Rapid Neutron Source Identification with Scatter-Based Spectrometers

David Breitenmoser, Shaun Clarke, Sara Pozzi
Department of Nuclear Engineering & Radiological Sciences
University of Michigan
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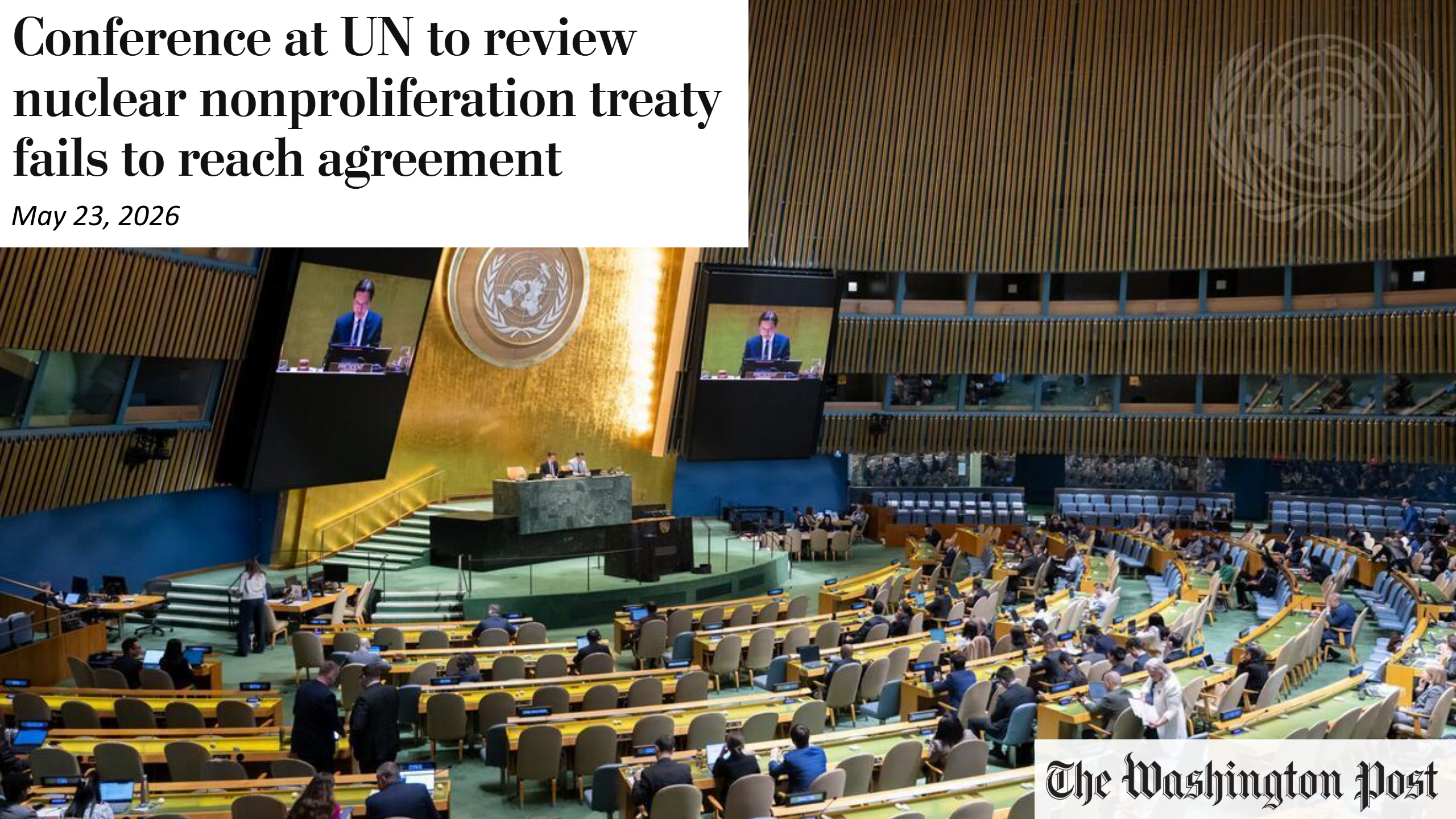
Fears of new arms race as US-Russia nuclear weapons treaty expires

February 19, 2026

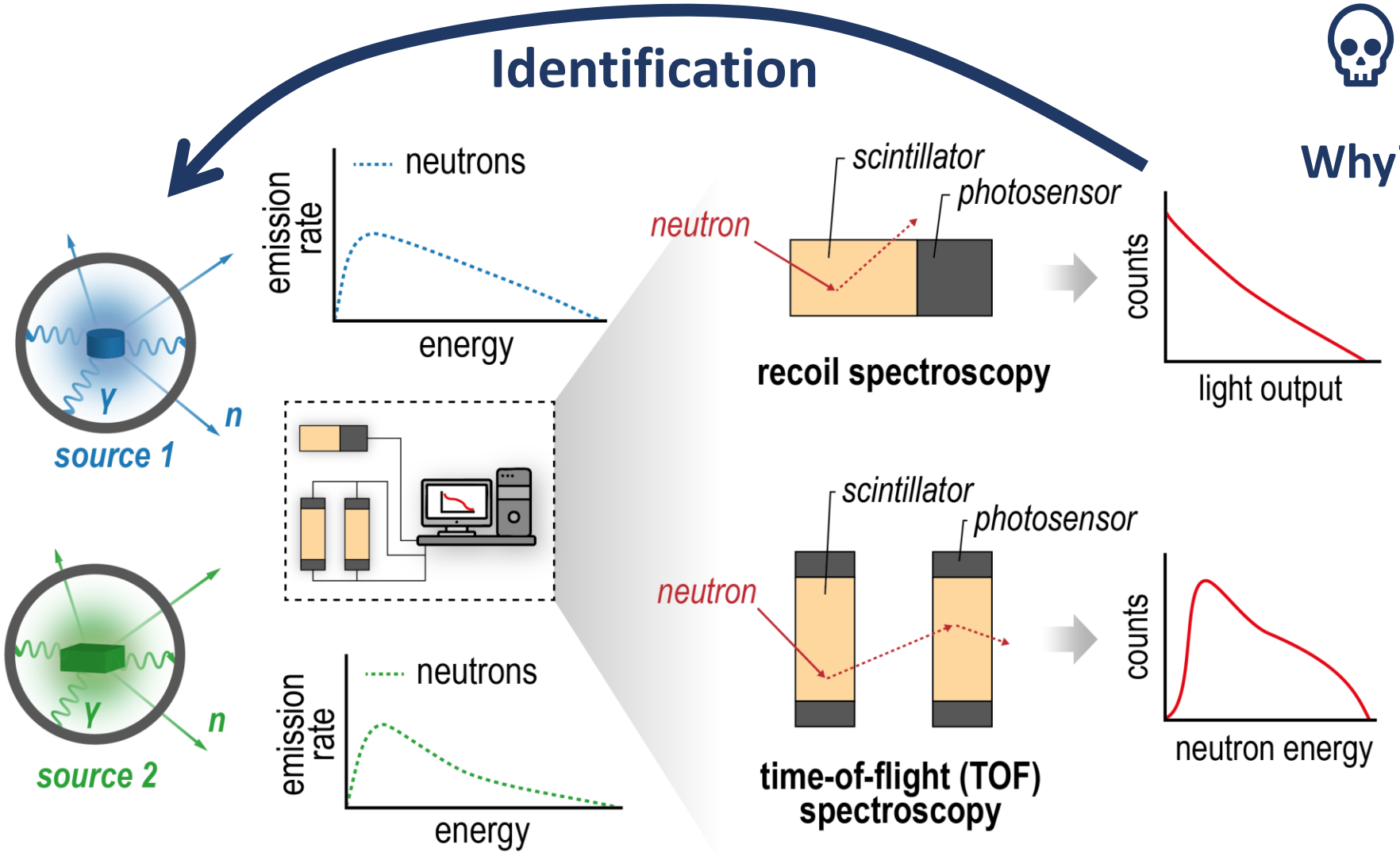
Conference at UN to review nuclear nonproliferation treaty fails to reach agreement

May 23, 2026



The Washington Post

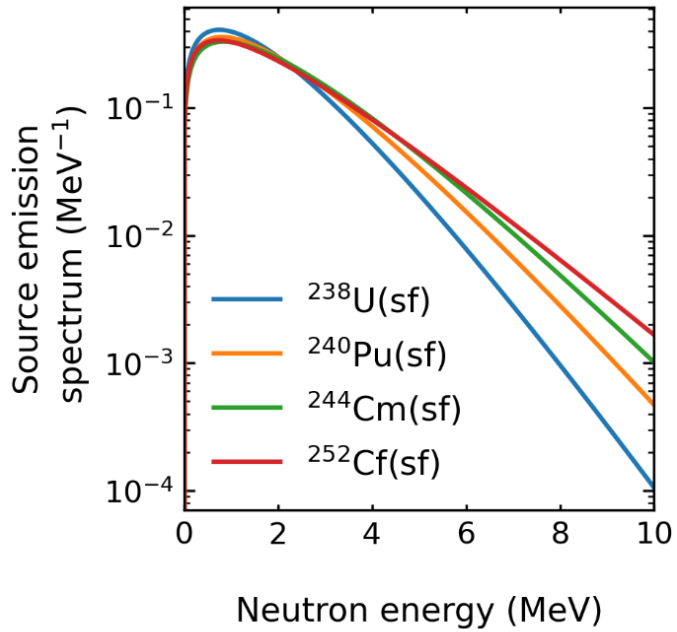
Goal: Detection & identification of special nulcear materials (SNMs)



Ill-posed problem

Why?

