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ADAPTIVE MULTILEVEL SPLITTING FOR MONTE CARLO PARTICLE TRANSPORT

- HENRI LOUVIN -

PHENIICS DOCTORAL SCHOOL DAYS

May 9th to 11th 2016

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INTRODUCTION

PhD at CEA since october 1st 2014, directed by

Cheikh DIOP (CEA) and **Tony LELIÈVRE** (CERMICS-ENPC)

And supervised by

Eric DUMONTEIL

Goal: Adapt a mathematical Monte Carlo variance reduction technique to the field of particle transport. Applications to shielding simulations in the code TRIPOLI-4®.

CONTENT

Monte Carlo particle transport

- Monte Carlo transport simulations
- Variance reduction

Adaptive Multilevel Splitting

- The AMS algorithm
- Implementation

Results

- Implementation validation
- Comparison between AMS and TRIPOLI-4®

Conclusion

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MONTE CARLO PARTICLE TRANSPORT

MC PARTICLE TRANSPORT

Goal of Monte Carlo particle transport simulations:

- Estimate a score (**flux**) in a volume of interest

How is it done?

- *n* particles are simulated
- The *i*-th particle contribution to the score is stored as $\hat{\varphi}_i$
- We define the **average flux** and its associated variance:

$$\bar{\varphi} = \frac{1}{n} \sum_{i=1}^{n} \hat{\varphi}_i \qquad \sigma^2 = \frac{1}{n} \sum_{i=1}^{n} \left(\hat{\varphi}_i - \bar{\varphi} \right)^2$$

MC PARTICLE TRANSPORT

If the attenuation is really strong:

- **Many particles will not reach the volume of interest**
- Their contributions will be null
- The variance or the computation time will explode

Variance reduction techniques:

- Modify the simulation behavior
- Reduce the variance **for a given computation time**

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THE AMS METHOD: ALGORITHM

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THE AMS METHOD

AMS: Adaptive Multilevel Splitting

- Theory :

  F.Cérou et A. Guyader. *Adaptive multilevel splitting for rare event analysis.* Stoch. Anal. Appl, 25(2):417-443, 2007.

- Application in molecular dynamics :

  D.Aristoff, T.Lelièvre, C.G.Mayne et I.Teo. *Adaptive multilevel splitting in molecular dynamics simulations*. ESAIM:Proc., 48:215-225, 2015.

THE AMS METHOD

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THE AMS METHOD

AMS is a **population control algorithm**. It takes place at the end of the simulation

A free parameter:

- An **importance function** denoted I :

$$I : \mathbb{R}^6 \rightarrow \mathbb{R}$$

- Associates an **importance** value to any point of the phase space

THE AMS METHOD

First step

- *n* particles are simulated

AMS iterations:

- Each particle **track** is given **a note** according to I
- The less interesting particles is suppressed
- One of the remaining particles is splitted
- We get a new set of *n* particles:
    - *1* new replica
    - *n-1* particles that were not suppressed

THE AMS METHOD

Stopping criterion:

- When the less interesting particle is in the volume of interest
- The total number of iterations is denoted *N*
- The probability of reaching the volume of interest is estimated by:

$$\alpha = \left(1 - \frac{1}{n}\right)^N$$

An **unbiased** estimate of the score is computed using the last generated points and weighting the result by *α*

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THE AMS METHOD: IMPLEMENTATION

