Particle theory in the precision era

"Before I came here I was confused about this subject. Having listened to your lecture I am still confused. But on a higher level." – E. Fermi

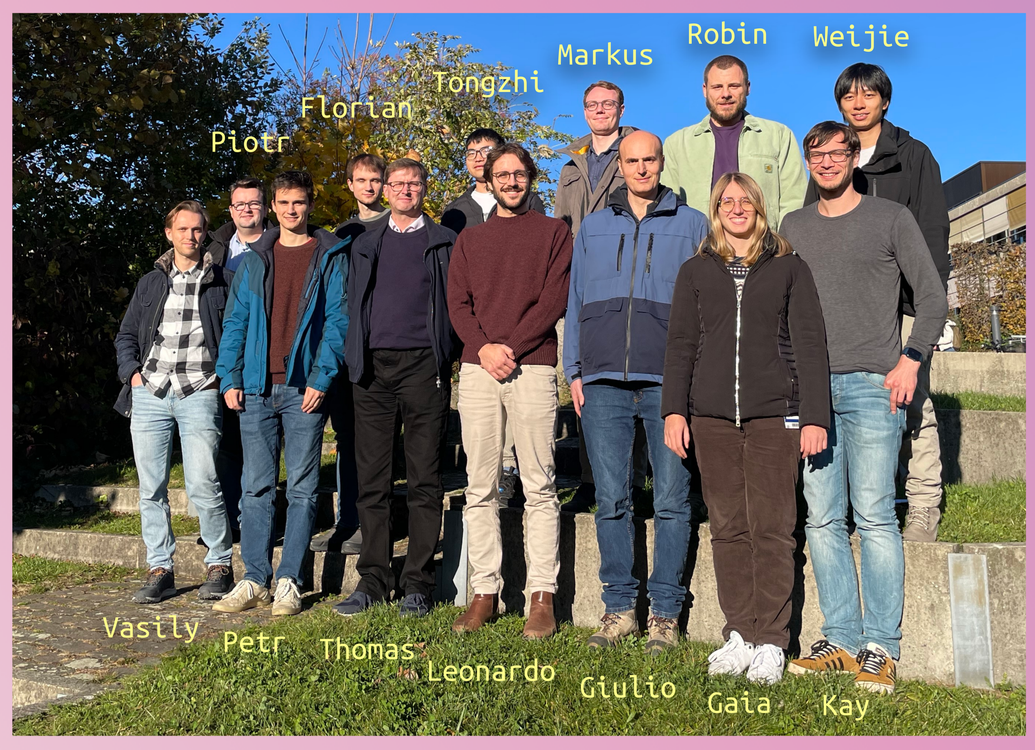
Leonardo Bonino, Weijie Feng & Gaia Fontana

Group of Prof. Dr. Thomas Gehrmann

Why are we not satisfied with the **Standard Model**?
- Uncertainties in fundamental parameters (m_W, m_Z, α_S, …)
- Open questions (neutrino masses, hierarchy problem, …)

New physics may be hidden in small deviations → **Precise Standard Model predictions needed**

Find out more about us!



Precision physics at the Large Hadron Collider (**LHC**): how to describe a proton-proton collision?

Factorisation formula $d\sigma \sim \sum_{a,b} f_a \otimes f_b \otimes d\hat{\sigma}_{ab}$

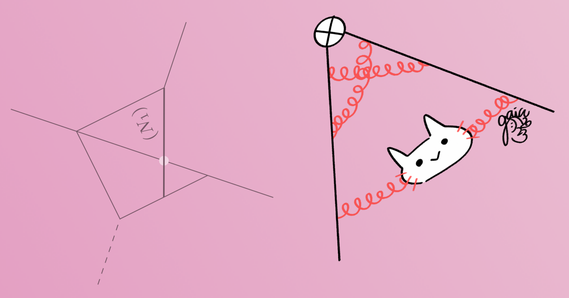
f_i parton distribution function (PDF)

