Impact of CLEO physics program

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The unknown impact

The very big picture

What is HEP

Very simple question

$$\boxed{\mathcal{L} = ?}$$

What is HEP

Very simple question

$$\mathcal{L} = ?$$

Not a very simple answer

Where is CLEO in all that?

$$\mathcal{L} = \mathcal{L}_{Kin} + \mathcal{L}_{Higgs} + \mathcal{L}_{Flavor}$$

- CLEO played a very important role in understanding the flavor part

The SM and beyond

Basics of HEP

Any proposed theory of nature is based on

- Imposed local symmetries (forces)
- Representations of the fermions and scalars (charges)

Then, the Lagrangian is

1. the most general one that obey the symmetries
2. it is renormalizable (no parameters with negative mass dimension)

The question: What is the Lagrangian of nature?

Namely, what are the symmetries and the fields in nature?

The SM

We have a theory that explain (almost) all experimental data

- The symmetry is $SU(3)_C \times SU(2)_L \times U(1)_Y$
- There are three generations of fermions

$$Q_L(3,2)_{+1/6} \qquad U_R(3,1)_{+2/3} \qquad D_R(3,1)_{-1/3}$$
$$L_L(1,2)_{-1/2} \qquad E_R(1,1)_{-1}$$

- The vev of the Higgs $H(1,2)_{+1/2}$ breaks the symmetry

$$SU(2)_L \times U(1)_Y \to U(1)_{EM} \qquad m_W \approx 80 \text{ GeV}$$

The SM parameters

The SM has 17 parameters

- 3 from the gauge sector (coupling constants and gauge bosons masses)
- 2 from the Higgs sector (vev and the Higss mass)
- 3 from the lepton sector (lepton masses)
- 10 from the flavor sector
  - 6 masses
  - 3 mixing angles
  - 1 CP violating phase

All parameters are equal

Not really...

- The more “interesting” parameters are those that have non trivial predictions. They are the gauge bosons, the Higgs, and the CKM parameters
- For example, we can measure the one CPV phase of the SM in many different independent ways. The electron mass, however, cannot be measured in many ways

The CKM matrix

The CKM matrix

Should I show it?

The CKM matrix

$$V_{ij} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \sim$$

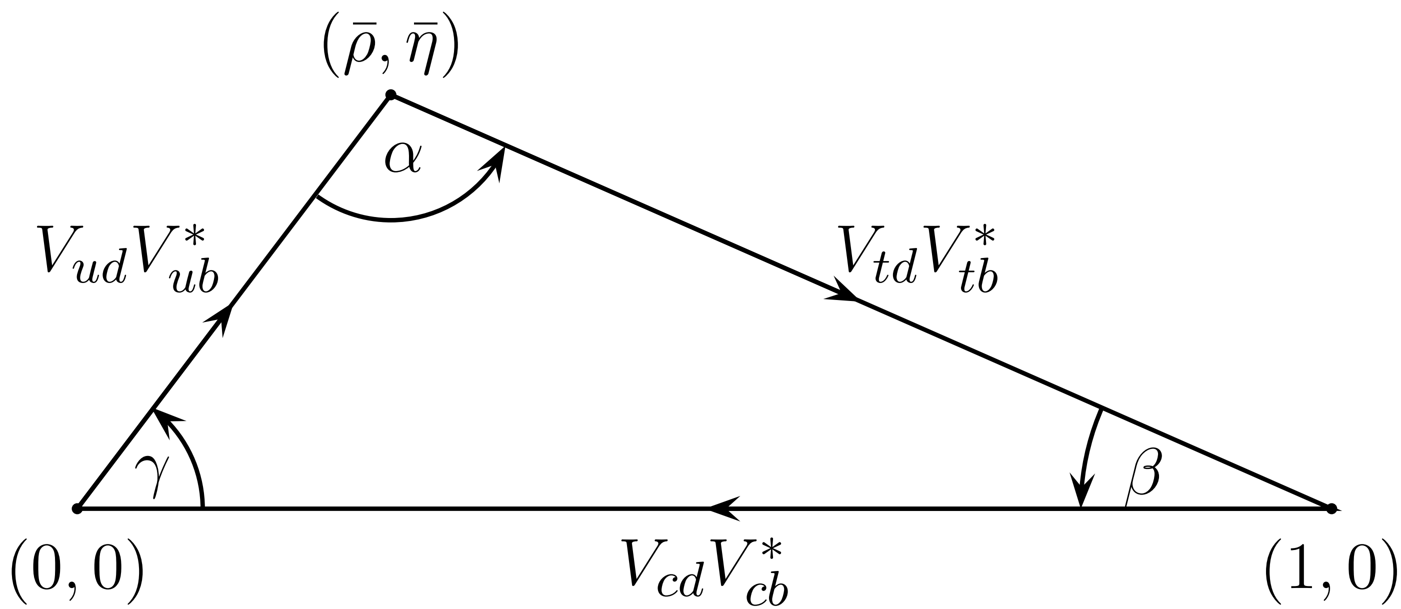
$$\begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

