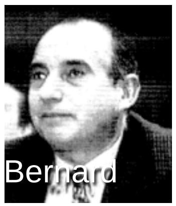
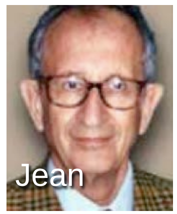
Jean Tran Thanh Van

50 years of Moriond

Daniel Treille

Tran was helped in this groundbreaking initiative by five colleagues: Bernard Grossetête, Fernand Renard, Michel Gourdin, Jean Perez Y Jorba and Pierre Lehmann.





"rencontres"
gathering of minds

1966: 20 participants

theorists and experimentalists

young and less young actors

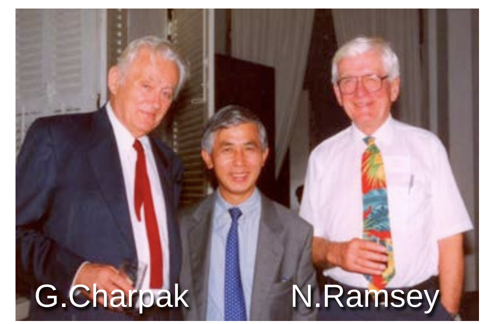
success and evolution

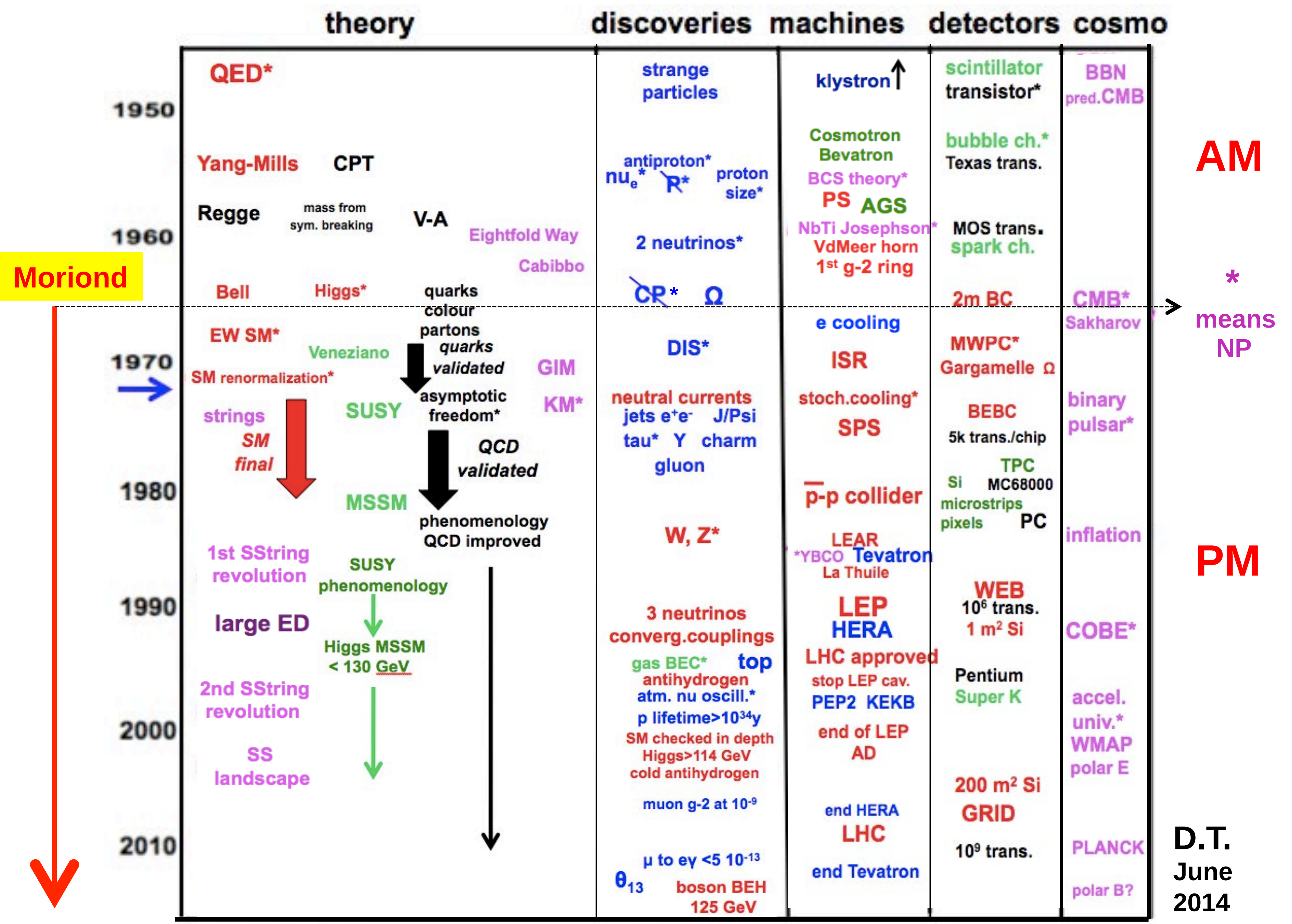
1970: add a biology meeting
1981: Moriond Astrophysics
developments: rencontres of Vallée d'Aoste, Blois, Vietnam
but unique spirit lives on

J.Cronin at 20 years of Moriond
"… profound effect on the way we communicate in particle physics"

same from Ludwik Celnikier at 40 years

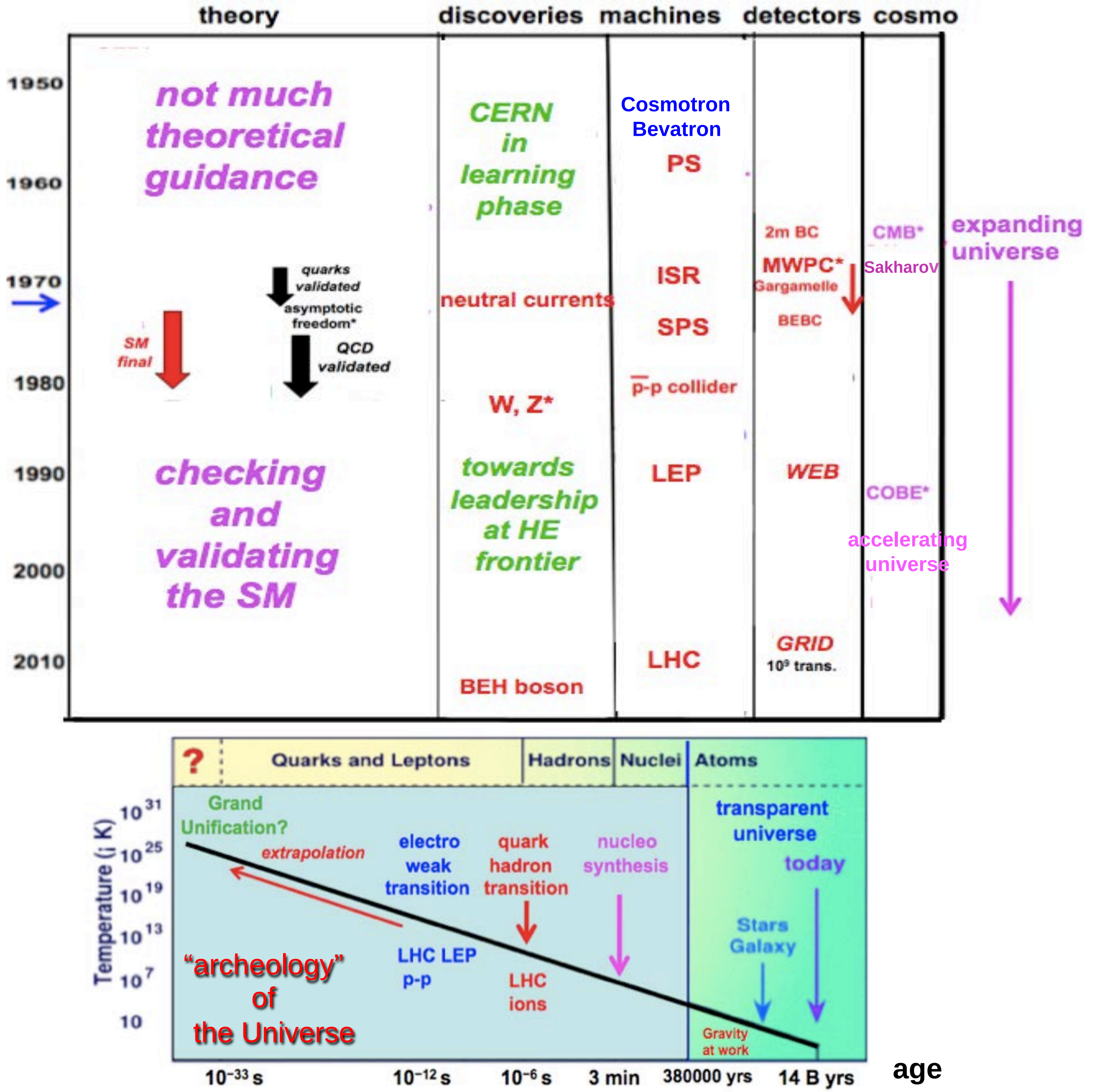
Humility of A.Martin in 67 summary:
"je ne vous cacherai pas combien il est embarrassant de tirer les conclusions d'une pareille rencontre"





theory
discoveries
machines
detectors
cosmo
1950
1960
1970
1980
1990
2000
2010
Moriond
QED*
Yang-Mills
CPT
Regge
mass from sym. breaking
V-A
Eightfold Way
Cabibbo
Bell
Higgs*
quarks
colour
partons
EW SM*
Veneziano
quarks validated
GIM
SM renormalization*
asymptotic freedom*
KM*
strings
SM final
SUSY
QCD validated
MSSM
phenomenology QCD improved
1st SString revolution
SUSY phenomenology
large ED
Higgs MSSM < 130 GeV
2nd SString revolution
SS landscape
strange particles
antiproton*
nu_e*
R*
proton size*
2 neutrinos*
CP*
Ω
DIS*
neutral currents
jets e^+e^-
J/Psi
tau*
Y
charm
gluon
W, Z*
3 neutrinos
converg.couplings
gas BEC*
top
antihydrogen
atm. nu oscill.*
p lifetime>10^{34}y
SM checked in depth
Higgs>114 GeV
cold antihydrogen
muon g-2 at 10^{-9}
μ to eγ <5 10^{-13}
$θ_{13}$
boson BEH 125 GeV
klystron
Cosmotron
Bevatron
BCS theory*
PS
AGS
NbTi Josephson*
VdMeer horn
1^{st} g-2 ring
e cooling
ISR
stoch.cooling*
SPS
$\bar{p}$-p collider
LEAR
*YBCO
Tevatron
La Thuile
LEP
HERA
LHC approved
stop LEP cav.
PEP2
KEKB
end of LEP
AD
end HERA
LHC
end Tevatron
scintillator
transistor*
bubble ch.*
Texas trans.
MOS trans.
spark ch.
2m BC
MWPC*
Gargamelle Ω
BEBC
5k trans./chip
TPC
Si
MC68000
microstrips
pixels
PC
WEB
10^6 trans.
1 m^2 Si
Pentium
Super K
200 m^2 Si
GRID
10^9 trans.
BBN
pred.CMB
CMB*
Sakharov
binary pulsar*
inflation
COBE*
accel. univ.*
WMAP
polar E
PLANCK
polar B?
AM
* means NP
PM
D.T.
June 2014

since 1966
much change
in the scenery!



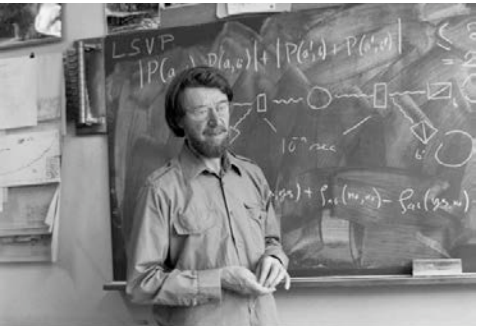
a good time to start… mirabilis 1964

Bell inequalities

ON THE EINSTEIN PODOLSKY ROSEN PARADOX*

J. S. BELL†
Department of Physics, University of Wisconsin, Madison, Wisconsin

(*Received* 4 *November* 1964)


John Bell and his famous theorem in 1982 (Image: CERN)


A.Aspect John Bell

Evidence for the 2π Decay of the K_2^0 Meson

Phys. Rev. Lett. **13**, 138 – Published 27 July 1964

J. H. Christenson, J. W. Cronin, V. L. Fitch, and R. Turlay

CP

A Measurement of Excess Antenna Temperature at 4080 Mc/s.

Penzias, A. A.; Wilson, R. W.
AA(Bell Telephone Laboratories Inc.), AB(Bell Telephone Laboratories Inc.)

Astrophysical Journal, vol. 142, p.419-421 (ApJ Homepage)
07/1965

CMB

BROKEN SYMMETRY AND THE MASS OF GAUGE VECTOR MESONS*

F. Englert and R. Brout
Faculté des Sciences, Université Libre de Bruxelles, Bruxelles, Belgium
(Received 26 June 1964)

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs
Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland
(Received 31 August 1964)

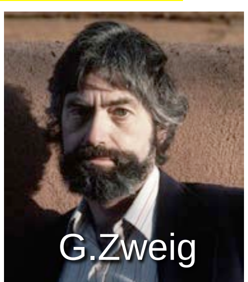
BEH boson

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
nia Institute of Technology, Pasadena, California

quarks

Received 4 January 1964



VOLUME 12, NUMBER 8 PHYSICAL REVIEW LETTERS 24 FEBRUARY 1964

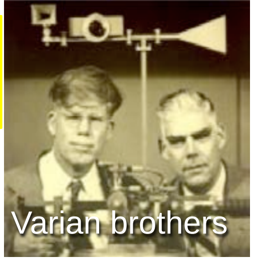
OBSERVATION OF A HYPERON WITH STRANGENESS MINUS THREE*

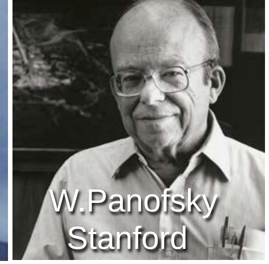
V. E. Barnes, P. L. Connolly, D. J. Crennell, B. B. Culwick, W. C. Delaney, W. B. Fowler, P. E. Hagerty,† E. L. Hart, N. Horwitz,† P. V. C. Hough, J. E. Jensen, J. K. Kopp, K. W. Lai, J. Leitner,† J. L. Lloyd, G. W. London,‡ T. W. Morris, Y. Oren, R. B. Palmer, A. G. Prodell, D. Radojičić, D. C. Rahm, C. R. Richardson, N. P. Samios, J. R. Sanford, R. P. Shutt, J. R. Smith, D. L. Stonehill, R. C. Strand, A. M. Thorndike, M. S. Webster, W. J. Willis, and S. S. Yamamoto
Brookhaven National Laboratory, Upton, New York
(Received 11 February 1964)