1. **Continuous emission spectra**
2. **High spectral similarity**

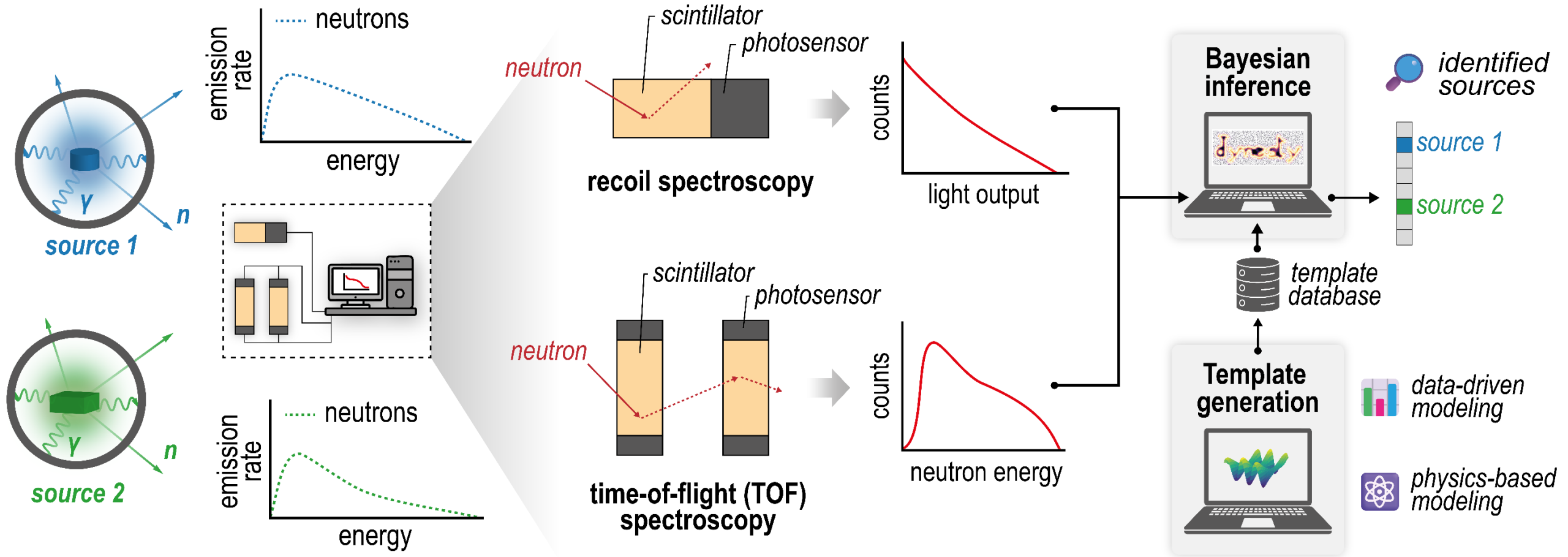


Methods

Key Ideas

Leverage continuous spectral data
→ *"Full-spectrum template matching"*

Include prior knowledge to solve inverse problem
→ *"Bayesian inference"*



Key Ideas

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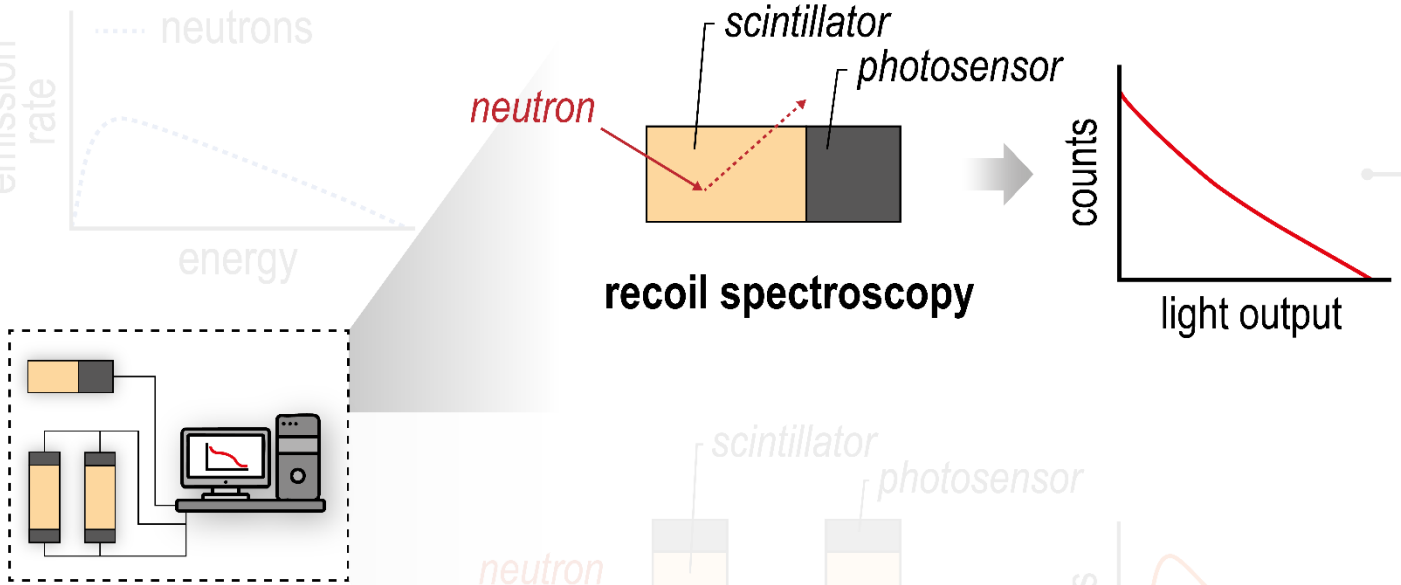
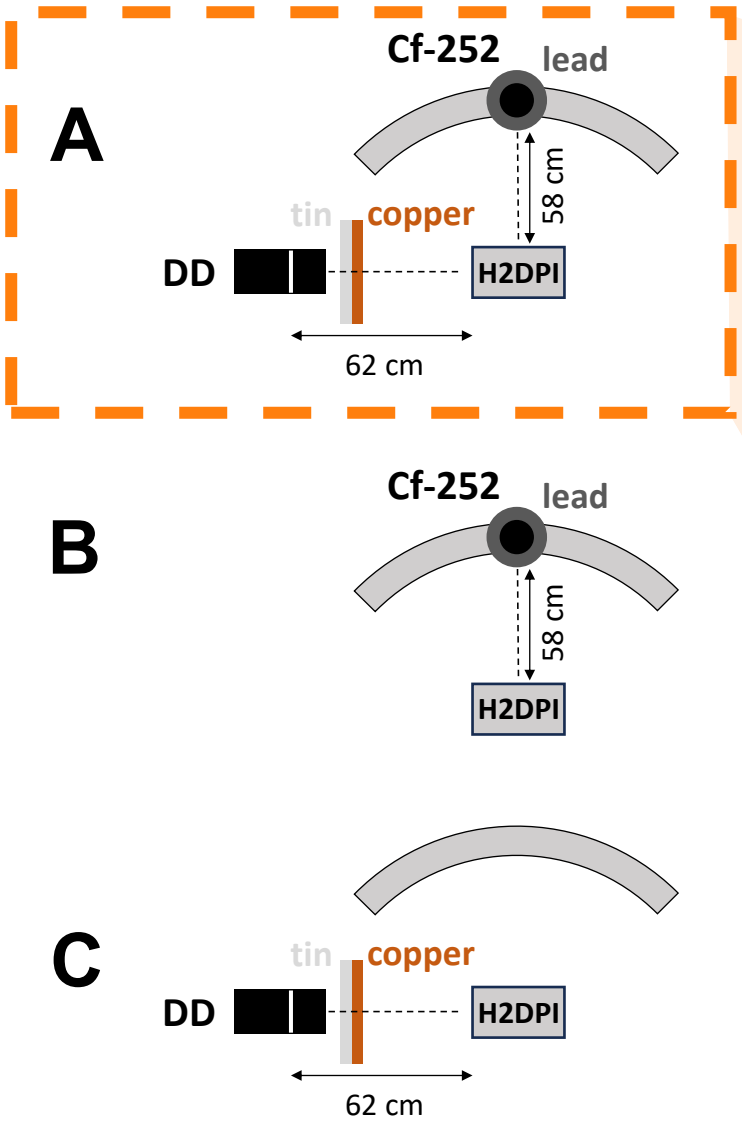
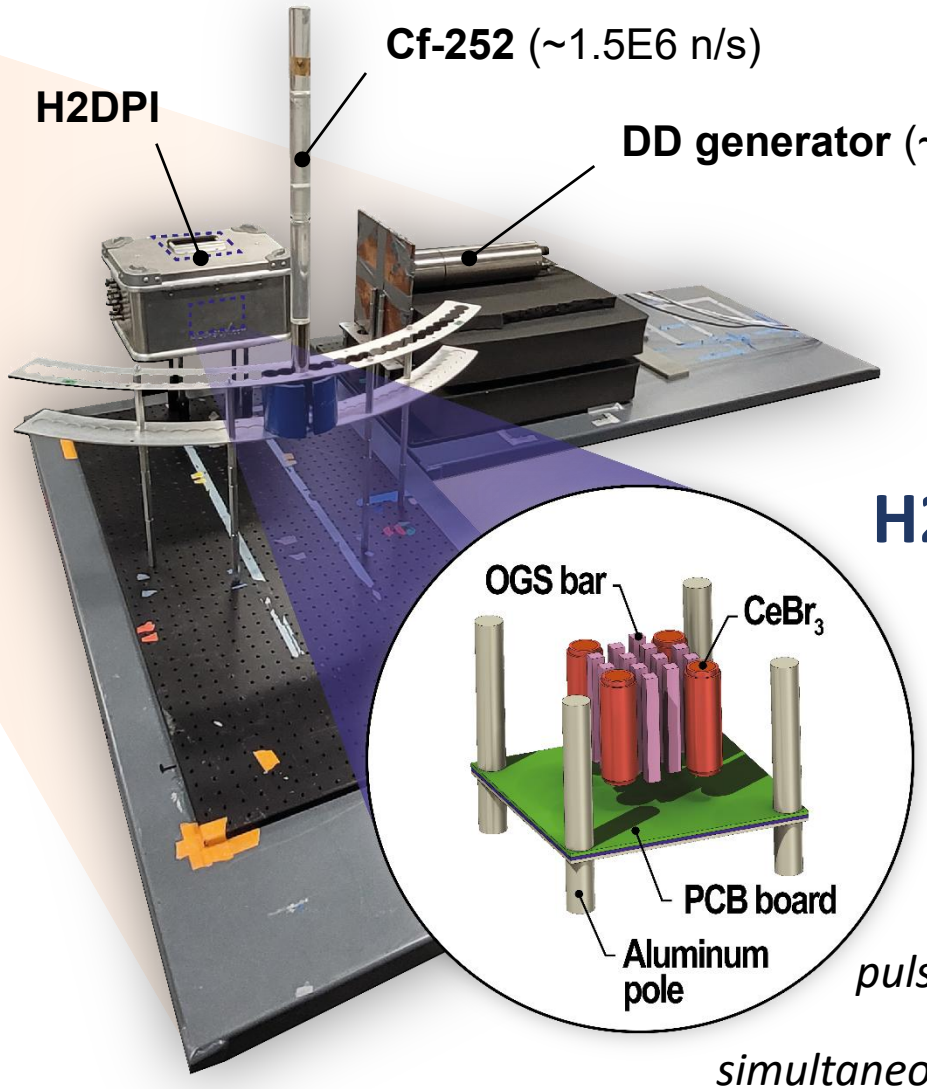


