Multi-task Convolution Neural Networks for the Chips Experiment

Josh Chalcraft Tingey
of University College London

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Abstract

LHCb is a b-physics detector experiment which will take data at the 14 TeV LHC accelerator at CERN from 2007 onward…

Declaration

This dissertation is the result of my own work, except where explicit reference is made to the work of others, and has not been submitted for another qualification to this or any other university. This dissertation does not exceed the word limit for the respective Degree Committee.

Andy Buckley

Acknowledgements

Of the many people who deserve thanks, some are particularly prominent, such as my supervisor…

Preface

This thesis describes my research on various aspects of the LHCb particle physics program, centred around the LHCb detector and LHC accelerator at CERN in Geneva.

For this example, I'll just mention Chapter **??** and Chapter 3.

Contents

"Writing in English is the most ingenious torture ever devised for sins committed in previous lives."
— James Joyce

Chapter 1.

Common blocks

hello ello llo

This .tex file aims to outline how various things should be implemented within the thesis from references to diagrams the symbols etc…

- We use english spelling of everything throughout the thesis

- Write the way that is natural in your head, so you are not contorting your thoughts to fit an unnatural style

- We capitalise just the first word in section, chapter and whole-document titling.

- Don't have unnecessary hyphens for weird phrases, just write it as you would in clear plain english

- Use short sentences most of the time to make work clearer and punchier. More than two lines is probably bad.

- Use the 'english comma' to show how to read the text

- Use non-breaking spaces all over the place

- spell out small numbers

- Prefer the default float-spec, [tbp],

- Also read booktabs' excellent manual on how table formatting should look: in short, never use vertical rules.

- Standard Model is capitalised

- Put all particle in italics (hepnames and hepparticles does this all for you)

- eV
- eV
- MINOS

eV

C++

eV

$\int \mathrm{d}x \sin^n x \cos^m x$.

- CHIPS
- NOvA
- MINOS

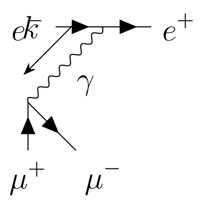
"Laws were made to be broken."
— Christopher North, 1785–1854

Section **??** Table **??** Ref. [**?**]

$\nu + p^+ \to n + e^+$

[1].

Once upon a time there was CHIPS which was very nice for NOvA which like to use 10 GeV because of MINOS which was very naughty



Symmetries, either intact or broken, have proved to be at the heart of how matter interacts. The Standard Model of fundamental interactions (SM) is composed of three independent continuous symmetry groups denoted $\mathrm{SU}(3) \times \mathrm{SU}(2) \times \mathrm{U}(1)$, representing the strong force, weak isospin and hypercharge respectively [**?**, **?**, **?**].

