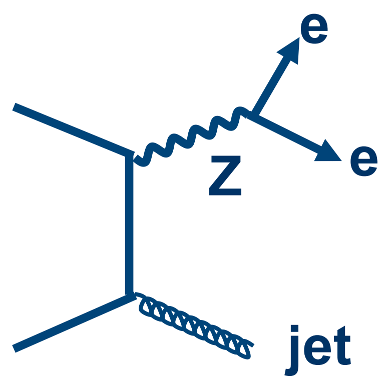
Zee+Jets studies at CMS

Lovedeep K. Saini, Suman B. Beri,
C. Lazaridis, Bryan Dahmes



Introduction

- Important on several counts:
  - Testing perturbative QCD
  - Precise measurement of Standard Model parameters
  - Detector calibration and so on…
- Z+jets have high cross-sections
  - an important background for many of new particle searches (Higgs, Supersymmetry) of LHC

⇒A comprehensive analysis of Z+jets aiming:

  ⇒Study the experimental reconstruction

  ⇒Selection techniques

  ⇒Basic Characteristics

Z Boson: Production and Decay Modes

- Weak Drell-Yan process: A quark from one hadron and an antiquark from another create a pair of oppositely charged leptons through exchange of a virtual photon or ***Z-boson.***
- Decay modes:
  - *Hadronic (B.R ~70%)*
    - The Z° boson decays to a quark / anti-quark pair.
    - The quarks are observed as a pair of jets.
  - *'Visible' leptonic (B.R ~4%)*
    - The Z° boson decays to a charged lepton / anti-lepton pair.
    - Taus decay *very* quickly to other particles and so they are not directly detected.
    - Electrons and muons do not decay too quickly and can be detected directly.
  - *'Invisible' leptonic (B.R ~20%)*
    - Neutrinos do not interact with matter very strongly and they are not detected by Detector, however their existence can be inferred by the measuring the momentum of particles before and after a collision. Since conservation of momentum is required, any *missing momentum* after the collision has been carried away by the undetectable neutrinos.

Trivia

- Zee+jets MC study@10TeV ($200pb^{-1}$)
  - Z+nJets: MadGraph MC event generator (based on LO calculation of the ME for final states at most 4 primary partons with pT>10GeV)
  - Multi-jet Events: PYTHIA, using a filter that selects e&mu enriched QCD samples.
  - W+njets : MadGraph and Pythia
  - TTbar Events: PYTHIA
    - All samples produced centrally by CMS collaboration (Summer08)

Analysis Effort

- Trigger
- Electrons
- Z Boson
- Jets
- Rate(s)
- Bkg. Est.
- Outlook

Trigger

- **Trigger**
- **Electrons**
- **Z Boson**
- **Jets**
- **Rate(s)**
- **Bkg. Est.**
- **Outlook**

- Single electron "HLT_Ele15_LW_L1R"
  - The L1 condition is L1_SingleEG10 (1 EM object with Et > 10GeV)
  - A single electron trigger, using the large pixel-matching window ("LW") at HLT.
  - The supercluster used to seed the pixel matching must have ET > 10 GeV and H/E < 0.2.
  - At least one HLT electron with ET > 15 GeV is required.
  - No isolation is required.

Electron Selection

- Trigger
- **Electrons**
- Z Boson
- Jets
- Rate(s)
- Bkg. Est.
- Outlook

- $|\eta|<2.5$, excluding barrel-endcap transition, $1.42<|\eta|<1.56$
- pT > 20GeV
- Electron Identification

	$\sigma_{i\eta i\eta}$	$\Delta\eta_{in}$
Barrel	0.0132	0.0077
Endcap	0.027	0.01

- Combined relative isolation

$$CombRelIso = \frac{EcalIso + HcalIso + TrkIso}{E_T^e}$$

Electron Selection

- Trigger
- **Electrons**
- Z Boson
- Jets
- Rate(s)
- Bkg. Est.
- Outlook

- $|\eta|<2.5$, excluding barrel-endcap transition, $1.42<|\eta|<1.56$
- pT > 20GeV
- Electron Identification

	$\sigma_{i\eta i\eta}$	$\Delta\eta_{in}$
Barrel	0.0132	0.0077
Endcap	0.027	0.01

- Combined relative isolation

$$CombRelIso = \frac{EcalIso + HcalIso + TrkIso}{E_T^e}$$

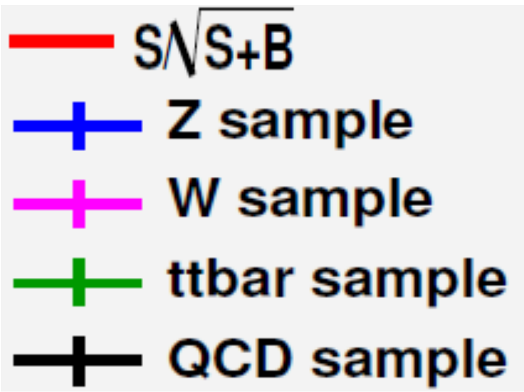
$\sigma_{i\eta i\eta}$

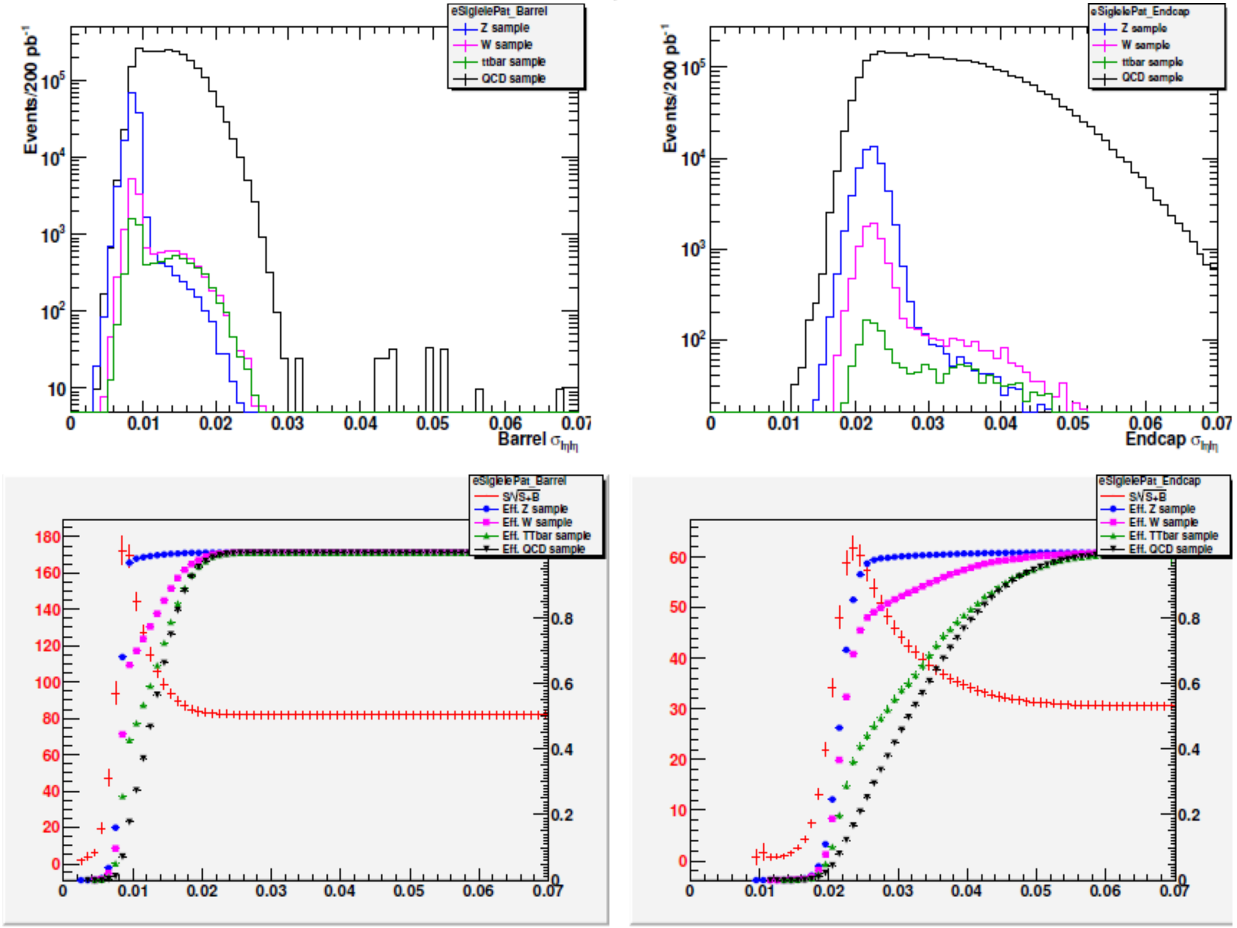
- Measures the RMS shower width in the η direction

