Precision Calculations in Particle Physics

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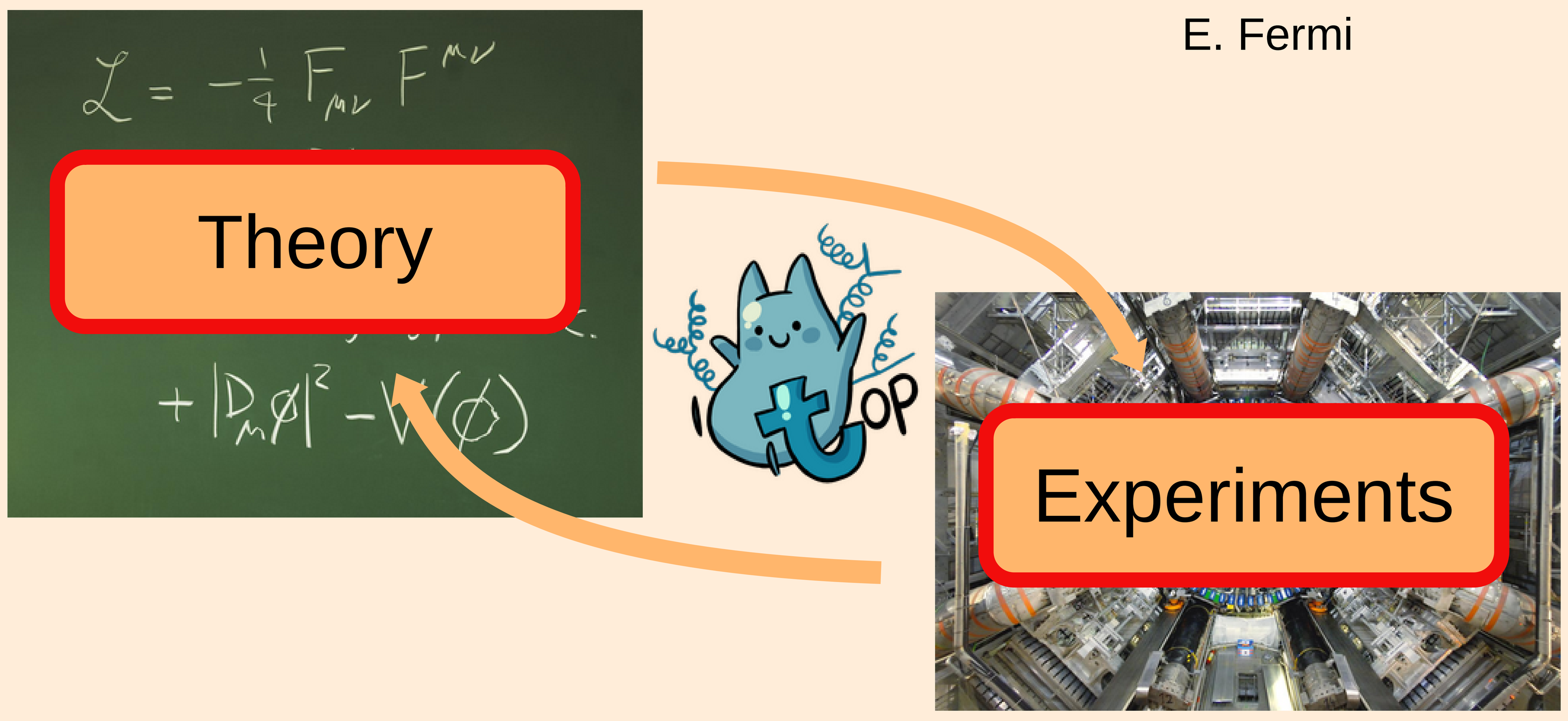
*"There are two possible outcomes: if the result confirms the hypothesis, then you've made a **measurement**. If the result is contrary to the hypothesis, then you've made a **discovery**."*

E. Fermi



Website

Video

Group of Prof. Dr. Thomas Gehrmann

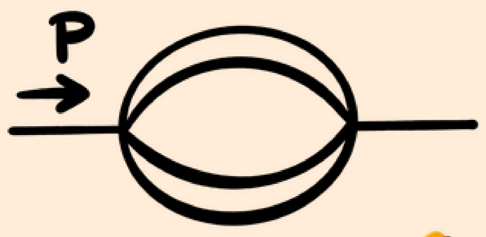
A N A L Y T I C S

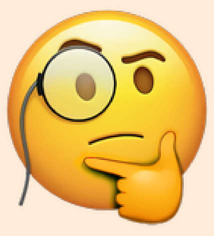
Fantastic functions and where to find them

The evaluation of multiloop Feynman diagrams requires **special functions**:

- Polylogarithms;
- Harmonic Polylogarithms;
- Goncharov multiple Polylogarithms;
- Elliptic Integrals;
- Unknown functions??

