

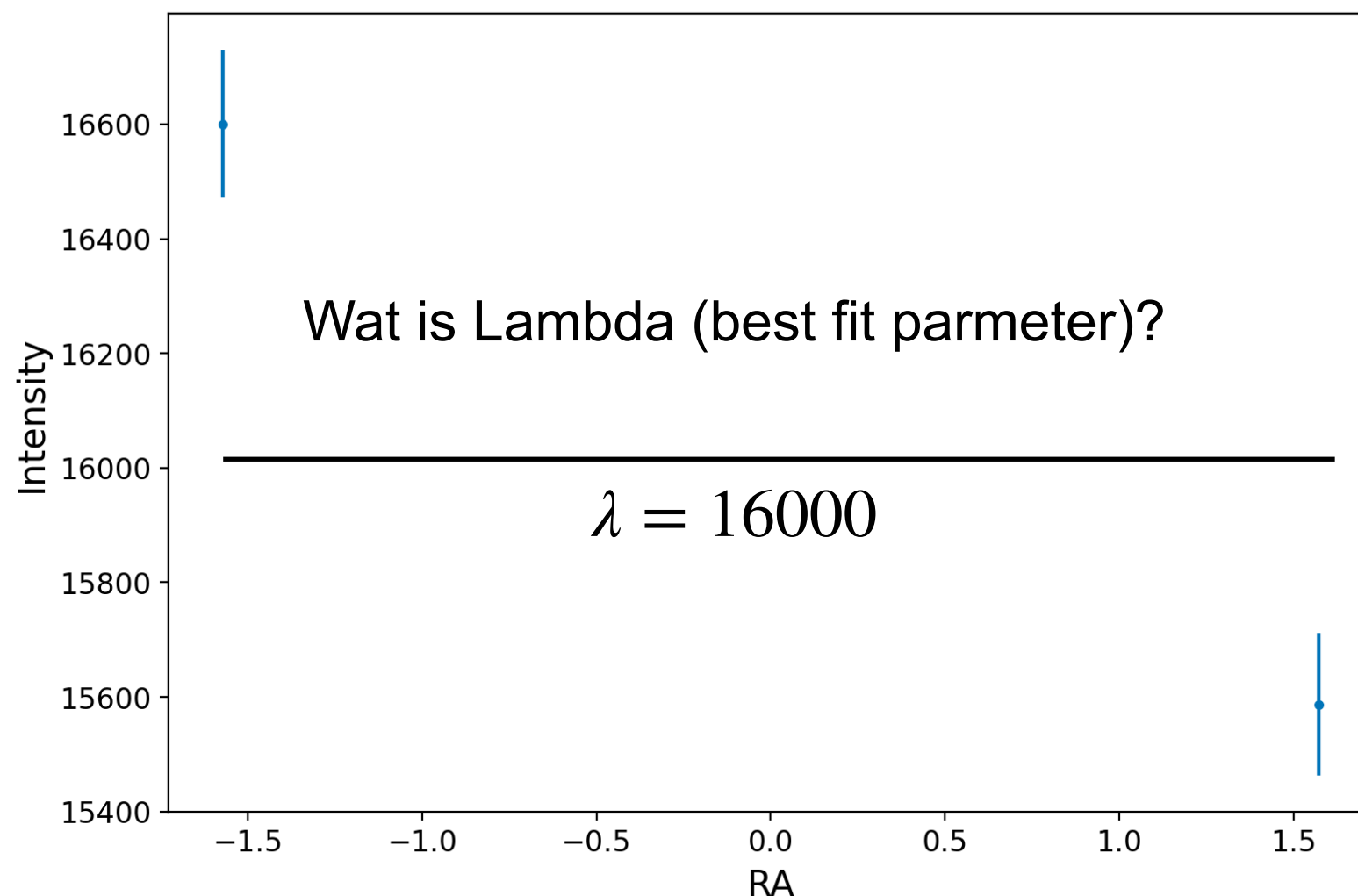


Lecture 6: Confidence

Recap

Likelihood fitting

- Given a probability distribution with a free parameter
- We wanted to fit that free parameter



Likelihood fitting

$$\mathcal{L}(x|\lambda) = \prod_{i=1}^N p(x_i|\lambda)$$

$$\mathcal{L}(x|\lambda) = \prod_{i=1}^N \frac{\lambda^{x_i}}{x_i!} e^{-\lambda}$$

Numerically

$$-\log(\mathcal{L}(x|\lambda)) = \sum_{i=1}^N x_i \log(\lambda) - \log(x_i!) - \lambda$$

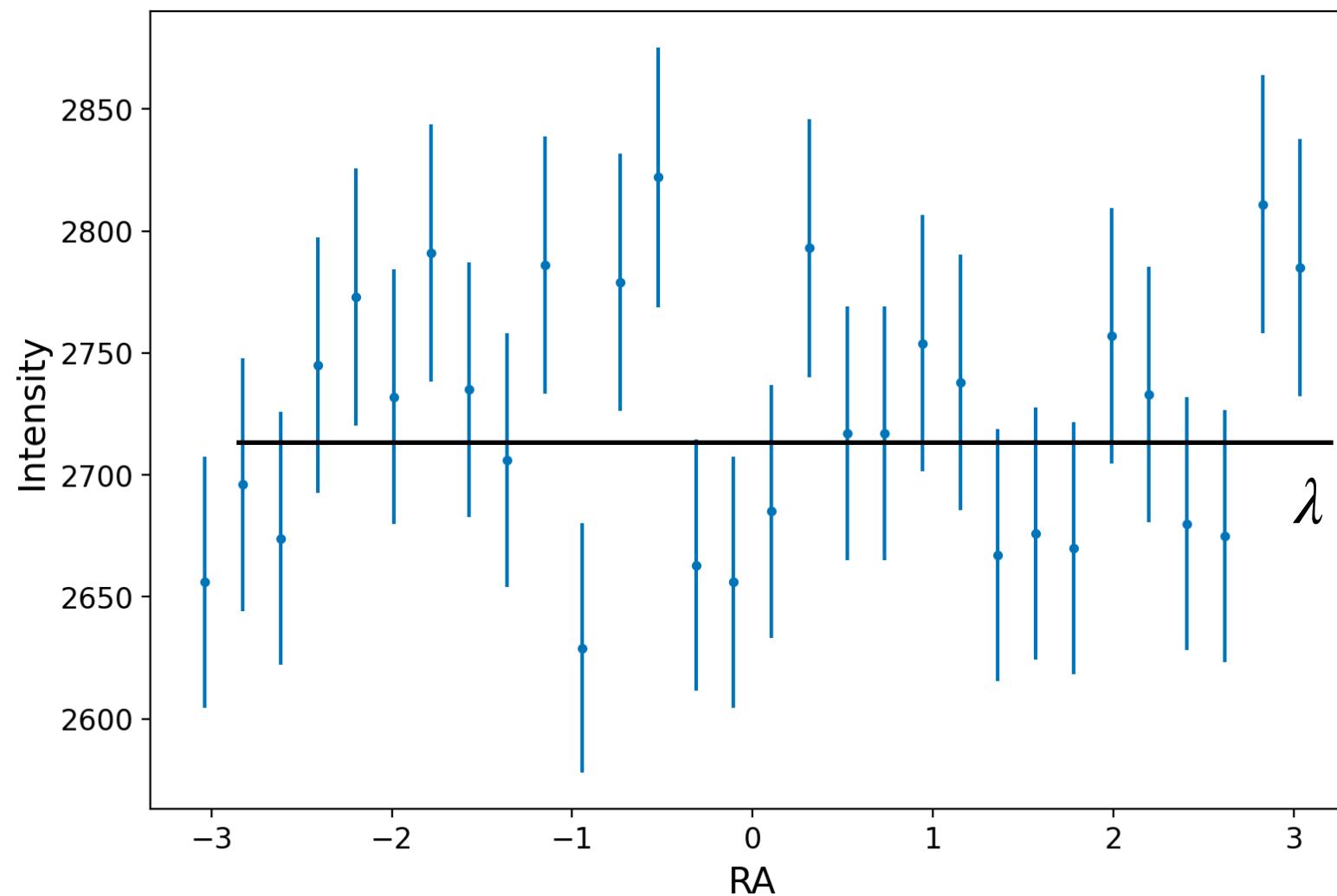
$$-\log(\mathcal{L}(x|\lambda)) = \sum_{i=1}^N -\frac{1}{2} \log(2\pi\lambda) + \frac{(x_i - \lambda)^2}{2\lambda}$$

$$\frac{d}{d\lambda} \log(\mathcal{L}(x|\lambda)) = 0 = \sum_{i=1}^N \frac{x_i}{\lambda} - 1$$

