# W and Z Measurements with Initial CMS Data

IoP HEPP Meeting 2008

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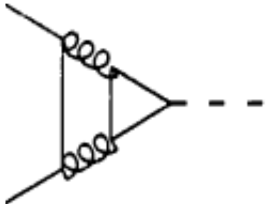
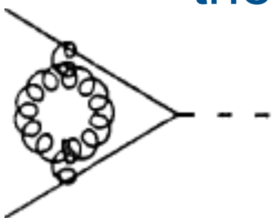
# Overview

- Motivation for measurements of W and Z using leptons
- The CMS detector
- Electron reconstruction
- Selections of $W \rightarrow e\nu$ and $Z \rightarrow ee$
- Measuring efficiencies using Tag and Probe
- Estimating background from data
- The cross-section measurement
- Summary

# W and Z : Motivation



- W and Z production well-understood theoretically
  - Except for PDF uncertainties, radiative corrections
- Ratios of cross-sections can
  - Provide precision test of standard model
  - Provide information on PDF parameterisations
- Production of W and Z have large cross-sections at LHC : ~190 nb and ~60 nb respectively
  - 10pb$^{-1}$ sufficient for a significant analysis
- Well isolated leptons with high transverse momenta
  - Distinctive in hadron collisions and readily triggered
- Measurements of W and Z production cross-sections and decays to leptons useful for our understanding of the CMS detector



# Philosophy of Analyses

- Focus on early data-taking period ($\int L dt = 10 pb^{-1}$)
- W and Z measurements will be among the first results from CMS
- The detector will be imperfectly understood
  - The analyses are designed to be insensitive to this
  - Used events fully simulated to represent a misaligned and miscalibrated detector
- Data-driven methods used where possible, rather than relying on Monte Carlo

