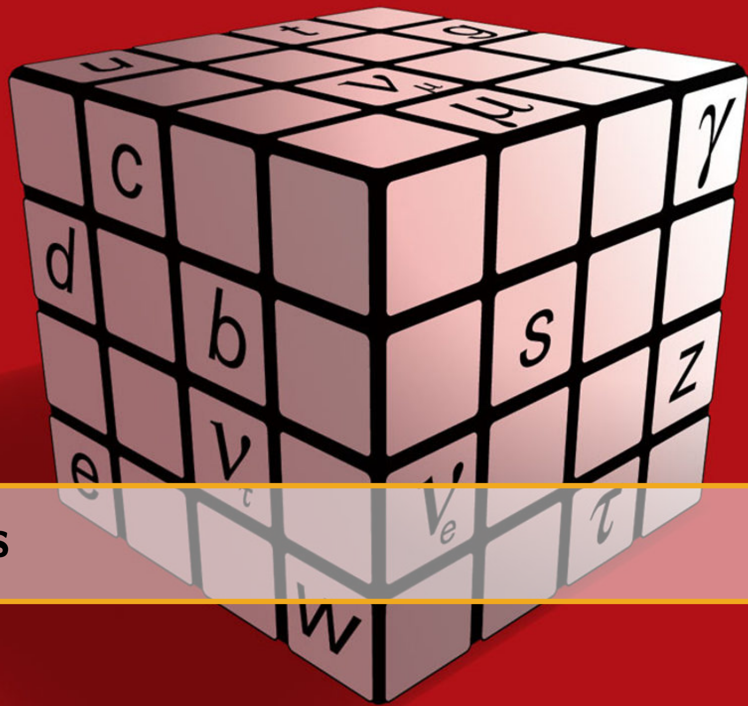

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Theory and Experiment

II

Simulation, Processing and Analysis

1. The SPACE Analysis

After introducing the detector workings, reconstruction and analysis techniques, background contributions and the signature of the signal, this chapter gives an overview of analysis. Starting from data processed with basic reconstructions and requirements a workflow was set up to try to discriminate events that are most likely of known physical interactions from the rare events that are sought for in this analysis. These events would originate from the theoretical particles with an anomalous charge (see Chapter **??**). The analysis was adopted the "SPACE" analysis, which stands for a "Search for Particle with Anomalous ChargE".

1.1 Filter selection

As explained in Section **??**, the data is processed through multiple filters. Since this analysis is the first of its kind in the collaboration, no processed dataset from other analyses was used. Filters had to be selected for proper comparison of data and Monte Carlo and I have chosen to optimize the signal to background ratio to select which filters should be included. An illustration is given in Fig. 1.1. This filter selection will be referred to as *Level2b*, as a simple addition to filter processing in Level2 (see Section **??**).

1.1.1 VEF

The Vertical Event Filter (VEF) is designed to be used for oscillation and Earth WIMP analyses and makes use of the string trigger (see Section **??**). An SMP that travel alongside a string, or closeby, can trigger optical modules while the total light yield of an event is low, making this filter an ideal addition to the filters that are selected. In addition, the filter removes HLC hits in the top 5 DOM layers to reduce the muonic component from air shower events. Other selection cuts, try to optimize the search efficiency for WIMP events in particular. For example, the LF zenith angle should be higher than $68.7°$. More information can be found in Ref. [**VEF2012**].

1.1.2 LowUp

The LowUp filter is again mainly designed for WIMP searches, but also atmospheric neutrino analysis and is mainly designed to capture up-going muons with an energy below 1 TeV. The majority of the events that are selected by this filter make use of the in-ice Volume Trigger (see Table **??**), but also the in-ice SMT8, in-ice String and SMT3-DeepCore triggers are run over for completeness. The selection cuts are loose selections required to look for up-going track-like particles. For example, the zenith angle of the reconstructed particle should have an angle of

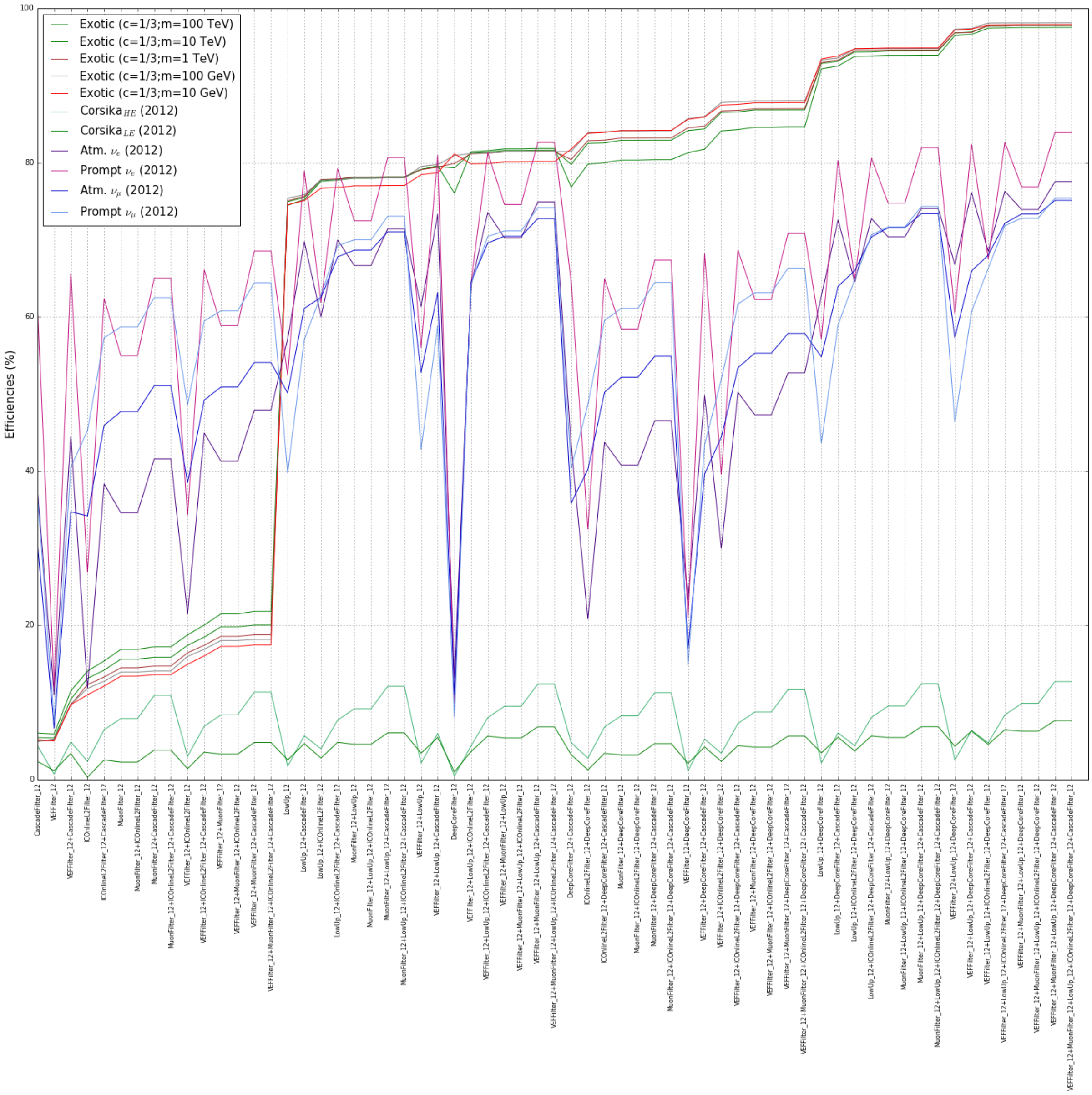


Figure 1.1: Illustration of the efficiencies of several filters and their possible combinations. The x-axis was determined by starting with filter selections that had a low efficiency in signal selection and range in function of performance. Five signal points for a fixed charge and different mass show similar results. Exotic SMPs with charges 1/2 and 2/3 show very similar results but are left out for a better visualization.

