Exclusive vector meson (photo)production and low x dynamics

Anna Stasto

PennState Eberly College of Science

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Why exclusive diffractive VM (photo)production?

- Unique sensitivity to gluon distribution of the target: gluon density squared.
- Semi-hard scale: can treat perturbatively even in photoproduction for heavier mesons.
- In ep DIS possibility to control the scale through the photon virtuality.
- Test the universality of dynamics between different VM.
- Momentum transfer dependence allows to access the impact parameter profile of the interaction radius.

Low x/dipole - type approaches to exclusive VM production Type analyzis was performed in 200 new and more precise data have been published by the HERA experiment H1 μ , and in the HERA experiment H1 in The LHCb collaboration have recently production and data on exclusive (ultraperiodiscussive (ultraperiodiscussi by accounting for the explicit *k^T* integration in the last step of the interaction. This is not the e - type approaches to exclusive viri new and more precise data have been published by the HERA experiment H_{A} , and induced by H_{A} , and in *Ryskin; Marti,Ryskin,Teubner;* Figure 1: Schematic picture of high energy exclusive *J/* production, ⇤*p* ! *J/ p*. The $\overline{\text{ow}}$ x/dipole - type approaches to exclusive V**^** is much greater than the *cc*¯-proton interaction time ⌧int. In the case of the simple two-gluon expression is the result of the *Ryskin*; and *Ryskin*; and *R^{<i>p*}, *R*_{*p*} is the *R*^{*p*} is the *R* EXCIUSIVE VI^VI

In the proton rest frame: the formation time *Jones, Martin, Ryskin,Teubner*

of dipole is much longer than the interaction $\begin{bmatrix} k_T \mid \mathcal{B} \mathcal{B} \end{bmatrix}$ \mathbf{r} and \mathbf{r} and \mathbf{r} production at \mathbf{r} $\frac{1}{2}$ of $\frac{1}{2}$ of $\frac{1}{2}$ in $\frac{1}{2}$ in the case of $\frac{1}{2$ *pp* ! *p* + *J/* + *p* process measured by LHCb. time with the target. Allows to factorize the process.

 γ^* \bar{c} *c p p p* J/ψ $x \geq d x'$ k_T $\big| \bigotimes \bigotimes \big| k_T$ **o** γ^* is sensitive to, and J/ψ data enable us to improve the determination of the gluon, but \mathcal{U} χ as to factorize the χ $\begin{bmatrix} 8 & 3 \ 9 & \pi' \end{bmatrix}$ $p \sim$ *p* shown in Fig. 1. The corresponding expression for the cross section in leading logarithmic (LO) \sim \mathcal{L} J_1 \bar{c} and \bar{c} in the low M $p \sim$ \sim $p \sim$ $p \sim$ shown in Fig. 1. The corresponding expression for the cross section in leading logarithmic (LO) \sim T the measured di↵ractive *J/* cross section. However, first, let us list the corrections to the L/ρ where ↵⁰ = 0*.*06 and *W*⁰ = 90 GeV. This slope grows more slowly with *W* than the formula $U \cup \mathcal{B}$, but is compatible with the slope and with the slope and with the slope and V 4 of [8] used below in Section 3 to calculate the gap survival probability *S*² in the case of $\begin{bmatrix} x & \Theta & \Theta \end{bmatrix} x'$ Thus it becomes possible, in principle, to extract the gluon density *xg*(*x, Q*¯²) directly from \sim \sim μ

 y/ψ ¹, y/ψ ², y/ψ ², y/ψ ², y/ψ

function leading order expression. Expression (1) is a simple first approximation, justified in the leading

Lowest order: non-relativistic
\napproximation to J/\Psi wave
\nfunction
\n
$$
\frac{d\sigma}{dt} (\gamma^* p \to J/\psi p) \Big|_{t=0} = \frac{\Gamma_{ee} M_{J/\psi}^3 \pi^3}{48\alpha} \left[\frac{\alpha_s (\bar{Q}^2)}{\bar{Q}^4} x g(x, \bar{Q}^2) \right]^2 \left(1 + \frac{Q^2}{M_{J/\psi}^2} \right)
$$
\n
$$
\bar{Q}^2 = (Q^2 + M_{J/\psi}^2)/4, \qquad x = (Q^2 + M_{J/\psi}^2)/(W^2 + Q^2)
$$

 $\overline{\text{C}}$ is the virtuality of the photon, $\overline{\text{C}}$ is the rest mass of the *J/* , and $\overline{\text{C}}$ centre*t* = 0. To describe data integrated over *t*, the integration is carried out assuming ⇠ exp(*Bt*) In principle need to take into account skewed gluon distribution. \int and to take into $\frac{2}{3}$ – the amplitude showld be much be multiplied by $\frac{2}{3}$ – $\frac{2}{3}$

