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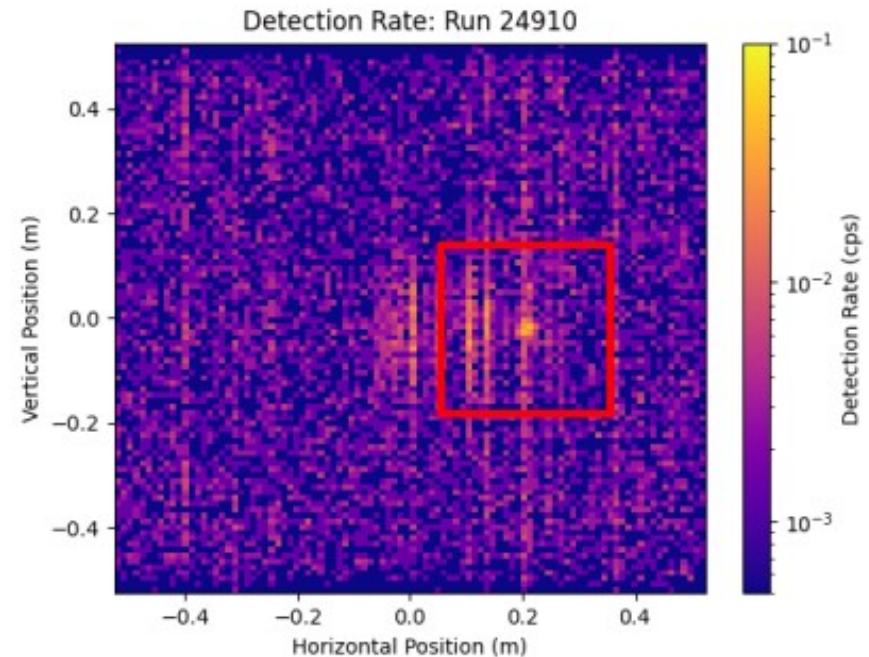
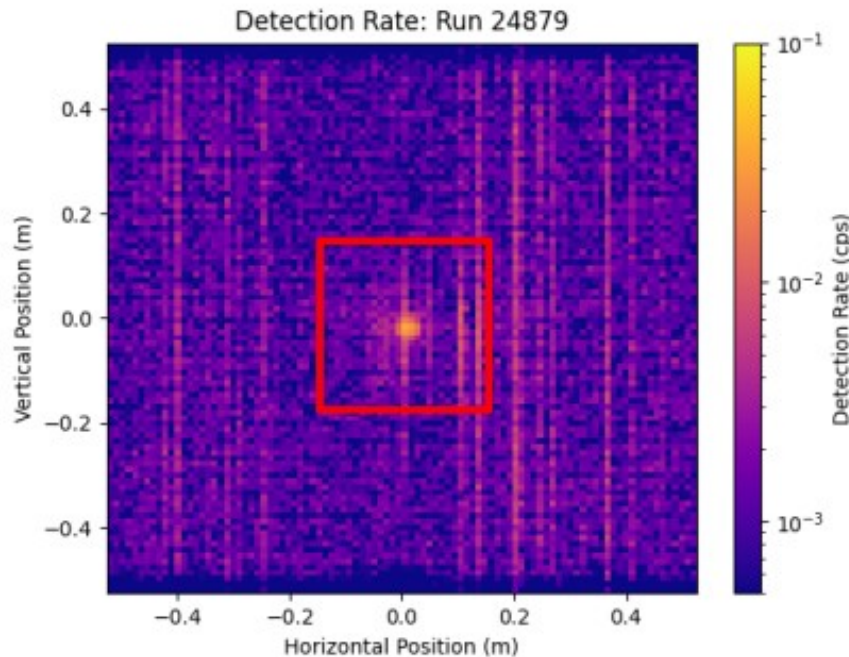
# Analyzing GPSANS data from 2021 Experiment

**Estimating fit error using multivariate  
parameter sampling, analyzing statistical  
effect of  $|B|$  on neutron oscillation**

# Region of Interest Definition

Size and position of roi defined by centering focus and finding square of size which contains 95% of detections

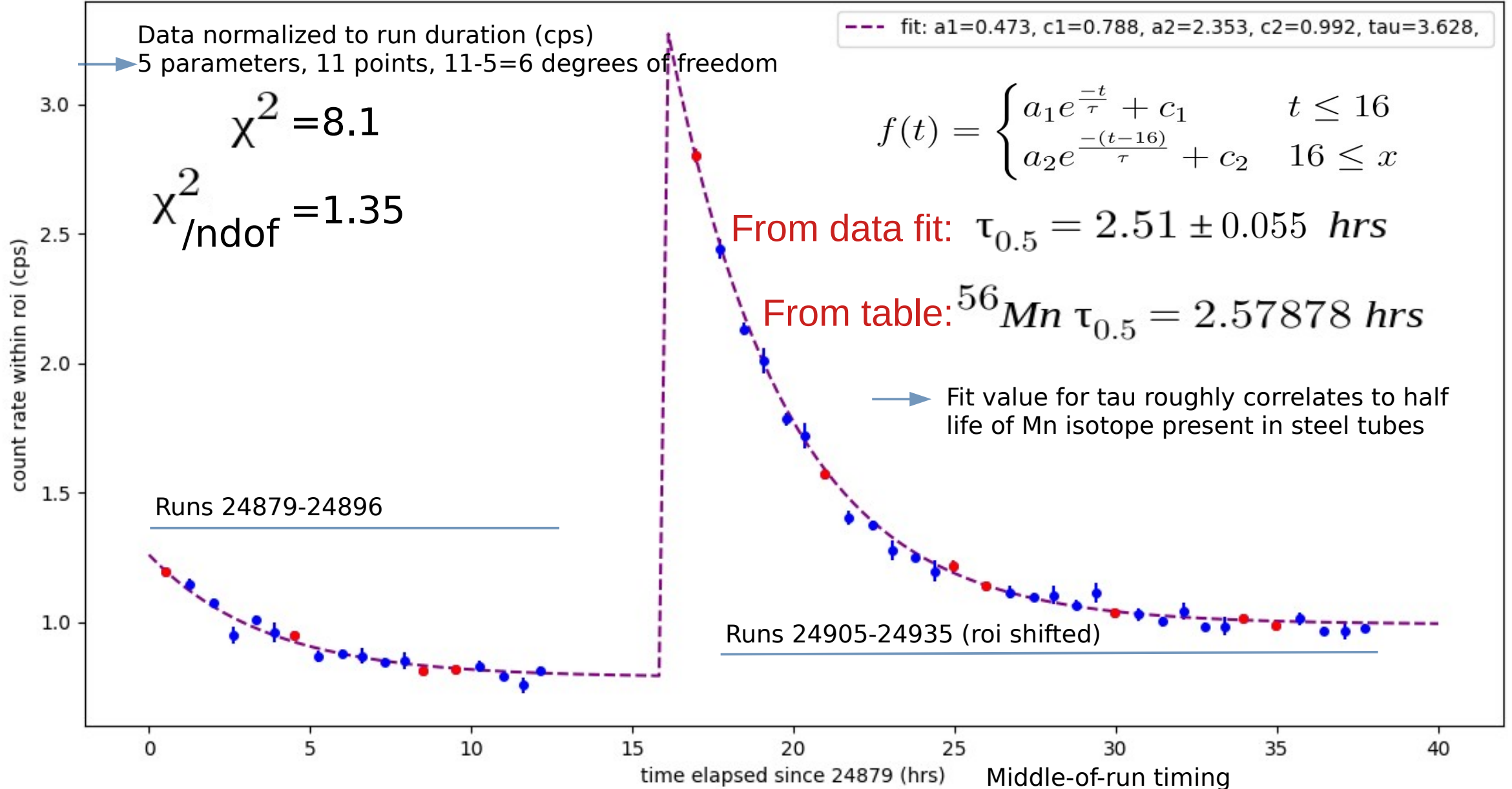
- Detector position shifted  $\sim 20\text{cm}$  between runs 24902-24904



