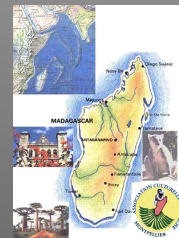


QCD & Physique Hadronique

LUPM 11 (10-11 Octobre 2011)
St Martin de Londres (Herault)

Stephan Narison

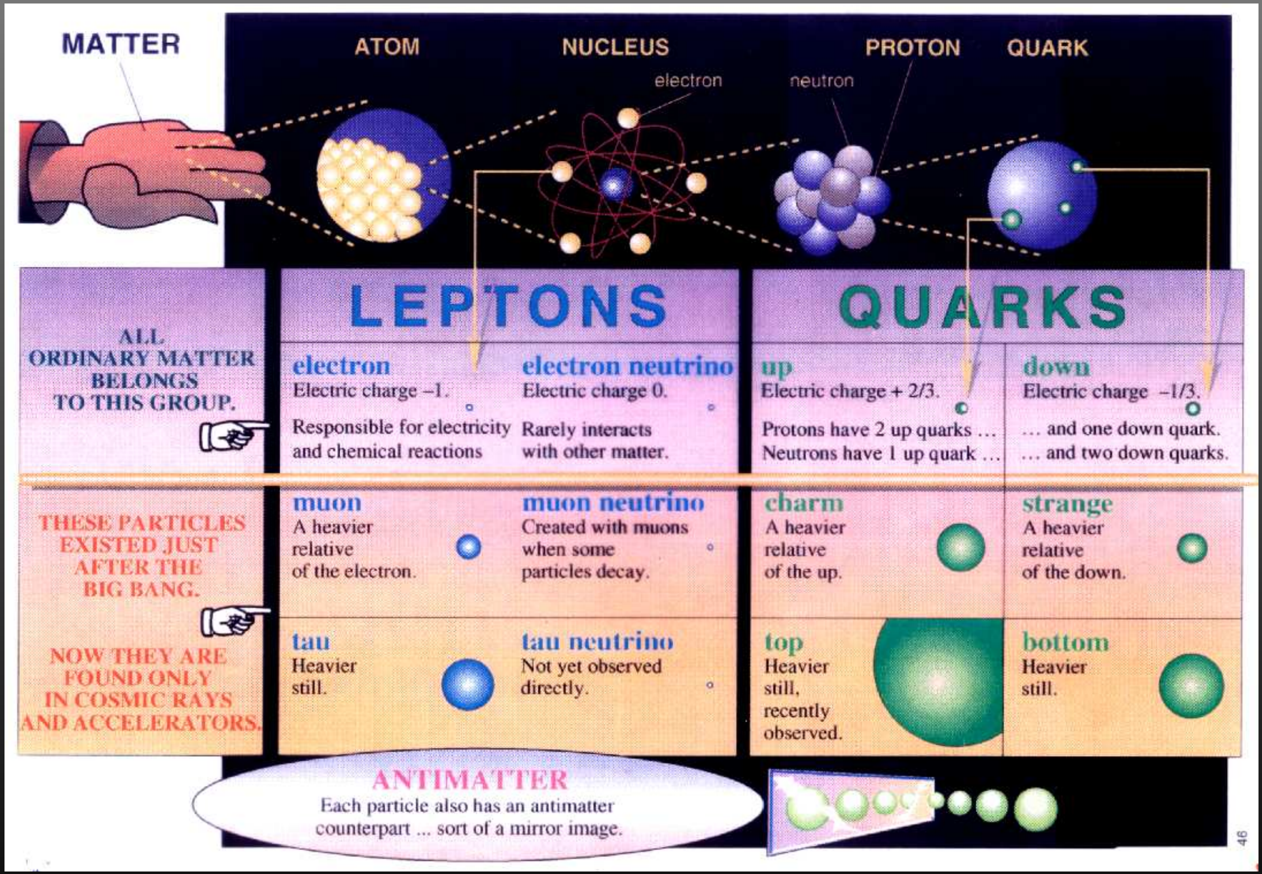
CNRS / IN2P3 - LUPM (Montpellier)

