Spin Correlations in Higgs Decays

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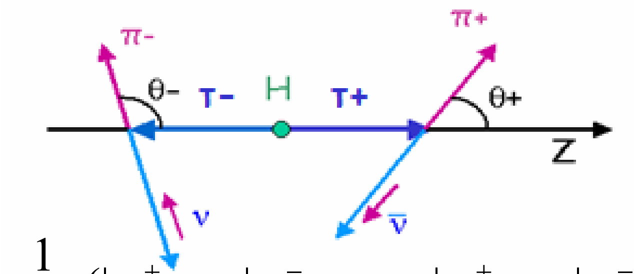
Outline

- Spin correlation in decay products: Quantum mechanical consideration
- Spin correlation in decay products: Quantum Field Theory considerations
- Scalar vs vector particles decays
- Simulations
- Conclusions

$$H \to \tau^+ + \tau^- \to \pi^+ \bar{\nu} + \pi^- \nu \qquad \sim 1.2\%$$

Spin correlation in decay products:
Quantum mechanical consideration



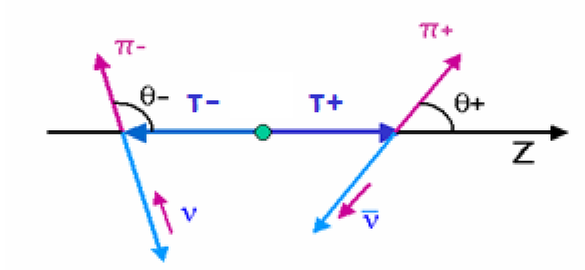
$$A_{0,0} = \frac{1}{\sqrt{2}}(|\tau^+,+>|\tau^-,+> - |\tau^+,->|\tau^-,->)$$

$$-\sin\frac{\theta_-}{2}e^{-i\phi_-/2}$$

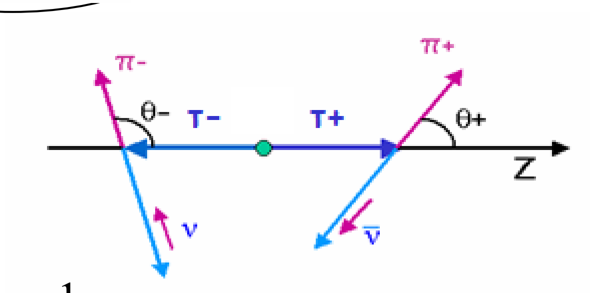
$$\sin\frac{\theta_+}{2}e^{i\phi_+/2}$$

$$\cos\frac{\theta_+}{2}e^{-i\phi_+/2}$$

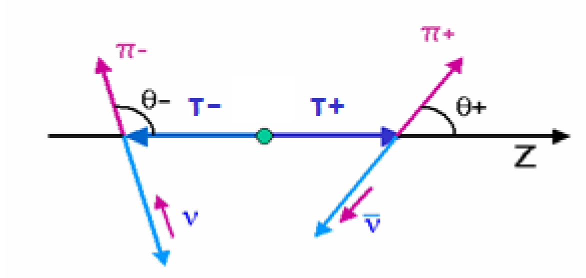
$$\cos\frac{\theta_-}{2}e^{i\phi_-/2}$$



$$A_{1,1} = |\tau^+,+>|\tau^-,->$$



$$A_{1,0} = \frac{1}{\sqrt{2}}(|\tau^+,+>|\tau^-,+> + |\tau^+,->|\tau^-,->)$$



$$A_{1,-1} = |\tau^+,->|\tau^-,+>$$

$$P_{J=0}(\theta^+,\theta^-,\varphi^+,\varphi^-) = |A_{0,0}|^2$$

$$P_{J=1}(\theta^+,\theta^-,\varphi^+,\varphi^-) = \frac{1}{3}(|A_{1,0}|^2 + |A_{1,-1}|^2 + |A_{1,1}|^2)$$

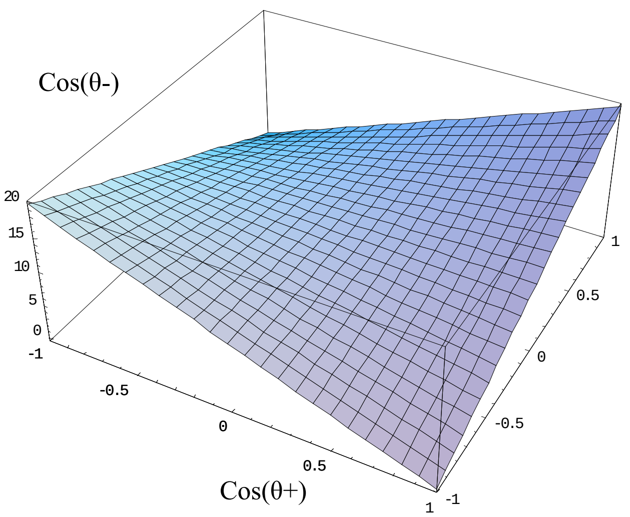
$$P_{J=0}(\theta^+,\theta^-) = \int_0^{2\pi} d\varphi^+ \int_0^{2\pi} d\varphi^- P_{J=0}(\theta^+,\theta^-,\varphi^+,\varphi^-)$$

