Energy Calibration for the Forward Detector at WASA-at-COSY

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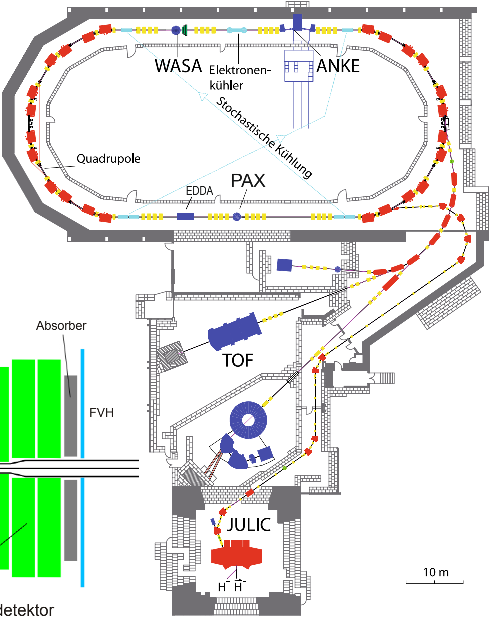
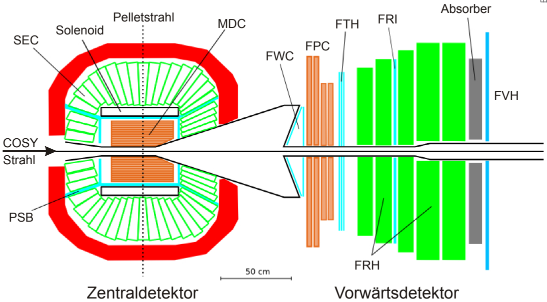
Experimental setup WASA-at-COSY

One physics topic:
Studies on meson production cross sections
e.g. of $p + d \rightarrow {}^3\mathrm{He} + \eta'$





The Forward Range Hodoscope

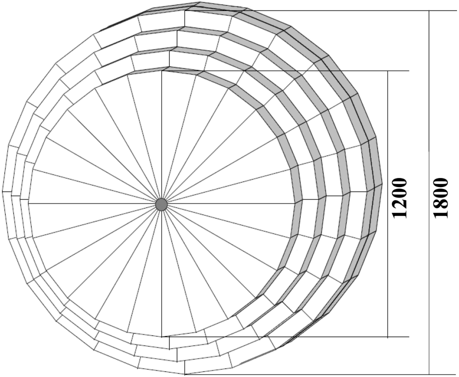
- Scattering angle + energy losses ⇒ four momentum
- A: digitalised ADC value
  ΔE: energy loss
- Only projections on the beam axis are comparable:

$$\begin{aligned} \Delta E_z &= \Delta E \cdot \cos\vartheta \\ A_z &= A \cdot \cos\vartheta \end{aligned}$$

- $f_{\mathrm{NU}}, f_{\mathrm{NL}}$: 3rd order polynomials ⇒ 8 parameters
- To be determined for each detector element, partly correlated

Energy reconstruction

$$\Delta E_z^{\mathrm{rec}} = f_{\mathrm{NL}}\left(\frac{A_z}{f_{\mathrm{NU}}(\vartheta)}\right)$$



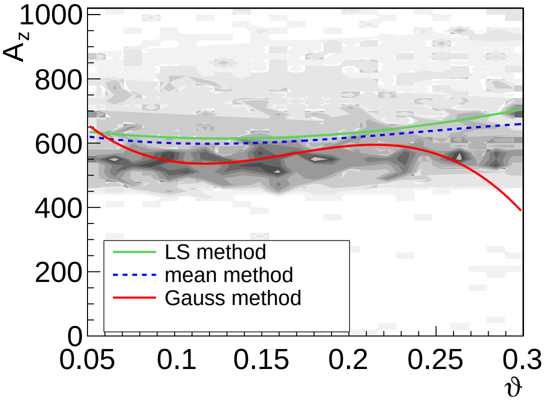
Non uniformity – angular dependence

$$\Delta E_z^{\text{rec}} = f_{\text{NL}}\left(\frac{A_z}{f_{\text{NU}}(\vartheta)}\right)$$