- Total counts per run within these roi were then recorded and plotted

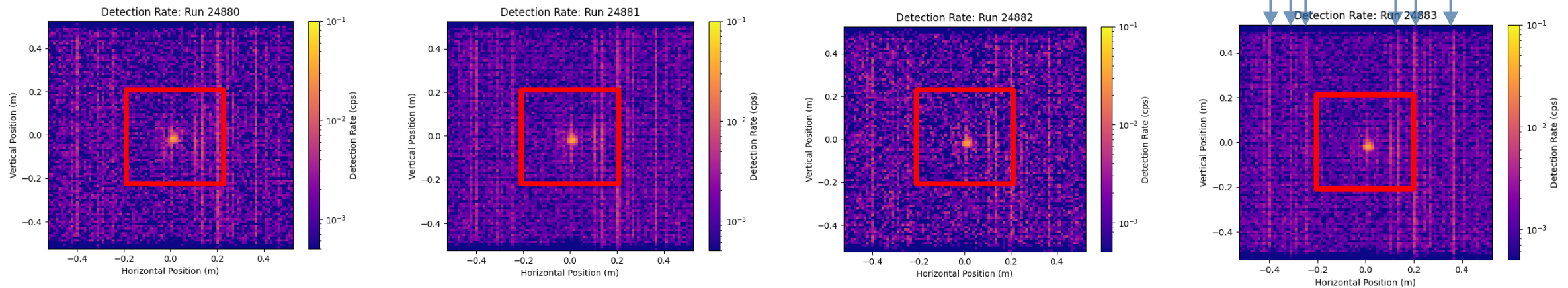
# Curve fitting to counts within ROI

**Red runs have field  $|B|=0$ , curve is fit to red points (assumes  $|B|=0$  has no effect)**

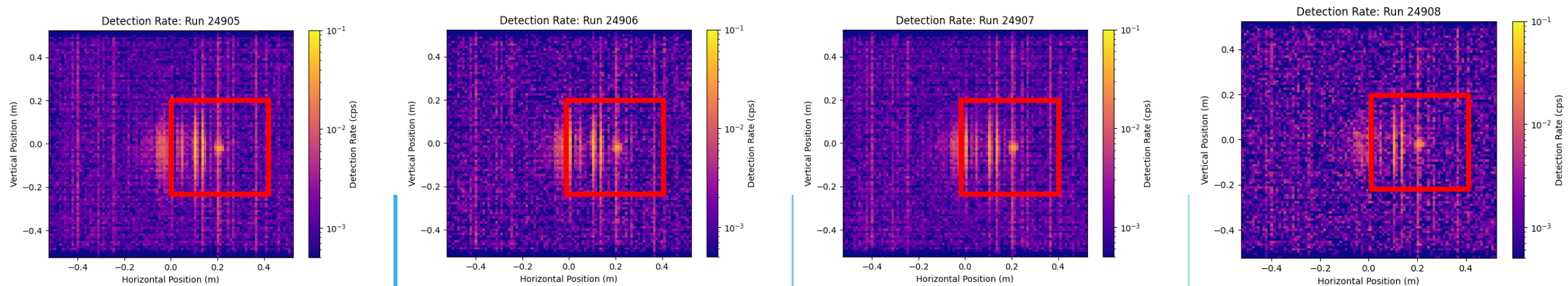


# Regions of Interest

- Different ROIs include different tubes, some tubes are more noisy than others, could explain difference in background value (c1,c2) of fit
- First Sequence (runs 24879-24902)**



## Second Sequence (runs 24904-24935), roi shifted 20cm



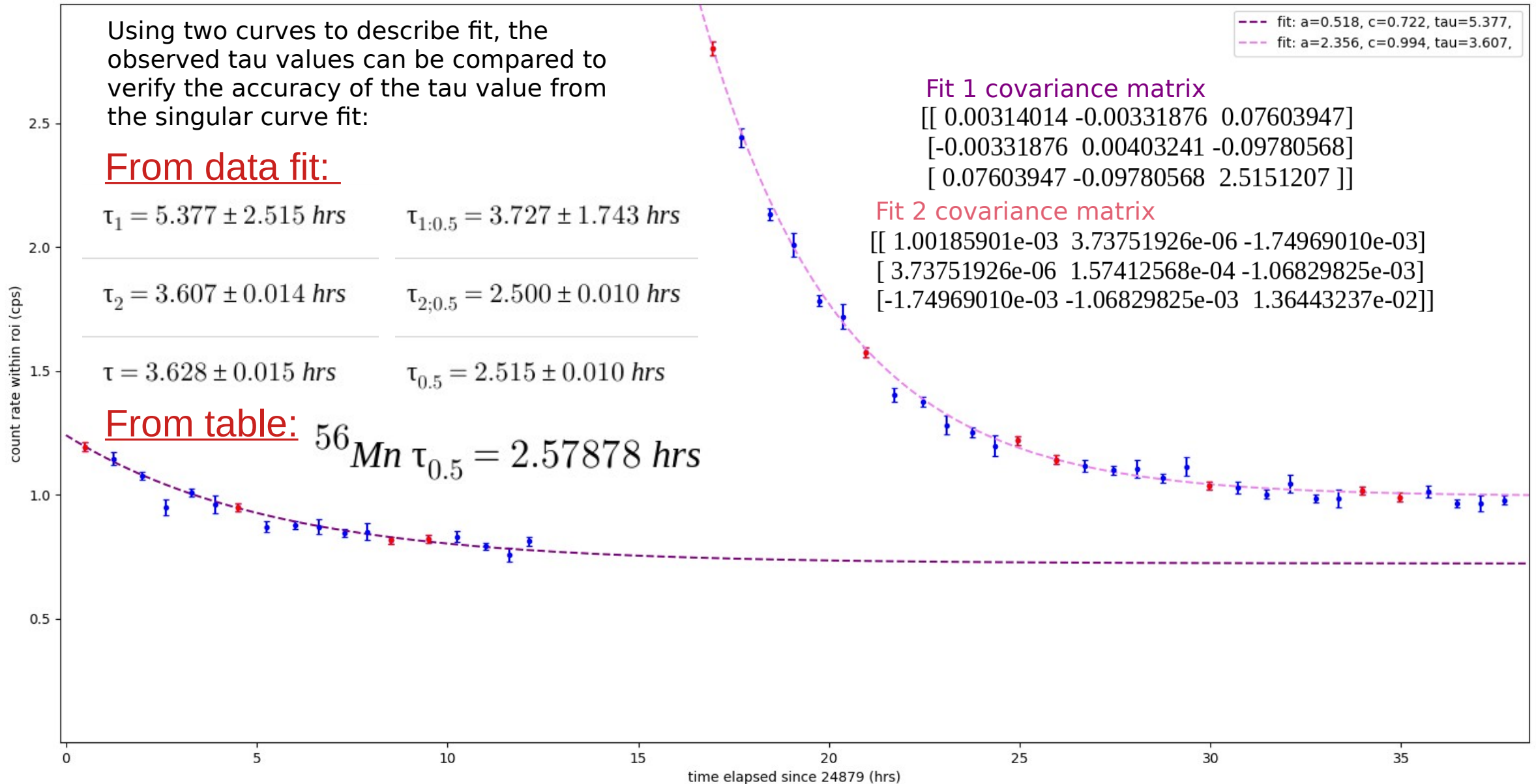
# Covariance Matrix for |B|=0, 5 parameters fit