80° or higher and the difference between the maximal z-coordinate and minimal z-coordinate of hit DOMs should be less than or equal to 600 m. More information can be found in Ref. [**LowUp2012**].

1.1.3 Online Muon L2

The Online Muon L2 filter is a subset of the Muon Filter (see Ref. **??**) and tries to select the most interesting muon-like events while reducing the rate of the filter from around 30 Hz to 5 Hz, reducing the data with a factor of 6. Historically this subset was processed data from the Muon Filter, but after realizing that this could be done online and because many analyses made use of this selection, it was chosen to implement it as a separate filter. The filter tries to select both up-going and down-going muons, with different selection cuts depending on the zenith angle of the particle reconstruction. The four selection ranges are defined as:

- $180° \geq \theta_{\text{MPE}} \geq 115°$
- $115° > \theta_{\text{MPE}} \geq 82°$
- $82° > \theta_{\text{MPE}} \geq 66°$
- $66° > \theta_{\text{MPE}} \geq 0°$

where the particle reconstruction was done with MPE (Section **??**), which was feasible if it only had to be done on the events passing the Muon Filter. The first two regions have an efficiency* higher than 99%. The down-going region require more stringent cuts to remove the less interesting muons from air showers. The variables used are the number ot hit DOMs, likelihood parameters, number of PEs and so on. More information can be found in Ref. [**OnlineMuonL22012**].

Verhoogt uw signaal niet zo veel omdat je enkel upgoing signaal gebruikte om dit te testen.

1.1.4 DeepCore

Additionally a DeepCore specialized filter was added to account for SMP tracks that partially traverse the more densly instrumented DC detector. Due to the low amount of light produced by these dim tracks, adding the DeepCore filter that is specialized for this part of the detector proved to be of significant importance.

The DeepCore filter was designed to look for very dim events coming from, e.g., dark matter, low-energy neutrino oscillations, and studies in observing atmospheric neutrinos below 100 GeV. The fiducial volume used for this filter consists of

- the bottom 22 DOMs on the IceCube strings 25, 26, 27, 34, 35, 36, 37, 44, 45, 46, 47 and 54;
- the bottom 50 DOMs on the DeepCore strings 79-86.

These strings are indicated in Fig. 1.2.

The filter uses the DeepCore SMT3 trigger and calculates the COG position. Two layers are used as a veto to remove events that probably originate from atmospheric muons. More information can be found in Ref. [**DeepCore2012**].

1.1.5 Burnsample checks

Before further processing, the burn sample (Section **??**) is compared over the different years that are used in the analysis. This is shown in Figure 1.3. More information on the burn sample can be found in Section **??**.

1.2 Quality cuts

The combined filter selection leads to a total rate of ~ 60 Hz, or ~ 1.9 billion events per year. MPE

*Here defined as having a reconstruction within 3° of the MC truth.

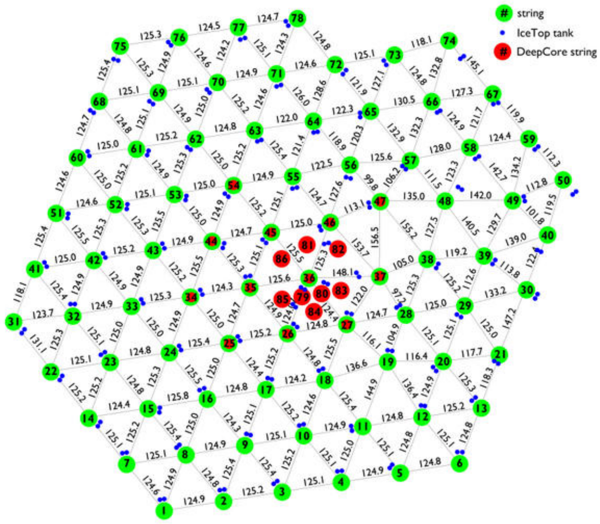


Figure 1.2: Aerial view of the IceCube strings (and IceTop tanks) where the DeepCore fiducial volume is defined by the DeepCore strings (red) and several surrounding in-ice IceCube strings (green and red).

De uitleg van temperature modulations is goed in Sam zijn thesis `https://arxiv.org/pdf/physics/0312102v1.pdf`
`https://arxiv.org/pdf/1310.1284.pdf`

Ook ergens een tabel maken met info over je data runs. Duidelijk maken wat de livetime is bv en ook zeggen van wanneer to wanneer een bepaalde run liep (2011: mei 2011- mei 2012)

Klaus zijn paper? `https://arxiv.org/abs/1806.05696`

1.3 Motivation

1.4 General strategy

1.5 Event cleaning

1.6 Variables

1.7 BDT results

1.8 Pull validation

1.9 Systematic Uncertainties

1.10 Results

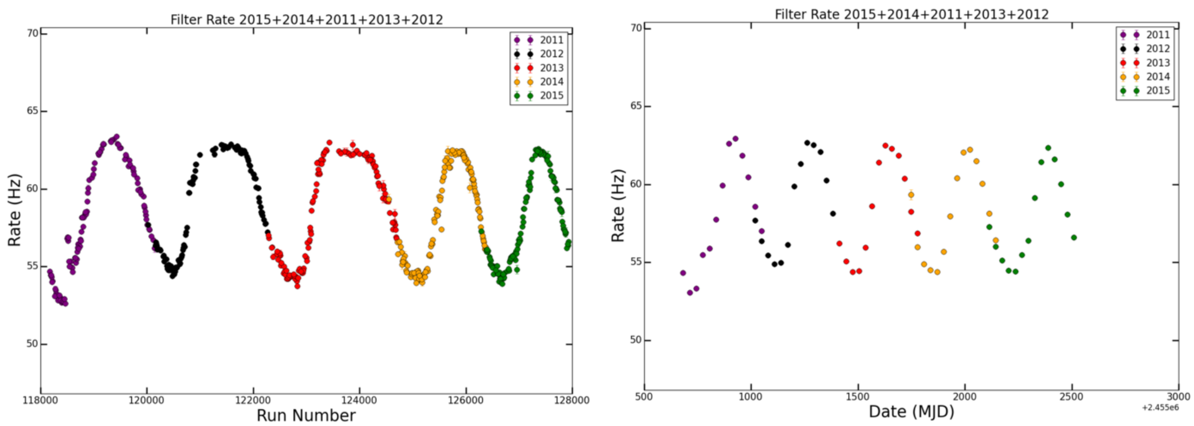


Figure 1.3: *Left:* Total rate of the combined filters in function of the run number. The sine wave pattern from seasonal variations in the atmosphere (see Section **??**) is clearly visible and consisten throughout the years. The x-axis is more spread out in the first years as there were more test runs. The shift in data rate in early 2011 runs is due to the DOM software change that was introduced in the Summer of 2011 [**2011rate**]. This phenomenon is well understood and since the changes are minimal it was chosen to keep these runs. *Right:* Total filter rate averaged per month. There is an overlap for each year because a new season doesn't necessarily start in the beginning of a month.