THE AMS METHOD

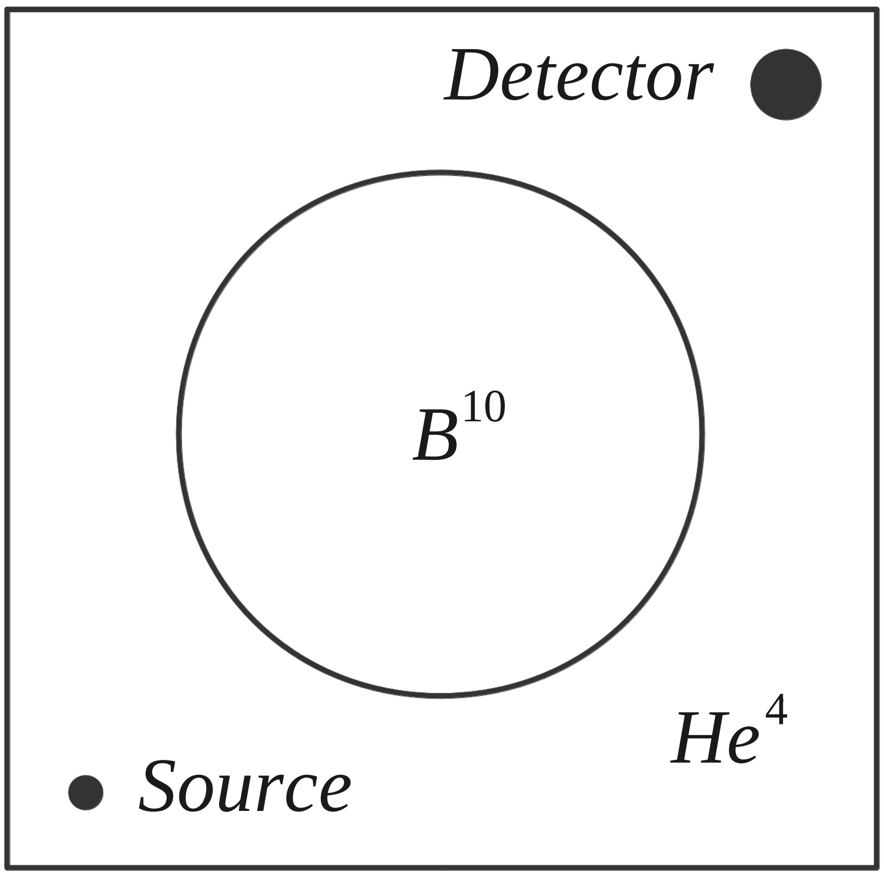
TRIPOLI-4® :

- 3D continuous-energy Monte Carlo particle transport code
- Dedicated to shielding, reactor physics, criticality, safety and nuclear instrumentation
- Developed at **CEA Saclay** since the mid-60s

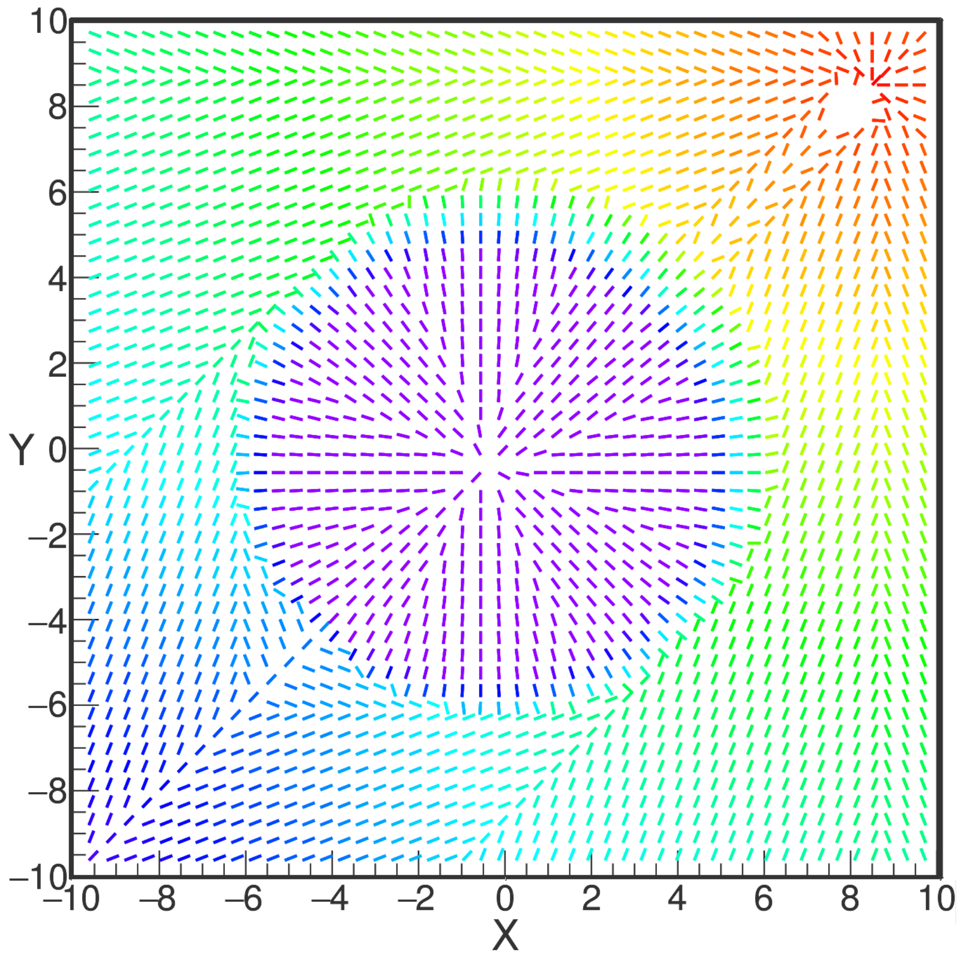
Existing variance reduction technique:

- “Exponential transform”
- Also uses an **importance map**
- Has a module that estimates the importance from the geometry

THE AMS METHOD



Example of geometry



Associated importance map

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RESULTS

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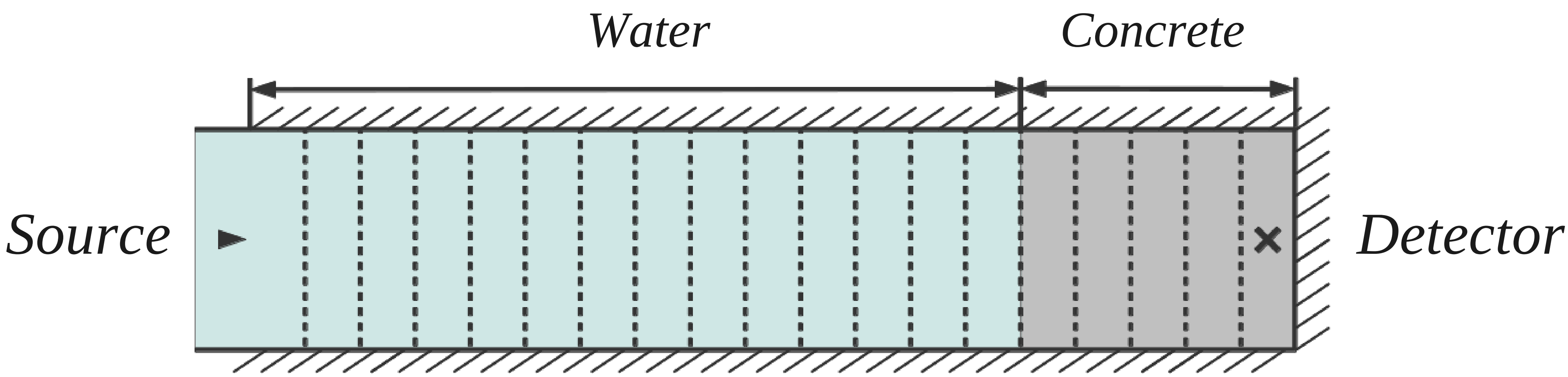
RESULTS

