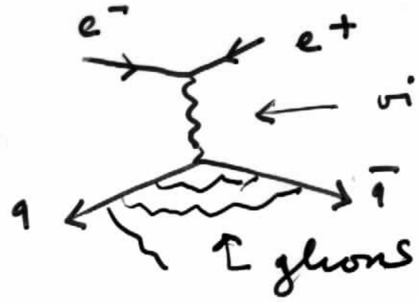
Forward-Backward Asymmetry for e^+e^--annihilation into hadrons

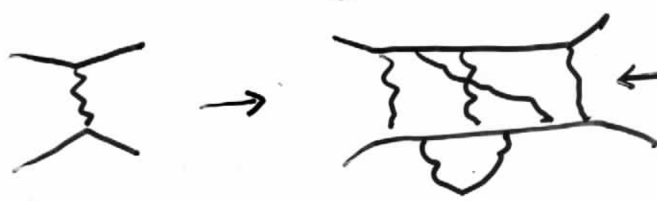
Ermolaev-Greco-Troyan, 2002

$e^+e^- \to$ hadrons $= (e^+e^- \to q\bar{q}) \times (q\bar{q} \to$ hadrons$)$

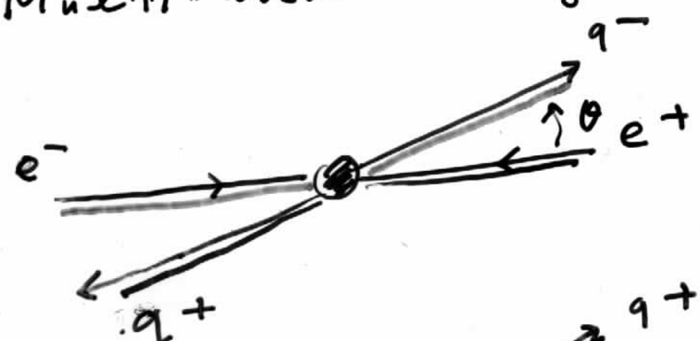
$e^+e^- \to q\bar{q}$:



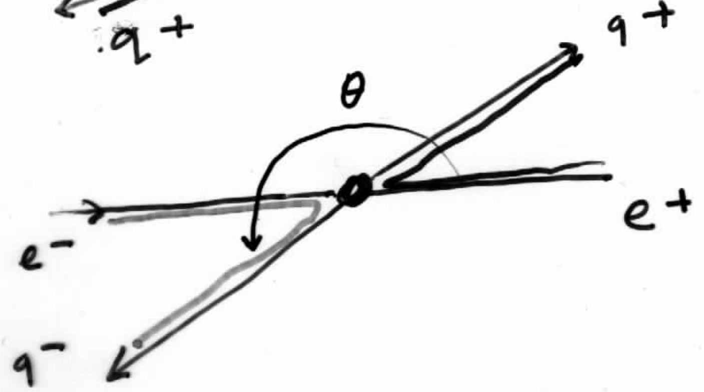
When $s \equiv (P_{e^-} + P_{e^+})^2 \gg (100\,\text{GeV})^2$, electroweak radiative corrections can yield double-logarithmic contributions:



Multi-boson exchange $\Rightarrow$ FBA.



$\theta \ll 1$ - Forward kinem.



