Strangeness Physics at COSY-TOF

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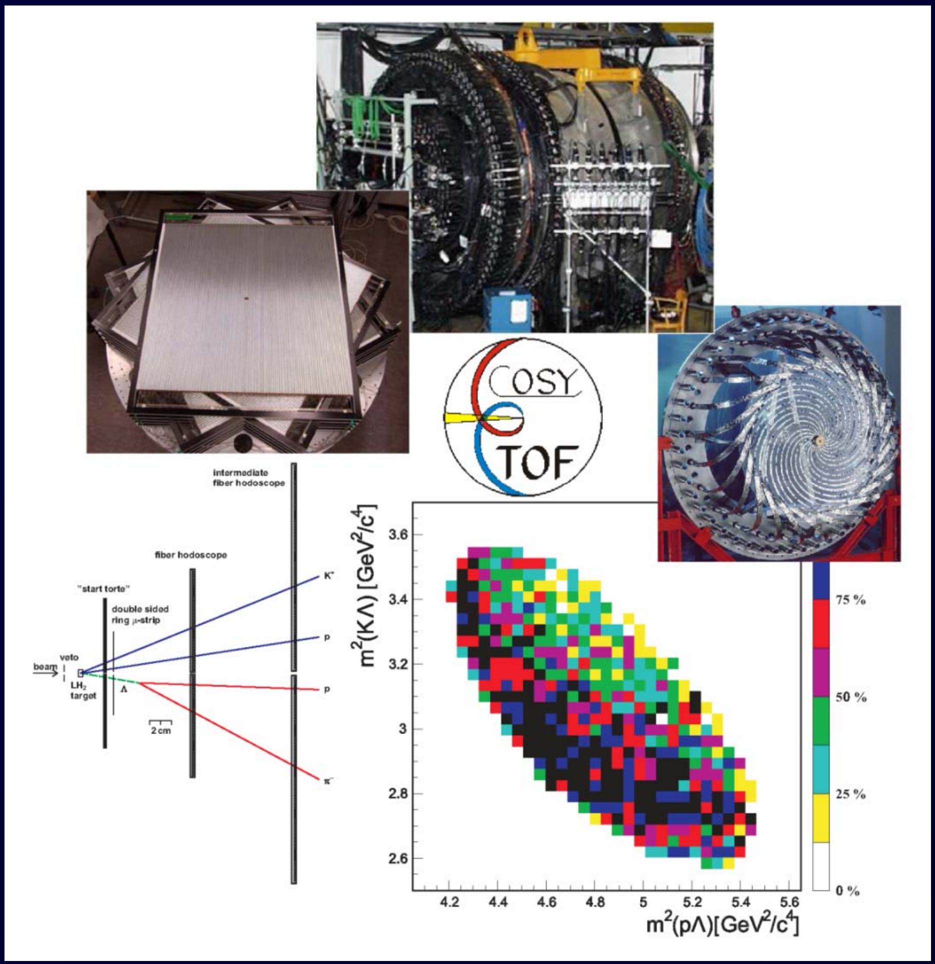
Outline



- Introduction
- Detector (+upgrade)
- Study of N^* resonances
- Studies with Pol. Beam
- YN interaction
- Other topics
- Summary & Outlook

Introductory remarks

- New opportunities with COSY-TOF upgrade & COSY polarized beam

⇒ best possible use of the instrumental capabilities

⇒ focus on key questions in hadron physics

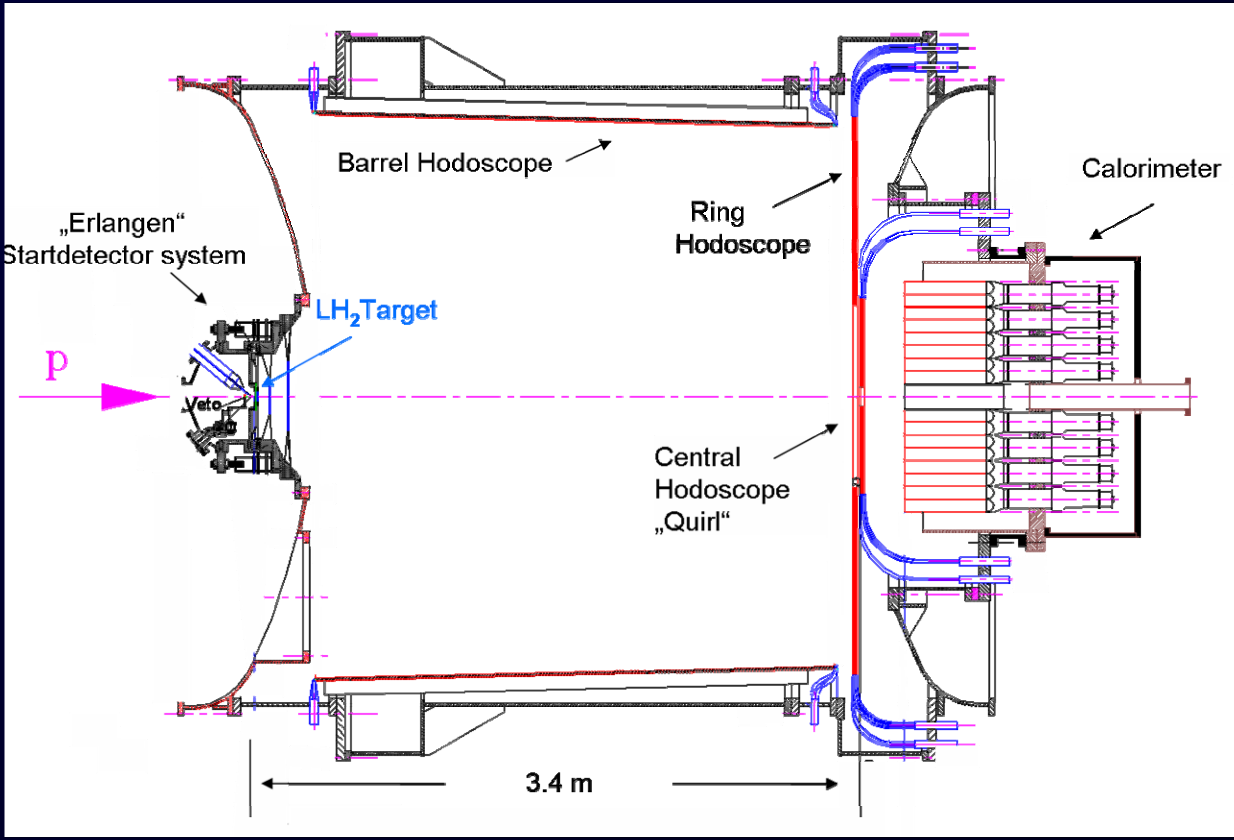
key issues identified:
- Strange decays of N^* resonances
- Hyperon-nucleon interaction

