Rapidity gap distribution in diffractive deep-inelastic scattering and parton genealogy

Stéphane Munier

Centre de physique théorique
École polytechnique, CNRS, Université Paris-Saclay

Based on work with A.H. Mueller
arXiv:1805.02847, PRD and 1805.09417, PRL (published Aug 2018)
and with Dung Le (in progress)

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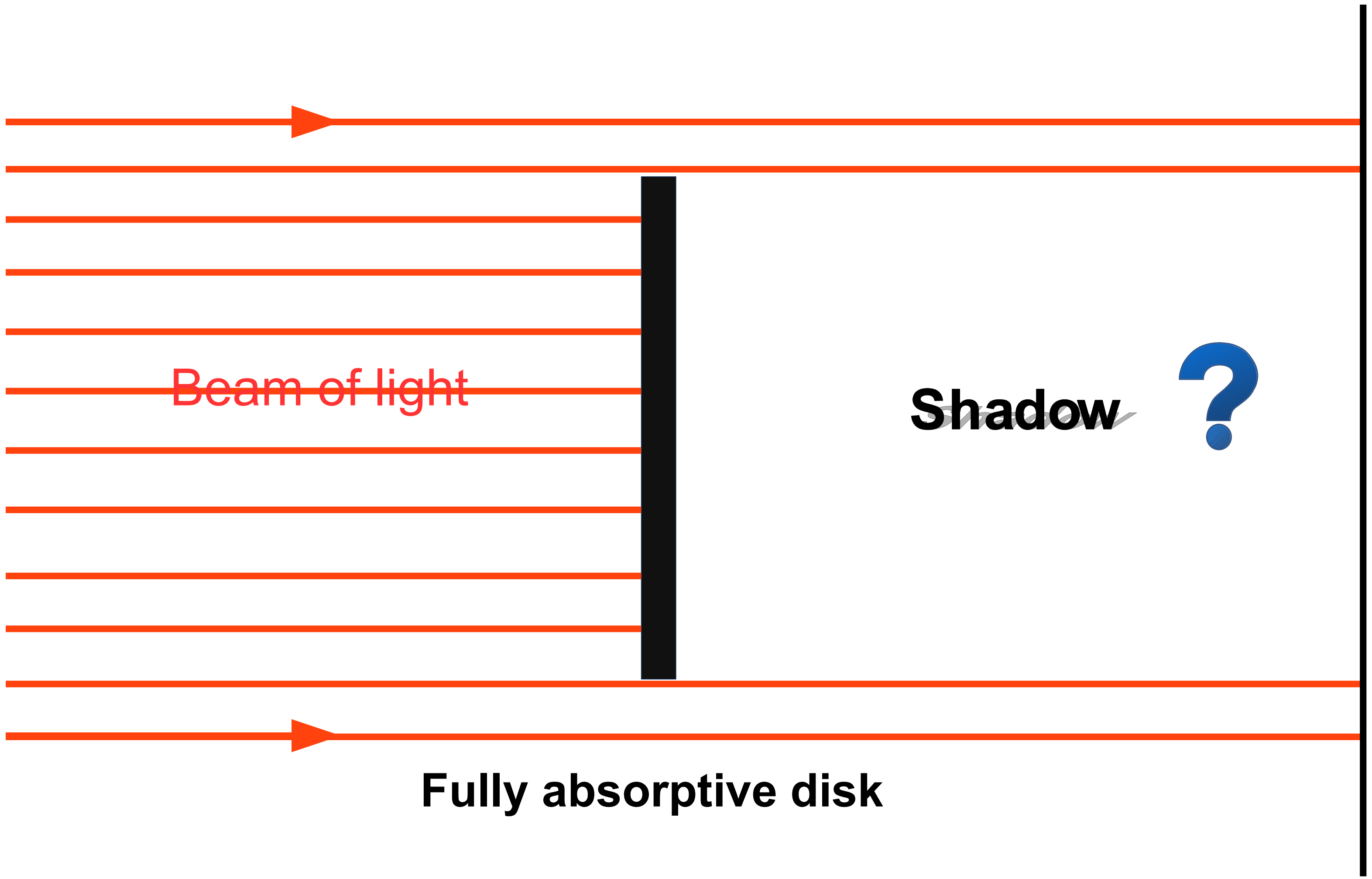
Diffraction in optics



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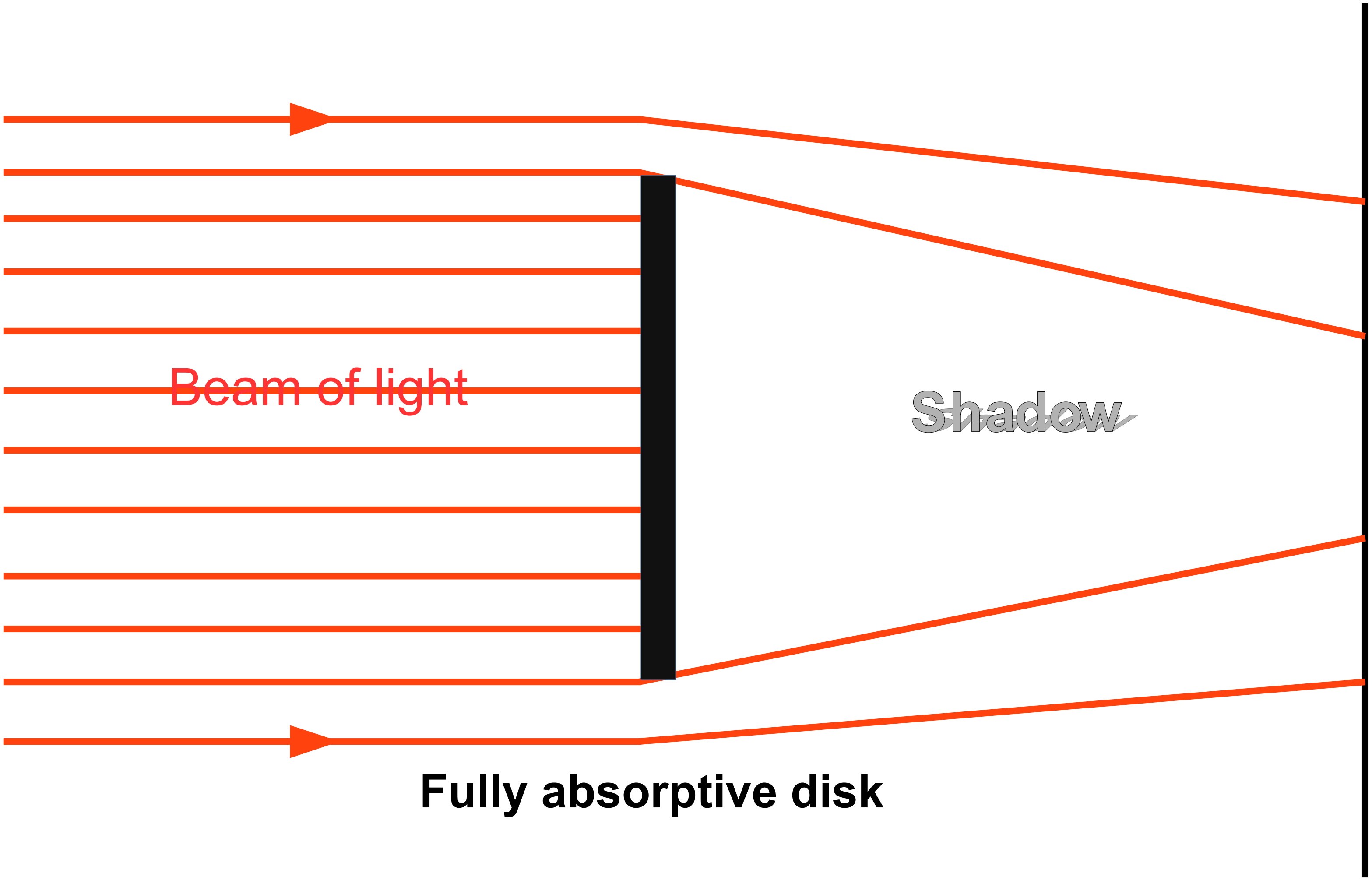
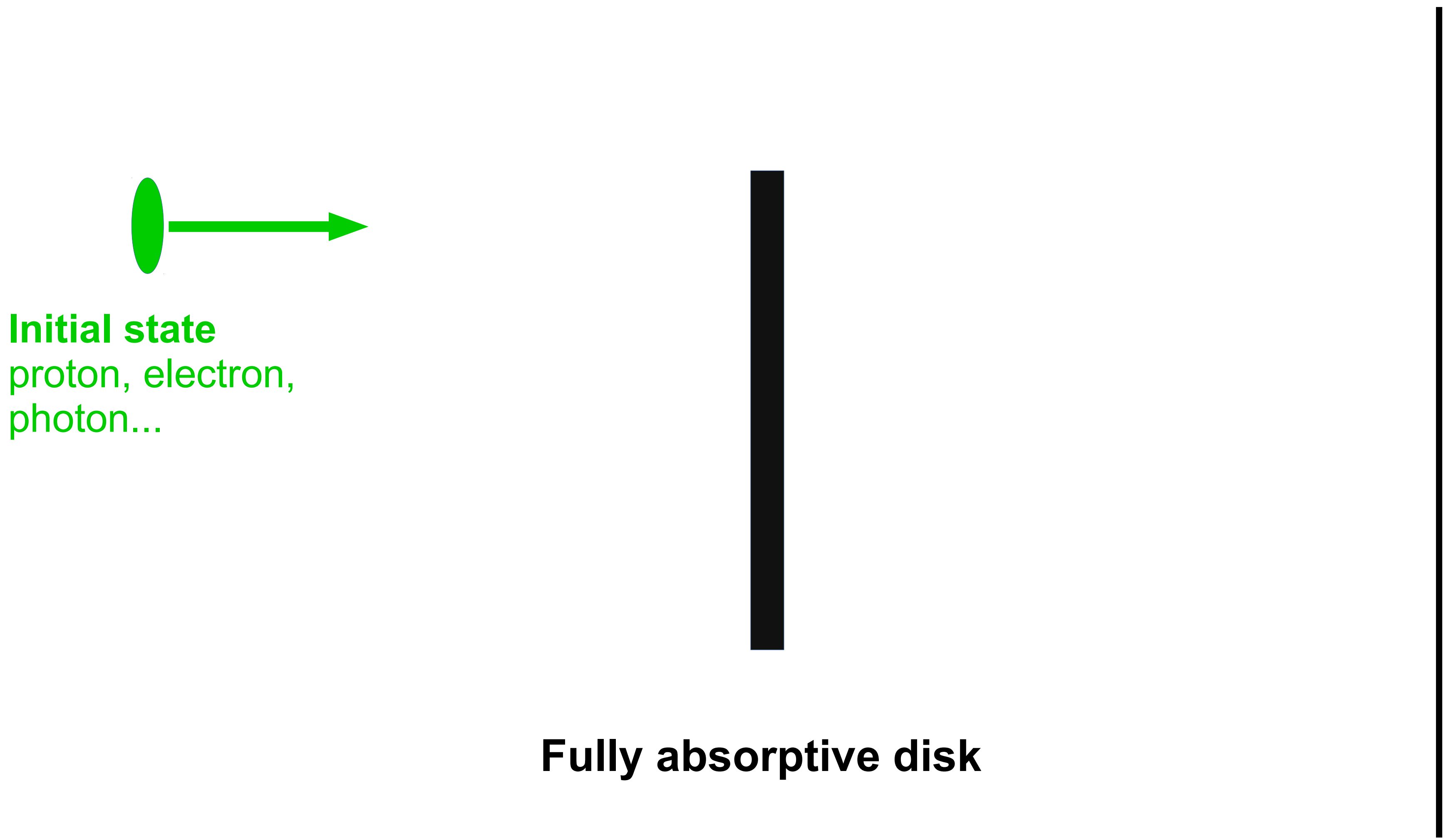


