Fisica Elettrodebole: rassegna teorica

Fulvio Piccinini

INFN, Sezione di Pavia

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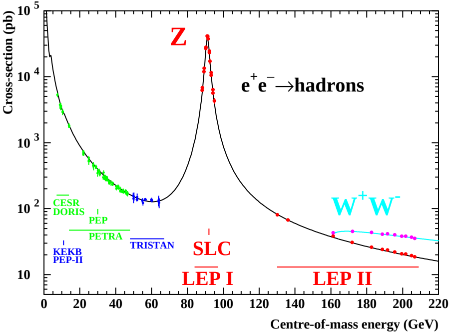
Outline

- The Standard Model at the start of LHC
  - electroweak precision observables
  - muon anomalous magnetic moment
  - the role of low/intermediate energy e^+e^- machines
- electroweak physics at LHC ($\sqrt{s} = 7$ TeV) (excluding Higgs physics)
  - Drell-Yan
  - Vector boson pair production
  - single top

tests of the electroweak sector span over a broad range of energies

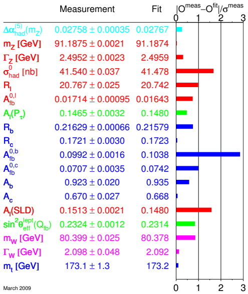
- experiments at e^+e^- precision machines



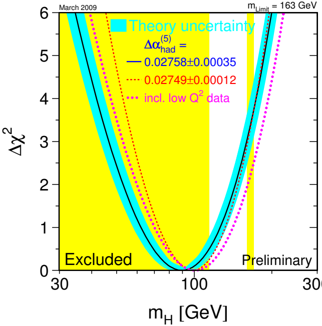
Phys. Rept. **427** (2006) 257

plus measurements at the high energy frontier hadronic colliders

status of electroweak precision observables



CERN-PH-EP/2009-023

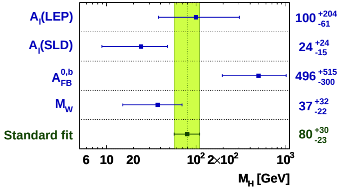


- Globally good agreement of SM predictions with measurements
- largest uncertainty on the Higgs mass determination from the hadronic contribution to the photon vacuum polarization

$$\alpha(M_Z) = \frac{\alpha(0)}{1 - \Delta\alpha_{\rm lept} - \Delta\alpha_{\rm top} - \Delta\alpha_{\rm had}}$$

tension in the data and correlation between param.

Results of the fit including only one exp. data at a time among the most sensitive ones to M_H



Correlation coefficients between the free fit parameters

Parameter	$\Delta\alpha_{\rm h}(M_Z^2)$	M_Z	$\alpha_s(M_Z^2)$	$m_{\rm top}$
$\ln M_H$	-0.395	0.113	0.041	0.309
$\Delta\alpha_{\rm h}(M_Z^2)$	1	-0.006	0.101	-0.007
M_Z		1	-0.019	-0.015
$\alpha_s(M_Z^2)$			1	0.021

Correlation between M_H and M_W (input): -0.49

H. Flächer et al., (GFitter Group), arXiv:0811.0009[hep-ph]

Important for the future: more precise determination of

- $\Delta\alpha_{\rm had}(M_Z^2)$ $\Rightarrow$ flavour factories
- M_W and $m_{\rm top}$ $\Rightarrow$ Tevatron, LHC
- $\delta M_W \simeq 7\times 10^{-3} m_{\rm top}$ to have same impact on $m_{\rm H}$ determination

status of $a_\mu = (g-2)/2$

- E821 measurement with an error of 0.5 ppm

$$a_\mu^{\rm exp} = 116592089(63) \times 10^{-11}$$

G.W. Bennet et al. (Muon (g-2)), Phys. Rev. **D73** (2006) 072003

Experimental proposal for further reduction to 0.14 ppm

R.M. Carey et al., (2009), Fermilab-Proposal-0989

J. Imazato, Nucl. Phys. Proc. Suppl. 129 (2004) 81, J-PARC Proposal

- on the theory side

$$a_\mu^{\rm SM} = a_\mu^{\rm QED} + a_\mu^{\rm EW} + a_\mu^{\rm HLO} + a_\mu^{\rm HHO}$$

