# Comparison of unfolding algorithms for monenergetic and continuous fast-neutron energy spectra methods

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## Motivation and Introduction

- **Neutron spectrometry without time-of-flight** can be useful in safeguards and nonproliferation applications, e.g. neutron imaging for material accountancy and verification (Fig. 1), to discriminate between fissile material and other neutron emitting sources.
- **Improved algorithms are needed to successfully recover the neutron energy spectrum from the observed light output response, which is an ill-conditioned inverse problem.**

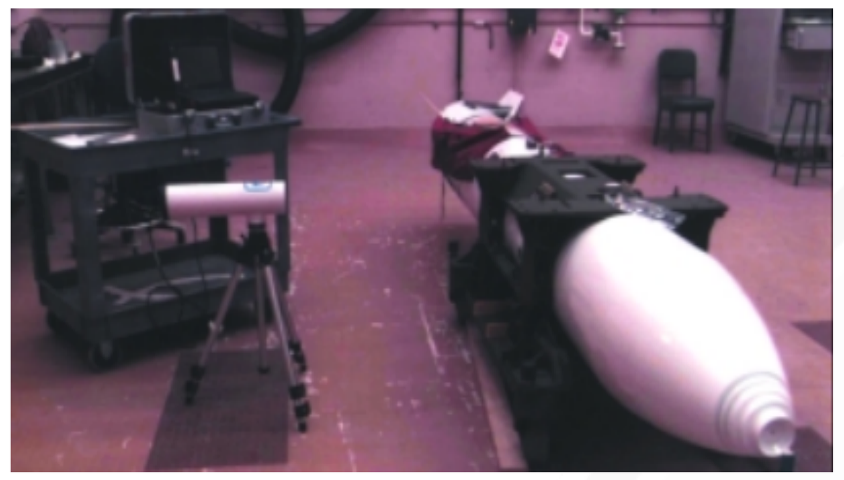


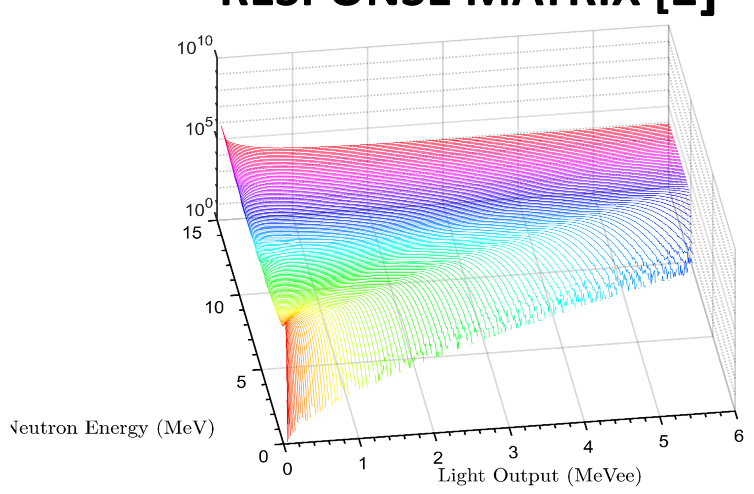
Fig. 1 Radiation Inspection System [1].

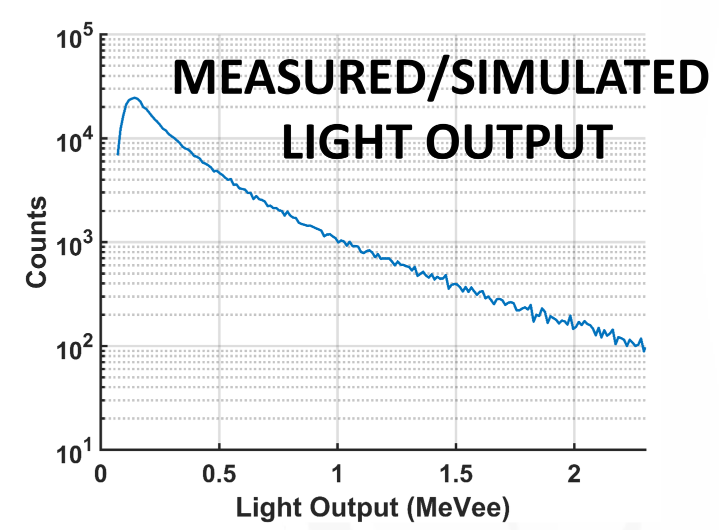
## Neutron spectra unfolding

$$z_{0i} + e_i = \sum_i R_{ij}\Phi_j \quad (i = 1 \ldots M)$$

- $z_{0i}$ - light output spectrum
- $M$ - # of detection channels
- $R_i(E)$ - detector response
- $\Phi(E)$ - neutron spectrum flux cm$^{-2}$

