INESS@WISARD: THE FIRST BETA SPECTRUM SHAPE MEASUREMENT AT WISARD

MORA WORKSHOP
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5 MAY 2022

KU LEUVEN

OUTLINE

Introduction

Beta spectrum shape measurements

Project idea

WISArD

First results

Set-up

Measurements

Analysis of experimental spectra

BETA DECAY PRECISION EXPERIMENTS

Beta correlation coefficients

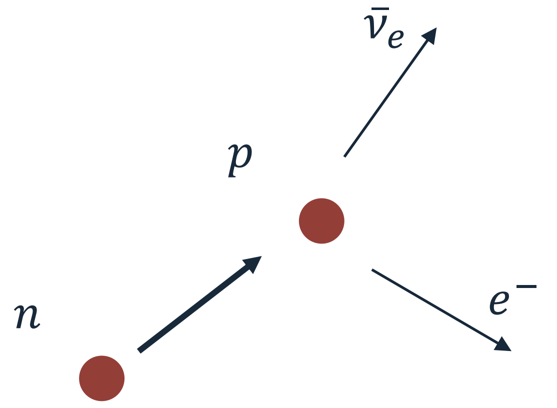
- $a_{\beta\nu}$
- A_{β}
- B_{ν}

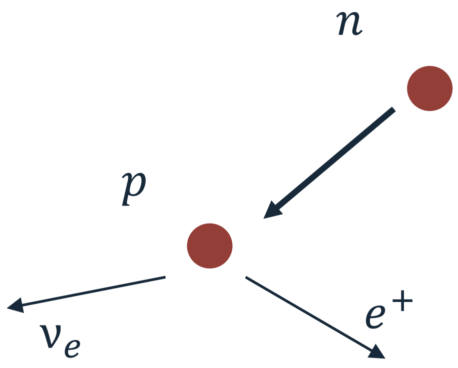
Ft-values

- Superallowed Fermi decays
- Mirror beta decay

Shape of the beta energy spectrum

Aim for a precision ≤ 10^{-3}

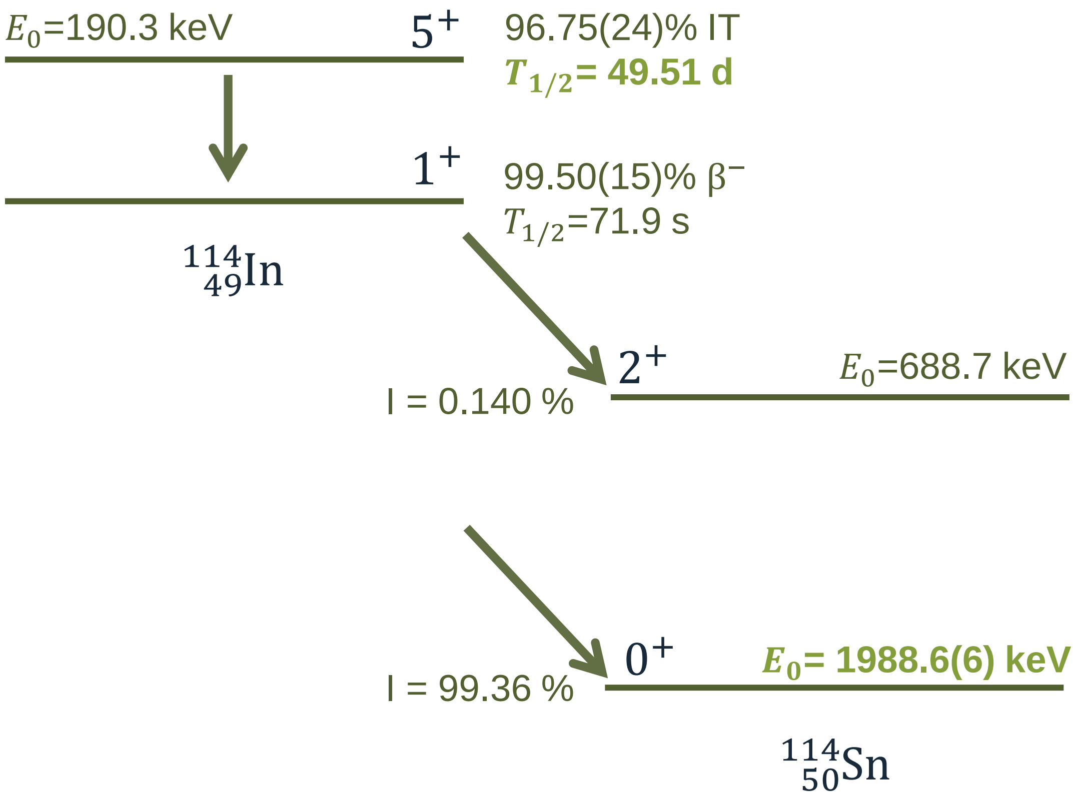




SPECTRUM SHAPE

Measure the beta-spectrum shape of $^{114}\mathrm{In}$

- Pure Gamow-Teller decay



SPECTRUM SHAPE

Measure the beta-spectrum shape of $^{114}\mathrm{In}$

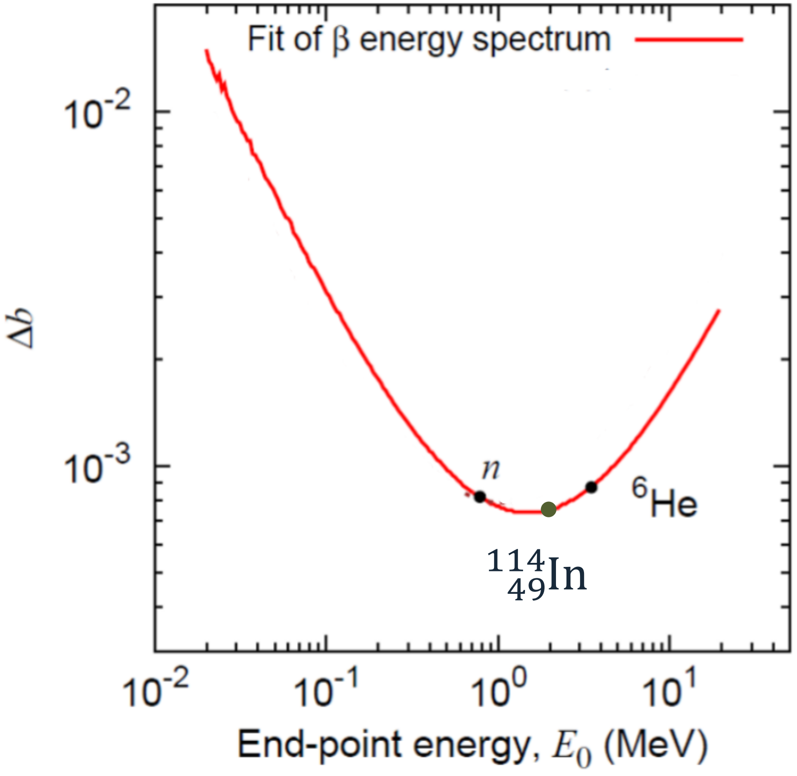
- Pure Gamow-Teller decay

Look for QCD influence on the decay

- Weak-Magnetism (b_{WM})

Look for BSM physics

- Fierz interference term



Ft values of mirror *β transitions and weak magnetism induced current in allowed nuclear β decay* N. Severijns *et al.*, 2022 *arXiv* 2109.08895
Influence of the recoil-order and radiative correction on the beta decay correlation coefficients in mirror decays S. Vanlangendonck *et al.* 2022 arXiv:2203.16936
Kinematic sensitivity to the Fierz term of β-decay differential spectra M. Gonález-Alonso and O. Naviliat-Cuncic, 2018

PROBING NEW PHYSICS WITH THE SPECTRUM SHAPE

What signal are we looking for?

Weak-Magnetism (b_{WM}):

$$w_{SM}(E) \approx w_{SM,0}(1 - \underbrace{\frac{2}{3}\frac{E_0}{Mc} b_{WM}}_{\text{Absorbed in normalisation}} + \underbrace{\frac{4}{3}\frac{E}{Mc} b_{WM}}_{\text{Dominant term}} - \frac{2}{3}\frac{1}{Mc}\frac{1}{E} b_{WM})$$

Fierz interference term:

$$w(E) = w_{SM}(1 + b_F \frac{m_e}{E})$$

High precision analytical description of the allowed β spectrum shape L. Hayen et al. 2018 Reviews of Modern Physics

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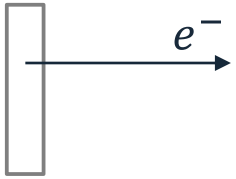
PRECISION SPECTRUM MEASUREMENT

Goal:

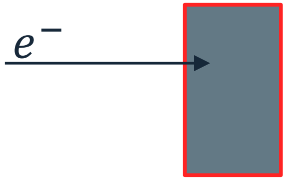
Measure as precise as possible the energy distribution of the electron emerging from beta decay

Several difficulties:

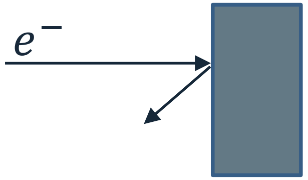
Energy loss (source):



Detector dead layer:



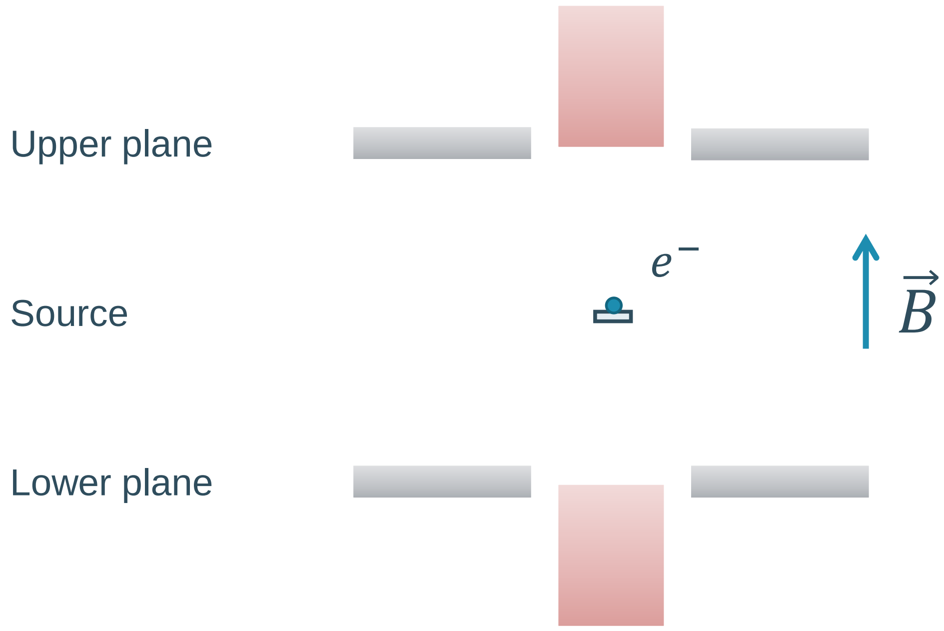
Backscattering:



Existing solutions available

Intrinsic problem!

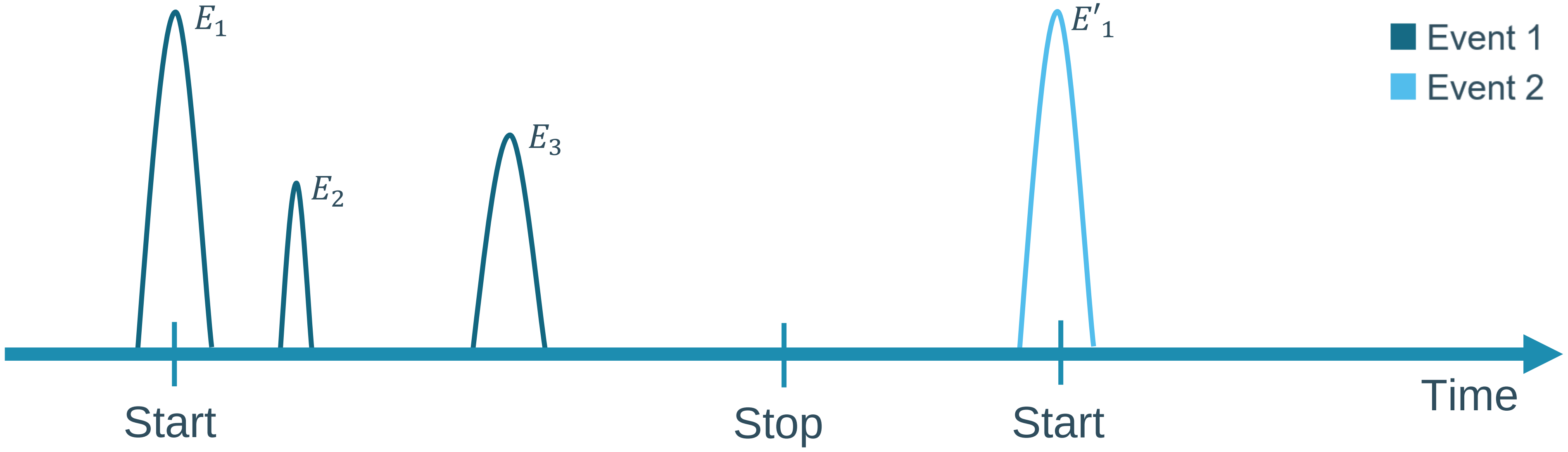
INTEGRATION TIME



Why WISArD?