Effectively, multiplicative factor taken into account *v*ely, multiplicative factor *Shuvaev,Golec-Biernat,Martin,Ryskin*
pto asserunt inco account **x** region of interest, we take the gluon to have the gluon to have the form α , where α , where α

$$
R_g = \frac{2^{2\lambda+3} \Gamma(\lambda + \frac{5}{2})}{\sqrt{\pi} \Gamma(\lambda + 4)}
$$
 with $\lambda(Q^2) = \partial [\ln(xg)] / \partial \ln(1/x)$

reasured are are surface the shuvaev, Golec-Biernat, Martin, Ryskin W also need to account for the fact that that that the two exchanged gluons carry di \sim

(skewed) gluon distribution. In our case *x*⁰ ⌧ *x* ⌧ 1, and the skewing e↵ect can be well

where *M* and *ee* are the mass and electronic width of the *J/* . The kinematic variables are 1**0** α counts for the main corrections for the main the LO formula and the LO formula and the LO formula and the the t How is dipole to pouply vacines to exclusive vi keep the value of α unchanged we have to account for the fact that α is a set of the fact that no additional gluons with α transverse momentum larger than γ^* are emitted in the exclusive process by including the exclusive process by in = exp(*Bt*), where the energy-dependent *t* slope parameter, *B*, has the form)*/*4 *, x* = (*Q*² + *M*² and *W* is the *p* centre-of-mass energy. We assume the *t* dependence to be exponential, i.e. \sum_{γ^*} and \sum_{γ^*} Low x/dipole - type approaches to exclusive VM production $\mathcal{L}_{\mathcal{N}}$ \overline{a} *J/* production [5] which is sensitive to, and enlarges, the low *x* interval. These *pp* ! *p*+*J/* +*p* γ^* and γ^* and inclusion of γ^* theoretical framework and necessitate the inclusion of absorption of absorption of absorption of absorptions.

Jones, Martin, Ryskin,Teubner Julies, *Multur, Sysk* **2 Jones, Martin, Ryskin, Teubner**

'NLO' improvement: including transverse momentum dependence in the gluon distribution integrated with the hard factor $\frac{p}{p}$ | *p T*(*k*² *^T , µ*² $\sum_{x}^{x} \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}^{x}$ approximation using the narral factor is the graded with the narral factor

where (*Q*²) = @ [ln(*xg*)] */*@ ln(1*/x*) (for a more detailed discussion see [10]). In other words,

$$
\left[\frac{\alpha_s(\bar{Q}^2)}{\bar{Q}^4} x g(x, \bar{Q}^2)\right] \longrightarrow \int_{Q_0^2}^{(W^2 - M_\psi^2)/4} \frac{dk_T^2 \alpha_s(\mu^2)}{\bar{Q}^2(\bar{Q}^2 + k_T^2)} \frac{\partial \left[xg(x, k_T^2) \sqrt{T(k_T^2, \mu^2)}\right]}{\partial k_T^2} + \ln \left(\frac{\bar{Q}^2 + Q_0^2}{\bar{Q}^2}\right) \frac{\alpha_s(\mu_{\rm IR}^2)}{\bar{Q}^2 Q_0^2} x g(x, Q_0^2) \sqrt{T(Q_0^2, \mu_{\rm IR}^2)}.
$$

Sudakov form factor:

 $T(k_T^2, \mu^2) = \exp \left[\frac{-C_A \alpha_s(\mu^2)}{4\pi} \right]$ 4π \ln^2 μ^2 k_T^2 ◆ *,* (4) $T(k_T^2, \mu^2) = \exp \left[\frac{-C_A \alpha_s(\mu^2)}{4\pi} \ln^2 \left(\frac{\mu^2}{k^2} \right) \right]$ $\left[\begin{array}{cc} 4\pi & \sqrt{k_T^2} \end{array} \right]$ ⁰*, Q*¯²). $\ln^2\left(\frac{\mu^2}{k^2}\right)$ $\lim_{T \downarrow 2} \int -C_A \alpha_s(\mu^2) \Big|_{1/2}$ *J/* $\frac{1}{2}$ $\frac{1}{2$ *J/*)*/*(*W*² + *Q*²)*.* (2) $T_1 = \exp \left[\frac{-\mathcal{C}_A \alpha_s(\mu)}{\mathcal{C}_I} \right] n^2 \left(\frac{\mu}{\mathcal{C}_I} \right)$ $\begin{array}{c|c|c|c|c|c} \hline \end{array}$ $\begin{array}{c|c|c} \hline \end{array}$ $\begin{array}{c|c|c} \hline \end{array}$ $\begin{array}{c|c|c} \hline \end{array}$ leading order expression. Expression (1) is a simple first approximation, $\frac{1}{2}$

$$
T=1 \quad \text{for} \quad k_T^2 \geq \mu^2
$$

 ↵*s*(*Q*¯²) itted in th than K_T are emitted in the process d*k*² *^T* ↵*s*(*µ*²) see (6) below. Recall that working in terms of *k^T* factorization we avoid the problem of the choice of the factorization scale *µ*^{*F*} , which is directed to the large uncertainty for **No additional gluons with transverse momenta larger** than k_T are emitted in the process **than** K are enneed in the process **than** K and K end K exponentially <u>n</u> ↵*s*(*Q*¯²) of-mass energy. Equation (1) gives the di↵erential cross section at zero momentum transfer, *A*^{*D*} *Q*² *deta above a determined gluons with transverse momer* than k_T are emitted in the process M amonto lorgor *x x*⁰ of the light-cone proton momentum, see Fig. 1. The generalised momentum of the generalised momentum α estimated from \mathcal{L} – the amplitude should be multiplied by \mathcal{L}

