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Gap survival effects and diffraction

- Why resummation
- Example: j+H+j
- Lessons from gap survival calculations
- Outlook towards diffraction

JHEP 0709:119 with Jeff Forshaw

Work in collaboration with Roman Pasechnik

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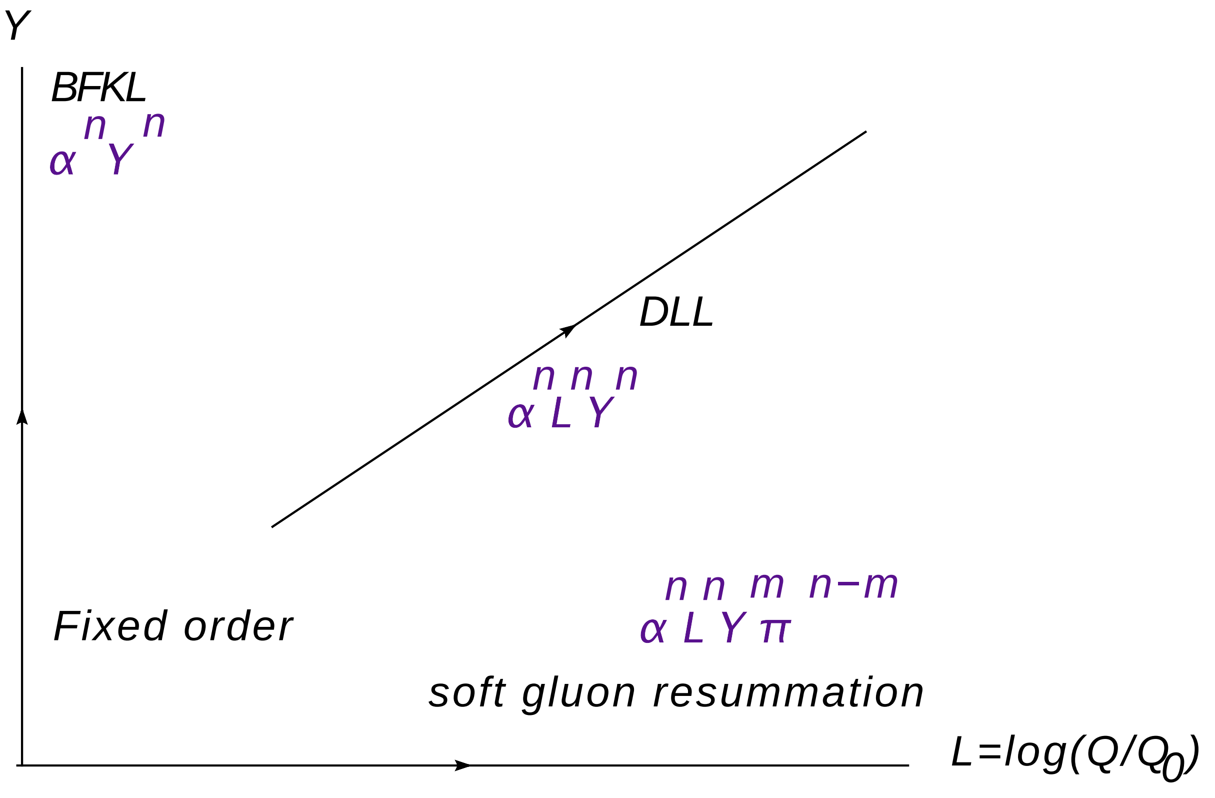
Why resummation?

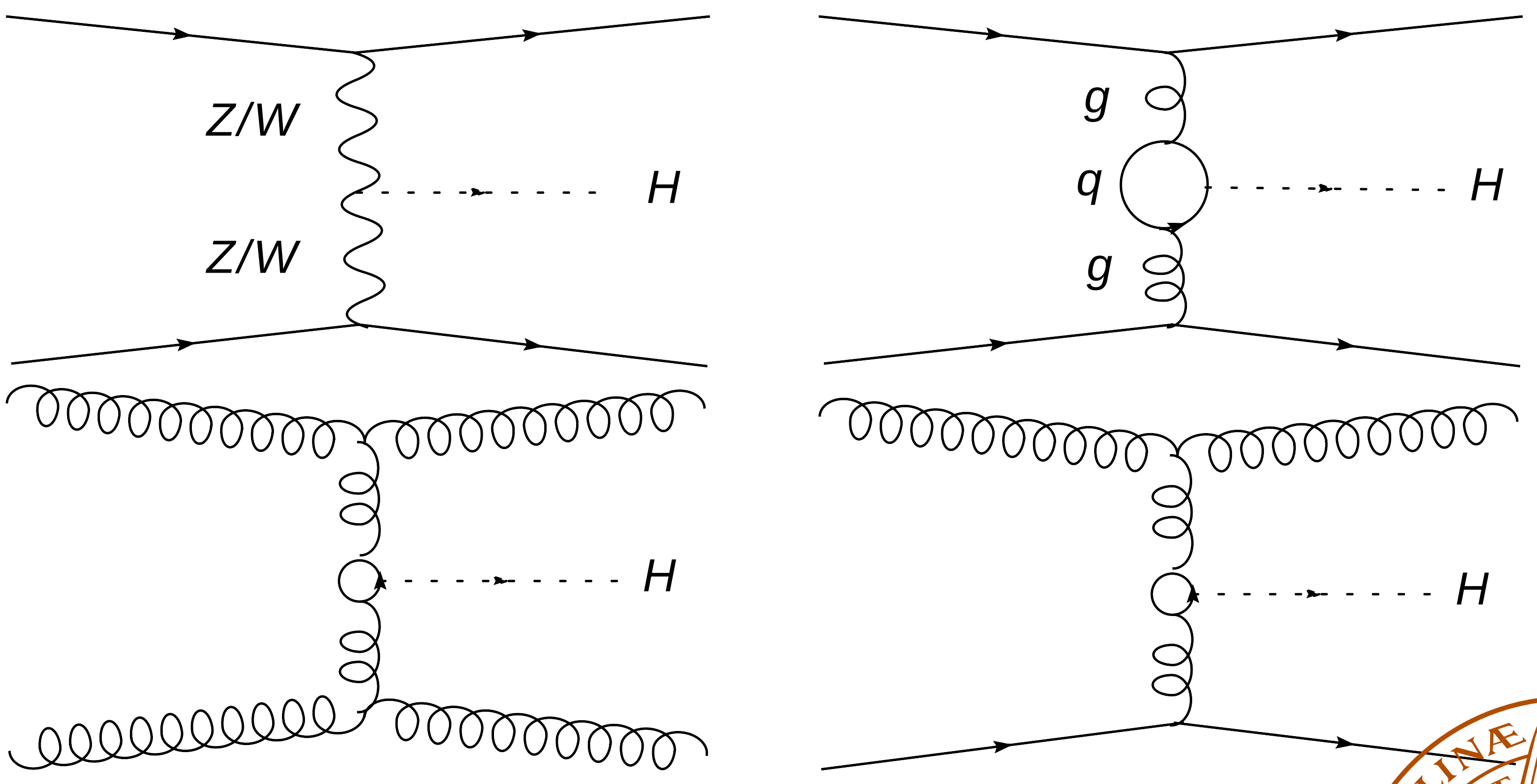
- Fixed order calculations are not always appropriate
- A propagator corresponding to a close to on shell particle may compensate the moderate smallness of α_s
- Collinear region, where a parton is emitted almost in same direction as parent parton
- Soft region, where a parton may be emitted in any direction, but has low momentum

