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Precision Measurement of the η-Mass at COSY-ANKE

using the Spin-Resonance Method for an Absolute Beam Momentum Determination

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Institut für Kernphysik

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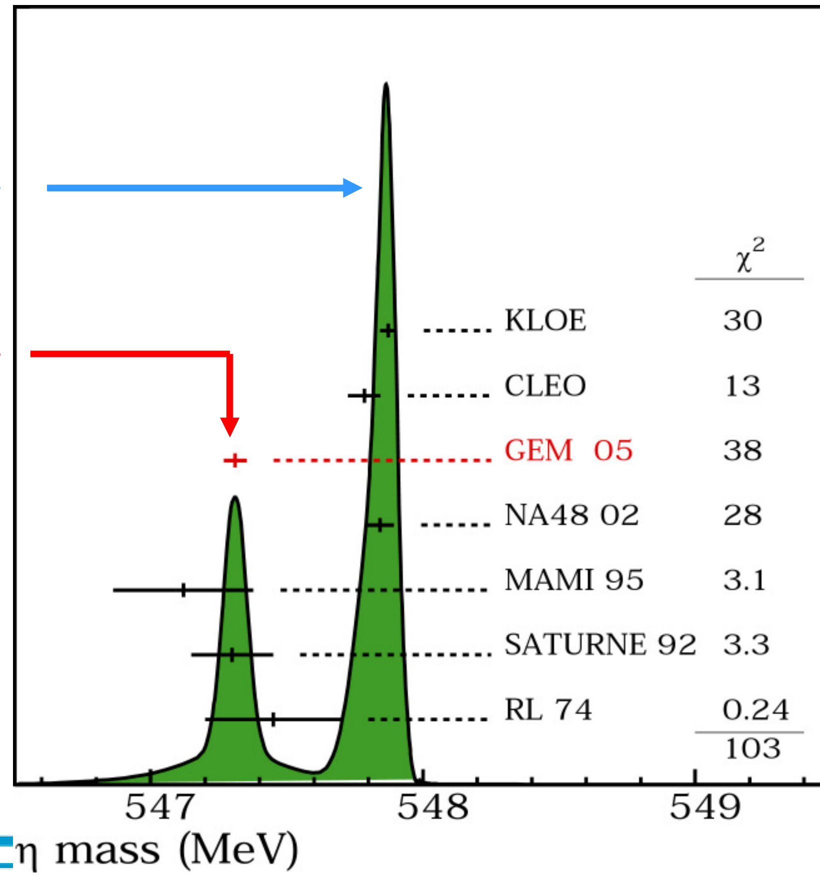
Motivation for η-Mass Measurements at ANKE

- „Current“ η-mass: (547.854 ± 0.024) MeV/c^2

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*
547.853±0.024 OUR AVERAGE				
547.874±0.007±0.029		AMBROSINO	07B	KLOE
547.785±0.017±0.057	16k	MILLER	07	CLEO
547.843±0.030±0.041	1134	LAI	02	NA48
• • • We do not use the following data for averages, fits, limits,				
547.311±0.028±0.032		[1] ABDEL-BARY	05	SPEC
547.12 ±0.06 ±0.25		KRUSCHE	95D	SPEC
547.30 ±0.15		PLOUIN	92	SPEC
547.45 ±0.25		DUANE	74	SPEC
548.2 ±0.65		FOSTER	65C	HBC
549.0 ±0.7	148	FOELSCHE	64	HBC
548.0 ±1.0	91	ALFF-...	62	HBC
549.0 ±1.2	53	BASTIEN	62	HBC



Inconsistencies ?!?

PLB 619 (2005) 281

Motivation for η-Mass Measurements at ANKE

- Precise determination of the η-mass with high accuracy

  Aim: $\Delta m_\eta \leq 50$ keV/c^2

Idea:

- Use a method independent of
  - shape of excitation function at threshold
  - partial waves / angular distributions

  to avoid inaccuracies of extrapolations

Clever solution:

- Pure kinematics!

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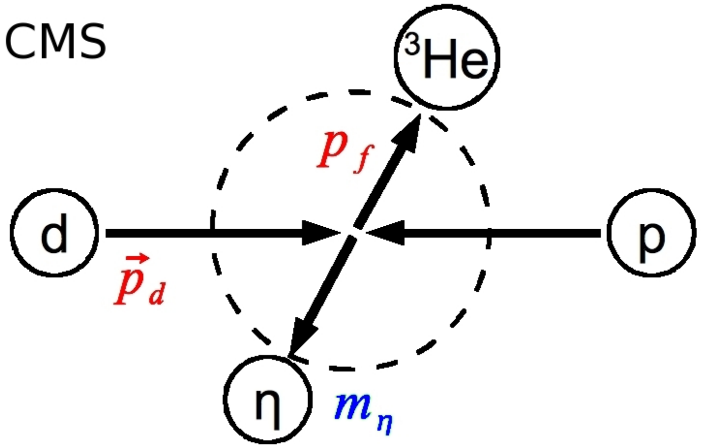
Mass Determination by Pure Kinematics

Idea:

- Use the two-particle reaction d+p→^{3}He+η
  - masses of all other particles are very well known
  - at fixed collision momenta p_d both ejectiles (η-meson and ^{3}He) have same fixed momentum p_f

- Mass m_η can be determined with highest precision if the momenta p_d and p_f are known with high accuracy



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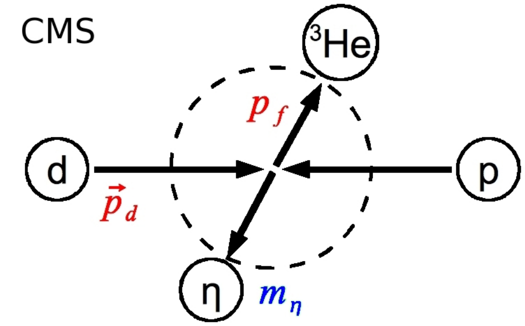


Kinematics on the Reaction d+p→^{3}He+η

- Total energy in the CMS:

$$\sqrt{s} = \sqrt{(E_d + E_p)^2 - (\vec{p}_d + \vec{p}_p)^2}$$
$$= \sqrt{2m_p\sqrt{m_d^2 + \vec{p}_d^{\,2}} + m_d^2 + m_p^2}$$

- Final state momentum:

