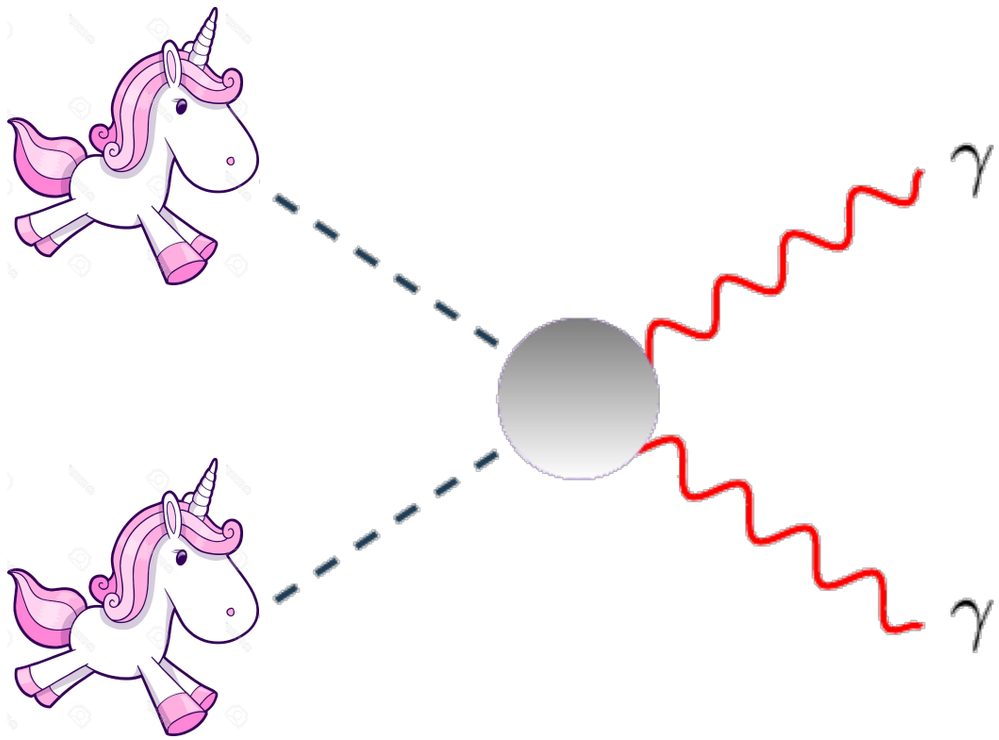
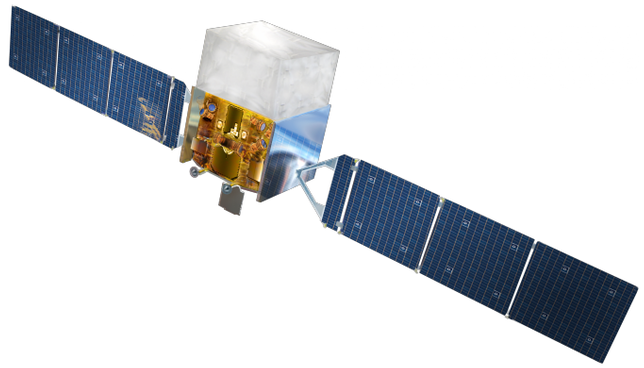
Recurrent deconvolution background method (RDBM)

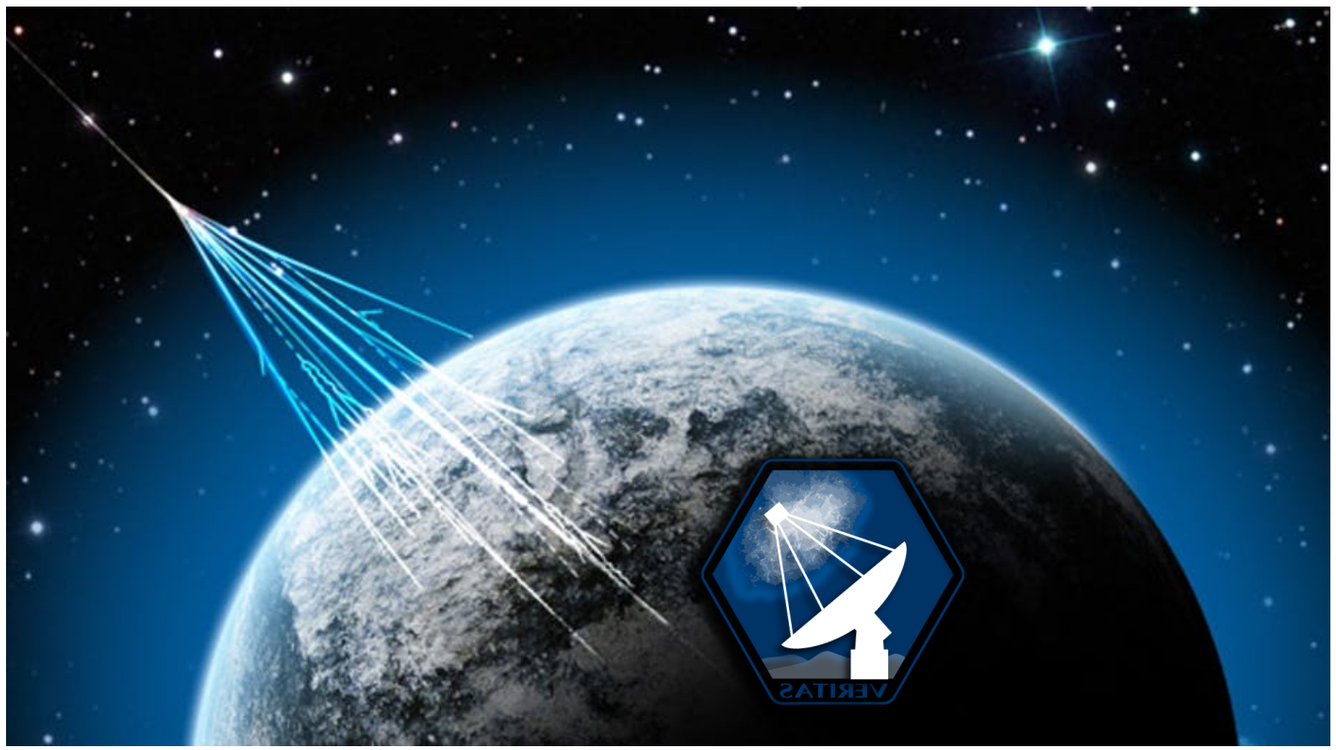
2019 Fermi School

Ruo Yu Shang and Vladimir Vassiliev

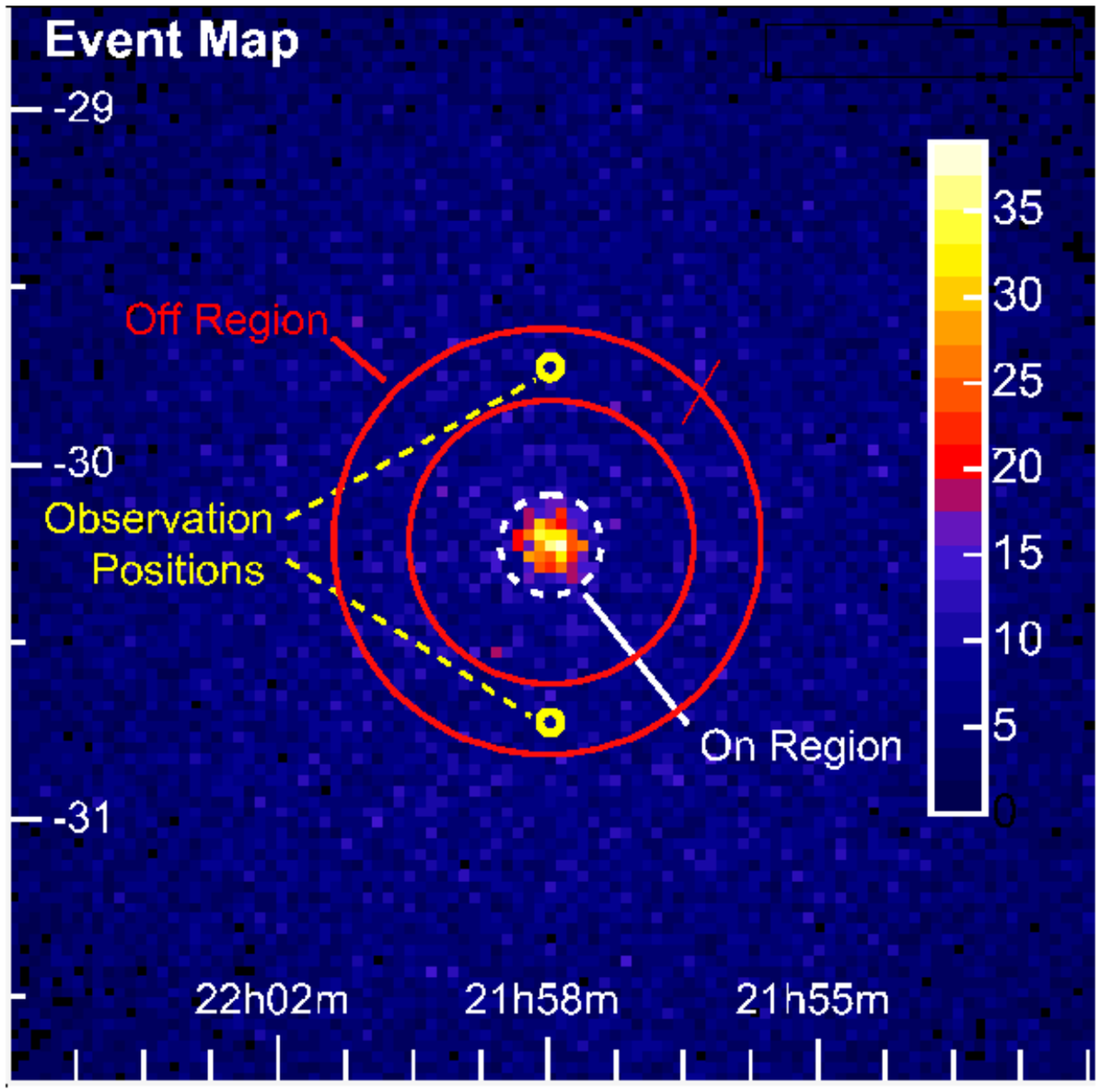
Search for Dark Matter via high energy γ ray.

