Lightborn Quantum-Platers

A Case on Antimatter: Comparing the energies of a bremsstrahlung generated photon beam scattered by electrons versus one by positrons.

Why We Want to Go:

One of the most difficult aspects of this competition for us was finding a topic that was not only fascinating, but was both practical and could contribute to particle physics as a whole. Our group was really excellent at coming up with ideas that fascinated us (with ideas that ranged from plasma acceleration to wave-particle duality), but none of them was practical in the DESY II Synchrotron. In the end, we found inspiration from last year's winners, Team Particle Peers, who researched the difference between matter and antimatter. As a group, we all agreed that the fact that our universe has not been completely annihilated was very fascinating. It would be a life-changing experience for us to be able to work with professionals to investigate one of the universe's greatest mysteries and to improve our understanding of physics as a whole.

Theoretical Background:

When the universe began at 0 linear time (Big Bang), all matter and antimatter were created in equal amounts. However, during the Lepton Epoch (1 second to 1 minute and 40 seconds after the Big Bang), the neutrinos (electron, muon, and tau) stopped interacting with other particles and leptons/antileptons started to annihilate.

The odd thing is that leptons and antileptons share almost all the same properties: spin, mass, mean life, with charge being the one exception (always opposite)[1]. It has been hypothesized that there is some difference between matter and antimatter that would account for the asymmetry; our group proposes a difference in energy levels between matter and antimatter after creating bremsstrahlung radiation. Bremsstrahlung radiation is a photon beam created by the energy lost when particles are slowed or stopped[2] (due to the Conservation of Energy($\frac{1}{2}m_A v_A^2 + \frac{1}{2}m_B \upsilon_B^2 = \frac{1}{2}m_A \upsilon_A'^2 + \frac{1}{2}m_B \upsilon_B'^2$).

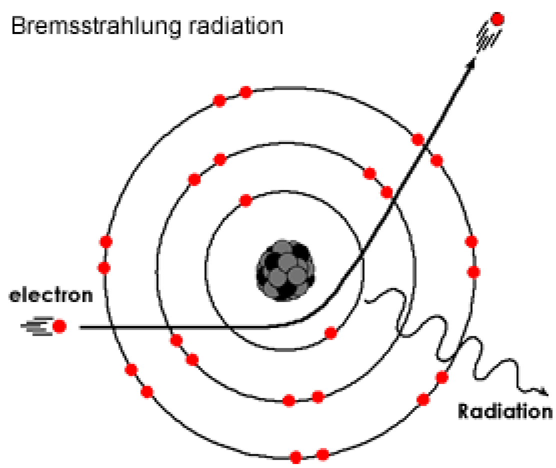

Figure. Bremsstrahlung Radiation from Scattering

We are hypothesizing that positrons give off more energy to the photon beam than electrons, meaning the positrons themselves have less energy or are "colder"[3]. Since they are colder, it is

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[1] CERN. "CERN Accelerating Science." *CERN*, home.cern/science/physics/matter-antimatter-asymmetry-problem.

[2] "Bremsstrahlung." *Bremsstrahlung - an Overview | ScienceDirect Topics*, www.sciencedirect.com/topics/physics-and-astronomy/bremsstrahlung.

[3] Would also applies for all types of antimatter (anti fermions and anti baryons alike)

more likely for them to form bonds with antiprotons, making antihydrogen, which would have a higher density and are more likely to be absorbed by black holes[4]. Black holes could very much be hiding all the missing antimatter in our universe, and by examining the scattered photons, we can indirectly compare the energy levels of electrons versus positrons.

Experiment Diagrams:

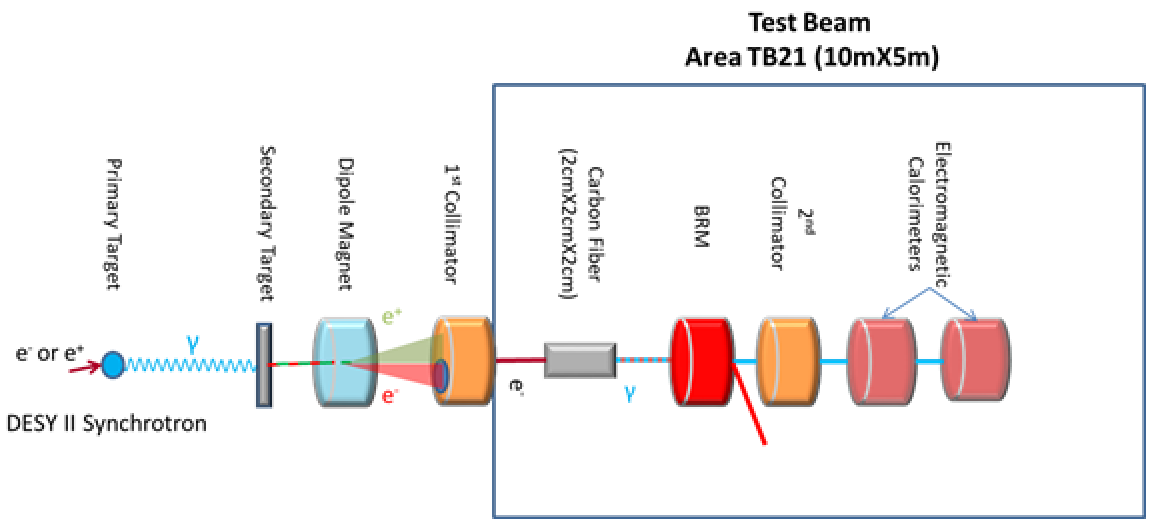

Figure: Schematic Diagram (electron)

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[4] *If the black hole were to only absorb the positrons, the black hole would become positively charged. On top of its immense gravitational force, it would also exhibit an electromagnetic attraction, which is not observed in reality. Thus is why the positrons must be absorbed with an antiproton to cancel the charges.

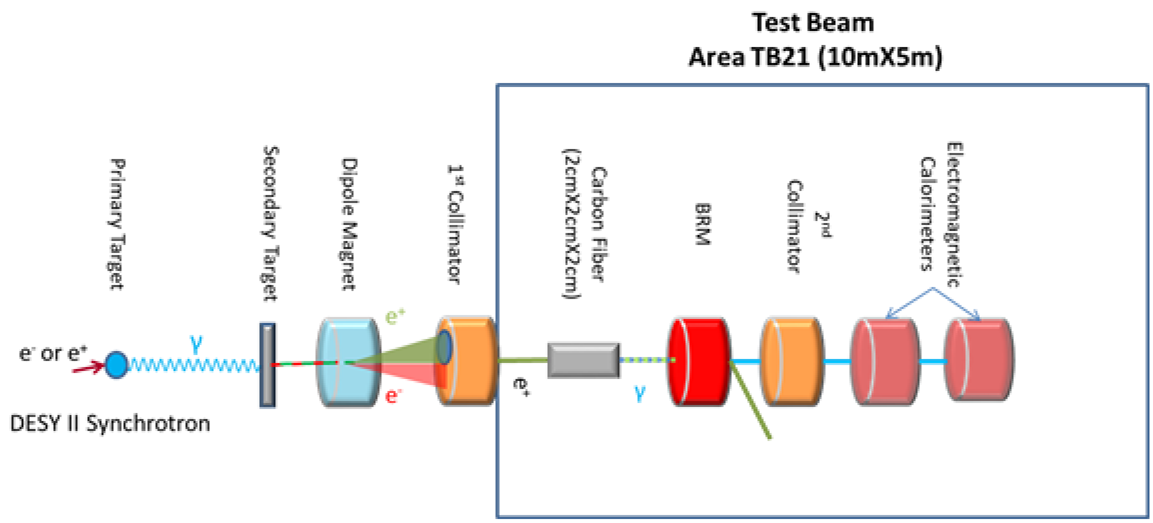

Figure: Schematic Diagram (positron)

Method:

The bremsstrahlung beam from electrons will be run at a separate time from the positron one, to avoid any interference. We will use one piece of carbon fiber for electrons, and use a new one(as similar as possible) for positrons.

Procedure

1. The original electron/positron beam will be accelerated to a range of 1-6 GeV(we conduct our experiment through a range of all energies), which will pass through the first collimator to create either a pure electron beam or a pure positron beam.

2. The beam will collide into a block of carbon fiber[5](radiator target), which will significantly slow down the beam as it passes through, creating bremsstrahlung radiation on the opposite side(beam of photons).
3. The bremsstrahlung photon beam(with energies in the gamma range due to non-continuous scattering) will then pass through the BRM in order to ensure the beam is a pure photon beam and to remove any excess electrons/positrons.
4. After the BRM, the photon beam will pass through the second collimator, which is used to control the photon beam flux and concentrate it.
5. To measure the energy of the photon beam, we will use two Electromagnetic Calorimeters (there will be a second one to see if time plays a role in the energy levels) for two measurements of energy.

Data Interpretation:

Equations for Bremsstrahlung Energy[6]

*See index for variable definitions

For cross section calculation[7]

$$\frac{d\sigma}{dk} = \left(\frac{1}{k}\right)4\alpha r_e^2\{\left(\frac{4}{3} - \frac{4}{3}y + y^2\right)\left[Z^2\left(L_{rad} - f(Z)\right) + ZL'_{rad}\right] + \frac{1}{9}(1 - y)\left(Z^2 + Z\right)\}$$

where y = k/E is the fraction of the electron's energy transferred to the radiated photon.