Single source neutron source identification in <10 min.

Neutron Spectroscopy





H2DPI System

12 organic glass scintillator bars (6 x 6 x 50 mm)

64-pixel SiPM photon sensors

waveform acquisition (500-MHz)

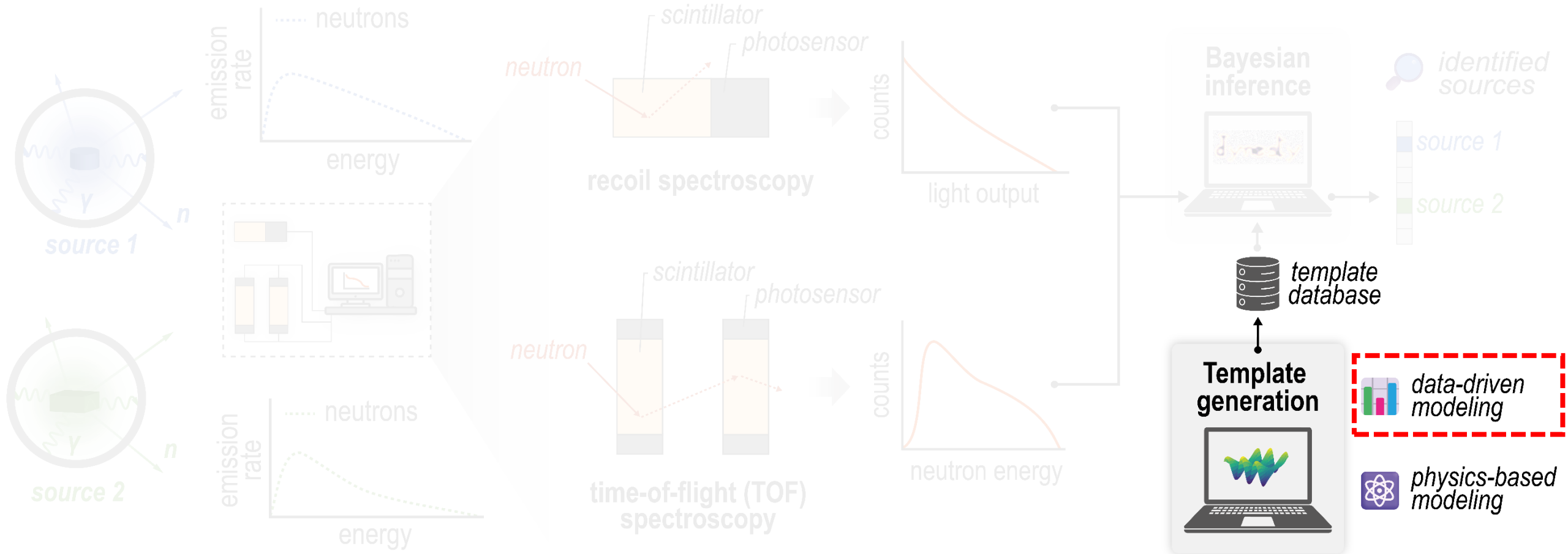
pulse-shape discrimination

simultaneous recoil & TOF spectroscopy

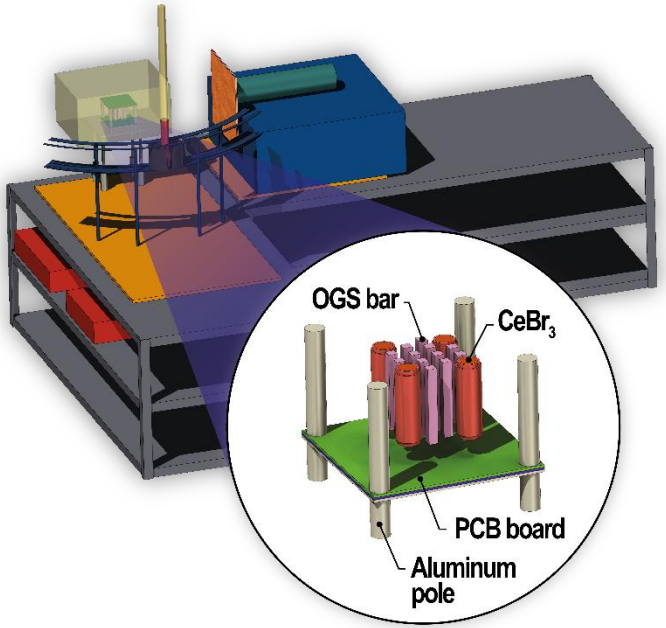
Template Generation

Leverage continuous spectral data
→ *"Full-spectrum template matching"*

Include prior knowledge to solve inverse problem
→ *"Bayesian inference"*



Physics-Based Template Modeling



Monte Carlo model

Monte Carlo Simulations

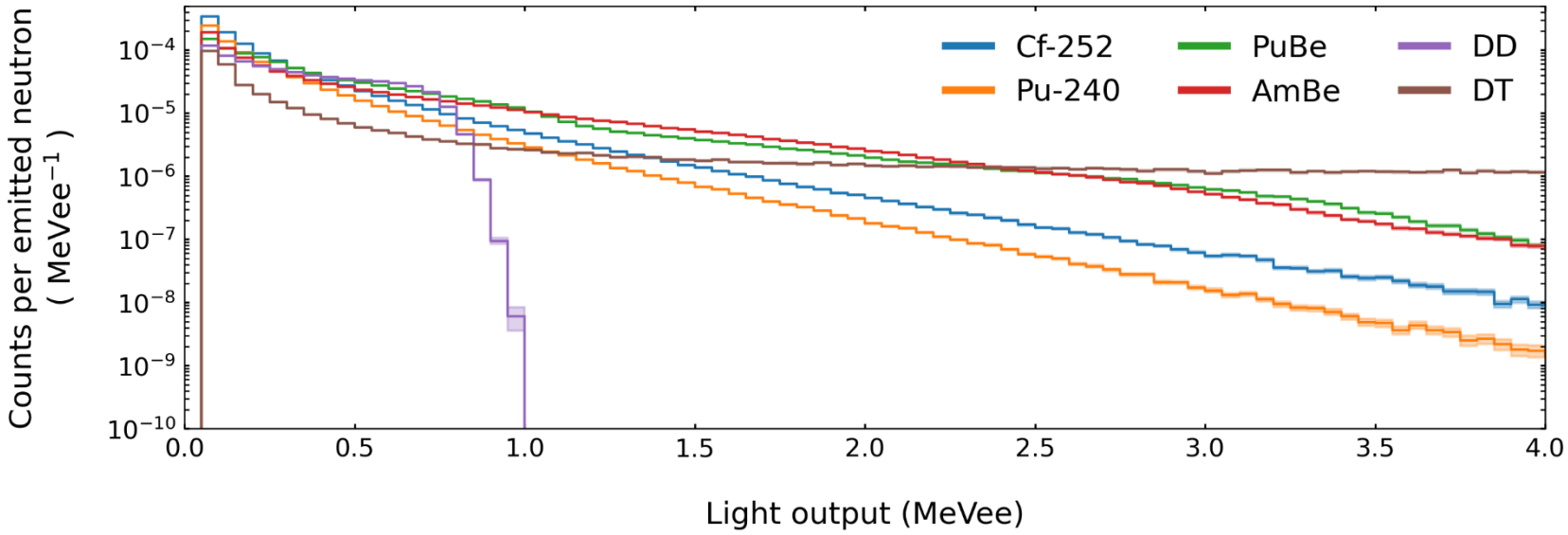
MCNPX-PoliMi code combined with benchmarked **postprocessing pipeline**

