Studies of $Z\gamma$ Production at the DØ Run II Detector with $1fb^{-1}$ of Data

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DPF 2006

Honolulu, Hawaii, October 29th - November 3rd, 2006

Overview

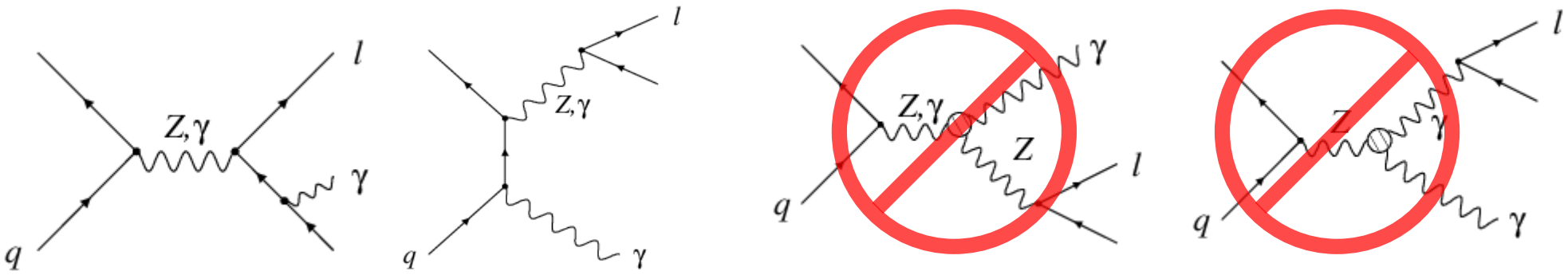
- **Motivation**
- **Event selection and photon identification**
- **Background**
- **Observed data and cross-section measurement**
- **Summary and plans**

Motivation

- **Measure cross-section of the Zγ process and compare it with the Standard Model prediction**

- **Search for new physics (or set limits on it) in gauge boson self-interactions:** SM forbids **Z** and **γ** self-interactions at tree-level

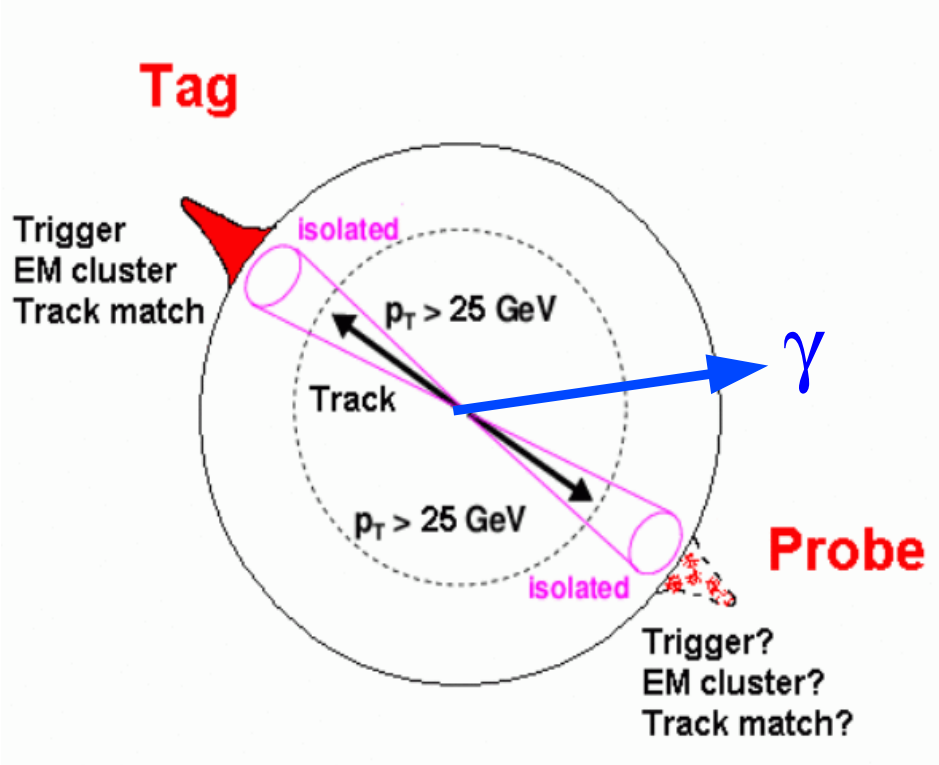
SM allowed **SM forbidden**



SM FSR **SM ISR** **Anomalous Zγ production**

$Z\gamma \rightarrow ee\gamma$ Event Selection (I)

