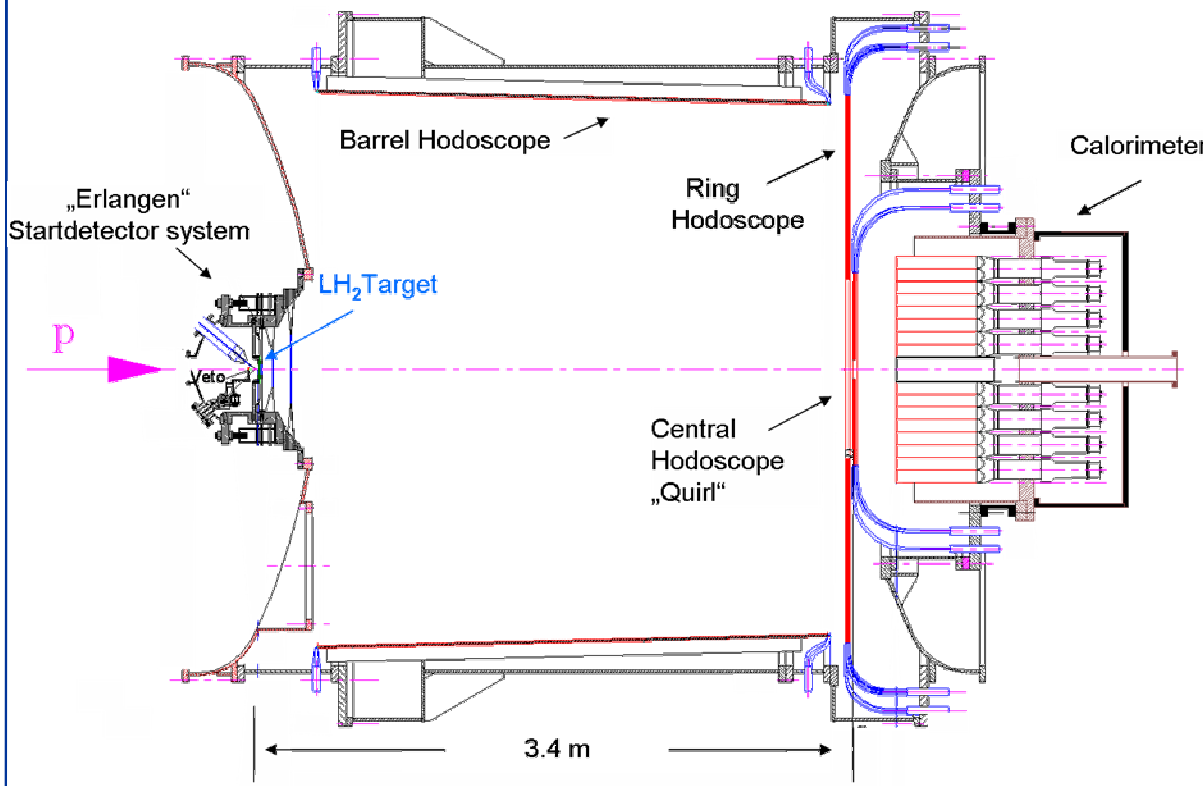
Phase space cooling: electron and stochastic

Beam momentum: maximum: 3.6 GeV/c

COSY-TOF - Detector

COSY - TOF - Detector

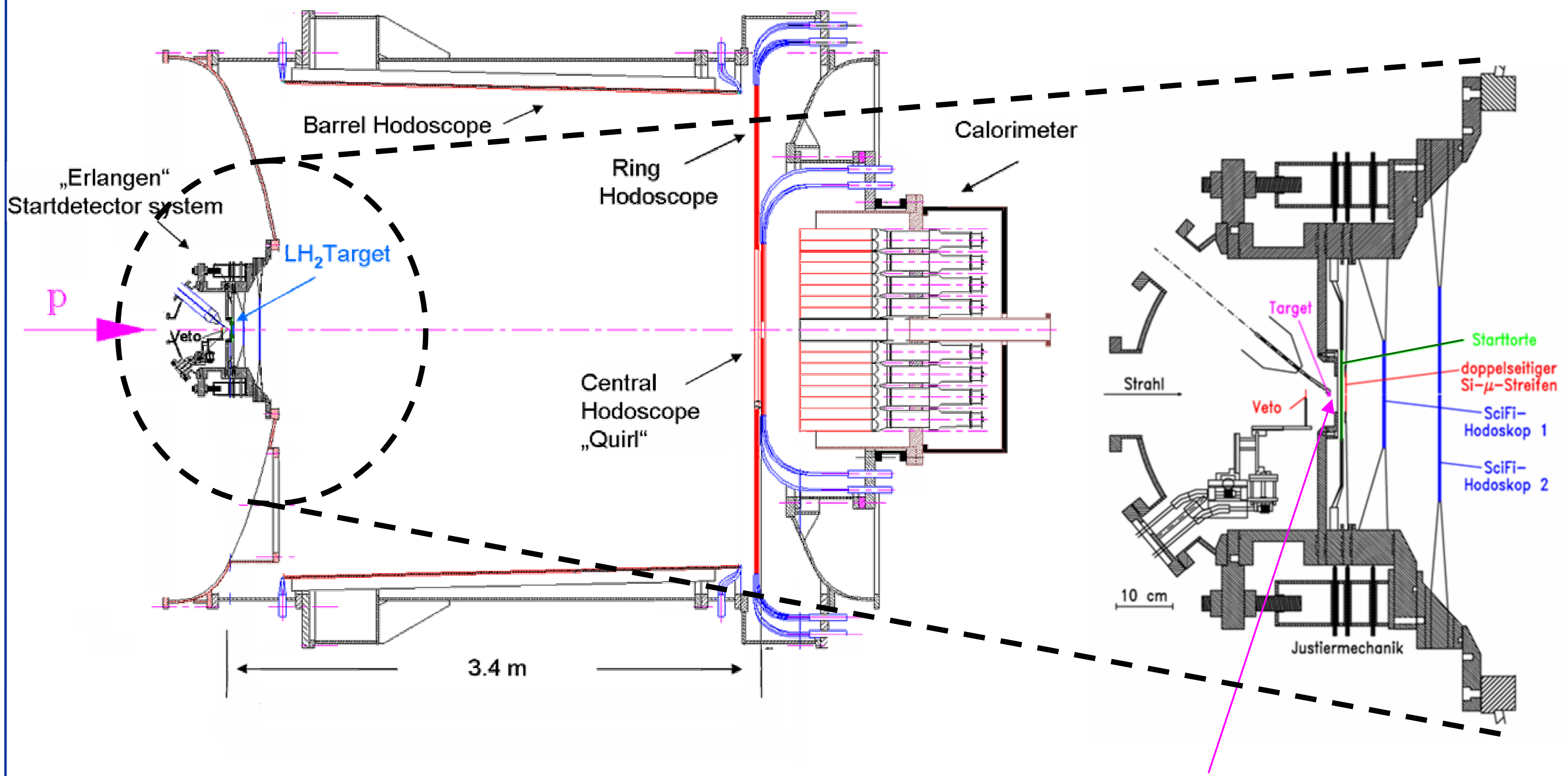
large angle (non magnetic) spectrometer with modular vacuum vessel



stop detector system

COSY - TOF

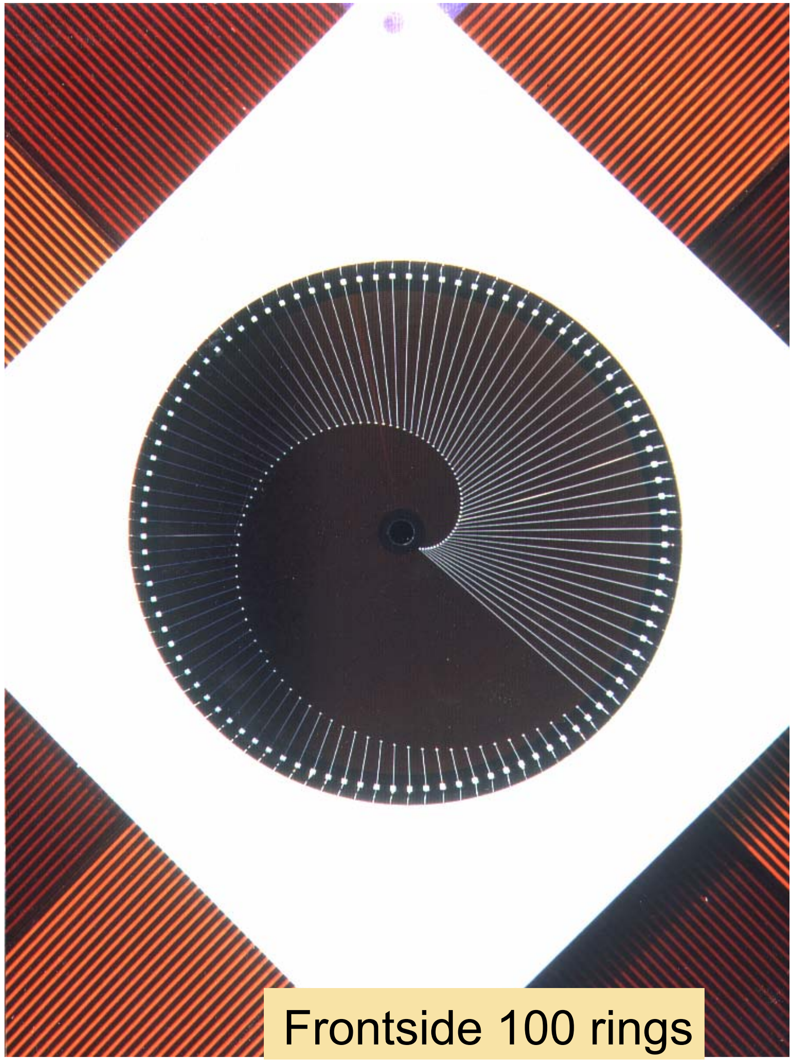
large angle (non magnetic) spectrometer with modular vacuum vessel

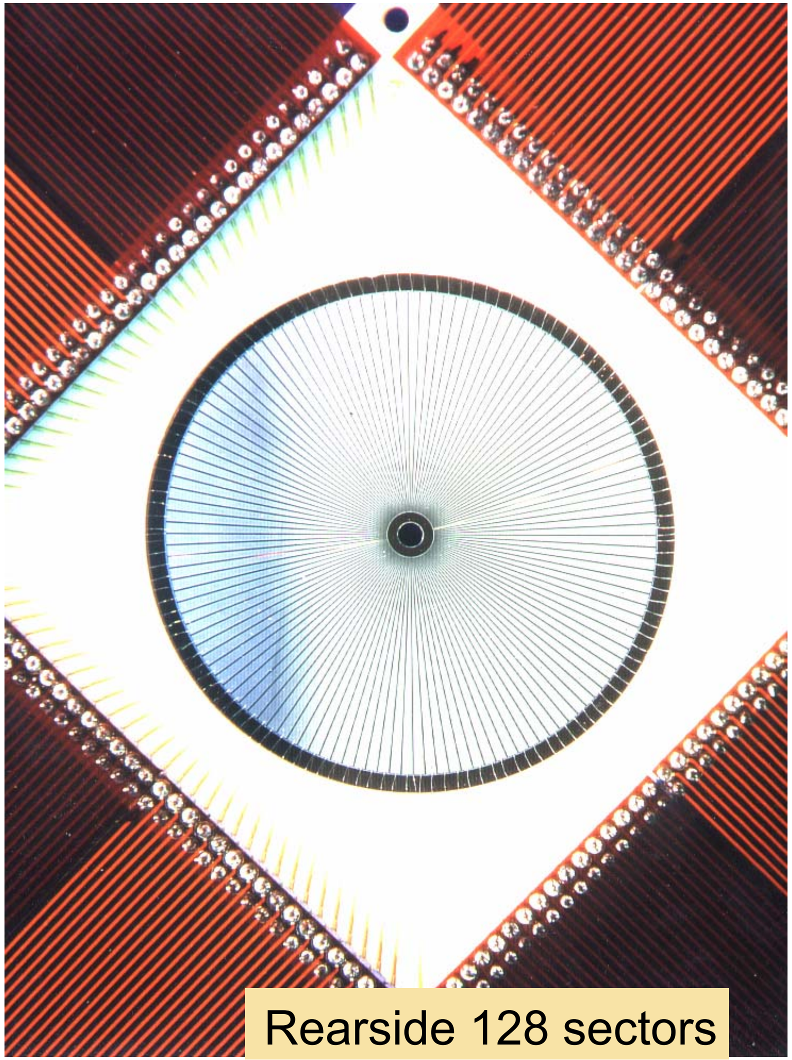


stop detector system

tiny liquid hydrogen target

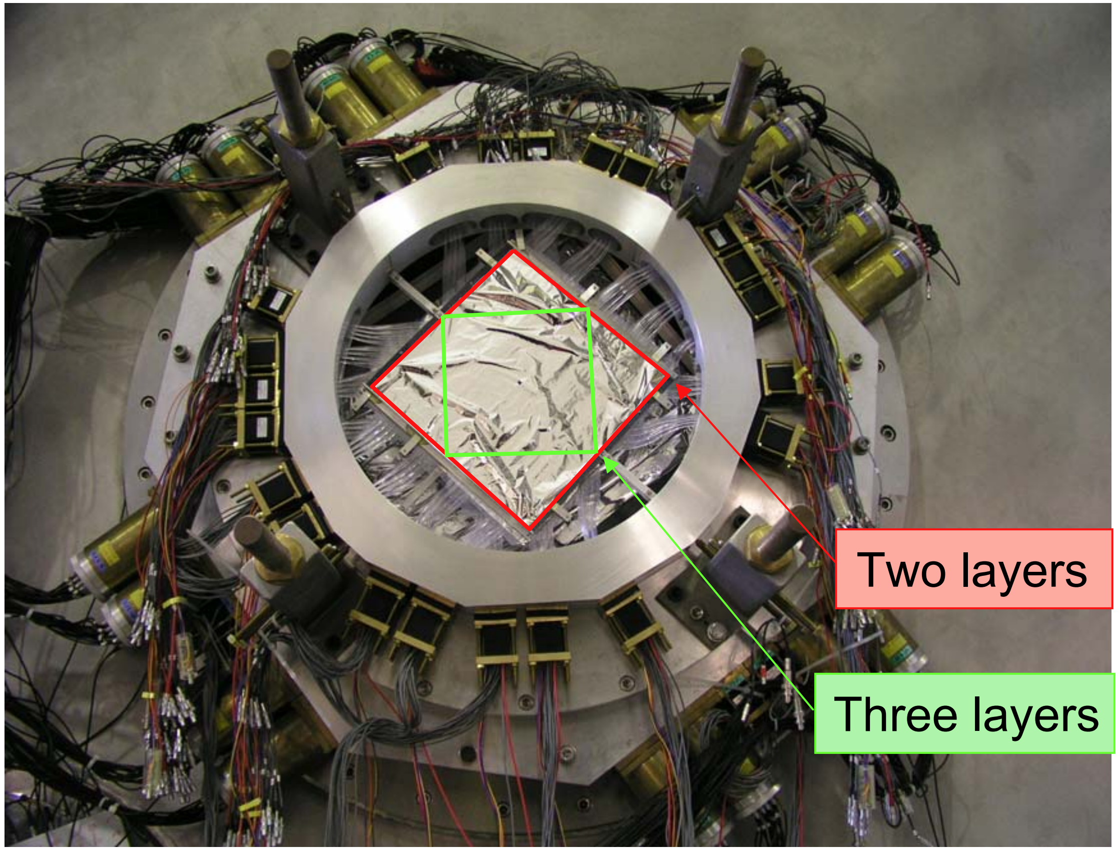
„Erlangen Start Detector“: Ring microstrip detector