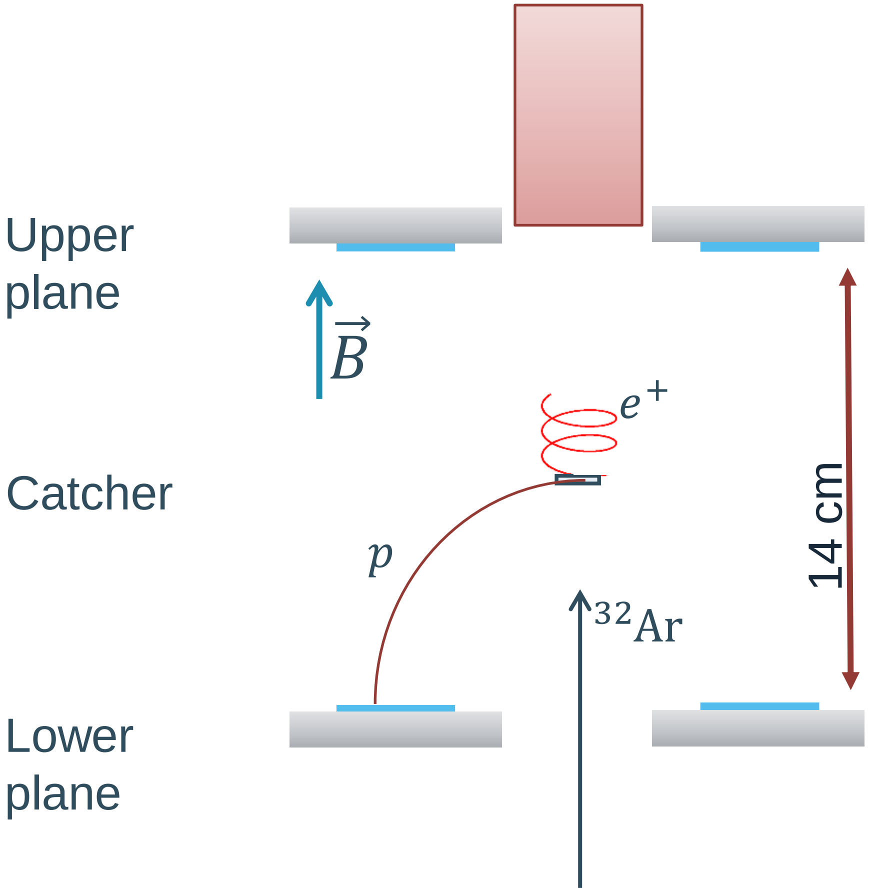
Due to the magnetic field:

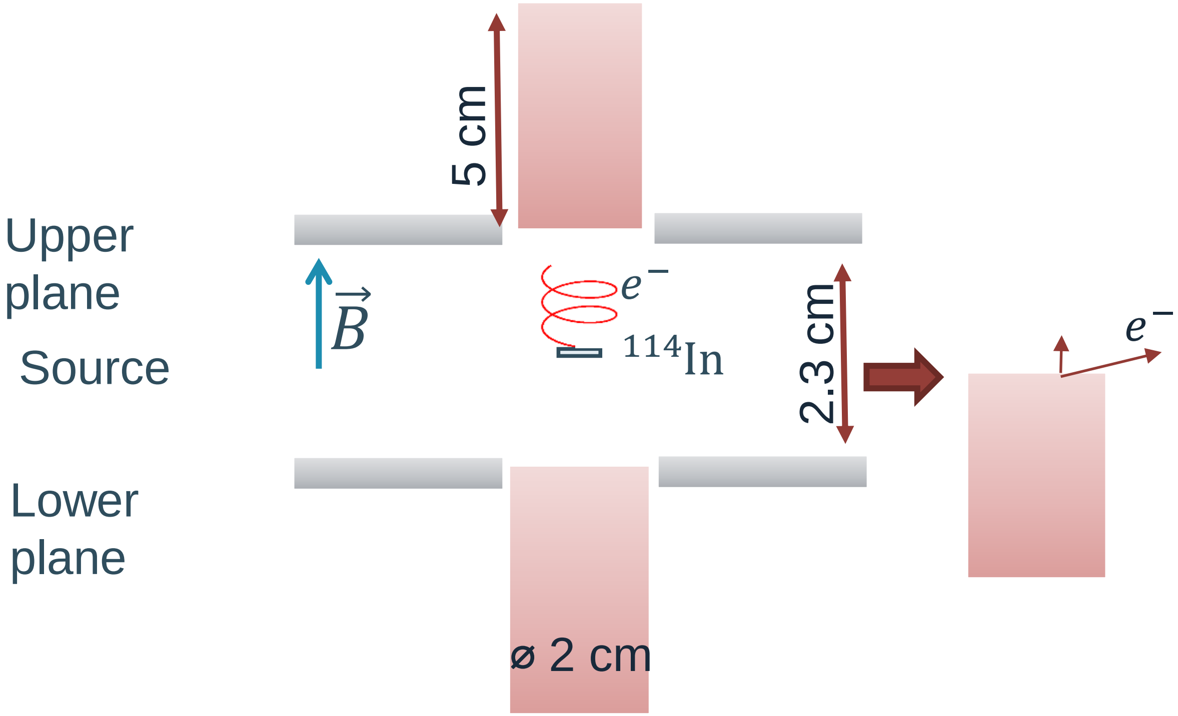
- Full solid angle
- Limiting the influence of backscattering



WISARD (2018)

INESS@WISARD





4 Silicon detectors on each plane

1 plastic scintillator

2 plastic scintillators (polystyrene)

+ SiPM – Hamamatsu S13360-6050CS

FIRST RESULTS

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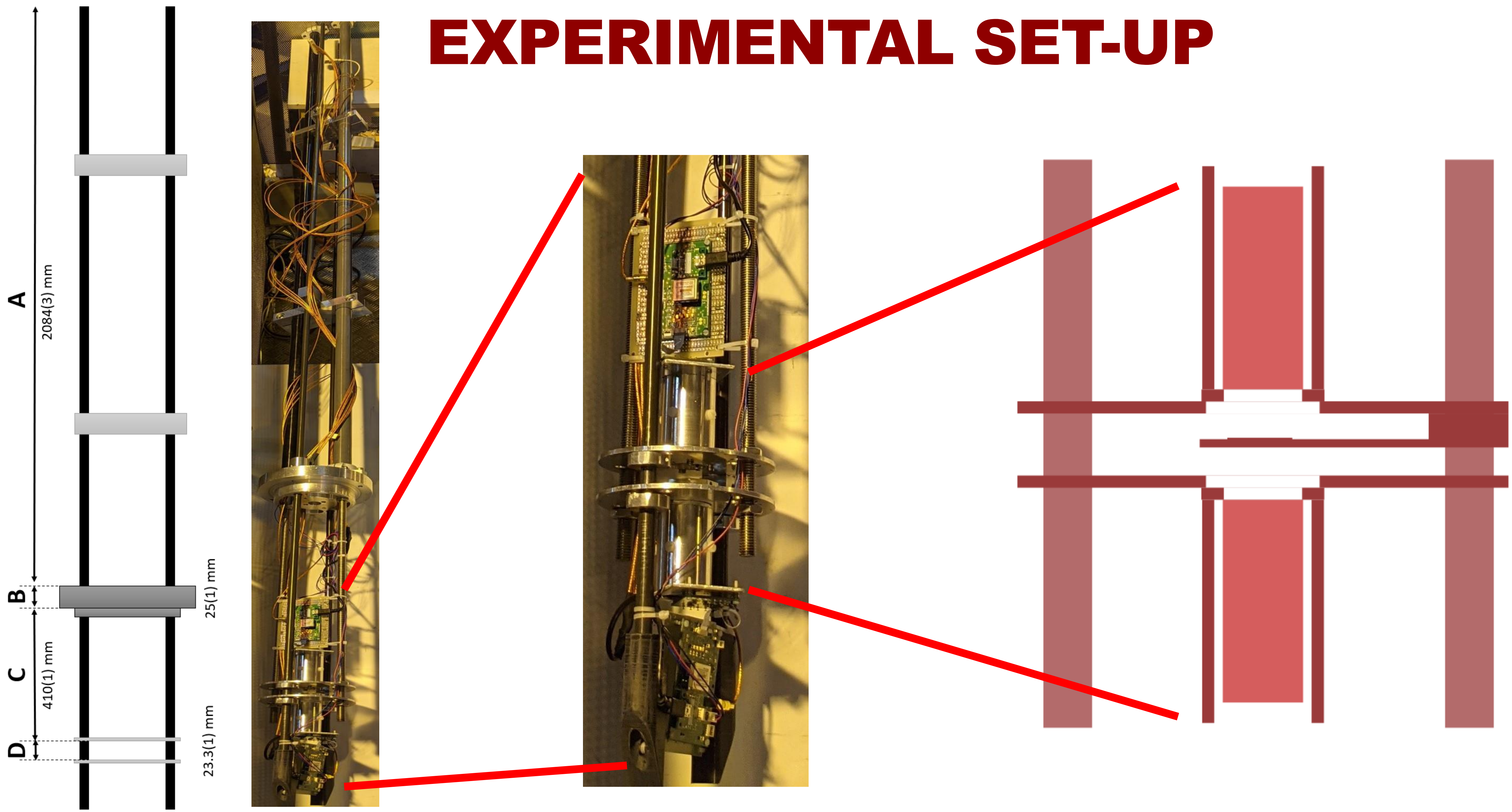
EXPERIMENTAL SET-UP



EXPERIMENTAL CAMPAIGN

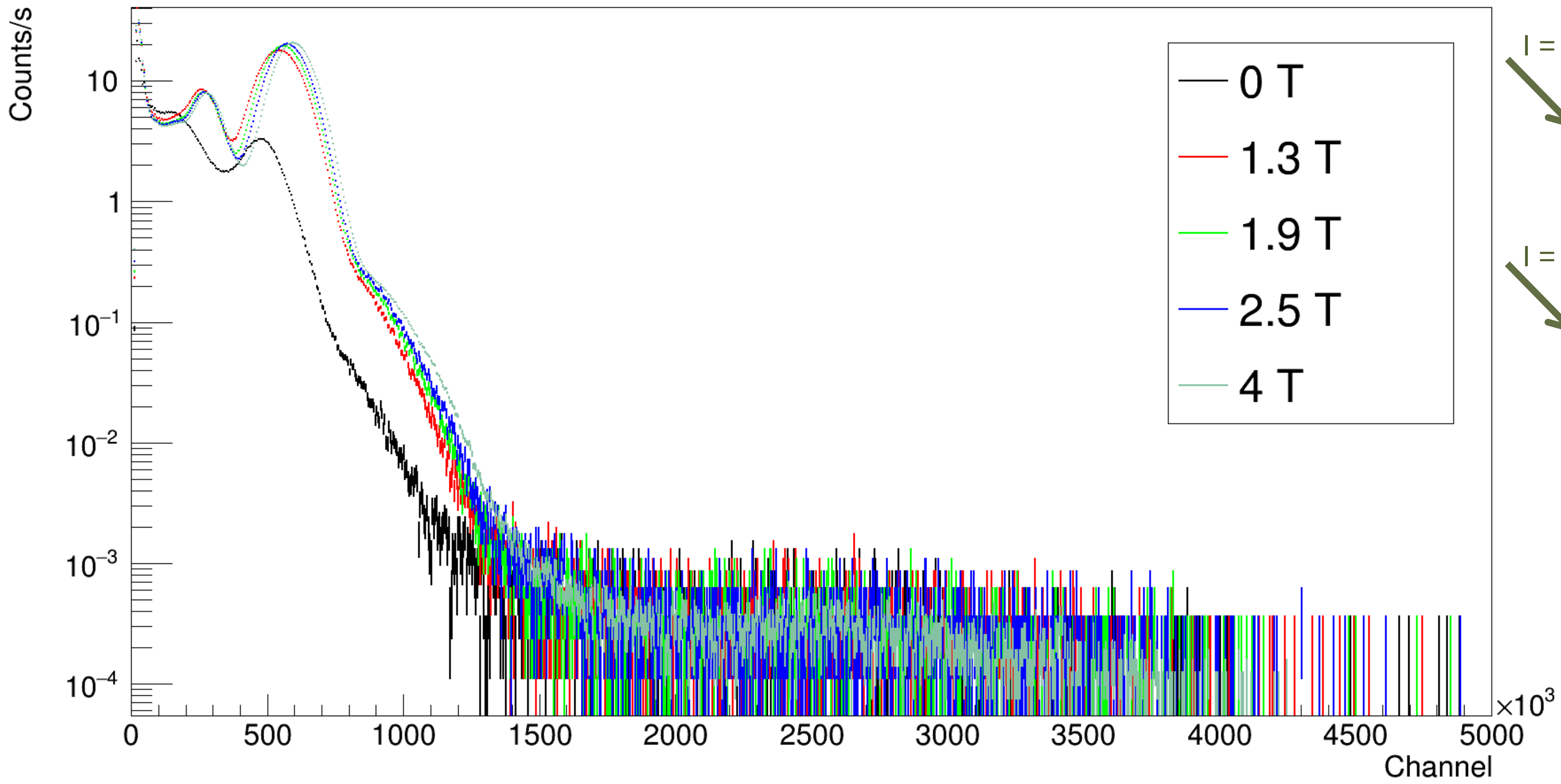
Characterization of the set-up

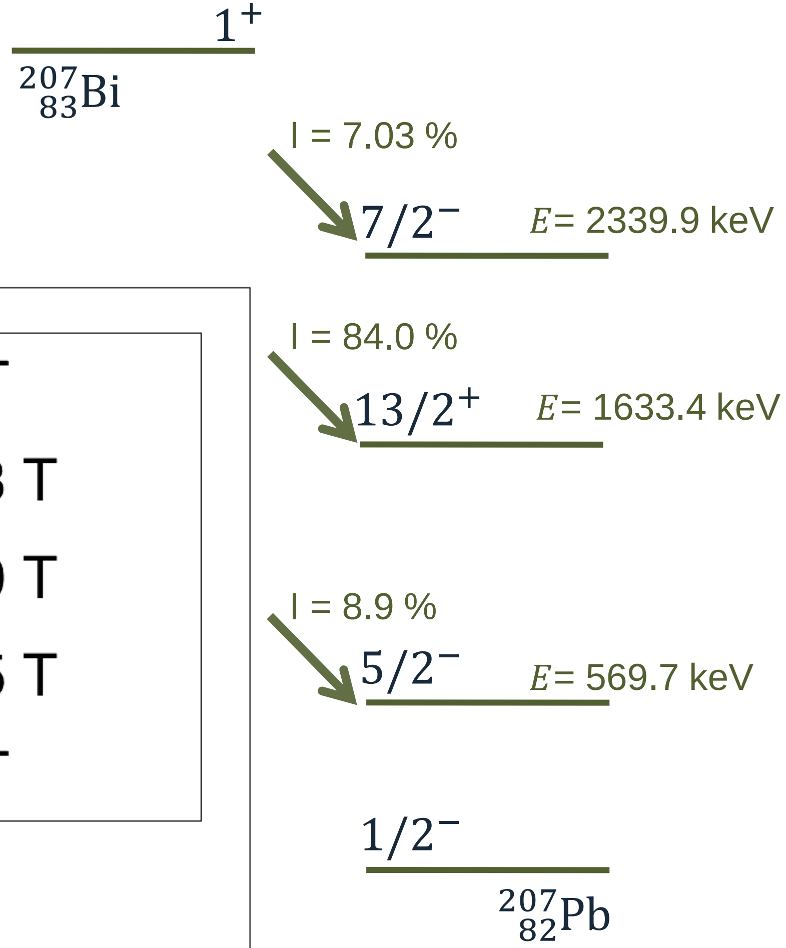
- $^{207}\mathrm{Bi}$
- $^{137}\mathrm{Cs}$
- $^{90}\mathrm{Sr}$
- Background

