PHYSICS AT THE TERA SCALE

Helmholtz Alliance

Soft Gluon Effects in Monte Carlos

Zoltán Nagy

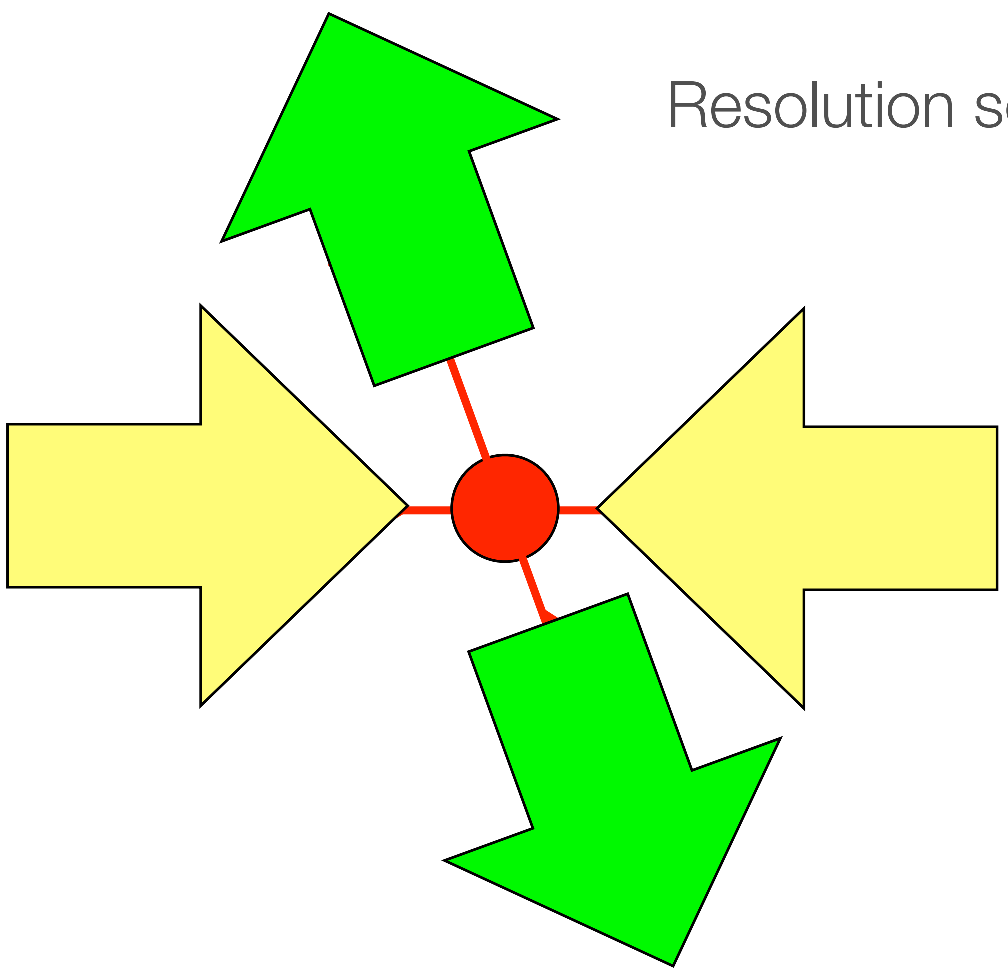
DESY

LHC Physics Discussions

February 21, 2011, DESY, Hamburg

Hadron-Hadron Collision

In hadron-hadron collision the picture is more complicated.



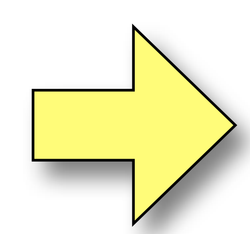
Resolution scale: 400 GeV

Decreasing the resolution scale more and more partons are visible and less absorbed by the incoming hadrons and the final state jets.

Important observation: The total cross section *is independent of* the resolution of the measurement (or detector).

We have to also consider the evolution of the final state jets.

Does perturbative QCD support this nice intuitive picture?



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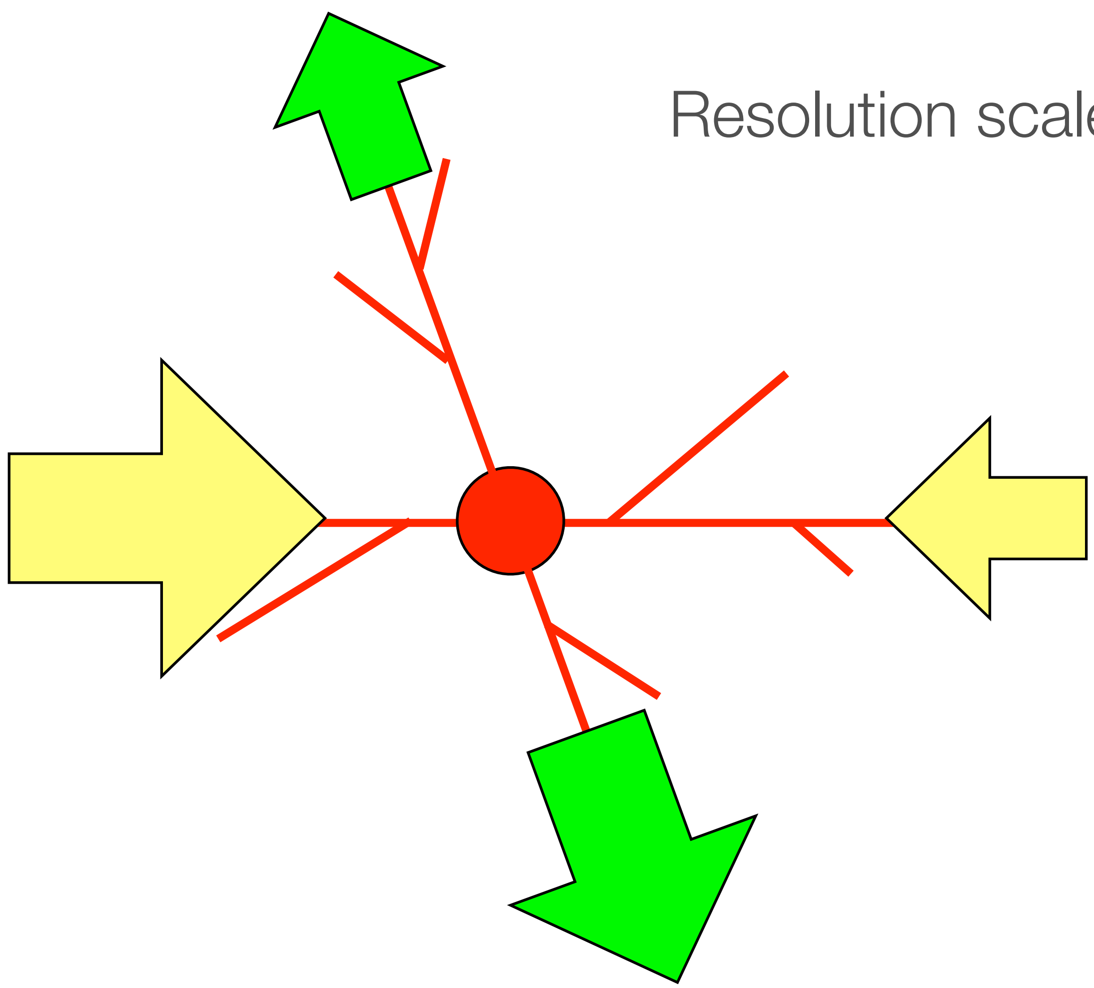

Resolution scale: 100 GeV

Decreasing the resolution scale more and more partons are visible and less absorbed by the incoming hadrons and the final state jets.

Important observation: The total cross section *is independent of* the resolution of the measurement (or detector).

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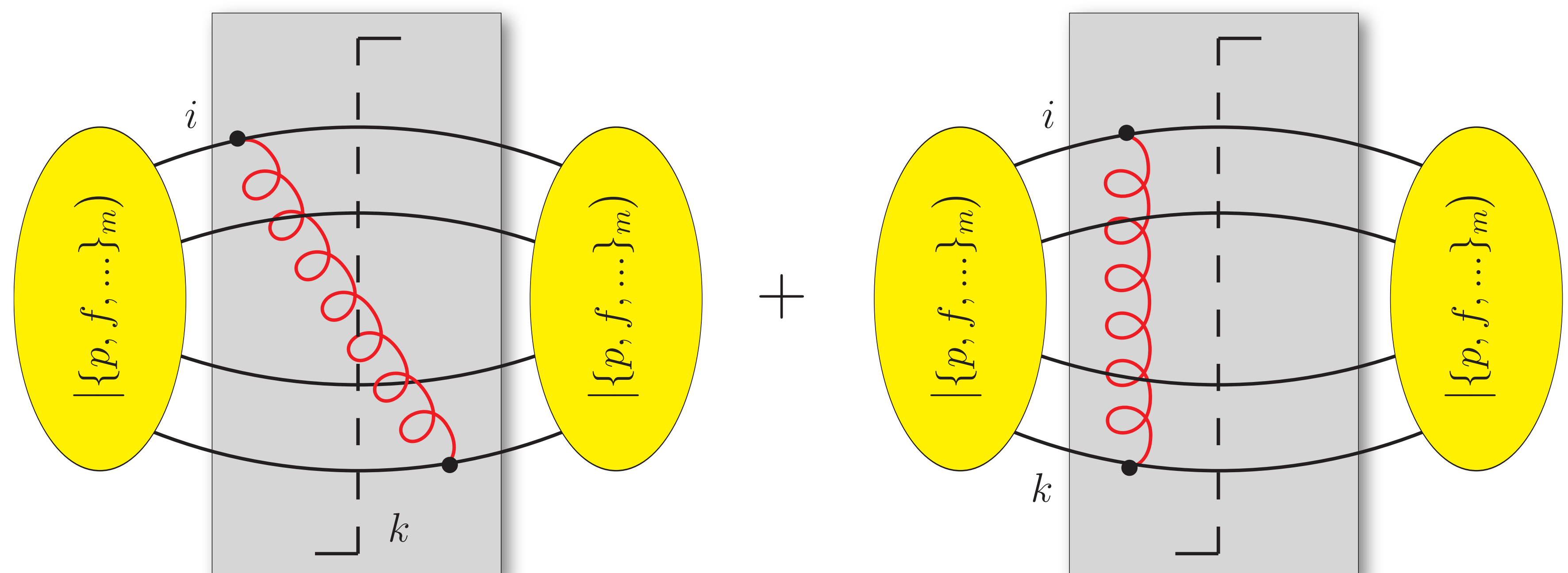
Parton Shower

