Exercises

1. Calculate the HERA ep collisions center of mass energy given $p_p = 820$ GeV and $p_e = 27.5$ GeV. If we want to have the same center of mass energy at an ep fixed target experiment, which value of p_e would be needed ?
2. Consider the three accelerator systems LHC, LEP and DAFNE for which we give some data here below:
   - LHC: protons, R = 4.3 km, $E_{max} = 7$ TeV, $T_{BC} = 25$ ns;
   - LEP: electrons, R = 4.3 km, $E_{max} = 100$ GeV, $T_{BC} = 22$ μs;
   - DAFNE: electrons, R = 15 m, $E_{max} = 500$ MeV, $T_{BC} = 2.7$ ns;

   Calculate for each accelerator the revolution frequency f, the number of bunches n_b and the maximum value of the magnetic field B_{max} required to hold particles in orbit. Using the plots shown in the slides 135 and 136, determine for DAFNE and LHC, the products $\sigma_x\sigma_y$.
3. Design a pp machine at $\sqrt{s} = 40$ TeV and $L = 10^{36} cm^{-2}s^{-1}$. Which values of σ_x and σ_y are needed to obtain the required value of the luminosity if the following limits have to be respected: $B < 10$T, N_1, $N_2 < 10^{11}$ / bunch, T_{BC} >10 ns.
4. Using the data of the two projects SuperB and SuperKEKB (given in slide 144), determine for both projects:
   - Center of mass energy;
   - Angular spread at the interaction point;
   - Number of particles per bunch and beam currents.
5. Calculate the space resolution needed to discriminate the charge of 1 TeV muons with 3 detector layers in a B=1 T magnetic field with an overall lever arm of 5 m.
6. Calculate the tme resolution needed to discriminate between muons and electrons of the same momentum, 500 MeV/c with two detectors at a distance of 3 m.
7. Define the thickness (in cm) of a lead absorber for electrons, muons and pions of the same momentum p = 100 GeV/c.
8. A neutron detector is exposed to a neutron beam having a rate of 23.2 kHz. Calculate the maximum acceptable dead time δt if we require an efficiency loss below 5%.
9. Define the mass resolution needed for observing a significant signal of J/ψ production if the number of expected candidates is S=24 and the uniform background per unit of mass is $b = 13$ MeV^{-1}.
10. We want to set-up a trigger to detect $Z \to \mu^+\mu^-$ decays in pp collisions at LHC. We have a low threshold (LT, p_T >4 GeV) and a high threshold (HT, p_T >20 GeV) single muon trigger. We have evaluated using a MC simulation the efficiencies of the two triggers for the muons coming from Z decays and they are ϵ(LT)=89.2%, ϵ(HT)=62.1%. Determine the efficiencies for triggering on Z decays in the two configurations: (1) LT1 AND LT2, (2) HT1 OR HT2 .
11. A charged kaon beam K^+ with a rate of 120 Hz is produced in a beam line. Our detector takes data for a total time of $\Delta t = 24$ hours and aims to count the total number of decays $K^+ \to e^+\nu_e$. The efficiency of our detector for this final state is e=63.2% with negligible uncertainty. Calculate the minimum value of the rejection power R for the $K^+ \to \mu^+\nu_m$ decay needed to maintain the uncertainty on N($K^+ \to e^+\nu_e$) below 10% ? (BR($K^+ \to e^+\nu_e$)= 1.581 10^5, BR($K^+ \to \mu^+\nu_m$)= 63.55%, neglect other possible backgrounds and uncertainties on the background.)

12. In an e^+e^- experiment at $\sqrt{s}$ =1.5 GeV, we count the number of $e^+e^- \to K^+K^-$ final states. At the end of the experiment, after the selection, we have N_{cand} =136. We estimate the background and it turns out to be $N_b = 13.2 \pm 0.9$. The selection efficiency is obtained by selecting 5922 events from a sample of 10^4 Montecarlo simulated $e^+e^- \to K^+K^-$ final states. Calculate the uncertainty on N($e^+e^- \to K^+K^-$). What is the dominant contribution to it ?

