Search for a Heavy Neutrino and Right-Handed W of The Left-Right Symmetric Model in pp Collisions at 7 TeV

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The content of this note is intended for CMS internal use and distribution only

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Search for a heavy neutrino and right-handed W of the left-right symmetric model in pp collisions at s=7 TeV

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Abstract

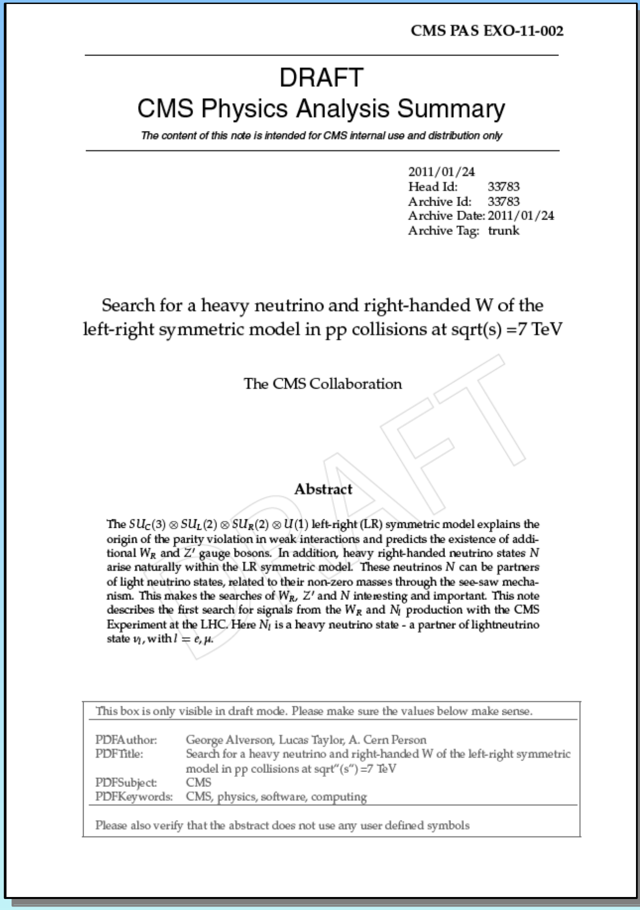
The $SU_C(3) \otimes SU_L(2) \otimes SU_R(2) \otimes U(1)$ left-right (LR) symmetric model explains the origin of the parity violation in weak interactions and predicts the existence of additional W_R and Z' gauge bosons. In addition, heavy right-handed neutrino states N arise naturally within the LR symmetric model. These neutrinos N can be partners of light neutrino states, related to their non-zero masses through the see-saw mechanism. This makes the searches of W_R, Z' and N interesting and important. This note describes the first search for signals from the W_R and N_l production with the CMS Experiment at the LHC. Here N_l is a heavy neutrino state - a partner of light neutrino state ν_l, with $l = e, \mu$. No excess over the background from the Standard Model processes is observed. For models with exact left-right symmetry (the same coupling in the right sector) we exclude the region in the two-dimensional parameter space (M_{W_R}, M_{N_l}) that goes up to $M_{W_R} = 1300$ GeV for $l = e$ and up to 1350? GeV for $l = \mu$.

This box is only visible in draft mode. Please make sure the values below make sense.

PDFAuthor: Mikhail Kirsanov, Jeremiah Mans
PDFTitle: Search for a heavy neutrino and right-handed W of the left-right symmetric model in pp collisions at s=7 TeV
PDFSubject: CMS
PDFKeywords: CMS, physics, software, computing

Please also verify that the abstract does not use any user defined symbols

Last update at the CMS LQ meeting Apr. 22



CMS PAS EXO-11-002

DRAFT
CMS Physics Analysis Summary

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2011/01/24
Head Id: 33783
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Search for a heavy neutrino and right-handed W of the left-right symmetric model in pp collisions at sqrt(s) =7 TeV

The CMS Collaboration

Abstract

The $SU_C(3) \otimes SU_L(2) \otimes SU_R(2) \otimes U(1)$ left-right (LR) symmetric model explains the origin of the parity violation in weak interactions and predicts the existence of additional W_R and Z' gauge bosons. In addition, heavy right-handed neutrino states N arise naturally within the LR symmetric model. These neutrinos N can be partners of light neutrino states, related to their non-zero masses through the see-saw mechanism. This makes the searches of W_R, Z' and N interesting and important. This note describes the first search for signals from the W_R and N_l production with the CMS Experiment at the LHC. Here N_l is a heavy neutrino state - a partner of lightneutrino state ν_l, with $l = e, \mu$.

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PDFAuthor: George Alverson, Lucas Taylor, A. Cern Person
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- **AN-2010-438**
- **PAS EXO-11-002**

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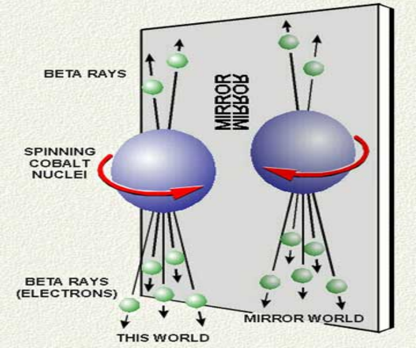
Outline

- Introduction
- 1 Left-right symmetric models
- 2 Heavy neutrino production and decay
- 3 Data and Monte Carlo Samples
- 4 Reconstruction of physical objects
- 5 Event Selection
- 6 Background Estimation
- 7 Cut Optimization
- 8 Systematic Errors
- 9 Results
- Conclusion

LR Symmetry: What and Why

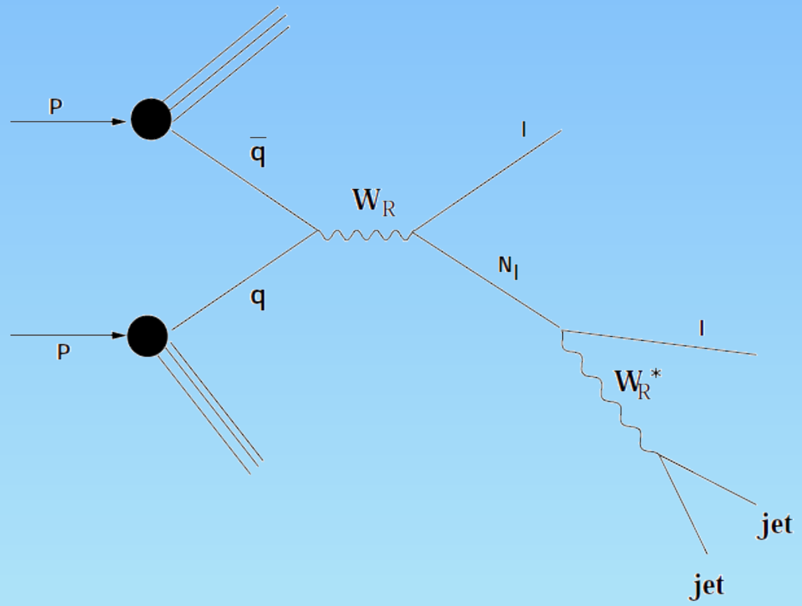
	Standard Model	Left-Right-Symmetric Extension
Gauge group	$SU(2)_L$ X $U(1)_Y$	$SU(2)_L$ **X $SU(2)_R$** X $U(1)_{B-L}$
Fermions	LH doublets: $Q_L = (u^i,d^i)_L$; $L_L = (l^i,\nu^i)_L$ RH singlets: $Q_R = u^i_R,\ d^i_R$; $L_R = l^i_R$	LH doublets: $Q_L = (u^i,d^i)_{L,}\ L_L = (l^i,\nu^i)_L$ RH doublets: $Q_R = (u^i,d^i)_{R,}\ L_R = (l^i,N^i)_R$
Neutrinos	ν^i_R do not exist ν^i_L are massless & pure chiral	N^i_R are heavy partners to the ν^i_L N^i_R Majorana in the Minimal LRSM
Gauge bosons	$W^\pm_L$, Z^0, γ	$W^\pm_L$, **$W^\pm_R$**, Z^0, **Z'**, γ