The parton shower is an fully exclusive evolution of the partonic final state.

$$\color{red}{\mathcal{U}(t,t')}\big|\rho(t')\big) = \mathbb{T}\exp\left\{\int_t^{t'} d\tau\,\big[\color{green}{\mathcal{H}_I(\tau) - \mathcal{V}_I(\tau)}\big]\right\}\big|\rho(t')\big)$$

Resolvable radiations *Unresolvable radiations*

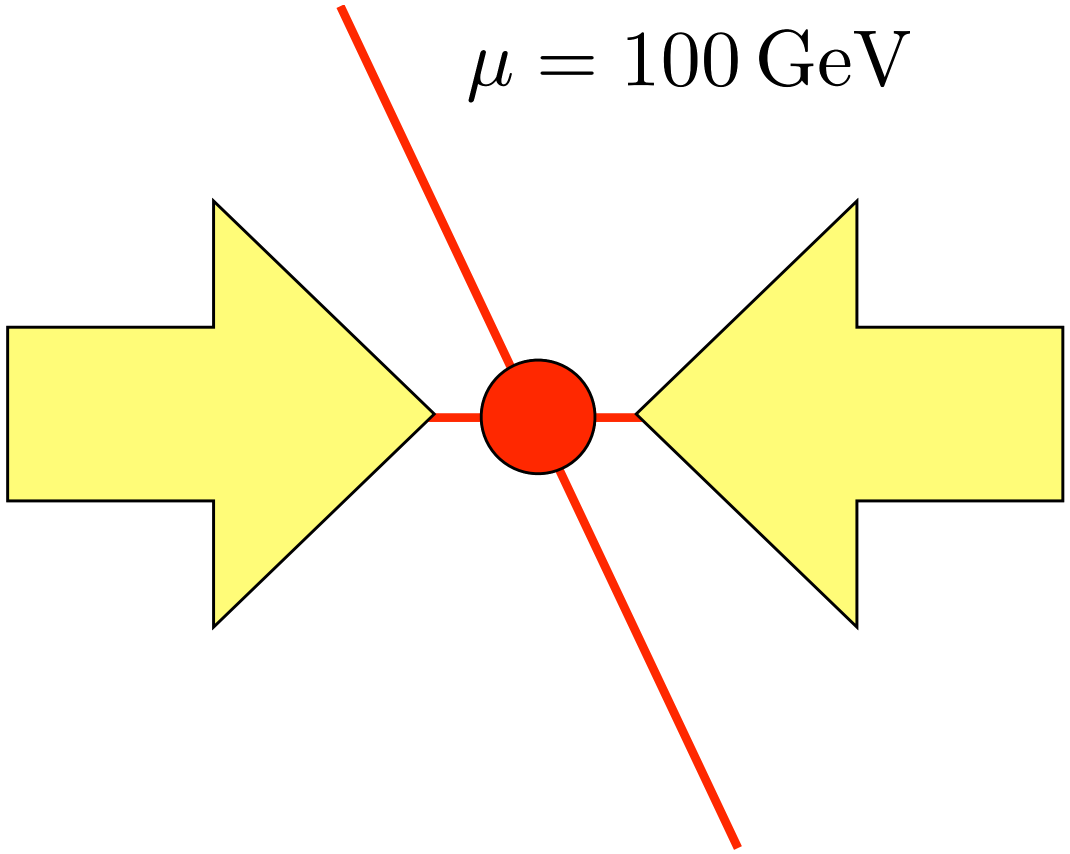
Note, in parton shower basically we don't have tunable parameter.



Is it possible to use this framework for MPI events? Does QCD support it?

Multi Parton Interaction

Let us see how it looks at hadron collider



In hadron-hadron collision the parton distribution function also absorbs the contribution of the multiple interactions and rescattering.

Our strategy:

- Identify factorazible singular contributions systematically.
- Sum up the strongly ordered radiations.
- Minimize the number of the *ad-hoc* assumptions and tuning parameters.

Now, one can try to define the evolution operator in the following form

$$\mathcal{U}(t,t') = \mathbb{T}\exp\left\{\int_t^{t'} d\tau\,\Big[\underbrace{\mathcal{H}_I(\tau) - \mathcal{V}_I(\tau)}_{\text{Single radiations}} + \sum_{\beta=\mathrm{MI,\,RS}} \underbrace{\{\mathcal{H}_\beta(\tau) - \mathcal{V}_\beta(\tau)\}}_{\text{Everything else}}\Big]\right\}$$

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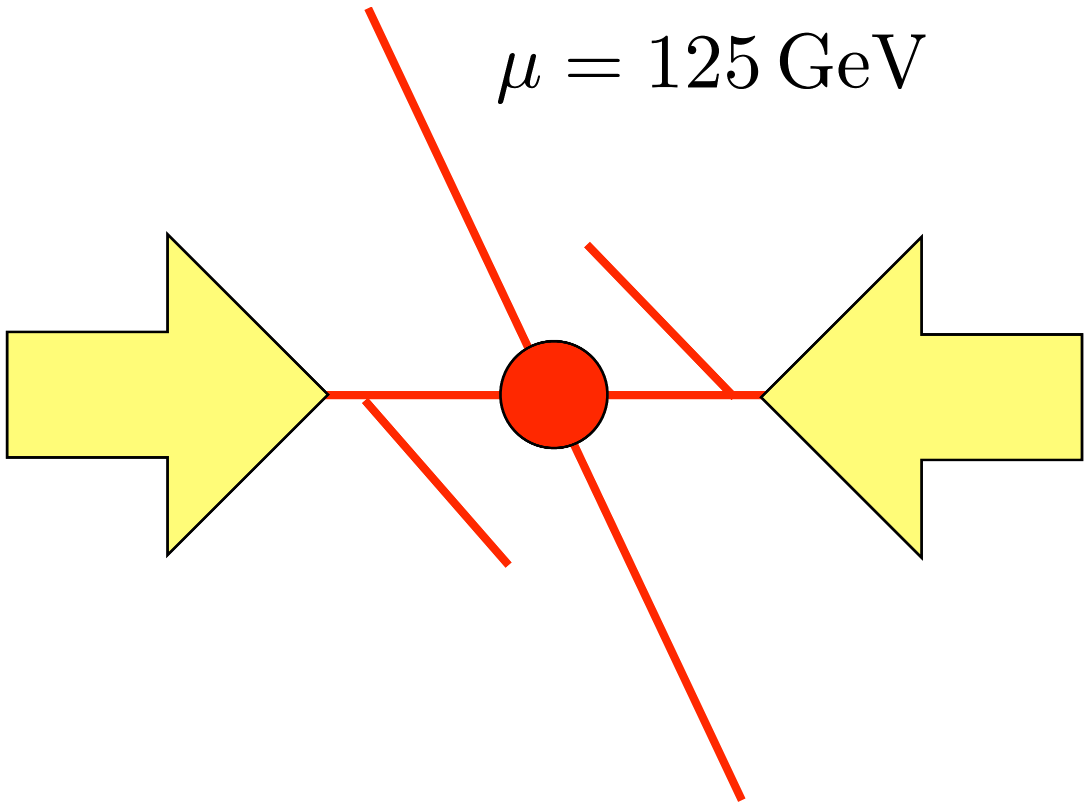

