Traditional Parameterization

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4s}\left[A_0(1+\cos^2\theta^*) + A_1\cos\theta\right]$$

$$A_1 = (C_L - C_R)^2\, Re(r(E)) + \frac{1}{2}(C_L^2 - C_R^2)^2 |r(E)|^2$$

$$r(E) = \frac{1}{4\pi}\frac{\sqrt{2}\, G_F M_Z^2}{E^2 - M_Z^2 + iM_Z\Gamma_Z}\frac{E^2}{\alpha}$$ (re-introduced

$$A_0 = 1 + \frac{1}{2}Re(r)(C_L + C_R)^2 + \frac{1}{4}|r|^2(C_L^2 + C_R^2)^2$$

$$F = \int_0^1 \frac{d\sigma}{d\Omega}d\Omega = \frac{2\pi\alpha^2}{4s}\left[A_0\left(1+\frac{1}{3}\right) + A_1\cdot\frac{1}{2}\right]$$

$$B = \int_{-1}^0 \frac{d\sigma}{d\Omega}d\Omega = \frac{2\pi\alpha^2}{4s}\left[A_0\left(1+\frac{1}{3}\right) - A_1\cdot\frac{1}{2}\right]$$

$$\frac{F-B}{F+B} = \frac{A_1}{\frac{8}{3}A_0} = \frac{3}{8}\cdot\frac{A_1}{A_0}$$

Most interesting these days...

$E \gg M_Z$

$$\underset{E\to\infty}{r(E)} = \frac{\sqrt{2}\, G_F M_Z^2}{4\pi\alpha} = \frac{1}{4\sin^2\theta_W \cos^2\theta_W}$$

Electroweak Unification $= 1.41$ $(\sqrt{2}\ ?)$

$$e_L^- e_R^+ \to \gamma^* \to \mu_L^- \mu_R^+$$

$$\frac{d\sigma}{d\Omega} = \frac{1}{4}\frac{\alpha^2}{E^2}\left| 1 + \underbrace{(-1+2\sin^2\theta_W)}_{\substack{\sin^2\theta_W - \cos^2\theta_W \\ -\cos 2\theta_W}}{}^2 \underbrace{\frac{1}{4\sin^2\theta_W\cos^2\theta_W}}_{\sin^2 2\theta_W} \right|^2 (1+\cos\theta^*)^2$$

$$= \frac{1}{4}\frac{\alpha^2}{E^2}\left| 1 + \frac{\cos^2 2\theta_W}{\sin^2 2\theta_W}\right|^2 (1+\cos\theta^*)^2$$

$$\boxed{\frac{d\sigma}{d\Omega} = \frac{1}{4}\frac{\alpha^2}{E^2}\frac{1}{\sin^4 2\theta_W}(1+\cos\theta^*)^2}$$

$$e_L^- e_R^+ \to \mu_R^- \mu_L^+ \quad (e_R^- e_L^+ \to \mu_L^- \mu_R^+)$$

$$\frac{d\sigma}{d\Omega} = \frac{1}{4}\frac{\alpha^2}{E^2}\left| 1 + \underbrace{(-1+2\sin^2\theta_W)}_{\sin^2\theta_W - \cos^2\theta_W}\cancel{2\sin^2\theta_W)} \frac{1}{\underset{2}{\cancel{4\sin^2\theta_W}}\cos^2\theta_W}\right|^2 (1-\cos\theta^*)^2$$

$$= \frac{1}{4}\frac{\alpha^2}{E^2}\left| 1 + \frac{\sin^2\theta_W - \cos^2\theta_W}{2\cos^2\theta_W}\right|^2 (1-\cos\theta^*)^2$$

$$= \frac{1}{4}\frac{\alpha^2}{E^2}\left| \frac{1}{2}\left(1 + \frac{\sin^2\theta_W}{\cos^2\theta_W}\right)\right|^2 (1-\cos\theta^*)^2$$

$$= \frac{1}{4}\frac{\alpha^2}{E^2} \cdot \frac{1}{4} \frac{1}{\cos^4\theta_W} (1-\cos\theta^*)^2$$

