The new 2E-2v spectrometer VERDI

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Motivation

Outline

- Motivation
- What is 2E-2v?
- What is VERDI?
- Previous and present work
- Present results
- Summary

Motivation

Gen IV reactors

- Unmoderated neutron spectrum
- Reduces minor actinide content of waste.
- Fragment yields essential for operation and waste disposal

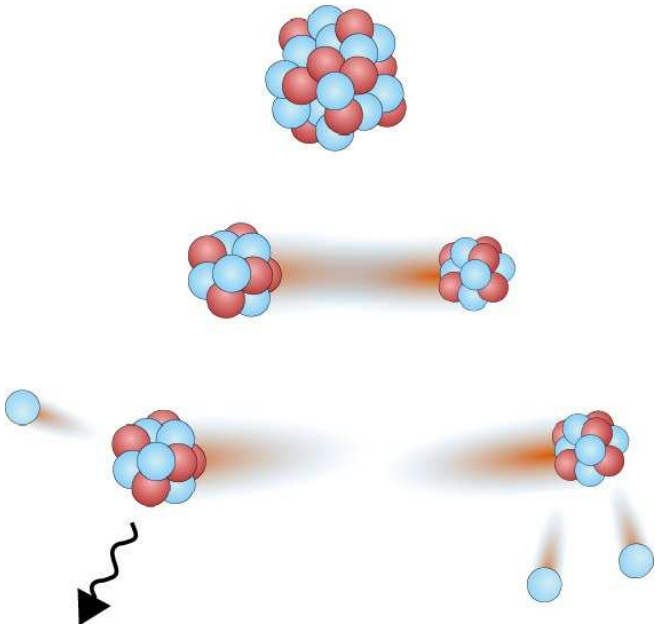
Few data above thermal energy

- Low fission cross section
- Lower intensity of available neutron beams in this energy range
- Most yield data from radio-chemical analysis or gamma tagging; no correlation between fragment kinetic energy and mass available

Theory struggle to describe the fission process accurately

- Theory needed for ND evaluation
- Fragment mass distribution (distribution width)
- Sharing of excitation energy among fragments -> neutron multiplicity

2E-2v Method



Measures **velocity** and **kinetic energy** of **both fragments**

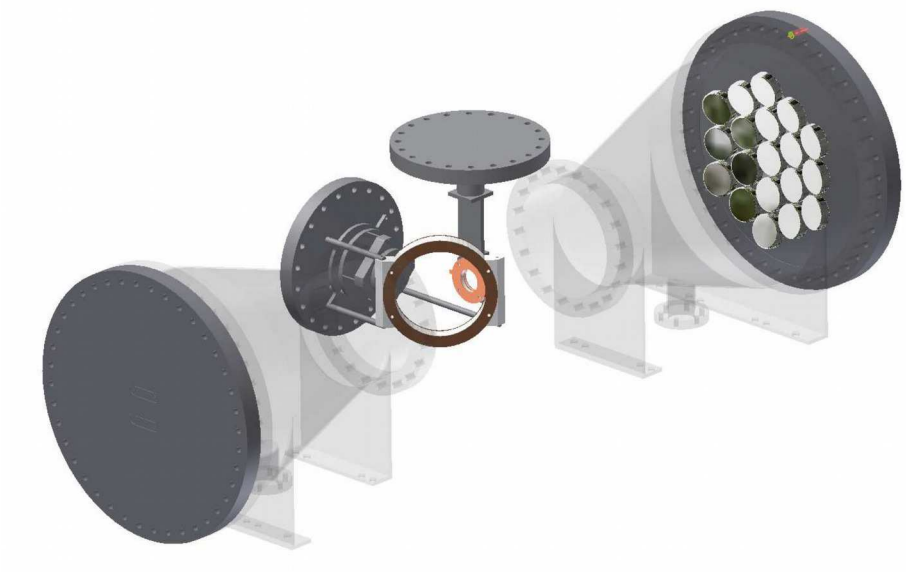
$$\frac{M_{1,\,pre}}{M_{2,\,pre}} = \frac{v_{2,\,pre}}{v_{1,\,pre}}$$ Pre-neutron mass

$$M_{post} = \frac{2\,E_{post}}{v^2_{post}}$$ Post-neutron mass

$$\nu = M_{pre} - M_{post}$$ Neutron multiplicity

Provides correlations between the **pre**-neutron and **post**-neutron observables **mass**, **kinetic energy** and **neutron multiplicity**

