DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

DESY 81-076
November 1981

RECENT RESULTS FROM DORIS

by

J. K. Bienlein

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DESY

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Abstract

New data on bottonium spectroscopy concern the search of $\gamma\gamma$-cascade decays of Υ' ($\Upsilon' \to \gamma\gamma\Upsilon$, $\Upsilon \to e^+e^-$ or $\mu^+\mu^-$) and yield one event giving a branching ratio $\leq 7\%$.

The Υ direct hadronic decays are used as a gluon factory and the gluon fragmentation is compared to quark fragmentation. Sphericity (and other topological quantities), charged multiplicity, particle correlations, γ-fraction, and inclusive spectra are equal. The phenomenological differences come from the different decay mechanisms (CONT $\to$ 2 quark jets vs. $\Upsilon \to$ 3 gluon jets). The only difference seen is an enhanced $\bar{p}$ yield of Υ and Υ' decays.

In a narrow energy scan in the energy regions 7.4-7.5 and 8.6-9.4 GeV no new resonance or new step is seen.

1. Review of work on DORIS since 1978

Table 1 Review of work on DORIS since 1978

1977 discovery of Υ, decision to upgrade DORIS

runs	DORIS	aim	further results
1978	single ring single bunch 10.1 GeV		
3 weeks 3 " 3 "		$\{\Upsilon$: Γ_{ee} Υ': ΔM, Γ_{ee}	Υ topology
1979 6½ weeks	improve components + operation	Υ: $B_{\mu\mu}$	inclusive spectra topology σ_{tot}
1980 7½ weeks		Υ': topology Γ_{ee}	$\Upsilon' \to \pi\pi\Upsilon$
10½ "		SCAN in CONT resonances? σ_{tot}	topology
1981-82	DORIS-II 11.2 GeV $L \to 10\times L$ less energy consumption		

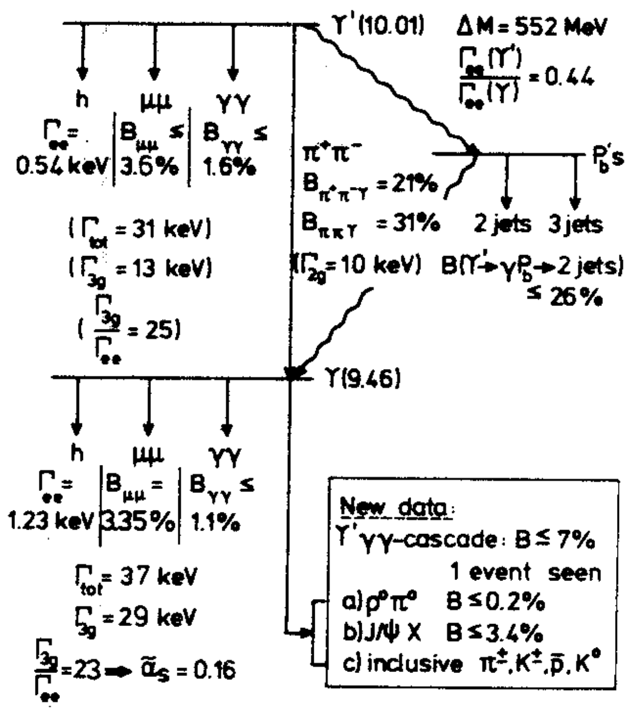
Table 1 gives a short review of the work at the DORIS e^+e^- storage ring at DESY since the discovery of the Υ resonance. Given are the changes of the machine: In 1978 conversion of the double ring-multibunch storage ring to single ring-single bunch and increase of maximum energy to 10.1 GeV to cover the Υ and Υ' resonances (Ref.1); in 1979 technical improvements resulted in a luminosity which was a factor 3 to 5 higher than 1978. Meanwhile a new improvement program was approved to achieve a further increase in maximum energy and luminosity and a reduction of energy consumption (Ref.2). Further on the running periods are given with the energy setting (Υ or Υ' with the neighbouring continua or the continuum in the c.m. energy range of 7.4 to 9.4GeV). The aim of the experiments was to measure the resonance parameters. Further results have been obtained on the resonance decays: topology, inclusive spectra, and the $\Upsilon' \to \pi\pi\Upsilon$ decay mode.

Table 2 lists the Institutions which formed the 4 collaborations working on DORIS since 1978.

Table 2: Collaborations at DORIS
PLUTO: Aachen, DESY, Hamburg, Siegen, Wuppertal
DASP-II: DESY, Dortmund, Heidelberg, Lund, ITEP Moscow
D-HH-HD-M: DESY, Hamburg (I. Institute), Heidelberg, MPI Munich
LENA: Carnegie-Mellon, Cracow, DESY, Erlangen, Hamburg (I. Institute), Michigan State, Nijmegen, Saclay, Tel-Aviv, Würzburg.

2. Bottonium spectroscopy

2.1. Summary of DORIS data



PS! Results obtained by using quarkonium models are in brackets.

