Parton showers and MLM matching

with MadGraph and Pythia

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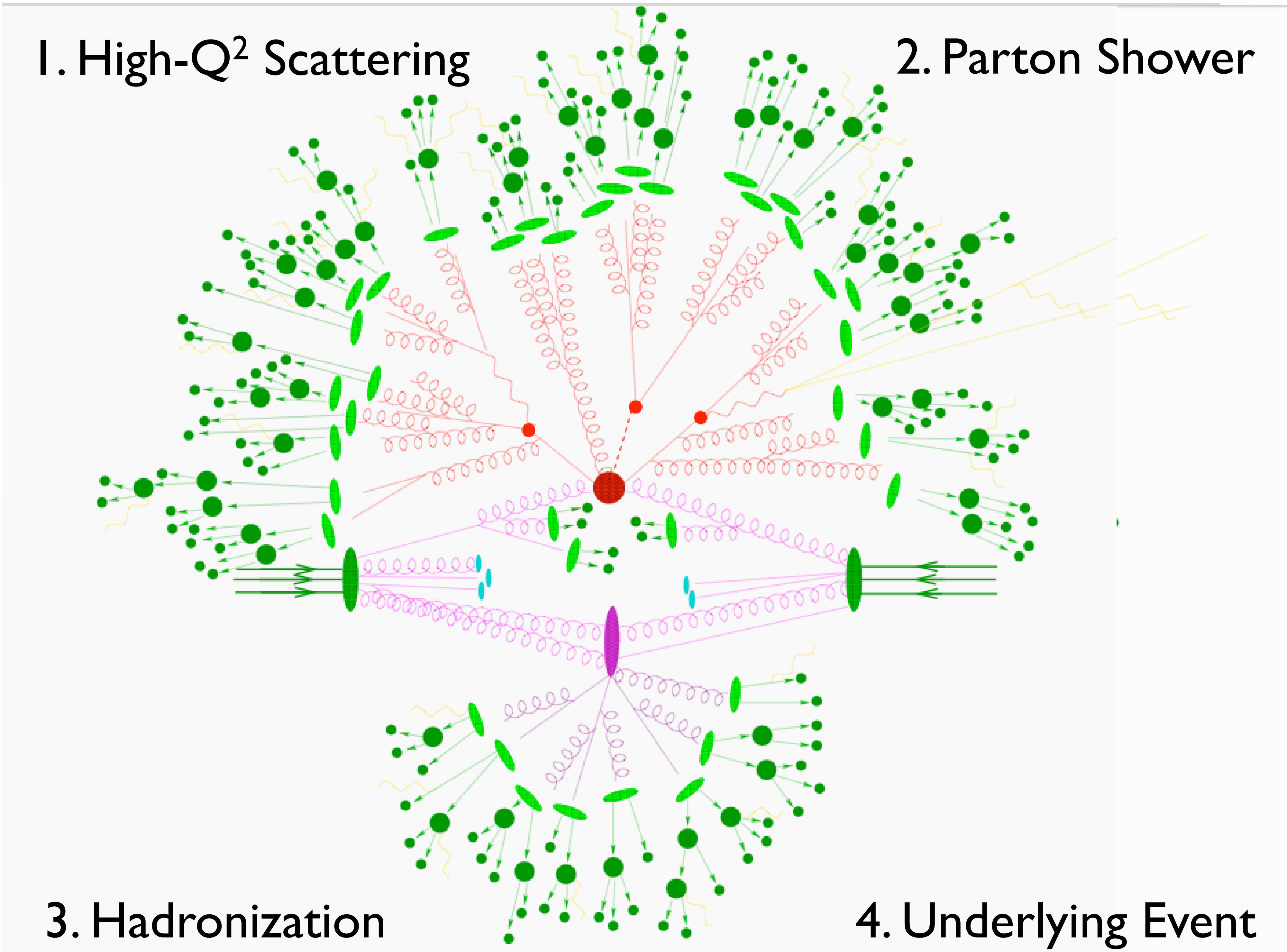
Lectures and exercises found at
https://server06.fynu.ucl.ac.be/projects/madgraph/wiki/SchoolKias

Outline of lecture

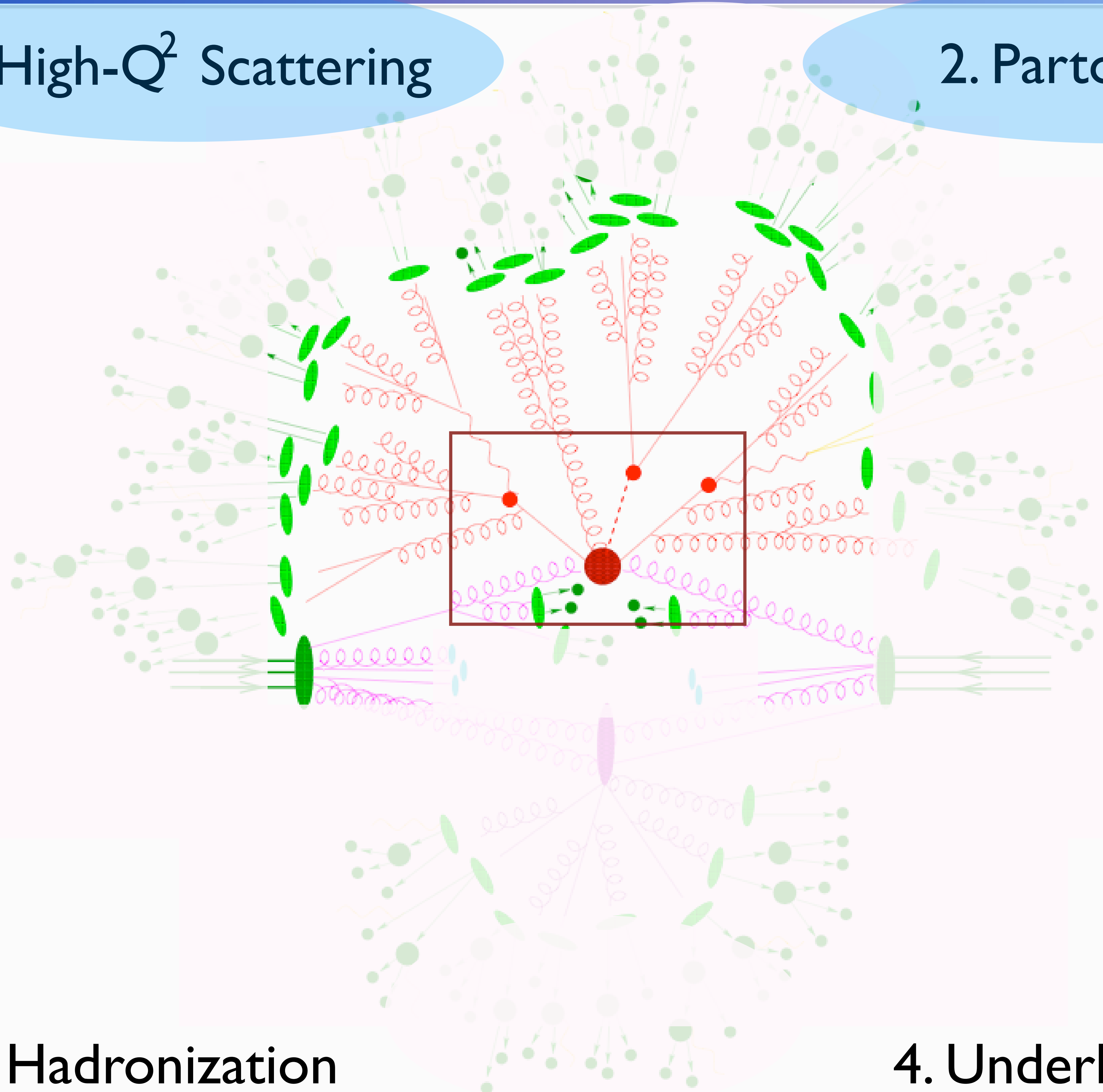
- Parton showering and the collinear approximation
- Final and initial state showers
- Matrix Elements vs. Parton showers
- MLM matching
- Matching in practice: MadGraph and Pythia
- Matching in BSM production

Reminder - stages of complete hadron collision simulation



1. High-Q^2 Scattering

2. Parton Shower



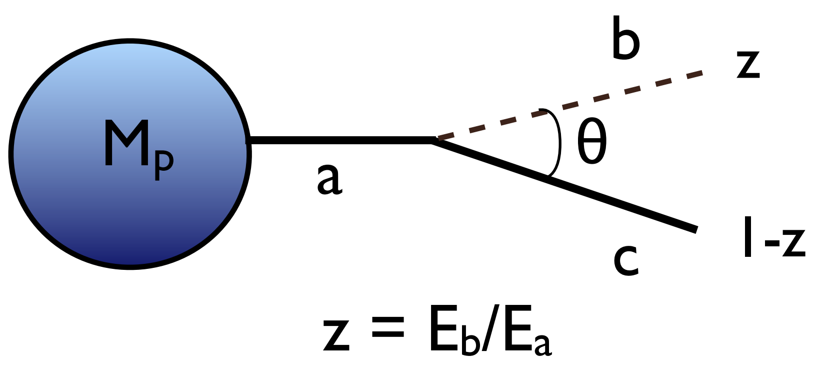
3. Hadronization

4. Underlying Event

Parton Shower basics

Matrix elements involving q →q g (or g → gg) are strongly enhanced when the final state particles are close in the phase space:

$$\frac{1}{(p_b+p_c)^2} \simeq \frac{1}{2E_bE_c(1-\cos\theta)} = \frac{1}{t}$$



soft and collinear

divergencies

Collinear factorization:

$$|M_{p+1}|^2 d\Phi_{p+1} \simeq |M_p|^2 d\Phi_p \frac{dt}{t}\frac{\alpha_S}{2\pi}P(z)dzd\phi$$

when θ is small.

Parton Shower basics

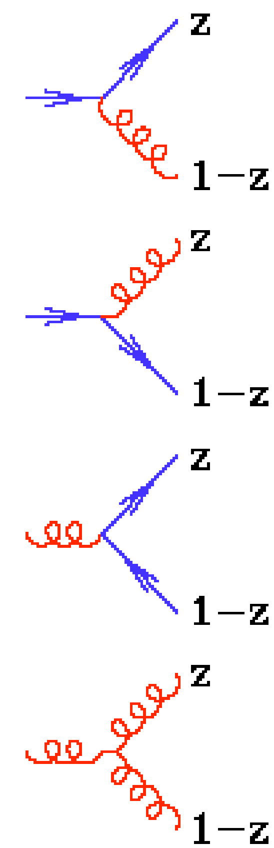
The spin averaged (unregulated) splitting functions for the various types of branching are:

$$\hat{P}_{qq}(z) = C_F \left[\frac{1+z^2}{(1-z)} \right],$$

$$\hat{P}_{gq}(z) = C_F \left[\frac{1+(1-z)^2}{z} \right],$$

$$\hat{P}_{qg}(z) = T_R \left[z^2 + (1-z)^2 \right],$$

$$\hat{P}_{gg}(z) = C_A \left[\frac{z}{(1-z)} + \frac{1-z}{z} + z(1-z) \right].$$



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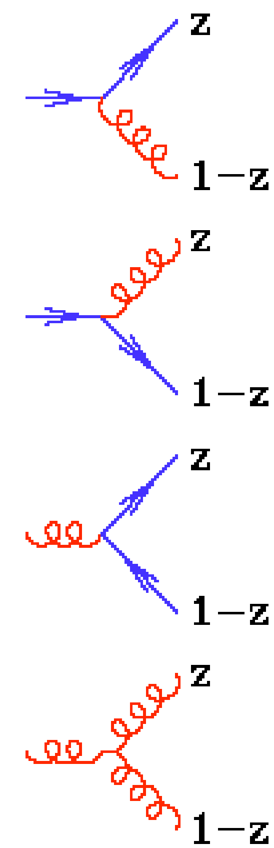

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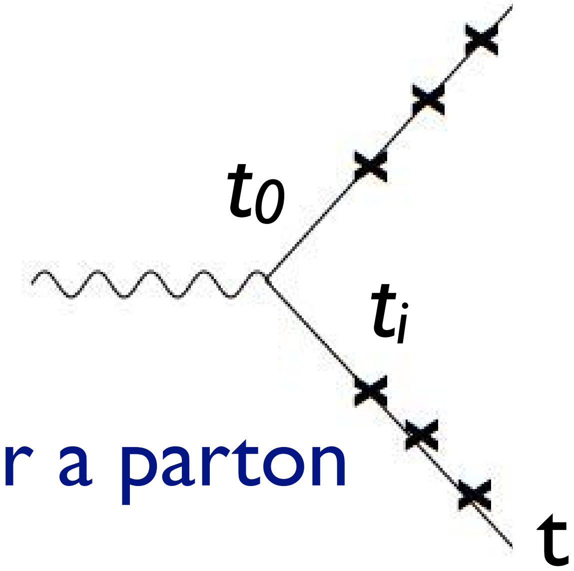
Comments:

* Gluons radiate the most
* There soft divergences in z=1 and z=0.
* P_{qg} has no soft divergences.

Parton Shower basics



- Now, consider the non-branching probability for a parton at a given virtuality t_i:

$$\mathcal{P}_{\mathrm{non-branching}}(t_i) = 1 - \mathcal{P}_{\mathrm{branching}}(t_i) = 1 - \frac{\delta t}{t_i}\frac{\alpha_s}{2\pi}\int_z^1 \frac{dz}{z}\hat{P}(z)$$

- The total non-branching probability between virtualities t and t_0:

$$\mathcal{P}_{\mathrm{non-branching}}(t, t_0) \simeq \prod_{i=0}^{N}\left(1 - \frac{\delta t}{t_i}\frac{\alpha_s}{2\pi}\int_z^1 \frac{dz}{z}\hat{P}(z)\right)$$

$$= e^{\sum_{i=0}^{N}\left(-\frac{\delta t}{t_i}\frac{\alpha_s}{2\pi}\int_z^1 \frac{dz}{z}\hat{P}(z)\right)}$$

$$\simeq e^{-\int_t^{t_0}\frac{dt'}{t'}\frac{\alpha_s}{2\pi}\int_z^1 \frac{dz}{z}\hat{P}(z)} = \Delta(t, t_0)$$

- This is the famous "Sudakov form factor"

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5. For each emitted particle, iterate steps 2-4 until branching stops.

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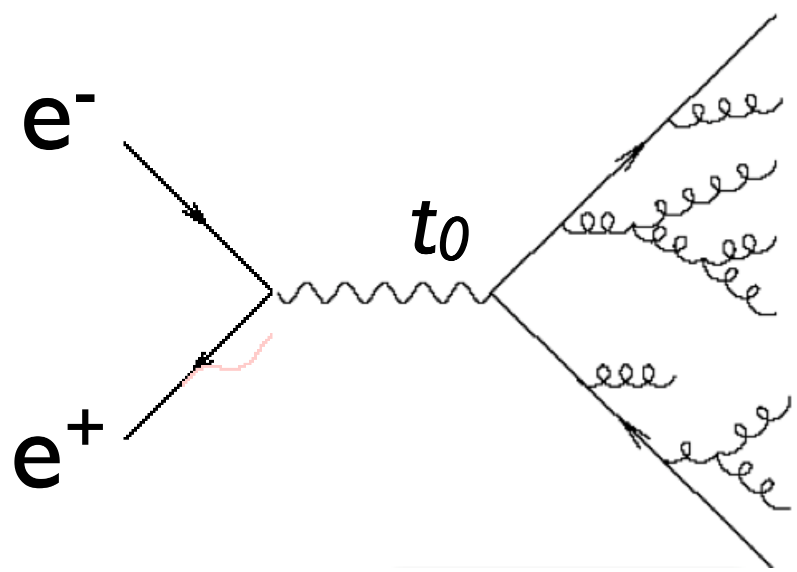
- The result is a “cascade” or “shower” of partons with ever smaller virtualities.



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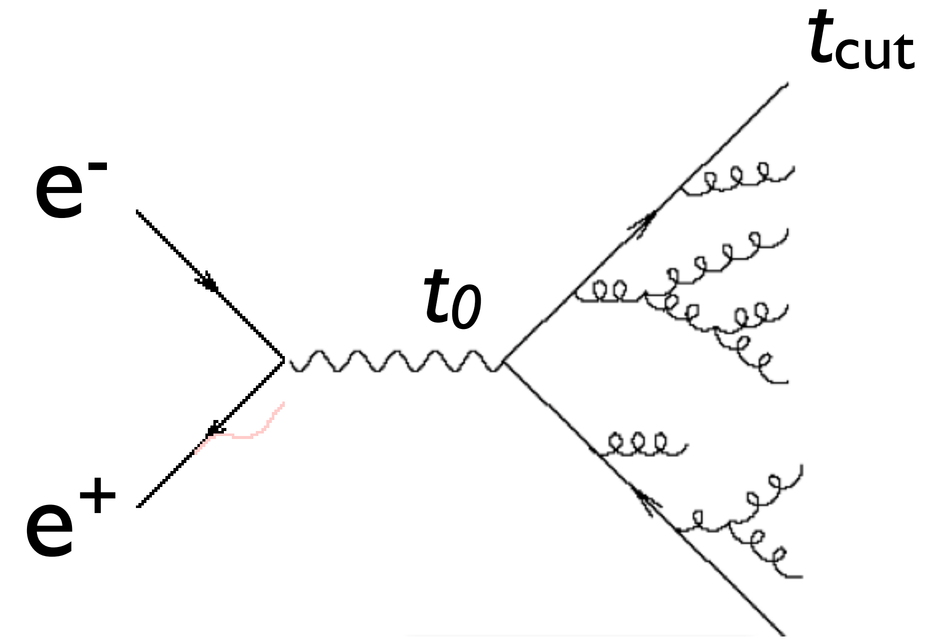
- The cutoff scale t_{cut} is usually set close to 1 GeV, and is the scale where non-perturbative effects start dominating over the perturbative parton shower.



Final-state parton showers

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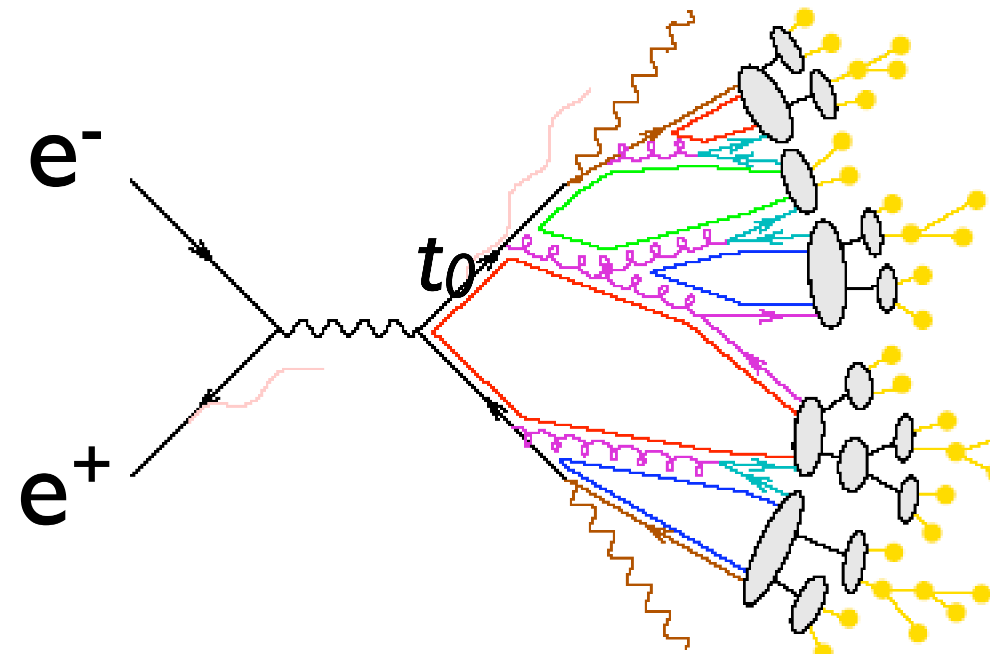
- The cutoff scale t_{cut} is usually set close to 1 GeV, and is the scale where non-perturbative effects start dominating over the perturbative parton shower.
- At this point, phenomenological models are used to simulate how the partons turn into color-neutral hadrons.
  Main point: Hadronization not sensitive to the physics at scale t_0, but only t_{cut}! (can be tuned once and for all!)

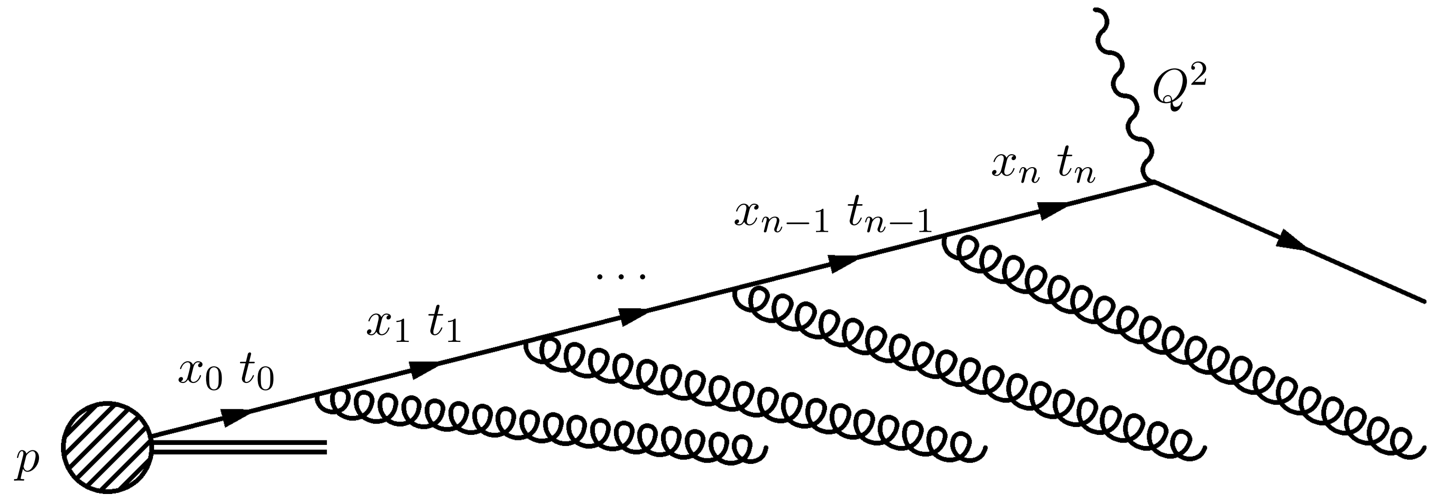


Wednesday, October 26, 2011

Initial-state parton splittings

- So far, we have looked at final-state (time-like) splittings
- For initial state, the splitting functions are the same
- However, there is another ingredient - the parton density (or distribution) functions (PDFs)
  - ➡ Probability to find a given parton in a hadron at a given momentum fraction $x = p_z/P_z$ and scale t
- How do the PDFs evolve with increasing t?

Initial-state parton splittings



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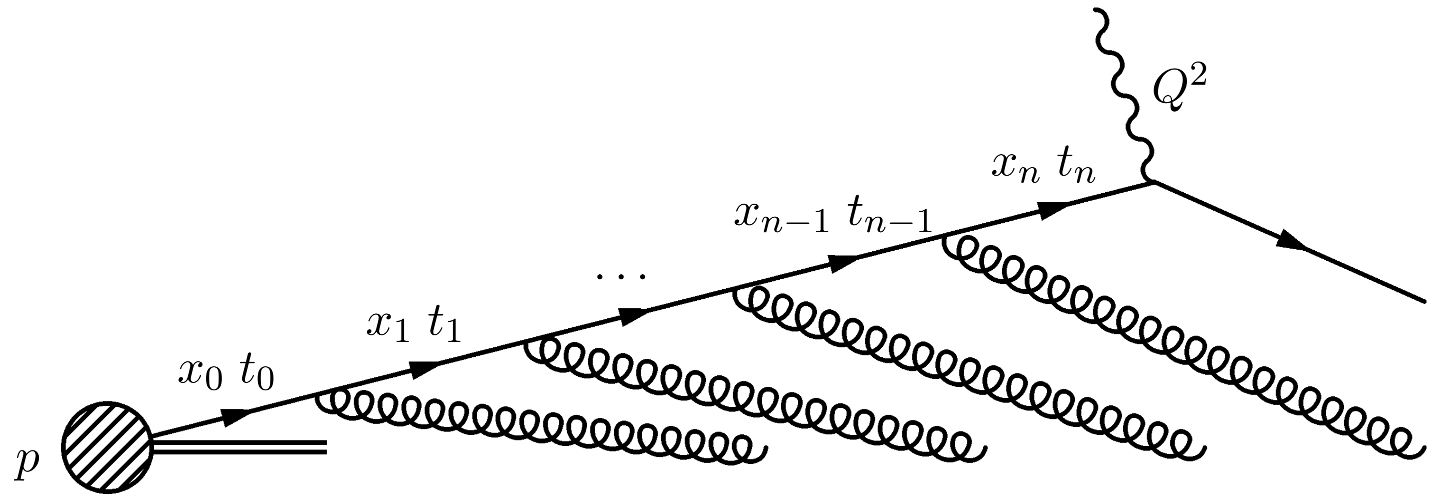

- Start with a quark PDF $f_0(x)$ at scale t_0. After a single parton emission, the probability to find the quark at virtuality $t > t_0$ is

$$f(x,t) = f_0(x) + \int_{t_0}^{t} \frac{dt'}{t'} \frac{\alpha_s}{2\pi} \int_x^1 \frac{dz}{z} P(z) f_0\left(\frac{x}{z}\right)$$

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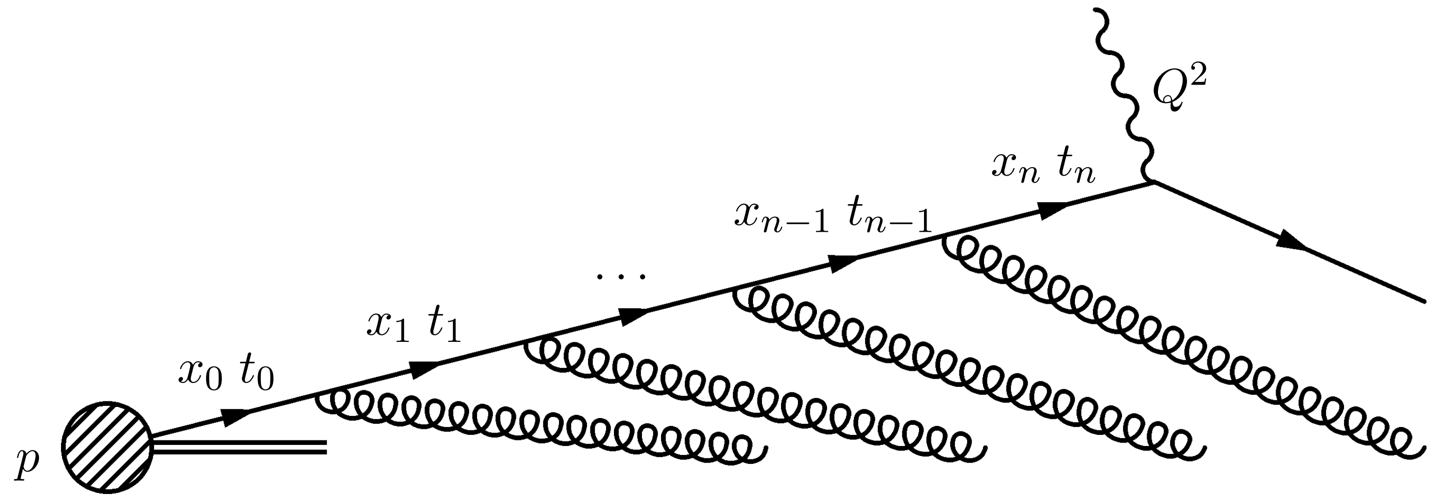

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- After a second emission, we have

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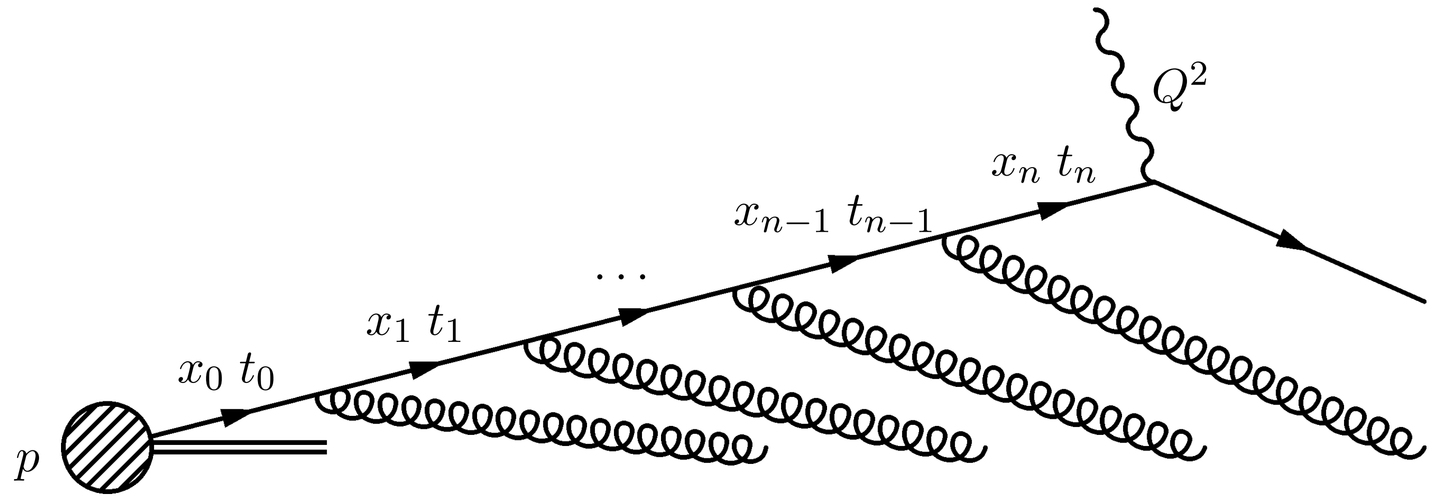

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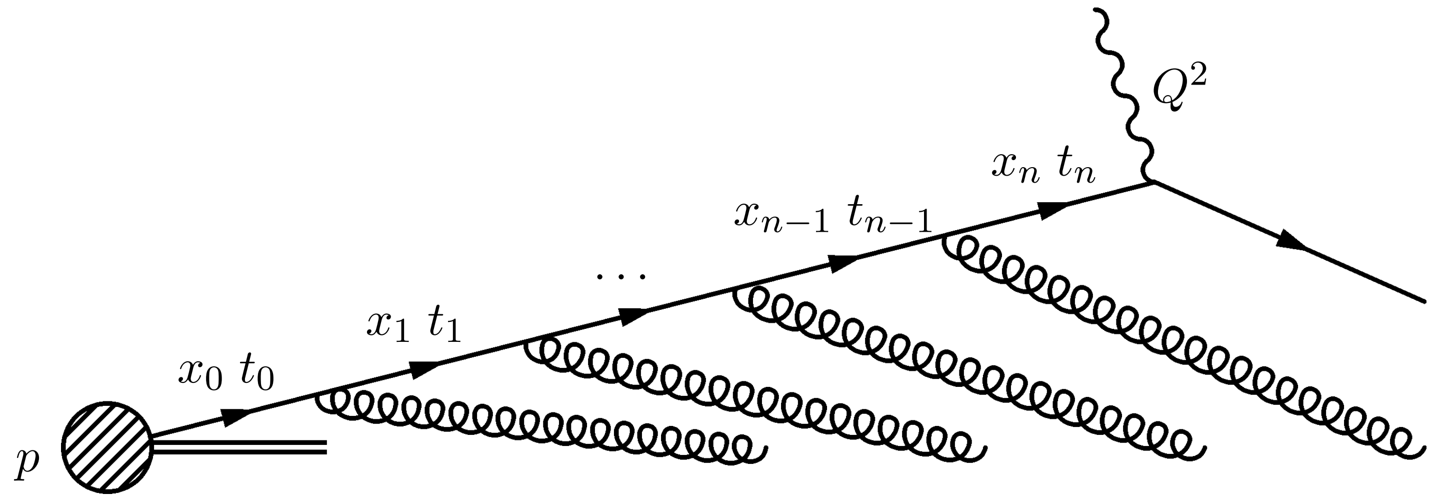
f(x/z, t')