t- distribution modeled in this approach: $\qquad \sigma \sim \exp(-Bt)$

$$
\sigma \sim \exp(-Bt)
$$

Q¯2 *Q*¯²*Q*² 0 Here we have assumed the behaviour of *xg*(*x, k*² $\frac{1}{2}$ *T* to be linear in *k*² T) T \sim T \sim $\frac{d}{dx}$ *d* α' $\ln(W/W_c)$! ^Z (*W*2*M*² $B(W) = (4.9 + 4\alpha' \ln(W/W_0)) \text{ GeV}^{-2}$ $B(W) = (A \ 0 + A \alpha)$ $\mathbf{F} \cdot \mathbf{y} \perp \mathbf{y}$

Exclusive production of vector mesons in the dipole approach p,Φ,J/ψ, Y production photon still fluctuates into \mathbf{r} and interacts with the proton and a vector \mathbf{r} EXCIUSIVE PIOUUCLIOII OI VECLOI IIIES Exclusive production of vector me $s_{\rm{th}}$ and $s_{\rm{th}}$ and interacts with the target pair and interaction \blacksquare

deem et al,

where helicity of where he has when where he has where he has when we have helped to the helicity of \vee Levin et al; werger, _{1, του},
Armesto, Rezeaian; *Nikolaev,Zkharov;* " *Strikman,Frankfurt,Rogers; Berger,AS;* \overline{a} \mathbf{h} olae
— .)
! dz Wikolaev,Zkharov;
Natrikman Frankfurt Rogers: and the final state of the final state of the final state of the final state of th T_{R} differential constants of the process Λ represents Λ \overline{a} $\overline{\mathsf{C}}$ $\sum_{j=1}^{n}$ elastically relations of **Armes** " "

 $\overline{\mathcal{L}}$

 Δ

$T_{\rm eff}$ differential cross section for the process is given by σ <u>cross section</u>

$$
\frac{d\sigma}{dt} = \frac{1}{16\pi} |A(x, \Delta, Q)|^2
$$

amplitude and differential control con

$$
A(x, \Delta, Q) = \sum_{h,\bar{h}} \int d^2 \mathbf{r} \int dz \, \Psi_{h,h^*}(\mathbf{r}, z, Q^2) \mathcal{N}(x, \mathbf{r}, \Delta) \, \Psi_{h,h^*}^V(\mathbf{r}, z)
$$

dipole cro where the security of $\frac{u}{v}$ is the helicity of $\frac{u}{v}$ dipole cross section The amplitude Cross section amplitude N (x, r, a) can be related to the scattering amplitude N(x, r, b) introduced to the scattering amplitude N(x, r, b) introduced to the scattering amplitude N(x, r, b) in the scattering

$$
\sigma_{\text{dip}}(x, \mathbf{r}) = \text{Im} \, i\mathcal{N}(x, \mathbf{r}, \Delta = 0)
$$

The differential cross section for the process is given by \mathcal{L} the process is given by \mathcal{L} which is the expression for the optical theorem for scattering of dipole amplitude

$$
\mathcal{N}(x, \mathbf{r}, \Delta) = 2 \int d^2 \mathbf{b} N(x, \mathbf{r}, \mathbf{b}) e^{i \Delta \cdot \mathbf{b}}
$$

integration over the impact parameter by the integration of the integration of the integration. d Stasto: Exclusive vm (photo)production and low x dynamics **and in the overall constant of the overall** Anna Stasto: Exclusive VM (photo)production and low x dynamics Anna Stasto: Exclusive VM (photo)production and low **x** dynamics

- interaction the vector meson value is meson value in the final state in the final state. The proton state is me
The proton state in the final state in the proton scatters of the proton scatters of the proton state is state r dipole size
	- impact parameter
	- Λ momentum transfer
- z , $(1-z)$ fraction of the longitudinal z $T \triangleq \int_{-\infty}^{\infty} \frac{d\mathbf{v}}{dt} \mathbf{v}(x, \mathbf{I}, \mathbf{v}) e^{-\mathbf{v}(x, \mathbf{I}, \mathbf{v})}$ carried by the quark(anti-quark) momentum of the photon

Low x - type approaches to exclusive VM production $T_{\rm F}$ be used the best calculate the light-from the light-fronte Poisson-tion peaked at a *q*² α α α α α $t \sim 10$ impact factor, the sets of σ sets of σ are summarized in an are summarized in a summarized in Low x - type approaches to exclusive *T,L*(*r, z*) = *^NT,Lz*(1 *^z*) exp