2. Summary and Discussion

Possible improvements: filter! Trigger! a speed cut... If multiple COGs, connection of both should be within time window.

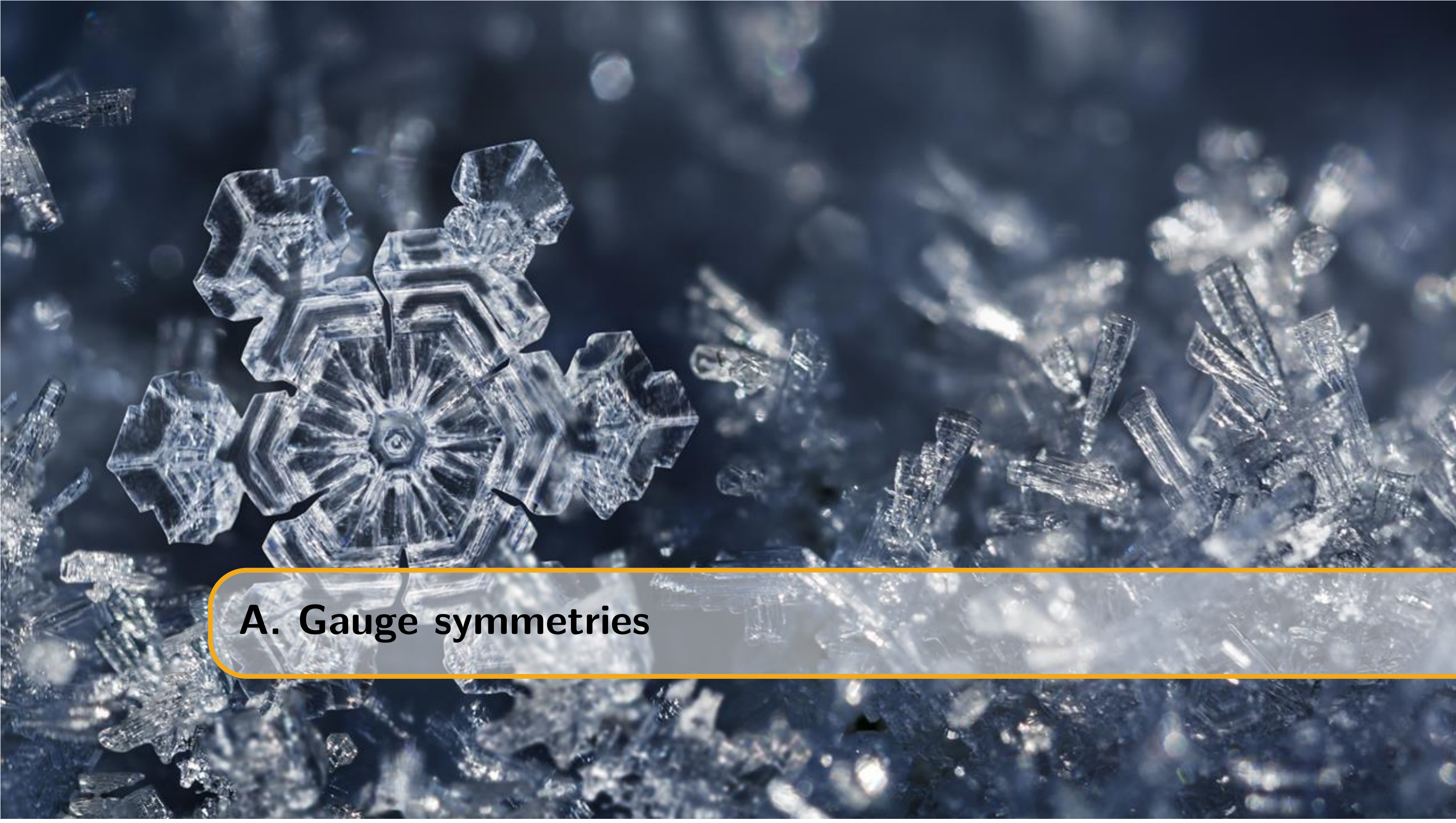
Other machine learning techniques.

Energy estimators (although probably wrong)

III

Additions

Appendices



A. Gauge symmetries

NOG NIET GEDAAN

The difference between global and local symmetries are not straightforward for everybody. In this appendix I try to give a better view of the matter.

Imagine that at each point in space and time there is a circle attached to it. If one shifts all circles of all points with a fixed angle the underlying physics hasn't changed. If we look at the whole in a different angle, nothing seems to be changed as everything holds the same relative orientation. This is a global symmetry. For local symmeries we instead shift each circle through a different angle, but an angle that changes smoothly from point to point and in a way that we can say how that angle is varying between different nearby regions. Then it will turn out that we can describe that rotation angle by means of a so-called gauge field, which just lets us transport the charged scalar field from one point in space time to another, taking account of how the rotation angle of the circle is changing. A gauge is a kind of coordinate system that is varying depending on the location with respect to some underlying space. In physics we are almost always concerned with space-time as the underlying space, and we are typically interested in theories that are invariant with respect to the choice of gauge or coordinate system.

Dan wat uitleg vanuit je QFT boek en de dingen hieronder: Je wilt je derivative anders doen werken in je theory onder een transformatie, maar daarvoor heb je een veld nodig. M.a.w.: dankzij een veld heb je lokale ijktransformatie mogelijk!

B. Planck's law

bron: http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/rayj.html

B.1 Electromagnetic waves in a cubical cavity

Suppose we have EM waves in a cavity at equilibrium with its surroundings. These waves must satisfy the wave equation in three dimensions:

$$\frac{\partial^2\Psi}{\partial x^2} + \frac{\partial^2\Psi}{\partial y^2} + \frac{\partial^2\Psi}{\partial z^2} = \frac{1}{c^2}\frac{\partial^2\Psi}{\partial t^2}. \tag{B.1}$$

The solution must give zero amplitude at the walls. A non-zero value would mean energy is dissipated through the walls which is in contradiction to our equilibrium assumption. A general solution takes the form of

$$\Psi(x,y,z,t) = \Psi_0 \sin k_1 x \sin k_2 y \sin k_3 z \sin k_4 t, \tag{B.2}$$

which, after requiring $k_n L = n\pi$ with $n = 0, 1, 2...$ and $k_4 \frac{\lambda}{2c} = \pi$, leads to

$$\Psi(x,y,z,t) = \Psi_0 \sin\left(\frac{n_1\pi x}{L}\right) \sin\left(\frac{n_2\pi y}{L}\right) \sin\left(\frac{n_3\pi z}{L}\right) \sin\left(\frac{2\pi ct}{\lambda}\right). \tag{B.3}$$

From the wave equation it is easy to find that

$$n^2 = n_1^2 + n_2^2 + n_3^2 = \frac{4L^2}{\lambda^2}, \tag{B.4}$$

which span up a sphere in "n-space" with a volume of $\frac{1}{8}\frac{4}{3}\pi n^{3/2}$, where the first term originates from the positive nature of $n_{1,2,3}$. Because there are two possible polarizations of the waves one has to multiply with an additional factor 2. The number of modes per unit wavelength is equal to

$$\frac{dN}{d\lambda} \times \frac{1}{L^3} = \frac{d}{d\lambda}\left[\frac{8\pi L^3}{3\lambda^3}\right] \times \frac{1}{L^3} = -\left[\frac{8\pi}{\lambda^4}\right]. \tag{B.5}$$

