QED FSR and Z pT

or:
Observables in Drell-Yan (and W)

Summary of a write-up for Les Houches

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1) The problem
2) Proposed observable definitions
3) Some implications

Z and W

The Z resonance is extremely useful at hadron colliders:
- electron and muon channels give very clear signals
- very low background

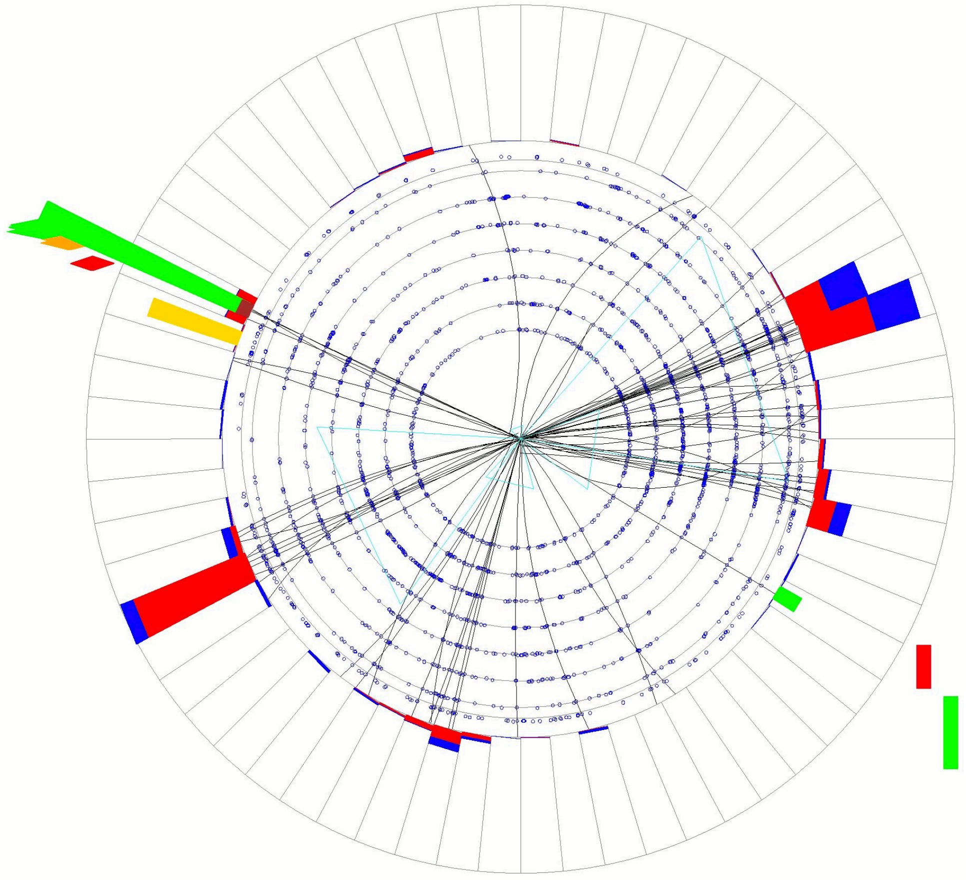
Used for calibration:
- determine lepton energy scale from shape and position of Z peak
- determine lepton efficiencies using “tag and probe”
- use production rate as luminosity monitor?

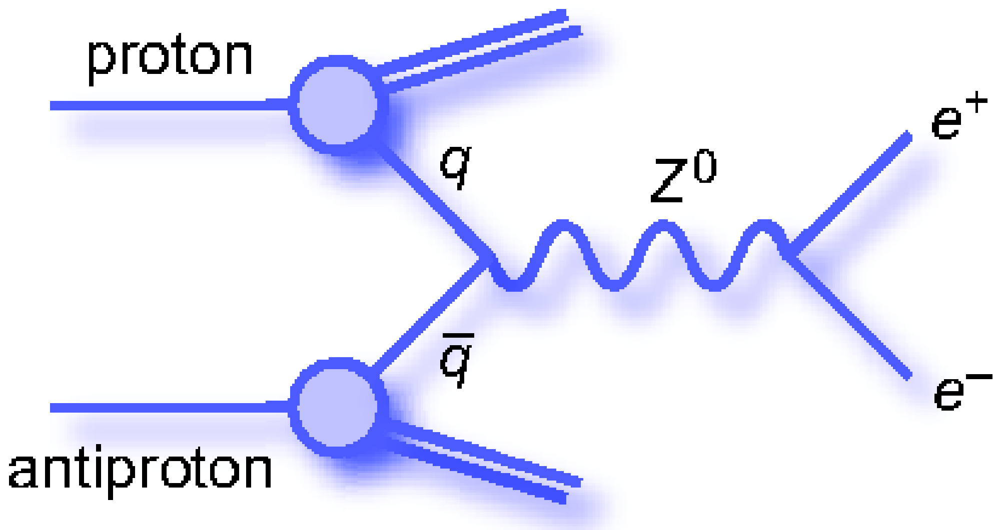
And to access a wide range of physics:
- PDFs from rapidity distribution, W charge asymmetry
- new physics in Afb, Z' search, etc
- Z pT or aT to measure hadronic recoil
    - resummation calculation at low pT, aT
    - pQCD at high pT
- Z+jet production: test pQCD, also main background to Higgs

