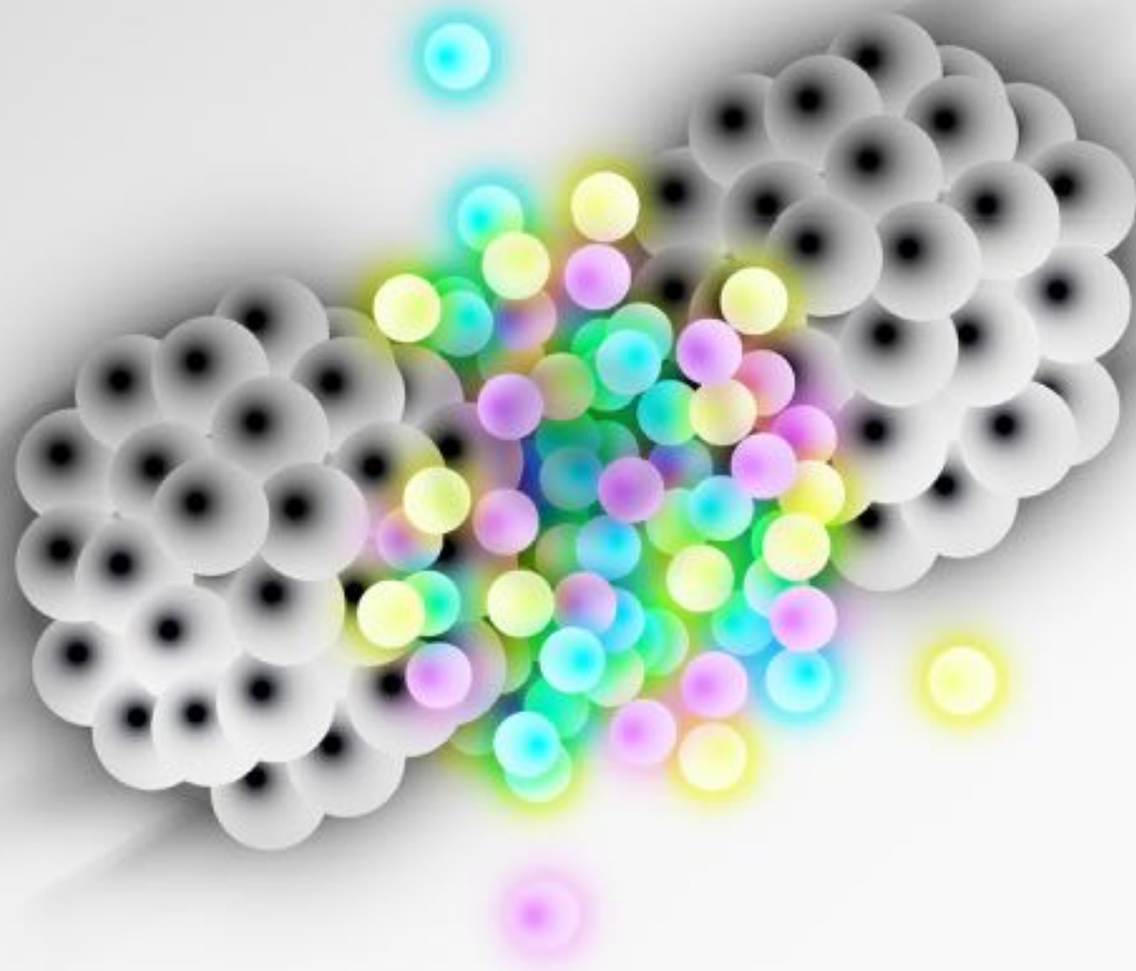
Monte Carlo Event Generators and Detector Simulation



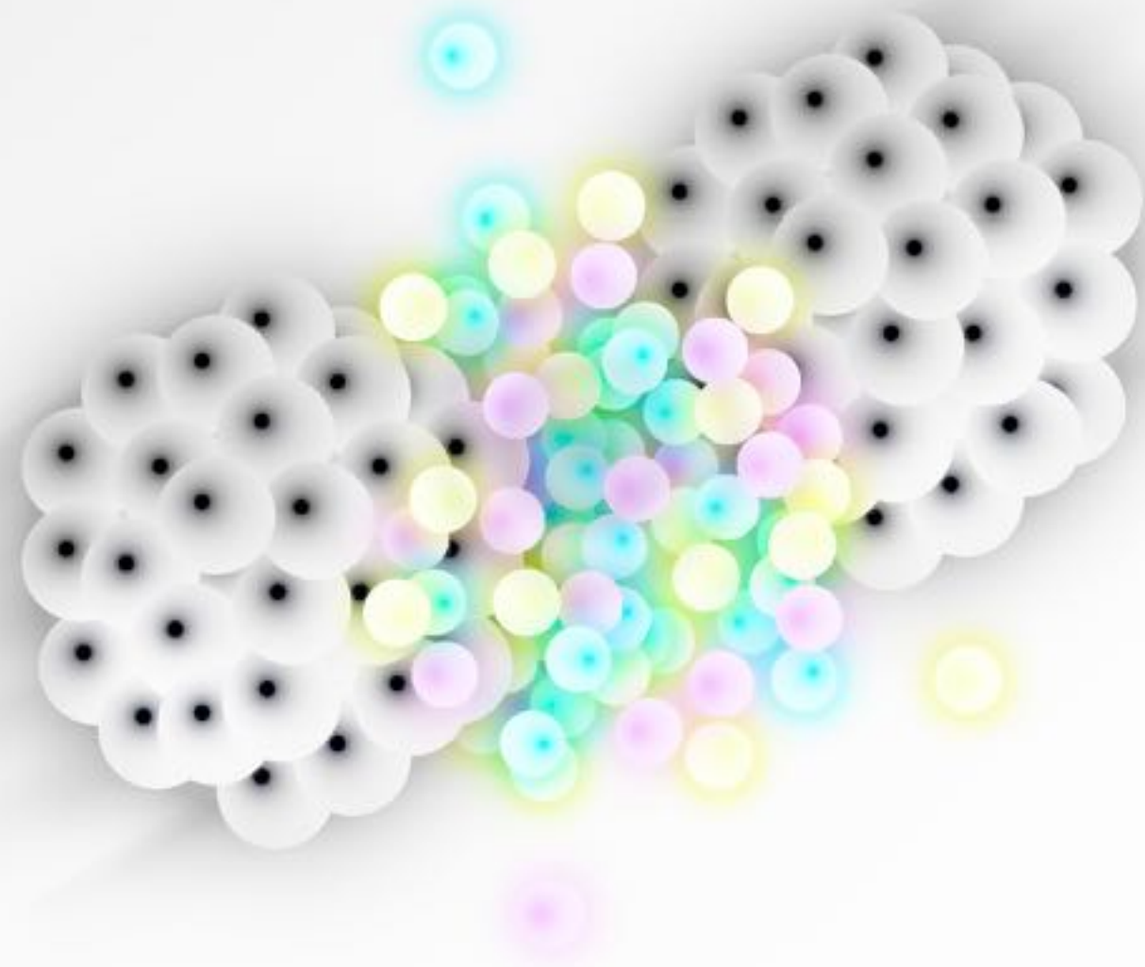
Liliana Apolinário (LIP)

Patrícia Gonçalves (LIP/IST)

Estágios de Verão LIP

July 2017, FCUL, Lisbon

Monte Carlo Event Generators



Liliana Apolinário (LIP)

Introduction I

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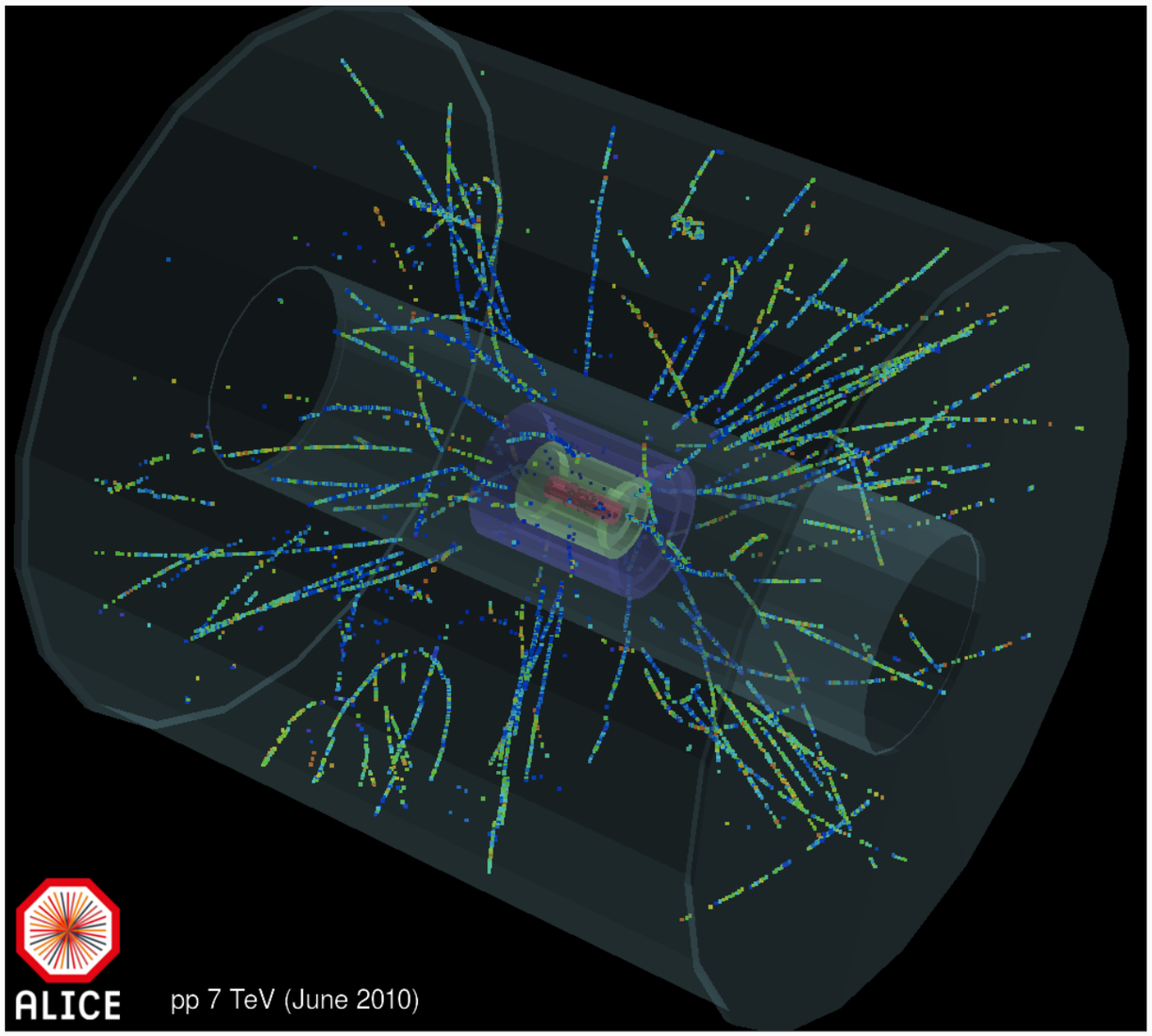

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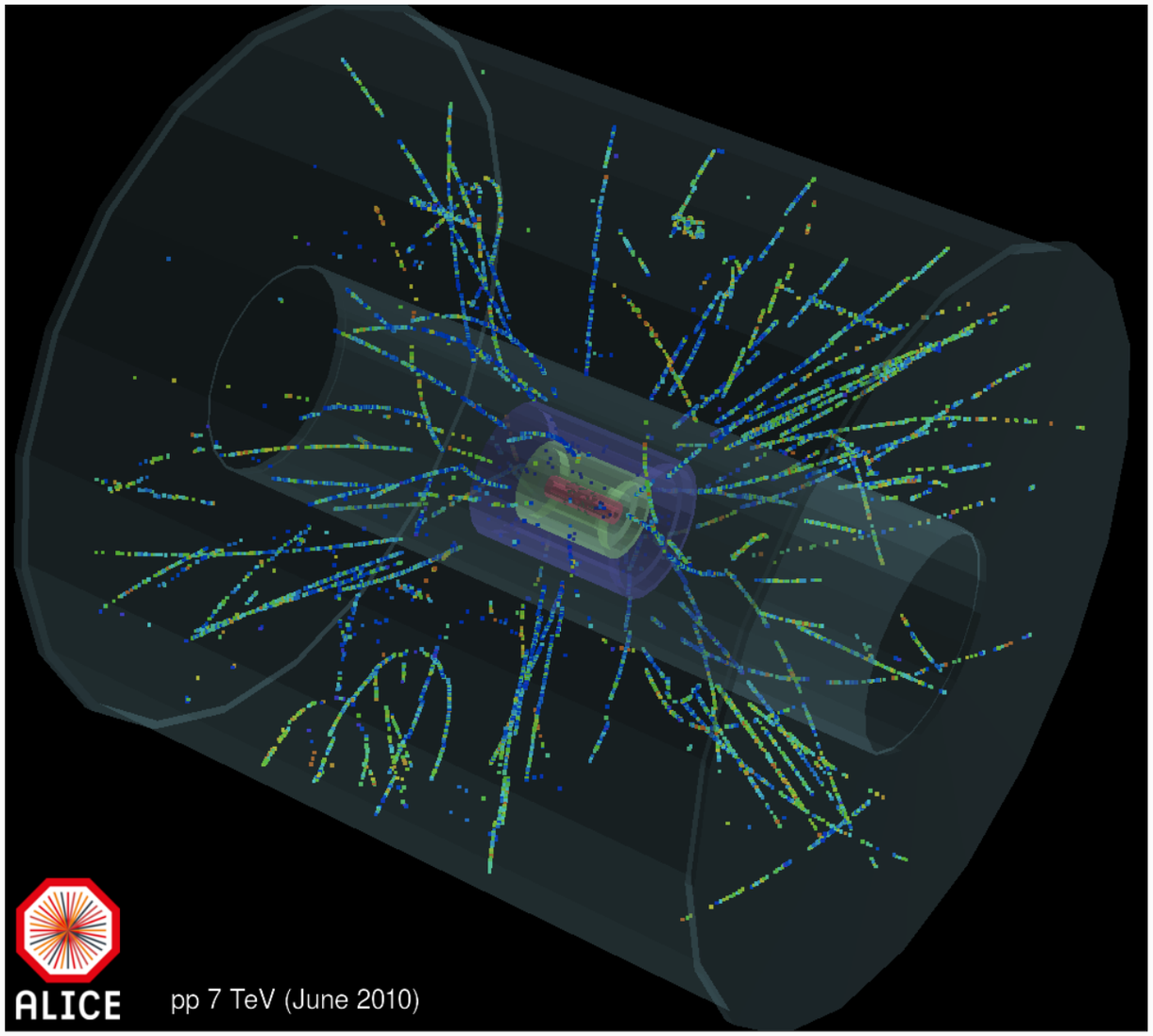

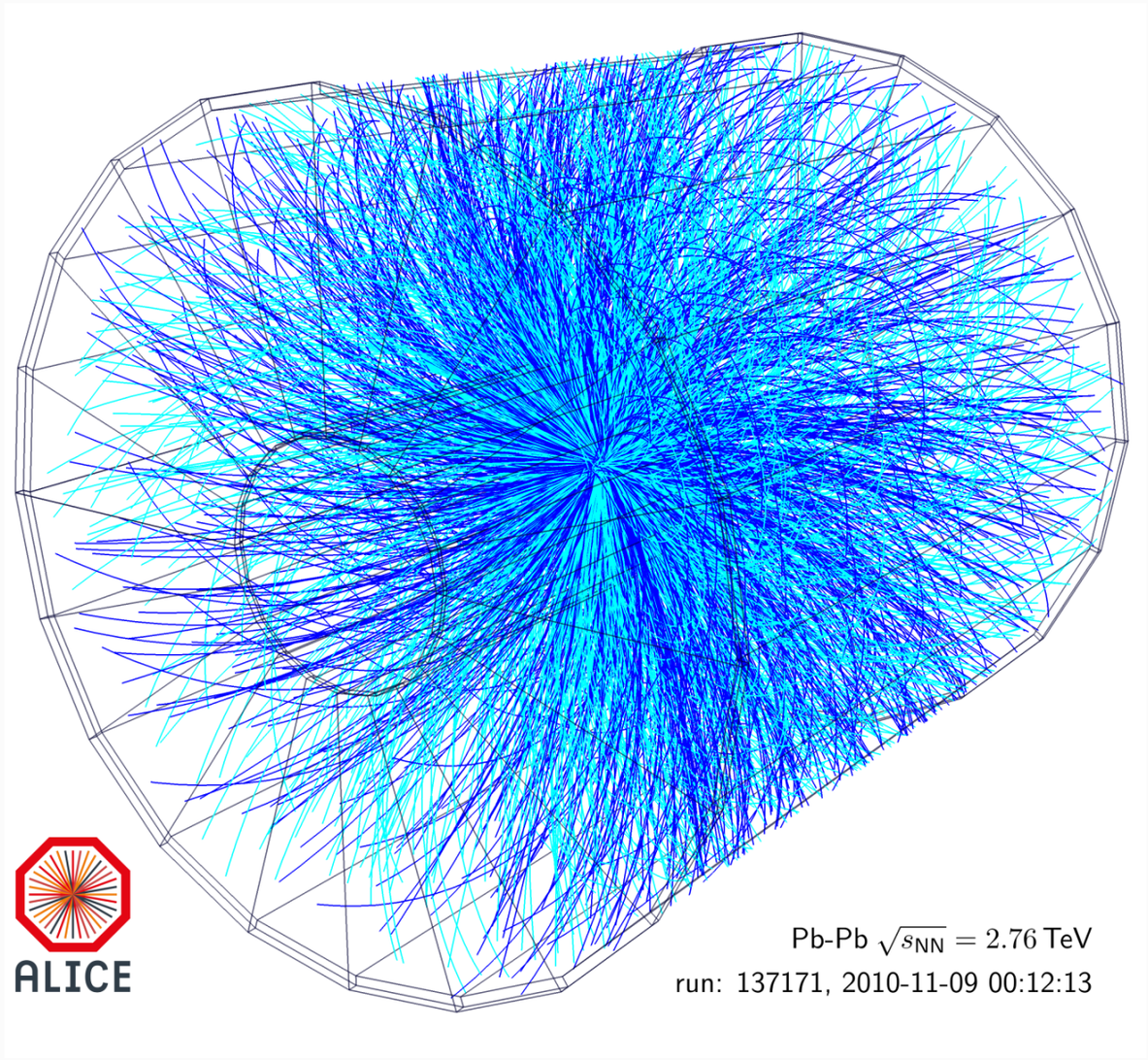

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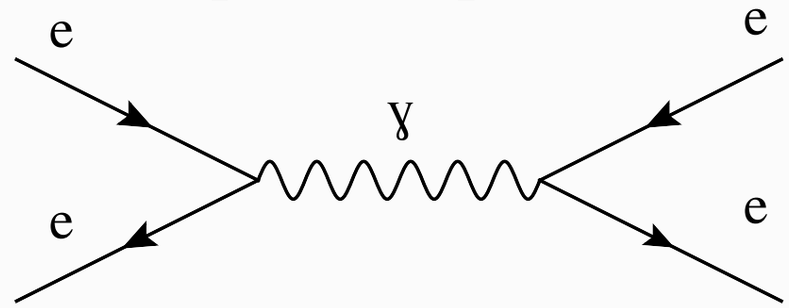

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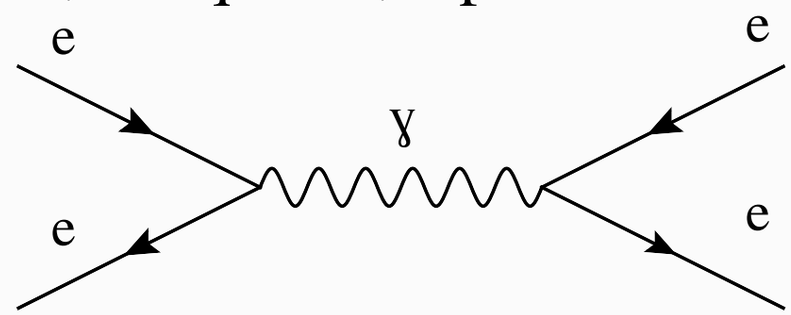

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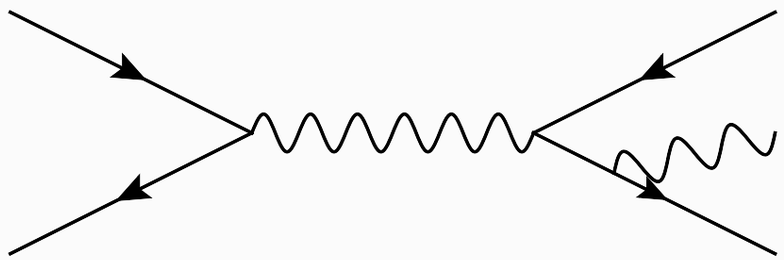

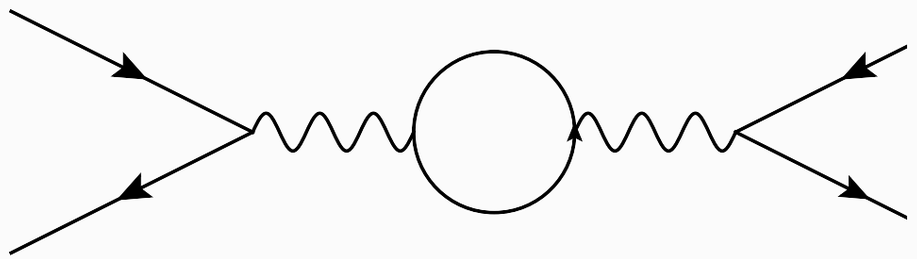

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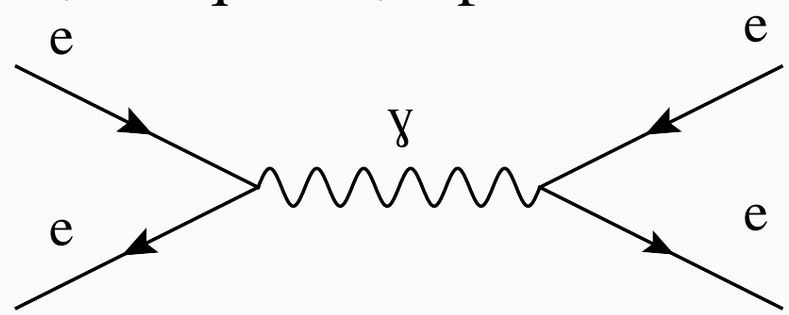

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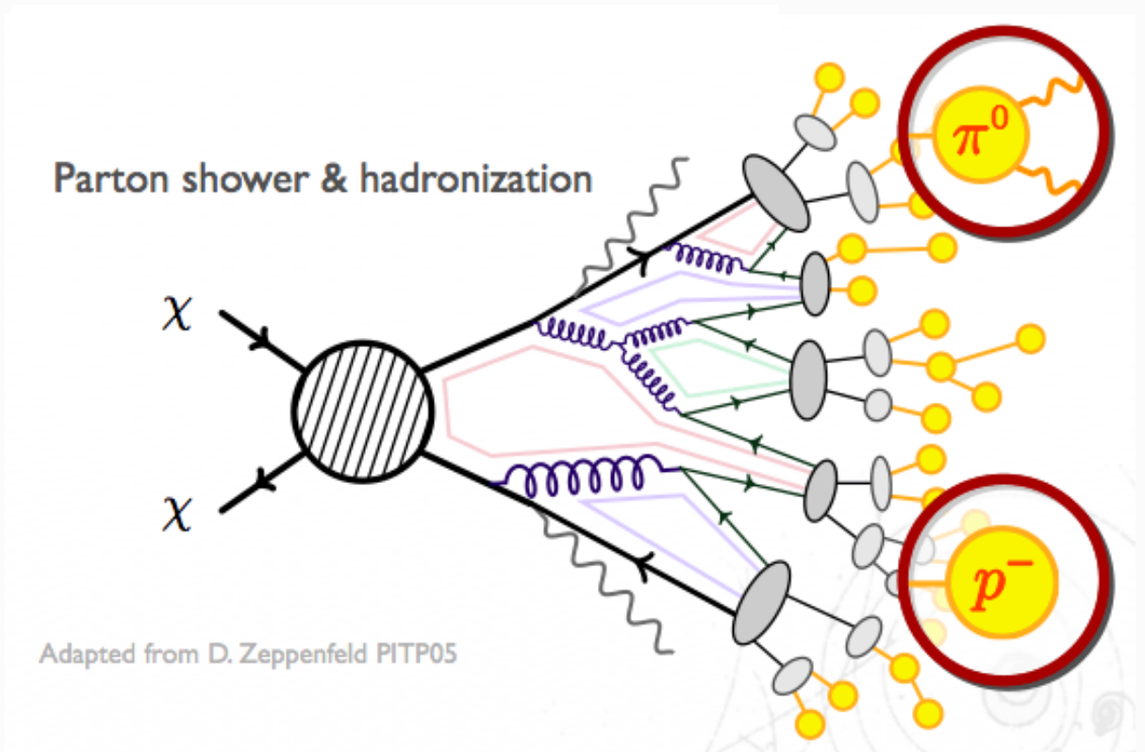