Ω

colliders

no klystron
no HEP…



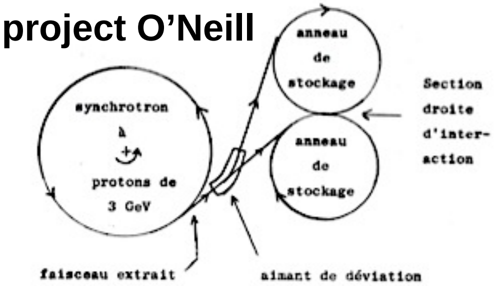


If $(E_2^!)^2 \gg 1$ and $(E_1^!)^2 \gg 1$,

$$E^2_{CM} = 2 + 4E_1^! E_2^! \simeq 4E_1^! E_2^!$$

Kerst

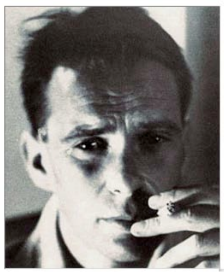
project O'Neill



Collider pioneers: Wideroe 43 Kerst et al, 56 Petoukhov 57 G.K.O'Neill 56

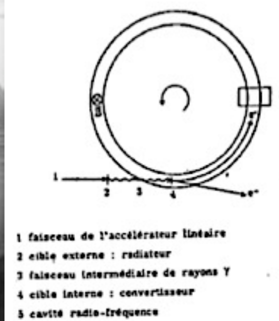
e^+e^-

J.Haissinski
Moriond 66

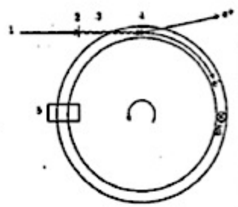


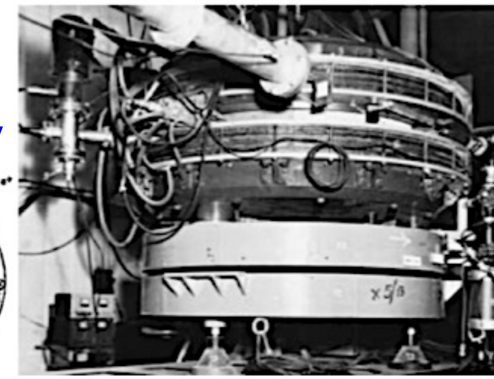
P.Marin

B.Touschek
Touschek effect



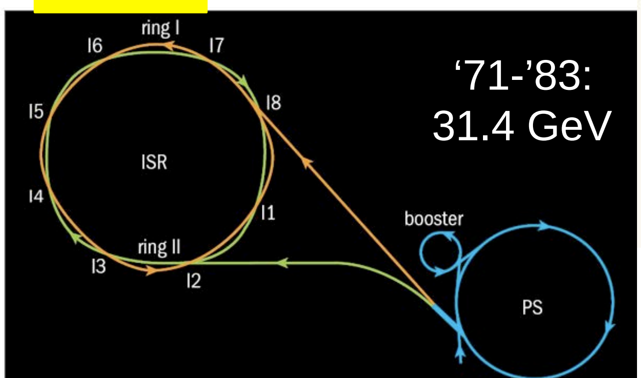
ADA 64
Frascati
LAL Orsay

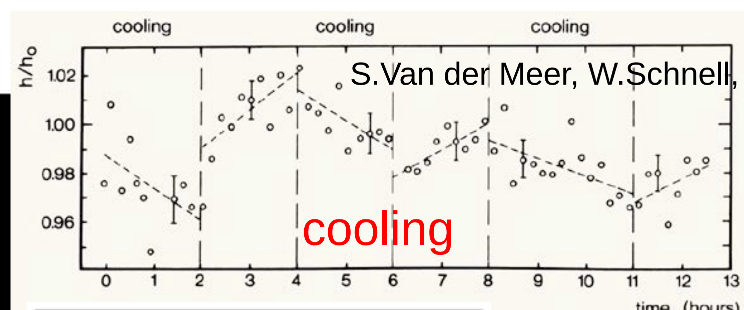




Then ACO, VEPP2, ADONE, DCI, CEA, SPEAR, DORIS, DAΦNE, etc, e.g. **J.Perez y Jorba 76 F.Renard**
machine problems: vacuum, instabilities, nonlinearities and ways to cure them e.g. **V.Silvestrini 69**

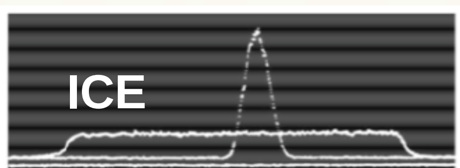
ISR



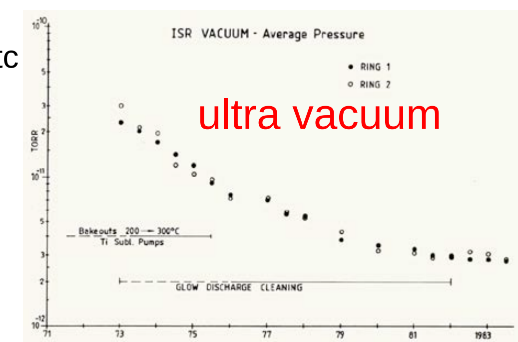


S.Van der Meer, W.Schnell, etc

cooling



antiprotons
CERN, Fermilab
LEAR, AD



ultra vacuum

SC low β quadrupoles

Detectors

the ancestors are not far away

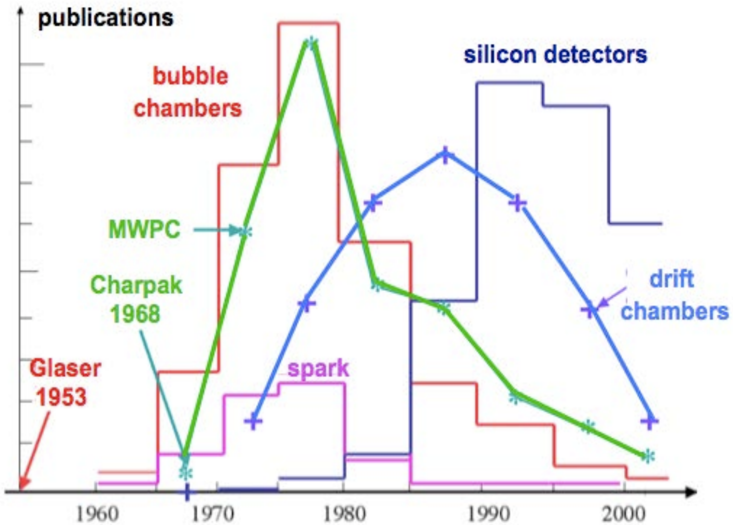
Wilson chamber 1912 Geiger-Muller 1928 scintillators 1947-50 BC 1953

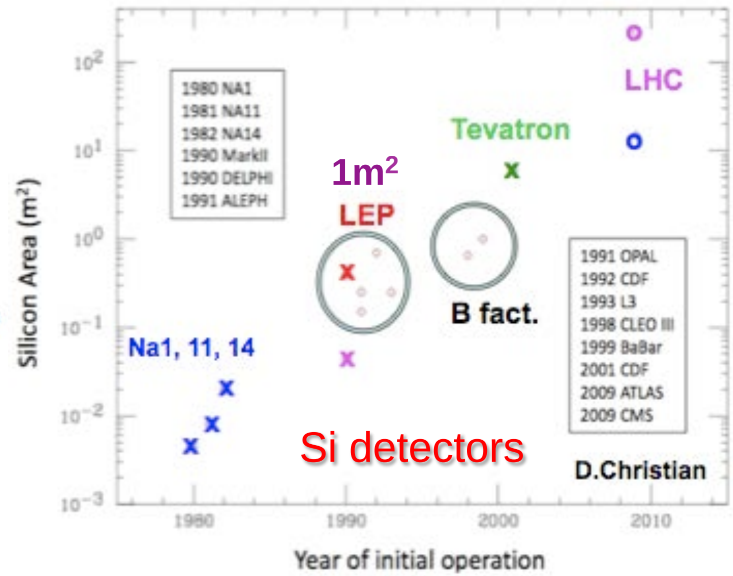
reign of bubble chambers

"années d'apprentissage"
success of big chambers

triggered detectors

49-59: spark chambers development
various read out methods, from film to filmless

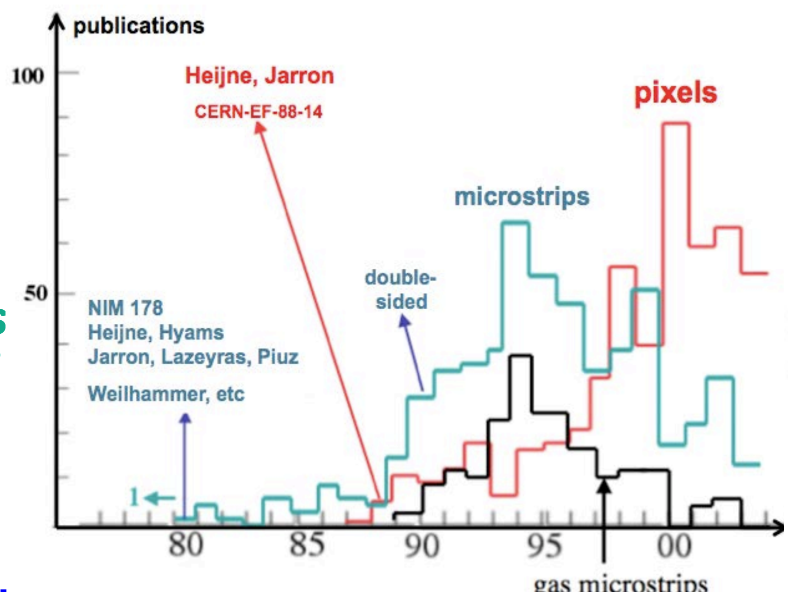




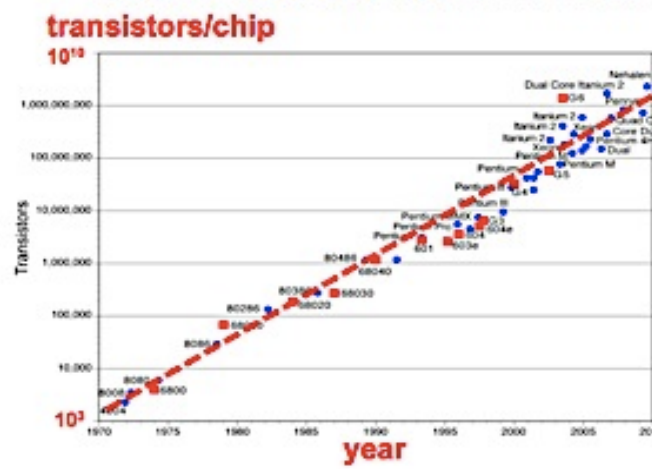
the 68 revolution

G.Charpak Nobel 1992

MWPC, drift chamber, multistep (F.Sauli), TPC (Nygren)



and vital role of micro electronics..



rise of Si detectors

from cm² to hundred m²
fast evolution of microelectronics

→identification of particles

T.Ypsilantis: RICH, $\overline{p}$

→calorimetry

→crucial role of R&D

radiation hardness, etc

→important spin off

https://indico.cern.ch/event/331449/

The Quark Story

Strange particles come in ‘47 – ’61: pre-BC techniques, cosmic rays, in BC mostly found in US

introduction of strangeness

Nishijima-Nakano
M. Gell-Mann
1953-1956

quarks simplest SU(3) representation
but not taken literally
M.Gell-Mann 1964
NP 1969

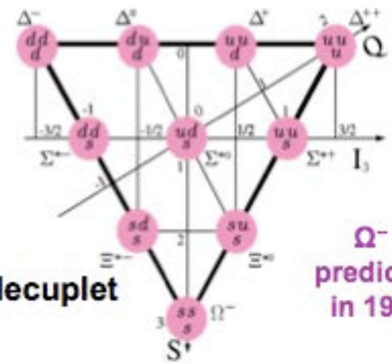
at CERN
G.Zweig
“aces”

$|\mathrm{Baryon}\rangle = |qqq\rangle$

$|\mathrm{Meson}\rangle = |q\bar{q}\rangle$

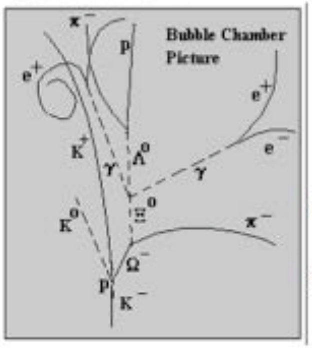
others?

the Eightfold Way
La Voie Octuple
G-M, Y.Ne’eman
1960



$J^P = \frac{3}{2}^+$ decuplet

Ω^- predicted in 1962



Ω^- found
1964
still in US

then reduction à la Mendeleev

However .....

D.Gross Nobel lecture

Fierce battle between S-matrix and field theory   see H.Pietschmann   UWThPh-2010-15

Regge theory $A(z) \propto s^{l(t)}$ $l(s) = ks$ logarithmically rising cross sections,

Pomeron   D.Leith 73

> A mysterious entity called the Pomeron has been regularly discussed here in La Thuile, often with the aside that no one under the age of (you choose: 40 ... 50 ... 60 ...) has any idea what it is. The other side of the coin is that colleagues over whatever age you chose do not really know what it is either, but they may at least know what it is supposed to stand for!

C.Quigg 2008

Duality Dolen, Horn, Schmid   Veneziano formula 1968

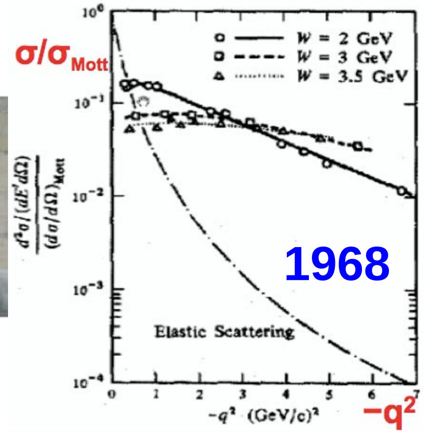
Bootstrap i.e. full democracy, no fundamental particle   S-matrix axioms   G.Chew, etc

Les Houches 1965   Chew, Analytic S-Matrix; Dalitz, Quark Models for the Elementary Particles;

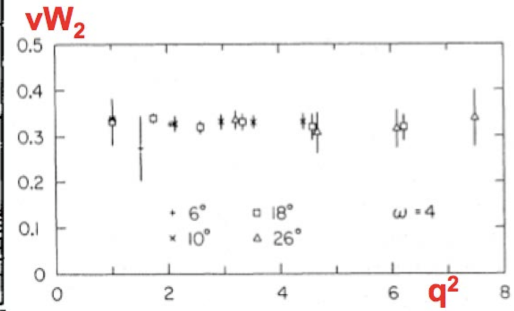
from the experimental side:

avalanche of resonances
end 70ies: ≈ 100 strongly interacting particles

L.Montanet



Friedman, Kendall, Taylor



scattering on pointlike charged spin ½ “partons” which will become the quarks

and Deep Inelastic Scattering

➔partons Bjorken scaling

➔quarks winning as fundamental objects

search for free quarks

C.Llewellyn Smith 81

M.Gell-Mann One atomic spectroscopist friend of mine rings me up, sometimes at midnight, to report his progress in a search for quarks in sea water. He has electrolysed a huge amount of sea

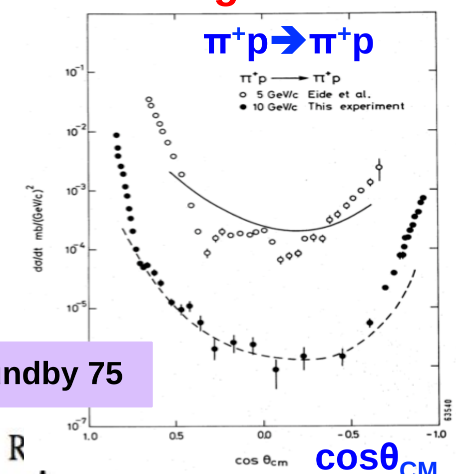
constituent and current quarks current algebra

➔large angle hadron scattering

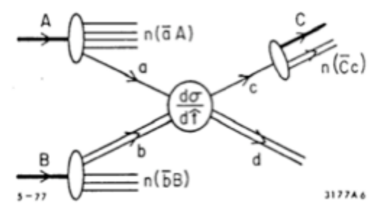
1973 ISR: partons are also pointlike for strong interaction

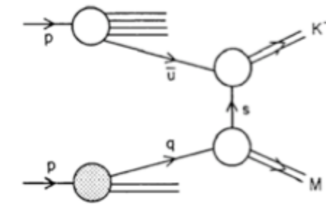
A.Yokosawa, G.Farrar 75
R.Blankenbecler 76

Constituent Interchange Model
no need to solve confinement

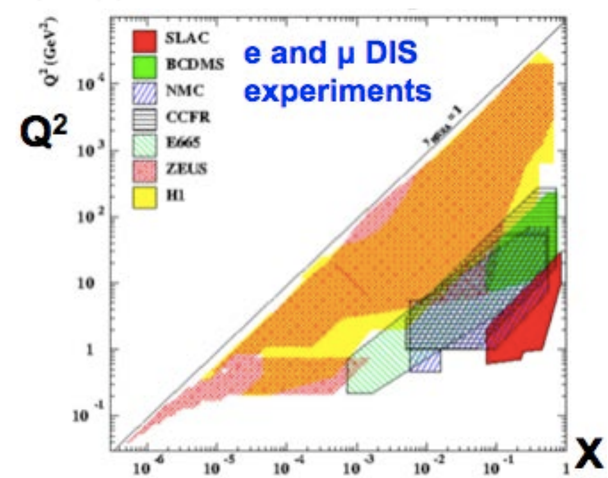


Lundby 75

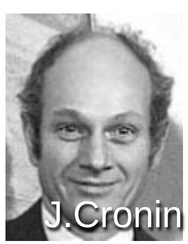


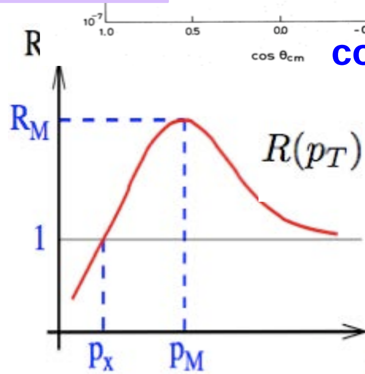


$$\frac{d\sigma}{d^3p/E}(pp \to K^- X) \sim \frac{\epsilon^{11}}{(p_T^2+m^2)^4} f(\theta_{c.m.}) \qquad \epsilon = \mathcal{M}^2/s = (1-x_T) \text{ at } \theta_{c.m.} = \pi/2$$



Cronin effect 78





$$R(p_T) = \frac{B}{A} \frac{d\sigma_{pA}/d^2p_T}{d\sigma_{pB}/d^2p_T}$$

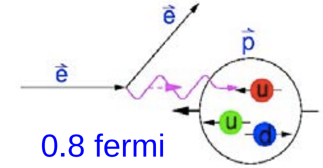
rescattering?

