Z' Bosons at Present and Future Colliders

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Outline

- Models upon models
- Z' goals
- Old colliders
- LHC
- New colliders
  - ILC
  - CLIC/muon collider

The nature of a Z'

- Many extensions to Standard Model predict a new neutral resonance
- Let's call a Z' spin 1 (usual definition)
- Can narrow properties of Z' Lagrangian using phenomenological arguments:
  - Fermion left-handed doublets should couple the same (would imply/induce Z-Z' mixing)
  - Fermion generation independence (would induce FCNC)

Models upon models

- Two broad categories of models:
  - ”Usual models” fit above constraints
    - (Effective) rank-5 GUTS:
      - E_6 (ψ, η)
      - SO(10) (χ, LR, ALR)
    - Any other consistent set of couplings you want to write down
  - ”Unusual models” evade above constraints
    - Little Higgs (extra quantum numbers protect mixing)
    - KK modes (same)
    - Light/heavy (3^{rd} generation not constrained)
    - Technirho (?)
    - ???

What to do with so many models

- Finding a resonance is the easy part
  - ”If you can't find a Z' at the LHC, you should turn it off.”
- Can't check every model against data
- Some models have free parameters (e.g., E_6)
- More model-independent approach needed
- Find Z' couplings to fermions (others?)

Constraints on Z'

- LEP rules out most Z' models to ~1 TeV by indirect search (dileptons)
- Tevatron rules out most Z' models to ~800 GeV by direct search (dijets)
- Low energy experiments (e.g., E-158) rule out most Z' models to ~1 TeV by dim-6 operators
- Get around these searches with, e.g., very small couplings

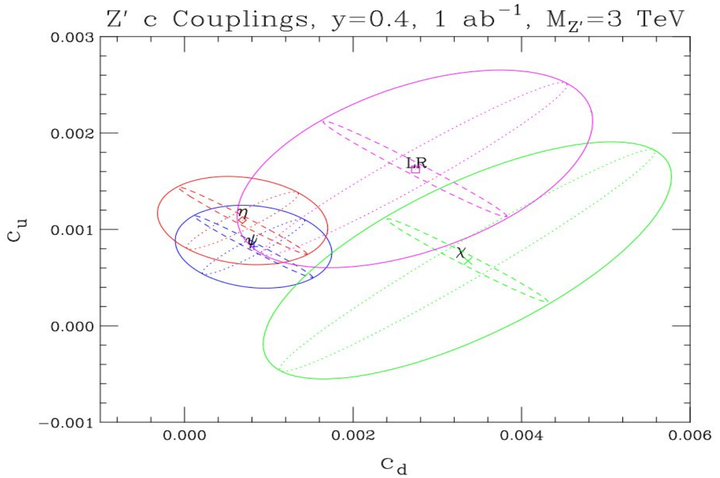
Z' Possibilites

- Group Z' possibilities at future colliders into mass categories:
  - Light: 1 TeV $< M_{Z'} <$ 2 TeV
  - Medium: 2 TeV $< M_{Z'} <$ 6 TeV
  - Heavy: 6 TeV $< M_{Z'} <$ 15 TeV
  - Other: very unusual scenarios/models

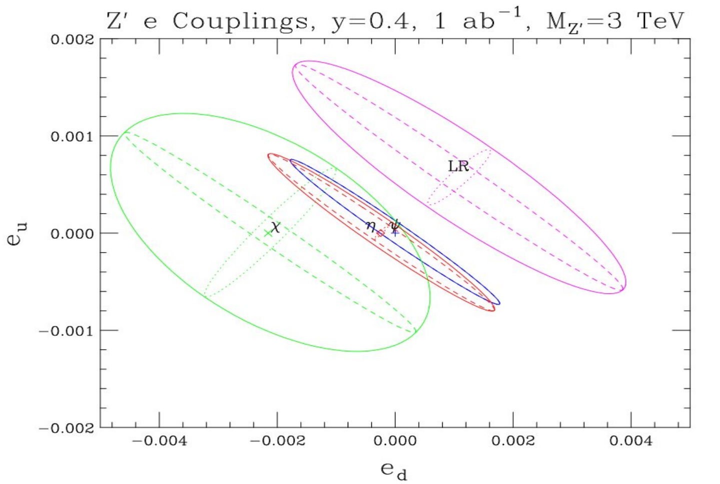
Z' at the LHC

- Z' must be made from quarks here
- QCD buries decays into quarks (tough possibility to see decays into b/t)
- Cleanest signal is dileptons
  - Discover up to ~6 TeV
  - Clean enough to do physics!
  - Get mass ($\Delta M \sim 0.1\% M$)
  - De-convolute B-W shape ($\Delta\Gamma \sim 0.1\% M$)
  - Begin extracting coupling parameters