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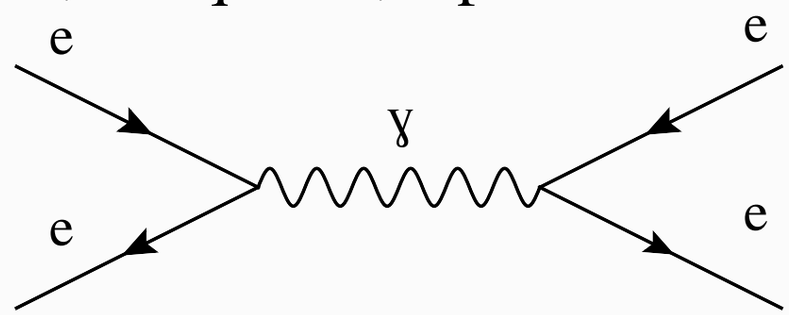

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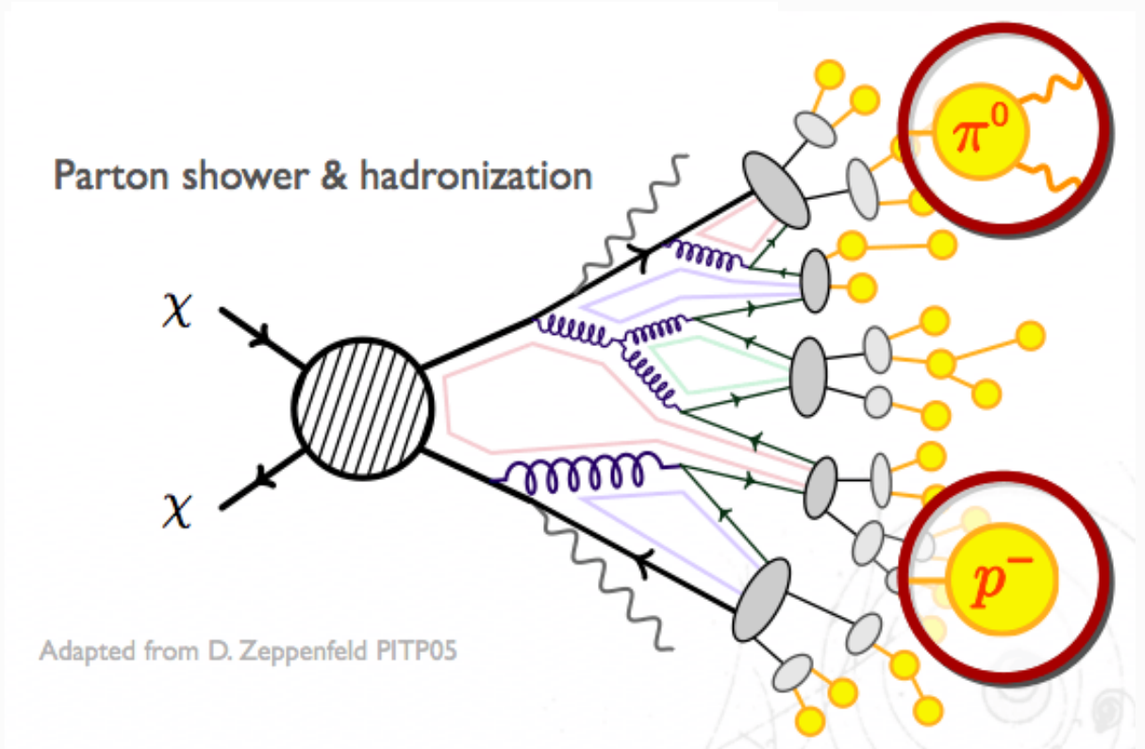
    Not easy to evaluate through analytical calculations…



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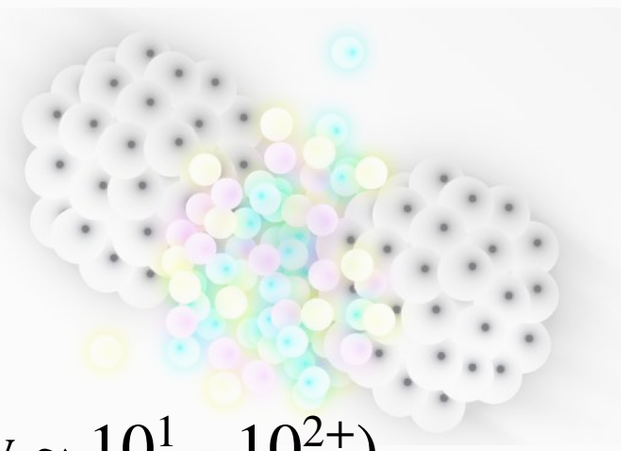

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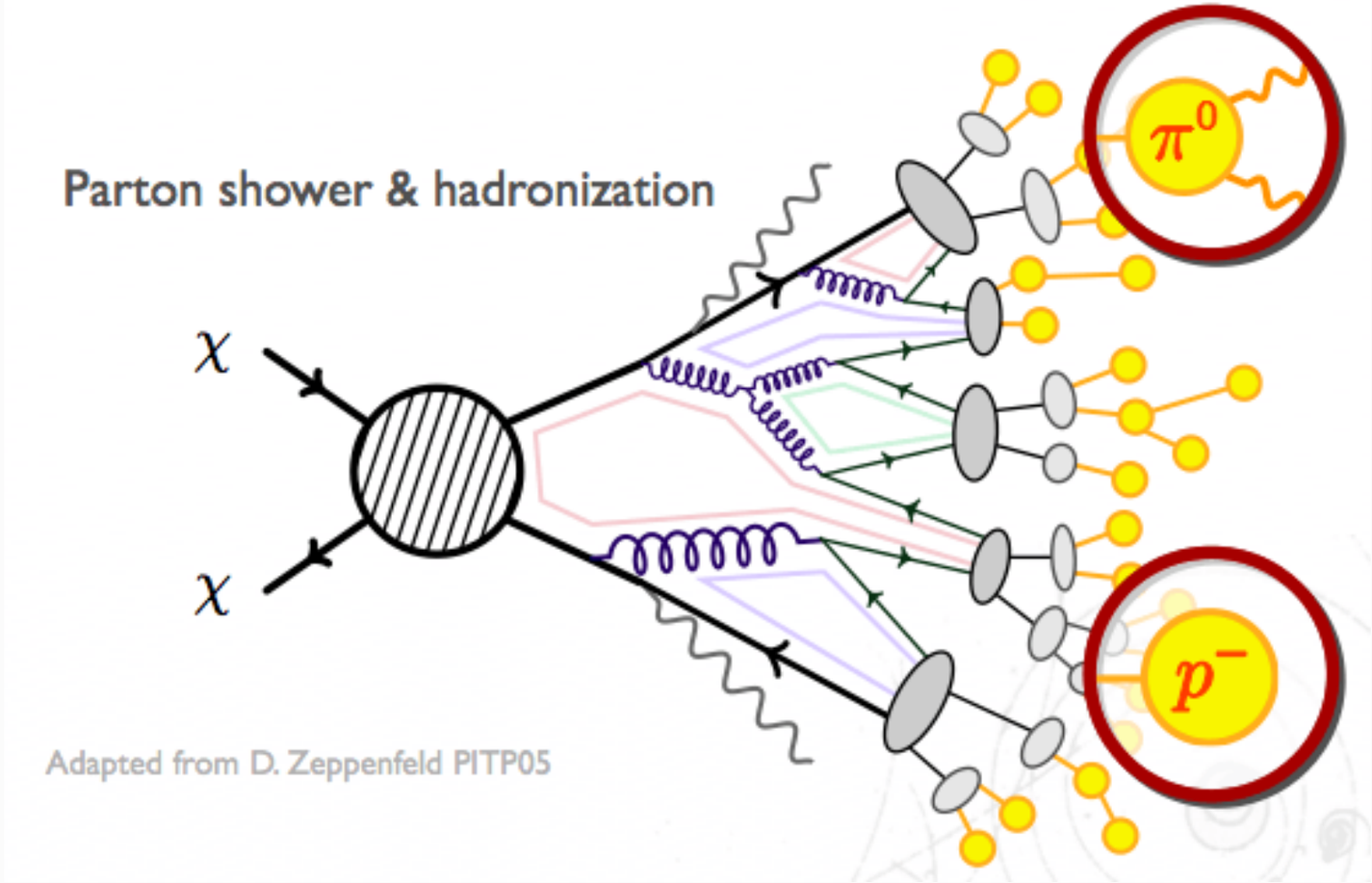

Picture becomes more complex, but original physics remains

(skeleton process has been dressed up and is no longer directly visible)

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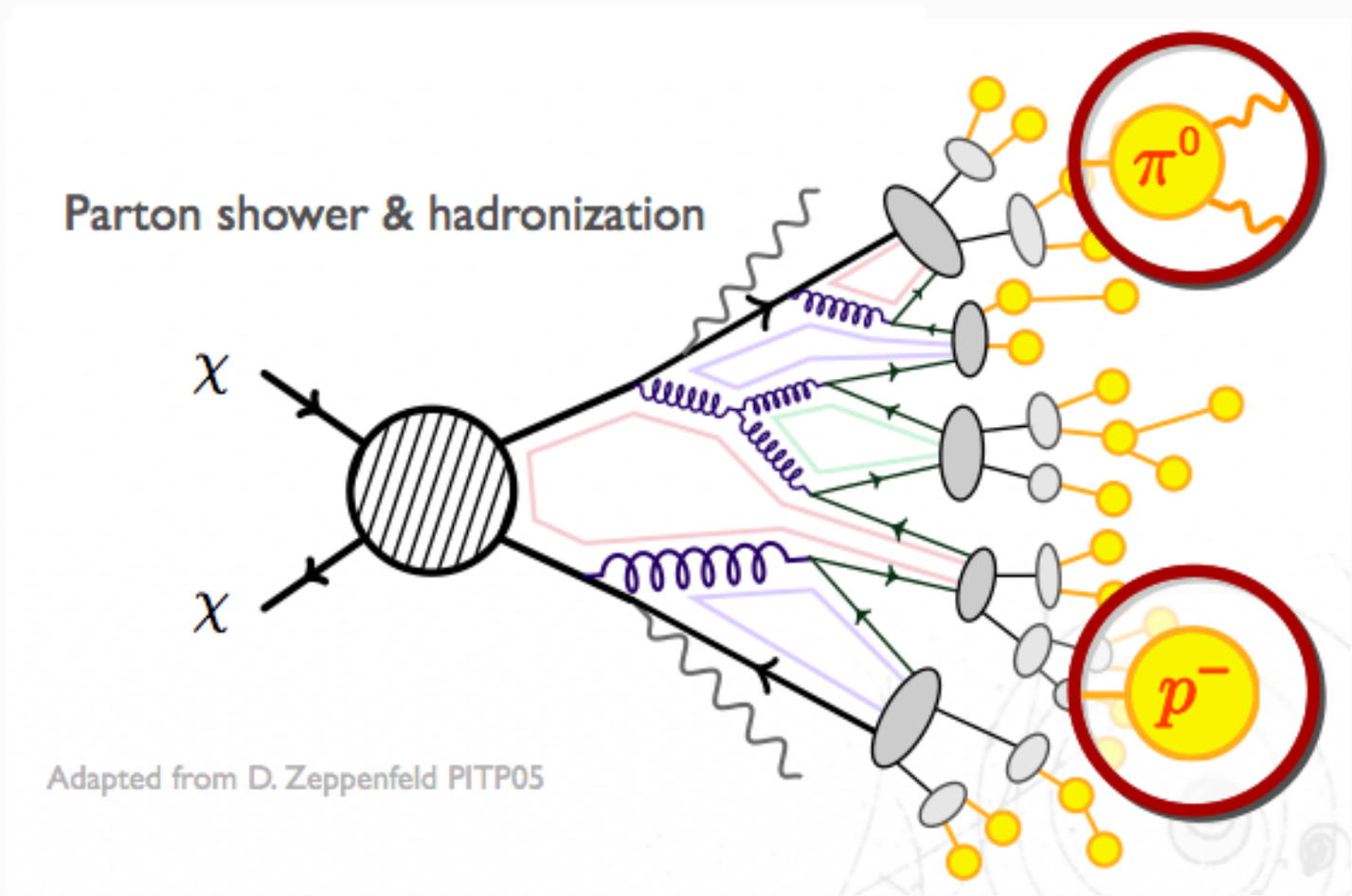

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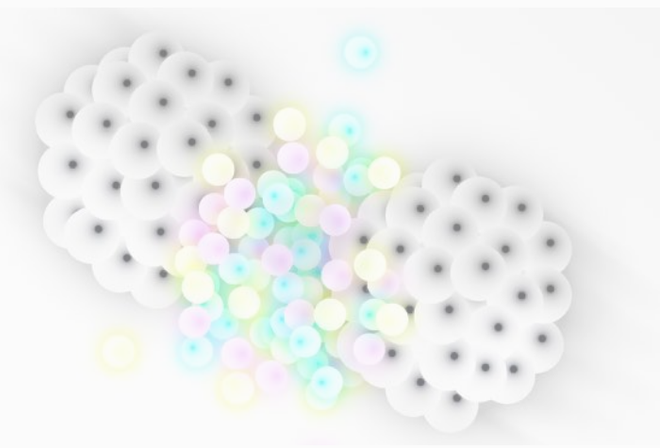
Event Generators to the rescue!

Introduction II

MC Event Generator

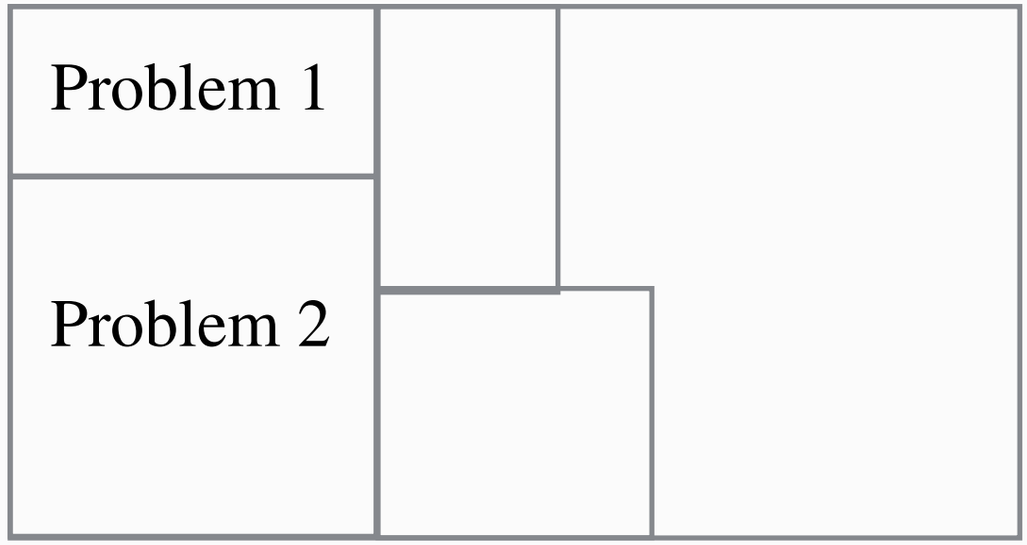
Introduction II



MC Event Generator

Problem 1	
Problem 2	

Introduction II



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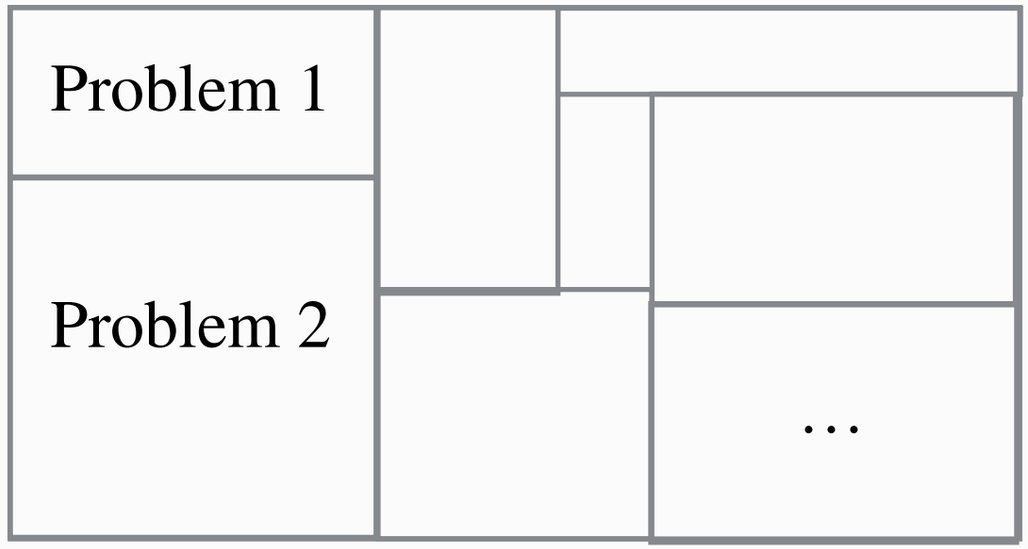
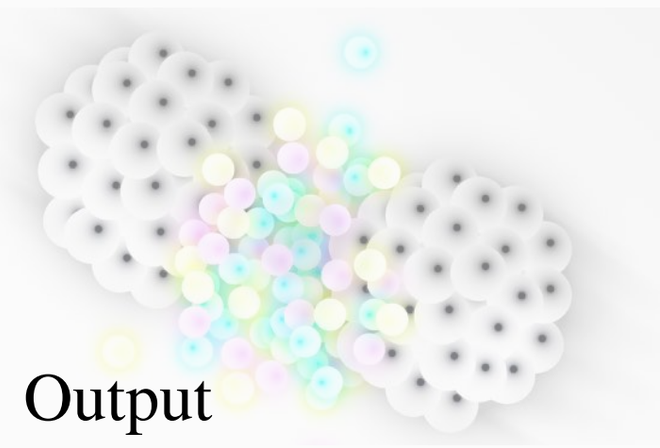


Factorization into simpler (and reasonably accurate) components

Introduction II



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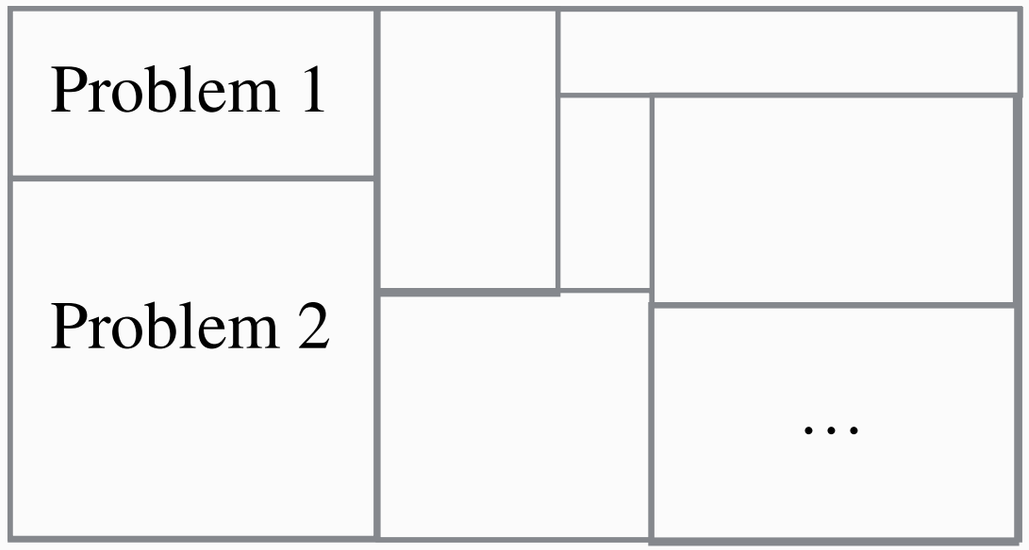

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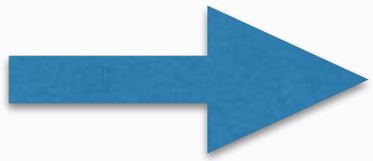


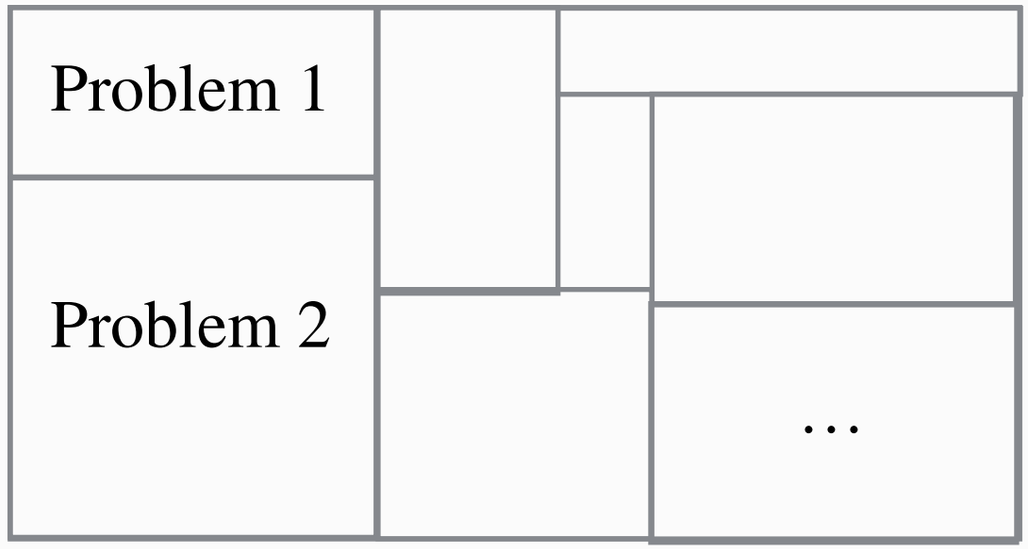
Output

Same average behaviour and fluctuations as real data

‘events’

Introduction II

MC Event Generator



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Detector performance (propagation, magnetic field, shower calorimeter, ….)

Detector Simulation GEANT

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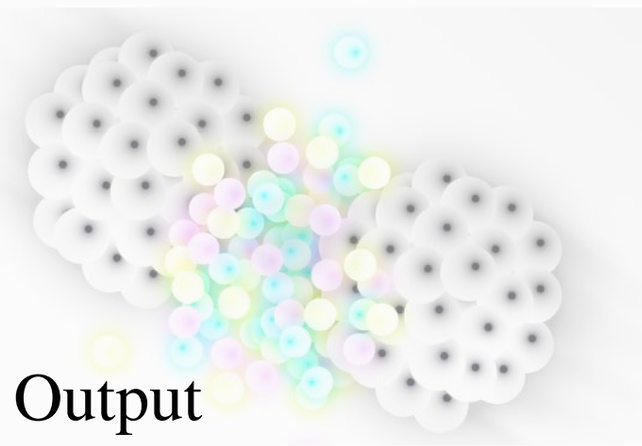

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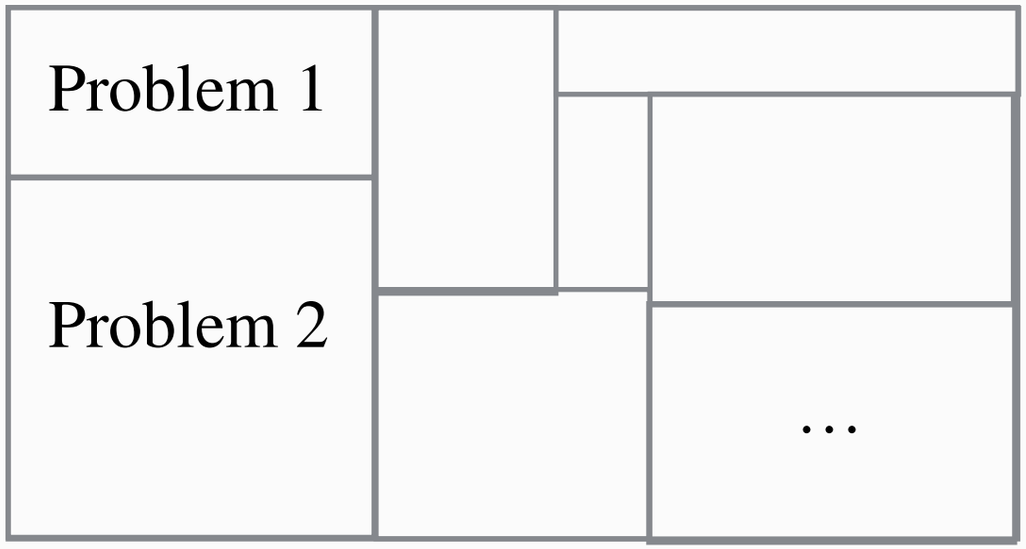

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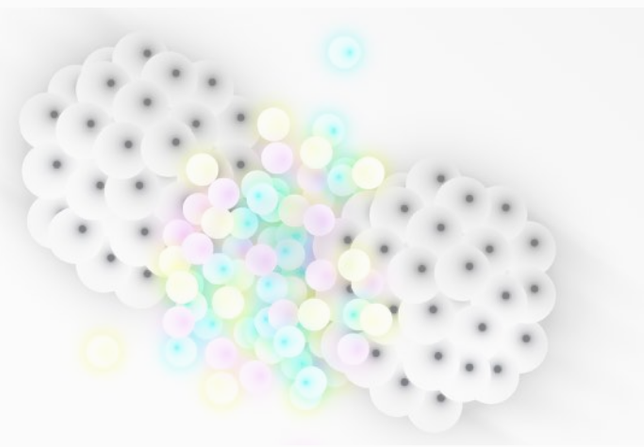
Detector Simulation GEANT

Final Output

Same format as the real data recorded by the detector

High Energy Collision



- Focus on a specific problem: high energy pp collision. What goes into this process?

