Physics with Single Photon plus Missing Energy Final States at DØ

Lake Louise Winter Institute 2009

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for the DØ collaboration

Outline

- Introduction
- The DØ detector and photon identification
- Non-collision background and the EM pointing algorithm
- Single photon selection and background estimation
- Results/Summary

New Physics Needed

we look for hints of new physics by studying:

Electroweak Force
(Zγ production)

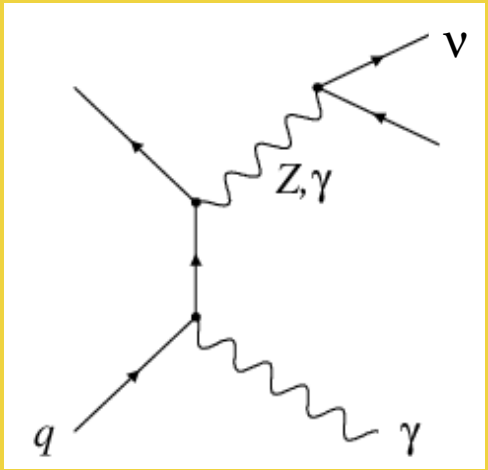
Gravitational Force
(LED)

$$q\,\bar{q} \rightarrow \gamma + \mathrm{MET}$$

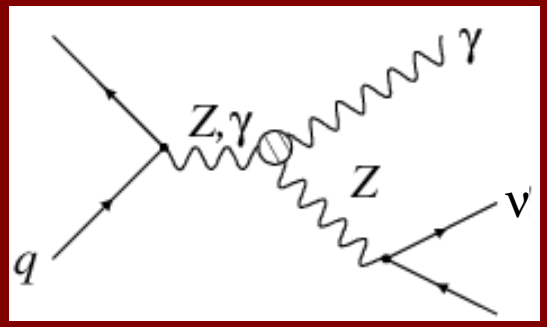
Clean signal, small QCD background, larger branching fraction (neutrinos) in case of Zγ

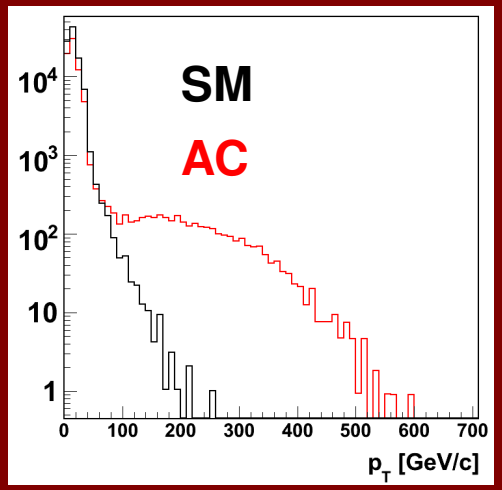
$Z\gamma \rightarrow \nu\bar{\nu}\gamma$ Production and Trilinear Anomalous Couplings (AC)

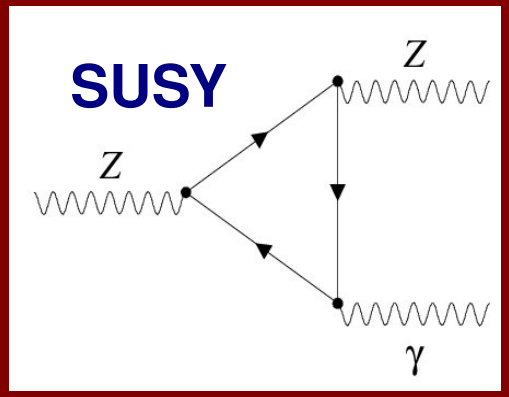
Standard Model



- Only contribution at tree level
- QED corrections at the 10^{-4} level







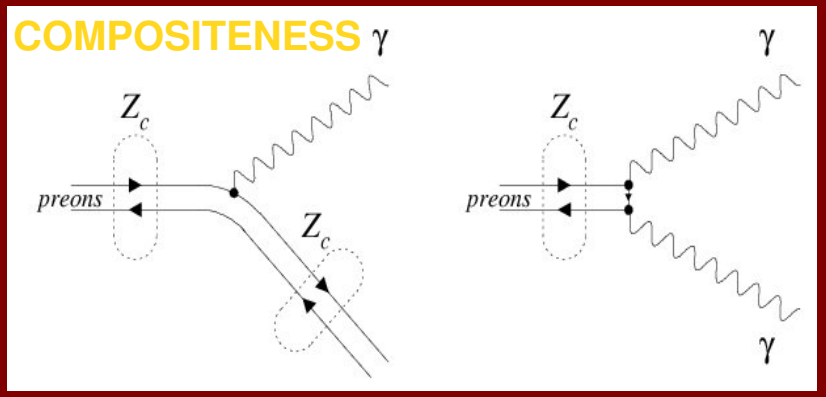
Beyond the Standard Model

ZZγ and **Zγγ** couplings can be parameterized by 8 form factors:

$$h_i^{Z,\gamma} = \frac{h_{i0}^{Z,\gamma}}{(1+\hat{s}/\Lambda^2)^n}$$

→ Low energy approx

Λ is the energy scale for new physics, we choose $n = 3$ for $h_{1,3}^{Z,\gamma}$ and $n = 4$ for $h_{2,4}^{Z,\gamma}$, which satisfy unitarity conditions. $\hat{s}$ is the square of the parton center of mass energy.



Large Extra Dimensions

- m_{EW} the only fundamental scale in nature.

- n large extra spatial dimensions (LED).
  - **large compared to the electroweak scale**
  - gravity is diluted in extra volume
  - SM particles bound to the 3D brane

- Large size of the extra volume R^n conceals the true (rather small) size of the fundamental Planck scale M_D (4+n D), the result: a large effective Planck scale M_{Pl} (4 D).

- **Hierarchy (fine tuning) problem is solved**,

- Constraints from astrophysics, cosmology, and table-top experiments (dark energy length scale!!) rule out n = 2.

$$M_{Pl} \sim G_N^{-1/2} \sim 10^{19}\,\text{GeV}$$

Planck scale

Great jump in energy
HIERARCHY PROBLEM

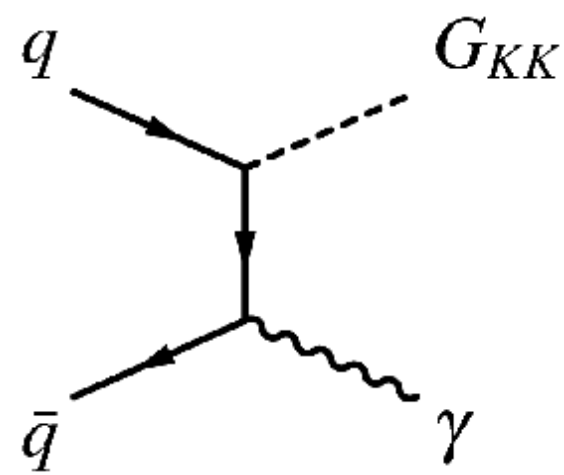
$$m_{EW} \sim 10^{3}\,\text{GeV}$$

Electroweak scale

$$M_{Pl}^2 = 8\pi\, M_D^{n+2} R^n$$

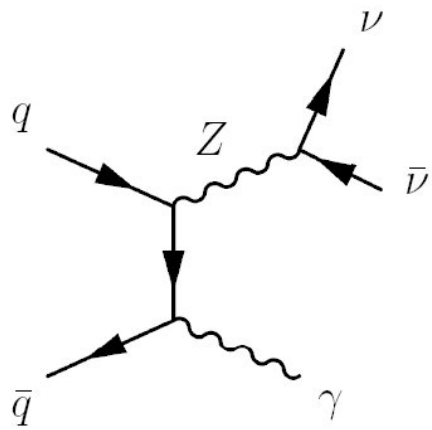
EW distance scale:

$$1\ \text{TeV}^{-1} \approx 10^{-19}\ \text{m}$$



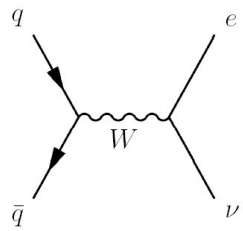
Backgrounds:Electroweak Boson Production

$Z+\gamma \rightarrow \nu\bar{\nu}+\gamma$



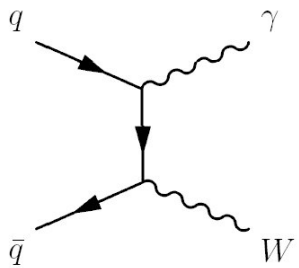
Signal for the Zγ and AC analysis. Irreducible physics **background for the LED analysis.**

$W \rightarrow e\nu$



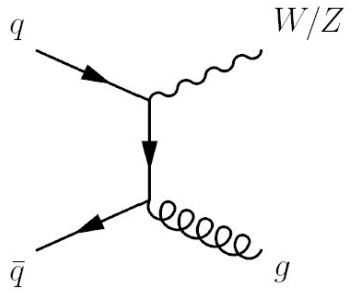
The electron is misidentified as a photon due to tracking inefficiency or hard bremsstrahlung.