- Trigger
- **Electrons**
- Z Boson
- Jets
- Rate(s)
- Bkg. Est.
- Outlook

$$\sigma_{i\eta\, i\eta} = \sqrt{\sum_i^{5x5} (\eta_i^{cryst.nr} \times 0.0175 + \eta^{seed\, cryst.} - \overline{\eta}_{5x5})^2 \times w_i \Big/ \sum_i^{5x5} w_i}$$

$$w_i = 4.2 + \ln E_i / E_{5x5}$$





(a) Barrel (threshold: 0.0132)

(b) Endcap (threshold: 0.027)

Electron Selection

- Trigger
- **Electrons**
- Z Boson
- Jets
- Rate(s)
- Bkg. Est.
- Outlook

- $|\eta| < 2.5$, excluding barrel-endcap transition, $1.42 < |\eta| < 1.56$
- pT > 20GeV
- Electron Identification

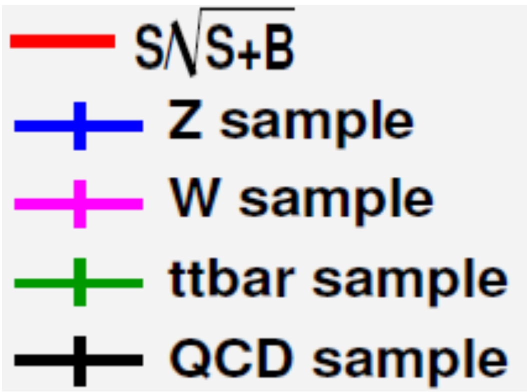
	$\sigma_{i\eta i\eta}$	$\Delta\eta_{in}$
Barrel	0.0132	0.0077
Endcap	0.027	0.01

- Combined relative isolation

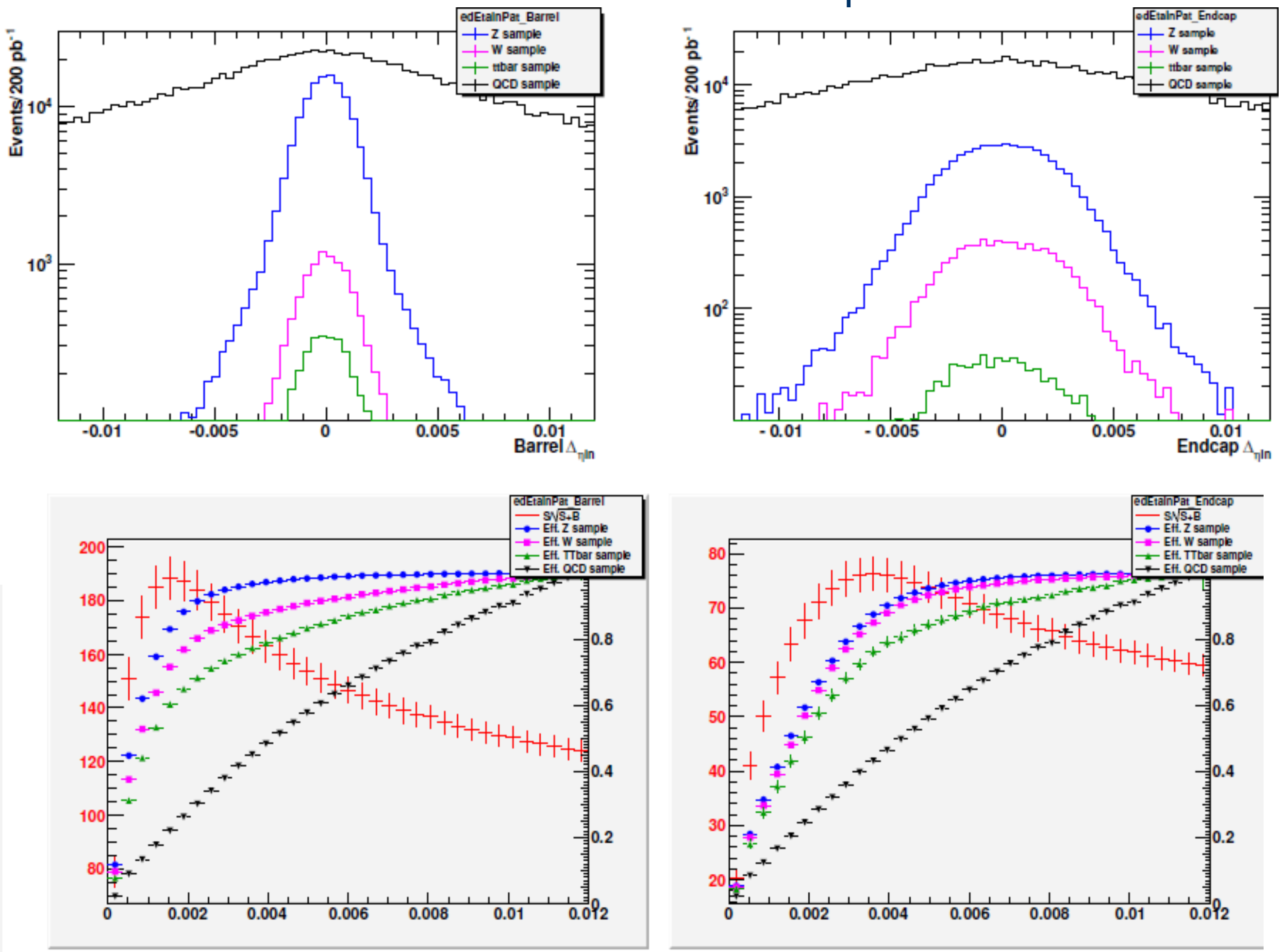
$$CombRelIso = \frac{EcalIso + HcalIso + TrkIso}{E_T^e}$$