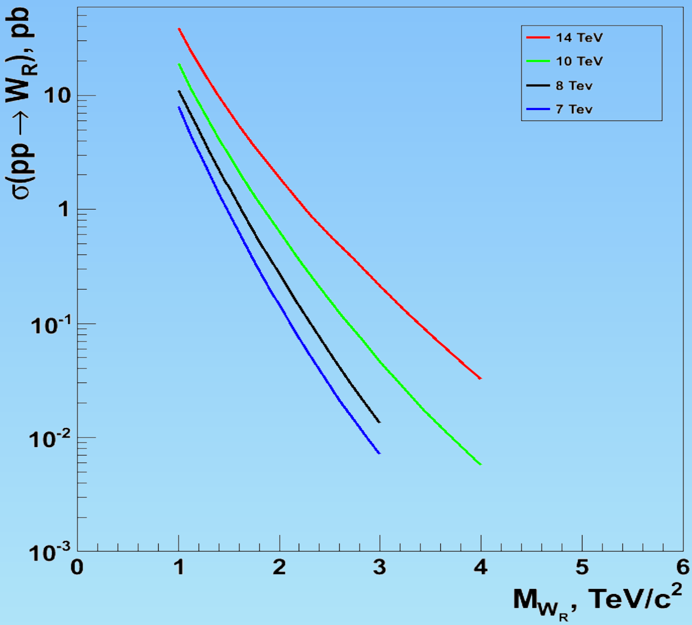


- Parity Violation, SM imposes by fiat
  - **LRSM explains by symmetry breaking at an intermediate mass scale**
- Neutrino Oscillations ⇒ Mass, SM forbids
  - **LRSM deploys a "see-saw mechanism"**

$$\nu_{heavy}\nu_{light} \sim |<H>|^2$$

Signature and Channels

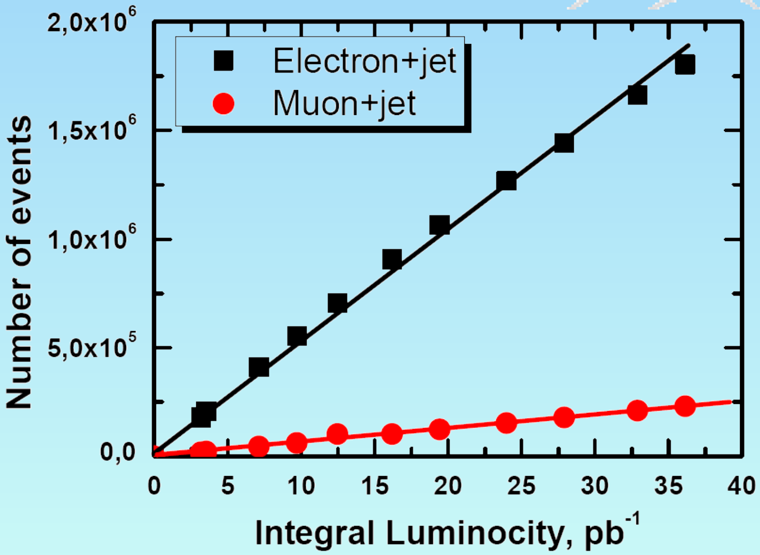




- **Looks like SM W-boson production with an additional decay**
- **No L-R mixing means N → off-shell W_R+ *l***
- **Cross sections depend on M(W_R) and M(N), LO values above**
- **Final signature is 2 leptons + 2 jets, *l* = *e* (INR) or *μ* (UMN)**

Data Samples

Dataset	CMSSW version	Run range	$\mathcal{L}_{int}$
EG/Run2010A-Dec22ReReco_v1	3_9_7	136035-144114	3.18
Electron/Run2010B-Dec22ReReco_v1	3_9_7	145762-149294	32.96
Mu/Run2010A-Dec22ReReco_v1	3_9_7	136035-144114	3.18
Mu/Run2010B-Dec22ReReco_v1	3_9_7	145762-149294	32.96
EG/Run2010A-Nov4ReReco_v1	3_8_6	136035-144114	3.06
Photon/Run2010B-Nov4ReReco_v1	3_8_6	146428-149294	32.78



No Prescale

BG MC Samples

Table 2: MC samples: the process, the dataset name, the number of generated events, cross section and associated error, cross section order and provenance (NLO or NNLO, taken from https://twiki.cern.ch/twiki/bin/viewauth/CMS/StandardModelCrossSections, exept for $t\bar{t}$, taken from [30], and tW, taken from https://twiki.cern.ch/twiki/bin/viewauth/CMS/ProductionFall2010). The Z+jets and W+jets samples are generated in separate files for 0 - 5 jets in several p_T bins, NNLO k-factor 1.29 is used. All samples were reconstructed with CMSSW version 3_8_X series.

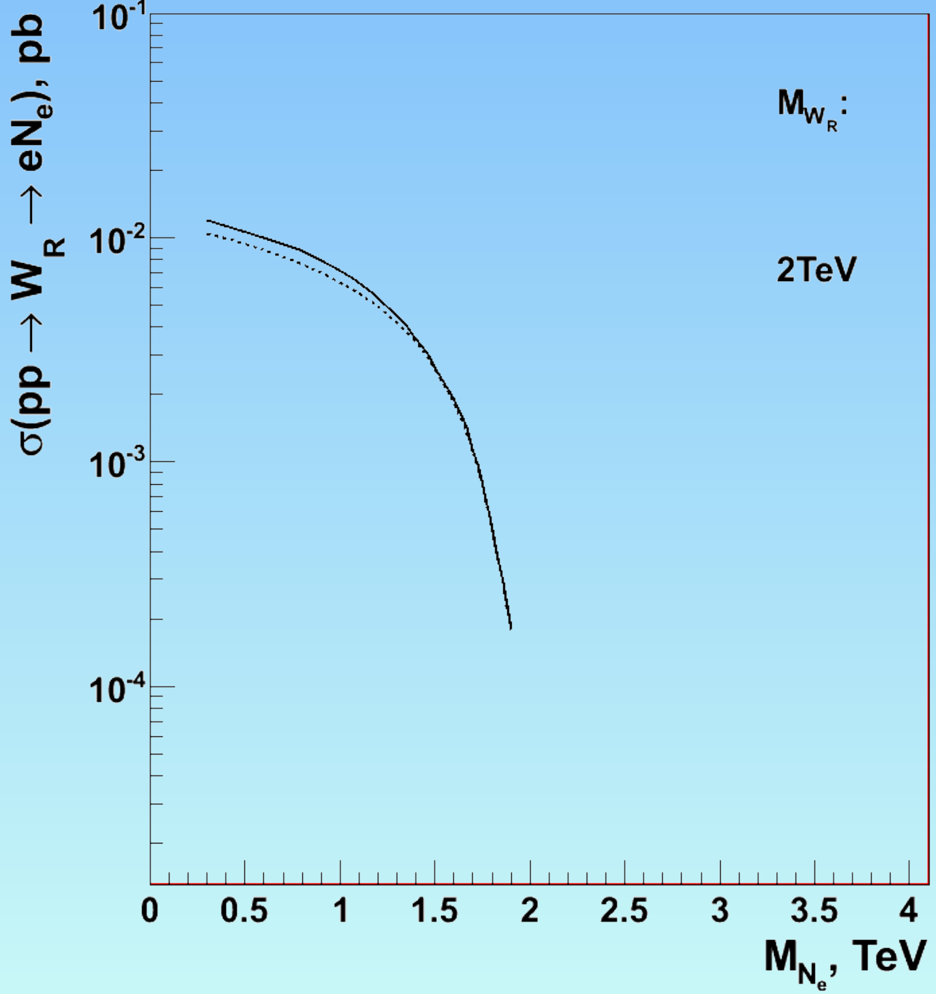
Process	Dataset	N events	σ, pb	$\delta\sigma$, pb	Order/Provenance
$t\bar{t} \to X$	TTJets_TuneZ2_7TeV-madgraph-tauola	1164732	167	± 24	Measured/TOP-10-005_v5
$Z \to X$	Z*Jets_ptZ-*to*_TuneZ2_7TeV-alpgen-tauola	2500000	3160	± 137	NNLO/SM Xsec twiki (recalculated)
$W \to X$	W*Jets_ptW-*to*_TuneZ2_7TeV-alpgen-tauola	7200000	25330	-	LO/Production Twiki
$W \to X$	WJets_7TeV-madgraph-tauola	10218854	31314	± 1558	NLO/SM Xsec twiki
$WW \to X$	WWtoAnything_TuneZ2_7TeV-pythia6-tauola	2061760	43	± 1.5	NLO/SM Xsec twiki
$WZ \to X$	WZtoAnything_TuneZ2_7TeV-pythia6-tauola	2194752	18.2	± 0.7	NLO/SM Xsec twiki
$ZZ \to X$	ZZtoAnything_TuneZ2_7TeV-pythia6-tauola	2113368	5.9	± 0.15	NLO/SM Xsec twiki
$t \to W + b \to X$	TW_dr_7TeV-mcatn lo	871720	0.1835	-	NLO/SM Xsec twiki

Table 3: Special MC samples: the dataset name, the version of CMSSW software used for the reconstruction, the number of generated events, and cross section. The cross-section for the $t\bar{t}$ sample is derived from the measured CMS cross-section [30], multiplied twice by the branching fraction for $W \to \mu\nu$.

