Physics Colloquium

July 7th, 2008

Evidence for Jet Structure in Hadron Production by $e^{+}\ e^{-}$ Annihilation

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1. Introduction

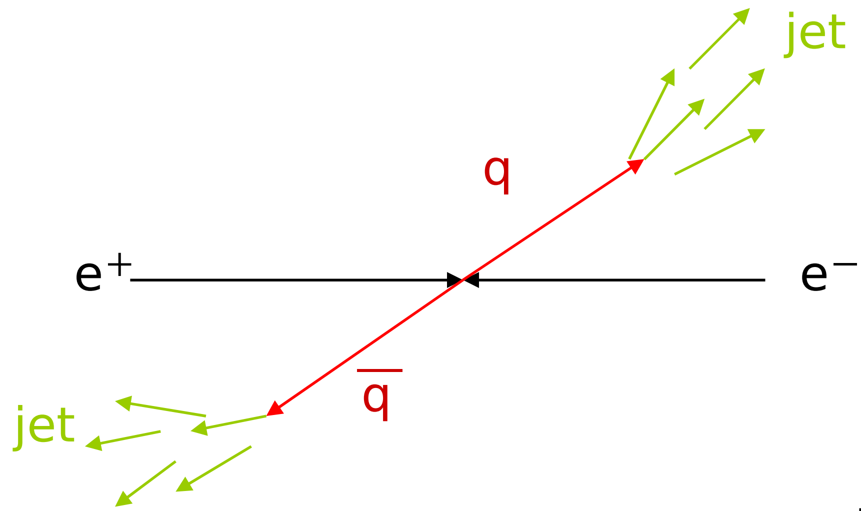
This paper reports the first evidence for <u>the existence of the hadron jet</u> in e^+e^- annihilation.

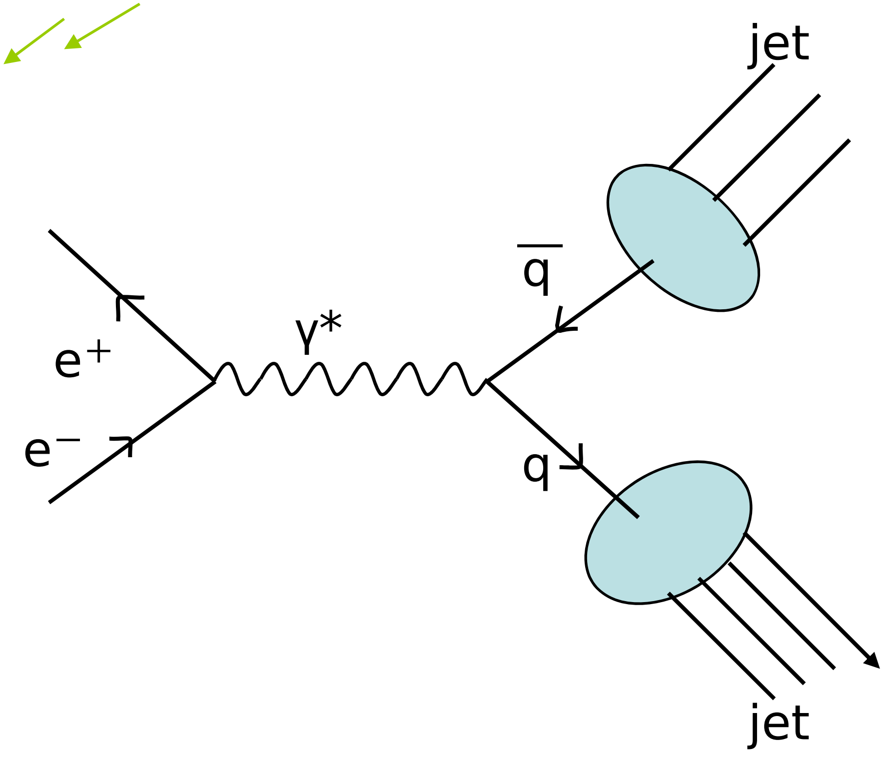
Jet : collimated sprays of hadrons

virtual photon

$$e^- + e^+ \rightarrow \gamma^* \rightarrow q + \overline{q} \rightarrow jet + jet$$

At large value of $E_{c.m}$ the hadron jets in e^+e^- annihilation can be observed.