 $\emph{Bautista},\emph{Fernandez}$ Tellez, Hentschinski plemented with DGLAP inspired kinematic corrections $\mathcal{Q}(\mathcal{Q})$ inspired been performed been performed been performed between performed been performed by $\mathcal{Q}(\mathcal{Q})$ *D* cuttota **L**_{on}

$$
\mathfrak{Im}\mathcal{A}_{T}^{\gamma^{*}p\rightarrow Vp}(W,0) = \alpha_{s}(\overline{M}\cdot Q_{0})\int_{\frac{1}{2}-i\infty}^{\frac{1}{2}+i\infty}\frac{d\gamma}{2\pi i}\int_{0}^{1}\frac{dz}{4\pi}\left[\hat{g}\left(x,\frac{M^{2}}{Q_{0}^{2}},\frac{\overline{M}^{2}}{M^{2}},Q_{0},\gamma\right)\cdot\Phi_{V,T}(\gamma,z,M)\cdot\left(\frac{M^{2}}{Q_{0}^{2}}\right)^{\gamma}\right]
$$

4⇡

^V)*^T* (*r*) *·* 0*N* (*x, r*)

0

*^f ^R*²

*mf ^R*²

✏2(2)

✓8*z*(1 *^z*)

= ↵*s*(*M · Q*0) ed from the BF the strong coupling the strong coupling \mathbf{g} is the convention over \mathbf{g} and \mathbf{g} *g*ˆ $\overline{}$ *x,* tegr *,* Dipole amplitude obtained from the BFKL unintegrated *^M*² *, Q*0*,* T \sim T Dipole amplitude obtained

wave function overlap Eq. (16). In particular we find the function over \mathcal{L}

=m*A*⇤*p*!*V p*

$$
G(x, \mathbf{k}^2, M) = \frac{1}{\mathbf{k}^2} \int_{\frac{1}{2} - i\infty}^{\frac{1}{2} + i\infty} \frac{d\gamma}{2\pi i} \hat{g}\left(x, \frac{M^2}{Q_0^2}, \frac{\overline{M}^2}{M^2}, \gamma\right) \left(\frac{\mathbf{k}^2}{Q_0^2}\right)^{\gamma}
$$

$$
\sigma_0 N(\boldsymbol{r},x) = \frac{4\pi}{N_c} \int \frac{d^2 \boldsymbol{k}}{\boldsymbol{k}^2} \left(1 - e^{i \boldsymbol{k} \cdot \boldsymbol{r}}\right) \alpha_s G(x, \boldsymbol{k}^2)
$$

Z

Z

V,T (*, z,M*) = ⁴⇡ *N^c d*2*r* $\overline{\text{u}}$ ction impact factor obtair !² *<u>ct</u> factor* **b** $\frac{1}{2}$ $\frac{1}{2}$ Vector meson photoproduction impact factor obtained from the dipole model in coordinate space $\overline{16}$

$$
\Phi_{V,T}(\gamma, z, M) = \frac{4\pi}{N_c} \int d^2 r \int \frac{d^2 k}{(k^2)^2} \left(1 - e^{ik \cdot r}\right) \left(\frac{k^2}{M^2}\right)^{\gamma} \left(\Psi_V^* \Psi\right)_T(r)
$$

*m*²

Figure 1: *Schematic picture of the high energy factorized amplitude for photo-production of vector mesons J/ ,* ⌥ *with zero momentum transfer t = 0. In the high energy limit the amplitude factorizes* Ξ \mathbf{r} ibution m ✓ ✏2*R*² 8*z*(1 *z*) ◆ Δ *f* Δ *z* Δ *f* Δ *modeled in this approach* (1) modeled in th *fR*² *F* and the state of the distribution modeled in this approach

Anna Stasto: Exclusive VM (photo)production and low **x** dynamics \overline{a} \mathbf{t} $\ddot{}$ o: Exclusi
. vm (photo⁾ 8*z*(1 *z*) production and low **x** dynamics ² *· ^m*²

◆

Low x dipole amplitude: including saturation to be specified at some initial value of \mathbf{S} to be specified at some initial value of $\mathcal{X} = \mathcal{X} \cup \mathcal{X} = \mathcal{X} \cup \mathcal{X}$ nplitude including saturation \mathcal{W}_{MAP} \longrightarrow \longrightarrow \longrightarrow \longrightarrow \longrightarrow \longrightarrow with \mathbf{c} the parameters equivalent to the

Glauber-Mueller parameterization often used; includes nonlinear effects *Motyka,Kowalski,Watt;* 'b-Sat model' $\mathcal{L} = \mathcal{L} \left(\mathcal{L} \right)$ 'b-Sat model'

$$
N_{GM}(r, b; Y = \ln 1/x) = 1 - \exp\left(-\frac{\pi^2}{2N_c}r^2xg(x, \eta^2)T(b)\right)
$$

$$
T(b) = \frac{1}{8\pi}e^{\frac{-b^2}{2B_G}}
$$

n <mark>low x non</mark> $\overline{\mathsf{in}}$ ilitar equation. Dantský - Kovčnegov eq Can be obtained from low x nonlinear equation: Balitsky - Kovchegov equation *Berger,AS* elastically with some momentum transfer t. an
and and an

