Bursts detection

with a
Bayesian Blocks–based pipeline

Carlo Campa

F. Ambrosino, P. Casella, R. La Placa et al.

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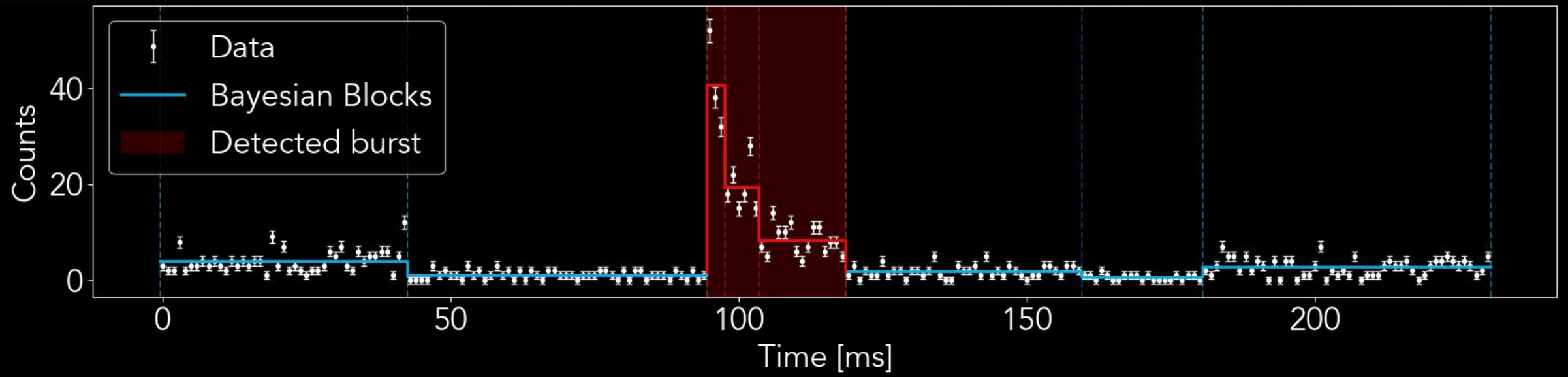
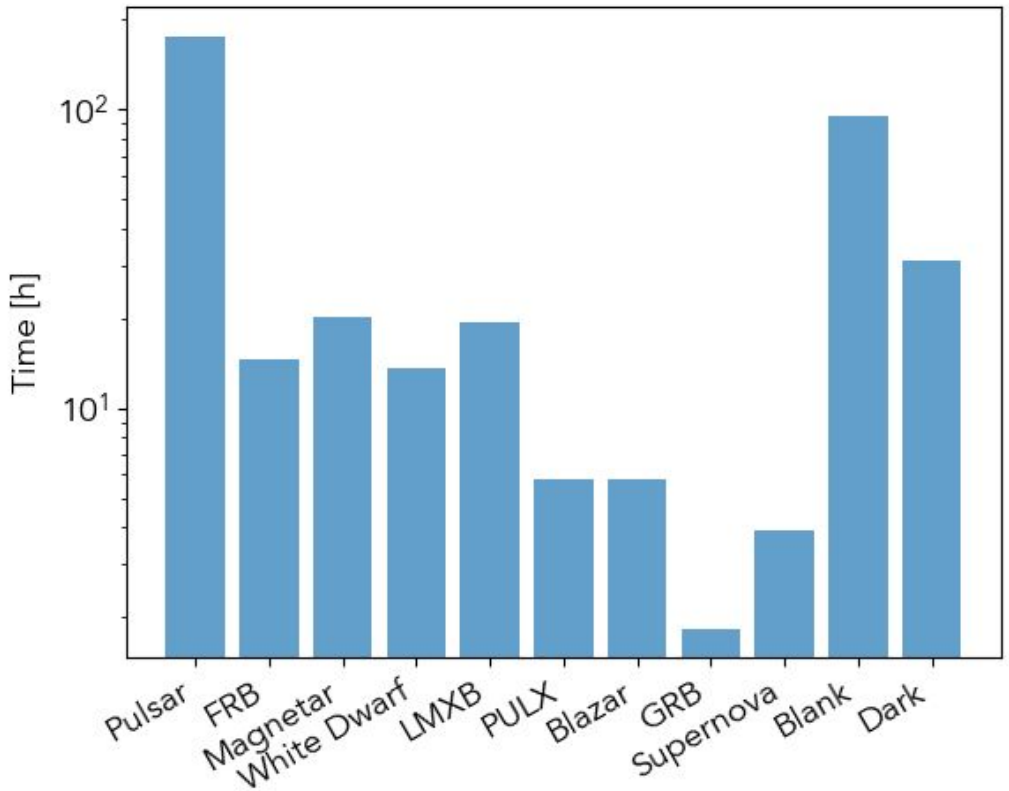
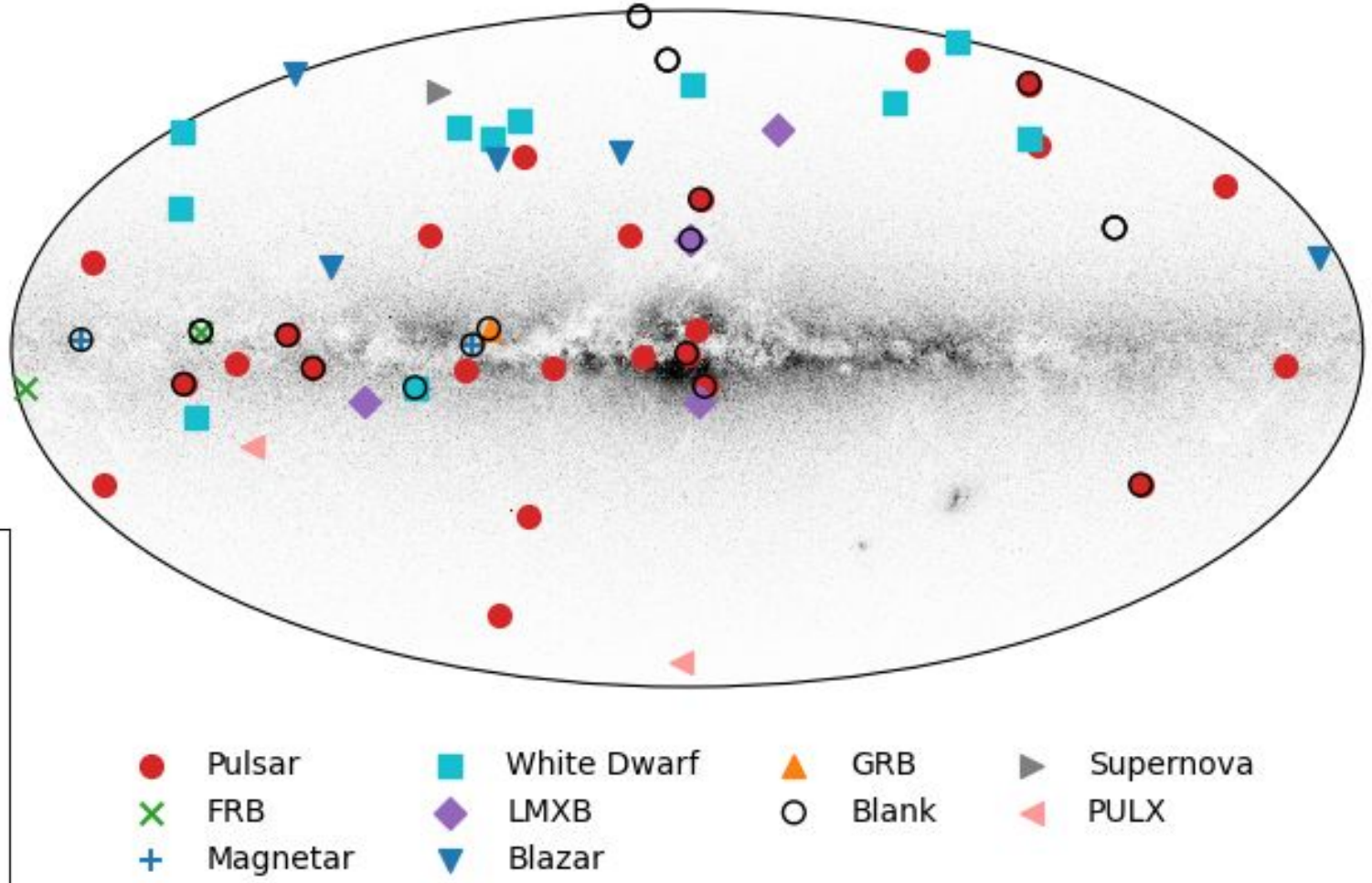
DI ASTROFISICA



Data

- 400 hours
- 52 astrophysical targets
- 4 blank fields

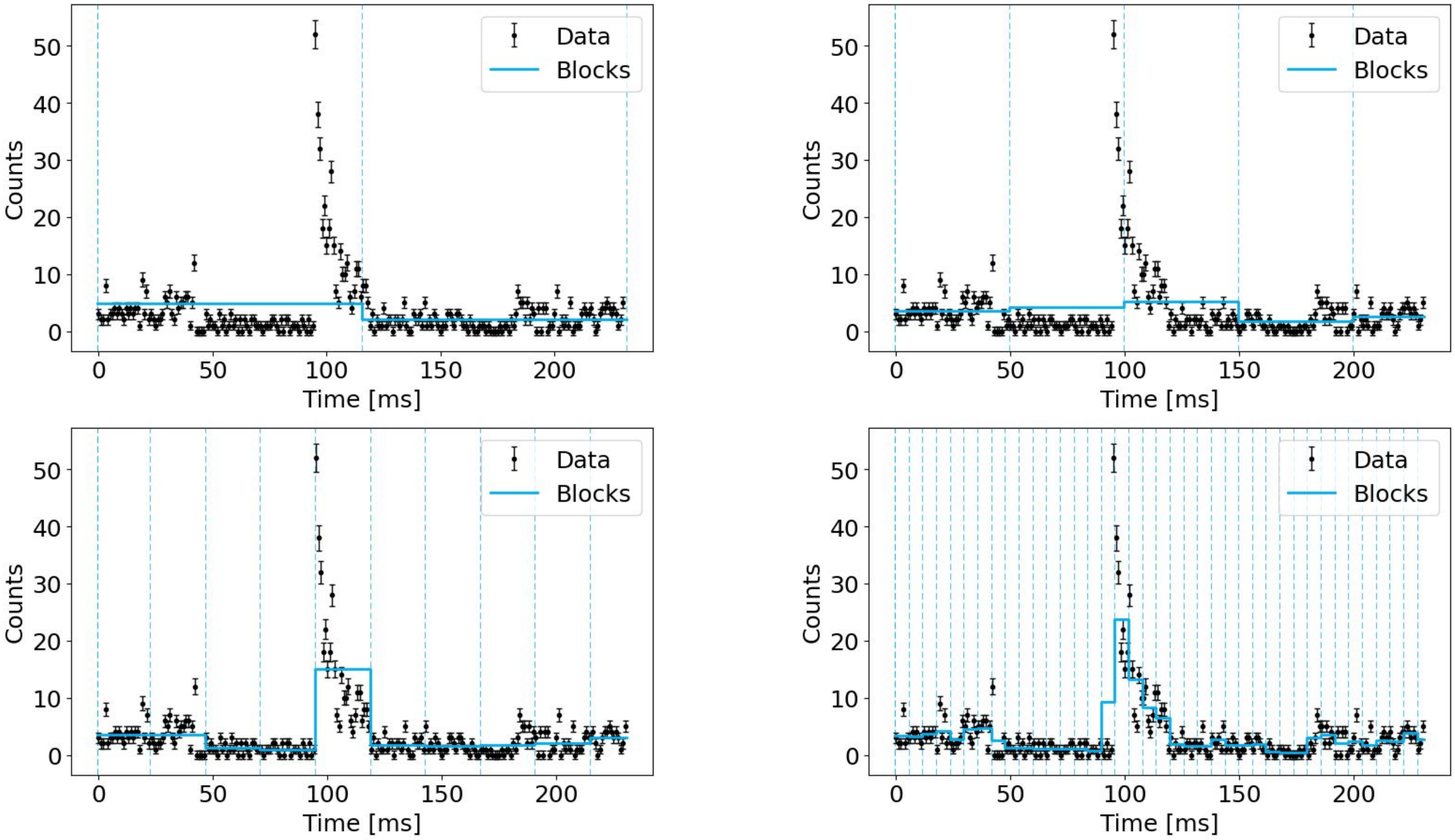




- Background data from sky detector
- Dark observations

Manual binning

Choosing the right binning is difficult



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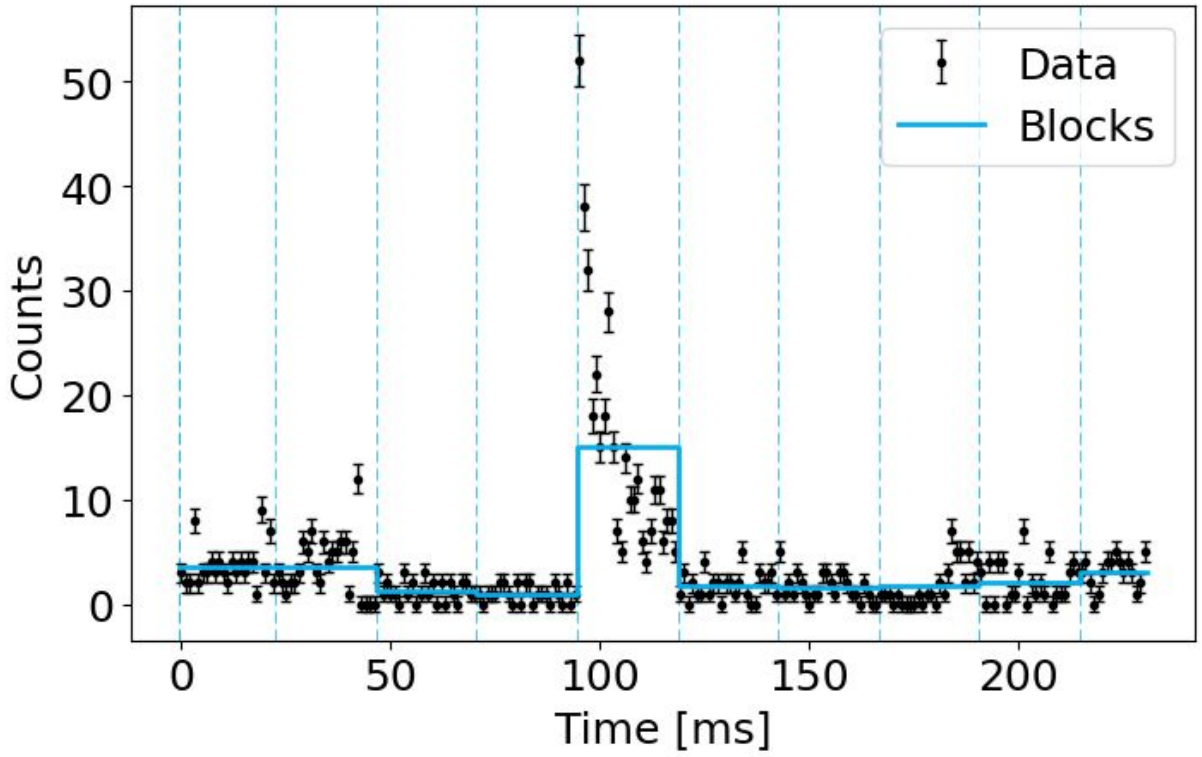
Choosing the right shift is difficult



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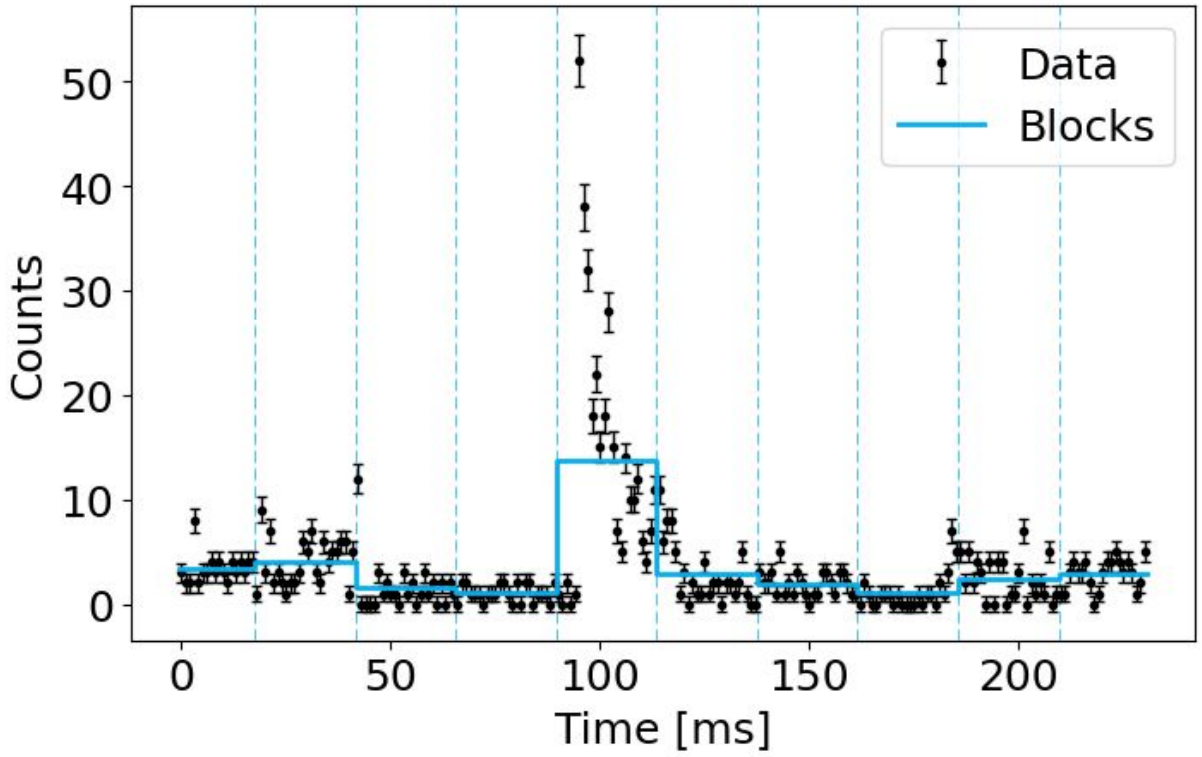

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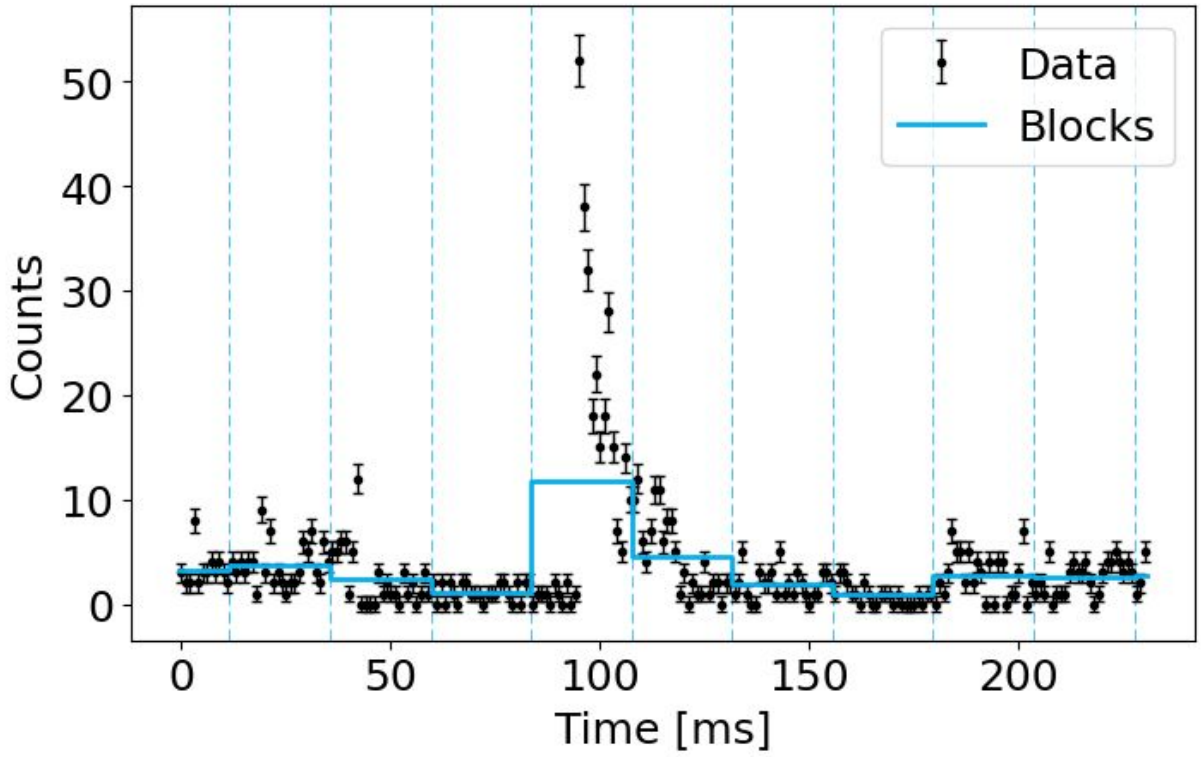

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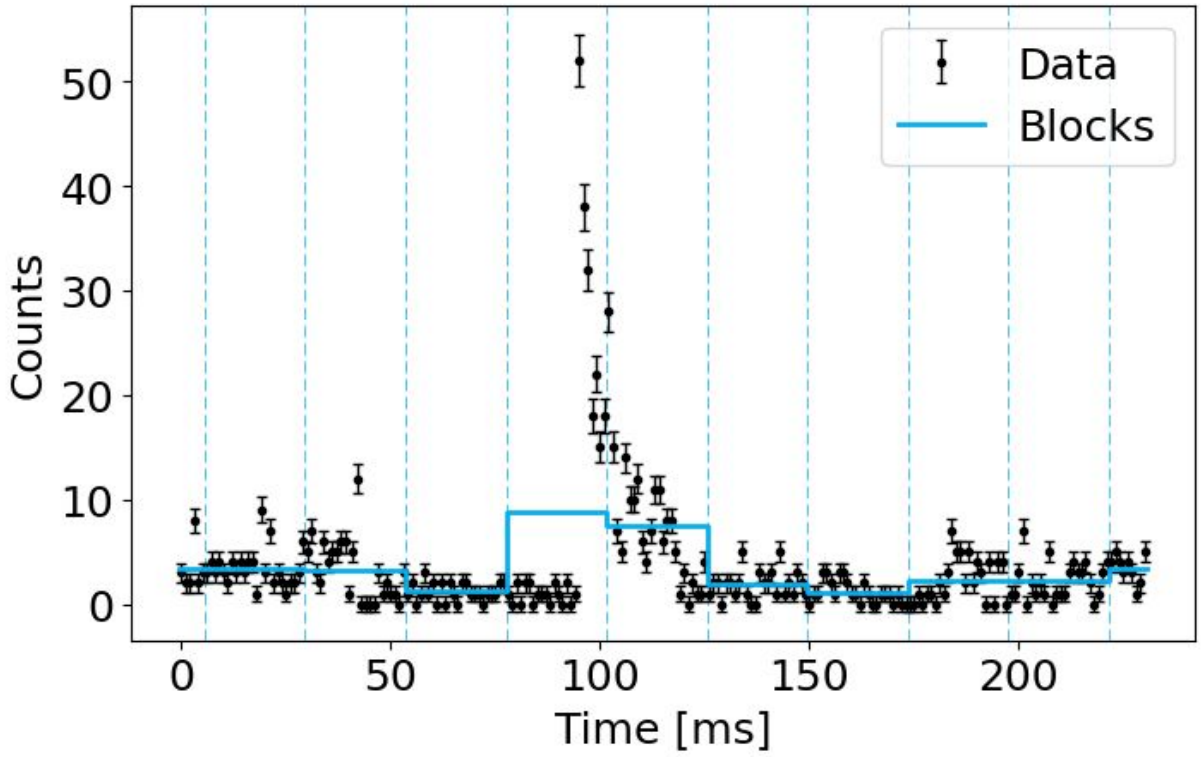

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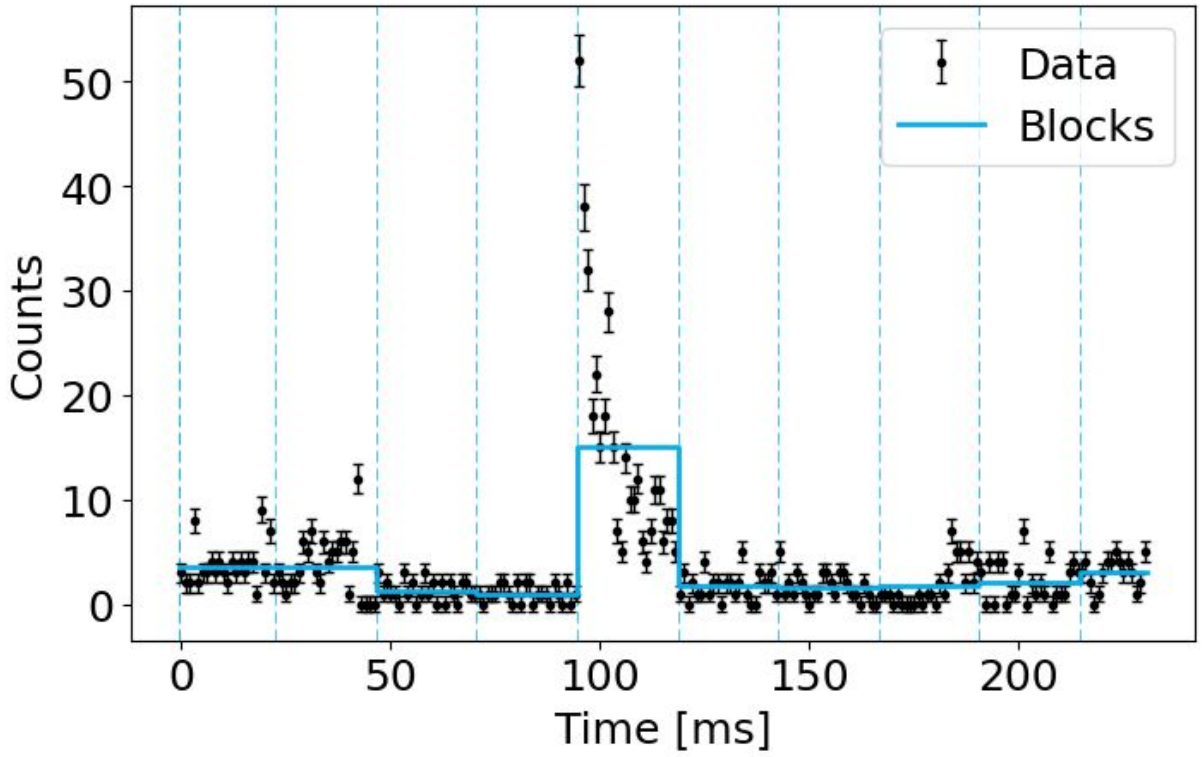
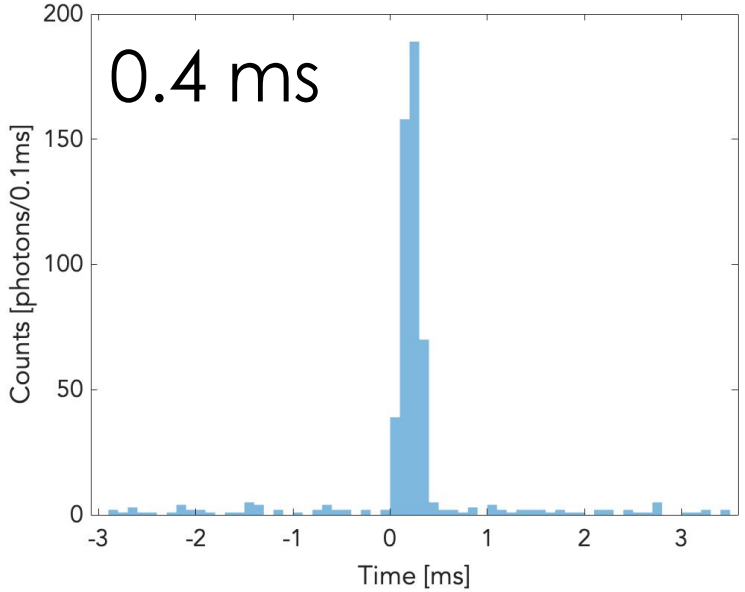
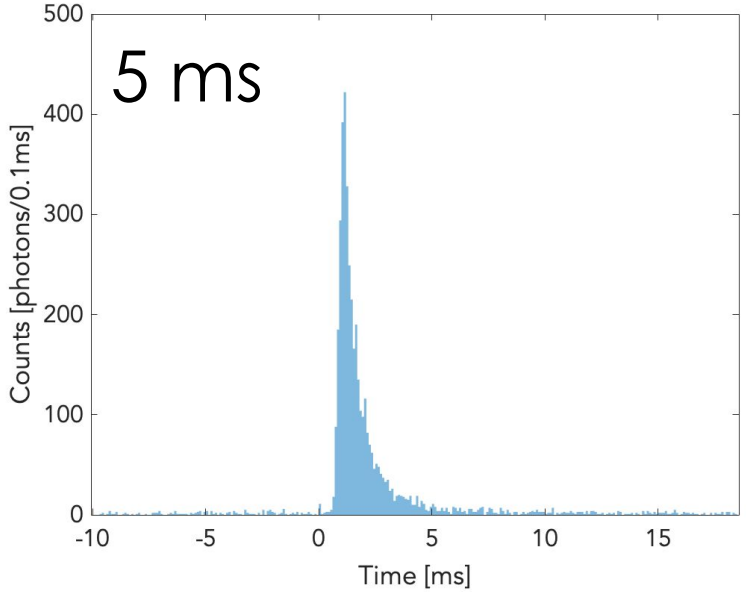
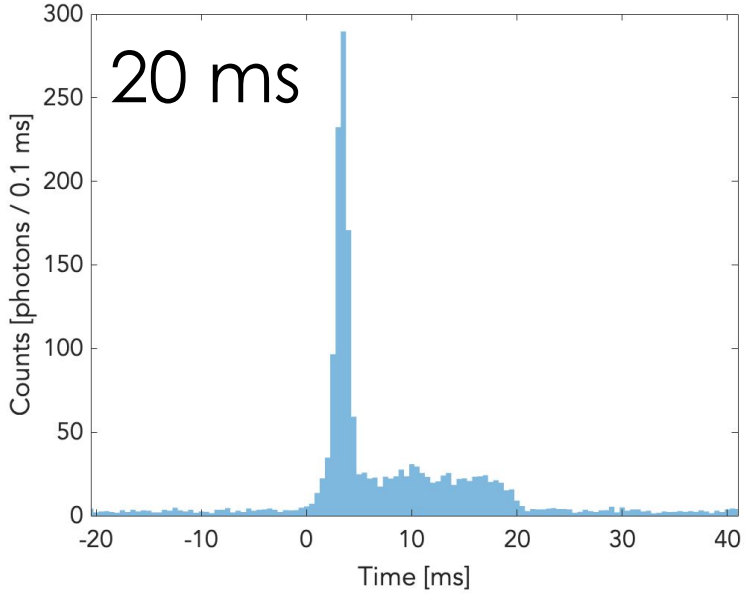