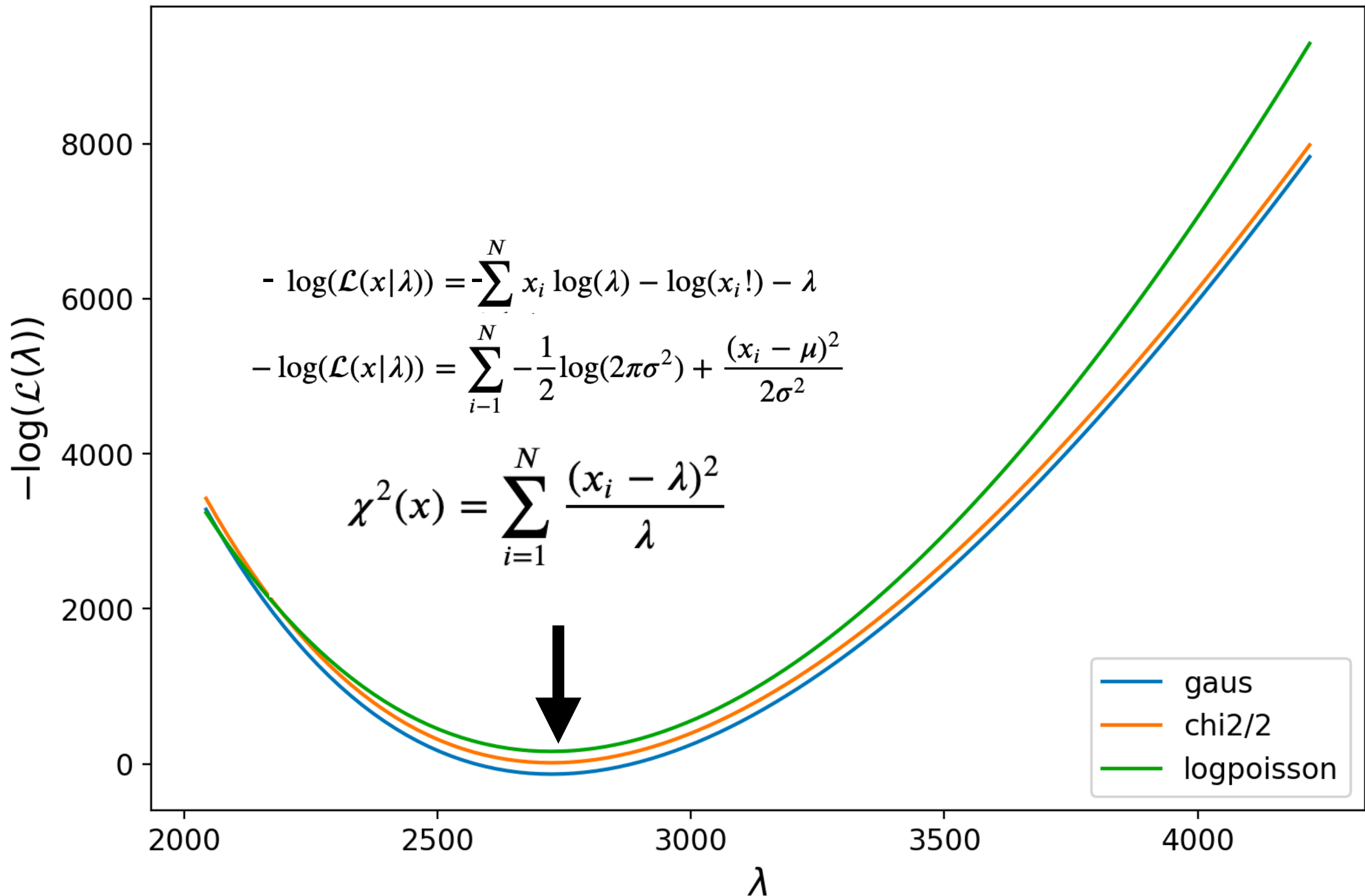
$$N\lambda = \sum_{i=1}^N x_i$$

$$\lambda = \bar{x}$$

Analytically



Likelihood fitting



χ^2 distribution

- χ^2 distribution is the sum of N independent variables X_i
 - Where the distributions X_i are distributed as normal
 - N denotes the number of degrees of freedom

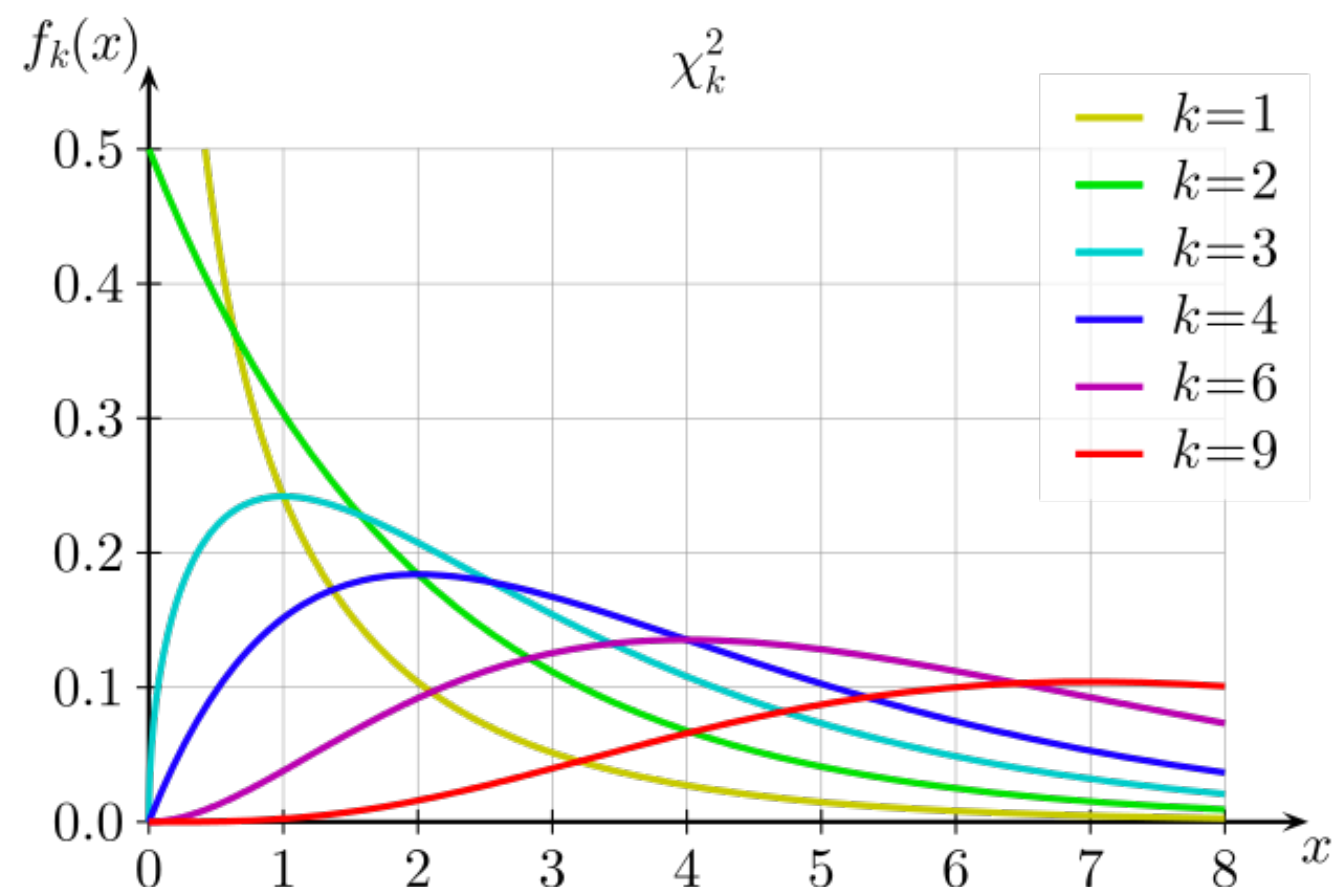
$$\chi^2(x, n) = \sum_{i=1}^N \frac{(x - \mu)^2}{\sigma^2}$$

$$E[\chi^2(x)] \approx N$$

$$E[\chi^2(x)/N] \approx 1$$

$$\text{Var}(\chi^2(x)) = 2N$$

$$\Delta\chi^2(x) = |\chi^2(x) - \chi^2(x \pm \sqrt{2N})|$$



Understanding

Important Properties

- Taylor expand in our floated parameter (μ in this case)

$$\chi^2(x, n) = \sum_{i=1}^N \frac{(x_i - \mu)^2}{\sigma_i^2} = \underbrace{\sum_{i=2}^N \frac{(x_i - \mu)^2}{\sigma_i^2}}_{\text{red box}} + \underbrace{\frac{(x_1 - \mu)^2}{\sigma_1^2}}_{\text{blue box}}$$

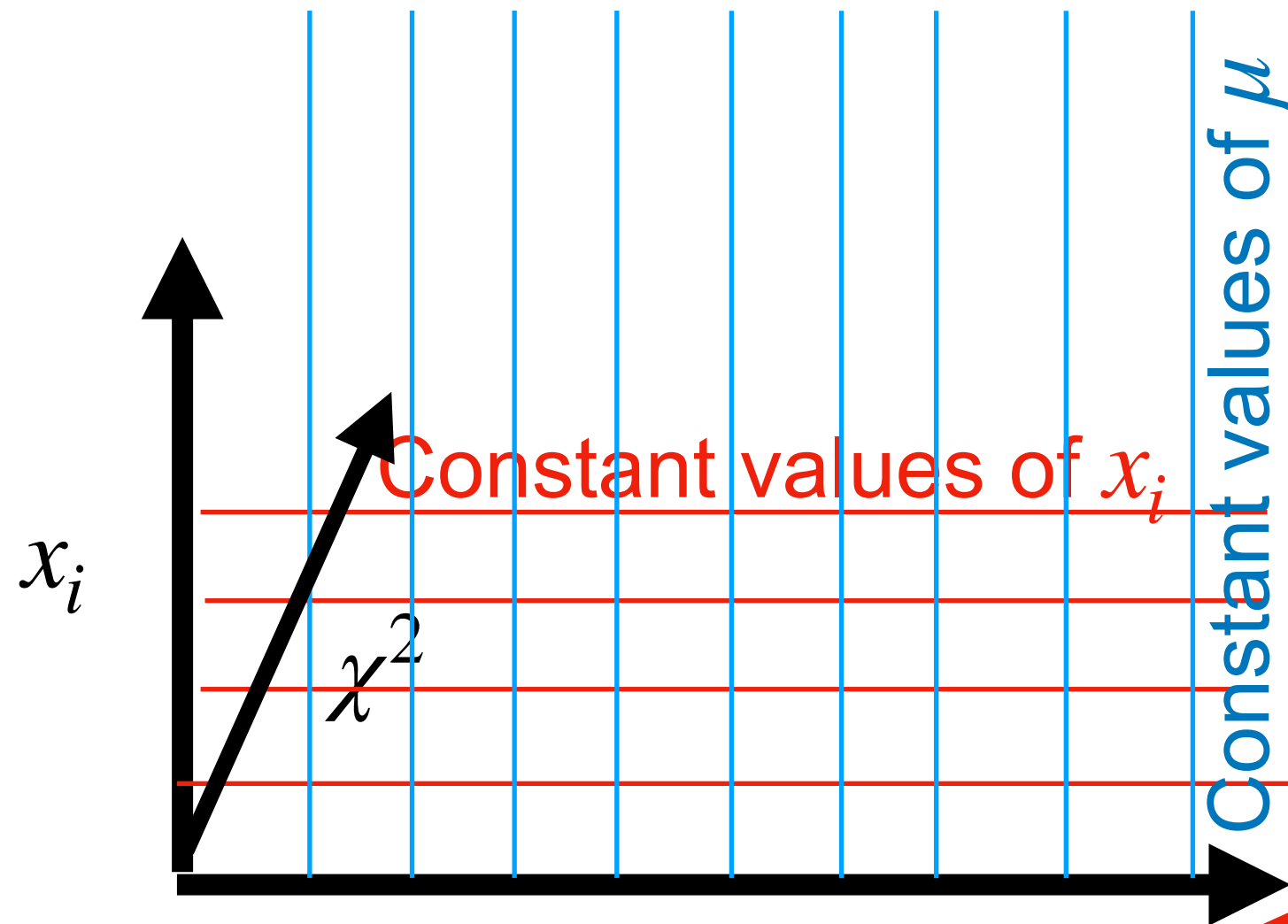
Consider this as a fixed constant



Motion of this point by 1 standard deviation in σ_1 causes $\Delta\chi^2 = 1$ from minimum

