Neutrinos via Charm Decays in Astrophysical Sources

by

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Abstract

Acknowledgements

Abbreviations

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2. Background

2.1. Particle Physics

The interaction and classification of elementary particles is currently most accurately described by the *Standard Model* (SM) of particle physics. From combining and generalizing the properties of *Quantum Mechanics* (QM) and *Special Relativity* (SR) emerges *Quantum Field Theory* (QFT) as the mathematical framework formalizing this construct. Certain features intrinsic to the SM require formulating additional gauge symmetries. Excitations occuring in the associated fields then correspond to various particles, of which the following paragraphs provide a brief overview. Since this work mainly deals with the statistical behavior of large quantities instead of individual particle probabilistics, a more detailed explanation is omitted.

Fundamental to the SM is a unitary $U(1) \times SU(2) \times SU(3)$ symmetry group, the generators of which can be understood as representing bosonic field quanta with the physical function of mediating interactions between fermionic spinor fields. Commutation relations equivalent to regular QM have to be fulfilled. Therefore, bosons must commute and have integer spin, whereas fermions must anticommute and have half integer spin.

Carriers of the strong force arise from SU(3) and are referred to as gluons. They couple to and themselves possess color charges, enabling color changing and self interaction. The only type of elementary fermions with non vanishing color charge are quarks, which exist in flavors of up and down, charm and strange, top and bottom, as well as the corresponding antiparticles. Appropriately, *Quantum Chromodynamics* (QCD) is the name given to the QFT governing any interaction involving color charge.

Weak, Electromagnetic, Electroweak, Higgs

Parity Violation, Mixing

Limits, Dark Matter, Dark Energy, Neutrino Oscillation, Quantum Gravity

General Relativity

Hadrons

Confinement, Asymptotic Freedom, Residual Nuclear Force, Decays

Leptons

Neutrinos, Decays

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Neutrinos

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A. Reference Frames

Depending on the application, energies in particle physics are either given as viewed from a suitable rest frame or independent from the choice of coordinate system altogether. One widely adopted formulation uses the Mandelstam variables

$$s = (p_1 + p_2)^2 \qquad t = (p_1 - p_3)^2 \qquad u = (p_1 - p_4)^2$$

to assign different channels in scattering processes via the squared momentum carried by the exchanged mediating particle. Implied in this context is the Minkowski inner product, making the above quantities manifestly Lorentz invariant.

When working with parametrizations defined for use in different subdisciplines it often becomes necessary to convert from center of mass energies $\sqrt{s}$ to the energy E of a projectile in the target rest frame. With $E^2 = \boldsymbol{P}^2 c^2 + M^2 c^4$ as well as momenta $P = (E, \boldsymbol{P})$ and $p = (mc^2, 0)$ one finds

$$s = (P + p)^2 = (E + mc^2)^2 - \boldsymbol{P}^2 = 2Emc^2 + m^2c^4 + M^2c^4$$

for the invariant mass. This relation is typically approximated as $s = 2Emc^2$ at high energies.

B. Cross Sections

Scattering

[1]

Production

Decay

C. Spectral Distributions

D. Pulsar Spindown

E. Implementation

In order to calculate neutrino spectra from hadronic distributions, several integrals have to be computed. Discretizing this task allows the general case

$$F(x,y) = \int dz\, G(x,z)\, H(z,y)$$

to be rewritten as a Riemann sum. Assuming G and H are integrable over a given interval,

$$F_{ij} = \sum\nolimits_k D_{kk}\, G_{ik}\, H_{kj}$$

converges to the exact solution for sufficiently small steps. Transforming variables

$$x \to x_i \qquad y \to y_j \qquad z \to z_k$$

and defining $D_{kk} = z_{k+1} - z_k$ leads to the above notation. It is easily shown how this expression in terms of indices translates to the product of corresponding matrices

$$\boldsymbol{F} = \boldsymbol{G}\boldsymbol{D}\boldsymbol{H}$$

as an equivalent formulation. Here the output $\boldsymbol{F} \in \mathbb{R}^{m\times n}$ is obtained from the inputs $\boldsymbol{G} \in \mathbb{R}^{m\times l}$ and $\boldsymbol{H} \in \mathbb{R}^{l\times n}$ as well as the square matrix $\boldsymbol{D} \in \mathbb{R}^{l\times l}$ that encodes all step sizes on its diagonal. These results enable quick and efficient implementation of the required calculations as program code, where array arithmetic operations can greatly increase execution speed.[1]

[1] In service of transparency and reproducability, the implementation can be viewed in this repository.

Bibliography

[1] D. Fagundes, M. Menon, *Nuclear Physics A* **880**, 1–11, ISSN: 0375-9474, DOI: 10.1016/j.nuclphysa.2012.01.017, arXiv: 1112.5115 [hep-ph] (2012).

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