Four parameters:

$$|V_{us}|, \quad |V_{cb}|, \quad |V_{ub}|, \quad \delta_{KM} \quad \text{or} \quad \lambda, \quad A, \quad \rho, \quad \eta$$

The UT

Cannot give a talk without it...



The CKM parameters

- Pre CLEO: V_{us} (or λ)
- CLEO: V_{cb} and V_{ub} (or A and $\rho^2 + \eta^2$)
- Mainly post CLEO: δ_{KM} (or η)

Cleo made a very big physics impact. You were a major part in determining the very basics fundamental parameters of the universe

CLEO impact: summary (almost)

CLEO was a major player in determining three of the fundamental constants of nature

CLEO impact: summary (almost)

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THIS IS BIG

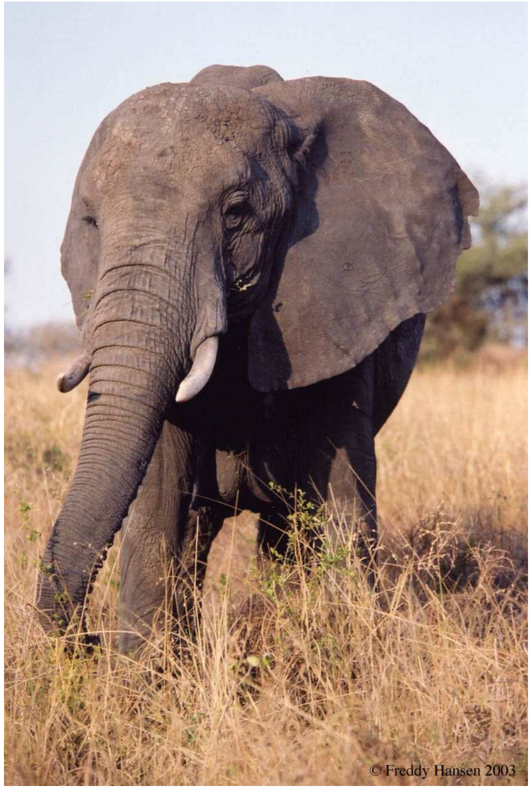
CLEO impact: summary (almost)

CLEO was a major player in determining three of the fundamental constants of nature

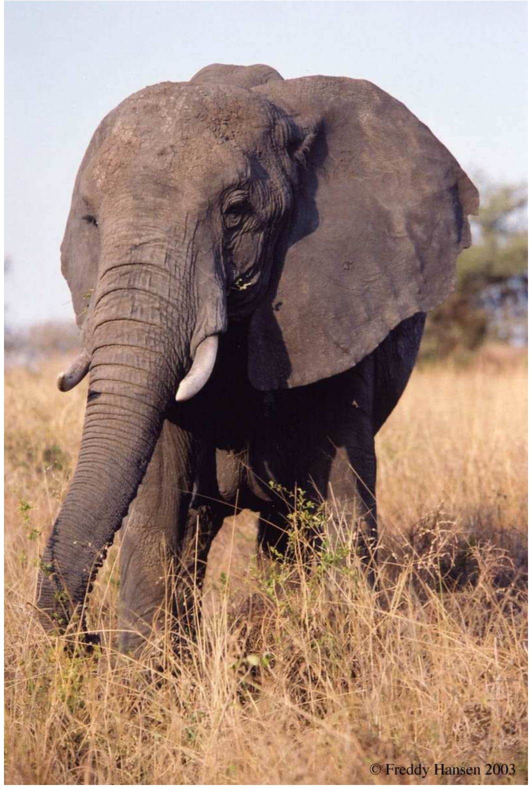
THIS IS BIG

Should I stop here? (Still have 37 min. to go...)

