Westfälische
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Hadron Physics at COSY

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Physics Case

- Hadron-hadron interaction
  - Nucleon-nucleon
  - Meson-nucleon and Meson-nucleus
  - Meson-meson
- Structure of particles
  - a_0/f_0, $\Lambda(1405)$
  - exotics, penta-quarks
- Meson/hyperon production processes
- Symmetries and symmetry breaking

COSY Accelerator

Energy range
0.045 – 2.8 GeV (p)
0.023 – 2.3 GeV (d)
(momentum 3.7 GeV/c)

Cooling
2 methods:
electron, stochastic

Polarization
p, d beams & targets

Beams
internal, extracted

Experiments, detectors
ANKE, TOF, WASA, …

COSY (Cooler Synchrotron) at Jülich (Germany)

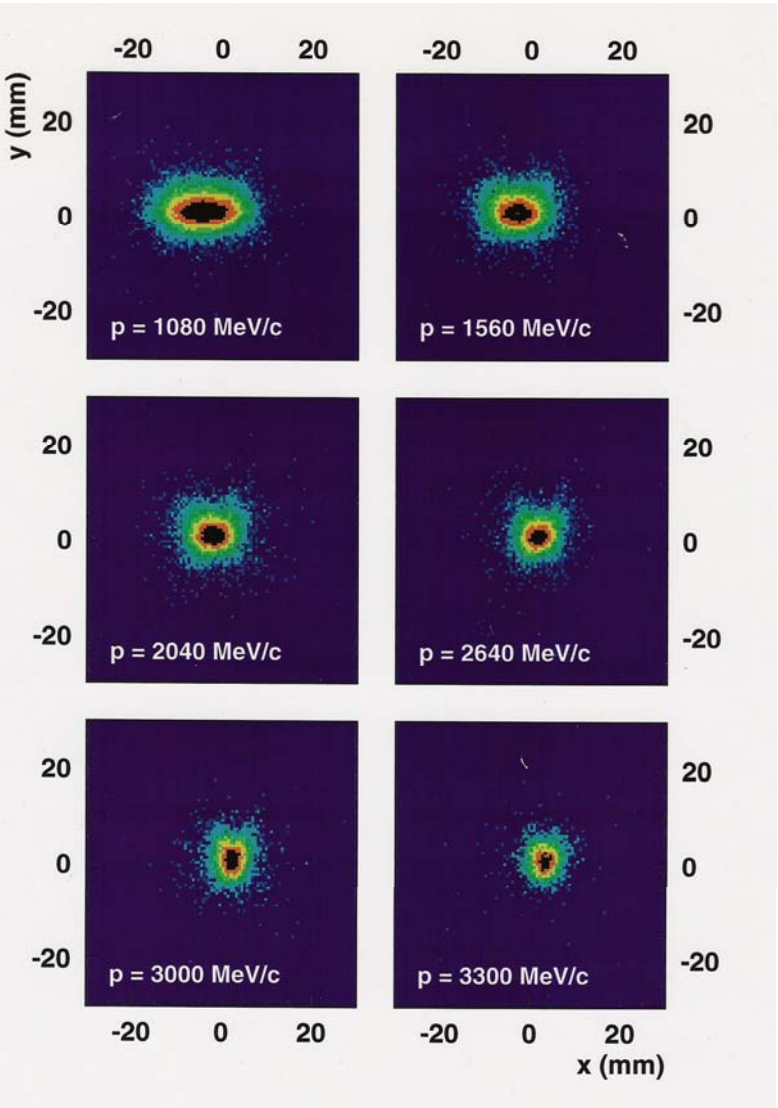
COSY Beam Parameters

- Beam quality:
  - without cooling: $\Delta p/p \sim 2 \cdot 10^{-4}$
  - electron cooling: $\Delta p/p \leq 5 \cdot 10^{-5}$ p_p<0.6 GeV/c
  - stochastic cooling: $\Delta p/p \leq 5 \cdot 10^{-5}$ p_p>1.5 GeV/c
  - $\varepsilon = \pi$ mm mrad 1mmØ·0,18°
- Beam intensities:
  - protons, unpolarized: $1 \cdot 10^{10}$ (cooled)
  - protons, polarized: $2 \cdot 10^{9}$ (cooled)
  - deuterons, unpolarized: $5 \cdot 10^{10}$ (cooled)
  - deuterons, polarized: $3 \cdot 10^{9}$ (cooled)

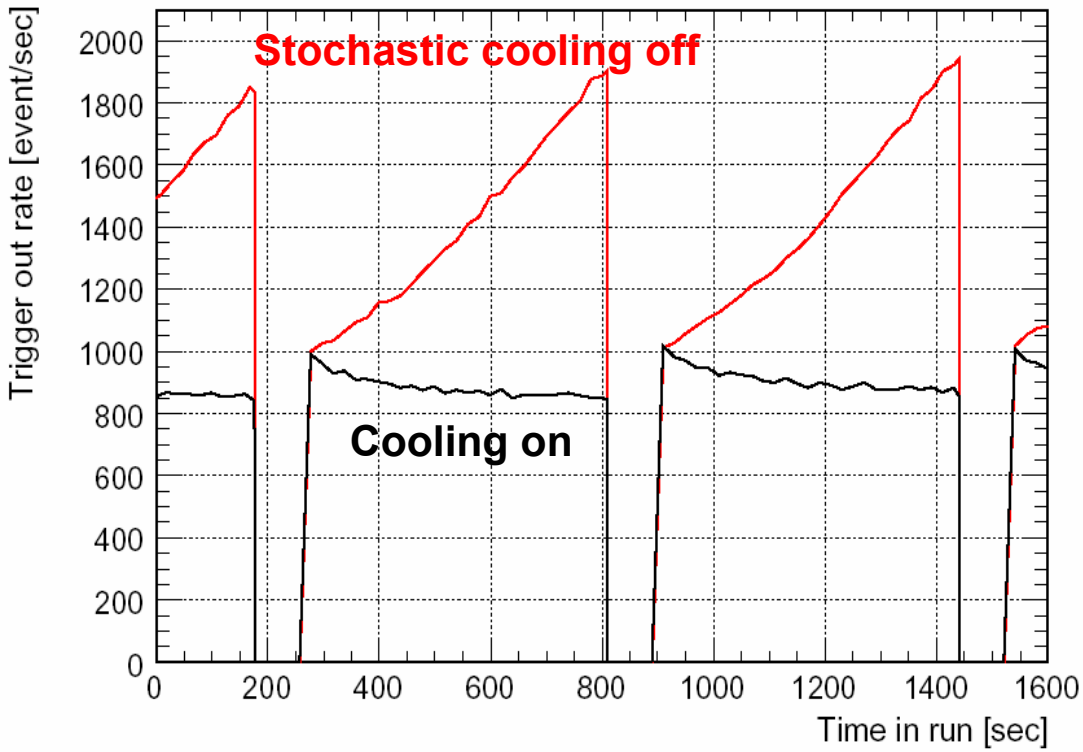
COSY Beam Parameters

- Extracted beam
  - 10^5 ... 10^9 protons/s in spill
  - slow extraction: 10 s ... > 10 min spill
    10(5) s inter-spill (un)cooled
  - fast extraction: $2 \cdot 10^9$ protons in 200 ns
    every 15 s
  - quasi-DC beam
  - polarized beam: deuterons and protons

COSY Beam Parameters



beam size decrease during acceleration (adiabatic shrinkage)



effect of stochastic cooling

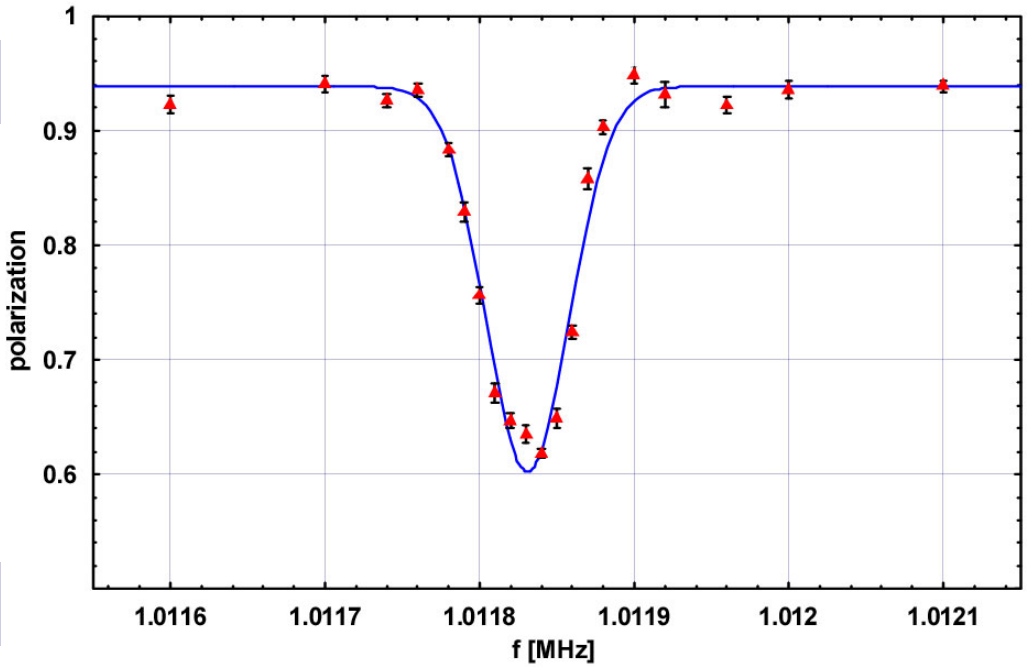
COSY Accelerator

- Absolute beam momentum determination
  - „conventionally“: $\Delta p/p \sim 1 \cdot 10^{-3}$
  - Spin-resonance method: $\Delta p/p \sim 3 \cdot 10^{-5}$

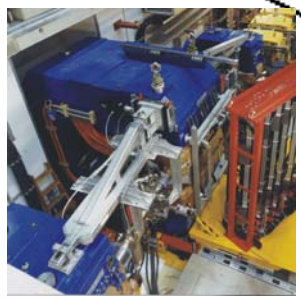
spin resonance method

$$\gamma = \frac{1}{|G|} \cdot \left(1 - \frac{f_{res}}{f_0}\right)$$

Schottky measurement



Current Experiments at COSY



COSY 11

WASA

ANKE

COSY

(Cooler Synchrotron)