etc etc etc

The problem:
- the Z (or W) is not an observable!
- theory corrections are applied to data to get to the “Z” -> model dependence!

Z Production





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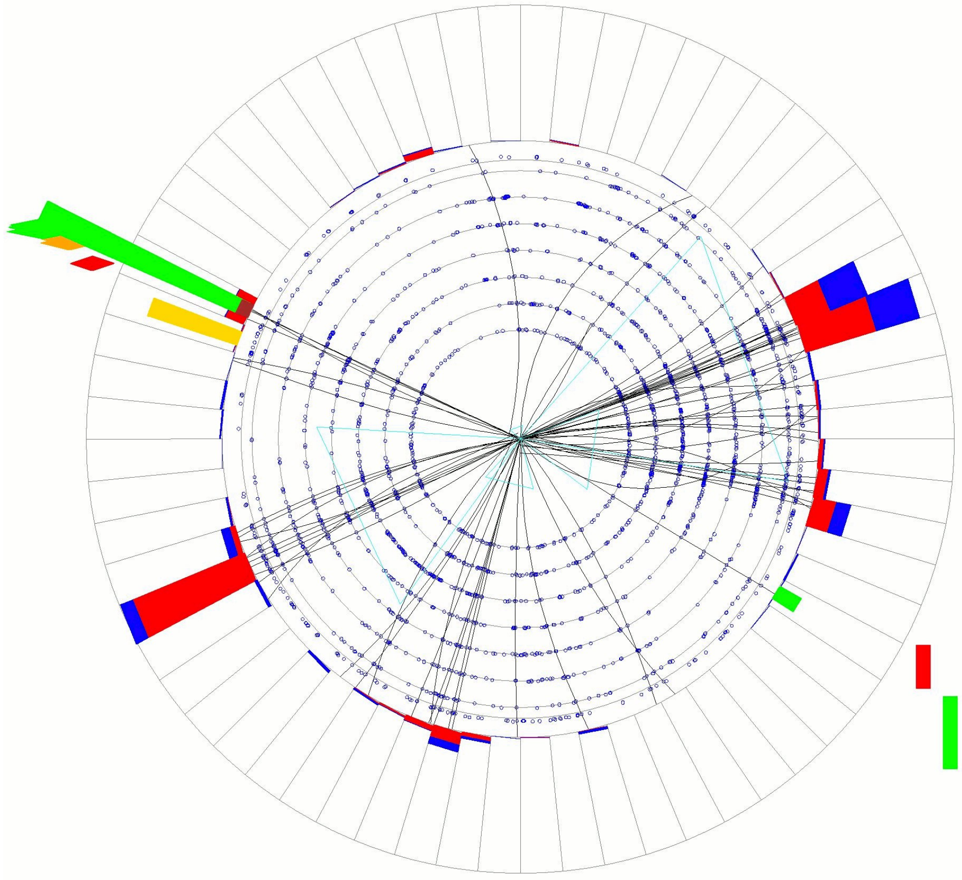
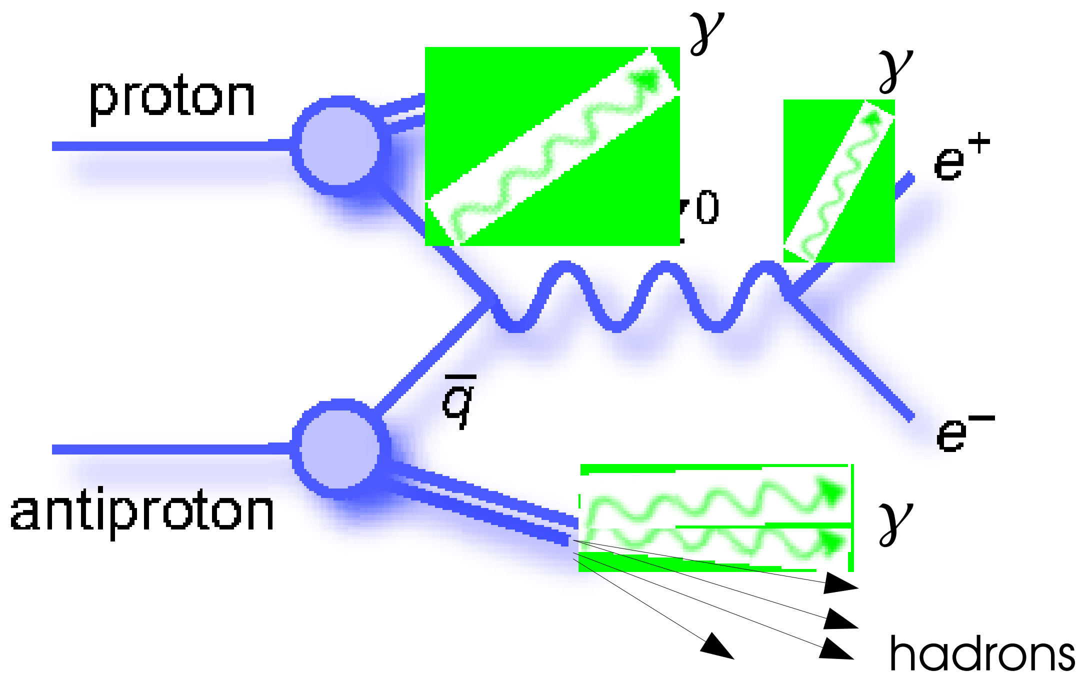