Big and bigger



Big and bigger



The flavor problems

The simple flavor problem

Why flavor

Flavor is interesting

- Fermion masses are (mainly) small and hierarchical
- Quark mixing angles are small and hierarchical
- FCNCs are very small
- The charged current is universal
- Neutrino and quark flavor are different

Flavor seems to have a lot to tell us

The problems

The flavor problems

- The SM flavor problem
- The EW hierarchy problem vs the SM flavor problem
- The NP flavor problem

Note: problems are good

The flavor problems

Flavor in the SM

The SM is doing great. The universal and the absence of FCNCs are explained. However,

- in the SM there is no explanation for fermion masses and mixings
- why most of the fermion masses are much smaller than the only scale in the theory, the weak scale?

The SM flavor problem

Does the structure in the fermion parameters indicate NP?

Two options:

- No. The flavor parameters are just input parameters. They are just what they are
- Yes. There is an underlying structure that explained it. Four example, broken flavor symmetries or split fermion is extra dimensions

The EW hierarchy problems

- The “natural” scale of nature is the Planck scale. The hierarchy problem:

$$\text{Why} \quad m_W \ll m_{Pl}$$

- In addition, we know that radiative corrections generate a Higgs mass close to the high scale (at or below the Planck scale). The fine tuning problem:

$$\text{Why} \quad m_H^T - m_H^{loop} \ll m_H^T + m_H^{loop}$$

Hierarchy vs fine tuning problems

- The EW sector has two problems, a hierarchy and a fine tuning problems
- It is often stated that fine tuning problems are “more severe”
- A term used for a hierarchy problem is “technically natural”. That is to say that radiative corrections do not affect the smallness of the parameter
- The SM flavor problem is a hierarchy problem
- Small m_u is technically natural, while small m_H is not

Scale separation

Another way to put it is as follows

- Small m_u requires a small parameter at one scale
- Small m_H requires connection between two scales. That is, physics at the high (say Planck) scale is relevant to the weak scale
- Scale separation is something we are so used to. Thus, we are saying that fine tuning problems are “more severe”
- Yet, I think that both problems provide indications for the presence of a more fundamental theory. The hierarchy problem is more severe since the number is smaller, and it points to the weak scale

The new physics flavor problem

The SM flavor puzzle: why the masses and mixing angles exhibit hierarchy. This is not what we refer to here

The SM flavor structure is special

- Universality of the charged current interaction
- FCNCs are highly suppressed

Any NP model must reproduce these successful SM features

The new physics flavor scale

- K physics: ϵ_K

$$\frac{s\overline{d}s\overline{d}}{\Lambda^2} \quad \Rightarrow \quad \Lambda \gtrsim 10^4 \text{ TeV}$$

- D physics: $D - \bar{D}$ mixing

$$\frac{c\overline{u}c\overline{u}}{\Lambda^2} \quad \Rightarrow \quad \Lambda \gtrsim 10^3 \text{ TeV}$$

- B physics: $B - \bar{B}$ mixing and CPV

$$\frac{b\overline{d}b\overline{d}}{\Lambda^2} \quad \Rightarrow \quad \Lambda \gtrsim 10^3 \text{ TeV}$$

There is no exact symmetry that can forbid such operators

Flavor and the hierarchy problem

There is tension:

- The hierarchy problem $\Rightarrow \Lambda \sim 1$ TeV
- Flavor bounds $\Rightarrow \Lambda > 10^4$ TeV

This tension is the NP flavor problem

Any TeV scale NP has to deal with the flavor bounds

$$\Downarrow$$

Such NP cannot have a generic flavor structure

Dealing with flavor

Any viable NP model has to deal with this tension.
Basically, there are two options

- Trying to solve both the SM and NP flavor problems at once
- Solve only the NP flavor problem

Examples:

- Two birds: SUSY alignment, RS with split fermions
- Only NP: Gauge mediation SUSY breaking

Where is the NP?