$W+\gamma \rightarrow l\nu+\gamma$



The charged lepton from a leptonic W boson decay is not detected.

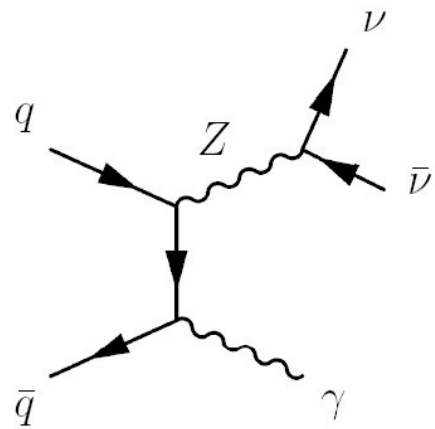
$W/Z+\text{jet}$



The jet is misidentified as a photon.

Backgrounds:Electroweak Boson Production

$Z+\gamma \rightarrow \nu\,\bar{\nu}+\gamma$

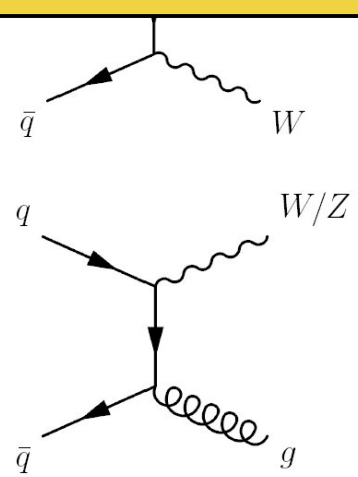


Signal for the Zγ and AC analysis. Irreducible physics **background for the LED analysis.**

Plus large background from **cosmic ray muons** and **particles from beam halo** depositing energy in the calorimeter.

$W \rightarrow e$ … tified as a … inefficiency … .

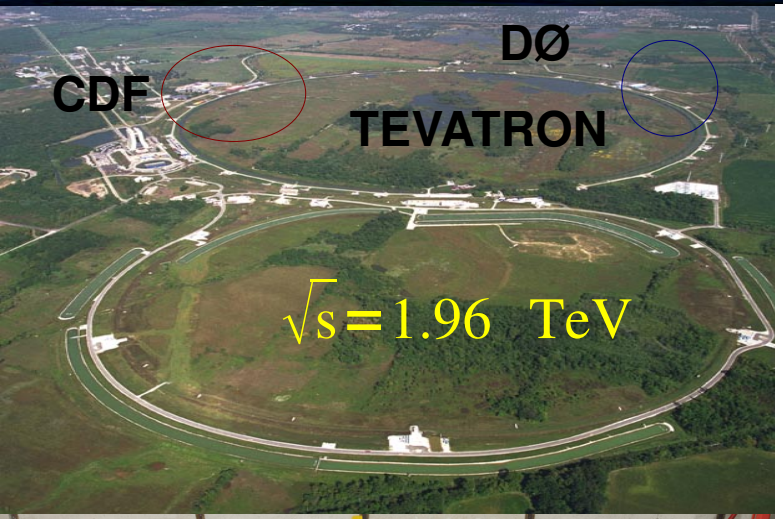
$W+\gamma \rightarrow l$ … m a leptonic W boson decay is not detected.