Fig.1 Bottonium spectroscopy (DORIS results)

Fig.1 **summarizes the published data on Υ and Υ' production and decay from DORIS (Refs. 3,4,5,6). The results give the leptonic** width Γ_{ee} of Υ and Υ' and the branching ratio $B_{\mu\mu}$ of Υ into μ-pairs. Then one can calculate the total width Γ_{tot} of Υ and the width Γ_{3g} of its direct decays. For the Υ' the decay $\Upsilon' \to \pi^+\pi^-\Upsilon$ has been observed and its branching ratio was measured. This allows, using rather general scaling laws of quarkonium models, to deduce the total width Γ_{tot} of Υ' and the width of its direct decay Γ_{3g}. Limits on the decays $\Upsilon, \Upsilon' \to 2\gamma$ are given by the LENA collaboration.

New results since last year have been obtained on the following topics:

a) For the exclusive final state $\rho^0\pi^0$ no significant enhancement was seen on the Υ giving a limit on the branching ratio

$B(\Upsilon \to \rho^0\pi^0) \leq 0.2\%$ (LENA).

b) The inclusive J/ψ production (by its e^+e^- decay) has not been seen on the Υ resonance nor in the continuum giving the limit $B(\Upsilon \to J/\psi\ X) \leq 3.4\%$ (LENA).

c) The inclusive spectra of charged particles ($\pi^\pm$, $K^\pm$, $\bar{p}$) from Υ and Υ' (DASP-II) and of K^0's from Υ (PLUTO) have been measured (see chapter 3.9 of this report).

d) A search for γγ-cascades from Υ' ($\Upsilon' \to \gamma\gamma\Upsilon$, $\Upsilon \to e^+e^-$ or $\mu^+\mu^-$) yielded 1 event giving a limit for the branching ratio $B(\Upsilon' \to \gamma\gamma\Upsilon) \leq 7\%$ (see below).

2.2. Search for Υ' radiative cascade decays (LENA)

A search for radiative cascade decays $\Upsilon' \to \gamma\gamma\Upsilon$, $\Upsilon \to \mu\mu$ or ee with the LENA detector was possible after a special energy calibration for low energies using cosmic ray muons (which deposit about 200 MeV in the detector). The search was made for events having two muons or two electron showers and two photons. The results are shown in Fig.2. This scatter plot gives for each event the energies of the two photons. One can see:

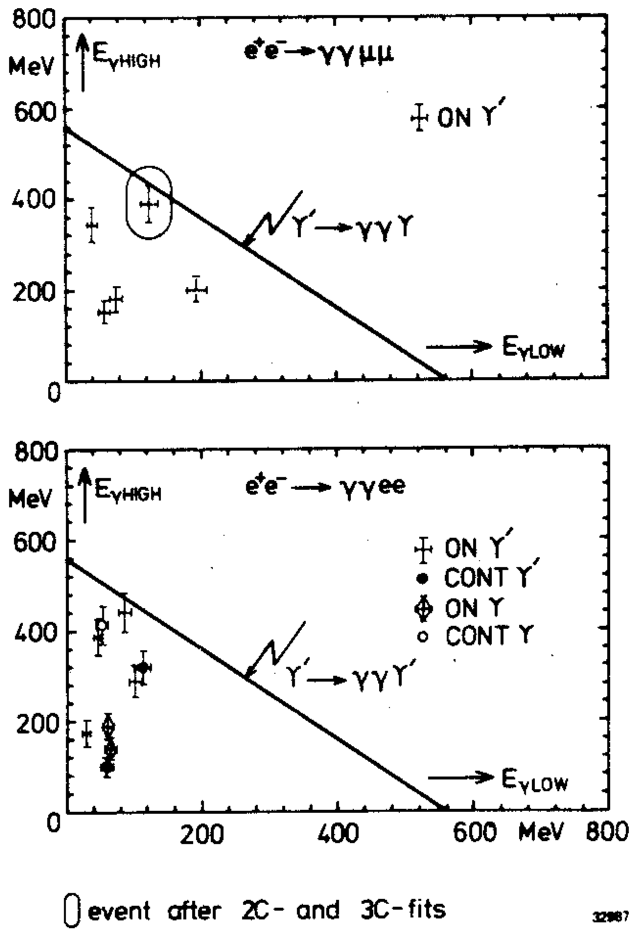


Fig.2 Search for Υ' γγ-cascades

- events populate only the low energy region (while the search was made for photons with energies up to 800 MeV),
- events from the radiative cascade decays $\Upsilon' \to \gamma\gamma\Upsilon$ will lie on the line $E_{\gamma HIGH} + E_{\gamma LOW} = \Delta M = 560$ MeV (the effect of the Υ recoil is smaller than the systematic error on its mass),
- for the μ-sample all 5 events which have been found are at energies ON Υ',

  for the e-sample 4 events are ON Υ' (37% of the integrated luminosity) while 5 events are found ON Υ or in the continuum (63% of the integrated luminosity).

