# W/Z+$\gamma$ Blessing

Feb. 25, 2005 ,  electroweak meeting

A. Goshaw, H. Hayward, B. Heinemann, M. Kirby, N. Tanimoto

# Outline

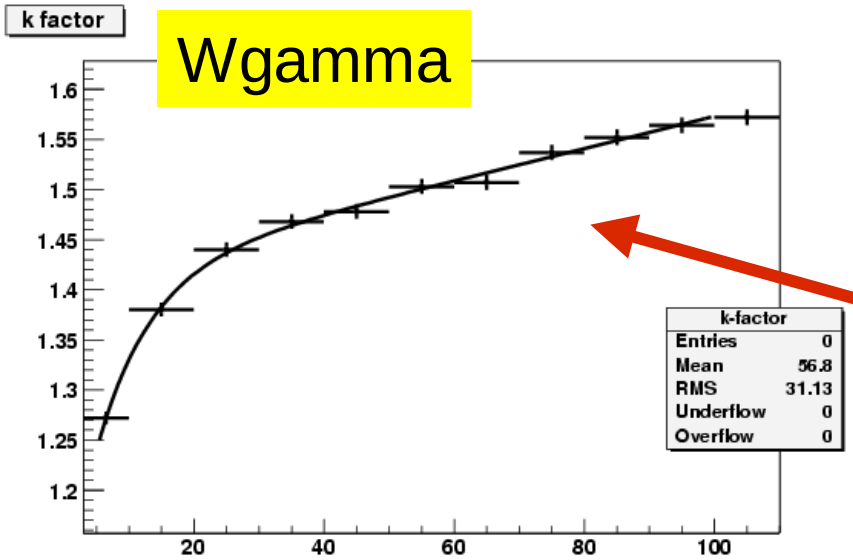
- Analysis overview
- Changes since preblessing:
  - K-factor
  - Bug in applying met correction in e channel
  - Bug(s) in photon ID efficiency from conversions
- Requests at preblessing:
  - Z yields versus time: with correct errors
  - Z mass versus time: with improved binning
  - Fake rate: compare prediction and observation for jet20, jet50, jet70 and jet100
  - Systematic studies on fake rate
- Results

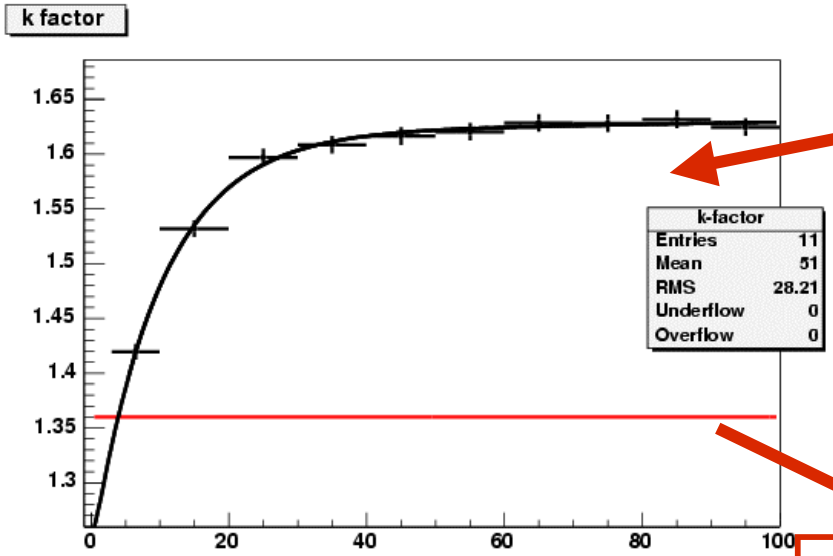
See also
http://www-cdf.fnal.gov/internal/people/links/BeateHeinemann/WgammaBlessing.html

# Analysis Overview/Reminder

- W/Z selection
  - Incl. selection based on incl. analyses
  - Verify incl. cross sections and yield versus time
- Photon selection
  - Follow photon group advice
  - Efficiency measured in Z->ee, conversions and random cones
- Background
  - Major issue: leading pi0 faking photon
- Signal acceptance and SM expectation
  - Use U. Baur's WGAMMA and ZGAMMA LO MC and apply k-factor
- Cross section for Et($\gamma$)>7 GeV and DR(l$\gamma$) >0.7

# K-factor

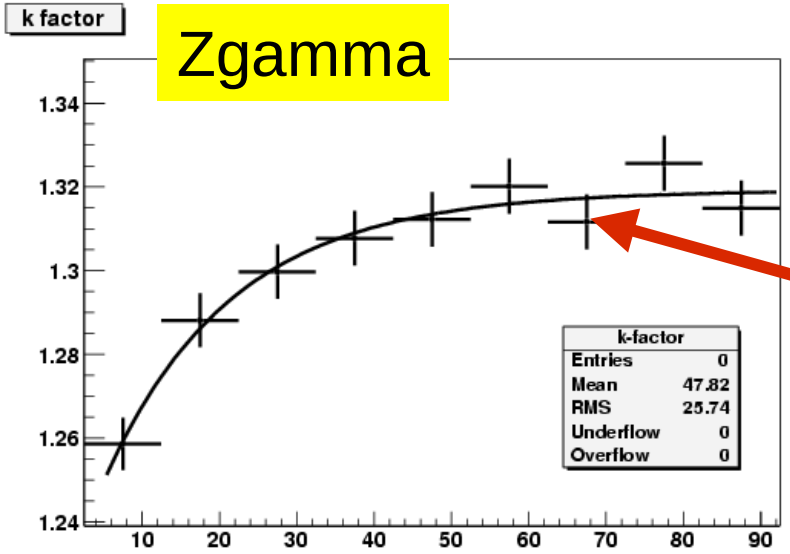


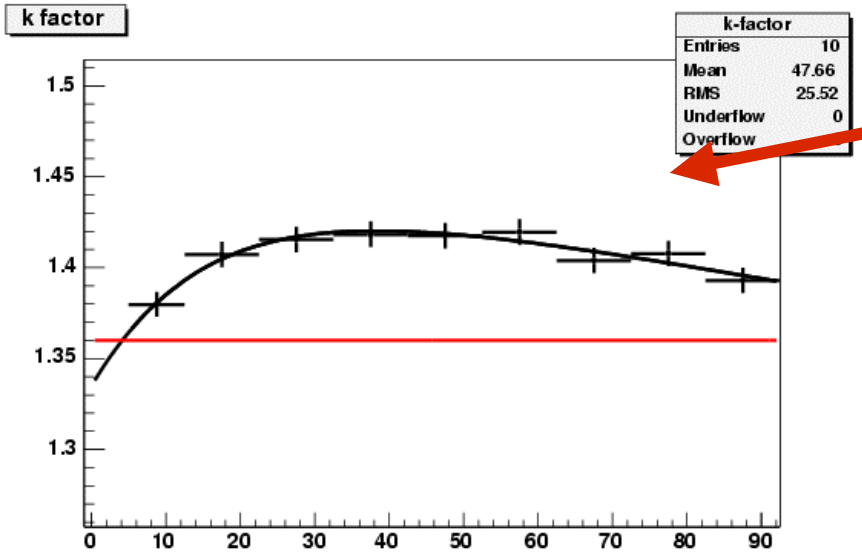

- Found mistake in calculation of k-factor
- Had calculated ratio of
  - NLO cross section with NLO pdf to
  - LO cross section with NLO pdf
- That's wrong: are now calculating ratio of
  - NLO cross section with NLO pdf (CTEQ5M)
  - LO cross section with LO pdf (CTEQ5L)
- Affects both Wgamma and Zgamma
- Verified by theorists: U. Baur, J. Stirling and A. Signer

Incl. W: J. Stirling

# K-factor




OLD




NEW

# Bug in Met correction

- Correcting MEt, the idea:
  - Exclude electrons, muons and photons from jet list
  - Correct for all remaining jets
- Bug: accidentally not excluded the photon from jet list in electron analysis
- Effect: get 5 (125->129) more events observed and 1 (118.46->119.54 ) more expected
- Zgamma and Wgamma muon channels not affected

# “Old” vs New Final Photon ID eff

OLD

| Cut | Random Cone | Conversion | Z -> ee | Applied |
|---|---|---|---|---|
| Cal Iso | f(Et) | - | 1.0 ±0.007 | f(Et) ±0.01 |
| N3D | 1.0 ±0.003 | - | 0.98 ±0.007 | 0.99 ±0.01 |
| Trk Iso | 1.0 ±0.003 | - | 0.99 ±0.006 | 0.995 ±0.005 |
| CES $\chi^2$ | - | 1.0 ±0.025 | 0.98 ±0.05 | 0.99 ±0.01 |
| 2nd CES strip E | 0.995±0.01 | 1.0±0.031 | 1.0 ±0.005 | 0.995 ±0.005 |
| 2nd CES wire E | 0.995 ±0.01 | 0.98 ±0.024 | 0.99 ±0.005 | 0.99 ±0.01 |

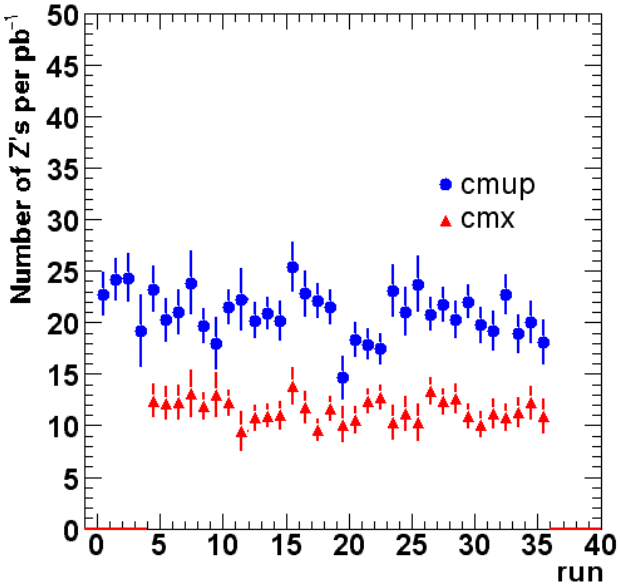
NEW

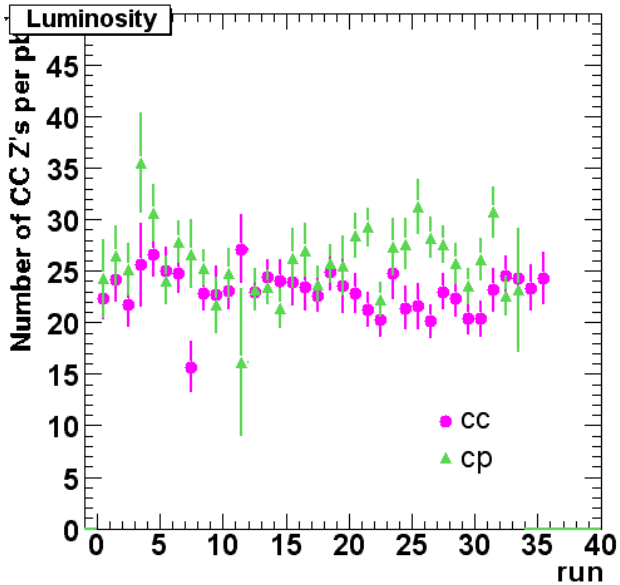
| Cut | Random Cone | Conversion | Z -> ee | Applied |
|---|---|---|---|---|
| Cal Iso | f(Et) | - | 1.01 ±0.01 | f(Et) ±0.01 |
| N3D | 1.0 ±0.003 | - | 0.98 ±0.01 | 0.99 ±0.01 |
| Trk Iso | 1.0 ±0.003 | - | 0.99 ±0.01 | 0.995 ±0.005 |
| CES $\chi^2$ | - | 1.01 ±0.01 | 0.98 ±0.004 | 0.99 ±0.015 |
| 2nd CES strip E | 0.995±0.01 | 1.01±0.02 | 1.0 ±0.003 | 1.0 ±0.01 |
| 2nd CES wire E | 0.995 ±0.01 | 0.99 ±0.01 | 0.99 ±0.004 | 0.99 ±0.005 |

