משרד החינוך
המינהל הפדגוגי
האגף למחוננים ולמצטיינים

Feasibility Study for Measuring the Branching Ratio of B->φ Mesons at Atlas

בדיקת היתכנות לסיכוי הדעיכה של מזונים B->φ בגלאי ״אטלס״

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Our Research Question:

In a high-energy environment, what is the probability that a B meson1 will decay into a φ (Phi) particle?

Background:

In the Large Hadron Collider[2] (LHC) - which is an enormous, underground, circular particle accelerator built in Geneva - protons are accelerated to more than 99.9999% the speed of light. Two beams of protons, accelerated in opposite directions, are made to collide into one another, precisely in the detector named "Atlas[3]". This particle detector can record all of the newly-made particles and hadrons that form as the result of the collision. One of the types of hadrons that can be formed in such an experiment is a pair of "B mesons". These B mesons always either form as a pair, or not at all (Two B or not Two B).

There are 8 types of B mesons. Four of them involve a regular b (bottom) quark, which has an electric charge of -1/3 eV: $b\bar{u}$ ('bottom' quark + 'anti-up' quark), $b\bar{d}$ ('bottom' quark + 'anti-down' quark), $b\bar{s}$ ('bottom' quark + 'anti-strange' quark), and $b\bar{c}$ ('bottom' quark + 'anti-charm' quark). The four remaining B mesons involve a $\bar{b}$ (‘b bar’ or 'anti-bottom') quark, which has an electric charge of 1/3 eV: $\bar{b}u$ ('anti-bottom' quark + 'up' quark), $\bar{b}d$ ('anti-bottom' quark + 'down' quark), $\bar{b}s$ ('anti-bottom' quark + 'strange' quark), and $\bar{b}c$ ('anti-bottom' quark + 'charm' quark). When a pair of B mesons is formed, one contains a b quark and the other contains a $\bar{b}$ quark.

The J/ψ (Jpsi) meson is made up of $c\bar{c}$ ('charm' quark + 'anti-charm' quark). It can be produced by many processes. One such process is the decay of a B meson. When the J/ψ meson is not produced from the decay of a B meson, its production point is the "Interaction Point” - IP (the point where the two beams collide). But because the B meson has a certain "lifetime", when the J/ψ meson is the product of a B meson decay, its production point is a certain distance away from the IP. This happens ONLY when the Jpsi is produced from the B meson.

The Phi (φ) meson is made up of $s\bar{s}$ ('strange' quark + 'anti-strange' quark). It also can be produced from many processes, among them the decay of a B meson.

In this study, we took a sample of data, in which there are J/ψ mesons which have production points that are not on the IP. This indicates the presence of a B meson, which also indicates that there has to be ANOTHER B meson (remember? Two B or not Two B) Using this technique, and this knowledge, we set out to find the percentage of Phi particles that were produced in a B meson decay.

Analysis:

All of the study was performed in the Linux operating system, using a program named "Root" by CERN, which is an object-oriented based program.

We searched for φ mesons using their decay into charged Kaons (K^+; K^-). We took all combinations of oppositely charged Kaons and calculated their invariant mass.

Our simulated file had multiple types of particles, simulating an actual proton collision: Phi particles that came from B mesons, Phi particles that **didn’t** come from B mesons, and “background”. The background is all the other particles that are created due to the collision, but are not “interesting” to the goal of the experiment. These can be any type of particles. We were interested **only** in the Phi particles that came from B mesons. The ratio between the B->φ particles and the background was very small: ~1:608. Our first goal was to find a set of selection criteria, in order to optimize the ratio. To find these selection criteria, we had to brainstorm and look into the particles’ characteristics, in order to differentiate between the types of particles. We called these criteria: “cuts”. One by one, we found this set, made up of 6 cuts:

- The cosine of the angle between the J/ψ direction and the φ direction should be larger than 0.9 (a small angle.) In other words, the direction of the J/ψ and the direction of the φ should be very close, because the both of the $B/\bar{B}$ mesons in a pair are very close.
- The ‘decay length’ of the φ particle – the distance between the φ’s production point and the IP – should be larger than 0, in order to remove the option of Phi particles that were produced on the IP, and reduce the background.
- Assuming the φ particle doesn’t originate on the IP, the cosine of the angle between the direction of its decay length and the direction of the particle’s momentum must be larger than 0.9 (a small angle,) reducing the chance of a wrongly-measured IP-originating φ particle.
- The cosine of the angle between each of the two tracks (making up the φ particle) and their respective jet must be larger than 0.975 – to make sure that they indeed are part of the jet.
- The momentum of the φ particle, on the plane that is perpendicular to the colliding beams, must be larger than 1.8 GeV.

These cuts lowered the B->φ : bg ratio to ~1:13. As shown in the plots below, it optimized the data very well. These plots show ticles’ mass. The ‘signal’ of the φ particle is easily seen around 1019 MeV.

