CSC Note: W and Z Inclusive Cross-section Measurement

ATLAS NOTE

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Electroweak boson cross-section measurements with ATLAS

Abstract

This report summarizes the ATLAS prospects for the analysis of W and Z production at the LHC. After a review of trigger and reconstruction performance in these final states, complete analyses of the W and Z total cross-sections are presented. Focusing on the early data taking phase, strategies are presented that allow a fast and robust extraction of the signals. A measurement precision of about X% can be achieved with Y pb^{-1}. Anticipating higher integrated luminosity, algorithms allowing the extraction of the Z differential cross-section are presented and evaluated. A number of applications of these measurements are finally presented.

ATLAS UK Meeting in Durham

10th January 2008

CSC Note Overview

Preliminary draft available (advanced status but not finalised yet):
https://twiki.cern.ch/twiki/bin/view/Atlas/InclusiveWZCSCNote

Contents

- **Exhaustive note:**
  - aim: Z and W inclusive cross section
    - $W \to e\nu$, $\mu\nu$
    - $Z \to ee$, $\mu\mu$
  - includes:
    - electron and muon Trigger eff.
    - reconstruction performance
    - stream data tests
    - early data measurements
    - higher luminosity measurements
    - differential cross-section meas.

Presentation Overview

Cannot give justice to all contributions in 20 min:

- ✓ **selection of most advanced analyses from note draft**
- ✓ **focus on *data-driven* methods for signal selection and cross-section meas. in early data and higher lumi scenarios**
- ✘ Trigger and Reconstruction performance (only brief reference)
  (already discussed in Trigger and Combined Performance sessions)
- ✘ Tests Stream data

Electron sector

- ❑ Trigger efficiency measurement
- ❑ Reconstruction performance measurement
- ❑ Z->ee selection with early data
- ❑ W->eν selection and cross-section measurement

Muon Sector

- ❑ Trigger efficiency measurement
- ❑ reconstrucion performance measurement
- ❑ Z->μμ selection with early data and higher luminosity

Differential cross-section measurements

- ❑ Z->ee, Z->μμ $d\sigma/dydp_T$ (D0 and alternative methods)

W and Z cross-sec measurement at LHC

Theory: W and Z x-sect known to <1% exluding PDF → Stringent test

Z production clean and fully reconstructed leptonic final states
W production high counting rate:

- **Precise measurement of differential x-sect**
  - **dσ/dpt**: QCD constraints, e.g. resummation
  - **dσ/dy**: PDF probe
- Improvements **on QCD beneficial to all physics at LHC**
- **Detector performance**
  - detector energy and momentum scales
  - detector resolutions
  - lepton identification efficiencies
- **Fundamental EW param**
  - Z forward-backward asymmetry, letpon universality, etc

Trigger

- **Initial lumi 10^{31} cm^{-2} s^{-1}**
  - less stringent requirements, lower PT thresholds, no isolation, simple selec.
    - *Z, W trig.:*
      - at least 1 ele (μ) pT>10 GeV
      - at least 2 ele (μ) pT>5 GeV (4 GeV)
- **Higher lumi 10^{33} cm^{-2} s^{-1}**
  - thighter requirements
    - *Z, W trig.:*
      - at least 1 ele (μ) pT>25 GeV (20 GeV)
      - at least 2 ele (μ) pT>15 GeV (10 GeV)

Measure Trigger efficiency from data, i.e. MC-independent:
Uncertainty important contribution to syst error on Z,W x-sect.

Tag&Probe, e.g. Z->ll:

- tag-lepton: tightly selected
- probe-lepton:used to make performance measurements

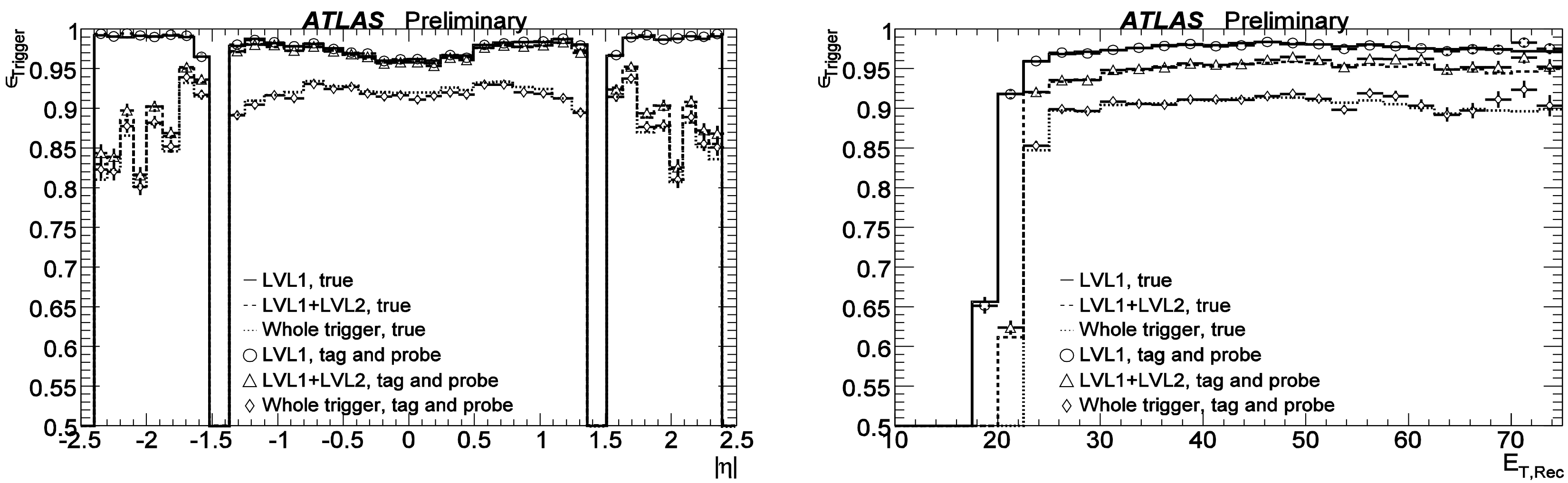
Electron Sector

Trigger efficiency

Electron

E25i Trig. Eff. Wrt *Offline* electron sel.

Z->ee Tag&Probe Sel.:
- tag-lepton: trig+tightly ele id (isEM)
- probe-lepton: loose, medium and tight ele id (isEM)



Overall Trigger Efficiency wrt Tight : 93.02% ±0.20 ±0.82

L2, EF eff. small bias ~0.1-0.4% wrt truth

QCD dijet and W->en effect ~ 0.01%

More details in talk by Mike Flowerdew (09/01/2008)

Reconstruction Performance

Electrons

Z->ee Tag&Probe Sel.:
- ❑ tag-lepton: trig+tight ele id (isEM)
- ❑ probe-lepton: cluster in opposite ϕ hemisphere

Two pass analysis :
1) Absolute offline container efficiency
2) IsEM efficiency relative to the container
The results are combined to produce the offline reconstruction efficiency

Absolute electron reconstruction eff

Loose isEM (50 pb^{-1})

$\|\eta\| \backslash P_t$	$15-25$	$25-40$	$40-70$
$0-0.8$	$88.88 \pm 1.21 \pm 1.17$	$92.41 \pm 0.42 \pm 0.91$	$93.29 \pm 0.74 \pm 1.88$
$0.80-1.37$	$87.55 \pm 2.69 \pm 3.30$	$90.75 \pm 0.55 \pm 0.29$	$92.69 \pm 0.45 \pm 0.19$
$1.52-1.80$	$83.18 \pm 2.17 \pm 3.13$	$83.00 \pm 1.17 \pm 0.93$	$85.87 \pm 1.12 \pm 0.79$
$1.80-2.40$	$72.66 \pm 2.81 \pm 5.00$	$80.47 \pm 0.92 \pm 2.41$	$80.54 \pm 0.87 \pm 0.36$

Tight isEM (50 pb^{-1})

$\|\eta\| \backslash P_t$	$15-25$	$25-40$	$40-70$
$0-0.8$	$63.15 \pm 2.85 \pm 4.85$	$64.68 \pm 0.97 \pm 0.56$	$66.54 \pm 0.90 \pm 0.42$
$0.80-1.37$	$59.29 \pm 3.52 \pm 4.71$	$63.34 \pm 1.23 \pm 0.00$	$68.03 \pm 1.10 \pm 1.23$
$1.52-1.80$	$38.58 \pm 5.08 \pm 1.95$	$54.77 \pm 1.83 \pm 1.17$	$62.89 \pm 2.05 \pm 4.93$
$1.80-2.40$	$51.70 \pm 3.02 \pm 2.36$	$58.81 \pm 1.39 \pm 1.58$	$61.82 \pm 1.44 \pm 0.19$

Tag&probe± stat± syst (MC-Truth)

- ❑ **Eff. increases up to 40 GeV, then constant**
- ❑ **Eff. drops in cracks η=1.57-1.8**
- ❑ **More details in Helen Hayward's talk**