No changes outside syst. errors

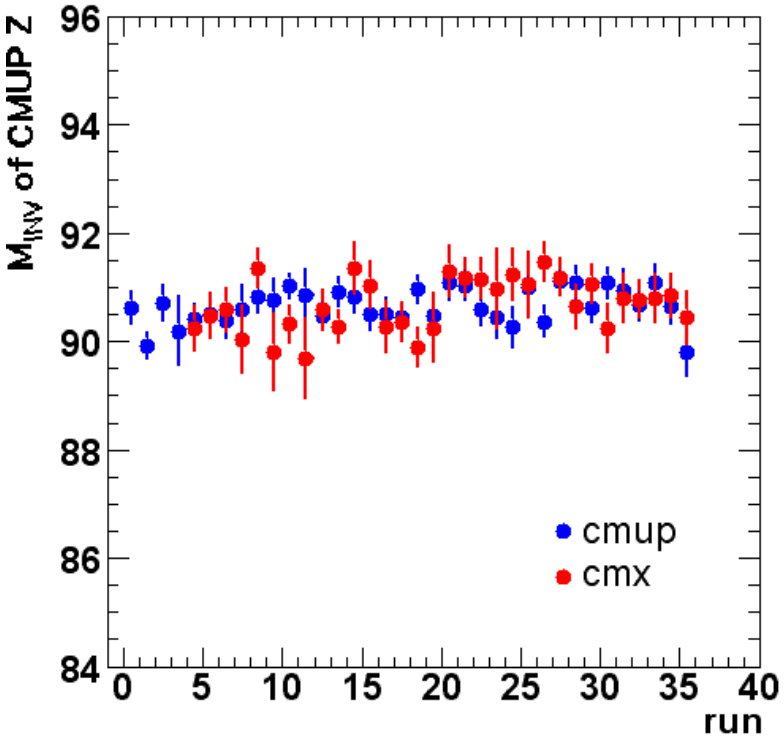
# Z yield versus time

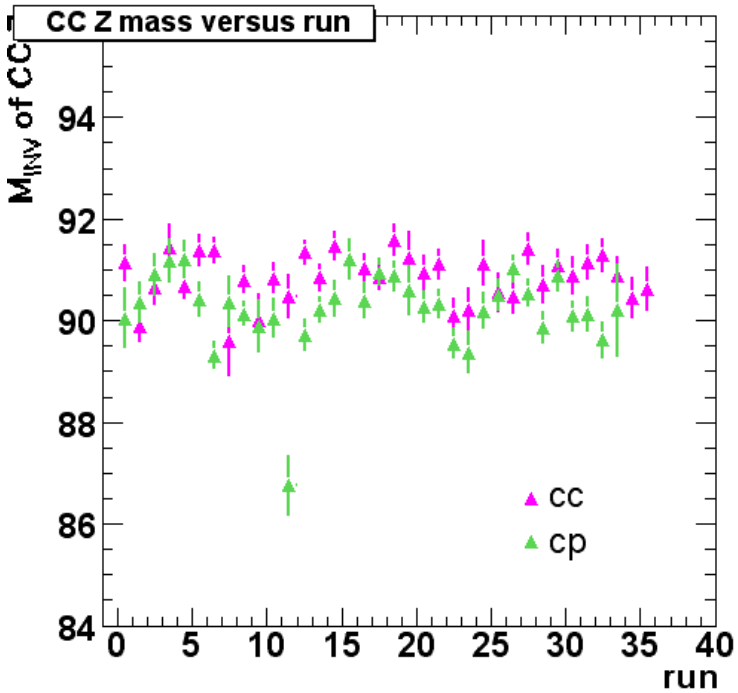
- Found bug in statistical error calculation: fixed
- Observations:
  - CMUP: dip at 20 (see in W too)
  - CMX: flat
  - CC: flat
  - CP: wiggly: Silicon used…unstable?
- Fit with flat line (pol0):
  - CMUP: chi2/ndf=41.7/35 ➔ P=20%
  - CMX: chi2/ndf=17.1/31➔ P=97.8%
  - CC: chi2/ndf=32.3/35 ➔ P=59.9%
  - CP: chi2/ndf=48.2/33 ➔4.3%
- Eric, Lucio, Victoria consulted on CMUP dip: no known problem
- Efficiency measured from data and incl. W and Z cross sections okay
- We believe it's okay but will try to understand CMUP issue



# Z mass versus time




- One dodgy bin in CP Z:
  - reason unclear as yet: investigating… (lumi only 0.3/pb)
  - But 3% in one channel negligible overall
- Else stable within 1% and checked that average okay/agrees with MC

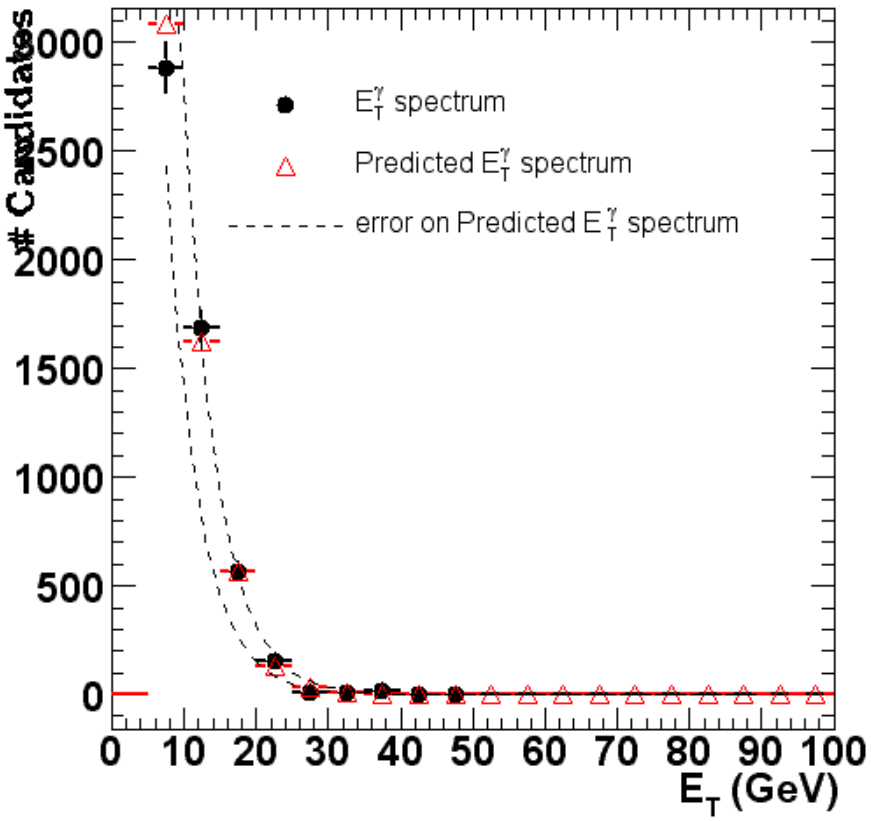
# Photon Fake Rate: Jet fragmentation into leading pi0

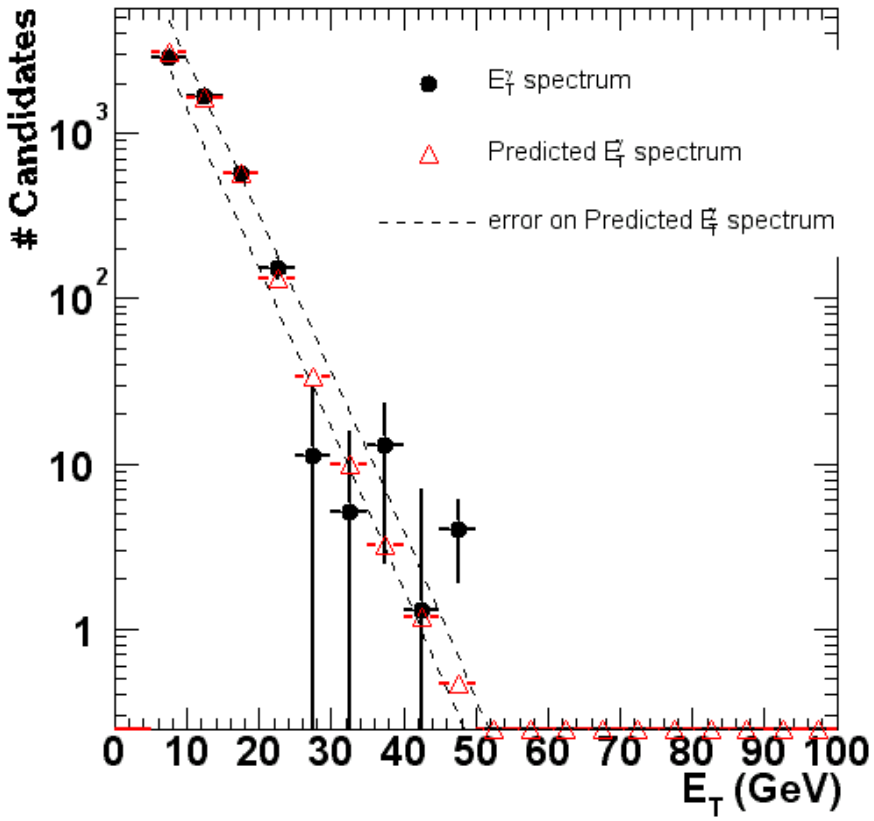
- Use incl jet data to estimate probability of jet faking isolated photon, i.e. photon generated in hadronisation process
- Important:
  - estimate fraction of prompt photons, i.e. photons generated in hard scatter
  - Translate jet Et into photon Et
  - Fraction of gluons in jet data similar to W+jet data
- Systematic studies following:
  - Compare $2^{nd}$ to $345^{th}$ jet ($2^{nd}$ jet is biased)
  - Apply fake rate to jet data and compare to observed spectrum
  - Change jet Et -> photon Et translation
  - Check gluon fraction

# Fake Rate

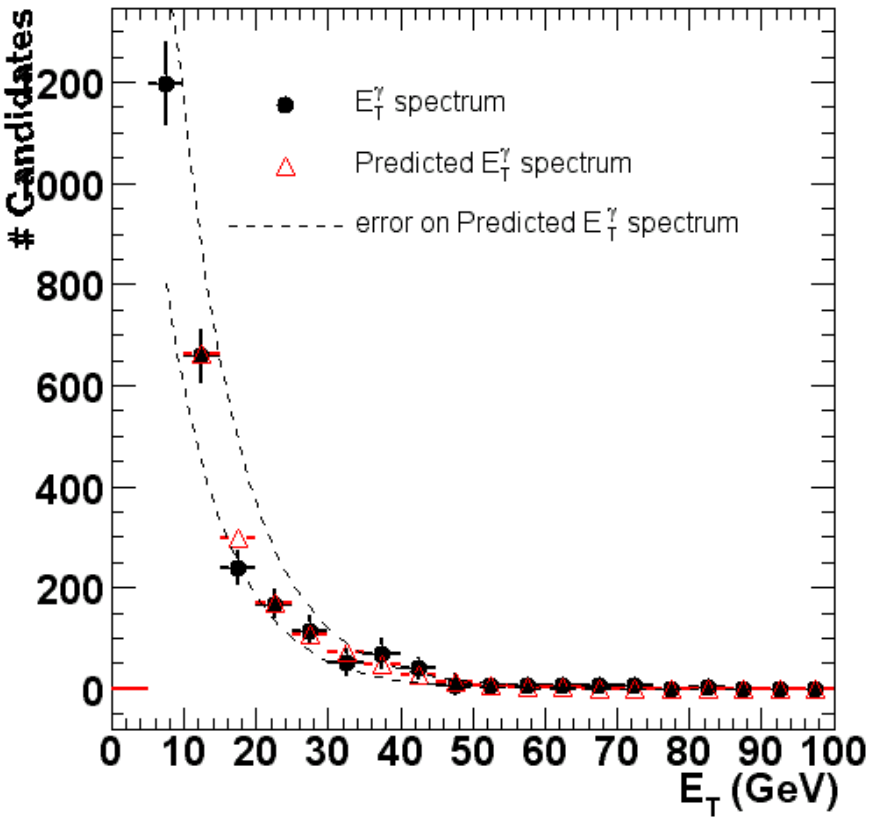
- Use combined fake rate from all samples and apply to the individual jet triggers (jet20, jet50, jet70 and jet100)
- Prediction includes:
  - Fake rate per jet
  - Translate jet energy into photon energy
- Observation includes:
  - True photons are subtracted using CES (CPR) method for Et<(>) 35 GeV
  - Else just full photon cuts and use photon energy
- Compare prediction to observation versus Et