**NEW SIMULATION RESPONSE MATRIX [2]**




**UNFOLDING ALGORITHM**

**NEUTRON SPECTRUM**

$$\frac{dL}{dx} = \frac{A\frac{dE}{dx}}{1 + B\left(\frac{dE}{dx}\right)}$$

$\frac{dE}{dx}$ = energy deposited per unit distance

$\frac{dL}{dx}$ = scintillation photons emitted per unit distance

A, B = constant coefficients

## Unfolding Methods

*Maximum Likelihood Estimation (MLE)*
- Pros: Commonly used method, fast run time, convex optimization
- Cons: Sensitive to Noise

*Maximum Posterior Estimation (MAP)*
- Pros: Robust to noise, fast run time, convex optimization
- Cons: Regularization parameter must be tuned

*Markov Chain Monte Carlo (MCMC)*
- Pros: Full posterior provides confidence measures, no tuning parameters
- Cons: Slower run time, burn-in time hard to predict

## Unfolding on simulated data

Monoenergetic neutron sources: 0.5-5 MeV

Radionuclide sources: AmBe, Cf-252, AmLi

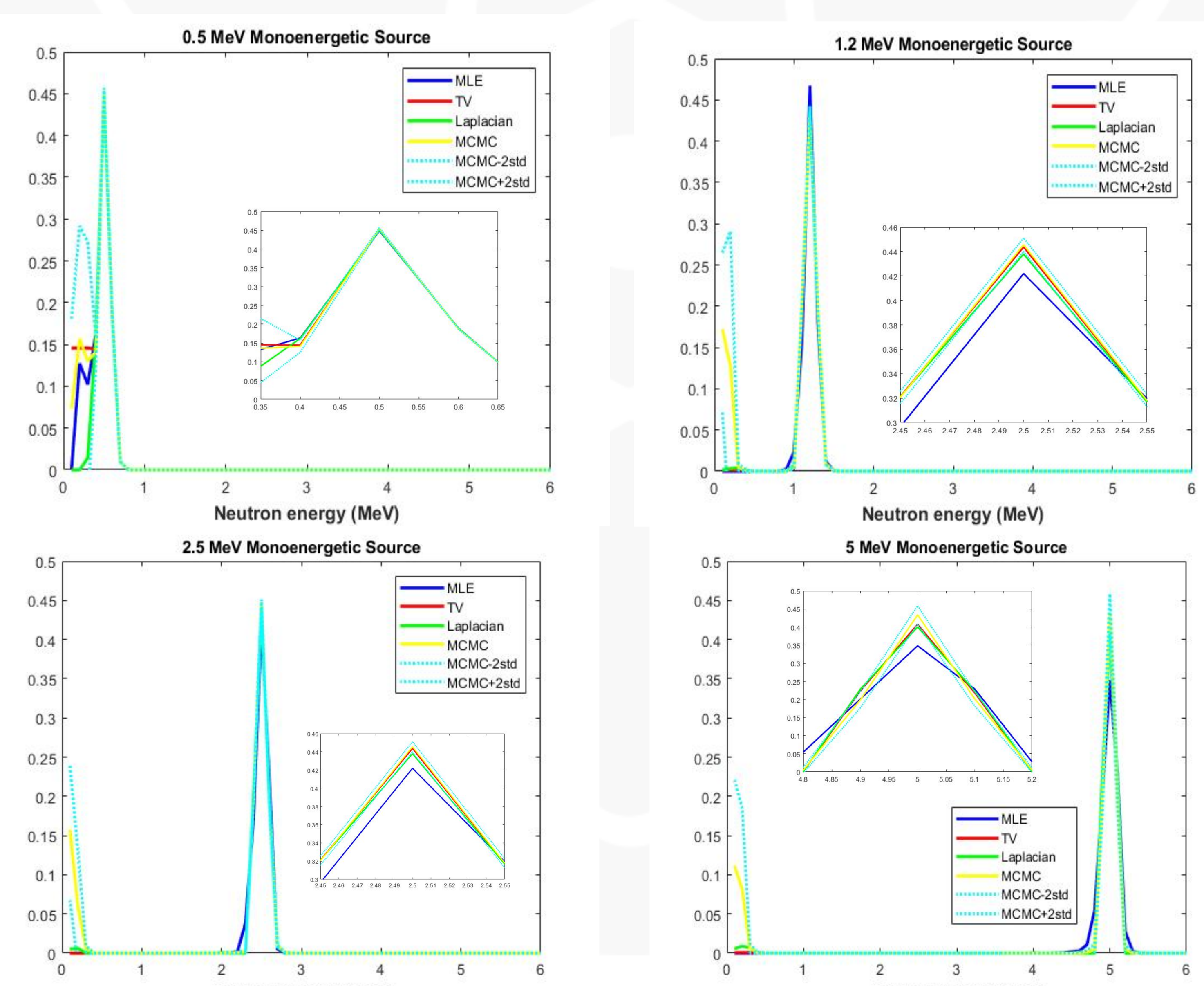



Fig. 2: Examples of unfolded spectra: 0.5MeV (Top left), 1.2MeV (Top right), 2.5MeV(Bottom Left) and 5 MeV (Bottom right)

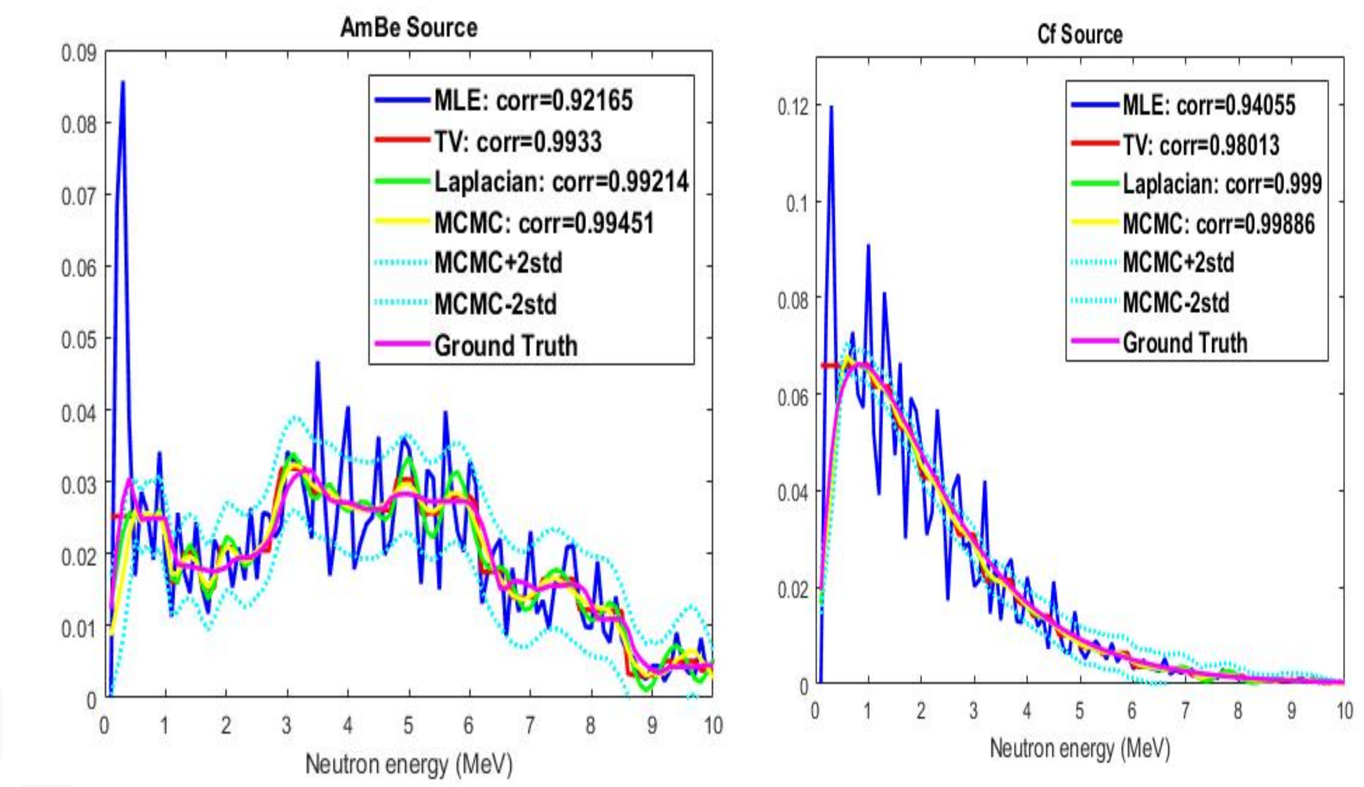



Fig. 3. Unfolded neutron energy spectrum from simulated continuous source, AmBe (left), Cf (right)