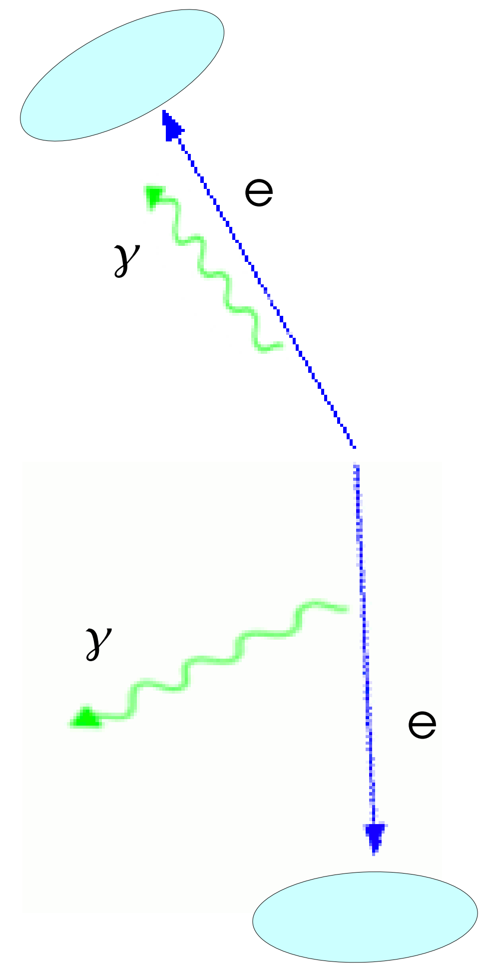
In published data measurements, typically:
- correct for detector resolution and efficiency
- correct from the measured dilepton the the (non-observable) Z
- extrapolate from measured phase space to full 4-pi coverage