Focus on partonic cross-section $d\hat{\sigma}_{ab}$
- **Perturbative QCD**: expansion in strong coupling constant $\alpha_S \sim 0.1$
- Thousands of Feynman diagrams → **amplitude techniques**
- **Infrared divergences** in loop and phase space integration → **antenna subtraction**

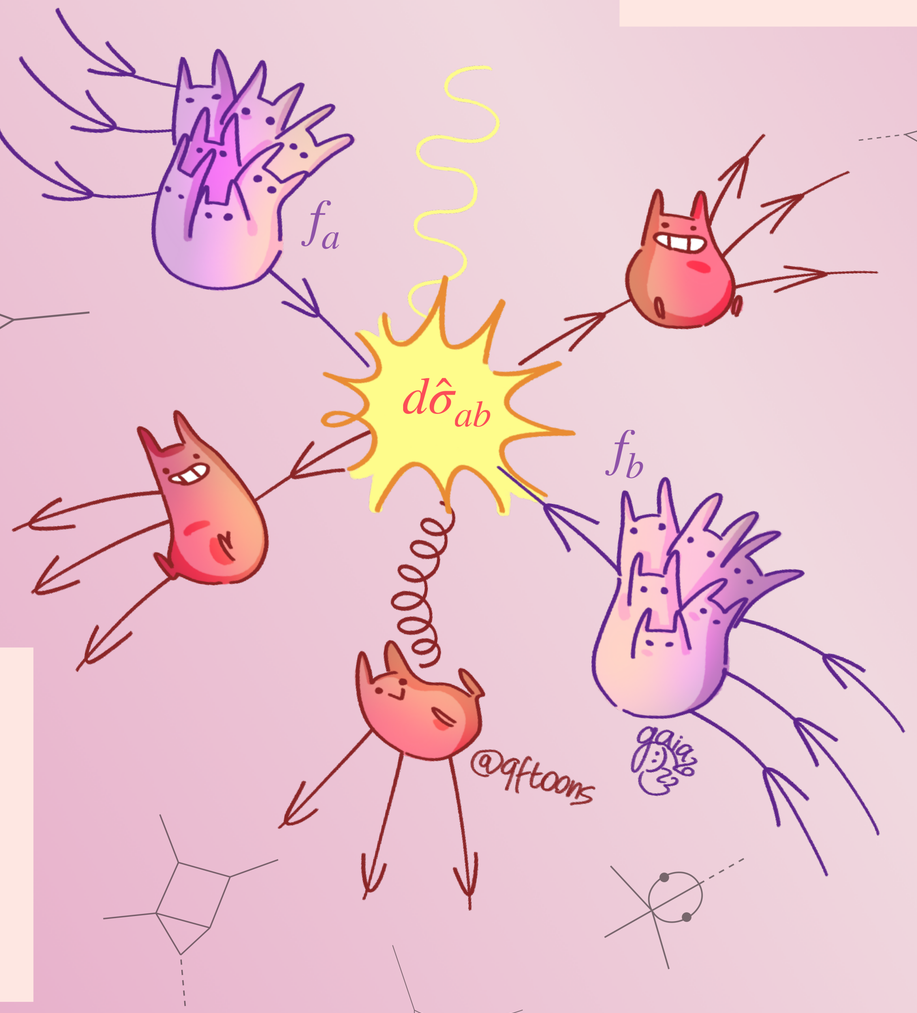
$$d\hat{\sigma}_{ab} = d\hat{\sigma}^{LO}_{ab} + \underbrace{\alpha_S\, d\hat{\sigma}^{NLO}_{ab}}_{\sim 10\%} + \underbrace{\alpha_S^2\, d\hat{\sigma}^{NNLO}_{ab}}_{\sim 1\%} + \underbrace{\alpha_S^3\, d\hat{\sigma}^{N^3LO}_{ab}}_{\sim 0.1\%} + \dots$$

Amplitude techniques
- Number of diagrams grows fast with perturbative order
- Hard **computer algebra** problems! (Mathematica, Maple, FORM)
  - Reduction of integrals to a basis with **integration by parts identities**
  - Special functions appear: Polylogarithms, Elliptic Polylogarithms, …