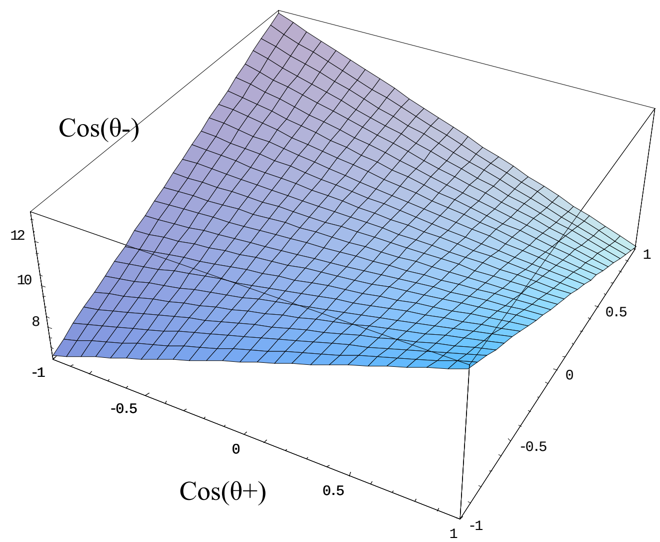
$$P_{J=1}(\theta^+,\theta^-) = \int_0^{2\pi} d\varphi^+ \int_0^{2\pi} d\varphi^- P_{J=1}(\theta^+,\theta^-,\varphi^+,\varphi^-)$$

After integration with respect to φ+ and φ- we have probabilities dependent only on θ+, θ-.

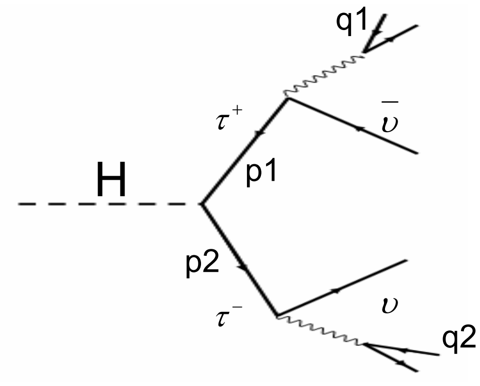
$$P_{J=0}(\theta^+,\theta^-) \sim (1+\cos\theta^+\cos\theta^-)$$

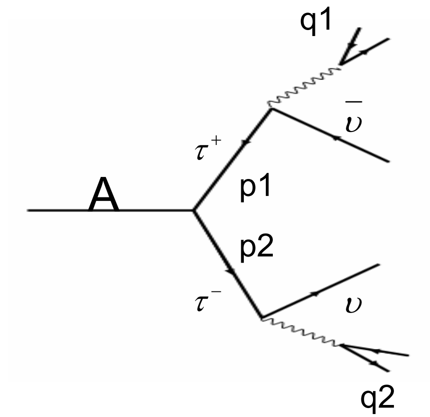
$$P_{J=1}(\theta^+,\theta^-) \sim (1-\frac{1}{3}\cos\theta^+\cos\theta^-)$$





Spin correlation in decay products: Quantum Field Theory considerations





Sudakov variables is used for extract the angular dependence:

$$q_1 = x_1 p_1 + u_1 p_2 + k_1^{\perp}$$
$$q_2 = x_2 p_2 + u_2 p_1 + k_2^{\perp}$$

$$\begin{cases} (q_2 p_2) = x_2 (p_2 p_2) + u_2 (p_1 p_2) \\ (q_1 p_1) = x_1 (p_1 p_1) + u_1 (p_2 p_1) \\ (q_2 p_1) = x_2 (p_2 p_1) + u_2 (p_1 p_1) \\ (q_1 p_2) = x_1 (p_1 p_2) + u_1 (p_2 p_2) \\ (q_1 q_2) = (x_1 x_2 + u_1 u_2)(p_1 p_2) + \\ + x_1 u_2 (p_1 p_1) + x_2 u_1 (p_2 p_2) + k_1^{\perp} k_2^{\perp} \end{cases}$$

$$u_{1,2} = -\frac{m^2 \cos\theta^{\pm}}{2\sqrt{\frac{M^4}{4} - 2m^2}}$$

$$x_{1,2} = \frac{1}{2}\left(1 - \frac{\cos\theta^{\pm}}{\sqrt{1 - \frac{m^4}{(\frac{M^2}{2} - m^2)}}}\right)$$