Diffraction in quantum mechanics



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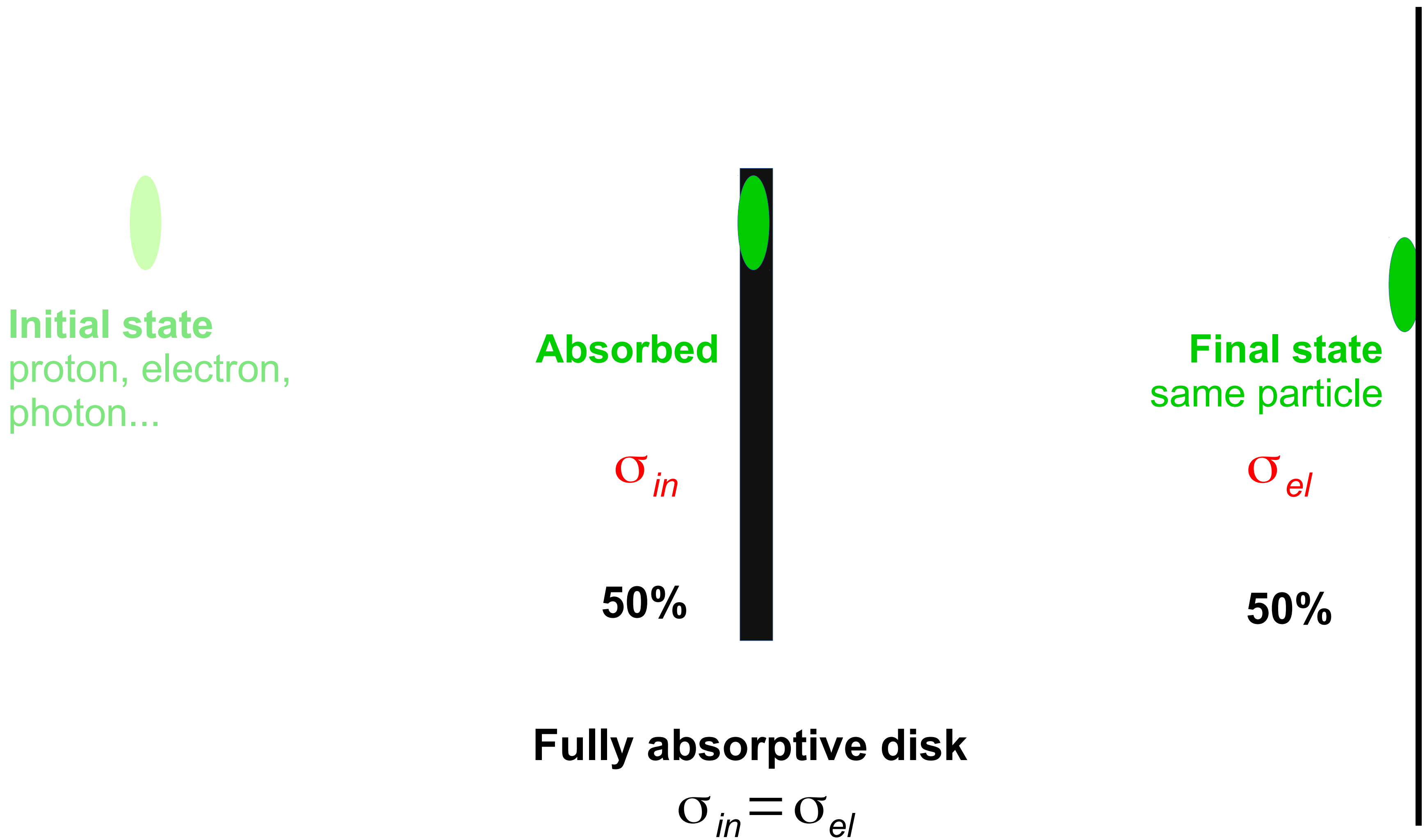

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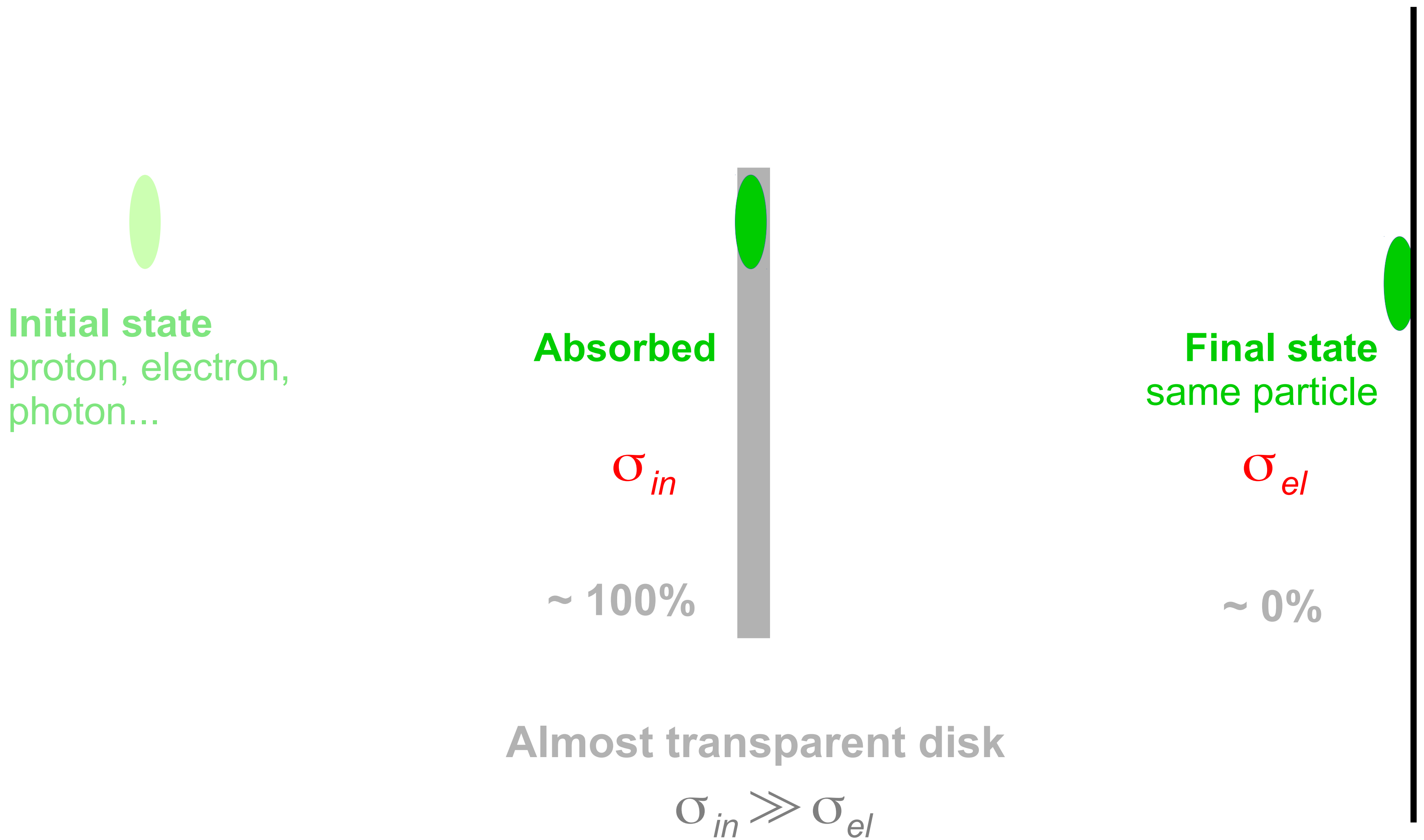
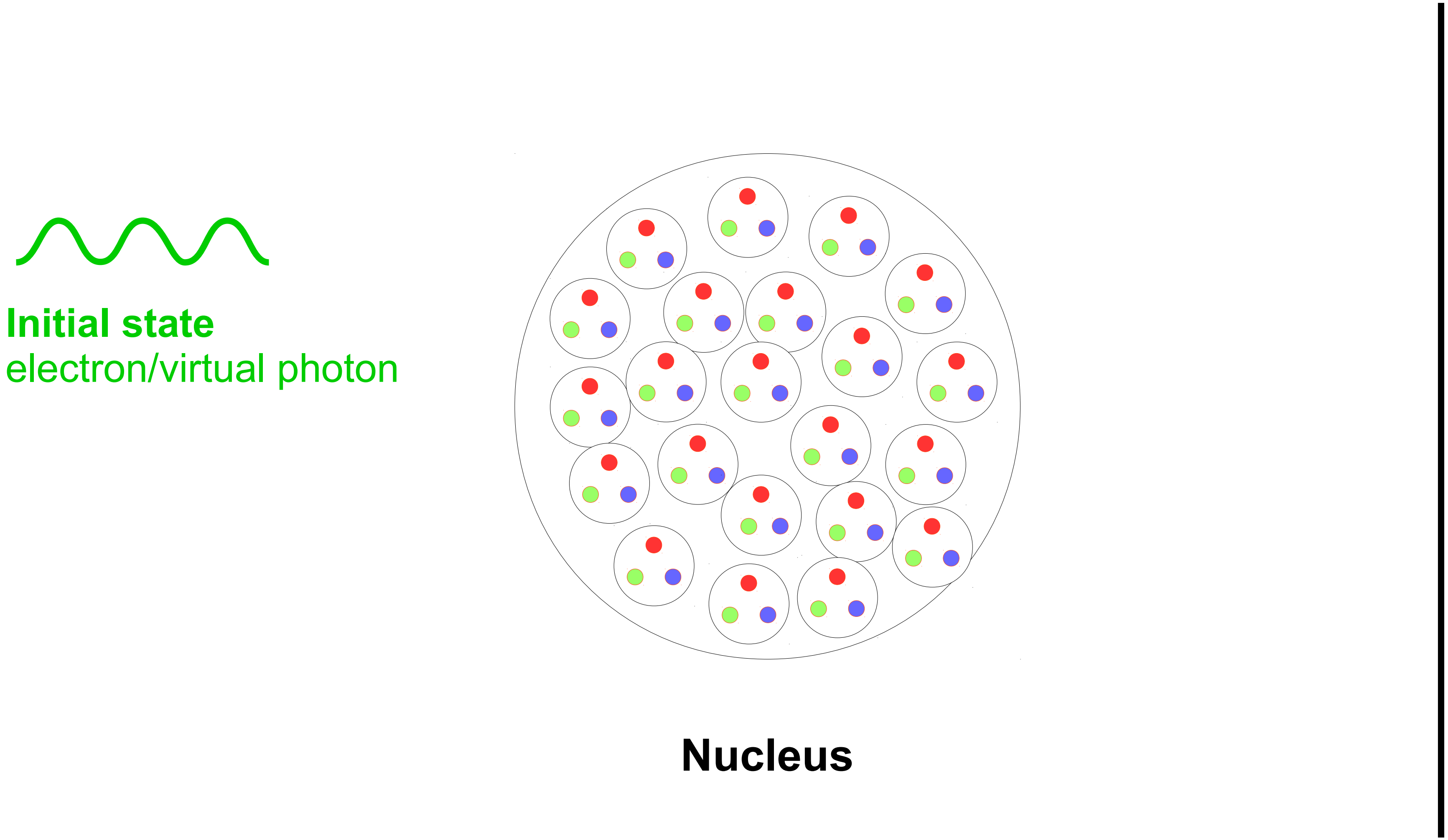
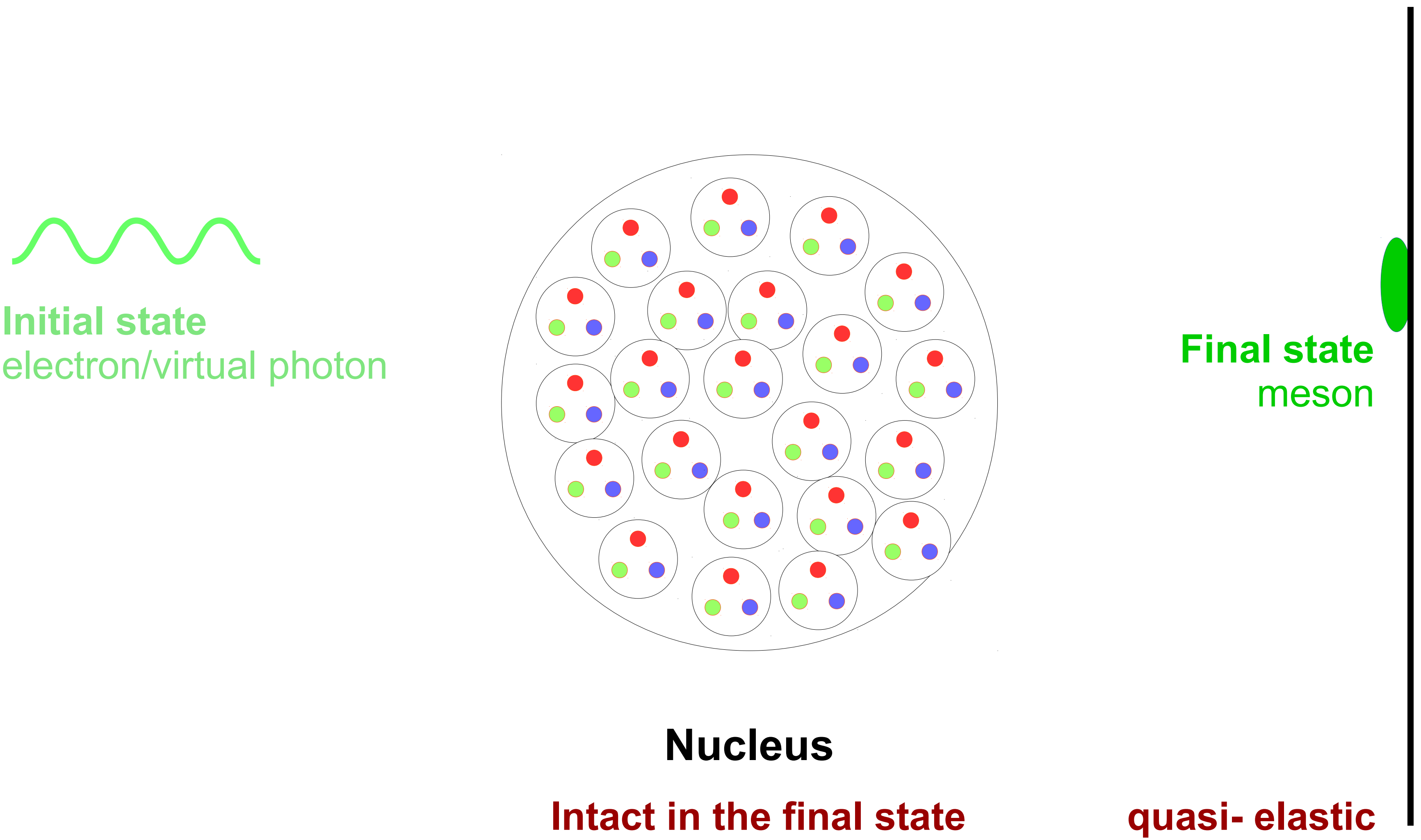