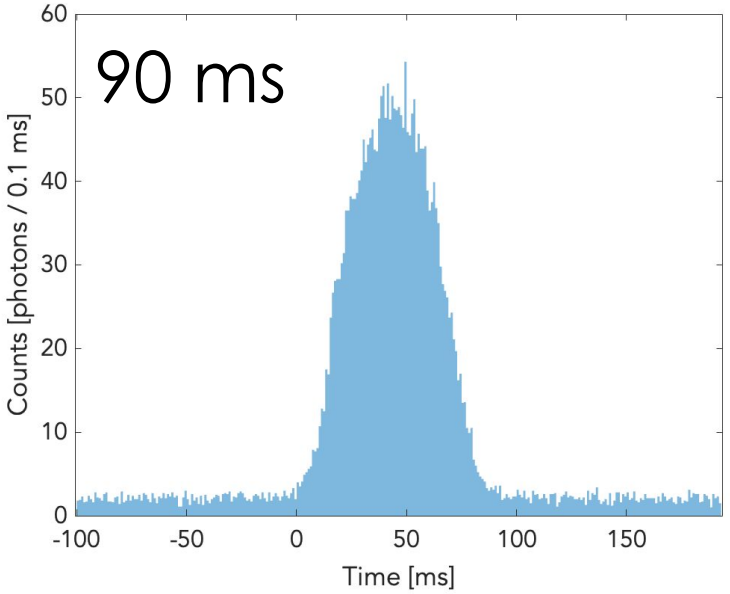
Pipeline requirements

FOBs over multiple timescales









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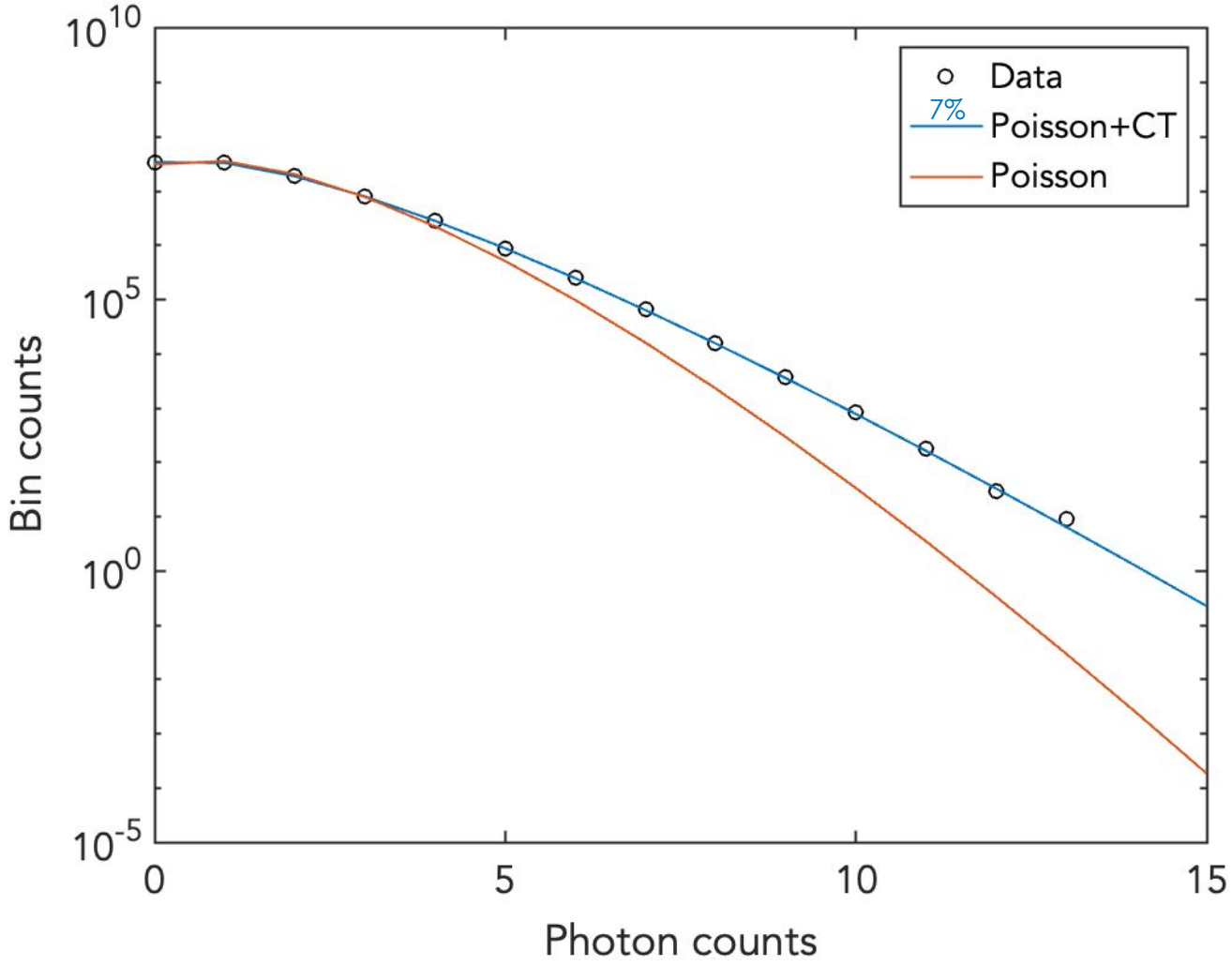
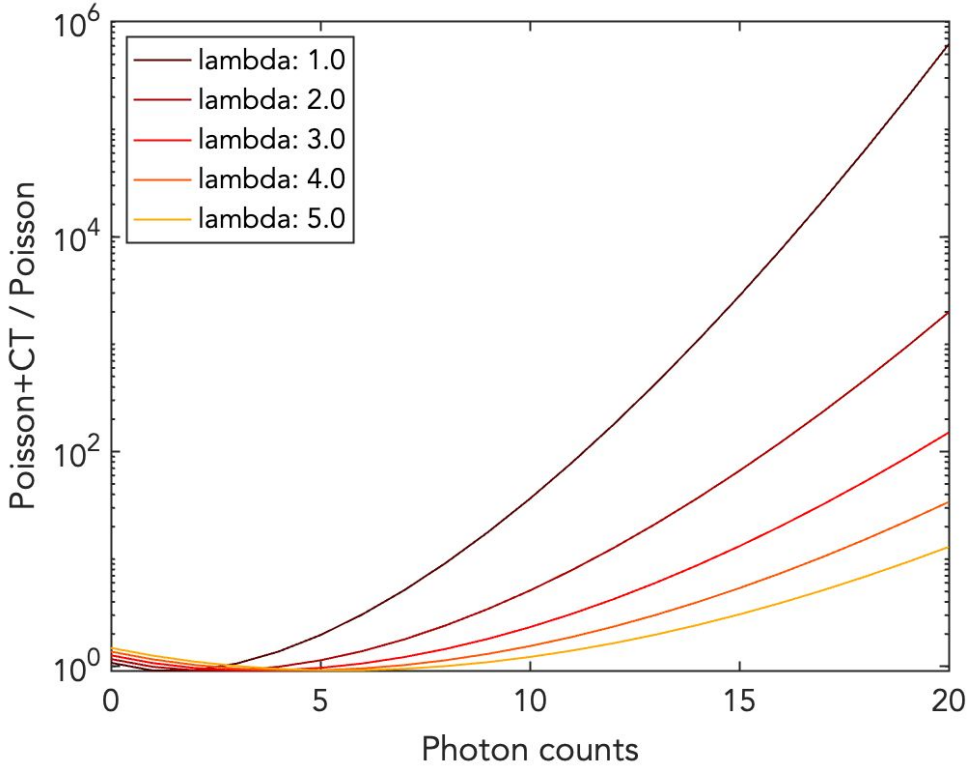


Crosstalk effect



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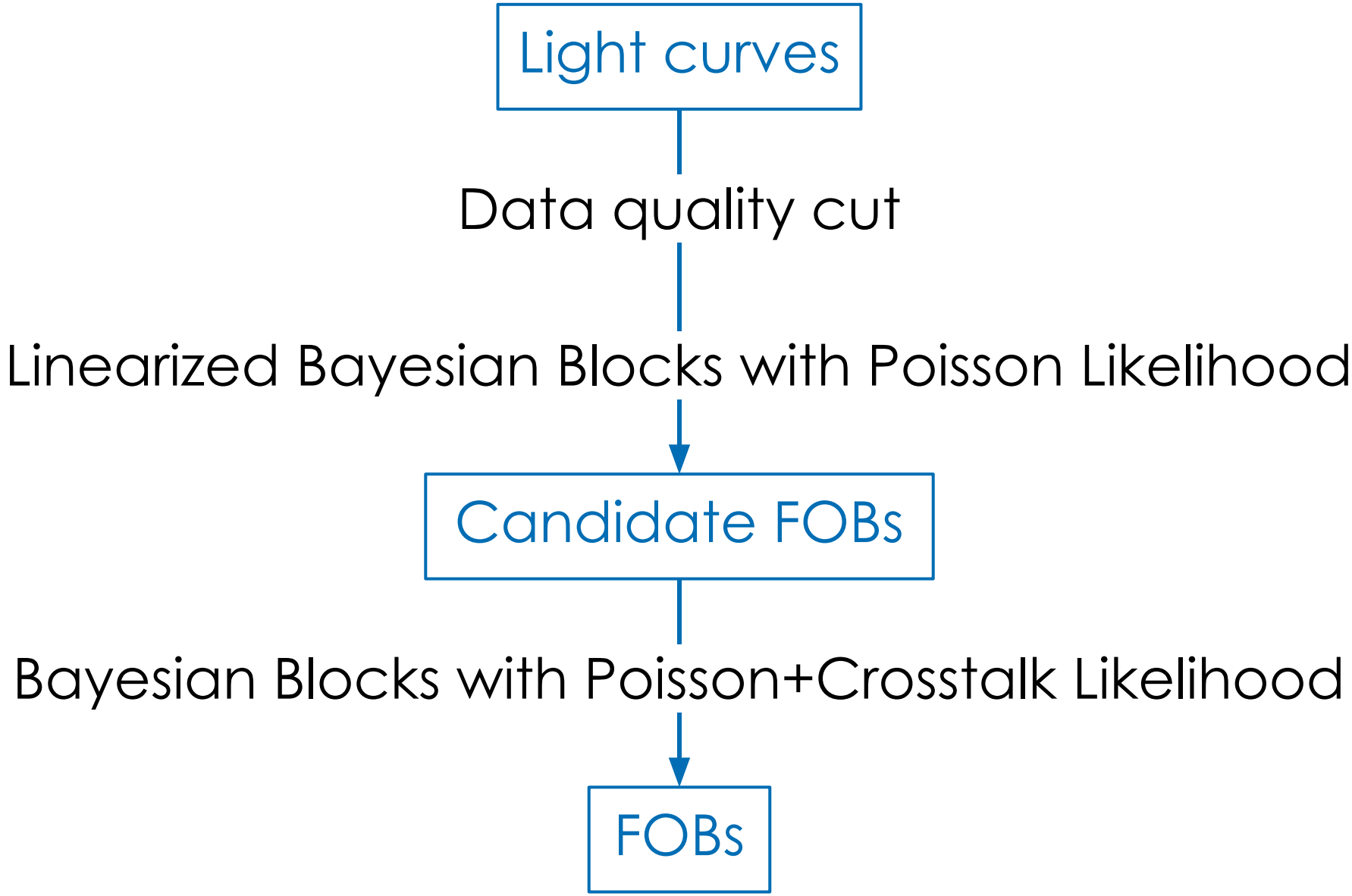

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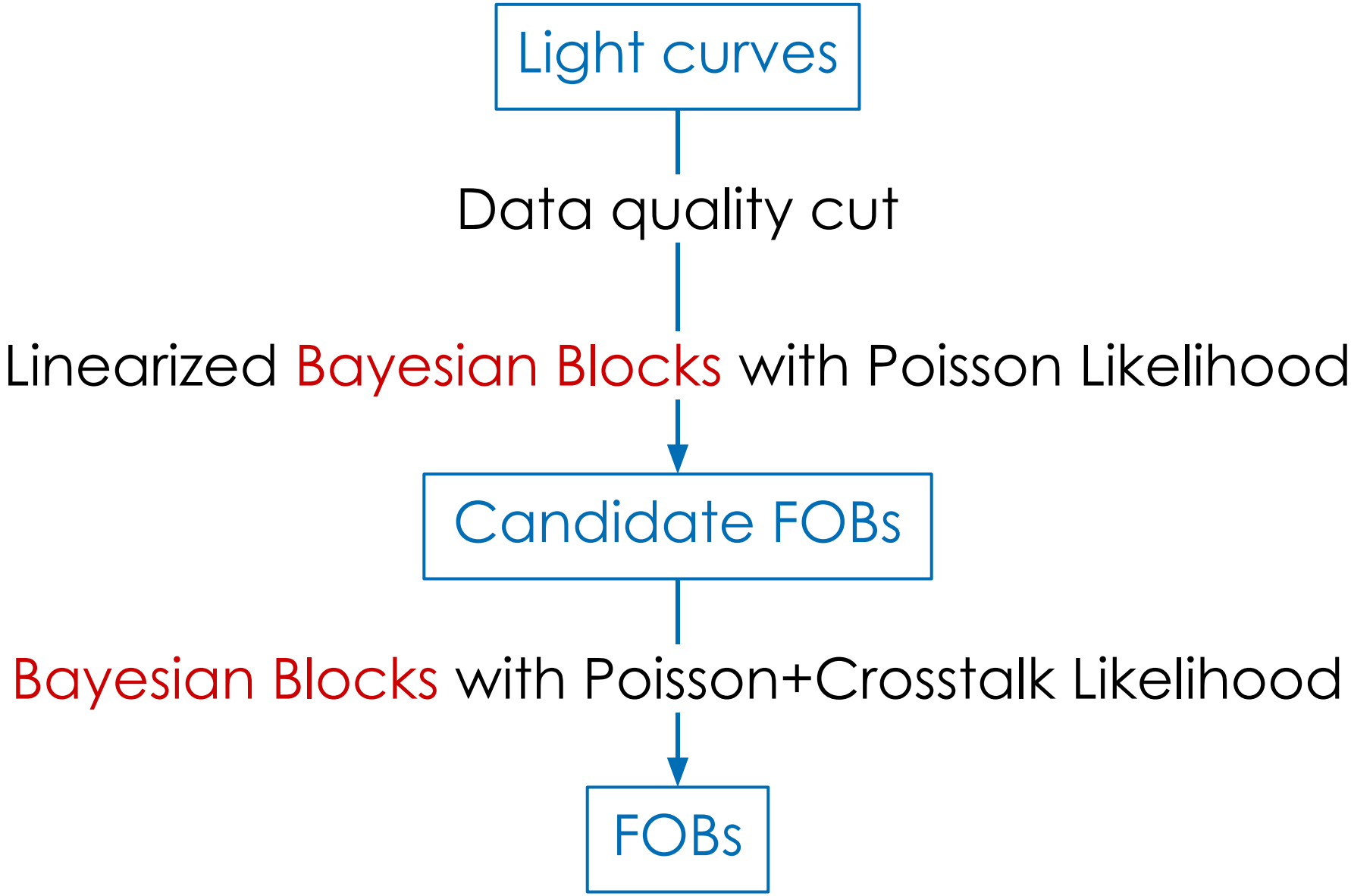

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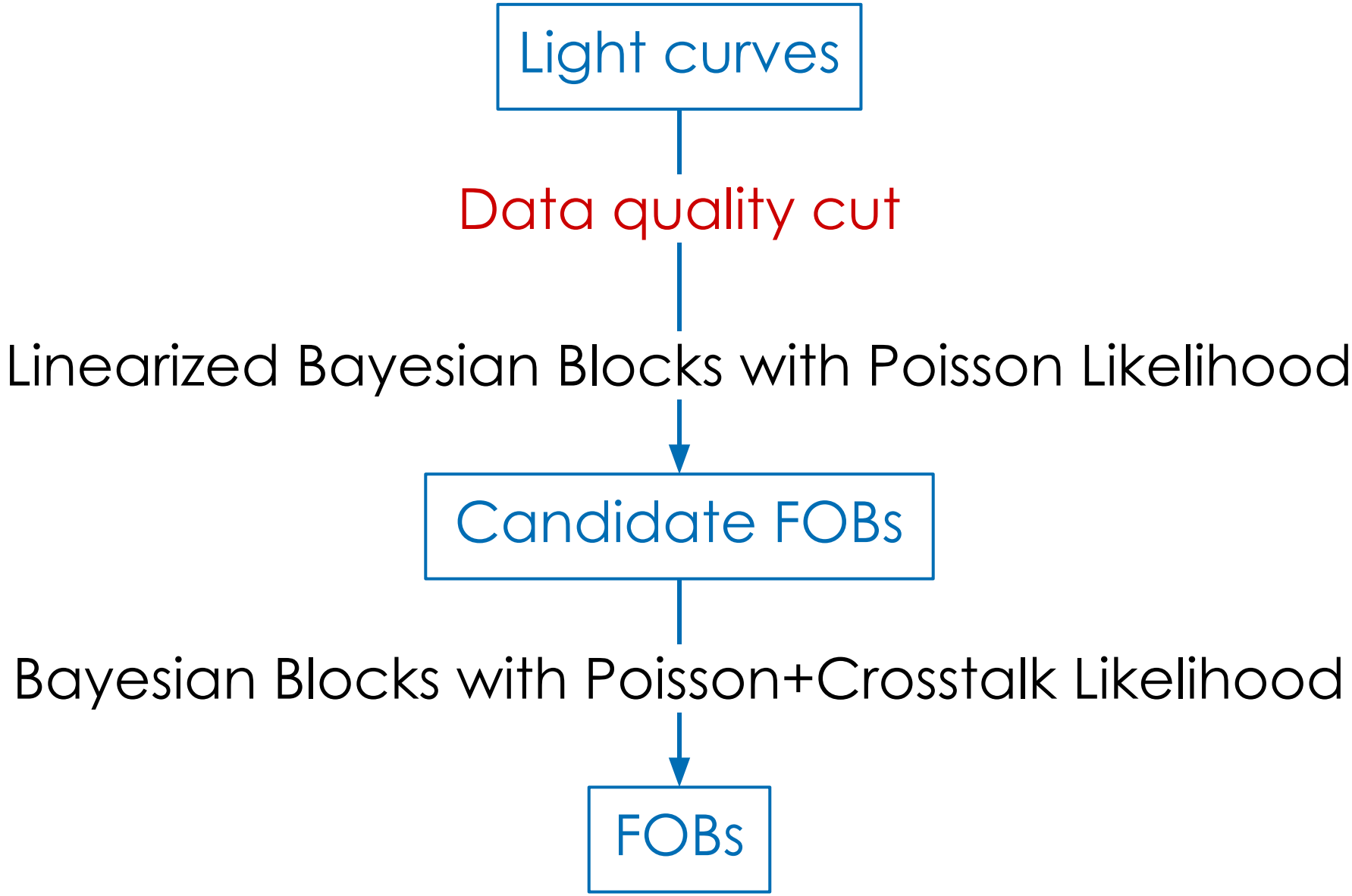
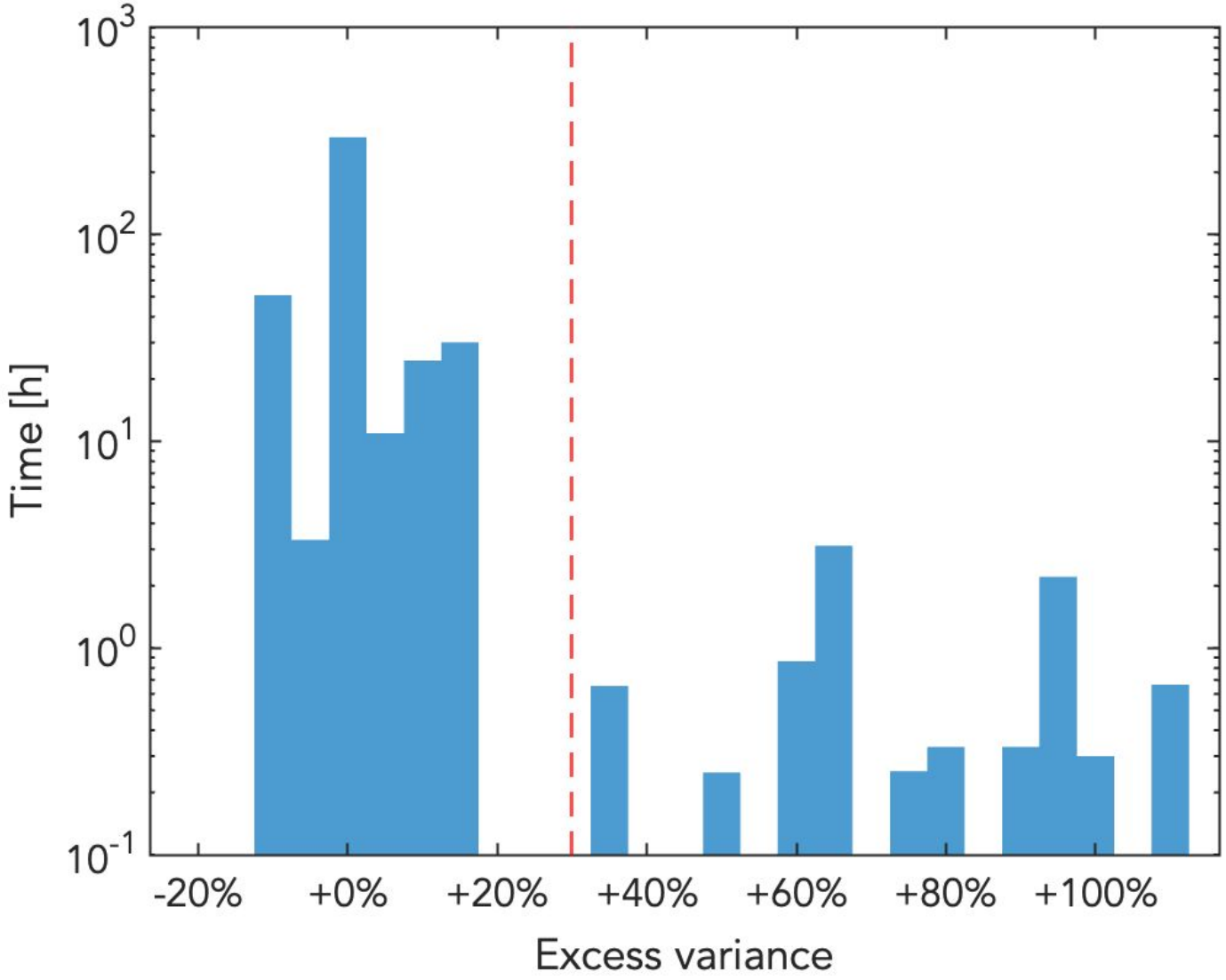


Data quality cut

To identify when target or background varies strongly on short timescales

$$\Delta = \left\langle \frac{s^2 - \sigma^2}{\sigma^2} \Big|_{5\,s} \right\rangle$$

Excess variance



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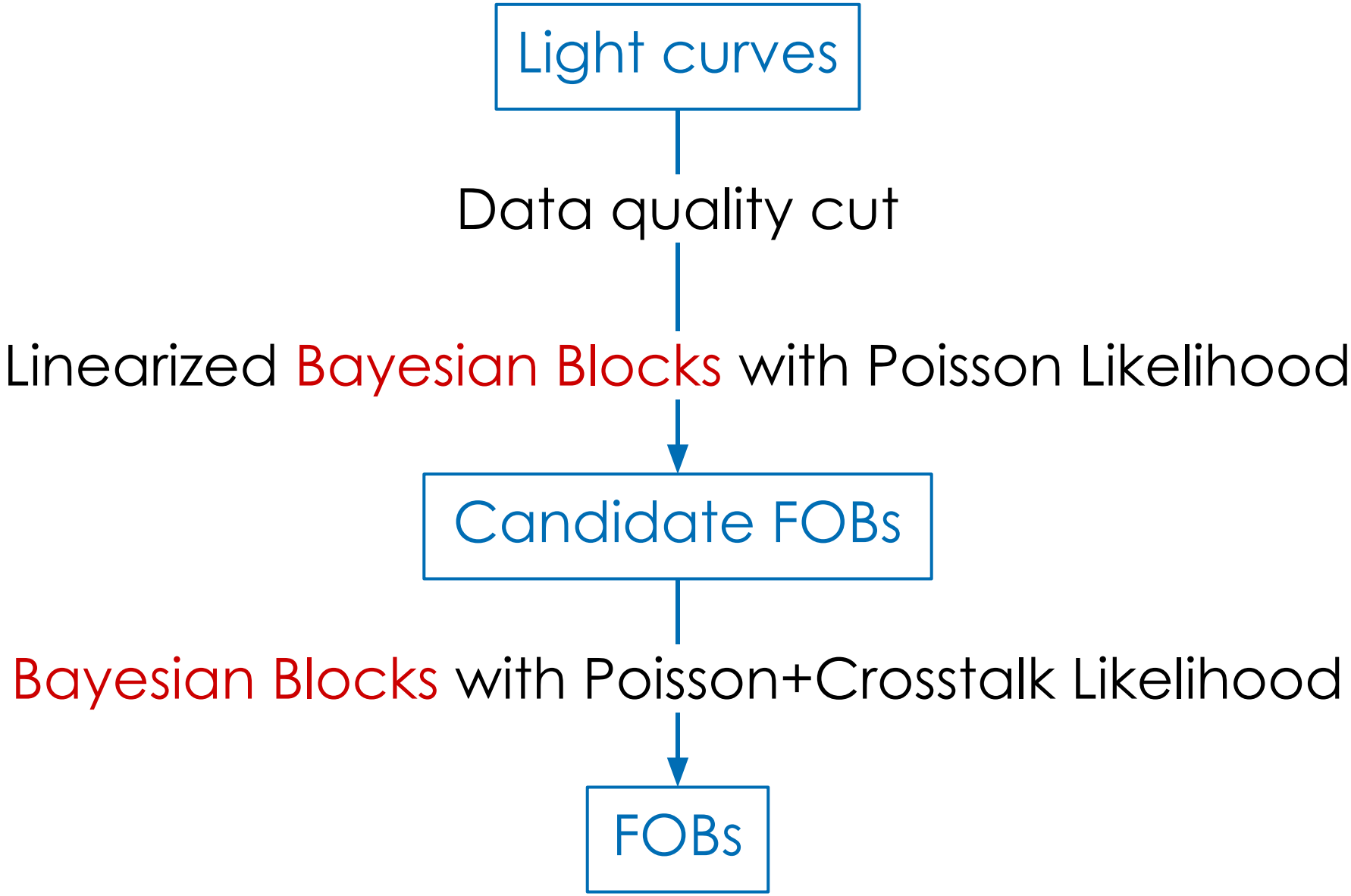

Bayesian Blocks

Statistical point of view

Scargle+2013

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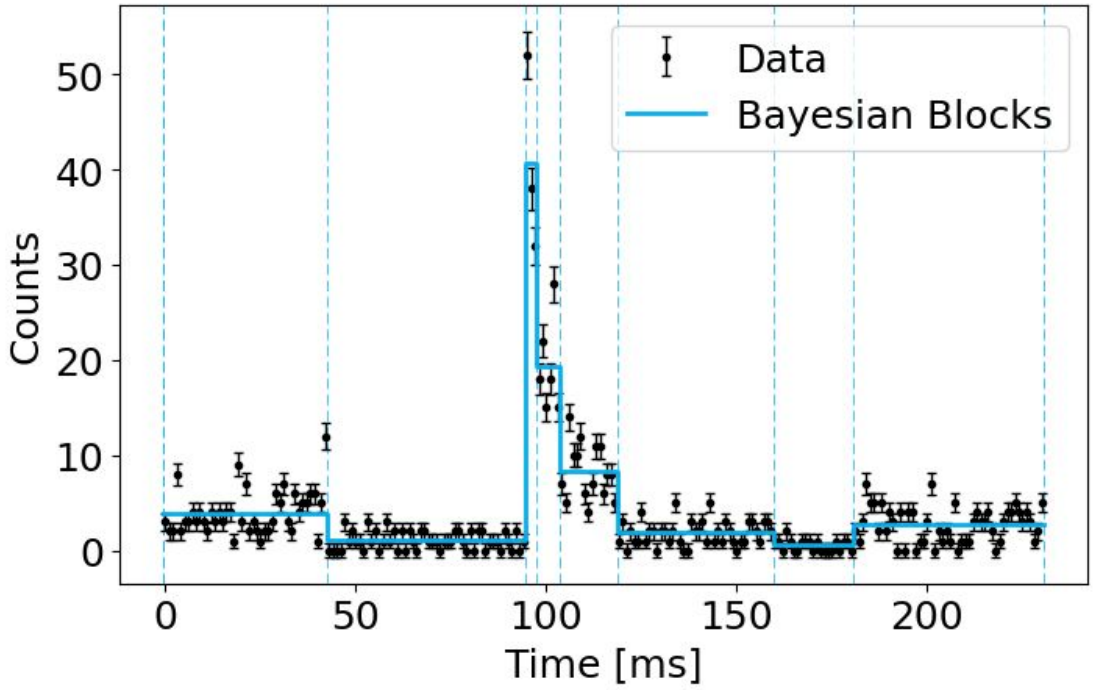
Posterior　　Likelihood　　Prior