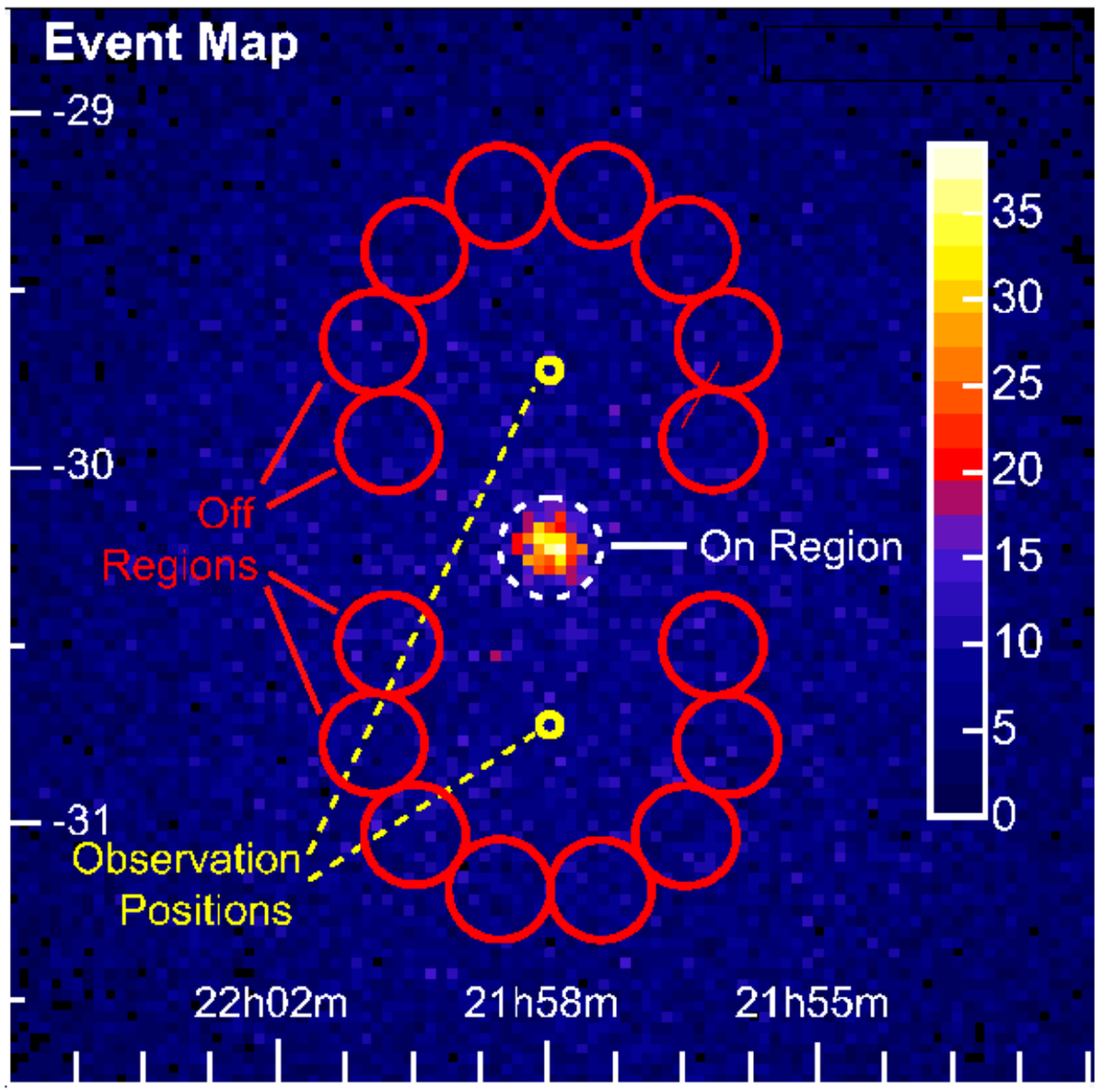






Traditional background methods: dark space in telescope FoV.

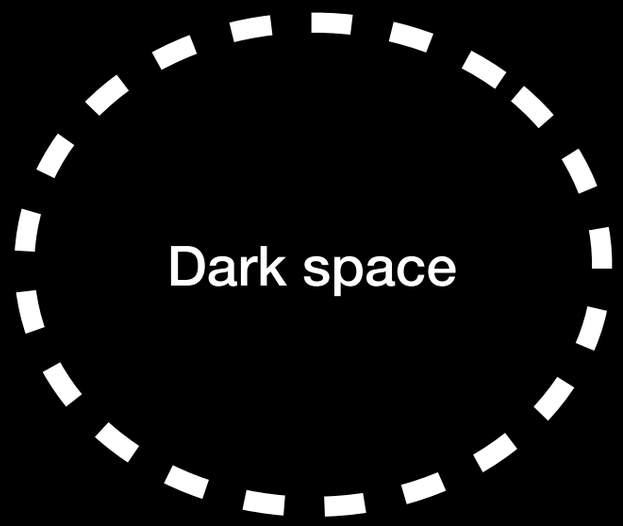




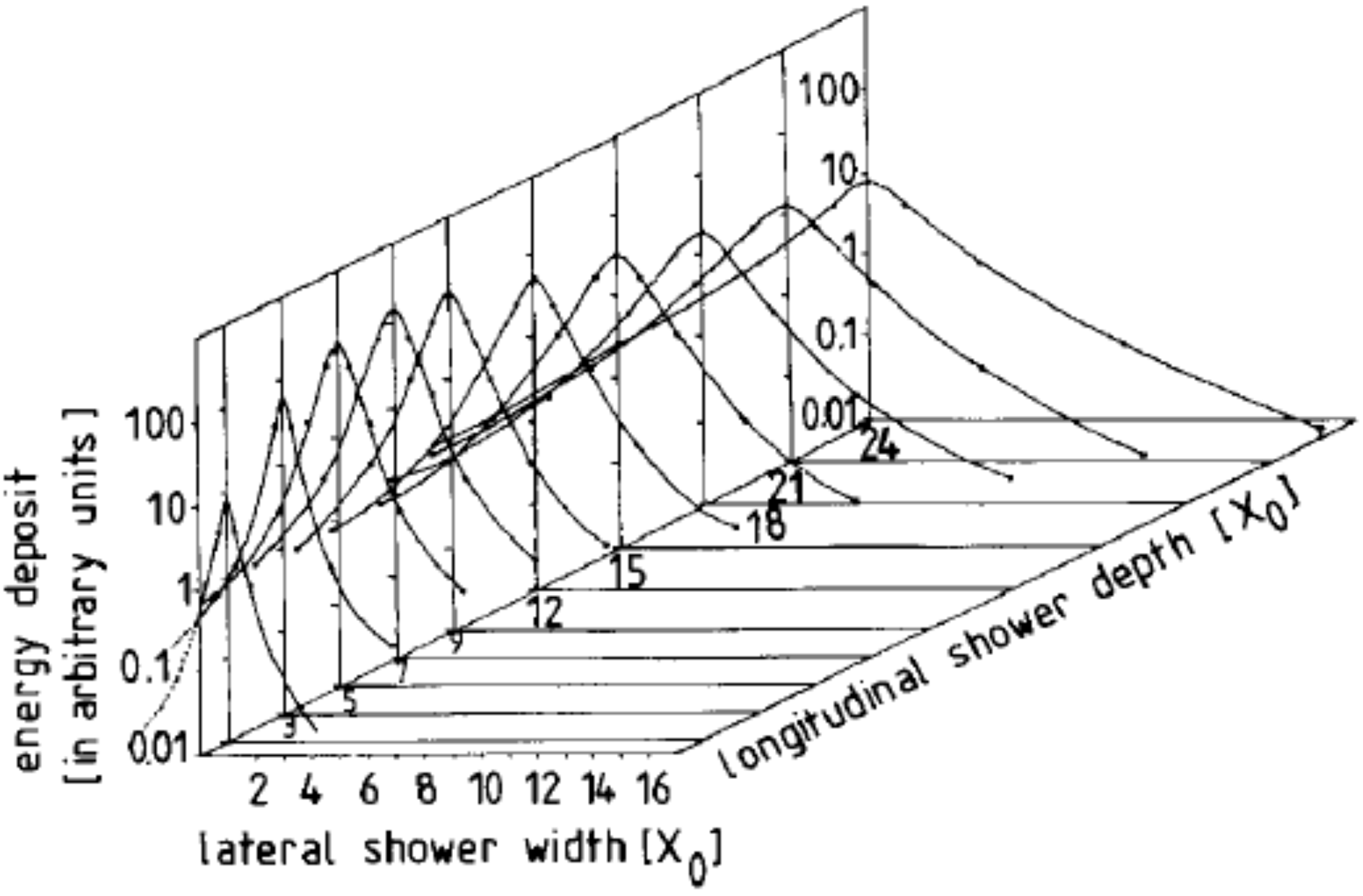
Sizes of extended sources are larger than telescope FoV.

Traditional background methods do not work.

