ECFA/LEP 38
16 September, 1978

"Onium" New Flavour Identification

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There are possibly new flavours appearing in the future LEP energy range. These new quarks might be observed as "onium" (bump in the cross-section, observation of a sudden change of sphericity of the events ...) or associated with old quarks in meson-like states qQ (mass peak observed in the $\dot{z}$ decay, semi-leptonic cascade decay, sphericity change associated with semi-leptonic decay) or finally by an increase of R $\left(\frac{\sigma \text{ hadronic}}{\sigma_{\mu\mu}}\right)$

Most of this note comes from previous work.

- CERN Yellow Report 76-18
- B. Wiik, talk at Les Houches
- Roy Schwitters, private communication

Search for "Onium"

Cross-section

$$\sigma(e^+e^- \to V \to f) = \frac{3\pi}{s} \frac{\Gamma_{ee}\,\Gamma_f}{(M-\sqrt{s})^2 + \Gamma^2/4}$$

if energy spread is larger than the resonance width.

$$\to \frac{M^2}{6M^2} \int \sigma_f d\sqrt{s} = \frac{\Gamma_{ee}\,\Gamma_f}{\Gamma} \qquad \text{if } f = \text{hadrons} \simeq \Gamma_{ee}$$

$$\text{if } f = \mu\mu \simeq \frac{\Gamma_{ee}\,\Gamma_{\mu\mu}}{\Gamma}$$

$$\Gamma_{ee} \sim \frac{e^2_Q}{M^2} |\psi_{(o)}|^2 \simeq e^2_Q$$

$$\int \sigma d\sqrt{s} \sim \frac{e^2_Q}{M^2}$$

if we normalized this result on the J/ψ production

$$\to \int \sigma d\sqrt{s} = 10000 \text{ nb MeV} \left(\frac{3}{M \text{ in GeV}}\right)^2 \left(\frac{e_Q}{2/3}\right)^2$$

the total cross-section (1γ exchange) is $\frac{87\text{nb}}{s} R = \frac{87.R}{M^2}$ nb

$$\text{so } \frac{\text{signal}}{\text{background}} = \frac{10 \text{ nb GeV} \left(\frac{3}{M}\right)^2 \left(\frac{e_Q}{2/3}\right)^2}{\frac{87\ R}{M^2} \times 2\,\delta E}$$

δ E is the σ of the beam spread (we will assume $\delta E = 1.23\ 10^{-3}$ E
R = 6)

$$\frac{\text{signal}}{\text{background}} = \frac{90\,(e_Q/{}^{2}/_{3})^2}{87 \times 6 \times 2 \times 1.23\ 10^{-3}\ E} = \frac{70}{E \text{ in GeV}}\left(\frac{e_Q}{2/3}\right)^2$$

$$= \frac{.083}{\delta\ E \text{ (in GeV)}}\left(\frac{e_Q}{2/3}\right)^2$$

Mass	e_Q	Signal/Background	rate/day	
60	1/3	.58	140	Use 40 events/ day for R = 1
60	2/3	2.4	560	
100	1/3	.35	84	
100	2/3	1.4	336	
140	1/3	.25	60	
140	2/3	1.0	240	
180	1/3	.20	9	Use 8 events/ day for R = 1
180	2/3	.80	36	

So to see a bump in the total cross-section at the onium mass will require very long scanning-time if one has to scan a full range of energy. As an example: with a mean signal/background of 1 (for a quark charge of 2/3), a 40 events/day luminosity per unit of R, for a 5σ effect 5 hours are needed per point. With at least 20 points per GeV and 50 GeV range, this rough scan will need 5000 efficient hours (for a quark charge 1/3, this will increase by 10).

But if other indications will give an approximate mass value for an onium within 1 GeV, a scan of 100 hours will give precise indication on the onium mass.

Change of Sphericity at the Onium Mass

What is known: At DORIS there is a large increase in sphericity when one crosses the Y mass.

Qualitatively one expects this to be the same for the next onium. Trying to be quantitative, one has to go through a model. We use the Monte-Carlo events of Drijard, Grote, Innocenti* for the 2-jet events and the 3-jet events ($q\bar{q}g$).

For 2-jet events the sphericity is always smaller than .01 (100 events with a mean value of $4.3\ 10^{-3}$). One could ask whether this Monte-Carlo simulation reproduces the DORIS result, it is not obvious and events seem to be too jet-like.

* see LEP/ECFA note

For 3-jet events ($q\bar{q}g$) generated according to J. Ellis, M.K. Caillard, and De Rujula, out of 79 events there are 2 events with a sphericity > .2 and 6 events with a sphericity > .1 (the mean value is .03).

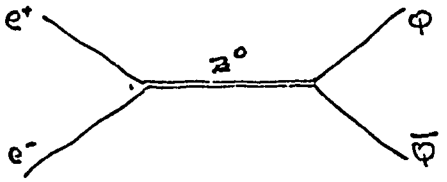
Taking these simulations for granted, i.e. no background for sphericity larger than .2, one can see how long one will have to scan to see at least two large sphericity events.