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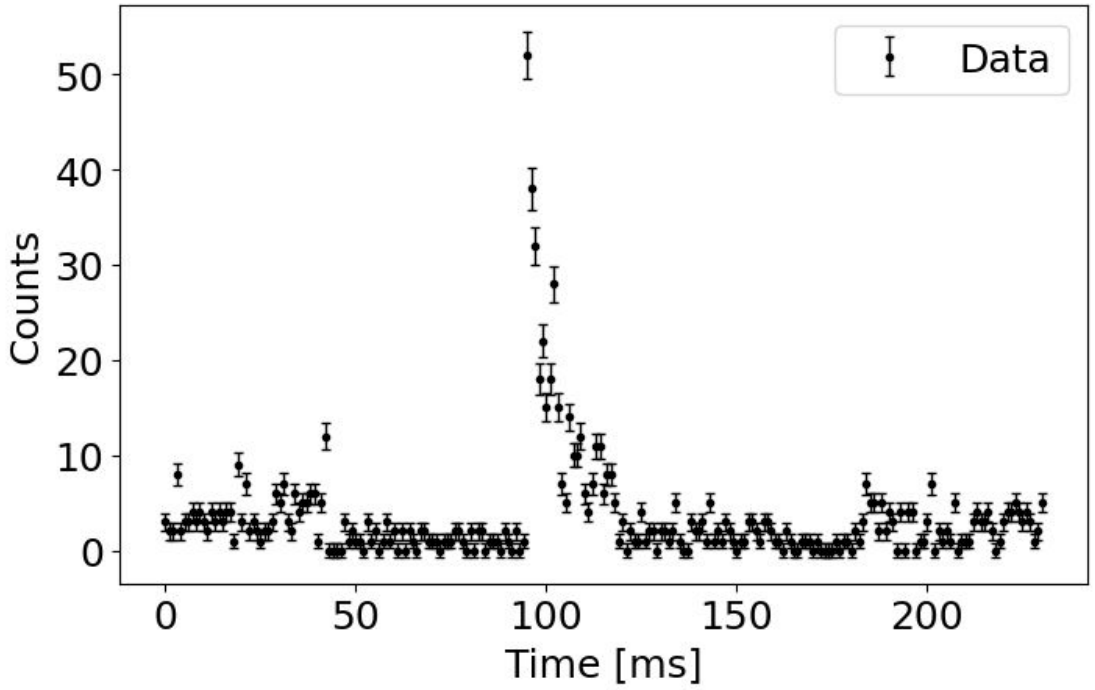

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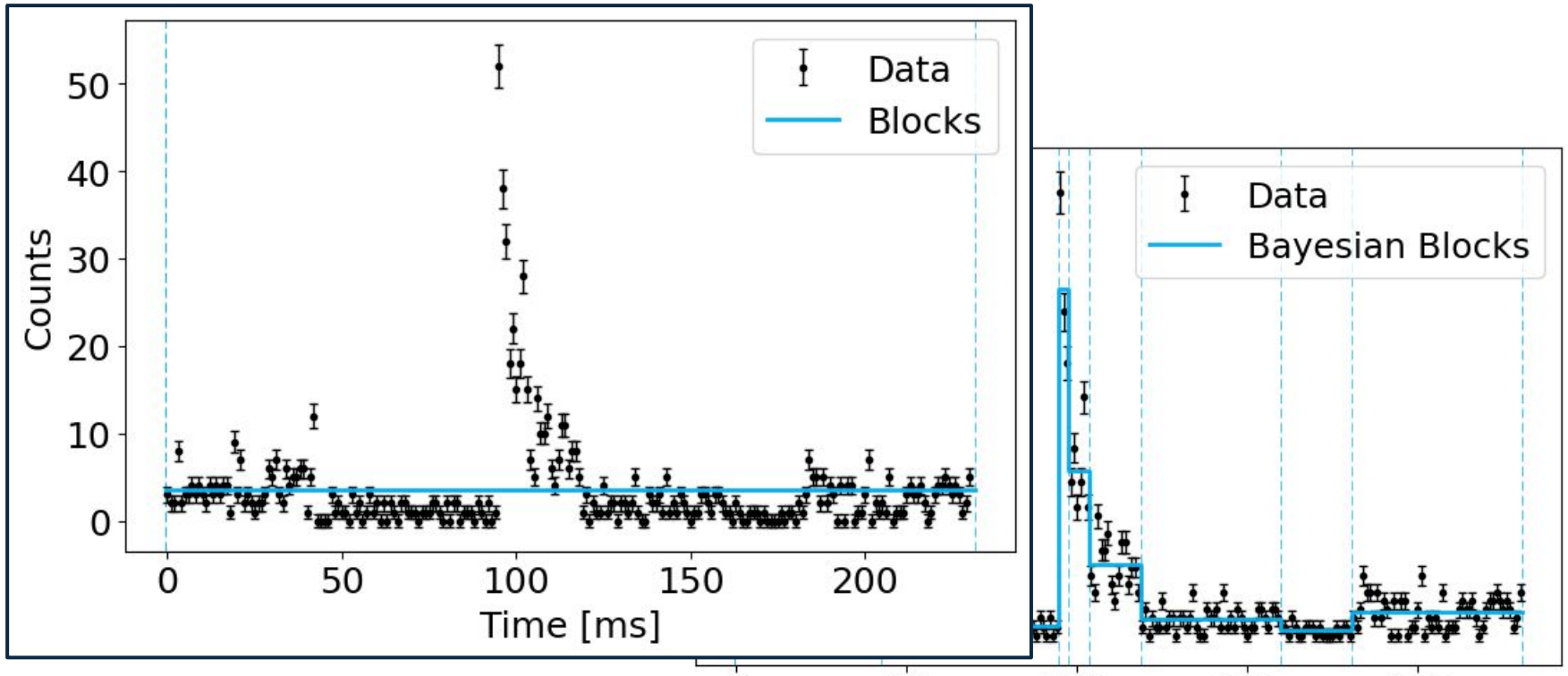

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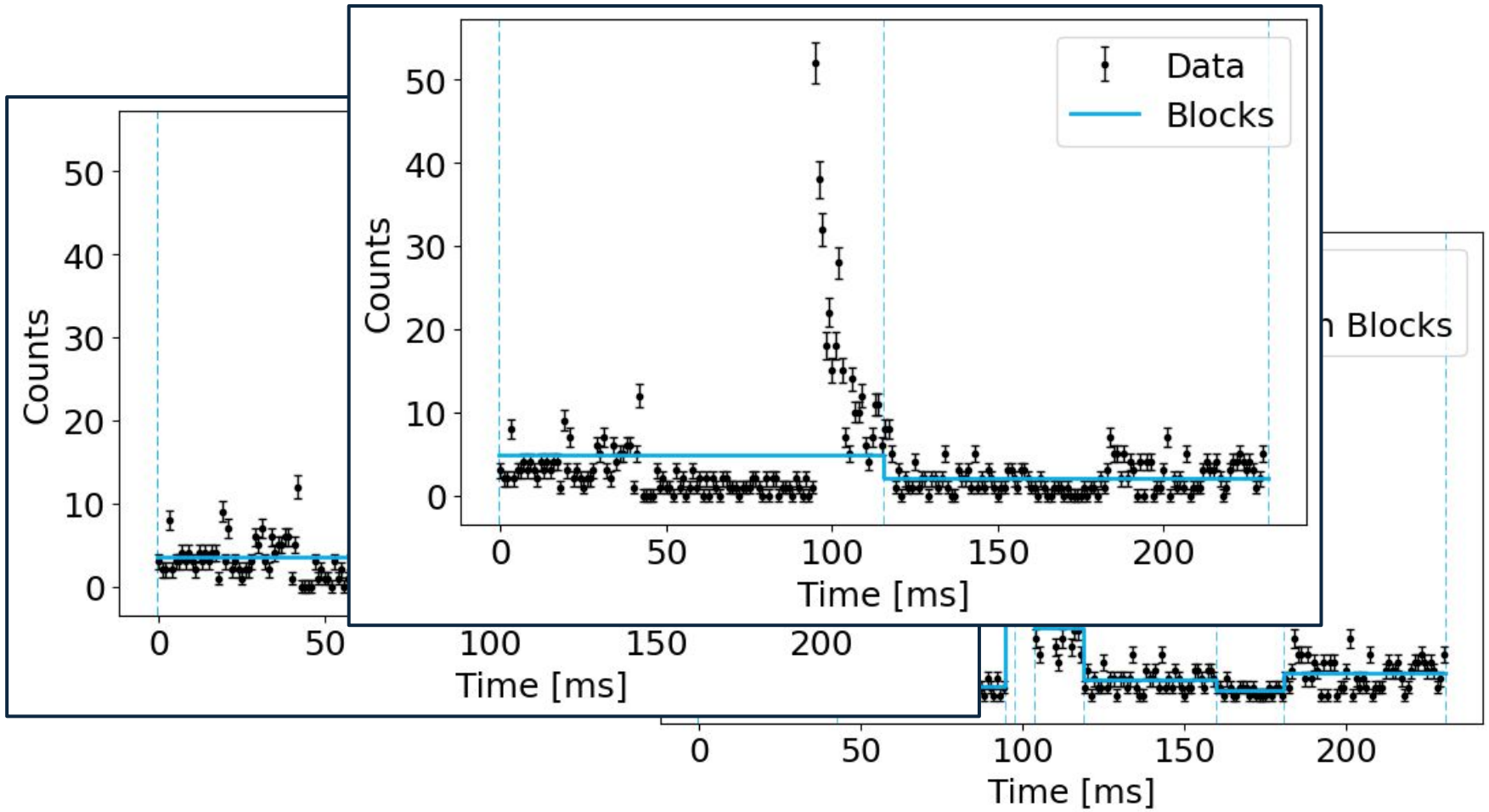

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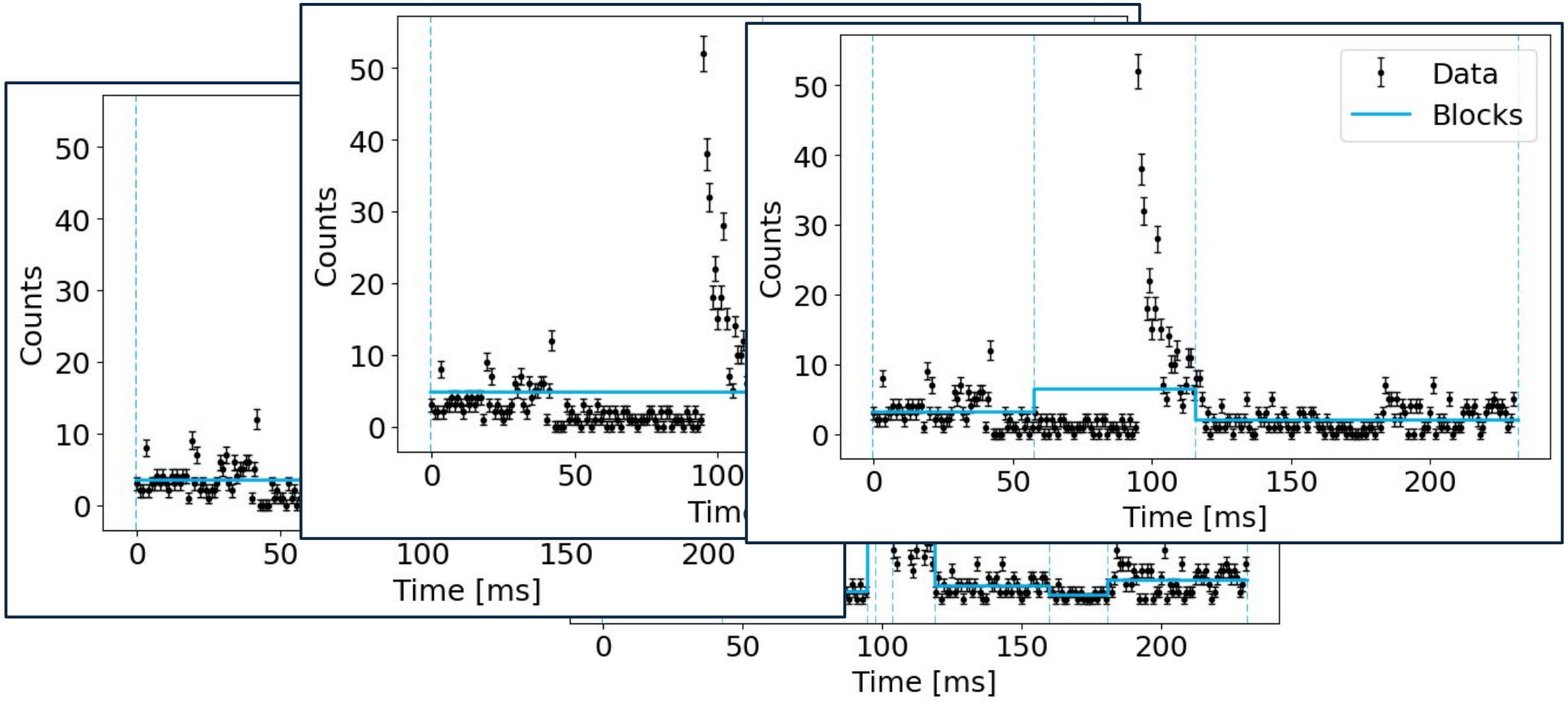

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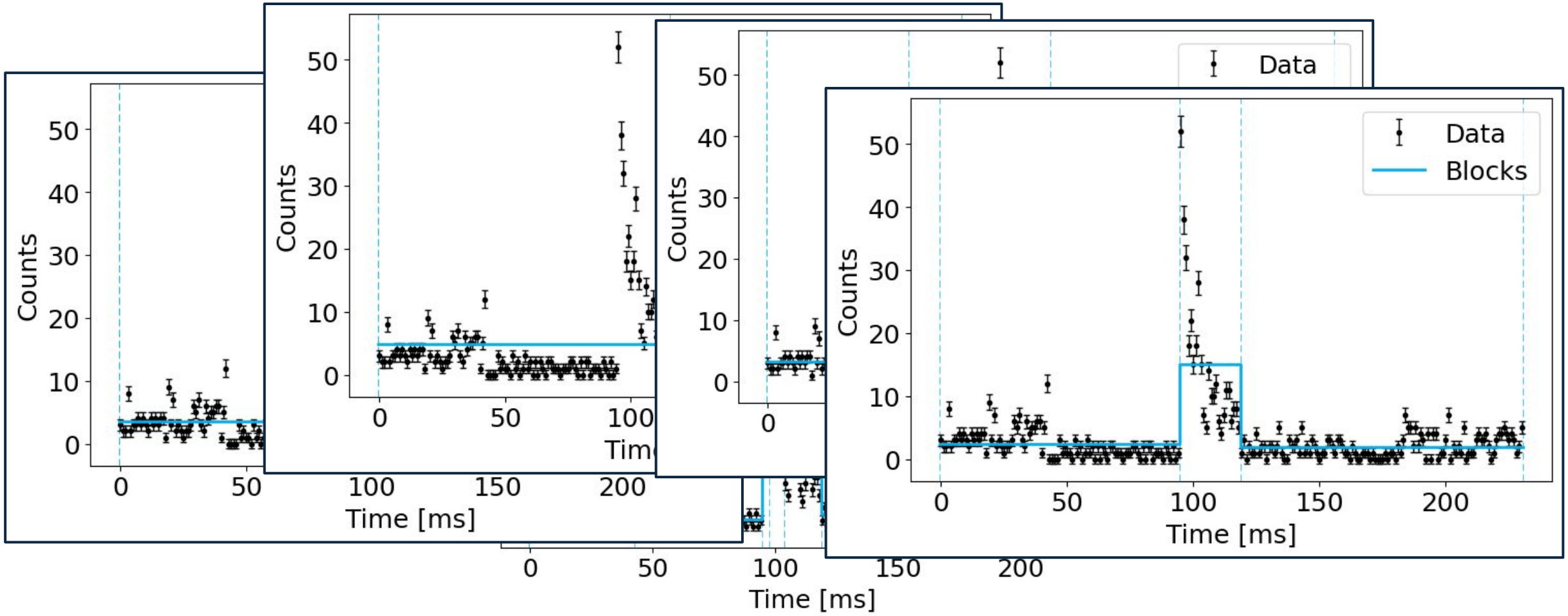

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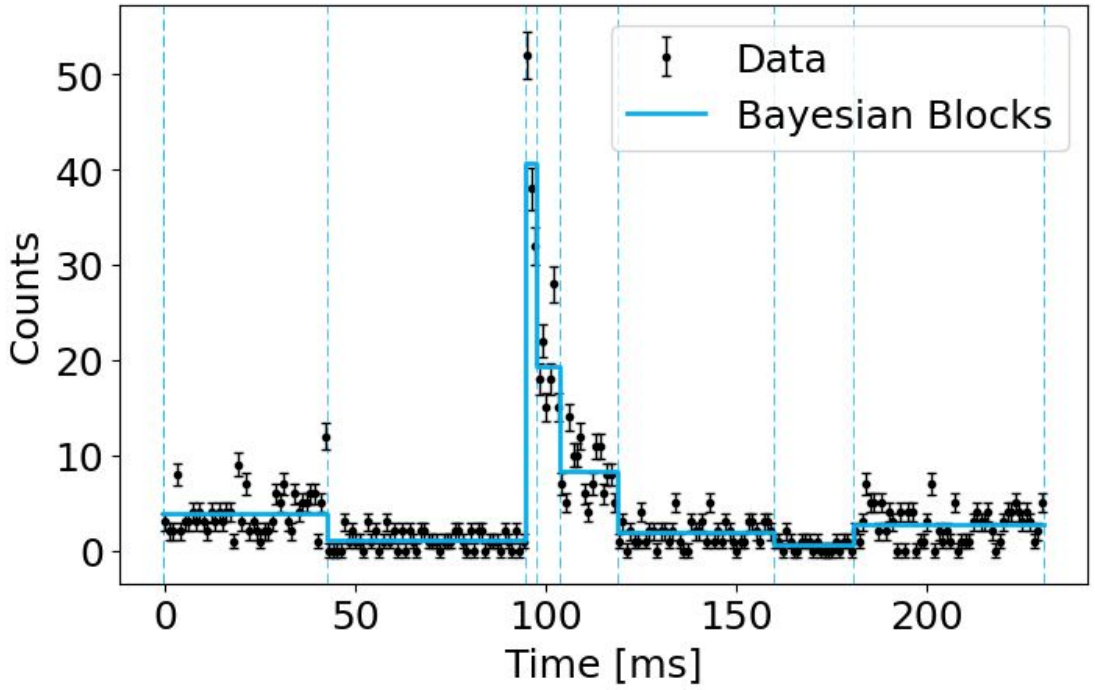

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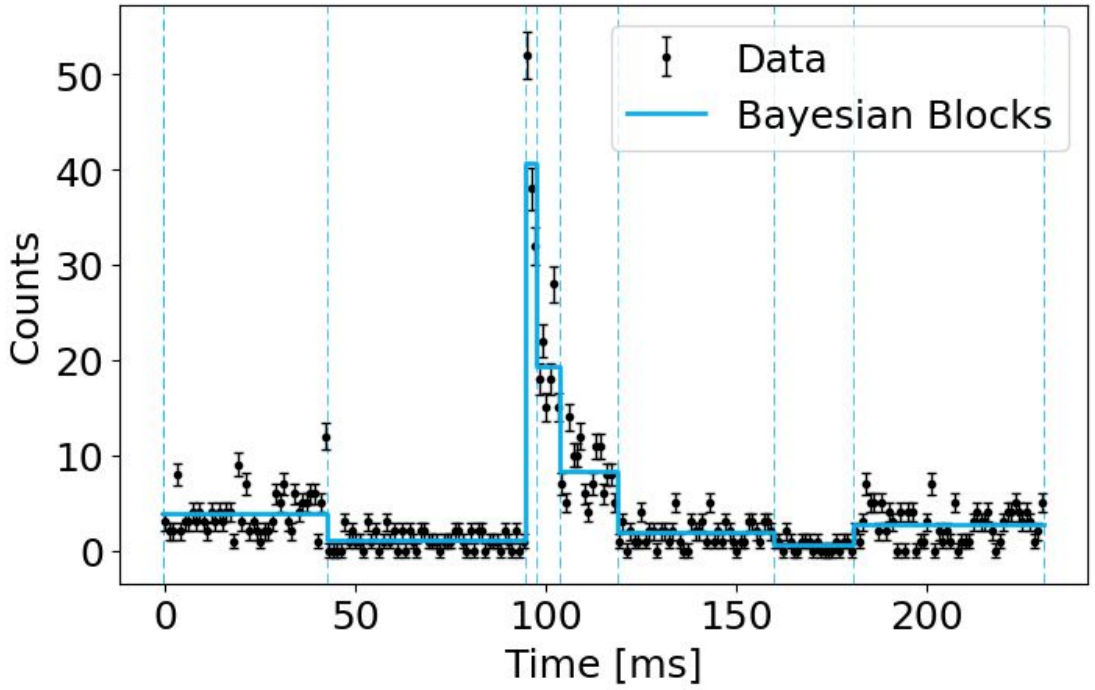
Posterior — Likelihood — Prior

$$L_{\text{model}} = \prod_{i \in \text{blocks}} L_i = \prod_{i \in \text{blocks}} \prod_{j \in \text{data}_i} P_{\text{Poisson}}(n_j; \lambda_i)$$



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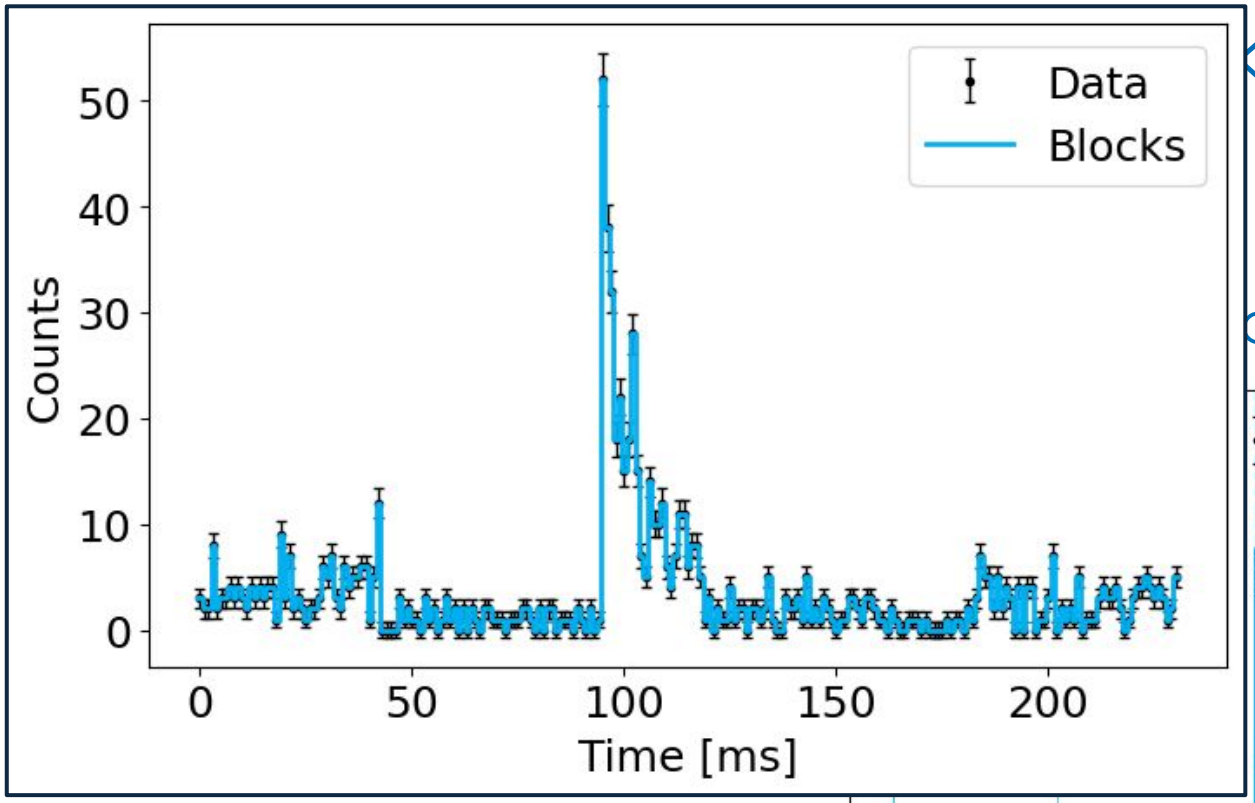

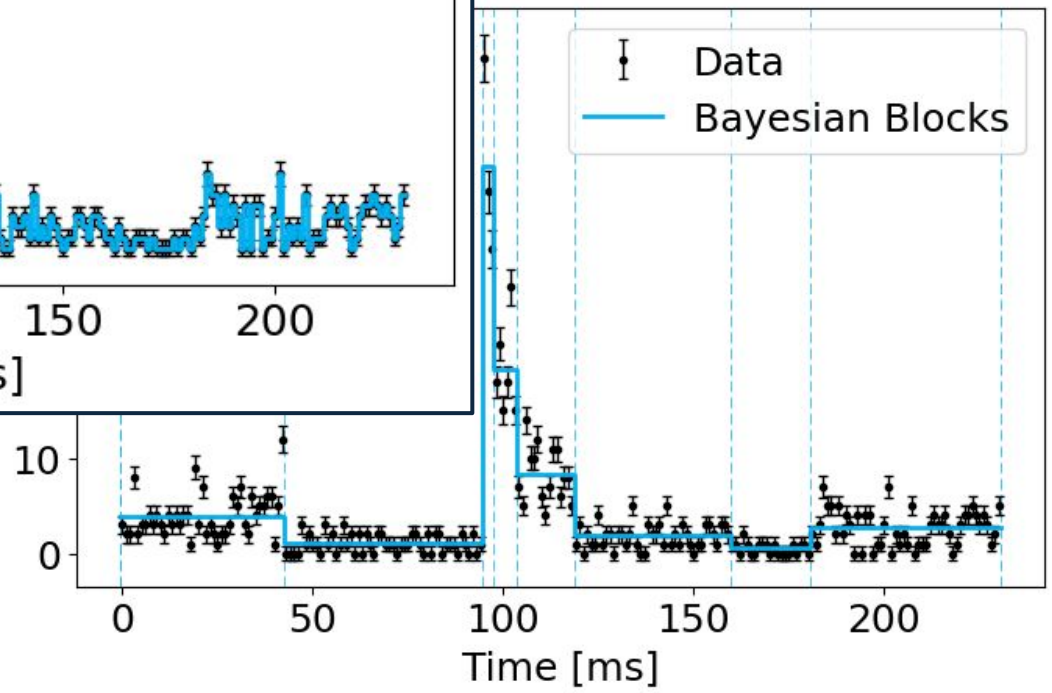

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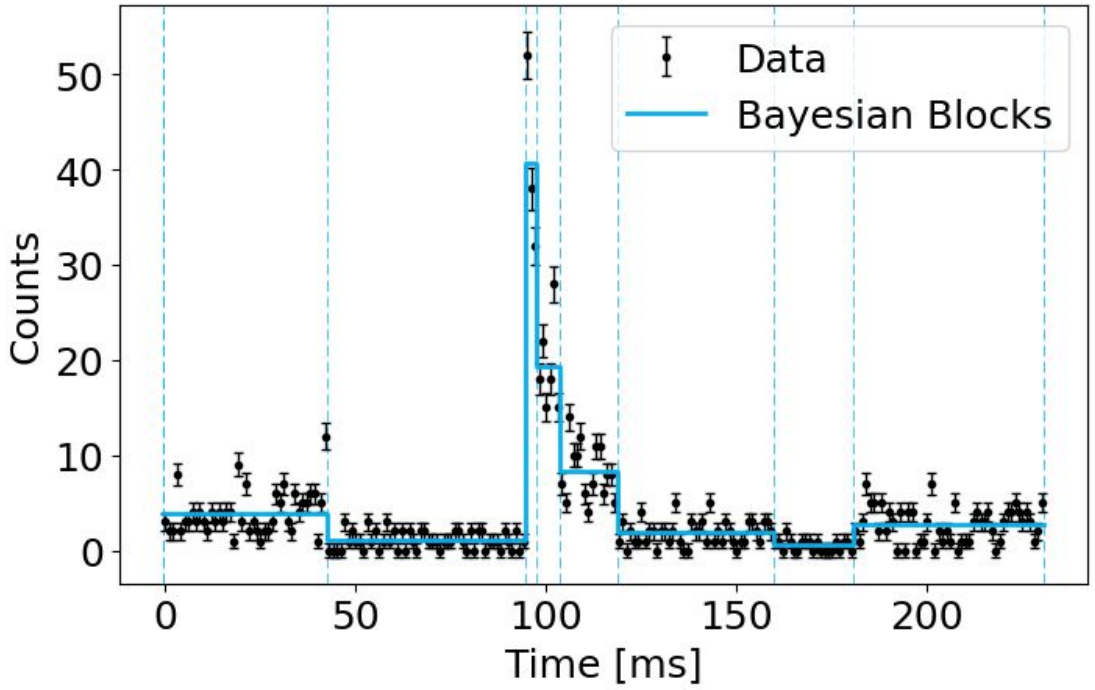
Posterior — Likelihood — Prior

$$P(N_{blocks}) = P_0 \gamma^{N_{blocks}}$$



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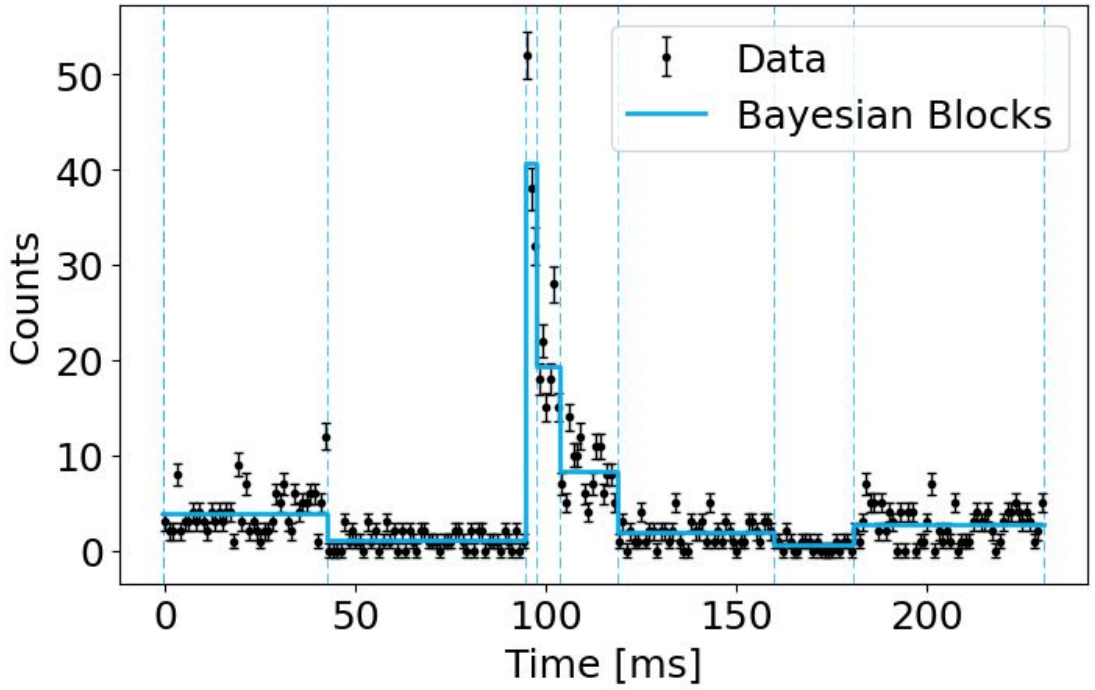