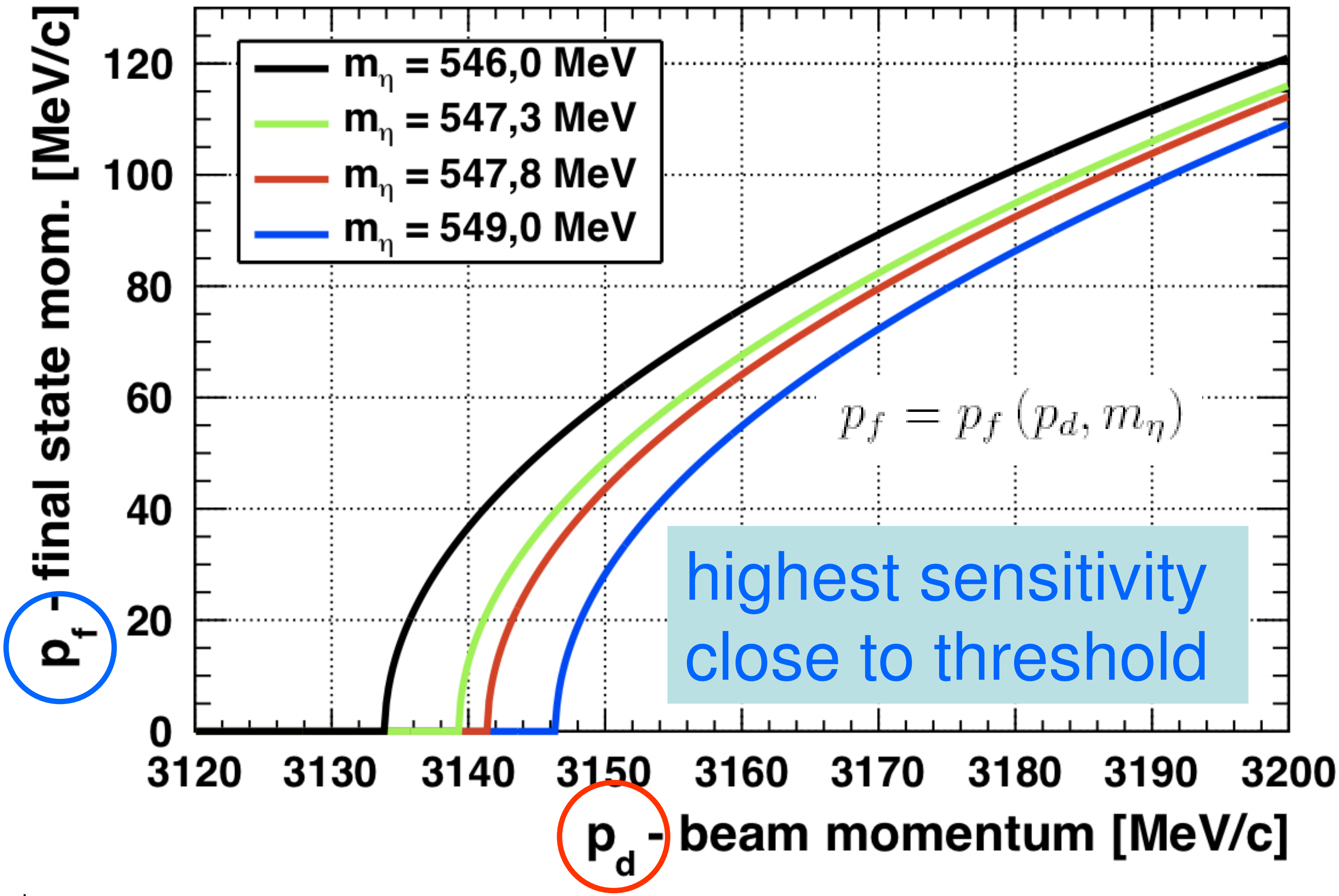
$$p_f = \frac{\sqrt{\left[s - (m_{^3\mathrm{He}} + m_\eta)^2\right] \cdot \left[s - (m_{^3\mathrm{He}} - m_\eta)^2\right]}}{2 \cdot \sqrt{s}}$$

- Final state momentum depends only on p_d and p_f !!!

$$p_f = p_f\,(p_d, m_\eta)$$

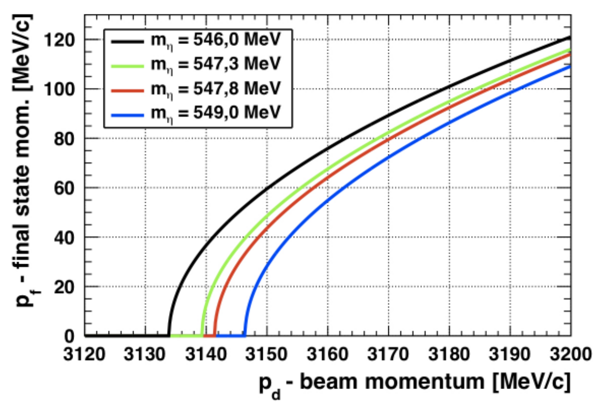
- All other parameters/masses are known well enough (eV level)

Kinematics on the Reaction d+p→^{3}He+η



Kinematics on the Reaction d+p→^{3}He+η

- Measure in an experiment these two momenta p_d and p_f with highest precision → mass m_η
- In principle only one measurement at one single beam momentum is sufficient



Better method:

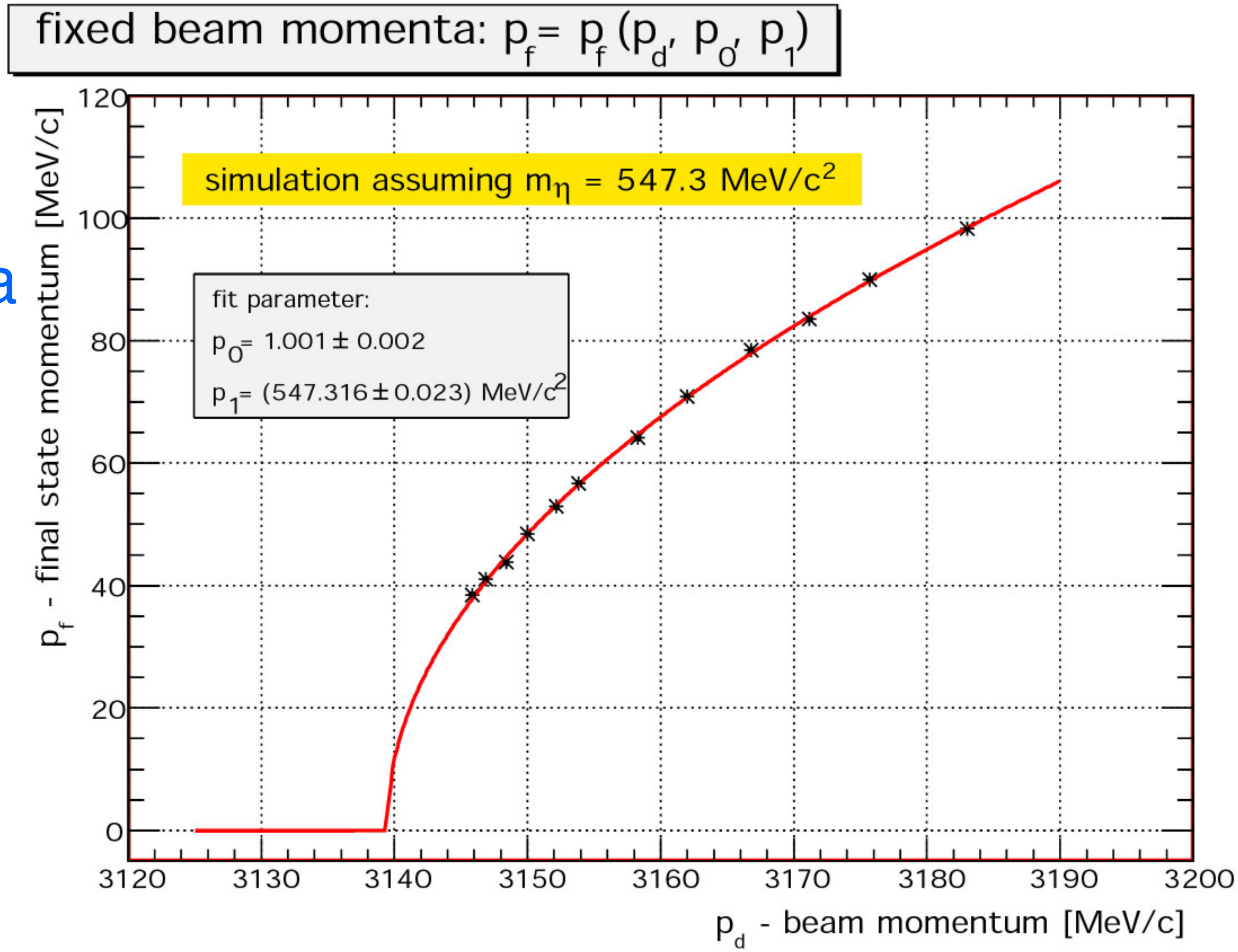
- Measurements at different beam momenta near the production threshold