EDDA

PISA

COSY 13

TOF

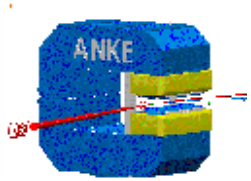
JESSICA

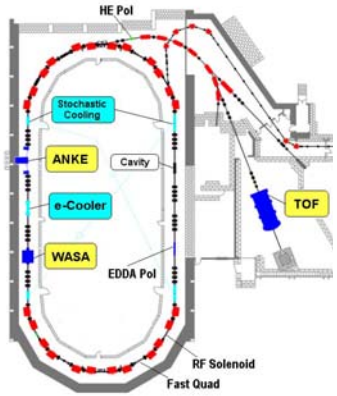
Big Karl

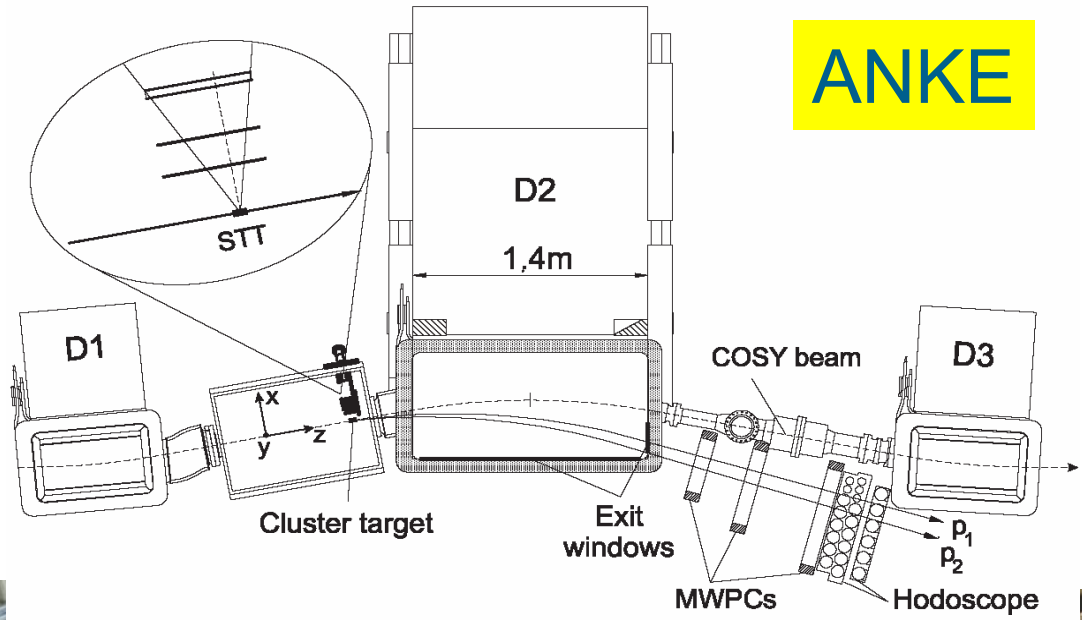
JULIC (Injector Cyclotron)

Schematic overview COSY Facility (FZ-Jülich)

Experiments: ANKE



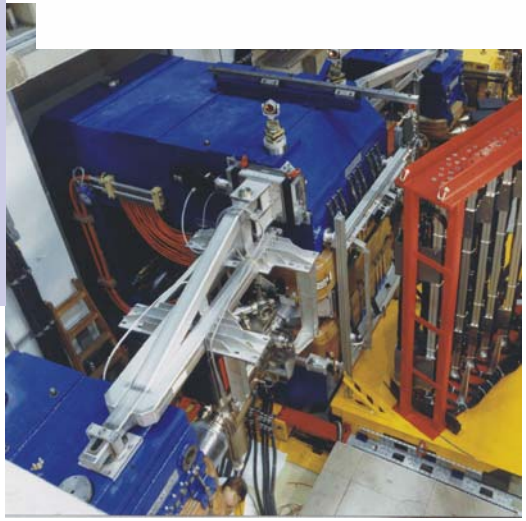


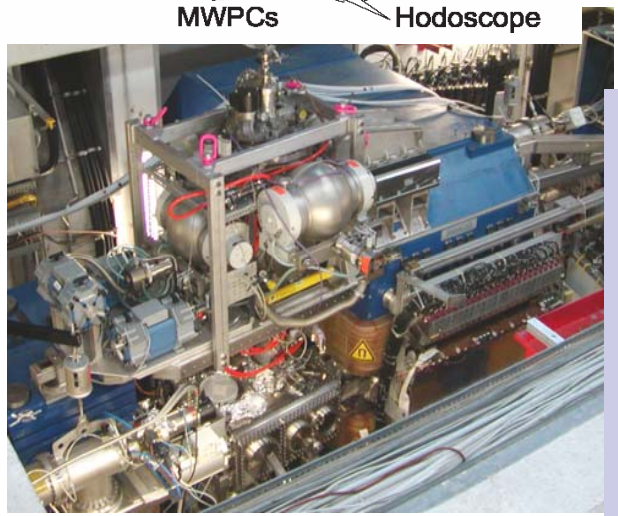


ANKE uses foil, cluster jet and polarized targets

ANKE is a magnetic forward spectrometer in COSY;

„chicane“



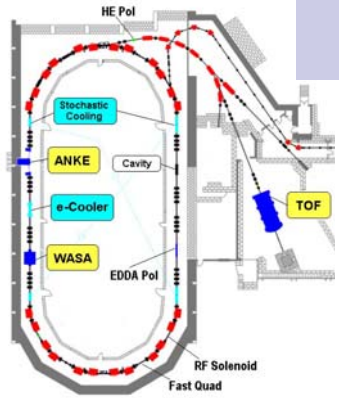


deuterons + spect. detector

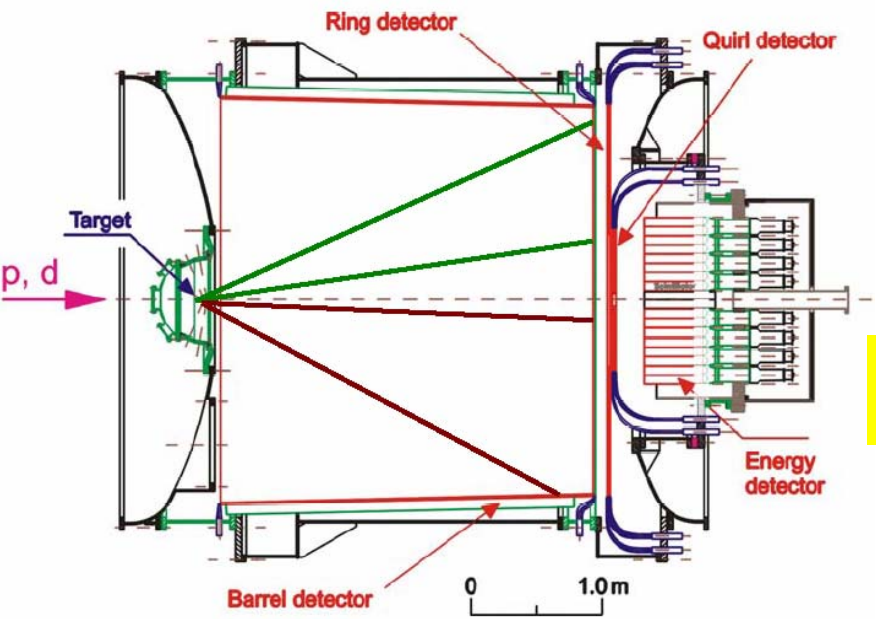
↔

effective neutron target

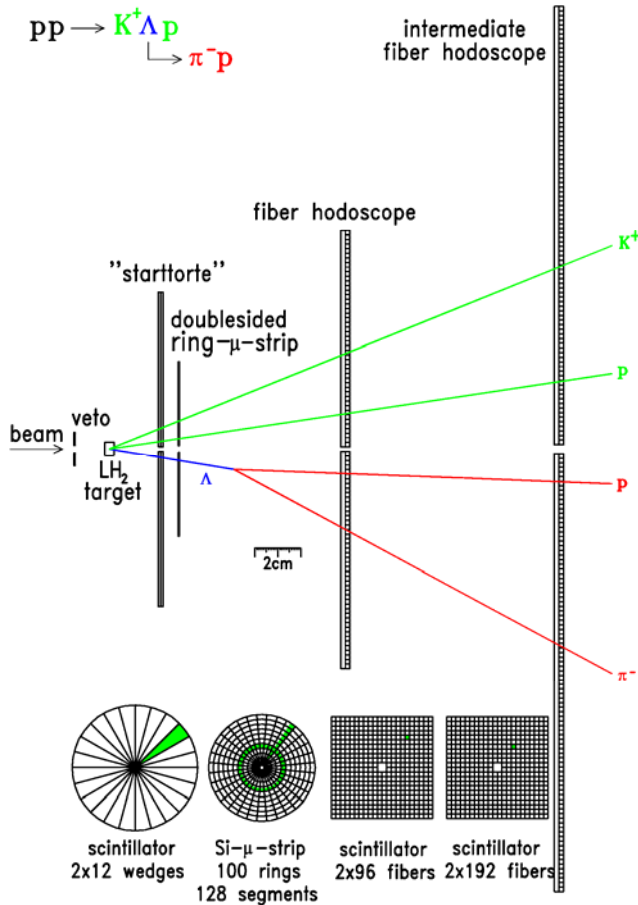
Experiments: TOF



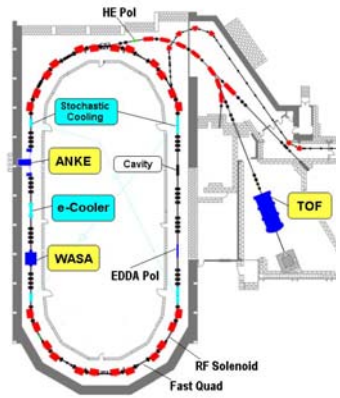
TOF is an external time-of-flight spectrometer high acceptance