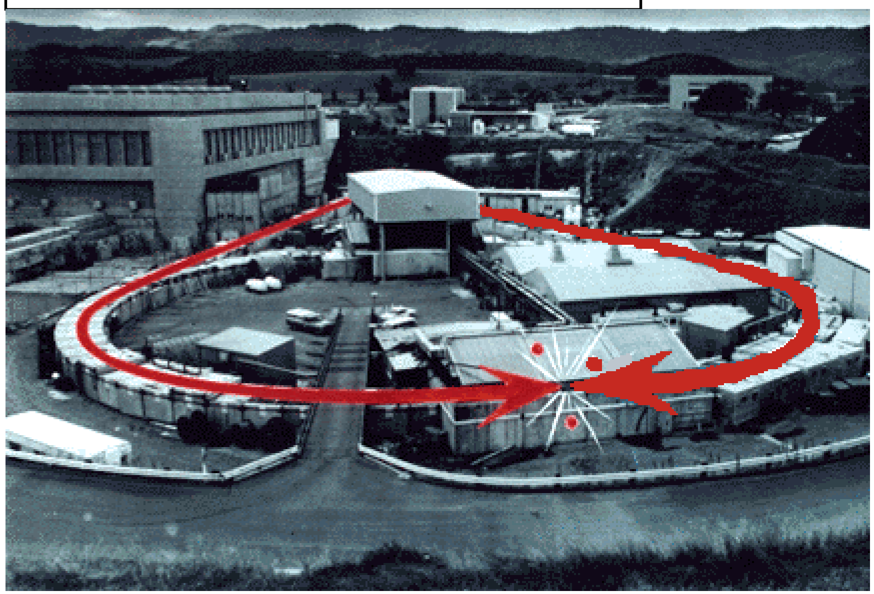


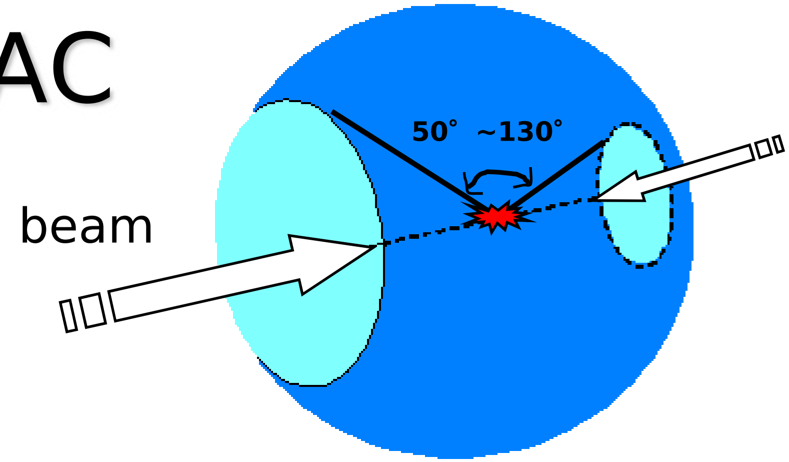


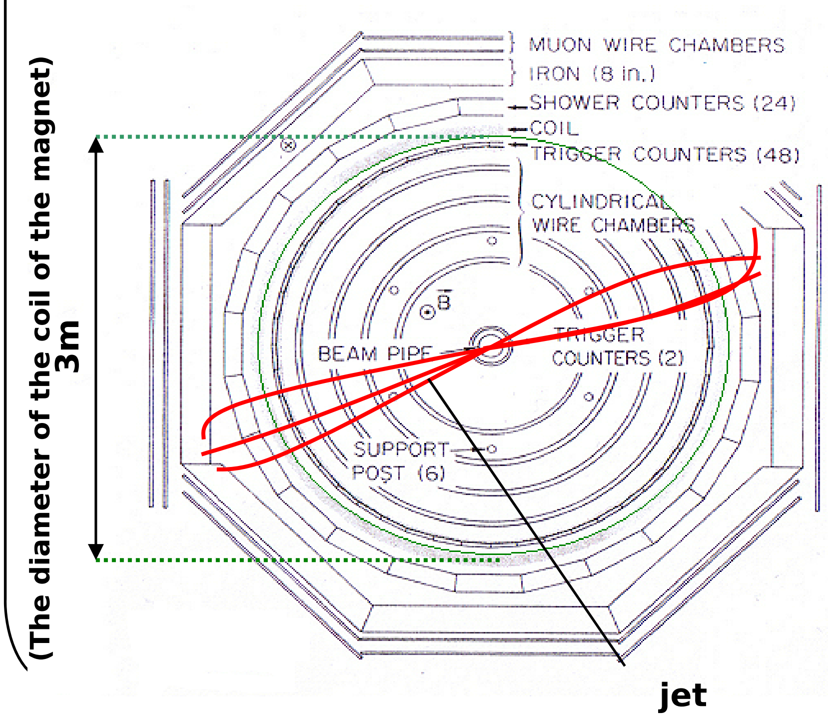
2. Experiment at SLAC

The experiment was carried out at the SPEAR storage ring of SLAC, USA.

Electron-positron collider







→ Data were collected at $E_{c.m.}$ of 3.0, 3.8, 4.8, 6.2 and 7.4 GeV.

3. Analysis

(1) Sphericity（球形指数）

Choose the axis which minimizes

the value of $\sum_i p_{\perp i}^2$ { where the summation is over all detected particles

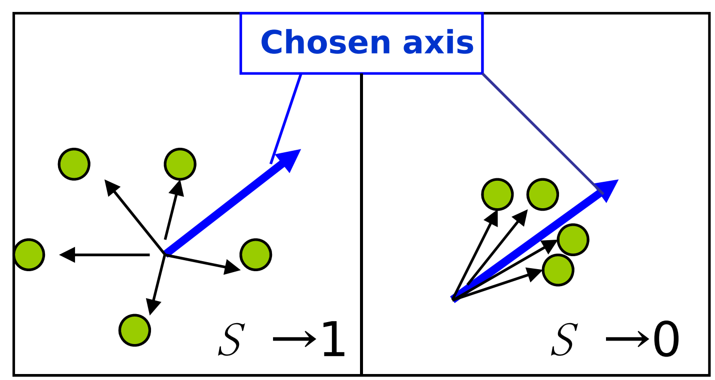
by iteration.

$p_{\perp}$: the transverse momentum with respect to the chosen axis.

The sphericity S determines how jet-like an event is.

$$S = \frac{3(\sum_i p_{\perp i}^2)_{\min}}{2\sum_i |\vec{p}_i|^2}$$

($\vec{p}_i$ is the momentum of each particle.)



(2) Two models : jet model and phase-space model

Monte Carlo simulation is an important method for comparison with data.

⇓

Simulation based on the two models

- ･Isotropic phase-space model
- ･Jet model

(3) The angular distribution of the jet axis

The angular distribution of the jet axis is expected to be

$$\frac{d\sigma}{d\Omega} \propto 1 + \alpha \cos^2\theta + P^2 \alpha \sin^2\theta \cos 2\varphi$$

(P : the polarization of the beams)