Early cross-section measurements

With early data (≤50pb-1) detector response may be imprecise

- **Simple and robust selection cuts**
- **based on Calorimeter Only**

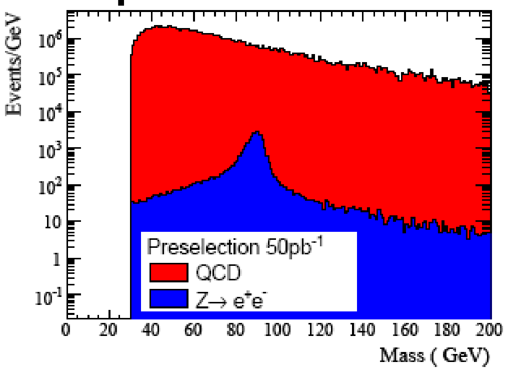
Z→ee

- **Preselection:**
  - 2 electron candidates from *ElectronContainer & PhotonContainer* ET>15 GeV
  - acceptance and crack removal cuts: $0<|\eta|<1.3$ & $1.6<|\eta|<2.4$
- **Electromagnetic Estimators (simpler sel than isEM):**
  - Simpler shower shape estimators
- **Isolation:**
  - use Etcone ($\Delta R=0.45$): Etcone/Et <0.2
- **Mass Distribution Fit:**
  - sig + bkg functions with resolution funct
    - Sig: relativistic Breit-Wigner with two gauss resolution funct.
    - Bkg: exponential

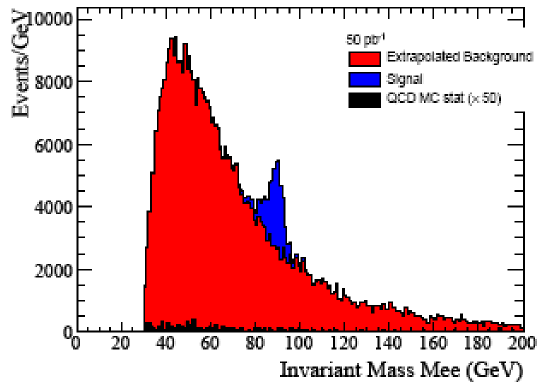
Early cross-section measurements

Z→ee

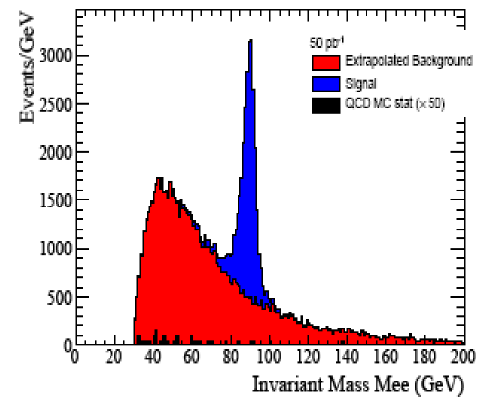
preselection



3 EM estimators

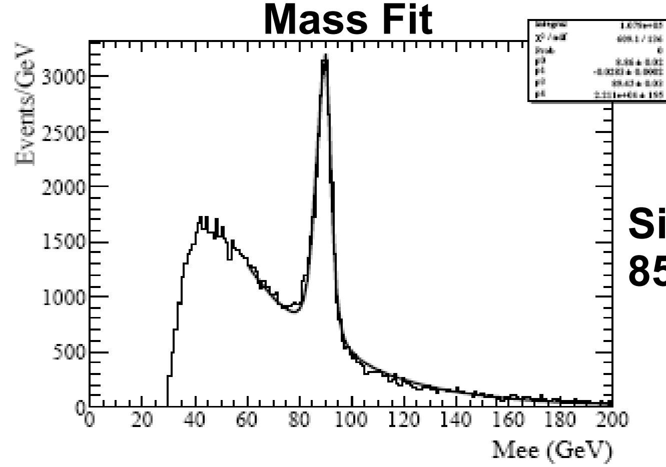


Isolation



- B-W width fixed (PDG value 2.4952 GeV)
- Gauss params fitted in lower and upper sides of mass peak then fixed to 2.89, 1.76 GeV
- Then **free fit params:**
  - B-W peak pos, norm, slope
  - bkg expo constant

Mass Fit



Signal Fit range 85-100 GeV

Stat error on x-sect for 1, 50 pb-1

Lum	3 Esti + Isol	3 Esti + Isol + Charge
1 pb^{-1}	4%	5.3%
50 pb^{-1}	0.56%	0.75%

Syst: 3% underestimation of signal events (poor signal shape), 3% overestimation of bkg events (MC stat)

Move to Tighter Selection as soon as possible to improve accuracy

$W \rightarrow e\nu$

Table 1: Datasets used for this analysis

Dataset	Dataset number	Number of events	σ(filt) [pb]
$W \rightarrow e\nu$	5104	187650	10900
$W \rightarrow \tau\nu$	5106	148300	3400
$Z \rightarrow ee$	5144	109900	1432
QCD dijets	5802	$3.3 \cdot 10^6$	$1.91 \cdot 10^8$

- **Lumi**
  - **Early cross section measurement**
    - Trig: *e20 (10^{31} menu)*
    - electron id : *medium isEM*
  - **High Luminosity measurement**
    - Trig: *e25i (10^{33} menu)*
    - electron id: *tight isEM*

- **Methods**
  - **Cut-based (' a al TDR')**
    - electron id (isEM flag)
    - acceptance and crack removal cuts: electron $|\eta|<1.37$, $1.52<|\eta|<2.4$
    - electron ET > 25 GeV
    - ETmiss> 25 GeV (MET_RefFinal)
    - jet veto: no jet with ET>30 GeV (ele-jet overlap removal $\Delta R<0.4$)
  - **Data-driven:**

ETmiss and Jet Cuts remove most of bkg but irreducible bkg under W peak difficult to estimate.

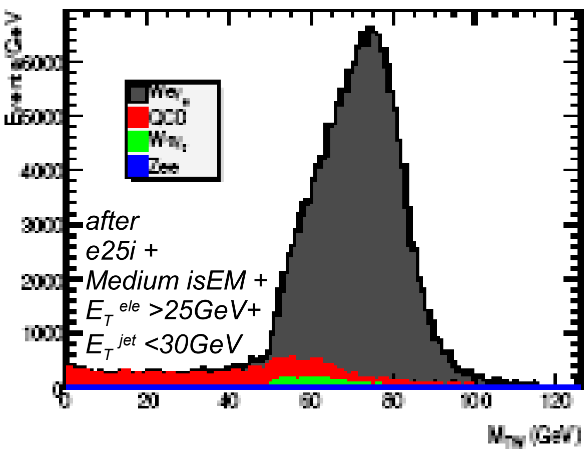
- electron id, acceptance and crack removal cuts
- **do Not apply ETmiss and Jet VetoCuts** to keep shape of bkg outside W peak
  - **reject Zee** (second largest bkg after ele id)
  - **fit and subtract QCD bkg**

→ *Results to finalize:*
Results only for
E25i trig and medium isEM

W → eν

Cut-based selection ('a la TDR')

Transverse mass



Low Lumi:

Table 2: Number of events selected for an integrated luminosity of 50 pb^{-1} using the isEM medium requirement and background rejection. For backgrounds, the ratio $\frac{N_B}{N_S}$ in percent is indicated. The quoted uncertainties are due to the limited Monte-Carlo statistics.

Selection	$W \to e\nu$ (N)	QCD $(f\ (\%))$	$W \to \tau\nu$ $(f\ (\%))$	$Z \to ee$ $(f\ (\%))$
Trigger/offline e-id	$(2.258 \pm 0.007) \cdot 10^5$	475 ± 28	3.35 ± 0.05	11.82 ± 0.04
$E_T^{miss} > 25$ GeV	$(1.861 \pm 0.007) \cdot 10^5$	24 ± 4	2.45 ± 0.04	0.268 ± 0.004
$E_T^{jet} < 30$ GeV	$(1.638 \pm 0.007) \cdot 10^5$	19 ± 4	2.23 ± 0.04	0.124 ± 0.004

High Lumi:

Table 5: Number of events selected for an integrated luminosity of 1 fb^{-1} using the isEM tight requirement and background rejection. For backgrounds, the ratio $\frac{N_B}{N_S}$ in percents is indicated. The quoted uncertainties are only statistical.

Selection	$W \to e\nu$ (N)	QCD $(f\ (\%))$	$W \to \tau\nu$ $(f\ (\%))$	$Z \to ee$ $(f\ (\%))$
Trigger/offline e-id	$3.7 \cdot 10^6 \pm 2 \cdot 10^3$	159 ± 18	3.3 ± 0.01	14.2 ± 0.02
$\not{E}_T > 25$ GeV	$3.1 \cdot 10^6 \pm 2 \cdot 10^3$	10 ± 3	2.4 ± 0.01	0.3 ± 0.003
$E_T^{jet} < 30$ GeV	$2.7 \cdot 10^6 \pm 2 \cdot 10^3$	8 ± 3	2.2 ± 0.01	0.1 ± 0.002

NB: Recoil cut removed wrt standard TDR cut as redundant for S/B

W → eν

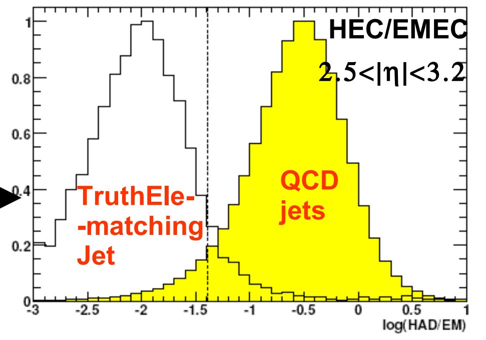
Data-driven Selection

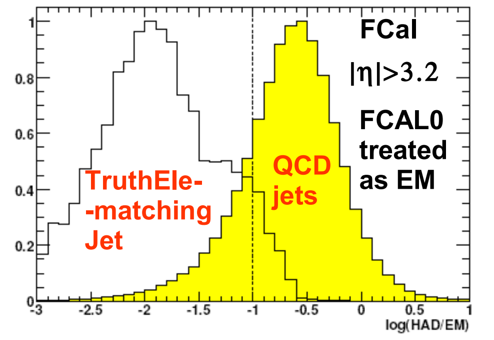
Zee rejection (after ele id and acceptance cut):