Frontside 100 rings


Rearside 128 sectors

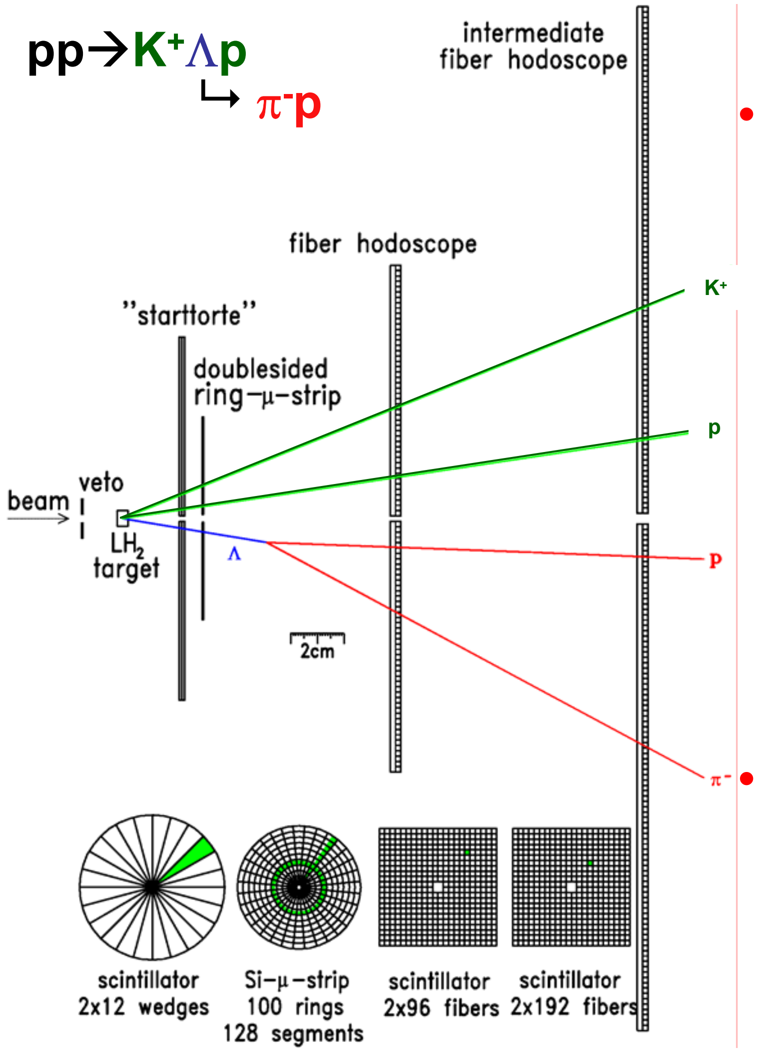
Experiment upgrade 2004

New fibre hodoscope with three layers



→ increase of efficiency and purity

Reaction pp → $K^+\Lambda p$



- Optimized for track- and vertex reconstruction
  - ↳ Starttorte
    doublesided Si-micro strip detector
    two fiber hodoscopes

complete geometric recon-struction of all charged particles

TimeOfFlight measurement

- Unique Strangeness-Trigger

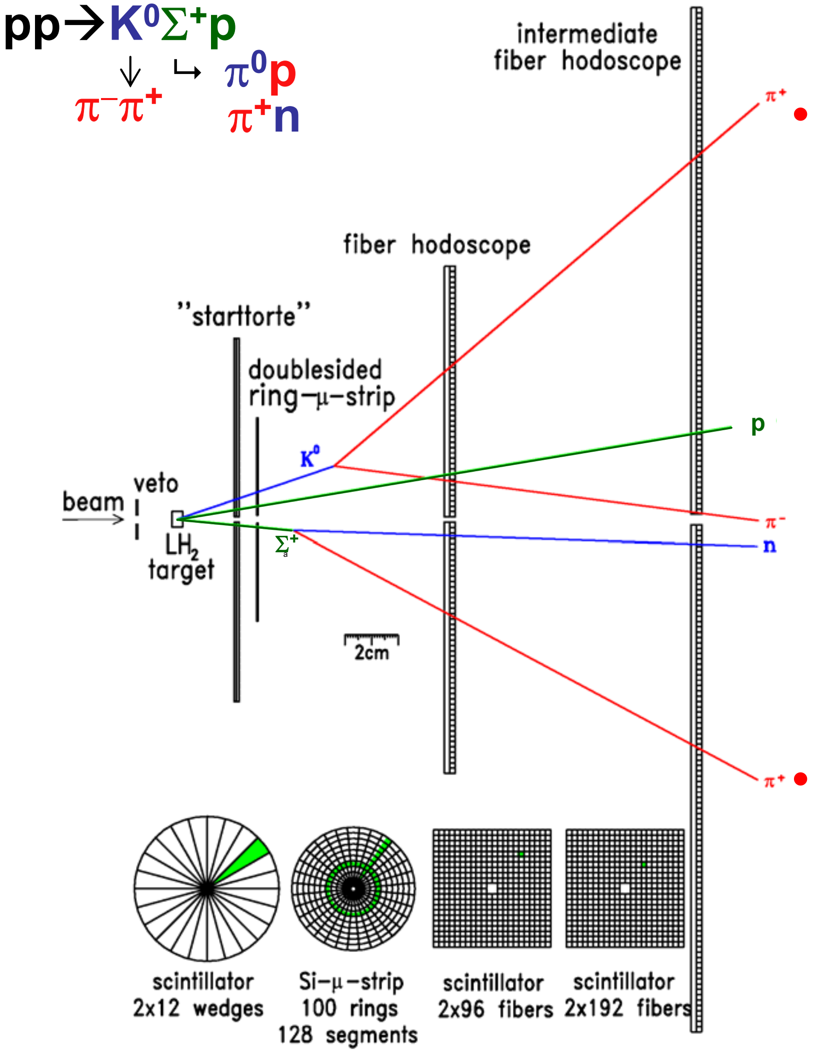
↳ increase of charged multiplicity:

2 → 4

for the reaction pp→$K^+\Lambda$p

$\Lambda \rightarrow \pi^-$p

Reaction pp → $K^0\Sigma^+p$



- Optimized for track- and vertex reconstruction
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TimeOfFlight measurement

- Unique Strangeness-Trigger

↳ increase of charged multiplicity:

2 → 4

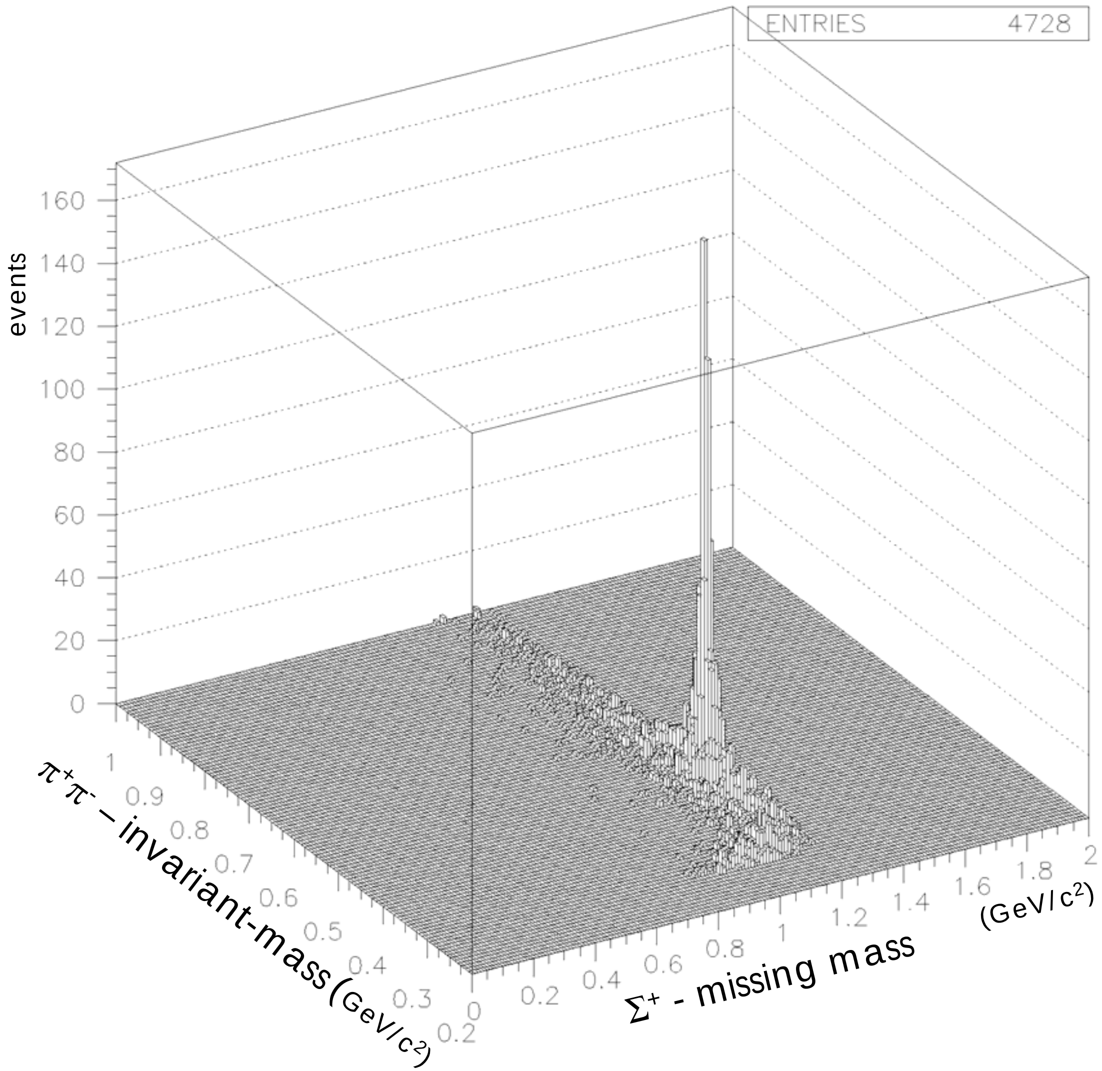
for the reaction pp→$K^0\Sigma^+p$

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

Physics at COSY-TOF

- **Strangeness Production in pp reaction**
  $pp \rightarrow K^0\Sigma^+p$,$pp \rightarrow K^+\Lambda p$
- Meson - Production in pp reaction (e.g. ω)
- ….