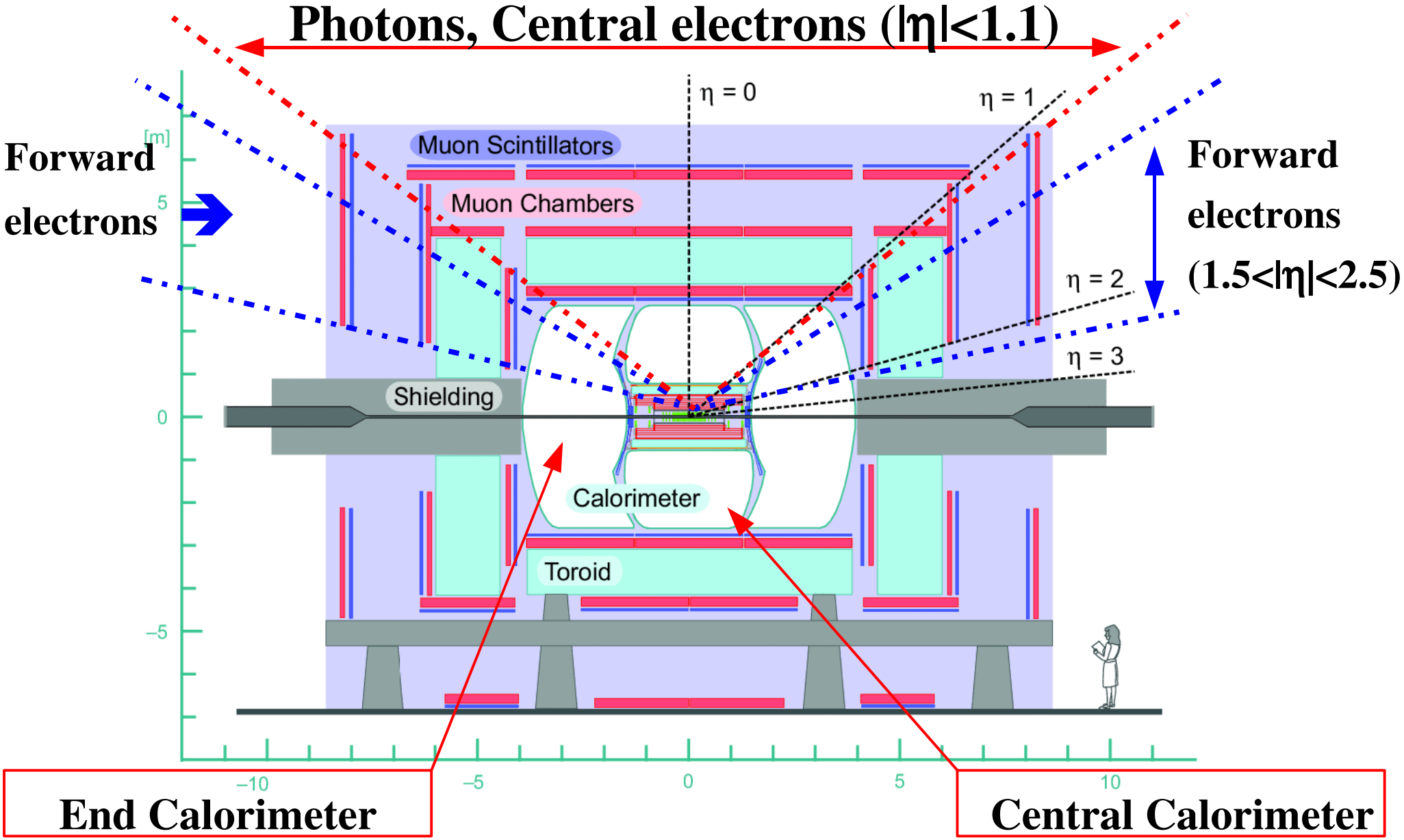
- **Signature of Z boson is 2 high-pt leptons and no/little missing energy:**
  - clean and well known signals
  - low background
  - lepton reconstruction and trigger efficiencies are measured using **'tag-and-probe'** method



- **Select events that:**
  - pass data quality requirements and fire single EM-trigger
  - contain 2 isolated high-p_T ($p_T >$ **25,15** GeV/c) EM clusters, depositing at least **90%** of energy in the EM calorimeter and with electron-like shower shape

