

# Measurements of the $^{238}\text{U}$ radiative capture cross section using $\text{C}_6\text{D}_6$

---

F. Mingrone  
on behalf of the n\_TOF collaboration

Nuclear data for Science and technologies – ND2013  
New York – March 5, 2013

# Motivations

- Improvement in the design of
  - Advanced nuclear systems
  - Nuclear fuel cycles
- EXFOR DATABASE: 25 datasets in the resolved resonance region and a few less in the unresolved BUT still inconsistencies for the capture cross section up to 25 keV



**NEA High Priority Request List**

**UNCERTAINTY IN THE CROSS SECTION BELOW 2%**

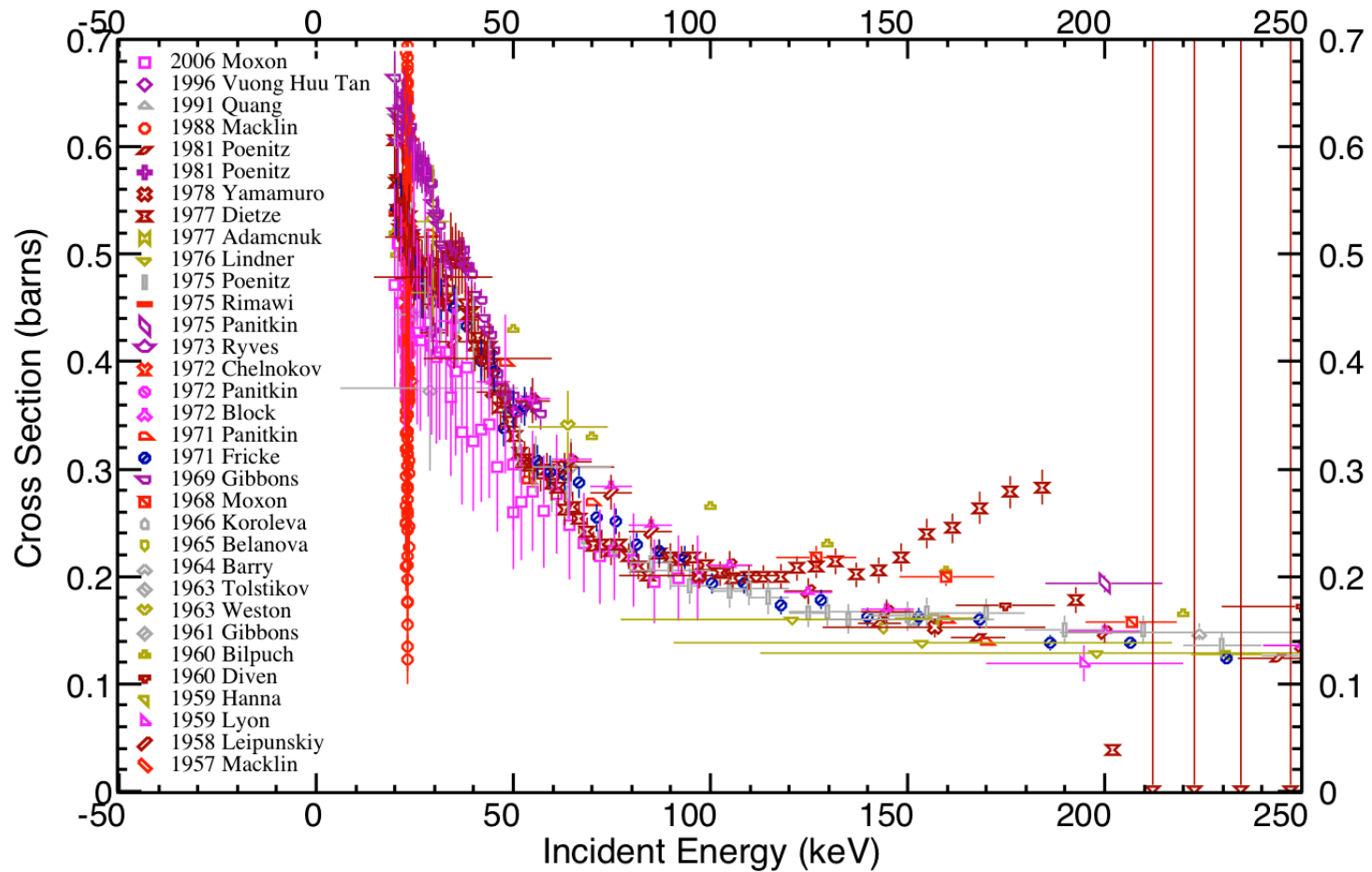
GELINA – contr. By C. Lampoudis

n\_TOF with TAC detection system – contr. By T. Wright

n\_TOF with C<sub>6</sub>D<sub>6</sub> detection system – this contribution

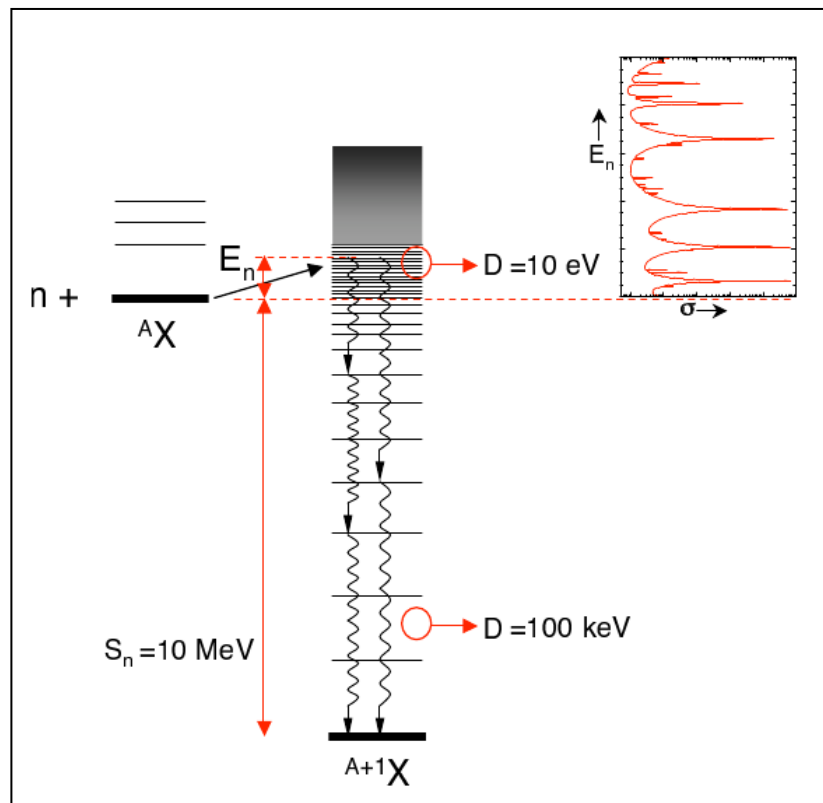
# Unresolved Resonance Region

92-U-238(N,G)92-U-239



# Time of Flight (ToF) technique: Capture measurements

- Extraction of the reaction cross section through the measurement of the **reaction yield**  $Y_c(E_n)$ :



$$Y = N \frac{C_w}{\varphi_n}$$

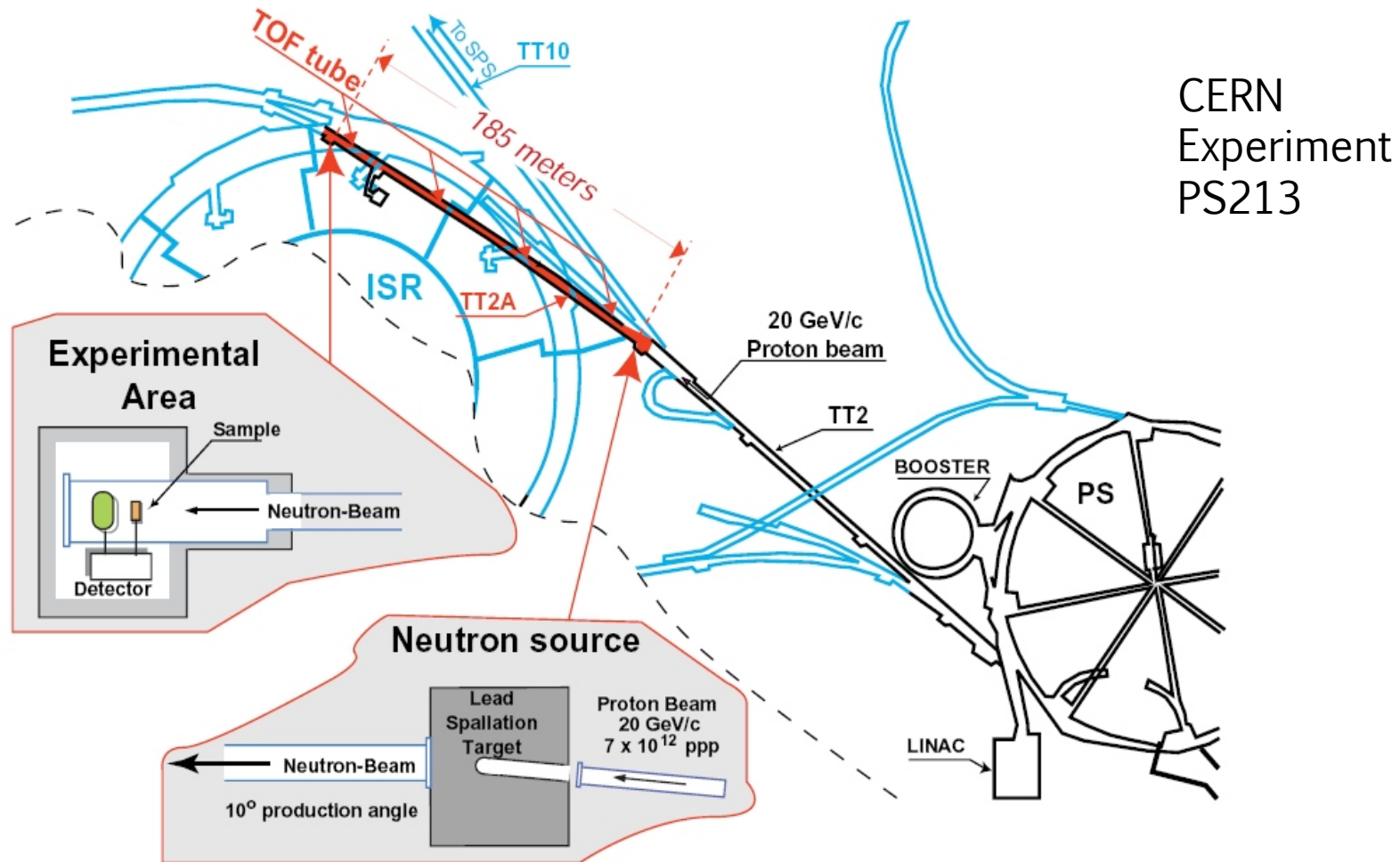
With:

$N$ : normalization factor

$C_w$ : weighted counts, background subtracted

$\varphi_n$ : neutron fluence at the sample position

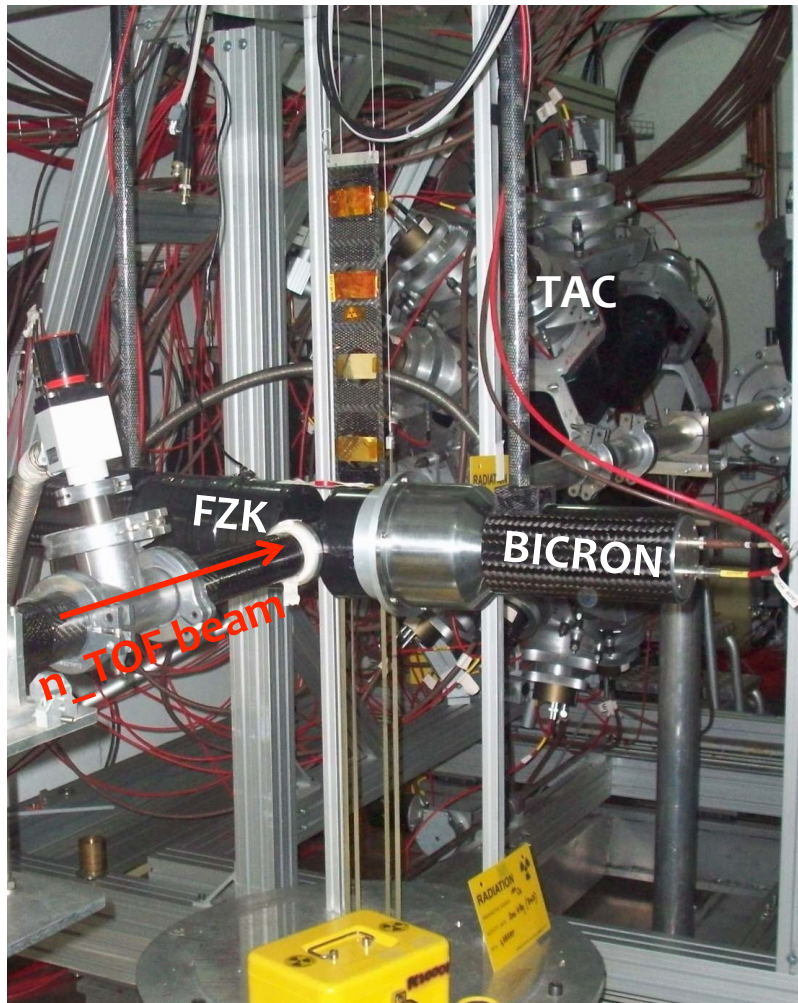
# n\_TOF facility at CERN



# n\_TOF facility: characteristics

Proton beam momentum	20 GeV/c
Intensity (dedicated mode)	$7 \times 10^{12}$ protons/pulse
Repetition frequency	1 pulse/2.4 s
Pulse width	7 ns (rms)
Neutrons/proton	300
Lead target dimensions	$\varnothing=60$ cm, h=40 cm
Cooling material	H <sub>2</sub> O
Moderation material	Borated Water
Moderator thickness in the exit face	1 cm cooling material + 4 cm moderator

# n\_TOF facility: capture measurements



## 2 experimental setups for capture measurements:

- **BaF<sub>2</sub> Total Absorption Calorimeter \***

- 40 BaF<sub>2</sub> crystals in a 4 $\pi$  geometry
- Able to detect the entire  $\gamma$ -cascade

\* T. Wright,  
ND2013 - PA

- **2 C<sub>6</sub>D<sub>6</sub> scintillation detectors**

- Low neutron sensitivity  
 $\epsilon_n / \epsilon_\gamma \sim 10^{-5}$
- Only one  $\gamma$ -ray detected per cascade  
→ PHWT

# Sample – from IRMM

Enriched metallic uranium rectangular plate (53x30 mm) enveloped inside a 20  $\mu\text{m}$  aluminum and a 25  $\mu\text{m}$  kapton thick foils. Sample is fixed using kapton tape on a fiber glass frame.



