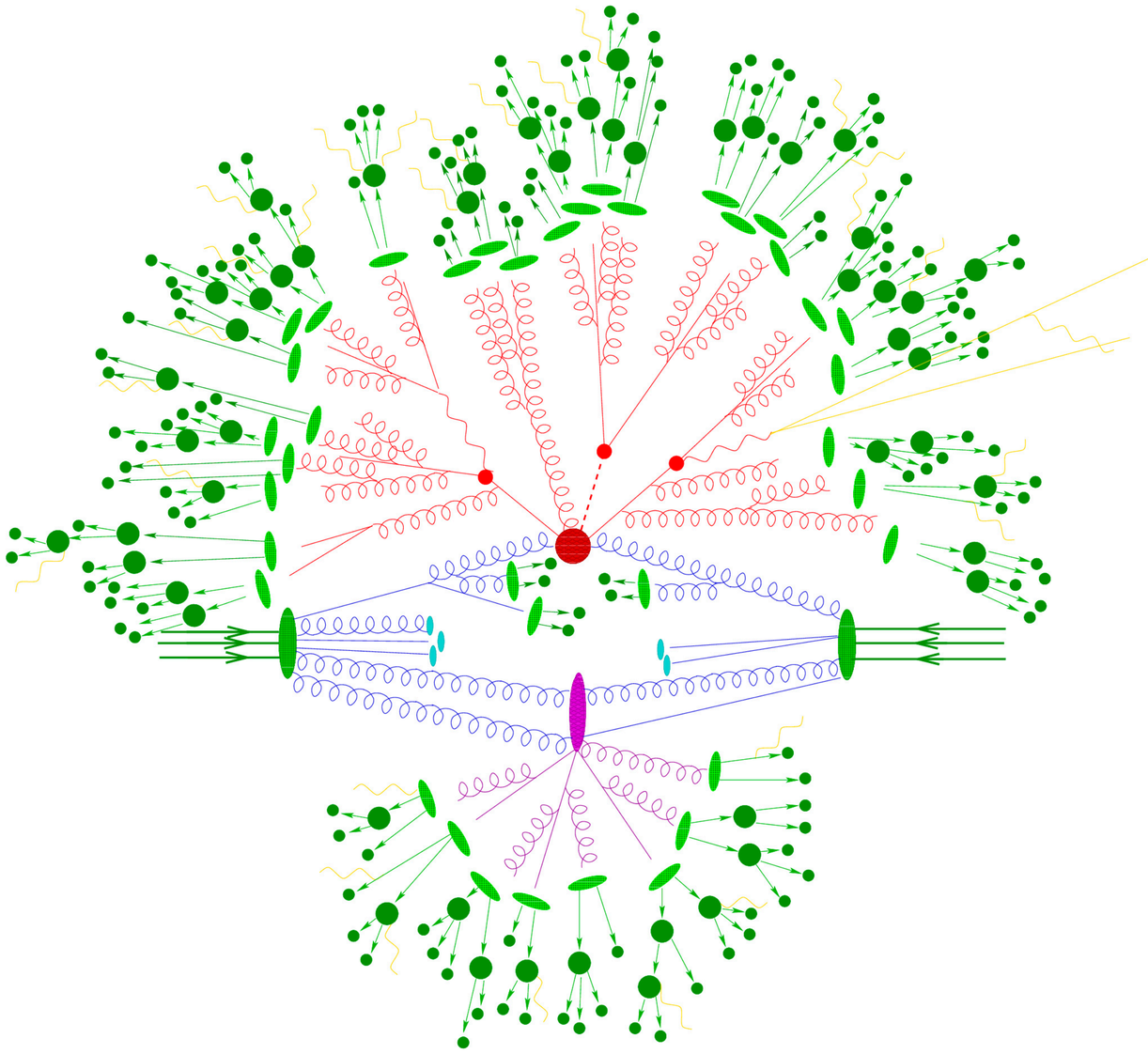
“Power Corrections” for High Precision Event Generators