$a_\mu = (g-2)/2$: theoretical calculations

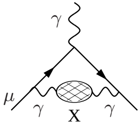
- QED perturbative corrections known up to 4 loops plus 5 loops partial calculation: $a_\mu^{\mathrm{QED}} = 116584718.10(16) \times 10^{-11}$

T. Aoyama, M. Hayakawa, T. Kinoshita; S. Laporta, E. Remiddi; M. Passera

- two loop electroweak radiative corrections: $a_\mu^{\mathrm{EW}} = 154(2) \times 10^{-11}$

A. Czarnecki, B. Krause, W.J. Marciano, A. Vainshtein

- a_μ^{HLO} vacuum polarization insertion in vertex correction
  $\Uparrow$



- $a_\mu^{\mathrm{HHO}} = a_\mu^{\mathrm{HHO}}(\text{vac. pol.}) + a_\mu^{\mathrm{HHO}}(\text{light by light})$
  $\Uparrow$
  bottleneck

vacuum polarization

- perturbation theory (PT) reliable for leptons and $top-$quark
- PT not reliable for light quark
- $\Rightarrow$ hadronic contribution could be calculated from QCD Lagrangian with Lattice QCD. However present estimates based on LQCD are not yet competitive on precision with other methods

A. Jüttner and M. Della Morte, arXive:0910.3755[hep-lat]

E. Shintani, S. Aoki, T. Chiu et al., PRD79 (2009) 074510

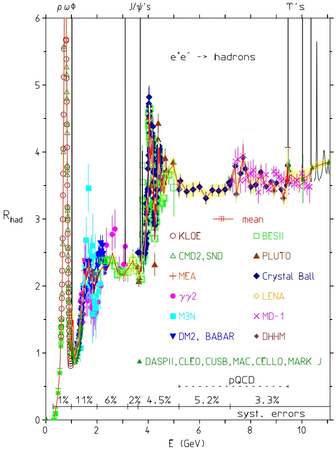
- through optical theorem we can use as input the total hadronic cross section measured experimentally at e^+e^- machines:

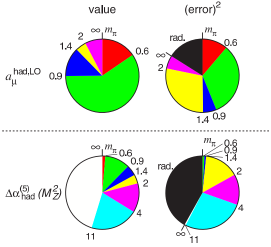
$$\Delta\alpha^{(5)}_{\rm had}(M_Z^2) = -\left(\frac{\alpha M_Z^2}{3\pi}\right) \mathrm{Re} \int_{4m_\pi^2}^{\infty} ds \frac{R(s)}{s(s - M_Z^2 - i\epsilon)}$$

$$a_\mu^{\rm HLO} = \left(\frac{\alpha^2}{3\pi^2}\right) \int_{4m_\pi^2}^{\infty} ds \frac{K(s)R(s)}{s}$$

- also τ decay data can be used

problem: determination of $R(s) = \frac{3s}{4\pi\alpha^2}\sigma_h^0(s)$ with $\sqrt{s} \leq 12$ GeV





G. Amelino-Camelia et al., arXiv:1003.3868[hep-ph]

recent activity on $R(s)$ determination

- recent progress in the reduction of the theoretical uncertainty at the 0.1% level for QED processes (Bhabha scattering, $\mu^+\mu^-$, $\gamma\gamma$ production, essential ingredients for absolute normalization)

  Balossini, Bignamini, Carloni Calame, G. Montagna, O. Nicrosini, F.P.; Arbuzov; Placzek, Jadach, Ward, Was et al.

- improvement on theoretical predictions for “radiative return” events

  Czyz, Kühn, Rodrigo, Trentadue, et al.