The DGLAP equation



$$t\frac{\partial}{\partial t}f_i(x,t) = \int_x^1 \frac{dz}{z}\frac{\alpha_s}{2\pi}P_{ij}(z)f_j\left(\frac{x}{z}\right)$$

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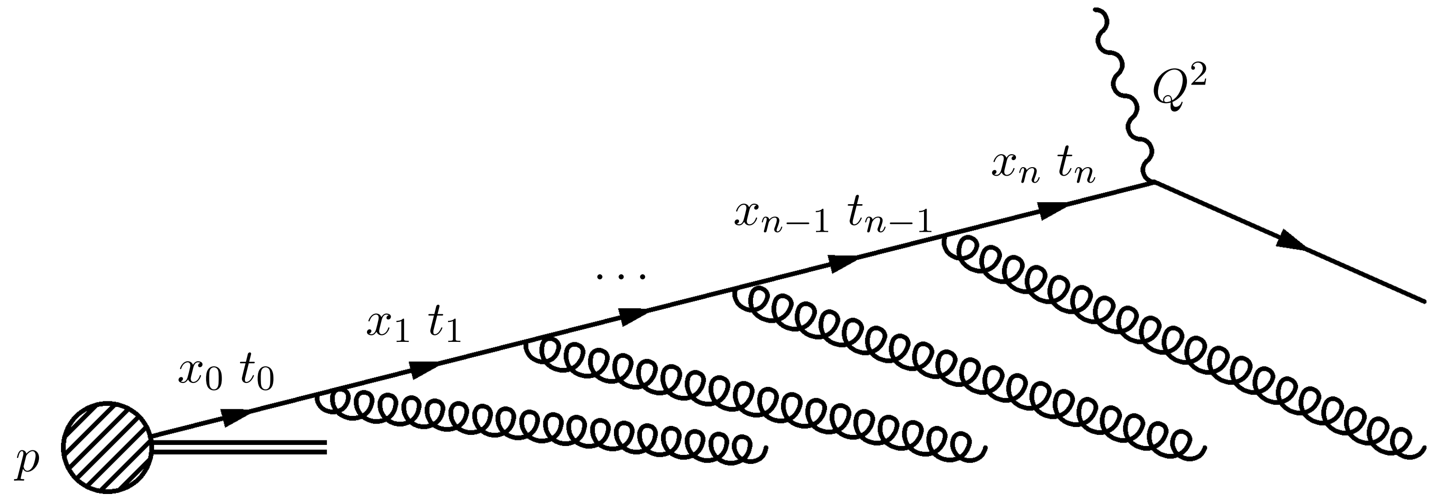

- So for multiple parton splittings, we arrive at an integral equation:

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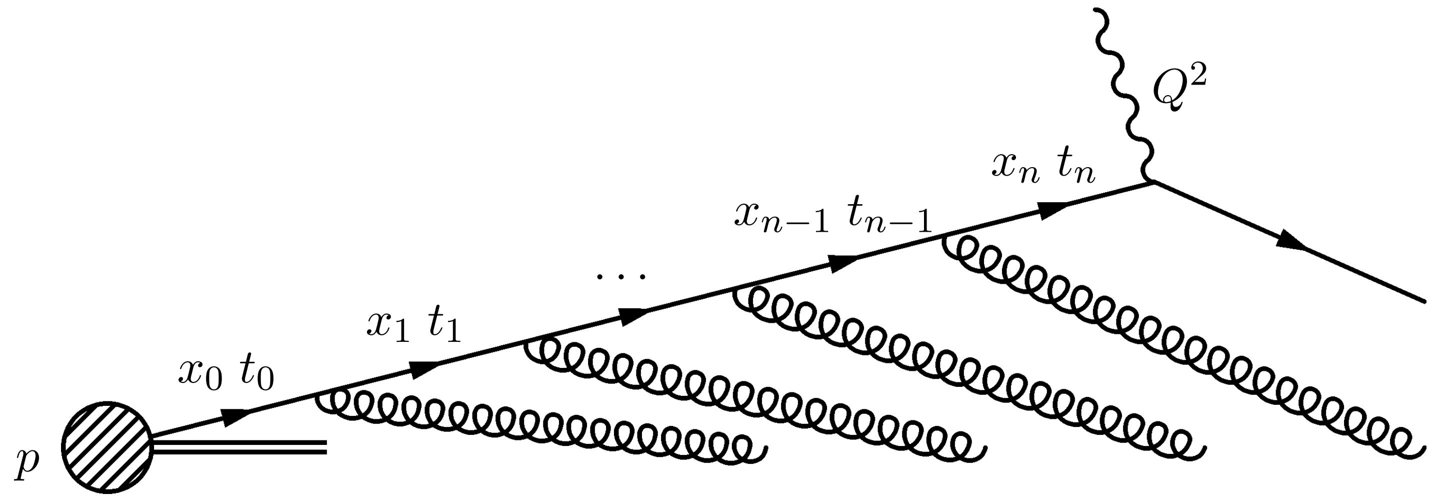

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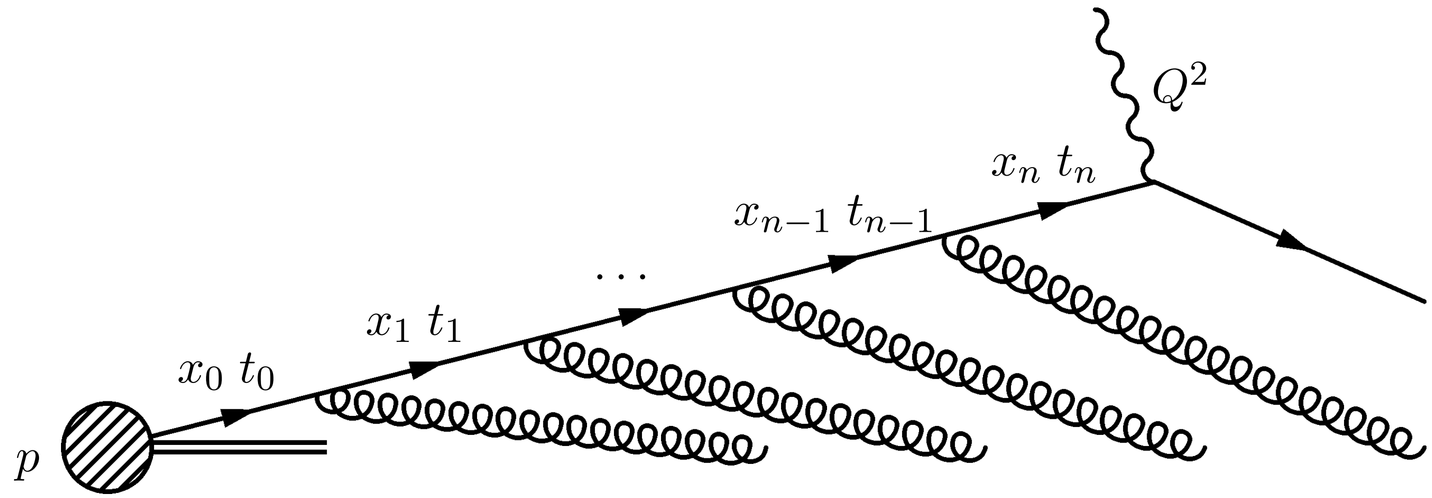
- This is the famous DGLAP equation (where we have taken into account the multiple parton species *i*, *j*). The boundary condition for the equation is the initial PDFs $f_{i0}(x)$ at a starting scale t_0 (again around 1 GeV).

The DGLAP equation



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- These starting PDFs are fitted to experimental data.

Initial-state parton showers

- To simulate parton radiation from the initial state, we start with the hard scattering, and then "devolve" the DGLAP evolution to get back to the original hadron: Backwards evolution!
- In backwards evolution, the Sudakovs include also the PDFs - this follows from the DGLAP equation and ensures conservation of probability:

$$\Delta_{Ii}(x,t_1,t_2) = \exp\left\{-\int_{t_1}^{t_2} dt' \sum_j \int_x^1 \frac{dx'}{x'} \frac{\alpha_s(t')}{2\pi} P_{ij}\left(\frac{x}{x'}\right) \frac{f_i(x',t')}{f_j(x,t')}\right\}$$

  This represents the probability that parton *i* will stay at the same *x* (no splittings) when evolving from t_1 to t_2.

- The shower simulation is now done as in FS shower!

Parton Shower MC event generators

- In both initial-state and final-state showers, the definition of t is not unique, as long as it has the dimension of scale:
- Different parton shower generators have made different choices:
  - ➡ Pythia (old): virtuality q^2
  - ➡ Pythia 6.4 and Pythia 8: p_T
  - ➡ Herwig: $E \cdot \theta$
  - ➡ Sherpa: original virtuality q^2, new shower ~ p_T
- All of the above are complete MC event generators with matrix elements, parton showers, hadronization, decay, and underlying event simulation.

Back to our favorite piece of art!

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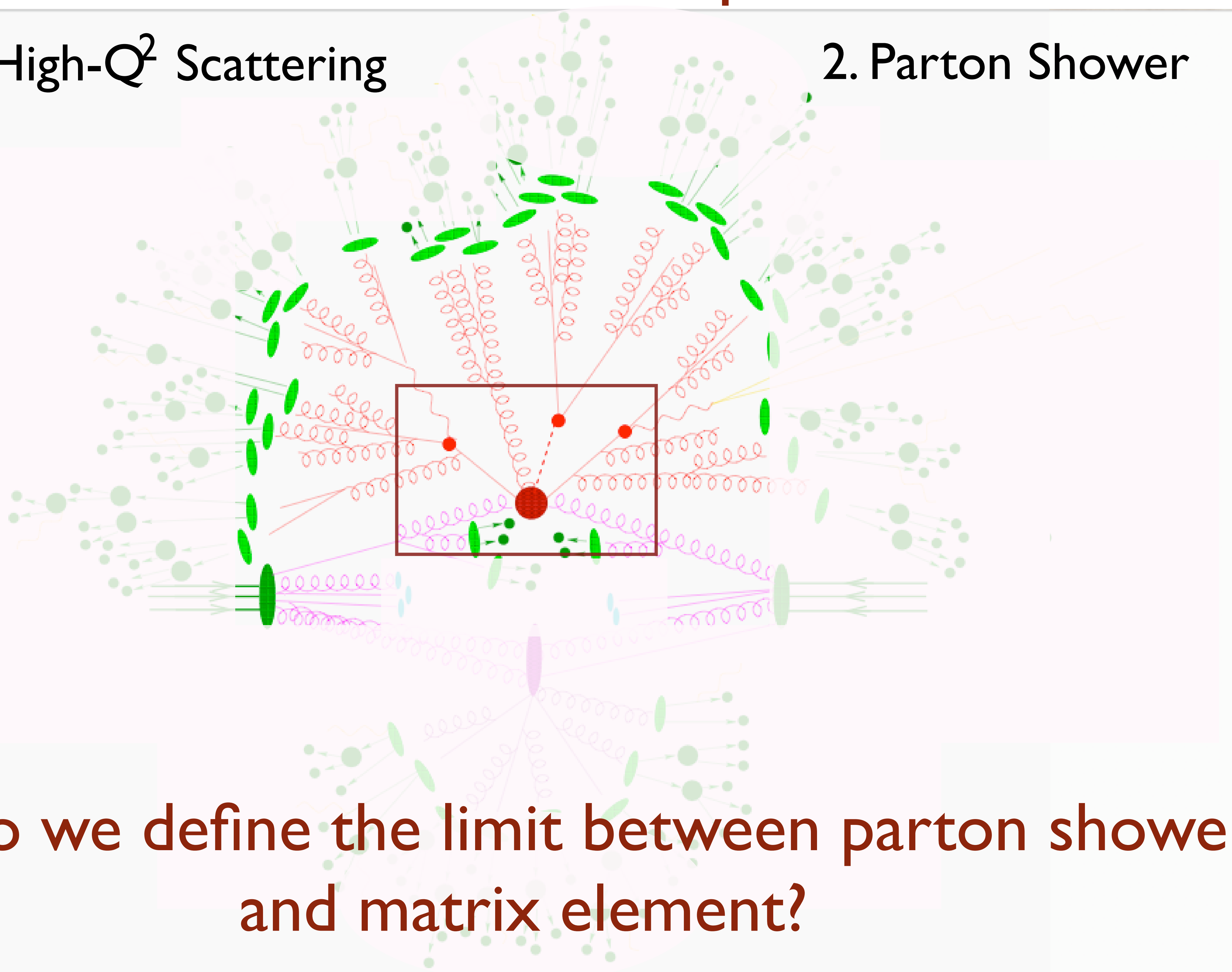

How do we define the limit between parton shower and matrix element?

Matrix Elements vs. Parton Showers

Matrix Elements vs. Parton Showers

ME

1. Fixed order calculation
2. Computationally expensive
3. Limited number of particles
4. Valid when partons are hard and well separated
5. Quantum interference correct
6. Needed for multi-jet description

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Approaches are complementary: merge them!

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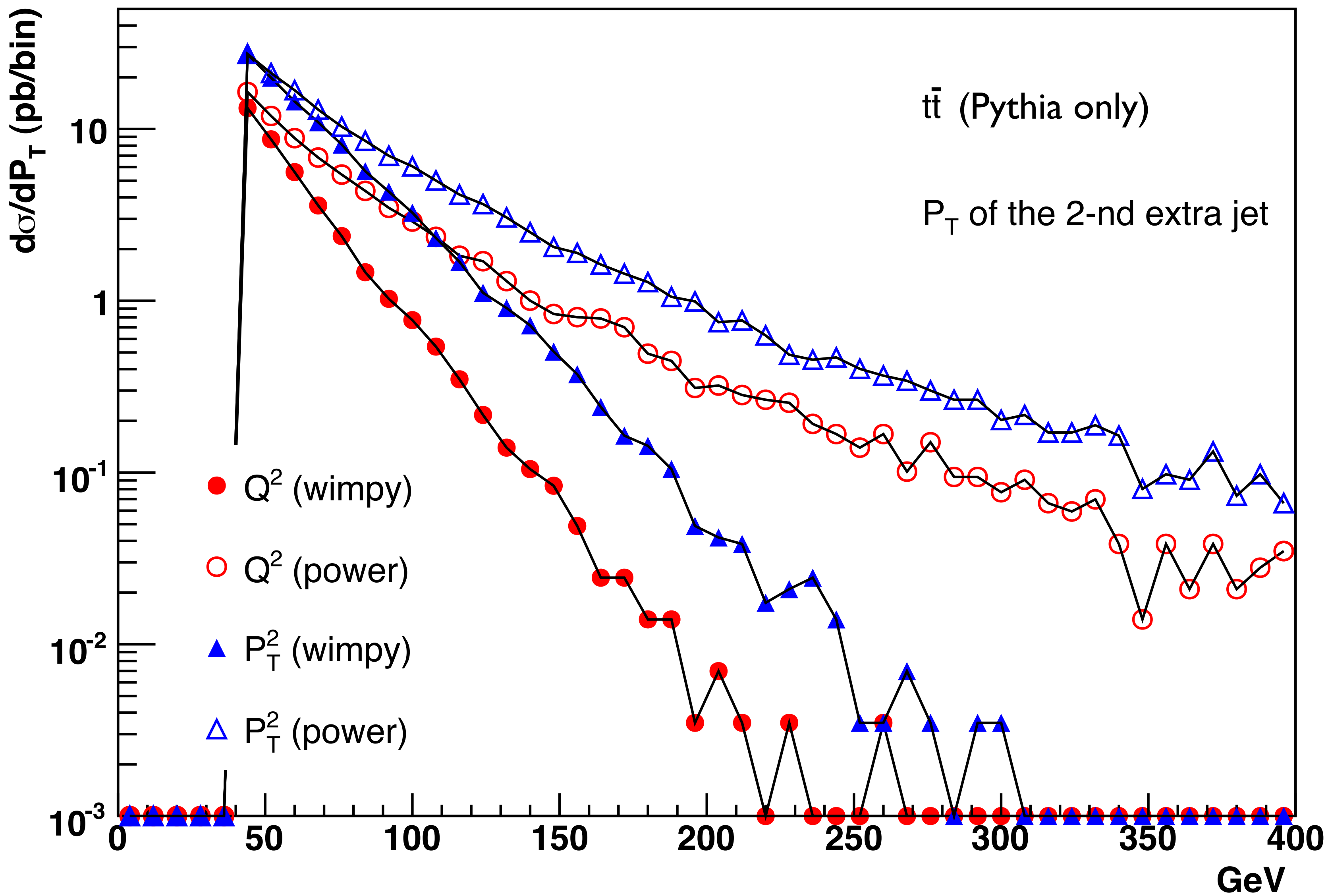
Difficulty: avoid double counting, ensure smooth distributions

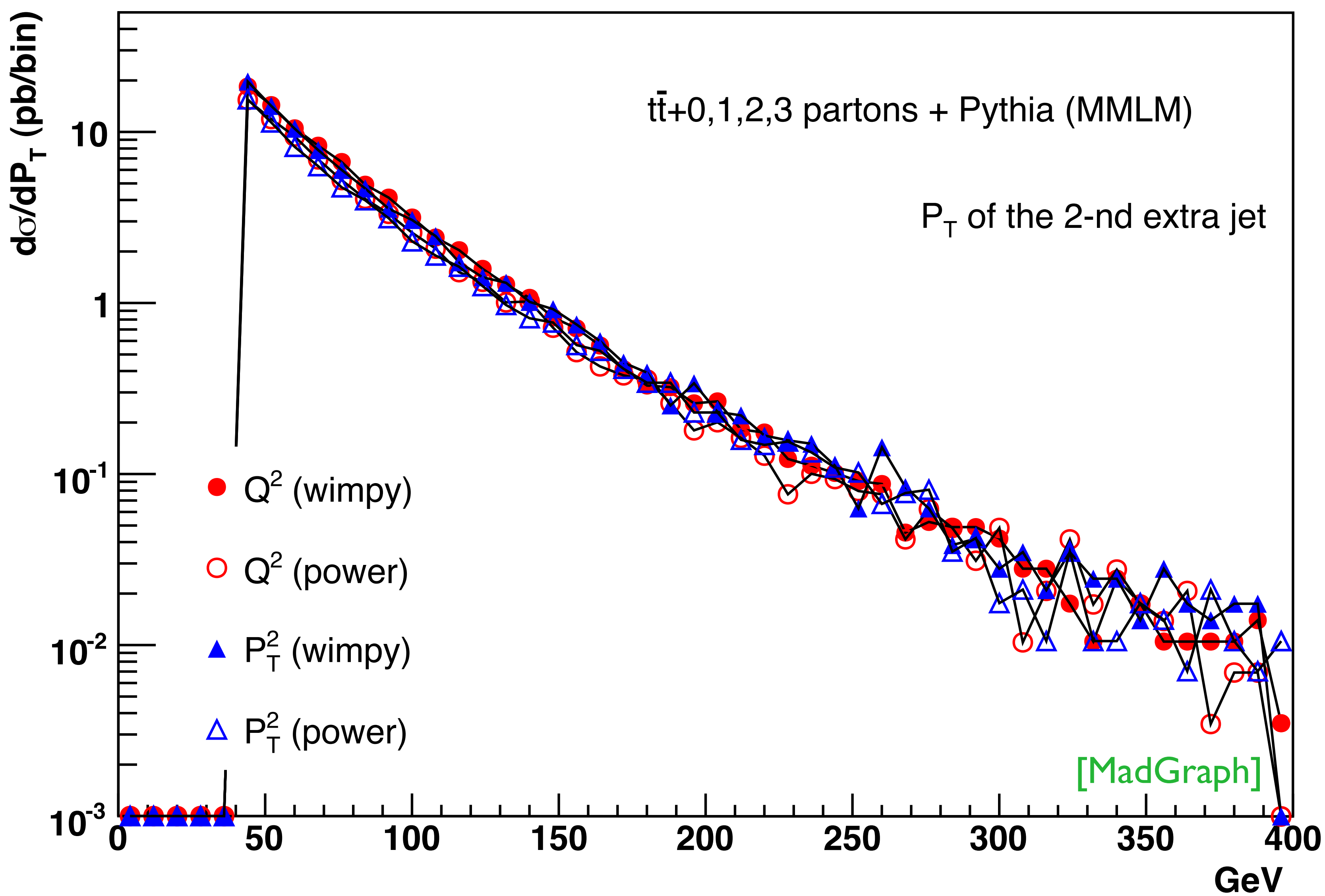
PS alone vs matched samples

In the soft-collinear approximation of Parton Shower MCs, parameters are used to tune the result ⇒ Large variation in results (small prediction power)

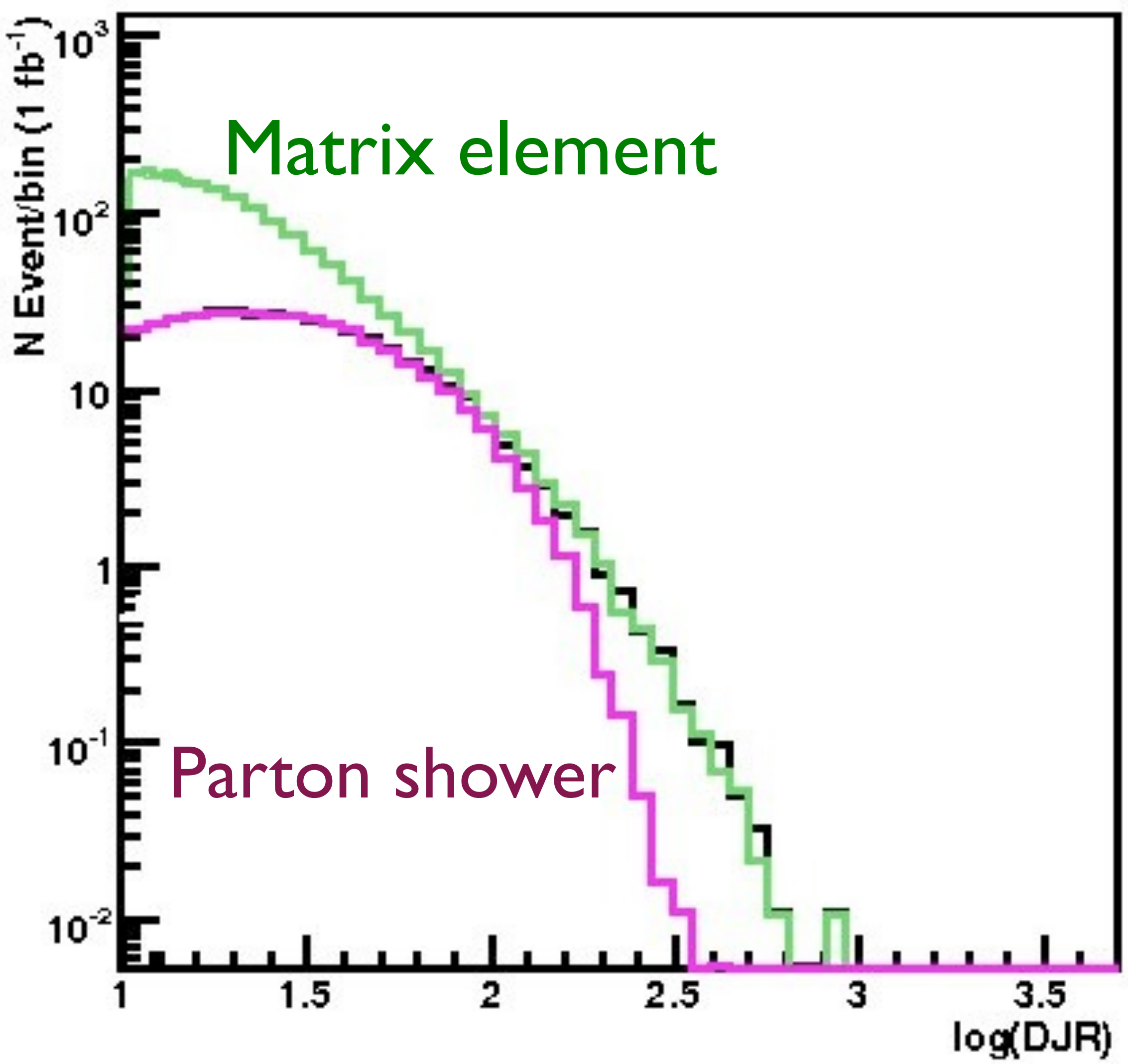


PS alone vs matched samples

In a matched sample these differences are irrelevant since the behavior at high pt is dominated by the matrix element.



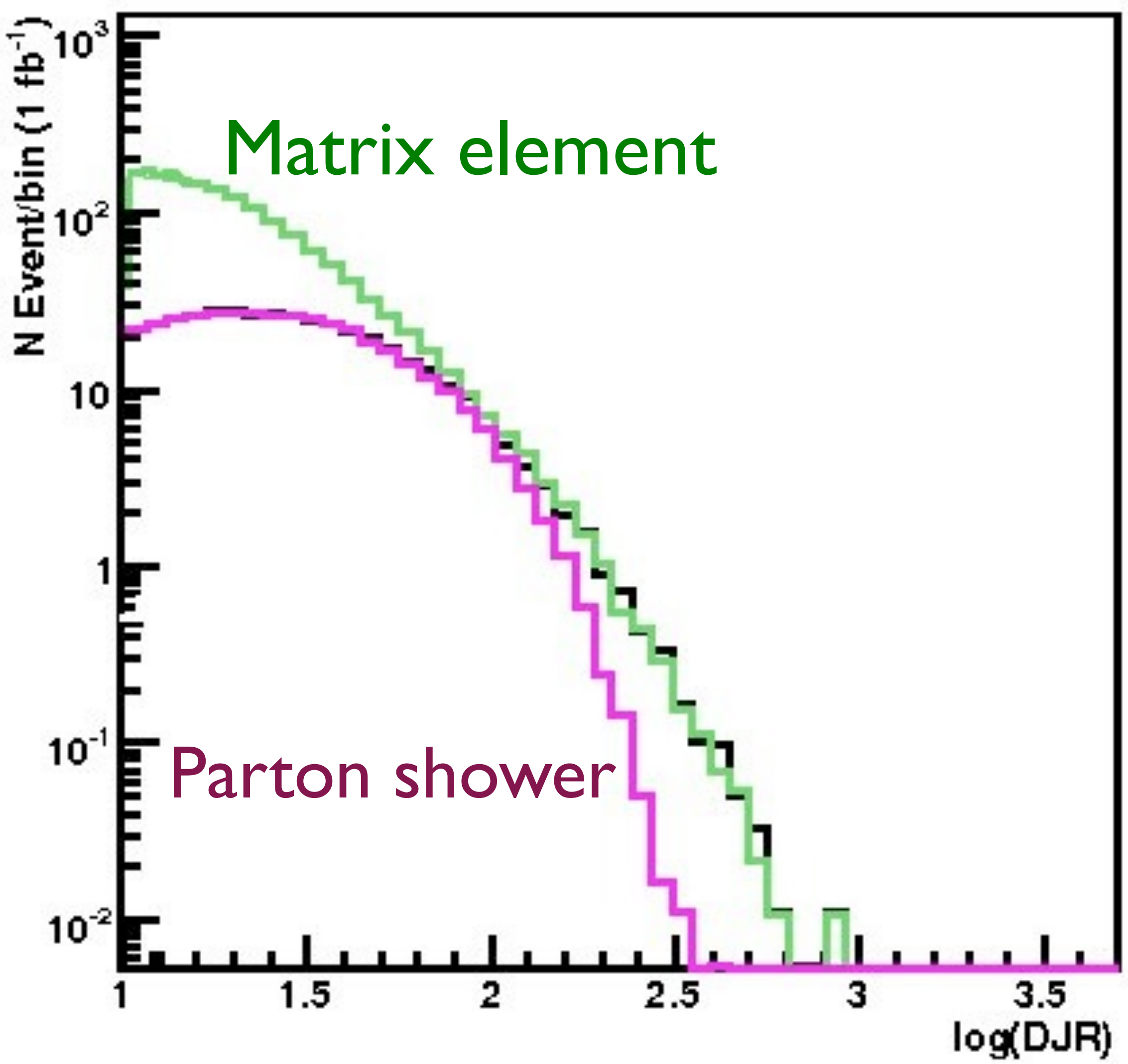
Goal for ME-PS merging/matching



2nd QCD radiation jet in top pair production at the LHC

Goal for ME-PS merging/matching

- Regularization of matrix element divergence



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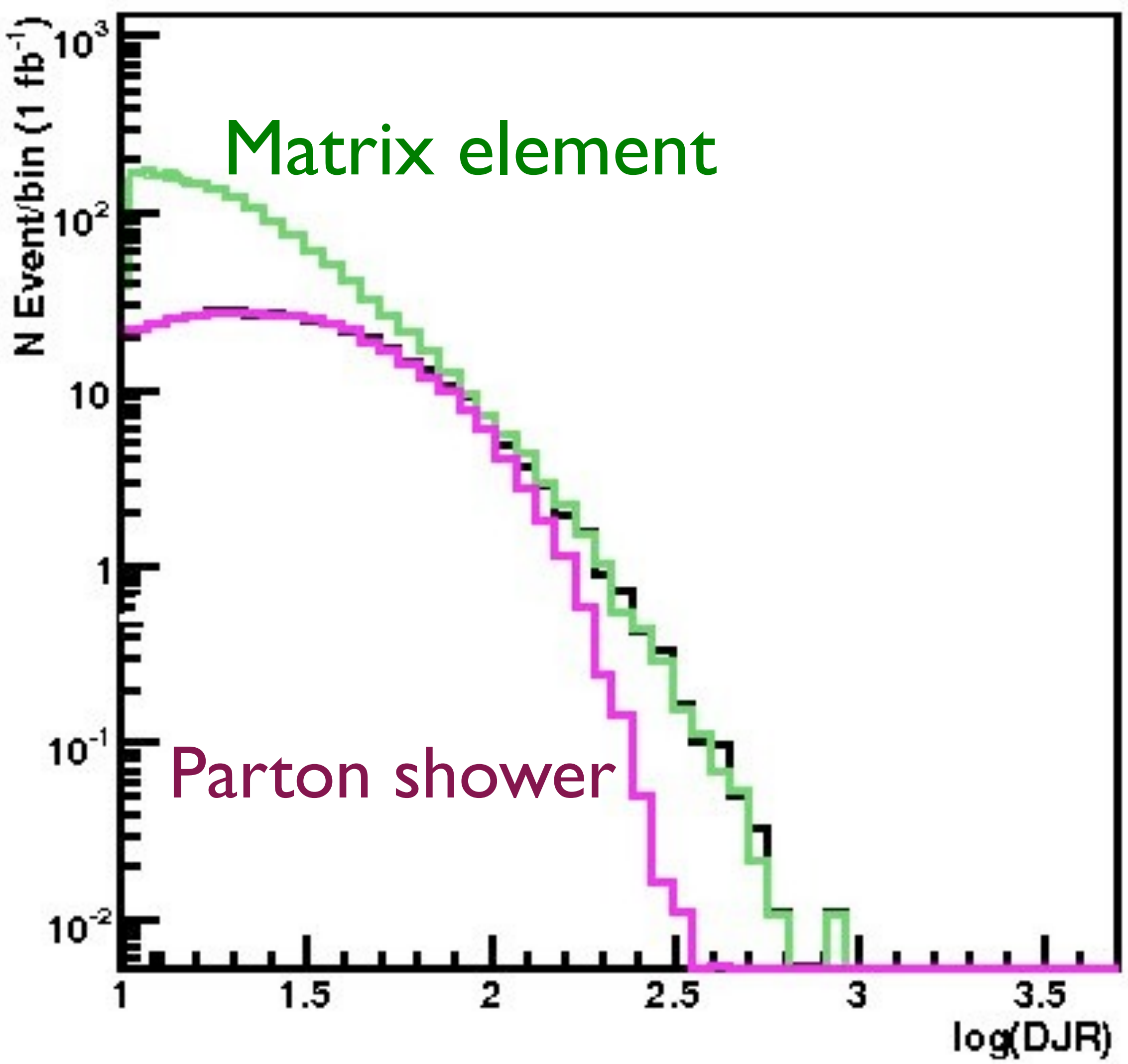

