PRELIMINARY RESULTS FROM THE VIP-2 EXPERIMENT

Fabrizio Napolitano on behalf of the VIP-2 Collaboration

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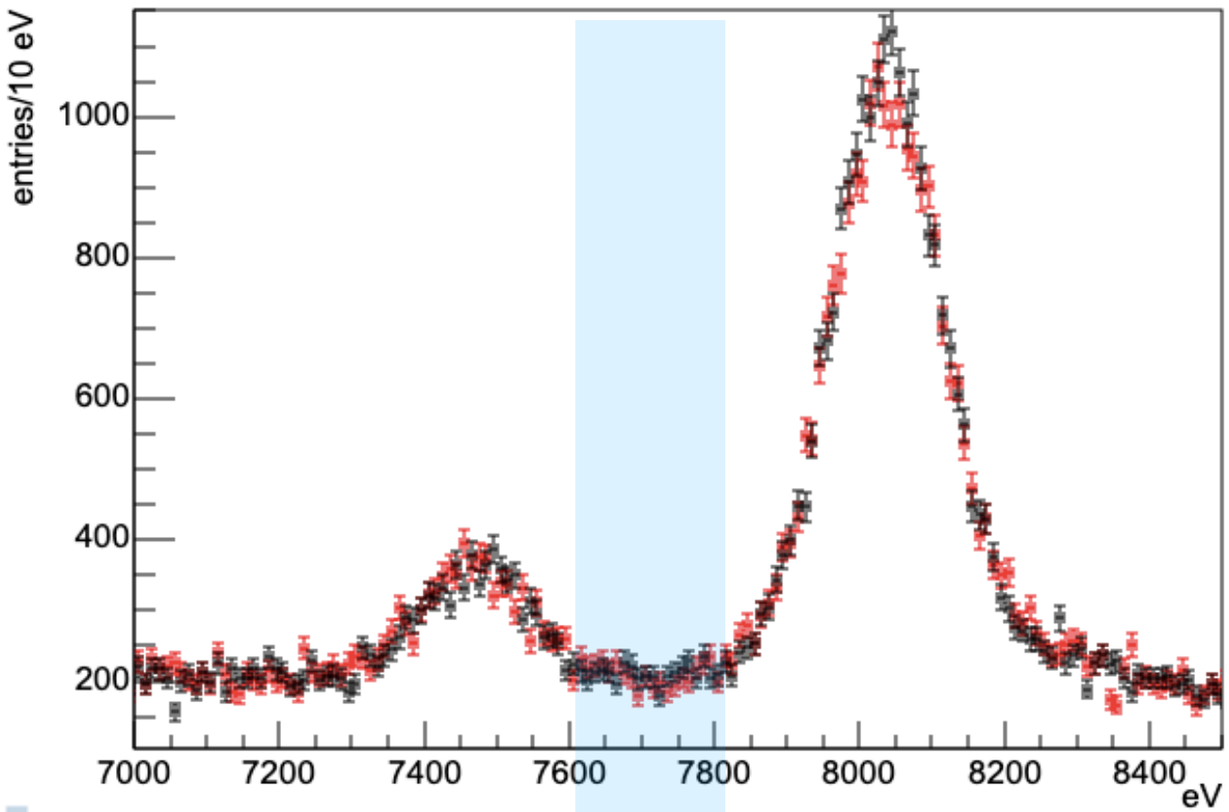
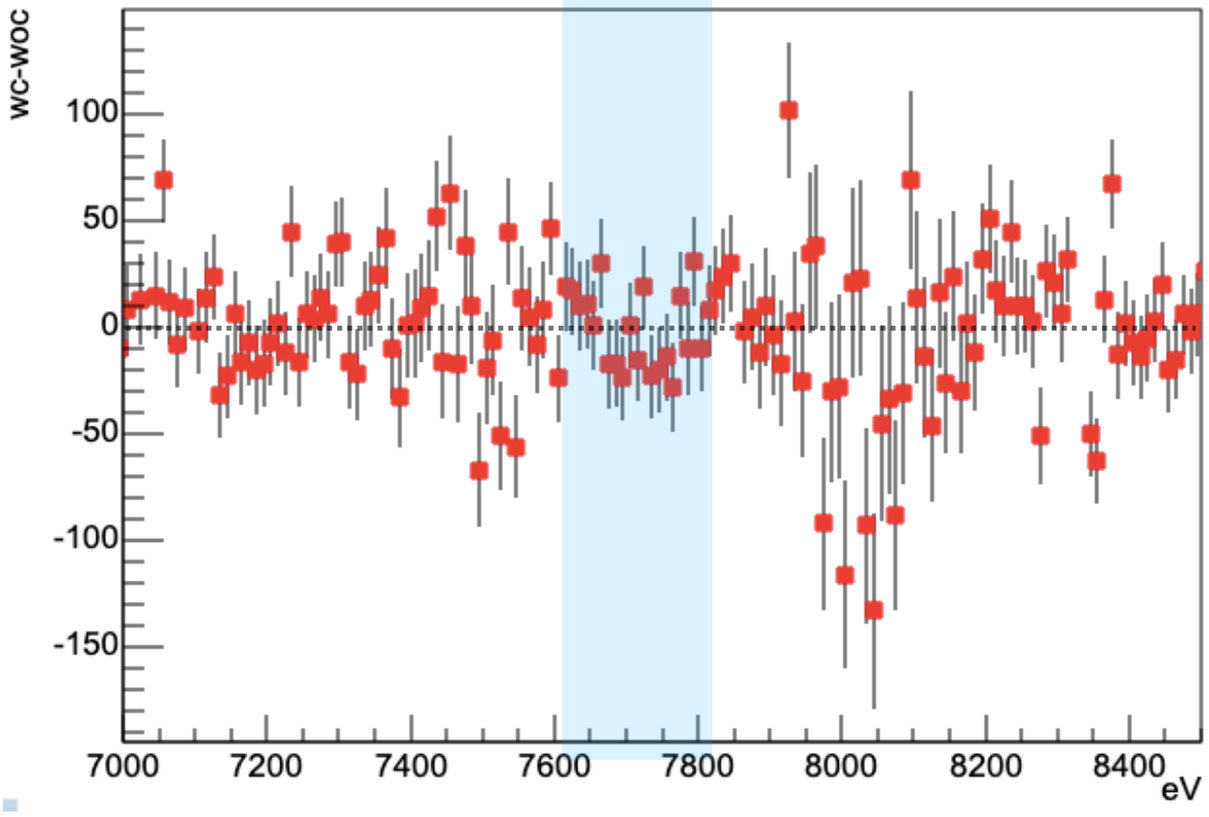
Symposium "Fundamental Physics with Exotic Atoms and Radiation Detectors"

ALL AVAILABLE VIP2 DATA

Period	Files	Current
May 2019	07/05/2019->14/05/2019	0A
May-June 2019	14/05/2019->12/06/2019	150A
June-July 2019	12/06/2019->10/07/2019	0A
July 2019	10/07/2019->29/07/2019	180A
August 2019	31/07/2019->04/09/2019	0A
September 2019	20/09/2019->01/10/2019	180A
October-November 2019	01/10/2019->05/11/2019	0A
November-December 2019	05/11/2019->19/12/2019	180A
December January 2020	19/12/2019->21/01/2020	0A
January February March 2020	21/01/2020->18/03/2020	180A
March May 2020	18/03/2020->04/05/2020	0A
May 2020	05/05/2020->07/07/2020	180A
July September 2020	09/07/2020->03/09/2020	0A
September 2020	03/09/2020->16/09/2020	180A
September October 2020	18/09/2020->06/10/2020	180A
October December 2020	06/10/2020->16/12/2020	Moduled
December January 2021	17/12/2020->08/01/2021	0A
January March 2021	08/01/2021->11/03/2021	180A
March May 2021	12/03/2021->11/05/2021	0A





17 SDD

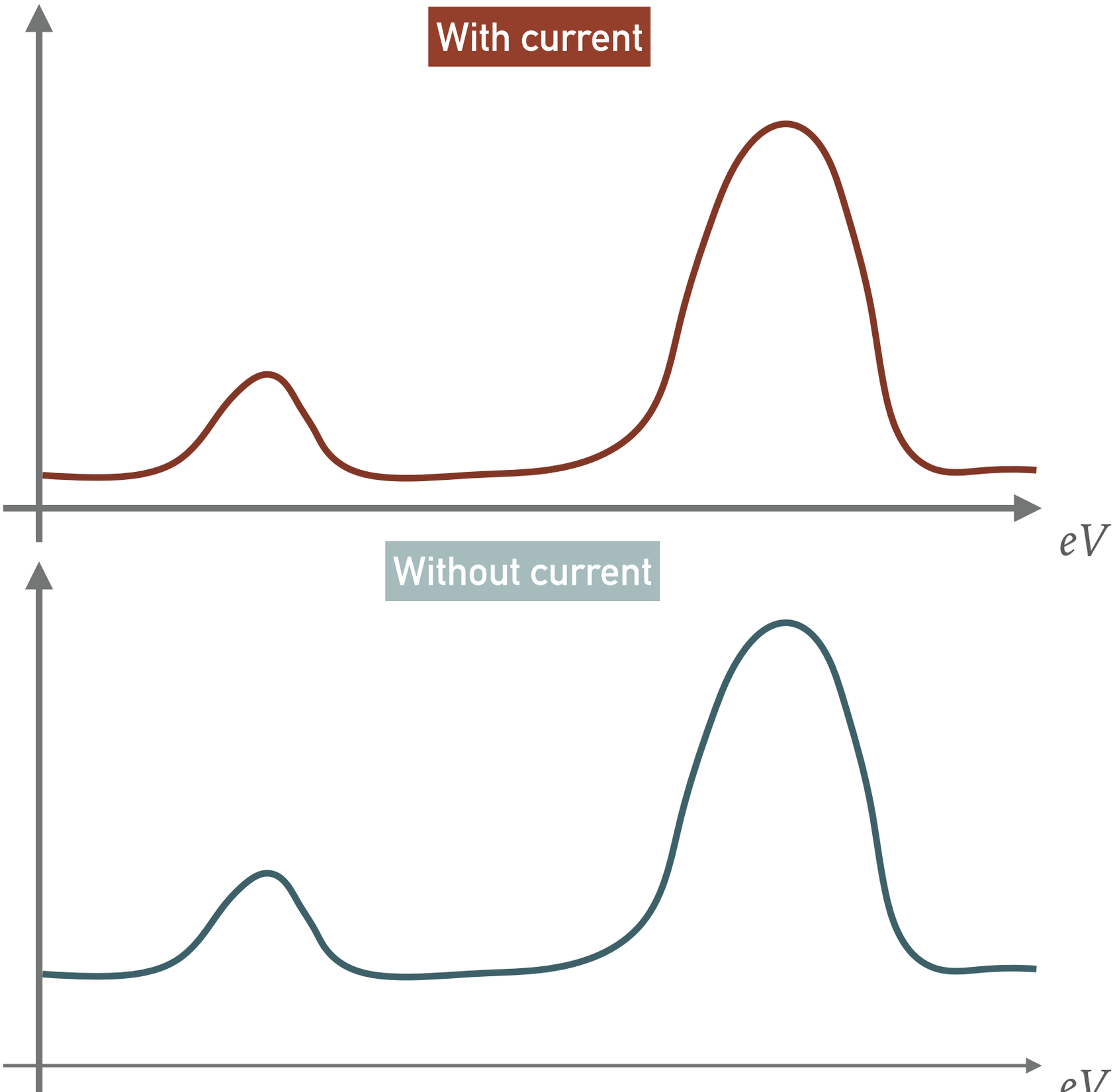
t^{wc} = 27110263 s = 314 days

t^{woc} = 26916404 s = 311 days

(Incl. 2499582 s @ 150A)

