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Title: MCNP6 CHARACTERIZATION OF NEUTRON DETECTABILITY OF HIGHLY ENRICHED URANIUM

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MCNP6 CHARACTERIZATION OF NEUTRON DETECTABILITY OF HIGHLY ENRICHED URANIUM

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Nuclear Engineering & Nonproliferation Division

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OUTLINE

- Introduction
  - Motivation
  - ROC curves
- MCNP6 Model
  - Detector model
  - HEU
  - Source & normalization
  - Parameter variations
- Results
- Conclusions/Future Work

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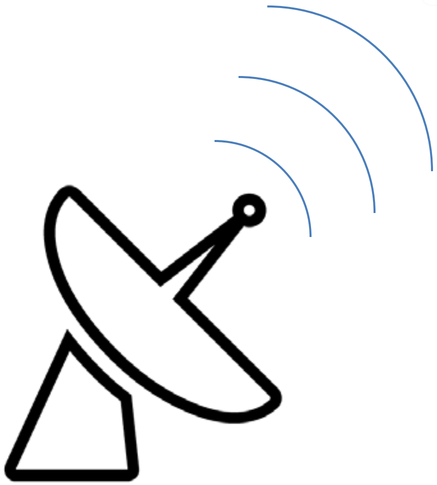
INTRODUCTION – Motivation

- How do we detect SNM?
  - active and passive interrogation
    - radiation detectors
      - ^{3}He neutron detector
- How do we quantify our ability to detect SNM?
  - count rate, energy spectrum, pulse shape, etc.
    - binary classification (TP, FP, TN, FN)
      - ROC curves
- How do we provide a real-time cost/benefit analysis?
  - parametrize data to inform algorithms

INTRODUCTION – ROC Curves

- Radar Receiver Operator Characteristic (1940s)
- Binary classification test
  - true positives vs. false positives
  - e.g. planes vs. birds
- Employed in numerous areas: psychology (1950s), radiology(1960), medicine (1970s), climatology (1980s), etc.



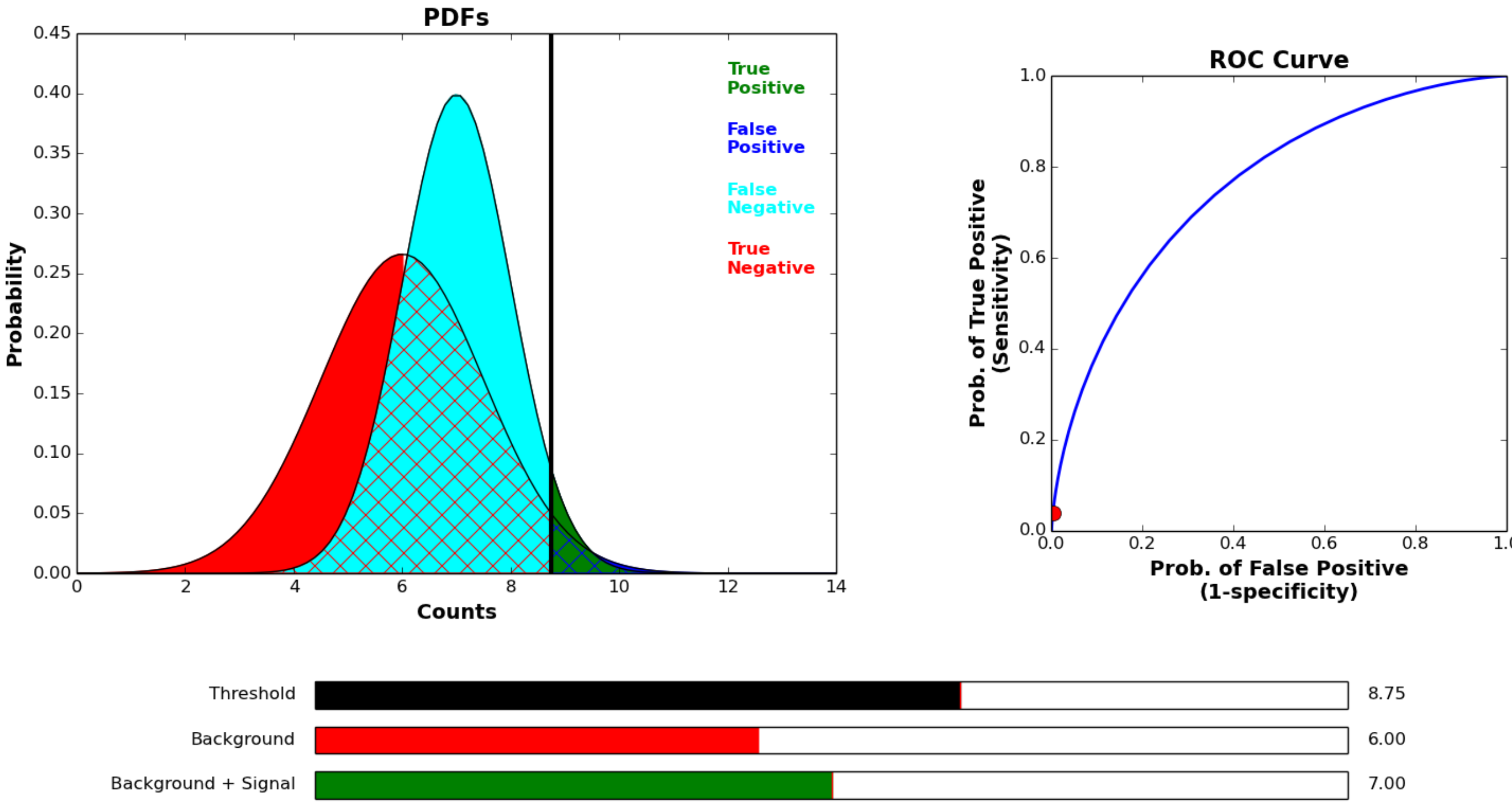
INTRODUCTION – ROC Curves

$P_0(T)$ = count distribution of background (PDF)

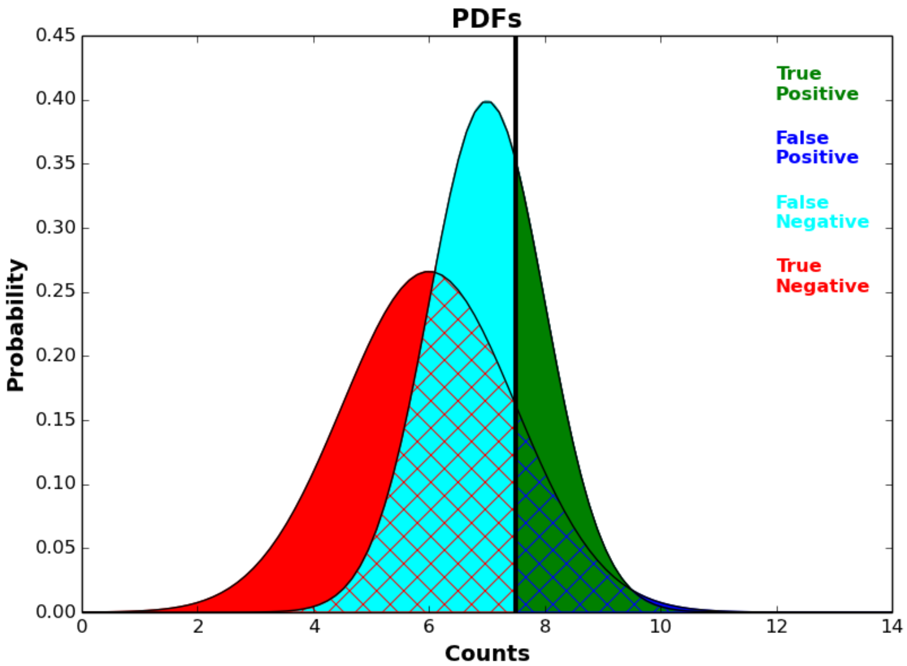
$P_1(T)$ = count distribution of signal + background (PDF)