To have diffraction, one needs strong absorption!

Diffraction in particle physics



Diffraction in particle physics



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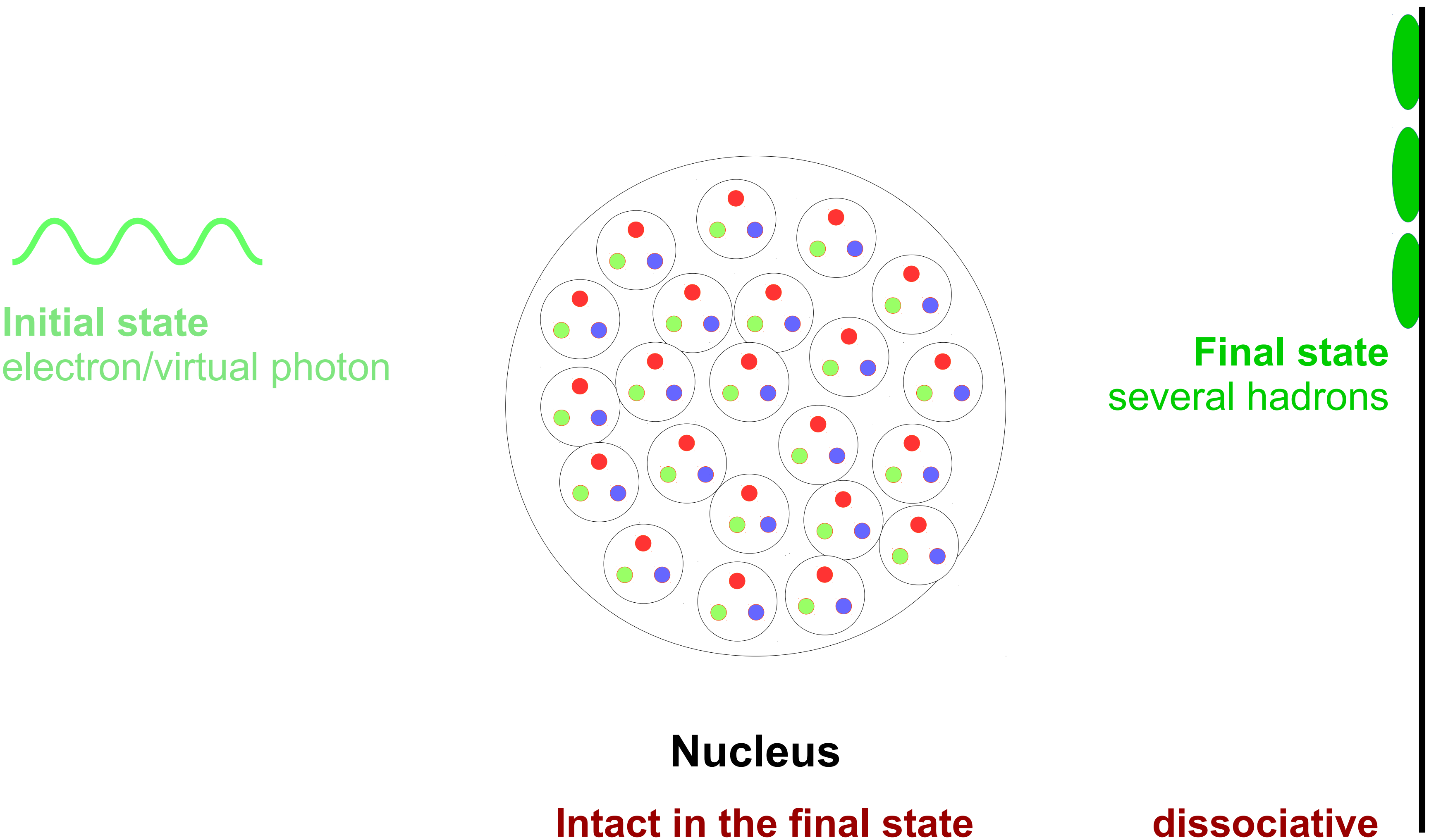
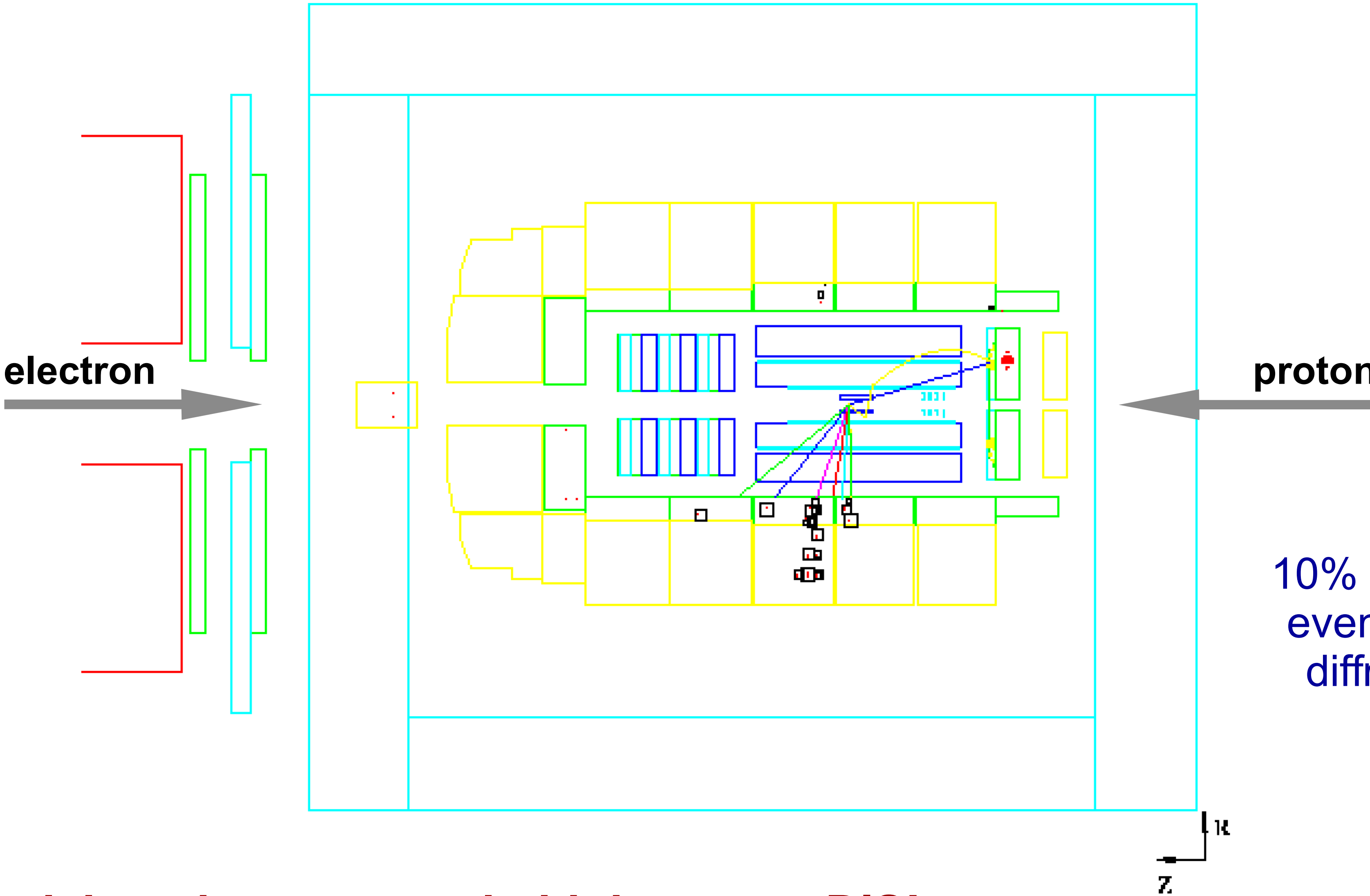