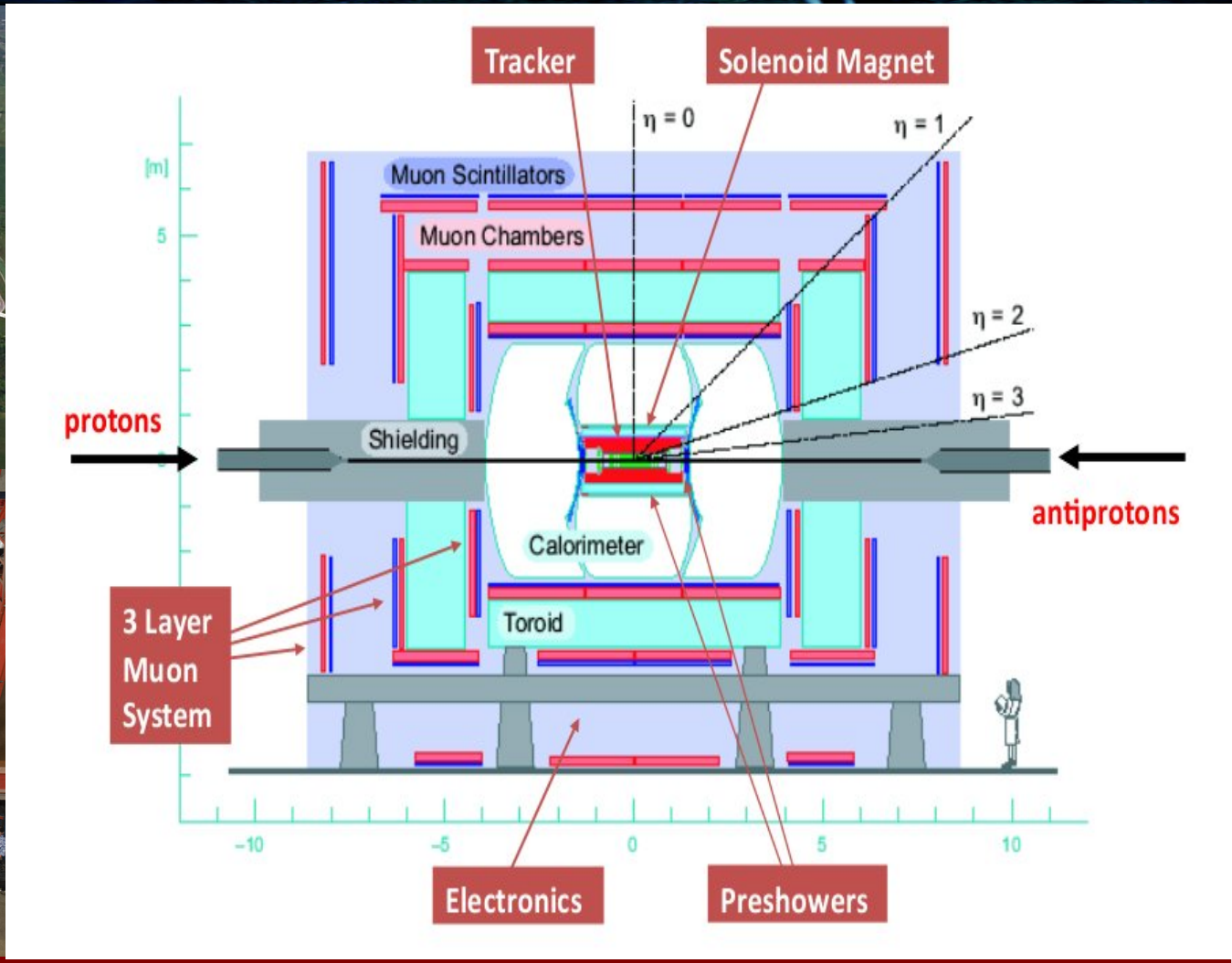


$W/Z+$ jet

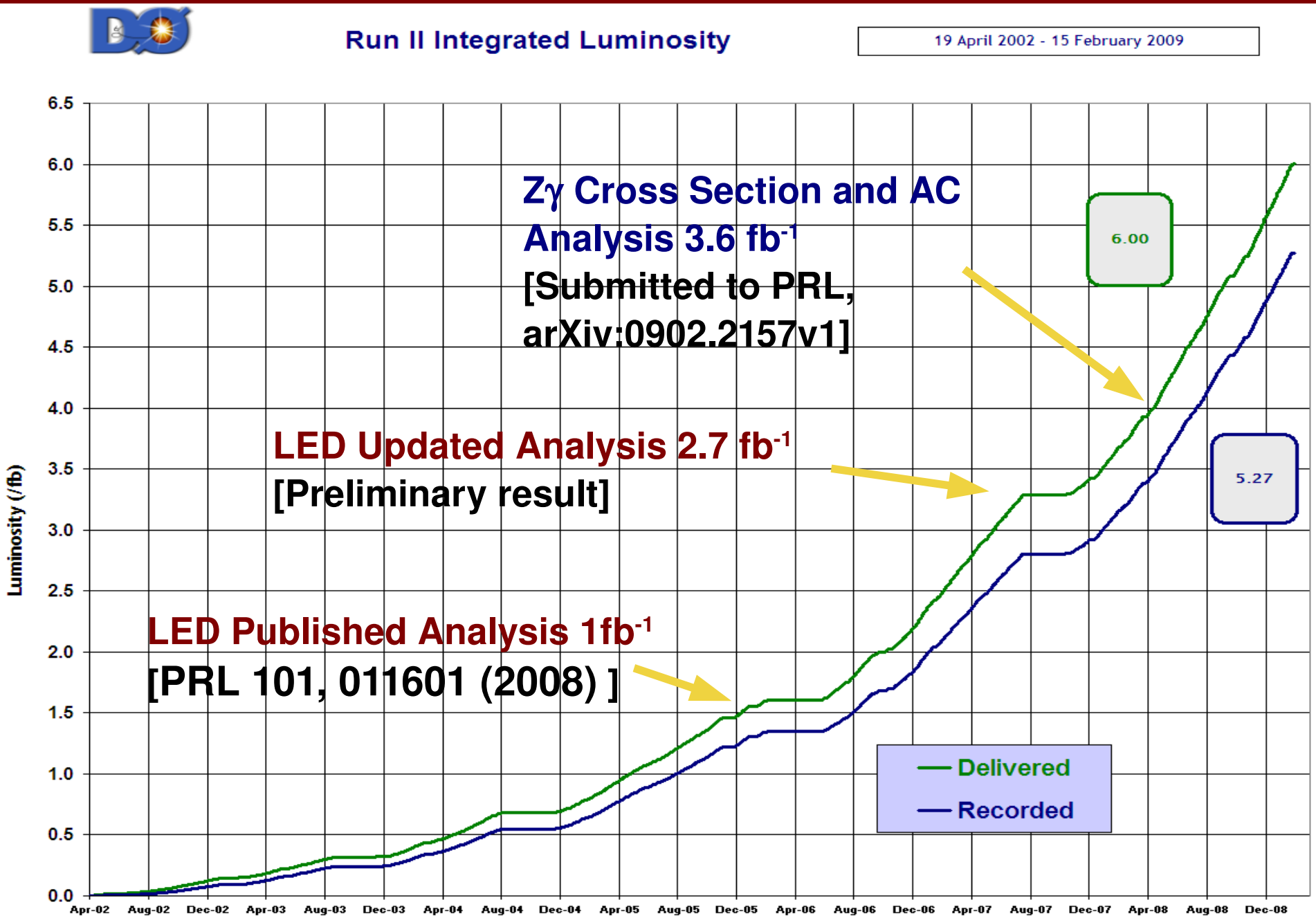
The jet is misidentified as a photon.

