7 percent - Surely you’re joking, Mr. Feynman

The problem was to find the right laws of beta decay. There appeared to be two particles, which were called a tau and a theta. [...] Not only did they seem to have the same mass, but they also had the same lifetime, which is a funny coincidence. [...]

At a meeting I went to, it was reported [...] At that particular time I was not really quite up to things: I was always a little behind. Everybody seemed to be smart, and I didn't feel I was keeping up.

So the next day, at the meeting, [...] I got up and said, "I'm asking this question for Martin Block: What would be the consequences if the parity rule was wrong?" [...] Lee, of Lee and Yang, answered something complicated, and as usual I didn't understand very well. [...]

Anyway, the discovery of parity law violation was made, experimentally, by Wu, and this opened up a whole bunch of new possibilities for beta decay theory. [...] But the data were so confusing that nobody could put things together. [...]

At one point there was a meeting in Rochester, the yearly Rochester Conference. I was still always behind, and Lee was giving his paper on the violation of parity. [...]

I brought the paper home and said to her, "I can't understand these things that Lee and Yang are saying. It's all so complicated."

"No," she' said, "what you mean is not that you can't understand it, but that you didn't invent it. You didn't figure it out your own way, from hearing the clue. What you should do is imagine you're a student again, and take this paper upstairs, read every line of it, and check the equations. Then you'll understand it very easily."

I took her advice, and checked through the whole thing, and found it to be very obvious and simple. I had been afraid to read it, thinking it was too difficult.

I went to Professor Bacher and told him about our success, and he said, "Yes, you come out and say that the neutron-proton coupling is V instead of T. Everybody used to think it was T. Where is the fundamental experiment that says it's T? Why don't you look at the early experiments and find out what was wrong with them?"

I went out and found the original article on the experiment that said the neutron proton coupling is T, and I was shocked by something. I remembered reading that article once before (back in the days when I read every article in the Physical Review it was small enough). And I remembered, when I saw this article again, looking at that curve and thinking, "That doesn't prove anything!"

Corrección: Derivadas númericas

El Tracker mide x_t, y calcula:

Velocidad

$$v_t = \frac{x_t - x_{t-1}}{\Delta t}$$

Aceleración

$$a_t = \frac{v_t - v_{t-1}}{\Delta t}$$

$$= \frac{\frac{x_t - x_{t-1}}{\Delta t} - \frac{x_{t-1} - x_{t-2}}{\Delta t}}{\Delta t}$$

$$= \cancel{\frac{x_t - x_{t-2}}{\Delta t^2}} \quad \frac{x_t - 2x_{t-1} + x_{t-2}}{\Delta t^2}$$

Aceleración media

$$\bar{a} = \frac{1}{N-3} \sum_{i=2}^{N} a_i$$

$$= \cancel{\frac{x_N - x_{N-1} - x_2 - x_1}{(N-3)\Delta t^2}}$$

$$= \frac{(x_N - x_{N-1}) - (x_2 - x_1)}{(N-3)\Delta t^2}$$

$$= \frac{v_N - v_2}{(N-3)\Delta t}$$

Modelando experimentos

o: ¿por qué agregar parámetros a un ajuste?

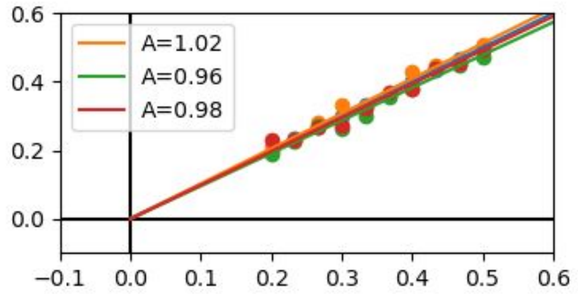
Resumen de hoy

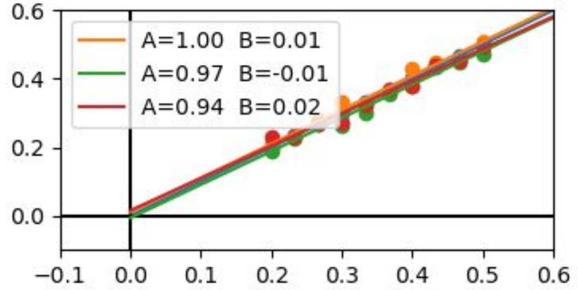
- ¿Cómo elegir (y refinar) un modelo?
- Discutir el problema de agregar parámetros extra:
    - Incrementa la incerteza de los parámetros
    - ¿Puede introducir inexactitudes o sesgos? No se.
    - Introduce sesgos en la predicción.
- Analizar 3 casos:
    - Tiempo total vs Número de periodo (péndulo)
    - Longitud vs. Periodo (péndulo)
    - Fuerza de rozamiento vs Normal (rozamiento)
- Yapa:
    - ¿Por qué el error de 20 periodos era igual que el de 1 periodo?