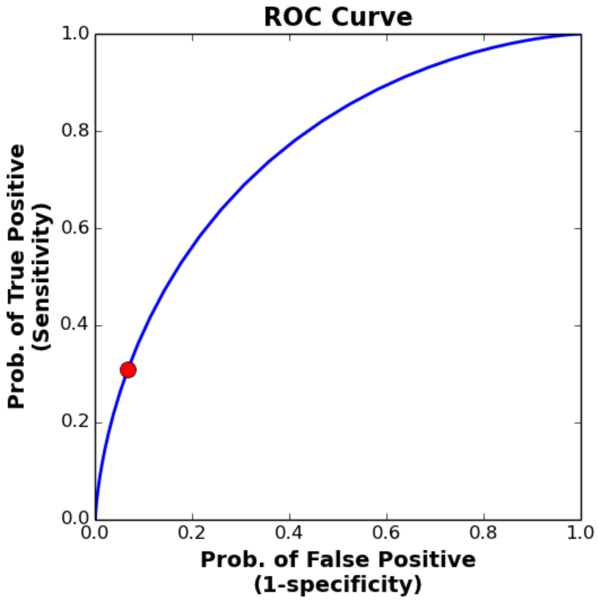
- Sensitivity = True positive rate $= \int_T^\infty P_1(T)dT$
  - Sensitivity = Probability of Detection
- Specificity = False positive rate $= \int_T^\infty P_0(T)dT$
  - (1 – Specificity) = Probability of False Alarm
- ROC Plot
  - X-axis = (1 – Specificity)
  - Y-axis = Sensitivity