$t^{wc}/t^{woc} = 1.0072022(6)$

Analysis Strategy



Analysis Strategy

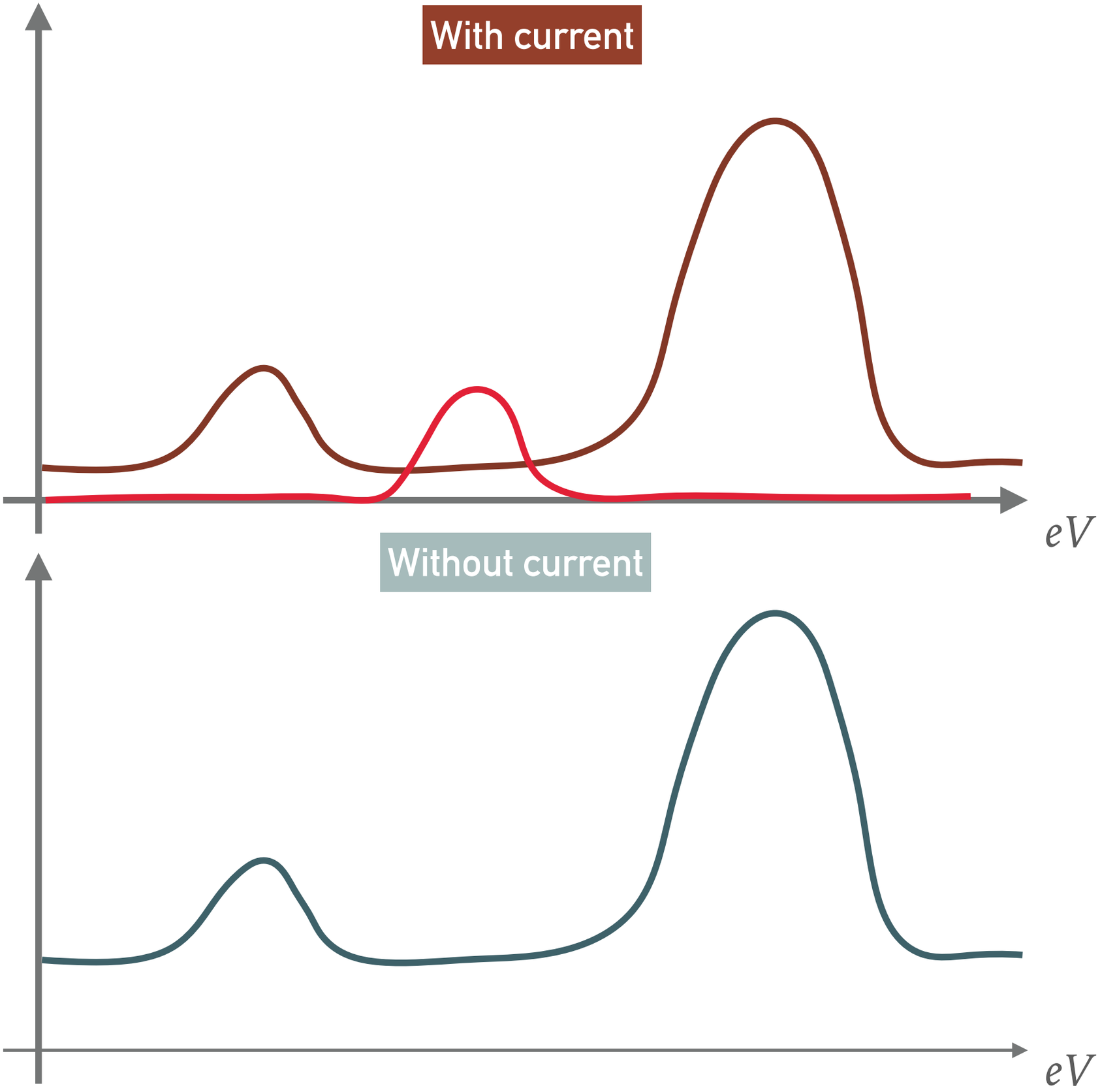
With current

8 params

$$= polynomial(1) + Gaussian\ Ni + Gaussian\ Cu$$

Without current

Analysis Strategy



Analysis Strategy

8 params

$$= polynomial(1) + Gaussian\ Ni + Gaussian\ Cu$$

1 param

$$= Gaussian\ PEPV$$

With current

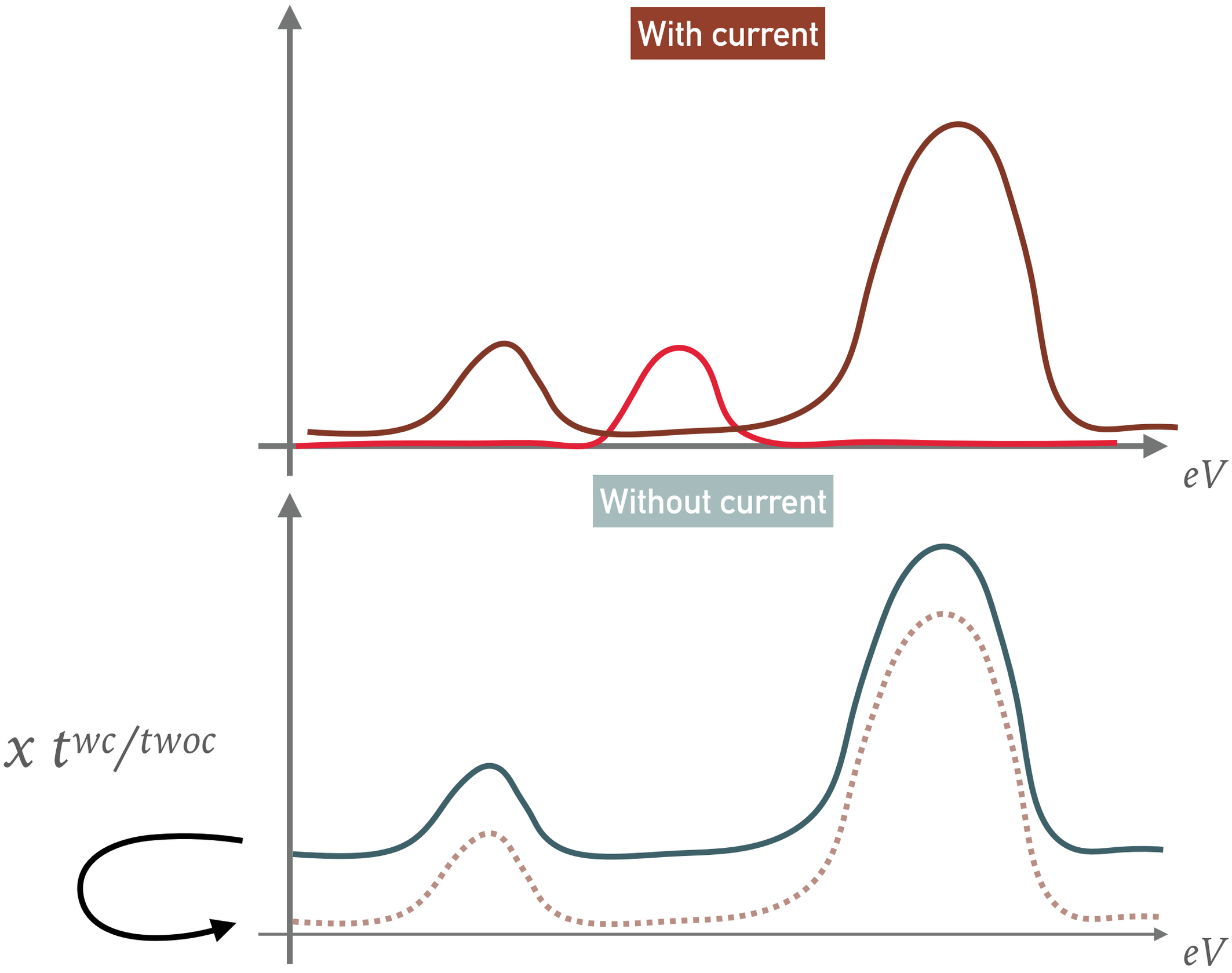
Without current

eV

eV

7

Analysis Strategy



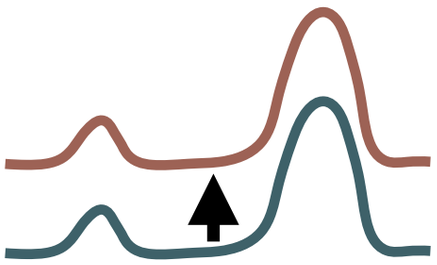
Analysis Strategy

8 params

$$= polynomial(1) + Gaussian\ Ni + Gaussian\ Cu$$

1 param

$$= Gaussian\ PEPV$$



$$= SCALE = Gaussian(t^{wc}/t^{woc})$$

Analysis Strategy

$$\mathrm{f}^{wc}(\boldsymbol{\theta}) = yield_{Ni} * Ni(\theta_{1,2}) + yield_{Cu} * Cu(\theta_{3,4}) + yield_{pol1} * pol_1(\theta_5) + yield_{PEPV} * PEPV(\theta_4)$$

$$\mathrm{f}^{woc}(\boldsymbol{\theta}) = (yield_{Ni} * Ni(\theta_{1,2}) + yield_{Cu} * Cu(\theta_{3,4}) + yield_{pol1} * pol_1(\theta_5))$$

Likelihood

Poissonian terms

$$\mathcal{L} = \mathrm{Poiss}(Data^{wc}|\mathrm{f}^{wc}(\boldsymbol{\theta})) \times \mathrm{Poiss}(Data^{woc}|\mathrm{f}^{woc}(\boldsymbol{\theta}) \times \mathrm{SCALE}) \times$$

$$\times \mathrm{Gaus}(\mathrm{SCALE} - t^{wc}/t^{woc}, 1e-3) \times \mathrm{Gaus}(\theta_1 - \mu_{Ni}, 2eV) \times \mathrm{Gaus}(\theta_3 - \mu_{Cu}, 2eV)$$

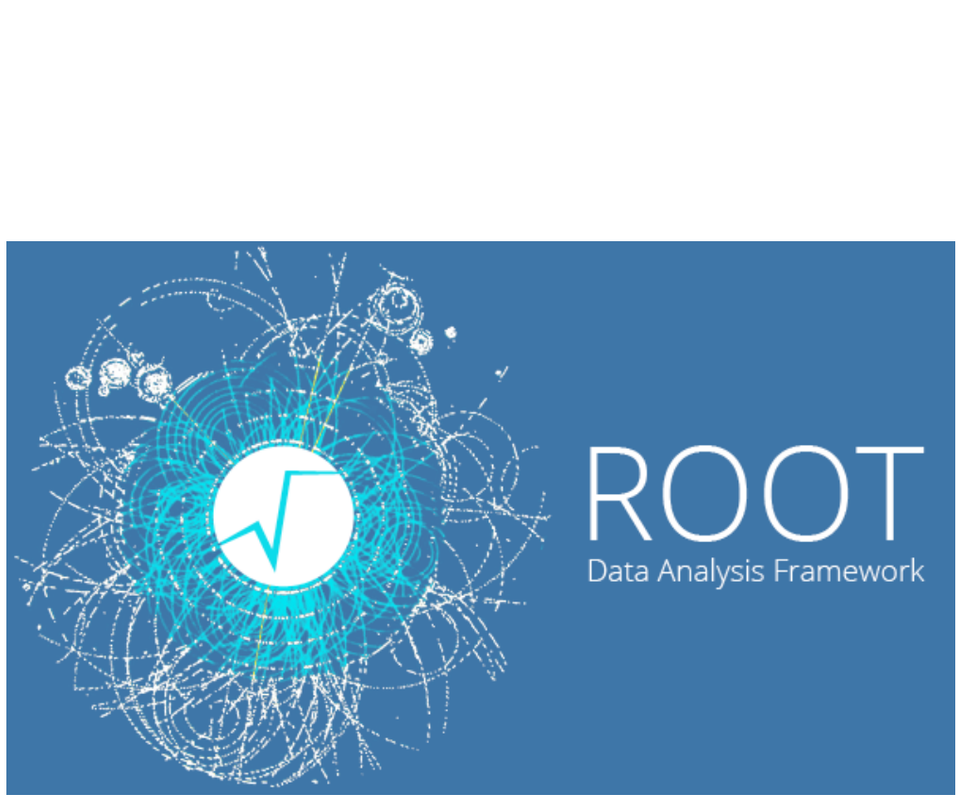
Constraints

Analysis Strategy

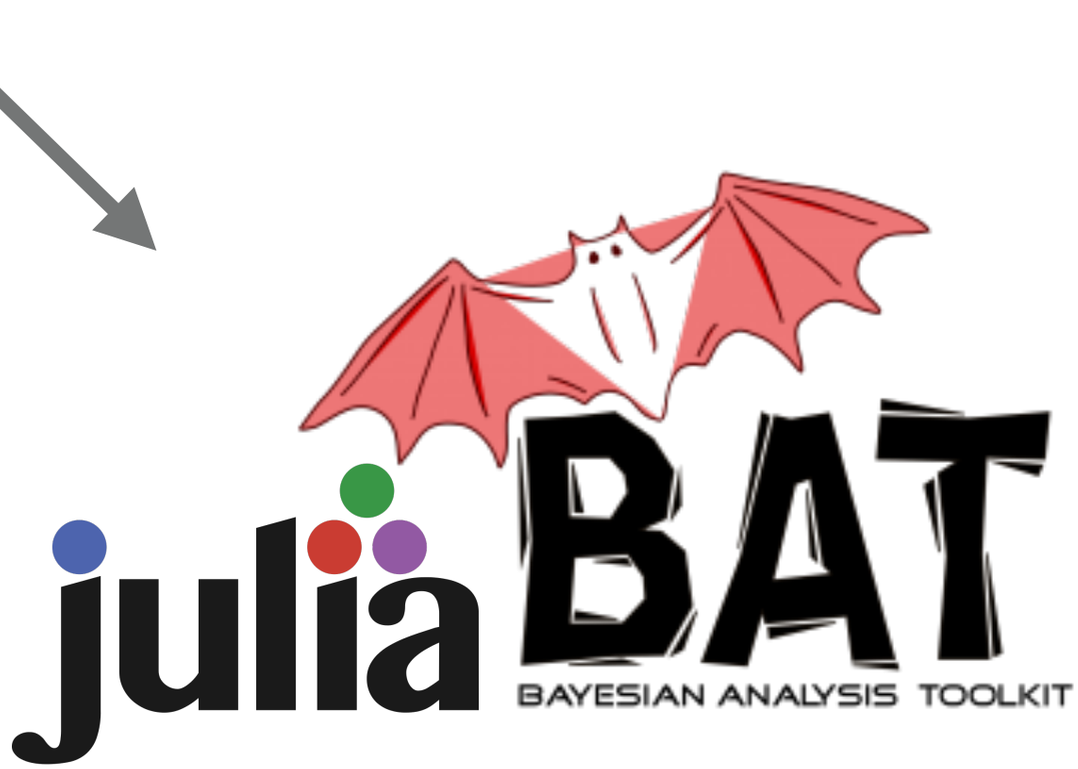
Likelihood

$$\mathcal{L} = \text{Poiss}(Data^{wc}|\text{f}^{wc}(\boldsymbol{\theta})) \times \text{Poiss}(Data^{woc}|\text{f}^{woc}(\boldsymbol{\theta}) \times \text{SCALE}) \times$$

$$\times \text{Gaus}(\text{SCALE} - t^{wc}/t^{woc}, 1e-3) \times \text{Gaus}(\theta_1 - \mu_{Ni}, 2eV) \times \text{Gaus}(\theta_3 - \mu_{Cu}, 2eV)$$



CLs Analysis



Bayesian Analysis

Analysis Strategy: CLs Method

maximizes L for specified μ

$$\lambda(\mu) = \frac{L(\mu, \hat{\hat{\boldsymbol{\theta}}})}{L(\hat{\mu}, \hat{\boldsymbol{\theta}})}$$

maximize L

Test-statistics for upper limits

$$q_\mu = \begin{cases} -2 \ln \lambda(\mu) & \hat{\mu} \leq \mu \\ 0 & \hat{\mu} > \mu \end{cases}$$