B.1.1 Classical approach

Following the principle of equipartition of energy, each standing wave mode will have an average enkergy kT with k the Boltzmann constant and T the temperature in Kelvin. The energy density is then:

$$\frac{du}{d\lambda} = -kT\frac{8\pi}{\lambda^4}. \tag{B.6}$$

In function of frequency $\nu = \frac{c}{\lambda}$:

$$\frac{du}{d\nu} = -\frac{c}{\lambda^2}\frac{du}{d\lambda} = \frac{8\pi kT\nu^2}{c^3}, \tag{B.7}$$

also known as the Rayleigh-Jeans law*. Problem: divergence

B.1.2 Quantum approach

The energy levels from a quantized harmonic oscillator are equal to

$$E_r = h\nu\left(r+\frac{1}{2}\right) = \frac{hc}{\lambda}\left(r+\frac{1}{2}\right) \quad \text{with} r = 0, 1, 2, ... \tag{B.8}$$

Implementing eq. B.4

$$E = \left(r+\frac{1}{2}\right)\frac{hc}{2L}\sqrt{n_1^2+n_2^2+n_3^2} \tag{B.9}$$

According to statistical physics the average energy is now not equal to kT but follows a probability distribution

$$p(\nu, r) = \frac{e^{\frac{-rh\nu}{kT}}}{\sum_{r=0}^{\infty} e^{\frac{-rh\nu}{kT}}}, \tag{B.10}$$

where we reference to the ground state of the oscillator: $E_r' = E_r - E_0$.

The average energy is now:

$$\begin{aligned}\langle E(\nu)\rangle &= \sum_{r=0}^{\infty} E(\nu, r)\cdot p(\nu, r) = \frac{\sum_{r=0}^{\infty} rh\nu\ e^{\frac{-rh\nu}{kT}}}{\sum_{r=0}^{\infty} e^{\frac{-rh\nu}{kT}}} \\ &= \frac{h\nu}{e^{h\nu/kT}-1}\end{aligned} \tag{B.11}$$

Substituting this for kT in eq. B.7 we find Planck's equation:

$$\frac{du}{d\nu} = \frac{8\pi h\nu^3}{c^3}\frac{h\nu}{e^{h\nu/kT}-1} \tag{B.12}$$

*This is often quoted per unit of staradian, which results in $\frac{2kT\nu^2}{c^3}$

C. Statistics

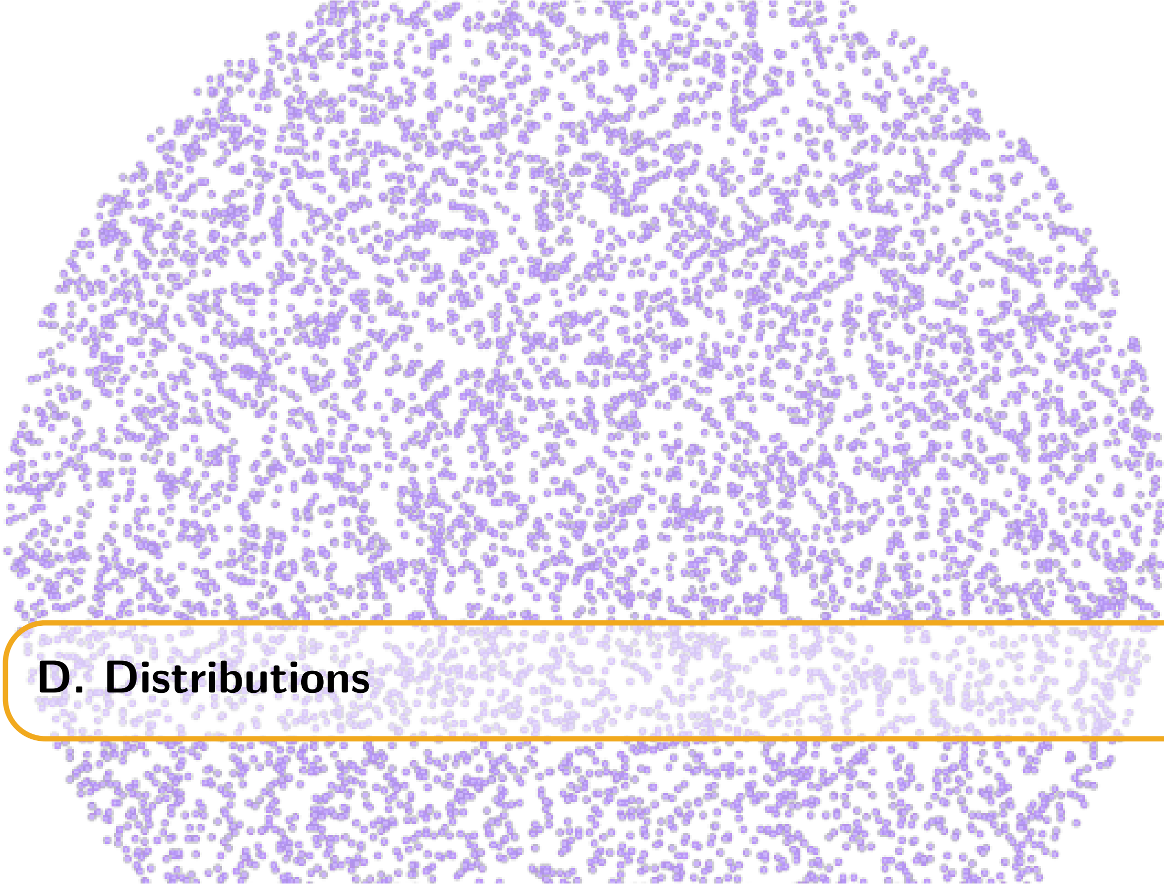
A word that is often mentioned in this work is “statistics”. It refers to the statistical error of a counting experiment, i.e. the Poissonian error. The Poisson distribution is a discrete probability of a certain number of $n$events occurring in a fixed time interval. The Poisson probability function is given by

$$P(n) = \frac{\lambda^n e^{-\lambda}}{n!}, \tag{C.1}$$

where λ is the expected number of events and also equal to the variance. An experiment that counted N events therefore has a statistical error of

$$\sigma = \sqrt{N} \tag{C.2}$$

In other words: higher statistics denotes a lower statistical error.



D. Distributions

D.1 Spherical random numbers

Most random number generators provide uniform distributions between the range $[0, 1]$. Assume we want to make a uniform distribution along a sphere with angles ϕ and θ and radius r, in spherical coordinates. Random numbers between $[0, \pi]$, $[0, 2\pi]$ and $[0, R]$ (the ranges of the coordinates) would not give a uniform distribution as illustrated in Fig. D.1 (left).
The differential surface area, dA, is equal to $dA(d\phi, d\theta) = r^2 \sin(\phi) d\phi d\theta$. If we want the distribution $f(v)$ to be constant for a uniform distribution, then $f(v) = \frac{1}{4\pi}$ since $\int\int_S f(v)dA = 1$ and $\int\int_S dA = 4\pi$. We want the distribution in function of the angles, so

$$f(v)dA = \frac{1}{4\pi} dA = f(r)f(\phi, \theta)d\phi d\theta. \tag{D.1}$$

Since we know the expression for dA, we find that

$$f(\phi, \theta) = \frac{1}{4\pi} \sin(\phi), \tag{D.2}$$

and separating the angles:

$$f(\theta) = \int_0^{\pi} f(\phi, \theta)d\phi = \frac{1}{2\pi}, \tag{D.3}$$

$$f(\phi) = \int_0^{2\pi} f(\phi, \theta)d\theta = \frac{\sin(\phi)}{2}, \tag{D.4}$$

where it is clear that $f(\phi)$ scales with $\sin(\phi)$; there are more points needed at the equator (this makes sense, as the surface at the equator is much larger!).