Process	Dataset	N events	σ, pb	$\delta\sigma$, pb	Order/Provenance
$t\bar{t} \to \mu\mu + jets + X$	PYTHIA6_Tauola_TTbar_mumu_TuneZ2_7TeV	193317	$167 * 0.11^2$=2.02	± 24	Measured/TOP-10-005_v5

MC Signal Samples

- **~100 mass points studied (up to $M(W_R)$=1.6TeV)**
- **10k events per point**
- **Only one neutrino flavor assumed reachable**
- **PYTHIA LO s's plotted**
- **$M(W_R)$ – dependent k-factor ~1.30 used (slow dependence)**



Electron Reco/Selection

- **PAT Framework used;**
- **“HEEP v3.0” electrons;**
- **Isolation cuts at the preliminary selection 3 times looser than standard HEEP;**
- **$p_t > 20$ GeV;**
- **Default “Swiss cross” S4/S1 spike rejection applied.**

Muon Reco/Selection

- **PAT muons with VBTF loose;**
- **Tracker isolation < 10 GeV;**
- **$\Delta R(\mu$, selected jets$) > 0.3$;**
- **$p_t > 20$ GeV;**

Jet **Reco/Selection**

	Electron Channel	Muon Channel	Standard?
Jet Collection	**akCaloJet5**	**akCaloJet5**	**PAT default**
Jet ID req'mnt	**LOOSE PURE09**	**LOOSE PURE09**	**Yes**
Jet Energy Corrections	**MC: L2L3** **Data: L2L3Residual**	MC: L2L3 Data: L2L3Residual	**Yes**
	Kinematics		
Final p_t threshold[1]	**> 40 GeV**	**> 40GeV**	**N/A**
$\|\eta\|$ acceptance	**< 2.5**	**< 2.5**	**In tracker coverage**
	Special Considerations		
Lepton Overlap	**Reject the jet**	**Reject the muon**	**N/A**

[1] Looser jet thresholds used only for QCD background / efficiency studies

Event Selection

Preliminary Selection:

- At least 1 lepton and 1 jet

Primary Selection:

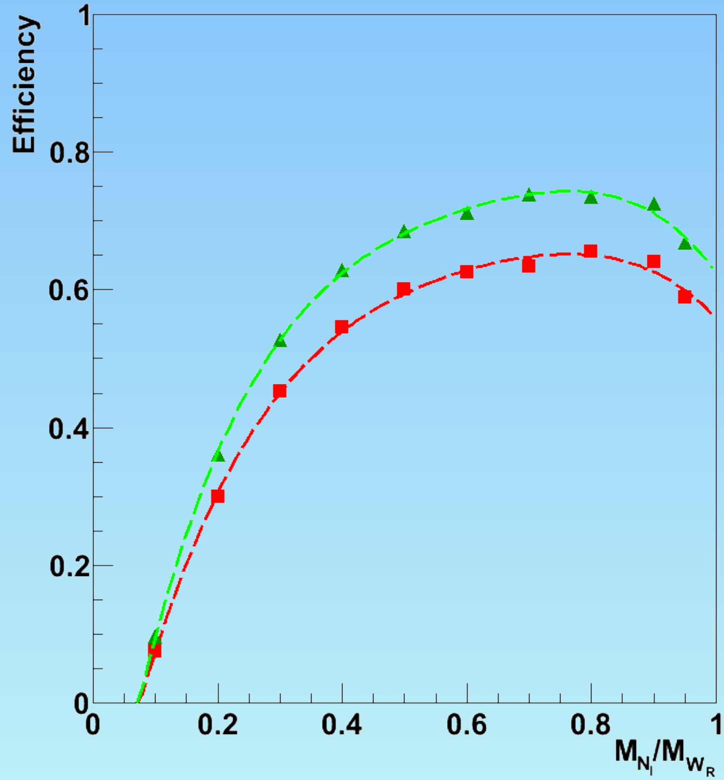
- At least 2 leptons
- At least 2 jets $p_t > 40$ GeV (two hardest used)
- Vertex of 2 leptons and 2 jets within 0.03 cm

Final Selection:

- One muon with VBTF Tight, trigger matched in $|\eta| < 2.1$
- One electron in the barrel
- One lepton $p_t > 60$ GeV
- “LOOSE PURE 09” Jet ID applied

Primary Selection Efficiency

- Defines the shape of the lower part of the sensitivity region
- Triangles – muons
- Squares - electrons



Backgrounds

- Expected from the SM processes with 2 or more leptons
- Some contribution from the QCD processes with fake leptons
- Most important backgrounds: tt production, Z+jets Renormalized from data, only shape from MC partly used (due to small statistics in data)
- QCD – from data
- Other, small (sum < 10%) backgrounds: W+jets, ZZ, ZW, WW, tW from MC

TTbar BG

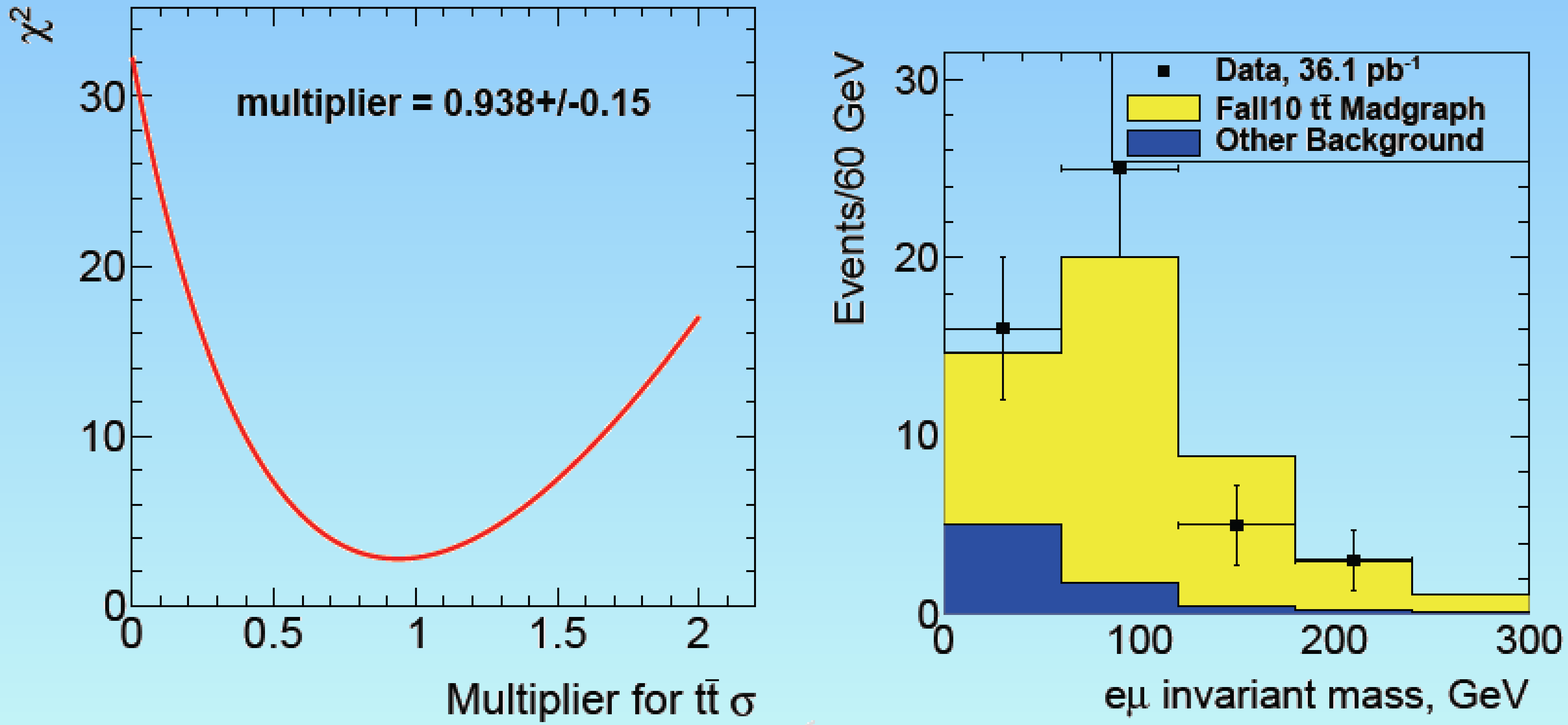
Checks of the tt BG with *e-μ* signature:

- **Require:**
  - **1 HEEP electron, 1 isolated muon, both with $p_t > 20$ GeV**
  - **At least 2 jets with $p_t > 20$ GeV,**
  - **Vertex** $\Delta z(e_1, e_2, j_1, j_2) < 0.03 \text{ cm}$
- **"jetProbabilityBJetTag" middle threshold 0.459**
- **Electron dataset, no additional events from muon dataset**
- **Good agreement for this process, which is our most important BG, so no need to renormalize**
- **We use the statistical error of possible normalization**