+ actual measurements

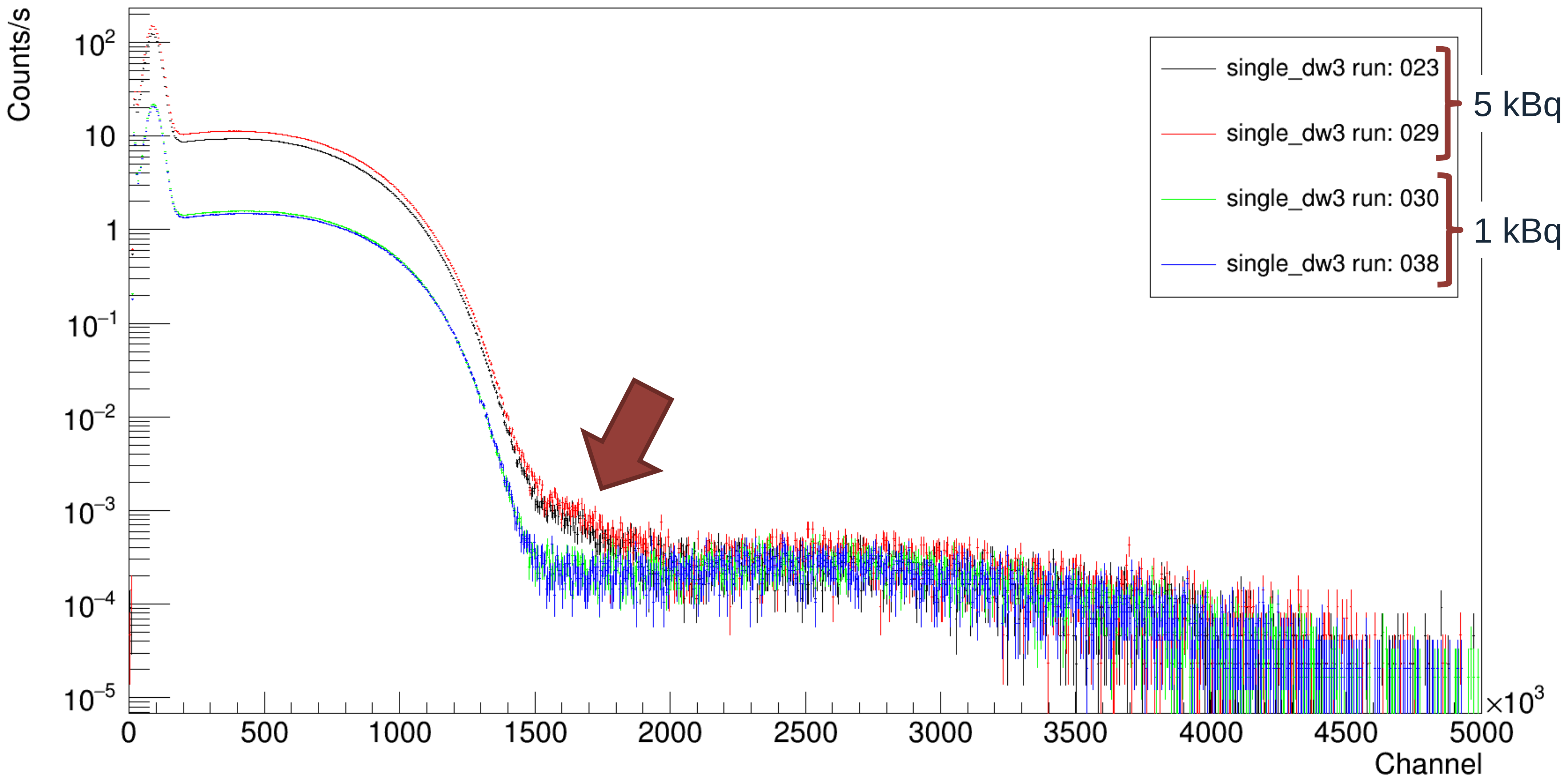
- $^{114}\mathrm{In}$ $\quad A = 1\ \&\ 5\ \mathrm{kBq}$

FIELD DEPENDENCE

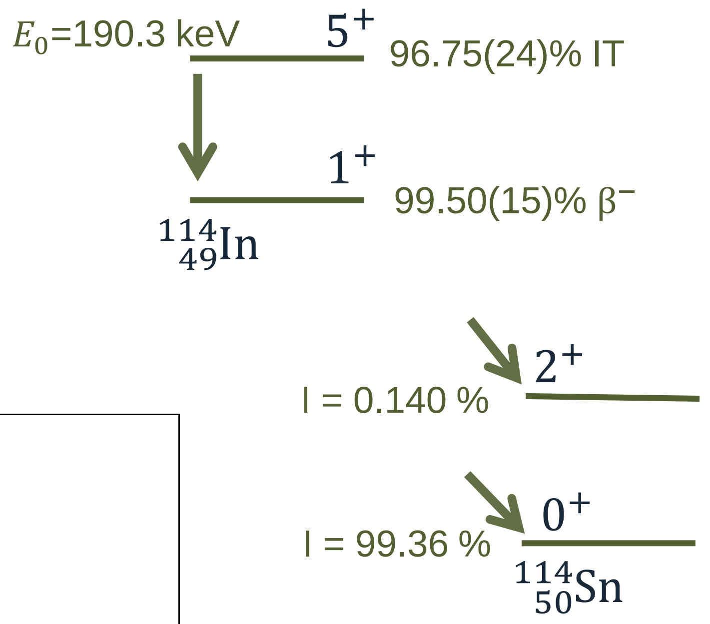


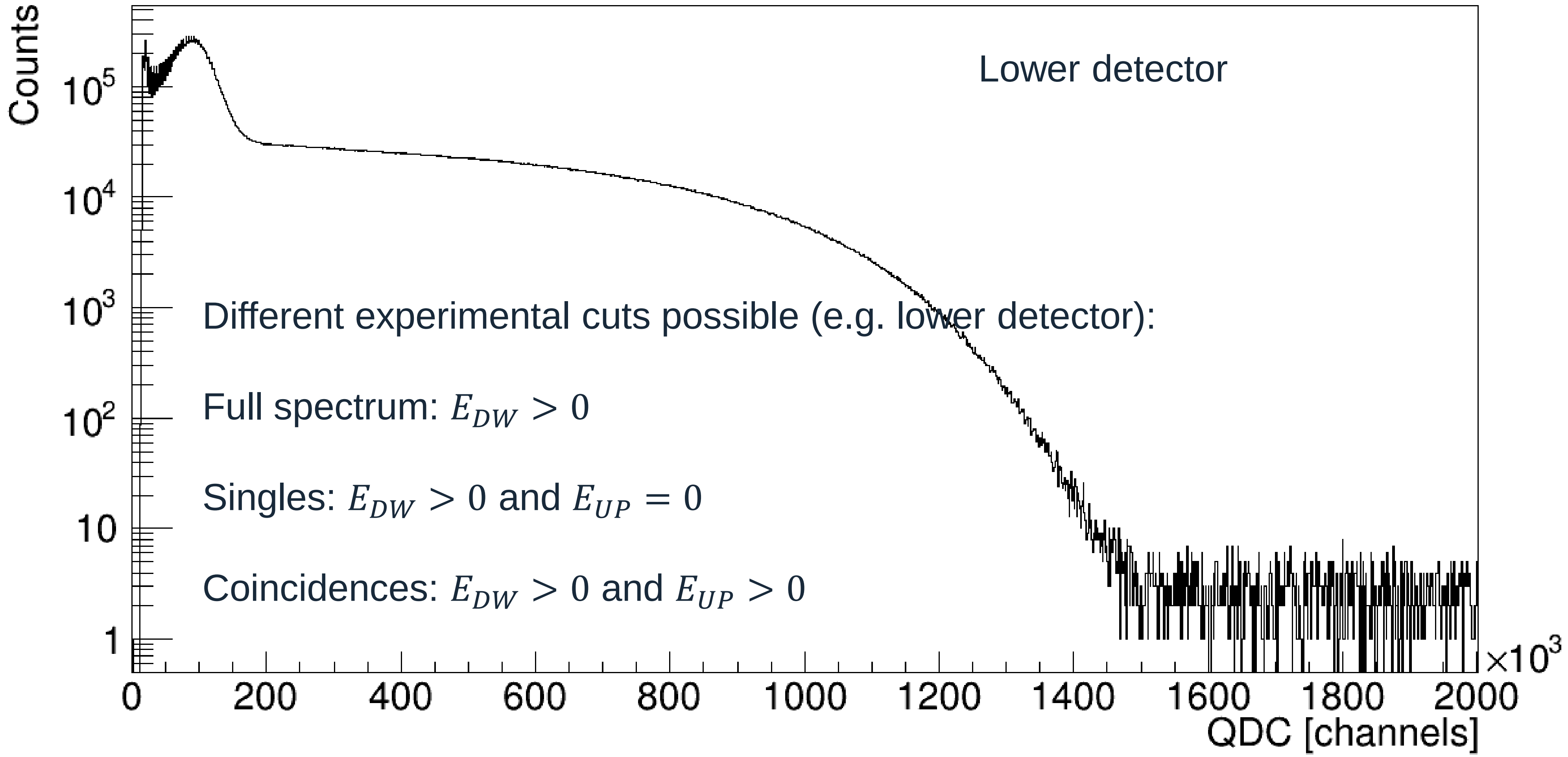


DIFFERENT ACTIVITY



EXPERIMENTAL RESULTS





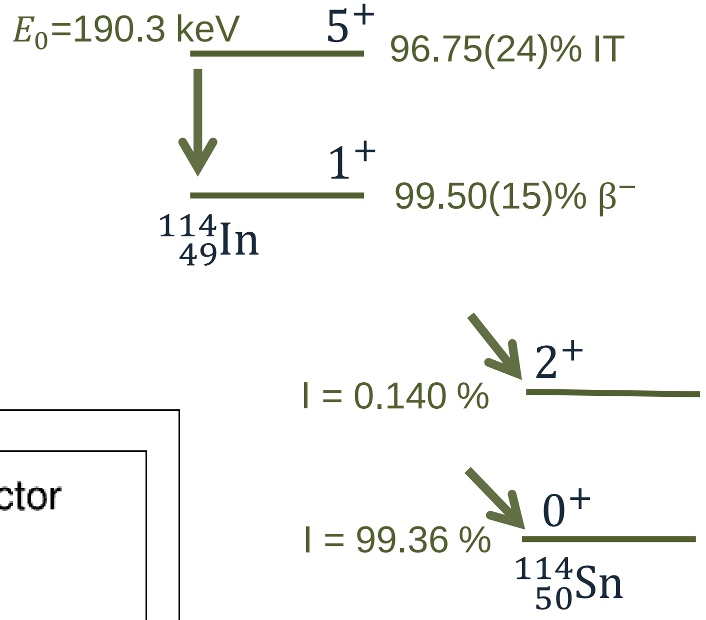
Different experimental cuts possible (e.g. lower detector):

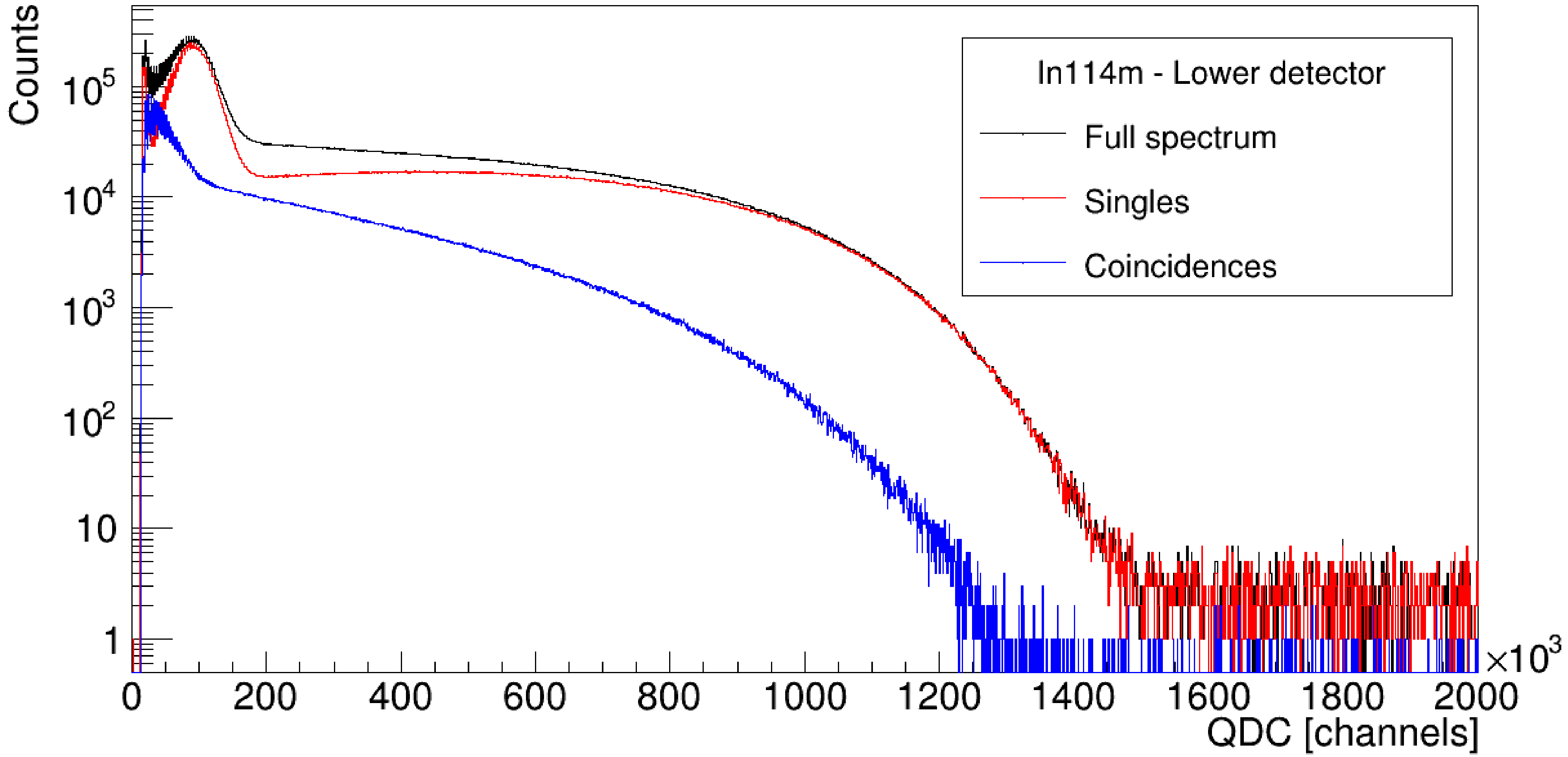
Full spectrum: $E_{DW} > 0$

Singles: $E_{DW} > 0$ and $E_{UP} = 0$

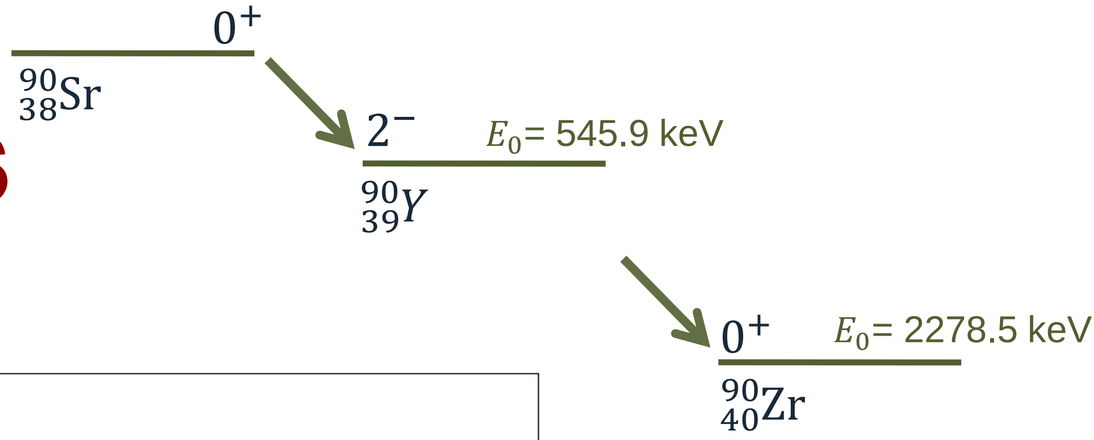
Coincidences: $E_{DW} > 0$ and $E_{UP} > 0$