4. Results

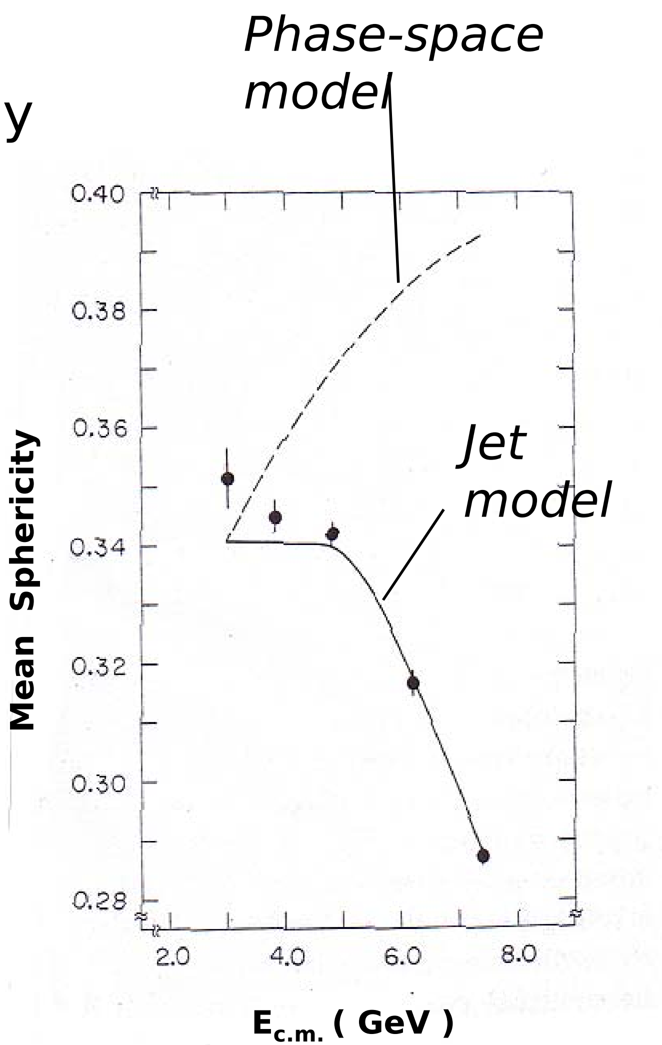
(1) Mean Sphericity vs. Center of Mass Energy

(The mean S of the data and the two models)

- The mean S of the data decreases with $E_{c.m.}$.
- The mean S of the jet model also decreases with $E_{c.m.}$. But the phase-space model increases with $E_{c.m.}$.

↓

The jet model agrees with the data. But the phase-space model does not.

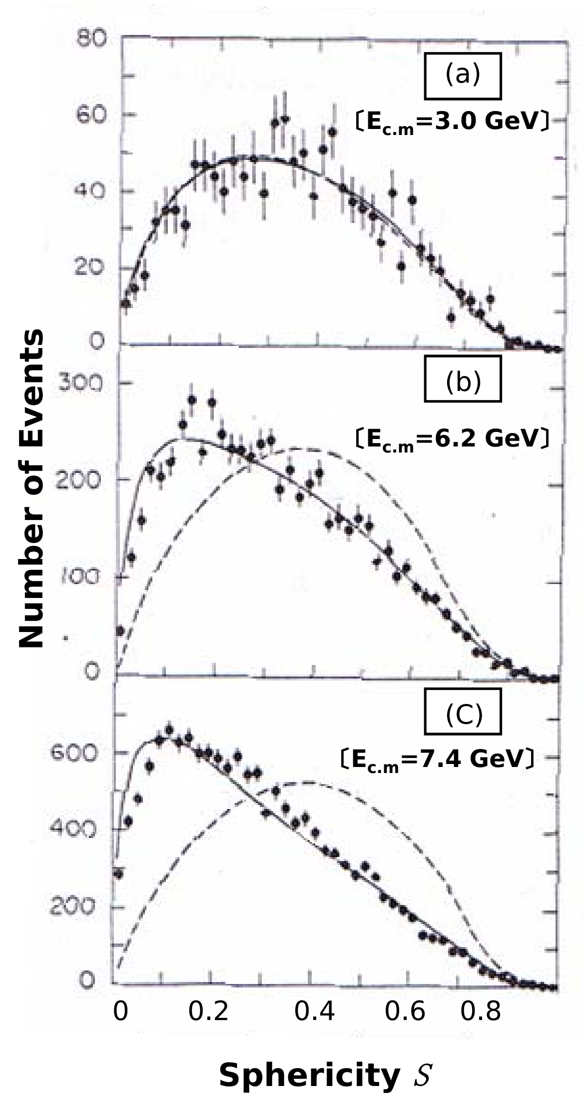


(2) Sphericity distribution of events

- **The data**
  The peak of S distribution shifts to lower value at higher energies.
- **The two models**
  Jet model : the peak of S distribution shifts to lower value at higher energies.