$\theta \sim \pi$ - Backward kinem

— (grey) way of (−) charge

— (black) way of (+) charge

$q^+ = u, \bar{d}, c, \bar{s}$

$q^- = d, \bar{u}, s, \bar{c}$

Forward scattering amplitude

Effect of Multi-EW-boson exchanges

$M_F \neq M_B$ ← Backward scattering amplitude

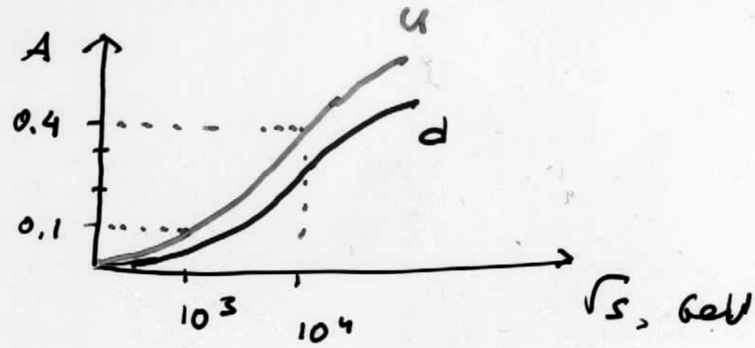
Forward cross section

$$\Rightarrow \quad A = \frac{d\sigma_F - d\sigma_B}{d\sigma_F + d\sigma_B} \neq 0.$$

Backward cross section

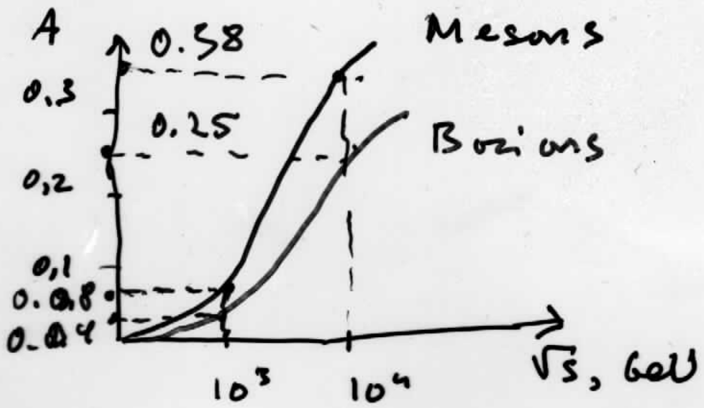
↑ FB asymmetry

Had quarks been experimentally detected, A would have depended on the total energy like that:



Hadronization effects change A. They are different for barions and mesons (all are charged).

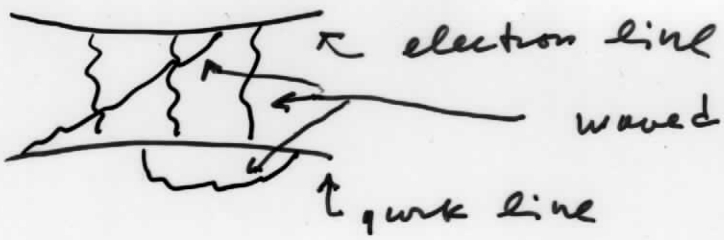
As a result,



Hadronization of quarks – numerically (JETSET)

Sub-process $e^+e^- \to q\bar{q}$ – analytically:

Infra-Red Evolution Equations



Convenient: $l_i \bar{l}^k \to q_{i'} \bar{q}^{k'}$

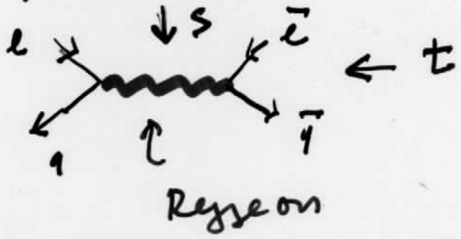
Most difficult case: $l_i, q_{i'}$ from left doublets

$\bar{l}^k, \bar{q}^{k'}$ from right doublets

Scattering amplitude is a matrix $M^{i\ k'}_{i'\ k}$

Both the Forward and the Backward kinematics are of the Regge type and are considered with the same technique.

Forward kinematics:



Initial t-channel isospin state $\frac{1}{2} \times \frac{1}{2} = 0 + 1$

0 ← isoscalar Reggeon; 1 ← isovector Reggeon

$$M^{i\ k'}_{i'\ k} = (P_0)^{i\ k'}_{i'\ k} \cdot M_0 + (P_1)^{i\ k'}_{i'\ k} M_1$$

M_0, M_1: invariant amplitudes

$$(P_0)^{i\ k'}_{i'\ k} = \frac{1}{2} \delta^i_{i'} \delta^{k'}_k , \quad (P_1)^{i\ k'}_{i'\ k} = 2 (t_A)^i_{i'} (t_A)^{k'}_k$$

t_A: su(2)-generators

$$P_A P_B = \delta_{AB} P_B$$

In order to get rid of Infra-Red singularitées (from virtual photons) we have to introduce an IR cut-off μ.

