Colour coherence in the fully unintegrated NLO evolution kernels of collinear factorization

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The Large Hadron Collider poses a challenge to theoretical calculations through:

- very precise measurments
- need of high accuracy QCD calculations also for *exclusive* (unintegrated) quantities
- huge range of energy scale requiring beyond LO calculations

A possible solution is the fully exclusive NLO Parton Shower Monte Carlo.

NLO Parton Shower Monte Carlo for QCD Initial State Radiation

Construction:

- based on the collinear factorisation (EGMPR, CFP),
- CFP=Curci-Furmanski-Petronzio scheme as a main guide (axial gauge, $\overline{MS}$).

The aims of the project:

- implementing *exactly* NLO DGLAP evolution,
- using new exclusive NLO kernels

Mission statement:

Single Feynman diagrams entering the NLO kernel are not gauge-invariant and may have soft singularities.

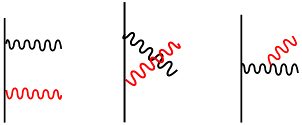
The construction of Monte Carlo requires good understanding of soft limit. In exclusive algorithm we have to do it diagram-by-diagram.

To obtain resonable Monte Carlo weights we need to reproduce soft singularities exactly, up to NLO. This must be done analytically, today I will only show graphical analysis.

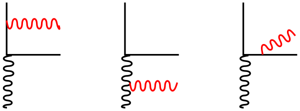
Example real diagrams

qq and qg LO amplitudes:

with additional gluon emisions (NLO corrections):

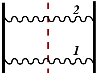


(non-singlet)

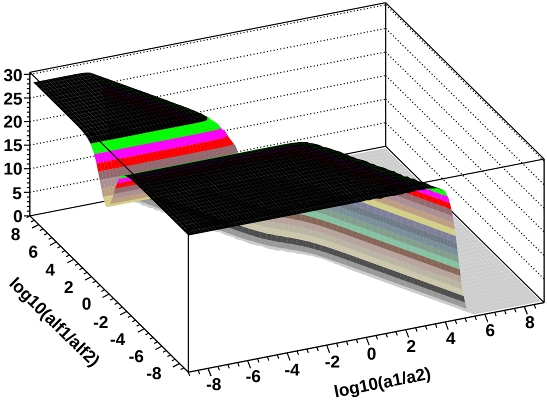


(singlet)

Black plateau is eikonal double-log singularity



Canyon $\sim P(z_1) \otimes P(z_2)|_{x=z_1 z_2}$, Cliff at equal virtualities.



Two-particles phase space parametrised with Sudakov variables:

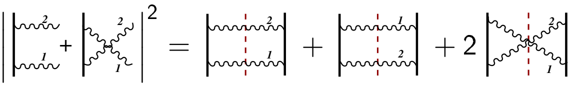
$$k_1 = \alpha_1 p + \alpha_1^- + k_{1\perp}, \qquad k_2 = \alpha_2 p + \alpha_2^- + k_{2\perp}$$

I will use rapidity-related: $a_i = \frac{k_{i\perp}}{\alpha_i}$ variables

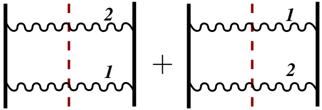
On the plots:

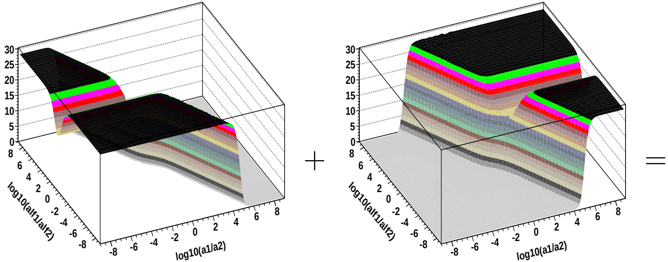
- normalisation to eikonal phase space $d\Psi = \frac{d\alpha_1}{\alpha_1}\frac{d\alpha_2}{\alpha_2}\frac{da_1}{a_1}\frac{da_2}{a_2}$,
- $\alpha_1 + \alpha_2 = 1 - x$ fixed and non-zero (at least one emission is hard)
- $\max\{a_1, a_2\} = Q$ (if $a_1 > a_2$, $a_1 = Q$ and $0 < a_2 < Q$)
- use $(\ln a_1/a_2, \ln \alpha_1/\alpha_2)$ variables