What resummations?



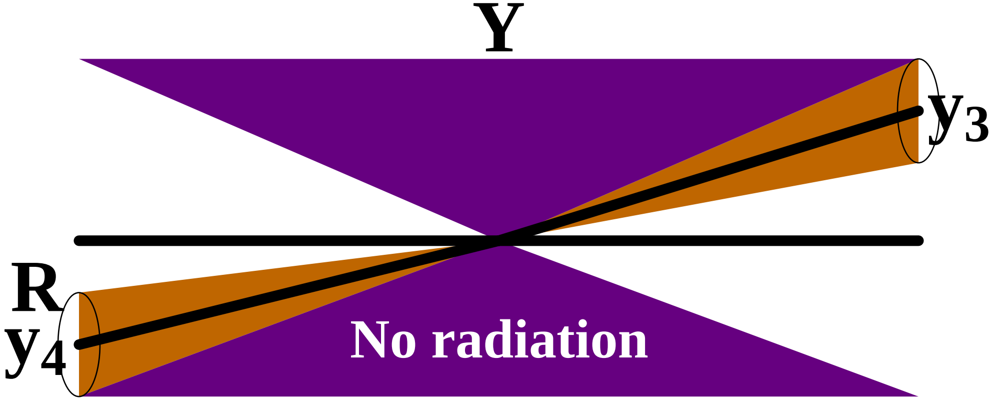
Example: j+H+j

Higgs colorless and (almost) irrelevant



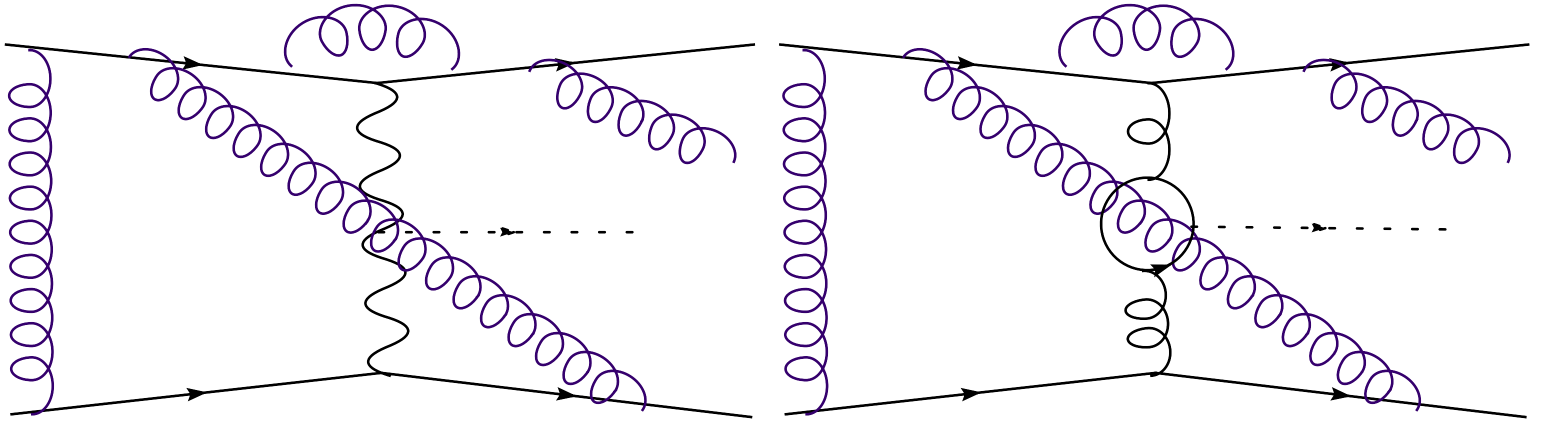
Observable

- We forbid $k_T > Q_0$ in the in-between jet region with rapidity interval Y, taken such that $Y = |y_3| + |y_4| - 2R$
- We consider the probability **not to** emit any gluon with transverse momentum larger than Q_0 within the rapidity gap. This we refer to as the **gap survival** probability



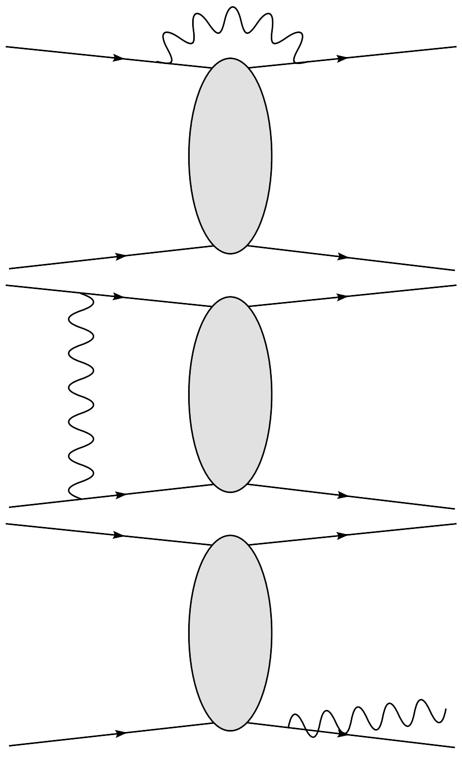
- For soft gluons the real and virtual corrections cancel $\rightarrow$ We can access the radiation by calculating the eikonal part of loop diagrams

Gluons to resum



- Quarks and gluons will radiate gluons
- Small α_s is compensated by large phase space (1/(small))
- **Soft** gluons $\rightarrow$ powers of $L = \log(Q^2/Q_0^2)$ and powers of rapidity Y or π, $\alpha_s^n L^n Y^m (i\pi)^{n-m}$, $m \leq n$
- Extra gluons may also change an initial color structure

Calculations - what to learn from QED?