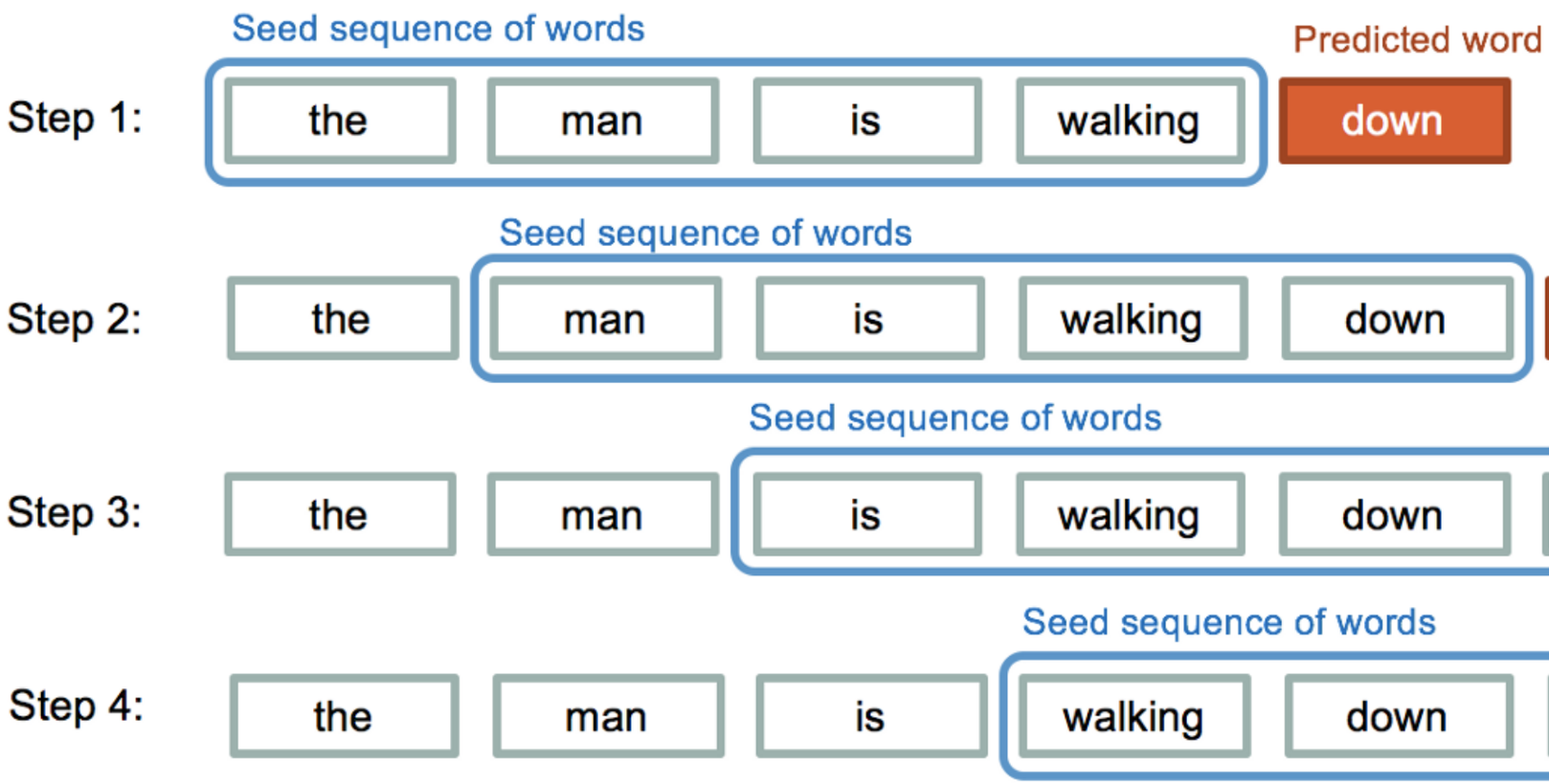
Taking OFF region from a different pointing is **expansive** and difficult to control **systematic uncertainties**.

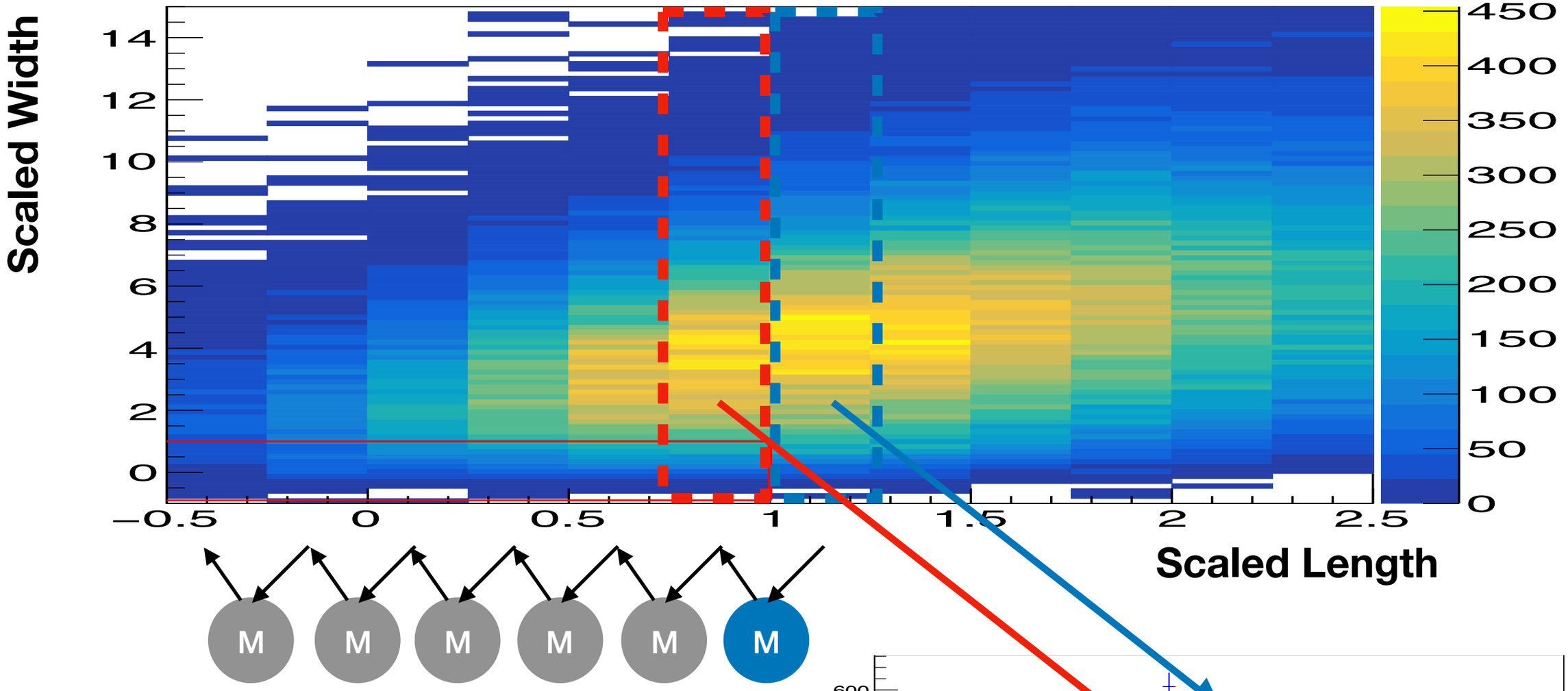


A new method exploits the correlation between shower
longitudinal and lateral development.