Diffraction in deep-inelastic scattering

A major highlight of HERA!



10% of HERA events were diffractive!

Surprising phenomenon in high-energy DIS!

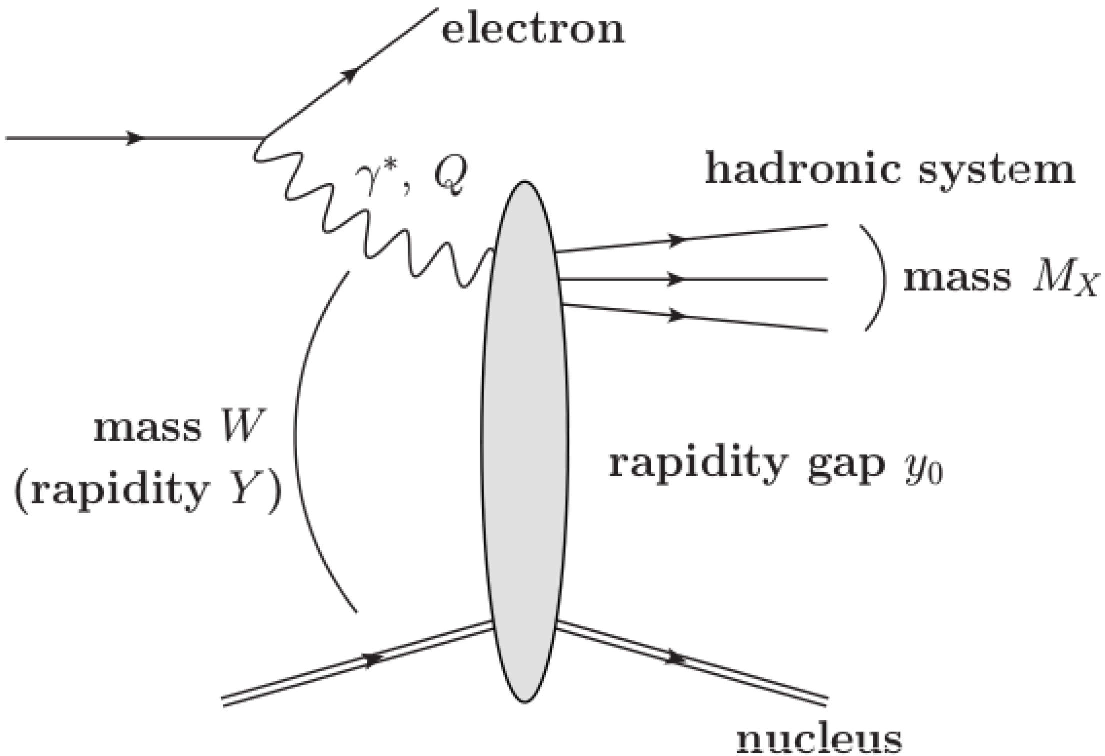
Its existence seems almost contradictory with the parton model...

Its observation boosted saturation physics!

[Golec-Biernat, Wüsthoff 1998]

Diffraction in deep-inelastic scattering

This talk: Diffractive dissociative electron-nucleus scattering



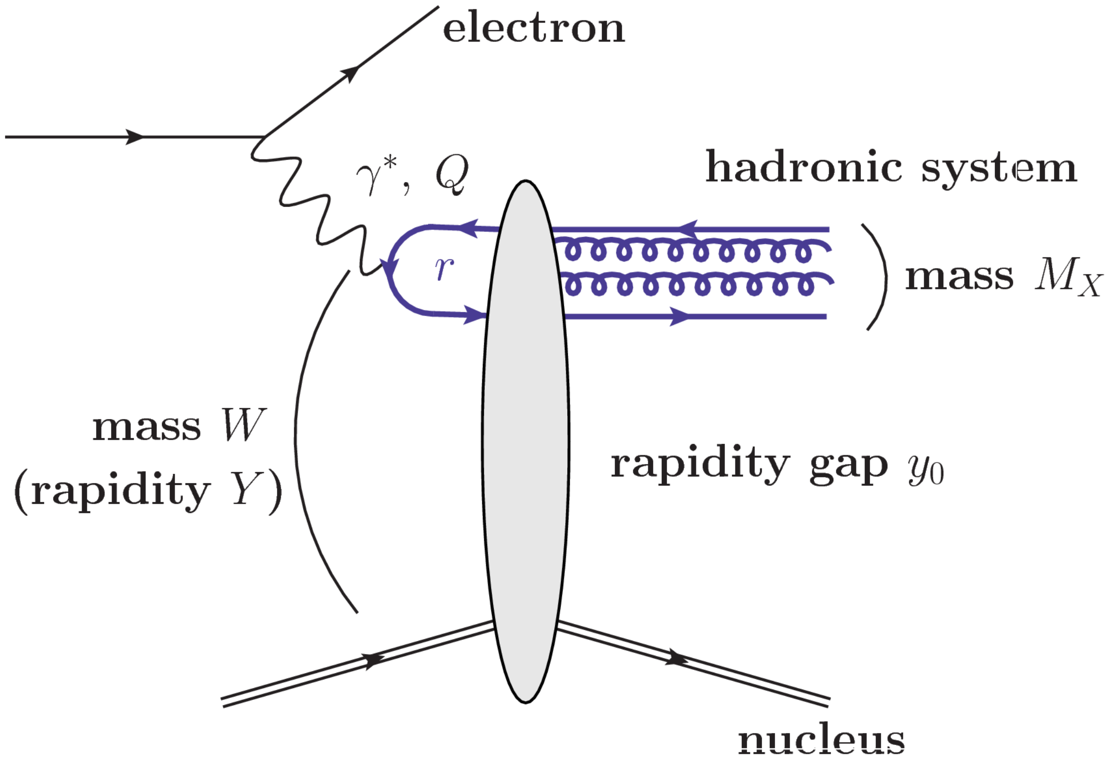
What is the distribution of the rapidity gap y_0?

$$\frac{d\sigma_{diff}}{dy_0}$$

Diffraction in deep-inelastic scattering

This talk: Diffractive dissociative electron-nucleus scattering
~ $q\bar{q}$ dipole-nucleus

[Nikolaev,Zakharov '90
Golec-Biernat, Wüsthoff 1998]



What is the distribution of the rapidity gap y_0?

$$\frac{d\sigma_{diff}}{dy_0}$$

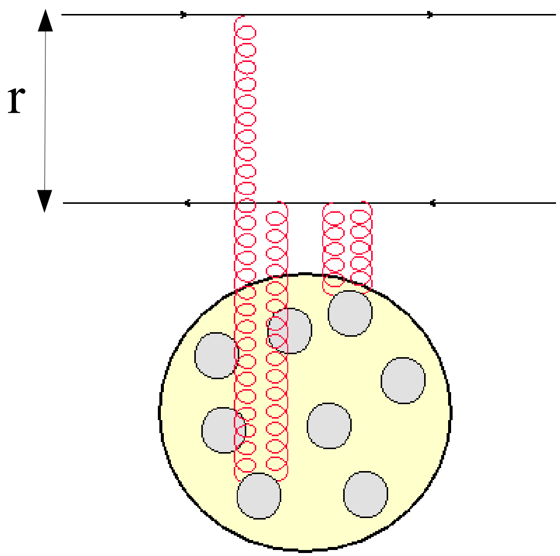
Outline

- Equation for the gap distribution
- Picture of onium-nucleus scattering
- Ancestry in branching random walks
- Numerical checks

Equation for the gap distribution

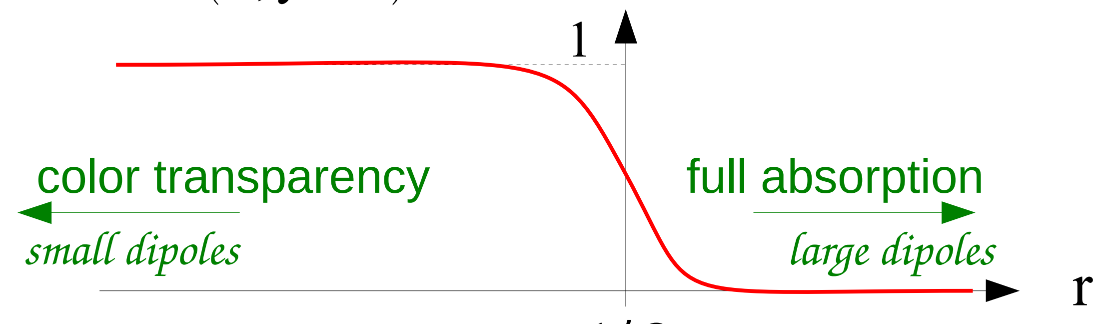
1)Total amplitude: the Balitsky-Kovchegov equation

Forward elastic S-matrix element for dipole-nucleus scattering: $\sigma_{tot} = 2(1 - S)$



$$S(r, y=0) = e^{-\frac{r^2 Q_A^2}{4}}$$

[McLerran, Venugopalan]



$1/Q_A$ = MV saturation mom.

