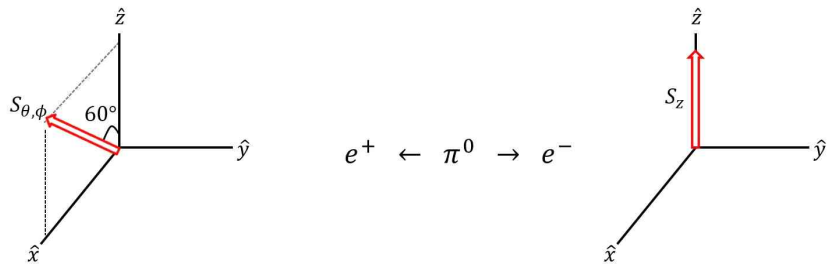
소속대학원		수험번호		성 명		감독교수 확 인	(인)

2013학년도 석사과정/석사·박사통합과정
후기모집 면접·구술고사 전공시험

2013. 5. 7 시행

1. (25 points) Consider the decay of a neutral pion with spin zero (π^0) initially at rest into an electron (e^-) and a positron (e^+). The positron and electron fly off in opposite directions after the decay. The spin measurement along the z-direction (S_z) is then performed for the electron, and that with 60 degree to x-direction ($S_{\theta,\phi}$ with $\theta = 60^\circ$, $\phi = 0$), as shown in the figure below, is performed for the positron.



(a) (6 points) Write down the spin state of the two particles right after the decay. Explain the reason that the state is in that configuration.

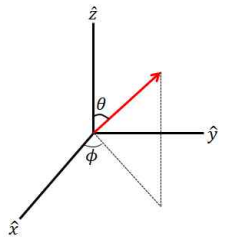
(b) (6 points) What is the probability for which both the spin measurements obtain the eigenvalue $\hbar/2$?

* If necessary, use the following formulas for the spin operator and corresponding eigenstates.

$$S_{\theta,\phi} = S_x \sin\theta\cos\phi + S_y \sin\theta\sin\phi + S_z \cos\theta$$

$$|\uparrow_{\theta,\phi}\rangle = \cos\frac{\theta}{2} e^{-i\phi/2}|\uparrow\rangle + \sin\frac{\theta}{2} e^{i\phi/2}|\downarrow\rangle$$

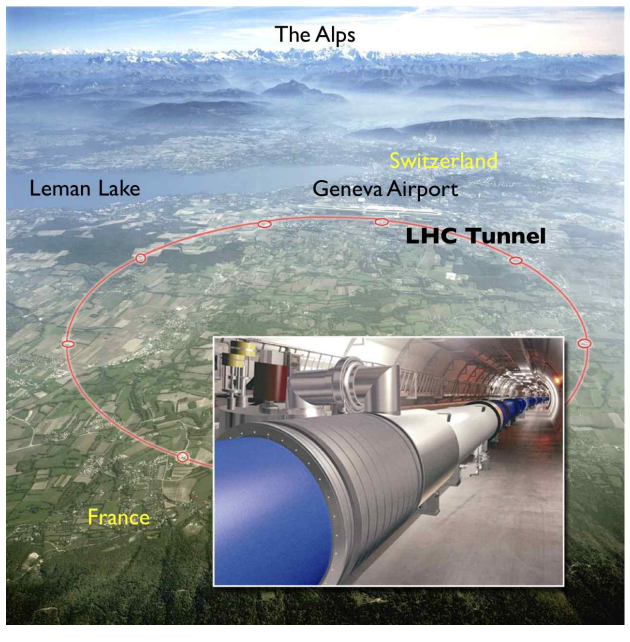
$$|\downarrow_{\theta,\phi}\rangle = -\sin\frac{\theta}{2} e^{i\phi/2}|\uparrow\rangle + \cos\frac{\theta}{2} e^{-i\phi/2}|\downarrow\rangle$$



(c) (6 points) What is the expectation value of the product of the two measurement outcomes?

(d) (7 points) Assume that the eigenvalue $\hbar/2$ was obtained for the electron spin measurement. Now we apply an external magnetic field at $t = 0$ along x-direction, then the Hamiltonian for the electron spin is given by the following form, $H = \hbar\omega(|\uparrow\rangle\langle\downarrow| + |\downarrow\rangle\langle\uparrow|)$, where ω is a constant in units of frequency. Write down the spin state of the electron at t and find the minimum t that only eigenvalue $-\hbar/2$ is obtained for the following electron spin measurement.

2. (25 points) Recently, the physicists at CERN have confirmed the discovery of Higgs particle, which gives mass to other elementary particles. The neutral Higgs particle, denoted as H_0 has been produced from the head-on collision of two protons, each accelerated to the energy of 4 TeV. The protons are accelerated by the Large Hadron Collider (LHC).