The background may have the following origins:

- decays $\Upsilon' \to \pi^0\pi^0\Upsilon \to 4\gamma\Upsilon$ where only two photons are seen in the detector,

- double bremsstrahlung to μ-pair or Bhabha events,
- Bhabha events whose showers develop two extra photons.

A further event reduction was done by applying kinematic fits. A 2C-fit is possible to $e^+e^- \to \gamma\gamma + (\mu\mu$ or ee) where the lepton energies are unknown. Furthermore a 3C-fit can be made to $\Upsilon' \to \gamma\gamma\Upsilon$, $\Upsilon \to \mu\mu$ or ee. Only one event remains. It is encircled in Fig.2. So one event which fulfils all the criteria for Υ' radiative cascade decays has been seen.

One can now derive the branching ratio:
- for the muon sample $B(\Upsilon' \to \gamma\gamma\Upsilon) < 36\%$ (90% CL),
- " " electron sample " $< 7\%$ (").

(The acceptance for electrons is higher than for μ-pairs).
Theoretical predictions range between 2 to 7%. So our conclusion is that no anomalous high branching ratio has been seen.

3. The Υ as a gluon factory.

What can we learn about the gluon from Υ-decays?

3.1. Is the Υ a gluon factory?

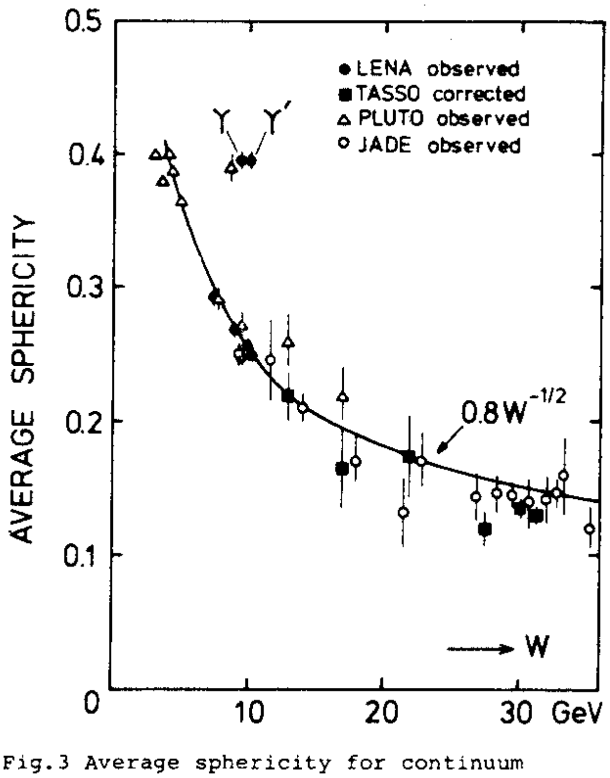


Fig.3 Average sphericity for continuum and Υ,Υ'.

The theory of strong interactions (QCD) predicts that the Υ decay proceeds via a 3-gluon intermediate state which then fragments into hadrons: $\Upsilon \to 3g \to h$'s.

That the mechanism for Υ decays is different from hadron production in the continuum is known since 1978 and is shown again in Fig.3. The average sphericity for Υ and Υ' decays is significantly higher than for the continuum which depends on the c.m. energy W.

At the first moment one might expect a 3-jet structure for $\Upsilon \to 3g \to h$'s. This is NOT visible (contrary to the 2-jet structure in the continuum which at 9.4 GeV is a VISIBLE phenomenon).

To learn about the Υ decay mechanism one has to compare the data with different models.

a) $\Upsilon \to 3g \to h$'s QCD matrix element

Field-Feynman fragmentation
b) $\Upsilon \to h's$ phase space with b1) π/K only
b2) pseudoscalar and vector mesons.

The PLUTO collaboration (Refs.3e,i) has checked many observables, e.g. thrust T and triplicity T3. Fig.4 shows the observed thrust distributions, using charged <u>and</u> neutral particles, for Υ decays and the 9.4 GeV continuum. The continuum data are well described by the quark-antiquark production mechanism and the fragmentation according to Field and Feynman. This can be considered as a test of the method. For the Υ decays the data are in agreement with the 3-gluon decay model and disagree with both kinds of phase space assumptions.