Asymptotic formulae +

Asimov dataset

$$p_\mu = \int_{q_{\mu,\mathrm{obs}}}^{\infty} f(q_\mu|\mu)\, dq_\mu$$

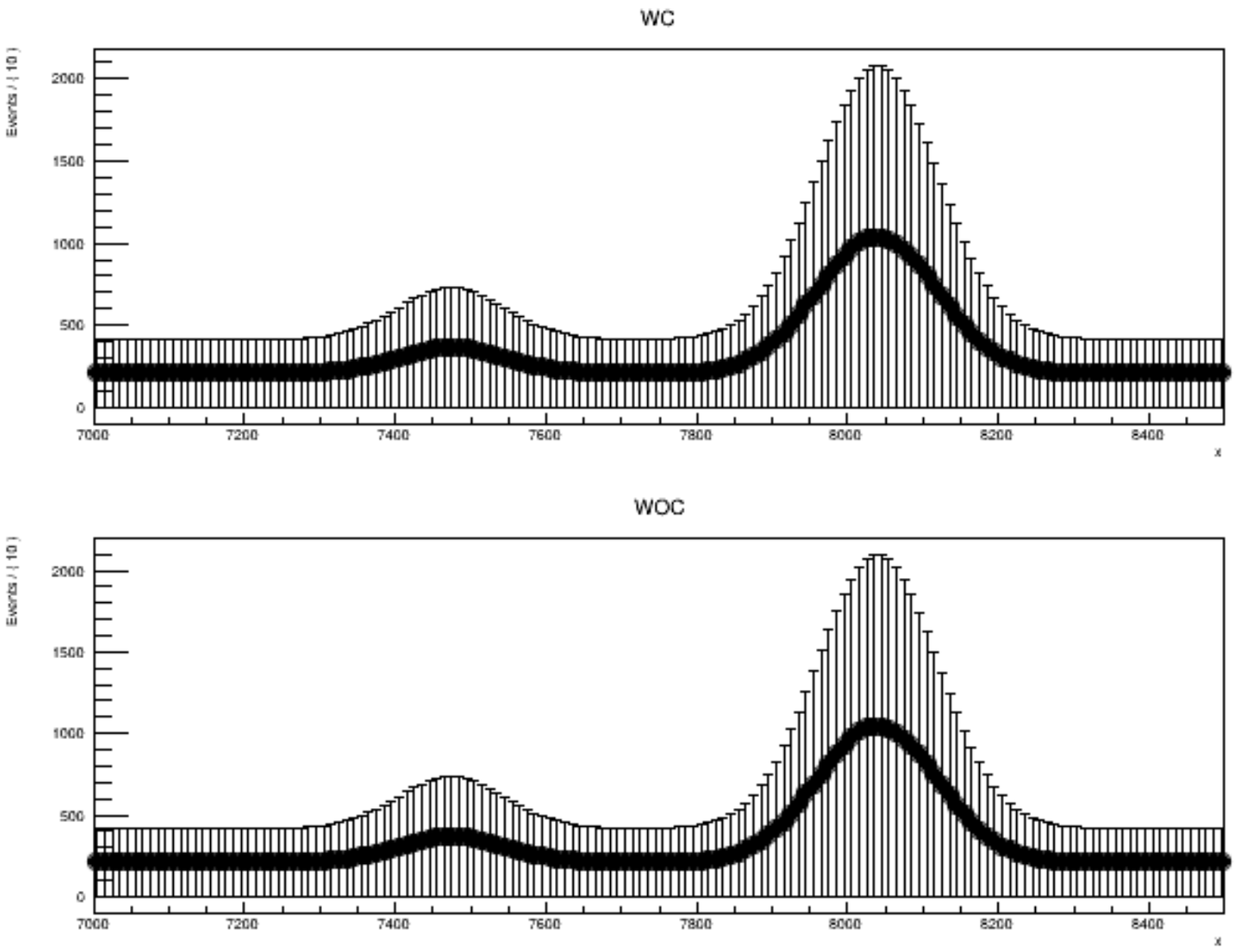
observed value of q_μ

pdf of q_μ assuming μ

$$\mathrm{CL_s} = \frac{p_\mu}{1 - p_0}$$

Avoid exclusion on models where we are not sensitive

Asimov Dataset

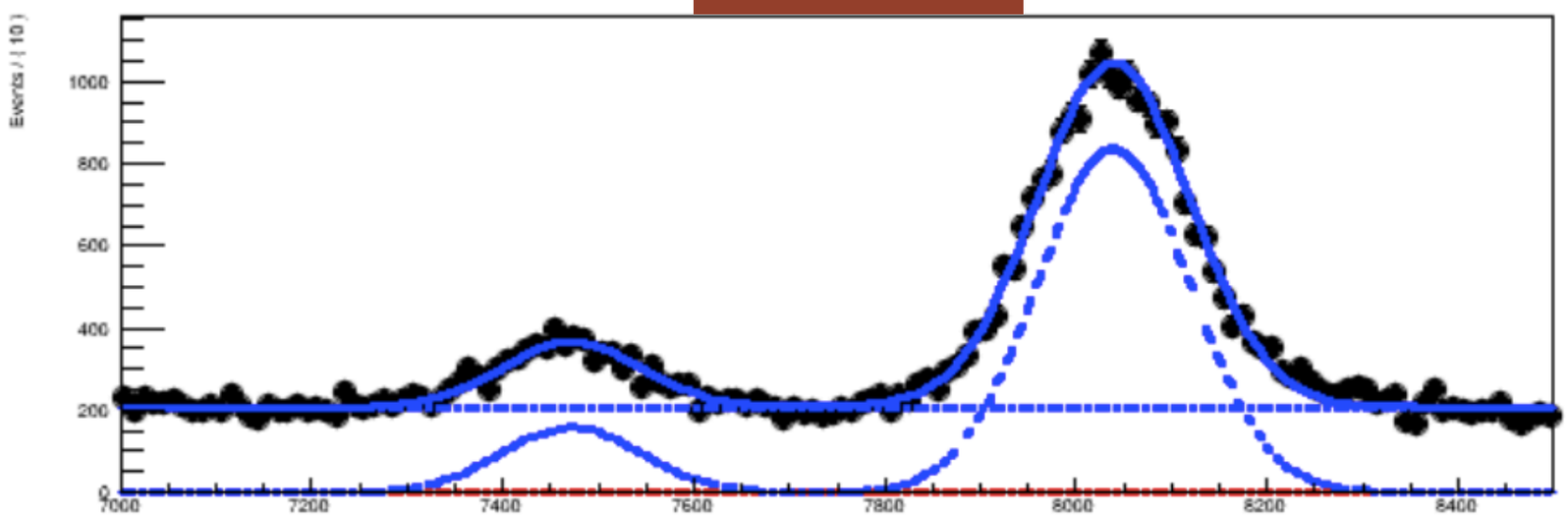


Asimov useful also to understand sensitivity of the experiment

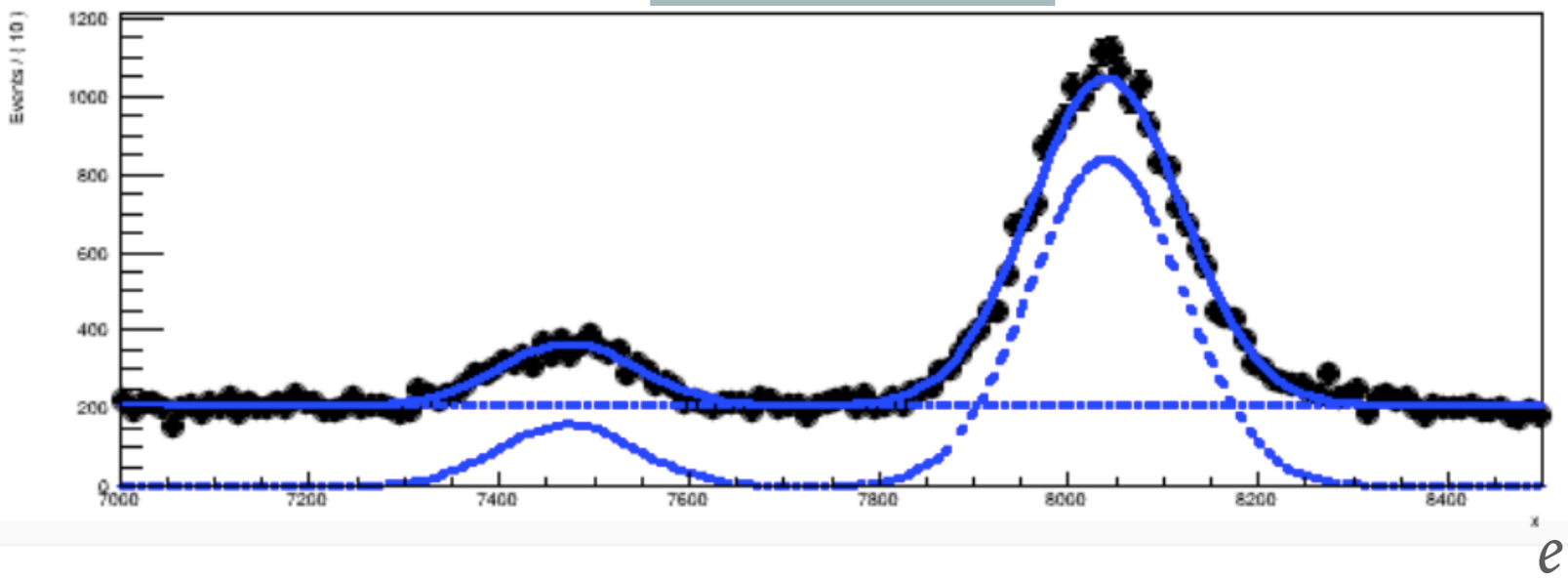
An Asimov dataset is generated for a particular set of model parameters such that the maximum likelihood best-fit value of all those parameters are equal to their generated values