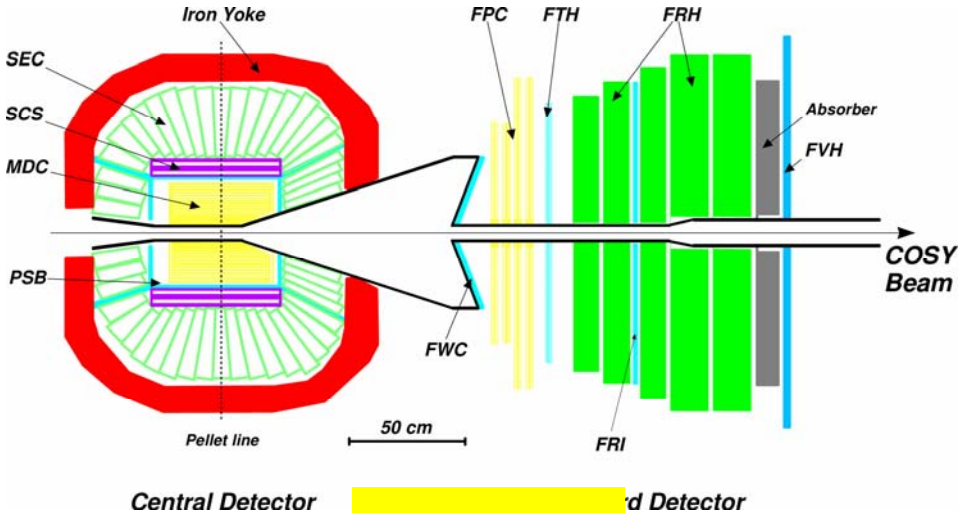


TOF



Experiments: WASA-at-COSY

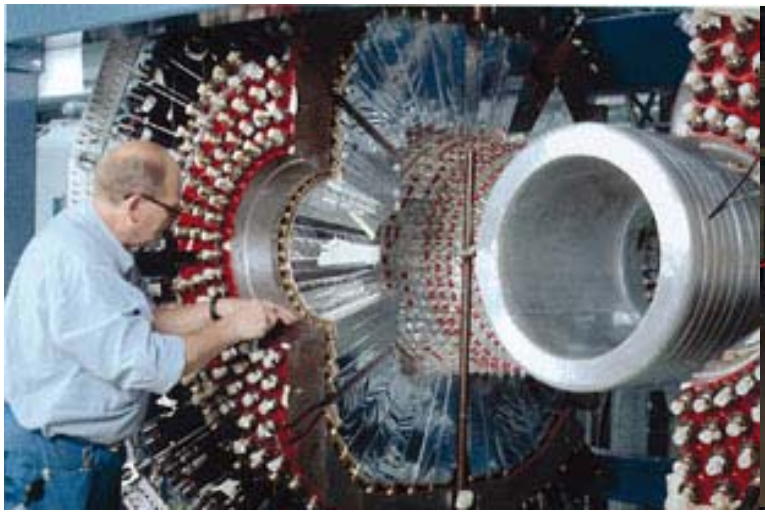


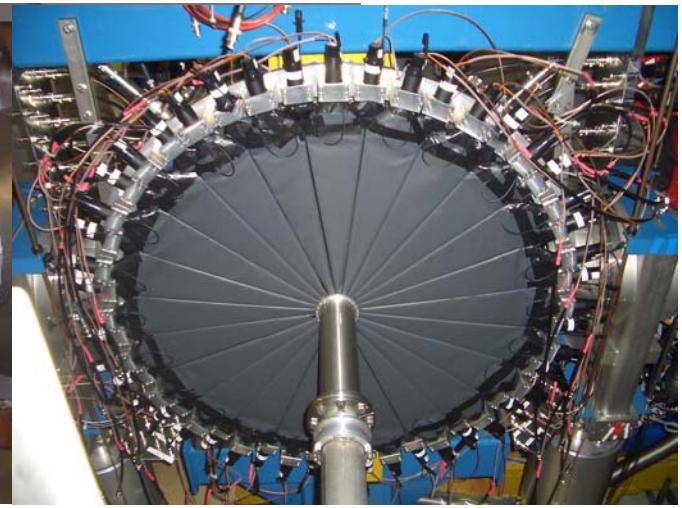


WASA is a 4π detector in COSY

EM calorimeter, SC solenoid, forward det´s, pellet target

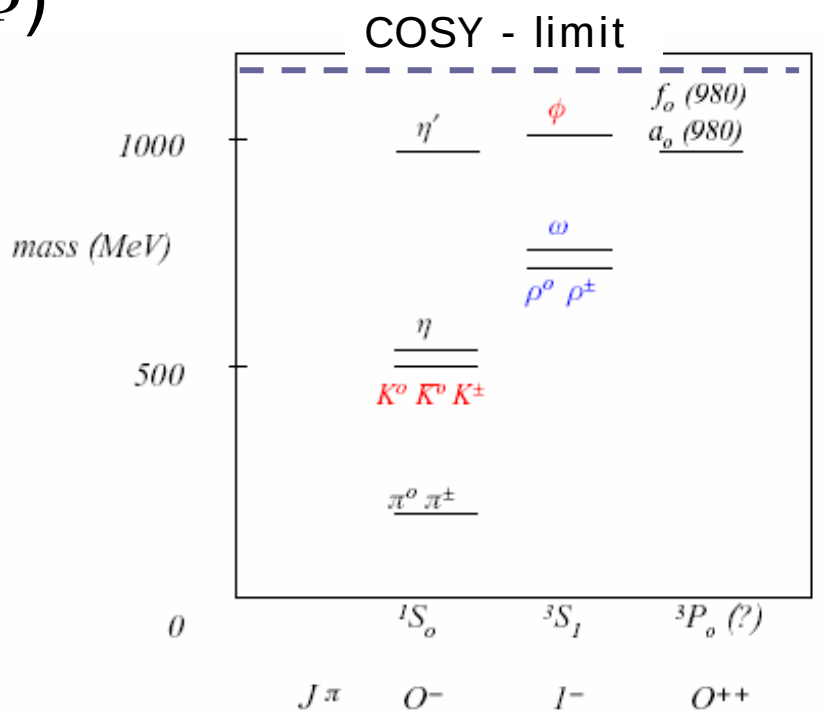
WASA





Meson Production at COSY

- Max. COSY beam momentum: 3.7 GeV/c allows for production of
  - pseudoscalar mesons (π, K, η, η')
  - vector mesons (ω, $\rho^{\pm,0}$, Φ)
  - scalar mesons (a_0, f_0)



Charge Exchange Breakup (CEB)

- Reaction: $\vec{d}+\vec{p} \rightarrow (pp)_{s\text{-wave}}+n$ CEB
- Precision data for low excitation energies:
  $\rightarrow {}^1S_0(pp)$
- Determination of analysing powers
  (A_{xx}, A_{yy}, ...)
- Information about spin-dependent charge-exchange amplitude np $\rightarrow$ pn

$$f_{np} = \alpha + i\gamma(\sigma_n + \sigma_p)n + \beta(\sigma_n \cdot n)(\sigma_p \cdot n) + \delta(\sigma_n \cdot m)(\sigma_p \cdot m) + \varepsilon(\sigma_n \cdot l)(\sigma_n \cdot l)$$

Charge Exchange Breakup (CEB)

- Reaction: $\vec{d}+p \rightarrow (pp)_{s\text{-wave}}+n$ CEB
- Precision data for low excitation energies:

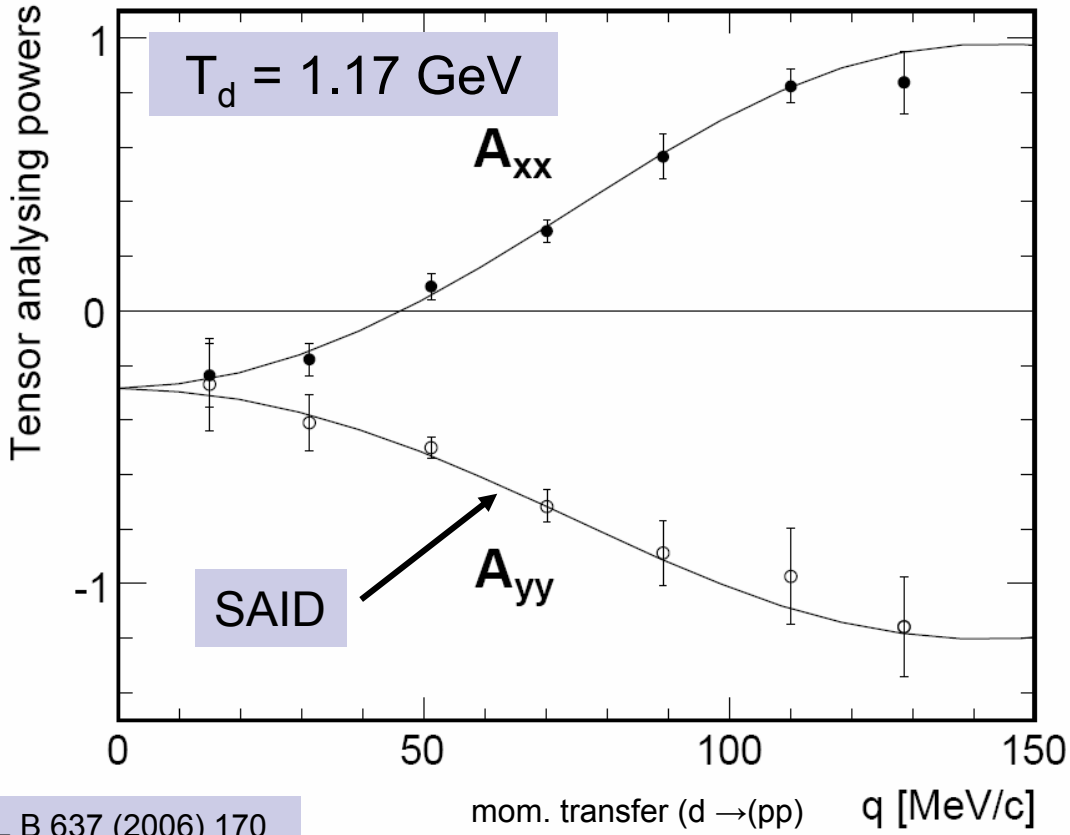
  $\rightarrow {}^1S_0(pp)$

analysing powers

A_{xx}, A_{yy}

$\leftrightarrow$

np-amplitudes



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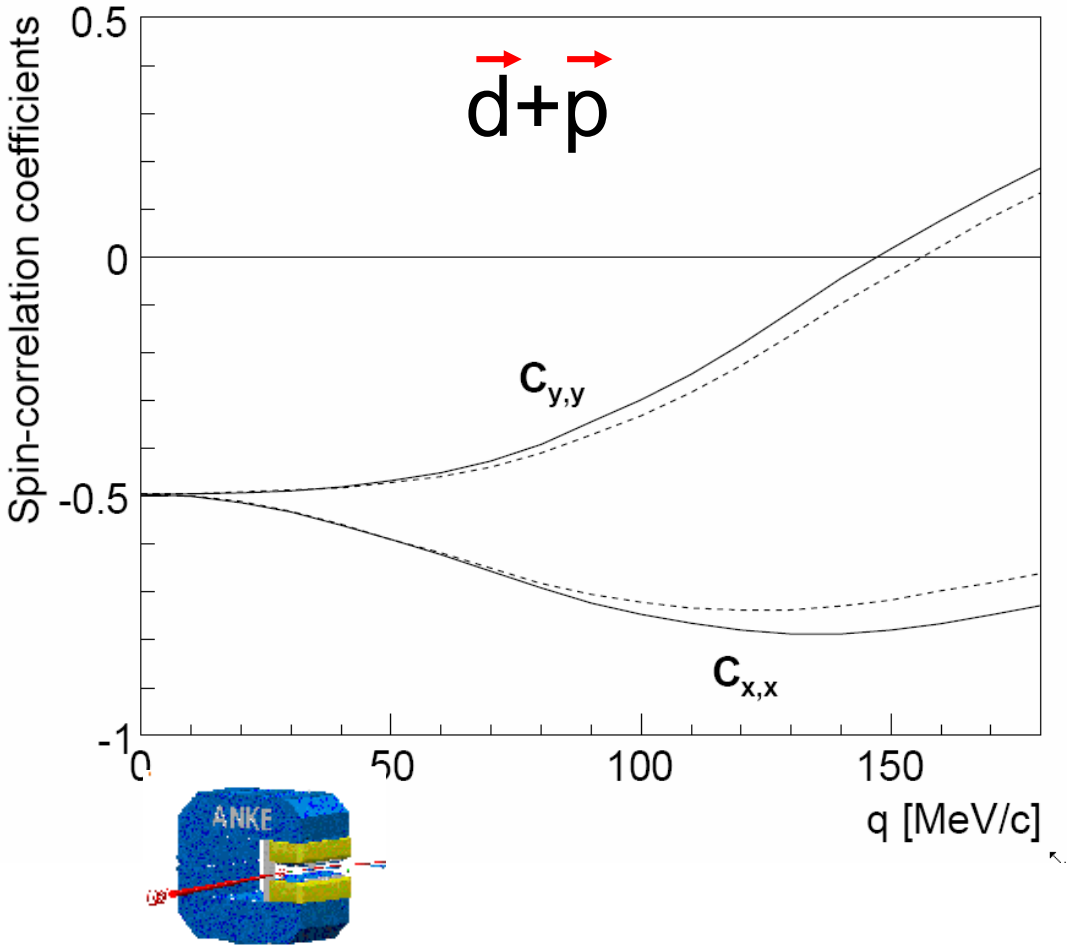
Charge Exchange Breakup (CEB)

- Double-spin experiments in preparation



- All components prepared
- ANKE ready for data taking
- Beam time sheduled

pp→(pp)X at COSY-ANKE

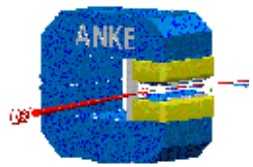
see talk: S. Dymov

Vector Meson Production

- Reactions:

  $pp \rightarrow pp\omega$, ω identification via missing mass

  $pp \rightarrow pp\Phi$, Φ identification via invariant mass of decay products (K^+K^-)



- Determination of total and differential cross sections
- Investigation of OZI-rule violation

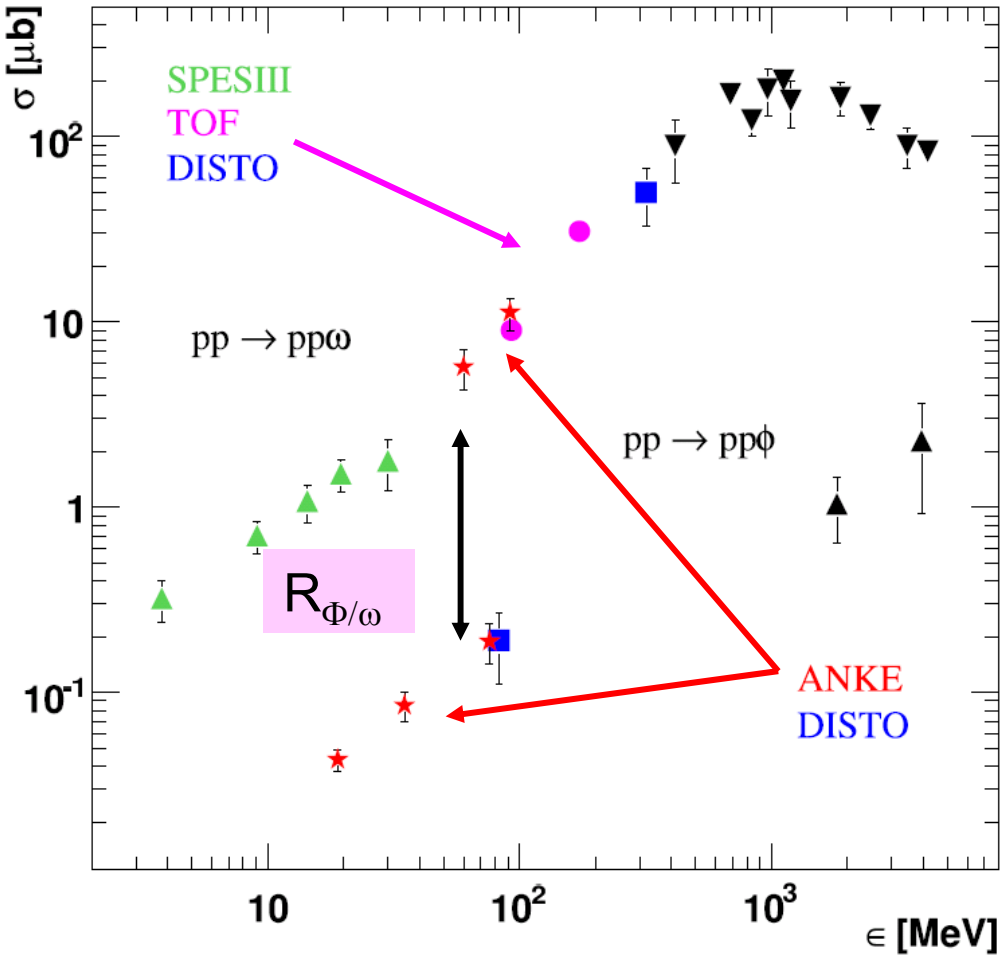
$$\Re_{\Phi/\omega} = \frac{\sigma_{pp\to pp\Phi}}{\sigma_{pp\to pp\omega}} = c \times \tan^2\left(\Delta\vartheta_V = 3.7^\circ\right) = c \times 4.2 \cdot 10^{-3} = c \times \Re_{OZI}$$

Vector Meson Production: pp→ppV

- Observation of s-wave-dominance close to threshold
- Indications for similar production processes ($d\sigma/d\Omega$)
- $R_{\Phi/\omega} \sim 7 \cdot R_{OZI}$ at Q = 93 MeV

pp→ppω at COSY-TOF

see talk: W. Ullrich



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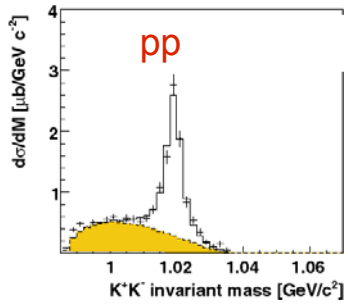
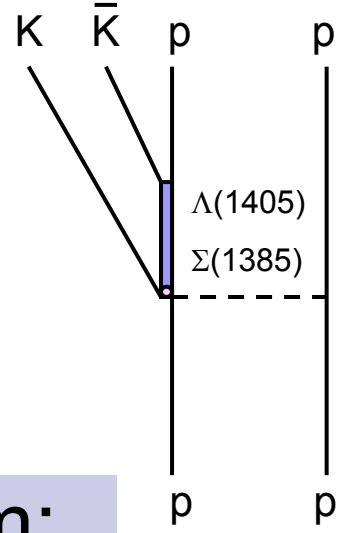
Meson Pair-Production: $pp \rightarrow pp K^+K^-$

- Production of non-strange meson?
  - $\Phi(1020)$ → test of OZI rule in NN
  - $a_0/f_0(980)$ → molecular state
    $\Gamma(a_0/f_0 \rightarrow KKbar)$?
- Hyperon production?
  - $pp \rightarrow pK^+Y(1385/1405)$
    $\rightarrow pK^+(pK^-)$
- Meson-Nucleon FSI?



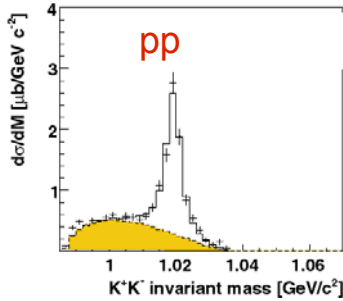


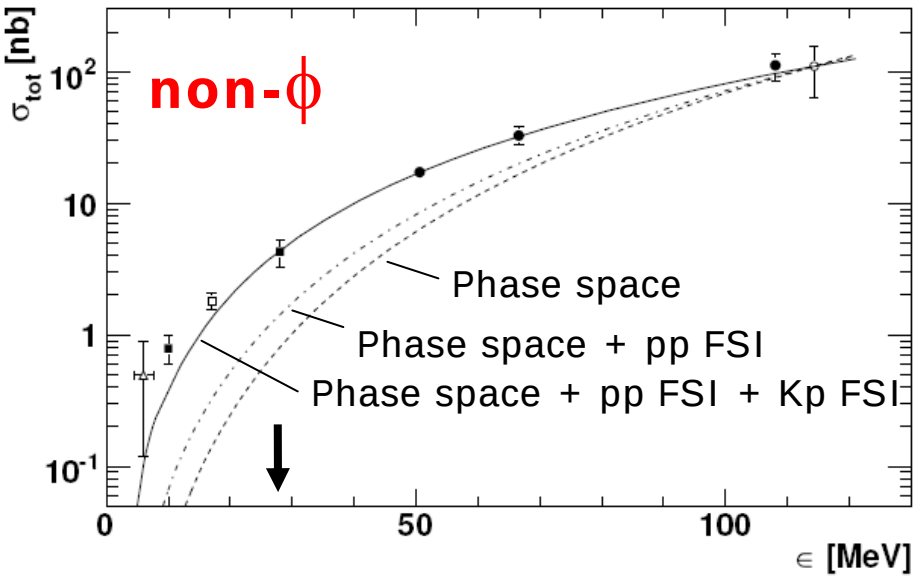
Which is/are the relavant mechanism:

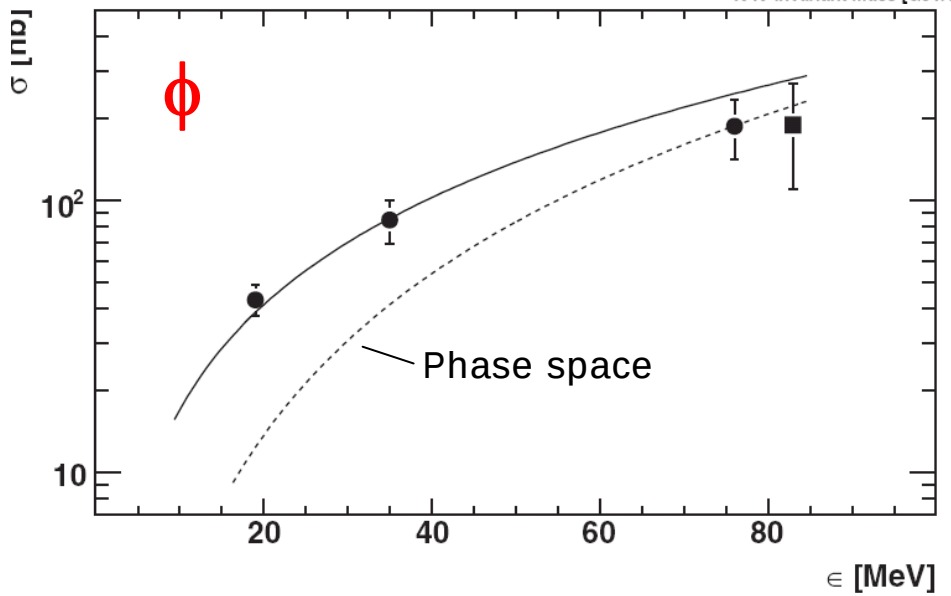
$pp \rightarrow pp a_0/f_0(980)$ $pp \rightarrow pK^+Y^*$

Meson Pair-Production: K^+K^-

- Precision data on kaon pair production
  - Investigation of final state interactions
  - Indications for production processes







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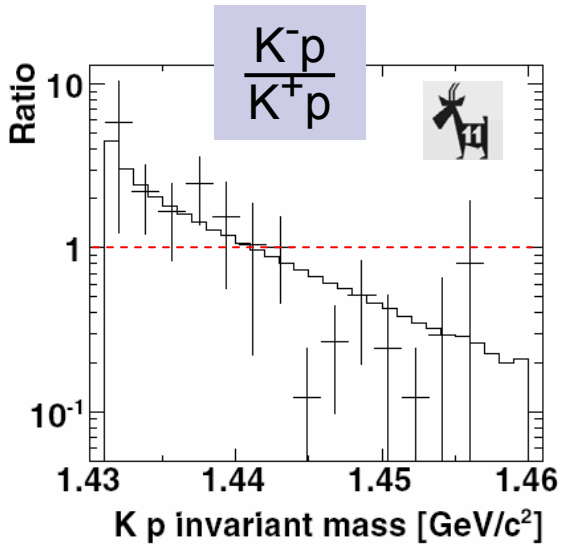
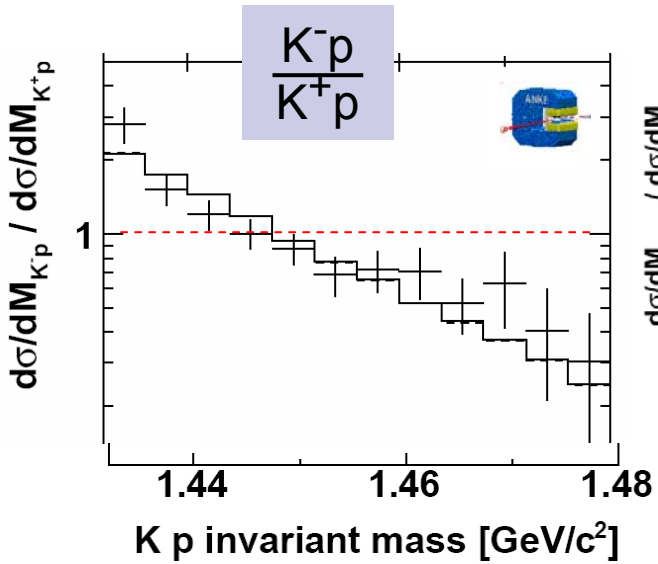
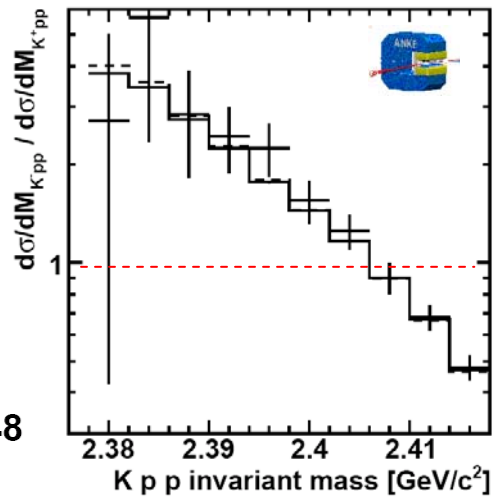
Meson Pair-Production: K^+K^-







$$F = F_{pp}(q_{pp}) \times F_{Kp}(q_{Kp_1}) \times F_{Kp}(q_{Kp_2})$$

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$$|F_{pp}(q)|^2 = \frac{q^2+\beta^2}{q^2+\alpha^2}$$

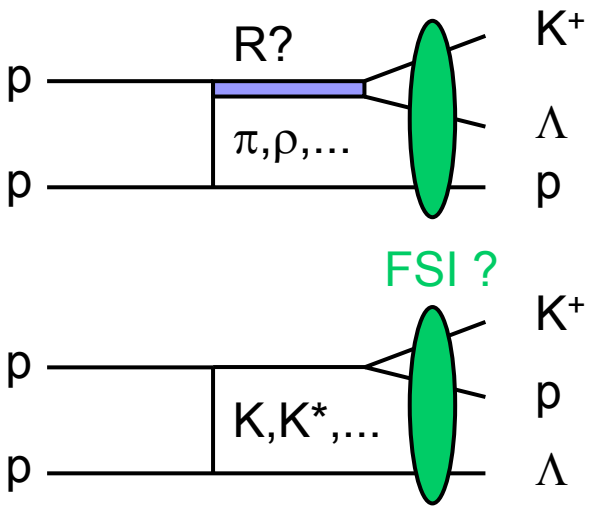
$$F_{Kp}(q) = \frac{1}{1-iqa}$$

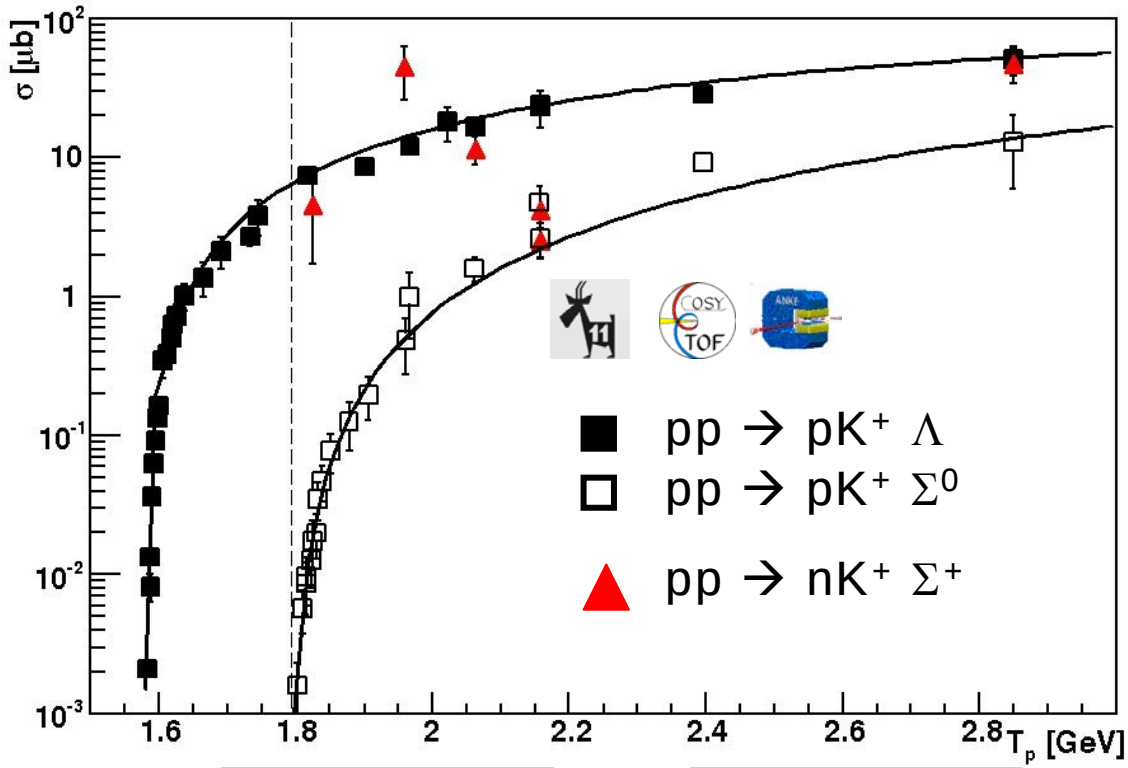
Quantitative description:

strong (K^-p) FSI: $|a| \sim 1.5$ fm no K^+p FSI

Hyperons: $pp \rightarrow pK^+Y$, $Y = \Lambda, \Sigma^+, \Sigma^0$

- Investigation of relevant production mechanism





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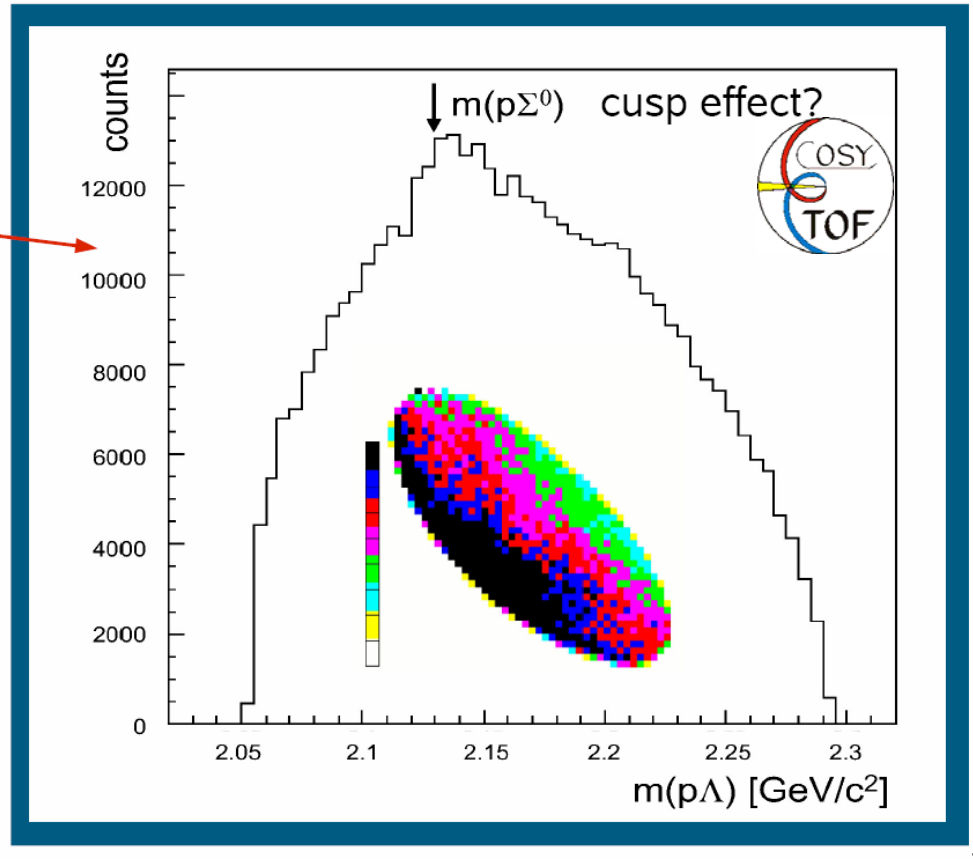
- total cross sections not sufficient