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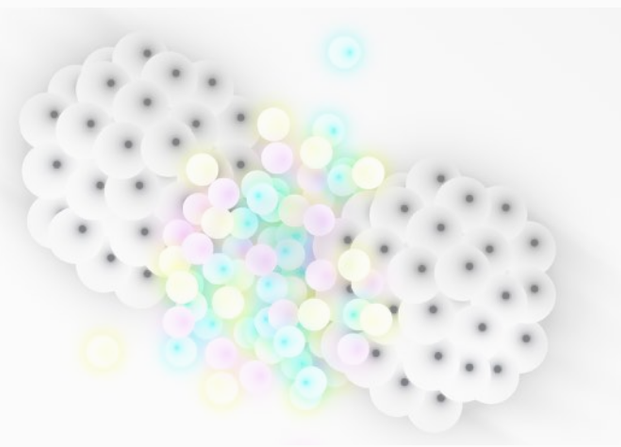

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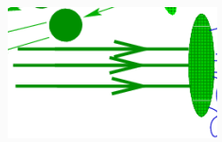

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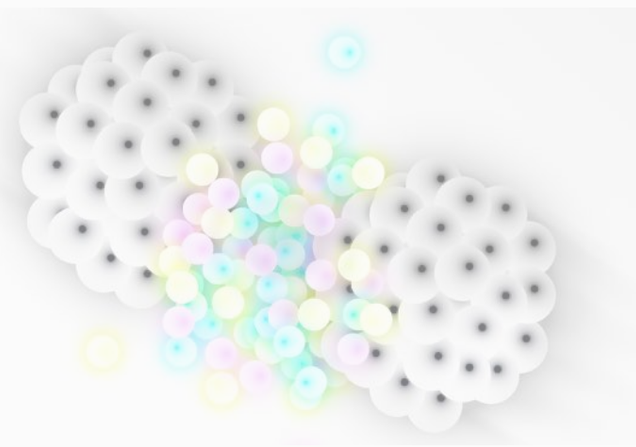

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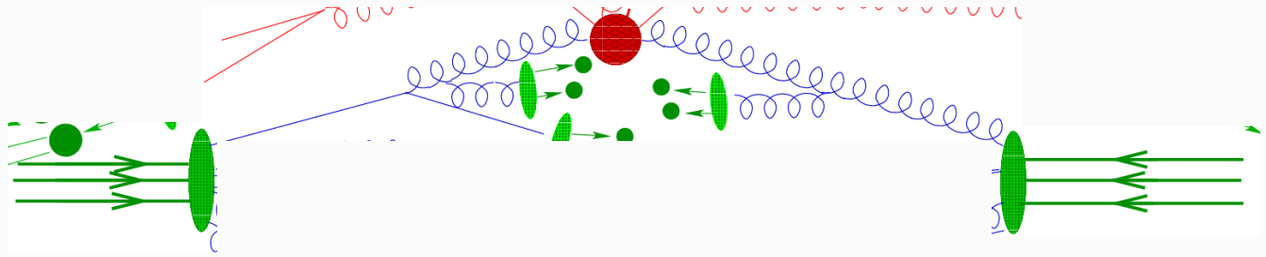

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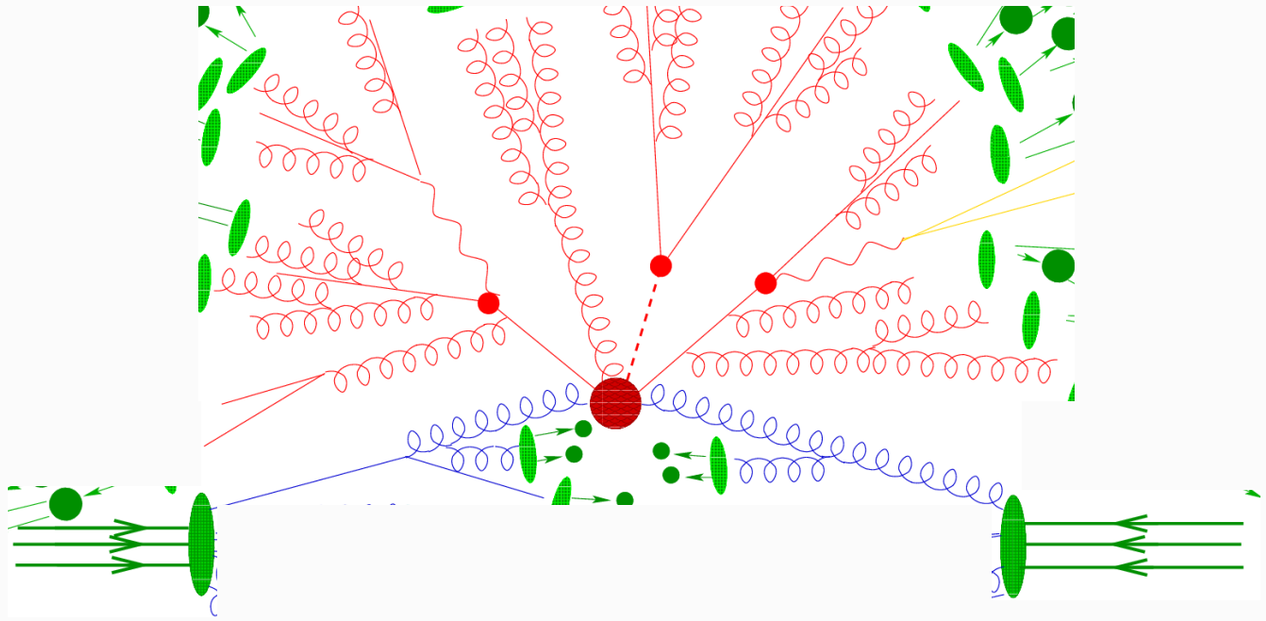

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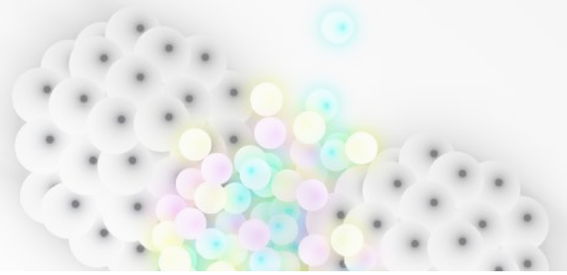

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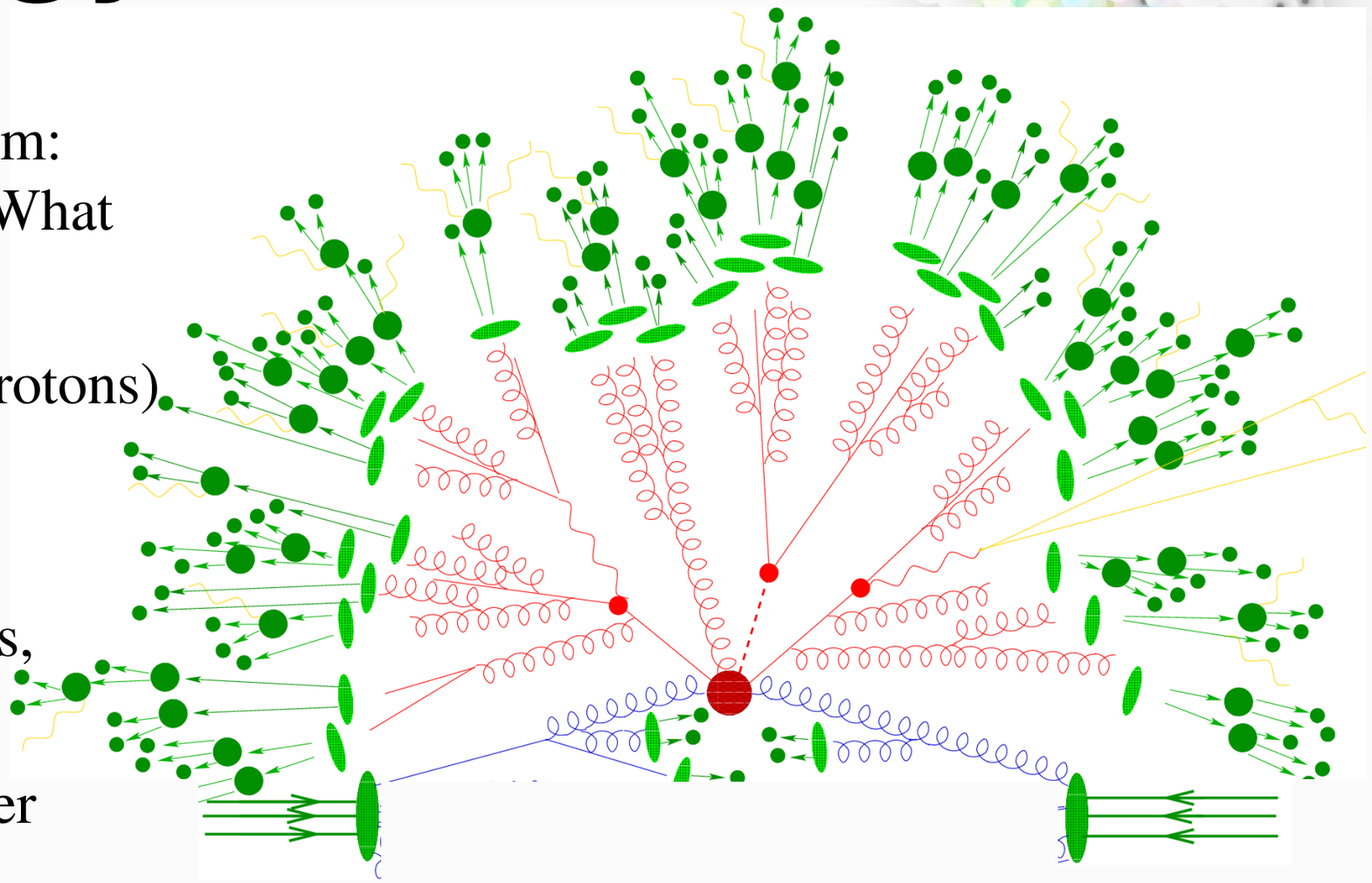

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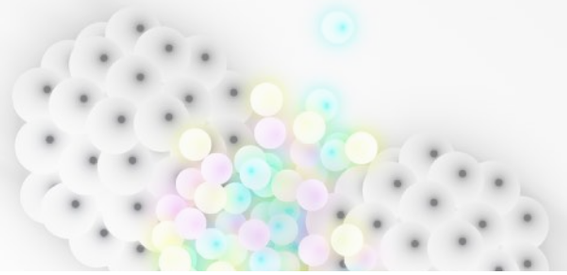

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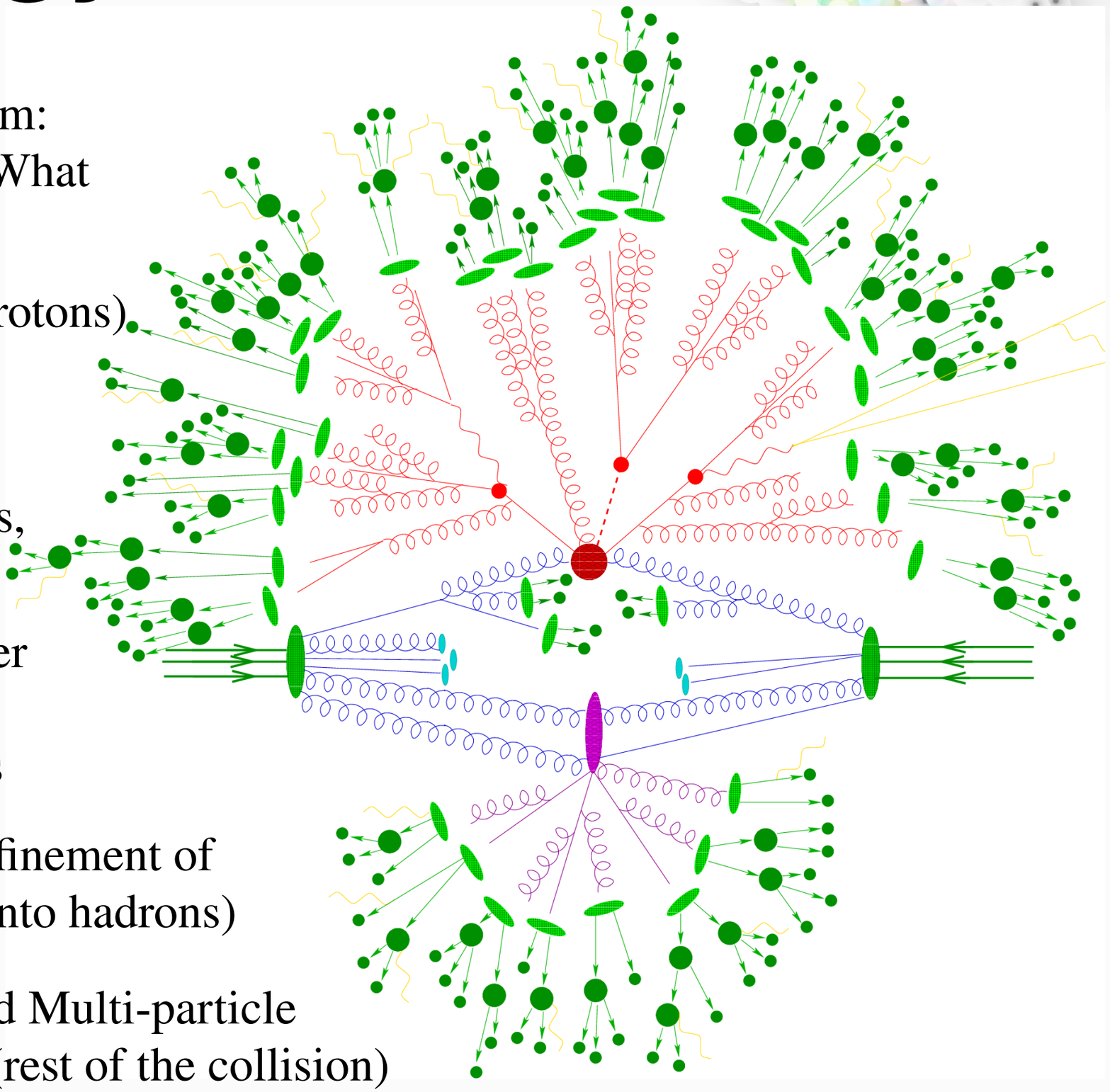
  - Beam Remnants and Multi-particle Interactions (MPI) (rest of the collision)



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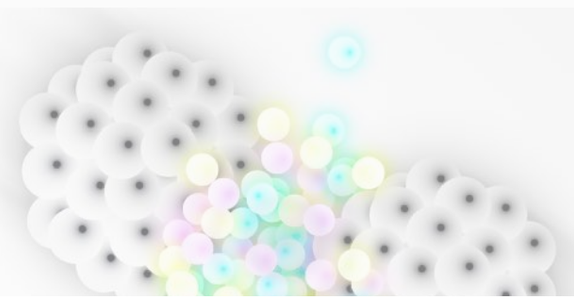

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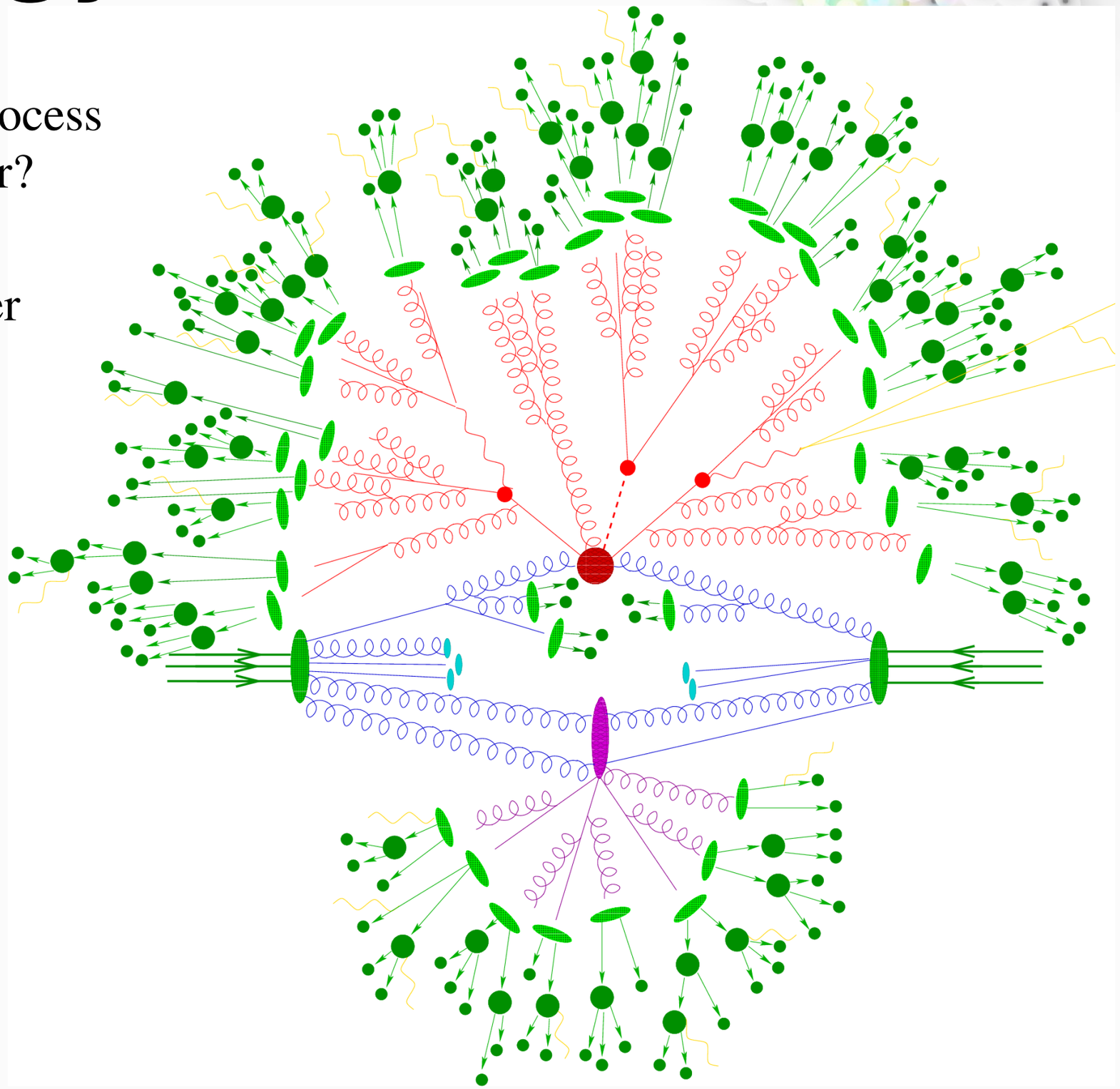

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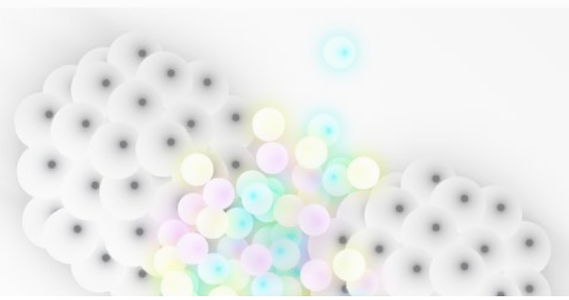

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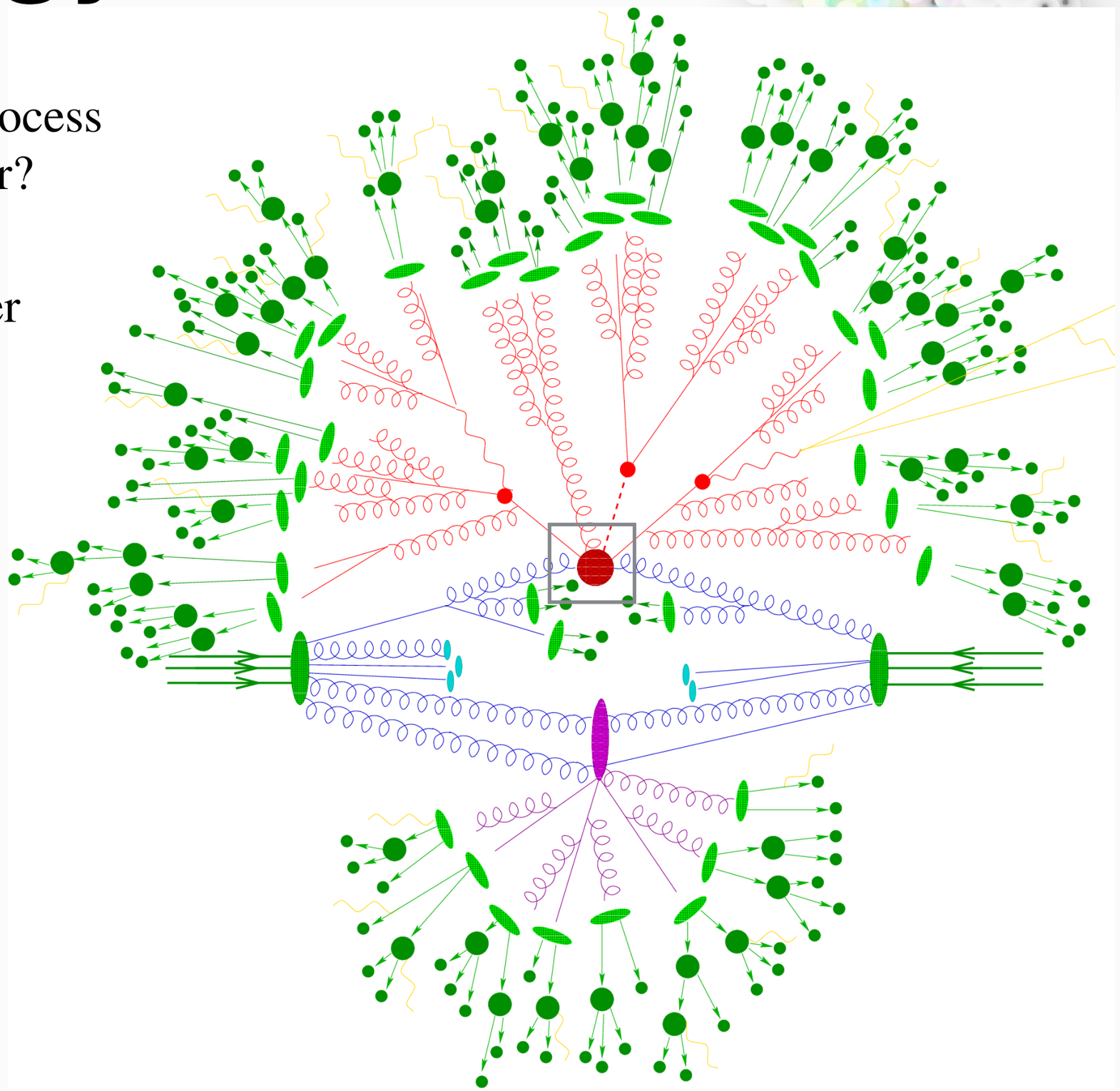