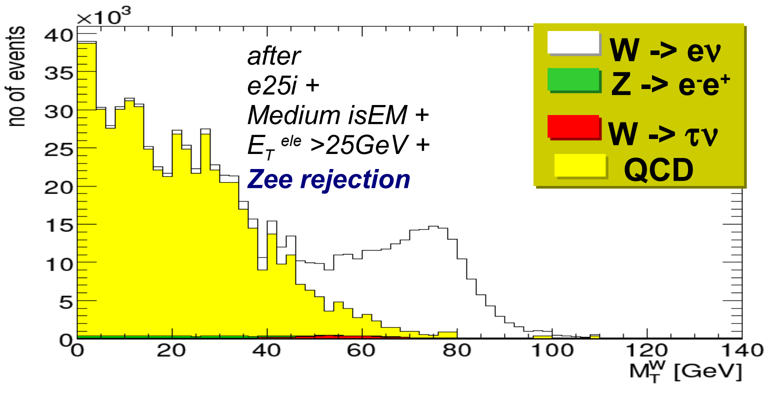
65<M_{inv}<130 cut using following combinations

To maximise acceptance:

- |η|<2.5: 1) opposite charge electron pair
  2) electron – photon candidate
- |η|>2.5: 3) electron – jet candidate
  (cut on ratio Had/EM ratio in jets)







Zee B/S cut from 25% to 2.7%
Negligible amount of rejected QCD,
Negligible amount of rejected W->eν & W->τν
No distortions on distributions

$W \rightarrow e\nu$

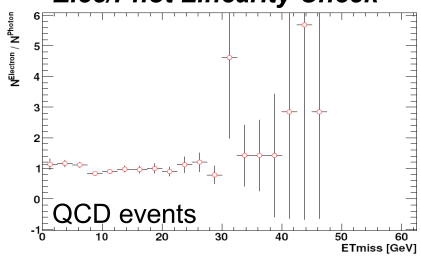
Data-driven Selection

QCD Subtraction:

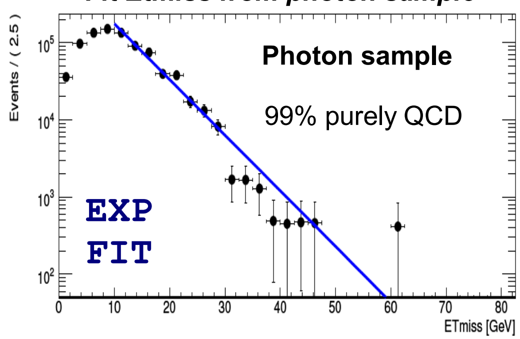
Fit QCD background from orthogonal QCD sample to access distr. tails under W peak

- **FIT ETmiss** from ***photon*** sub-sample in range ETmiss >10 GeV (99% purely QCD)
- **Normalise** to ***electron***-subsample in side-band (10<ETmiss<22.5 GeV)
- **Subtract fit under W peak**: ETmiss>22.5 GeV

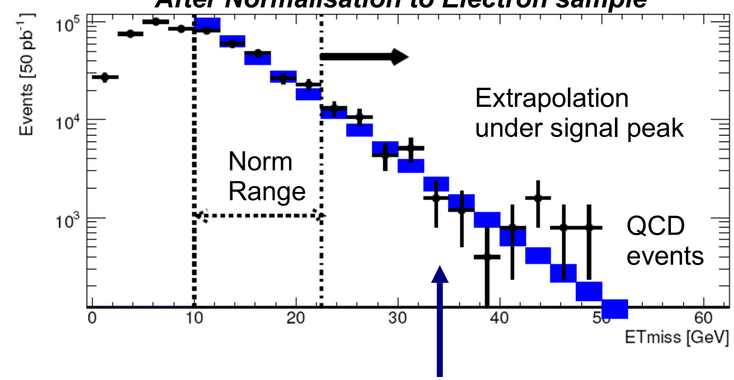
Elec/Phot Linearity Check

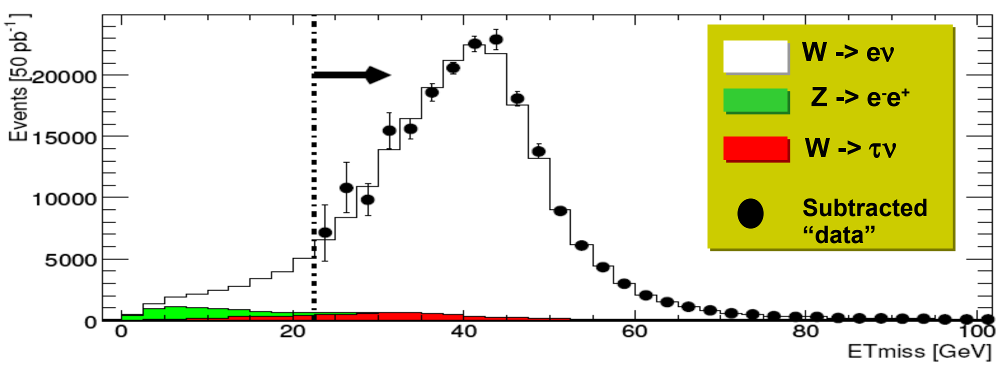


Fit Etmiss from photon sample



After Normalisation to Electron sample





Fit uncertainty dominated by QCD MC sample stat.

S/B uncertainty for QCD ~3.5% compatible with cut based selection (dominated by MC stat).

Param improvement by expo+polynomial ETmiss>10GeV

$W \to e\nu$
Cross-section measurements

$$\sigma B = \sum_i \frac{N_W^i - N_B^i}{A^i \times \varepsilon_e^i \times \varepsilon_t^i \times \int L dt}$$

I = (ET, η) bin
A = geom & kine acceptance
ε_t = trig eff.
ε_e = ele id eff.

However due to limited QCD MC stat.
Only global formula applied

Low Lumi Result:

Table 4: $W \to e\nu_e$ cross section measurement results for 50 pb^{-1}

N_W	$2.0 \cdot 10^5 \pm 4 \cdot 102$	
N_{QCD}	$3.1 \cdot 10^4 \pm 6.2 \cdot 10^4$	→ Conservative 200% from QCD fit
$N_{W\tau\nu}$	$3.6 \cdot 10^3 \pm 610^1$	
N_{Zee}	$2.0 \cdot 102 \pm 10^1$	
A (%)	29.5 ± 2.5	
$\varepsilon_{trigger}$ (%)	93.5 ± 0.2	**From data-driven tag&probe**
$\varepsilon_{electron}$ (%)	73.6 ± 0.2	**From data-driven tag&probe**
$\int Ldt$ (pb^{-1})	100 ± 10	→ Assumed 10%
K-factor	1.22 ± 0.04	→ NNLO corr.
$\sigma B \pm (stat) \pm (syst) \pm (lumi)$ (nb)	$19.9 \pm 0.04 \pm 10.4 \pm 2.0$	

Muon Sector

Trigger efficiency

Muon

- **Trigger:**
  - Early data: single muon 6 GeV threshold
  - Higher Lumi: single muon 20 GeV

Z->μμ Tag&Probe Sel.:

- ❑ **Low Lumi (50 pb^{-1}):**
  - ❑ tracks from stand-alone muon system
  - ❑ isolation cuts based on ID only
- ❑ **Higher Lumi (1 fb^{-1}):**
  - ❑ combined tracks (muon system+ID)
  - ❑ isolation based on ID and Calo

Data Sets used (Sig. & Bkg)

Sample	Software Version	Cuts	Cross-section $[pb^{-1}]$	Number of simulated Events
$Z \rightarrow \mu\mu$	12.0.6	$M_{\mu\mu} > 60\,GeV$ $1\mu : \lvert\eta\rvert < 2.8, p_T > 5\,GeV$	1497	252050
$b\bar{b} \rightarrow \mu\mu$	12.0.6	$2\mu : p_T > 6GeV, \lvert\eta < 2.5\rvert$ $1\mu : p_T > 15\,GeV$	~ 4000	141700
$W \rightarrow \mu\nu$	12.0.6	$1\mu : \lvert\eta\rvert < 2.8, p_T > 5\,GeV$	11946	198450
$t\bar{t} \rightarrow W^+bW^-b$	12.0.6	no all hadronic decay	461	48750
$Z \rightarrow \tau\tau$	12.0.6	$\tau\tau \rightarrow ll, M_{\mu\mu} > 60\,GeV$ $1\mu : \lvert\eta\rvert < 2.8, p_T > 5\,GeV$	77	2750

Cosmics bkg contribution negligible

Isolation Variables:

- ❑ Inner Detector based variables

  (n. tracks in hollow cone, sum pt in hollow cone)

- ❑ Calorimeter based variables

  (sum calo cell ET in hollow cone, jet E in cone)

Cuts on tag&probe tracks

Cut on	Requirement
Charge	opposite
Invariant Mass Requirement	$\lvert 91.2\,GeV - M_{\mu\mu}^{rec}\rvert < 10\,GeV$
Transverse Momentum p_T	$> 20\,GeV$
$N_{0.05<r<0.5}^{ID}$	≤ 4
$\sum_{0.05<r<0.5} p_T^{IDTracks}$	$\leq 8\,GeV$
$\sum_{0.05<r<0.5} E_T$	$\leq 6\,GeV$
$E_{r<0.5}^{Jet}$	$\leq 15\,GeV$