Can view the distribution of just x_1 as just a χ^2 of 1 DOF

Visualization



$$\chi^2(x, n) = \sum_{i=1}^N \frac{(x_i - \mu)^2}{\sigma_i^2}$$

A function of x_i and μ

Visualization

$$\chi^2(x, n) = \sum_{i=1}^N \frac{(x_i - \mu)^2}{\sigma_i^2} + C_x$$

Chi-2 of N-degrees of freedom

$$\chi^2(x, 1) = \frac{(\mu - \mu_0)^2}{\sigma_\mu^2} + C_{mu}$$

Chi-2 of 1-degree of freedom

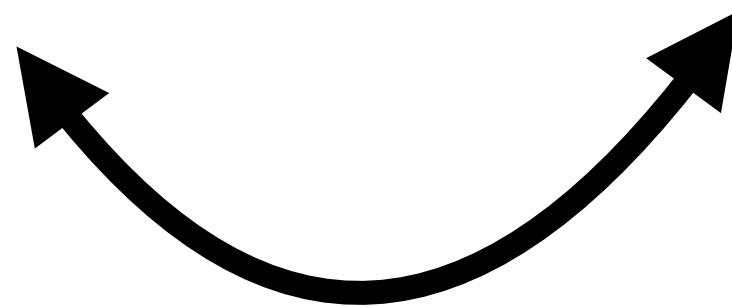
Visualization

$$\chi^2(x, n) = \sum_{i=1}^N \frac{(x_i - \mu)^2}{\sigma_i^2} + C_x$$

Chi-2 of N-degrees of freedom

$$\chi^2(x, 1) = \frac{(\mu - \mu_0)^2}{\sigma_\mu^2} + C_{mu}$$

Chi-2 of 1-degree of freedom



These are the same formula

$$\chi^2(x_i, \mu) = \chi_{min}^2(x_i, \mu_0) + \frac{1}{2} \frac{\partial^2}{\partial \mu^2} \chi_{min}^2(x_i, \mu_0) (\mu - \mu_0)^2$$

Important Properties

- Taylor expand in our floated parameter (μ in this case)

$$\chi^2(x, n) = \sum_{i=1}^N \frac{(x - \mu)^2}{\sigma^2}$$

$$\chi^2(x_i, \mu) = \underbrace{\chi_{min}^2(x_i, \mu_0)}_{\text{Frozen}} + \underbrace{\frac{1}{2} \frac{\partial^2}{\partial \mu^2} \chi_{min}^2(x_i, \mu_0)}_{\text{Varying}} (\mu - \mu_0)^2$$

$$\Delta \chi^2(x, n) = 1 \rightarrow (\mu \rightarrow \mu \pm \sigma)$$

$$1 = \frac{1}{2} \frac{d}{d\mu^2} \chi^2(\mu_0) \sigma^2$$

Important Properties

- Taylor expand in our floated parameter (μ in this case)

$$\chi^2(x, n) = \sum_{i=1}^N \frac{(x - \mu)^2}{\sigma^2}$$

$$\chi^2(x_i, \mu) = \chi_{min}^2(x_i, \mu_0) + \frac{1}{2} \frac{\partial^2}{\partial \mu^2} \chi_{min}^2(x_i, \mu_0) (\mu - \mu_0)^2$$

Frozen

Varying

$$\Delta\chi^2(x, n) = 1 \rightarrow (\mu \rightarrow \mu \pm \sigma) \quad \textbf{Wilk's Theorem}$$

$$1 = \frac{1}{2} \frac{d}{d\mu^2} \chi^2(\mu_0) \sigma^2 \rightarrow$$

$$\sigma^2 = \frac{2}{\frac{d}{d\mu^2} \chi^2(\mu_0)}$$

An Example

Recall that if we vary take the average over N

Our uncertainty on the mean goes as

$$\sigma_{\mu} = \sigma \sqrt{\frac{1}{N}}$$

An Example

$$\Delta\chi^2 = 1 = \sum_{i=1}^N \frac{(x - \mu_0 + \sigma_\mu)^2}{\sigma^2} - \sum_{i=1}^N \frac{(x - \mu_0)^2}{\sigma^2}$$

$$1 \approx \sum_{i=1}^N \frac{(x - \mu_0 + \sigma_\mu)^2}{\sigma^2} - \sum_{i=1}^N \frac{(x - \mu_0)^2}{\sigma^2}$$

$$1 = \frac{1}{\sigma^2} \sum_{i=1}^N (x - \mu_0 + \sigma_\mu)^2 - (x - \mu_0)^2$$

$$1 = \frac{1}{\sigma^2} \sum_{i=1}^N \sigma_\mu^2 + 2\sigma_\mu(x - \mu_0)$$

$$1 = \frac{N\sigma_\mu^2}{\sigma^2}$$

$$\sigma_\mu^2 = \frac{\sigma^2}{N}$$



For a poisson distribution we recover the variance per bin

Important Properties

- Taylor expand in our floated parameter (μ in this case)

$$\chi^2(x_i, \mu) = \chi_{min}^2(x_i, \mu_0) + \frac{1}{2} \frac{\partial^2}{\partial \mu^2} \chi_{min}^2(x_i, \mu_0) (\mu - \mu_0)^2$$

χ^2 distribution of 1 degree of freedom
 $V[\chi^2(x)] = 1$

$$\Delta \chi^2 = 2 \Delta \log L = 1$$

For one degree of freedom

Important Properties

- Taylor expand in our floated parameter (μ in this case)

$$\chi^2(x_i, \mu) = \chi_{min}^2(x_i, \mu_0) + \frac{1}{2} \frac{\partial^2}{\partial \mu^2} \chi_{min}^2(x_i, \mu_0) (\mu - \mu_0)^2$$

$$\frac{1}{2} \frac{d^2 \chi^2}{d\mu^2} \rightarrow \frac{1}{\sigma^2}$$

$$\frac{\partial^2 \chi^2}{\partial \theta^2} = \frac{2}{\sigma_\theta^2}$$

For any floated parameter
uncertainty of that parameter is
given by the 2nd derivative of χ^2

This is known as Wilk's Theorem

$$\sigma_\theta^2 = \left(\frac{\partial^2 \log L}{\partial \theta^2} \right)^{-1}$$

Important Properties

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$$\chi^2(x_i, \mu) = \chi_{min}^2(x_i, \mu_0) + \frac{1}{2} \frac{\partial^2}{\partial \mu^2} \chi_{min}^2(x_i, \mu_0) (\mu - \mu_0)^2$$

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Multiple Dimensions

- For N variables the expansion is the same

$$\chi^2(x_i, \vec{\theta}) = \chi_{min}^2(x_i, \vec{\theta}) + \frac{1}{2}(\theta_i - \theta_0)^T \left[\frac{\partial^2}{\partial \theta_i \partial \theta_j} \chi_{min}^2(x_i, \vec{\theta}_0) \right] (\theta_j - \theta_0)$$