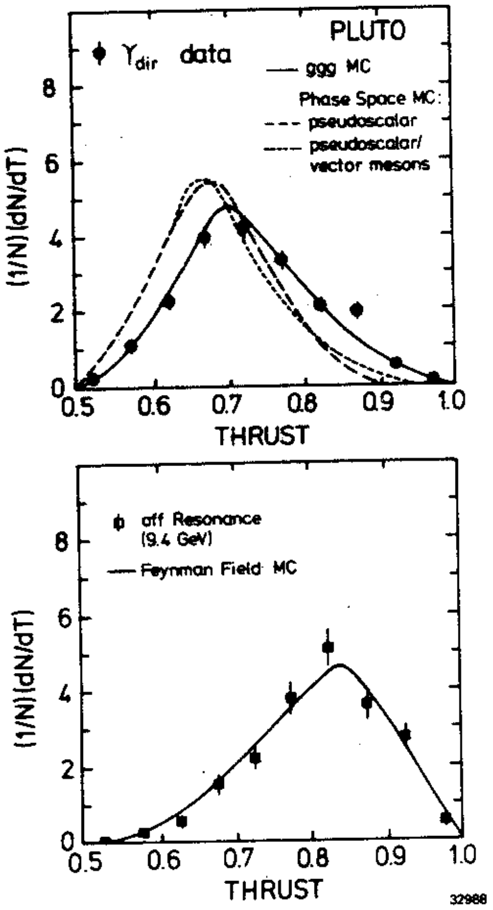


Fig.4. Thrust distributions for Υ_{dir} and continuum.

So we can use the direct Υ decays as a gluon factory.

3.2. The strong coupling constant

As the Υ decay proceeds via 3 gluons the partial width of its direct decays Γ_{3g} is proportional to α_s^3 (α_s = running coupling constant of QCD). The ratio of Γ_{3g} and Γ_{ee} (the leptonic width) is independent of the bottonium wave function One finds in lowest order:

$$\frac{\Gamma_{3g}}{\Gamma_{ee}} = 1\ 440\ \frac{(2/3)^2}{e_Q^2} \cdot \tilde{\alpha}_s^3 .$$

We use the notation $\tilde{\alpha}_s$ to indicate that it is obtained from experimental data using the lowest order QCD formula . The aim is to compare α_s at various energies. Fig. 5 shows the experimental results for J/ψ and Υ compared to the theoretical expectation of $\tilde{\alpha}_s(Q^2)$ for various values of Λ_M (we use Q^2 = mass^2 of the quarkonia). $\alpha_s(J/\psi)$ is scaled up to four flavors to allow for a smooth Λ value.

Result: The experimental data agree with the energy dependence of the strong coupling constant, but the errors are still so large that a constant α_s cannot be excluded.

Better data are clearly needed (for Υ and J/ψ).

P.S. Higher order corrections as recently calculated (Ref.7) do not change these conclusions.

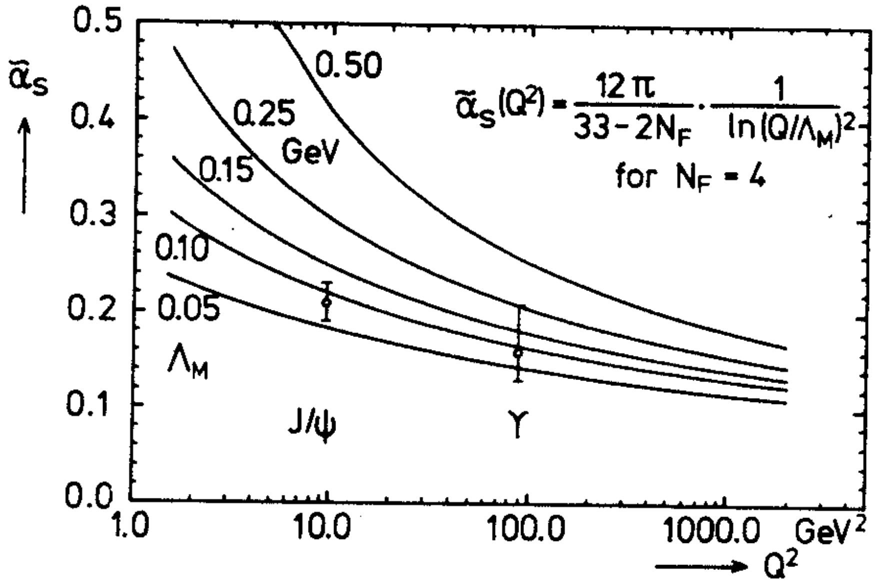


Fig.5 Energy dependence of the strong coupling constant α_s

3.3. Gluon spin

The gluon spin can be determined from the angular distribution of the thrust axis:

$$w(\Theta_T) \sim 1 + \alpha_T \cdot \cos^2\Theta_T$$

The theoretical predictions are:

$$\text{CONT} \rightarrow q\bar{q} \qquad \alpha^{q\bar{q}} = +1$$

$$\Upsilon, \Upsilon' \rightarrow 3g \quad \langle\alpha_T\rangle^{3g} = +0.39 \text{ for spin-1 gluons}$$
$$= -1.0 \text{ " spin-0 " .}$$

Fig.6 shows a compilation of experimental results. The data for the continuum give for c.m. energies of W = 7.4 GeV to 36 GeV an average of $\alpha^{q\bar{q}} = (1.10 \pm 0.14)$ in good agreement with the prediction of spin-1/2 quark - antiquark production. The thrust axis for Υ and Υ' decays is, because of the smaller average thrust, more difficult to determine and as a consequence the data scatter. The average of experimental data, $\langle\alpha_T\rangle^{3g} = (+0.33 \pm 0.16)$, is in agreement with the expectation for vector gluons and in disagreement with the assumption of scalar gluons.

