Colour coherence of soft gluons in the fully unintegrated NLO singlet kernels

Magdalena Sławińska

IFJ PAN, Cracow
in collaboration with S. Jadach, A. Kusina and M. Skrzypek

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The study presented here is a part of the development of
KRKMC - fully exclusive NLO Parton Shower Monte Carlo

- based on the collinear factorisation:
  Ellis, Georgi, Machacek, Politzer, Ross (EGMPR),
  Curci, Furmanski, Petronzio (CFP),
- CFP scheme as the main guide (axial gauge, $\overline{MS}$).
- aims at implementing **exactly** NLO DGLAP evolution of PDFs,
- uses new exclusive (fully unintegrated) NLO kernels

Mission statement:

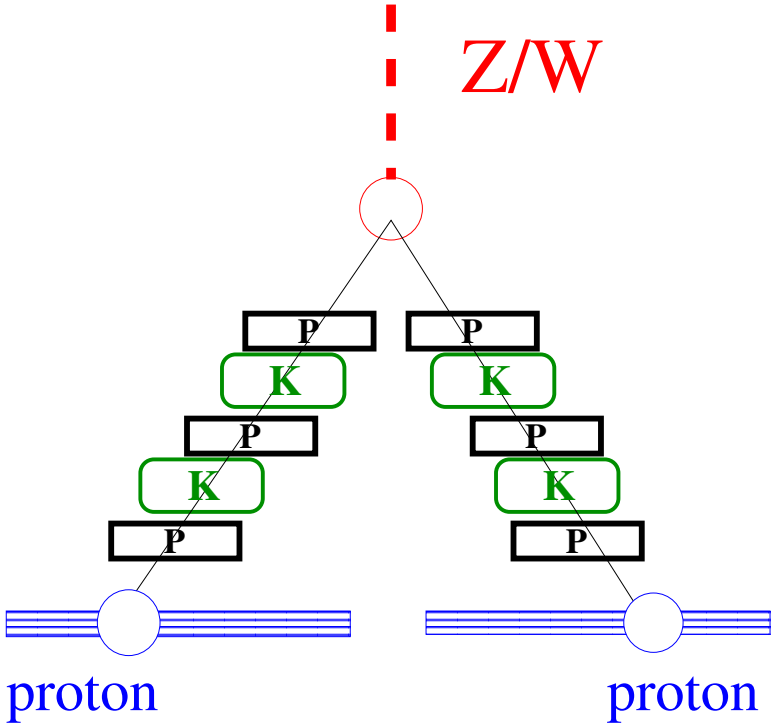
We construct the NLO Parton Shower by inserting NLO corections into a simpler LO shower. This is done by the reweighting procedure:

1. We generate the particles' kinematics for each emission from the simpified (crude) distribution.
2. This configuration enters with the weight $= \frac{\text{exact NLO diagram}}{\text{crude distribution}}$

Single Feynman diagrams entering the NLO kernel may have **soft singularities**. Hence, the Monte Carlo **weights will explode**, unless the crude exactly reproduces the soft singularities of NLO diagrams.

This analysis must be done analytically diagram-by-diagram, today I will only show graphical analysis.

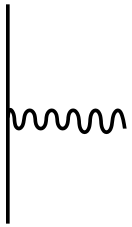
Kernels of collinear factorization

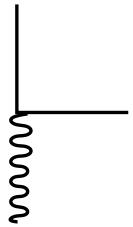


Kernels – two-particle-irreducible Feynman diagrams between projection operators

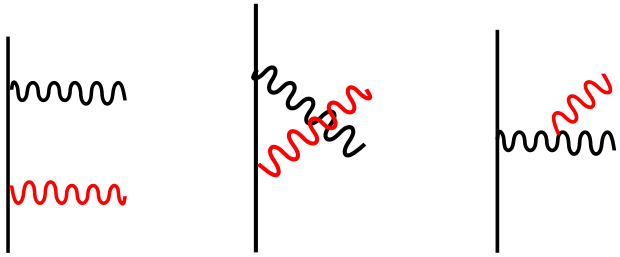
Example real diagrams in the kernel **K**

LO qq and qg amplitudes:

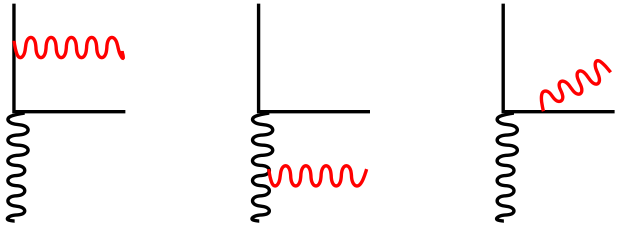




NLO corrections from additional gluon emisions:

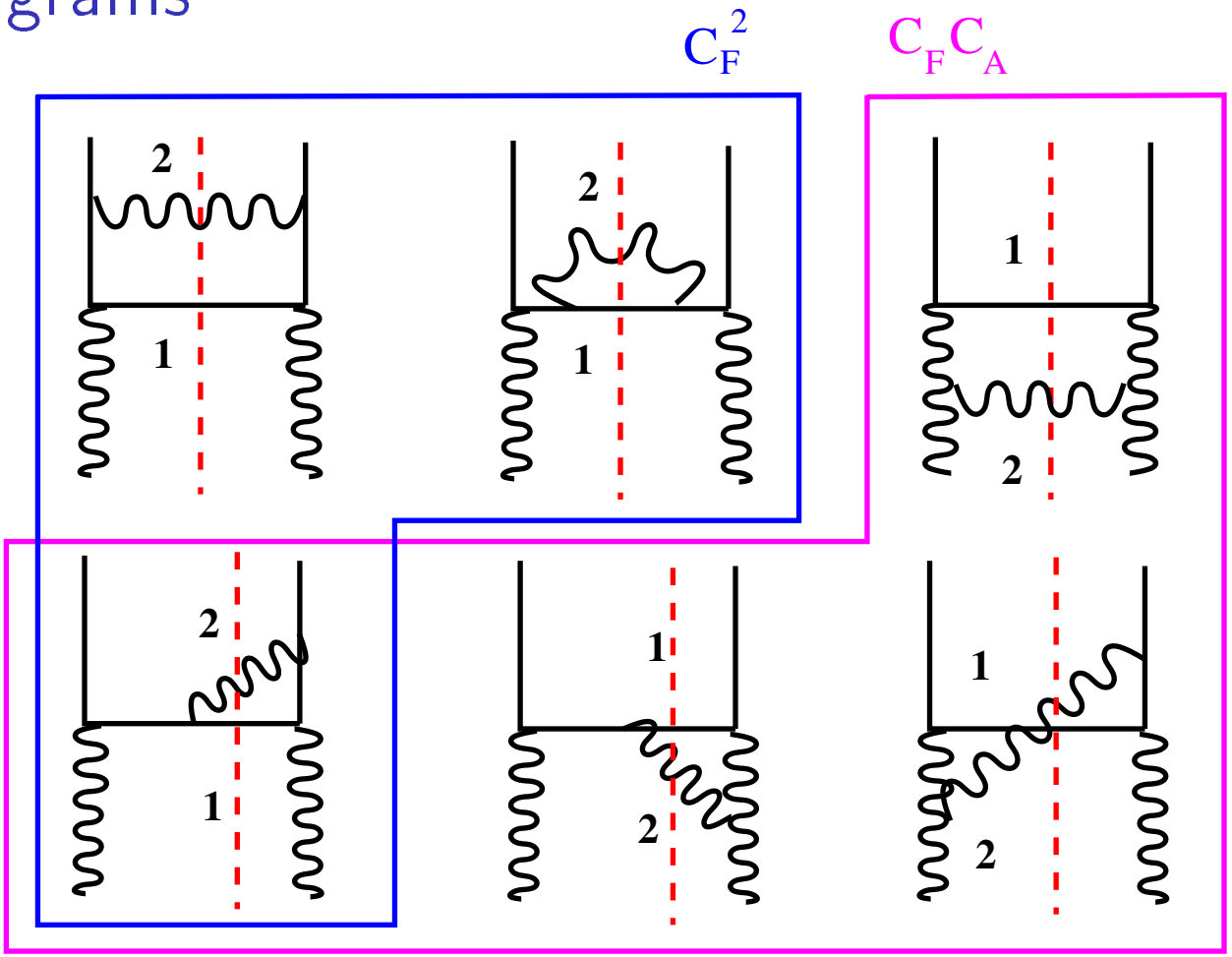


(non-singlet)