|     | a1        | c1        | a2        | c2        | tau       |
|-----|-----------|-----------|-----------|-----------|-----------|
| a1  | 9.74E-04  | -3.31E-04 | -3.24E-05 | -2.02E-05 | 2.57E-04  |
| c1  | -3.31E-04 | 2.26E-04  | 6.71E-05  | 4.18E-05  | -5.33E-04 |
| a2  | -3.24E-05 | 6.71E-05  | 1.12E-03  | 4.87E-07  | -1.93E-03 |
| c2  | -2.02E-05 | 4.18E-05  | 4.87E-07  | 1.78E-04  | -1.20E-03 |
| tau | 2.57E-04  | -5.33E-04 | -1.93E-03 | -1.20E-03 | 1.53E-02  |

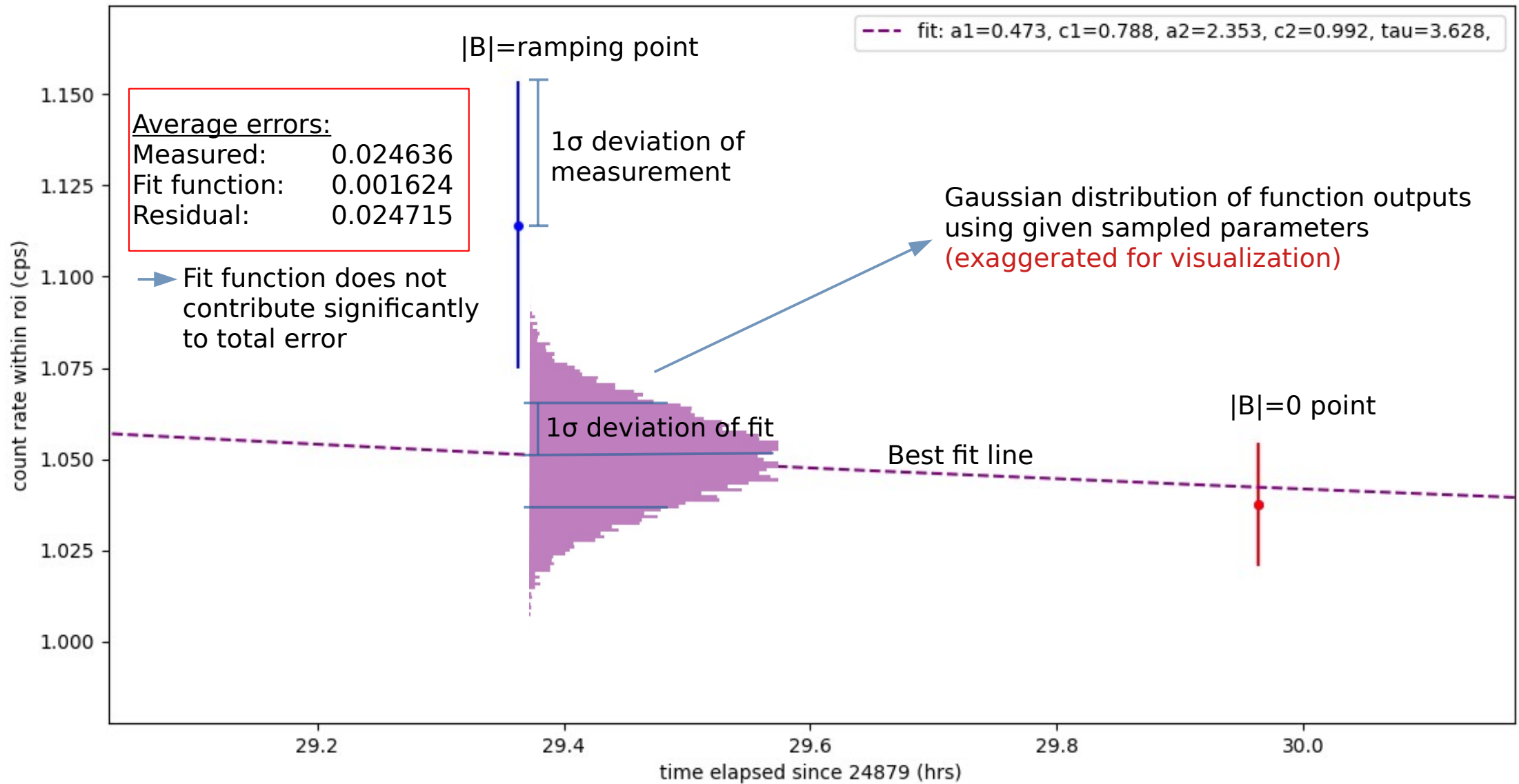
- Covariance matrix shows correlation between variables, diags show standard deviation of each variable
- symmetric positive definite matrix

$$f(t) = \begin{cases} a_1 e^{\frac{-t}{\tau}} + c_1 & t \leq 16 \\ a_2 e^{\frac{-(t-16)}{\tau}} + c_2 & 16 \leq x \end{cases}$$

# Resilience of fit



# Visualization of Sampling Process



# Using cov. Matrix to find fit error

(1) For each time value, find estimated countrate using best fit function  $f(t)$  with **optimal params**

(2) take 5d correlated gaussian sample for params using **cov**, find  $f(t, p')$  estimated countrate given those params

(3) find difference between best fit estimate (1) and sampled params estimate (2)

(4) repeat steps (2)-(3) 100,000 times, find standard deviation of difference found in (3)  
→ standard deviation = error for  $f(t)$  found in (1)

$$f(t) = \begin{cases} a_1 e^{\frac{-t}{\tau}} + c_1 & t \leq 16 \\ a_2 e^{\frac{-(t-16)}{\tau}} + c_2 & 16 \leq x \end{cases}$$

- **Error for points = standard deviation of fit value for each point**
- **Using numpy function:**  
`np.random.mult(params, cov matrix)`
  - **Samples params for fit' function given covariance matrix from scipy fit**