$e^-_R e^+_L \to \mu^-_R \mu^+_L$

$$\frac{d\sigma}{d\Omega} = \frac{1}{4}\frac{\alpha^2}{E^2} \left| 1 + \frac{4\sin^4\theta_W}{4\sin^2\theta_W \cos^2\theta_W} \right|^2 (1+\cos\theta^*)^2$$

$$= \frac{1}{4}\frac{\alpha^2}{E^2} \left| 1 + \frac{\sin^2\theta_W}{\cos^2\theta_W} \right|^2 (1+\cos\theta^*)^2$$

$$= \frac{1}{4}\frac{\alpha^2}{E^2} \frac{1}{\cos^4\theta_W} (1+\cos\theta^*)^2$$

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unpolarized...

$$\frac{d\sigma}{d\Omega} = \frac{1}{2} \cdot \frac{1}{4}\frac{\alpha^2}{E^2} \left[\left(\frac{1}{\sin^4 2\theta_W} + \frac{1}{\cos^4\theta_W} \right) (1+\cos\theta^*)^2 + 2 \cdot \frac{1}{4} \frac{1}{\cos^4\theta_W} (1-\cos\theta^*)^2 \right]$$

$$= \frac{1}{4}\frac{\alpha^2}{E^2} \left[\overbrace{\frac{1}{2}\left(\frac{1}{\sin^4 2\theta_W} + \frac{3}{2\cos^2\theta_W} \right)}^{A_2} (1+\cos^2\theta^*) + \overbrace{\left(\frac{1}{\sin^4 2\theta_W} + \frac{1}{2\cos^2\theta_W} \right)}^{A_1} \cos\theta^* \right]$$

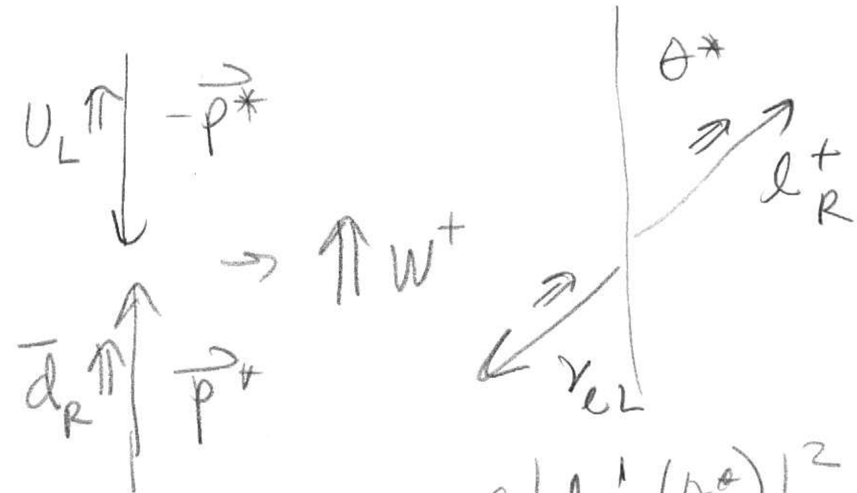
2.26 > 1 (pure QED)

2.83

$$A_{FB} = \frac{3}{8} \cdot \frac{A_1}{A_2} = \frac{3}{8} \frac{2.83}{2.26} = \underline{\underline{0.47}}$$