Hyperon Production: $pp \rightarrow pK^+\Lambda$

High statistics Dalitz plot at 3.06 GeV/c

320.000 $pK^+\Lambda$

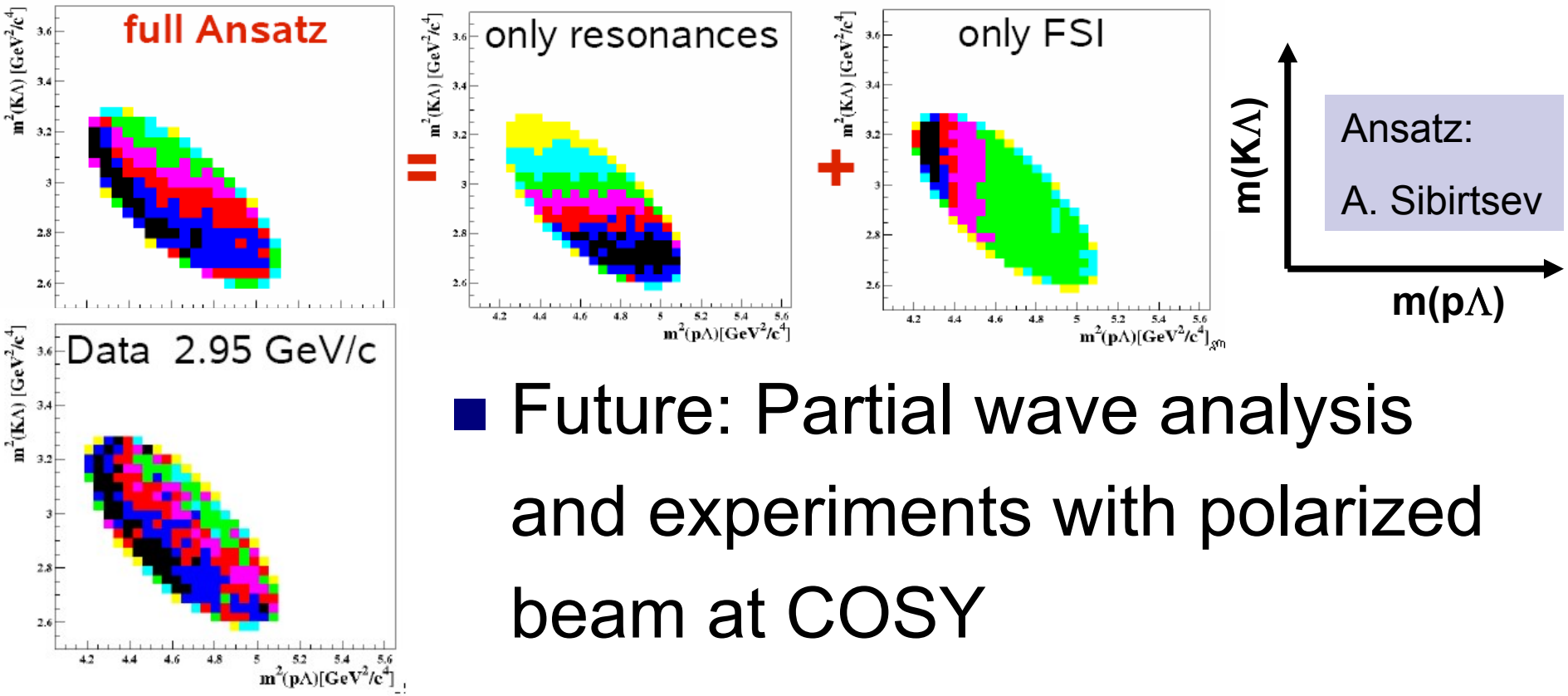


- Indication for cusp effect
- Data indicate contributions from nucleon resonances and $p\Lambda$ FSI

Hyperon Production: $pp \rightarrow pK^+\Lambda$

- Indications for contributions from: N*(1650) N*(1710) N*(1720)

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

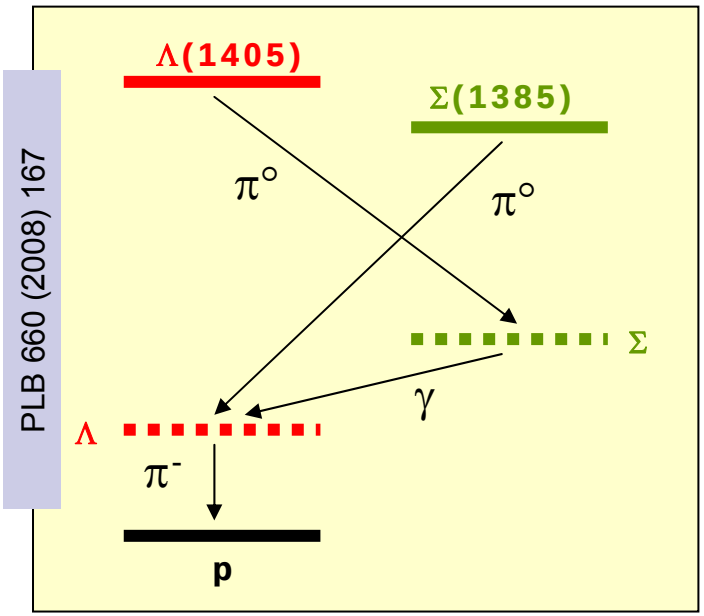


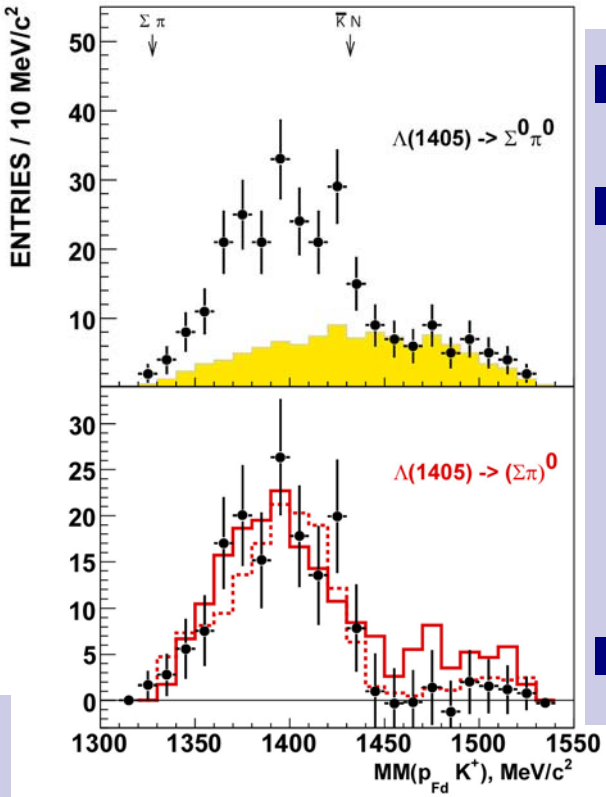
- Future: Partial wave analysis and experiments with polarized beam at COSY

Hyperon Production: $\Lambda(1405)$

- Reaction (p_{beam}=3.65 GeV/c):

$$pp \rightarrow pK^+\Sigma^0(1385) \rightarrow pK^+(\Lambda\pi^0) \rightarrow pK^+(p\pi^-)\pi^0$$
$$pp \rightarrow pK^+\Lambda(1405) \rightarrow pK^+(\Sigma^0\pi^0) \rightarrow pK^+(\Lambda\gamma)\pi^0 \rightarrow pK^+(p\pi^-)\gamma\pi^0$$





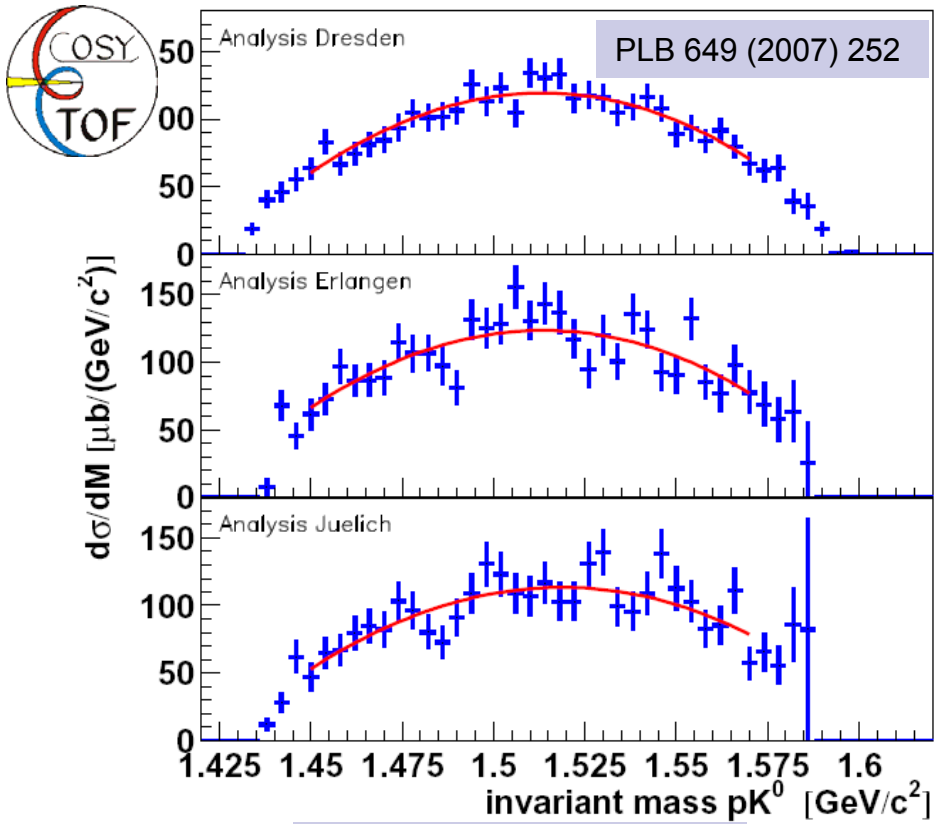
- σ_{total}~4.5 μb
- similar line-shape for $\Sigma^0\pi^0$ and $\Sigma^+\pi^-$ /$\Sigma^-\pi^+$
- $\bar{K}$N-influence

