J/Ψ, Fifty years later

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- From many models to one theory.
- From dream to expectation.

The purpose of this talk is to argue that the phase transition from Many models to One Theory occurred in 1974, half a century ago.

In fact, it was rather a roughening transition, from 1974 to 1976

An important milestone was the 17th International Conference on High-energy Physics (Rochester Conference) in London, July 1974, the last meeting of the Dark Ages.

The theoretical landscape in the nineteen sixties – The Dark Ages

• The theoretical high energy physics landscape was fragmented in many disconnected domains, having no common trends and often ignoring each other. Many models, no theory

• For strong interactions the main approach was based on the assumed analyticity properties of the S-matrix elements.

• But we had also specific models for some processes, or for some corners of the phase space, peripheral models, eikonal approximations, longitudinal phase space approximation, parton model, $\cdots$

• For weak interactions we had the Fermi $V - A$ model. It had no logical connection with the others.

• Quantum field theory was noticeable mainly by its absence. A totally marginal subject confined to precision calculations in quantum electrodynamics. It was not even taught in many Universities.

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- For most physicists it was a wild theoretical speculation with no connection to the real world.

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- Neutral currents
  Evidence, but ???

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  A whole new hadronic world because you don't know how to suppress some tiny weak interaction processes??

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- The Ratio R should be a constant
  In violent disagreement with experiment

The R-puzzle

$$R(Q^2) = \frac{\sigma(e^+ + e^- \to \mathrm{hadrons})}{\sigma(e^+ + e^- \to \mu^+ + \mu^-)}$$

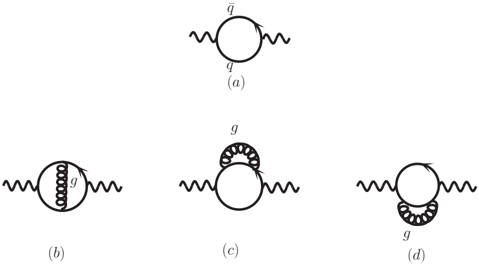
The parton model result

$$R(Q^2) = \sum_i e_i^2$$

With the three known quarks $R = 3(4/9 + 1/9 + 1/9) = 2$

The R-puzzle

The QCD corrections at order α_s are given by the diagrams:



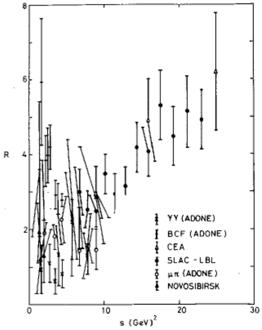
$$R(Q^2) = \sum_i e_i^2 \left(1 + \frac{\alpha_s(Q^2)}{\pi} + \mathcal{O}(\alpha_s^2)\right)$$

with

$$\alpha_s(Q^2) = \frac{1}{4\pi b_0 \ln(Q^2/\Lambda^2)} \text{ and } \Lambda \sim \mathcal{O}(200 \text{ MeV})$$

R should approach the value of 2 from above

The R-puzzle



A compilation of all early measurements of the ratio R, as presented in the 1974 London International Conference on High Energy Physics by Burton Richter.

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- 'I have won already several bottles of wine by betting for the neutral currents and I am ready to bet now a whole case that if the weak interaction sessions of this Conference were dominated by the discovery of the neutral currents, the entire next Conference will be dominated by the discovery of the charmed particles."

The discovery

In November 1974, SPEAR decided to go back and sweep the region above 3 GeV in fine steps of 1 MeV. To their great surprise they obtained a totally different picture.