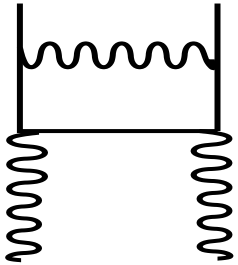


(singlet)

Singlet diagrams

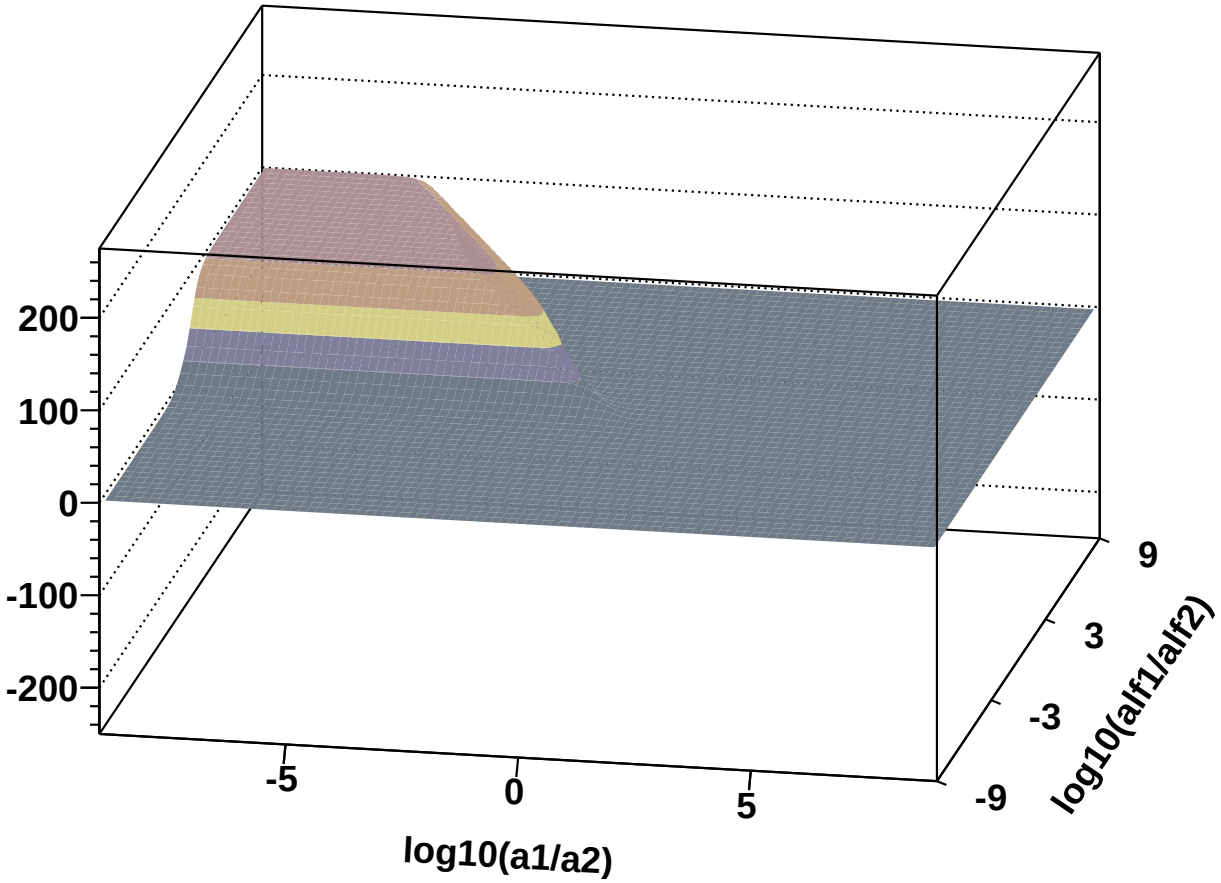


1 - quark, 2 - gluon



Brown plateau is eikonal double-log singularity

Diagonal cliff at equal virtualities ($v_i = \frac{k_{\perp i}}{\sqrt{\alpha_i}}$)



