# Key experiments for WASA@COSY

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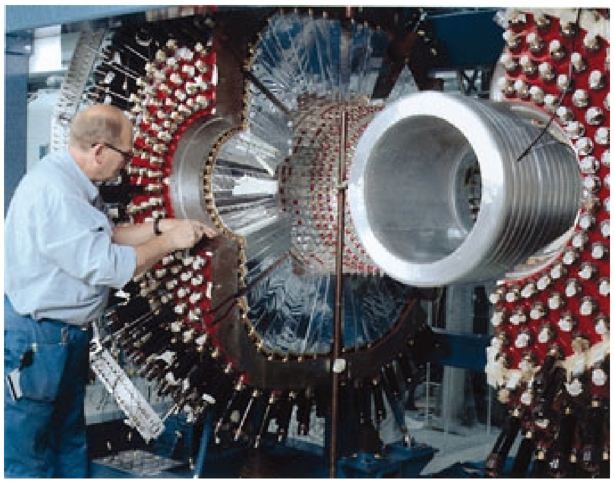
*in der Helmholtz-Gemeinschaft*



Toast given by:

Markus Büscher
Forschungszentrum Jülich
Germany

# The Accelerator: COSY-Jülich

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COSY (Cooler Synchroton)
at FZ-Jülich:

- (polarized) p & d beams
- phase-space cooling
  - electron & stochasting cooling
- p = 0.30 – 3.70 GeV/c
  - pp $\rightarrow$ pp X ($m_X \leq 1.1$ GeV/c$^2$)
  - dd $\rightarrow$ $\alpha$ X ($m_X \leq 1.03$ GeV/c$^2$)
  - pp $\rightarrow$ pK$^+$ Y* ($m_{Y*} \leq 1.5$ GeV/c$^2$)
- internal & extracted beams

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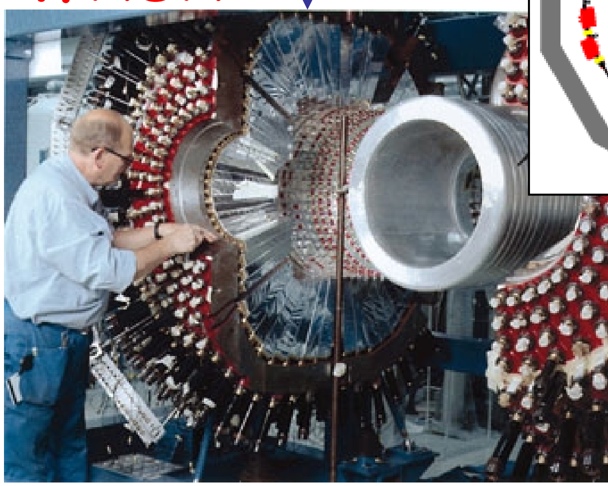
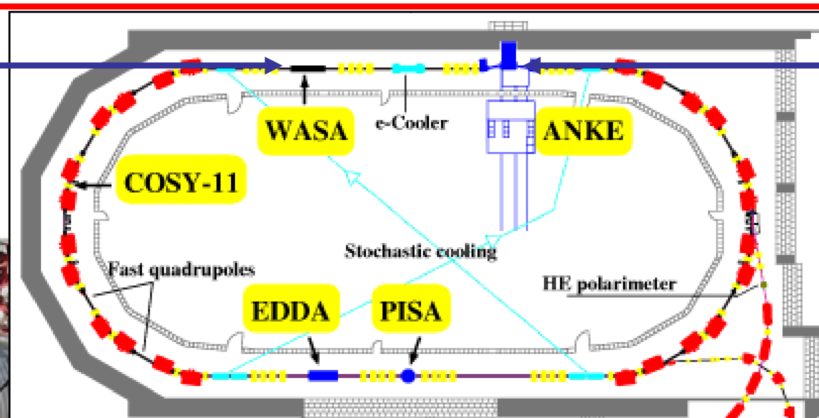
# The detector: WASA

Ready for experiments in 2007

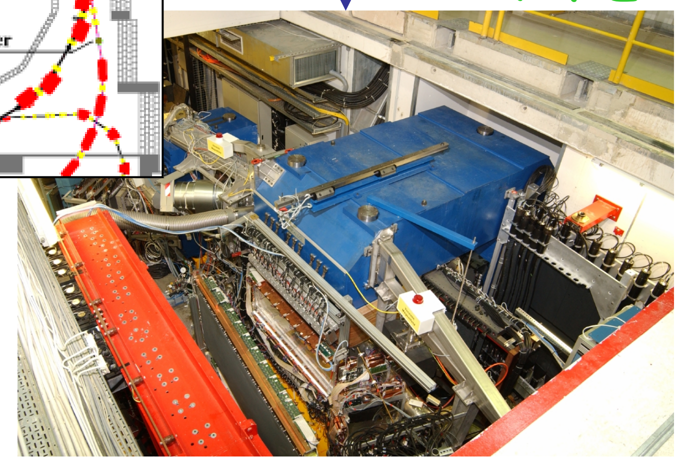
In operation since 1998

WASA






ANKE



-currently at CELSIUS (Uppsala)
-nearly 4$\pi$ coverage
-charged and neutral particle i.d.
-frozen pellet target ($\mathcal{L} \sim 10^{32}$ cm$^{-2}$s$^{-1}$)

-forward spectrometer (small acceptance)
-optimized for $K^+/K^-$ detection
-cluster jet target ($\mathcal{L} \sim$ few$\cdot 10^{31}$ cm$^{-2}$s$^{-1}$)
-polarized target ($\mathcal{L} < 10^{30}$ cm$^{-2}$s$^{-1}$)

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# The proposal (fall 2004)

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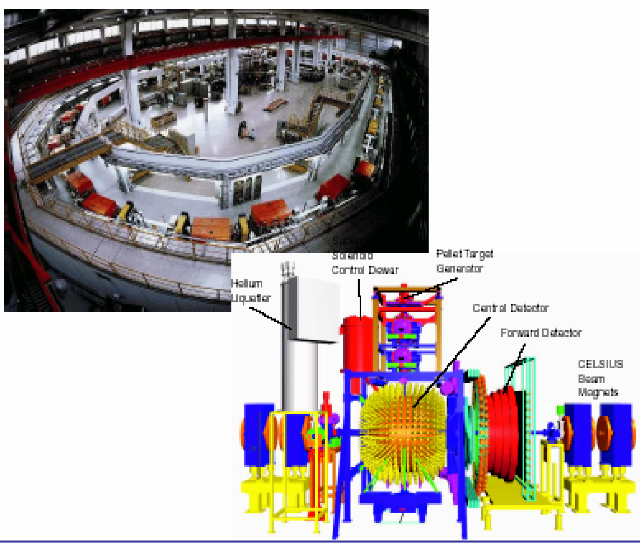
## Proposal

for the

## Wide Angle Shower Apparatus (WASA) at COSY-Jülich

The WASA@COSY collaboration

Jülich, August 23, 2004
version 1.4

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CGSWHP Caucasian-German School and Workshop on Hadron Physics

# Symmetries ...

## here: Isospin

Other symmetries (C, CP, ...): talk my M.Wolke on $\eta$, $\eta'$ decays

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# Isospin violation (C. Hanhart, V. Hejny)