pp → Σ^+K^0p: reconstructed masses

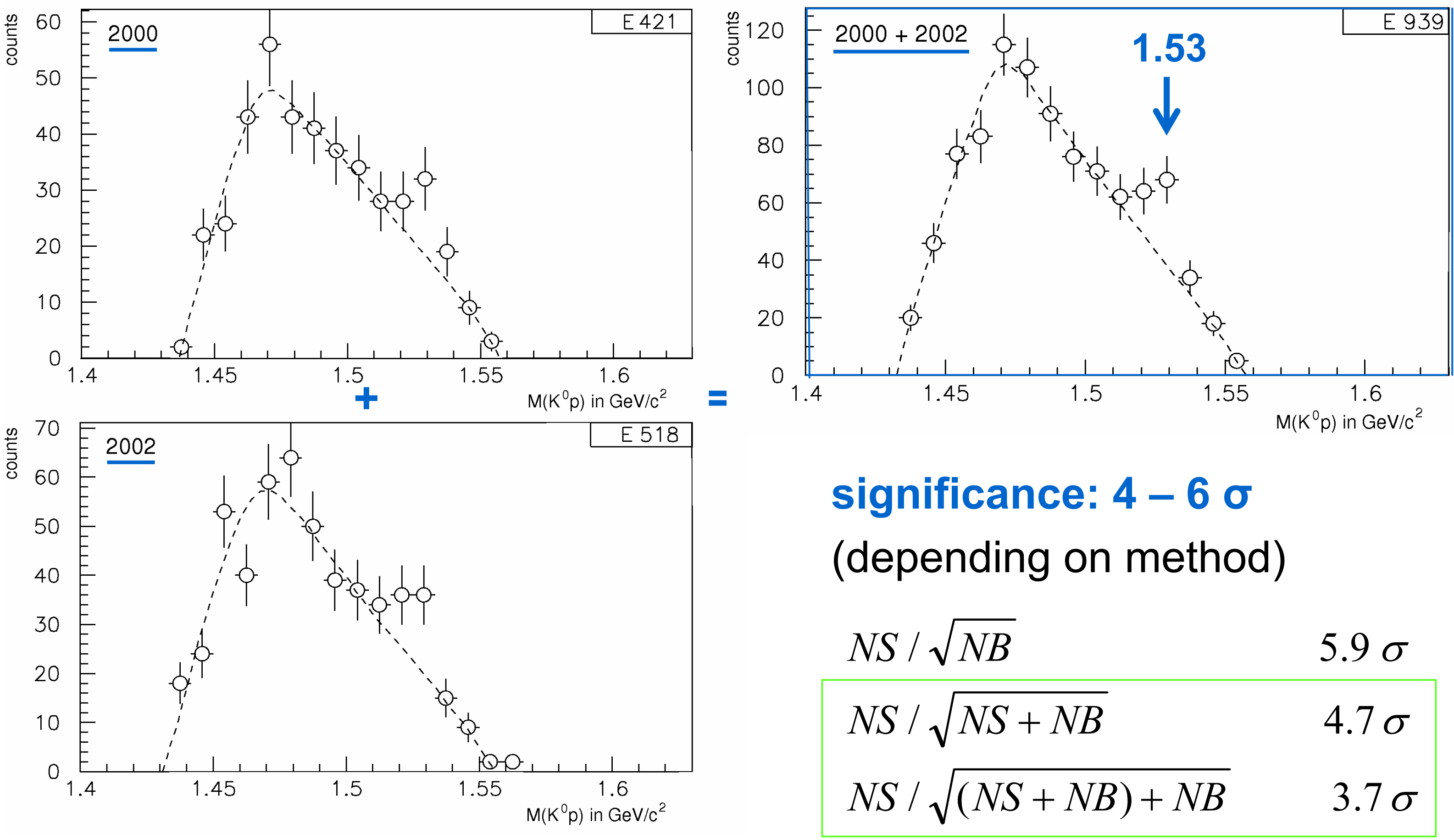


P_{beam} = 2.95 GeV/c

Runs 2000 + 2002

$pp \rightarrow \Sigma^+ K^0 p$: K^0p mass spectra

P_{beam} = 2.95 GeV/c



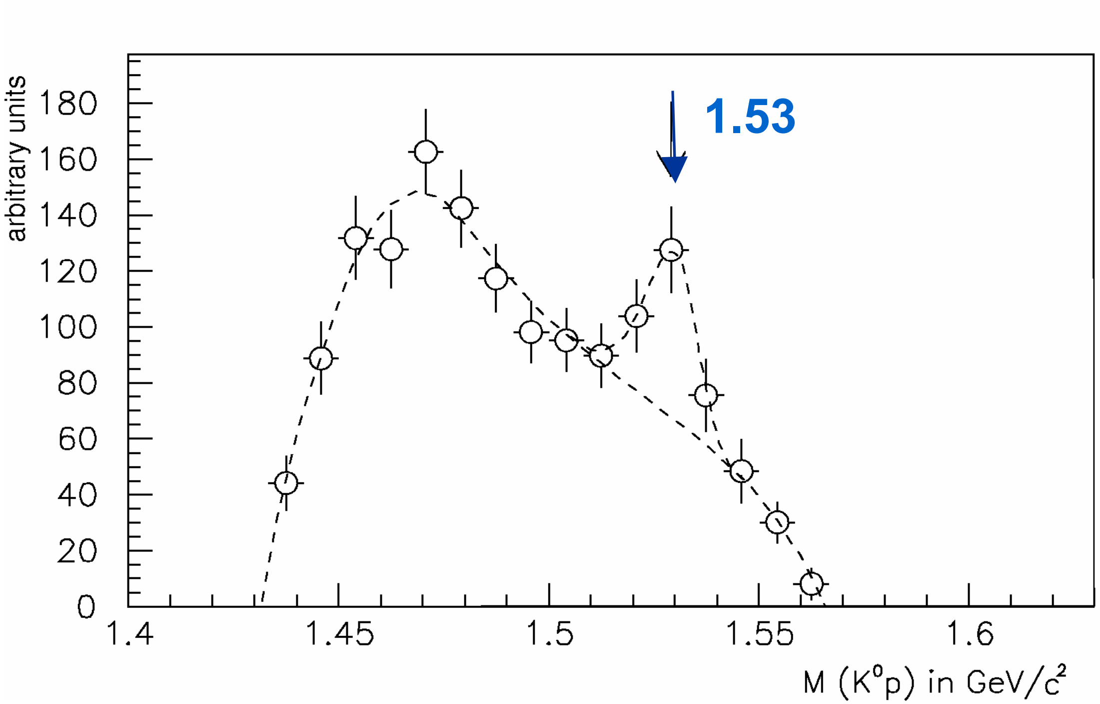
significance: 4 – 6 σ

(depending on method)

$NS / \sqrt{NB}$	$5.9\,\sigma$
$NS / \sqrt{NS + NB}$	$4.7\,\sigma$
$NS / \sqrt{(NS + NB) + NB}$	$3.7\,\sigma$

COSY TOF

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

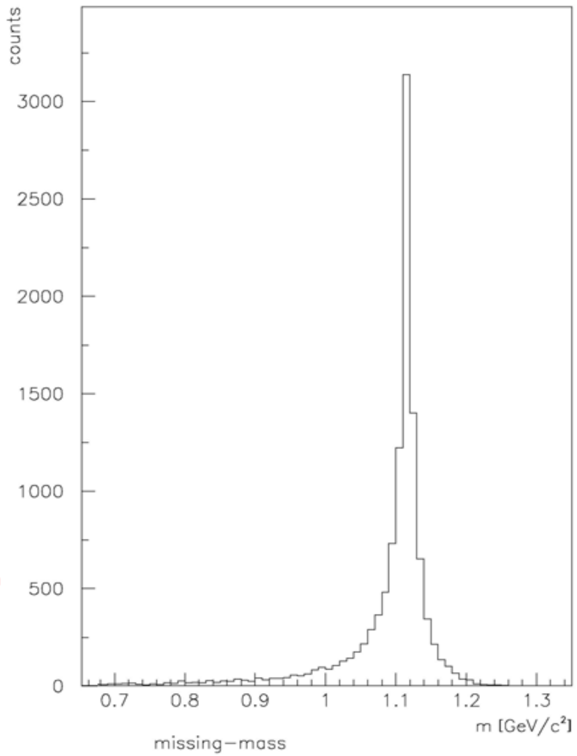


Mass 1530 ± 5 MeV/c²
Width ≤ 18 ± 4 MeV/c² (FWHM)
Strangeness S = + 1
Cross section: $0.4 \pm 0.1_{stat} \pm 0.1_{sys}$ µb

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

Measurement (Oct./Nov. 2004): $pp \rightarrow K^0 \Sigma^+ p$

- improved experimental setup
- 10^9 raw events taken to tape
- expect about factor 5 in pK_s events over published result
  (> 5000 pK_s events, 300 in peak if signal persists)
- analysis ongoing and improved with respect to
  - blind analysis: ½ of the data to optimize analysis, rest for result
  - independent analysis at several institutes in parallel with different codes, emphasis on different detector aspects
  - systematics of Monte-Carlo treatment
  - use of redundant information (ToF of proton and pions, energy losses, ...)
  - common calibration database

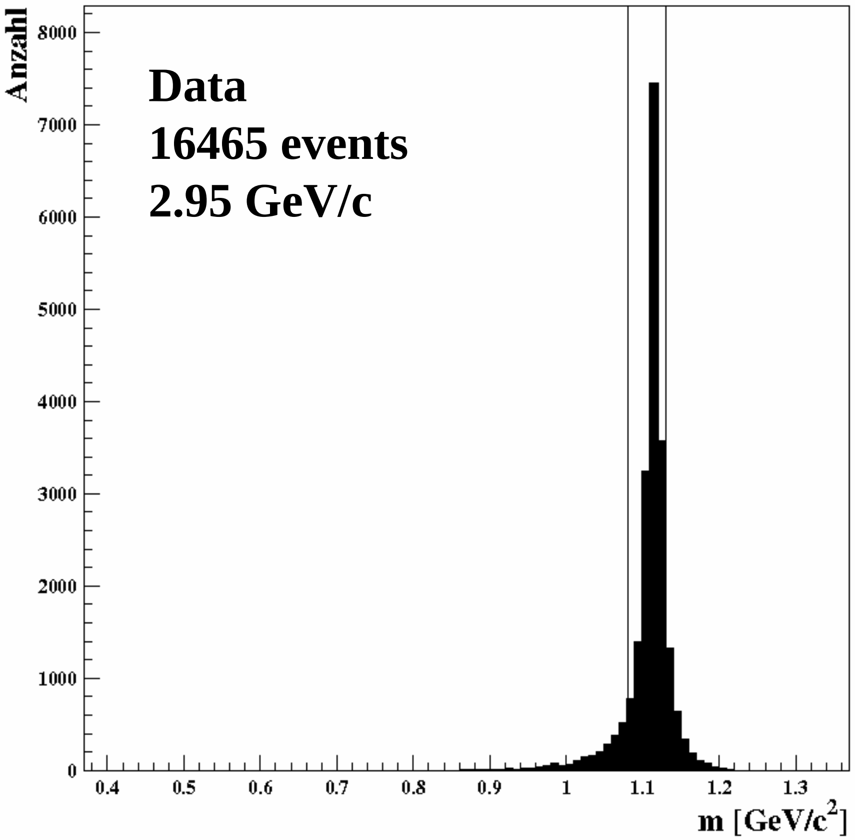


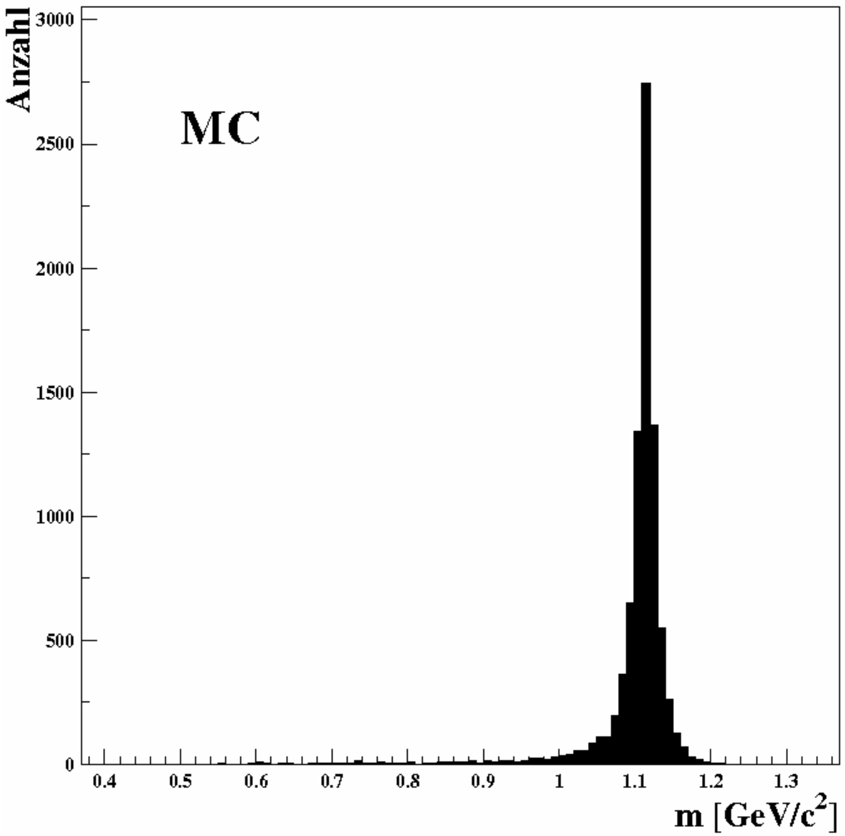
Subsample of $pp \rightarrow \Lambda K^+ p$:

0.7% of data

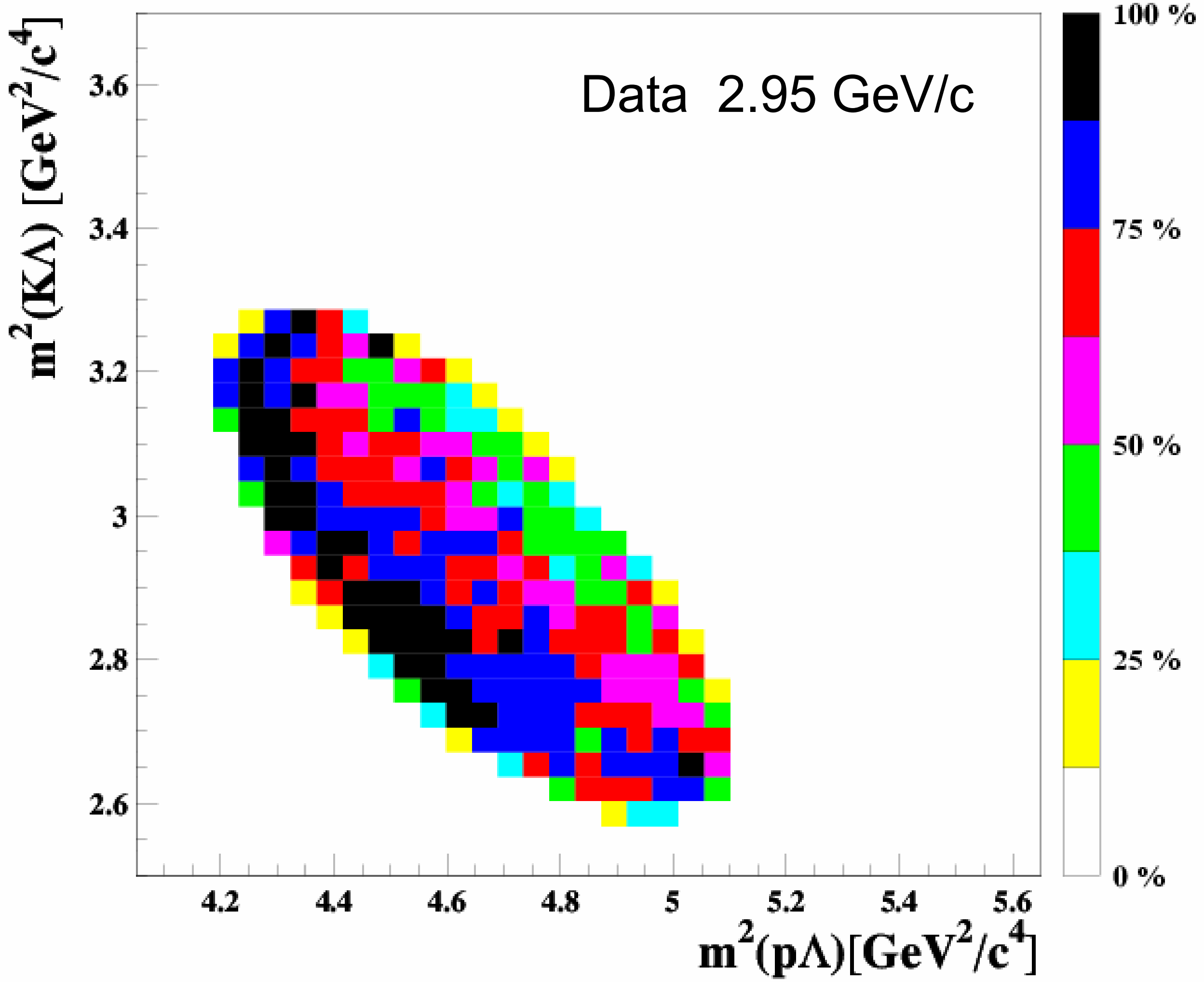
pp → $K^+\Lambda p$: Reconstruction of Λ events

Beam momentum: 2.95 / 3.20 / 3.30 GeV/c





pp → $K^+\Lambda p$: Dalitz plot analysis



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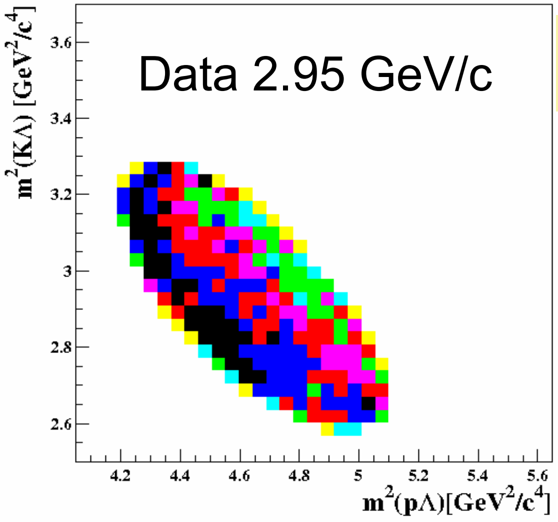

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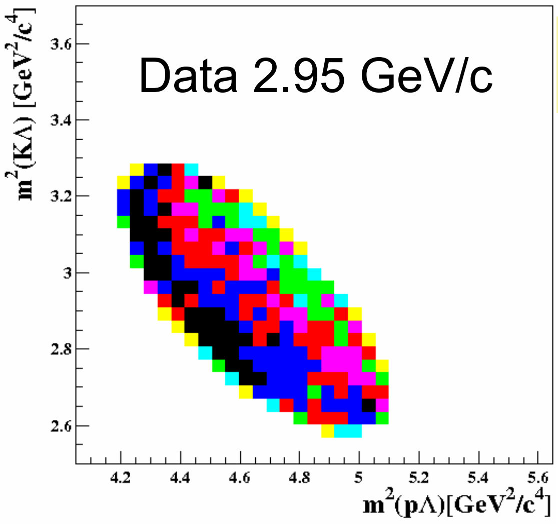
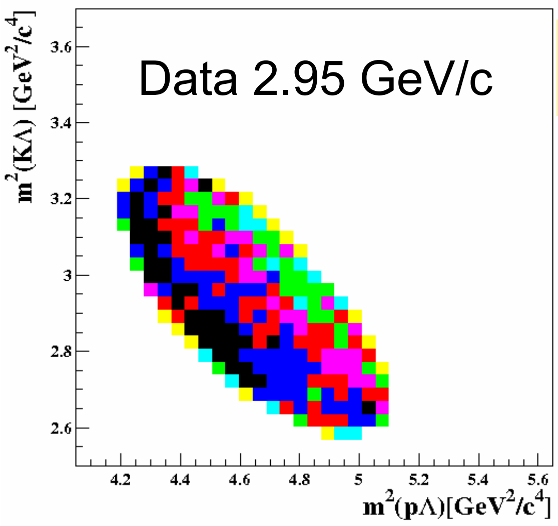


Model calculation of Sibirtsev

$$\frac{d^2\sigma}{dm_{K\Lambda}^2 dm_{p\Lambda}^2} = (flux)\cdot\left|\left(\sum_R (C_R \cdot A_R) + C_N\right)\cdot(1 + C_{FSI}\cdot A_{FSI})\right|^2$$

pp → K⁺Λp: Dalitz plot analysis



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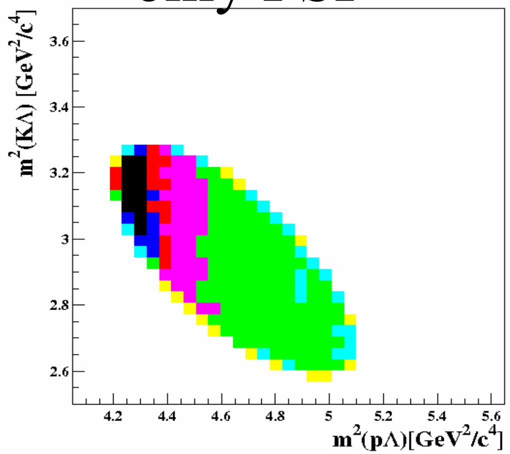
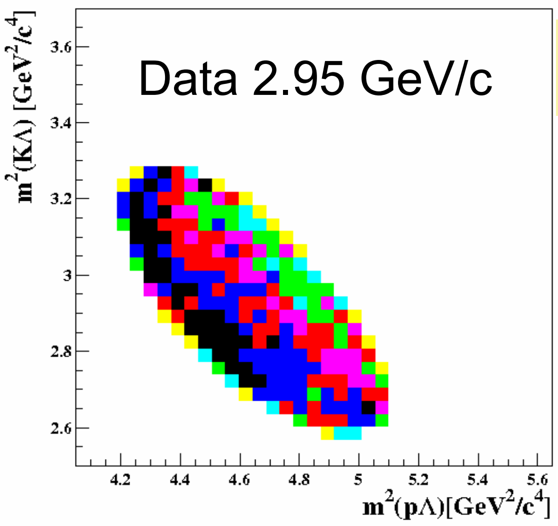
only FSI



pp → $K^+\Lambda p$: Dalitz plot analysis



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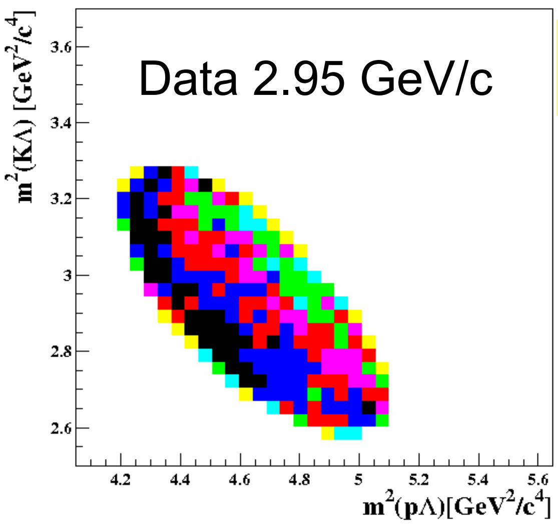
included resonances:

N*(1650)

N*(1710)

N*(1720)

pp → $K^+\Lambda p$: Dalitz plot analysis



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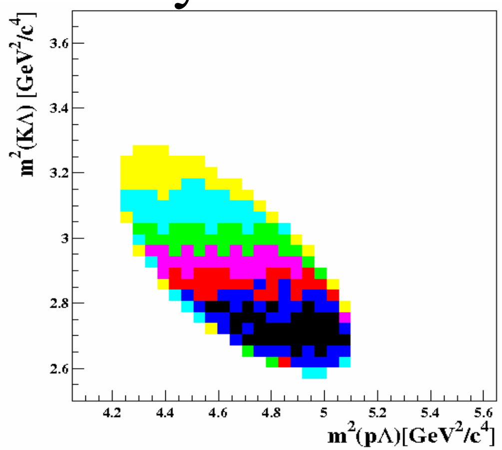
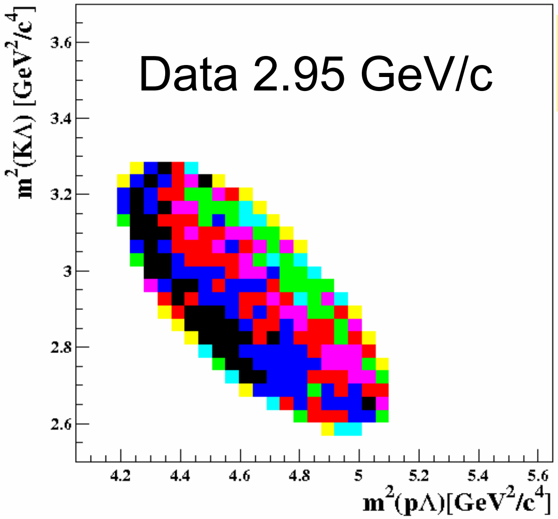
only resonances

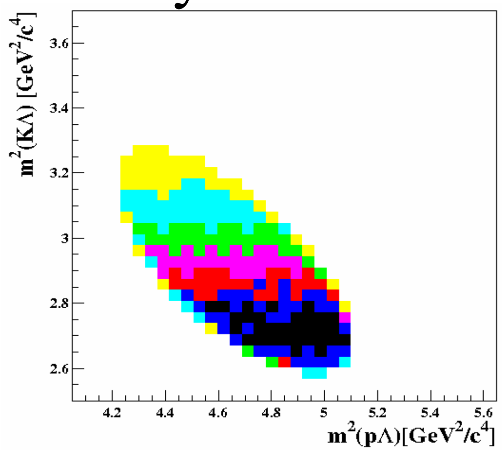


pp → $K^+\Lambda p$: Dalitz plot analysis



Model calculation of Sibirtsev

$$\frac{d^2\sigma}{dm^2_{K\Lambda}\,dm^2_{p\Lambda}} = (flux)\cdot\left|\left(\sum_R (C_R \cdot A_R) + C_N\right)\cdot\left(1 + C_{FSI}\cdot A_{FSI}\right)\right|^2$$



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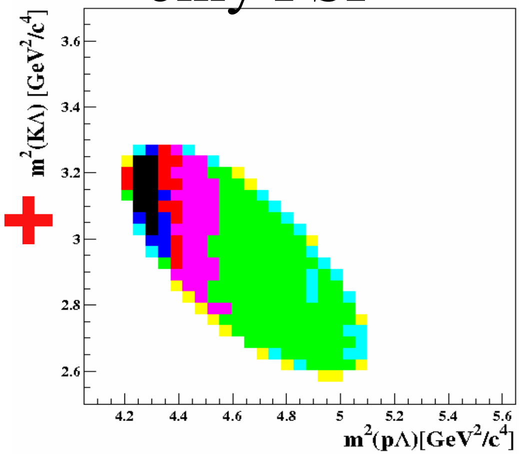
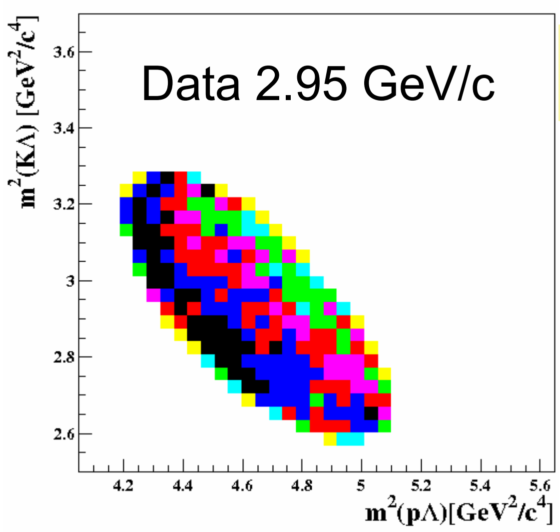


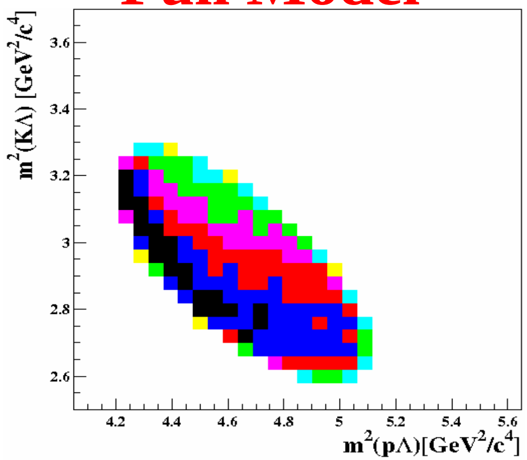


pp → K⁺Λp: Dalitz plot analysis

Model calculation of Sibirtsev

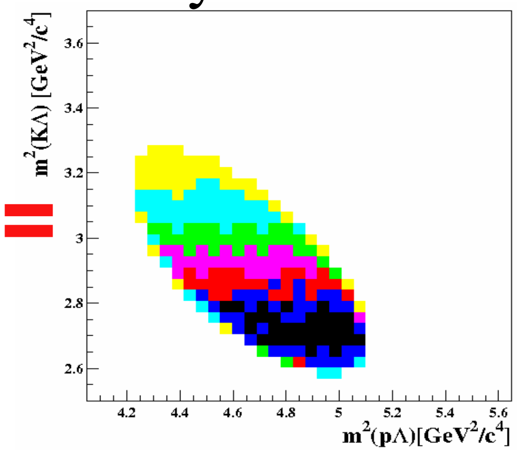
$$\frac{d^2\sigma}{dm^2_{K\Lambda}\,dm^2_{p\Lambda}} = (flux)\cdot\left|\left(\sum_R (C_R\cdot A_R)+C_N\right)\cdot\left(1+C_{FSI}\cdot A_{FSI}\right)\right|^2$$