On the plots:

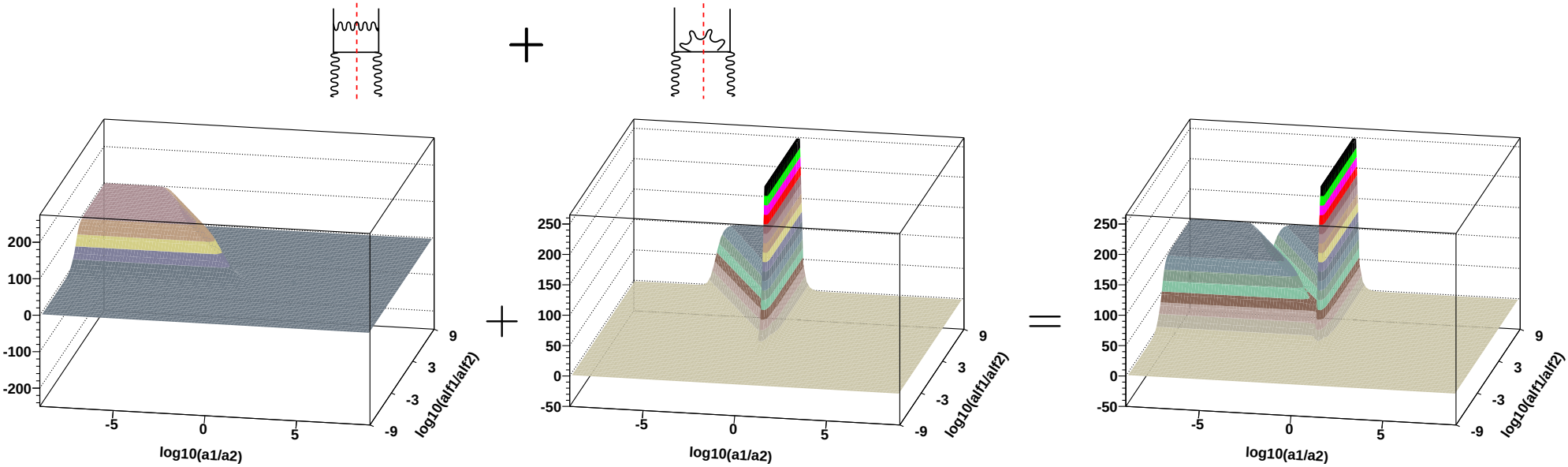
- Two-particles phase space parametrised with Sudakov variables:

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

- rapidity-related: $a_i = \frac{|k_{i\perp}|}{\alpha_i}$ variables
- normalisation to eikonal phase space $d\Psi = \frac{d\alpha_1}{\alpha_1}\frac{d\alpha_2}{\alpha_2}\frac{da_1}{a_1}\frac{da_2}{a_2}$,
- azimuthal angles integrated out,
- $\alpha_1 + \alpha_2 = 1 - x$ 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,
- and study the soft Sudakov limit $\begin{cases} k_{\perp i} \to 0 \\ \alpha_i \to 0 \end{cases}$ while $a_i = const$

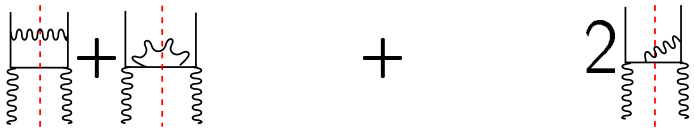
Diagrams $\sim C_F^2$

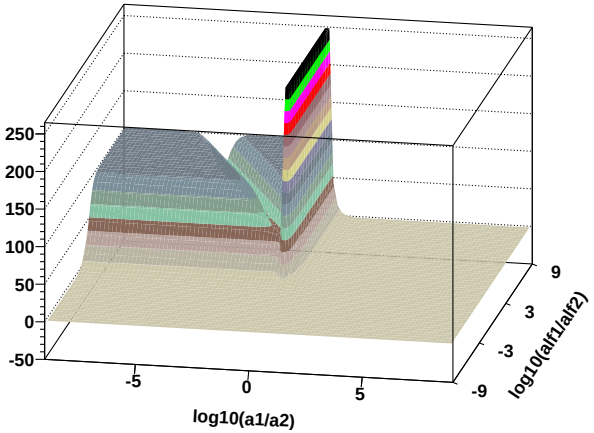
Emission of a soft gluon from a quark. Plateaux bordered by equal virtualities – wrong virtuality ordering