ROC CURVE – Sensitivity << Specificity



ROC CURVE – Sensitivity < Specificity



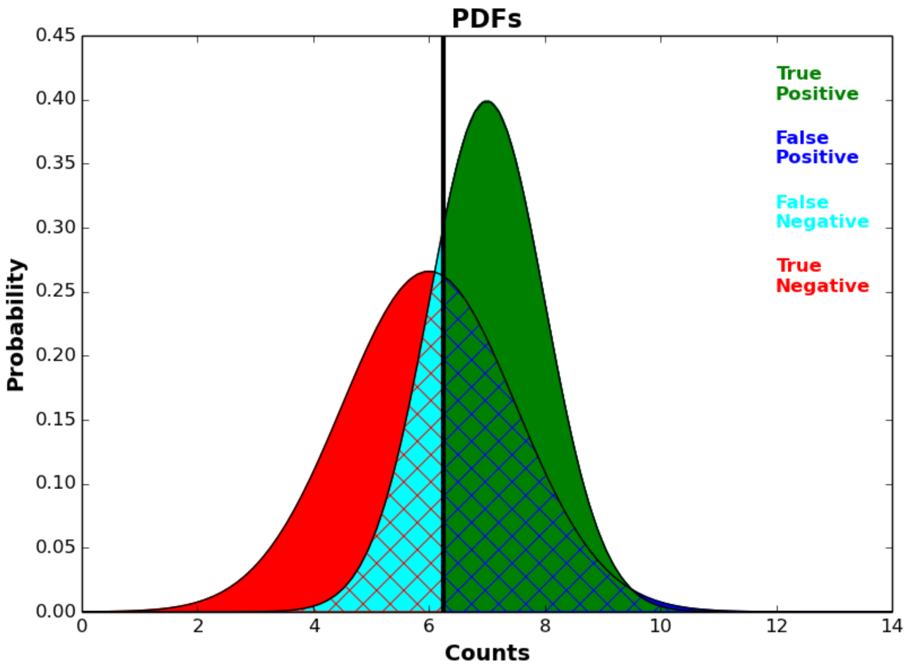


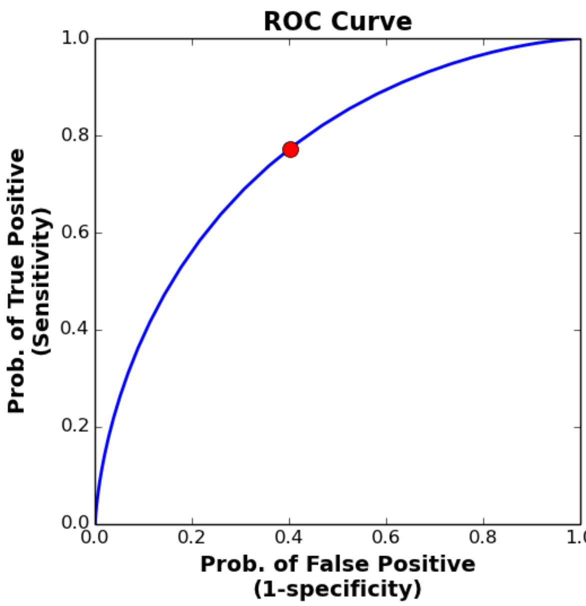
Threshold 7.50

Background 6.00

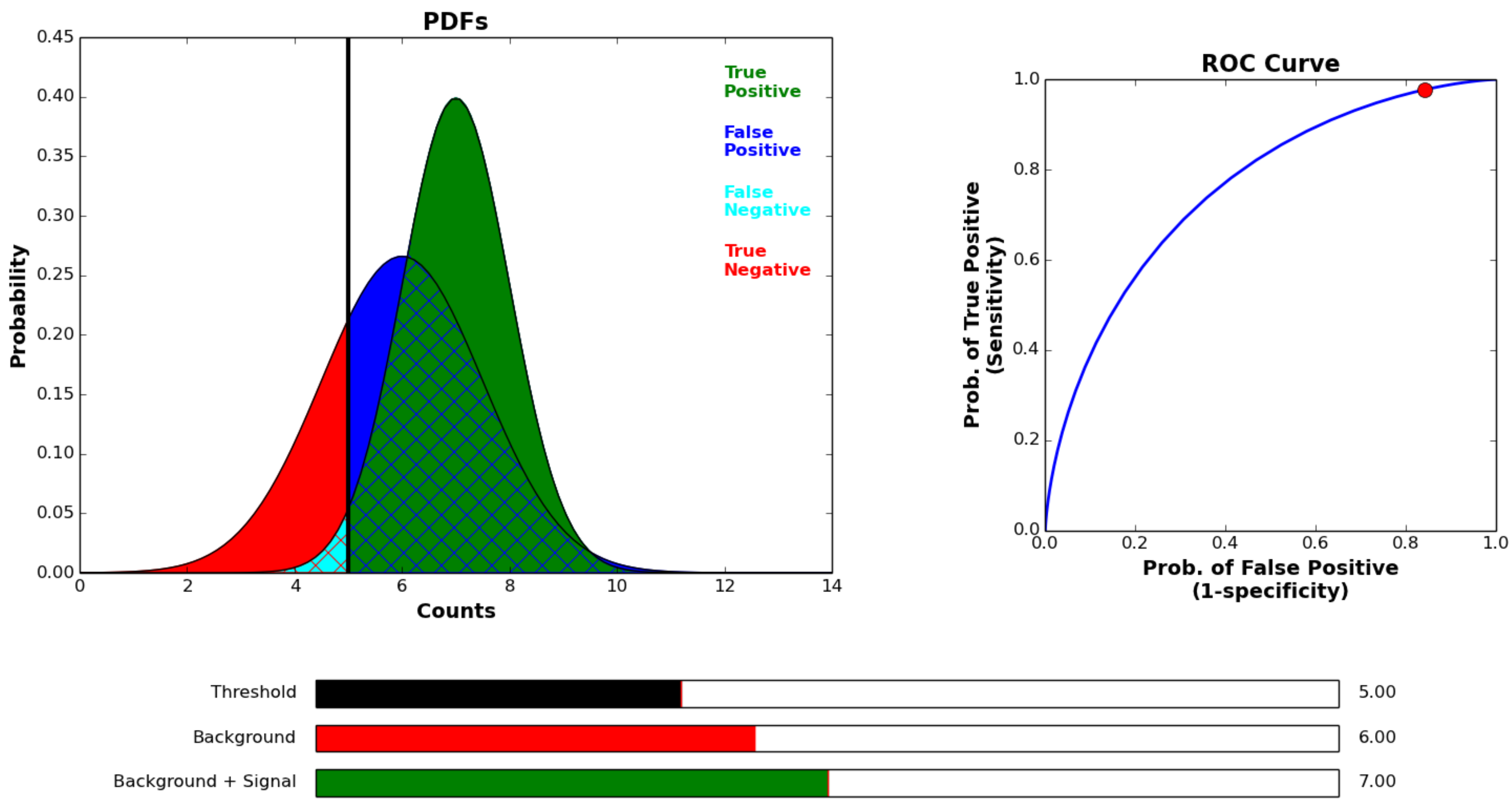
Background + Signal 7.00

ROC CURVE – Sensitivity > Specificity





ROC CURVE – Sensitivity >> Specificity



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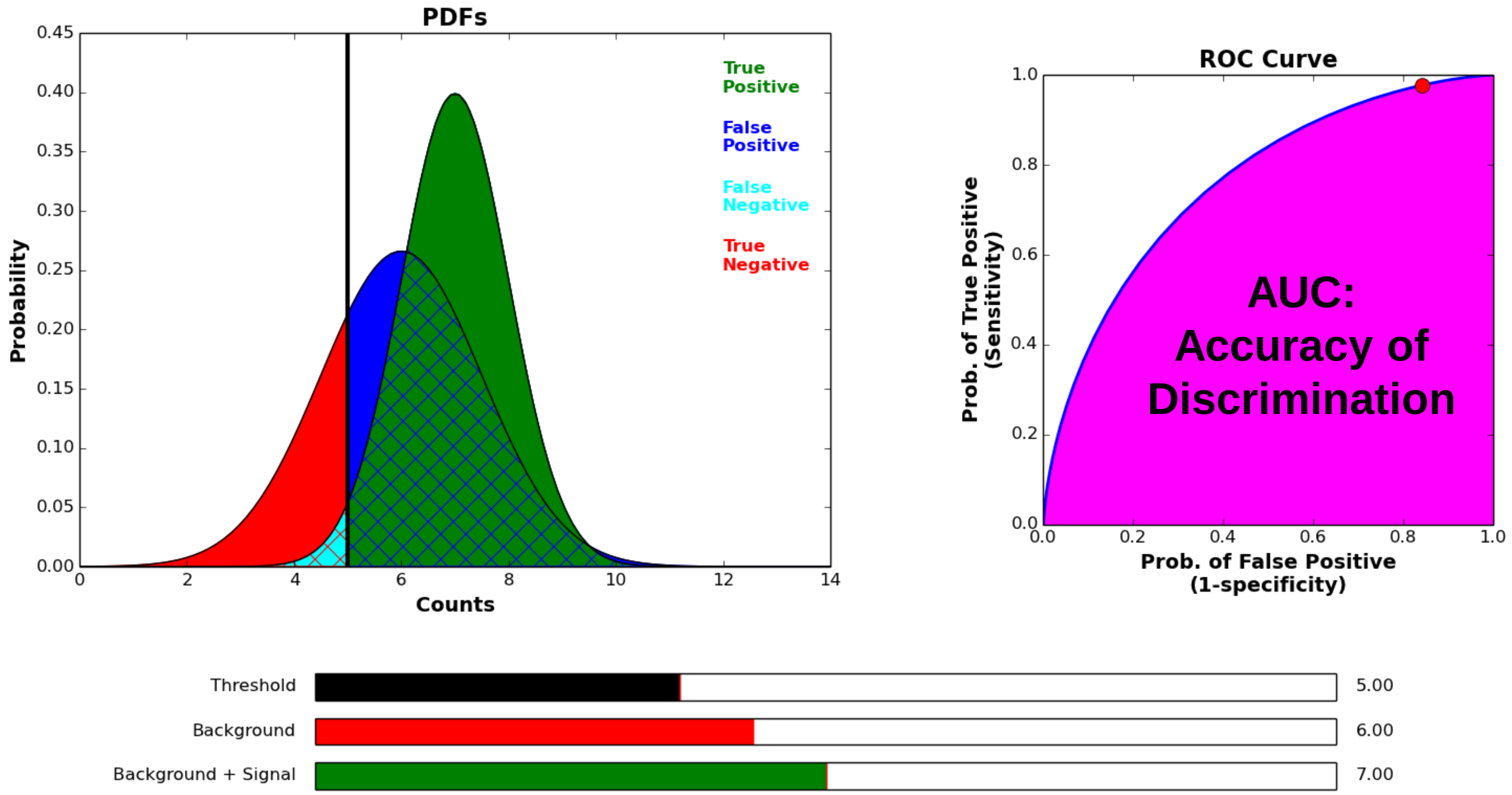
ROC CURVE – Sensitivity >> Specificity