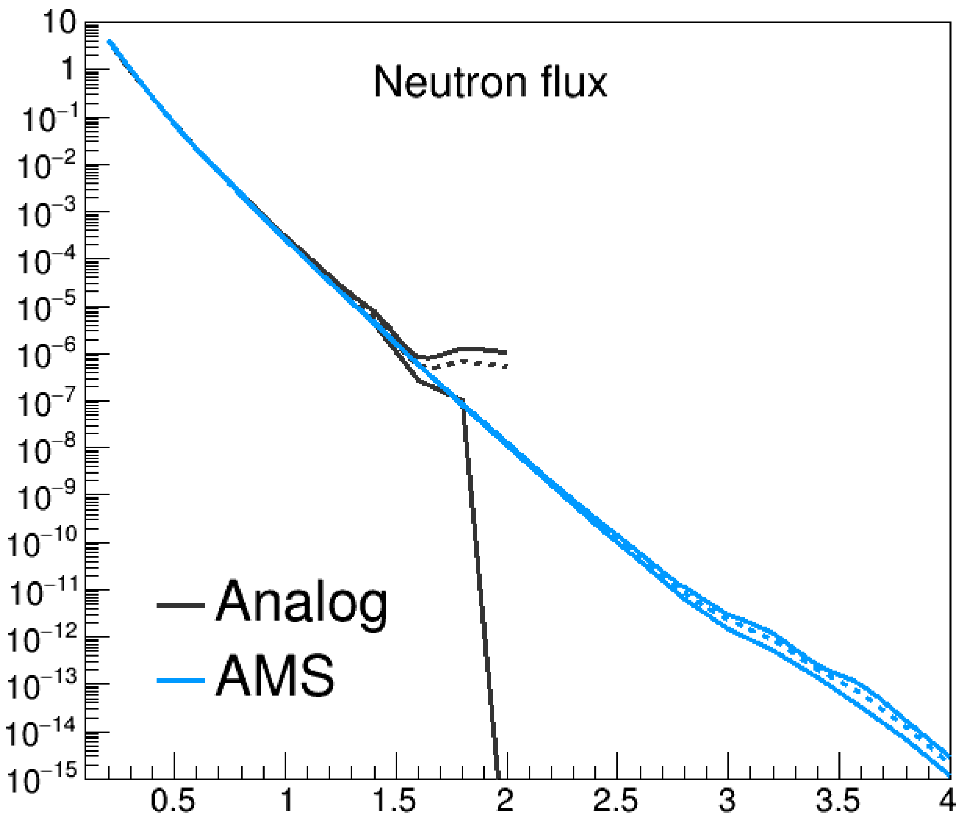
Illustration of the variance reduction use:

- We want to estimate the neutron flux attenuation when traversing 3m of water and 1m of concrete
- The neutron source is mono-directional at the entrance of a box with perfect reflectors around it
- The flux is estimated every 20cm between the source and the detector



RESULTS

Neutron flux and associated standard deviation obtained with **AMS**, compared to an **analog** calculation (i.e. without variance reduction)



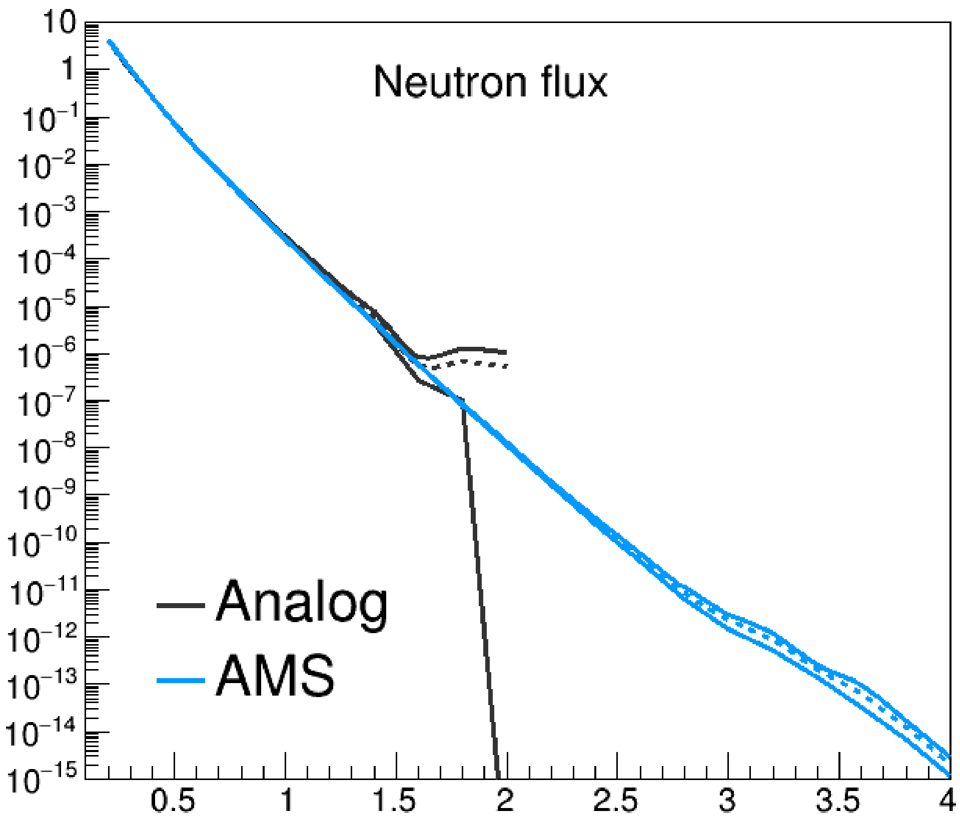
Distance from source (*m*)