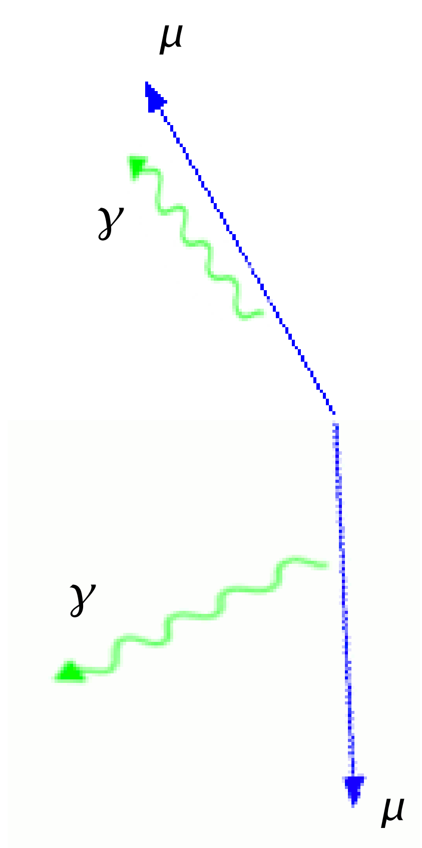
The result is a mix of measurement and (significant) theory corrections

Propose definitions of "observables", based on the particles that enter the detector

Observables

A measured electron:
- a cluster of energy in the calorimeter
- the sum of all EM energy in the cluster
  - electron + FSR + photons from underlying event
- wider angle FSR is "lost"
  - ie cannot be associated with electron





A measured muon:
- curved track in tracking detector
- ALL FSR is lost, underlying event has no effect

Particle Level

Data should still be corrected for detector resolution and efficiency

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In simulation, construct "Z" and "W" from the particles entering the detector:

1) Consider all particles with ctau > 10 mm as "stable" (ie reach the detector)

2) Muon: any stable muon. ie after QED FSR, to mirror a tracking detector

3) Electron: combine EM energy in a cluster, to mirror a calorimeter
- eg, a cone with R=0.2 (suitable for Tevatron)

4) Missing ET: vector sum of all neutrinos in event

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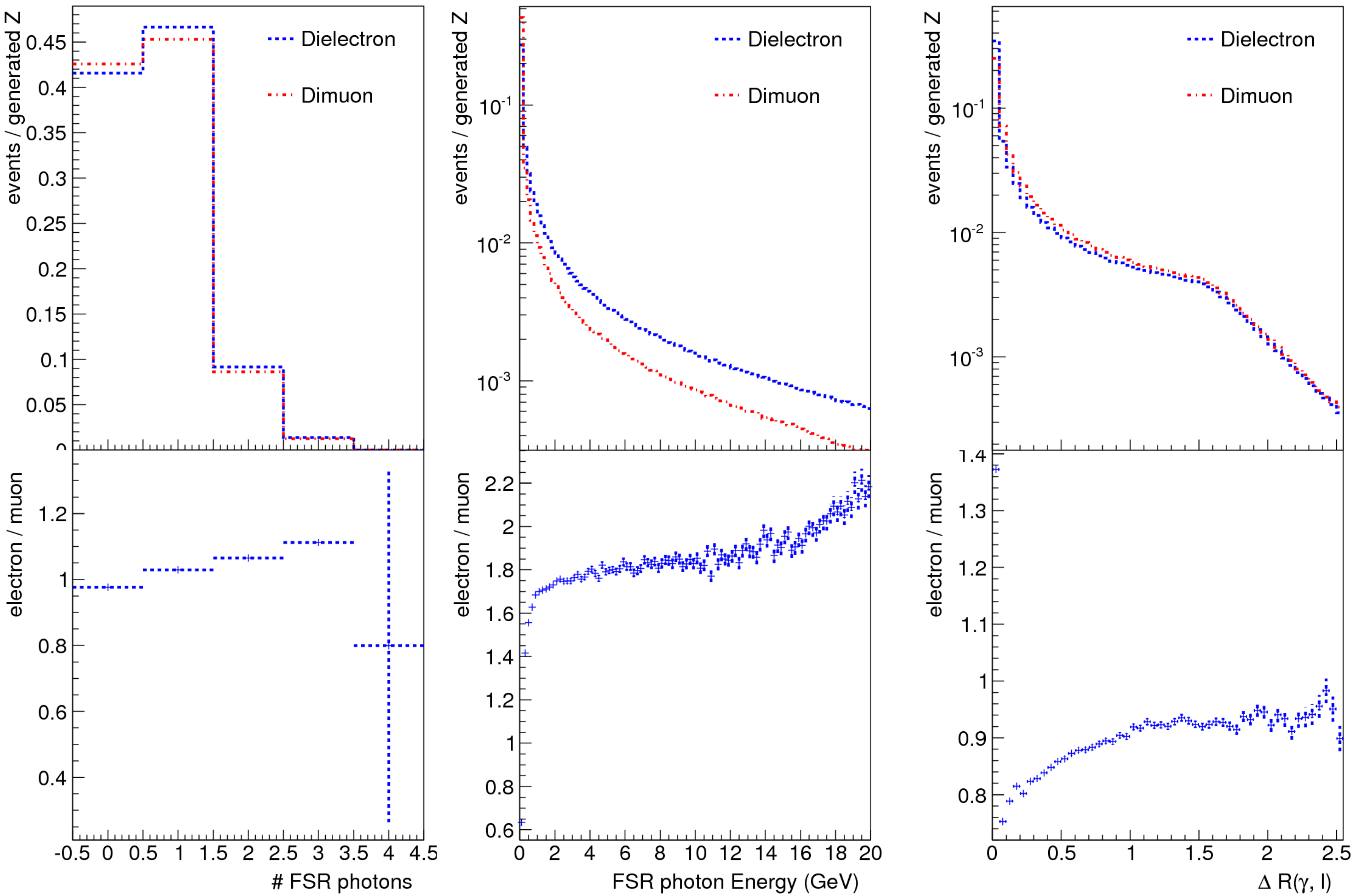
5) Dilepton (Z) selection should mirror data:
- consider all leptons in acceptance range (eg $|eta|<2.5$)
- make opposite sign pairs, keep those in mass range (eg 65-115 GeV)
- when >1 pair, pick "best" in same way as for data
  - eg closest to Z mass