Medium Z' at the LHC

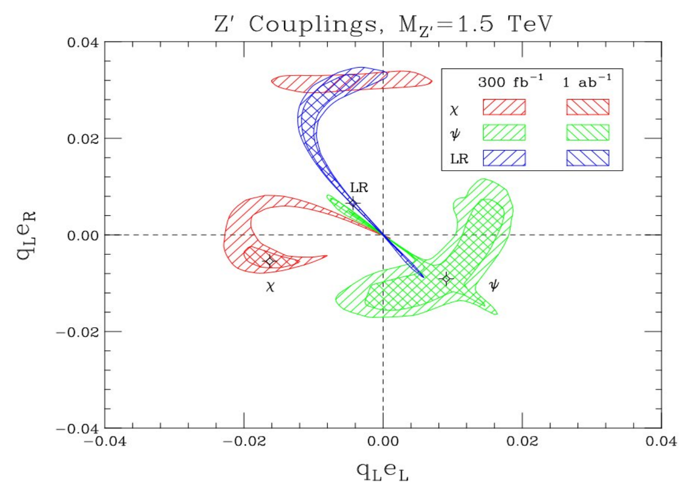


Petriello, SQ

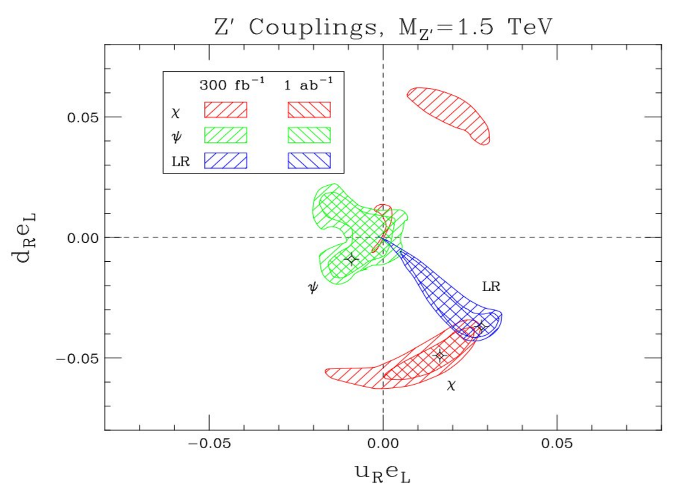


- Only on-peak measurements useful
  - F/B, rapidity distributions
- $c_q = (q_L^2+q_R^2)(e_L^2+e_R^2)/24\pi\Gamma$
  $e_q = (q_L^2-q_R^2)(e_L^2-e_R^2)/24\pi\Gamma$
- No sign determination!
- Enough to differentiate/rule out typical models

Light Z' at the LHC



Li, Petriello, SQ



- On + off-peak measurements give signs
- Get width ΔΓ ~ 1 GeV
- Some directions in parameter space determined much better than others
- More than enough to rule out other models
- q X e degeneracy

LHC Drawbacks

- Rapidity/F-B asymmetry measurements sufficient to determine couplings only for 4 free coupling parameters, ”usual” models (u_L=d_L)
  - Test other models individually
- Degeneracy in coupling space (can trade q for e) unless lucky in heavy quarks
- Limited precision, poorly measured directions