→ determination and exclusion of systematic uncertainties in the determination of p_f

Experiment at ANKE: Monte-Carlo Simulation

Nice feature of this method:

- If the final momenta p_f are wrong by a fixed factor there is NO effect on the mass m_η
- An offset in p_f appers as a bad χ^2 of the fit



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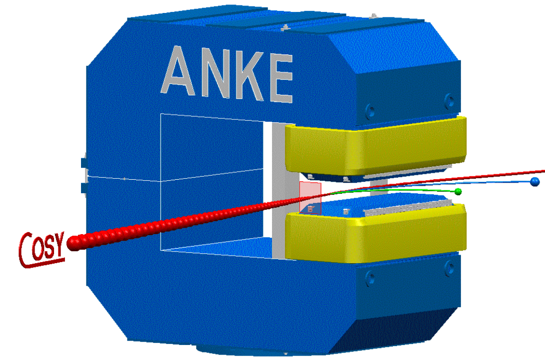
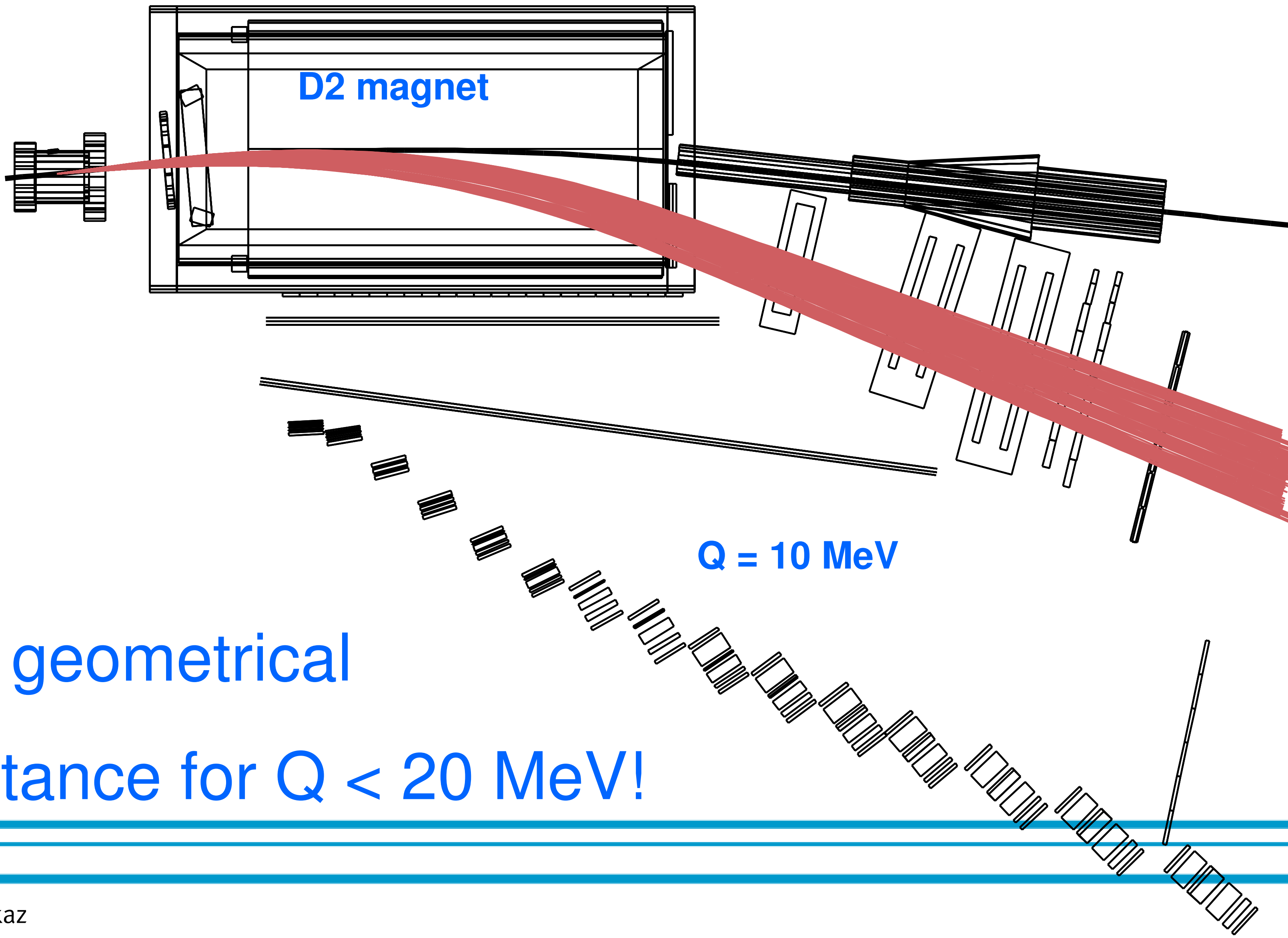
The Reaction dp→^{3}Heη at ANKE