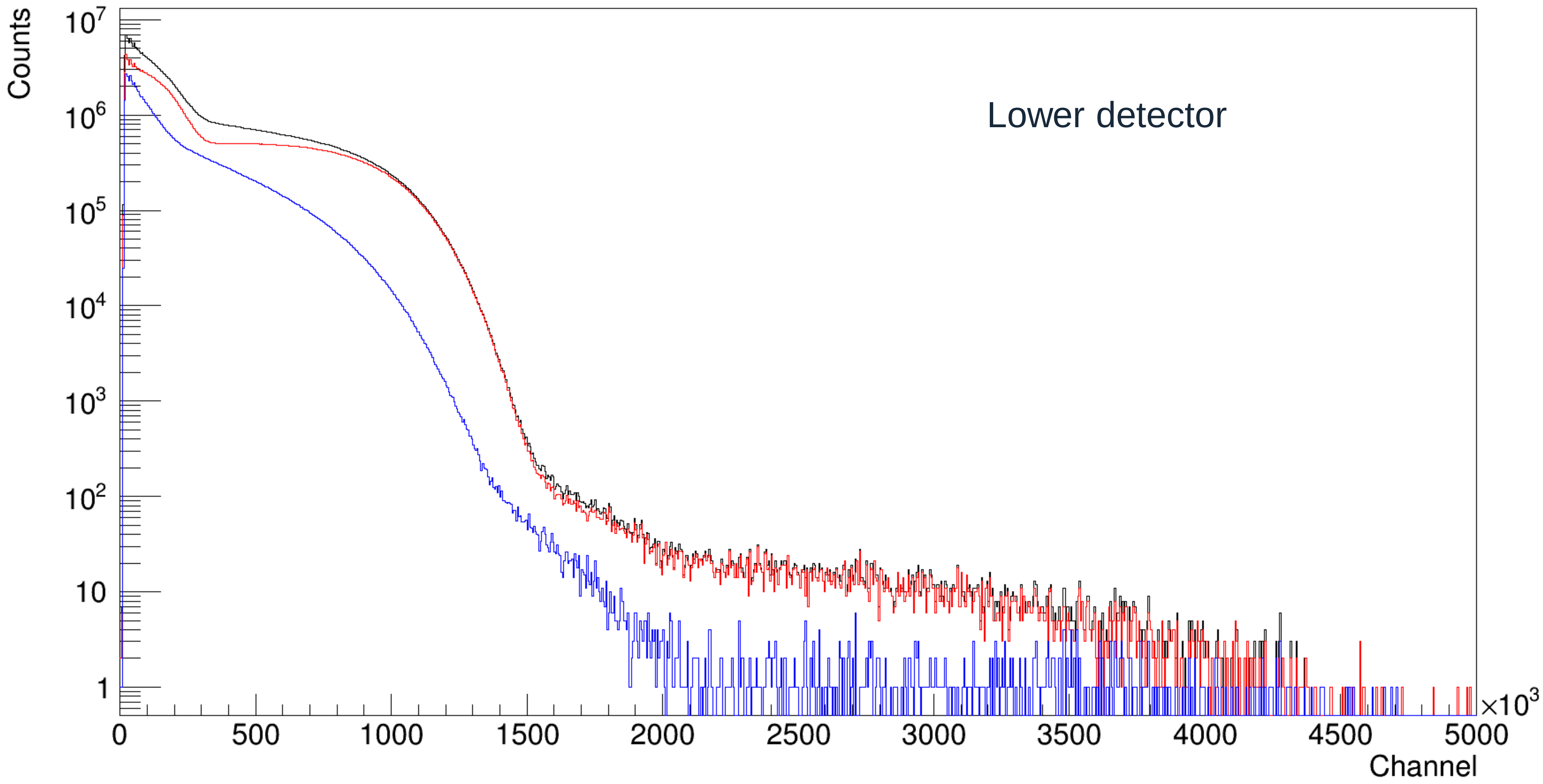
EXPERIMENTAL RESULTS



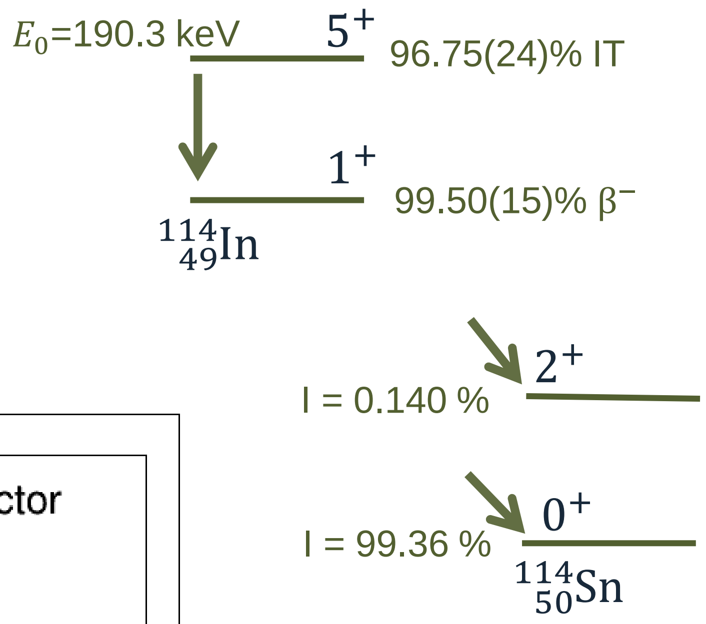


EXPERIMENTAL RESULTS

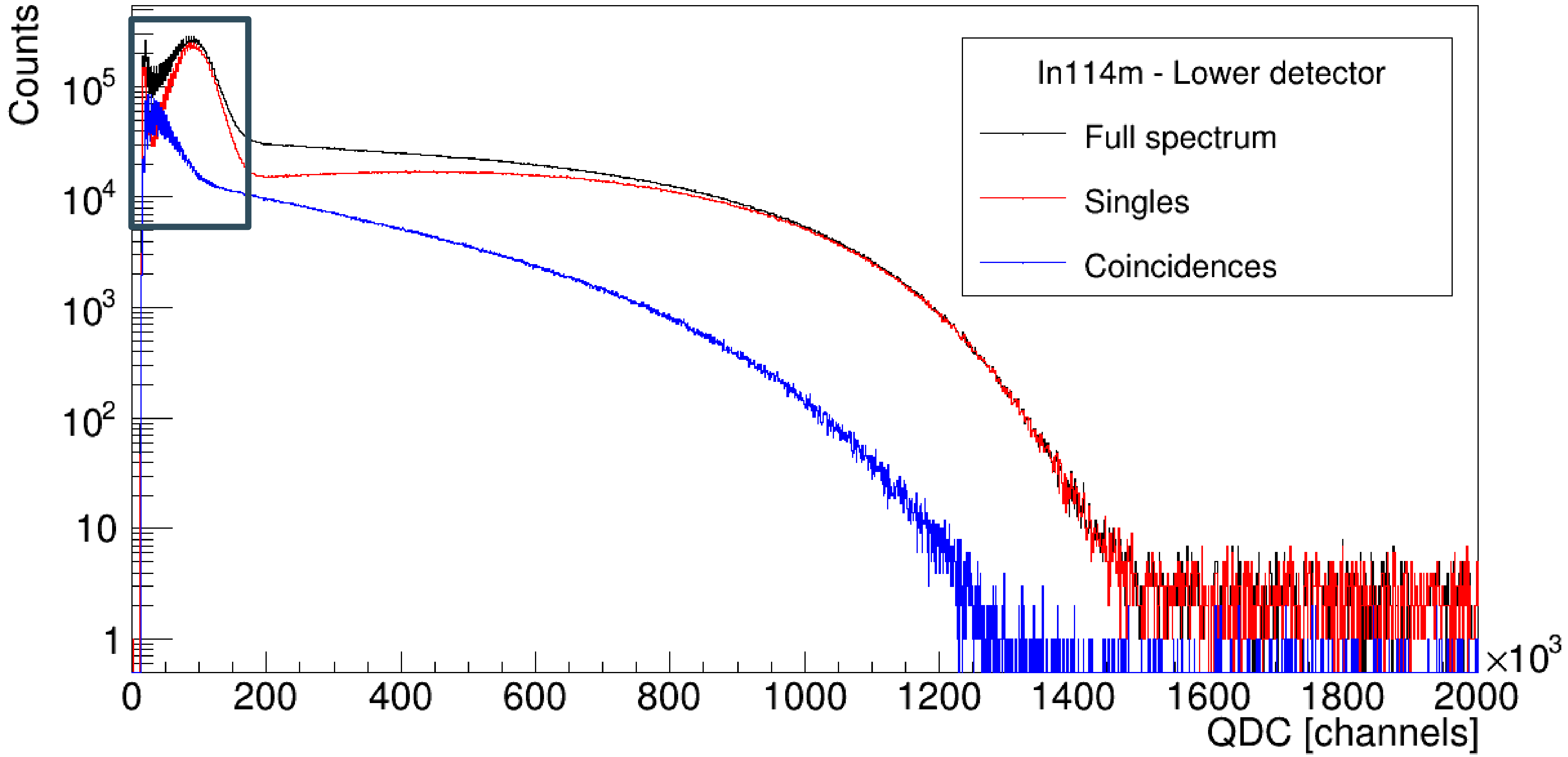




EXPERIMENTAL RESULTS

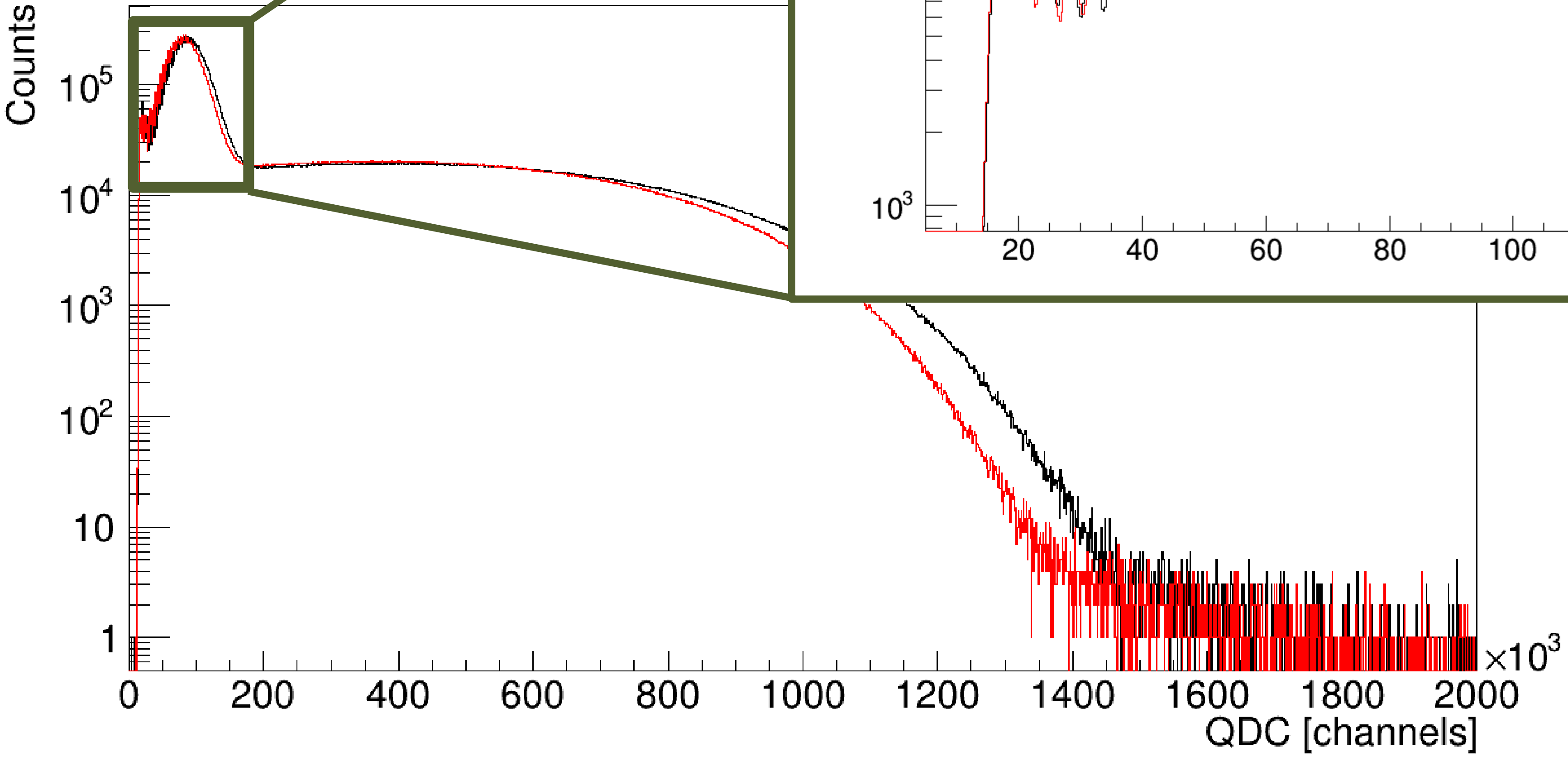


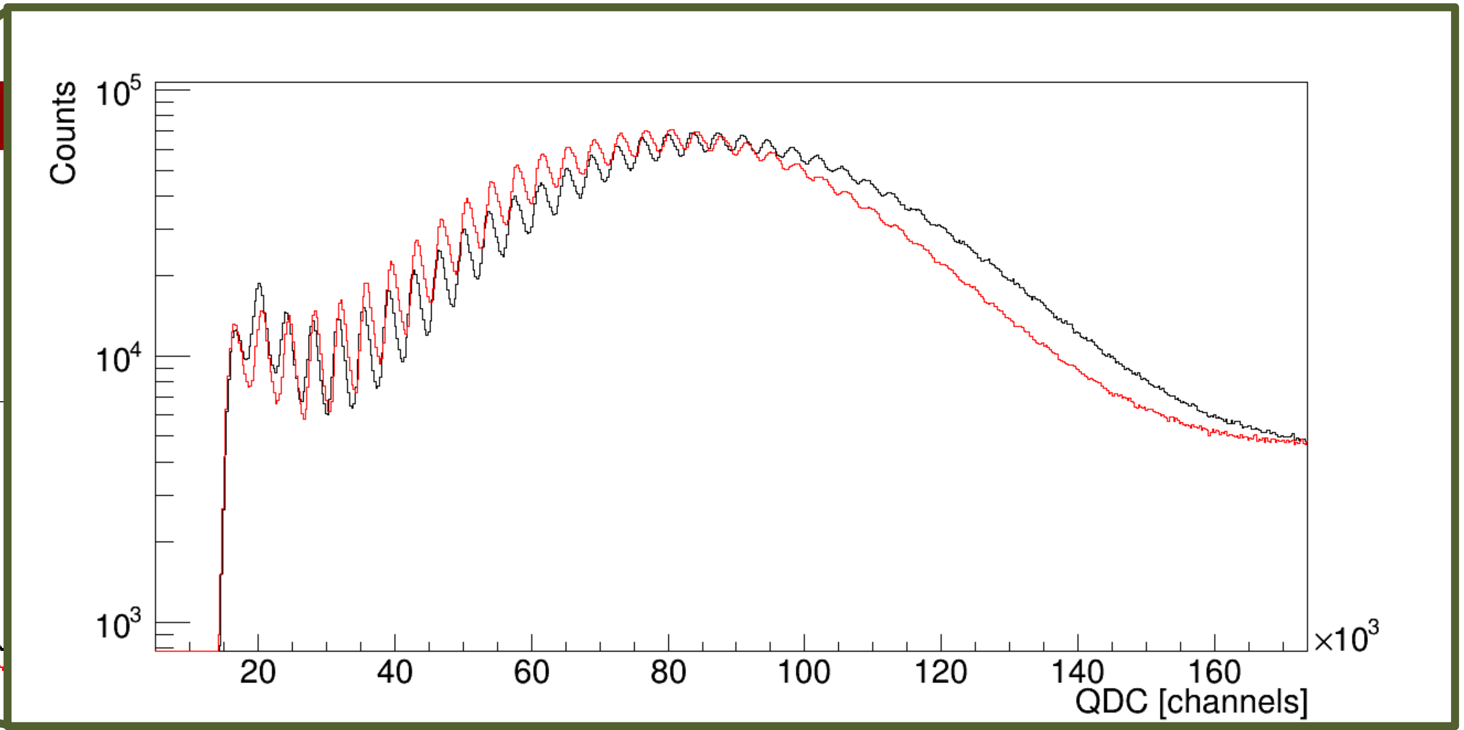
Peaks at low energy?