# Error propagation for correction

→ *measured* − *fitted* = *residual rate*

$$R_m - R_f = R_r \quad (\text{Total measured} - \text{background effect}) = \text{isolated } |B| \text{ effect we are looking for}$$

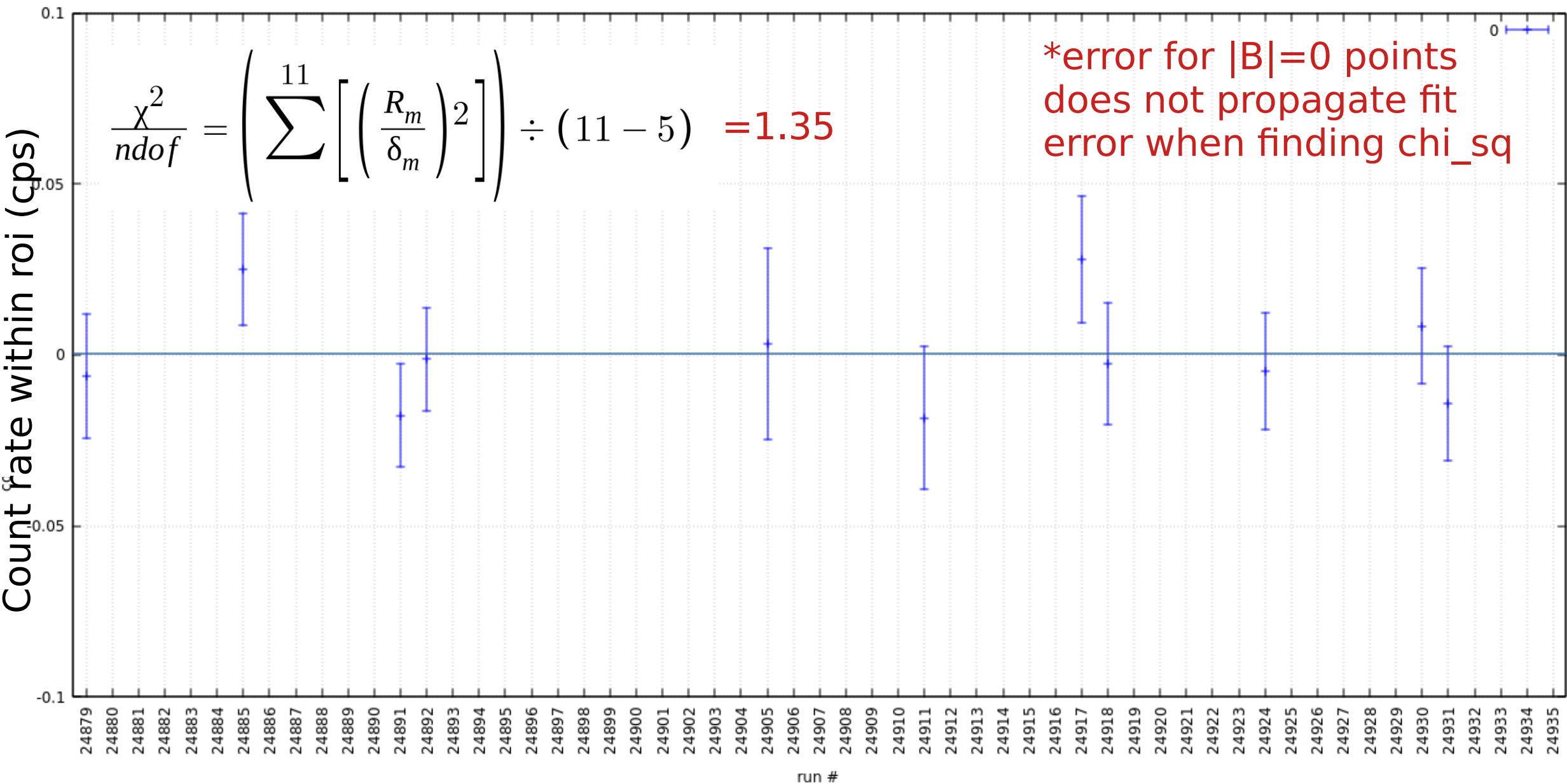
→  $\delta_m = \frac{\sqrt{N}}{\Delta t}$  Error for countrate value defined as sqrt(total counts within roi)/ total duration of run

$\delta_f =$  Error for fit defined as 1 standard deviation of fit' value for each point, and fit'(t) calculated with parameters sampled from given covariance matrix

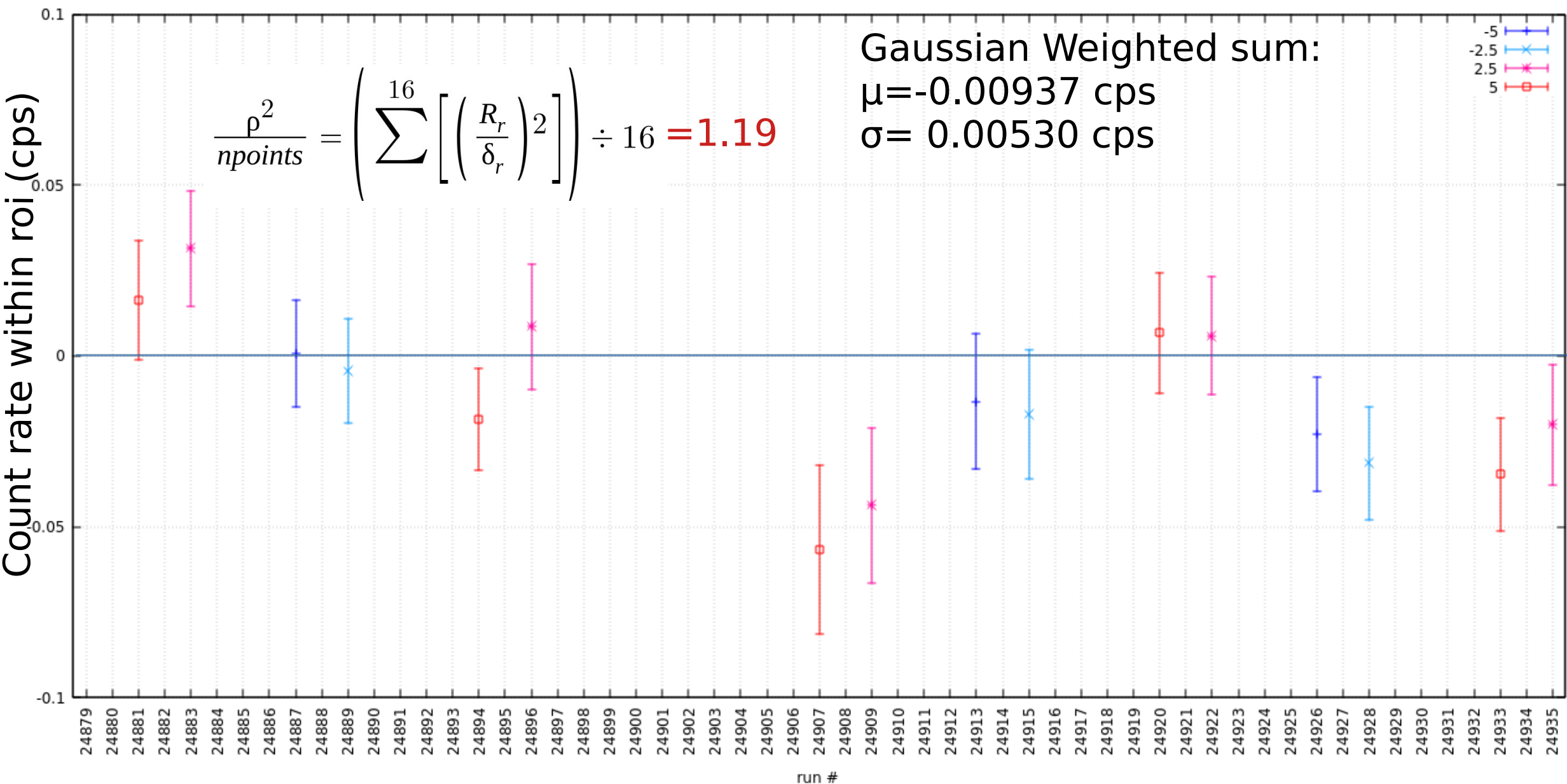
→  $\delta_r = \sqrt{\delta_m^2 + \delta_f^2}$  Error for residual rate found by adding component rates in quadrature