13. After my selection I know, based on the simulation, that 25% of the selected events are signal events and 75% are background events. How many total candidates I need to collect in such a way I can observe the signal with at least 5 st.dev. significance ?

14. How much integrated luminosity do I need to measure at <1% a process of cross-section = 1 nb ? (specify the hypotheses).

15. In the 2011+2012 LHC dataset (corresponding to about 25 fb^{-1}), a sample of 2.24×10^5 $t\bar{t}$ events has been collected. We know that $\sigma(pp \to t\bar{t} + X)$ is 177 ± 5 pb. How large is the efficiency for $t\bar{t}$ events assuming no background ?

16. We perform a cross-section measurement and obtain: N_{cand} =128, $N_b = 14 \pm 2$, $\epsilon = 0.523 \pm 0.002$, $L_{int} = 2.43pb^{-1} \pm 1.8$ %: calculate the resulting cross-section with its uncertainty. In case this is a measurement of $e^+e^- \to \pi^+\pi^-$ at $\sqrt{s} = 1$ GeV, determine the value of the pion time-like form factor with its uncertainty. The formula relating the cross-section to the form factor $F_\pi(s)$ is the following:

$$\sigma(s) = \frac{\pi\alpha^2}{3s}\beta_\pi^3|F_\pi(s)|^2$$

17. The SM expected semi-leptonic K_S charge asymmetry is 3×10^{-3}. At DAFNE we expect to produce a sample of 1.2×10^9 K_S. The B.R.($K_S \to \pi e\nu$)=B.R.($K_S \to \pi^+e^-\nu$)+B.R.($K_S \to \pi^-e^+\nu$)=6.95×10^{-4}. Which error can I reach on the charge asymmetry measurement ? How many K_S do we need to have a 5σ evidence of the asymmetry ?

18. The Higgs boson production at a linear collider happens mainly through the reaction $e^+e^- \to ZH$. If M_H = 125 GeV, and the cross-section $\sigma(e^+e^- \to ZH, \sqrt{s} = 300$ GeV) = 220 fb, which value of luminosity do we need to get O(10^6) events in 1 year of data taking ? How many final states with two muons and two photons from the $Z \to \mu^+\mu^-$ and $H \to \gamma\gamma$ simultaneous decays do we get in the same period ? Evaluate the maximum and minimum photon energies from the Higgs.

19. Consider the reaction $e^+e^- \to K^+K^-$ at a ϕ-factory. Which fraction of events have at least one kaon decaying within a sphere of R = 20 cm ? In which fraction of events both kaons decay within the same sphere ?

20. With reference to the AMS detector: which space resolution is required on each tracker plane if we want to discriminate electrons from positrons up to p=200 GeV at the 3σ level ? (B=0.15 T).

21. A detector operating at an e^+e^- collider is limited in the polar angles: $45< \theta <135^o$. Evaluate the detector acceptance in three different situations: for isotropically emitted particles, for particles emitted according to a $\sin^2\theta$ law and for particles emitted according to a $1 + \cos^2\theta$ law.

22. Consider the Higgs production (M_H=125 GeV) at a pp collider at $\sqrt{s}$ = 14 TeV. Evaluate the interval in rapidity y and the minimum value of x for direct Higgs production.

23. The NA62 experiment aims to observe the rare decay $K^+ \to \pi^+\nu\nu$ (expected BR=2×10^{-10}) with a beam of K^+ (N(K^+)=10^{12}). Evaluate the rejection power needed to reject the main background channel, namely $K^+ \to \pi^+\pi^0$ to measure the BR($K^+ \to \pi^+\nu\nu$) with an uncertainty below 10%.

24. The expected rate of neutrinos interacting in our detector is 0.23×10^{-3} evts/day, and the efficiency for the detection of the interaction is 43.2%. Evaluate the probability to detect at least a neutrino in the first 24h of operation, in the first year and in the first 10 years.