➔systematic exploration of the nucleon with all probes

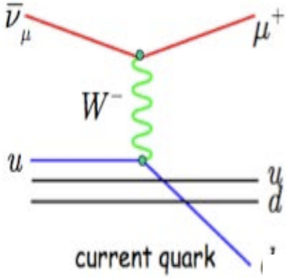
the proton our daily life

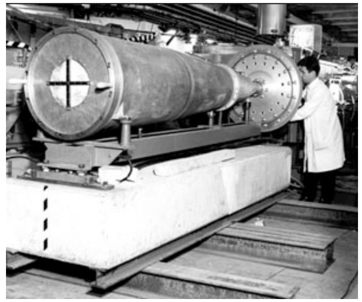
1957 in Stanford e⁻ scattering
finite size of the proton
Hofstadter NP 1961

1968 in Stanford the proton contains
point-like objects NP 1990



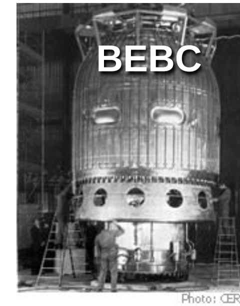
➔ neutrino scattering





van der Meer horn

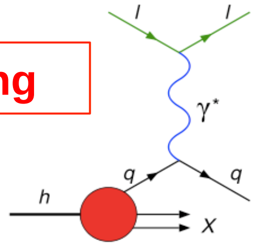
CHARM. NOMAD, CHORUS, US expts



and GARGAMELLE
decided in 65

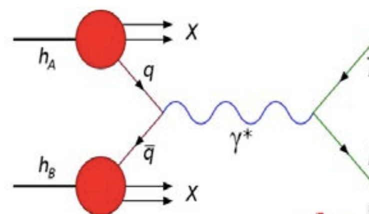
➔ muon scattering

EMC, NA4
E203 E665

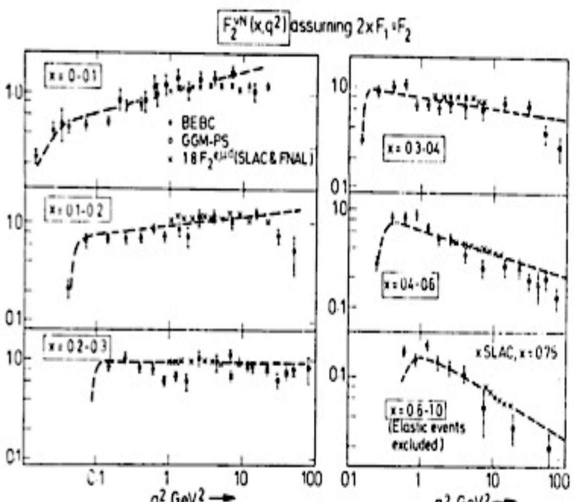


➔ hadron scattering

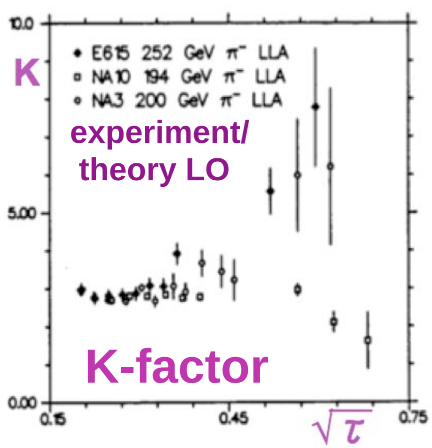
Select photon or lepton in final state
WA11, NA3, WA70, etc



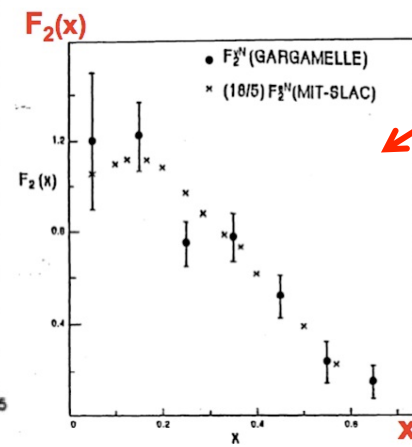
HERA (e-p) took over



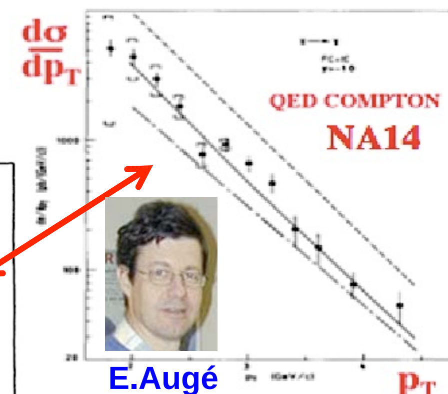
scaling violation, a lot of work
to decrease systematic errors



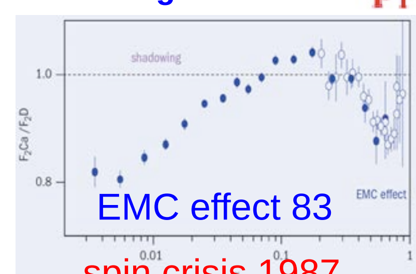
J.Peoples 80
"QCD not yet proven"



fractional charge



E.Augé



EMC effect 83

spin crisis 1987

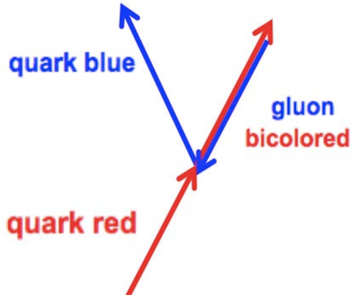
The road to QCD see Guido

Color **Greenberg 64 symmetric quark model explains π^0, R ratio**

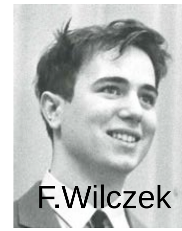
65 Han-Nambu three sets of quark triplets Integer electric charge

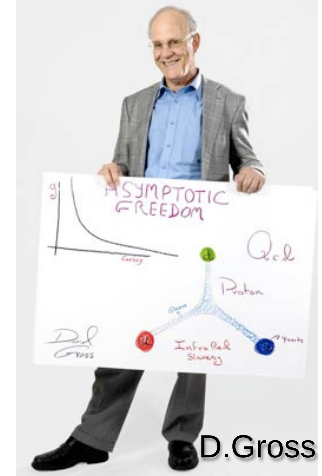
Gell-Mann-Zweig versus Han-Nambu quarks C.Llewellyn Smith 74

71-72 Fritsch-Gell-Mann name "gluons", "QCD"



1973 Asymptotic Freedom



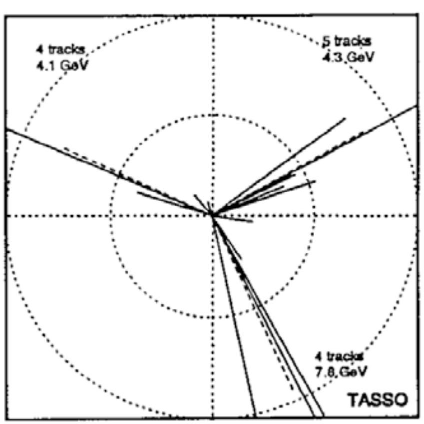


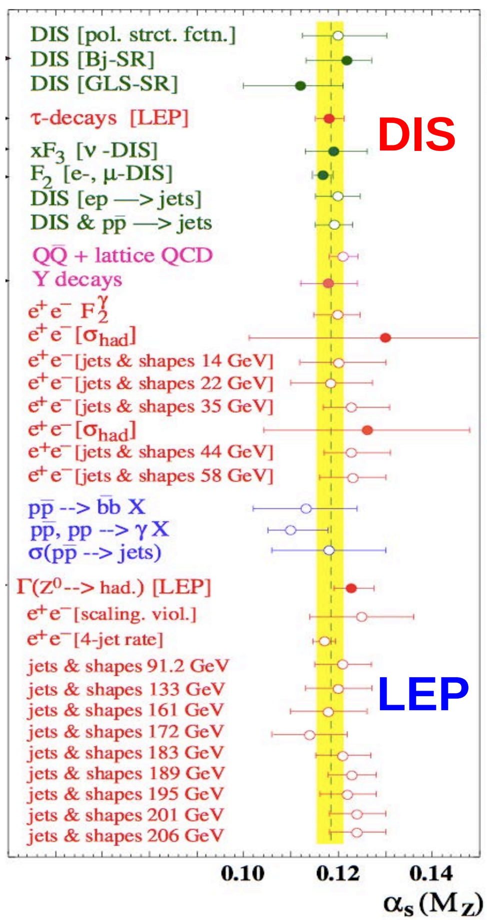
72-77 DGLAP evolution equations see G.Altarelli 1106.3189

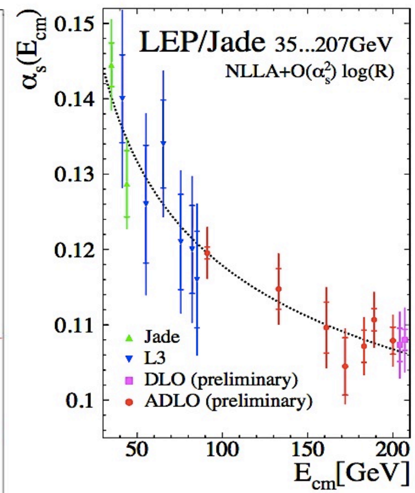
J.Ellis 76 no evidence yet of Asymptotic Freedom tells how to "sniff out glue"

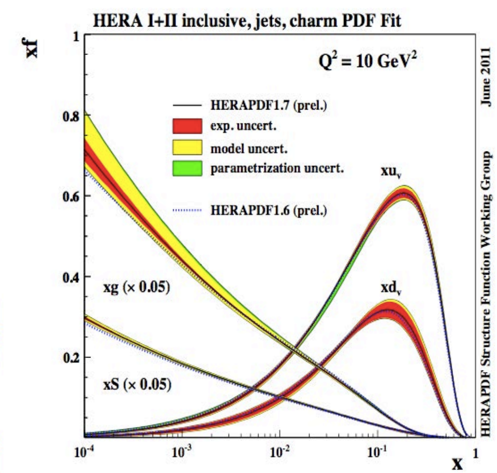
L.Hand 79 QCD or not? Need gluon

DESY quark jet 78
gluon jet 79







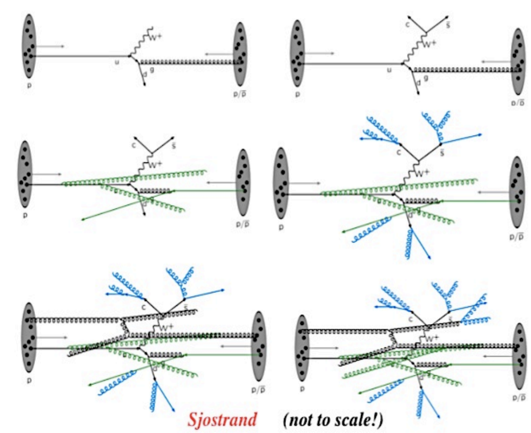


HERA: accurate knowledge of the structure functions

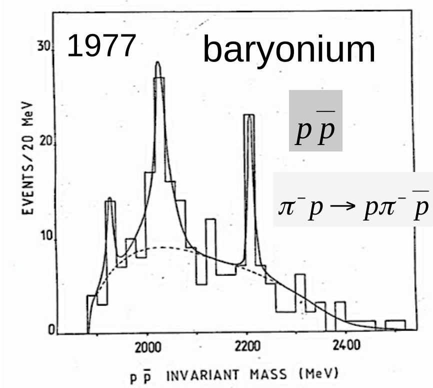
higher orders needed

K.Ellis 2006 etc
monumental work !

vital for LHC

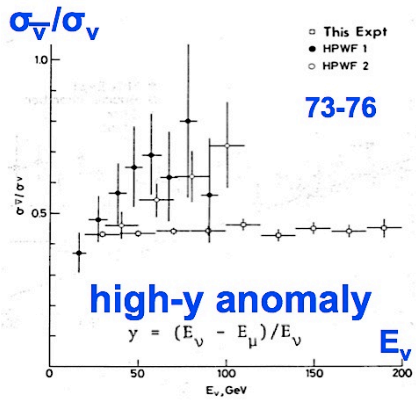


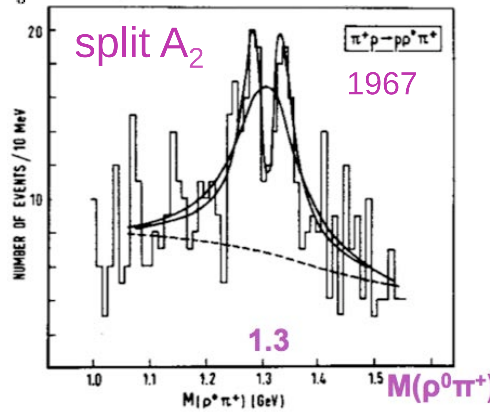
"pandemonium"

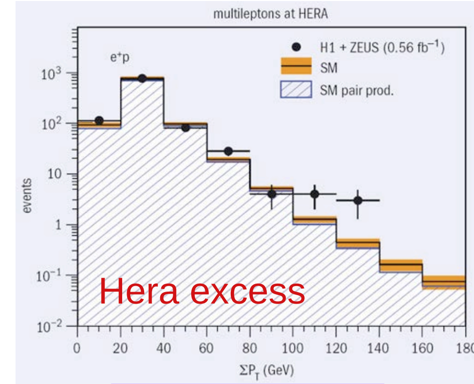


Measurements on niobium spheres which show unambiguously the existence of fractional charges of $\frac{1}{3}e$ are reported.

Fairbanks 81



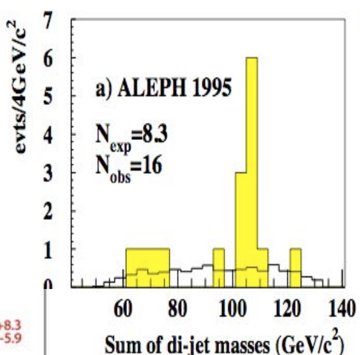


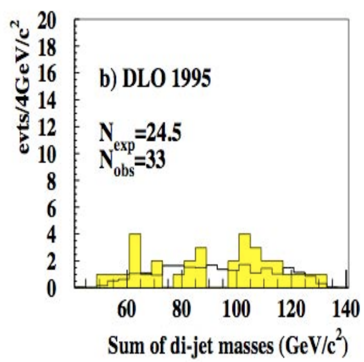


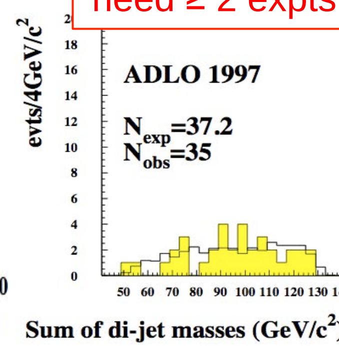
J.F:Grivaz 97

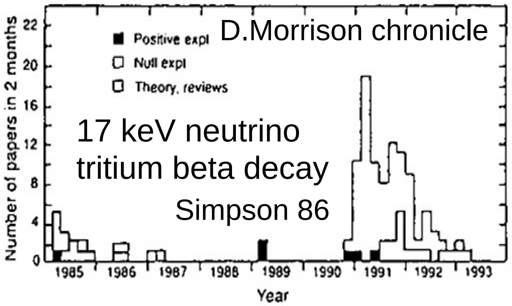
need ≥ 2 expts

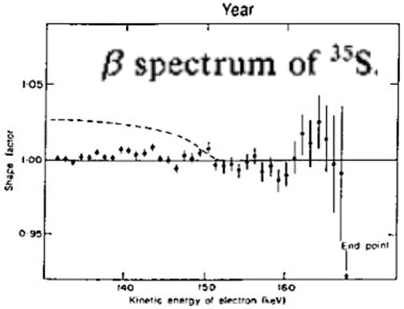
"Evidence For Achions Or Axions " in 2 photons
Helmut Faissner, Les Arcs 1981



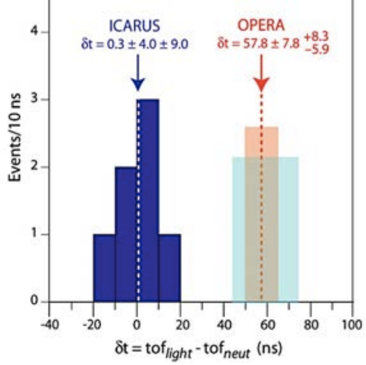








superluminal neutrinos



[12]The Moriond Workshops play an extremely important role in speculative/controversial issues. They provide a forum for those working in the field to meet, present papers, and have both formal and informal discussions and criticism. For a discussion of the role that the Moriond workshops played in another controversial episode, that of the fifth force, a proposed modification of Newton's law of gravity, see Franklin (1993a).