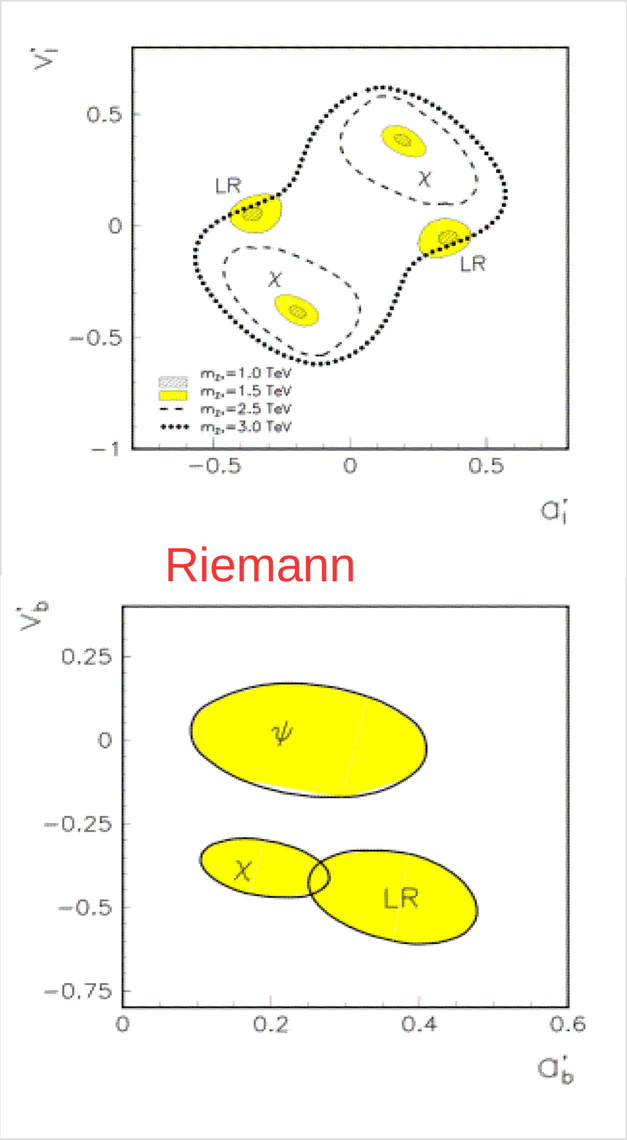
Lepton colliders

- Deviations in dilepton observables off-peak sufficient to discover Z' up to ~6X c.o.m. energy
  - ILC: discover light, medium Z' if not found at LHC (small coupling to quarks)
  - CLIC/muon collider: discover heavy Z' far past LHC mass range
- If mass known, measure couplings off-peak
  - leptons$\rightarrow$leptons + leptons$\rightarrow$quarks gives all combinations, no degeneracy, better precision than LHC

Lepton colliders (cont'd)

- To determine individual couplings, need the following:
  - Some way to separate left, right-handed couplings (Forward/backward asymmetry, polarization asymmetry)
  - Differentiation of different final state particles (tags on heavy quarks)

ILC



- Discover Z' if weakly coupled to quarks
- Leptonic couplings well-determined for light Z'
- Quark coupling extraction depends on lepton extraction, b tagging, c (!) tagging
- In principle can get mass, couplings if not found at LHC (hard)

Rizzo

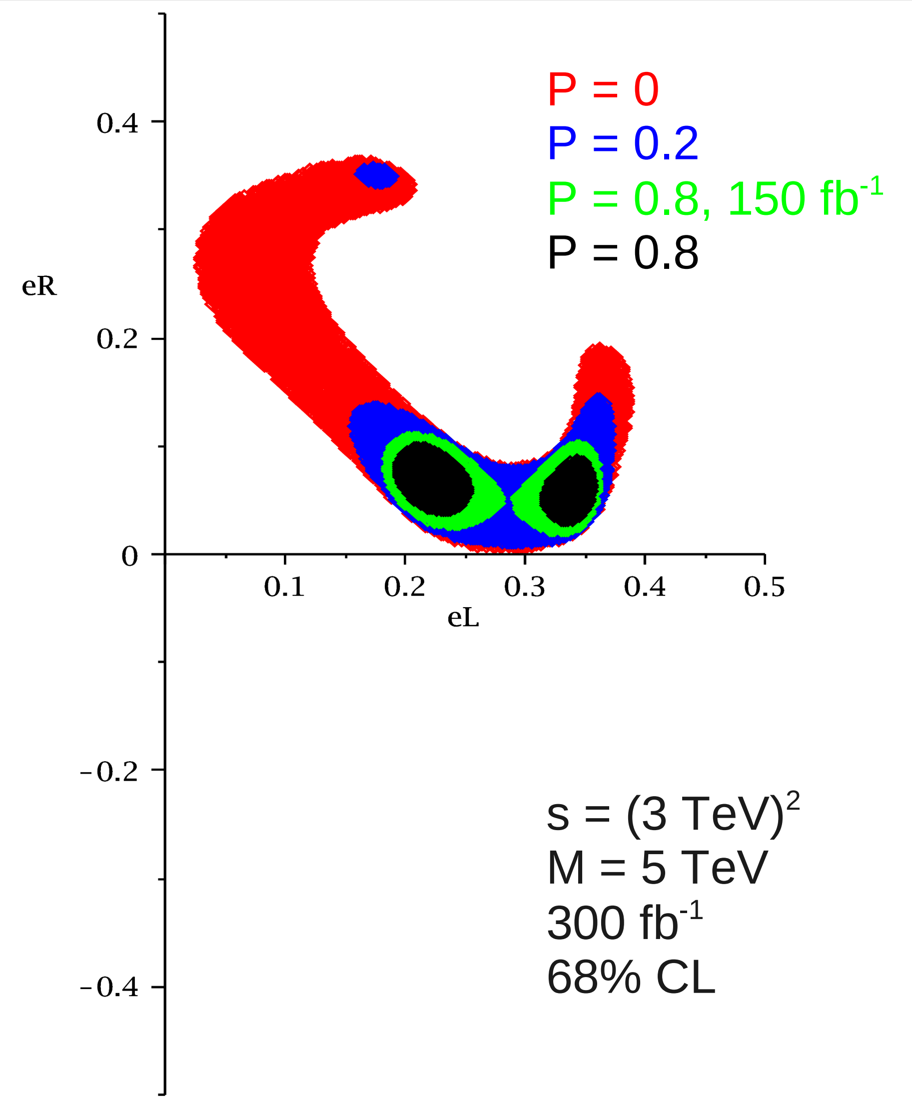
CLIC/Muon collider

- Scale ILC results with energy
- Light Z': Z' factory?
- Polarization assumed in previous studies, but redundant to angular information
  - Cross check; sort out KK Z', γ'? Rizzo
  - Is polarization necessary for good results? Is it worth a cut in luminosity? Is "natural" polarization sufficient?