Davide Napoletano, GGI Workshop ’23

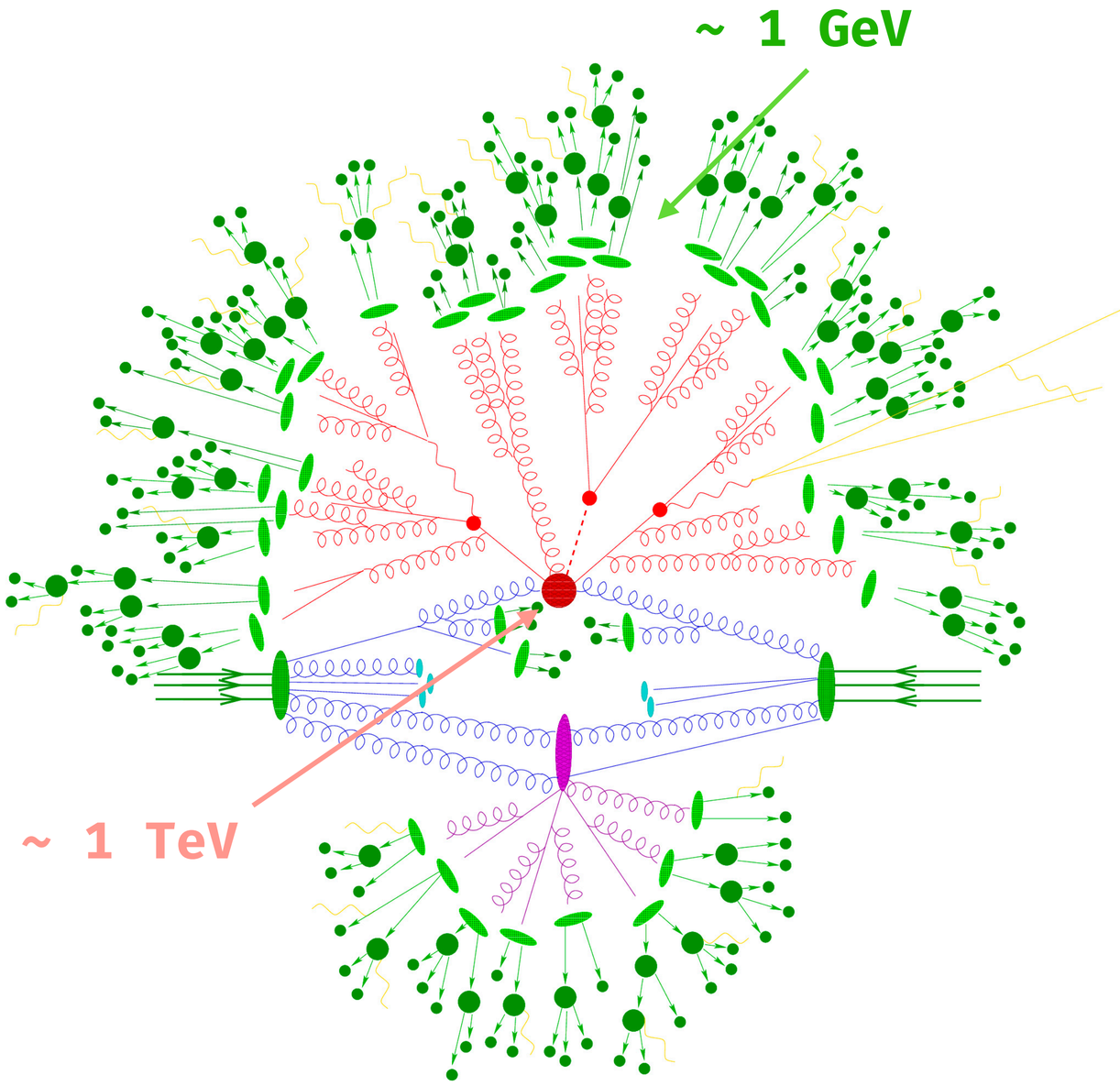
Introduction

- MC community devoted to describe



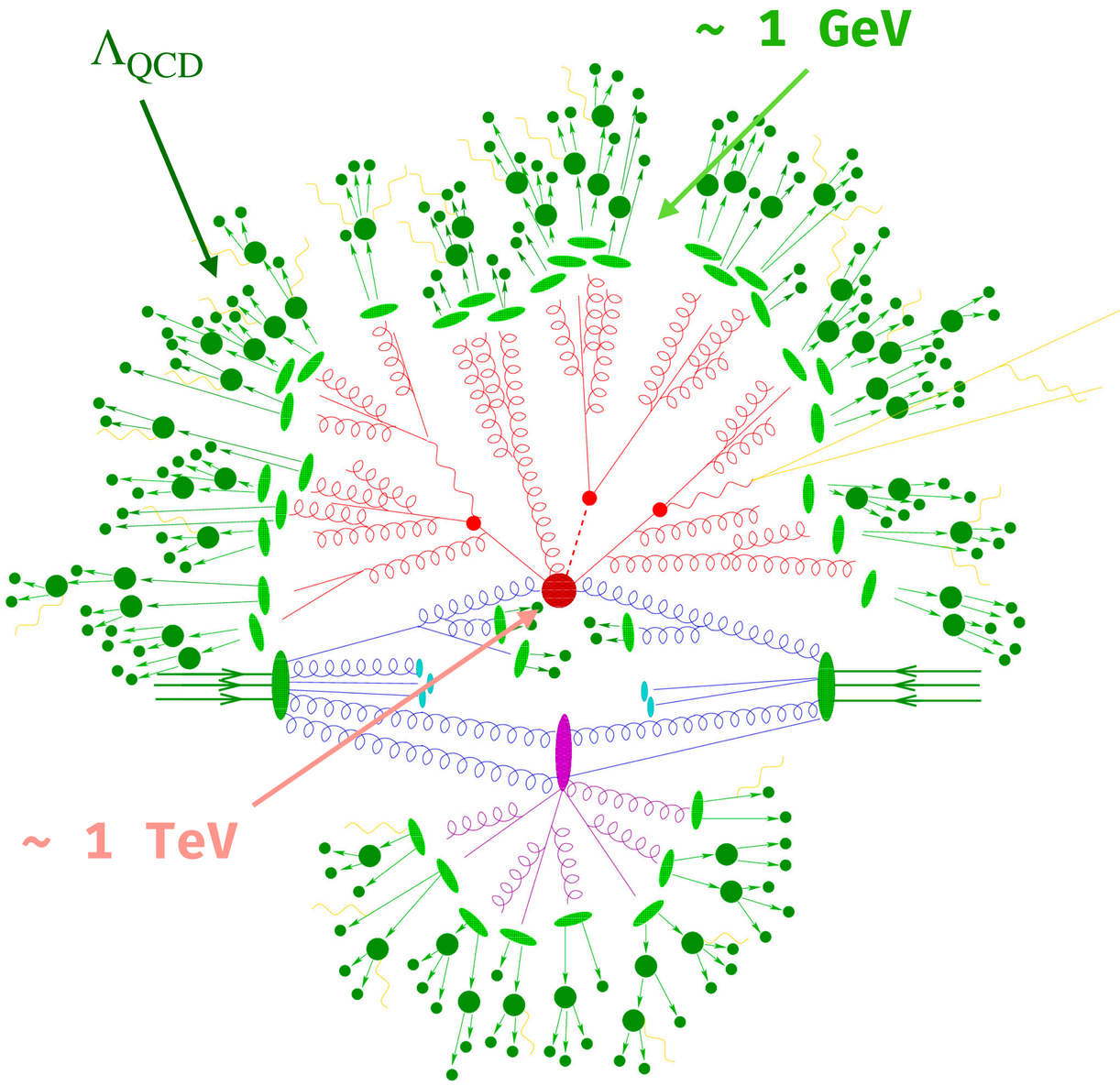
Introduction

- The strength of MC generators lies in factorisation of energy regimes!

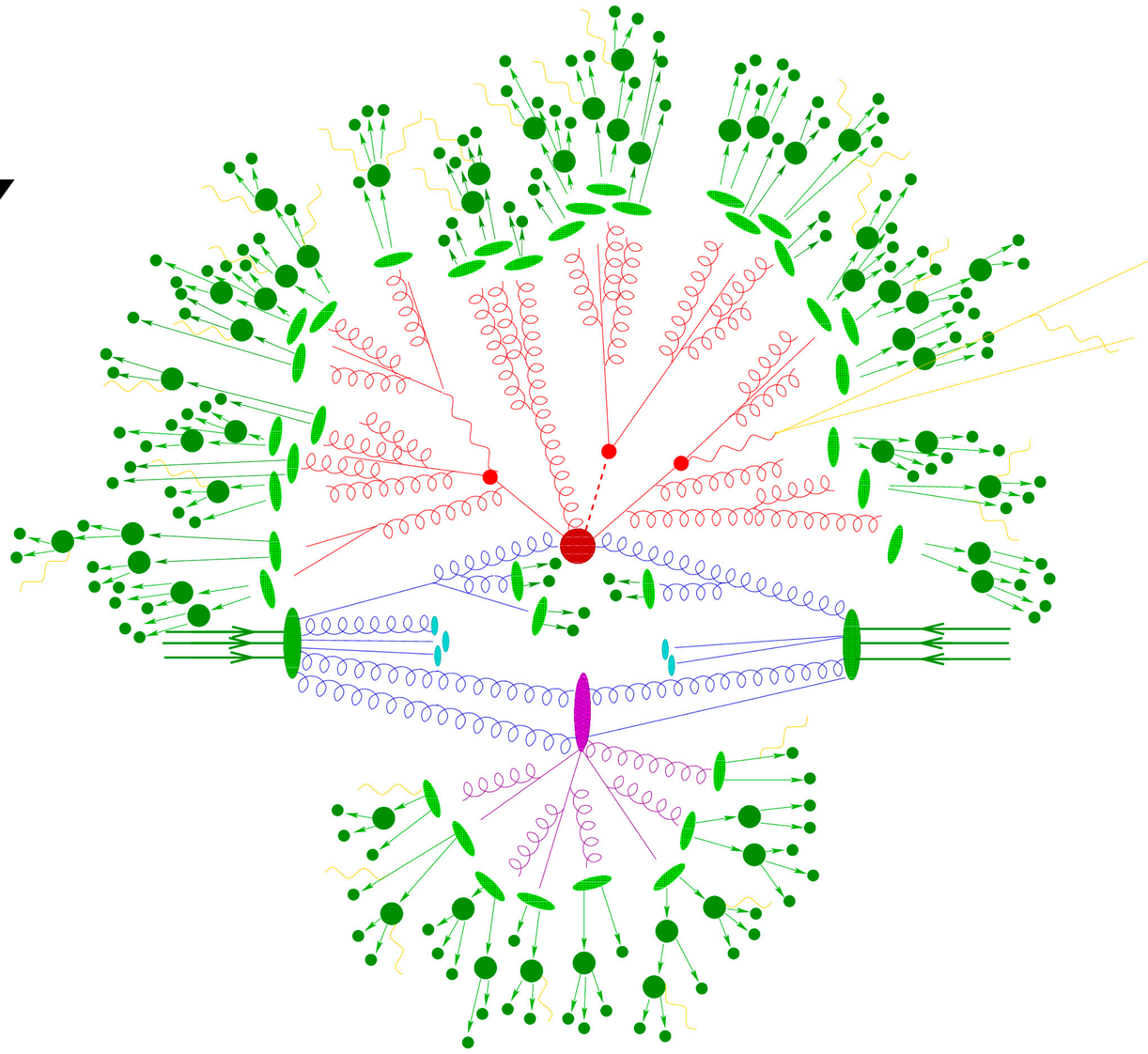


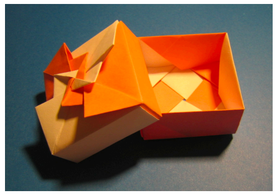
Introduction

- This makes it possible to separately improve each of the “components”!