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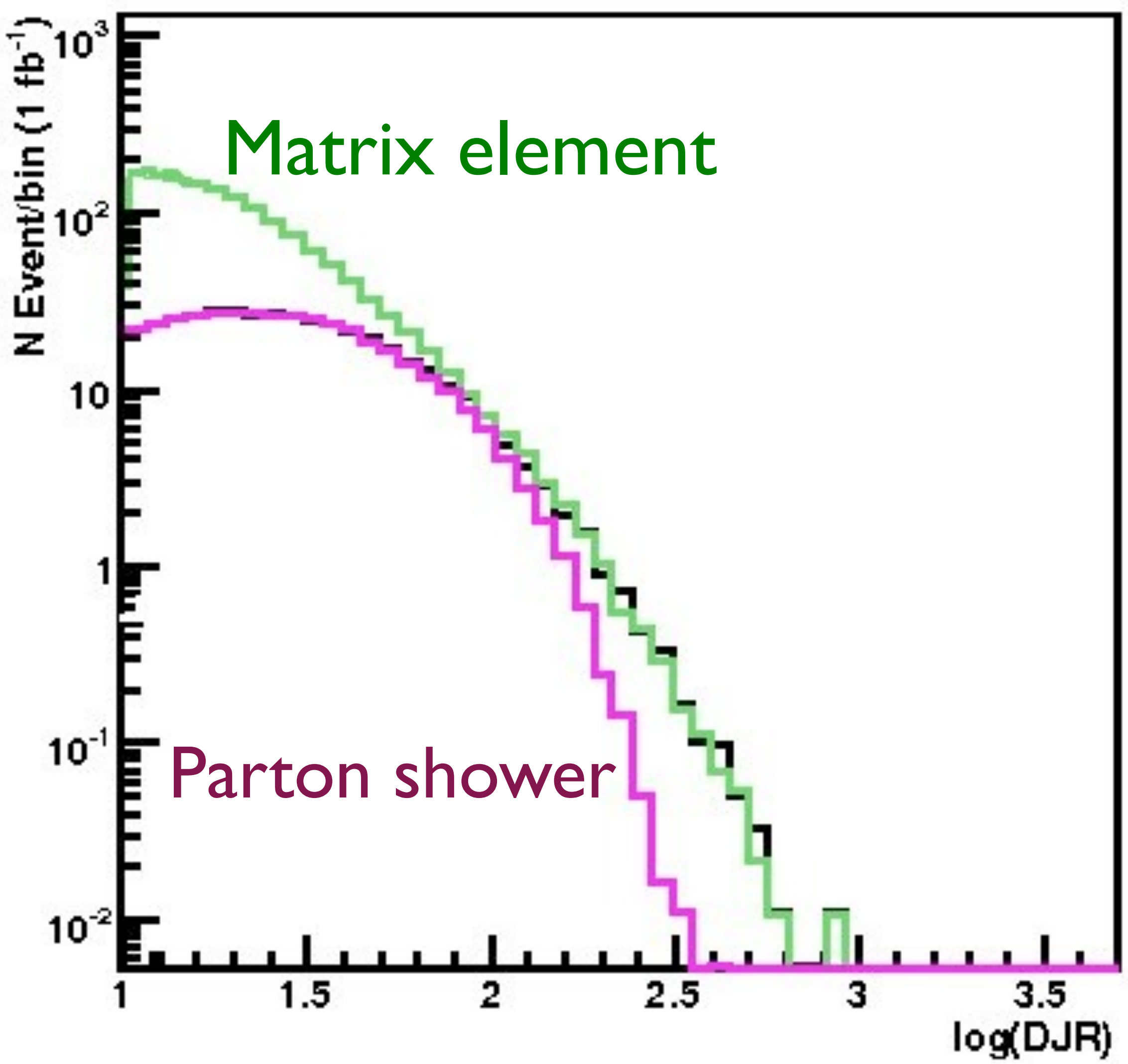

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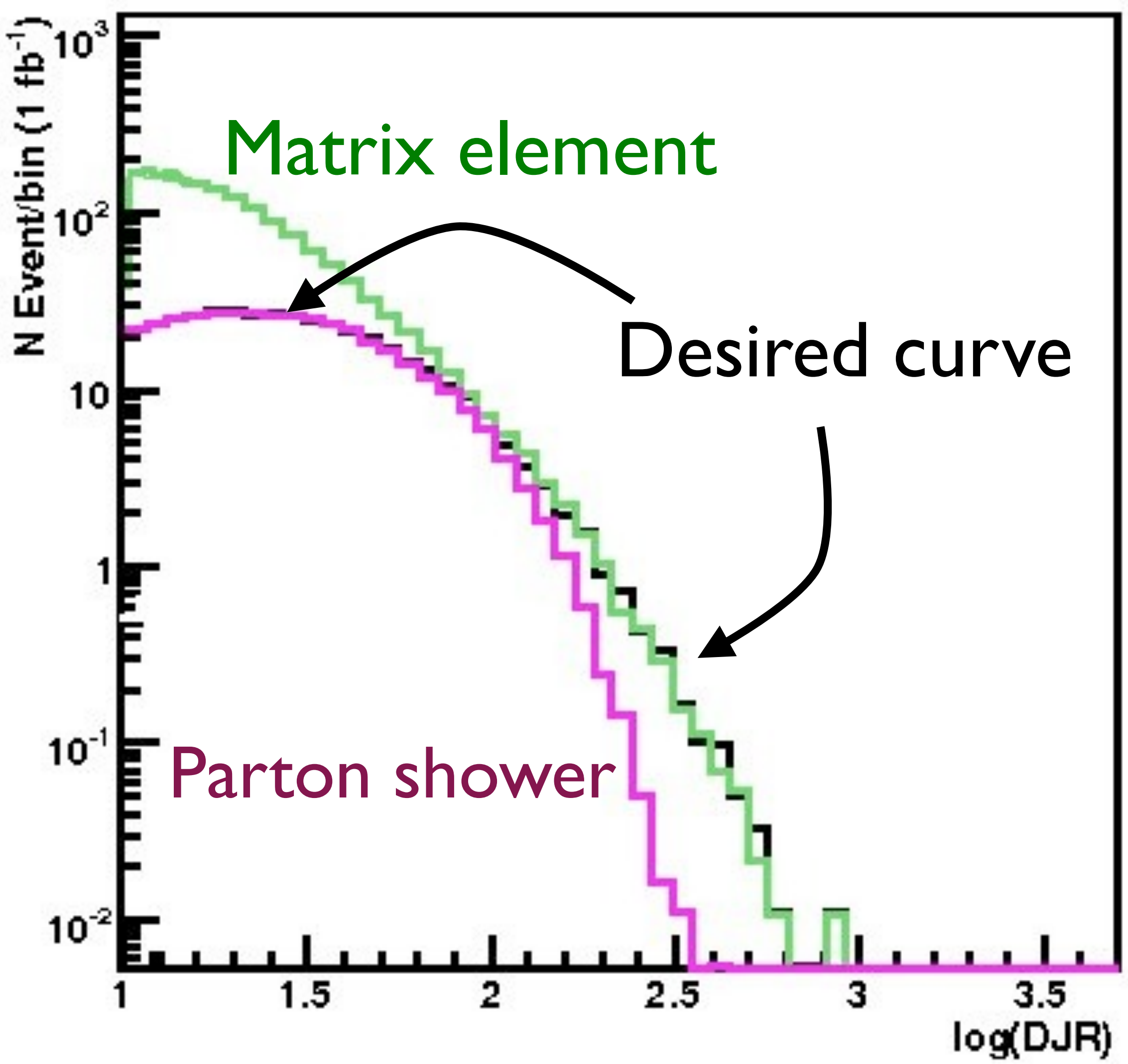

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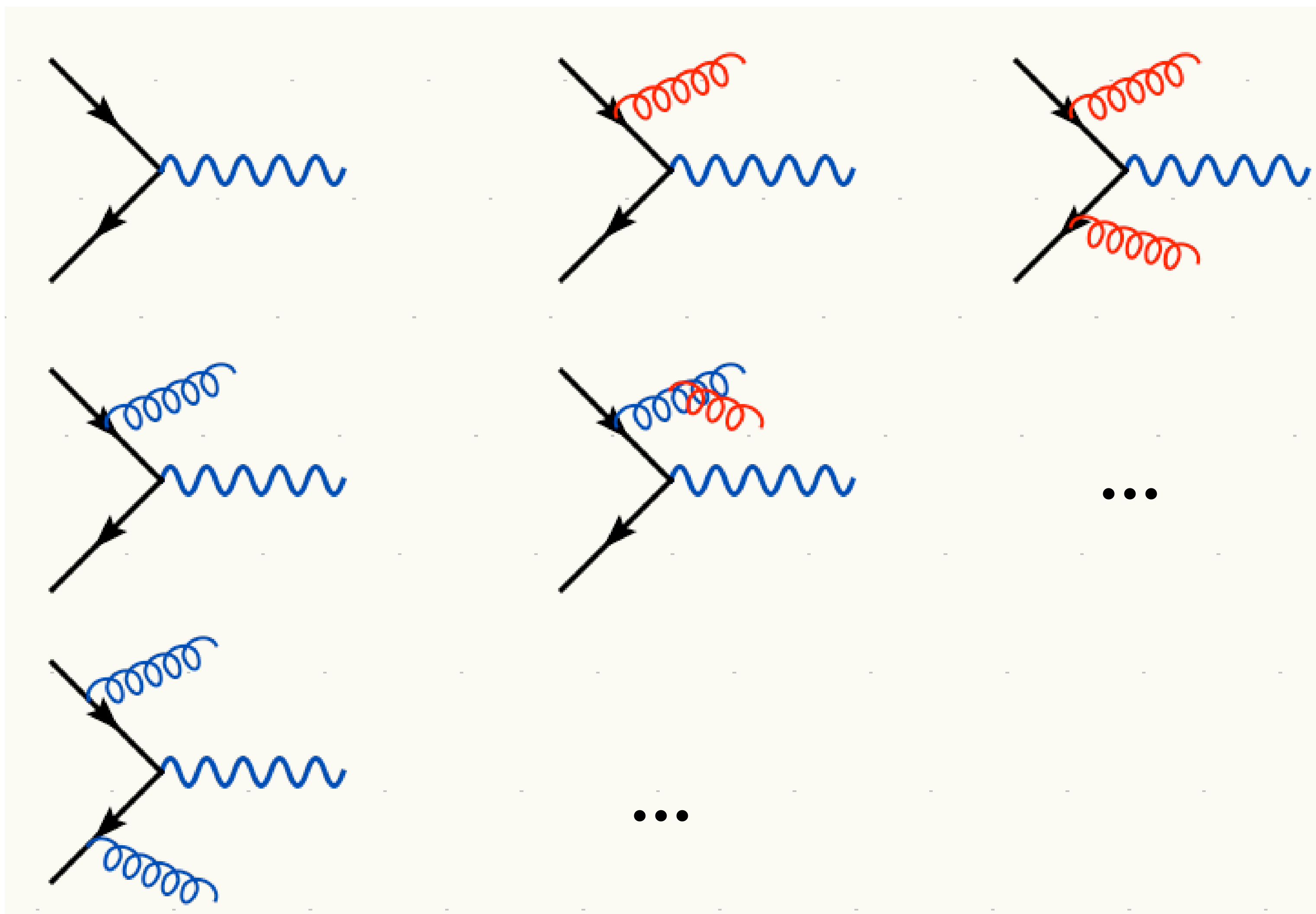
Merging ME with PS

[Mangano]
[Catani, Krauss, Kuhn, Webber]

PS →

ME ↓



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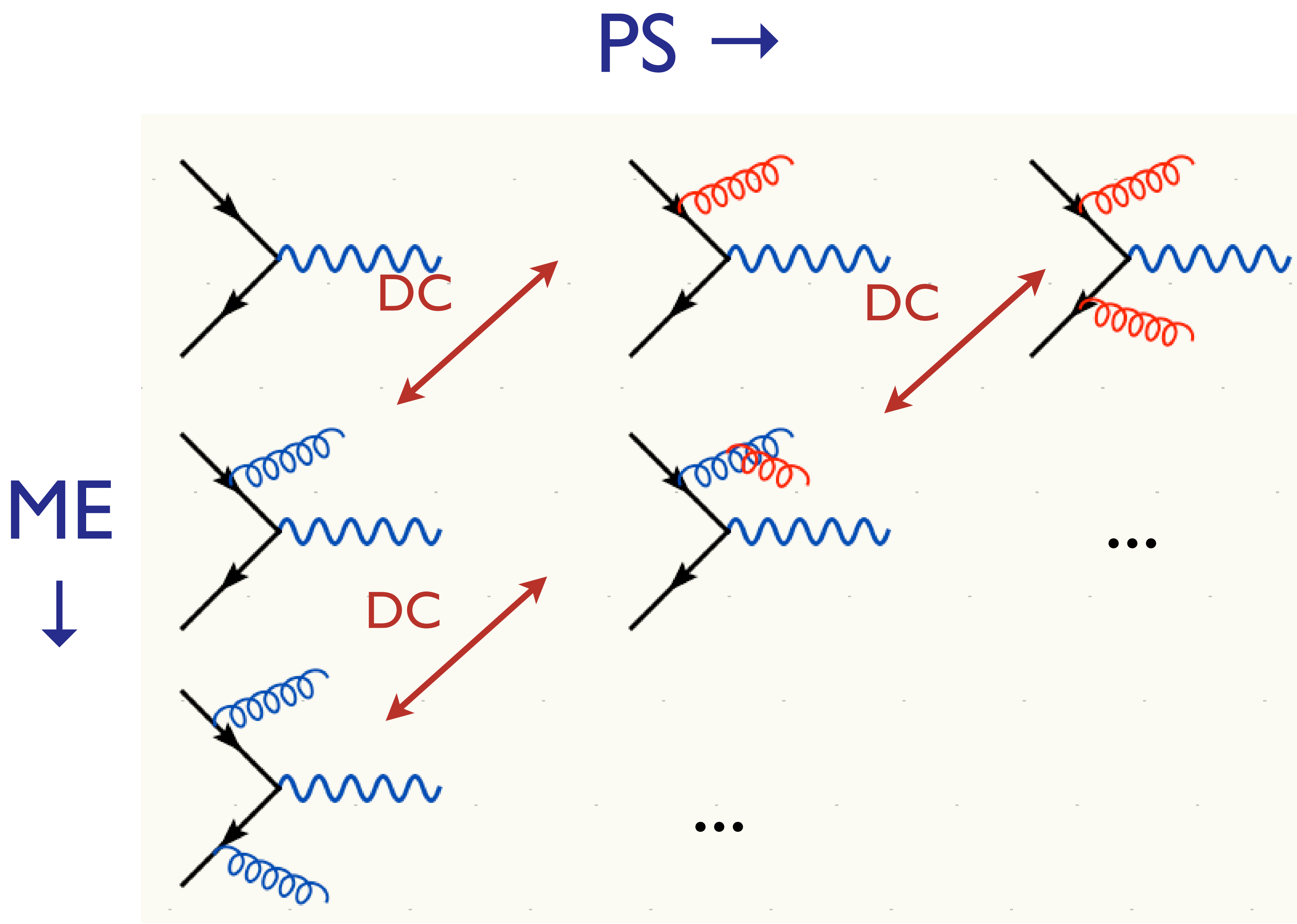

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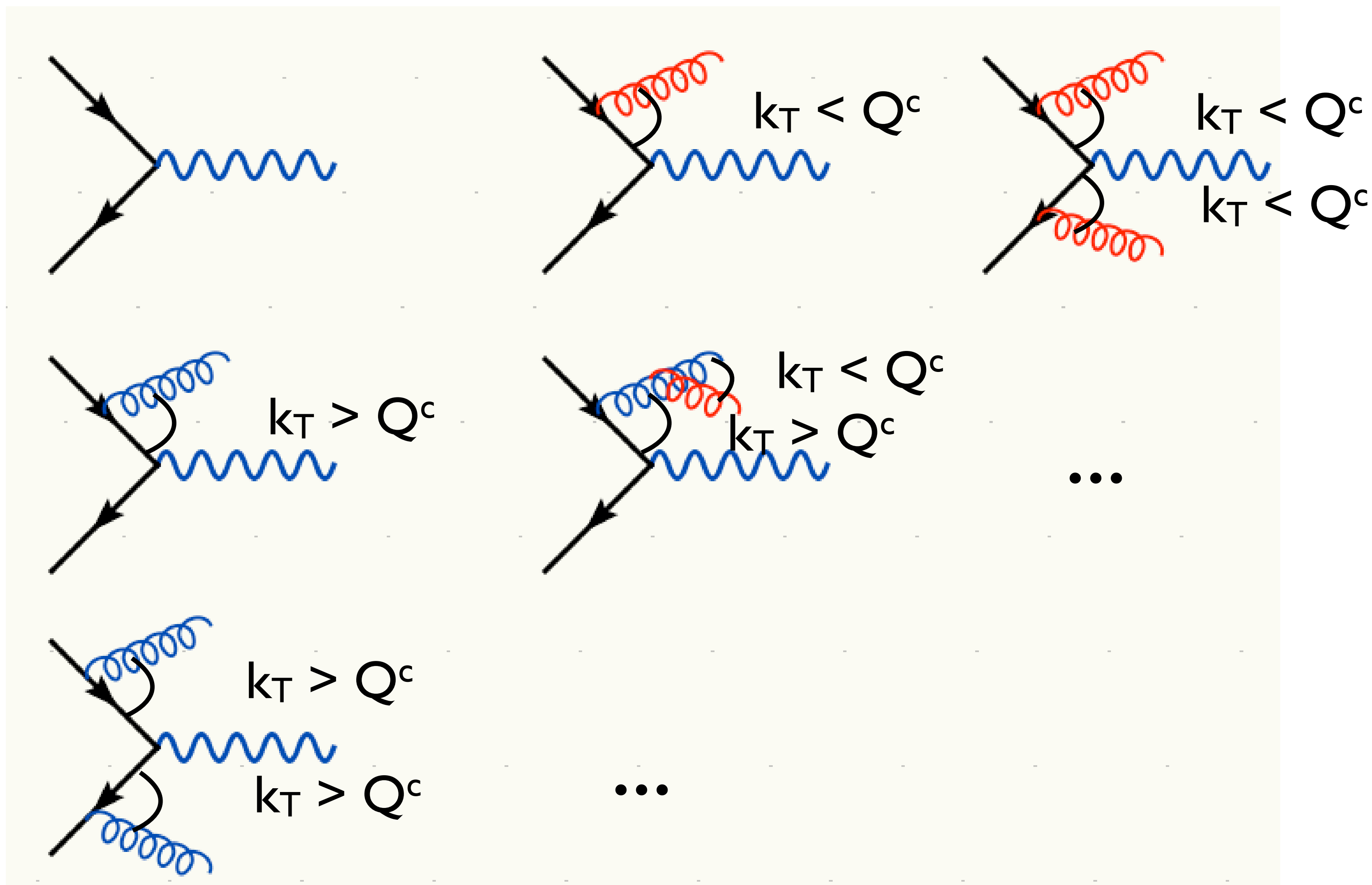

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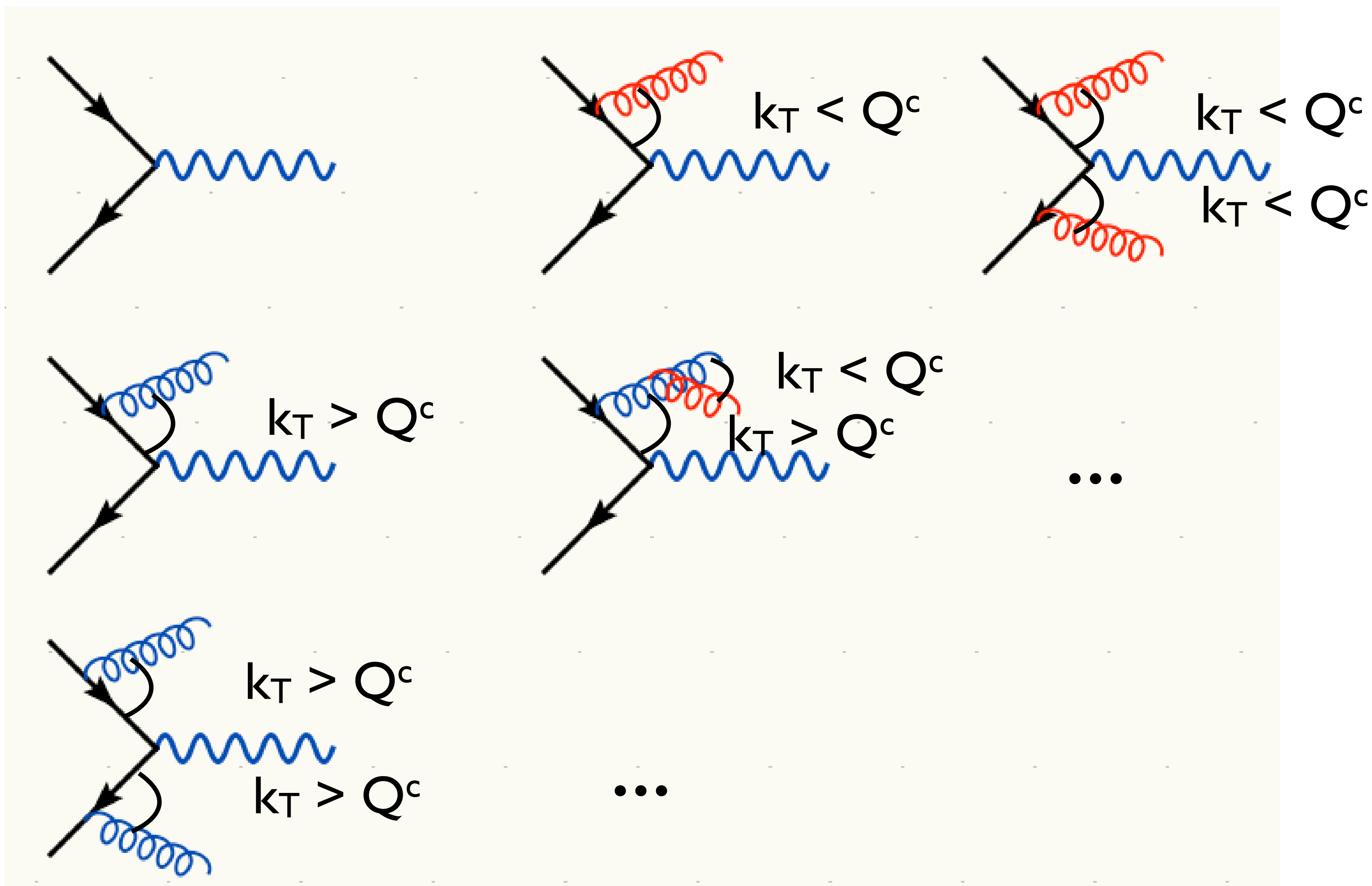
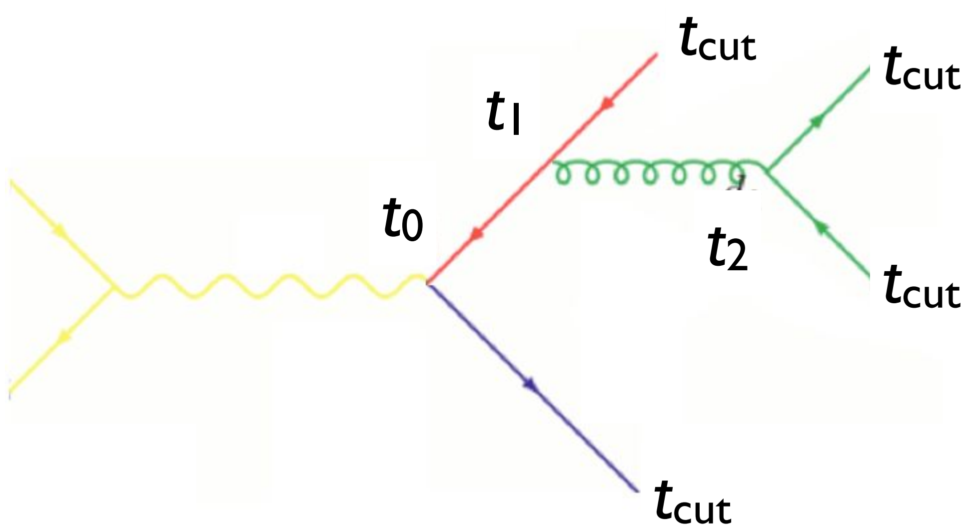


Double counting between ME and PS easily avoided using phase space cut between the two: PS below cutoff, ME above cutoff.

Merging ME with PS

- So double counting no problem, but what about getting smooth distributions that are independent of the precise value of Q^c?
- Below cutoff, distribution is given by PS
  - need to make ME look like PS near cutoff
- Let's take another look at the PS!

Merging ME with PS



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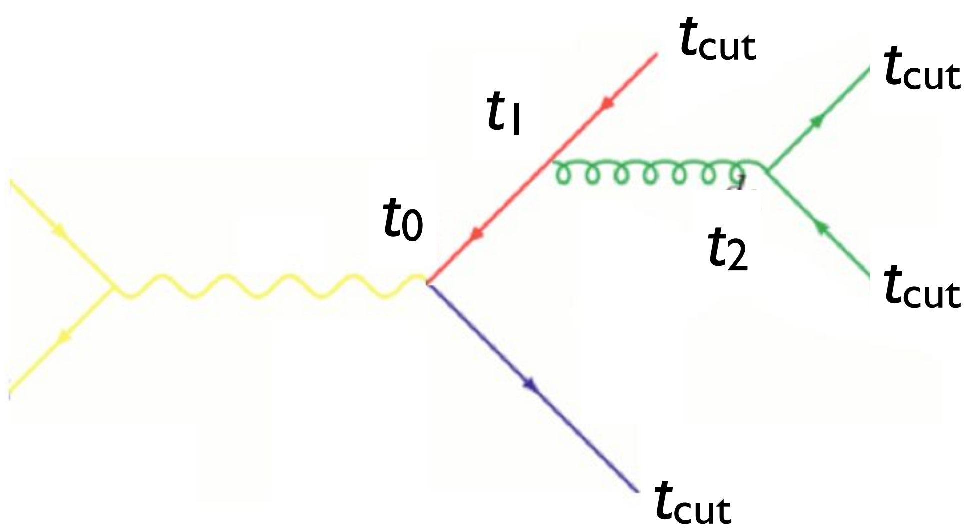
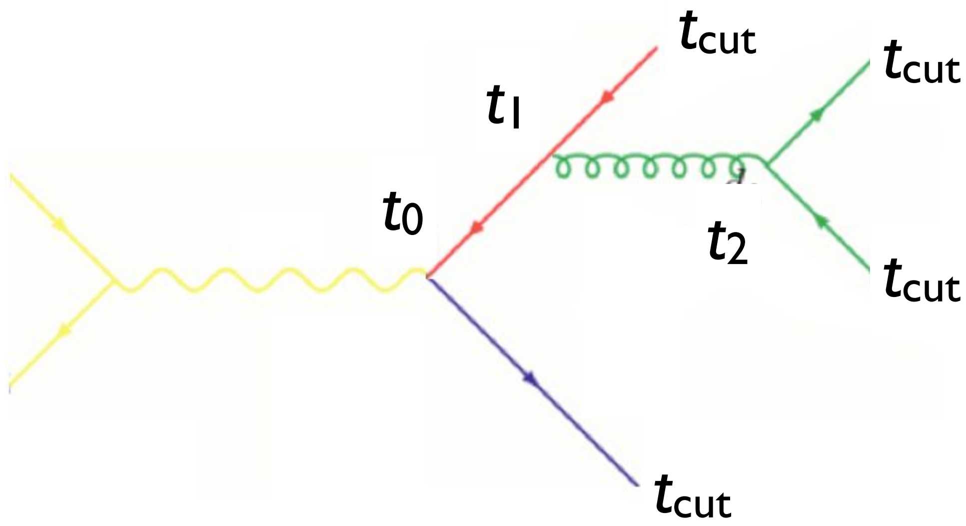


- How does the PS generate the configuration above?

Merging ME with PS



- How does the PS generate the configuration above?
- Probability for the splitting at t_1 is given by

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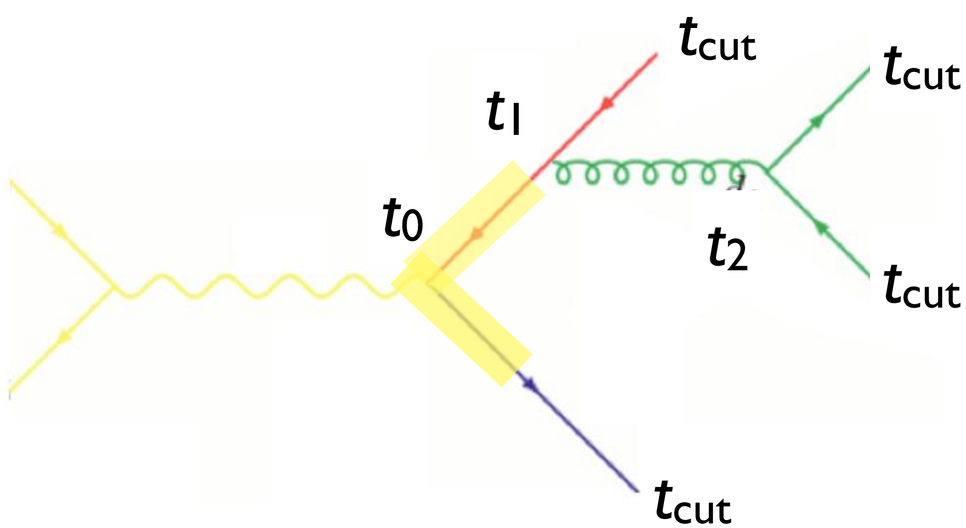

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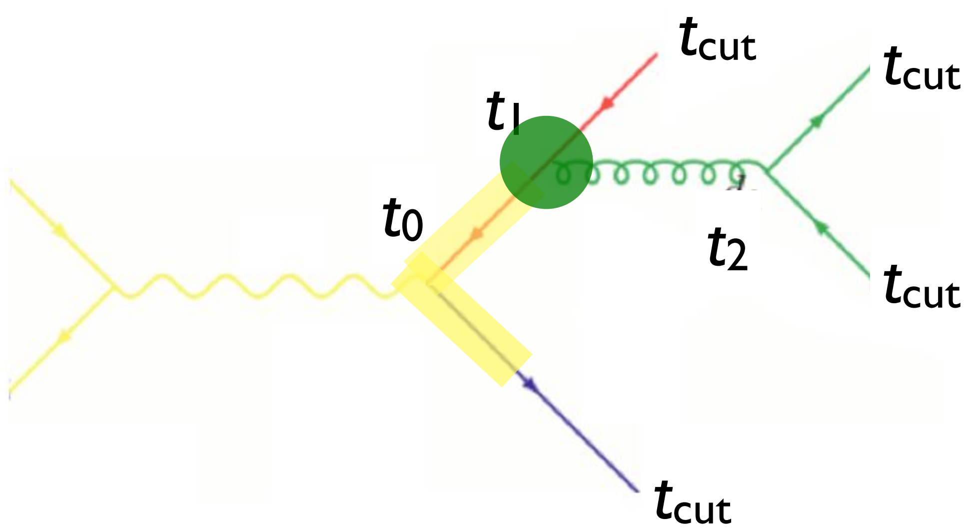

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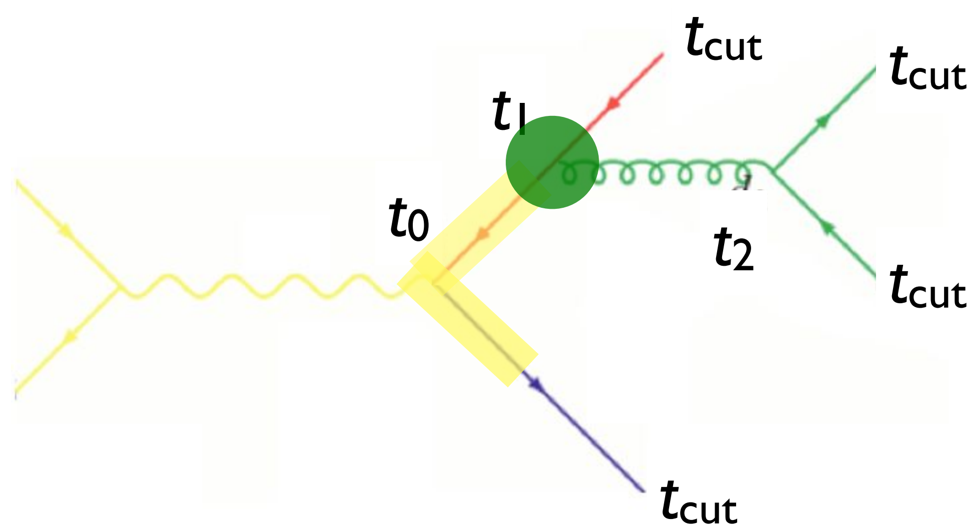