NOTATION: squared matrix elements = cut-diagrams:



Non-singlet diagrams $\sim C_F^2$





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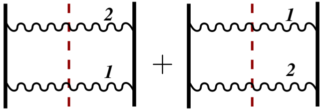
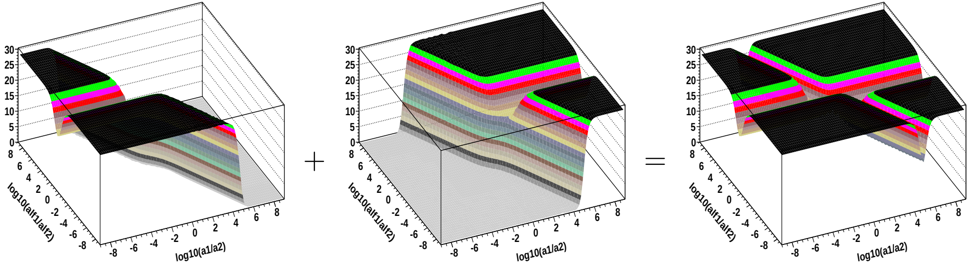
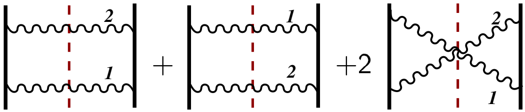
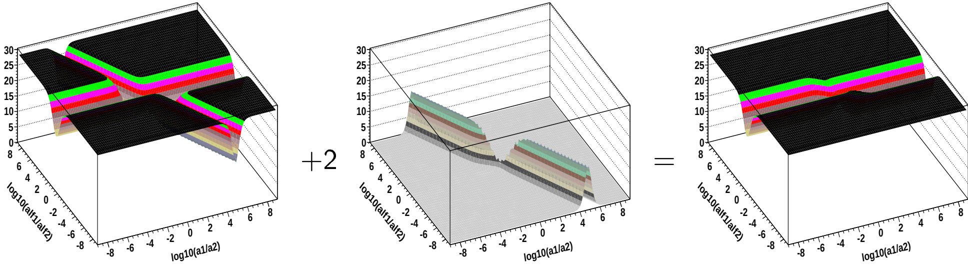




The remaining infinite canyon at equal virtualities spoils eikonal soft limit! (Cliffs are due to quark propagators.)

Non-singlet diagrams $\sim C_F^2$

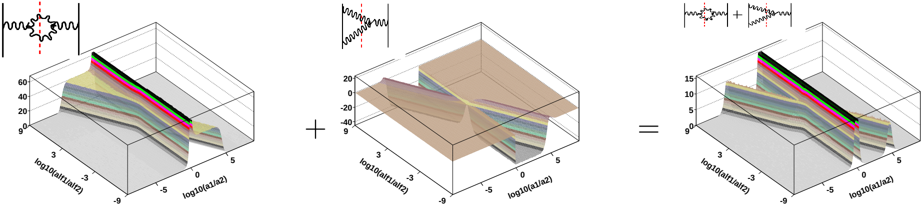




Interference cures SOFT EIKONAL LIMIT, i.e. fills in bad canyon!
Remaining canyon at $\alpha_1 \sim \alpha_2$ due to $\sim P(z_1) \otimes P(z_2)|_{x=z_1 z_2}$ is OK.