ID-based (low&high lumi)

Calo-based (high lumi)

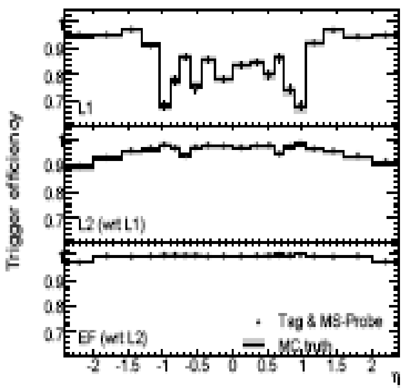
Early data: rely only on one type of isolation (I.D. chosen)

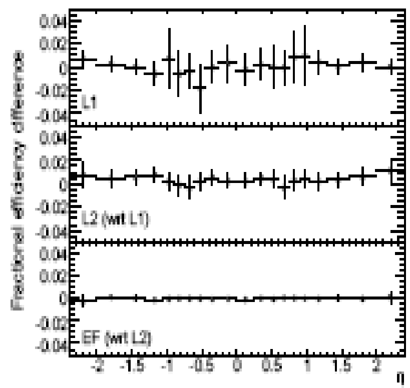
Trigger efficiency

Muon

Trig. Eff. Results Referred to *Offline Muon Spectrometer* reco eff.
(Wrt ID offline reco eff also studied)

Low Lumi Results





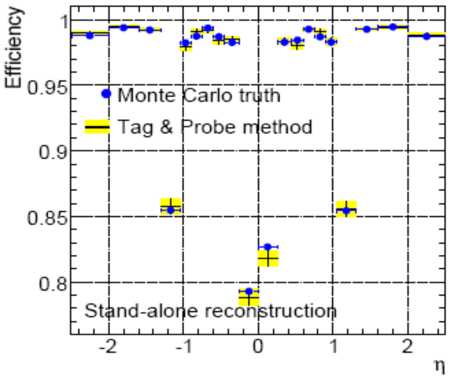
Low luminosity - MS probe ($\int \mathscr{L} dt = 50\ pb^{-1}$)			
Detector region	Barrel ($\lvert\eta\rvert < 1.05$)	Endcap ($1.05 < \lvert\eta\rvert < 2.4$)	Overall ($0 < \lvert\eta\rvert < 2.4$)
Trigger Efficiency	76.94	87.83	82.13
Statistical Uncertainty	0.41	0.34	0.27
$\lvert\varepsilon_{TRUTH} - \varepsilon_{TP}\rvert$	0.17	0.64	0.33
Expected Background Contribution	0.00	0.00	0.00
Overall Systematic Uncertainty	0.17	0.64	0.33

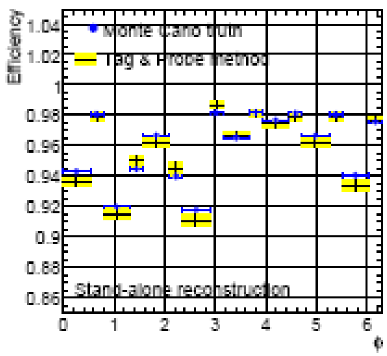
- **Agreement Tag&Probe with MC better than 1%** (2% in cracks η=0, |η|=1.05)
- **Overall syst uncertainty <0.5% in both low and high lumi**

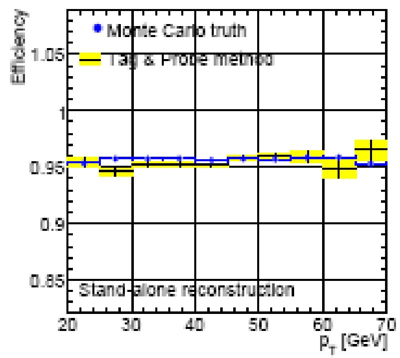
Reconstruction Performance

Muons (Z->μμ)

Tag&Probe Reco Efficiency: Tag&Probe compared with MC-truth (Truth-match ΔR=0.05)







Detector Region	Barrel ($\|\eta\| < 1.05$)	Endcap ($\|\eta\| > 1.05$)	Overall
Efficiency	0.940	0.960	0.952
Statistical Uncertainty ($50\,pb^{-1}$)	0.002	0.002	0.001
Statistical Uncertainty ($1\,fb^{-1}$)	0.000	0.000	0.000
$\|\varepsilon_{Truth} - \varepsilon_{T\&P}\|$	0.001	0.002	0.002
Expected Background Contribution	0.002		
Overall Systematic Uncertainty	0.002	0.003	0.002

Good ageement: negligible correlations between tag and probe tracks

P_T resolution:

$$p_T \to s \cdot f(p_T, \sigma),$$

s = momentum pt scale
σ = pt resolution
f= 1/pt random smearing funct., width σ
e.g. gauss

Method:
vary parameters s, σ in simul.
to reproduce measured Z mass peak

Uncertainty	$\int \mathscr{L}dt = 50\,pb^{-1}$
Momentum Scale Δs	$(5 \pm 7) \cdot 10^{-4}$
Momentum Resolution $\Delta\sigma$	$(11.6 \pm 3.0)\%$

Z->μμ:
- **reco eff. similar for standalone muon system & ID combined**
- **pt resolution significantly better for combined reco**

Early cross-section measurements

Z→μμ

- **Trigger:**
  - Early data: single muon 6 GeV threshold
  - Higher Lumi: single muon 20 GeV
- **Muon Reconstruction:**
  - Early data: Standalone Muon Spectrometer
  - Higher Lumi: Combined with Inner Detector (better momentum resolution)

Data Sets used (Sig. & Bkg)

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Cut on	Requirement
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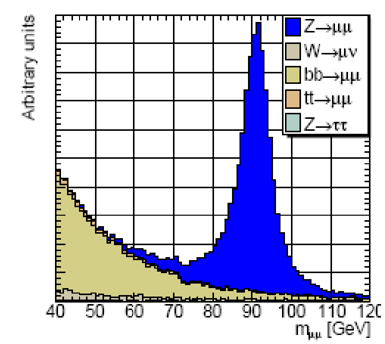
$N_{0.05<r<0.5}^{\text{ID Tracks}}$	≤ 4
$\sum_{0.05<r<0.5} p_T^{\text{ID Tracks}}$	$\leq 8\,GeV$

Early data: rely only on one type of isolation: I.D. chosen

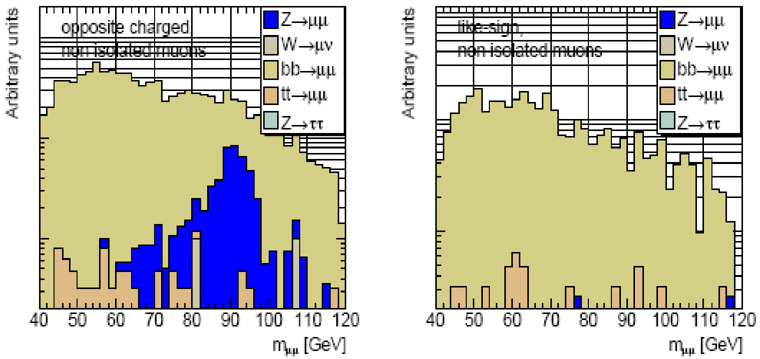
- **Off-line selection:**
  - 2 opposite charged muons with $\lvert\eta\rvert<2.5$
  - muon pT >20 GeV (reduce error on x-sect measurement)
  - $\lvert 91.2\ \text{GeV} - M_{\mu\mu}\rvert < 20$ GeV
  - isolation cuts:
    inner detector based variables

Process	$Z \to \mu\mu$	$b\bar{b} \to \mu\mu$	$W \to \mu\nu$	$Z \to \tau\tau$	$t\bar{t} \to W^+bW^-\bar{b}$
Cut Name	**Number Of Events**				
True Events	141132	673480	2011349	12964	77619
Triggered Events	126578	339782	1236212	2970	23190
2 opposite charged tracks	112380	438057	38301	1372	11685
Invariant mass cut	102305	8688	1216	47	785
p_T cuts	93052	4225	122	38	452
Isolation cuts	86287	62	30	38	224

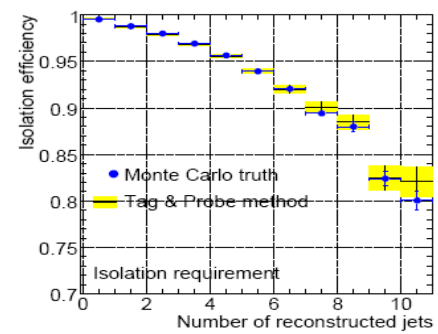


Early cross-section measurements

$Z \to \mu\mu$ Systematics Studies



- ❑ **Background Estimation**
  - ❑ **Z → ττ** from MC
  - ❑ **tt**: x-sect known to ~15% precision (mainly PDF uncert.)
    - ❑ muon reco & trig eff asumed equivalent to Z events
    - ❑ isolation (larger had activity): assumed lept. decayed tt equivalent to Z boson with 2 jets ET> 50 GeV
      - ❑ iso eff from Z data: 10% syst error wrt tt MC truth
  - ❑ **QCD:** use QCD enriched sub-sample,i.e. 2 like-sign non-iso muons (N_{LS})
    - ❑ count N_{LS} from data (indep. from isol prob.)
    - ❑ ratio $r_{OS, LS}$ of isol. Opposite-sign μ / isol like-sign μ from MC
    - ❑ $N_{LS} * r_{OS, LS}$ = QCD bkg contribution, 100% syst uncert. Assumed
  - ❑ **W→ μν**
    - ❑ equivalent to Z → μμ + μ , remove di-boson events by subtracting 3-tight isol muon events
      - ❑ conservative syst error 50% estimated
  - ❑ **cosmic** muons neglected
- ❑ **Kinematic cuts**
  - ❑ **muon pT resolution**: small impact on ε_{all} (<0.002)
  - ❑ **momentum scale**: larger impact on ε_{all} (<0.003)
- ❑ **isolation cuts** (related to n. jets in event)
  - ❑ tag&probe method: $\Delta\varepsilon_{ISO}$ = 0.003 syst due to bkg contribution