Equation for the gap distribution

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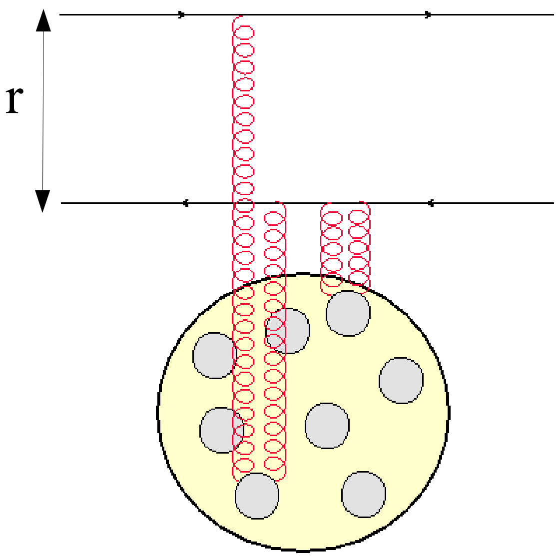

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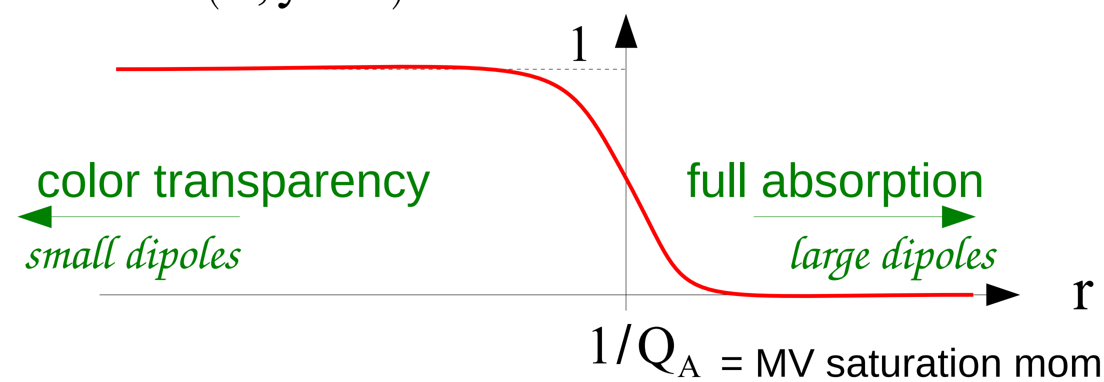
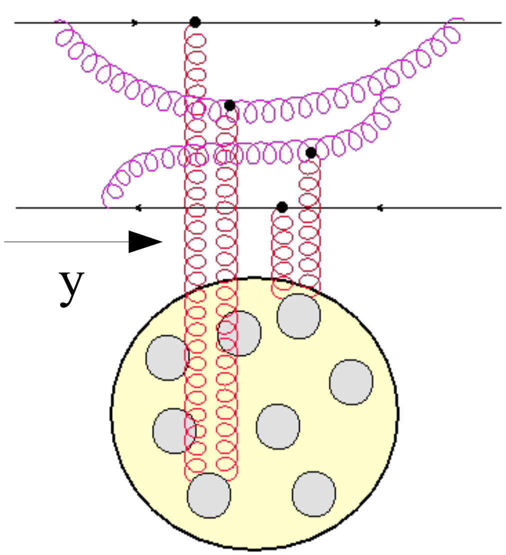
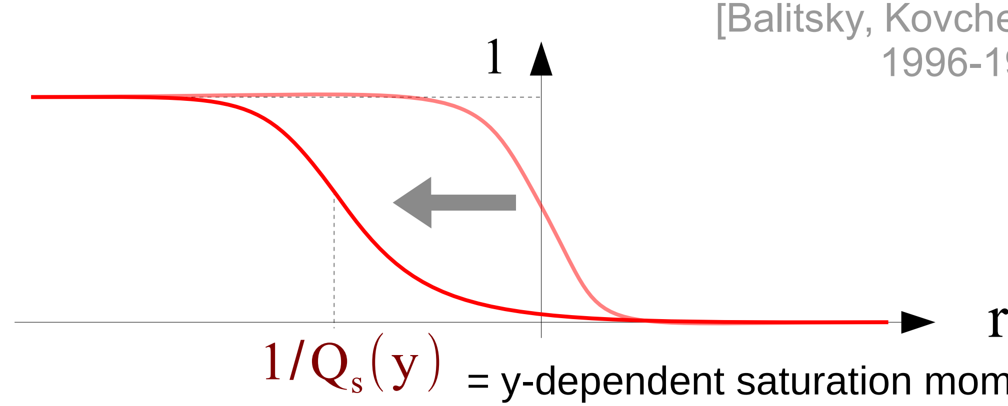




$$\partial_y S(r,y) = \bar{\alpha} \int \frac{d^2 r'}{2\pi} \frac{r^2}{r'^2 (r-r')^2} \left[S(r',y) S(r-r',y) - S(r,y) \right]$$

[Balitsky, Kovchegov 1996-1999]



Equation for the gap distribution

2) Diffractive cross section: the Kovchegov-Levin equation

[Kovchegov, Levin 2000
Hatta, Iancu, Marquet, Soyez, Triantafyllopoulos 2006]

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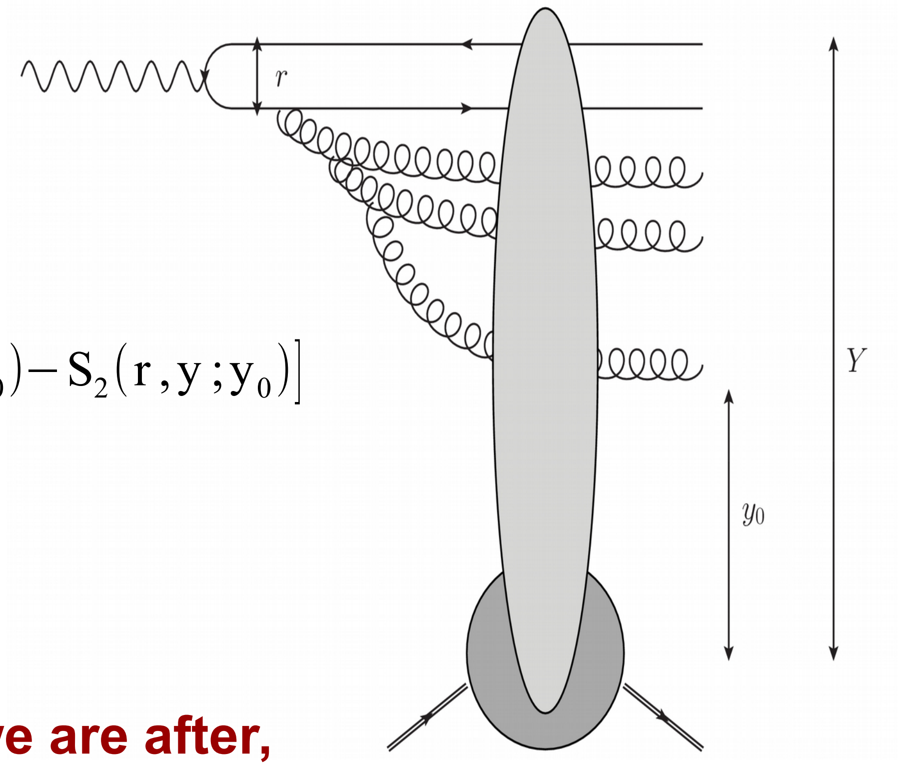
Define S_2 as $$S_2(r, y_0; y_0) = \left[S(r, y_0) \right]^2$$

for $y>y_0$: $$\partial_y S_2(r, y; y_0) = \bar{\alpha} \int \frac{d^2 r'}{2\pi} \frac{r^2}{r'^2 (r-r')^2} \times \left[S_2(r', y; y_0) S_2(r-r', y; y_0) - S_2(r, y; y_0) \right]$$

$$\frac{d\sigma_{diff}}{dy_0} = -\frac{\partial}{\partial y_0} S_2(r, Y; y_0)$$



The solution to these equations is what we are after, but they are difficult to solve!

Outline

- ✯ Equation for the gap distribution
- ✯ Picture of onium-nucleus scattering
- ✯ Ancestry in branching random walks
- ✯ Numerical checks

Picture of onium-nucleus scattering

Total cross section

$$\sigma_{tot}(r,Y)=2[1-S(r,Y)] \qquad \partial_y S(r,y)=\bar{\alpha}\int \frac{d^2 r'}{2\pi}\frac{r^2}{r'^2(r-r')^2}[S(r',y)S(r-r',y)-S(r,y)]$$

Solution:

$$Q_s^2(Y)\simeq Q_A^2\frac{e^{\text{const}\times\bar{\alpha}Y}}{(\bar{\alpha}Y)^{3/2\gamma_0}} \qquad 1-S \underset{rQ_s(\widetilde{Y})\ll 1}{} \ln\frac{1}{r^2 Q_s^2(Y)}\underset{(\gamma_0\simeq 0.63)}{[r^2 Q_s^2(Y)]^{\gamma_0}} \ll 1$$

Picture of onium-nucleus scattering

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Picture of onium-nucleus scattering

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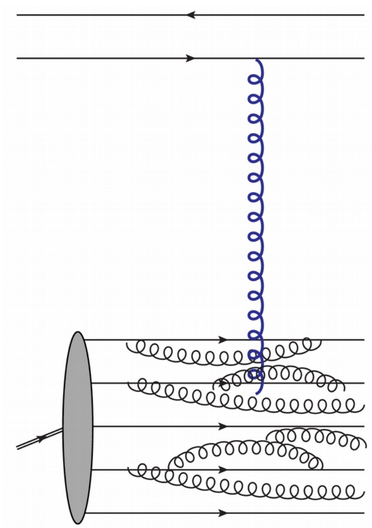
Onium restframe