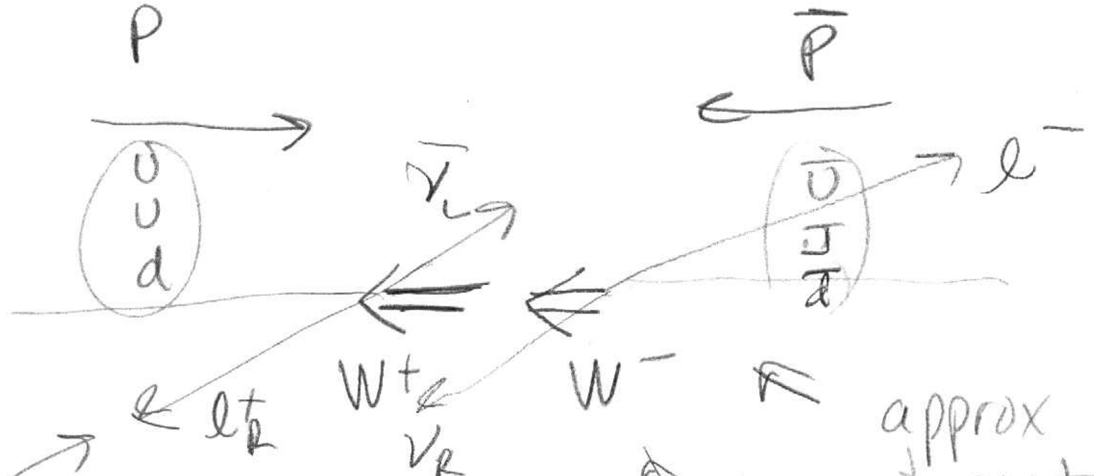
Another good process

$$\underbrace{u\,\bar{d}}_{\text{all} \sim \text{massless}} \to W^+ \to \underbrace{\ell^+ \nu_e}$$



$$\propto |d^1_{11}(\theta^*)|^2$$

Tevatron



approx at rest

likes small angles

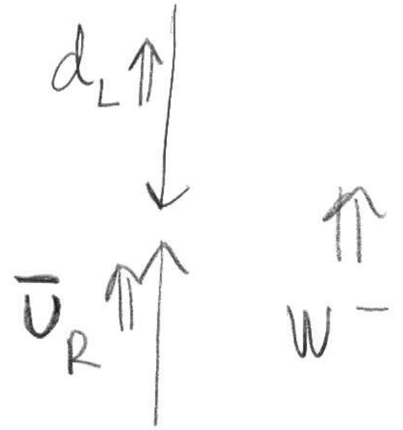
$$\propto \frac{1}{4}(1+\cos\theta^*)^2$$

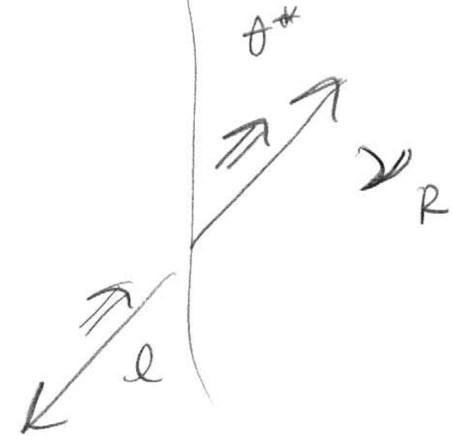
spin points at the matter

W^- ?

$\bar{u} d$

$W^- \to l^- \bar{\nu}_R$





Cross Section

$$\sigma \;\propto\; \frac{1}{(\text{energy})^2}$$

"Narrow Width" approximation

$$\sigma_W = \frac{\pi}{3}\sqrt{2}\,\underbrace{G_F M_W^2}_{\text{dimensionless}}\,|V_{qq'}|^2\,\underbrace{\delta(\hat{s} - M_W^2)}_{\text{dimensions of } 1/E^2}$$

CKM remember

totally ignores $1/Q^4$ at high mass, width

$$\frac{d\sigma_T}{dP_z} = \int \frac{d\sigma}{dM^2\,dP_z} = \frac{\pi}{3}\sqrt{2}\,G_F M_W^2\,|V_{qq'}|^2 \times \frac{1}{s}\,\frac{d\mathcal{L}_{u\bar{d}}}{d\tau}$$

Rapidity

rapidity $\rightarrow y \equiv \frac{1}{2}\ln\frac{E+p_z}{E-p_z} = \frac{1}{2}\ln\frac{\sqrt{M_{ee}^2+p_z^2}+p_z}{\sqrt{M_{ee}^2+p_z^2}-p_z}$

$$x_1 = \frac{E+p_z}{\sqrt{s}} \qquad x_2 = \frac{E-p_z}{\sqrt{s}}$$

$$y = \frac{1}{2}\ln\frac{x_1}{x_2}$$

$$\frac{x_1}{x_2} = e^{2y}$$

$$x_1 x_2 = \frac{M^2}{s}$$

$$x_1^2 e^{-2y} = \frac{M^2}{s}$$

$$\boxed{x_1 = \frac{M}{\sqrt{s}}e^{y} \qquad x_2 = \frac{M}{\sqrt{s}}e^{-y}}$$

could transform to

$\frac{d^2\sigma}{dM\,dy}$ actually easier.

Decays

Problem : $Z^0 \to l^+ l^- \simeq 3.3\%$ per charged lepton.