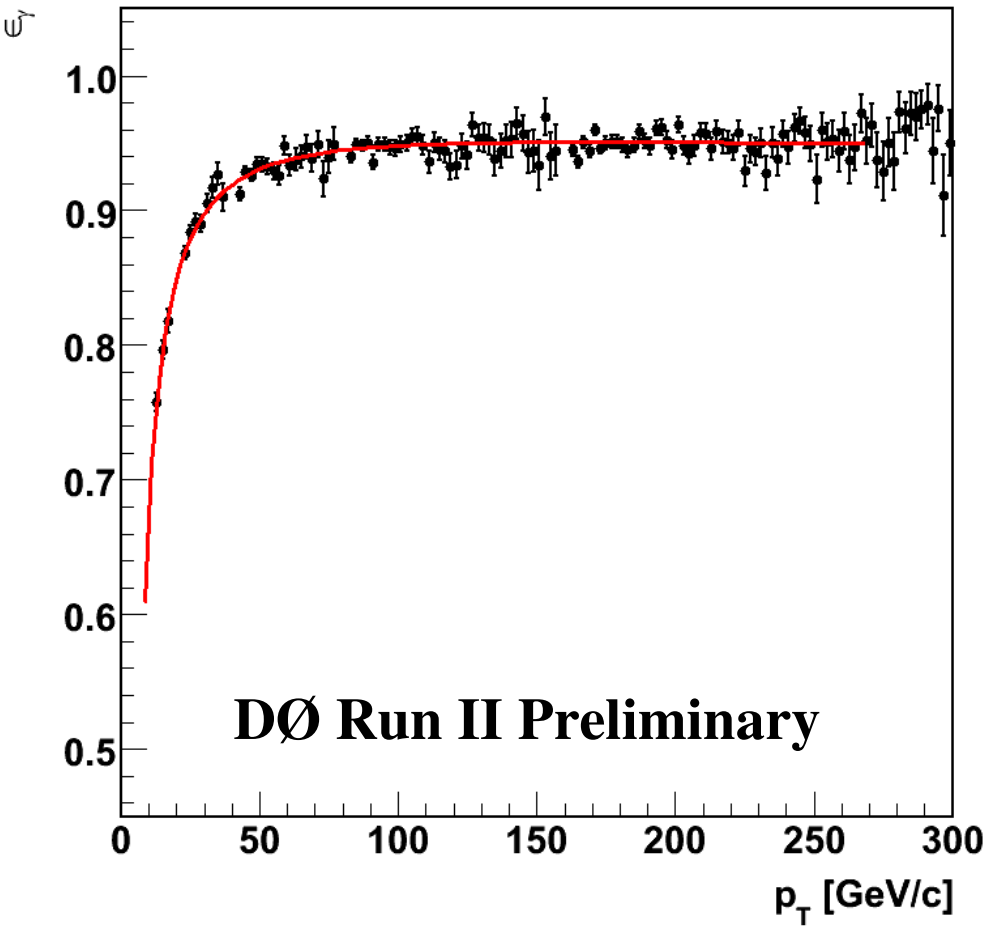
$Z\gamma \rightarrow ee\gamma$ Event Selection (II)

- **Further on we select events with additional photon candidates for the $Z\gamma$ final state:**
  - isolated (in the calorimeter and the tracker) EM shower with $p_T > 7$ GeV/c, with **96%** of its energy deposited in the central EM calorimeter and separated from both leptons ($dR_{e\gamma} > 0.7$)
  - challenging task to reconstruct photon – no track, high QCD background, no discovered natural source of high-p_T di-photon resonance (e.g. **$H \rightarrow \gamma\gamma$**)


Photons, Central electrons (|η|<1.1)
Forward electrons
Forward electrons (1.5<|η|<2.5)
η = 0
η = 1
η = 2
η = 3
Muon Scintillators
Muon Chambers
Shielding
Calorimeter
Toroid
[m]
5
0
–5
–10
–5
0
5
10
End Calorimeter
Central Calorimeter