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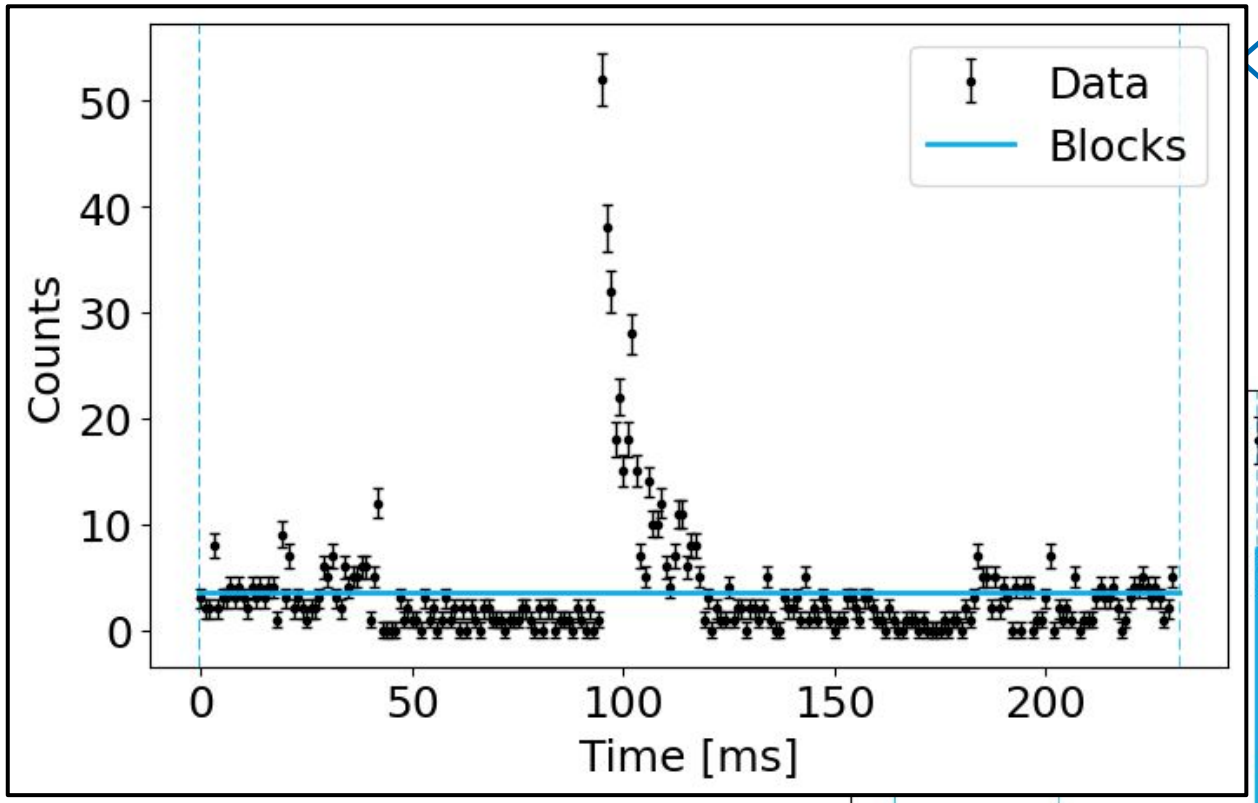

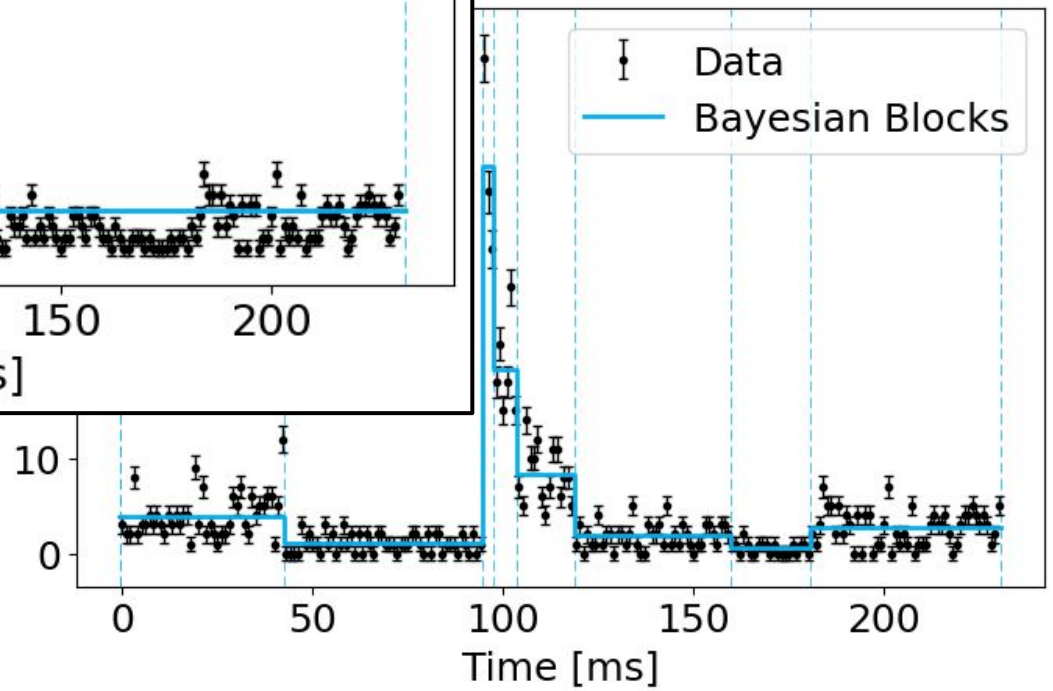

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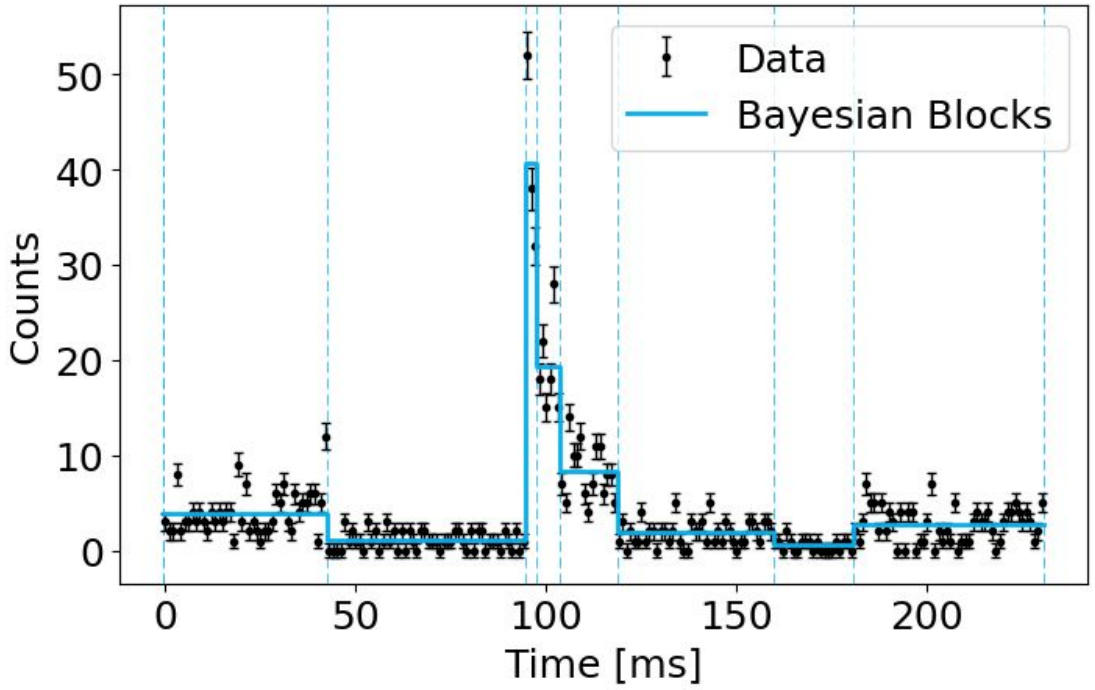

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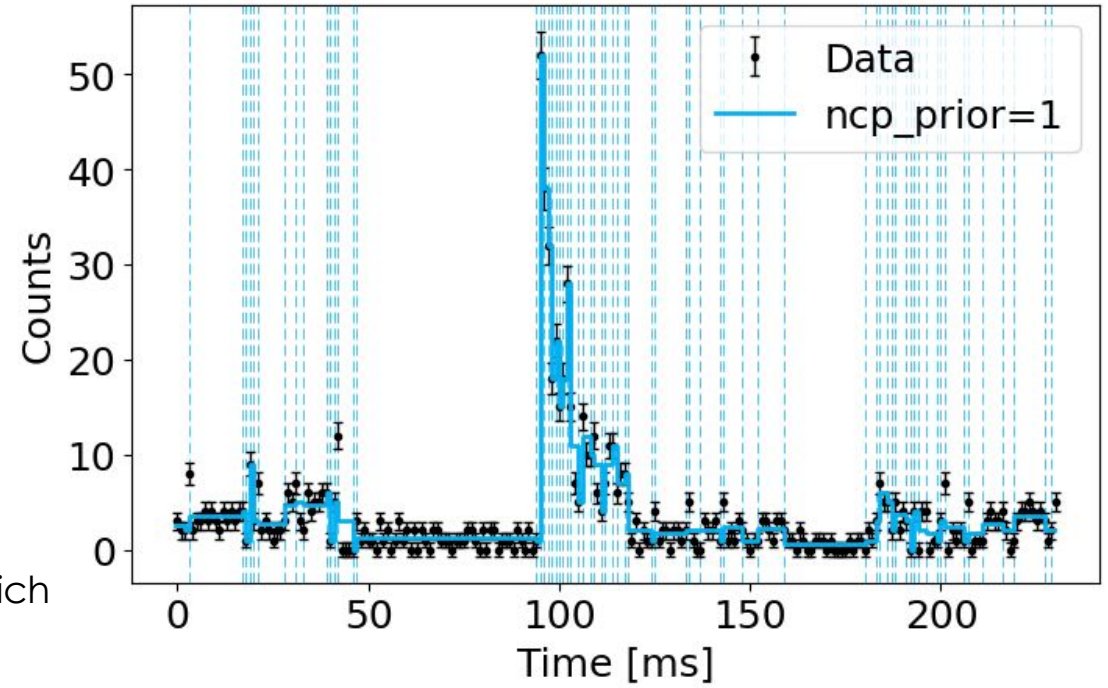

Plot made using bayesian_blocks from astropy.stats with fitness=measures (which uses Gaussian likelihood by default)

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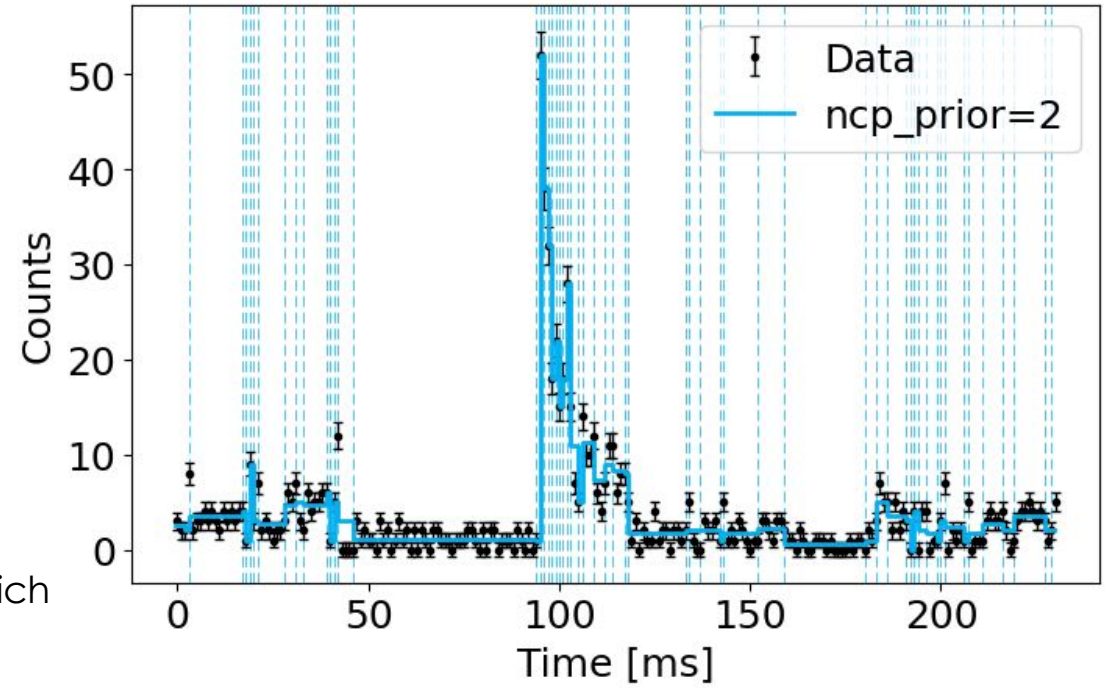

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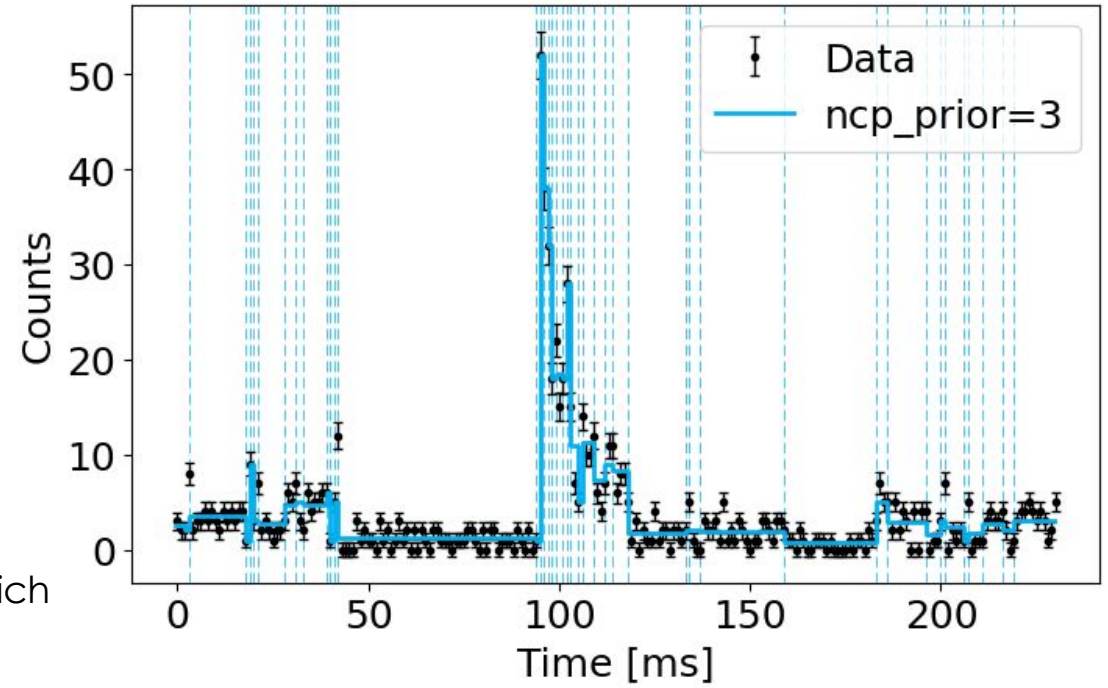

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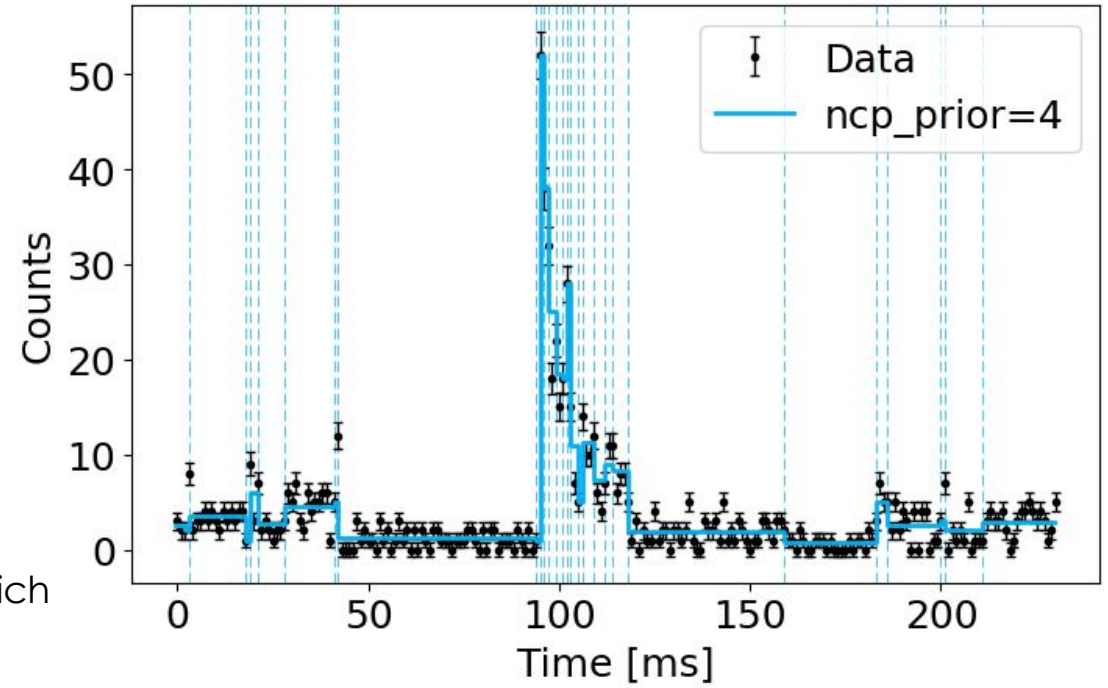

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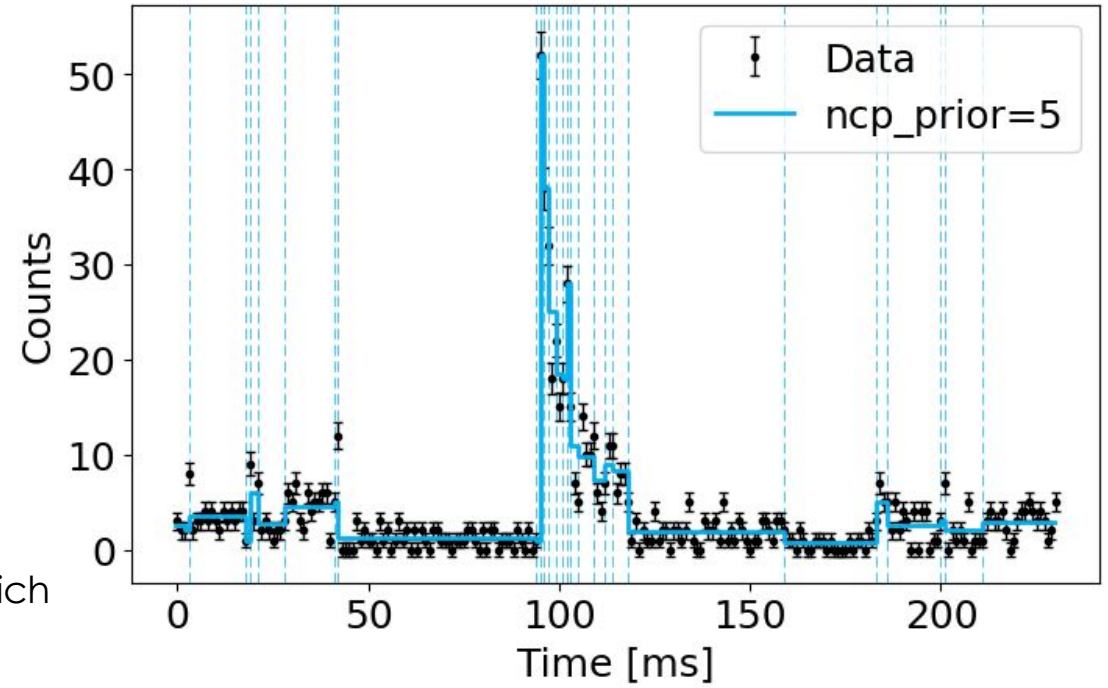

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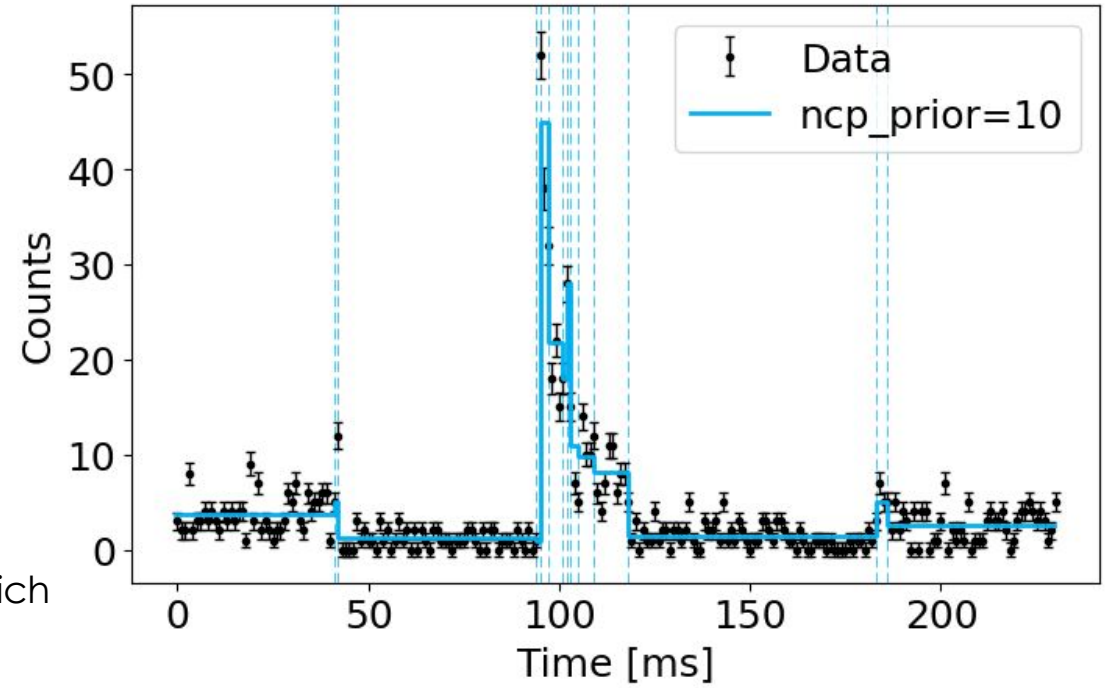

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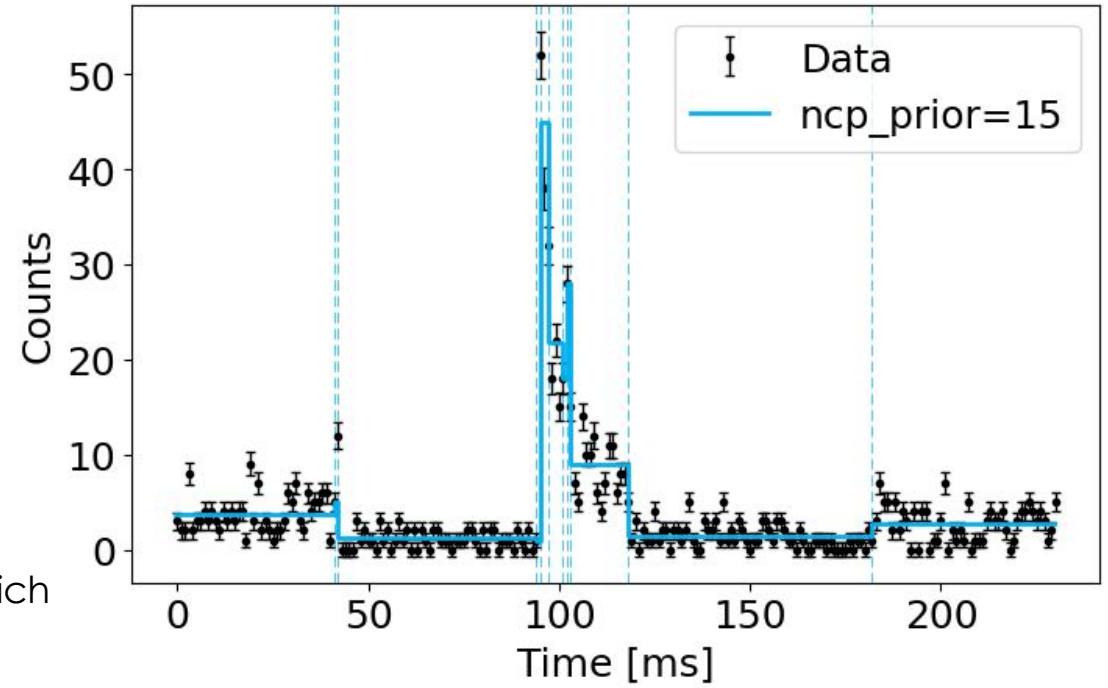

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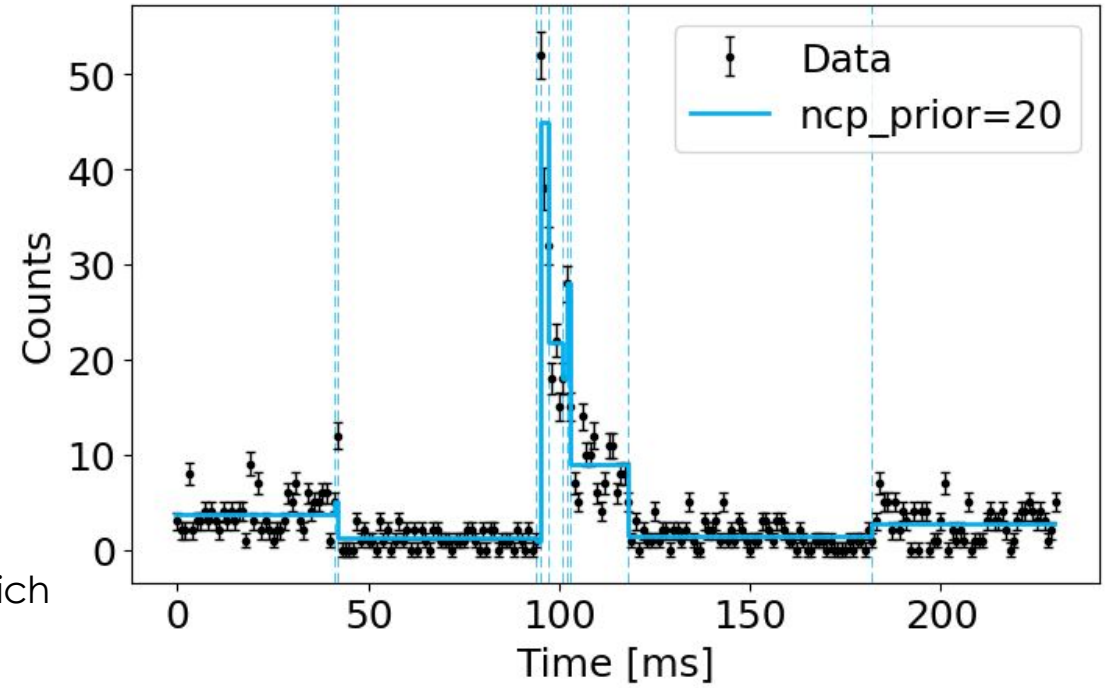