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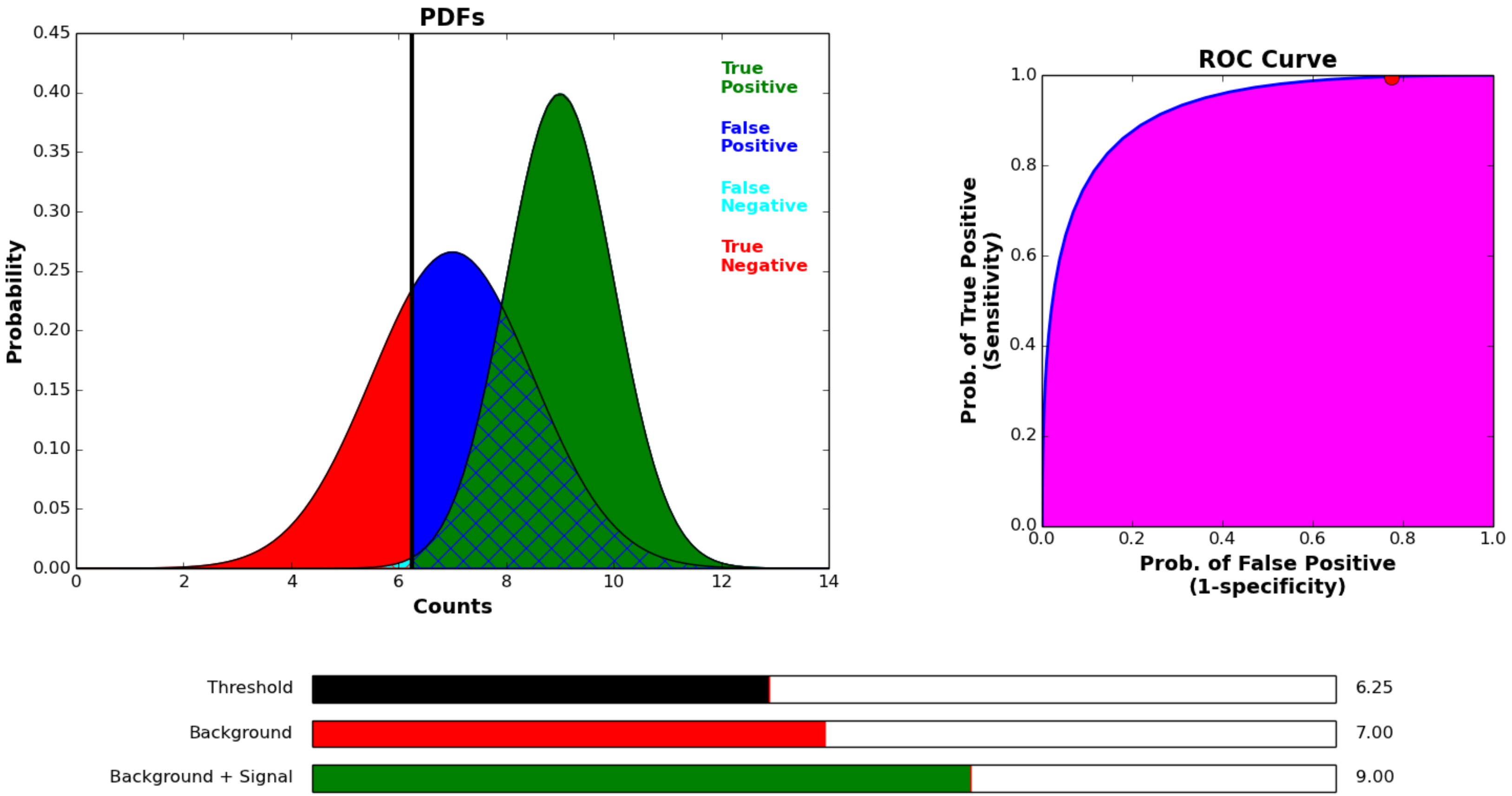
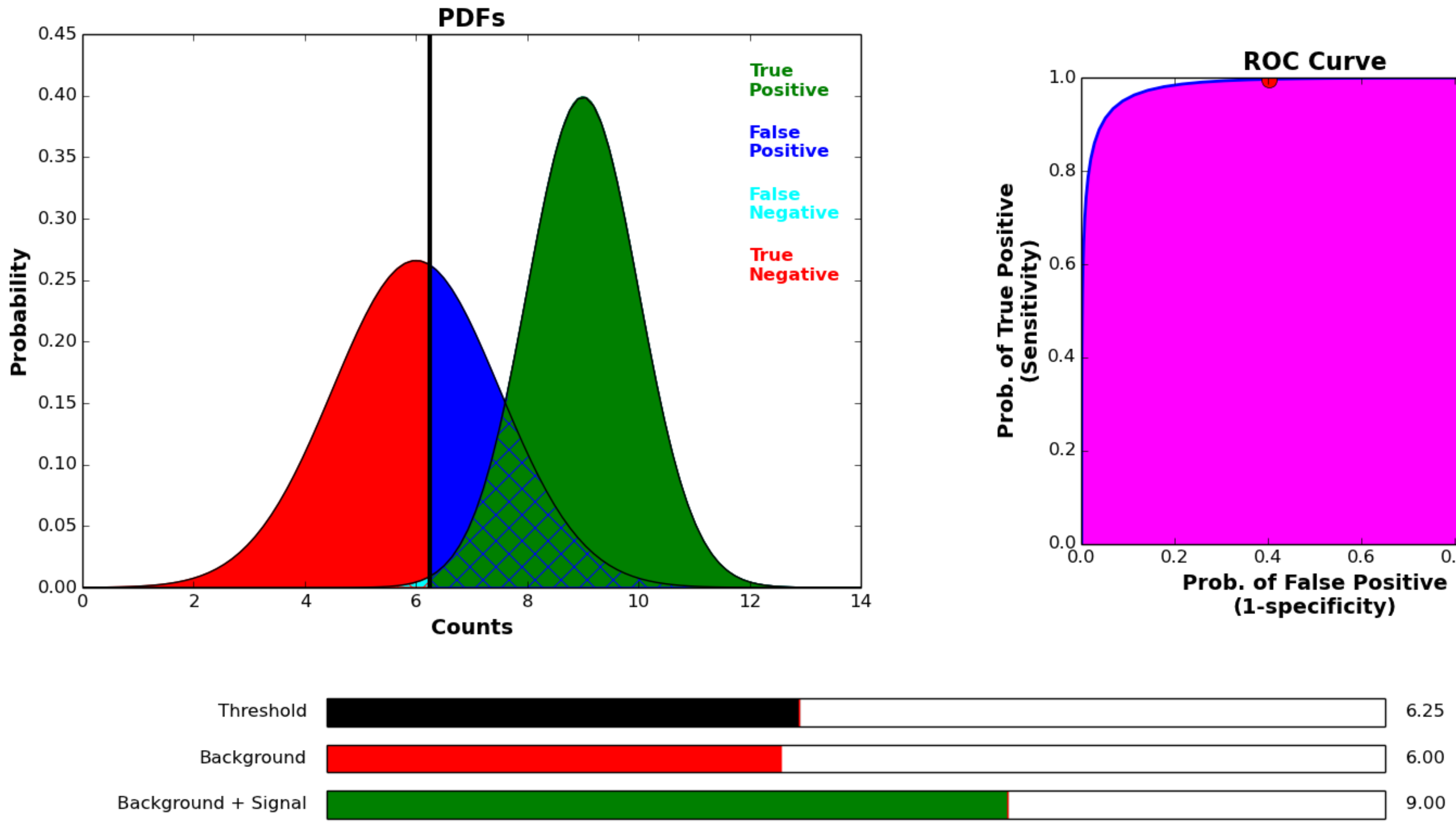
ROC CURVE – Better Detector

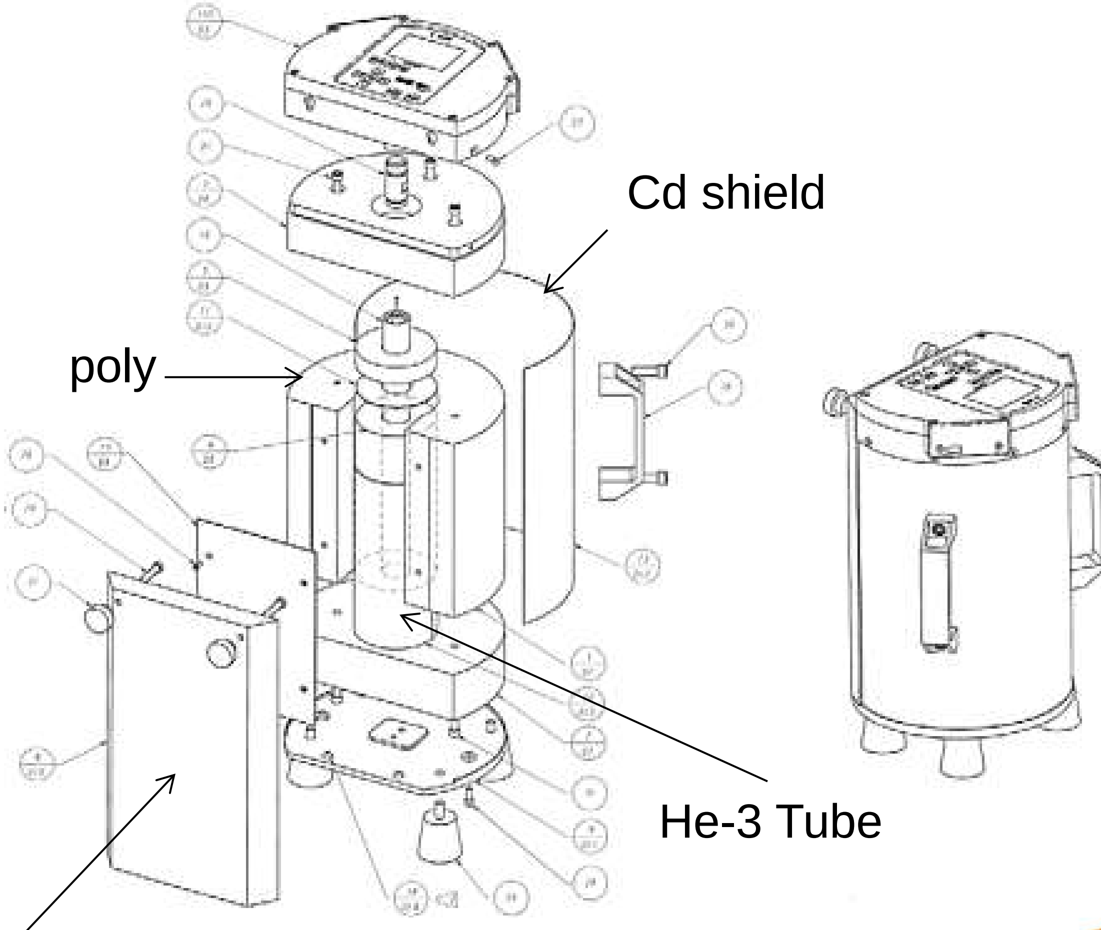


ROC CURVE – Better Shielding



MCNP6 MODEL - Detector Model

- **LANL SNAP-3 Detector**
  - **Shielded Neutron Assay Probe, model 3**
- **^{3}He proportional counter with CO_2 quench gas**
- **MCNP model made by John Mattingly [1]**