Percent-level precision needed to compare with Run 3 LHC data



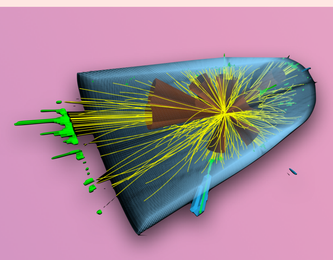
Find us in Irchel **Y36 K-floor**

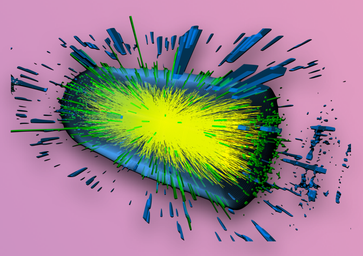


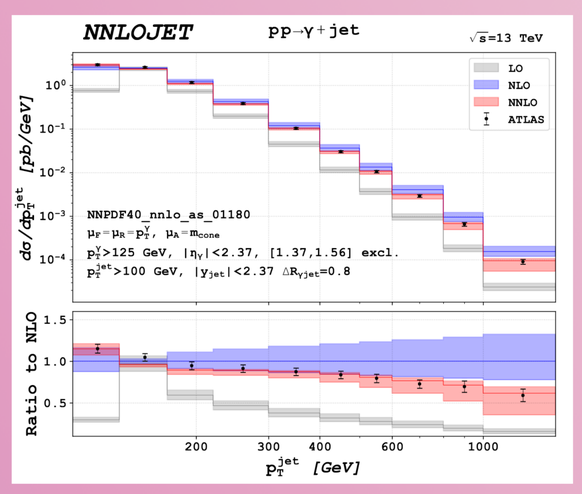
Divergences in amplitudes:
- **Soft** and **collinear** (many legs)
- Explicit poles from **loop integration** (many loops)

How do we get a **finite** cross section?

Phenomenology studies with NNLOJET
- Hundreds of particle combinations
- $10^5 - 10^6$ CPU hours → **supercomputers**
- Comparison with **accelerator data** (LHC, LEP, …)
- Reduced theoretical **uncertainties** ✓
- Hints of **New Physics**?





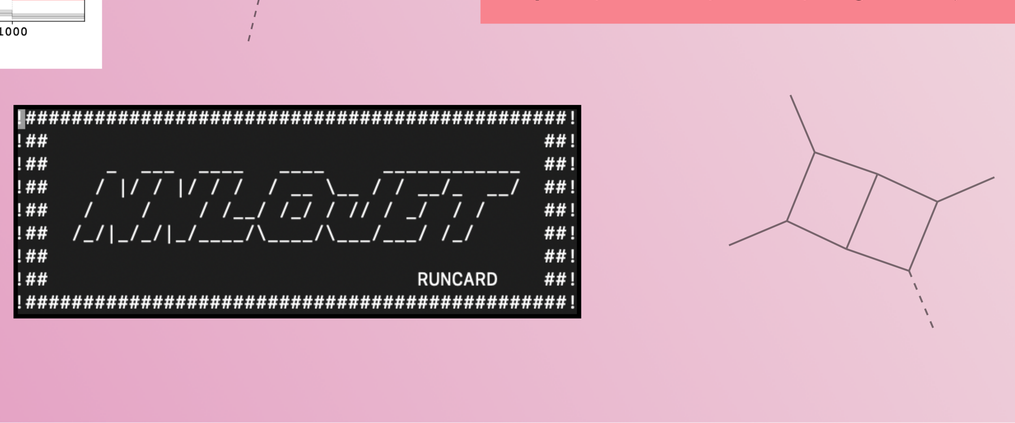


Antenna subtraction

Construct **subtraction terms** which mimic divergent behaviour to achieve **numerical** cancellation of divergences

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

→ **Monte Carlo** integration in code ***NNLOJET*** (Fortran, Maple, FORM, C++, Python)



European Research Council
Established by the European Commission

Swiss National Science Foundation