# CMS Detector

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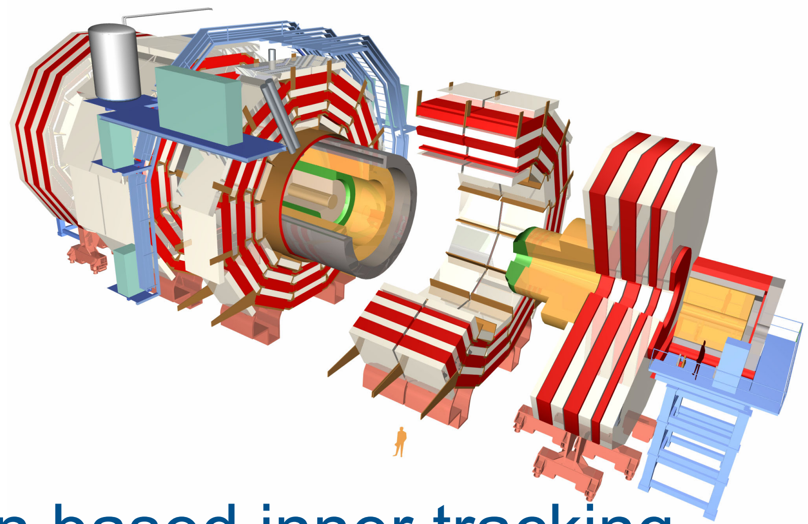
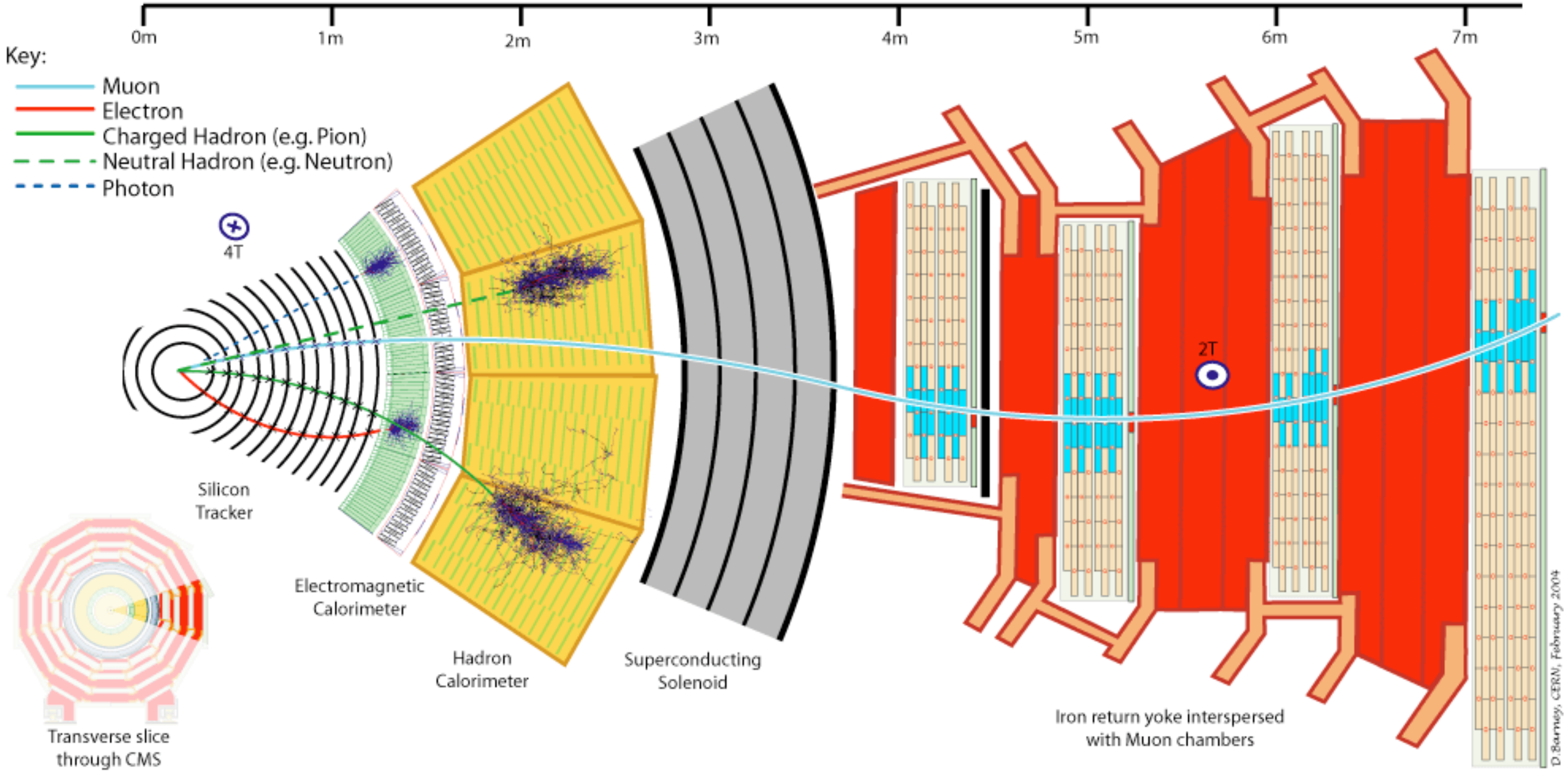
- CMS is optimised for a wide range of physics at LHC
  - 4T large radius solenoid



- Large, fine-grained, silicon based inner tracking
- Hermetic, fully active, $PbWO_4$ crystal electromagnetic calorimeter (ECAL) within the solenoid
- Level 1 trigger system hardware based
- High Level Trigger (HLT) software on commodity PCs