High Energy Collision

- How to describe such a process through an event generator?
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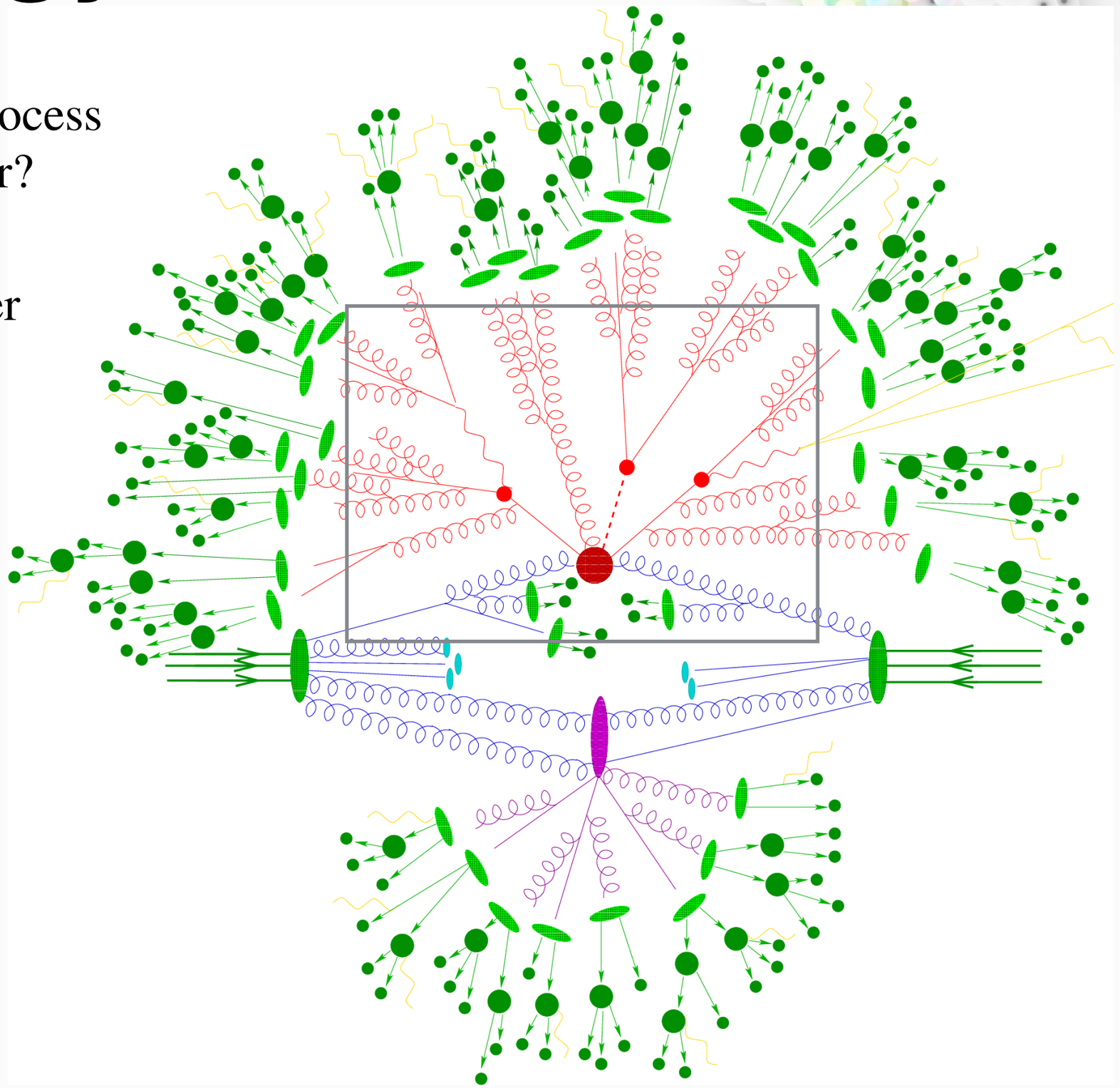
    - Initial-state shower and final-state shower



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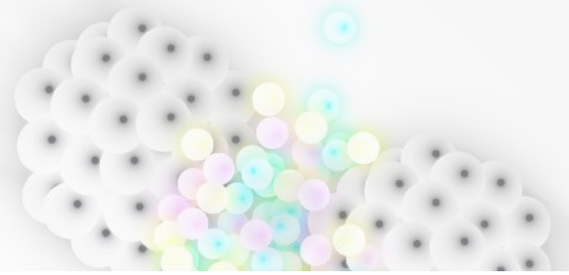

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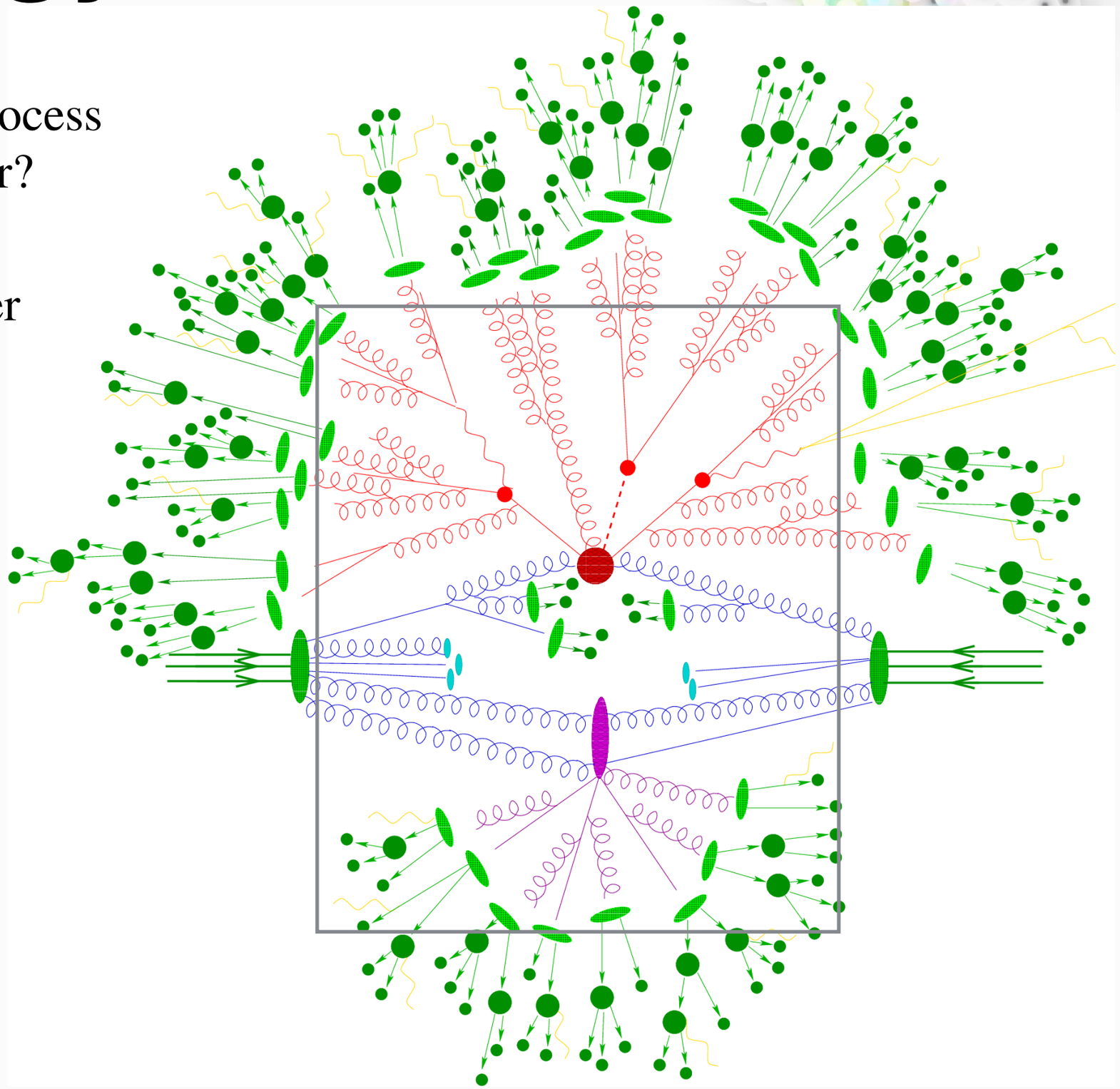

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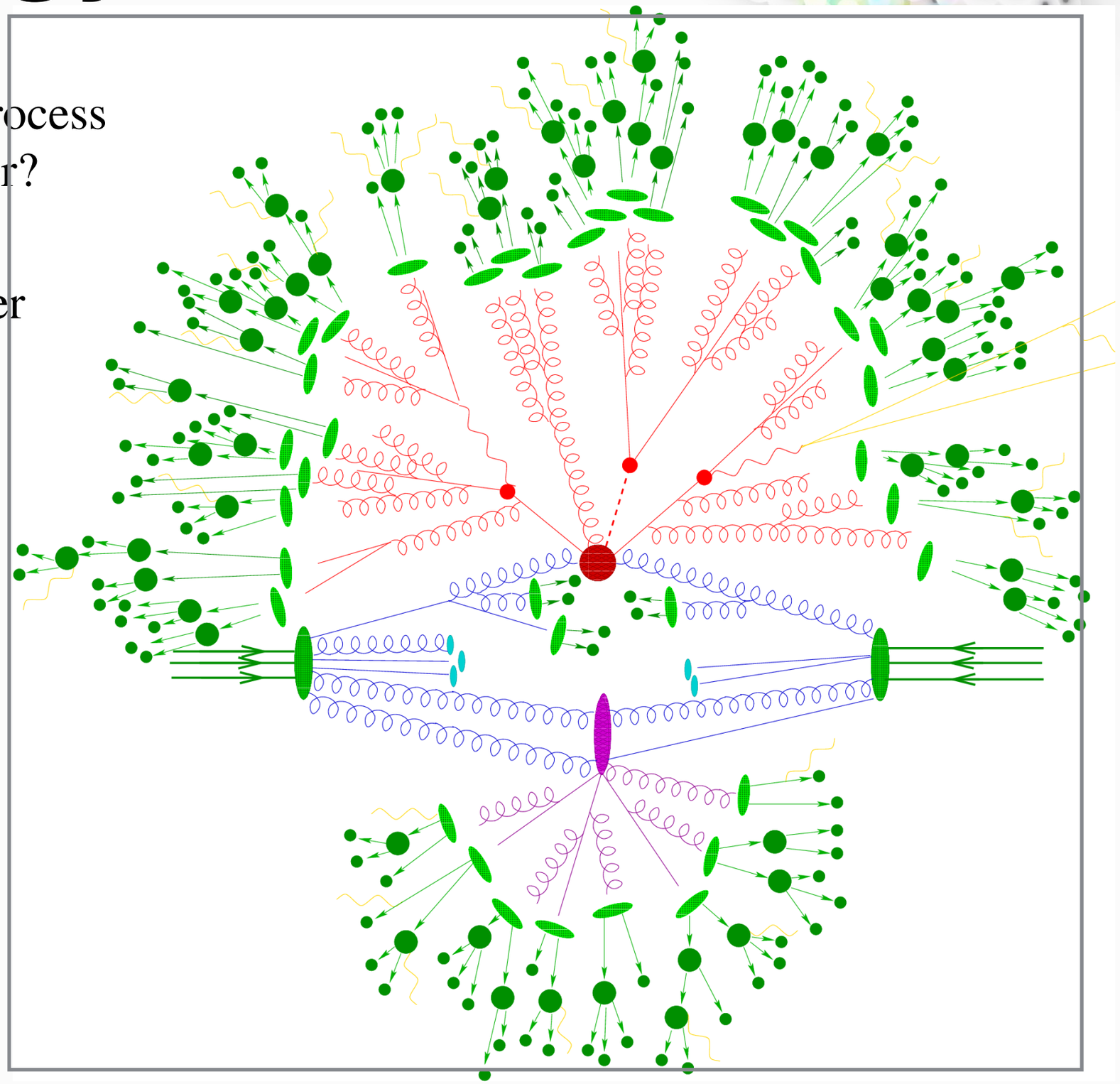

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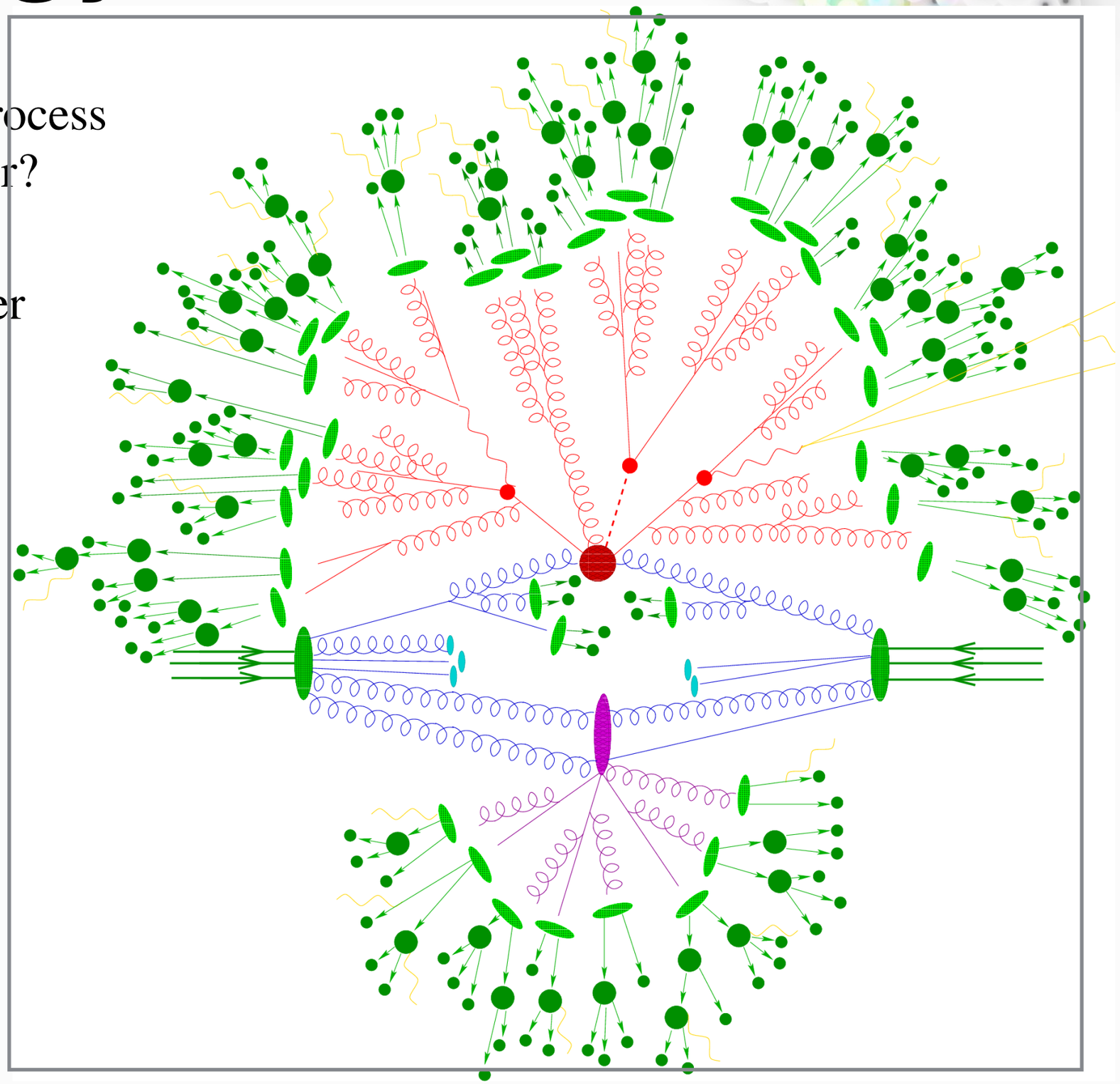
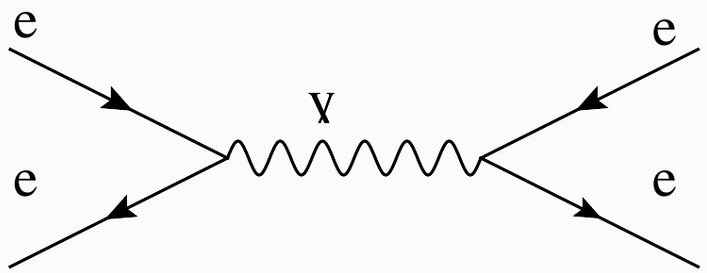
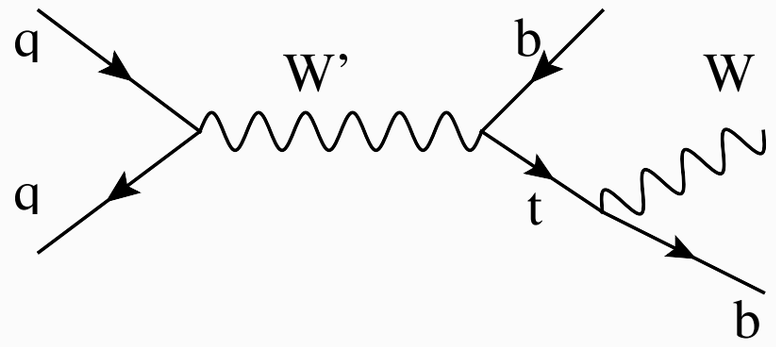
Separation in energy scale ⟶



Hard Process

- Simple high energy process, like 2→1, 2→2, 2→3, … that can be <u>calculated analytically from first principles</u>:





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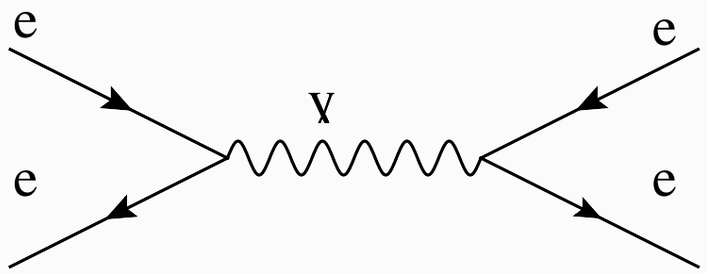

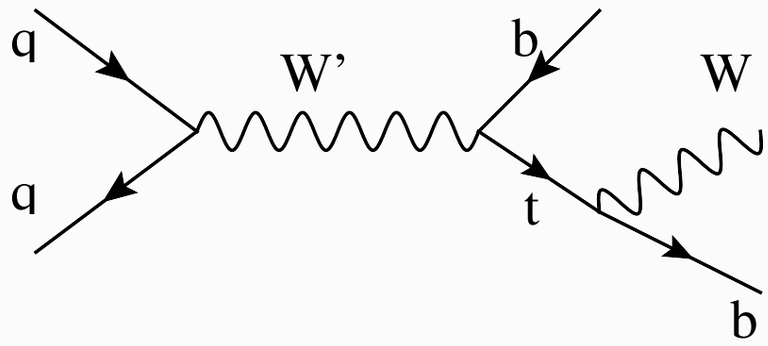

- What gives the main characteristics of the event
  - SM: Hard QCD, Soft QCD, Heavy-Flavour, DIS, W/Z, Higgs Production…
  - BSM: Technicolor, Compositeness, SUSY, …

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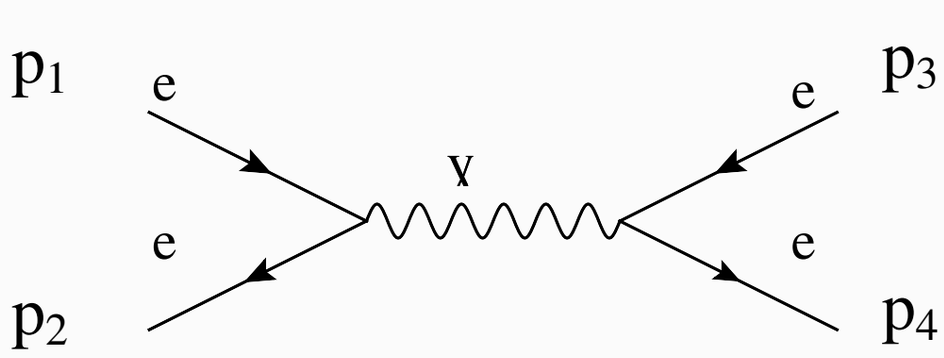
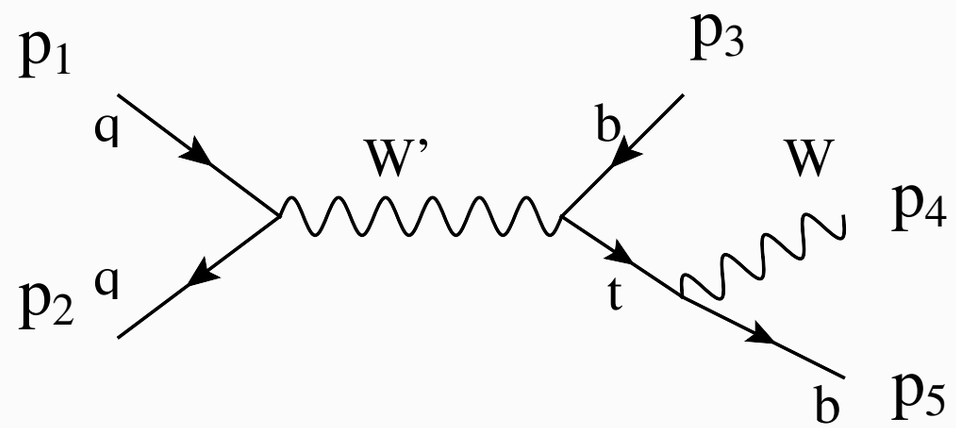
- Simple high energy process, like 2→1, 2→2, 2→3, … that can be <u>calculated analytically from first principles</u>:

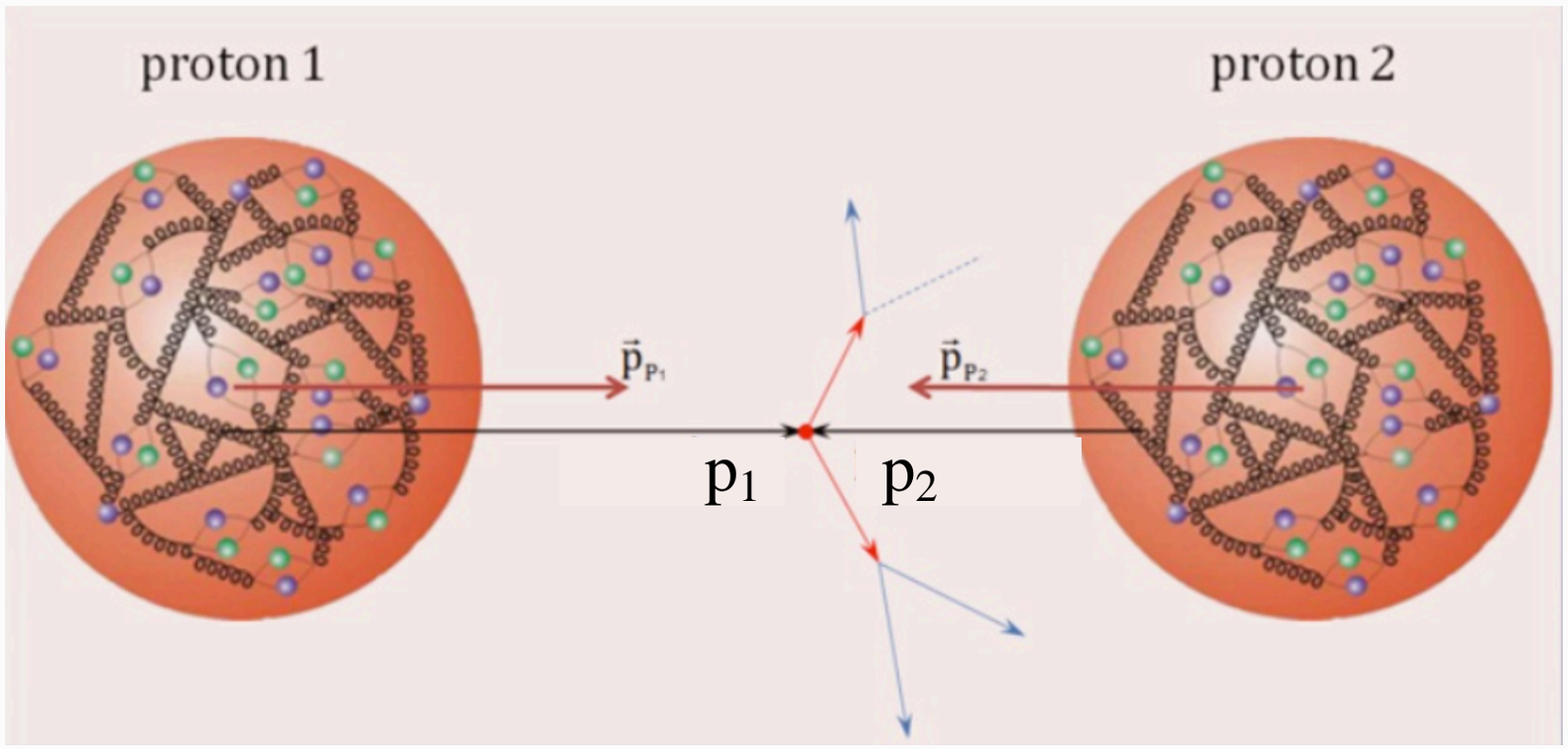




- What gives the main characteristics of the event
  - SM: Hard QCD, Soft QCD, Heavy-Flavour, DIS, W/Z, Higgs Production…
  - BSM: Technicolor, Compositeness, SUSY, …
- Given the topology and kinematics, one can evaluate the cross-section, σ.

