QCD resummation effects in inclusive production of a forward J/psi and a backward jet at the LHC

Lech Szymanowski

National Centre for Nuclear Research, Warsaw

GDR QCD 2017, 4-6 December 2017, Orme des Merisiers

in collaboration with

R. Boussarie (INP, Kraków)
B. Ducloué (Institut de physique théorique, Université Paris Saclay, CEA, CNRS)
S. Wallon (LPT Orsay, CNRS / Université Paris Sud, Université Paris Saclay)

Based on arXiv:1709.02671 [hep-ph]
The partonic content of the proton

The various regimes governing the perturbative content of the proton

- **"usual" regime:** $x_B$ moderate ($x_B \gtrsim .01$):
  Evolution in $Q$ governed by the QCD renormalization group
  (Dokshitzer, Gribov, Lipatov, Altarelli, Parisi equation)

\[ \sum_n (\alpha_s \ln Q^2)^n + \alpha_s \sum_n (\alpha_s \ln Q^2)^n + \cdots \]

  - LLQ
  - NLLQ

- Perturbative Regge limit: $s_{\gamma^* p} \to \infty$ i.e. $x_B \sim Q^2 / s_{\gamma^* p} \to 0$
  in the perturbative regime (hard scale $Q^2$)
  (Balitskii Fadin Kuraev Lipatov equation)

\[ \sum_n (\alpha_s \ln s)^n + \alpha_s \sum_n (\alpha_s \ln s)^n + \cdots \]

  - LLs
  - NLLs
One of the important longstanding theoretical questions raised by QCD is its behaviour in the perturbative Regge limit $s \gg -t$.

Based on theoretical grounds, one should identify and test suitable observables in order to test this peculiar dynamics.

![Diagram](image)

**Hard scales:** $M_1^2, M_2^2 \gg \Lambda_{QCD}^2$ or $M_1'^2, M_2'^2 \gg \Lambda_{QCD}^2$ or $t \gg \Lambda_{QCD}^2$

where the $t$–channel exchanged state is the so-called **hard Pomeron**.
Introduction

MN jets at full NLLx

J/Ψ and jet production

How to test QCD in the perturbative Regge limit?

What kind of observable?

- perturbation theory should be applicable:
  selecting external or internal probes with transverse sizes \( \ll 1/\Lambda_{QCD} \)
  (hard \( \gamma^* \), heavy meson (\( J/\Psi \), \( \Upsilon \)), energetic forward jets) or by choosing large \( t \) in order to provide the hard scale.

\[ \Rightarrow \text{semi-hard processes with } s \gg p_{T,i}^2 \gg \Lambda_{QCD}^2 \text{ where } p_{T,i}^2 \text{ are typical transverse scale, all of the same order.} \]
Some examples of processes

- **inclusive**: DIS (HERA), diffractive DIS, total $\gamma^*\gamma^*$ cross-section (LEP, ILC)
- **semi-inclusive**: forward jet and $\pi^0$ production in DIS, Mueller-Navelet double jets, diffractive double jets, high $p_T$ central jet, in hadron-hadron colliders (Tevatron, LHC)
- **exclusive**: exclusive meson production in DIS, double diffractive meson production at $e^+e^-$ colliders (ILC), ultraperipheral events at LHC (Pomeron, Odderon)
Dynamics of resummations

Small values of $\alpha_s$ (perturbation theory applies if there is a hard scale) can be compensated by large logarithmic enhancements.

DGLAP

$$k_{T_{n+1}} \ll k_T$$

$$x_{1}, k_{T_1}$$

$$x_{2}, k_{T_2}$$

$$\cdots$$

$$\sum (\alpha_s \ln Q^2)^n$$

BFKL

$$x_{n+1} \ll x_n$$

$$x_{1}, k_{T_1}$$

$$x_{2}, k_{T_2}$$

$$\cdots$$

$$\sum (\alpha_s \ln s)^n$$

When $\sqrt{s}$ becomes very large, it is expected that a BFKL description is needed to get accurate predictions.
Perturbative QCD in a fixed order approach

