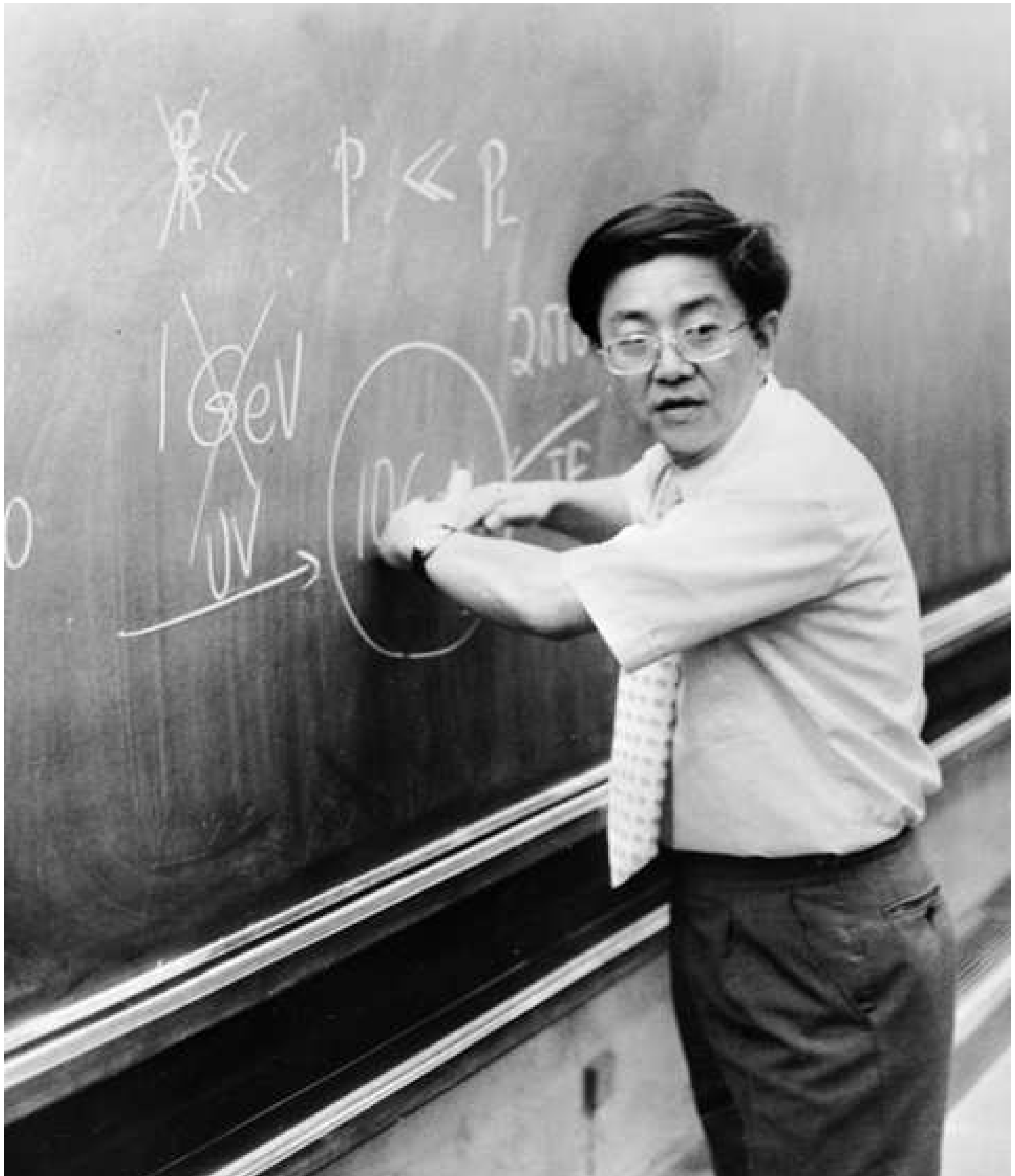
PERSPECTIVES IN

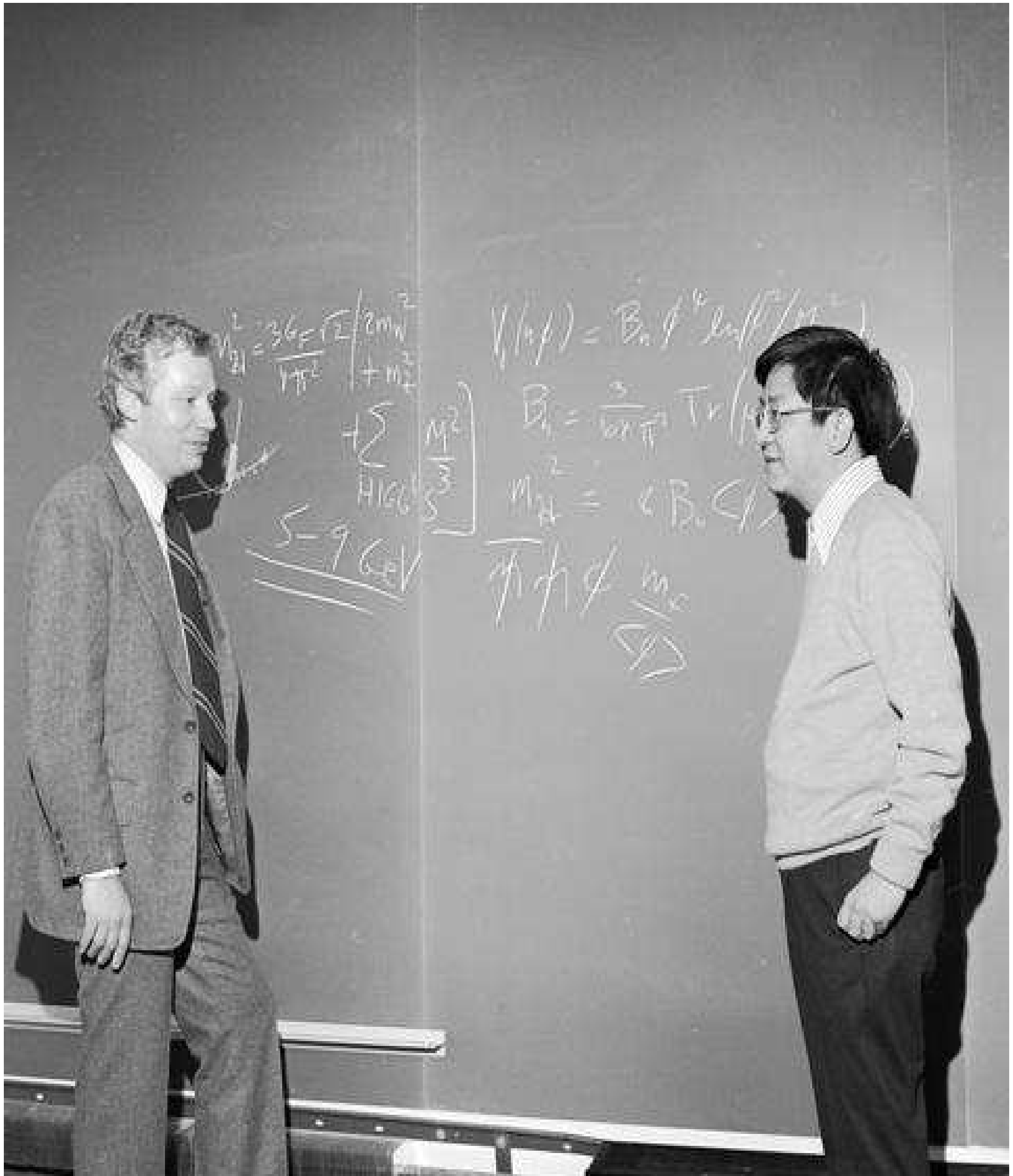
HIGH ENERGY PHYSICS

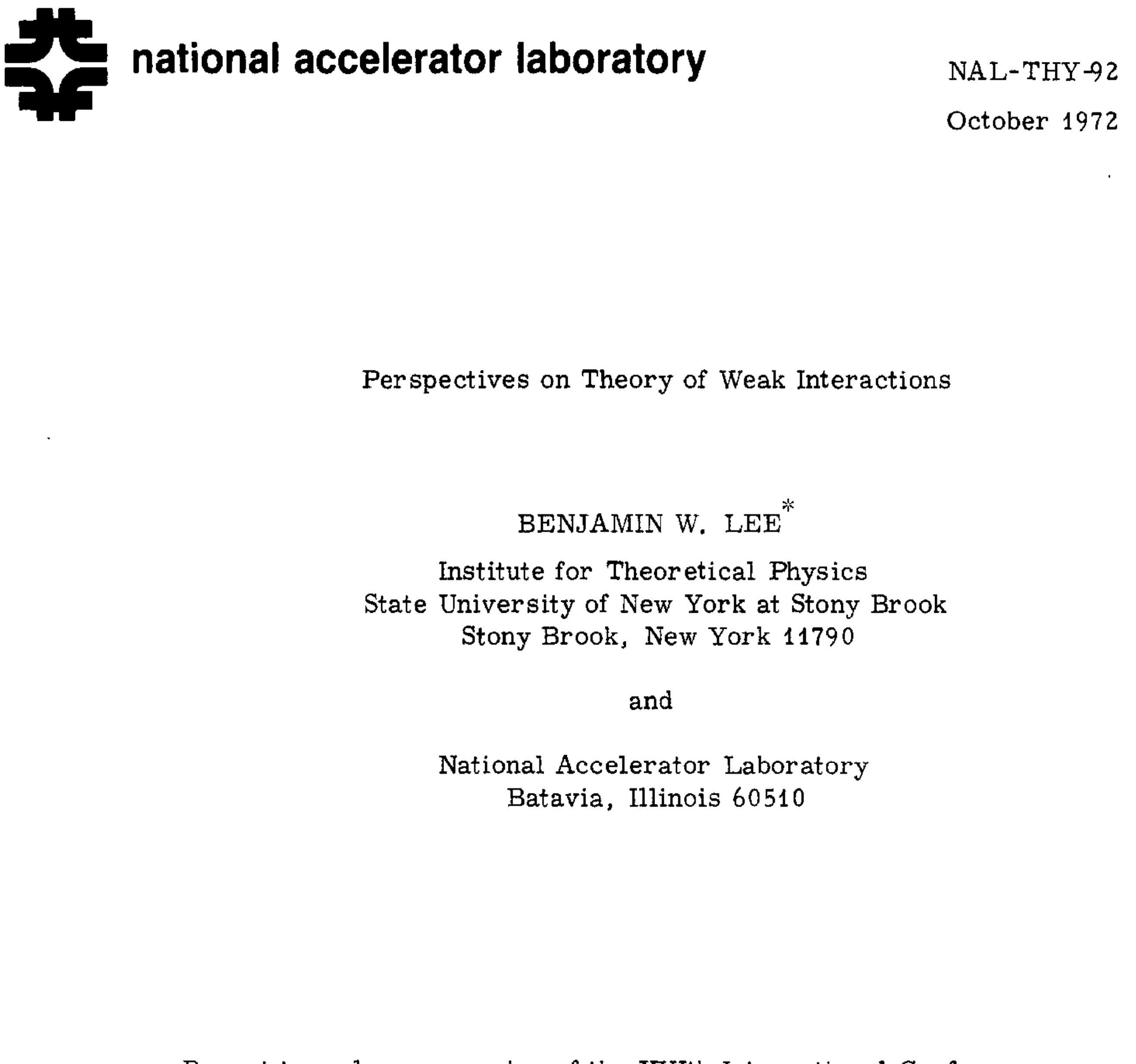
In Memory of

Benjamin Whiso Lee (Jan. 1 1935 - June 16 1977)

J. Iliopoulos, LPTENS, Pohang, June 2009




HIGGS
5–9 GeV



national accelerator laboratory

NAL-THY-92
October 1972

Perspectives on Theory of Weak Interactions

BENJAMIN W. LEE*

Institute for Theoretical Physics
State University of New York at Stony Brook
Stony Brook, New York 11790

and

National Accelerator Laboratory
Batavia, Illinois 60510

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- According to SPIRES they have received more than twelve thousand citations

Early papers. π, K interactions

- P-Wave Resonance in Pion-Pion Scattering. Benjamin W. Lee, Michael T. Vaughn (Pennsylvania U.) . Jun 1, 1960. 2pp. Published in Phys.Rev.Lett.4:578-580,1960.

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Early papers: Sp. Sym. Breaking