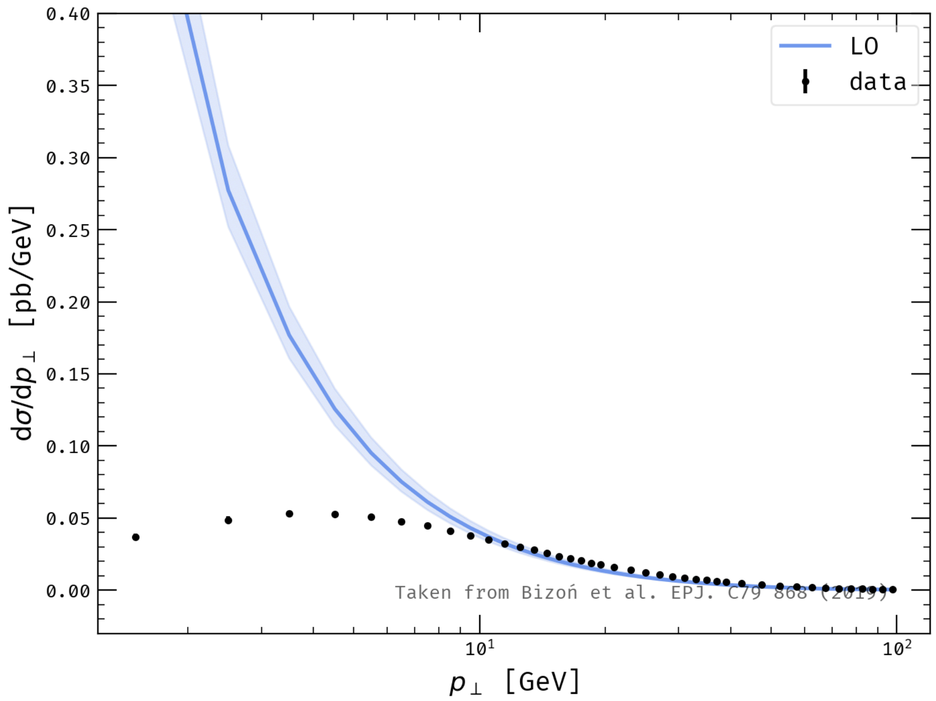


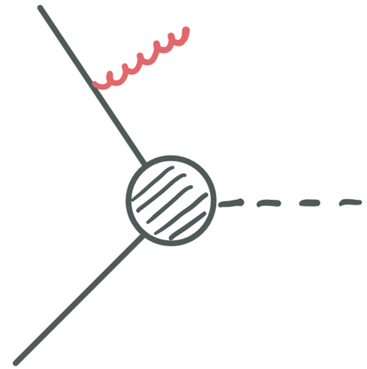
Introduction



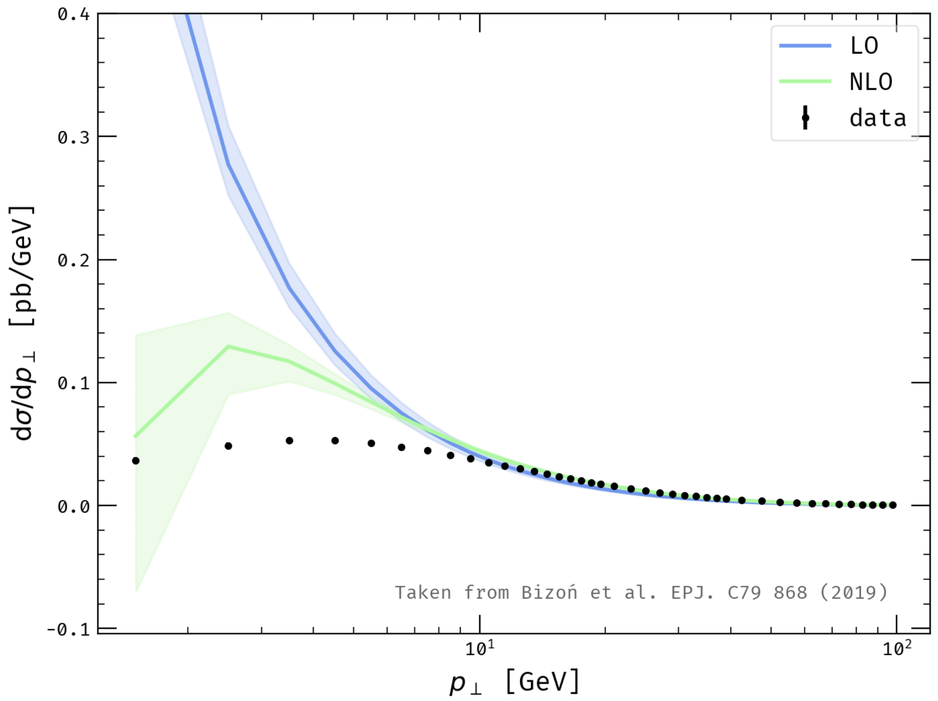


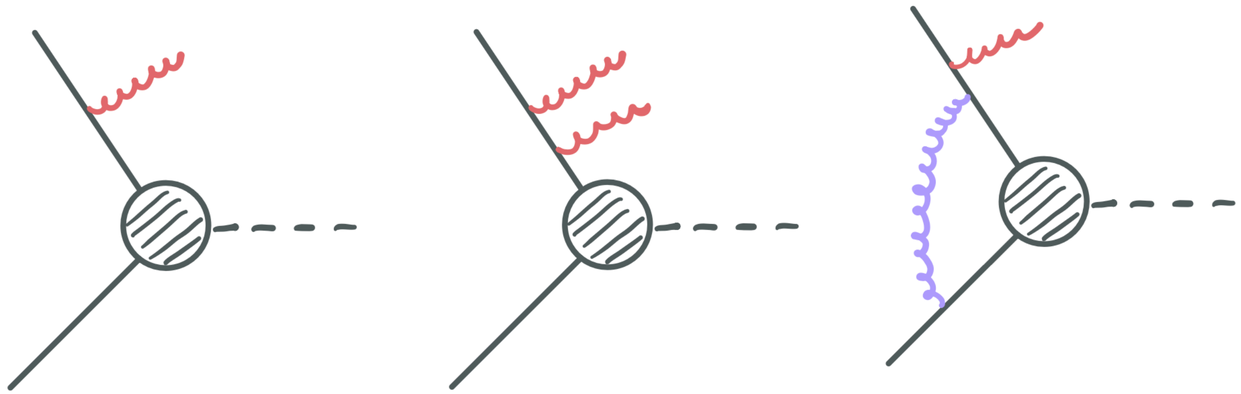
Hard Scattering





Hard Scattering

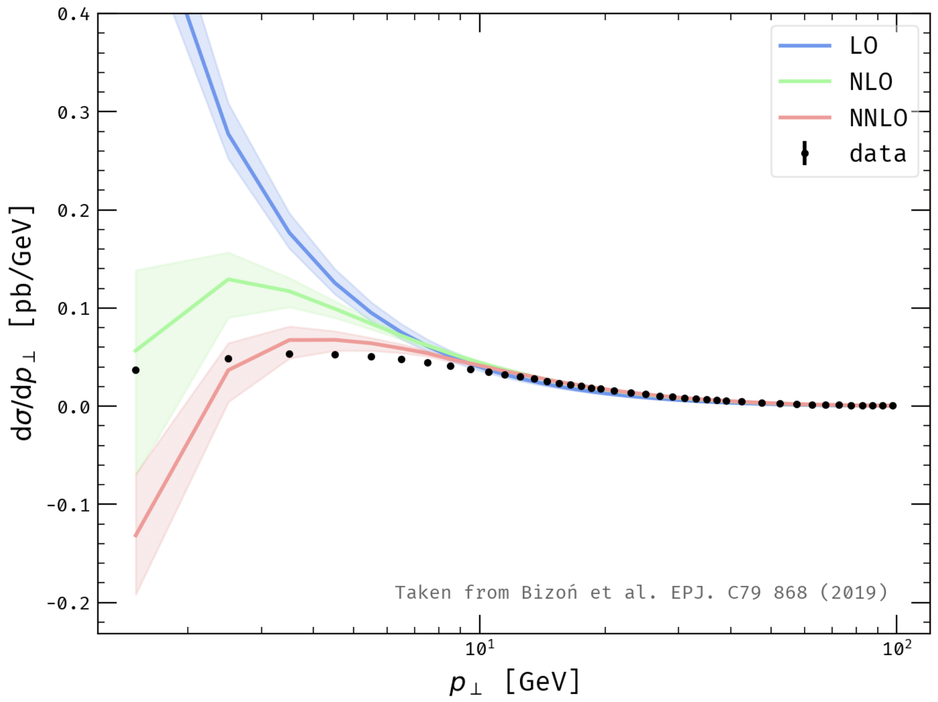


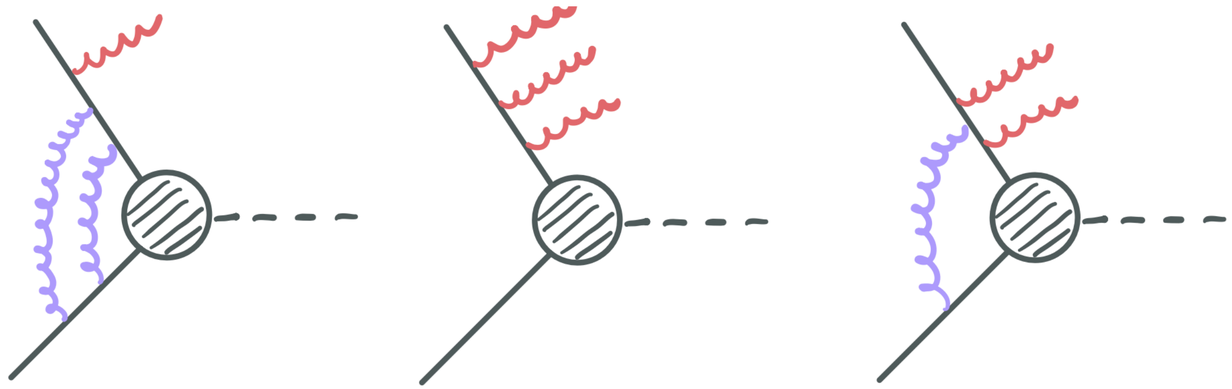


- To do this at NLO need subtraction of IR divergences!