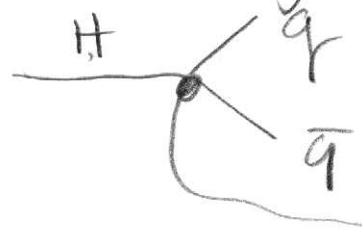
$W^\pm \to l^\pm \overset{(-)}{\nu}_e \sim 10\%$

At LHC, TeV, $Z^0 \to q\bar{q} \to$ jets

$W \to q_1 \bar{q}_2 \to$ jets

hard to separate from background.

Higgs Boson

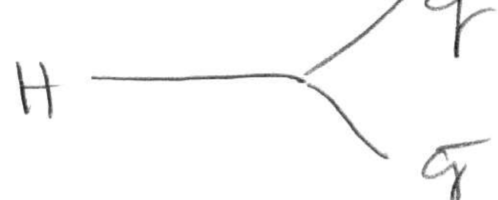
1. Spin - 0.
2. mass a "free parameter"
3. Essential for completing standard model.
   Keeps "wrong helicity" branching ratios from ∞
4. 

   $\propto m_q$ (!)

Makes Mass

H → condensed field

Key point:



$\Gamma(H^0 \to q\bar{q}) \propto m_q^2$

$\Rightarrow$ Heavy Quarks favored

$\Rightarrow$ Z^0Z^0, W^+W^- also favored (if m_H large enough)

(5) LEP:

$$115\text{ GeV} \leq M_H \leq \underbrace{165\text{ GeV}}$$

not above $H^0 \to Z^0 Z^0$

barely $H^0 \to W^+W^-$

no $H^0 \to t\bar{t}$

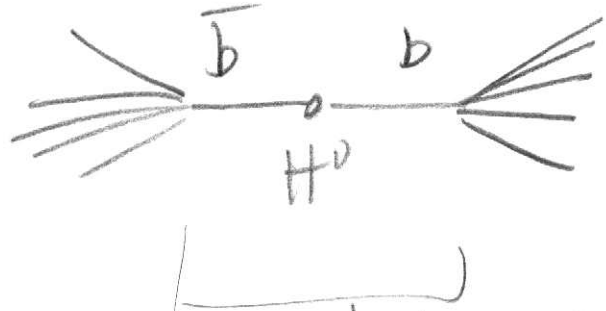
What does it do?

mostly $H^0 \to b\bar{b}$ (plot).

$\Rightarrow$ really hard

$\Rightarrow$ hope

1.5 ps life



separated vertizes.

"Golden Mode" $\Rightarrow$ $H^0 \to Z^0 Z^0$

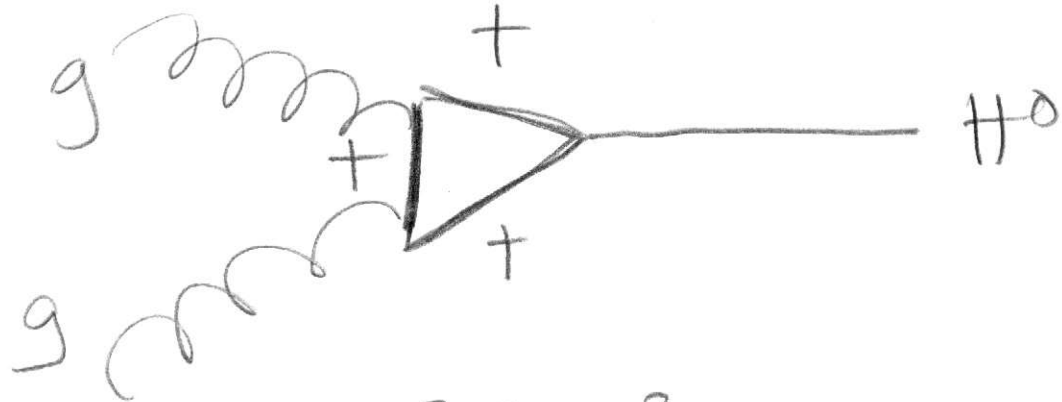
$\hookrightarrow 4\ell$

$2\ell 2\nu$

"Discovery" plot

Production:

Mainly



$$\sigma = \frac{\alpha_s^2 G_F M_H^2}{\pi\sqrt{2}\, 2^5 3^2}\, \delta(\hat{s} - M_H^2)$$

(narrow width)

⇒ you calculate

⇒ plot

⇒ discovery plot.