25. In 2003 and 2004 several experiments announced the obervation of a *pentaquark*, a clear resonance in the KN invariant mass at a mass of about 1530 MeV. In the following the mass estimates of the first 10 experiments are given. What can we say about the overall consistency of these measurements ?

- LEPS 1540±10
- DIANA 1539±2
- CLAS-1 1542±5
- SAPHIR 1540±6
- nBC 1533±5
- CLAS-2 1555±10
- HERMES 1526±3
- ZEUS 1522±3
- COSY-TOF 1530±5
- SVD 1526±5

26. The most updated values of the parameter $\mu = \sigma/\sigma_{SM}$ for the Higgs boson from ATLAS for the three main channels are given below:
    - $\mu_{\gamma\gamma}$=1.55 ± 0.30
    - μ_{ZZ} = 1.43±0.37
    - μ_{WW} = 0.99±0.29

    Evaluate the compatibility among the three independent ATLAS results and calculate the best overall estimate of μ from ATLAS. Then evaluate the compatibility with the SM expectation (μ=1).

27. A detector aims to observe the $e^+e^- \to n\overline{n}$ process in e^+e^- collisions at $\sqrt{s}$ = 2 GeV. The strategy consists in identifying $\overline{n}$ annihilations through the measurement of the β of the particle. The detector is an alluminium sphere of radius R=1 m and thickness 3 cm where the $\overline{n}$ annihilates surrounded by tracking and ToF detectors that measure respectively the annihilation position and time and hence its velocity. We know that:
    - the $e^+e^- \to n\overline{n}$ cross-section at 2 GeV is equal to 1 nb;
    - the $\overline{n}$ -iron annihilation cross-section is = 720 mb;
    - we have collected an integrated luminosity of 0.54 pb^{-1};
    - a combinatorial background of 3800 evts per unit of β is expected in this data sample;
    - the annihilation point resolution is $\sigma(r)$=1.5 cm.

    Which is the the ToF resolution required to observe the $n\overline{n}$ signal ?

28. The fraction of K_L produced in e^+e^- collisions at the ϕ peak interacting in the KLOE calorimeter is approximately 5%. Determine the K_L-lead cross-section, using the following assumptions: The KLOE calorimeter is assumed to be a single lead layer 12 cm thick; The inner surface of the KLOE calorimeter is 2 m away from the e^+e^- interaction region.

29. The VLHC program (Very Large Hadron Collider) proposes proton-proton collisions at a center of mass energy between 40 and 50 TeV and a luminosity larger than 10^{35}cm^{-2}s^{-1}, in a ring with a radius of 17.5 km. The project requires a time between bunch crossings not smaller than 25 ns (as it is for LHC). How many bunches can be put ? If we know that the total proton-proton cross-section at this energy is about 100 mb, evaluate the average value of the pile-up. Finally evaluate the minimum value of x and the maximum value of y for the production of an Higgs boson (M_H=125 GeV) and a second exotic Higgs boson having a mass of 5 TeV.

30. Consider the decay $\phi \to \eta\gamma$ in the center of mass frame of ϕ. Calculate the energy of the photon and the maximum and minimum energy of the photons in case the η decays in $\gamma\gamma$. We want to identify this decay looking at the inclusive photon spectrum form a sample of 10^6 ϕ produced at rest. If we know that the combinatorial photon spectrum in the energy region between 300 and 400 MeV is almost flat with a number of events equal to 300 evts/MeV/$10^4\phi$, determine the energy resolution required to observe with enough significance the searched decay. Is the KLOE calorimeter resolution good enough for this task ?

31. A reactor emits neutrinos isotropically. The flux is $2\times10^{18}\nu$/s/sr. We install a neutrino detector based on water at a distance od 1.25 km from the reactor with the purpose to measure the flux from the reactor at this distance and see if it is significantly reduced with respect to the expectation. The neutrino interaction cross-section is 10^{-42} cm^2 and our detector efficiency is 50%. How much water shall we use to be sensitive to a flux decrease of at least 10% in one year of data taking ?