5) Lepton + MET (W) selection should mirror data:
- eg highest pT lepton inside acceptance, combined with MET

FSR Properties

Does any of this actually make a difference?

Test sample: p pbar->Z->ee and Z->mumu, Pythia 6.421, tune Perugia 6



Implications I

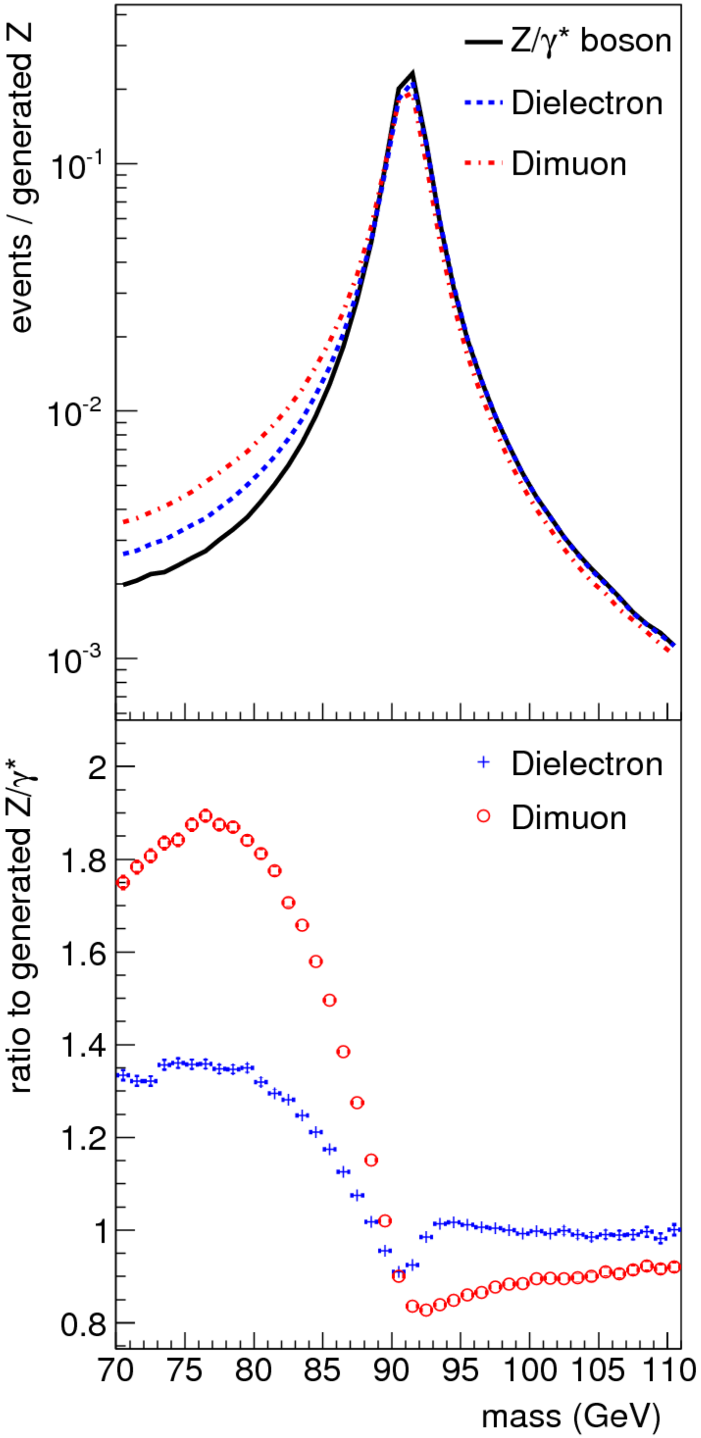
FSR -> dilepton system lower energy than "Z"
- Direct effect on dilepton mass distribution