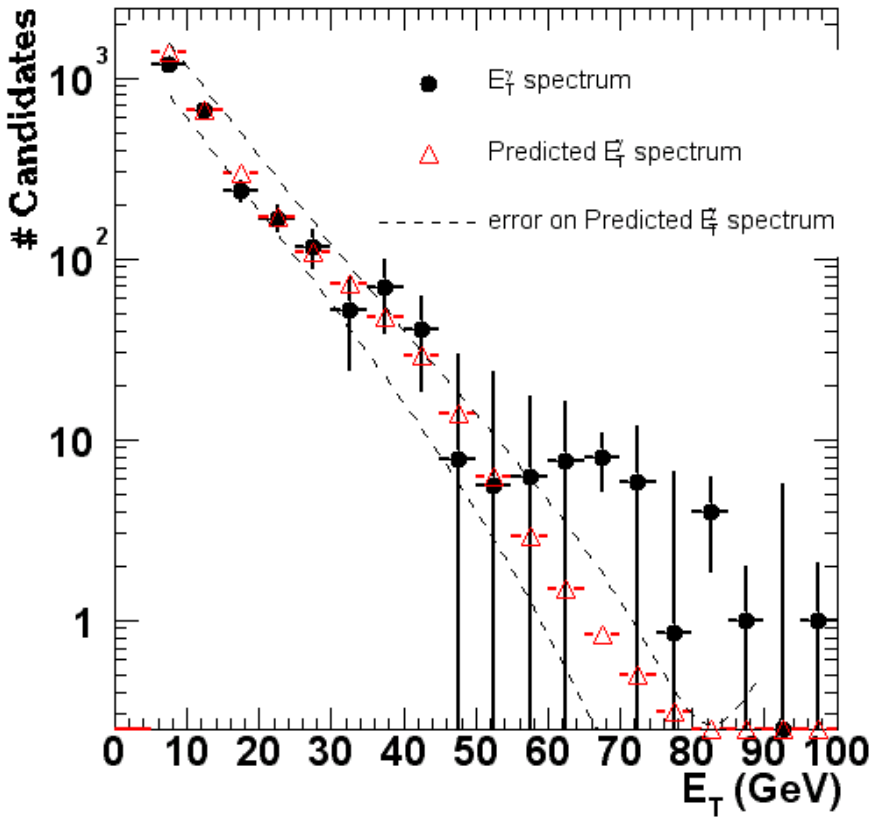
# Fake Rate: jet20



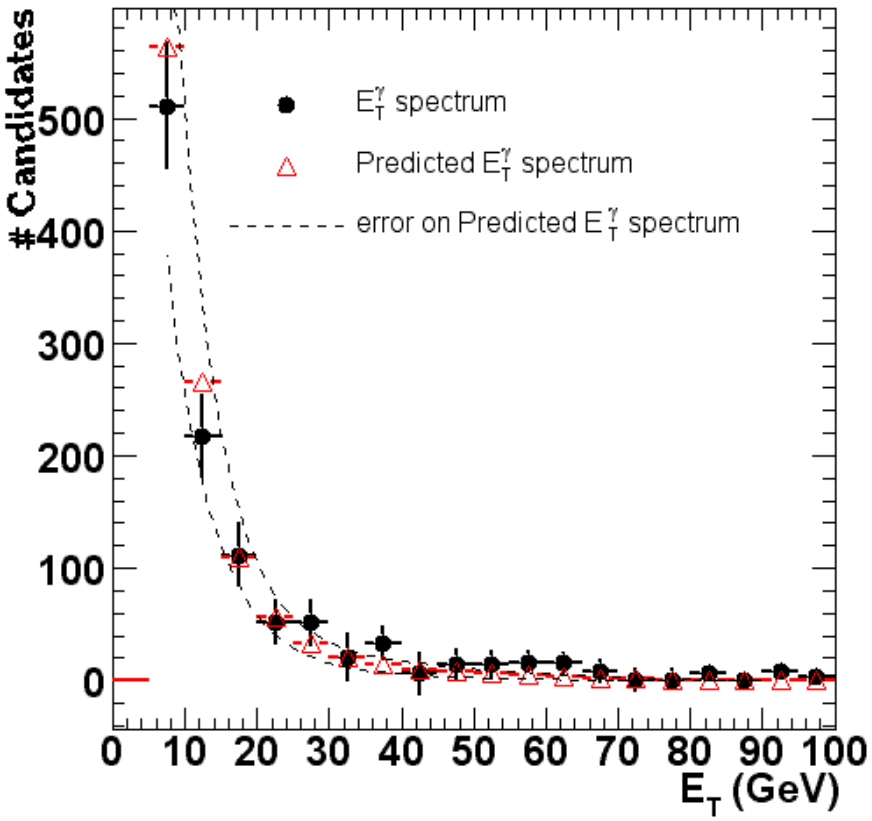



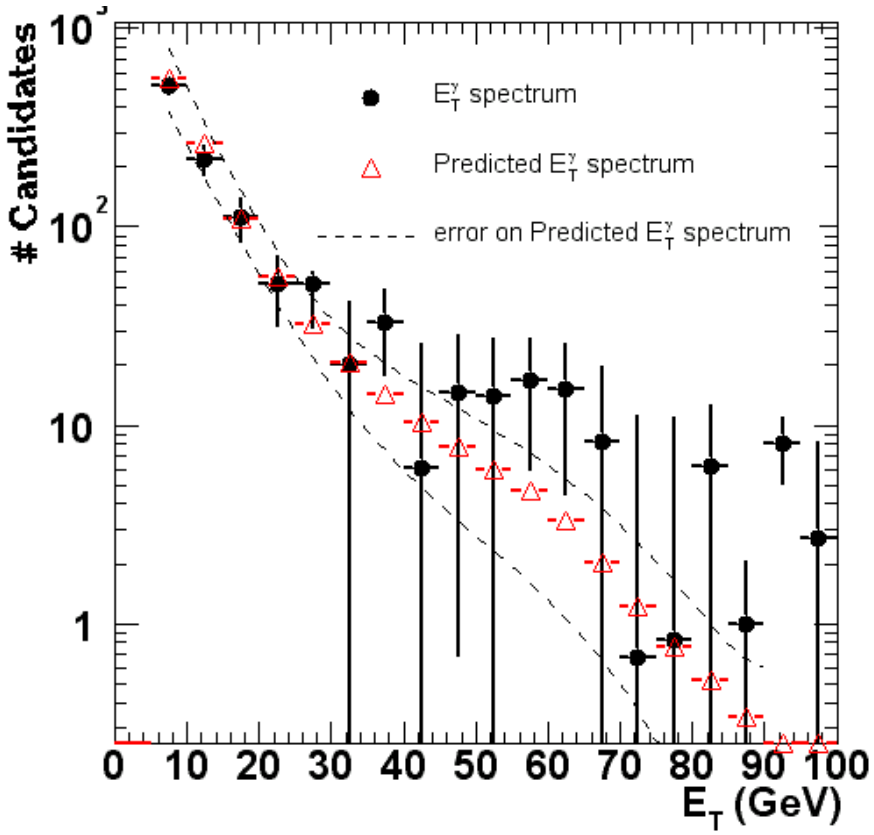
# Fake rate: jet50



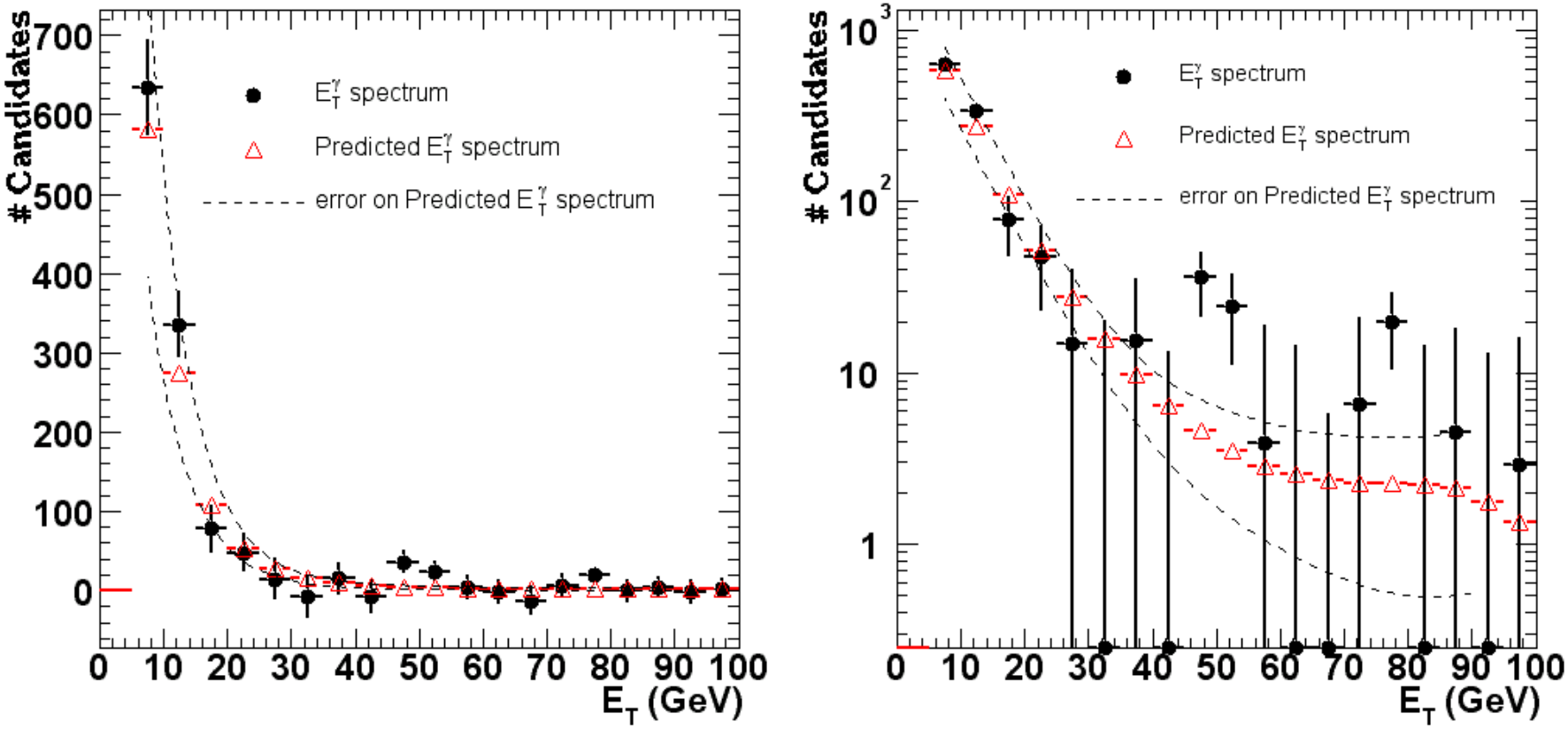



# Fake Rate: jet70

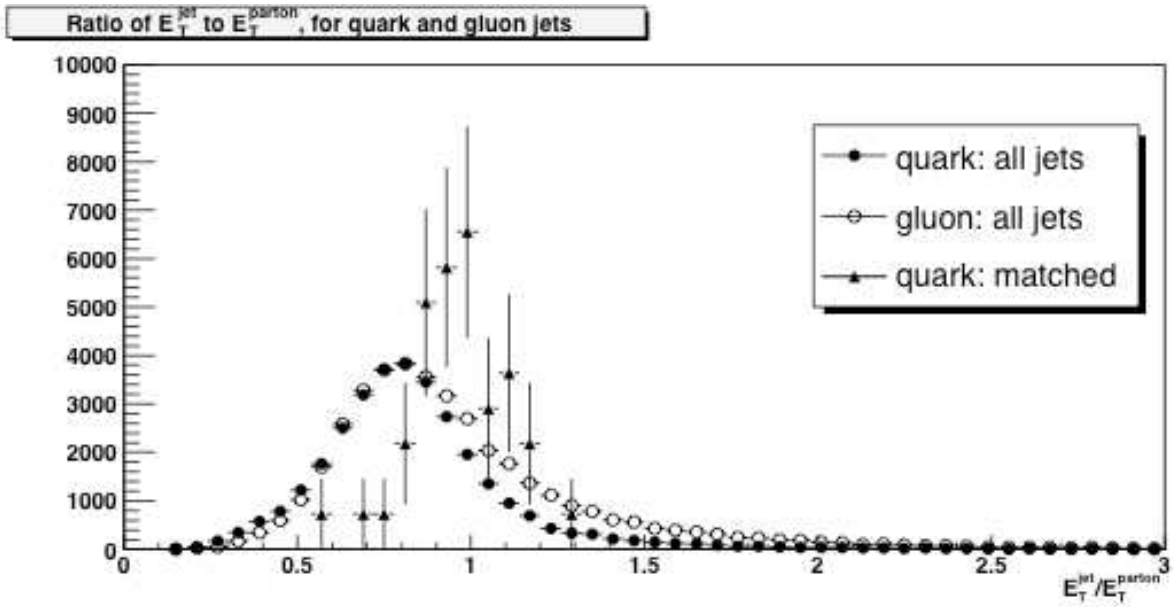


# Fake Rate: jet100



# Jet Et ➔ Photon Et



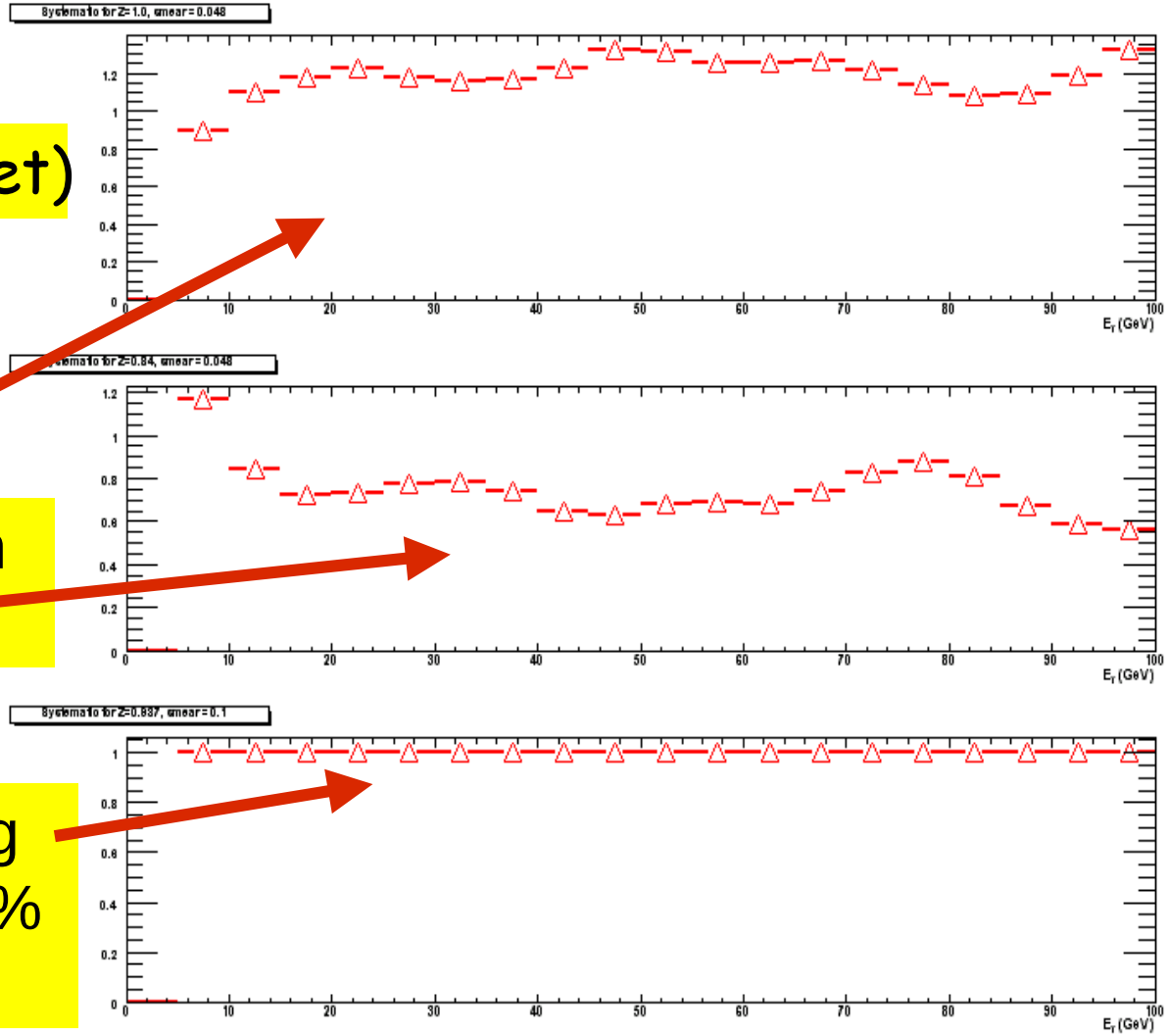

- Calorimeter response difference between generic jets and leading $\pi^0$ jets
  - Taken into account implicitly by fake rate
  - But also emulates difference in jet Et spectrum
- 10% shift in $E_T$ results in 30% change in fake rate
  - ->30% systematic error on fake rate
  - Probably overestimate ➔ will improve for publication