[Catani-Seymour, FKS,…]

Hard Scattering

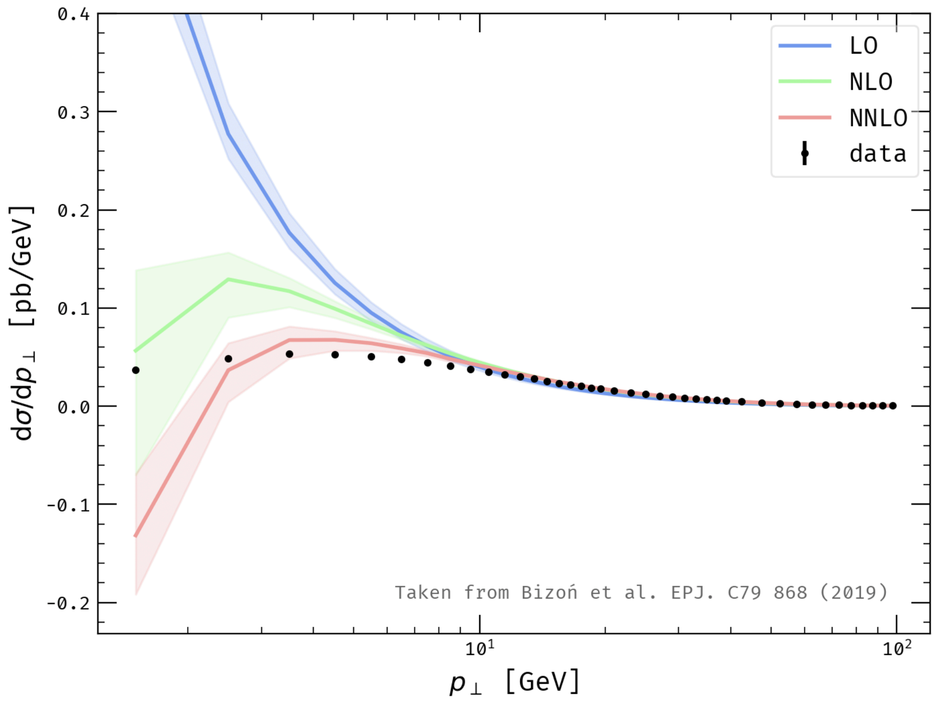




- At NNLO many methods, none implemented in general purpose tools…

[Antenna, ColorFull, Slicing, Analitic…]

Hard Scattering

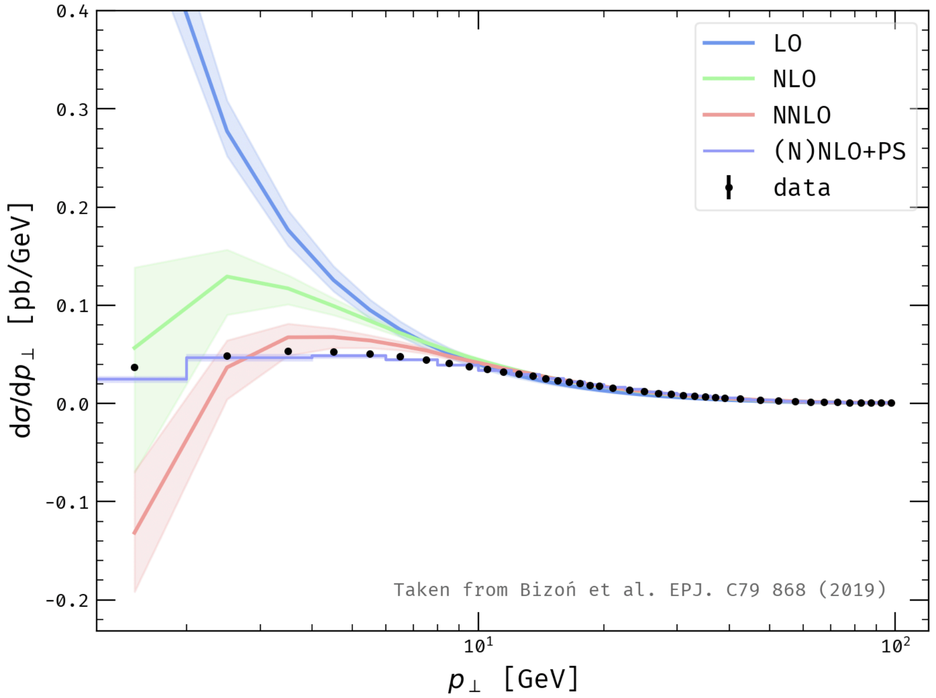


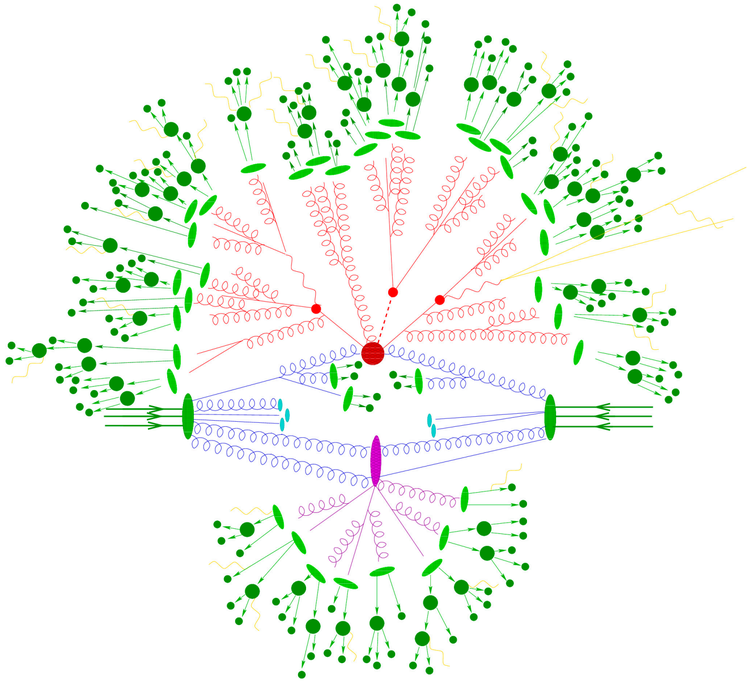
- This has been the core focus of developments in MC over the last ~ years i.e. how to include higher fixed order correction!