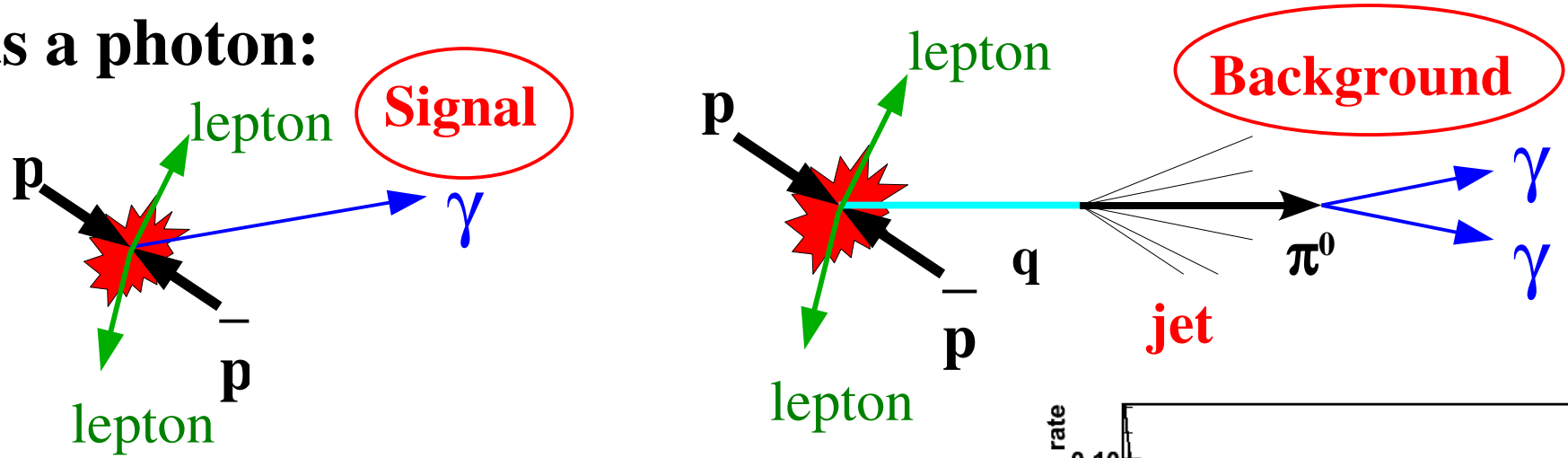
Photon Efficiency

- **We measure photon efficiency using data and Monte Carlo simulation:**
  - treat photons as electrons, choose and tune selection criteria on **Z→ee** data
  - measure photon efficiency on photon+jet Monte Carlo
  - correct for the electron/photon shower difference using Monte Carlo