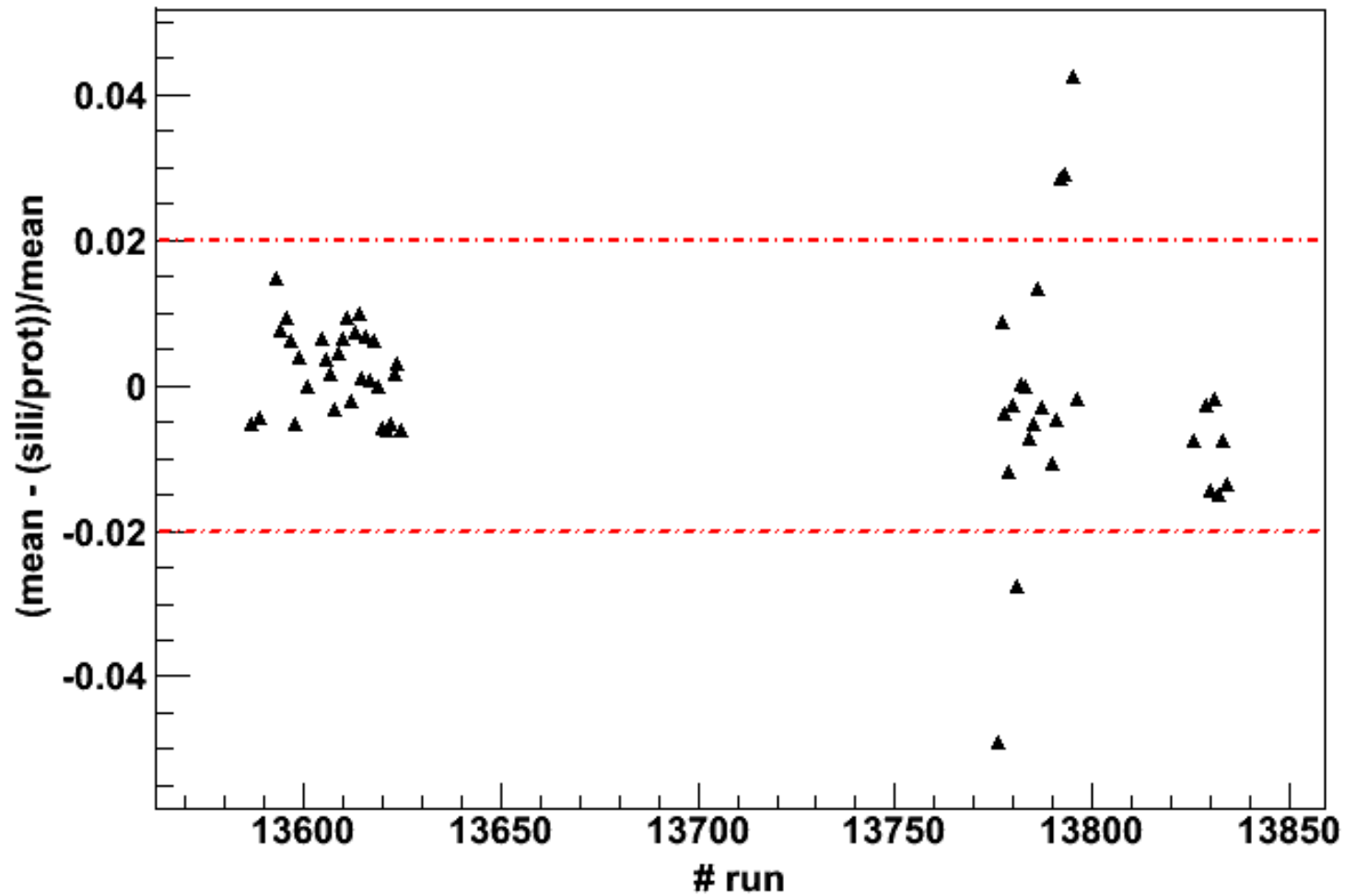
<b>MASS</b>	6.125 $\pm$ 0.002 g 9.7 $\times$ 10 <sup>-4</sup> atoms/ barn
<b>% 238 U</b>	99.99 %
<b>% 235 U</b>	< 11 ppm
<b>% 233-234-236 U</b>	< 1 ppm each
<b>EXPECTED RADIOACTIVITY</b>	12.4 kBq/g (76 kBq)



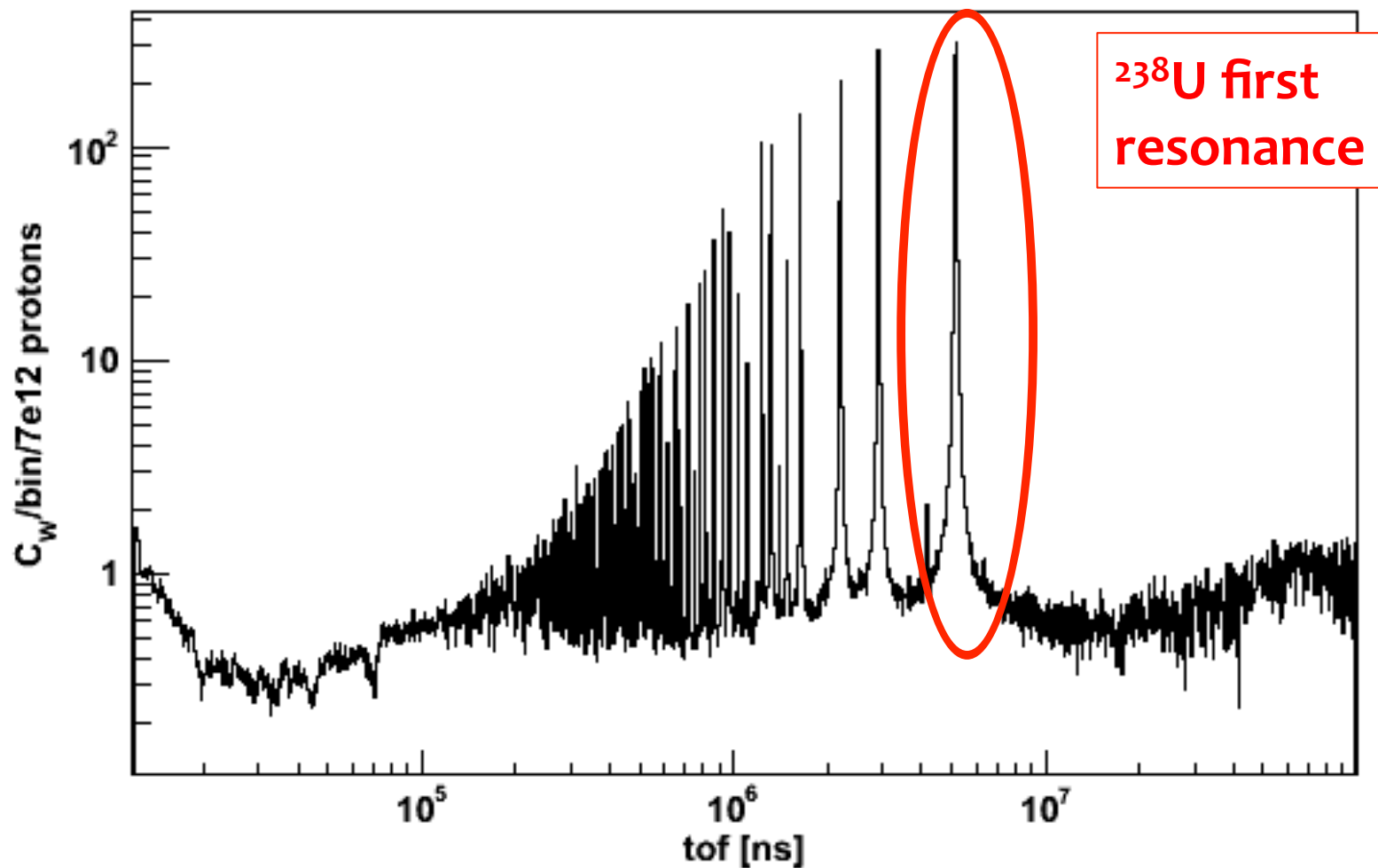
# Radiative capture on $^{238}\text{U}$ campaign

Sample	Date (year 2012)
$^{238}\text{U}$	March 29 – April 03, April 25 – 27, April 30 – May 02; filters: April 5 – 6, April 11 – 16
Empty Frame	March 28 – 2; filters: April 9 – 11
$^{238}\text{U}$ packing (Dummy)	April 21 – 22
Beam off background	March 28, April 5, April 11
Pb	April 03 – 04; filters: April 8 – 9
C (5 mm)	April 4 – 5, April 17; filters: April 7 – 8
C (10 mm)	April 19 – 20; filters: April 28 – 30
Au (50 $\mu\text{m}$ )	April 5, April 16
Au (300 $\mu\text{m}$ )	April 17 – 18; filters: April 27 – 28
Ag	May 02