We assume $\mu \sim M_{W,Z}$

Therefore, $M_{0,1} = M_{0,1}(s, \mu^2)$. Now we can drop all masses and evolute $M_{0,1}$ with respect to μ.

It is convenient to use the Sommerfeld-Watson (Mellin) transform:

$$M_i^{(\pm)} = \int_{-i\infty}^{i\infty} \frac{d\omega}{2\pi i} \left(\frac{s}{\mu^2}\right)^{\omega} \xi^{(\pm)}(\omega)\, F_i^{(\pm)}(\omega), \quad i = 0,1$$

$$\xi^{(\pm)} = (e^{-i\pi\omega} \pm 1)/2 \quad \text{- signature factors}$$

Born approximation:

$$F_i^{(+)} = \frac{a_i}{\omega}, \quad a_0 = \frac{3g^2 + g'^2 Y_1 Y_2}{4}$$

$$a_1 = -\frac{g^2 + g'^2 Y_1 Y_2}{4}$$

$g' = g \tan\theta_W$, $Y_{1,2}$ - hypercharges

Beyond Born:

numerical factors

$$\omega F_i^{(+)} = a_i + \frac{b_i}{8\pi^2} \frac{d}{d\omega} F_i^{(+)} + \frac{1}{8\pi^2} \left(F_i^{(+)}\right)^2$$

$$b_0 = \frac{g'^2 (Y_1 - Y_2)^2}{4}, \quad b_1 = \frac{2g^2 + g'^2 (Y_1 - Y_2)^2}{4}$$

Solution: $$F_i^{(+)} = a_i \frac{D_{p_i-1}(\omega/\lambda_i)}{D_{p_i}(\omega/\lambda_i)},$$

with $\lambda_i = \sqrt{b_i/8\pi^2}$, D_p – Parabolic cylinder function

$p_i = a_i/b_i$.

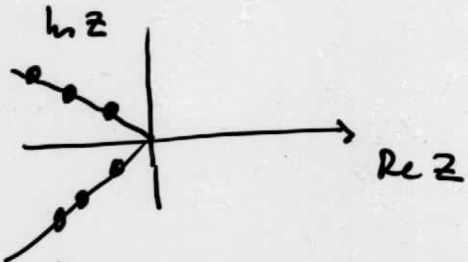
$-t \lesssim M^2_{W,Z}$: $$M_i^{(+)} = a_i \int_{-i\infty}^{i\infty} \frac{d\omega}{2\pi i} \left(\frac{s}{\mu^2}\right)^{\omega} \frac{D_{p_i-1}(\omega/\lambda_i)}{D_{p_i}(\omega/\lambda_i)}$$

$s \gg -t \gg M^2_{W,Z}$: $$M_i^{(+)} = a_i \int_{-i\infty}^{i\infty} \frac{dl}{2\pi i} \left(\frac{s}{t}\right)^{l} \frac{D_{p_i-1}(l+\lambda_i \ln t/\mu^2)}{D_{p_i}(l+\lambda_i \ln \frac{t}{\mu^2})}$$

singularities of the integrands are zeros of $D_{p_i}(z)$: If $D_p(z)=0$,

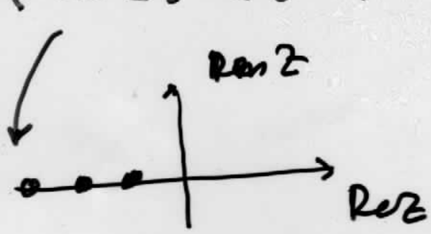
$$M_i \sim s^z$$

$p<0$



$\operatorname{Re} z_i < 0 \Rightarrow$ intercepts are negative

$1>p>0$



$p>1$

some of zeros are positive

$\Rightarrow$ some intercepts are positive

Forward kinematics:

isoscalar Reggeon
$$\begin{cases} P_u = \dfrac{3g^2 + g'^2 Y_1 Y_2}{g'^2 (Y_1+Y_2)^2} \approx 25 \\[2ex] P_d = \dfrac{3g^2 - g'^2 Y_1 Y_2}{g'^2 (Y_1-Y_2)^2} \approx 6 \end{cases}$$