fission: *Cf-252, Pu-240*

(α,n): *AmBe, PuBe*

fusion: *DD, DT*

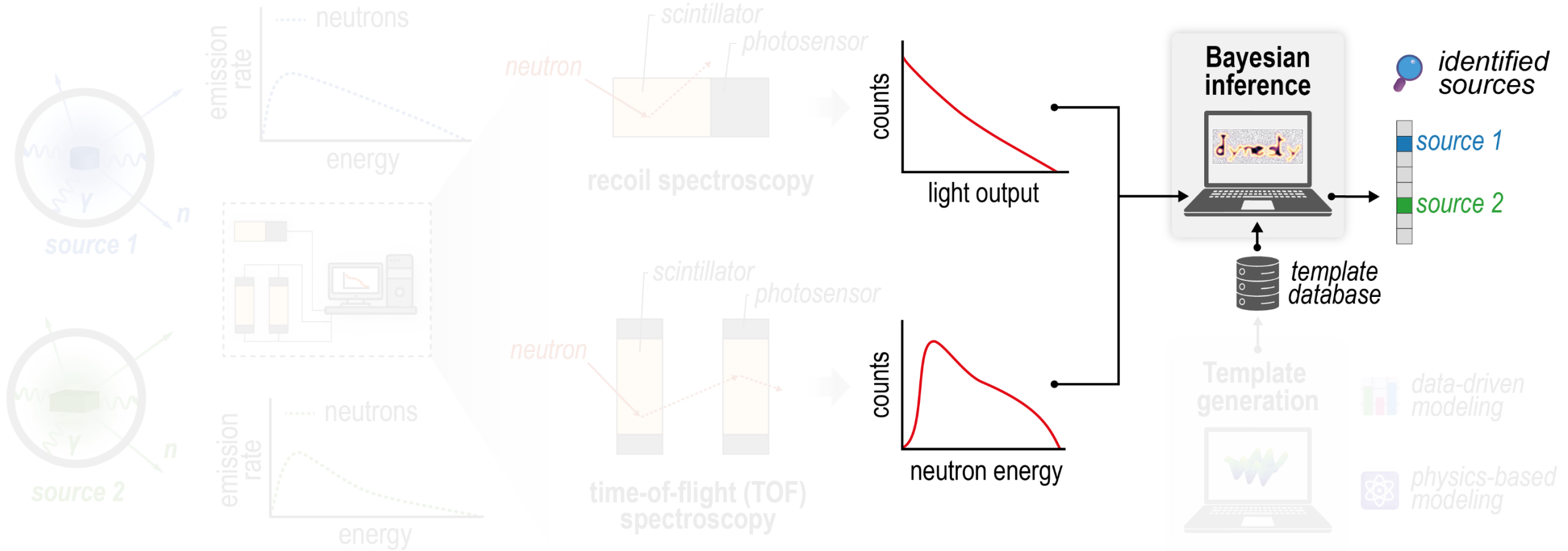
Spectral templates



Bayesian Inference

Leverage continuous spectral data
→ *"Full-spectrum template matching"*

Include prior knowledge to solve inverse problem
→ ***"Bayesian inference"***



Bayesian Inference

Probabilistic Bayesian approach:

Probability of a source model $\mathcal{M}$ being true given some data $\mathcal{D}$:

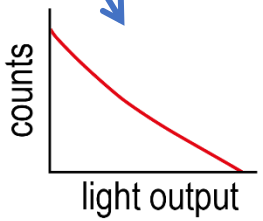
$$p(\mathcal{M}|\mathcal{D})$$

$\mathcal{M}_1$={Cf-252,PuBe}

$\mathcal{M}_2$={Cf-252}

...

model $\mathcal{M}$



data $\mathcal{D}$

Source identification ⇔ Model comparison

$$\frac{p(\mathcal{M}_1|\mathcal{D})}{p(\mathcal{M}_2|\mathcal{D})} \triangleq$$ *relative odds of model 1 over model 2 given the data*

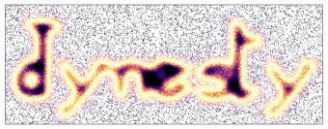
Intuitive and straight forward interpretation:

Rel. odds	log(rel. odds)	Significance
3:1	~1.0	~1.8σ
10:1	~2.3	~2.4σ
100:1	~4.6	~3.3σ
10,000:1	~9.2	~4.5σ

No closed-form solutions to compute relative odds!

Nested sampling

details: negative binomial likelihood
1024 live points
$\Delta \log \mathcal{Z}$ tolerance: 0.1



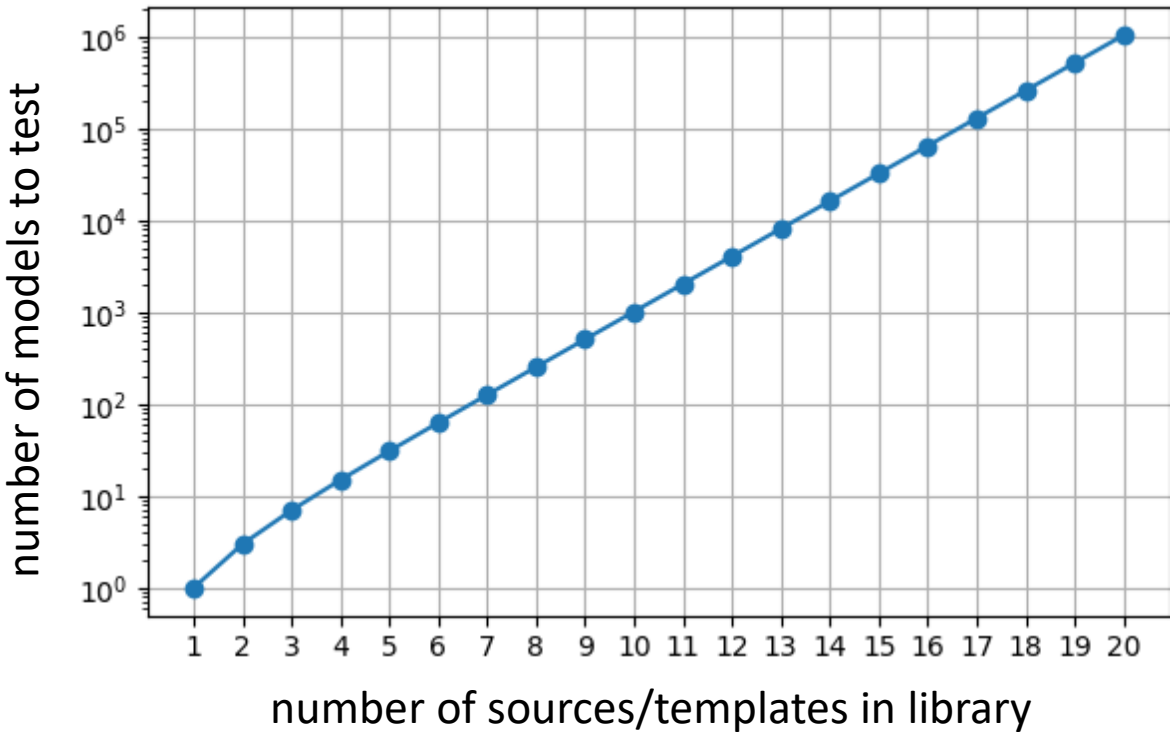
Speagle et al., *Mon. Not. R. Astron. Soc.* 493, 3132–3158 (2020).