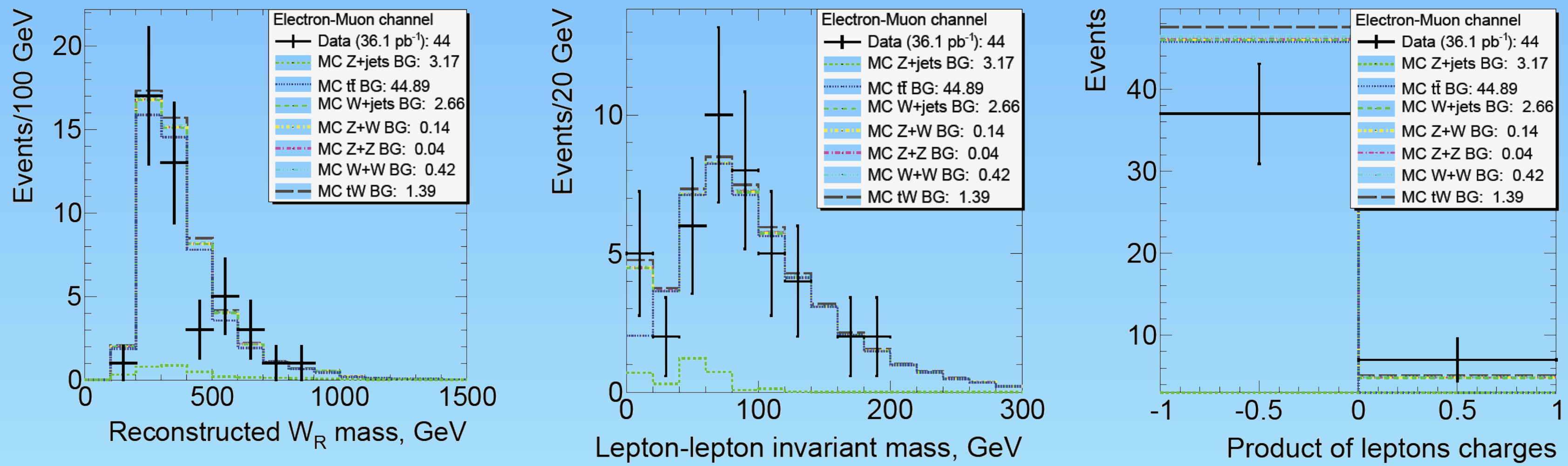
Compare with S.Choi, J.Goh, M.S.Kim et al., AN-2010-380:

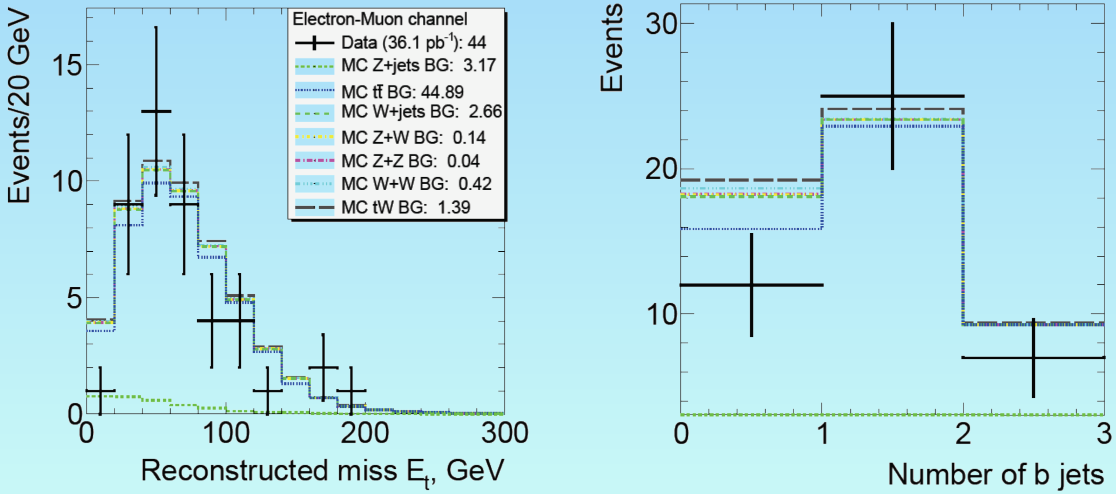
- **Good agreement in spite of different ID**

TTbar BG, e-μ channel



TTbar BG, e-μ channel

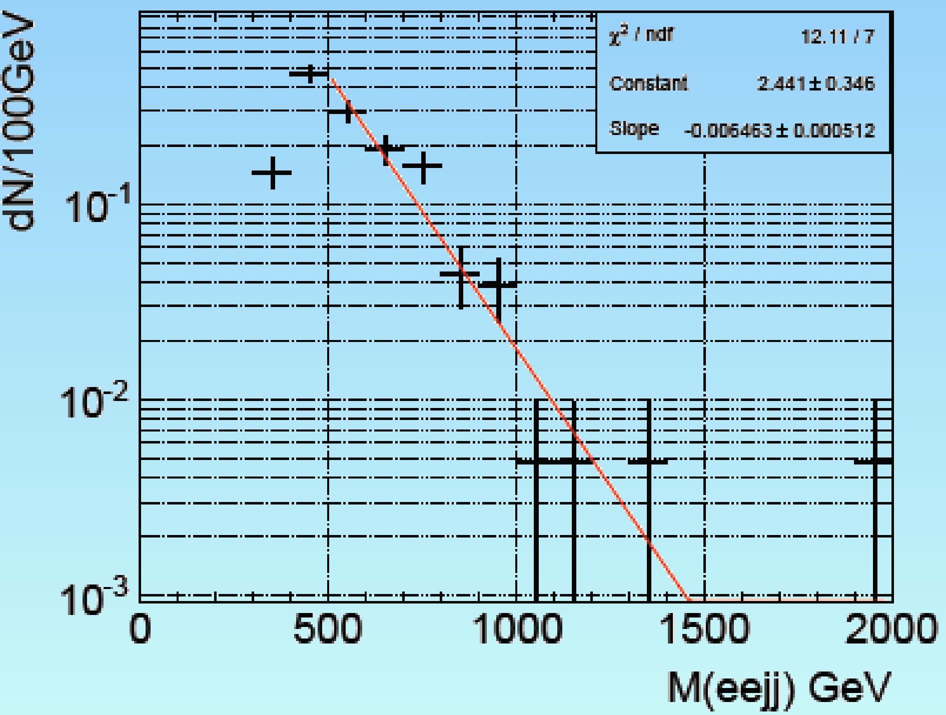


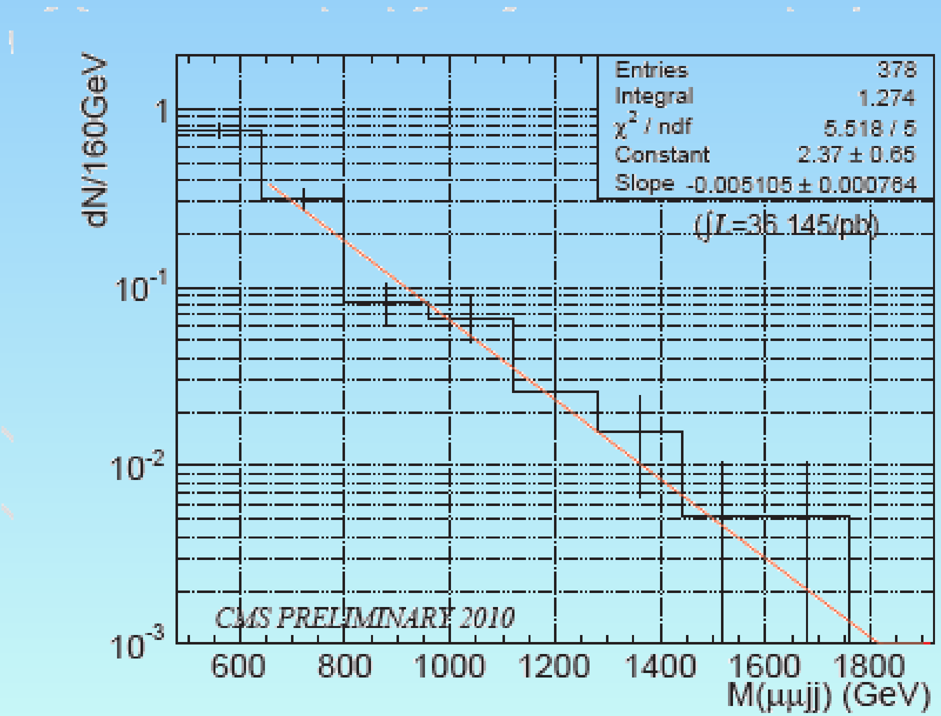


GOOD
Agreement
No Rescale,
k = 1

TTbar BG

- **Sufficient MC statistics to fit exponential slope.**





Z+jets BG and Data

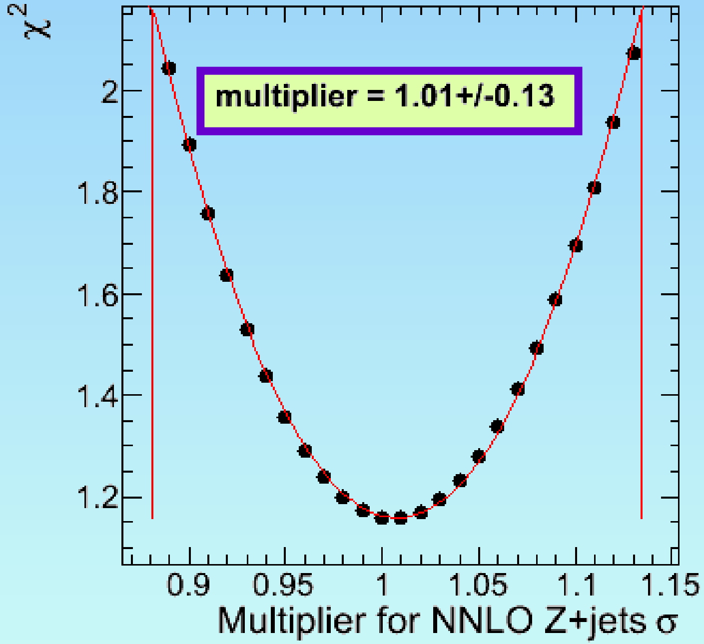
Normalize MC Alpgen binned samples to data:

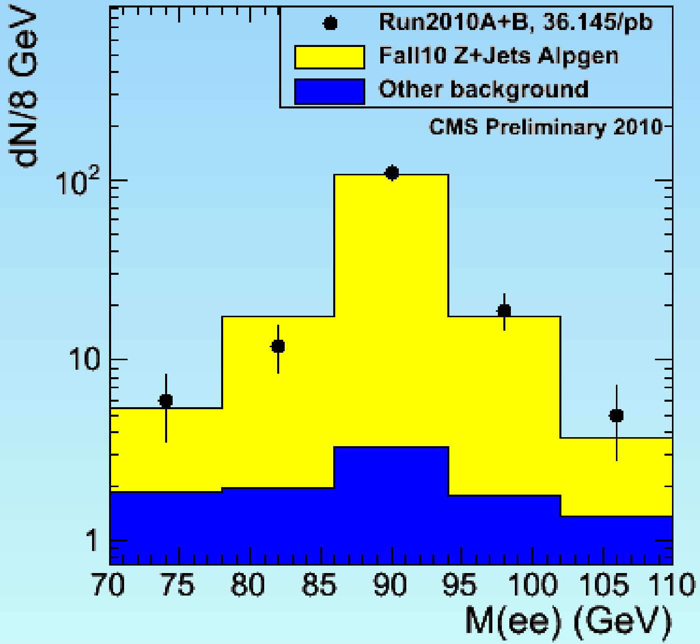
- **Apply 4-object selection, subsequently assume leptons in narrow window around the Z-peak are pure;**
- **Weight MC sample via χ^2 minimization to peak in data**
- **Use the new MC normalization to estimate Z+Jets BG**

Z+jets BG, *Electron* Channel

Requirements:

- 2 HEEP electrons, $p_t > 20$ GeV;
- 2 PAT jets, $p_t > 40$ GeV, $|\eta| < 2.5$;
- At least one electron in barrel.

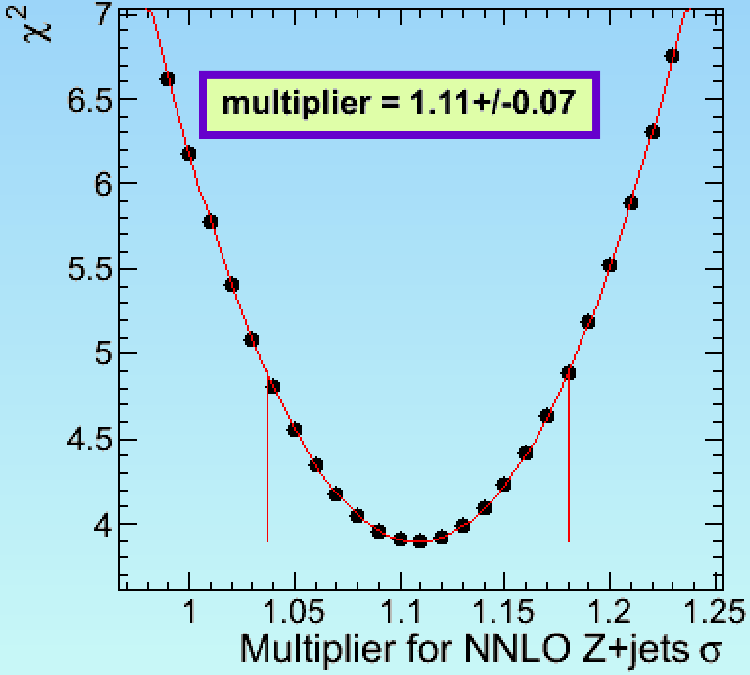


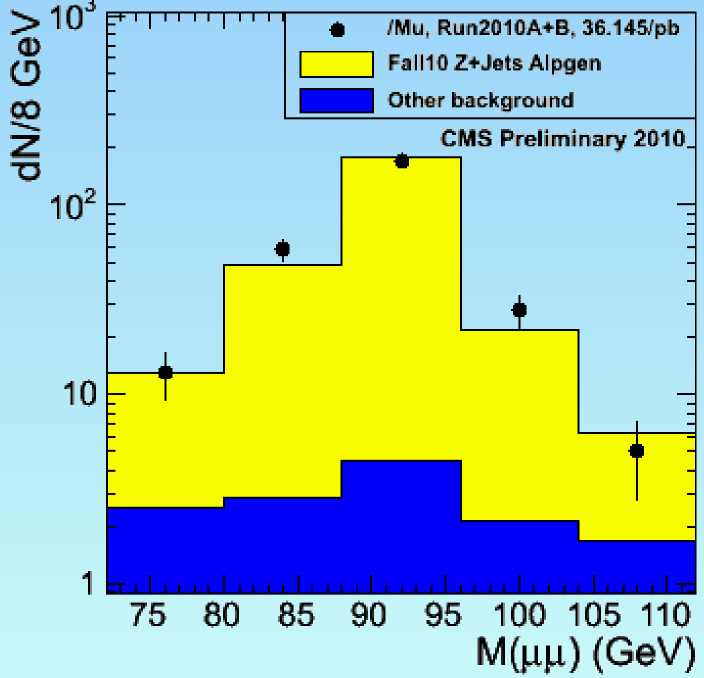


Z+jets BG, *Muon* Channel

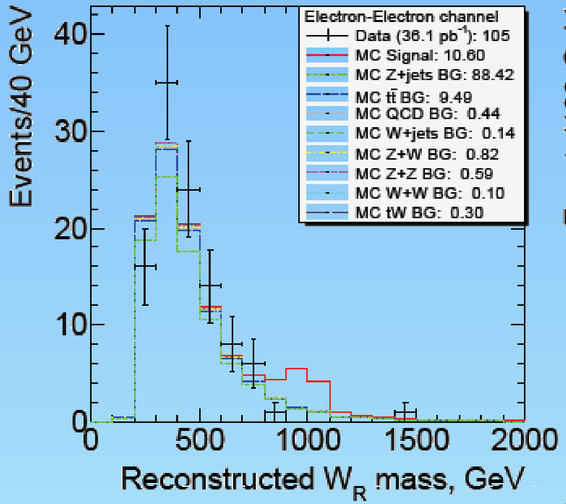
Requirements:

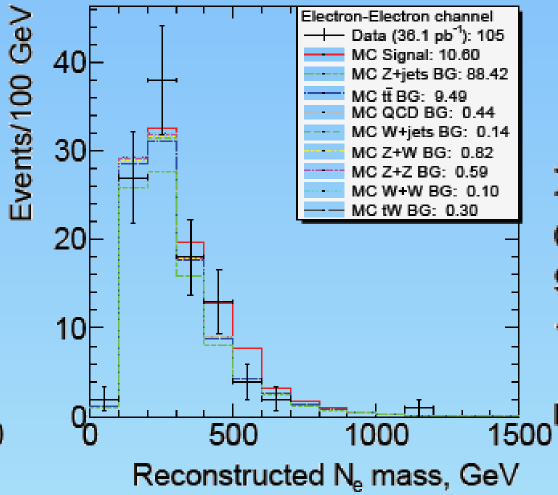
- **2 muons, at least 1 tight muons, $p_t > 20$ GeV;**
- **2 PAT jets, $p_t > 40$ GeV, $|\eta| < 2.5$.**





