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This is the outline of the presentation; it is divided into four sections.

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So, let's start with the first one, the goal of the thesis...

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... which is to precisely measure the value of the strong coupling constant, alpha strong, together with its main uncertainty contributions from the cross section of events with two jets, that depends on alpha strong itself. I will define jets in just a minute. Alpha strong is the coupling constant associated to the strong interaction, that is the component of the Standard Model of particle physics which regulates the interactions among quarks and gluons, collectively known as partons. The three Feynman diagrams depicted here, useful for my analysis, represent the possible interaction vertices among partons, and alpha strong quantifies the intensity of those interactions. It is important to provide measurements of alpha strong because, at present, it is the least precisely measured coupling constant in the Standard Model, with a precision of 7.6 times 10 to the sixth parts per billion, to be compared, for example, to the 0.15 parts per billion of the electromagnetic fine structure constant. Its large uncertainty makes alpha strong a limitation from both the theoretical point of view and the experimental one, as it potentially prevents the discovery of new physics effects.

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In this work, the measurement of alpha strong is derived employing, for the first time, LHCb data samples. As visible in the figure, where a comparison with the CMS experiment is shown, LHCb covers a complementary phase space region of proton-proton collisions. The same reasoning also holds for ATLAS and the other main collider experiments. Therefore, LHCb can measure alpha strong in regions never explored before for this aim.

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I will now expand more on the LHCb detector and talk about the physics objects used in my analysis to extract alpha strong, hadronic jets.

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The Large Hadron Collider beauty experiment is one of the four largest detectors at the LHC, CERN. In the figures a side view and a top view of the layout of LHCb are presented. They refer to its Run 2 conditions, which is the data taking period in which the samples I analyzed were collected. LHCb is a single-arm spectrometer equipped with planar detectors that are placed along the LHC beam axis, and it probes the forward region of proton-proton collisions. In this work, the information coming from three types of detectors is exploited: trackers, calorimeters (both electromagnetic and hadronic) and muon stations.

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As far as jets are concerned, the starting point is the partons produced in the final state of a proton-proton collision, that undergo the processes called fragmentation and hadronization, at the end of which they are confined into hadrons. A jet is an object which carries the properties of the proton-proton collision without the complexity of considering the produced particles individually. In fact, a jet is not a single particle, but a collection of particles in the form of a collimated conical spray. So, the detection of a jet depends on its definition, given by a jet reconstruction algorithm. The first step is the selection of tracks and calorimeter clusters, that are the inputs for the clustering algorithm, which groups the inputs into jets. Then, each jet is assigned a four-momentum according to a specific recombination scheme, and the jet energy is corrected to account for detector inefficiencies and non-uniformities and for possible background processes. Some quantities related to jets that will be useful in the following are summarized in the drawing that represents a reconstructed jet cone in the reference frame of a p-p collision, where the proton beams travel along the z direction. The transverse momentum, p_T, is the projection of the three-momentum of the jet in the xy plane, transverse to the beam direction. The pseudorapidity, eta, is connected to the polar angle, theta, between the z axis and the three-momentum. The azimuthal angle, phi, is the angle between the x axis and the transverse momentum in the transverse plane.

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In the plot, the LHCb jets selection efficiency is reported. It can be seen that it reaches values up to 97%. Two LHCb samples containing hadronic jets are used for the analysis. The first one, named dijet, contains events with two reconstructed jets. The second one, Z+jet, contains events with a Z^0 boson decaying into a $\mu^+\mu^-$ pair and produced back-to-back with a jet in the transverse plane, xy. They are both collected at a center of mass energy of 13 TeV and integrated luminosity of 1.6 fb^{-1}, and the selection cuts applied to both samples regard the jets transverse momentum, that must be above 20 and below 100 GeV, and the jets pseudorapidity, that must be in the range 2.2-4.2, corresponding to the LHCb fully instrumented region.

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I will now explain the stages of the analysis procedure that brought to the measurement of alpha strong.