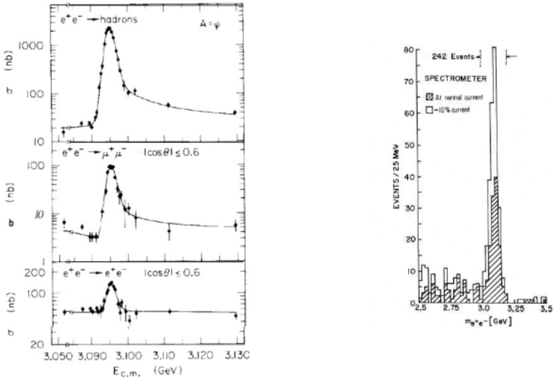

Figure 2.1: The discovery of the J/ψ meson in November 1974 independently by two experiments, SPEAR (left) and AGS (right). Both exhibit peaks in the oppositely charged dielectron mass spectrum consistent with the J/ψ mass at 3.1 GeV.

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- Okubo-Zweig-Iizuka (OZI) rule
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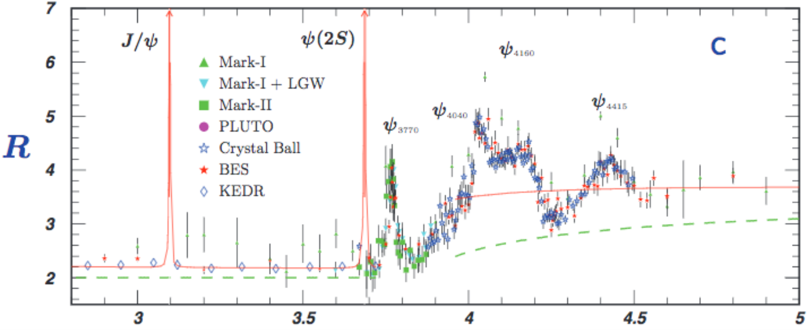
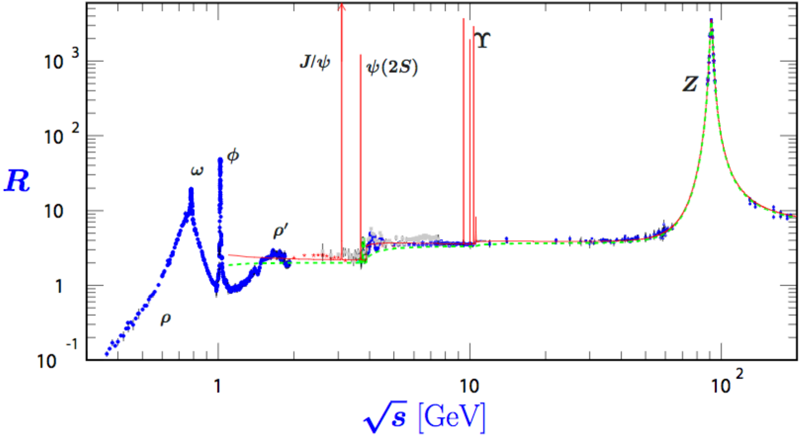
- Good explanation in QCD and a prediction (post-diction ?) of $\Gamma_{J/\Psi} \approx 80$ keV !!!



The value of R for energies between 3 and 5 GeV



The ratio R from low energies, up to and above the Z mass. The green curve is the parton model prediction and the red one includes QCD corrections. Remarkable agreement.

What next?

A striking feature of the data is that perturbation theory is reliable – outside the region of strong interactions – beyond any expectation! Why?

$A_n \sim \alpha^n (2n-1)!!$

Perturbation theory breaks down when $A_n \sim A_{n+1}$

$2n+1 \sim \alpha^{-1}$

For QED $n >> 1$; For QCD ???

$\Rightarrow$ It seems that we have an experimental fact saying that perturbation theory can be trusted, even if we do not fully understand why.

What next?

In a talk I gave at a meeting of the European Physical Society in 2011, I said:

I want to exploit this experimental fact and argue that the available precision tests of the Standard Model allow us to claim with confidence that new physics is present at the TeV scale and the LHC can, probably, discover it.
The argument assumes the validity of perturbation theory and it will fail if the latter fails. But, as we just saw, perturbation theory breaks down only when strong interactions become important. But new strong interactions imply new physics.

My conclusion was that, for LHC, which was about to start operating, new physics was around the corner!

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THANK YOU