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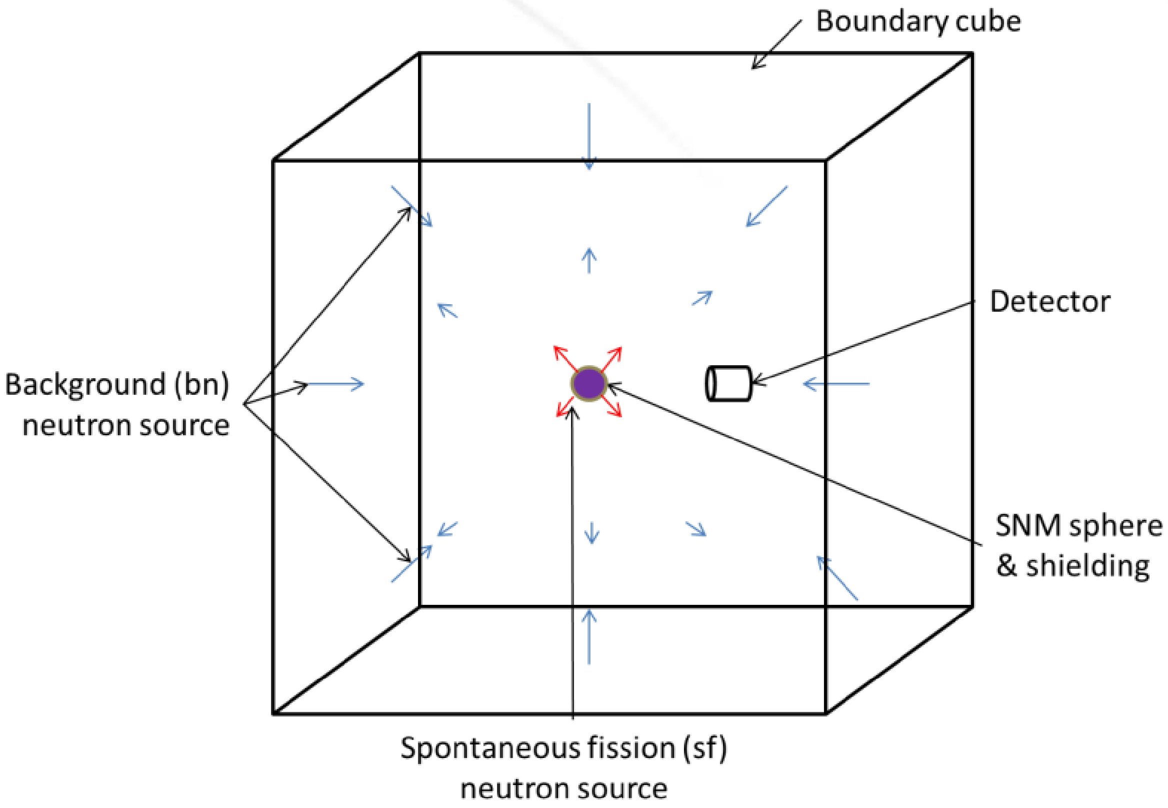
MCNP6 MODEL – HEU Isotopics

- HEU modeled after Godiva IV delayed-critical experiments performed by Russell D. Mosteller [2]
- 98.5 wt% uranium
- 1.5 wt% molybdenum
- ρ = 19.05 g/cm^3

Isotope	Weight Fraction
^{92}Mo	0.0022260
^{94}Mo	0.0013875
^{95}Mo	0.0023880
^{96}Mo	0.0025020
^{97}Mo	0.0014325
^{98}Mo	0.0036195
^{100}Mo	0.0014445
^{233}U	0.0001266
^{234}U	0.0105958
^{235}U	0.9178510
^{236}U	0.0066558
^{238}U	0.0497706

MCNP6 MODEL – Source

- Simplified geometry
  - HEU sphere
  - Shielding
  - Ambient air
- Sources
  - Spontaneous fission neutrons
  - Cosmic background neutrons



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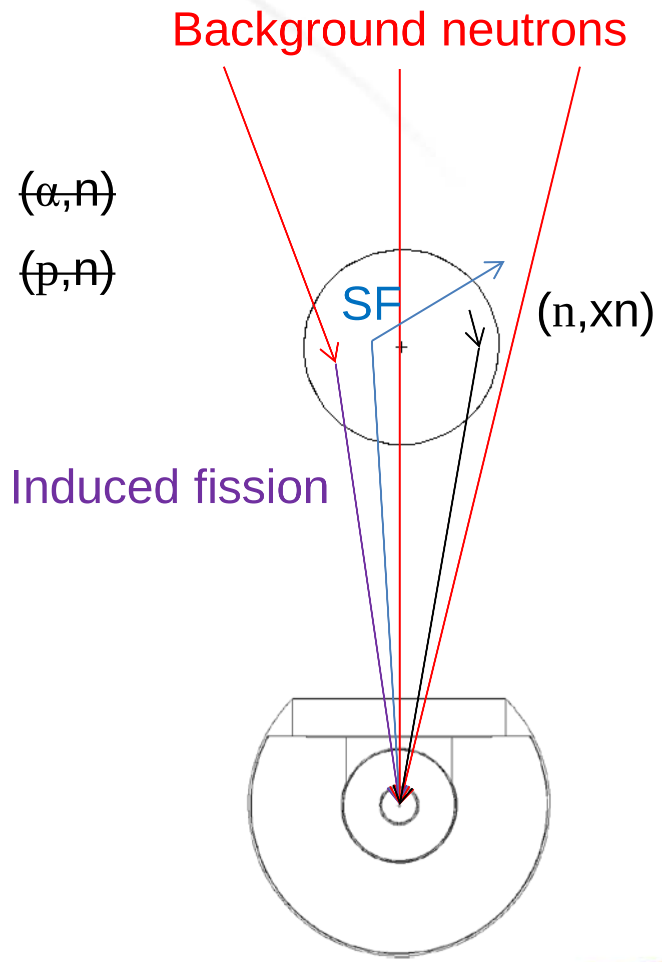


MCNP6 MODEL – Normalization

BN $= \frac{(A_s)\, I_{flux}\, T}{3.7} = \frac{6(2000\ cm)^\wedge 2}{3.7}\left(0.015449\ \frac{n}{cm^2 s}\right)(1000\ s)$

SF $= \sum_i Act_i * SFBR_i * T$

MCNP6 MODEL – Normalization

$$\text{BN} = \frac{(A_s)\, I_{flux}\, T}{3.7} = \frac{6(2000\ cm)^\wedge 2}{3.7}\left(0.015449\ \frac{n}{cm^2 s}\right)(1000\ s)$$

Surf. Cards

```
5 rpp -1000 1000 -1000 1000 -1000 1000
```

MCNP6 MODEL – Normalization

SNLL measured data

$$\text{BN} = \frac{(A_s)\, I_{flux}\, T}{3.7} = \frac{6(2000\ cm)\hat{}2}{3.7}\left(0.015449\ \frac{n}{cm^2 s}\right)(1000\ s) = 100{,}212{,}324$$

Data Cards

```
sdef par=-bn loc= 37.7   -122.7   0.196
```

Elevation scaling, see: *MCNP6 Elevation Scaling of Cosmic Ray Backgrounds, LA-UR-14-21331*

background.dat

38.0 -120.0 1.69514 330 09/01/2013

flux (n/cm2/s) 4.75779E-02 . . . . .