$\Delta_u^F \approx 0.13$, $\Delta_d^F \approx 0.08$

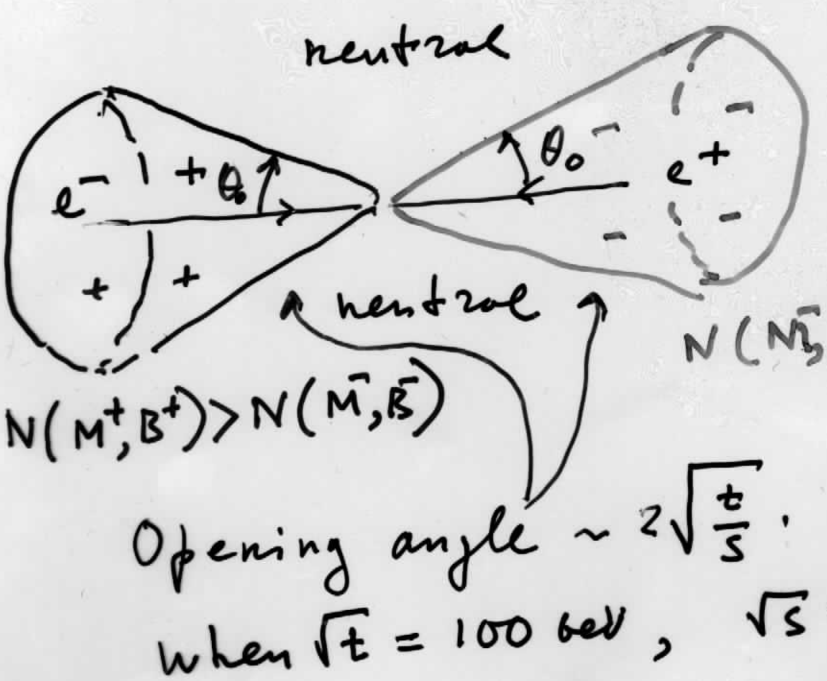
Backward kinematics: $P_u \approx P_d \approx -\frac{1}{4}$

QED, $e^+e^- \to \mu^+\mu^-$: $P = -1/4$ Gorshkov - Gribov - Frolov - Lipatov, 1967

Universal behavior of the backward scattering.

intercepts ≈ -0.27

The cases when the lepton and the quarks have other helicities are considered the same way.



$N(M^+, B^+) > N(M^-, B^-)$ $N(M^-, B^-) > N(M^+, B^+)$

Opening angle $\sim 2\sqrt{\frac{t}{s}}$.

when $\sqrt{t} = 100$ GeV, $\sqrt{s} = 1$ TeV,

$\theta_0 \approx 10°$.

Conclusion

1. Accounting for the electroweak DL contributions for e^+e^--annihilation into hadrons leads to the Forward-Backward Asymmetry (FBA) for charged hadrons

2. Value of FBA is

When $\sqrt{s} = 1$ TeV, $\begin{cases} 0.08 & \text{Mesons} \\ 0.05 & \text{Barions} \end{cases}$

When $\sqrt{s} = 10$ TeV, $\begin{cases} 0.37 & \text{Mesons} \\ 0.25 & \text{Barions} \end{cases}$

and steeply rises with increase of the annihil. energy.

3. FBA exists also for proton-antiproton collisions ~~at~~ high energies:

$p\bar{p} \to$ charmed mesons, ~~barions~~