The COSY-TOF detector

large angle (non magnetic) spectrometer with modular vacuum vessel

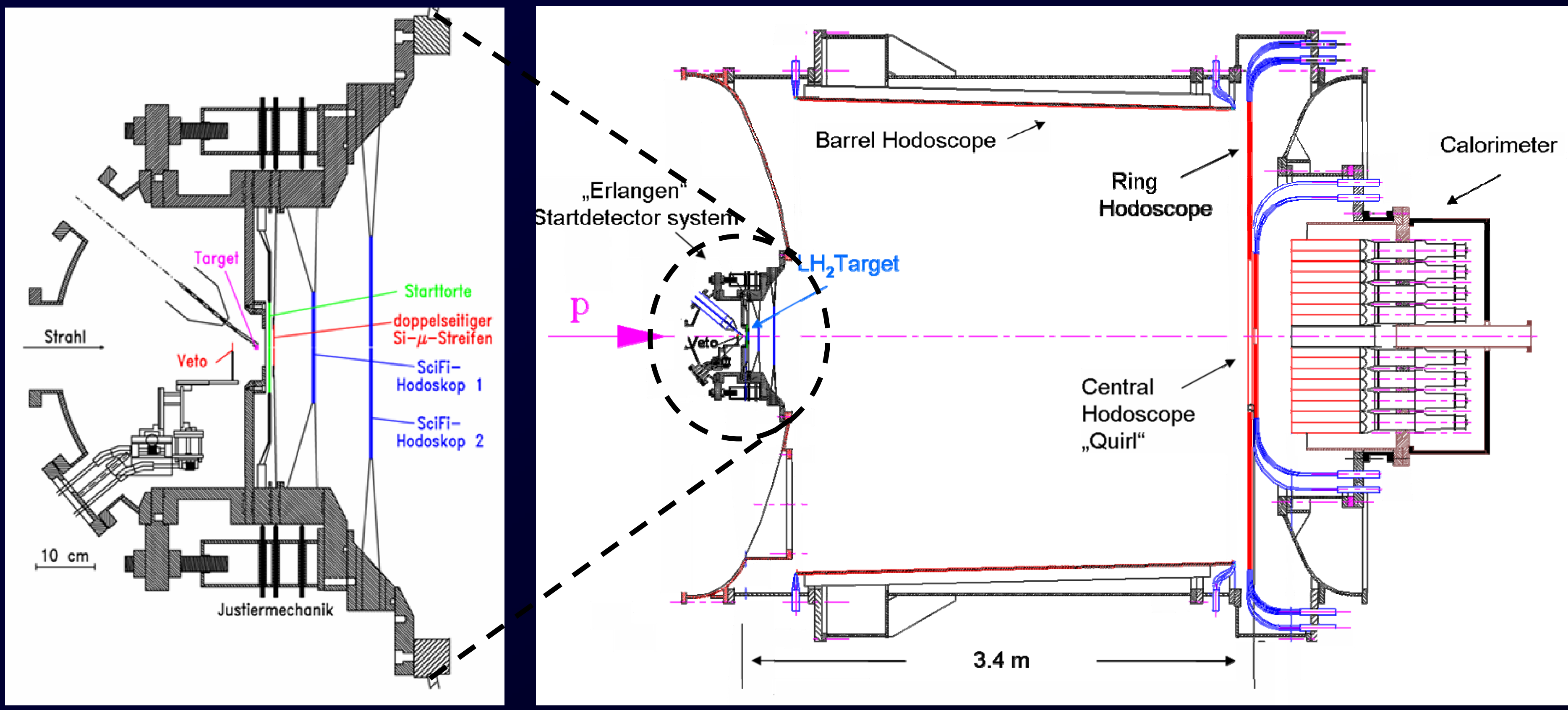
4π acceptance

azimuthal symmetry



The COSY-TOF detector

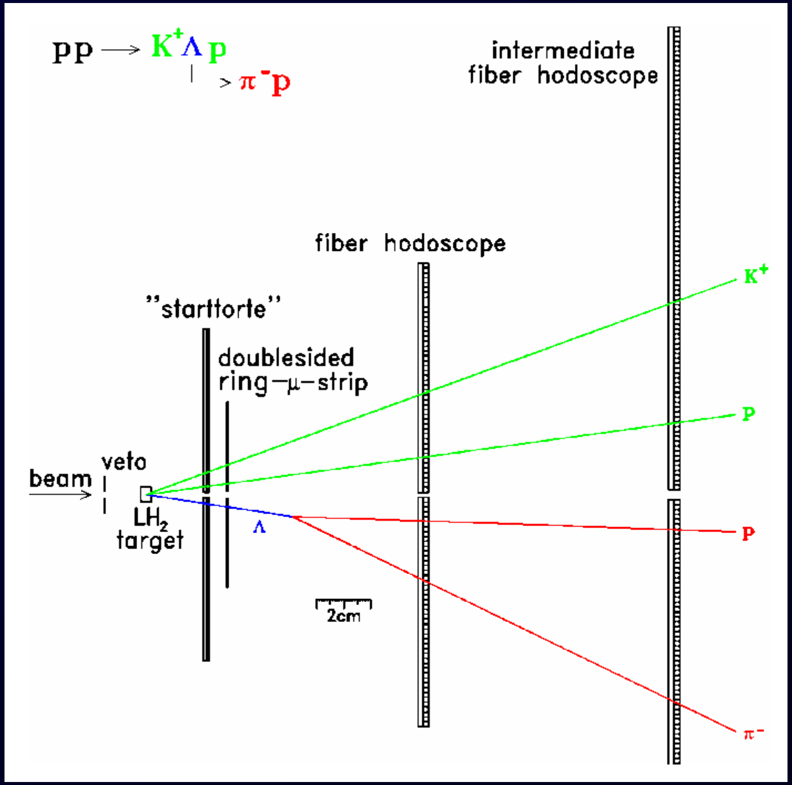
large angle (non magnetic) spectrometer with modular vacuum vessel



The COSY-TOF detector

complete geometric reconstruction of all charged particles

- delayed vertex reconstruction: Λ, Σ^+, K_s
- „strangeness“ trigger: $\Lambda \to p\pi^-$, $K_s \to \pi^+\pi^-$

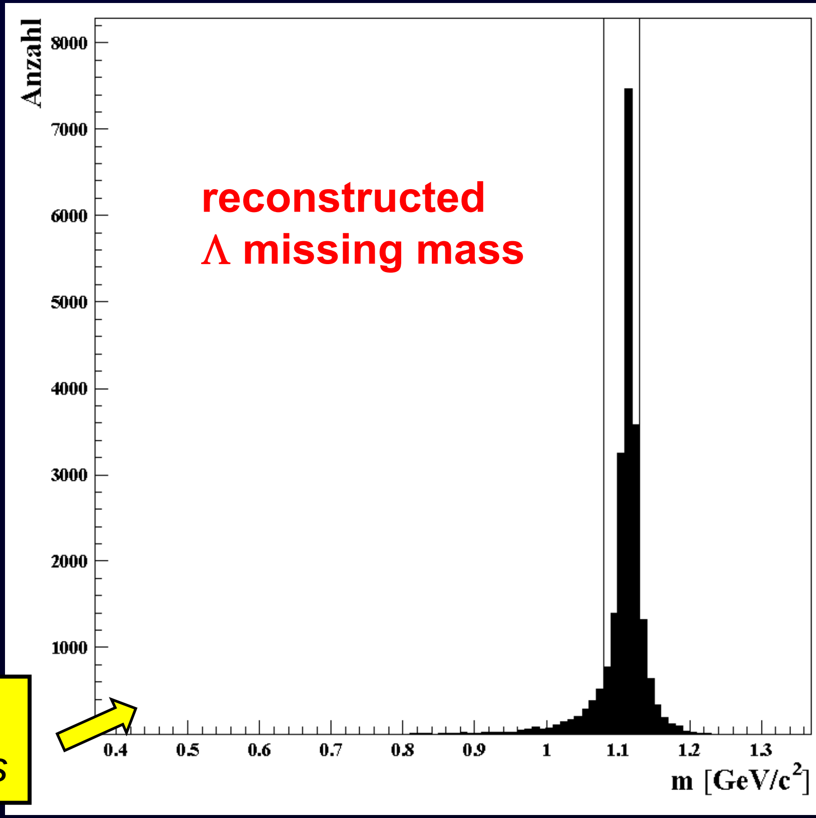


The COSY-TOF detector

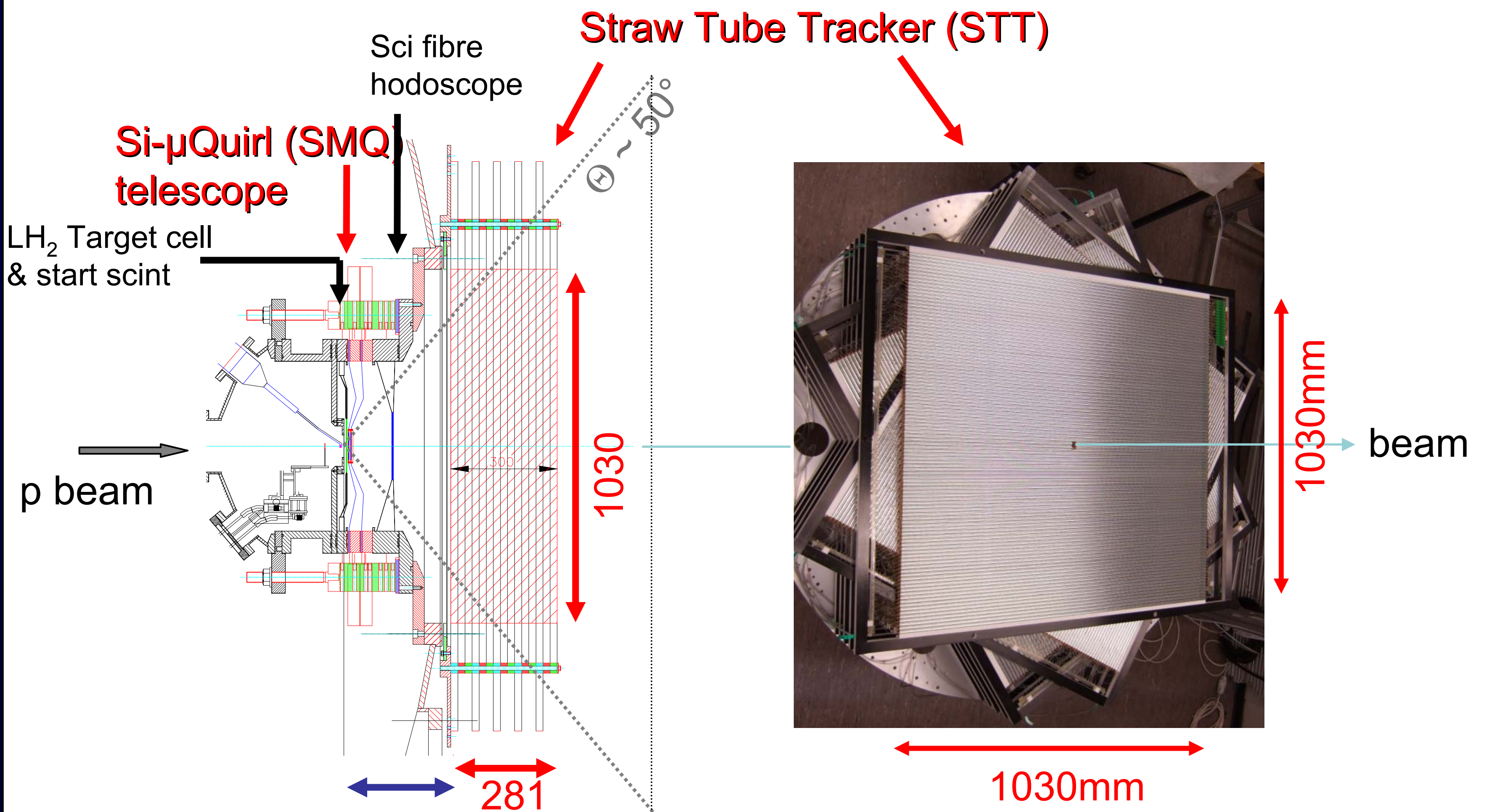
complete geometric reconstruction of all charged particles

