Anonymous Referee #1

First we would like to thank Referee #1 for the time dedicated to provide the comments and suggestions for the interactive discussion. The comments had definitely improved the manuscript clarity and overall presentation. We hope that the updated version is satisfactory. Below you will find a point by point description of how each comment and suggestion was addressed.

The depolarization ratio is an important property to characterize different aerosol types. An exact measurement of this quantity is therefore an important issue. The manuscript describes a method to assess and to correct for the diattenuation of receiving optics and the rotation angle between the laser and the receiver. Both quantities can be determined by the use of the Delta 90 ◦ calibration, which is an important method for the proper characterization of a lidar system. The description (figures and formulas) needs to be improved.

Thank you for the suggestion. The figures and formulas are updated accordingly.

Major Remarks:

1. Equation (4) is wrong. If you multiply two vectors you'll get a scalar. The first vector (i_E, q_E, ...) seems to be I_E, but should be the matrix M_E.

This is correct, thank you for pointing this mistake. We had remediated this issue in the updated version.

2. p6, l14 How do you assure that there is no misalignment of the additional polarization filters after the PBS? Or which error would a misalignment by 1 ◦ introduce to the depolarization? Please comment on this.

Thank you for pointing this out. A rotation error of 1 degree for the linear polarization filters will reflect in an even lower effect since the errors will compensate each other. Numerical simulations show that the effects of misalignment errors within 1 degree will be lower than the Rayleigh depolarization. New text was included in the manuscript to describe these effects.

New text:

"...any additional rotation of the polarization filters used for reducing the cross talk could be neglected since these effects are well below the Rayleigh depolarization for rotation angles lower than 1 $\degree$."

3. p8, l18 What do mean by "all effects"? Be more precise.

Yes, the text is too vague. Thank you. The text was replaced with a more concise description.

Old text:

"Usually this calibration does not take into account all effects that have to be corrected in the depolarization profile resulting in erroneous depolarization values especially in highly depolarizing aerosol layers."

New text:

“Usually this procedure can introduce additional uncertainties since for an accurate calibration at least two reference points are required.“

4. p8, l30 – p9, l8 I am not sure whether it is necessary to introduce the “45 calibration”. The problems with this calibration are already discussed in Freudenthaler et al., 2009. Just keep the focus on the Delta 90 calibration. In the following text I would recommend to skip the quotation marks “ “ around the Delta 90 calibration.

The “45 calibration” is introduced to give the reader a chronological view of the available calibration methods and their limitations and to reduce the chance that the reader wonders why the authors did not include the “45 calibration” in the study. We still have the feeling that a short introduction of the method is welcomed. If the reviewer is not satisfied with this motivation we will remove this section in the following iteration. The quotation marks were removed in the following sections. Thank you for these remarks.

5. p9, l26 You mention a set of two relative Delta 90 calibrations, but the equations (24) and (25) make use of only one calibration measurement.

Yes indeed, but the text clearly states that the plus/minus sets will be used to determine the geometric mean of the two:

“The calibration constant is determined by using the geometric mean of the two p/m 45 measurements. The two measurements are designed to compensate each other even for cases where the 45 rotation uncertainty is large with respect to the initial zero position given by the PBS.....”

6. p10, l5-9 This is a very important and interesting point. You will use only one calibration method (the Delta 90 calibration) to assess different parameters of your lidar system (at different positions in the system). It would be good to state this clearly already in the introduction, because this could be something like a red line through your paper. For persons not so experienced in the lidar business it would help to start with the calibration effort.

Thank you for this suggestion. We had modified the text to better explain the role of this calibration technique.

New text:

“This study aims to present the available techniques developed to calibrate the lidar depolarization channels in EARLINET with focus on one particular technique (delta90 calibration). This technique will be further used to assess the influence of lidar optics on depolarization products (i.e., the assessment of the receiving optics diattenuation parameter and the rotation of the plane of polarization of the laser around the light propagation axis with respect to the PBS) in order to reduce the corresponding uncertainties.”