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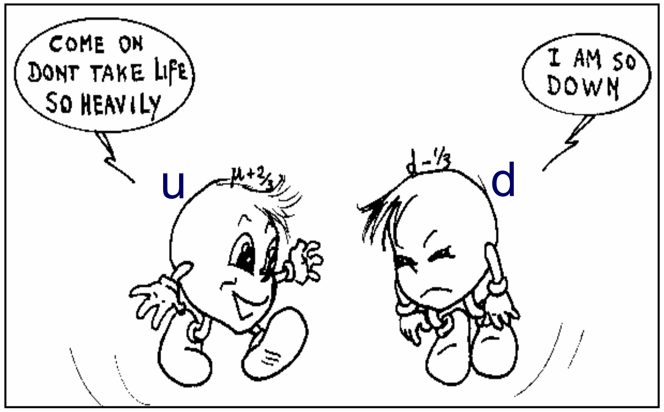
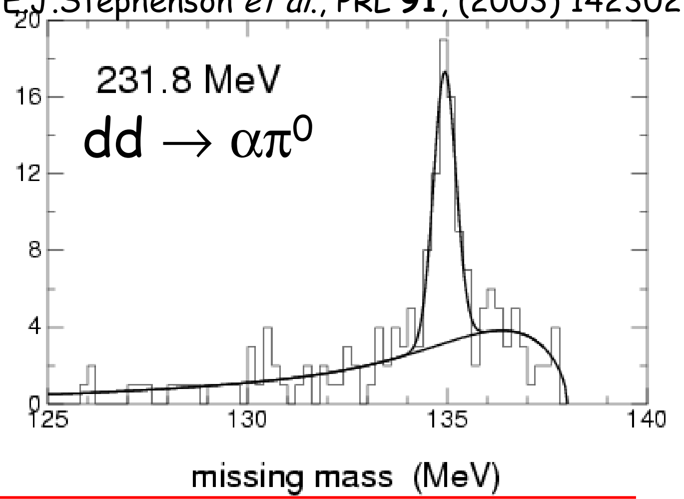
- Isospin is an approximate symmetry of QCD
  - ⇨ quark-mass differences, $m_u \neq m_d$
  - ⇨ different el.-magn. corrections, $q_u \neq q_d$




- Isospin violation (IV) is an experimental handle on these effects

- Recent precision measurements
  - ⇨ $np \rightarrow d\pi^0 : A_{fb} = (17.2 \pm 8 \pm 5.5) \cdot 10^{-4}$
    A.K.Opper *et al.*, PRL **91**, (2003) 212302
  - ⇨ $dd \rightarrow \alpha\pi^0$ at IUCF
    $\sigma_{tot}$ (Q ≈ 1.4 MeV) = 12.7 ± 2.2 pb
    $\sigma_{tot}$ (Q ≈ 3.0 MeV) = 15.1 ± 3.1 pb
    direct measurement of (IV-amplitude)$^2$

E.J.Stephenson *et al.*, PRL **91**, (2003) 142302

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# Understanding IV ... ?

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- Various terms contribute to IV:
  - ⇨ Coulomb isospin mixing
  - ⇨ IV in $\pi$N scattering (leading in np $\rightarrow$ d$\pi^0$, suppressed in dd $\rightarrow \alpha\pi^0$)
  - ⇨ isospin mixing of mesons ($\pi$-$\eta$, $\rho$-$\omega$)
  - ⇨ heavy meson exchange
  - ⇨ $\Delta$ excitations
  - ⇨ ...
- Large theory collaborations study IV in terms of $\chi$PT
  - ⇨ disentangle all contributing terms (no dominant one in dd $\rightarrow \alpha\pi^0$)
- First questions:
  - ⇨ strength of *p*-waves in dd $\rightarrow \alpha\pi^0$ (parameter free)
    (IUCF data close to threshold are consistent with *s*-wave)
  - ⇨ contributions from the $\Delta$?

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# IV with WASA@COSY

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- What's next:
  - ⇨ study *p*-waves further above threshold (here: $Q \approx 60$ MeV )
  - ⇨ lowest partial waves: $^3P_0 \rightarrow s$, $^5D_1 \rightarrow p$
  - ⇨ however: - due to the symmetry in initial state, *s*- and *p*-waves do not interfere in an unpolarized experiment
    - *s*-*d*, *p*-*p* interference have same energy and angular dependence → hard to disentangle
  - ⇨ at least single (beam or target) polarization experiment needed

- Furthermore:
  - ⇨ at $Q \approx 170$ MeV contributions from $\Delta$ resonance will be enhanced
  - ⇨ best observable should be $\pi^0$ in *p*-wave
  - ⇨ again: polarization helpful

# $dd \to \alpha\,\pi^0$ with WASA

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$\rightarrow$

- Measurement of differential cross sections in $dd \to \alpha\pi^0$ at:
  - $p_d \approx 1.2$ GeV/c: development of p-waves
  - $p_d \approx 1.6$ GeV/c: contribution of $\Delta$ resonance to IV
  - ($p_d \approx 2.35$ GeV/c: sign of real part of $\eta\alpha$ scattering length)

- Low cross sections require high luminosities $\approx 10^{32}$ cm$^{-2}$s$^{-1}$
  - ⇨ Pellet target
  - ⇨ High (polarized!) beam intensities $\geq 10^{10}$ deuterons
  - ⇨ Estimated beam time ~3 months for full program

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# $dd \to \alpha\ (\pi^0\eta)$ vs. $dd \to \alpha\ \pi^0$

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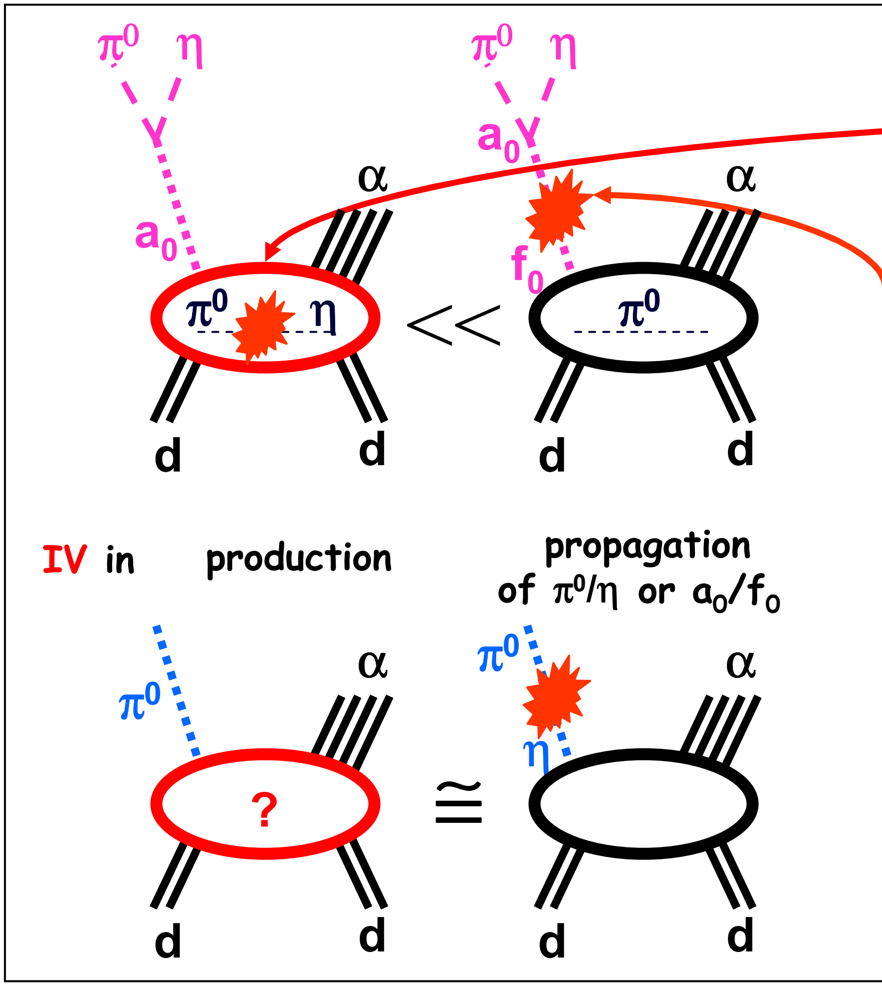