→  $R_r = (R_m - R_f) \pm \sqrt{\delta_m^2 + \delta_f^2}$  **Final value for residual rate**

# Residue of |B|=0 points : finding chi^2

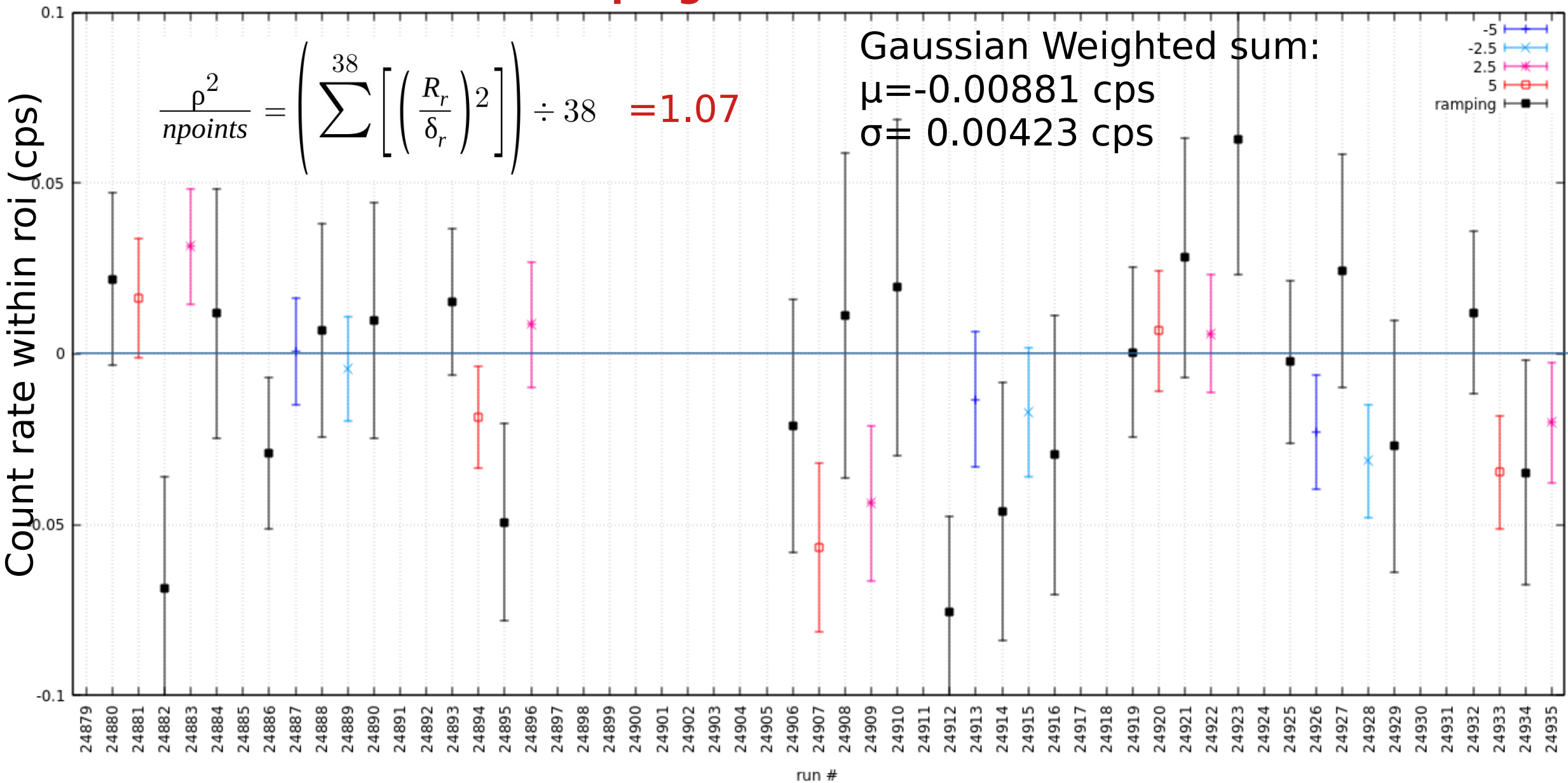


# Residue with propagated error for runs |B|=-5,-2.5,2.5,5

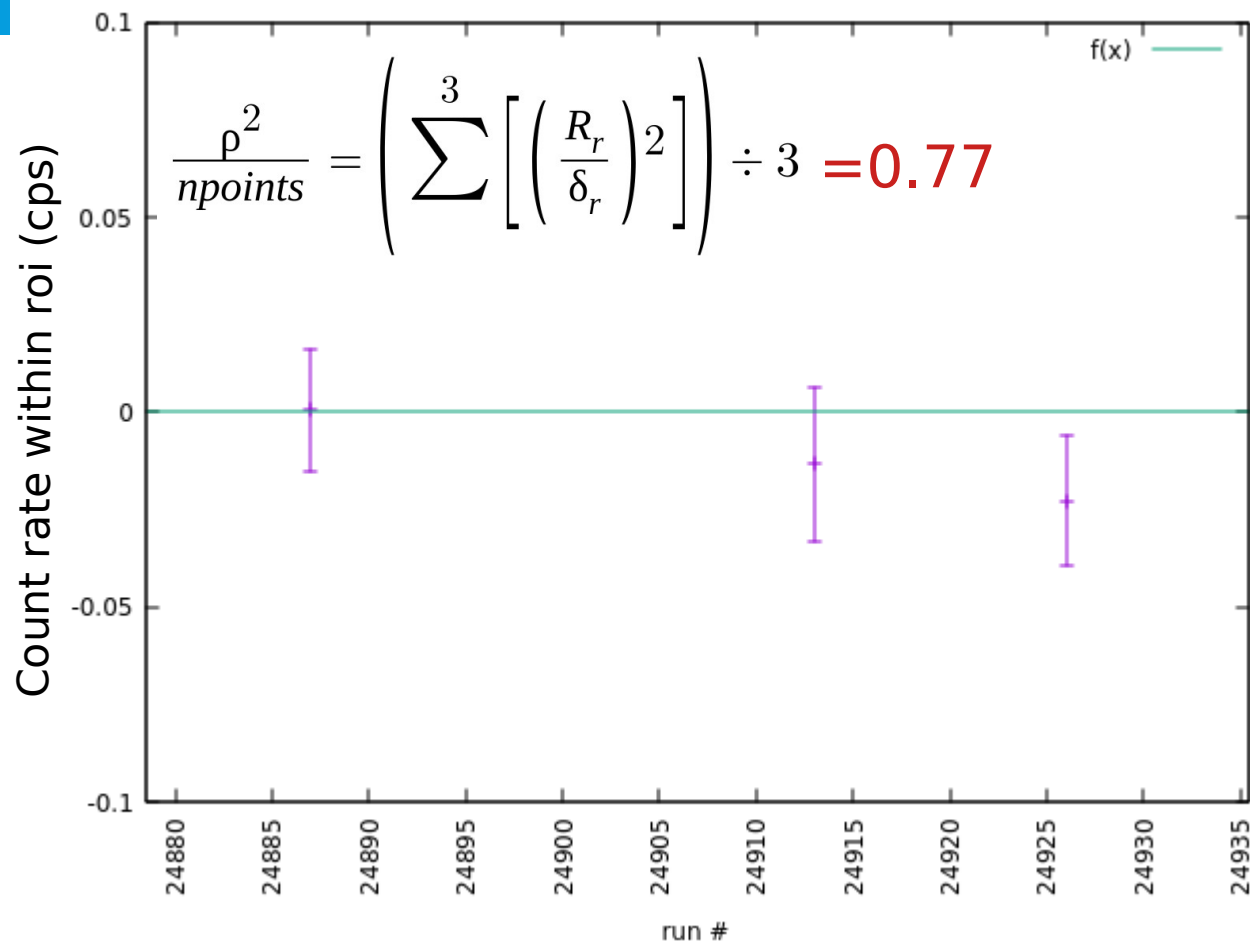


# Residue with final error for runs $|B| \neq 0$

**\*Ramping runs in black**



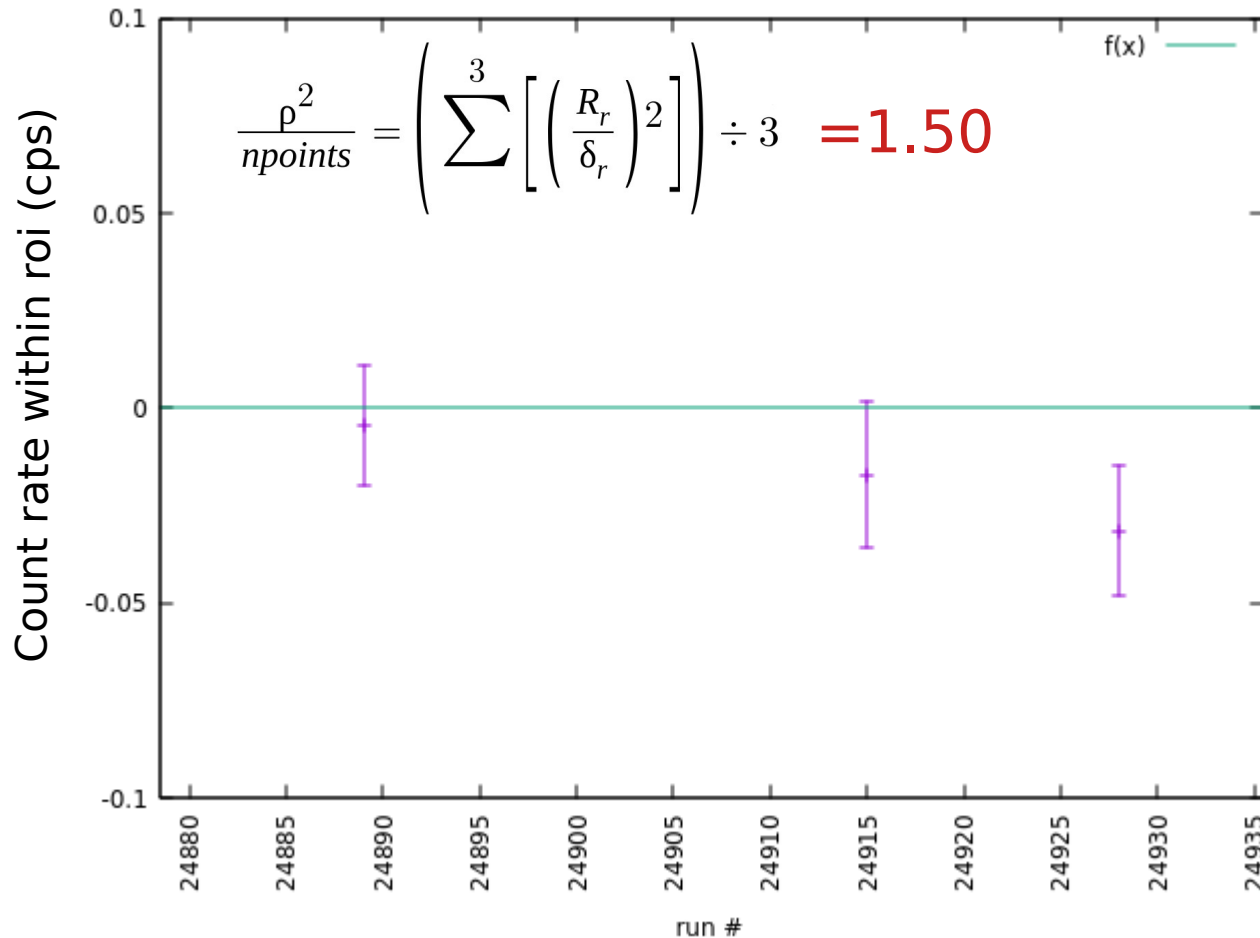
(residue per point)  $|B| = -5.0\text{T}$



Gaussian Weighted sum:  
 $\mu = -0.01147$  cps  
 $\sigma = 0.01188$  cps

| #run  | corrected counts ▶ | error        | B  |
|-------|--------------------|--------------|----|
| 24887 | 0.000595614738     | 0.0156598062 | -5 |
| 24913 | -0.0133341242      | 0.0198329428 | -5 |
| 24926 | -0.0227873336      | 0.0167062451 | -5 |