"Banana" graph:





$$\mathrm{Li}_{s+1}(z) = \int_0^z \mathrm{d}t\, \frac{\mathrm{Li}_s(t)}{t}, \quad \mathrm{Li}_1(z) = -\log(1-z)$$

Surely you're joking, Mr. Feynman!

Thousands of different **Feynman integrals** are needed to compute loop scattering amplitudes. We use IBP relations to reduce them to a basis of **Master Integrals.**

$$I = \sum_{i=1}^{n} c_i M_i$$

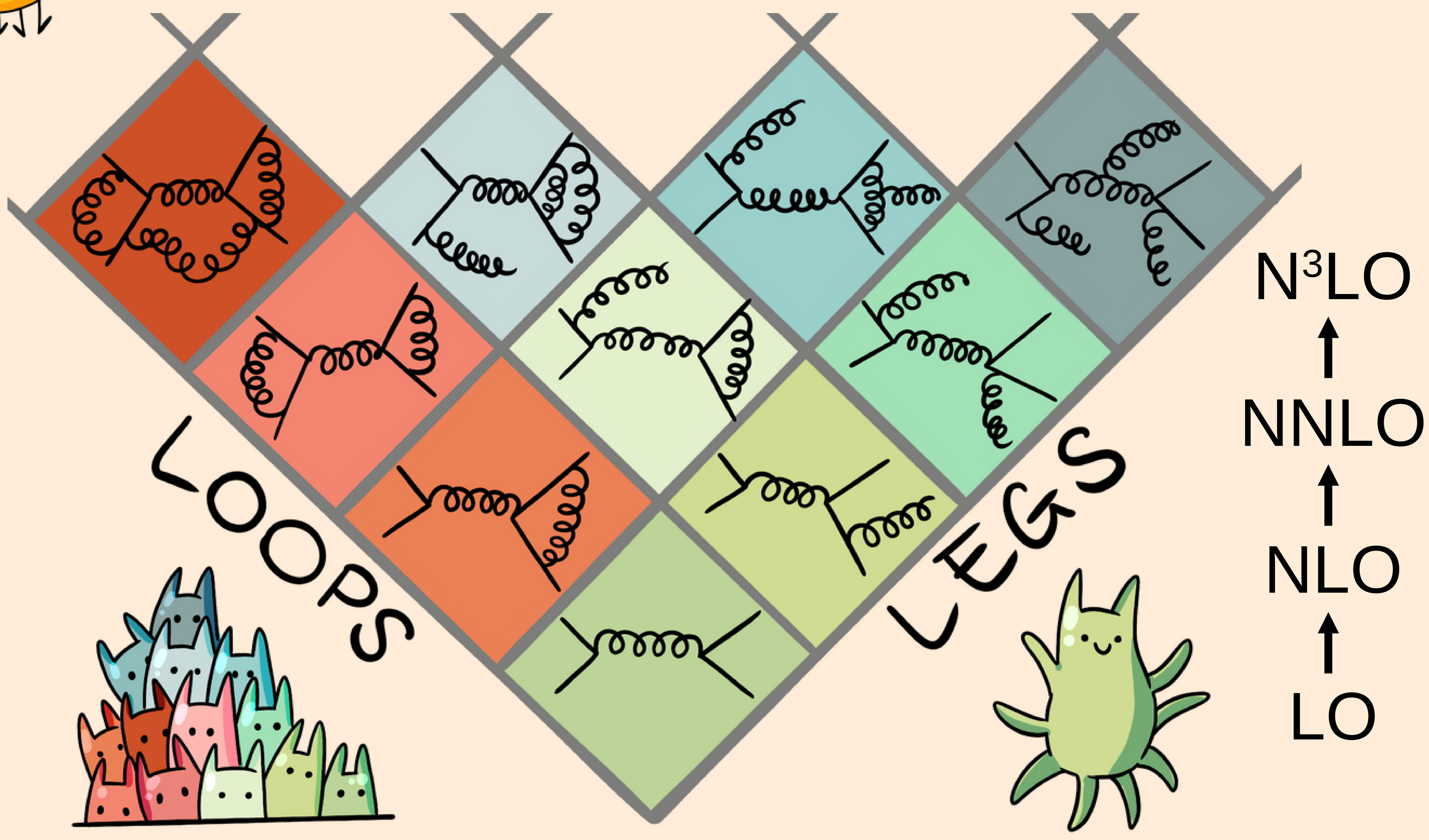
$$\int \mathrm{d}k \frac{\partial}{\partial k^\mu}\left(\frac{q^\mu}{\prod_k D_k^{n_k}}\right) = 0$$