- MIPs have identical energy losses

$\Rightarrow$ Pure angular effects

- Plot $A \cdot \cos(\vartheta)$ vs. ϑ
- Fit f_{NU} as 3rd order polynomial



MIP spectrum with differently fitted polynomials Layer 4 element 23

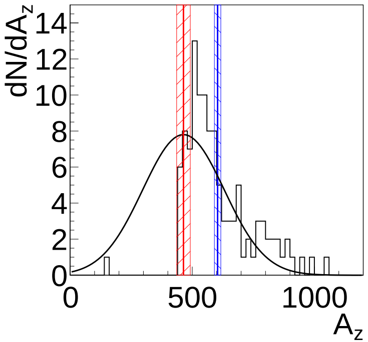
Non uniformity – fitting algorihms

Least Square method (LS)

- Minimize χ^2
- $\chi^2 = \sum_{i=1}^{N} \delta_i^2$
- $\delta_i^2 = \left(\frac{y_i - f(x_i)}{\sigma_i}\right)^2$

Mean and Gauss method

- Projections along A_z axis
- Mean value or mean of Gaussian fit



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Mean and Gauss method

- Projections along A_z axis
- Mean value or mean of Gaussian fit

Least Trimmed Square method (LTS)

- Iteratively minimisation of $\chi^2 = \sum_{i=1}^{h} (\delta^2)_{i:n}$
- $(\delta^2)_{i:n}$: *ordered* residuals
- $h < N$ predefined value,e.g., $h/N = 60\,\%$

Non uniformity – angular dependence

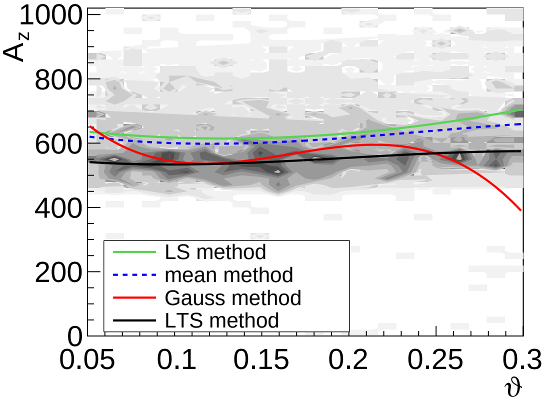
$$\Delta E_z^{\mathrm{rec}} = f_{\mathrm{NL}}\left(\frac{A_z}{\boldsymbol{f_{\mathrm{NU}}(\vartheta)}}\right)$$

- MIPs have identical energy losses

$\Rightarrow$ Pure angular effects

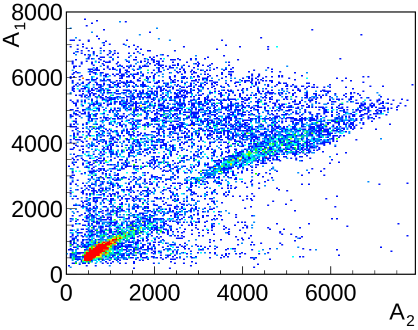
- Plot $A \cdot \cos(\vartheta)$ vs. ϑ
- Fit f_{NU} as 3rd order polynomial

$\Rightarrow$ Best results with Least Trimmed Squares method (LTS)