$\Delta\eta_{in}$

- Trigger
- **Electrons**
- Z Boson
- Jets
- Rate(s)
- Bkg. Est.
- Outlook



- Quantifies the match between the gsf track trajectory and the ECAL supercluster
- Difference between the η position of the supercluster and the η direction of the GSF track at the vertex extrapolated to the ECAL



(a) Barrel (threshold: |0.0077|)

(b) Endcap (threshold: |0.01|)

Electron Selection

- Trigger
- **Electrons**
- Z Boson
- Jets
- Rate(s)
- Bkg. Est.
- Outlook

- $|\eta|<2.5$, excluding barrel-endcap transition, $1.42<|\eta|<1.56$
- pT > 20GeV
- Electron Identification

	$\sigma_{i\eta i\eta}$	$\Delta\eta_{in}$
Barrel	0.0132	0.0077
Endcap	0.027	0.01

- Combined relative isolation

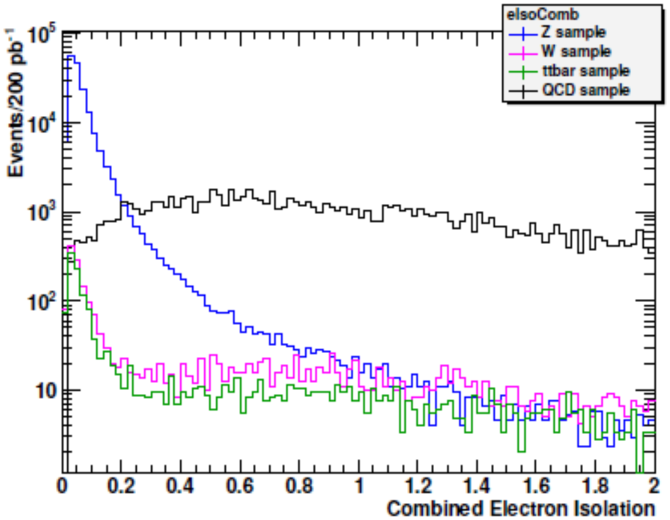
$$CombRelIso = \frac{EcalIso + HcalIso + TrkIso}{E_T^e}$$

Combined relative isolation

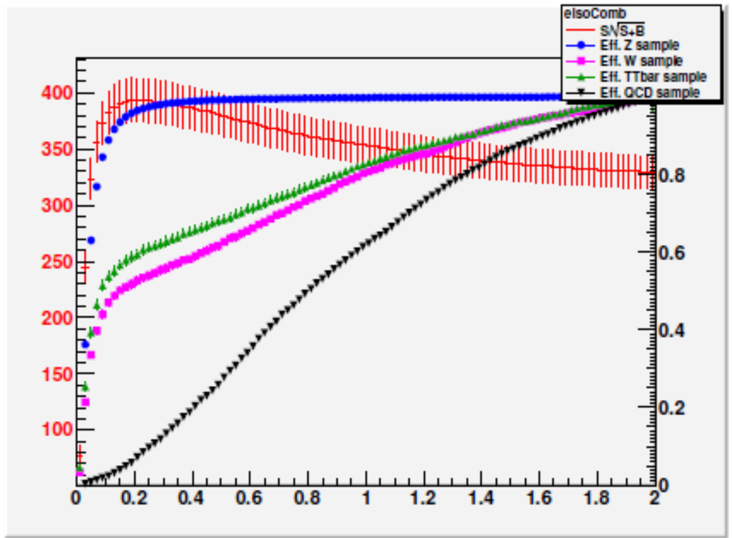
- Trigger
- **Electrons**
- Z Boson
- Jets
- Rate(s)
- Bkg. Est.
- Outlook

$$CombRelIso = \frac{EcalIso + HcalIso + TrkIso}{E_T^e}$$

- EcalIso is the sum of the ECAL RecHits, HcalIso is the sum of the HCAL calo towers, and TrkIso is the sum of the track p_T
- Each within a cone of $\Delta R<0.4$ centered around the supercluster position (EcalIso and HcalIso) or track direction at vertex (TrkIso).



(a) Combined relative isolation (threshold 0.35)



(b) Efficiency and significance plots for combined relative isolation

Electron Selection

- Trigger
- **Electrons**
- Z Boson
- Jets
- Rate(s)
- Bkg. Est.
- Outlook

- $|\eta|<2.5$, excluding barrel-endcap transition, $1.42<|\eta|<1.56$
- pT > 20GeV
- Electron Identification

	$\sigma_{i\eta i\eta}$	$\Delta\eta_{in}$
Barrel	0.0132	0.0077
Endcap	0.027	0.01

- Combined relative isolation

$$CombRelIso = \frac{EcalIso + HcalIso + TrkIso}{E_T^e} < 0.35$$

Z Reconstruction

- Trigger
- Electrons
- **Z Boson**
- Jets
- Rate(s)
- Bkg. Est.
- Outlook

- Reconstructed from a pair of oppositely charged electrons fullfilling electron selection crietria
- Mass window between $70<M_Z<110$GeV

Jet selection

- Trigger
- Electrons
- Z Boson
- **Jets**
- Rate(s)
- Bkg. Est.
-

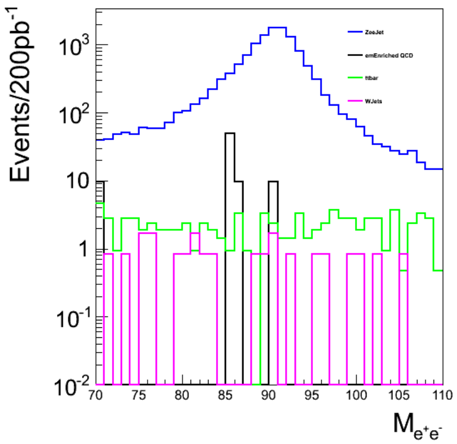
- SISCone algorithm used
- Used both the "kinds":
  - Jets from calorimetric deposits "CaloJets"
  - Jets from clustering of the flow of particles "PFJets"
- Selection cuts:

	CaloJets	PFJets
Cross-object removal	No electrons in a $\Delta R<0.5$ cone around jet axis	
JEC	L2L3 level jet energy corrections	Not Available
p_T	>30GeV (Corrected)	>15GeV
$\|\eta\|$	<2.5	