The Problem with Bayes…

One nested sampler run takes $\mathcal{O}(1)$ s

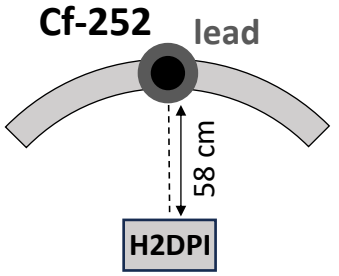
Curse of dimensionality

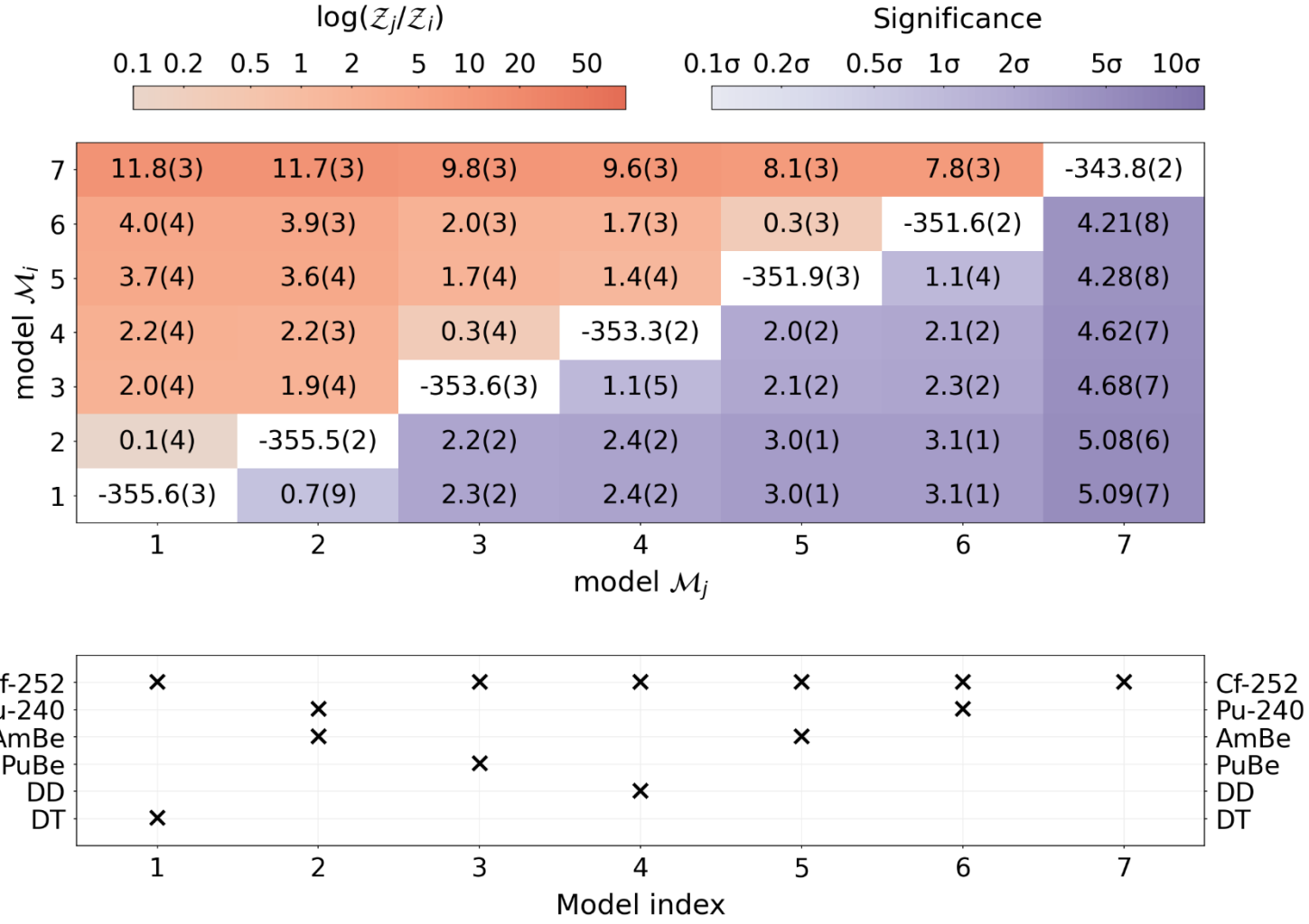
Explore iteratively using adaptive pursuit



Results

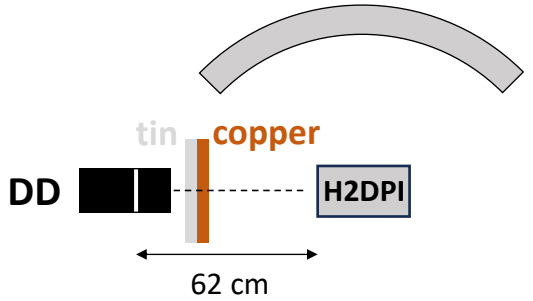
Cf-252

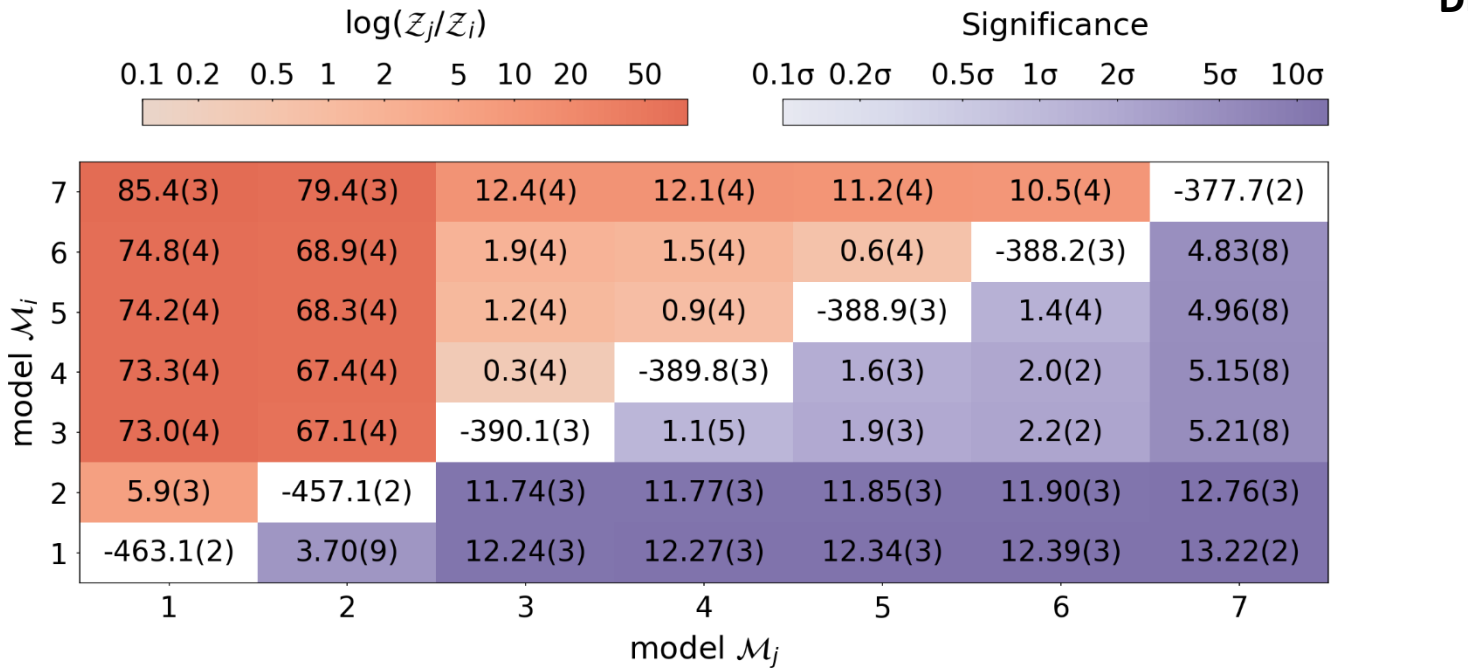

Cf-252
lead
58 cm
H2DPI

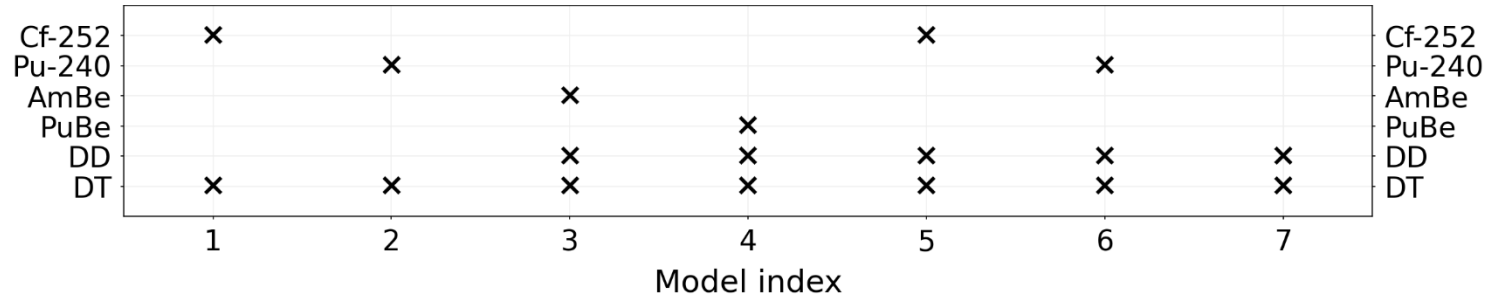

log($\mathcal{Z}_j/\mathcal{Z}_i$)
0.1 0.2 0.5 1 2 5 10 20 50
Significance
0.1σ 0.2σ 0.5σ 1σ 2σ 5σ 10σ
model $\mathcal{M}_i$
7 11.8(3) 11.7(3) 9.8(3) 9.6(3) 8.1(3) 7.8(3) -343.8(2)
6 4.0(4) 3.9(3) 2.0(3) 1.7(3) 0.3(3) -351.6(2) 4.21(8)
5 3.7(4) 3.6(4) 1.7(4) 1.4(4) -351.9(3) 1.1(4) 4.28(8)
4 2.2(4) 2.2(3) 0.3(4) -353.3(2) 2.0(2) 2.1(2) 4.62(7)
3 2.0(4) 1.9(4) -353.6(3) 1.1(5) 2.1(2) 2.3(2) 4.68(7)
2 0.1(4) -355.5(2) 2.2(2) 2.4(2) 3.0(1) 3.1(1) 5.08(6)
1 -355.6(3) 0.7(9) 2.3(2) 2.4(2) 3.0(1) 3.1(1) 5.09(7)
1 2 3 4 5 6 7
model $\mathcal{M}_j$

