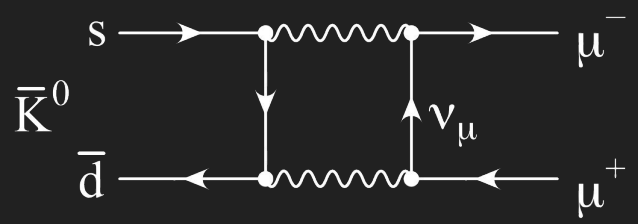
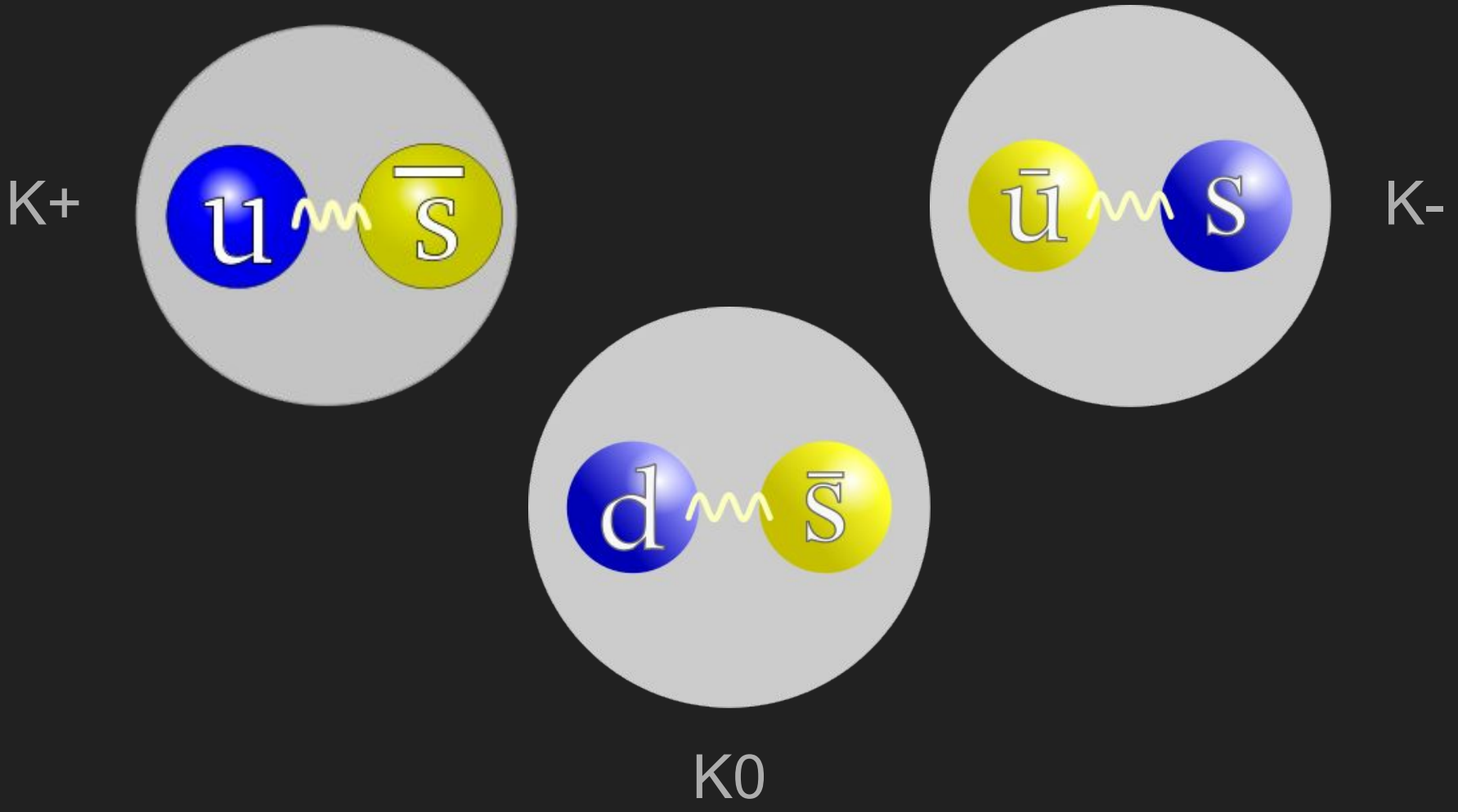
High Intensity Kaon Experiments (HIKE)

w/ NA62

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K0

The neutral Kaon K^0 and its antiparticle $\overline{K}^0$ are not observed directly, but in superposition with each other via the mass eigenstates:

(a) The short lived 'K-Short' (K_S^0) with a lifetime of about 0.08954 ns[5]. It can be described as (upto a factor of $\epsilon_K \sim \mathcal{O}(10^{-3})$):

$$K_S^0 = \frac{\left(K^0 - \overline{K}^0\right)}{\sqrt{2}} \tag{1}$$

(b) The long lived 'K-Long' (K_L^0) with a lifetime of about 51.16 ns[6]. It can be described as (upto a factor of $\epsilon_K \sim \mathcal{O}(10^{-3})$):

$$K_L^0 = \frac{\left(K^0 + \overline{K}^0\right)}{\sqrt{2}} \tag{2}$$

[Ks => K1 ; KL => K2]

CP Violation-

- Parity Violation - Wu Experiment ; 1957 Nobel Prize in Physics
- CP Violation - 1980 Nobel Prize in Physics
  - *Indirect* CP Violation:

$$K_1 = \frac{\left(K^0 - \overline{K}^0\right)}{\sqrt{2}} \qquad (CP = +1)$$

$$K_2 = \frac{\left(K^0 + \overline{K}^0\right)}{\sqrt{2}} \qquad (CP = -1)$$

for small ϵ:

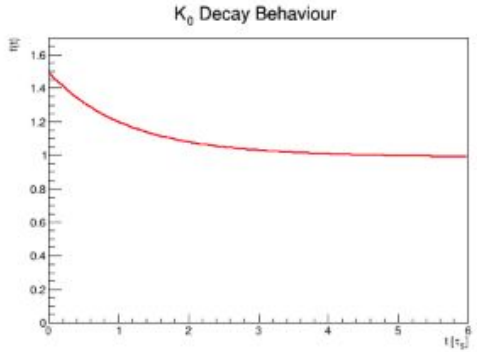
$$K_S = K_1 + \epsilon K_2$$
$$K_L = K_2 + \epsilon K_1$$

  - *Direct* CP Violation: <- Our Focus

    CP violation during the decay of the neutral Kaon itself and was discovered in 2002 at CERN by the NA48 experiment, which is the predecessor of the NA62 experiment

Kaon Decay-

$$f(t) = C_L.e^{-t/\tau_L} + C_S.e^{-t/\tau_S} + 2.D.C_{int}.cos(\phi_0 - \Delta mt).e^{-t/\tau}$$



$$\tau = \frac{2}{\frac{1}{\tau_L} + \frac{1}{\tau_S}}$$

$$D = \frac{N_{K^0} - N_{\overline{K^0}}}{N_{K^0} + N_{\overline{K^0}}}$$

4 variables of interest:

- CL
- CS
- Cint
- ϕ0

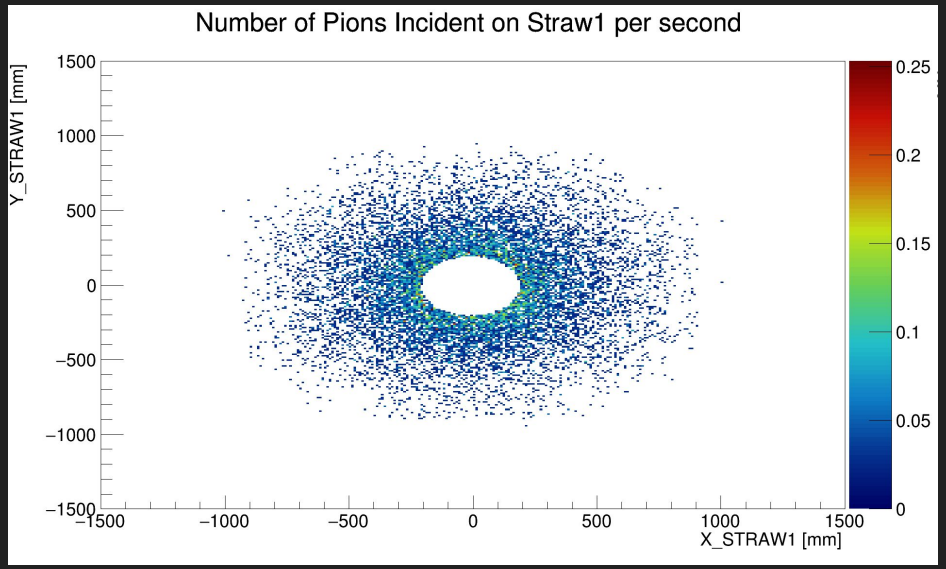
At CERN, the LHCb & NA48 experiment obtained a conditional value for 'D':