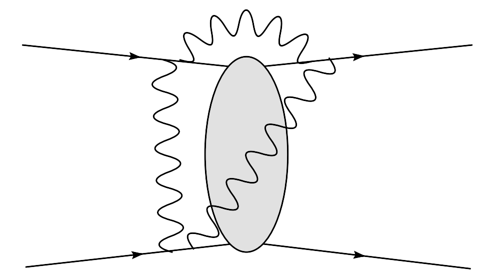


- Vertex correction diagram diverges for soft photons

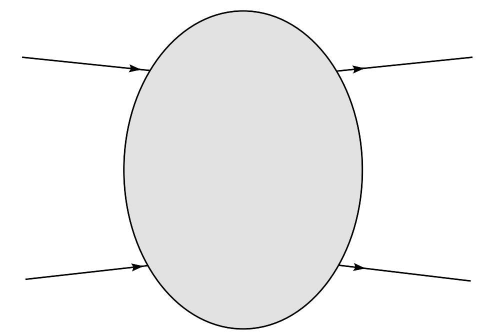
- t plus u channel contributions give in addition a Coulomb phase
  $\longrightarrow$ Not extra interesting for QED

- Amplitude for emitting soft photons also diverges

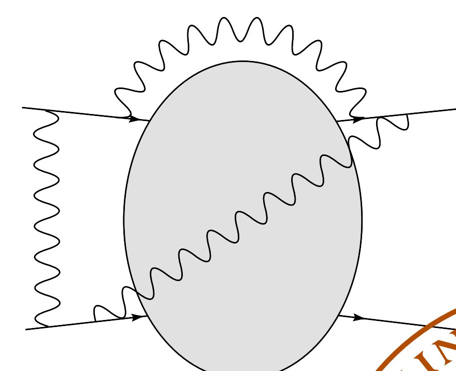
- Need an all order resummation of photons
- Too complicated in general, but can be done when photons strongly ordered in transverse momenta are preferred



- First add one extra photon...
- Then treat that diagram as the hard process



- Add new softer photons
- Treat the resulting diagram as the hard process... and so on
- This is OK, as long as “messed up” photons are kinematically suppressed



QCD

- In QCD the color structure complicates the calculations
- Need a color basis

  For the quark-quark case we use the singlet-octet basis

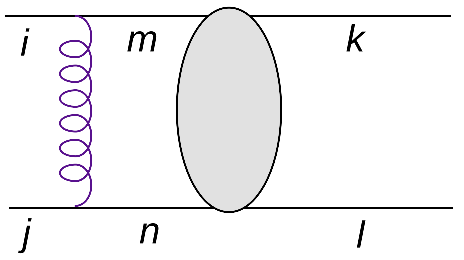
$$\begin{aligned} \text{general amplitude} &= (\text{singlet part}, \text{octet part}) \\ M_{j+H+j} &= (M_{EW}, M_{QCD}) \end{aligned}$$

- Note, this basis refers to the **exchange**, we sum over incoming or outgoing quarks as we are "color blind"
- Again infinities in loop corrections cancel real emission

  $\longrightarrow$ we can access real emission by calculating virtual correction
- Need to sort contributing diagrams in this basis
- For processes with external gluons, the principle is the same, but the basis contains more states corresponding to higher multiplets

Color treatment

- The hard scattering can be a color singlet



$$C^{(1)}_{mnkl} = \delta_{mk}\delta_{nl}$$

or a color octet

$$C^{(8)}_{mnkl} = (T^a)_{mk}(T^a)_{nl} = \frac{1}{2}\left(\delta_{ml}\delta_{kn} - \frac{1}{N}\delta_{mk}\delta_{nl}\right)$$

- The color effect of exchanging a t-channel gluon is

$$T^a_{im}T^a_{jn}C^{(1)}_{mnkl} = C^{(8)}_{ijkl}$$

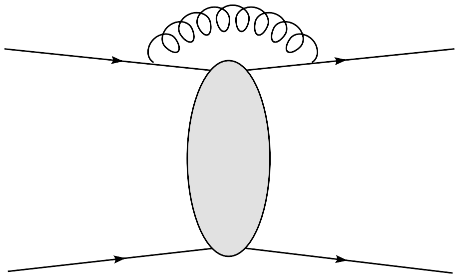
$$T^a_{im}T^a_{jn}C^{(8)}_{mnkl} = \frac{N^2-1}{4N^2}C^{(1)}_{ijkl} - \frac{1}{N}C^{(8)}_{ijkl}$$

- This should be multiplied with the kinematic part associated with t-channel gluon exchange
- The effect of vertex corrections and u-channel gluons can be treated similarly
- In the end all the contributions are added, resulting in a matrix describing the color structure and the radiation probability

$$\mathbf{\Gamma} = \sum_{i<j} \mathbf{\Gamma}_{ij}^{C} \Omega_{ij}$$

where $\mathbf{\Gamma}_{ij}^{C}$ describes the effect on the color structure and Ω_{ij} is the result of phase space integration

- Vertex corrections do not change whether the total exchange is a singlet or an octet exchange $\longrightarrow$ only diagonal entries

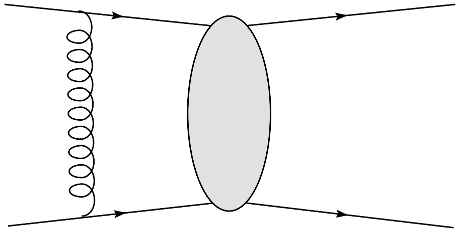


- After integrating the loop momentum over the observed momentum region this gluon exchange can be viewed as a diagonal matrix acting on the hard interaction

$$\xi \begin{pmatrix} \frac{N^2-1}{4N}\rho(Y, y_3, y_4) & 0 \\ 0 & \frac{-1}{2N}\rho(Y, y_3, y_4) \end{pmatrix} \begin{pmatrix} M_{EW} \\ M_{QCD} \end{pmatrix}$$

where $\xi = \int_{Q_0}^{Q} \alpha_{\mathrm{s}}(q_T)\frac{dq_T}{q_T}$ and the basis is the normalized version of the singlet-octet basis