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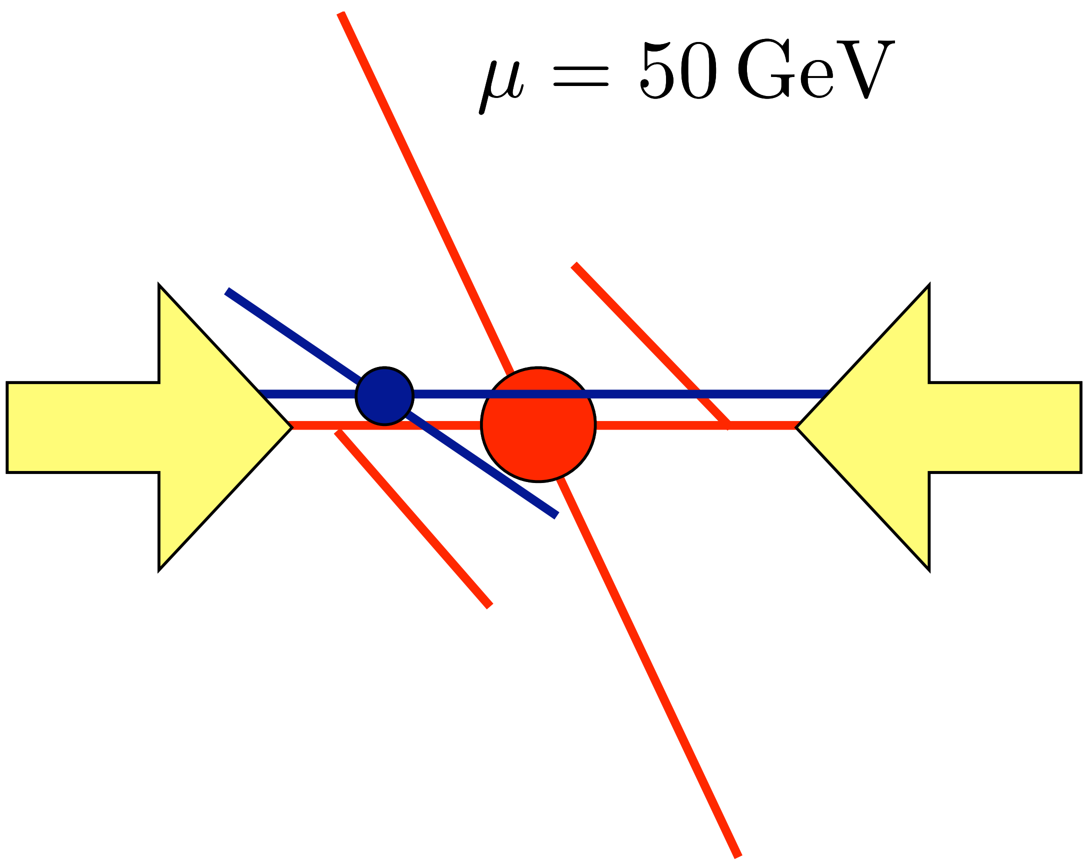

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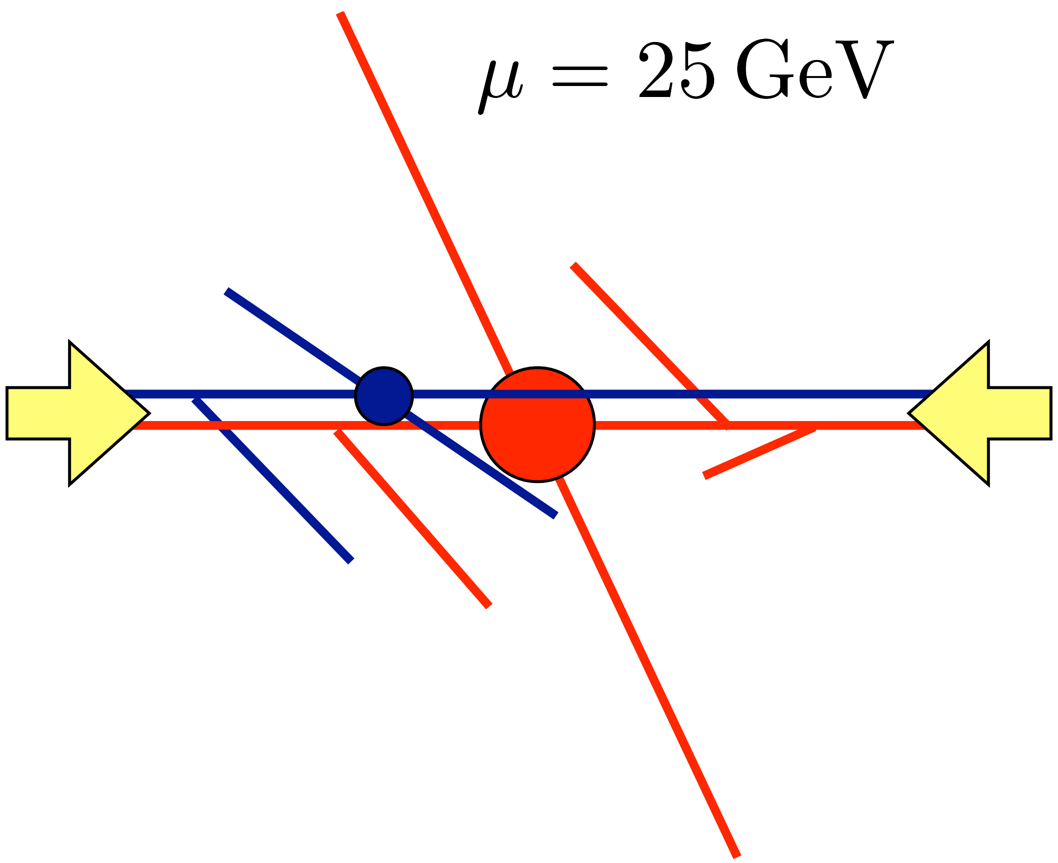

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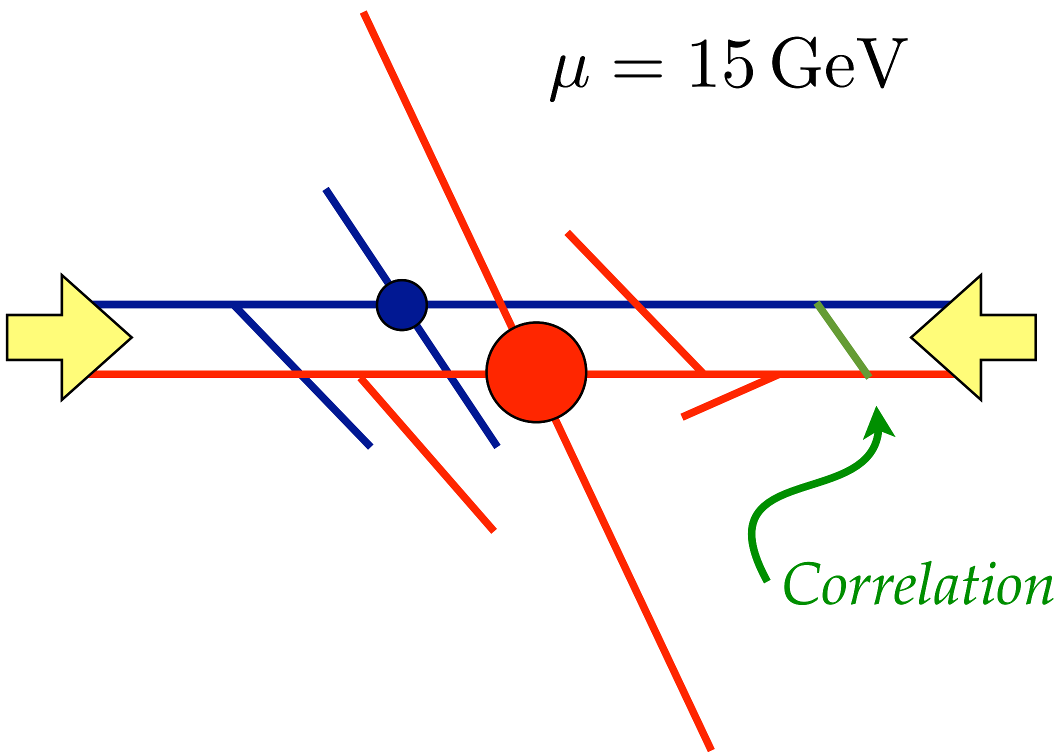

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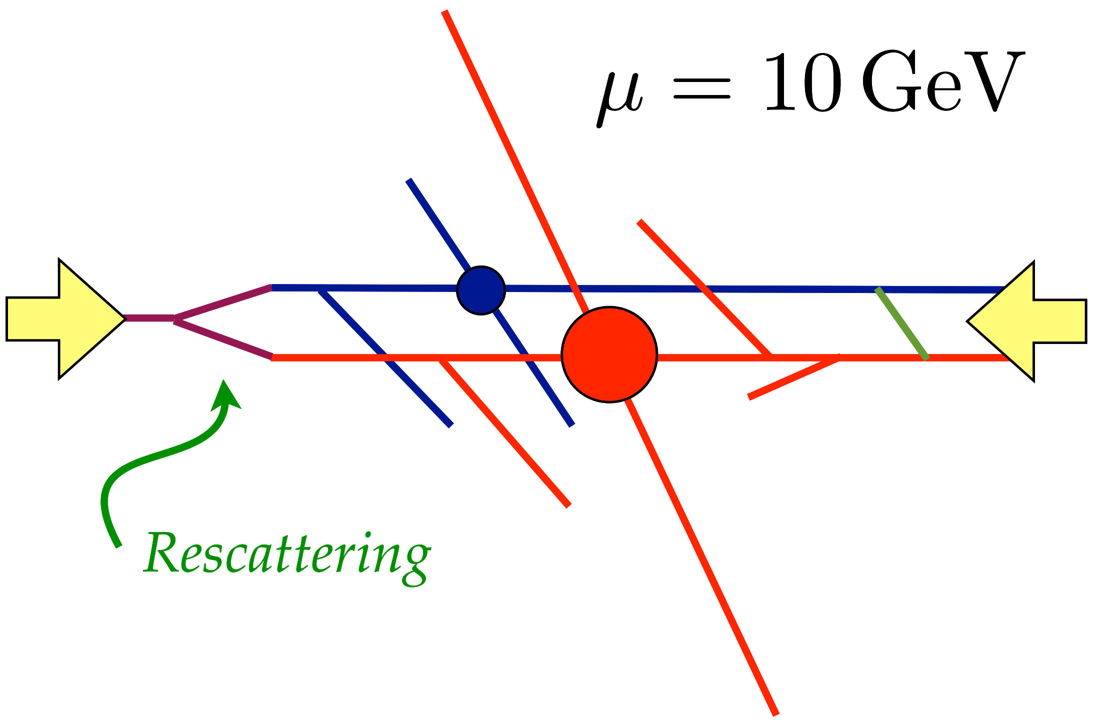