Full Model



=

only resonances



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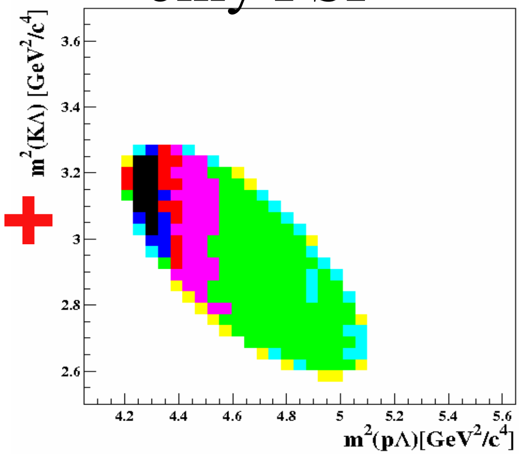
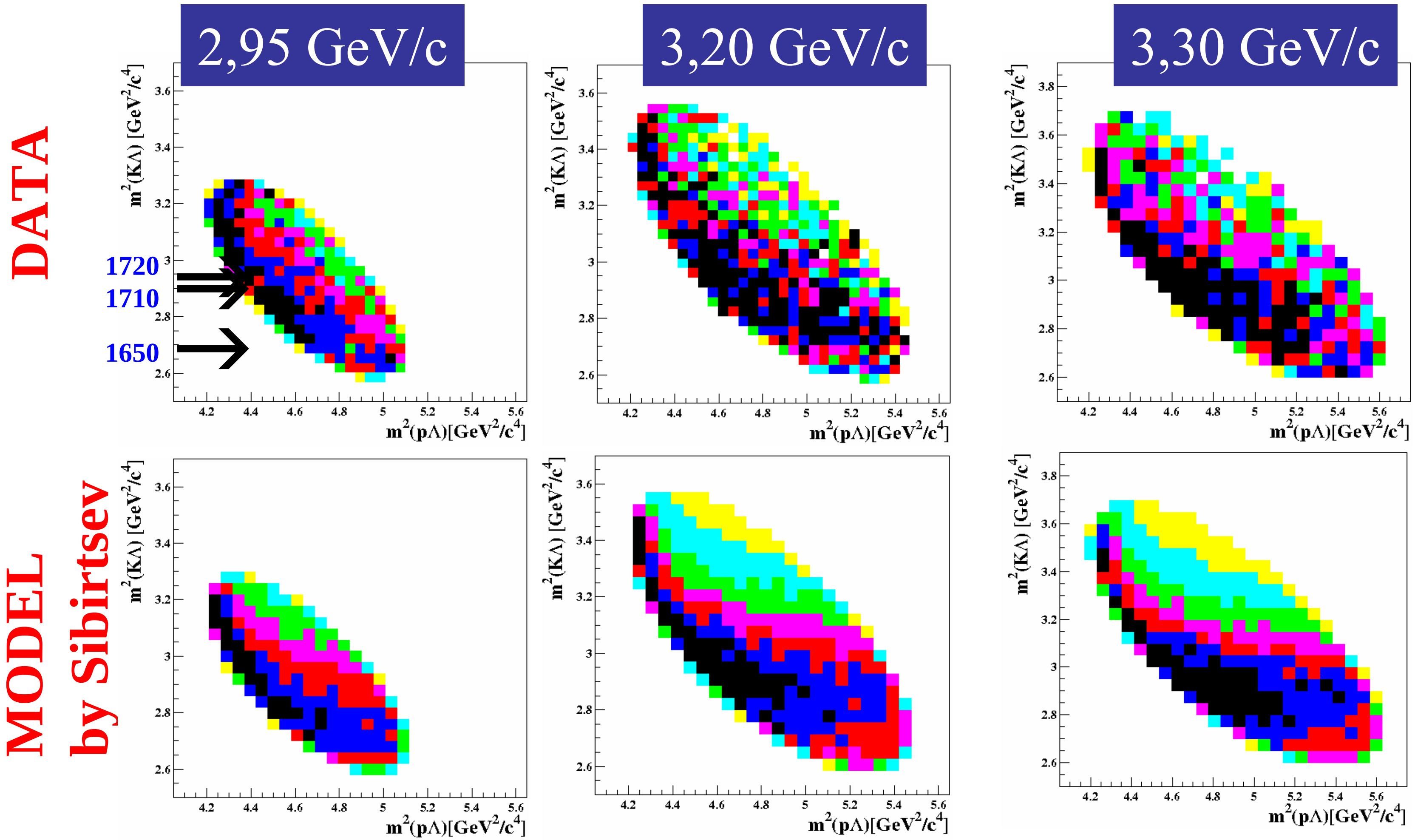
only FSI

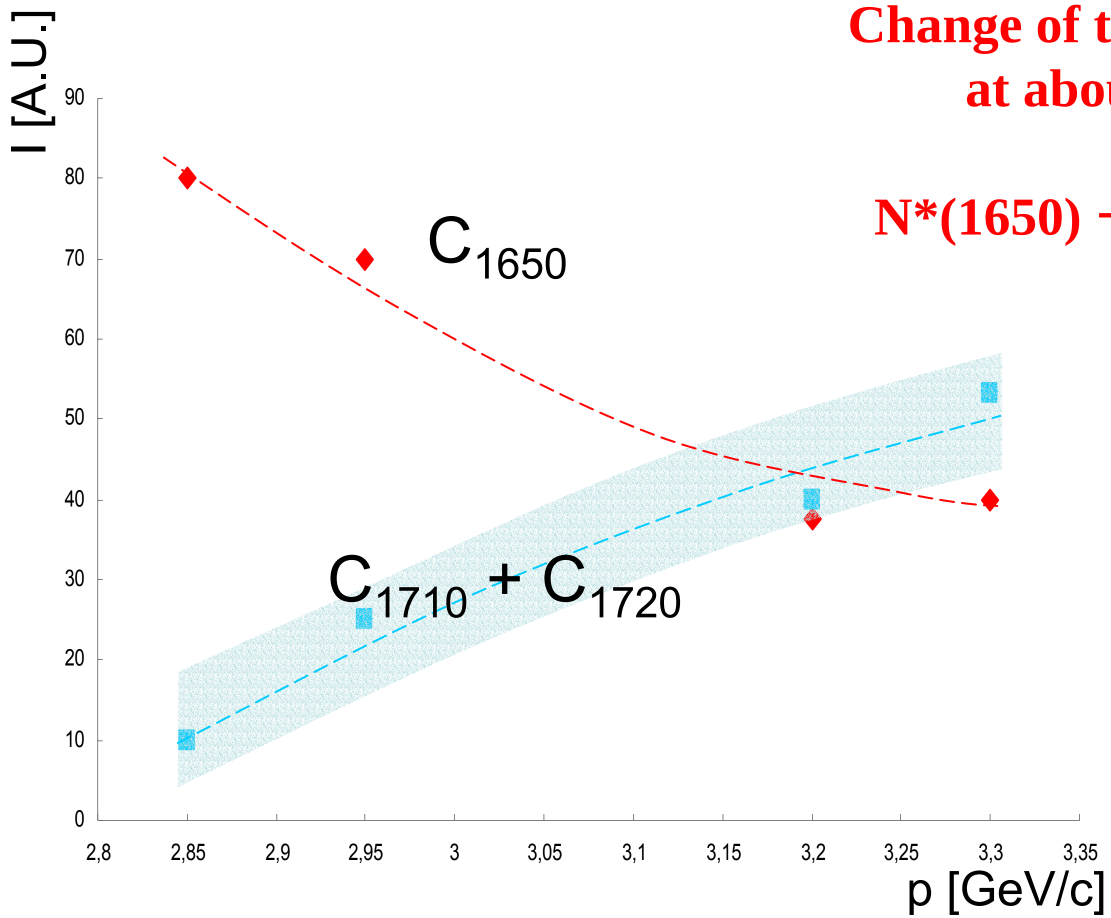


pp → $K^+\Lambda p$: Dalitz plots

Results with unpolarized beam



pp → $K^+\Lambda p$: Results of analysis 2



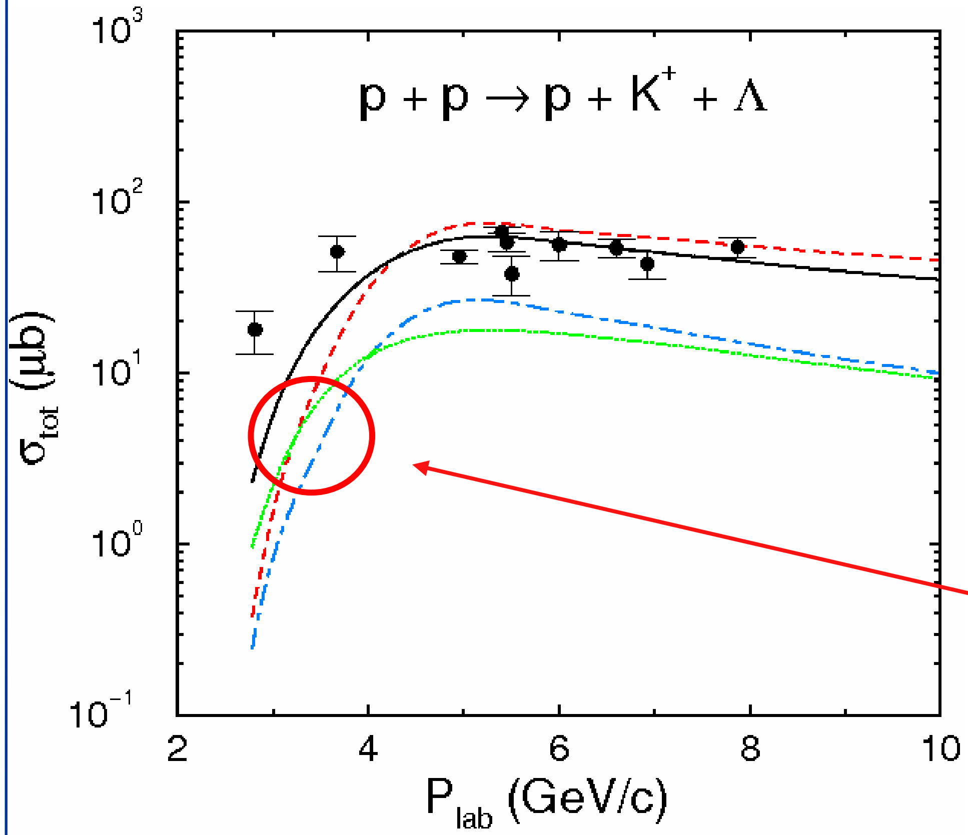
Change of the <u>dominant resonance</u> at about p_{beam}=3 GeV/c :

N*(1650) → N*(1710) / N*(1720)

COSY TOF

pp → $K^+\Lambda p$: Calculation of Shyam

Phys. Rev C60 (1999) 055213



Data: Bubble chamber measurements

(J.T.Balewski et al., Phys.Lett. B388(1996) 420)

σ_{tot} : solid line

influence of each single N*-resonance:

1710: dashed line

1650: dotted line

1720: dash-dotted line

Change of the <u>dominant resonance</u> at 3 GeV/c beam momentum:

N*(1650) → N*(1710)

pp → $K^+\Lambda p$: Results of analysis 1

Strong contribution of N*-Resonances:

→ π - exchange dominant

→ K – exchange small contribution

Future physics at COSY-TOF

- Strangeness Production in $\vec{p}p$ reaction
- Strangeness Production in $\vec{p}n$ reaction
- Strangeness Production in $\vec{p}\vec{p}$ reaction

Motivation for using polarized beam

At the moment: No discrimination between N*(1710) and N*(1720)

