PROCEEDINGS OF SCIENCE

Early ATLAS B-physics with the first 10 - 100 pb^{-1}

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The B-physics program of the ATLAS experiment at the LHC with the early data is presented. These data will allow us to measure the production cross sections for B hadrons and heavy quarkonia in pp collisions at a center-of-mass energy of 14 TeV to a reasonable precision. The B-physics trigger scheme employing single or di-muon algorithms is discussed. The potential for extracting the polarization of vector states from the decays $J/\psi \rightarrow \mu^+\mu^-$ and $\Upsilon \rightarrow \mu^+\mu^-$ is also presented.

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[*] Speaker

1. Introduction

ATLAS is one of the general-purpose experiments at the LHC with a main focus on the searches for new phenomena and studies of physics beyond the Standard Model (SM) based on high p_T particles. Even though the B-physics processes appear in low p_T range the ATLAS detector is able to provide measurements for B-physics based on the precise tracking and vertexing, the muon identification and the dedicated trigger scheme [1]. The ATLAS experiment has a full B-physics program with clearly defined trigger strategies for all luminosity phases of the LHC.

The ATLAS trigger system is composed of three levels of event selection and aims to reduce the event rate from the 40 MHz bunch crossing rate to ~200 Hz to mass storage. The level-1 trigger is hardware based while the level-2 and Event Filter are based on algorithms that implement the final event selection. A bandwidth of 5% - 10% of event rate will be dedicated for B-physics related interests. The B-physics trigger menu is presented in section 2.

The inclusive production cross section for $b\bar{b}$ pairs at LHC at a center of mass energy of 14 TeV is expected be about 500 μb corresponding to more than 10^5 produced $b\bar{b}$ pairs per second at an instantaneous luminosity of 10^{33} cm^{-2}s^{-1}. This makes the trigger for the B-physics events in the LHC environment a real challenge. Already at the initial phase of the LHC operation B-physics measurements will provide a great opportunity to test and understand the detector and the trigger performance.

Measurements with early data will include inclusive B hadron and quarkonia (J/ψ, Y) production to study various aspects of trigger and detector performance. Exclusive decay channels of B^+ and B_d^0 with two muons in the final states will be studied for measuring mass and lifetime as well as production cross-sections.

2. B-Physics Trigger

ATLAS B-physics has an efficient, fast and clean trigger based on muons. Many B-physics channels involve a di-muon final state. The most effective trigger for such events uses the di-muon signature from the lowest level. The critical point to the detection of these B signals in ATLAS is to achieve high trigger efficiency for low-p_T di-muon events, keeping an acceptable trigger rate. There are two different trigger algorithms implemented at level-2 for selecting di-muon events form a resonance like J/ψ and Y.

2.1 Topological di-muon trigger

The first algorithm, referred as Topological di-muon trigger asks for two muons at Level 1 with separate regions of interest (RoI) around each muon direction. The two muons are confirmed separately in each ROI and subsequently combined to form a resonance candidate and to apply a vertexing and a mass cut. This algorithm is perfectly suited to B-physics channels with di-muon final states which have much smaller cross sections than those for single muons of the same p_T.

2.2 TrigDiMuon algorithm

The second algorithm, referred as TrigDiMuon, starts with a level-1 single muon trigger. The muon is confirmed at level-2 and a second track is searched in the Inner Detector in a wider η and φ region around the first muon in the Inner detector. The second track is extrapolated to the muon spectrometer. If a sufficient number of muons hits are found in the Muon Spectrometer, the track is tagged as muon. Invariant mass and vertexing cuts applied after the search for the second muon. Since this method does not explicitly require the second muon at level-1, it has an advantage for reconstructing J/ψ at low-p_T . The second scheme will be applied for early data.

Measurements of the cross sections require the good understanding of the event selection efficiency. To measure trigger efficiency with real data $J/\psi \rightarrow \mu\mu$ the tag-and-probe method decays will be used in the low p_T region. The tag-and-probe method uses di-muon final states for measuring the single muon trigger efficiency. A single triggered muon from a reconstructed di-muon decay of a specific particle identified by mass cuts provides the tag that allows us to probe the trigger efficiency of the second muon. Figure 1 shows the efficiency of the level-1 single muon trigger with respect to the offline selection obtained by the tag-and-probe method and the efficiency estimated from muons coming from J/ψ Monte Carlo sample.