32. We want to measure the ep elastic cross-section with high precision in the q^2 range between 10 and 25 GeV^2. For this purpose we design an ep symmetric collider with a luminosity of 10^{35}cm^{-2}s^{-1}. The project of the electron ring should respect the following limits: B$\leq$ 0.2 T; beam currents I$<$ 1 A. Moreover the detector requires T_{BC} >50 ns.

    - Calculate the proton and electron momenta for the $q^2 = 25$ GeV^2 maximum energy configuration;
    - Define possible values of the ring radius R, of the number of electrons per bunch N_e and of the dissipated power, and, assuming $N_e = N_p$, evaluate the product $\sigma_x\sigma_y$;
    - Rate of elastic collisions at $q^2 = 25$ GeV^2 if $\sigma(ep \to ep) = 1.2$ nb$/E_e$(GeV), where E_e is the energy of electrons in an equivalente fixed target experiment;
    - Define a possible time of flight system to discriminate between emerging electrons and protons.

33. Consider the two decays $\phi \to \pi^0\gamma$ and $\phi \to \eta\gamma$ at a ϕ-factory. To distinguish between the two decays we set a cut at an energy of 430 MeV. Using the energy resolution of the KLOE calorimeter determine which is the probability that a $\phi^0\gamma$ event is wrongly identified as $\eta\gamma$ event and viceversa. Which is the fraction of $\eta\gamma$ events in the selected sample of $\pi^0\gamma$?

34. We study the charge exchange reaction $\pi^-p \to \pi^0 n$ with a fixed target experiment. We use a negative pion beam of energies between 1 and 10 GeV and a liquid hydrogen target 5 m thick. The charge exchange cross-section in the energy range of the experiment is about 1 μb. Evaluate:

    - the negative pion flux needed to get a sample of about 10^{10} events in 1 month of data taking;
    - define a possible detector design to identify the $\pi^0 n$ final states and reject the large background with charged hadrons;
    - define a method to discriminate between photons and neutrons.

35. We perform a measurement of the cross-section for $e^+e^- \to W^+W^-$ at $\sqrt{s}$=200 GeV at LEP. At the end of the selection the data we have are the following:

    - $N_{cand} = 1590$
    - N_b=640 (evaluated from side-bands)
    - $\epsilon = 0.246 \pm 0.015$
    - $L = 253pb^{-1} \pm 1\%$

    Calculate the value of the measured cross-section with its total uncertainty.

36. In the first period of LHC operation the average instantaneous luminosity was $10^{32}cm^{-2}s^{-1}$ and the time between the bunch crossing was T_{BC}=50 ns. Calculate in that regime the probability to have more than one interaction in a single bunch-crossing. If the gaussian sigma of each bunch was $?_Z =$ 9 cm, evaluate the probability that in case of 2 interactions the distance between the two vertices was lower than 1 cm.

37. A high intensity pulsed proton beam is directed onto a target. Downstream the target a magnet system sweeps away all the charged particles so that only neutral particles reach the experimental region, namely photons and neutrons in the kinetic energy range between 5 and 100 MeV. The detector is located 5 m from the target and measures the Time of Flight of photons and neutrons. Draw schematically the arrival time distribution of all the particles. If the repetition rate of the proton beam is 10 MHz, determine the kinetic energy of the neutrons that can be confused with the photons.

38. We study antiprotons annihilations at rest in an hydrogen target and we want to select the two processes $p\overline{p} \to \pi^+\pi^-$ and $p\overline{p} \to K^+K^-$. Calculate the momenta of the pions and of the kaons and estimate the ratio of the rates of the two processes. Compare two possible systems to discriminate between the

two final states: one based on 3 stations in a 0.3 T magnetic field and one based on a time of flight counter. In both cases a radius of L = 2 m is available. Determine the space resolution in the first case and the time resolution in the second case needed to obtain an acceptable separation.