Z+jets BG


Electron-Electron channel
Data (36.1 pb^{-1}): 105
MC Signal: 10.60
MC Z+jets BG: 88.42
MC $t\bar{t}$ BG: 9.49
MC QCD BG: 0.44
MC W+jets BG: 0.14
MC Z+W BG: 0.82
MC Z+Z BG: 0.59
MC W+W BG: 0.10
MC tW BG: 0.30
Events/40 GeV
0
10
20
30
40
0
500
1000
1500
2000
Reconstructed W_R mass, GeV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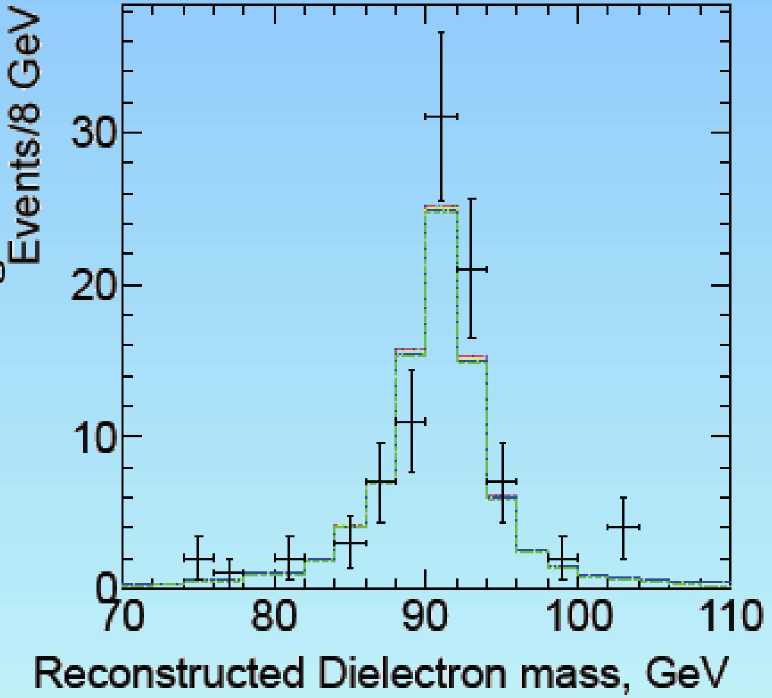
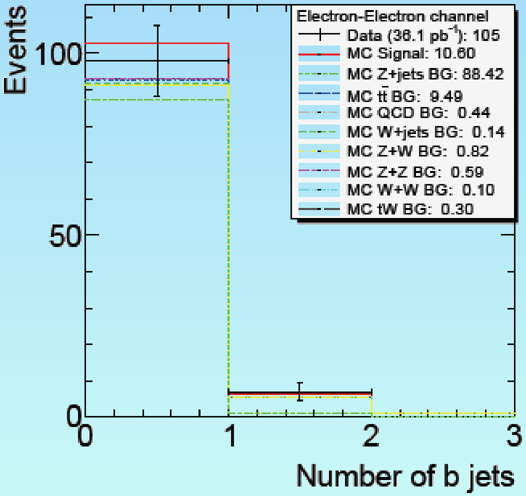
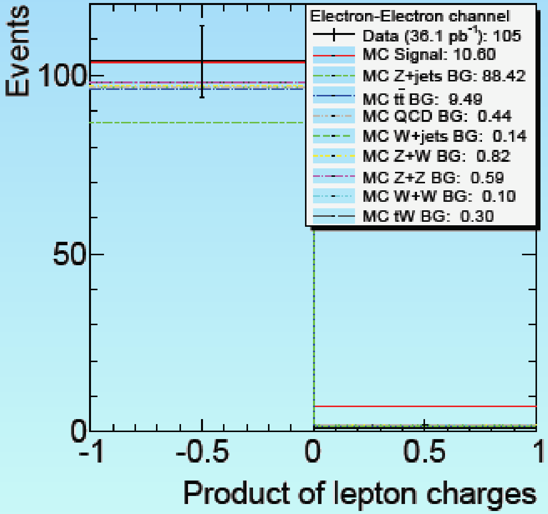
MC QCD BG: 0.44
MC W+jets BG: 0.14
MC Z+W BG: 0.82
MC Z+Z BG: 0.59
MC W+W BG: 0.10
MC tW BG: 0.30
Events/100 GeV
0
10
20
30
40
0
500
1000
1500
Reconstructed N_e mass, GeV


Events/8 GeV
0
10
20
30
70
80
90
100
110
Reconstructed Dielectron mass, GeV

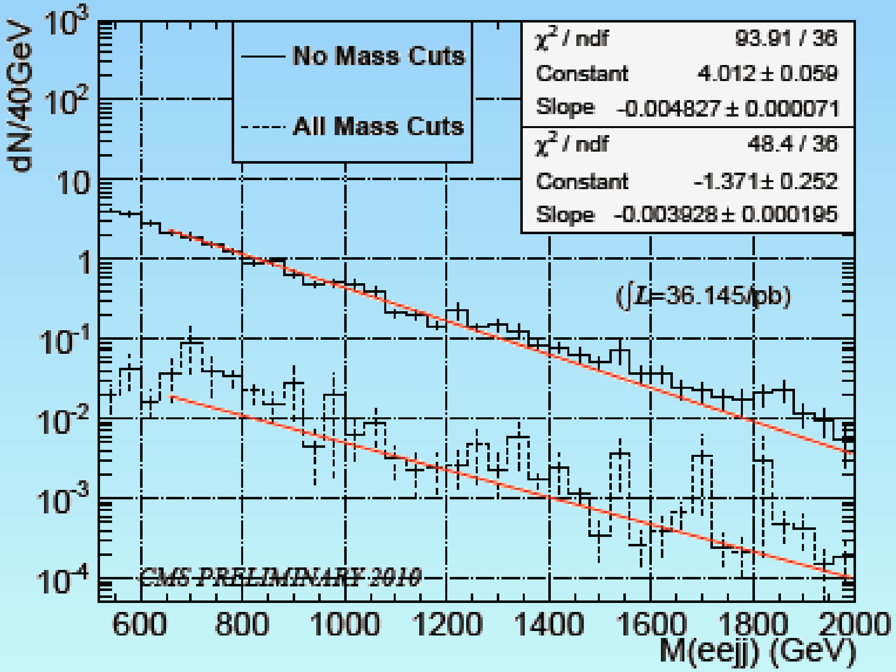

Electron-Electron channel
Data (36.1 pb^{-1}): 105
MC Signal: 10.60
MC Z+jets BG: 88.42
MC $t\bar{t}$ BG: 9.49
MC QCD BG: 0.44
MC W+jets BG: 0.14
MC Z+W BG: 0.82
MC Z+Z BG: 0.59
MC W+W BG: 0.10
MC tW BG: 0.30
Events
0
50
100
0
1
2
3
Number of b jets


Electron-Electron channel
Data (36.1 pb^{-1}): 105
MC Signal: 10.60
MC Z+jets BG: 88.42
MC $t\bar{t}$ BG: 9.49
MC QCD BG: 0.44
MC W+jets BG: 0.14
MC Z+W BG: 0.82
MC Z+Z BG: 0.59
MC W+W BG: 0.10
MC tW BG: 0.30
Events
0
50
100
-1
-0.5
0
0.5
1
Product of lepton charges