Automatic elevation scaling factor 0.2779

1.32219E-02

MCNP6 MODEL – Normalization

SF $= \sum_i Act_i * SFBR_i * T$

Act_i can be found in print table 44 or easily calculated

cinder.dat

```
#3209: 2340920  U 234    H-L=   7.7535E+12 DKref:e .
 Eb=  1.2300E-02, Eg=  1.6100E-03, Ea=  4.8419E+00, SFBF=  1.7300E-11
```

MCNP6 MODEL – Normalization

$$\text{NHB} = (\mathbf{BN} + \boldsymbol{SF})$$

HEU [kg]	5	10	20	30	40
SF	2,039	4,077	8,154	12,231	16,308
BN	100,212,324	100,212,324	100,212,324	100,212,324	100,212,324
NHB	100,214,363	100,216,401	100,220,478	100,224,555	100,228,632

$$\text{NPS} = \mathbf{NHB} * \ \mathbf{1000\ batches}$$

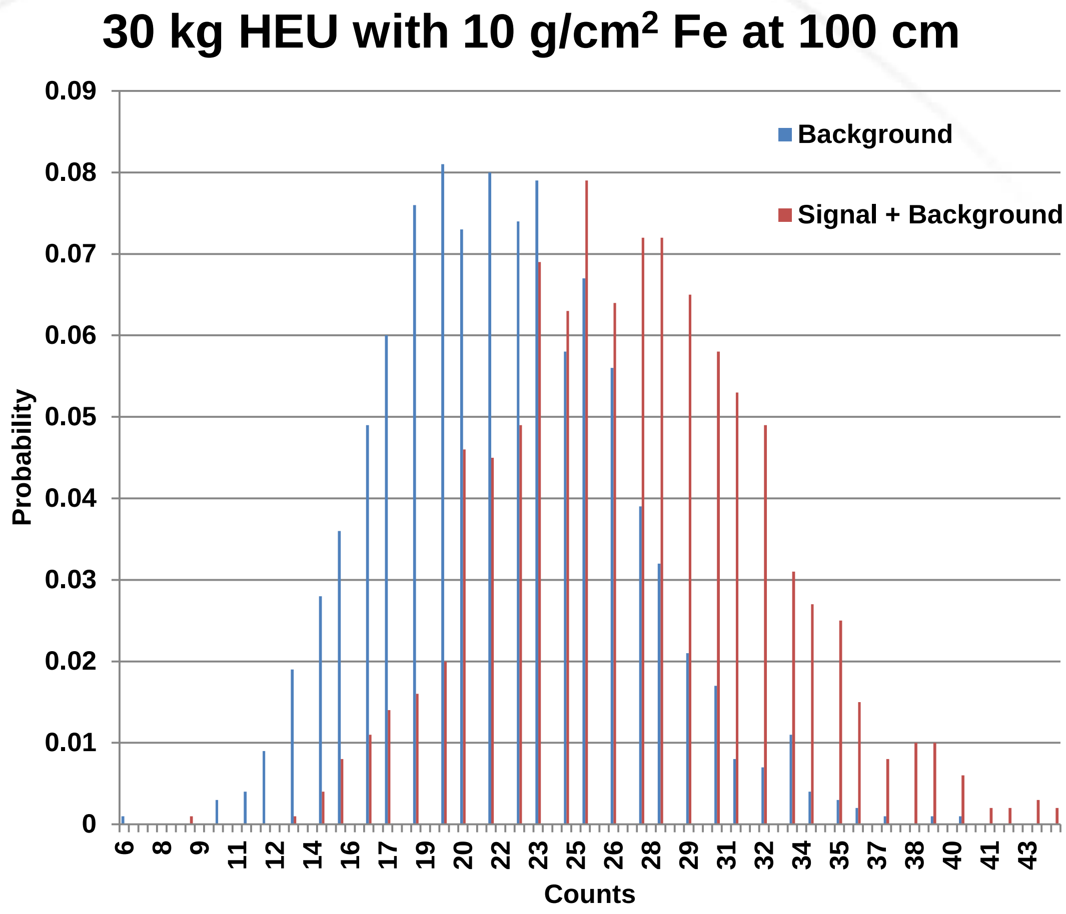
FTn ROC $\mathbf{NHB}$ $\mathbf{m}$

MCNP6 MODEL – Parameter variation

Parameter	Values				
HEU Mass [kg]	5	10	20	30	40
Detector Distance [cm]	50	100	200	300	400
Shield Thickness [g/cm^2]	1	5	10	15	
Shield Material	Pb	Fe	H_2O		

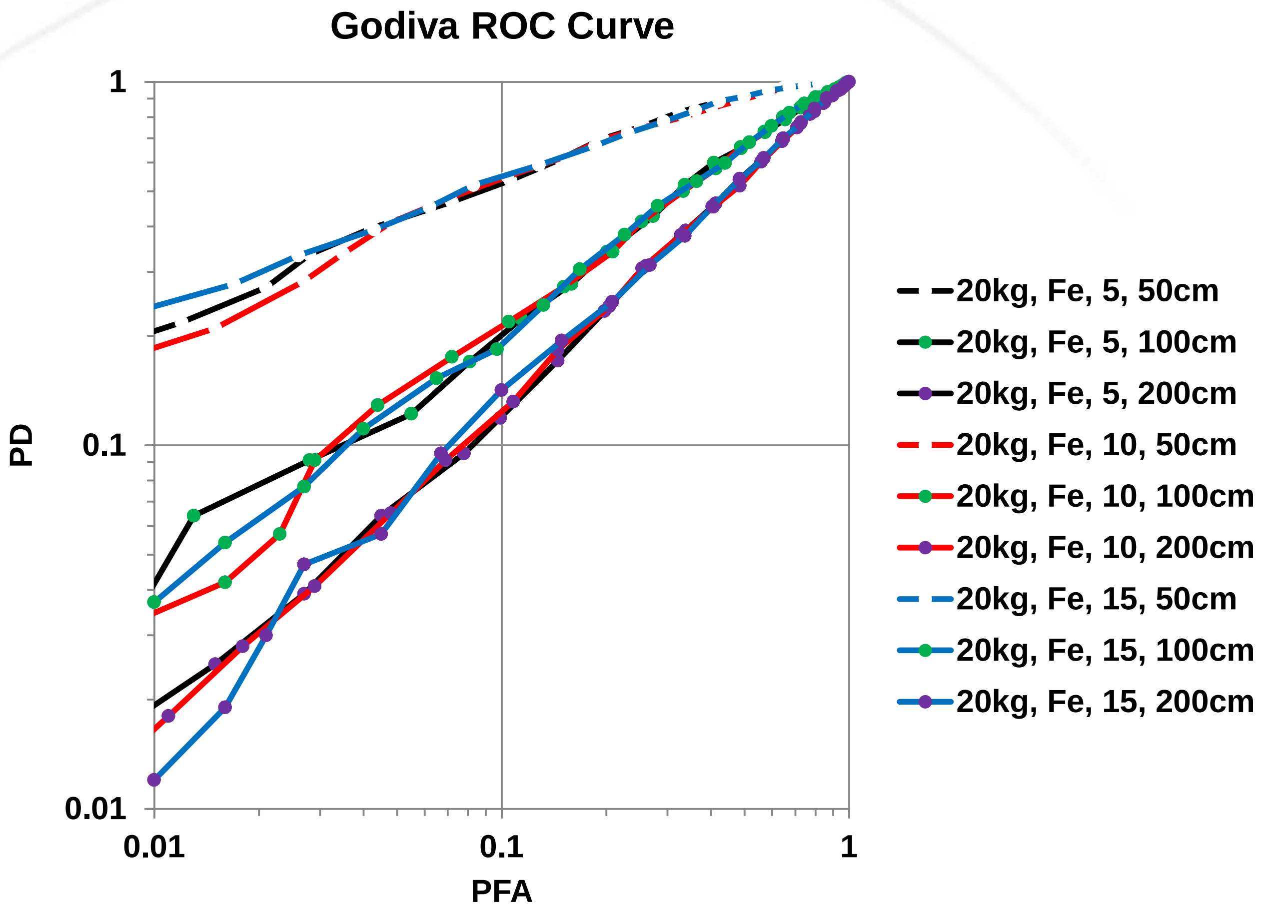
300 parameter combinations (35 too close to critical to simulate)