MLE parameters

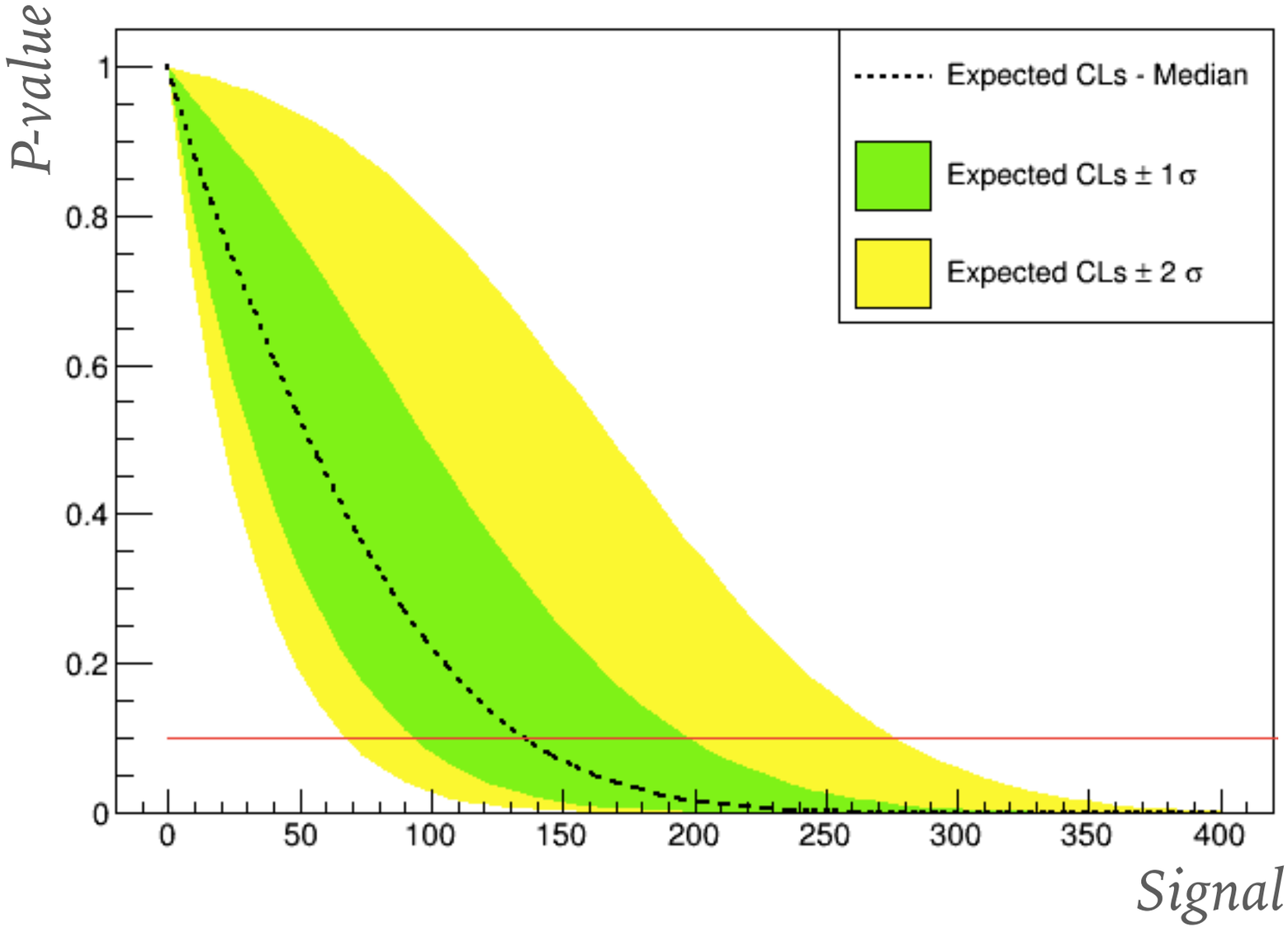
With current



Without current

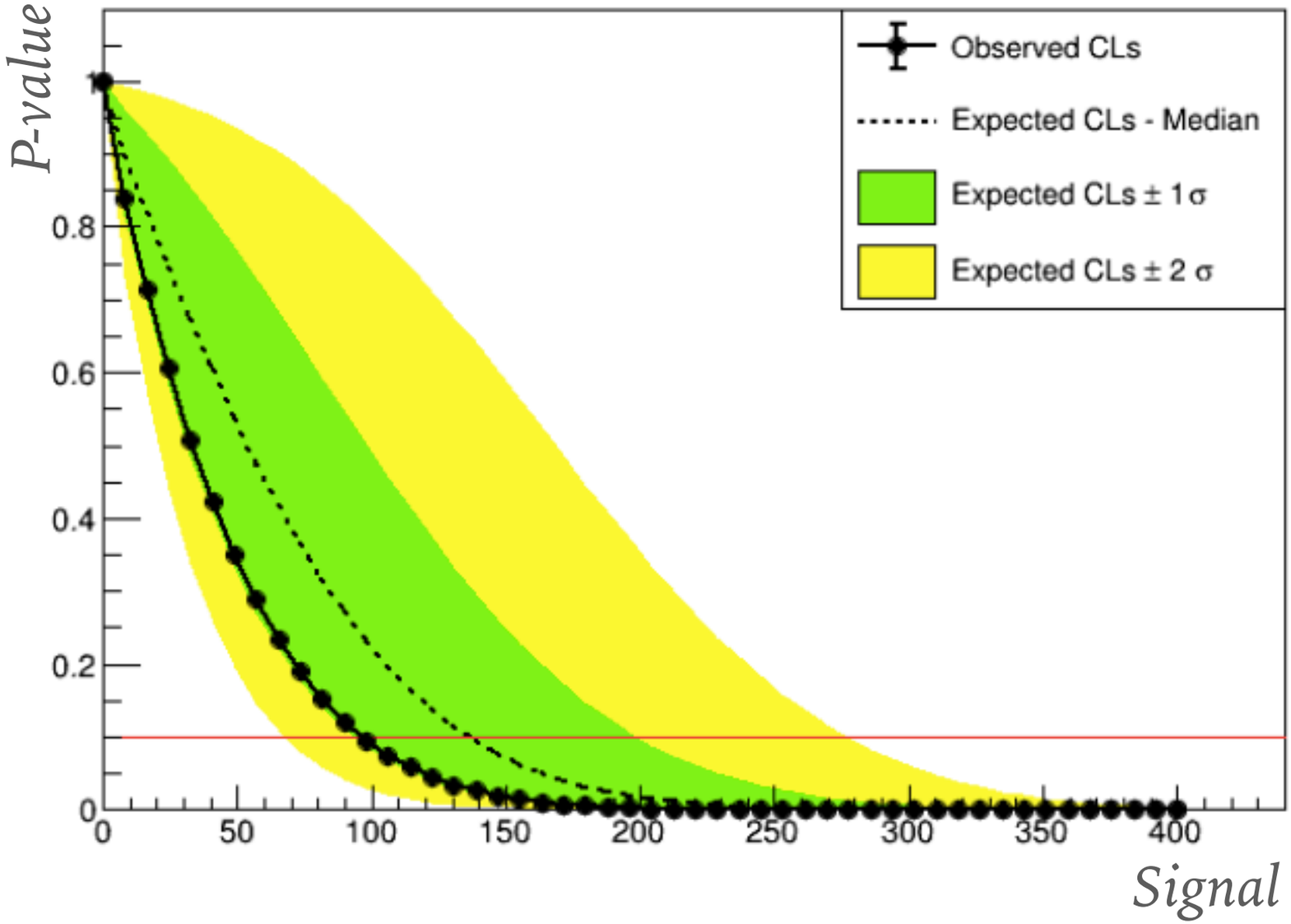


Expected limits



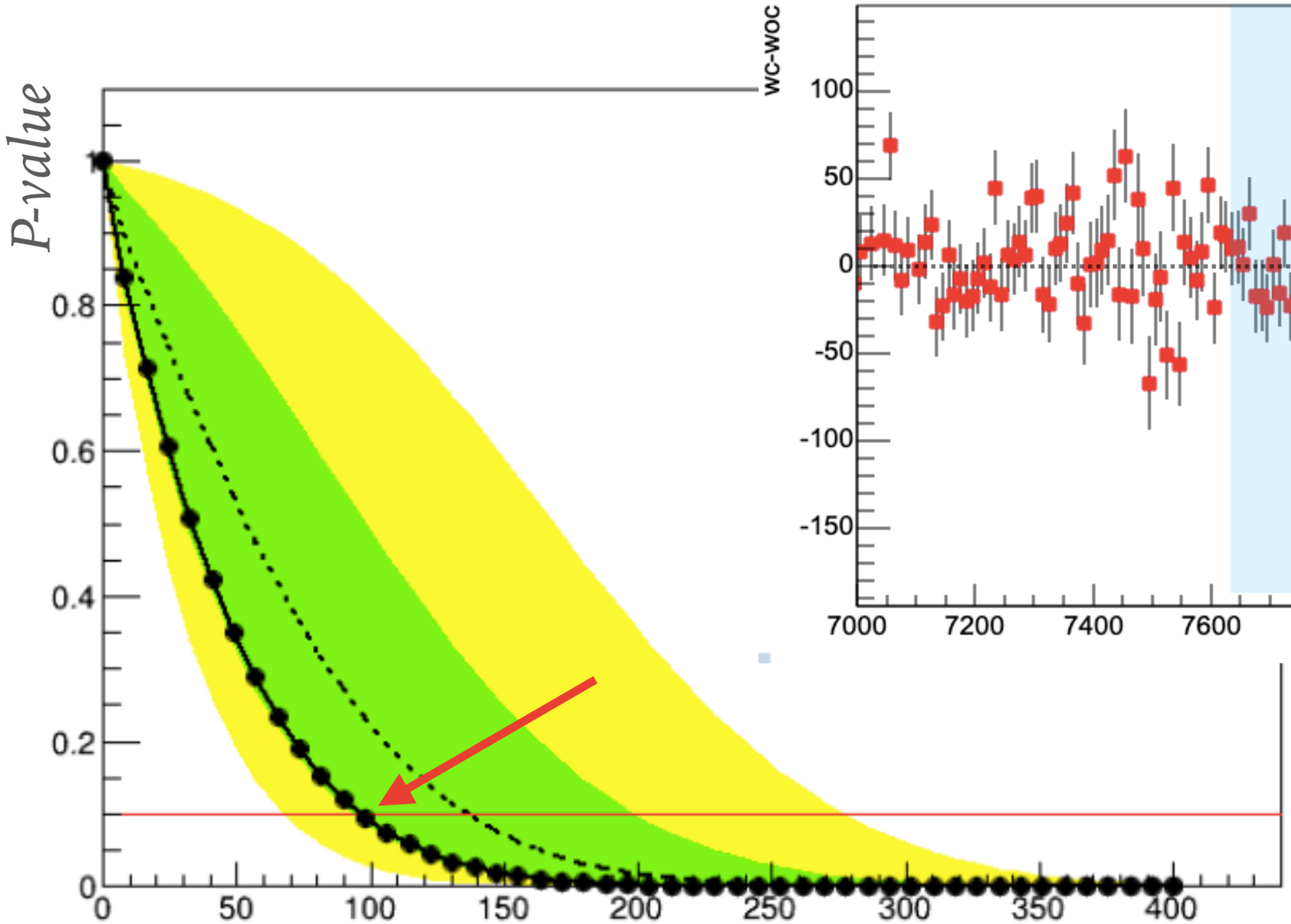
Expected 90% Upper Limit on Signal: 136

Expected+Observed limits



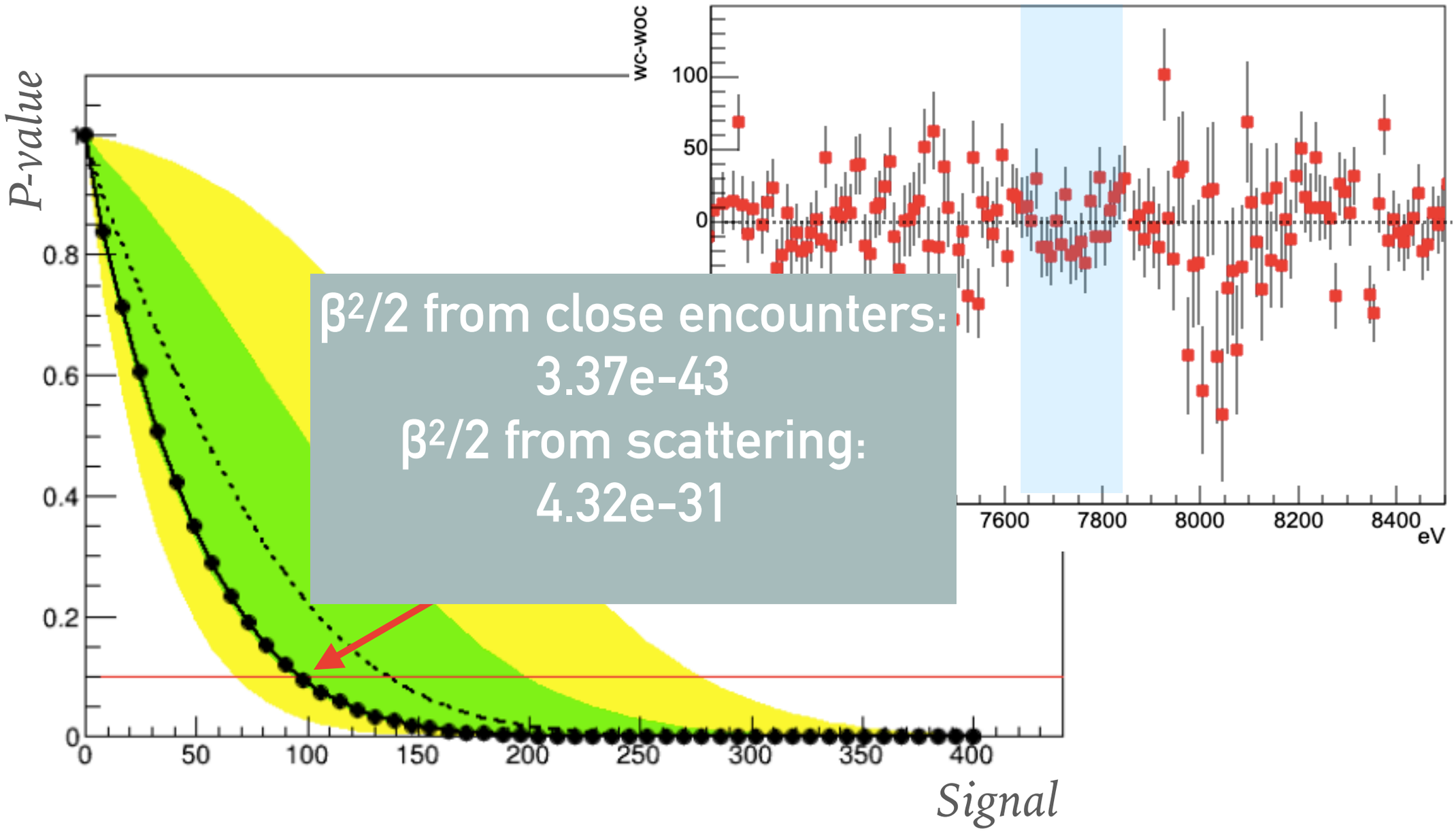
Observed 90% Upper Limit on Signal: 97

Expected+Observed limits



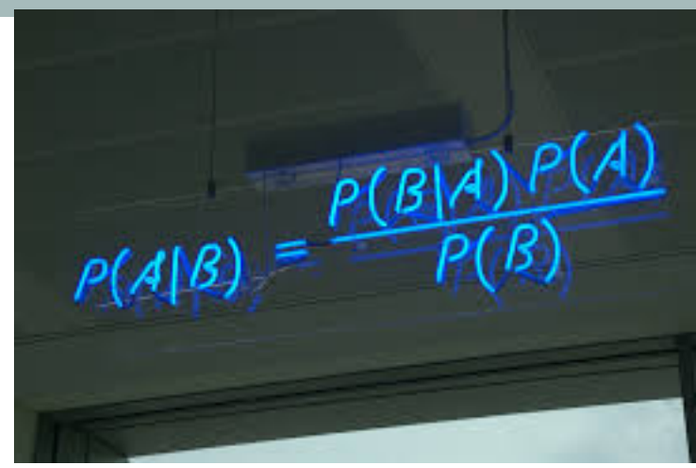
Observed 90% Upper Limit on Signal: 97

Expected+Observed limits



Observed 90% Upper Limit on Signal: 97

Bayesian Analysis Method



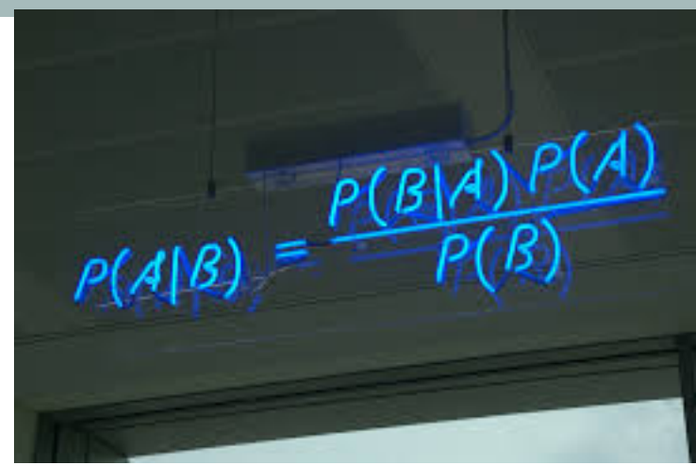
$$p(\boldsymbol{\theta}|\mathcal{D}, M) = \frac{p(\mathcal{D}|\boldsymbol{\theta}, M)p(\boldsymbol{\theta}|M)}{\int \mathrm{d}\boldsymbol{\theta}\, p(\mathcal{D}|\boldsymbol{\theta}, M)p(\boldsymbol{\theta}|M)}$$

Free params

Dataset

Model

Bayesian Analysis Method



Posterior probability density

Likelihood

Prior

$$p(\boldsymbol{\theta}|\mathcal{D}, M) = \frac{p(\mathcal{D}|\boldsymbol{\theta}, M)p(\boldsymbol{\theta}|M)}{\int \mathrm{d}\boldsymbol{\theta}\, p(\mathcal{D}|\boldsymbol{\theta}, M)p(\boldsymbol{\theta}|M)}$$

Free params

Dataset

Model

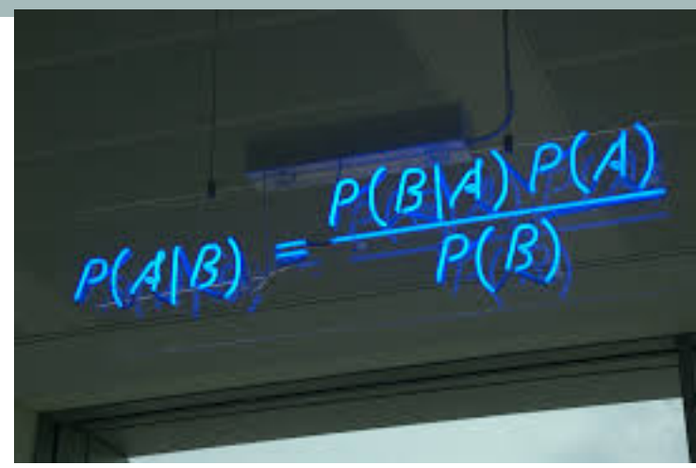
Evidence (Z)

$$Z = P(\mathcal{D}|M) = \int \mathrm{d}\boldsymbol{\theta}\, p(\mathcal{D}|\boldsymbol{\theta}, M)p(\boldsymbol{\theta}|M)$$

Marginalized Probability density

$$p(\theta_i|\mathcal{D}, M) = \int p(\boldsymbol{\theta}|\mathcal{D}, M) \prod_{i \neq j} \mathrm{d}\theta_j$$

Bayesian Analysis Method



Posterior probability density

Likelihood

Prior

Can be many

Non trivial

$$p(\boldsymbol{\theta}|\mathcal{D},M) = \frac{p(\mathcal{D}|\boldsymbol{\theta},M)p(\boldsymbol{\theta}|M)}{\int \mathrm{d}\boldsymbol{\theta}\, p(\mathcal{D}|\boldsymbol{\theta},M)p(\boldsymbol{\theta}|M)}$$

Free params

Dataset

Model

Evidence (Z)

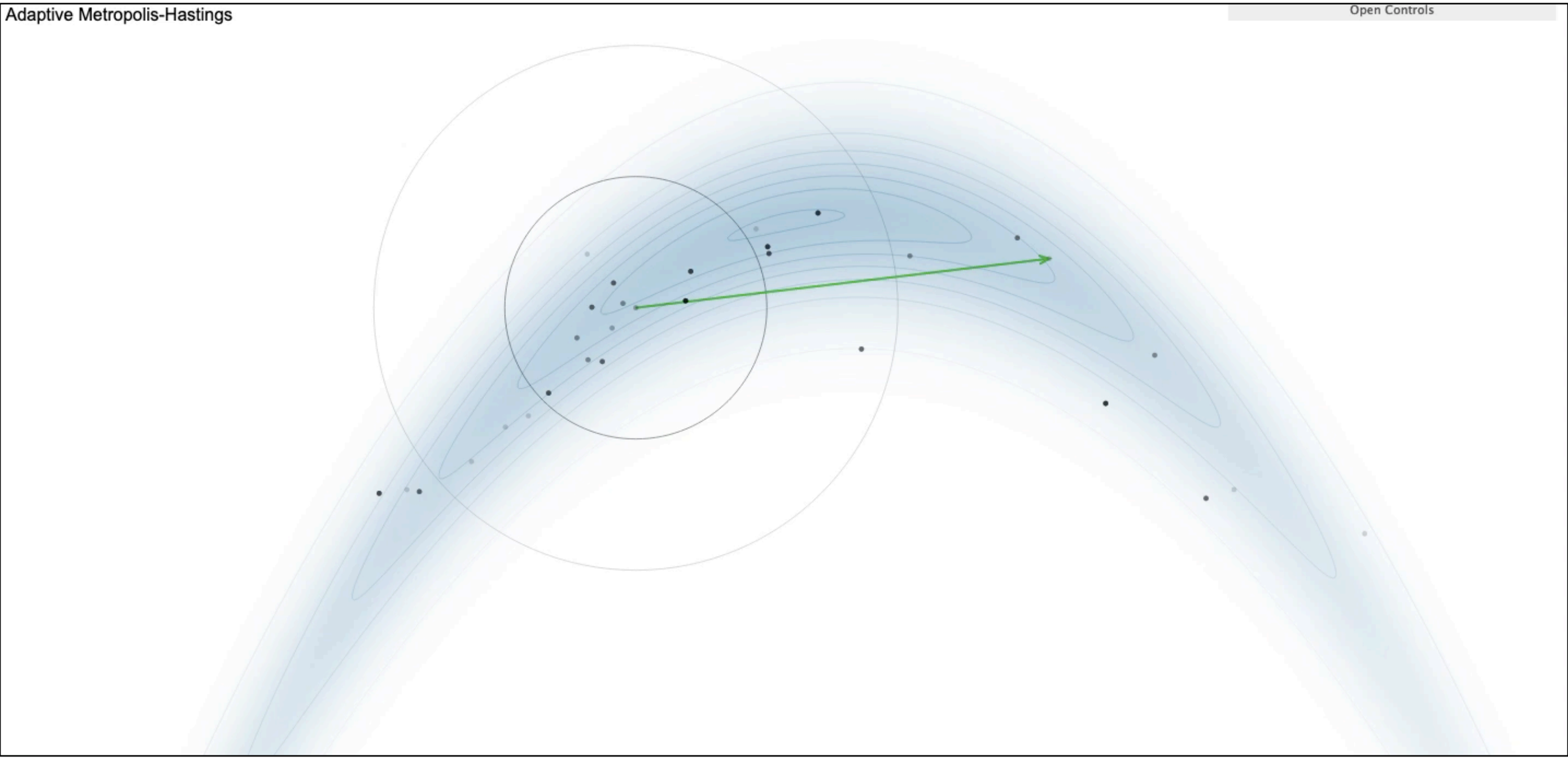
$$Z = P(\mathcal{D}|M) = \int \mathrm{d}\boldsymbol{\theta}\, p(\mathcal{D}|\boldsymbol{\theta},M)p(\boldsymbol{\theta}|M)$$

Numerically intensive

Marginalized probability density

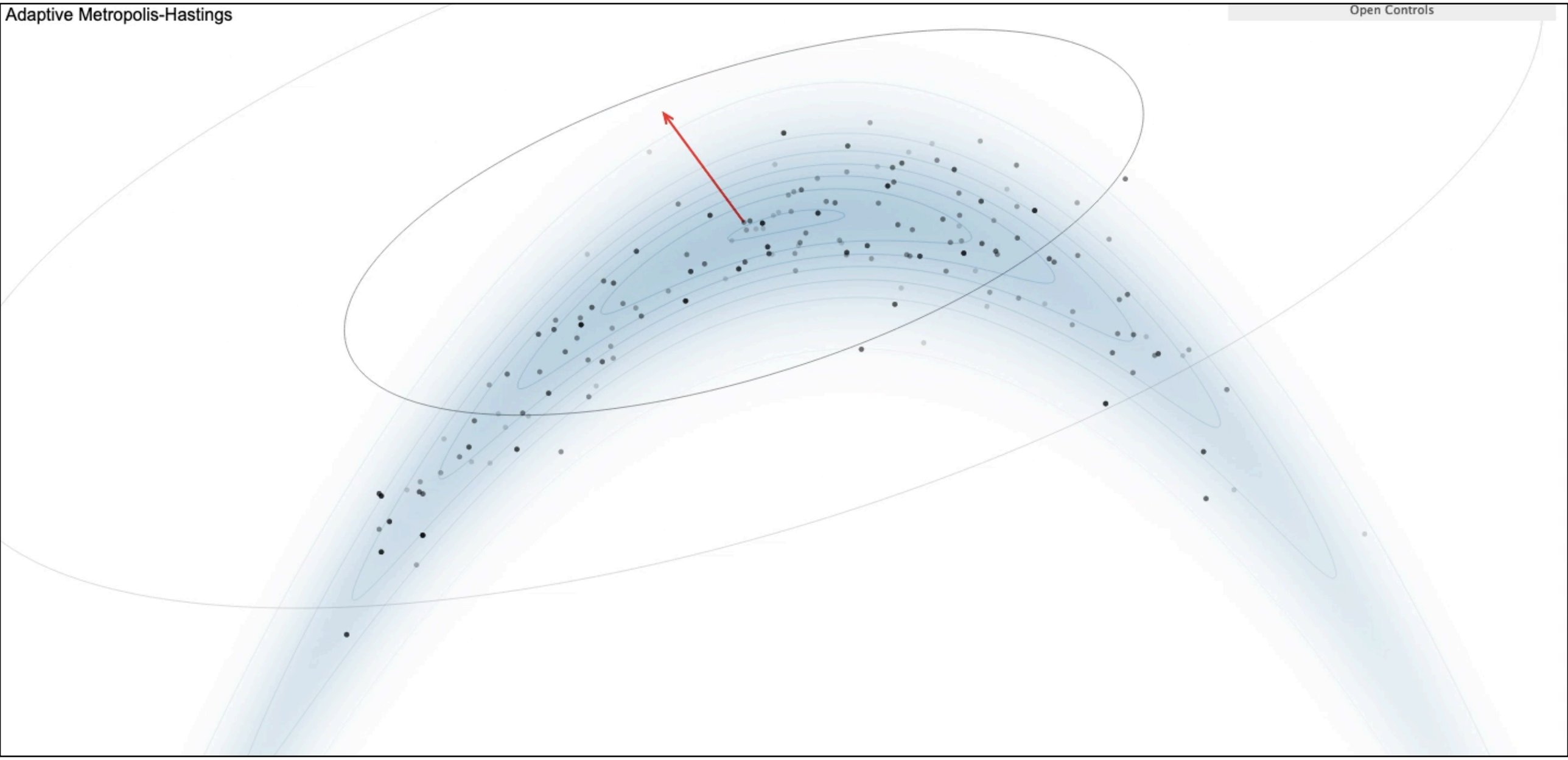
$$p(\theta_i|\mathcal{D},M) = \int p(\boldsymbol{\theta}|\mathcal{D},M) \prod_{i\neq j} \mathrm{d}\theta_j$$