Another test of the gluon spin is possible by comparing the widths $\Gamma(\psi' \rightarrow \pi\pi J/\psi)$ and $\Gamma(\Upsilon' \rightarrow \pi\pi\Upsilon)$ (Ref.6c).

3.4 Gluon fragmentation

We want to answer the question: Is the gluon fragmentation different from the quark

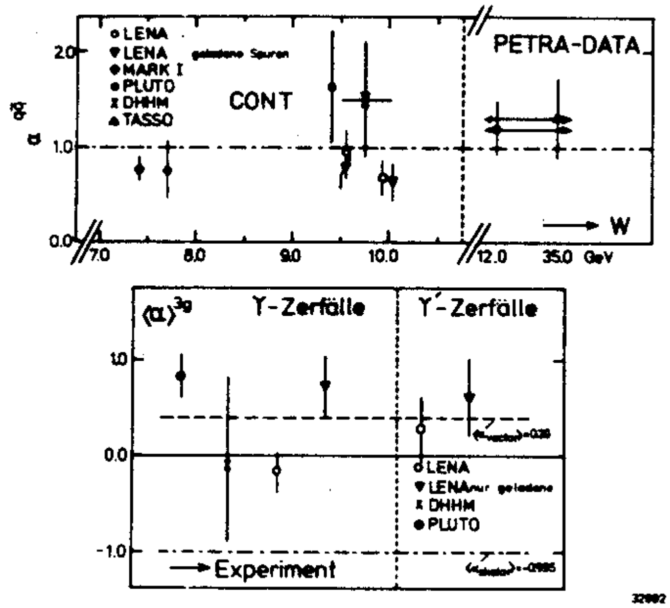


Fig.6 Compilation of the thrust axis angular distributions

fragmentation?

Theory expects for gluon jets:

a) a higher multiplicity (factor 9/4), because gluons are color octets while quarks are color triplets (Ref.8),

b) more isoscalar particles (e.g. η, η', ω, about 2 to 6 times more η's), because gluons are flavor neutral while quarks are flavored. This should result in a higher γ-fraction for gluon jets (Ref.8b).

A first view to the data shows differences for Υ decays and continuum reactions ($\Delta \overset{\text{def}}{=} \Upsilon_{DIR} - \text{CONT}$):

$$\Delta\langle S\rangle = 0.13 \quad \text{(see Fig.4)}$$

$$\Delta\langle n_{ch}\rangle = 0.55 \quad \text{(corrected for acceptance, Ref.6d)}$$
$$= 1.3 \quad \text{(corrected for acceptance, Ref.3e)}$$

Both quantities are higher for Υ_{DIR} than for the continuum, but $\langle n_{ch}\rangle$ not by a factor of 9/4.

It is very important to see that these differences do <u>not</u> reflect a different fragmentation. They are understood by the assumptions

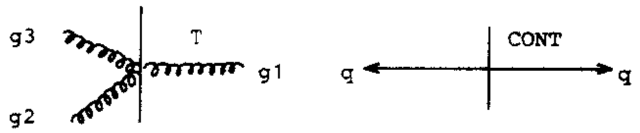
$\Upsilon \to 3g$	compared to	CONT $\to q\bar{q}$
QCD matrix element	|	quark parton production
	g-fragmentation = q-fragmentation	
3jets of $\sim$ 3 GeV each	|	2 jets of 4.7 GeV each

So the difference in phenomenology comes from the fact that Υ_{DIR} decays via a 3 particles (gluons) intermediate state while the continuum reactions go via a 2 particles (quarks) intermediate state. The fragmentation of both kinds of intermediate particles (gluons and quarks) into hadrons is the same.

P.S.: From the QCD matrix element we expect $\langle \Delta n_{ch} \rangle = 0.7$ (Ref.3i).

3.5. "Single" jets (LENA)

Until now we have always studied events. But we have seen that events are different because of the mechanisms $\Upsilon \to \underline{3}g$ vs. CONT $\to \underline{2}q$. We want to compare gluon jets with quark jets directly from the data. So we cut the events at the vertex perpendicular to the thrust axis. The picture shows the idea and gives the mean energies of high energetic gluon jet (g1) and the quark jet for the data used. It has to be mentioned that the selection of the high energetic gluon jet is very difficult. At the moment we can only enrich one side of the Υ_{DIR} decays with a "single" gluon jet.



$\langle E_{g1-jet} \rangle = 4.3$ GeV $\quad \langle E_{q-jet} \rangle = 4.5$ GeV

Result: The direct comparison of "single" jets of gluons and quarks at about the same jet energy does not show any difference, quarks and gluons show the same fragmentation.