# Jet Et -> Photon Et

Et( $\gamma$ )=0.94*Et(jet)

Changed between 0.84…1.04

Gaussian smearing Changed from +-5% to +-10%




- Change by +-10% in Et results in +-30% in fake rate

# Gluon versus Quark

- Fake rate 10 times large for quark than for gluon jets in MC
- Important that gluon fraction same in jet and W+jet samples:
  - Pythia MC says: 66% in W+jets, 70% in jets
- A 10% uncertainty on gluon faction results in 13% error in fake rate

# Fake Rate: conclusion

- Checks on jet20, jet50, jet70 and jet100 samples work within systematic error quoted:
  - powerful x-check!
- Several systematic check show no deviations larger than quoted error
- Error dominated by
  - jet Et -> photon Et translation at low Et<20 GeV
  - Prompt photon fraction at Et>20 GeV
- Need better understanding for publication to reduce error:
  - Remove fragmentation uncertainty by using emObject as denominator?
  - Test on more samples?
  - Use only 345$^{th}$ jet? Include St5 and MinBias data?

# Results with 200 /pb

# W+γ: muon channels

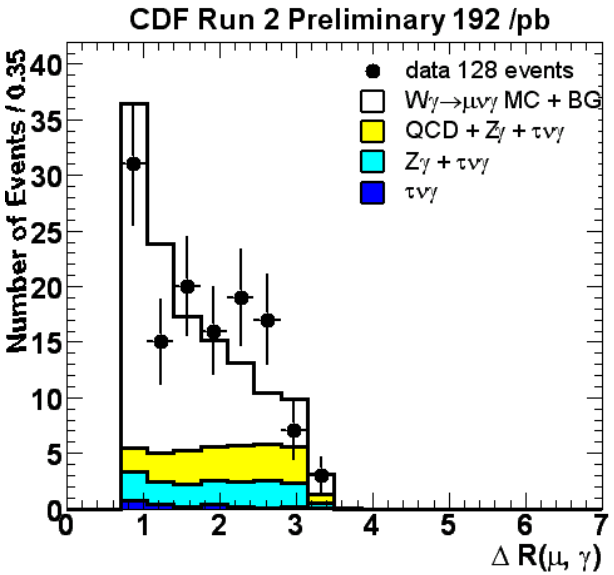
N. Tanimoto

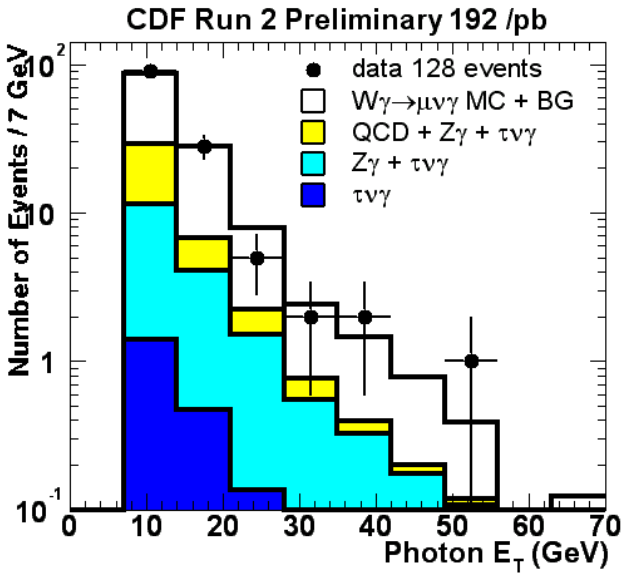
| | CMUP | CMX |
|---|---|---|
| Z+g MC | 63.46+-1.17+-3.79 | 31.54+-0.87+-1.87 |
| Z+jet BG | 13..90+-0.0+-4.20 | 7.55+-0.0+-2.28 |
| Z+g | 11.72+-0.26+-0.70 | 5.62+-0.19+-0.33 |
| W+g (tau) | 1.44+-0.17+-0.09 | 0.86+-0.14+-0.05 |
| Total SM | 90.52+-1.20 +-5.70 | 45.56+-0.91 +-2.97 |
| data | 93 | 35 |

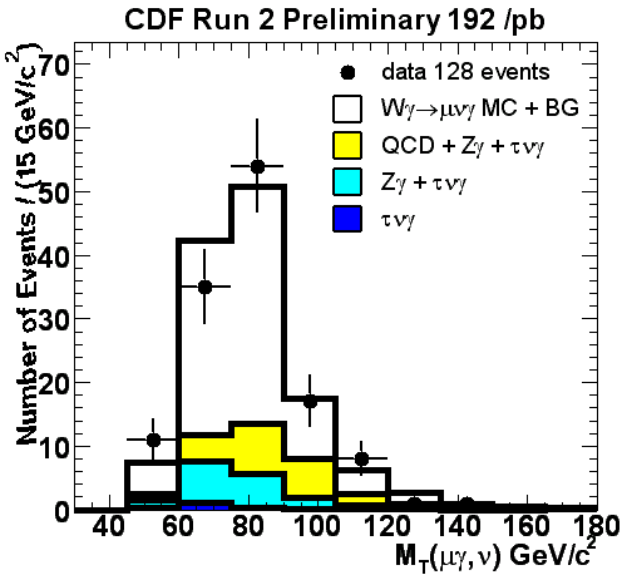
CMUP: sigma*BR=20.1+-2.9(stat)+-1.8(sys)+-1.2(lumi) pb
CMX: sigma*BR=12.8+-3.6(stat)+-1.7(sys)+-0.8(lumi) pb

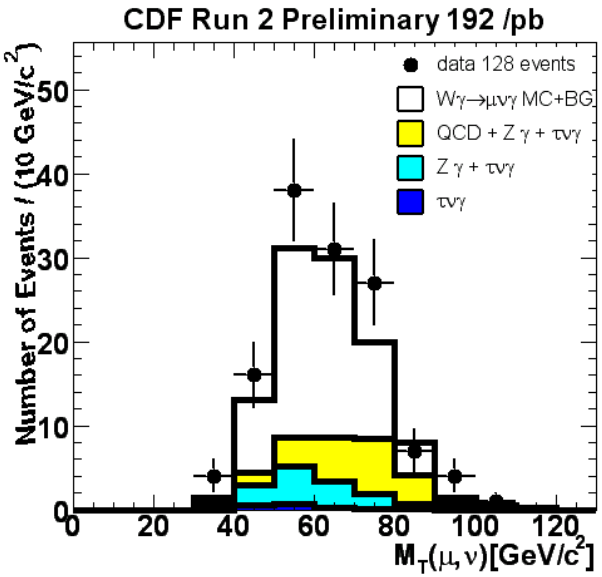
SM: 19.3+-1.4 pb

# Wγ Plots: muon channel



# W+γ: electron channel

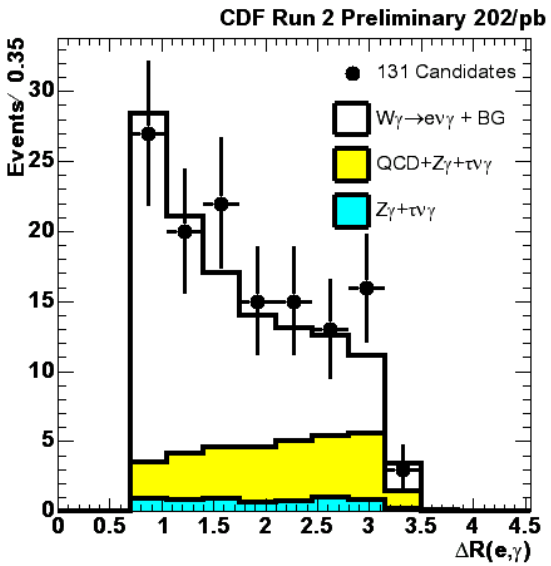
M. Kirby

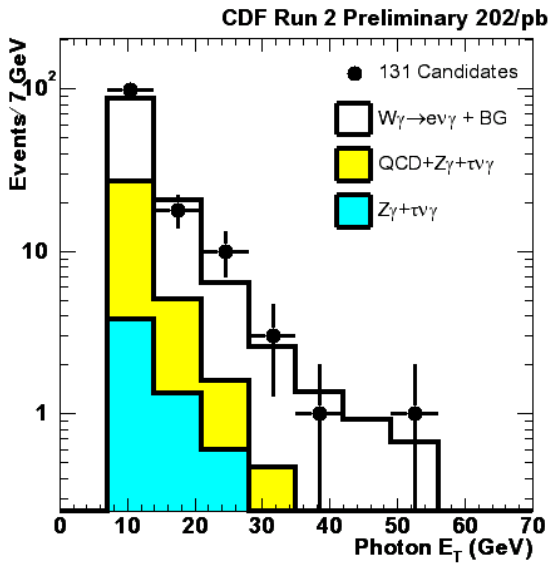
| | Central (198.3/pb) |
|---|---|
| W+γ MC | 85.51+-1.49+-4.45 |
| W+jet BG | 28.07+-0.0+-8.48 |
| Z+γ | 5.03+-0.19+-0.26 |
| W+γ (tau) | 0.93+-0.15+-0.05 |
| Total SM | 119.54+-1.51+-9.57 |
| data | 131 |

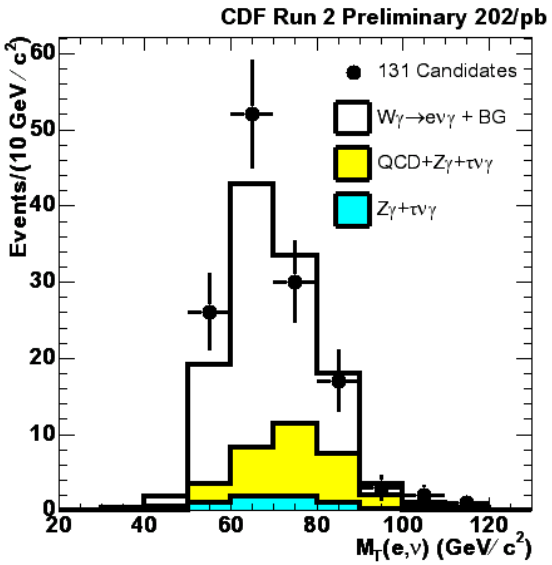
Central: sigma*BR=21.9+-2.6(stat)+-2.2(sys)+-1.3(lumi) pb

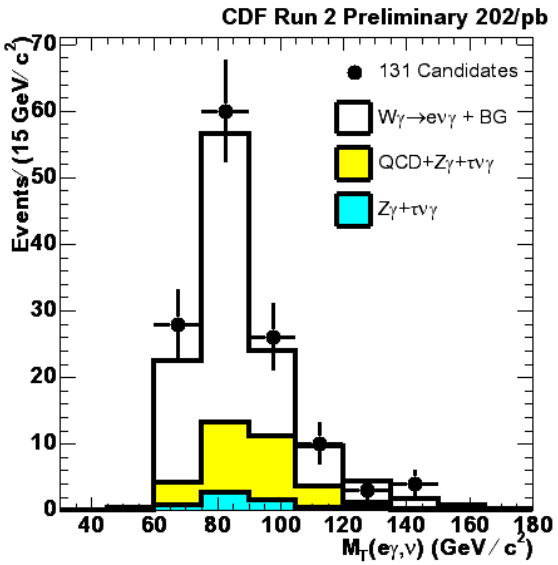
SM: 19.3+-1.4 pb

# Wγ Plots: electron channel



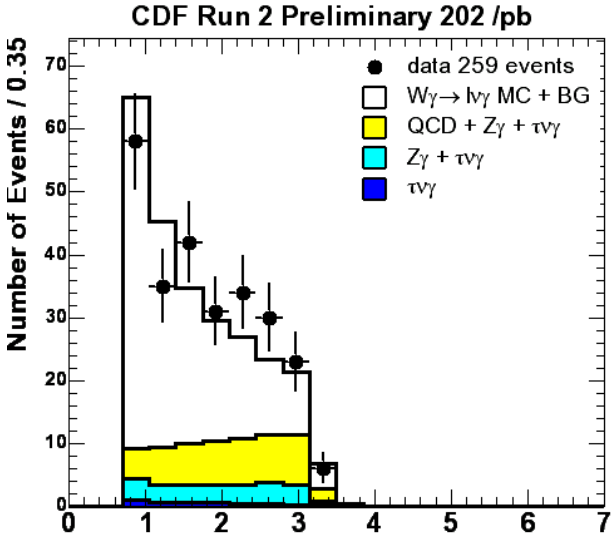
# W+γ: central electron+muon channels

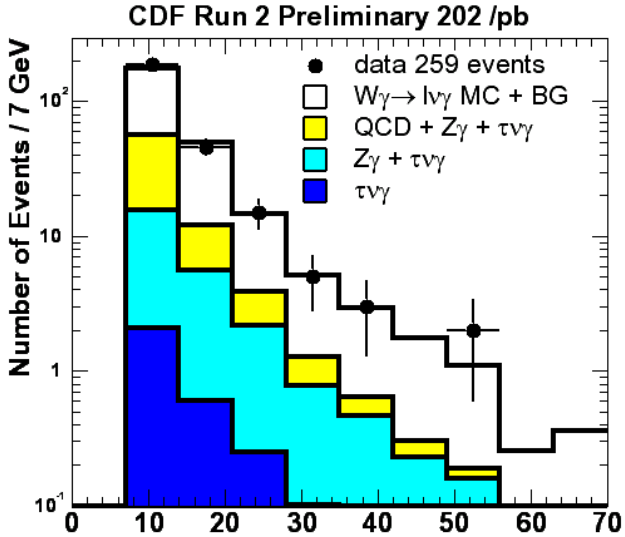
| | Nexp (L=198.3/pb) |
|---|---|
| W+γ MC | 180.51+-2.08+-11.2 |
| W+jet BG | 49.52+-0.10+-14.95 |
| Z+γ | 22.37+-0.38+-1.20 |
| W+γ (tau) | 3.23+-0.24+-0.17 |
| Total SM | 255.63+-2.13+-26.43 |
| data | 259 |