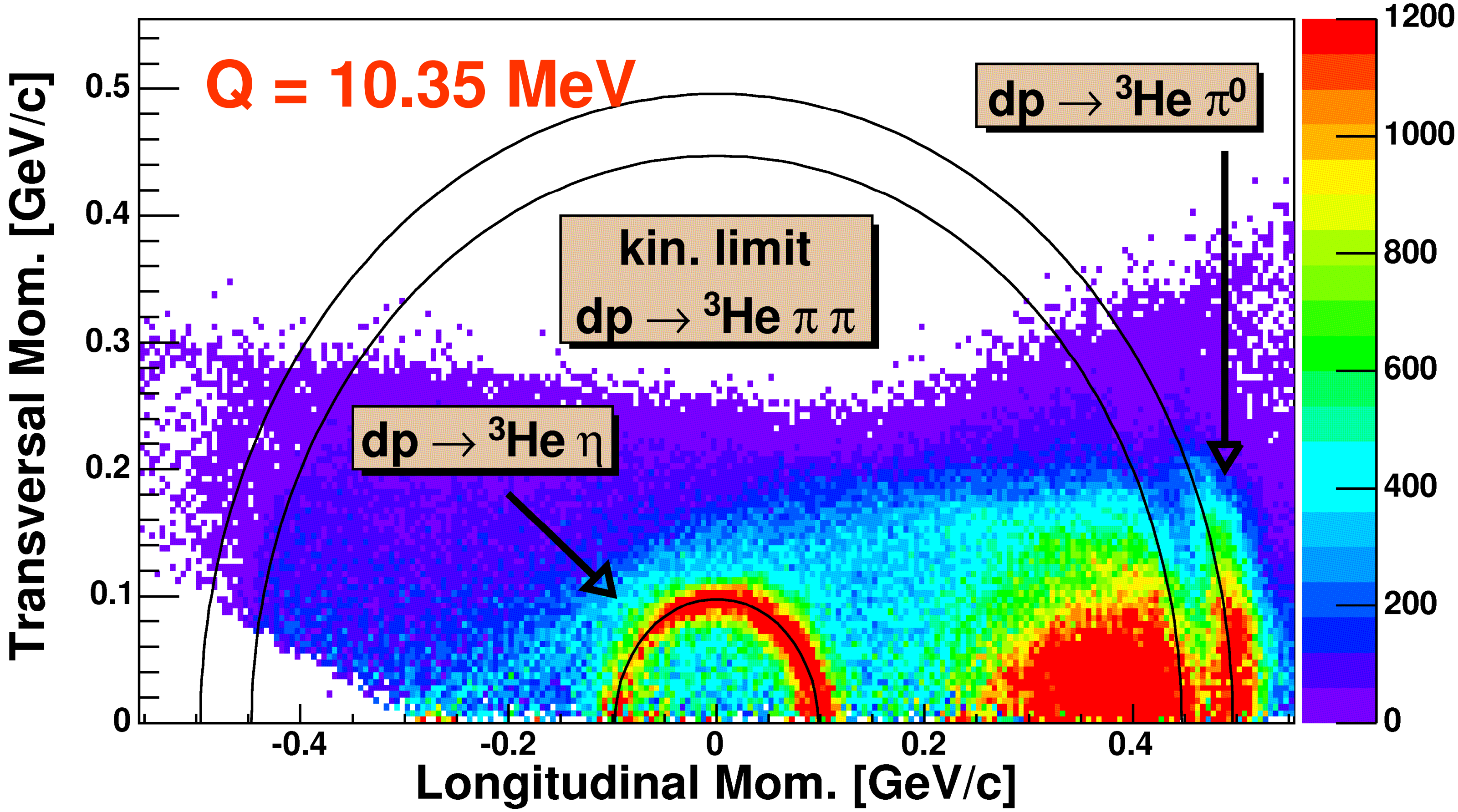


100% geometrical

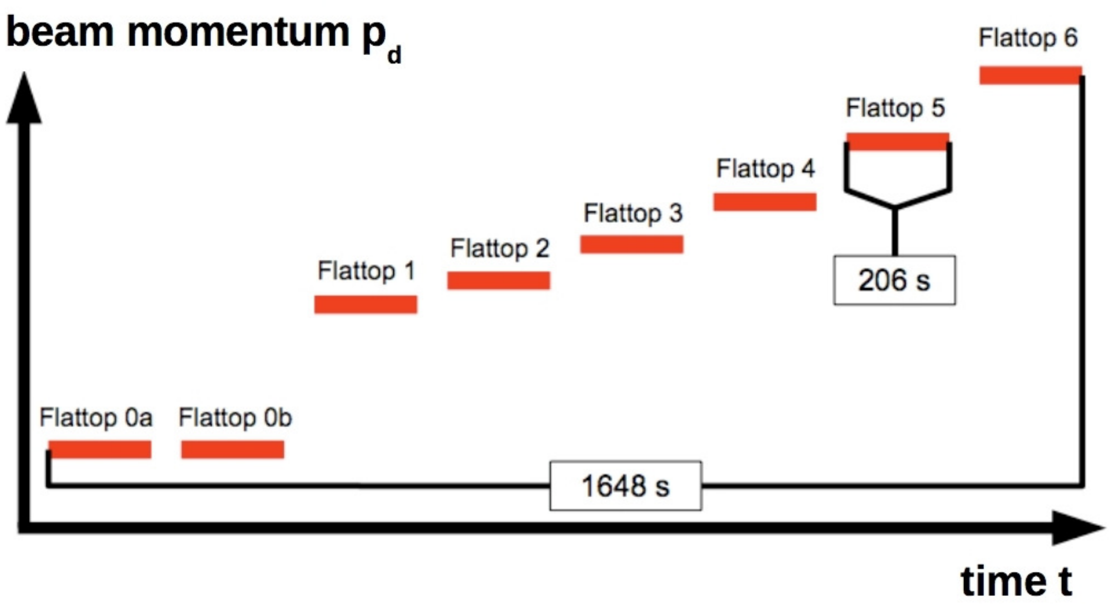
acceptance for Q < 20 MeV!

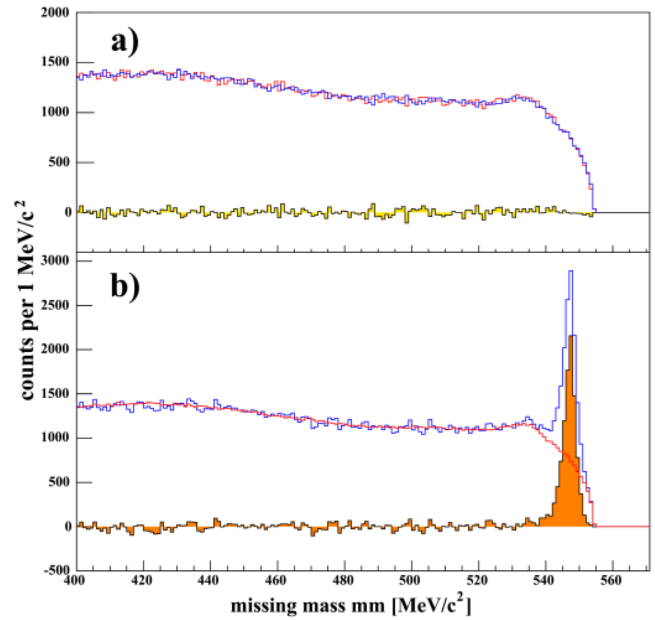
The Reaction dp→^{3}Heη at ANKE

- Two-body reaction: Momentum locus!



Operation of COSY: Supercycles





- Flattop 0a / 0b : Subthreshold → background subtraction
- Flattop 1-6 : Q > 0 MeV → η-meson production
- 3 Supercycles : Q < - 5 MeV, 15 x Q > 0 MeV (1-15 MeV)

The Reaction $dp \rightarrow {}^3He\eta$ at ANKE

- ANKE allows for this reaction to determine the final state momentum with a precision of $\Delta p_f \sim 150$ keV/c
- For the envisaged precision of $\Delta m_\eta \leq 50$ keV/c^2 it will be necessary to determine the COSY deuteron beam momentum with an accuracy of $\Delta p_d / p_d < 10^{-4}$!!!

Problem:

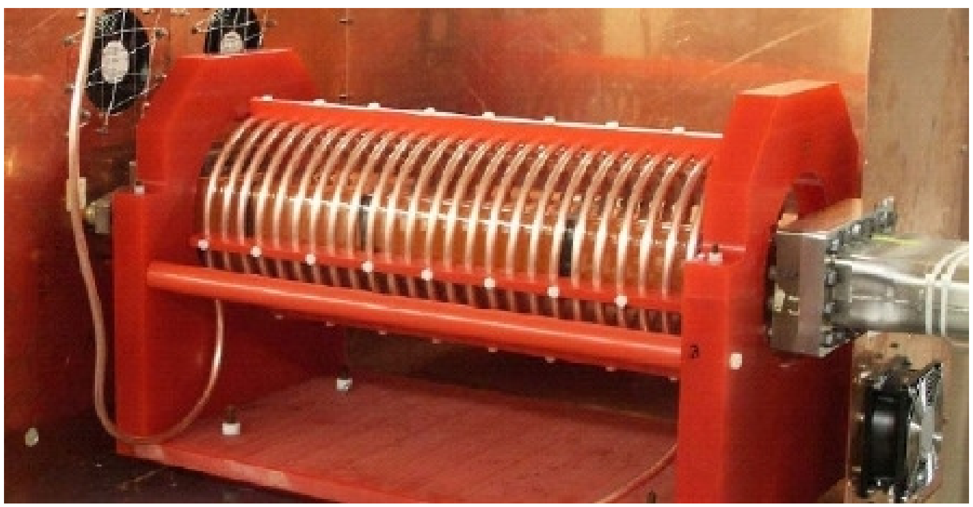
- With conventional methods it is only possible to gain a resolution of $\Delta p_d / p_d \sim 10^{-3}$