- delayed vertex reconstruction: Λ, Σ^+, K_s
- „strangeness“ trigger: $\Lambda \to p\pi^-$, $K_s \to \pi^+\pi^-$

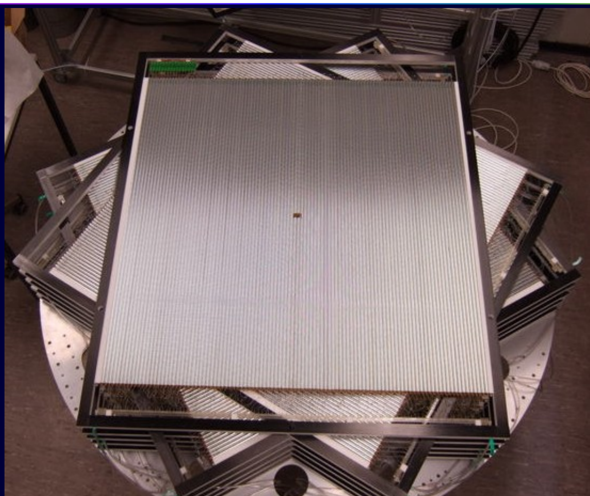
no background from non-strange final states



Detector upgrade



Detector upgrade: Strawtube tracker



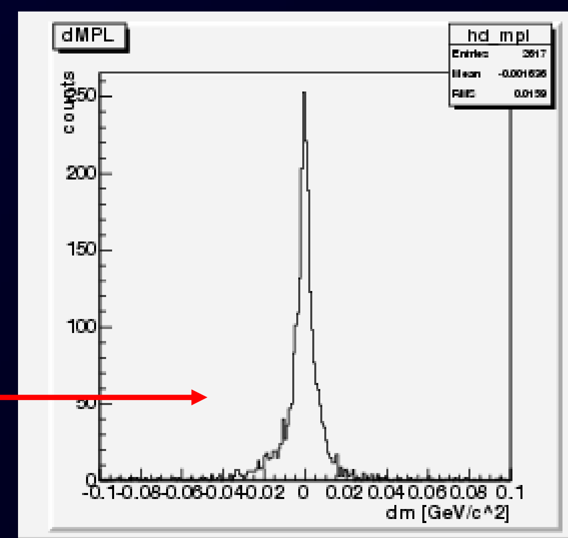
- resolution better than 100 μm / wire
- close to 100 % efficiency / wire

$\Rightarrow$ **improved mass resolution**

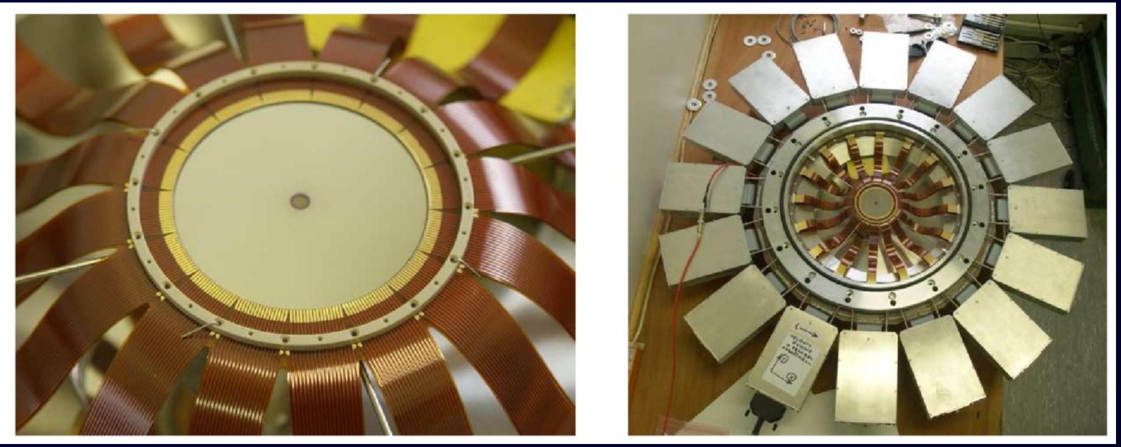
$\Rightarrow$ **improved reconstruction efficiency**

Inv. mass of $p\Lambda$ system:
Improvement by at least a factor 2

Old setup without kin. Fit:	14 MeV (FWHM)
Old setup with kin. Fit:	8 MeV (FWHM)
Straws without kin. Fit : ongoing,	~6 MeV (FWHM)
Straw with kin. Fit:	ongoing !!!



Detector upgrade: Si-Quirl telescope

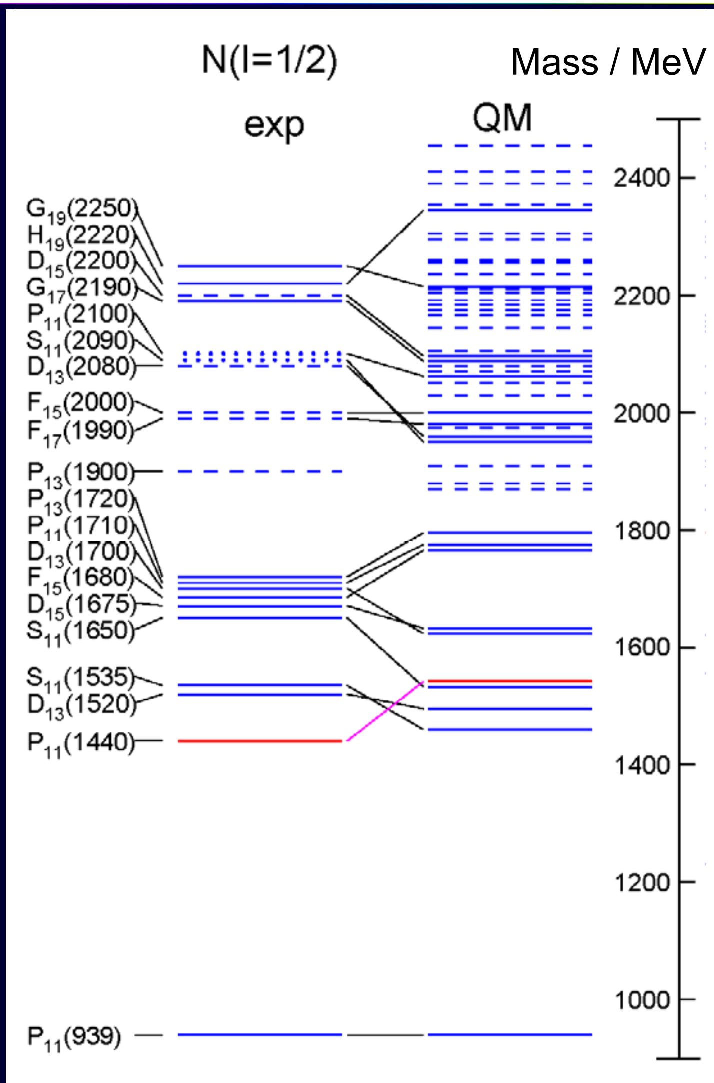


- position close to target (2.5 cm)
- 75 mm diameter, 4 mm ∅ hole
- 256 archimedian spirals on each side
- wafer thicknesses: 65 μm … 500 μm

⇒ **more flexibility, telescope option**

⇒ **no polar angle dependent rate effects**

Study of N* resonances



Quark Model: Capstick & Roberts

Nucleon spectrum not understood:

Prerequisite for understanding „strong" QCD as a whole

→ study coupling to strangeness

KΛ: little known, KΣ: nothing known

Baryon	Status	Mass	Width	ΛK	ΣK
S_{11}	****	1645-1670	145-185	3-11	?
D_{15}	****	1670-1680	130-165	<1	?
F_{15}	****	1680-1690	120-140	?	?
D_{13}	***	1650-1750	50-150	<3	?
P_{11}	***	1680-1740	50-250	5-25	?
P_{13}	****	1700-1750	150-300	1-15	?
P_{33}	***	1550-1700	250-450	-	?
D_{33}	****	1670-1750	200-400	-	?