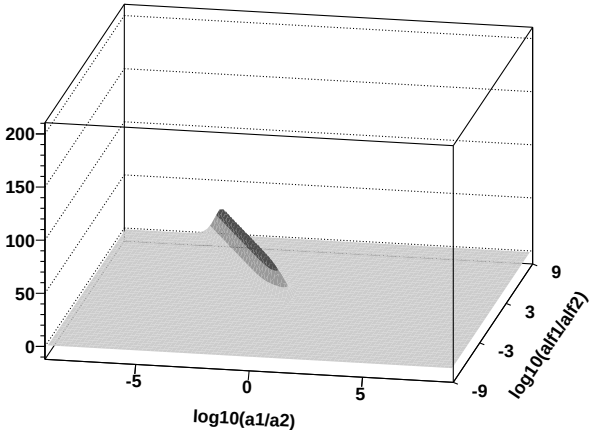
The sum is a quadratic plateau with the canyon at equal virtualities.

Diagrams $\sim C_F^2$

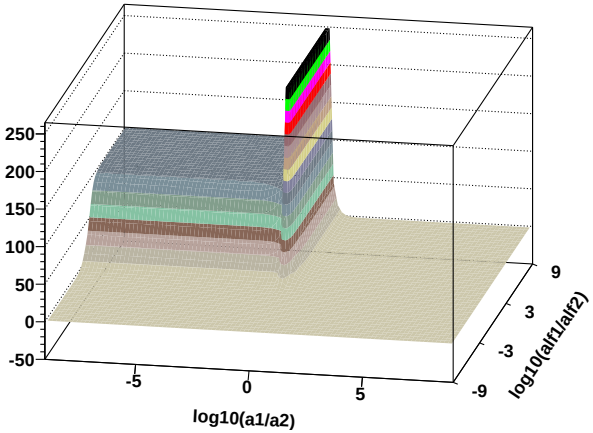




$+2$



$=$



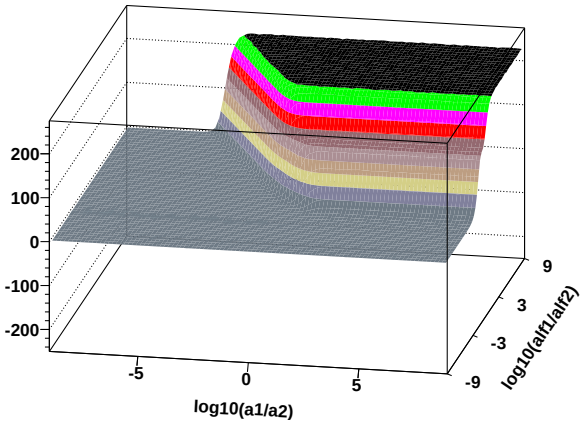
The canyon cancelled by the interference.

Uniform plateaux bordered by $a_1 = a_2$

Virtuality ordering turns out to be wrong!

Diagrams $\sim C_F C_A$

Emission of a soft gluon from a quark.



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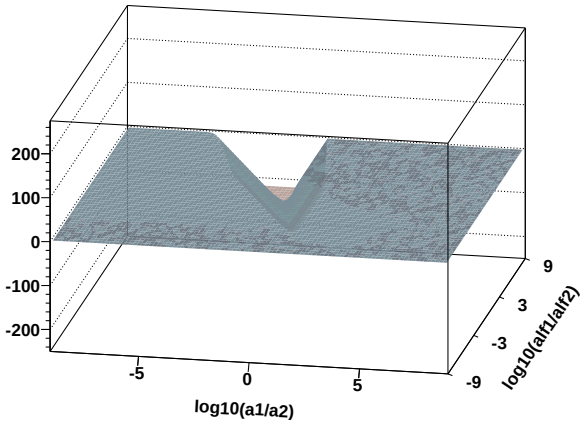