- Still, fixed order description misses something…

Parton Shower

- Still need to run down to the GeV scale





Parton Shower

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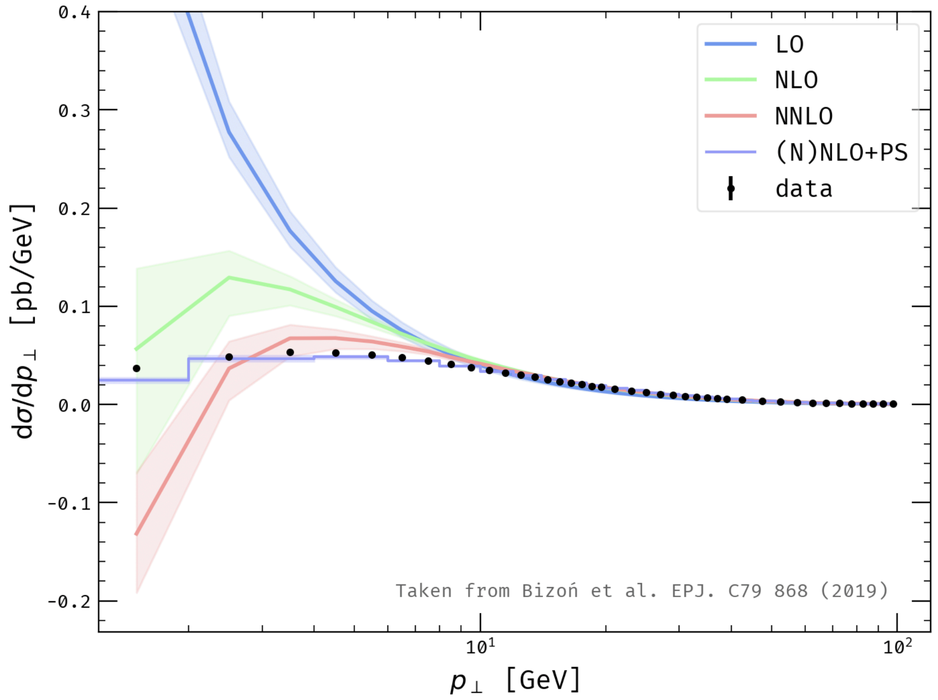


A MODEL FOR PARTON SHOWERS IN QCD*

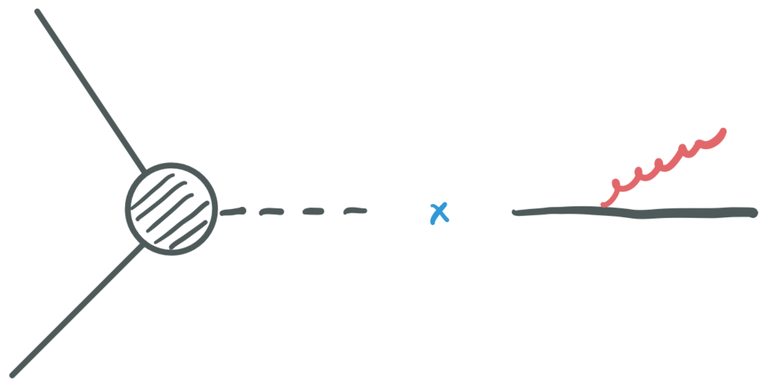
Geoffrey C. FOX and Stephen WOLFRAM[1]
California Institute of Technology, Pasadena, California 91125, USA

Received 27 December 1979

A Monte Carlo model for the development of parton jets in QCD is described. Explicit low-order calculations are supplemented by leading logarithmic approximations for higher orders.

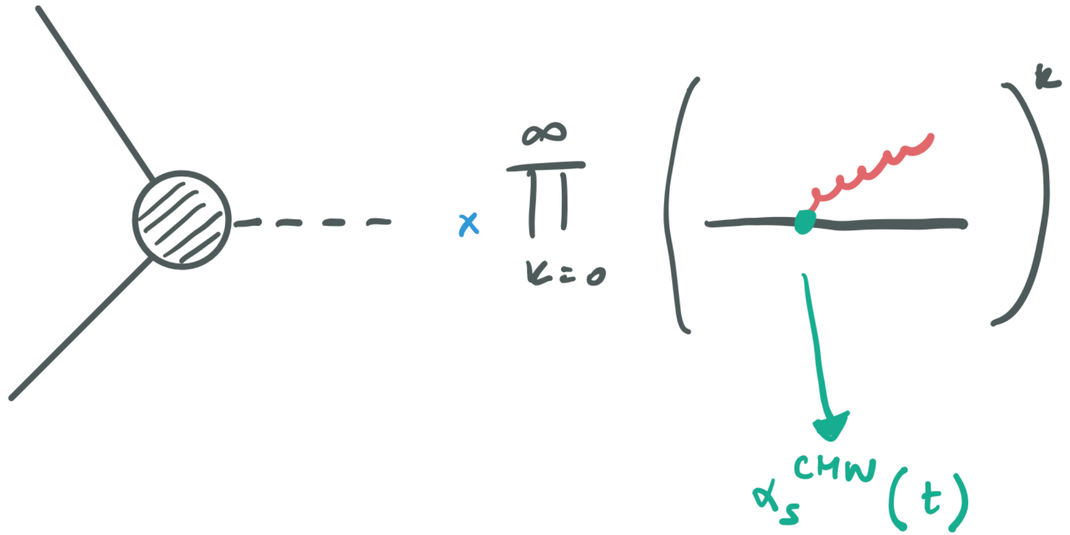
Parton Showers

- Various implementation with various degrees of technical details
- Accuracy of perturbative ingredients unchanged since the 90s



Parton Showers

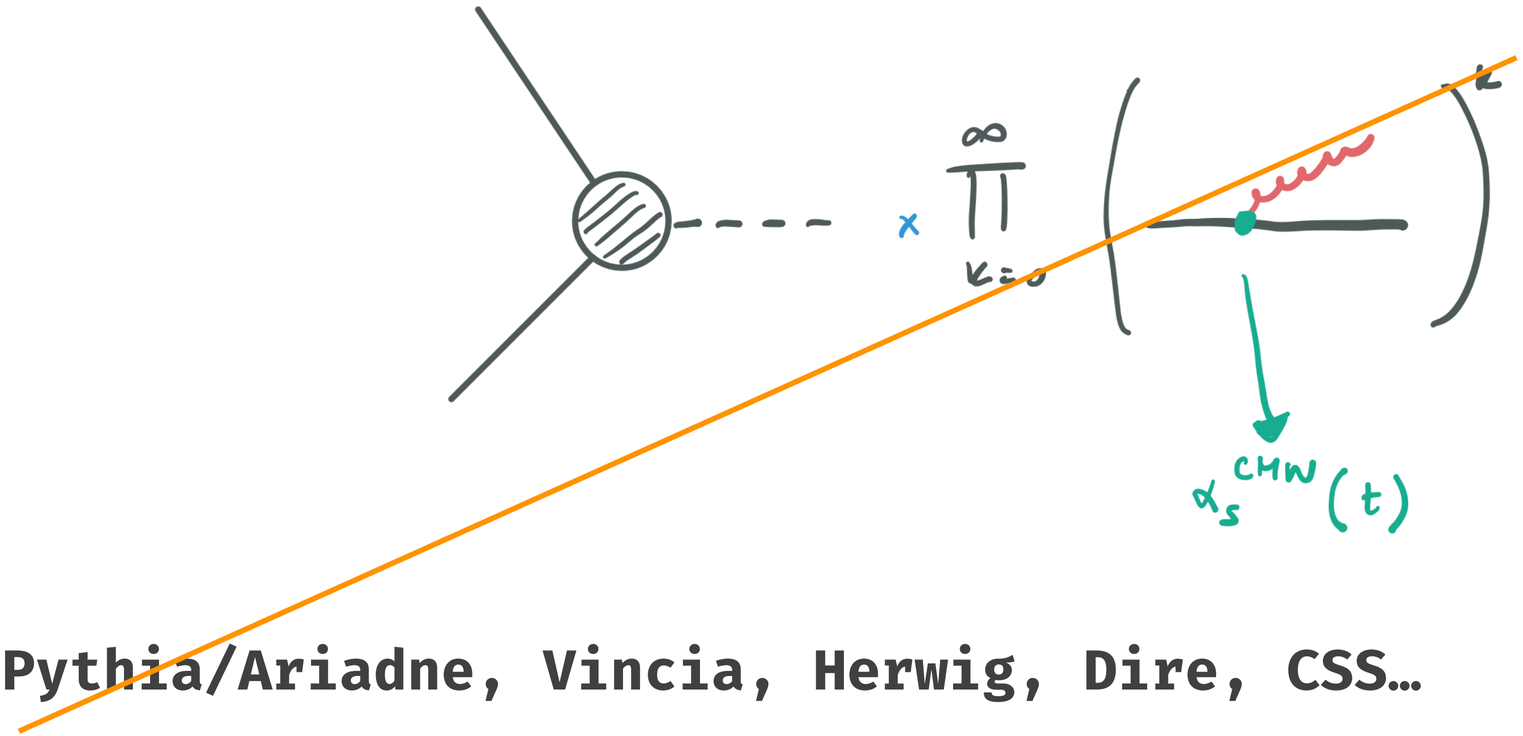
- Various implementation with various degrees of technical details
- Accuracy of perturbative ingredients unchanged for 20 or so years