In his summary[3] of this conference one year ago, the first three experimental topics mentioned by John Collins were the excess of high Q^2 events at HERA, the excess of high E_T inclusive jets in CDF data, and the excess of $W+1$ jet events, relative to W's without jets, reported by DØ. At this meeting, important new results were presented that bear directly on these topics, to which I now turn.

Strovink 98

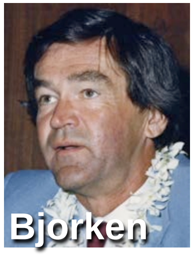
under scrutiny

- ✧ 3.5 keV line?
- ✧ DB Heidelberg?
- ✧ DAMA oscillation?

towards three generations

muon 1937 its neutrino 1962
strangeness 1953-56

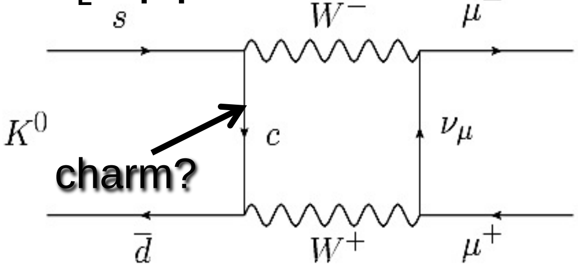
1963
Cabibbo
angle
accounting for
strangeness
production

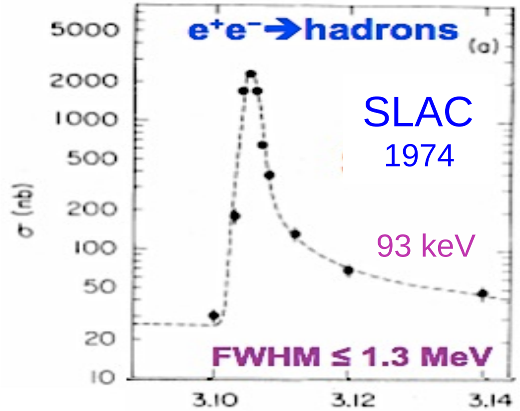


Bjorken, Glashow 64

GIM
1970

$K_L \rightarrow \mu^+\mu^-$ unobserved then





J/Psi: Richter-Ting NP 1976

charmonium charm 1976
2^{nd} generation is there

Kobayashi Maskawa
1973 / NP 2008
a third generation?

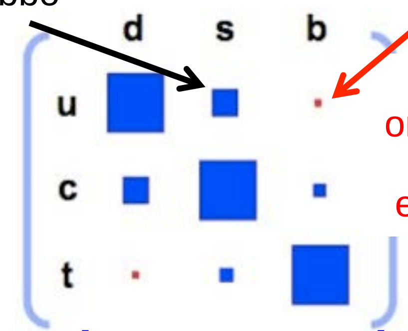
tau lepton
M.Perl 1975 NP 1995

quark top: see later

LEP: 3 ν-species

3^{rd} generation is there

Cabibbo



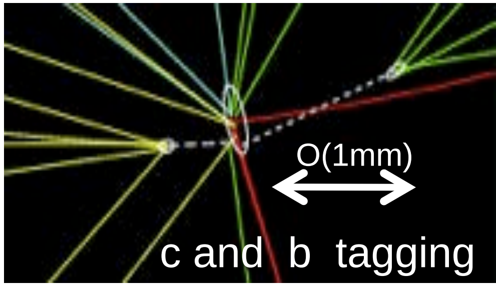
phase
may be one key of our existence

the CKM matrix
relationship between quarks

stimulating, but some frustration at CERN…
then lot of heavy flavor spectroscopy (SPS, LEP, LHC, Tevatron, etc)

example of hadroproduction

Flavour	Experiment
charm	NA11, NA16, NA27, E743, NA32, WA75, WA82, E769, E791, E706
beauty	NA10, WA78, UA1, E706/E672, E771
both	E653, E789, WA92, CDF, HERA-B



20 CERN SPS exp^{ts} on heavy flavor physics 60 exp^{ts} in Omega spectrometer

However, ...

❖ **Charm**

anticipated   missed

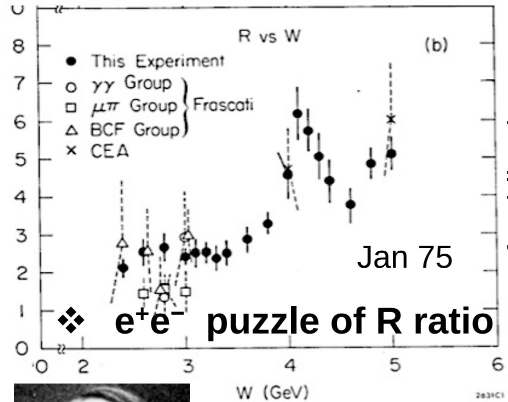
✧ Charm spectroscopy launched Si det industry

✧ Charmonium anticipated? CERN trauma charm search at Ω PS

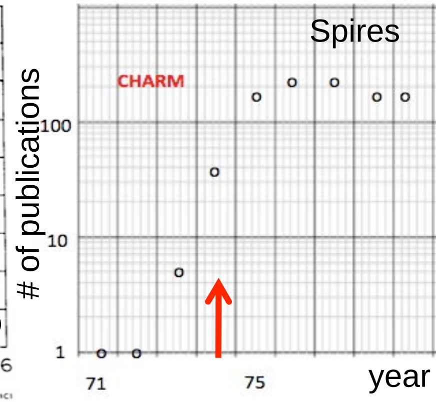
spectroscopy, potential

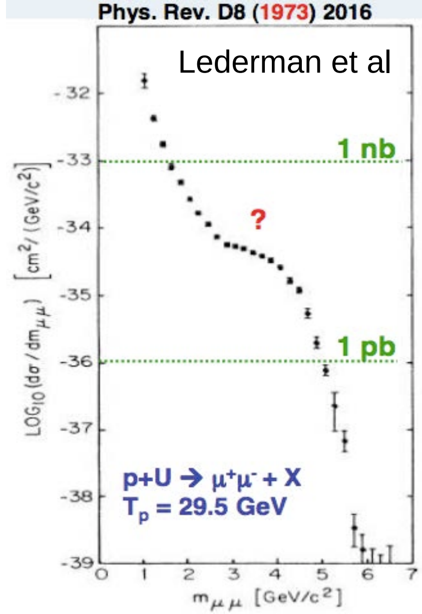
"There are just three possibilities: **S.Glashow** april 1974

1. Charm is not found and I eat my hat
2. Charm is found by hadron spectroscopy, and we celebrate
3. Charm is found by outlanders, and you eat your hats."



❖ e^+e^- **puzzle of R ratio**





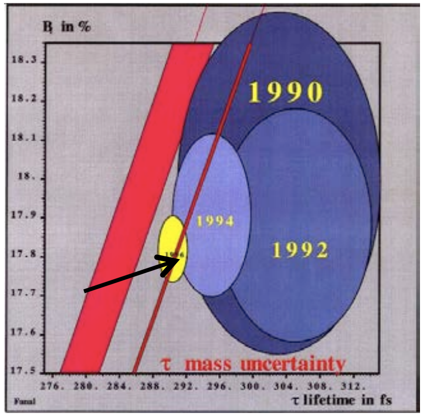
$$\Gamma_{\psi_c} \simeq 0.2\,(m_{\psi_c}/m_\psi)\,\Gamma_\psi \simeq 2\,MeV$$

$$\frac{\Gamma(\psi_c \to \ell^+\ell^-)}{\Gamma_{\psi_c}} \simeq 1\% \quad \text{for } R = 8\ (m_{\phi_c} = 2)$$

M.K.Gaillard et al 1974

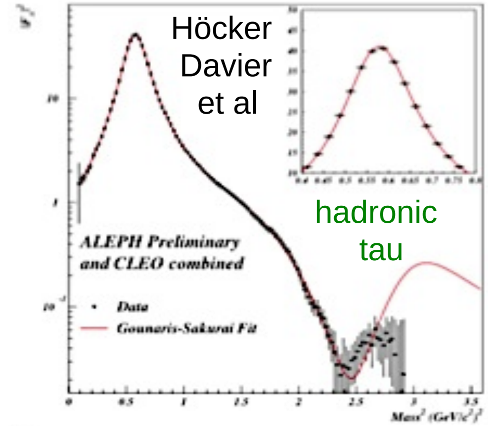
BR

H.Videau



world enterprise BES, LEP, CESR

lifetime



hadronic tau

❖ 3rd generation or more?

Harari 76

Upsilon, first at 6 GeV ('Oops-Leon'), then at 9.5 GeV (1977)

Tau in 1975   M.Perl and L.Lederman 78

1978: ϒ in PLUTO and DASP at DORIS

1979 CLEO and CUSB at CESR

Tau controversy   Paschos 89

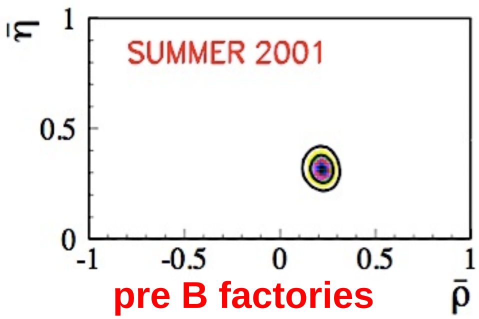
solved, then tau used as a laboratory

Was the b-quark seen at ISR?

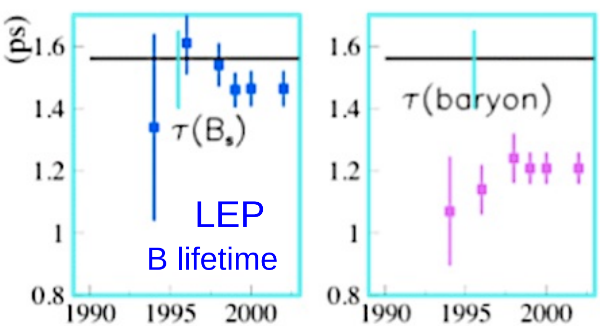
mixing: UA1 1986, ARGUS at DORIS2 1987

emphasis on B physics, lattice   Paschos 89

Then PETRA LEP B factories   LHC



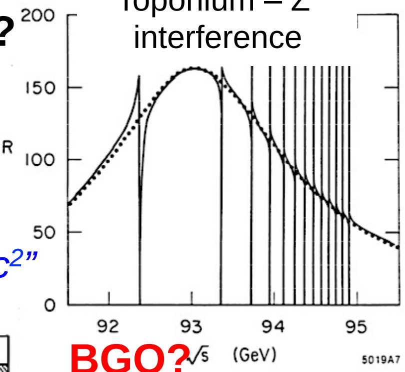
pre B factories



Top story

Does Bare Bottom Rule Out the Topless E6 Model (1983)?

Toponium – Z interference



Search for the top quark with UA1 M.Della Negra, les Arcs 89

Heavy top production as a source of WW events 86 – 87 D.Denegri 89

84 "Agreement with the process W→ tb followed by t → blv, 30 GeV/c^2 < m_{top} < 50 GeV/c^2"

89 UA + CDF > 61-77 GeV/c^2

BGO?

83: Wyler et al (τ_B), Glashow et al (τ_B); Ibanez Ross 92

Peoples 80 toponium > 38 GeV

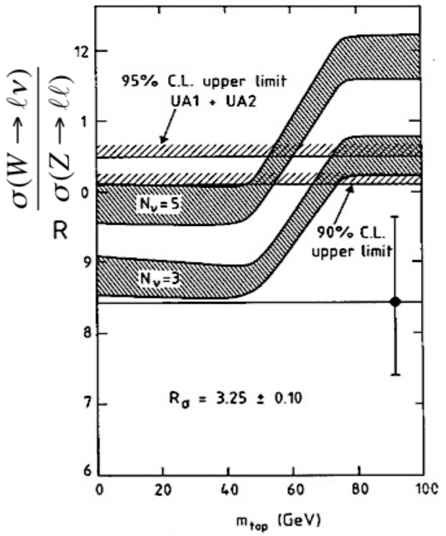
Paschos 89 top very likely > 60 GeV

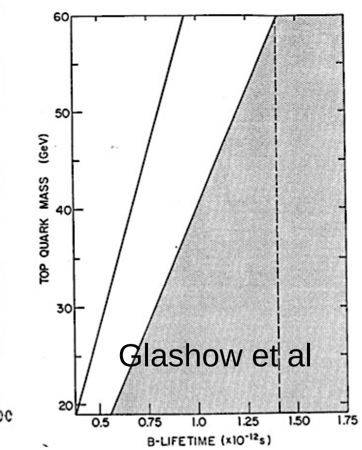
Quigg 91 M_t > 89 GeV Barbieri 93 M_t > 108 GeV

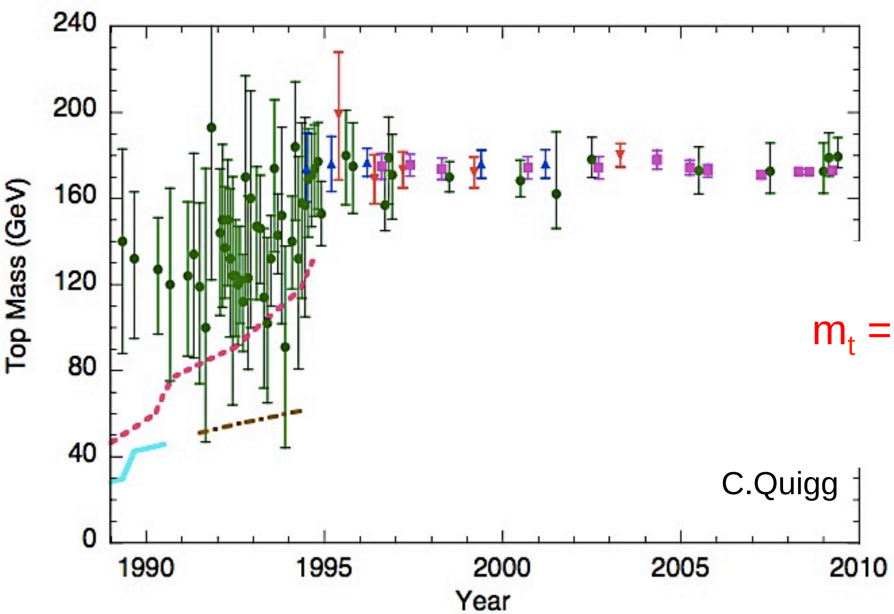
C.Jarlskog 90 (Langacker) $M_t = 143^{+37}_{-44}$

Dydak 91 LEP1 indirect $m_t = 131^{+27}_{-32}$ + Higgs

Quigg 94 $m_t = 177^{+11+18}_{-11-19}\,GeV$







direct 1996

m_t = 172 ± 6 GeV

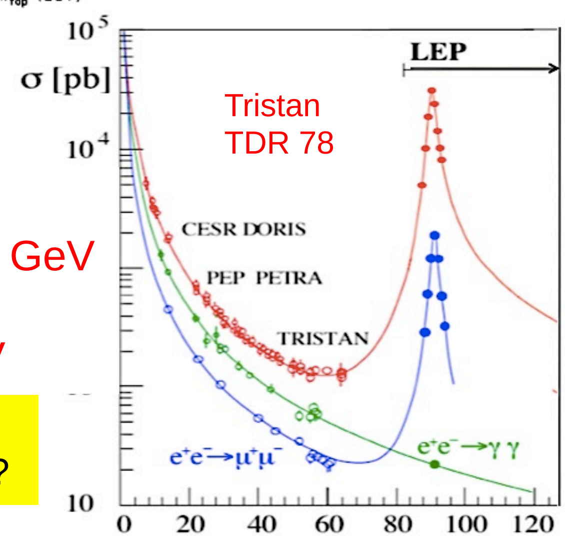
Now (world average)

m_t = 173.34 ± 0.27 ± 0.71 GeV

indirect

$m_t = 175.8^{+2.7}_{-2.4}$ GeV

but what does this value actually mean?