1) this is used in calorimeter and tracker calibration
- energy scale and resolution

Do not want calibration to compensate for FSR!

- peak position mostly unaffected
  - energy scale
- upper edge of peak mostly unaffected
  - resolution
- using the lower edge of the peak relies on FSR

2) Also affects Drell-Yan cross section
- typically measured in mass range
- for, eg 65-115:
  - net loss of 0.9% in Z->ee
  - net loss of 2.1% in Z->mumu

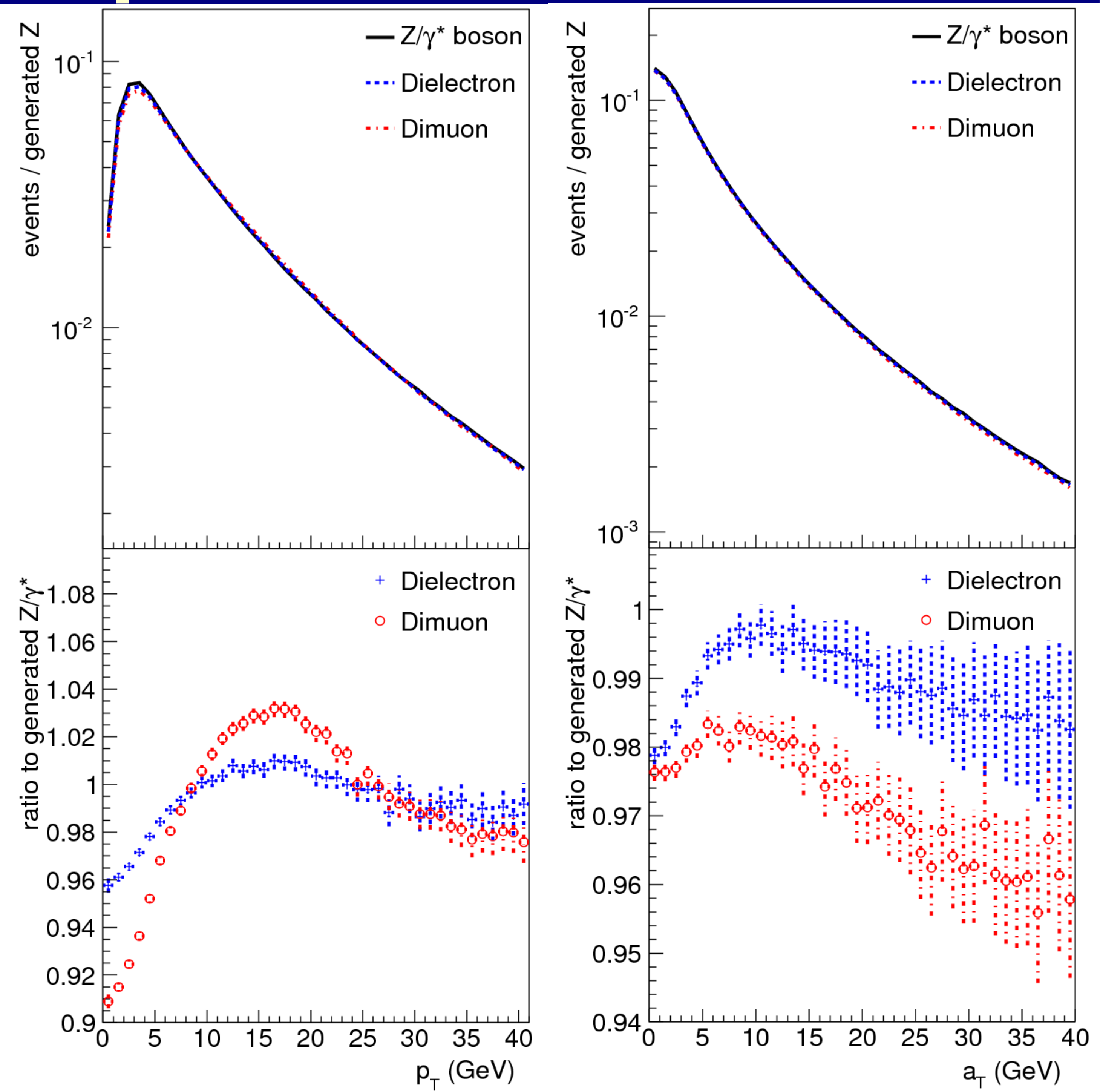


Implications II

Look at Z pT:
~4% effect in Z->ee
~10% in Z->mumu