Parton Distributions

- Initial topology and kinematics is not fixed, but rather sampled from the parton distribution of the two incoming protons…



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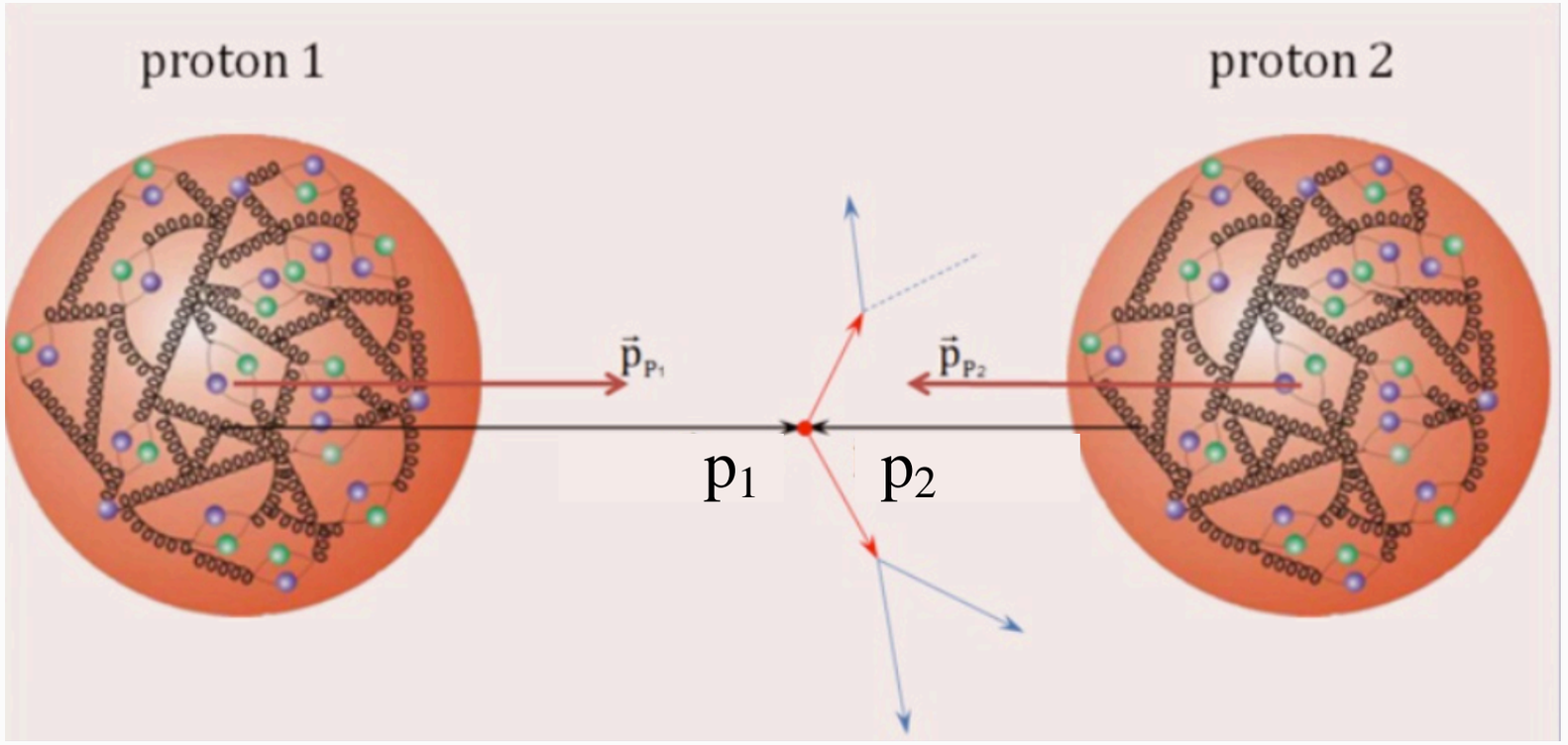

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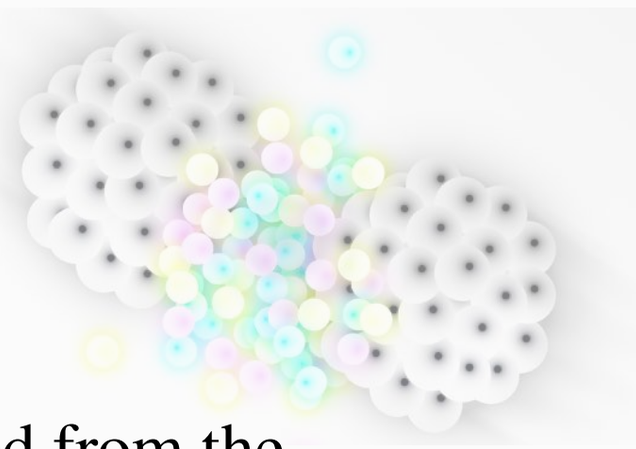

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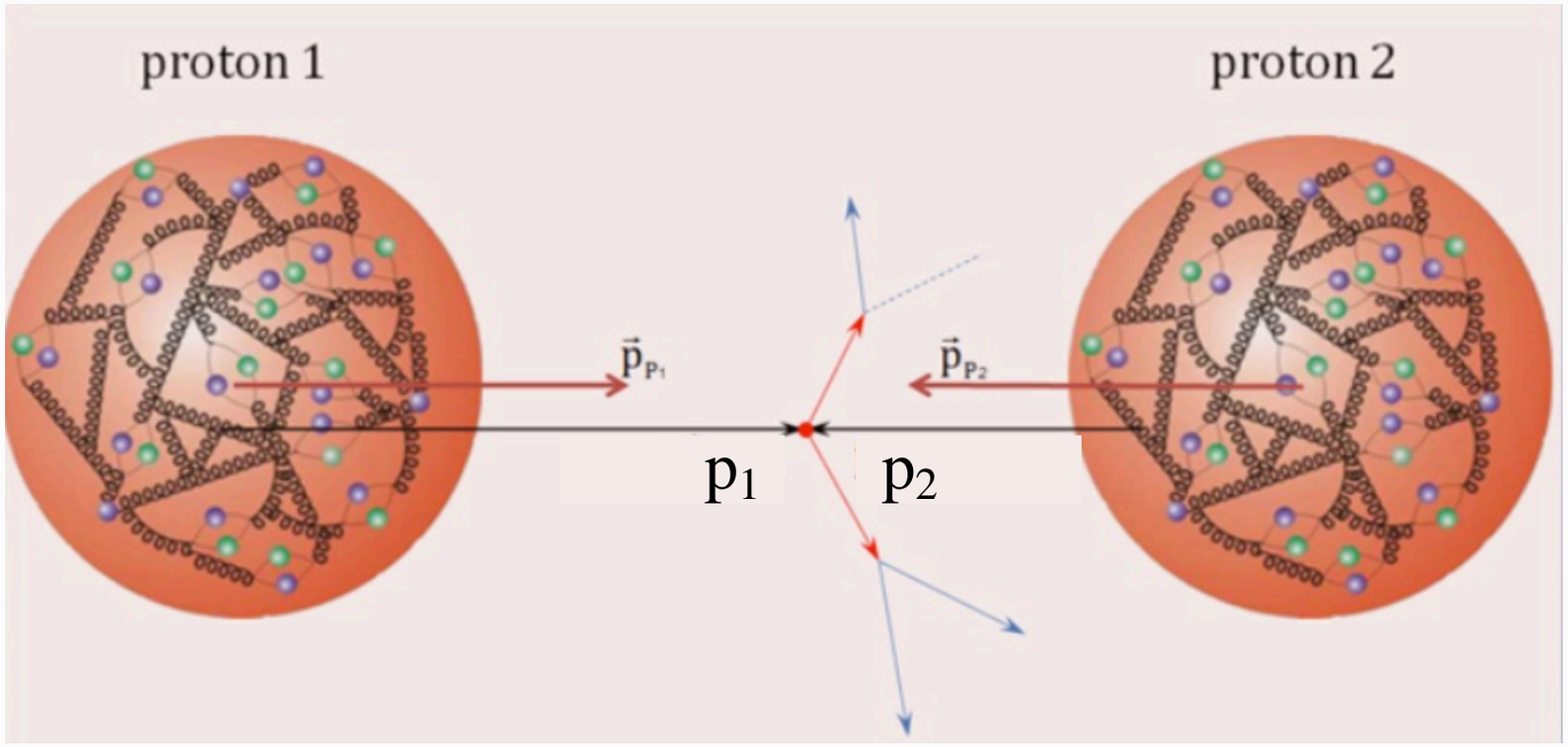
↘

Elementary cross-section
(hard process)



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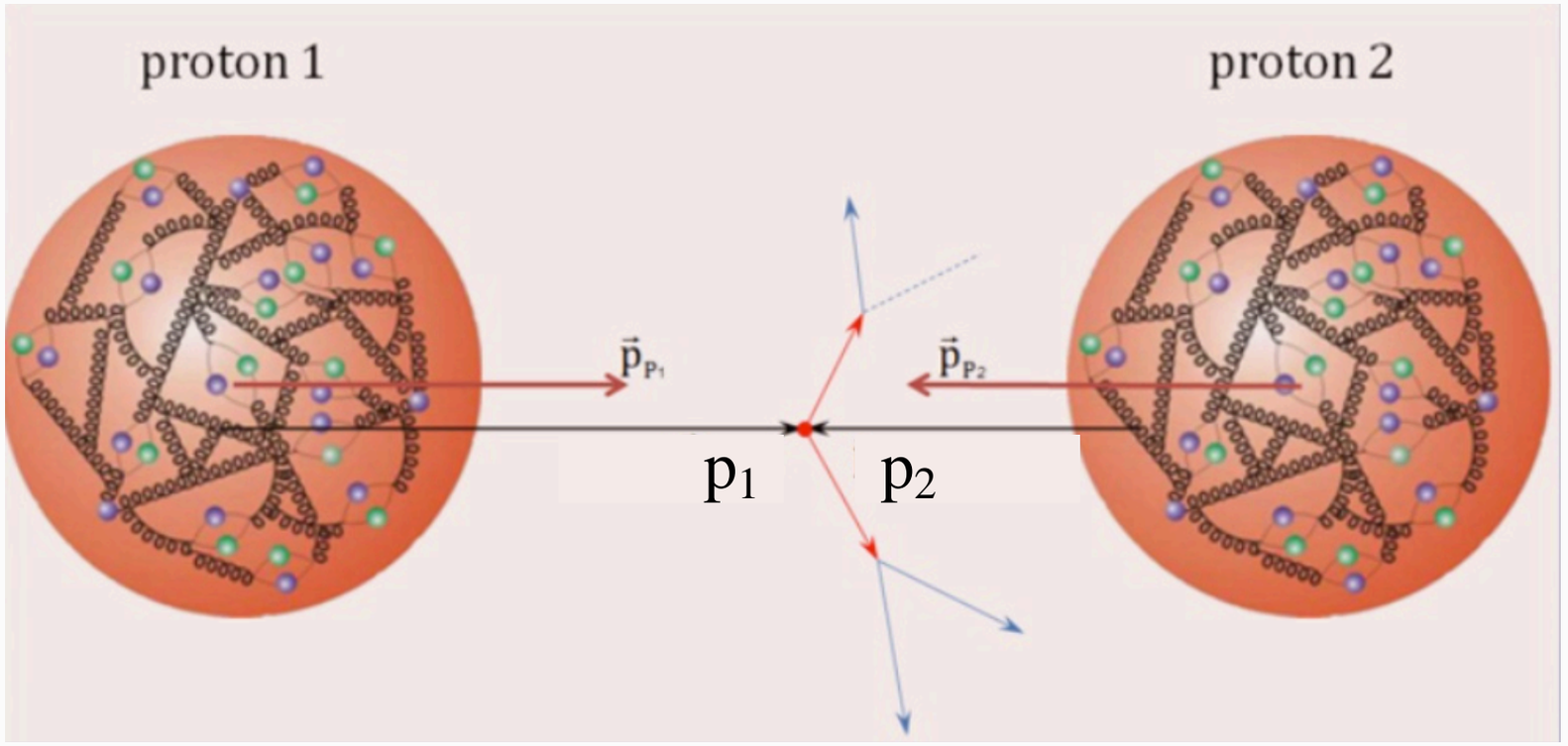
Parton Distribution Functions (PDFs)

Elementary cross-section (hard process)

Probability to find a parton ‘i’ inside beam particle '1' carrying a fraction x_1 of the total momentum

(dependent on the hard process scale, Q^2)



Parton Distributions

- Derivation from first principles does not yet exist. But its evolution, in Q^2, can be described analytically.
  - Rely on parameterisations:
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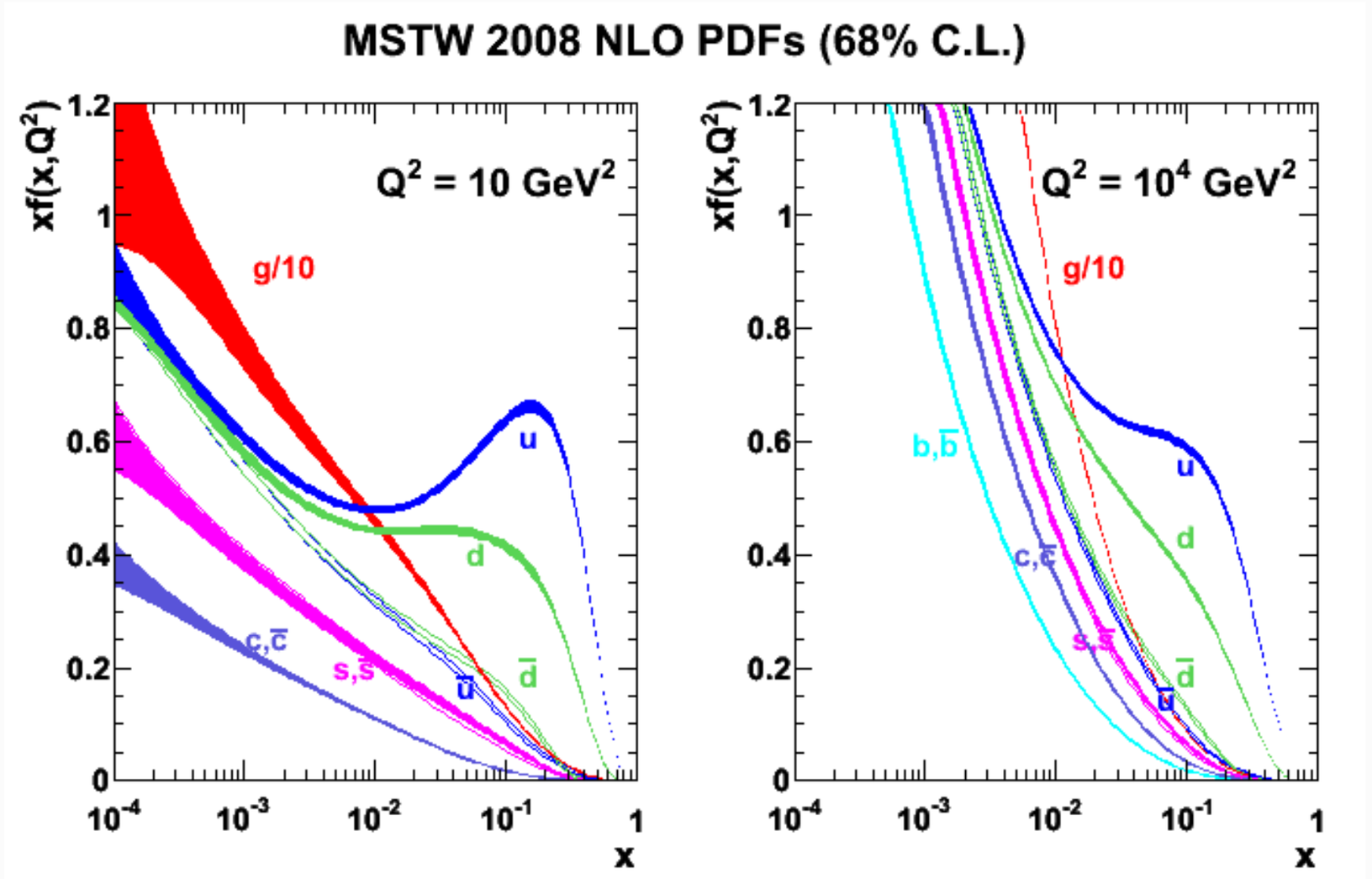
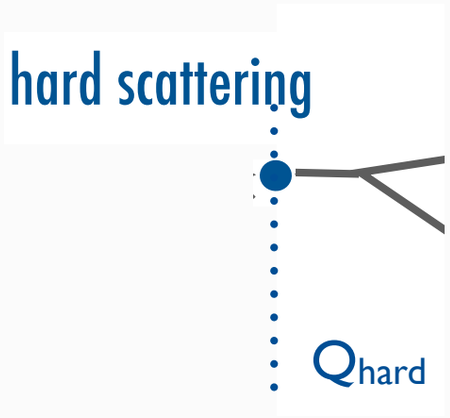
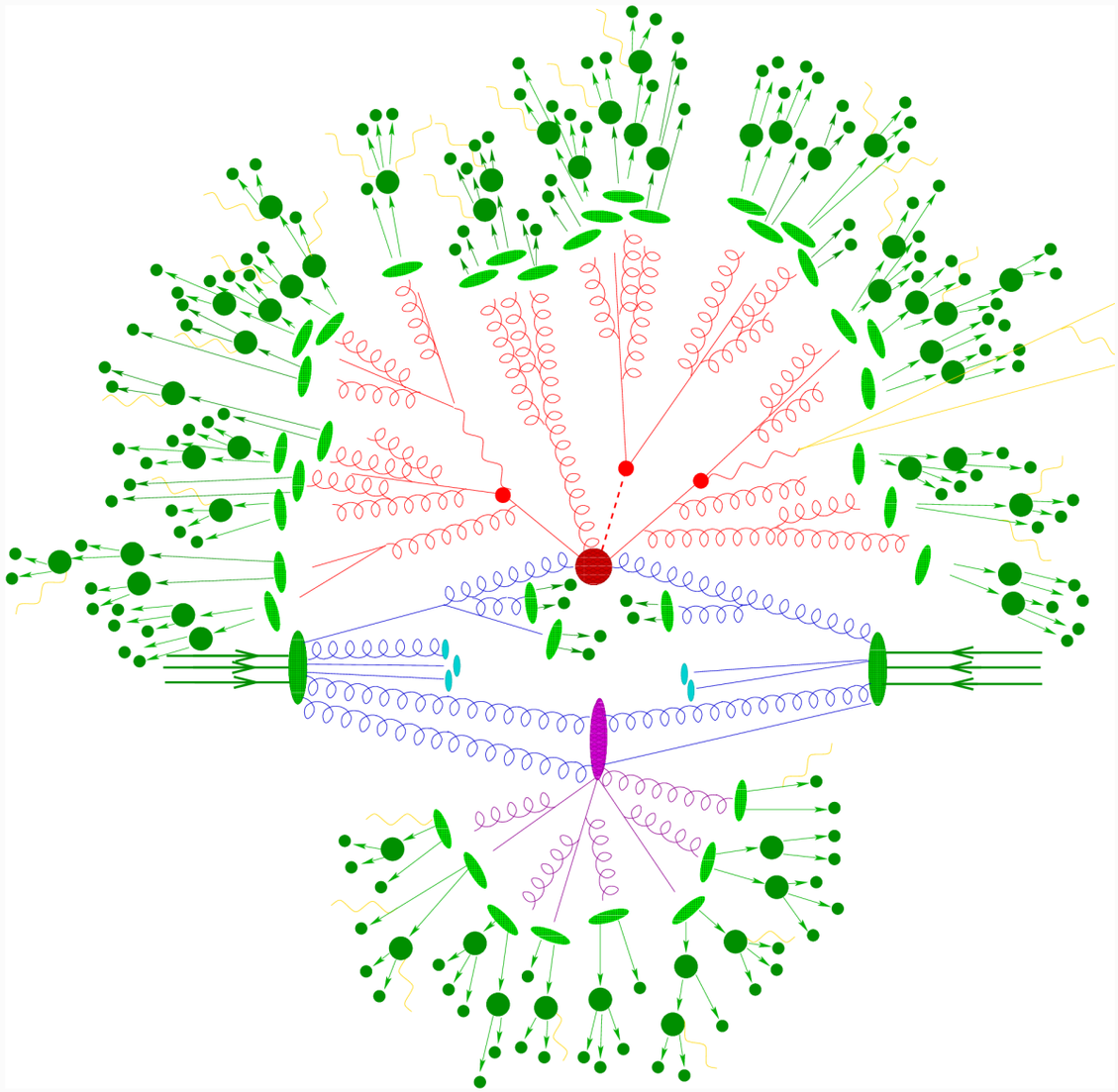


Initial- and Final-State Showers

- Corrections to generate multi-particle production, 2→3, 2→4, etc…





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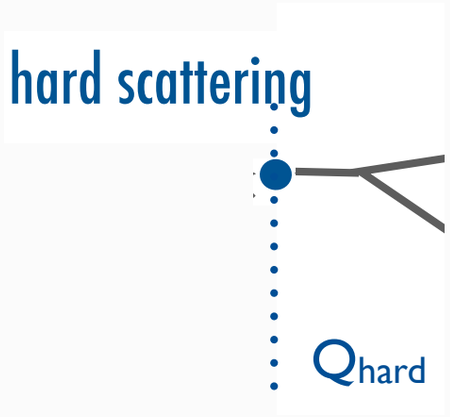

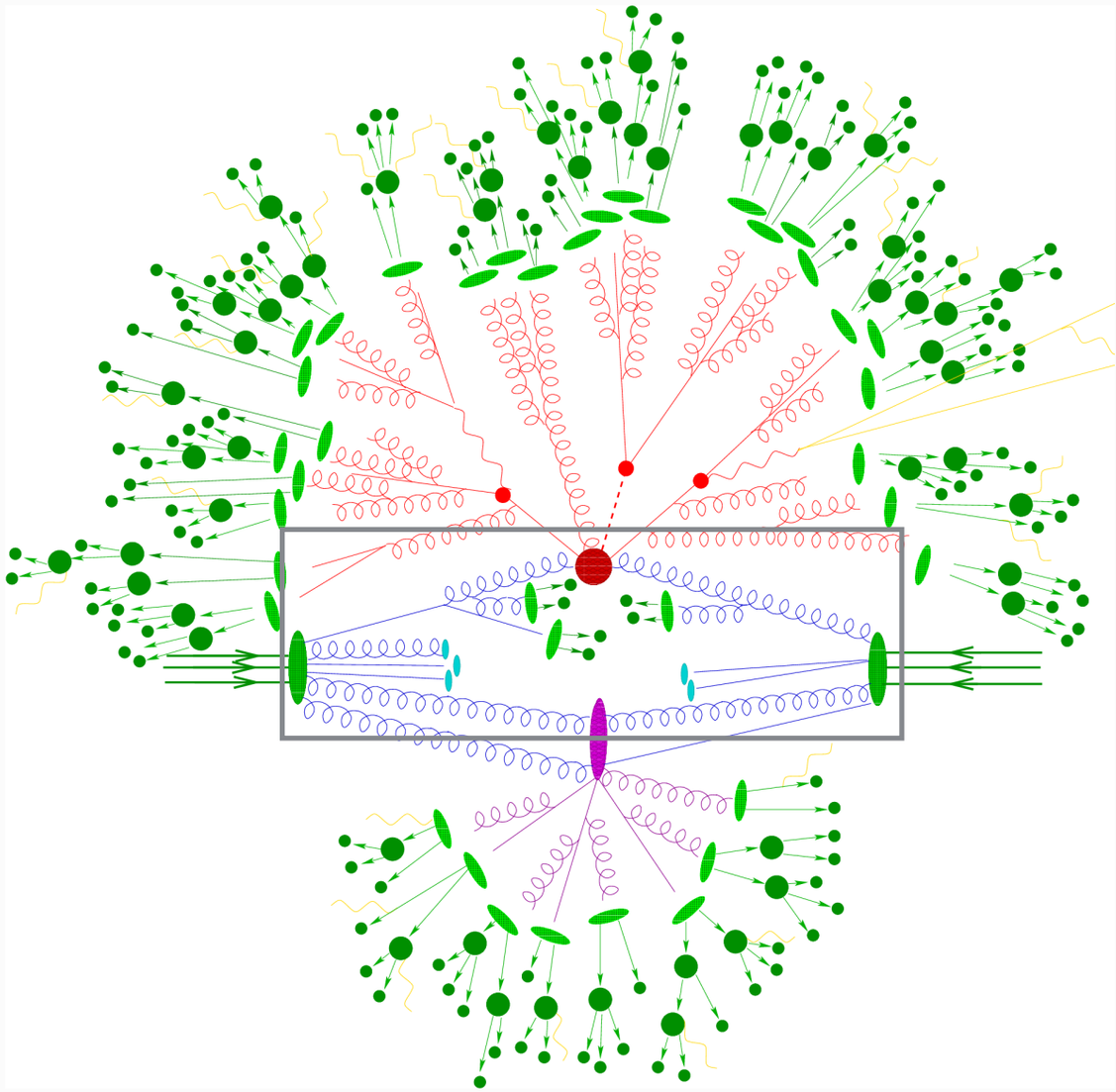

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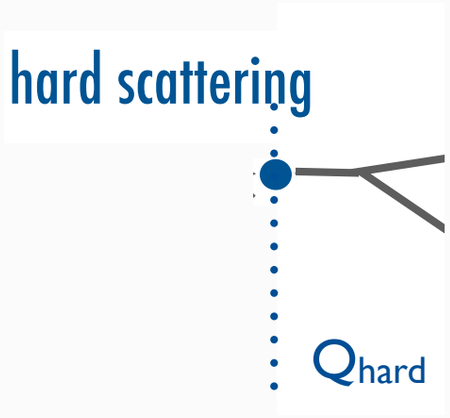