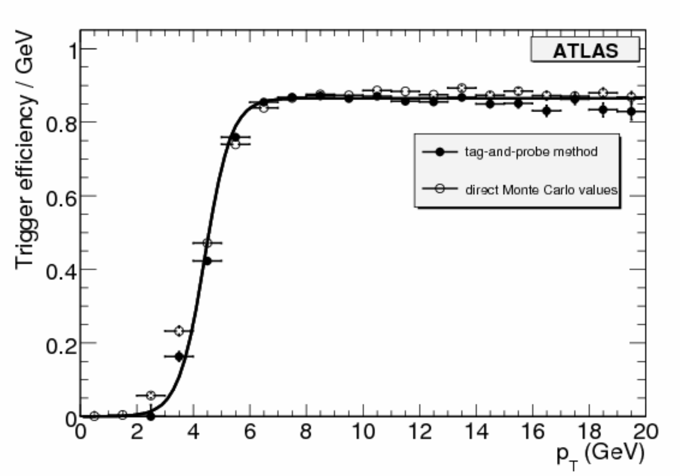


Figure 1: The overall efficiency of the level-1 single muon trigger obtained by the tag-and-probe method and from J/ψ Monte Carlo sample (see text).

3. Measurements with $B^+ \rightarrow J/\psi\ K^+$

The large production cross section of $b\bar{b}$ pairs will allow the observation of the exclusive $B^+ \rightarrow J/\psi(\mu^+\mu^-)K^+$ decay during the initial low luminosity phase of the LHC. The measurement of well known properties of the B^+ hadron, like mass and lifetime, will be used to test and monitor the detector performance. This channel will also be used as a reference channel in the searches for rare B decays.

The di-muon trigger will be used for the event selection with one muon requiring $p_T>6$ GeV and a second one with $p_T> 4$ GeV. The first step in the offline event selection procedure is the J/ψ reconstruction by combining two muons. Two oppositely charged muons with $p_T1(2)>6(3)$ GeV are fitted to common vertex and the invariant mass is required to be within a mass window of 120 MeV around the J/ψ mass. A cut on the proper decay length $\lambda>0.1$ is imposed in order to reduce the combinatorial background from the prompt J/ψs. The proper decay length λ is defined as

$$\lambda = L_{xy}\frac{m_B}{p_T^B}$$

where m_B and p_T^B represent the mass and the transverse momentum B meson and L_{xy} is the transverse decay length which is actually the measured radial displacement of the secondary B-decay vertex from the beamline.

All tracks with positive charge and inconsistent with coming from primary vertex are considered as K^+ candidates. The reconstructed J/ψ together with the K^+ candidate are fitted to a common vertex. The vector of the sum of the J/ψ and K^+ momentum vectors has to point to the primary vertex to be retained.

The invariant mass distribution of the B^+ candidates is fitted by using the maximum-likelihood method, where the probability density function for the signal region is a Gaussian and a linear function for the background. The precision on the mass measurement is estimated to be σ=42.2±1.3 MeV. The relative error scaled properly for an integrated luminosity of 10 pb^{-1}. The total efficiency of the B^+ reconstruction is estimated to 29.8±0.8% from Monte-Carlo studies.

The differential cross-section is obtained in different bins of p_T of the B^+ using the number of signal events as well as the efficiency from maximum likelihood fit to the invariant mass distribution. The total cross section is determined with the same procedure but for the whole p_T region of the B^+.

Table 1 shows the results for an integrated luminosity of 10 pb^{-1} where the total production cross-section can be measured with a statistical precision better than 5% and the differential cross-section can reach a precision around 10%. The systematic uncertainties are expected to mainly due to the luminosity and branching ratio.

p_T-range	$p_T \in[10,18]$	$p_T \in [18,26]$	$p_T \in [26,34]$	$p_T \in [34,42]$	$p_T \in [10,\infty]$
Statistical + ε [%]	7.7	6.9	10.5	13.9	4.3
total [%]	16.1	15.8	17.6	19.8	14.8

Table 1: Statistical and total uncertainties for the $B^+\rightarrow J/\psi\ K^+$ differential and total cross-section measurements for an integrated luminosity of 10 pb^{-1}. Total uncertainties include luminosity and branching ratio systematic uncertainties.