RESULTS



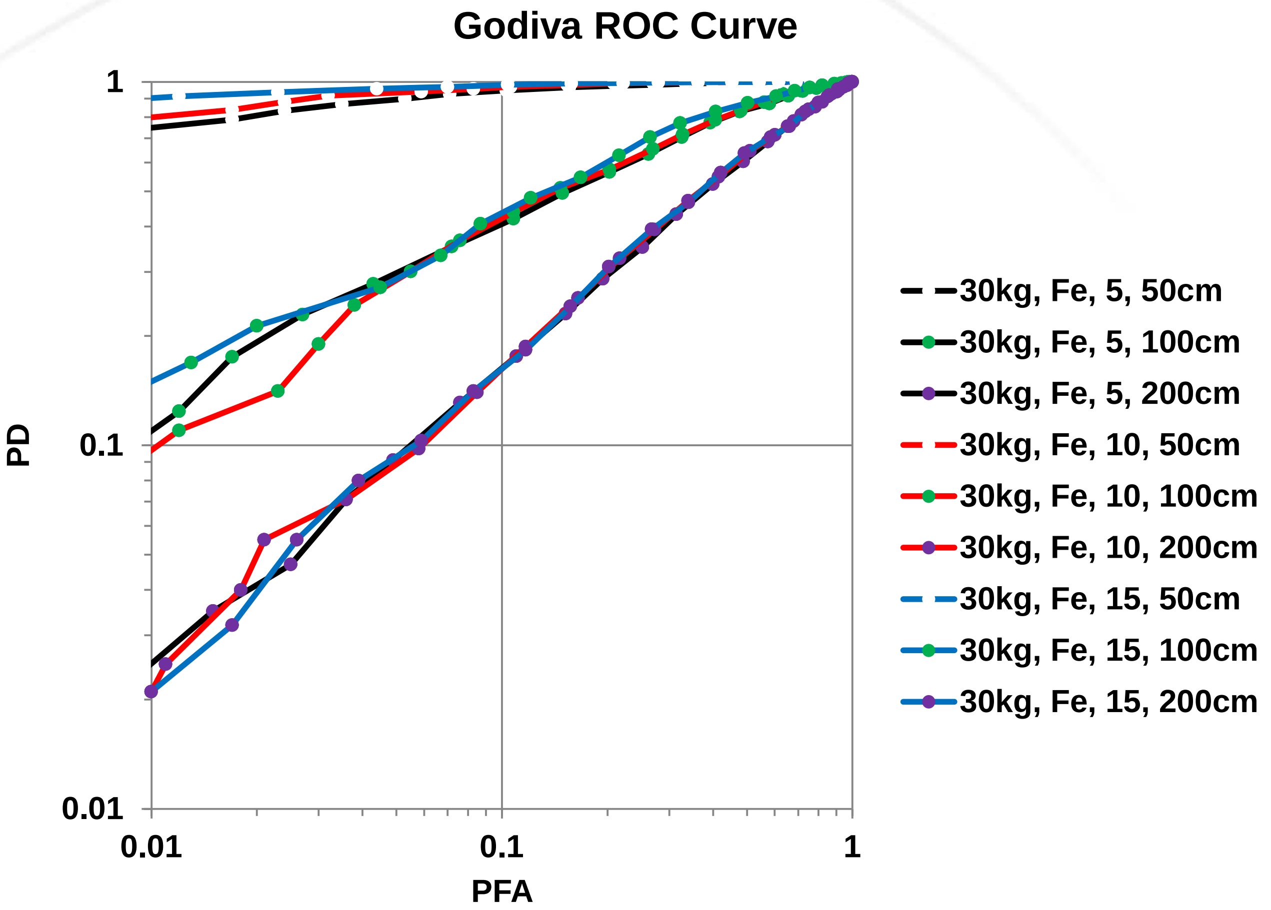
30 kg HEU with 10 g/cm² Fe at 100 cm
Background
Signal + Background
Probability
Counts
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
6 8 9 11 12 14 16 17 19 20 22 23 25 26 28 29 31 32 34 35 37 38 40 41 43

RESULTS

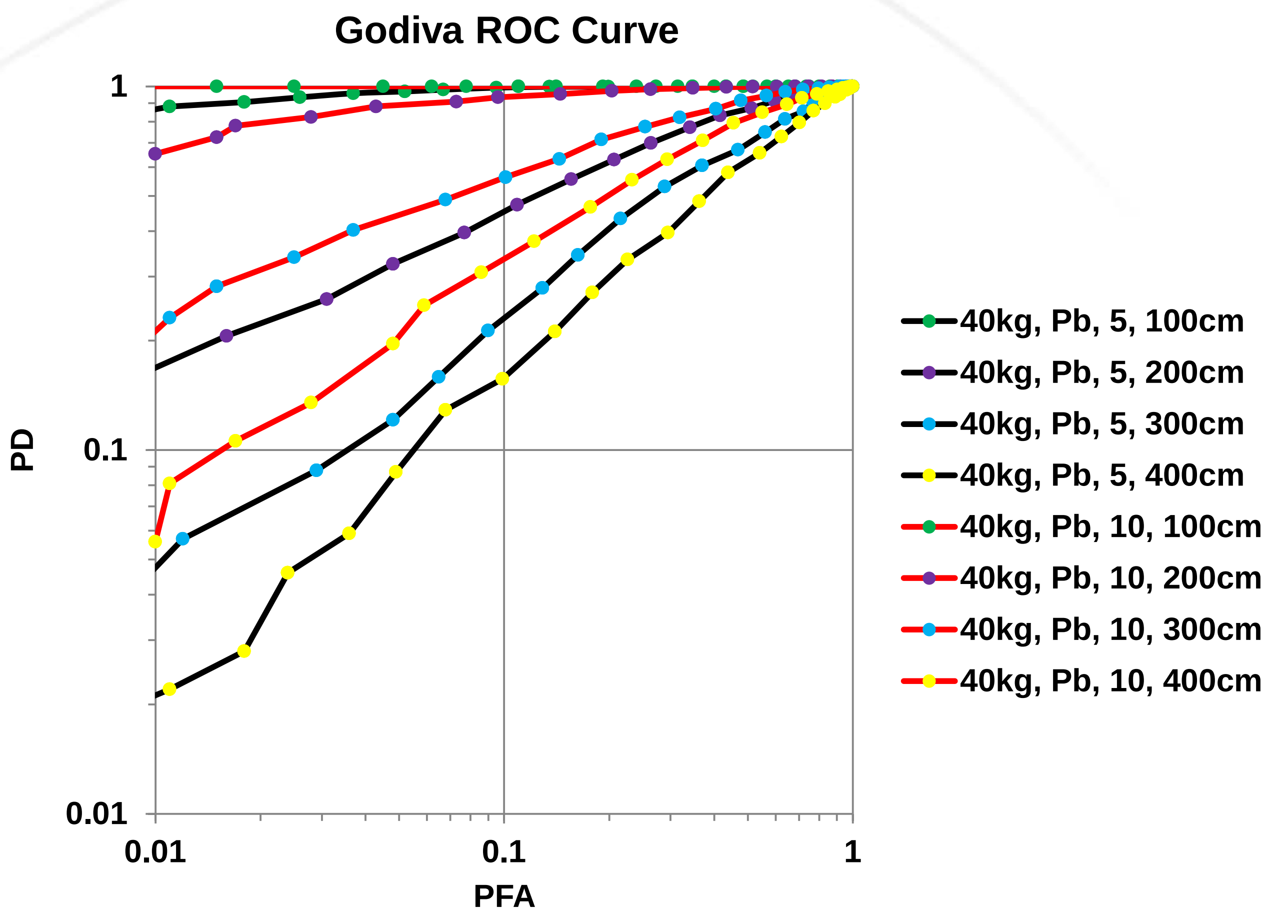


Godiva ROC Curve
1
0.1
0.01
PD
0.01
0.1
1
PFA
20kg, Fe, 5, 50cm
20kg, Fe, 5, 100cm
20kg, Fe, 5, 200cm
20kg, Fe, 10, 50cm
20kg, Fe, 10, 100cm
20kg, Fe, 10, 200cm
20kg, Fe, 15, 50cm
20kg, Fe, 15, 100cm
20kg, Fe, 15, 200cm