$$
\frac{dN(\mathbf{r}_{01}, \mathbf{b}_{01}, Y)}{dY} = \frac{\alpha_s N_c}{\pi} \int \frac{d^2 \mathbf{r}_2 \mathbf{r}_{01}^2}{\mathbf{r}_{20}^2 \mathbf{r}_{12}^2} \left[N(\mathbf{r}_{20}, \mathbf{b}_{01} + \frac{\mathbf{r}_{12}}{2}, Y) + N(\mathbf{r}_{12}, \mathbf{b}_{01} - \frac{\mathbf{r}_{20}}{2}, Y) \right]
$$

$$
-N(\mathbf{r}_{01}, \mathbf{b}_{01}, Y) - N(\mathbf{r}_{20}, \mathbf{b}_{01} + \frac{\mathbf{r}_{12}}{2}, Y)N(\mathbf{r}_{12}, \mathbf{b}_{01} - \frac{\mathbf{r}_{20}}{2}, Y)
$$

- Typically BK solved in a local approximation: without x prompt of the initial condition the interest of the interest of the initial condition (2.12) depending to the i of the dipole size and impact parameter. A nontrivial dependence on the angle between vectors r and b is not present in the initial condition, instead being dynamically generated being dynamicall vectors replacement in the initial condition, instead being the internation of the internation of the internation of the international dependence of the international dependence of the international dependence of the inter when the initial condition is evolved with the BK equation is equation. impact parameter dependence. Successful description of variety of data.
- Can be solved (at least numerically) relatively easily.
- Generates the saturation scale that divides the dense and dilute regime.

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 $\frac{p}{q}$

 γ^*

 r

b

N

p \longrightarrow

0

 $Q = \frac{1}{r}$

 p^\prime

V

r

What about spatial distribution?

Usual approximation:

 $N(\mathbf{r}, \mathbf{b}, Y) = N(\mathbf{r}, Y)$

- The target has infinite size.
- Local approximation suggests that the system becomes more perturbative as the energy grows.
- But this cannot be true everywhere (IR in QCD)

Impact parameter profile

What about spatial distribution?

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Impact parameter profile

Solving impact parameter dependent BK equation

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Solving impact parameter dependent BK equation

Solving impact parameter dependent BK equation

Impact parameter profile of the interaction region

- Saturation for small impact parameters
- No saturation for large impact parameters (system is still dilute)
- Initial impact parameter profile is not preserved
- Power tail in b is generated, this is due to perturbative evolution and lack of confinement effect.

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Angular correlations Difficult problem → (4 + 1) dimensions. ngular $b_{01} =$

 $\mathbf{x}_0 + \mathbf{x}_1$

2

 $x_{01} = x_0$ –

Angular correlations present in the solution

Amplitude larger for aligned configurations of the dipole

Could be relevant for the angular sensitive observables

Sensitivity through diffractive dijet in photoproduction/DIS

 Hatta,Xiao,Yuan; Altinoluk,Armesto,Beuf,Rezaeian;

Impact Parameter

N(y)

 \mathcal{I}_1 was used is a nature cuton on the daughter process x_{02} and x_{12} where method that was used is a hard cutoff on the daughter dipoles x_{02} and x_{12} where the kernel i ϵ se dipole size**nd tial condition and teutotr to play edipoles** method that was used is a hard cutoff on the daughter dipoles x_{02} and x_{12} where the kernel is ese dipole siz**es laticali Conception and leutoit tosida**. \bm{n} amplitude. With this mass parameter the modified kernel becomes Eq. (2.11) is a differential equation in rapidity and hence suitable initial conditions need method that was used is a hard cutoff on the daughter dipoles x_{02} and x_{12} where the ker
se dipole size**nd tial conduction and the utoff for dipoles** choosing to use the initial condition $\frac{1}{2}$ and $\frac{1}{2}$ $\frac{1}{2}$