χ^2 distribution of 1 degree of freedom
 $V[\chi^2(x)] = 1$

Hessian of
 the χ^2 distribution

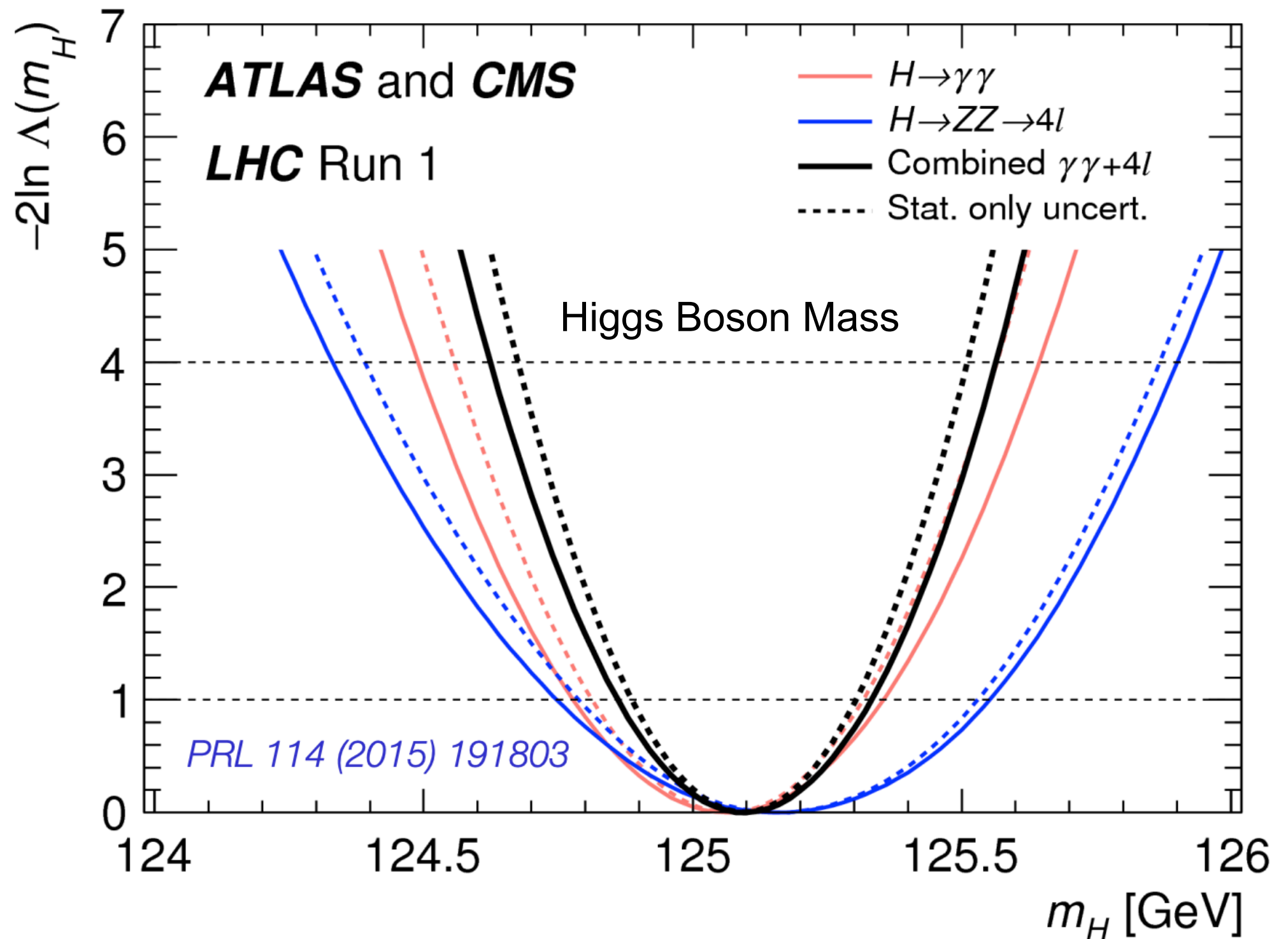
$$\Delta \chi^2 = 2 \Delta \log L = 1$$

For one degree of freedom

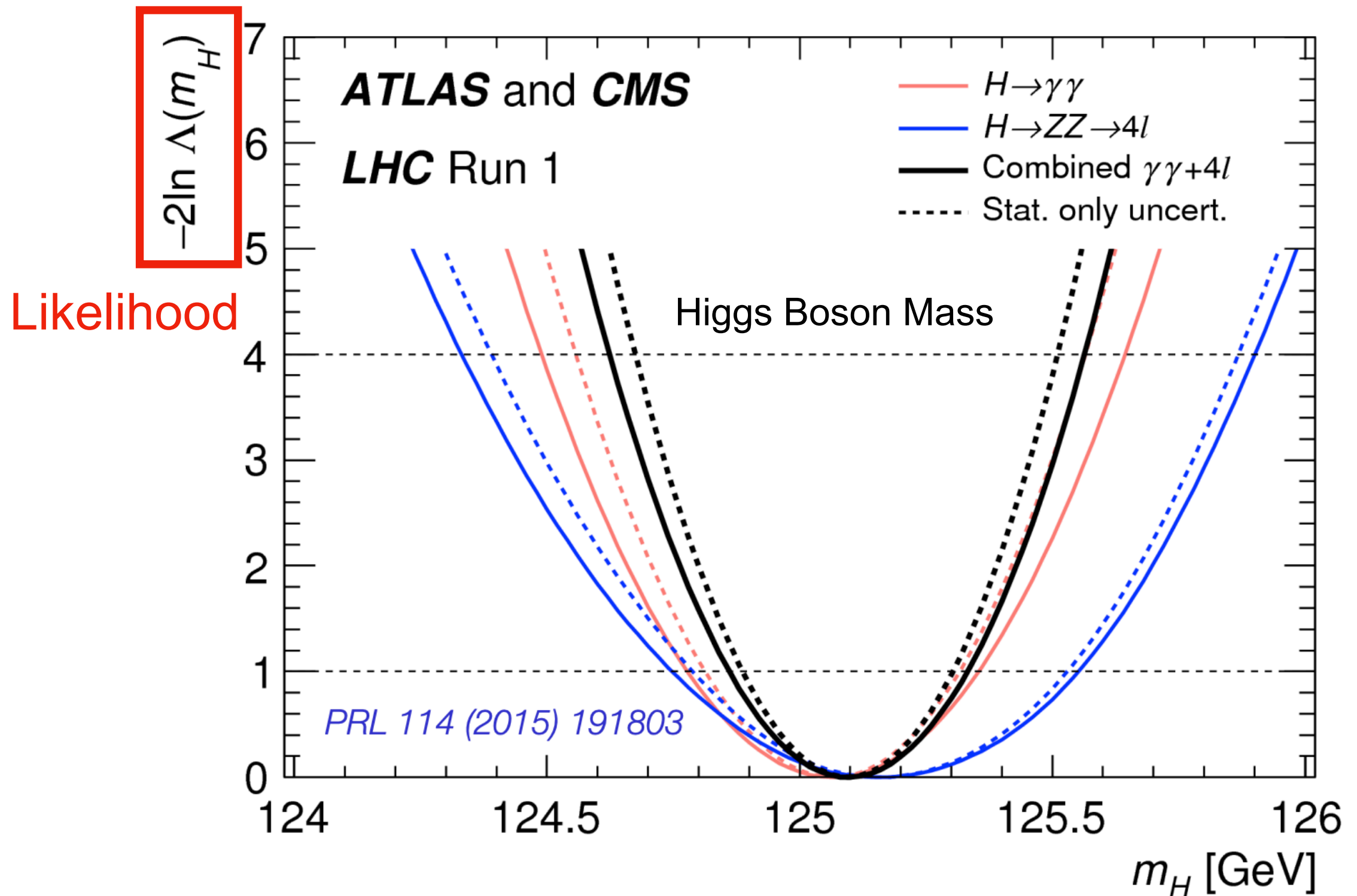
This is known as Wilk's Theorem

$$\sigma_{ij}^2 = \left(\frac{\partial^2 \log L}{\partial \theta_i \partial \theta_j} \right)^{-1}$$