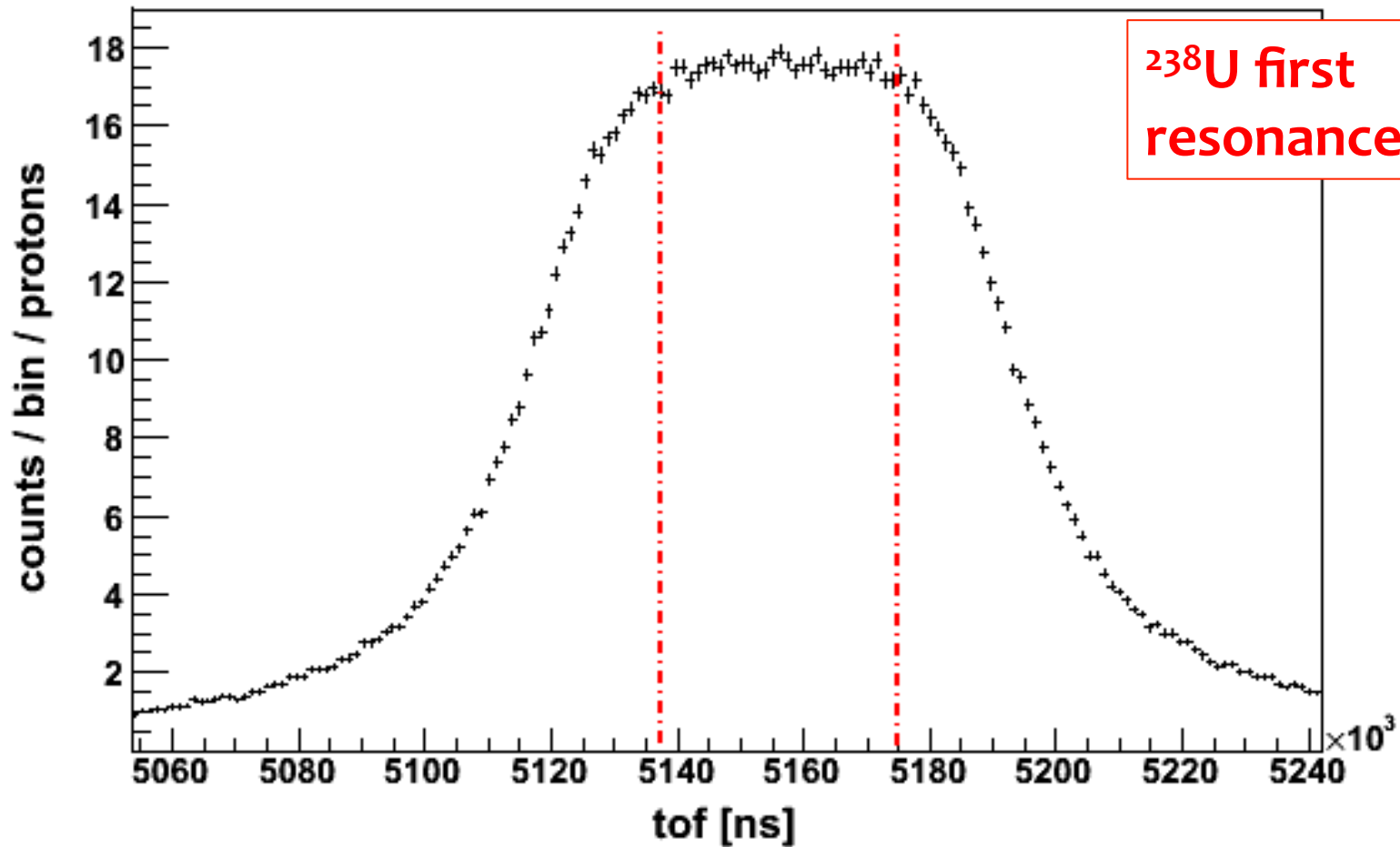
# Flux stability



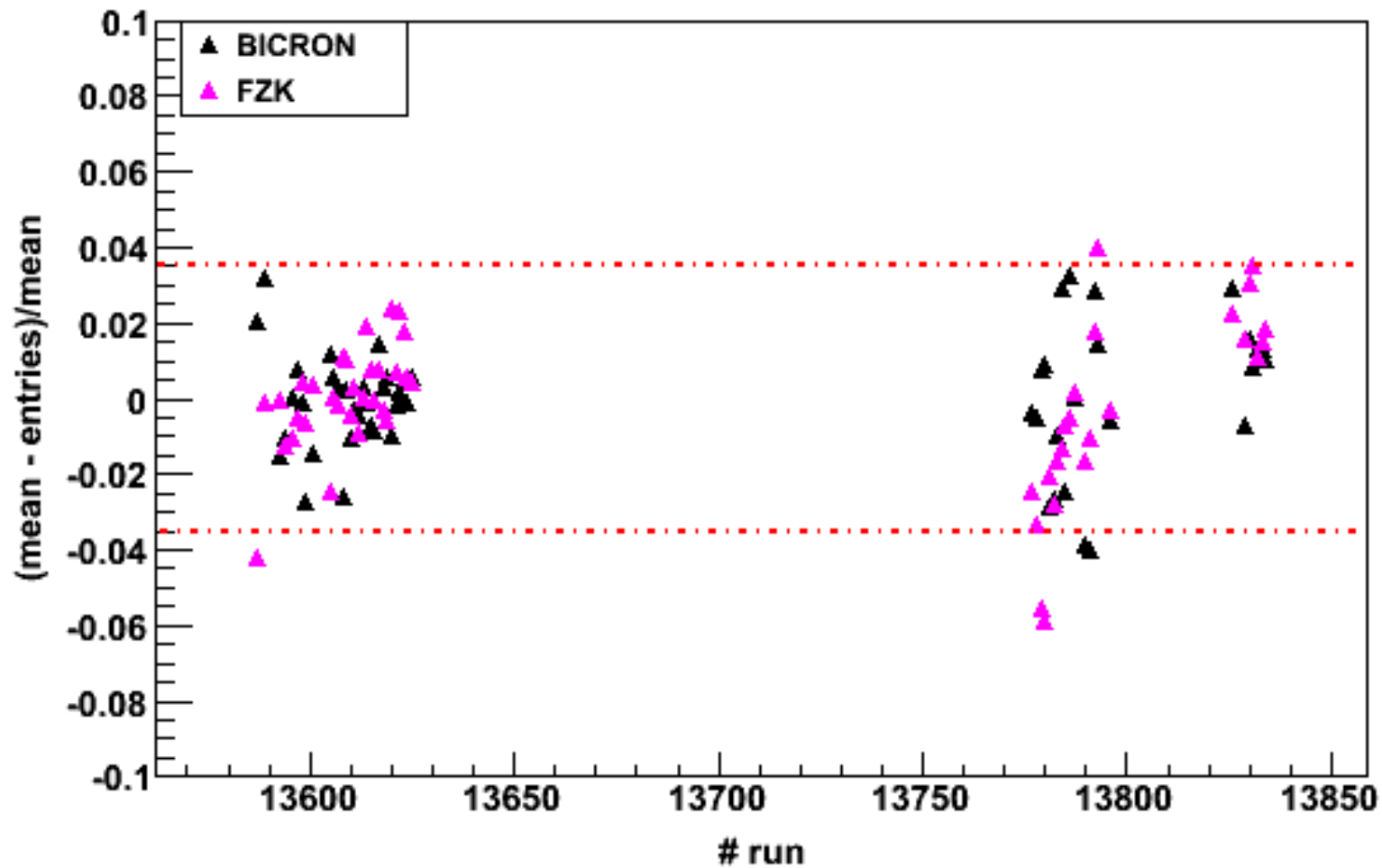
# $C_6D_6$ counts stability



# $C_6D_6$ counts stability

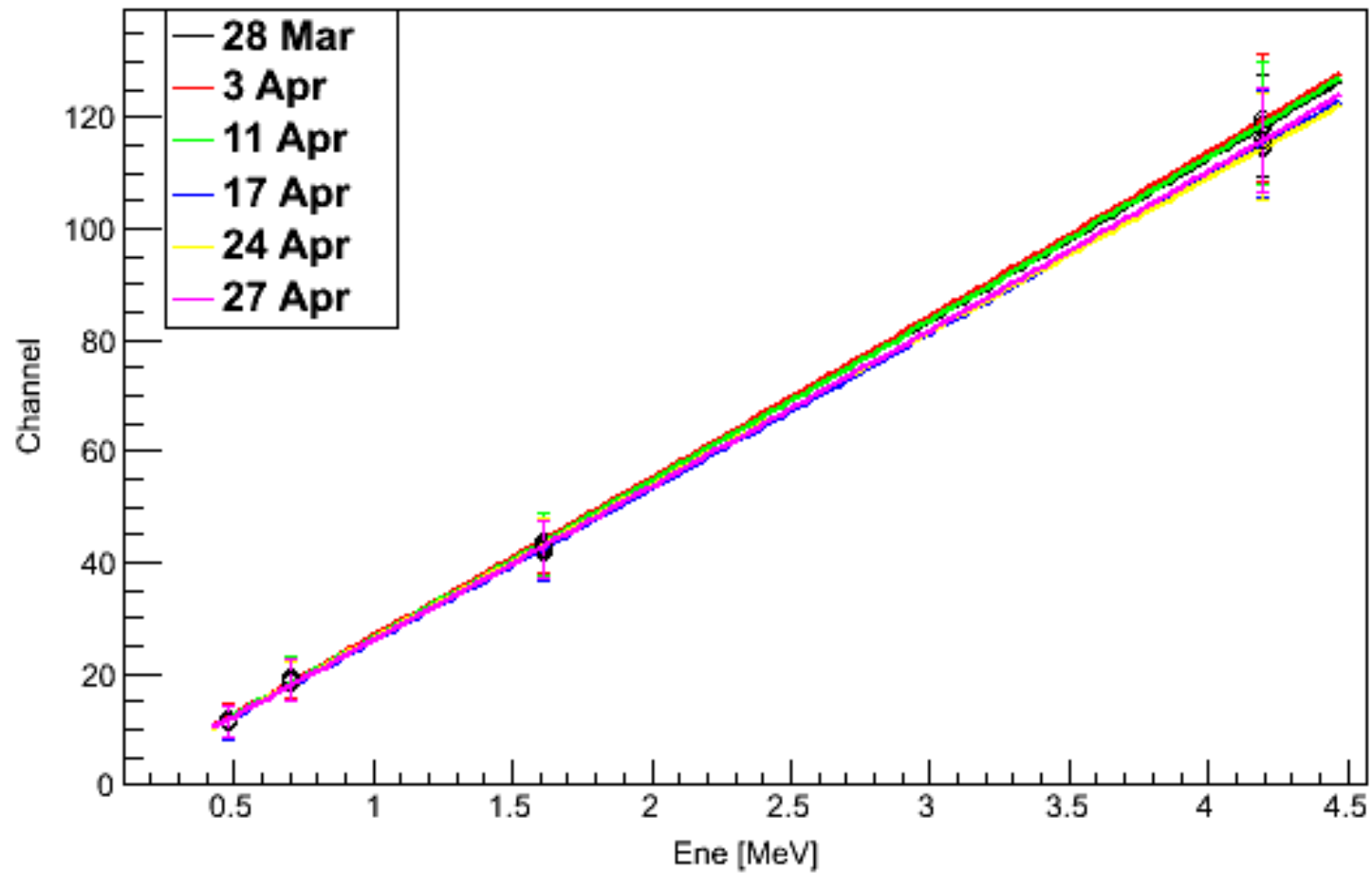


# $C_6D_6$ counts stability

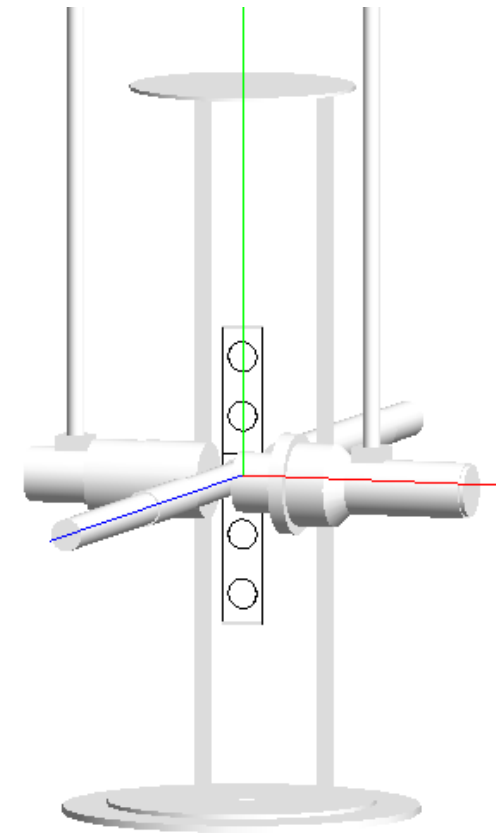
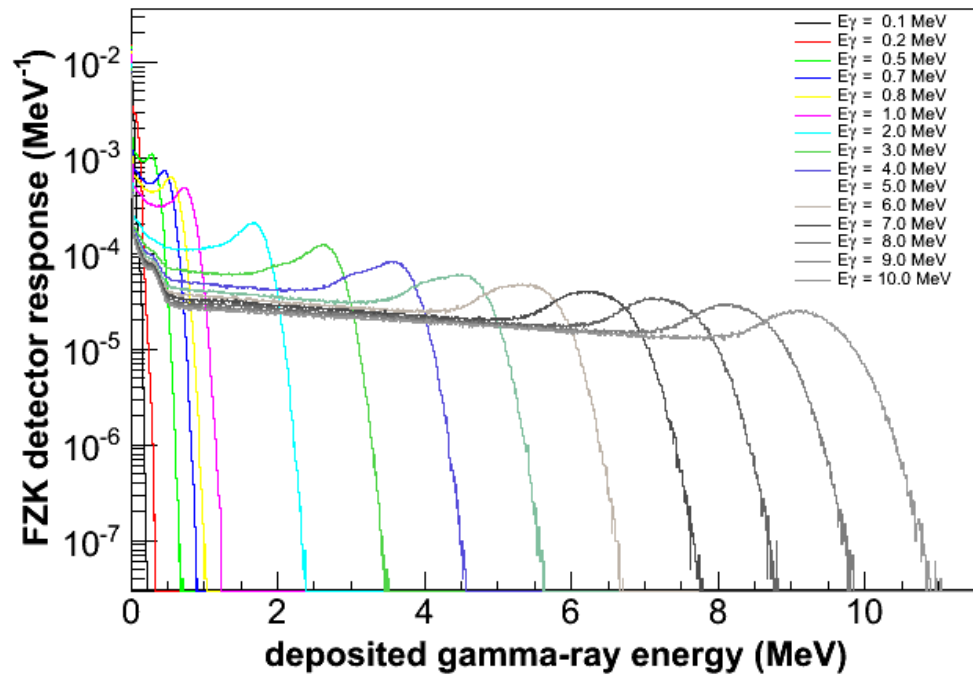
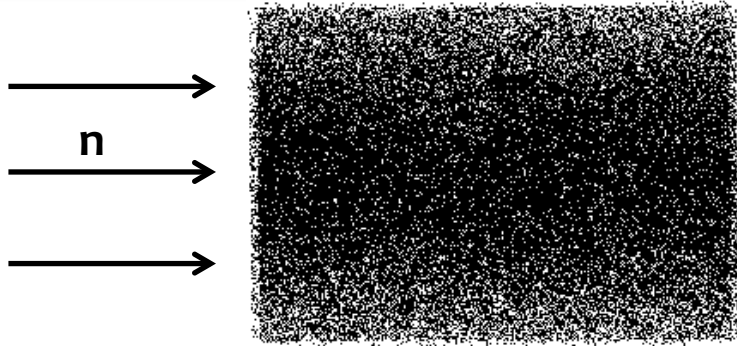


