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

K. Demmich, F. Bergmann, P. Hüsemann, N. Hüsken, A. Täschner and A. Khoukaz
for the WASA-at-COSY collaboration

Westfälische Wilhelms-Universität Münster, Institut für Kernphysik

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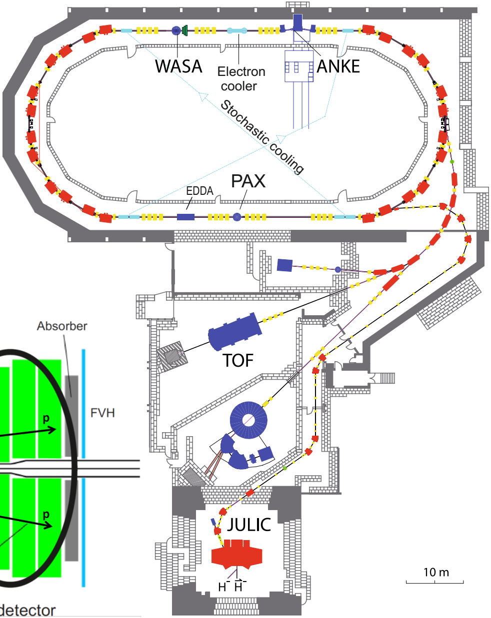
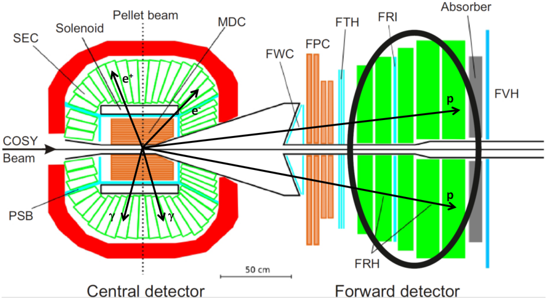
One physics topic:
Studies on rare and
and forbidden meson decays
e.g. of $\eta \rightarrow \pi^0 + e^+ + e^-$





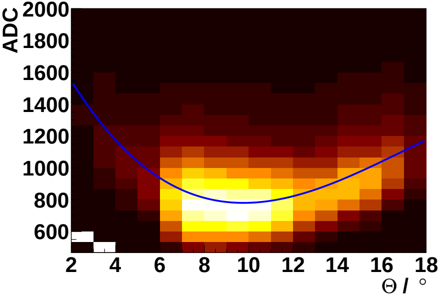
Motivation for an optimized calibration of the forward detector

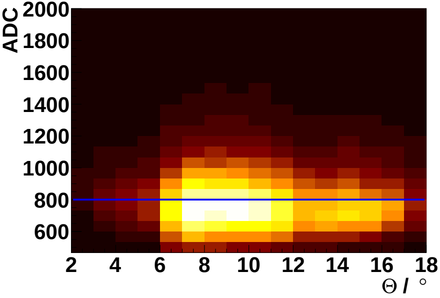
$p + p \to p + p + \eta$
$\eta \to \pi^0 + e^+ + e^- \to \gamma + \gamma + e^+ + e^-$

- Forward detector energies for η identification (missing mass)
- Special case for forbidden decays:
  - Strict cuts to handle direct multi pion background
  - Very narrow missing mass peak for high signal/background ratio required
  - Kinematic fitting relies on precise kinematic values
- Calibration parameters observed to be time dependent (over days/weeks)

Energy reconstruction

- Scintillators/photomultipliers give ADC values
- Calibration needed to reconstruct ΔE
- Two corrections:
  - Non uniformity: dependence on the polar angle $\vartheta \Rightarrow f_{NU}$
  - Non linearity in the energy dependence $\Rightarrow f_{NL}$
- Non uniformity correction by means of elastically scattered protons





Non linearity correction

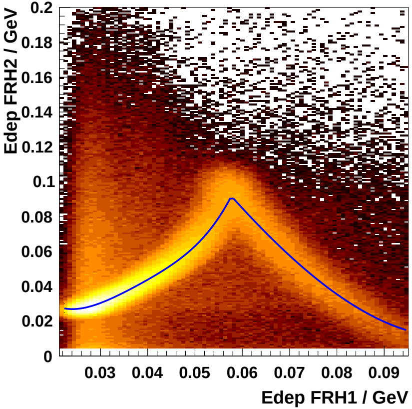
- Goal: Find calibration parameters for which real data (RD) und Monte Carlo (MC) data fit

1. Fit a function to simulated energy loss bands
2. Fit real data to this function

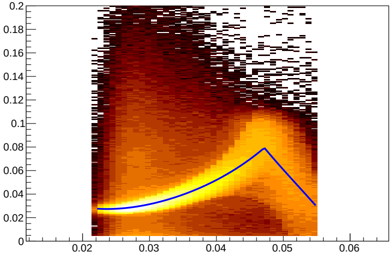
- Use 2-dimensional fit algorithm for both steps
- Handle background
- Calibrate all FRH layers simultaneously
- Use all possible layer combinations (e.g. 1-vs-2, 1-vs-3)

$\Rightarrow$ IMPORTANT: Use same fit algorithm for MC and RD to avoid systematic effects

Fitting Monte Carlo data - how it should look like



FRH layer 1 vs layer 2



layer 1 vs layer 3

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Fitting Monte Carlo data

- Adjusted χ^2 fitting for 2-dimensional histograms
- $\boldsymbol{\chi^2 = \sum_{bins} w_i \cdot \min(\delta_i^2, \delta_{\mathrm{max}}^2)}$
- $\delta_i = (y_i - f_{\mathrm{MC}}(x_i))/\sigma(x_i)$
- $(x_i, y_i) =$ center of bin i; $w_i =$ content of bin i
- $f_{\mathrm{MC}}(x)$: fit function
- $\sigma(x)$: standard deviation of the distribution (from x-binwise y-projections)
- $\delta_{\mathrm{max}} =$ predefined threshold,
- e.g., $\delta_{\mathrm{max}} = 2$ means
  „fit all data within a 2σ environment,
  everything outside is background"