3.6. Particle correlations (LENA)

One studies the angular correlation between two particles, more precisely, between the most energetic and the second energetic particle (angle ϑ). Fig.7 shows the data for the continuum and the sum of ($\Upsilon_{DIR} + \Upsilon'_{DIR}$). They are compared to theoretical expectations.

Data	Monte Carlo	Results	
CONT	$q\bar{q}$ + Field-Feynman		2 peaks, 2nd energetic particle mostly opposite (max at $\sim 160^\circ$)
$\Upsilon_{DIR}+\Upsilon'_{DIR}$	3g + " (—)	agrees	1 peak + shoulder, 2nd energetic particle mostly opposite (max at $\sim 135^\circ$)
	phase space (--)	worse	

The result is again that the 3-gluon matrix element plus gluon fragmentation like quarks (e.g. Field-Feynman parametrization) describe the data correctly.

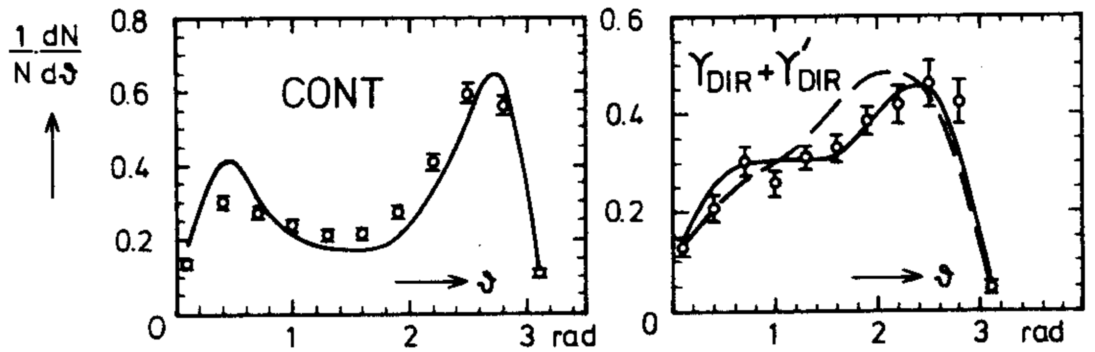


Fig.7 Angular correlation between most and 2nd energetic particle

3.7. γ-fraction (LENA)

Fig.8 shows the γ-fraction (average photon energy, $<E_{\gamma}>/W$), corrected for acceptance. The γ-fraction is constant for continuum energies between 5 and 35 GeV. Also the γ-fraction for Υ_{DIR} and Υ'_{DIR} decays is the same, $<E_{\gamma}>/W = (28 \pm 3)\%$. This means that any enhanced η production must be small.

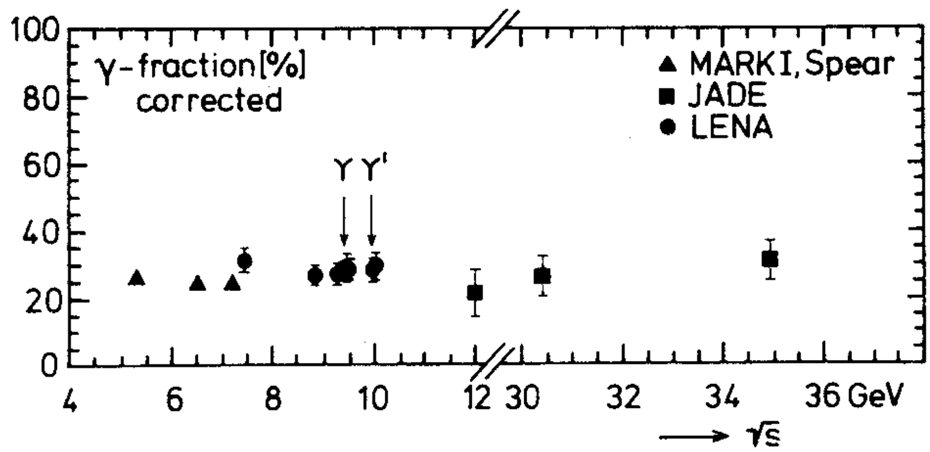


Fig.8 γ-fraction

3.8. Inclusive spectra and particle production (DASP-II)

The inclusive cross section (normalized and Lorentz-invariant) for charged hadron production, $e^+e^- \to h^{\pm}X$, $h^{\pm} = \pi^{\pm}, K^{\pm}, \bar{p}$ is shown in Fig.9. No difference is seen between Υ_{DIR}, Υ'_{DIR}, and the continuum for slope and particle momenta.

The K^0 inclusive spectrum has been measured for Υ_{DIR} and the continuum by the PLUTO collaboration (Ref.3f). They see an indication of a steeper slope on Υ_{DIR}.