- recent joint WG of theorists and experimentalists

  S. Actis et al., arXiv:0912.0749[hep-ph]

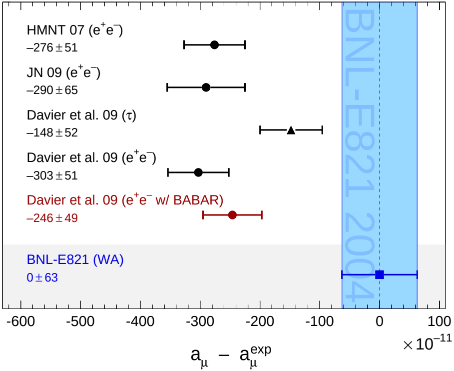
$\delta\Delta\alpha^{(5)}_{\rm had} \times 10^5$	Request on R
22	Present
7	$\delta R/R \sim 1\%$ up to J/ψ
5	$\delta R/R \sim 1\%$ up to Υ

- experiments at the DAΦNE upgrade and VEPP2000 (Novosibirsk) will be crucial to reach the 1% level experimental error in the region up to $\sqrt{s} \simeq 2.5$ GeV

  G. Amelino-Camelia et al., arXiv:1003.3868[hep-ph]

- further improvements foreseen at SuperB factories by means of radiative return method

present status of a_μ

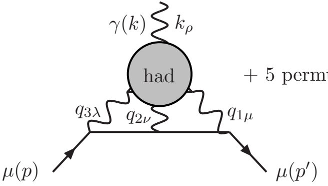


- SM theoretical predictions differ by 3-4 σ's from measurement
- determinations based on e^+e^- data in mutual agreement
- clash with determination based on τ data

M. Davier, arXiv:1001.2243[hep-ph]

the ultimate limiting factor: light by light scattering

It can be calculated only by means of models



$+ 5$ permutations of the q_i

F. Jegerlehner, A. Nyffeler, Phys. Rept. 477 (2009) 1

spread of contributions to $a_\mu^{\rm LbyL} \times 10^{11}$

group	estimate
BPP	83 ± 32
HKS,HK	89.6 ± 15.4
KN	80 ± 40
MV	136 ± 25
BP, MdRR	110 ± 40
PdRV	105 ± 26
N, JN	116 ± 39

A. Nyffeler, arXiv:1001.3970[hep-ph]

electroweak physics @ LHC: Drell-Yan

- easy detection: high $p_\perp$ leptons pair or lepton+missing $p_\perp$
- large cross sections. At LHC vs. Tevatron:
  - $\sigma(W) \simeq 9(@7\,\mathrm{TeV})18(@14\,\mathrm{TeV})$ nb ($\simeq 2$ nb @Tevatron)
  - $\sigma(Z) \simeq 1(@7\,\mathrm{TeV})2(@14\,\mathrm{TeV})$ nb ($\simeq 0.2$ nb @Tevatron)
  - good statistics with $\mathcal{L} \simeq 1$ fb^{-1} to obtain results similar to final Tevatron results
- main physics motivations
  - ⋆ detectors calibration
  - ⋆ PDF validation and constraint
  - ⋆ W mass and Γ measurement
  - ⋆ collider luminosity monitoring (as done at LEP with Bhabha)
  - ⋆ background to New Physics searches
- Precise theoretical prediction are strongly required

relevant observables

- PDF constraints $\Rightarrow$ W and Z rapidity distribution, lepton(s) rapidity distribution
- collider luminosity $\Rightarrow$ inclusive cross section
- W mass and width determination $\Rightarrow$ M_T^W distribution, scaled M_T^W/M_T^Z distribution
- Background to New Physics $\Rightarrow$ invariant (transverse) mass distribution tail

status of theoretical calculation/tools

- fully exclusive NLO QCD corrections to W/Z production (**MCFM**)