Verdi design



Energy

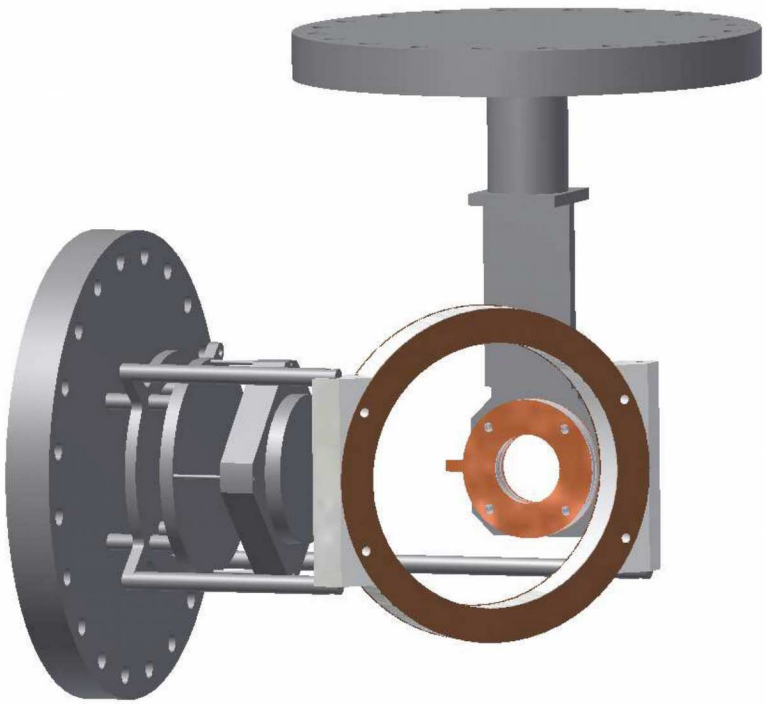
- 2 arrays of 16 Si detectors
- Pairs facing each other
- Each detector 450 mm^2

Time-of-Flight

- **Start**: Electrons emitted from target detected by Micro Channel Plate (MCP)
- **Stop**: Si detector

- Maximum solid angle coverage (0.5% of 4π) at relatively short flight path (50 cm)
- Excellent energy (0.5%) and timing resolution (150 ps)
- Energy losses only in target backing and silicon detector dead layer

FIssion Electron ToF Start (FIETS)



- Target backing also acts as electron emitter foil
- Acceleration grid close to target
- Electrons deflected 90° by electrostatic mirror (two grids)
- MCP detects electrons
- One mirror and one MCP on each side of the target