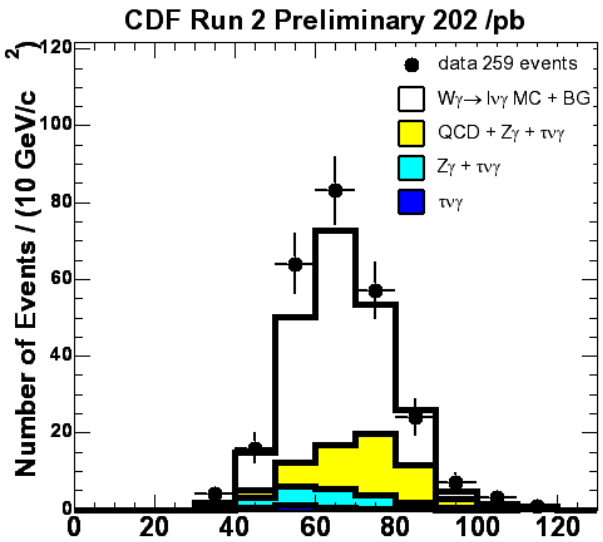
Central: sigma*BR=19.7+-1.7(stat)+-2.0+-1.2 pb

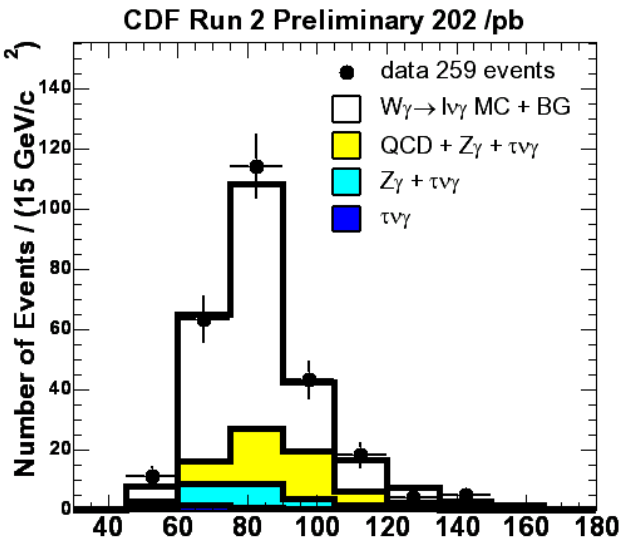
SM: 19.3+-1.3 pb

# Wγ Plots: central e+mu channel



# Z+g channels

H. Hayward

| | CC e | CP e | $\mu$ $\mu$ |
|---|---|---|---|
| Z+g MC | 19.95+-1.11 | 11.97+-0.83 | 33.84+-1.84 |
| Z+jet BG | 1.44+-0.43 | 1.10+-0.33 | 1.90+-0.57 |
| Fake Z+g | 0.23+-0.12 | 0.034+-0.14 | <<0.1 |
| Total SM | 21.61+-1.20 | 13.10+-0.91 | 35.74+-1.92 |
| data | 23 | 11 | 35 |

CC: sigma*BR=5.8+-1.2(stat)+-0.3(sys)+-0.3(lumi) pb
CP: sigma*BR=4.5+-1.3(stat)+-0.4(sys)+-0.3(lumi) pb
MM: sigma*BR=5.3+-0.9(stat)+-0.3(sys)+-0.3(lumi) pb

SM: 5.4+-0.4 pb

# Z+γ combined

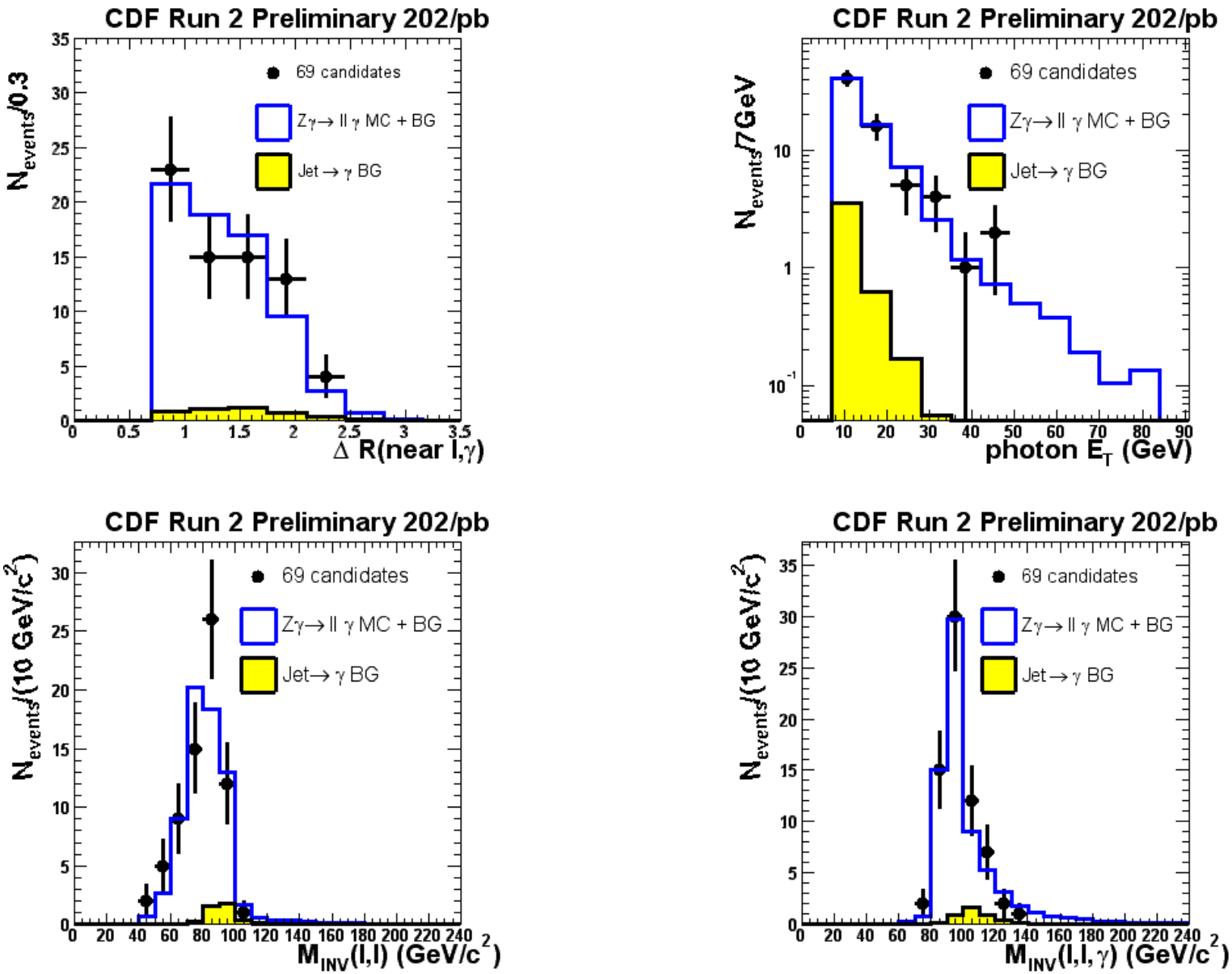
H. Hayward

| | Combined e and $\mu$ |
|---|---|
| Z+g MC | 65.76+-3.76 |
| Z+jet BG | 4.44+-1.33 |
| Fake Z+g | 0.26+-0.20 |
| Total SM | 70.46+-4.00 |
| data | 69 |