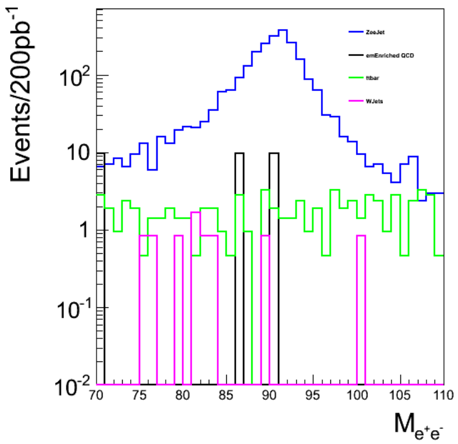
Z mass Vs # jets

- Trigger
- Electrons
- Z Boson
- Jets
- **Rate(s)**
- Bkg. Est.
- Outlook

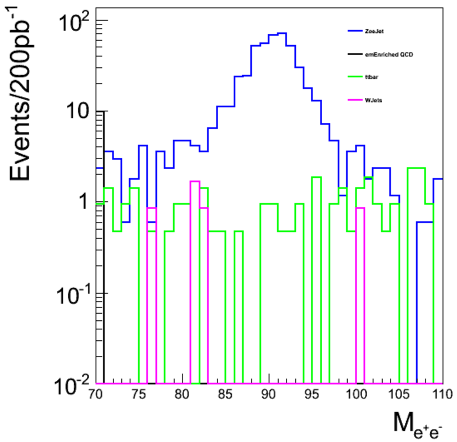
Z+≥1Jet



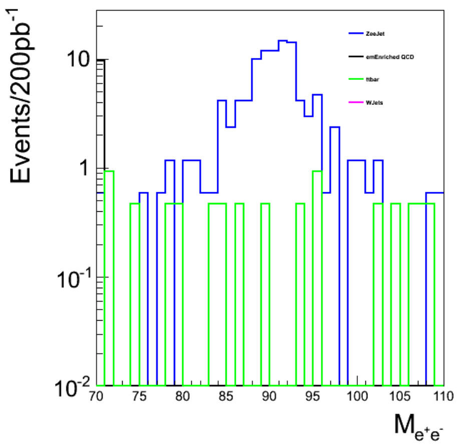
Z+≥2Jets



Z+≥3Jets



Z+≥4Jets

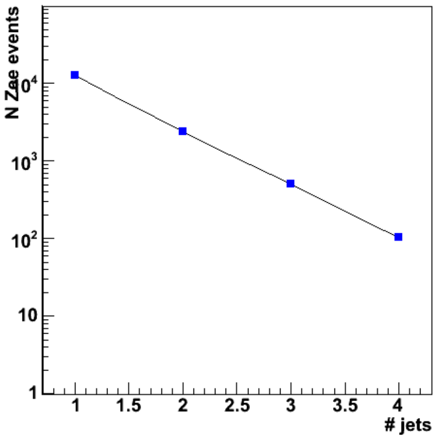


Z sample
W sample
ttbar sample
QCD sample

Event Rate

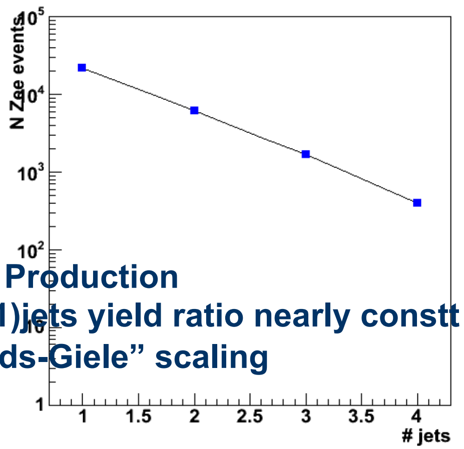
- Trigger
- Electron
- Z Boson
- Jets
- **Rate(s)**
- Bkg. Est.
- Outlook

CaloJets:



Sample	Z+≥1Jet	Z+≥2Jet	Z+≥3Jet	Z+≥4Jet
Zee+Jets	12684	2405	505	104
Ttbar	86	67	30	7
QCD	78	29	9	0
W+jets	19	8	4	0
S/B	111.2	48.0	21.5	9.8

PFJets:



Sample	Z+≥1Jet	Z+≥2Jet	Z+≥3Jet	Z+≥4Jet
Zee+Jets	22067	6127	1659	399
Ttbar	89	73	39	17
QCD	136	29	9	0
W+jets	25	8	4	0
S/B	147.7	77.5	40.1	19.5

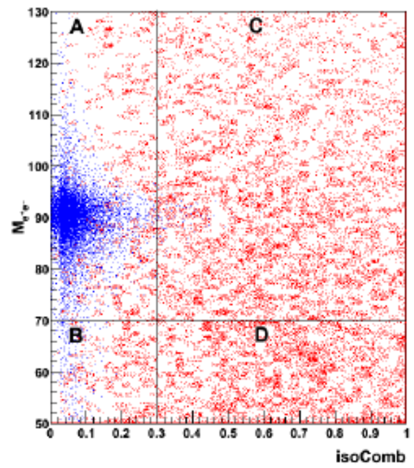
- **$(\alpha_S)^n$ law of Multijet Production**
- **Z+njets over Z+(n+1)jets yield ratio nearly constt**
- **Referred as "Berends-Giele" scaling**

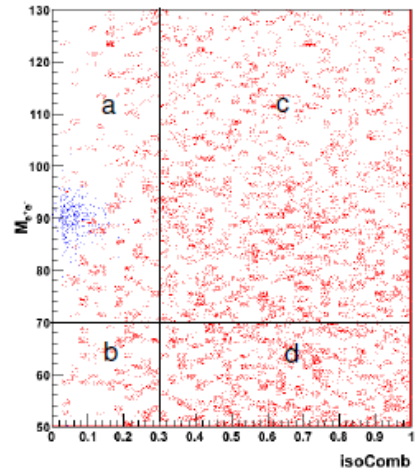
Background Estimation (Z+≥1CaloJets)

- Trigger
- Electrons
- Z Boson
- Jets
- Rate(s)
- **Bkg. Est.**
- Outlook

ABCD (Matrix) Method:

- Lookout for two uncorrelated variables : x, y
- The cuts c1 and c2 on “x” and “y” create 4 disjoint boxes in “x-y” plane
  - $QCD_A/QCD_B=QCD_C/QCD_D$ (B, C, D signal free)
- Suffers from: Correlations (small here), Signal Contamination
- ABCD_xyz: (Extension of ABCD)
  - Find inverting variable “z” be uncorr. to x,y
  - Since z is uncorrelated to x, y: A flipping cut on z will leave “box ratios” unchanged.
  - Insensitive to signal contamination
    - Invert the selection (“z variable”)
    - $QCD_A=r1*r2*QCD_D$
      - $r1= QCD_C/QCD_D=n_c/n_d$
      - $r2=QCD_B/QCD_D=n_b/n_d$
    - $QCD_A=QCD_D*(n_b/n_d)*(n_c/n_d)$
- Here are the numbers from an earlier study done with somewhat different selection criteria (study going on for presented selection criteria)
  - Expected Signal events: 10881+-104
  - From ABCD_xyz: 10787
  - Bias=1%
  - Expected Background events: 2879+-54
  - From ABCD_xyz: 2974+-137
  - Bias= 3.3%