- Does Spontaneous Breakdown of Symmetry Imply Zero-Mass Particles? Abraham Klein, Benjamin W. Lee (Pennsylvania U.) . 1964. Published in Phys.Rev.Lett.12:266-268,1964.

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Early papers: σ-model renormalization

- Renormalization of the sigma model. Benjamin W. Lee (Orsay, LPT & IHES, Bures-sur-Yvette) . Dec 1968. Published in Nucl.Phys.B9:649-672,1969.

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Gauge theories: Renormalization

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Some late papers

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- An SU(3) x U(1) Theory of Weak and Electromagnetic Interactions. Benjamin W. Lee, Robert E. Shrock (Fermilab) Jun 1977. 140pp. Published in Phys.Rev.D17:2410,1978.

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- Development of Unified Gauge Theories: Retrospect. Benjamin W. Lee (Fermilab) 1977. 13pp. Talk presented at the Annual Meeting of the American Phys. Soc., Chicago, Ill, Feb 7-10, 1977. Published in Gauge Theories and Neutrino Physics, Jacob, 1978:147 (QCD161:J29)

NEW PHYSICS AT THE

L H C

where Ben’s loss is most painfully felt

Machine parameters

-Circumference: 26658.883 m

-Beam energy: 450 GeV - 7000 GeV

-Nb of protons per bunch: 1.15×10^{11}

-Nb of bunches: 2808

-Circulating beam current: 0.582 A

-Stored energy per beam: 23.3 MJ - 362 MJ

-Peak luminosity: $10^{34} cm^{-2} sec^{-1}$

Precision measurements

at a given energy scale

allow for qualitative predictions

at the next energy scale.

EXAMPLES:
1) Yukawa's prediction of the π meson.

The Physics was accurate, the details were not

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1) Yukawa's prediction of the π meson.

The Physics was accurate, the details were not

2) The absence (with high accuracy!) of strangeness changing neutral current transitions and the smallness of the $K_1 - K_2$ mass difference allowed the prediction of charmed particles.