- t and u channel diagrams may change an octet exchange in to a singlet exchange and opposite



- These diagrams are much more interesting for QCD
- The result (in the normalized basis) is

$$\xi \begin{pmatrix} 0 & \sqrt{\frac{N^2-1}{4N^2}} i\pi \\ \sqrt{\frac{N^2-1}{4N^2}} i\pi & -\frac{1}{N} i\pi + \frac{N}{2} Y + \frac{N}{2} \rho(Y, y_3, y_4) \end{pmatrix} \begin{pmatrix} M_{EW} \\ M_{QCD} \end{pmatrix}$$

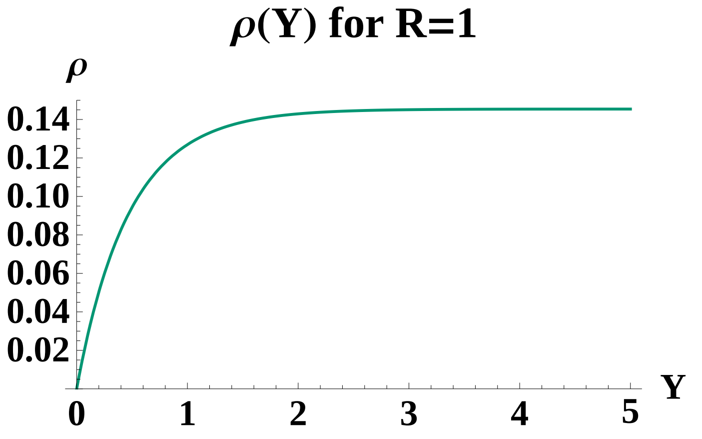
ρ-terms, present for QED as well

Y-terms, even radiation in rapidity, leading in color

$i\pi$-terms $\rightarrow$ not just a (Coulomb) phase only significant for SU(small)

- Resumming gluons gives (in the normalized basis)

$$\mathbf{M} = \exp\left[-\frac{2}{\pi}\xi\mathbf{\Gamma}\right]\begin{pmatrix} M_{EW} \\ M_{QCD} \end{pmatrix}$$



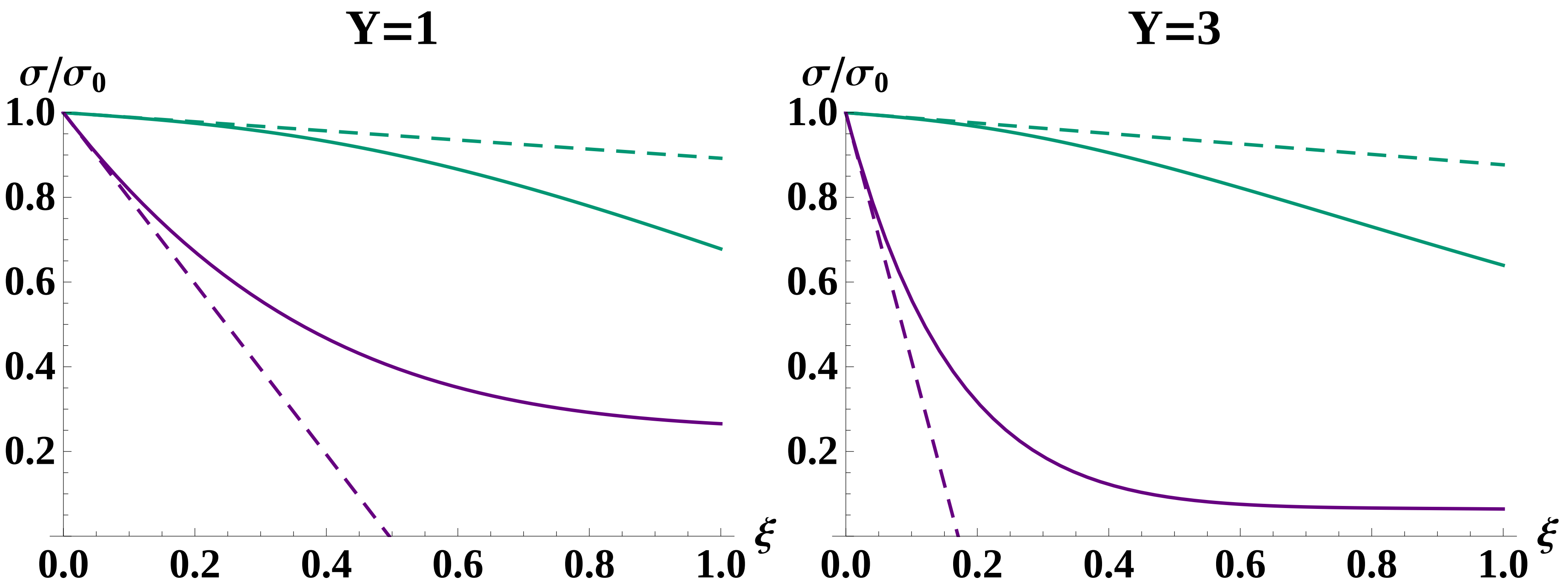
where

$$\mathbf{\Gamma} = \begin{pmatrix} \frac{N^2-1}{4N}\rho(Y,y_3,y_4) & \sqrt{\frac{N^2-1}{4N^2}}i\pi \\ \sqrt{\frac{N^2-1}{4N^2}}i\pi & -\frac{1}{N}i\pi + \frac{N}{2}Y + \frac{N^2-1}{4N}\rho(Y,y_3,y_4) \end{pmatrix}$$