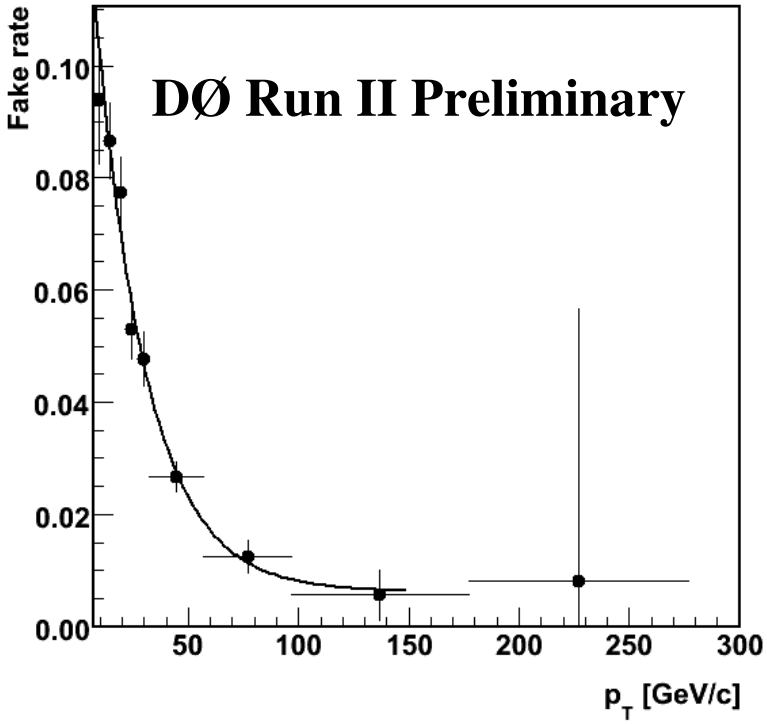


- **Photon ID efficiency is above 90% for high-p_T photons**

- **Largest background is Z+jet where a jet is misidentified as a photon:**

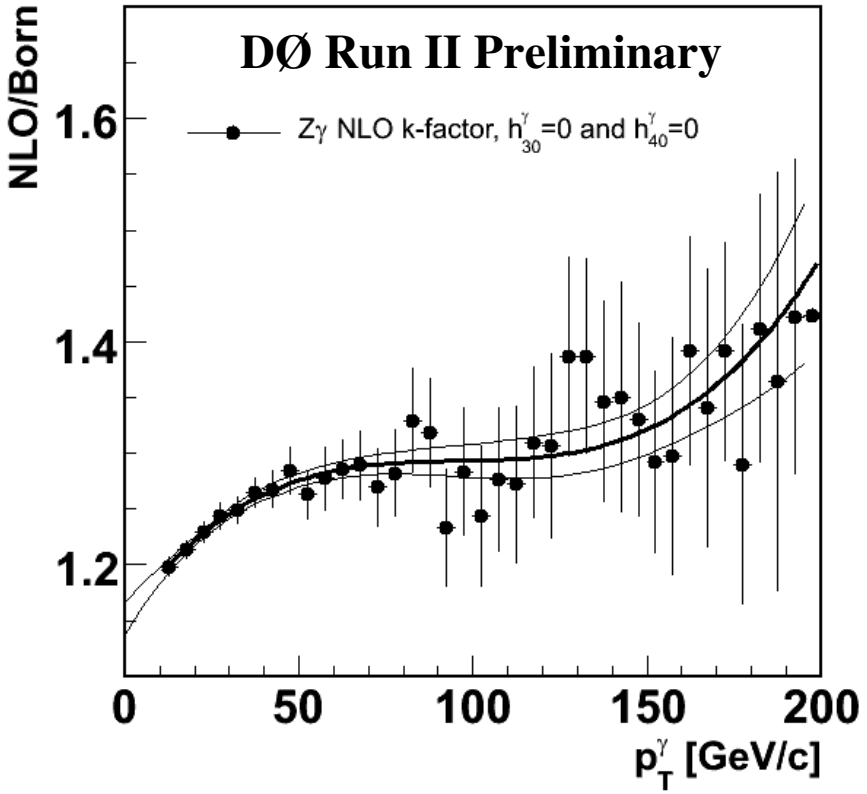


- **Measure jet mis-id rate using jet-enriched sample and correct for direct photon production:**
  - count jets and EM objects passing photon selection criteria
  - misidentification rate is: $f_{QCD} = \frac{N_{Passed}}{N_{Total}}$



Monte Carlo Sample

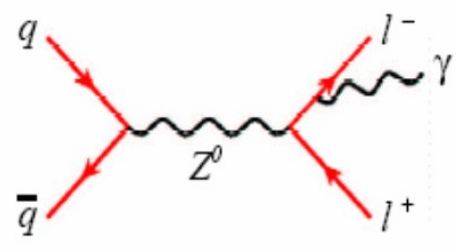
- **In our studies we use LO Baur Monte Carlo Zγ generator:**
  - NLO corrections are important at high $p_T(\gamma)$ and $M(Z\gamma)$ - most sensitive region to anomalous couplings
  - we correct LO photon p_T with p_T-dependent k-factor (obtained from NLO generator)



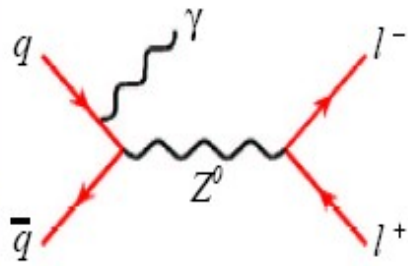
- **Parameterized Monte Carlo Detector Simulation is then used to calculate reconstruction efficiencies and acceptance of the event selection criteria**