# Calibrations

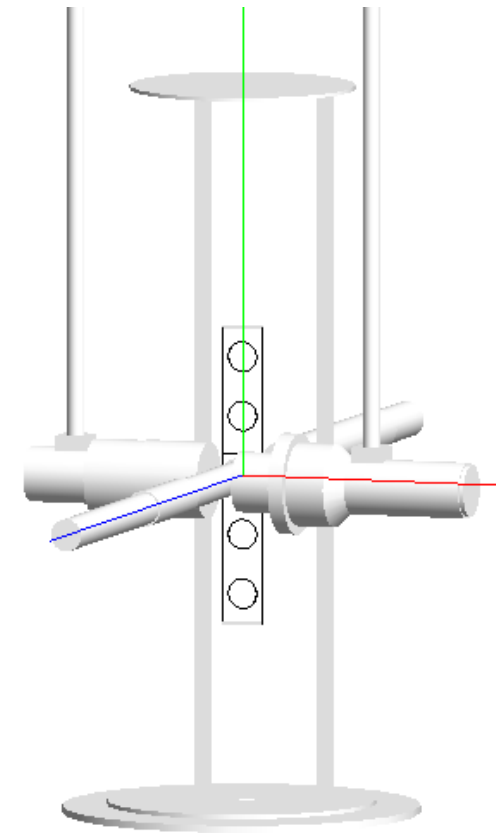
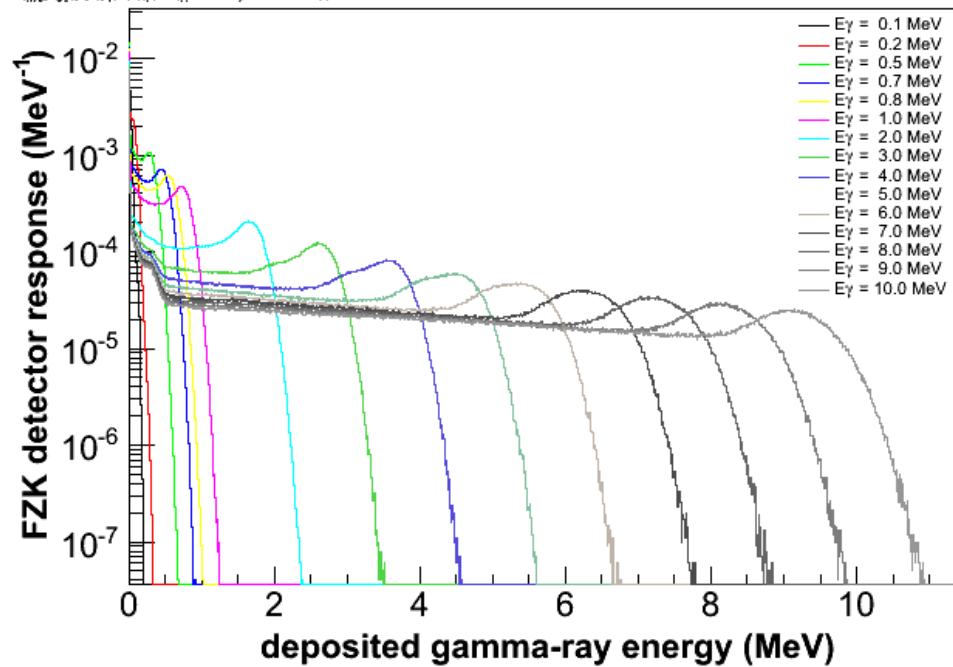
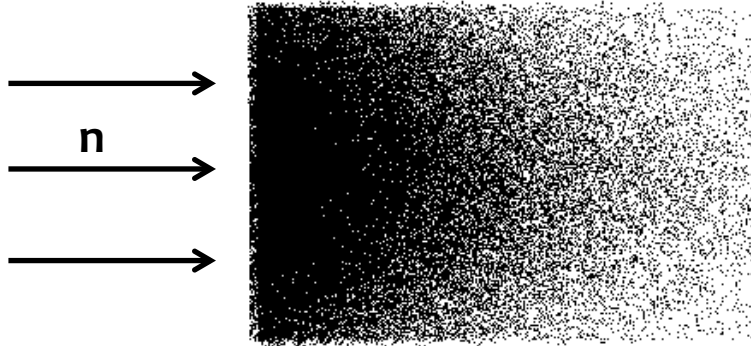
Calibration - FZK