N* resonances in KΛ production

COSY-TOF data:

Phys. Lett. B 632 (2006) 27

⇒ **Importance of N* resonances in strangeness production**

considered states:

$S_{11}(1650)\ 1/2^-$

$P_{11}(1710)\ 1/2^+$

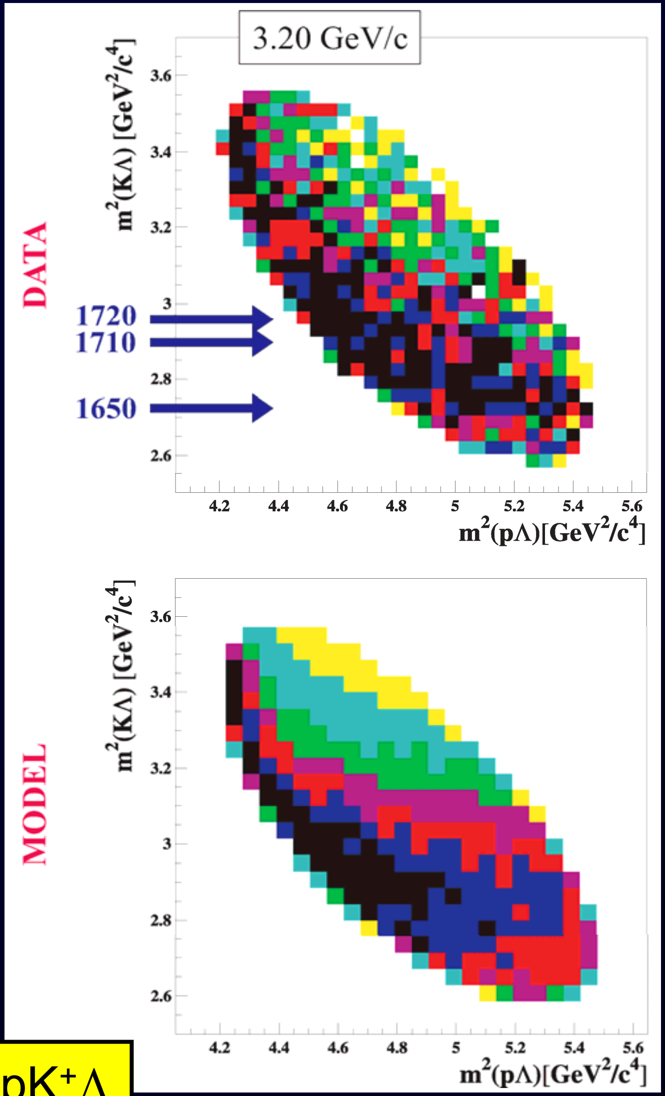
$P_{13}(1720)\ 3/2^+$

Dalitz plot:

combined effect of N* and pΛ final state interaction

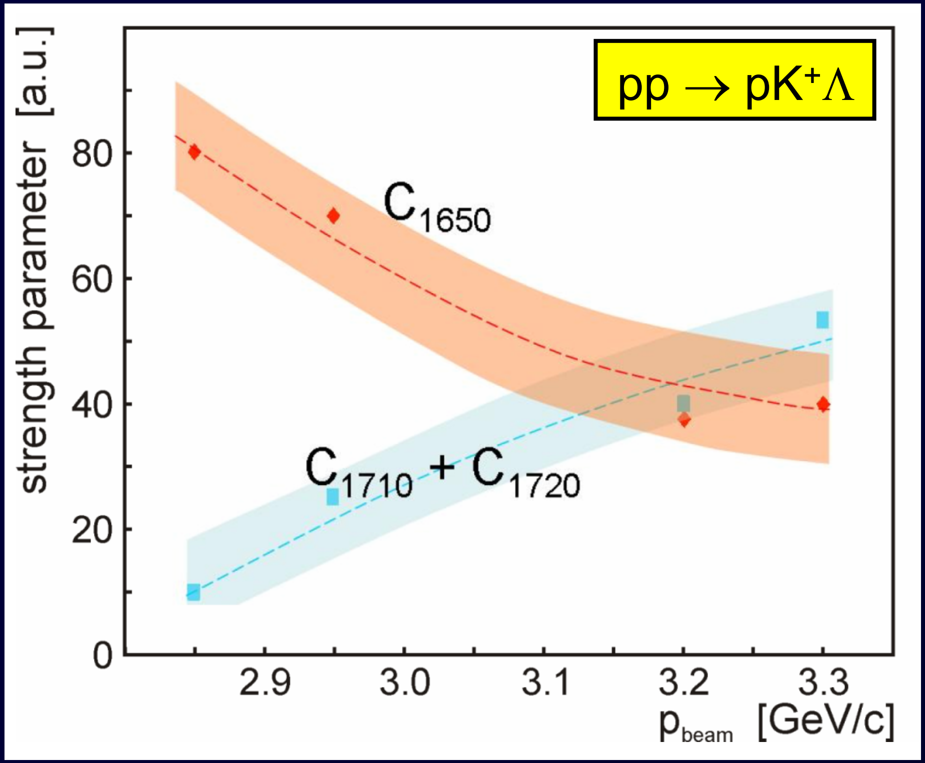
structures described by theoretical model

A. Sibirtsev *et al.*, Eur. Phys. J. A 27 (2006) 269



$pp \to pK^+\Lambda$

N^* resonances in $K\Lambda$ production



Theoretical model (A. Sibirtsev *et al.*) used to extract strength parameters for N^* contribution

energy dependence of N^* contribution observed

present data not sufficient to

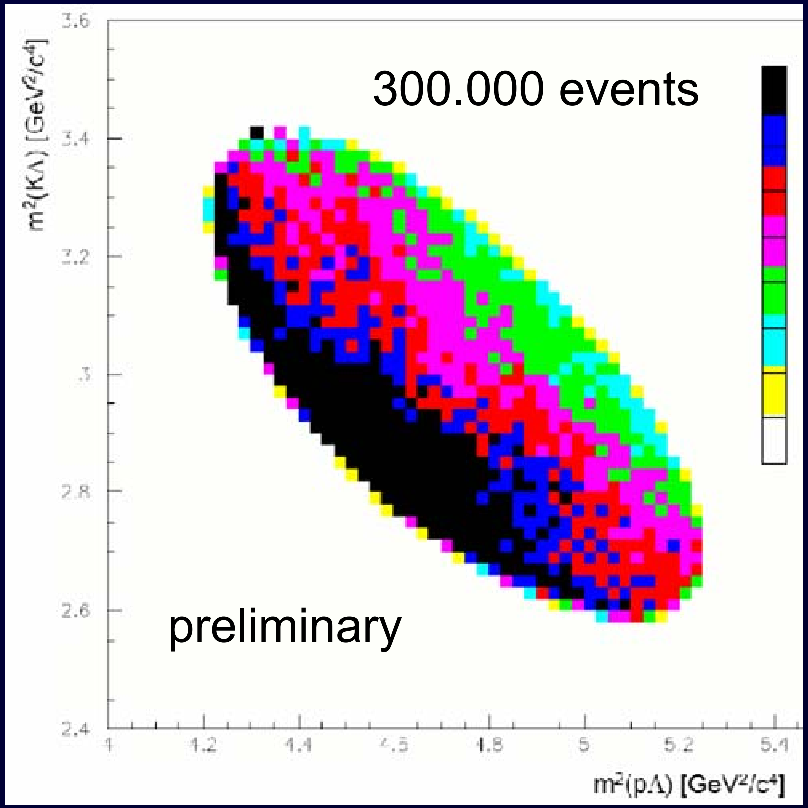
- distinguish overlapping N^* with different quantum numbers
- determine resonance properties: M, Γ, $b_{K\Lambda}$
- access N^* with mass ~ 1.9 GeV/c^2

New data on $\vec{p}p \to pK^+\Lambda$ excitation function from threshold to COSY limit