Where is the NP?

- There are theoretical hints that we have NP at the weak scale
- There are NP models that solve the hierarchy problem and still have no major effects on flavor
- Still, we expect to see small deviation from the SM

Where is the tail?

$b \to s\gamma$

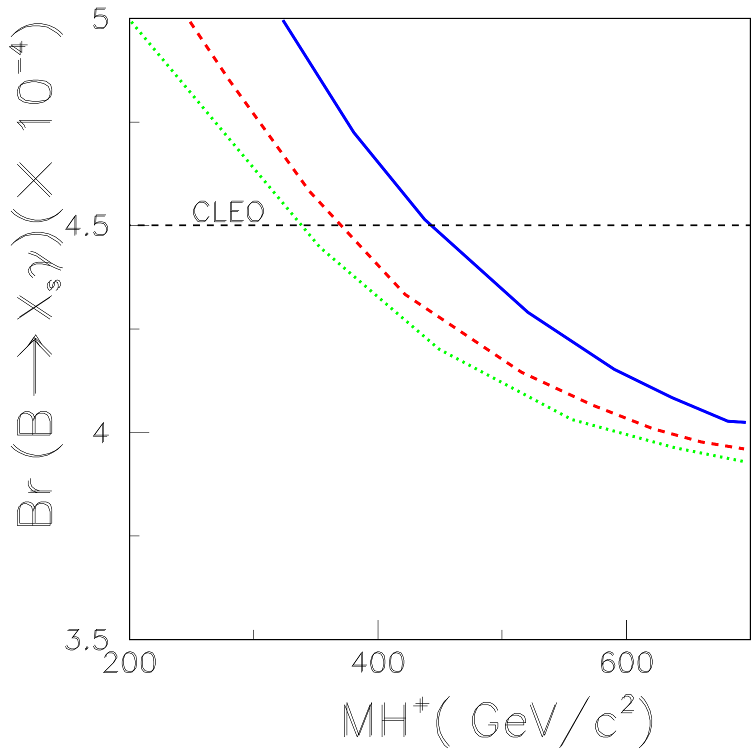
- Take SUSY as an example for physics beyond the SM. It has charged Higgs that big large contribution to $b \to s\gamma$
- What is the naive expectation of m_{H^+}?
- If you ask a person on the street