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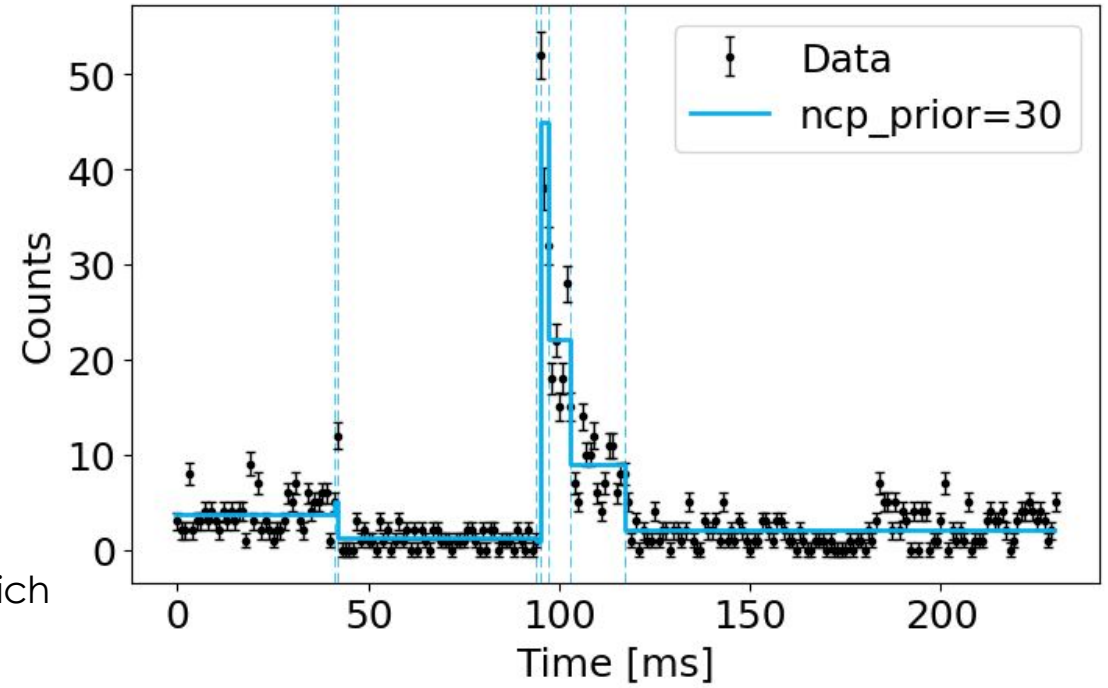

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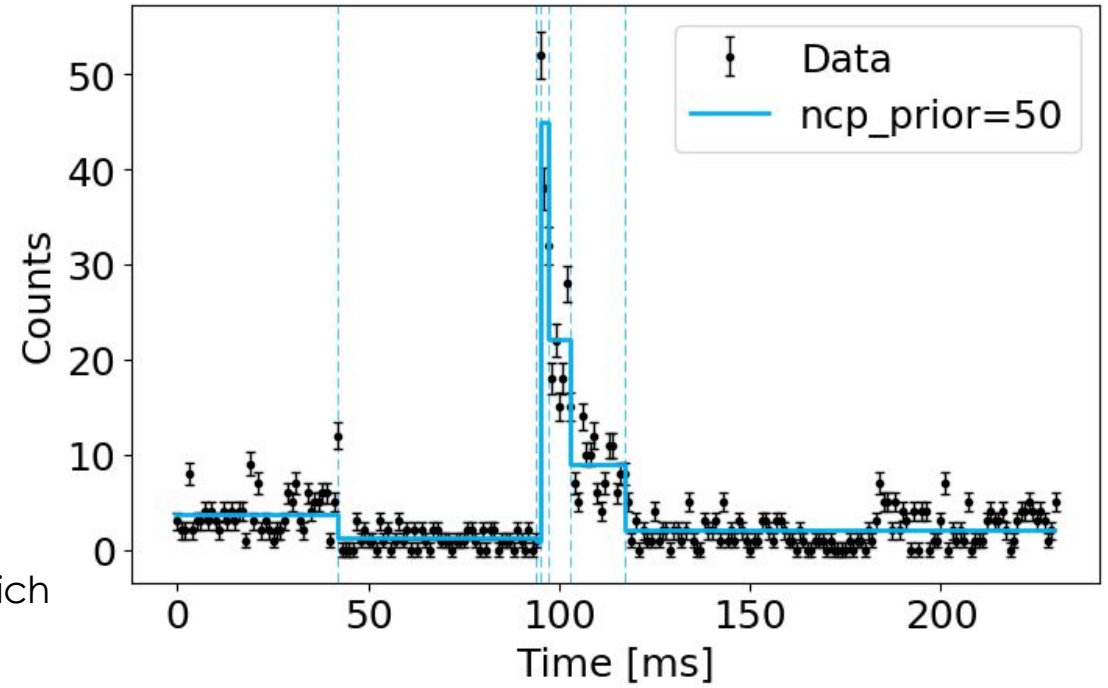
$$P(N_{blocks}) = P_0 \gamma^{N_{blocks}} \quad (\text{ncp\_prior} = -\ln(\gamma))$$



Plot made using bayesian_blocks from astropy.stats with fitness=measures (which uses Gaussian likelihood by default)

Bayesian Blocks

Statistical point of view

Scargle+2013

$$P(\text{Model}\,|\,\text{Data}) \propto P(\text{Data}\,|\,\text{Model}) \times P(\text{Model})$$

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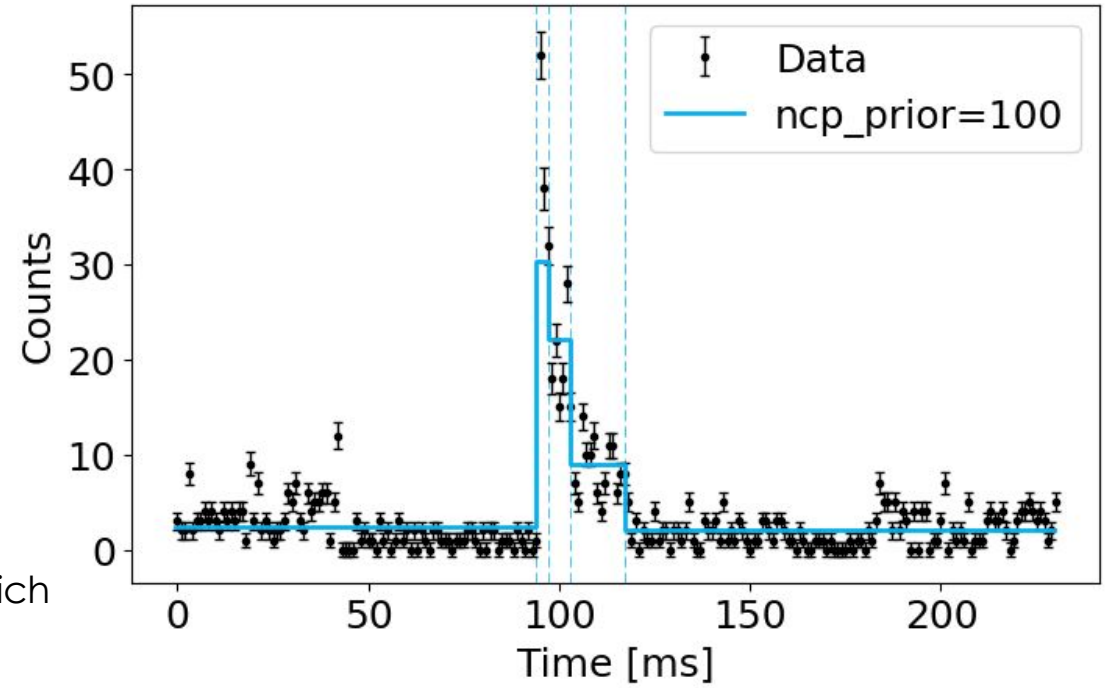

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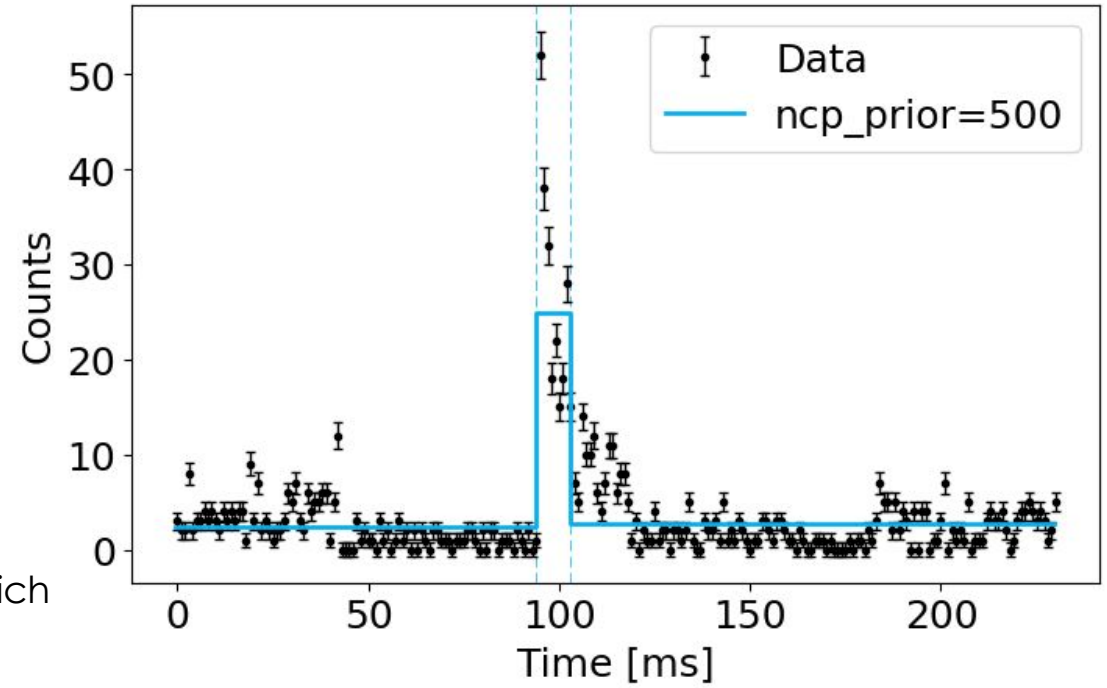

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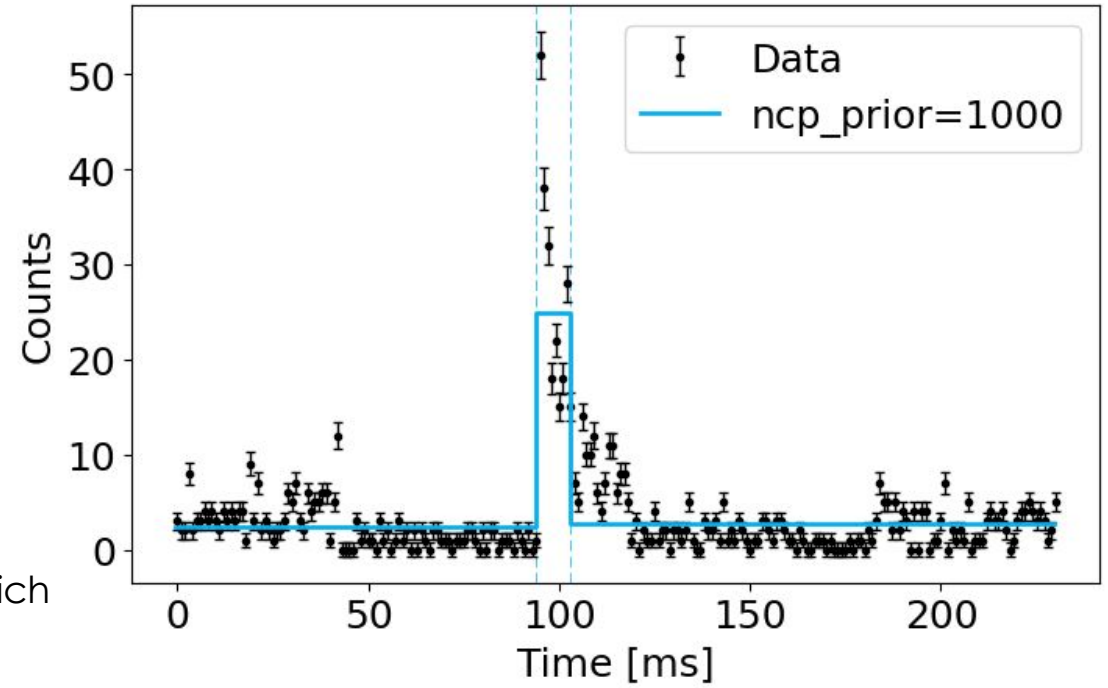

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Bayesian Blocks

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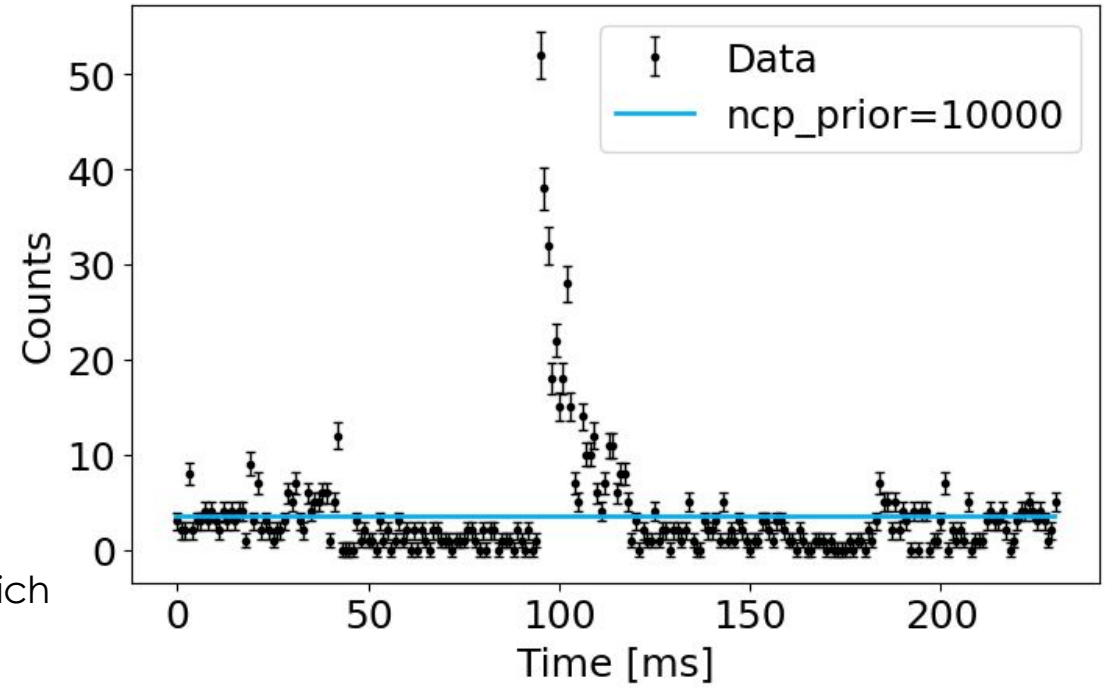
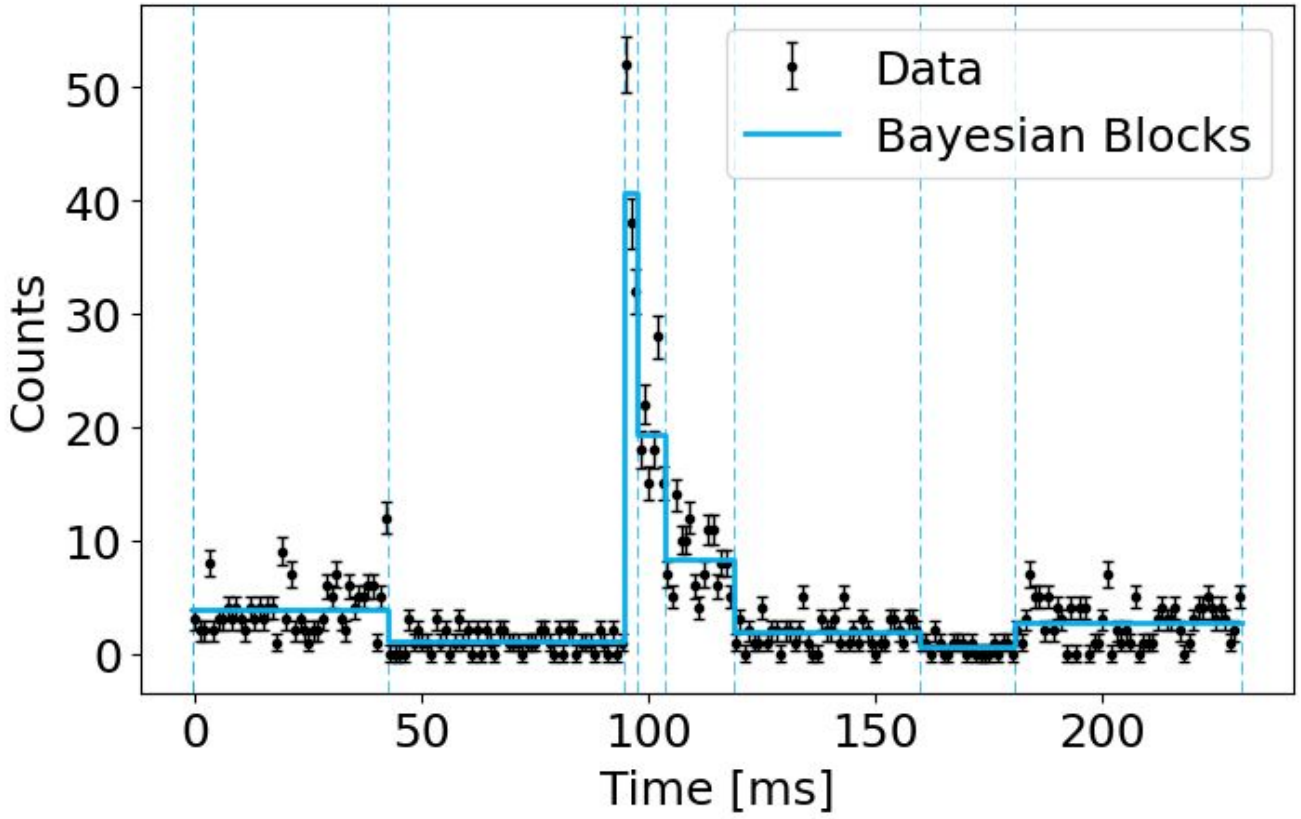


Plot made using bayesian_blocks from astropy.stats with fitness=measures (which uses Gaussian likelihood by default)

Bayesian Blocks Interpretive point of view

Scargle+2013

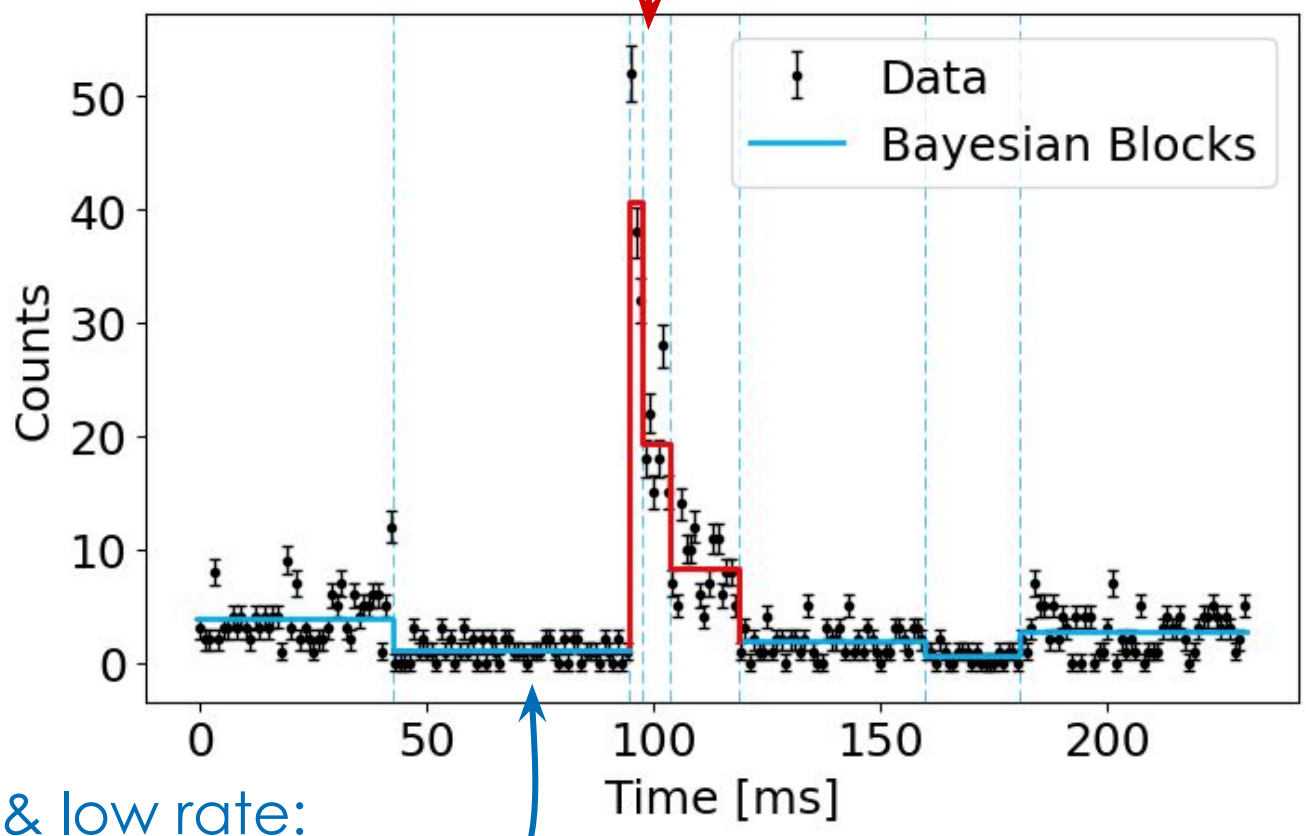


Bayesian Blocks Interpretive point of view

Scargle+2013

Short block(s) & high rate:

FOB candidate

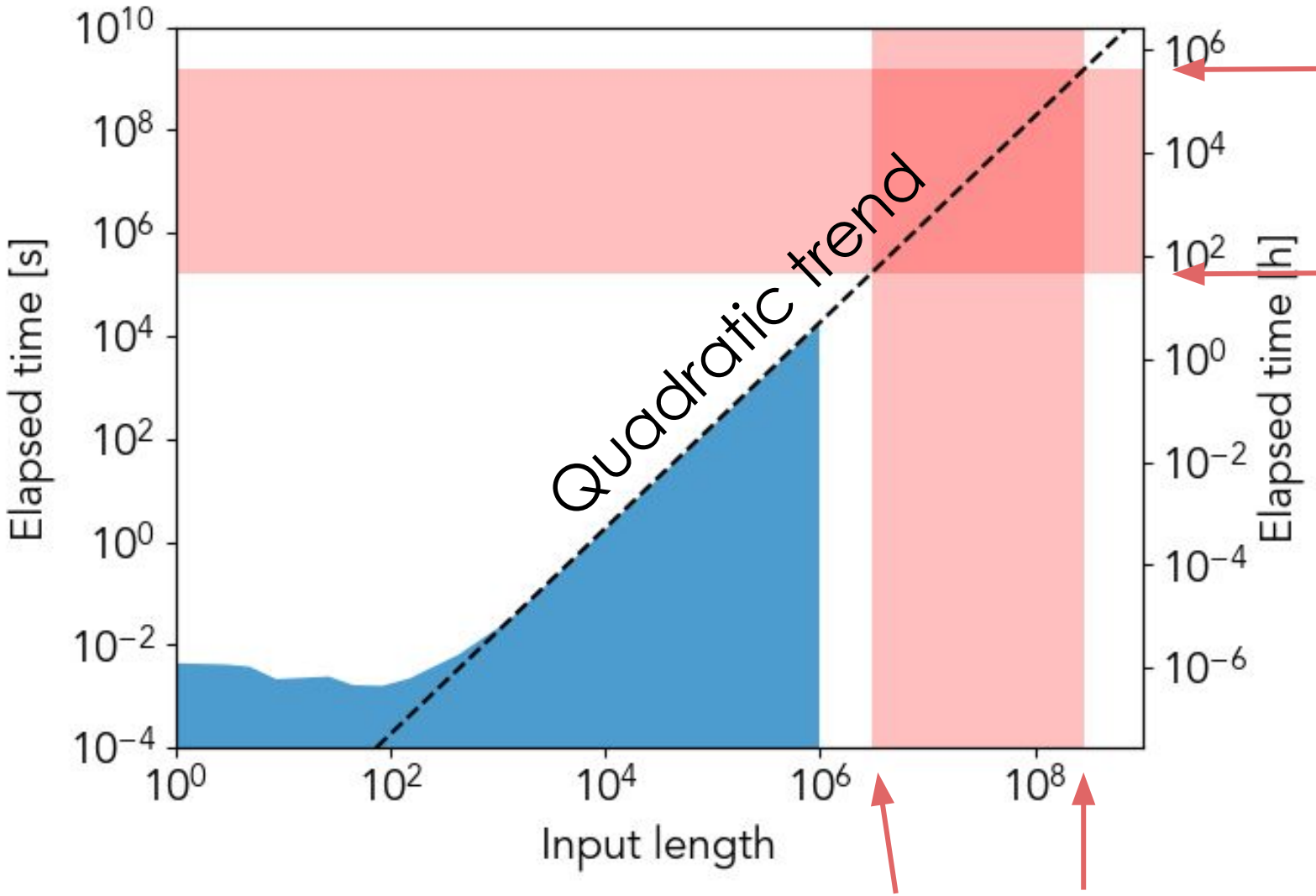


Long block & low rate:

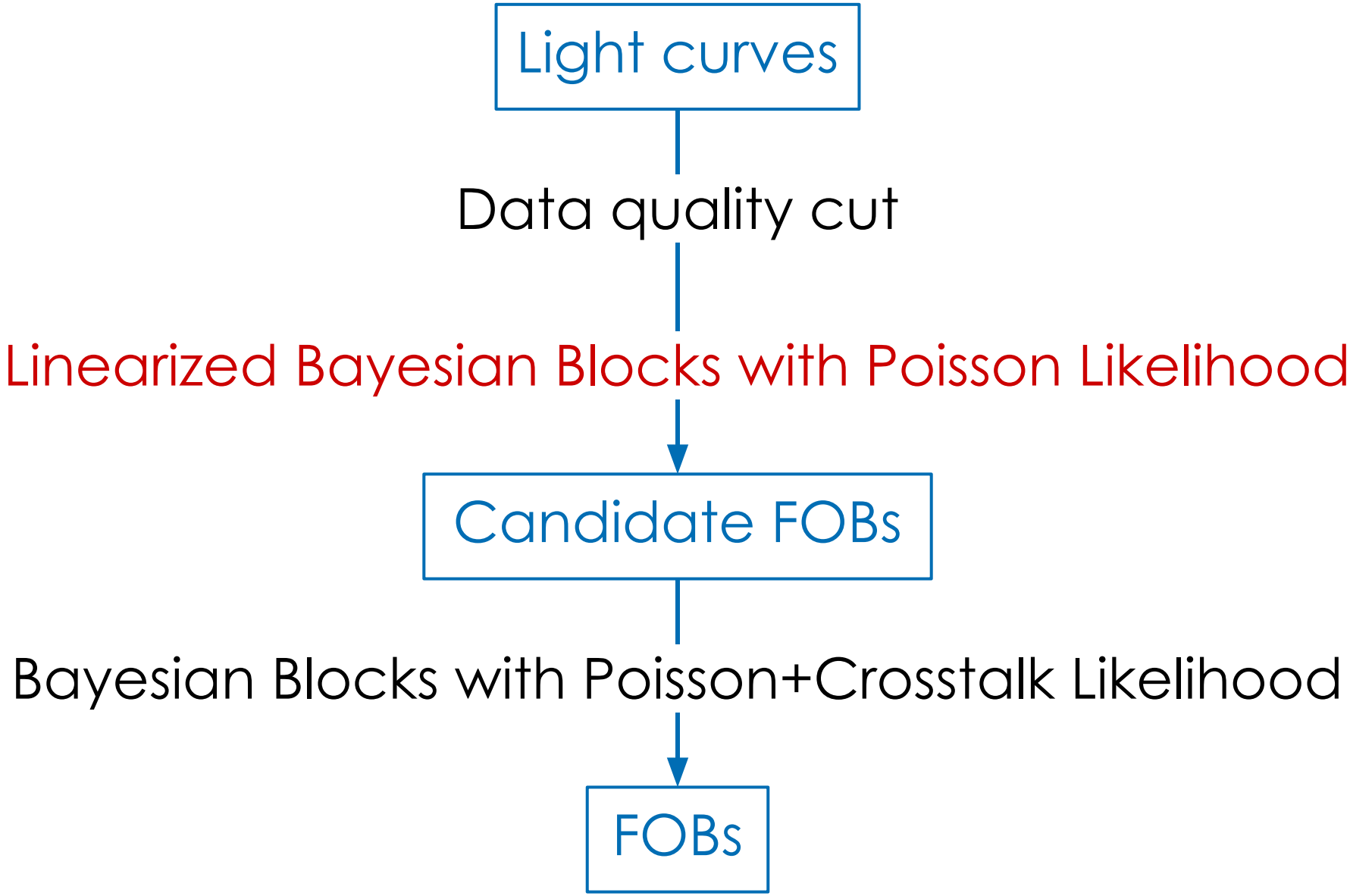
stable emission

Bayesian Blocks Quadratic scaling of time

Scargle+2013

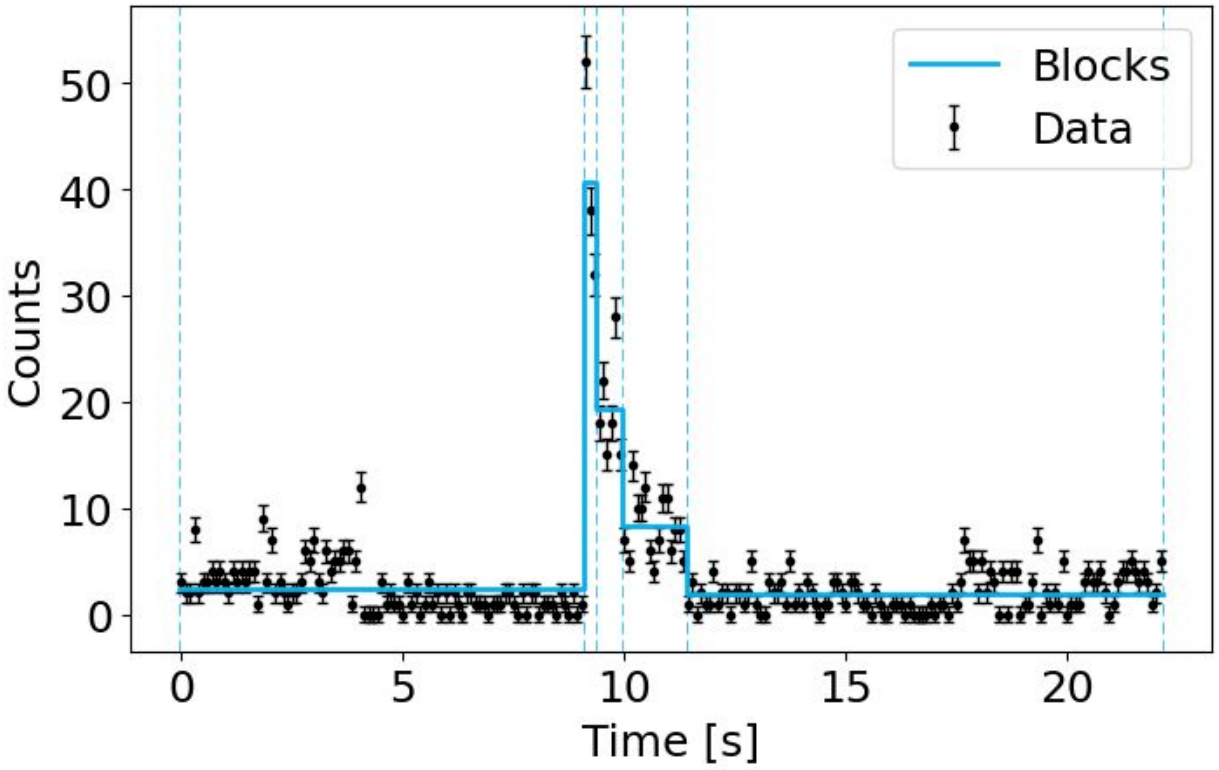


Pipeline structure

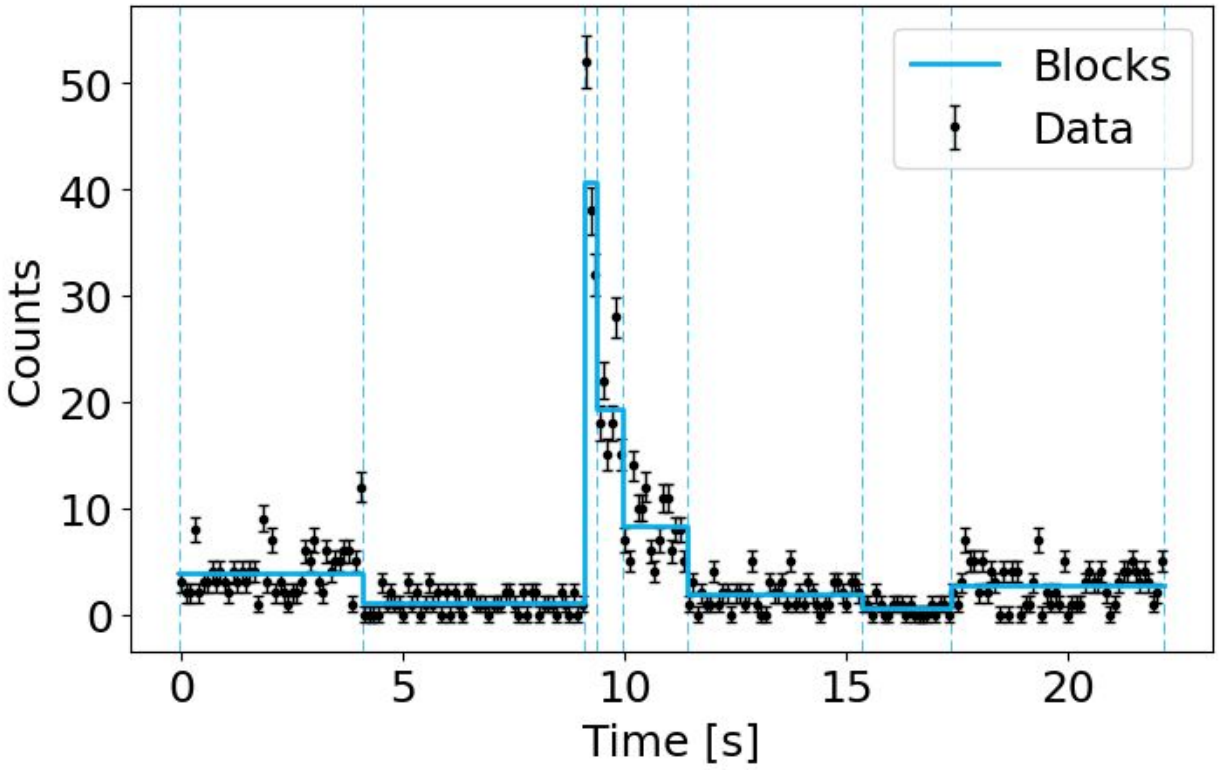


Linearized Bayesian Blocks

Search restricted to partitions with block lengths below 5 seconds

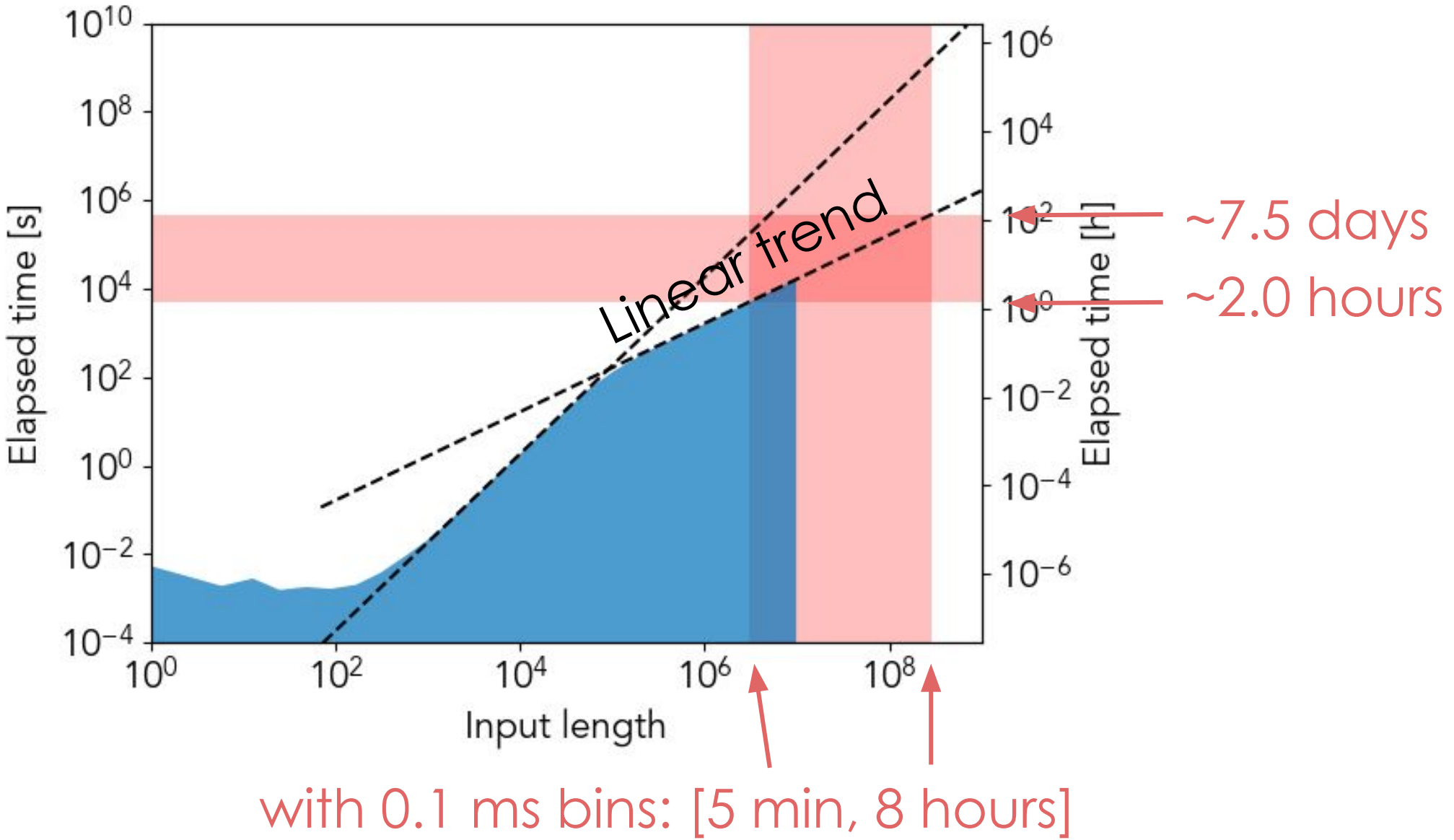


X

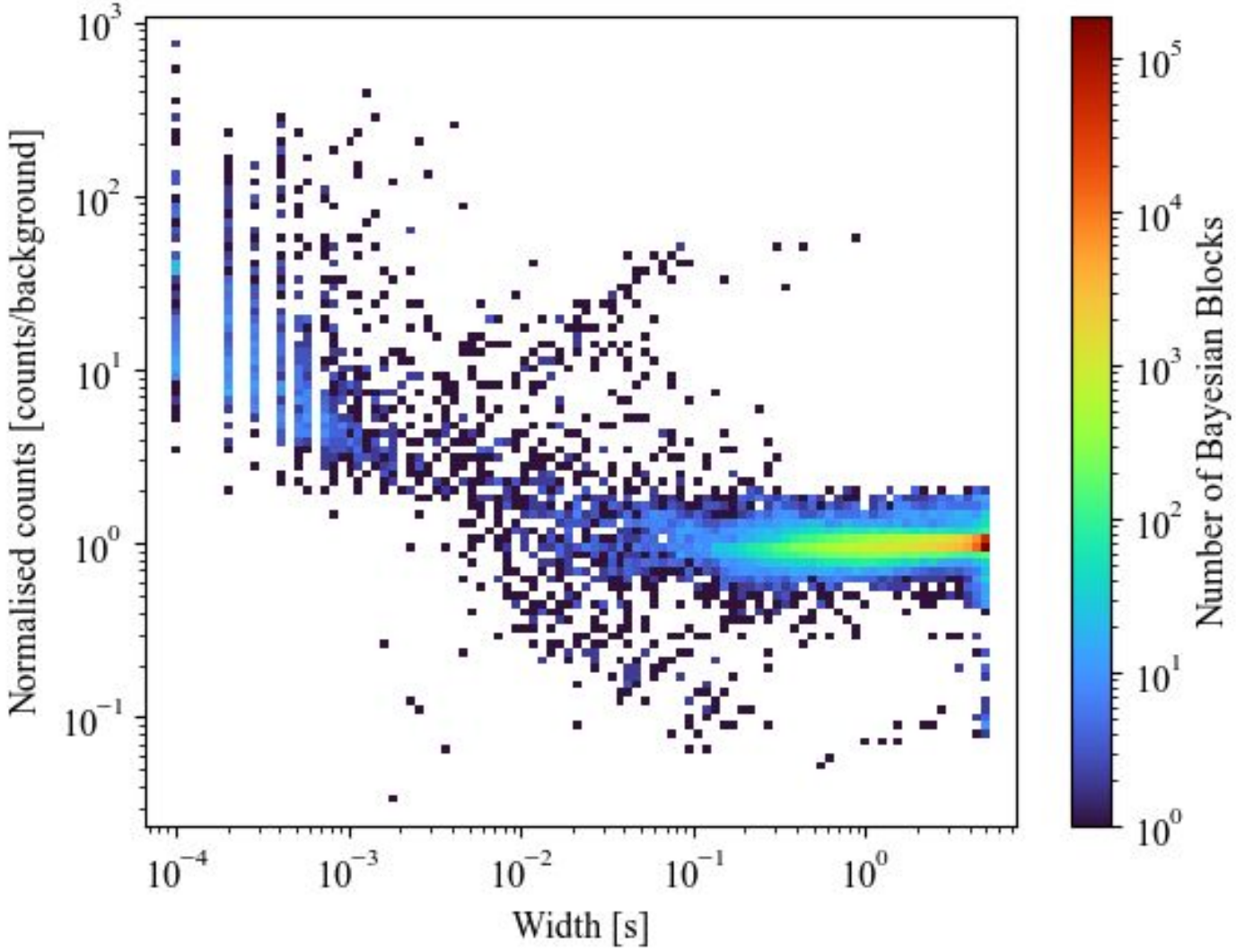


✓

Linearized Bayesian Blocks

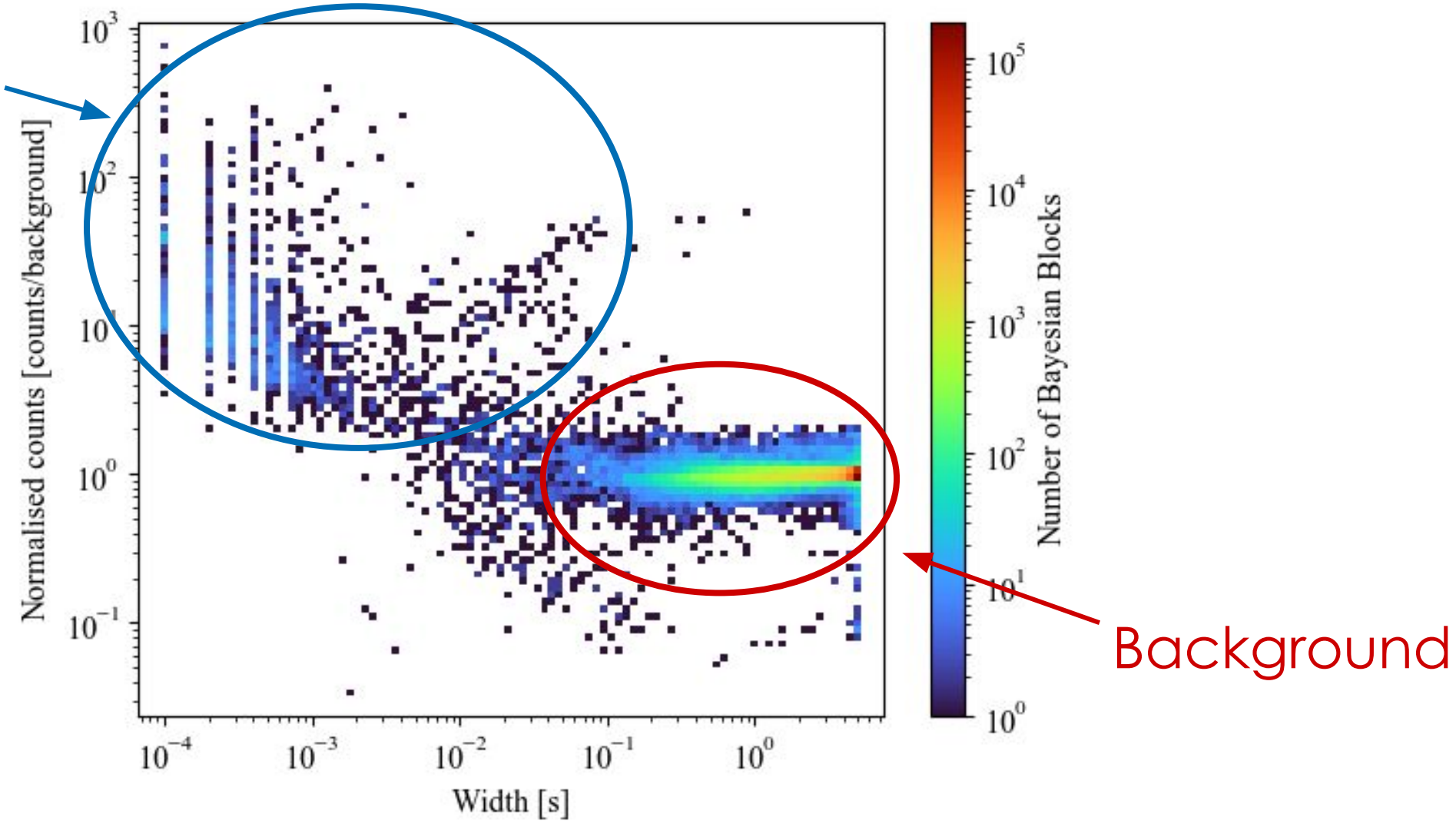


Linearized Bayesian Blocks



Linearized Bayesian Blocks

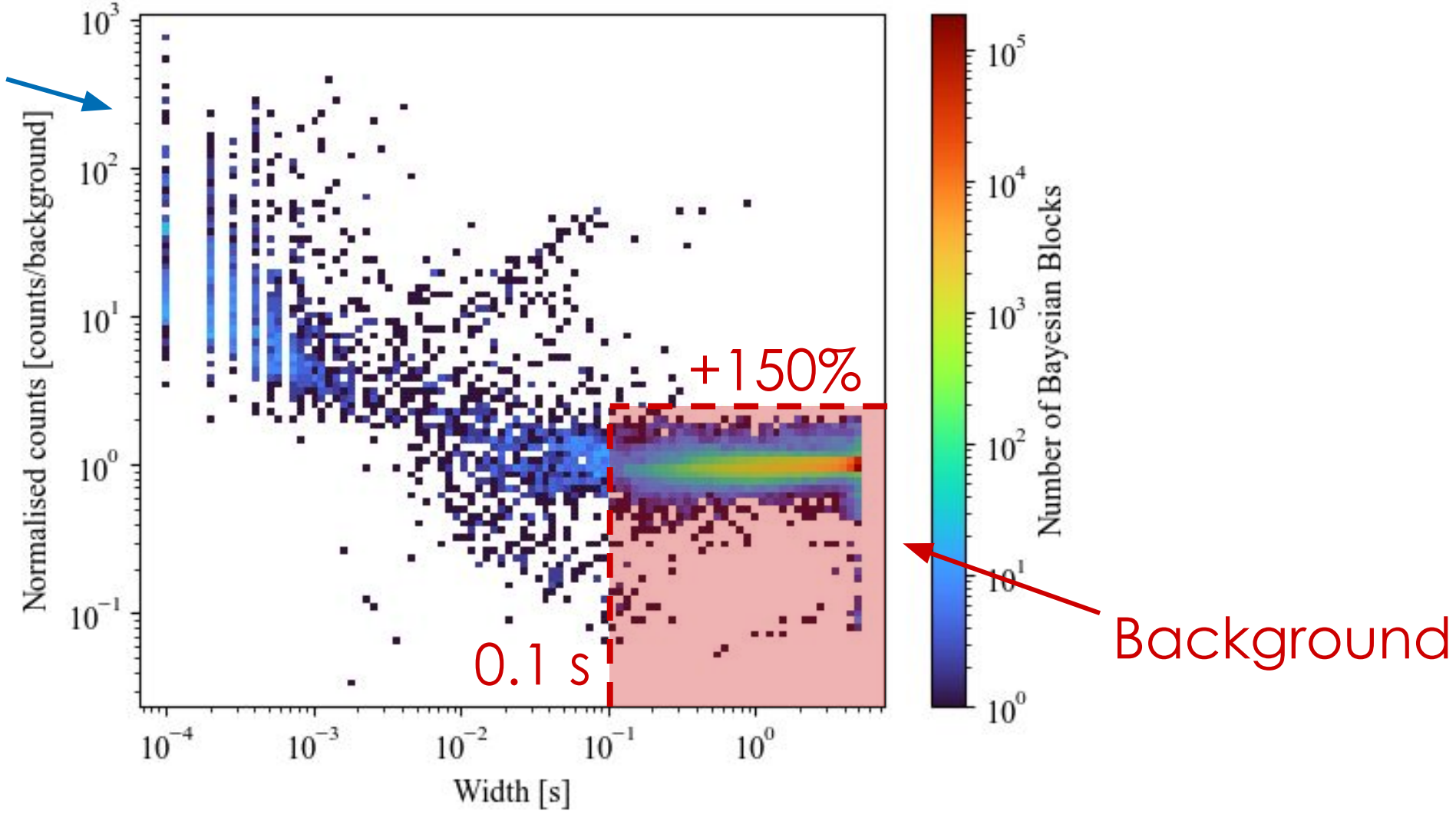
Candidate FOBs



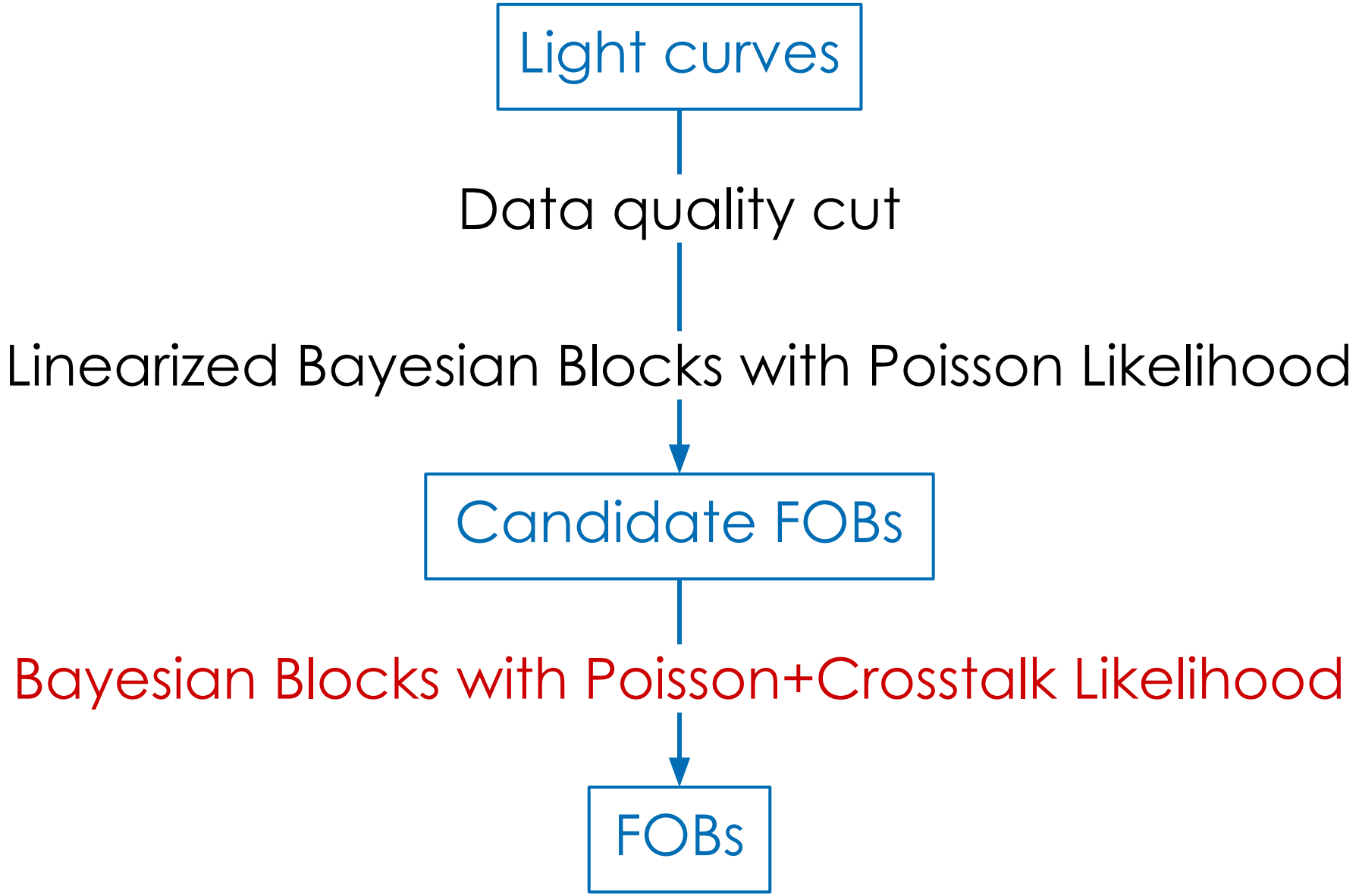
Background

Linearized Bayesian Blocks

Candidate FOBs



Pipeline structure



Poisson+CT–likelihood Bayesian Blocks

Repeated search within a 1 s–radius around each candidate FOB, with ad hoc likelihood and prior

Bayesian Blocks

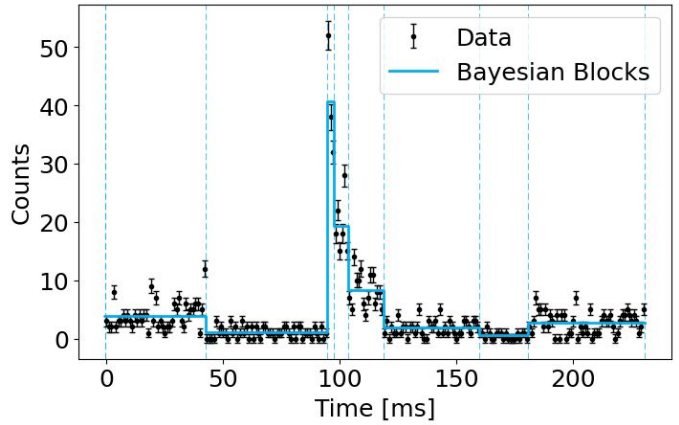
Statistical point of view

Scargle+2013

$$P(\text{Model} \mid \text{Data}) \propto P(\text{Data} \mid \text{Model}) \times P(\text{Model})$$

Posterior — Likelihood — Prior

$$L_{\text{model}} = \prod_{i \in \text{blocks}} L_i = \prod_{i \in \text{blocks}} \prod_{j \in \text{data}_i} P_{\text{Poisson}}(n_j; \lambda_i)$$



Poisson+CT–likelihood Bayesian Blocks

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Bayesian Blocks

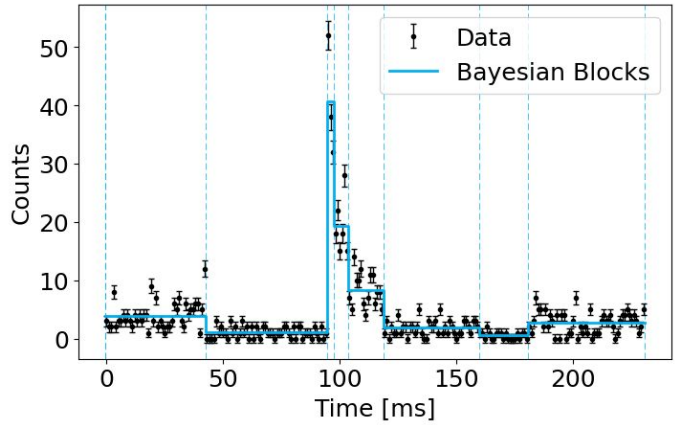
Statistical point of view

Scargle+2013

$$P(\text{Model} \mid \text{Data}) \propto P(\text{Data} \mid \text{Model}) \times P(\text{Model})$$

Posterior — Likelihood — Prior

$$L_{\text{model}} = \prod_{i \in \text{blocks}} L_i = \prod_{i \in \text{blocks}} \prod_{j \in \text{data}_i} P_{\text{Poisson+CT}}(n_j; \lambda_i, \varepsilon_{CT})$$



Poisson+CT–likelihood Bayesian Blocks

Repeated search within a 1 s–radius around each candidate FOB, with ad hoc likelihood and prior

Bayesian Blocks

Statistical point of view

Scargle+2013

$$P(\text{Model} \mid \text{Data}) \propto P(\text{Data} \mid \text{Model}) \times P(\text{Model})$$

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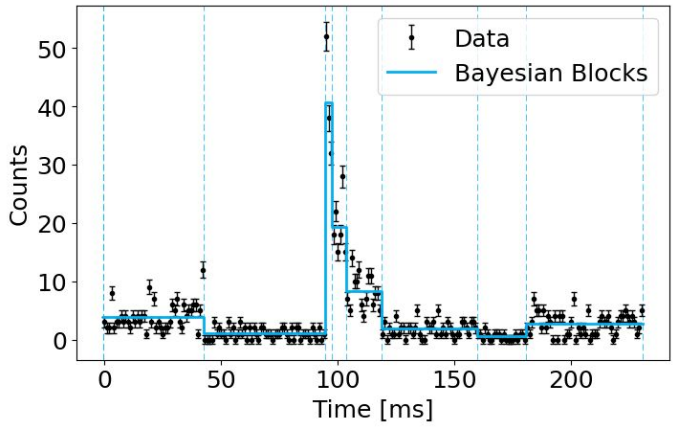

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Repeated search within a 1 s–radius around each candidate FOB, with ad hoc likelihood and prior