$\propto \frac{1}{t} \approx \frac{1}{-m_N\, m_{a_0/f_0}}$

$\propto \frac{1}{m_{a_0/f_0}\,\Gamma_{a_0/f_0}}$

"The $a_0/f_0$ are rather narrow, overlapping resonances"

$$CSB\left(\frac{\text{Propagation}}{\text{Production}}\right) \approx \left(\frac{m_N}{\Gamma_{a_0/f_0}}\right) \approx 20$$

Details in: C.Hanhart, nucl-th/0306073


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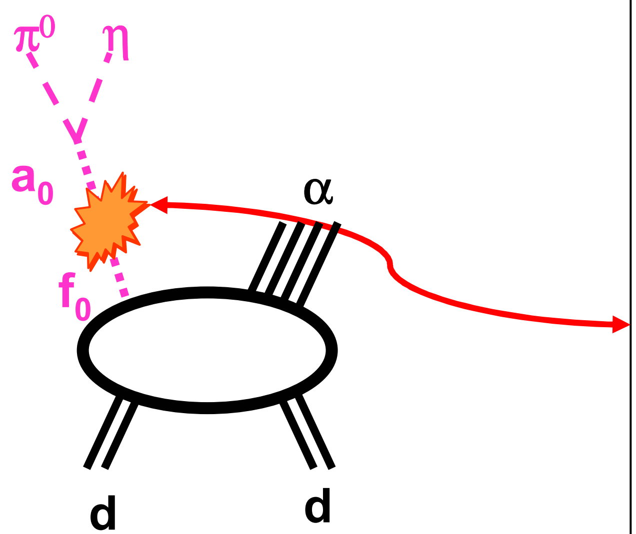
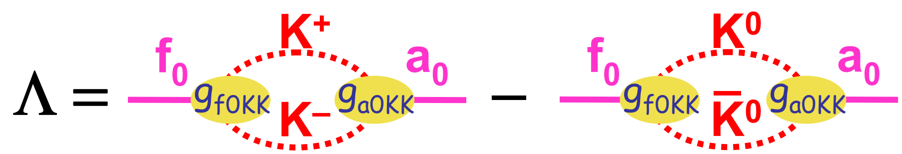
# More $a_0$-$f_0$ mixing ...



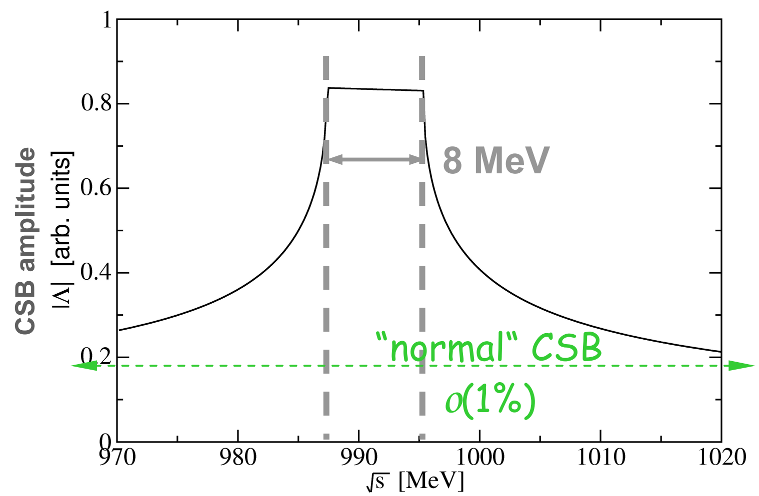

$$\frac{d\sigma}{dm}\left[dd \to \alpha(\pi^0\eta)\right] =$$

(Product of mixing amplitude $\Lambda$ and production operator)$^2$

**Further enhancement: "Kaon loops"**




$$\Lambda = \langle f_0 | T | a_0 \rangle = i\, g_{f_0KK}\, g_{a_0KK} \sqrt{s}\left(p_{K^0} - p_{K^+}\right) + o\left(p_K^2\right)$$




N.N.Achasov *et al.*, PL B **88**, 367 (1979)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# Why $g_{a_0 K\bar{K}}$ and $g_{f_0 K\bar{K}}$?

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☐ Determine the ($K\bar{K}$) contents of the $a_0/f_0$ mesons!

**Evidence that the $a_0(980)$ and $f_0(980)$ are not elementary particles**

V. Baru[a,b], J. Haidenbauer[b], C. Hanhart[b], Yu. Kalashnikova[a], A. Kudryavtsev[a]

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Editor: J.-P. Blaizot

Physics Letters B 586 (2004) 53–61

The knowledge of $g_{K\bar{K}}$ allows one to calculate $W_{a0/f0}$:

$$W_{a0(f0)} = \int_{-50\text{ MeV}}^{50\text{ MeV}} w_{a0(f0)}(E)\,dE.$$

$$w(E) = \frac{1}{2\pi}\Gamma_P + \bar{g}_{K\bar{K}}\sqrt{mE}\,\Theta(E) \times \left[\left(E - E_f - \frac{1}{2}\bar{g}_{K\bar{K}}\sqrt{-mE}\,\Theta(-E)\right)^2 + \frac{1}{4}\left(\Gamma_P + \bar{g}_{K\bar{K}}\sqrt{mE}\,\Theta(E)\right)^2\right]^{-1}$$

$W_{a0/f0}$ "measures" the admixture of mesonic ($K\bar{K}$) components in the $a_0/f_0$ mesons
$W_{a0/f0}$ = 0.7 corresponds to a "bare" $q\bar{q}$ state

Current data: $W_{a0}$ = 0.24 ... 0.49 and $W_{f0}$ = 0.14 ... 0.23

large uncertainties but the $a_0/f_0$ seem to have a significant mesonic component

# Exotic hadrons ...

## "exotic hadrons" := not ($q\bar{q}$ or $qqq$)

"(genuine) exotic":

quantum numbers exclude $q\bar{q}$ or $qqq$
obvious candidates, e.g. Hybrids ($J^{PC}=0^{+-}$), Pentaquark ($S=+1$)

"cryptoexotic":

quantum numbers compatible with $q\bar{q}$ or $qqq$
interpretation model dependent, e.g. $a_0/f_0(980)$ ($J^{PC}=0^{++}$)

## ... both are equally important!

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# Pentaquark $\Theta^+$ (also) at WASA

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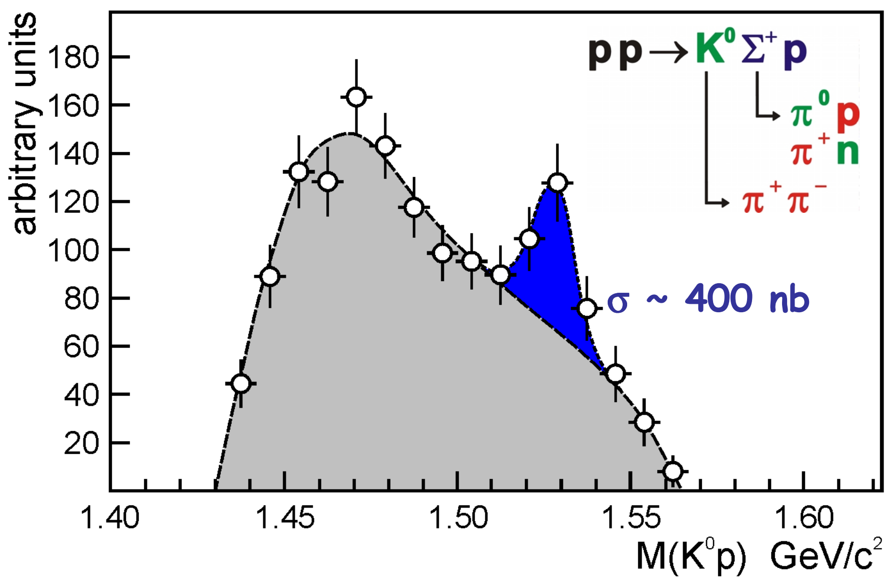
TOF:




Plan for 2005: $\vec{p}n \to \Theta^+\Lambda$

$\vec{p}\vec{p} \to \Theta^+\Sigma^+$

- Parity of the $\Theta^+$

C. Hanhart *et al.*, PL B **590** (2004) 39
talk by Yu. Uzikov

WASA:

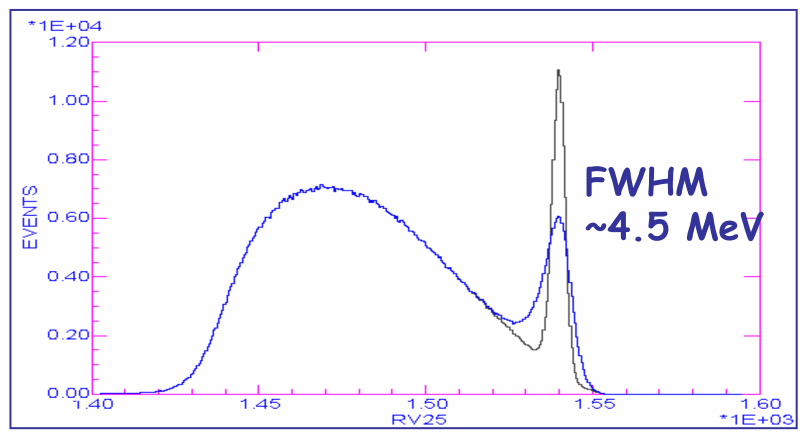
- Various (neutral) decay channels

Example:

$\vec{p}\, d \to p\ \Lambda\ \theta^+$ @$T_p$=1360 MeV

$\Lambda \to p\pi^-$

$\theta^+ \to pK^0 \to p\ \pi^0\ \pi^0$, $\pi^0 \to \gamma\gamma$, $\pi^0 \to \gamma\gamma$




Rate estimate ($\mathcal{L}$=$10^{32}$ $cm^{-2}s^{-1}$, σ=400 nb):

**~170,000 detected $\Theta^+$/day**

# The Λ(1405) (A. Gillitzer)

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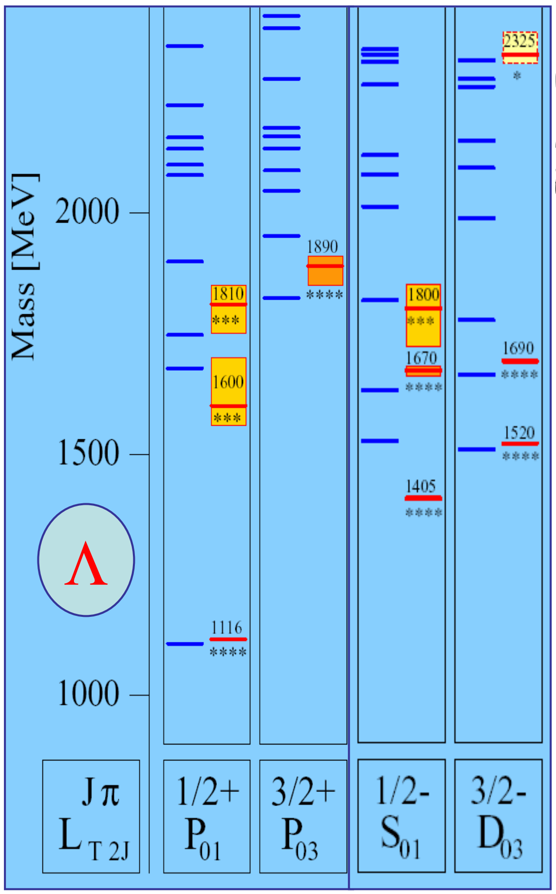
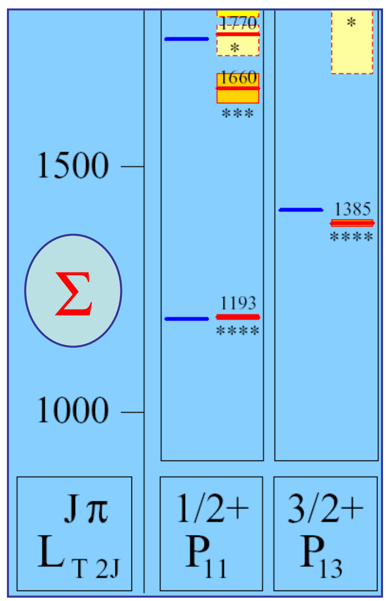
## Problem to reproduce the Λ(1405) in

