Neutral current observables & neutrino scattering

Jens Erler (IF-UNAM)

Workshop on Beyond the Standard Model in Nuclear Physics

University of Wisconsin, Madison  October 15, 2011
Outline

- Weak mixing angle
- Weak charges
- Deep inelastic scattering
- New physics sensitivities
- Open questions
Weak mixing angle
Definition

- $J_\mu^Z = \cos \theta_W J_\mu^0 - \sin \theta_W J_\mu^Y$
- $J_\mu^Y = \sin \theta_W J_\mu^0 + \cos \theta_W J_\mu^Y$

in SM: $\sin^2 \theta_W = g'^2 / (g^2 + g'^2) = 1 - M_W^2/M_Z^2$

one-loop corrections:

- to measure it, need to eliminate QED:
  - Z pole ($A_{FB}$)
  - parity violation
  - neutrinos
uncertainty in prediction is small except possibly in the hadronic transition region JE, Ramsey-Musolf (2005) reconsider?
Z pole discrepancy

\[
\sin^2 \theta_{\text{eff}}
\]

\[
A_{\text{FB}}^{0,l} \quad 0.23099 \pm 0.00053
\]
\[
A_{\text{FB}}^{0,b} \quad 0.23221 \pm 0.00029
\]
\[
A_{\text{FB}}^{0,c} \quad 0.23220 \pm 0.00081
\]
\[
A_{\text{SLD}}^{0} \quad 0.23098 \pm 0.00026
\]
\[
Q_{\text{had}} \quad 0.2324 \pm 0.0012
\]

Average 0.23153 \pm 0.00016

\[
\chi^2/\text{d.o.f.}: 11.8 / 5
\]

$m_t = 172.7 \pm 2.9$ GeV

$sábado 15 de octubre de 2011$
Z pole discrepancy

- to decide need new experiments
Z pole discrepancy

- to decide need new experiments
- if new results fall between the two Z-pole values:
  - two fluctuations of 2 $\sigma$ in opposite directions
  - if light Higgs $\sim$ 115-145 GeV found at LHC then SM confirmed
  - if no light Higgs found then $> 5 \sigma$ conflict between direct and indirect Higgs data
Status of $M_H$

- new value confirms SLC:
  - tension between direct and indirect data (how much depends on $M_H$)
- new value confirms LEP:
  - $> 3 \sigma$ conflict between $\sin^2\theta_W$ and $M_W$
Status of $M_H$

- new value confirms SLC:
  - tension between direct and indirect data (how much depends on $M_H$)
- new value confirms LEP:
  - $> 3 \, \sigma$ conflict between $\sin^2 \theta_W$ and $M_W$
Status of $M_H$

- new value confirms SLC:
  - tension between direct and indirect data (how much depends on $M_H$)
- new value confirms LEP:
  - $> 3 \, \sigma$ conflict between $\sin^2\theta_W$ and $M_W$
Status of $M_H$

- new value confirms SLC:
  - tension between direct and indirect data (how much depends on $M_H$)
- new value confirms LEP:
  - $> 3\,\sigma$ conflict between $\sin^2\theta_W$ and $M_W$
Weak charges
$Q_{W^e}$ and $Q_{W^p}$

- Physics:
  - measure $\sin^2\theta_W$ (most important derived SM quantity)
  - shed light on $A_{FB}(b)$ vs. $A_{LR}$ discrepancy ($\sim 3\sigma$)
  - SM suppression ($\sim 1 - 4 \sin^2\theta_W$) enhances NP effects
  - unlike Z-pole measurements (which are sensitive to modifications of Z-couplings), new physics amplitudes not overwhelmed by Z resonance
$Q_{W^e} (E158@SLAC & MOLLER)$
**Q_{W^e} (E158@SLAC & MOLLER)**

- **Impact and sensitivity level:**
  - E158 (final) first measurement; by far more precise than ν-e elastic scattering
  - MOLLER (approved) will break ground and be on par with the world’s best measurements from LEP & SLC at much lower cost
  - Without GigaZ, Q_{W^e} may also provide best $\sin^2\theta_W$ at an ILC
**$Q_{W^e}$ (E158@SLAC & MOLLER)**

- **impact and sensitivity level:**
  - E158 (final) first measurement; by far more precise than $\nu$-$e$ elastic scattering
  - MOLLER (approved) will break ground and be on par with the worlds best measurements from LEP & SLC at much lower cost
  - without GigaZ, $Q_{W^e}$ may also provide best $\sin^2 \theta_W$ at an ILC

- **theory:**
  - clean leptonic probe
  - 1-loop radiative corrections done, 2-loop underway *Aleksejevs, Barkanova, Ilyichev, Kolomensky, Zykunov (2010)*
$Q_{w^p}$ (Qweak & P2@Mainz)
$Q_{wp}$ (Qweak & P2@Mainz)

- impact and sensitivity level:
  - Qweak (running) first measurement; will likely be best $\sin^2\theta_w$ at low energy for rest of decade
  - P2 (proposed) may cut error in half; comparable to MOLLER. Hydro-Møller polarimeter useful for other polarization asymmetries?
Q_{\text{w}p} (Q\text{weak} & P2@Mainz)

- Impact and sensitivity level:
  - Q\text{weak} (running) first measurement; will likely be best $\sin^2\theta_W$ at low energy for rest of decade
  - P2 (proposed) may cut error in half; comparable to MOLLER. Hydro-Møller polarimeter useful for other polarization asymmetries?