N*(1710) P_{11}	N*(1720) P_{13}
$I(J^P) = 1/2(1/2^+)$	**$I(J^P) = 1/2(3/2^+)$**

Goal: Separation with polarized beam

Search for other resonances

COSY TOF

Further motivation for using polarized beam

Resonance	M (MeV)	Γ (MeV)	$g^2_{N\pi}$	$g^2_{N\eta}$	$g^2_{\Lambda K}$	$g^2_{\Sigma K}$
N(1440)P_{11}	1450 ± 50	250 ± 150	1	-	-	-
PDG	1440^{+30}_{-10}	350 ± 100				
N(1520)D_{13}	1526 ± 4	112 ± 10	0.62 ± 0.06	0.04 ± 0.03	0.03 ± 0.02	0.31 ± 0.09 **
PDG	1520^{+10}_{-5}	120^{+15}_{-10}				
N(1535)S_{11}	1530 ± 30	210 ± 30	0.39 ± 0.10	0.95 ± 0.20	0.30 ± 0.10	0.30 ± 0.10 **
PDG	1505 ± 10	170 ± 80				
N(1650)S_{11}	1705 ± 30	220 ± 30	1.10 ± 0.20	0.40 ± 0.10	0.10 ± 0.10	0.50 ± 0.15
PDG	1660 ± 20	160 ± 10				
N(1675)D_{15}	1670 ± 20	140 ± 40	0.32 ± 0.15	0.04 ± 0.04	0.39 ± 0.20	0.25 ± 0.20
PDG	1675^{+10}_{-5}	150^{+30}_{-10}				
N(1680)F_{15}	1667 ± 6	102 ± 15	$0.95^{+0.05}_{-0.10}$	$0.00^{+0.05}_{-0.00}$	$0.05^{+0.10}_{-0.05}$	$0.00^{+0.05}_{-0.00}$
PDG	1680^{+10}_{-5}	130 ± 10				
N(1700)D_{13}	1725 ± 15	100 ± 15	0.29 ± 0.15	0.51 ± 0.15	0.13 ± 0.10	$0.07^{+0.12}_{-0.07}$
PDG	? ± 50	100 ± 50				
N(1720)P_{13}	1?50 ± 40	380 ± 40	0.39 ± 0.10	0.43 ± 0.12	0.16 ± 0.05	0.02 ± 0.02
PDG	1720^{+30}_{-70}	250 ± 50				
N(1840)P_{11}	1840^{+15}_{-40}	140^{+30}_{-15}	0.31 ± 0.10	0.09 ± 0.05	0.06 ± 0.03	0.54 ± 0.10
PDG	1720 ± 30	100^{+150}_{-50}				
N(1870)D_{13}	1875 ± 25	80 ± 20	0.04 ± 0.04	0.21 ± 0.10	0.03 ± 0.03	0.72 ± 0.30
N(2000)F_{15}	1850 ± 25	225 ± 40	0.85 ± 0.20	$0.07^{+0.11}_{-0.07}$	$0.03^{+0.07}_{-0.03}$	$0.05^{+0.10}_{-0.05}$
PDG	~ 2000					
N(2070)D_{15}	2060 ± 30	340 ± 50	0.71 ± 0.10	0.26 ± 0.05	0.01 ± 0.01	0.02 ± 0.02
N(2170)D_{13}	2166^{+50}_{-80}	300 ± 65	$0.67^{+0.20}_{-0.30}$	0.13 ± 0.05	$0.10^{+0.15}_{-0.10}$	$0.10^{+0.15}_{-0.10}$
PDG	~ 2080					
N(2200)P_{13}	2200 ± 30	190 ± 50	$0.08^{+0.12}_{-0.08}$	$0.89^{+0.08}_{-0.15}$	$0.02^{+0.08}_{-0.02}$	$0.01^{+0.08}_{-0.01}$

Hyperon production in γ-induced reactions:

Partial Wave Analysis

(Sarantsev et al. Eur.Phys.J. A.25, 30(2005), 441)

N(1650) S_{11} M =1705 ± 30 MeV

N(1710) P_{11} not seen !!

Open questions !!

→ COSY -TOF

Motivation D_{NN}

spin transfer coefficient

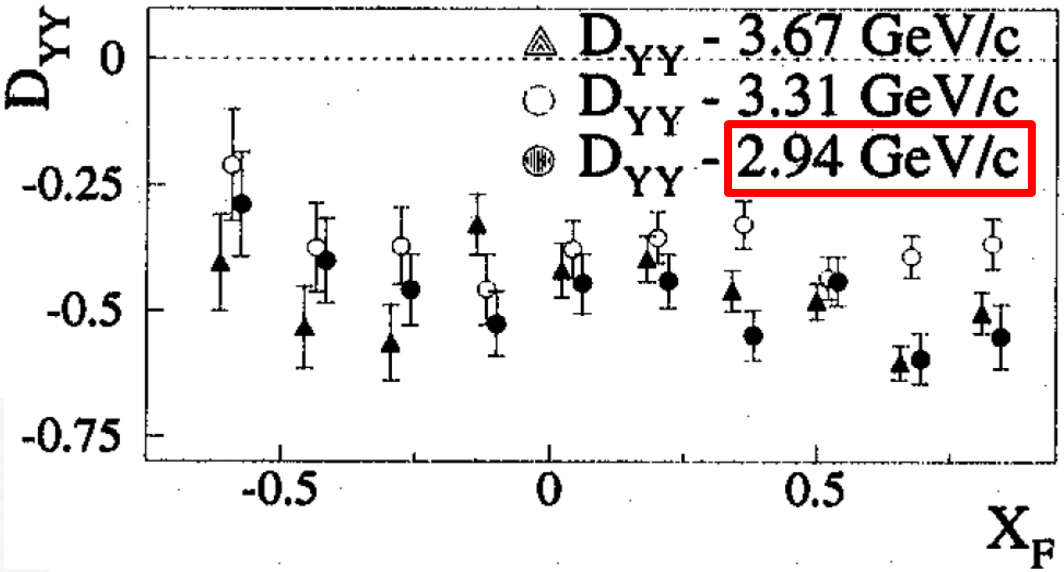
component of the beam polarization along the production plane normal that is retained by the final state lambda

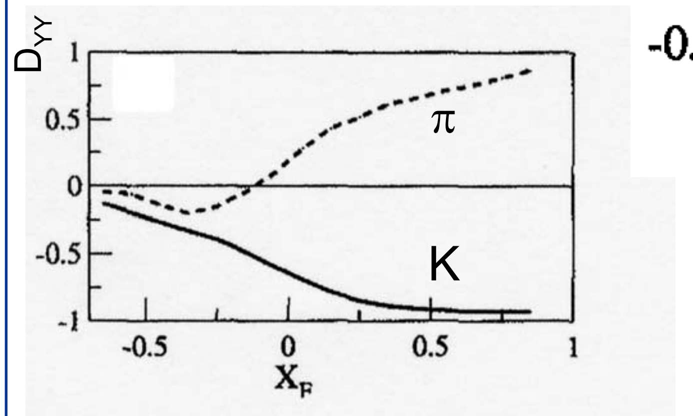
vs

fractional longitudinal momentum of the Λ

DISTO

Nucl.Phy.A691(2001)329-335





COSY-TOF measurement
at 2.95 GeV/c (lowest point of DISTO)

Meson exchange model Laget (Phys. Lett **B259**(1991) 24)

D_{NN} Estimation

$$D_{NN} = \frac{1}{2P_B\langle\cos\psi\rangle}\left[P_{\Lambda\uparrow}(1+A_N P_B\langle\cos\psi\rangle) - P_{\Lambda\downarrow}(1-A_N P_B\langle\cos\psi\rangle)\right]$$

ψ is the angle between the normal to the Λ production plane and spin direction of the beam proton

with A_N small (<0.2)

$$\boxed{D_{NN} \approx \frac{1}{2P_B\langle\cos\psi\rangle}\left[P_{\Lambda\uparrow} - P_{\Lambda\downarrow}\right]}$$

COSY TOF

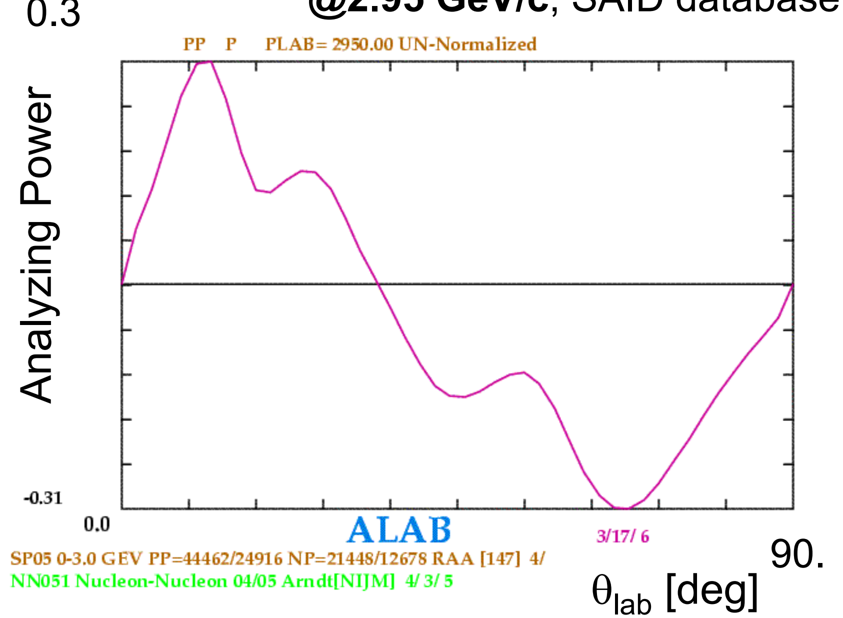
Beam Polarization

Beam Polarization is measured using elastic scattering by comparison with EDDA

Beam Polarization = Asymmetry / Analyzing Power

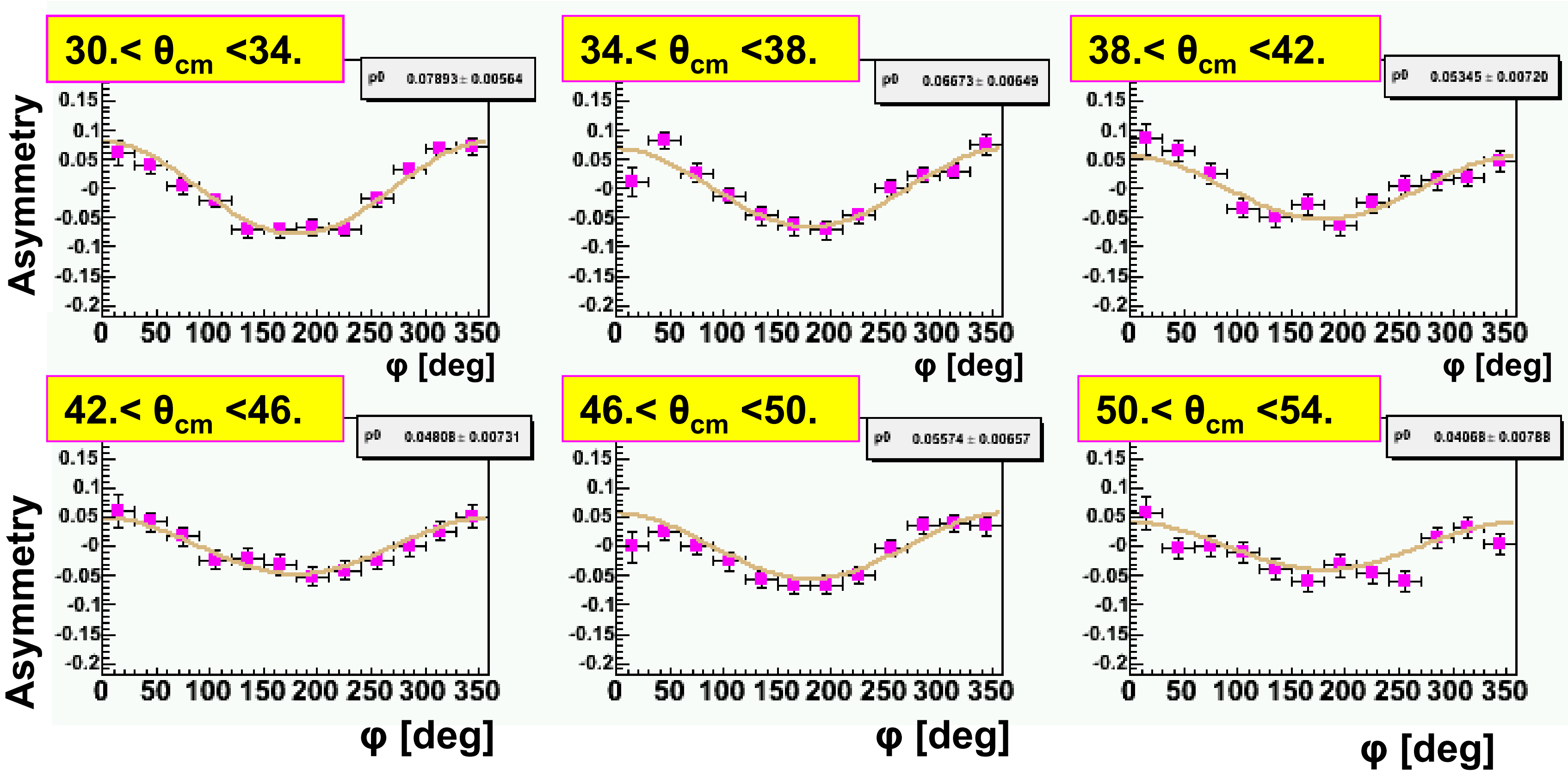
$$Asy = \frac{N\uparrow - N\downarrow}{N\uparrow + N\downarrow}$$