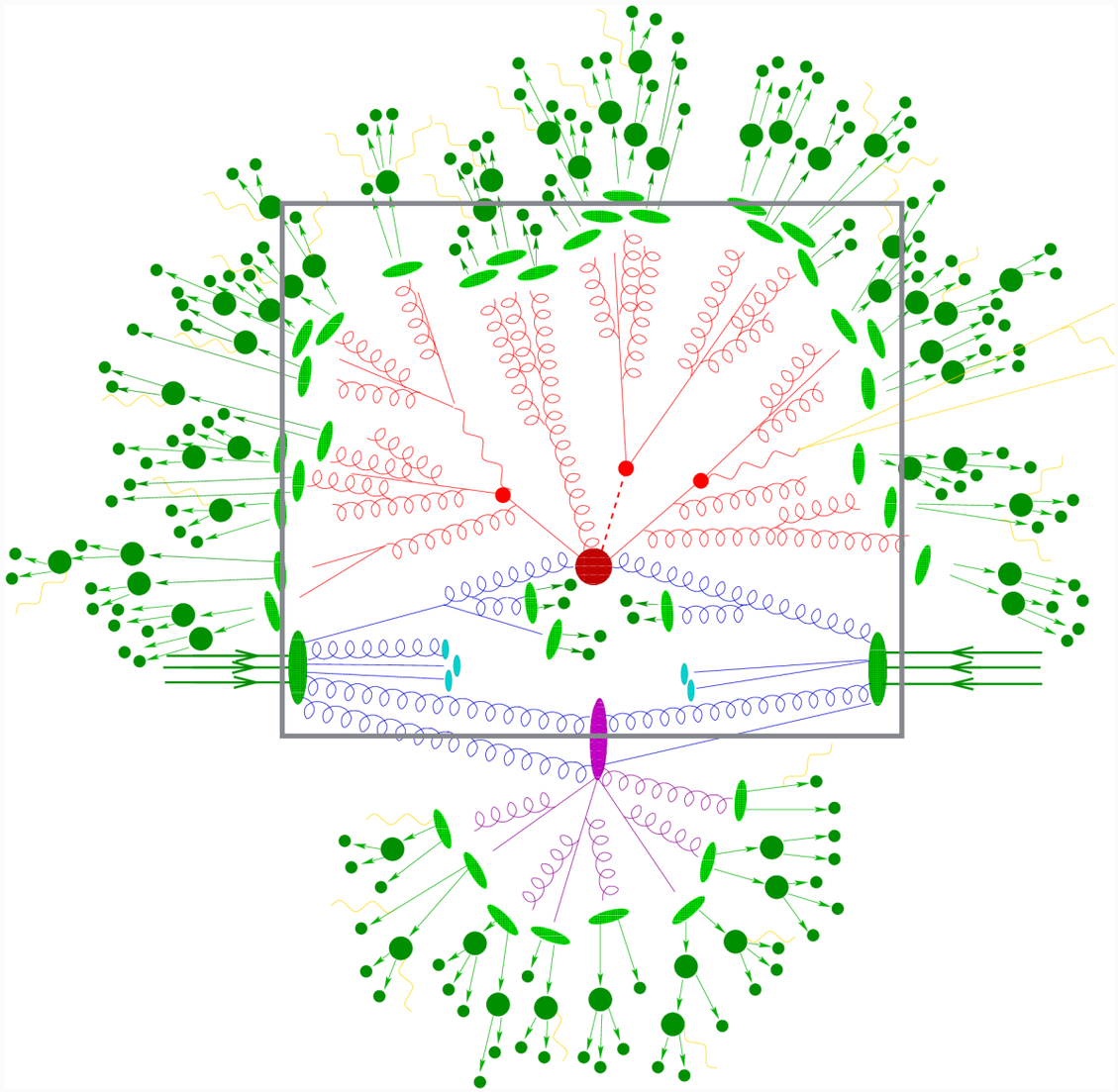

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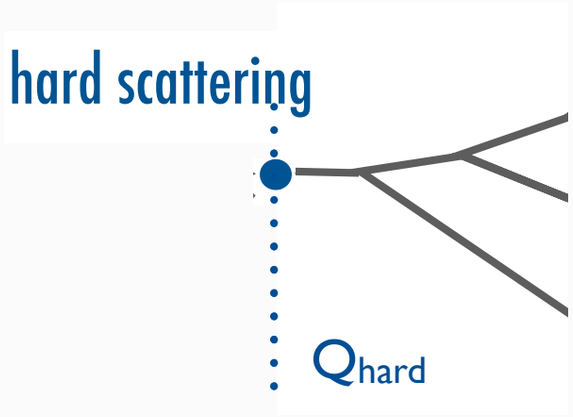

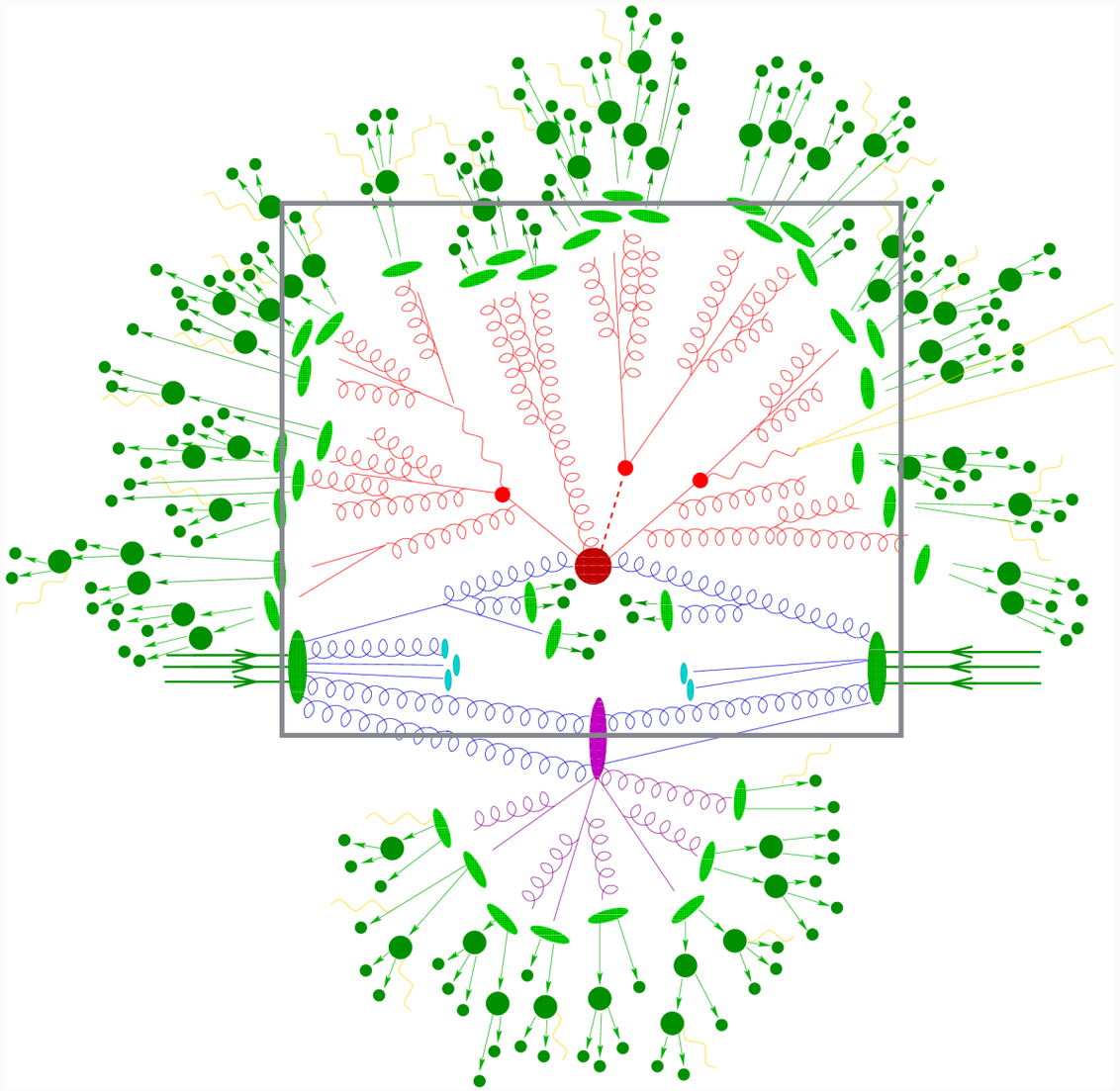

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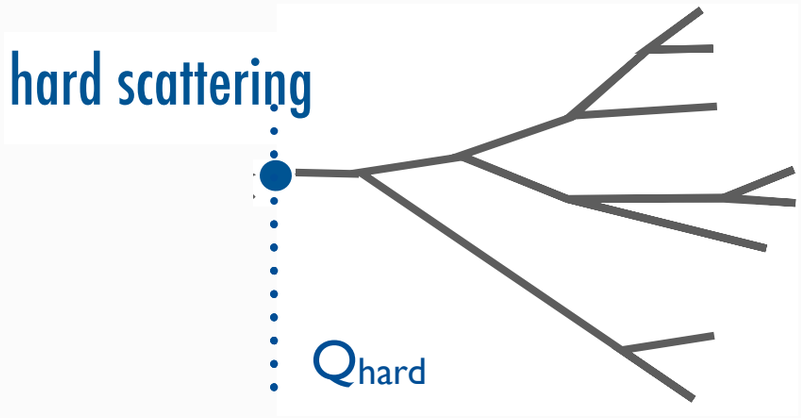

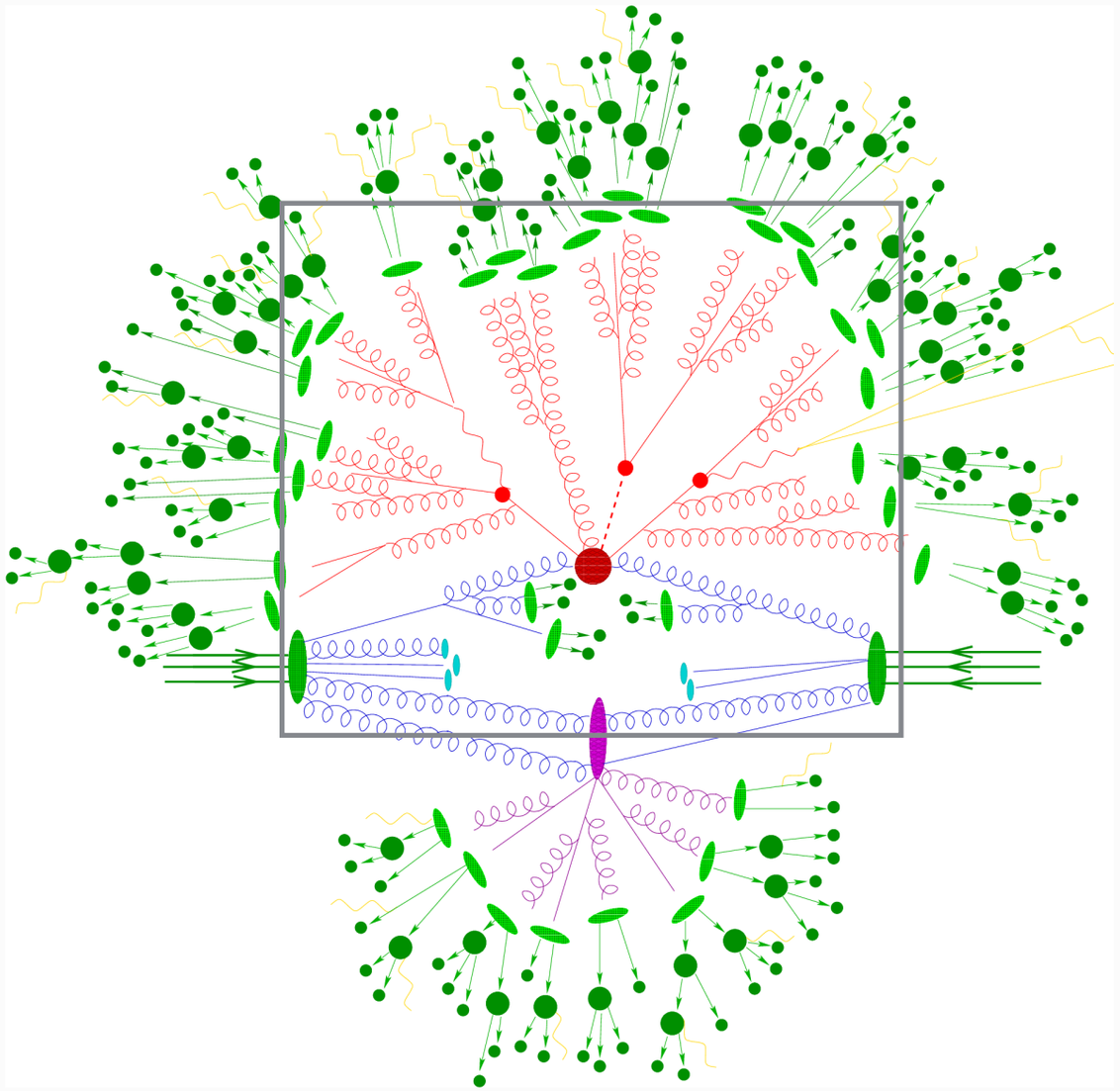

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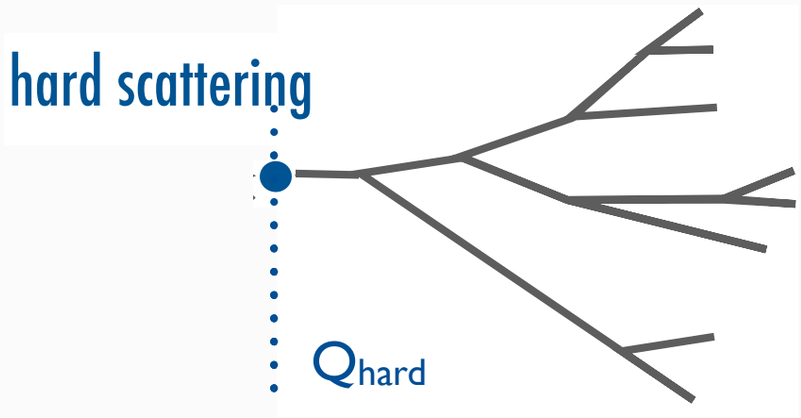

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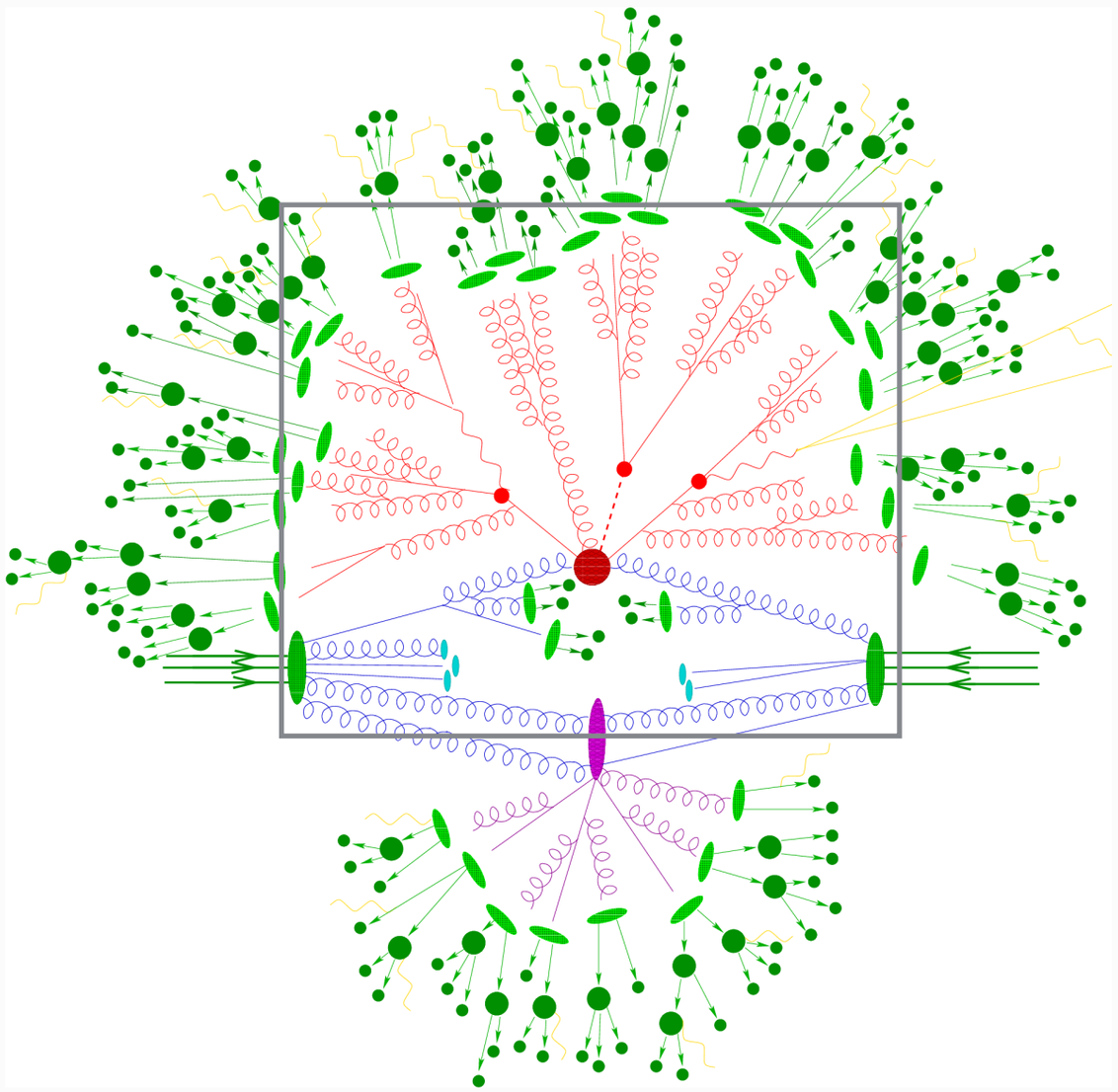

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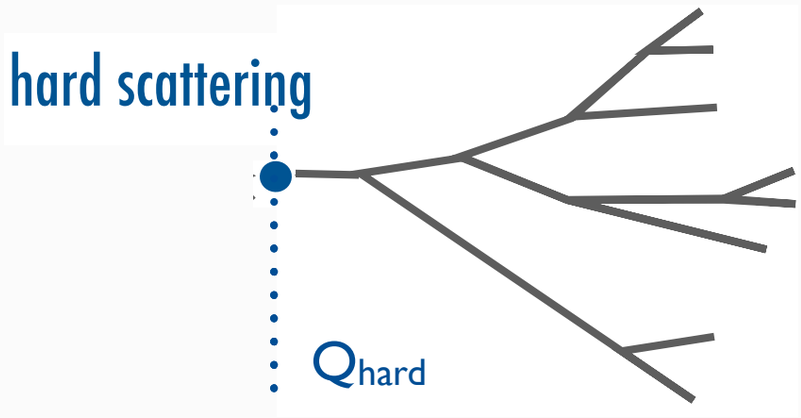
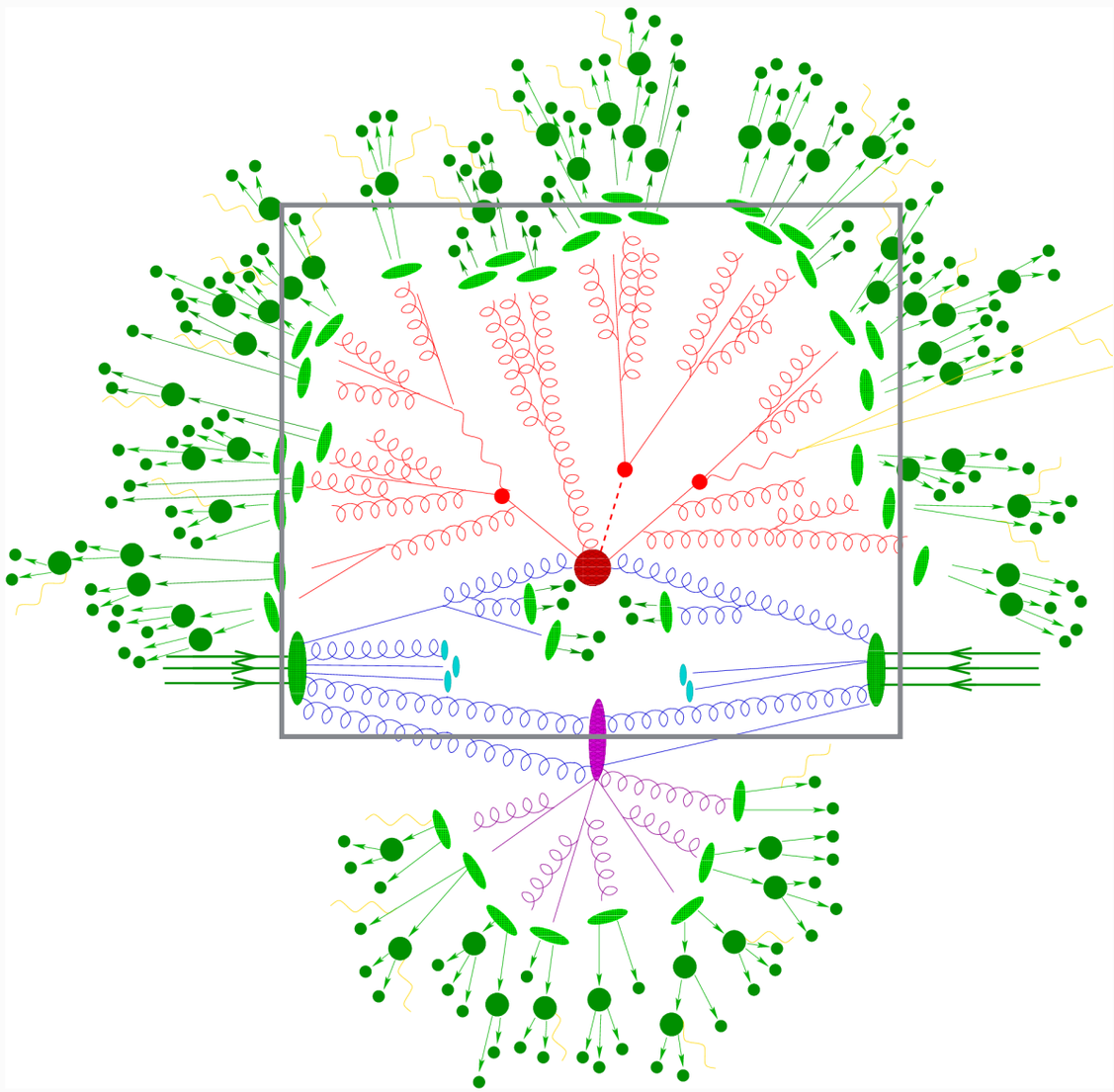


$$\frac{d^2\sigma^h}{dyd^2p_T} = \int dx_a dx_b f_a(x_a,\mu_f) f_b(x_b,\mu_f) \frac{d\sigma_{ab\to c}(x_a p_a, x_b p_b, \mu, \mu_f, \mu'_f, p_T/z)}{d\hat{t}} D_c^h(z,\mu'_f)$$



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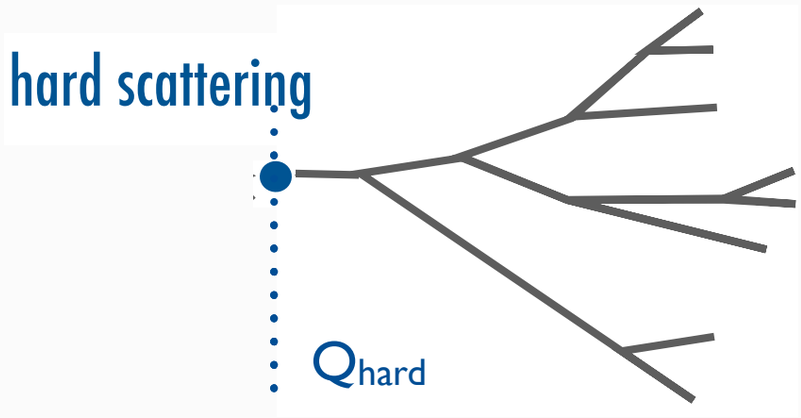