$$m_{H^+} \sim m_Z$$

- They are right! We should see the tail of the NP with $b \to s\gamma$

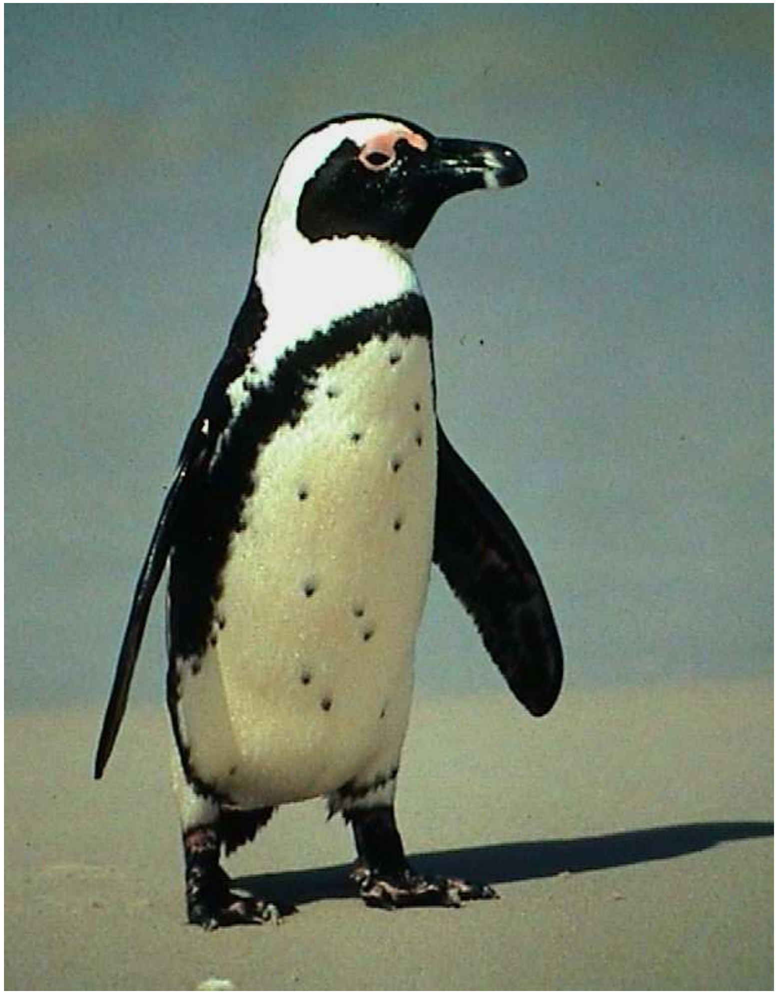
Bounds on M_H

M.H. Diaz, hep-ph/9905422



We do not see any deviation. No tail...

$b \to s\gamma$ is tailless



No tail theorem

When we do not see a tail, most likely, the whale is not around

No tail theorem

- $b \to s\gamma$ is just one example
- Many measurements by now. The SM is just perfect
- It is a real puzzle. What is the new physics that stable the Higgs?
- Flavor and LEP data make it such that there is no good idea for the answer

This is where CLEO had a huge impact! Verifying the SM picture of flavor

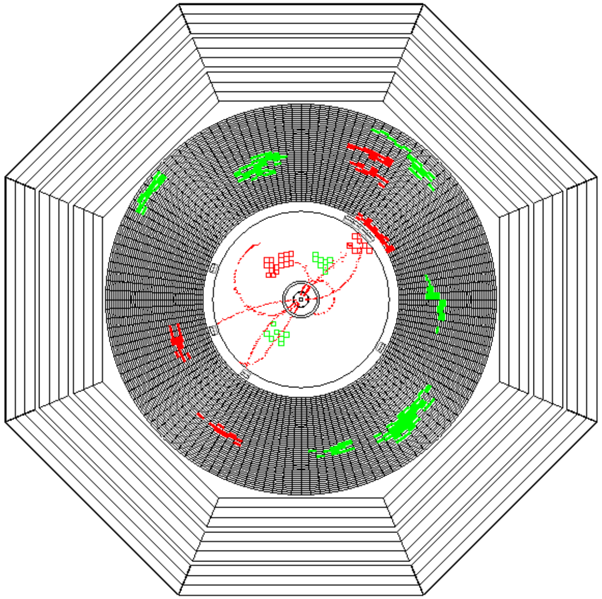
The SM flavor puzzle

The unknown fine tuning problem

Two numbers that seems unrelated

The unknown fine tuning problem

Two numbers that seems unrelated



The real SM flavor problem

An average person will tell us that

$$\theta_{ij} \sim 1$$

- Before CLEO all we knew was $\theta_C \sim 0.22$
- V_{cb} and V_{ub} are very small
- Masses and mixing angles have hierarchies

How come the flavor parameters (masses and mixing angles) are so different?

The SM flavor puzzle

Is there an underlining mechanism for the flavor structure?

- No (cannot be...)
- Yes. So what it is?
  - Extra dimension (RS)
  - Abelian Horizontal symmetry
  - Non-Abelian Horizontal symmetry

What it tells us?

Maybe the NP is such that it explain it all (all in one...)

- Explain why the weak scale is small
- Explain why we did not see it yet
- Explain the hierarchies