EXPERIMENTAL RE

0	0	0	0	0	0
0	0	0	0	0	0
0	0	1	0	0	0
0	0	0	1	0	0
0	0	0	0	0	0
0	0	0	0	1	0





FASTER

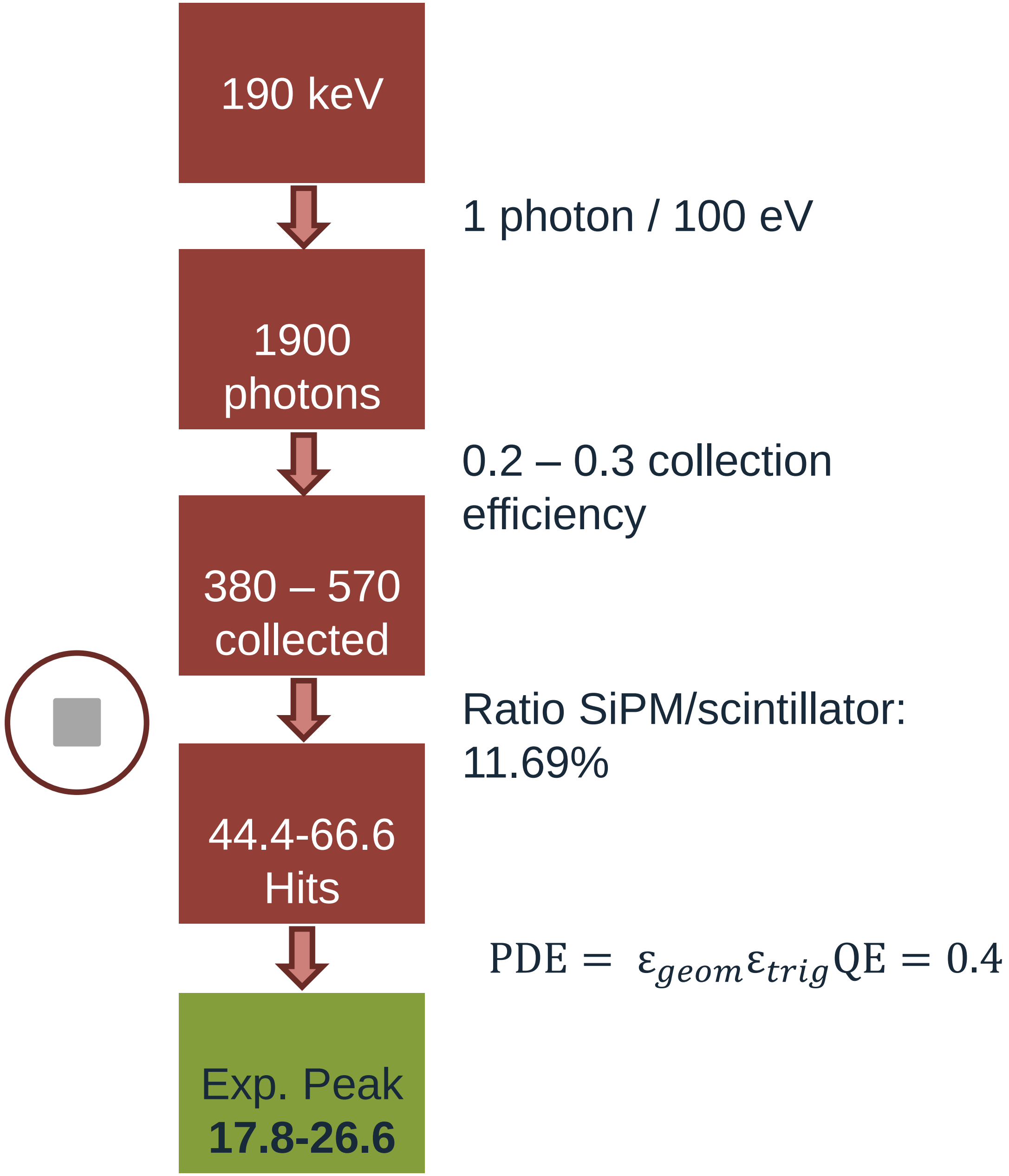
SINGLE PIXEL?

Use 190keV IT in $^{114m}_{49}\mathrm{In}$ spectrum

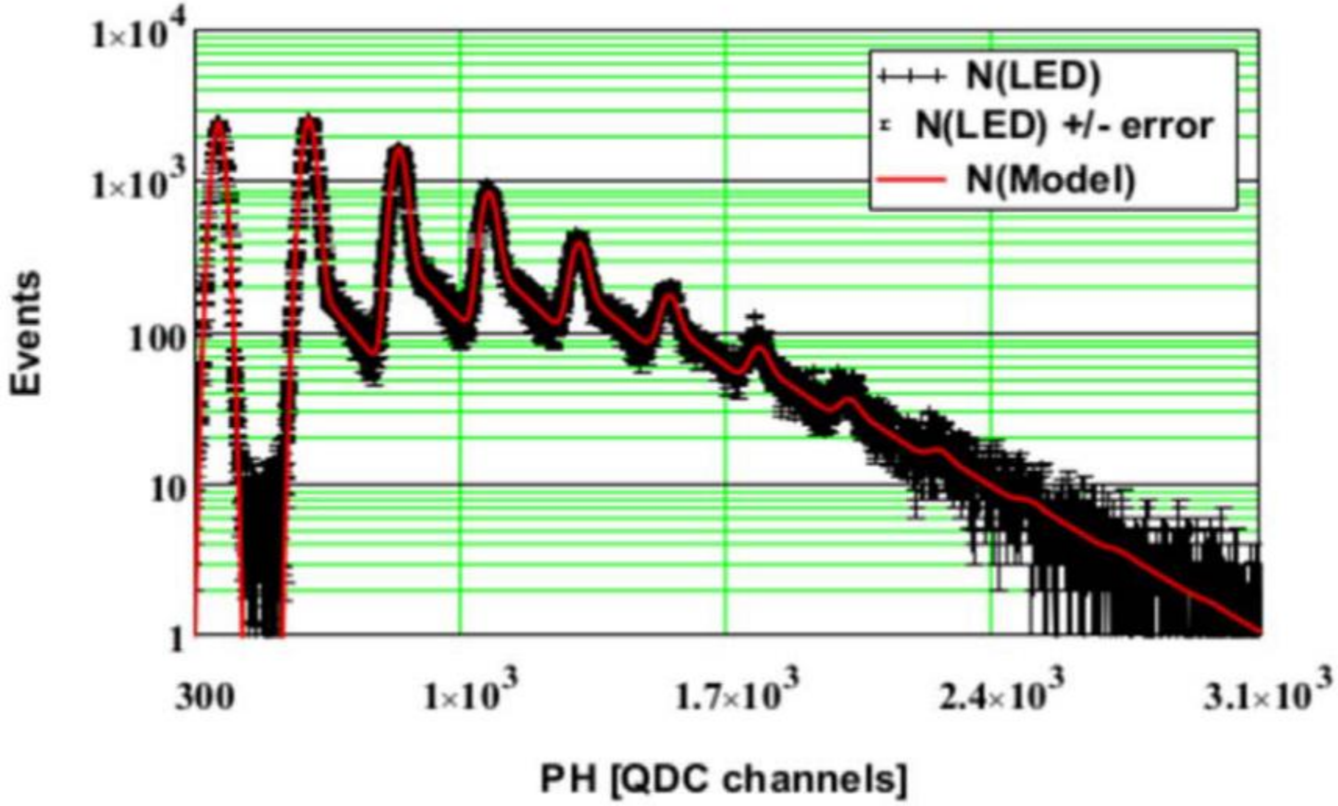
→ 18-19 peaks

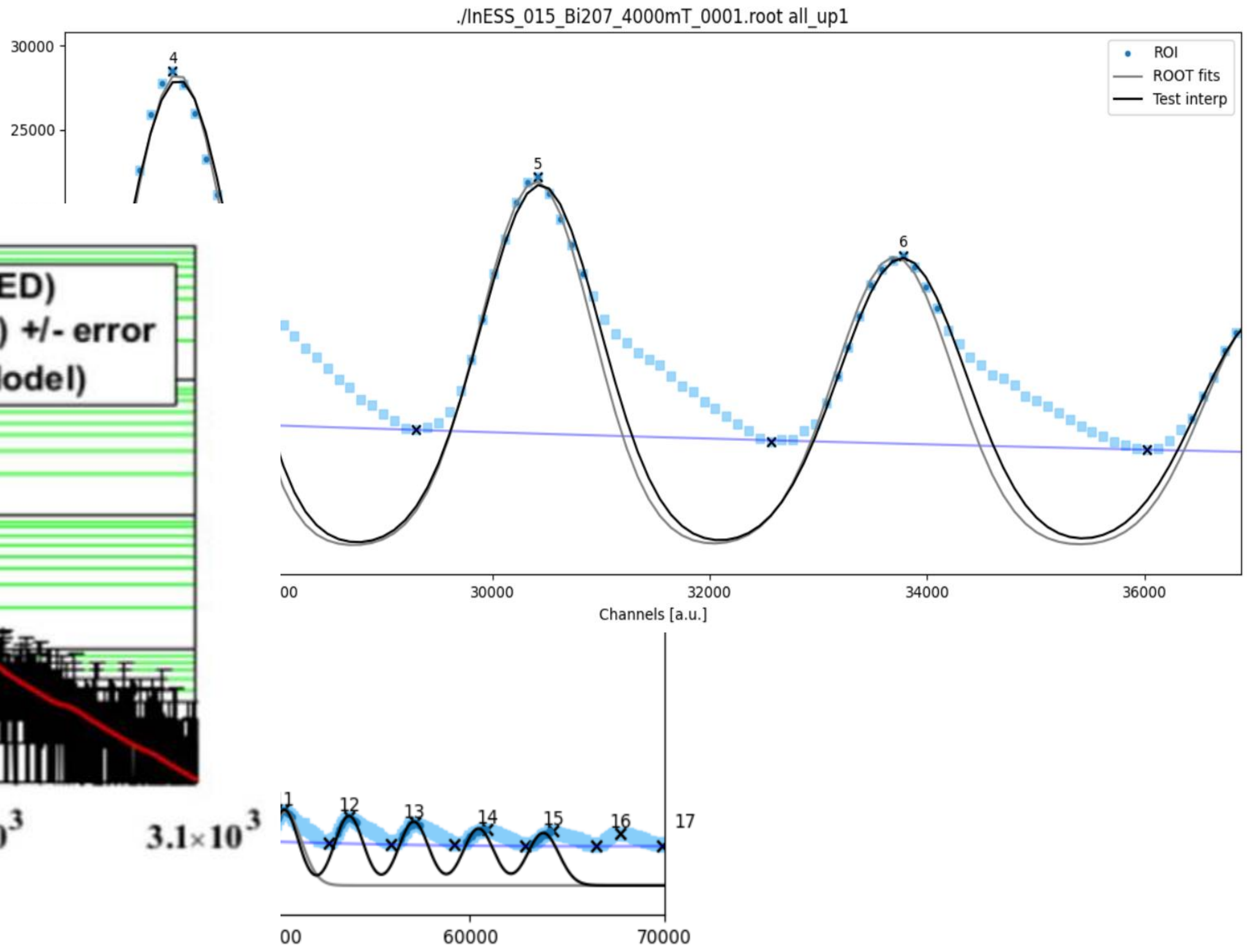
With 5-6 additional missed peaks due to threshold

23 – 25 peaks observed



Gaussian fits



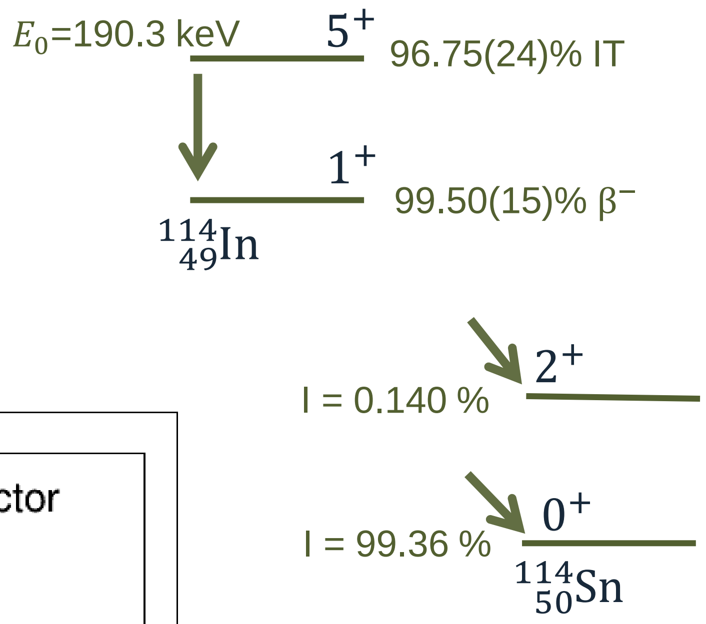


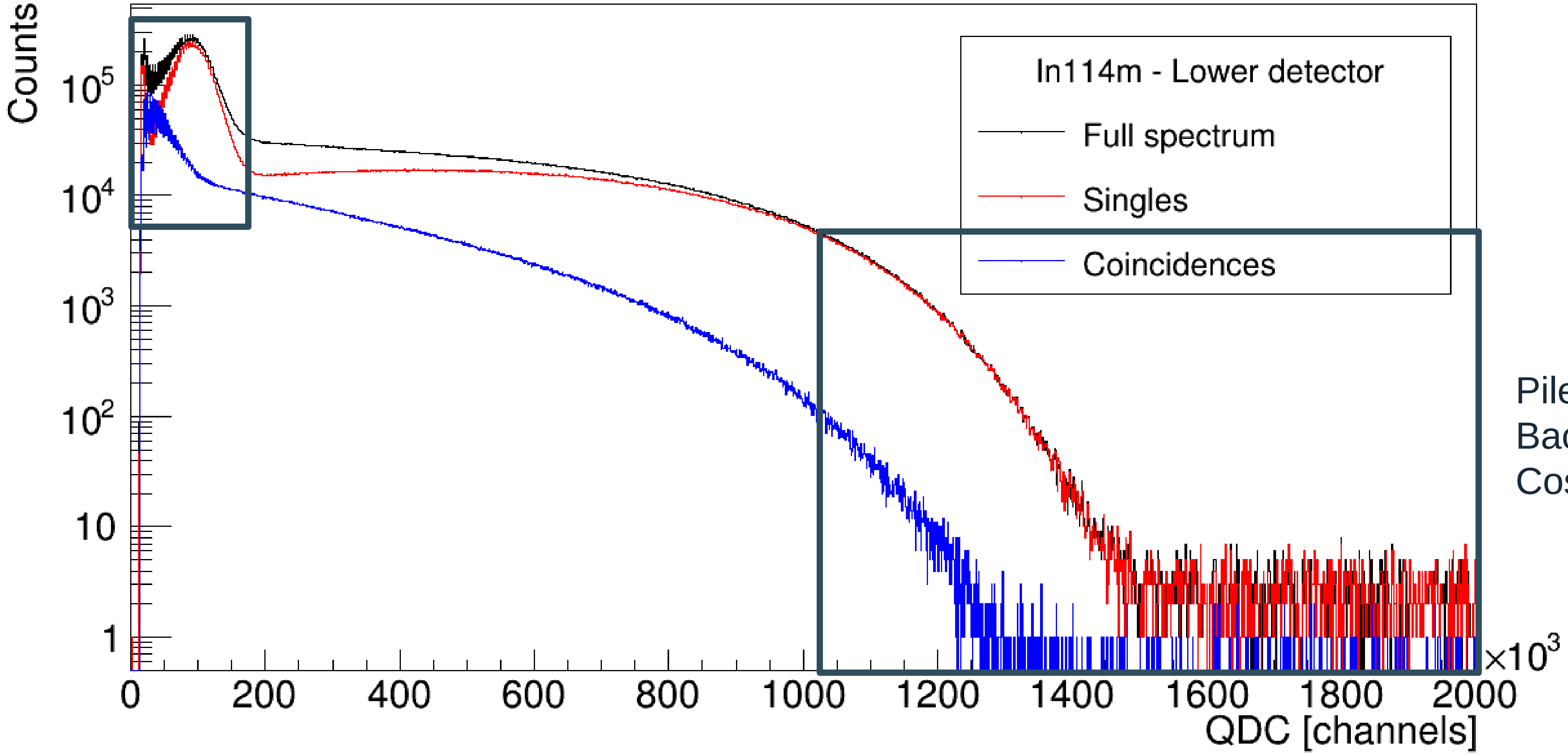
Channels [a.u.]