# Electron Objects

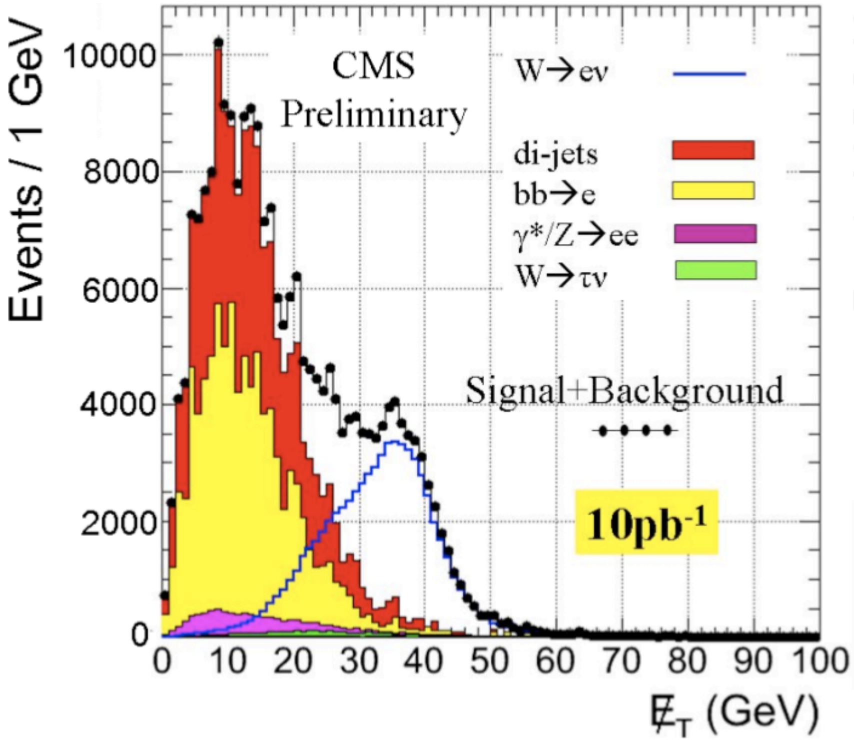



- For this analysis, electrons (ECAL 'supercluster' + track) must
  - Have supercluster, $E_T$ > 20 GeV in ECAL fiducial region
  - Pass track isolation
  - Pass electron identification criteria : cluster shape properties and track-supercluster matching

# Robust Selections

**W→eν selection :**

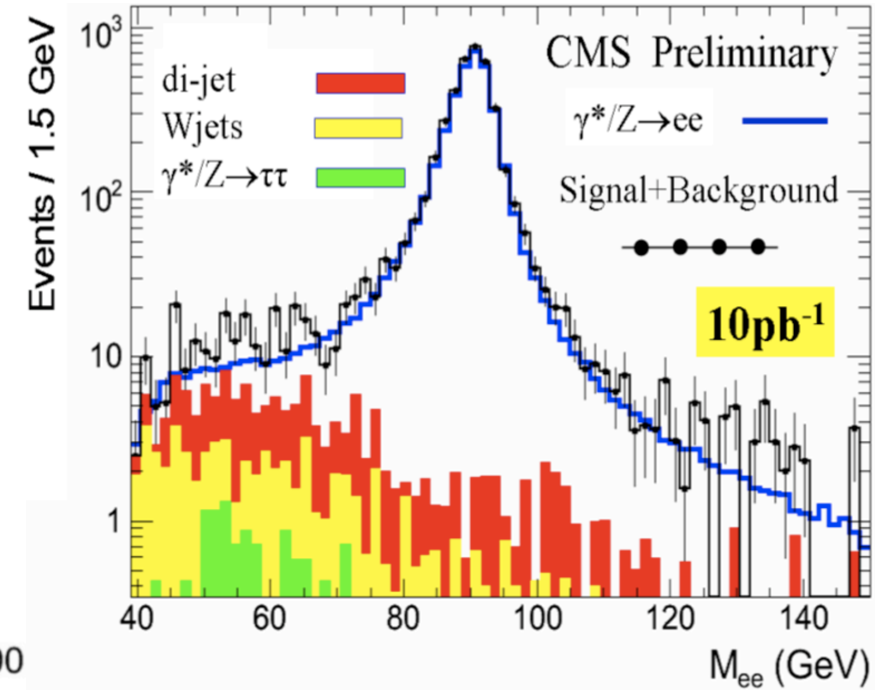
- **Pass single electron HLT path**
- **≥1 selected electron**