4. Heavy Quarkonium Physics

The production rate of heavy quarkonia like J/ψ and Υ is expected to be large from the first period of low luminosity of the LHC. The analysis of the $J/\psi \to \mu^+\mu^-$ and $\Upsilon \to \mu^+\mu^-$ decays will give the opportunity to check various QCD models that describe the quarkonia production mechanism. These channels can be used for the detector alignment as well as for the calibration of trigger, tracking and muon system.

4.1 Prompt J/ψ and Υ Reconstruction and background separation

The di-muon trigger is suitable for J/ψ and Υ event selection requiring two muons with p_T greater than 6GeV and 4 GeV respectively. Oppositely charged muons are combined to form pairs. If the invariant mass of the two muons is above 1 GeV, the two tracks are refitted to a common vertex. The pair is considered as a quarkonium candidate if the invariant mass of the refitted tracks is within 300 MeV of the nominal mass in the case of J/ψ , or 1 GeV in the case of ϒ.

The background contributions are expected to come mainly from $b \to J/\psi + X$ decays and the continuum of di-muon final states from $b\bar{b}$, $c\bar{c}$ events and Drell-Yan. In order to suppress the background additional cuts are applied on the pseudo-proper time t. The pseudo-proper time is defined as

$$\textit{Pseudo-proper time} = \frac{L_{xy} \cdot M_{J/\psi}}{p_T^{J/\psi} \cdot c}$$

where $M_{J/\psi}$ and $p_T^{J/\psi}$ represent the mass and the transverse momentum of the *J*/ψ candidate, *c* is the speed of light in vacuum and L_{xy} is the transverse decay length as defined previously. Prompt J/ψs typically have zero proper time while indirect J/ψs coming from B-hadron decays and hence having an exponentially decaying pseudo-proper time distribution. A cut on pseudo-proper time at 0.2 ps gives prompt J/ψ efficiency of 95% with 5% contamination as shown in figure 2.

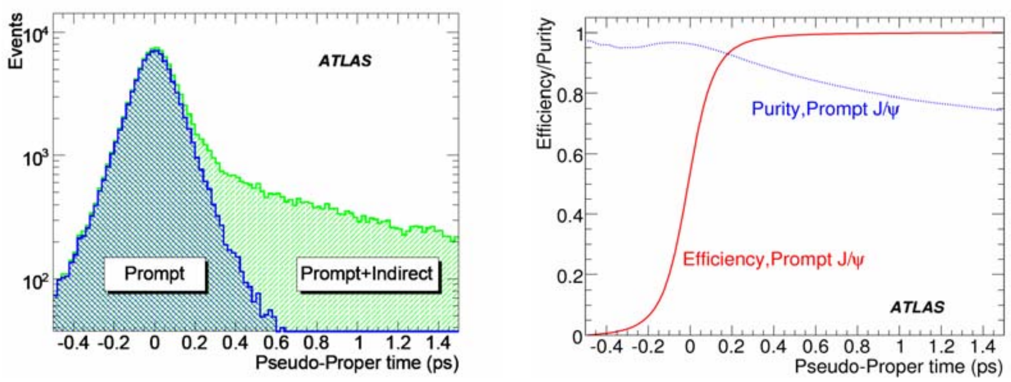


Figure 2: Pseudo-proper time distribution for reconstructed prompt J/ψ (dark shading) and the sum of prompt and indirect J/ψ candidates (lighter shading) (left). Efficiency (solid line) and purity (dotted line) for prompt J/ψ candidates as a function of the pseudo-proper time cut. Statistics correspond to the integrated luminosity of 6 pb^{-1}.