@2.95 GeV/c, SAID database



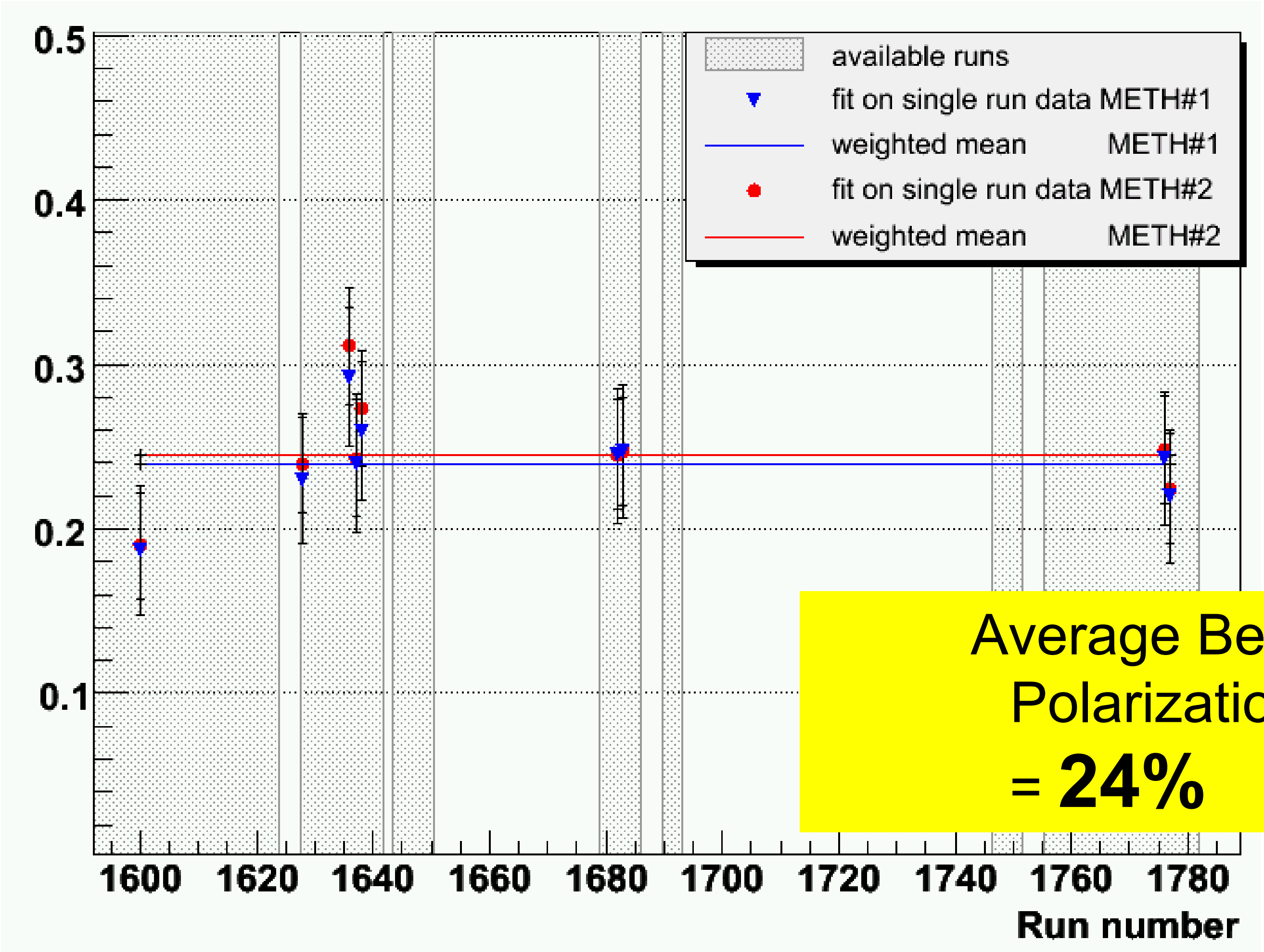
Asymmetry measurement with TOF:

Fit in several θ_{cm}-steps:



Beam Polarisation 2002 @ p_{beam} 2.95GeV/c

COSY-TOF is a polarimeter

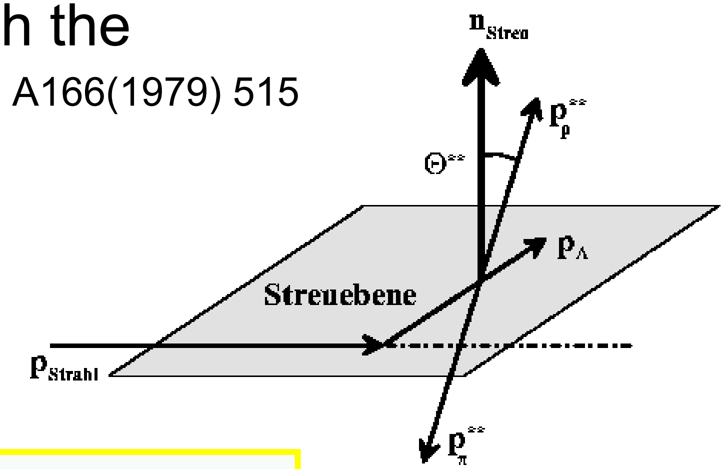


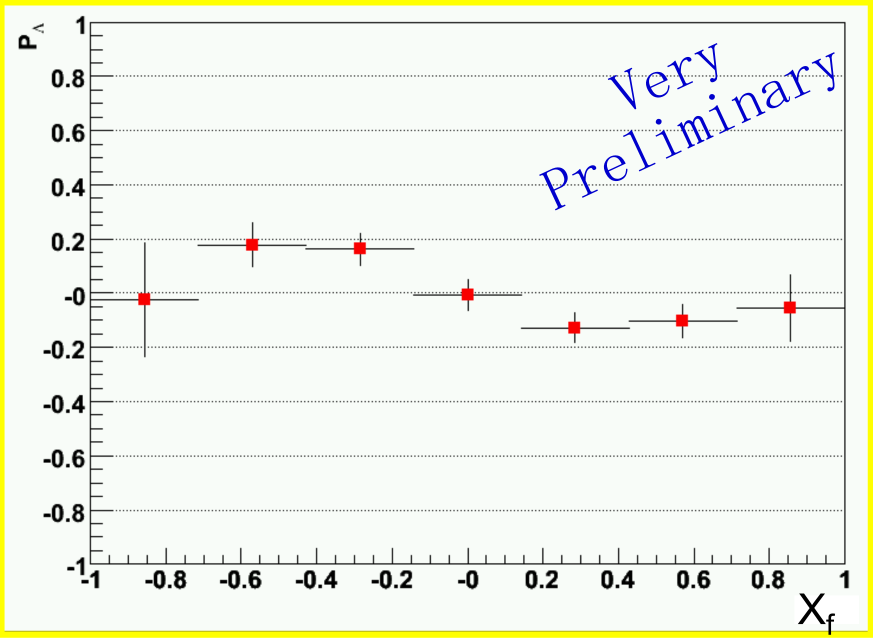
Average Beam Polarization = **24%** (±2% stat)

Λ-Polarisation 2002 @ p_{beam} 2.95GeV/c

The Λ polarization is calculated with the "weighted sum method" Nucl.Instr.Meth A166(1979) 515

$$P_\Lambda = \frac{1}{\alpha} \cdot \frac{\sum_i \cos \Theta_i^{**}}{\sum_i \cos^2 \Theta_i^{**}}$$





D_{NN} Estimation

Estimate for a future beam time of 1 week:

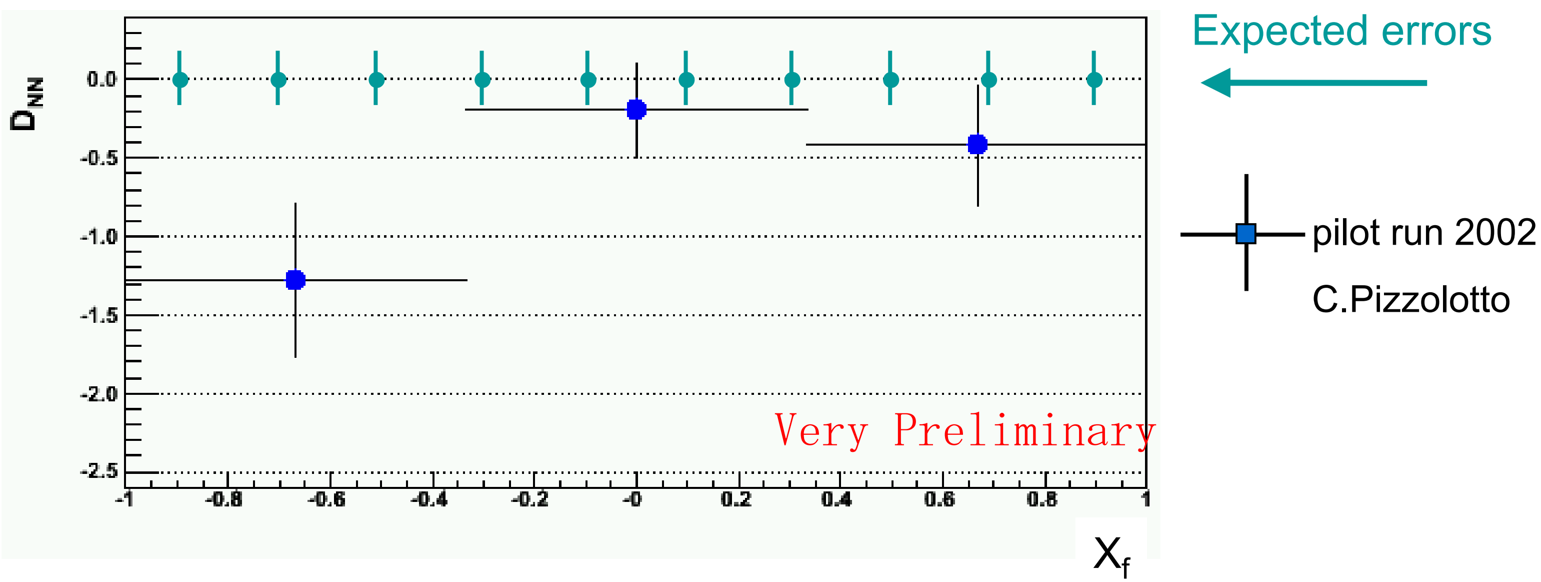
Number of events I: estimated using the 2004 run:

With the upgraded apparatus about 10000 events per day

→ factor of 5 compared to the pilot run (2002).

Polarization: expected 50% compared to 24% in the pilot run

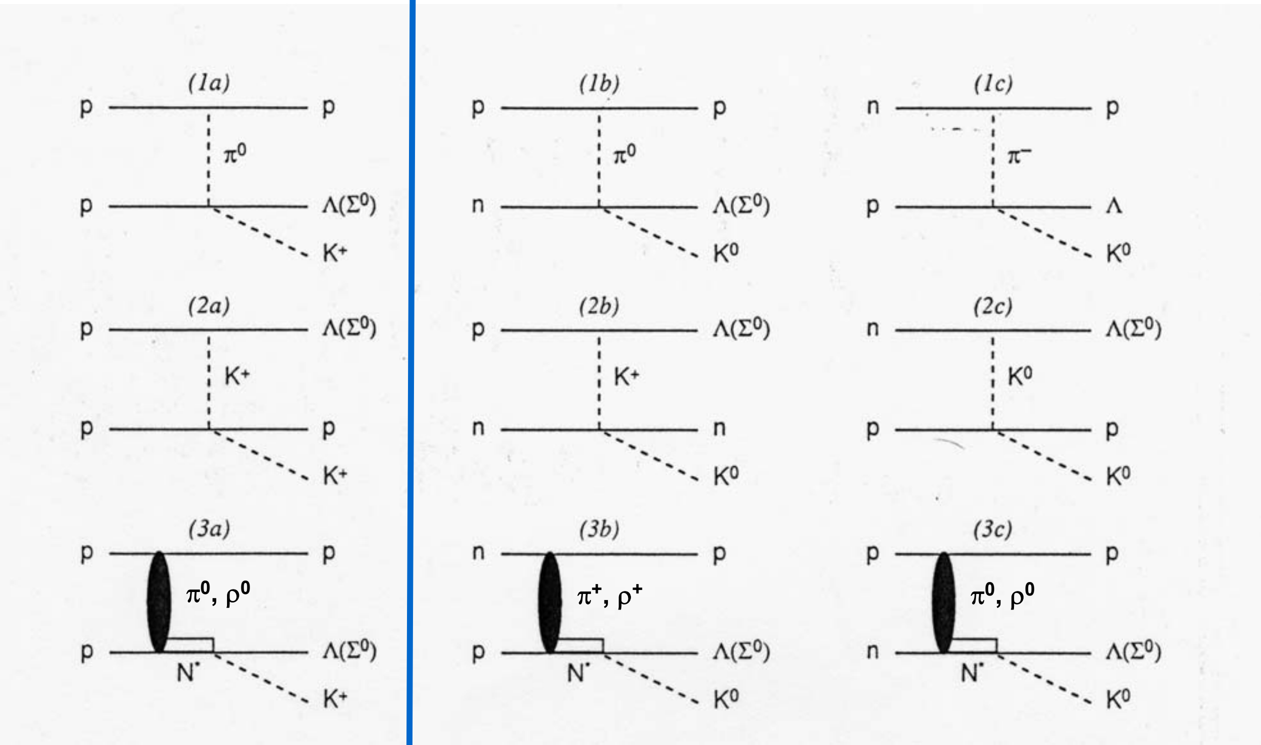
Gain in figure of merit: P^2 x I = 20



Motivation $\vec{p}$n reaction

NEW PHYSICS @ COSY (no exclusive data in the COSY range)

pp → pK$^+\Lambda$ | pn(p) → pK$^0\Lambda$(p)



Exclusive measurement with COSY-TOF

Motivation

Very recently: ANKE inclusive K^+ production measurement in pd collisions (M.Büscher et al. Eur.Phys.J. A.22, 301(2004), nucl-ex/0401031)

$$\frac{\sigma(pn \rightarrow nK^+\Lambda)}{\sigma(pp \rightarrow pK^+\Lambda)}$$

Compaired to isospin algebra:

Fäldt, Wilkin (Z. Phys. A 357, 241(1997), Eur. Phys. J. A24, 431(2005)):

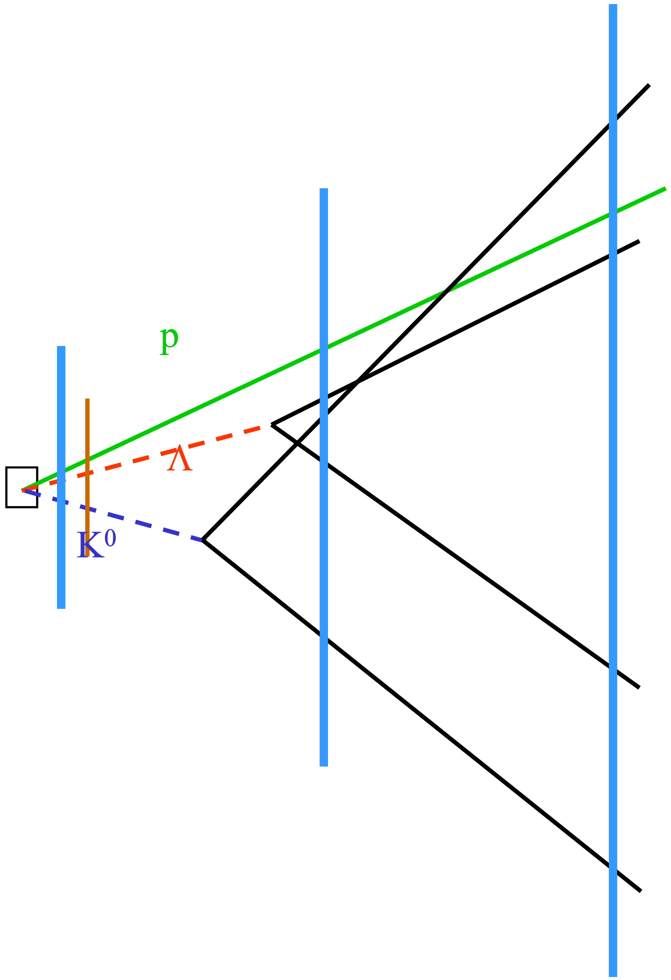
<u>Experimental difficulty:</u>

Separation of the Λ-reaction-channel from the other hyperons (Σ^0, Σ^+) in the inclusive K^+-meson-momentum-spectra.