**Missing transverse energy after selection**

**Z→ee selection :**

- **Pass single electron HLT path**
- **≥2 selected electrons**




**Invariant mass after selection**

# Efficiencies – Tag and Probe

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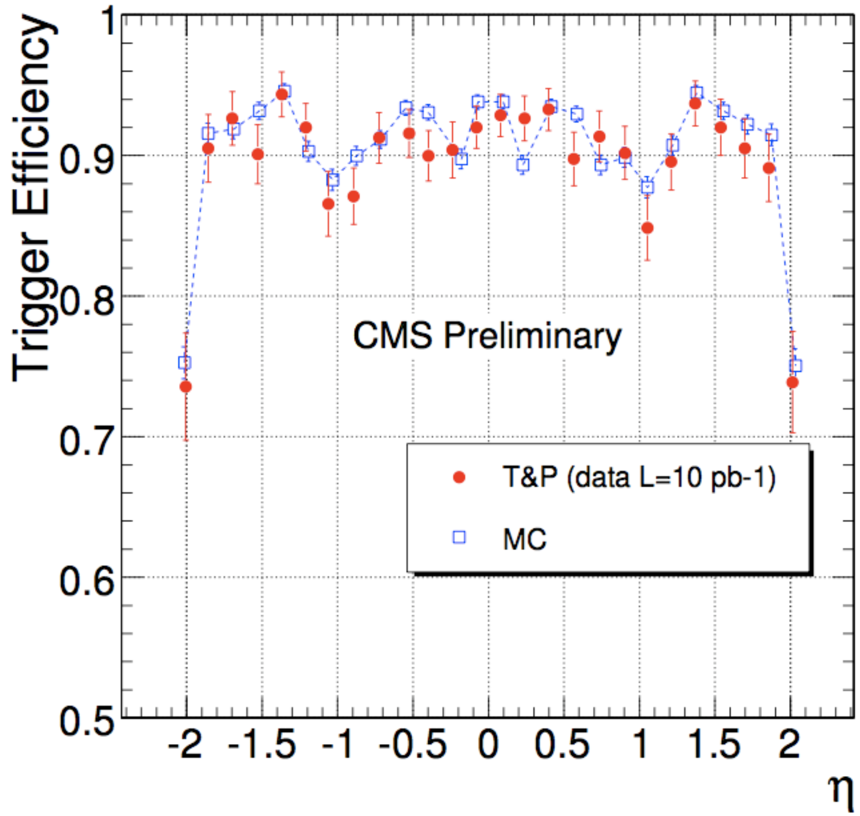
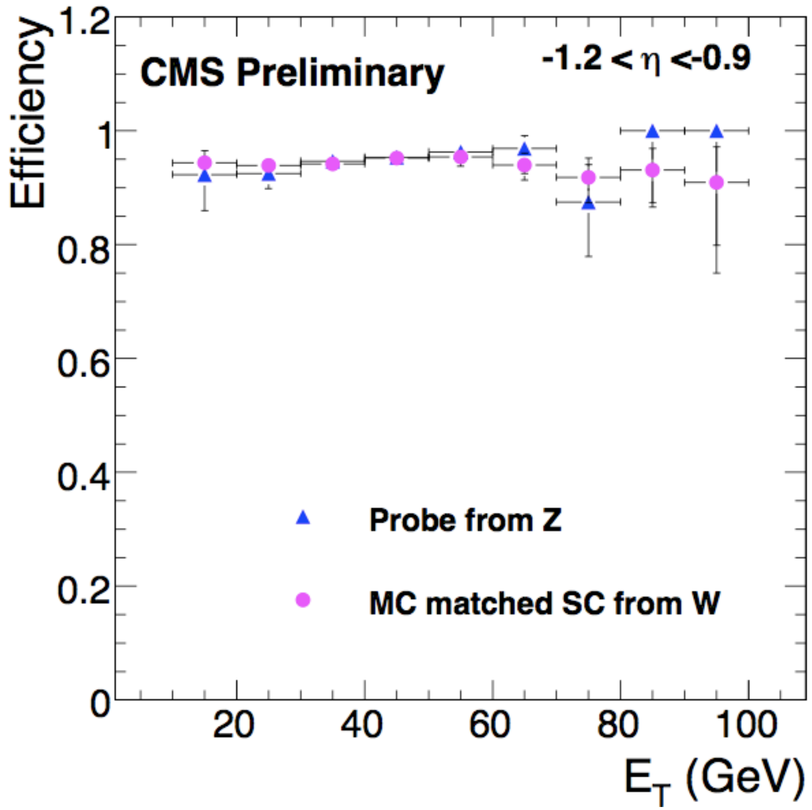
- Trigger, reconstruction and selection measured from data by the "Tag and Probe" method
- An unbiased and pure sample of leptons is selected from $Z \rightarrow ll$ events (single lepton trigger used)
  - One lepton has tight criteria imposed on it, "**tagging**" the event – it must be able to pass the trigger
  - The **probe** need satisfy only very loose criteria, ensuring an unbiased sample
  - An invariant mass cut on the **tag-probe** pair ensures the purity of the **probe** sample
- The **probe** sample then used to determine efficiencies