Hard processes in QCD and collinear factorization

- This is justified if the process is governed by a hard scale:
  - Virtuality of the electromagnetic probe
    - in elastic scattering $e^\pm p \rightarrow e^\pm p$
    - in Deep Inelastic Scattering (DIS) $e^\pm p \rightarrow e^\pm X$
    - in Deep Virtual Compton Scattering (DVCS) $e^\pm p \rightarrow e^\pm p \gamma$
  - Total center of mass energy in $e^+e^- \rightarrow X$ annihilation
  - $t$-channel momentum exchange in meson photoproduction $\gamma p \rightarrow M p$
  - Mass of a heavy bound state e.g. $J/\Psi$, $\Upsilon$

- A precise treatment relies on collinear factorization theorems

- Scattering amplitude
  
  \[ \text{convolution} = \text{partonic amplitude} \otimes \text{non-perturbative hadronic content} \]
  
  (computed at a given fixed order)
Semi-hard processes: resummed QCD at large $s$

**QCD in the perturbative Regge limit**

$$ s \gg M^2_{\text{hard scale}} \gg \Lambda^2_{\text{QCD}} $$

The amplitude can be written as:

$$ \mathcal{A} = \sim s + \left( \sim s (\alpha_s \ln s) + \cdots \right) + \left( \sim s (\alpha_s \ln s)^2 + \cdots \right) + \cdots $$

this can be put in the following form:

$$ \sigma_{\text{tot}}^{h_1 h_2 \rightarrow \text{anything}} = \frac{1}{s} \text{Im} \mathcal{A} \sim s^{\alpha_\text{P}(0)-1} $$

with $\alpha_\text{P}(0) - 1 = C \alpha_s + C' \alpha_s^2 + \cdots$

$C > 0$: Leading Log $\mathbb{P}$omeron

Balitsky, Fadin, Kuraev, Lipatov
Opening the boxes: Impact representation $\gamma^* \gamma^* \rightarrow \gamma^* \gamma^*$ as an example

- **Sudakov decomposition:**
  \[ k_i = \alpha_i p_1 + \beta_i p_2 + k_{\perp i} \quad (p_1^2 = p_2^2 = 0, \ 2p_1 \cdot p_2 = s) \]

- write
  \[ d^4 k_i = \frac{s}{2} d\alpha_i d\beta_i d^2 k_{\perp i} \quad (k = \text{Eucl.} \leftrightarrow k_{\perp} = \text{Mink.}) \]

- $t$–channel gluons have non-sense polarizations at large $s$: $\epsilon_{NS}^{up/down} = \frac{2}{s} p_{2/1}$

\[
\begin{align*}
\mathcal{M} &= \frac{is}{(2\pi)^2} \int \frac{d^2 k}{k^2} \Phi^{up}(k, r - k) \int \frac{d^2 k'}{k'^2} \Phi^{down}(-k', -r + k') \\
&\quad \times \int \frac{d\omega}{2\pi i} \left( \frac{s}{s_0} \right)^\omega G_\omega(k, k', r) \\
&\quad \left\uparrow \text{multi-Regge kinematics} \right\downarrow
\end{align*}
\]

\[ \Rightarrow \text{set } \alpha_1 = 0 \text{ and } \int d\beta_1 \Rightarrow \Phi^{\gamma^* \rightarrow \gamma^*}(k_1, r - k_1) \text{ impact factor} \]

\[ \Rightarrow \text{set } \beta_n = 0 \text{ and } \int d\alpha_n \Rightarrow \Phi^{\gamma^* \rightarrow \gamma^*}(-k_n, -r + k_n) \]
Only a few higher order corrections are known

- Higher order corrections to BFKL kernel are known at NLL order (Lipatov Fadin; Camici, Ciafaloni), now for arbitrary impact parameter $\alpha_S \sum_n (\alpha_S \ln s)^n$ resummation

- Impact factors are known in some cases at NLL
  - $\gamma^* \rightarrow \gamma^*$ at $t = 0$ (Bartels, Colferai, Gieseke, Kyriileis, Qiao; Balitski, Chirilli)
  - Forward jet production (Bartels, Colferai, Vacca; Caporale, Ivanov, Murdaca, Papa, Perri; Chachamis, Hentschinski, Madrigal, Sabio Vera)
  - Inclusive production of a pair of hadrons separated by a large interval of rapidity (Ivanov, Papa)
  - $\gamma_L^* \rightarrow \rho_L$ in the forward limit (Ivanov, Kotsky, Papa)
Mueller-Navelet jets: Basics

Mueller-Navelet jets

- Consider two jets (hadrons flying within a narrow cone) separated by a large rapidity, i.e. each of them almost fly in the direction of the hadron “close” to it, and with very similar transverse momenta.