The Apparatus: DØ Detector at the Tevatron



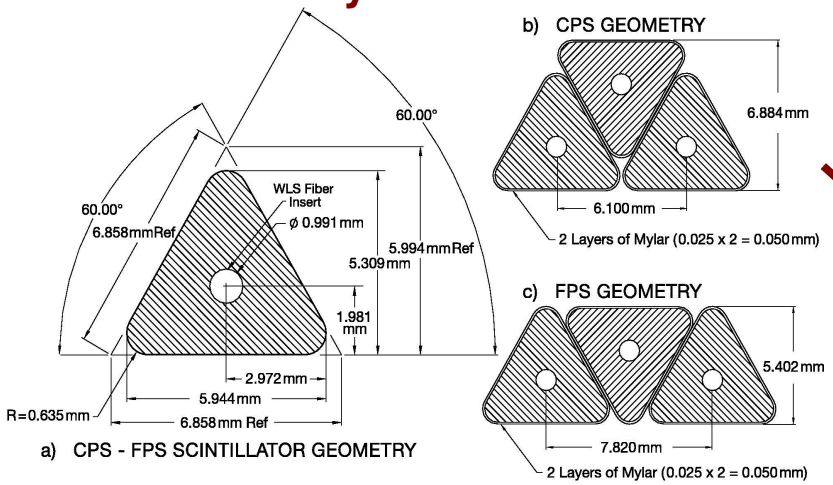


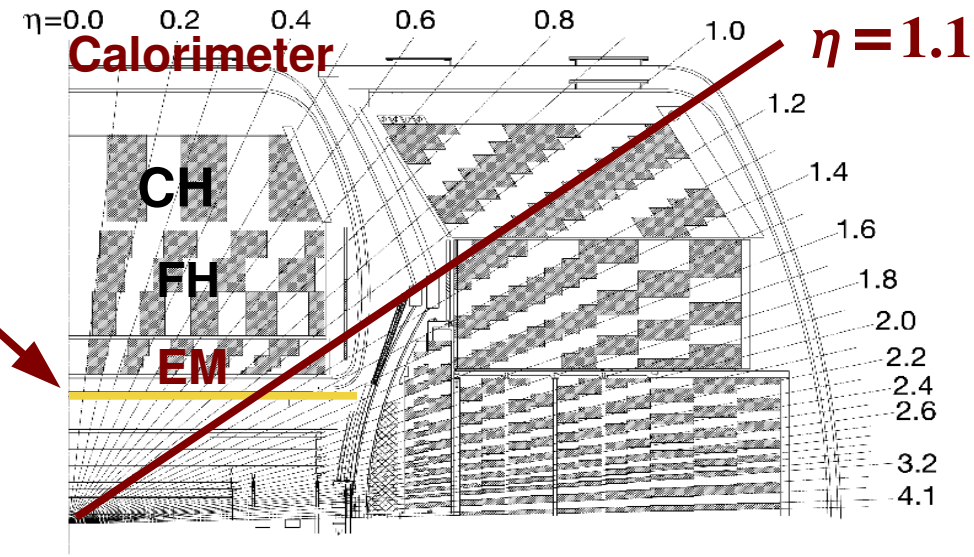
Data Taken at DØ



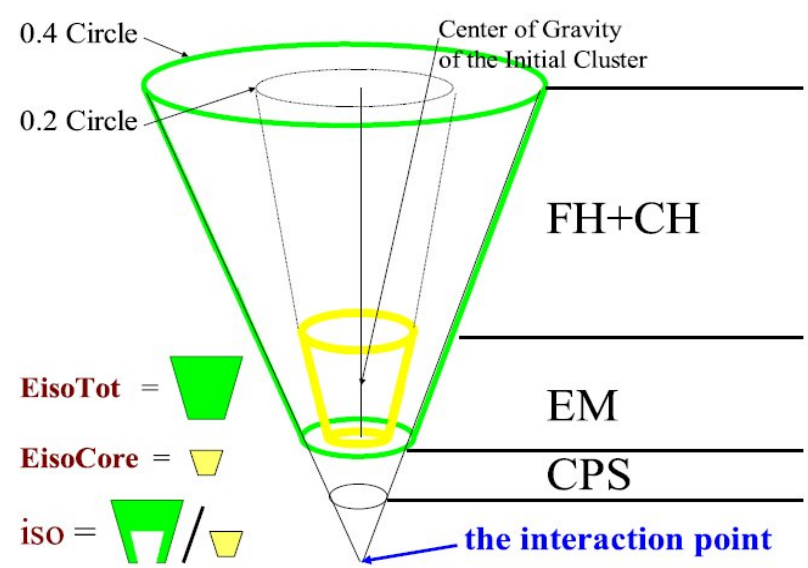
Photon Identification

Preshower System





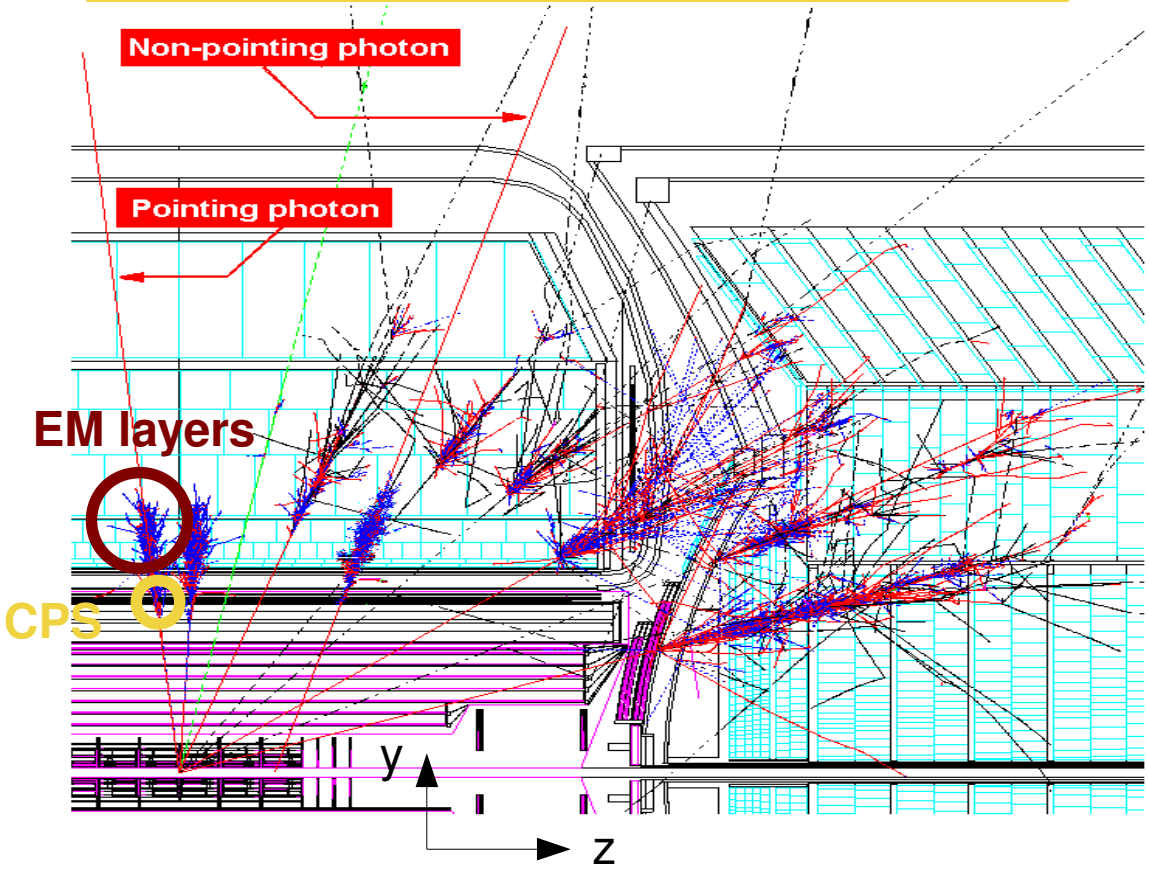
- ➲ Photons are identified as narrow deposits of energy, mainly in the electromagnetic part of calorimeter.
- ➲ Are isolated in the calorimeter and in the tracker.
- ➲ Photons do not leave tracks. We make sure there are no tracks associated with them.
- ➲ Matched to a central preshower (CPS) cluster, which improves position and energy determination.



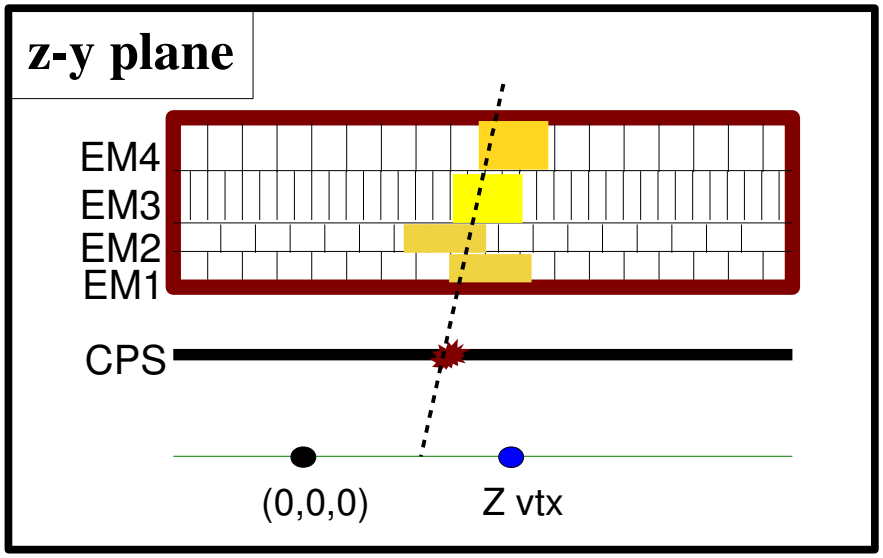
Calorimeter Cluster Isolation

Electromagnetic (EM) Cluster Pointing Algorithm

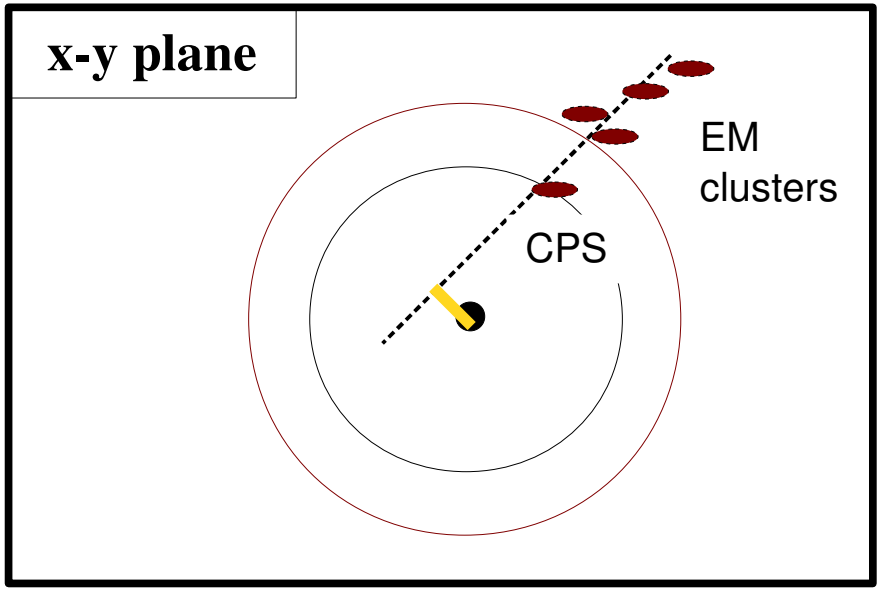
- EM cluster pointing algorithm calculates the direction of the EM shower.
- It is based solely on the central preshower (CPS) and EM calorimeter clusters.
- Energy-weighted centroid coordinates at each layer in the EM calorimeter are calculated.