OBSERVATIONS:

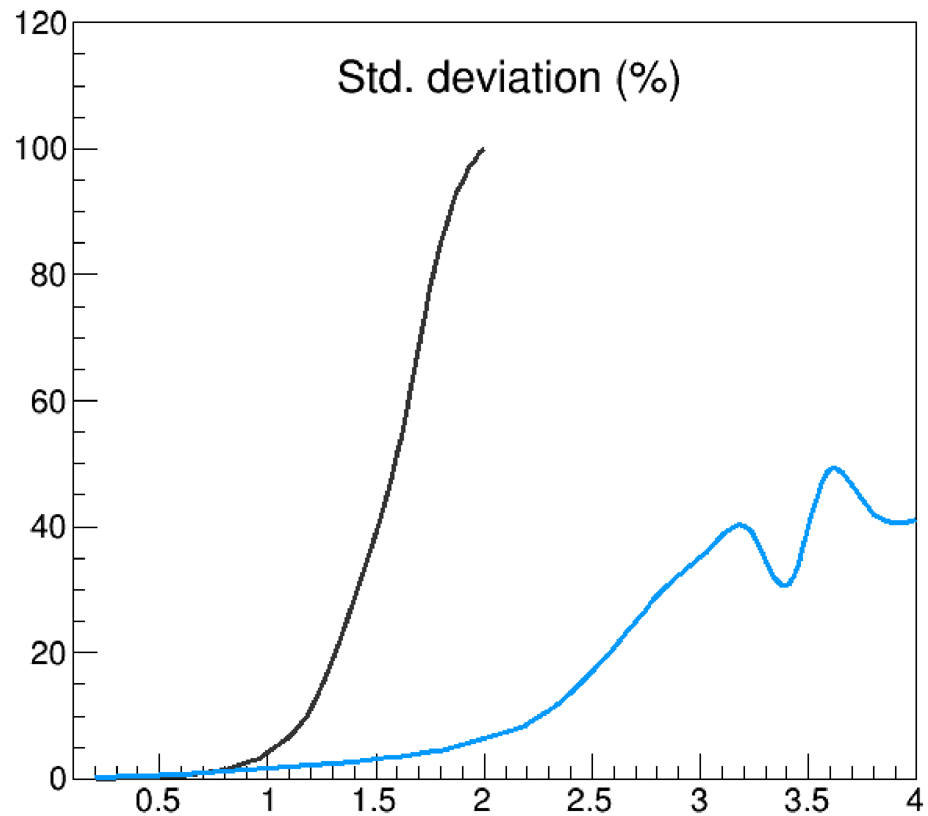
- **Very good accordance** with the reference near the source
- The analog simulation has **no results** deeper than 2m
- AMS is able to yield results **all the way** to the detector (and probably beyond)

RESULTS

Neutron flux and associated standard deviation obtained with **AMS**, compared to an **analog** calculation (i.e. without variance reduction)