$\Rightarrow$ better statistics

$\Rightarrow$ polarized beam

N^* resonances in $K\Lambda$ production



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N^* studies with polarized beam

sensitivity study with Bonn-Gatchina PWA

(see also PWA of $\gamma p \to \Lambda K^+$, $\Sigma^0 K^+$, $\Sigma^+ K^0$ data

A.V. Anisovich *et al.*, hep-ph/0703216

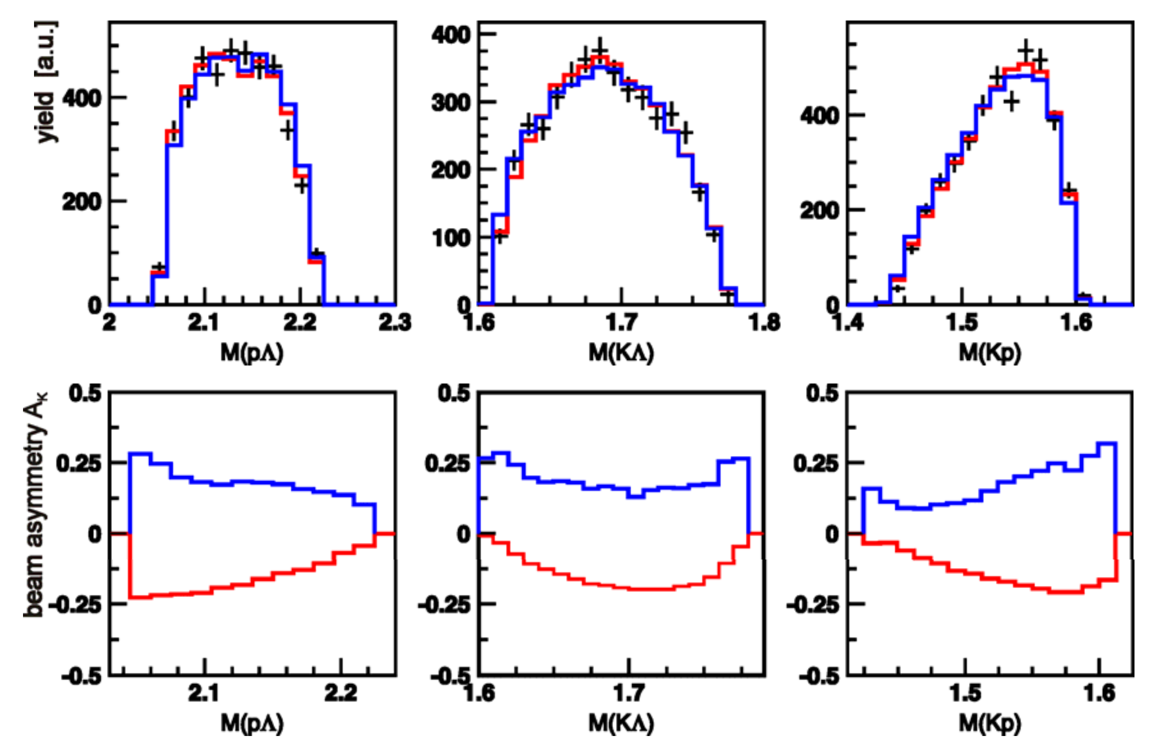
A.V. Sarantsev *et al.*, EPJA 25 (2005) 441)

considered: $S_{11}(1650)$, $P_{11}(1710)$ in the final state

two solutions found, describing unpolarized cross sections equally well

separation power is obtained with polarization observables

many more observables



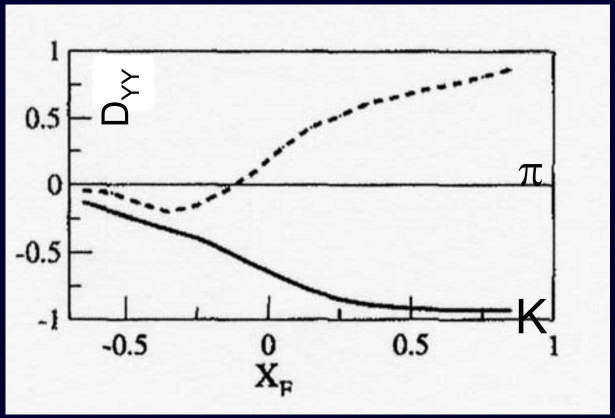
D_{NN} studies with polarized beam

spin transfer coefficient

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

vs

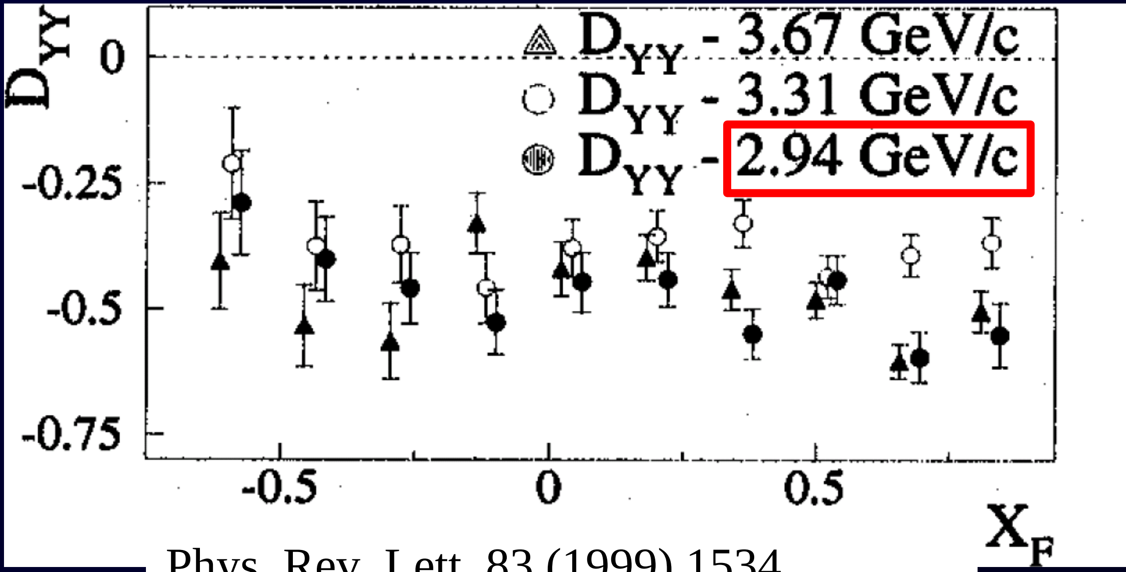
fractional longitudinal momentum of the Λ



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

DISTO

Nucl.Phy.A691(2001)329-335

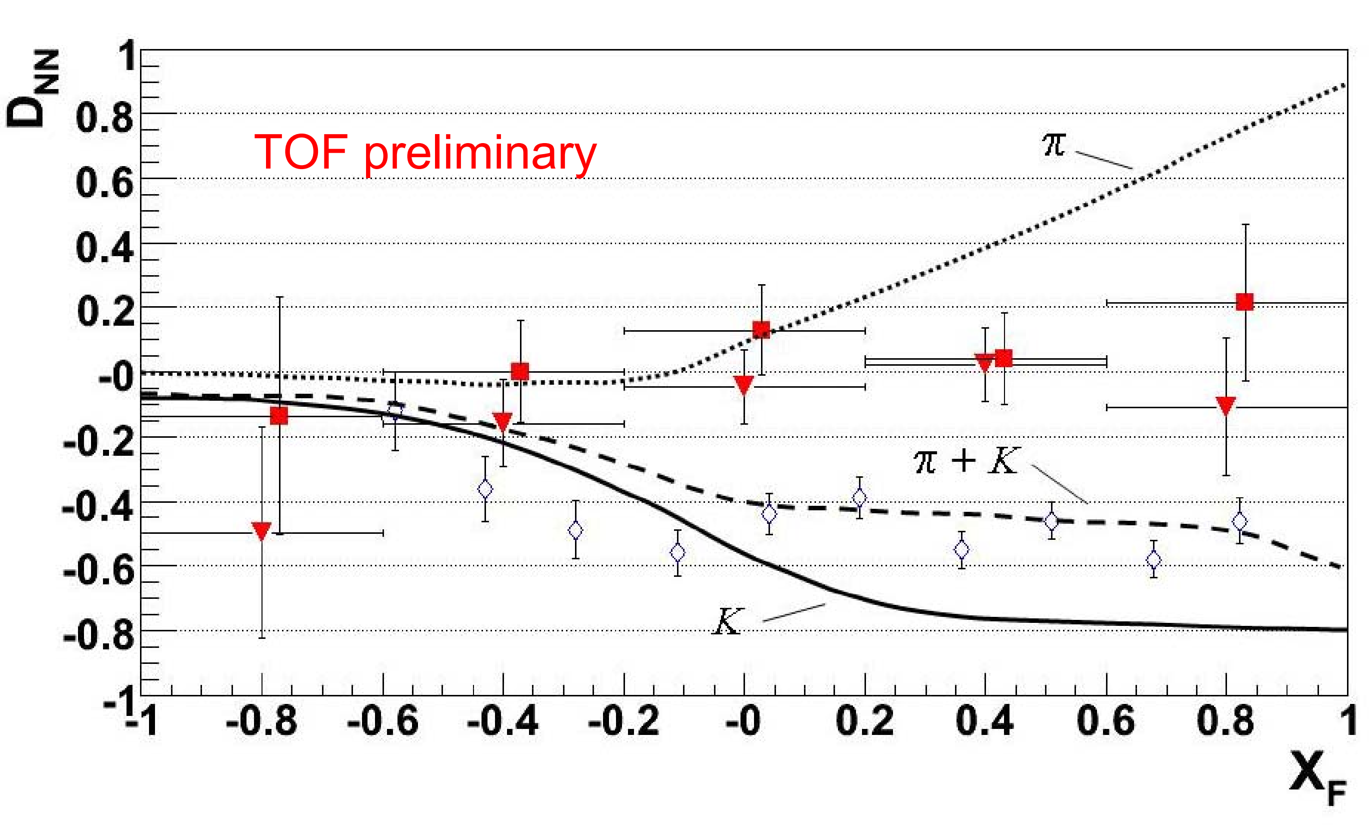


Phys. Rev. Lett. 83 (1999) 1534.
Nucl. Phys. B Proc. Suppl. 93 (2001) 58.