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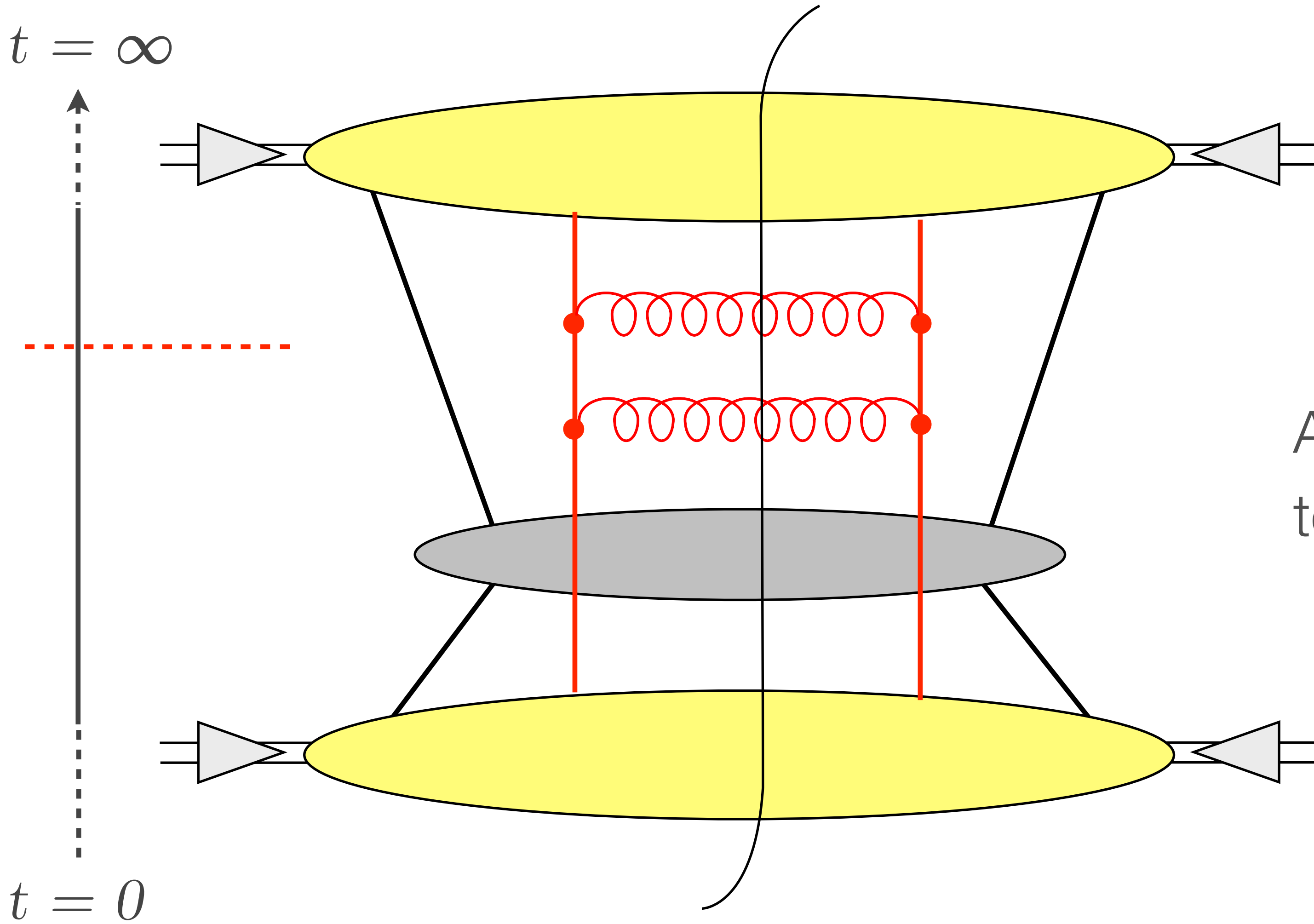
Multi Parton Interaction



We need this at least at leading color level.

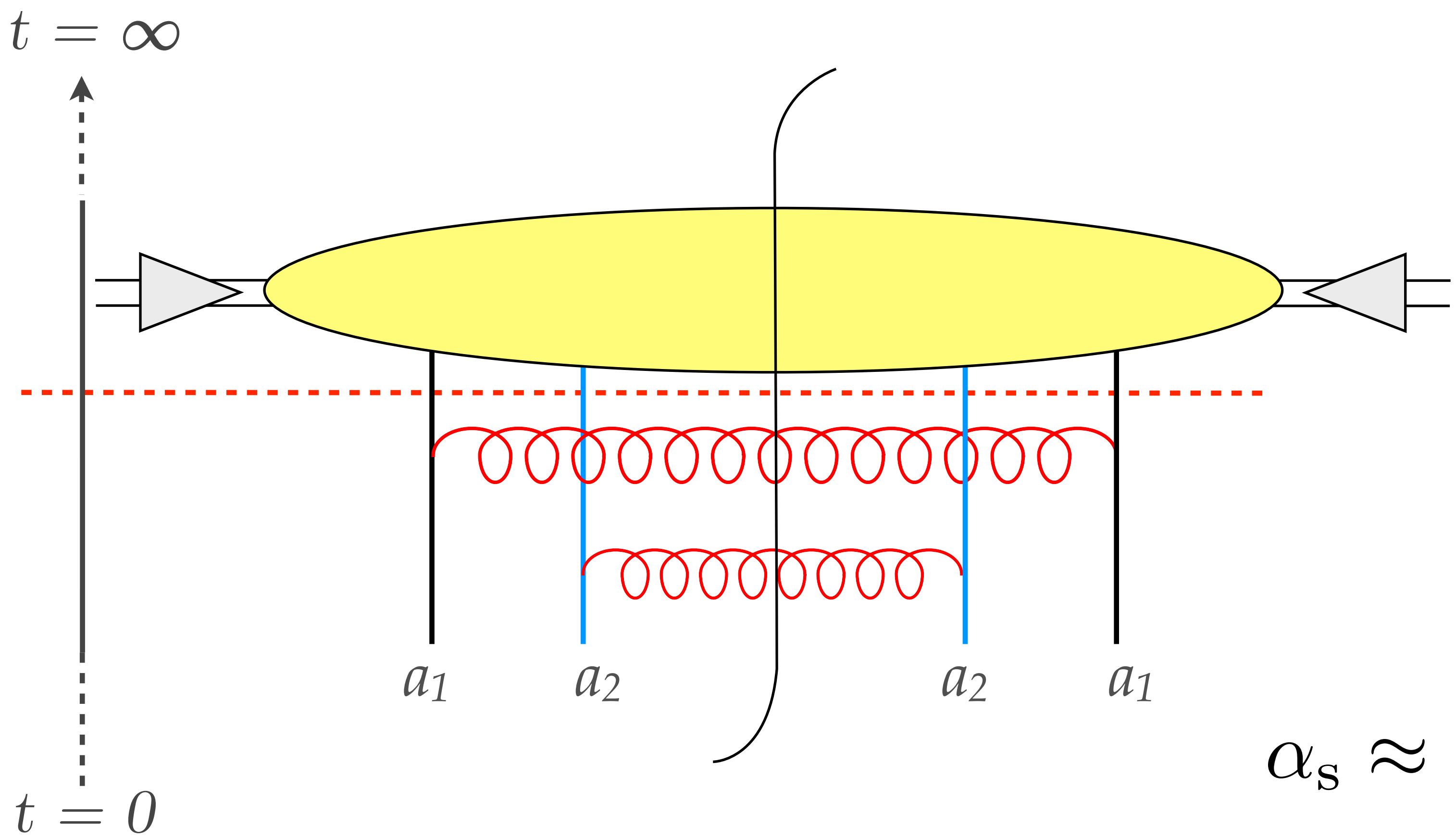
$$\mathcal{H}_{\mathrm{MI}}(t) = \left(\frac{\alpha_{\mathrm{s}}}{2\pi}\right)^2 \mathcal{O}(e^t)$$

Actually the real scaling is weaker due to the *power suppression*:

$$e^{t-t_0} \sim \frac{\Lambda^2_{\mathrm{QCD}}}{p^2_\perp}$$

- This is important in the very small pT regions and negligible in the large pT regions but it is hard to tell how import in the intermediate region. The cumulative effect could be sizable.
- Important to note that this is an NLO contributions. Thus, compared to the standard shower this is also suppressed by an extra power of α_s.
- Requires multi parton PDF (mPDF).
- Implemented in HERWIG & PYTHIA. (No "proper" mPDF implemented.)