1-S is like the transparency of the boosted nucleus

Picture of onium-nucleus scattering

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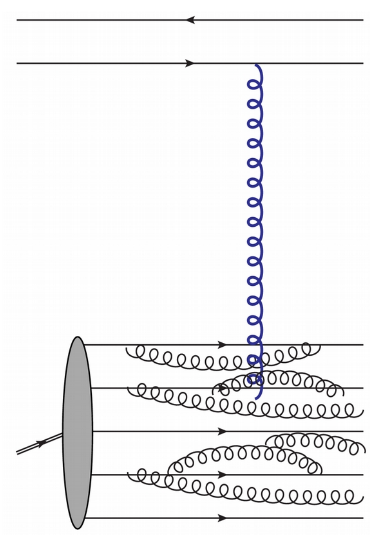
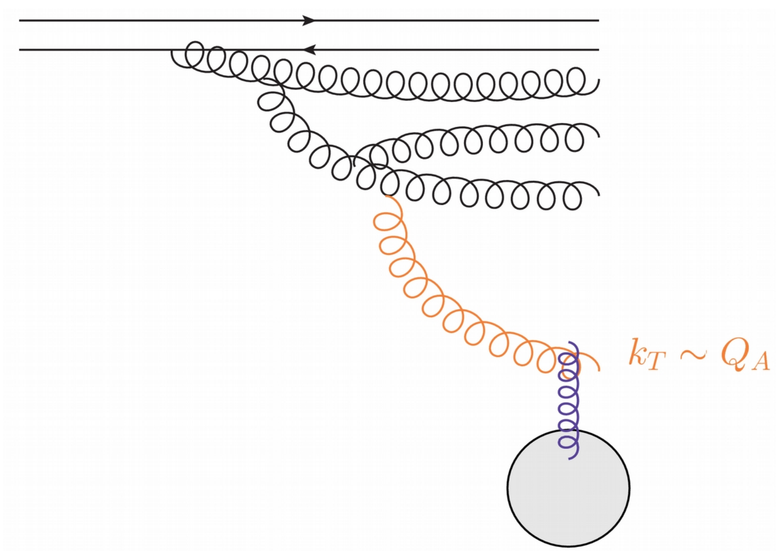


1-S is like the transparency of the boosted nucleus

Nucleus restframe



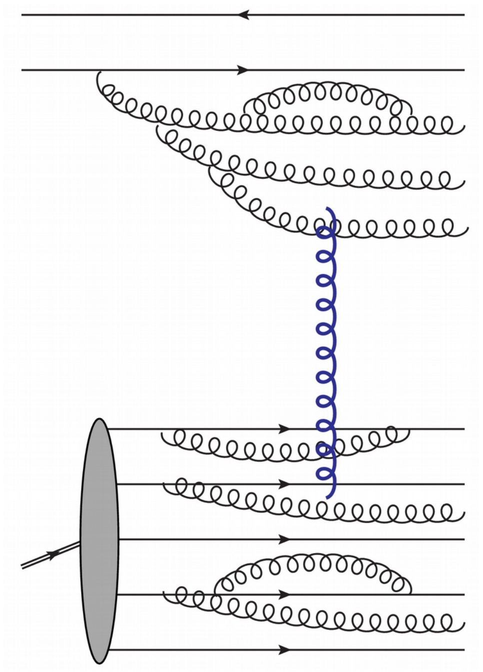
1-S is like the probability to have a gluon of transverse momentum larger than the nuclear saturation momentum in the boosted onium Fock state

Picture of onium-nucleus scattering

Total and diffractive cross section in the y_0 frame

in which the nucleus has rapidity y_0

Total



Picture of onium-nucleus scattering

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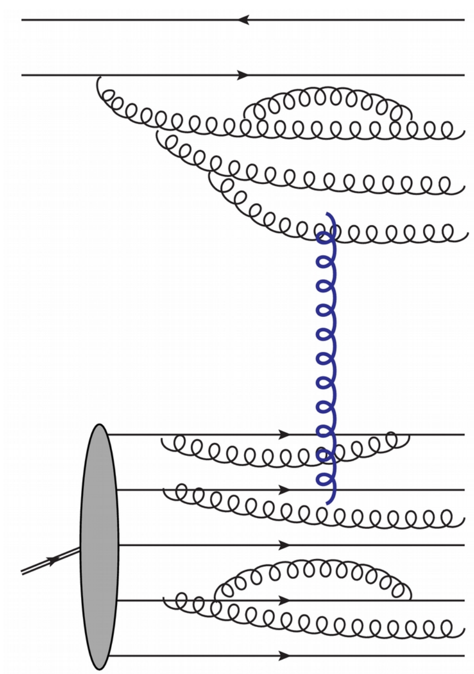
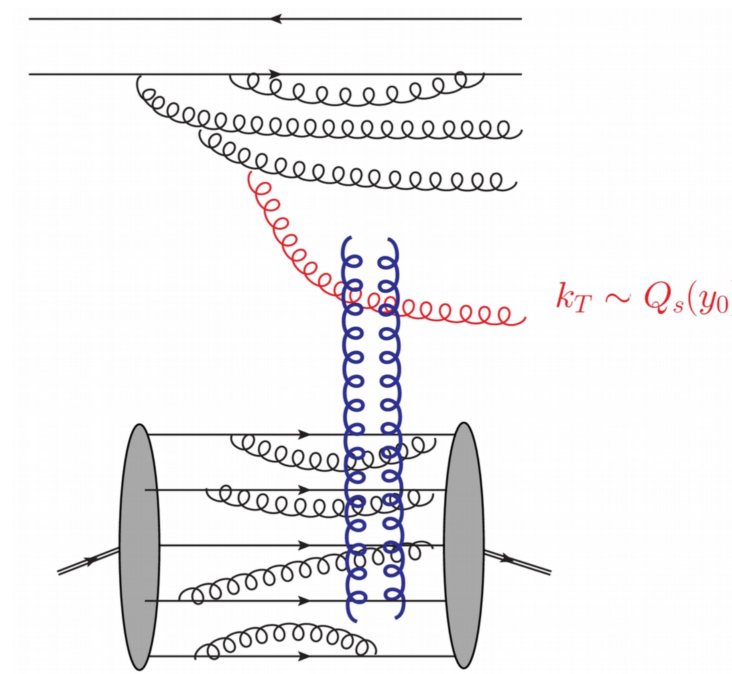


Diffractive



The scattering between the state of the onium and the evolved nucleus needs to be elastic

This requires an unusually low-k_T gluon at rapidity y_0

Picture of onium-nucleus scattering

Total and diffractive cross section in the y_0 frame

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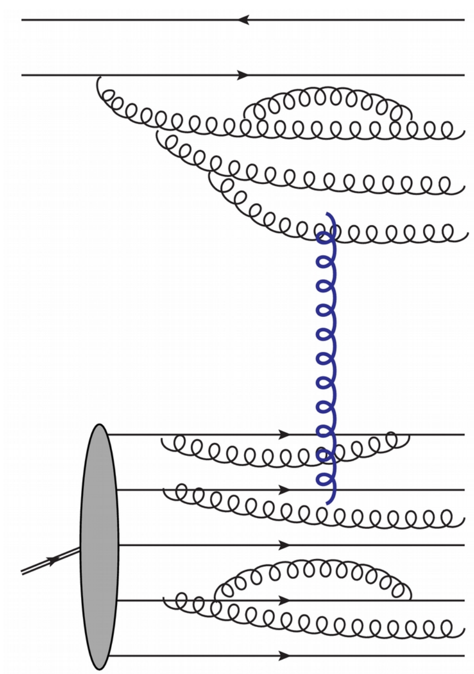

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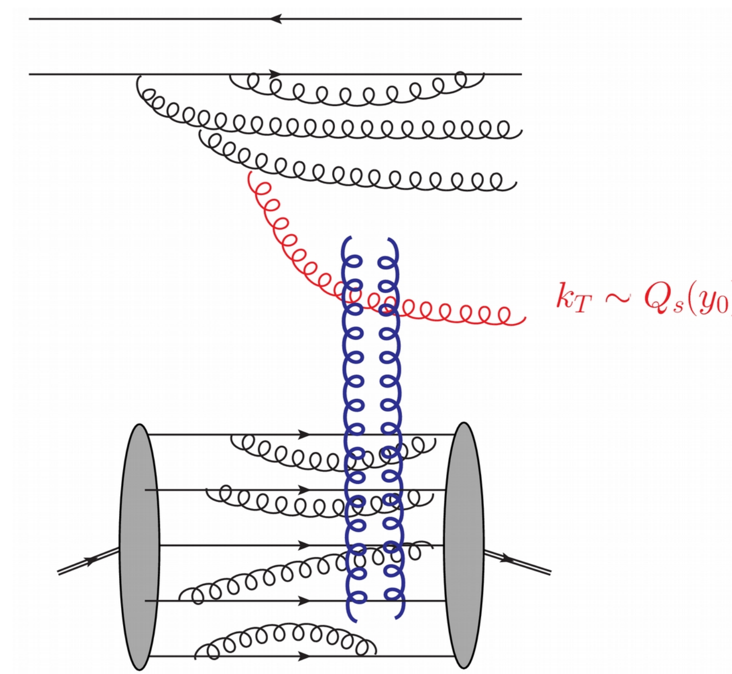

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This requires an unusually low-k_T gluon at rapidity y_0

Probability given by the BK equation!

$$\frac{1}{\sigma_{tot}}\frac{d\sigma_{diff}}{dy_0} = \text{const} \times \left[\frac{\bar{\alpha}\,Y}{\bar{\alpha}\,y_0\left(\bar{\alpha}\left(Y - y_0\right)\right)}\right]^{3/2}$$

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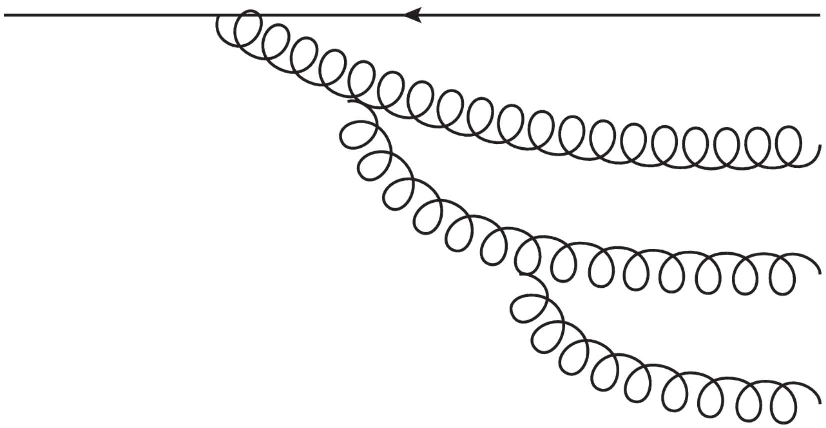
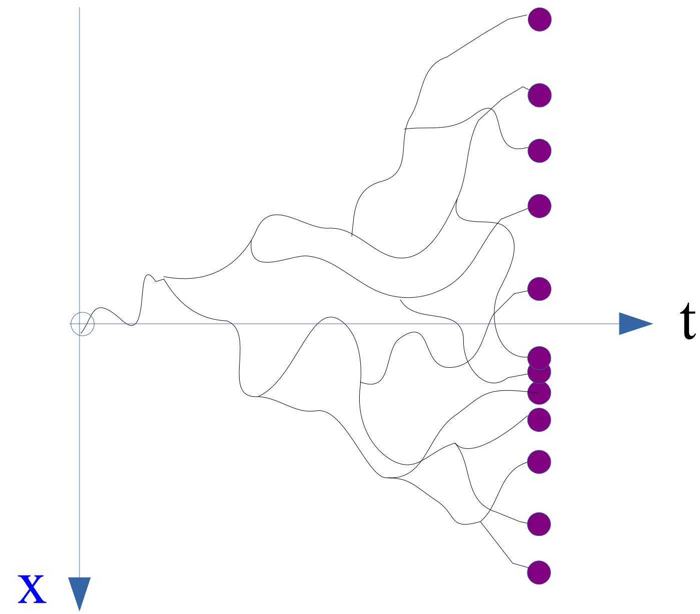
- ✯ Ancestry in branching random walks
- ✯ Numerical checks