Prediction of interaction vertex z-position



Distance of closest approach (DCA)

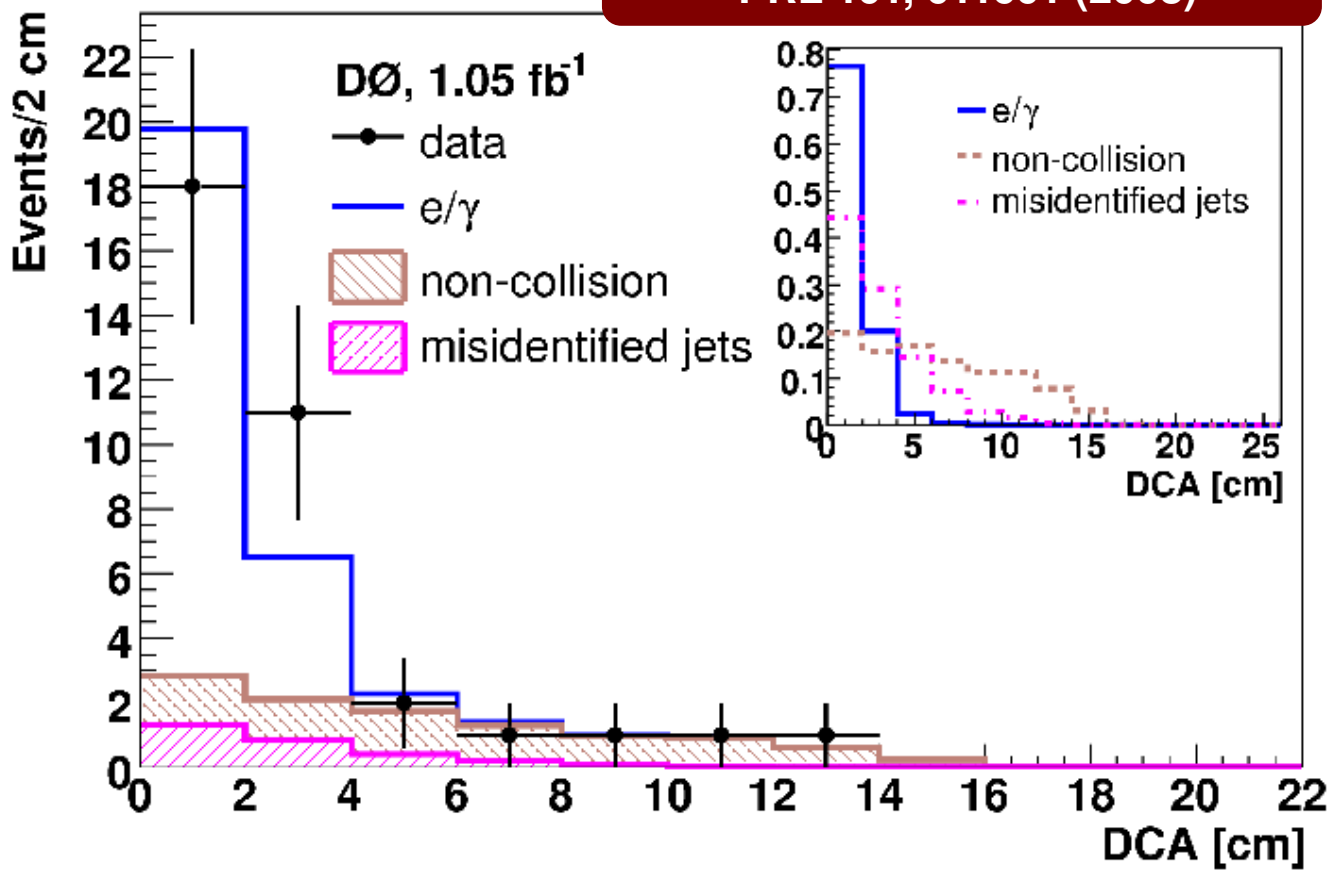


The Photon Sample and DCA Template Fit

Photon selection:

- ➲ pT > 90 GeV
- ➲ MET > 70 GeV, to guarantee no multijet background.
- ➲ No jets with pT > 15 GeV to avoid large MET due to mismeasurement of jet energy.
- ➲ No muons and no energetic tracks in the event.
- ➲ Some differences in the efficiency of selection requirements between analyses.

PRL 101, 011601 (2008)



We fit the DCA distribution in the photon sample to a linear sum of the three templates

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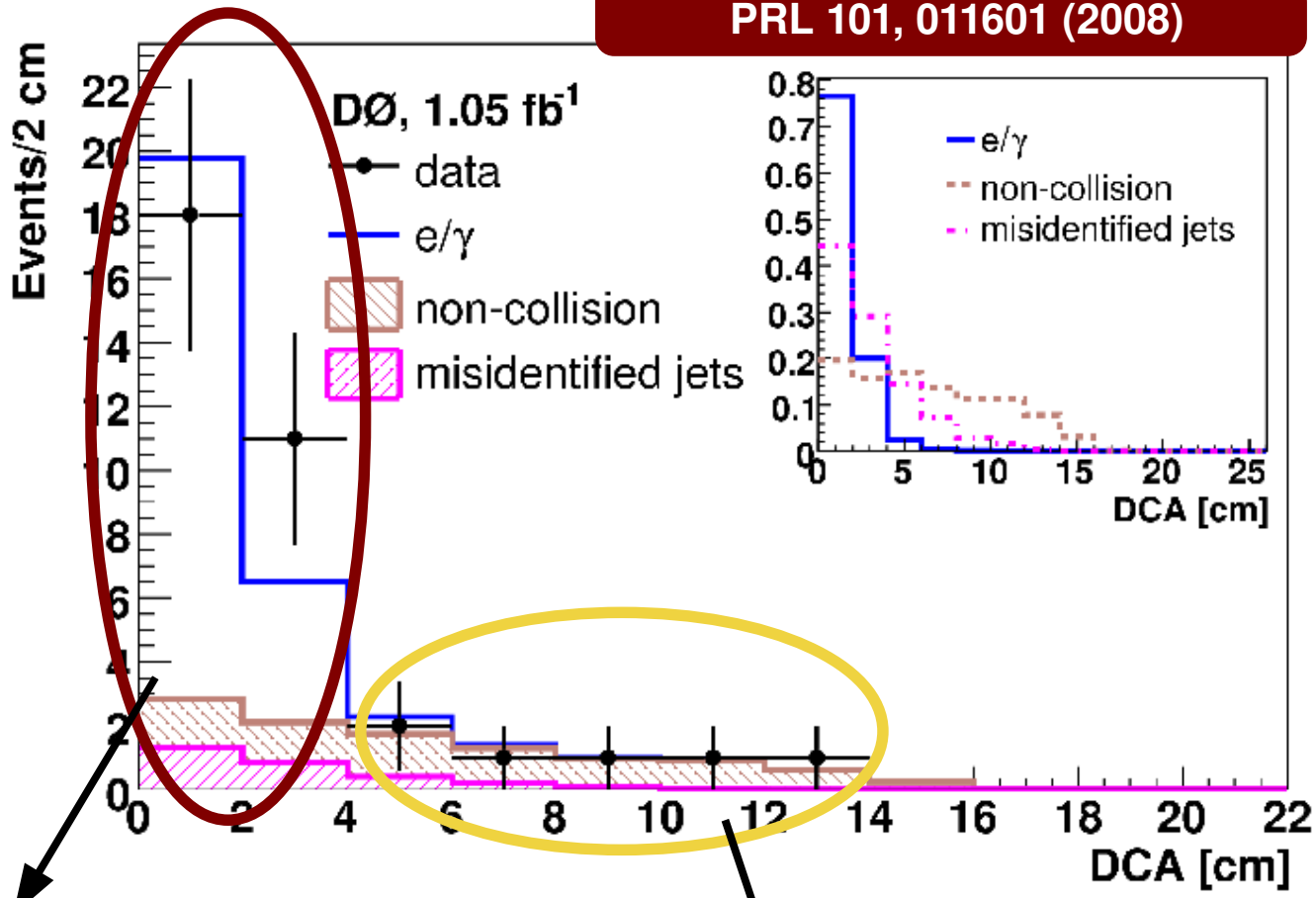


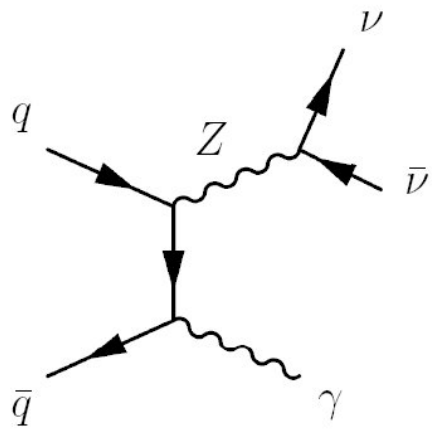
Most of signal-like events concentrated in this region (e/gamma) events + EM jets.