Standard IRS

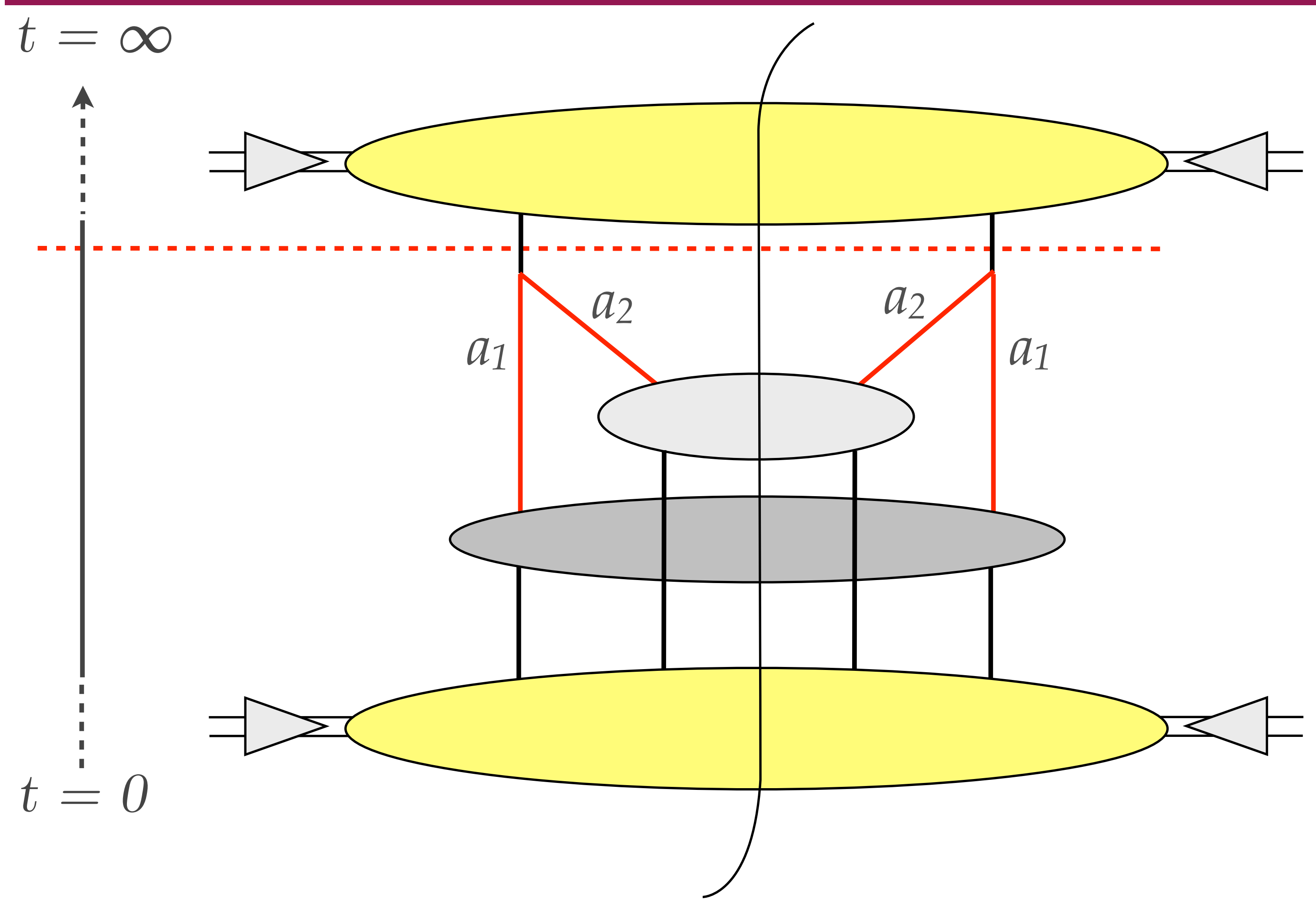


$$\mathcal{H}_{\mathrm{I}}(t) = \frac{\alpha_{\mathrm{s}}}{2\pi}\mathcal{O}(t^2) + \frac{\alpha_{\mathrm{s}}}{2\pi}\frac{1}{N_c^2}\mathcal{O}(t) + \left(\frac{\alpha_{\mathrm{s}}}{2\pi}\right)^2\mathcal{O}(t^3)$$

$$\alpha_{\mathrm{s}} \approx \frac{1}{N_c^2} \approx 0.1$$

- This is the standard shower evolution. Adds LL and NLL contributions. Not power suppressed.
- Since the MPI kernel is NLO contribution we should consider the standard shower at NLO level as well. (Just to be systematic.)
- If we consider NLO terms then we need subleading color contributions, too.
- Adds correction to the primary interaction as well as to the MPI contributions.
- It is implemented only at LO level in HERWIG & PYTHIA.

Rescattering



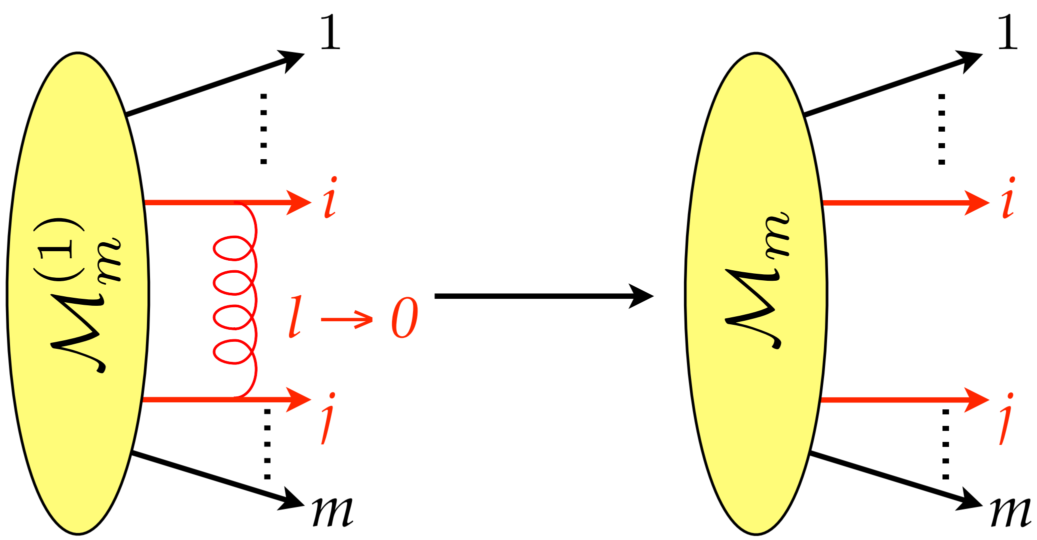
$$\mathcal{H}_{\mathrm{RS}}(t) = \frac{\alpha_{\mathrm{s}}}{2\pi}\mathcal{O}(t) + \left(\frac{\alpha_{\mathrm{s}}}{2\pi}\right)^2 \mathcal{O}(t^2)$$

This is the most problematic contribution

$$\mathcal{V}_{\mathrm{RS}}(t) = 0$$

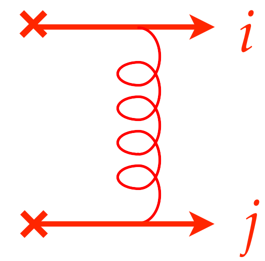
- This operator can be applied on states with at least two chains. (They are already power suppressed.)
- No corresponding factorizable virtual contribution. ➠ No associated Sudakov factor.
- Only NLL contribution to the MPI terms.
- Some level it is implemented in PYTHIA.

Virtual Contributions



This is a singular operator
only in the color space.