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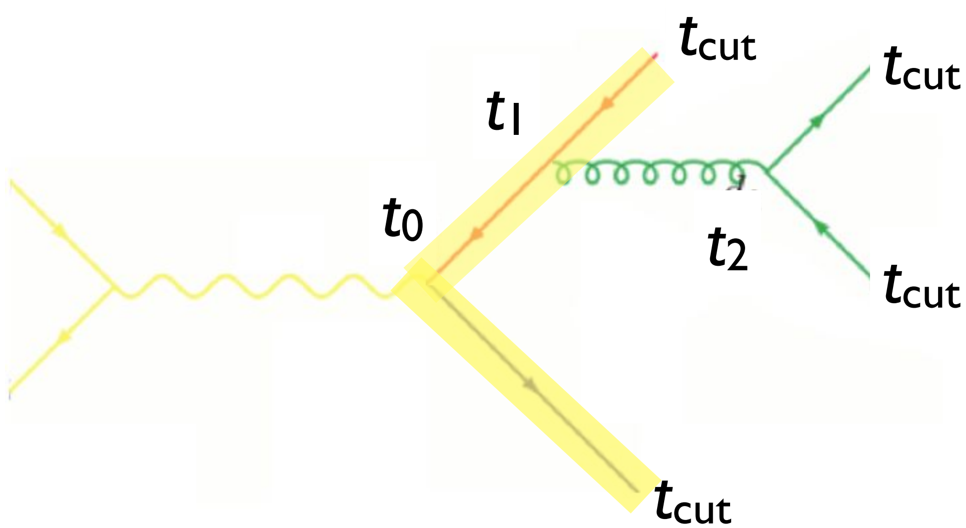

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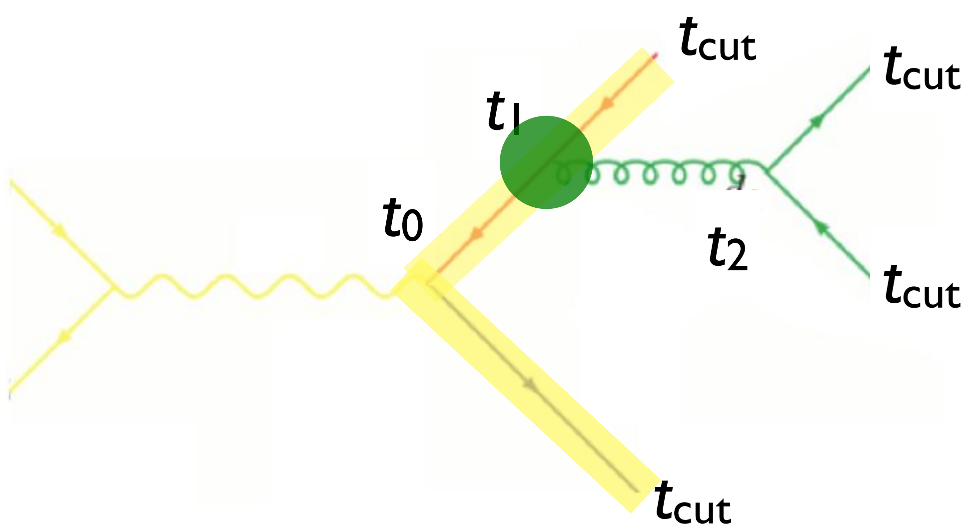

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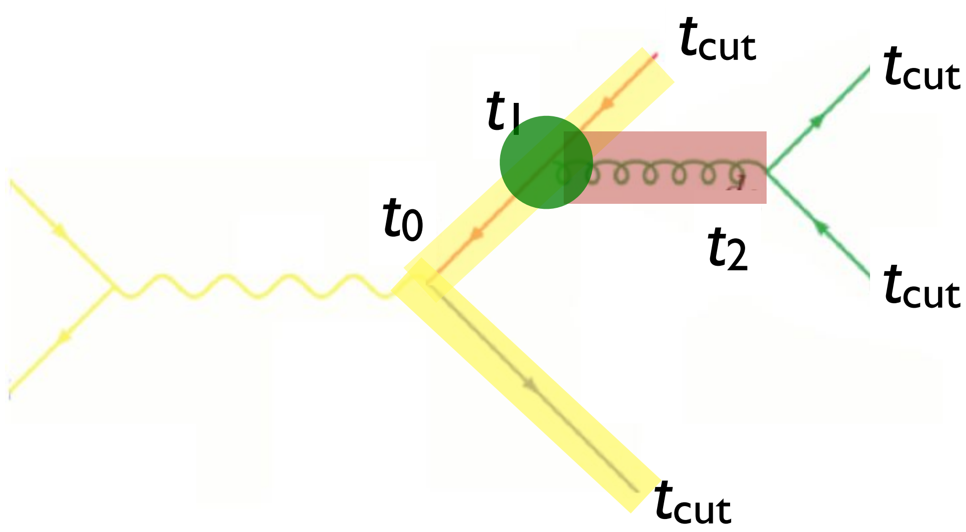

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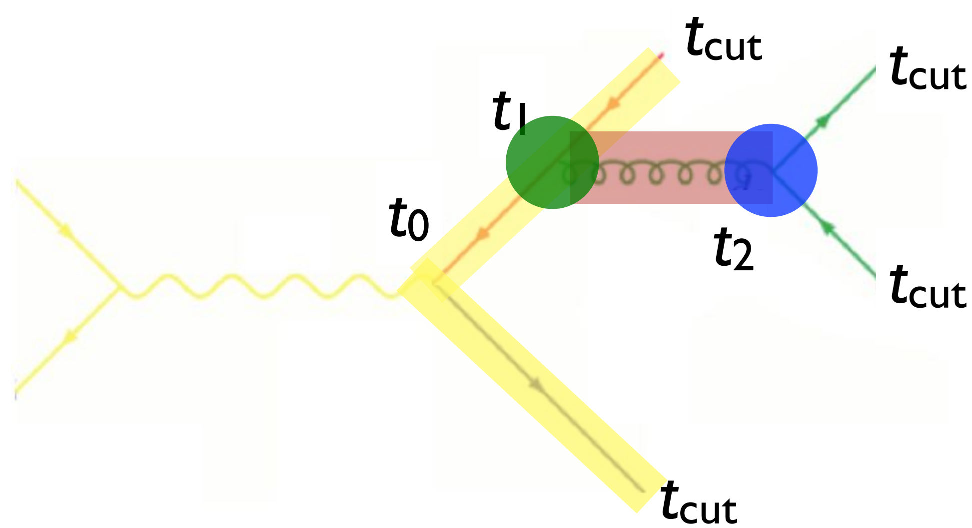

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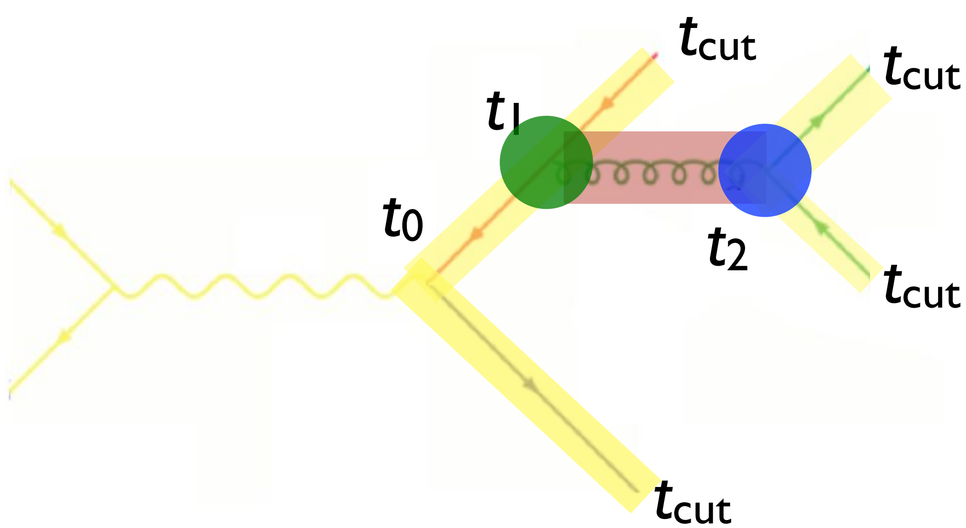

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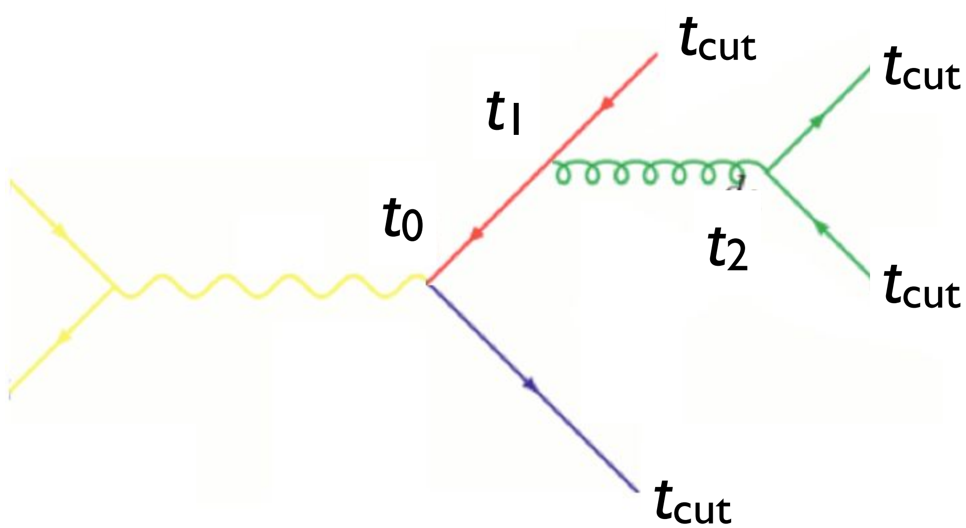

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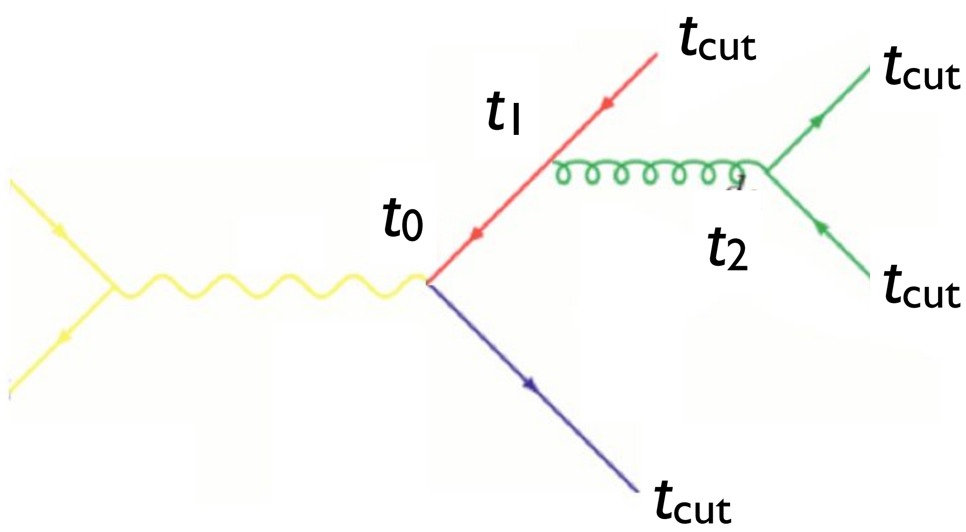

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Corresponds to the matrix element
BUT with α_s evaluated at the scale of each splitting

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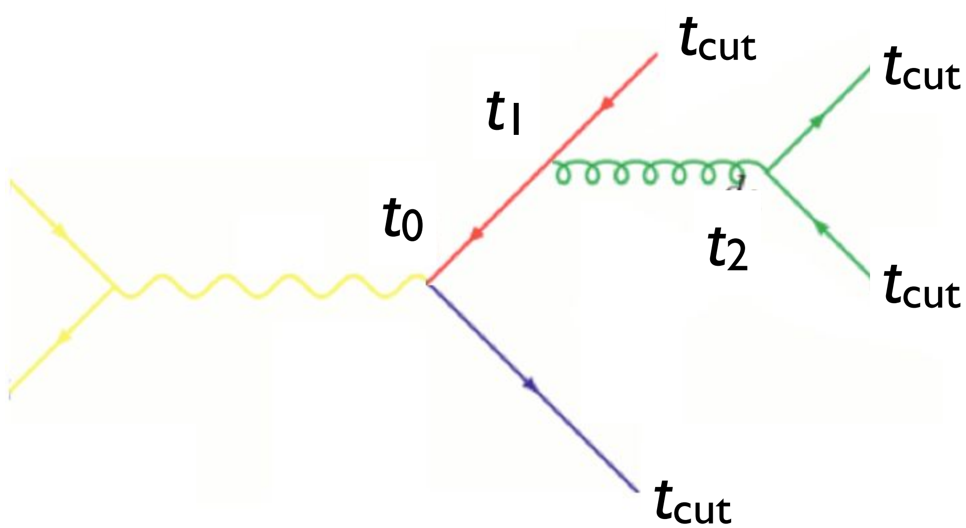

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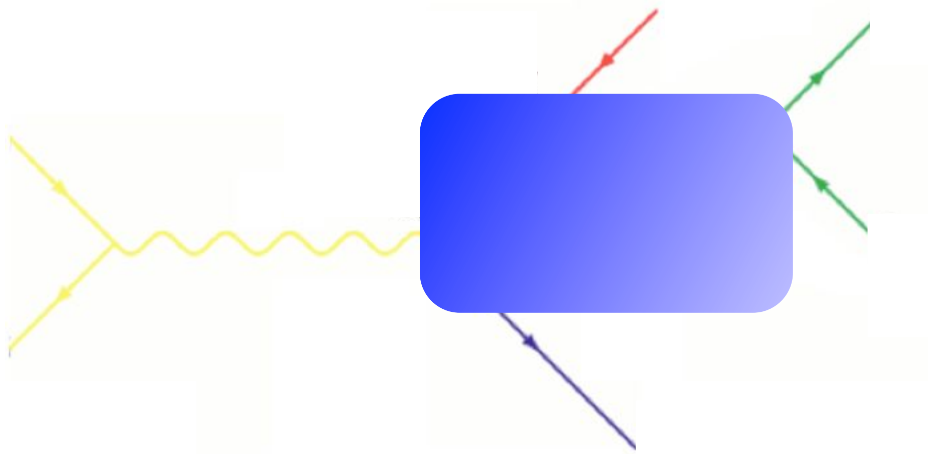
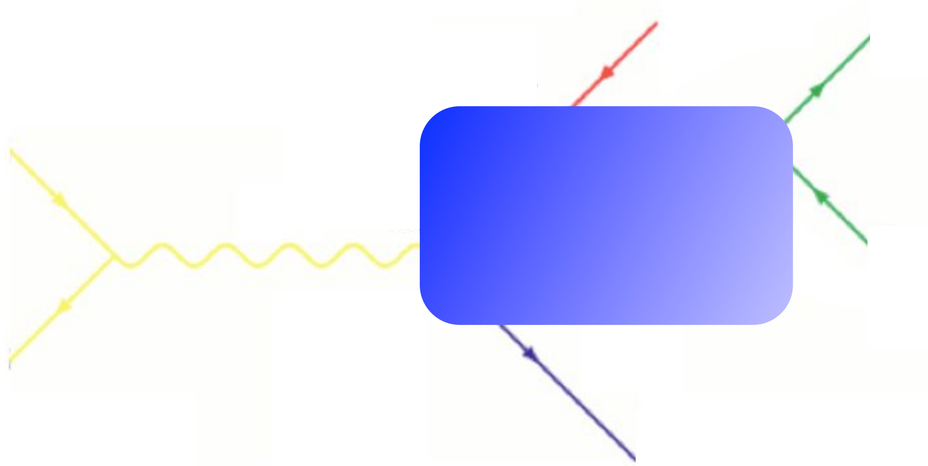
Sudakov suppression due to disallowing additional radiation above the scale $t_{\rm cut}$

Merging ME with PS



$$|\mathcal{M}|^2(\hat{s}, p_3, p_4, \ldots)$$

Merging ME with PS



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- To get an equivalent treatment of the corresponding matrix element, do as follows:

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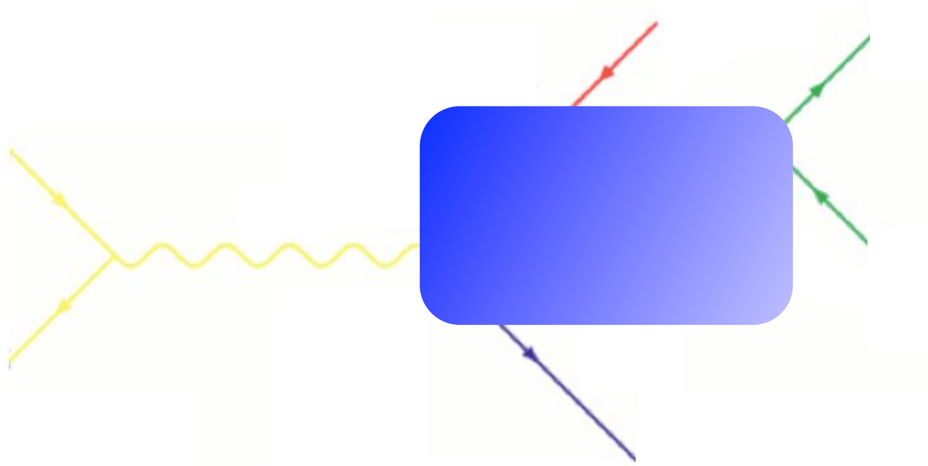

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    1. Cluster the event using some clustering algorithm
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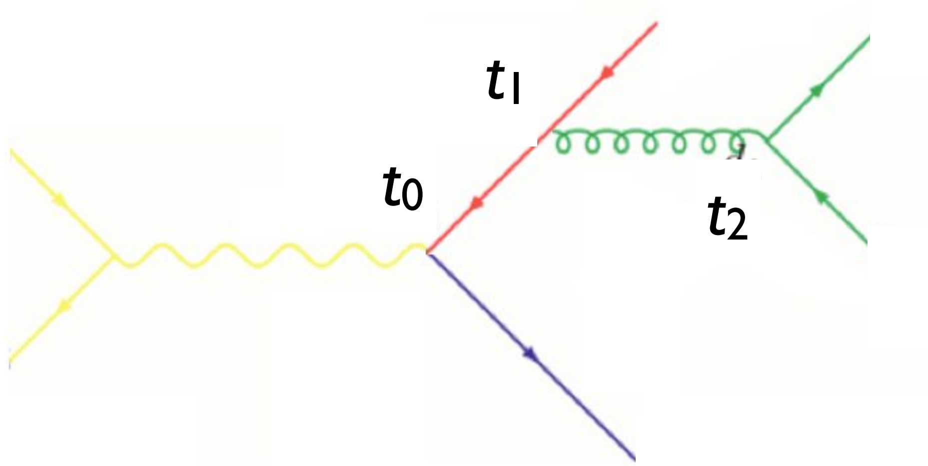

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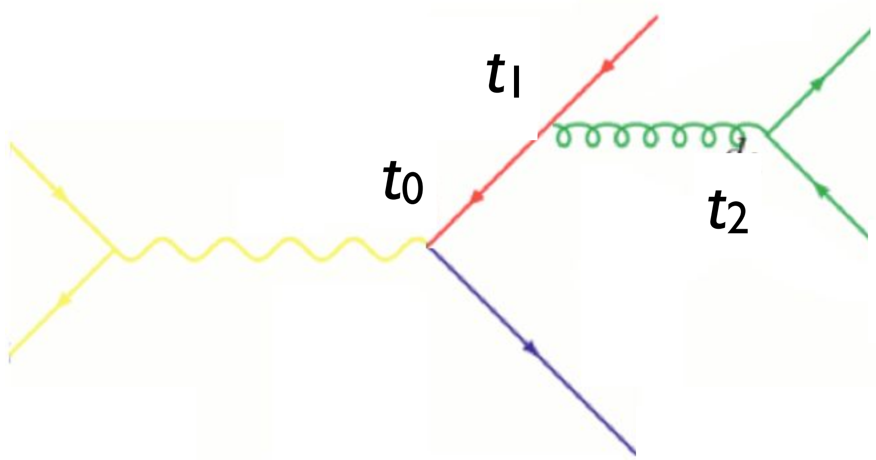

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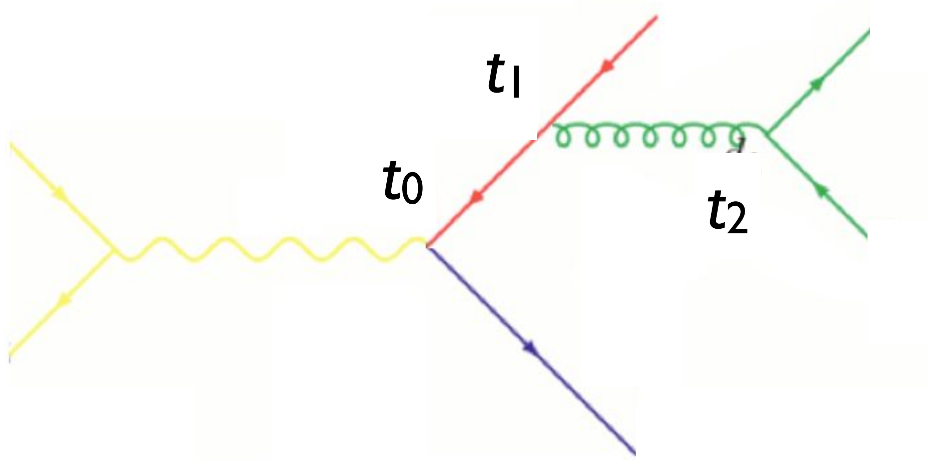

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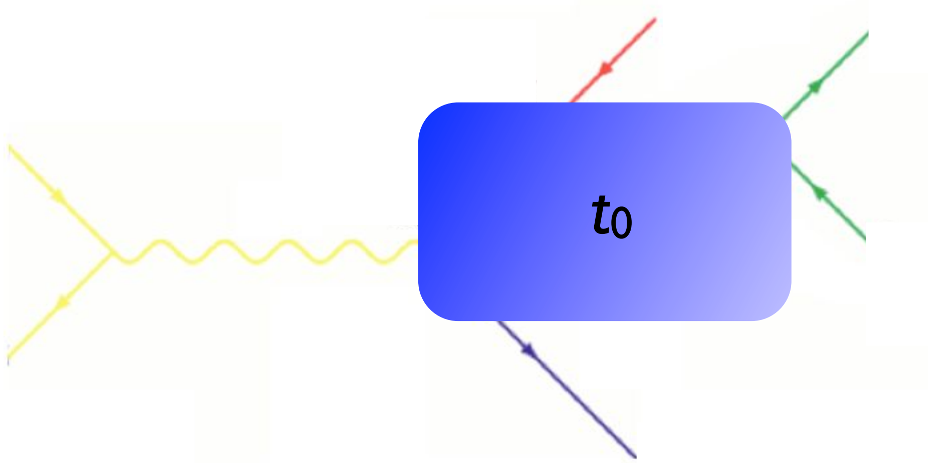
  3. Use some algorithm to apply the equivalent Sudakov suppression $(\Delta_q(t_{\rm cut}, t_0))^2 \Delta_g(t_2, t_1)(\Delta_q({\rm cut}, t_2))^2$

MLM matching

[M.L. Mangano, 2002, 2006]
[J.A. et al 2007, 2008]



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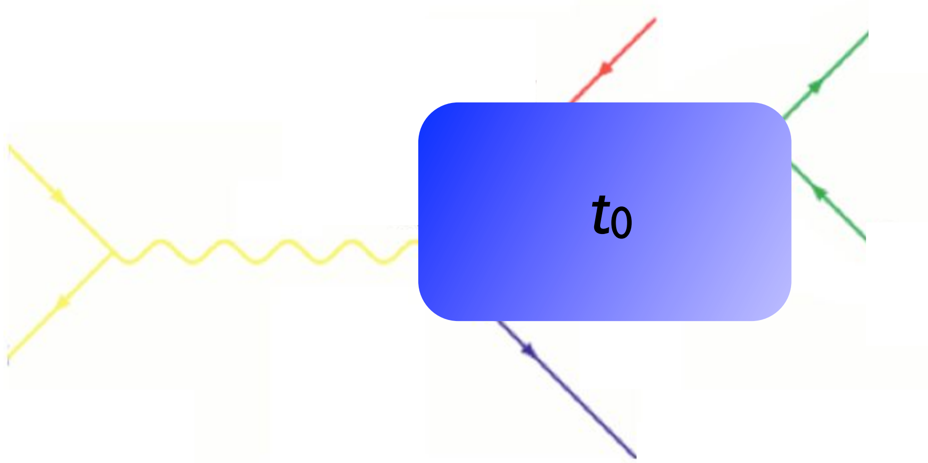
- The simplest way to do the Sudakov suppression is to run the shower on the event, starting from t_0!



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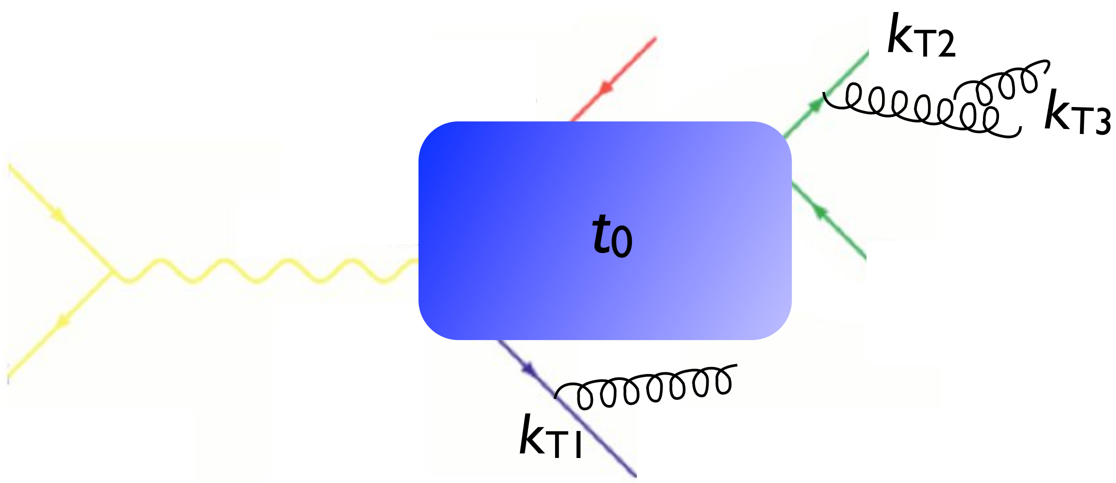

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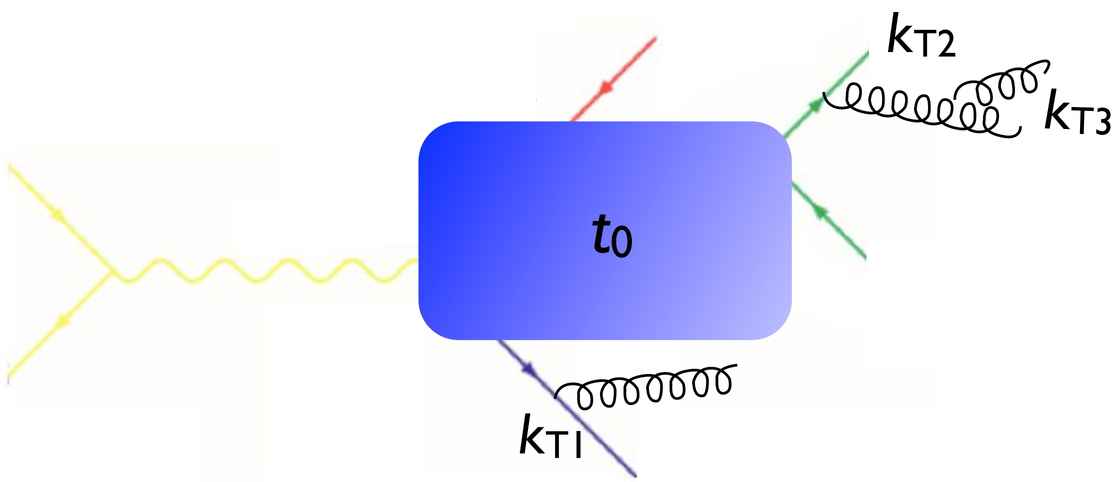

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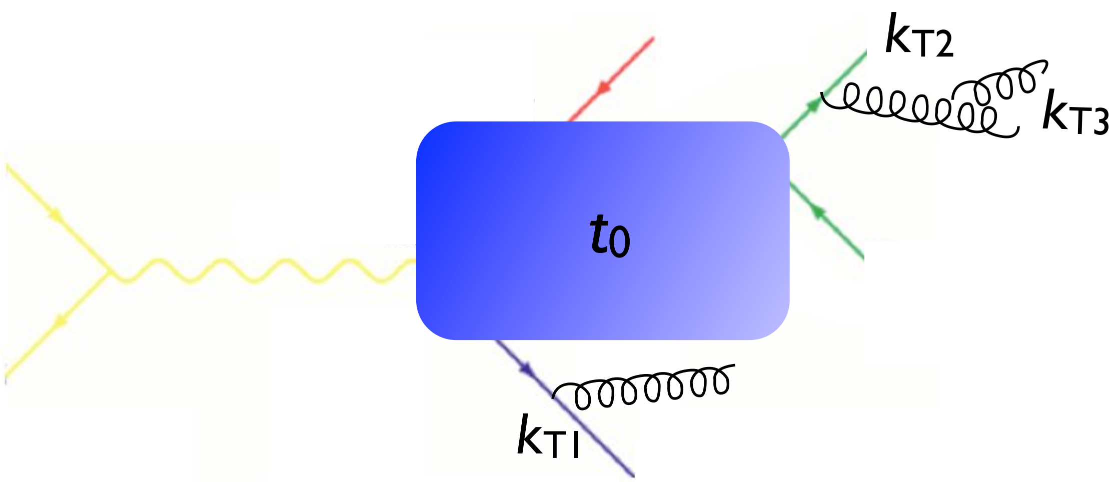

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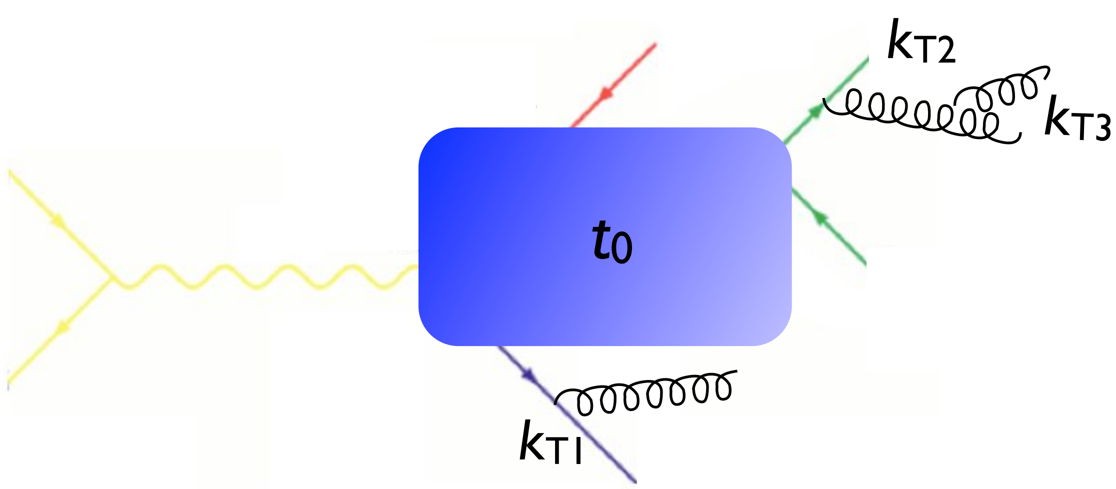

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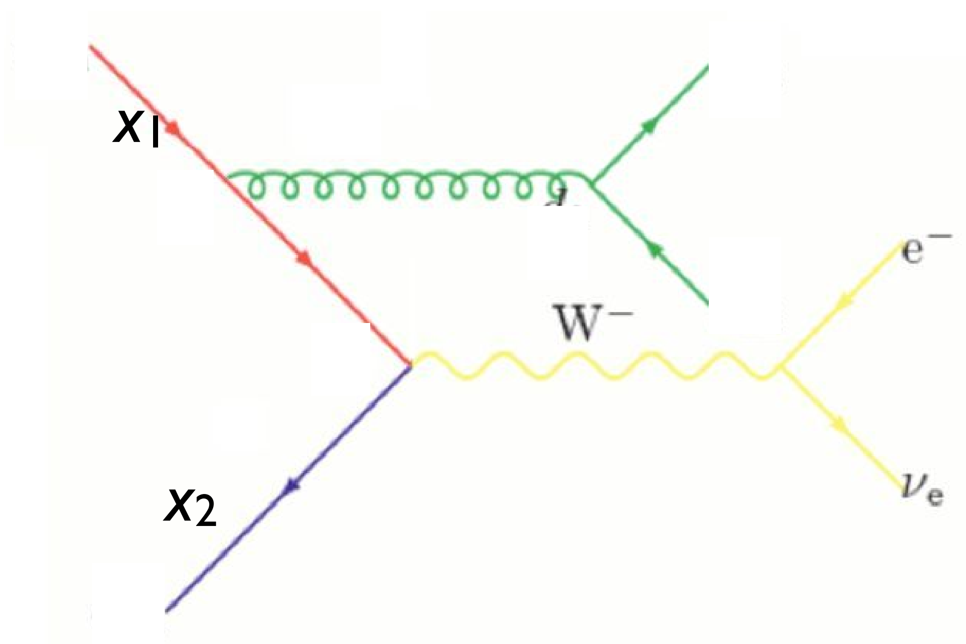
- Allows matching with any shower, without modifications!