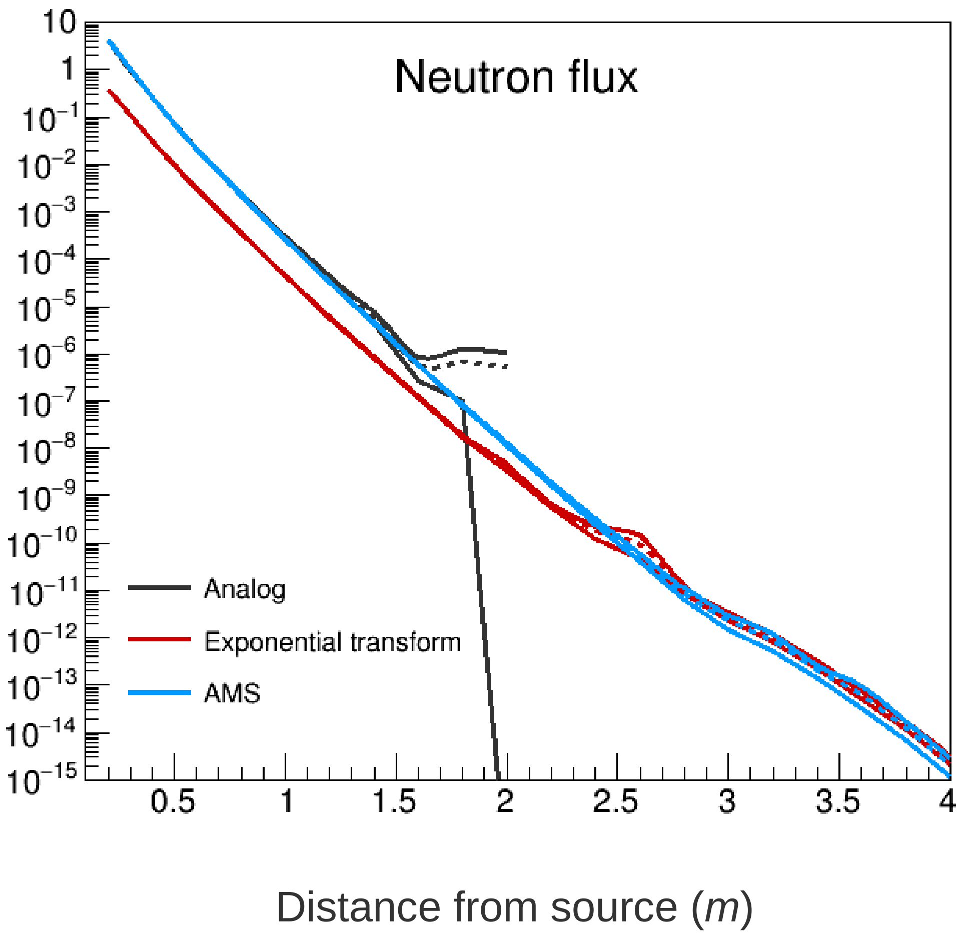
Distance from source (*m*)



Distance from source (*m*)

RESULTS

Neutron flux and associated standard deviation obtained with **AMS**, compared to an **analog** calculation and the **current variance reduction** method of TRIPOLI-4®