- Pure LO collinear treatment: these two jets should be emitted back to back at leading order:
  - $\phi \equiv \Delta \phi - \pi = 0$ ($\Delta \phi = \phi_1 - \phi_2$ = relative azimuthal angle)
  - $k_{\perp 1} = k_{\perp 2}$. No phase space for (untagged) multiple (DGLAP) emission between them.
Mueller-Navelet jets: LL fails

**Mueller Navelet jets at LL BFKL**

- In LL BFKL ($\sim \sum (\alpha_s \ln s)^n$), emission between these jets $\rightarrow$ strong decorrelation between the relative azimuthal angle jets, incompatible with $p\bar{p}$ Tevatron collider data.

- A collinear treatment at next-to-leading order (NLO) can describe the data.

- Important issue: non-conservation of energy-momentum along the BFKL ladder. A LL BFKL-based Monte Carlo combined with e-m conservation improves dramatically the situation (Orr and Stirling).
Mueller-Navelet jets: beyond LL

Mueller Navelet jets at NLL BFKL

- up to $\sim 2010$, the subseries $\alpha_s \sum (\alpha_s \ln s)^n$ NLL was included only in the exchanged Pomeron state, and not inside the jet vertices. Sabio Vera, Schwennsen, Marquet, Royon.

- our studies have shown was that these corrections are very important. Colferai, Schwennsen, L.Sz, S. Wallon, Ducloué, L.Sz., S. Wallon.

  for similar studies and results: Caporale, Ivanov, Murdaca, Papa, Caporale, Murdaca, Sabio Vera, Salas.

Quasi Multi-Regge kinematics (here for NLL BFKL)
$k_T$-factorized differential cross section

$$\frac{d\sigma}{d|k_{J,1}| d|k_{J,2}| dy_{J,1} dy_{J,2}} = \int d\phi_{J,1} d\phi_{J,2} \int d^2k_1 d^2k_2$$

$$\times \Phi(k_{J,1}, x_{J1}, -k_1)$$

$$\times G(k_1, k_2, \hat{s})$$

$$\times \Phi(k_{J,2}, x_{J2}, k_2)$$

with $\Phi(k_{J,2}, x_{J2}, k_2) = \int dx_2 f(x_2) V(k_2, x_2)$

$f \equiv$ PDF

$x_J = \frac{|k_J|}{\sqrt{s}} e^{y_J}$
Mueller-Navelet jets at NLL: Renormalization scale fixing

Renormalization scale uncertainty

- We used the Brodsky-Lepage-Mackenzie (BLM) procedure to fix the renormalization scale.

- The BLM procedure resums the self-energy corrections to the gluon propagator at one loop into the running coupling.

- First attempts to apply BLM scale fixing to BFKL processes lead to problematic results. Brodsky, Fadin, Kim, Lipatov and Pivovarov suggested that one should first go to a physical renormalization scheme like MOM and then apply the 'traditional' BLM procedure, i.e. identify the $\beta_0$ dependent part and choose $\mu_R$ such that it vanishes.

We followed this prescription for the full amplitude at NLL.
Mueller-Navelet jets at NLL: comparison with the data

Comparison with the data

recall: $\varphi = 0 \Leftrightarrow$ back-to-back

$$\frac{1}{\sigma} \frac{d\sigma}{d\varphi} = \frac{1}{2\pi} \left\{ 1 + 2 \sum_{n=1}^{\infty} \cos(n\varphi) \langle \cos(n\varphi) \rangle \right\}.$$ 

$6 < Y < 9.4$

$35 \text{ GeV}^2 < k_{J,1}, k_{J,2}$

Ducloué, L.Sz., S. Wallon.
Other effects and references

- **Full NLL description**

- **BLM renormalization scale fixing and comparison with data**

- **Energy momentum violation**: the situation is much improved when including full NLL corrections

- **Multiparton description of Mueller-Navelet jets**: two uncorrelated ladders suppressed at LHC kinematics

- **Sudakov resummation effects**: in the almost back-to-back region, and at LL, the resummation as been performed: no overlap with low-x resummation effects
Inclusive forward $J/\Psi$ and backward jet production at the LHC

Why $J/\Psi$?