with

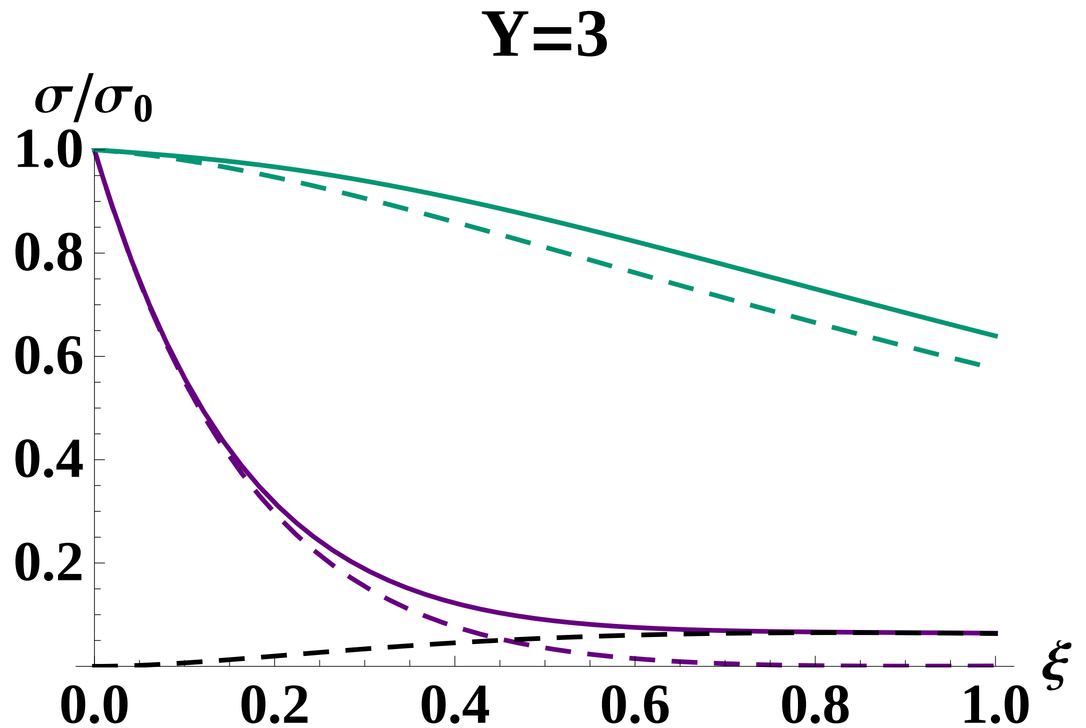
$$\rho(Y,y_3,y_4) = \frac{1}{2}\left(\log\frac{\sinh(|y_3|+Y/2)}{\sinh(|y_3|-Y/2)} + \log\frac{\sinh(|y_4|+Y/2)}{\sinh(|y_4|-Y/2)}\right) - Y.$$

Gap survival for qq



The gap survival cross section normalized to the lowest order cross section as a function of $\xi = \int_{Q_0}^{Q} \alpha_s(q_T) \frac{dq_T}{q_T}$ for initial octet (gg $\rightarrow$ H) and initial singlet (WBF) exchange. **Dashed lines** are the order α_s results.

Gap survival for qq, decomposed



The **colored dashed lines** are the octet part of initial octet exchange and the singlet part of initial singlet exchange. The **black dashed** line is the octet part of initial singlet exchange *and* the singlet part of initial octet exchange

Concluded for j+H+j

We have resummed logarithms in (hard scale)/(jet veto scale) to all orders up to

- Jet algorithm dependence (Dasgupta, Delenda, Banfi, Appleby)
- Non global logs (Dasgupta, Salam)
- "Super leading logs" (Forshaw, Seymour, Kyrieleis, Keates, Marzani)

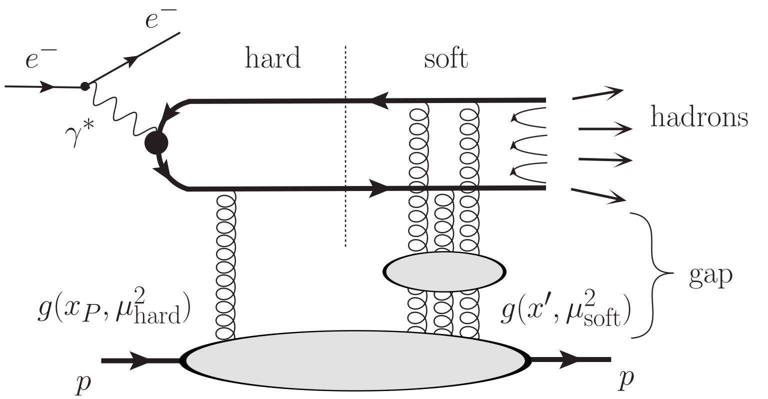
Resummation can help to distinguish between weak boson fusion and gluon-gluon fusion for Higgs production in association with forward jets

Lessons from gap survival calculations

- Treating the full color structure becomes important when large logarithms are summed
- In QCD the $i\pi$-terms don't give just a phase, but rearrange the color structure such that octets are turned into singlets which have a chance to survive
- The gap survival contribution is dominated by the singlet for large logarithms
- This is in agreement with diffraction models
- Judging from plateau in plot, identifying a singlet and a gap survival event may not be a bad idea

Outlook towards diffraction

- In the PEI model (Pasechnik, Enberg and Ingelman 2010) calculations are done in impact parameter space
- The diffractive part is identified with the singlet
- However, so far only leading contributions in N_c to order α_s^2 are kept, we like to improve on this ..



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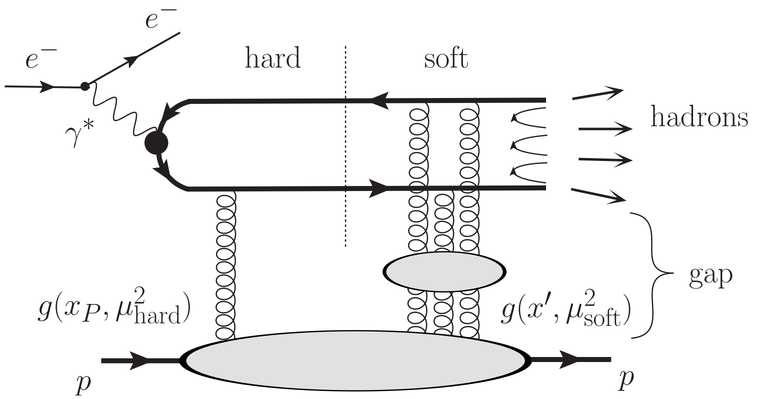
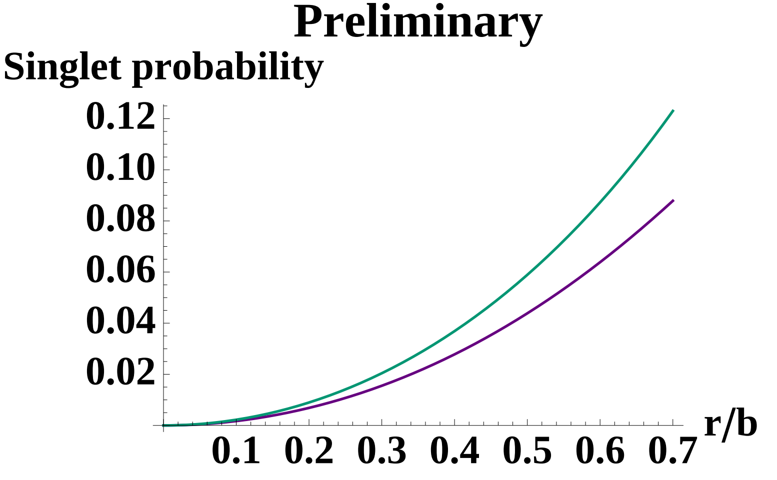
- Singlet in PEI model and with full color resummation for $\alpha_s = 0.5$ and $m_g = 0.7$ GeV