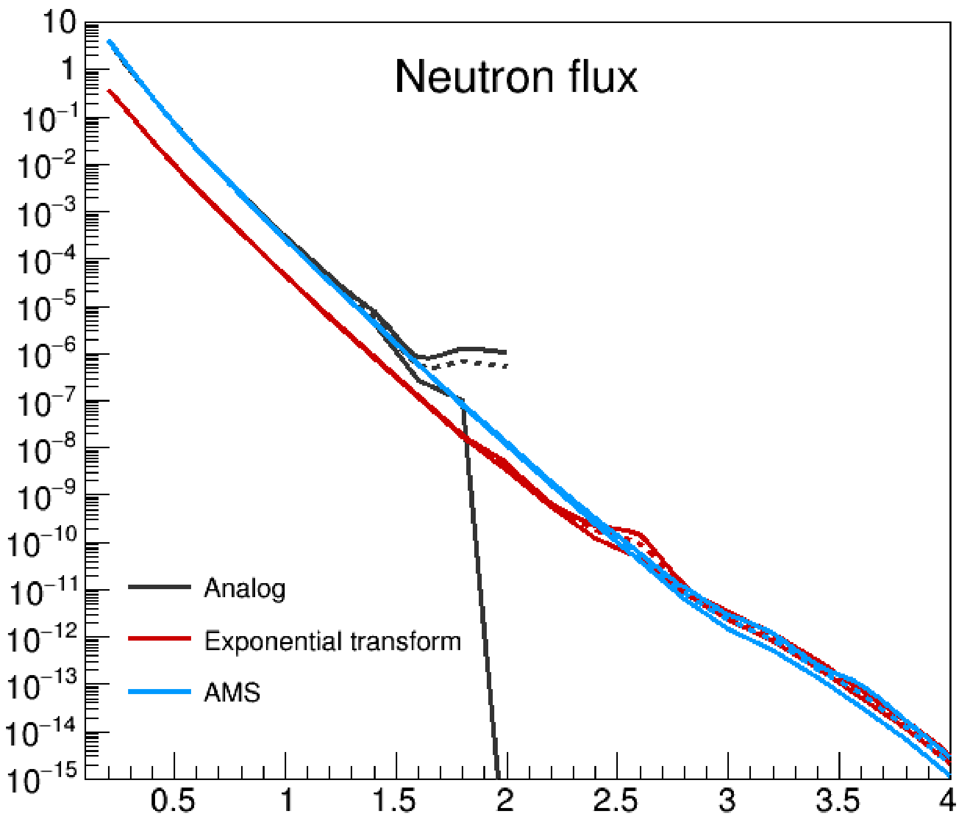


OBSERVATIONS:

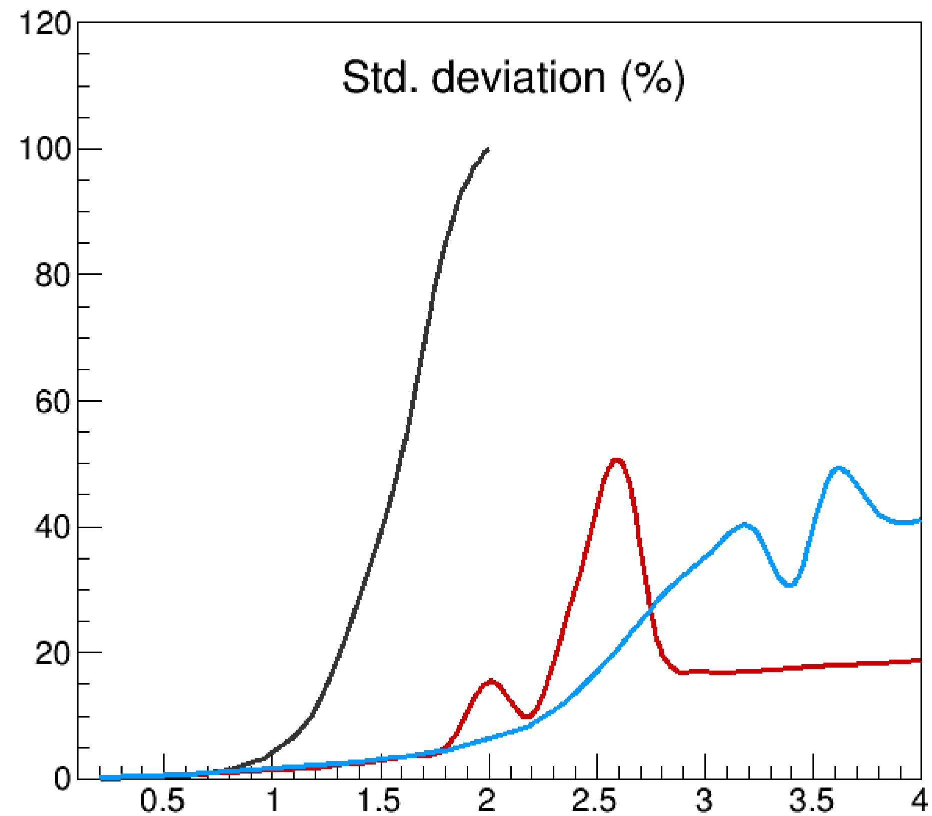
- Very good accordance between AMS and the exponential transform **near the detector**
- The exponential transform results away from the detector **can't be trusted**
- The importance map used to get results with exponential transform had to be optimized