Solution: Spin resonance method

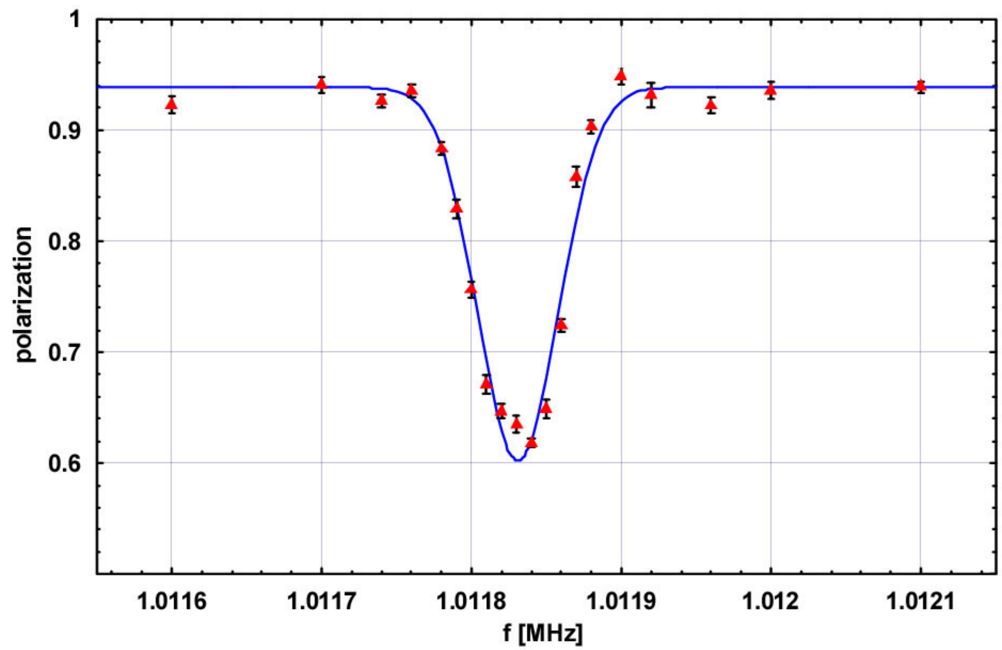
New Beam Momentum Determination at COSY

Artificial spin resonance at COSY:

- Induced by a horizontal magnetic rf-field (solenoid)
- Depolarization of a vertical polarized deuteron beam



rf solenoid at the COSY beam line



solenoid frequency f_r

New Beam Momentum Determination at COSY

- Spin resonance condition:

$$f_r = (1+\gamma \cdot G_d) \cdot f_0$$

$$\gamma = \frac{1}{G_d} \cdot \left(\frac{f_r}{f_0} - 1 \right)$$

$$p_d = m_d \sqrt{\gamma^2 - 1}$$

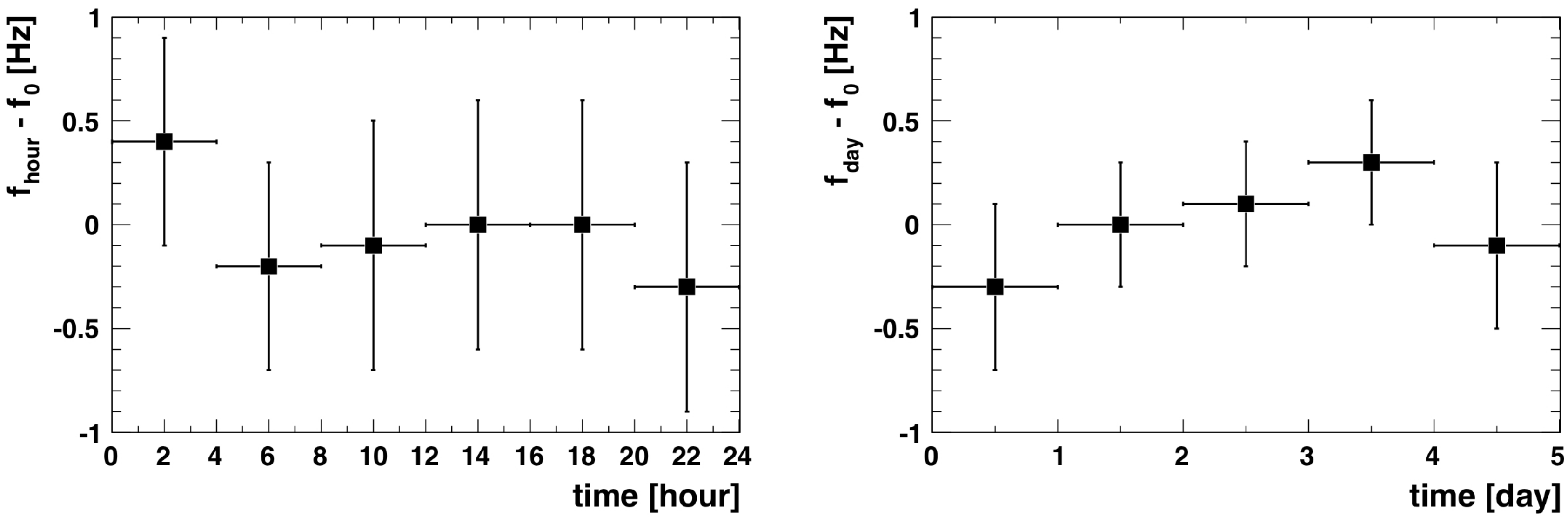
f_r	:	resonance frequency
f_0	:	revolution frequency
G_d	:	gyramagnetic anomaly

$G_d = -0,1429872725 \pm 0,0000000073$

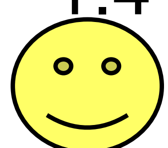
- Measurement of the (fixed) beam momentum p_d by
  - determination of the revolution frequency f_0
  - determination of the resonance frequency f_r

Determination of the Revolution Frequency f_0

- Use of Schottky device (1000th harmonic)
- Schottky spectra stored every ~ 30 s



- Frequency Stability (5 d) : $\Delta f_0 < \pm$ 1 Hz (f_0 ~ 1.4 MHz)
- Systematic uncertainty : ± 6 Hz