$\otimes \int \frac{d^d l}{(2\pi)^d}$



$$\mathcal{V}_I(t)$$

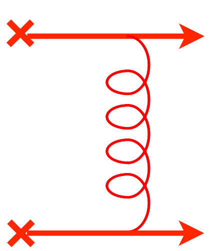
In standard parton shower this operator is obtained from the unitarity condition

$$\big(1\big|\mathcal{V}_I(t) = \big(1\big|\mathcal{H}_I(t)$$

Always real

But it turns out that we have imaginary contribution from the virtual graphs

$\int \frac{d^d l}{(2\pi)^d}$



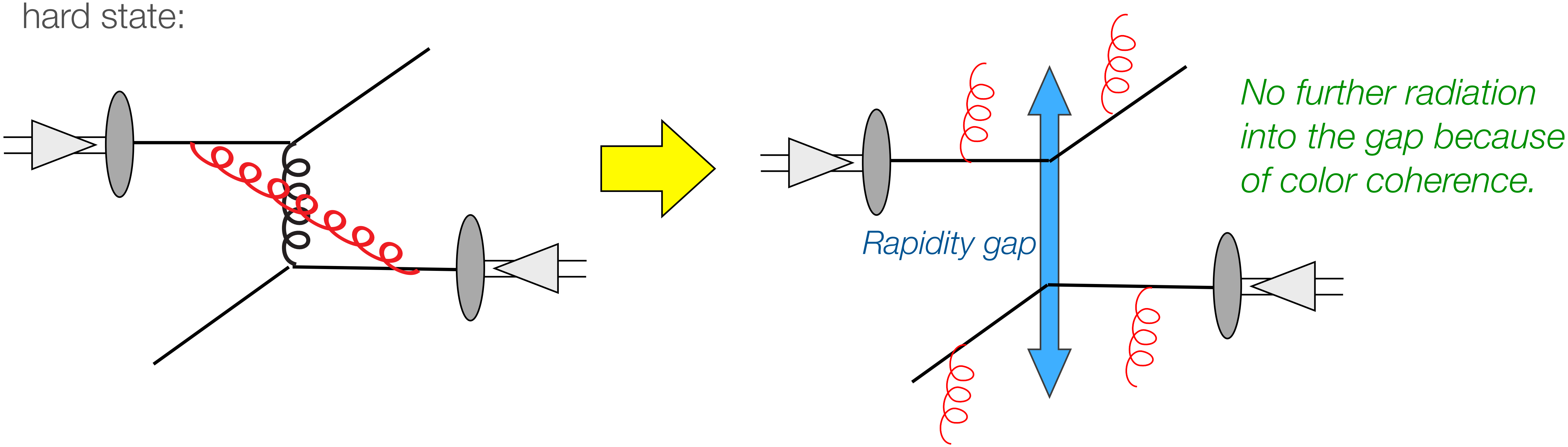
$$\propto \mathcal{V}_I(t) + \underbrace{\mathrm{i}\pi\widetilde{\mathcal{V}}(t)}_{\text{Coulomb gluon}} \quad \text{and} \quad \big(1\big|\widetilde{\mathcal{V}}(t) = 0$$

What can Coulomb gluon do?

Coulomb Gluon

1. Coulomb gluon changes the color configuration and the color flow. It is pure virtual contribution, thus it is unresolvable. *It does the same thing what color reconnection does.*

2. It always make color correlation between the two incoming partons. Let's consider a color octet hard state:



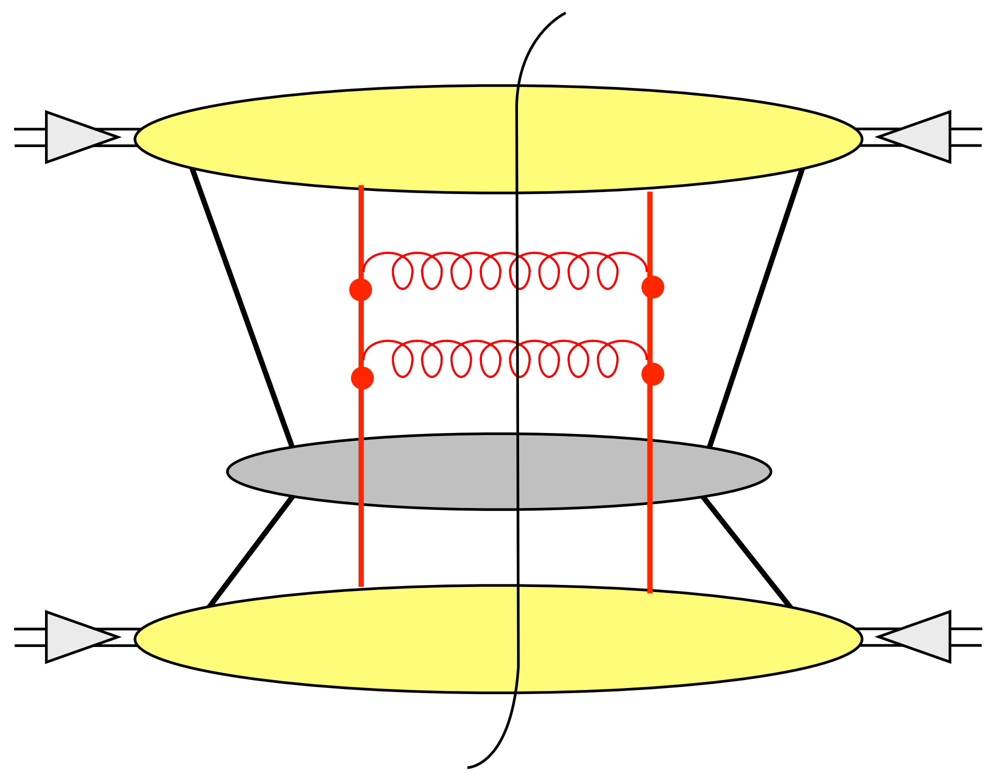
This is a contribution to the diffractive events.

3. Leads to *"Super Leading Logs"* in the case of some non-global observables.

Do we have Coulomb like contribution in the MPI virtual graphs?

MPI: Coulomb Gluon

In the MPI part the “resolvable” radiation comes from extra 2 →2 scattering. This is very singular in the low pT region. This singularity must be cancelled by the corresponding virtual graps.



Real 2 →2 scattering adds two extra jets

Pythia and Herwig put this graph into a simple probabilistic framework and exponentiate the extra 2→2 process.

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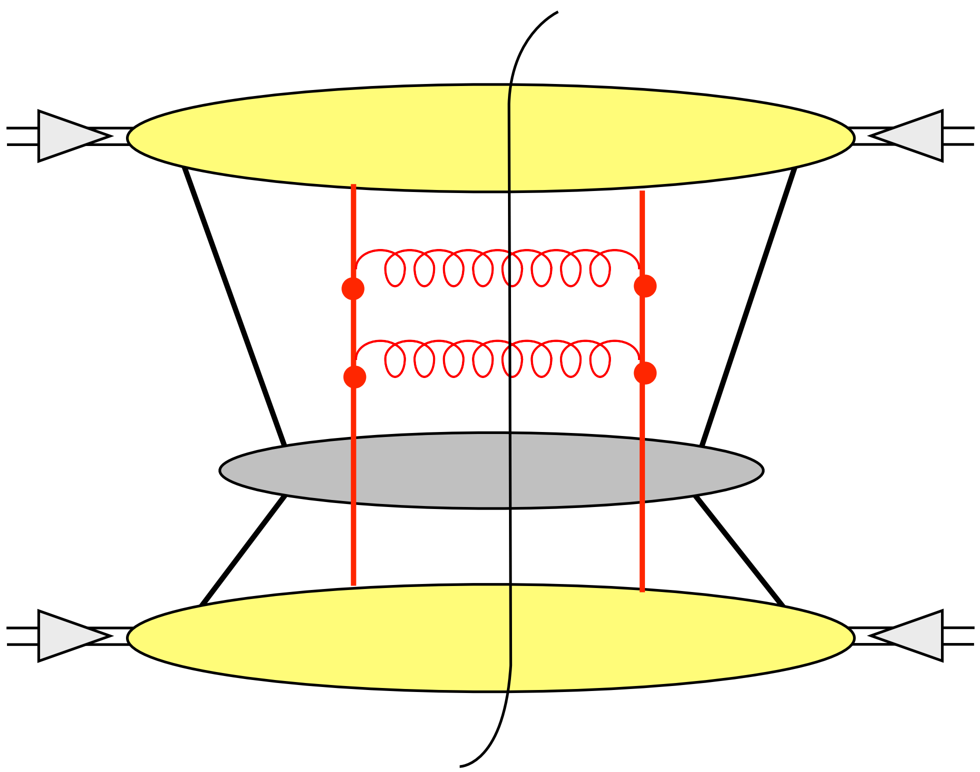