### Quark models

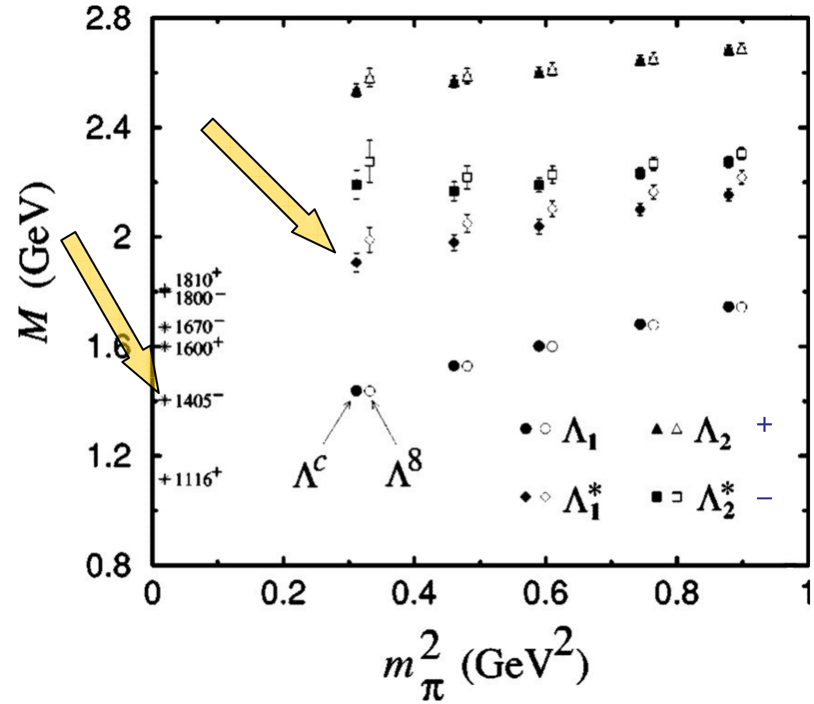



U. Löring, B.C. Metsch, H. Petry, EPJ A **10** (2001) 447

### Lattice QCD

W. Melnitchouk *et al.*, PR D **67** (2003) 114506

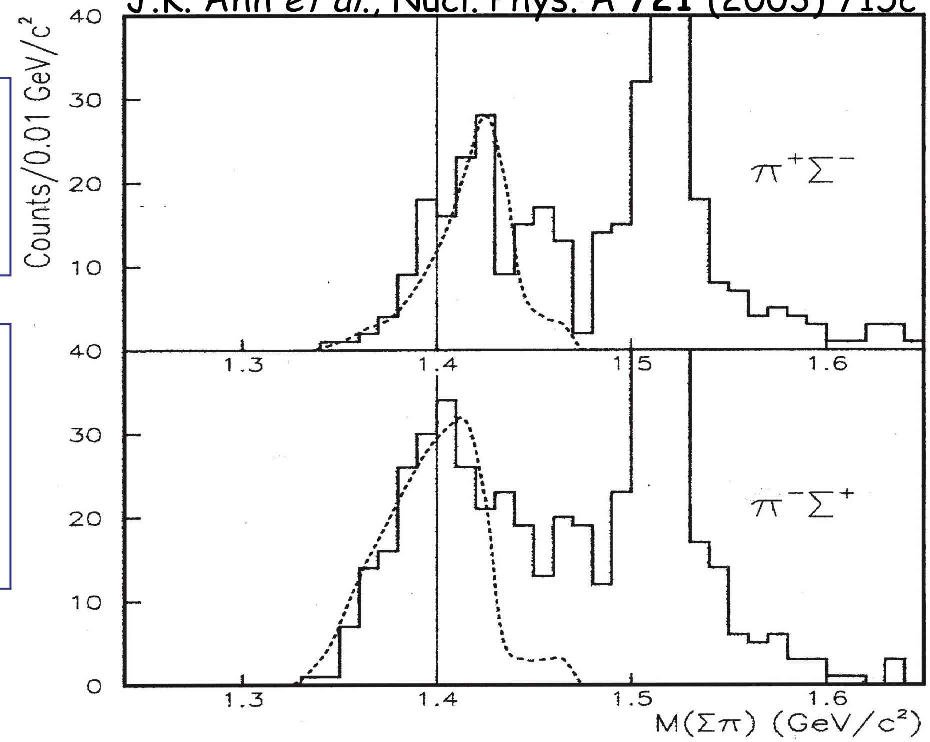



For physical $m_\pi$ ⇒ too high Λ(1405) mass

# Data on the $\Lambda(1405)$

Photon induced $\Lambda(1405)$ and $\Sigma(1385)$ production:
$p(\gamma, K^+\pi)\Sigma$ reaction at SPring-8/LEPS

J.K. Ahn *et al.*, Nucl. Phys. A **721** (2003) 715c




$\pi^+\Sigma^-$ and $\pi^-\Sigma^+$ have different distributions

Indication for meson-baryon nature:
J.C.Nacher, E.Oset, H. Toki and A. Ramos, Phys. Lett. B 455 (1999) 55

No *pp* data! No data for $\Lambda(1405) \rightarrow \Sigma^0\pi^0$ !

# A new hyperon?

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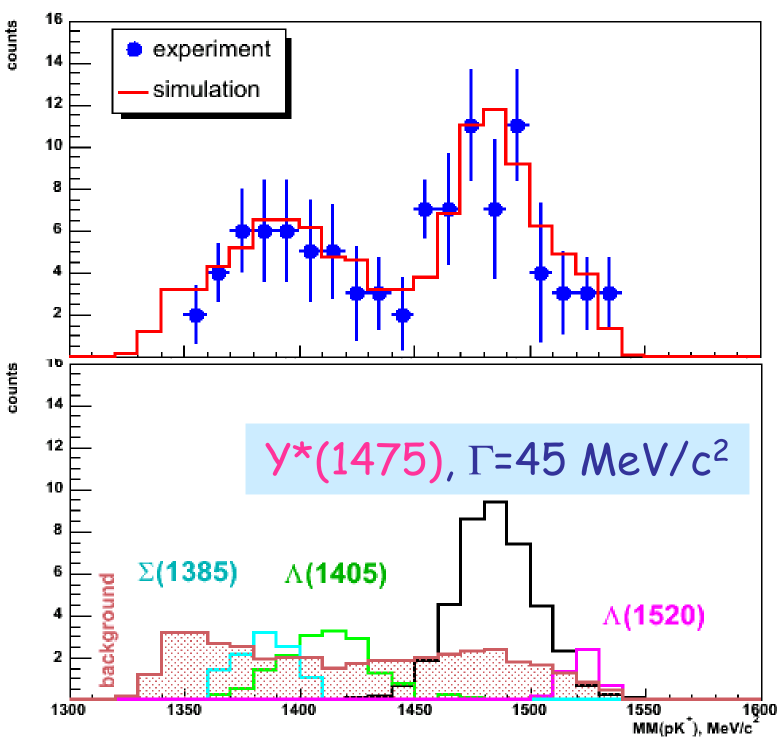
**ANKE:**

$p(2.83\ \text{GeV})p \to pK^+\pi^+\Sigma^-$




**WASA:**

Neutral decay channels, e.g.

$pp \to pK^+Y^*(1475)$

? ☐ $\Lambda\pi^0$

☐ $p\pi^-\pi^0$

☐ Is it a $\Lambda(I=0)$ or a $\Sigma(I=1)$ ?

$\Lambda(1475) \to \Lambda\pi^0$

$\Sigma(1475) \to \Lambda\pi^0$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# Hadrons in the nuclear medium

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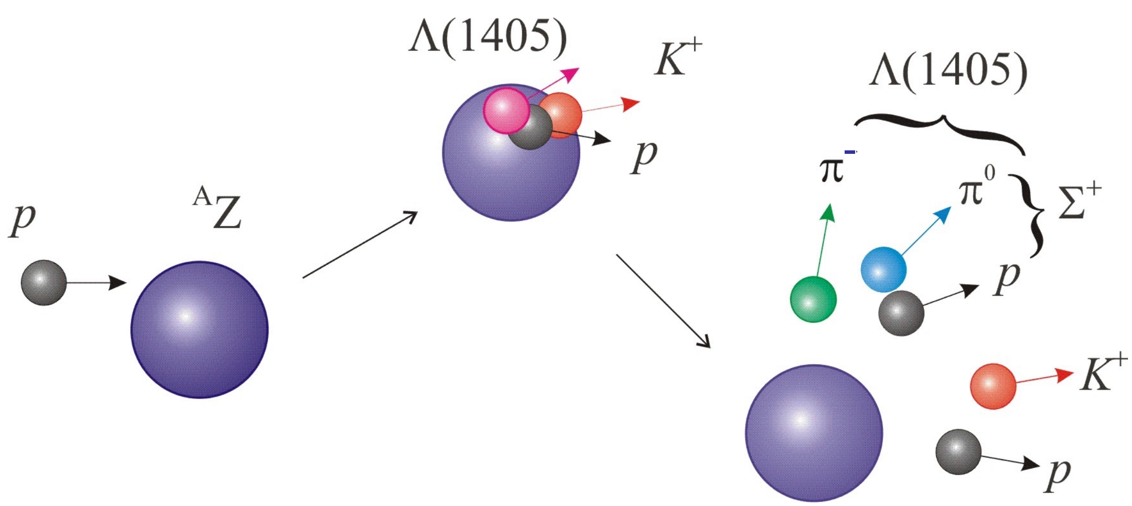
- model predictions: $\Lambda(1405)$ is a $\bar{K}N$ bound state
  $\Lambda(1405)$ dissolves in nuclear matter
- naive expectation:
  $\langle r^2 \rangle_{\bar{K}N} > \langle r^2 \rangle_{qqq} \;\Rightarrow\; \sigma_{abs}$ larger for „molecular" state
- measure $pA \rightarrow \Lambda(1405)X$ as fct. of $A$ (semi-exclusive)
- compare with $pA \rightarrow \Sigma(1385)X$
- cross section ratios
- spectral shapes