- Pythia/Ariadne, Vincia, Herwig, Dire, CSS…

New generation showers

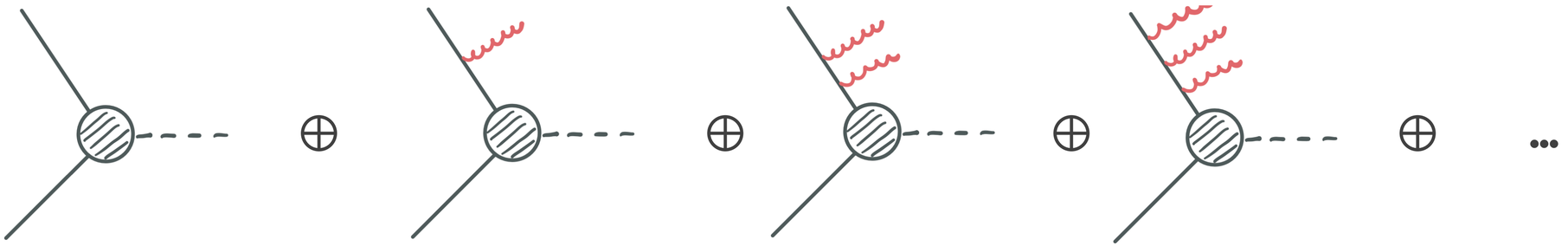
- LO splittings and CMW scheme not enough, be careful of t or recoil (PanScales, Alaric, Deductor, Herwig, Amplitude Evolution)



- Pythia/Ariadne, Vincia, Herwig, Dire, CSS…

Matching & Merging

- Merging multiple multiplicities with Sudakov vetoes [CKKW-L, FxFx]



- Matching higher order calculations with standard showers already non-trivial (NN(N)LO + PS) –> what about even higher order showers?

Matching & Merging

- Merging multiple multiplicities with Sudakov vetoes [CKKW-L, FxFx]

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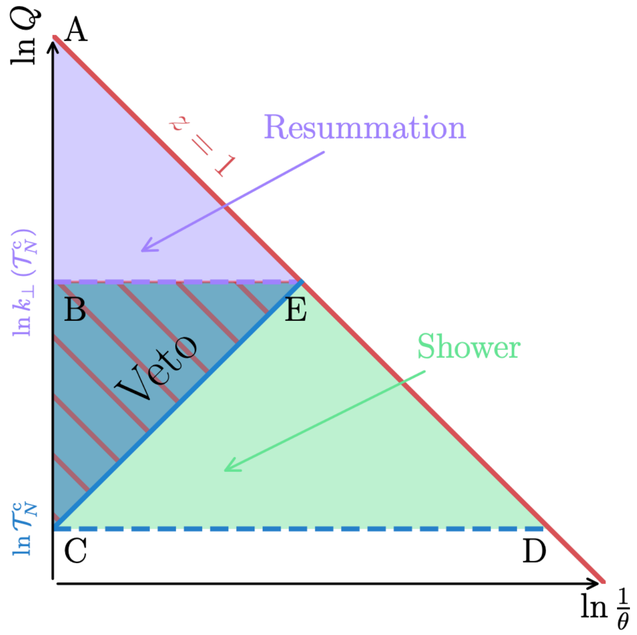
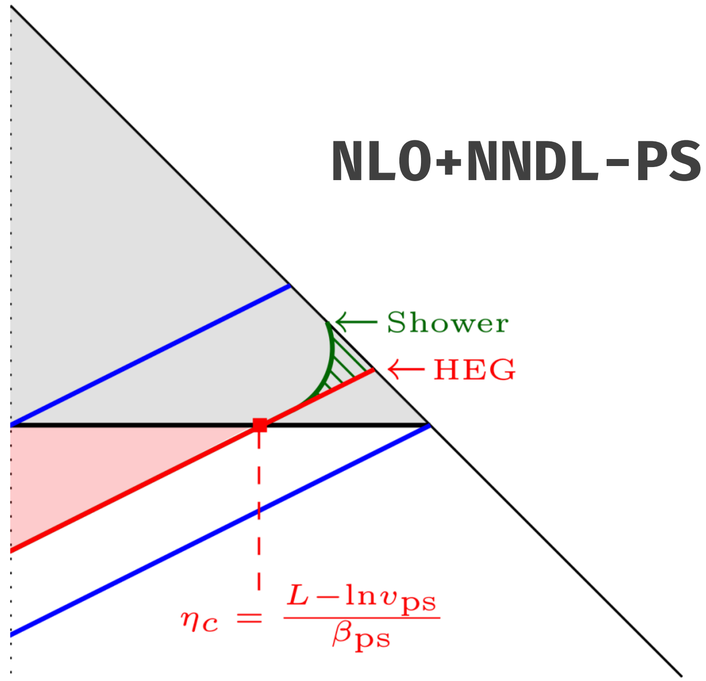
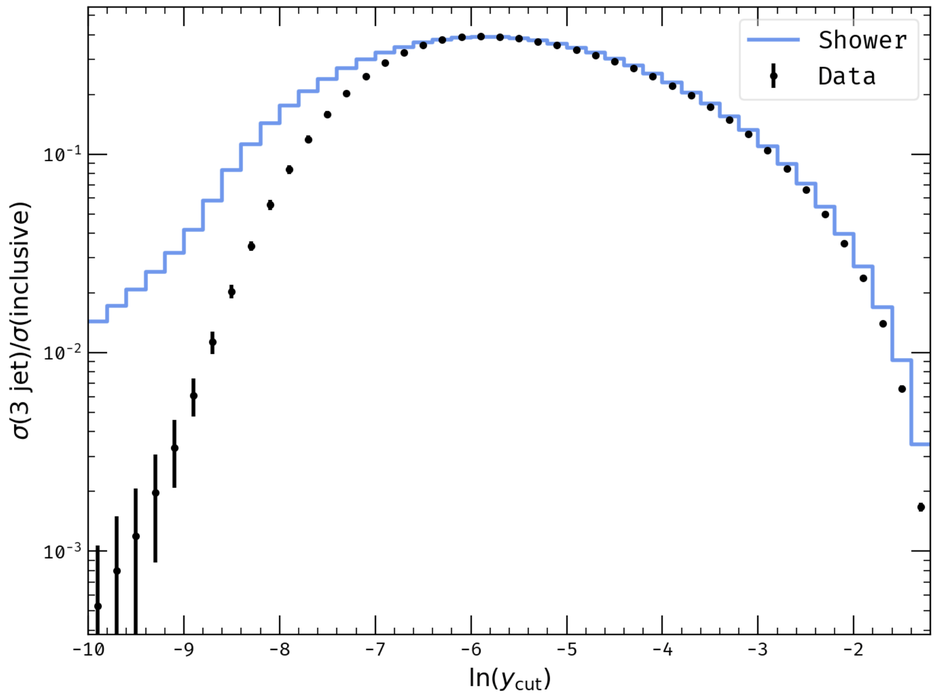
NNLO+PS