Vers l'Infiniment Petit : Le Modèle Standard

Vers l'Infiniment Petit : *Le Modèle Standard*

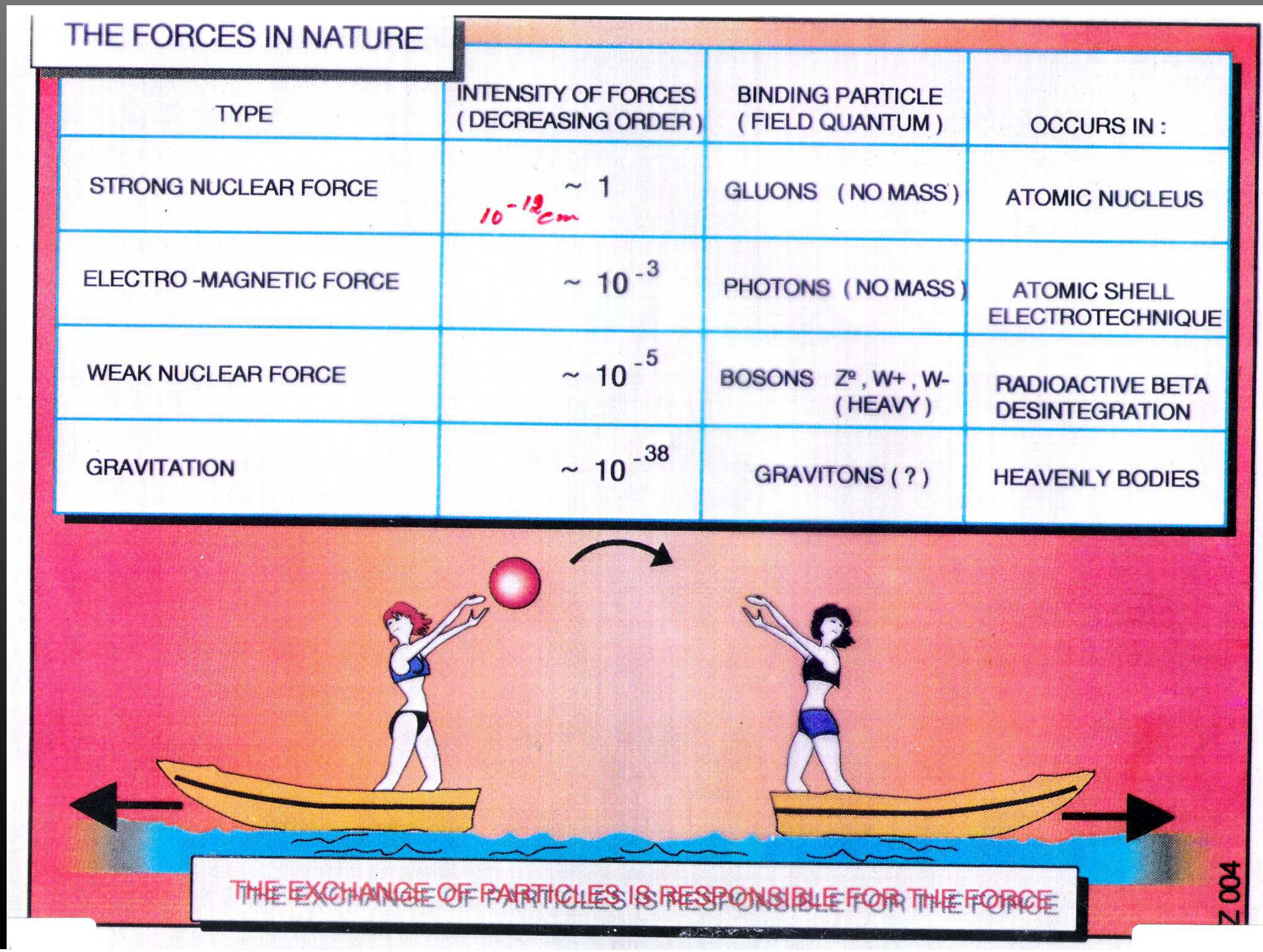
- 6 quarks ⊕ 6 leptons constituents

Glashow-Weinberg-Salam : Prix Nobel 1979



• Quelles sont les Forces qui regissent la Nature ?

Forces electromagnetique, faible, forte & gravitation

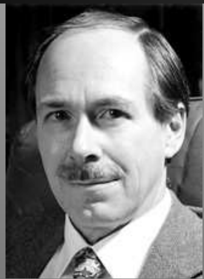


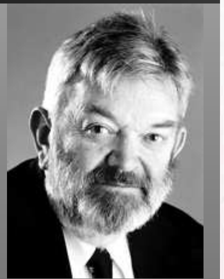
THE FORCES IN NATURE

TYPE	INTENSITY OF FORCES (DECREASING ORDER)	BINDING PARTICLE (FIELD QUANTUM)	OCCURS IN :
STRONG NUCLEAR FORCE	~ 1 10^{-12} cm	GLUONS (NO MASS)	ATOMIC NUCLEUS
ELECTRO -MAGNETIC FORCE	~ 10^{-3}	PHOTONS (NO MASS)	ATOMIC SHELL ELECTROTECHNIQUE
WEAK NUCLEAR FORCE	~ 10^{-5}	BOSONS Z^o, W+, W- (HEAVY)	RADIOACTIVE BETA DESINTEGRATION
GRAVITATION	~ 10^{-38}	GRAVITONS (?)	HEAVENLY BODIES

G. t'Hooft-M. Veltman

Prix Nobel 1999



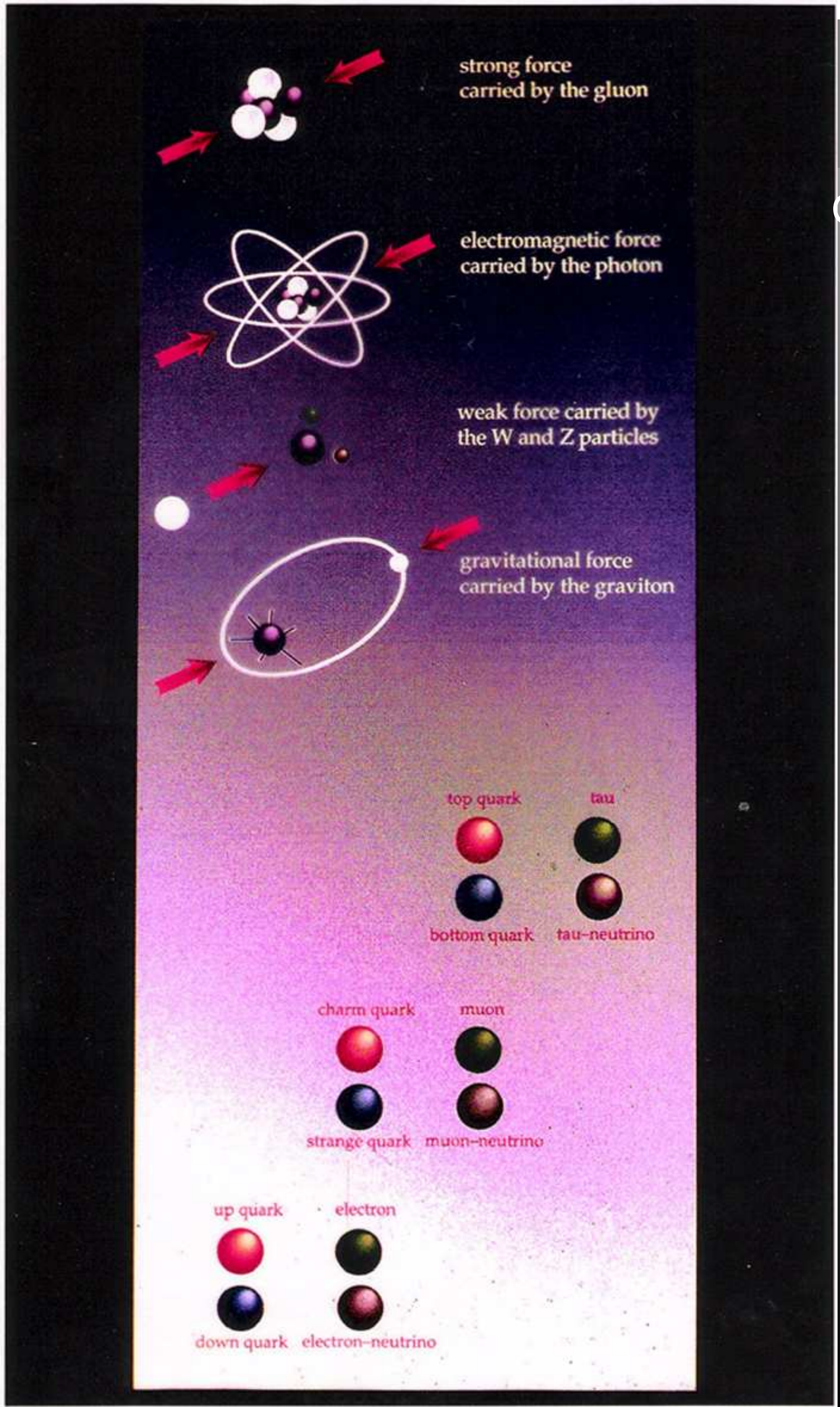


D. Gross, D. Politzer,

F. Wilczek

Prix Nobel 2004

Chromodynamique Quantique (QCD)



C. Rubbia V. Der Meer

Prix Nobel 1984

Le Boson de Higgs

1 maillon manquant du modèle standard:

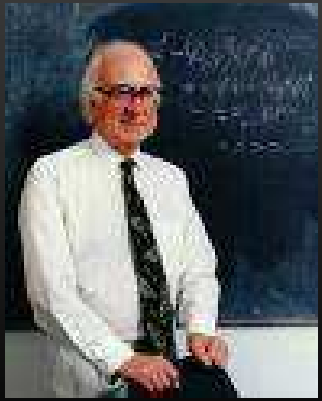
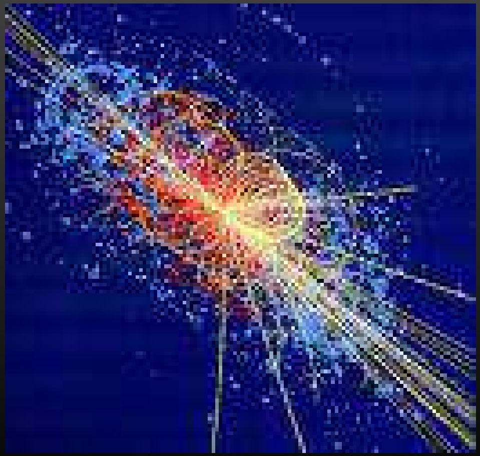
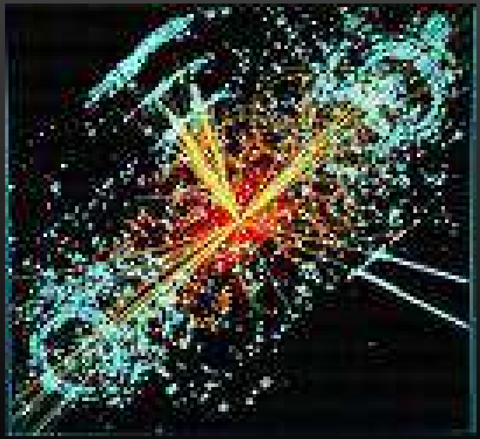
La particule de Dieu ?

Le Boson de Higgs

1 maillon manquant du modèle standard:

La particule de Dieu ?

- Donne des masses aux quarks, leptons, bosons de jauge
- On prédit sa masse autour de 100 GeV : visible au LHC !
- Sa (non) decouverte est cruciale pour l'avenir de la physique

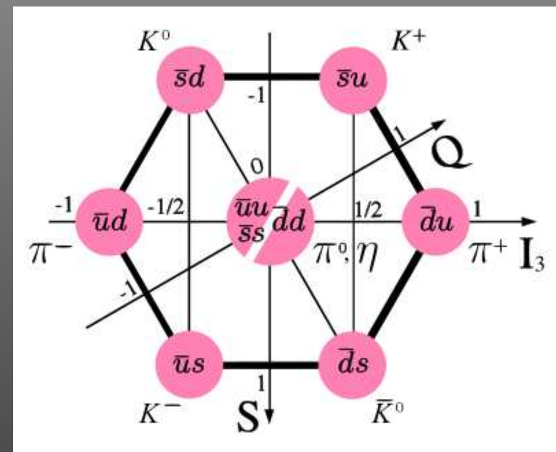




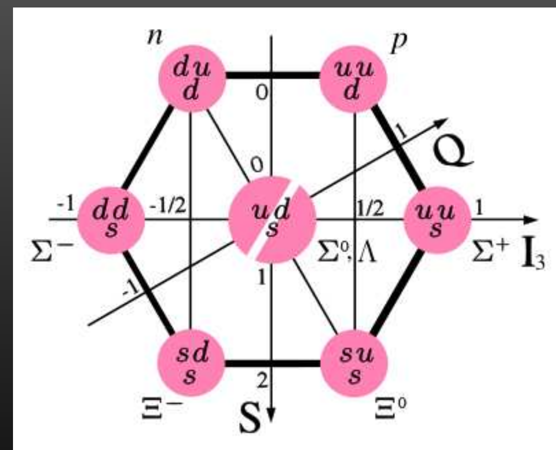
● Les Hadrons des quarks u, d, s ?

- Modèle des quarks de Gell-Mann (Prix Nobel 1969)

  a) Mesons : $\bar{q}_1 q_2$: $M_\pi = 140$ MeV

  b) Baryons : $q_1 q_2 q_3$: $M_p = 1$ GeV





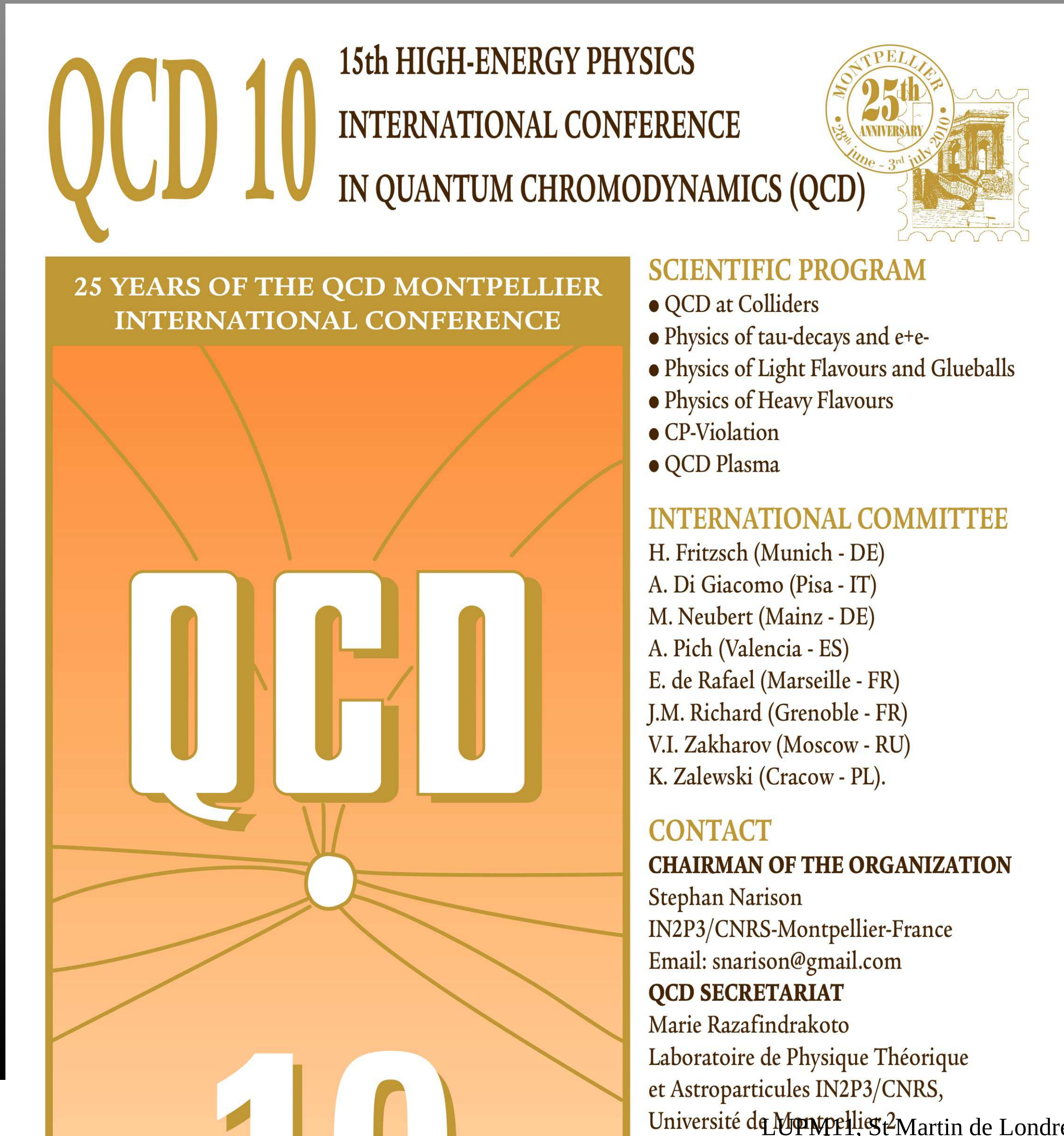
- Décrit maintenant par la Chromodynamique Quantique (QCD):