Calibration procedures

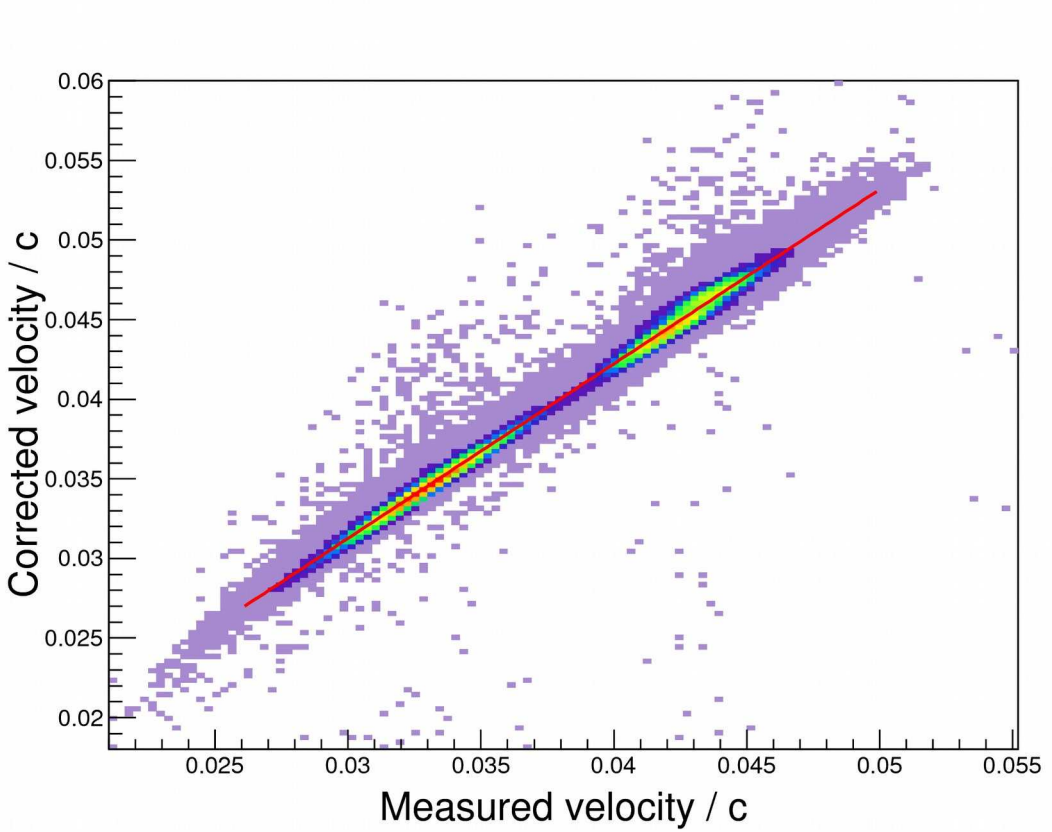
Calibration needed

- Calibration against something known, e.g. ^{252}Cf(sf), needed
- Plasma effects in silicon detectors
  - PDT – Plasma Delay Time
  - PHD – Pulse Height Defect

Calibration procedures

Plasma Delay Time (PDT)

- Uses energy measurement and known neutron multiplicities to correct velocity
- Only the linear relationship of the measured and corrected velocity is used in the final analysis



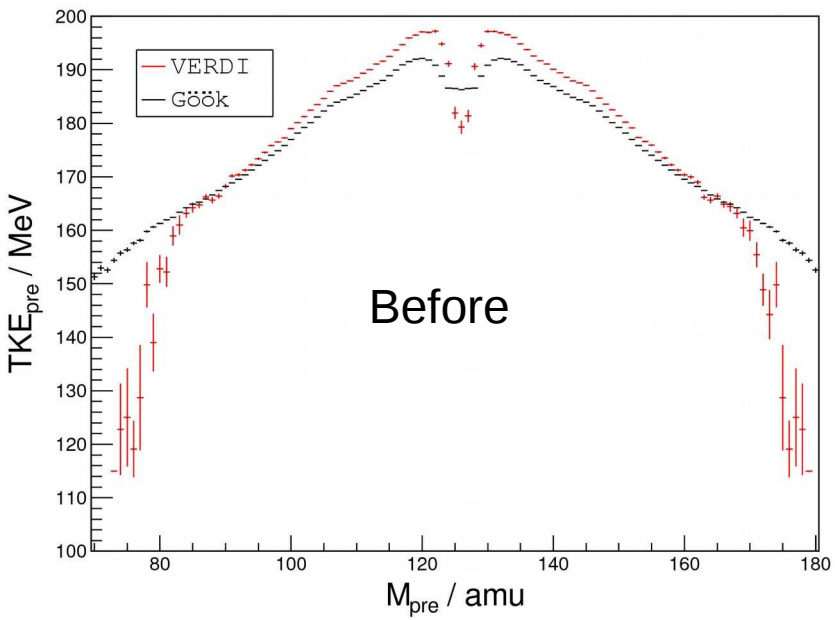
Calibration procedures

Pulse Height Defect (PHD)