sigma*BR=5.3+-0.6(stat)+-0.3(sys)+-0.3(lumi) pb

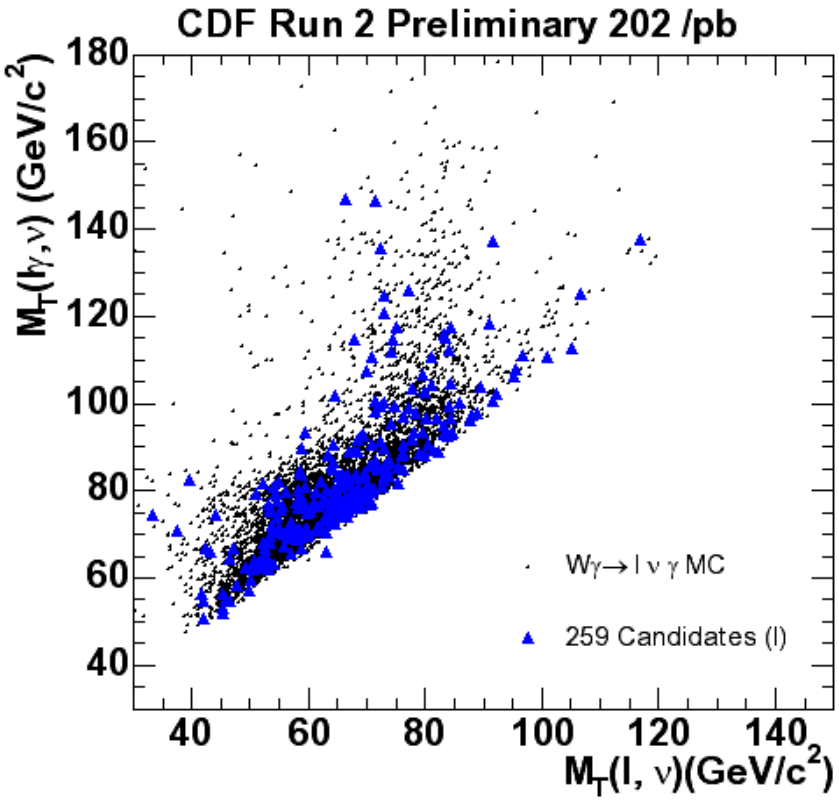
SM: 5.4+-0.4 pb

# Z+γ kinematics: all channels combined

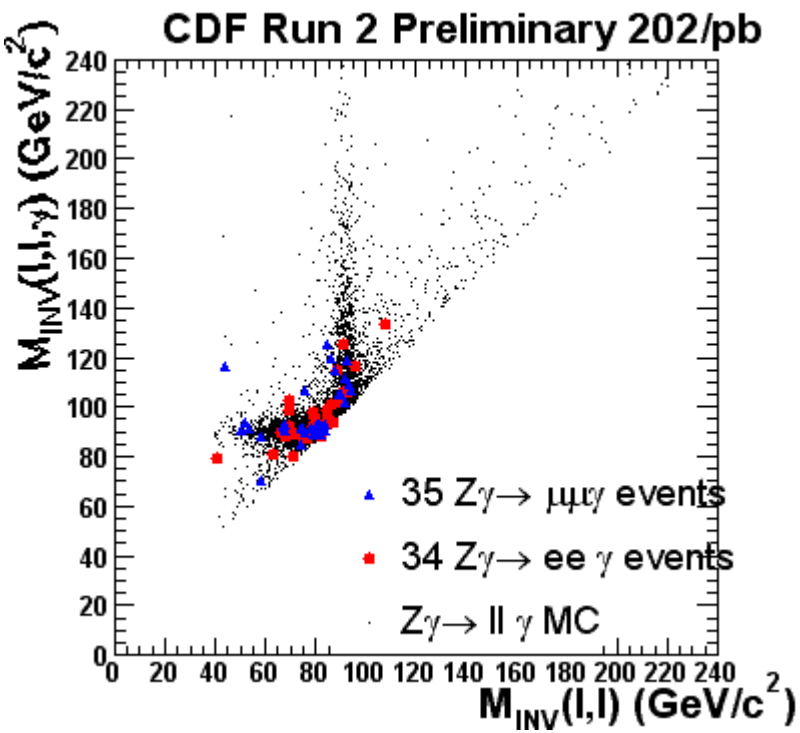


# 3-body versus 2-body masses

WGamma

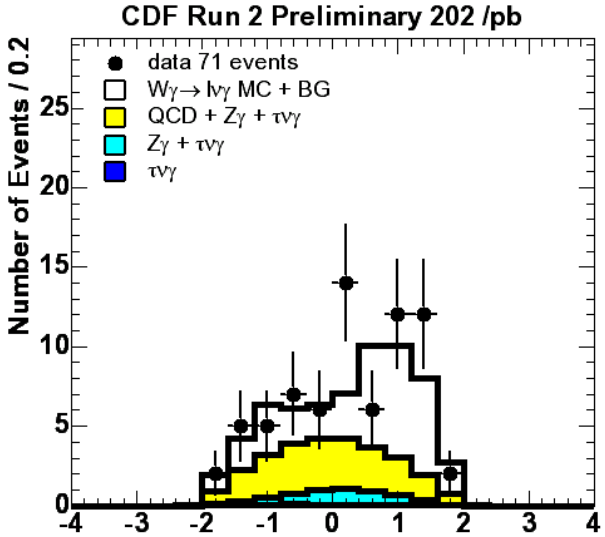


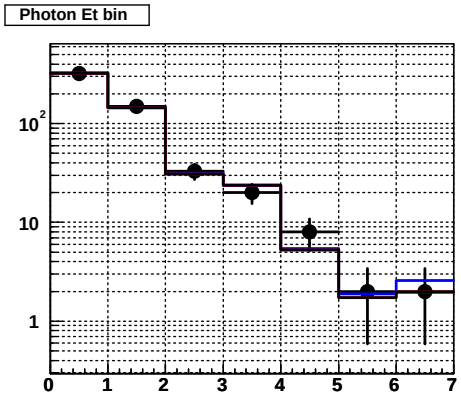

ZGamma

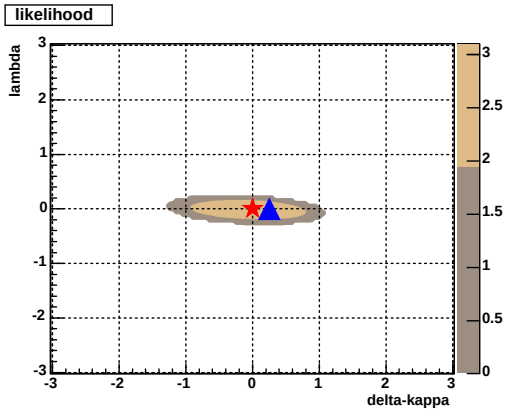


# Conclusion and Outlook

- Conclusions
  - K-factor mistake fixed
  - Bug in Met corrections fixed
  - Fake rate checks accomplished but improvements and more rigorous syst. Error necessary
  - Final results in good agreement with SM
- Outlook
  - Plug W+central photon (close)
  - Radiation Amplitude Zero
  - Trilinear Coupling analyses
  - Publish!



# Backup Slides

# Z->ll Cross-Section

- Z(CC): $\sigma$ =248 $\pm$4(stat) $\pm$9(sys) $\pm$15(lum)
- Z(CP): $\sigma$ =245 $\pm$4(stat) $\pm$9(sys) $\pm$15(lum)
- Z(CMUP): $\sigma$ =263 $\pm$4(stat) $\pm$11(sys) $\pm$16(lum)
- Z(CMX): $\sigma$ =253 $\pm$5(stat) $\pm$11(sys) $\pm$15(lum)

- **SM prediction: $\sigma$ =252.9 (NNLO)**

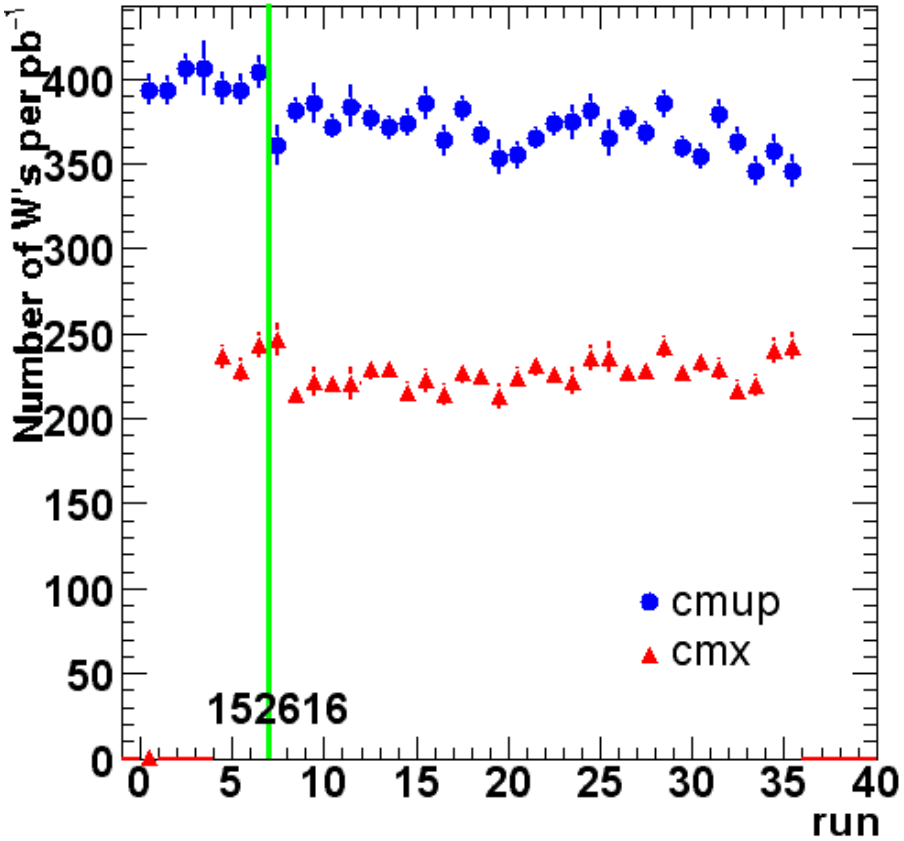
# Inclusive σ(W)

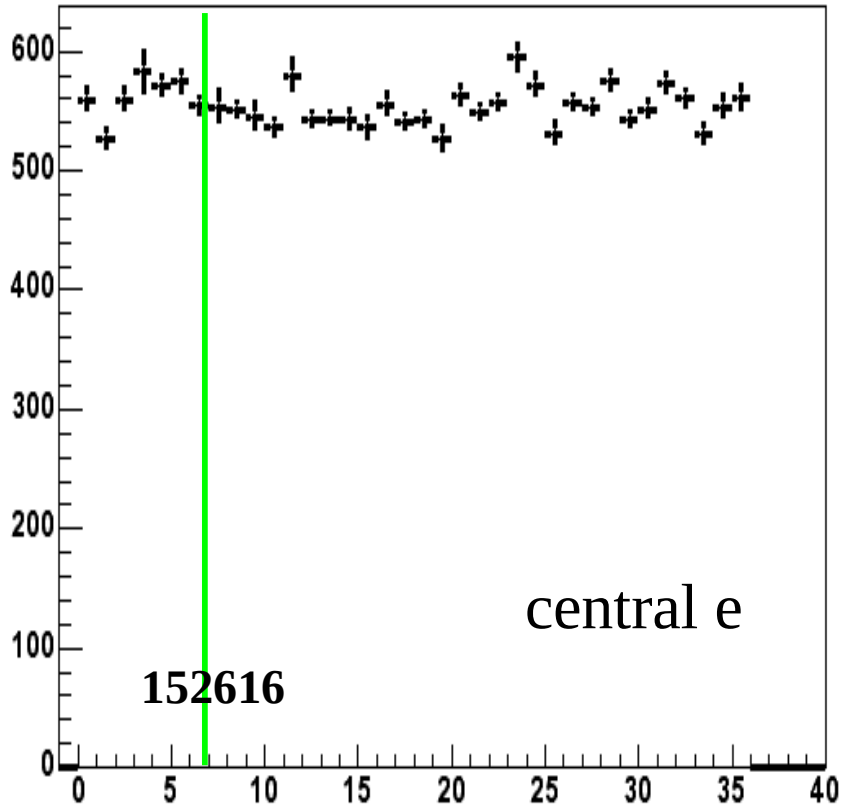
- NNLO Theory 2.73 nb
  - W. James Stirling et.al.
- Central electron
  - σ(W) = 2.75 nb
    - ±0.01 stat ±0.07 syst ±0.18 lum
  - 4.5% BG
- CMUP muon
  - σ(W) = 2.77 nb
    - ±0.01 stat ±0.07 syst ±0.18 lum
  - 9.43% BG
- CMX muon
  - σ(W) = 2.78 nb
    - ±0.01 stat ±0.07 syst ±0.18 lum
  - 9.21% BG

- Using same version of MC material as Wγ MC
- Same MC ID eff corrections and trigger efficiencies

$$\sigma = \frac{N_{cand} - N_{bkg}}{A * eff_{MC} * Z0_{data} * \int L}$$

# Run dependence of yield: W's



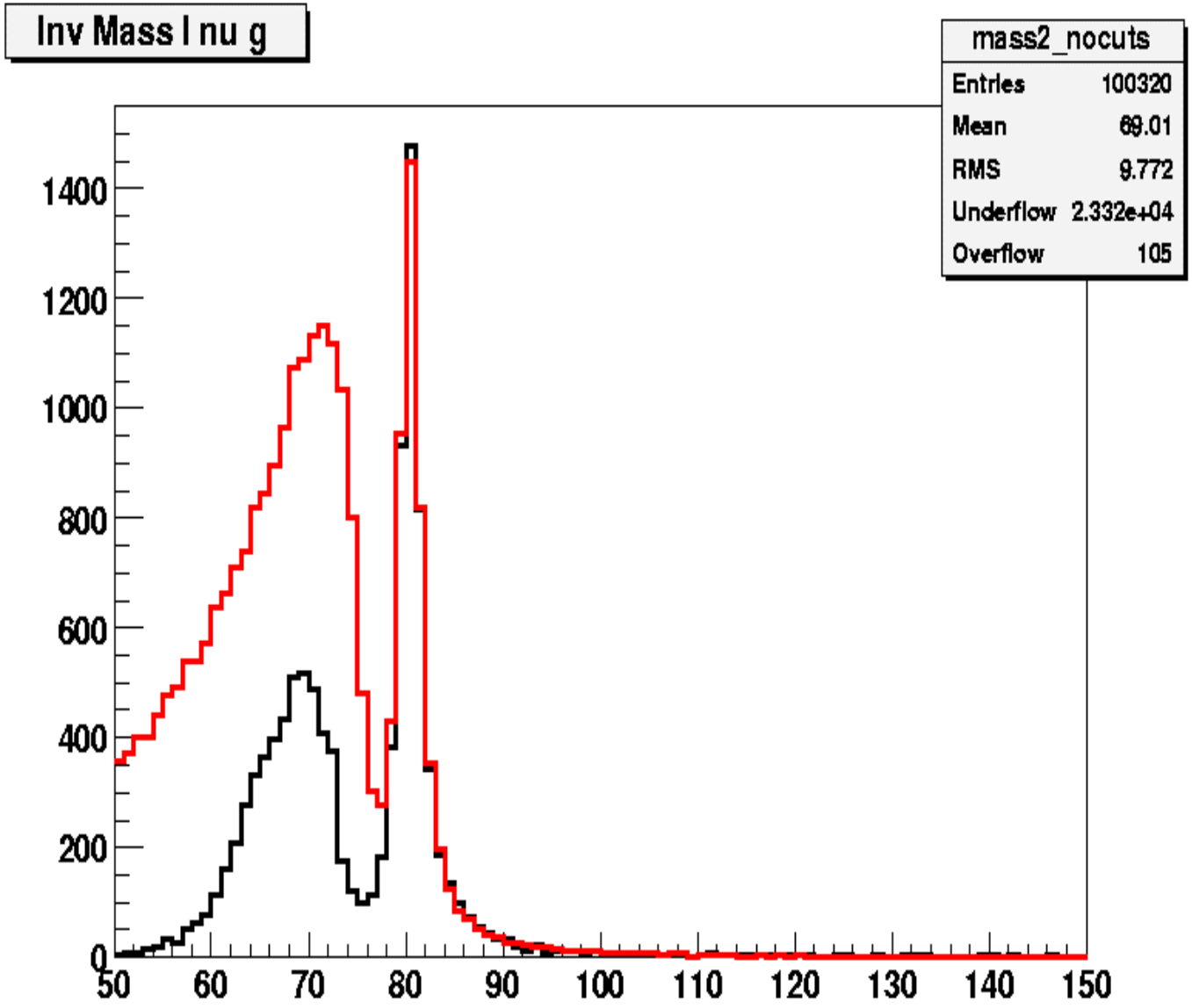
# NLO corrections

- Use U. Baur's NLO wgam & zgam programs to determine $E_T^{\gamma}$ dependent correction
  - hep-ph/9305314
- NLO wgam & zgam do not include inner brem
- Correct inner brem terms with NLO inclusive W & Z correction (1.36)
  - Stirling, et. al. from CDF note 6681