  La théorie de la Couleur

Les Series de Conference Internationales

Les Series de Conference Internationales

- QCD-Montpellier depuis 1985 (Euroconferences 1994-2000)



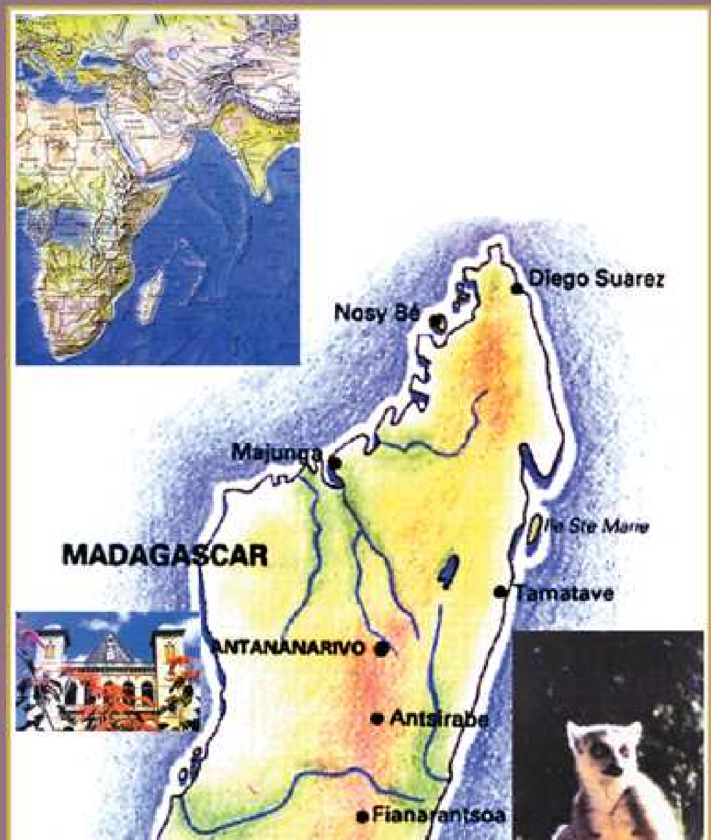
- Photo QCD 2010

- HEP-MAD (Antananarivo) depuis 2001

HEP-MAD 11

5th High-Energy Physics International Conference in Madagascar

25-31th august 2011 (Antananarivo)



Scientific program

Physics at LHC and at some other accelerators
QCD (non) perturbative phenomena
Weak decays and CP-violation
Physics beyond the standard model
Astroparticles and neutrino oscillations

International committee

E. Aslanides (Marseille-FR)
J. Ellis (CERN-CH)
A. Di Giacomo (Pisa-IT)
M. Neubert (Mainz-D)
A. Pich (Valencia-ES)
E. de Rafael (Marseille-FR)
J.M. Richard (Lyon-FR)
V. I. Zakharov (Moscow-RU)
K. Zalewski (Cracow-PL)

Chairman of the organization

Stephan Narison (Montpellier-FR)
Laboratoire Univers et Particules de Montpellier (LUPM)
UM2, Place Eugene Bataillon,
34090 Montpellier Cedex 05 FR

- Photo HEP-MAD 2011

Developpement de l’HEP à Madagascar

- Creation de l’Institut de recherche iHEP-MAD en 2004

  Voir le site: http://www.lpta.univ-montp2.fr/users/qcd/ihepmadtitle.html

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- Vulgarisation: univs, centres culturels, lycées & collèges, presses,...

Exploration de l'Infiniment Petit

- Accélerateur des particules: LHC au CERN

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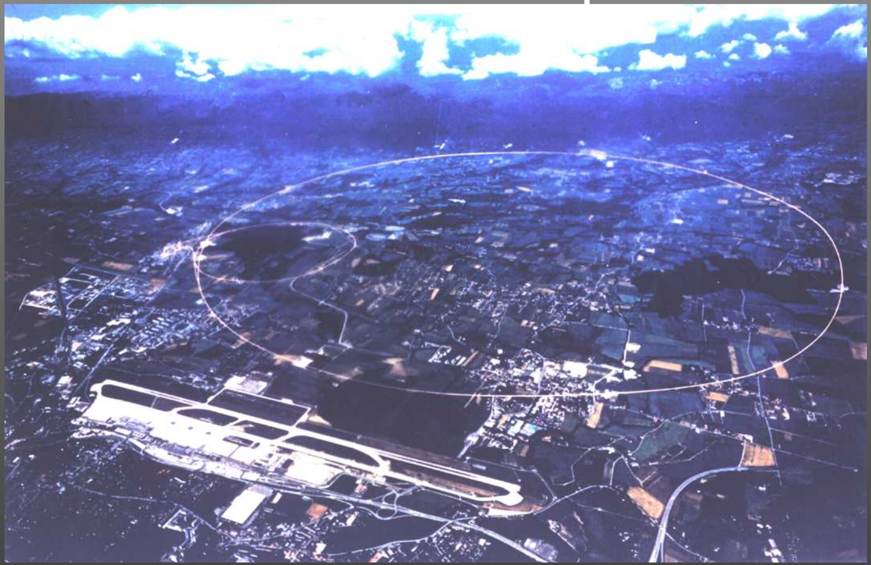


Tunnel de 27km; 100m au-dessous du sol; Energie de 7000 GeV = 70 fois le LEP = 7 fois le Tevatron (peut fondre 500kg de cuivre); 600 miilions de choc proton/proton par sec et 10^{17} pendant toute la durée de l’experience; Côut: 2.6 Milliards d’Euros + 1.2 Milliard pour le personnel.