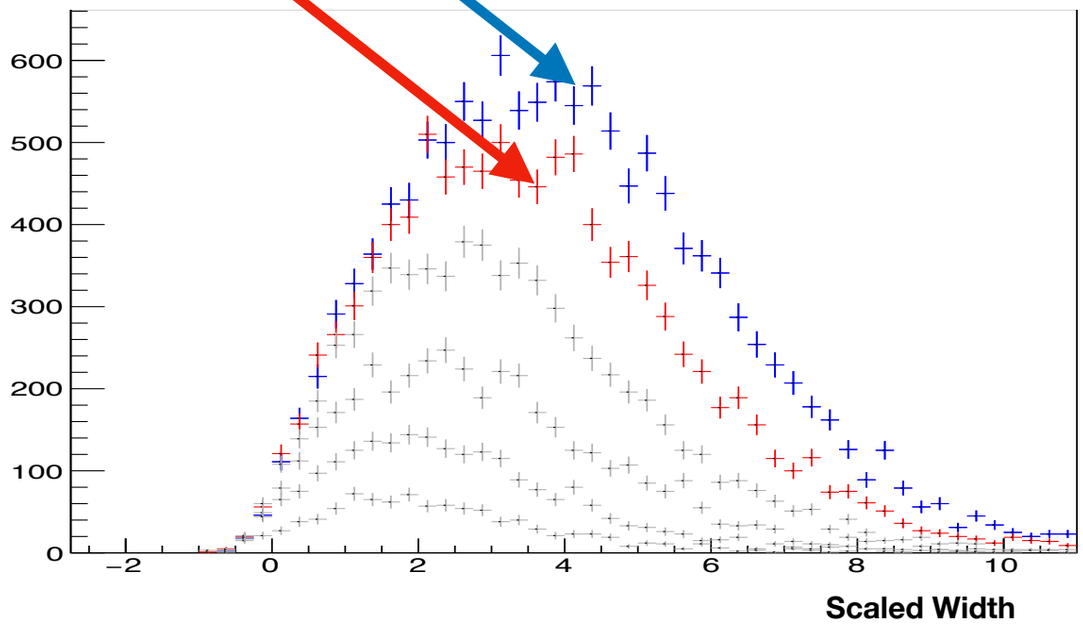


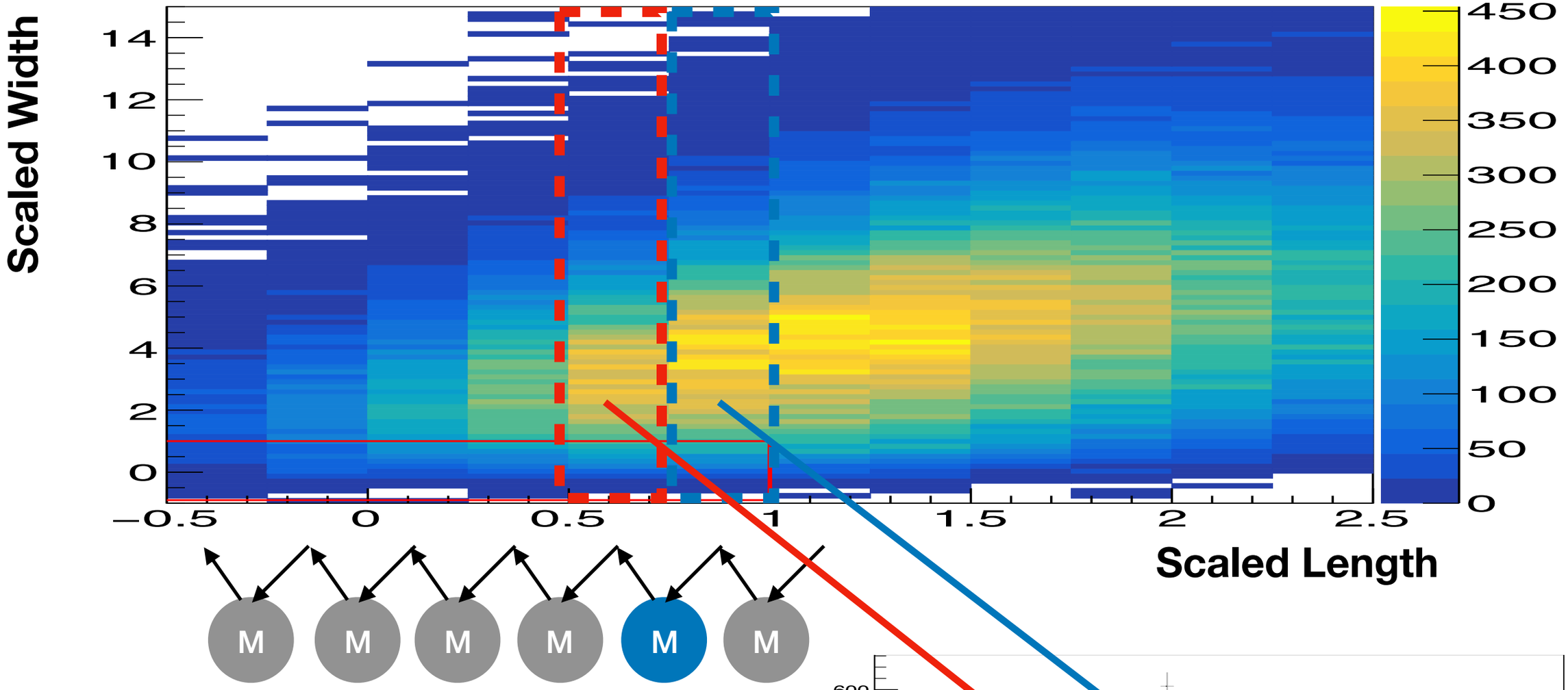
And it also borrows the idea of Recurrent Neural Network.
(the algorithm that automatically generates text in your cell phone)



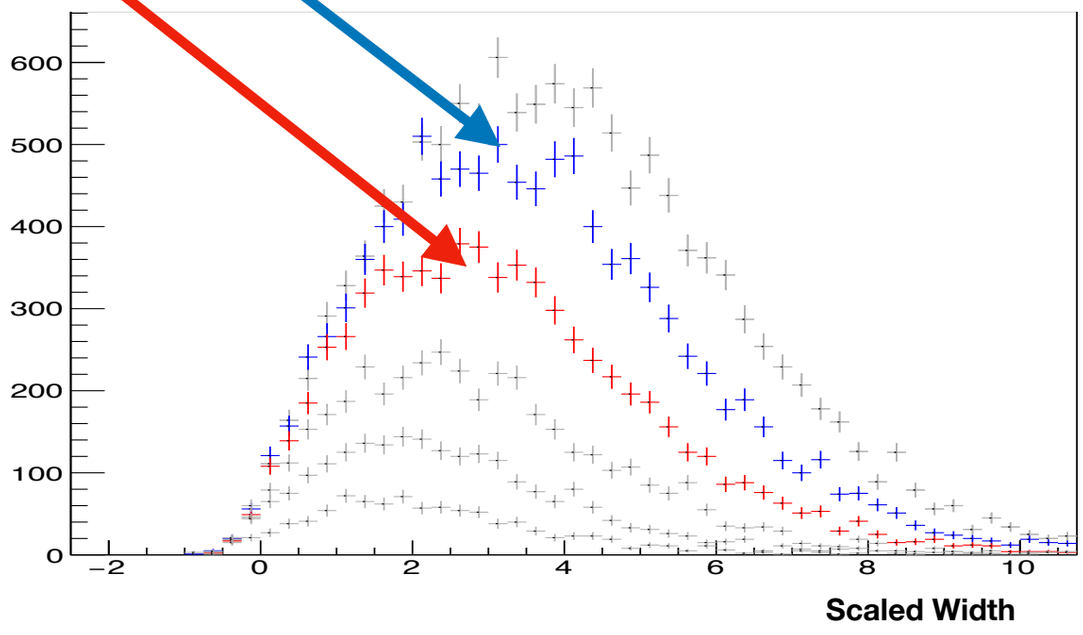


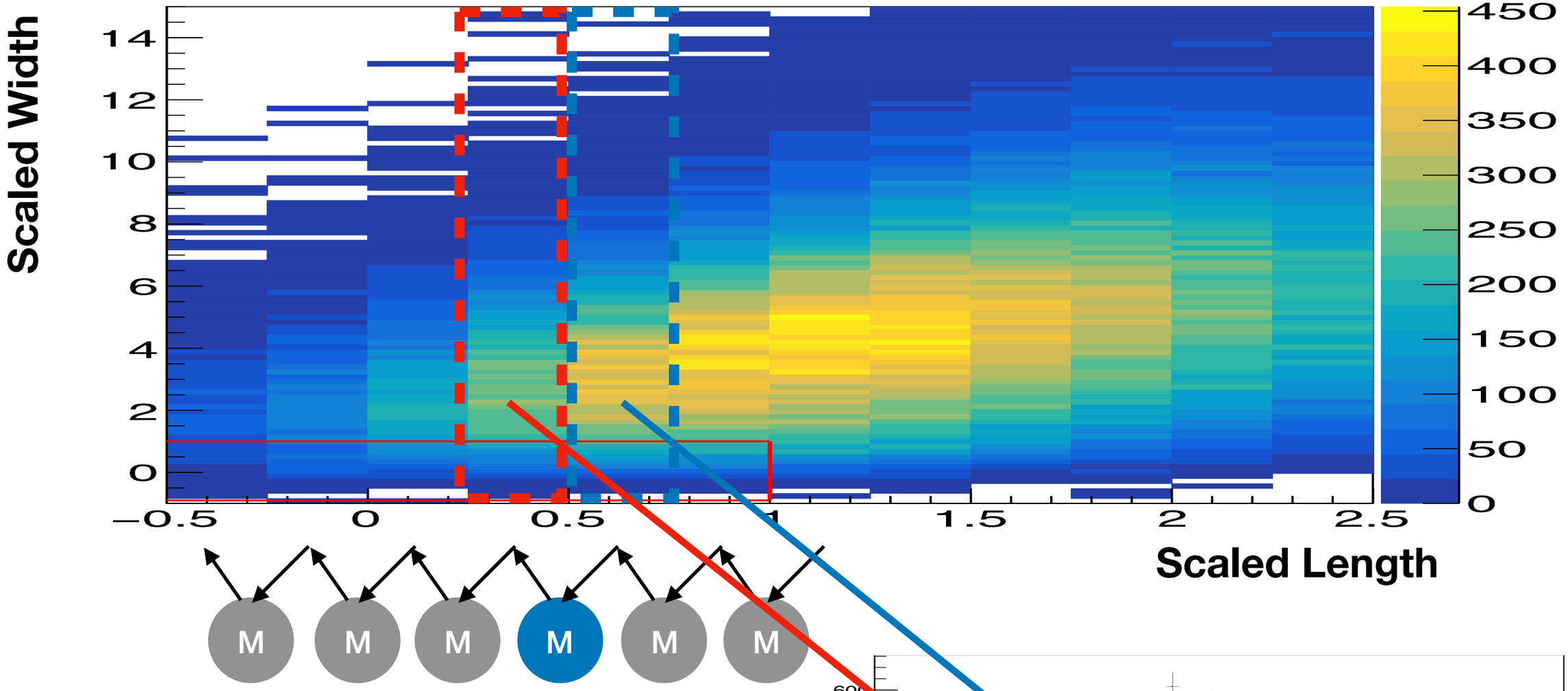
We will build a mapping function M, which transforms the blue layer to the red layer.