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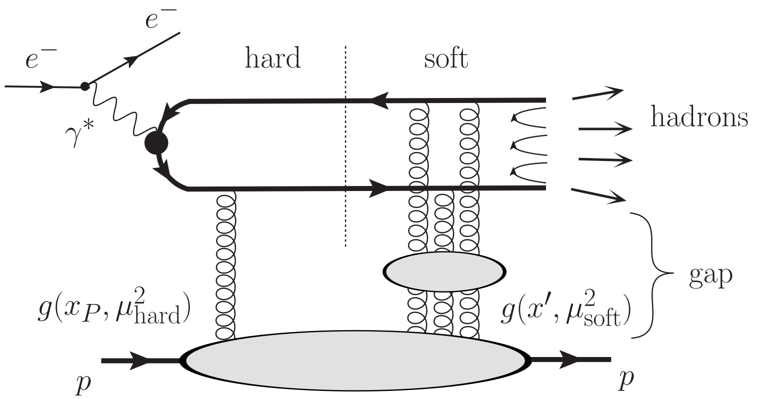
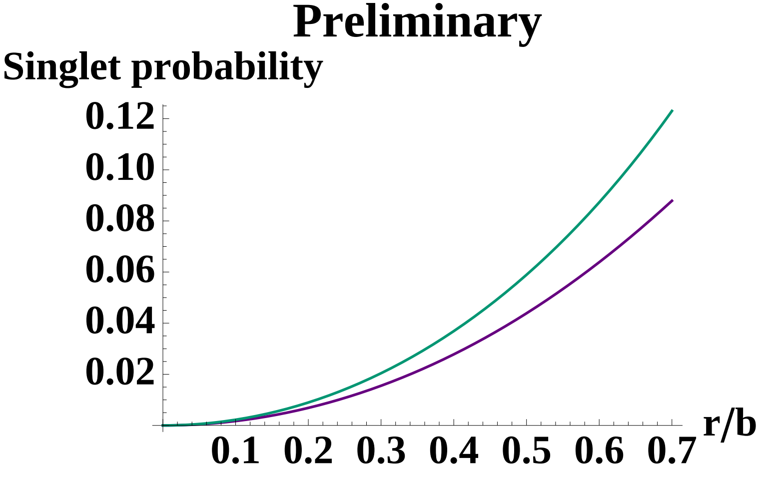
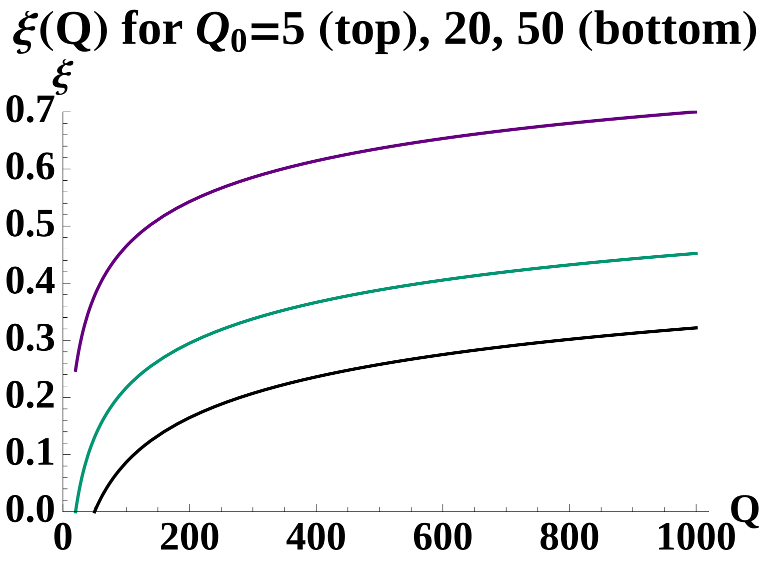