Exploration de l'Infiniment Grand

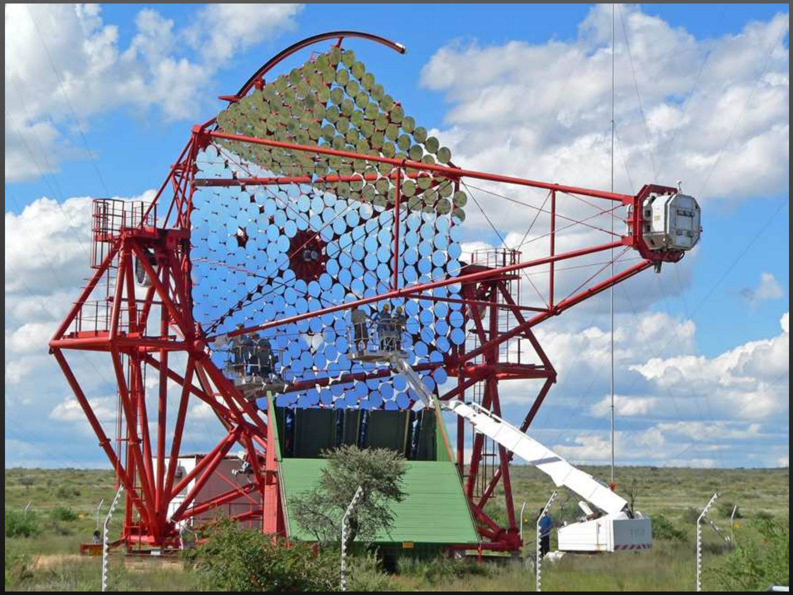
- Fermi Gamma-ray Space Telescope

Exploration du Cosmos dans la région : 10 keV-300 GeV

- Origine des rayons cosmiques
- Mecanisme de la matière noire
  (96% de l'univers!)
- Accéleration de Jets de matière
  près des trous noirs
- ...

• Telescope HESS High Energy Stereoscopic System

Le site et telescopes de Namibie (Afrique) (de Georges Vasileiadis)

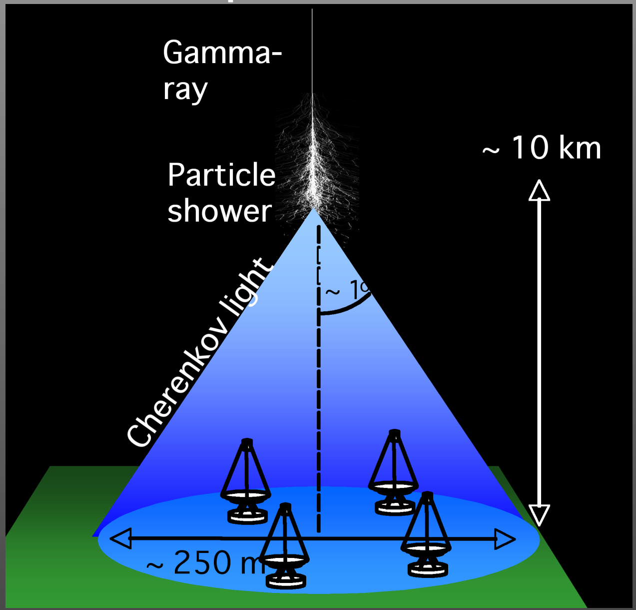


Detection de rayons gamma cosmiques de Hautes Energies (TeV)

$$\gamma \rightarrow e^+ e^-$$

$$e^+ \rightarrow \gamma e^+ \ldots$$

$$e^- \rightarrow \gamma e^- \ldots$$



provenant des supernova ou du coeur des etoiles près des trous noirs au centre de la voie lactée à 15 millions d'année-lumière

Supernova Cassiopeia — explosion en 1680

Crabe Nebula — explosion en 1054, decouv. en 1989

Cygnus A — decouv. en 1939

- Telescope ESO European Southern Observatory

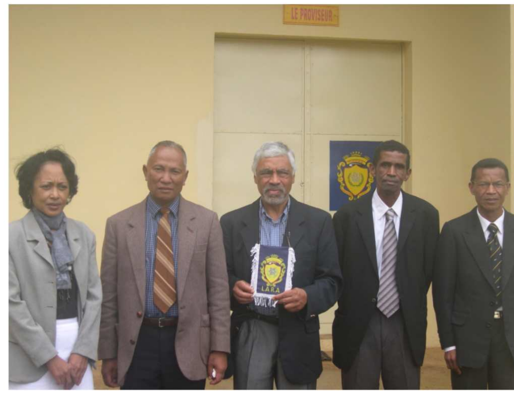
Le site de Paranal: désert de Chili (de Edmond Giraud)

Etude d'amas de galaxies et d'étoiles à 50 millions d'annèes lumière

- Les élèves et les enseignants



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  R. Albuquerque (Sao Paulo - Cotutelle de thèse Montpellier): Contrat FAPESP
  M. Nielsen & F. Navarra (Sao Paulo): Contrat FAPESP
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- Charmonium: desintegration & facteurs de forme

  J.M. Richard. (Grenoble): Lab. Franco-Chinois

  Z. Guo (Doctorant - Beijing): Lab. Franco-Chinois

  Q. Zhao (Beijing): Lab. Franco-Chinois

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  SVZ sum rules : 30 + 1 years later.

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- Mesons scalaires legers et gluonium

  Substructure of the sigma(600) and $f_0(980)$ from gamma-gamma scattering

  G. Mennessier, S. N., X.-G. Wang (Beijing), Phys.Lett. B696 (2011) 40-50.

  The sigma and $f_0(980)$ from $Ke_4 + \pi - \pi$ scatterings data

  G. Mennessier, S. N., X.-G. Wang (Beijing), Phys.Lett.B688:59-66,2010.

  Gluonium nature of the $\sigma/f_0(600)$ from its coupling to $K\bar{K}$.

  R. Kaminski (Cracow) , G. Mennessier, S. N., Phys.Lett.B680:148-153,2009.

- Baryons lourds

Mass-splittings of triple heavy baryons in QCD

S. N., R. Albuquerque (Montpellier & Sao Paulo) (a paraitre)

Mass-splittings of doubly heavy baryons in QCD

S. N., R. Albuquerque (Montpellier & Sao Paulo), Phys.Lett. B694 (2010) 217-225

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  Relation between Tcc,bb and Xc,b from QCD. J.M. Dias, S. N., F.S. Navarra, M. Nielsen, J.-M. Richard, Phys.Lett. B703 (2011) 274-280

  On the nature of the X(3872) from QCD.

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- Charmonium: desintegration & facteurs de forme

  The branching ratio $\psi(3770) \to J/\psi + \pi^0$ in QCD

  Z.-K. Guo, S.N., J.-M. Richard, Q. Zhao (à paraitre)

- Quantification sur le cone de lumière, renormalization

  Pierre Grangé, E. Werner,...