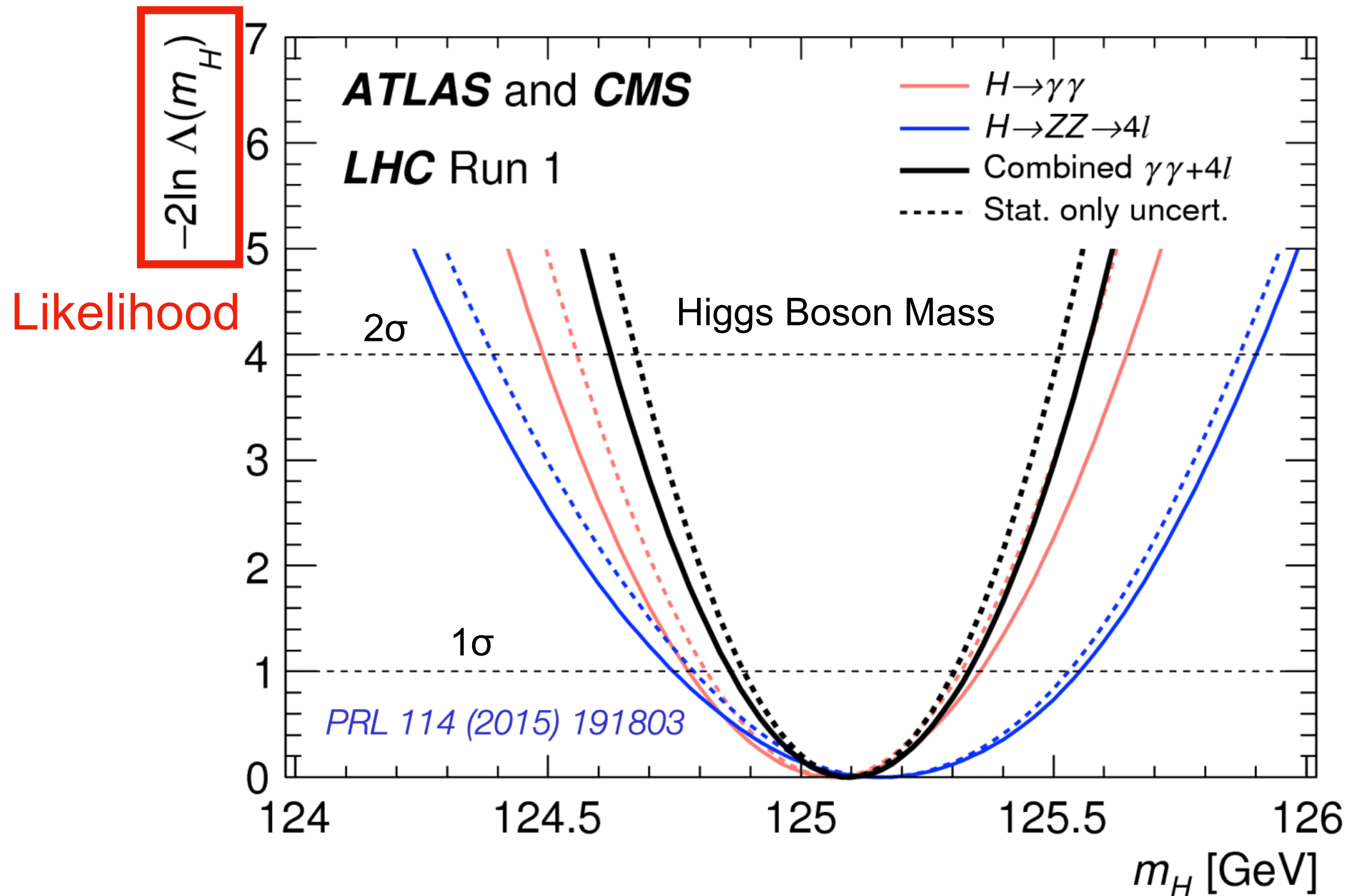
Making a Measurement



Making a Measurement



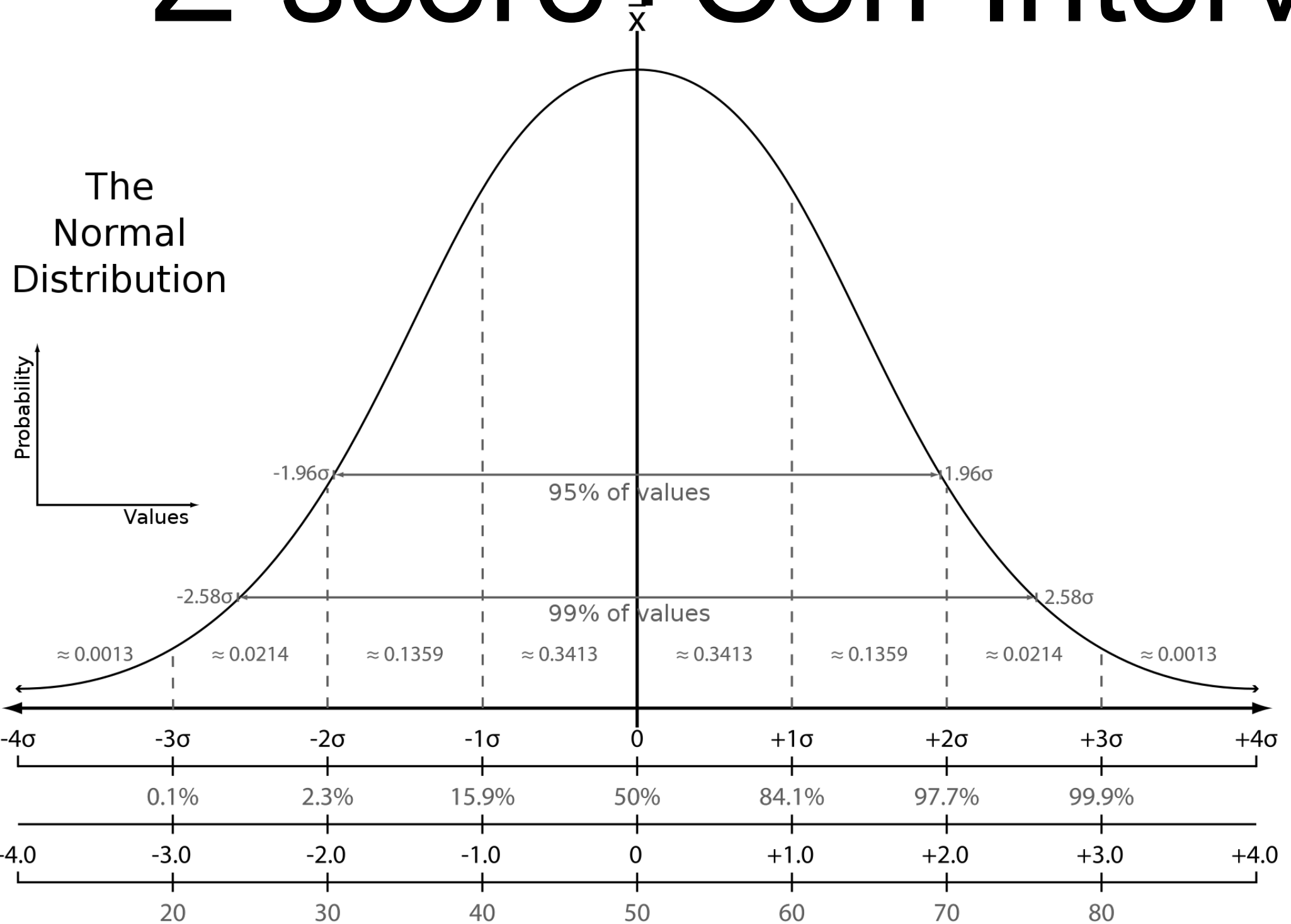
Making a Measurement

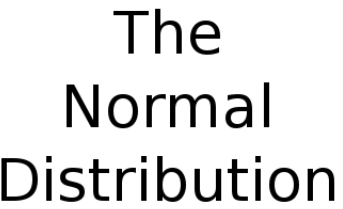




Confidence Intervals

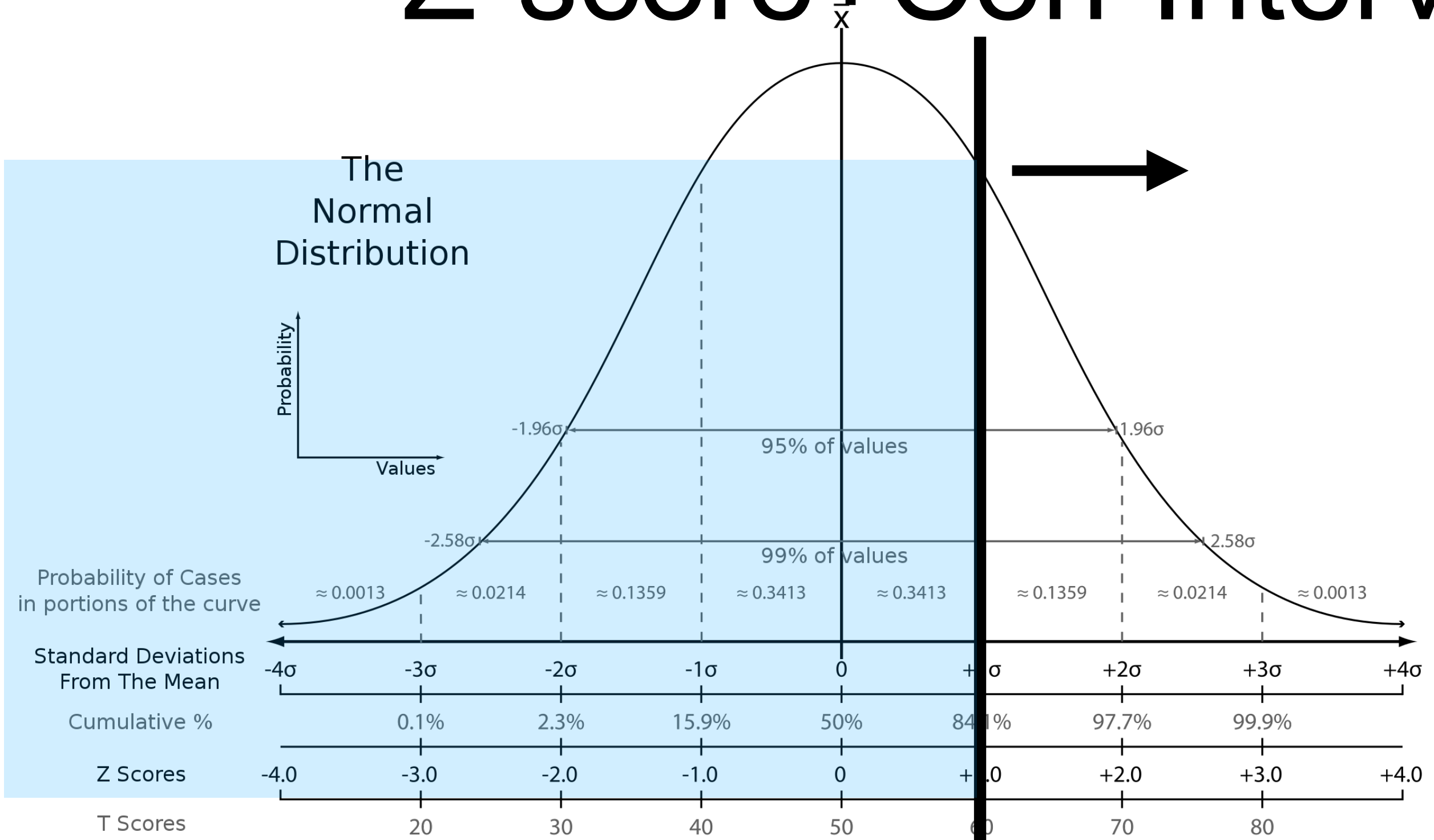
Z-score+Con-Interval



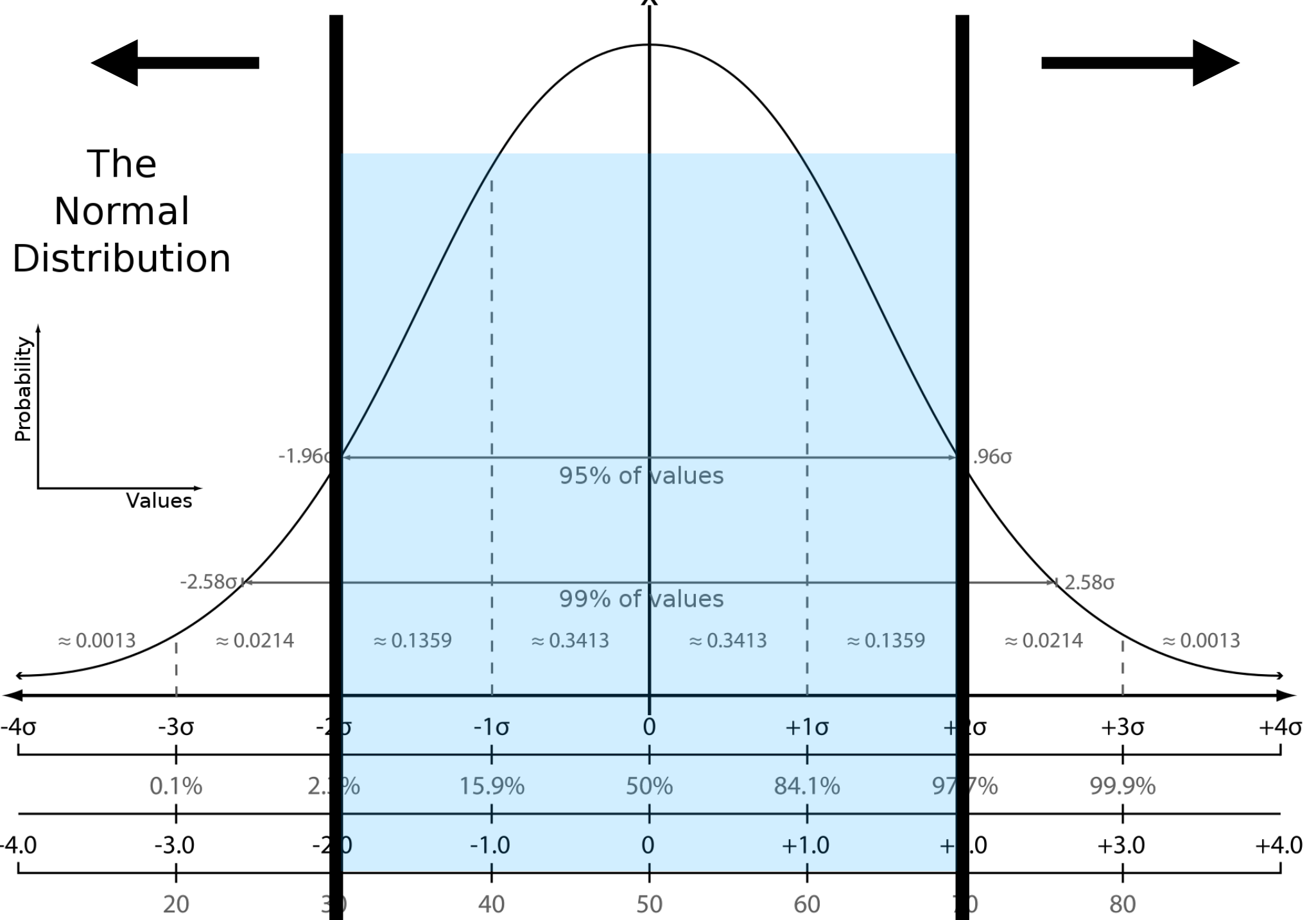


Z-score of 1: 68% chance of being within 1 standard deviation

Z-score+Con-Interval

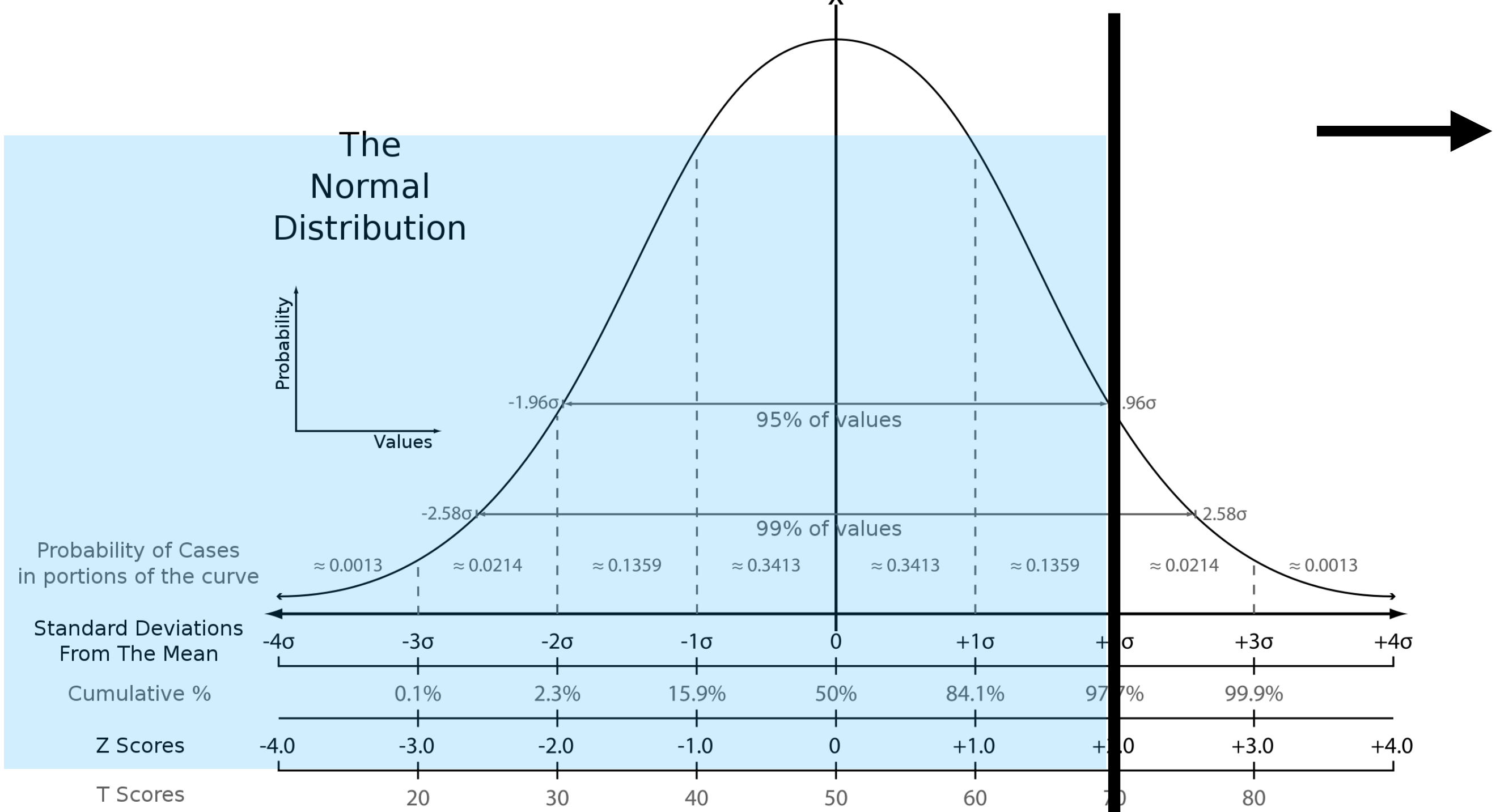


Z-score+Con-Interval



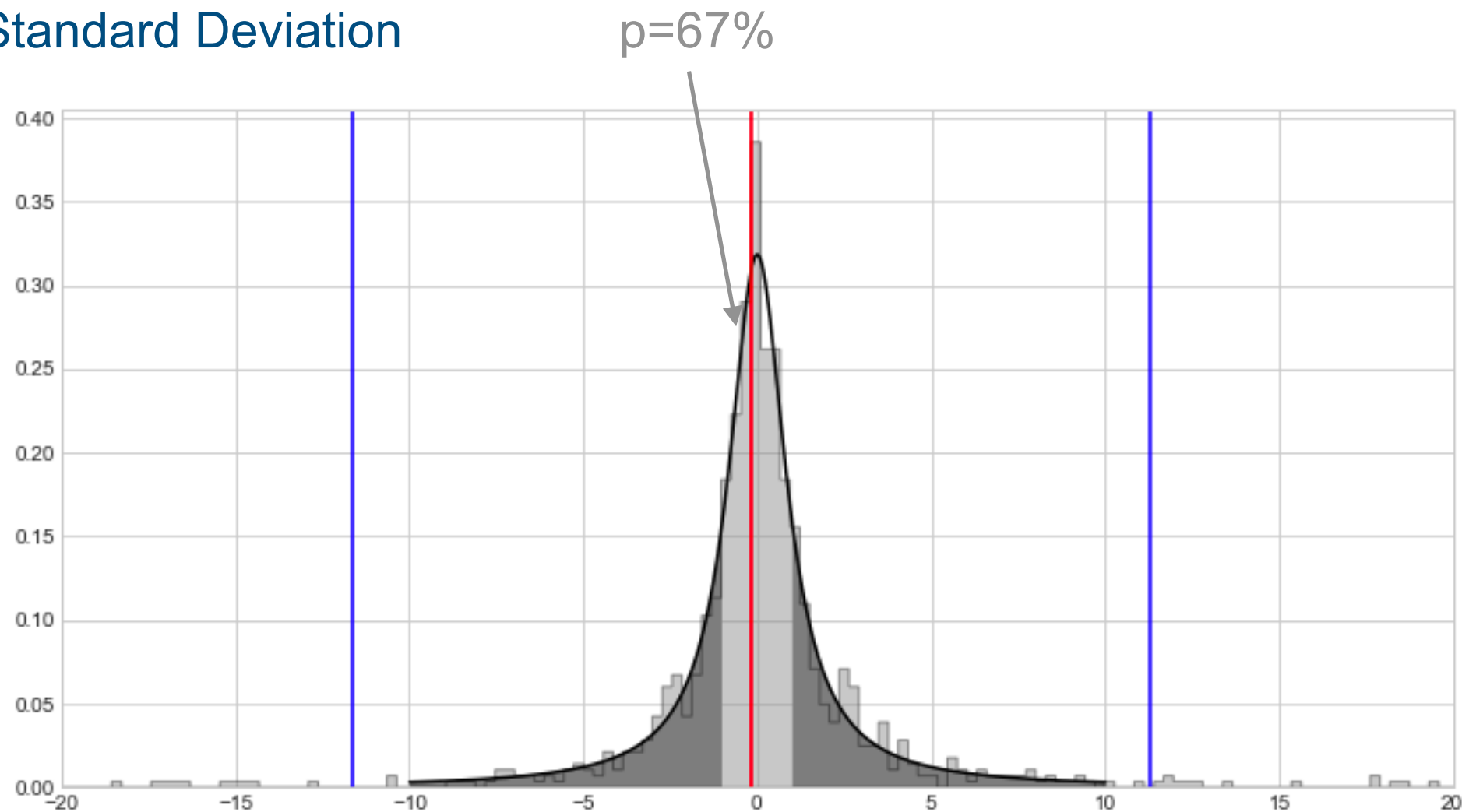
Z-score of 2: 95% chance of being within 2 standard deviation

Z-score+Con-Interval



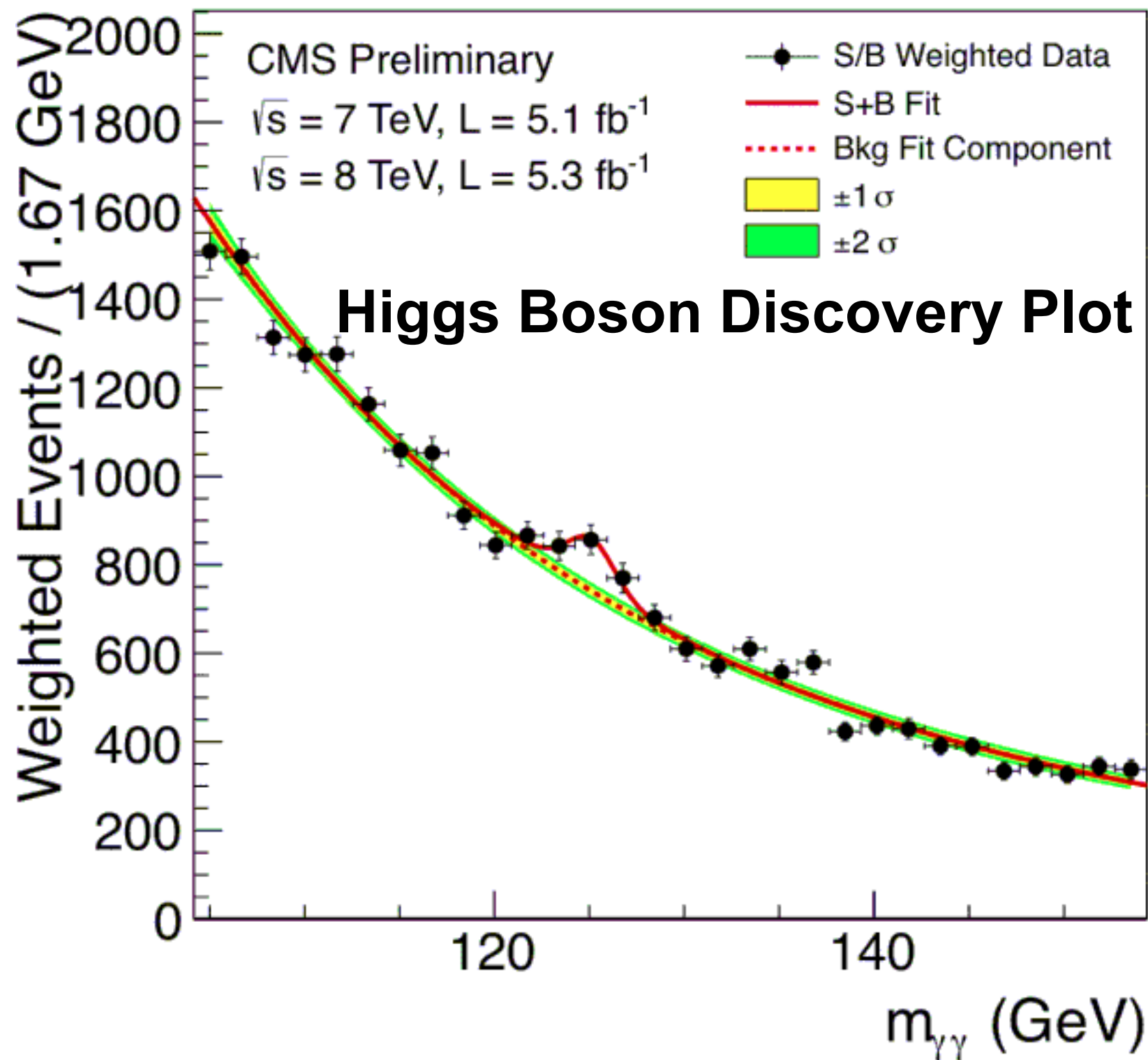
Z-score+Con-Interval

Standard Deviation



- Z score works on any system
- However standard deviation does not necessarily reflect the z-score

Confidence Plots



The rules of significance

- How significant is our measurement? (High Energy physics rules)
- 3 sigma is considered “Evidence”
- 5 sigma is considered “Discovery”

<https://understandinguncertainty.org/explaining-5-sigma-higgs-how-well-did-they-do>



The screenshot shows the homepage of the 'Understanding Uncertainty' website. The header features a yellow 'uu' logo and a navigation bar with links: Home, Blog, Articles, Videos, Animations, Guest Articles, Links, and About Us. The main content area displays a blog post titled 'Explaining 5-sigma for the Higgs: how well did they do?' by david, dated 08/07/2012. The post includes a warning that the content is for statistical pedants and begins with a recap of Higgs results. On the right side, there is a search bar, a dropdown menu for featured content, and a main menu link.

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Understanding Uncertainty

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Home » Blogs » david's blog

Explaining 5-sigma for the Higgs: how well did they do?