Adaptive Metropolis-Hastings MCMC



https://chi-feng.github.io/mcmc-demo/app.html?algorithm=RandomWalkMH&target=banana

Adaptive Metropolis-Hastings MCMC



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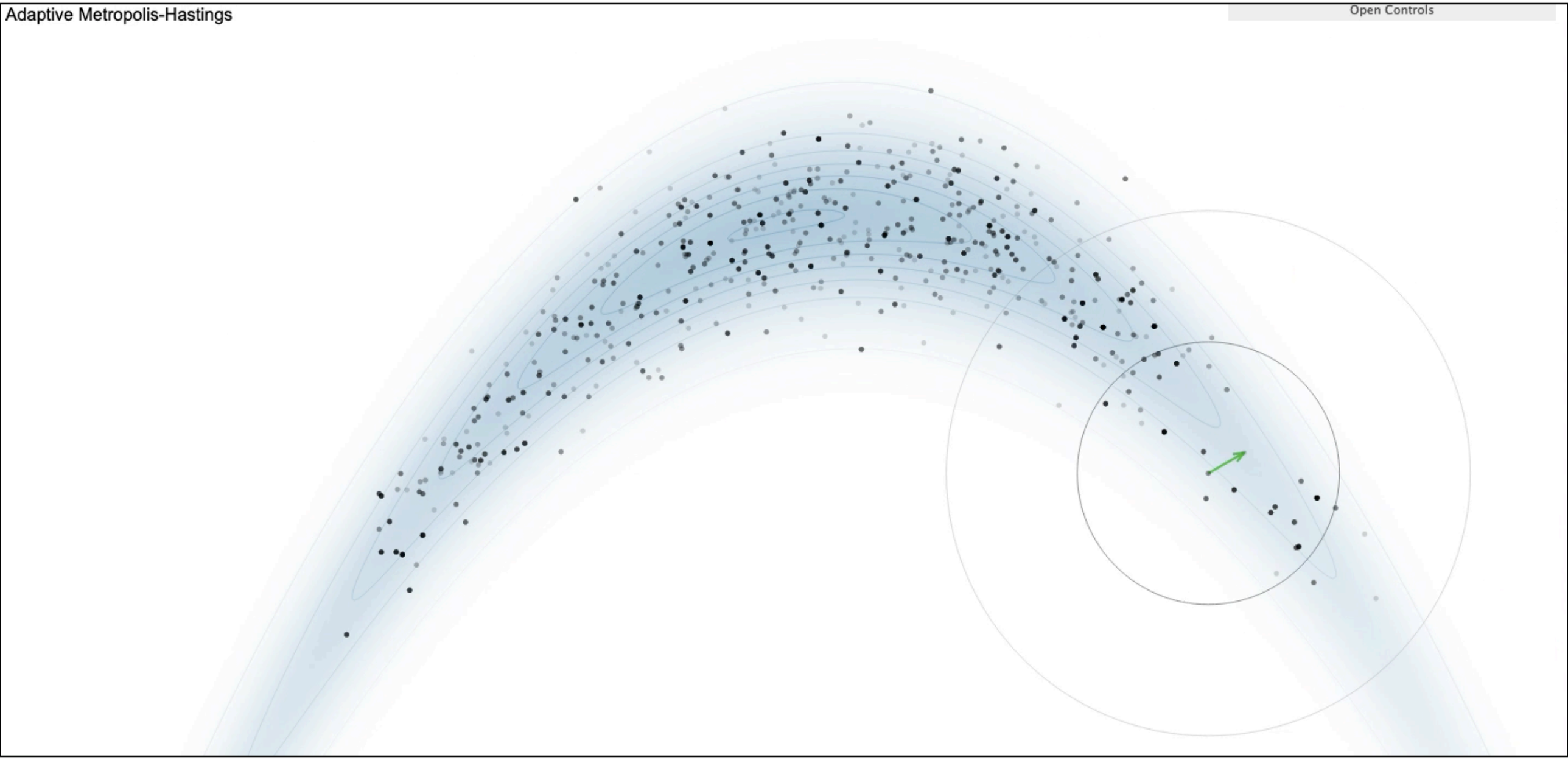
Adaptive Metropolis-Hastings MCMC



https://chi-feng.github.io/mcmc-demo/app.html?algorithm=RandomWalkMH&target=banana

Bayesian Analysis Method

Likelihood

$$\mathcal{L} = \text{Poiss}(Data^{wc}|\text{f}^{wc}(\boldsymbol{\theta})) \times \text{Poiss}(Data^{woc}|\text{f}^{woc}(\boldsymbol{\theta}) \times \text{SCALE}) \times$$

$$\times \text{Gaus}(\text{SCALE} - t^{wc}/t^{woc}, 1e-3) \times \text{Gaus}(\theta_1 - \mu_{Ni}, 2eV) \times \text{Gaus}(\theta_3 - \mu_{Cu}, 2eV)$$

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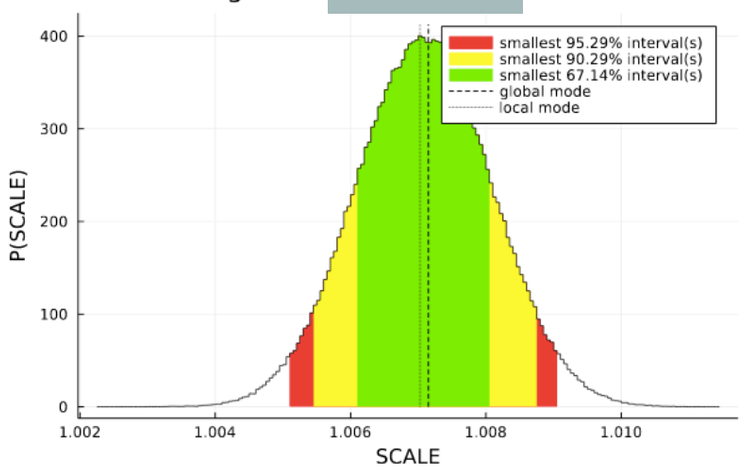
Scorporate Constraints from the Likelihood