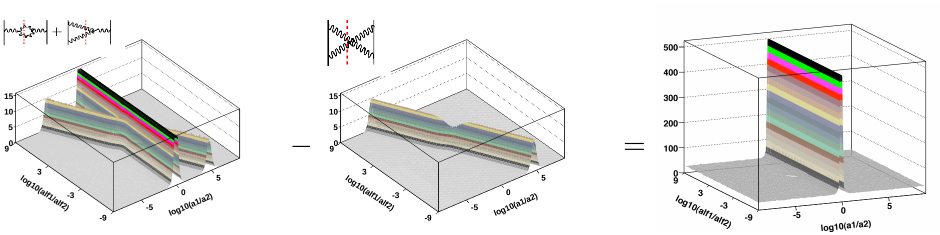
The ridge $a_1 = a_2$ is the collinear singularity of the gluon pair

Triangular plateax are double-log singularities



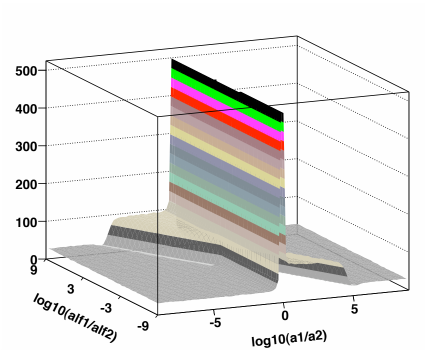
Plateaux disappear after adding interference, but a familiar ridge still spoils the soft limit.

After adding both interferences

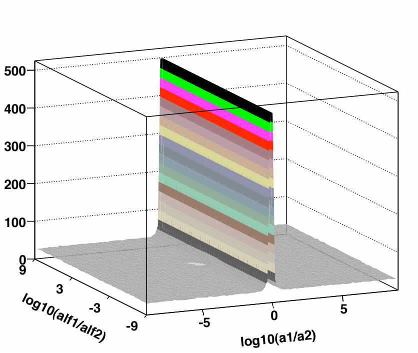


The soft limit is OK

All non-singlet diagrams



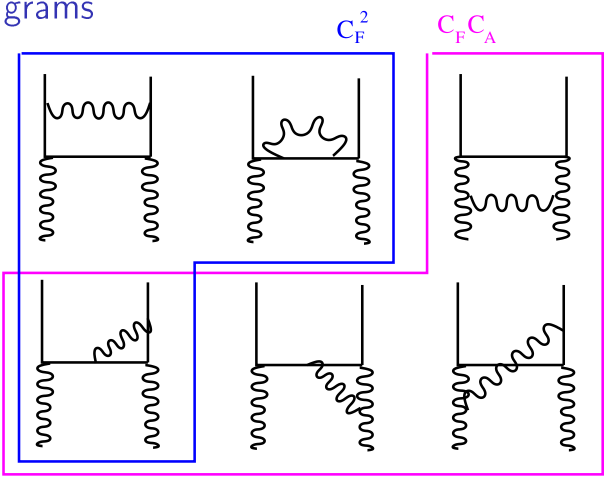
only "amplitude squared" diagrams



interferences added

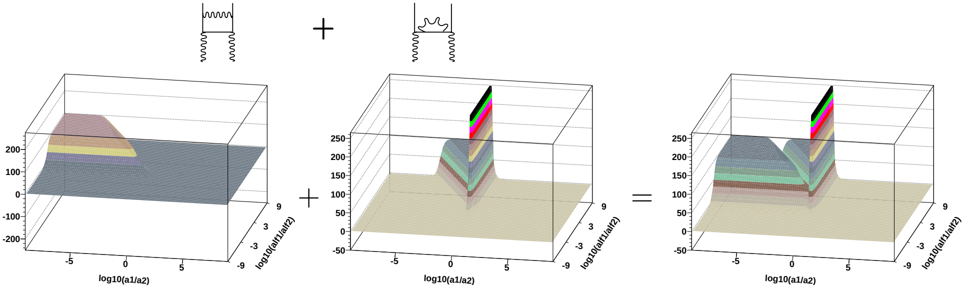
Both double- and single- logs cancelled after adding interferences.