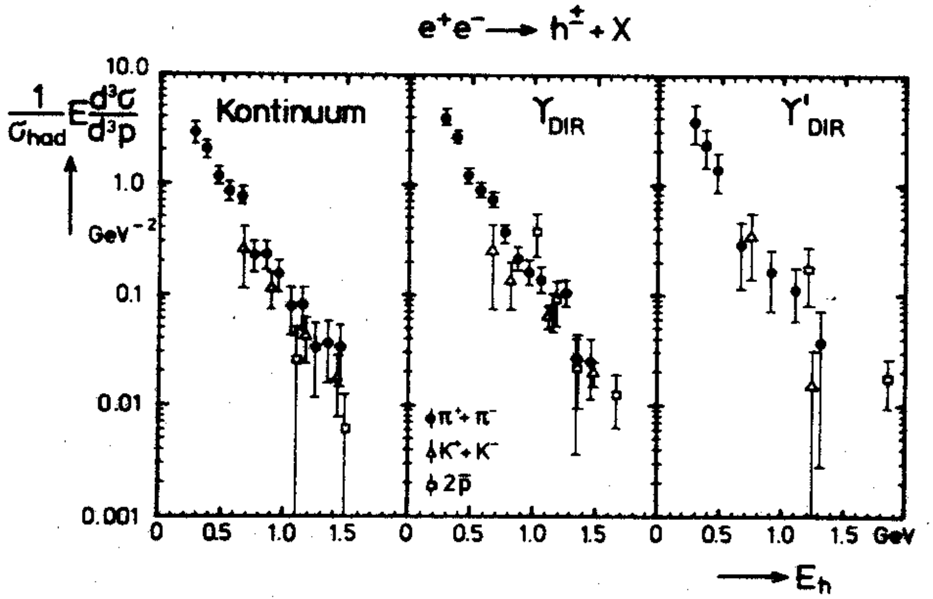


Fig.9 The inclusive spectra for the continuum, Υ_{DIR} and Υ'_{DIR}

The mean charged energy can be determined from the exclusive spectra. Table 3 gives those results (DASP-II) together with the γ-fraction (LENA). The mean charged energy as well as the γ-fraction are equal for Υ_{DIR} and the continuum. One can see that about 20% of the total energy are not yet identified.

Table 3	Υ_{DIR}	CONT	result
$\langle E_{ch} \rangle / W$	(48 ± 4)%	(52 ± 8)%	equal
$\langle E\gamma \rangle / W$	(28 ± 3)%		equal
missing	∿ 20%		K^0, ν, n?

The particle yields (in % of charged particles) are displayed in Fig.10. The lines are drawn to guide the eye. Here the particle yields for $\pi^{\pm}$, $K^{\pm}$, and K^0 are equal for direct decays and the continuum. But the DASP-II collaboration observes an increased antiproton yield of Υ_{DIR} and Υ'_{DIR} decays. The difference is (6.6 ± 2.4)%, i.e. 2.8 standard deviations.

So the only hint for a different gluon fragmentation which is observed is the enhanced antiproton production. Is copious baryon production connected with gluon fragmentation? Theory predicts a 1.3 to 2.3 times higher baryon production in gluon fragmentation than in quark jets (Ref.9).

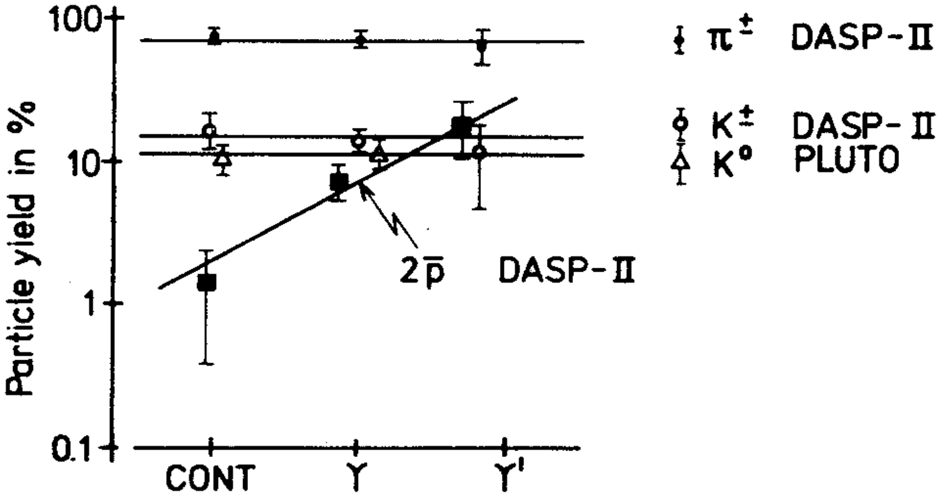


Fig.10 Particle yield in the continuum and for Υ_{DIR} and Υ'_{DIR}

4. Some results on the 7.4-9.4 GeV continuum

4.1. Narrow energy scan (LENA)

An energy scan in the regions of W = 7.4-7.5 GeV and 8.6-9.4 GeV was done with a narrow step width. The motivation is: 1. The region was unexplored, DORIS can cover it. 2. Non-standard theories (e.g. "liberated" color) predict important effects in this energy region. 3. The Mark I collaboration found at Spear in the 5-7.4 GeV energy region that R is 16% higher than the QCD expectation (with a systematic uncertainty of 10%) (Ref.10).