At x_0 =0.01 use Glauber-Mueller formula: $\mathcal{C}(r,b)$ $\sum_{\text{cell}} \prod_{\text{cell}} \prod_{\text{cell}} x^K = \frac{d\bar{x}_{0p}^2 \bar{\alpha}_s \frac{1}{x_{0p}^2 \bar{x}_{1p}^2}}{d\bar{x}_{0p}^2 \bar{x}_{1p}^2} \Theta(\frac{1}{\sqrt{n^2}} - \bar{x}_{02}^2) \Theta(\frac{1}{\sqrt{n^2}} - \bar{x}_{12}^2) \sqrt{T(b)} = \frac{1}{\sqrt{n^2}} \sum_{\text{cell}} \prod_{\text{cell}} \prod_{\text{cell}} \prod_{\text{cell}} \prod_{\text{cell}} \prod_{\text{cell}} \prod_{\text$ $dz \frac{d^2\mathbf{x}_2}{dx}$ is the total to this non-perturbative regime or at what scale this occurs at $\left(\frac{d}{z}\right)^{-1}$ At $x_0 = 0.01$ use Glating the mass or a pion of m^2 | $+ K_1^2$ | x_{12} | $\frac{1}{r^2}$ $+ m^2$ | | $K = d\overline{x_0}^2 - \overline{\Delta} \overline{2}^2$ $\overline{\Delta}$ $\$ $K = dx_0^2$ x_{01} x_0^2 of x_{12}^2 $\frac{\Theta(\frac{1}{\sqrt{1 - \frac{1}{n}}})}{\Theta(\frac{1}{\sqrt{1 - \frac{1}{n}}})}$ $\frac{1}{m^2} - x_0^2$ $\frac{2}{02}$) $\Theta(\frac{1}{m})$ $\frac{1}{m}e^{x^2+2} \sqrt{T(b)} \equiv \frac{1}{2}e^{\frac{-b^2}{2B_G}}$ ernel can be expanded into three terms, one of $\frac{1}{r^2}$ $\overline{x^2_{02}}$ $\cos w_{\text{cm}}^2 \frac{3}{2} 1 \frac{1}{x^2}$ $\overline{x^2_{12}}$ and α cross term. Each of the dz $\overline{\mathbf{z}}$ \approx $d^2\mathbf{x}_2$ $\frac{d^2\mathbf{x}_2}{d^2\mathbf{x}_2}$ $\frac{K^2}{2}$ $\int \frac{z}{x^2}$ $\pm m^2$ $\sqrt{}$ $+ K_1^2$ $\left(x_{12}\sqrt{\frac{z}{x_{01}^2}}\right)$ $+m^2$ $\sqrt{ }$ $\bigcap x \mid Z \mid \xi_1$ $\sqrt{\frac{1}{10} \frac{c^2}{x^2}}$ $\frac{1}{2}$ $\sqrt{\gamma}$ \bm{F}_1 x^{02} \sqrt{m} $+m²$ $\overline{\searrow}$ $\frac{1}{2}$ $\frac{1}{2}$ ϕ = $\frac{1}{2}$
ioa x arm \mathbf{A} t $\mathbf{x}_0 = 0.01$ use Glating the parameters to the parameters of m^2 $N(r, b, Y) = \frac{1}{r} \int x^2 dx$ $\overline{2}N$ $x^2x^2y^2$ Δ Λ (*r, b, Yo* = li 14 x) k if $\frac{1}{10}$ and $\frac{1}{2}$, $\frac{1}{2}$ $\frac{1}{2}$ ӭѱ^Ӏ҇ $T(b) = \frac{1}{2}$ 8π e $-b^2$ $2B_G$ $\lim_{x \to 0}$ one of $\frac{1}{x_{02}^2}$ as wen $\lim_{x \to 2} \frac{1}{x_{12}^2}$ and $\lim_{x \to 2} \frac{1}{x_{02}^2}$ form. Each of the

with of the mass manneter in ithis parameter.
With parameters from Kowalski, Motyka, Watt Need to implement the cutoff to regulate large dipole sizes, hem seperatel
amperizesint \mathbb{R}^1 as the slowdown in the evolution at small dipoles is from a scale in the large dipole regime which α cutting the kernel; the effect that each different cut α is the cut section. We discussed in the next section. ϵ to the kernel can have a cut placed on them seperately gorresponding to which dipole is present $\max_{\mathbf{p}} \mathbf{p}$ is the complex was additional contributions from regions where $x^2 \geq \frac{1}{100}$ vet $x^2 \geq \frac{1}{2}$ by $\frac{1}{100}$ the presenting $\sum_{i=1}^{n}$ and $\sum_{i=1}^{n}$ as these contributions are non-existant in the previous, it cion. is to the refiler can have a cut, placed on them seperately iorresponding to which enjoile is presen
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tionel by hand we regard this slowdown as artificial. \max the kerne like this gives additional gontributions from regions, where x^2 $\frac{1}{2}$ vet $x^2 \leq \frac{1}{2}$
beeds into dipole sizes which are below the scale $\frac{n}{2}$. This small-dipole suppression slows the evolument Fran**ic Bryth**
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2016 $\frac{1}{2}$ BGXR413ULfDhs-firom-76650n5 Where x^2 Need to implement the cutoff to regulate large dipole sizes, aced on them seperately corresponding to which dipole is presen
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wdown as artificial $\frac{101}{18}$ a $\frac{103}{4}$ d $\frac{104}{100}$ is not $\frac{104}{100}$ and $\frac{10}{2}$ $\frac{10}{2}$