  Campbell, Ellis

- fully exclusive NNLO QCD corrections to W/Z production

  Anastasiou et al.; Melnikov, Petriello; Catani, Ferrera, de Florian, Grazzini

- resummation of LL/NLL p_T^V/M_V logs (**RESBOS**)

  Balazs, Yuan; Bozzi, Catani, Ferrera, de Florian, M. Grazzini

- NLO QCD merged with MC Parton Shower (**MC@NLO**, **POWHEG**)

  Frixione, Webber; Alioli, Nason, Oleari, Re

- fully exclusive NLO EW (**W/ZGRAD**, **HORACE**, **SANC**)

  Zykunov et al.; Dittmaier, Krämer; Arbuzov, Bardin et al.,

  Baur, Wackeroth; A. Arbuzov, et al.; Carloni Calame, Montagna, Nicrosini, Vicini

- Leading Log multiphoton radiation (**HORACE**, **WINHAC**)

  Carloni Calame, Montagna, Nicrosini, Treccani; Jadach, Płaczek

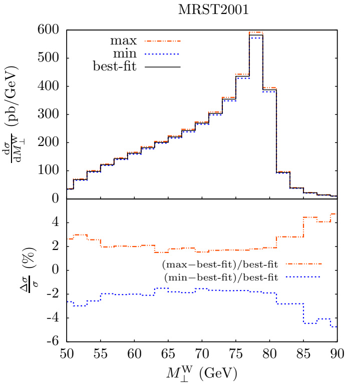
- NLO EW merged with multiphoton radiation (**HORACE**, **WINHAC**)

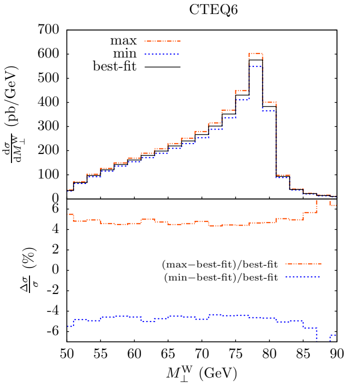
  Carloni Calame, Montagna, Nicrosini, Vicini; Jadach, Płaczek

- Combination of QCD and EW corrections

  Balossini, Montagna, Carloni Calame, Montagna, Nicrosini, P., Vicini

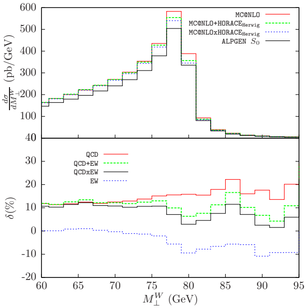
importance of PDF knowledge

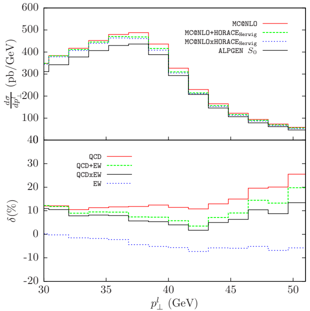




Balossini, Carloni Calame, Montagna, Nicrosini, P., Vicini

Electroweak $\otimes$ QCD @ the LHC

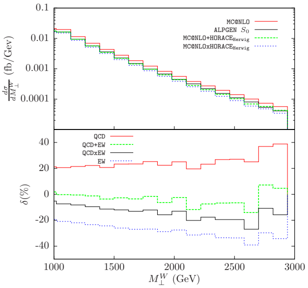


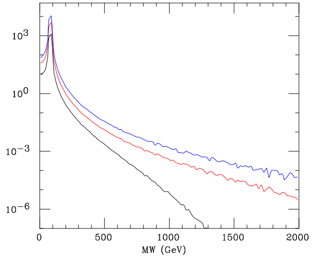


Balossini, Carloni Calame, Montagna, Nicrosini, P., Vicini (2010)

- Around the W peak, for both $M_\perp^W$ and $p_\perp^\ell$ NLO QCD corrections are positive and tend to compensate negative electroweak contributions
- The above picture is for $\sqrt{s} = 14$ TeV but it is valid also @7 TeV
- QED radiative corrections dominate in the peak region (even if pure EW contributions are considered in the high precision M_W determination already at Tevatron)

when electroweak corrections become strong...