# Efficiencies - Example



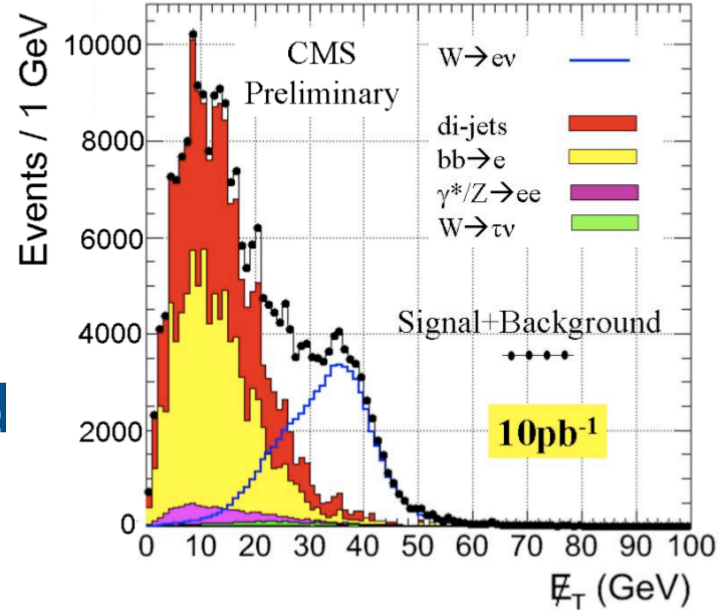

**Single muon trigger efficiency for muons with $p_T$ > 20 GeV, in selected $Z \rightarrow \mu\mu$ events**




**Supercluster-Track matching efficiency for superclusters in ECAL fiducial region and $E_T$ > 20 GeV**

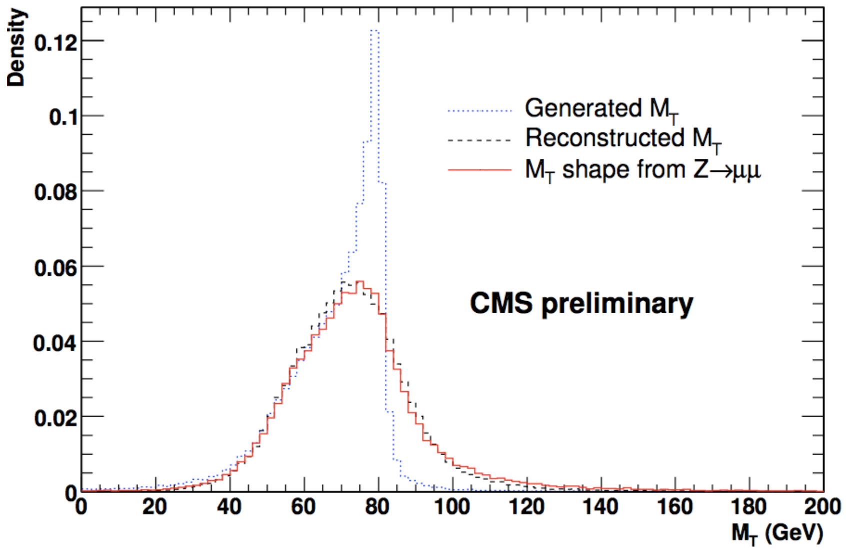
# W Background Estimation I

- Small electroweak backgrounds can be reliably estimated from simulation
- QCD backgrounds much larger and are difficult to simulate : must be determined from data
  - One jet may fake an electron; missing $E_T$ arises from badly measured energy
  - b decays are source of real electrons
- Two data-driven techniques explored – "Template" and "Matrix"