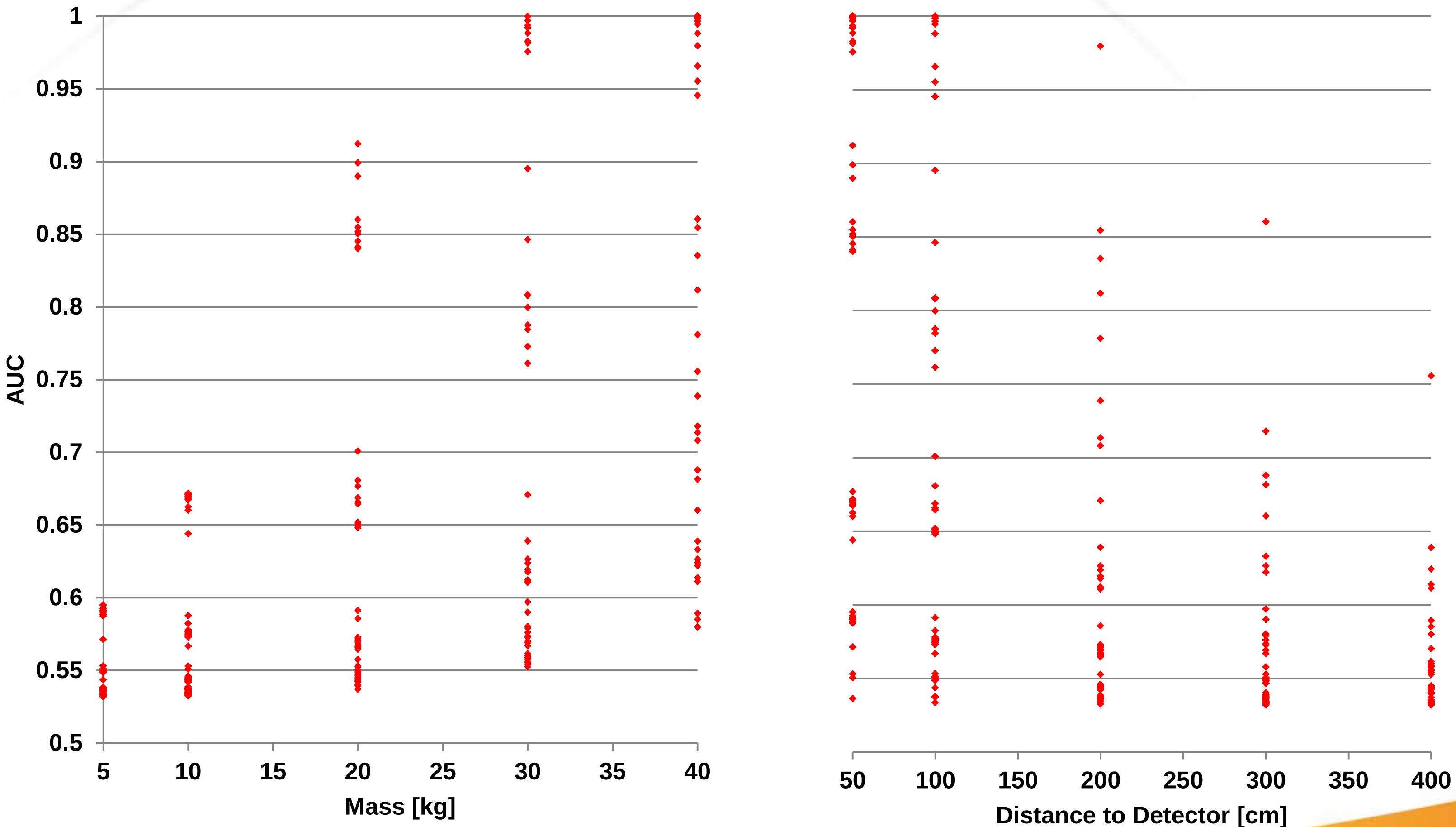
RESULTS


Godiva ROC Curve
PD
PFA
1
0.1
0.01
0.01
0.1
1
30kg, Fe, 5, 50cm
30kg, Fe, 5, 100cm
30kg, Fe, 5, 200cm
30kg, Fe, 10, 50cm
30kg, Fe, 10, 100cm
30kg, Fe, 10, 200cm
30kg, Fe, 15, 50cm
30kg, Fe, 15, 100cm
30kg, Fe, 15, 200cm

RESULTS


Godiva ROC Curve
1
0.1
0.01
PD
0.01
0.1
1
PFA
40kg, Pb, 5, 100cm
40kg, Pb, 5, 200cm
40kg, Pb, 5, 300cm
40kg, Pb, 5, 400cm
40kg, Pb, 10, 100cm
40kg, Pb, 10, 200cm
40kg, Pb, 10, 300cm
40kg, Pb, 10, 400cm

RESULTS



AUC
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
5
10
15
20
25
30
35
40
Mass [kg]
50
100
150
200
250
300
350
400
Distance to Detector [cm]

CONCLUSIONS/FUTURE WORK

- The FT ROC feature of MCNP6 along with new tagging features has been used to perform an initial parameter study of the neutron detectability of a specific HEU composition.
- A similar photon study is currently being performed
  - *IEEE 2015 Nuclear Science Symposium and Medical Imaging Conference,* San Diego, California, USA, October 31 – November 7, 2015.
- Once these initial simulations are completed a full suite of parameters (SNM, enrichment, detectors, etc.) will be run and the results will populate a parametrized database.

ACKNOWLEDGEMENTS

- [1] J. MATTINGLY, “Polyethylene-Reflected Plutonium Metal Sphere: Subcritical Neutron and Gamma Measurements,” SNL report SAND2009-5804 rev. 1 (2009)
- [2] R.D. MOSTELLER, “Godiva-IV Delayed-Critical Experiments and Description of an Associated Prompt-Burst Experiment,” NEA/NSC/DOC (95)03/II

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MCNP6 - Features

Description of feature keywords.		
Keyword	**Parameters**	**Description**
FT PHL	[n t_1 b_1 …] [det]	Allows n tallies to be added together to form the signal for a detector. Each pair of t_n and b_n correspond to the tally number and the TF bin it is to be placed. An optional built-in detector response function may also be used to convert deposited energy to charge or MeVee light yield.
FT SCX	k	The SCX special tally treatment allows the user to separate tally contributions based on the k source distribution bin that produced it (in this case BN, or SF)
FT FFT	[LKJI]	Allows the user to toggle (1/0) which physics packages will receive the FFT treatment. I = n induced f (library) J = p induced f (library) K = sf L = n and p induced f (models)

Description of feature keywords.		
Keyword	**Parameters**	**Description**
FT ROC	nhb [m]	An associated TF card is used to separate tallies into two components, signal and noise. nhb determines the number of histories per batch and m is the maximum number of batches, (default = 100).
TF	$i_1 - i_{16}$	First 8 entries classify bin entries as signal + noise and the second 8 entries as noise.
CF	$c_1 \ldots c_k$	Allows the user to separate tally contributions based on whether the particle history ever passed through (+ entry) or collided in (- entry) the listed cells. [NEW FEATURE]
PRDMP	ndp ndm mct ndmp dmmp	Since each batch is an independent count sample, the 2nd entry (ndm) on the prdmp card must be the same as the number of histories per batch (ROC parameter nhb).