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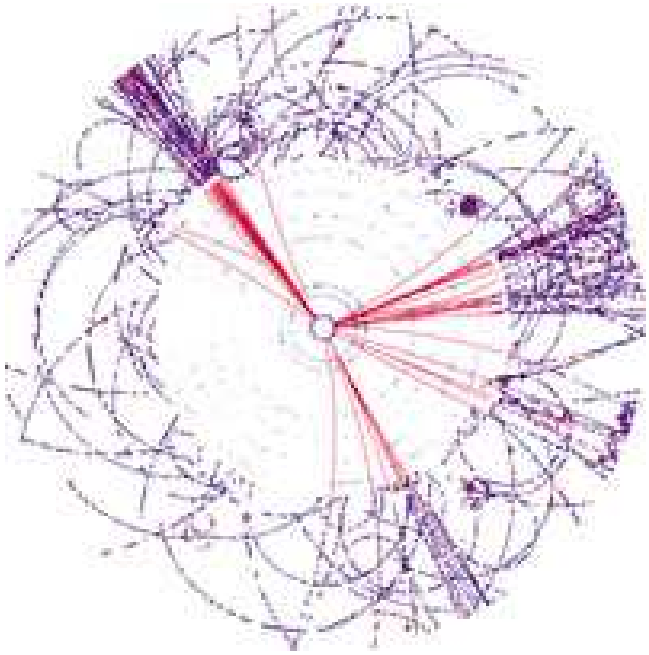
Particle Physics

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Project 1

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to be delivered per e-mail and/or hard copy by Monday April 3rd.

In the following, make use of the CompHEP program to check your results when needed and to document the "qualitative discussions".

1 Particles and interactions

State whether the following reactions or particle decays are allowed or not.

- Classify them according to the underlying interaction and draw the corresponding Feynman graphs.
- For each particle decay, indicate the lifetime and the branching ratio.
- What conservation laws, invariance principles, or other mechanisms account for the suppressing or forbidding of some processes.
- ∗ Choose one process for each of the three interactions (electromagnetic, weak and strong) and describe (very) briefly:
  - the principle of the measurement,
  - the outcome of the experiment.

1. $n \to pe^-\overline{\nu}_\mu$
2. $\Omega^- \to \Xi^0 e^-\overline{\nu}_e$
3. $\pi^+ n \to \Lambda K^+$
4. $K^- p \to K^0 n$
5. $\gamma\gamma \to \gamma\gamma$
6. $gg \to gg$
7. $e^+e^- \to J/\psi \to \rho\pi$
8. $\nu_\mu n \to p\mu^-$
9. $p\overline{p} \to \Lambda\overline{\Lambda}$
10. $p \to ne^+\overline{\nu}_e$
11. $J/\psi \to D^+D^-$
12. $\Upsilon \to B^+B^-$
13. $K_s \to \pi^+\pi^-\pi^0$
14. $\tau^- \to \nu_\tau\overline{\nu}_\mu\nu_\mu e^-\overline{\nu}_e$
15. $e^+e^- \to W^+W^-$
16. $e^+e^- \to \gamma\gamma\gamma$
17. $e^+e^- \to 4-jet$
18. $pp \to 4-jet$
19. $e^+e^- \to \nu\overline{\nu}\gamma\gamma$
20. $Z^0 \to \gamma\gamma$

2 τ-lepton production and decay

- Introduce (briefly) the τ-lepton: its place in the standard model, its discovery and consequences.
- At low e^+e^- center of mass energies, τ-pair production proceeds through photon exchange

$$e^+e^- \to \tau^+\tau^- \tag{1}$$

- Make use of Feynman rules in QED to calculate the differential cross-section $\frac{d\sigma_\tau}{d\cos\theta}$, where θ is the scattering angle between τ^- and e^-, as well as the total cross-section σ_τ, as function of the center of mass energy, $\sqrt{s}$.

- What is the expected rate (number of events) at $\sqrt{s} = 20, 50$ and $91\ GeV$, assuming an integrated luminosity of 10 pb^{-1} and an overall detection efficiency $\epsilon \sim 50\%$?

- Compare to $e^+e^- \to \mu^+\mu^-$ and (qualitatively) to $e^+e^- \to e^+e^-$. Why is it important to make measurements of all 3 lepton-pair final states?

- **Make use of Feynman rules (SM electroweak) to calculate the differential and integrated cross-sections** $\frac{d\sigma_\tau}{d\cos\theta}$

- Discuss qualitatively τ-pair production as $\sqrt{s}$ increases **(cross-section, angular distribution, electroweak asymmetry). Make use of CompHEP.**

- How does τ lepton decay? What is the experimental signature?

- One of the experimental background processes is hadron production. Justify and explain how to reduce it.

- Calculate the ratio $R_h = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$
  - Just below the "charm" production threshold,
  - above that threshold but below the b-quark production threshold.

$*$ The τ neutrino was already "inferred" when the tau was discovered. Report briefly on a more recent direct evidence of ν_τ.

- Draw the Feynman graphs and write down the amplitudes for the processes

$$\nu_\tau e^- \to \nu_\tau e^- \tag{2}$$

$$\nu_\tau d \to \tau^- u. \tag{3}$$

$*$ Use cross-section results (from a text book **and/or CompHEP**) to briefly discuss the problem with the Fermi theory of weak interactions and the way the problem was solved in the Standard Model.