SVZ Non-Perturbative Sum Rules

alternative to Lattice calculations

♣ One of the Outstanding Discoveries of the 20th century

Shifman Vainshtein Zakharov : Sakurai's price 1999

♡ Bridge between High AND Low energy QCD regions

$$\Pi_H(Q^2 \equiv -q^2) \equiv i\int d^4x\, \langle 0|\mathcal{T}\, J_H(x) J_H^\dagger(0)|0\rangle$$

$$= \int_{t<}^{\infty} \frac{dt}{t + Q^2 + i\varepsilon}\mathrm{Im}\Pi(t) + \text{subtraction terms}$$

$$\textit{QCD OPE} = \textit{EXP DATA}$$

$J_H(x)$: Hadronic current

$$\bar\psi\Gamma\psi,\ \psi\psi\psi,\ \alpha_s G^2,\ g\bar\psi G\psi,\ \bar\psi\Gamma_1\psi\bar\psi\Gamma_2\psi, \ldots$$

Different Forms of the Sum Rules

- Improvement of the dispersion relation
  - Exponential (Borel/Laplace) SVZ

$$\text{Moments } \mathcal{L}_i(\tau) = \int_{t_<}^{\infty} dt \, \exp^{-t\tau} \, \text{Im}_i\Pi(t)$$

$$\text{Ratio } \mathcal{R}_i(\tau) \equiv -\frac{d}{d\tau} \log \mathcal{L}_i(\tau) \simeq M_{R_i}^2 \quad \equiv \text{Resonance Mass}^2$$

$$\text{Double Ratio } \sqrt{\frac{\mathcal{R}_1}{\mathcal{R}_2}} \simeq \frac{M_{R_1}}{M_{R_2}} \quad \equiv \text{Resonance Mass} - \text{splitting}$$

exponential enhances the low energy contribution.

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exponential enhances the low energy contribution.

  - Moments & FESR

$$\mathcal{M}_n = \int_{t_<}^{t_c} dt \; t^n \; \text{Im}\Pi(t)$$

Moments : $n \leq 0$ heavy quarks SVZ

FESR : $n \geq 0$ light quarks Lugunov-Soloviev-Tavkhelidze 67, Bramon-Etim-Greco 72, Shankar 77, Floratos-SN-de Rafael 79, ...

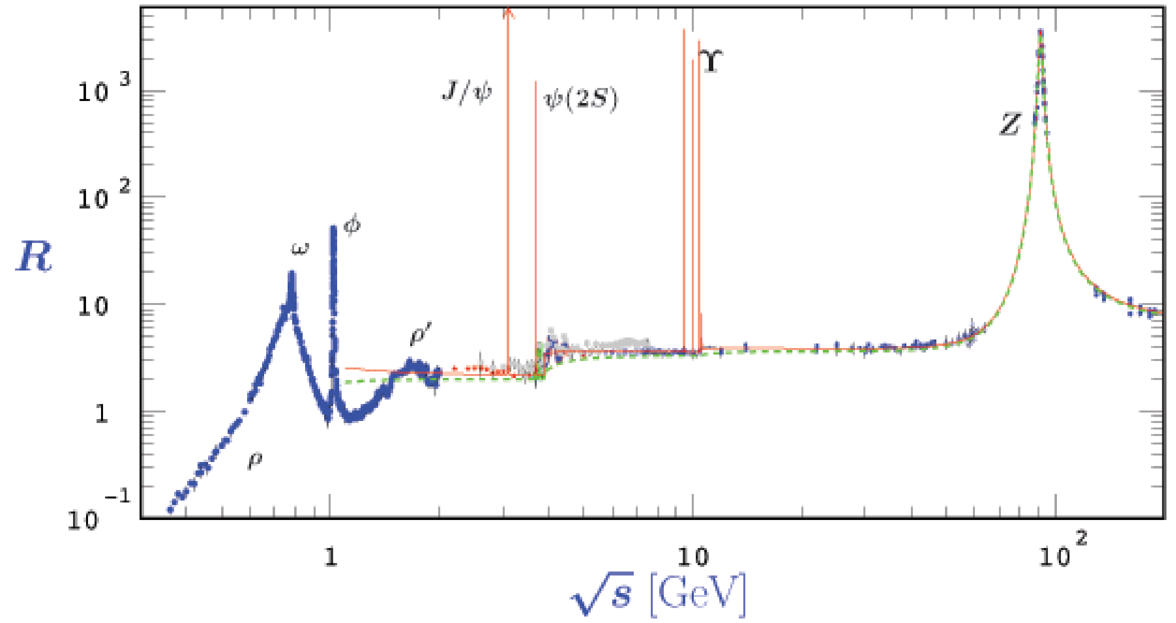
not accurate for extracting power corrections : $\neq$ of large numbers

The Adler function in e^+e^-

- $D(Q^2)$ mesurable in $e^+e^- \to \gamma, Z \to$ Hadrons process

$$D(Q^2) \equiv -Q^2 \frac{d}{dQ^2} \Pi(Q^2) = \frac{1}{12\pi^2} \int_{t_<}^{\infty} ds \, \frac{R(s)}{(s+Q^2)^2}$$

DM2, LEP, CLEO, BABAR, BELLE, BES



B. Richter, S. Ting Prix Nobel 1976 : decouverte du J/ψ

The SVZ-OPE for the Adler function

♣ $D(Q^2)$ known in QCD using the SVZ-OPE

$$D(Q^2) \equiv -Q^2 \frac{d}{dQ^2}\,\Pi(Q^2) = \sum_{p=0,1,2,\ldots} \frac{C_{2p}\langle 0|O_{2p}|0\rangle}{Q^{2p}}$$

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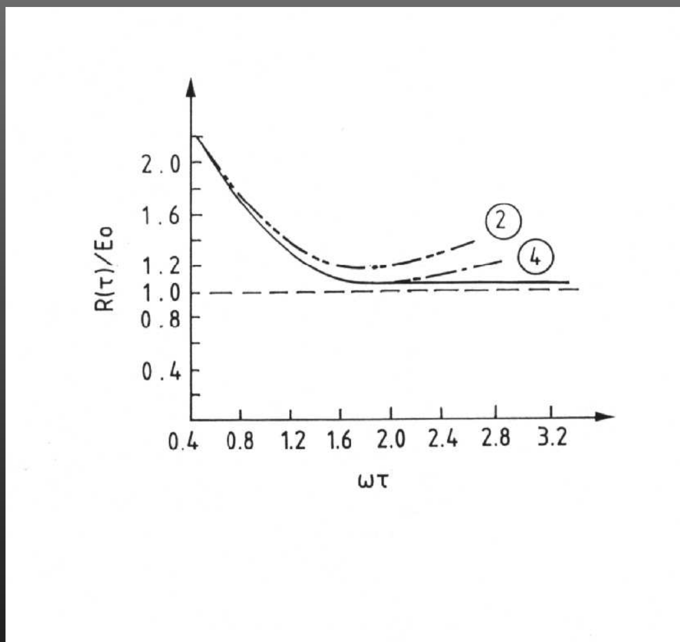
♢ Anatomy of the OPE in terms of QCD parameters