- ❑ **Other** (prim. Vertex, misalign., pile-up, min-bias): studied, no dominant in early run

Early cross-section measurements

$Z \rightarrow \mu\mu$ Systematics Results

$$\varepsilon_{All} = ((\varepsilon_{Trigger})^2 + 2 \cdot \varepsilon_{Trigger} \cdot (1 - \varepsilon_{Trigger})) \cdot (\varepsilon_{MS})^2 \cdot \varepsilon_{kinematics} \cdot (\varepsilon_{Isolation})^2$$

Syst. Break-down (100 pb^{-1})

Efficiency	Trigger	Muon Reconstruction	Kinematic Cuts	Isolation
Background Contribution	0.002	0.002	-	0.003
$\lvert\varepsilon_{\mathrm{Truth}} - \varepsilon_{T\&P}\rvert$	0.003	0.009	0.003	0.001

Uncertainty $\frac{\Delta\varepsilon_{All}}{\varepsilon_{All}} \approx 0.004(\mathrm{stat}) \pm 0.022(\mathrm{sys})$ **Not including theoretical uncertainties (PDF etc.)**

Higher Lumi measurements

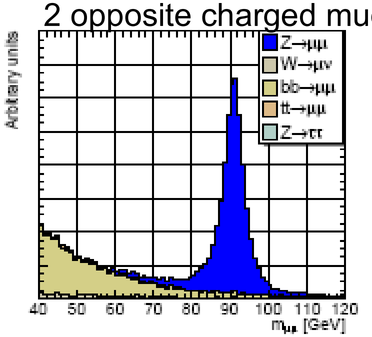
Z→μμ

Assume detector response is better understood at higher lumi run (1 fb^{-1})
- **More complex analysis algorithms and tighter selection**

Cut on	Requirement
Charge	opposite
Invariant Mass Requirement	$\|91.2\,GeV - M_{\mu\mu}^{rec}\| < 15\,GeV$
Transverse Momentum p_T	$> 20\,GeV$
$N^{ID\ Tracks}_{0.05<r<0.5}$	≤ 4
$\sum_{0.05<r<0.5} p_T^{ID\ Tracks}$	$\leq 8\,GeV$
$\sum_{0.05<r<0.5} E_T$	$\leq 10\,GeV$
$E^{Jet\ Energy}_{r<0.5}$	$\leq 25\,GeV$

Process	$Z\to\mu\mu$	$b\bar{b}\to\mu\mu$	$W\to\mu\nu$	$Z\to\tau\tau$	$t\bar{t}\to W^+bW^-\bar{b}$
Cut Name	Number Of Events				
Triggered events	126578	339782	1236212	2970	23190
2 opposite charged tracks	110063	360200	18507	1183	9913
Invariant mass cut	100237	5879	699	14	549
p_T cuts	91554	2937	122	9	338
Isolation cuts	82293	0	0	9	148

Only requirement:
2 opposite charged muons



Off-line selection (differences wrt low Lumi)

- combined reconstruction
- since pT resolution improved
  - Z width decreased
    - reduced mass window: 15 GeV (still $5\sigma_Z$)
- Isolation cuts:
  - inner detector based variables
  - calorimeter based variables

Sample	Two opposite charged reconstructed muons	Invariant mass cut	p_T cuts	Isolation cuts
Signal S	653696	595337	543766	488762
Background B	2315159	42418	20228	935
$\frac{S}{S+B}$	0.220	0.933	0.964	0.998

0.5 M selected Z->mm events with 1 fb^{-1}

Overall sel eff.:

$$\frac{\Delta\epsilon_{All}}{\epsilon_{All}} \approx 0.001(stat) \pm 0.007(sys)$$

Bkg contamination reduced (tighter cuts)
Smaller uncertainty on Trig. Eff.

Expected syst uncertainty (1 fb^{-1})

Efficiency	Trigger	Muon Reconstruction	Kinematic Cuts	Isolation
Background Contribution	0.001	0.001	-	0.002
$\|\epsilon_{Truth} - \epsilon_{T\&P}\|$	0.002	0.002	0.001	0.001

Differential Cross-section measurements

Differential Cross-section measurements

D0 Method

Z→ee

Category i	Definition	n_i
1	All events	364 750
2	Fiducial and kinematics (gen.)	163 198
3	Trigger and offline (fiducial, kinematics and ID)	82210
4	Intersection of categories 2 and 3	80859

Selection

- ❑ **On/Off-Line:**
  - ❑ Trig. 2e15i, 2 oppos. charged ele
  - ❑ tight isEM
- ❑ **Fiducial+Kine:**
  - ❑ |η|<2.5, PT>20 GeV
  - ❑ 75 GeV< M_{ee}<105 GeV

Z→μμ

Category i	Definition	n_i
1	All events	445650
2	Fiducial and kinematics (gen.)	234610
3	Trigger and offline (fiducial, kinematics and ID)	181652
4	Intersection of categories 2 and 3	180260

Selection

- ❑ **On/Off-Line:**
  - ❑ Trig. mu20i, 2 oppos. charged μ,
  - ❑ reconstructed in Muon Spectrometer & ID
  - ❑ ID-based Isolation

Cut	Z events	W events	$b\bar{b}$ events
Before cuts	22,529	37	785
Ntracks<6	22,320	15	200
$E_{T,cone}$<20 GeV	22,103	7	47

- ❑ **Fiducial+Kine:**
  - ❑ |η|<2.5, 1st μ PT>20 GeV, 2nd μ PT>15 GeV
  - ❑ 76 GeV< M_{ee}<106 GeV

Negligible bkg contamination

x-sect in y,pt bins (σ_α)

$$\sigma_\alpha = \frac{S_\alpha}{L_{int}} \frac{d_\alpha - b_\alpha}{\varepsilon_\alpha A_\alpha}$$

$$S_\alpha = \frac{n_{3,\alpha}}{n_{4,\alpha}}, \quad \varepsilon_\alpha = \frac{n_{3,\alpha}}{n_{2,\alpha}}, \quad A_\alpha = \varepsilon_{filter}\frac{n_{2,\alpha}}{n_{1,\alpha}}, \quad d_\alpha = n_{3,\alpha}$$

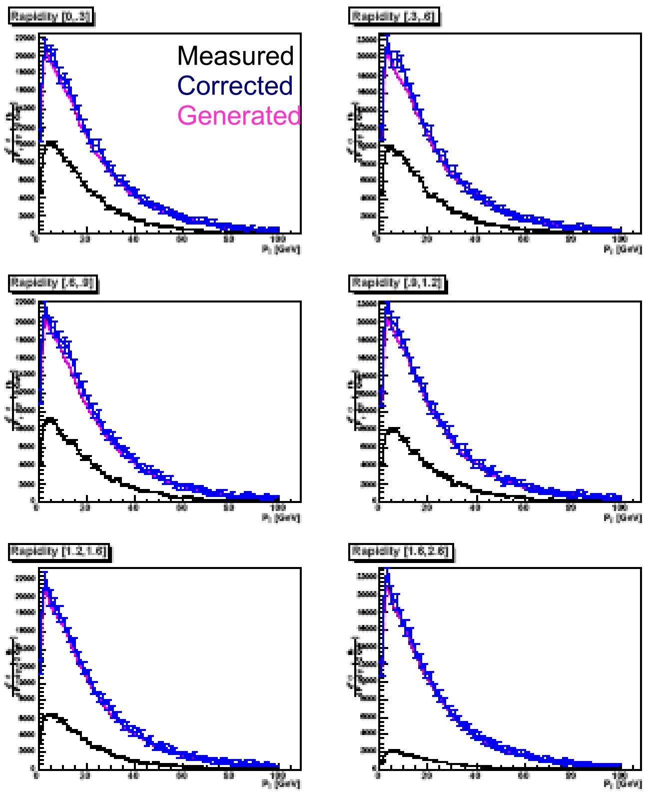
Det smearing corr **Event Sel eff** **Gom Accept.** **Event Count**

Differential Cross-section measurements

D0 Method Results

Z→ee

Binning:
- 50 pt bins 0<pT<100 GeV
- 6 y bins 0<|y|<2.6



Z→μμ

Binning:
- 50 pt bins 0<pT<100 GeV
- 9 y bins 0<|y|<2.7

Lumi 0.2015 fb^{-1}

Good agreement With MC Truth

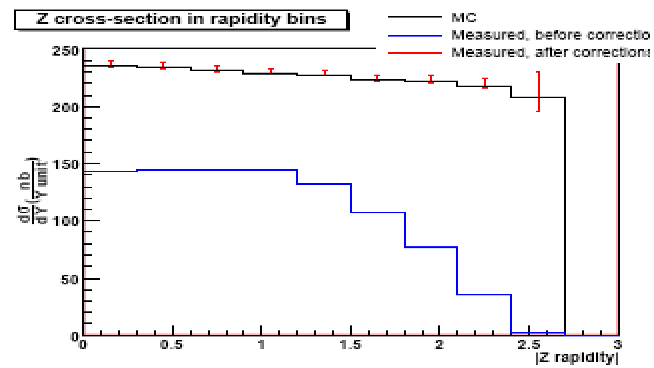
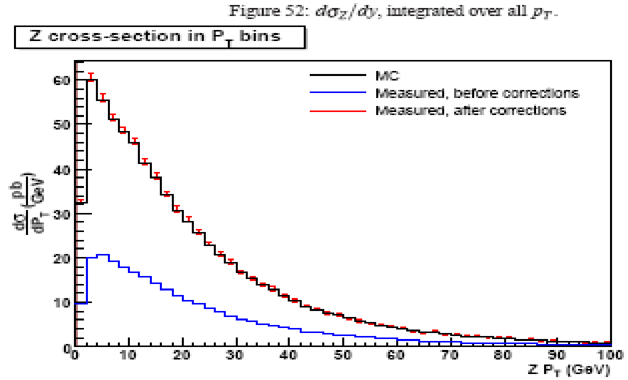


Figure 52: $d\sigma_Z/dy$, integrated over all p_T.