- Numerous $J/\psi$ mesons are produced at LHC
- $J/\psi$ is "easy" to reconstruct experimentaly through its decay to $\mu^+\mu^-$ pairs
- The mechanism for the production of $J/\psi$ mesons is still to be completely understood (see discussion later), although it was observed more than 40 years ago E598 collab 1974; SLAC-SP collab 1974
- Any improvement of the understanding of these mechanisms is important in view of QGP studies since $J/\Psi$ suppression (melting) is one of the best probe. Cold nuclear effects are numerous and known to make life more complicate
- The vast majority of $J/\psi$ theoretical predictions are done in the collinear factorization framework: would $k_t$ factorization give something different?
- We will perform an MN-like analysis, considering a process with a rapidity difference which is large enough to use BFKL dynamics but small enough to be able to detect $J/\psi$ mesons at LHC (ATLAS, CMS).
\[ \hat{s} = x x' s \]

\[
\frac{d\sigma}{d y_V d|p_V\perp|d\phi_V d y_J d|p_J\perp|d\phi_J} = \sum_{a, b} \int d^2 k\perp d^2 k'\perp \\
\times \int_0^1 dx \ f_a(x) \ V_{V,a}(k\perp, x) \\
\times G(-k\perp, -k'\perp, \hat{s}) \\
\times \int_0^1 dx' \ f_b(x') \ V_{J,b}(-k'\perp, x'),
\]
Master formula

\( \hat{s} = x x' s \)

\[
d\sigma = \sum_{a,b} \int d^2 k_\perp d^2 k'_\perp \times \int_0^1 dx f_a(x) V_{V,a}(k_\perp, x) \times G(-k_\perp, -k'_\perp, \hat{s}) \times \int_0^1 dx' f_b(x') V_{J,b}(-k'_\perp, x'),
\]
The NRQCD formalism

Quarkonium production in NRQCD

- We will first use the Non Relativistic QCD (NRQCD) formalism
  Bodwin, Braaten, Lepage; Cho, Leibovich ....

- There is no proof of NRQCD factorization at all orders.

- Basically, one expands the quarkonium state with respect to the velocity $v \sim \frac{1}{\log M}$ of its constituents:

$$|V\rangle = O(1)|Q\bar{Q}[^3 S_1^{(1)}]\rangle + O(v)|Q\bar{Q}[^3 P_j^{(8)}]g\rangle + O(v^2)|Q\bar{Q}[^1 S_0^{(8)}]g\rangle +$$

$$+ O(v^2)|Q\bar{Q}[^3 S_1^{(1,8)}]gg\rangle + O(v^2)|Q\bar{Q}[^3 D_j^{(1,8)}]gg\rangle + \ldots$$

$\Rightarrow$ all the non-perturbative physics is encoded in Long Distance Matrix Elements (LDME) obtained from $|V\rangle$

$\Rightarrow$ the hard part (series in $\alpha_s$) is obtained by the usual Feynman diagram methods

$\Rightarrow$ the cross-sec. = convolution of (the hard part)$^2$ * LDME

- In NRQCD, the two $Q$ and $\bar{Q}$ share the quarkonium momentum: $p_V = 2q$

- The relative importance of color-singlet versus color-octet mechanisms is still subject of discussions.

$\Rightarrow$ the vertex $V$ in LO and we consider case with $Q\bar{Q}$-pair with the same spin and orbital mom. as $J/\Psi : |Q\bar{Q}[^3 S_1^{(1)}]\rangle$ and $|Q\bar{Q}[^3 S_1^{(8)}]gg\rangle$ Fock states
The $J/\psi$ impact factor: NRQCD color singlet contribution

From open quark-antiquark gluon production to $J/\psi$ production

NRQCD color-singlet transition vertex:

$$[v(q)\bar{u}(q)]^{ij}_{\alpha\beta} \rightarrow \frac{\delta^{ij}}{4N} \left(\frac{\langle O_1 \rangle_V}{m}\right)^{1/2} [\hat{e}^*_V (2\hat{q} + 2m)]_{\alpha\beta}$$

$\langle O_1 \rangle_V$ from leptonic $J/\Psi$ decay rate
The $J/\psi$ impact factor: NRQCD color octet contribution