- Theory:
  - Q\text{weak}: most hadronic effects addressed by extrapolating to $Q^2 = 0$
  - e-scattering needs extra $\gamma$-Z box correction to extract $Q_{\text{w}p}$ \Rightarrow large uncertainty of $\pm 3\%$. Data input needed: JLab? Mainz?
  - P2: $Q^2 \sim 0.0022$ GeV$^2$ is low enough to use form factors Aleksejevs, Barkanova, Zykunov (2010) and to keep $\gamma$-Z box error small ($\pm 0.4\%$)
$Q_{w}^{Cs}$ and $Q_{w}^{TI}$ (APV)
$Q_{w}^{Cs}$ and $Q_{w}^{TI}$ (APV)

- impact and sensitivity level:
  - give independent linear combination in $C_{1u}-C_{1d}$ plane
$Q_{W}^{Cs}$ and $Q_{W}^{Tl}$ (APV)

- impact and sensitivity level:
  - give independent linear combination in $C_{1u}$-$C_{1d}$ plane
- Leading uncertainties of $Q_{W}^{Cs}$ (the most precise APV)
  - Measurement: 0.35% *Wood et al. (1997)*
  - Atomic theory: 0.29% *Porsev, Beloy, Derevianko (2009)*
  - Stark vector transition polarizability: 0.17%
**$Q_w^{\text{Cs}}$ and $Q_w^{\text{Tl}}$ (APV)**

- **impact and sensitivity level:**
  - give independent linear combination in $C_{1u}-C_{1d}$ plane
- **Leading uncertainties of $Q_w^{\text{Cs}}$ (the most precise APV)**
  - Measurement: 0.35% *Wood et al. (1997)*
  - Atomic theory: 0.29% *Porsev, Beloy, Derevianko (2009)*
  - Stark vector transition polarizability: 0.17%
- **Atomic theory largely cancels in isotope ratios $R \equiv Q_w^1/Q_w^2$**
  - but is **doubly** suppressed: $\Delta R/R \approx \Delta(Q_w^p/Q_w^n) Z \Delta N/N_1 N_2$
  - $\Rightarrow$ need **large isotope spread**; Yb$^+$, Ra$^+$ has $\Delta N = 8, 12$
\[ Q_w(\text{Ra}^+) \]

- PV in single trapped ions
- \text{Ra}^+: Alkali-like
- claimed sensitivity: 50× larger effect, 5× more precise than APV in Cs. \textit{Jungmann, Willmann}
- atomic theory would need similar improvement
  - this will need great effort, but is there any obvious road block?
  - can polarizabilities be improved accordingly?
- nuclear theory (neutron skin, etc) to be improved as well
Deep inelastic scattering
Parity violating eDIS
Parity violating eDIS

- 6 GeV PVDIS (offline analysis stage) and 1.1 GeV follow-up “baseline” experiment or SoLID (approved)
Parity violating eDIS

- 6 GeV PVDIS (offline analysis stage) and 11 GeV follow-up “baseline” experiment or SoLID (approved)

- Impact and sensitivity level:
  - SoLID 54x more precise than SLAC result *Prescott et al.* (1979)
Parity violating eDIS

- 6 GeV PVDIS (offline analysis stage) and 11 GeV follow-up “baseline” experiment or SoLID (approved)

- impact and sensitivity level:
  - SoLID 54× more precise than SLAC result *Prescott et al. (1979)*

- Physics:
  - hadronic axial-currents
  - will supersede any existing (poorly known) constraints on $C_{2i}$ from elastic scattering (almost impossible to interpret)
  - measure $\sin^2\theta_W$ with roughly $Q_{\text{weak}}$ precision
Parity violating eDIS
Parity violating eDIS

- theory liabilities will be turned into assets:
  - charge symmetry violation (vary $x$)
  - higher twist operators (vary $Q^2$)
  - $d/u$ parton distributions (replace $D$ by $H$)
  - EMC effect (replace light by heavy nuclei)
Parity violating eDIS

- theory liabilities will be turned into assets:
  - charge symmetry violation (vary $x$)
  - higher twist operators (vary $Q^2$)
  - $d/u$ parton distributions (replace $D$ by $H$)
  - EMC effect (replace light by heavy nuclei)
- how to proceed in practice?
  - Multi-dimensional fit?
  - Should be decided beforehand!
Parity violating eDIS

- theory liabilities will be turned into assets:
  - charge symmetry violation (vary x)
  - higher twist operators (vary $Q^2$)
  - d/u parton distributions (replace D by H)
  - EMC effect (replace light by heavy nuclei)

- how to proceed in practice?
  - Multi-dimensional fit?
  - Should be decided beforehand!