7. p10 chap. 3.2.1 A HWP calibrator works for single wavelength lidar systems only. In multiple wavelength lidar systems a HWP must be placed in front of each PBS, but not in front of the receiving optics. This should be mentioned.

Since the calibration is performed before the measurements and later on removed from the optical chain, the HWP effect on the other available channels should be neglected. The effects that the HWP has on other detection channels are removed once the calibration is completed and the HWP is removed. This limitation applies if the HWP is used to correct laser rotation effects (plane of polarization of the laser) – method later explained in the paper.

8. p12, eq (26) and eq (27): Do you mean D_O ("O like orange") or D_0 (0 – zero)? You use both notations throughout the manuscript, not only in these two equations. Please choose one notation for the entire manuscript.

Thank you for this suggestion. It should be "O like orange" from "receiving Optics". Modifications have been made

9. p13, l1, l4 What do you mean by "retrieved measured" and "simulated measured"? It is simulated or measured? Maybe something like "simulated apparent calibration factor" (see Freudenthaler, 2016) and "retrieved calibrated signal ratio" as you call delta in Fig 4. Please use one name for a certain quantity throughout the entire manuscript*

Updated text:

"According to these simulations, the effects of alpha are also dependent on atmospheric depolarization: as atmospheric depolarization decreases, the dependence between the calibrated signal ratio and alpha is more significant. In real situations, the optical misalignment for alpha will not exceed 10-15 degrees, but in order to present a complete dependency of the calibrated signal ratio, Fig 4.a shows the behaviour of the latter for alpha ranging from 0 to 180 degrees. Simulations of measured calibration factor, obtained using the mechanical rotation in front of the PBS (Fig 4.c) show the dependency of the latter with atmospheric depolarization for alpha ranging from 0 to 10 degrees."

10. p13, l23 and Fig 5c How do you get the uncertainty of 25%? For the known value of alpha = 10 and D_0 = 0.25, Y would be -0.45. You have to assume some uncertainty for alpha and D_0, which you have not mentioned.

Yes, this is correct. Since the assessment of Y is dependent of D_O, for D_O values ranging from 0 to 0.25, Y would range between -0.55 to -0.45. This implies a retrieved alpha value ranging from 10 to 12.5 degrees: a 25% offset from the real 10 degree value. A revised text was included in the manuscript. Thank you for pointing this drawback.

Updated text:

"According to simulations (Fig 5.c), uncertainties associated to the assessment of alpha (for the analytical correction) can go up to 25% for a 10 degrees initial offset and a diattenuation value ranging from 0 to 0.25."

11. p13, chap 3.4.2 You discuss the possibility of correcting alpha with a HWP or mechanical rotator in front of the PBS. At this point you should discuss the possibility of turning the linear polarizer in front of the PMT (setup 2c) to correct for alpha. It should lead to similar results as the rotation of the PBS.

This is correct. A comment on this detection setup has been included.

New text:

“In case of the total – cross detection setup (Figure 2.c), the experimental correction of α could also be accomplished by rotating the linear polarizer placed in front of the detection module.“

12. p15, l17 Why you use alpha(Y)? Is there a reason for the dependence on Y? Please explain it or change it. This holds for the following text

Yes it is. Y is the parameter used to determine alpha from the calibration signals. Still, for this section it is not mandatory to always use alpha(Y). The updated manuscript considders this suggestion.

13. p15, l31 and Table 3 You mention a correction of a_L. Please indicate the value and its uncertainty for a_L.

New text was included:

“....shows lower values in the free troposphere and values reaching 0.42 in the ice cloud. For this case study, the polarization parameter of the laser was determined to be 0.970 $\pm$ 0.005. After correction of..”

14. Fig 8 The color scale for the time-height plot looks unorganized and has no description. Why is there a grey line between the color plot and the color scale? The same holds for Fig 9a, 10a, 11a.

Thank you for pointing this out. The colour scale should have a.u. Modifications have been made to all figures. The grey line is meant as a graphical separation between the end of the plot and the colour scale. If the format of the publication requires no extra graphical elements, the grey line can be easily removed.