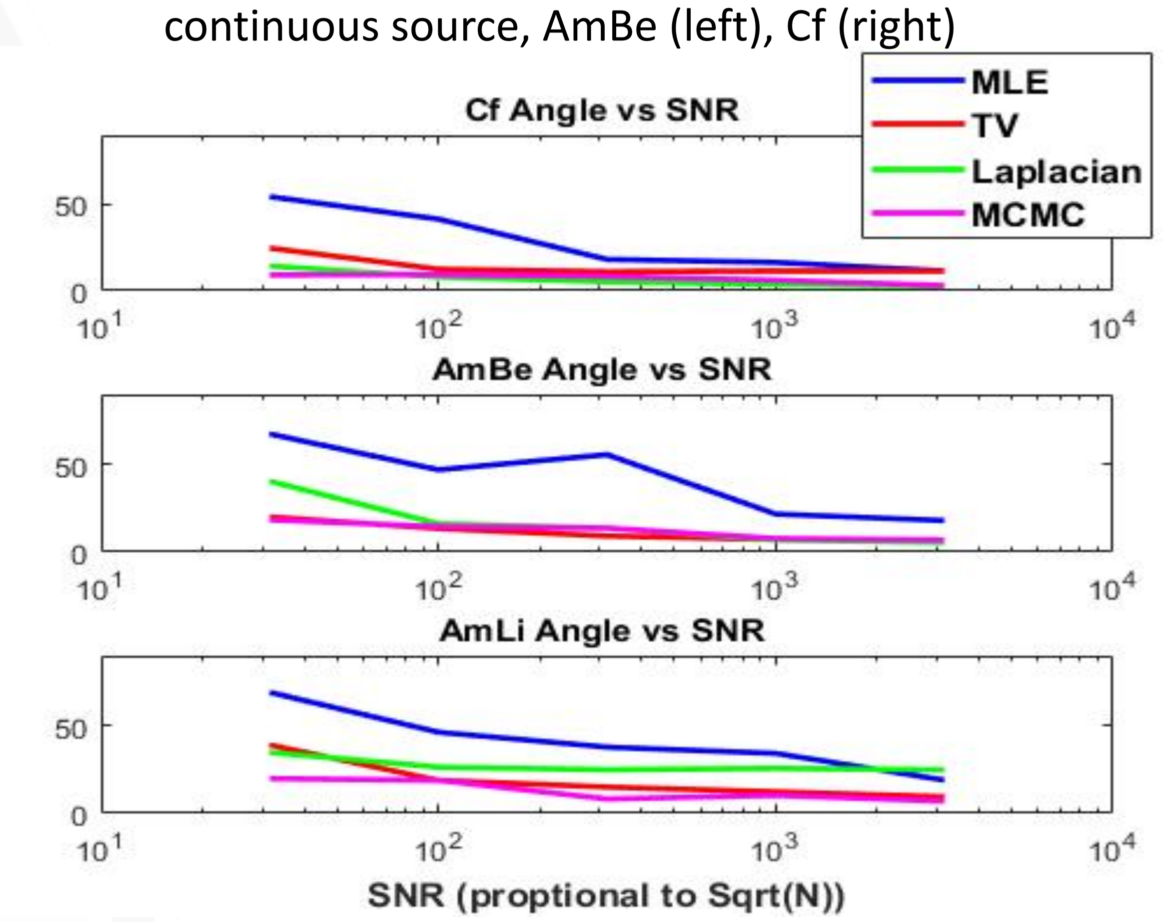



Fig. 4 Angle vs SNR ratio plot.

$Angle = \cos^{-1}(Corr)$ *is close to 0 when error is small*

## Conclusions and Future Work

- Algorithms are compared for simulated monenergistic neutron sources and continuous sources. Unlike traditional MLE methods, the MCMC method provides better unfolding results, and it provides a quantitative way to evaluate the uncertainty of the result
- Based on the simulated result, all the methods would require 10000 event counts to be able to recover the neutron spectrum
- Future work: experimental data with simulated response matrix
- Future work: jointly perform pulse shape discrimination and unfolding to improve fidelity at low energies.

## References

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