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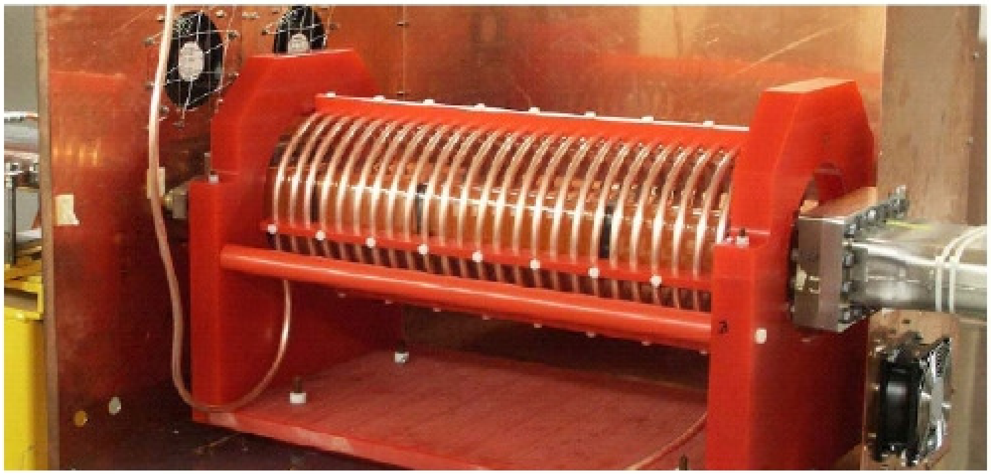
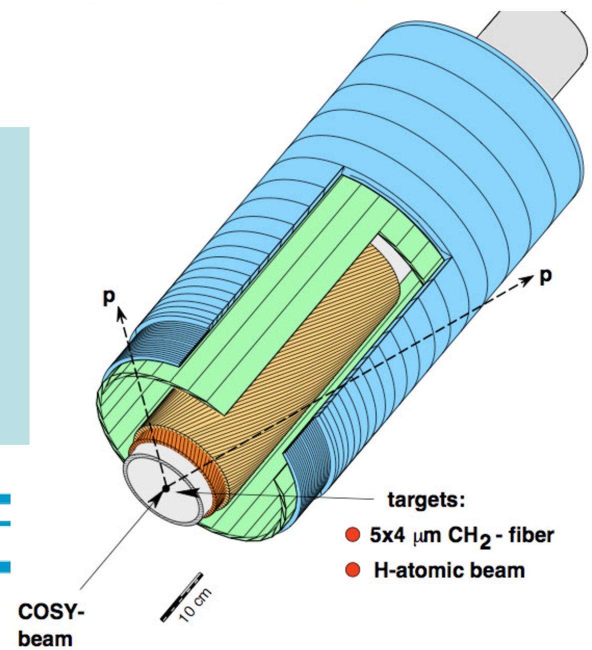
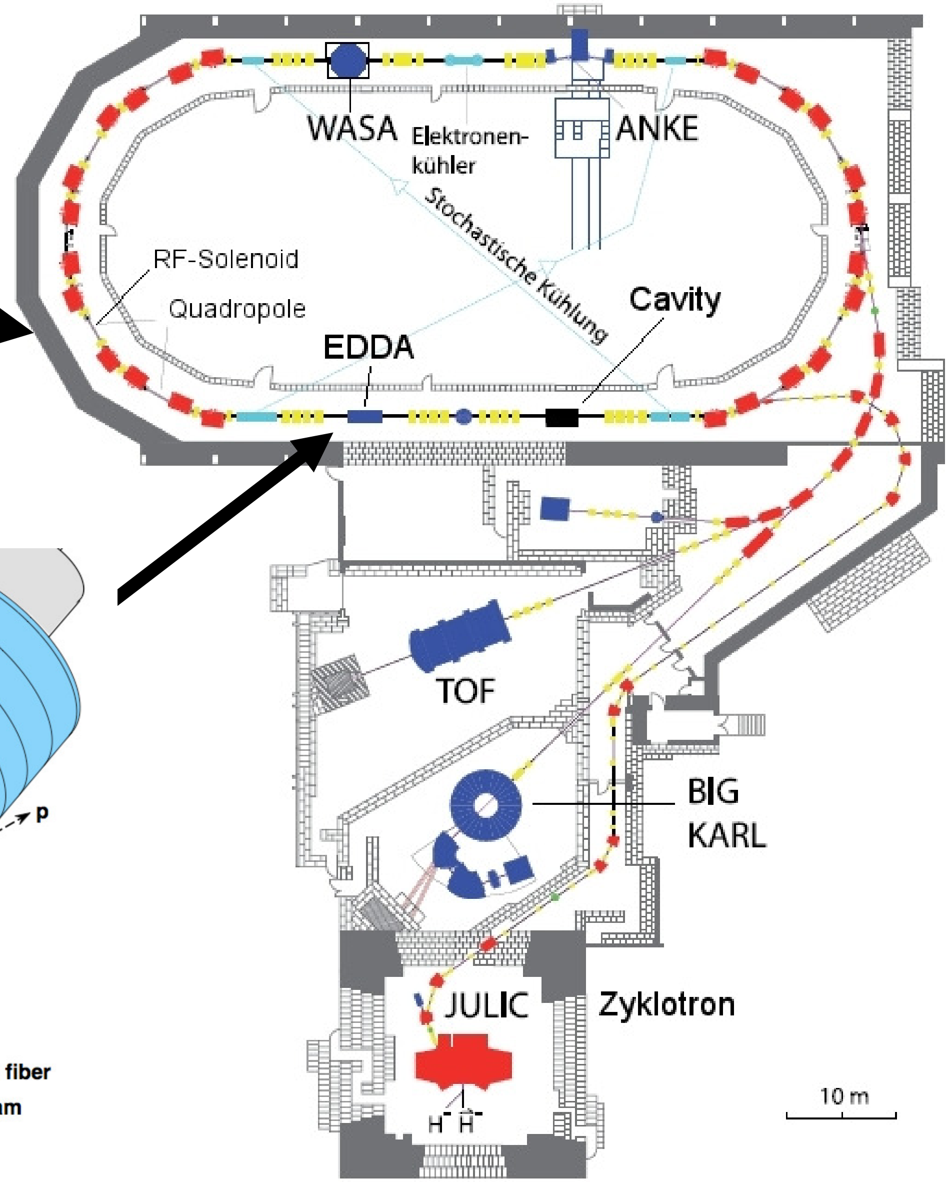
Determination of the Spin Resonance Frequency f_r







EDDA detector used as beam polarimeter

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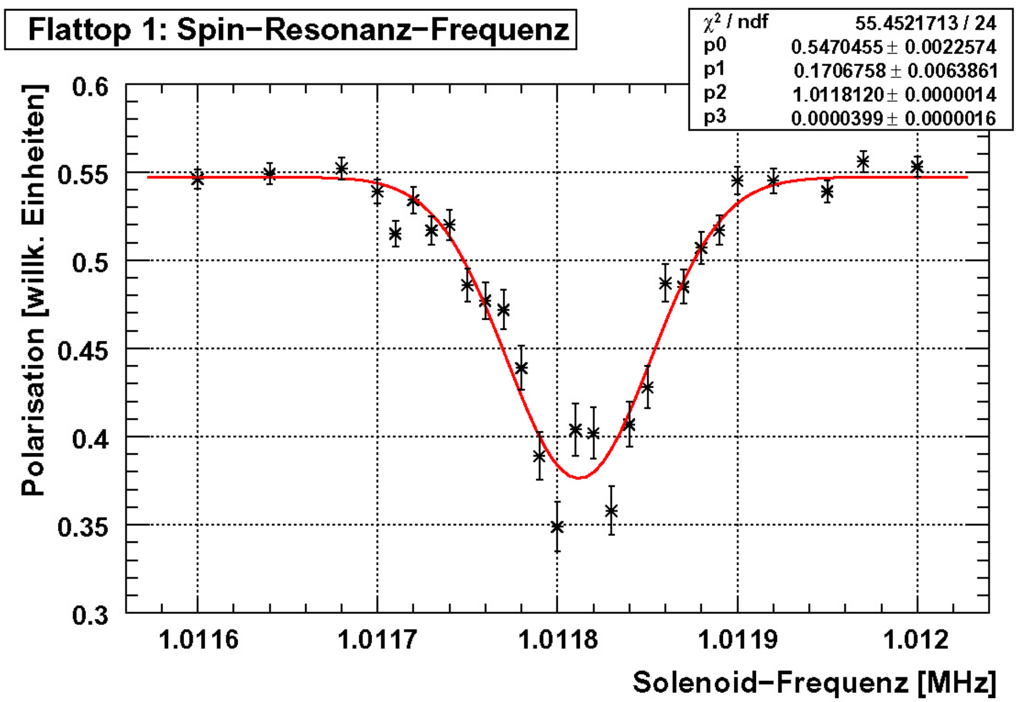
Determination of the Spin Resonance Frequency f_r

- For each single energy the spin resonance spectrum has been measured (~2h each) at the beginning and the end of the beam time



Method to describe the data and to identify f_r:

- Fit each resonance curve using a gaussian + offset
- Subtract the offset
- Scale the data/curves to unity