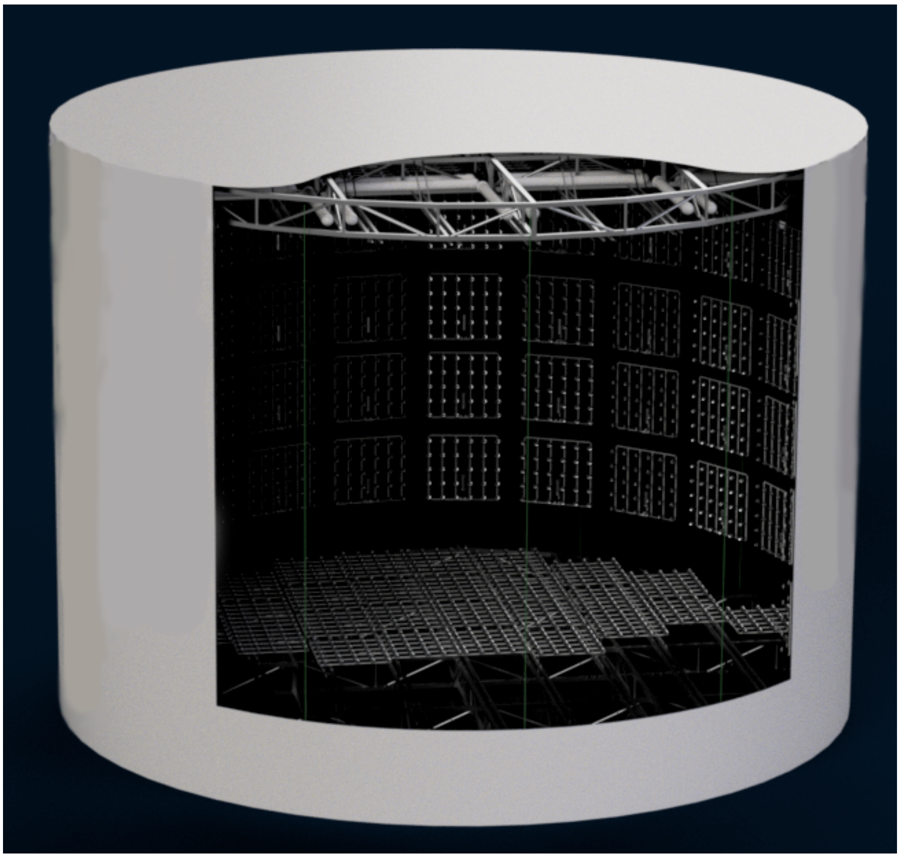


Figure 1.1.: CKM Fitter constraints on α from combined $B \to \pi\pi$, $B \to \rho\pi$ and $B \to \rho\rho$ decay analyses.

1.1. Neutral meson mixing

We can go a long way with an effective Hamiltonian approach in canonical single-particle quantum mechanics. To do this we construct a wavefunction from a combination of a generic neutral meson state $|X^0\rangle$ and its anti-state $|\overline{X}^0\rangle$:

Since both b-hadrons are preferentially produced in the same direction and are forward-boosted along the beam-pipe, the detector is not required to have full 4π solid-angle coverage. LHCb takes advantage of this by using a wedge-shaped single-arm detector with angular acceptance 10-300 mrad in the horizontal (bending) plane [?].