QFT result

$$P_{J=0}^{QFT} \sim \frac{16m^2}{\frac{M^2}{2}-m^2}(1+\cos\theta^+\cos\theta^-)+$$
$$+16(1+\cos\theta^+\cos\theta^-)-$$
$$-(\frac{64}{\frac{M^2}{2}-m^2}+\frac{64}{m^2})(k_1^\perp k_2^\perp)$$

$$P_{J=1}^{QFT} \sim \frac{64m^2}{\frac{M^2}{2}-m^2}-$$
$$-32(1-\cos\theta^+\cos\theta^-)-$$
$$-\frac{128}{\frac{M^2}{2}-m^2}(k_1^\perp k_2^\perp)$$

Non-relativistic case

$$P_{J=0}^{QFT} \sim 32(1+\cos\theta^+\cos\theta^-)$$

$$P_{J=1}^{QFT} \sim -96(1-\frac{1}{3}\cos\theta^+\cos\theta^-)$$

Relativistic case – m<<M

$$P_{J=0}^{QFT} \sim 16(1+\cos\theta^+\cos\theta^-)$$

$$P_{J=1}^{QFT} \sim -32(1-\cos\theta^+\cos\theta^-)$$

Quantum mechanical result

$$P_{J=0} \sim (1+\cos\theta^+\cos\theta^-)$$

$$P_{J=1} \sim (1-\frac{1}{3}\cos\theta^+\cos\theta^-)$$

Comparison of methods

- J=0: For scalar particle (Higgs) decay -COINCIDE
- J=1: Quantum mechanical approach

$$P_{J=1} \sim (1 - \frac{1}{3}\cos\theta^{+}\cos\theta^{-})$$

- J=1: QFT approach
  - Coincide for non-relativistic tau's (m ~ M/2)

$$P_{J=1}^{QFT} \sim (1 - \frac{1}{3}\cos\theta^{+}\cos\theta^{-})$$

  - For relativistic tau's (m <<M) – factor 3 difference – only longitudinal polarization of heavy vector "Higgs" survive

$$P_{J=1}^{QFT} \sim (1 - \cos\theta^{+}\cos\theta^{-})$$

Experimental consideration

$$p_\tau = \frac{1}{2}\sqrt{M_H^2 - 4m^2} \approx M_H/2 = E_\tau$$

$$p_\pi^* = \frac{m^2 - m_\pi^2}{2m} \approx \frac{m}{2}$$

$$E_\pi^* = \frac{m^2 + m_\pi^2}{2m} \approx \frac{m}{2}$$

$$\beta_\tau = \frac{p_\tau}{E_\tau} \approx 1 \qquad \gamma_\tau = \frac{E_\tau}{m} \approx \frac{M_H}{2m}$$

$$E_{\pi^\pm} = \gamma_\tau (E_{\pi^\pm}^* \pm \beta_\tau p_{\pi^\pm}^* \cos\theta^\pm) \approx$$
$$\approx \frac{M_H}{2m}\frac{m}{2}(1 \pm \cos\theta^\pm) = \frac{M_H}{2}(1 \pm \cos\theta^\pm)$$

Collinear approximation

$$\sum \vec{p}_T = 0 \qquad \vec{p}_T = (p_x, p_y)$$

$$\vec{p}_H = c_- \vec{p}_{\pi^-} + c_+ \vec{p}_{\pi^+}$$

$$\vec{p}_{T,H} = \vec{p}_{T,jet} = c_- \vec{p}_{T,\pi^-} + c_+ \vec{p}_{T,\pi^+}$$

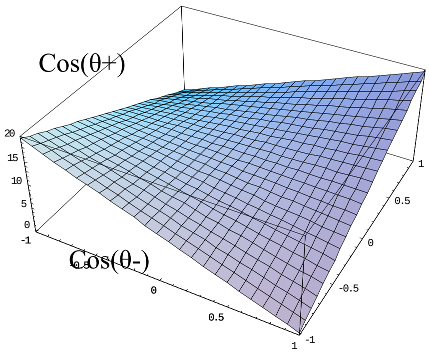
6 unmeasured variables
two kinematic constraints