Thomas 73, $\pi^-p \rightarrow K^0(\Sigma\pi)^0$

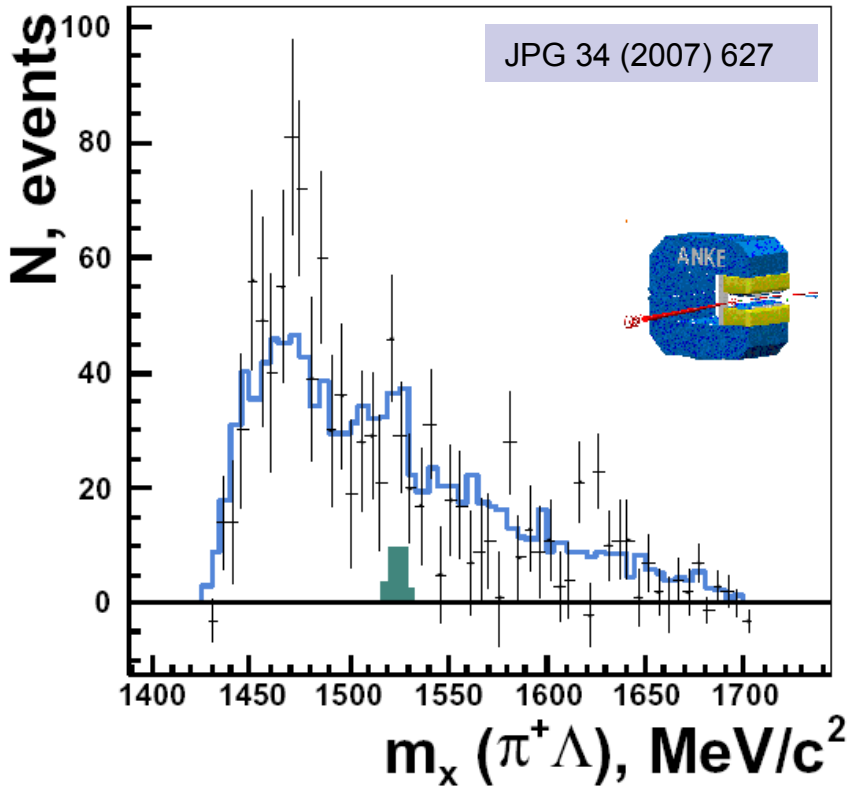
Hemmingway 84, $K^-p \rightarrow \pi^+\pi^-(\Sigma^+\pi^-)$

Pentaquarks: $\Theta^+(1540)$

- Reactions: $pp \rightarrow (pK^0)\Sigma^+$ and $pp \rightarrow (pK^0)\pi^+\Lambda$



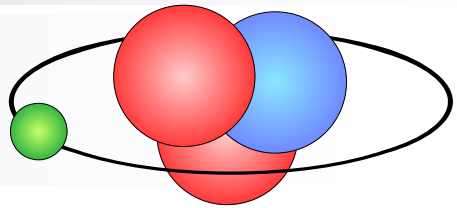
$\sigma_{pp \rightarrow \Theta^+\Sigma^+} < 0.15$ μb



$\sigma_{pp \rightarrow \Theta^+\pi^+\Lambda} < 0.058$ μb

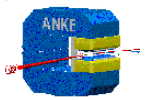
- no evidence found → upper limits

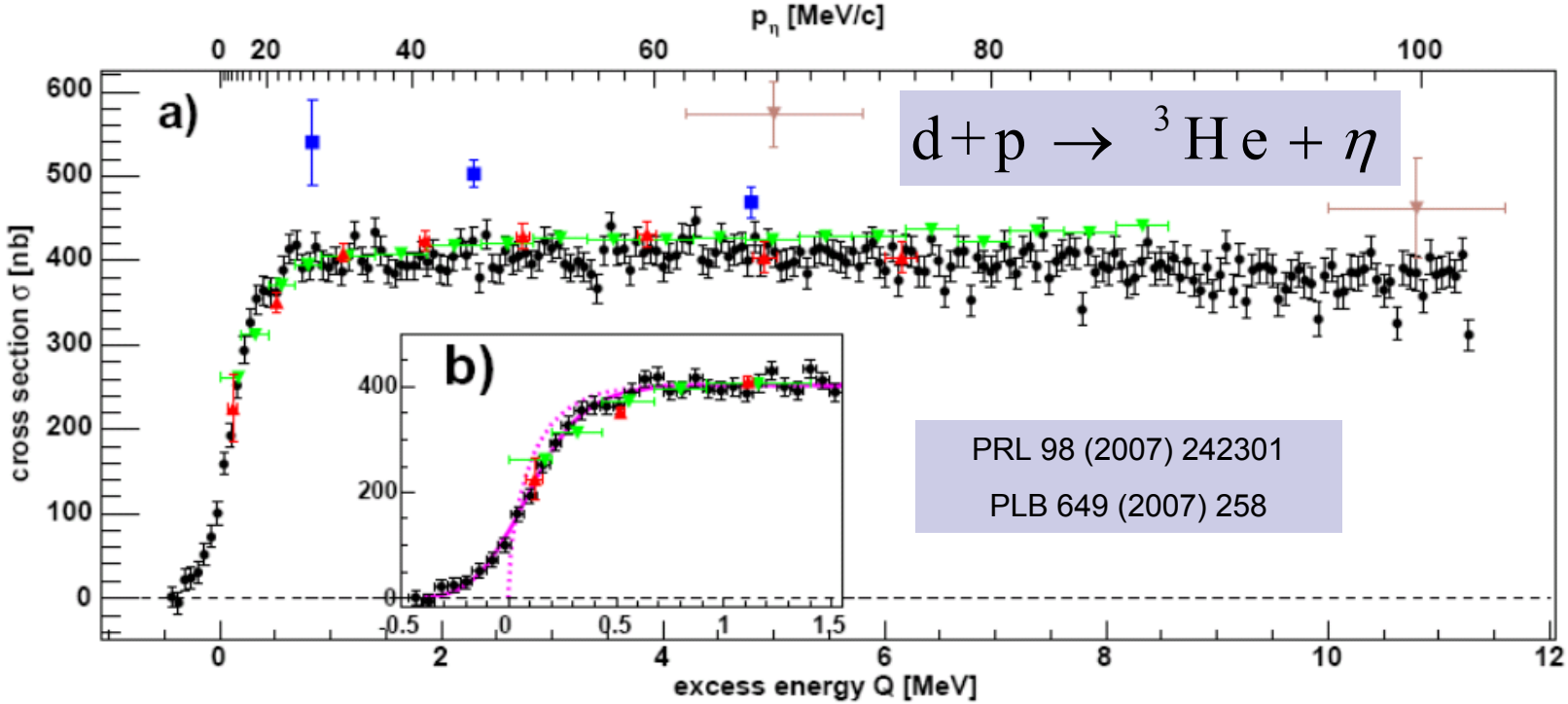
η–^{3}He Interaction Studies



- Indications for a quasi-bound η-^{3}He state at SATURNE (pd) and MAMI (γ^3He)

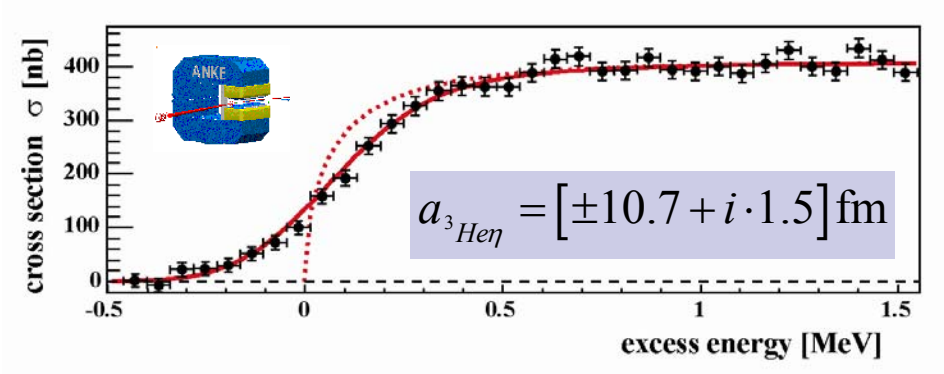
  → Precision measurements on total and differential cross sections



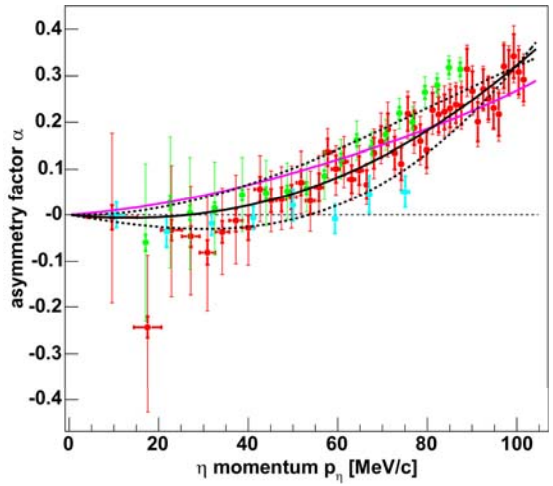


η–^{3}He Interaction Studies

- Steep rise of σ_{tot} indicates a strong η-^{3}He FSI



- Angular asymmetry α>0 for p_η>40 MeV/c
- Strong variation of phase and magnitude of s-wave amplitude with p_η
  → quasi-bound state?