From open quark-antiquark production to $J/\psi$ production

NRQCD color-octet transition vertex:

$$[v(q)\bar{u}(q)]^{ij}_{\alpha\beta} \rightarrow t^{d}_{ij} d_{8} \left( \frac{\langle O_{8} \rangle V}{m} \right)^{1/2} [\hat{\epsilon}_{V} (2\hat{q} + 2m)]_{\alpha\beta}$$

\[\langle O_{8} \rangle_{V} \text{ varied in } [0.224 \times 10^{-2}, 1.1 \times 10^{-2}] \text{GeV}^{3}\]
The Color Evaporation Model

Quarkonium production in the color evaporation model

Relies on the local duality hypothesis
Fritzsch, Halzen ...

Consider a heavy quark pair $Q\bar{Q}$ with $m_{Q\bar{Q}} < 2m_{Qq}$
$Q\bar{q}$ = lightest meson which contains $Q$
e.g. $D-$meson for $Q = c$

it will eventually produce a bound $Q\bar{Q}$ pair after a series of randomized soft interactions between its production and its confinement, independently of its color and spin.

It is assumed that the repartition between all the possible charmonium states is universal.

Thus the procedure is the following:

- Compute all the Feynman diagrams for open $Q\bar{Q}$ production
- Sum over all spins and colors
- Integrate over the $Q\bar{Q}$ invariant mass
The $J/\psi$ impact factor: relying on the color evaporation model

From open quark-antiquark gluon production to $J/\psi$ production

$$\sigma_{J/\psi} = F_{J/\psi} \int_{4m_c^2}^{4m_D^2} dM^2 \frac{d\sigma_{c\bar{c}}}{dM^2}$$

$F_{J/\psi}$: varied in $[0.02, 0.04]$, purely known
Numerical results

- Two CMS energies: $\sqrt{s} = 8\text{TeV}$ and $\sqrt{s} = 13\text{TeV}$

- $|p_V\perp| = |p_J\perp| = p\perp$

- Four different kinematic configurations:
  - $0 < y_V < 2.5$, $-6.5 < y_J < -5$, $p\perp = 10 \text{ GeV}$ CASTOR@CMS
  - $0 < y_V < 2.5$, $-4.5 < y_J < 0$, $p\perp = 10 \text{ GeV}$
  - $0 < y_V < 2.5$, $-4.5 < y_J < 0$, $p\perp = 20 \text{ GeV}$
  - $0 < y_V < 2.5$, $-4.5 < y_J < 0$, $p\perp = 30 \text{ GeV}$

  main detectors at ATLAS and CMS

- uncertainty band: due to variation of non-pert. constants and scales $\mu_R$, $\mu_F$
Cross section at $\sqrt{s} = 8$ TeV

$0 < y_V < 2.5, -6.5 < y_J < -5$, $p_\perp = 10$ GeV $\quad 0 < y_V < 2.5, -4.5 < y_J < 0$, $p_\perp = 10$ GeV

**Figure:** Cross section at $\sqrt{s} = 8$ TeV as a function of the relative rapidity $Y$ between the $J/\psi$ and the jet
Cross section at $\sqrt{s} = 8$ TeV cntd

$\frac{d\sigma}{d|p_{V\perp}|d|p_{J\perp}|dY}$ [nb.GeV$^{-2}$]

$\frac{d\sigma}{d|p_{V\perp}|d|p_{J\perp}|dY}$ [nb.GeV$^{-2}$]

0 < $y_V$ < 2.5, -4.5 < $y_J$ < 0, $p_{\perp}$ = 20 GeV 0 < $y_V$ < 2.5, -4.5 < $y_J$ < 0, $p_{\perp}$ = 30 GeV

**Figure:** Cross section at $\sqrt{s} = 8$ TeV as a function of the relative rapidity $Y$ between the $J/\psi$ and the jet

$\Rightarrow$ color-octet dominates over color-singlet specially for large $p_{\perp}$

$\Rightarrow$ color-octet and color-evaporation model give similar results
Introduction

MN jets at full NLL

$J/\Psi$ and jet production

Cross section at $\sqrt{s} = 13$ TeV

\begin{align*}
\frac{d\sigma}{d|p_{V\perp}| \, d|p_{J\perp}| \, dY} \begin{bmatrix} \text{nb.GeV}^{-2} \end{bmatrix}
\end{align*}