Analysis (cont.):

The probability that a B meson will decay into a Phi particle can be stated in the simple equation:

Br = SphiB/#B

Where ‘Br’ stands for “Branching Ratio” (the probability we are trying to measure), ‘SphiB’ is the number of Phi particles that came from B mesons (B->φ), and ‘#B’ is the total number of B mesons. Sadly, we don’t know the number of B->φ particles, so SphiB can be exchanged as:

SphiB = Sphi * P

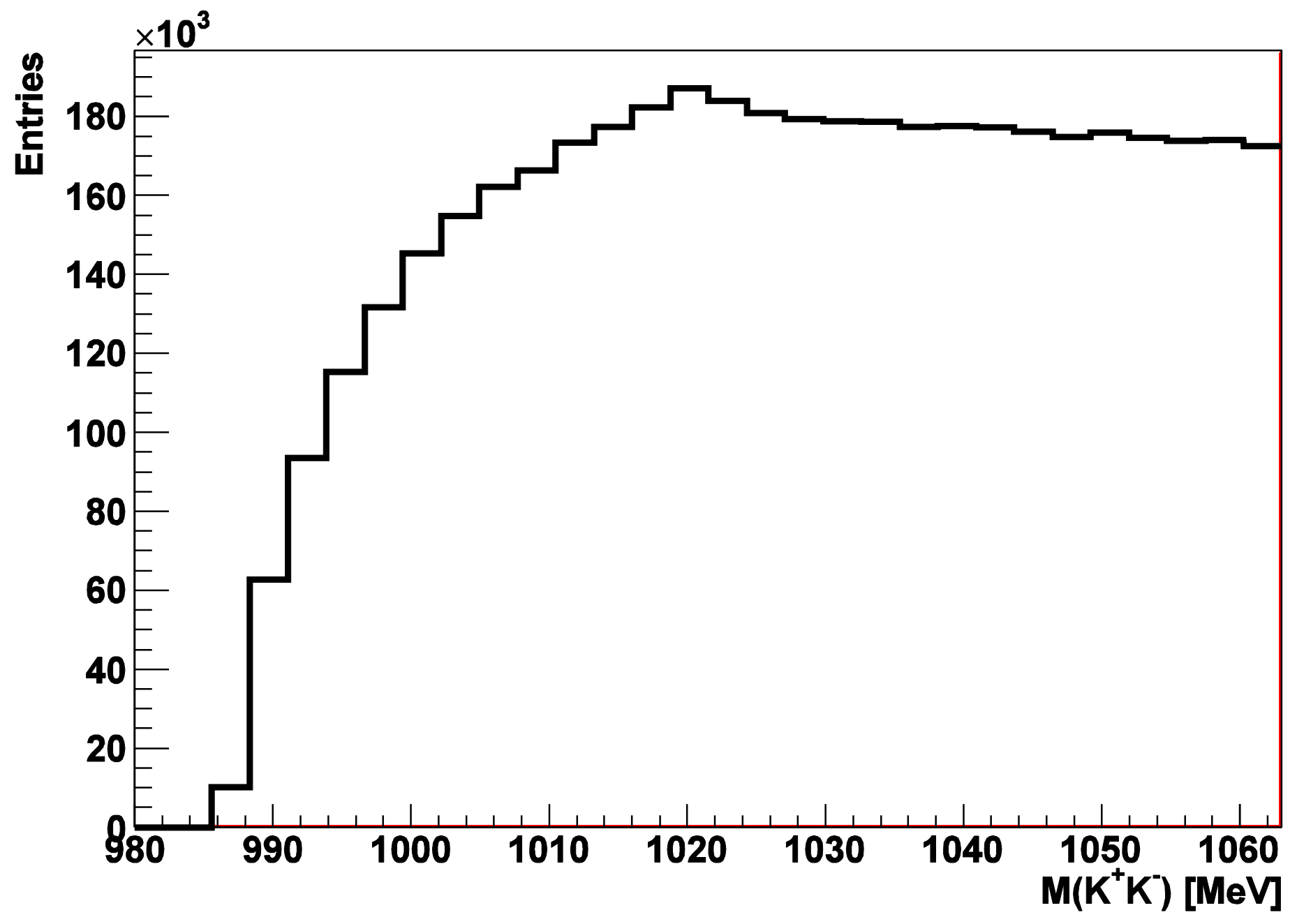
Where ‘Sphi’ is the total number of Phi particles in the experiment, and ‘P’ is the **probability** that the Phi particle decayed from a B meson.

Using data from our sample file, we calculated our ‘P’: ~0.57; with an error smaller than 0.01.