# Simulated Detectors Response: Uniform emission

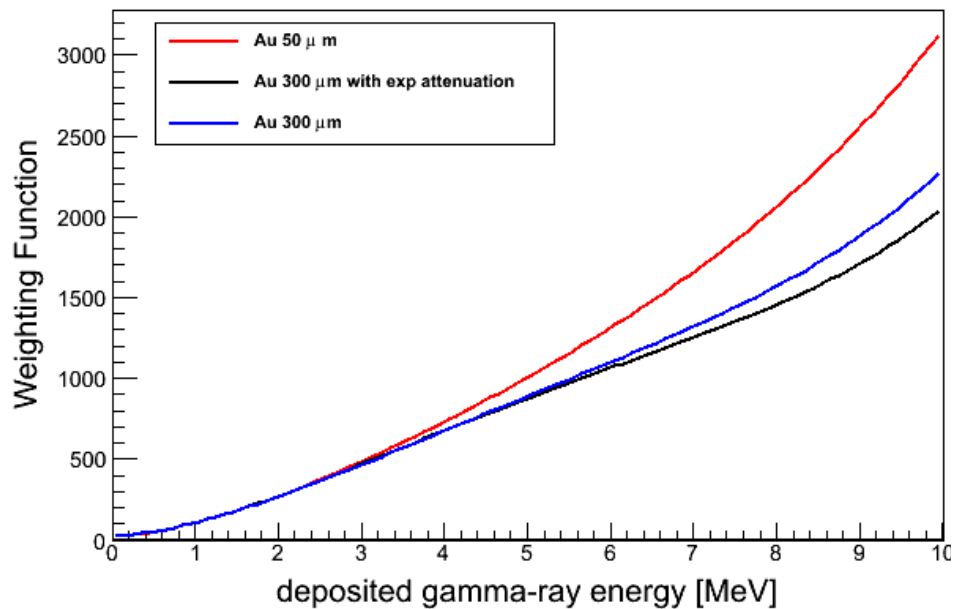


# Simulated Detectors Response: Exponential attenuation

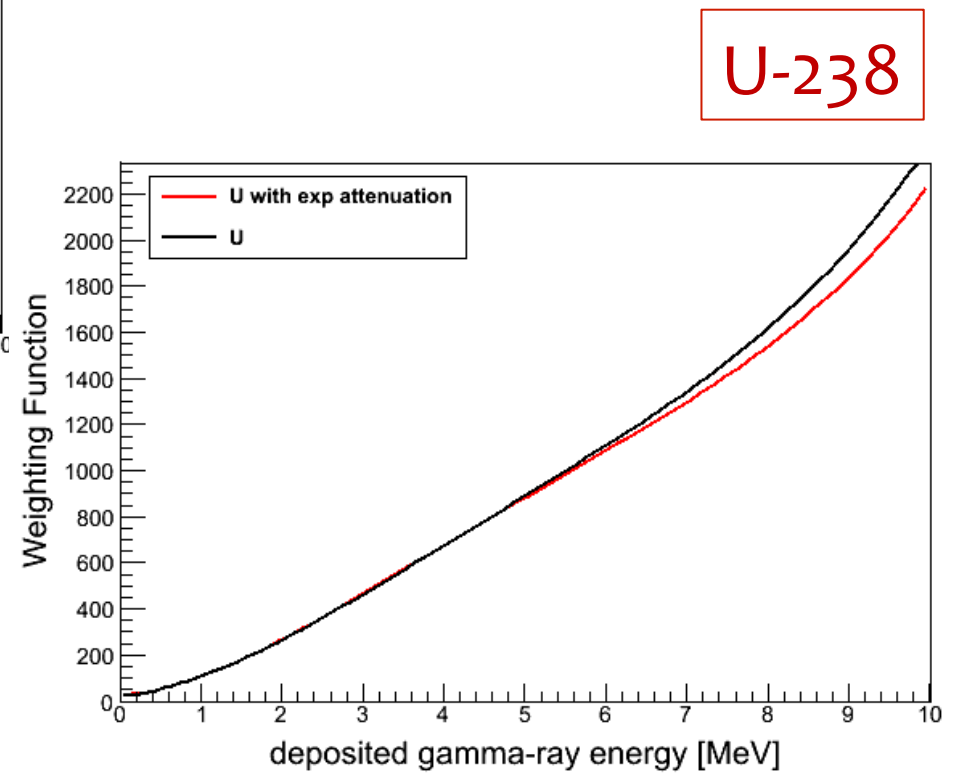




# Weighting Functions

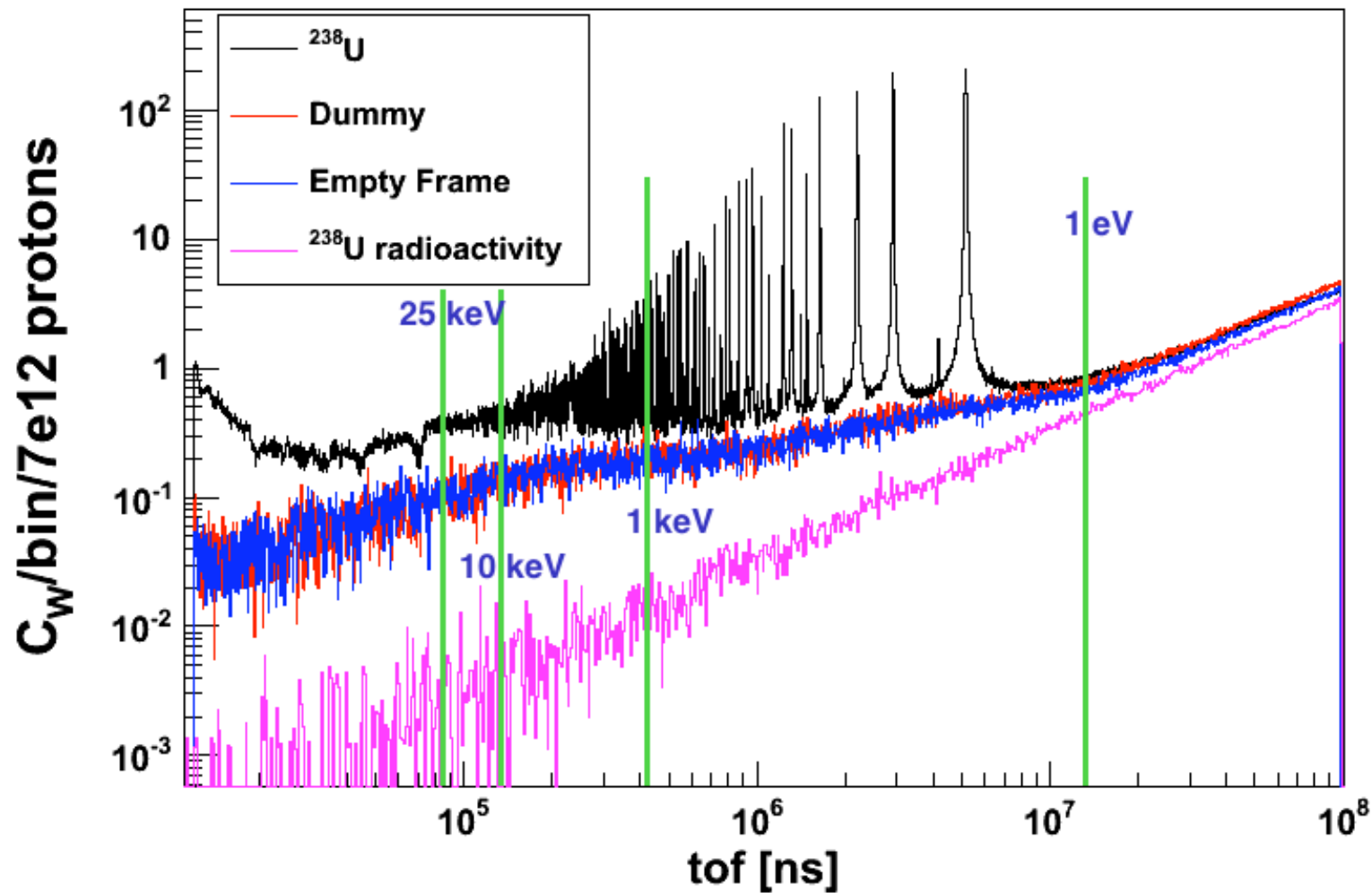


GOLD

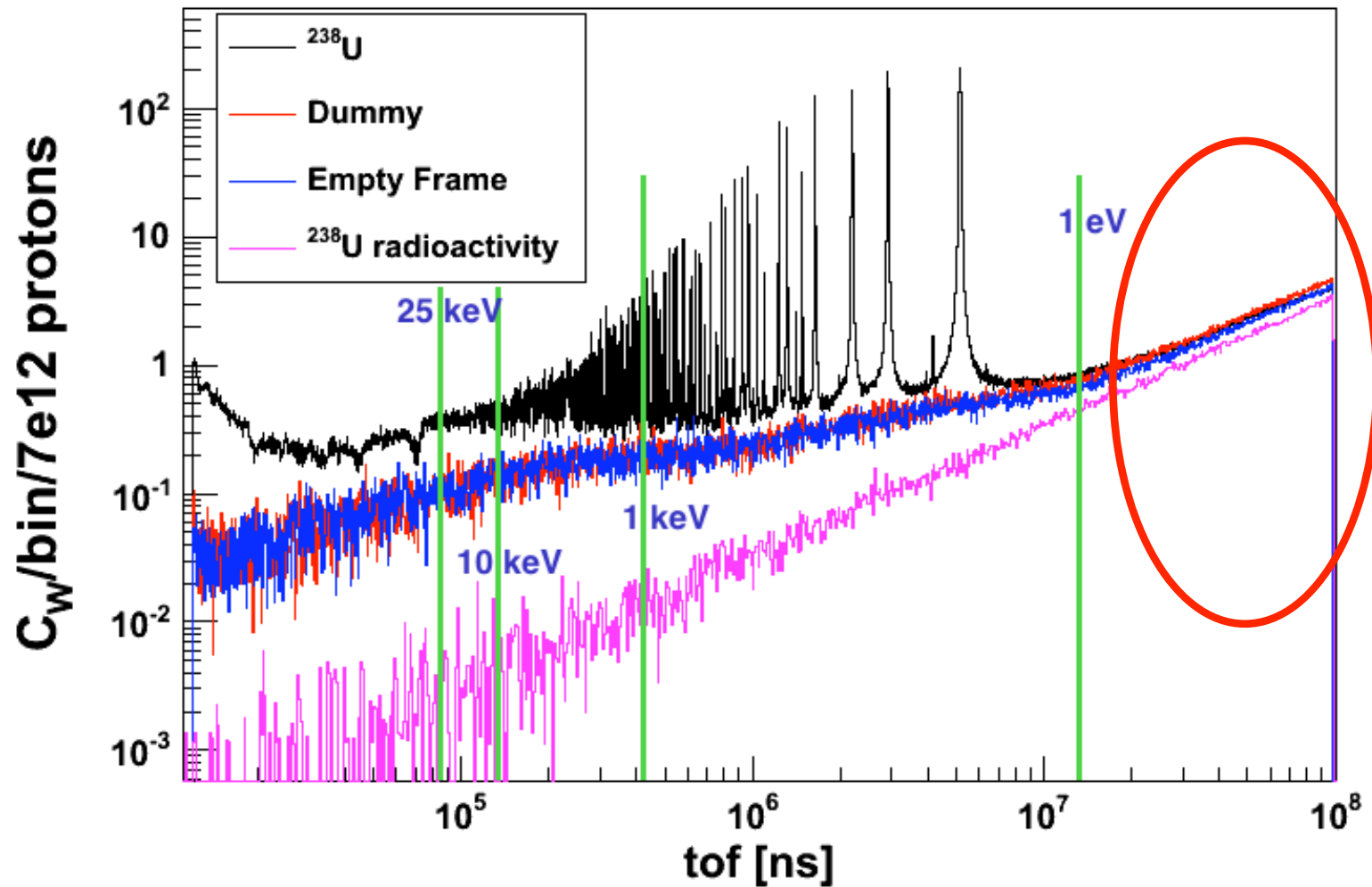


U-238

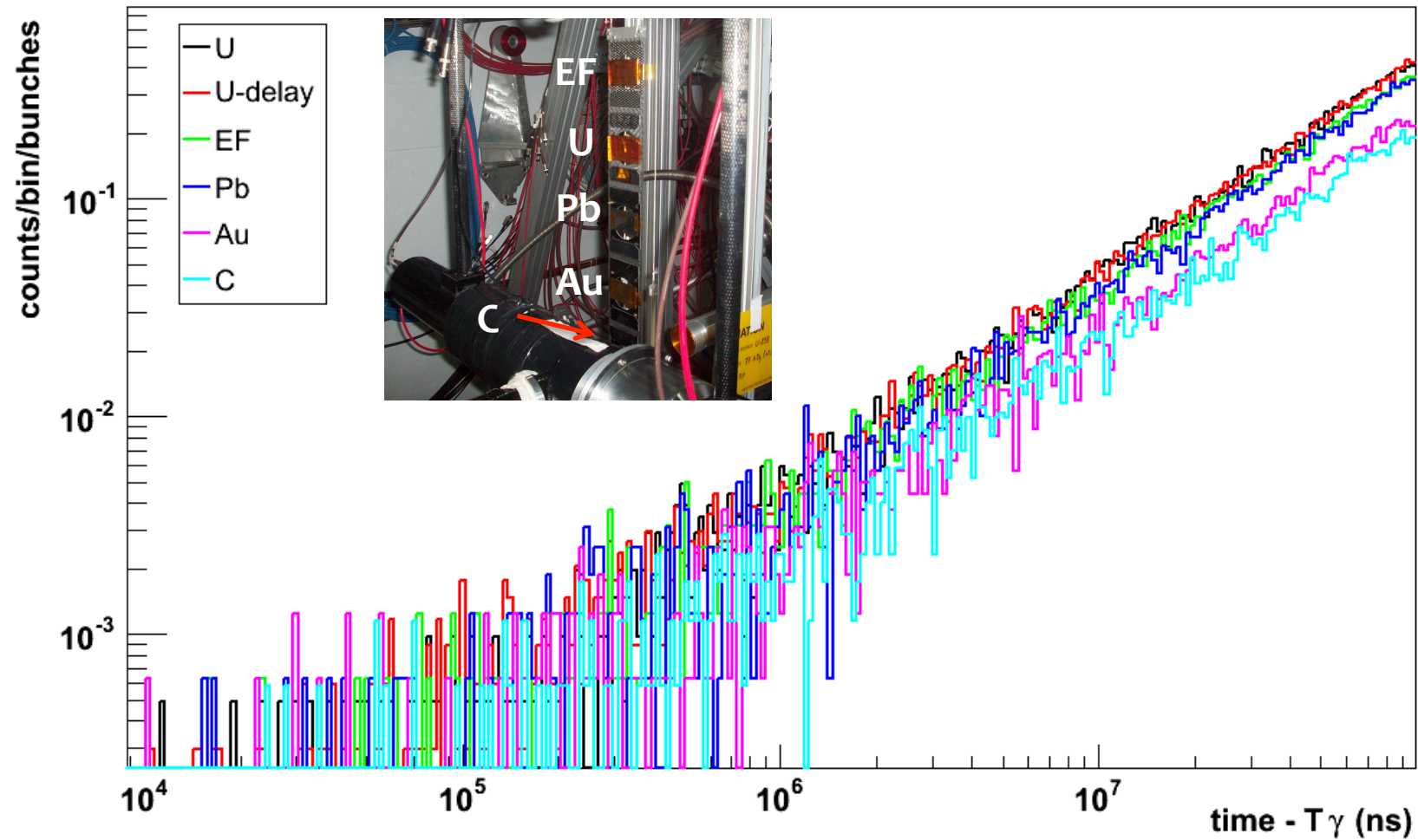
# $^{238}\text{U}(n, \gamma)^{239}\text{U}$ : TOF spectra



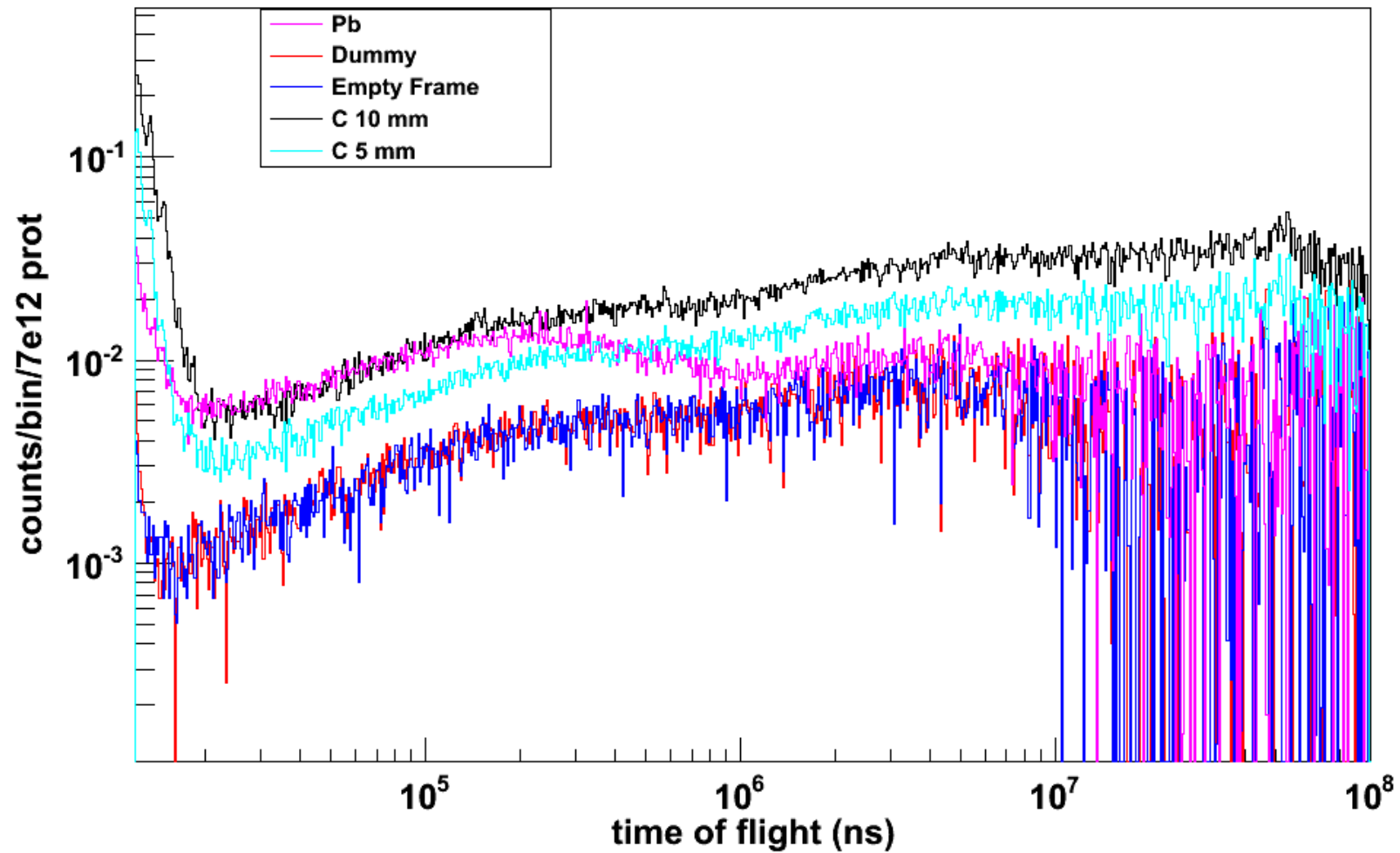
# $^{238}\text{U}(n, \gamma)^{239}\text{U}$ : TOF spectra



# Beam Off background



# Backgrounds



# Normalization: saturated resonance technique

	BICRON	FZK
$^{\text{nat}}\text{Ag}$	$0.915 \pm 0.003$	$1.090 \pm 0.003$
Au 50 $\mu\text{m}$	$0.913 \pm 0.003$	$1.110 \pm 0.003$
Au 300 $\mu\text{m}$ flat WF	$0.902 \pm 0.002$	$1.101 \pm 0.002$
Au 300 $\mu\text{m}$ exp WF	$0.911 \pm 0.002$	$1.113 \pm 0.002$
U flat WF	$0.856 \pm 0.002$	$1.013 \pm 0.002$
U exp WF	$0.862 \pm 0.001$	$1.030 \pm 0.001$