Cf-252
Pu-240
AmBe
PuBe
DD
DT
1 2 3 4 5 6 7
Model index

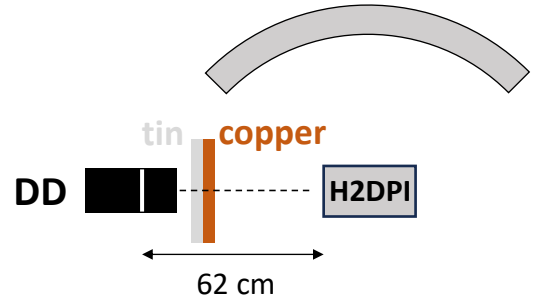
DD

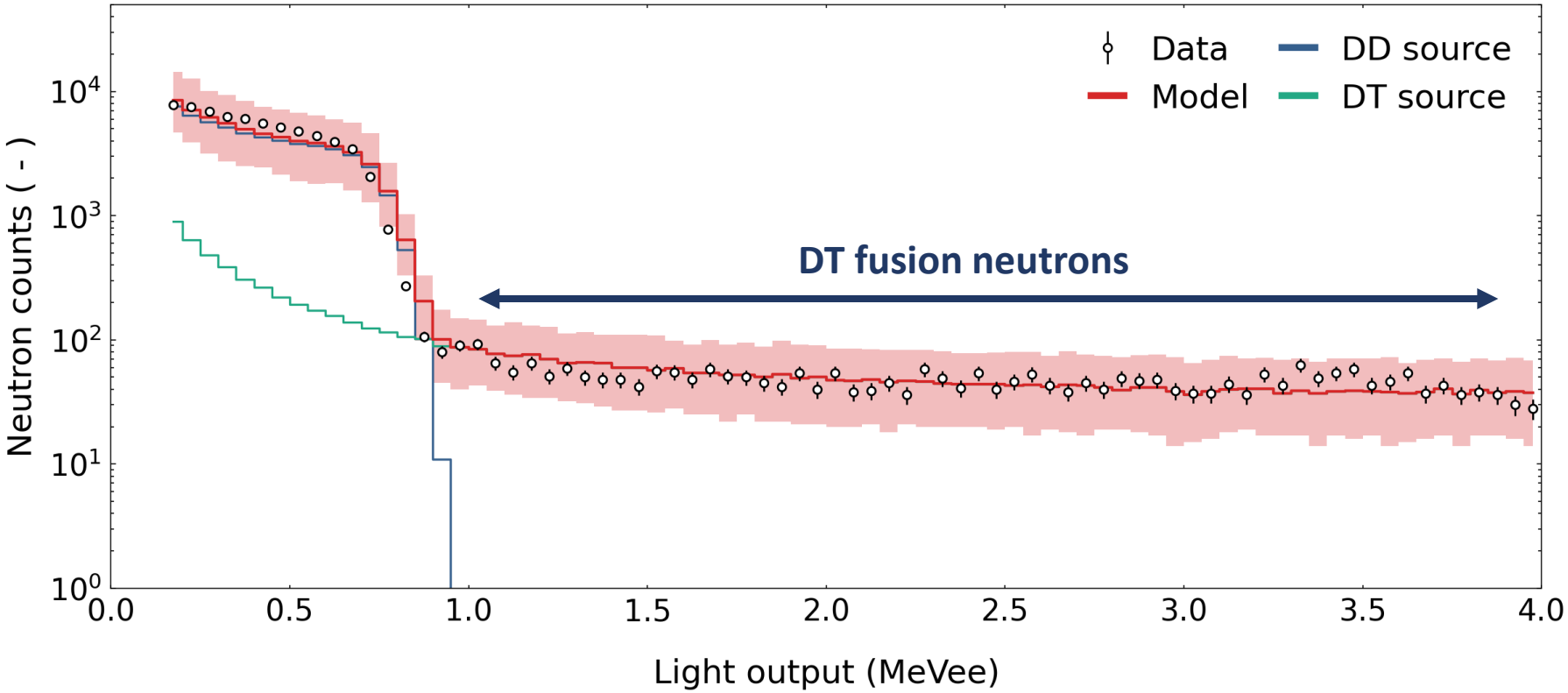

tin
copper
DD
H2DPI
62 cm


log($\mathcal{Z}_j/\mathcal{Z}_i$)
0.1 0.2 0.5 1 2 5 10 20 50
Significance
0.1σ 0.2σ 0.5σ 1σ 2σ 5σ 10σ
model $\mathcal{M}_i$
7 85.4(3) 79.4(3) 12.4(4) 12.1(4) 11.2(4) 10.5(4) -377.7(2)
6 74.8(4) 68.9(4) 1.9(4) 1.5(4) 0.6(4) -388.2(3) 4.83(8)
5 74.2(4) 68.3(4) 1.2(4) 0.9(4) -388.9(3) 1.4(4) 4.96(8)
4 73.3(4) 67.4(4) 0.3(4) -389.8(3) 1.6(3) 2.0(2) 5.15(8)
3 73.0(4) 67.1(4) -390.1(3) 1.1(5) 1.9(3) 2.2(2) 5.21(8)
2 5.9(3) -457.1(2) 11.74(3) 11.77(3) 11.85(3) 11.90(3) 12.76(3)
1 -463.1(2) 3.70(9) 12.24(3) 12.27(3) 12.34(3) 12.39(3) 13.22(2)
1 2 3 4 5 6 7
model $\mathcal{M}_j$

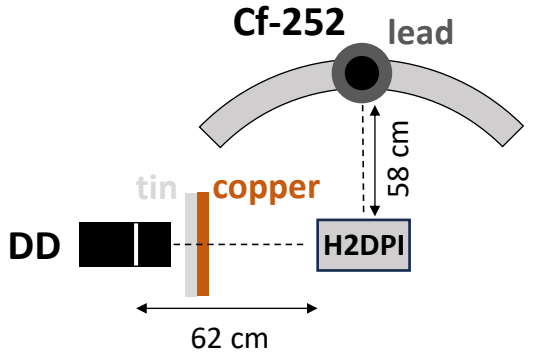

Cf-252
Pu-240
AmBe
PuBe
DD
DT
1 2 3 4 5 6 7
Model index

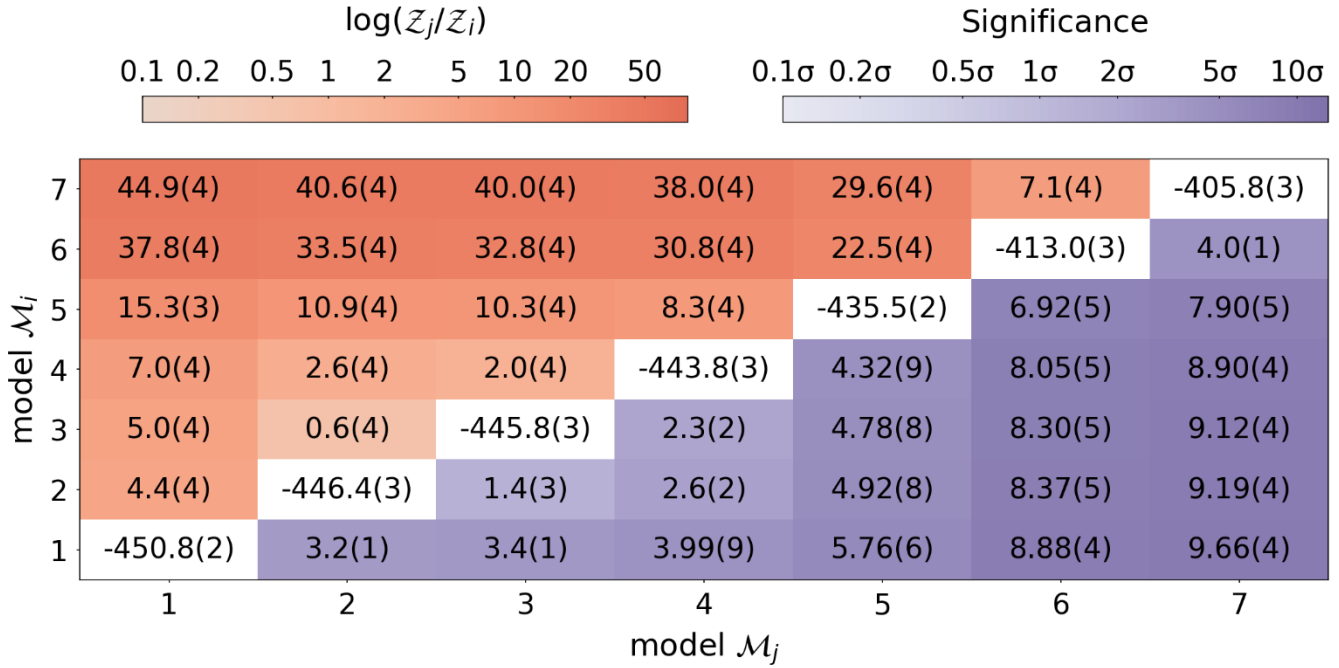
DD(+DT)