In bayesian framework they are interpreted as Priors

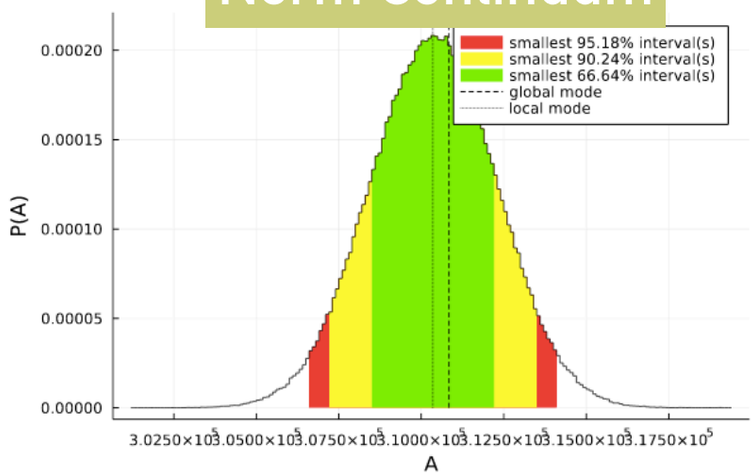
Bayesian Analysis Method

Check on all parameters

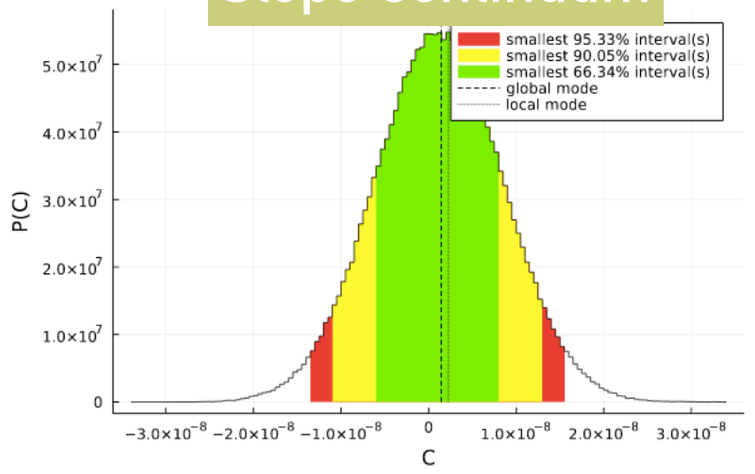
SCALE



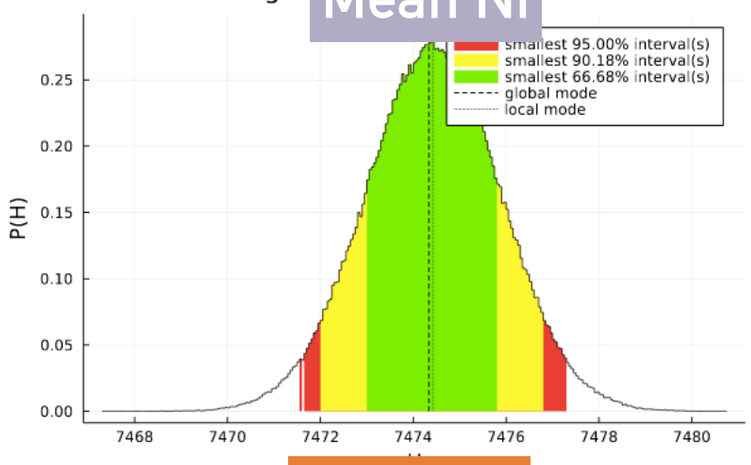
Norm Continuum



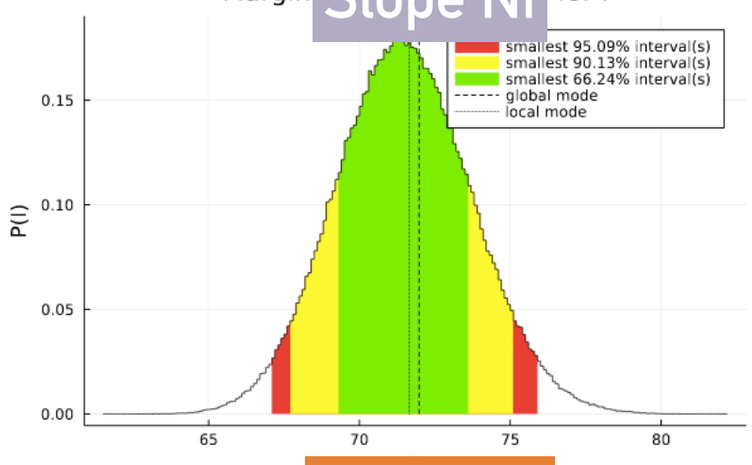
Slope Continuum



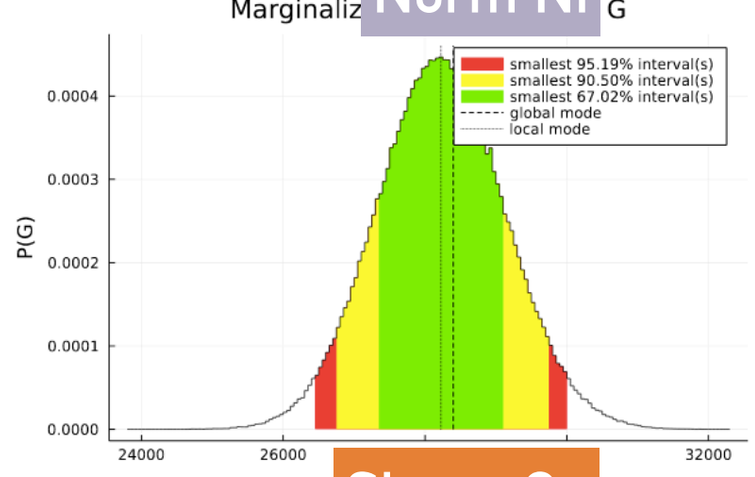
Mean Ni



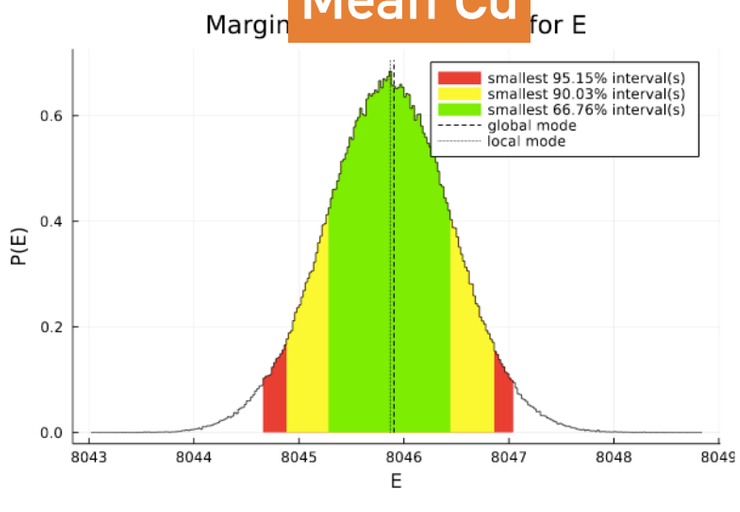
Slope Ni



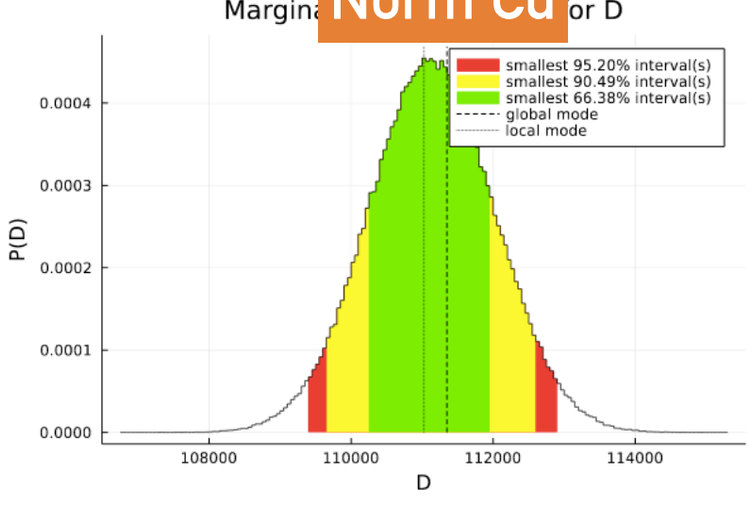
Norm Ni



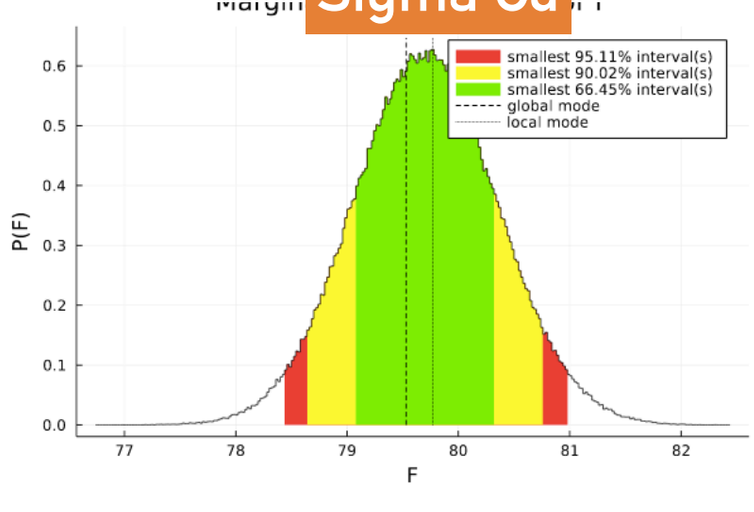
Mean Cu



Norm Cu

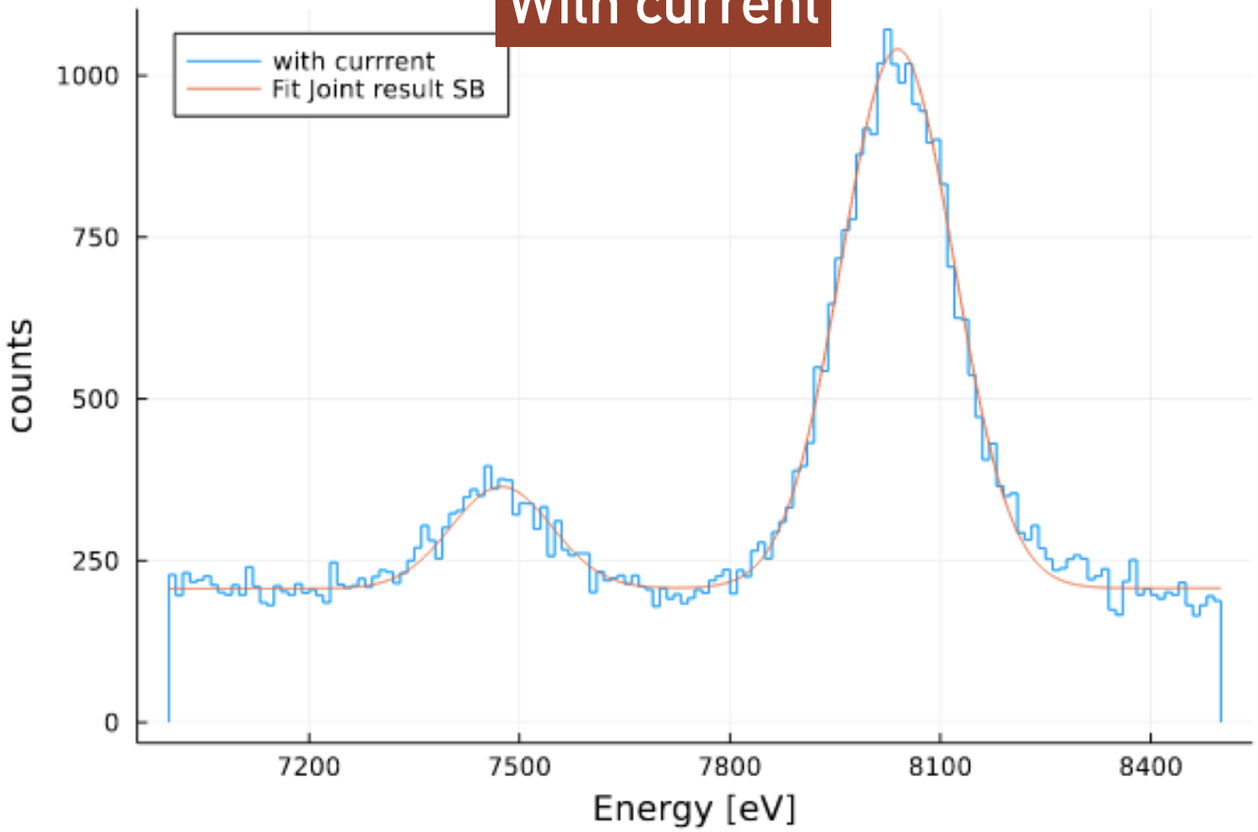


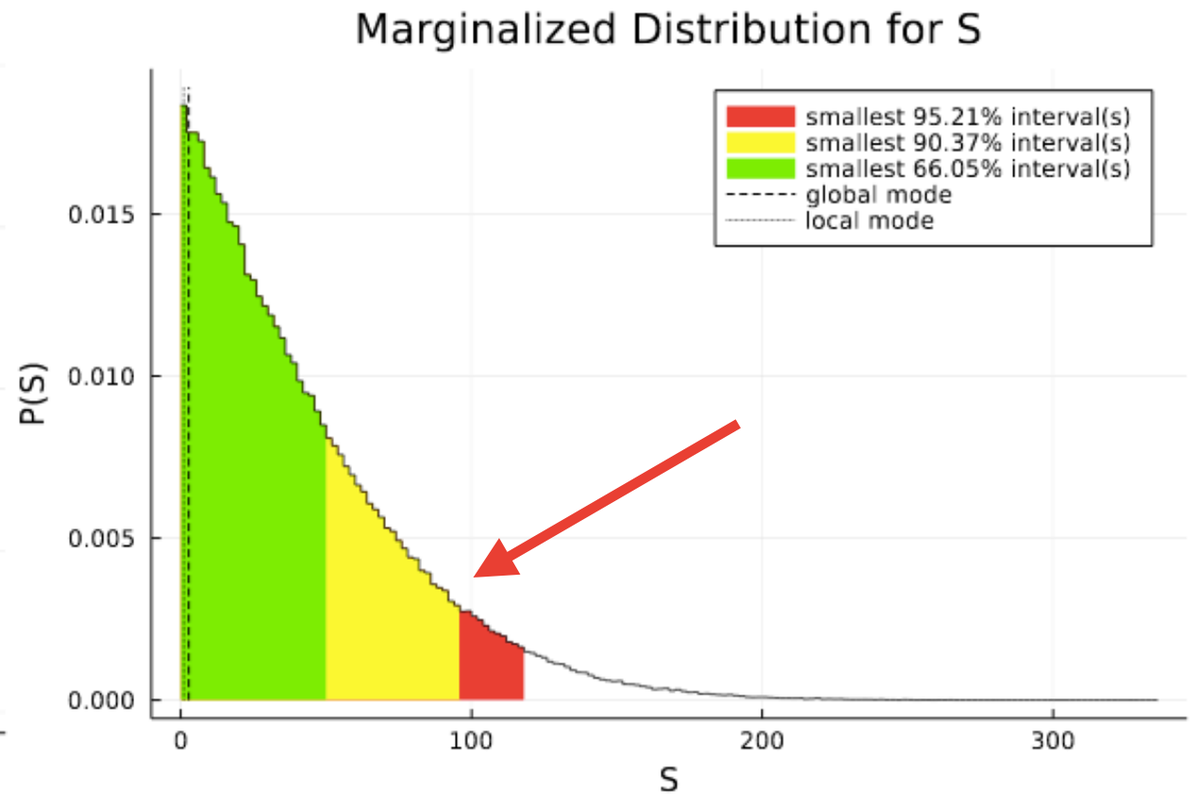
Sigma Cu



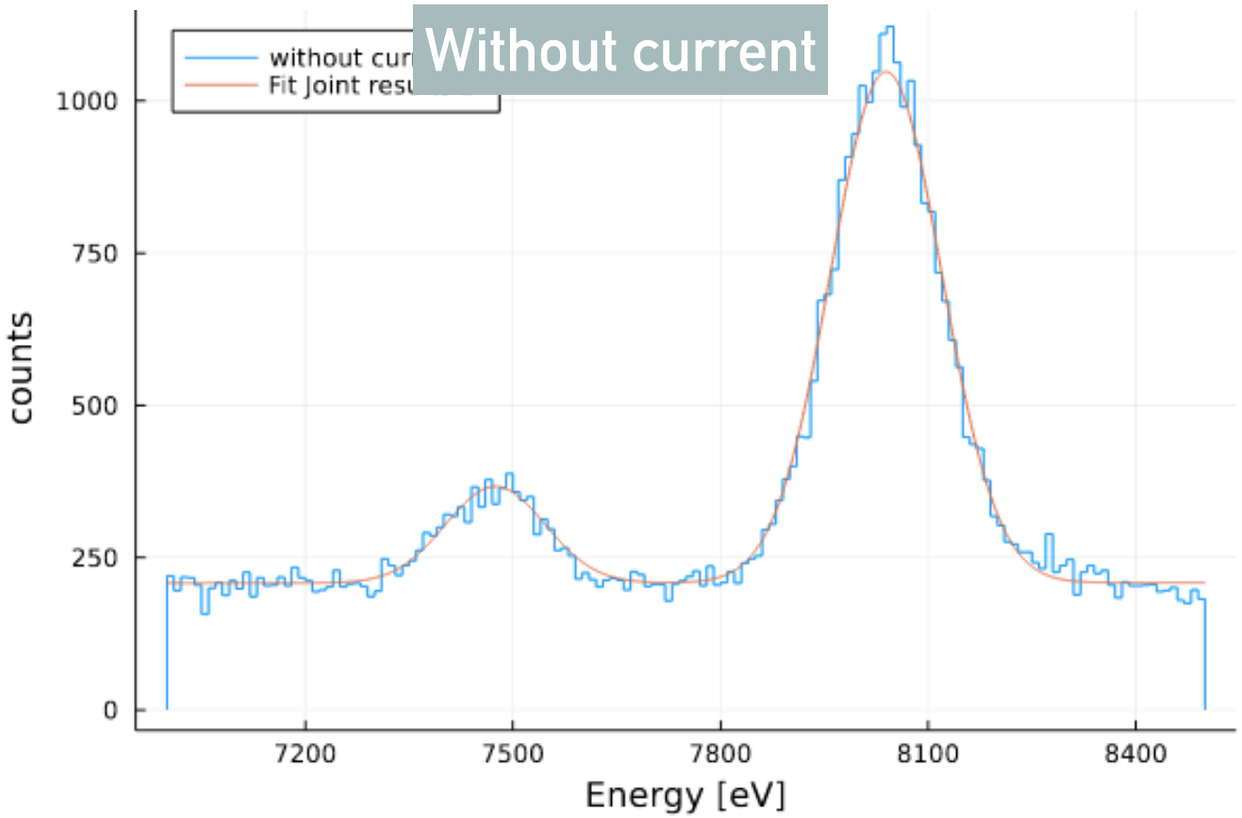
Bayesian Analysis Method

With current





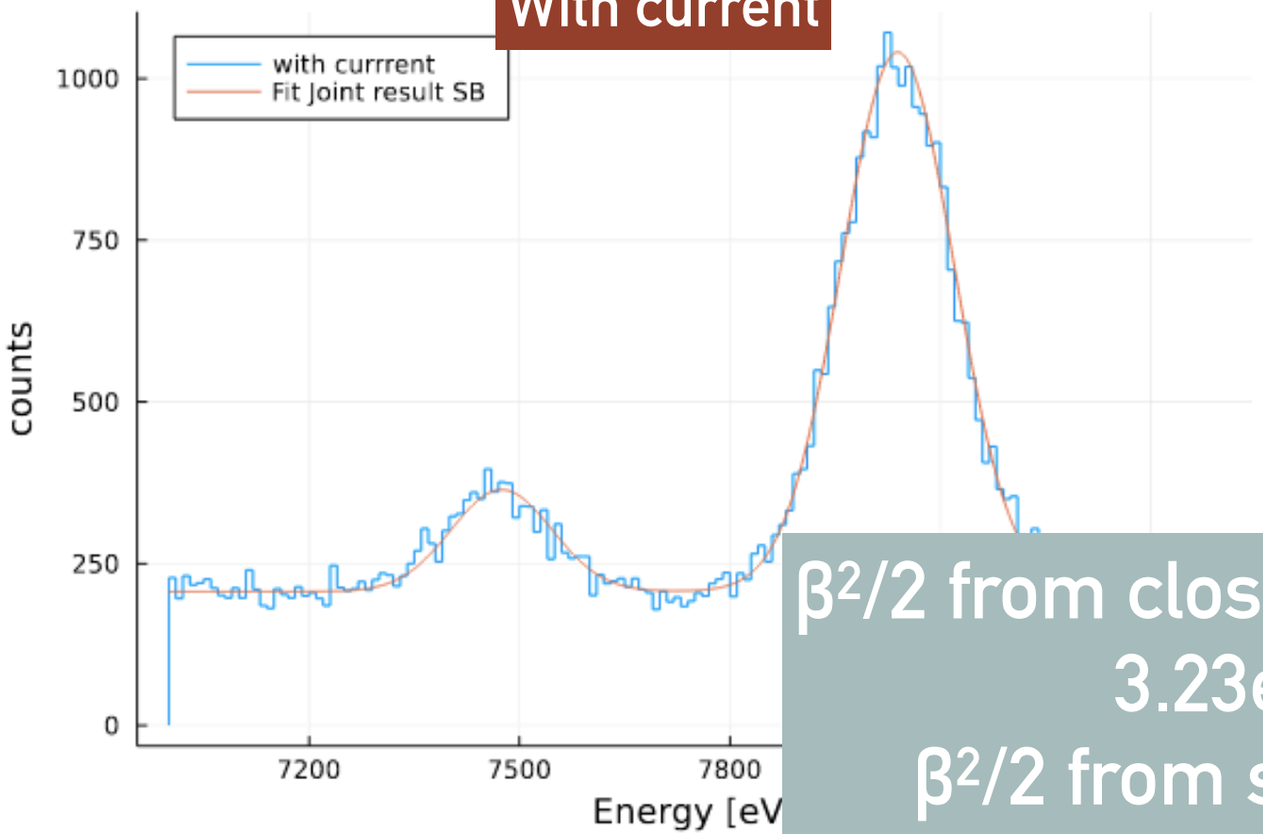
Without current

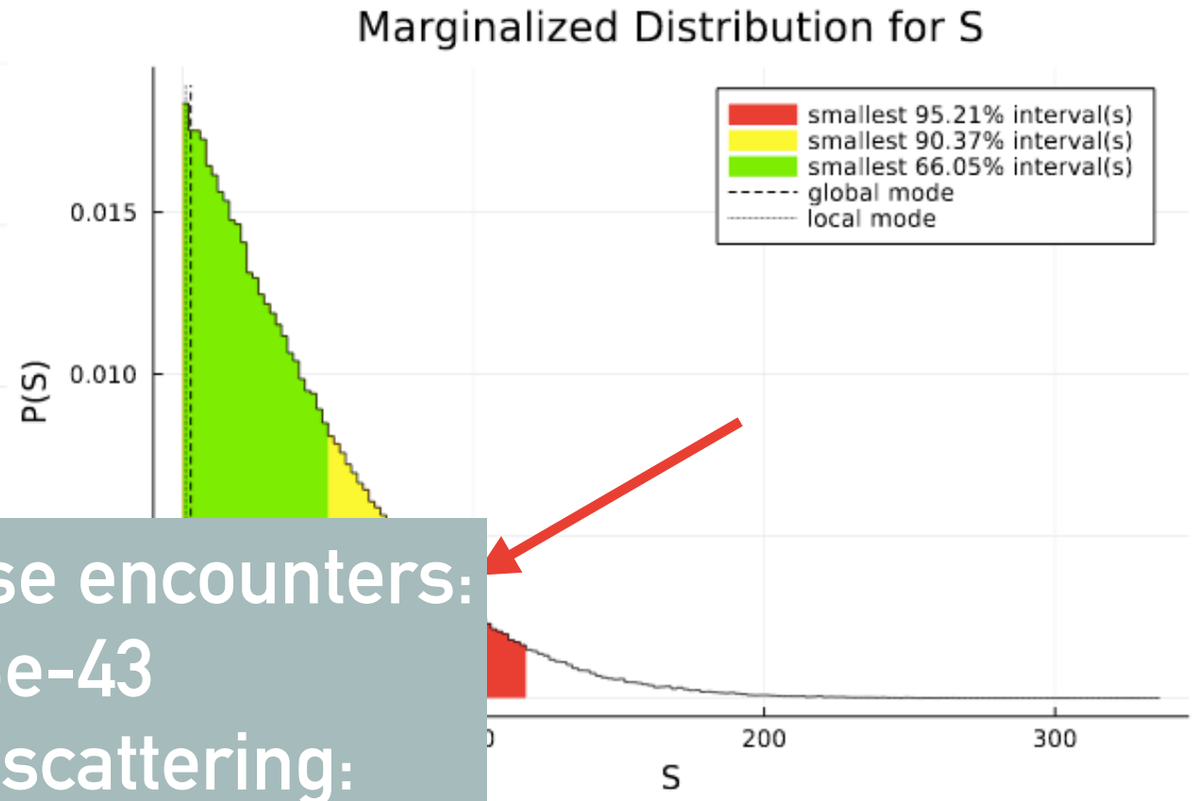


90% Upper Limit on Signal: 93

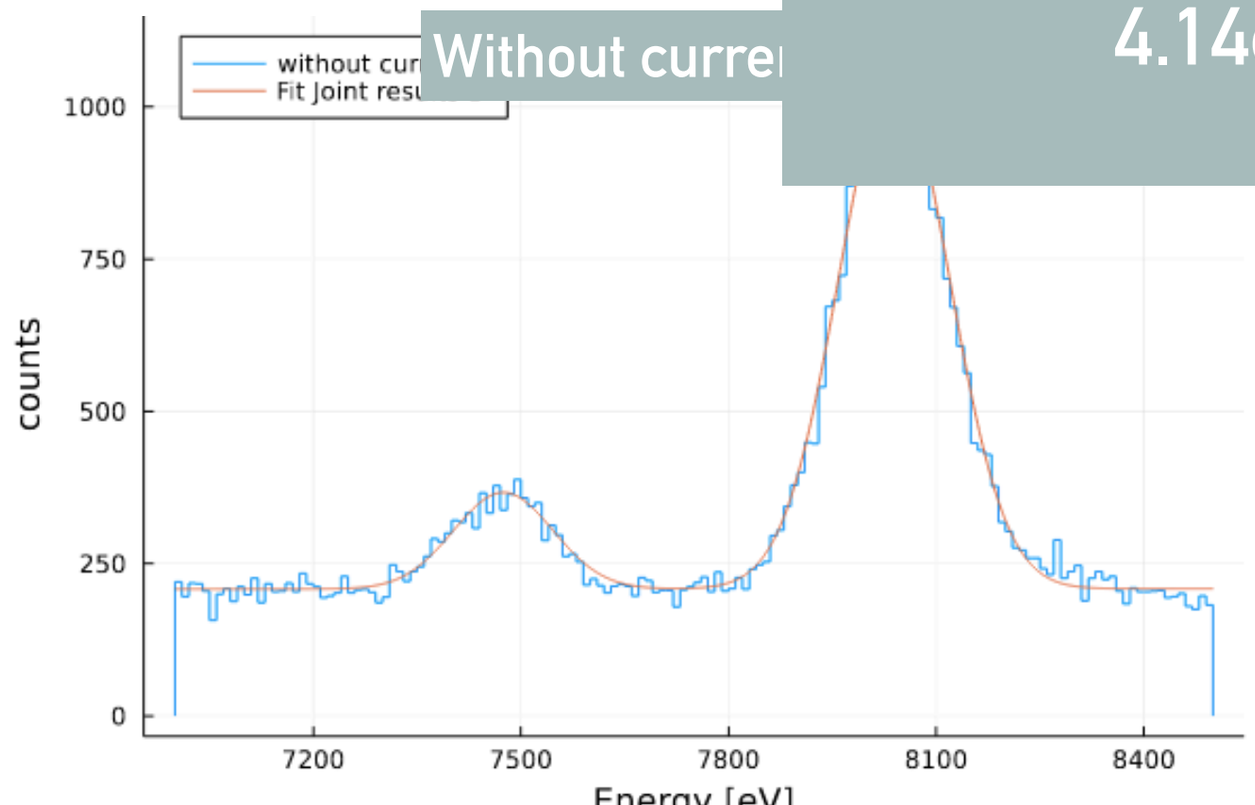
Bayesian Analysis Method

With current





Without curre

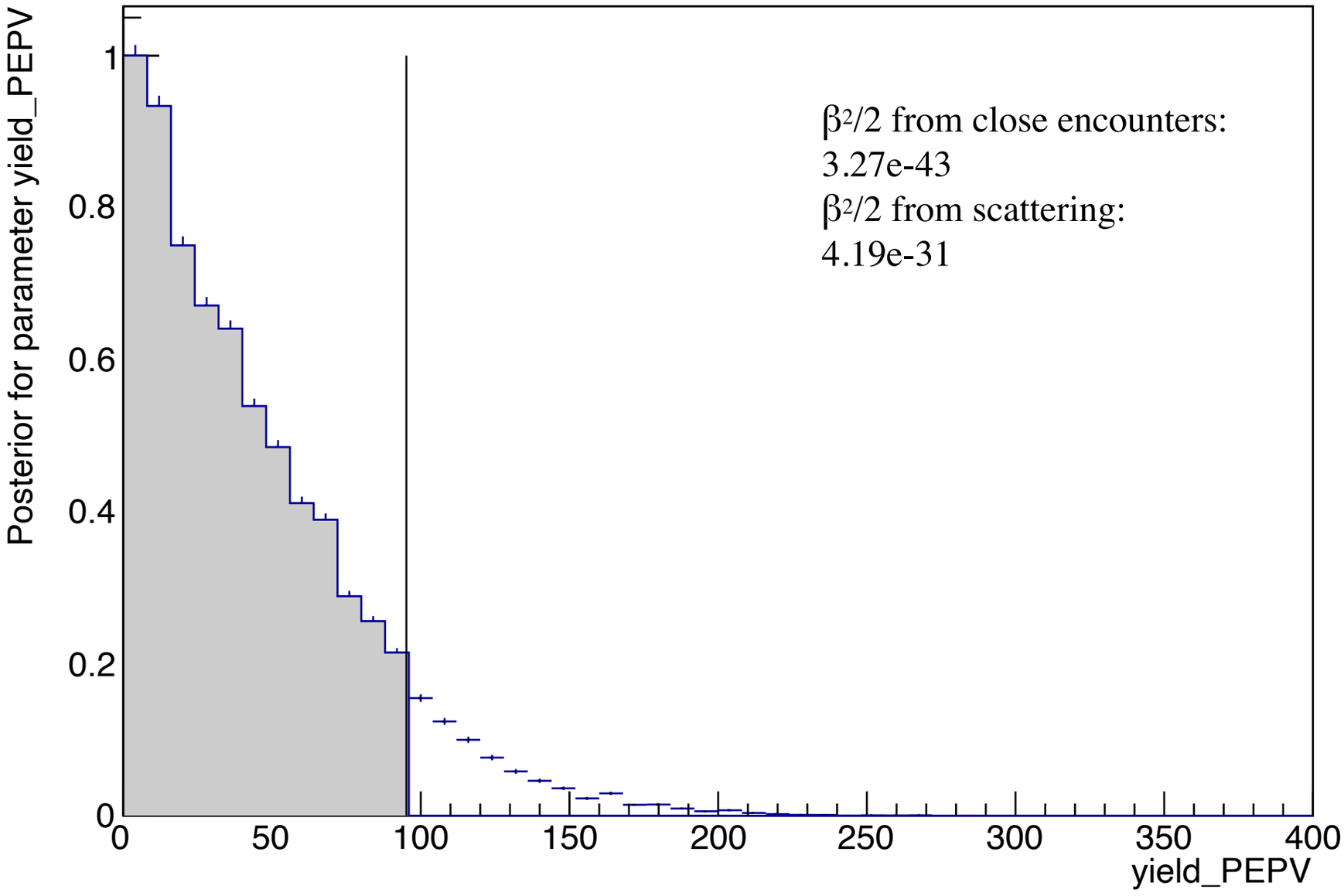


$\beta^2/2$ from close encounters: 3.23e-43

$\beta^2/2$ from scattering: 4.14e-31