In the same way New Physics is predicted for LHC

THE STANDARD MODEL

$$U(1) \times SU(2) \times SU(3)$$

THE STANDARD MODEL

$$U(1) \times SU(2) \times SU(3)$$

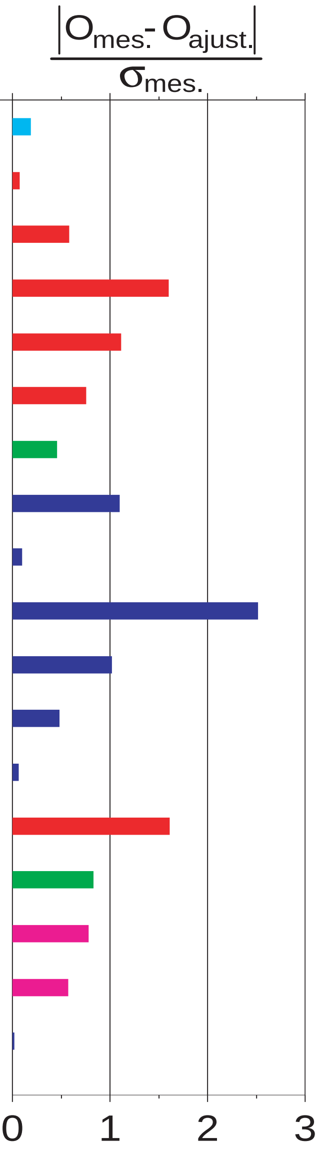
$$\Downarrow$$

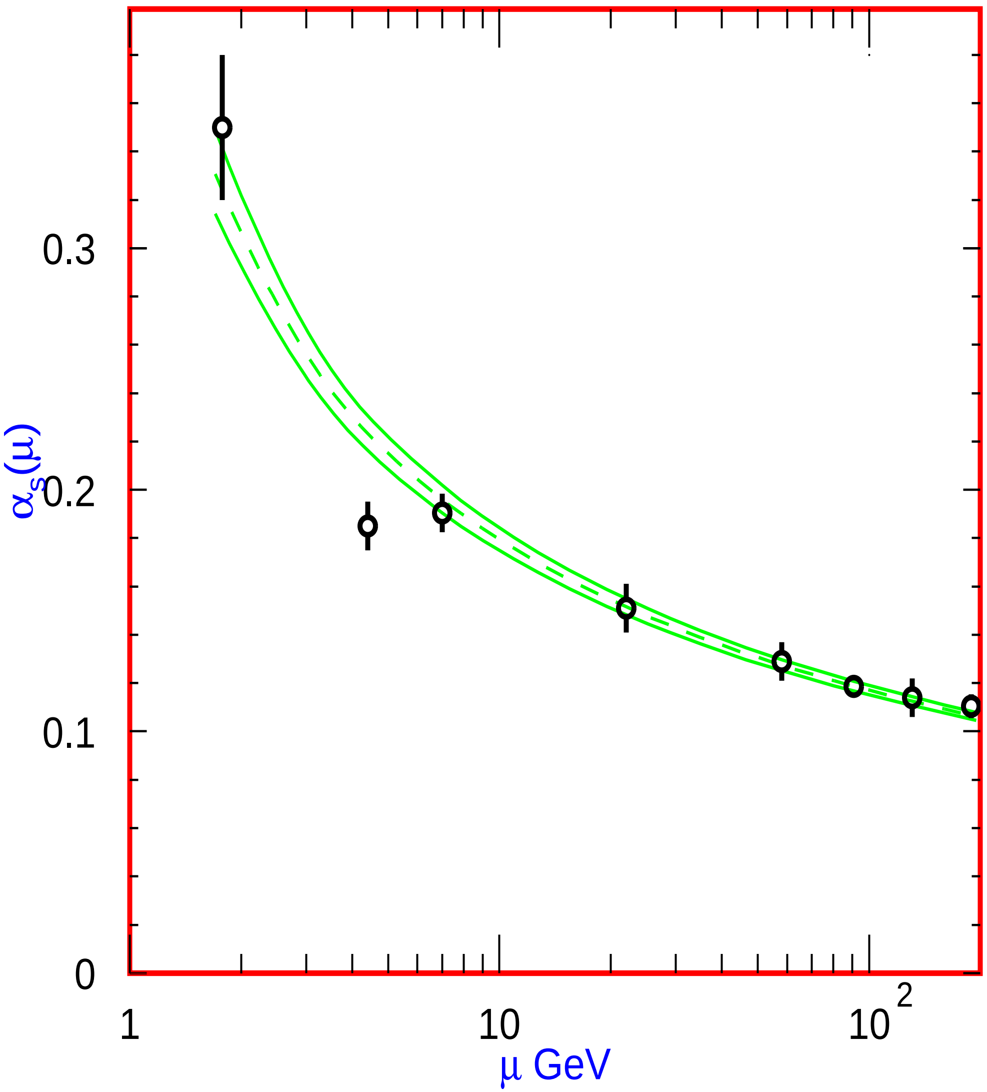
$$U(1)_{em} \times SU(3)$$

THE STANDARD MODEL

HAS BEEN ENORMOUSLY SUCCESSFUL

Observable	Mesure	Ajustement
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02761 ± 0.00036	0.02768
m_Z [GeV]	91.1875 ± 0.0021	91.1873
Γ_Z [GeV]	2.4952 ± 0.0023	2.4965
σ_{had}^0 [nb]	41.540 ± 0.037	41.481
R_l	20.767 ± 0.025	20.739
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01642
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1480