- all of these issues also affect vDIS.
  - how (in)direct is the interconnection?
vDIS
vDIS

- CHARM, CDHS, CCFR, NuTeV
  - all correlated through theory inputs & assumptions
vDIS

- CHARM, CDHS, CCFR, NuTeV
  - all correlated through theory inputs & assumptions
- NuTeV: $\sim 3\ \sigma$ deviation in $g_L^2$ ($g_R^2$ agrees but less precise)
  - difficult to explain *entire* effect by BSM physics
vDIS

- CHARM, CDHS, CCFR, NuTeV
  - all correlated through theory inputs & assumptions
- NuTeV: ~ 3 σ deviation in $g_L^2$ ($g_R^2$ agrees but less precise)
  - difficult to explain *entire* effect by BSM physics

Physics:

- 4-Fermi operators in $\nu$-sector
- vDIS historically important in constraining $\sin^2\theta_W$ but this has become less of a motivation
- can imaging a physics program as rich as in eDIS and addressing the same questions; feasible?
vDIS

- theory:
  - QCD corrections to structure functions
  - strange quark asymmetry (NLO PDFs and new data)
  - $d/u$ (and to a lesser extent $\overline{d}/\overline{u}$) within CSC context
  - CSV from quark mass differences
  - CSV from QED splitting
  - QED & EW radiative corrections
  - nuclear effects (shadowing, isovector EMC, etc)
New physics sensitivities

following talk by John Ng for specific and realistic model
Sensitivities to new physics

\[ \Lambda_{\text{new}} \approx [\sqrt{2} \, G_F \, \Delta Q_W]^{-1/2} = 246.22 \text{ GeV} / \sqrt{\Delta Q_W} \]

- \( \Lambda_{\text{new}} \approx 3.4 \text{ TeV} \) (\( Q_{W^e} \) from E158)
- \( \Lambda_{\text{new}} \approx 4.6 \text{ TeV} \) (\( Q_{W^p} \) from Qweak)
- \( \Lambda_{\text{new}} \approx 2.5 \text{ TeV} \) (\( C_{ij} \) from SoLID)
- \( \Lambda_{\text{new}} \approx 7.5 \text{ TeV} \) (\( Q_{W^e} \) from MOLLER)
- \( \Lambda_{\text{new}} \approx 6.3 \text{ TeV} \) (\( Q_{W^p} \) from P2@Mainz)
- \( \Lambda_{\text{new}} \approx 3.7 \text{ TeV} \) (\( g_R^2 \) from NuTeV)
- \( \Lambda_{\text{new}} \approx 5.2 \text{ TeV} \) (\( Q_{W^n} \) from APV in Cs)
E₆ models & parity violation

68% exclusion limits
Mₗ' = 1.2 TeV

- APV (Boulder)
- E158 (SLAC)
- MOLLER
- Qweak
- SOLID

α COS β

sábado 15 de octubre de 2011
Complementarity with colliders

![Graph showing excluded regions for $g'$ and $M_{Z'}^{-1}$](image)

- 95% C.L. this analysis
- 85% C.L. this analysis
- 68% C.L. this analysis
- 95% C.L. CDF analysis
- 95% C.L. PE
- 95% C.L. EWPD

Excluded region for $Z_\chi$ and $X$
Open questions
Open questions
Open questions

• should νDIS still be used in EW fits?
Open questions

- should νDIS still be used in EW fits?
- what other ν scattering expts could be competitive? ν-e?
Open questions

- should νDIS still be used in EW fits?
- what other ν scattering expts could be competitive? ν-e?
- what is the best strategy for eDIS to address the various QCD and EW issues in an unbiased way (to be settled before SoLID starts data taking)?
Open questions

- should νDIS still be used in EW fits?
- what other ν scattering expts could be competitive? ν-e?
- what is the best strategy for eDIS to address the various QCD and EW issues in an unbiased way (to be settled before SoLID starts data taking)?
- what progress (theory and expt) can be expected for γ-Z box?
Open questions

- should $\nu$DIS still be used in EW fits?
- what other $\nu$ scattering expts could be competitive? $\nu$-e?
- what is the best strategy for eDIS to address the various QCD and EW issues in an unbiased way (to be settled before SoLID starts data taking)?
- what progress (theory and expt) can be expected for $\gamma$-Z box?
- if all low energy measurements of $\sin^2\theta_W$ happen, RGE error would no longer be negligible. Double-check result!
Open questions

- should νDIS still be used in EW fits?
- what other ν scattering expts could be competitive? ν-e?
- what is the best strategy for eDIS to address the various QCD and EW issues in an unbiased way (to be settled before SoLID starts data taking)?
- what progress (theory and expt) can be expected for γ-Z box?
- if all low energy measurements of $\sin^2\theta_W$ happen, RGE error would no longer be negligible. Double-check result!
- what else can sub percent polarimetry be used for in the context of BSM physics?