NLO+NNDL-PS

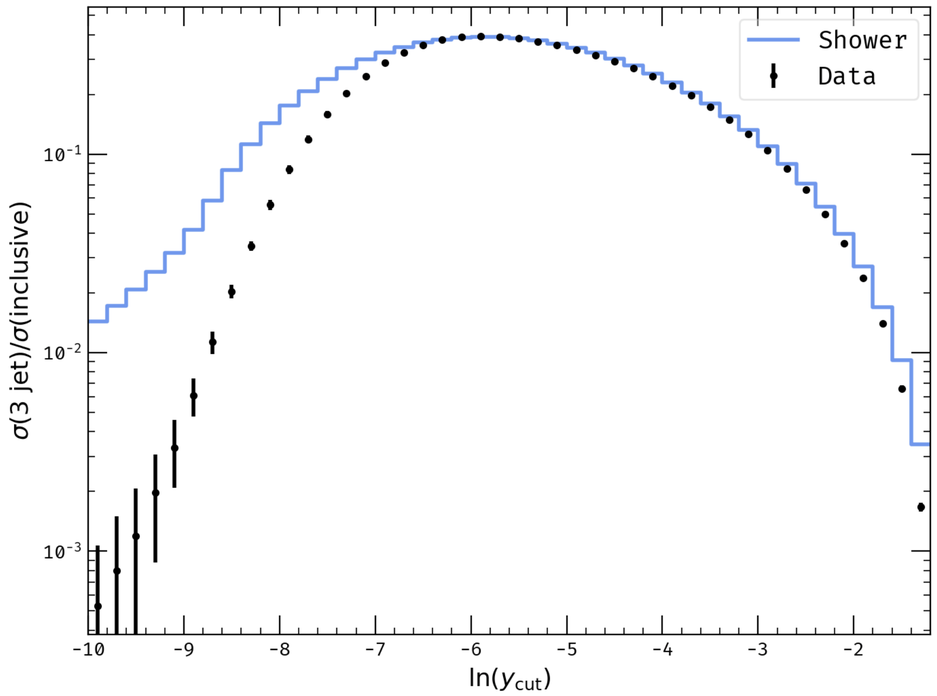


NP Corrections



- Take e^+e^-, look at a global observable

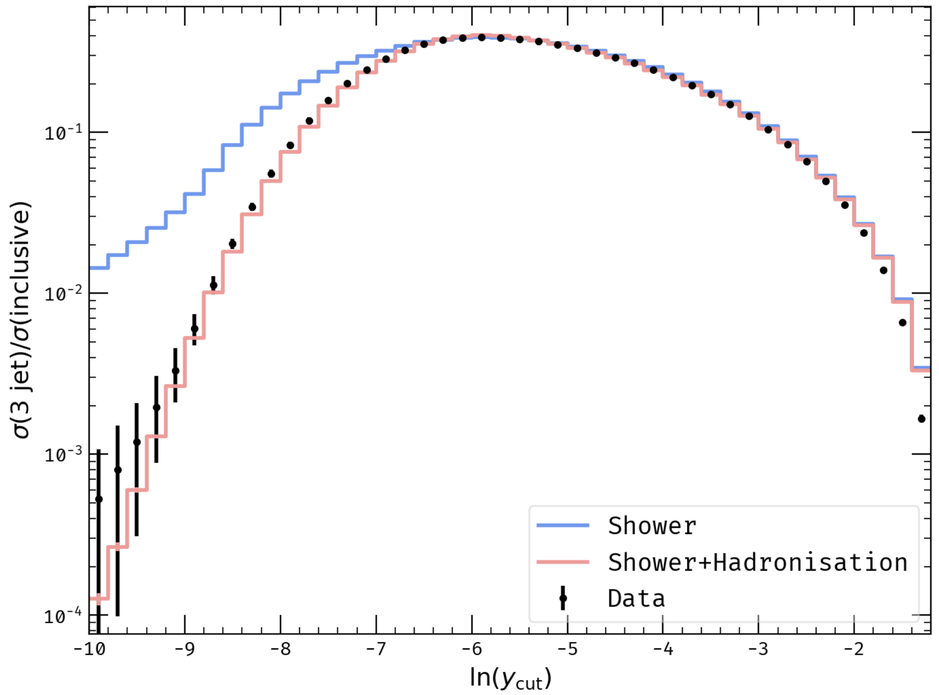
NP Corrections



- Take e^+e^-, look at a global observable

- The shower description is still not enough…

NP Corrections

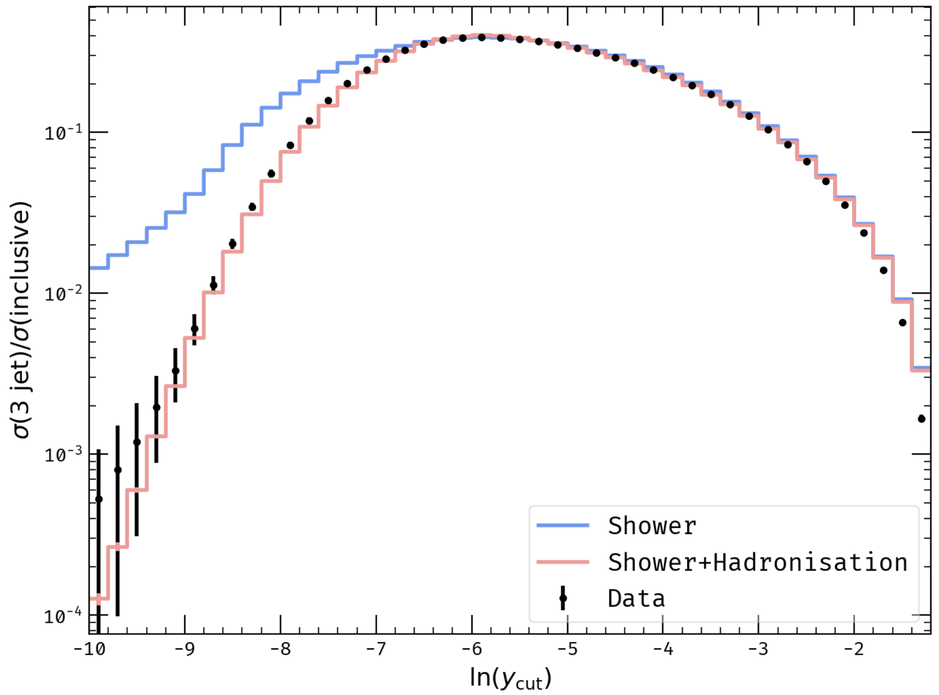


- We still need to parametrise what happens between 1GeV -> Λ_{QCD}

Tuning!

[Strings, Clusters…]

NP Corrections



- We still need to parametrise what happens between 1GeV -> Λ_{QCD}

Tuning!

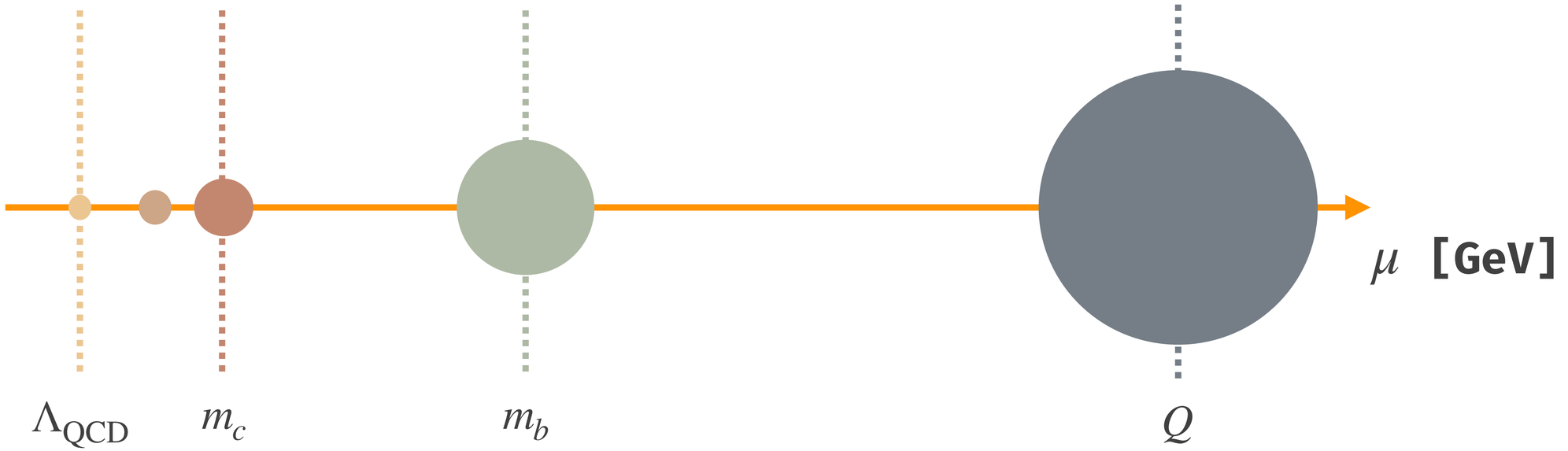
- Really universal? Perturbative/NP?