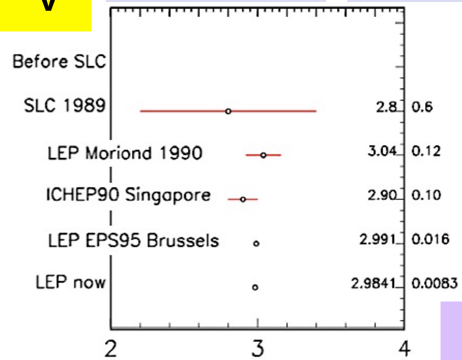
Early 1960	CERN initiates feasibility study : ν flux and shielding (Krienen, Steinberger, Salmeron) bubble chambers (EP and NPA) and counter-cloud chamber chamber (Faissner)
May 1960	SPC: very promising
Summer 1960	AGS at BNL completed : Lederman, Schwartz and Gaillard propose 10 t spark chamber
November 1960	CERN decides to carry out ν experiment in 2 stages (#1) quick 2-3 weeks run in June 1961
May 1961	Alarm : v.Dardel measures secondary π flux and concludes that ν flux was overestimated by factor 10
June 1962	BNL finds two ν species

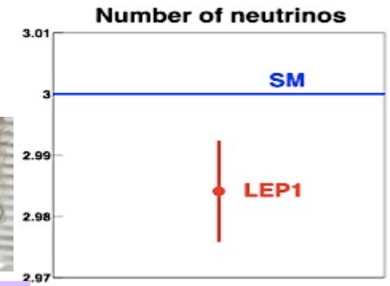
the 2 neutrinos

D.Haidt

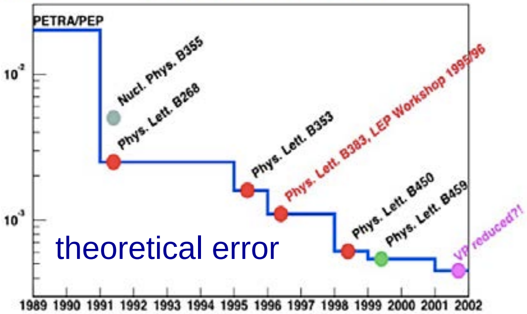
N_ν

Steigman 86 Paschos 89 N_ν<4 astro <5.5 W and Z





C.Jarlskog 90 $"N_\nu" \equiv \Gamma_{inv} / \Gamma_\nu \leq N_{fam}$



theoretical error

Bhabha cross section, luminometers

	A	D	L3	O	
1992	0.15	0.38	0.50	0.41	%
1995	0.080	0.09	0.068	0.034	%

an example of a great collaboration between theorists and experimentalists

Number of Neutrinos
LEP1
single gamma: 3.00 ± 0.08
lineshape: 2.9835 ± 0.0083

radiative return promising for future

Neutrino saga

S.P.Rosen 86 G.Altarelli 2014
F.Vannucci 87
M.Deutsch 88, etc

Dydak 91 17 keV neutrino?

20 years of solar ν puzzle

discovery of oscillations

but not in the domain of accelerators, until long baselines as Minos, T2K

PS191 NOMAD

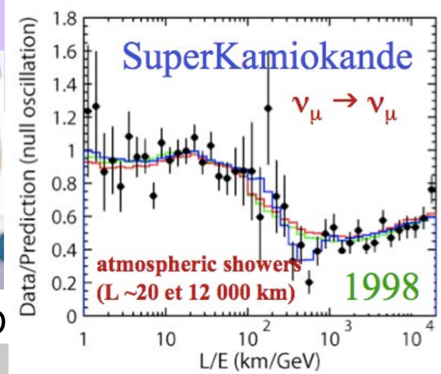
measure PMNS matrix

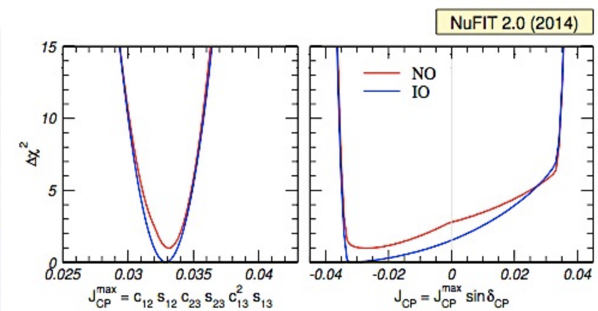
SNO 2000-04, Kamland, Daya Bay 2012, ...

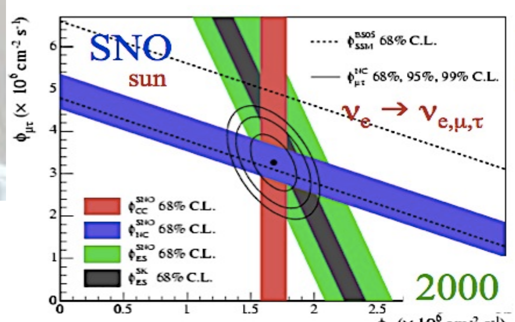
hierarchy? CP violation?

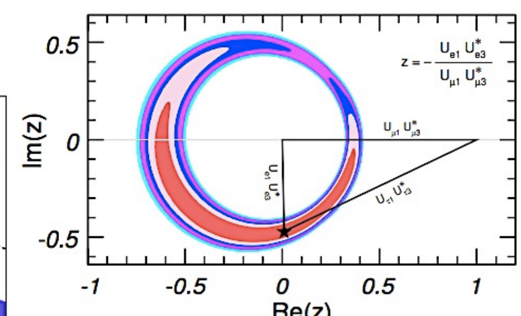
neutrinoless double beta decay?

sterile ν? LSND Kayser 2003 eV, keV, GeV?



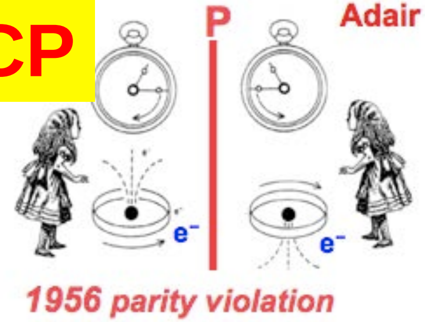




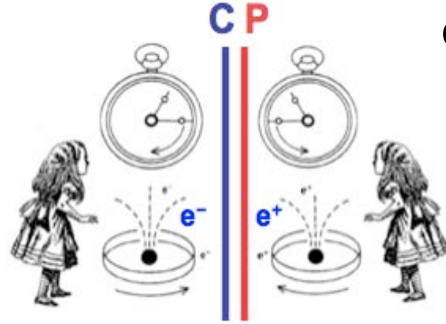


a summary in 1409.5439

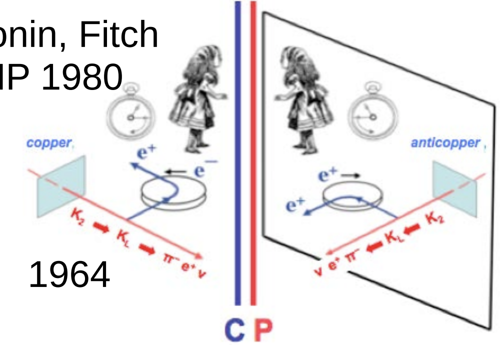
CP



Lee, Yang, Wu



Cronin, Fitch
NP 1980



R.Turlay

Superweak theory?

Wolfenstein 64

$$|K_L\rangle = (|K_2\rangle + \epsilon|K_1\rangle)(1+|\epsilon|^2)^{-1}$$

$$G_{sdsd}(\bar{s}\mathcal{O}d)(\bar{s}\mathcal{O}d) + \text{h.c.},$$

10^{-10} to 10^{-11} of G_F

Silvestrini
Steinberger 69
compare η_{00} and η_{+-}

Schwitters 82
expt^s assembled to measure R at 1%

Paschos 89
CP 25th anniversary
Direct CP violation
$\rho_{CERN} = 33 \pm 11\ 10^{-4}$
disagrees with SW
E 731 not yet ready

Dydak 91
Penguins considered
Paschos prediction

Barbieri 93
$\rho_{731} = (7.4 \pm 5.2 \pm 2.9)\ 10^{-4}$
$\rho_{CERN} = (23 \pm 7)\ 10^{-4}$

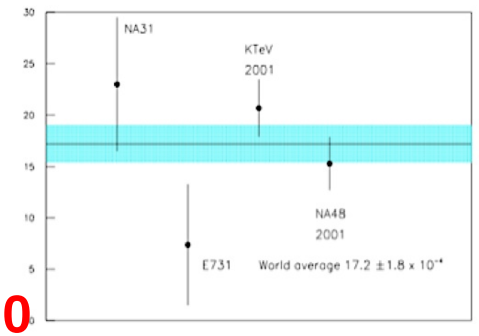
J.Ellis 99
$\rho_{KTeV} = (28.0 \pm 4.1)\ 10^{-4}$

world average
$Re(\varepsilon'/\varepsilon) = (16.3 \pm 2.2) 10^{-4}$

KM 73
$$\frac{|\eta_{00}|^2}{|\eta_{+-}|^2} = \frac{\Gamma(K_L \to \pi^0\pi^0)}{\Gamma(K_S \to \pi^0\pi^0)} \frac{\Gamma(K_S \to \pi^+\pi^-)}{\Gamma(K_L \to \pi^+\pi^-)} \approx 1 - 6\,\varepsilon'/\varepsilon$$
ρ

Proof direct CP violation: NA31, NA48, 1986-2001
See L.Fayard talk «CERN 60 Years »

focus then on K rare decays



CP Lear
$p\bar{p} \to \pi^- K^+ \bar{K}^0 \quad p\bar{p} \to \pi^+ K^- K^0$

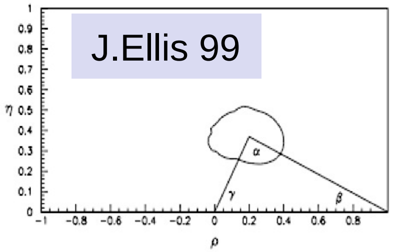
direct measurement of non invariance by time reversal

$P(K_0 \to \bar{K}_0) - P(\bar{K}_0 \to K_0) \neq 0$ at 5σ

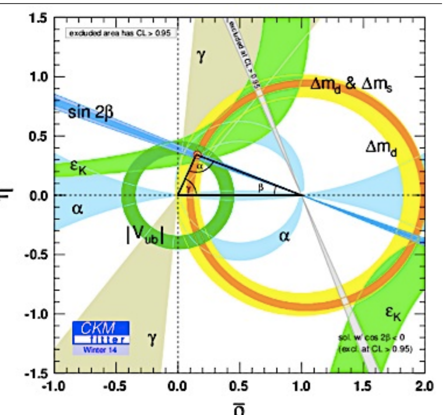
CPT conservation demonstrated 50 time more precisely than before

CPT **does the antiatom behaves as the atom?**

CP violation in B physics emphasized by Paschos 89



LEP, among others,
was involved
then domain of
B factories and LHCb

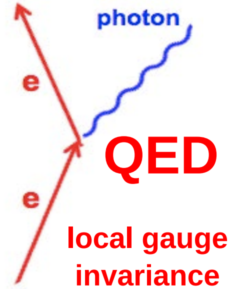


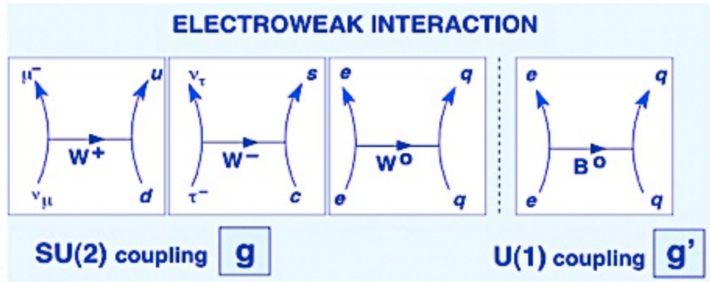
outstanding work !

Towards the EW Standard Model

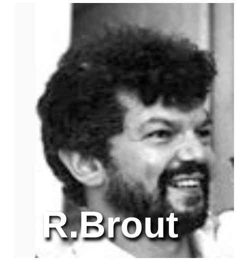
QM

Feynman et al 1949





$$\begin{pmatrix}\gamma \\ Z\end{pmatrix} = \begin{pmatrix}\cos\theta_W & \sin\theta_W \\ -\sin\theta_W & \cos\theta_W\end{pmatrix}\begin{pmatrix}B^0 \\ W^0\end{pmatrix}$$



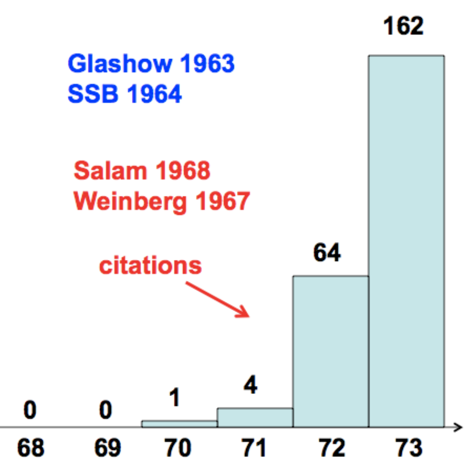
happy end the BEH mechanism 1964 Nobel 2013

a "true"theory 1971 Nobel 99 with Veltman

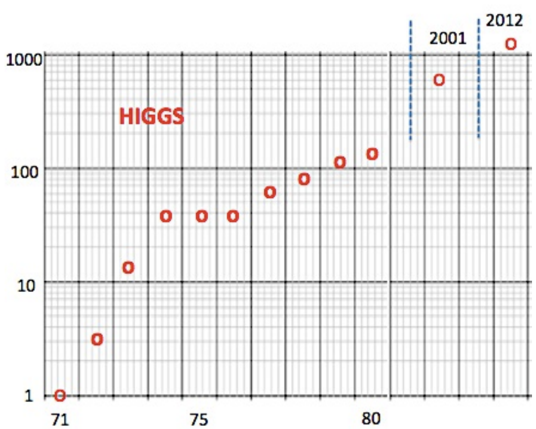
Clear mission: look for W, Z and the BEH boson CERN did very well !

Some delay in the heads…QED still under check alternative e.g. Georgi Glashow 1972

Weinberg 67
$m_W = (78 \pm 3)$ GeV
$m_Z = (89 \pm 3)$ GeV
+ 3GeV of radiative corrections



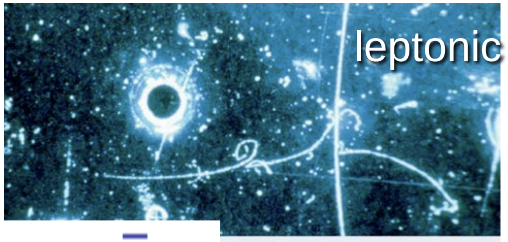
see A.de Rujula

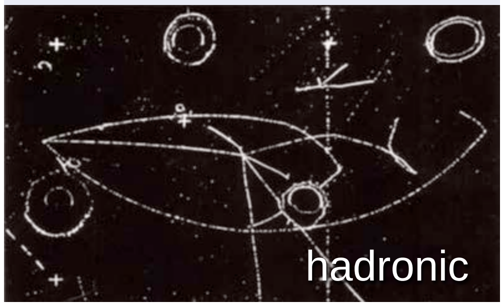


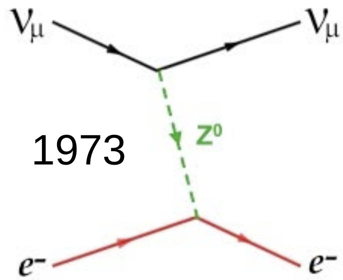
- **doubts?**
  - J.Ellis 76 Quantum Asthenodynamics
    "that many people now believe to exist though no-one knows what it is"
  - Bjorken Sakurai 80 Technicolor?
- **conviction**
  - Iliopoulos 73 (Higgs-Kibble)
  - Rosner 73 *"waiting for W,Z, charm, heavy lepton"*
  - C.L. Smith 81 *"SM healthy, but need W, Z, prove confinement"*