Figure: Cross section at $\sqrt{s} = 13$ TeV as a function of the relative rapidity $Y$ between the $J/\Psi$
Cross section at $\sqrt{s} = 13$ TeV cntd

$$\frac{d\sigma}{d|p_{V\perp}|\,d|p_{J\perp}|\,dY}[\text{nb}.\text{GeV}^{-2}]$$

$$\frac{d\sigma}{d|p_{V\perp}|\,d|p_{J\perp}|\,dY}[\text{nb}.\text{GeV}^{-2}]$$

0 $< y_V < 2.5$, $-4.5 < y_J < 0$, $p_{\perp} = 20$ GeV

0 $< y_V < 2.5$, $-4.5 < y_J < 0$, $p_{\perp} = 30$ GeV

**Figure:** Cross section at $\sqrt{s} = 13$ TeV as a function of the relative rapidity $Y$ between the $J/\psi$ and the jet,

$\Rightarrow$ color-octet dominates over color-singlet specially for large $p_{\perp}$

$\Rightarrow$ color-octet and color-evaporation model give similar results

$\Rightarrow$ slight increase of cross sec. when $\sqrt{s} = 8$ TeV $\rightarrow \sqrt{s} = 13$ TeV
Variation of $\langle \cos \varphi \rangle$ at $\sqrt{s} = 8$ TeV

$$\varphi = |\phi_V - \phi_J - \pi|$$

**Figure**: Variation of $\langle \cos \varphi \rangle$ at $\sqrt{s} = 8$ TeV as a function of the relative rapidity $Y$ between the $J/\psi$ and the jet.
Variation of $\langle \cos \varphi \rangle$ at $\sqrt{s} = 8$ TeV cntd

$\varphi = |\phi_V - \phi_J - \pi|$

Figure: Variation of $\langle \cos \varphi \rangle$ at $\sqrt{s} = 8$ TeV as a function of the relative rapidity $Y$ between the $J/\psi$ and the jet

$0 < y_V < 2.5$, $-4.5 < y_J < 0$, $p_{\perp} = 20$ GeV; $0 < y_V < 2.5$, $-4.5 < y_J < 0$, $p_{\perp} = 30$ GeV
Variation of $\langle \cos \varphi \rangle$ at $\sqrt{s} = 13$ TeV

$\varphi = |\phi_V - \phi_J - \pi|$

![Graph showing variation of $\langle \cos \varphi \rangle$](image)

$0 < y_V < 2.5, -6.5 < y_J < -5, p_\perp = 10$ GeV; $0 < y_V < 2.5, -4.5 < y_J < 0, p_\perp = 10$ GeV

**Figure:** Variation of $\langle \cos \varphi \rangle$ at $\sqrt{s} = 13$ TeV as a function of the relative rapidity $Y$ between the $J/\psi$ and the jet
Variation of $\langle \cos \varphi \rangle$ at $\sqrt{s} = 13$ TeV cntd

$\varphi = |\phi_V - \phi_J - \pi|$

Figure: Variation of $\langle \cos \varphi \rangle$ at $\sqrt{s} = 13$ TeV as a function of the relative rapidity $Y$ between the $J/\psi$ and the jet

$0 < y_V < 2.5, \ -4.5 < y_J < 0, p_\perp = 20$ GeV; \hspace{1em} $0 < y_V < 2.5, \ -4.5 < y_J < 0, p_\perp = 30$ GeV

all 3 models lead to similar decorrelation effects and are compatible with the case when $V_{J/\psi} \rightarrow$ LO $V_{jet}$

passing from $\sqrt{s} = 8$ TeV to $\sqrt{s} = 13$ TeV increases slightly decorrelation effects
Summary

- The production of Mueller-Navelet was successfully described using the BFKL formalism.

- We applied the same formalism for the production of a forward $J/\Psi$ meson and a backward jet, using both the NRQCD formalism and the Color Evaporation Model.

- This new process could constitute a good probe of importance of color-singlet contribution versus the color-octet contribution in NRQCD.

- More predictions about azimuthal correlations can be delivered.

- A comparison with a fixed order treatment is planned.

- A complete NLL study is very challenging: requires to compute the NLO vertex for $J/\Psi$ production.

- Preliminary experimental studies (ATLAS) are very promising.
MERCI / THANK YOU