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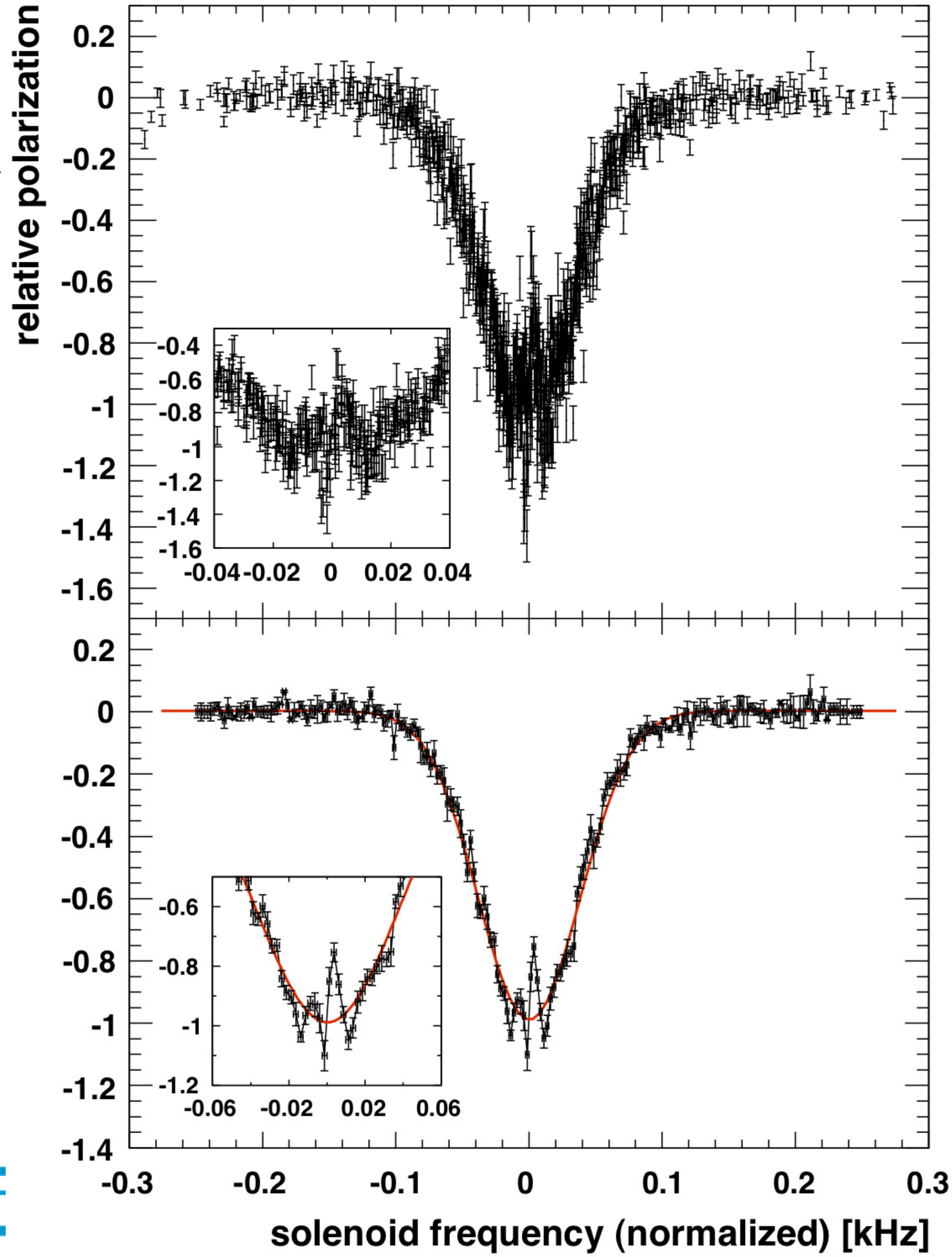
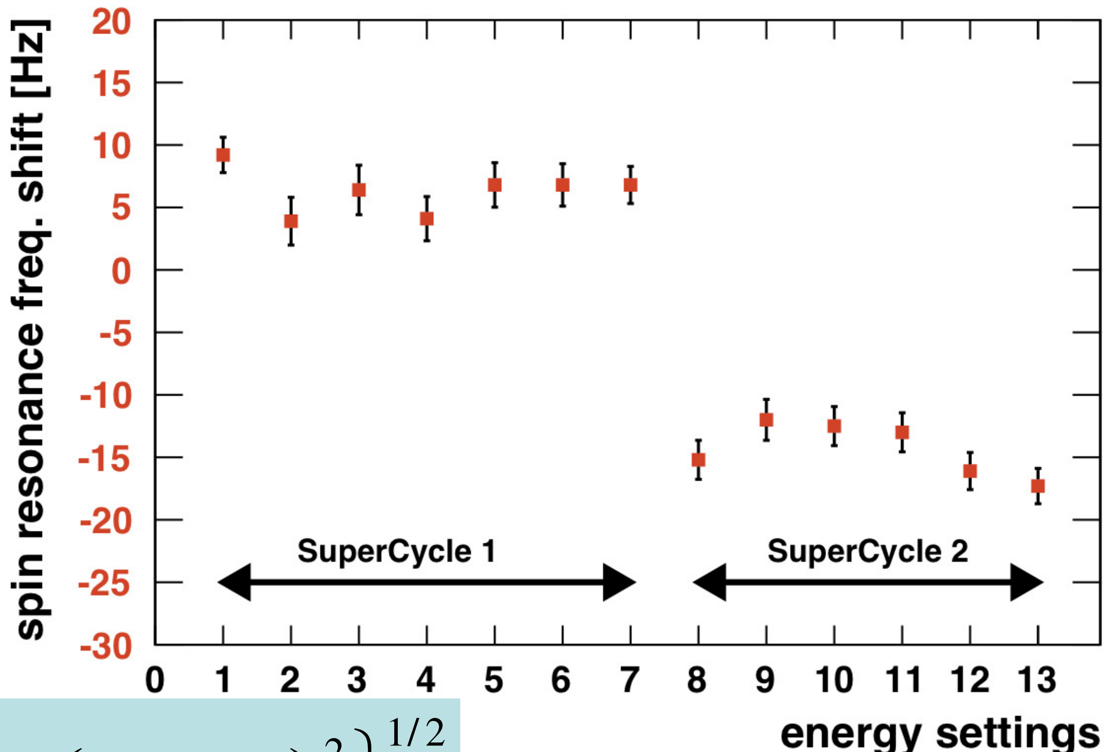
Spin Resonance at COSY

- The obtained data can be described by gaussians
- Structures in the center of the peak are caused by the used barrier bucket cavity (for compensation of energy loss in the target)
- f_r (~1 MHz) can be extracted with an accuracy of a few Hz



Long Term Stability: Spin Resonance Frequency

- During approx. one week f_r shifts by up to 15 Hz
  → most probably effect of (in)stability of the COSY beam orbit
- Orbit length calculation:



$$\gamma = \frac{1}{\sqrt{1 - \frac{s^2 f_0^2}{c^2}}}$$

$$f_r = (1 + \gamma \cdot G_d) f_0$$

$$s = c \cdot \left\{ \frac{1}{f_0^2} - \left(\frac{G_d}{f_r - f_0} \right)^2 \right\}^{1/2}$$