The question is now how one can get a sample to follow the distribution of $f(\phi)$. For this, we use the *inverse transform sampling* method where one makes use of the cumulative distribution function, $F(\phi)$, which increases monotonically

$$F(\phi) = \int_0^{\phi} f(\phi')d\phi' = \frac{1}{2}\left(1 - \cos(\phi)\right). \tag{D.5}$$

The method shows that if u is a random variable drawn from a uniform distribution, we have to find the inverse function of F,

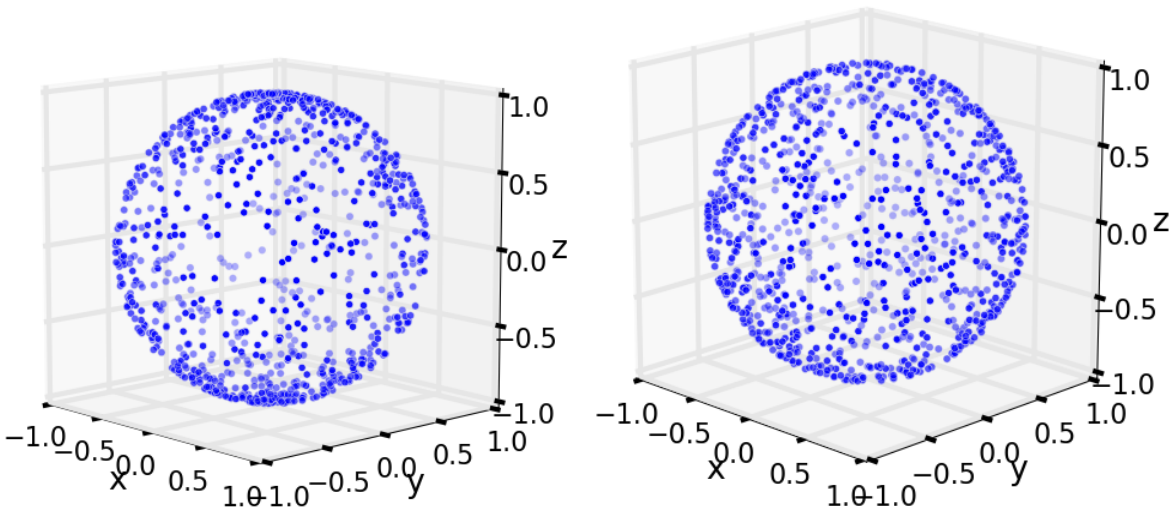


Figure D.1: *Left:* Illustration of a uniform sampling in angles ϕ and θ that doesn't give a uniform spherical distribution. *Right:* Illustration of a good spherical distribution.

$$F(F^{-1}(u)) = u \tag{D.6}$$

$$\frac{1}{2}\left(1-\cos(F^{-1}(u))\right) = u \tag{D.7}$$

$$F^{-1}(u) = \arccos(1-2u). \tag{D.8}$$

In other words: if u is a random variable drawn from a uniform distribution, then $\phi = \arccos(1-2u)$ follows a distribution necessary for a uniform spherical distribution. Similarly, $\theta = \frac{1}{2\pi}u$.

D.2 Power law distributions

Analogous to what was written in the previous section, one can produce a power law distribution from random numbers using the inverse transform sampling method:

$$\begin{aligned}
f(E) &= A \cdot E^{-\gamma} \quad \text{(powerlaw)} \\
F(E) &= \int_{E_{min}}^{E} A \cdot E^{-\gamma} dE = u \quad \text{(inverse sampling, u random number [0,1])} \\
&= A\left[\frac{E^{-\gamma+1}}{-\gamma+1}\right]_{E_{min}}^{E} \\
&= \frac{A}{-\gamma+1}\left(E^{-\gamma+1} - E_{min}^{-\gamma+1}\right)
\end{aligned} \tag{D.9}$$

Because we know that $F\left(F^{-1}(u)\right) = u$, we can find an expression for $F^{-1}(u)$:

$$\begin{aligned}
u &= \frac{A}{-\gamma+1}\left(\left(F^{-1}(u)\right)^{-\gamma+1} - E_{min}^{-\gamma+1}\right) \\
&\Rightarrow \\
F^{-1}(u) &= \left(\left(\frac{-\gamma+1}{A}\cdot u\right) + E_{min}^{-\gamma+1}\right)^{1/(-\gamma+1)}
\end{aligned} \tag{D.10}$$

To find A, we use the property of a CDF:

$$F(E_{max}) = 1 \Rightarrow A = \frac{-\gamma+1}{E_{max}^{-\gamma+1} - E_{min}^{-\gamma+1}}, \tag{D.11}$$