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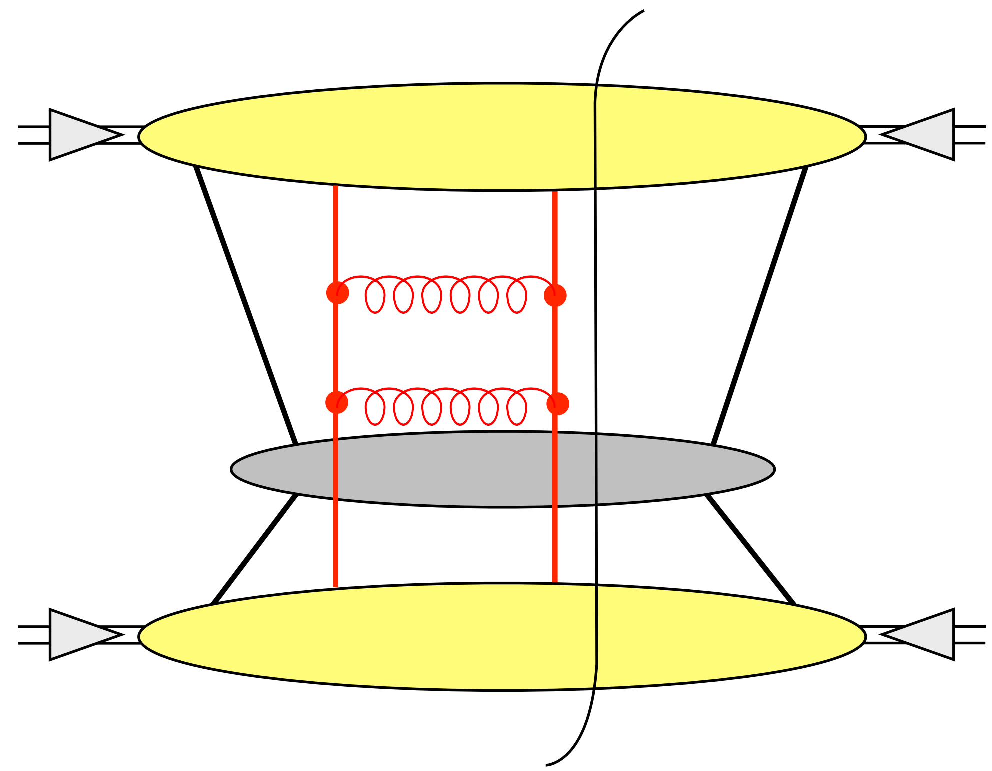
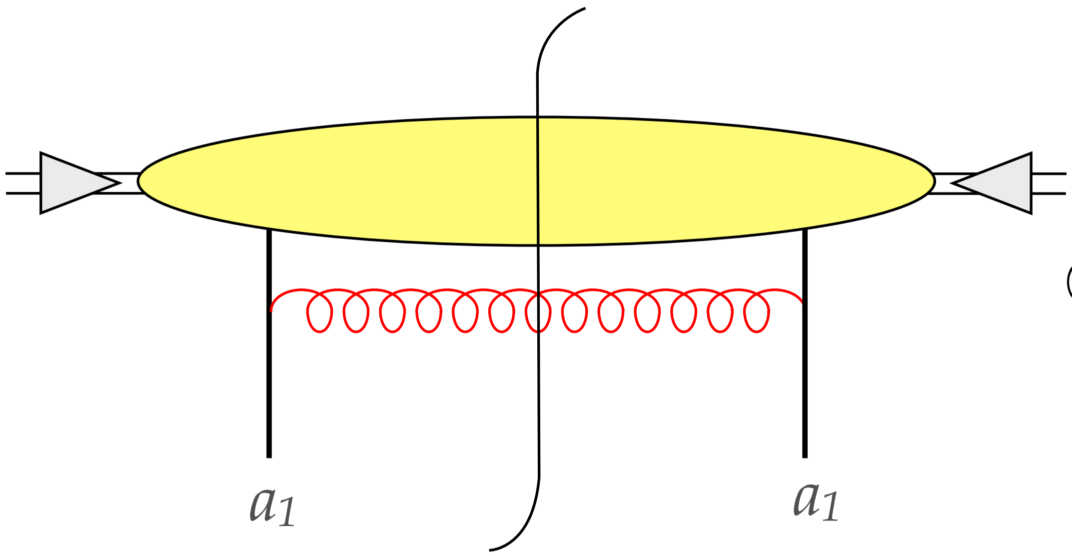


Corresponding virtual graph.
This is a forward elastic scattering contribution.
It can produce Coulomb gluon term ➠ *Color reconnection effect*

Pythia and Herwig put this graph into a simple probabilistic framework and exponentiate the extra 2➝2 process.

Single Parton PDF

The PDF has a operator product definition



$$\propto 2p^+ \int \frac{dz^-}{2\pi} e^{ixz^-p^+} \langle p | \bar{q}(0) q(z) | p \rangle$$

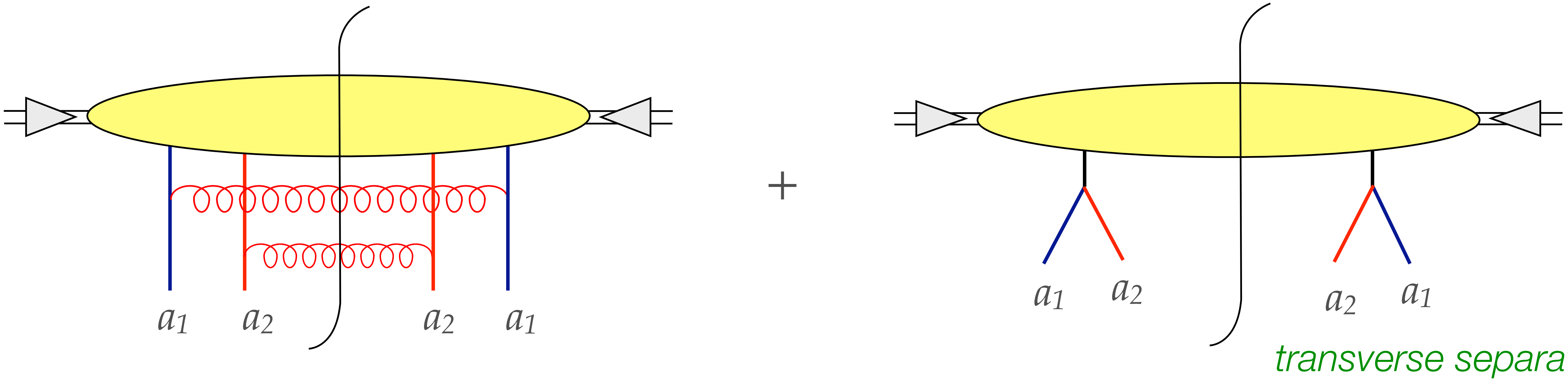
This expression is UV divergent and needed to be renormalized.

$$\mu \frac{d}{d\mu} f_{a/H}(x,\mu) = \sum_b [P_{a,b} \otimes f_{b/H}](x,\mu)$$

The UV singularity in the PDF corresponds to the IR singularity in hard part of the cross section. Everything is consistent.

How does it work in the mPDF case?

Multi Parton PDF



$$\propto 2p^+ \int \frac{dz_2^-}{2\pi} e^{ix_2 z_2^- p^+} \int \frac{dz_1^-}{2\pi} e^{ix_1 z_1^- p^+} \langle p | \bar{q}(-\tfrac{1}{2}z_2)\Gamma_2 q(\tfrac{1}{2}z_2)\bar{q}(y - \tfrac{1}{2}z_1)\Gamma_1 q(y + \tfrac{1}{2}z_1) | p \rangle$$

This operator is also UV divergent and needed to be renormalized. RGE provides the generalized DGLAP equation.

For $y \neq 0$ we have a homogeneous DGLAP equation, there is no contribution from 2→4 transitions

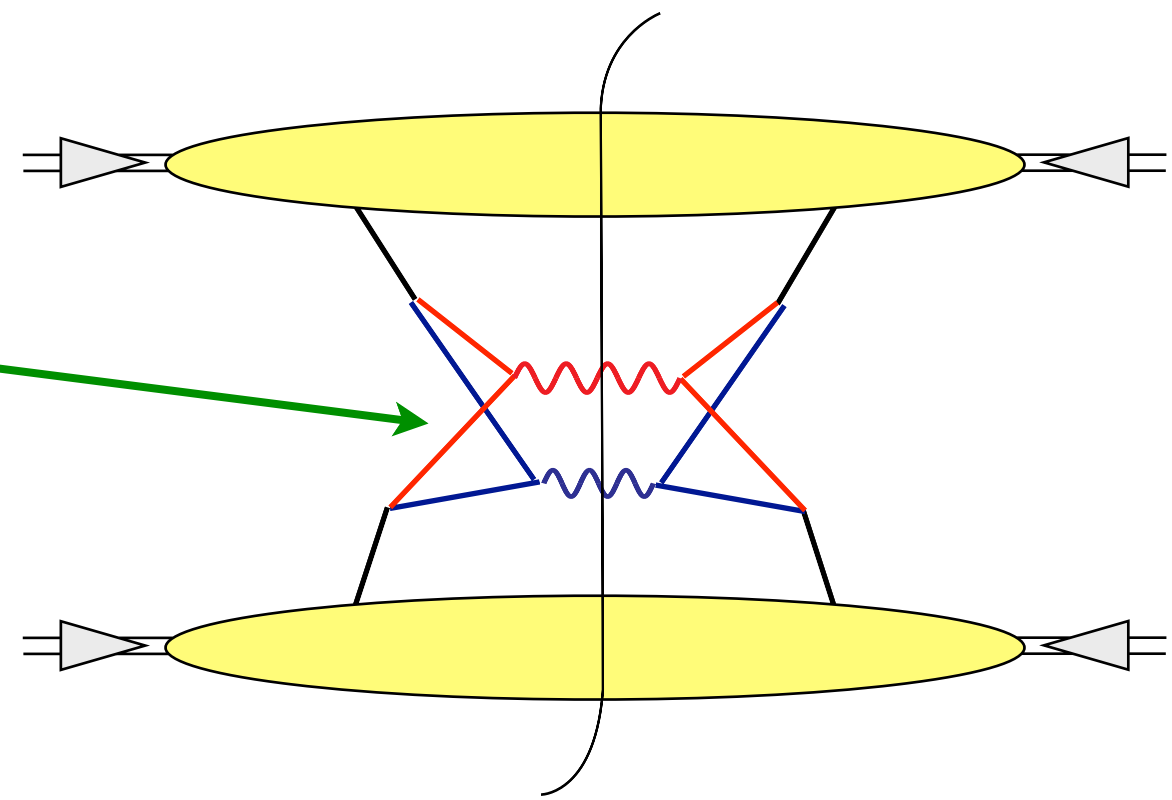
$$\frac{d}{dt} F(x_i, y) = P \otimes_{x_1} F + P \otimes_{x_2} F$$