Neutral Currents

first major achievement of CERN maturity



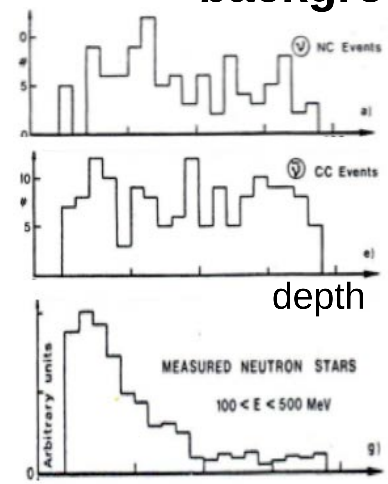




i.e. indirect evidence of Z^0

- Gargamelle: decided end 1965
- CERN and CEA
  Weisskopf, Gregory
- a real odyssey…
  much scepticism to fight
- “alternating currents”
  HPWF
  chronicles, e.g. Rousset

background

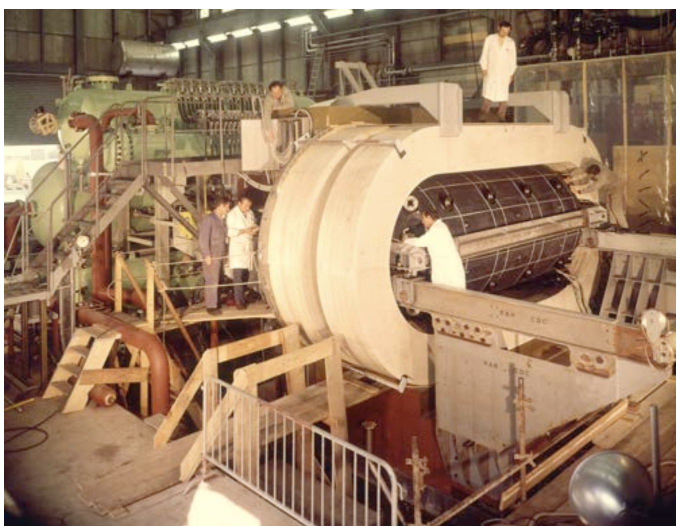


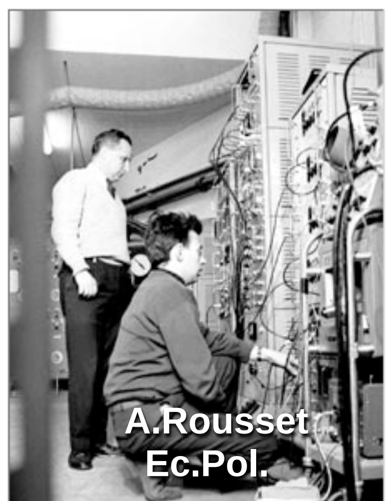
Fry and Haidt

neutrinos
flat

neutrons
near edges

Gargamelle freon CF_3Br $12m^3$

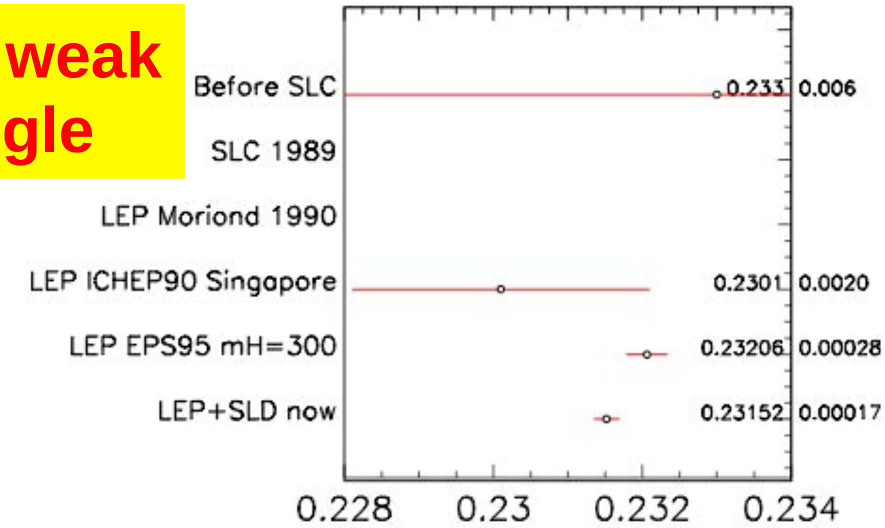


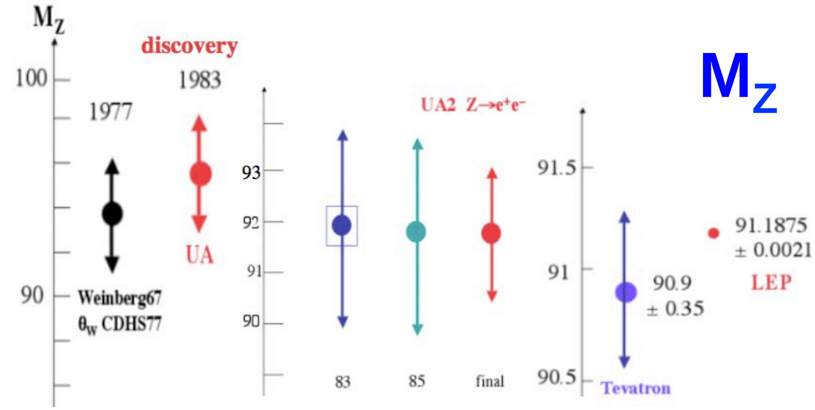


subsequent neutrino experiments
R (NC/CC) predicts M_Z near 92 GeV

talks by P.Musset 71, 75 A.M. Lutz 73, P.Fayet 74 (proposing APV), L.Kluberg 74 V.Brisson 76 NC in real time!

The weak angle





M_Z

J.Ellis

A strange story… 1981

$$\sin^2\theta_W^{(\nu_\mu;l)}(0) = 0.2104 \text{ for } \nu_\mu\text{-lepton scattering at } q^2 = 0$$

$$\sin^2\theta_W^{(\nu;h)}(-20\ \mathrm{GeV}^2) = 0.2098 \text{ for deep-inelastic } \nu\text{-hadron scattering.}$$

Marciano

$$\sin^2\hat\theta_W(m_W) = 0.214 \pm 0.002$$

radiatively corrected[8] experimental average

$$\sin^2\hat\theta_W(m_W) = 0.215 \pm 0.012$$

GUTS 3: SUSY GUTS 2

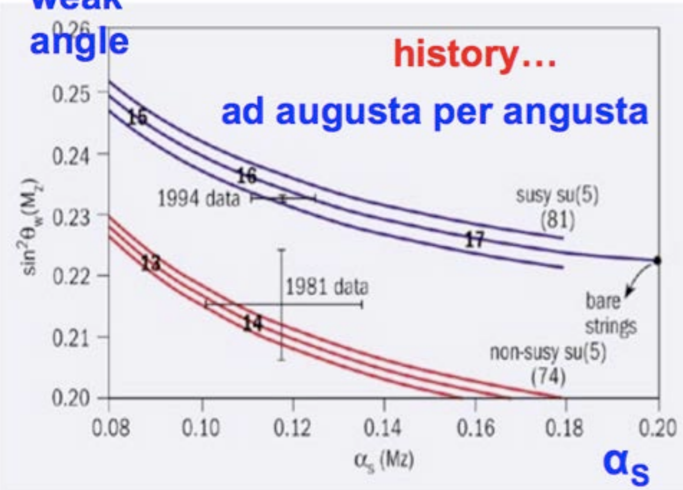
$$m_X = (1 \text{ to } 4) \times 10^{14}\ \mathrm{GeV}$$

Various honourable people find

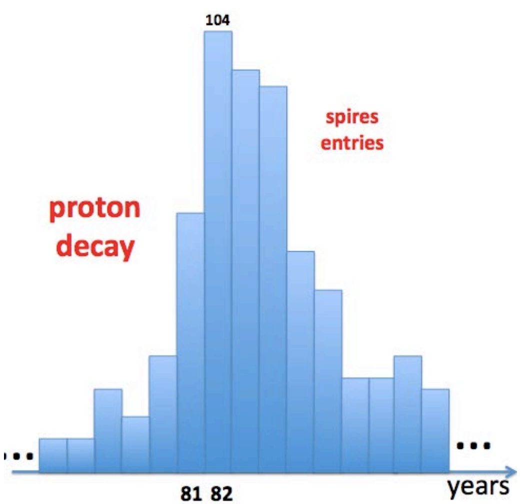
$$\tau_N = (0.6 \text{ to } 25) \times \left(\frac{m_X}{5\times10^{14}\,\mathrm{GeV}}\right)^4 \times 10^{30}\ \text{years}$$

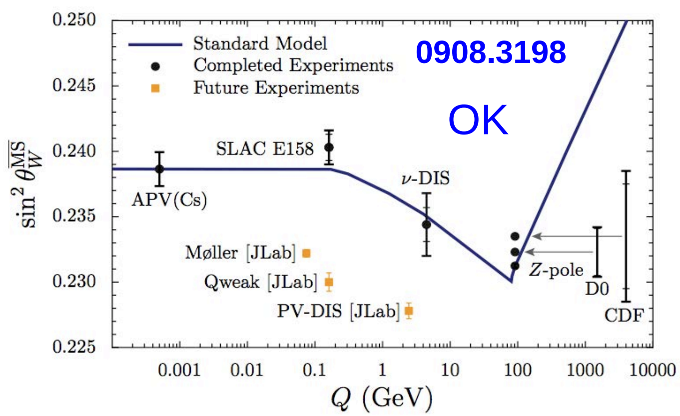
the proton decay fever…

weak angle



α_s





0908.3198

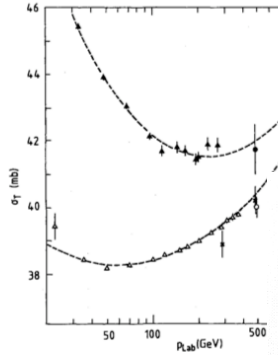
OK

NuTeV anomaly

ISR

M. Jacob: *"A brilliant start": 71-74* *"A somewhat difficult period": 75-77*
"A very active and interesting programme": 78-83

M. Jacob

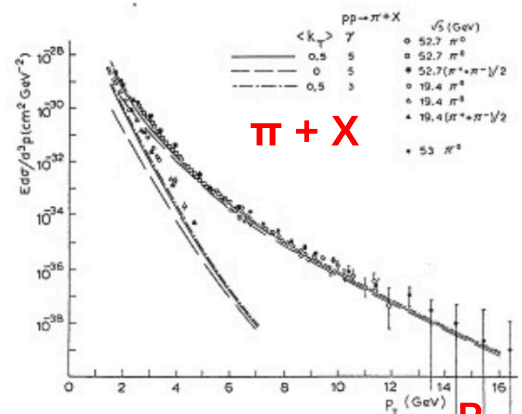


rising total cross-section

G.Bellettini
76 86

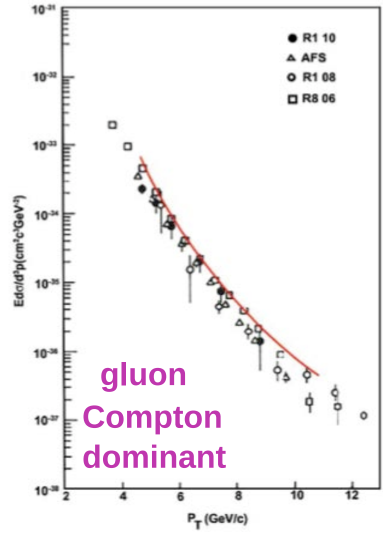
1973: discovery of the large p_T phenomena
partons point-like relative to the strong interaction

direct photons:
1979 to the end.
Discovered at ISR.
Important test of QCD



π + X

P_T

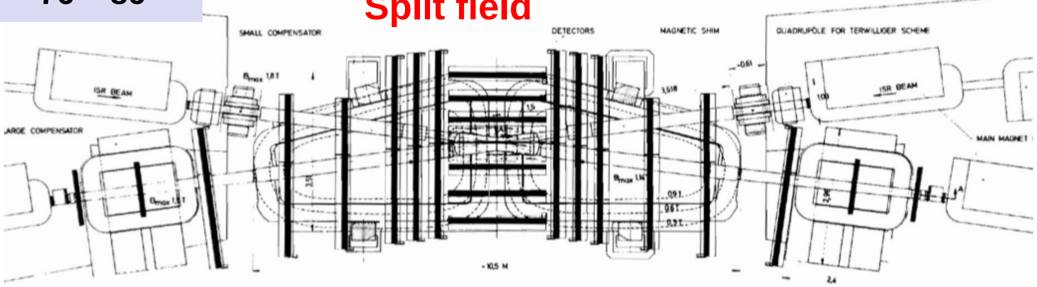


gluon Compton dominant

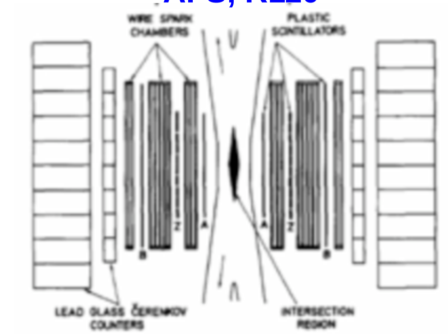
great success of the machine

but J/Psi (74), charm, beauty (77), tau (75), gluon found elsewhere

Split field



AFS, R110



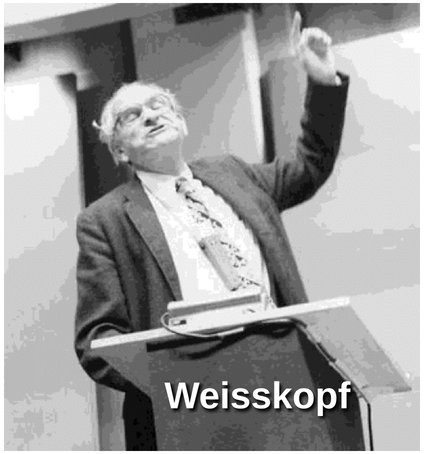
focus on forward region **lack of theoretical guidance**

End of ISR in 83

some moral support was needed

M. Jacob:
"I come to bury Caesar not to praise him"
Marc Antony, in Julius Caesar

V.Weisskopf:
"It does not matter where discoveries are made."

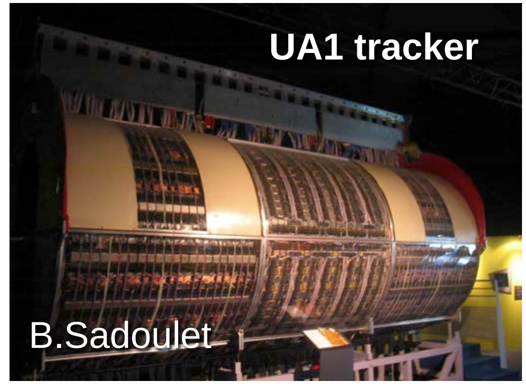


.. it came next....

The p-$\bar{p}$ collider

aim: discover W, Z

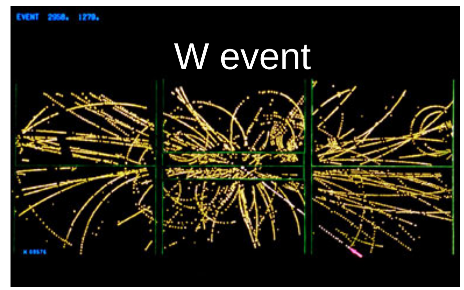
fast decisions, fast realisation
great machine, great detectors
hermeticity, redundancy,
innovating techniques

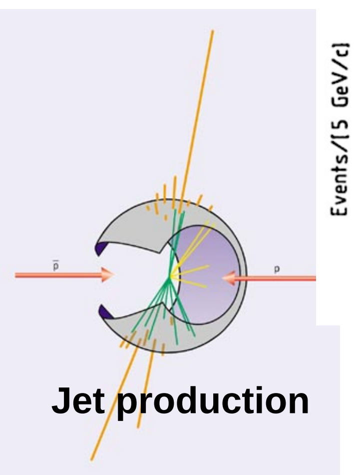


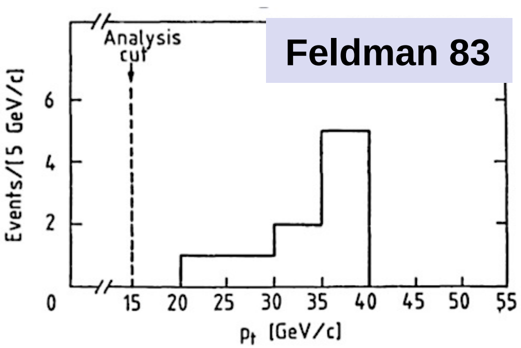
C.Rubbia's determination in somewhat adverse climate *1976 paper by C.Rubbia, P.McIntyre and D.Cline*
1977 proposal to CERN and Fermilab, feasibility study *1978 success of ICE* *1979 approval of the expts*

physics "au rendez vous": hadronic jets, W, Z, etc

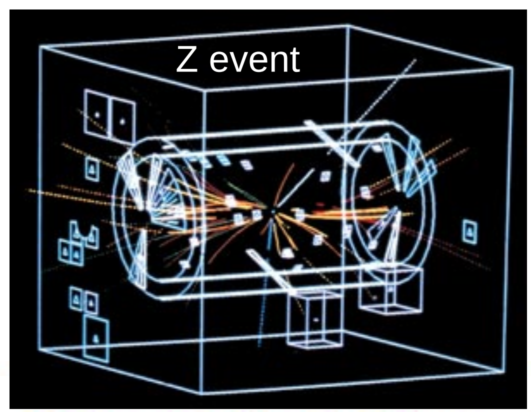
Discovery 1983







P.Darriulat



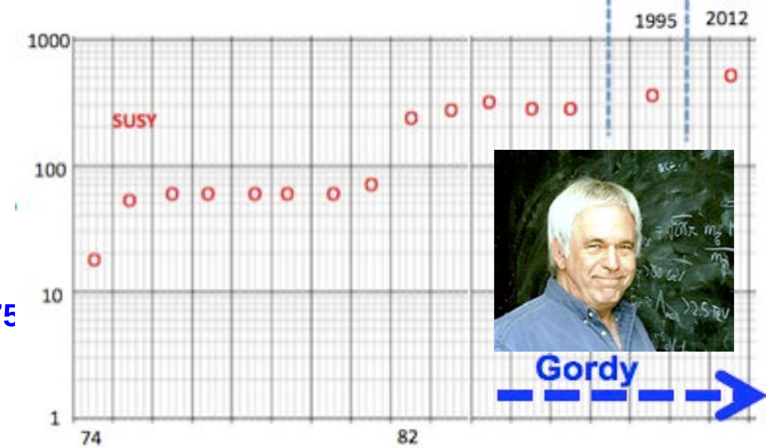
other goodies — **angular distribution of parton-parton scattering** — **proton structure functions role of gluons at small x** — **prompt γ, multi jet final states, pt of W, beauty mixing**

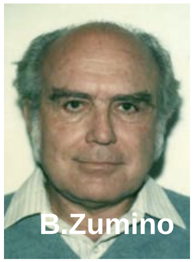
"L'espoir changea de camp, le combat changea d'âme" (D.Denegri and V.Hugo)

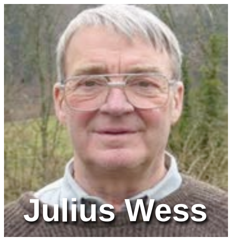
SUSY Schwitters 82 in Moriond quarks, leptons and SUSY "super meeting" with P.Fayet, G.Farrar, J.Ellis

"Even experimentalists cannot fail to be infected"
by the enthusiasm of the super theorists"

After Russians **Wess Zumino** 74 to 76 **Fayet** 74 to 80 **Fayet-Ferrara** 75
Phenomenology Farrar-Fayet 78 **Witten** 78 82 **Haber-Kane** 84







Barbieri 93

We were told by Gordy Kane [48] that there are "eight indications that nature is supersymmetric at the electroweak scale". He agrees that one solid argument would be enough, in fact better than eight vague ones, but - he says - many indirect arguments can give, altogether, a significant indication.