Branching random walks



$\simeq$



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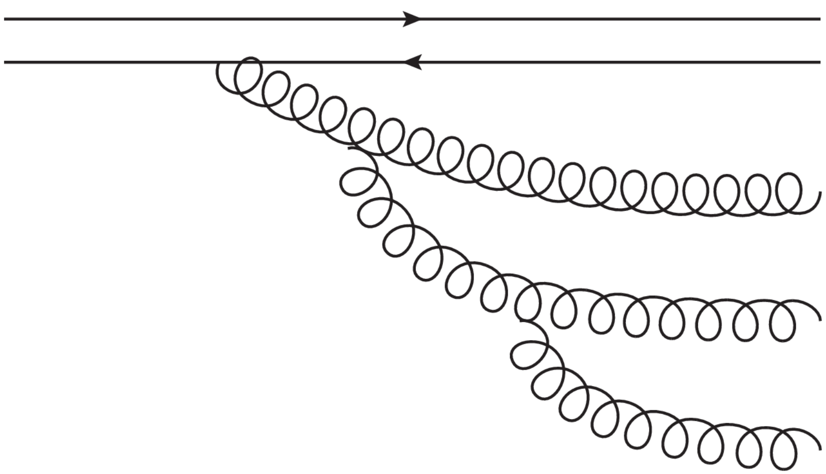
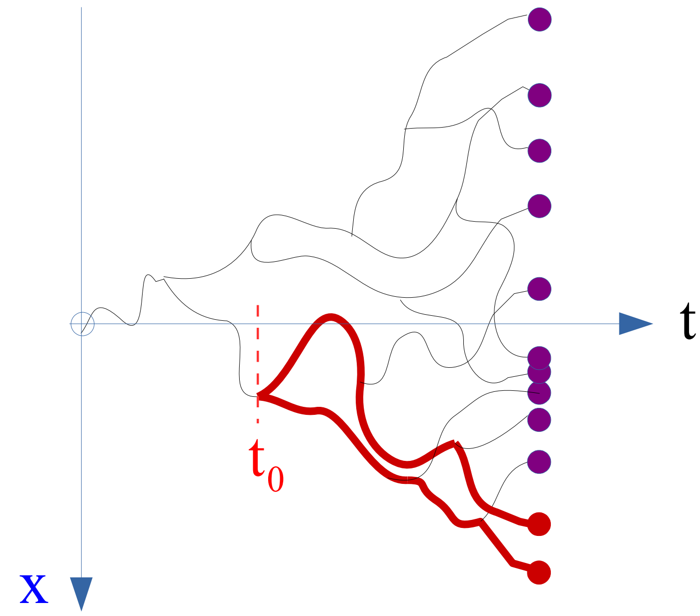
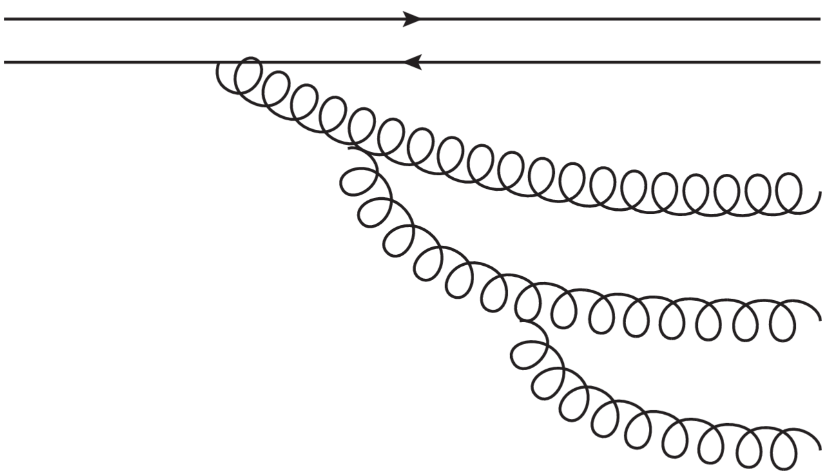


$\simeq$



Distribution of decay time of most recent common ancestor?

Branching random walks



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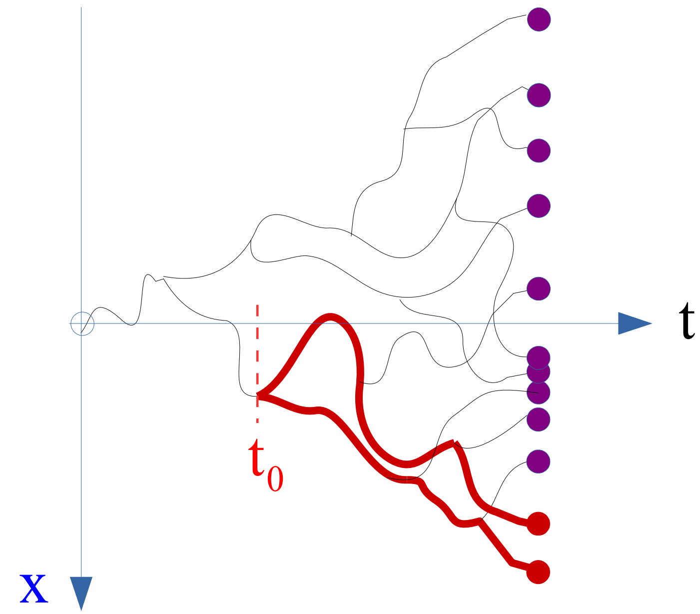


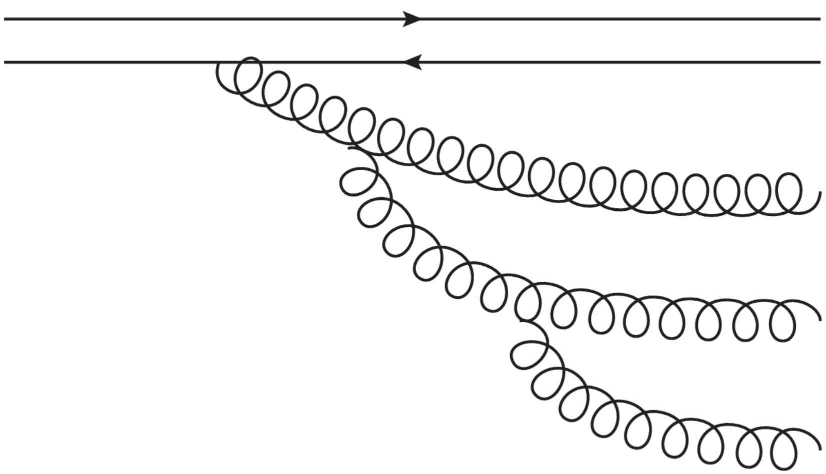
Distribution of decay time of most recent common ancestor?

$$\frac{dp}{dt_0} = \frac{1}{\sqrt{4\pi}} \times \left[\frac{t}{t_0(t-t_0)}\right]^{3/2}$$

[Derrida, Mottishaw 2016]

(for branching Brownian motion with diffusion constant 2 and splitting rate 1)

Branching random walks



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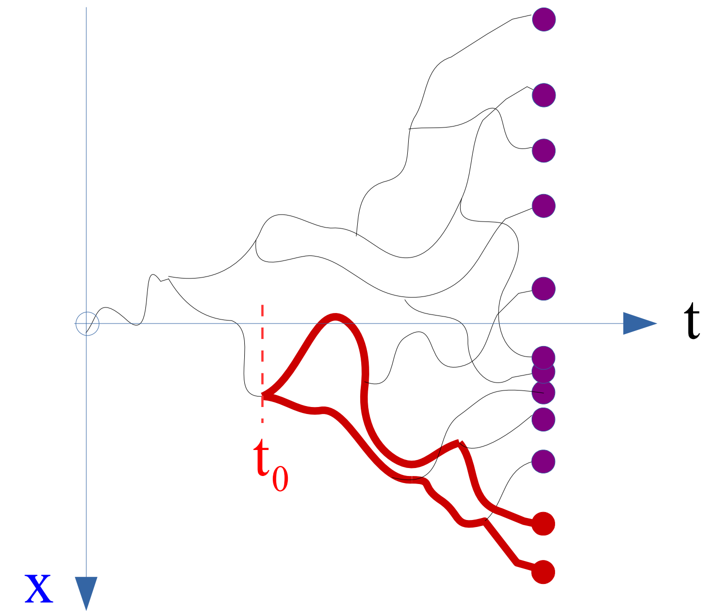

Distribution of rapidity gaps:

$$\frac{1}{\sigma_{tot}}\frac{d\sigma_{diff}}{dy_0}=\text{const}\times\left[\frac{\bar{\alpha}Y}{\bar{\alpha}y_0(\bar{\alpha}(Y-y_0))}\right]^{3/2}$$

$\simeq$

$\bar{\alpha}Y \Leftrightarrow t$

$\bar{\alpha}y_0 \Leftrightarrow t_0$

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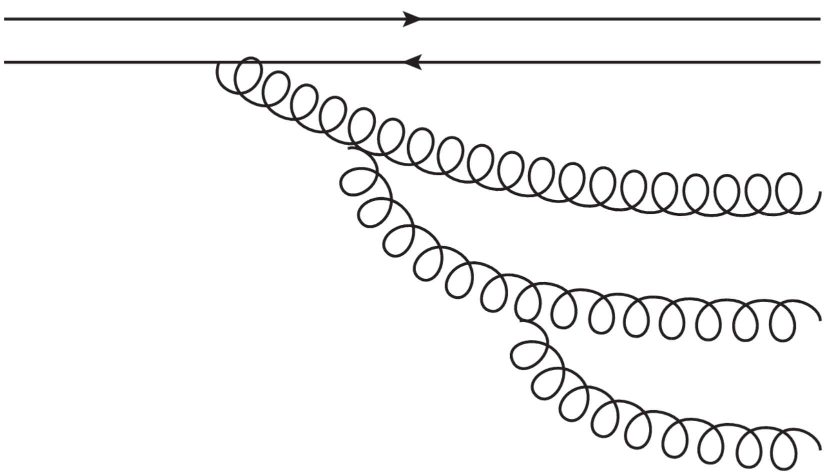