We fit the DCA distribution in the photon sample to a linear sum of the three templates

Non-collision events + some misidentified jets

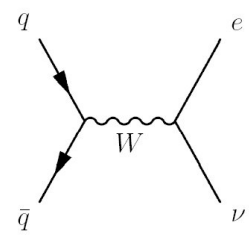
Estimation of Remaining Backgrounds

$Z+\gamma \rightarrow \nu\bar{\nu}+\gamma$



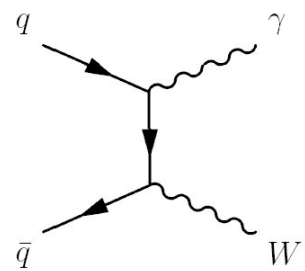
➲ Estimated from a sample of Monte Carlo events generated with PYTHIA.

$W \rightarrow e\nu$



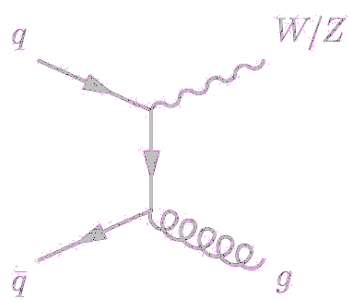
➲ Estimated from a sample of isolated electrons from data and the measured rate of electron-photon mis-identification

$W+\gamma \rightarrow l\nu+\gamma$



➲ Estimated from a sample of Monte Carlo events generated with PYTHIA.

W/Z + jet



Estimated from DCA fit

$Z\gamma \rightarrow \nu\bar{\nu}\gamma$ Production Cross Section

3.6 fb^{-1} of data, $\epsilon_{\nu\bar{\nu}\gamma} \sim 25\%$	
Background	**Number of events**
W → eν	9.67 ± 0.30 (stat) ± 0.30 (syst)
non-collision	5.33 ± 0.39 (stat) ± 1.91 (syst)
W/Z + jet	1.37 ± 0.26 (stat) ± 0.91 (syst)
W + γ	0.90 ± 0.07 (stat) ± 0.12 (syst)
Total Background	**17.3 ± 0.6 (stat) ± 2.3(syst)**
Data Candidates	**51**
SM Predicted	**33.7 ± 3.4**

$$\sigma \cdot \mathrm{Br} = \frac{N_{cand} - N_{bkg}}{\epsilon_{\nu\bar{\nu}\gamma} \cdot \int L \cdot dt}$$

- Perform 10^8 pseudo-experiments to test the background only hypothesis.
- Calculate the probability of estimated background fluctuating to the number of observed events

Measured cross section x Br:

32 ± 9 (stat+sys) ± 2 (lum) fb

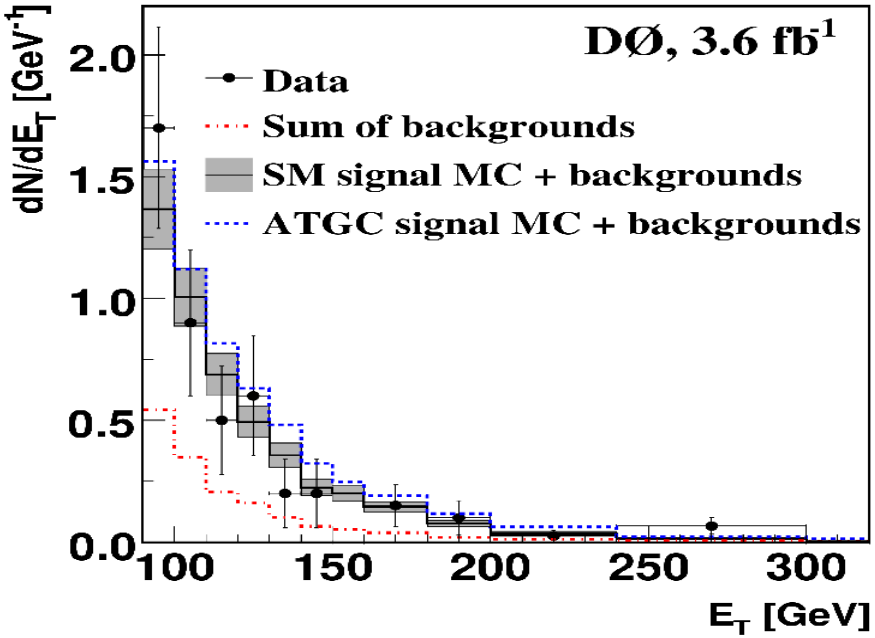
SM NLO cross section x Br:

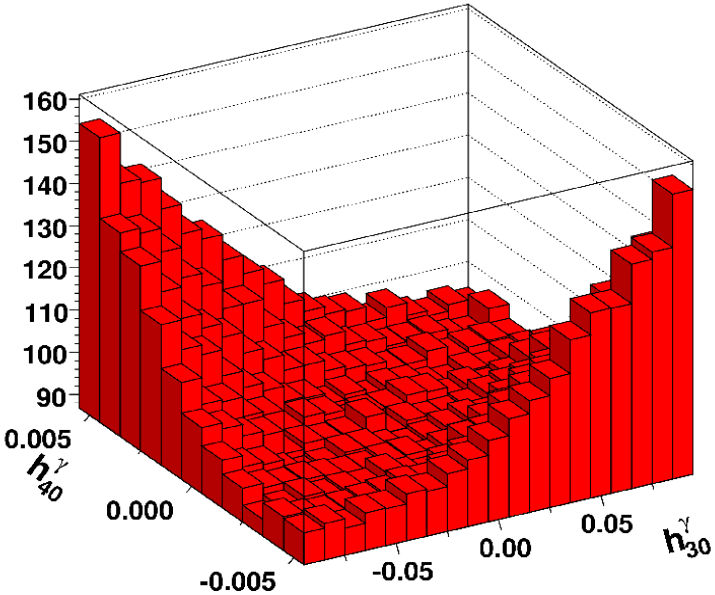
39 ± 4 fb

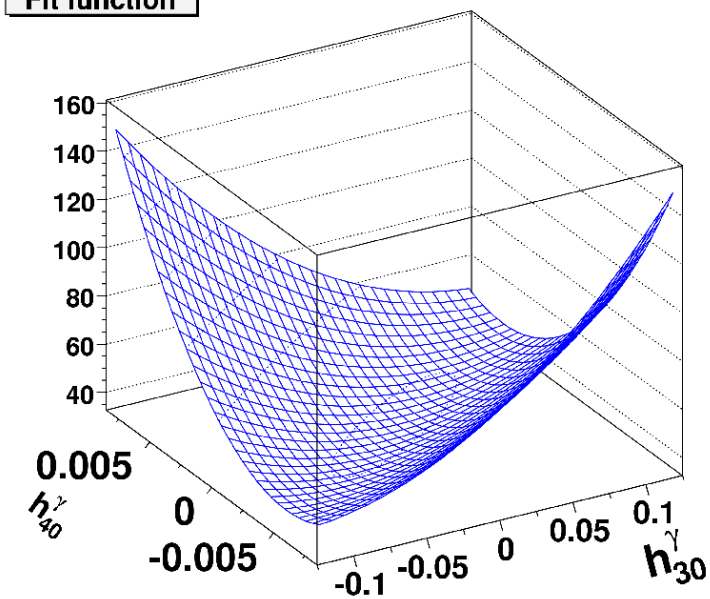
Probability = 3.1 x 10^{-7} or 5.1σ

First observation of $Z\gamma \rightarrow \nu\bar{\nu}\gamma$ production at the Tevatron!!!!