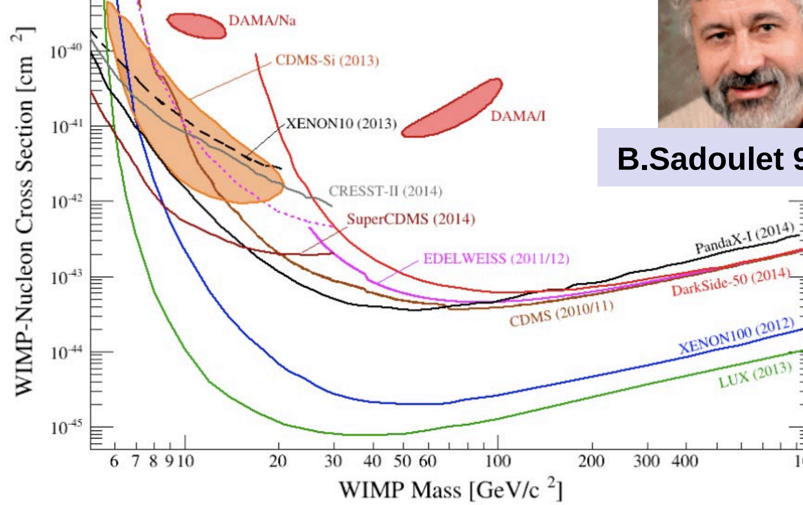
Higgs phenomenology in MSSM $M_h = f(g, g')$

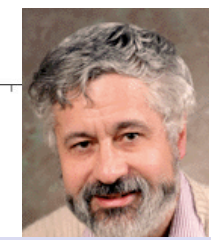
after radiative corrections (91) and M_t (172 ± 6 GeV in 96)

$M_h <$ 130 GeV need LEP220 to explore fully (1994)

LSP as Dark Matter?

bolometers versus noble liquids





B.Sadoulet 91

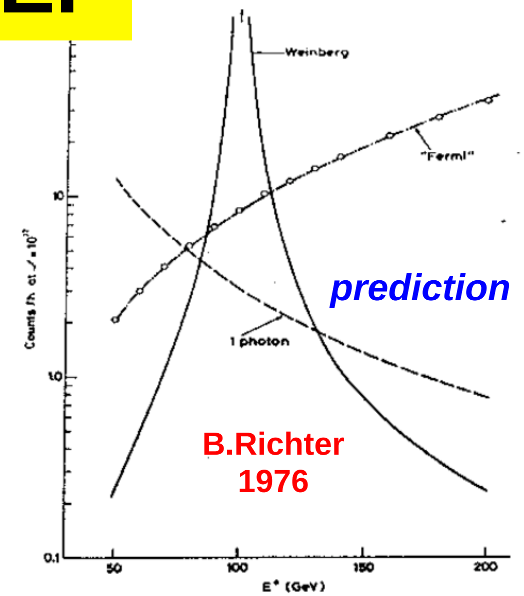
LEP chargino excluded below 103 GeV LSP?
LHC: nothing yet, but no exclusion if LSP> 500 GeV
no sign from flavor physics, but g−2 of the muon ?
"naturalness"? compressed spectra? NMSSM?

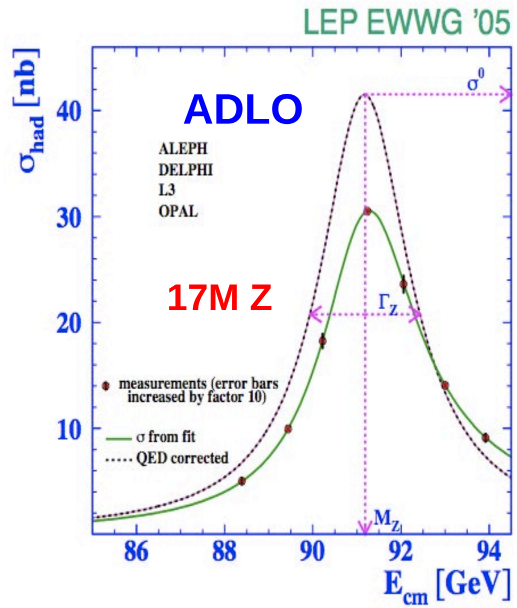
Can SUSY ever be declared dead?
BEH boson about where expected. From its mass, can one get upper limits e.g. on stop mass?

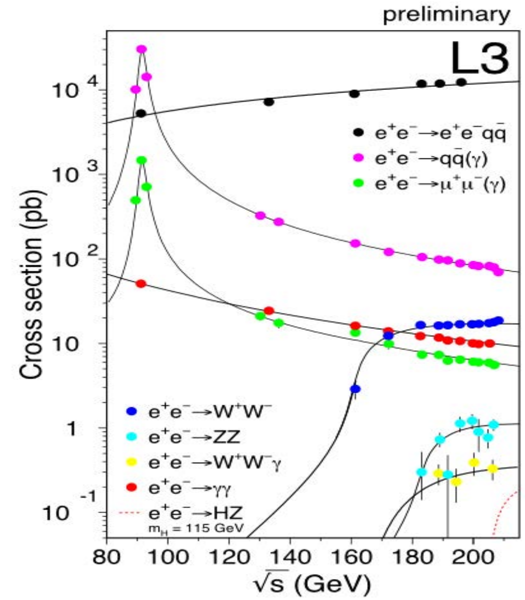
not MACHOS, etc.
why not axion? Fayet 81 P.Sikivie in audience

LEP

great machine 4 good detectors clean, subtle physics SM validated at loop level







LC: Tigner 65, Balakin, Skrinsky 71 (79)
idea of having LHC in the same tunnel

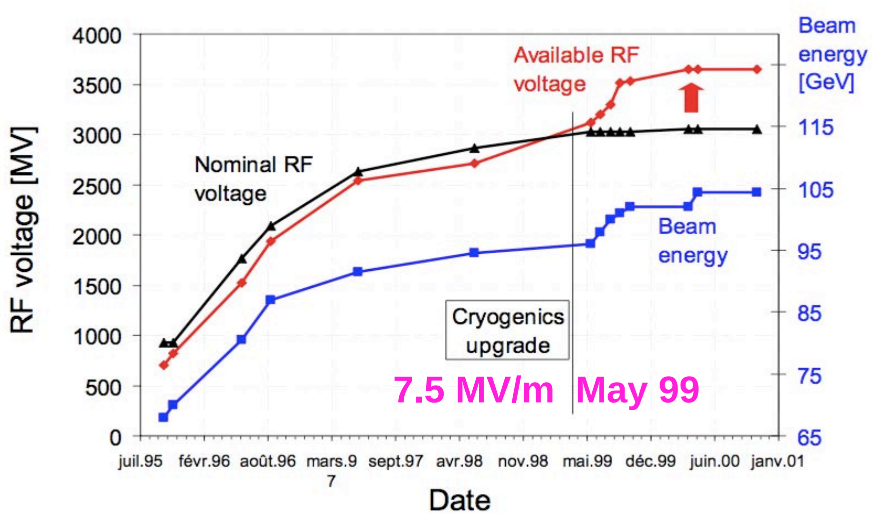
E.Picasso PL

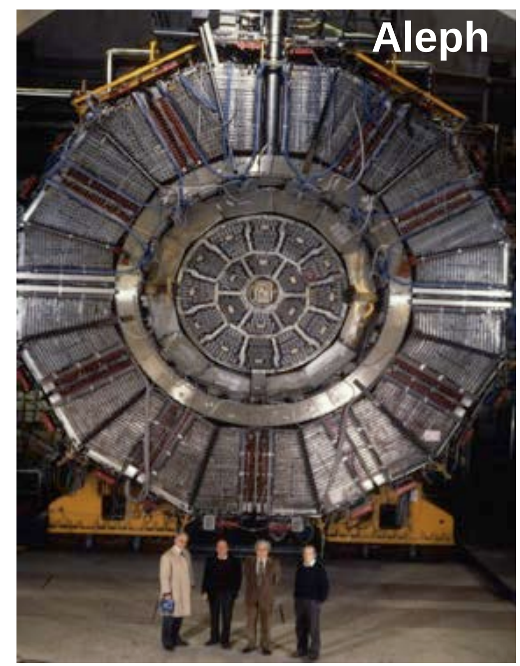
quasi perfect planning

LEP Design Report 1984:
26.6km, 125 GeV/beam

machine: luminosity at high E
4 times better than foreseen

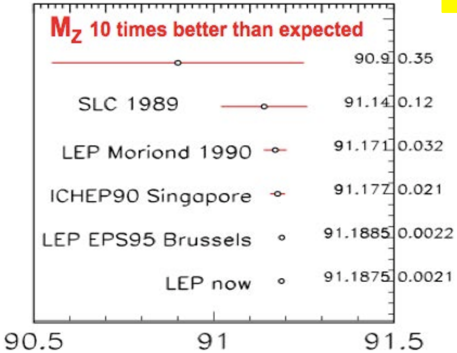
SC RF cavities
E.Picasso, H.Lengeler
Ph.Bernard C.Benvenuti





for measurements LEP did much better than expected

Quantity	*Expected error*	*Achieved*
m_Z	50 to 20 MeV	**2.1 MeV**
m_W	100 MeV	**39 MeV**
N_ν	0.3	**0.008**
$A_{FB}^{0,\mu}$	0.0035	**0.0013**
$A_{FB}^{0,b}$	0.0050	**0.0017**
A_τ	0.0110	**0.0043**



A_{LR} from SLC $m_W \pm 16$ MeV Tevatron

evidence for loops beyond α running

B.Pietrzyk

$g_A^l = -0.50123 \pm 0.00026$

4.7 σ from −1/2

$\Delta\rho = 0.005 \pm 0.001$

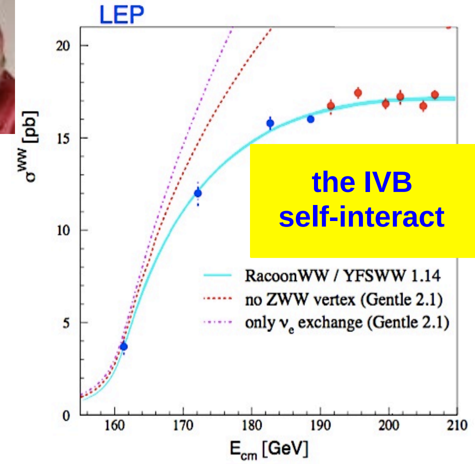
M_W and relation with G_μ

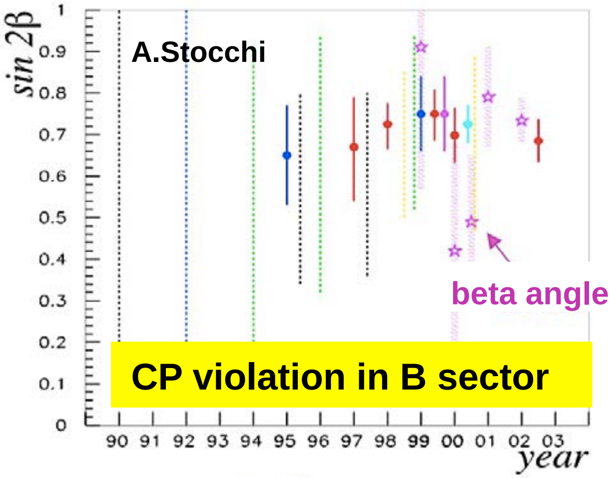
$\Delta r = 0.033 \pm 0.002$

$\Delta r_W = \Delta r - \Delta\alpha =$

-0.026 ± 0.002

13 σ away from 0 !

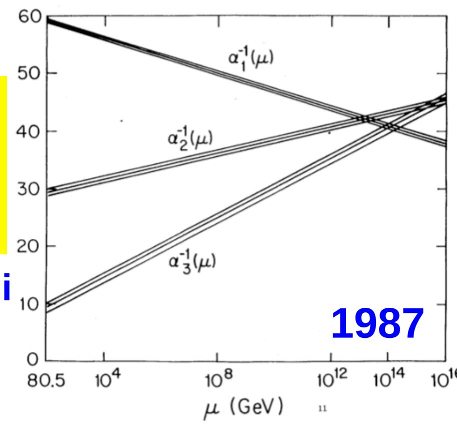


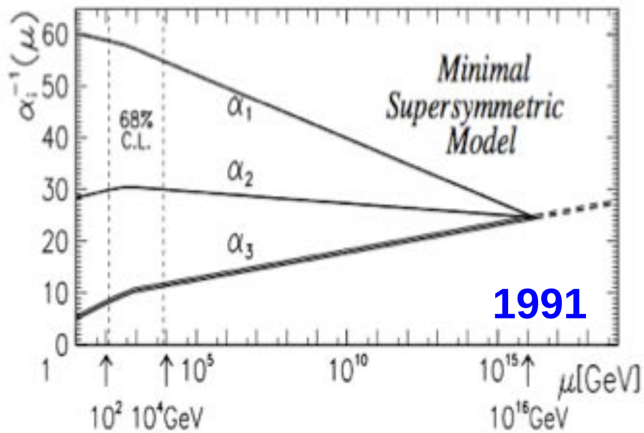


CP violation in B sector

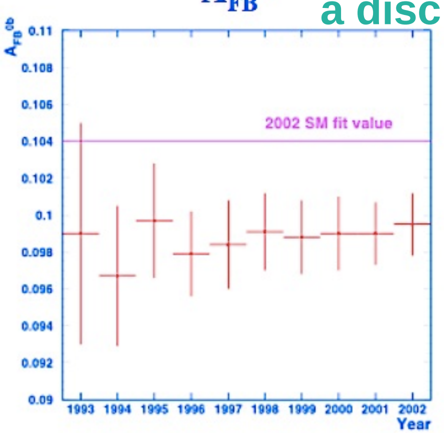
SUSY GU saga

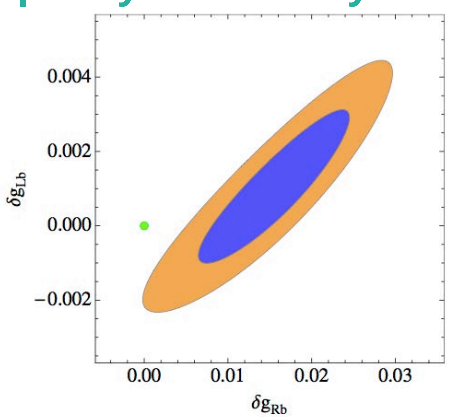
U.Amaldi et al





A_{FB}^b a discrepancy which stayed





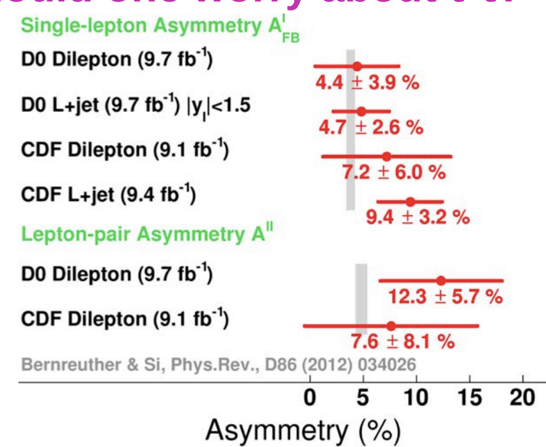
still at work…

T.Gehrmann 2014

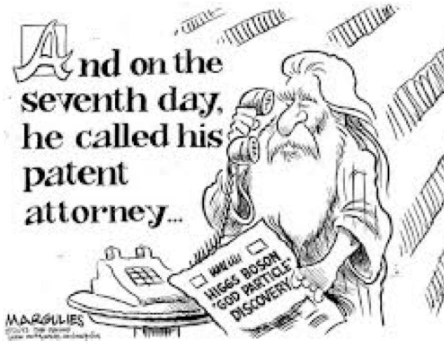
QCD NNLO (2 part.) fully massive

Bernreuther, Gehrmann et al 2006

should one worry about $t\text{-}\bar{t}$?