Limit on Signal: 93

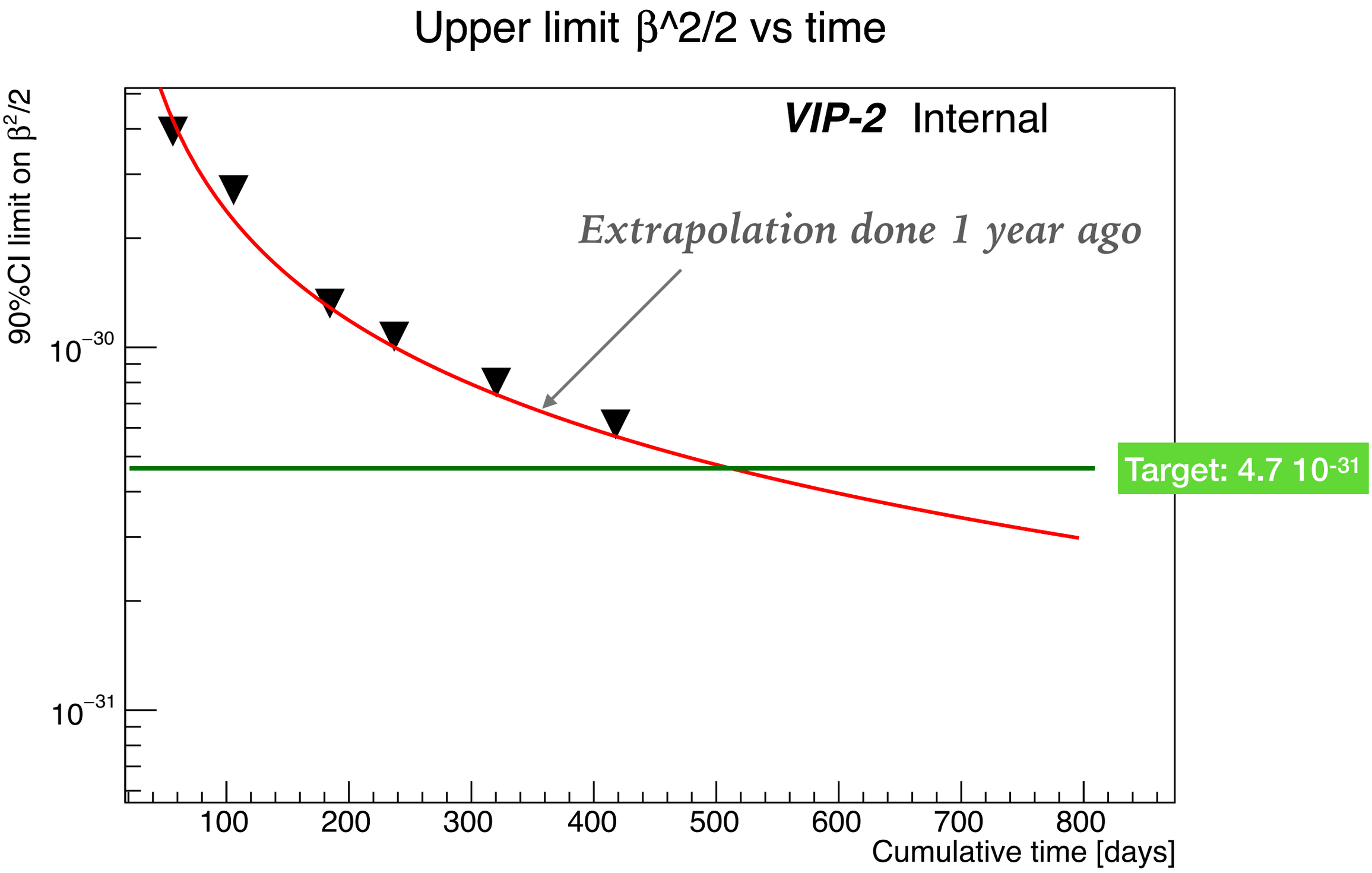
RooStat Bayesian - Bonus



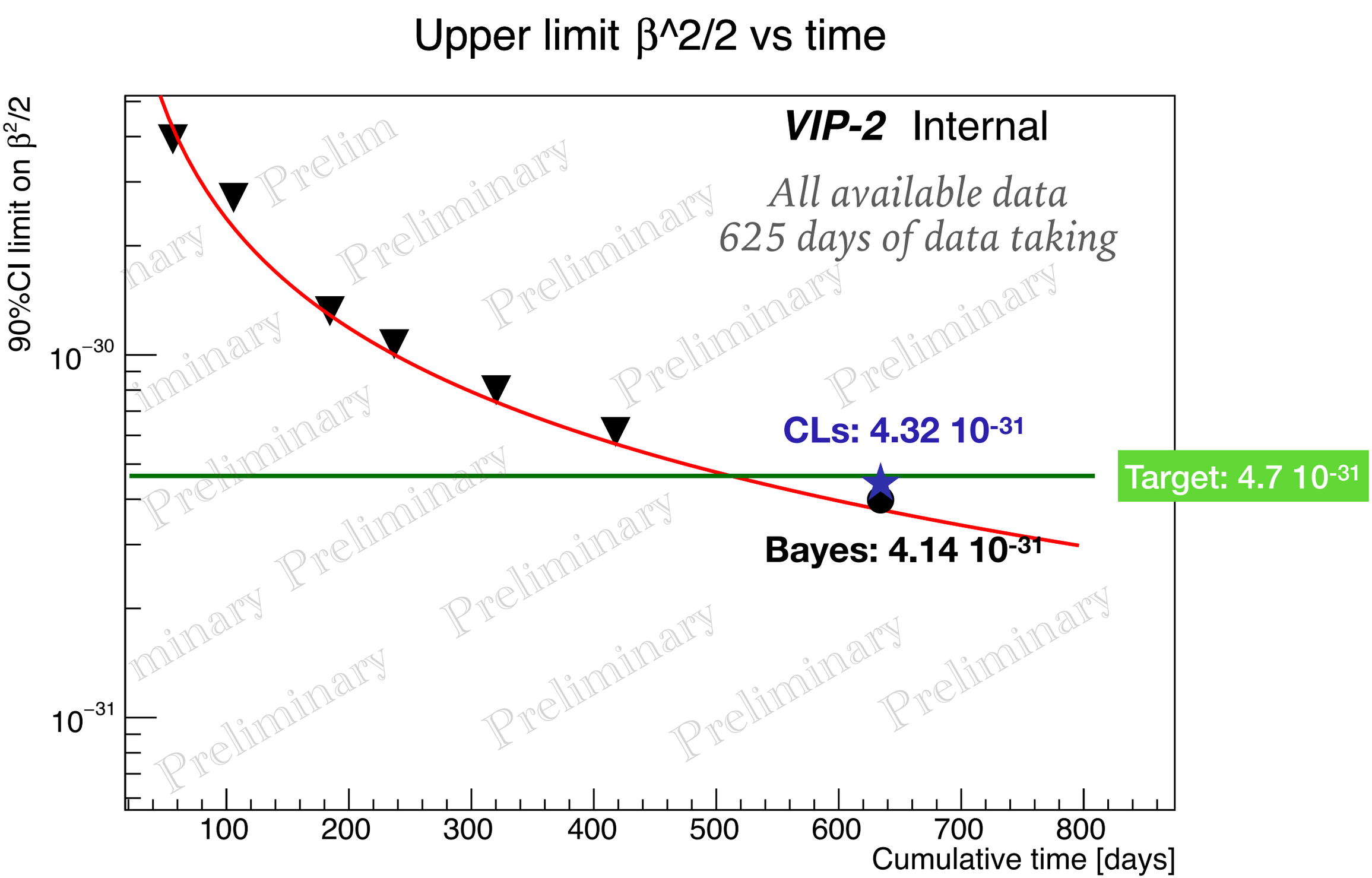
90% Upper Limit on Signal: 94

RooStat provides a crosscheck with another independent framework

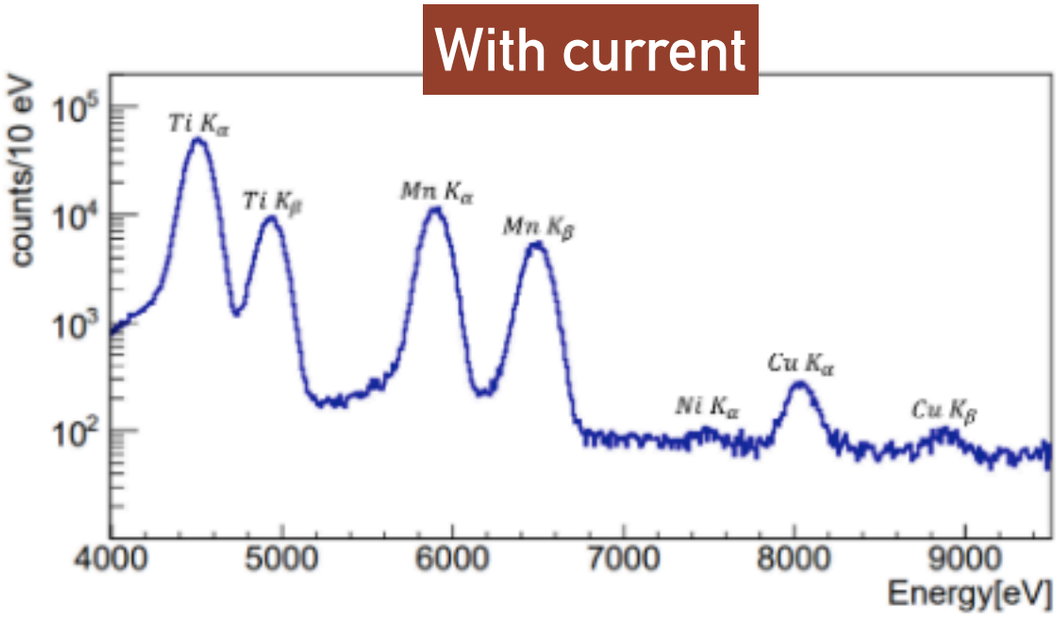
VIP-2 Limits as of Now

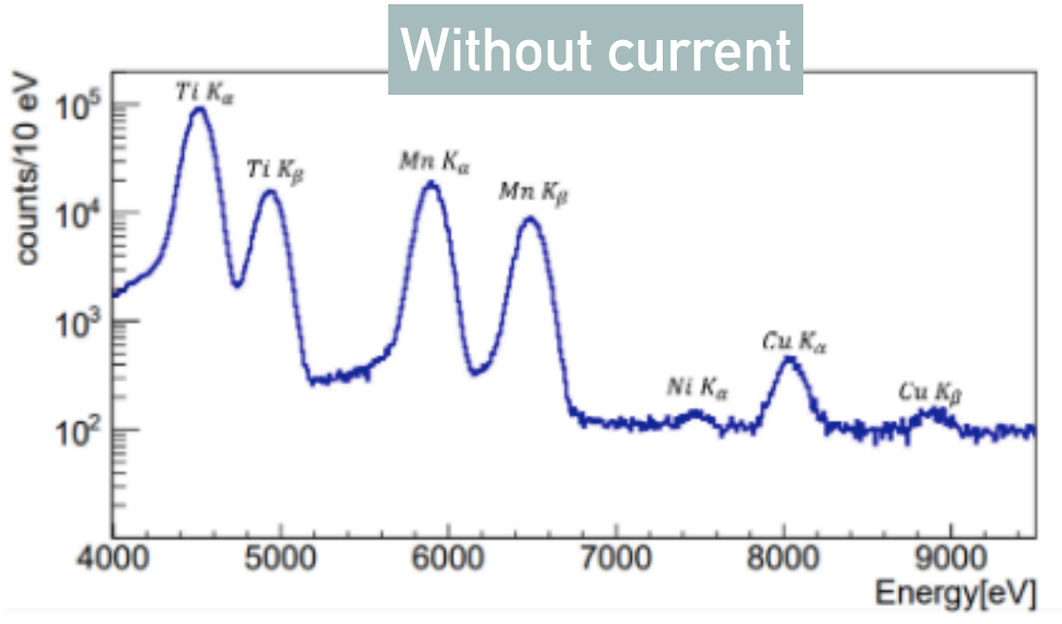


VIP-2 Limits as of Now

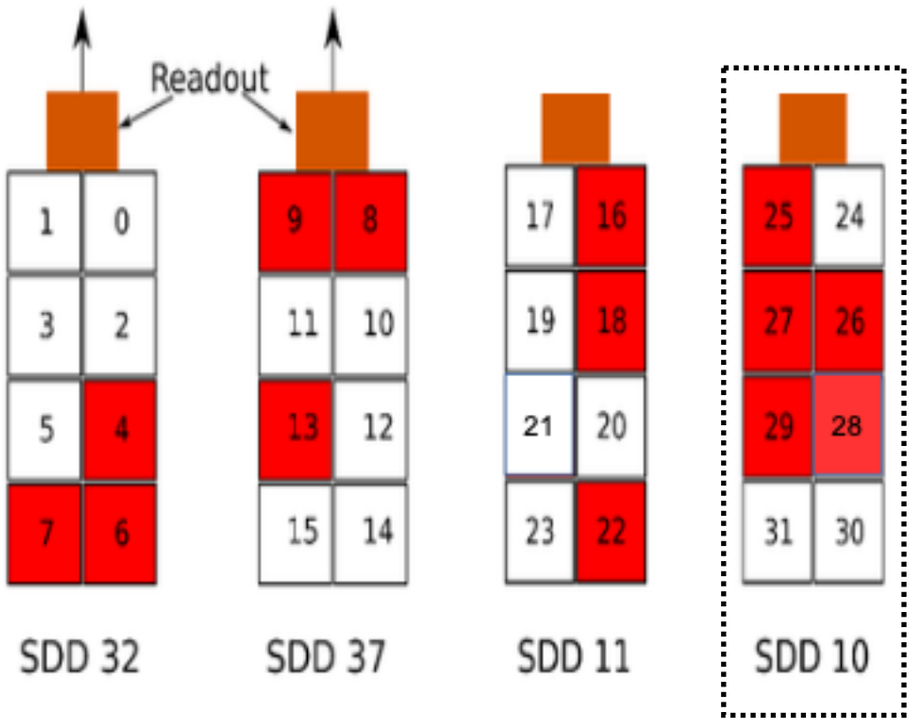


VIP-2 Before shielding: proceeding publication





40 days (@ 100 A) and 61 days (@ 0 A) of data taking before setup finalization



Divided dataset: SDD10 not working in part of the dataset & different shielding conditions

VIP-2 Before shielding: proceeding publication

no shielding

$counts^{wc1} = 3781$

$counts^{woc1} = 5851$

$t^{wc1} = 3613855$ s

$t^{woc1} = 5622814$ s

shielding

$counts^{wc2} = 1071$

$counts^{woc2} = 1673$

$t^{wc2} = 3442984$

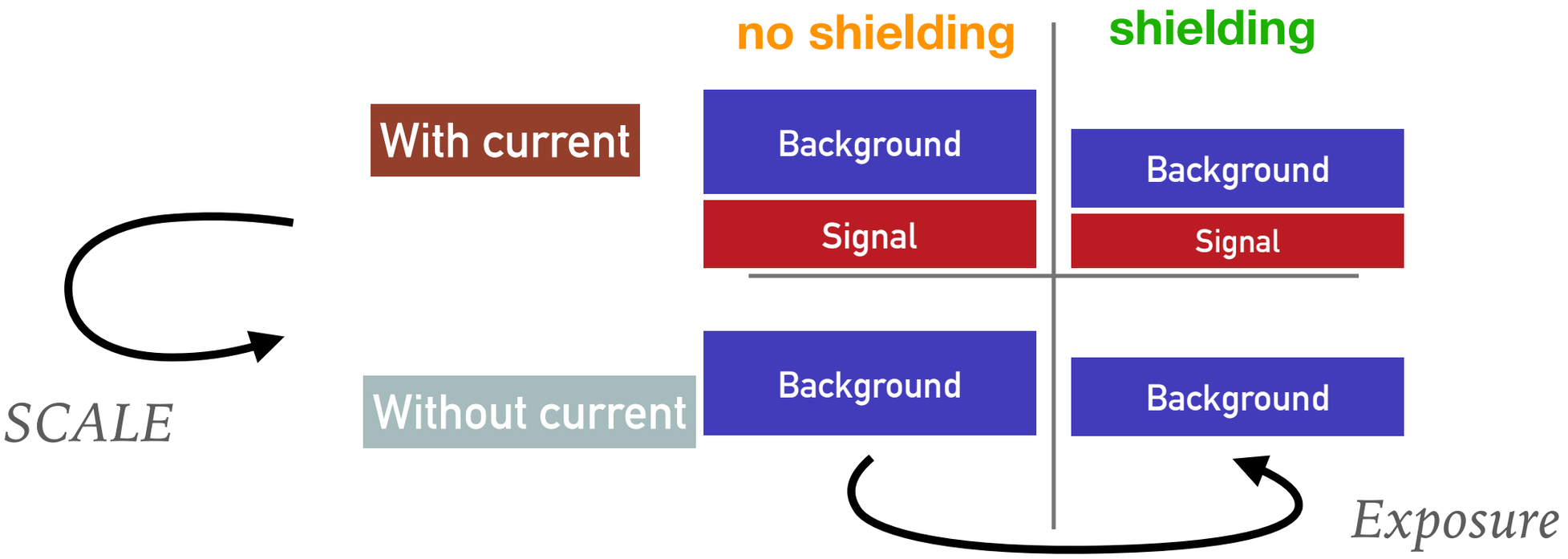
$t^{woc2} = 5248077$

$$L = \text{Poiss}(N^{1,wc}|S^1 + B^1) \times \text{Poiss}(N^{1,woc}|B^1 \times SCALE^1) \times \text{Poiss}(N^{2,wc}|S^2 + B^2) \times \text{Poiss}(N^{2,woc}|B^2 \times SCALE^2)$$