The results of the LENA collaboration are shown in Fig.11. Given is R_{vis}, i.e. the number of hadronic events is not yet corrected for detector acceptance. The major cut on event selection is for the visible energy $E_{vis} \geq 0.9$ GeV. The relative change of acceptance with c.m. energy was corrected.

The results are:

1. No narrow resonance is seen. The limits are

$$\Gamma_{ee} \frac{\Gamma_h}{\Gamma_{tot}} \leq 233 \text{ eV (90\% CL)}.$$

2. No step is seen. The fit to a straight line with slope gives

$$R_{vis} = R_o + R'(9.5 \text{ GeV} - W), \quad R_o = 3.02 \pm 0.08, \quad R' = -0.05 \pm 0.08.$$

The fit to a constant R gives

$$R_{vis} = 2.99 \pm 0.05.$$

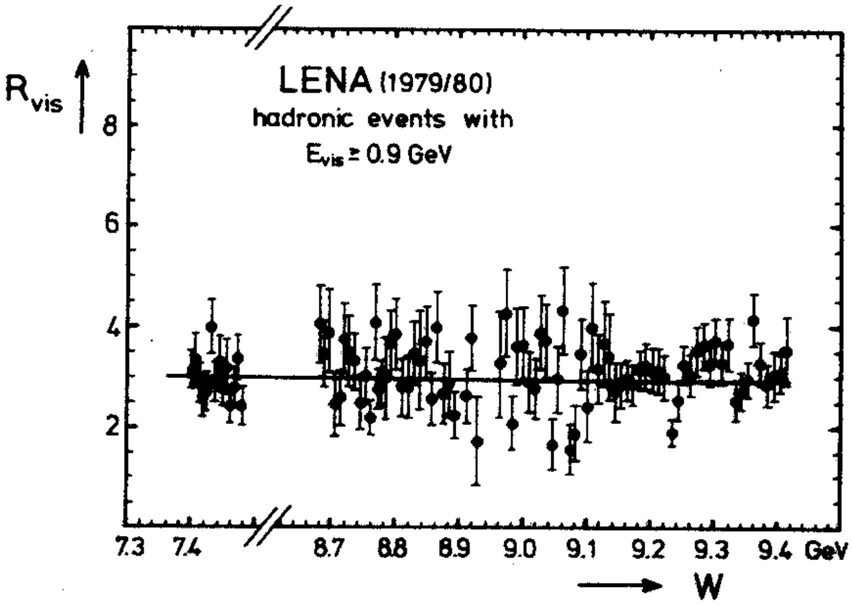


Fig.11 Resonance search in the energy region 7.4-9.4 GeV

4.2. Compilation of R from DORIS

Table 4 gives a compilation of the measurement of R at DORIS

Table 4: Compilation of R from DORIS

experiment	energy W GeV	R	ref
DASP-I	> 4.5	4.3±0.5	11
PLUTO	5.0	3.85±0.04	3g
"	7.7	3.92±0.26	3g
D-HH-HD-M	9.4	3.8±0.7	5c
PLUTO	"	3.67±0.23±0.29	3h
DASP-II	"	3.73±0.16±0.28	NEW
average	9.4	3.70±0.14±0.29	

(The first error is always statistical, the second systematic).

With these improved data one may now try to estimate the strong coupling constant α_s via the QCD correction to R:

$$R = R_{parton}(1 + \frac{\alpha_s}{\pi}).$$

One finds at an energy of 9.4 GeV:

$$\alpha_s = 0.35 \pm 0.13 \pm 0.27.$$

5. Summary

1. Bottonium spectroscopy
   search for radiative cascade decays $\Upsilon' \rightarrow \gamma\gamma\Upsilon$
      1 event seen: $\Upsilon' \rightarrow \gamma\gamma\Upsilon$, $\Upsilon \rightarrow \mu\mu$
      BR $\leq$ 7%, no anomalous high branching ratio
   all results agree with standard quarkonium models
   investigation of spin forces still missing
2. What have we learned about the gluon?
   $\Upsilon \rightarrow$ 3 gluons (phase space is excluded), Υ decays can serve as a gluon factory
   gluons have spin 1
   gluons fragment like quarks (at $\sim$ 4.4 GeV jets)
      Field-Feynman parametrization is very good
      observables used for measurement of fragmentation properties
         multiplicity and its moments.
         jet topology (e.g. thrust, "single" jets)
         2-particle correlations
         γ-fraction
         mean charged energy
         inclusive spectra
      difference between quark and gluon fragmentation: antiproton yield is
         higher for Υ_{DIR}
3. Continuum (7.4-9.4 GeV)
   no resonance, no step
   R(9.4 GeV) = 3.70 ± 0.14 ± 0.29.

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