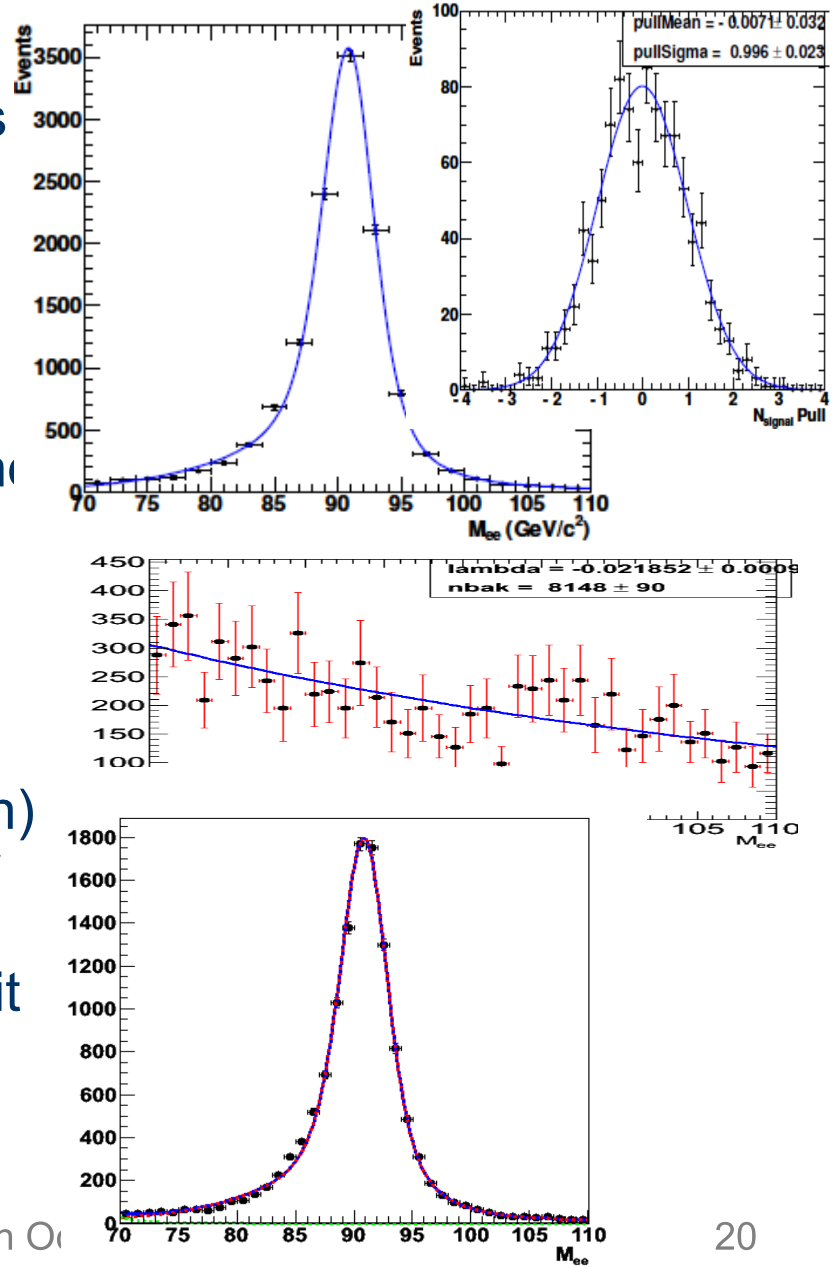


Background Estimation (Z+≥1CaloJets)

- Trigger
- Electrons
- Z Boson
- Jets
- Rate(s)
- **Bkg. Est.**
- Outlook

Template method

- Use function/template fits of the signal and backgrounds for dilepton invariant mass
- Signal parameterization: Voigtian (Breit weigner convolved with gauss) an bifurcated Gauss composite shapes
- Background parameterization: Shape studied in “anti-lepton” (inverting isolation) sample and described by exponential.
- Perform a extended ML fit to dilepton inv mass to estimate the signal and background yields.



Outlook

- Trigger
- Electrons
- Z Boson
- Jets
- Rate(s)
- Bkg. Est.
- **Outlook**

- We examined the experimental sensitivity to Zee+jets processes at CMS using Monte Carlo simulation of 10TeV collisions for 200pb^{-1} of data.
- Event rates have been calculated for inclusive Z +1,2,3,4 jets processes for CaloJets as well as PFJets.
- Study is being done to estimate residual backgrounds.
- To estimate systematic uncertainties
- …………………
- ……………

Backup

$\sigma\eta\eta$

$$\sigma^2_{\eta\eta} = \frac{\sum_i^{5x5} w_i \left(\eta_i - \bar{\eta}_{5x5}\right)^2}{\sum_i^{5x5} w_i} \qquad w_i = 4.2 + \ln E_i \big/ E_{5x5}$$

– define $\Delta\eta$ = number of crystals from seed * average crystal η + seed η – mean η of 5x5 pos

– only done to make the values the same as $\sigma_{\eta\eta}$, could work exclusively in crystal coordinates if wanted to

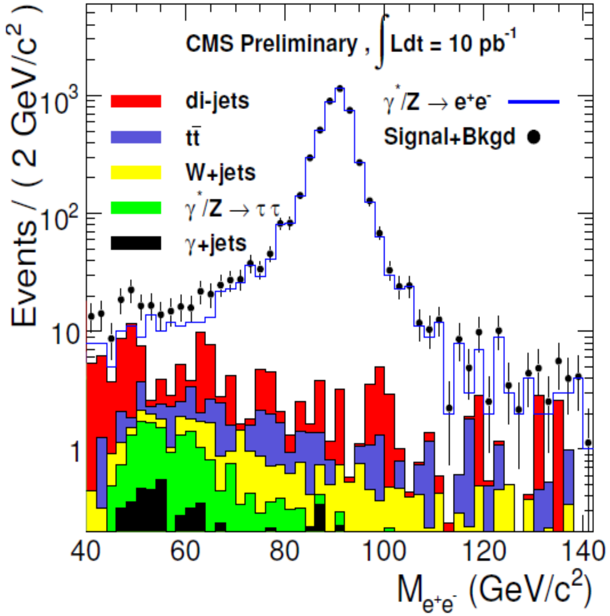
$$\sigma_{i\eta\, i\eta} = \sqrt{\sum_i^{5x5} (\eta_i^{cryst.\,nr} \times 0.0175 + \eta^{seed\,cryst.} - \bar{\eta}_{5x5})^2 \times w_i \Big/ \sum_i^{5x5} w_i}$$

$$w_i = 4.2 + \ln E_i \big/ E_{5x5}$$

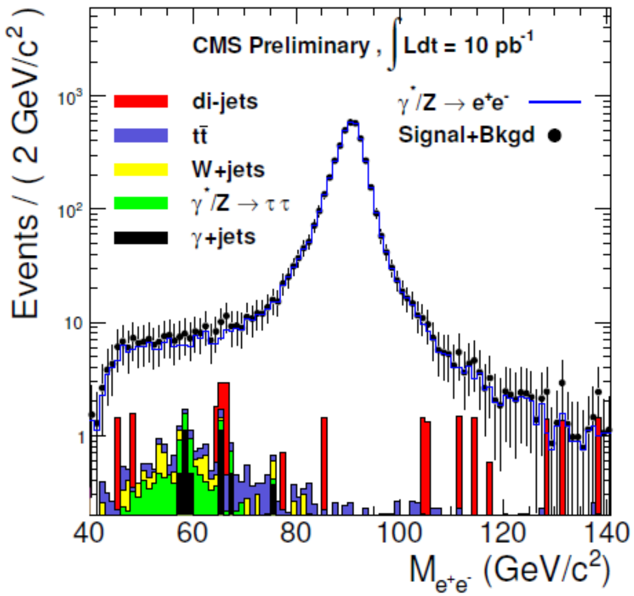
Background Estimation

Why ?

$$\sigma_{Z/\gamma^*} \times BR(Z/\gamma^* \to e^+e^-) = \frac{N^{pass}_{Z/\gamma^*} - N^{bkgd}_{Z/\gamma^*}}{A_{Z/\gamma^*} \times \epsilon_{Z/\gamma^*} \times \int Ldt}$$