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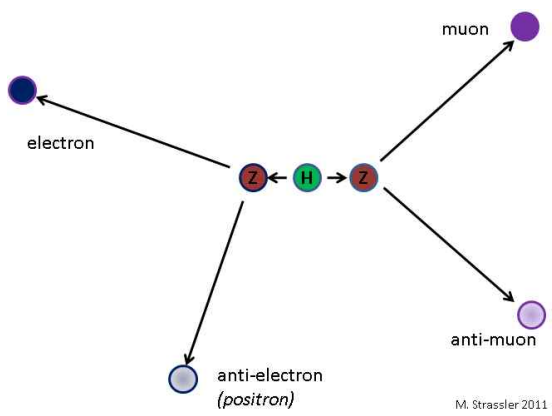
The LHC is a circular accelerator with 27 km of circumference. Total of 3.2×10^{14} protons are making 11,000 revolutions counter-clockwise per second in the tunnel.

(a) (5 points) If the two protons with energy of 4 TeV each undergo head-on, completely inelastic collision, what is the maximum energy available to produce new particles?

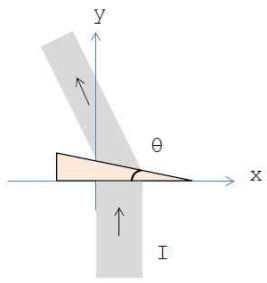
(b) (9 points) The produced Higgs particle can decay into many particles. In one scenario, Higgs particle can decay into 4 particles, electron, anti-electron, muon and anti-muon. The detectors at LHC measures the momenta and energies of the final 4 particles. From the measured momenta ($\vec{p_1}$, $\vec{p_2}$, $\vec{p_3}$, $\vec{p_4}$) and energies (E_1, E_2, E_3, E_4) of these particles, Explain how you can deduce the mass of the Higgs particle, M_H.



(c) (11 points) The circulating protons can be considered as current. Calculate the magnetic field generated by this current at the center of the circular ring.

In the actual experiment, equal number of protons are circulating in clockwise directions producing zero net current. For this problem, calculate the magnitude of the magnetic field produced by the protons circulating counter-clockwise.

3. (25 points) As shown in the figure below, a prism with index of refraction n is placed on the x-z plane and a light beam propagating along the y direction is incident on the bottom surface of the prism. The light intensity is I, its wavelength is λ, and the beam area is A. Assume no reflection from the prism surfaces.



(a) (5 points) By analyzing light's momentum change, find the force acting on the prism.

Next, in the following experimental setup, an isosceles prism with mass m and index of refraction n is placed on the frictionless x-z plane, and its motion is restricted along the x direction. The size of the prism along the z direction is d. The prism is irradiated with a light having a uniform intensity I and passing after a slit that is located below the prism.

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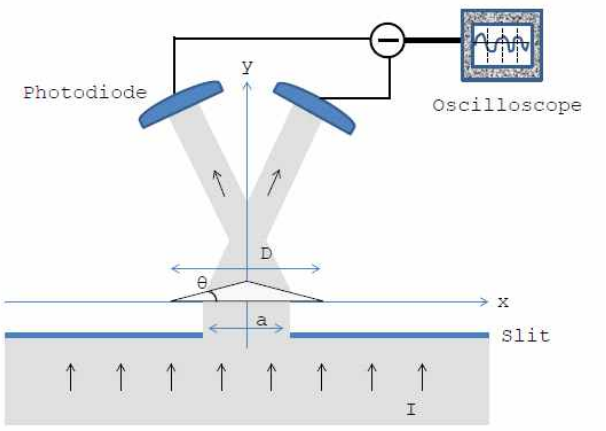
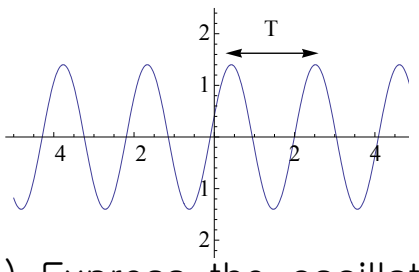


Because of the shape of the prism, the light can be refracted to left or right as illustrated in the figure above. The power of each refracted beam is measured by a photodiode detector, and we monitor the difference of the signals from the two detectors with an oscilloscope. Initially, the slit width a is smaller than the prism width D.

(b) (8 points) If the prism is displaced, it can oscillate along the x direction. Explain why. In the case of small oscillations, the signal in the oscilloscope would look like the following graph. Explain why.



(c) (7 points) Express the oscillation period T in terms of the given physical parameters.

(d) (5 points) Now, we suddenly widen the opening of the slit to have $a = 2D$. Draw a graph of the signal expected in the oscilloscope, and explain why.

4. (25 pts) Electrons can be used in seeing small things, playing the role of light. An electron beam goes through a sample and is focused by a lens to form an image on the screen. (Assume that the sample is thin along the propagation direction of the electron beam and hence the electrons can go through the sample.)

(a) (13 pts) If the energy of incident electrons is too high, the sample itself will be degraded while being imaged because an electron colliding with an atom can transfer energy to the atom. Roughly speaking, 3 eV of energy is required to break a single covalent bond (regardless of the kind of participating atoms). Suppose that our sample is composed of carbon atoms. Estimate the maximum electron energy for non-destructive imaging.

(b) (5 pts) Now suppose that we investigate a similar sample composed of silicon atoms. Will the maximum electron energy for non-destructive imaging be higher or lower than that for the carbon structure? Explain your answer.

(c) (7 pts) The resolution (or clearness) of the electron beam imaging depends on the kind of the material being imaged. Which one provides a better resolution among the two (carbon and silicon) structures? You should explain your answer.