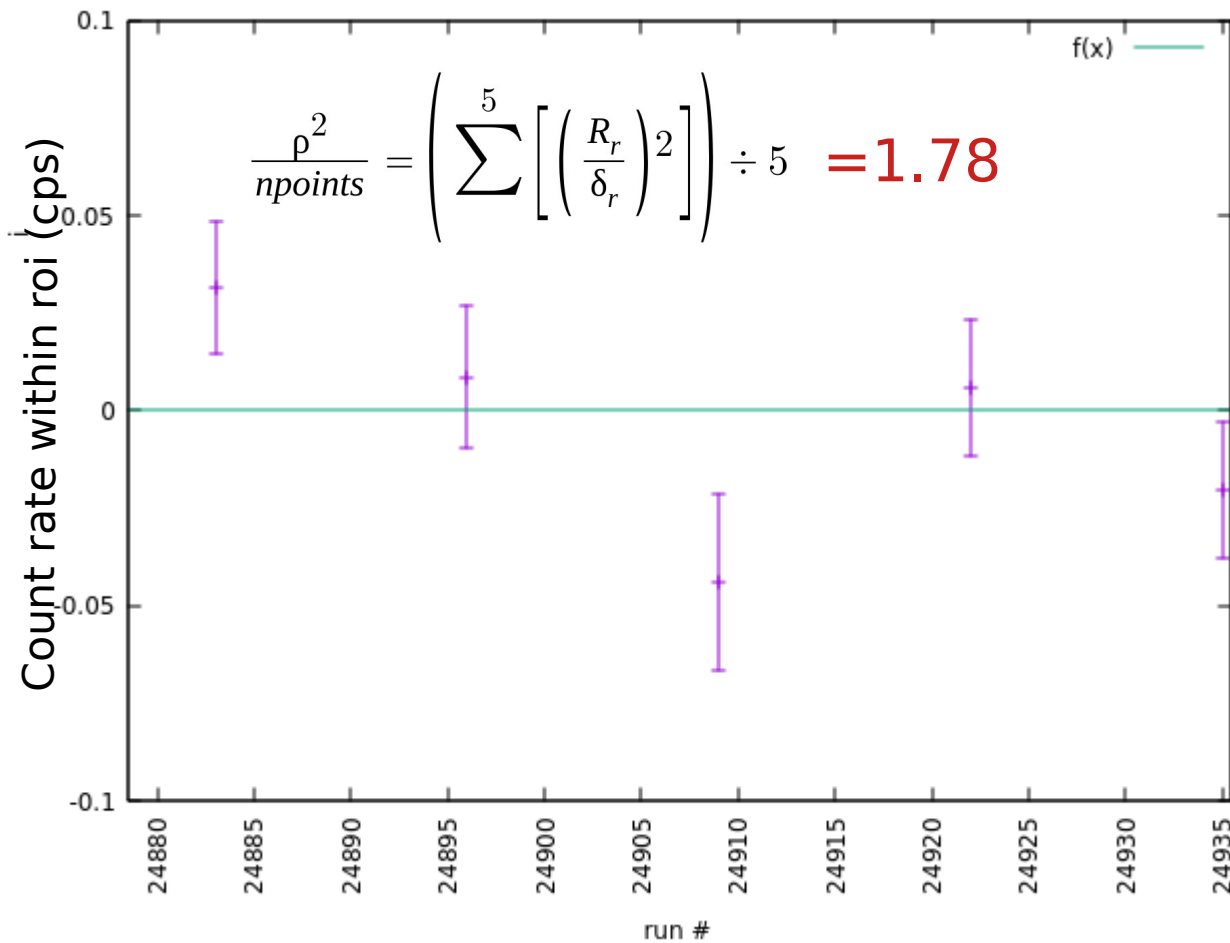
# |B|=-2.5T



Gaussian Weighted sum:  
 $\mu = -0.01731$  cps  
 $\sigma = 0.01180$  cps

| #run  | corrected counts | error        | B    |
|-------|------------------|--------------|------|
| 24889 | -0.00433777537   | 0.0153618211 | -2.5 |
| 24915 | -0.017016683     | 0.0188619339 | -2.5 |
| 24928 | -0.0313999617    | 0.0165443089 | -2.5 |