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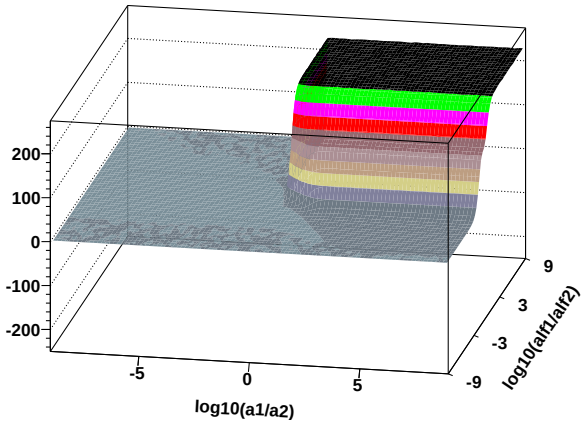
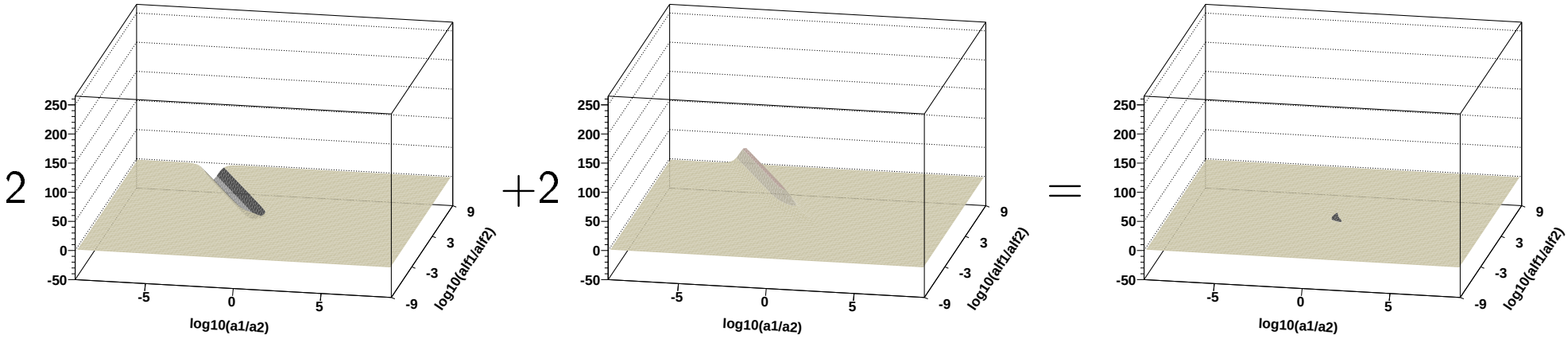


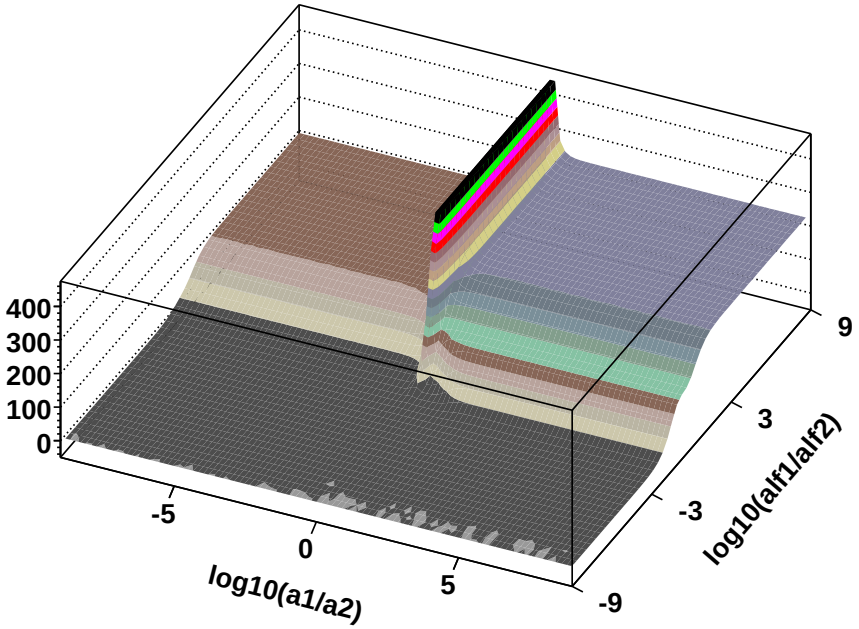
Interference corrects the plateau boundaries.

