PHYSICS

How do I determine the rest mass of a J/ψ particle from CMS Dimuon Data?

Asked 2 years, 4 months ago Modified 2 years, 4 months ago Viewed 262 times

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Essentially, I'm using CMS Dimuon data, from the decay of a J/ψ particle, to prove that momentum is 'conserved' in relativistic collisions. However, I'm unable to find how I can do this. I thought of using the **Dispersion Relation** formula which is $E^2 = p^2 + mc^2$ but I'm not sure how I'd apply it to the data. I have the relativistic 4-vector with energy, p_x, p_y, p_z, and transverse momentum for both dimuons produced, along with their invariant masses.

Here is where I obtained the data from: http://opendata.cern.ch/record/301

I'm using Octave to process this data, and I'm not sure what operations I should be performing, or if I should even be calculating the rest mass of the J/psi particle?

I essentially need help with trying to understand how I can prove conservation of momentum with this data (and if finding the rest mass is one way), how I proceed to do that? Moreover, if there are other ways to show this?

special-relativity particle-physics momentum standard-model particle-detectors

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edited Oct 24, 2020 at 7:22
Qmechanic ♦
184k 38 476 2112

asked Oct 23, 2020 at 21:09
DPanda
13 4

$E^\wedge 2 = p^\wedge 2 + mc^\wedge 2$ The second term is missing a c^2 and the third term is missing a square. As is, this is dimensionally inconsistent. – G. Smith Oct 24, 2020 at 0:02

What collision are you talking about? One that produces the J/psi? If so, what do you know about the momenta of the colliding particles? – G. Smith Oct 24, 2020 at 0:12

You are asking two different questions: How do you determine the J/psi rest mass, and how do you show that momentum is conserved in some process (a collision?) that you haven't specified. – G. Smith Oct 24, 2020 at 0:14

In your profile you do not indicate your level of physics studies. Is this a homework problem? – anna v Oct 24, 2020 at 4:36

@anna v I'm a high school student (12th Grade) studying in the IB, and I'm trying to produce for my 'Extended Essay' which is essentially a 4000 word paper on a topic of my choice, so I chose this topic.

– DPanda Oct 25, 2020 at 10:46

2 Answers

Sorted by: Highest score (default)

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The answer to the question in the title is:

For each pair of muons in an event

1. Add the two PX values to get the total PX
2. Do the same for PY and PZ and then combine these 3 to get the total momentum
3. Add the two energy values to get the total energy
4. Then calculate the combined invariant mass from $M^2 = E^2_{total} - P^2_{total}$ (This is NOT anything to do with dispersion relations, I don't know where that came from). As you are working with energies in GeV, masses in GeV/c^2 and momenta in GeV/c, the cs all cancel.

This doesn't really answer the question in the body of the question - how to prove conservation of momentum. That is assumed in steps 1 and 2. Each proton proton collision produces many particles and you could test conservation of momentum by adding all their momenta and showing they give zero, but this data only gives two so that can't be done.

Never mind: there are other, better ways of testing momentum conservation, and more interesting things to do with this very nice data.

By the way: the experiment actually measures the $Q \times P_T$, phi and polar angle (related to eta) for each track, and identifies them as muons so it knows their mass. Everything else in each table row is derived from these basic measurements.

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answered Oct 24, 2020 at 8:54

RogerJBarlow
9,547 1 18 42

I attempted to perform the calculation in step 4 on my dataset following the previous steps, however, it produces a non-real value for the two masses (M^2 = -34.6703385). Am I supposed to account for the transverse momentum as well in this case, and if so how should I do that? Additionally, the primary motivation of my investigation is to show that momentum is in fact conserved in relativistic collisions. Is there a better dataset I can use to achieve this, as you mentioned there are better ways? – DPanda Oct 24, 2020 at 18:52

PX and PY are the transverse momenta. You seem to have made a mistake in calculating M^2: for the first event it is (13.706+3.67389)^2- (4.88649-0.68325)^2-(0.5296-2.508)^2-(12.5569+3.56917)^2 which is 20.42. The mass is actually given in the final column. – RogerJBarlow Oct 24, 2020 at 19:27