R_b	0.21638 ± 0.00066	0.21566
R_c	0.1720 ± 0.0030	0.1723
$A_{fb}^{0,b}$	0.0997 ± 0.0016	0.1037
$A_{fb}^{0,c}$	0.0706 ± 0.0035	0.0742
A_b	0.925 ± 0.020	0.935
A_c	0.670 ± 0.026	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1480
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.425 ± 0.034	80.398
Γ_W [GeV]	2.133 ± 0.069	2.094
m_t [GeV]	178.0 ± 4.3	178.1




$\alpha_s(\mu)$
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10
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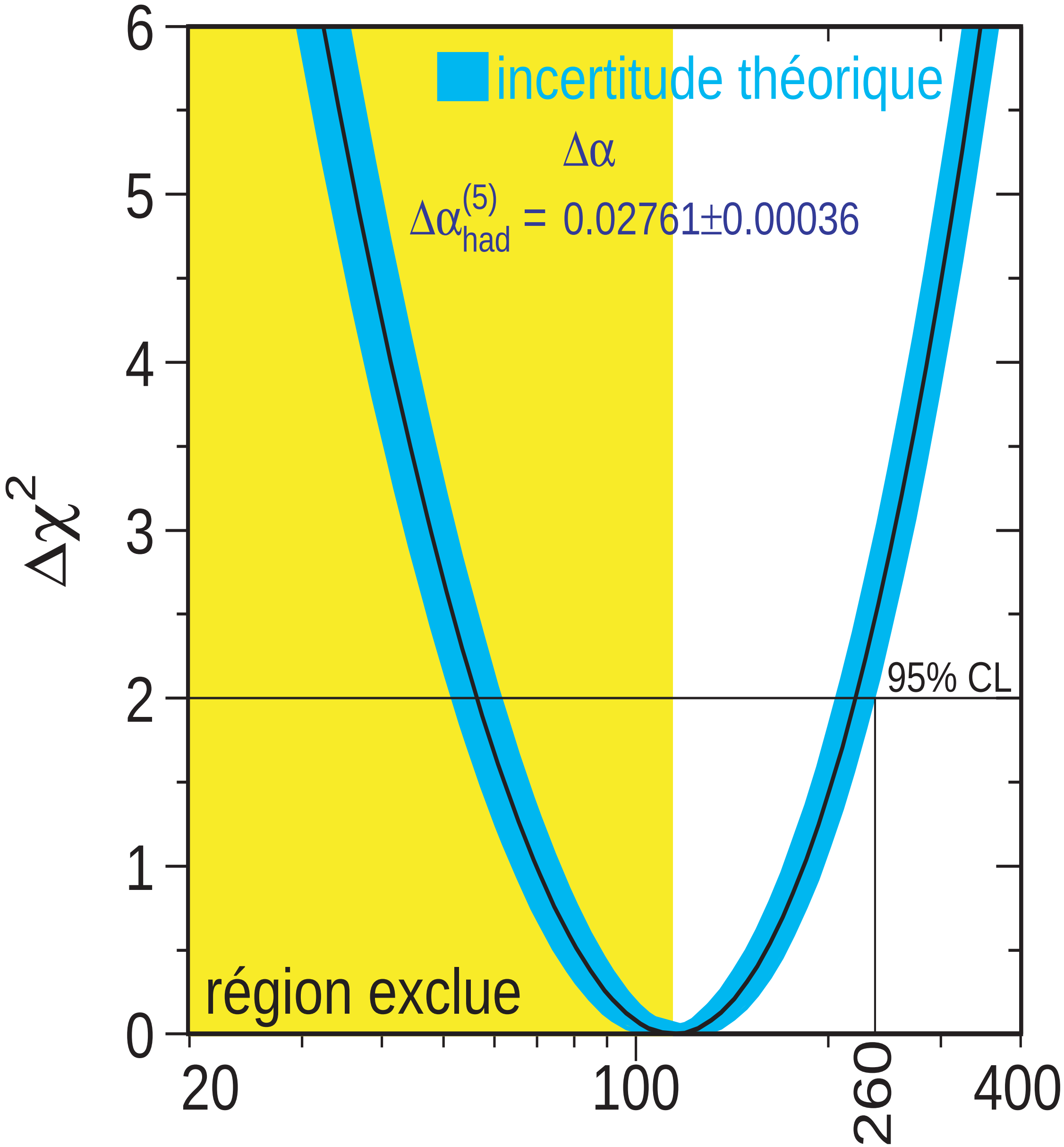
μ GeV


6
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🟦 incertitude théorique
Δα
$\Delta\alpha^{(5)}_{had}$ = 0.02761±0.00036
95% CL
région exclue
20
100
260
400