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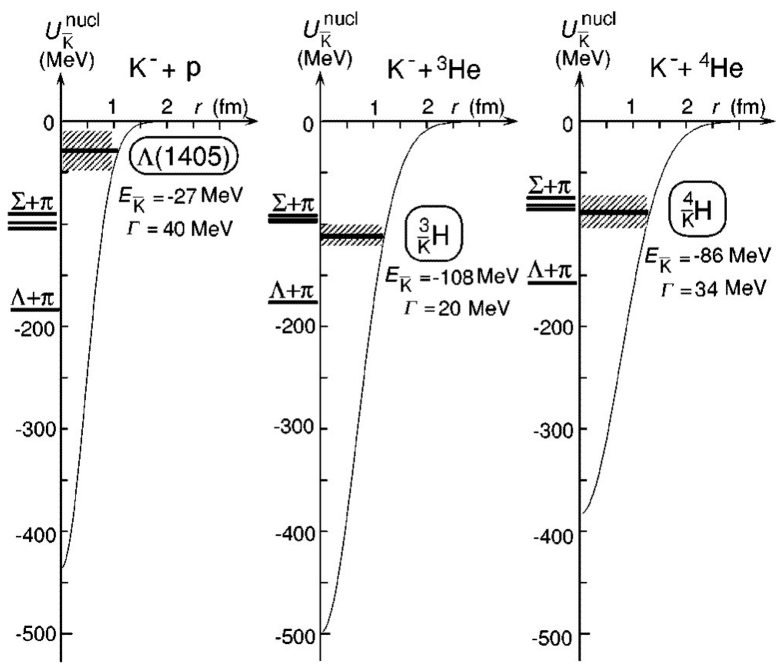
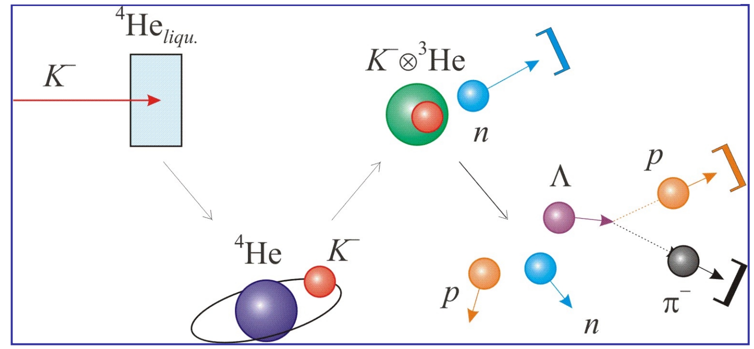
# Potential model based on Λ(1405)

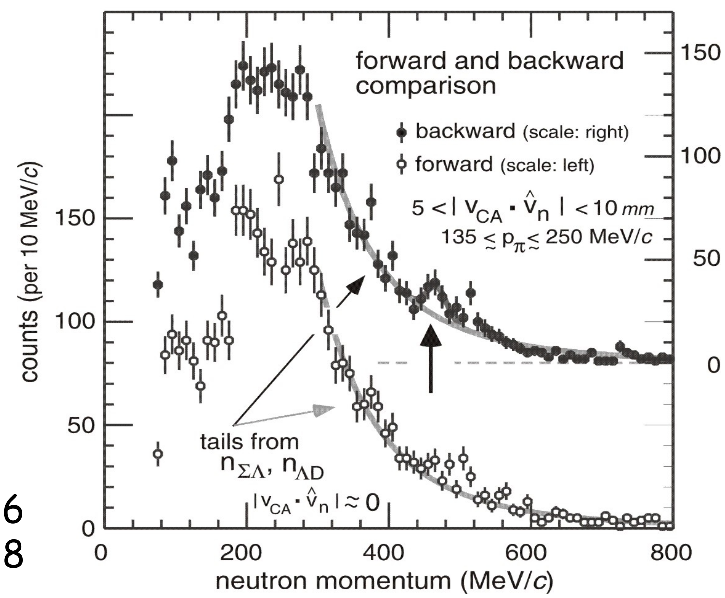
## ... predicts very deep $K^-$ potentials




Y. Akaishi, T. Yamazaki, PR C **65** (2002) 044005

## $^4$He(stopped $K^-$,n) at KEK




M. Iwasaki *et al.*, NIM A **473** (2001) 286
M. Iwasaki *et al.*, nucl-ex/0310018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# Summary …

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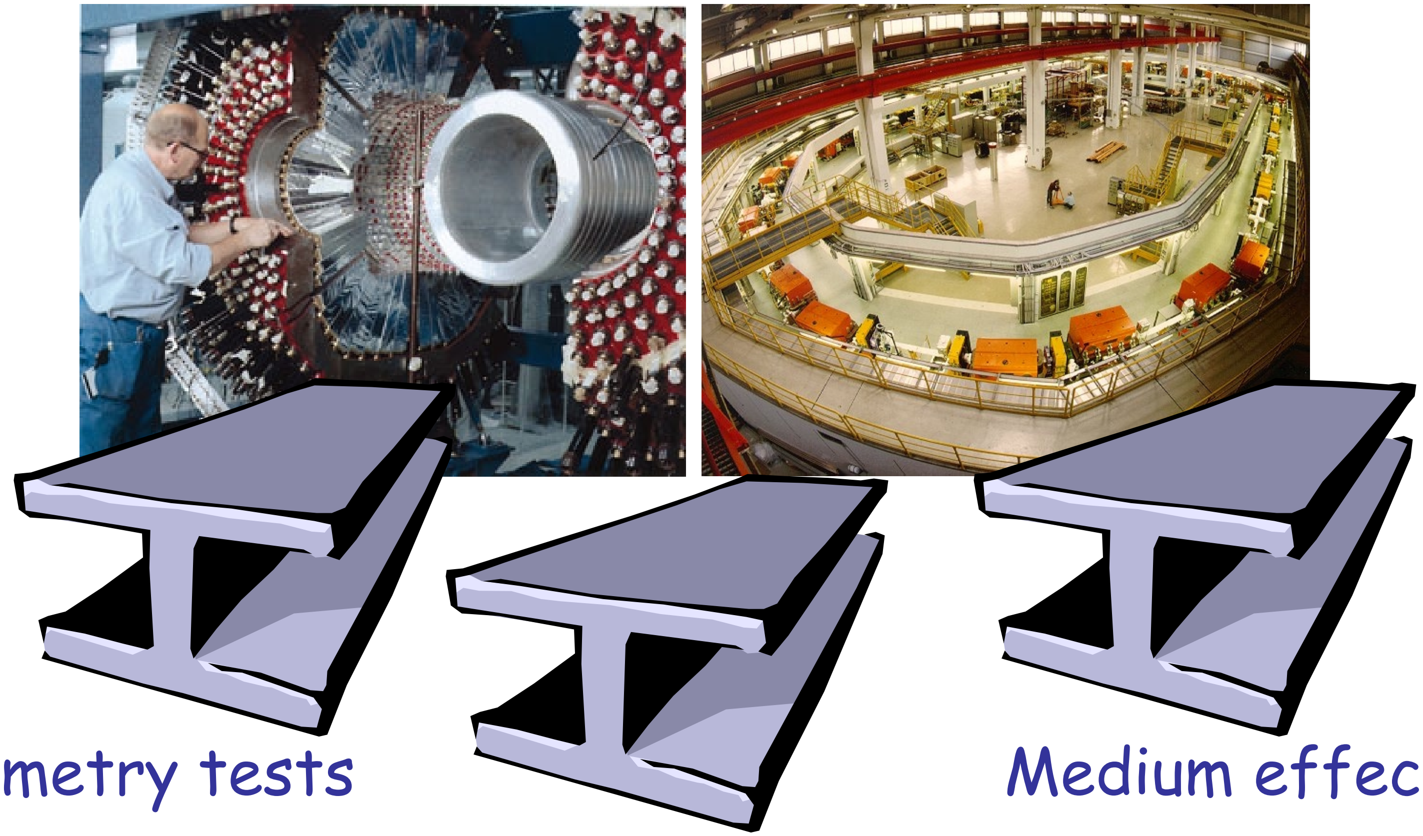

Symmetry tests

Medium effects

Structure of hadrons

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# Spare foils ...