 $\begin{array}{cccc} \mathbf{F} & \mathbf$ T and the first method that was used is a hard cutoff on the daughter dipoles T where T $\min_{\mathbf{C}}$ continement: $x_{02} \cdot x_{12}$ $K = dx_{02}^2 \bar{\alpha}_s$ $\lceil 1$ x_{02}^2 $\Theta(\frac{1}{\sqrt{2}})$ $\frac{1}{m^2} - x_0^2$ $\frac{2}{02}$) + $\frac{1}{x^2}$ x_{12}^2 **CO**
Θ(Th $\frac{T h e}{m^2}$ Bati $\frac{2}{3}$ ky-P2 $x_{02} \cdot x_{12}$ $x_{02}^{2}x_{12}^{2}$ $\Theta(\frac{1}{\sqrt{2}})$ $\frac{1}{m^2} - x_0^2$ $\binom{2}{02}$ Θ($\frac{1}{22}$ $\frac{1}{m^2} - x_{12}^2$ $\overline{}$ $\begin{bmatrix} \omega_{02} \\ \vdots \\ \omega_{0n} \end{bmatrix}$ $\partial \Theta(\vec{H} \vec{e} \cdot B$ ali $\vec{t} \vec{s}$ ky P \vec{P} escription p_1 p_2 p_3 p_4 p_5 p_6 p_7 p_7 p_8 p_9 p_1 p_2 p_3 p_4 p_5 p_6 p_7 p_8 p_9 p_1 p_2 p_3 p_4 p_5 p_6 p_7 p_8 p_9 p_1 p_2 p_3 p_4 p_5 p_7 p_8 p_9 p_1 i_1 in i_2 in $\frac{1}{2}$ in $\frac{1}{2}$ in $\frac{1}{2}$ is $\frac{1}{2}$ in $\frac{1}{2}$ are given in Table 1. We use x_{02} . x_{12} and x_{02} and x_{12} and x_{02} at x_{12} $\frac{1}{x_{12}^2}$ $\frac{1}{x_{12}^2}$ budgeyy 1 $\frac{1}{x_{02}^2}$ $\frac{1}{x_{12}^2}$ $\frac{1}{x_{02}^2}$ $\frac{1}{x_{12}^2}$ $\frac{1}{x_{02}^2}$ $\frac{1}{x_{12}^2}$ $\frac{1}{x_{12}^2}$

 \mathcal{L} weather unstable $\approx 1/$ extention of (12 - 13) cannot be applied to (16) as this leads to regimes where the contribution c
he BK $\bigoplus_{\mathcal{P}} \mathbb{E} \bigoplus_{\mathcal{P}} \bigoplus_{\mathcal{P}} \text{unstapll}_c \cong \frac{1}{\sqrt{2B_G}} \times \frac{250 \text{ MeV}}{350 \text{ MeV}}$ {{n&4}}}}}
K = d*x* 02 C
; theuK over2 $\mathbf{\hat{w}^{2}_{1}}$ BStead $\frac{1}{\sqrt{\frac{1}{1+\frac{$ <u>@^u d</u>epha E\$
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s (16) [14] kinet at fident materily, overe sext digiterment et die op men eves not see dine tien melv an meri $\lim_{x\to a} \text{c} \lim_{x\to a} (16)$. These cuts tame the coupling at la $\frac{1}{2}$ \mathbb{R}^e dipole size \overline{d} and provides some (but no ndence to the IR regulation of the coupling. The entire kernel can be cut with step functions as ^m² , making the DIV research culture cut than the previous ($K = dx_0 \overline{v}_c m^2$) $K_1 (mx_{10}^2) - 2K_1 (mx_{10}^2) K_1 (mx_{10}^2) \frac{x_{02} \cdot x_{12}}{x_{02}^2}$ cah) be killed off cinerly, but employed and intercription function besser (unctions) can be rain utibis kernel, and its (behavior is of special juligrest or der can dimpliment similar routs for halsecbilding $x_{\mathsf{P} \mathsf{P} \mathsf{P}}^2$ parameter (19). These caus value ule coupling at faige dipole sizes and provide
nuch smoother cutoff and reduces to the LO Kernel (9) for small dipole sizes. $K = dx_{02}^2 \bar{\alpha}_s m^2$ \mathbb{R} $K_1^2(mx_{02}^2) + K_1^2(mx_{12}^2) - 2K_1(mx_{02}^2)K_1(mx_{12}^2)$ $|\mathbf{r}$ i \mathbf{r} i \mathbf{r} l $|\mathbf{\mathcal{O}}$ op $|$ **"**
| ${\mathop{\mathrm{gal}}\nolimits}$ implimentation of the running coupling that dens comes from calculation that we consider is $B_{\rm eff}$ (16) [4] (as stated early the Kovchegov-Waigert Prescription man every desser for purely animaries), \log scheme (16). These cuts tame the coupling at large dipole sizes and provides some (but no indence to the IR regulation of the coupling. The entire kernel can be cut with step functions as extention of $(12 - 13)$ cannot be applied to (16) as this leads to regimes where the contribution of he BK to become unstable. Cutoff included both in the evolution kernel and in the GM initial condition. and inplimantation of the rupping country that has gones of the calculation are sprint as the previous rice in the condition of the equality of the new warner can
A (16) IA Las stated: sarly due IKO KHE 2004 also in 21 the infinition was digital ig scheffie (16). These cuts tame the coupling at large dipole sizes and pro
fuch smoother cutoff and reduces to the LO Kernel (9) for small dipole size: α and the dipole size and integration of the dipole size and incremented to the angle between α is an α of (10 angle α) and the angle between α in α be BK Gutoffie unstable $\simeq 1/\sqrt{2}B_G \sim 350 \text{ MeV}$ $\sqrt{2}B_G \simeq 2$ $K = dx_{02}^2 \alpha_s m^2 \left[K_1^2 \left(m x_{02}^2 \right) + K_1^2 \left(m x_{01}^2 \right) \right]$ x is a confirmed that dependent ϵ and ϵ is the set of ϵ is the condition ϵ $\sum_{i=1}^{N} \sum_{i=1}^{N} \sum_{j=1}^{N} \sum_{j=1}^{N}$ when the initial condition is evolved with the BK equation. Hight to (16) as this leads to regimes where the contribution of $\left(\frac{\sqrt{2}D_{G}^{2}+5500 \text{ mC}}{K_{1}^{2}(m_{12})-2K_{1}(m_{12})}\right)$ $\left(\frac{\sqrt{2}D_{G}^{2}-\frac{1}{2}500 \text{ mC}}{K_{1}^{2}(m_{12})}\right)$