Onium mass	e_Q	Number of hours needed to see 5.3 onium events (i.e. > 2 with 90% CL) if sphericity > .2
60	1/3	1
100	1/3	1.5
140	1/3	2
180	1/3	14

So if for high mass onium one can make a sphericity cut at .2 a scan of (1.5 x 20 x 50) 1500 hours will be OK. If for any reason sphericity of onium events would be smaller or tails of jets even larger (i.e. a cut in sphericity at .1) such a scan would be much longer. If for any reason useful luminosity would be 4 times smaller, 6000 hours of scan would be necessary.

As a conclusion, direct onium search by scan seems to be difficult even if sphericity signature is more powerful than bump in total cross-section.

Search for qQ State in the Z^0 Peak



A known proportion of $Q\bar{Q}$ pairs are produced at the Z^0 peak (See R formulae). These Q quarks will be dressed with ordinary quarks (u, d, s, c ...) to build new states q.

These states will decay weakly (semi-leptonic decay, hadronic decay, or cascade down via hadronic decay ($(qQ)^* \rightarrow qQ$ + hadrons).

1) Hadronic Decays : Search for Invariant Mass

$MZ^o = 86$ GeV $\quad\quad \sin^2\theta = .23 \quad\quad$ rate of Z^o per day $\simeq 10^4$

The number of $Q\bar{Q}$ pairs produced per day is around 15% of the total Z^o production for a new Q with a mass smaller than $MZ^o/2$. Assuming a hadronic branching ratio of 1% per channel, this will lead us to 300 events in a given channel for 500 hours of running time. Now detection efficiency has to be folded in and the background has to be looked at. The larger the Q mass, the larger the p_t of hadron debris from $q\bar{Q}$ states and the smaller the background coming from multiple combinations of hadrons will be.

2) Semi-leptonic Decay

As an example we will look at the cascade decay of a top meson

$$\begin{array}{l} T \to B\,\ell^\pm\,\nu \\ \quad \hookrightarrow C\,\ell^\pm\,\nu \\ \qquad \hookrightarrow K\,\ell^\pm\,\nu \end{array}$$

So $e^+e^- \to T\bar{T}$ will be a source of multilepton final states. Assuming a 10% branching ratio for all semi-leptonic decay, we have the following ratio for 500 hours of running time at the Z^o peak.

Number of Z^o Events	Number of $T\bar{T}$	Number of Dileptons	Trileptons	Quadri-leptons
$2\cdot10^5$	$3\cdot10^4$	1200	240	4

If it is not clear how to disentangle different contributions, $T\bar{T}$ events will lead to lepton-charge correlation on each side improving the rejection of the background. Furthermore, charm or K will help to find a solution. This technique to prove the existence of new states may well be powerful.

Search for ΔR Step*

$$R = \frac{\sigma(e^+e^- \to \text{hadrons})}{(e^+e^- \to \mu^+\mu^-)}$$. When R is a purely electromagnetic process it is called R_γ and on the Z^o pole it is called R_Z. Crossing a new threshold will increase R by ΔR.

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* Taken from M.K. Gaillard and J. Ellis CERN Yellow Report 76-18, page 55

$$\frac{\Delta R_\gamma}{R_\gamma} = \frac{4\,\Delta N_p + \Delta N_n + 3\Delta N_{HL}}{4N_p + N_n + 3\,N_{HL}}$$

$$\frac{\Delta R_Z}{R_Z} = \frac{\left(\begin{array}{l}3(2 - \frac{16}{3}\sin^2\theta_W + \frac{64}{9}\sin^4\theta_W)\,\Delta N_p + 3(2 - \frac{8}{3}\sin^2\theta_W + \frac{16}{9}\sin^4\theta_W)\,\Delta N_n \\ +(2 - 8\sin^2\theta_W + 16\sin^4\theta_W)\,\Delta N_{HL}\end{array}\right)}{\left(\begin{array}{l}3(2 - \frac{16}{3}\sin^2\theta_W + \frac{64}{9}\sin^4\theta_W)\,N_p + 3(2 - \frac{8}{3}\sin^2\theta_W + \frac{16}{9}\sin^4\theta_W)\,N_n \\ +(2 - 8\sin^2\theta_W + 16\sin^4\theta_W)\,N_{HL}\end{array}\right)}$$

Where N_p and N_n are the numbers of 2/3 and -1/3 quark charge and N_{HL} the number of heavy leptons.

With $R_\gamma = 6$	$\frac{\Delta R_\gamma}{R_\gamma}$	22%	5%	17%
	$\frac{\Delta R_Z}{R_Z}$	14%	17%	5%
		$\Delta N_p = 1$	$\Delta N_n = 1$	$\Delta N_{HL} = 1$

Even in the most unfavourable case ($\Delta N_n = 1$ for pure e.m. case) 40 hours of running time will give a 5 effect. So the result will depend more on the ability to control systematic error.

Conclusion

Even if new quark threshold will be more difficult to find at LEP energies, existing different possibilities could hopefully be successful.