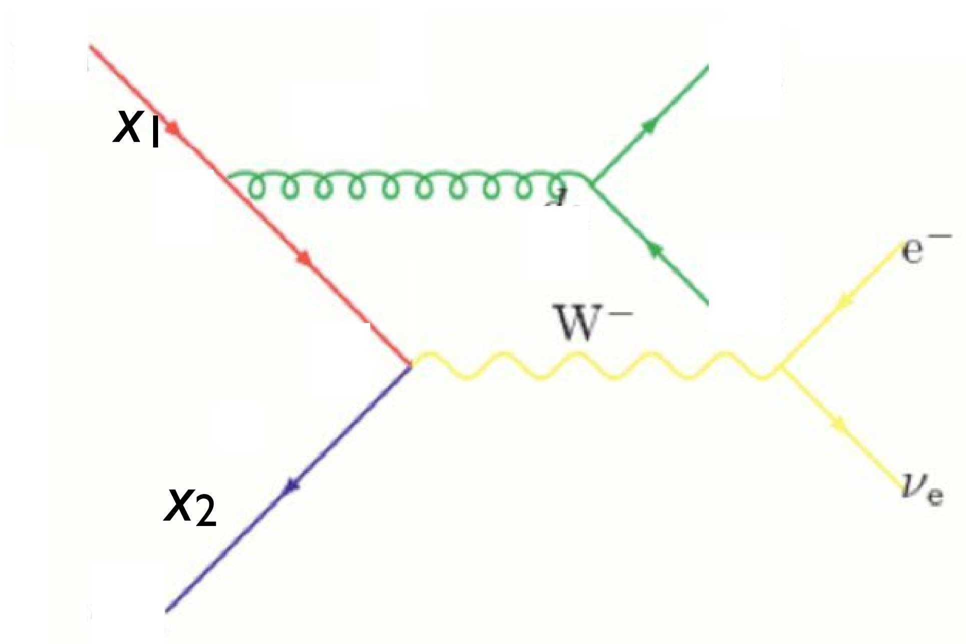
Wednesday, October 26, 2011

MLM matching for initial state radiation



MLM matching for initial state radiation

- We are of course not interested in e^+e^- but p-p(bar) - what happens for initial state radiation?



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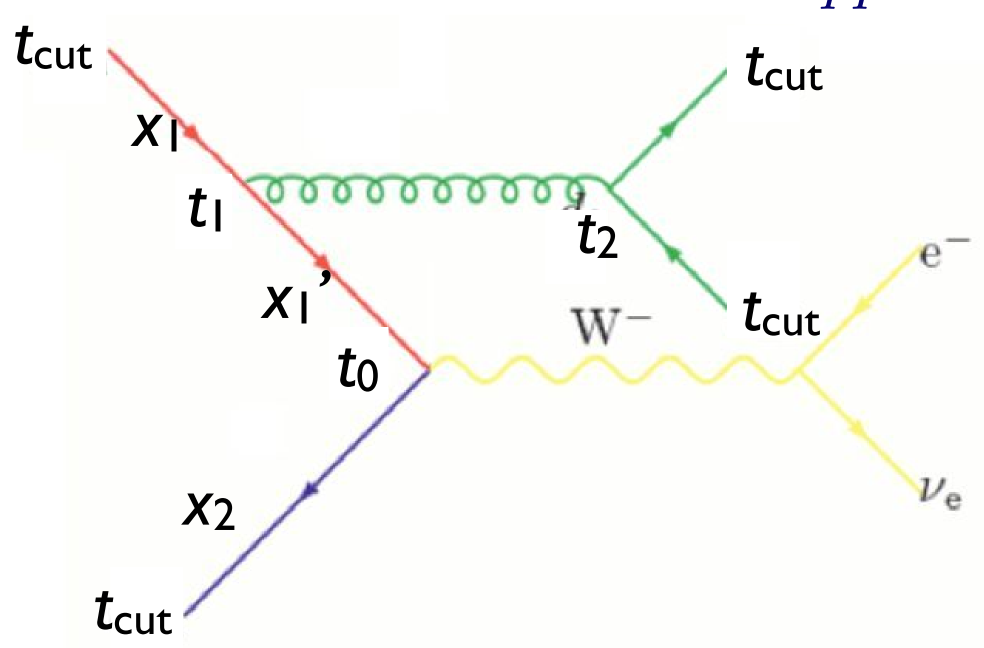

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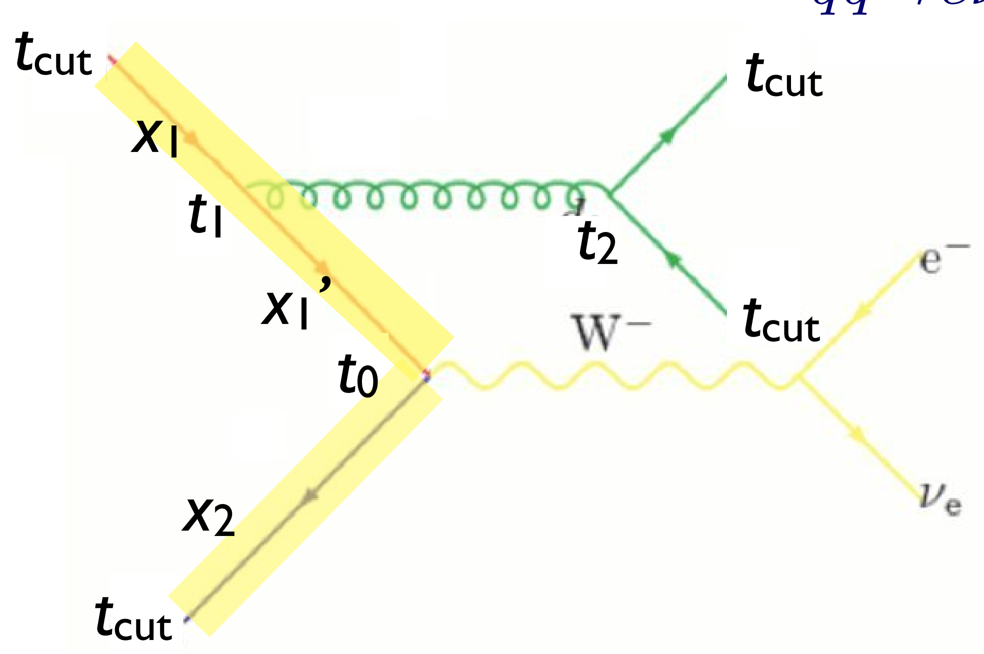

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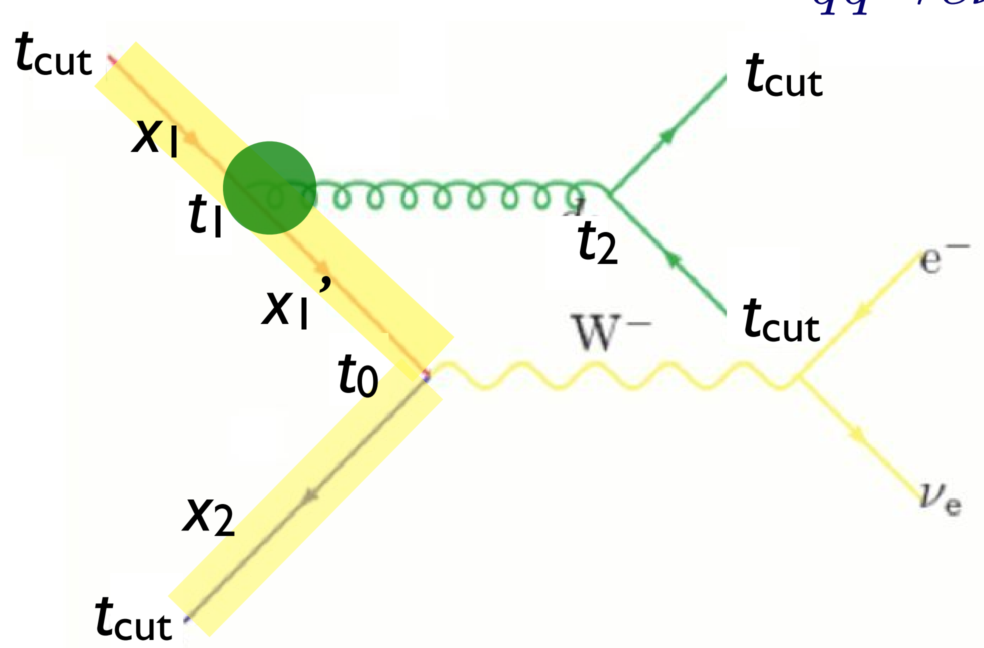

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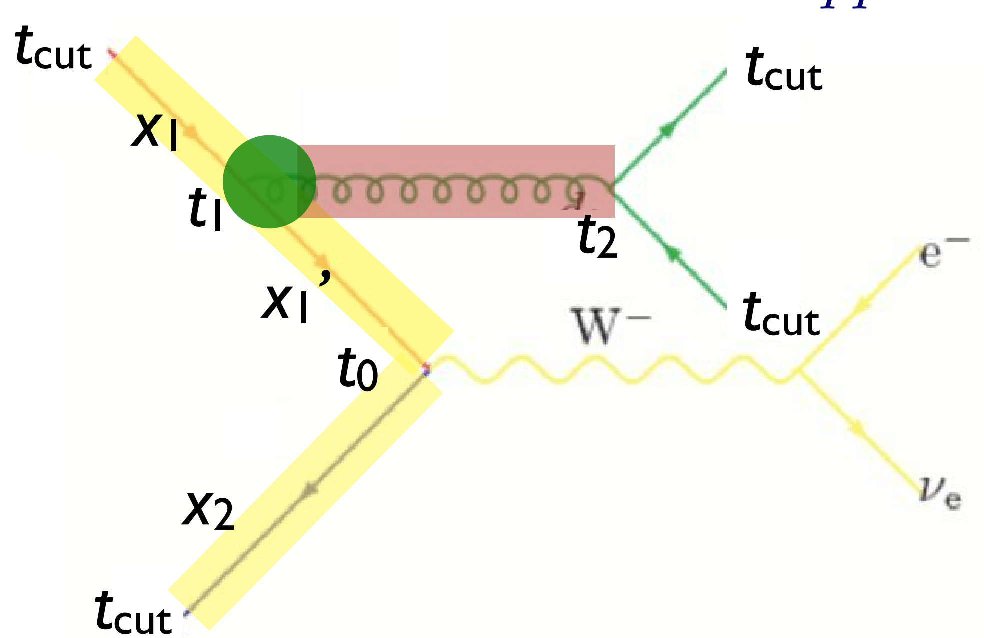

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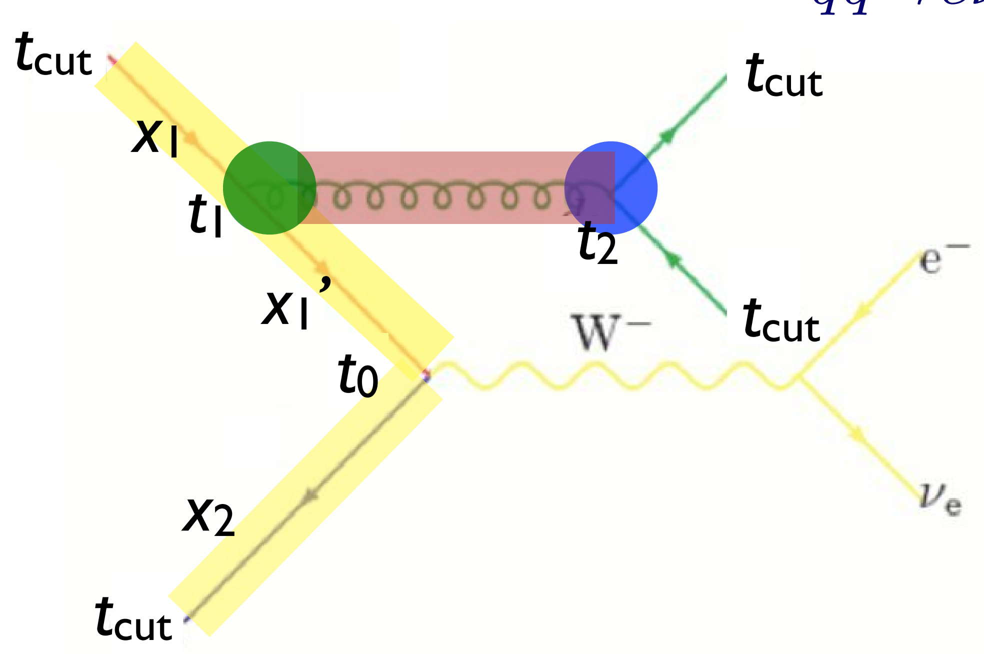

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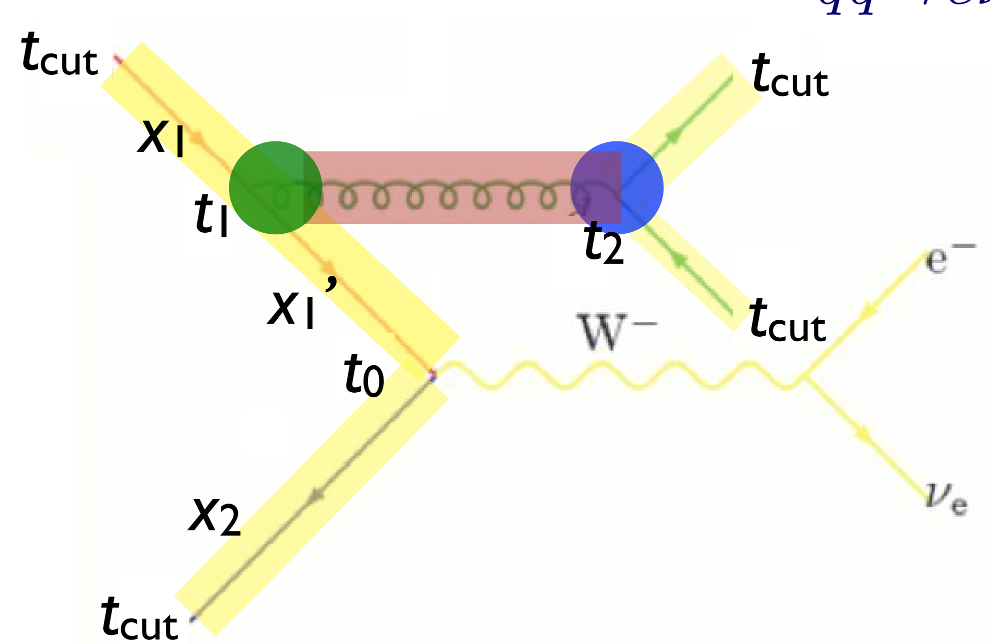

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$$(\Delta_{Iq}(t_{\rm cut},t_0))^2\Delta_g(t_2,t_1)(\Delta_q(t_{\rm cut},t_2))^2\frac{\alpha_s(t_1)}{2\pi}\frac{P_{gq}(z)}{z}\frac{f_q(x_1,t_1)}{f_q(x_1',t_1)}\frac{\alpha_s(t_2)}{2\pi}\frac{P_{qg}(z')}{z'}$$
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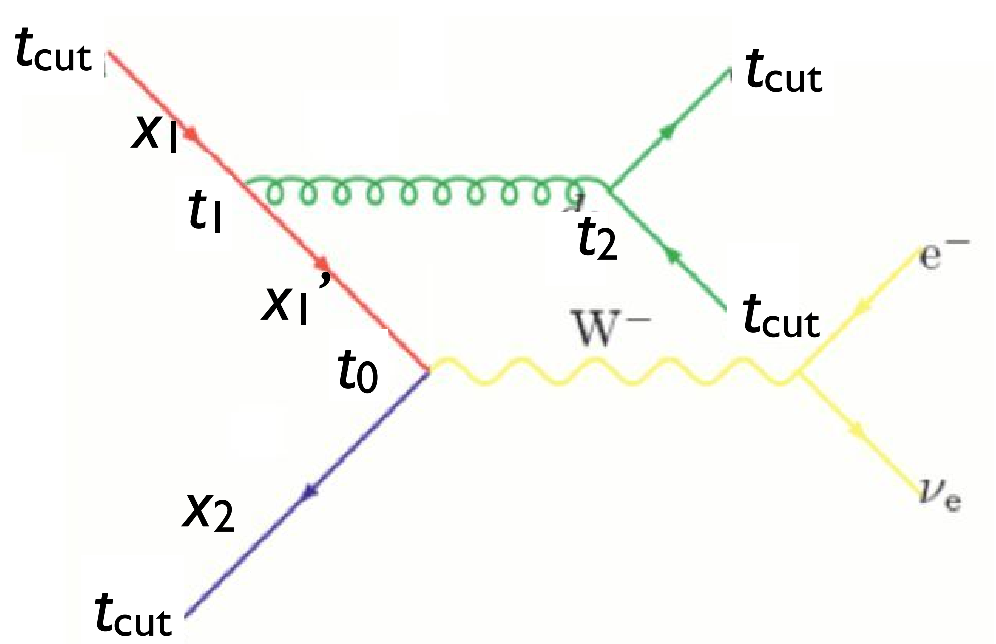
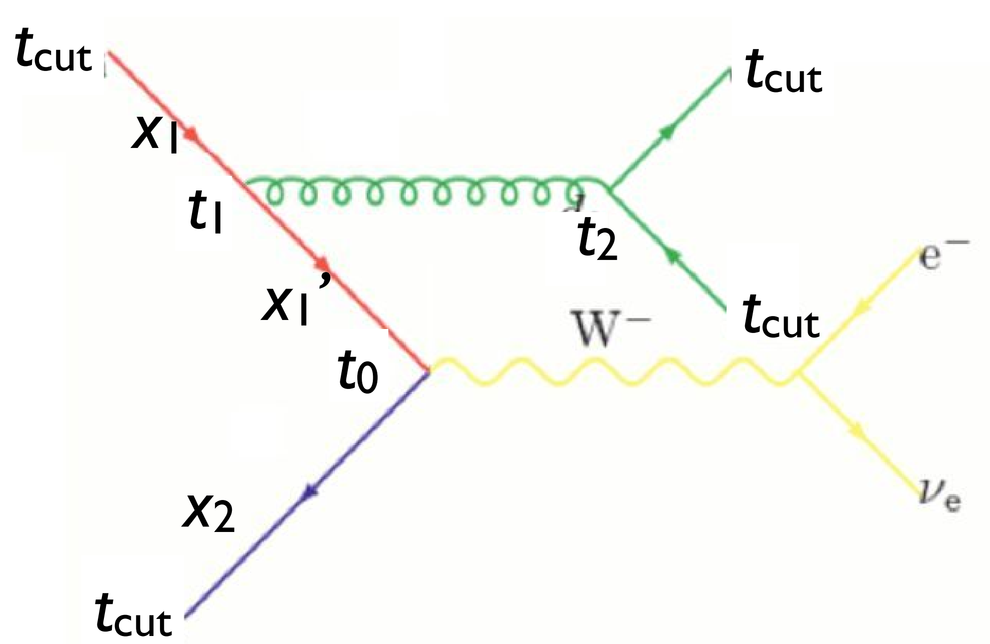


MLM matching for initial state radiation

$$(\Delta_{Iq}(t_{\rm cut},t_0))^2\Delta_g(t_2,t_1)(\Delta_q(t_{\rm cut},t_2))^2\frac{\alpha_s(t_1)}{2\pi}\frac{P_{gq}(z)}{z}\frac{f_q(x_1,t_1)}{f_q(x_1',t_1)}\frac{\alpha_s(t_2)}{2\pi}\frac{P_{qg}(z')}{z'}$$

$$\times\hat\sigma_{q\bar q\to e\nu}(\hat s,\ldots)f_q(x_1',t_0)f_{\bar q}(x_2,t_0)$$

ME with α_s evaluated at the scale of each splitting



MLM matching for initial state radiation

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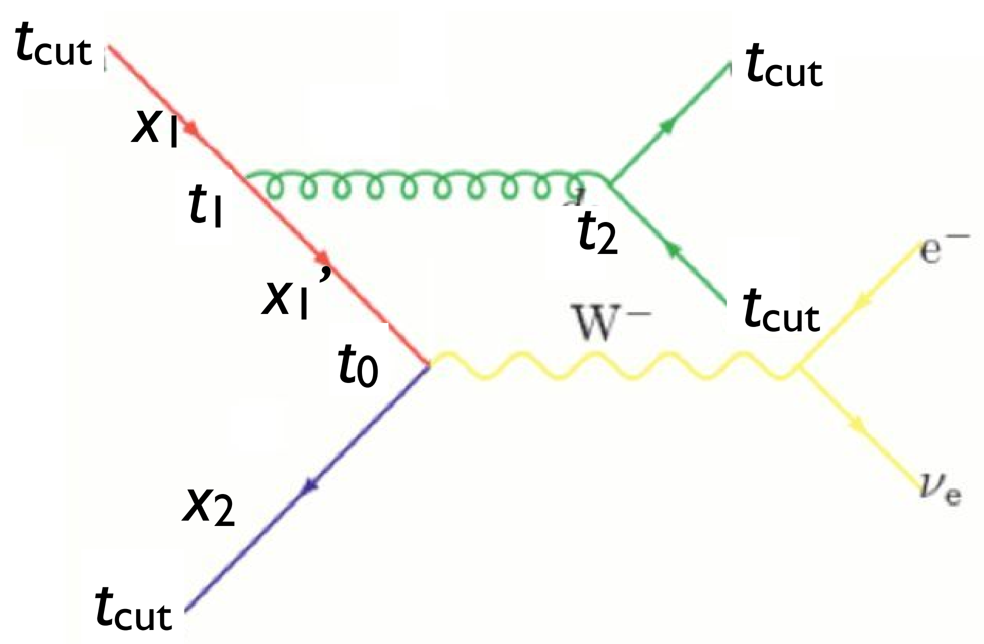
ME with α_s evaluated at the scale of each splitting

PDF reweighting



MLM matching for initial state radiation

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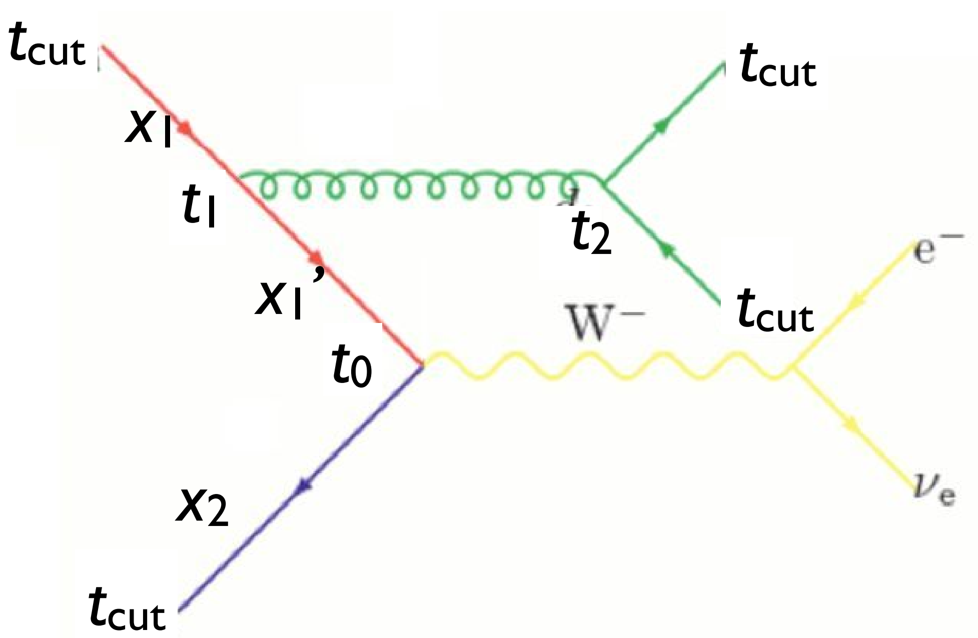
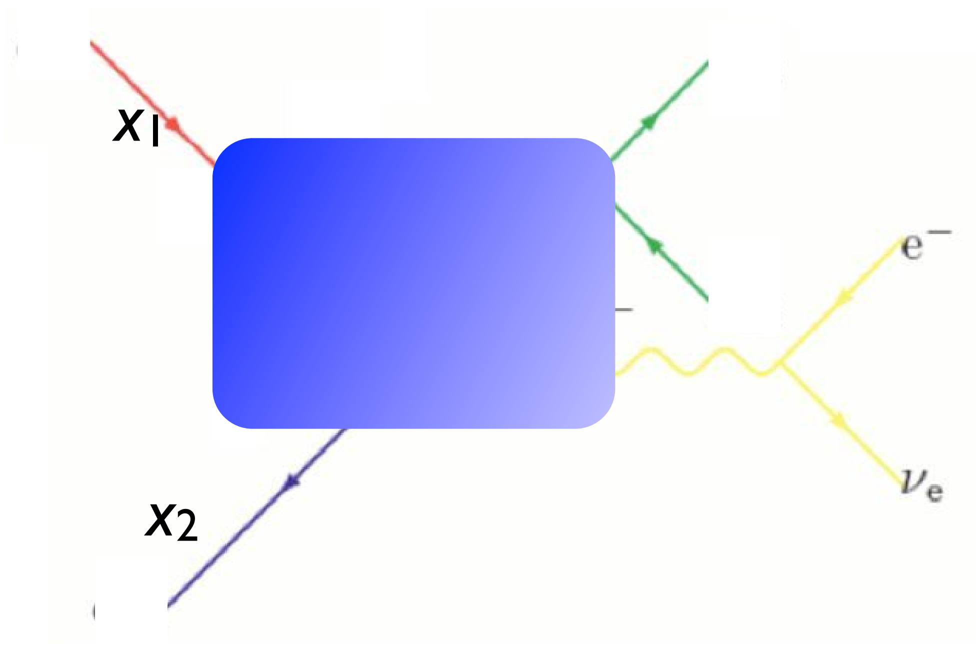
ME with α_s evaluated at the scale of each splitting

PDF reweighting

Sudakov suppression due to non-branching above scale $t_{\rm cut}$

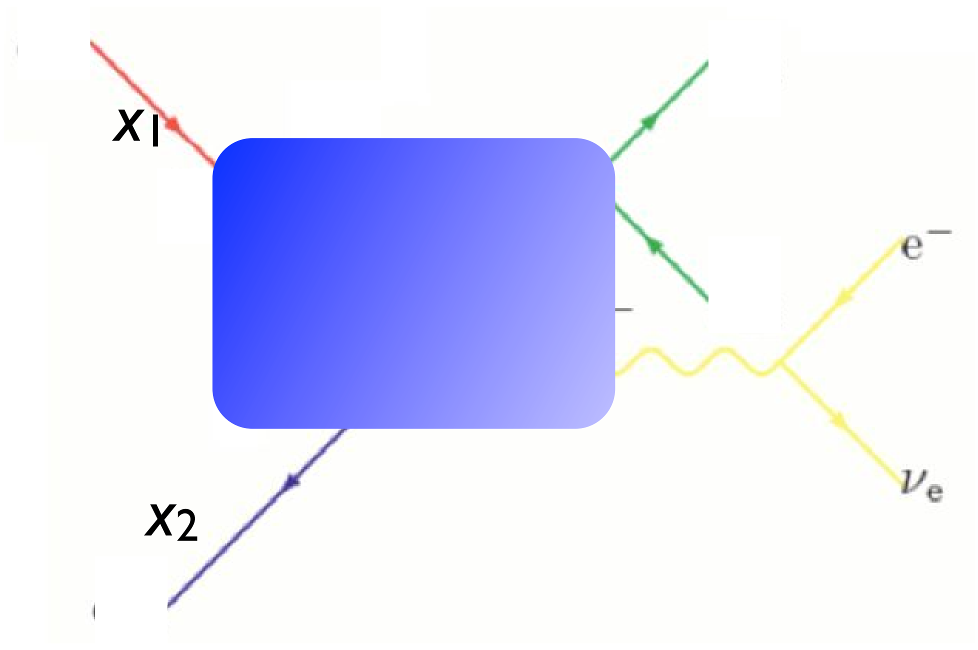


MLM matching for initial state radiation



MLM matching for initial state radiation

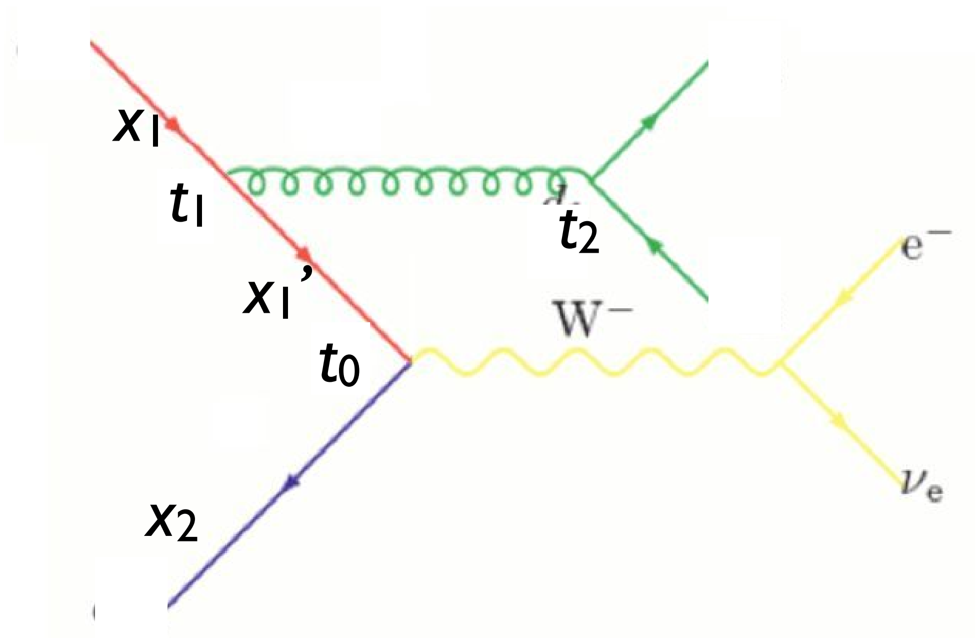
- Again, use a clustering scheme to get a parton shower history, but now reweight both due to α_s and PDF



MLM matching for initial state radiation

- Again, use a clustering scheme to get a parton shower history, but now reweight both due to α_s and PDF

$$|\mathcal{M}|^2 \to |\mathcal{M}|^2 \frac{\alpha_s(t_1)}{\alpha_s(t_0)} \frac{\alpha_s(t_2)}{\alpha_s(t_0)} \frac{f_q(x_1', t_0)}{f_q(x_1', t_1)}$$