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

D_{NN} studies with polarized beam

Meson exchange modell (Laget)



Red points:
TOF data
▼ 2.75 GeV/c
■ 2.95 GeV/c
preliminary

Blue points:
◊ DISTO
at 2.94 GeV/c

→ Needs clarification!

Hyperon-nucleon interaction

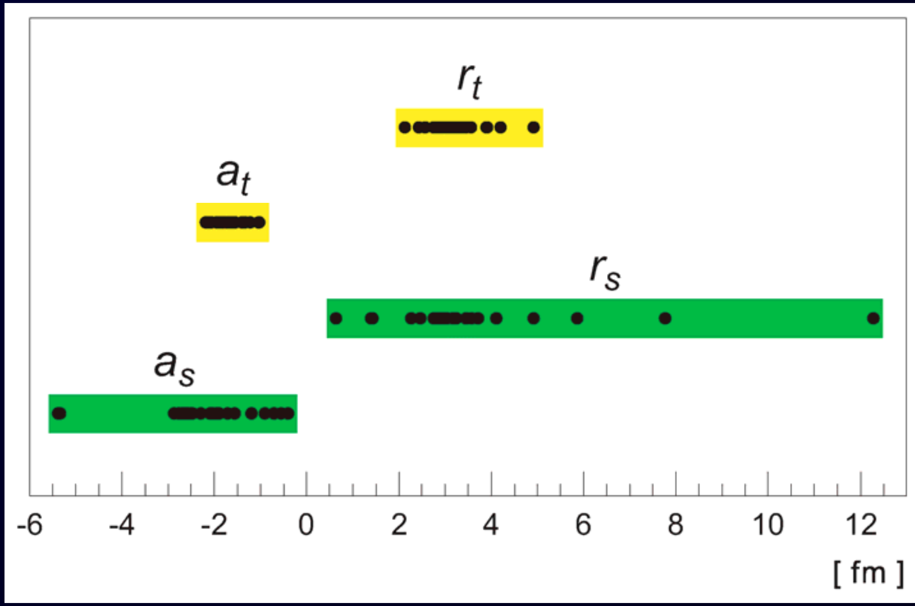
Important to improve understanding of:

- SU(3) flavor symmetry breaking of QCD
- Formation of hypernuclei
- Hyperon degrees of freedom for the EOS of nuclear matter

  e.g. structure of neutron stars

- poor data base:
  - little known on ΛN interaction
  - nothing known on ΣN interaction

$\Rightarrow$ large uncertainty in Λp scattering length



Hyperon-nucleon interaction

Model-free determination of Λp and $\Sigma^+ p$ scattering length in production reactions as $pp \rightarrow pK^+\Lambda$

A. Gasparyan *et al*., PRC 69 (2004) 034006

a_s requires double polarization

$\Rightarrow a_t$ can be measured with single polarized measurement:

$\vec{p}p \rightarrow pK^+\Lambda$ at $\theta_{K,\,cm} = 90^o \pm \Delta\theta$

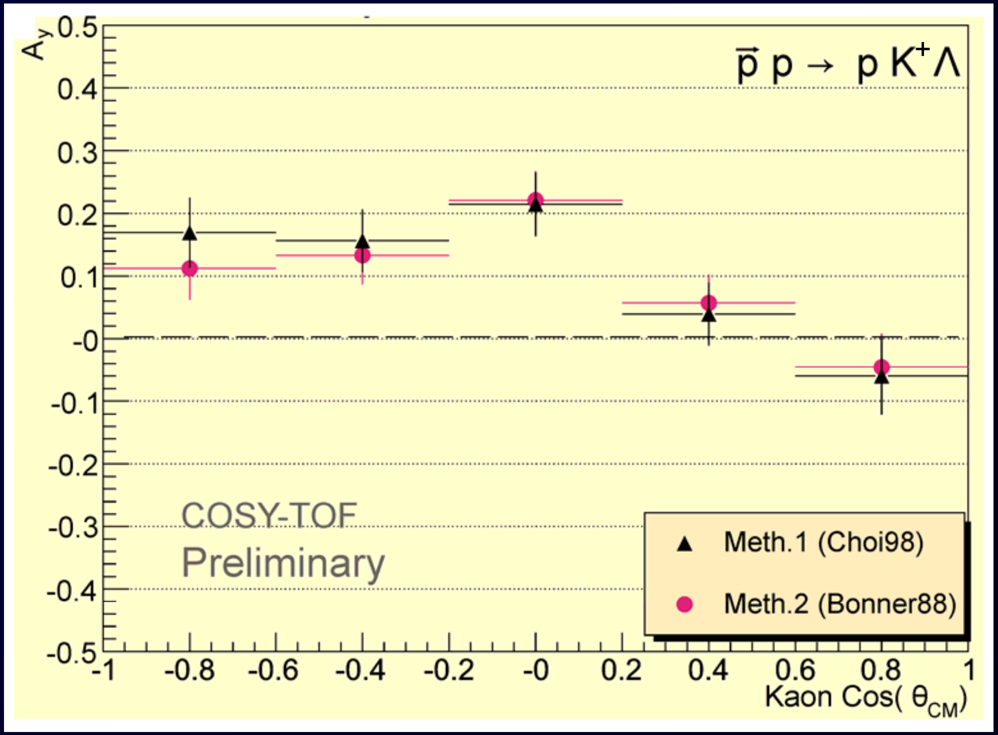
Hyperon-nucleon interaction

- goal:
  measure a_t (Λp) to 0.3 fm accuracy

- analysis of COSY-TOF data indicate ~20% analyzing power

- required Λp inv. mass resolution < 5 MeV achievable with straw tube tracker

- excess energy ~ 50 – 100 MeV



- determine unpolarized Σ^+p scattering length

Other topics

- $K^{-}pp$ system below threshold
  - existence of bound nuclear kaonic clusters?
  - measurement at highest possible COSY beam momentum
  - combination with study of N^* resonances

- η production (pol)
- ω production (pol)

} coupling to N^* resonances

parallel to strangeness program, reduced trigger

- 2π production on nuclear targets

Summary & Outlook

- 1st step: implement straw tube tracker & silicon quirl telescope
- commissioning of whole system in 2008
- full program on N* resonance studies in $\vec{p}p \to pK^+\Lambda$
- complementary information from $pp \to pK^0\Sigma^+$, $pK^+\Sigma^0$
- lowest energy: simultaneous measurement of a_t ($p\Lambda$)
- highest energy: simultaneous study of K^-pp binding
- exploratory study of N* in pn induced reactions

entrance channel	beam momentum (GeV/c)	time (weeks)	physics goal
$\vec{p}p$	2.70	3 + 2	$N^* \to K\Lambda, K\Sigma, \Lambda p$ int.
	2.95	3	$N^* \to K\Lambda, K\Sigma$
	3.15	3	$N^* \to K\Lambda, K\Sigma$
	3.35	4	$N^* \to K\Lambda, K\Sigma, K^-pp$
$\vec{p}d$	2.95	2	$N^* \to K\Lambda, K\Sigma$
pd, p^{14}N	1.45	2	nuclear medium effects

Additional

N^* studies with polarized beam

sensitivity study with Bonn-Gatchina PWA — A.V. Anisovich *et al.*, hep-ph/0703216