Singlet diagrams



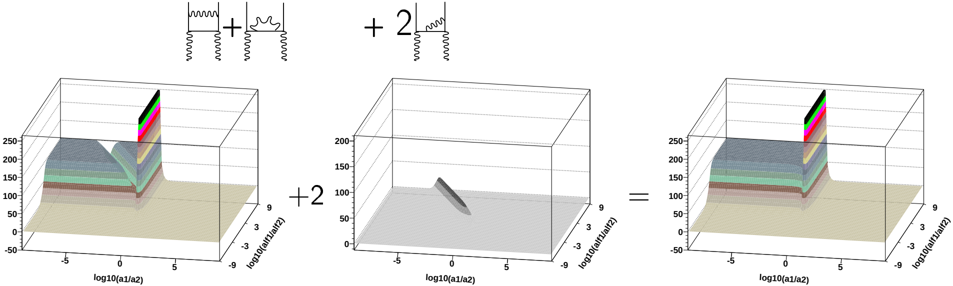
1- quark, 2 - gluon

Emission of a soft gluon from a quark. Plateaux bordered by equal rapidities – wrong virtuality ordering



The sum is a quadratic plateau with the canyon at equal virtualities.

Singlet diagrams $\sim C_F^2$



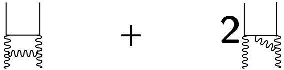
The canyon cancelled by the interference.

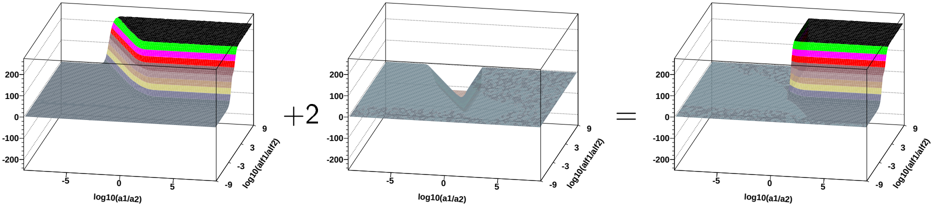
Uniform plateaux bordered by $a_1 = a_2$

Virtuality ordering turns out to be wrong!

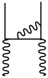
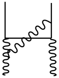
Singlet diagrams $\sim C_F C_A$

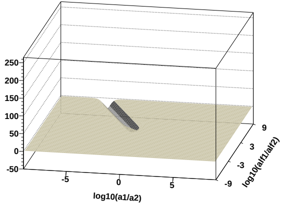
Emission of a soft gluon from a quark.

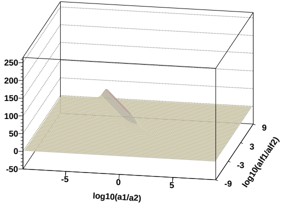


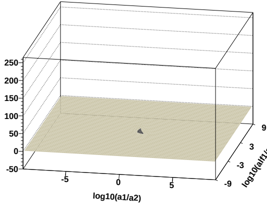


Singlet diagrams $\sim C_F C_A$

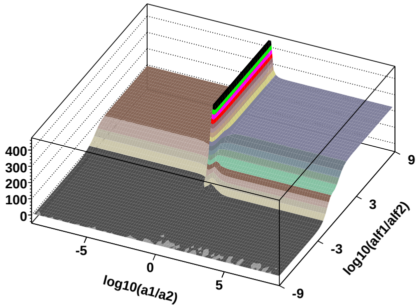
2  + 2 

2 

+2 

= 

All singlet diagrams



- 2 plateaux
  - brown - soft gluon emitted from quark $\sim C_F^2$
  - navy-blue - soft gluon emitted from gluon $\sim C_F C_A$

  borderline lies at $a_1 = a_2$
- central ridge - collinear singularity

Conclusions:

- Restoration of gauge invariance crucial (color coherence) in cancelling infra-red singularities
- Anguar ordering everywhere!
- We understand the soft limits of NLO exclusive kernels
- Analytical formulae crucial for defining crude distributions for *exclusive NLO Monte Carlo*