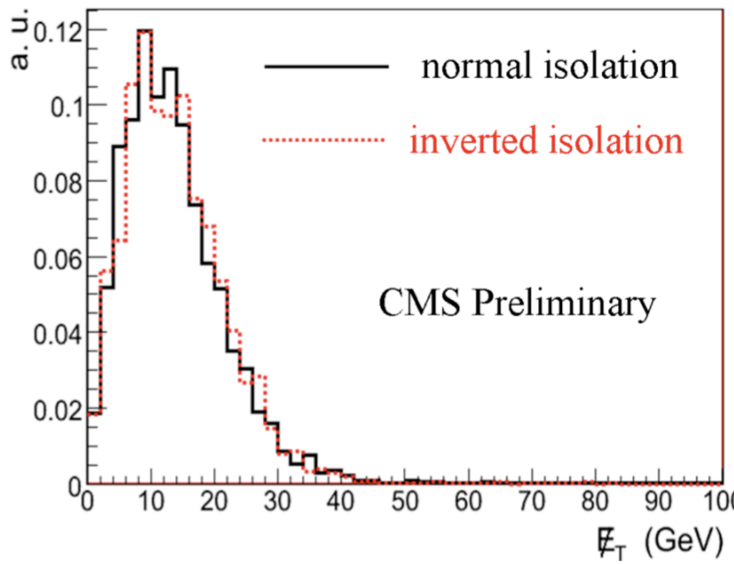


# The "Template" Method

- Templates – predefined shapes of distribution of some background discriminating variable
- Determine from data for signal and background
- Simultaneously fit background and signal shapes to distribution observed in selected sample – estimates yields




W→lν shape estimated from Z→ll data




Shape of QCD di-jet background to W→eν

# Measuring the Cross-Section

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$$\sigma(pp \rightarrow W) \times Br(W \rightarrow l\nu) = \frac{N_{observed} - N_{background}}{\varepsilon \times A \times \int L dt}$$ (Similarly for pp→Z)

| | |
|---|---|
| $N_{selected} - N_{bkgd}$ | $67954 \pm 674$ |
| Tag&Probe $\varepsilon_{total}$ | $65.1 \pm 0.5$ % |
| Acceptance | $52.3 \pm 0.2$ % |
| Int. Luminosity | $10\ pb^{-1}$ |
| $\sigma_W \times BR(W \rightarrow e\nu)$ | $19.97 \pm 0.25$ nb |
| cross section used | 19.78 nb |

| | |
|---|---|
| $N_{selected}$ | $3914 \pm 63$ |
| $N_{bkgd}$ | assumed 0.0 |
| Tag&Probe $\varepsilon_{total}$ | $68.1 \pm 0.6$ % |
| Acceptance | $32.39 \pm 0.18$ % |
| Int. Luminosity | $10\ pb^{-1}$ |
| $\sigma_{Z/\gamma^*} \times BR(Z/\gamma^* \rightarrow e^+e^-)$ | $1775 \pm 34$ pb |
| cross section used | 1787 pb |

- Errors in table are purely statistical
- Systematic errors anticipated
  - Int lumi ~ 10%
  - Signal yield ~5% (for W→eν)
  - Acceptance ~1%

# Summary

- In recent months, CMS has focused on preparing analyses for early data
  - (https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults)
- Measurement of inclusive $pp \rightarrow W \rightarrow l\nu$ and $pp \rightarrow \gamma^{*}/Z \rightarrow ll$
  - Detector simulated with miscalibration and misalignment
  - Robust selections applied to account for these imperfections
  - Realistic, data-driven methods developed to determine efficiencies and signal and background yield
- Important to "rediscover" the Standard Model
  - For understanding CMS
  - Step toward potential discoveries
- These analyses will be further developed and LHC collision data is eagerly anticipated later in 2008