$$\frac{N_{K^0}}{N_{\overline{K^0}}} = 1.8 \quad => \quad D = \frac{2}{7}$$

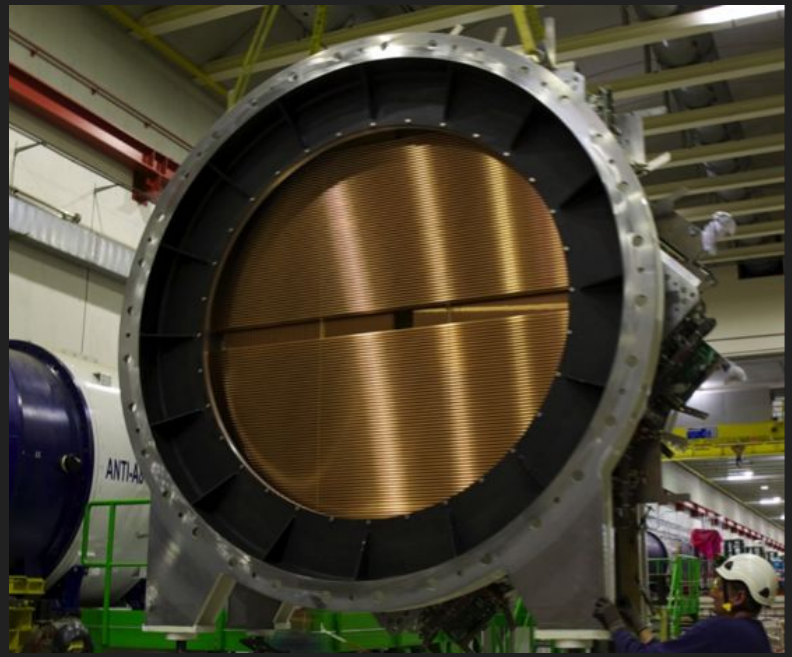
Event Rate Estimation-

To test the viability of the experiment and to generate a realistic amount of MCs for the simulations, it is pertinent to calculate the expected number of K0 → μ+μ− decays over the whole course of the experiment's run (currently expected to run for 5 years)

Example:



Integral = 352.013 **MHz**



Muon Event Rate Estimation Over 5 years-

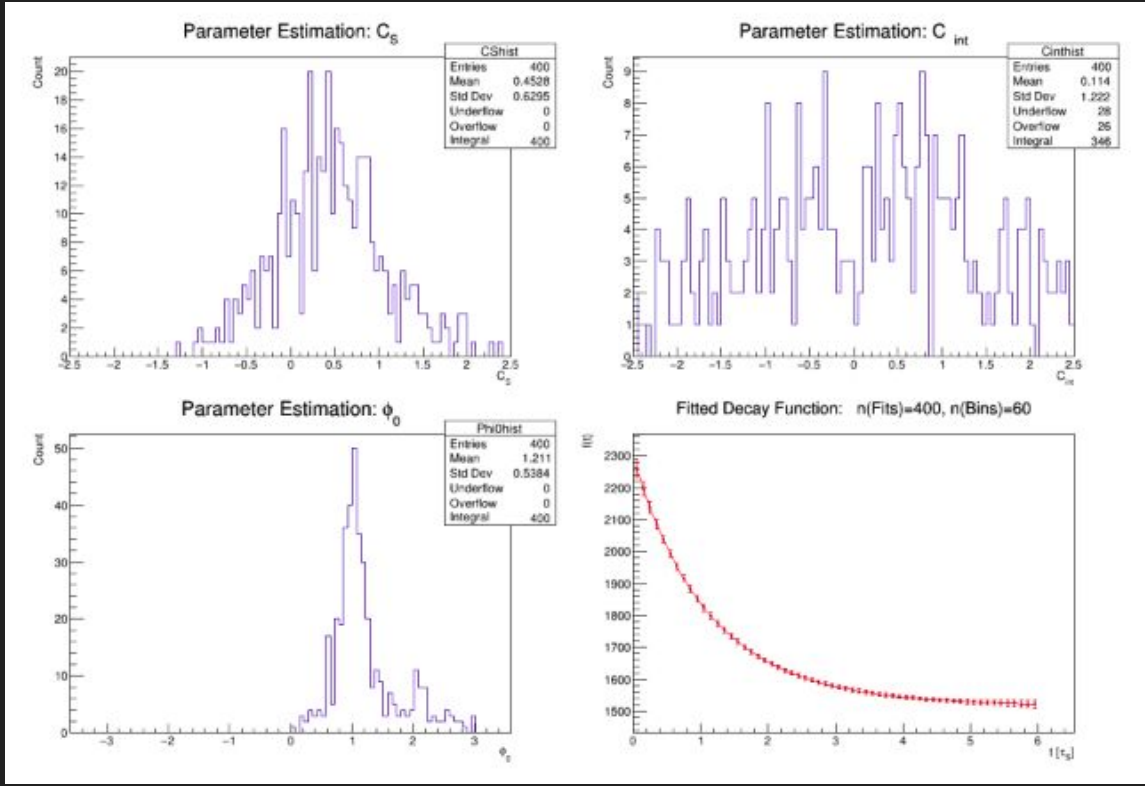
The annual rate of K0 -> μ+μ− decays was found to be ~**43,300**. For 5 years, this amounts to ~**200k** events, which is an abysmal total given the sensitivity of this experiment. The annual breakup was:

- Annual KL Frequency = 35,100
- Annual KS Frequency = 5,700
- Annual Kint Frequency = 2,500

Now to test if the parameters can be estimated even under 'ideal' conditions (no background) with the estimated 200k events. When normalised to CL (s.t. CL = 1), the theoretical values of:

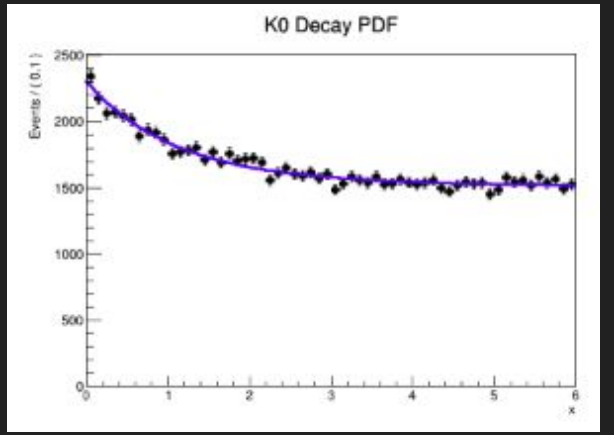
- Cs ~ 0.43
- Cint ~ 0.12
- $\phi 0$ ~ 0.20 (Very well constrained)

Using ROOT's TF1 Fitting:



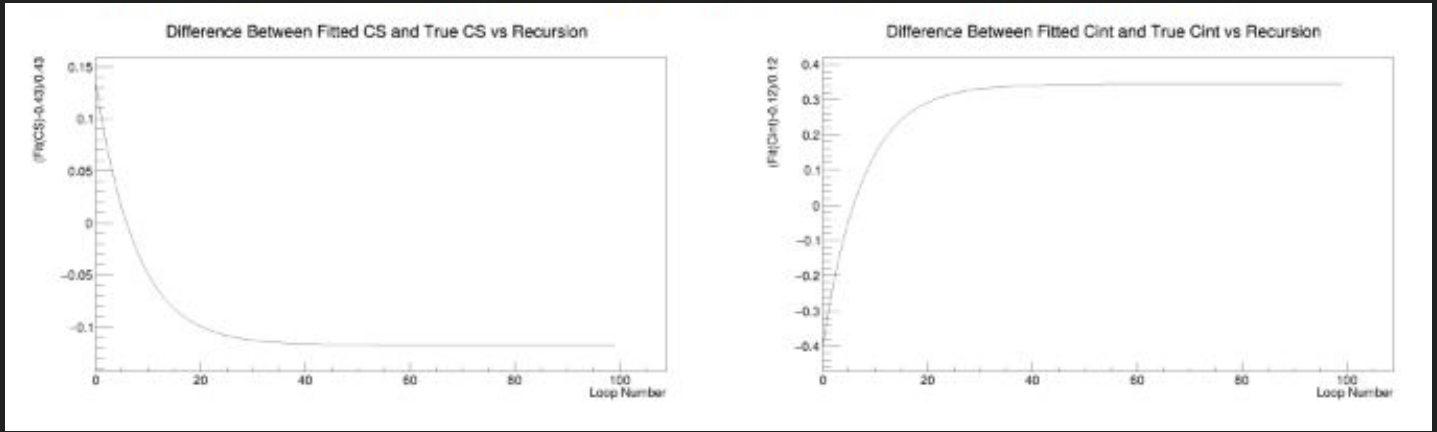
Using ROOT's Roofit:

Good Fit?---------->



Looks great! :D

What do the fitted parameters look like?



11% Error

32% Error

:(

What if we subtracted CL and then fit?

Dilution Constant	end point (tauKS)	no. of bins	no.of histograms		CS	CS Error	CS %Error	Cint	Cint Error	Cint %Error	Const. Phi0?	Phi0	Phi0 Error
0.285714286	3	100	100		0.404	0.1019	0.2522	0.1341	0.02347	0.1750	FALSE	0.5729	0.518
0.285714286	5	100	100		0.4199	0.05919	0.1410	0.1232	0.01391	0.1129	FALSE	0.2342	0.2185
0.285714286	6	100	100		0.4337	0.04109	0.0947	0.1189	0.01108	0.0932	FALSE	0.2321	0.1308
0.285714286	7	100	100		0.4281	0.029	0.0677	0.1204	0.007872	0.0654	FALSE	0.2073	0.07693
0.285714286	7.4	100	100		0.4306	0.02476	0.0575	0.1193	0.006671	0.0559	FALSE	0.1988	0.04975
0.285714286	8+	100	100		NOT WORKING								

Looks like Cs gives us ~5.75% error and Cint gives us ~5.59% error! **:D**

Let’s spend ~1.5 months trying to make this work!

…….false stability..?

(When stddev. of individual fits doesn’t equal stddev. of means of numerous fits)

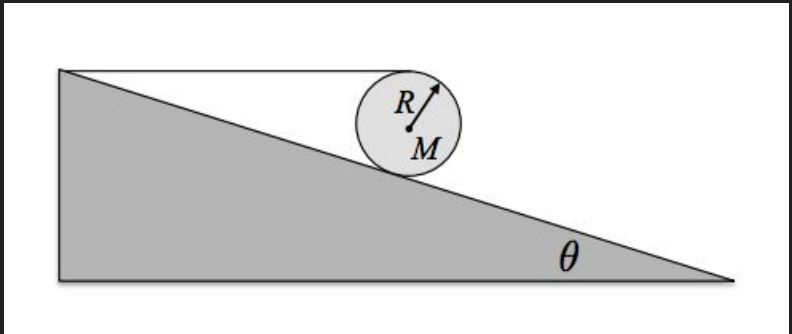
Here, RooFit was used to generate MCs according to ONLY [Cs+Cint] and the same was then fitted using RooFit. The input parameter (left) and the results (right) are shown here. Although this fit returned the best results and was the best bet for a long time (hence attempts to recreate it after producing full f(t) MCs), it was found that this fit was extremely unstable in that the likelihood of the parameters being within 90% error was approximately the same as the likelihood of their actual values, and hence the fit was returning values close to the initially set guess estimates for the parameters consistenlty even though the true uncertainty (internal fit error) was closer to 90% in the case of both CS and Cint. Bottom line is that the errors shown here are an illusion as these were extracted from the std. dev. of the means of the fits rather than the internal fit errors (which are the same in case of the other attempted fits on this document).

Don’t Take Things as Given - Always Check Multiple Times

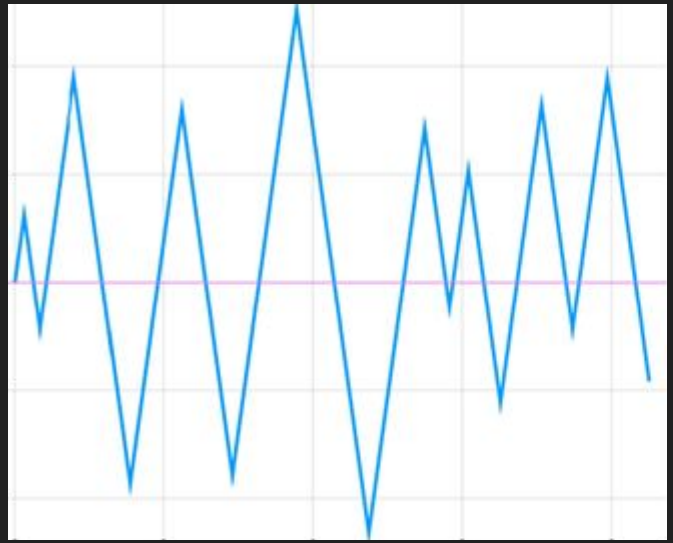
Answer?