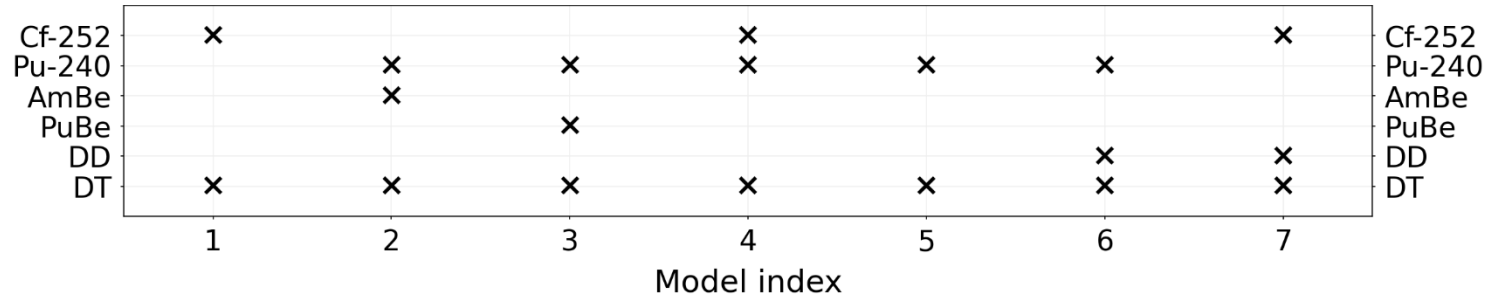

tin
copper
DD
H2DPI
62 cm


Data
Model
DD source
DT source
DT fusion neutrons
Neutron counts (-)
Light output (MeVee)
10^0
10^1
10^2
10^3
10^4
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

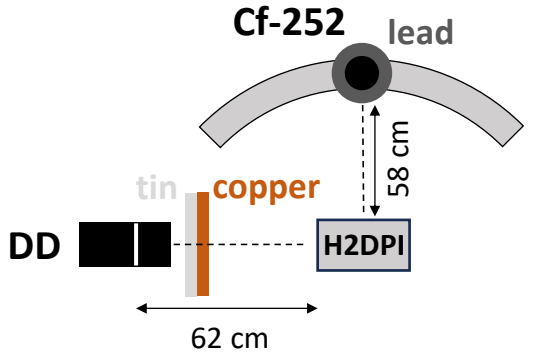
Cf-252+DD(+DT)


Cf-252
lead
58 cm
tin
copper
DD
H2DPI
62 cm

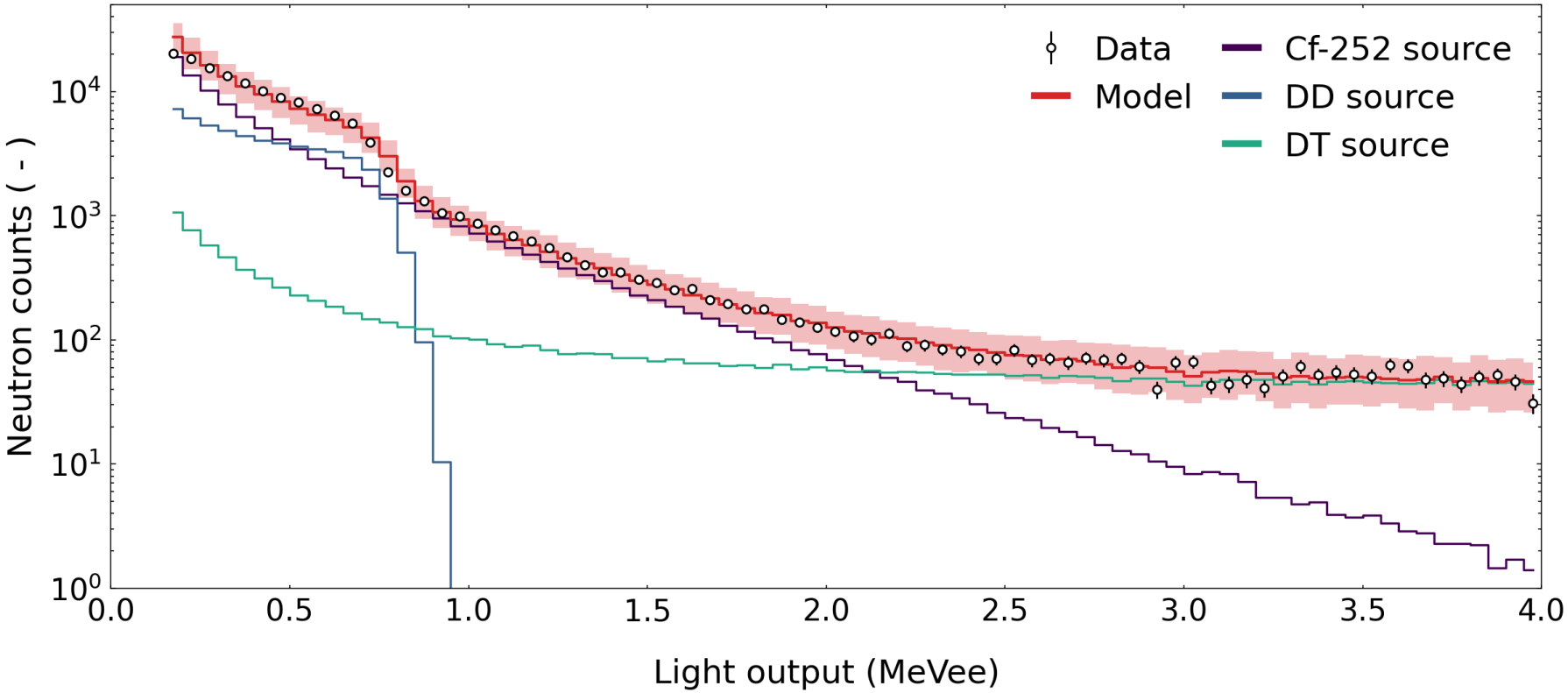

log($\mathcal{Z}_j/\mathcal{Z}_i$)
0.1 0.2 0.5 1 2 5 10 20 50
Significance
0.1σ 0.2σ 0.5σ 1σ 2σ 5σ 10σ
model $\mathcal{M}_i$
7 44.9(4) 40.6(4) 40.0(4) 38.0(4) 29.6(4) 7.1(4) -405.8(3)
6 37.8(4) 33.5(4) 32.8(4) 30.8(4) 22.5(4) -413.0(3) 4.0(1)
5 15.3(3) 10.9(4) 10.3(4) 8.3(4) -435.5(2) 6.92(5) 7.90(5)
4 7.0(4) 2.6(4) 2.0(4) -443.8(3) 4.32(9) 8.05(5) 8.90(4)
3 5.0(4) 0.6(4) -445.8(3) 2.3(2) 4.78(8) 8.30(5) 9.12(4)
2 4.4(4) -446.4(3) 1.4(3) 2.6(2) 4.92(8) 8.37(5) 9.19(4)
1 -450.8(2) 3.2(1) 3.4(1) 3.99(9) 5.76(6) 8.88(4) 9.66(4)
1 2 3 4 5 6 7
model $\mathcal{M}_j$


Cf-252
Pu-240
AmBe
PuBe
DD
DT
1 2 3 4 5 6 7
Model index

Cf-252+DD(+DT)



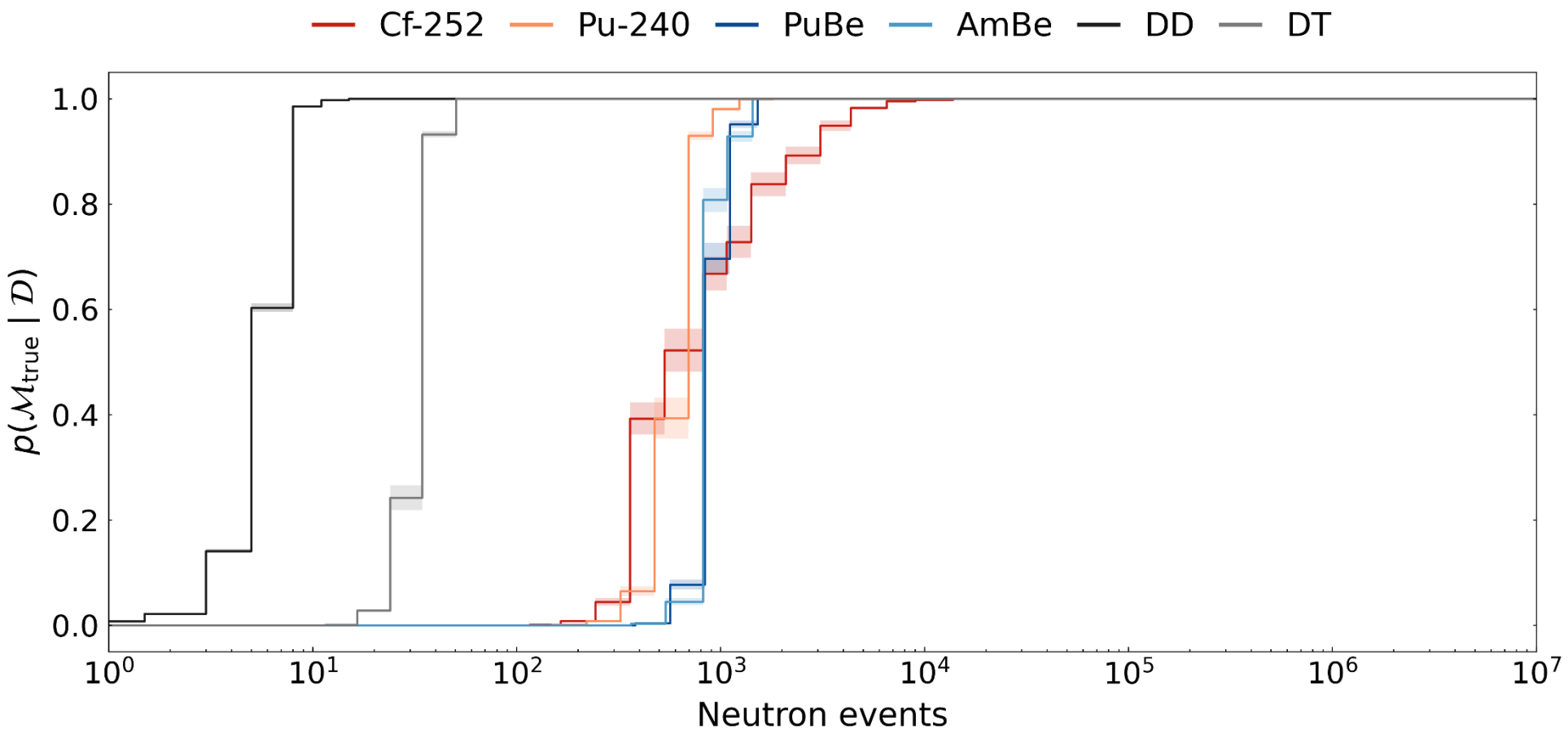
? How many events do we really need



Single-Source Identification

? How many events do we really need?