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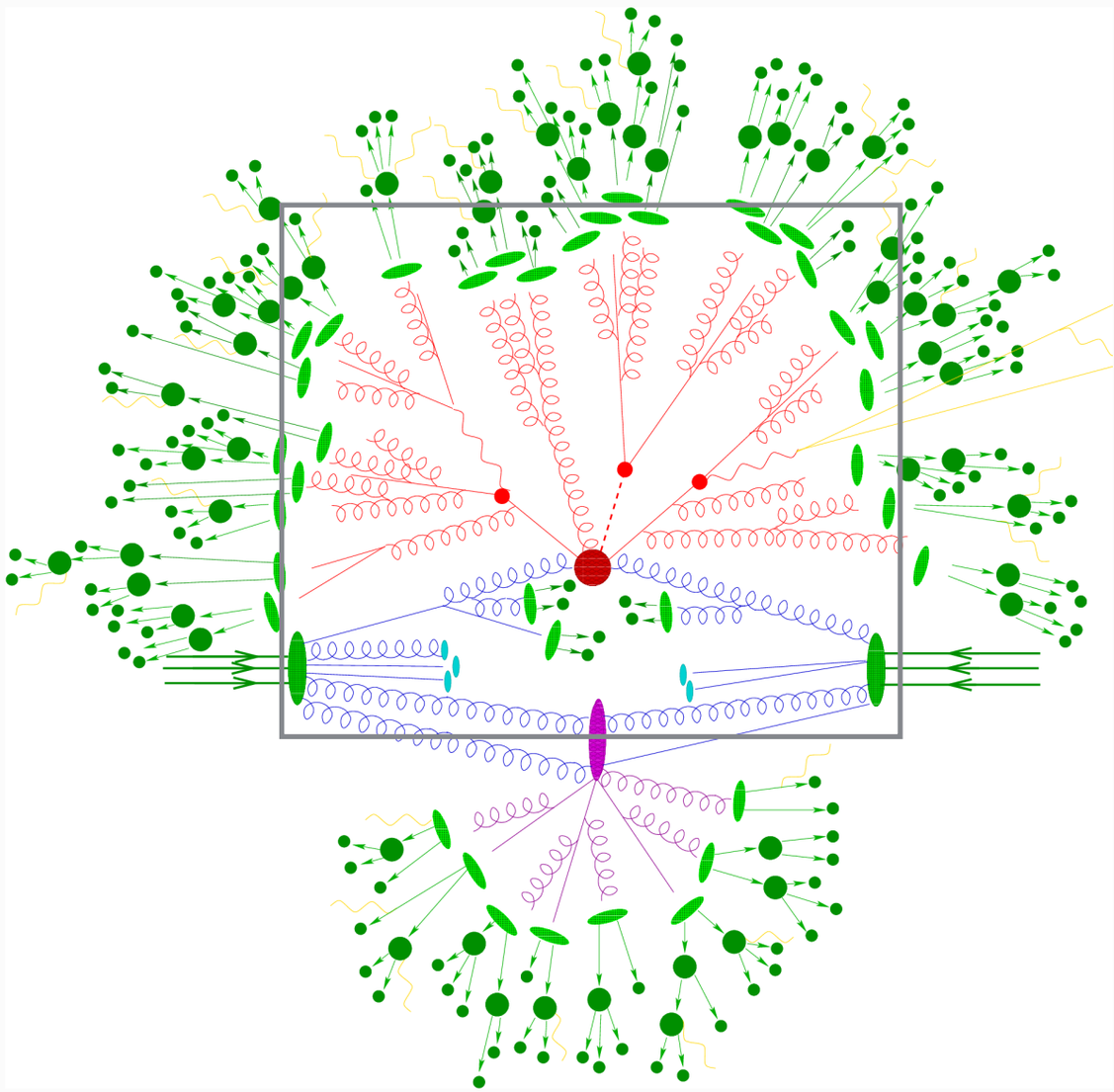
Fragmentation function (FF) of parton ‘c’ into product ‘h’



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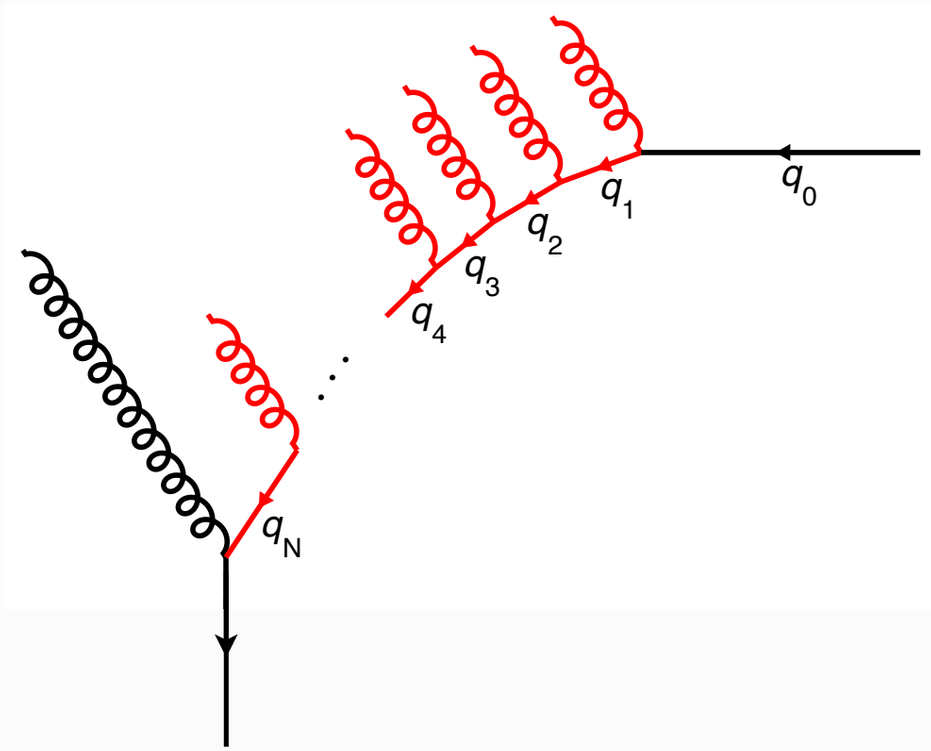

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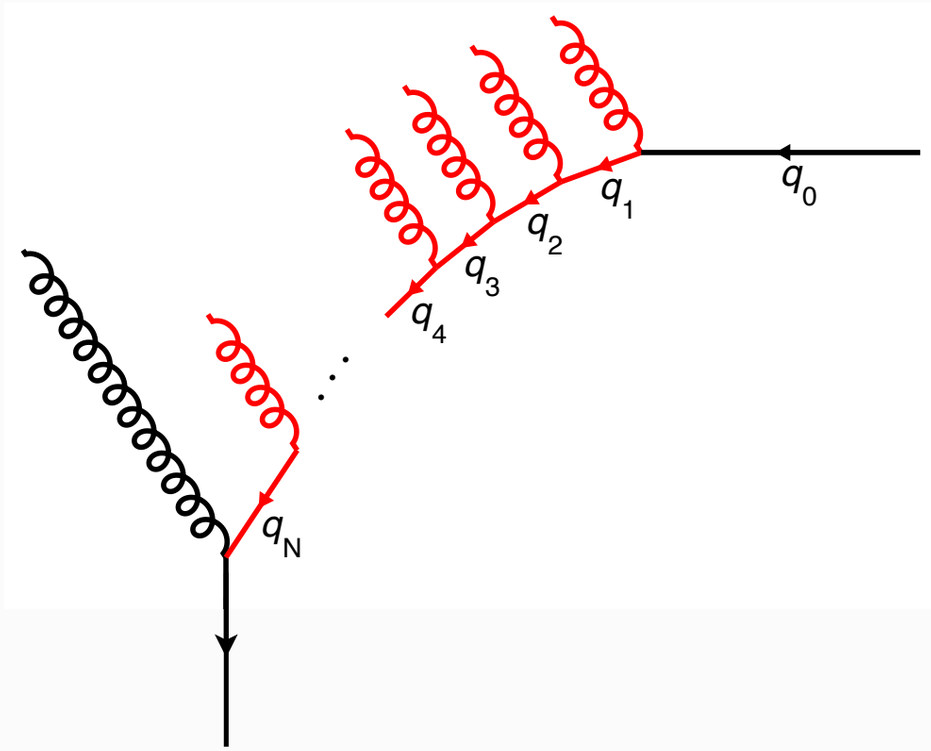
Splitting Function (SF)

Probability of parton ‘b’ splits into parton ‘a' with a fraction of energy z



Monte Carlo Techniques

- Quantum mechanics = amplitudes (concept of randomness)
- Event generators = Monte Carlo techniques
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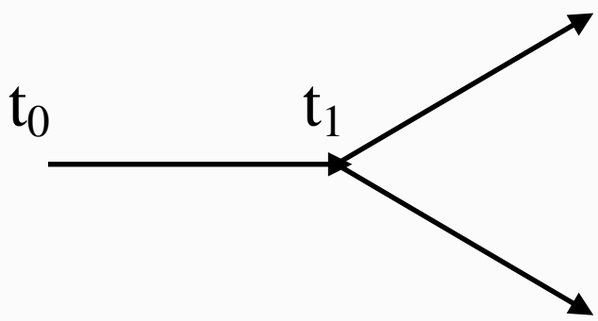

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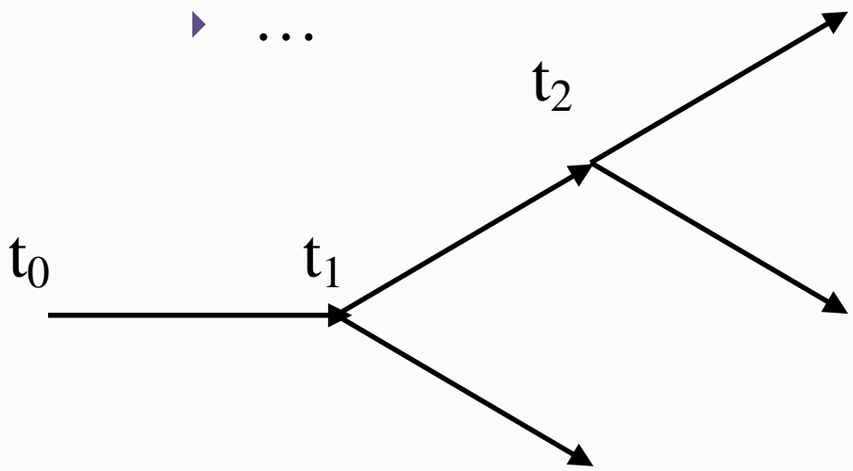

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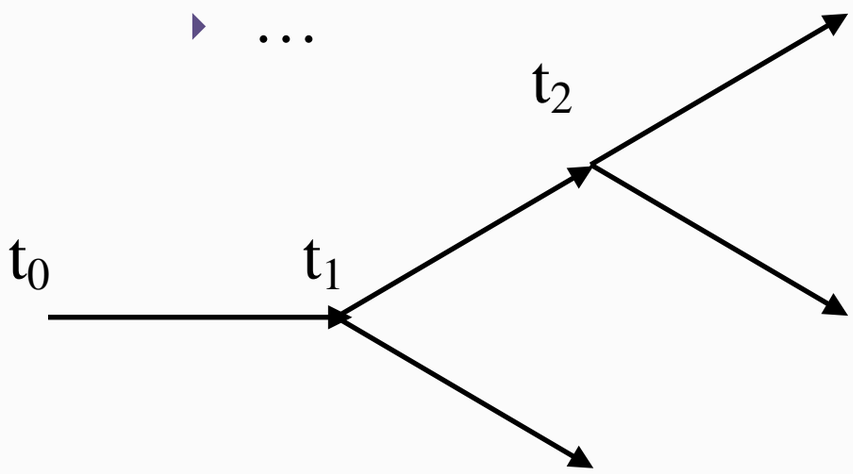

Probability of not decay between t_0 and t_1

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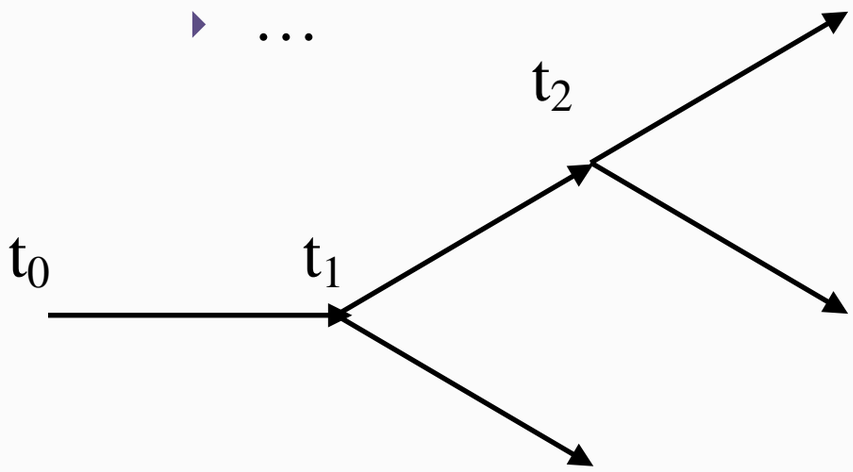

Just like a radioactive decay!

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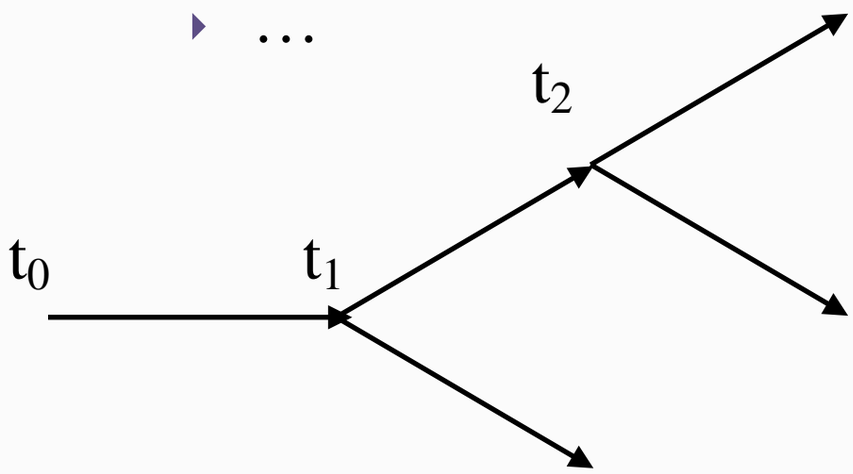

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Given a random number, R, what is t_1?

At t_1, it decays.

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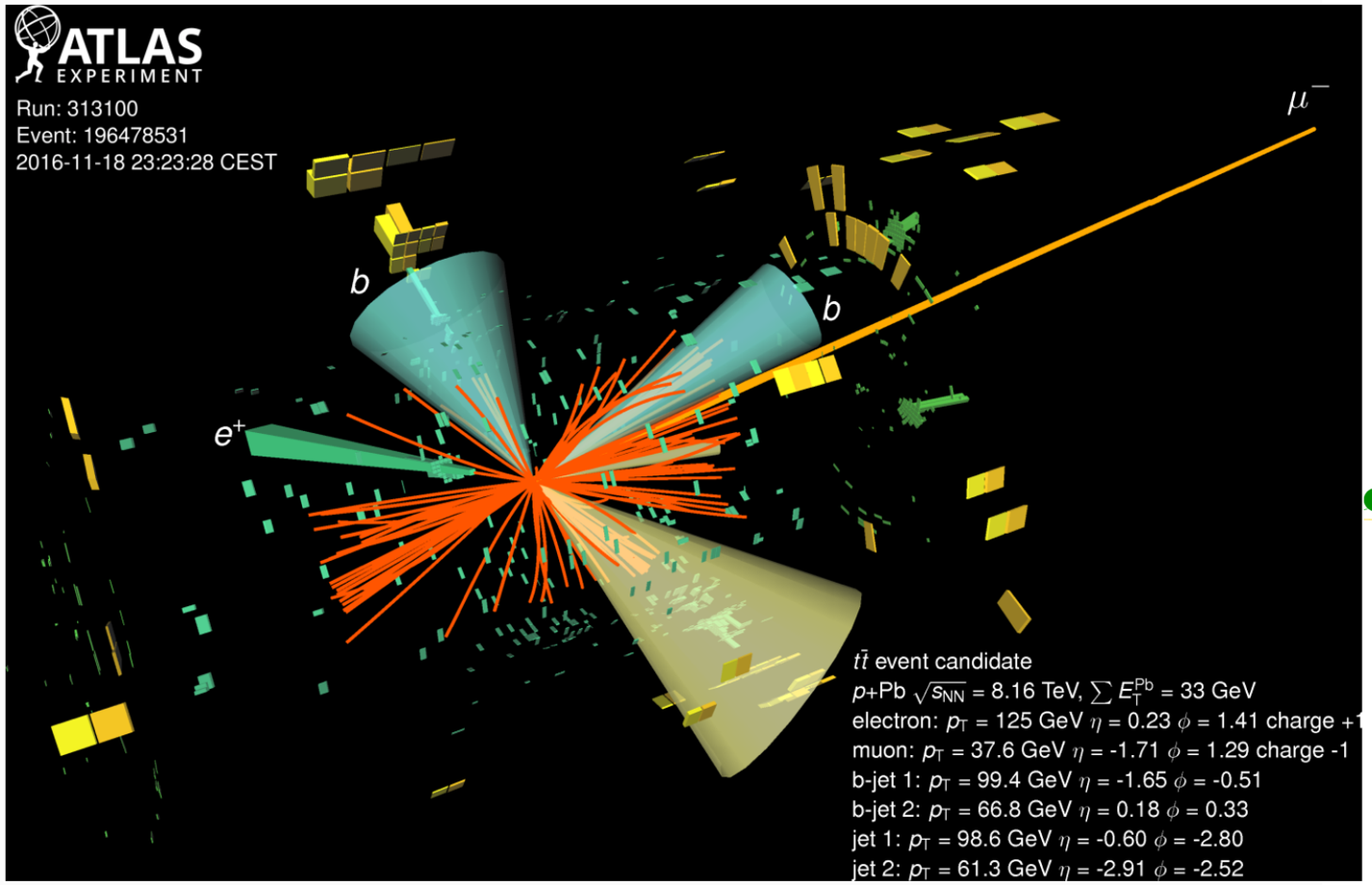
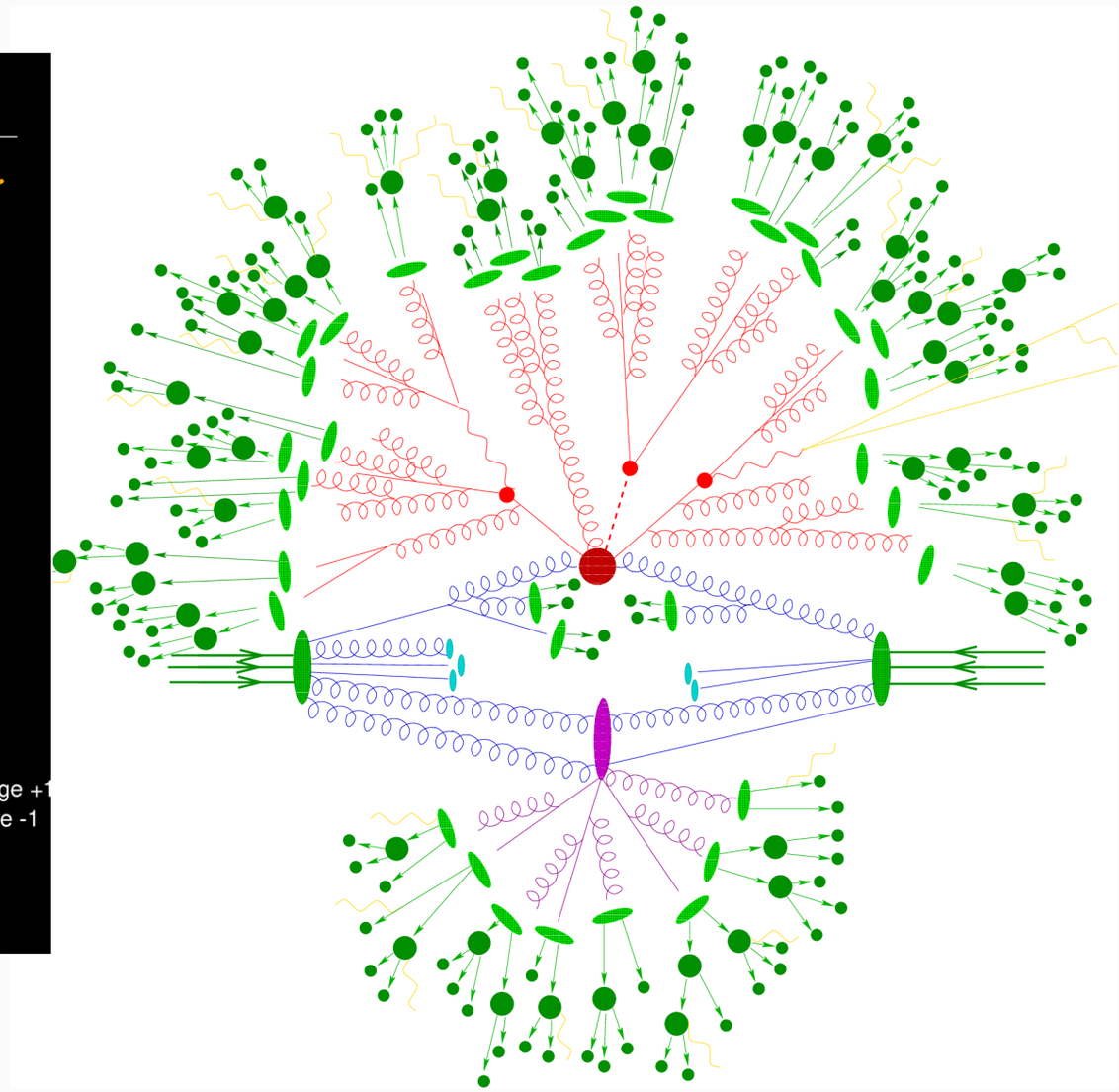
- Results into spray of partons/particles that will form jets;
  - Resulting pattern will contribute to the event structure (2, 3,… jet event)





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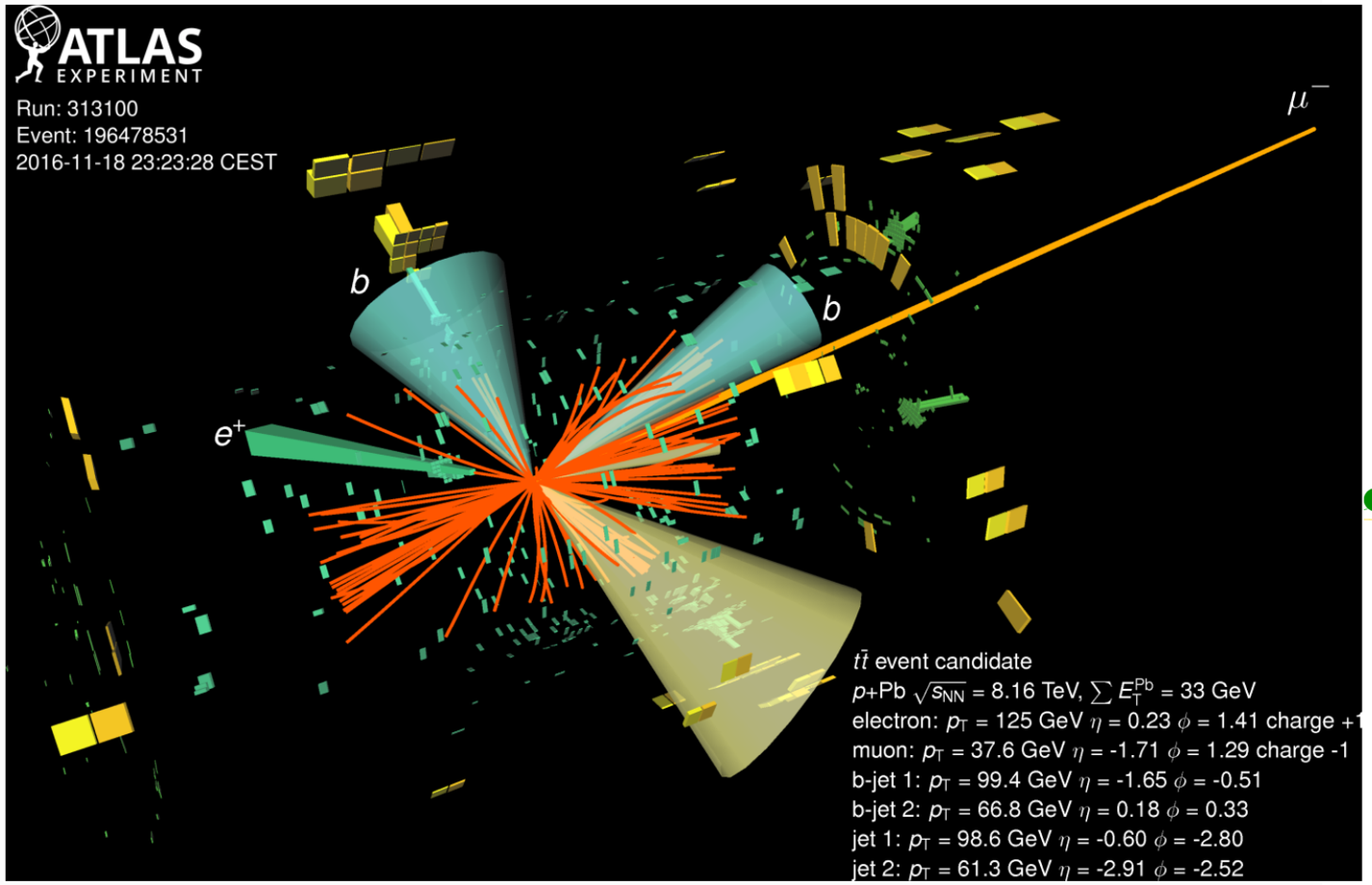
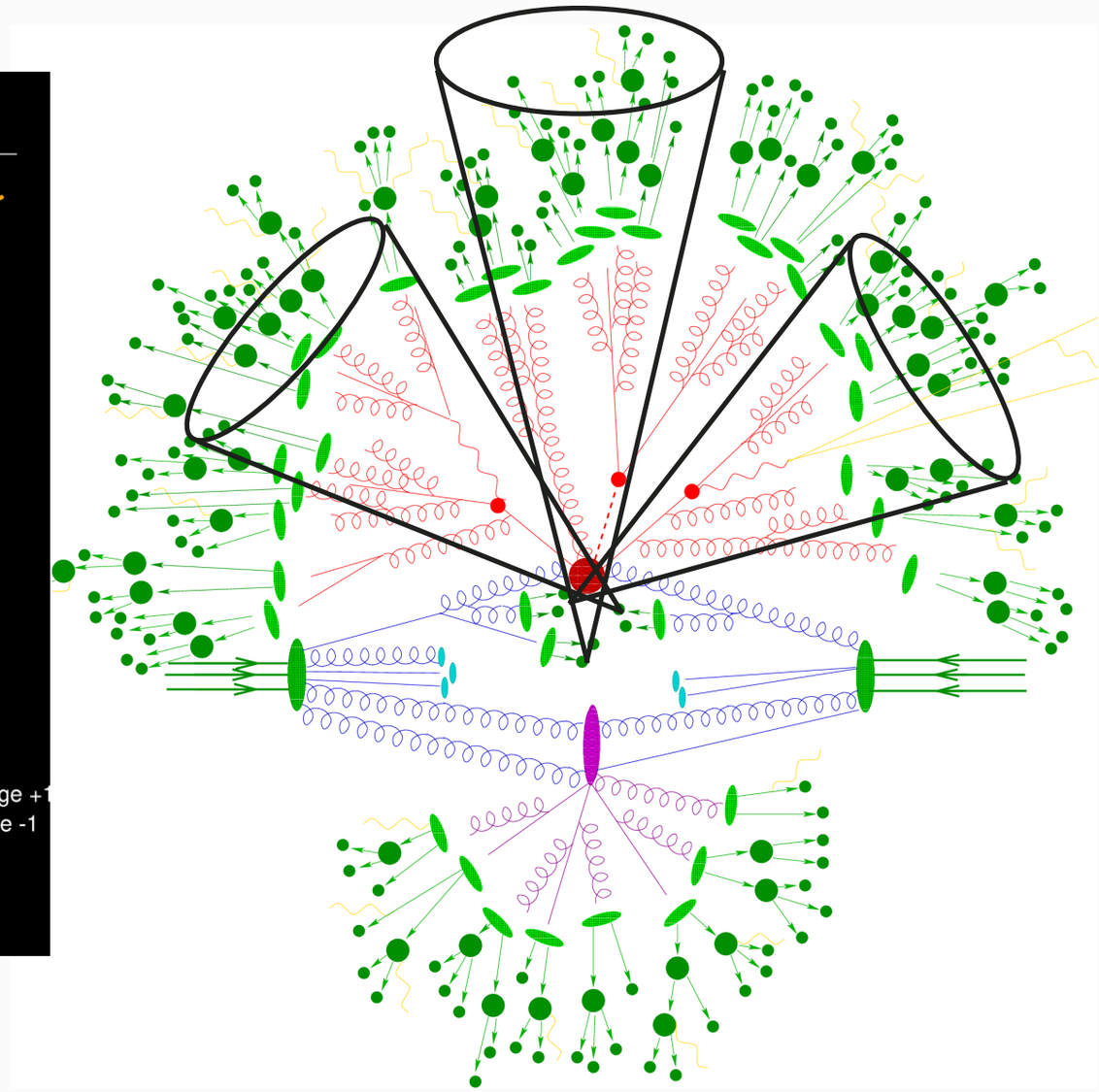
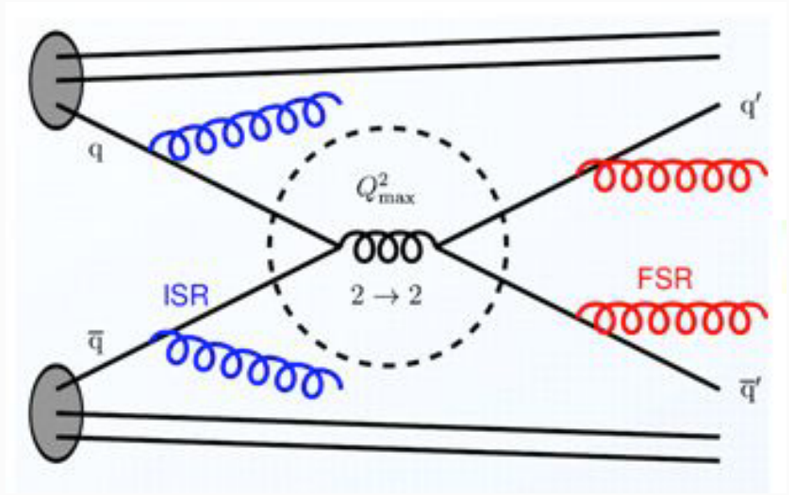