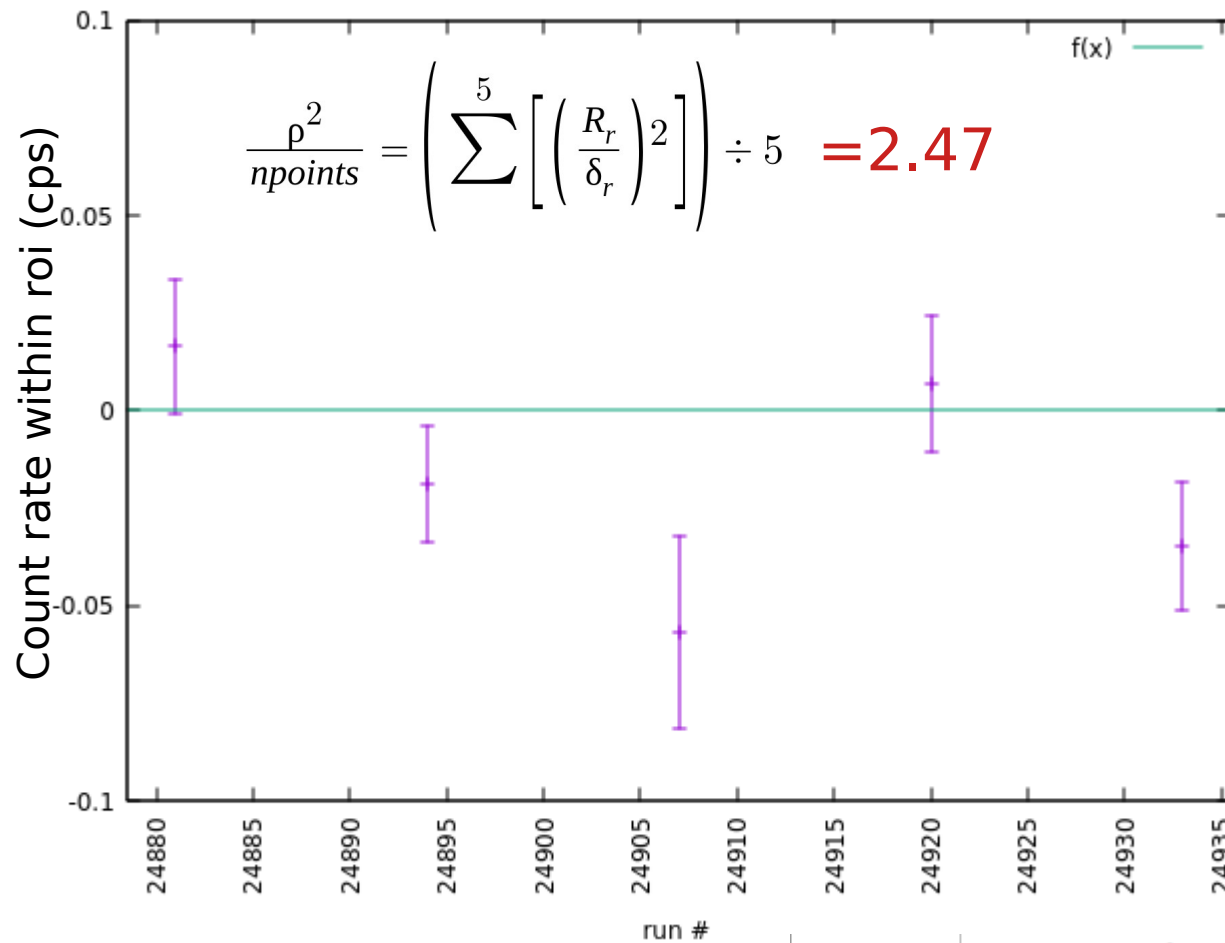
$$|B|=2.5T$$



Gaussian Weighted sum:  
 $\mu=0.00138$  cps  
 $\sigma=0.00977$  cps

| #run  | corrected counts within <u>roi</u> | error        | B   |
|-------|------------------------------------|--------------|-----|
| 24883 | 0.0314349476                       | 0.0168019511 | 2.5 |
| 24896 | 0.00863990393                      | 0.0183027262 | 2.5 |
| 24909 | -0.0437128771                      | 0.0226577458 | 2.5 |
| 24922 | 0.00585317692                      | 0.0172674944 | 2.5 |
| 24935 | -0.0201436788                      | 0.0175670429 | 2.5 |

$$|B|=5.0T$$



$$\frac{\rho^2}{n_{points}} = \left( \sum^5 \left[ \left( \frac{R_r}{\delta_r} \right)^2 \right] \right) \div 5 = 2.47$$

Gaussian Weighted sum:  
 $\mu = -0.01312$  cps  
 $\sigma = 0.00958$  cps

| #run  | corrected counts within <u>roi</u> | error        | B |
|-------|------------------------------------|--------------|---|
| 24881 | 0.016430161                        | 0.0173544826 | 5 |
| 24894 | -0.0186506426                      | 0.01484266   | 5 |
| 24907 | -0.0565596898                      | 0.0246868891 | 5 |
| 24920 | 0.00682909841                      | 0.0175408731 | 5 |
| 24933 | -0.0346497445                      | 0.0163839068 | 5 |

### **Beam Intensity Measurements:**

-Lowell Beam:  $9.93 \times 10^8$  neutrons/s  
-Au Foil:  $7.4 \times 10^8$  neutrons/s

$$\mu = -0.01312 \text{ n/s}$$

$$\text{Intensity} = 8.7 \times 10^8 \text{ n/s}$$

$$\mu/\text{intensity} = -1.5\text{E-}11$$

-Average Intensity:  $8.7 \times 10^8$  neutrons/s

$$\sigma/(\text{intensity-estimated error}) = 1.3\text{E-}11$$

-Estimated Error:  $1.3 \times 10^8$  neutrons/s

-Relative Error: 15%

### **Considering |B|=5.0T**

Gaussian Weighted sum of corrected data:

$$\mu = -0.01312$$

$$\sigma = 0.00958$$

### **Gives:**

Signal < 0.0026 [n/s] (95% Confidence Limit)

Signal < 0.0060 [n/s] (97.7% Confidence Limit)

Signal < 0.0092 [n/s] (99% Confidence Limit)

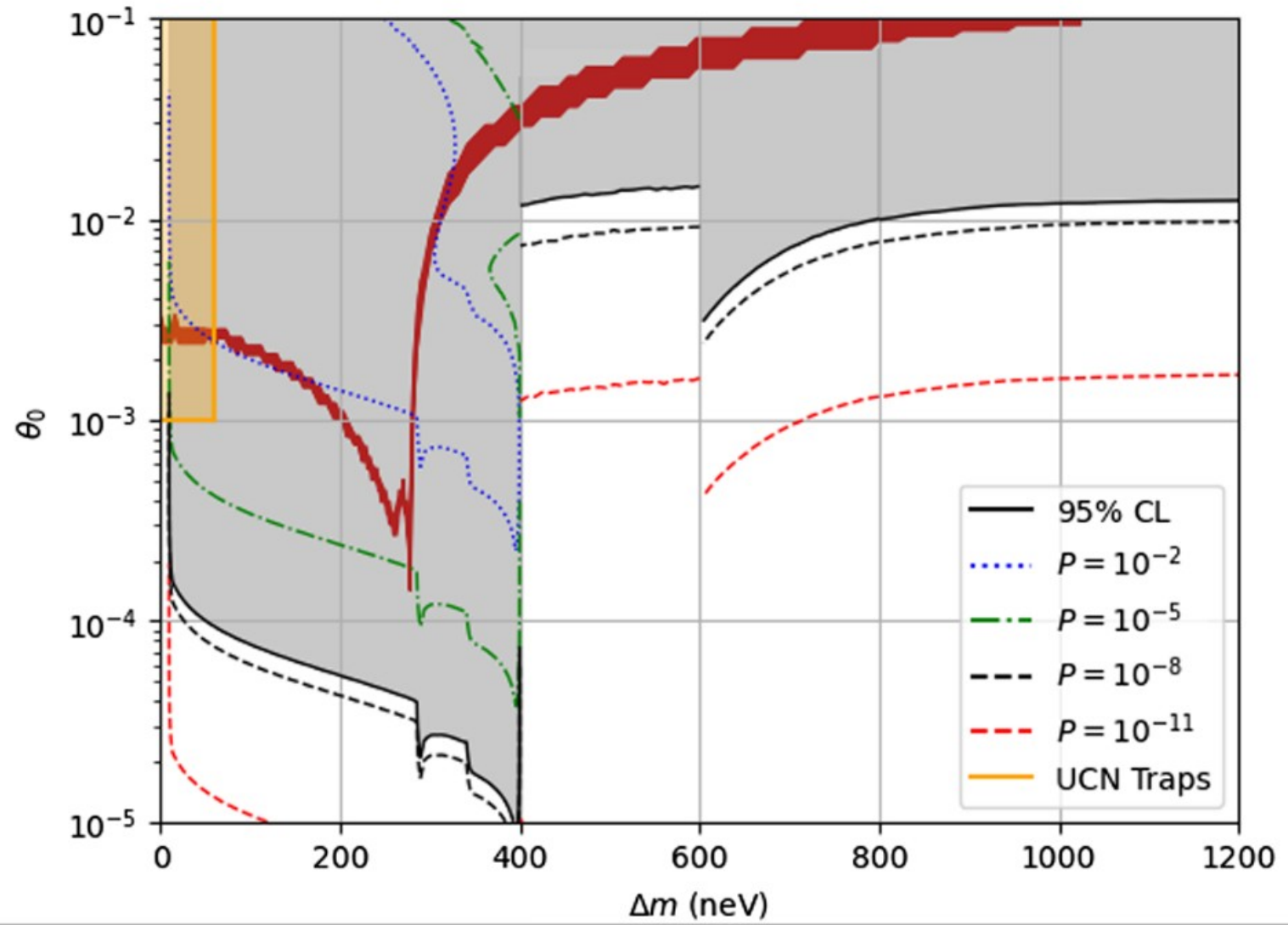


FIG. 3. The parameter space of the mirror matter model [19] excluded with 95% C.L. (gray region) and prediction consistent with the neutron lifetime anomaly (red band). Calculated probability of transmission is given by the dashed contour lines. The region 400–600 neV uses a different dataset.