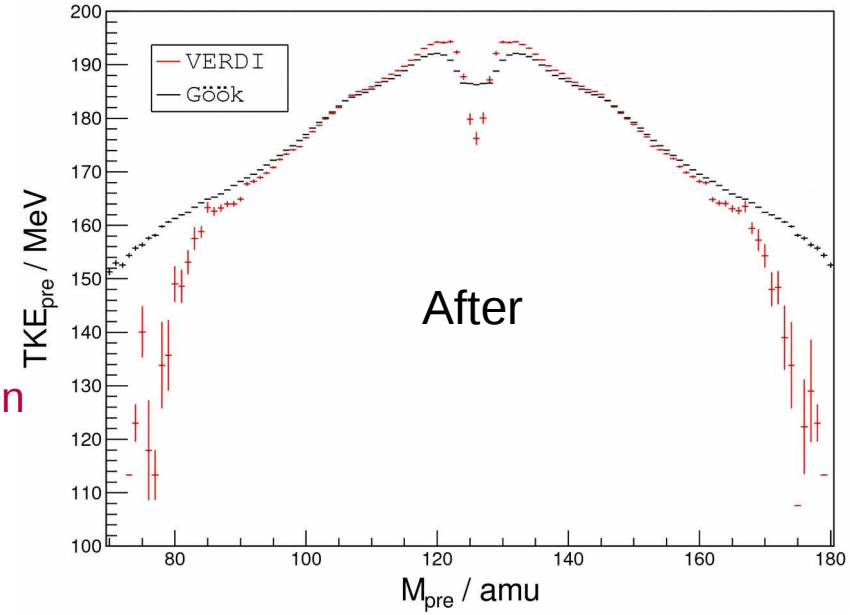
- Mainly follows the procedure in

  H.W. Schmitt et al., Phys. Rev. 137 (1965), B837

- Modification to include lower masses (ternary particles)
- Recalculates new values of the Schmitt parameters iteratively
- Calibration based on matching <TKE_{pre}> = 184.1 MeV



Recalibration



^{252}Cf Measurements

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Previously

- Excellent results from single MCP setup
- Energy distribution agreed well with Schmitt et al.
- Published: **M.O. Frégeau et al., NIM A 817(2016), 35**

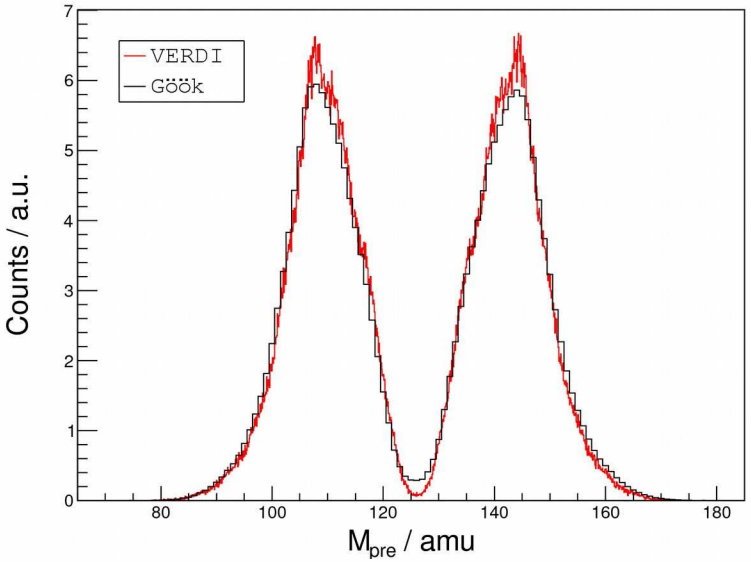
New results

- ToF for both fragments provided by a double MCP setup
- Recalibration of energy
- Extends energy calibration to lower masses (ternary particles)
- Reproduce recommended value of average TKE
- Work in progress, current state, single detector pair
- All observables are symmetrised and compared to Göök et al.
  (ionisation chamber + liquid scintillators)
  A. Göök et al., Phys. Rev. C90 (2014), 064611