Differential Cross-section measurements

Alternative Method

Original attempts to extract cross-section and reconstruction efficiencies simultaneously

$$N_{ij}^{\alpha} = \varepsilon_i \varepsilon_j P_{ij}^{\alpha} \mathscr{L} \Delta\sigma^{\alpha}$$

P^{a}_{ij} = prob. Z produced in bin α decays in lepton bins i, j (from MC)
$\varepsilon_i,\varepsilon_j$ = lept. Reco eff. (not expected to depend on α, but not necessary assumption)
L = int. lumi
$\Delta\sigma^{\alpha}$ = Z prod. X-sec in bin α

P^{a}_{ij} incorporates
all detector effects,
i.e. resolution effects

→ **Over-constraint system with unknowns $\Delta\sigma^{\alpha}$ and $\varepsilon_i,\varepsilon_j$**

Problem at low stat solved by non const binning and average eff.: $\mathscr{L}\Delta\sigma^{\alpha} = \dfrac{N_{ij}^{\alpha}}{<\varepsilon_i><\varepsilon_j> P_{ij}^{\alpha}}$

Method agrees to previous method when only 1 lept. bin in Et and η: $\mathscr{L}\Delta\sigma^{\alpha} = \dfrac{N^{\alpha}}{\varepsilon^{\alpha}\varepsilon^{\alpha}A^{\alpha}}$

Complete method tested on Z->$\mu\mu$:

- N. Bins Z P_T = 10 $0<P_T^Z<60$ GeV
- N. Bins Z y =5 $|y^Z|<2.5$
- N. Bins μ-ET = 1 (no μ reco pt-dependence above 10 GeV)
- N. Bins μ–η = 7 (dictated by det geometry)

Differential Cross-section measurements

Alternative Method Results

Figure 54: $\mathscr{L}\Delta\sigma$ versus y^Z, for each bin in p_T^Z.

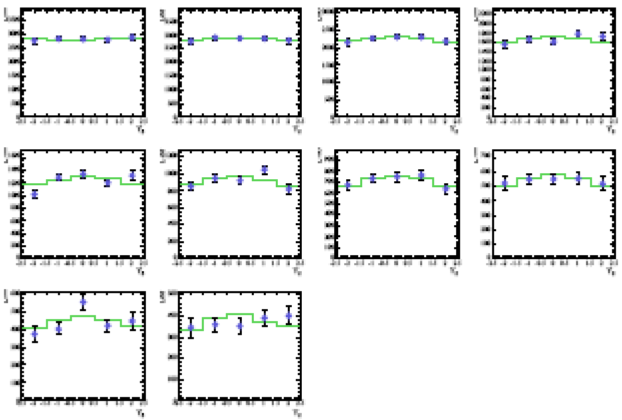
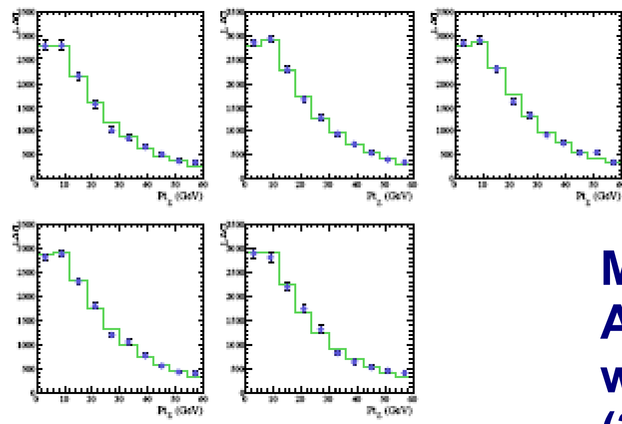
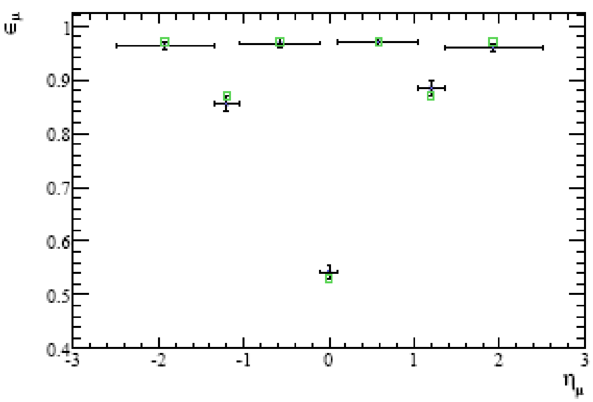


Figure 55: $\mathscr{L}\Delta\sigma$ versus p_T^Z, for each bin in y^Z.



Measured and truth Agree well within stat precision (3-20%)

Figure 56: Reconstructed efficiency versus η.



η dependence of reco eff. (precision ~2%)

Conclusion

- Extensive CSC note;
- tools and algorithms are in place to analyze early LHC data (<= 50 pb-1);
- higher lumi data (~1 fb-1) not overlooked;
- perfom mesurements of W and Z cross sections;
- Data-driven methods have been developed to estimate efficiencies, systematic uncertainties and background contamination;

EXTRA

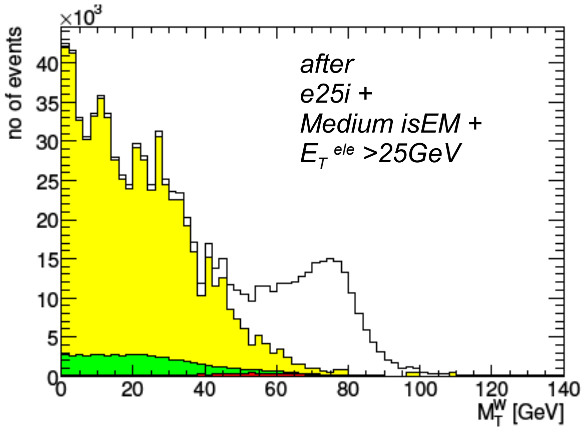
Electron identification

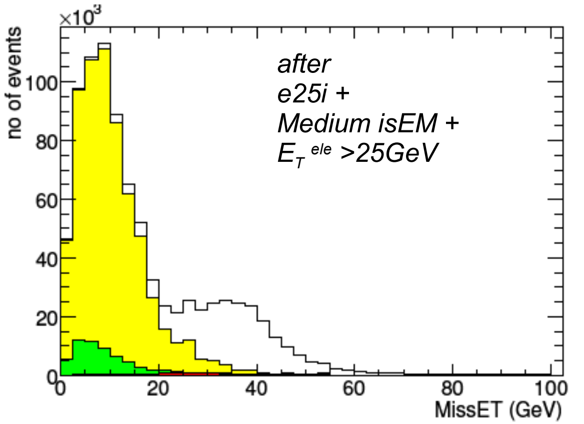
Table 2: Flags used for offline electron identification

tightness	IsEM bit mask	selection applied
loose	(IsEM & 0x7)==0	loose track-cluster matching
		hadronic leakage cut
		shower shapes in second EM sampling
medium	(IsEM & 0x3FF)==0	standard track-cluster matching
		hadronic leakage cut
		shower shapes in first and second EM sampling
tight	IsEM == 0	as medium plus
		cut n b-layer hit
		cuts on TR ratio