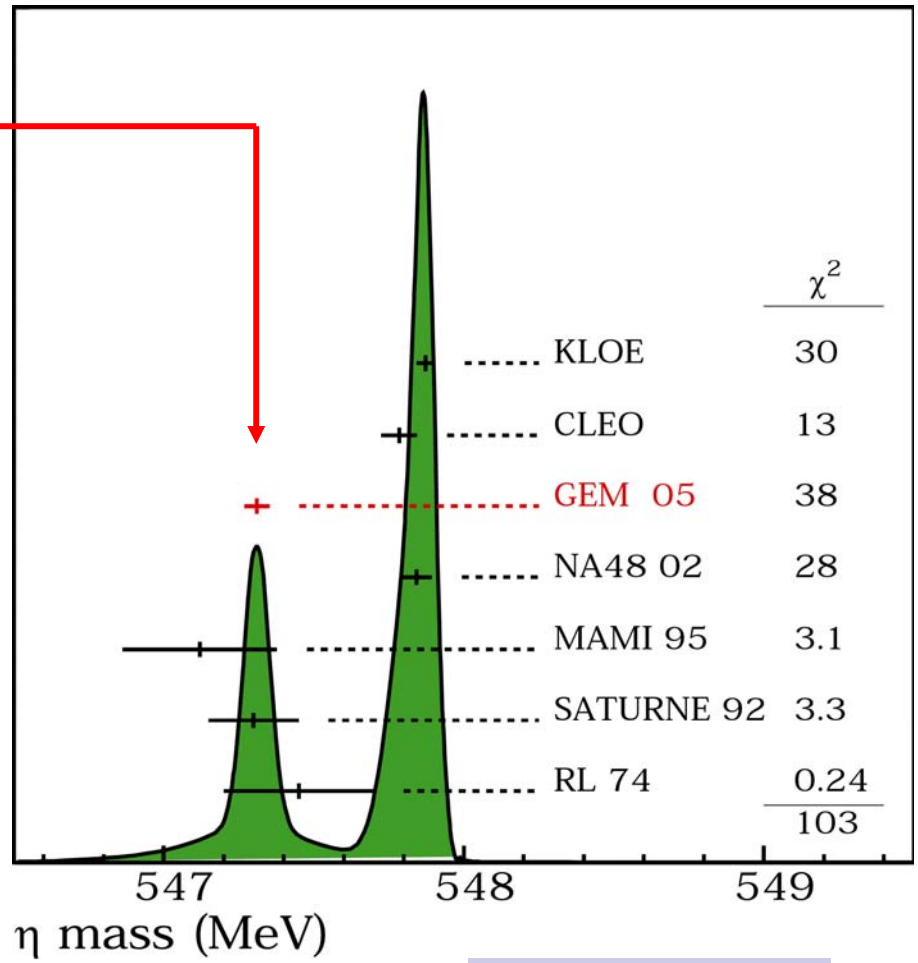


- further measurements: dp $\rightarrow$ (→) ^{3}He η

η-Meson Mass

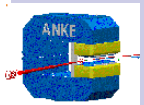
- New possibility at COSY: η-meson mass

GEM:	$pd \rightarrow {}^3He\eta$
SATURNE:	$pd \rightarrow {}^3He\eta$
NA48:	$\pi^- p \rightarrow \eta n$
MAMI:	$\gamma p \rightarrow \eta p$
KLOE:	$\phi \rightarrow \eta \gamma$
CLEO:	$\Psi(2s) \rightarrow \eta\ J/\psi$



Further investigations at COSY: $d+p \rightarrow {}^3He+\eta$

$\Delta m \sim 50$ keV



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Meson Decay Studies: WASA-at-COSY

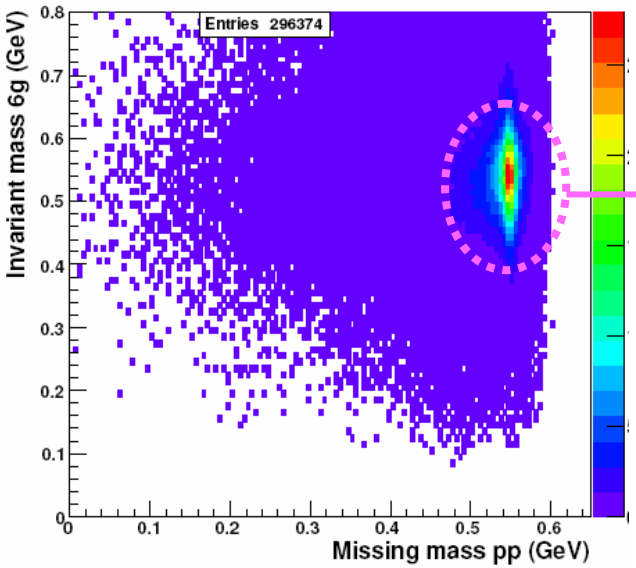
- Decays of the η-meson:
  - strong decays forbidden in lowest order
  - first order electromagnetic decays also forbidden

  $\rightarrow$ rare and very rare decays test fundamental symmetries

$\eta \not\rightarrow 4\pi^0$	CP-Tests
$\eta \not\rightarrow \pi^+\pi^-e^+e^-$	
$\eta \not\rightarrow \pi^0e^+e^-$	C-Test
$\eta \not\rightarrow 3\pi^0\gamma$	

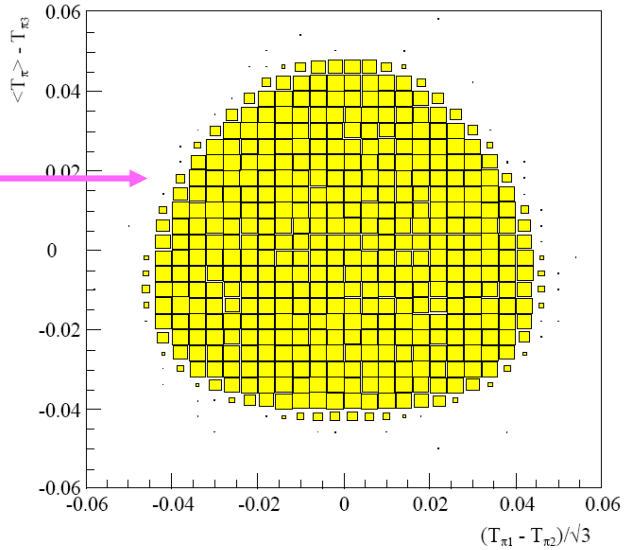
η-Meson Decay Studies

- WASA-at-COSY
  - Commissioning run in April 2007
  - Reaction: $pp \rightarrow pp\eta \rightarrow pp(3\pi^0) \rightarrow pp(6\gamma)$
  - > 10^5 $\eta \rightarrow 3\pi^0$ events recorded



$\eta \rightarrow \pi^\circ \pi^\circ \pi^\circ$

Expt´l
Dalitz-plot



η-Meson Decay Studies

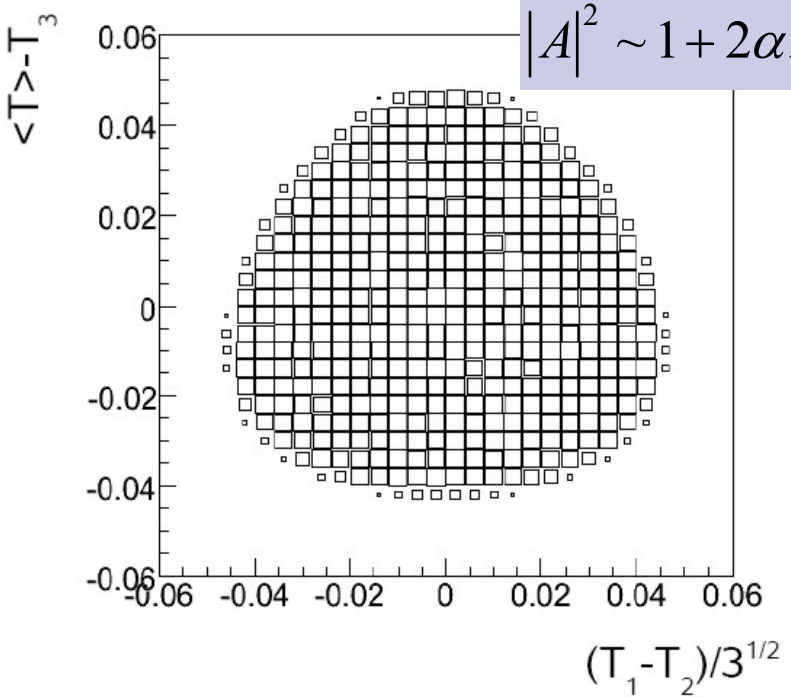
- Mesurement of the slope parameter α is a sensitive test of QCD predictions

$$x = \frac{1}{\sqrt{3}}\left(T_{\pi_1} - T_{\pi_2}\right)$$

$$y = \left(\frac{1}{3}\sum T_{\pi_i}\right) - T_{\pi_3}$$

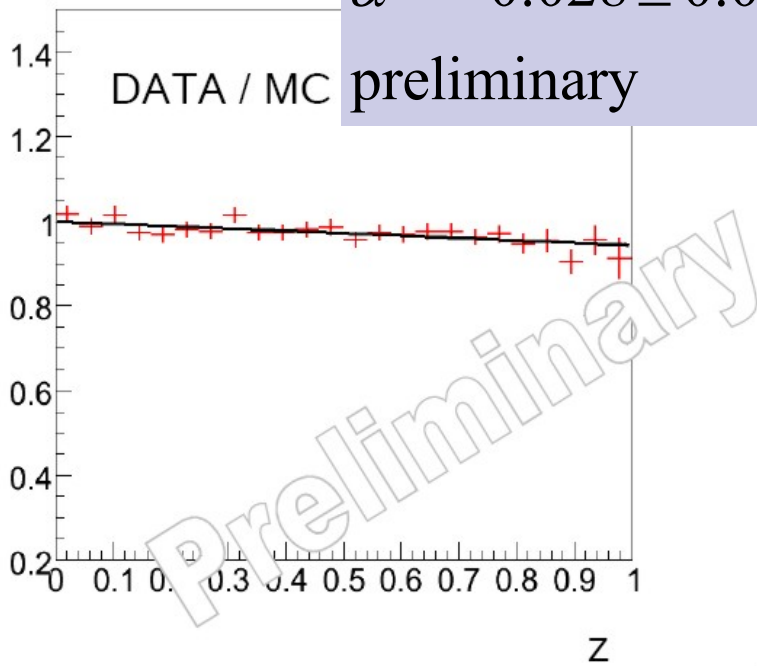
$$z = \frac{6}{\left(m_\eta - 3m_{\pi^0}\right)^2} \cdot \sum_{i=1}^{3}\left(E_{\pi_i} - \frac{m_\eta}{3}\right)^2 = \frac{r^2}{r_{\max}^2}$$

$$|A|^2 \sim 1 + 2\alpha z$$



$$\alpha = -0.028 \pm 0.008$$

preliminary



WASA-at-COSY Program

- $\eta^{(,)}$-decays and meson production
- Pion-Pair production: ABC-Effect
- Isospin violation in $\vec{d}d \rightarrow \alpha\pi^0$

see talk: M. Bashkanov

d	+	d	$\rightarrow$	α	+	π^0
0		0	$\rightarrow$	0		1

violates isospin conservation

$$P_{CS}:\ dd \rightarrow \alpha\pi^0 \quad \Rightarrow \quad dd \rightarrow \alpha\left(-\pi^0\right)$$

violates charge symmetry

- investigation of p-wave contribution
- first successful measurements on dd $\rightarrow {}^3He+n+\pi^0$ $\rightarrow$ study of ISI(dd) and background

Summary

- COSY is an excellent machine to study hadron physics with hadronic probes
  - High precision + spin
- Complementary detector facilities at COSY allow to investigate a broad and exciting field of physics:

- Hadrons
- Interactions
- Spectroscopy

- Symmetries
- Spin
- ...