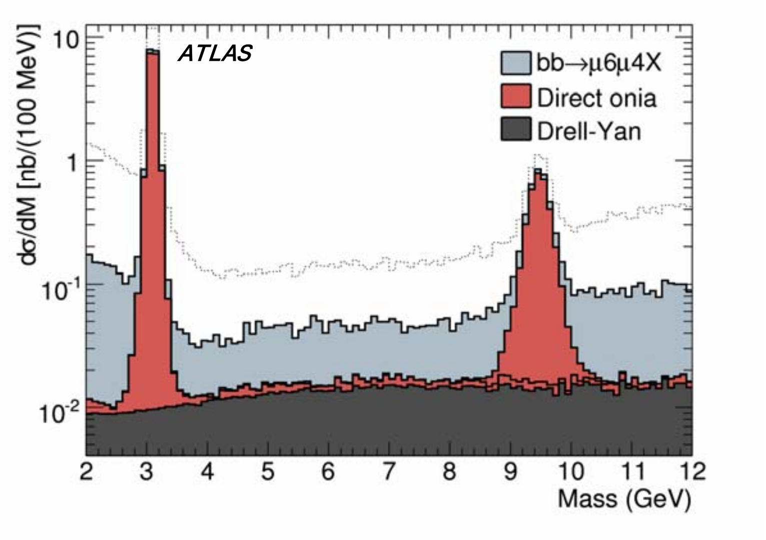


Figure 3: The invariant mass distribution of di-muons from various sources, reconstructed with di-muon trigger which asks for two muons at Level 1 with p_T greater than 6 and 4 GeV (μ6μ4), with the requirement that both muons are identified as coming from the primary vertex and with a pseudo-proper time cut of 0.2 ps. The dotted line shows the cumulative distribution without vertex and pseudo-proper time cuts.

4.2 Polarization Measurements

ATLAS is capable of detail checks of the predictions of various models for the onia production like the Color-Singlet (CSM) or Color-Octet model (COM) [2][3], as well as the degree of polarisation of J/ψ and Υ. These measurements will help to understand the production mechanisms. The polarisation of the quarkonium state can be determined by measuring the parameter $\alpha = (\sigma_T - 2\sigma_L)/(\sigma_T + 2\sigma_L)$ which may vary between +1 for 100% transversely polarised, to −1 for 100% longitudinally polarised production. This can be achieved by measuring the distribution of the polarisation angle θ* which is defined as the angle between positive muon direction in quarkonium rest frame and quarkonium direction in lab frame.

Using di-muon trigger, both muons from J/ψ must have relatively large p_T. This affects the polarization angle distribution since there is little or no information for high $|\cos\theta^*|$. Another possibility is to trigger on single muon requiring a muon with p_T>10 GeV at level-1 and a second track with p_T>0.5 GeV can be reconstructed offline. Figure 4 shows the acceptance of the polarisation angle with di-muon and single muon trigger for J/ψ (left) and Υ (right). The samples for both J/ψ and Υ were generated with zero polarization.

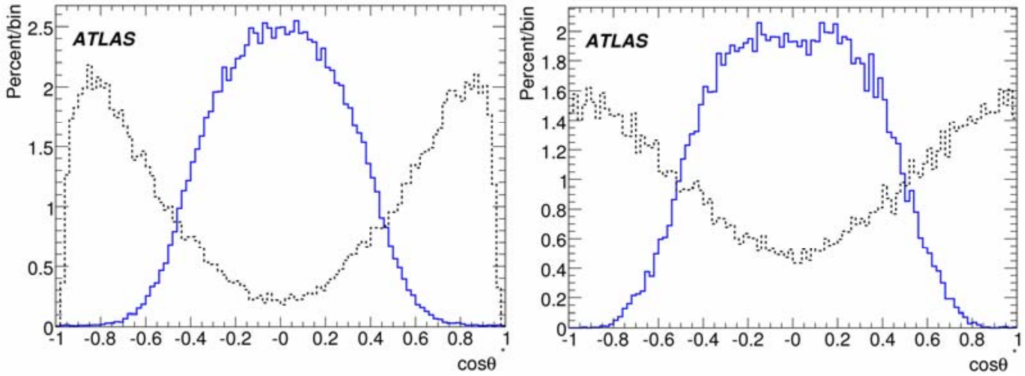


Figure 4: Reconstructed polarisation angle distribution for di-muon triggers (solid line) and a single muon trigger (dashed line), for J/ψ (left) and Y (right). The distributions are normalised to unit area.

The single and di-muon data should be combined together and corrected for acceptance and efficiencies providing excellent coverage almost the entire range of cos(θ*). Studies have been performed with MC data samples generated with fully transverse/ longitudinal polarisation and one with zero polarisation. Figure 5 shows the resultant distributions for $\alpha_{gen}=\pm1$. It is clear that ATLAS is able to measure the polarisation angle in these limit cases.