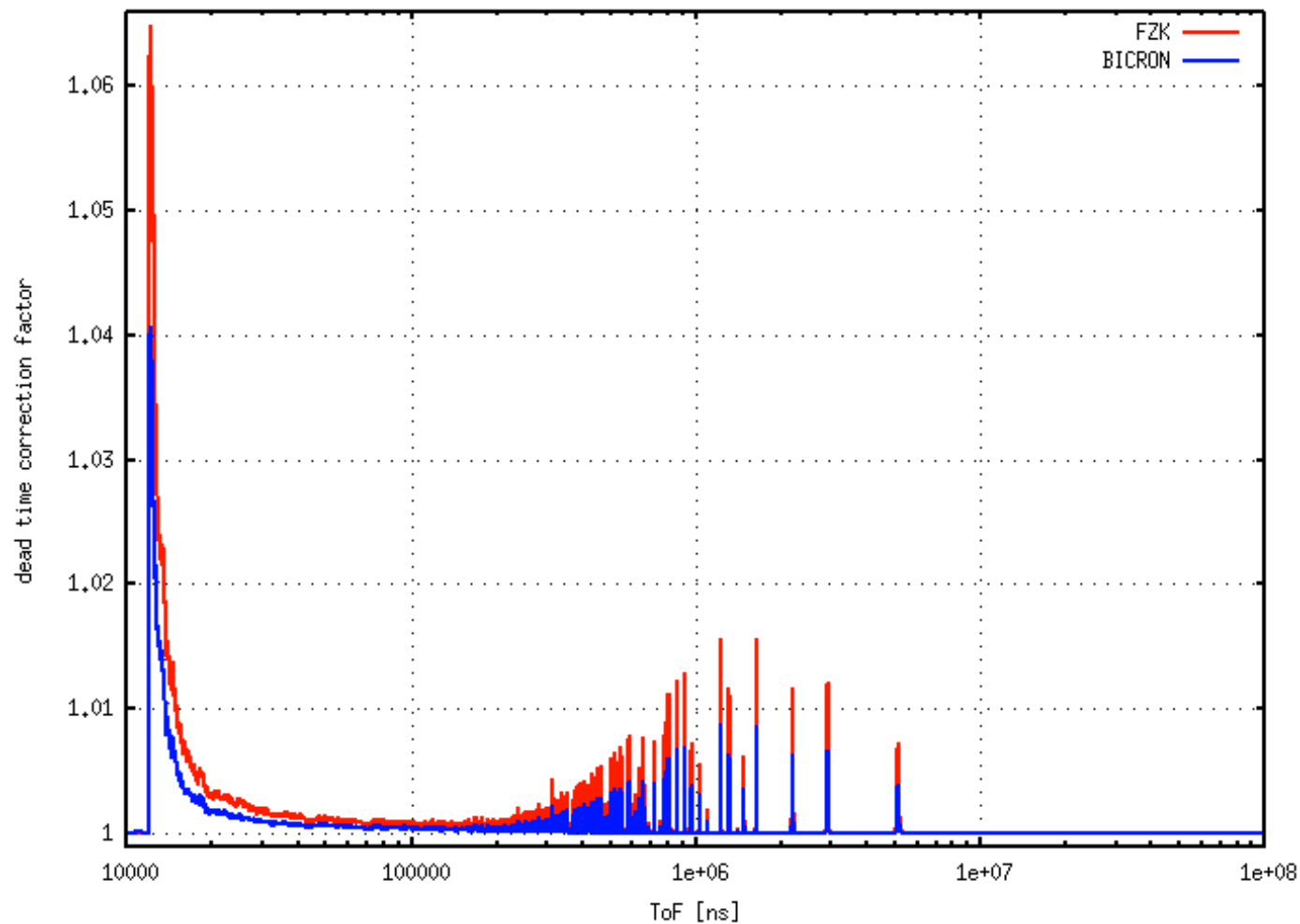
Uncertainties due only to counting statistic

# Normalization: saturated resonance technique

	BICRON	FZK
$^{\text{nat}}\text{Ag}$	$0.915 \pm 0.003$	$1.090 \pm 0.003$
Au 50 $\mu\text{m}$	$0.913 \pm 0.003$	$1.110 \pm 0.003$
Au 300 $\mu\text{m}$ flat WF	$0.902 \pm 0.002$	$1.101 \pm 0.002$
Au 300 $\mu\text{m}$ exp WF	$0.911 \pm 0.002$	$1.113 \pm 0.002$
U flat WF	$0.856 \pm 0.002$	$1.013 \pm 0.002$
U exp WF	$0.862 \pm 0.001$	$1.030 \pm 0.001$

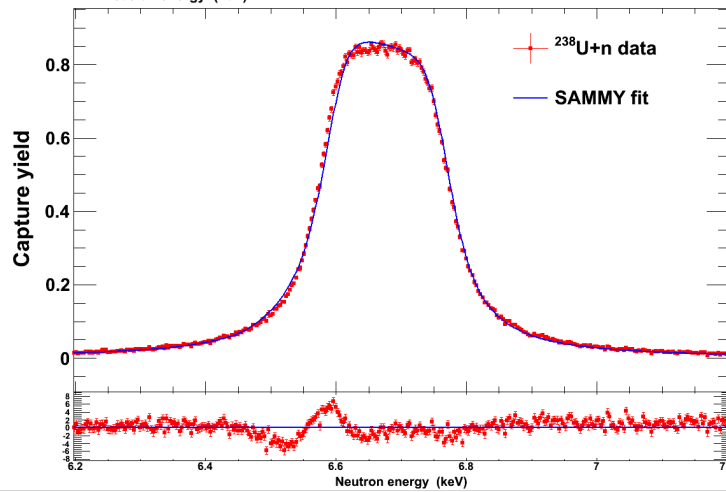
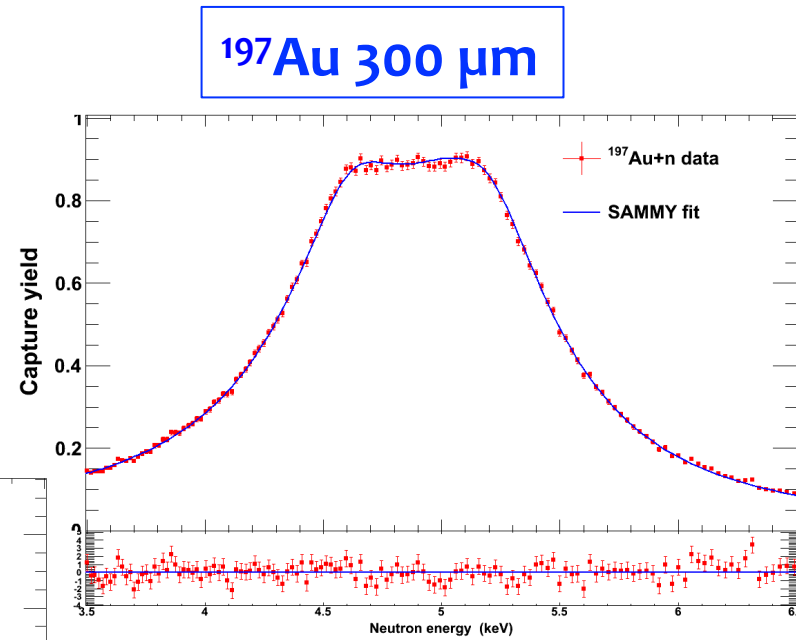
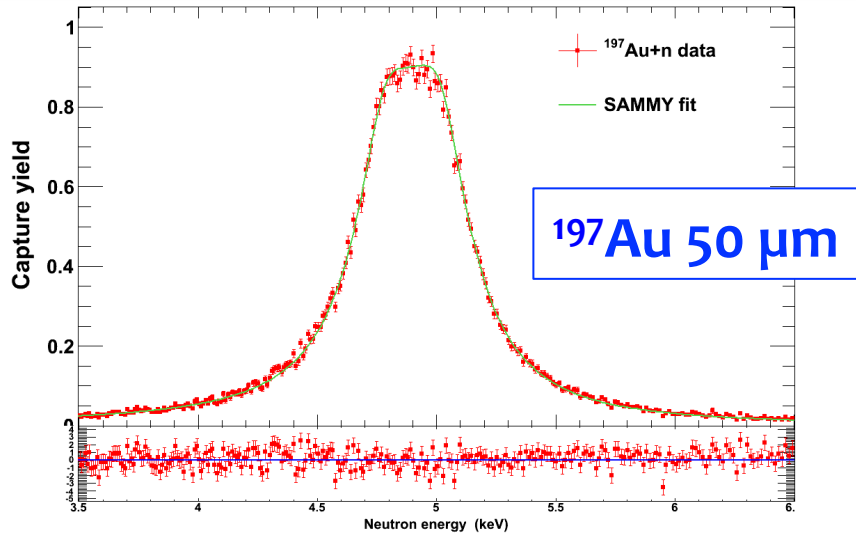
Uncertainties due only to counting statistic