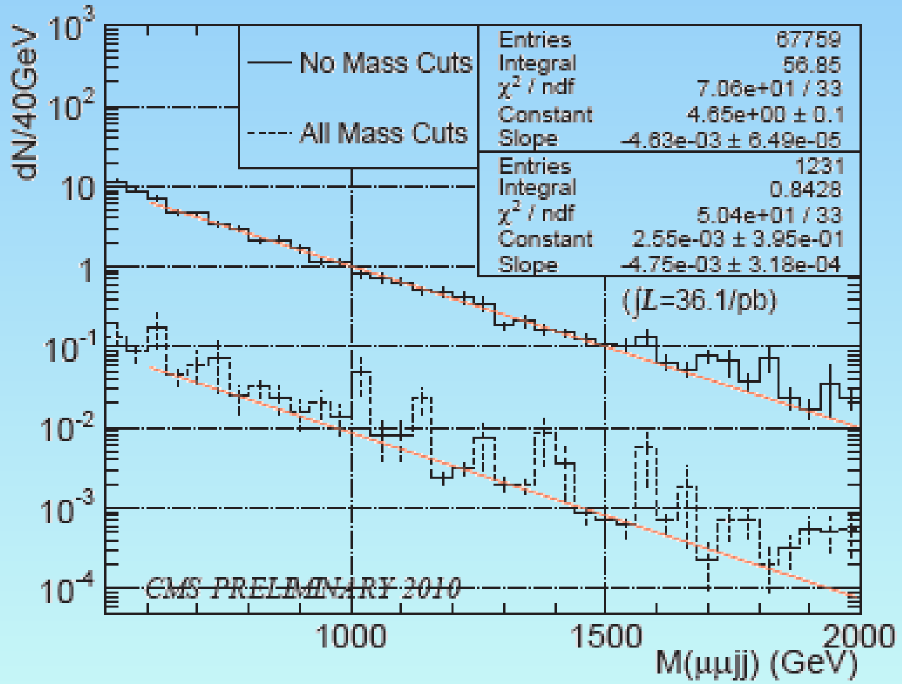
Z+jets BG

Exponential fit

ee channel

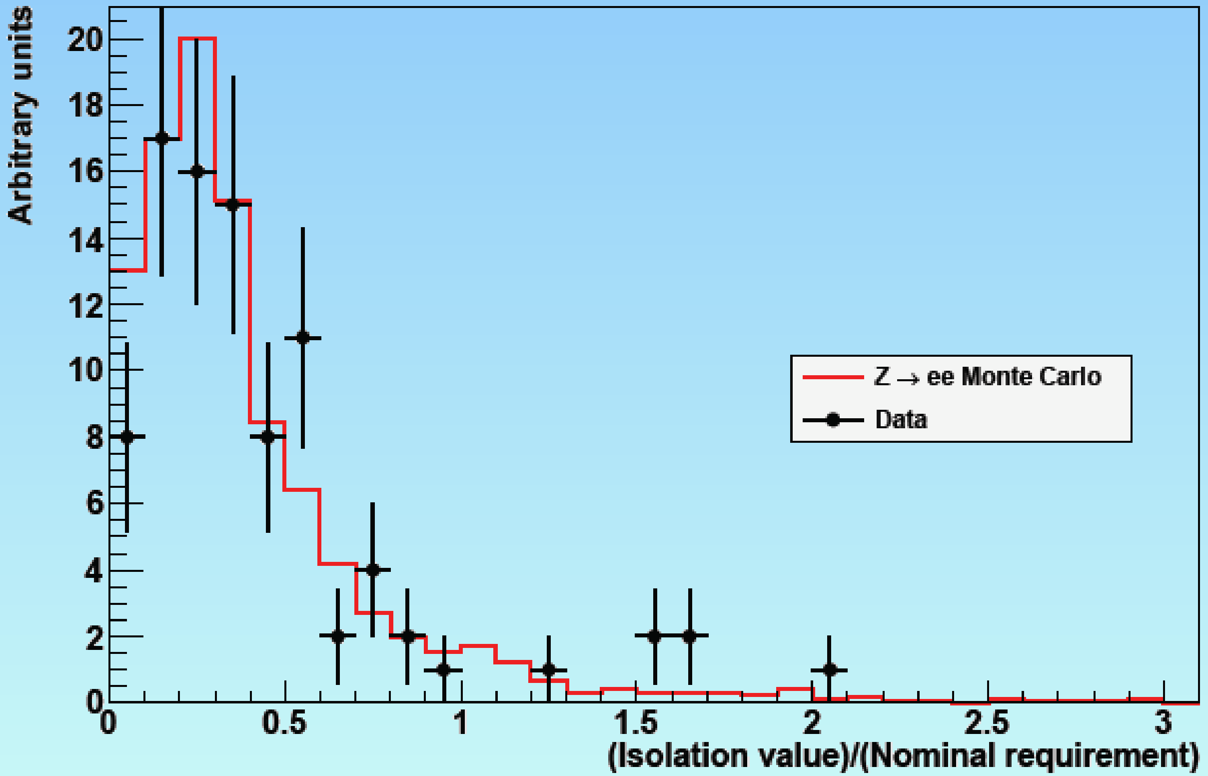


μμ channel



Isolation cut check

- **2 Electrons from the Z peak**
- **Electrons with a jet within 0.5 < R < 0.8**

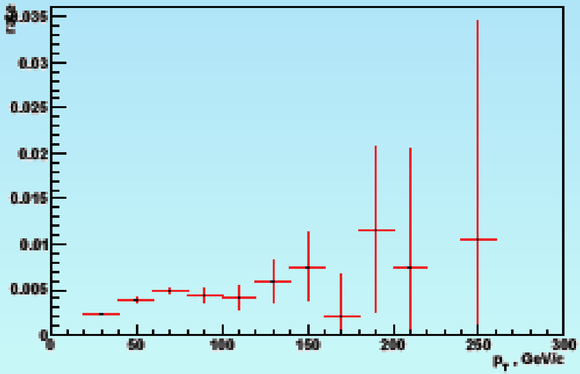


QCD BG, *Electron* Channel

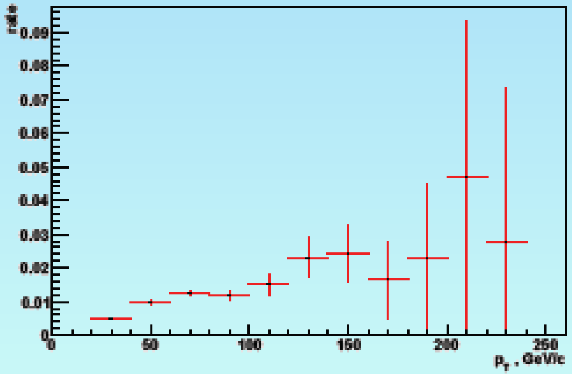
1st Step:

- **Fake rates determined using events with isolated cluster – jet back-to-back ($\Delta\phi > 2.7$), p_t^{miss} < 20 GeV, any number of jets;**
- **p_t ~ 20 – 40 GeV: linear interpolation from 0.004 and 0.012;**
- **p_t > 40 GeV compatible with flat: 0.0075 barrel, 0.033 endcap 1 and 0.04 in endcap 2.**

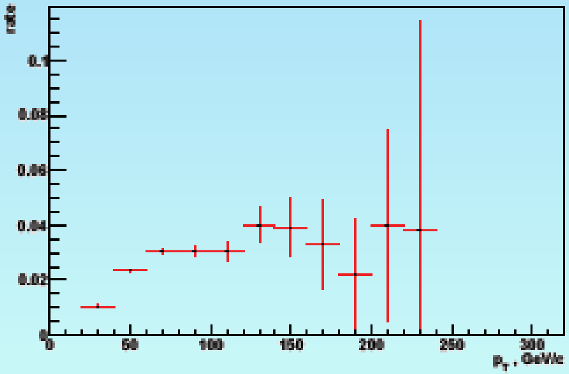
Fake rate barrel



Fake rate endcap 1



Fake rate endcap 2



QCD BG, *Electron* Channel

2nd Step:

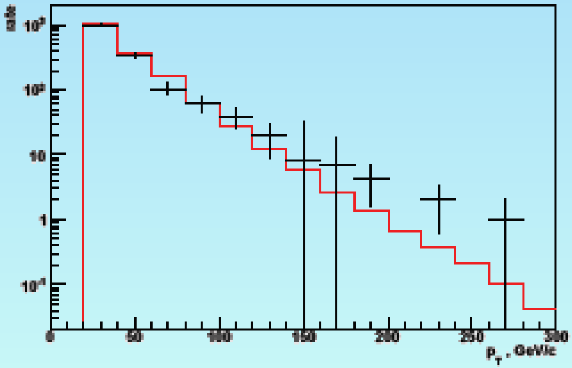
- **Produce QCD BG sample**
- **Take events with at least 2 isolated superclusters**
- **Calculate probability as a product of the two fake rates, use it as a weight**
- **Use this sample in the analysis, adding it to other samples**

QCD BG, *Electron* Channel

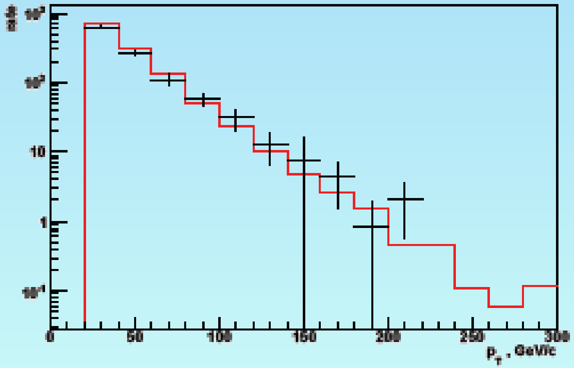
3rd Step:

- **Closure test**
- **Using fake rate and ccj events predict number of ecj;**
- **Require < 2 electrons and $p_t^{miss} < 20$ GeV;**
- **Take 2*σ as uncertainty of the method: 18%**