[5] Dimensions of 20cm by 3cm by 14cm.
[6] http://pdg.lbl.gov/2019/reviews/rpp2018-rev-passage-particles-matter.pdf
[7]Probability distribution of energy of all the photons

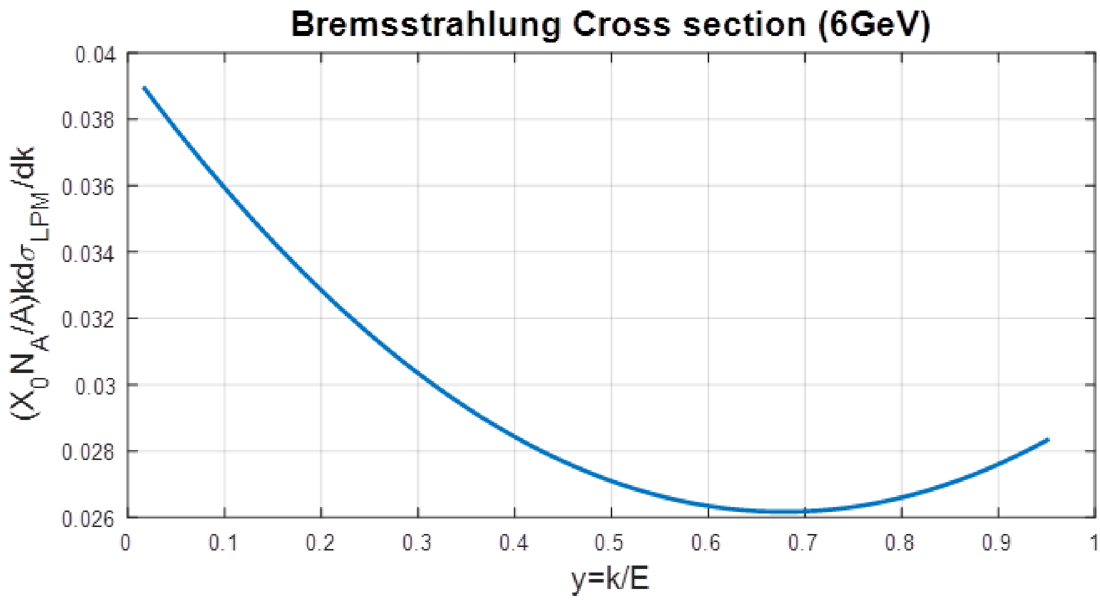

Figure. Example Distribution

The number of photons with energies between k min and k max emitted by an electron travelling a distance d ≪ X0 is:

$$N_\gamma = d/X_0[\frac{4}{3}\ln ln\left(\frac{k_{max}}{k_{min}}\right) - \frac{4\left(k_{max}-k_{min}\right)}{3E} + \frac{k_{max}^2-k_{min}^2}{2E^2}]$$

We will use these equations to calculate the distribution of bremsstrahlung energies and use it as comparison for our actual results. The expected value will represent the current model for electrons/positrons, and using the Chi-square test, we can see if there is a discrepancy in the current model.

Then, using statistical analysis tools, i.e histograms, distribution function fitting, to process the sufficient data set. We will specifically be examining the distributions, tails, and outliers (if any) in order to identify statistical differences between the two beams. Even the slightest difference, down to the millionths, could explain the matter-antimatter asymmetry.

What we hope to take away:

We've already taken away so much from this experience, through our immense growth and learning in the topics of particle physics and theoretical physics. When we began this experiment, almost all of us were new to particle physics and knew very little about quantum mechanics as well. Now we have been able to explore these topics, and we are arguably more interested than we were when we started. Ideally, we'd also like to take away a once-in-a-lifetime experience where we were able to work alongside the explorers and pioneers of the future to understand our world better. Our school curriculums have not allowed us to explore physics yet, so this experience has given us a valuable taste of a subject we are all very interested in. Overall, this experiment has really challenged us to think outside the box and exposed us to the complexity of the universe, which we strive to continue learning in our future!

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Symbol	Definition	Value or units
k	Bremsstrahlung photon energy	GeV
α	Fine structure constant (e	1/137.035999139(31)
r_e	Classical electron radius	2.8179403227(19) fm

Z	Atomic number of absorber	n/a
N_A	Avogadro’s number	6.022140857(74) x10^{23} mol^{-1}
X_0	Radiation Length	g cm^{-2}
A	Atomic mass of absorber	g mol^{-1}
E	Incident particle energy γMc^2	GeV
L_{RAD}	Tsai calculation for radiation length	4.618497486
L'_{RAD}	Tsai calculation for radiation length(prime)	5.890557981

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Always Quantumplating-

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