There are some examples that are getting close

Example: Randall-Sundrum

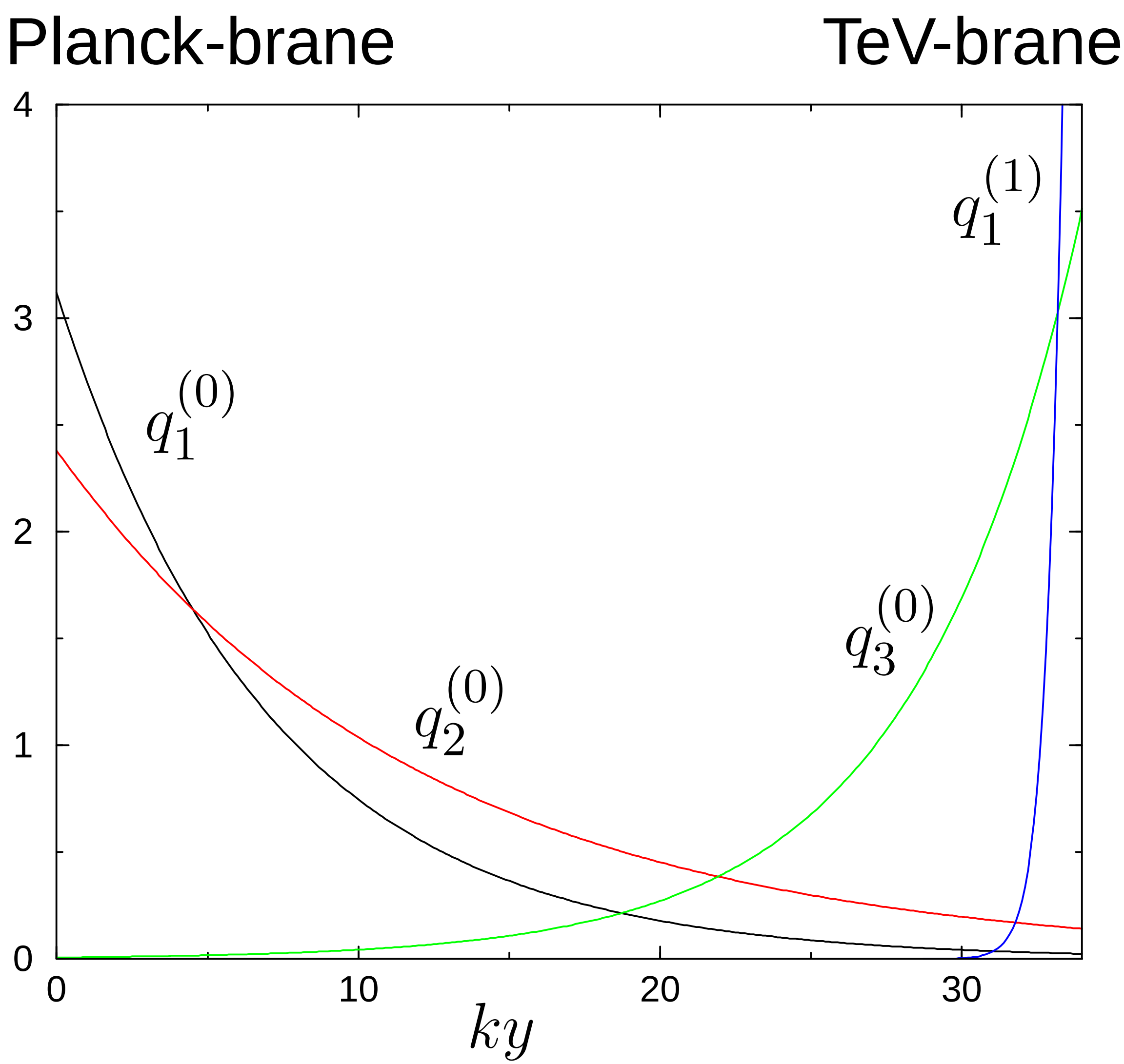
- The RS model solves the hierarchy problem with one extra non-factorizable dimension: $m = M_{\rm PL} \exp(-ky)$
- Solving the hierarchy problem requires a “TeV brane” at $ky \sim 40$, where the Higgs is localized
- Placing the fermions in the bulk can generate the observed flavor structure
- Generic new operators appear with scale of order

$$\Lambda \sim M_{\rm PL} \exp(-ky^f)$$

  where y^f is the “localization” of the fermion f
- Heavy fermions have larger y^f and thus larger flavor violation effects

Fermions in Randall-Sundrum

Huber; Agashe et al.



- The effective NP scale is $\Lambda \sim M_{\rm PL} \exp(-ky)$
- Explain both the SM and NP problems with mild fine-tuning

Conclusions

To put it mildly

- We always wanted to know how the universe works
- CLEO was a major player in understanding how the universe works
- I think this is good enough...