[Strings, Clusters…]

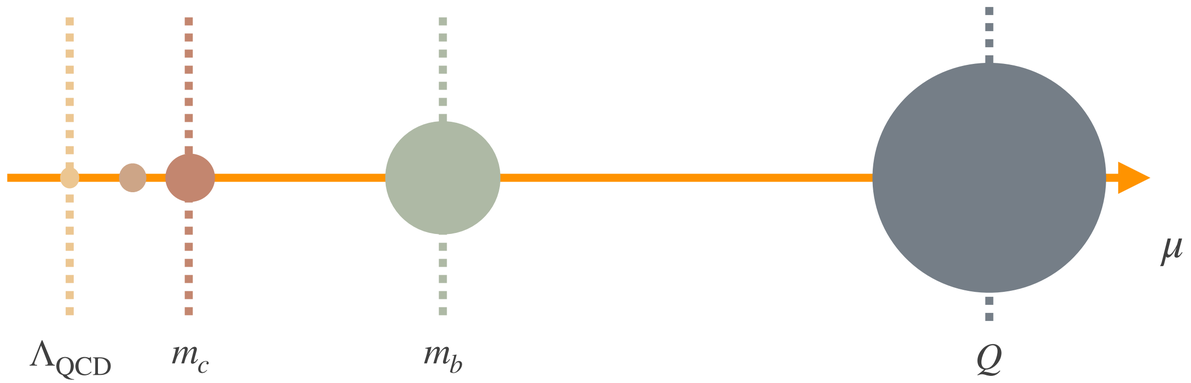
Quark Masses

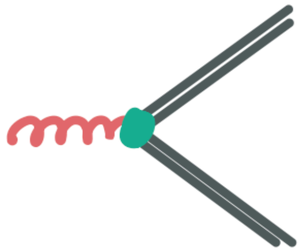
- So far this amounts to replacing splitting functions and kinematics

- Clear interplay of scales…



Quark Masses





$$\alpha_s\left(m_{QQ}^2,\ t,\ m_{QQ}^2+t,\ \sqrt{m_{QQ}^2\cdot t},\ \cdots\right)$$

Quark Masses

[Seymour, Nuclear Physics B 436 (1995) 163-183]

- Evolution of heavy quarks, take $\gamma^* -> qqQQ$, the matrix element reads

$$\frac{\mathrm{d}\sigma}{\sigma_0} \propto \frac{\mathrm{d}K_\perp^2}{K_\perp^2} \cdots$$

- If we take the QQ as if emitted from an off shell gluon

$$\frac{\mathrm{d}\sigma}{\sigma_0} \propto \frac{\mathrm{d}k_\perp^2}{k_\perp^2} \cdots$$

However, the following holds:

$$K_\perp^2 = k_\perp^2 + \left(1 - \frac{k_\perp}{\sqrt{s}} e^{-y}\right) m_g^2 \sim k_\perp^2 + m_g^2$$

Quark Masses

- Evolution of heavy quarks, take $\gamma^* -> qqQQ$, the matrix element reads

$$\frac{\mathrm{d}\sigma}{\sigma_0} \propto \frac{\mathrm{d}K_\perp^2}{K_\perp^2} \cdots$$

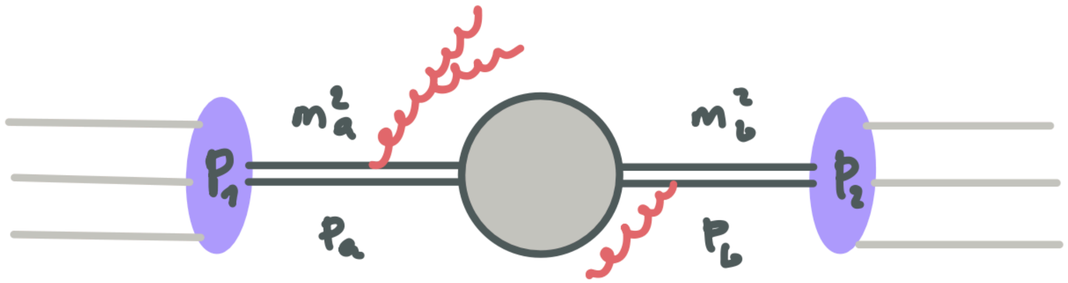
- If we take the QQ as if emitted from an off shell gluon

$$\frac{\mathrm{d}\sigma}{\sigma_0} \propto \frac{\mathrm{d}K_\perp^2}{K_\perp^2 - m_g^2} \cdots$$

=> Cannot simply plug massive splitting functions!

- (The total integral is unaffected, but distributions do differ !)

Quark masses



$$\mathrm{d}\sigma_{\mathrm{NNLO}} = \Delta[\mathrm{d}\sigma_{\mathrm{RV}}^{\mathrm{div}}] + \cdots = \left[\frac{\alpha_s(\mu)}{2\pi}\right]^2 \frac{2C_A C_F\,\pi^2}{\epsilon}\left[\frac{1}{2v}\ln\left(\frac{1-v}{1+v}\right)+1\right]\left(\frac{1-v}{v}\right)\mathrm{d}\sigma_{\mathrm{LO}} + \cdots ,$$

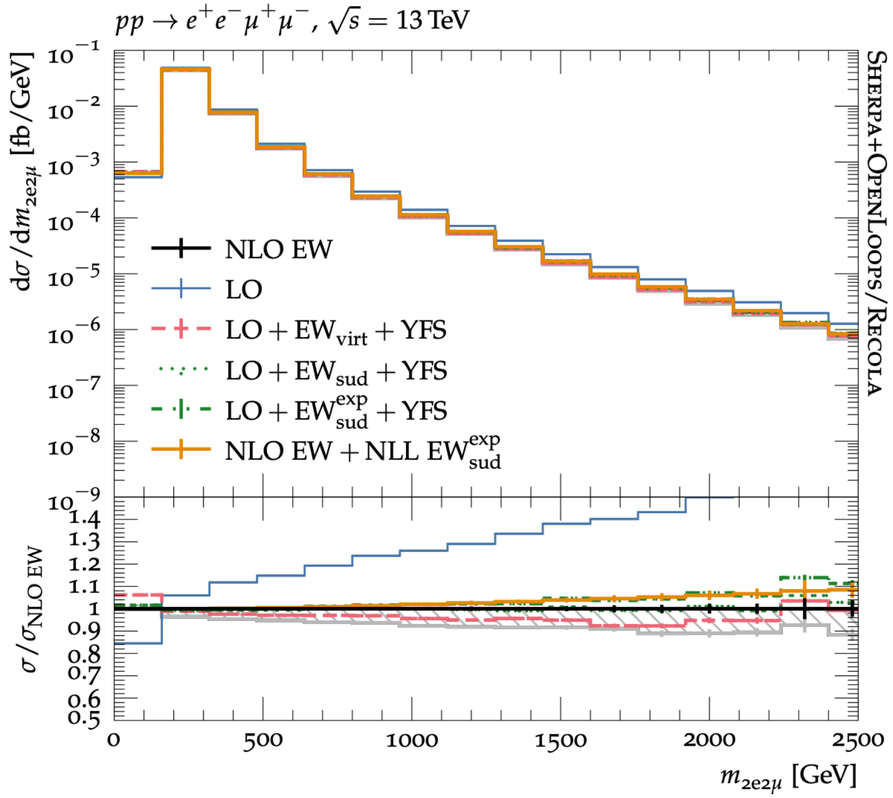
- **Absent at NNLO if ma or mb = 0**

- **(But retaining the full mass is necessary e.g. if an intrinsic charm is assumed)**

ElectroWeak Corrections/Photons

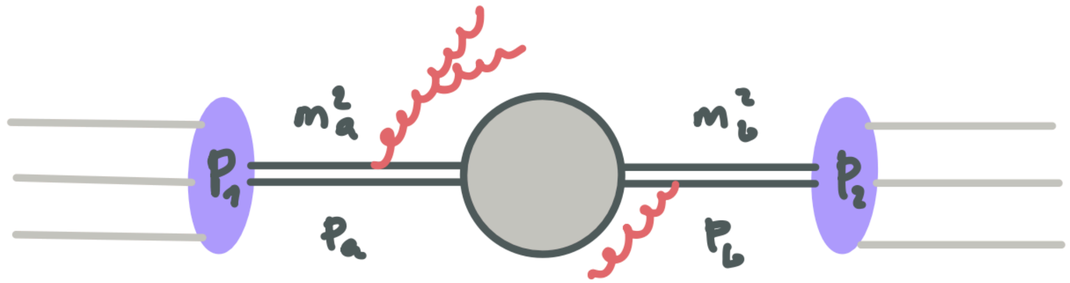
- Most GPMCG come equipped with some form of EW corrections, fixed order, or in the Sudakov approximation

- Still some work to do on fully fledged EW showers, EW final states?



ElectroWeak Corrections/Photons

- At high enough energies $Q^2 \gg m_W^2$



- Same issues as for the massive quarks!