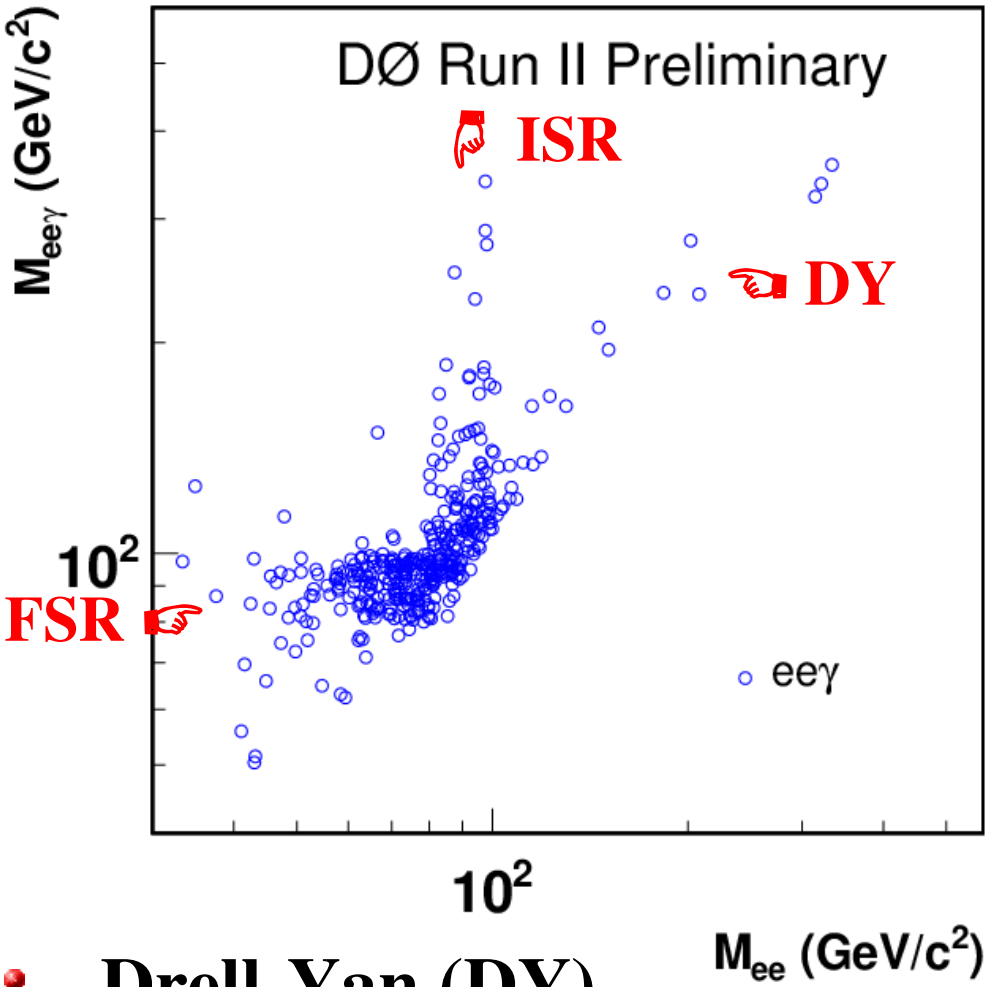
Observed Processes

- **Final State Radiation:**
  - **Z** production (not **Zγ**)
  - softer photons

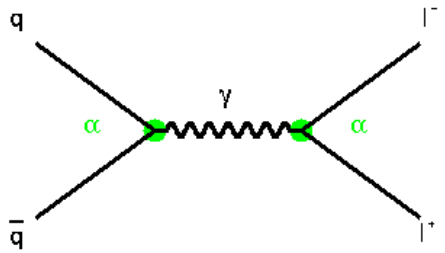


- **Initial State Radiation:**
  - **Zγ** production
  - photons are harder, than in FSR
  - ISR is most sensitive to AC