Events in-between peaks attributed delayed cross-talk and after-pulsing (AP)
More discharges = more AP

On the characterisation of SiPMs from pulse-height spectra V. Chmill *et al.* 2017

EXPERIMENTAL RESULTS

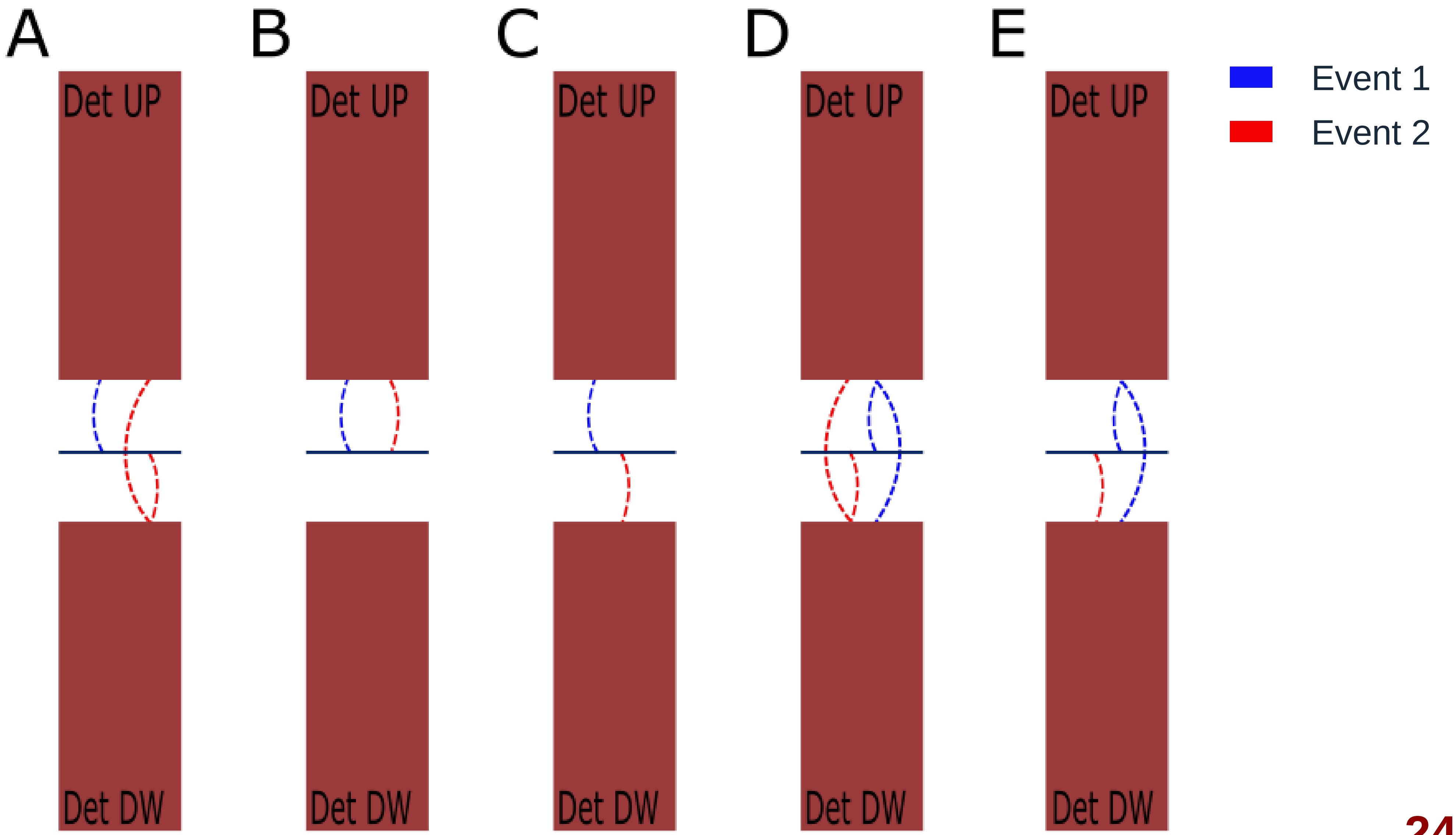




Pile-up?
Background?
Cosmic muons?

PILE-UP

Summation of two independent events

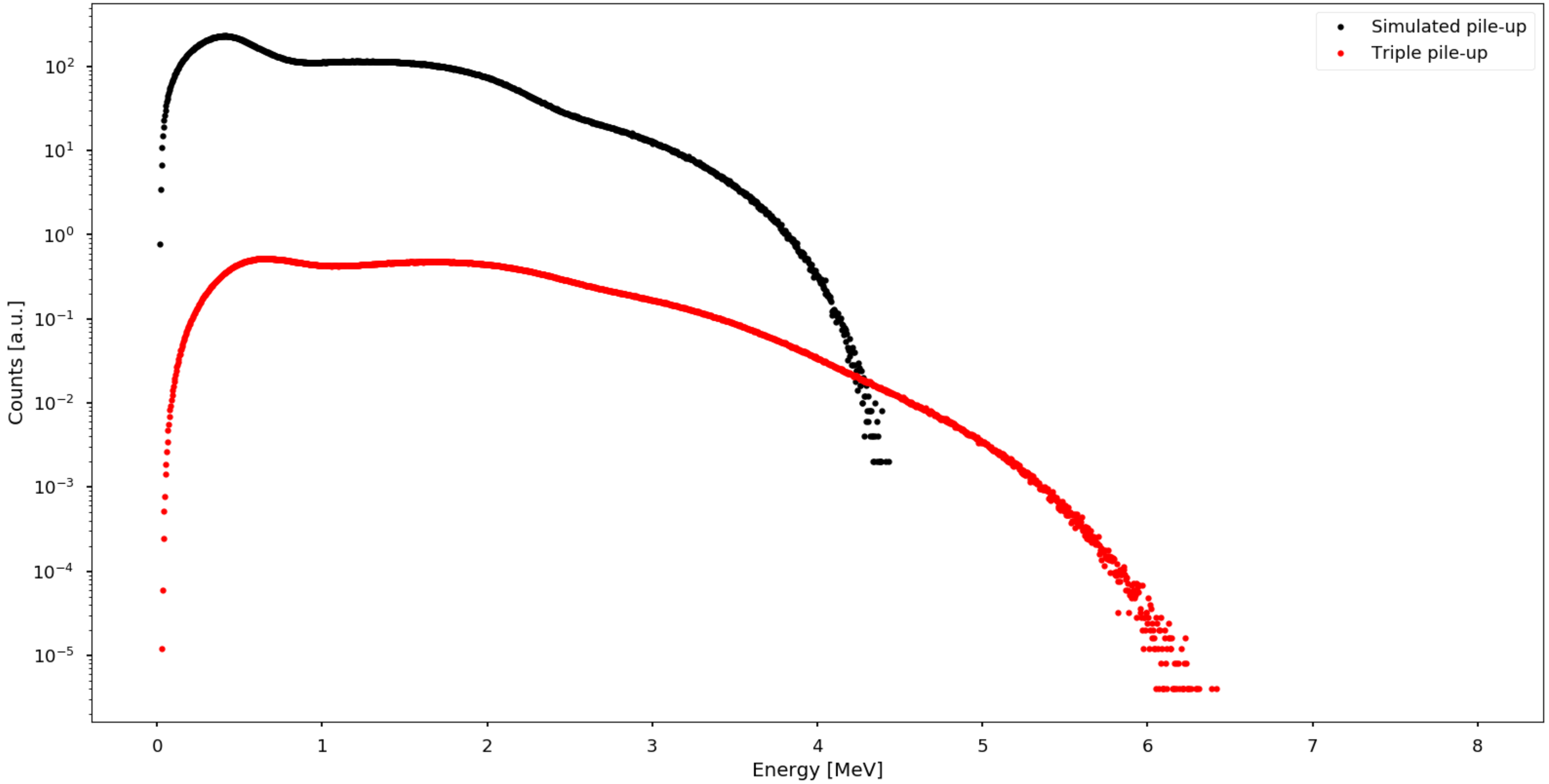


PILE-UP

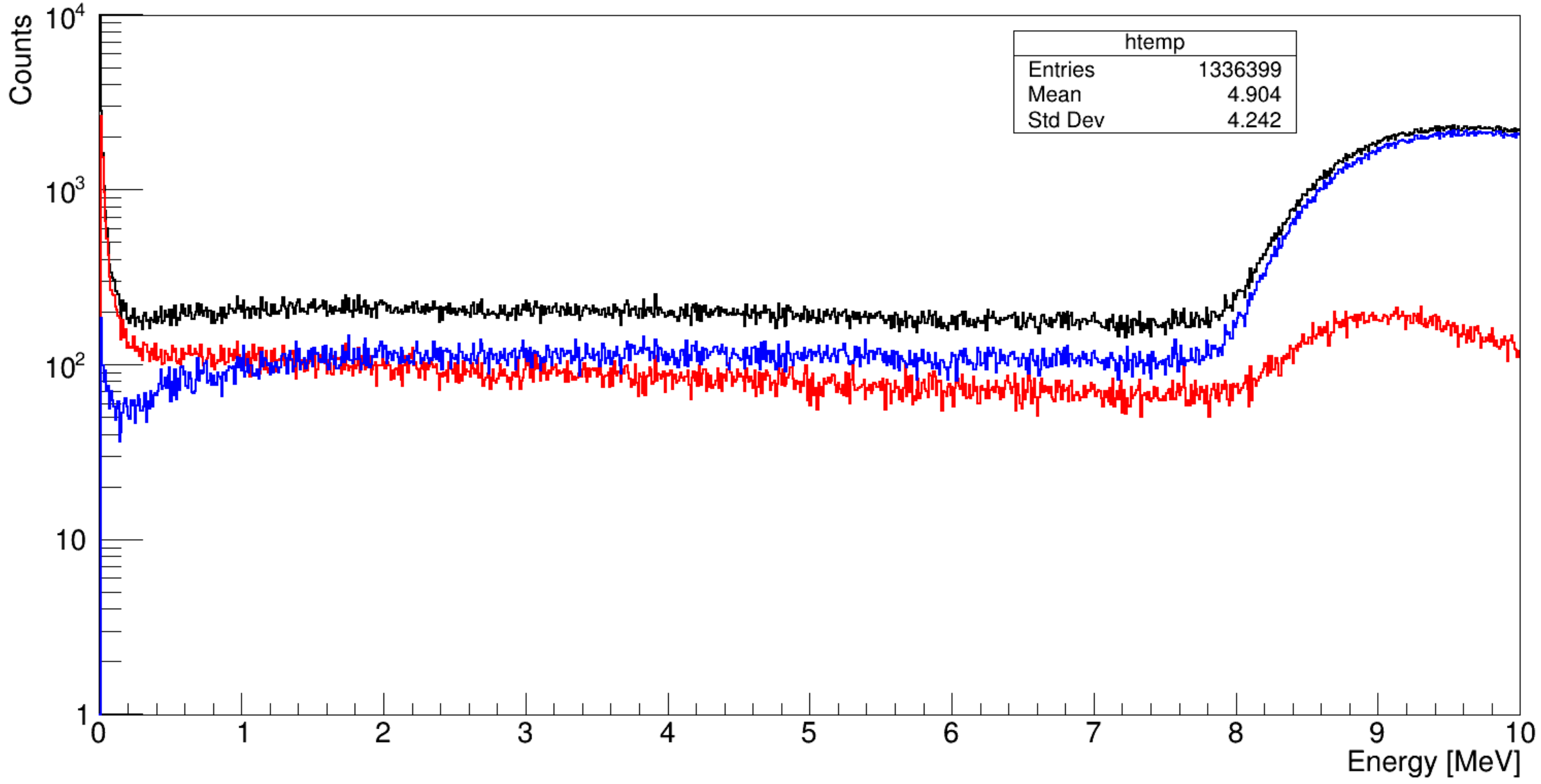
Poisson distribution

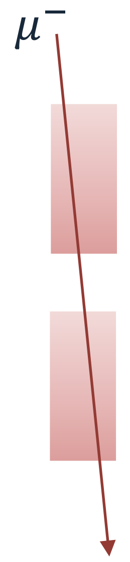
MC routine to generate a high statistics spectrum and rescale according to the expected (or fitted) pile-up rate

Example for ^{90}Sr:

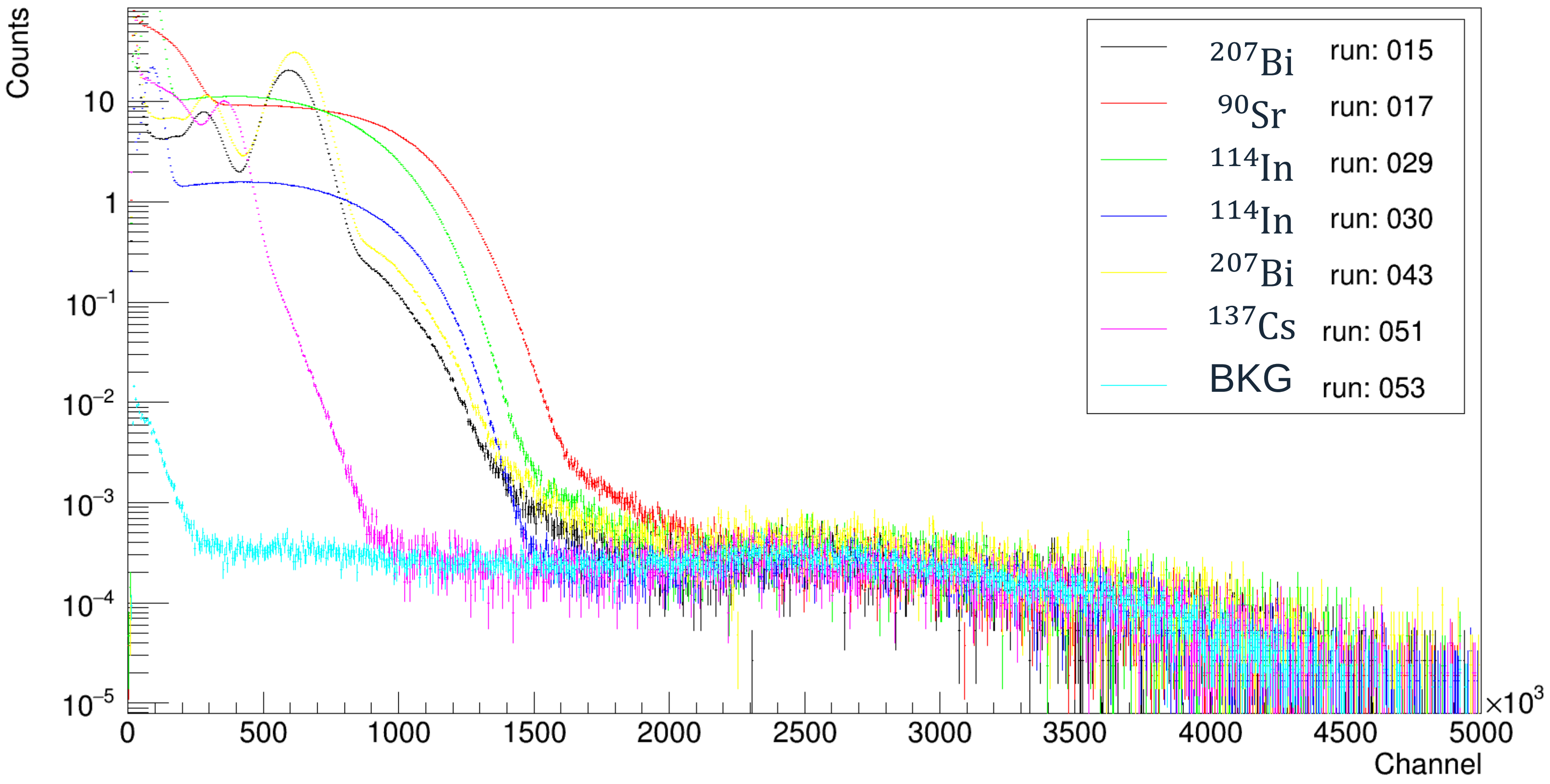


COSMIC MUONS



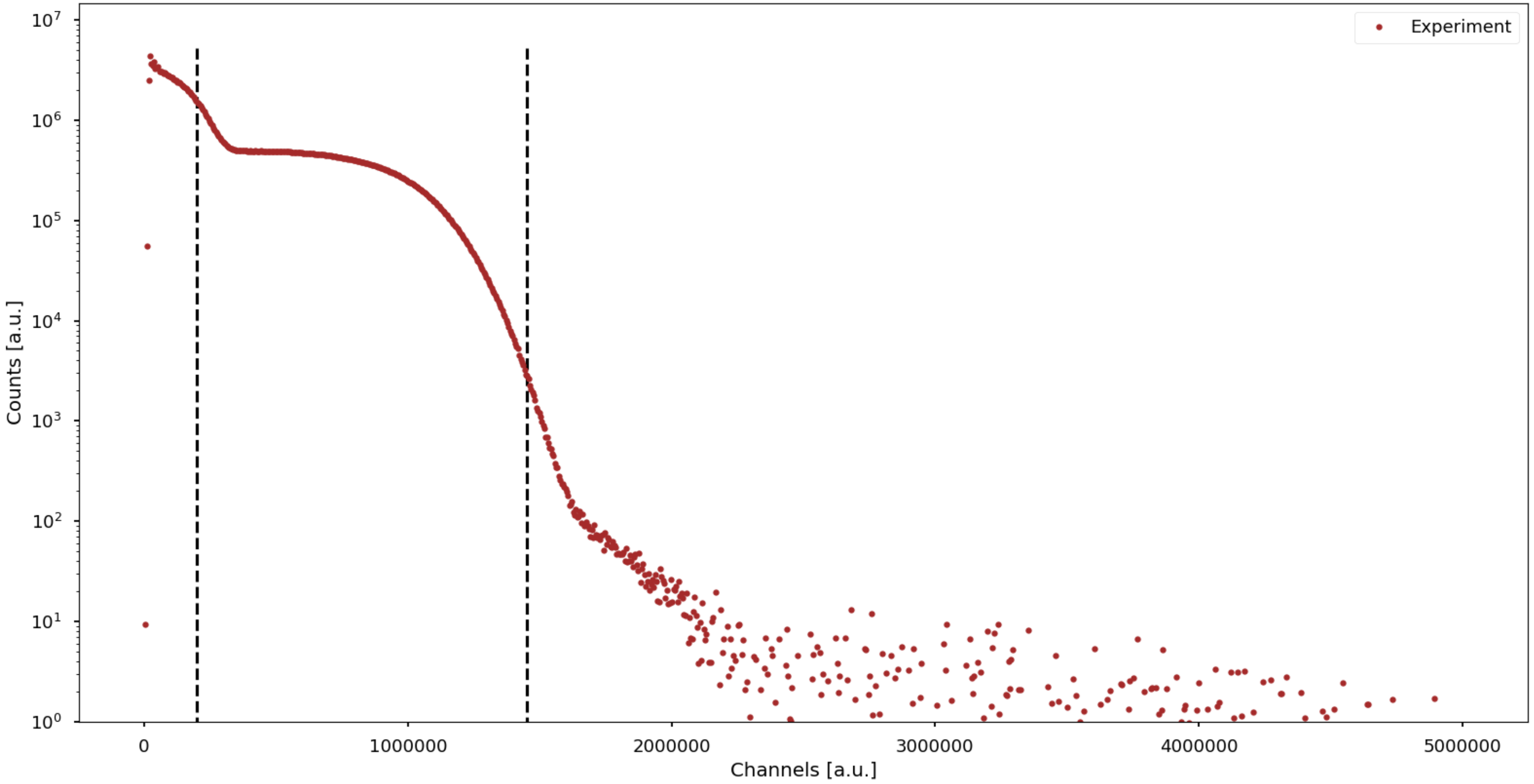


BACKGROUND


Counts
10
1
10^−1
10^−2
10^−3
10^−4
10^−5
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
×10^3
Channel
207Bi run: 015
90Sr run: 017
114In run: 029
114In run: 030
207Bi run: 043
137Cs run: 051
BKG run: 053

FIT SPECTRA

PRELIMINARY RESULTS!



Pile-up: P_{pile}, P_{back}

Calibration: $a_0 + a_1 x(+a_2 x^2)$

Resolution: $(\sigma_0+)\sigma_1\sqrt{E} + \sigma_2 E^2$

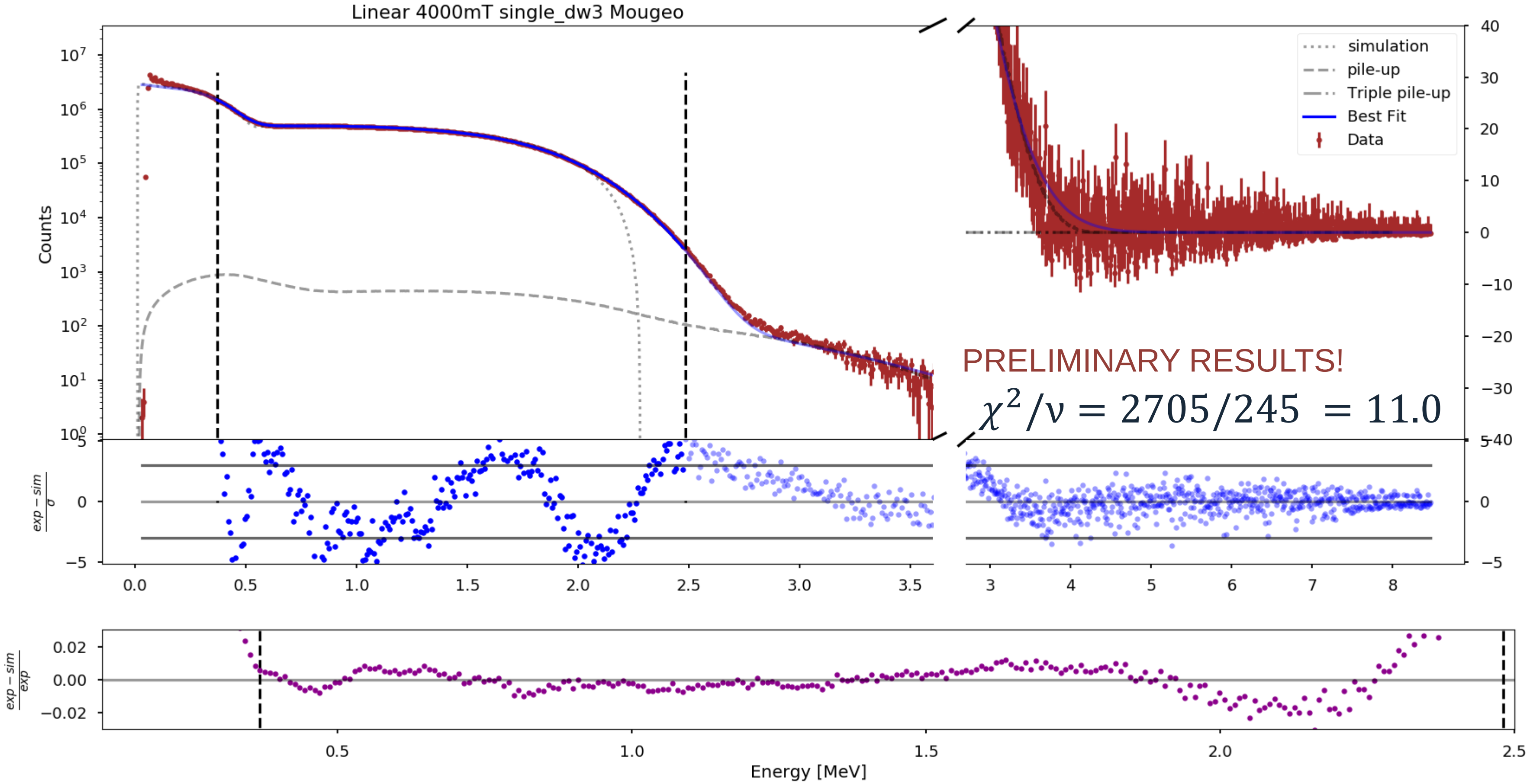
Norm: A

Conditions:

a_0, σ_0<<

Toward a measurement of weak magnetism in 6He decay X. Huyan *et al.*, 2016

FIT SPECTRA



PRELIMINARY RESULTS!

Pile-up: P_{pile}, P_{back}

Calibration: $a_0 + a_1 x(+a_2 x^2)$

Resolution: $(\sigma_0+)\sigma_1\sqrt{E} + \sigma_2 E^2$

Norm: A

Conditions:

a_0, σ_0<<

$A = 3.49(18)$

$\sigma_1 = 0.09(4)$

$\sigma_2 = 0.03(2)$

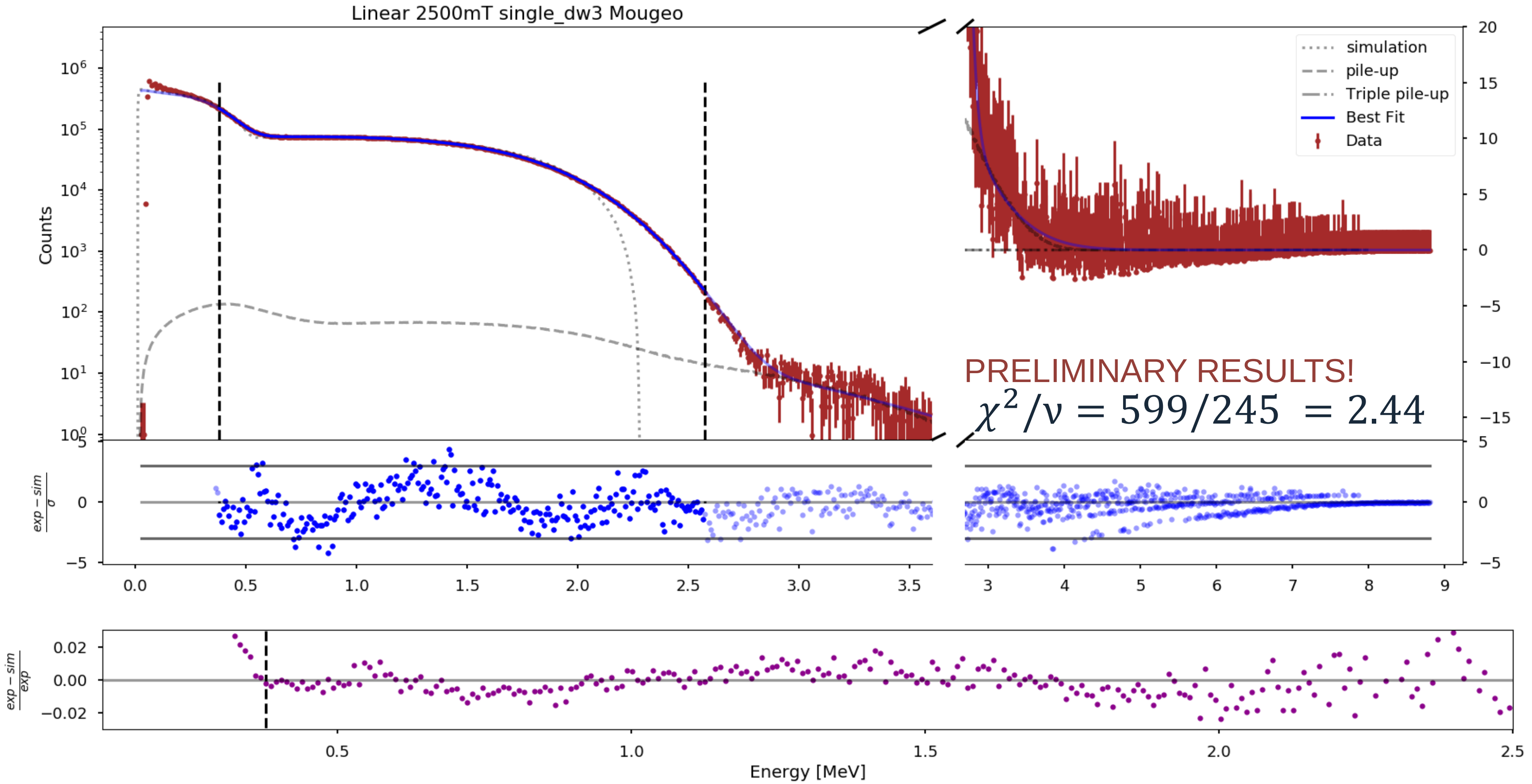
$a_0 = 0.026(16)$

$a_1 = 1.69(3)$

Toward a measurement of weak magnetism in 6He decay X. Huyan *et al.*, 2016

FIT SPECTRA

PRELIMINARY RESULTS!