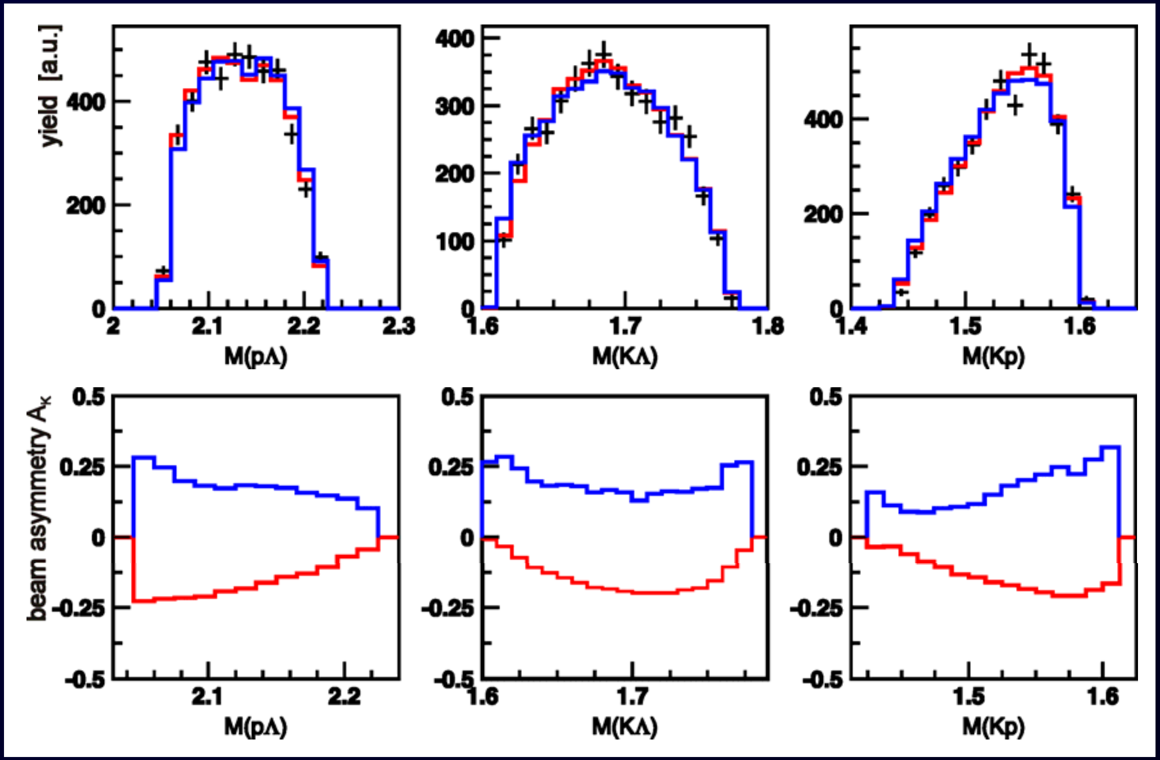
(see also PWA of $\gamma p \to \Lambda K^+$, $\Sigma^0 K^+$, $\Sigma^+ K^0$ data — A.V. Sarantsev *et al.*, EPJA 25 (2005) 441)

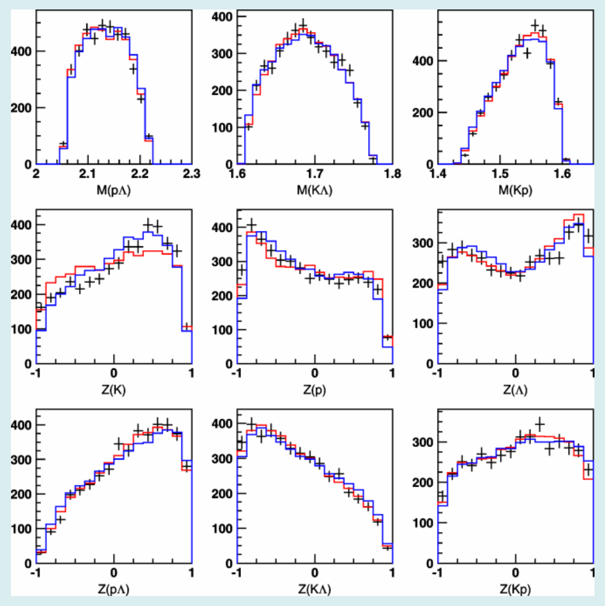
1.Solution (red)

Initial. pp interaction $^3P_2$, $^3P_0$, $^1S_0$

2. Solution (blue)

Initial. pp interaction $^3P_2$, $^3P_1$, $^1S_0$



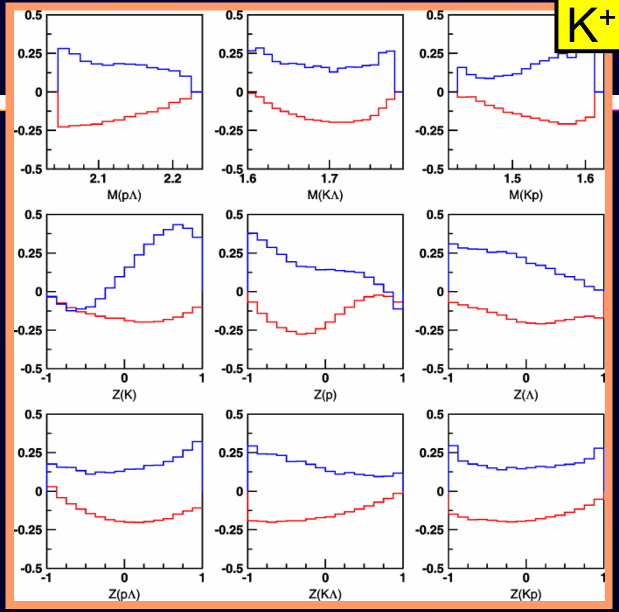


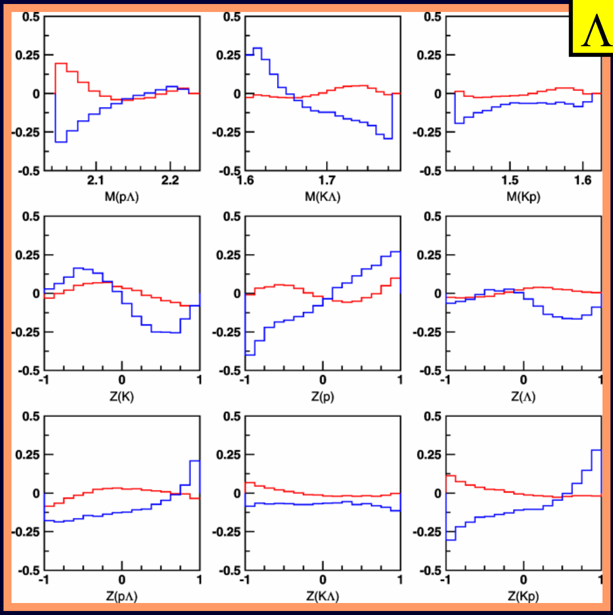
more observables …

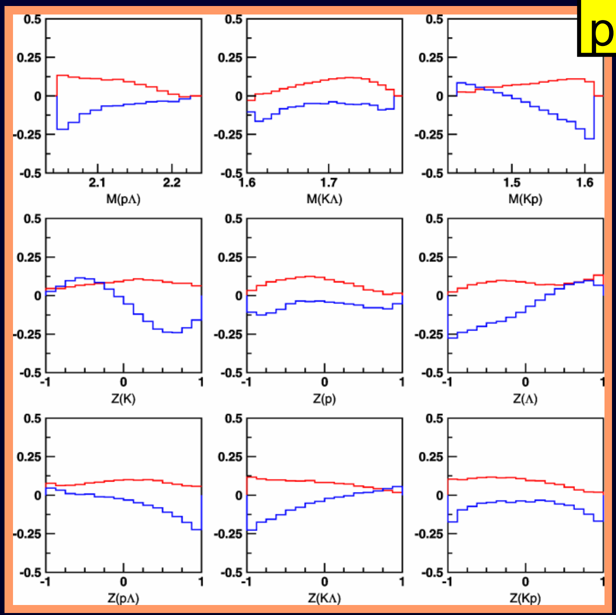
← unpolarized

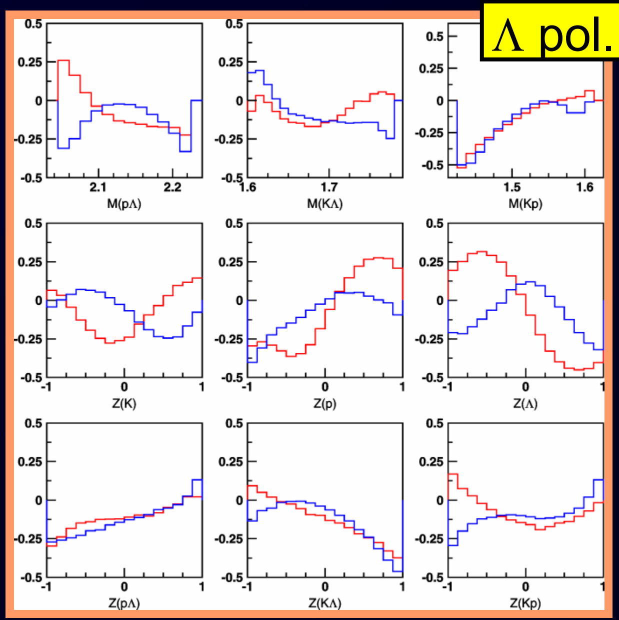
- pΛ, $K^+\Lambda$, K^+p inv. mass
- K^+, p, Λ ang. distribution
- pΛ, $K^+\Lambda$, K^+p ang. distribution
- K^+, p, Λ asymmetries, Λ pol.