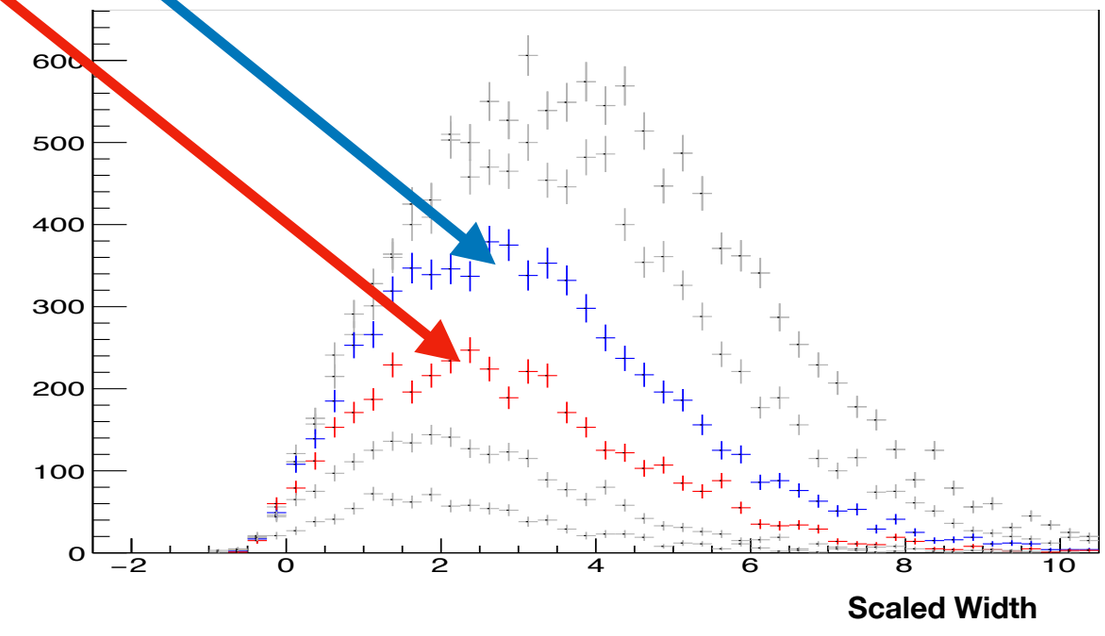


If we succeeded, we can continue the same process for the next layer…

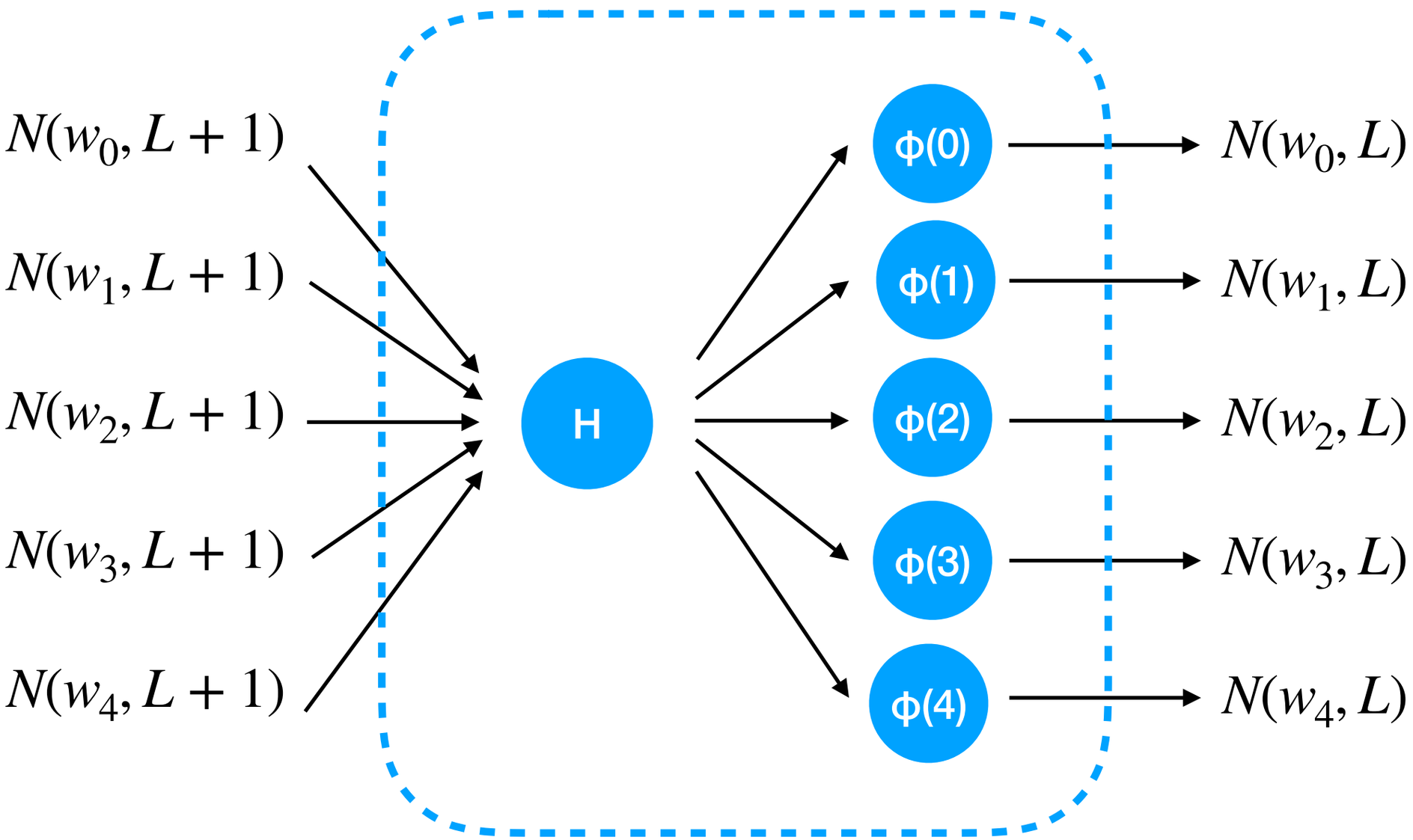




… until we complete the prediction for the blinded region.



Here is the structure of the mapping function:



$$N(w_i, L) = \phi(w_i) \sum H(w_i - w_j) N(w_j, L+1)$$

The inverse kernel in the mapping function has a Gaussian form:

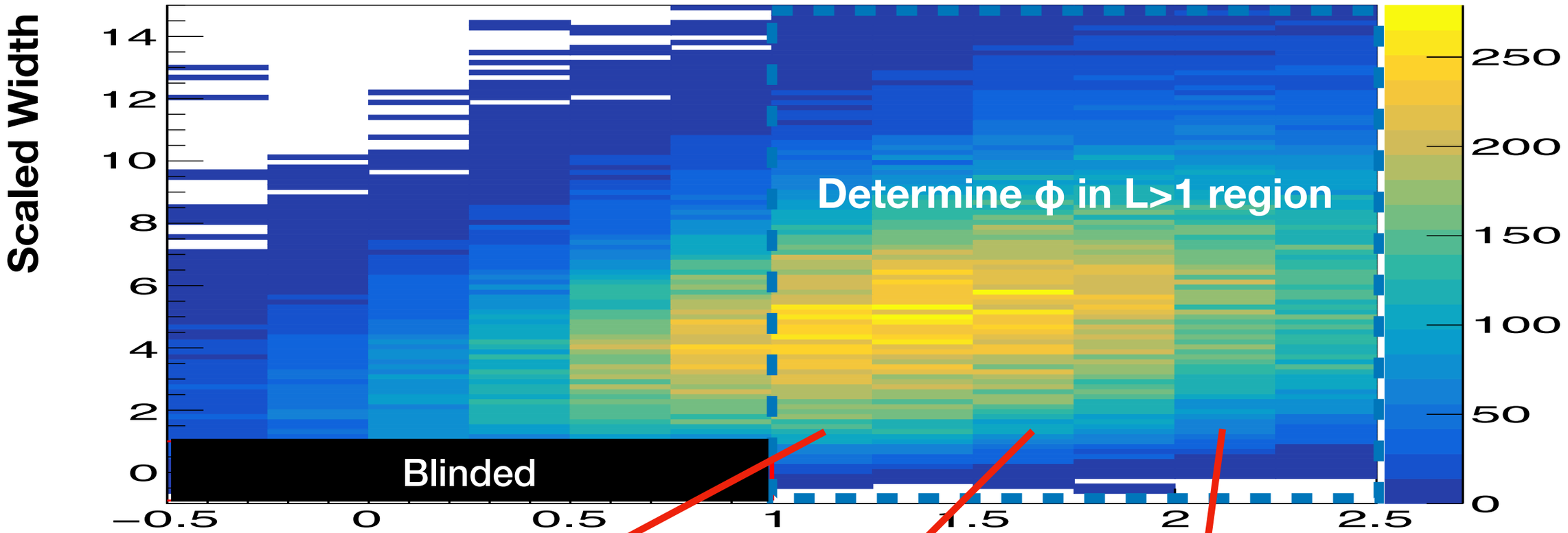
$$H^{-1}(w_i - w_j) = A \exp\left(-\frac{(w_i - w_j - x)^2}{2\sigma^2}\right)$$

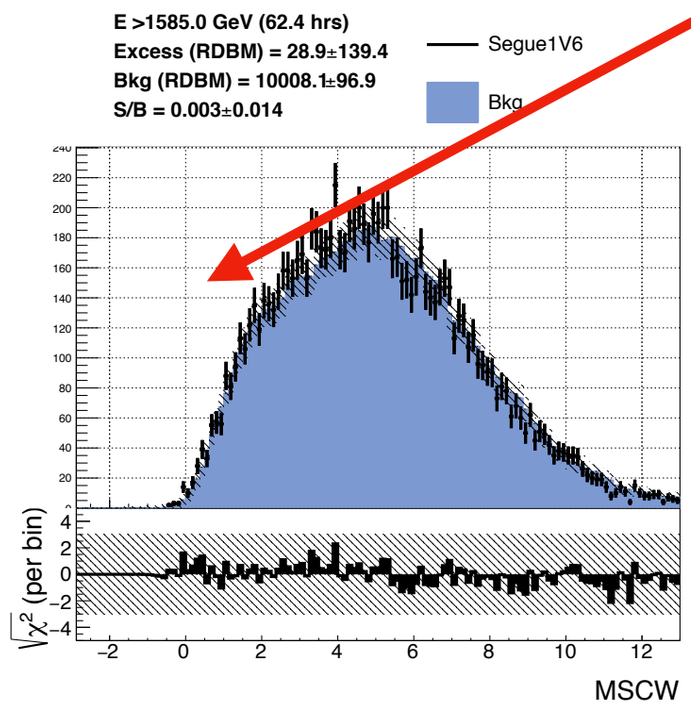
And an activation function:

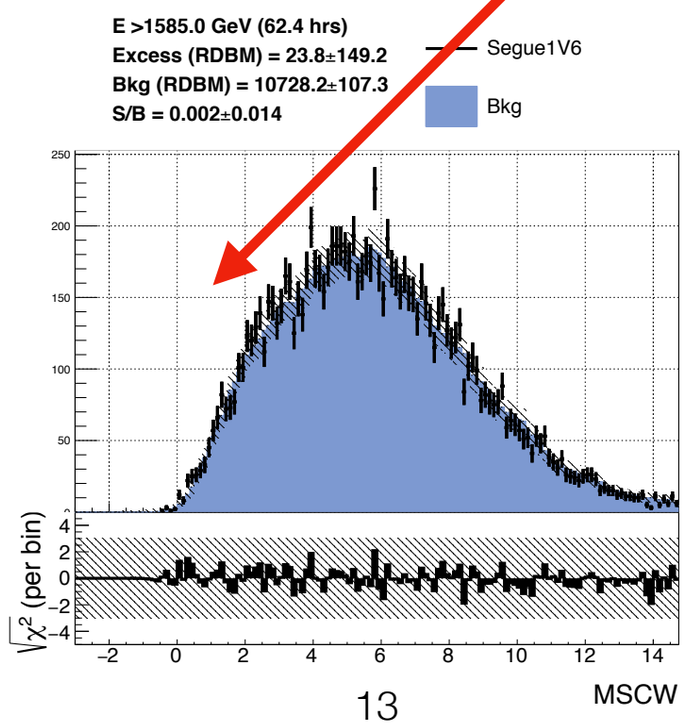
$$\phi(w_i) = \begin{cases} 1, & \textbf{if } w_i - t_1 \geq 0 \\ 0, & \textbf{if } w_i - t_2 \leq 0 \\ \big((w_i - t_2)/(t_1 - t_2)\big), & \textbf{otherwise} \end{cases}$$

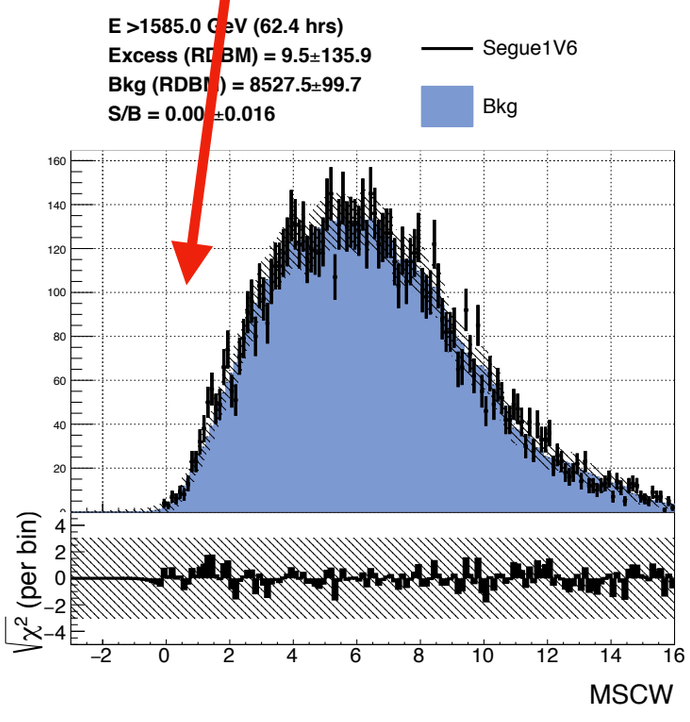
These parameters are determined by minimizing:

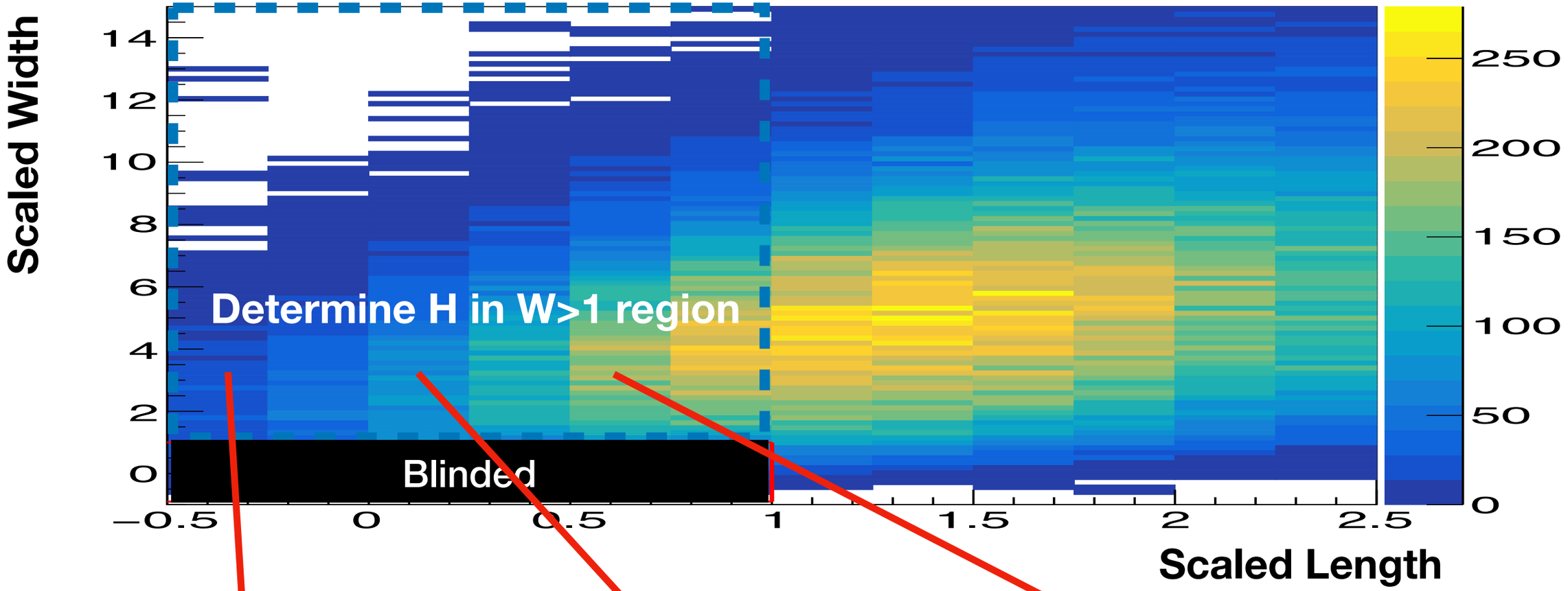
$$\chi^2 = \sum_{\textbf{unblinded}} \frac{(N_{data}(w) - N_{bkg}(w))^2}{\sigma^2_{data} + \sigma^2_{bkg}}$$

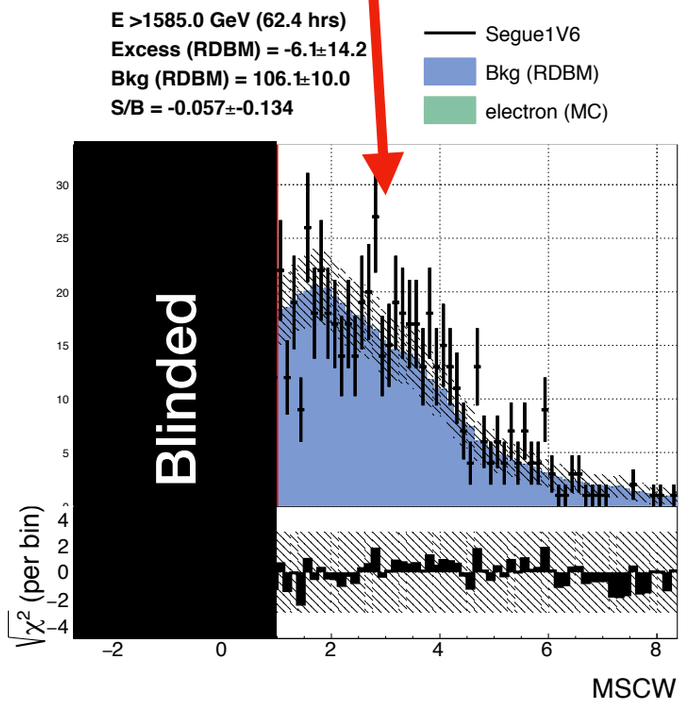

Scaled Width
Scaled Length
Determine ϕ in L>1 region
Blinded

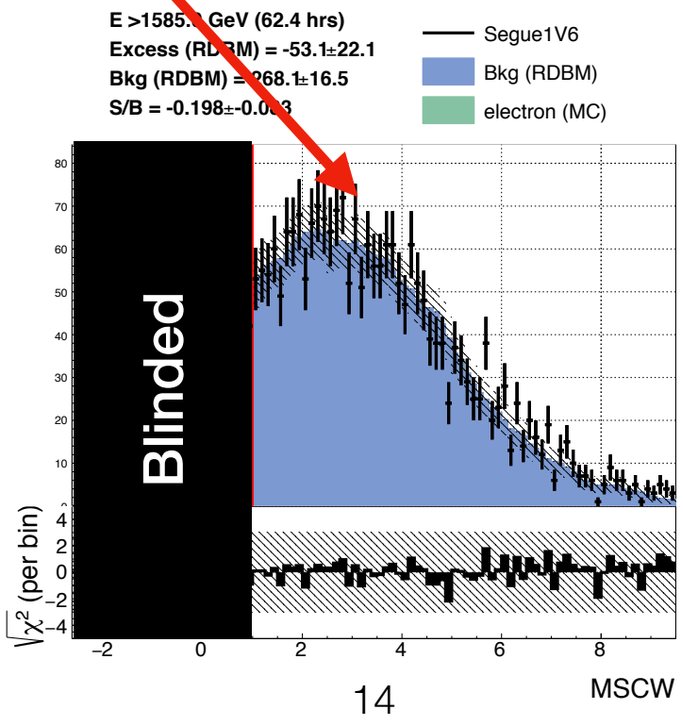

E >1585.0 GeV (62.4 hrs)
Excess (RDBM) = 28.9±139.4
Bkg (RDBM) = 10008.1±96.9
S/B = 0.003±0.014
Segue1V6
Bkg
MSCW