→ **Additional important information from exclusive measurement of the reaction $pn(p) \rightarrow pK^0\Lambda(p)$: <u>COSY- TOF</u>**

Reaction Pattern

$pn(p) \rightarrow pK^0\Lambda(p)$



Unique signature:

2 „V's" corresponding to the delayed decays of Λ and K^0

Event candidate

$pn(p) \longrightarrow pK^0\Lambda(p)$

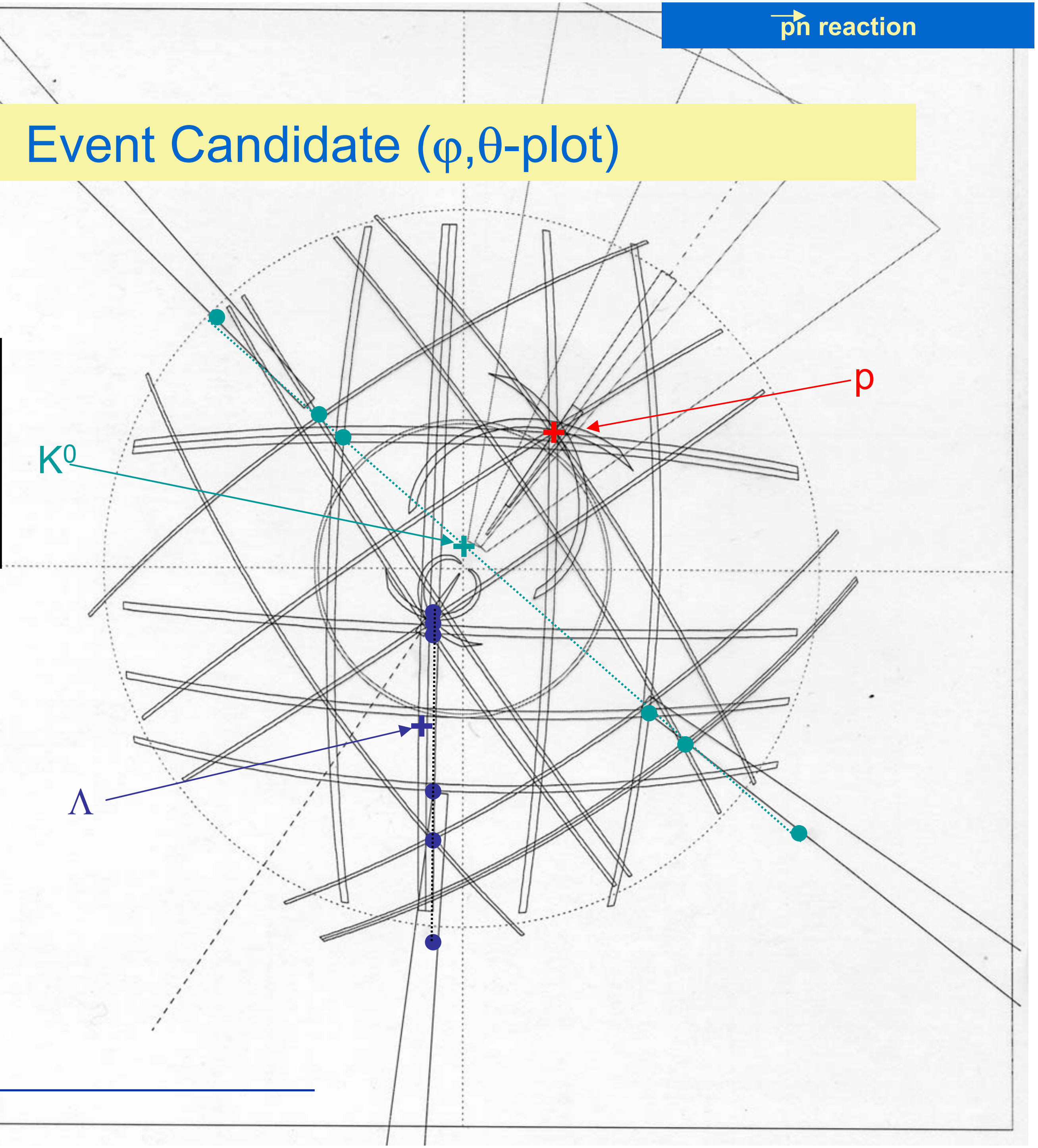
from test run

Event Candidate (φ,θ-plot)

Event candidate

$pn(p) \longrightarrow pK^0\Lambda(p)$

from test run



Summary

- Strong contribution of N*-Resonances in the channel $pp \rightarrow K^+ \Lambda p$
- Existence of other resonances ?
- Measurements with LD_2-target
  ↳ $pn \rightarrow K^0 \Lambda p$
- Measurements with polarized beam
  ↳ D_{NN}

Outlook

- Existence of the penta-quark state Θ^{+} ?
- Existence of the isospin partner Θ^{++} ?

Outlook

In the case of Θ^+ confirmation

↓

Future measurements

$\vec{p}n \rightarrow \Lambda K^0p$ using a LD_2 target, successful tests in 2002/04

pol. beam + Λ-polarization → towards parity of Θ^+

$\vec{p}\vec{p} \rightarrow \Sigma^+K^0p$ polarized beam + polarized target → Θ^+ parity

Experiment upgrade

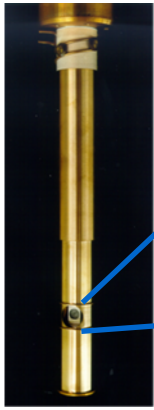
2006/7: additional tracker (straw - tubes) → $p\Lambda$ – scattering - length

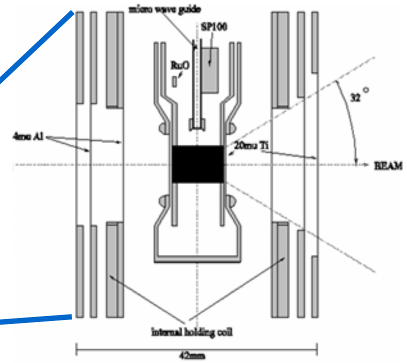
2007: polarized target

Polarized frozen spin target for TOF

- Frozen spin technique well suited for low intensity external beams
- High polarization ~ 80%
- PS185/3 set up will be used
- preparation at Bochum and Bonn

  → Installation at COSY-TOF

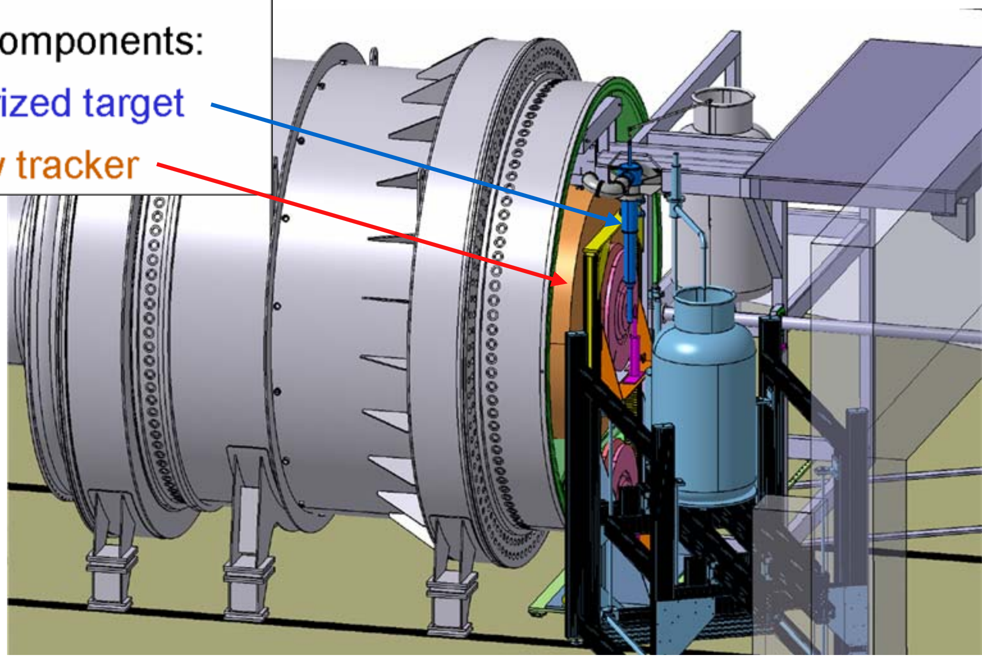




Acceptance: ± 32°
Dimensions: 9mm x 6mm
P_{max} (butanol): p ~ 80%
alternative material in Test

<u>Set up at COSY-TOF</u>

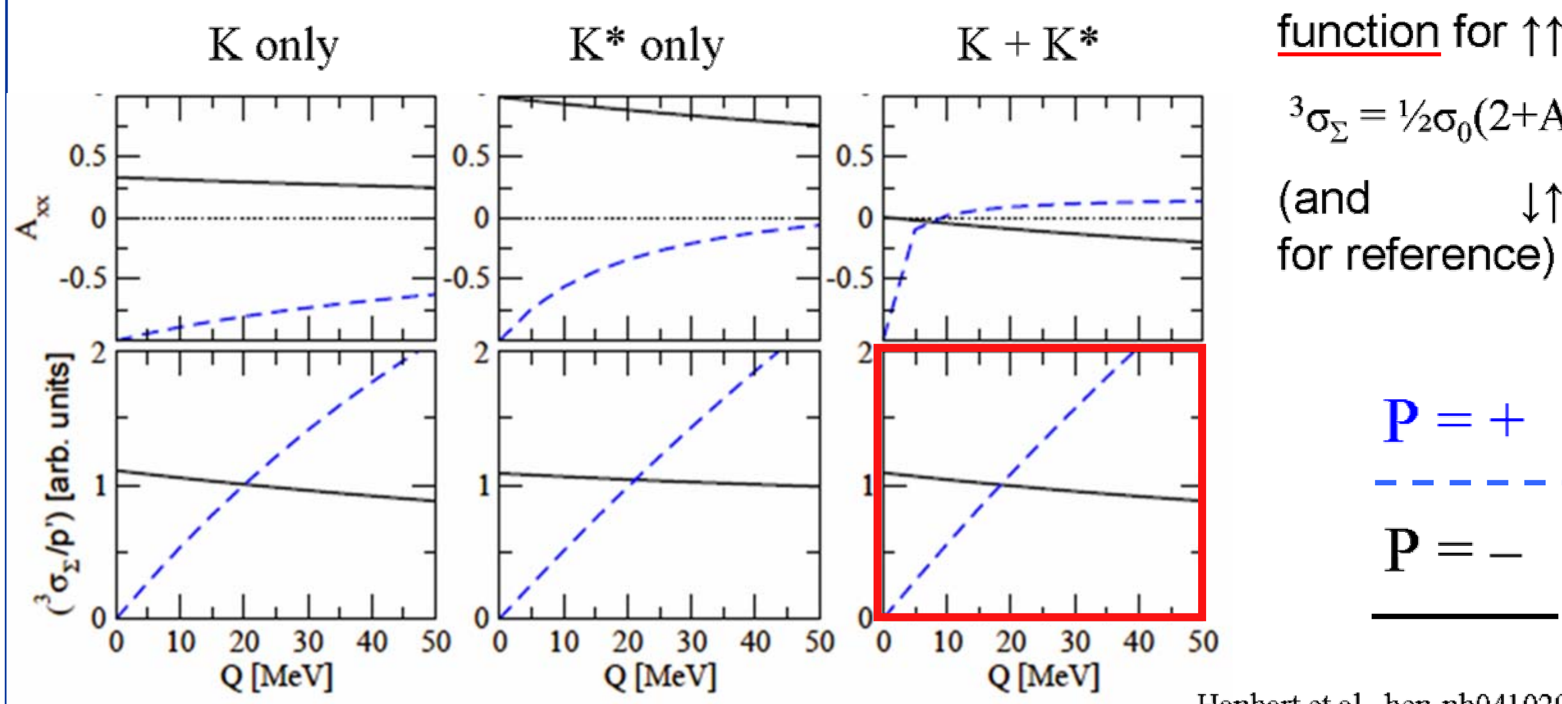
New components:
- polarized target
- straw tracker



Measurement of the parity of Θ+

Observable: $^3\sigma_\Sigma = ½\sigma_0(2+A_{xx}+A_{yy})$

$pp \to \Sigma^+\Theta^+$



measure excitation function for ↑↑ ($^3P_{0,1}$)

$^3\sigma_\Sigma = ½\sigma_0(2+A_{xx}+A_{yy})$

(and ↓↑ ($^1S_0$) for reference)

Hanhart et al., hep-ph0410293; PLB590(04)39; PLB606(05)67