What we have learnt

What we have learnt

Perturbation theory is remarkably reliable

What we have learnt

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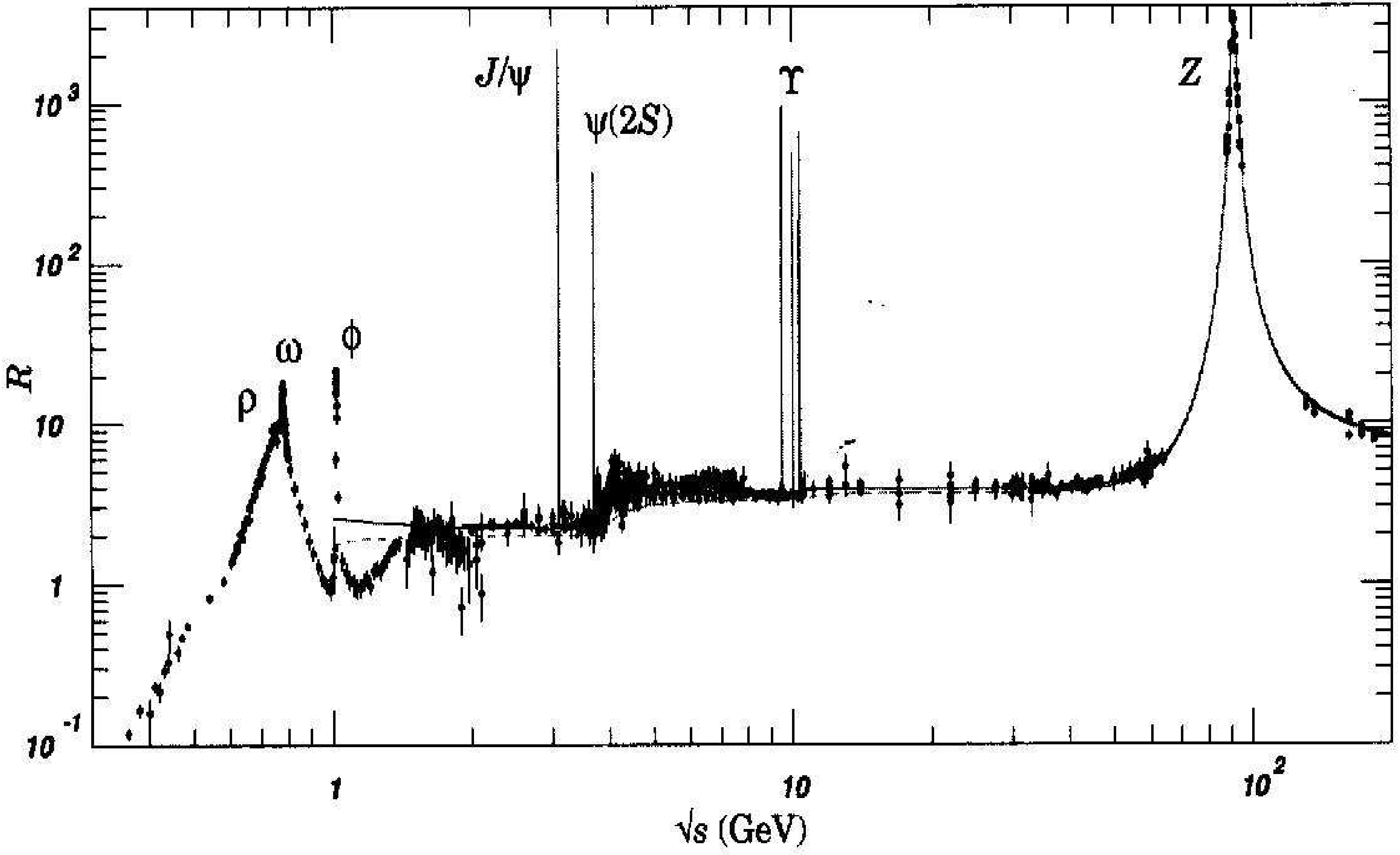
Outside the region of strong interactions