# Dead Time correction

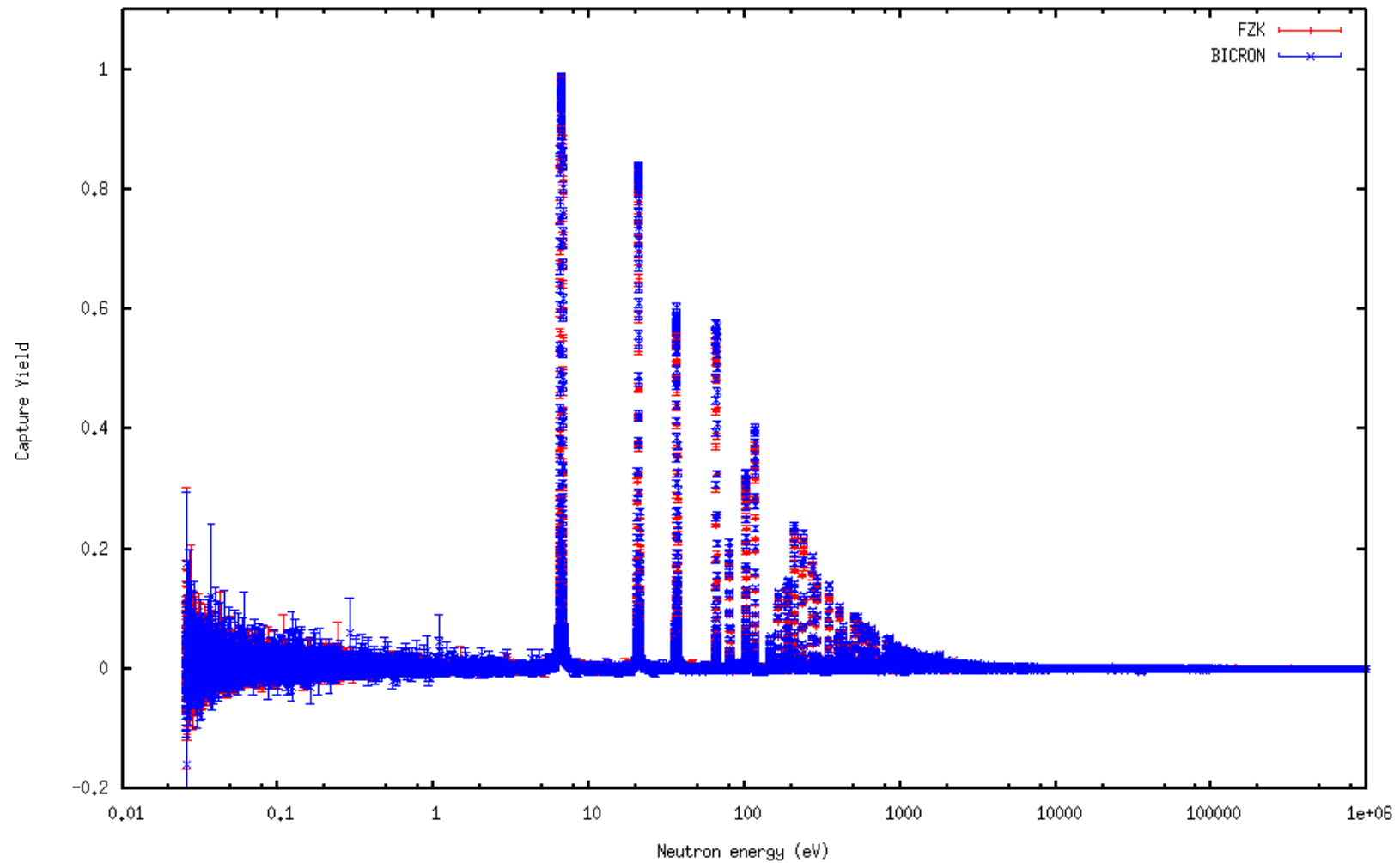




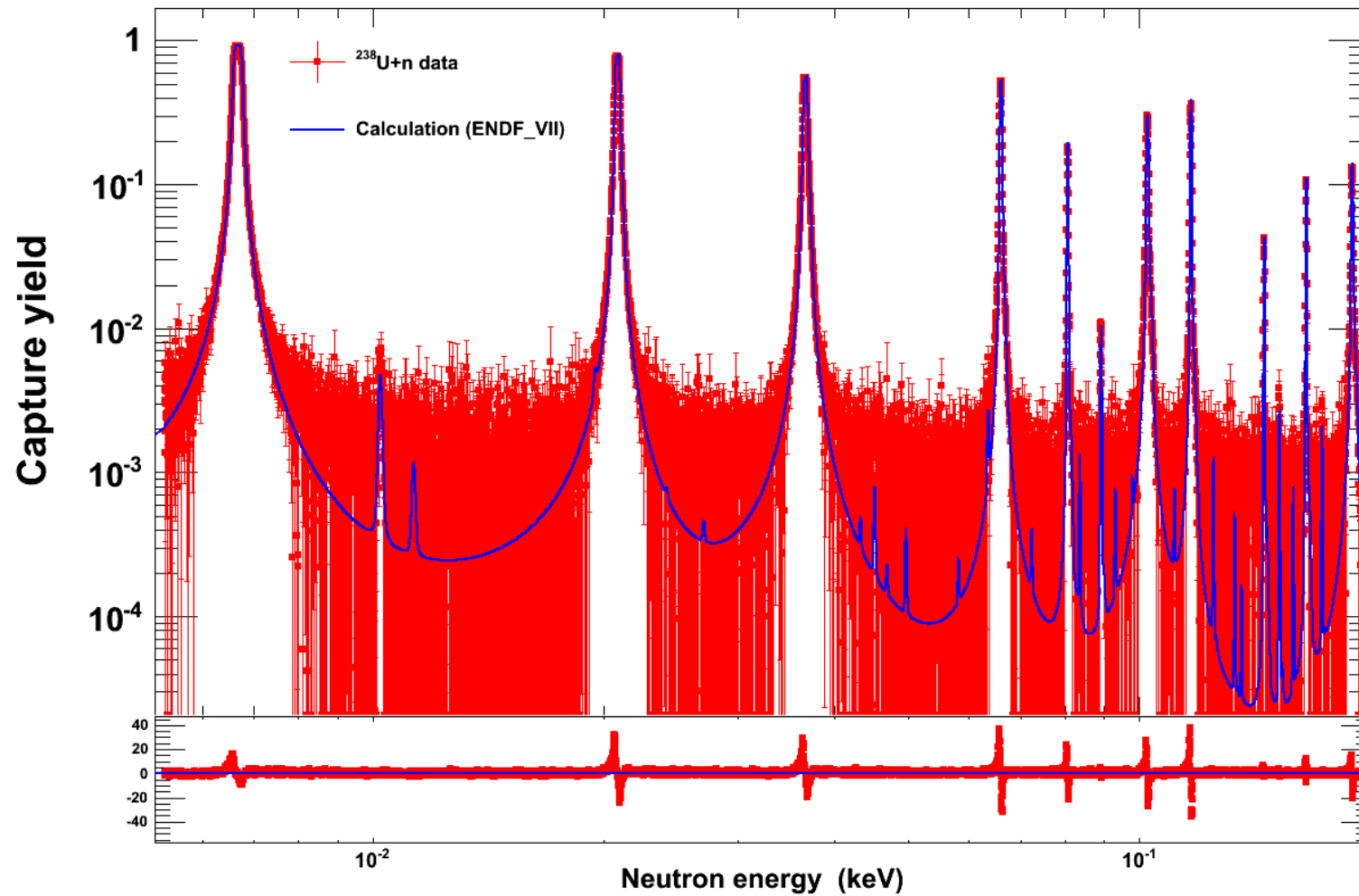
# Normalization fits



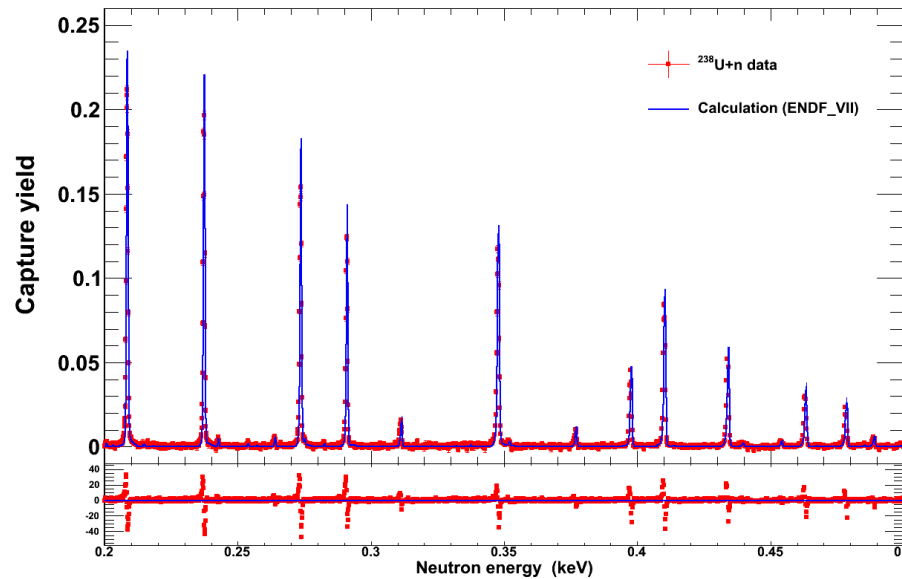
# $^{238}\text{U}$ Yield – BICRON and FZK



# $^{238}\text{U}$ Yield

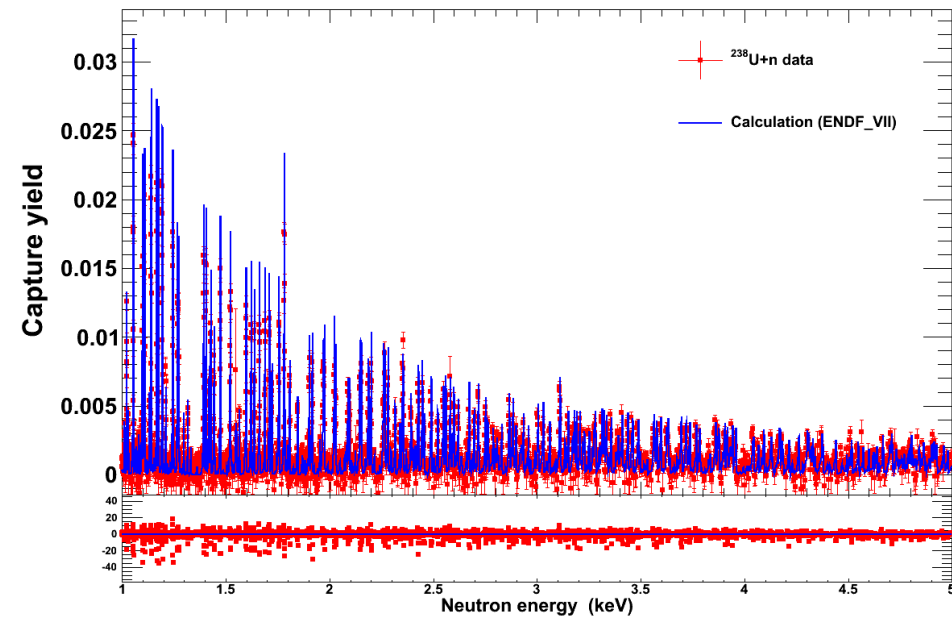


# $^{238}\text{U}$ Yield



10 eV region

keV region



# Conclusions

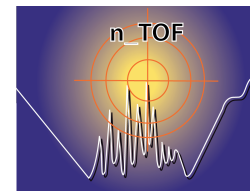
- $^{238}\text{U}(n, \gamma)$  cross section measurement performed with  $\text{C}_6\text{D}_6$  on April 2012 at n\_TOF (accurate data rejection + calibrations – 6 calibration lines extracted, background subtraction, self-normalization)
  - counting statistics uncertainty (background subtracted)
    - $\sim 2\text{-}3\%$  (RRR),  $\sim 3\%$  (URR)
  - self-normalization uncertainty  $\sim 0.5\%$
- To do: Resonance Shape Analysis + URR
- Other two measurements at n\_TOF (TAC) and GELINA to reach 2% accuracy

# Acknowledgements

## The n\_TOF Collaboration

F. Mingrone,<sup>1,\*</sup> C. Massimi,<sup>1</sup> S. Altstadt,<sup>2</sup> J. Andrzejewski,<sup>3</sup> L. Audouin,<sup>4</sup> M. Barbagallo,<sup>5</sup> V. Bécaries,<sup>6</sup> F. Bečvář,<sup>7</sup> F. Belloni,<sup>8</sup> E. Berthoumieux,<sup>8,9</sup> J. Billowes,<sup>10</sup> D. Bosnar,<sup>11</sup> M. Brugger,<sup>9</sup> M. Calviani,<sup>9</sup> F. Calviño,<sup>12</sup> D. Cano-Ott,<sup>6</sup> C. Carrapiço,<sup>13</sup> F. Cerutti,<sup>9</sup> E. Chiaveri,<sup>8,9</sup> M. Chin,<sup>9</sup> N. Colonna,<sup>5</sup> G. Cortés,<sup>12</sup> M.A. Cortés-Giraldo,<sup>14</sup> M. Diakaki,<sup>15</sup> C. Domingo-Pardo,<sup>16</sup> I. Duran,<sup>17</sup> R. Dressler,<sup>18</sup> C. Eleftheriadis,<sup>19</sup> A. Ferrari,<sup>9</sup> K. Fraval,<sup>8</sup> S. Ganesan,<sup>20</sup> A.R. García,<sup>6</sup> G. Giubrone,<sup>16</sup> I.F. Gonçalves,<sup>13</sup> E. González-Romero,<sup>6</sup> E. Griesmayer,<sup>21</sup> C. Guerrero,<sup>9</sup> F. Gunsing,<sup>8</sup> A. Hernández-Prieto,<sup>9,12</sup> D.G. Jenkins,<sup>22</sup> E. Jericha,<sup>21</sup> Y. Kadi,<sup>9</sup> F. Käppeler,<sup>23</sup> D. Karadimos,<sup>15</sup> N. Kivel,<sup>18</sup> P. Koehler,<sup>24</sup> M. Kokkoris,<sup>15</sup> M. Krtička,<sup>7</sup> J. Kroll,<sup>7</sup> C. Lampoudis,<sup>8</sup> C. Langer,<sup>2</sup> E. Leal-Cidoncha,<sup>17</sup> C. Lederer,<sup>25</sup> H. Leeb,<sup>21</sup> L.S. Leong,<sup>4</sup> R. Losito,<sup>9</sup> A. Mallick,<sup>20</sup> A. Manousos,<sup>19</sup> J. Marganec,<sup>3</sup> T. Martínez,<sup>6</sup> P.F. Mastinu,<sup>26</sup> M. Mastromarco,<sup>5</sup> E. Mendoza,<sup>6</sup> A. Mengoni,<sup>27</sup> P.M. Milazzo,<sup>28</sup> M. Mirea,<sup>29</sup> W. Mondalaers,<sup>30</sup> C. Paradela,<sup>17</sup> A. Pavlik,<sup>25</sup> J. Perkowski,<sup>3</sup> A. Plompen,<sup>30</sup> J. Praena,<sup>14</sup> J.M. Quesada,<sup>14</sup> T. Rauscher,<sup>31</sup> R. Reifarth,<sup>2</sup> A. Riego,<sup>12</sup> M.S. Robles,<sup>17</sup> C. Rubbia,<sup>9,32</sup> M. Sabaté-Gilarte,<sup>14</sup> R. Sarmiento,<sup>13</sup> A. Saxena,<sup>20</sup> P. Schillebeeckx,<sup>30</sup> S. Schmidt,<sup>2</sup> D. Schumann,<sup>18</sup> G. Tagliente,<sup>5</sup> J.L. Tain,<sup>16</sup> D. Tarrío,<sup>17</sup> L. Tassan-Got,<sup>4</sup> A. Tsinganis,<sup>9</sup> S. Valenta,<sup>7</sup> G. Vannini,<sup>1</sup> V. Variale,<sup>5</sup> P. Vaz,<sup>13</sup> A. Ventura,<sup>27</sup> M.J. Vermeulen,<sup>22</sup> V. Vlachoudis,<sup>9</sup> R. Vlastou,<sup>15</sup> A. Wallner,<sup>25</sup> T. Ware,<sup>10</sup> M. Weigand,<sup>2</sup> C. Weiß,<sup>21</sup> T. Wright,<sup>10</sup> and P. Žugec<sup>11</sup>

This work is supported by the European Commission within the FP7 project ANDES (FP7-249671)