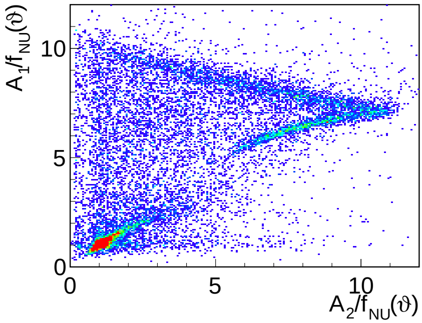


MIP spectrum with differently fitted polynomials Layer 4 element 23

Non uniformity – results

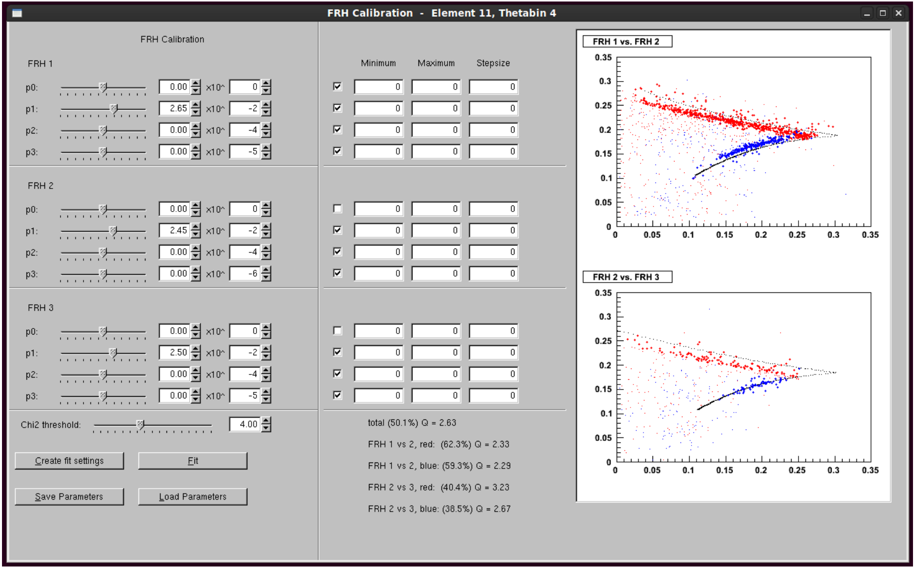


Uncalibrated data

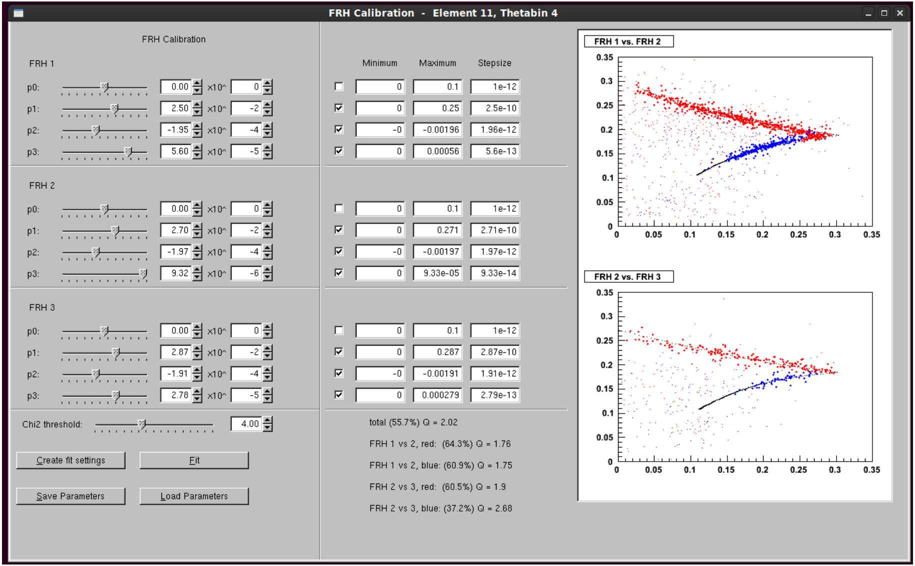


After non uniformity calibration

Non linearity – energy dependence



Non linearity – energy dependence



Bounded sum of the square of the errors

Usual least square approach:

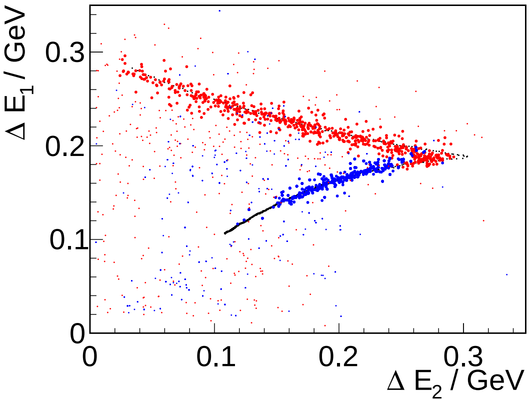
$$\chi^2 = \sum_{i=1}^{N} \delta_i^2$$

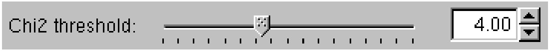
$$\delta_i^2 = \left(\frac{y_i - f(x_i)}{\sigma_i}\right)^2$$