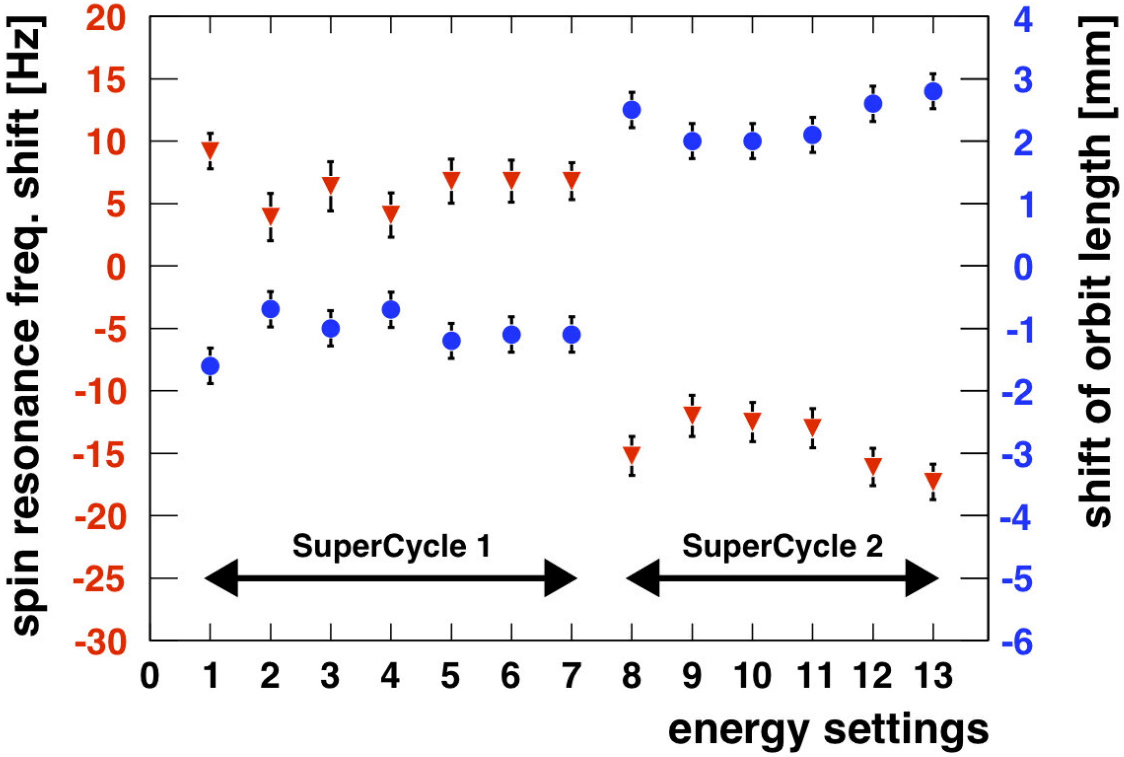
s = Orbit

Determination of the COSY Orbit Lenth

- COSY beam orbit can be determined with an accuracy of $\Delta s < 1$ mm !!!
- Orbit changes during a week by up to $\delta s = 3$ mm

Possible Explanation:

Stability of cooling water of dipole power supplies



Beam Momentum Determination

$$\gamma = \frac{1}{G_d} \cdot \left(\frac{f_r}{f_0} - 1 \right) \qquad p_d = m_d \sqrt{\gamma^2 - 1}$$

- Spin resonance frequency f_r: ± 15 Hz
- Beam revolution frequency f_0: ± 6 Hz

$$\Delta p_d / p_d = 6 \cdot 10^{-5}$$

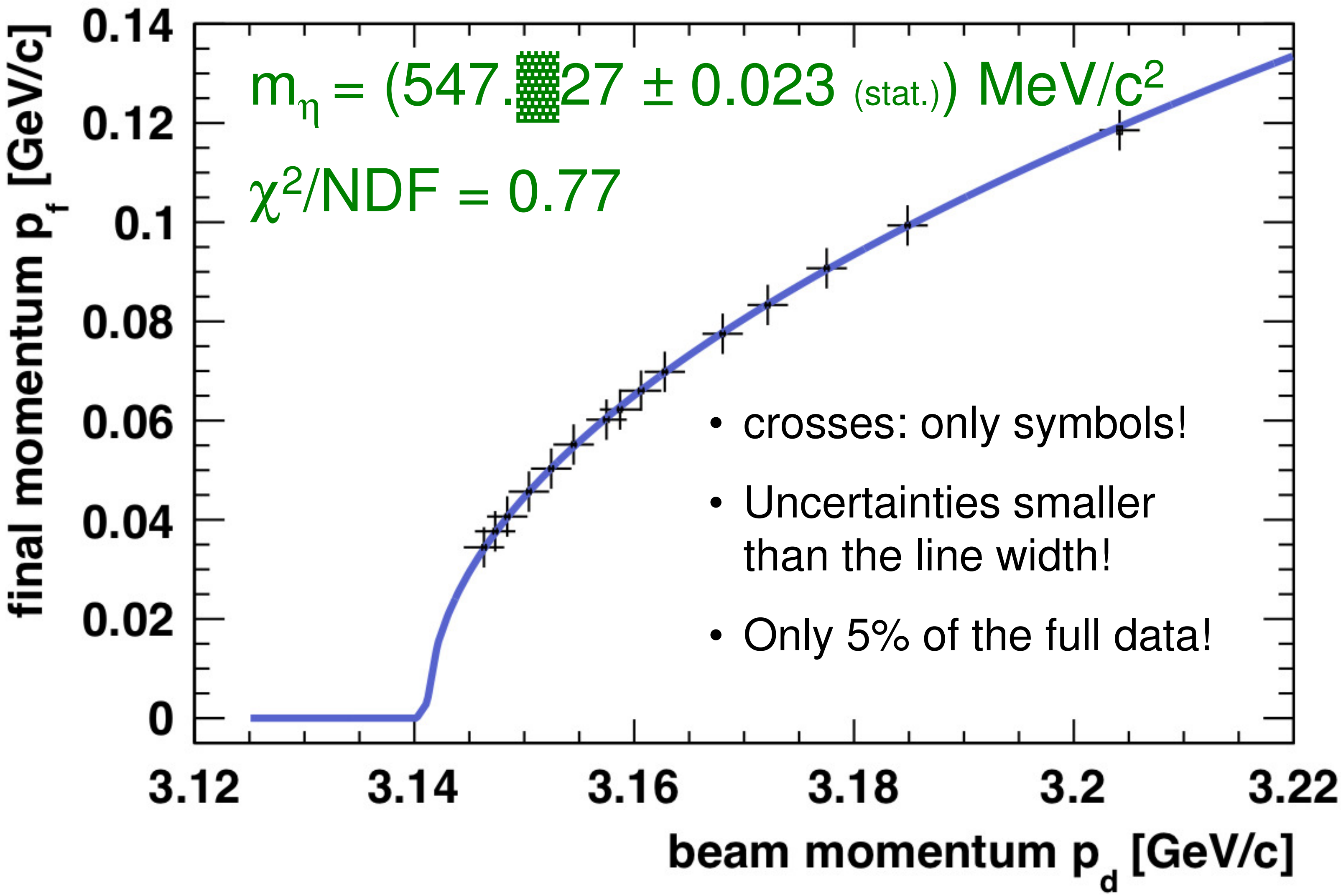
→ Reached accuracy for the beam momentum:

Δp_d = 170 keV/c at p_d ~ 3100 MeV/c

P. Goslawski et al., Phys. Rev. ST-AB, 13, 022803 (2010)

→ Together with Δp_f ~ 150 keV/c the design goal of of $\Delta m_\eta \leq$ 50 keV/c² can be reached!

Preliminary Results: η-Mass at ANKE



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Summary

- The COSY beam momenta have been determined using the spin resonance method with an accuracy of **Δp = ±170 keV/c**
- This resolution corresponds to an uncertainty for the η-meson of **Δm_η = ±40 keV/c^2**
- The beam orbit has been determined with an accuracy of **Δs < 1 mm**
- The COSY beam orbit can vary during a week by **$\delta s \sim$ 3 mm** magnet cooling?

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By the way…

- The presented results and the observed width of the spin resonance curve allow to estimate an upper limit for both the
  - orbit spread/distribution
  - beam momentum spread/distribution

$$\frac{\Delta f_0}{f_0} = \eta \cdot \frac{\Delta p}{p}$$

Results:

- beam momentum: $\frac{\delta p}{p} < 5 \cdot 10^{-4}$
- orbit distribution: ds ~ 10-12 mm

Summary/Outlook

- In total more than 10^6 η-meson production events are on disk.
- The final analysis of the $d+p \rightarrow {}^3He+\eta$ reaction data is currently in progress.
- Already the preliminary result shows that the goal of the ANKE experiment ($\Delta m_\eta \leq 50$ keV/c^2) will be reached.

Thank you....