Marcus Diehl talk in DESY

For $\int dy\, F(x,y)$ we have contribution from 2→4 transitions

Multi Parton PDF

Let us study the 2➞4 transitions in the hard matrix elements. In this example we have double Z boson production



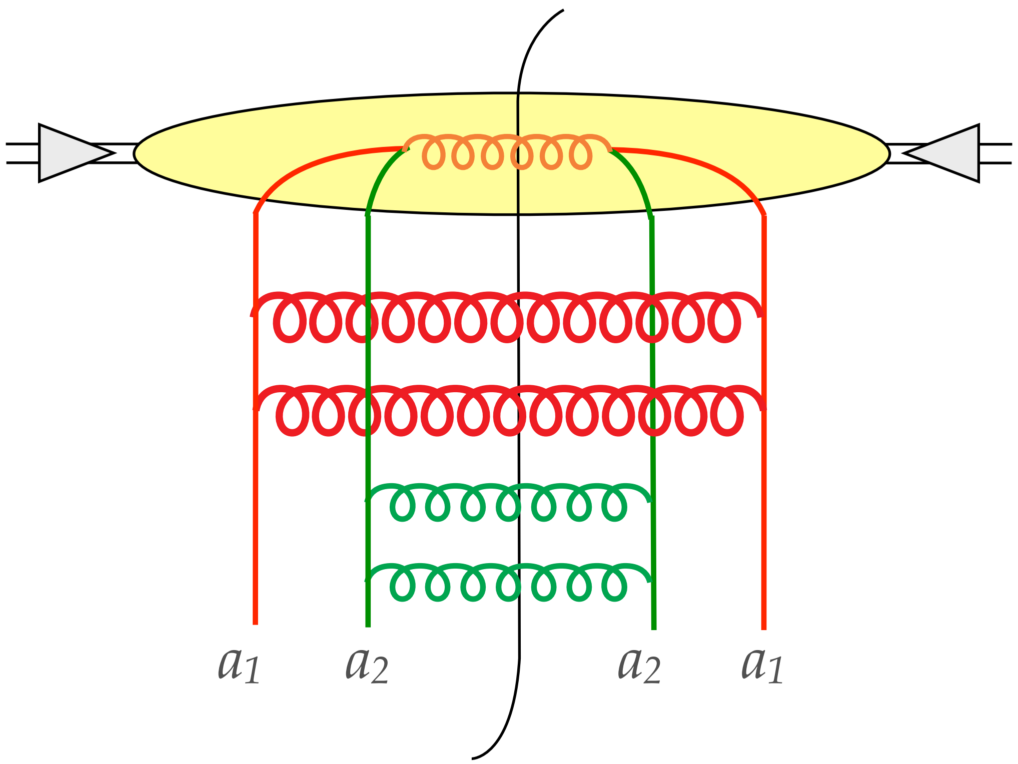
There is a 1-loop graph in this process.
This loop integral is perfectly finite,
there is *NO IR singularities*.

This tells we should NOT consider the
2➞4 transitions.

Look like there is some inconsistency
between the two approaches...

Color of mPDF

In Pythia of Herwig the effective mPDF is always color singlet state. But it can be a color octet state



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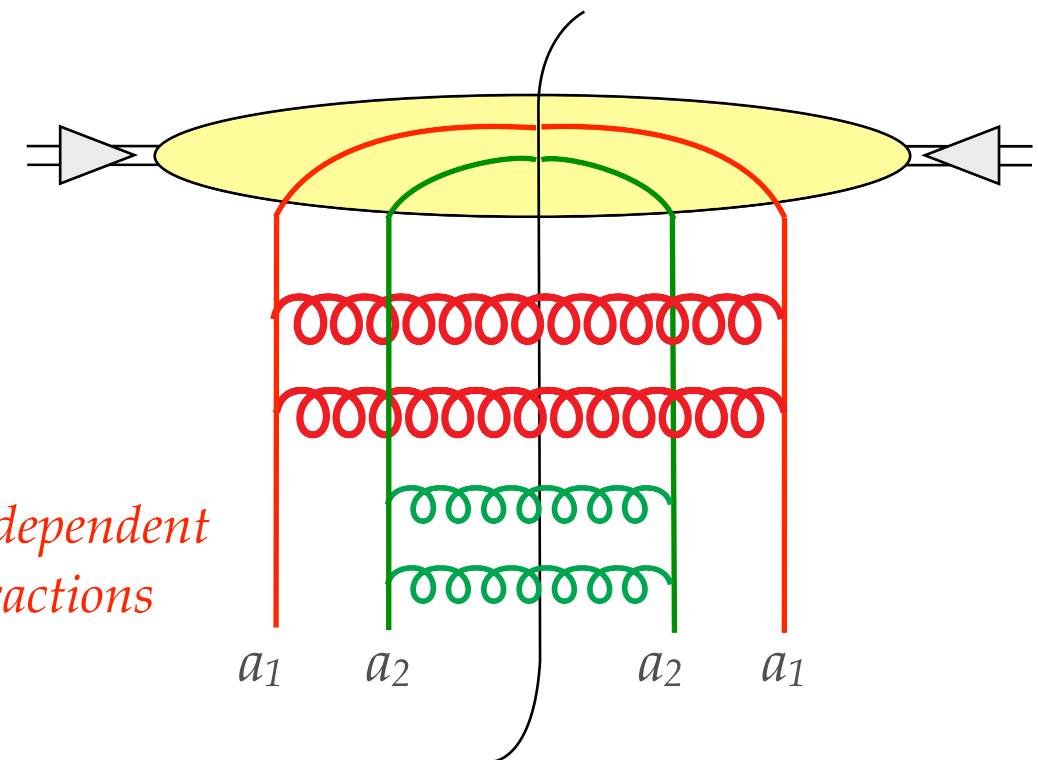
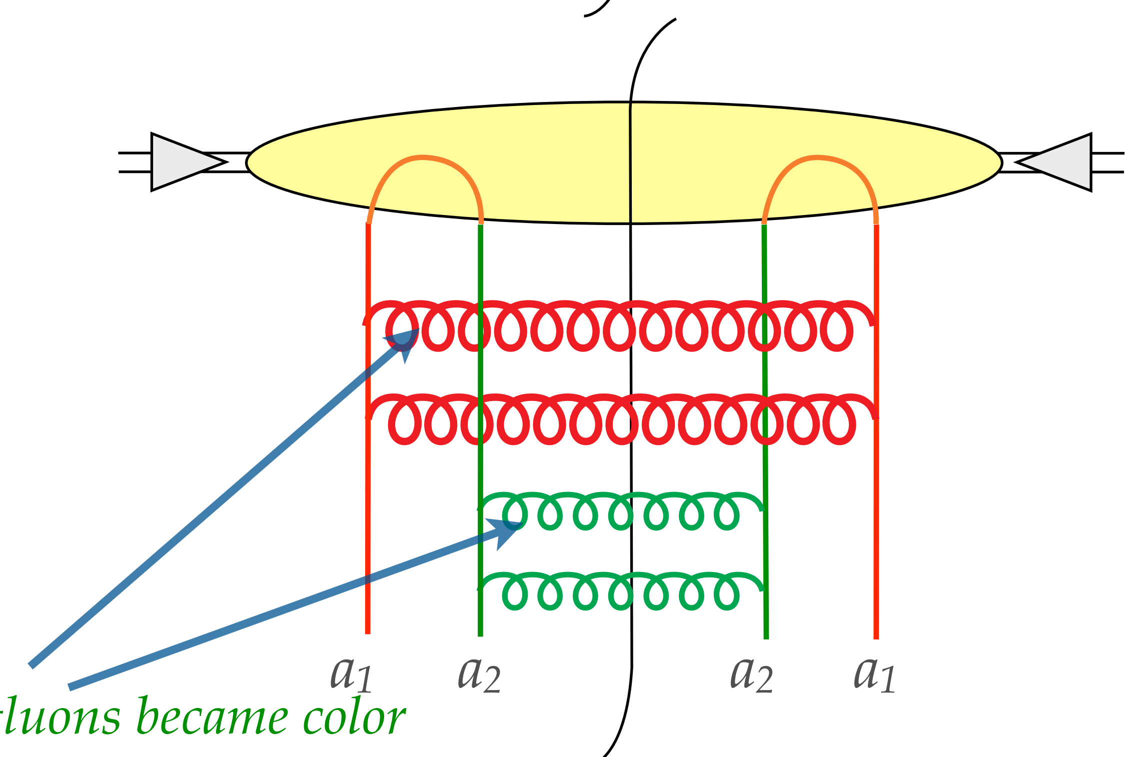


Two independent interactions

$+$



These two gluons became color connected.

➠ *Color reconnection effect in the perturbative part.*

Conclusion

- Multiple Interaction is very complicated from theory point of view.
- There are MC tool available mostly based on some tunable models (Color reconnection, simple mPDF assumption,...)
- Some perturbative effects are not included in our MC (Coulomb gluon,...)
- Lack of theorems (factorization,...)