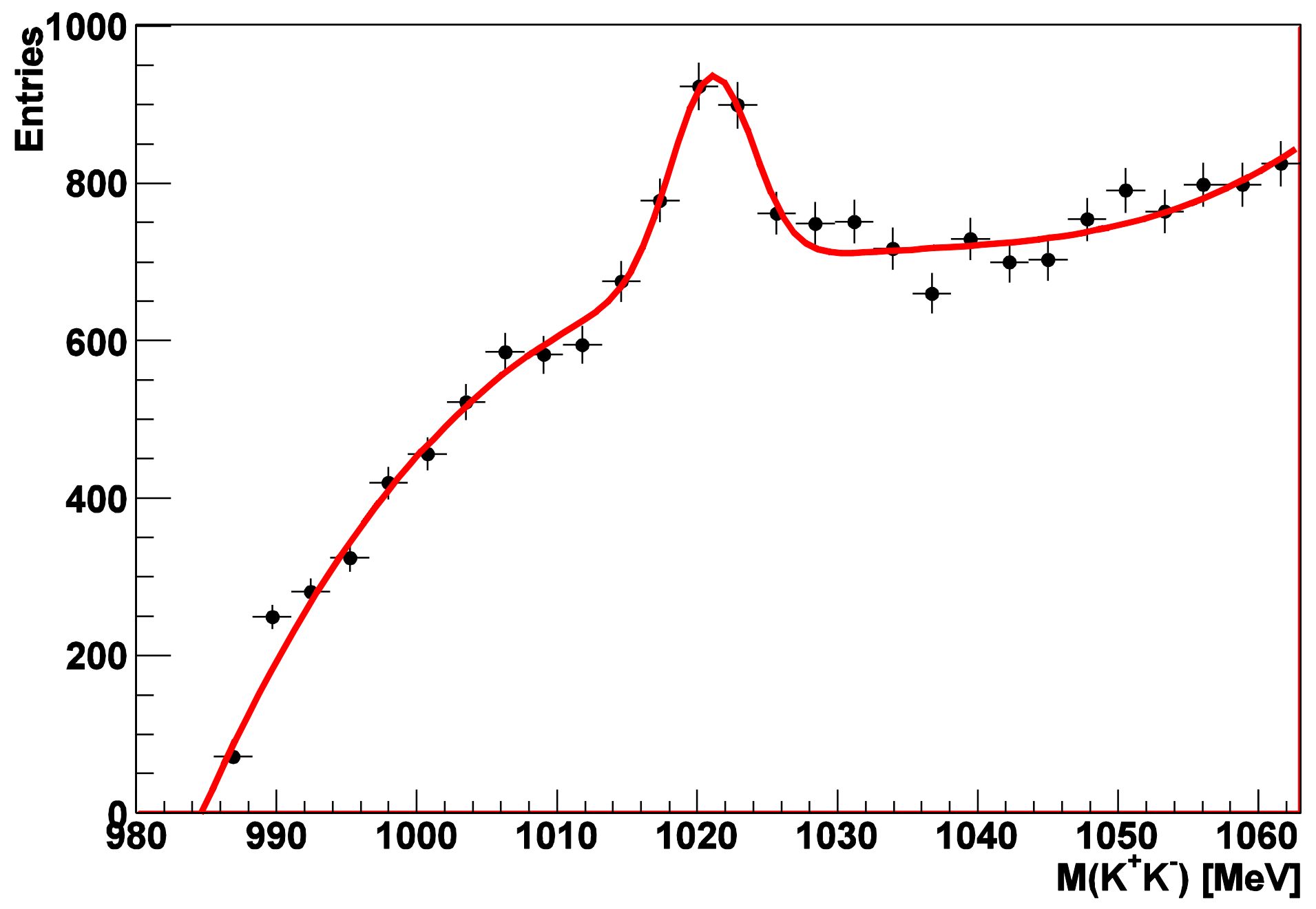
The total number of Phi particles can be found by calculating the integral below the **signal** that we see in the graph. But because the graph shows only the particles that **passed the cuts**, we must upgrade the equation to include the chance a particle has to pass all cuts, marked with the letter ε (epsilon):

Br = (Sphi * P) / (#B * ε)

Using the sample data file once again, we calculated our ‘ε’ to be ~0.18; again with an error smaller than 0.01.



Invariant mass distribution of φ candidates,
prior to applying any selection criteria



Invariant mass distribution of φ candidates,
after applying the chosen selection criteria

Results:

In this way, we could turn to a large data file, equipped with our equation and calculated probabilities, and run a test study, to attempt to find the number of Phi particles that decayed from B mesons.

Hence, we obtained a branching ratio of 0.0107 ± 0.0010, compared to the original branching ratio in the file used of 0.0112.

Conclusion:

We have demonstrated that using the above kinematical cuts, we can obtain an accuracy of 9% on the branching ratio of B->φ. This accuracy will increase with statistics, using a larger data sample, which suggests that such a search is possible at Atlas.

Future Expectations:

My personal hope is that I will be given a chance to travel to CERN in Geneva and work on the ATLAS detector. If this came about, I would like to continue this feasibility study and turn it into a measurement with real ATLAS data.

Bibliography:

[1] - K. Nakamura et al. (Particle Data Group), J. Phys. G 37, 075021 (2010)

[2] - http://public.web.cern.ch/public/en/lhc/lhc-en.html

[3] - http://atlas.ch/