$W \rightarrow e\nu$

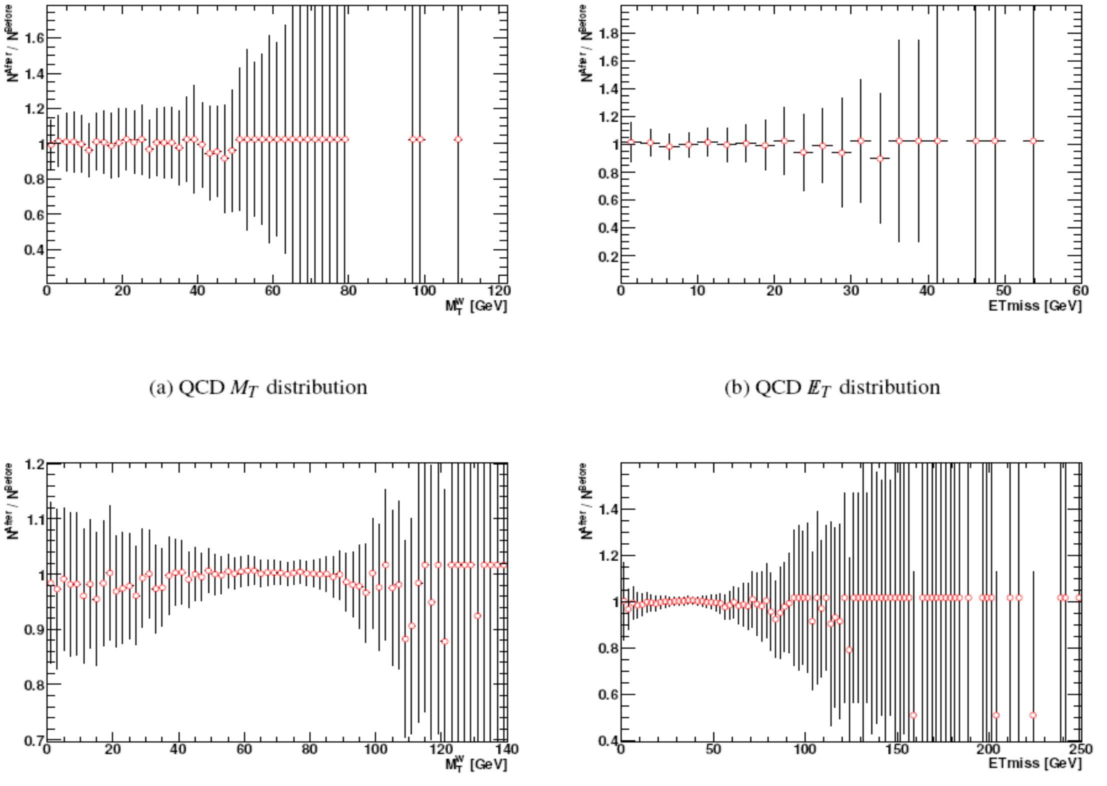
Cut-based selection ('a la TDR')





W → eν

Z->ee removal



(a) QCD M_T distribution

(b) QCD $\not{E}_T$ distribution

(c) $W \to e\nu$ M_T distribution

(d) $W \to e\nu$ $\not{E}_T$ distribution

$W \rightarrow e\nu$

Electron Trigger efficiency
Used for W->en x-section measurement

- $p_T > 25$ GeV
- egamma = 1
- IsEM = (0x7: loose, 0x3FF: medium, 0xF0F: tight)
- Two good offline electrons as described above
- Equal and opposite charge
- Reconstructed mass 70GeV →100GeV

Tag&Probe

Event type	Dataset Number	Generator	Sim/Rec version	Number of events	Cross section (including filter efficiency) (pb)
Z→ee inclusive	5144	Pythia	12.0.31/12.0.61	476300	1432

Measurement	Candidate	Level	Sample	Truth	Offline	L1	L2	EF
Data	Tag	All	All	×	✓ (tight)	✓	✓	✓
	Probe	L1	N1	×	✓	×	×	×
	Probe	L1	N2	×	✓	✓	×	×
	Probe	L2	N1	×	✓	✓	×	×
	Probe	L2	N2	×	✓	✓	✓	×
	Probe	EF	N1	×	✓	✓	✓	×
	Probe	EF	N2	×	✓	✓	✓	✓
Truth	Tag	All	All	✓	×	×	×	×
	Probe	L1	N1	✓	✓	×	×	×
	Probe	L1	N2	✓	✓	✓	×	×
	Probe	L2	N1	✓	✓	✓	×	×
	Probe	L2	N2	✓	✓	✓	✓	×
	Probe	EF	N1	✓	✓	✓	✓	×
	Probe	EF	N2	✓	✓	✓	✓	✓

Table 2: Tag and probe requirements

$W \rightarrow e\nu$

Electron Trigger efficiency
Used for W->en x-section measurement

Trigger Level	wrt loose	wrt medium	wrt tight
LVL1	97.63 (0.02)	97.80 (0.02)	97.88 (0.03)
	97.64 (0.02)	97.79 (0.02)	97.86 (0.02)
LVL2	95.46 (0.03)	97.48 (0.03)	97.29 (0.03)
	95.67 (0.03)	97.40 (0.02)	97.21 (0.03)
EF	93.82 (0.03)	95.28 (0.04)	97.74 (0.03)
	94.23 (0.03)	95.66 (0.03)	97.89 (0.02)
Whole trigger	87.44 (0.05)	90.84 (0.05)	93.08 (0.04)
	88.02 (0.05)	91.11 (0.04)	93.12 (0.04)

Global eff.

Table 3: Tag and probe global efficiencies. Statistical uncertainty given in parenthesis. Upper number is the data measurement and lower number is the truth measurement.

Loose isEM

Level	$\|\eta\|$	25GeV $< p_T <$ 40GeV	$p_T >$ 40GeV
L1	0-0.8	96.71 (0.05)	97.11 (0.05)
	0.8-1.37	97.89 (0.06)	98.48 (0.05)
	1.52-1.8	95.54 (0.13)	98.94 (0.07)
	1.8-2.4	98.97 (0.05)	99.20 (0.05)
L2	0-0.8	97.81 (0.05)	98.37 (0.04)
	0.8-1.37	97.23 (0.07)	98.29 (0.05)
	1.52-1.8	90.75 (0.19)	93.15 (0.18)
	1.8-2.4	85.23 (0.19)	85.50 (0.19)
EF	0-0.8	94.27 (0.08)	94.27 (0.08)
	0.8-1.37	91.38 (0.12)	91.75 (0.11)
	1.52-1.8	96.35 (0.13)	96.99 (0.13)
	1.8-2.4	95.41 (0.12)	95.86 (0.12)
Overall	0-0.8	89.17 (0.10)	89.83 (0.09)
	0.8-1.37	86.98 (0.13)	88.81 (0.12)
	1.52-1.8	83.54 (0.23)	89.40 (0.22)
	1.8-2.4	80.48 (0.21)	81.31 (0.21)

Medium isEM

Level	$\|\eta\|$	25GeV $< p_T <$ 40GeV	$p_T >$ 40GeV
L1	0-0.8	96.83 (0.06)	97.15 (0.05)
	0.8-1.37	98.19 (0.06)	98.58 (0.05)
	1.52-1.8	97.03 (0.13)	99.15 (0.07)
	1.8-2.4	99.01 (0.06)	99.27 (0.05)
L2	0-0.8	99.54 (0.02)	99.76 (0.03)
	0.8-1.37	99.21 (0.04)	99.53 (0.03)
	1.52-1.8	95.21 (0.16)	95.96 (0.16)
	1.8-2.4	87.71 (0.20)	87.35 (0.20)
EF	0-0.8	95.60 (0.07)	95.18 (0.07)
	0.8-1.37	93.10 (0.11)	93.17 (0.10)
	1.52-1.8	98.44 (0.10)	98.55 (0.10)
	1.8-2.4	97.74 (0.09)	97.92 (0.09)
Overall	0-0.8	92.14 (0.09)	92.25 (0.08)
	0.8-1.37	90.69 (0.13)	91.42 (0.11)
	1.52-1.8	90.94 (0.21)	93.76 (0.19)
	1.8-2.4	84.88 (0.21)	84.91 (0.21)

Tight isEM

Level	$\|\eta\|$	25GeV $< p_T <$ 40GeV	$p_T >$ 40GeV
L1	0-0.8	96.80 (0.07)	97.14 (0.06)
	0.8-1.37	98.36 (0.06)	98.64 (0.05)
	1.52-1.8	97.52 (0.12)	99.17 (0.07)
	1.8-2.4	99.05 (0.06)	99.22 (0.05)
L2	0-0.8	99.58 (0.02)	99.78 (0.02)
	0.8-1.37	99.30 (0.04)	99.58 (0.03)
	1.52-1.8	95.30 (0.17)	96.05 (0.17)
	1.8-2.4	87.75 (0.20)	87.52 (0.21)
EF	0-0.8	97.95 (0.06)	97.80 (0.05)
	0.8-1.37	96.77 (0.08)	96.69 (0.08)
	1.52-1.8	98.89 (0.09)	99.05 (0.08)
	1.8-2.4	98.41 (0.08)	98.78 (0.07)
Overall	0-0.8	94.42 (0.09)	94.79 (0.08)
	0.8-1.37	94.52 (0.11)	94.98 (0.10)
	1.52-1.8	91.92 (0.22)	94.35 (0.19)
	1.8-2.4	85.54 (0.21)	85.79 (0.22)

$W \to e\nu$

Electron Identification and reconstruction efficiency
Used for W->en x-section measurement

- $P_t > 25GeV$
- $\eta < 2.4$, cracks excluded $(1.37 < \eta < 1.52)$
- *egamma* author

Tag&Probe

convolution of
Absolute Electron efficiency
isEM wrt electron container

Global Eff.

Luminosity	Eff. (Signal)	Stat.	Data - MC	S - (S+BK)
50 pb^{-1}	89.77	0.19	0.30	0.34
1 fb^{-1}	89.39	0.04	0.61	0.26

Table 1: Loose Electron

Luminosity	Eff. (Signal)	Stat.	Data - MC	S - (S+BK)
50 pb^{-1}	75.68	0.29	0.21	0.71
1 fb^{-1}	75.18	0.07	0.30	0.46

Table 2: Medium Electron

Luminosity	Eff. (Signal)	Stat.	Data - MC	S - (S+BK)
50 pb^{-1}	62.27	0.37	0.14	0.28
1 fb^{-1}	62.28	0.09	0.49	0.56

Table 3: Tight Electron

Differential Eff.