Estadística

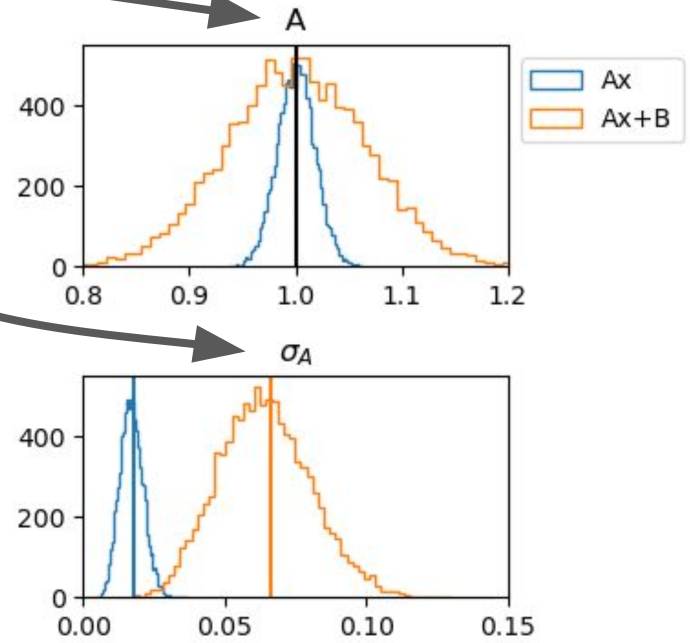
Agregando parámetros extra

Supongamos que tenemos un modelo real **y = Ax**:





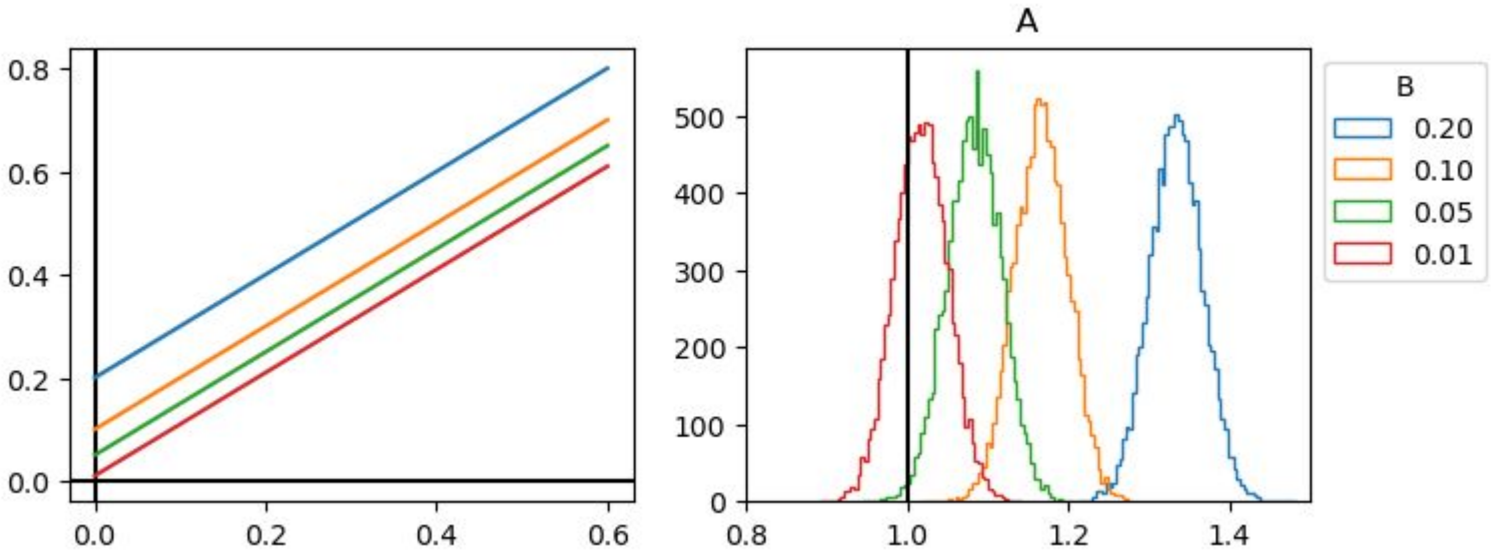

```
params, cov = curve_fit(func, x, y)

sigmas = np.sqrt(np.diag(cov))
```



Agregar parámetros extra agrega incerteza en los parámetros.