Bayesian Blocks Statistical point of view Scargle+2013

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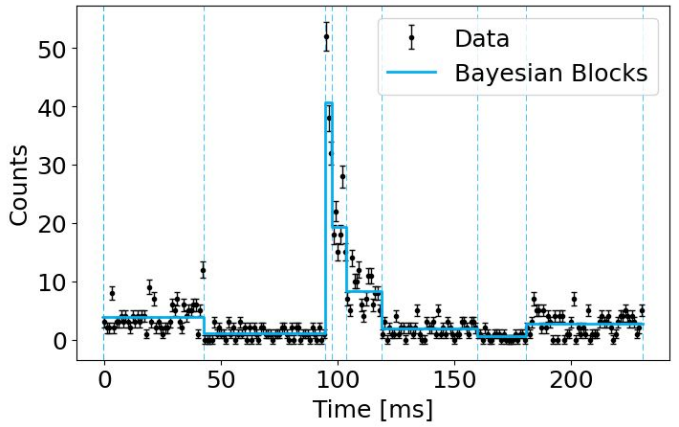
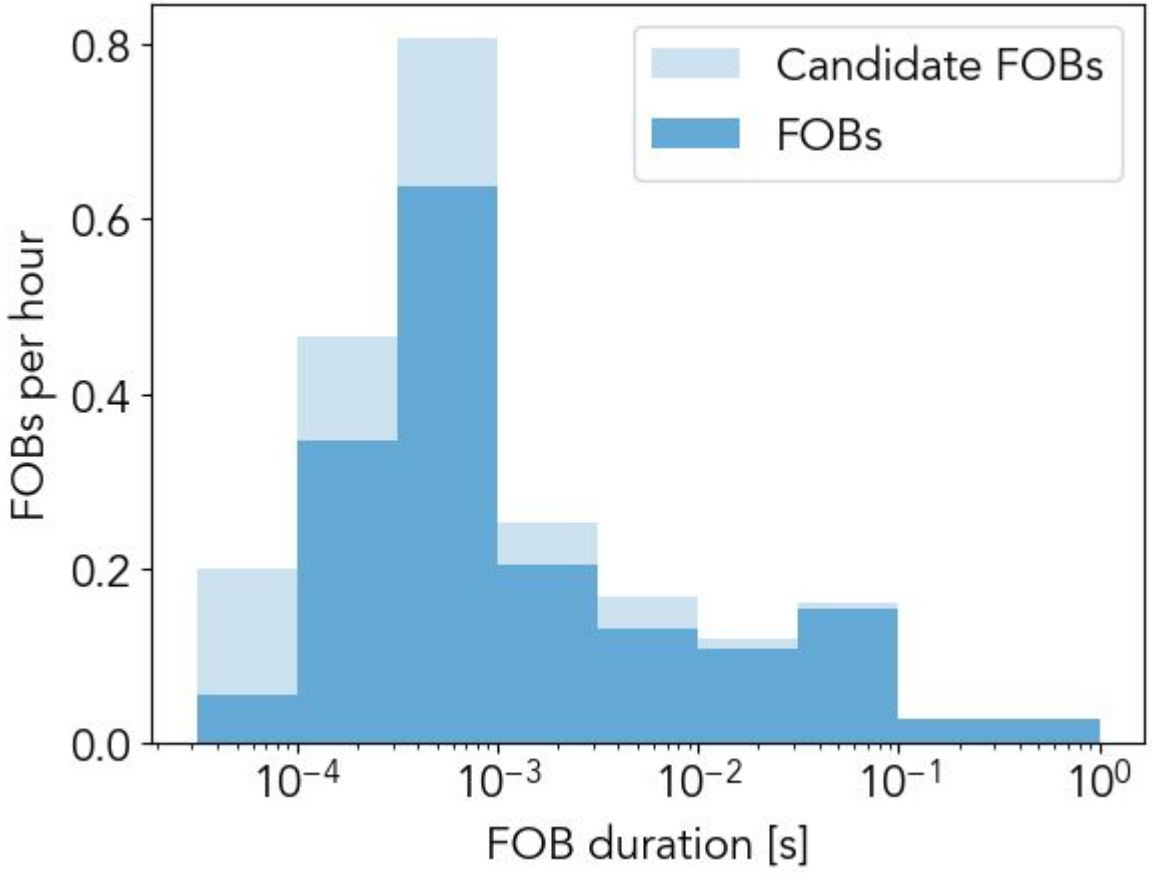


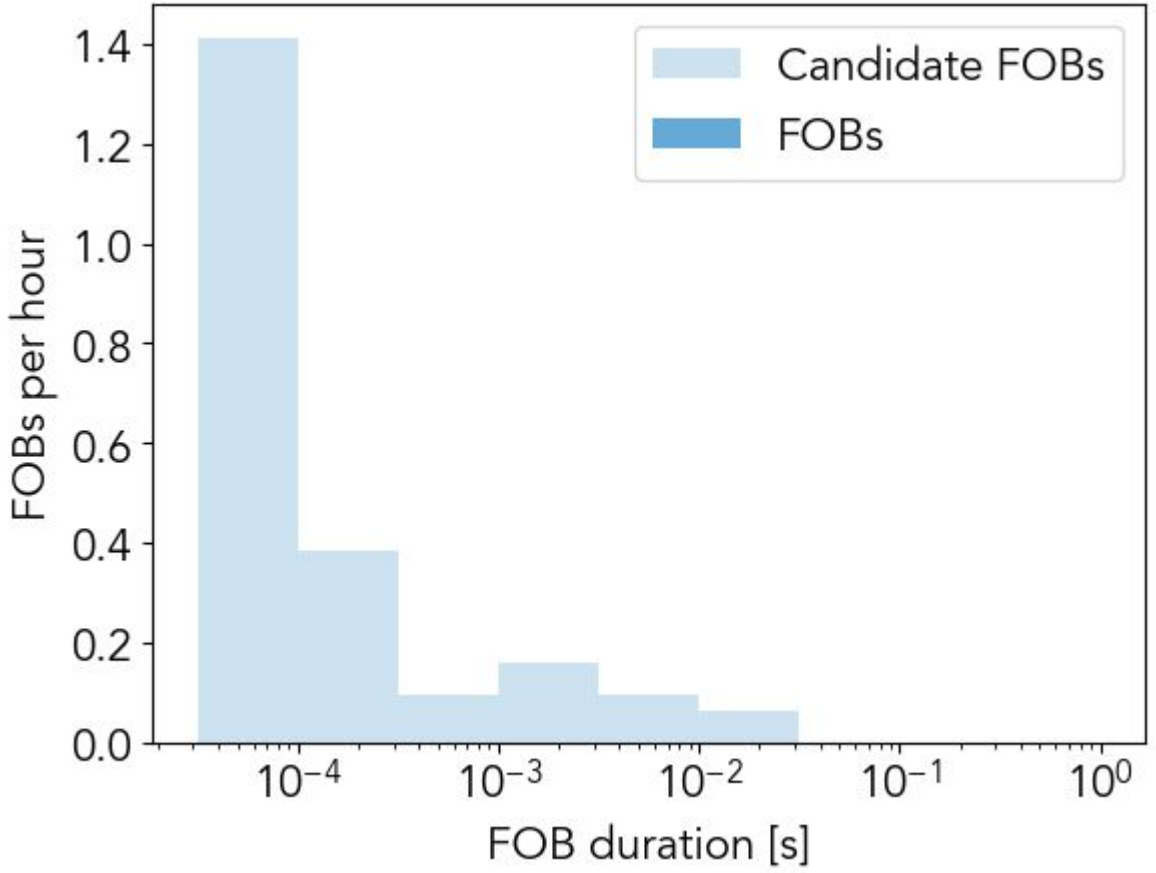
Calibrated with dark observations

Poisson+CT–likelihood Bayesian Blocks

From **real** observations

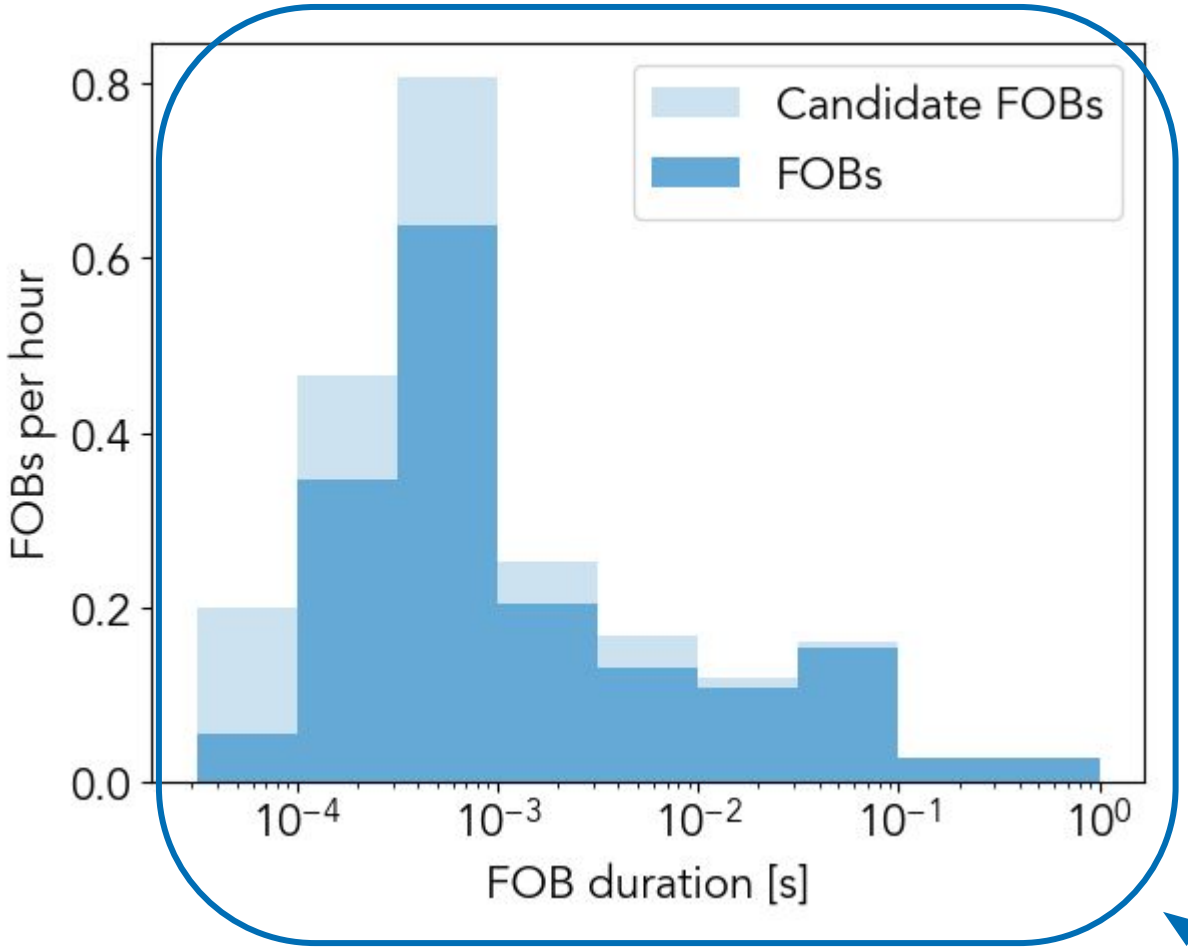


From **dark** observations

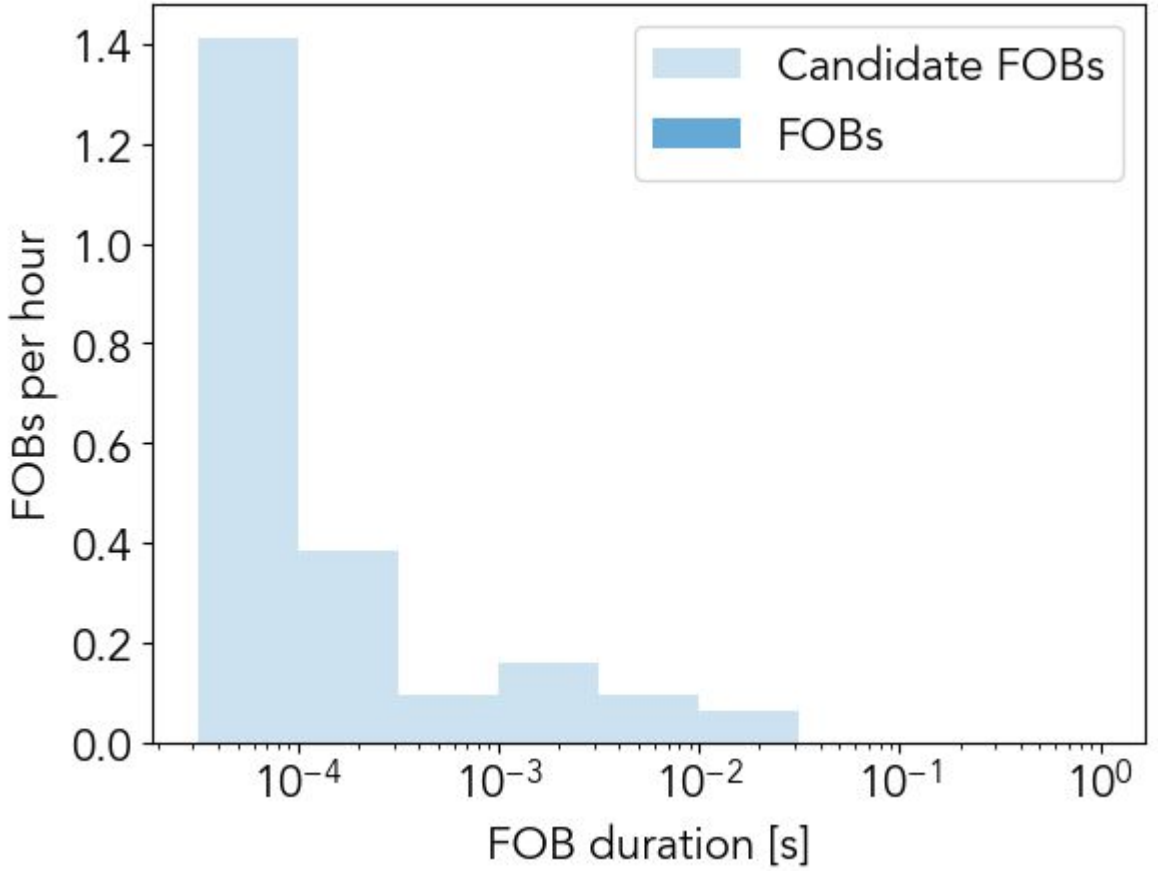


Poisson+CT–likelihood Bayesian Blocks

From **real** observations

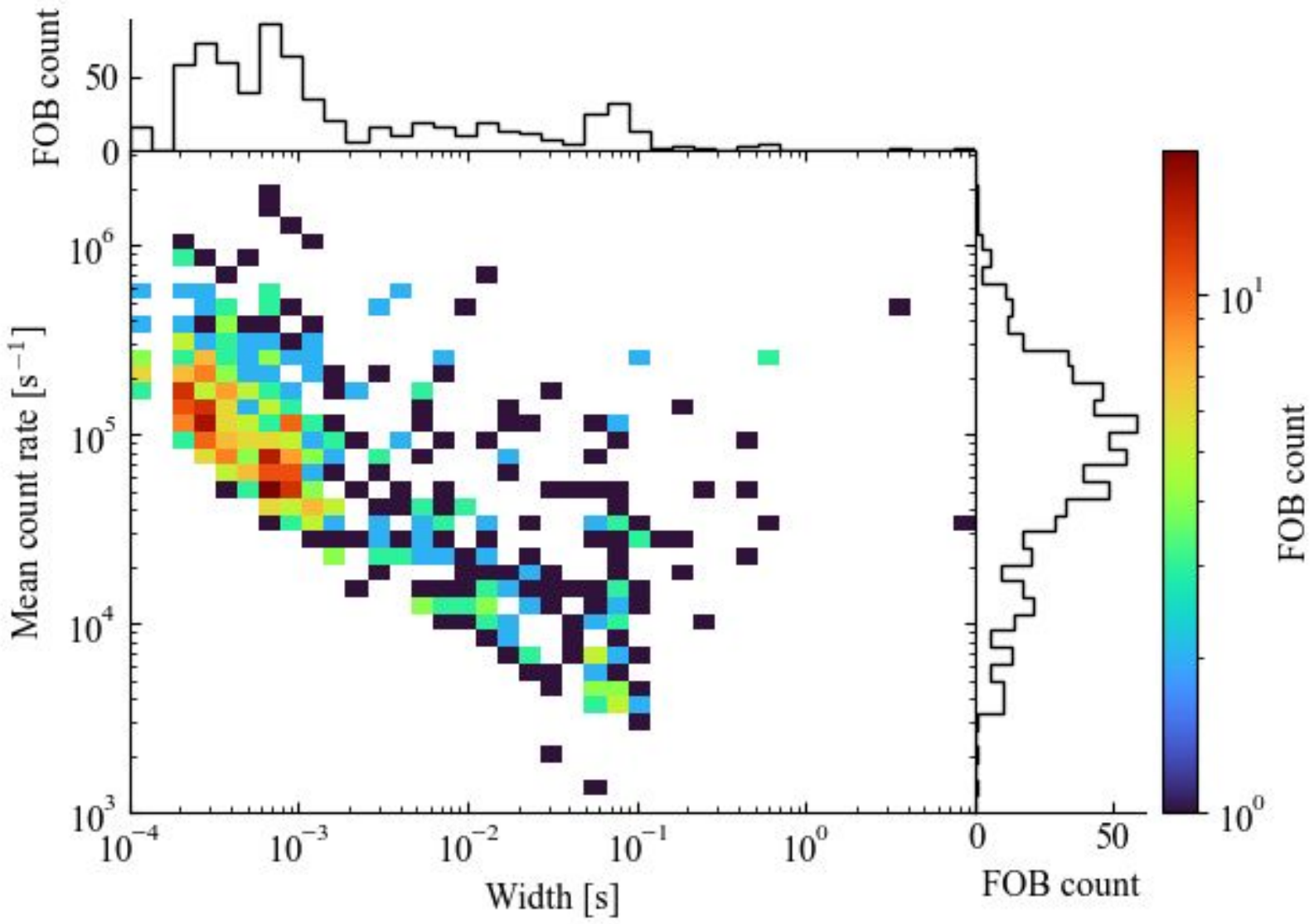


From **dark** observations

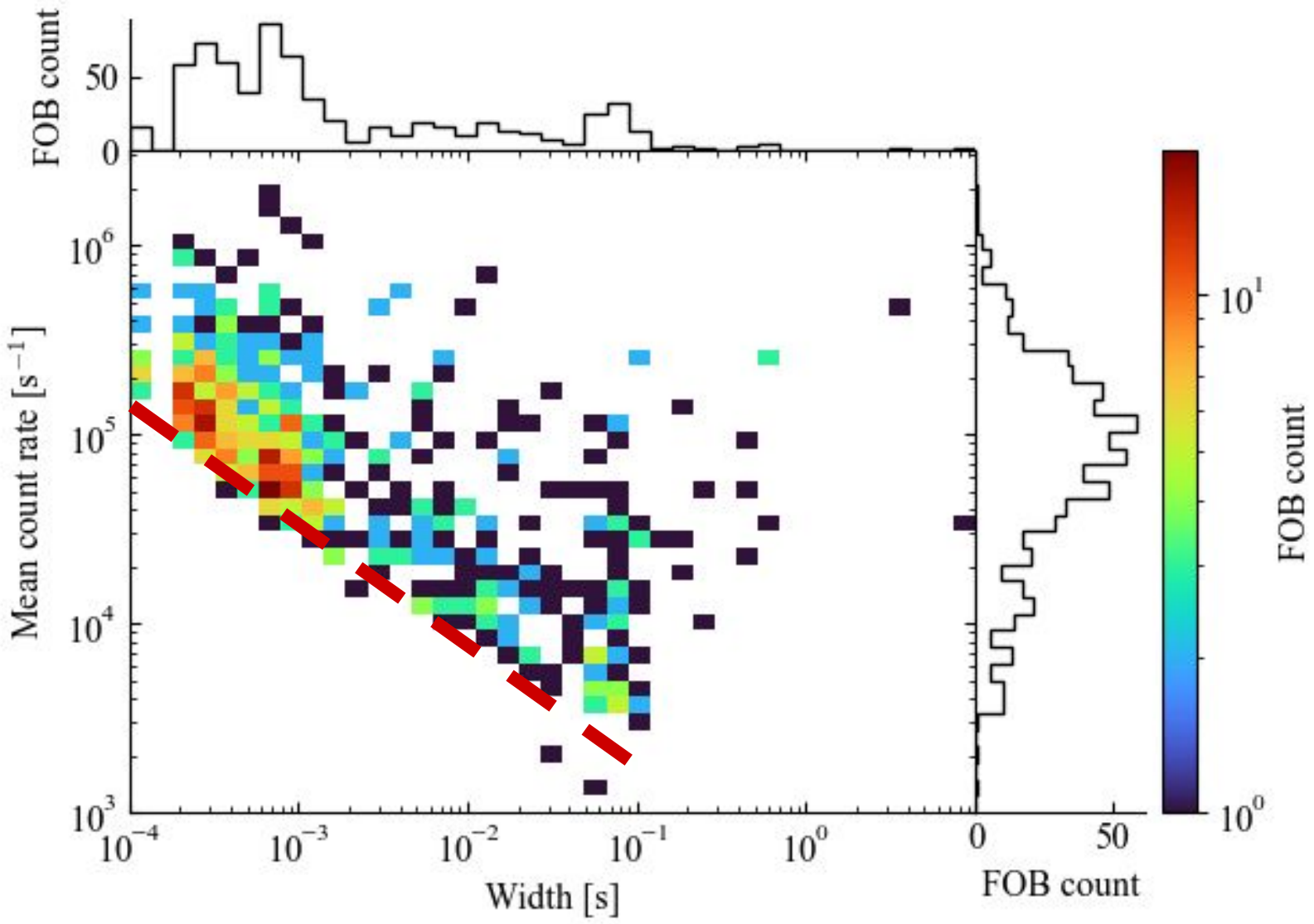


Final FOBs!

Pipeline sensitivity



Pipeline sensitivity



Pipeline sensitivity

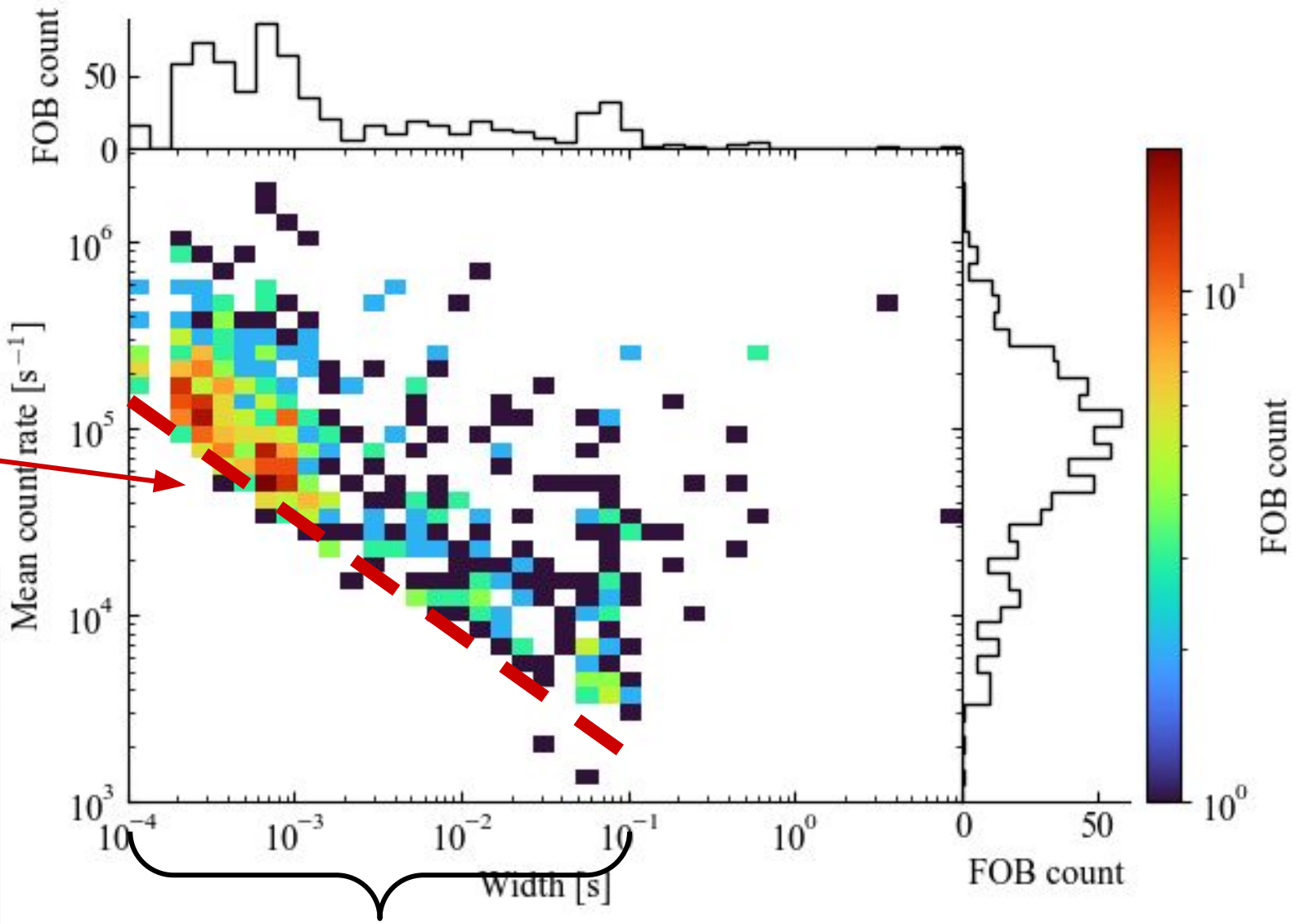
Equivalent Poisson

single-trial threshold

p-value ≈ 10^{-12} –10^{-13}

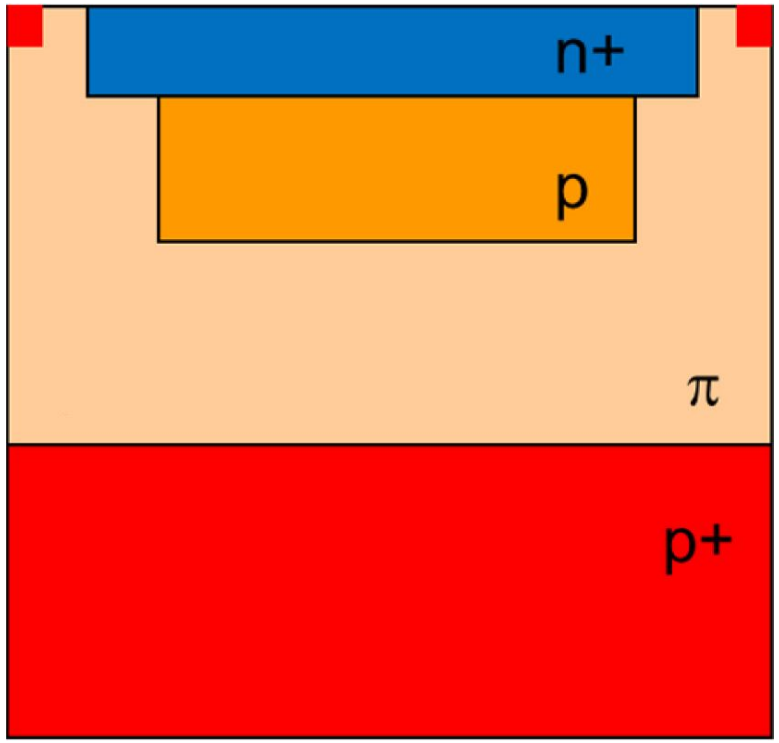
(z-score ≈ 6–7)

Integrated time	p-value (multi-trial)	z-score (multi-trial)
1 hour	3.6×10^{-5} – 3.6×10^{-6}	4.0 – 4.5
390 hours	1.4×10^{-2} – 1.4×10^{-3}	2.2 – 3.0



3 orders of magnitude

Crosstalk, or, *better yet,* correlated noise



[Sketches adapted from Piemonte & Gola, 2019]

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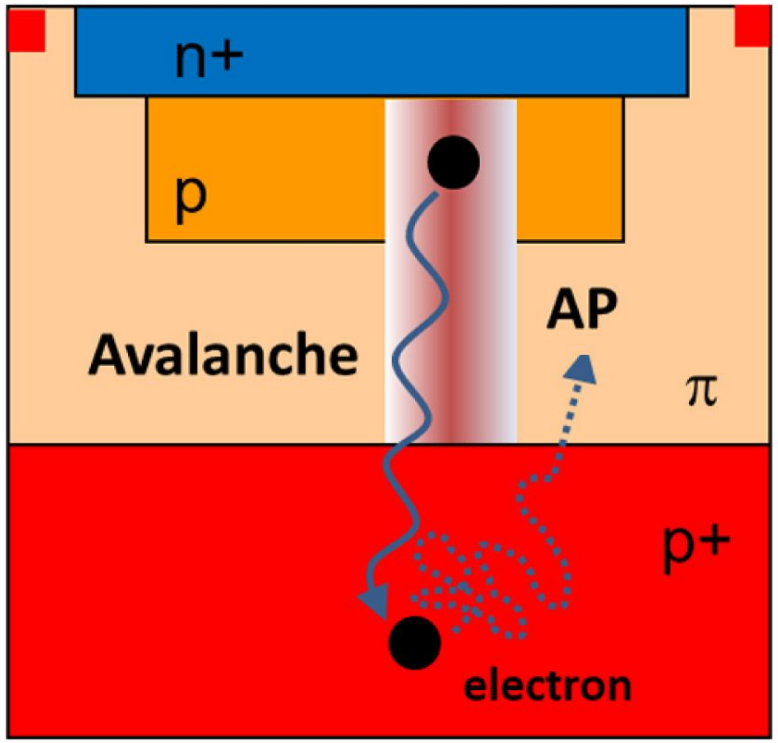