RESULTS

Neutron flux and associated standard deviation obtained with **AMS**, compared to an **analog** calculation and the **current variance reduction** method of TRIPOLI-4®



Distance from source (*m*)



Distance from source (*m*)

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CONCLUSION

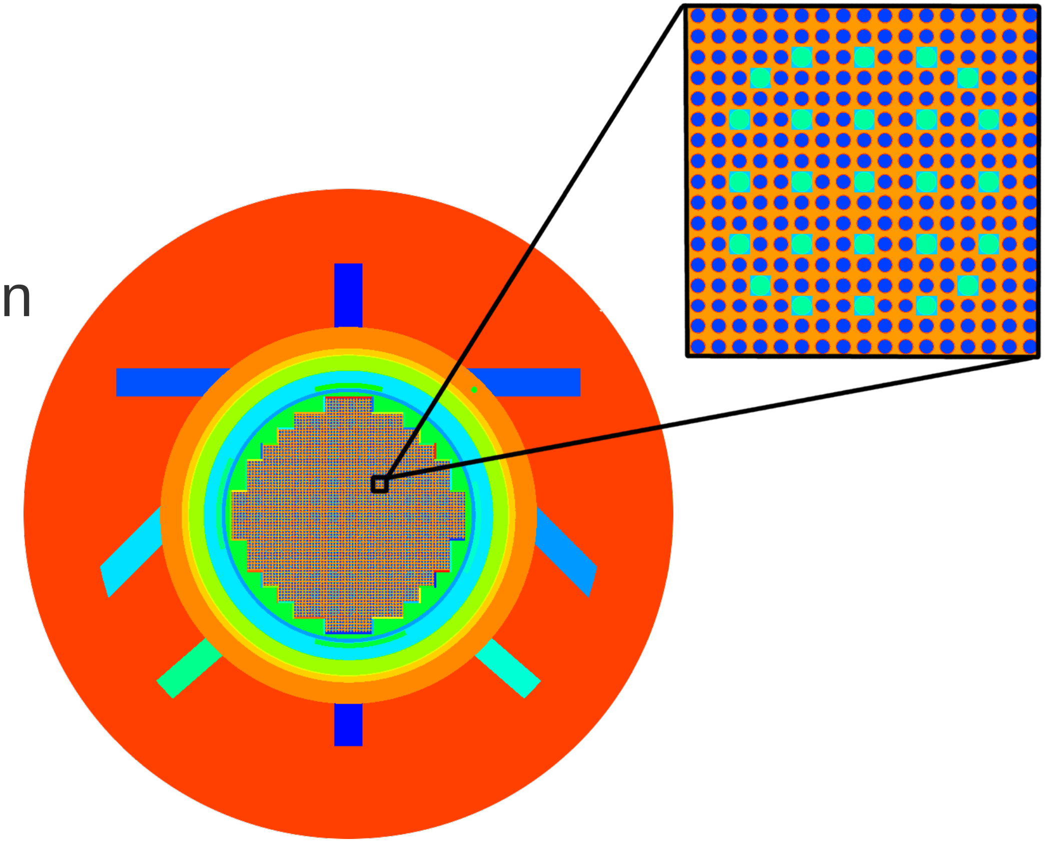
CONCLUSION

Implementation:

- The AMS implementation in TRIPOLI-4® is **over** and **stable**
- The method will be available in the developer's version of the code **soon**

Testing:

- The AMS efficiency is tested in many problems, from **simple cases** to **full nuclear cores**



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