Yes, sorry I realized the mistake. I found the invariant mass to be consistent with that given in the dataset. So by finding the invariant mass for all the events, and computing the average of that, I should find a value within a small uncertainty of the mass of a J/psi particle (3.1 GeV/c^2) right? This can, to an extent, demonstrate the conservation of momentum holds in HEP right? – DPanda Oct 24, 2020 at 19:44

Treat the like sign and unlike-sign pairs separately. There is no signal in the like sign pairs and they can be used to talk about the background to the like pairs. Maybe if you showed that the mass did not depend on the total energy that would demonstrate something like what you want. – RogerJBarlow Oct 24, 2020 at 19:47

@RogerJBarlow "There is no signal in the like sign pairs and they can be used to talk about the background to the **unlike** like pairs". Conservation of momentum is a law, and has been assumed in generating these data. There is no way to "prove"=validate conservation of momentum from just this . data set. – anna v Oct 25, 2020 at 4:14

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The data set you link to just has the muons, so there is no information about the interaction that produced them. Only the four vectors of a possible decay.

> to prove that momentum is 'conserved' in relativistic collisions.

Momentum and energy conservation are **laws**, extra axioms, set so that the theory fits the data. The laws can only be validated, not proven. They have been continuously validated in all data, from classical mechanics to special relativity mechanics. They are validated in all particle physics interactions. Only at the very high masses and velocities that the observations need General Relativity to be fitted there is a region of obscurity.

> I essentially need help with trying to understand how I can prove conservation of momentum with this data

As stated above the conservation of momentum is an axiom included in the four vector algebra of special relativity, no proof can be given.

> (and if finding the rest mass is one way)

The rest mass of the two muons is simply the length of the four momentum , if you add the two muon four vectors the length of the sum is the mass of the J/Ψ candidate.

Conservation of momentum is inherent in the algebra of the data you are given, so there is no way to prove it.

One could show *consistency* of momentum conservation with a decay, only if there is an independent measurement of the four momentum of the incoming particle and the four momenta of the outgoing ones. Then measurement errors will introduce an uncertainty , that should be small in order to have the law of conservation of momentum hold. This cannot be done with the data in the link, because there is no independent measurement of the J/Ψ.

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edited Oct 24, 2020 at 5:13

answered Oct 24, 2020 at 5:01

anna v

229k 19 234 628

I phrased in incorrectly. The motivation is to demonstrate conservation of momentum, rather than prove it, as it is a law, using the which the data is in fact produced. I'm hoping to demonstrate using the invariant mass, energy, and momentum, that momentum is conserved in particle collider collisions, with the J/psi dataset, and a similar one I found here: opendata.cern.ch/record/5206 Is there a better way of demonstrating this idea, because I'm not able to find data for before-after 4 momenta. Or are there other calculations I can perform, pertaining to relativistic effects? – DPanda Oct 25, 2020 at 10:48

Where can I find data for the 'independent measurement of the four momentum of the incoming particle and the four momenta of the outgoing ones." One of my limitations is that I'll be processing my data using my computer and Octave, and I don't have much experience with ROOT or the CERN VM. Right now my plan is to find the invariant mass using the data I have gathered, and demonstrate that it is within a small uncertainty of the rest mass of the parent particle. My investigation is only for a high school paper, but would this suffice? – DPanda Oct 25, 2020 at 10:56

I think it should suffice to show that there is a particle in that mass interval. for unlike charges, whereas there is none for like charges. You cannot find such data in the way you found this educational set. It is complicated many-particle events that have to be fitted with complicated formulas. In low energies it was simpler. see this picture en.wikipedia.org/wiki/Omega_baryon#/media/File:Omega_Baryon.svg . If momentum were not conserved (incoming to outgoing) the complicated hypothesis of omega - would not fit a distinct mass when a lot of events are accumulated. – anna v Oct 25, 2020 at 11:55

Thank you for the feedback. I will proceed with analyzing the relativistic kinematics and showing the particle being present for unlike charges, and none for like charges. Is there anything specific I should be aware of when addressing the topic from this lens? – DPanda Oct 25, 2020 at 23:11