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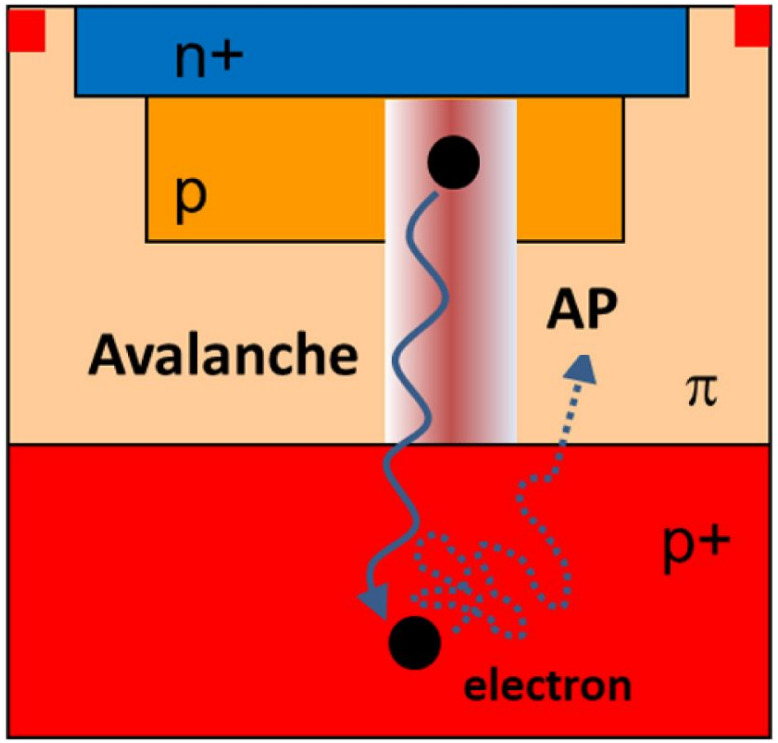
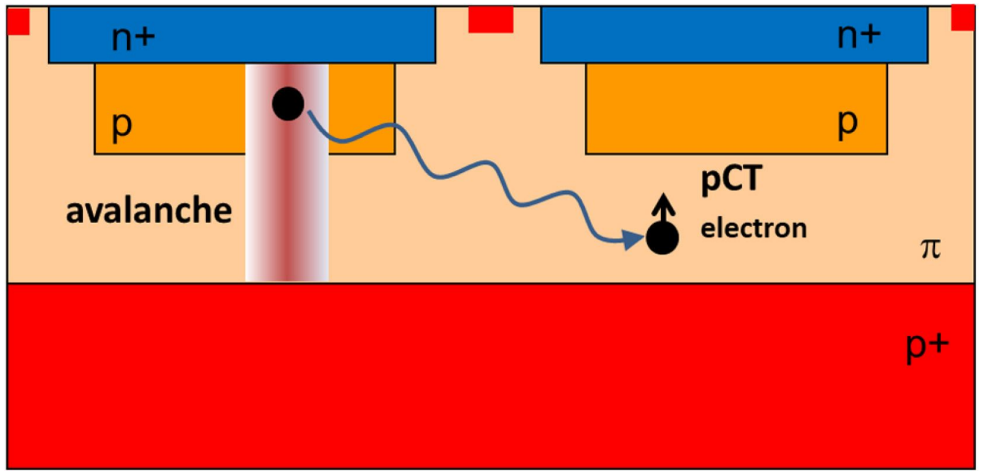
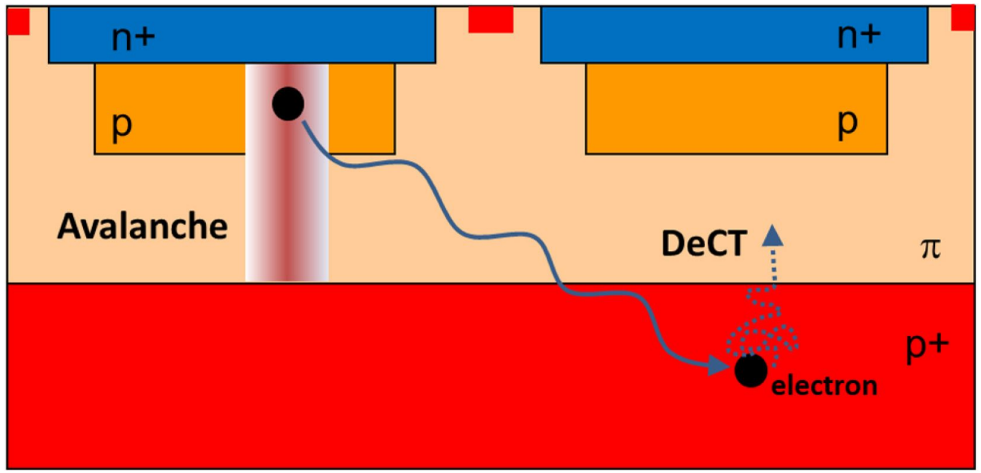




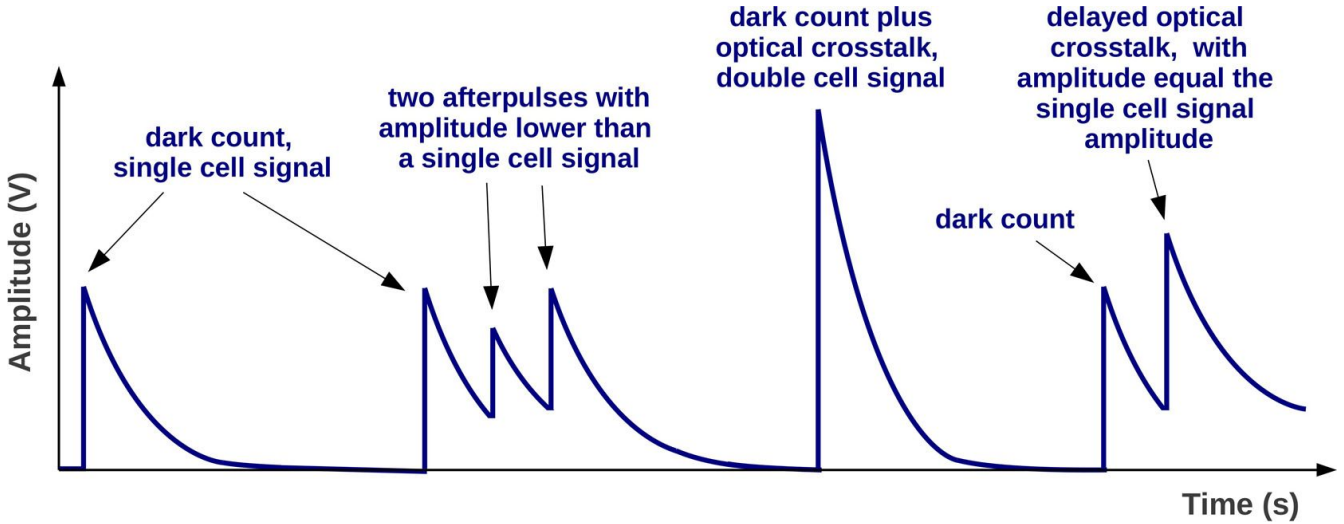
Prompt crosstalk



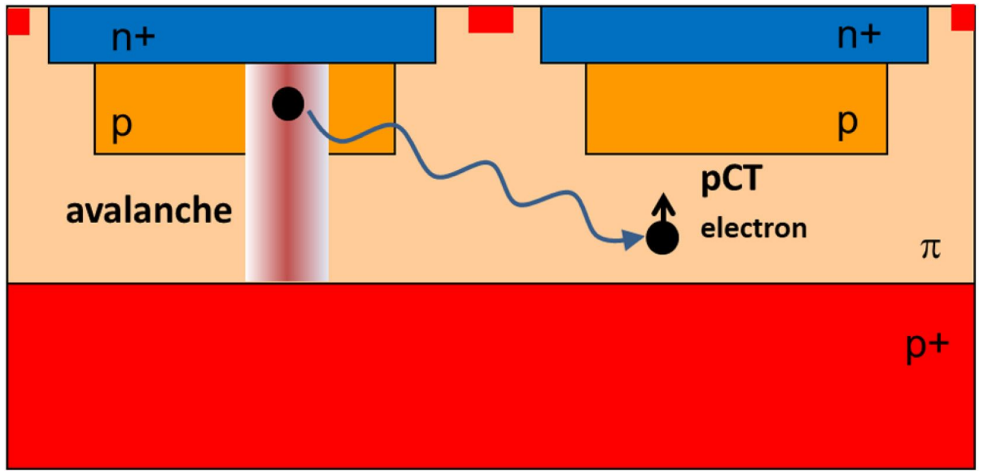
Delayed crosstalk

[Sketches adapted from Piemonte & Gola, 2019]

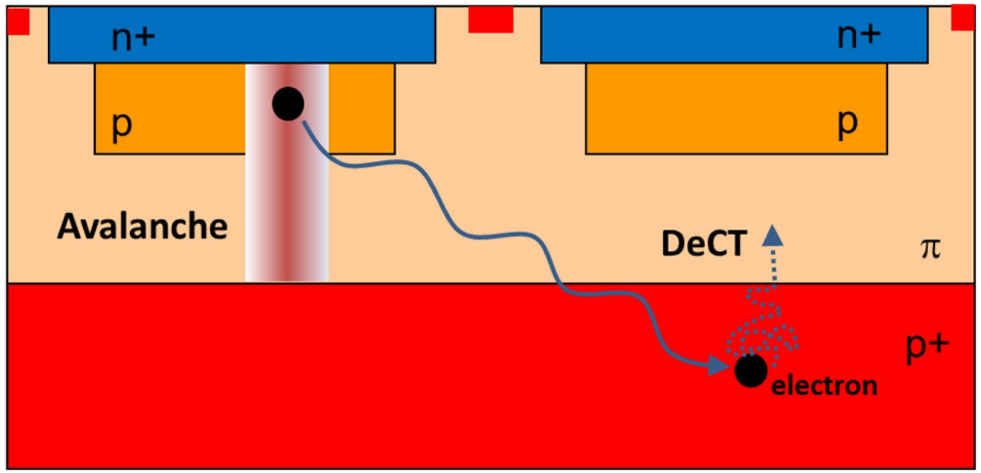
Crosstalk, or, *better yet,* correlated noise



[Acerbi & Gundacker, 2019]



Prompt crosstalk



Delayed crosstalk

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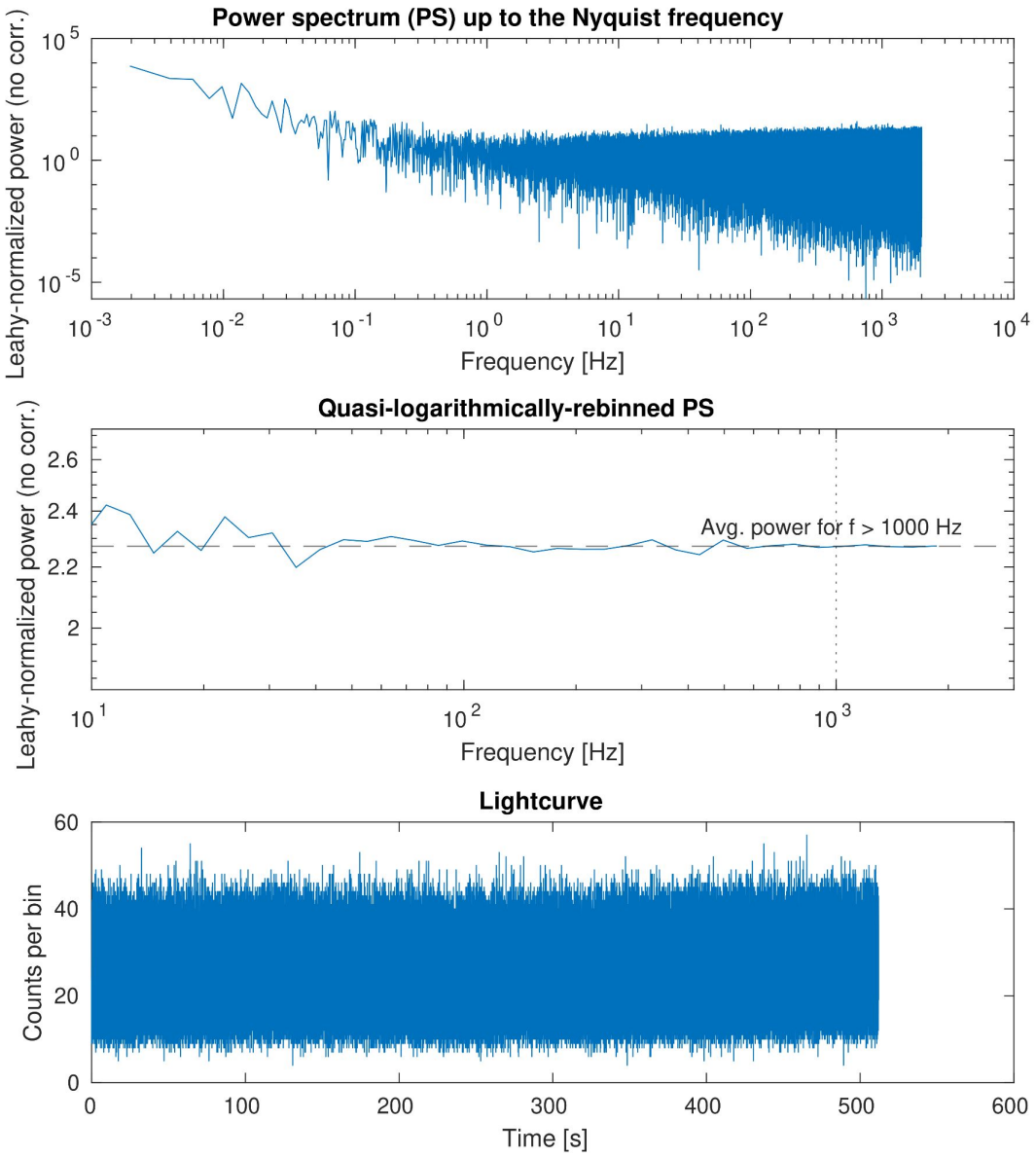
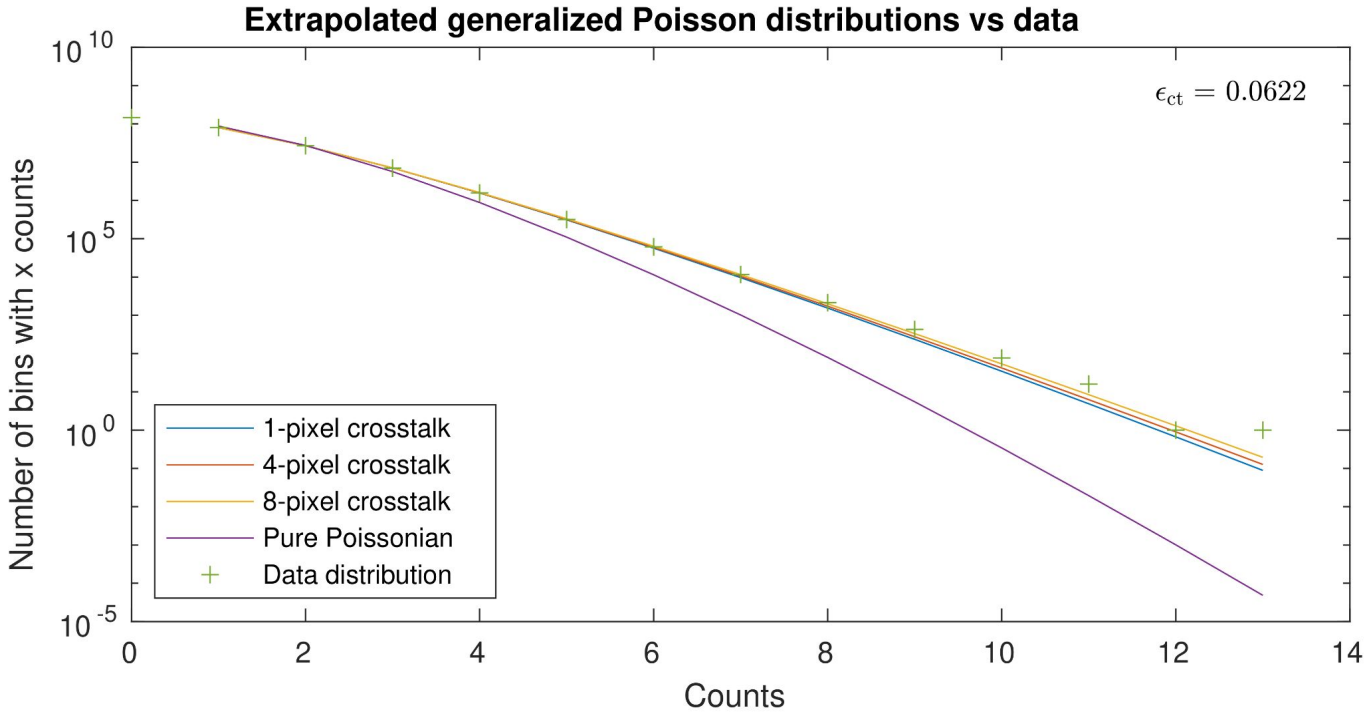
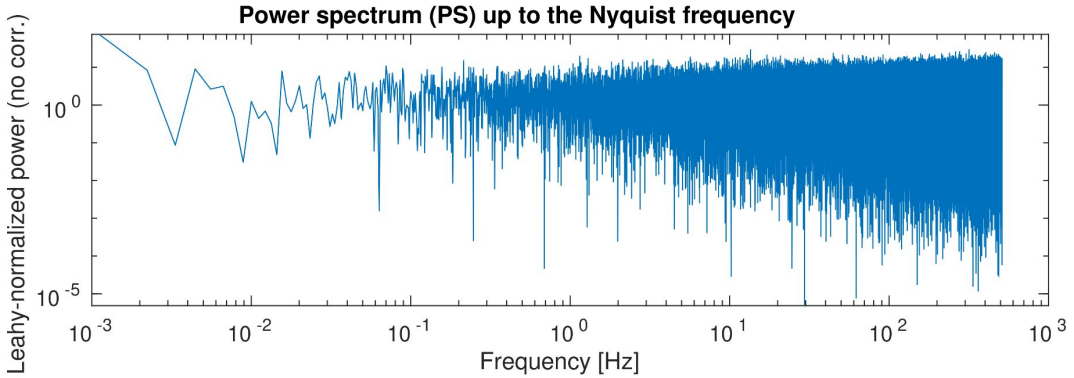
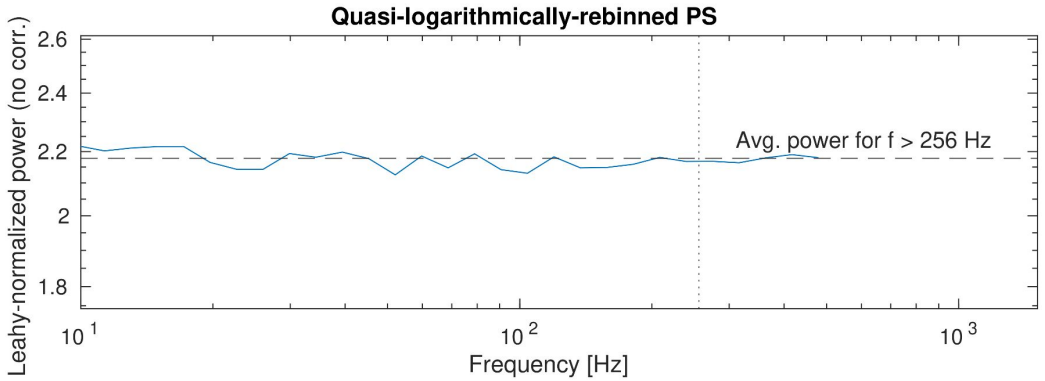


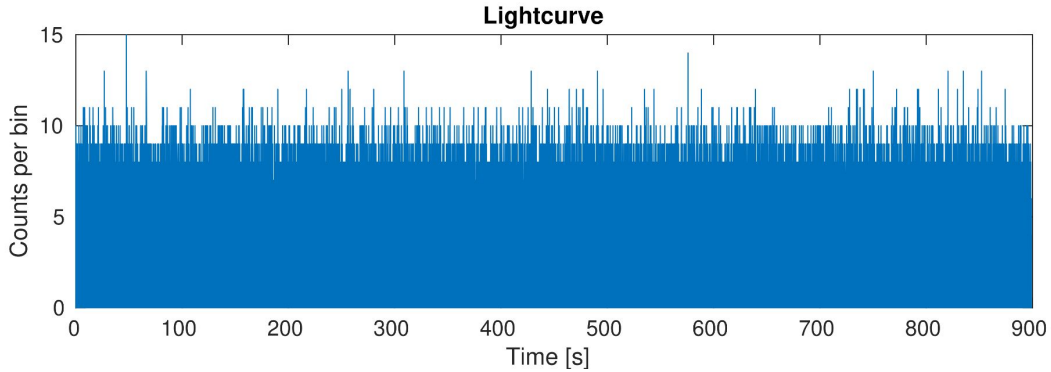
SiFAP2



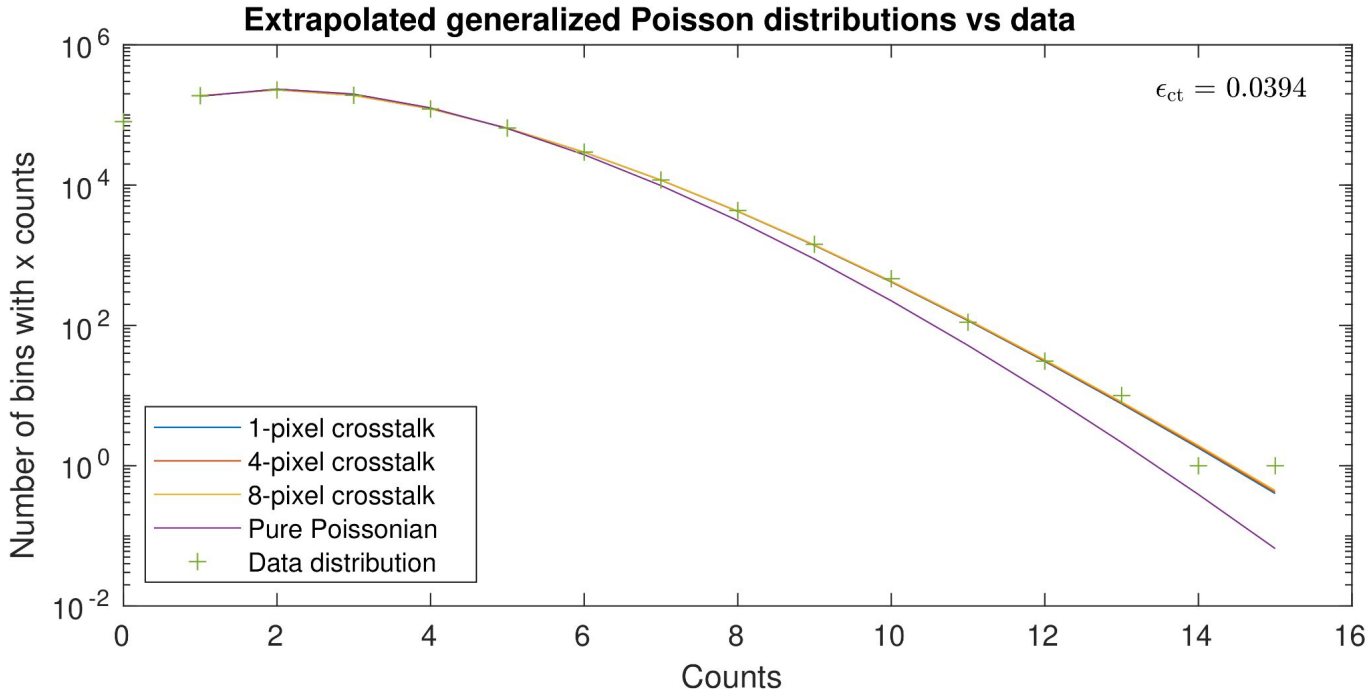
Crosstalk, or, *better yet*, correlated noise





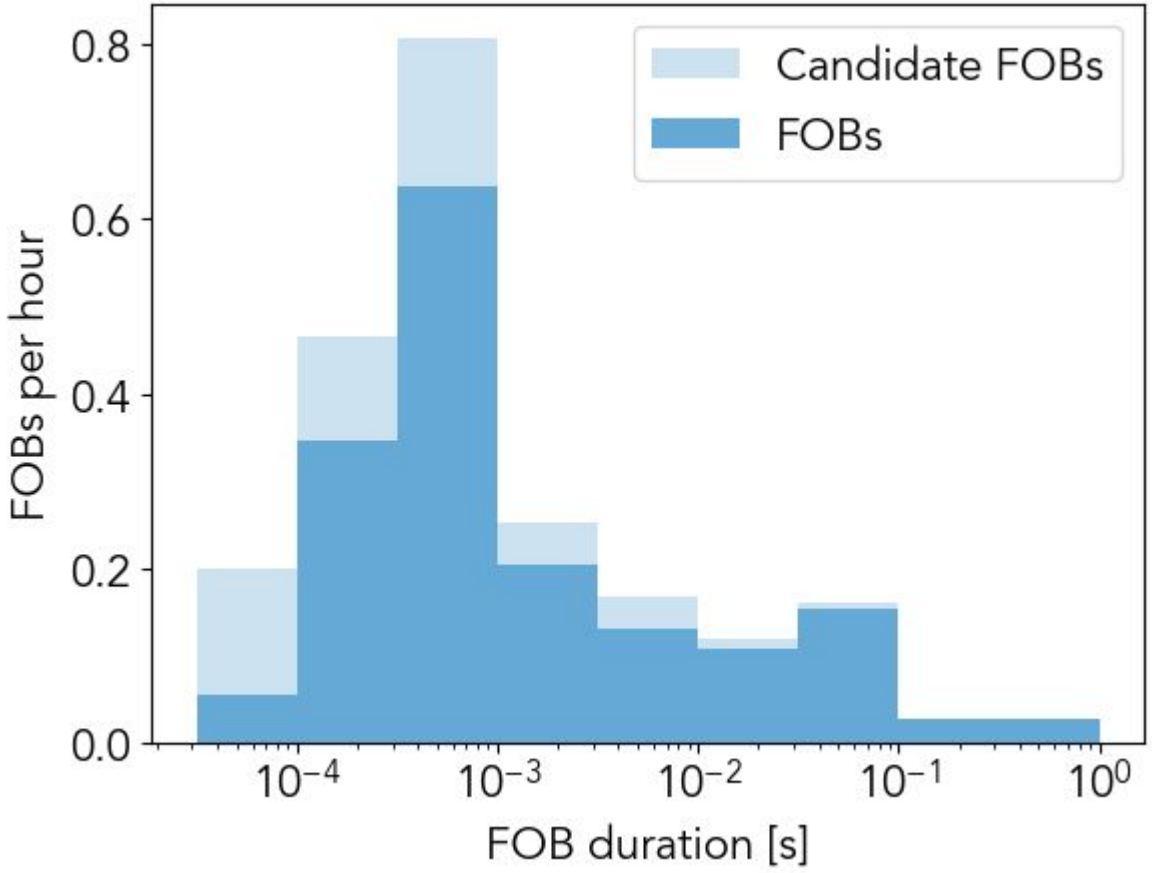


Aqueye+

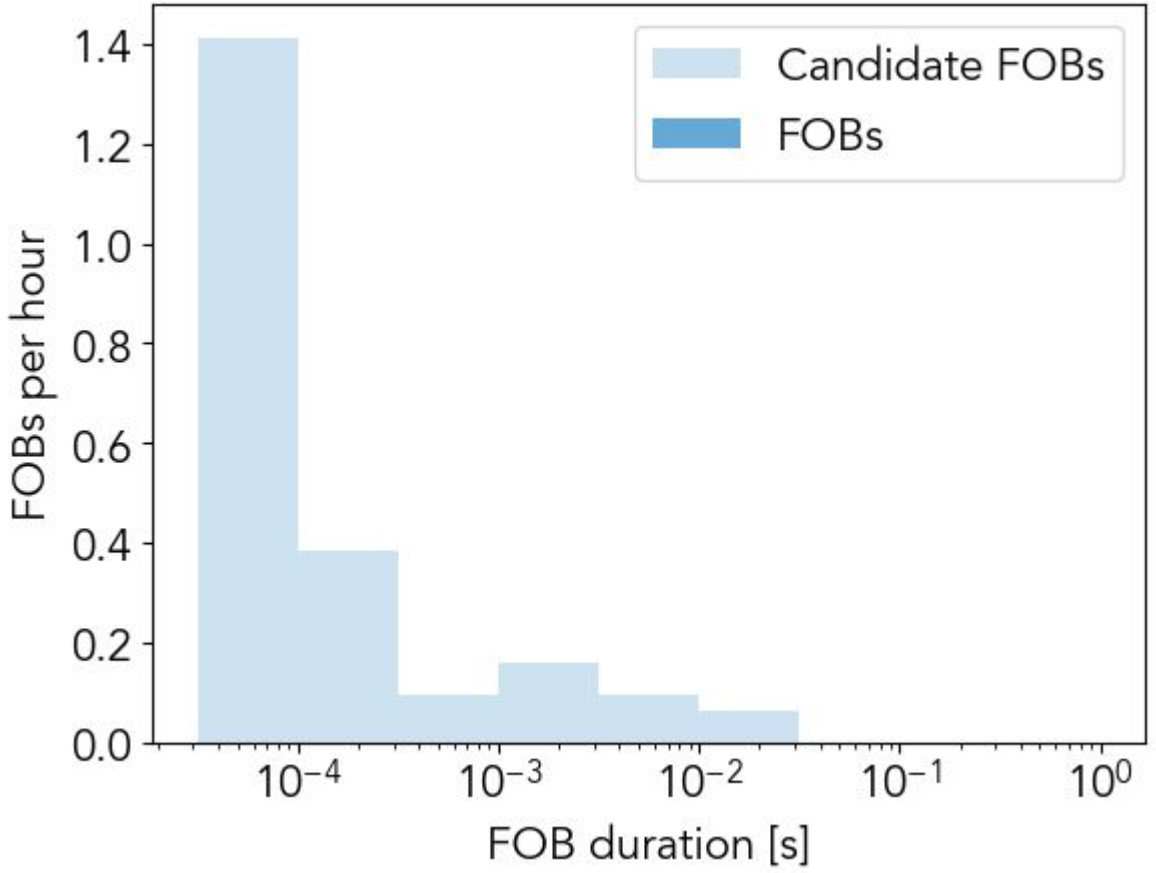


Poisson+CT–likelihood Bayesian Blocks

From **real** observations



From **dark** observations



Crosstalk, or, *better yet*, correlated noise