Omitiendo parámetros reales

Supongamos que tenemos un modelo real **y = Ax+B**:



Omitir parámetros agrega sesgos (o bias) en los parámetros.

Resumen

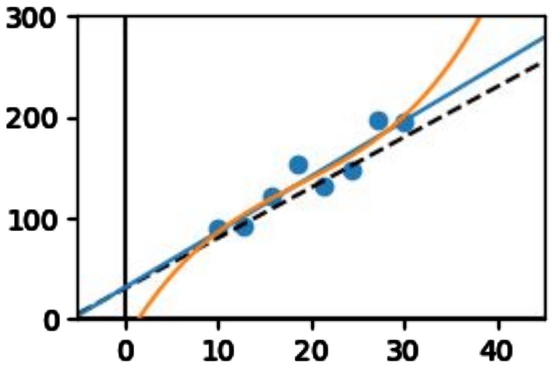
Omitir parámetros reales, aumenta el sesgo

Agregar parámetros extra, no agrega(ría) sesgo

Agregar parámetros extra, aumenta la incerteza

Entonces, ¿agregamos parámetros extra porque mejor impreciso que inexacto?

$$y = Ax$$



Analicemos los experimentos

Péndulo

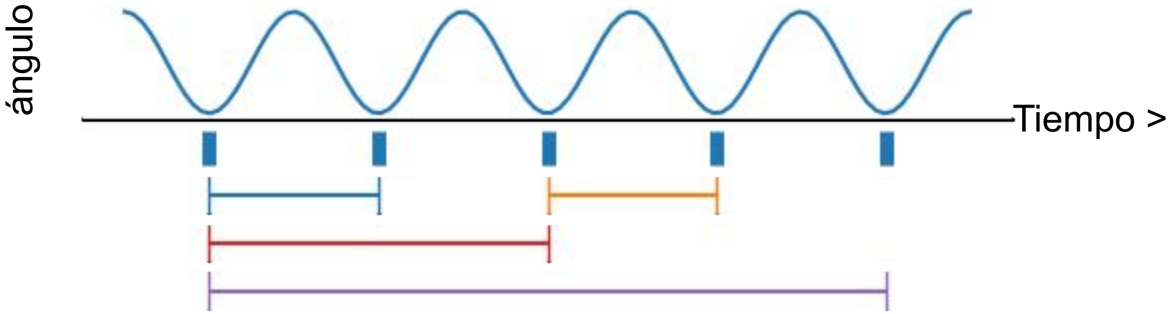
1. Error de cada medición
2. Tiempo total vs número de periodo
3. Longitud vs periodo^2

Rozamiento

1. Parábola
2. Fuerza de rozamiento vs Normal
3. ¿Ángulo del Phyphox o del Tracker?

Péndulo

Error de un intervalo de tiempo

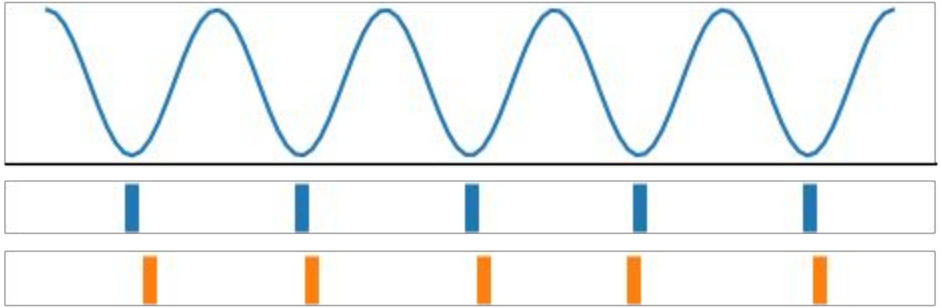


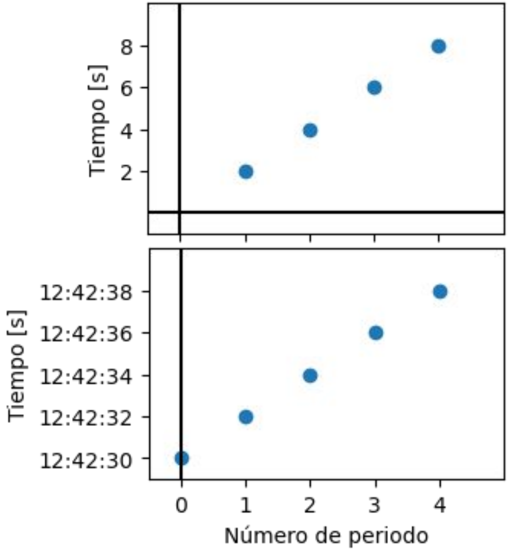
El error de cualquier intervalo de tiempo es el mismo.