# The light scalar resonances

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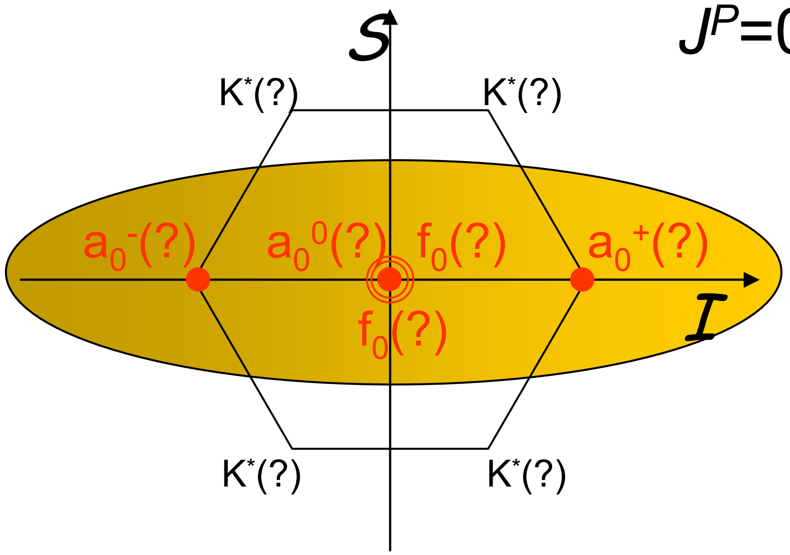
## Nonet of light scalar mesons




## Possible candidates

COSY

- $f_0(500)$ ("σ")
- κ(800)
- $f_0(980)$
- $a_0(980)$

} 9 states

- $f_0(1370)$
- $K_0^*(1430)$
- $a_0(1450)$
- $f_0(1500)$
- $f_0(1710)$

} 10 states

**Nature of these states??**

„Genuine" $q\bar{q}$
4-quark states
$K\bar{K}$ molecules

# The $a_0/f_0(980)$ at COSY

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| Reaction | Where? | Result | Goal |
|---|---|---|---|
| $pp \to pp\ K^+K^-$ | COSY-11<br>ANKE | $a_0^0/f_0$ contribution?? | |
| $pp \to d\ K^+\underline{K}^0$<br>$\to d\ \pi^+\eta$ | ANKE<br>WASA | $a_0^+$ channel dominates | First „simple" experiment for WASA (≥2006) |
| $pn \to d\ K^+K^-$<br>$\to d\ \pi^0\eta$ | ANKE<br>WASA | (Feb. 2004) | Angular asymmetries<br>$a_0$-$f_0$ mixing |
| $pd \to {}^3He\ K^+K^-$<br>$\to {}^3H\ K^+\underline{K}^0$ | MOMO | $a_0^0/f_0$ contribution?? | |
| $dd \to {}^4He\ K^+K^-$<br>$\to {}^4He\ \pi^0\eta$ | ANKE<br>WASA | Winter '04/05? | Isospin violation<br>$a_0$-$f_0$ mixing |

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# First Results on the $a_0^+$

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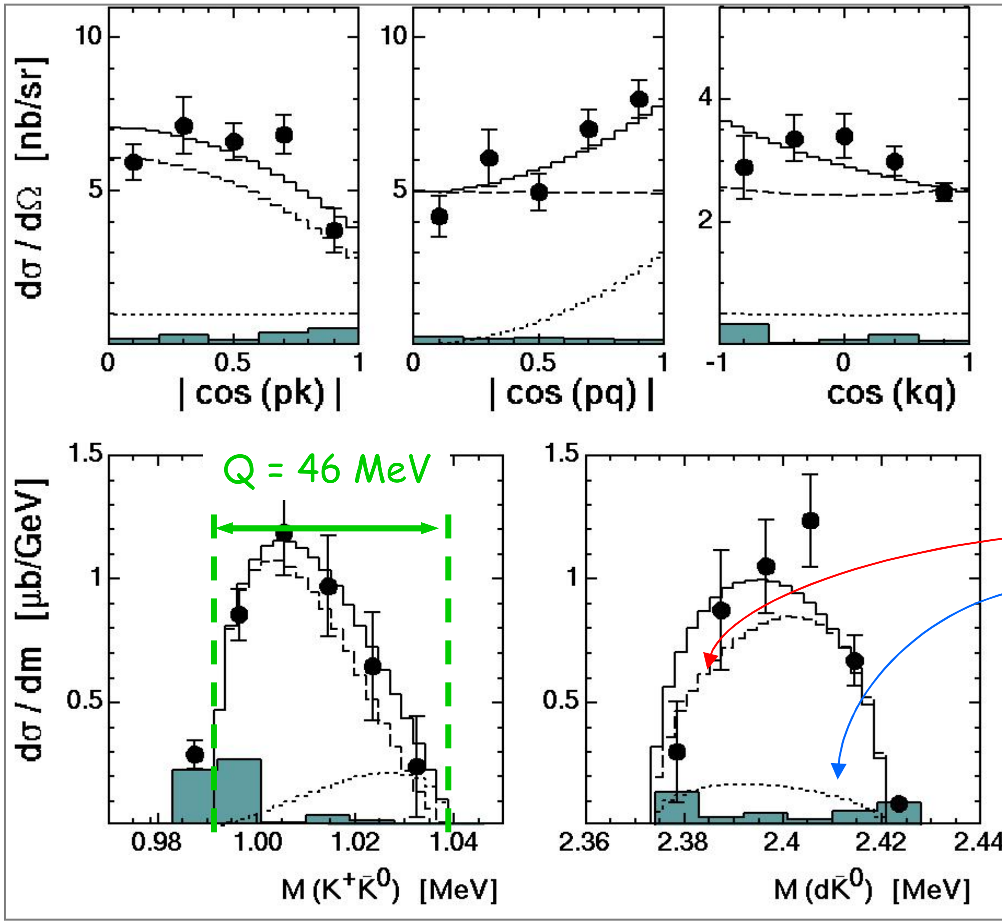
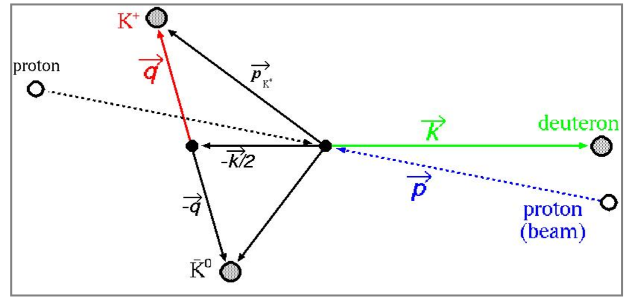
$p\,p \rightarrow d\,K^+\bar{K}^0$ (ANKE)




Fit:
$[(K\bar{K})_P\, d]_S + [(K\bar{K})_S\, d]_P$

$\sigma(pp \rightarrow da_0^+ \rightarrow dK^+\bar{K}^0) = 83\% \cdot \sigma_{tot}$