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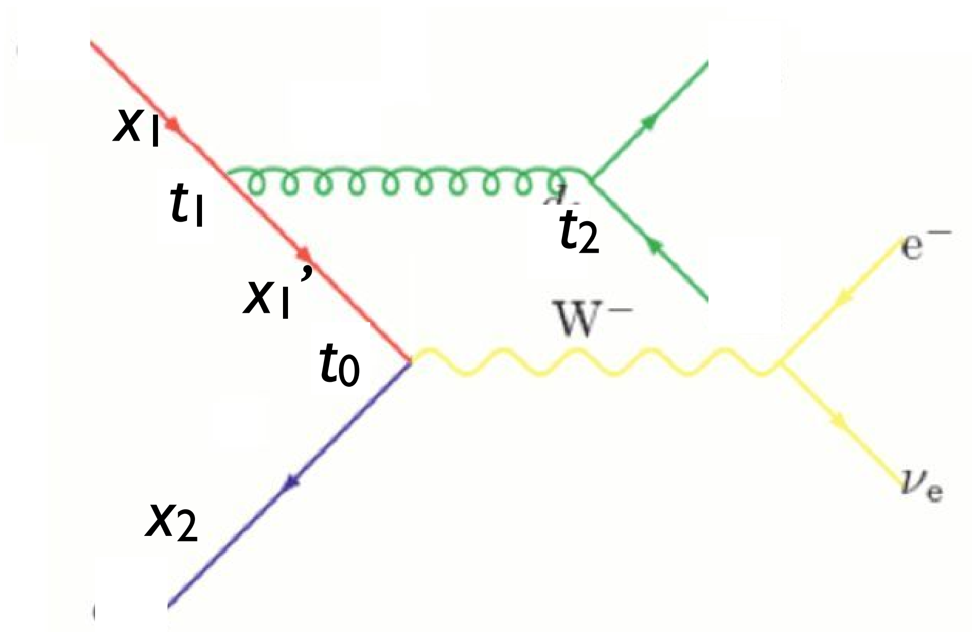
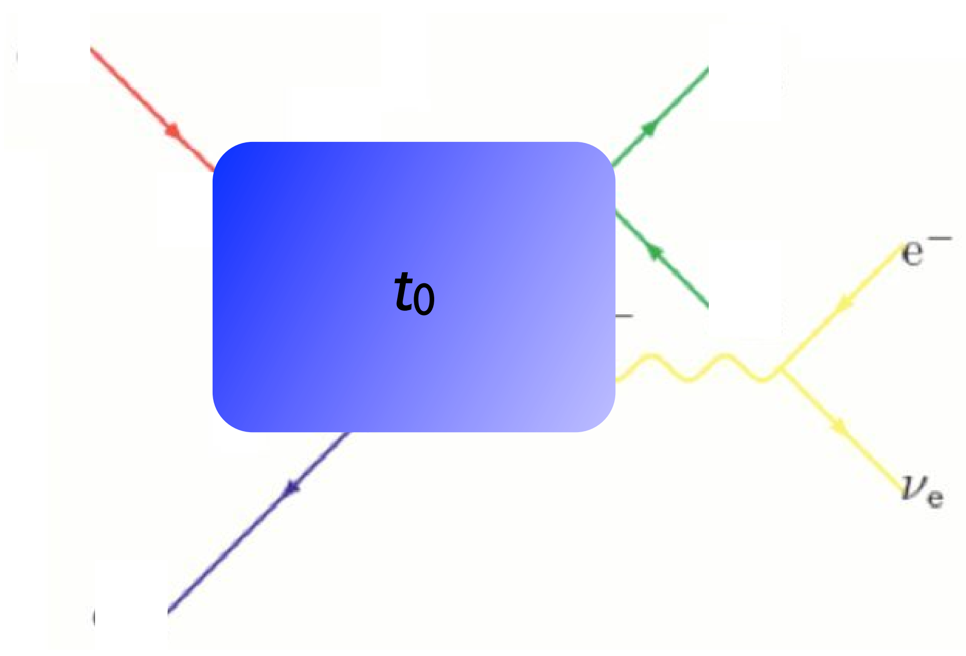
$$|\mathcal{M}|^2 \to |\mathcal{M}|^2 \frac{\alpha_s(t_1)}{\alpha_s(t_0)} \frac{\alpha_s(t_2)}{\alpha_s(t_0)} \frac{f_q(x_1', t_0)}{f_q(x_1', t_1)}$$

- Remember to use first clustering scale on each side for PDF scale: $\mathcal{P}_{\text{event}} = \hat{\sigma}(x_1, x_2, p_3, p_4, \ldots) f_q(x_1, t_1) f_{\bar{q}}(x_2, t_0)$

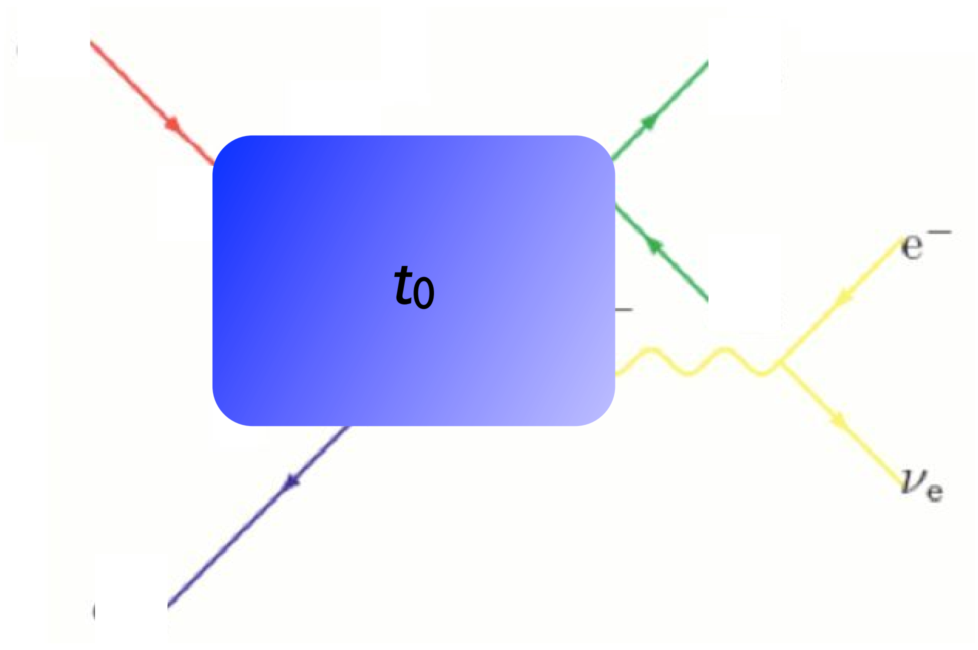


MLM matching for initial state radiation



MLM matching for initial state radiation

- And again, run the shower and then veto events if the hardest shower emission scale $k_{T1} > t_{cut}$



MLM matching for initial state radiation

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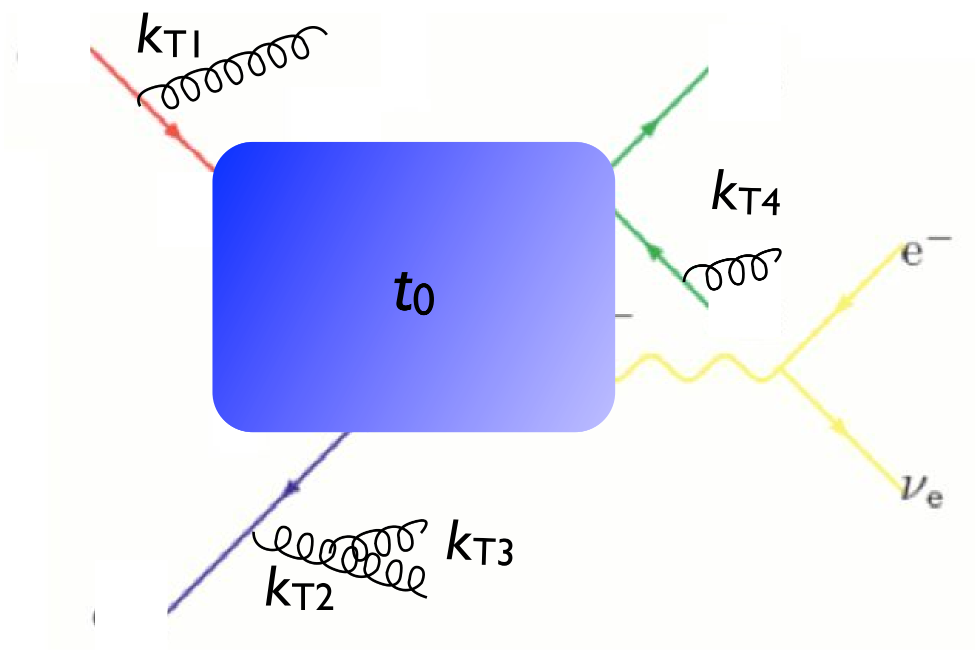
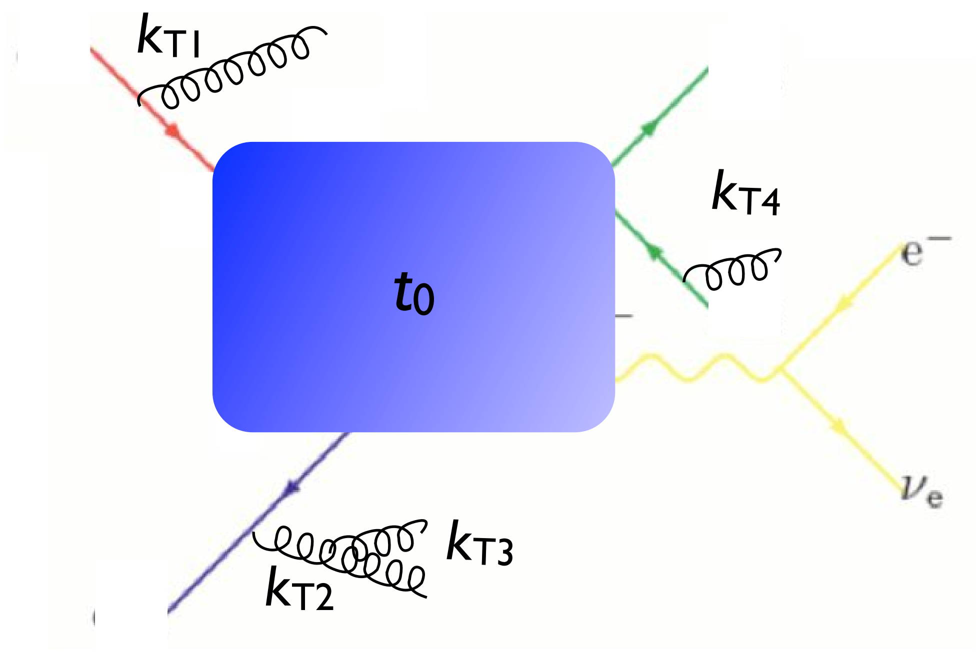


MLM matching for initial state radiation

- And again, run the shower and then veto events if the hardest shower emission scale $k_{T1} > t_{\text{cut}}$
- The resulting Sudakov suppression from the procedure is
$$(\Delta_{Iq}(t_{\text{cut}}, t_0))^2(\Delta_q(t_{\text{cut}}, t_0))^2$$
which again is a good enough approximation of the correct expression $(\Delta_{Iq}(t_{\text{cut}}, t_0))^2\Delta_g(t_2, t_1)(\Delta_q(t_{\text{cut}}, t_2))^2$
(much better than in e+e-, since the main suppression here is from Δ_{Iq})



MLM matching schemes in MadGraph

MLM matching schemes in MadGraph

- We have a number of choices to make in the above procedure. The most important are:
  1. The clustering scheme used to determine the parton shower history of the ME event
  2. What to use for the scale t_0 (factorization scale)
  3. How to divide the phase space between parton showers and matrix elements

MLM matching schemes in MadGraph

- We have a number of choices to make in the above procedure. The most important are:
  1. The clustering scheme used to determine the parton shower history of the ME event
  2. What to use for the scale t_0 (factorization scale)
  3. How to divide the phase space between parton showers and matrix elements
- In MadGraph and the MadGraph-Pythia interface, there are three different schemes implemented:
  a. Cone jet scheme (original MLM scheme from AlpGen)
  b. k_T-jet MLM scheme
  c. "Shower-k_T" scheme

MLM matching schemes in MadGraph

1. The default clustering scheme used inside MadGraph to determine the parton shower history is the Durham k_T scheme. For e^+e^-:

$$k_{Tij}^2 = 2\min(E_i^2, E_j^2)(1 - \cos\theta_{ij})$$

and for hadron collisions, the minimum of:

$$k_{Tibeam} = m_i^2 + p_{Ti}^2 = (E_i + p_{zi})(E_i - p_{zi})$$

and

$$k_{Tij}^2 = \min(p_{Ti}^2, p_{Tj}^2)R_{ij}$$

with $R_{ij} = 2[\cosh(y_i - y_j) - \cos(\phi_i - \phi_j)] \simeq (\Delta y)^2 + (\Delta\phi)^2$

Find the smallest k_{Tij} (or k_{Tibeam}), combine partons *i* and *j* (or *i* and the beam), and continue until you reach a 2 → 2 (or 2 → 1) scattering.

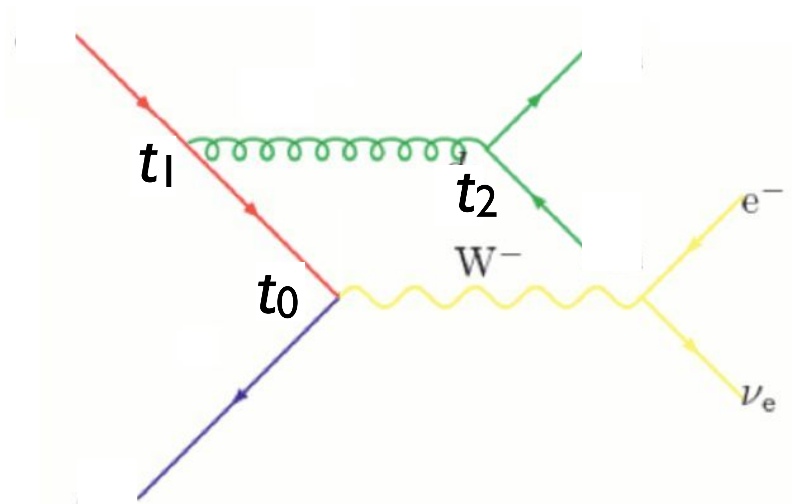
MLM matching schemes in MadGraph

Additional notes:

- MadGraph only allows clustering according to valid diagrams in the process. This means that, e.g., two quarks or quark-antiquark of different flavor are never clustered, and the clustering always gives a physically allowed parton shower history.
- For on-shell s-channel propagators, the clustering value is the invariant mass.
- If there is an on-shell propagator in the diagram, only clustering according to diagrams with this propagator is allowed.

MLM matching schemes in MadGraph

2. The clustering provides a convenient choice for factorization scale t_0:



Cluster back to the 2 → 2 (here $q\bar{q} \to W^- g$) system, and use the W boson transverse mass in that system.

- Special treatment (still beta) for
  - ➡ Processes with final-state b quarks that are considered as heavy particles (the 4-flavor scheme)
  - ➡ Processes with t-channel color singlet exchange, e.g. weak boson fusion processes.

MLM matching schemes in MadGraph

MLM matching schemes in MadGraph

3. How to divide the phase space between PS and ME:
   This is where the different schemes differ!

MLM matching schemes in MadGraph

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   This is where the different schemes differ!
   a. Cone jet MLM scheme:
      - Use cuts in p_T (p_T^{ME})and ΔR between partons in ME
      - Cluster events after parton shower using a cone jet algorithm with the same ΔR and $p_T^{match} > p_T^{ME}$
      - Keep event if all jets are matched to ME partons (i.e., all ME partons are within ΔR of a jet)

MLM matching schemes in MadGraph

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      - Keep event if all jets are matched to ME partons (i.e., all ME partons are within ΔR of a jet)
   b. k_T-jet MLM scheme:
      - Use cut in the Durham k_T in ME
      - Cluster events after parton shower using the same k_T clustering algorithm into k_T jets with $k_T^{match} > k_T^{ME}$
      - Keep event if all jets are matched to ME partons (i.e., all partons are within k_T^{match} to a jet)

MLM matching schemes in MadGraph

3. How to divide the phase space between PS and ME:
   This is where the different schemes differ!

   c. Shower-k_T scheme:
      - Use cut in the Durham k_T in ME
      - After parton shower, get information from the PS generator about the k_T^{PS} of the hardest shower emission
      - Keep event if $k_T^{PS} < k_T^{match}$

Summary of MLM algorithm

1. Generate ME events (with different parton multiplicities) using parton-level cuts ($p_T^{ME}/\Delta R$ or k_T^{ME})
2. Cluster each event and reweight α_s and PDFs based on the scales in the clustering vertices
3. Run the parton shower with starting scale $t_0 = m_T$.
4. Check that the number of jets after parton shower is the same as ME partons, and that all jets after parton shower are matched to the ME partons (using one of the schemes in the last slides) at a scale Q^{match}. If yes, keep the event. If no, reject the event. Q^{match} is called the *matching scale*.

One more subtlety: the highest multiplicity sample

Highest multiplicity sample

- For the highest jet multiplicity that we generate with the matrix element, we need to allow additional jets above the matching scale Q^{match}., since we will otherwise not get a jet-inclusive description.
- However, we need to reject events with additional jets above the scale of the softest ME parton to avoid double counting.
- For the k_T MLM and shower-kT schemes, the clustering scales of the ME partons are communicated to Pythia using an additional line in the LHE event file written by MadEvent.

How to do matching in MadGraph+Pythia

Example: Simulation of pp→W with 0, 1, 2 jets (comfortable on a laptop!)

```
mg5> generate p p > w+, w+ > l+ vl @0
mg5> add process p p > w+ j, w+ > l+ vl @1
mg5> add process p p > w+ j j, w+ > l+ vl @2
mg5> output
```

```
In run_card.dat:
…
  1 = ickkw        <- Matching on
…
  0 = ptj          <- No cone matching
…
 15 = xqcut        <- kT matching scale
```

Matching on

No cone matching

k_T matching scale

Matching automatically done when run through MadEvent and Pythia!

How to do matching in MadGraph+Pythia

- By default, k_T-MLM matching is run if xqcut > 0, with the matching scale QCUT = max(xqcut*1.4, xqcut+10)
- For shower-kT, by default QCUT = xqcut
- If you want to change the Pythia setting for matching scale or switch to shower-k_T matching:

```
In pythia_card.dat:
…
! This sets the matching scale, needs to be > xqcut
QCUT = 30
! This switches from kT-MLM to shower-kT matching
! Note that MSTP(81)>=20 needed (pT-ordered shower)
SHOWERKT = T
```

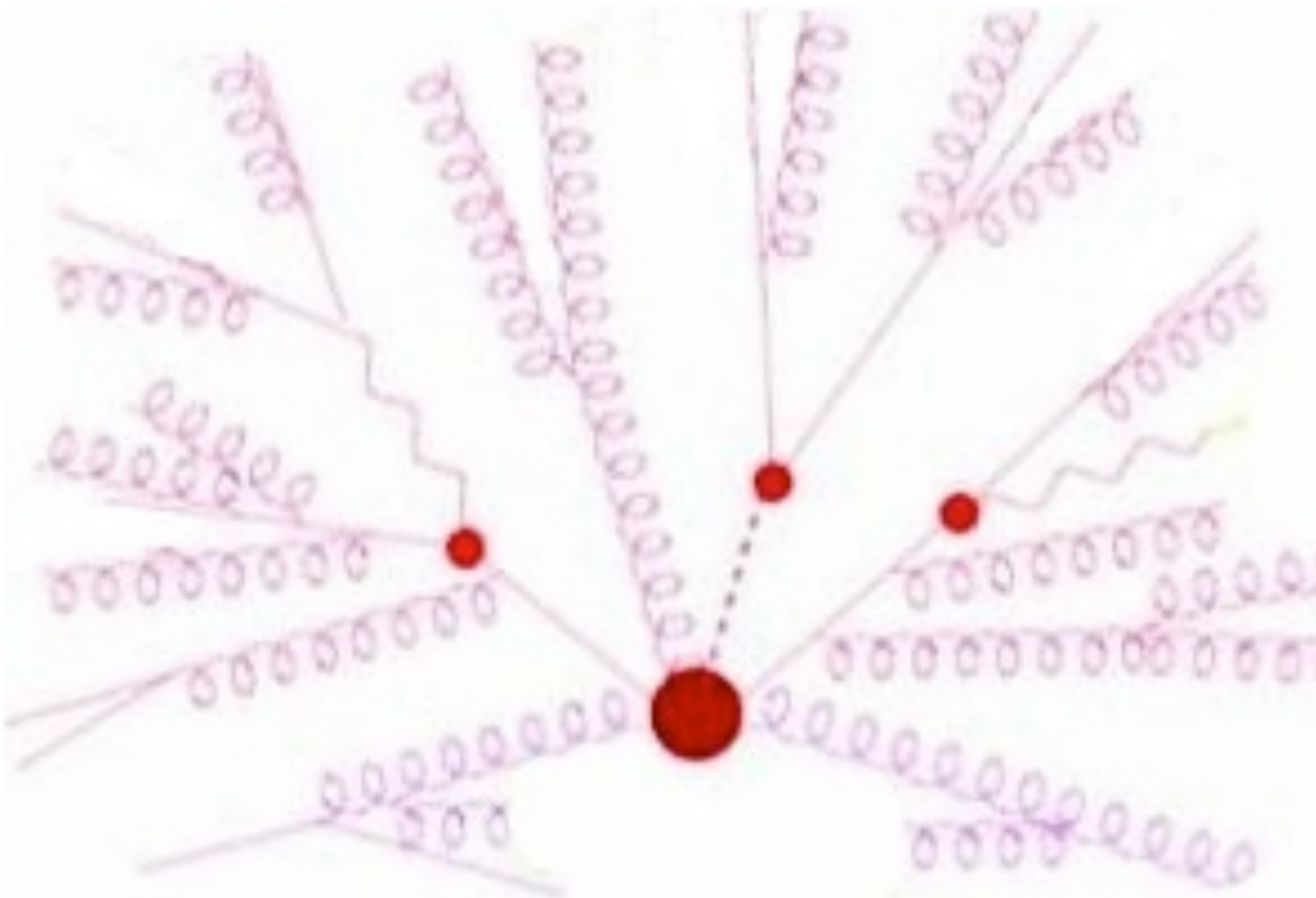
How to do validate the matching

- The matched cross section is found at the end of the Pythia log file
- The matched cross section (for X+0,1,... jets) should be close to the unmatched cross section for the 0-jet sample
- The matching scale (QCUT) should typically be chosen around 1/6-1/3 x hard scale (so xqcut correspondingly lower)
- The differential jet rate plots should be smooth
- When QCUT is varied (within the region of validity), the matched cross section should not vary significantly

"Differential jet rate plots"?

- The "differential jet rates" are simply the clustering scales in k_T jet clustering
- The $0 \rightarrow 1$ diff. jet rate (DJR1) is the p_T of the last remaining jet after clustering
- The $1 \rightarrow 2$ diff. jet rate (DJR2) is the smallest of the p_T of the 2nd last remaining jet and the k_T between the 2nd jet and the 1st jet
- Note that only radiated jets (not jets from decays) are included in the jet rate plots

"Differential jet rate plots"?



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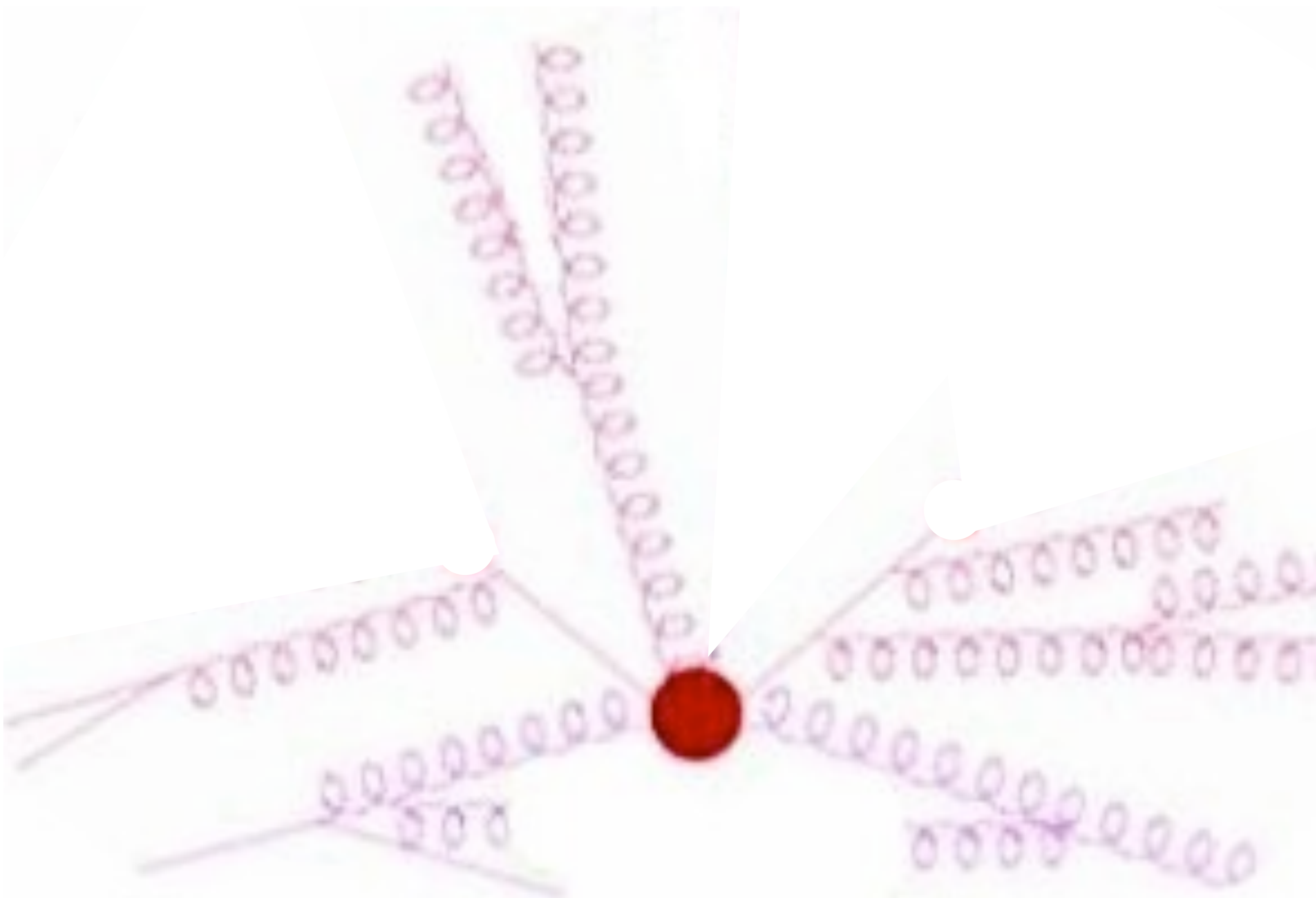

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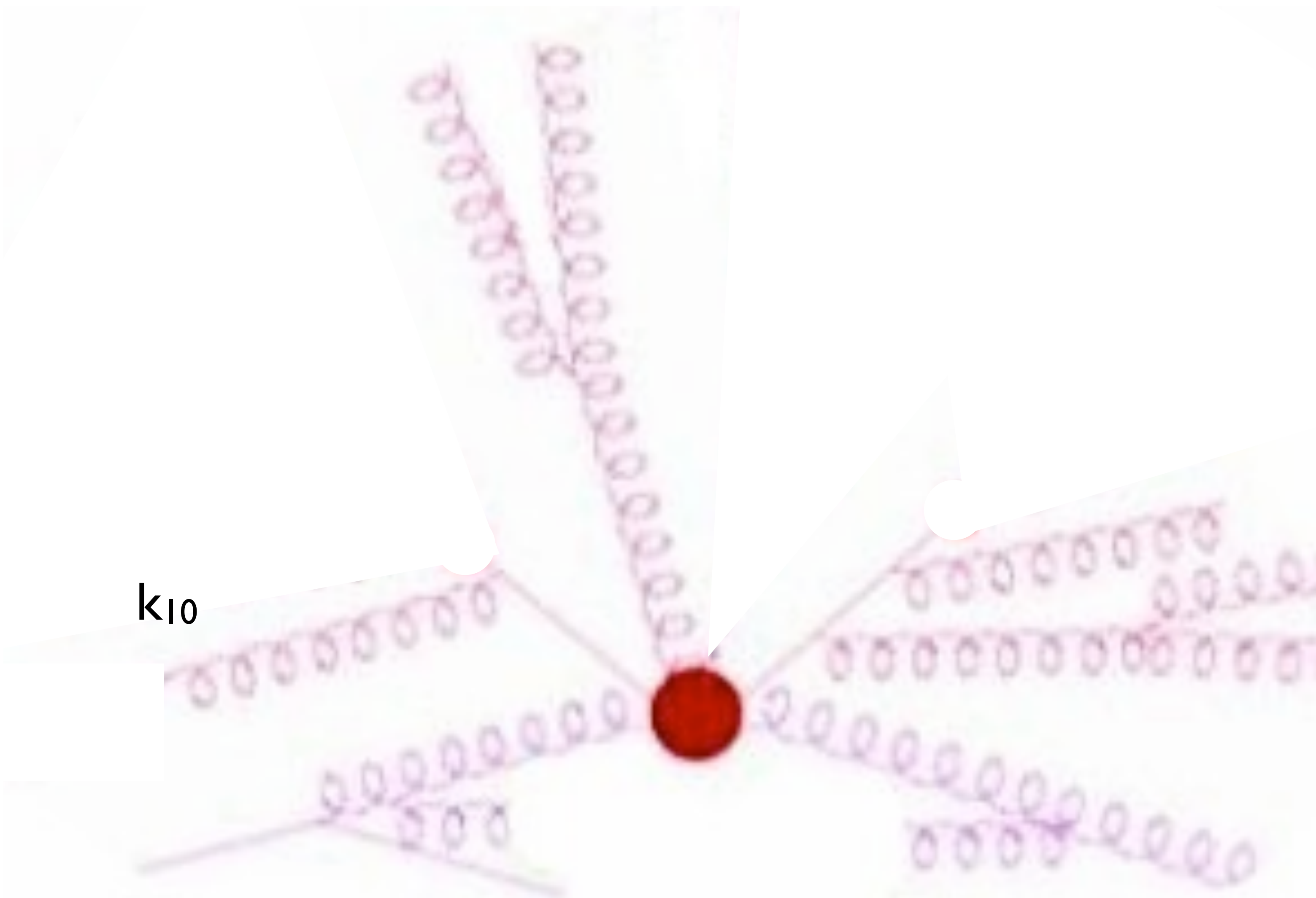

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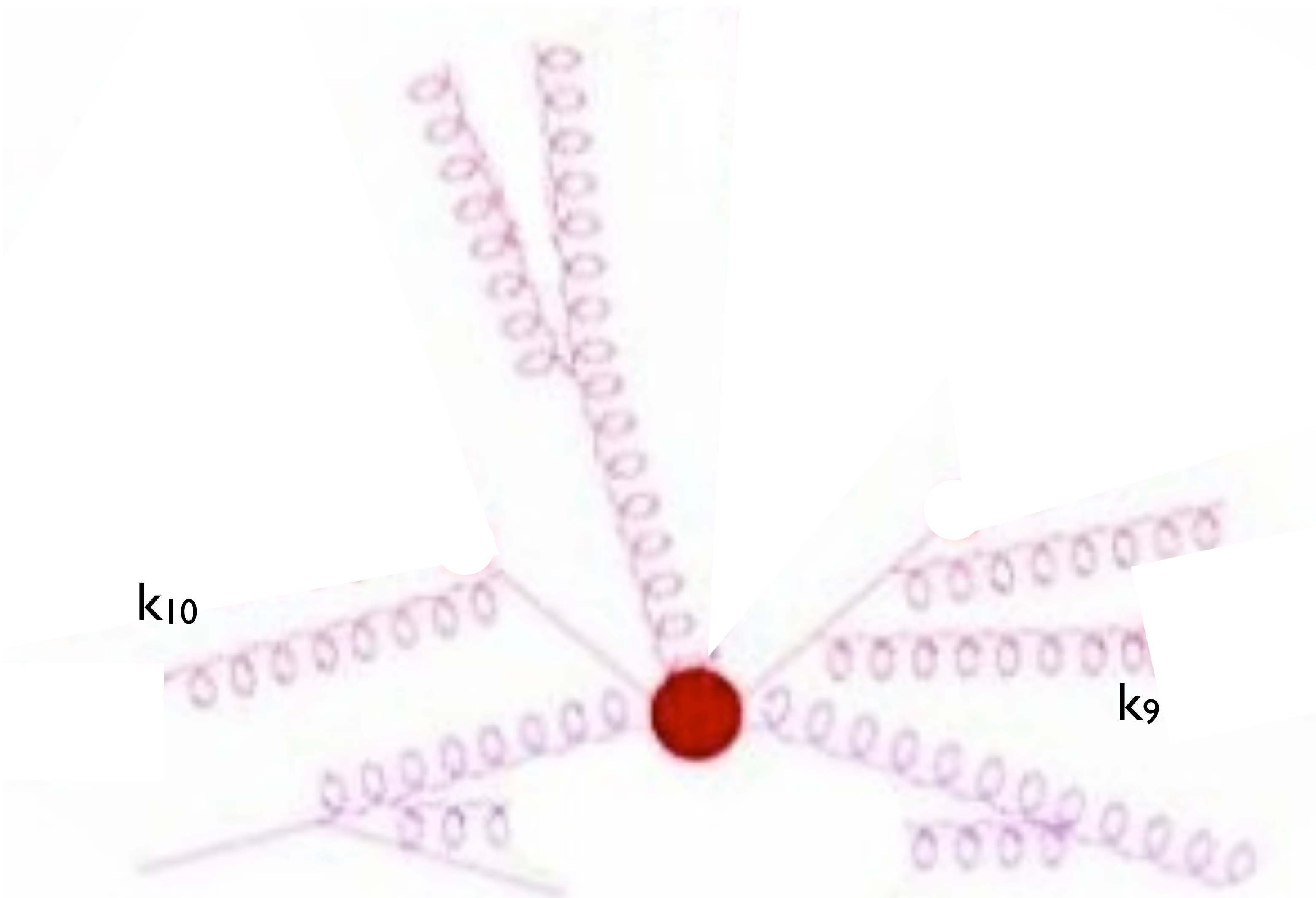