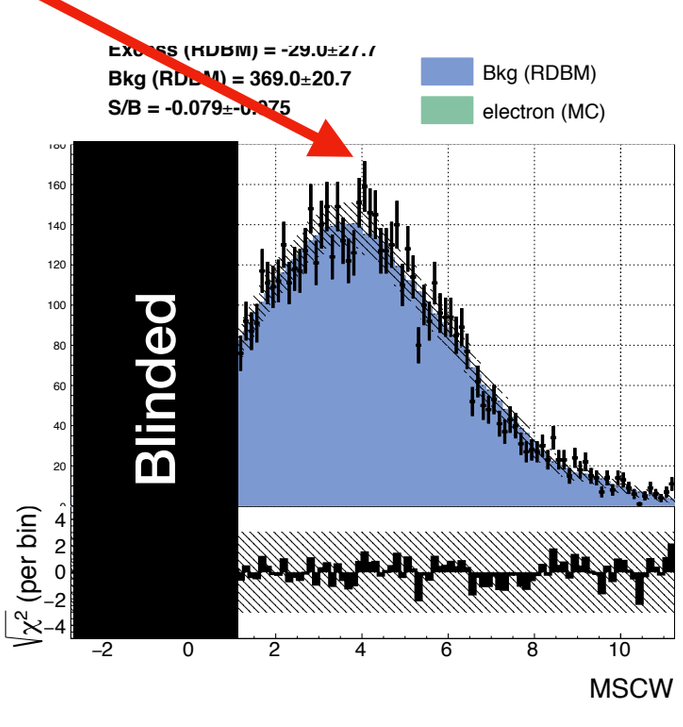

E >1585.0 GeV (62.4 hrs)
Excess (RDBM) = 23.8±149.2
Bkg (RDBM) = 10728.2±107.3
S/B = 0.002±0.014
Segue1V6
Bkg
MSCW

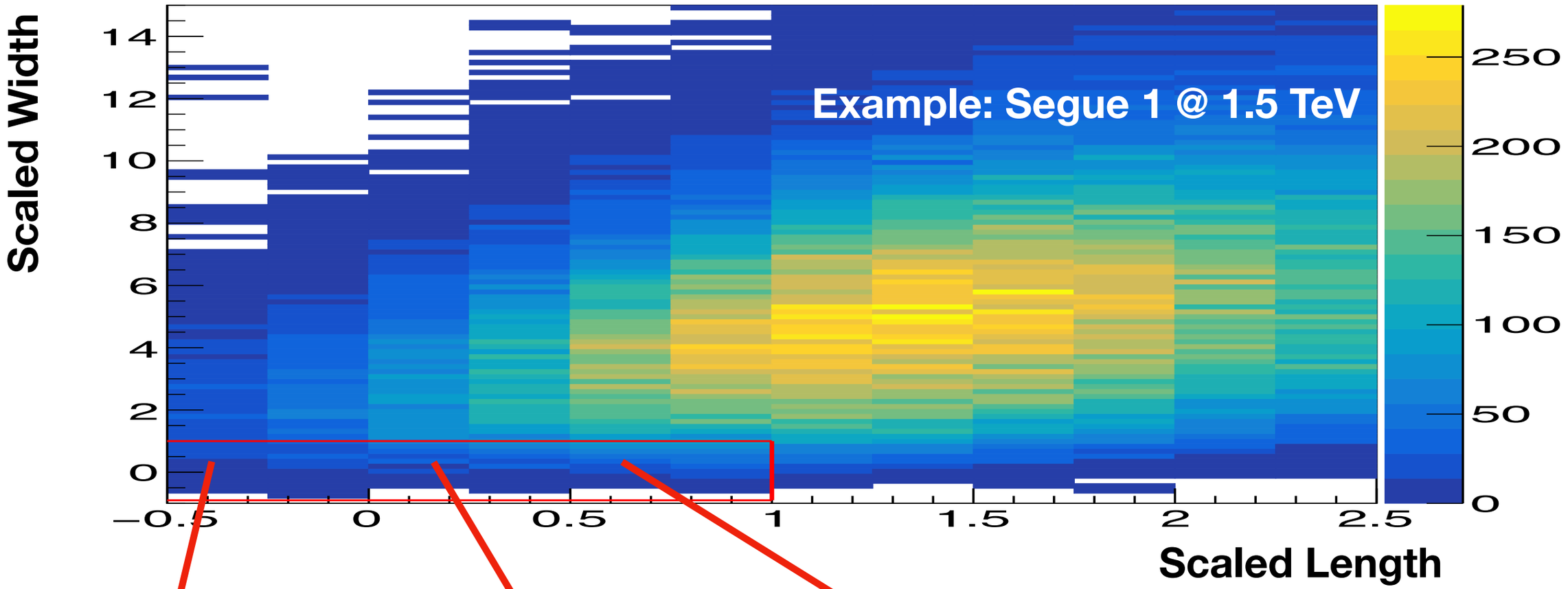

E >1585.0 GeV (62.4 hrs)
Excess (RDBM) = 9.5±135.9
Bkg (RDBM) = 8527.5±99.7
S/B = 0.00 ±0.016
Segue1V6
Bkg
MSCW

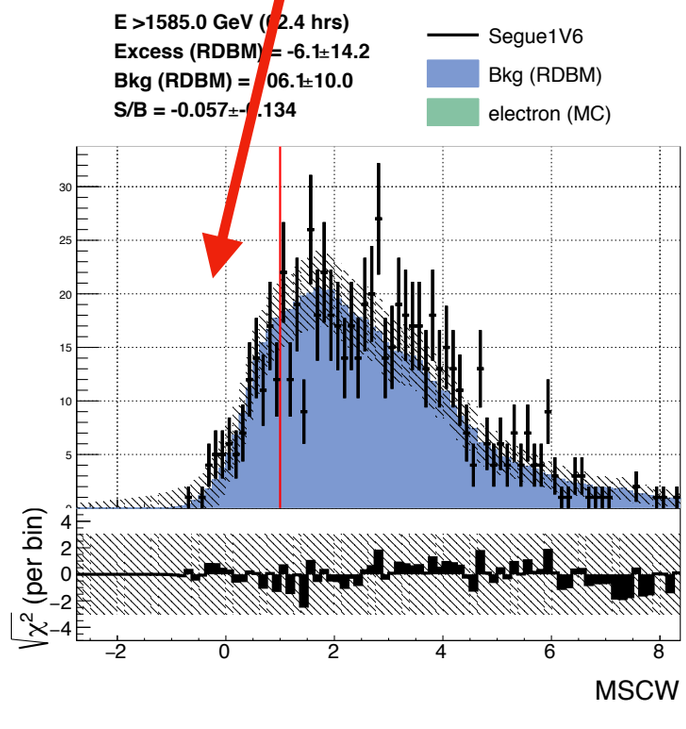

Scaled Width
Scaled Length
Determine H in W>1 region
Blinded

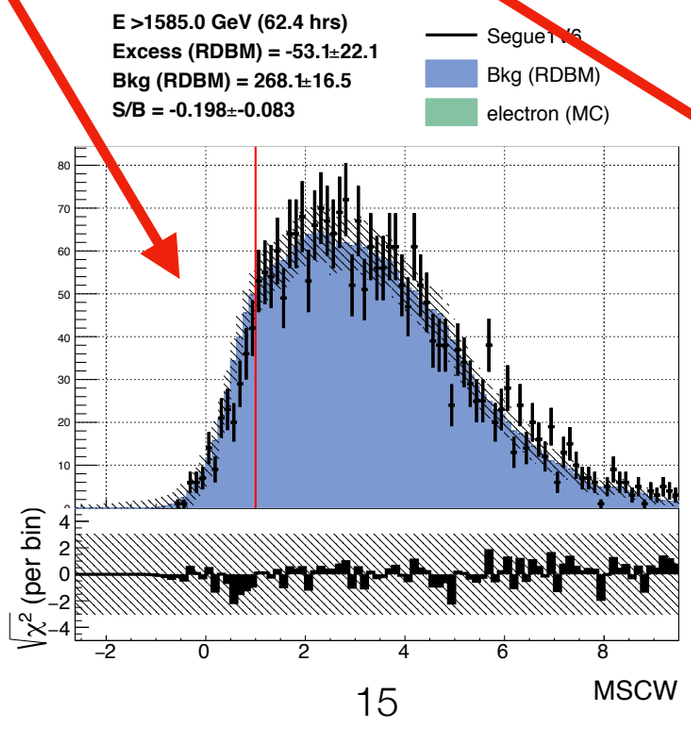

E >1585.0 GeV (62.4 hrs)
Excess (RDBM) = -6.1±14.2
Bkg (RDBM) = 106.1±10.0
S/B = -0.057±-0.134
Segue1V6
Bkg (RDBM)
electron (MC)
Blinded
MSCW