Limits on Anomalous Couplings







- Generate **2D grid** of Zγ events with non zero values of $h_{30}^{Z,\gamma}$ and $h_{40}^{Z,\gamma}$.
- For each pair of $h_{30,40}^{Z,\gamma}$ **calculate the likelihood** at each point between data E_T spectrum and simulation + background to estimate result of the fit.
- Measure 95% C.L. limits by setting other couplings to zero.

Limits on Anomalous Couplings

In a previous DØ publication [**PLB 653 (2007)**] :

electron + muon channel, Λ = 1.2 TeV, 1 fb^{-1}	
$Z\gamma\gamma$	$\lvert h_{30}\rvert < 0.085$, $\lvert h_{40}\rvert < 0.0054$
$ZZ\gamma$	$\lvert h_{30}\rvert < 0.083$, $\lvert h_{40}\rvert < 0.0054$

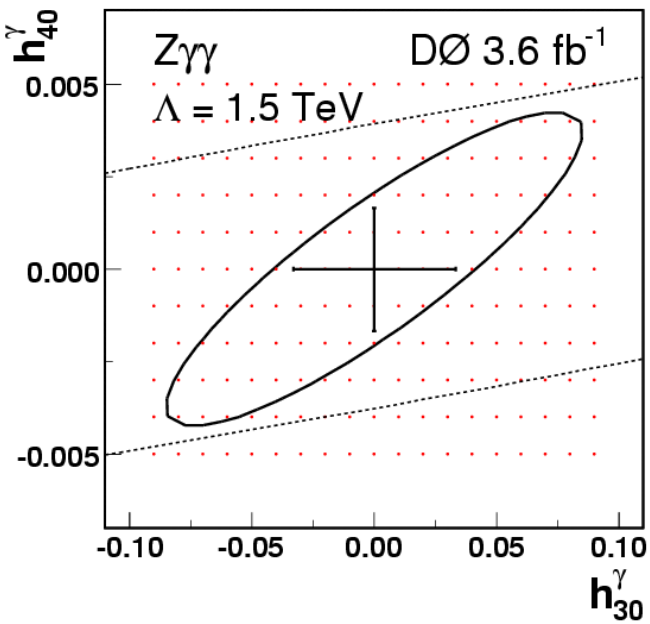
This analysis, neutrino channel only:

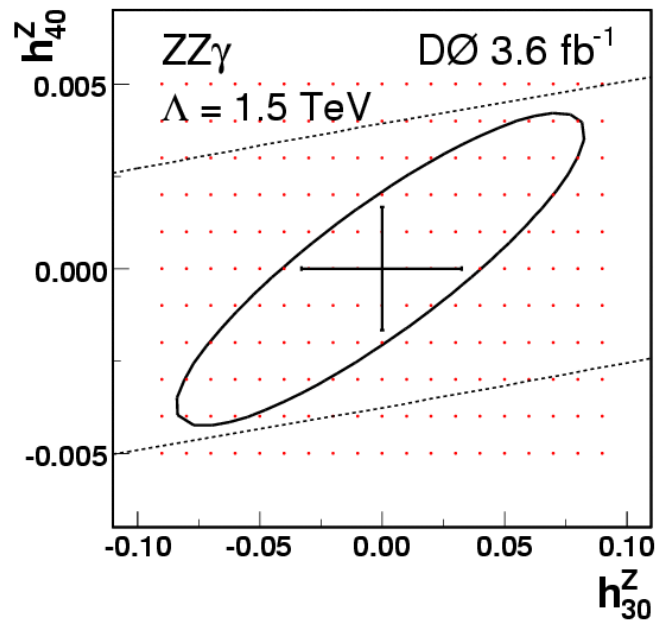
neutrino channel, Λ = 1.5 TeV, 3.6 fb^{-1}	
$Z\gamma\gamma$	$\lvert h_{30}\rvert < 0.037$, $\lvert h_{40}\rvert < 0.0020$
$ZZ\gamma$	$\lvert h_{30}\rvert < 0.036$, $\lvert h_{40}\rvert < 0.0020$

Combination:

neutrino + elect. + muon, Λ = 1.5 TeV	
$Z\gamma\gamma$	**$\lvert h_{30}\rvert < 0.033$, $\lvert h_{40}\rvert < 0.0017$**
$ZZ\gamma$	**$\lvert h_{30}\rvert < 0.033$, $\lvert h_{40}\rvert < 0.0017$**

h_{30}^{Z}, h_{40}^{Z}, and h_{40}^{γ} improve on the LEP2 constraints. They are the most restrictive to date!!!

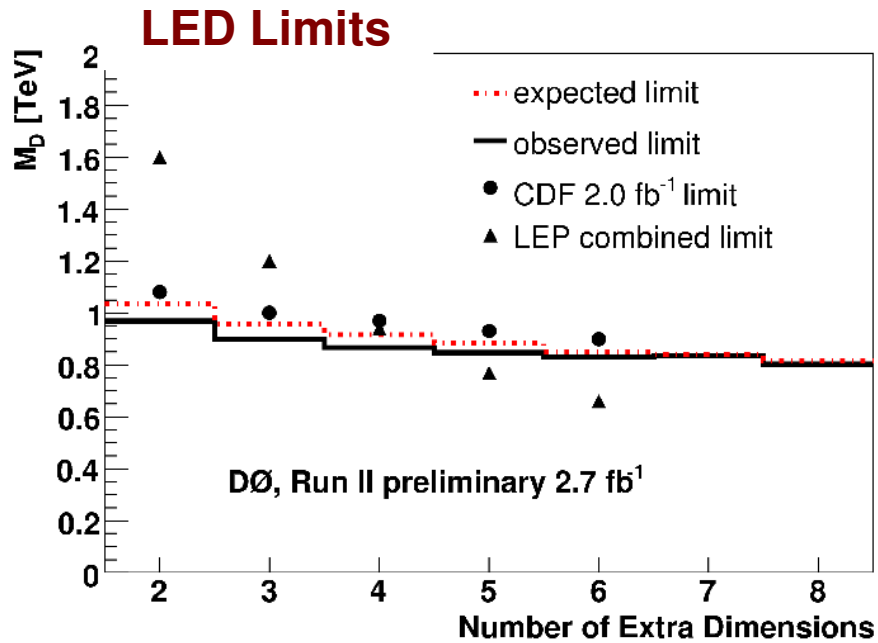


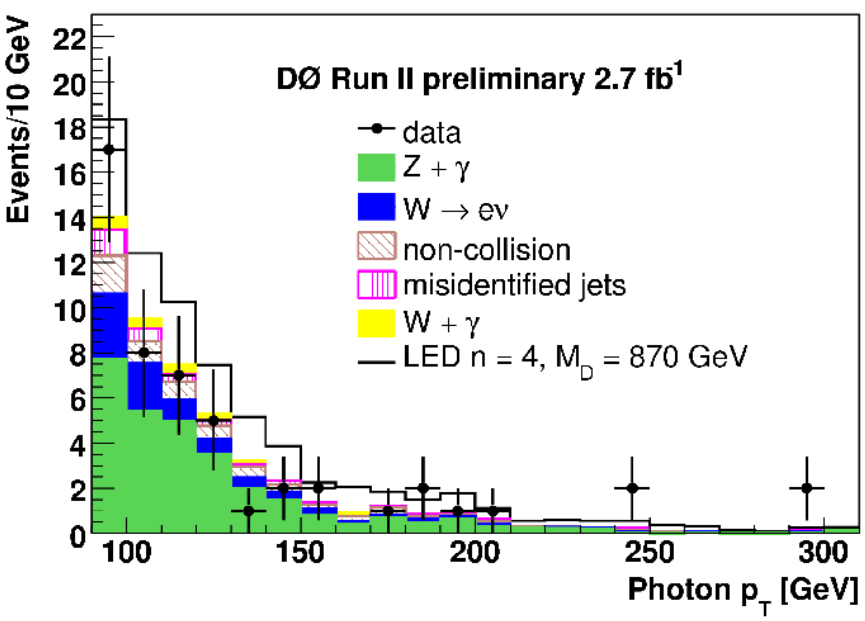


COMBINED

LED Results and Limits on M_D

2.7 fb^{-1} of data	
Background	**Number of events**
$Z + \gamma$	29.5 ± 2.5
$W \rightarrow e\nu$	8.5 ± 1.7
non-collision	6.6 ± 2.3
mis-id jets	3.1 ± 1.5
$W + \gamma$	2.22 ± 0.3
Total Background	**49.9 ± 4.1**
Data Candidates	**51**





n	Observed (expected) cross section limit (fb)	Observed (expected) M_D lower limit (GeV)
2	19.0 (14.6)	970 (1037)
3	20.1 (14.7)	899 (957)
4	20.1 (14.9)	867 (916)
5	19.9 (15.0)	848 (883)
6	18.2 (15.2)	831 (850)
7	15.9 (14.9)	834 (841)
8	17.3 (15.0)	804 (816)