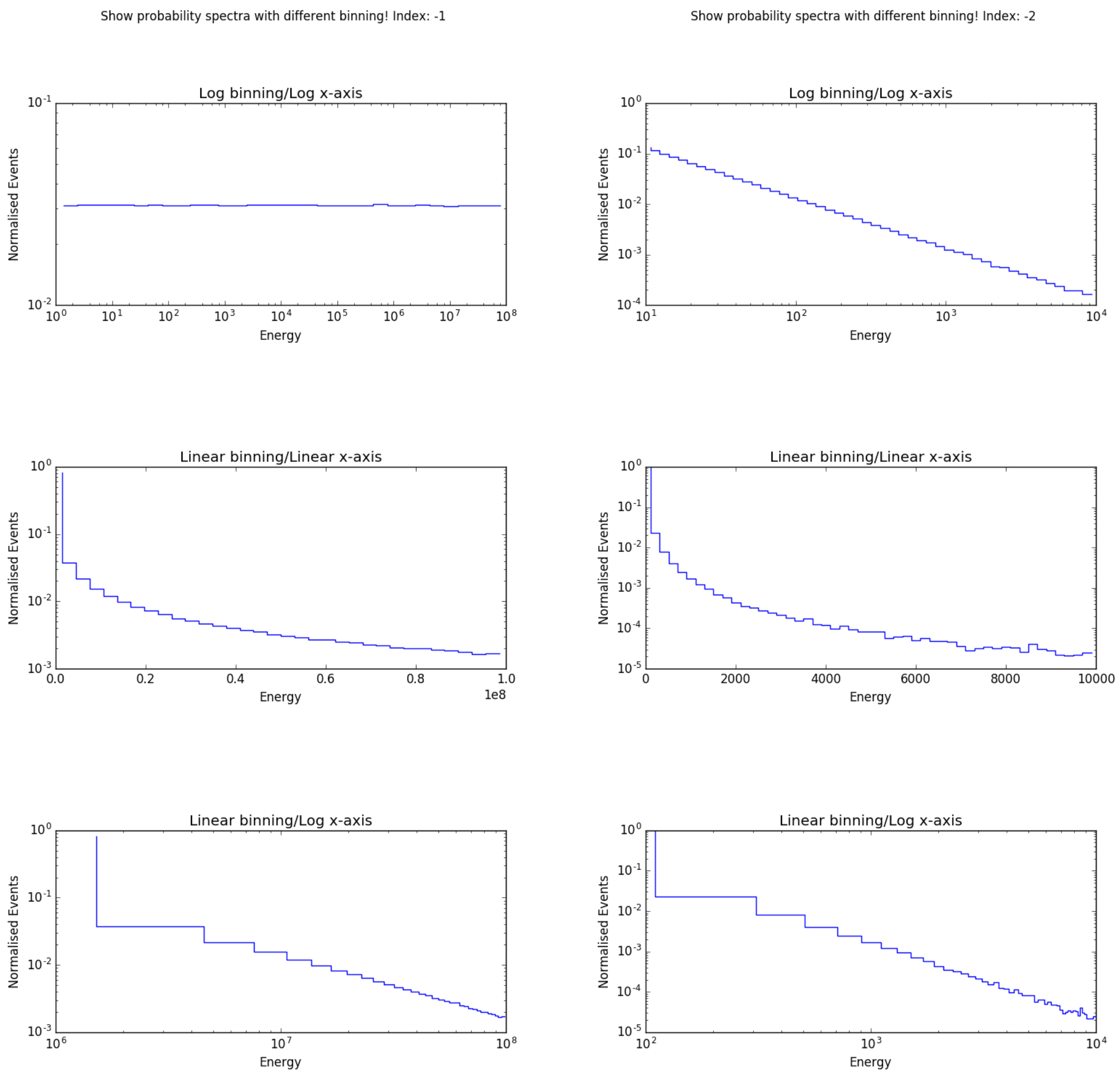


Figure D.2: *Left:* Histograms with different binnings showing the behavior of an energy spectrum with spectral index -1. *Right:* Histograms with different binnings showing the behavior of an energy spectrum with spectral index -2.

leading to

$$F^{-1}(u) = \left((1-u)\cdot E_{min}^{-\gamma+1} + u \cdot E_{max}^{-\gamma+1}\right)^{1/(-\gamma+1)}, \tag{D.12}$$

which shows how one can draw a distribution in function of E following $f(E)$ with a uniform random number u.

For $\gamma =$ -1, the computations are analogous and one can see that this will produce a uniform distribution in log space. This is shown in Fig. D.2.

$$\begin{aligned} E &= E_{min} \cdot 10^{u \cdot \log \frac{E_{max}}{E_{min}}} \\ &= 10^{u[\log E_{min}, \log E_{max}]} \end{aligned} \tag{D.13}$$

D.3 Angular distributions

As seen in Section D.1, the differential space angle $d\Omega$ is equal to

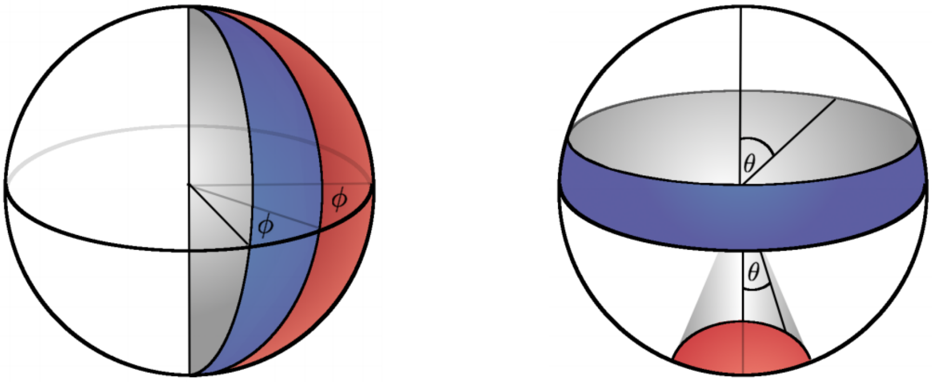


Figure D.3: Illustration of angle distributions in spherical coordinates. The blue and red surfaces are equal in size. The left figure clearly shows the surface to be proportional to the azimuth. The right figure shows how there is a non-trivial dependence on the zenith angle for equal partitions on the surface of a sphere.

$$d\Omega = \sin(\theta) d\theta d\phi. \tag{D.14}$$

If one shows the distribution of ϕ and/or θ, then this is the same as showing partial integrations per bin. We find that

$$\Omega \propto \cos(\theta), \tag{D.15}$$

or in other words: the space angle is proportional to the azimuth and the cosine of the zenith. An example is shown in Fig. D.3.

D.4 Weighting

A method that is often used in simulations is *weighting*. The simulated and expected differential flux of particles is often not the same, mainly due to two reasons:

- The flux has no uniform power law behavior. As can bee seen in Fig. **??**, there can be multiple "kinks" and changes in a spectrum. Instead of simulating the flux according to one model, a general uniform flux is used and later reweighted to be able to fit to other models more easily.
- A steep power law indicates very few events at the highest energy bins. This means large CPU time would be necessary to simulate these events. As an example, let us assume two different fluxes

$$f_1 = A \cdot x^{-1}, \tag{D.16}$$

$$f_2 = B \cdot x^{-2}, \tag{D.17}$$

where $A = 10^3$ and $B = 10^4$, so the fluxes cross at a value of $x^{-1+2} = x = \frac{10^4}{10^3} = 10$. In the interval $x \in [10^3, 10^4]$, the number of events for f_1 is equal to 10^3, whereas for f_2 this is equal to 9.

Simulating with harder spectra* leads to more statistics in high-energy bins.

The weights can be generally written down as

$$w = \frac{dN_{exp}}{dA d\Omega dE dt} \times \frac{dA d\Omega dE}{dN_{sim}}. \tag{D.18}$$

*Harder spectra equals to a lower gamma, since there will be more high-energy events.

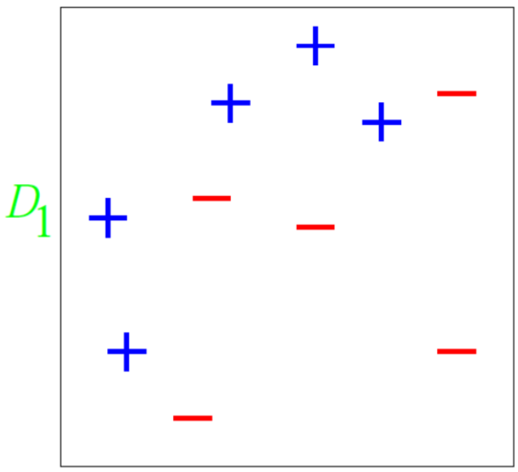
A disadvantage of using weights is that certain events with a high weight are rare but can dominate or obscure the sample in the tails of certain distributions.

E. AdaBoost: simple example

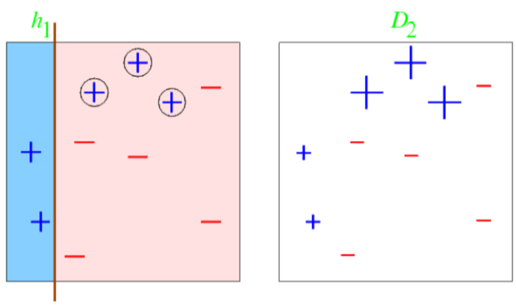
Consider a binary decision tree classification with 10 training examples. The illustrations below are 2D variable distributions.

We give each event an equal weight, making the weight distribution D_1 uniform. For this simple example, each of our classifiers will be an axis-parallel linear classifier (simple cut in one of the two variables).