..and the BEH boson?



A PHENOMENOLOGICAL PROFILE OF THE HIGGS BOSON

John ELLIS, Mary K. GAILLARD * and D.V. NANOPOULOS **
CERN, Geneva

Received 7 November 1975 Nucl. Phys. B106 (1976) 292

G.Dissertori
Royal Society 2014

We should perhaps finish with an apology and a caution. We apologize to experimentalists for having no idea what is the mass of the Higgs boson, unlike the case with charm [3,4] and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons we do not want to encourage big experimental searches for the Higgs boson, but we do feel that people performing experiments vulnerable to the Higgs boson should know how it may turn up.

➔LHC Lausanne 1984 C.L.Smith

Extensive studies of Higgs boson production were reported at Lausanne[15,16] which lead to the conclusion that discovering a conventioanl heavy Higgs boson will be difficult even at 20 TeV., the energy we assume in the following discussion.

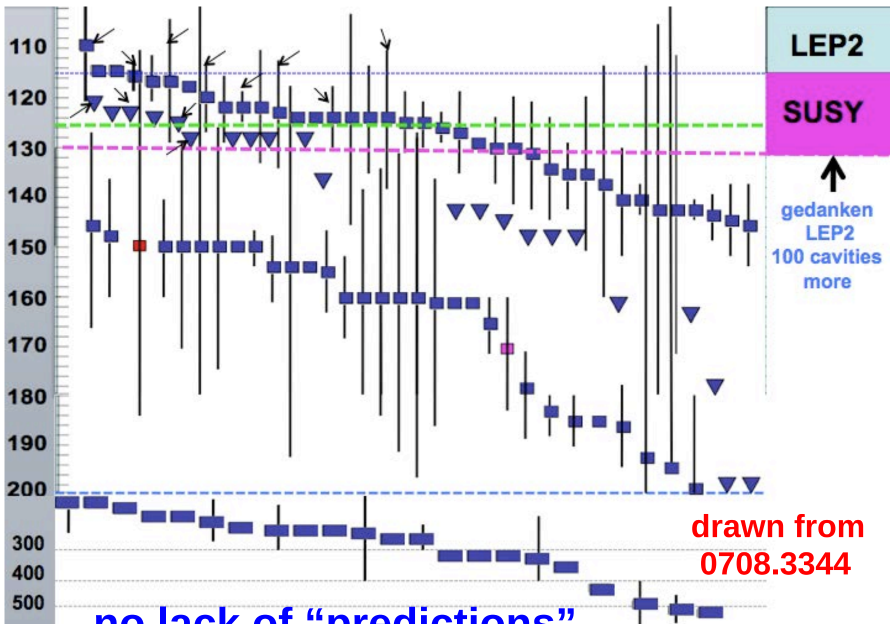
but m_{top} increased and in 1987 $L=10^{34}$ was suggested

➔LEP Aachen 1986 Higgs study group

"Clearly the 4 jet events are not useful if M_H= 80-90 GeV since there could be complete confusion with WW and ZZ production,..."

"LEP200 should detect the Higgs if $40 \leq M_H \leq 80$ GeV, but it will be difficult. It is not at all clear that hadron colliders (of any energy) would be able to detect the Higgs at all."

B tag considered in 1990 one can cross the Z, mass reach $2E_b - 100$, became $2E_b - M_Z$



drawn from 0708.3344

no lack of "predictions"

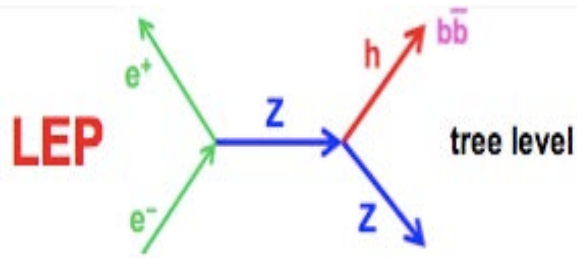
The maximum energy of LEP 2 was determined by the decision in 1996 to discontinue the industrial production of the superconducting cavities. Whether the potential of LEP should have been better fully exploited up to its reasonable limit of 220 GeV in the centre-of-mass and whether this would have lead to the discovery of the Higgs particle as a number of models seemed to suggest [36,37], is a matter of speculation. The quest for the Higgs particle will hopefully end with the results obtained by the Tevatron and the LHC. In any case, LEP will stand as a landmark in the development of particle accelerators.

K.Hubner

285 produced. 384 could have been installed, giving 2E = 220 GeV

..and the BEH boson?

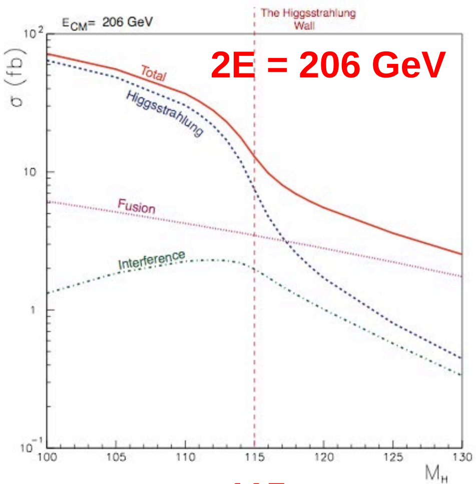
before LEP, basically no limit   Paschos 89 $2<M_H<3.6$ excluded

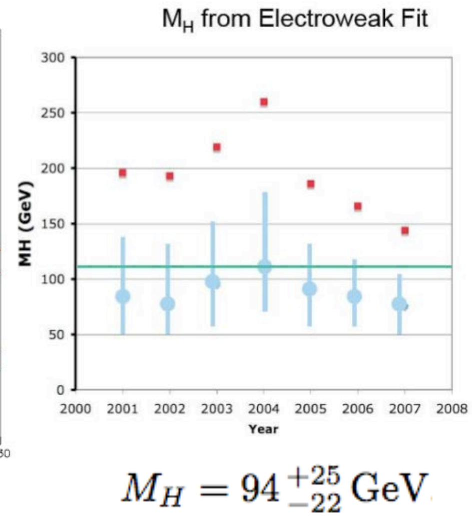


LEP2 mass reach

$m_h \approx 2E - M_Z$

recognized in 1993 as attainable





in 2000: 2E = 206 GeV   no way to increase E with the available SC RF

few candidates at 115 GeV, mostly in Aleph

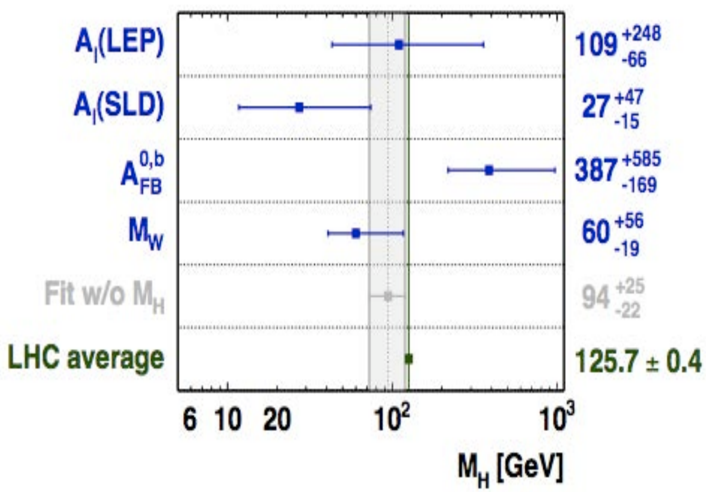
LEP stopped in great turmoil…   P.Janot 2000 2001

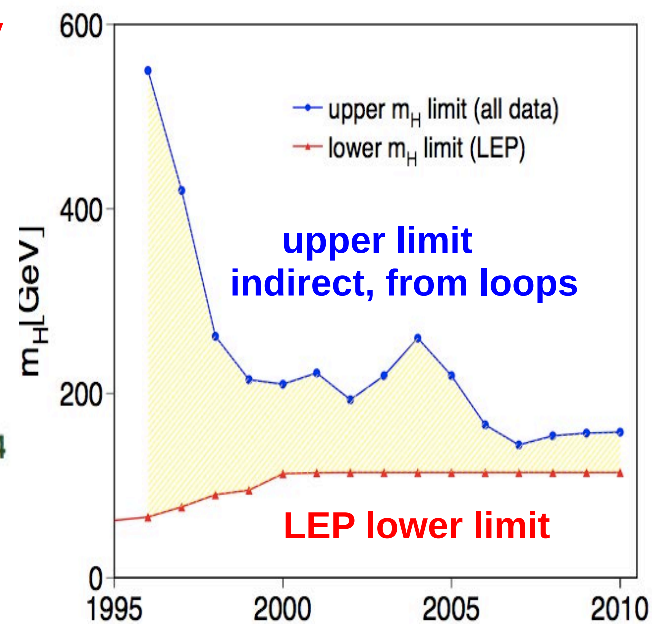
LHC answered in 2012: nothing at 115 GeV, something at 125 GeV

1996: decision to stop the production of SC RF cavities.

$220 - M_Z = 129$ GeV
MSSM (1994) $m_h<130$ GeV
220 GeV CM asked for in 1994 in the name of SUSY

SUSY or not, a pity…



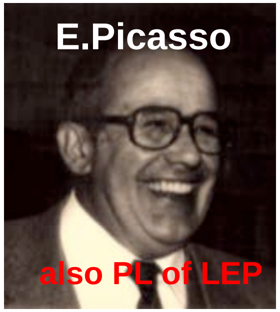


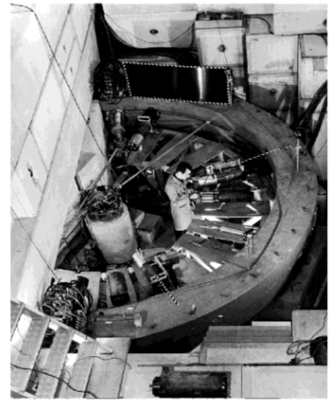
legacy from LEP and Tevatron to LHC…

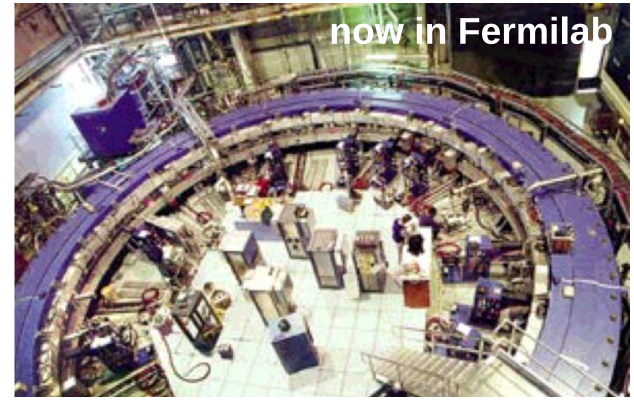
and LHC did very well but 1 boson to 4 l/10^{13} pp interactions instead of 1 / about 10^2 e^+e^- annihilations

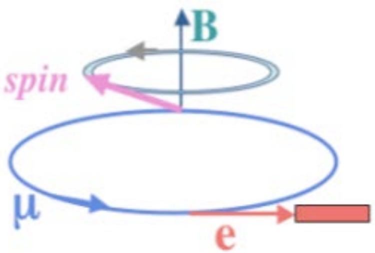
muon g−2

"g–2 is not an experiment: it is a way of life." John Adams (DG of CERN 1971-1975)

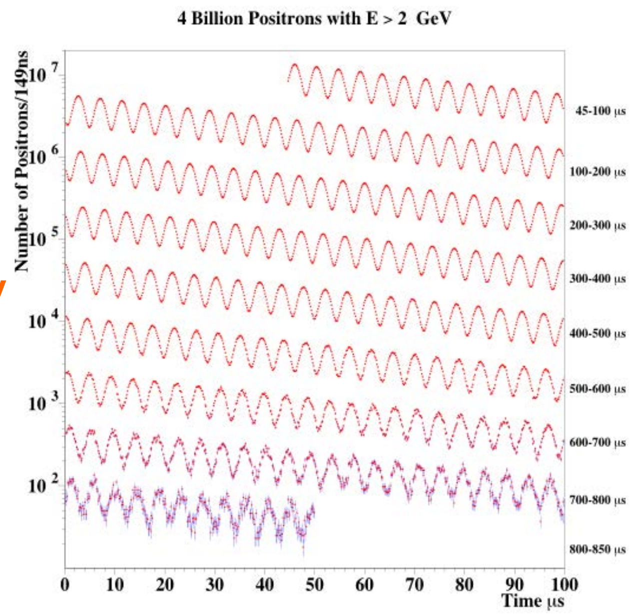






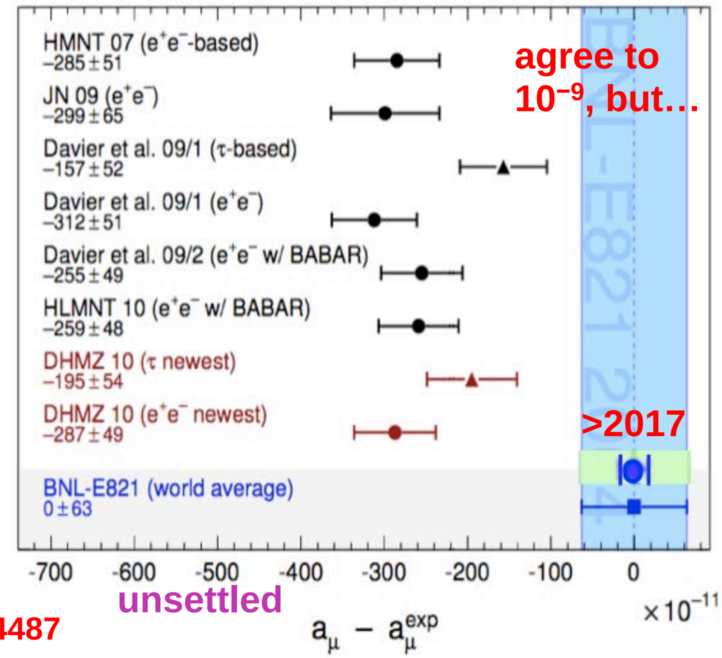


beat between frequency of rotation of the μ and frequency of precession of its spin



g should be 2, but loops…
12672 five-loops…

superb work both theoretical and experimental



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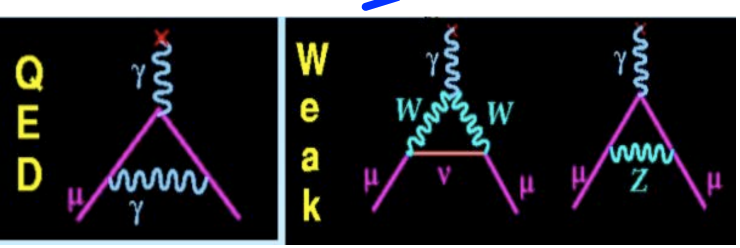
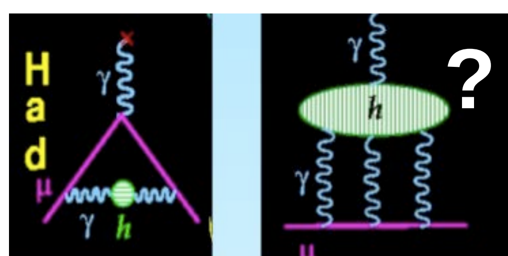
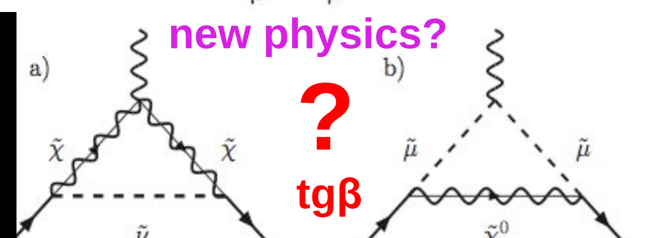






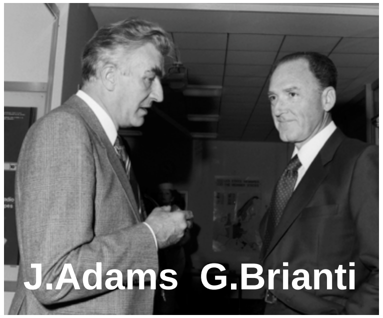
multiple apologies
for omissions
high intensity frontier
rare decays, EDMs, etc
Brookhaven, PSI, etc

discovery of BEH boson
prodigious collective success
many key actors to praise
technical coordinators,
etc


A.Hervé


M.Nessi


C.Benvenuti



full exploitation
of LHC mandatory

a discovery would
help for the future…

most discussed option

iff…

50 years of Moriond

félicitations, un très grand merci
et tous nos voeux pour la suite