Submitted by david on Sun, 08/07/2012 - 1:17pm

Warning, this is for statistical pedants only.

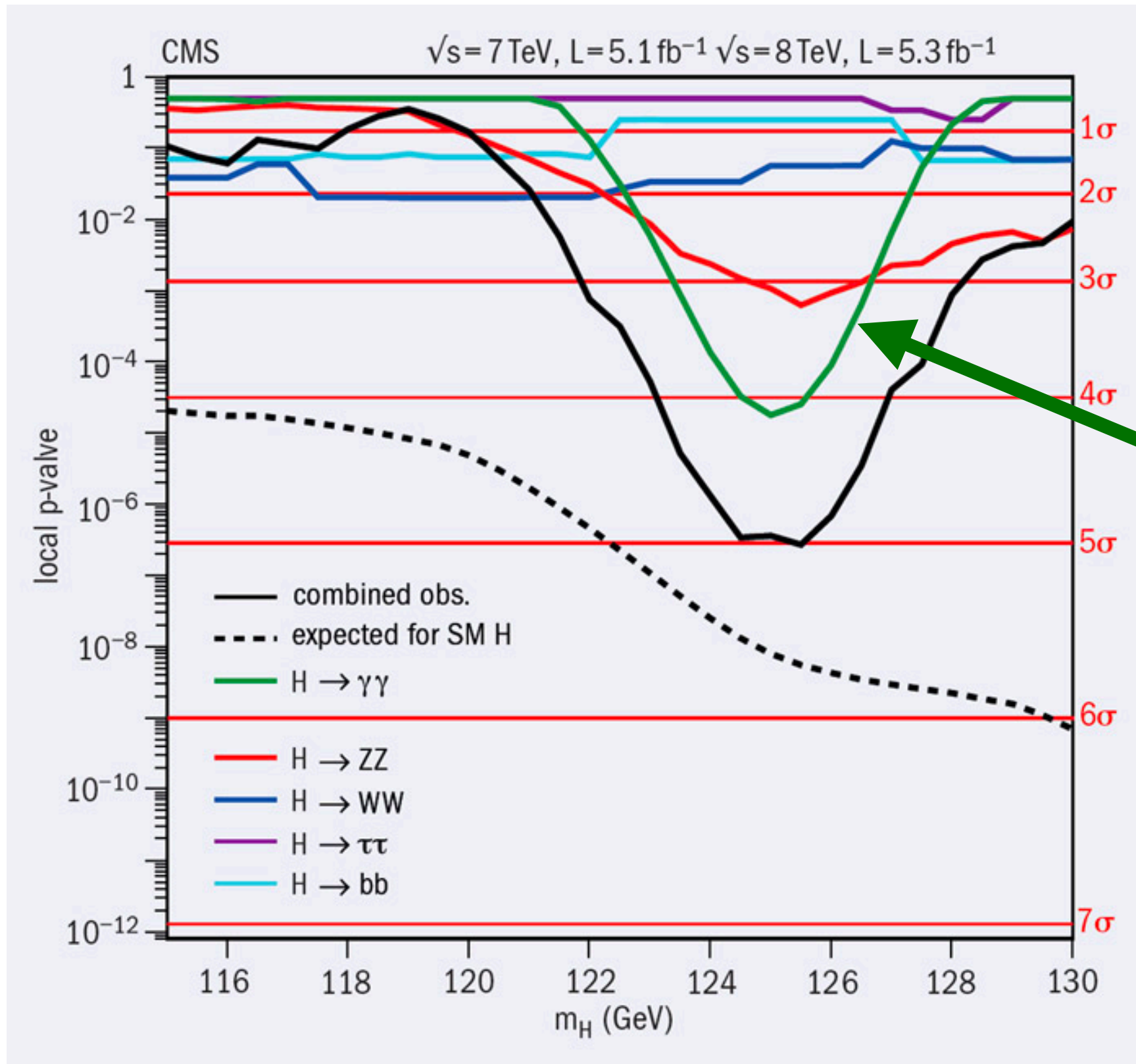
To recap, the results on the Higgs are communicated in terms of the numbers of

Search

- Featured Content -

Main menu

Confidence Plots

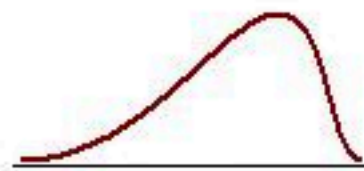


Moments

$$\mu_n = m^n(x) = E[x^n p(x)] = \int_{-\infty}^{\infty} x^n p(x) dx$$

Skewness

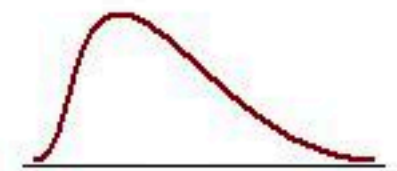
The coefficient of Skewness is a measure for the degree of symmetry in the variable distribution.



Negatively skewed distribution
or Skewed to the left
Skewness < 0



Normal distribution
Symmetrical
Skewness = 0

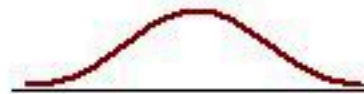


Positively skewed distribution
or Skewed to the right
Skewness > 0

- Moments are a way to characterize the function
- n=1 is mean
- n=2 is variance
- n=3 is Skew
- n=4 is kurtosis

Kurtosis

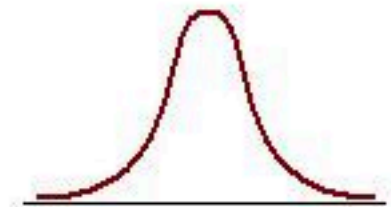
The coefficient of Kurtosis is a measure for the degree of peakedness/flatness in the variable distribution.