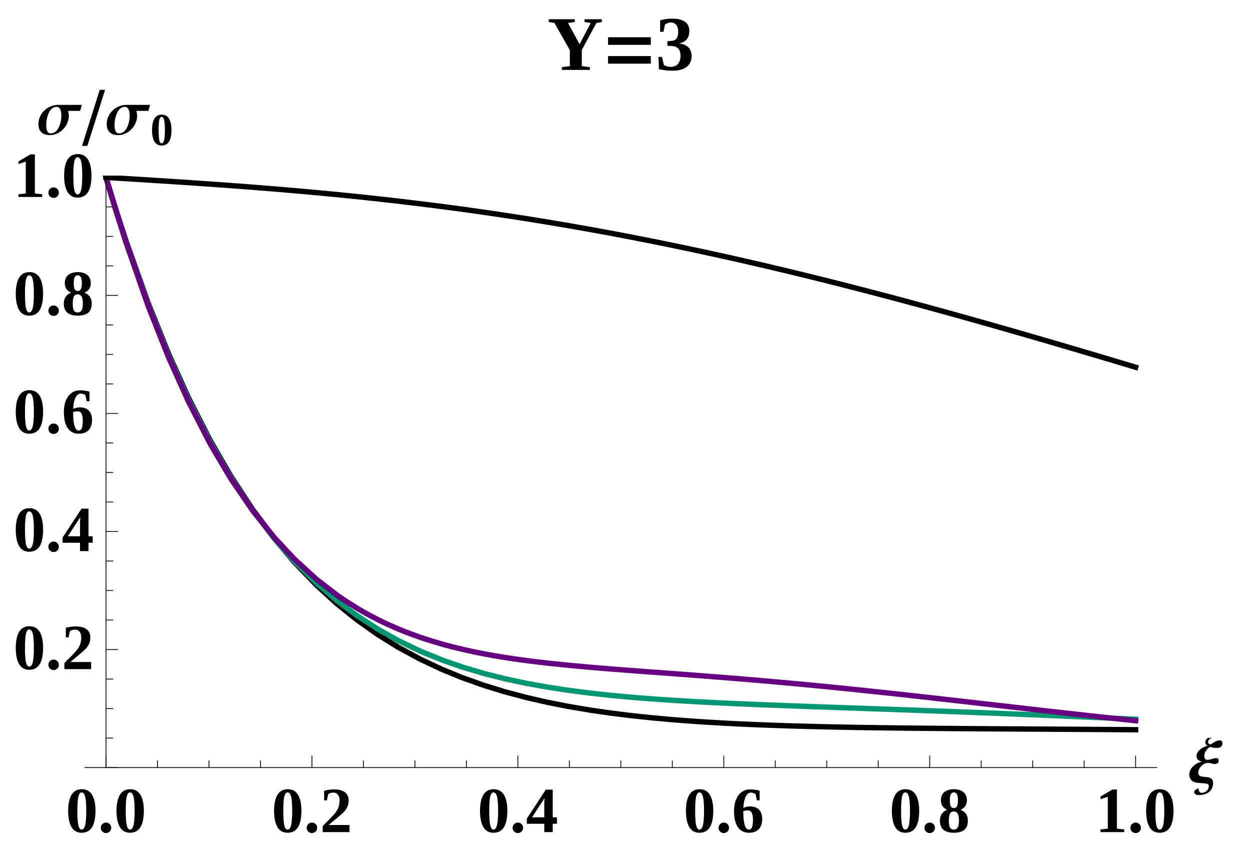
Thank you for your attention

Backup: $\boldsymbol{\xi = \int_{Q_0}^{Q} \alpha_s(q_T)\frac{dq_T}{q_T}}$



- The function $\xi = \int_{Q_0}^{Q} \alpha_s(q_T)\frac{dq_T}{q_T}$ depending on Q for fixed Q_0, $Q_0 = 5$, $Q_0 = 20$ and $Q_0 = 50$.

Backup: Gap survival for qq qg and gg



The gap survival probability for **quarks**, **gluons** and **one quark and one gluon**, **dashed** lines without $i\pi$ terms.

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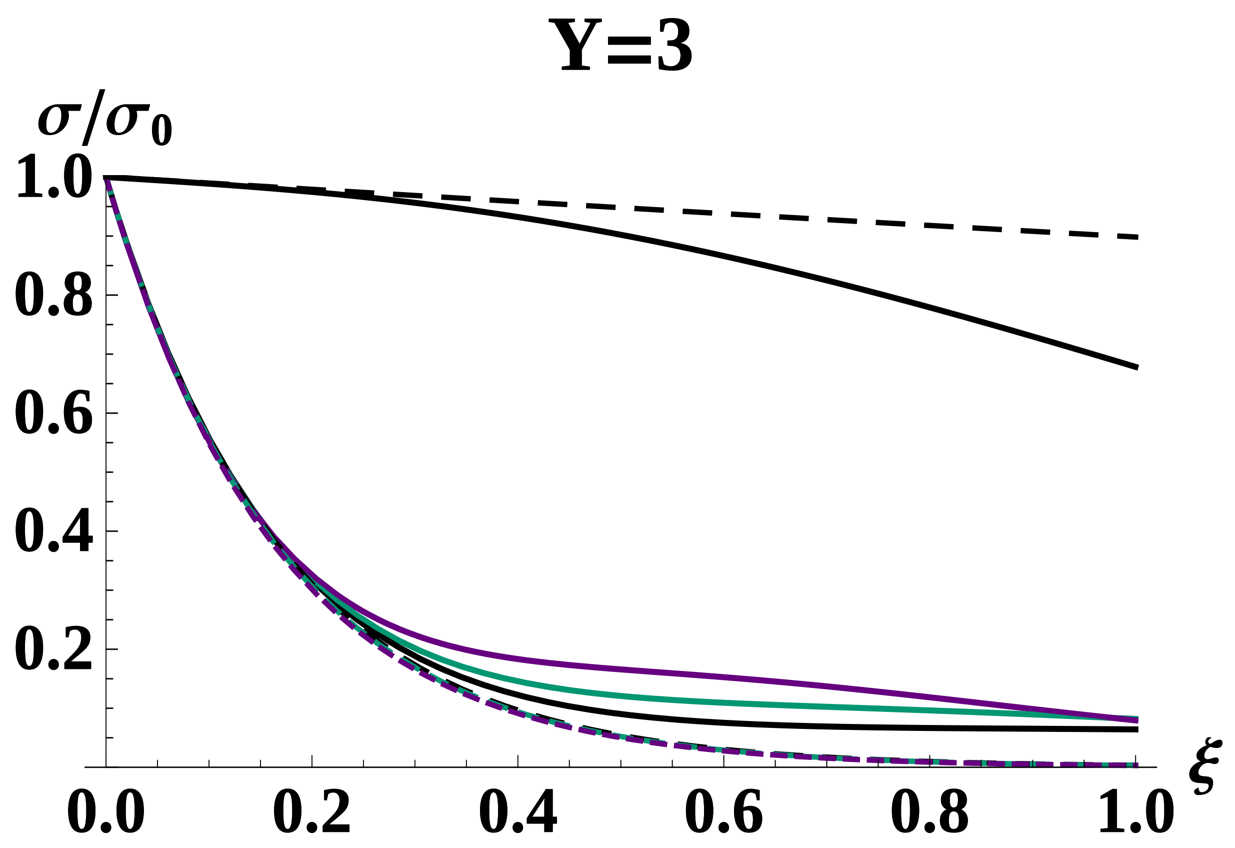
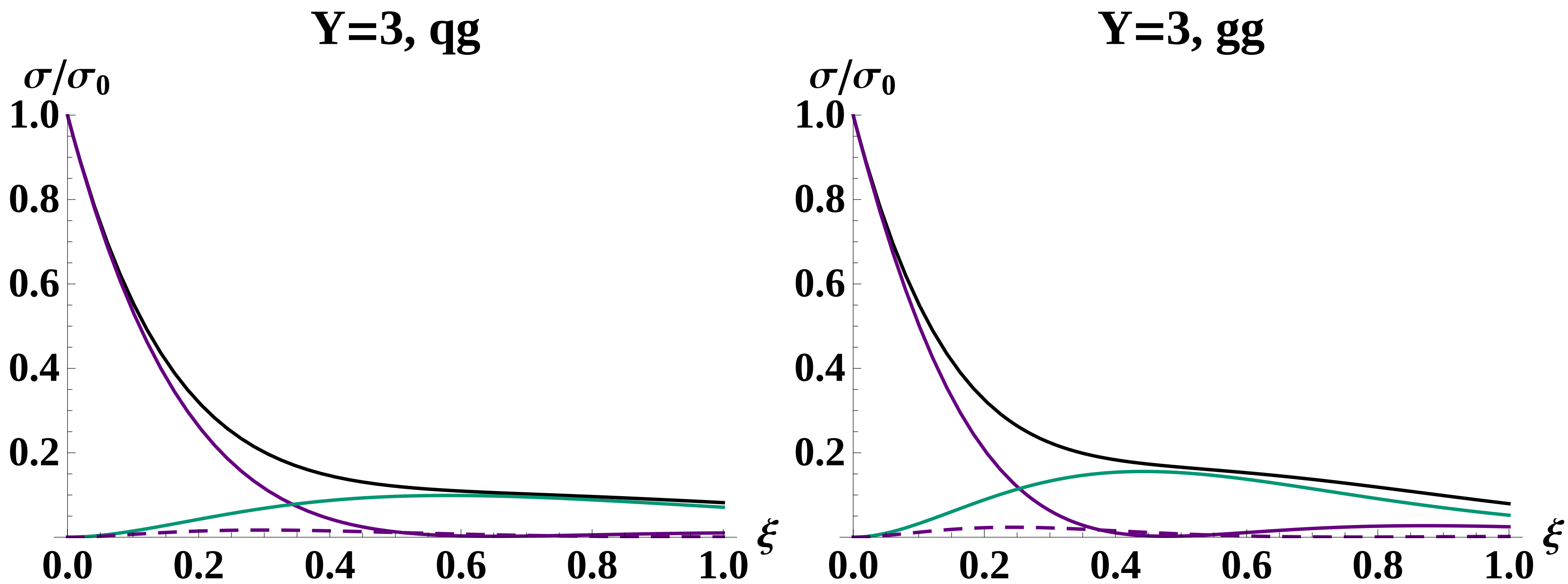