Bounded least squares:

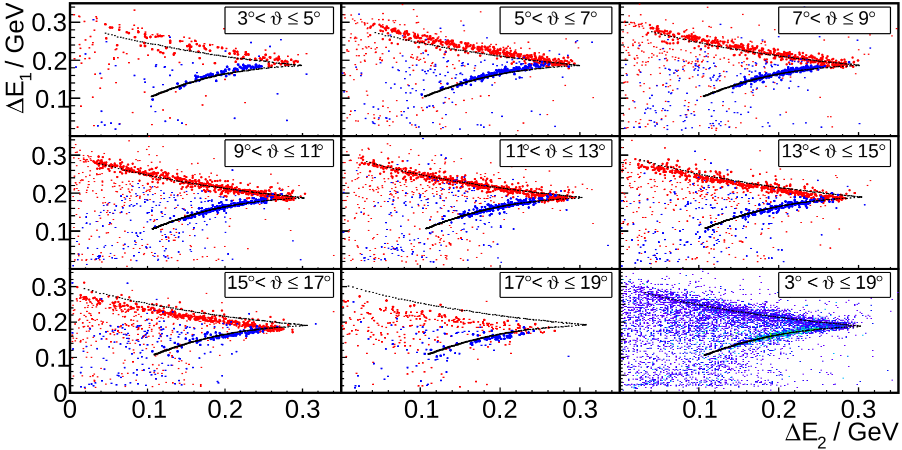
$$Q^2 = \sum_{i=1}^{N} q_i^2$$

$$q_i^2 = \min\left(\delta_i^2; \delta_{max}^2\right)$$

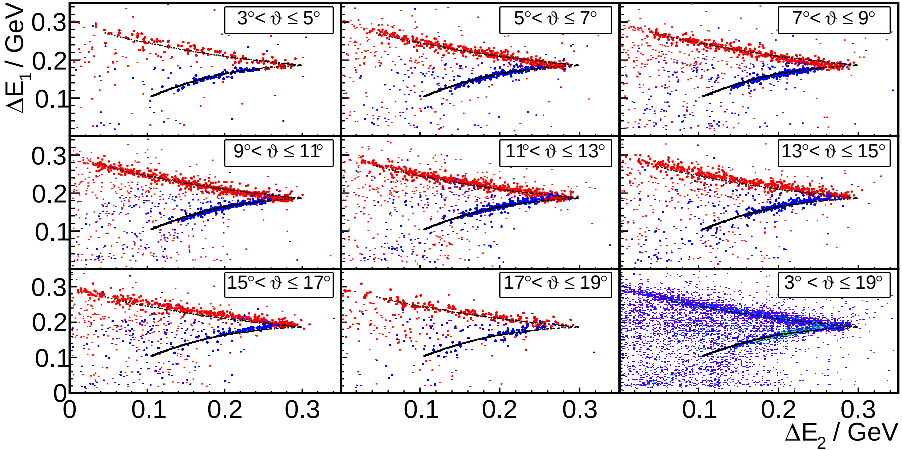




Check non uniformity parameters



Corrected non uniformity parameters



Conclusion

- Software with graphical user interface
- Powerful tool for FRH energy calibration
- Non uniformity calibration and fine calibration without user interactions
- Non linearity parameters can be found and controlled quickly by the use of the GUI and fit
- Complete detector calibration within a few days possible

$\Rightarrow$ **Significant calibration speed up**

- Suitable for all possible reactions
  $p + p \rightarrow p + p + X$,
  $p + d \rightarrow {}^{3}He + X$ and
  $d + d \rightarrow {}^{4}He + X$
- Suitable for other detector components