polarized →

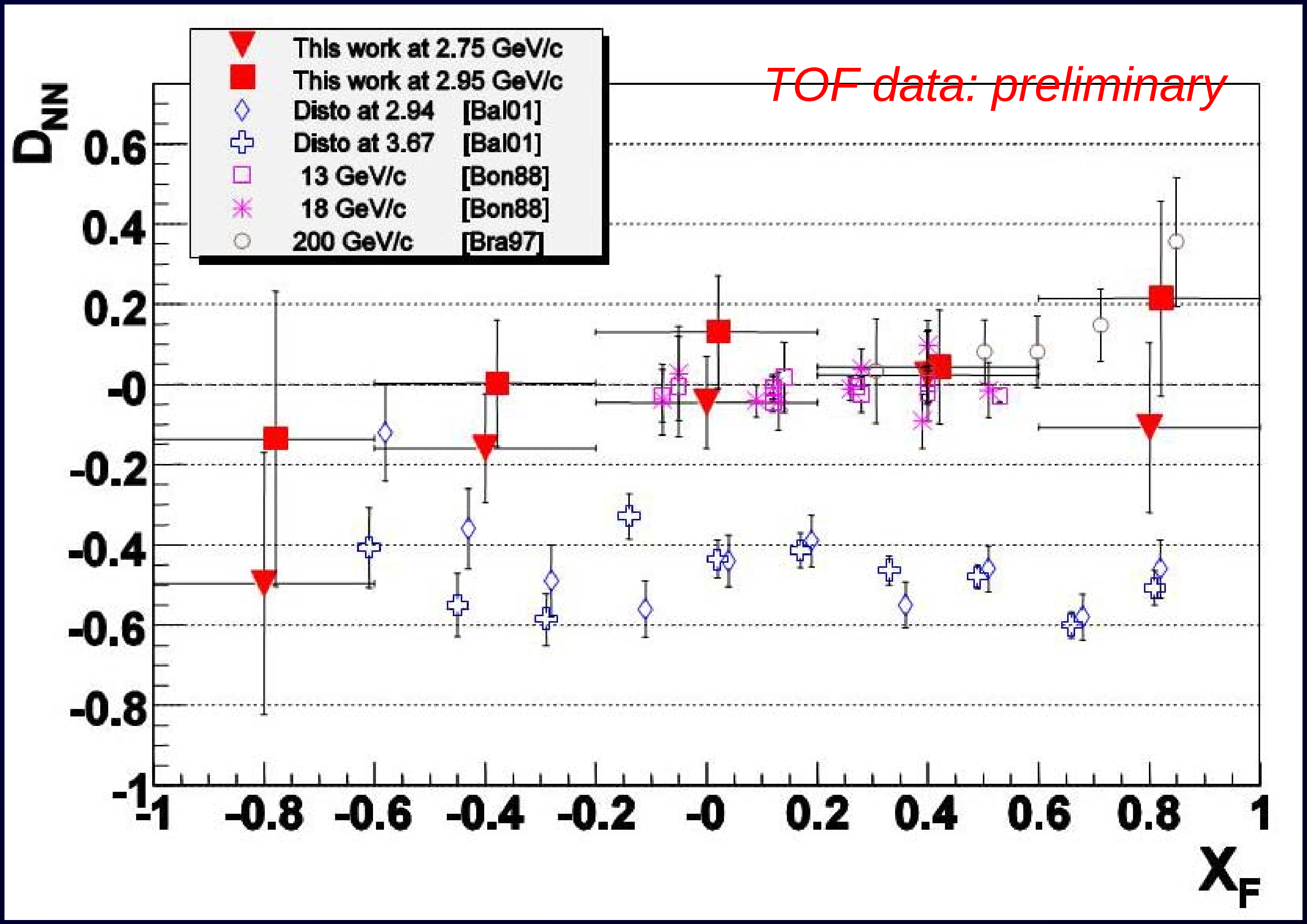








D_{NN} studies with polarized beam



Example of different formulas: lambda polarization

Weighted Sum: [Besset79]

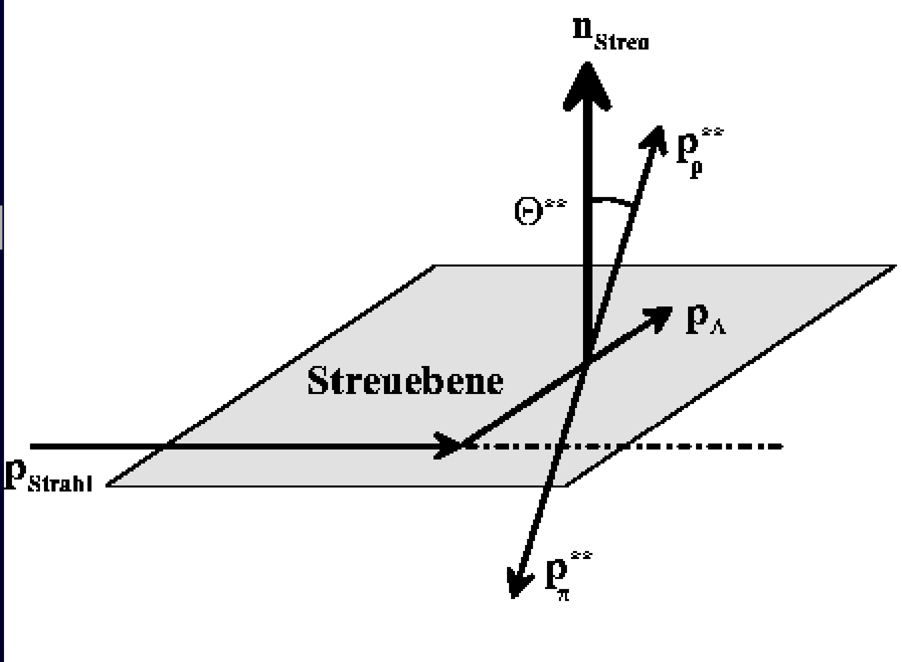
$$P_\Lambda = \frac{1}{\alpha} \frac{\sum_i n_i \cos(\theta_i^{**})}{\sum_i n_i \cos^2(\theta_i^{**})}$$

Up-Down Integral: [Bonner88]

$$P_\Lambda = \frac{2}{\alpha} \left(\frac{N_2 - N_1}{N_2 + N_1} \right)$$

$$N_1 = \int_{-1}^{0} f(\cos\theta^{**})\, d(\cos\theta^{**})$$

Self analyzing decay

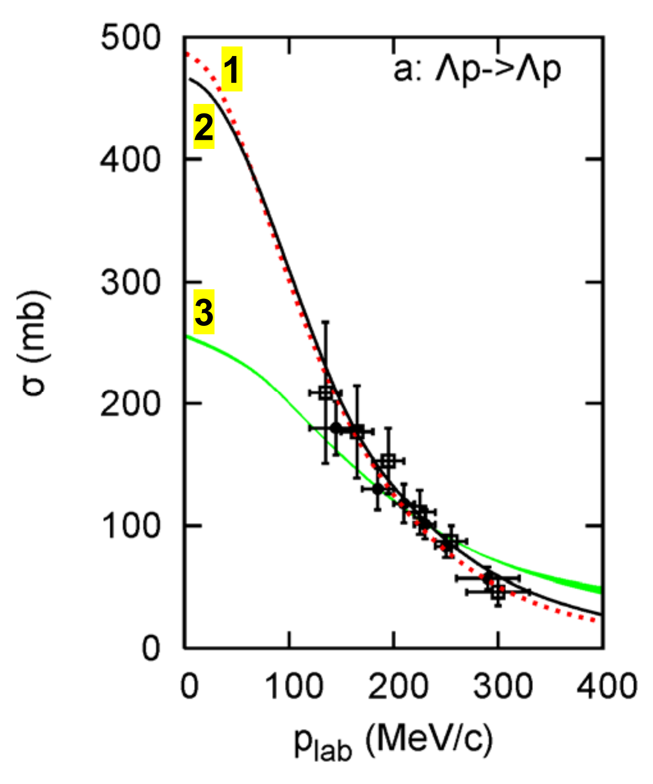


Symmetric Bins: [Choi98]

$$P_\Lambda(\theta_i^{**}) = \frac{1}{\alpha\ \cos\theta_i^{**}} \left(\frac{\int_{\theta_i^{**}}^{\theta_i^{**}+\Delta\theta} dN - \int_{\pi-(\theta_i^{**}+\Delta\theta)}^{\pi-\theta_i^{**}} dN}{\int_{\theta_i^{**}}^{\theta_i^{**}+\Delta\theta} dN + \int_{\pi-(\theta_i^{**}+\Delta\theta)}^{\pi-\theta_i^{**}} dN} \right)$$

Hyperon-nucleon interaction

- theory: YN reactions ↔ hypertriton to be described consistently



1: chiral EFT — H. Polinder et al., NPA 779 (2006) 244

2: Jülich ’04 model — J. Haidenbauer, U.-G. Meißner, PRC 72 (2005) 044005

3: Nijmegen NSC97f potential — Th.A. Rijken et al., PRC 59 (1999) 21