J/ψ
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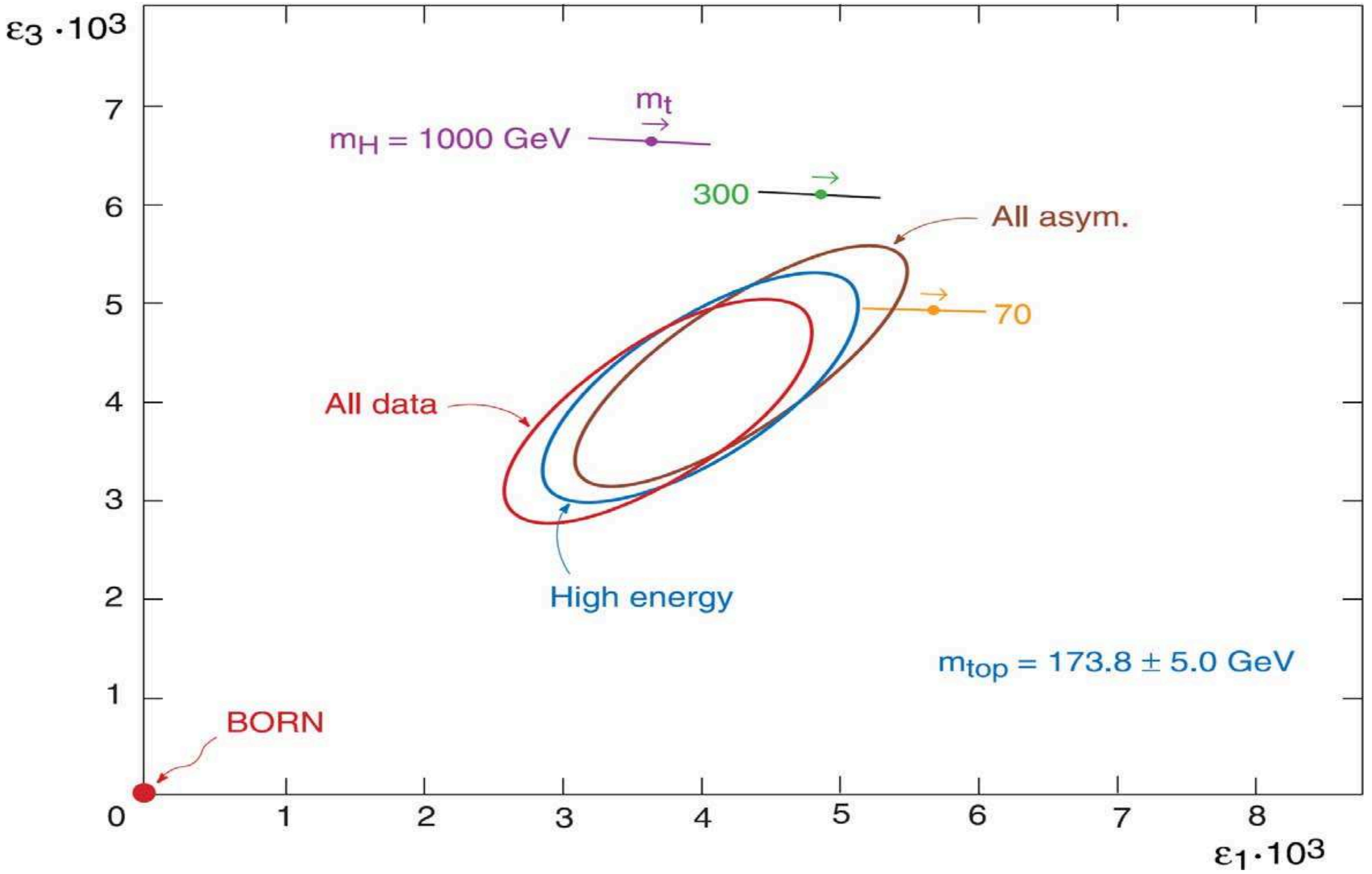

Figure 6: Data vs theory in the ϵ_3-ϵ_1 plane (notations as in fig.5)

Why?

-We do not really understand why.

Why?

Dyson's argument:

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

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

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

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

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 will be unravelled at the LHC.
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.

First task of LHC

Study the Higgs sector of the theory.

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Study the Higgs sector of the theory.

Limits on the Standard Model Higgs mass:

1) $m_H \geq$ 114 GeV (Exp.)

2) m_H = 85^{+39}_{-28} GeV (From global fit)

3) $m_H \leq \mathcal{O}$(1TeV) (Validity of perturbation)

4) $m_H \geq \mathcal{O}$(130GeV) (Vacuum stability)

$$\mathbf{m_H^2} \sim \lambda$$

$$\frac{d\lambda}{dt} = \frac{3}{4\pi^2}[\lambda^2 + 3\lambda h_t^2 - 9h_t^4 + ...]$$

Validity of perturbation

The Landau pole does not occur up to Λ

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$$\Lambda \sim 1TeV \rightarrow m_H \leq 0.8TeV$$