⋮

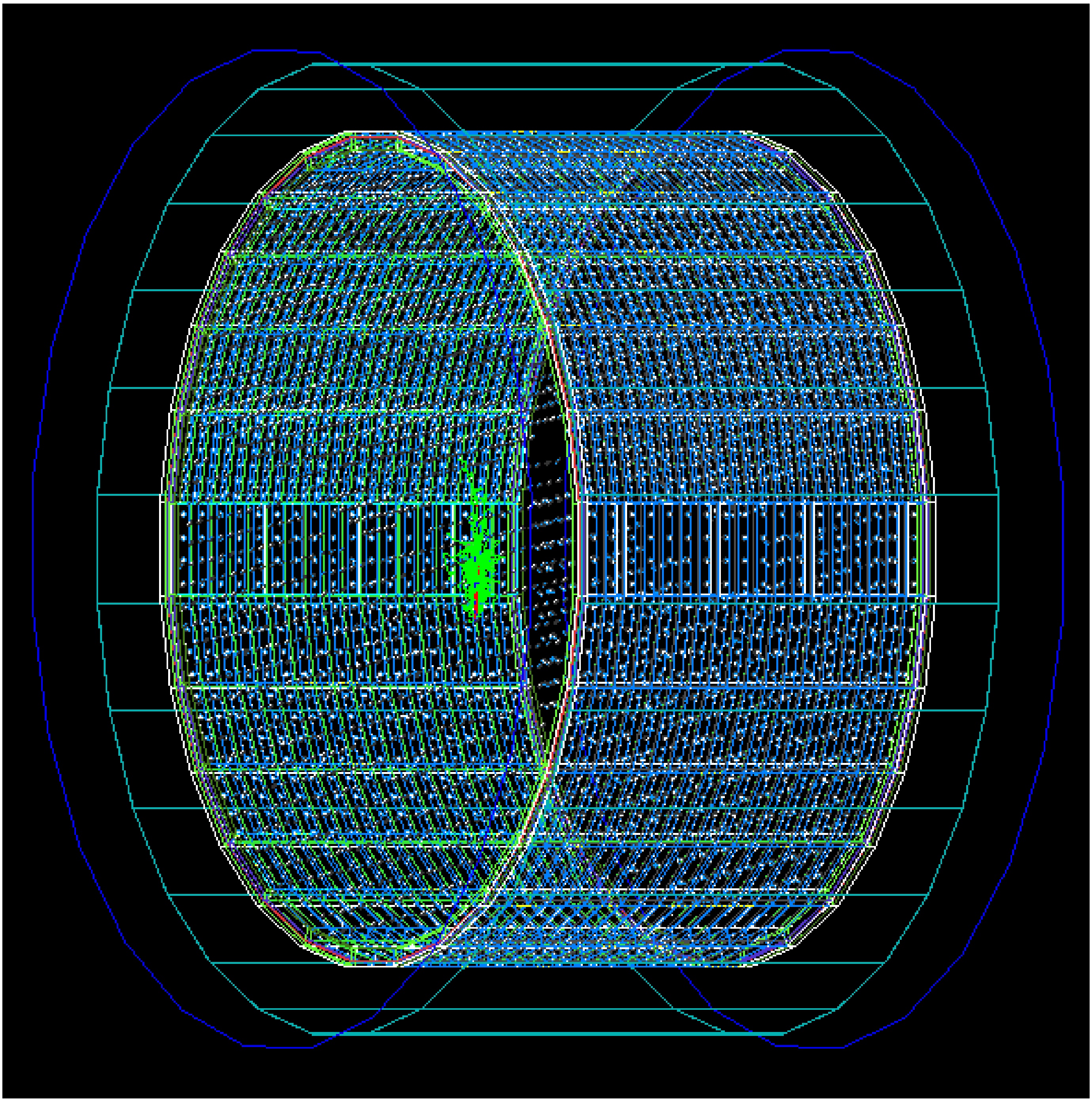


Figure 1.2.: Cross-section view of LHCb, cut in the non-bending y–z plane.

The detector is illustrated in Figure 1.1, showing the overall scale of the experiment.

$$|\psi(t)\rangle = a(t)|X^0\rangle + b(t)|\overline{X}^0\rangle \tag{1.1}$$

which is governed by a time-dependent matrix differential equation,

$$\imath\frac{\partial}{\partial t}\begin{pmatrix} a \\ b \end{pmatrix} = \underbrace{\begin{pmatrix} M_{11} - \frac{\imath}{2}\Gamma_{11} & M_{12} - \frac{\imath}{2}\Gamma_{12} \\ M_{12}^* - \frac{\imath}{2}\Gamma_{12}^* & M_{22} - \frac{\imath}{2}\Gamma_{22} \end{pmatrix}}_{\mathbf{H}} \begin{pmatrix} a \\ b \end{pmatrix}. \tag{1.2}$$

The single-sided detector design was chosen in preference to a two-armed design since the detector dimensions are restricted by the layout of the IP8 (ex-Delphi) cavern in which LHCb is located. Using all the available space for a single-arm spectrometer more than compensates in performance for the ∼50% drop in luminosity.

1.2. The Čerenkov mechanism

A Huygens construction in terms of spherical shells of probability for photon emission as the particle progresses along its track shows an effective “shock-front” of Čerenkov emission. This corresponds to an emission cone of opening angle θ_C around the momentum vector for each point on the track,

$$\cos\theta_C = \frac{1}{n\beta} + \frac{\hbar k}{2p}\left(1 - \frac{1}{n^2}\right) \tag{1.3a}$$

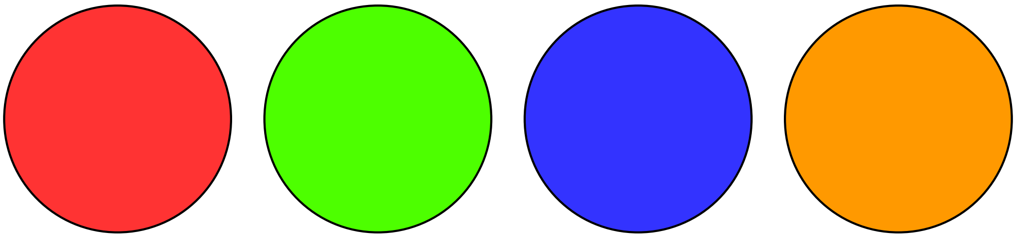
$$\sim \frac{1}{n\beta} \tag{1.3b}$$

where $\beta \equiv v/c$, the relativistic velocity fraction.

1.3. Trigger system

An overview of the LHCb trigger characteristics broken down by level is shown in Table 1.1.

Here are some funky floats using "continued captions", i.e. for a semantically collected group of float contents which are too numerous to fit into a single float, such as the pretty circles in the following figure:



(a) Example 1a **(b)** Example 1b **(c)** Example 1c **(d)** Example 1d

Figure 1.3.: Demonstration of `subfig` continued captions.

This mechanism means that the same float label is used for both pages of floats. Note that we can refer to Figure 1.3 in general, or to Figure 1.3g on page 7 in particular!

Just for the hell of it, let's also refer to Section 1.1.