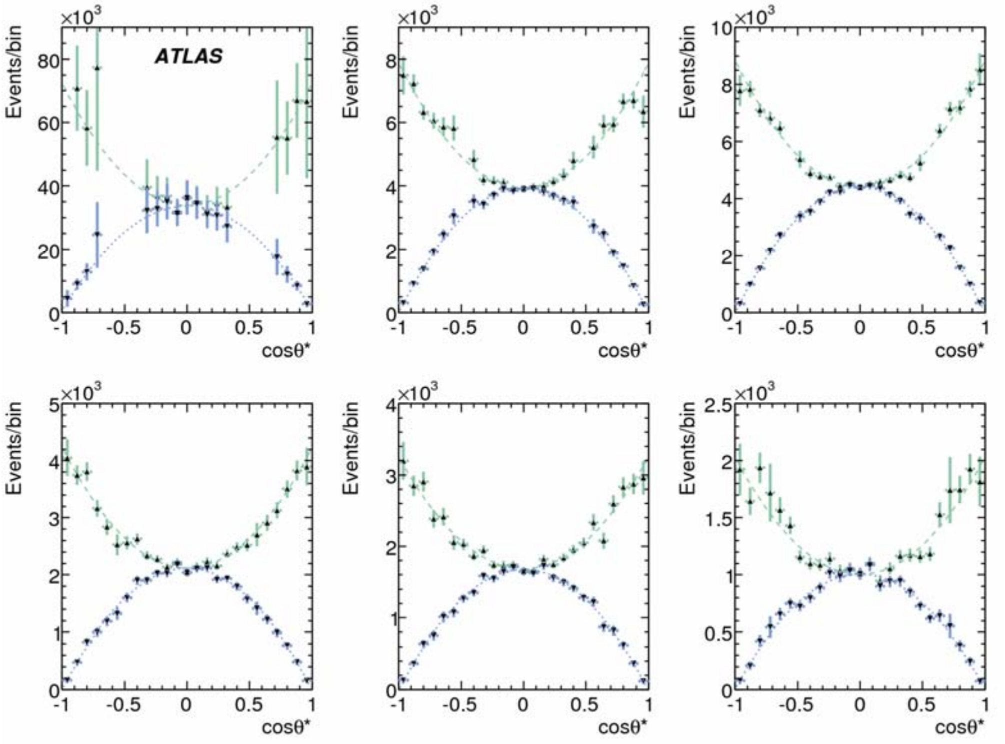


Figure 5: Combined and corrected distributions of polarisation angle cosθ* for longitudinally ($\alpha_{gen}= -1$, dotted lines) and transversely ($\alpha_{gen}= +1$, dashed lines) polarised J/ψ mesons, in p_T slices. The p_T slices correspond to p_T ranges (left to right, top to bottom) 9−12 GeV, 12−13 GeV, 13−15 GeV, 15−17 GeV, 17−21 GeV and above 21 GeV. Statistics correspond to 10 pb^{-1}.

5. Physics and Detector Performance Measurements with $B_d \to J/\psi K^{0*}$

The large cross section of the $B_d^0 \to J/\psi(\mu^+\mu^-)K^{0*}(K^\pm\pi^\mp)$ channel will allow to measure the mass and proper lifetime of B_d meson with the early data with sufficient precision to allow extensive studies and checks of the detector performance.

The events are selected by dimuon trigger with thresholds of $p_T > 6$ GeV and $p_T > 4$ GeV for the two muons. First the J/ψ is reconstructed by two oppositely charged muons with p_T>4GeV and p_T >6GeV and $|\eta| < 2.4$ which are fitted to a common vertex. If the muon pair has an invariant mass within a mass window of 3σ around the J/ψ mass it is assumed that the two muons originated from the J/ψ decay.

The $K^{0*} \to K^\pm\pi^\mp$ decay is reconstructed by combining two oppositely charged tracks, which are not identified as muons, with $p_T > 0.5$ GeV and $|\eta| < 2.5$ to a common vertex. After a cut on the invariant mass, this pair of tracks forms a K^0* candidate. The J/ψ and the K^0* candidates are fitted to a common vertex which has to have transverse momentum greater than 10 GeV. The four tracks are assumed to be form B_d^0 if the invariant mass lies within a mass window of ±12σ around the B_d^0 mass. In early data, loose cuts will be used with no vertex and displacement cut. Figure 6 shows the distributions of the reconstructed B^0_d. mass and decay time expected with integrated luminosity of 10 pb^{-1}.