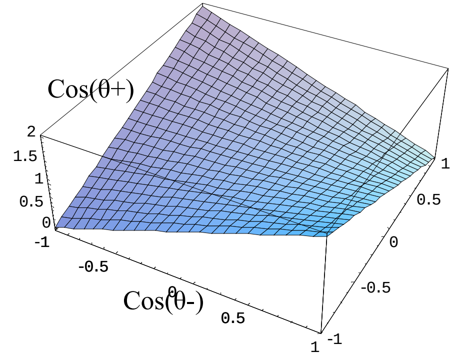
$$c_- = \frac{p_{jet,x} p_{\pi^+,y} - p_{jet,y} p_{\pi^+,x}}{p_{\pi^-,x} p_{\pi^+,y} - p_{\pi^+,x} p_{\pi^-,y}}$$

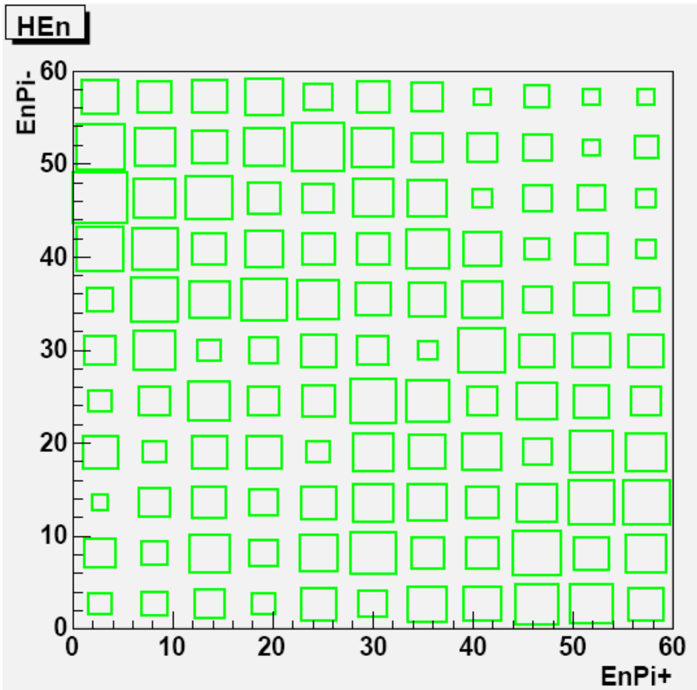
$$c_+ = \frac{p_{jet,y} p_{\pi^-,x} - p_{jet,x} p_{\pi^-,y}}{p_{\pi^-,x} p_{\pi^+,y} - p_{\pi^+,x} p_{\pi^-,y}}$$

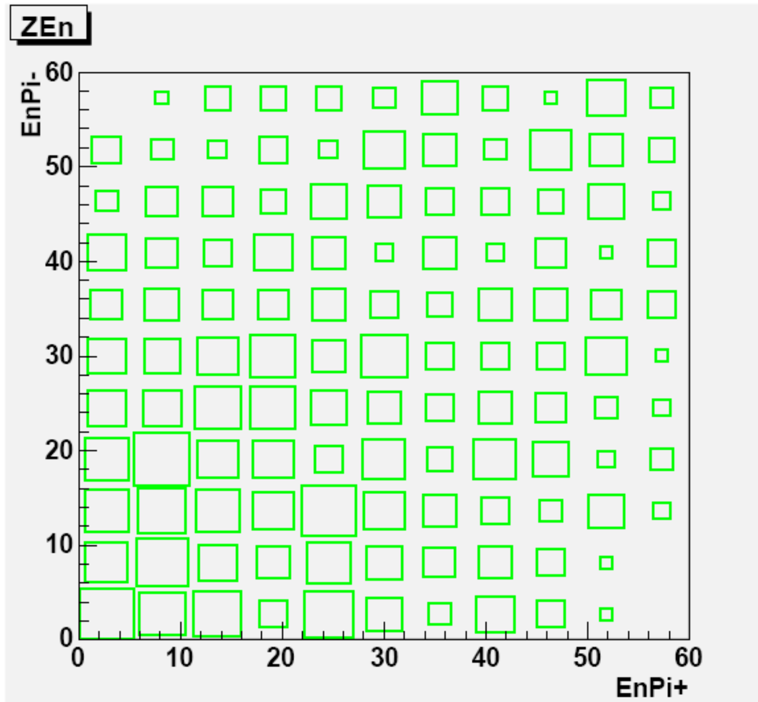
$$M_H^2 = (c_- p_{\pi^-} + c_+ p_{\pi^+})^2 - (c_- \vec{p}_{\pi^-} + c_+ \vec{p}_{\pi^+})^2$$

Simulations for ATLAS detector at LHC (PYTHIA with TAUOLA)









Outlook

- Separation of signals from background (Z^0)
- Applications for other decays (W bosons, t –quarks?)
- Search of new particles, SUSY?