$$T = t_{final} - t_{inicial} \qquad\qquad \sigma_T^2 = \sigma_{t_{final}}^2 + \sigma_{t_{inicial}}^2 = 2\sigma_t^2$$

Podemos medir directamente $\longrightarrow$ $\sigma_T = \sqrt{2}\,\sigma_t$ $\longleftarrow$ Podemos calcular indirectamente

Tiempo en función del número de periodo





Sin error

	cronometro
0	0.0
1	2.0
2	4.0
3	6.0
4	8.0

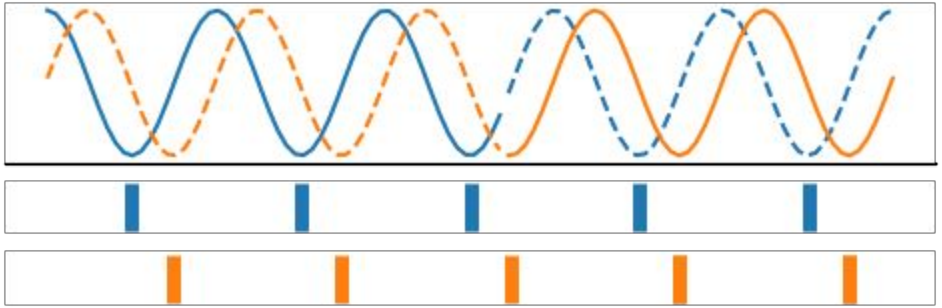
Con error

	cronometro	vueltas	suma
0	-0.04	NaN	NaN
1	1.99	2.03	2.03
2	3.79	1.80	3.83
3	6.16	2.37	6.20
4	7.82	1.66	7.86

$$t(n) = T\,n + t_0$$

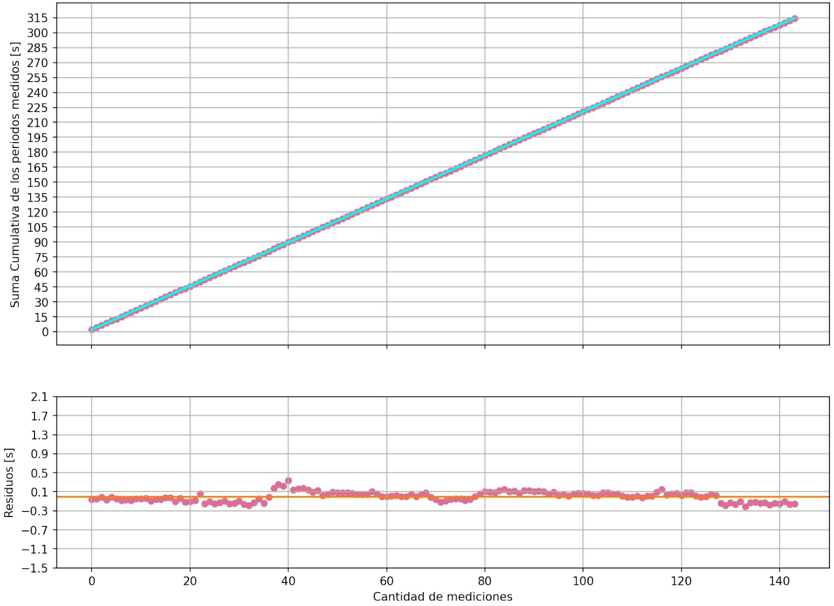
$$y = A\,x + B$$

Concatenando las mediciones



$$t(n) = T\,n + t_0$$

$$y = A\,x + B$$



Longitud vs periodo del péndulo

¿El modelo fisico estaba mal, porque había que agregarle una constante?

$$T = 2\pi\sqrt{\frac{L}{g}} \longleftrightarrow T^2 = \frac{(2\pi)^2}{g}L + B$$

La gráfica está desplazada hacia arriba con respecto al modelo expresado teóricamente.