MPI and Beam Remnants

- The initiator shower of the hard scattering takes only a fraction of the total beam energy. What is left behind is called the (coloured) beam remnant



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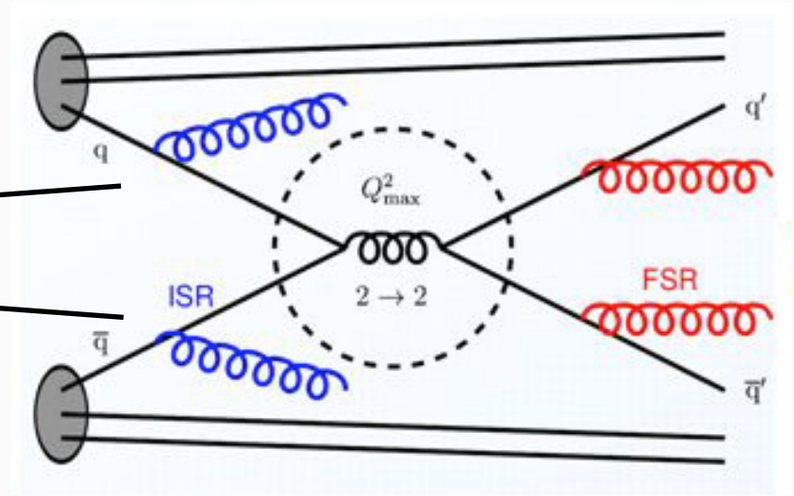

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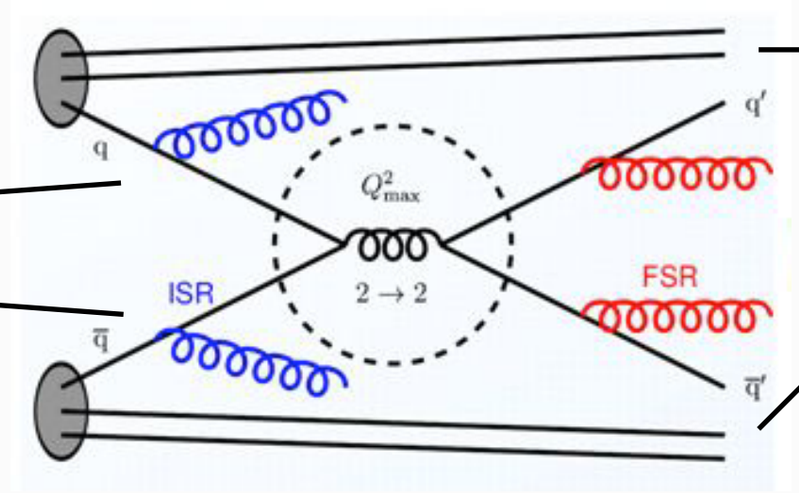

Beam Remnants → Underlying event (bkg)

(Color connected to the hard process)

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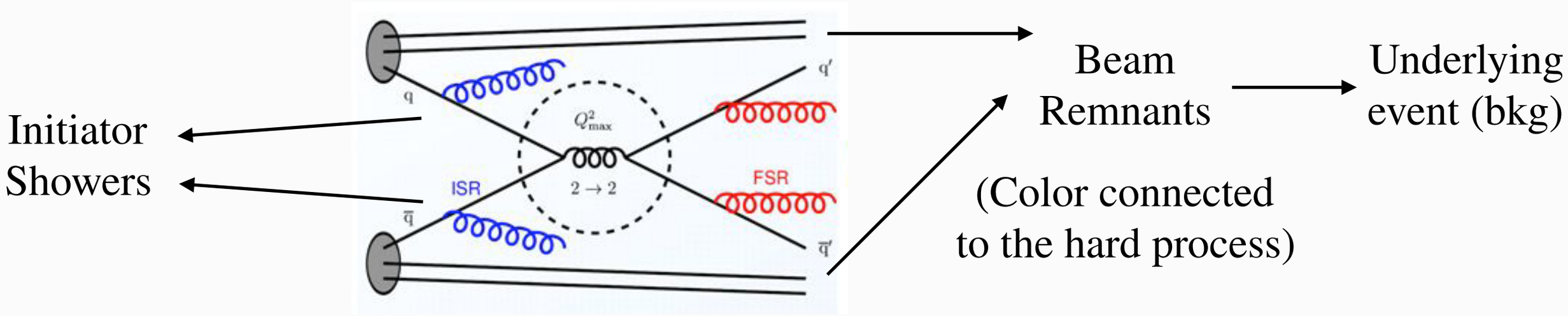
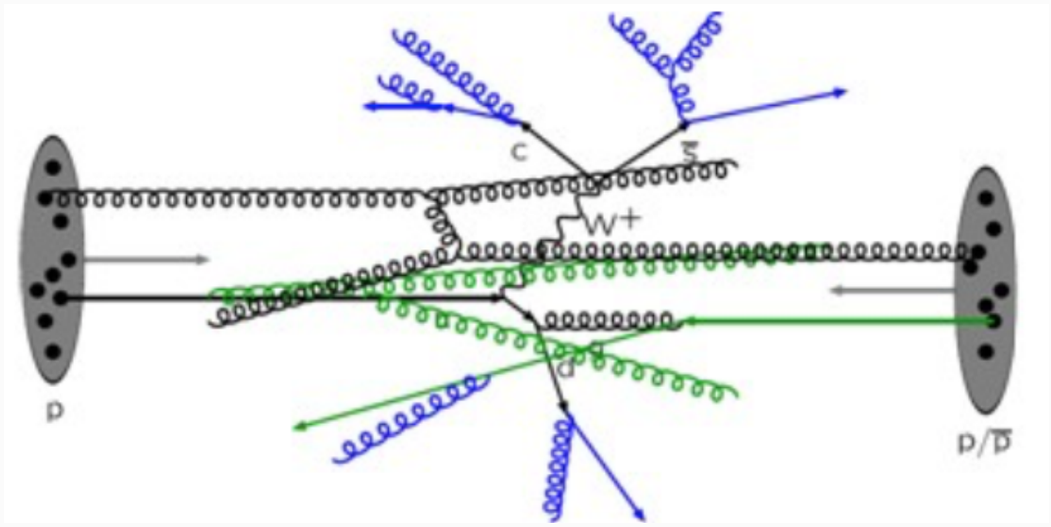
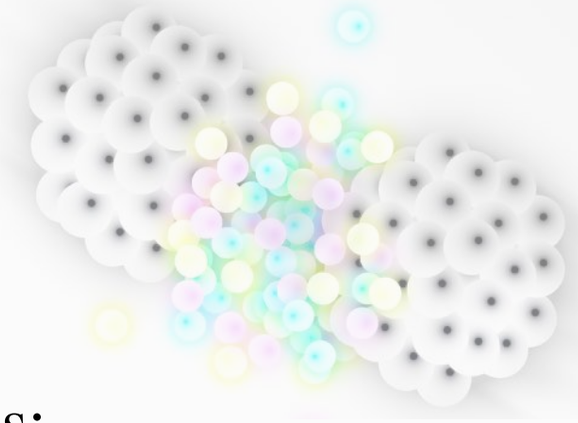


- Dominant 2→2 QCD cross-sections are divergent for $p_T \to 0$ but drop rapidly for large p_T.
  - Probability of multiple parton interactions is not negligible for ep, pp or AA collisions



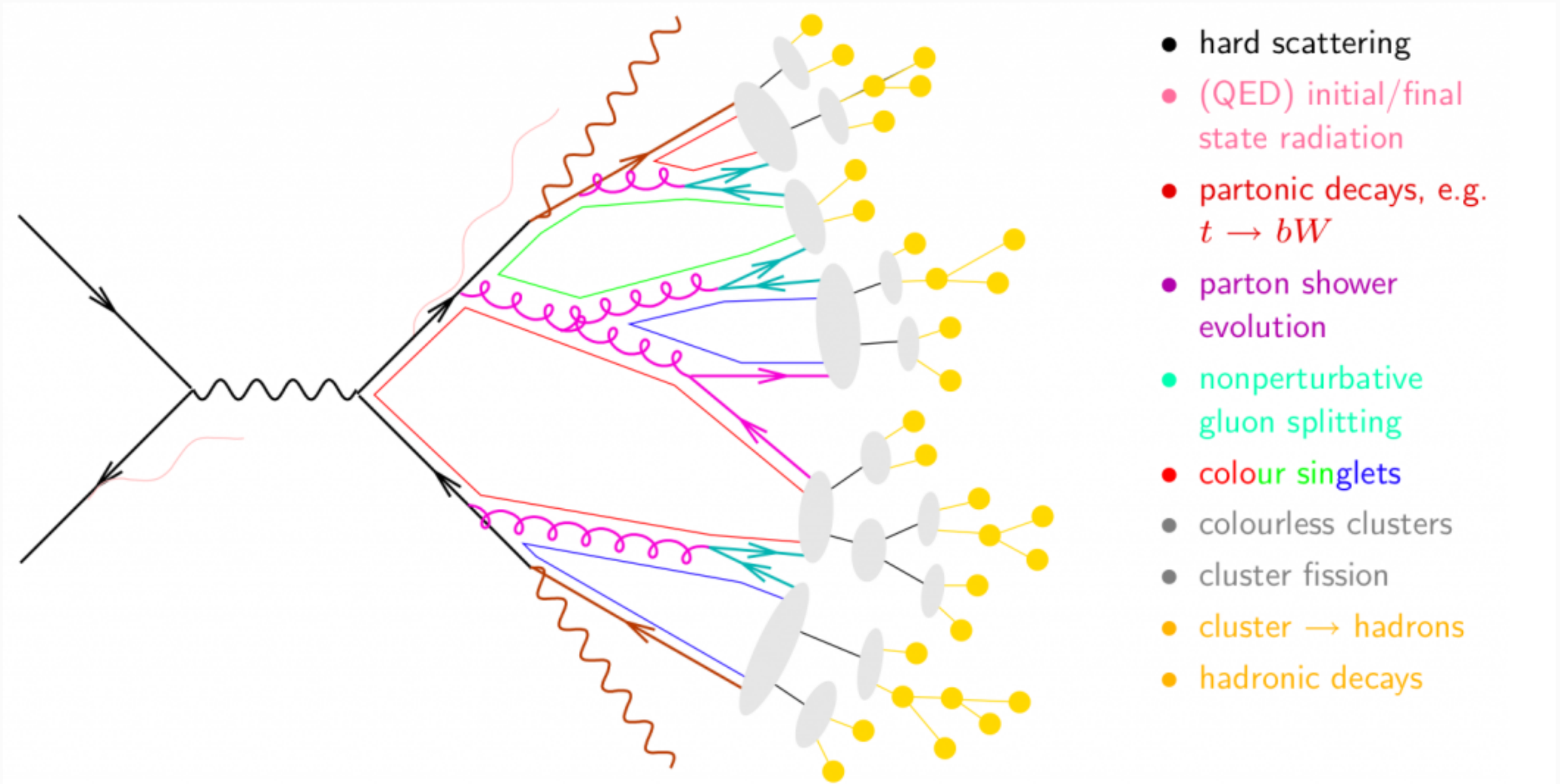
Hadronization



- Mechanism that confines back quarks and gluons into hadrons;
- QCD perturbation theory, formulated in terms of quarks and gluons, is valid at short distances only
- At long distances, in the confinement regime, coloured pardons are transformed into hadrons, a process called hadronization (or fragmentation)
- Fragmentation process not understood from first principles (rely on phenomenological models)
  - All of them rely on the color flow between the constituents

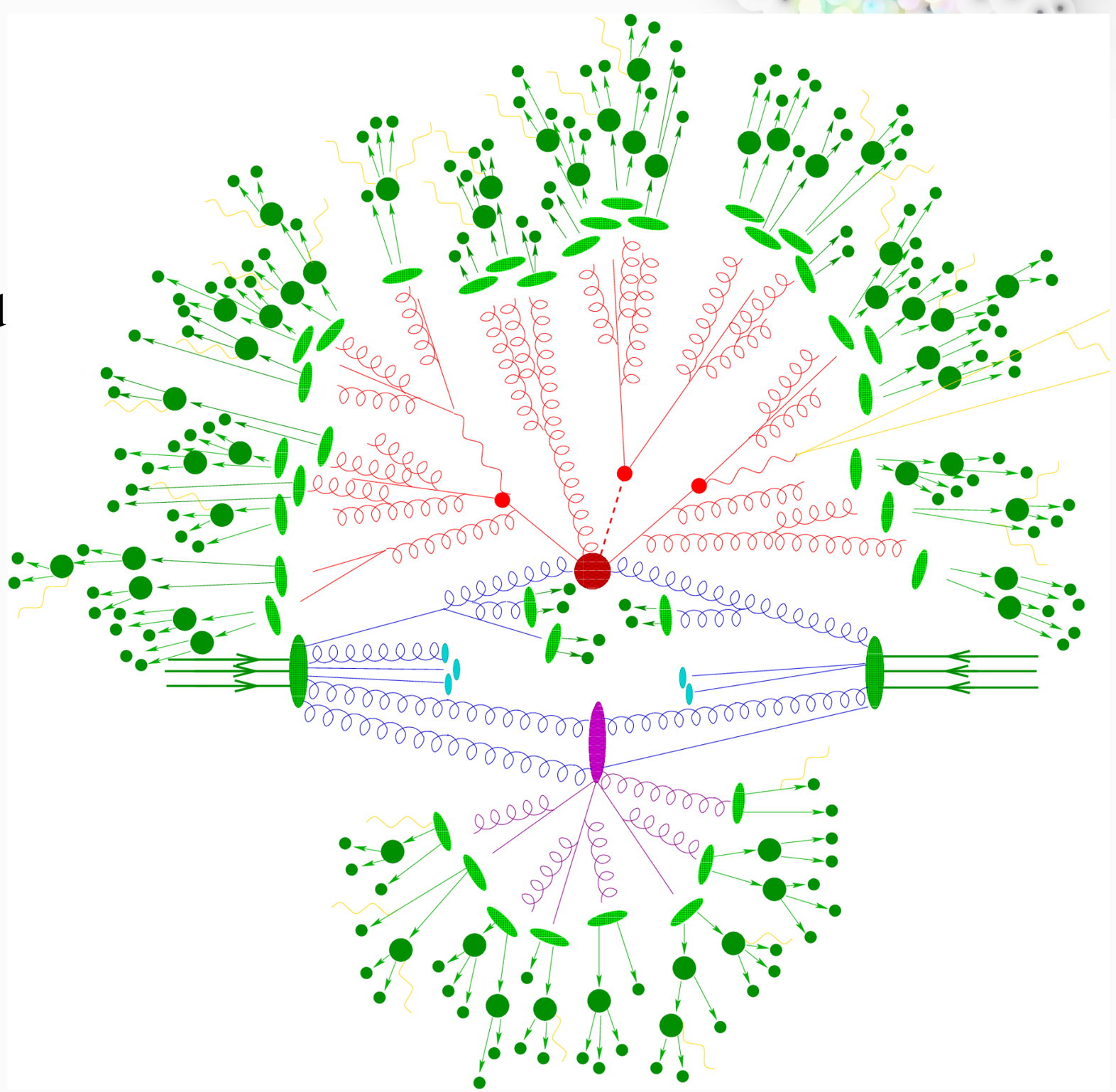
Hadronization

- Mechanism that confines back quarks and gluons into hadrons;



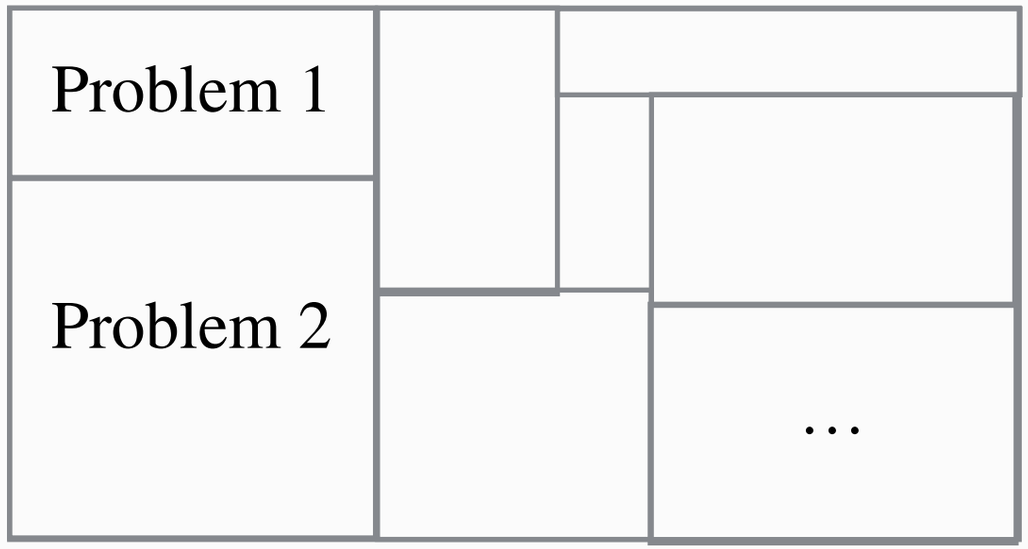
Summary

- Result of an Event Generator:
  - ‘Real’ event as if could be observed by a perfect detector.
  - Output can be used now to interface to the detector simulation



More MC Event Generators

- Typical hadronic event generator (PYTHIA) contains the subprocesses mentioned so far:



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Hard Scattering	
IS Shower PDFs	FS Shower FFs
Beam Remnants/MPI	Hadro

More MC Event Generators

- Typical hadronic event generator (PYTHIA) contains the subprocesses mentioned so far:

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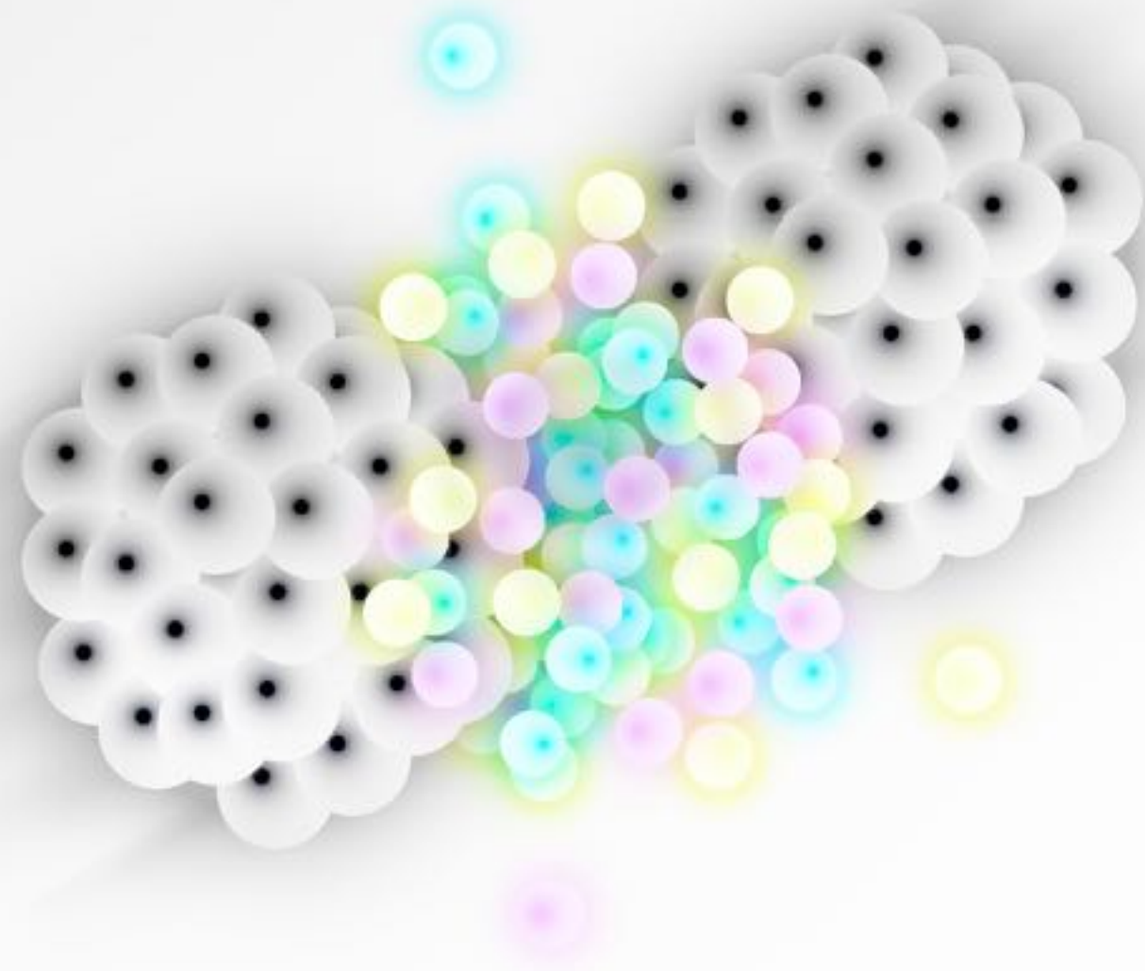
- Other type of event generators include:
  - Cosmic Rays (for Extensive Air Showers)
  - Heavy-ions (+ Nuclear initial-state, High multiplicity, soft processes, in-medium energy loss, Collective behavior of the medium)
  - Multi-purpose parton event generators (BSM physics)
  - …

Detector Simulation



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