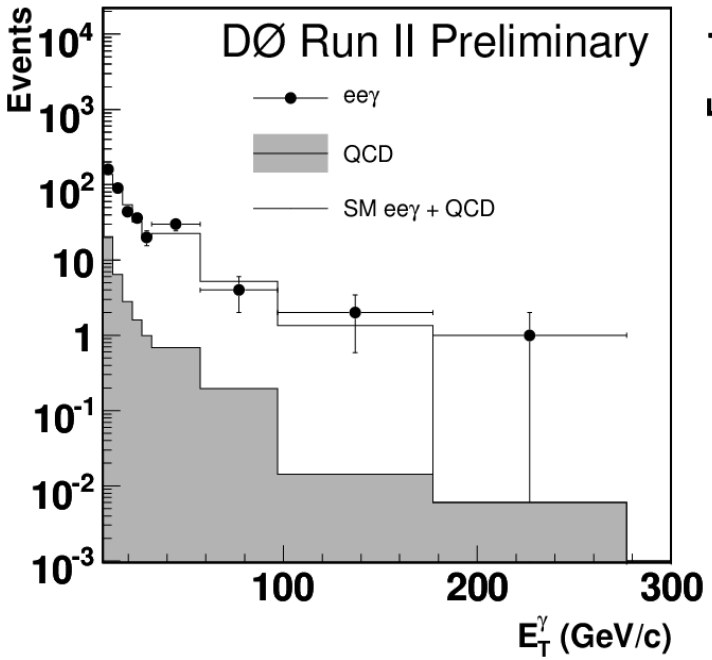


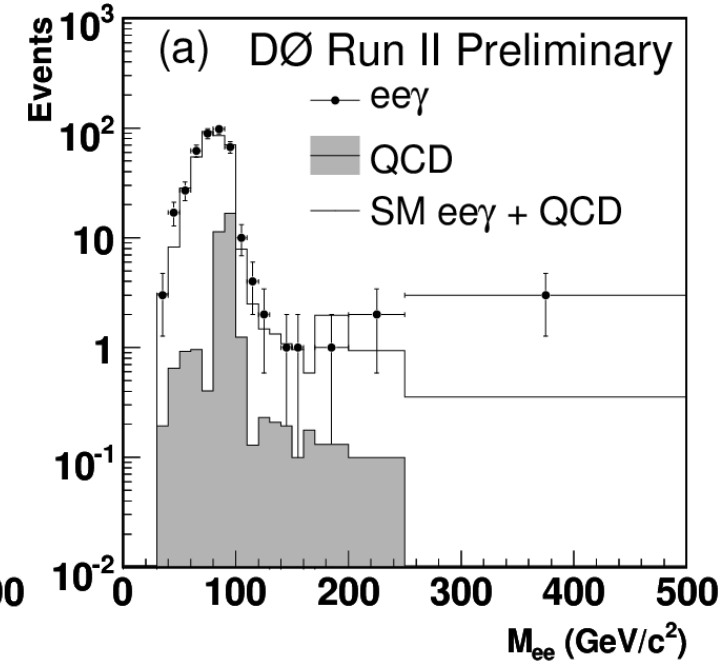
- **Drell-Yan (DY)**

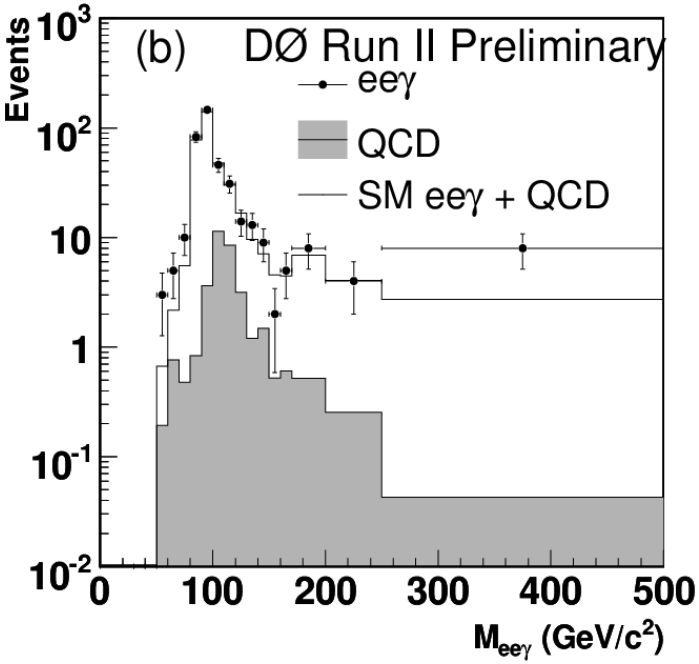


Data

- **Using ~1 fb^{-1} di-electron events enriched dataset we observe:**
  - **387 $Z\gamma \rightarrow ee\gamma$** candidate events
  - **33.1 ± 6.4 Z+jet** background events
- **SM predicts: 327.3 ± 19.5 $Z\gamma \rightarrow ee\gamma$** events (total **360.4 ± 20.6**)







Cross-section Measurement (I)

- **Cross-section for $Z\gamma$ × the branching ratio for $Z \rightarrow ee$:**

$$\sigma \times BR = \frac{(N_{cand} - N_{bkg})}{(\epsilon_{ee\gamma} L_{Int.})}$$

- **Total event selection efficiency is:** $\epsilon_{Tot} = Acc \times \epsilon_{Trig} \times \epsilon_{EM} \times \epsilon_{\gamma}$
  - ε_{TOT}(central) = **0.053 ± 0.003**; ε_{TOT}(central/forward) = **0.023 ± 0.002**

Requirement	Central Calorimeter Topology	Central + Forward Calorimeter Topology
N (Zgamma)	256 +/- 16	131 +/- 11.4
N (QCD)	18.3 +/- 3.0(stat) +/- 2.9(syst)	14.8 +/- 2.5 (stat) +/- 2.2 (syst)
Total eff	0.053 +/- 0.003	0.023 +/- 0.002
Luminosity, fb^{-1}	1026 +/- 62	1026 +/- 62
σ x BR, pb	4.40+/-0.30(stat)+/-0.28(syst)+/-0.26(lumi)	4.86+/-0.48(stat)+/-0.40(syst)+/-0.29(lumi)
NLO prediction:		
N (Zgamma)	228 +/- 16.9	99.1 +/- 9.8
σ x BR, pb	4.2 +/- 0.2	4.2 +/- 0.2

Cross-section Measurement (II)

- **We use the Best Linear Unbiased Estimate (BLUE) technique to combine central and central/forward cross-section measurements taking into account correlations between channels**

- **The combined cross-section is measured to be:**

$$\sigma \times Br(Z\gamma \rightarrow ee\gamma)_{\text{combined data}} = 4.51 \pm 0.37(\text{stat + syst}) \pm 0.27(\text{lumi})\ \text{pb}$$

$$\sigma \times Br(Z\gamma \rightarrow ee\gamma)_{\text{theory NLO}} = 4.2 \pm 0.2\ \text{pb}$$