15. For all Fig 8 - 11 Please indicate the vertical smoothing length for your profiles.

Thank you for pointing this out. The updated version of the manuscript includes this information: “... particle depolarization ratio profile at 532 nm - smoothed data, 45 minutes time average, 45 m vertical smoothing”

16. p16, l25-30 and Fig 9 The Granada measurement is presented in unorganized way. I would recommend to skip it as you have already an example for Saharan dust over Potenza or to take into consideration the following comments:

- Every plot starts at a different height.

The updated version of the manuscript solves this issue. Thank you for indicating this.

- Up to 7 or 8 km height would be sufficient.

The height was limited to 8 km

- Heights are about ground or sea level?

The heights are plotted relative to ground level. The plots were updated to provide this information.

- Why the back trajectories are calculated for so close height ranges? Why at 2000 UTC and not 2100 UTC?

The heights are calculated for close height ranges aiming to have all points inside the studied layer. The difference between 2000 UTC and 2100 UTC is not significant. We had updated Fig. 9 according to the suggestions.

"One hour average", the red lines in Fig 9a show only 50 minutes

This is correct. Thank you for pointing this issue. The figure caption was modified to indicate the correct time averages.

- p16, l26-27 If the particle linear depolarization ratio is close to the molecular depolarization in the low aerosol height ranges, then something is wrong. The particle linear depolarization ratio depends on the aerosol type, if there are only few aerosols, the particle linear depolarization ratio gets noisy but not close to the molecular depolarization.

Thank you for pointing this out, this was a typo – the comment was referring to the volume depolarization ratio.

- 0.22 (two significant digits are enough) is quite low for mineral dust. Please compare it to literature values. It could be polluted or mixed dust.

This is correct. The text was updated accordingly. Thank you for this suggestion.
Updated text:
"Measurements performed using the Granada lidar system (Mulhacen) in July 2012 show the presence of a distinct layer between 2.5 and 5 km (Fig 9.a-c). The volume linear depolarization ratio shows high values in the aerosol layer (0.22) and levels close to the molecular depolarization in the low aerosol height ranges. The back trajectories model indicates that the corresponding air mass originates in Northern Sahara, and was transported for over five days over NW Africa and the Atlantic Ocean (Fig 9.d). According to the back trajectories and the particle linear depolarization values retrieved for these altitudes, the aerosol present in the air mass consist of polluted or mixed mineral dust (Gross et al., 2011)."

"several days" How many?

The text was updated accordingly:
New text:
"...The back trajectories model indicates that the corresponding air mass originates in Northern Sahara, and was transported for over five days over NW Africa and the Atlantic Ocean...."

17. p16, l31 – p17, l3 and Fig 10 The Potenza case is better organized. Again: The plots up to 7 or 8 km would enlarge the interesting part (for example the Munich case is shown up to 5 km to focus on the interesting part). Height about ground level or about sea level is important for a mountain station like Potenza. The shown measurement starts on 6th August 2012 00:00 UTC, the profiles indicate 05.08.2012. The abbreviation PBL is not explained.

The text was updated accordingly, thank you

18. p17, l23 and Fig. 5 What do you mean by "effective diattenuation"? Where is the difference to "diattenuation" (of the receiving optics)?

The name effective diattenuation was initially used in the early stage of the manuscript. The updated version uses only diattenuation. The naming was a typo. Thank you for pointing this out.

19. p17, l33 – p18, l4 The HWP might be the best solution for single wavelength lidar systems. Please discuss the use of dual wavelength polarization measurements as well.

Please see remark 7. This type of calibrator can be applied to any multi wavelength lidar instrument.

20. p18, l5-10 Not only here, but in the whole conclusion: Please do not forget to discuss the calibration by a linear polarizer.