CLIC vs. Muon collider

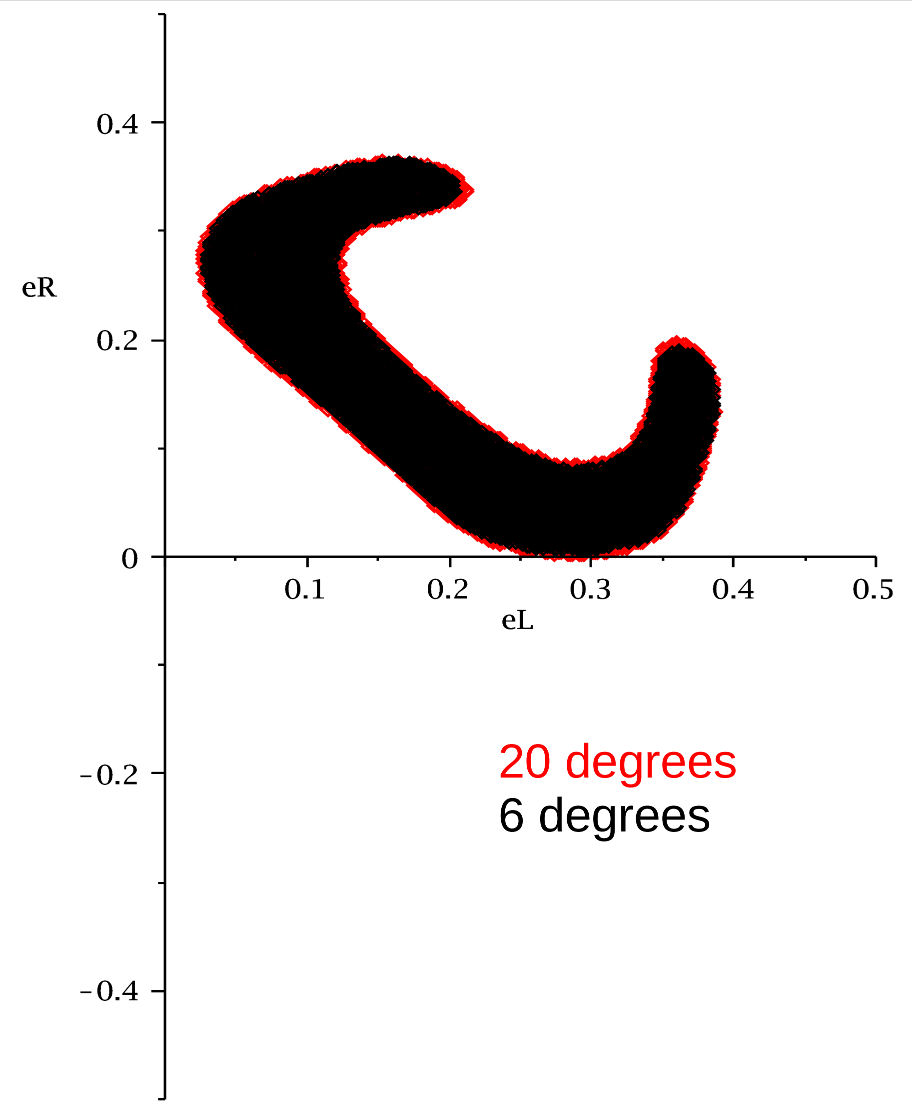
- CLIC
  - At least electrons polarized to 80%
  - Heavy quark tagging probably easier
  - More detector coverage (easier to ID top decays)
  - More ISR (easy radiative return to peak) Freitas
- Muon collider
  - Probably automatic 20% polarization
  - Better energy resolution
    - Trace of BW shape
    - More Z' if width very narrow
  - Less ISR
  - What if Z' doesn't couple to electrons?

The case for polarization



- Off peak, too few events for good F/B separation
- Polarization much more efficient at separating L/R couplings

What about cone angle?



- Angular distribution only handle on quark couplings, leptons if no polarization
- Size of cone doesn't seem to matter

Z' Outlook

- A Z' is only interesting if we find out what it is
- LHC can certainly narrow it down, but still missing information
- Future letpon colliders should be able to measure more parameters, and better
- What kind of collider we need will depend on Z' mass
- More study needed on polarization, heavy quark (incl. top) ID

Bonus Material