- Efficiency : Tag and Probe
- Background Contamination :
  - MC Studies
  - Data Driven Methods
    - ABCD Method
    - Template Method
  - Or (?) a combination of both
- Cross Checking the Tag-Probe Efficier

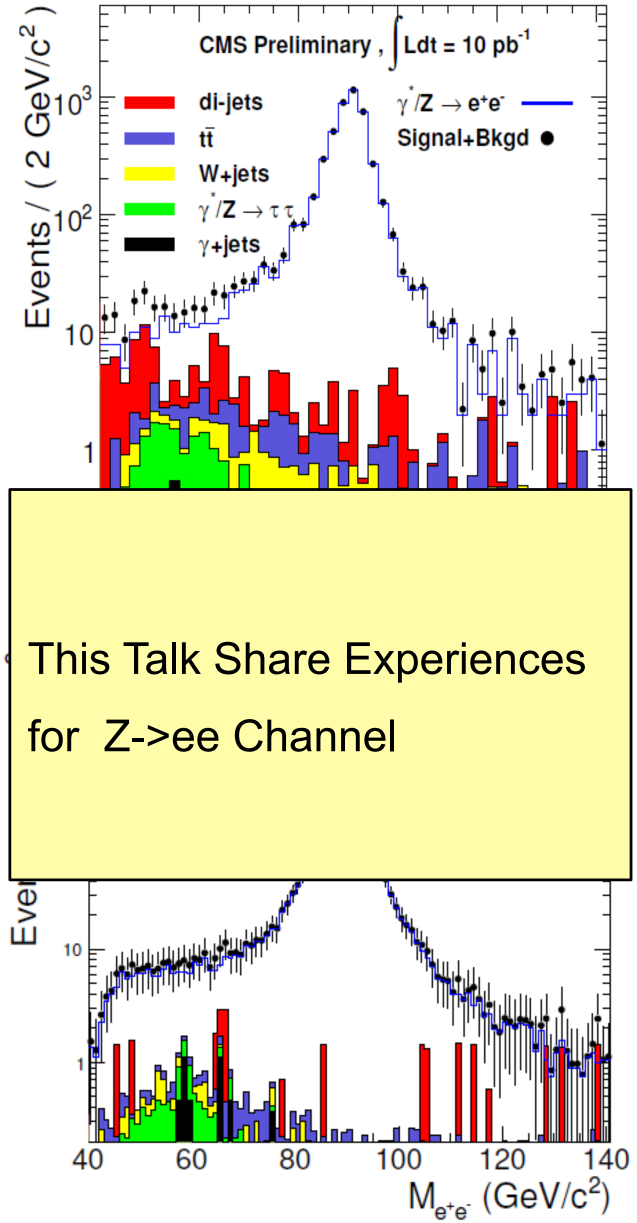


Background Estimation

Why ?

$$\sigma_{Z/\gamma^*} \times BR(Z/\gamma^* \to e^+e^-) = \frac{N^{pass}_{Z/\gamma^*} - N^{bkgd}_{Z/\gamma^*}}{A_{Z/\gamma^*} \times \epsilon_{Z/\gamma^*} \times \int Ldt}$$

- Efficiency : Tag and Probe
- Background Contamination :
  - MC Studies
  - Data Driven Methods
    - ABCD Method
    - Template Method
  - Or (?) a combination of both
- Cross Checking the Tag-Probe Efficiencies.



This Talk Share Experiences

for Z->ee Channel

Event Selection

- Preselection Cuts
  - event passes the single electron HLT
  - two GsfElectrons in ECAL fiducial ($|\eta|$ <2.5 with 1.4442< $|\eta|$ <1.560 excluded)
  - two GsfElectrons with supercluster E_T >20.0 GeV

- Electron Isolation

	Track ΣP_t (GeV)	Ecal ΣE_T (GeV)	Hcal ΣE_T (GeV)
Barrel	7.2	5.7	8.1
Endcap	5.1	5.0	3.4

CMS AN -2009/098

- Electron Identification

	$\sigma_{i\eta i\eta}$	$\Delta\phi_{in}$	$\Delta\eta_{in}$
Barrel	0.01	n.a.	0.0071
Endcap	0.028	n.a.	0.0066

- Dilepton Mass Window

$70 < M_{e,e} < 110$ GeV

Event Rates

Selection Criterion	$\gamma^*/Z \to e^+e^-$	dijets
unweighted number of events	455787	
cross section (pb)	2276	
preselection Efficiency	1	
event weight for 10 pb^{-1}	0.0499	
weighted number of events	22745	
single electron HLT	12050	9413479
two GsfElectrons, E_T >20.0 GeV, in fiducial	5208	108190
both pass electron Isol. defined in Table 4	4753	385
both pass electron ID defined in Table 2	4541	33
70< $M_{e,e}$ <110 GeV	4258	6

CMS AN -2009/098

Assymetric Selection

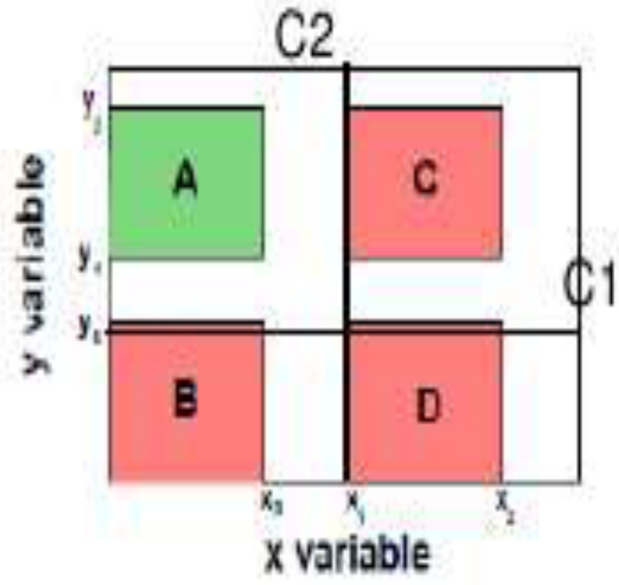
- Impose Strict requirements on one of leptonic legs.(Tag)
- Other leg has to pass some/all of cuts, the tag is required to pass. (Probe)
- Tag Requirements:
  - Supercluster-Track matching
  - Isolation Criteria
  - Identification Criteria
- Probe Requirements:
  - Supercluster-trackmatch (gsf electron)
- Tag and Probe (BOTH) pass pT threshold and fiducial requirements

Sel.	Zee	Weν	Zττ	ttbar	Wτν	QCD	g+Jet
Events	22743	n.a	n.a	n.a	n.a	n.a	n.a
Trigger	12156	30081	1675	1761	7638	9413478	74178
Tag+Gsf	5168	195	36	139	35	3368	164
Tag+Iso	4755	10	17	22	1	205	16
Tag+Id	4546	2	10	19	0	33	4
MW	4263	0	1	5	0	6	0

Event Rate with successively tighter probe

ABCD Advertisement

- Lookout for two uncorrelated variables : x, y
- The cuts C1 and C2 on "x" and "y" create 4 disjoint boxes in "x-y" plane
  - Uncorrelation implies that,
    - (QCD_A)/(QCD_B) = (QCD_C/QCD_D
    - QCD_A = (QCD_B)*(QCD_C/QCD_D)-
- So, if signal in C, B, and D is small.
- So from relation(1),
  - QCD_A = (N_B)*(N_C/N_D)--- (2)
- Hence we get a data-driven estimate for the background contamination in the box A !!!