The text about the linear polarizer was included in the text:

"The drawback of the HWP in front of the receiving optics is related to the limited number of lidar systems it can be applied to. For instruments designed to measure the depolarization using the cross and total channels, the correction of alpha can also be realized by rotating one optical component inside the receiving unit (linear polarizer)."

21. Appendix, p19 How are your angles alpha, beta and gamma defined? As rotation around the propagation axis or with respect to the PBS? p15, l17 you state: "the rotation of the plane of polarization of the laser with respect to the PBS: alpha(Y)." The axis of propagation and all angles around it are defined by the orientation of the PBS. Please make a clear statement when introducing the angles.

The mentioned angles are defined as rotation around the propagation axis with respect to the position of the PBS. Rotation around the propagation axis indicates how the module is rotated. The reference element is considered to be the position of the PBS around the propagation axes (it gives information on how we define the rotation axes of the PBS).

22. The cited literature seems to be at the situation of 2015 where the paper was submitted for the first time (except of the accompanying papers by Bravo-Aranda and Freudenthaler, both AMT 2016). Please update the reference list to include more recent publications.

Thank you for this suggestion. We updated the bibliography accordingly.

23. Table 1: If we can rotate the emitted light with a HWP to +- 45, it should also be possible to mechanically rotate the emission unit to +- 45 leading to the same result. A linear polarizer could also be placed in the emitter unit as described in Chapter 8.3 in Freudenthaler, AMT 2016. Please add these two possibilities in the column "position".

p10 l26 specifies this option to mount the calibrator in the emission unit.

A column for single or multiple wavelength use could be added, as the mechanical rotator and the polarizer rotator can be used for several wavelengths, whereas the HWP can be used for a specific wavelength only.
The HWP can be used for a specific depolarization channel but also within multi-wavelength lidar instruments since after the calibration, the module will be removed. This only applies when trying to correct the alpha angle by means of the HWP.

24. Table 2: How do you explain the differences between your Table 2 and Table 5 in Bravo-Aranda et al., AMT 2016 regarding the Munich lidar system? You report D_0 = 0.059 (at 532 nm ?), the other publication reports D_0 = 0.011 at 532 nm. Or is it valid for different years? The Potenza lidar system differs by the sign only, D_0 = +0.055 (this manuscript), D_0 = -0.055 (Bravo-Aranda, 2016).
The lidar instruments are subject to permanent upgrades and it is possible that the value used for this study is not similar to the value used in Bravo-Aranda et al., AMT 2016. For this manuscript we used data collected in 2010 to provide a conclusive example of volcanic ash episode.
The correct value in case of Potenza is -0.055. We already discovered the typo after submitting this version of the manuscript. The table was updated accordingly. Thank you.

25. Table 3: Please specify the height range (for "cloud" and "free troposphere") used for your average.
In the updated manuscript the height range is specified, Thank you.

26. I dare that the figures (Fig 4-11) do not fulfill the standard of the journal. A professional plot program should be used.
Figures 8 to 11 have been updated using a professional plot program (Origin). For figures 4 to 7 the results provided by the professional plotting software provided similar graphical output. Fonts and quality of the graphics were modified to better fit the journal standards

Minor Comments:

- The Spanish institute affiliations are without street name, while all other institutes are located in a certain street and number.
The final version of the manuscript will include all missing information. Thank you for this remark.

There should be a space between the number and the unit, for example 3.5 km and 532 nm. Please go through your entire manuscript to check this.
We had made the suggested modifications in the updated version

- p3,l2 methods (add plural s)
- p3, l14 "(\alpha)" is not necessary in the introduction.
- p4, l20-21 Change to normal fond (not italic, not bold).
We had made the suggested modifications.

- p15, l19-21 "we will only consider the post measurement analytical correction" and one line later you start with the experimental correction for alpha and Fig 7c. For the post measurement analytical correction, did you use alpha = 10 or alpha =-0.04 ? Please state this clearly at the beginning of the discussion about the post measurement analytical correction.

This statement was referring to the next section of the manuscript. The text was updated accordingly.