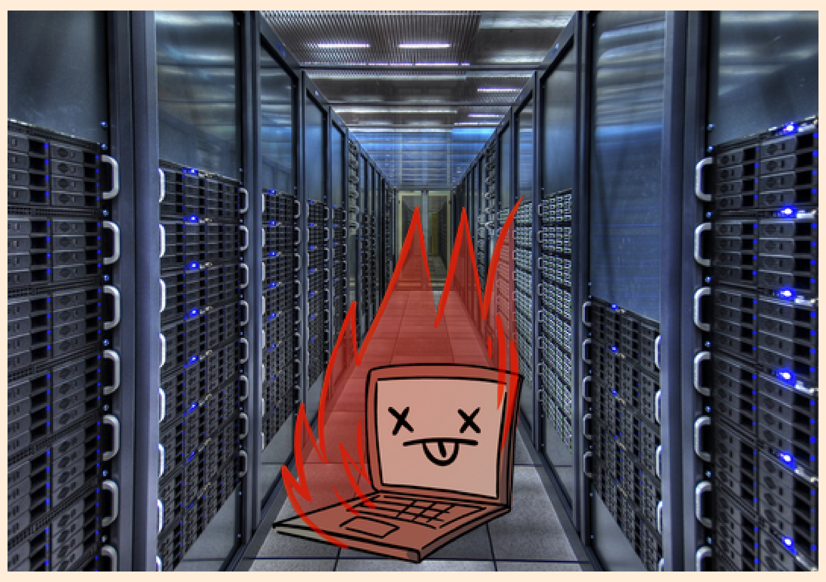
Let the computer do the math!

Computer algebra programs are used to perform **symbolic calculations** which would be unfeasible on paper: **Mathematica, Maple**, **FORM**, **Fermat**, **GiNac**...

```
Solve[{x + y + z == 2, 2 x - 6 z == -2, 3 z + y == 1}, {x, y, z}] (* linear systems *)

{{x → 5, y → -5, z → 2}}

DSolve[D[f[x], x] == f[x] / x, f[x], x] (* differential equations *)

{{f[x] → x c1}}

Series[Gamma[1 - ε] * Gamma[1 + ε] / ε^2, {ε, 0, 3}] (* Laurent expansion *)
```

$$\frac{1}{\epsilon^2} + \frac{\pi^2}{6} + \frac{7\pi^4\epsilon^2}{360} + O[\epsilon]^4$$



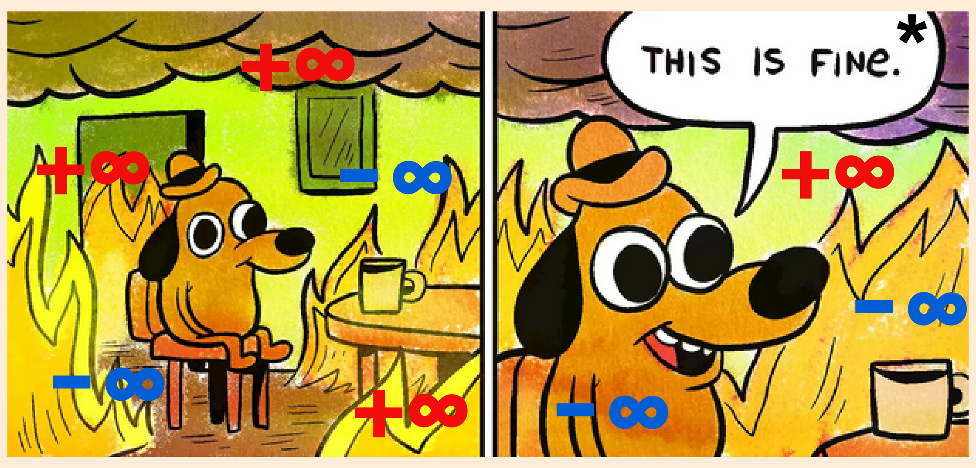


Monte Carlo is the way

To reproduce the exprimental setup we rely on **numerical simulations**, in particular to **Monte Carlo event generators**. In our group we develop ***NNLOJET***.