  Phase-space model : the peak of S distribution stays around 0.4.

(Small sphericity : collimated hadrons)



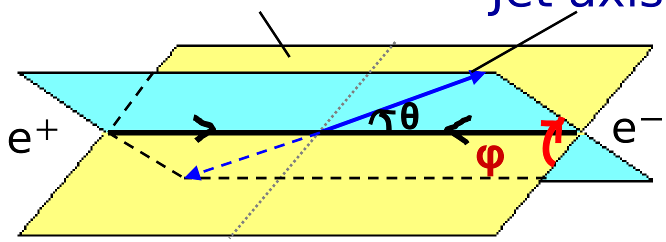
At $E_{c.m.}$ = 6.2 and 7.4 GeV

The jet model agrees with the data. But the phase-space model does not.

→ ***The figures in this page and previous page indicate that the jet model agrees with the data.***

⇒ **This is an evidence for jet**

(3) Another evidence for jet



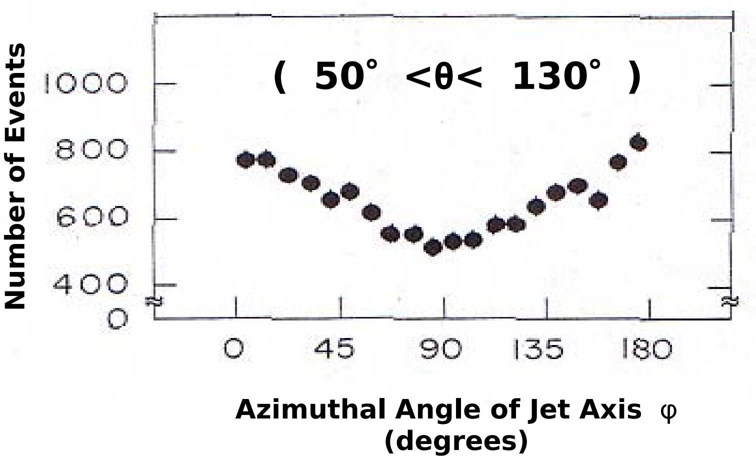
φ : the azimuthal angle of the jet axis with respect to the plane of the storage ring.

At 7.4 GeV the beam is transversely polarized due to synchrotron radiation.

$$P^2 = 0.47 \pm 0.05$$

The angular distribution of the jet axis is expected to be

$$\frac{d\sigma}{d\Omega} \propto 1 + \alpha\cos^2\theta + P^2\alpha\sin^2\theta\cos 2\varphi$$



Experimental data : The angular distribution of the jet axis indeed has dependence on azimuthal angle φ.

Another evidence for jet

5. Summary

- This paper reports the first evidence for the existence of the hadron jet.
- The hadron jet is produced in e^+e^- annihilation.
- The experiment was carried out at SLAC-SPEAR.
- Data were collected at $E_{c.m.}$ of 3.0, 3.8, 4.8, 6.2 and 7.4 GeV.
- Sphericity is an important quantity for the analysis.

  →The mean S of the data decreases with $E_{c.m.}$.

  →The peak of S distribution shifts to lower value.
- Two models (jet model and phase-space model) are compared with data.

  →The jet model agrees with the data.

  →The phase-space model disagrees with the data.

⇨ **These are evidence for jet.**

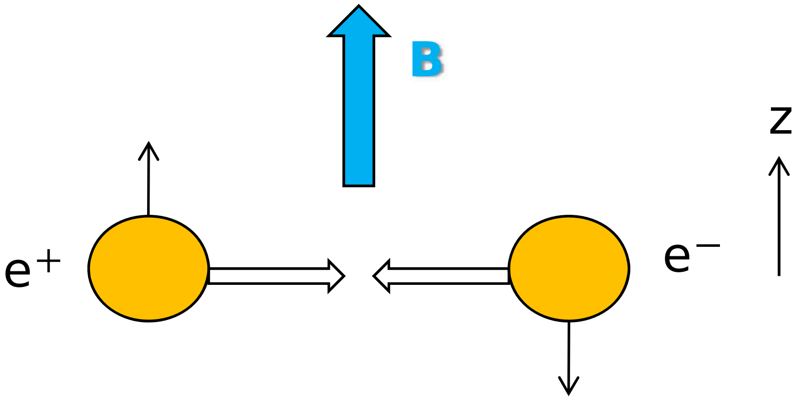
- The distribution of the jet axis has dependence on azimuthal angle φ.