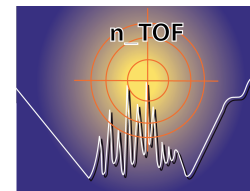


# Thank you!

---

Federica Mingrone

mingrone@bo.infn.it

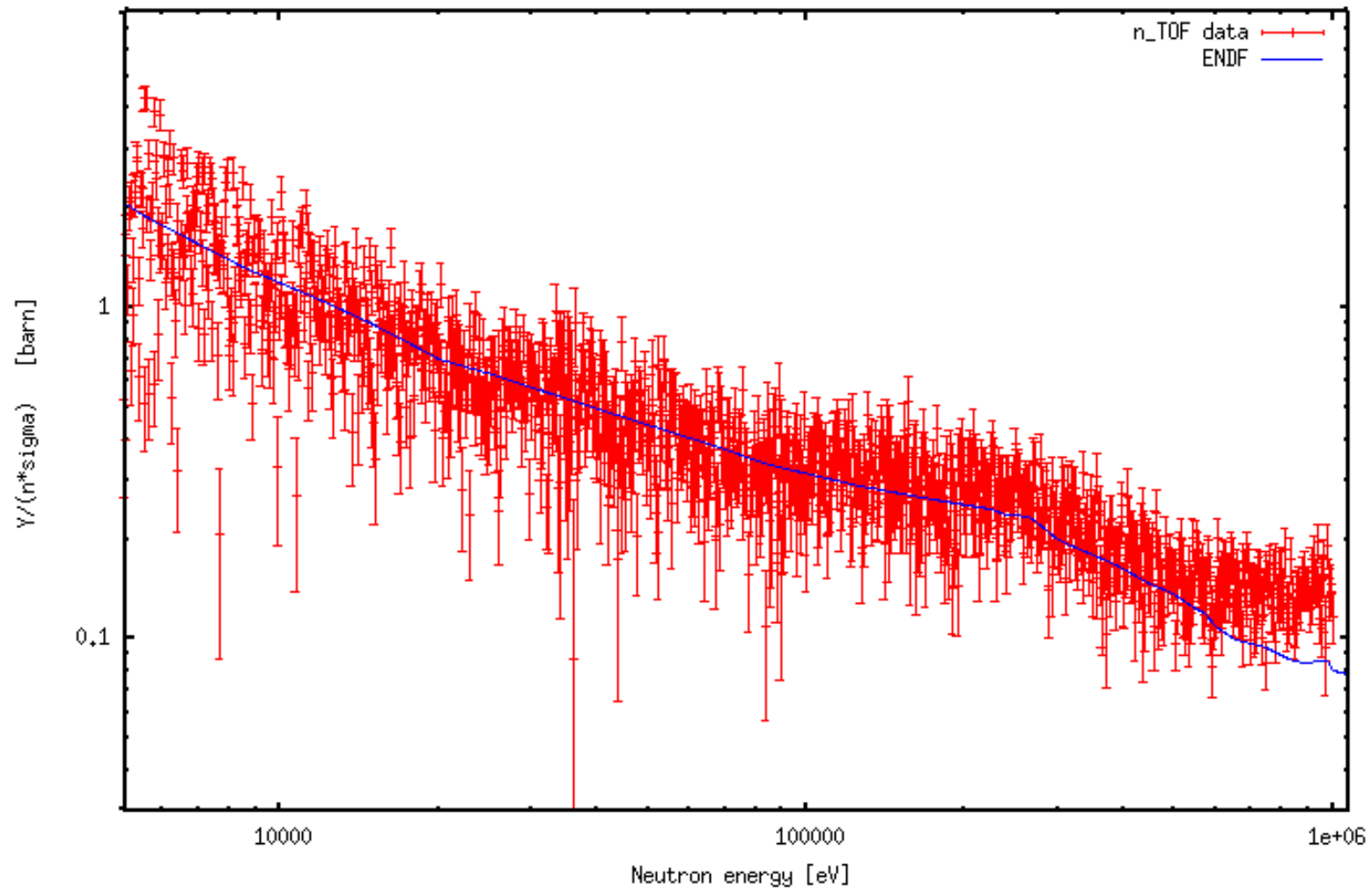


# BACKUP

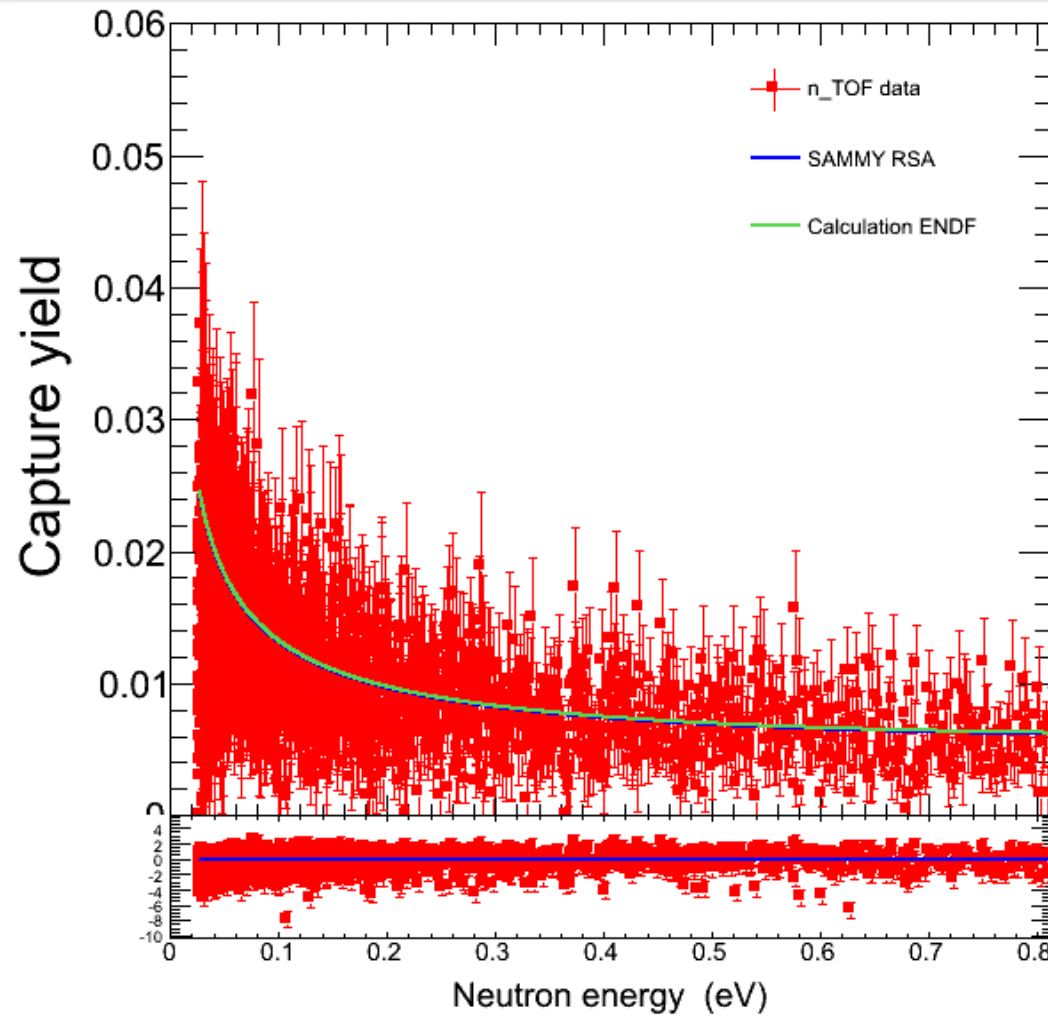
---



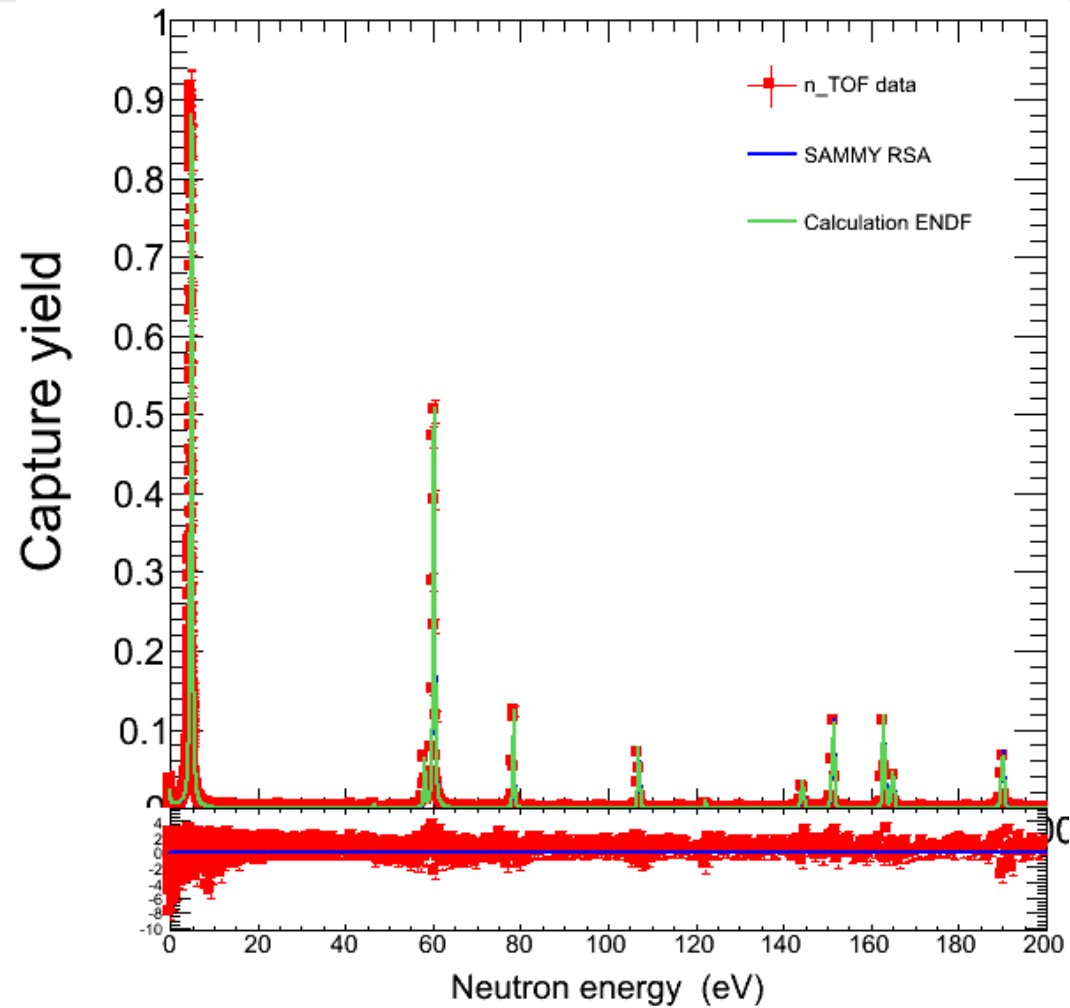
# Unresolved Resonance Region: GOLD



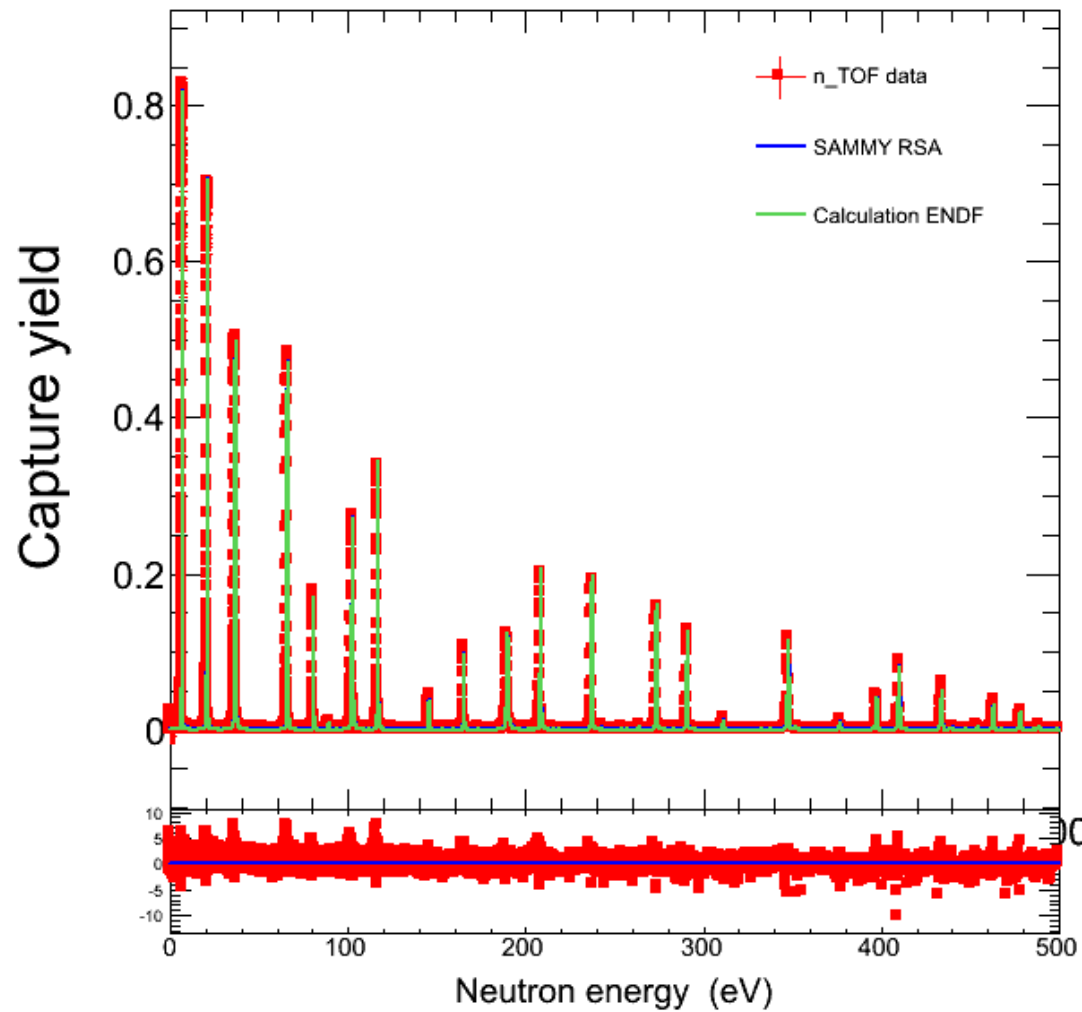
# Yield Au: thermal



# Yield Au: 0-200 eV



# Yield $^{238}\text{U}$ : 0-500 eV



# Counting statistic uncertainties