Summary and Conclusions

- We tested the strength of the electroweak force and searched for KK gravitons leaking to large extra dimensions in the hope to find hints of new physics.

- We observed the production of $Z\gamma \rightarrow \nu\bar{\nu}\gamma$ process for the first time at the Tevatron (arXiv:0902.2157v1).

- No physics beyond the Standard Model from studying Zγ production. We set limits on the form factors for the trilinear anomalous couplings ZZγ and Zγγ, which are the best at hadron colliders. Three out of four improve on constraints set by LEP2 (arXiv:0902.2157v1).

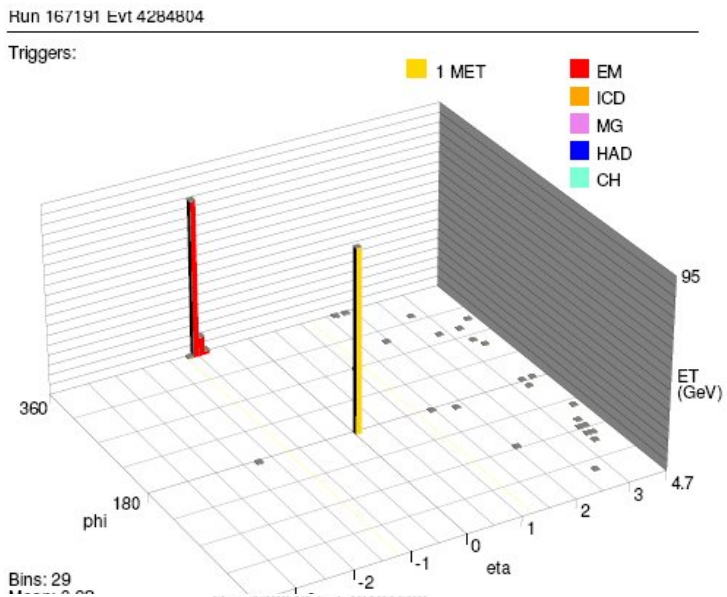
- No evidence for the presence of LED has been found up to ~ 1 TeV. We set limits on the fundamental Planck scale.

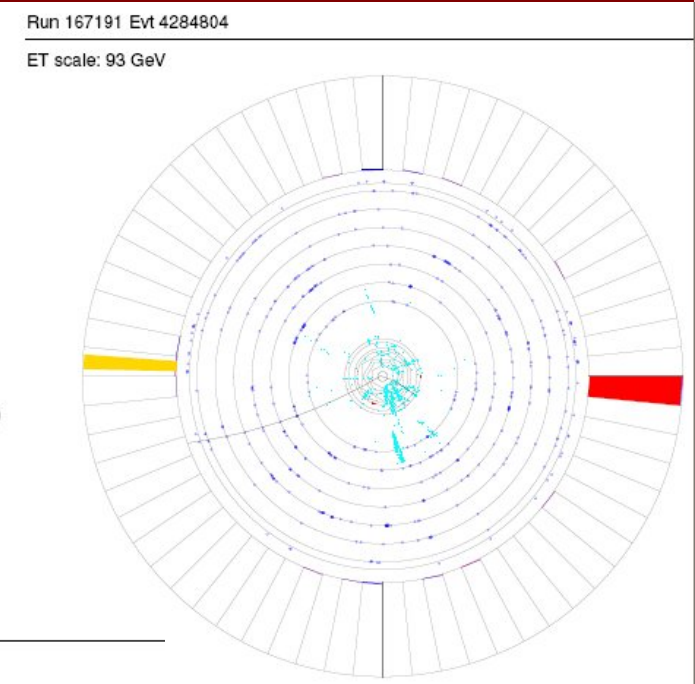
Backup Slides

Backup Slides

Non-collision: Beam Halo and Cosmic Rays

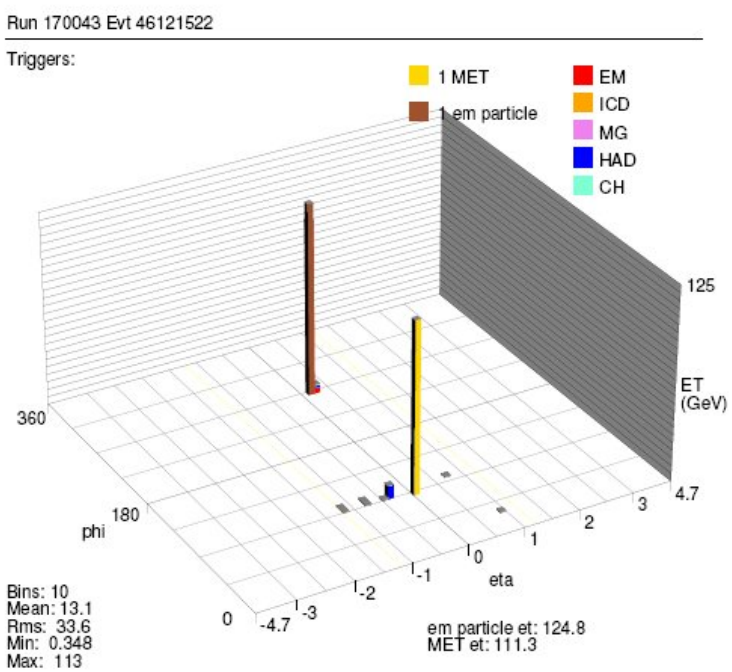
Beam Halo



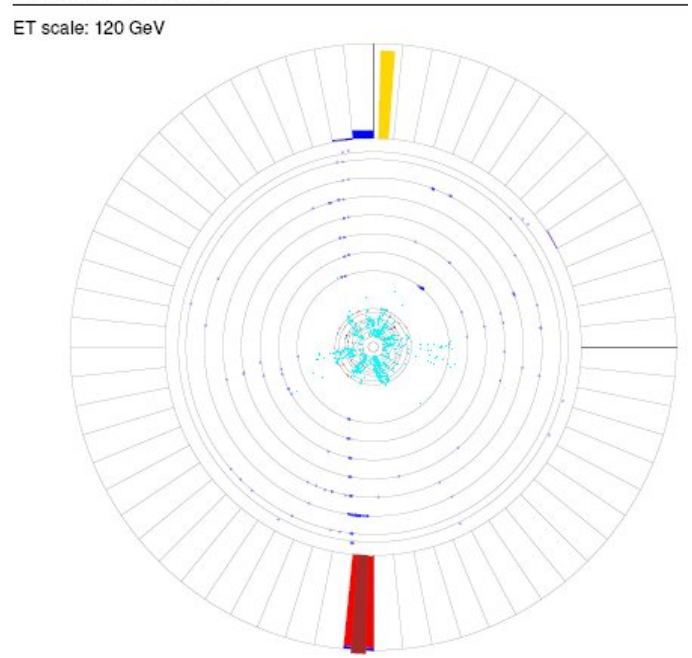


(b) $x - y$ view

Cosmic rays



(a) $\eta - \phi$ lego plot



(b) $x - y$ view