 \sim anna Stasto: Express \sim Were \rm{recon} us cases mention rd_weit curring off a remet with a fixed doubling $\bar{\alpha}_s$, the fusion of the running
lculated in: Exclusive which are a series of $\frac{2}{3}$ and $\frac{2}{3}$ and $\frac{2}{3}$ and $\frac{2}{3}$ and $\frac{2}{3}$ and \frac of to be equivalent [6]. We choose the s 12 d were reconciled to be equivalent [6]. We choose the scheme of [4] as it was easier to impliment and were reconciled to be equivalent [6]. We choose the scheme of [4] as it was easier to implim us cases mentioned were cutting off of a kernel with a fixed doubling α_s . Inclusion of the running $N_e \alpha_s (x^2$ Refit the indusive H E $\frac{1}{\sqrt{2}}$ $\frac{d}{d}$ data $\frac{f_0}{d} \left(\frac{d^2}{d^2} \right)$ and $\frac{1}{d}$ $\frac{1}{4}$ x_{01}^2 \mathbb{R} efit the inglusive HERA data for x_{max}^2 $_{\text{max}}^2$ N_{α} ($\alpha^{2}R$) of it the industry $HFR A$ dota for R_{α}) us cases mention care cutting off of a kerner with a fixed doubling α_s , linct **Anna Stasto: Exclusive VM (photo)production and low x dynamics**

Evolved solution for the dipole amplitude

Small x evolution leads to the broader distribution in impact parameter Change of shape with decreasing x

r \mathbf{A}

Exclusive process: photo(production) and DIS $0³$ γ* p => ρ p

0 5 10 15 20 25 $2^{10} \cdot 12$ 0 5 10 15 20 1**4**5 0 2^{10} 1^2 $\begin{array}{cccc} 0 & 5 & 10 \\ 0 & 5 & 3 & 15 \end{array}$ 145

Exclusive diffraction 1 Q^2 = 10.9 GeV² $Q^2 = 9.7$ GeV \circ Q^2 = 13.5 GeV² $Q^2 = 8.3 \text{ GeV}^2$ $\widetilde{\circ}$

11 Figure 6: Equippendence of the vector of the vector of the vector section \mathbf{r}_i experience is resourched and the front danger of the front data are from the second to the second the second $\frac{1}{2}$ ρ production: normalization systematically underestimated especially at low scales energy dependence is reasonably described

 Q^2 = 3.3 GeV²

γ* p => φ p **Anna Stasto: Exclusive VM (photo)production and low x dynamics**

> \sim \sim 6.6 GeV \sim

 $γ^*$ p =

15

Correction from skewedness 4 of [8] used below in Section 3 to calculate the gap survival probability *S*² in the case of *p* p *p* p *p* p *p* p

diffractive exercisive employed calculation and low x agricultures. Anna Stasto: Exclusive VM (photo)production and low x dynamics
 Anna Stasto: Exclusive VM (photo)production and low x dynamics

Differential cross section 10^3 $Q^2 = 0.05 \text{ GeV}^2$ \mathcal{P} p \mathcal{P} 10^{3} $Q^2 = 8.9 \text{ GeV}^2$ $\mathcal{L} = \mathcal{L}$

17

Diffractive slope

• The value of B_D is closely related to the transverse size of the interaction region which is a combination of the size of the VM and the size of the gluon hot-spot in the proton.

proton

- In the case of the lighter mesons it is the first one which prevails.
- For heavier mesons, it is the larger size of the gluon distribution in the proton. Thus it does not depend on Q^2 that much.

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Slope vs energy

- Reasonable description of the diffractive slope from dynamical prediction based on BK evolution with cutoff
- By making mass regulator smaller, the slope can be increased
- Functional dependence on energy could help determine type of cutoff: sharp or exponential

Summary and outlook

- Exclusive diffractive VM production using solution to the impact parameter dependent BK equation
- Coupling no longer regularized by saturation only. Need cuts on large dipoles. Large sensitivity to this regularization.
- Extra corrections: skewed gluon distribution, non-perturbative modification to the photon wave function.
- Exclusive diffraction of vector mesons, good description of data, in bins of t,W,Q, especially for heavier vector mesons. Lighter VM overall shape is reproduced, normalization is not well reproduced.
- Energy dependence of the diffractive slope generated by the model, depends on the phenomenological parameters, mainly set by the cutoff on the large dipoles.
- Looking forward to the more measurements of the energy dependence of tdistribution for J/ψ from LHC.