Here are some funky floats using "continued captions", i.e. for a semantically collected group of float contents which are too numerous to fit into a single float, such as the pretty circles in the following figure

1.4. Convolutional Neural Networks

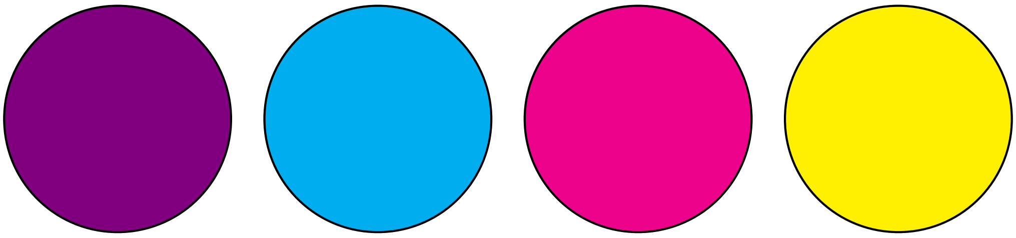
1.5. CHIPS Events

The expected beam flux at the CHIPS detector location is found from reweighting current

We can use current NuMI beam simulations

	L0	L1	HLT
Input rate	40 MHz	1 MHz	40 kHz
Output rate	1 MHz	40 kHz	2 kHz
Location	On detector	Counting room	Counting room

Table 1.1.: Characteristics of the trigger levels and offline analysis.



(e) Example 1e **(f)** Example 1f **(g)** Example 1g **(h)** Example 1h

Figure 1.3.: Demonstration of `subfig` continued captions (continued).

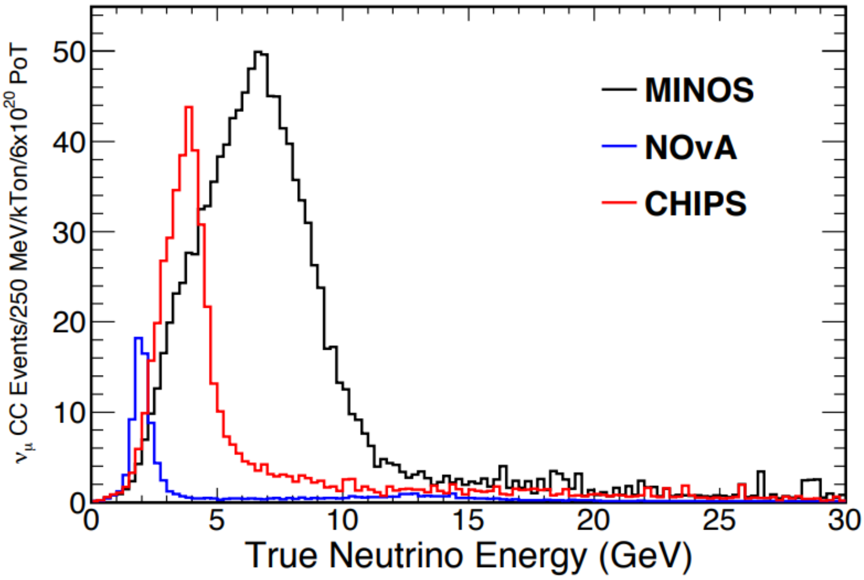


Figure 1.4.: CKM Fitter constraints on α from combined $\mathrm{B} \to \pi\pi$, $\mathrm{B} \to \rho\pi$ and $\mathrm{B} \to \rho\rho$ decay analyses.

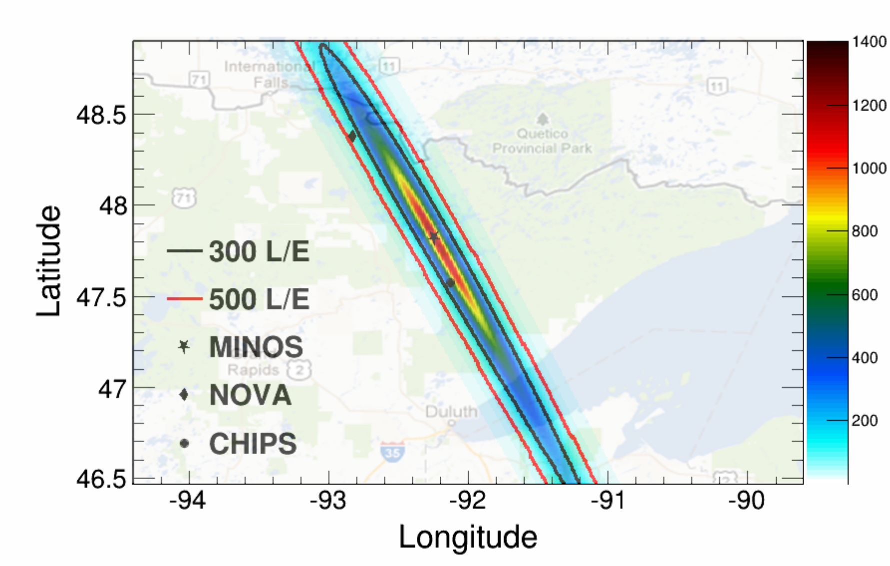


Figure 1.5.: CKM Fitter constraints on α from combined $B \to \pi\pi$, $B \to \rho\pi$ and $B \to \rho\rho$ decay analyses.