And Z aT:
~2% effect in Z->ee
~0.5% in Z->mumu

Critical variables in tuning!



Reproduce the Z?

Previous publications of Z pT:

- corrected from measure leptons to Z
- corrected to 4pi acceptance

Is it possible to reproduce these using stable particles?

Try to catching more FSR:

- increase the electron cone size: 0.5 and 1.0
- note: these are not observables!

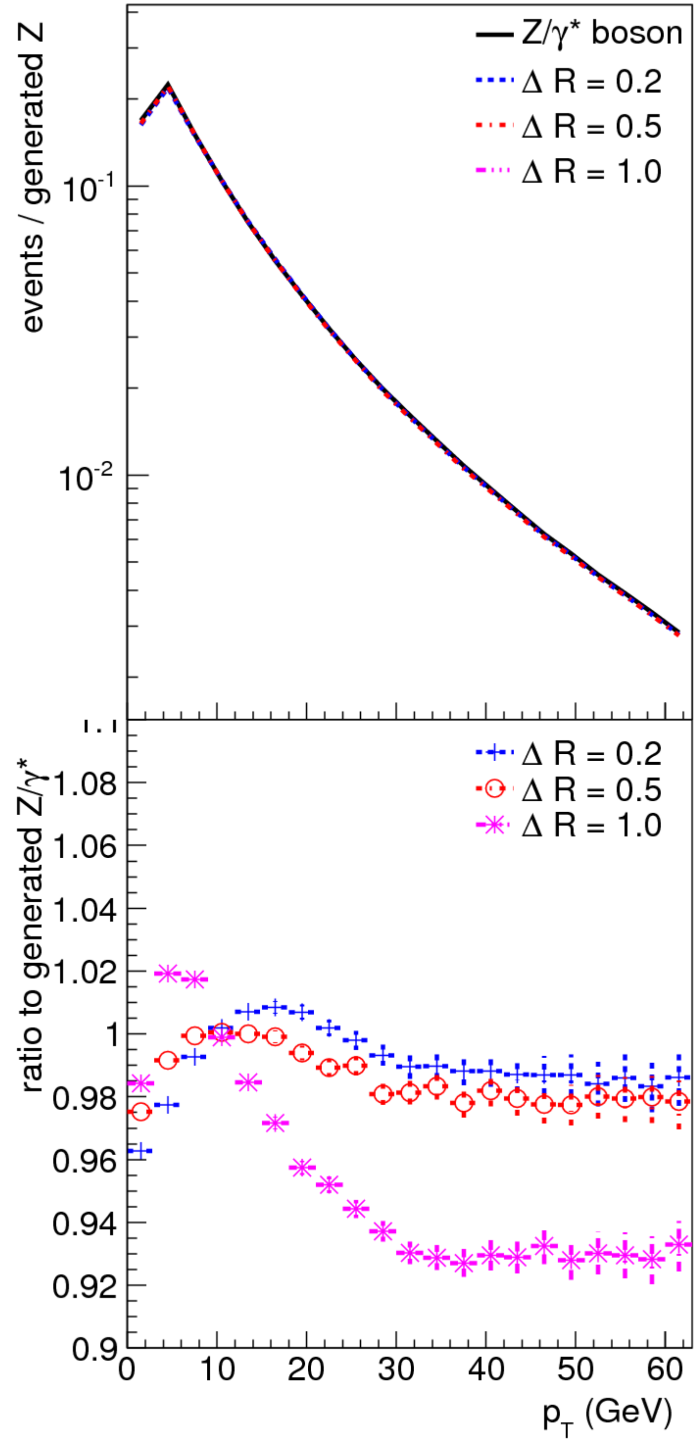
0.5 cone moves closer to Z

1.0 goes too far

- catch too many underlying event photons

Cannot reproduce previous measurements!