Pile-up: P_{pile}, P_{back}

Calibration: $a_0 + a_1 x (+a_2 x^2)$

Resolution: $(\sigma_0+)\sigma_1\sqrt{E} + \sigma_2 E^2$

Norm: A

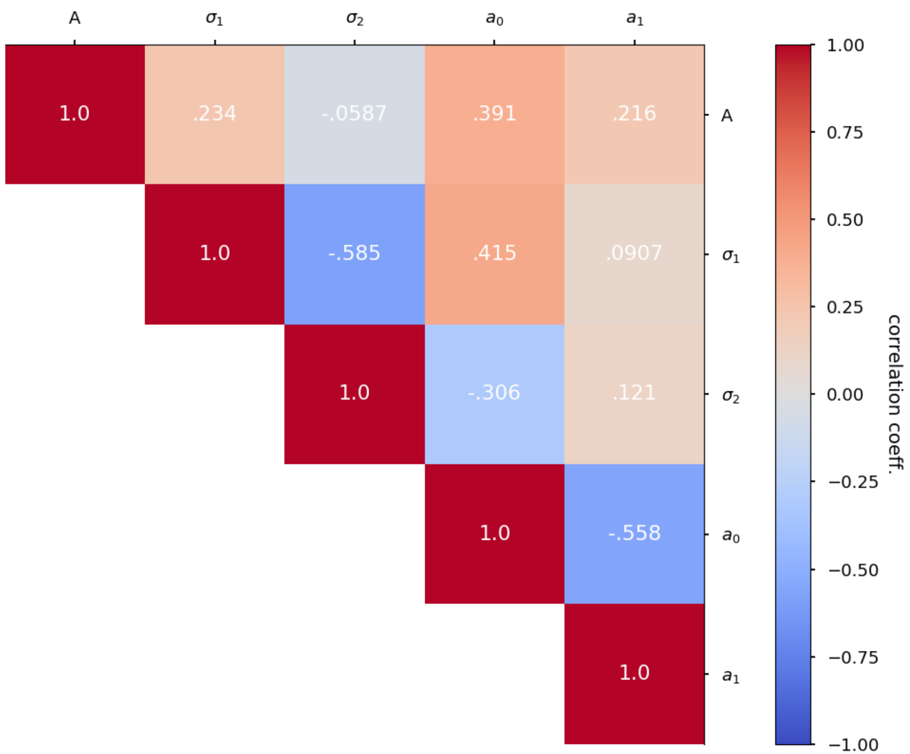
Conditions:

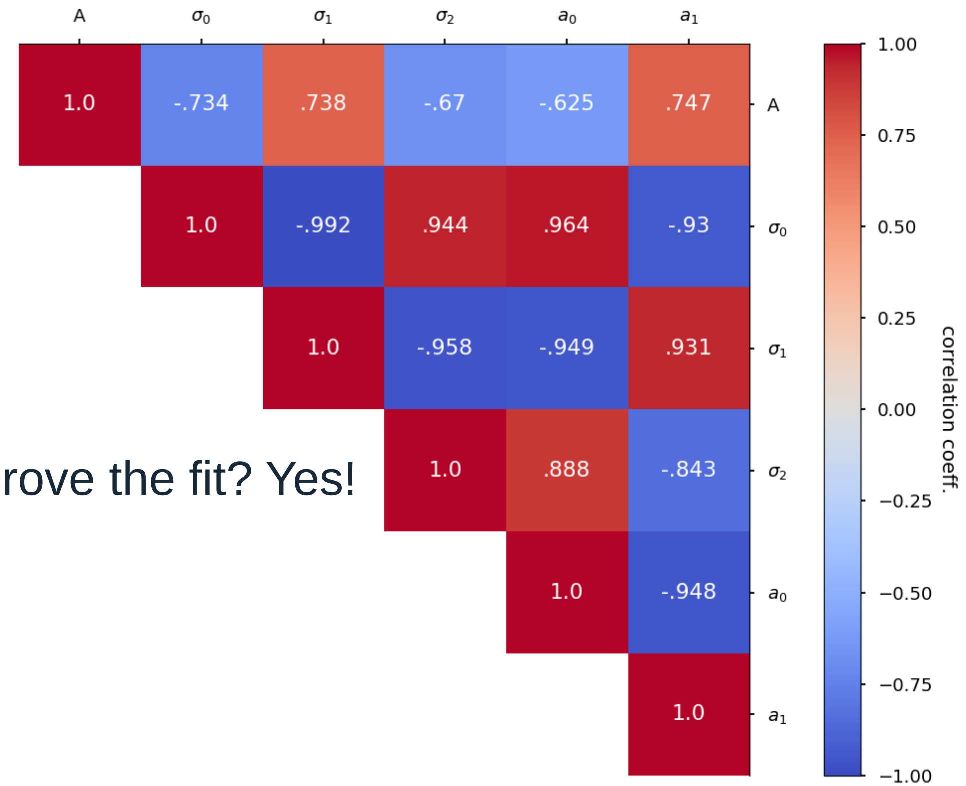
a_0, σ_0<<

$$A = 0.80(3)$$
$$\sigma_1 = 0.10(5)$$
$$\sigma_2 = 0.03(3)$$
$$a_0 = 0.023(24)$$
$$a_1 = 1.76(4)$$

Toward a measurement of weak magnetism in 6He decay X. Huyan *et al.*, 2016

FIT SPECTRA





Can we further improve the fit? Yes!

$\boldsymbol{A = 0.79(6)}$

$\boldsymbol{\sigma_0 = 0.06(24)}$

$\boldsymbol{\sigma_1 = 0.06(50)}$

$\boldsymbol{\sigma_2 = 0.04(6)}$

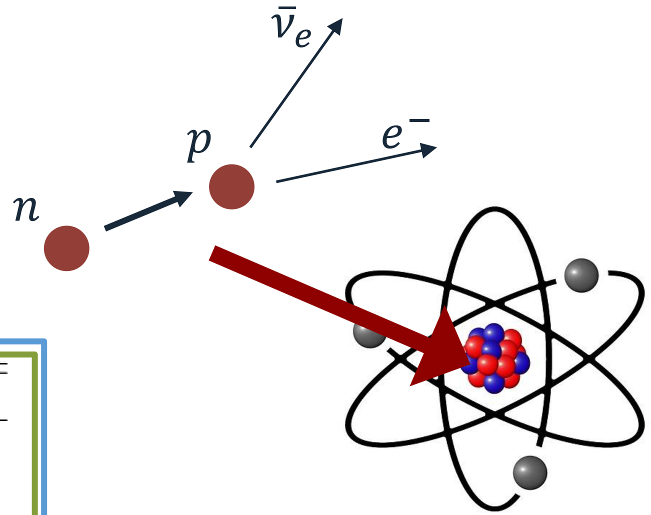
$\boldsymbol{a_0 = 0.03(7)}$

$\boldsymbol{a_1 = 1.7(1)}$

$\chi^2/\nu = 450.2/244 = 1.85$

The same is true when using a quadratic calibration

THEORETICAL DESCRIPTION SPECTRUM SHAPE



$^{114}_{49}\mathrm{In}$

$^{90}_{38}\mathrm{Sr} + ^{90}_{39}\mathrm{Y}$

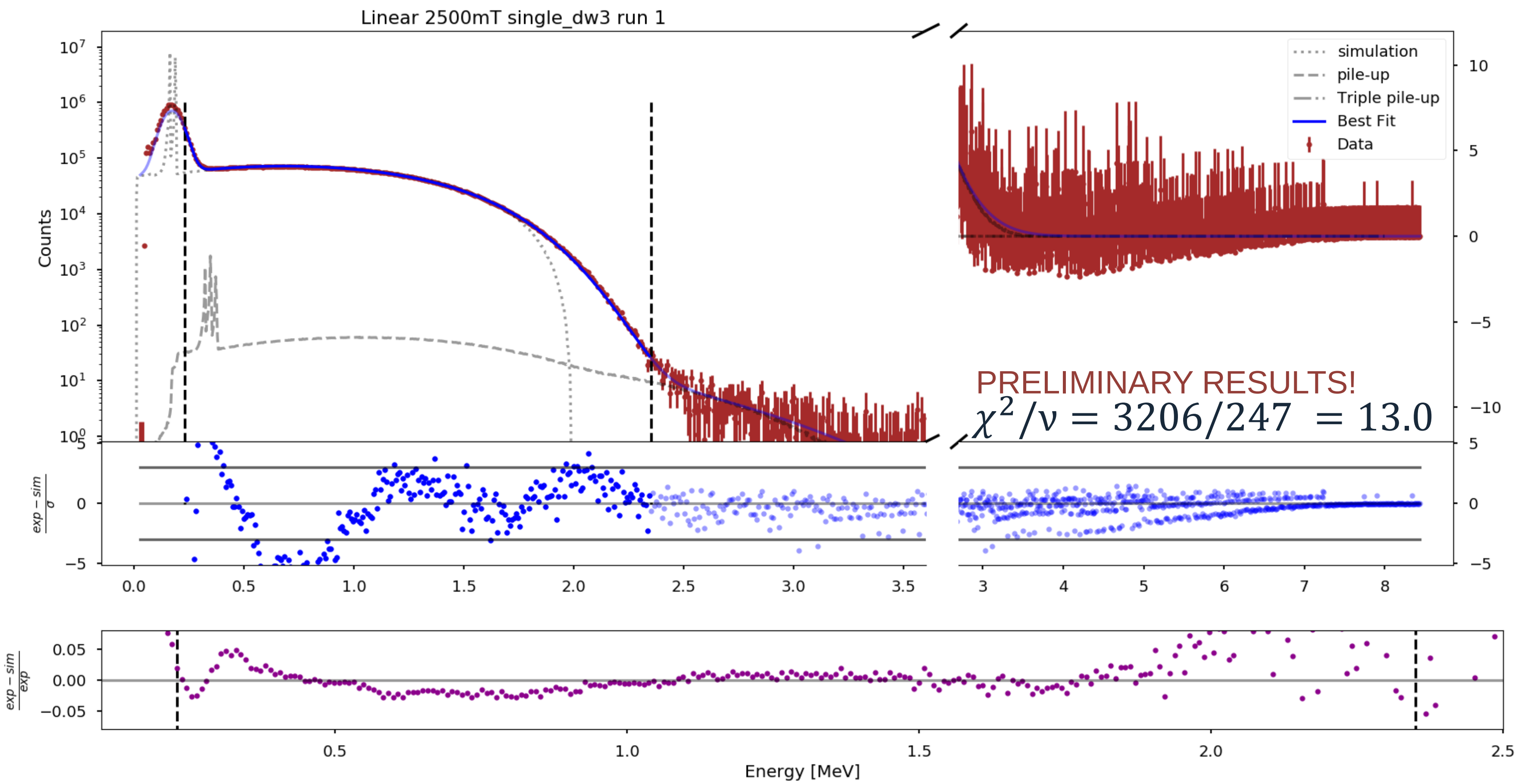
Category	Effect	Formula	Magnitude
Phase space		$pW(W_0 - W)^2$	Unity or larger
Electrostatic	Fermi function	F_0	
	Finite size nucleus	L_0	
Radiative corr.		R	
Recoil-order	Shape factor	C	
	Isovector correction	C_I	
Atomic	Atomic exchange	X	$10^{-1} - 10^{-2}$
	Atomic mismatch	r	
	Atomic screening	S	
	Shake-up & Shake-off	included in r	
Higher order	Diffuse nucl. surface	U	
	Nuclear deformation	D_{FS} & D_C	
	Recoil Coulomb corr.	Q	$10^{-3} - 10^{-4}$
	Recoiling nucleus	R_N	
	Molecular screening	ΔS_{Mol}	
	Molecular decay	Case by case	
	Bound state β decay	Γ_b/Γ_c	$< 1 \times 10^{-4}$
	Neutrino mass	negligible	

First forbidden unique decay add: $q^2 + \lambda_2 p^2$

High precision analytical description of the allowed β spectrum shape L. Hayen *et al.* 2018 Reviews of Modern Physics
Reliability of usual assumptions in the calculation of β and ν spectra X. Mougeot 2015 Physical Review C

FIT SPECTRA

PRELIMINARY RESULTS!



Pile-up: P_{pile}, P_{back}

Calibration: $a_0 + a_1 x (+a_2 x^2)$

Resolution: $(\sigma_0 +) \sigma_1 \sqrt{E} + \sigma_2 E^2$

Norm: A

Conditions:

$a_0, \sigma_0 <<$

$A = 1.20(5)$

$\sigma_1 = 0.10(1)$

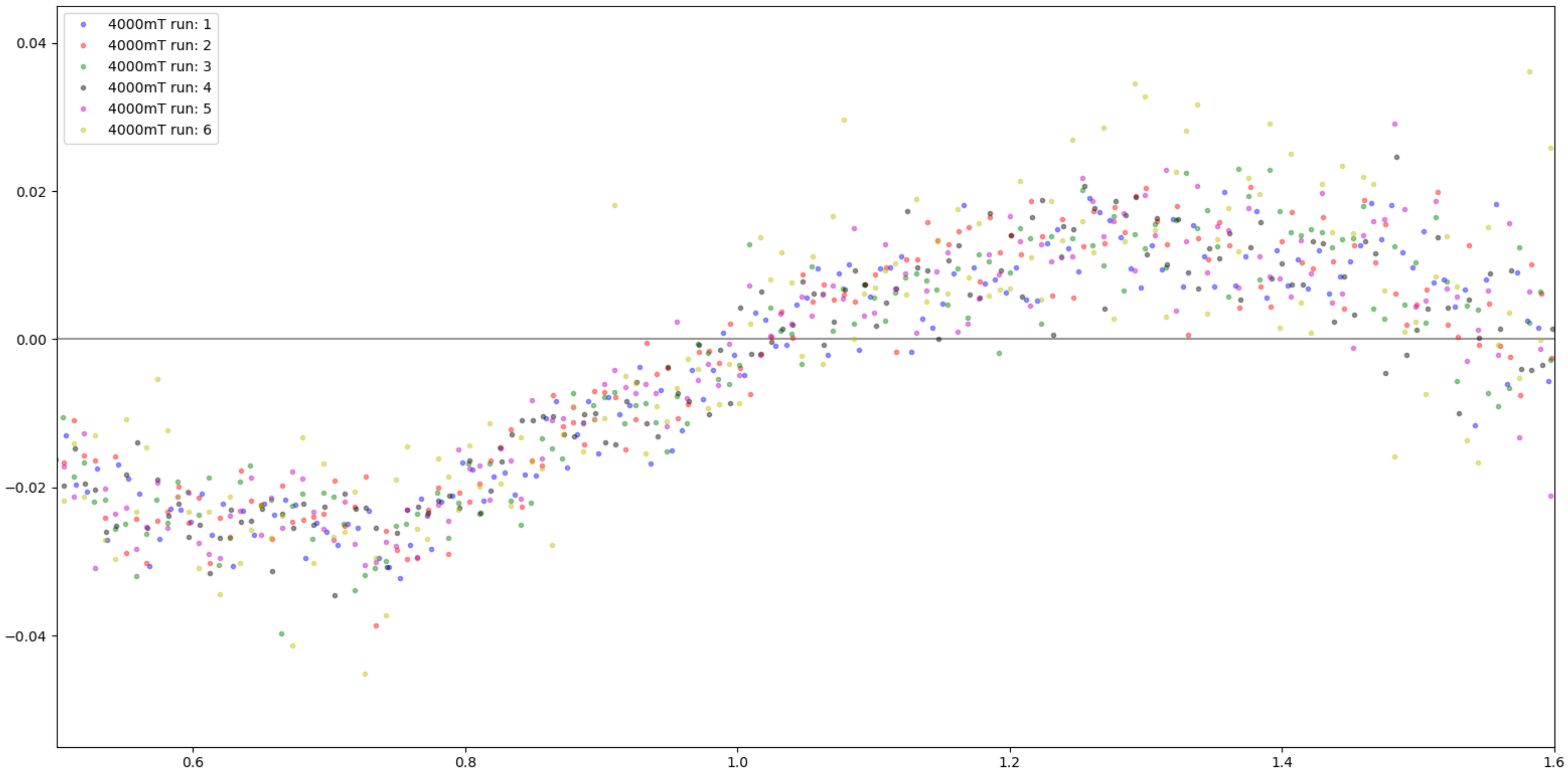
$\sigma_2 = 0.03(8)$

$a_0 = 0.023(11)$

$a_1 = 1.68(9)$

Toward a measurement of weak magnetism in 6He decay X. Huyan *et al.*, 2016

FIT RESIDUALS



(EXPERIMENTAL) OUTLOOK

Use full theoretical description of $^{114m}_{49}\mathrm{In}$ spectra to obtain b_{WM}

Investigate experimental improvements:

Replace mylar source foil: 2 μm (aluminized) → 500 nm (non-aluminized)

Detectors:

- SiPM matrix
- Si(Li) detectors

Other interesting isotopes?

THANK YOU FOR YOUR ATTENTION!

Please feel free to ask questions or provide your feedback!

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