Current NuMI beam experiments

Once upon a time there was CHIPS which was very nice for NOvA which like to use 10 GeV

Chapter 2.

Introduction

blah blah blah

Chapter 3.

Neutrino oscillations: theoretical background and current status

Consider a simple two body decay Neutrino physics covers the widest possible range of Proposal of a mysterious undetector particle to explain beta decays in the 1930s through to the resolutions of a 30-year problem with the confirmation of oscillations in the early 2000s and onto the precision era. Neutrino oscillations first discoveed in 1957 when Bruno Pornecorvo proposed a model in which neutrinos oscilate to antineutrinos and back, similar to the kain. It was actually shown that neutrinos iscilate from one flavour to another. The field of neutrino physics is ever expanding with a new generation of experiments planned for the coming years. This chapter aims to provide an introduction to neutrino

3.1. A history of neutrino oscillations

In the early 20th century, beta decays were assumed to follow the simple two-body process, $A \rightarrow B + e$, where a nuclei spontaneously an electron, and only an electron. To conserve both energy and angular momentum the ejected electron must have a discrete kinetic energy defined by the different in binding energies between the initial and final nuclei. However, in 1914, J. Chadwick instead measured a continuous energy spectrum for the electron [1], placing this theory in doubt.

W. Pauli finally proposed a 'desperate solution' to this paradox in 1930 [2]. If a light, neutrally charged, spin 1/2 particle was also produced in the interaction, the continuous energy distribution could be explained. Initially this mysterious new particle was named the 'neutron'. But, to avoid confusion with the heavy baryon of the same name discovered in 1932, E. Fermi renamed it the 'neutrino' when he formalised beta decay in 1934 [3].

The following month, H. Bethe and R. Peierls used Fermi's work to estimate the cross-section of the inverse beta decay process $\nu + p^+ \to n + e^+$ [4]. They calculated a value of less than the very small $10^{-44} cm^2$ and declared 'there is no practically possible way of observing the neutrino.' Although extensive neutrino detection has proved possible, it hinted at the huge difficulties experimentalists would face hunting down the neutrino and measuring it's properties in the years to come.

After an initial tentative identification if 1953, F. Reines and C. Cowan made the first confirmed observation of the neutrino in 1956 [5]. Electron antineutrinos produced in the Savannah River Plan nuclear reactor were detected via the inverse decay process outlined in the previous paragraph. A 'club-sandwich' detector of three 1500 litre liquid scintillator tanks and two 200 litre cadmium doped water target tanks, was constructed in an underground room of the reactor building. A total of 330 photomultiplier tubes were then able to measure the prompt positron annihilation signal followed by the gamma ray burst from the neutron capture in cadmium, the signature identification for the interaction.

Brookhaven two kinds of neutrinos in Ref. [6] - Muon neutrino discovered by the 'long track' from the decays of pions from a reactor in 1988, got a nobel prize. - In 1962 at the alternating gradient synchrotron at Brookhaven, neutrinos created from pion decays together with muons were observed t produce only muons not electrons, this then confirmed the existence of the muon neutrino. - Neutrinos originating from pion decays primary produce muons, not electron. Detected as single long tracks in a spark chamber. - Got the 1988 nobel prize for this discovery of the second neutrino. - Distinct from the previously known electron neutrino - The neutrinos produced by the pions decay from a accelerator beam, were not the same as the neutrinos observed in beta decay - Did so by observing that it was far more likely that the neutrinos pro-duced in the decay of pions would interact to create muons, as opposed to electron - First experiment to construct and use an artificial neutrino beam - 34 identified muon events in total no electrons.

Discovery of the tau lepton [7] Also precise z-resonance measurement at lep in the 1990's [8] Finally measured by DONUT in 2000 [9] - evidence for the third neutrino, finally discovered at DONUT in 2000 - After the discovery of the tau lepton in 1975 [7], this suggested the existence of the third neutrino which DONUT found in 2000. - DONUT finally found the tau neutrino in 2000 using 800GeV protons from the Tevatron.