Balossini, Carloni Calame, Montagna, Nicrosini, P., Vicini (2010)

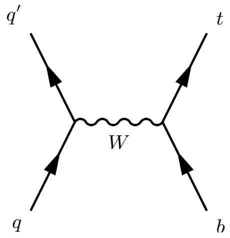
- The effect of Sudakov Logs present in the EW NLO calculation $\simeq \alpha \log^2(\hat{s}/M_W^2)$ will be manifest in the future at high energy and luminosity
- Already in the region 100–200 GeV, used to determine Γ_W, Sudakov Logs can become relevant in the near future

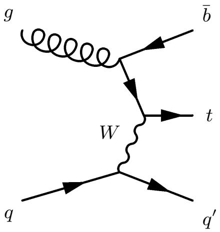
vector boson pair production

- Up to now triple gauge boson self-interactions have been tested at LEP1 (indirectly) and LEP2 (directly through the $W^+W^- \to 4f$ final states) up to $\simeq 200$ GeV
- Limits have been put on anomalous TGC's without disentangling γW^+W^- and ZW^+W^- vertices
- In addition to $hh \to W^+W^-$, at hadron colliders we can probe separately the contributions of γW^+W^- and ZW^+W^- couplings, through the processes $hh \to W\gamma$, $hh \to WZ$
- and also anomalous couplings in the neutral sector (forbidden in the SM) can be probed through the final states ZZ and $Z\gamma$
- the larger cross section at LHC (7 TeV) and the sensitivity to larger VV invariant masses should compensate the lower luminosity w.r.t. Tevatron
- QCD and (Sudakov log. expansions of) EW corrections known

Accomando, Denner, Kaiser, Pozzorini; Frixione, Nason, Ridolfi

single top production





$\sigma(\text{Tevatron}) \simeq 1\,\text{pb}$ $\sigma(\text{Tevatron}) \simeq 2\,\text{pb}$

$\sigma(\text{LHC@7TeV}) \simeq 5\,\text{pb}$ $\sigma(\text{LHC@7TeV}) \simeq 60\,\text{pb}$

$\sigma(\text{LHC@14TeV}) \simeq 10\,\text{pb}$ $\sigma(\text{LHC@14TeV}) \simeq 150\,\text{pb}$

- Amplitudes proportional to Wtb coupling
- $\Rightarrow$ direct measurement of $|V_{tb}|$

single top

- NLO + higher order QCD corrections known (contained in size)

Stelzer, Sullivan, Willenbrock; Cao, Schwienhorst, Yuan

Frixione, Laenen, Motylinski; Kidonakis

Campbell, Frederix, Maltoni, Tramontano

- EW + SUSY corrections (some benchmark points) at few % level

Beccaria et al., PRD 77 (2008) 113018

- present PDF induced uncertainty at few % level

$\Rightarrow$ single top allows a "model independent" determination of $|V_{tb}|$

- first cross section measurement at Tevatron

CDF Coll., PRD78 (2008) 012005; D0 Coll., PRL 101 (2008) 252001; TevEwWG (20

- measured $\delta|V_{tb}| \simeq 10\%$

Thanks to higher cross section, LHC@7 TeV and $\mathcal{L} \simeq$1 fb^{-1} will be competitive with final Tevatron measurements

Summary

- Electroweak fit globally in agreement with SM prediction with preference for a light Higgs
- Some tension in the data is still present
- muon anomalous magnetic moment shows a 3σ deviation
- results at flavour factories important to reduce the uncertainties of theoretical predictions
- precision results on M_W and $m_{\rm top}$ at Tevatron further constrain the electroweak fit
- LHC @7 TeV and 1 fb^{-1} could confirm the precision of final Tevatron data on electroweak physics
- the available phase space should increase slightly the sensitivity to anomalous TGC's and large mass DY