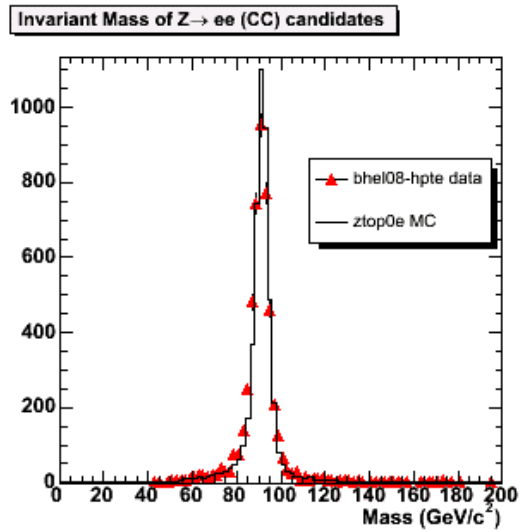
# NLO corrections

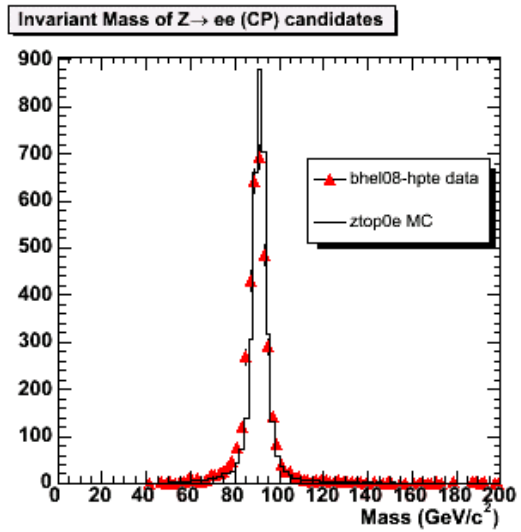
- Parton level cut on Invariant Mass of decay leptons to cut on process
  - Wg MC
    - > 76 GeV/$c^2$ apply k(Et)
    - < 76 GeV/$c^2$ apply 1.36
  - Zg MC
    - > 85 GeV/$c^2$ apply k(Et)
    - < 85 GeV/$c^2$ apply 1.36
- Separate corrections for $W\gamma$ and $Z\gamma$

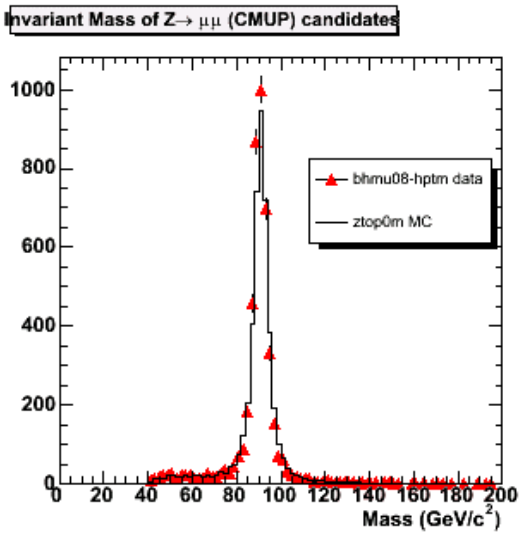
# $M_{inv}(l,\nu)$

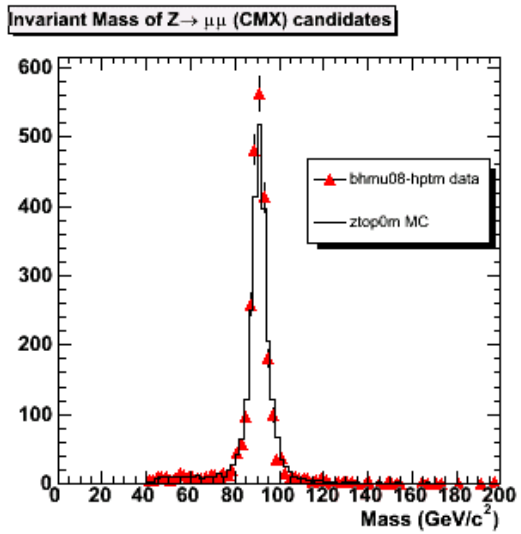

Inv Mass l nu g
mass2_nocuts
Entries 100320
Mean 69.01
RMS 9.772
Underflow 2.332e+04
Overflow 105
1400
1200
1000
800
600
400
200
0
50
60
70
80
90
100
110
120
130
140
150

# Z mass peaks


Invariant Mass of Z→ ee (CC) candidates
bhel08-hpte data
ztop0e MC
Mass (GeV/c²)


Invariant Mass of Z→ ee (CP) candidates
bhel08-hpte data
ztop0e MC
Mass (GeV/c²)


Invariant Mass of Z→ μμ (CMUP) candidates
bhmu08-hptm data
ztop0m MC
Mass (GeV/c²)


Invariant Mass of Z→ μμ (CMX) candidates
bhmu08-hptm data
ztop0m MC
Mass (GeV/c²)

# Fake Rate Methodology

- The raw fake rate is the fraction of jets which pass the photon criterion

$$P_{RAW} = \frac{N_\gamma^{obs}}{N^{jet}} = \frac{(N_\gamma^{true} + N_\gamma^{fake})}{N^{jet}}$$

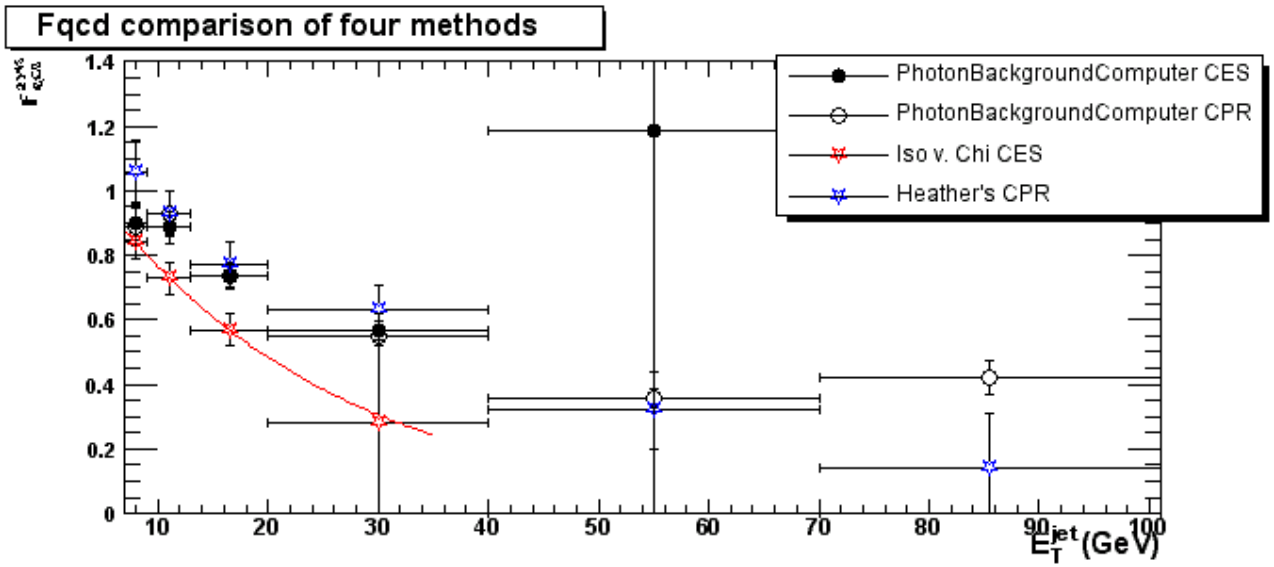
- However the sample is contaminated by real photons

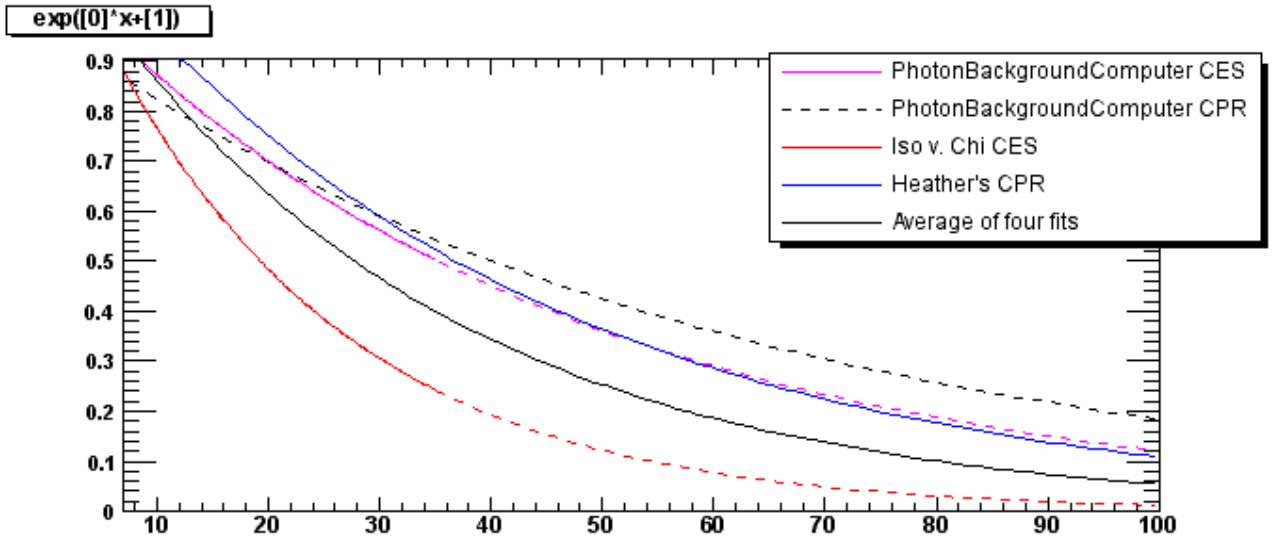
$$F_{QCD} = \frac{N_\gamma^{fake}}{N_\gamma^{obs}} = \frac{N_\gamma^{fake}}{N_\gamma^{fake} + N_\gamma^{true}} = 1 - F_\gamma$$

  - Must remove this fraction:

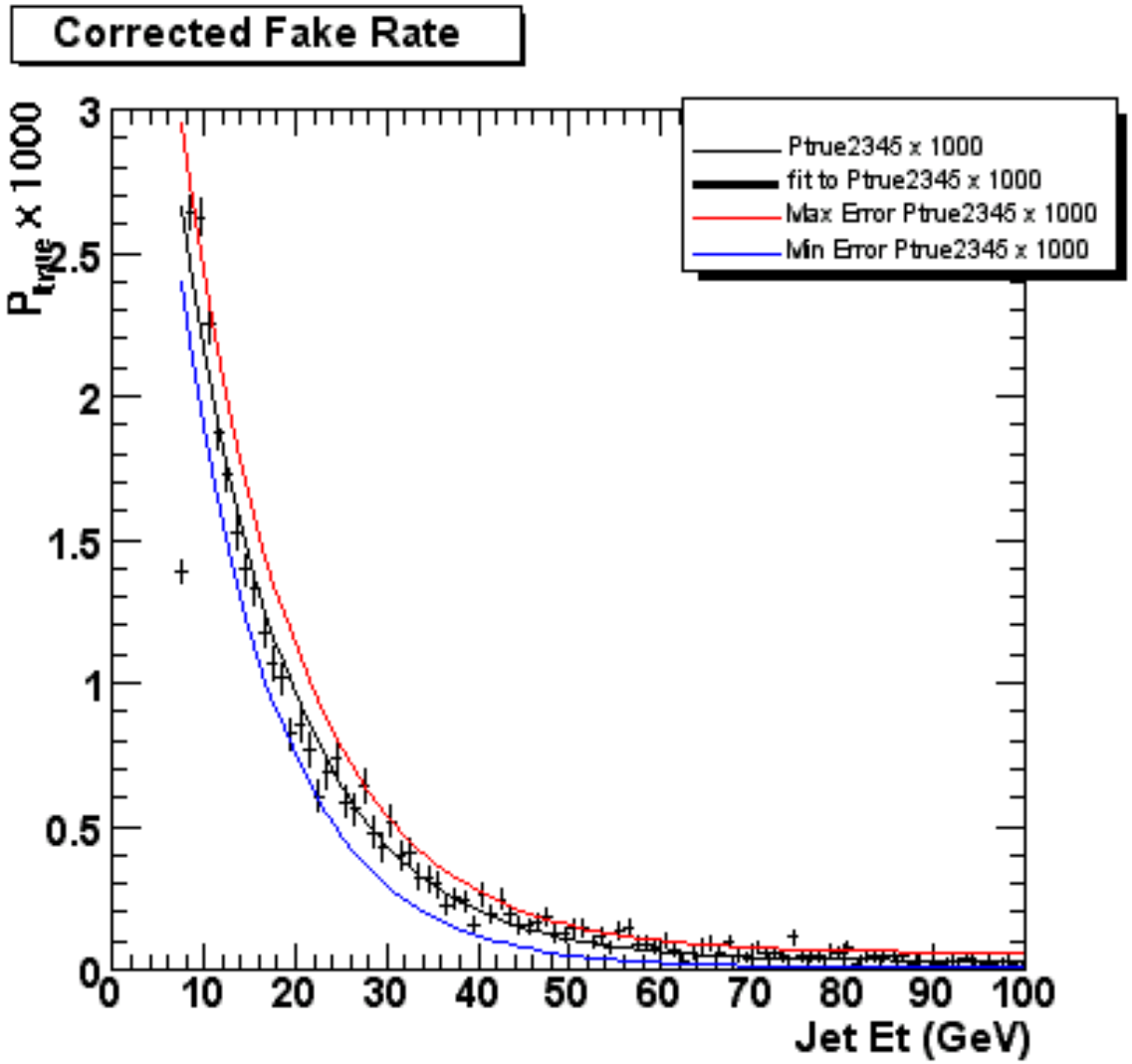
$$P_{true} = F_{QCD} \times P_{raw}$$

# Comparison of Methods

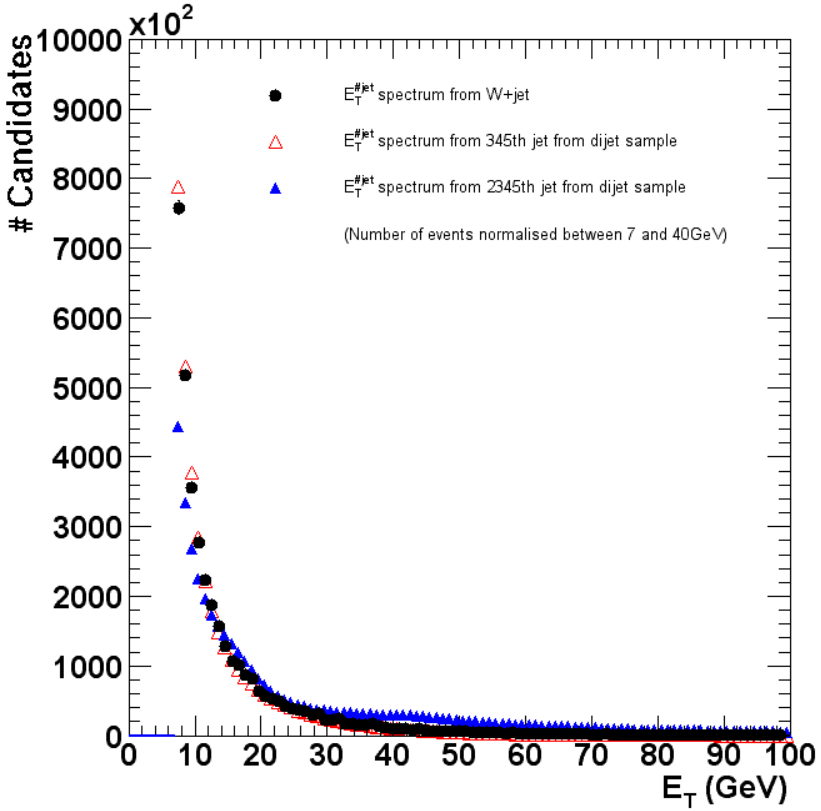


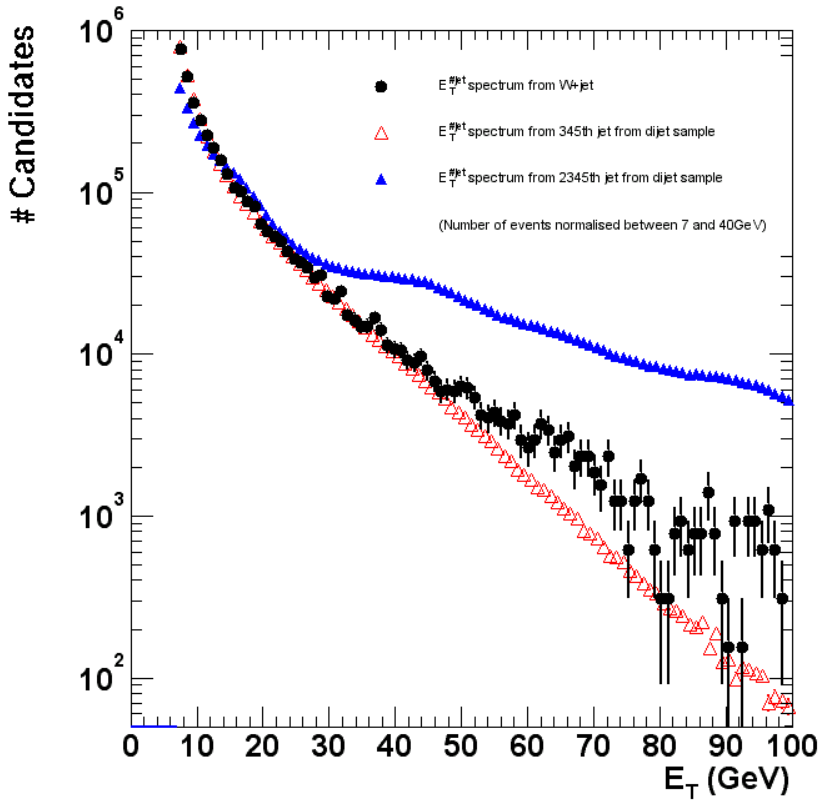



# Final Fake Rate



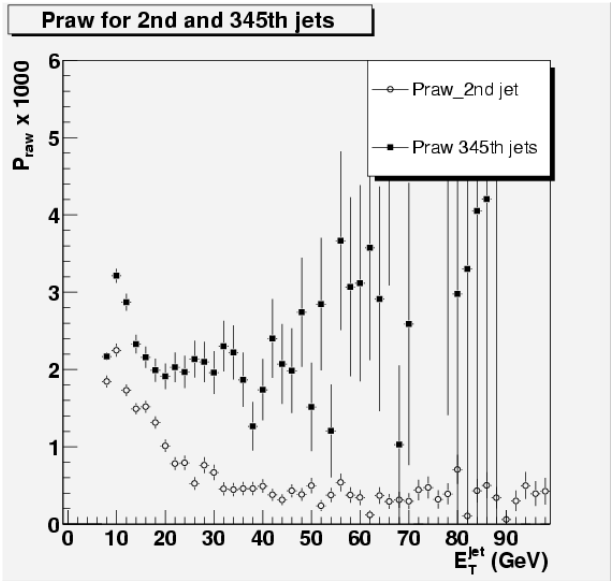
# Jet Et spectrum: W+jet versus jet triggers

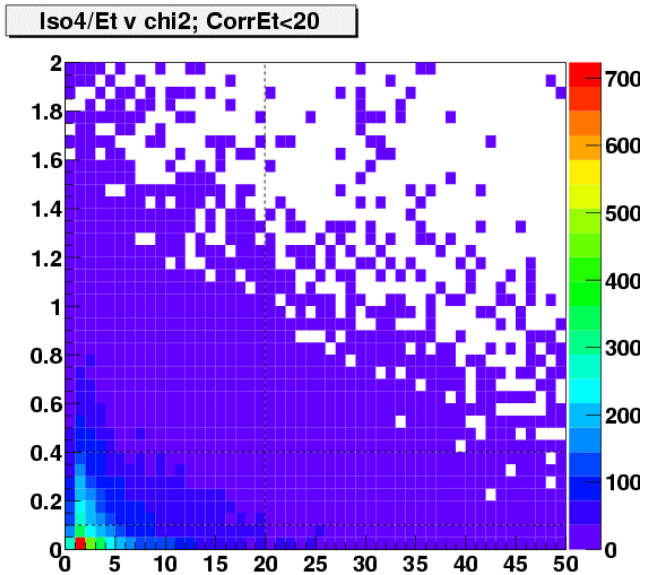


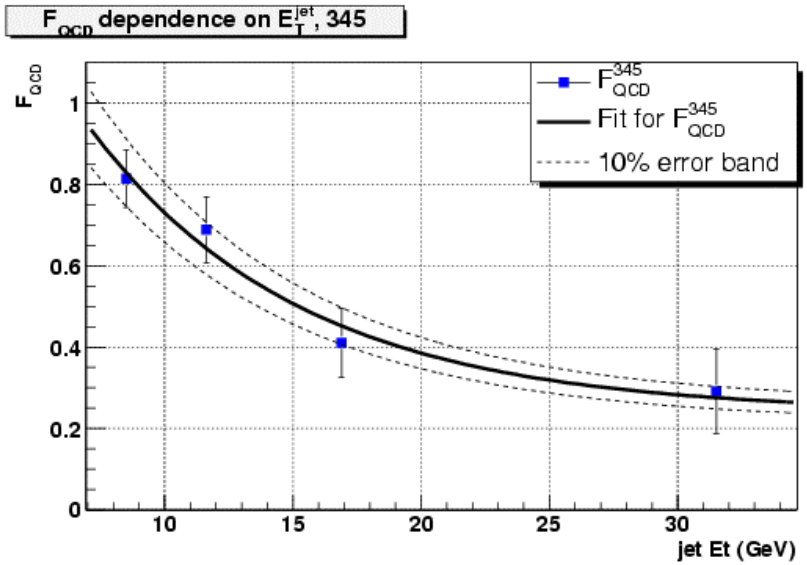



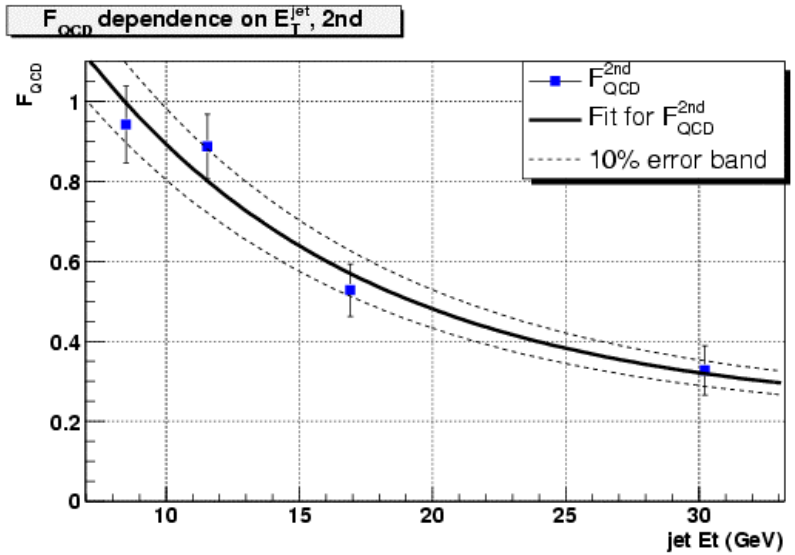

- Et spectrum similar in Jet triggers and W+jets
- Difference due to trigger bias for 2nd jet
- 3rd jet unbiased and dominates at low Et

# Photon Fake Rate: Details

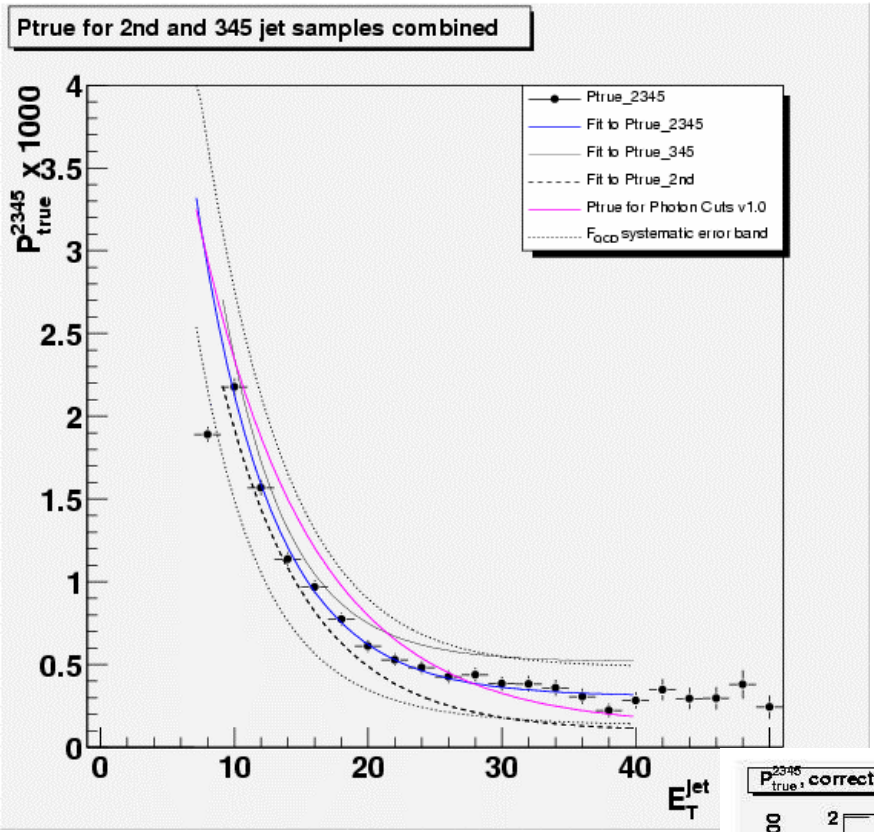


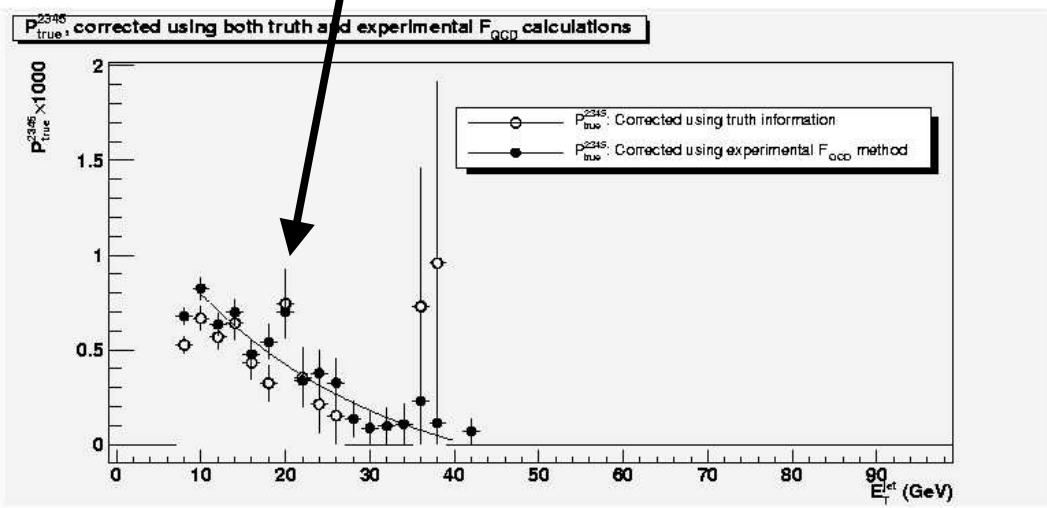



# Photon Fake Rate




- Systematic Error: 30-80%
- 2nd and 345th jets agree
- Procedure verified in MC: compare rate of isolated pi0's at HEPG level to observed rate




H. Hayward