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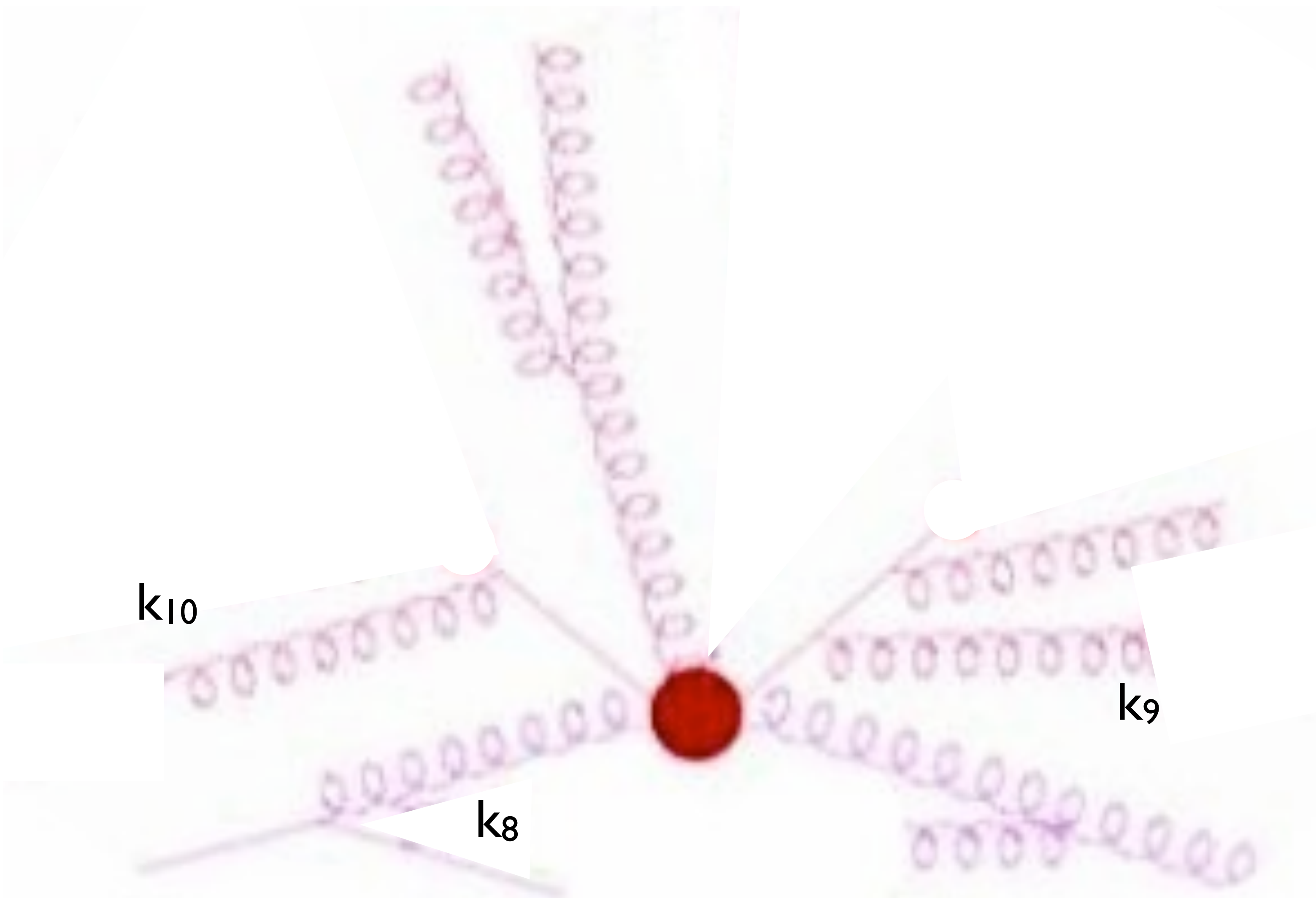

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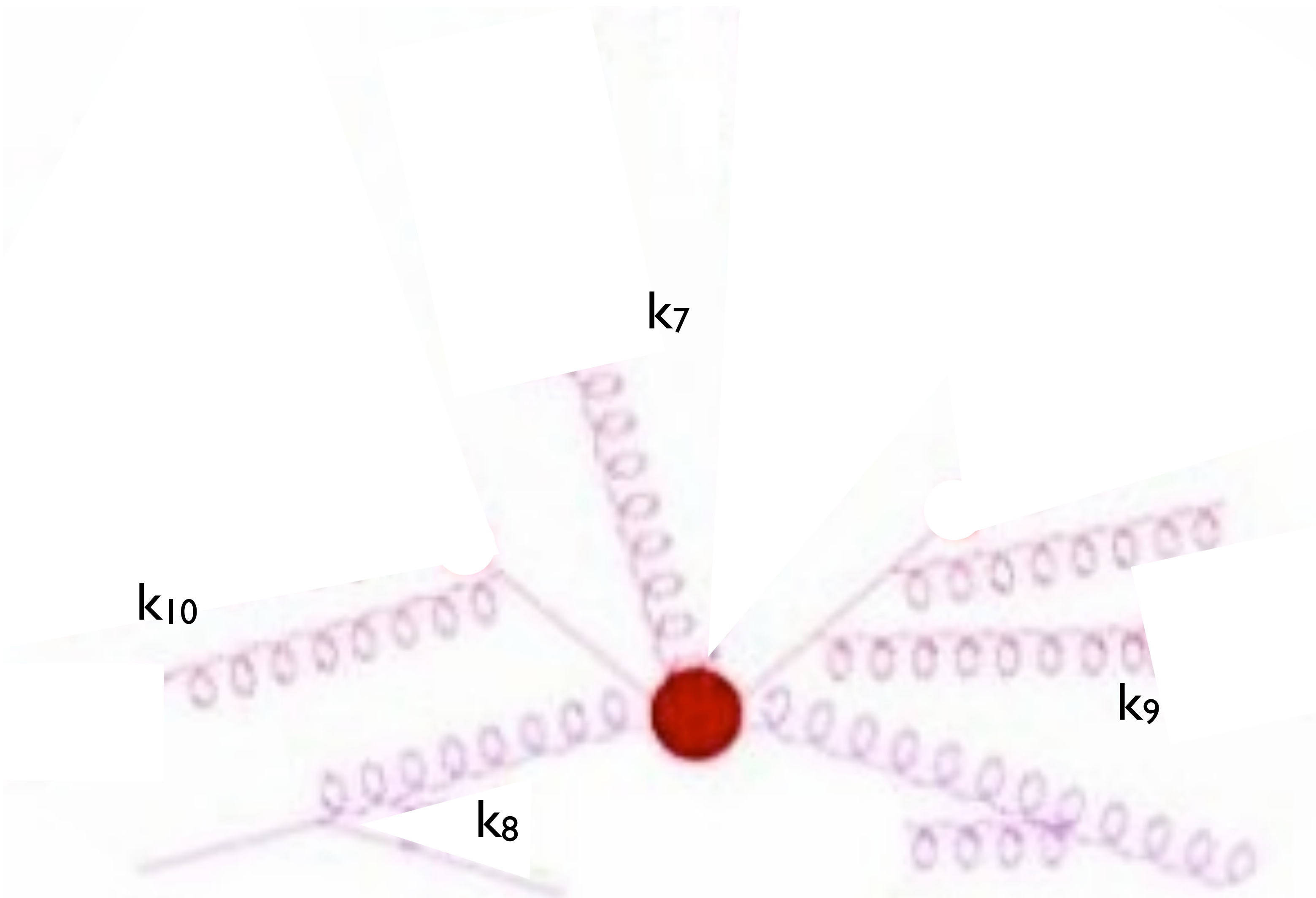

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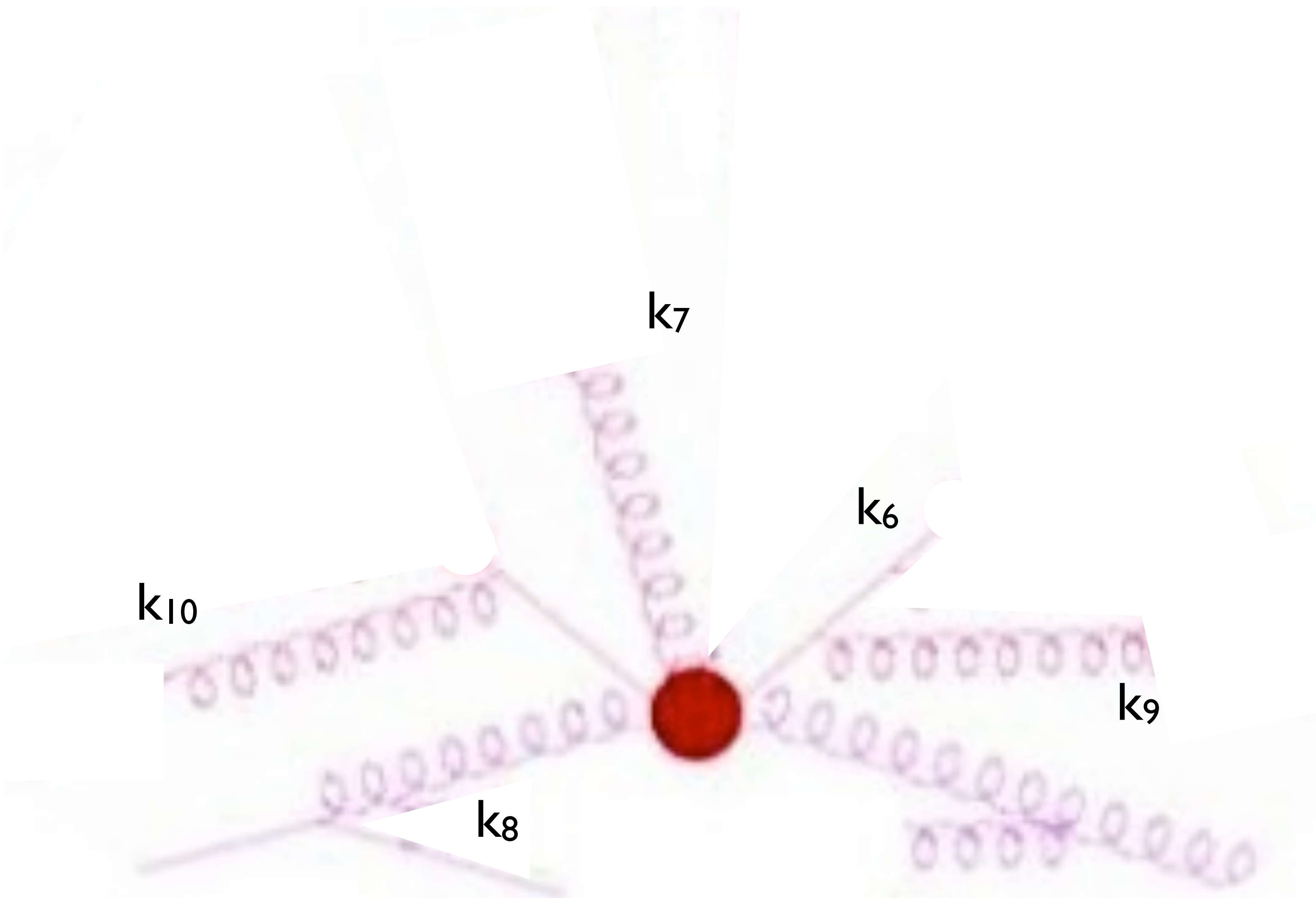

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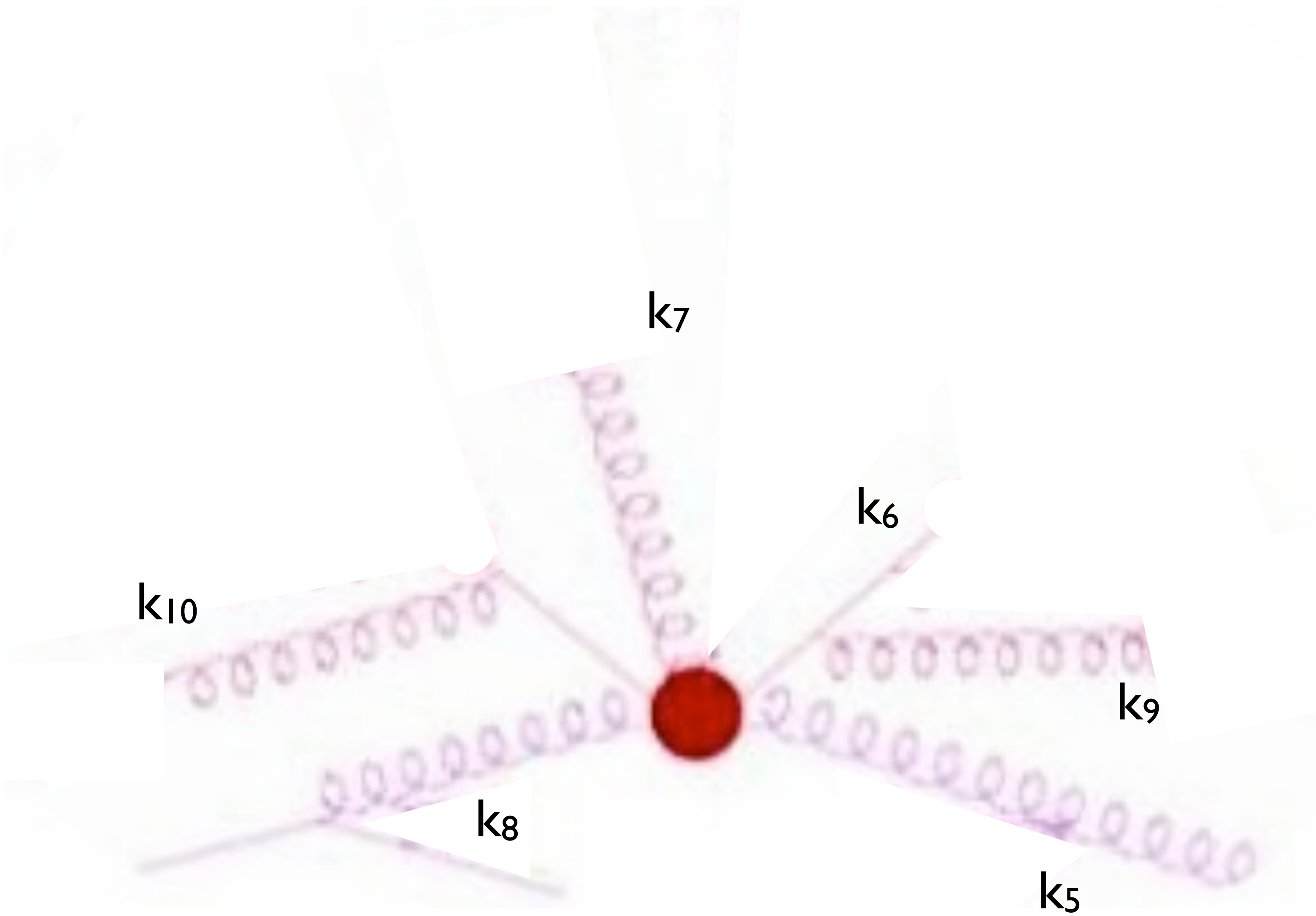

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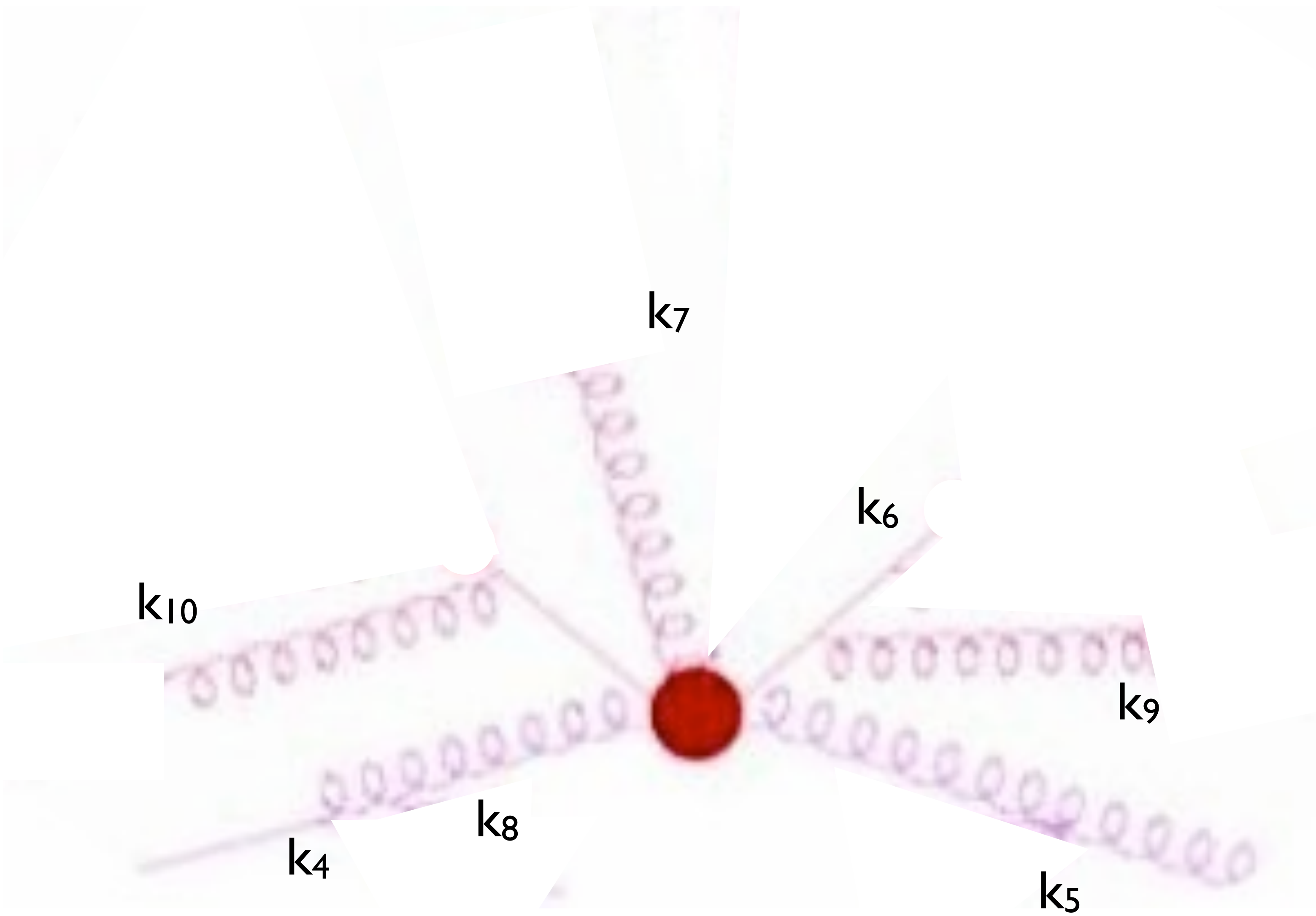

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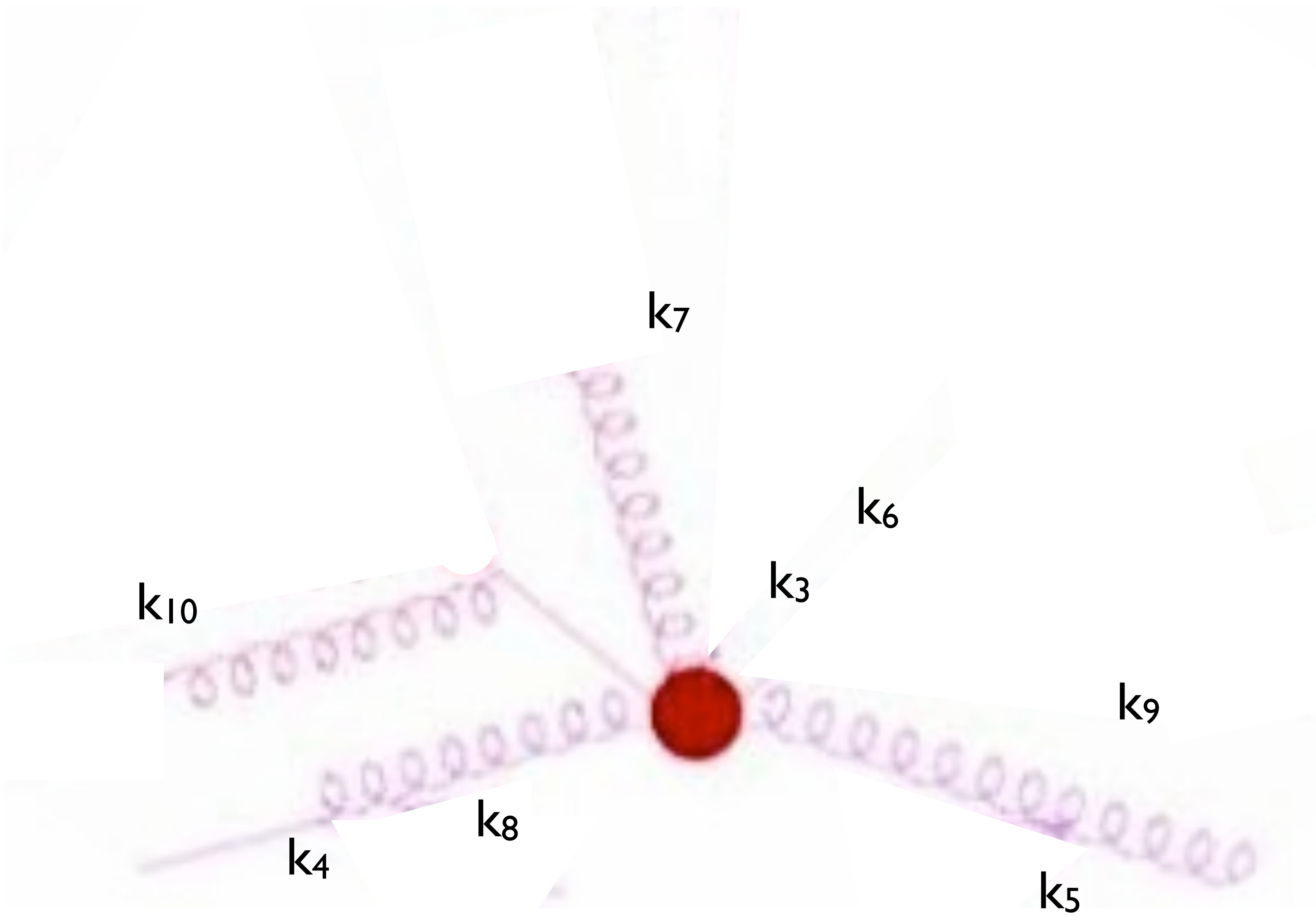

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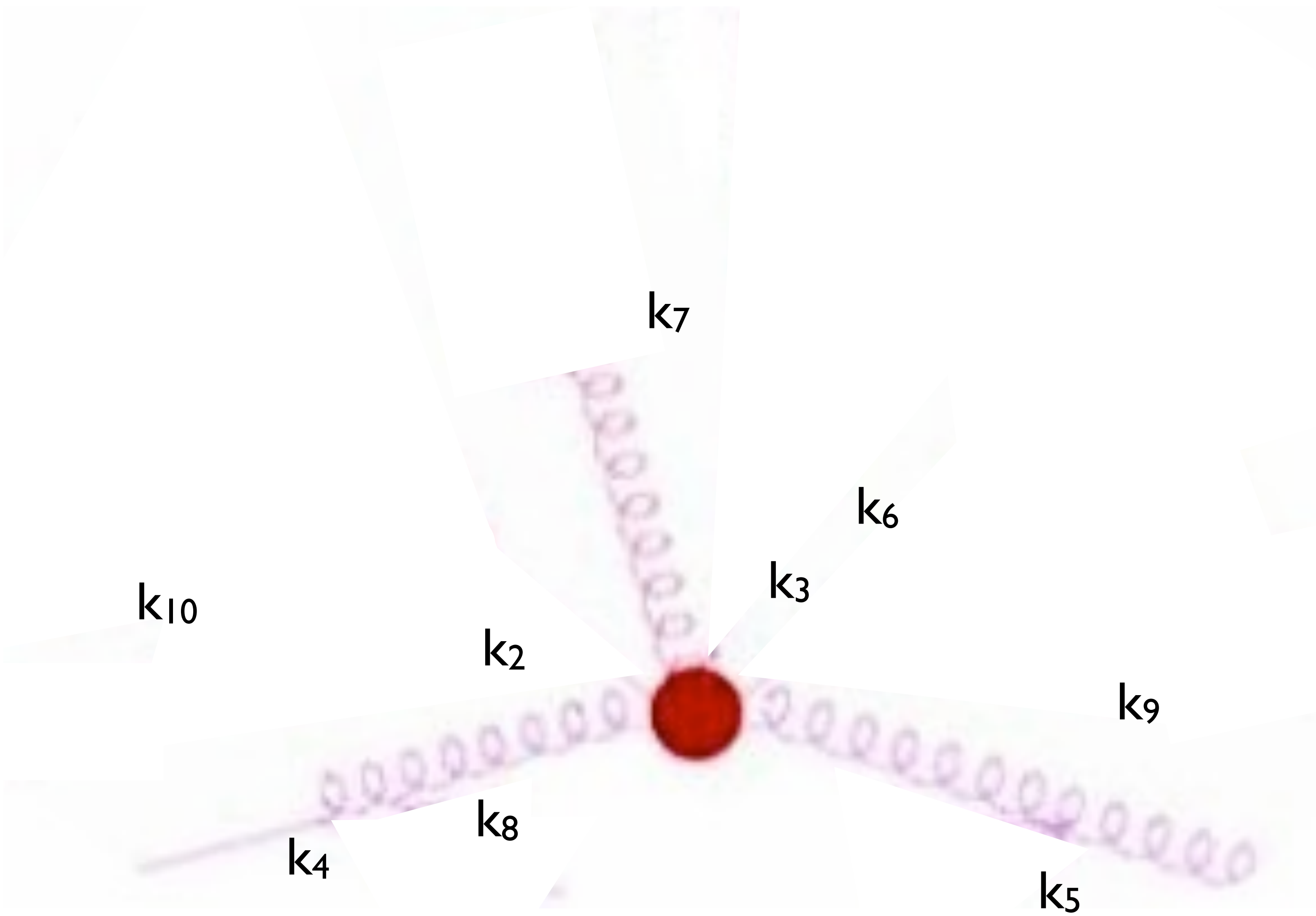

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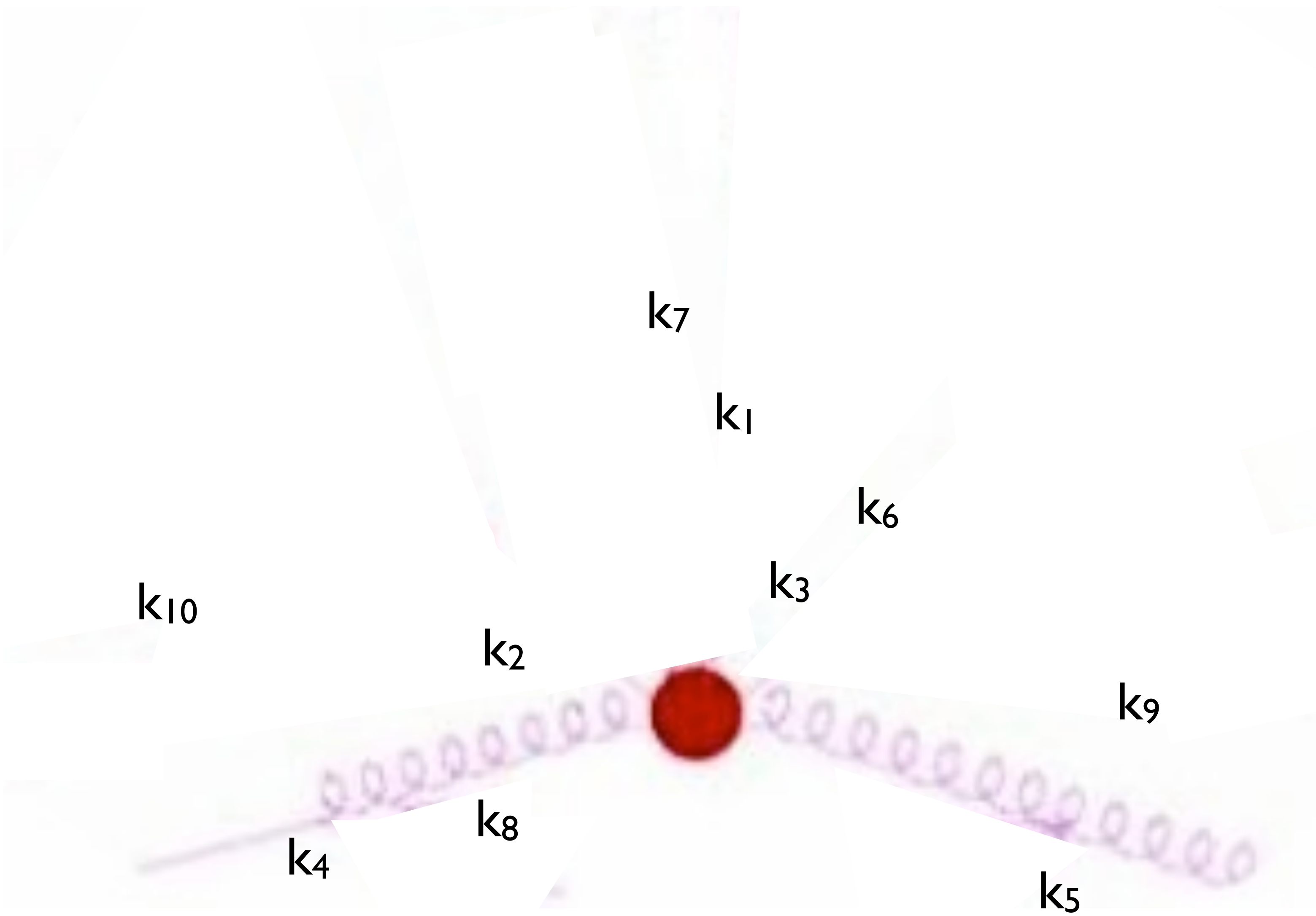
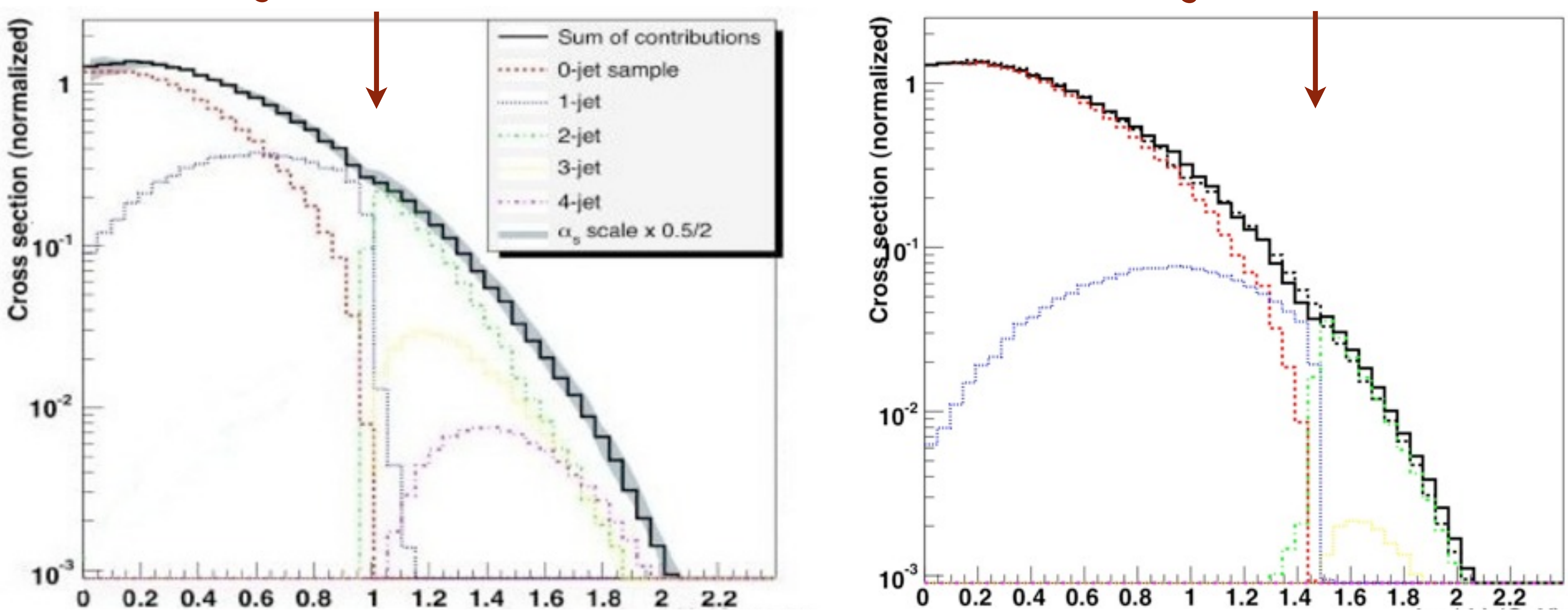