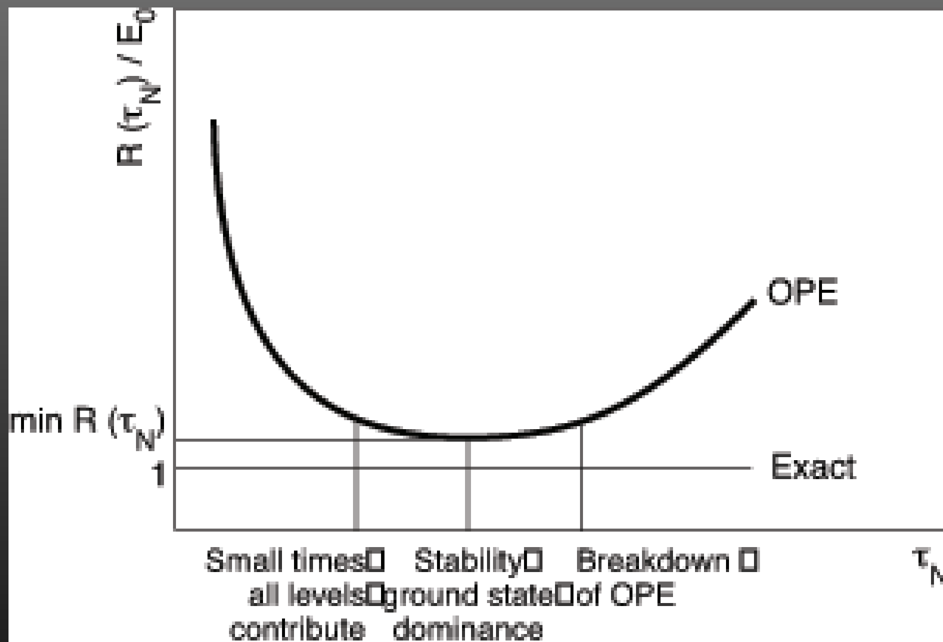
- $p = 0$: usual PT series $(a_s \equiv \alpha_s/\pi)$:
  $C_0 \equiv \sum_n c_n \alpha_s^n = 1 + a_s + 1.640\ a_s^2 + 6.371\ a_s^3 + 49.076\ a_s^4 +$
  $\Delta_N \equiv \sum_{n>N} c_n \alpha_s^n$??
- $p = 1$: $\overline{m}_q^2$: small corrections
- $p = 2$: $\langle \alpha_s\ G^2 \rangle, \quad m_q \langle \overline{\psi}_q \psi_q \rangle$: gluon and quark condensates
- $p = 3$: $\alpha_s \langle \overline{\psi}_q \psi_q \rangle^2$: four-quark condensates

Theoretical Progresses

♣ 1st Step

- Quant. Mec. & Non-Rel. Bell-Bertlmann (BB), NSVZ 81





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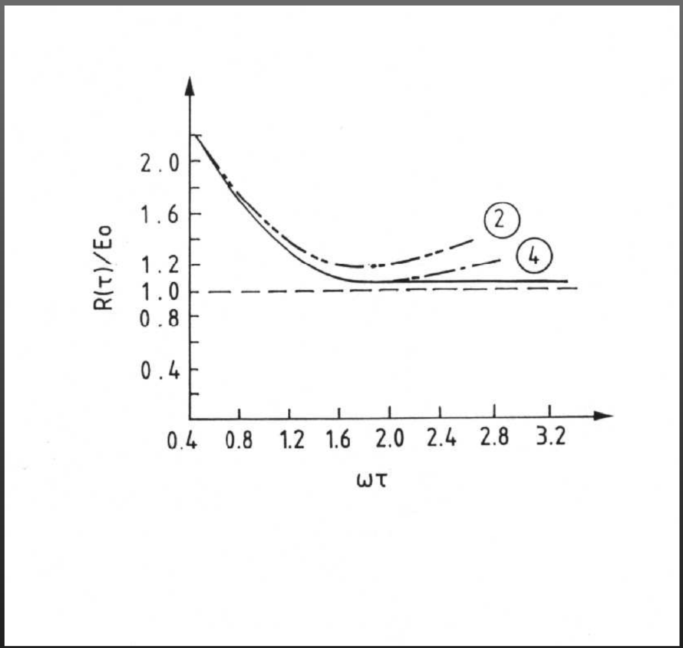
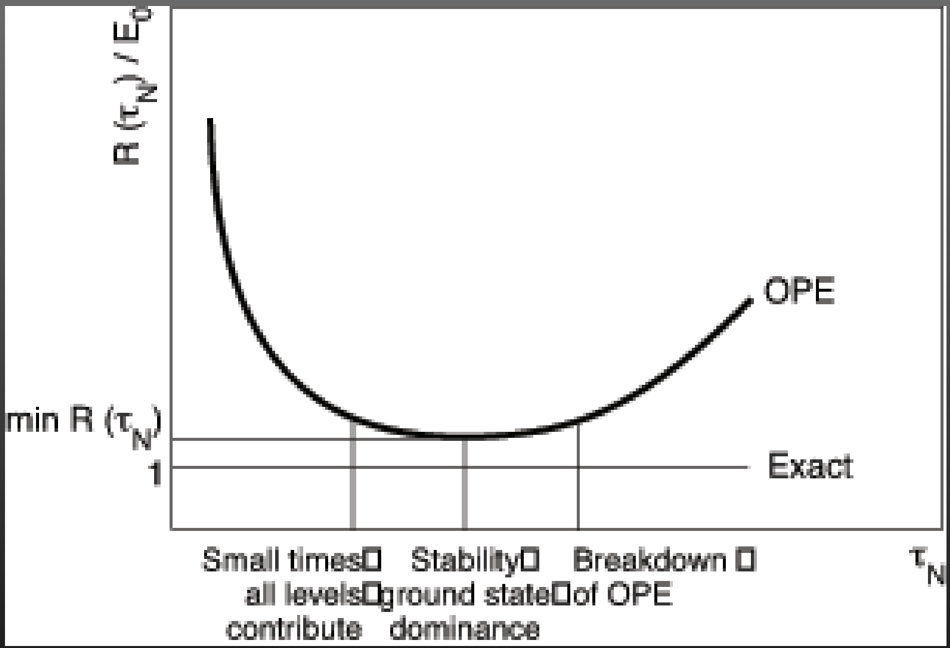
- Quant. Mec. & Non-Rel. Bell-Bertlmann (BB), NSVZ 81





- Radiative corrections into Exponential SR :

  Inverse Laplace NOT Borel transform SN- de Rafael 1981

♣ 2nd Step

- Mixing of operators under renormalization
  Tarrach 82, Espriu-Tarrach 82, SN-Tarrach 83,...
- Absorption of Mass singularities into the quark condensate
  Becchi-SN-de Rafael-Yndurain (BNRY) 81, Broadhurst-Generalis (BG) 84,
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♡ 3rd step

- ChPT constraints on the pion spectral function
  Bijnens-Prades-de Rafael 95
- Question on duality violation for spectral function
  Shifman 00, Cata-Golterman-Peris 09, G-Alonso-Prades-Pich, de Rafael,

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♠ Dual to $1/Q^2$ from a tachyonic gluon mass at short distance ?