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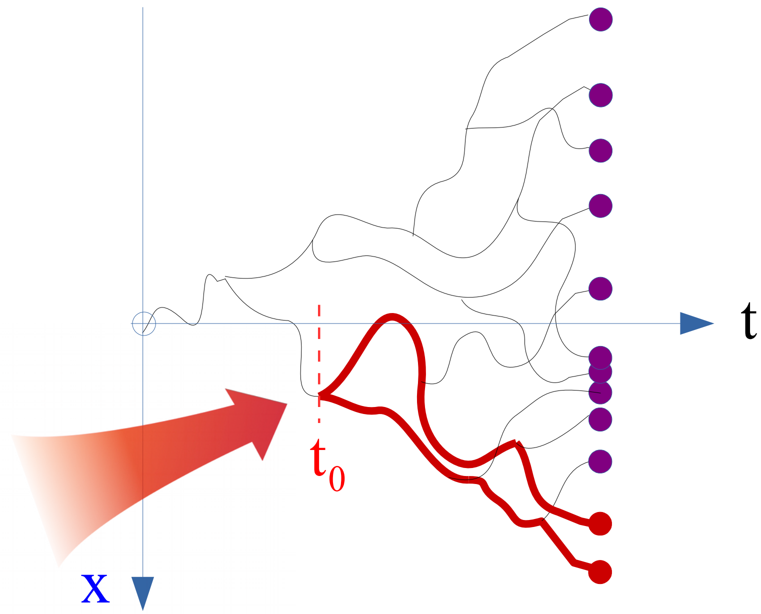

Distribution of rapidity gaps:

$$\frac{1}{\sigma_{tot}}\frac{d\sigma_{diff}}{dy_0} = \text{const} \times \left[\frac{\bar\alpha Y}{\bar\alpha y_0(\bar\alpha(Y-y_0))}\right]^{3/2}$$

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[Derrida, Mottishaw 2016]

(for branching Brownian motion with diffusion constant 2 and splitting rate 1)

Physical reason for the correspondence:
The common ancestor is an unusually large fluctuation! (here: large value of x)

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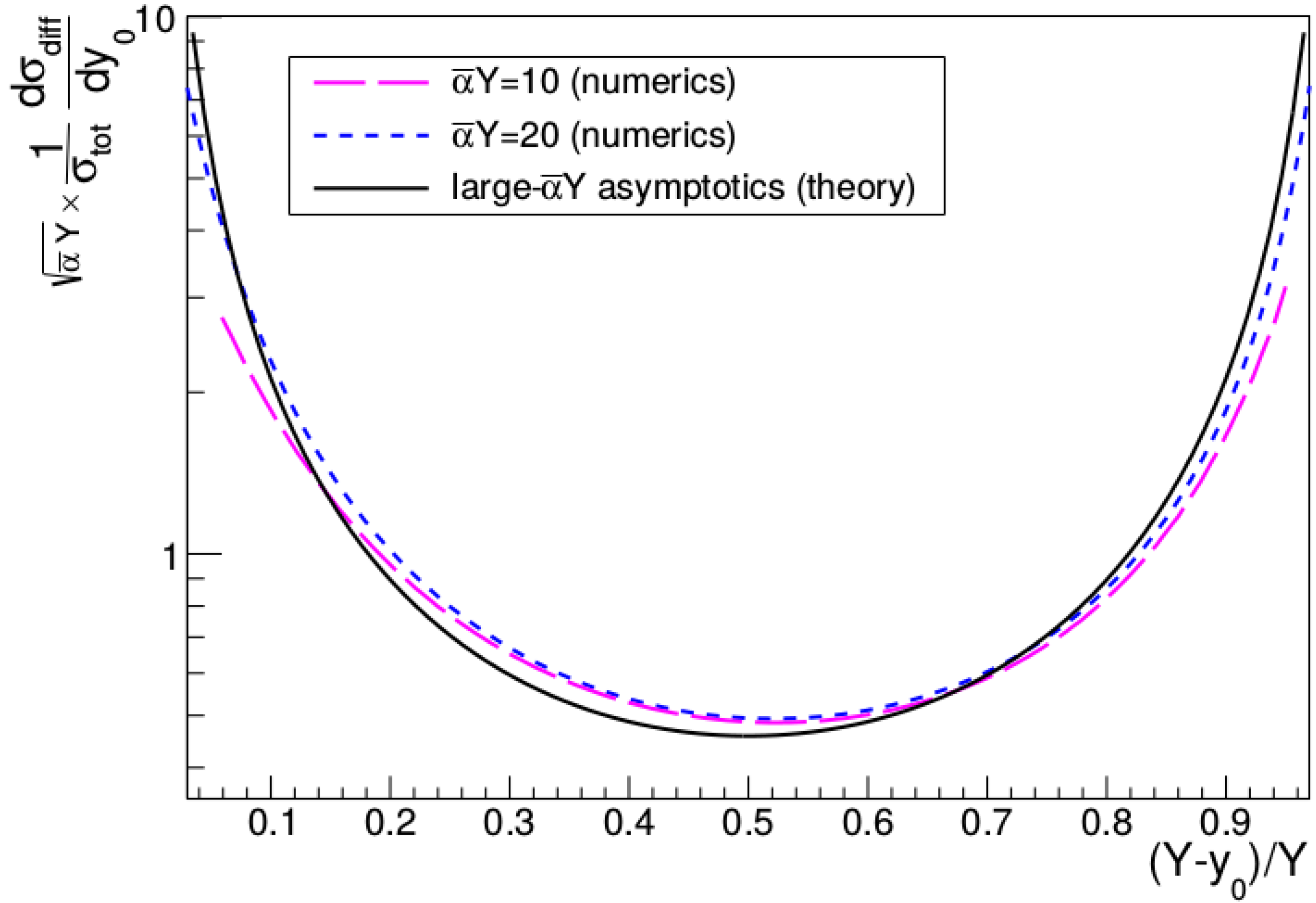
Comparison to numerics

Very large-Y asymptotics

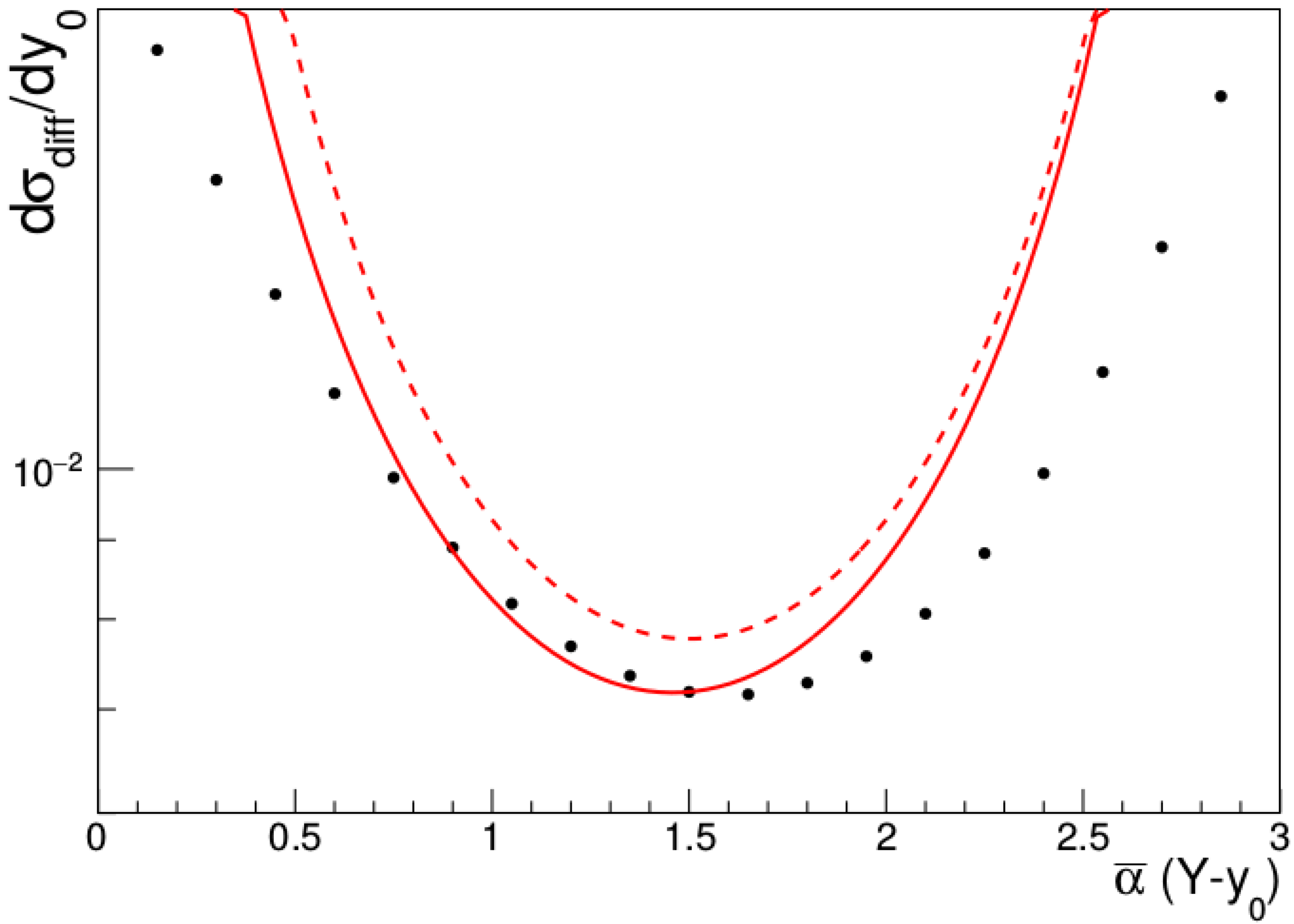


Theory: $\frac{1}{\sigma_{tot}} \frac{d\,\sigma_{diff}}{dy_0} = \text{const} \times \left[\frac{\bar{\alpha}\, Y}{\bar{\alpha}\, y_0 \left(\bar{\alpha} \left(Y - y_0 \right) \right)} \right]^{3/2}$

Numerics: Solution to the Kovchegov-Levin eq.

Comparison to numerics

Realistic rapidities (EIC) $\bar{\alpha}\, Y = 3$



Theory: $\frac{d\,\sigma_{diff}}{dy_0} \sim \left[\frac{\bar{\alpha}\, Y}{\bar{\alpha}\, y_0 (\bar{\alpha}(Y - y_0))} \right]^{3/2}$

Numerics: Solution to the Kovchegov-Levin eq.

Summary

- We have predicted, up to an overall constant, the rapidity gap distribution in diffractive dissociation of a virtual photon off a nucleus:

$$\frac{1}{\sigma_{tot}}\frac{d\sigma_{diff}}{dy_0}=\text{const}\times\left[\frac{\bar{\alpha}\,Y}{\bar{\alpha}\,y_0\left(\bar{\alpha}\left(Y-y_0\right)\right)}\right]^{3/2}$$

Partonic interpretation: the rapidity gap is due to a **large fluctuation** (unusually low-transverse momentum gluon) in the course of the QCD evolution of the onium Fock state

- There is a deep analogy between this distribution and the distribution of the time at which common ancestors of extreme particles in branching random walks decay

Outlook

- We may have an even closer analogy between diffraction and genealogy: The overall constant in the distributions may be the same!

  What about the finite-rapidity corrections?

  Work in progress...