Matching results

W+jets production at the Tevatron for MadGraph+Pythia (kT-jet MLM scheme)

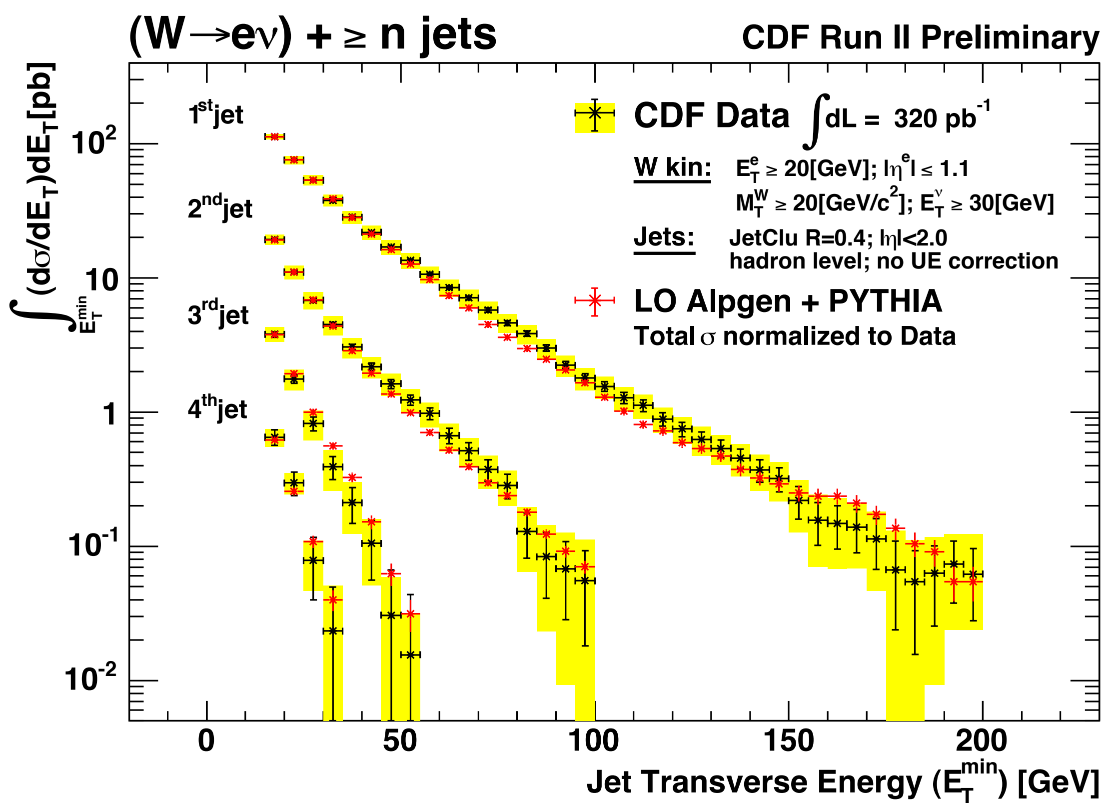
Q^{match} = 10 GeV Q^{match} = 30 GeV

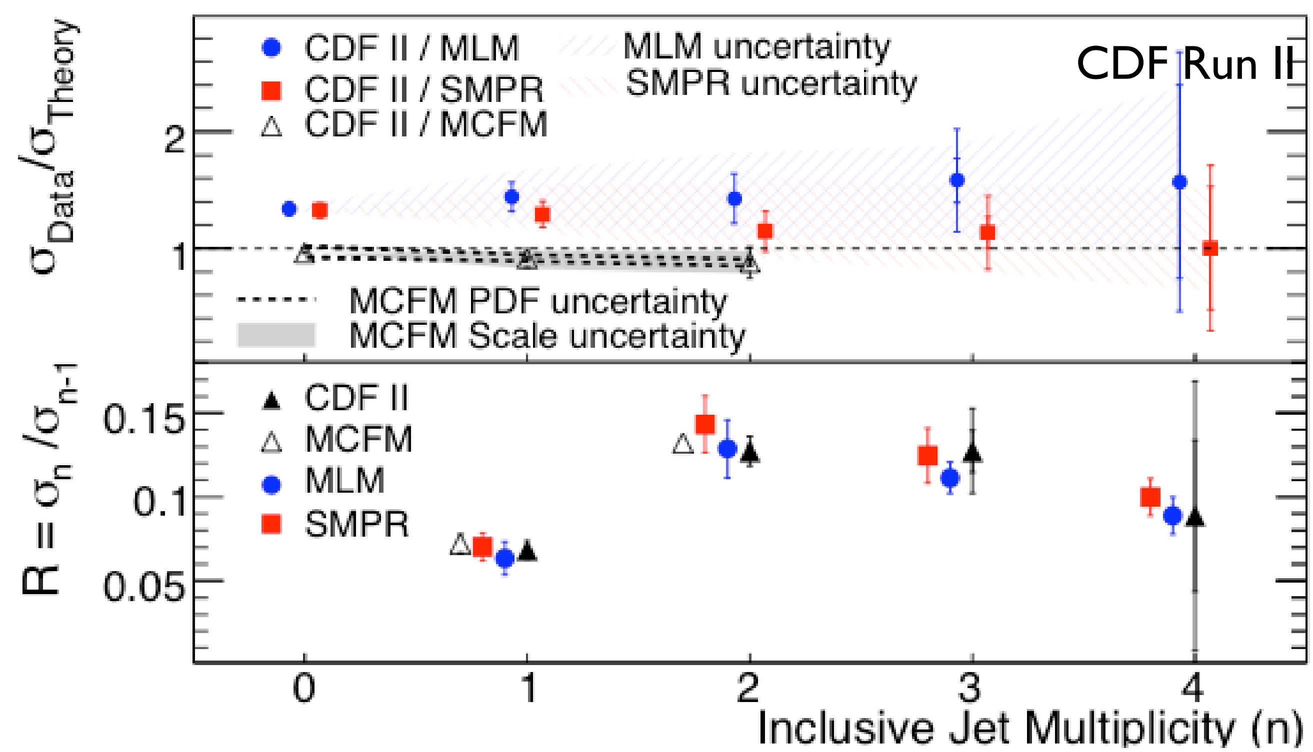


log(Differential jet rate for 1 → 2 radiated jets ~ pT(2nd jet))

Jet distributions smooth, and stable when we vary the matching scale!

Comparing to experiment: W+jets at CDF





- Very good agreement in shapes (left) and in relative normalization (right).
- Matched samples obtained via different matching schemes (MLM and CKKW) consistent within the expected uncertaintes.
- Bonus: NLO rates in outstanding agreement with data.

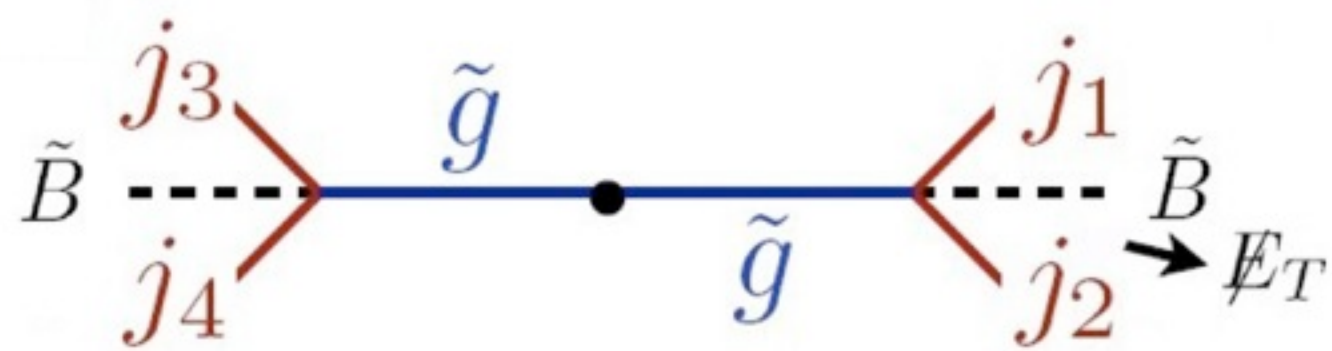
Matching in New Physics production

J.A., de Visscher, Maltoni [arXiv:0810.5350]

- We know that matching of ME+PS is vital for jet production in SM backgrounds
- But is it relevant for heavy BSM particle production?
  - ➡ Very hard jets from decays
  - ➡ Parton showers expected to be more accurate for larger masses
- Using gluino and squark production as example
- Turns out there are many cases where matching is necessary for precise description!

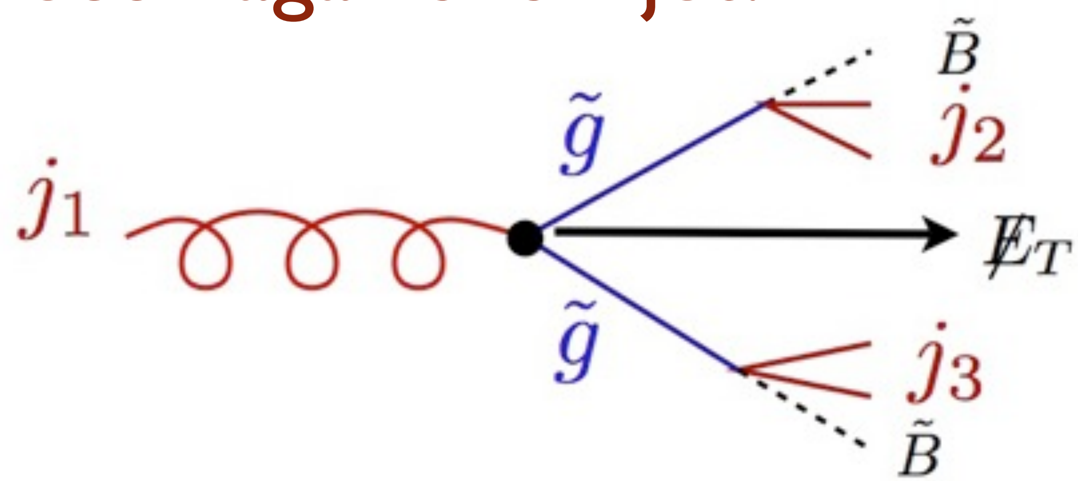
Example

- Example: Gluinos that decay to two quarks+LSP with free ratio of gluino/LSP mass
- Special difficulty when decay products nearly mass-degenerate with produced particle
- No (small) missing transverse energy in decay



Example

- Example: Gluinos that decay to two quarks+LSP with free ratio of gluino/LSP mass
- Special difficulty when decay products nearly mass-degenerate with produced particle
- No (small) missing transverse energy in decay
  - ➡ Need recoil agains ISR jet!



Example

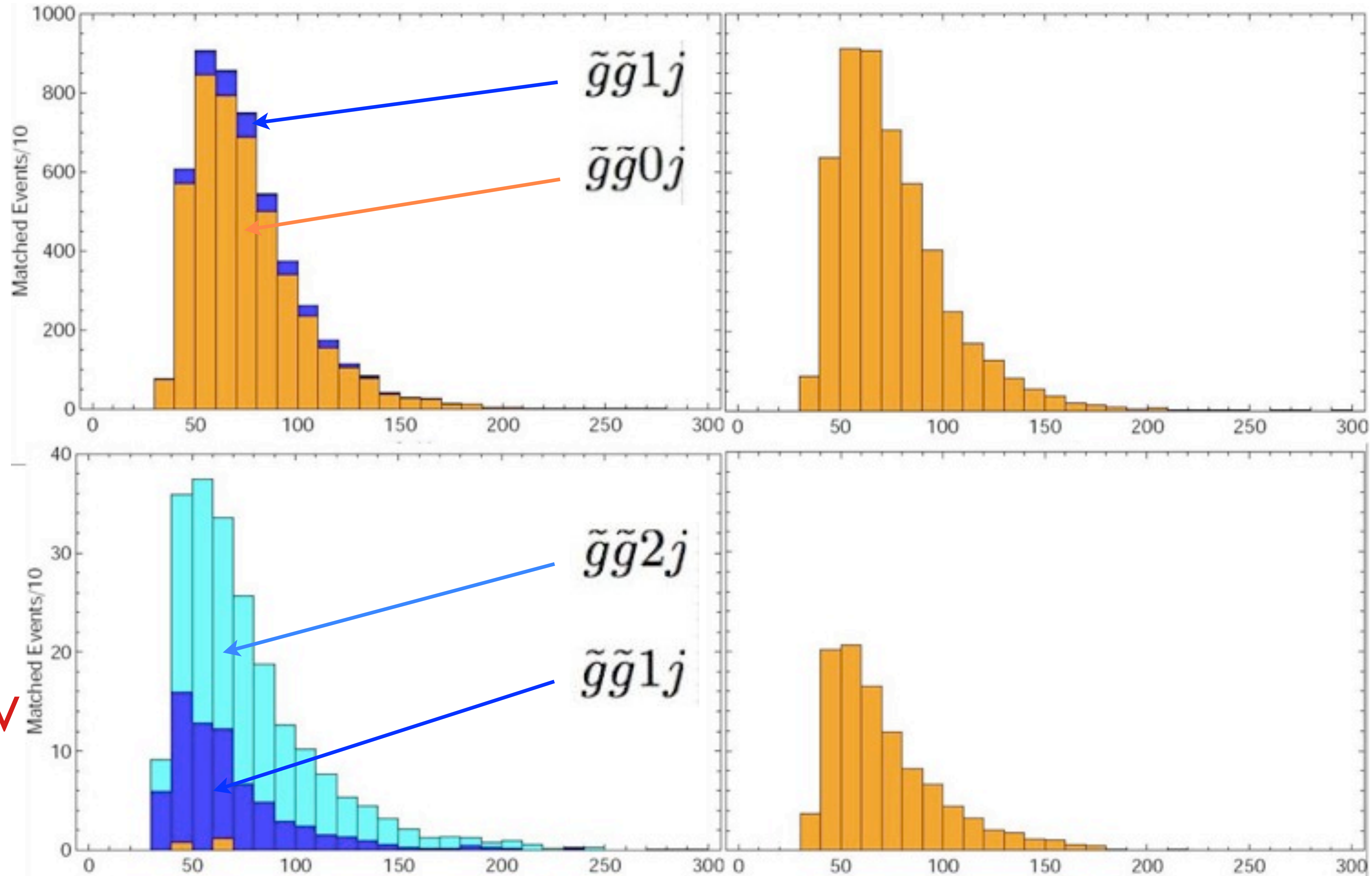
Matched | Unmatched

$M_{\tilde{g}}$ = 150 GeV

M_{LSP} = 40 GeV

$M_{\tilde{g}}$ = 150 GeV

M_{LSP} = 130 GeV

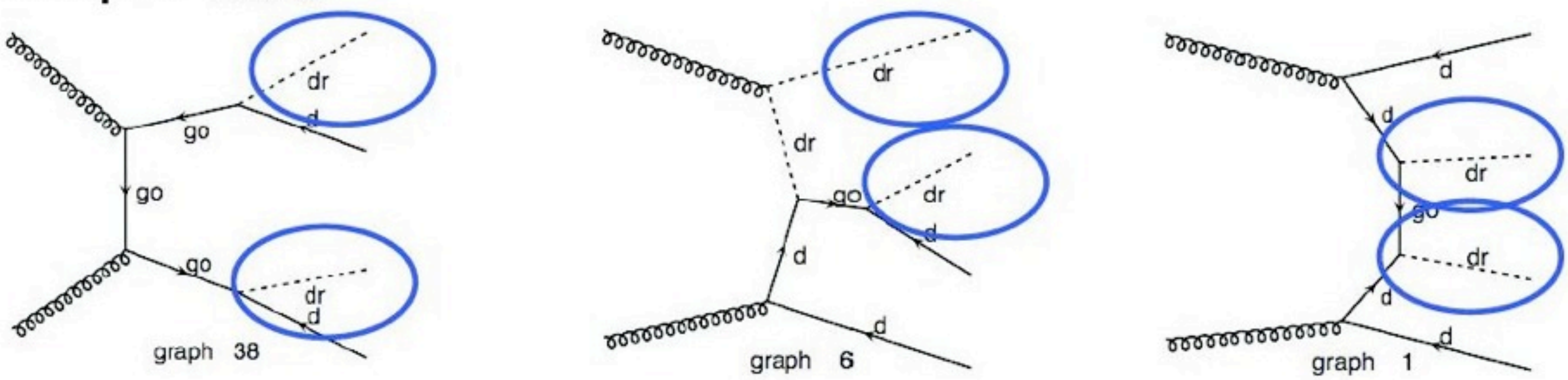


$p_T(j1)$ in GeV at the Tevatron, after 2-jet and missing E_T cuts

Double counting of decays

- Special difficulty in e.g. SUSY matching:
  Double counting of decays to jets!

Example: $\tilde{q}\tilde{q}jj$



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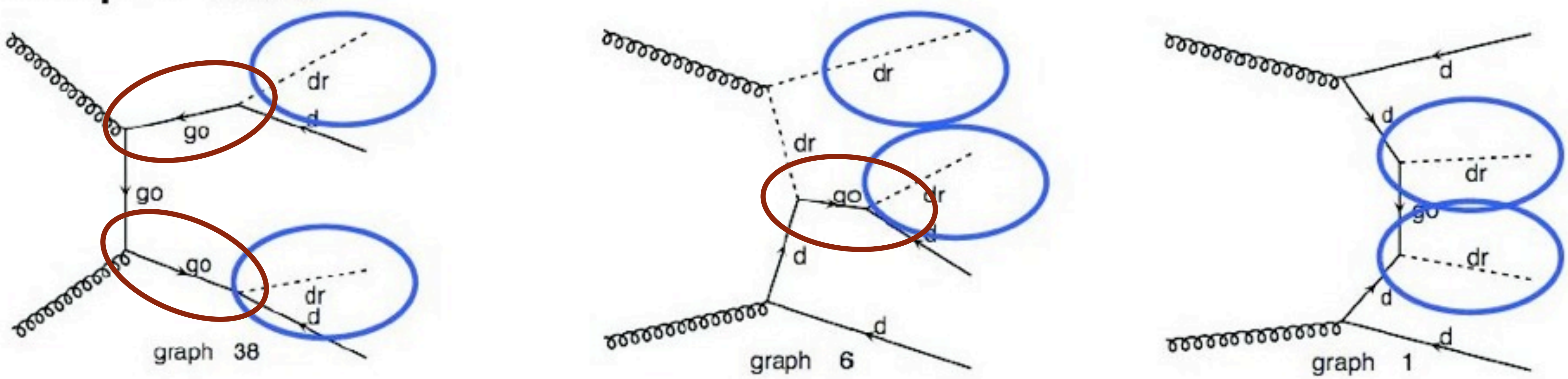
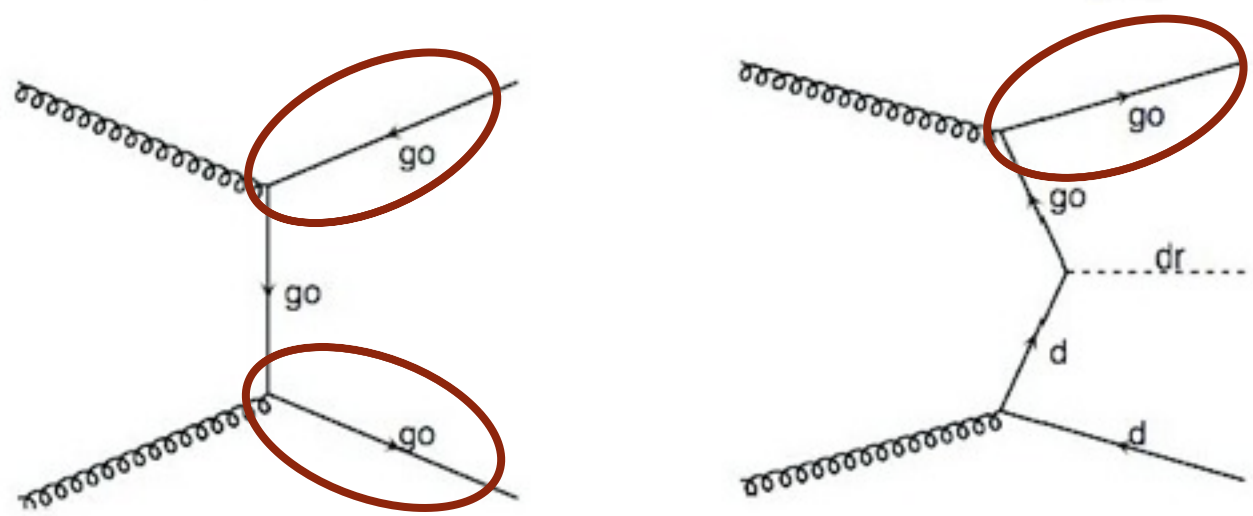




Decays double-counted with on-shell gluino production and subsequent decay

Wednesday, October 26, 2011

Double counting of decays

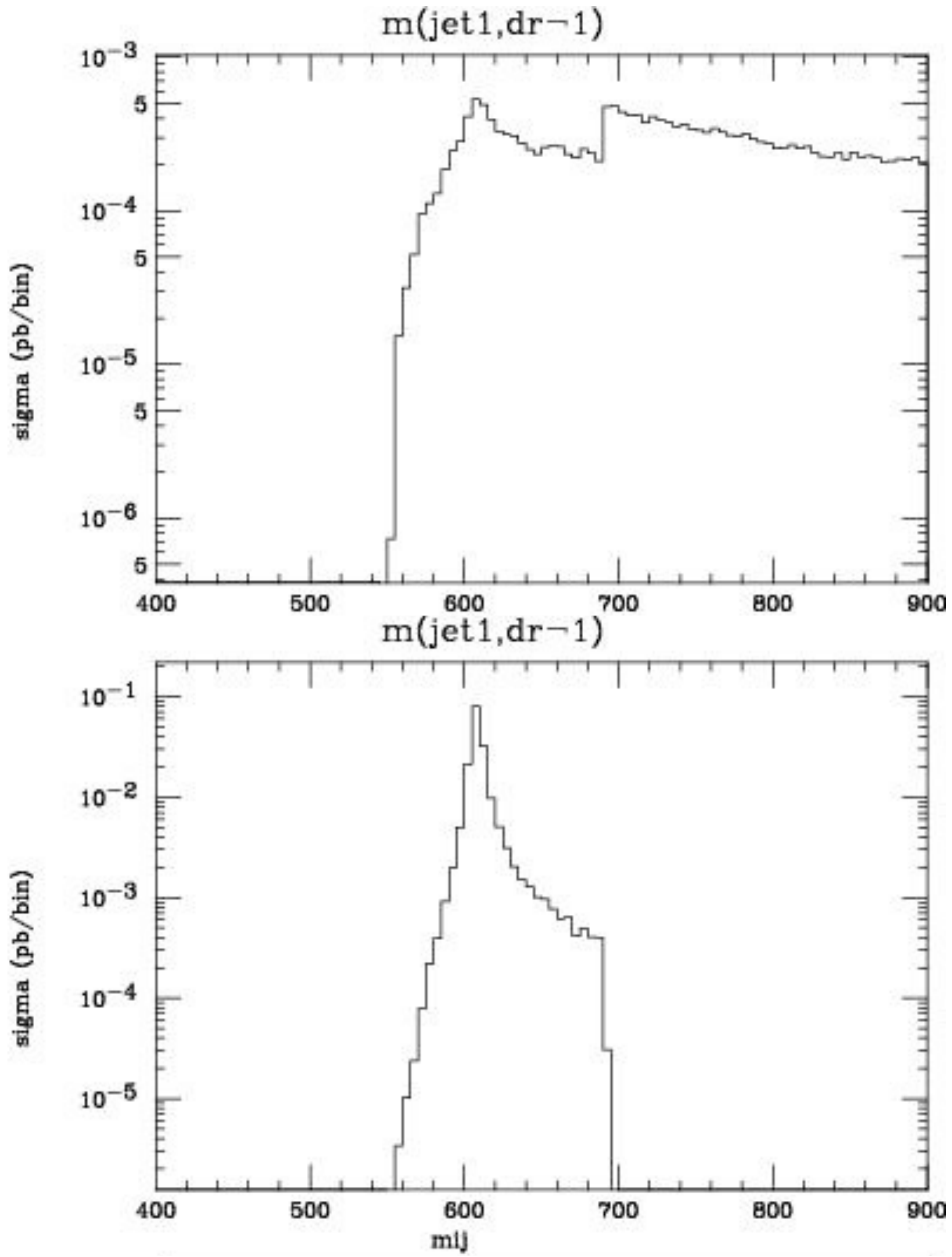
- This has been solved in recent versions of MadGraph 5 by the new "$" syntax
```
mg5> import model_v4 mssm
mg5> generate p p > dr dr~ j j $ go
```
- This removes any on-shell gluinos from the event generation (where on-shell is defined as $m \pm n \cdot \Gamma$ with n set by `bwcutoff` in the run_card.dat)
- The corresponding region is exactly filled if you run gluino production with gluinos decaying to dr j (using the same `bwcutoff`).

Double counting of decays

Invariant mass distributions of d_r squark and d quark

p p > dr dr~ d $ go

p p > dr go, go > dr~ d



Wednesday, October 26, 2011

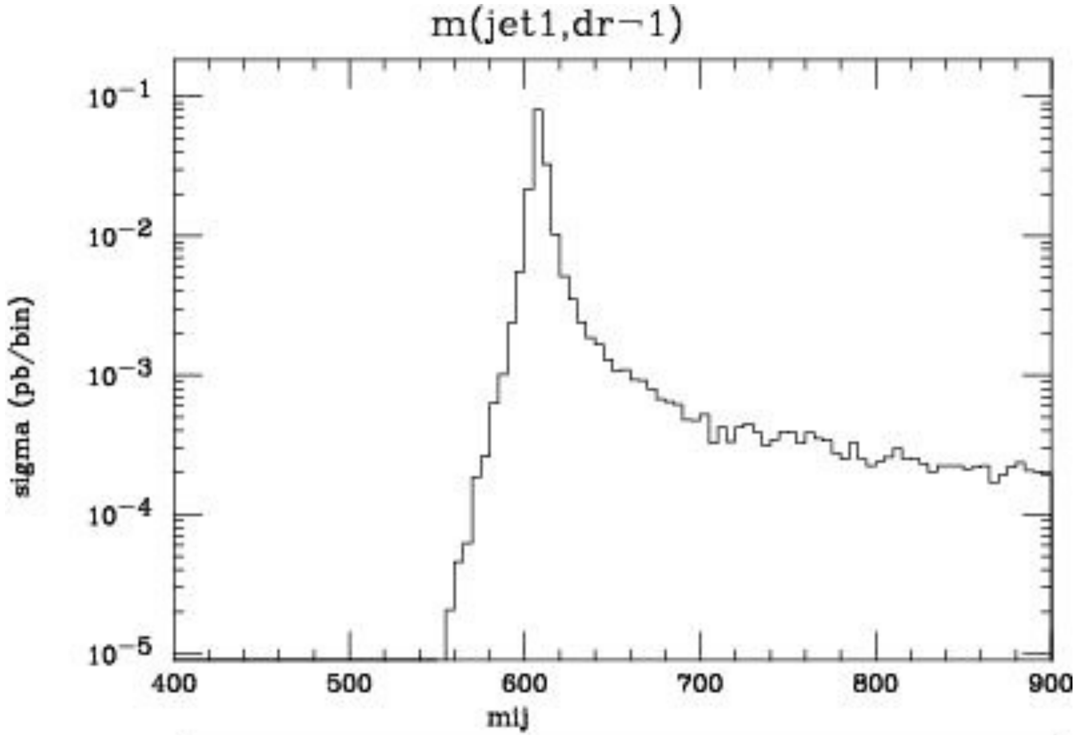
Double counting of decays

Invariant mass distributions of d_r squark and d quark

p p > dr dr~ d $ go

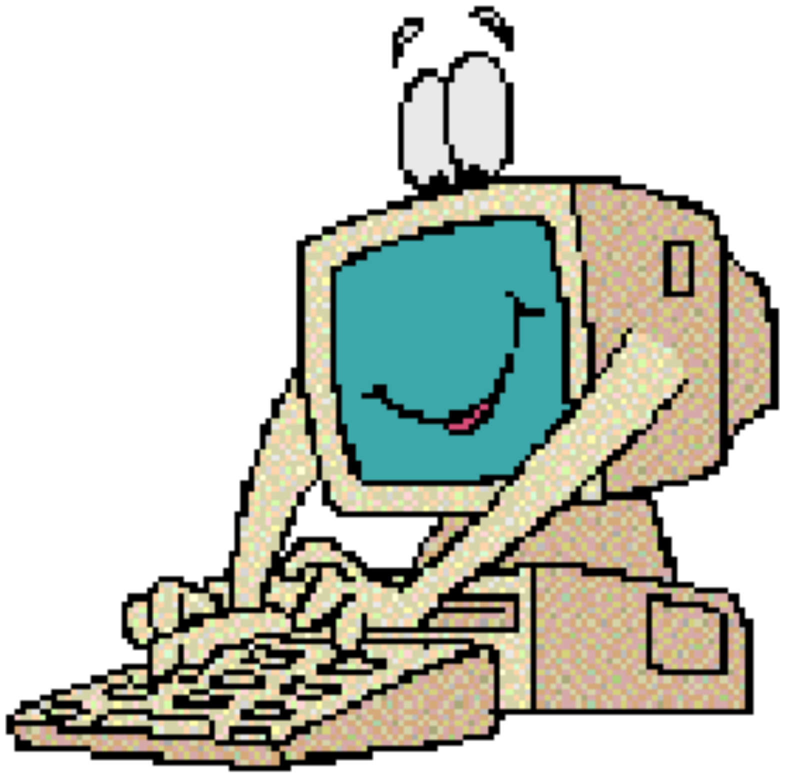
+

p p > dr go, go > dr~ d



Demonstration

- We have gone through a lot of material in a short time...
- Let me do a real-time demonstration and repeat the important steps
- As you will see,
  it's all really easy to use!



Thanks for listening!

- Time for tutorial! Your turn to play around!
- Again, please work in groups
- I will ask you to run different processes and compare the results, so please identify who has the most powerful computer in the group!
- Matching is easy, powerful, and a lot of fun!