Validity of perturbation

The Landau pole does not occur up to Λ

$$\Lambda \sim 1TeV \rightarrow m_H \leq 0.8TeV$$

$$\Lambda \sim 10^{16}GeV \rightarrow m_H \leq 180GeV$$

Vacuum stability

$$\lambda > 0$$

for $\Lambda \sim 10^{16} GeV$

$$m_H \geq 130 GeV$$

Possible (Predictable) LHC Results

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1) A Light Higgs is found

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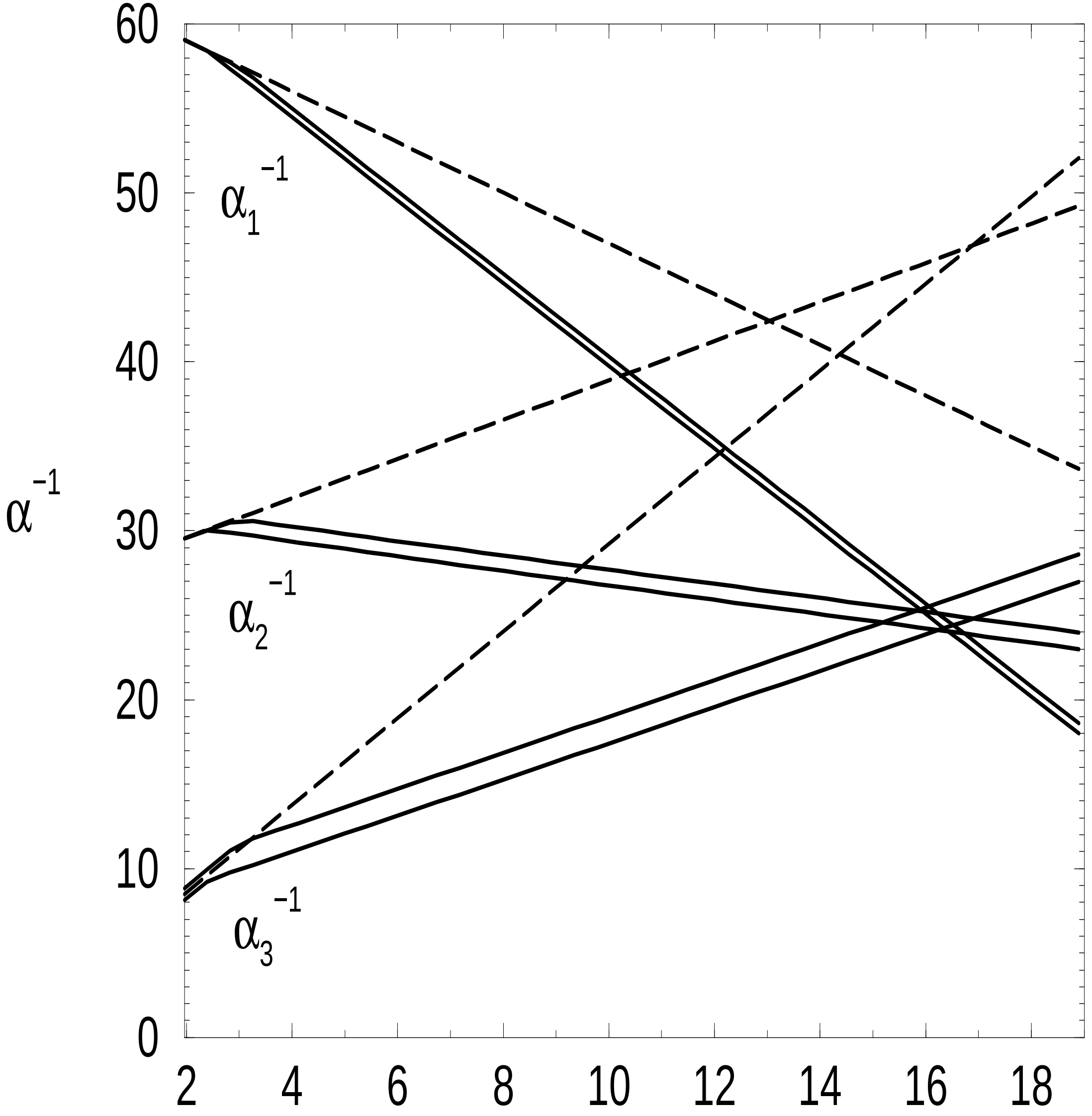
Hierarchy

Possible (Predictable) LHC Results

1) A Light Higgs is found

Hierarchy

$\Rightarrow$ -Supersymmetry


α^{-1}
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20
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40
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8
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12
14
16
18

Possible (Predictable) LHC Results

1) A Light Higgs is found

Hierarchy

$\Rightarrow$ -Supersymmetry

Possible solution of the dark matter problem

Possible (Predictable) LHC Results

1) A Light Higgs is found

Hierarchy

$\Rightarrow$ -Large extra dimensions

Possible (Predictable) LHC Results

2) No Light Higgs is found

New Strong Interactions

Possible (Predictable) LHC Results

2) No Light Higgs is found

New Strong Interactions

1) Technicolor

The Higgs boson is a bound state of new, heavy fermions

Possible (Predictable) LHC Results

2) No Light Higgs is found

New Strong Interactions

2) Little Higgs

The Higgs boson is a pseudo-Goldstone boson of a new symmetry

Possible (Predictable) LHC Results

THE ABSENCE OF A LIGHT HIGGS IMPLIES NEW PHYSICS

BUT A LIGHT HIGGS IS UNSTABLE WITHOUT NEW PHYSICS

CONCLUSIONS

THE TIME FOR SPECULATIONS WILL BE SOON OVER!

L.H.C. IS COMING

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NEVER BEFORE AN EXPERIMENTAL FACILITY WAS LOADED WITH SO GREAT EXPECTATIONS