Beware !!!
REAL LIFE SITUATION IS MUCH MORE DIFFICULT !!!
- Finding uncorrelated variables is difficult
- Signal contamination in the boxes may not be small
- Background if too small, may show false correlations

ABCD Robustness

An Easy Toy Exercise:

- Tag+Gsf (QCD MC.)
- Test the ABCD

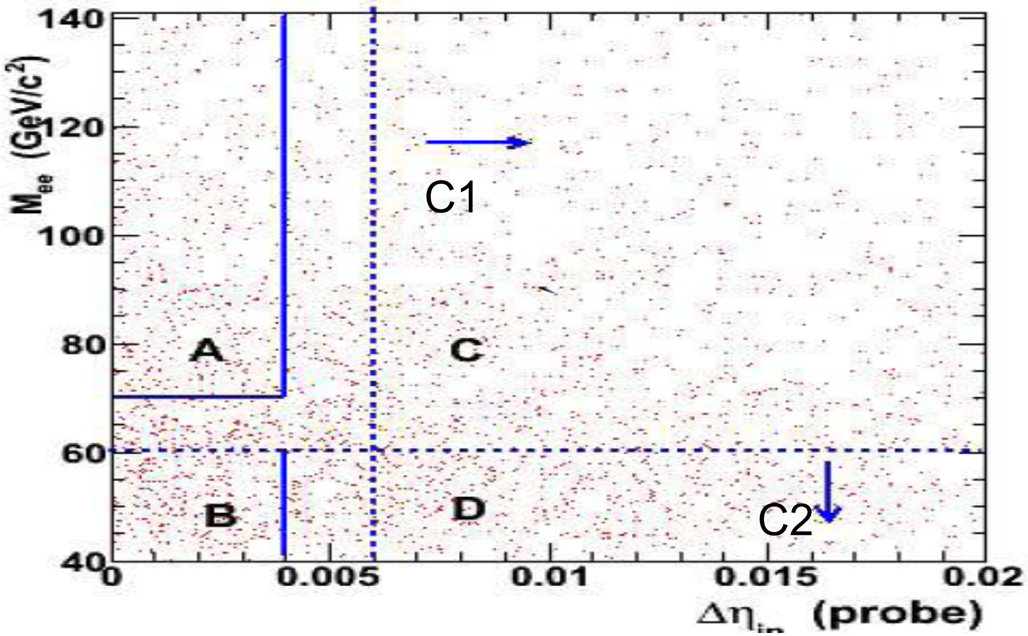
We select following pair:

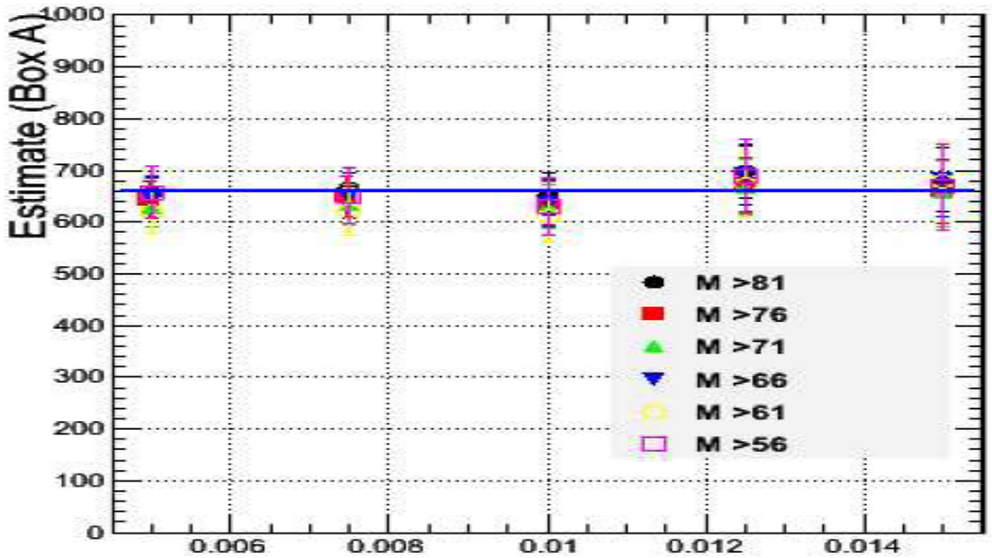
- Dilepton Invariant Mass
- Probe DelEtaIn

Cuts C1, C2, C1` and C2` define the boxes A, B, C and D.

Estimated number of events in box A, must not change if boxes B, C and D are varied.

- Estimates were found to be consistent with in a thin band.
- Next we see how it fares in presence of signal.





ABCD Application

Signal+Background
- Signal Contamination
- Simple ABCD breaks.

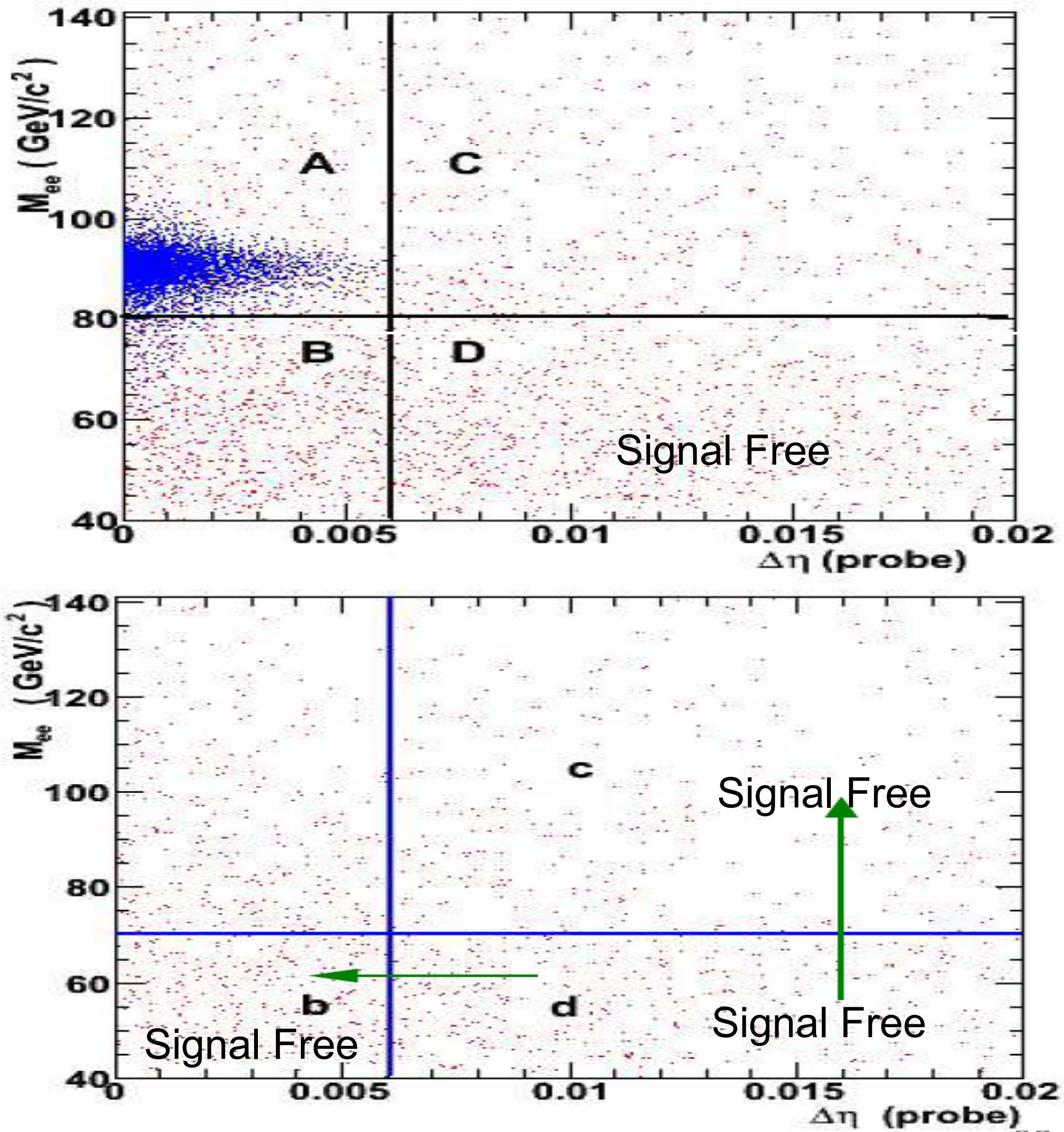
Extend ABCD to ABCD_xyz
- Find inverting variable
- "z" be uncorr. to x, y