Diagrams $\sim C_F C_A$



The infinite canyon/ridge cancelled.
Only the little hill in the central region remains.

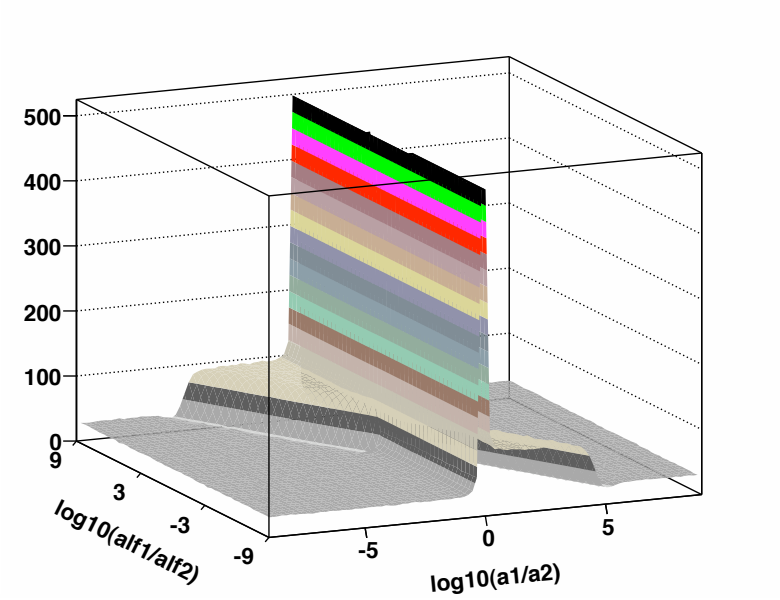
All singlet diagrams



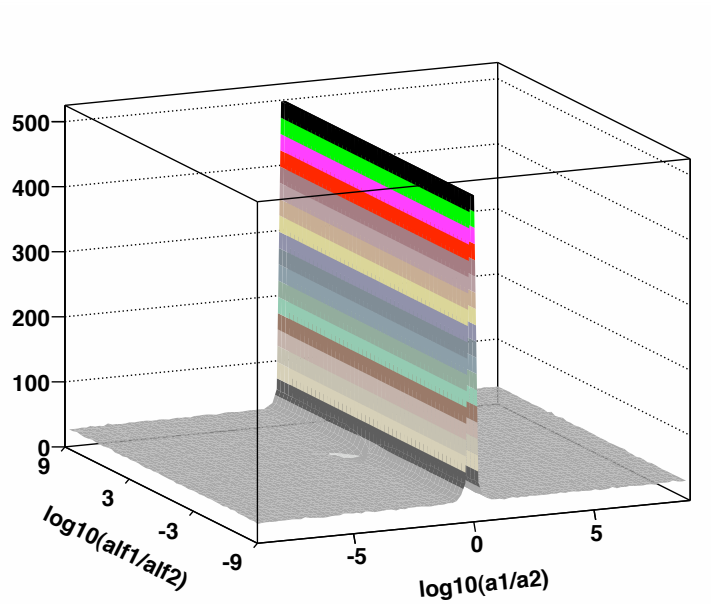
- 2 plateaux
  - brown - soft gluon emitted from quark $\sim C_F^2$
  - navy-blue - soft gluon emitted from gluon $\sim C_F C_A$

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

Quick overview: non-singlet kernels



only "squared amplitudes"



interferences added

Both double- and single- infrared logs cancelled after adding interferences. Collinear singularity remains.

Angular ordering is preferred.

Conclusions:

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