- $\sum_{n>N} c_n \alpha_s^n \simeq C a_s \lambda^2/Q^2 \qquad \lambda^2 \leq 0$: $\quad N \approx 10$ Lattice
  Zakharov-Gubarev-Polikarpov, Chetyrkin-SN-Zakharov 95, SN-Zakharov 09
- Short PT series + power corrections $\equiv$ long PT series.

Traditional Hadron Phenomenology

♣ Impressive wide areas of applications: kalashnikov !

- ρ meson, gluon condensate, charm mass since 1979: SVZ
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- Gluonium since Novikov SVZ 80, SN 83, SN-Veneziano 89
- Light Hybrids Latorre-Pascual-SN 87, Chetyrkin-SN 00, SN 09
- Heavy Hybrids Govaerts-Reinders-Rubinstein-Weyers 85, SN-book 04
- Four-quarks, molecules Latorre-Pascual 85, SN 86; Sao Paolo, Chinese,...; Matheus-SN-Nielsen-Richard 07
- Hadronic decays Vertex Navarra et al... Light Cone De Fazio
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♡ SN books : WSC 89, Cambridge 04

PT QCD parameters

♣

Param	Values	Sources
QCD coupling		
$\alpha_s(M_Z)$	$0.1192(10)$	τ-decay SN 09
		[0.1191(27) Z-width]
		0.1189(10) average (Bethke, PDG)
Running Q. Masses	[MeV] $\mathcal{O}(\alpha_s^3)$	
$\overline{m}_u(2\ \mathrm{GeV})$	(2.8 ± 0.2)	average SN09
$\overline{m}_d(2\ \mathrm{GeV})$	(5.1 ± 0.2)	"
$\overline{m}_s(2\ \mathrm{GeV})$	(96.1 ± 4.8)	"
$\overline{m}_c(m_c)$	(1261 ± 16)	J/ψ Q^2-mom SN10, SN11
$\overline{m}_b(m_b)$	(4177 ± 11)	Υ Q^2 & Exp-mom SN10, SN11

SVZ power corrections *SNB 04 Chap. 27*

d	NPQCD param.	Values [GeV]^d	Sources
3	$\frac{1}{2}\langle\bar{u}u+\bar{d}d\rangle(2)$	$-(0.254\pm.015)^3$	(pseudo)scal,
	GMOR: $\delta_\pi\times10^{-2}$	5 ± 0.5 (6.2 ± 1.6)	LSR (less sens α_s) FESR
	$\langle\bar{d}d\rangle/\langle\bar{u}u\rangle$	$1-9\times10^{-3}$	non-norm. ord.(pseudo)scal,
	$\langle\bar{s}s\rangle/\langle\bar{d}d\rangle$	0.74 ± 0.03	non-norm. ord.(pseudo)scal
			$\oplus$ light & heavy baryons
4	$\langle\alpha_s G^2\rangle$	$(7\pm1)10^{-2}$	e^+e^-, $\Upsilon-\eta_b$, J/ψ LSR
	Lattice	Adriano 85, Rakow 09	τ : unconclusive
5	$g\langle\bar{\psi}\sigma_{\mu\nu}\frac{\lambda^a}{2}\psi G_a^{\mu\nu}\rangle$	$M_0^2=(0.80\pm0.02)$	Light baryons, B, B^*
	$\equiv M_0^2\alpha_s^{1/3\beta_1}\langle\bar{\psi}\psi\rangle$		
6	$g^3 f_{abc}\langle G^aG^bG^c\rangle$	$(8.2\pm1.0)\langle\alpha_s G^2\rangle$	J/ψ-LSR SN10
	$\rho\alpha_s\langle\bar{\psi}\psi\rangle^2$	$(4.5\pm0.3)10^{-4}$	$\rho=2.1\pm0.2$

Correlated Estimate of $1/Q^2$

♣ $1/Q^2-$term : tachyonic gluon mass SN95a, 95b, 09

Channels	$-(\alpha_s/\pi)\lambda^2$ in GeV$^2\times 10^2$
e^+e^- data	
$\mathcal{R}(\tau)$	6.5 ± 0.5
$\pi-$sum rule	
$\mathcal{L}_\pi$	12 ± 6
Average	7 ± 3
τ-decay : large $\beta-\sum_1^4$ PT series	
Fixed Order PT	2.6 ± 0.8
Contour Improved	5.9 ± 0.8

Effect of $1/Q^2$ on α_s from τ-decays

- α_s from τ-decay SN09

$$R_\tau \equiv \frac{\Gamma(\tau \to \nu_\tau + \mathrm{hadrons}|_{\Delta S=0})}{\Gamma(\tau \to l + \bar{\nu}_l + \nu_\tau)}$$

$$= 3|V_{ud}|^2 S_{EW}(1 + \delta^{(0)} + \delta'_{EW} + \delta_m^{(2)} + \delta_{\mathrm{svz}} + \delta_{\mathrm{NST}})$$

Corrections	Size $\times 10^3$
$\delta_{svz} = \Sigma_4^8 \delta^{(D)}$	$-(7.8 \pm 1.0)$
$\delta_{ST} \equiv \delta_{svz} + \delta_m^{(2)} + \delta_\pi + \delta_{a_0}$	$-(10.9 \pm 1.1)$
δ_{inst}	$-(0.7 \pm 2.7)/20$
δ_{DV}	$-(15 \pm 9)$ Cata-Golterman-Peris
$\delta_{tach} \equiv large\ \beta - \Sigma_1^4 PT$	(17 ± 5) FO
	(39 ± 5) CI
$\delta_{NST} \equiv \delta_{inst} + \delta_{DV} + \delta_{tach}$	(2.0 ± 9.4) *FO*
	(24.0 ± 10.6) *CI*

$$R_{\tau,V+A}|_{exp} = 3.479 \pm 0.011 \quad \Longrightarrow$$

$$\alpha_s(M_\tau) = 0.3276(34)_{ex}(10)_{st}(85)_{nst} \quad \text{FO}$$

$$= 0.3221(48)_{ex}(14)_{st}(121)_{nst} \quad \text{CI}$$

$\Longrightarrow$

PT	$\alpha_s(M_\tau)$	$\alpha_s(M_Z)$	Ref.
FO	$0.3276\ (34)_{\rm ex}(86)_{\rm th}$	$0.1195\ (4)_{\rm ex}(10)_{\rm th}(2)_{\rm ev}$	SN 09
CI	$0.3221\ (48)_{\rm ex}(122)_{\rm th}$	$0.1188\ (6)_{\rm ex}(15)_{\rm th}(2)_{\rm ev}$	
$\langle\ \rangle$	$0.3249\ (29)_{\rm ex}(75)_{\rm th}$	$0.1192\ (4)_{\rm ex}(9)_{\rm th}(2)_{\rm ev}$	
Z		$0.1191\ (27)_{\rm ex}(2)_{\rm th}$	BCK, DAVIER et al.
$\langle\ \rangle$		0.1189 (10)	BETHKE, PDG

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- ♡ $1/Q^2$ term: seems to improve many existing phenomenology