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Thanks to an initial fast simulation study of proton-proton collisions producing two jets at Leading Order, the chosen figure of merit to extract alpha strong is the inclusive dijet cross section, which displays clear differences with respect to the alpha strong value, that was tuned varying the Parton Distribution Functions loaded at generator level. Three values of alpha strong were studied. Using the general proportionality formula reported in point 1 between the cross section of a process and counting the number of collected events, with proportionality factors given by efficiencies and integrated luminosity, the inclusive dijet cross section can be extracted from the experimental dijet sample. The dijet and Z+jet sets are then used as calibration samples to derive the required correction factors for the jets transverse momentum, that allow to compute the efficiency that enters the previous formula. From the comparison between the simulated and experimental cross sections, the alpha strong value is obtained. The main contributions to the alpha strong uncertainty are propagated from the ones of the cross section, that come from the statistics, the correction factors, and the integrated luminosity. The latter carries a constant contribution, that is independent of the specific study.

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Since the Monte Carlo is not affected by detector effects, data and Monte Carlo samples are different. Therefore, in this study two correction factors for the jets transverse momentum are computed to account for these differences. Here they are named K* and F*, and they are related to the so-called Jet Energy Scale and Jet Energy Resolution. The Jet Energy Scale is the mean value of the ratio of the true p_T of a jet, that would be measured before its interaction with the detector, to the reconstructed p_T, that comprises all detector effects. The Jet Energy Resolution, instead, is the width of the ratio of the difference between reconstructed and true p_T to the true p_T. K*, the scale factor, and F*, the smearing factor, are extracted in bins of jet p_T from two distributions, respectively: R_Z, that is the ratio of the jet p_T to the p_T of the Z^0 boson, used for the Z+jet sample, and R_{12}, that is the ratio of the difference of the p_T of the two jets to their sum, used in the dijet sample. The resulting K* and F* correction factors are reported in the plots on the bottom of the slide as a function of jet p_T.

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Therefore, the efficiency associated to these correction factors is calibrated on the Monte Carlo and is computed as the ratio of the number of corrected simulated events in the dijet sample with two jets in the fiducial region to the total number of events of the Monte Carlo sample. It is also multiplied by all the needed pre-scales and phase space factors. Then, the experimental dijet cross section can be computed according to the aforementioned formula from the data dijet sample. The resulting experimental cross section is reported here, and amounts to about 1.3 times 10 to the seventh pb. The contributions to its error are shown individually, and are due to the statistics of the data sample, the systematic correction factors, and the integrated luminosity. This can be compared to the simulated cross section with the current world average of the alpha strong value, that is about 1.37 times 10 to the seventh pb.

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The methods I just described allowed to obtain interesting results, that I will now show.

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As already anticipated, the value of the strong coupling constant is derived from the intersection between the experimental dijet cross section, the horizontal red line in the plot, and the blue fit line of the three simulated cross sections, as a function of alpha strong. The measured alpha strong value obtained with these procedures is 0.114. The errors are directly propagated from those of the dijet cross section, and the total error is about 0.009.

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This work allowed to measure for the first time the strong coupling constant in the forward region of p-p collisions with the LHCb detector and it is deemed satisfactory, as alpha strong results compatible with the world average and the most precise single measurement ever, that was obtained by ATLAS in 2023 and is equal to the world average. Also, even if the uncertainty is higher than the one obtained in other works dealing with jets, for example the CMS ones, it is of the same order of magnitude. The primary outcome of this work is that the statistics is not the limiting factor to the alpha strong uncertainty, so with this analysis strategy it is mandatory to refine the energy correction procedures to lower the systematic uncertainty, that is now the largest error. Providing a constant contribution, the integrated luminosity could potentially become the only limiting factor to the error in the context of this analysis.

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There are several ways to carry on the work I just presented. As already mentioned, the extraction of the correction factors can be improved, and also the initial simulation study can be enhanced, for example generating events at Next-to-Leading Order. Other approaches can be explored, such as using differential measurements or ratios of distributions, in which many systematic uncertainties cancel out, in particular the integrated luminosity one. Lastly, the analysis can be adapted to the current Run 3 data taking and also prepared for the future LHCb upgrades. In particular, the development of the electromagnetic calorimeter could allow to employ events of the type photon+jet to calibrate the jet energy.