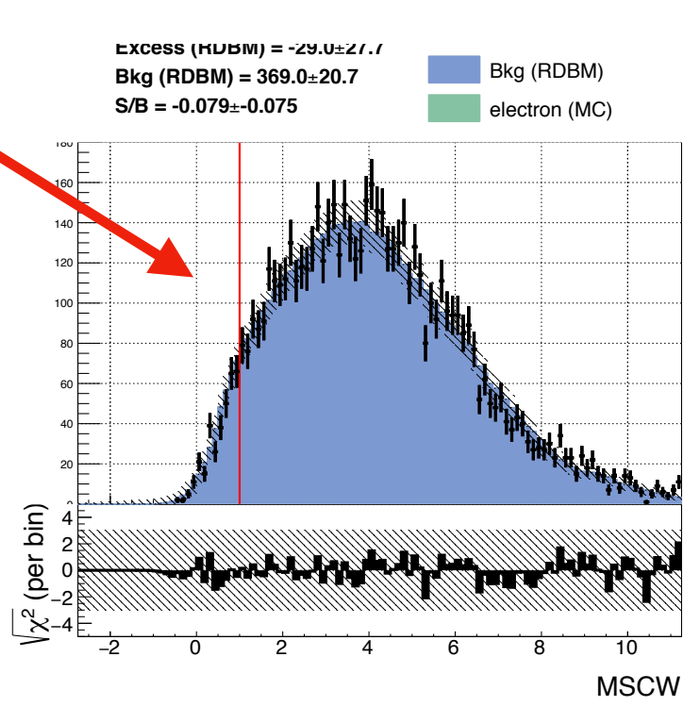

Segue1V6
Bkg (RDBM)
electron (MC)
Blinded
MSCW


Bkg (RDBM) = 369.0±20.7
Bkg (RDBM)
electron (MC)
Blinded
MSCW

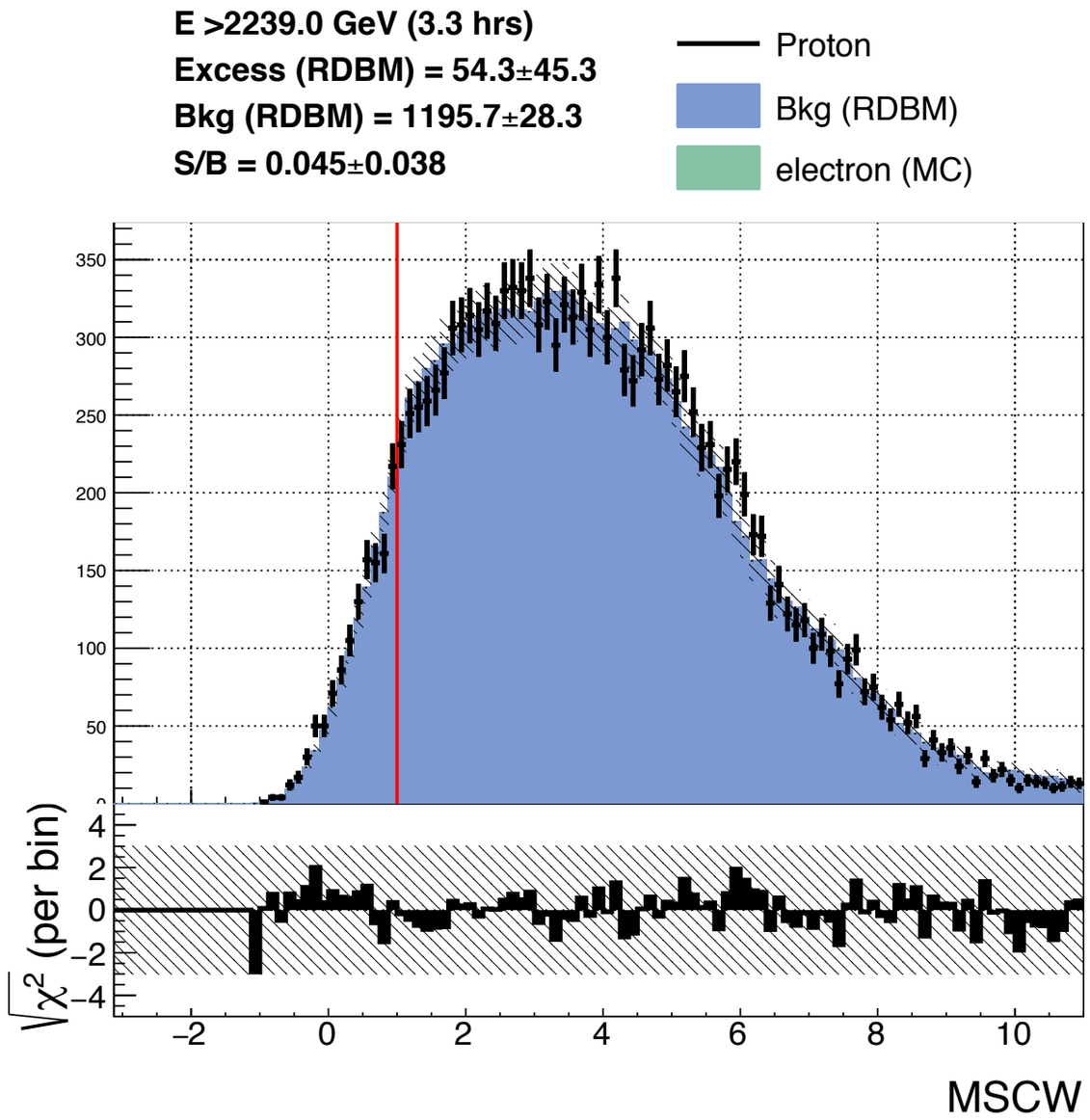

Example: Segue 1 @ 1.5 TeV
Scaled Width
Scaled Length


E >1585.0 GeV (62.4 hrs)
Excess (RDBM) = -6.1±14.2
Bkg (RDBM) = 206.1±10.0
S/B = -0.057±0.134
Segue1V6
Bkg (RDBM)
electron (MC)
MSCW

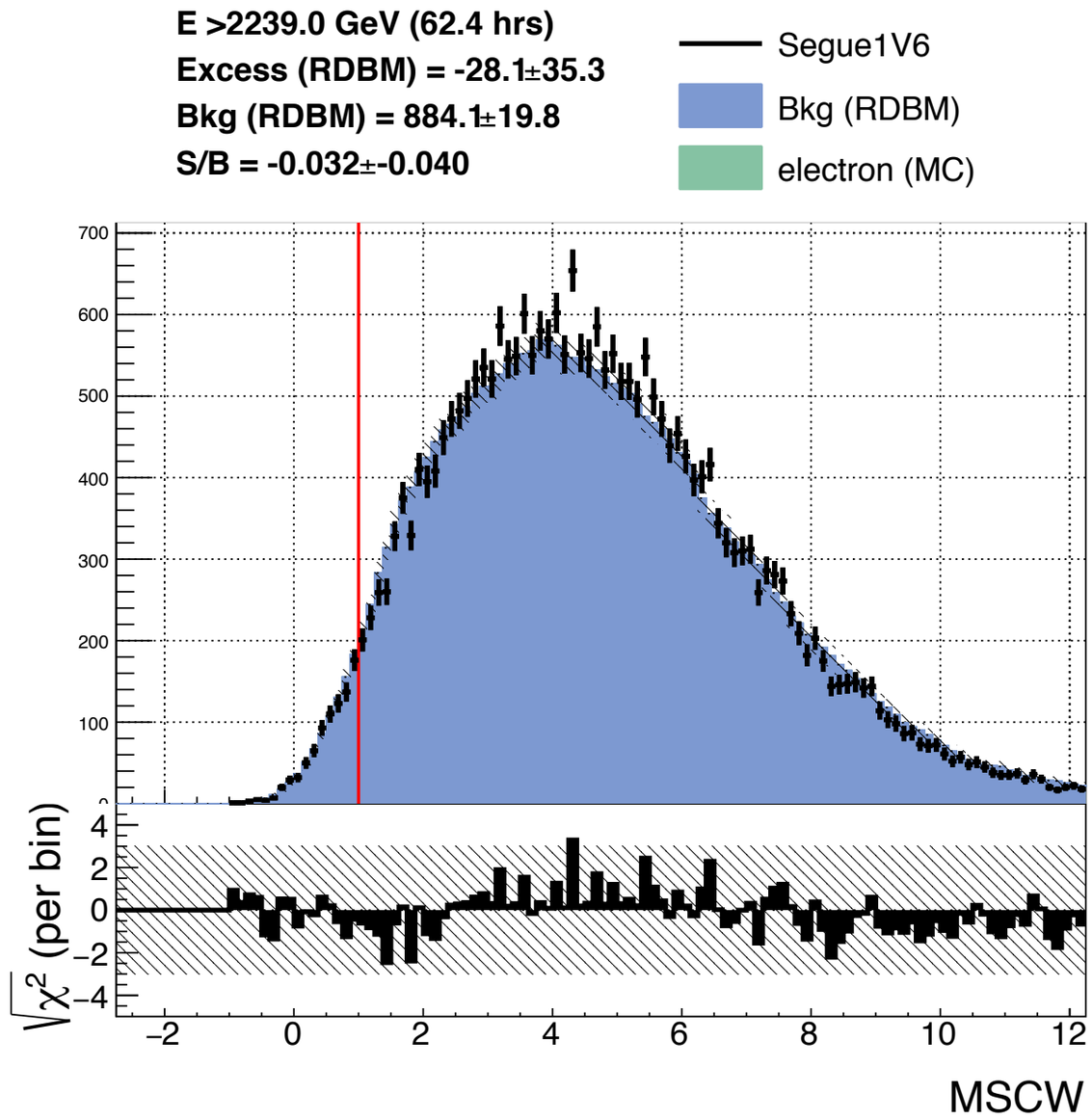

E >1585.0 GeV (62.4 hrs)
Excess (RDBM) = -53.1±22.1
Bkg (RDBM) = 268.1±16.5
S/B = -0.198±-0.083
Segue1V6
Bkg (RDBM)
electron (MC)
MSCW


Bkg (RDBM) = 369.0±20.7
S/B = -0.079±-0.075
Bkg (RDBM)
electron (MC)
MSCW

Examples of Closure Tests



Proton MC



Data from Segue 1

Conclusion

- Recurrent Deconvolution Background Method has a wide range of applications (**large clusters, Galactic halo**) for current and future gamma-ray telescope arrays.

- It utilizes the correlation between **longitudinal** and **lateral** shower developments and the idea of **Recurrent Neural Network**.

- It's **NOT a real neural network**. We impose strong constraints on the "neuron", parameter space of the model is largely limited. But it also allows us to interpret the **parameters with physical meanings**.

Backup

Example of validations on 8 point sources (ON region excluded)