Everything blows up

In intermediate steps of high order calculations, **infinities** arise. These infinities need to be properly **regularized** so they can cancel in the final finite result. This is done with **subtraction methods**.



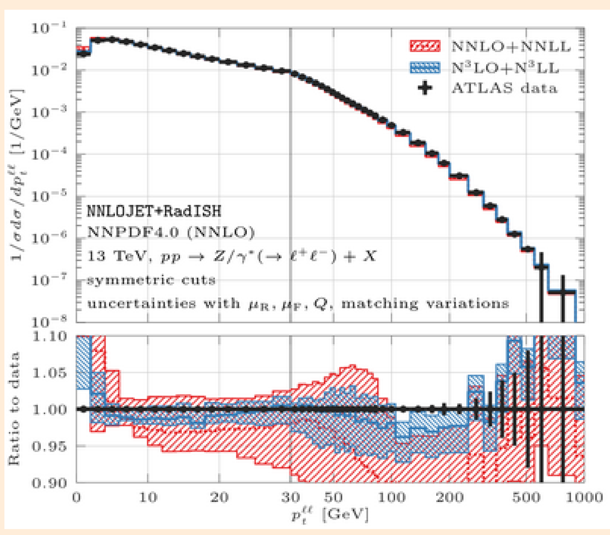
* thanks to **ANTENNA SUBTRACTION**

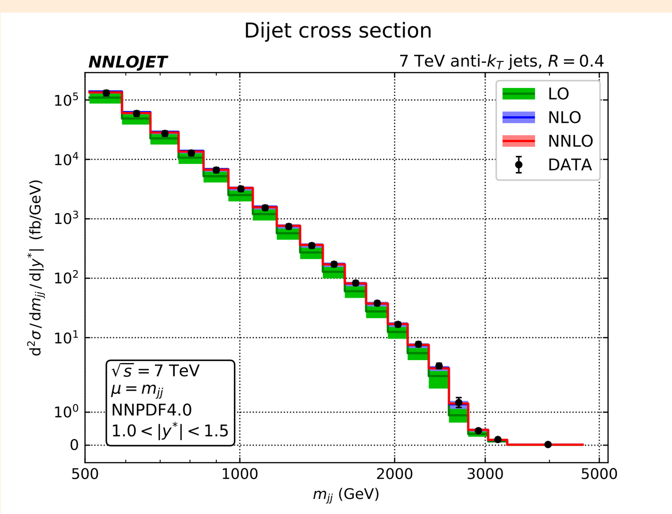
$$\mathrm{d}\hat\sigma_{NLO} = \int_n [\mathrm{d}\hat\sigma^V - \mathrm{d}\hat\sigma^T] + \int_{n+1} [\mathrm{d}\hat\sigma^R - \mathrm{d}\hat\sigma^S]$$

N U M E R I C S

May the precision be with you

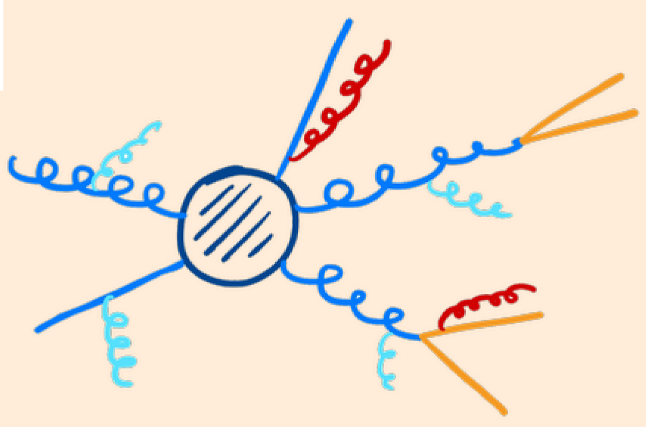
To probe the Standard Model, **precise theoretical predictions** are crucial. Discrepancies between data and theory can hint to the presence of **new physics**. For benchmark processes we reach N^3LO precision!





Particle party

The complexity of precision calculations dramatically increases with the number of particles involved. The next frontier of NNLO calculations is represented by **2→3 processes.**



I see you!

In some measurements experiments identify strongly interacting particles in the final-state. On the theoretical side, this requires a **fragmentation function** to describe the transition from quarks and gluons to hadrons.