Initial distribution



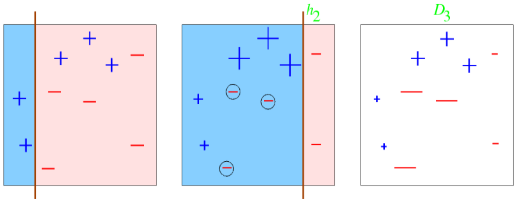
Round 1



- Error rate of h_1: $\epsilon_1 = 0.3$; weight of h_1 (see Eq. **??**): $\alpha_1 = \frac{1}{2}\ln\left(\frac{1-\epsilon_1}{\epsilon_1}\right) = 0.42$

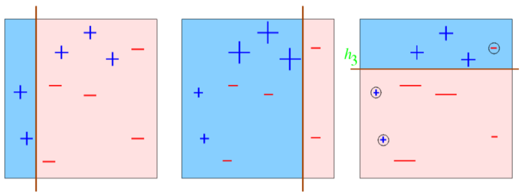
- An event that is misclassified gets a higher weight: weight multiplied with $\exp(\alpha_1)$
- An event that is correcly classified gets a lower weight: weight multiplied with $\exp(-\alpha_1)$

Round 2



- Error rate of h_1: $\epsilon_1 = 0.21$; weight of h_2 (see Eq. **??**): $\alpha_2 = \frac{1}{2}\ln\left(\frac{1-\epsilon_2}{\epsilon_2}\right) = 0.65$
- An event that is misclassified gets a higher weight: weight multiplied with $\exp(\alpha_2)$
- An event that is correcly classified gets a lower weight: weight multiplied with $\exp(-\alpha_2)$

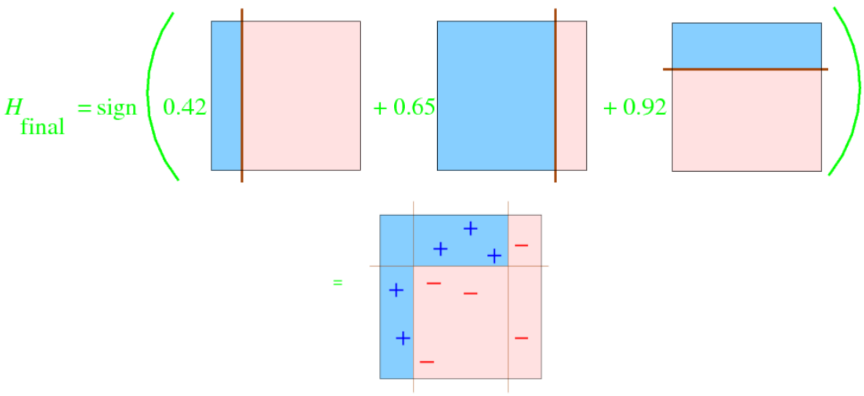
Round 3

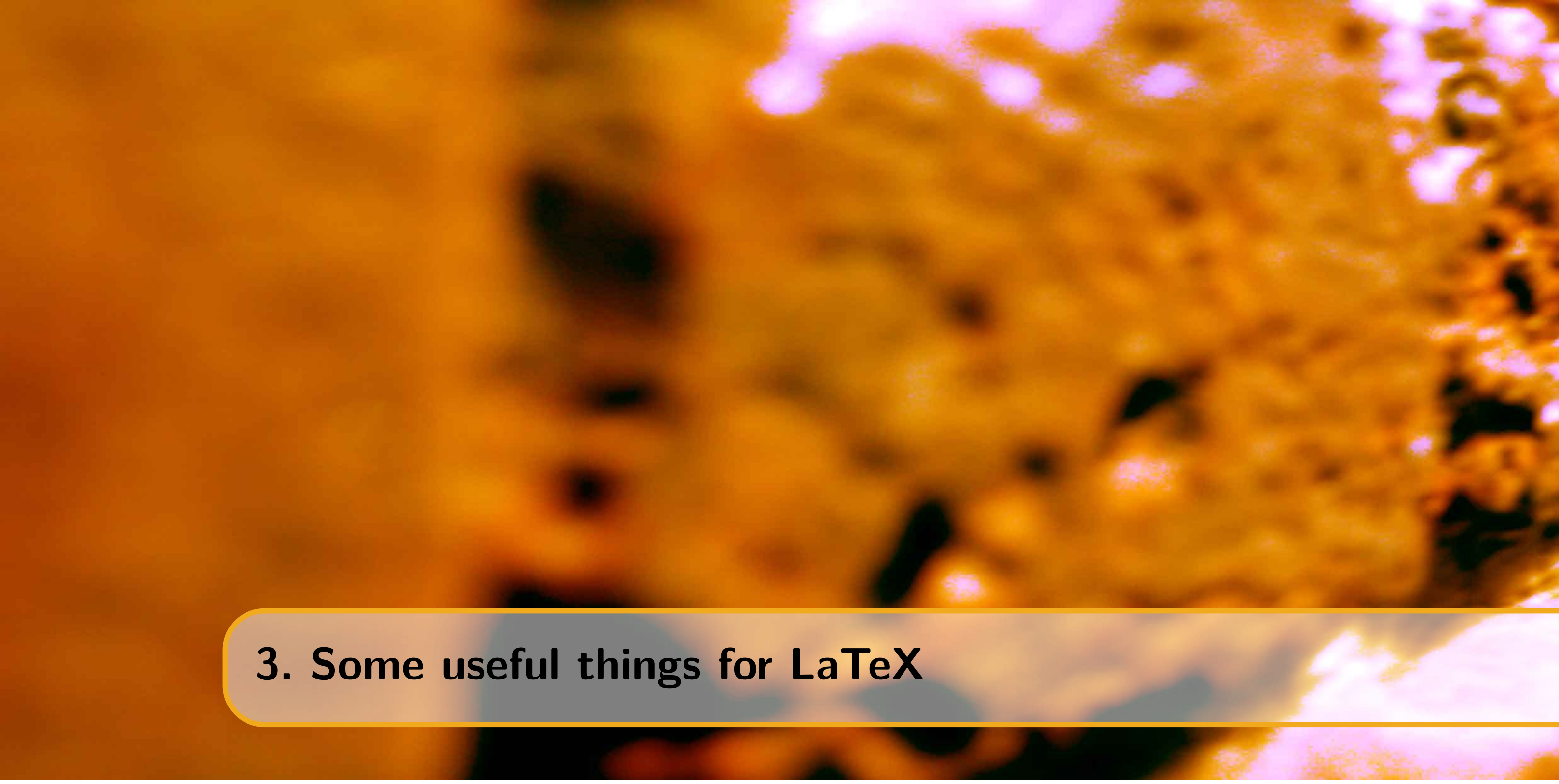


The error rate of h_1: $\epsilon_1 = 0.21$; weight of h_2 (see Eq. **??**): $\alpha_2 = \frac{1}{2}\ln\left(\frac{1-\epsilon_2}{\epsilon_2}\right) = 0.65$
Let us suppose to stop after this round, we now have a forest of 3 decision classifiers: h_1, h_2, h_3.

Final step

The final classifier is a weighted linear combination of all the classifiers:





3. Some useful things for LaTeX

3.1 Definitions

This is an example of a definition. A definition could be mathematical or it could define a concept.