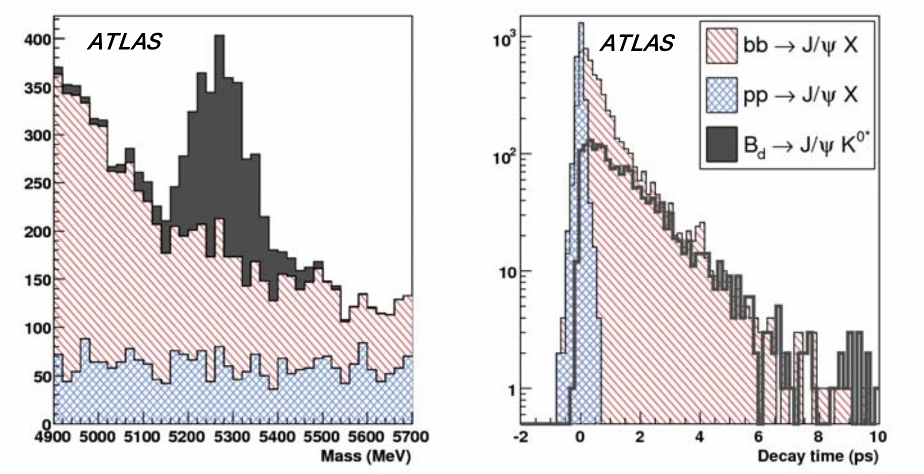
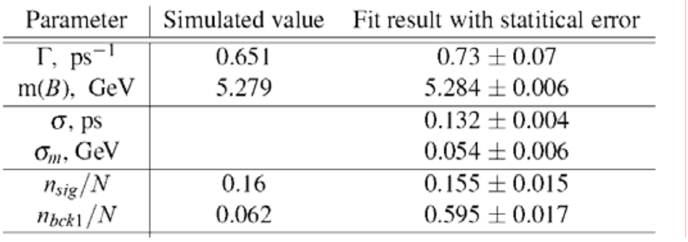


Figure 6: Distributions of the reconstructed B_d^0 mass and decay time expected with integrated luminosity of 10 pb^{-1}.

Simultaneous Maximum Likelihood fit is applied to mass and decay time in order to extract signal mass and lifetime from data. The fit results are summarised in Table 2. The mass of the B_d^0 can be measured with a precision of 10^{-3} and the average lifetime can be measured with an uncertainty of 10% with integrated luminosity of 10 pb^{-1}.



Parameter	Simulated value	Fit result with statitical error
Γ, ps^{-1}	0.651	0.73 ± 0.07
m(B), GeV	5.279	5.284 ± 0.006
σ, ps		0.132 ± 0.004
σ_m, GeV		0.054 ± 0.006
n_{sig}/N	0.16	0.155 ± 0.015
n_{bck1}/N	0.062	0.595 ± 0.017

Table 2: Mass and lifetime results from the Maximum Likelihood fit for B_d^0 corresponding to a integrated luminosity of 10 pb^{-1} . Errors are statistical only.

6. Conclusions

The ATLAS B-physics program will run from the earliest days with an efficient, fast and clean B-physics trigger scheme which will allow collecting large samples of B-hadrons and Quarkonium throughout the lifetime of the experiment. Already with the first pb^{-1}, mass and lifetime measurements of exclusive channels will serve to validate and monitor ID performance and alignment. J/ψ and Y resonances will provide calibration points. Further more the effort will concentrate on total and differential cross sections of B-hadrons, onia Polarization measurements as well as mass and lifetime measurements.

Acknowledgements

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References

[1] G. Aad. et al. [ATLAS Collaboration], CERN-OPEN-2008-020 (2008).

[2] See e.g. V. G. Kartvelishvili et al. Sov. J. Nucl. Phys. 28 (1978) 280; M. Gluck et al. Phys. Rev. D 17 (1978) 2324; V. G. Kartvelishvili, A. K. Likhoded, Sov. J. Nucl. Phys. 39 (1984) 298; E. L. Berger and D. L. Jones, Phys. Rev. D 23 (1981) 1521; B. Humpert, Phys. Lett. B 184 (1987) 105.

[3] J.-P. Lansberg, Eur.Phys.J.C60:693-703, 2009.