^{252}Cf Measurements - mass

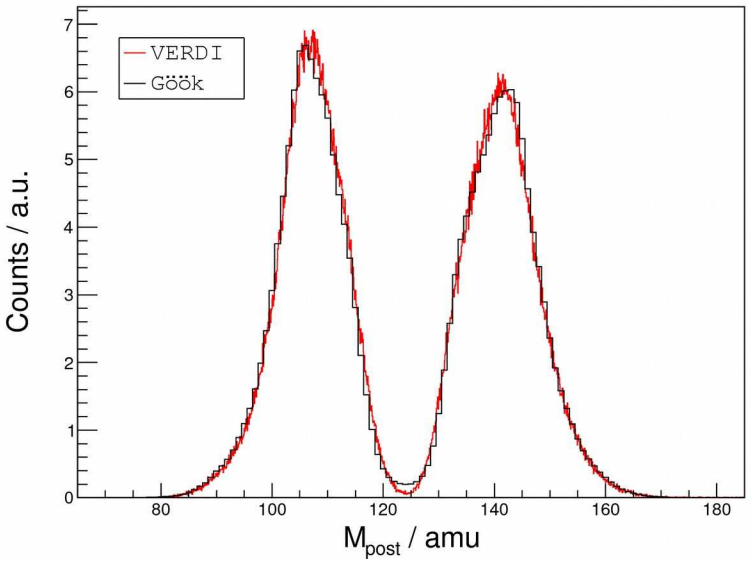
Pre-neutron mass

- Agrees well
- Better resolution due to the good timing resolution of the MCPs



Post-neutron mass

- Agrees well
- Small discrepancy around heavy peak

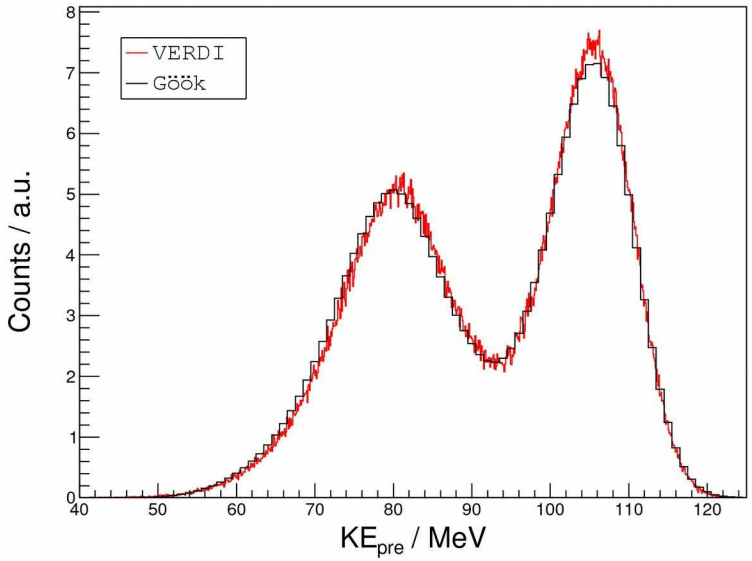


Detector pair 0:0 - 1:2

^{252}Cf Measurements - energy

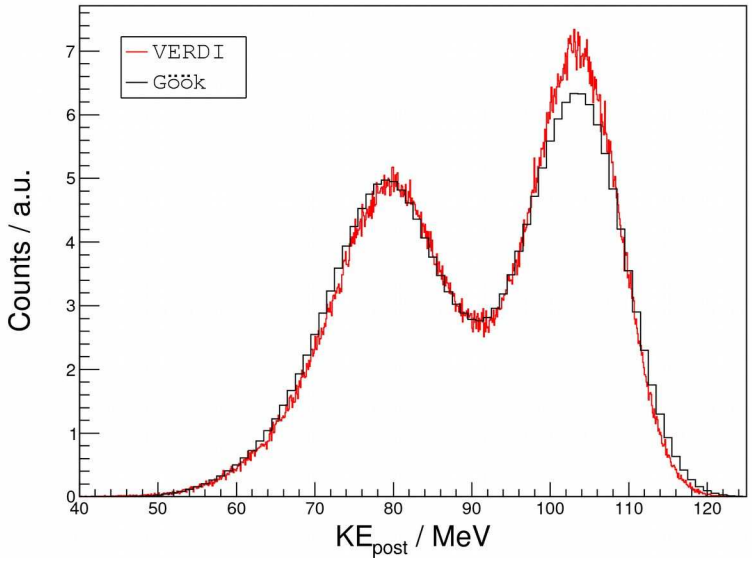
Pre-neutron kinetic energy

- Agrees well
- Göök <TKE> = 184.1 MeV
  VERDI <TKE> = 184.8 MeV
  (within 0.4%)