- Fig 4 Please add in the caption "delta" b) (0◦: 10◦) In my opinion the eta* plot (Fig 4c) is not useful to show. Or it has to be discussed in more detail. What are the implications for the parameter K?*

We would like to keep Figure 4.c since it shows the importance of performing the alpha correction before the actual calibration.

"Simulated measured calibration factor (eta*), obtained using the mechanical rotation in front of the PBS (Fig 4.c) show the dependency of the latter with atmospheric depolarization for alpha ranging from 0 to 10 degrees. This dependency alters the experimental retrieval of the measured calibration factor whenever alpha is considerable large (>5). A good practice would be to assess and correct for the alpha angle before performing the depolarization calibration."

- Fig 5 It would be better to show in Fig 5 a+b only the range from 0 to 20

The negative section of the plot is included for historical reasons: during internal review process, several contributors had comments regarding the (-20 - 0) range. For this reason we would like to keep this layout of the plot.

All following minor comments were taken into consideration for the updated version of the manuscript. We would like to thank again the reviewer for the time spent to provide the detailed comments of this review.

- p7, eq (15) Please consider the rules for notation as you stated correctly on p3, l27 "bold italic fonts are used for the Stokes vectors, bold for the Mueller matrices and italic for the scalar variables". The same holds for G_S and H_S in eq (16) and (17).

*- p7, l8 Use capital E as index. u_E = sin (2 alpha) * a_L*

- p7, eq (21) Please use capital R and T.

- p8, l23 "This method" To which of the two mentioned methods you are referring. Be more precise

- p8, l31 "the larger is the error...

- p9, l21-22 “Table 1 summarizes main advantages and disadvantages when using different calibration techniques for the Delta 90 calibration.” Put this sentence a little earlier (p9, l18), before you start describing how to find the zero degree position.

*- p9 eq (24) What is eta*_pol ? It is not introduced. eta* would be sufficient.*

- p10, l17 polarizing beam splitter

- p11, l5 and Fig 3 “optical rotator calibrator” please do not use different words for the same thing throughout your manuscript. “HWP calibrator” or “optical rotator calibrator” ?

- p11, l29 use \citet{} instead of \citep{} command.

- p12, l3-4 “measuring two depolarization channels at 532nm and a 90setup” Reshape this part, the lidar does not measure a channel nor a setup.

- p12-13, chap. 3.4 You are talking about the depolarization ratio, not the polarization ratio. It occurs 5 times in this chapter the wrong expression.

- p13, l11-12 The polarization parameter (a) is not the atmospheric depolarization that you show in your figure.

- p13, l12 “the diattenuation parameter” of the receiving optics.

- p13, l22 “The analytical correction of alpha can be performed by” determining G_S, H_S and K “using Eq. (16), (17) and (21).”

- p15, l2-3 Already said on p12, l11-12

- p15, l16 polarization

- p15, l31 “lower values” – Give numbers.

- p15, l33 Put the citation in one bracket.

- p16, l19 “use the same”

- p17, l22 its placement . . . keep normal text font

- p17, l27-28 “while the method[s] that use the calibrator in front of the PBS allow[s] to take into account . . . ” Plural or singular?

- p18, l10 “number of lidar systems it can be applied to” You mean single wavelength lidar systems or what are the other limiting factors?

- p18, l20, l23 Do not use “+” in the text. Use “and”.

- p18, l26 0.01 - 0.03

- Appendix A: D has to be italic. M_S has to be written with a capital S.

- Keep the alphabetical order of your reference list (e.g. Reichardt should not appear after Winkler, page 25)

- When citing make sure, that David. G, et al, 2012 appears as David et al, 2012

*- Table 3: The index “pol” in eta*_pol is not used elsewhere in the case study. In Fig 8 it is just called eta*.*

- Fig 6 In the caption: “measured depolarization ratio” – “calibrated signal ratio delta” would be better.*

- Fig 6b in the title of the diagram the ‘ is missing for epsilon.

- Fig 8 In the caption “one hour average” – the red lines indicate just 45 minutes. What is correct?