$$\times \text{Gauss}(SCALE^1, t^{1,wc}/t^{1,woc}, 0.001) \times \text{Gauss}(SCALE^2, t^{2,wc}/t^{2,woc}, 0.001)$$

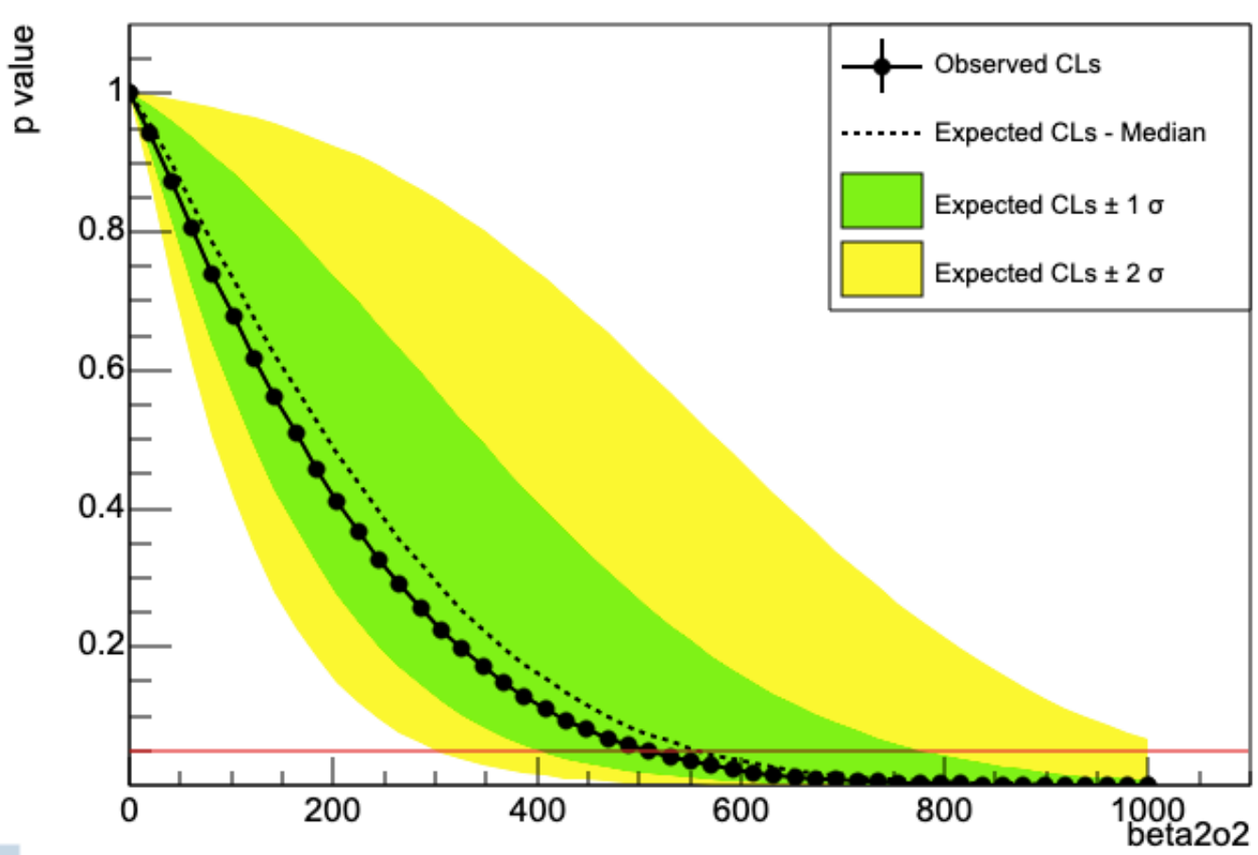
where $S^{1,2} = F^{1,2}\beta^2/2\epsilon^{1,2}$

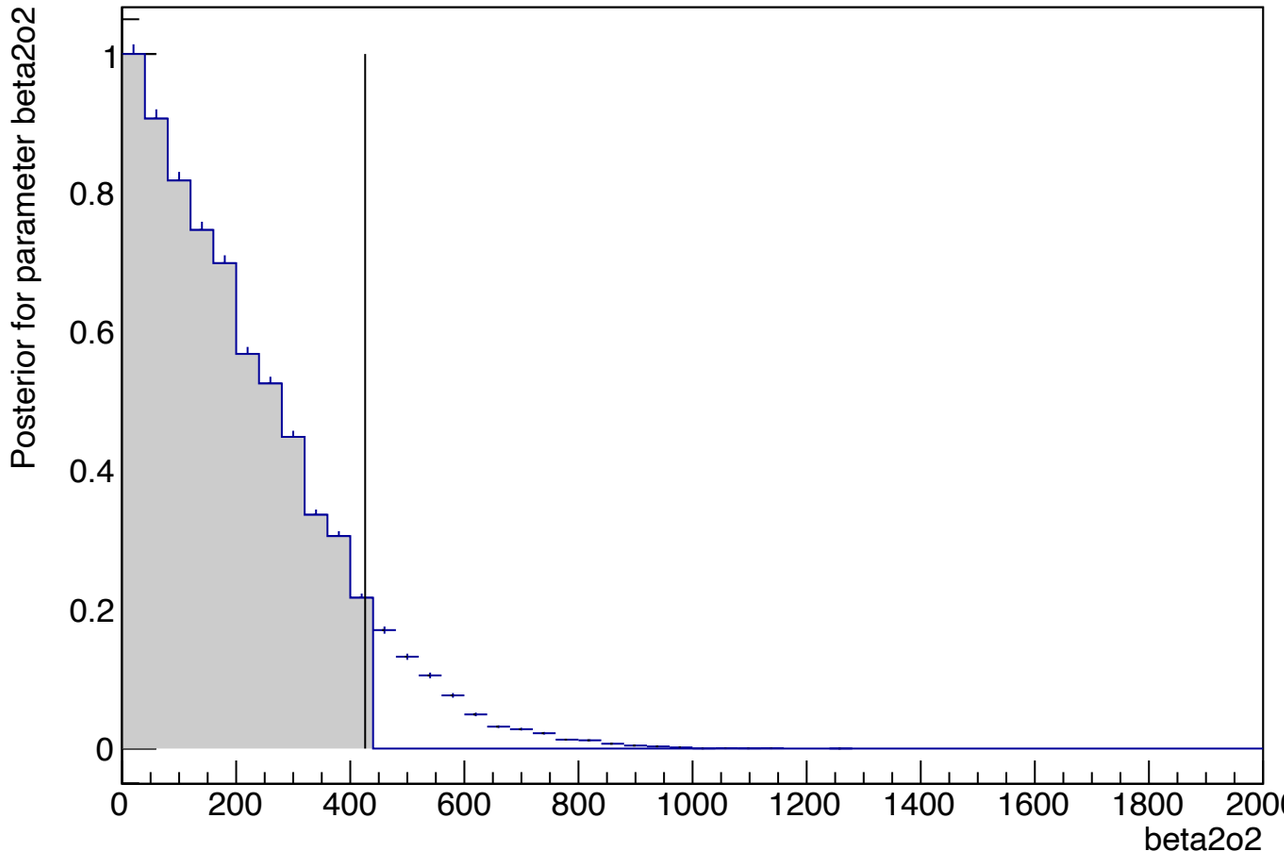
and F is a factor which depends only on the $t^{1,2,wc}$

Counting experiment with two signal and two control regions



VIP-2 Before shielding: proceeding publication





$\beta^2/2$ from close encounters:
3.4-43
$\beta^2/2$ from scattering:
4.3e-31

Conclusions

- *Statistical Model for VIP-2 analysis ready*
- *Two-facet approach for the data analysis using well established tools: ROOT and BAT*
  - *Modified frequentist CLs -> more conservative*
    $\beta^2/2$ from scattering: ***4.32e-31***
  - *Bayesian Limit ->*
    $\beta^2/2$ from scattering: ***4.14e-31***
    - *Bayesian method repeated with independent method -> RooStat & yields very similar results*
- *Publication using partial shielding on the way*

Many thanks for the attention!

Questions?

VIP-2 Limits as of Now