Definition 3.1.1 — Definition name. Given a vector space E, a norm on E is an application, denoted $||\cdot||$, E in $\mathbb{R}^+ = [0, +\infty[$ such that:

$$||\mathbf{x}|| = 0 \;\Rightarrow\; \mathbf{x} = \mathbf{0} \tag{3.1}$$

$$||\lambda\mathbf{x}|| = |\lambda| \cdot ||\mathbf{x}|| \tag{3.2}$$

$$||\mathbf{x} + \mathbf{y}|| \leq ||\mathbf{x}|| + ||\mathbf{y}|| \tag{3.3}$$

3.2 Remarks

This is an example of a remark.

R The concepts presented here are now in conventional employment in mathematics. Vector spaces are taken over the field $\mathbb{K} = \mathbb{R}$, however, established properties are easily extended to $\mathbb{K} = \mathbb{C}$.

3.3 Corollaries

This is an example of a corollary.

Corollary 3.3.1 — Corollary name. The concepts presented here are now in conventional employment in mathematics. Vector spaces are taken over the field $\mathbb{K} = \mathbb{R}$, however, established properties are easily extended to $\mathbb{K} = \mathbb{C}$.

3.4 Propositions

This is an example of propositions.

3.4.1 Several equations

Proposition 3.4.1 — Proposition name. It has the properties:

$$\left| ||\mathbf{x}|| - ||\mathbf{y}|| \right| \leq ||\mathbf{x} - \mathbf{y}|| \tag{3.4}$$

$$||\sum_{i=1}^{n} \mathbf{x}_i|| \leq \sum_{i=1}^{n} ||\mathbf{x}_i|| \quad \text{where } n \text{ is a finite integer} \tag{3.5}$$

3.4.2 Single Line

Proposition 3.4.2 Let $f, g \in L^2(G)$; if $\forall \varphi \in \mathcal{D}(G)$, $(f, \varphi)_0 = (g, \varphi)_0$ then $f = g$.

3.5 Examples

This is an example of examples.

3.5.1 Equation and Text

■ **Example 3.1** Let $G = \{x \in \mathbb{R}^2 : |x| < 3\}$ and denoted by: $x^0 = (1, 1)$; consider the function:

$$f(x) = \begin{cases} \mathrm{e}^{|x|} & \text{si } |x - x^0| \leq 1/2 \\ 0 & \text{si } |x - x^0| > 1/2 \end{cases} \tag{3.6}$$

The function f has bounded support, we can take $A = \{x \in \mathbb{R}^2 : |x - x^0| \leq 1/2 + \epsilon\}$ for all $\epsilon \in]0; 5/2 - \sqrt{2}[$. ■

3.5.2 Paragraph of Text

■ **Example 3.2 — Example name.** Nam dui ligula, fringilla a, euismod sodales, sollicitudin vel, wisi. Morbi auctor lorem non justo. Nam lacus libero, pretium at, lobortis vitae, ultricies et, tellus. Donec aliquet, tortor sed accumsan bibendum, erat ligula aliquet magna, vitae ornare odio metus a mi. Morbi ac orci et nisl hendrerit mollis. Suspendisse ut massa. Cras nec ante. Pellentesque a nulla. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Aliquam tincidunt urna. Nulla ullamcorper vestibulum turpis. Pellentesque cursus luctus mauris.

■

3.6 Exercises

This is an example of an exercise.

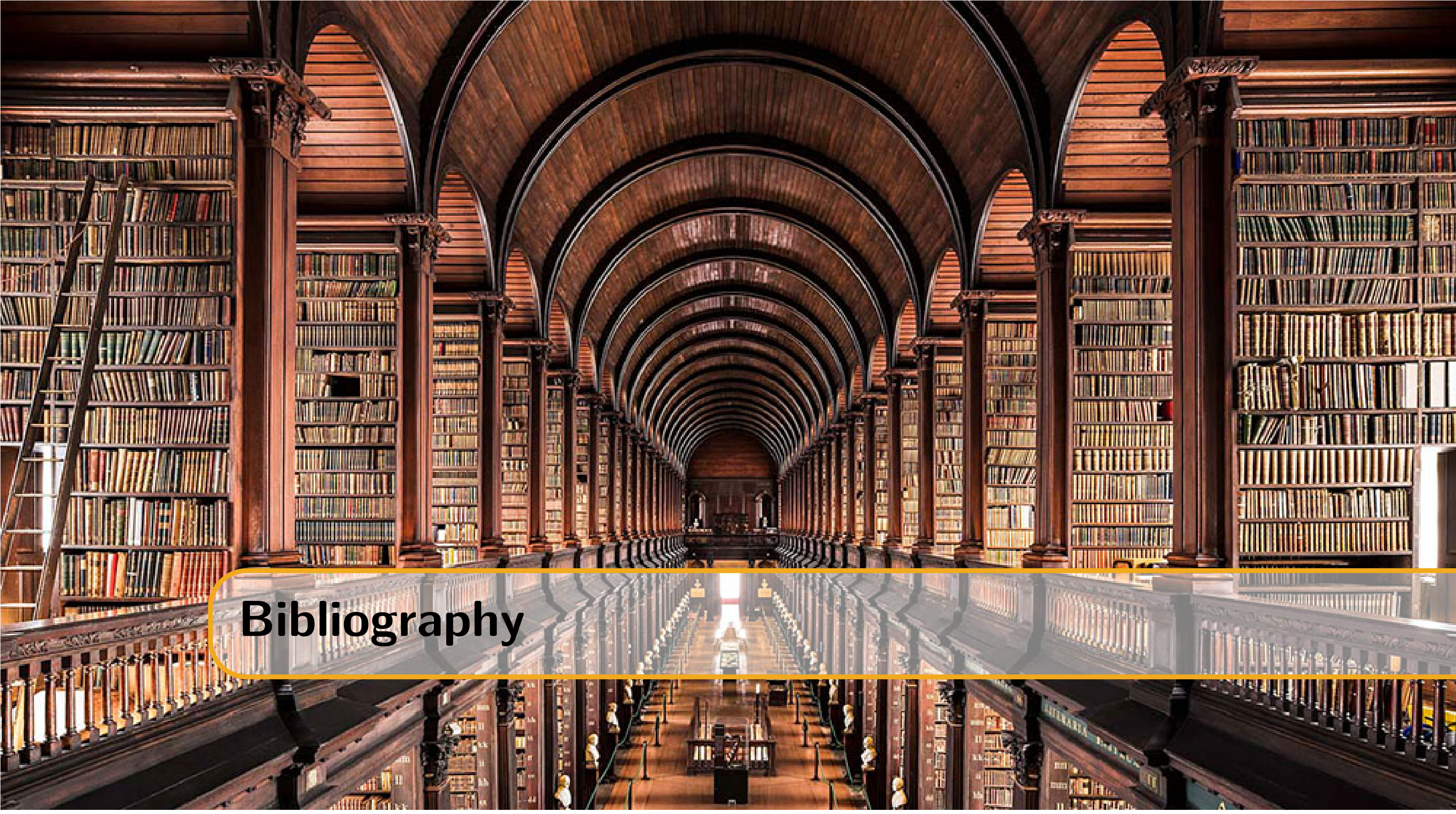
Exercise 3.1 This is a good place to ask a question to test learning progress or further cement ideas into students' minds. ■

3.7 Problems

Problem 3.1 What is the average airspeed velocity of an unladen swallow?

3.8 Vocabulary

Define a word to improve a students' vocabulary.
Vocabulary 3.1 — Word. Definition of word.



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