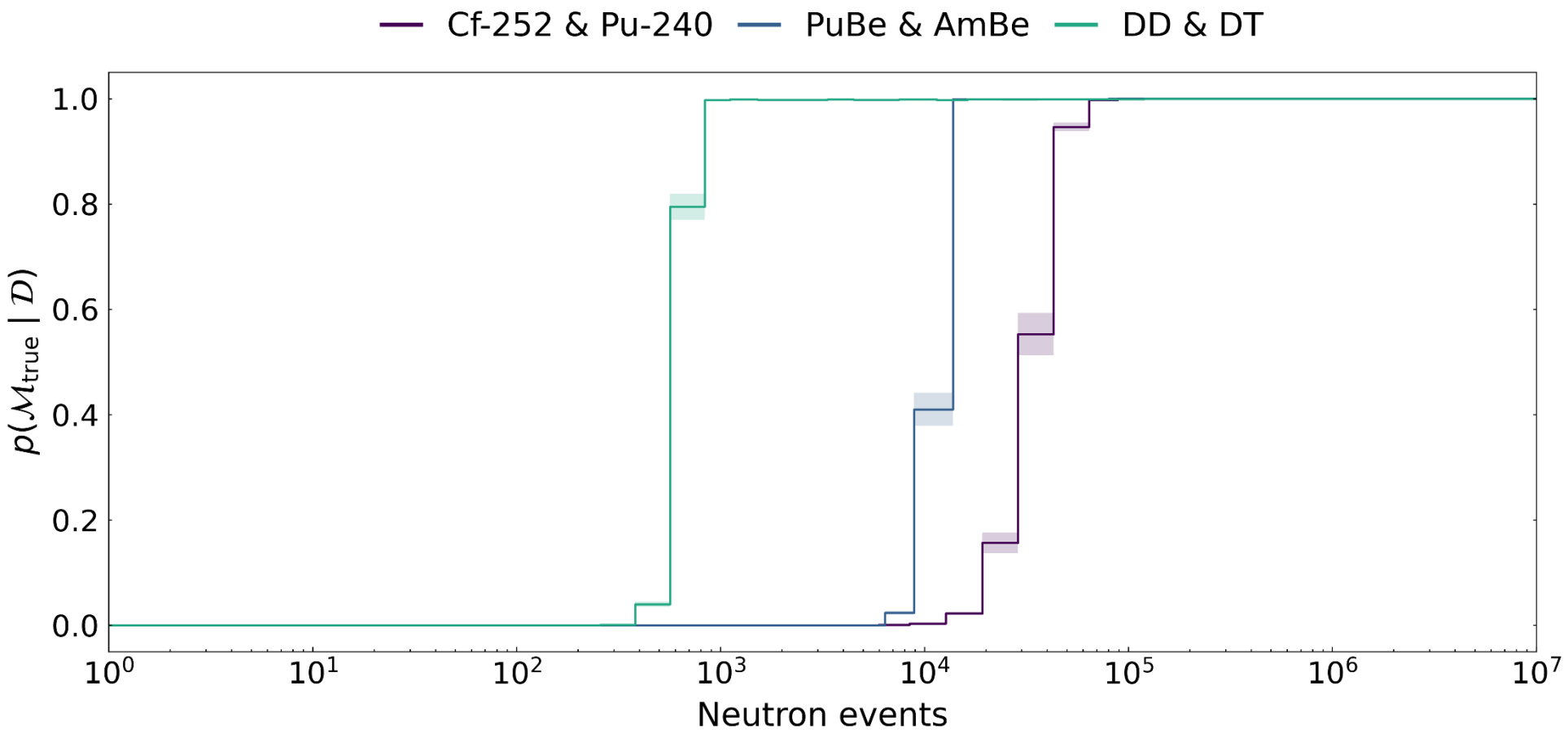
1E1 – 1E4 (<1s – 4 min. for given setup)



Two-Source Identification

? How many events do we really need?

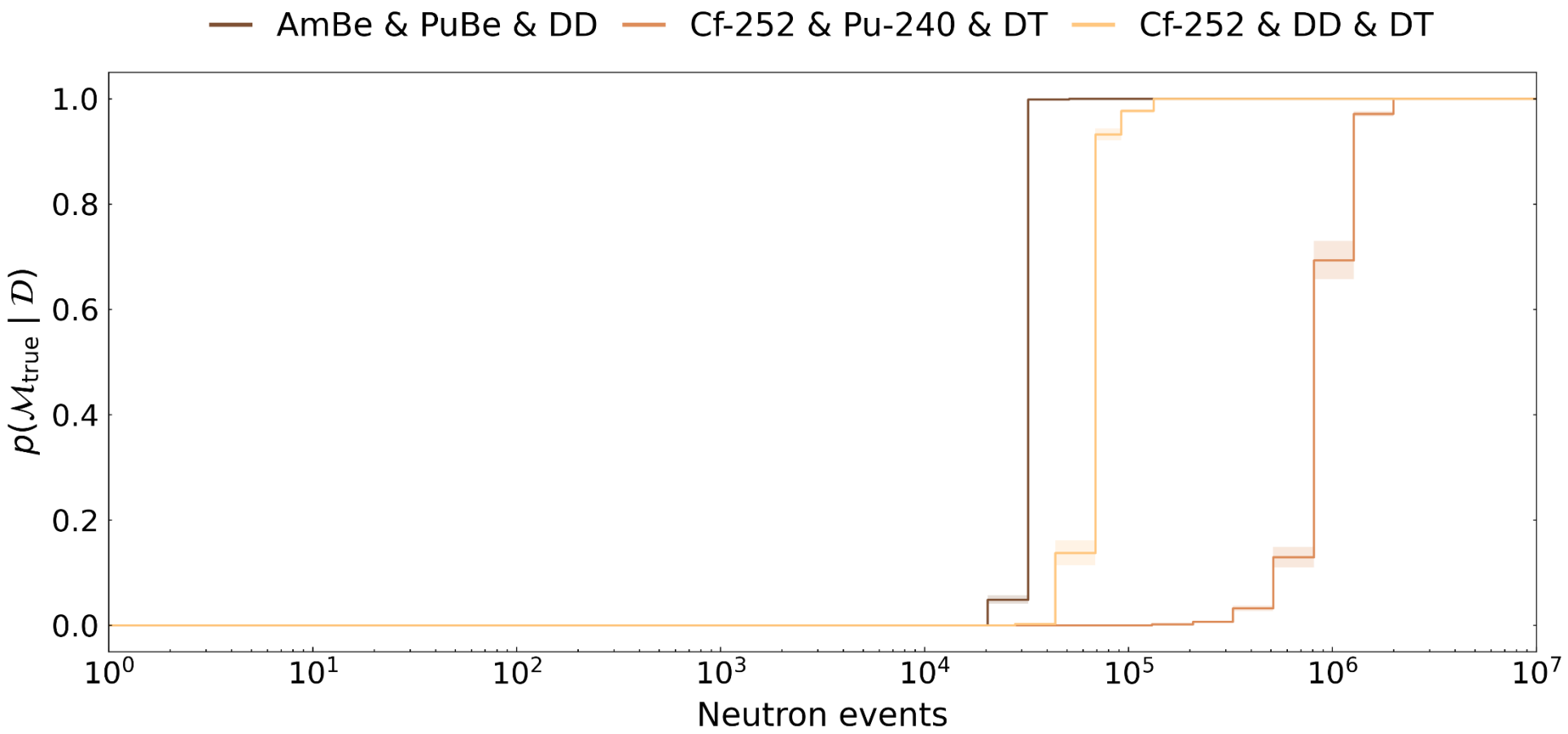
1E3 – 1E5 (20s – 20 min. for given setup)



Three-Source Identification

? How many events do we really need?

4E4 – 2E6 (7 min. – 6 h for given setup)



Conclusion

Conclusion

First demonstration of **high-confidence** (>4σ) neutron identification with recoil spectroscopy for single and multi-source cases

Rapid identification (<10 min.) for single-source cases. Multi-source identification speed expected to meet same standard with commercial organic scintillator spectrometers (e.g. 5 inch EJ309)

New remote capability for detecting and verifying special nuclear materials but also in other fields like nuclear fusion (DD,DT)