Markov-Chain Monte-Carlo Fitting (Hopeful)

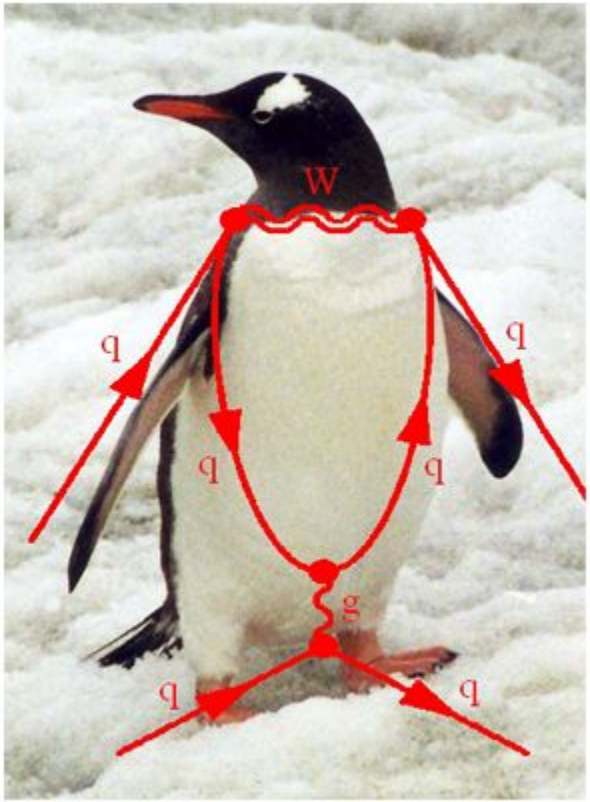
Maximum Likelihood:



MCMC Fitting:



CONCLUSIONS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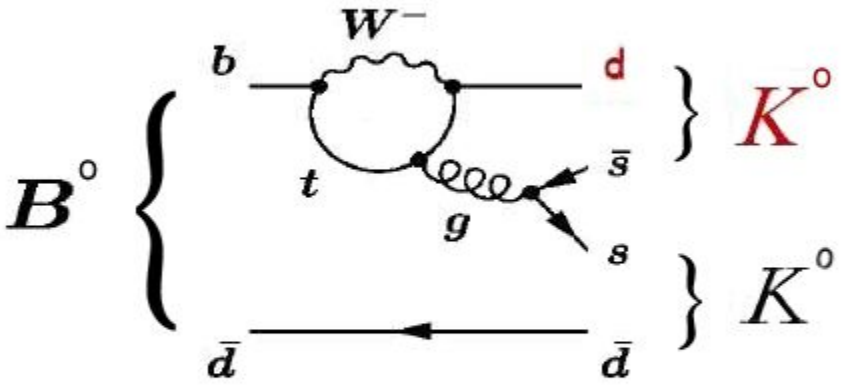
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Preliminary Equations:

$$N_{\pi\pi} = N_{PoT} \cdot P_{prod\,K} \cdot P^{(FV)}_{reach+decay} \cdot Br(K \to \pi^+\pi^-) \cdot \varepsilon_{signal}$$

$$\varepsilon_{signal} = A_{geom} \cdot A_{sel} \ldots\ldots\ldots\ldots$$

$$P_{prod\,K} = \frac{\int_{p_1,\theta_1}^{p_2,\theta_2} \frac{d^2N}{dpd\theta} dpd\theta}{\int_{0,-\pi}^{\infty,\pi} \frac{d^2N}{dpd\theta} dpd\theta}$$

$$\frac{d^2N}{dpd\Omega} = BX\frac{(1-X)^A(1+5e^{-DX})}{\left(1+{(p\theta)^2}/{C}\right)^4} \quad \text{with} \quad X = \frac{p}{E_0}$$