Cuts C1, C2, define the boxes A, B, C and D in xy plane.

Since z is uncorrelated to x, y: A flipping cut on z will leave "box ratios" unchanged.

- If D is free of signal:

QCD_A =(r1)*(r2)*(N_d)
r1 = QCD_C/QCD_D =N_c/N_d
r2 = QCD_B/QCD_D =N_b/N_d



ABCD_xyz SomeResults

<u>Variables Used:</u>

- Invariant Mass
- DelEtaIn(probe)
- Dilepton Signedness

<u>Cuts to define the boxes:</u>

C1 = M>80, C2 = DelEtaIn<0.0(

- A = c1 && c2
- B = !c1 && c2
- C = c1 && !c2
- D = !c1 && !c2

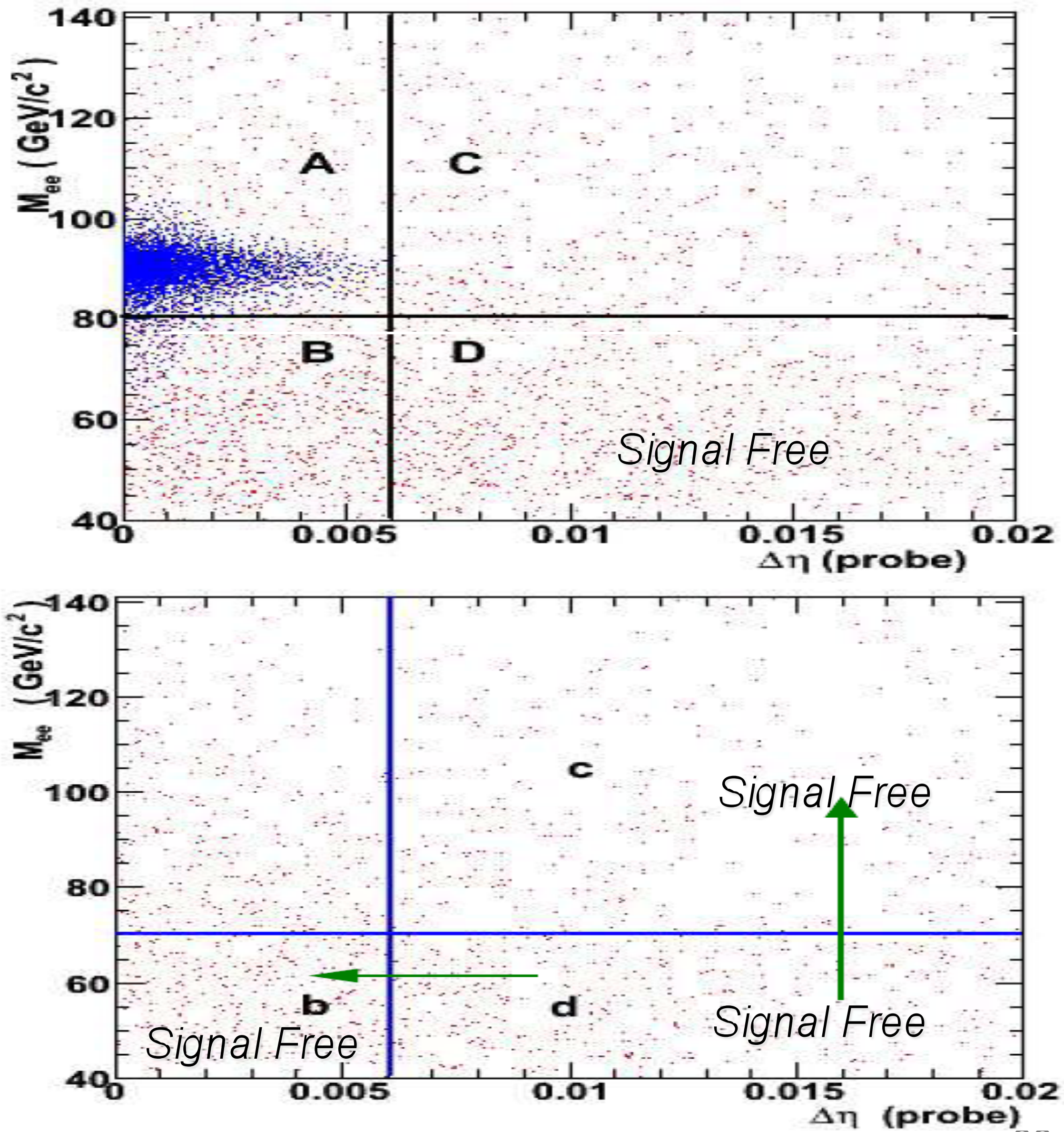
<u>Inverting Variable:</u>

C3 = Q<1

- nominal = C3
- inverted = !C3

<u>Estimated Numbers:</u>

- Est. QCD (Box A):663+/-60
- MC QCD(Box A):596+/-24
- Bias:0.11



ABCD_xyz for Tag and Probe

Question: Can we use ABCD_xyz to estimate background in Tag+SC collection (with respect to which various efficiencies are estimated) ?

Answer: We try doing it. But now we are not permitted to decide box boundaries, rather we have use the cuts suggested by user. Use all but three of the selection criteria to define a tag electron, and let the remaining 3 to act as x, y, z.

WARNING: No boundary or anyother cut other than Pt theshold and fiducial requiremnt is to be applied at PROBE arm.

Outlook and Plans

- ABCD_xyz as a natural extension to the traditional ABCD method has been shown to work in principle.
- Further studies with box boundaries consistent with nominal cuts, and tag-probe selections fully consistent with nominal selection have shown many difficulties.
  - Backgrounds are very-very small
  - Estimates very-very sensitive to signal contamination in inverted selections.

Efforts are underway to make method work for

- Tag+SC selection.
- Tag+Id selection.

So that a cross-check to current “peak-fitting” method used in Tag-Probe could be developed.