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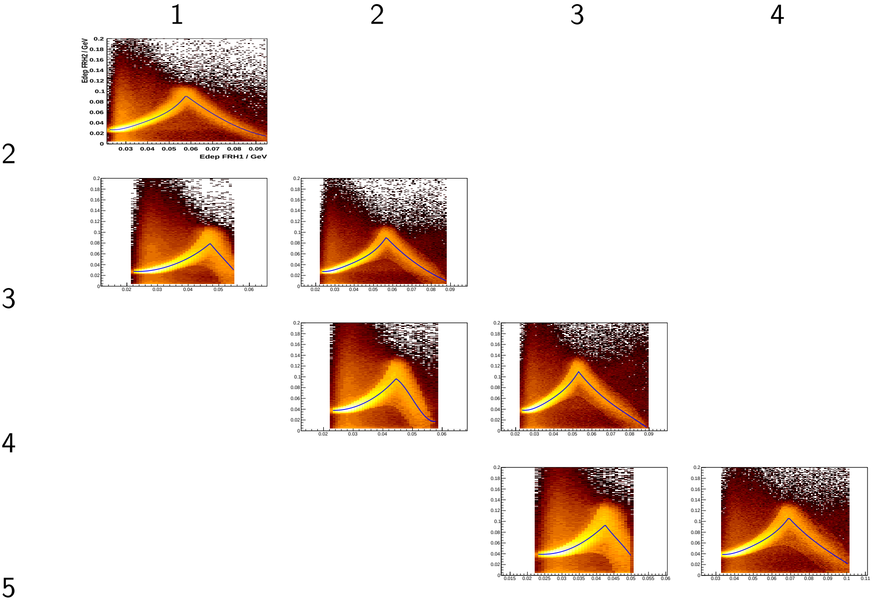
Fitting Monte Carlo data - results

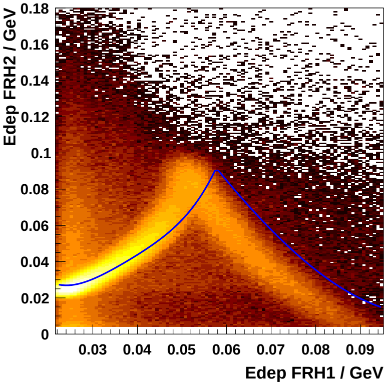


Fitting real data

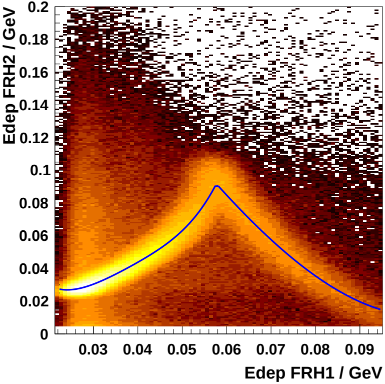
- Vary calibration parameters (TMinuit: Migrad+Minos)

$\Rightarrow$ Rescaling histogram axes

- Calculate χ^2 as in MC fitting for each ΔE plot
- Find parameter set that minimizes the overall averaged χ^2

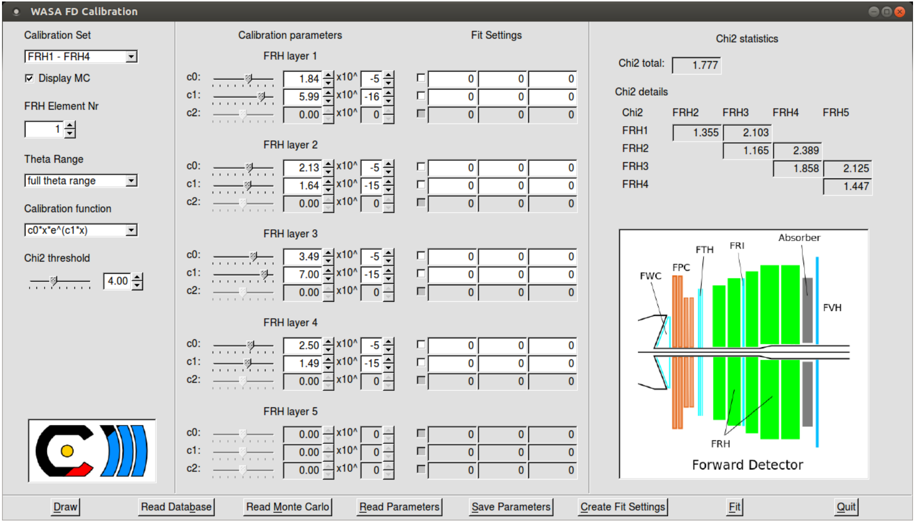


Before fit



After fit

User control



Conclusion

- $p + p \rightarrow p + p + \eta$
- $\eta \rightarrow \pi^0 + e^+ + e^-$
- Calibration software to find energy reconstruction parameters
- Highly automated but full control
- Based on matching measured and simulated energy loss bands
- Algorithm to handle 2d histograms with background

Outlook

- Check existing calibration
- Careful recalibrations, run-by-run corrections
- Analysis of 10^9 $pp \rightarrow pp\eta$ events for a new upper limit of the C-parity violating decay $\eta \rightarrow \pi^0 e^+ e^-$
- Each analysis of these data sets will benefit from a careful calibration