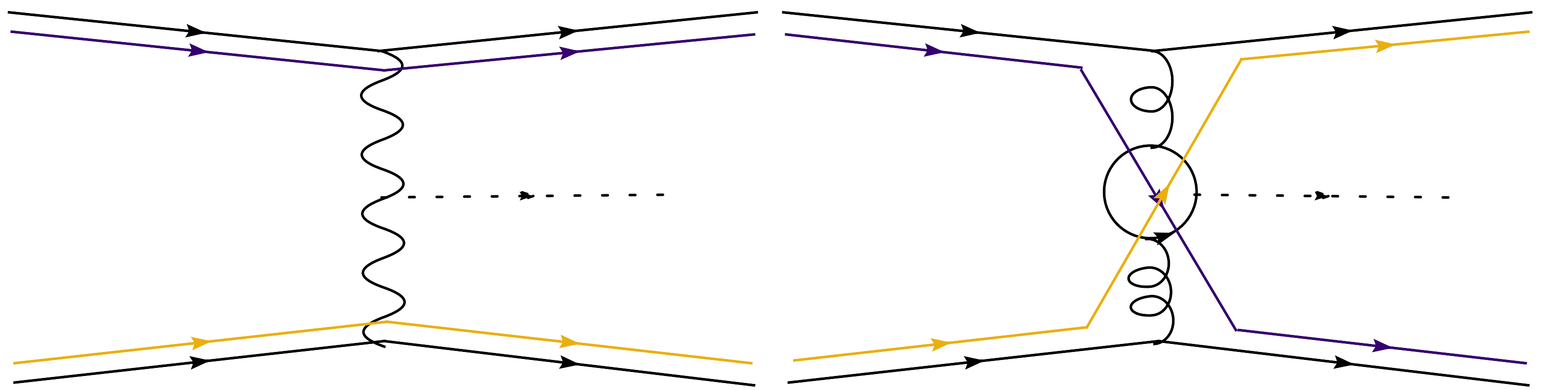
The gap survival probability for **quarks**, **gluons** and **one quark and one gluon**, **dashed** lines without $i\pi$ terms.

Backup: Gap survival for qg and gg, decomposed



Black lines are the total gap survival probabilities, purple is the **octet part** and green corresponds to **singlet**. **Dashed lines** represent higher multiplets (symmetric octet for qg and decuplets for gg).

Backup: acceleration of color!



- All accelerated charges radiate
- For weak boson fusion the color is not being accelerated much $\sim p_T$
- For gluon-gluon fusion the change in momentum is rather $\sim \sqrt{s}$

Backup: Why resummation for Higgs?

- We like to measure the Higgs couplings to weak boson fusion
- ... and to the top quark
- We can use the different radiation pattern associated with weak boson fusion and gluon-gluon fusion to distinguish the processes

Backup: gg $\rightarrow$ gg (H)

- Same principle, but more complicated
- Solution 1: Use multiplets and Young tableaus to keep track of color structure
- Example $8 \otimes 8 = 1 + 8 + 8 + 10 + \overline{10} + 27$

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- $\longrightarrow$ Orthogonal basis to deal with the color structure
  Oderda, Sterman, Kidonakis

- In the (non-normalized) basis $1 + 8^s + 8^a + (10 + \overline{10}) + 27$ the result of resummation is:

$$\Gamma_{gg} = \frac{3}{2}\rho(Y, y_3, y_4)\,\mathbf{1} + \begin{pmatrix} -\frac{3}{4}\pi i & 0 & -3\pi i & 0 & 0 \\ 0 & \frac{3}{2}Y & -\frac{3}{4}\pi i & -\frac{3}{2}\pi i & 0 \\ -\frac{3}{8}\pi i & -\frac{3}{4}\pi i & \frac{3}{2}Y & 0 & -\frac{9}{8}\pi i \\ 0 & -\frac{3}{5}\pi i & 0 & 3Y - \frac{3}{4}\pi i & -\frac{9}{10}\pi i \\ 0 & 0 & -\frac{1}{3}\pi i & -\frac{2}{3}\pi i & 4Y - \frac{5}{4}\pi i \end{pmatrix}$$

with

$$\rho(Y, y_3, y_4) = \frac{1}{2}\left(\log\frac{\sinh(|y_3| + Y/2)}{\sinh(|y_3| - Y/2)} + \log\frac{\sinh(|y_4| + Y/2)}{\sinh(|y_4| - Y/2)}\right) - Y.$$