Platykurtic distribution
Low degree of peakedness
Kurtosis < 0

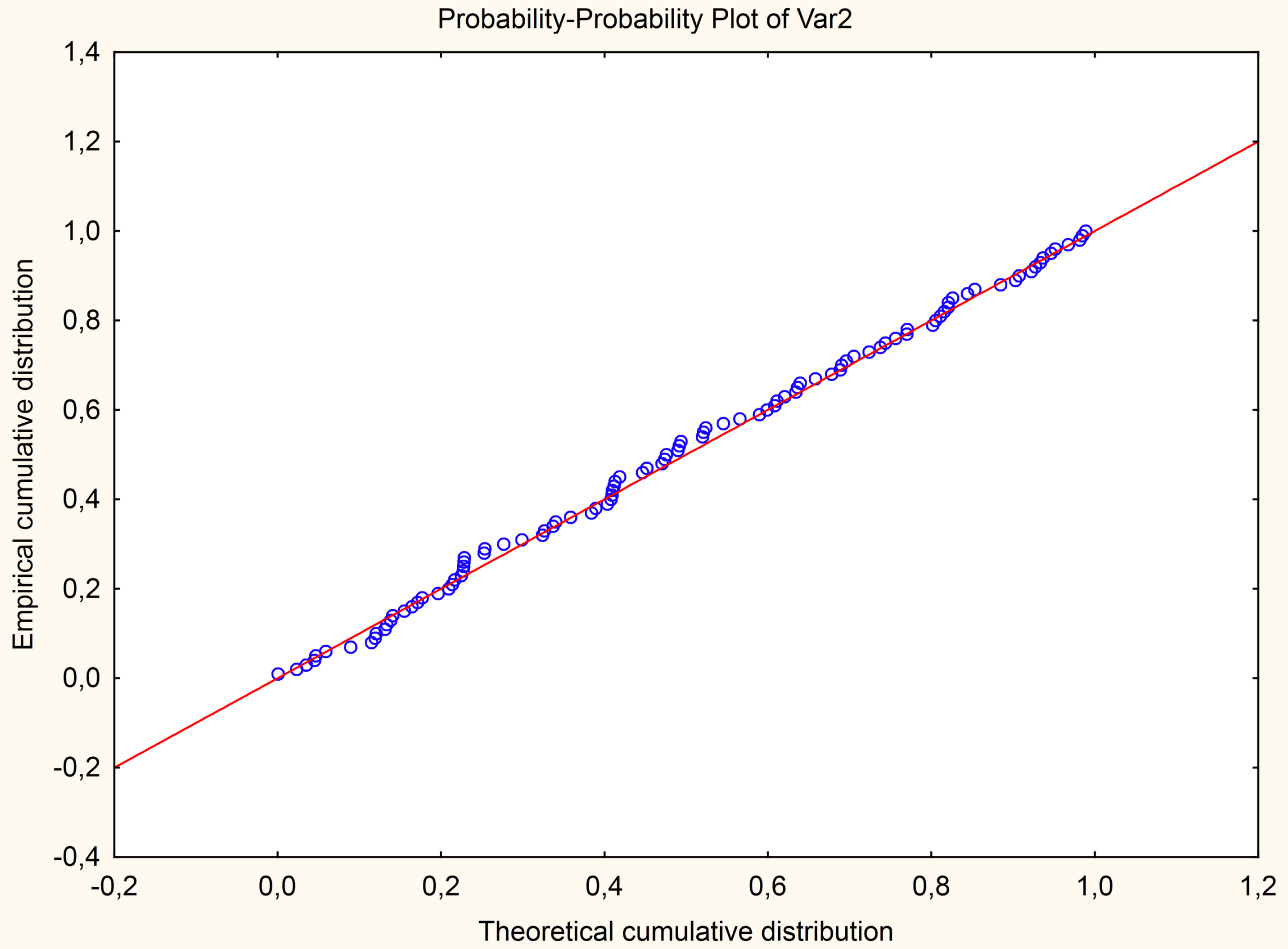


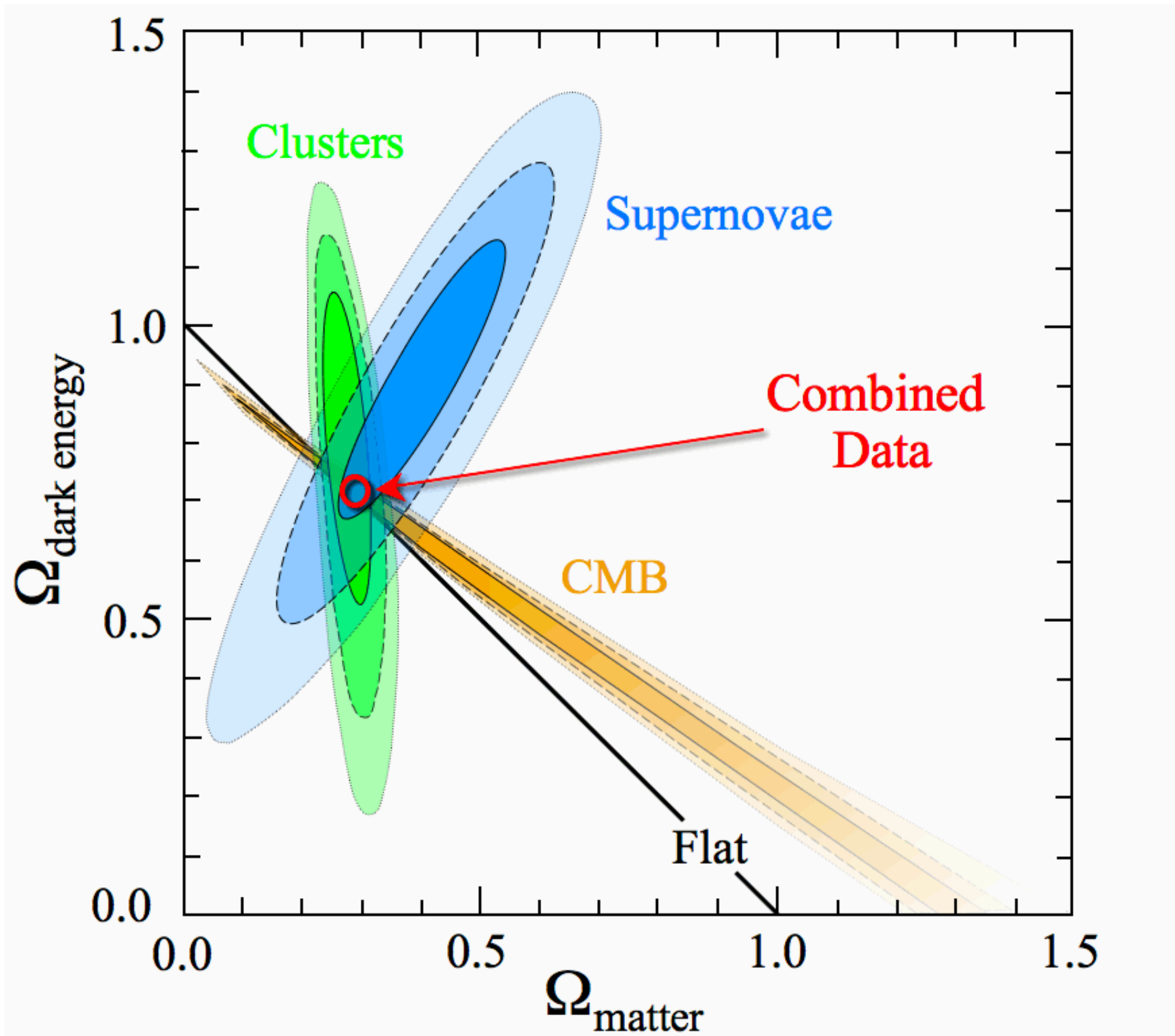
Normal distribution
Mesokurtic distribution
Kurtosis = 0



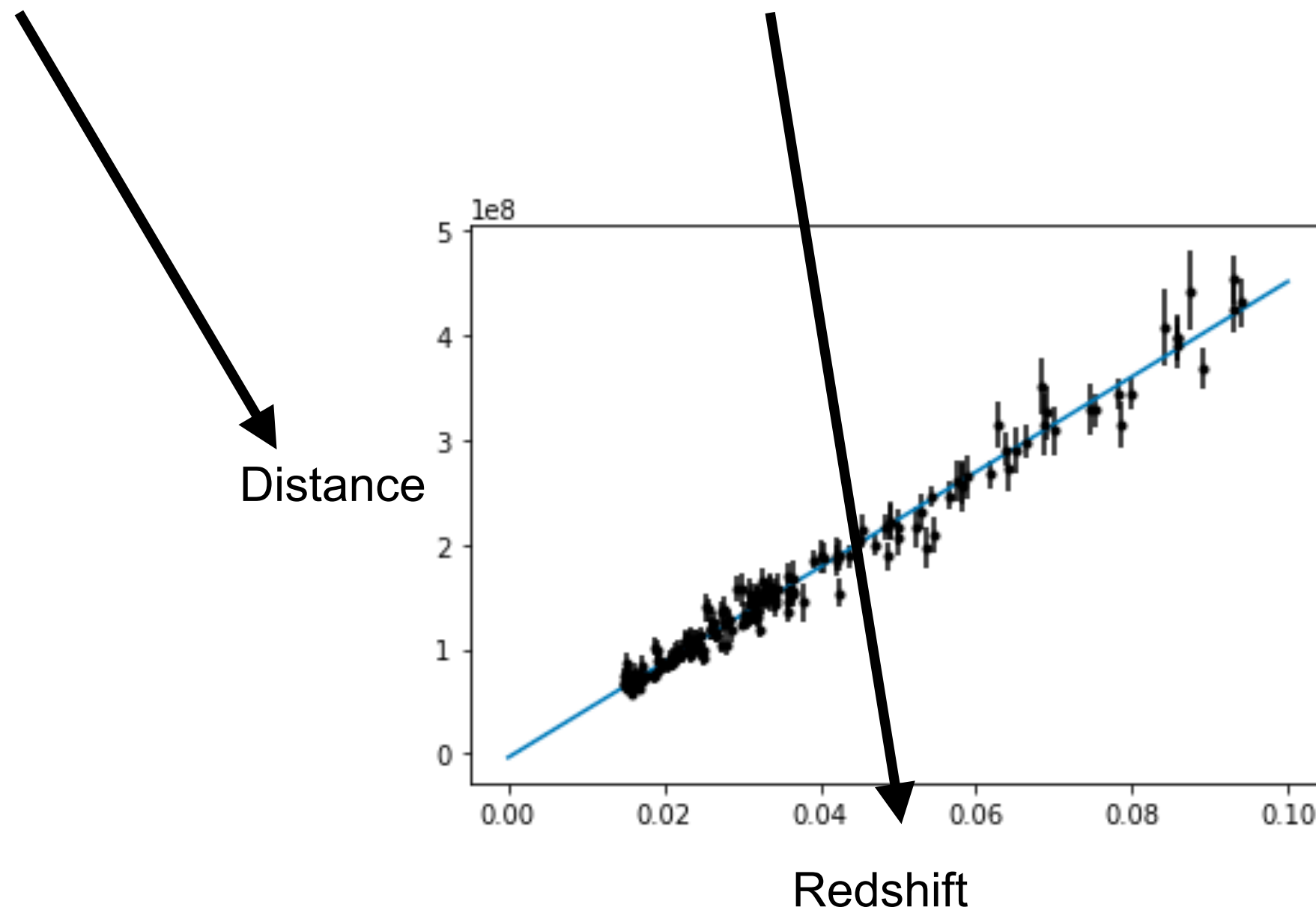
Leptokurtic distribution
High degree of peakedness
Kurtosis > 0

Dn_plot





Friedmann Equations



Friedmann Equations

$$\left(\frac{h}{h_0}\right)^2 = (\Omega_m + \Omega_{\text{DM}})a^{-3} + \Omega_r a^{-4} + \Omega_K a^{-2} + \Omega_\Lambda$$

$$1 = (\Omega_m + \Omega_{\text{DM}}) + \Omega_r + \Omega_K + \Omega_\Lambda$$

Formula at time now

$$1 = \Omega_M + \Omega_\Lambda \text{ or } \Omega_\Lambda = 1 - \Omega_M$$



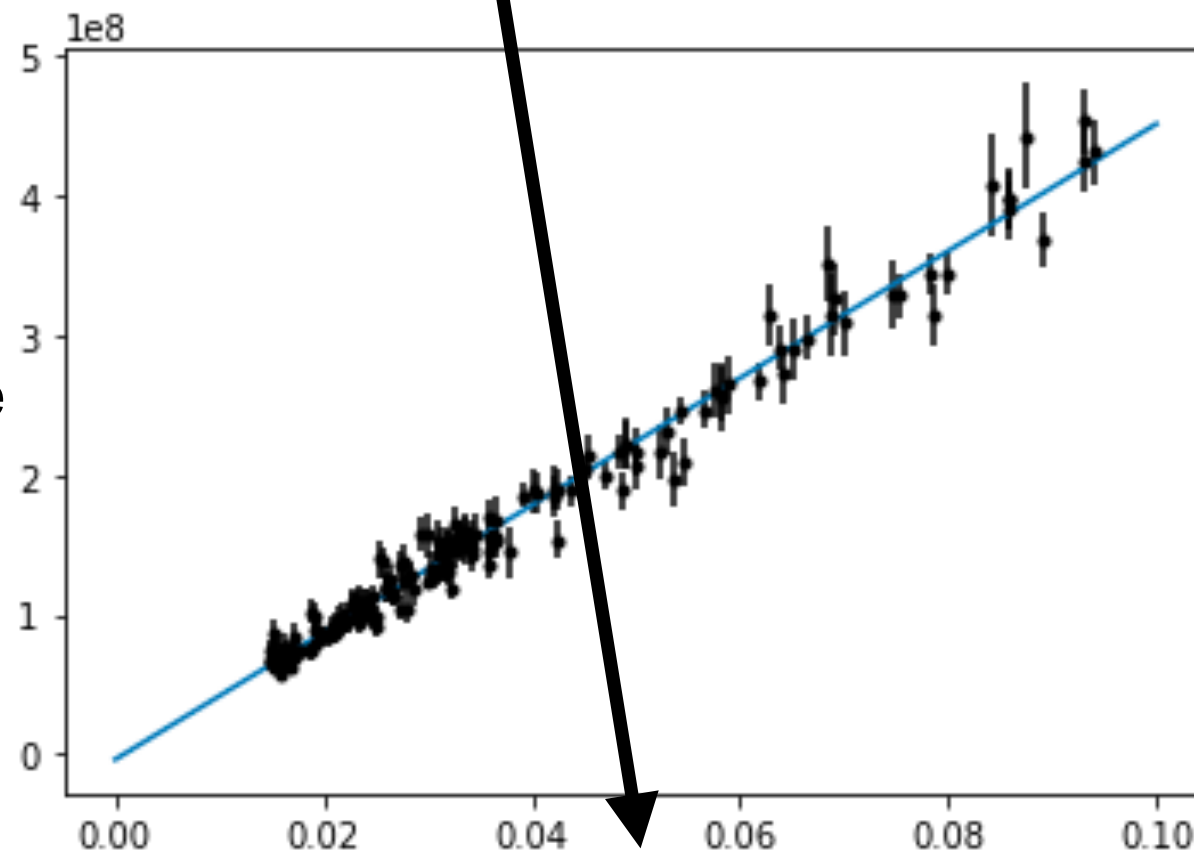
Removing Terms

$$\left(\frac{h}{h_0}\right)^2 = (\Omega_M)a^{-3} + 1 - \Omega_M$$

Friedmann Equations

$$d(z) = ct' = (1+z)ct = (1+z) \frac{c}{h_0} \int_0^z \frac{dz'}{\sqrt{\Omega_M(1+z')^3 + 1 - \Omega_M}}$$

Distance



Redshift

Our final expansion Plot