⇨ **This is another evidence for jet.**

Jet became later an important subject of QCD (quark-gluon physics).

・ ビームの偏極について

シンクロトロン加速器にて加速された電子・陽電子ビームはシンクロトロン放射をして徐々に偏極される(sokolov-terenov効果)。このとき陽電子は磁場と同じ向きに、電子は磁場とは反対向きに偏極される。今回のSLACの実験ではビームの偏極度をPとして



$$P^2 = 0.47 \pm 0.05$$

という値となっている。また対消滅により生成される仮想光子のスピンのz成分は0。つまりスピンの方向は貯蔵リング面内にあることがわかる。

・ ジェット軸の角度分布

$$\frac{d\sigma}{d\Omega} \propto 1+\alpha\cos^2\theta + P^2\alpha\sin^2\theta\cos 2\varphi \qquad \left\{ \alpha = \frac{\sigma_T - \sigma_L}{\sigma_T + \sigma_L} \right\}$$

σ_T ：Transverse production cross section
σ_L ：Longitudinal production cross section

⇨ $\alpha = 0.78 \pm 0.12$

ジェット軸の角度分布 ： $\frac{d\sigma}{d\Omega} \propto 1 + (0.78 \pm 0.12)\cos^2\theta$

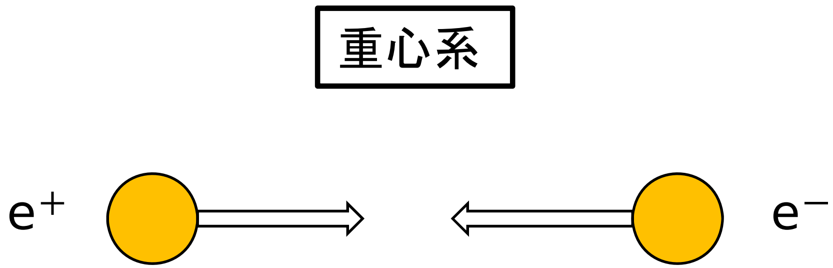
・ 仮想光子について

運動量保存則により光子の4元運動量は

$$q^{\mu} = (\frac{2E}{c},0,0,0)$$

つまり光子の不変質量が

$$M = \frac{2E}{c^2} \neq 0$$



$$(\frac{E}{c}, p_1,0,0)$$

$$(\frac{E}{c},-p_1,0,0)$$

となりゼロではなくなるので、この光子は仮想光子であると考えられる。

・ 球形指数について

$$T = \sum_i \begin{pmatrix} \vec{p}_i^{\,2} - p_{i1}^2 & -p_{i1}p_{i2} & -p_{i1}p_{i3} \\ -p_{i2}p_{i1} & \vec{p}_i^{\,2} - p_{i2}^2 & -p_{i2}p_{i3} \\ -p_{i3}p_{i1} & -p_{i3}p_{i2} & \vec{p}_i^{\,2} - p_{i3}^2 \end{pmatrix}$$

この行列の固有値を得るために対角化させる

$$T\vec{u}_k = \lambda_k \vec{u}_k \qquad (k=1,2,3)$$

λ_3は最小の固有値。かつ固有ベクトルにたいして垂直方向の運動量成分の2乗和を表す。このλ_3の固有ベクトルがジェット軸と定義される。

$$S = \frac{3\lambda_3}{\lambda_1 + \lambda_2 + \lambda_3} = \frac{3(\sum_i p_{i\perp}^2)_{\min}}{2\sum_i \vec{p}_i^{\,2}}$$