$\|\eta\| \setminus P_t$	15 – 25	25 – 40	40 – 70
0 – 0.8	88.88 ± 1.21 ± 1.17	92.41 ± 0.42 ± 0.91	93.29 ± 0.74 ± 1.88
0.80 – 1.37	87.55 ± 2.69 ± 3.30	90.75 ± 0.55 ± 0.29	92.69 ± 0.45 ± 0.19
1.52 – 1.80	83.18 ± 2.17 ± 3.13	83.00 ± 1.17 ± 0.93	85.87 ± 1.12 ± 0.79
1.80 – 2.40	72.66 ± 2.81 ± 5.00	80.47 ± 0.92 ± 2.41	80.54 ± 0.87 ± 0.36

Table 4: Loose identification efficiency

$\|\eta\| \setminus P_t$	15 – 25	25 – 40	40 – 70
0 – 0.8	76.48 ± 4.70 ± 4.14	79.47 ± 0.80 ± 1.19	83.39 ± 0.68 ± 0.33
0.80 – 1.37	72.59 ± 3.83 ± 1.80	77.95 ± 1.08 ± 0.74	82.84 ± 0.85 ± 1.23
1.52 – 1.80	47.02 ± 7.30 ± 1.18	61.21 ± 1.80 ± 0.63	69.36 ± 1.95 ± 4.28
1.80 – 2.40	56.83 ± 3.89 ± 0.93	61.79 ± 1.42 ± 1.37	65.31 ± 1.38 ± 0.42

Table 5: Medium identification efficiency

$\|\eta\| \setminus P_t$	15 – 25	25 – 40	40 – 70
0 – 0.8	63.15 ± 2.85 ± 4.85	64.68 ± 0.97 ± 0.56	66.54 ± 0.90 ± 0.42
0.80 – 1.37	59.29 ± 3.52 ± 4.71	63.34 ± 1.23 ± 0.00	68.03 ± 1.10 ± 1.23
1.52 – 1.80	38.58 ± 5.08 ± 1.95	54.77 ± 1.83 ± 1.17	62.89 ± 2.05 ± 4.93
1.80 – 2.40	51.70 ± 3.02 ± 2.36	58.81 ± 1.39 ± 1.58	61.82 ± 1.44 ± 0.19

Table 6: Tight identification efficiency

Reconstruction Performance

Muons

MC-Truth Study:

Reco Efficiency

$$\epsilon := \frac{N_{\text{Correctly Reconstructed Tracks}}}{N_{\text{Monte Carlo Truth Muons}}}$$

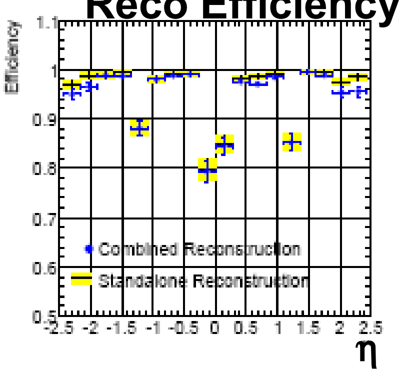
Truth-match ΔR=0.05

Momentum pt Reslution

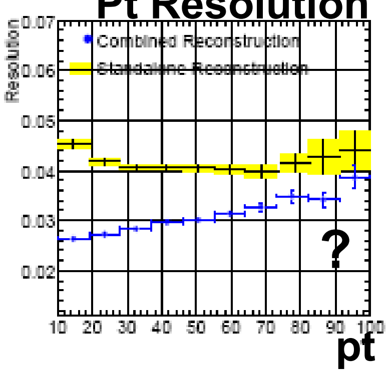
$$\rho := \frac{\frac{1}{p_T^{Truth}} - \frac{1}{p_T^{Reconstructed}}}{\frac{1}{p_T^{Truth}}} = 1 - \frac{p_T^{Truth}}{p_T^{Reconstructed}}.$$

Gaus fit:
Width = resol
Mean = mom-scale

Reco Efficiency



Pt Resolution



Z->μμ:

- eff. Similar for standalone & combined
- resolution significantly better for combined reco

$W \rightarrow e\nu$
Cross-section measurements

$$\sigma B = \sum_i \frac{N_W^i - N_B^i}{A^i \times \varepsilon_e^i \times \varepsilon_t^i \times \int L dt}$$

I = (ET, η) bin
A = geom & kine acceptance
ε_t = trig eff.
ε_e = ele id eff.

However due to limited QCd MC stat.
Only global formula applied

Low Lumi Result:

Table 4: $W \rightarrow e\nu_e$ cross section measurement results for 50 pb^{-1}

N_W	$2.0 \cdot 10^5 \pm 4 \cdot 102$	
N_{QCD}	$3.1 \cdot 10^4 \pm 6.2 \cdot 10^4$	→ Conservative 200% from QCD fit
$N_{W\tau\nu}$	$3.6 \cdot 10^3 \pm 6 \dot{1}0^1$	
N_{Zee}	$2.0 \cdot 102 \pm 10^1$	
A (%)	29.5 ± 2.5	
$\varepsilon_{trigger}$ (%)	93.5 ± 0.2	} **From data-driven tag&probe**
$\varepsilon_{electron}$ (%)	73.6 ± 0.2	
$\int Ldt$ (pb^{-1})	100 ± 10	→ Assumed 10%
K-factor	1.22 ± 0.04	→ NNLO corr.
$\sigma B \pm (stat) \pm (syst) \pm (lumi)$ (nb)	$19.9 \pm 0.04 \pm 10.4 \pm 2.0$	

High Lumi Result:

Table 6: $W \rightarrow e\nu_e$ cross section measurement results for 1 fb^{-1}

N_W	$3.0 \cdot 10^6 \pm 2 \cdot 10^3$	
N_{QCD}	$2.1 \cdot 10^5 \pm 10^5$	→ Assumed 50% as in CDF run II
$N_{W\tau\nu}$	$6.0 \cdot 10^4 \pm 2 \cdot 10^2$	
N_{Zee}	$3.9 \cdot 10^3 \pm 6 \cdot 10^1$	
A (%)	29.1 ± 2.5	
$\varepsilon_{trigger}$ (%)	93.08 ± 0.04	} **From data-driven tag&probe**
$\varepsilon_{electron}$ (%)	71.35 ± 0.04	
$\int Ldt$ (pb^{-1})	1000 ± 50	→ Assumed 10%
K-factor	1.22 ± 0.03	→ NNLO corr.
$\sigma B \pm (stat) \pm (syst) \pm (lumi)$ (nb)	$19.8 \pm 0.01 \pm 2.4 \pm 1.0$	

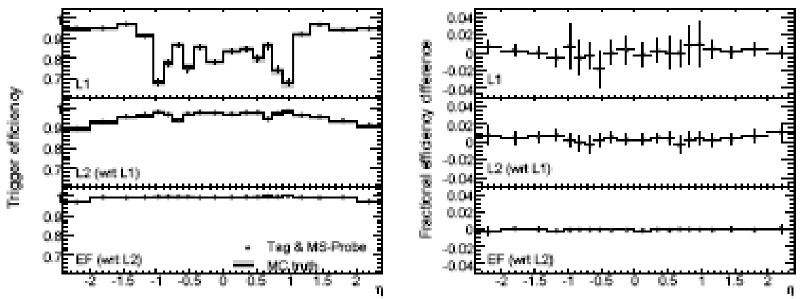
Trigger efficiency

Muon

Trig. Eff. Results Referred to *Offline Muon Spectrometer* reco eff.

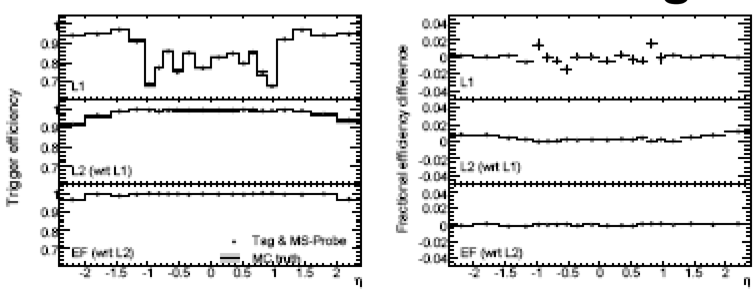
(Wrt ID offline reco eff also studied)

Low Lumi Results



Low luminosity - MS probe ($\int \mathcal{L} dt = 50\ pb^{-1}$)			
Detector region	Barrel ($\lvert\eta\rvert < 1.05$)	Endcap ($1.05 < \lvert\eta\rvert < 2.4$)	Overall ($0 < \lvert\eta\rvert < 2.4$)
Trigger Efficiency	76.94	87.83	82.13
Statistical Uncertainty	0.41	0.34	0.27
$\lvert\varepsilon_{TRUTH} - \varepsilon_{TP}\rvert$	0.17	0.64	0.33
Expected Background Contribution	0.00	0.00	0.00
Overall Systematic Uncertainty	0.17	0.64	0.33

High Lumi Results



High luminosity - MS probe ($\int \mathcal{L} dt = 1000\ pb^{-1}$)			
Detector region	Barrel ($\lvert\eta\rvert < 1.05$)	Endcap ($1.05 < \lvert\eta\rvert < 2.4$)	Overall ($0 < \lvert\eta\rvert < 2.4$)
Trigger Efficiency	78.27	90.40	84.37
Statistical Uncertainty	0.10	0.07	0.06
$\lvert\varepsilon_{TRUTH} - \varepsilon_{TP}\rvert$	0.00	0.47	0.42
Expected Background Contribution	0.00	0.00	0.00
Overall Systematic Uncertainty	0.00	0.47	0.42

- **Agreement Tag&Probe with MC better than 1%** (2% in cracks η=0, $|\eta|$=1.05)
- **Overall syst uncertainty <0.5% in both low and high lumi**