- without "cheating"



Combining

Electron and muon channels:
- independent statistics
- uncorrelated systematics

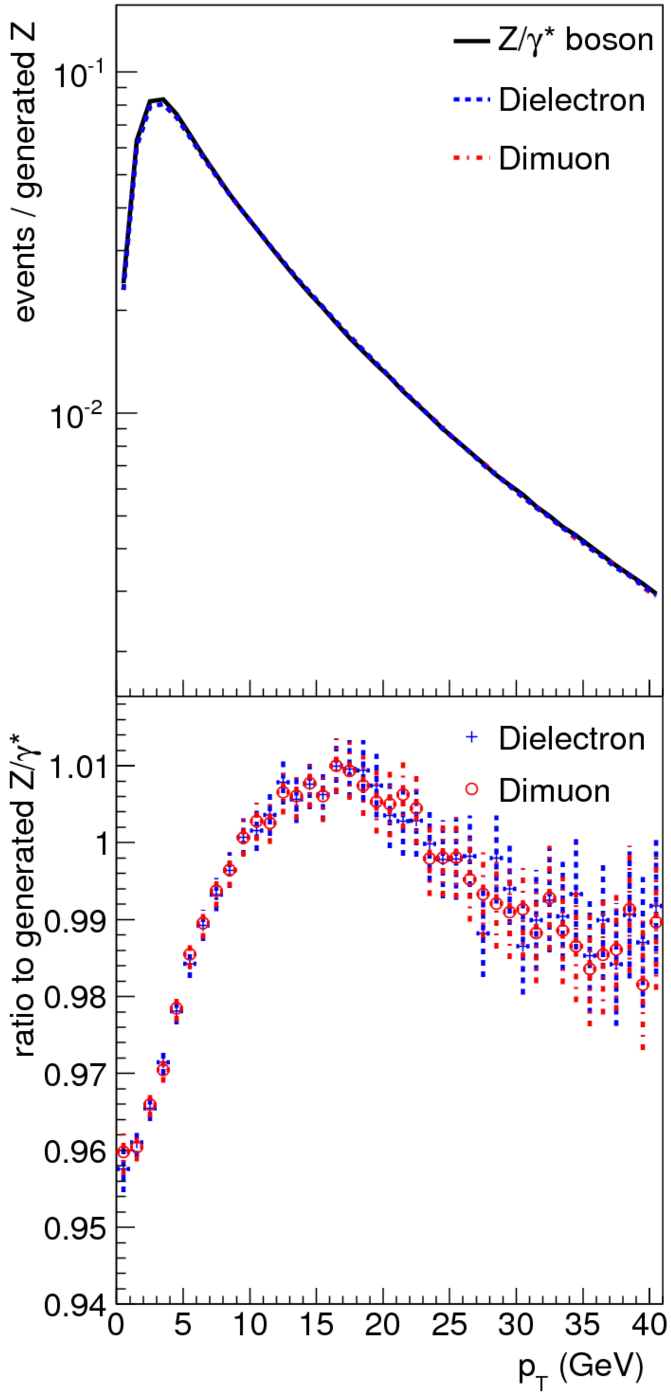
-> combine!

But, have shown we measure different things
- different total cross section and kinematics
- due to different detector response to FSR

Can correct both to 4pi Z, then combine.

A minimally model dependent combination:
- limit both leptons to same phase space
- correct muons for narrow angle FSR
  - ie to same level as electons
- then combine

In simulated Z->mumu:
- either apply same correction used in data
- or directly treat muons like electrons
  - (or just generate one channel)



Conclusions

Publish observables!

- in both experiment and theory papers

To date, all published Z pT results are of "boson-level" quantities:

- both experimental and theoretical results
- cannot be implemented in RIVET!
- only three D0 Z+jet papers use the particle level

Need to address this for Tevatron "legacy" measurements, and LHC

There are several topics for discussion:

- best particle level electron definition for LHC experiments
- how best to handle lepton isolation requirements
  - can measure efficiency in data and correct the measured spectrum
- best definition of particle level MET
  - experimental MET is a complicated quantity...
- how to handle event vetos at particle level
  - eg second lepton veto in W analysis.