$\sigma_{tot}(pp \rightarrow dK^+\bar{K}^0) = (38 \pm 2_{stat} \pm 14_{sys})$ nb

V.Kleber et al., PRL **91**, 172304 (2003)
nucl-ex/0304020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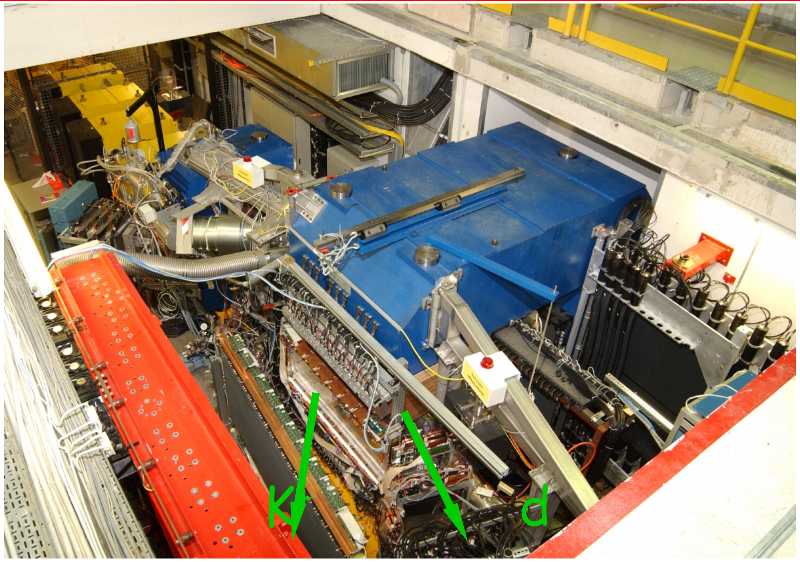
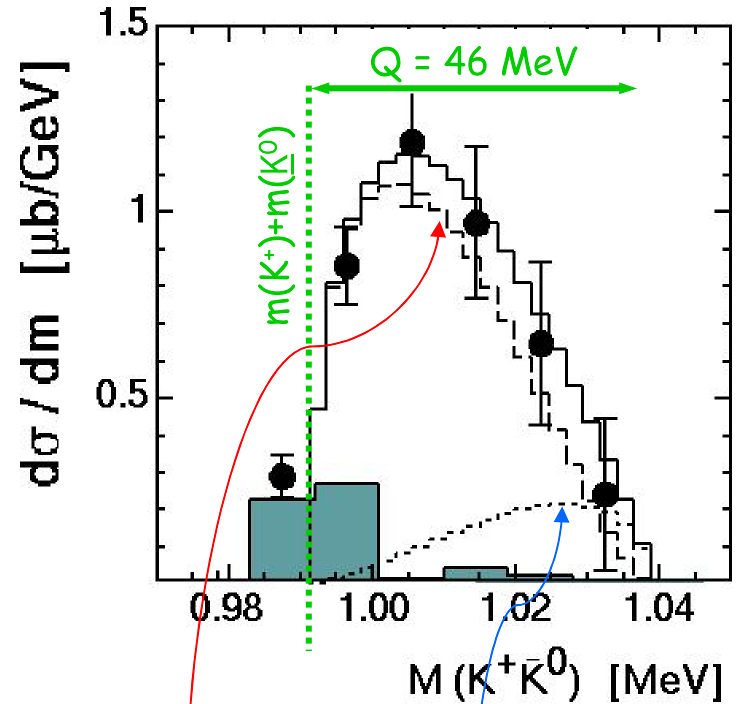
# p(2.65 GeV)p→dK$^+\overline{K}^0$ at ANKE

V.Kleber et al., PRL **91**, 172304 (2003)




- $K^+d$ coincidence measurement
- Identification of pp→d$K^+$X events via TOF, ΔE and particle momenta
- Identification of pp→d$K^+\underline{K}^0$ events via d$K^+$ missing mass

Fit:

$[(K\underline{K})_S d]_P + [(K\underline{K})_P d]_S$

✂ Dominance of $a_0^+$ channel

$\sigma_{tot}(pp \rightarrow dK^+\underline{K}^0) = (38 \pm 2_{stat} \pm 14_{sys})$ nb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# $a_0/f_0$ mixing in pn interactions

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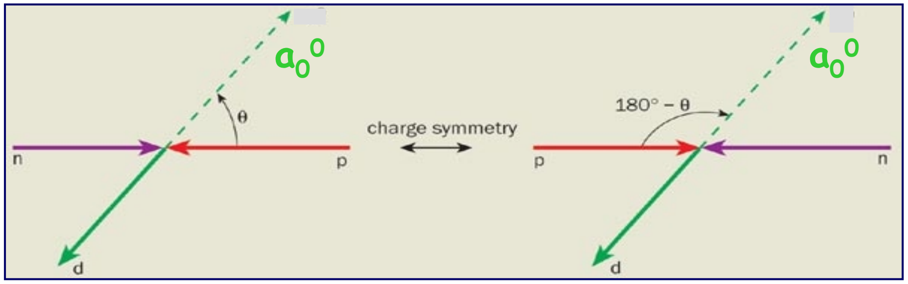
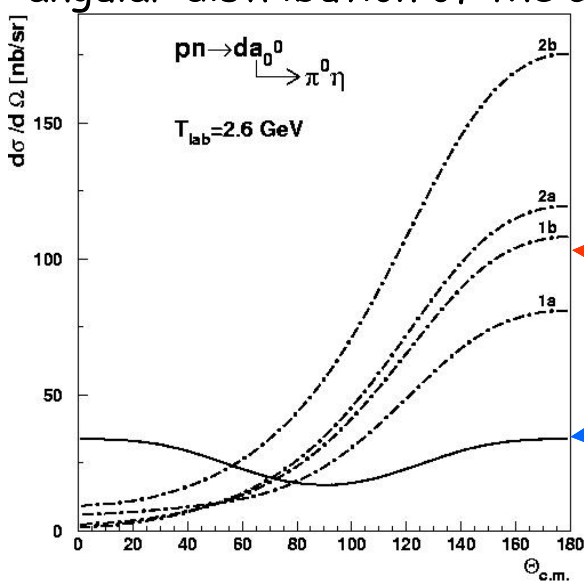



✄ Look, e.g., for angular asymmetries around 90° in pn → d+Meson reactions

angular distribution of the $a_0$



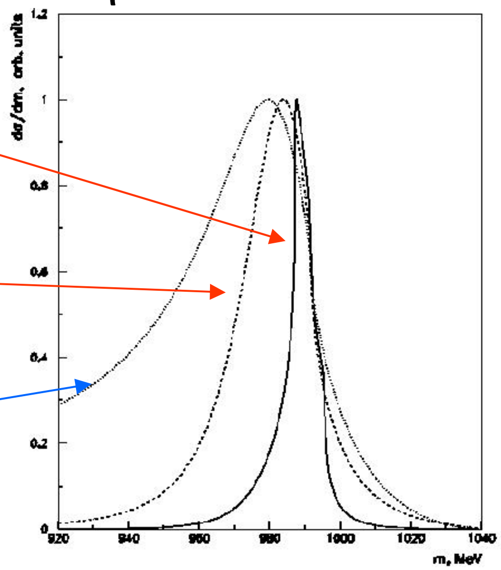

$pn \to pn(d)\ \pi^0\eta$

Kaon loops

„direct" $a_0$-$f_0$ or π-η mixing

no mixing

πη mass distribution




V.Grishina et al., PLB **521**, 217 (2001)

V.Kudryavtsev et al., PRC **66**, 015207 (2002)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# $g_{a_0KK}$ and $g_{f_0KK}$

Parameters and results for the $a_0$ meson.

| Ref. | $M_R$ | $\Gamma_{\pi\eta}$ | $\bar{g}_{K\bar{K}}$ | $W_{a_0}$ |
|---|---|---|---|---|
| [18] | 1001 | 70 | 0.224 | 0.49 |
| [19] | 999 | 146 | 0.516 | 0.29 |
| [20] | 1003 | 153 | 0.834 | 0.24 |
| [20] | 992 | 145.3 | 0.56 | 0.29 |
| [21] | 984.8 | 121.5 | 0.41 | 0.36 |

- S. Teige, et al., PR D 59 (2001) 012001: $\pi^- p$ data from BNL
- D.V. Bugg, et al., PR D 50 (1994) 4412: analysis of $p\bar{p}$ data from CB
- N.N. Achasov, A.N. Kiselev, PR D 68 (2003) 014006: analysis of KLOE data
- A. Antonelli, hep-ex/0209069: Radiative $\phi$ decays (KLOE)

Parameters and results for the $f_0$ meson.

| Ref. | $M_R$ | $\Gamma_{\pi\pi}$ | $\bar{g}_{K\bar{K}}$ | $W_{f_0}$ |
|---|---|---|---|---|
| [22] | 969.8 | 196 | 2.51 | 0.17 |
| [23] | 975 | 149 | 1.51 | 0.23 |
| [21] | 973 | 253 | 2.84 | 0.14 |
| [24] | 996 | 128.8 | 1.31 | 0.21 |

- M.N. Achasov, et al., PL B 485 (2000) 349: Radiative $\phi$ decays (SND)
- R.R. Akhmetshin, et al., PL B 462 (1999) 380: Radiative $\phi$ decays (CMD-2)
- A. Antonelli, hep-ex/0209069: Radiative $\phi$ decays (KLOE)
- N.N. Achasov, V.V. Gubin, PR D 63 (2001) 094007: Rad. $\phi$ decays (SND, CMD-2)