# ADDITIONAL SLIDES

# Selections – Electrons Additional

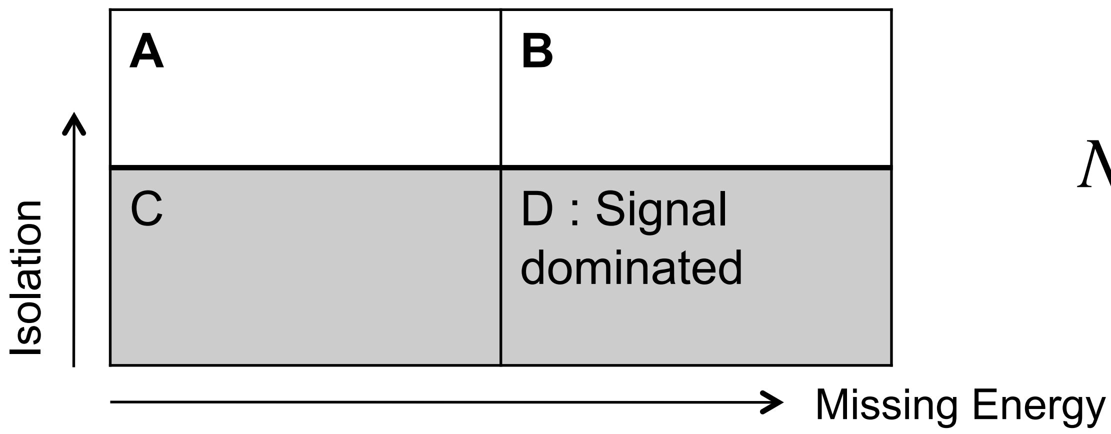
- ECAL fiducial region is $|\eta|<1.4442$ and $1.56<|\eta|<2.5$ (excludes the barrel-endcap transition)
- Track Isolation :
  - sum over all tracks with $p_T > 1.5$ GeV, within an annular cone (limits $0.02 < \Delta R < 0.6$) centred on the electron :

$$\sum_{track}\left(\frac{p_T^{track}}{p_T^{ele}}\right)^2 < 0.02$$

- Electron Identification :
  - cuts on ratio of hadronic energy deposited behind supercluster to supercluster energy
  - Cluster shape in η
  - Matching between supercluster position and track direction at vertex in both η and φ

# W Background Estimation IV

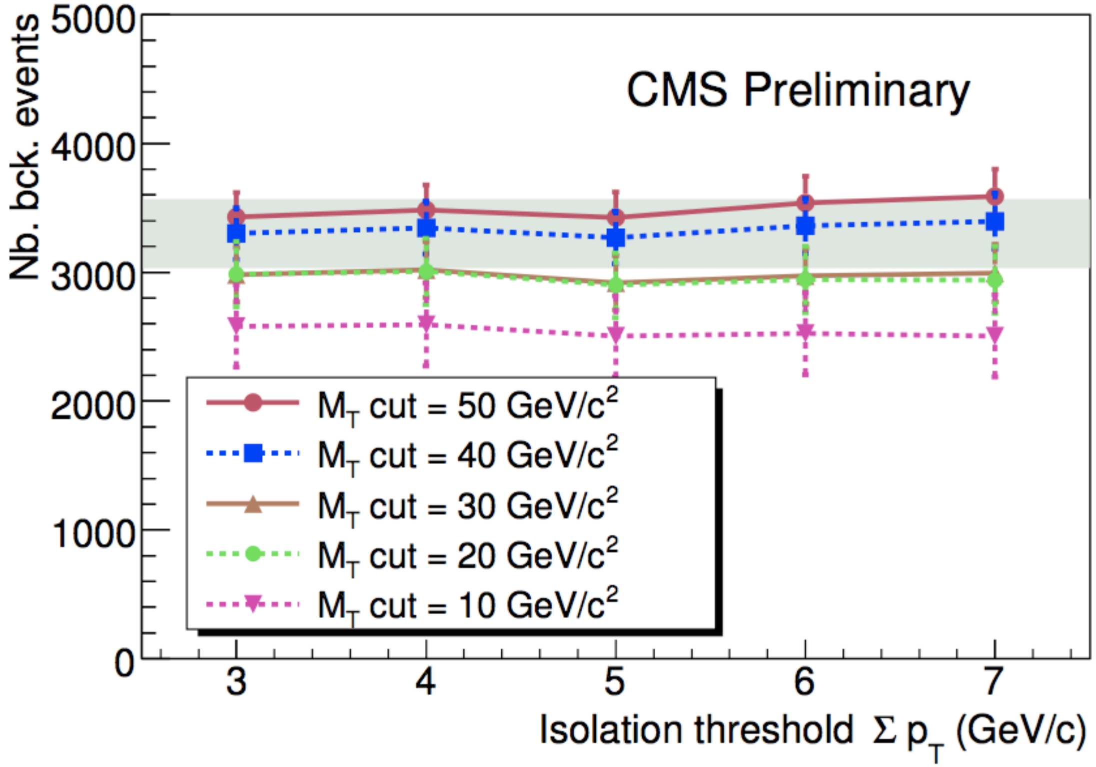
- "Matrix" method has been used to estimate background
  - Uses two uncorrelated background discriminating variables to form 4 regions – 1 signal dominated and the others ~ signal free
  - Number of QCD background events in signal region D = $N_{QCD}$