- In 2000 the DONUT experiment at the tevatron collider in fermilab performned a direct detection of the tau neutrino completing the three flavour picture. - Experiments at the LEP e+e- collider in the 1990s made precision measurmnets of the z decay width, from a fir to the data in showed there are exactly three active generations of neutrinos. - This indicates the number of active neutrino states can only be 1.984+-0.008. Therefore, any as yet undiscovered neutrinos must be sterile, in that they do not couple to the weak interaction.

Homestake deficit observation in Ref. [10] first SSU predictions used to compare against homestake in Ref. [11] Kamiokande II deficit in Ref. [12] SAGE experiment deficit in Ref. [13] GALLEX experiment deficit in Ref. [14] SSM Prediction for Ga in Ref. [15] - As the standard model of particle physics was developed, neutrinos were presumed to be massless and occur only in the three flavour eigenstates. - Various hints that this was not the case kept appearing, leading to neutrino oscillations, by witch one neutrino can oscillate to another flavour and the non-zero masses that follow as a direct consiquence from this. - In the solar neutrino sector there is the "solar anomaly" noting a deficit of electron neutrino compared to predications made by the standard solar model (SSM) - First observed at the Homestack experiment, neutrinos ineracted with the chlorine creating radioactive argon atoms, beause it is a noble gas it does not bing to the perchloroethylene and it can be extracted by purging the liquid with gaseous helium and then extracted from the helium with a cooled carbon trap. - Gallium was also used by other experiments and kamiokande also observed the deficit. - Also the fluxes measured where not consistent, depending on the energy range probed. Hinting at oscillations dependent on energy, - 400 000 litresof perchloroethylene (a dry-cleaning fluid), containing520 tof chlorine, placed in the Homestake Mine,1.5 kmunderground [24]. - he reported experimental rate was about two thirds less than what was expected from theStandard Solar Model (SSM). This large discrepancy, known as thesolar neutrino problem, wasinitially believed to be an experimental flaw. - This is where the future DUNE detector will be housed, nice full circle - This is in the solar sector

SNO oscillation measurement in Ref. [16] - neutrino oscillations were one way of explaining this deficit if some of the electron neutrinos converted flavour in flight. - SNO finally answered the question when it was able to measure three channels with different relation between te flyx or electron neutrinos and the other neutrinos. SNO could prove that the electron neutrinos are changing flavour. WHile the total flux of all neutrinos remains constant and in agrrement with the SSM. - 1kton tank of heavy (D2O deuterium) water, able to detect three different channels of neutrino interaction -

Cherenkov experiment, with 9500 8inch photomultiplier tubes detectro the light from neutrino interactions. - Since each of the rates for the three channels has a different relation between the flux of electron neutrinos and the others, SNO could confirm electron neutrinos are changing flavour, with the total flux being constant and in agreement with the SSM. - electron neutrino CC, NC and elastic scattering also. - total rate was consistent but less electron neutrinos than expected as they had oscillated. - However, only electron neutrinos canundergo CC interactions, as solar neutrinos do not have enough energy to produce muonor tau leptons. -

Atmospheric kamiokande deficit in Ref. [17] IMD detector atmospheric deficit in Ref. [18] Superkamiokande direction atmospheric neutrinos in Ref. [18] - This is in the atmospheric sector

3.2. Neutrino oscillation theory

blah blah blah

3.3. Current status and the future

3.3.1. Atmospheric

3.3.2. Accelerator experiments

3.3.3. Reactor experiments

3.3.4. The future

blah blah blah

Appendix A.

Pointless extras

"Le savant n'étudie pas la nature parce que cela est utile;
il l'étudie parce qu'il y prend plaisir,
et il y prend plaisir parce qu'elle est belle."
— Henri Poincaré, 1854–1912

Appendixes (or should that be "appendices"?) make you look really clever, 'cos it's like you had more clever stuff to say than could be fitted into the main bit of your thesis. Yeah. So everyone should have at least three of them...

A.1. Like, duh

Padding? What do you mean?

A.2. $\boldsymbol{y = \alpha x^2}$

See, maths in titles automatically goes bold where it should (and check the table of contents: it *isn't* bold there!) Check the source: nothing needs to be specified to make this work. Thanks to Donald Arsenau for the teeny hack that makes this work.

Colophon

This thesis was made in $\LaTeX\,2_\varepsilon$ using the “hepthesis” class [19].

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