

# From Many Models to ONE THEORY

As seen through the Moriond meetings

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Jean Iliopoulos

ENS, Paris

# The twentieth century was the century of revolutions in Physics

- Relativity - Special and General
- Atoms and atomic theory
- ...
- Quantum Mechanics
- Particles and Fields
- Gauge theories and Geometry
- Each one involved new physical concepts, new mathematical tools and new champions

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- ▶ It has been a conservative revolution : Things changed just enough so that they could remain the same.
- ▶ Yet, it influenced profoundly our way of looking at the fundamental laws of Nature.
- ▶ Not surprisingly, it was mostly rejected by the champions of the previous revolutions.

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- 20 Participants
- Almost all talks were in French
- The subjects were mostly of local interest :

Photoproduction, Electroproduction, The deuteron,  
Some projects for  $e^+ - e^-$  physics

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*For a more detailed discussion see : [ArXiv 2501.10233](https://arxiv.org/abs/2501.10233)*

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Quantum field theory was noticeable mainly by its absence. Many physicists had only vague and often erroneous ideas about it and, to a certain extent, this misunderstanding has survived even today.

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- ▶ There were also parallel meetings in Biology with some effort to teach biology to particle physicists.

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- ▶ The first time the term “Yang-Mills” was pronounced was in Moriond 1973.

- I want to emphasise the statement : “... like every other Conference or Workshop in our field ... ”
- None of the basic ingredients of gauge theories, such as non-abelian gauge theories, the BEH mechanism, Yang-Mills quantisation, etc, ever made it into a major HEP Conference before 1972.
- The few isolated physicists working in these fields were ignorant of each other's work and often had to rediscover these results again and again.
- Here I want to present only one example from my personal experience : The Weinberg 1967 Model.

*For a more complete discussion, see : [ArXiv 2501.10233](https://arxiv.org/abs/2501.10233)*

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▶ **WHY??**

- Widespread mistrust towards Quantum Field Theory.
- Problem with the title : “A model of Leptons” : All this complicated theory for just one process ?
- Few could appreciate the problems which the paper was solving.  
Ex. The intermediate vector bosons : since they were not known to exist, who cared how they were getting their masses ?
- Nobody had seen weak neutral currents.

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and invariant under **gauge** transformations

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- ▶ Even the Founding Fathers **Feynman, Schwinger, Landau, ...** had lost faith in renormalised quantum field theory.
- ▶ For most physicists the Standard Model was a wild theoretical speculation with no connection to **the real world**.

# The Price of the Standard Model

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Rejected by many people, unknown mass.
- ▶ Neutral currents.  
Evidence, but???

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- ▶ A fourth quark, with all the associated hadron spectroscopy. In particular, a new  $1^-$  meson!
  - In order to suppress decays like  $K^0 \rightarrow \mu^+ \mu^-$  or a large  $K_1 - K_2$  mass difference.  
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- ▶ Admittedly, it takes a solid faith in quantum field theory to accept such claims.

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- ▶ The Ratio  $R$  should be a constant.

In violent disagreement with experiment.

# The $R$ -puzzle

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

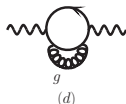
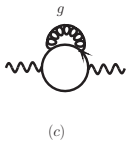
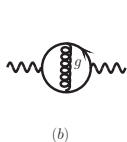
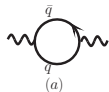
The parton model result :

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

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

# The $R$ -puzzle

The QCD corrections at order  $\alpha_s$  are given by the diagrams :



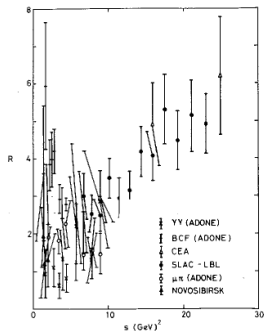
$$R(Q^2) = \sum_i e_i^2 \left( 1 + \frac{\alpha_s(Q^2)}{\pi} + \mathcal{O}(\alpha_s^2) \right)$$

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 phase transition :

**Many Models  $\Rightarrow$  ONE THEORY**

occurred between 1974 and 1976 with the discovery of  $J/\psi$  and the charmed particles.

We now have a unique theory of universal validity.

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**and our best wishes to our friend Van !**