$$N_{QCD} = \frac{N_B N_C}{N_A}$$

- Can estimate signal contamination of regions A, B and C

# W Background Estimation V




- Background events in W signal region evaluated by matrix method, for various definitions of background regions (signal region fixed)
- True number of background events with statistical uncertainties are shown as grey band

# Theoretical Uncertainties I

- The theoretical uncertainties expected in the measurement of the $pp \rightarrow \gamma^{*}/Z \rightarrow ll$ inclusive cross section have been studied
  - Higher order terms & EWK corrections, PDF and renormalisation scales
- Using MC@NLO interfaced to PHOTOS, the overall theoretical uncertainty has been demonstrated to be ≈ 1%
- Comparisons were carried out between MC@NLO+PHOTOS and ResBos-A

# Theoretical Uncertainties II

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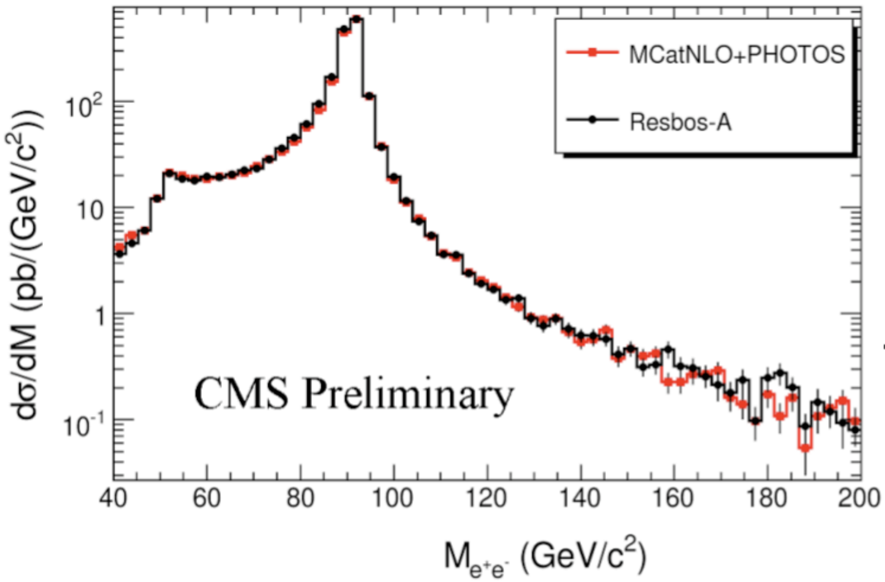
**Comparison of $\gamma^*/Z \rightarrow ee$ invariant mass distributions between MC@NLO+PHOTOS and ResBos-A**




**Uncertainty on acceptance of $\gamma^*/Z \rightarrow ee$ due to PDFs, against electron |η| cut**