1. Sobreestimado el valor de los períodos
2. Subestimando la longitud del hilo (por hilo extensible)
3. No sea válida la aproximación de ángulos pequeños (por ángulo inicial fue demasiado grande)
4. No sea válido despreciar la resistencia con el aire

En 4 y 5, dicen que el período es más grande.

$$\left.\begin{aligned} T^2 &= \frac{(2\pi)^2}{g}(L - L_0) \\ T &= \frac{2\pi}{\sqrt{g}}\sqrt{L - L_0} \end{aligned}\right\}$$

$$T = \frac{2\pi}{\sqrt{g}}\sqrt{L} + T_0$$

Ir a simulación en Colab

Rozamiento

Parábola

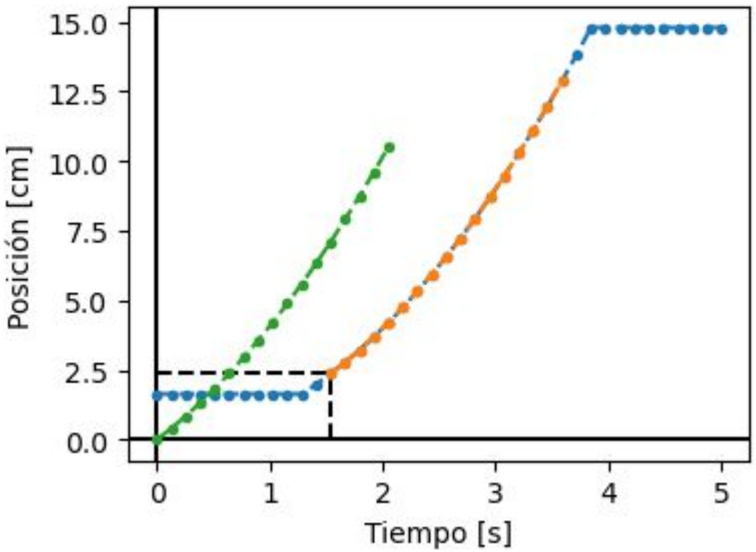
¿Conocemos alguna constante de integración?

Aceleración constante:

$$\ddot{x} = \frac{d^2x}{dt^2} = a(t) = ?a$$

$$\dot{x} = \frac{dx}{dt} = v(t) = at$$

$$x(t) = \frac{1}{2}at^2$$



¡No olvidarse de las constantes de integración!

Hacer esto (y no poner x_0) equivale a decir que medimos ese primer punto con precisión infinita.

Fuerza de rozamiento vs Normal

$$F_r \propto N \longrightarrow F_r = \mu_d N$$

$$\begin{cases} F_r = mg\sin\alpha - ma_x \\ N = mg\cos\alpha \end{cases}$$

$$\cancel{m}g\sin\alpha - \cancel{m}a_x = \mu(\cancel{m}g\cos\alpha)$$

$$y = \mu x$$

$$y(\alpha) = \frac{a_x}{g} = \sin(\alpha) - \mu\cos(\alpha)$$

Tracker vs Phyphox

¿A quién le creemos?

¿Qué ángulo miden?

Tracker: respecto del eje x del video.

Phyphox: respecto de la dirección de la gravedad.

Pero, ¿podemos usar el ángulo del Tracker? ¿Para qué?

“Más facil” de medir.

Aporta otra medición independiente.

Fuerza de rozamiento vs Normal

$$F_r \propto N \longrightarrow F_r = \mu_d N$$

$$\begin{cases} F_r = mg\sin\alpha - ma_x \\ N = mg\cos\alpha \end{cases} \rightarrow \cancel{m}g\sin\alpha - \cancel{m}a_x = \mu(\cancel{m}g\cos\alpha)$$

$$y(\alpha) = \frac{a_x}{g} = \sin(\alpha) - \mu\cos(\alpha)$$

$$y(\alpha) = \frac{a_x}{g} = \sin(\alpha - \alpha_0) - \mu\cos(\alpha - \alpha_0)$$

```
def func(x, mu, x0):
    return np.sin(x - x0) - mu * np.cos(x - x0)

params, cov = curve_fit(
    f=func,
    xdata=angulo,
    ydata=aceleracion / g,
    sigma=error_aceleracion / g,
    p0=[0.5, 0],  # Parámetros iniciales
)
```

Resumen

Agregar parámetros extra -> incrementa incerteza

Omitir parámetros “reales” -> introduce sesgos

Hay que pensar en el experimento para entender que modelo usar.