Post-neutron kinetic energy

- Agrees well
- Discrepancy around light peak (high energy)
- Göök <TKE> = 181.4 MeV
  VERDI <TKE> = 182.1 MeV
  (also within 0.4%)



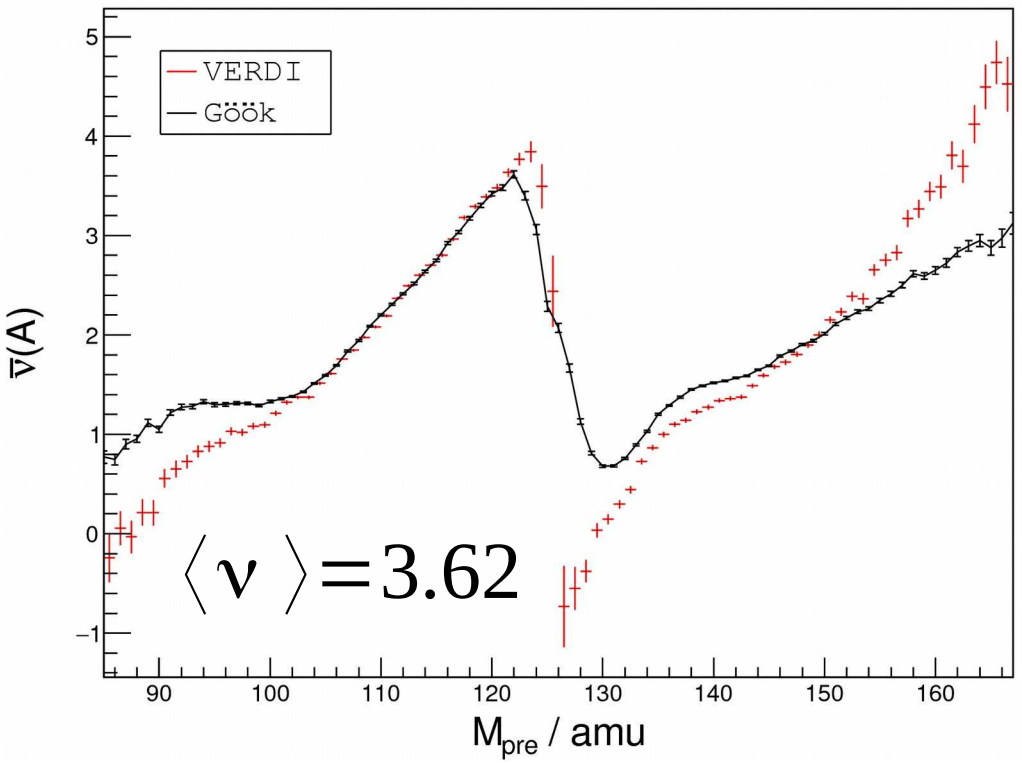
Detector pair 0:0 - 1:2

^{252}Cf Measurements - <ν>

Average neutron multiplicity

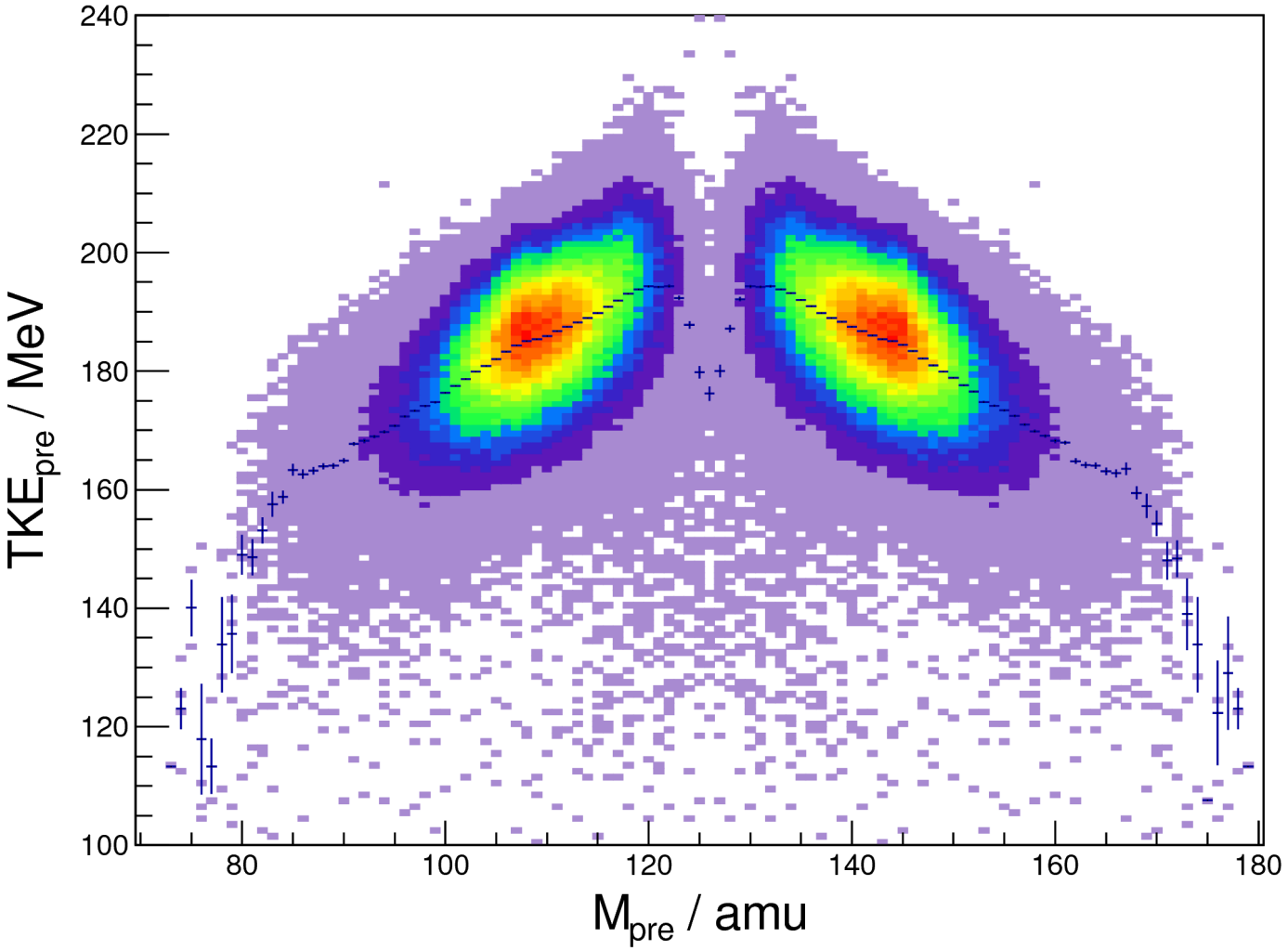
- Difference between pre and post mass
- <ν> within 4% of recommended value
- Problems around symmetry
  - Limited post mass resolution
  - Diffusion of Cf into backing
  - More work needed on recalibration procedure

Detector pair 0:0 - 1:2



^{252}Cf Measurements - TKE

Detector pair 0:0 - 1:2



Conclusions

Summary

- Upgrades to both the spectrometer and the methodology
- Generally good agreement with previous data
- Some problems
  - Calibration does not always converge
  - Negative <ν> around symmetry

Outlook

1) Continued development of calibration procedure
2) New mid section to accomodate neutron beam
3) Measure $^{235}U(n_{th},f)$ to verify the method
4) Correlated data for other fissioning systems

That's all Folks!

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Thank you for your attention!

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