Plans

- **Work on finalizing and combining the cross-section results in electron and muon channels, as well as setting limits on trilinear $ZZ\gamma$ and $Z\gamma\gamma$ anomalous couplings is almost done**

- **Preliminary version of the paper is ready, by the end of 2006 we will have the complete $Z\gamma$ paper ready for publishing**

- **We also hope to combine our results with the CDF results to increase the sensitivity to the anomalous couplings**

Results

- We presented $Z\gamma \rightarrow ee\gamma$ cross-section measurement for photon $p_T > 7$ GeV/c, separation from leptons $dR_{e\gamma} > 0.7$ and di-electron mass $M_{ee} > 30$ GeV/c^2 using 1 fb^{-1} of data:

$$\sigma \times BR(Z\gamma \rightarrow ee\gamma)_{data} = 4.51 \pm 0.37(stat+syst) \pm 0.27(lumi) \text{ pb}$$

- The measured cross-section agrees well within errors with the NLO SM prediction:

$$\sigma \times BR(Z\gamma \rightarrow ee\gamma)_{theory\ NLO} = 4.2 \pm 0.2 \text{ pb}$$

BACKUP SLIDES

Dataset

- **DØ Common Sample Group Dataset: 2EMhighpt (p17.09.01 and p17.09.03)**

- **Runs 166503 – 213063 (Oct. 2002 – Dec. 2005, v8-v14 trigger lists)**

- **We include runs that pass all data quality requirements**

Electron Selection Criteria

- **Electron candidates selection (from $Z \rightarrow ee$):**
  - pass unprescaled **single EM trigger**
  - **2 EM clusters with:**
    - $|ID| < 12$
    - isolation < 0.2
    - EMfraction > 0.9
    - $|\eta| < 1.1$ or $1.5 < |\eta| < 2.5$, at least one cluster must be in the Central Calorimeter
    - $p_T > 25(15)$ GeV/c
    - electron likelihood > 0.2
    - $M_{ee} > 30$ GeV/c^2

Photon Selection Criteria

- **Photon candidate(s) selection:**
  - **EM cluster with:**
    - |ID| < **12**
    - isolation < **0.07**
    - EMfraction > **0.96**
    - cluster must be in the Central Calorimeter (|η| < **1.1**)
    - p_T > **7** GeV/c
    - shower width at EM3 sigphi3 < **14** cm^2
    - separation from electrons dR > **0.7**
    - sum of track energies in hollow cone around the photon candidate trisoHC(0.05-0.4) < **1.5** GeV

Electron Efficiencies Table

$$\epsilon_{Tot} = Acc \times \epsilon_{Trig} \times \epsilon_{EM} \times \epsilon_{\gamma}$$

Requirement	Central Calorimeter	Central + Forward Calorimeter
Geom. Acc.	0.095 +/- 0.003	0.057 +/- 0.002
Trigger eff	0.99 +/- 0.01	0.99 +/- 0.01
Electron eff	0.734 +/- 0.020	0.553 +/- 0.030
Photon eff	0.762 +/- 0.043	0.742 +/- 0.042
Total eff	0.053 +/- 0.003	0.023 +/- 0.002
N (Zgamma)	256 +/- 16	131 +/- 11.4
N (QCD)	18.3 +/- 3.0(stat) +/- 2.9(syst)	14.8 +/- 2.5 (stat) +/- 2.2 (syst)
Luminosity, fb^{-1}	1026 +/- 62	1026 +/- 62
σ x BR, pb	4.40+/-0.30(stat)+/-0.28(syst)+/-0.26(lumi)	4.86+/-0.48(stat)+/-0.40(syst)+/-0.29(lumi)
NLO prediction:		
N (Zgamma)	228 +/- 16.9	99.1 +/- 9.8
σ x BR, pb	4.2 +/- 0.2	4.2 +/- 0.2

More on BLUE Technique

- **Uncertainty components summary Table for the BLUE technique:**

Parameter	Central Cal. Error	Central/Forward Cal. Error	Correlation, %
Eff_{CC} electron	0.1199	0.1324	100
$Eff_{EC/CC}$ electron	0.1199	0.2637	--
Eff photon	0.1444	0.1637	100
Acceptance	0.1389	0.1609	--
Eff trigger	0.0444	0.0491	100
Background	0.0772	0.1393	100
Signal events	0.2962	0.4768	--
Total syst uncert.	0.2772	0.4019	
Total stat uncert.	0.2962	0.4768	
Total uncertainty	0.4056	0.6236	