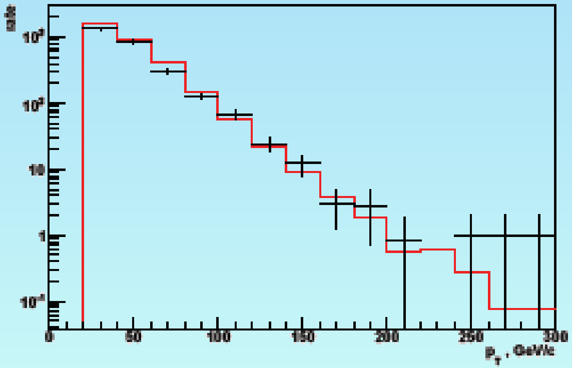
Fake rate barrel



Fake rate endcap 1



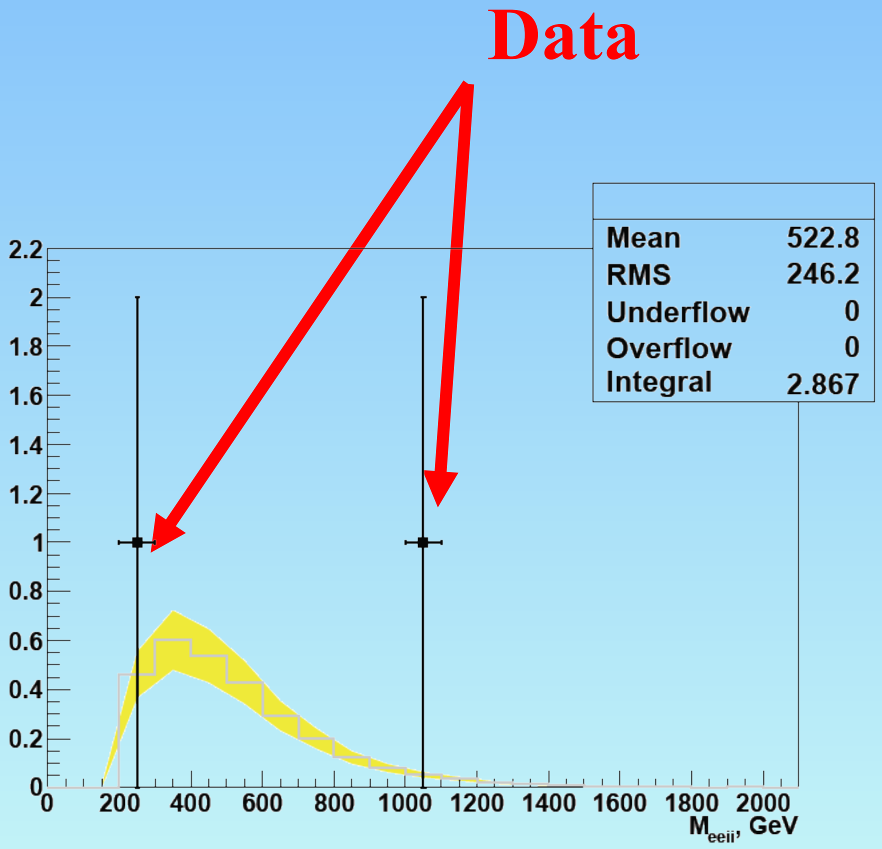
Fake rate endcap 2



QCD BG, *Electron* Channel

Comparison with data:

- **BG, selection *ee* same sign (reduces other SM background)**
- **$p_t > 20$ GeV,**
- **Requirement of one in the barrel removed;**
- **$M_{ll} > 120$ GeV**
- **MC: dominated by QCD, other SM < 0.5. Within uncertainty**



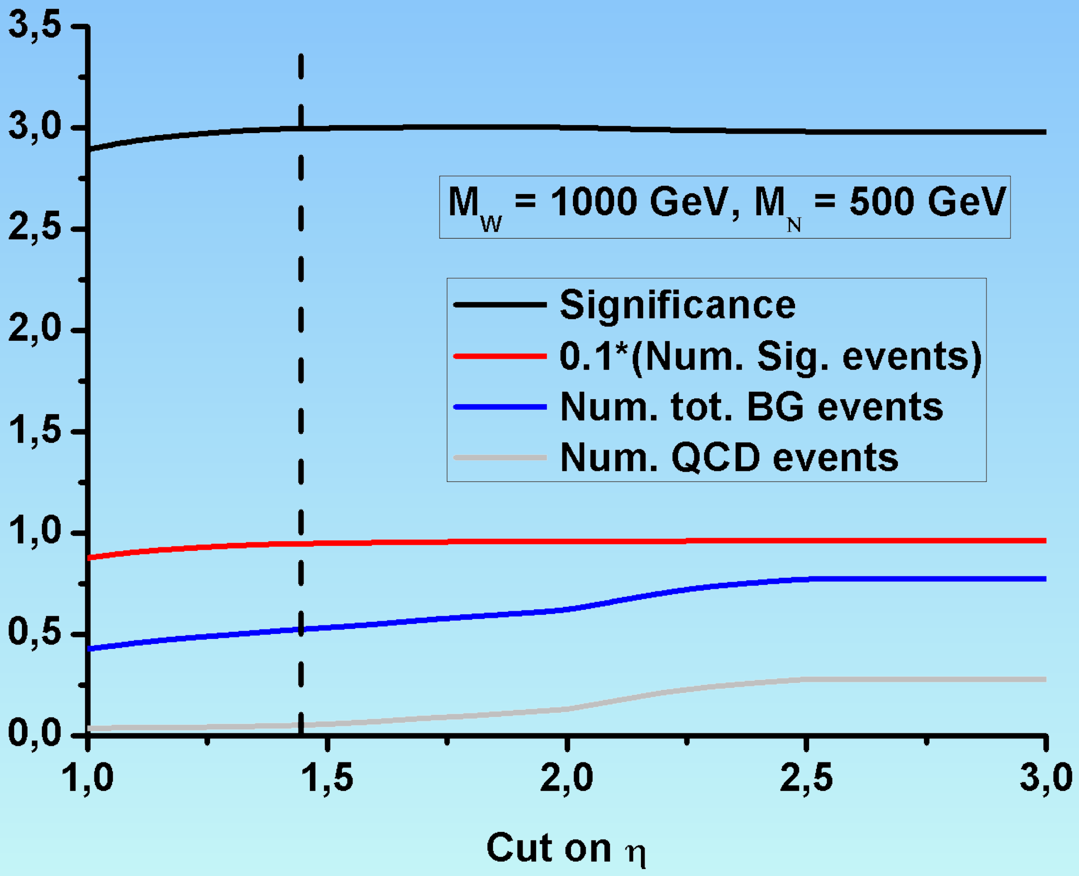
Cuts Optimization

- Optimization of significance function:

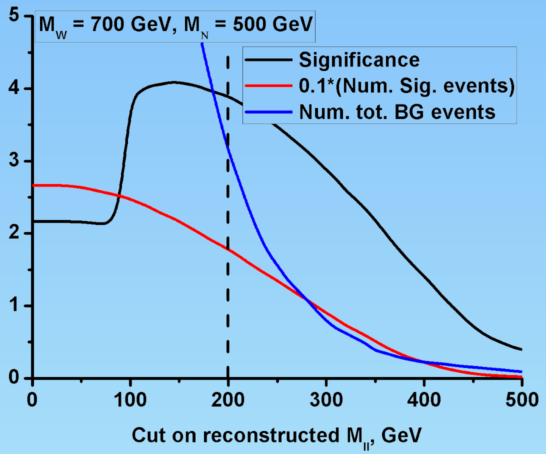
$$\frac{S}{\sqrt{S+B}}$$

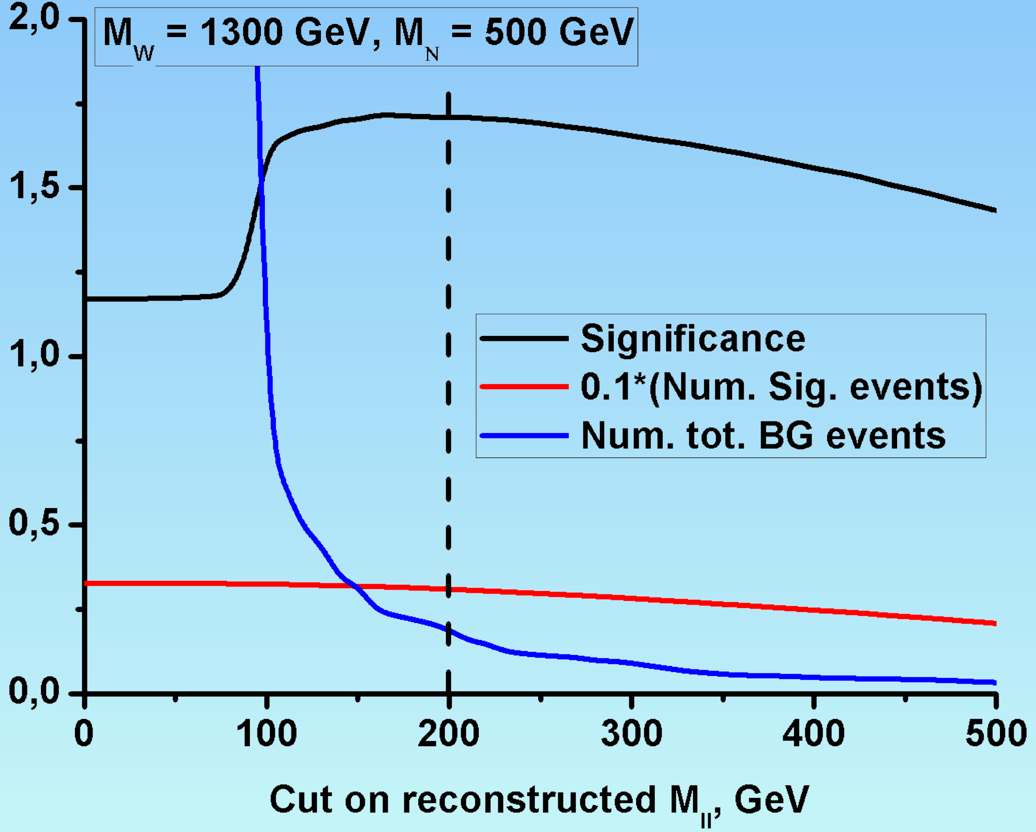
- At least one electron in barrel for electron channel to suppress QCD;
- $M_{ll} > 200$ GeV common for all mass points significantly reduce Z+jets;
- M_{w} cut selected individually for each W_R mass, but common for neutrino masses reduce all BG.

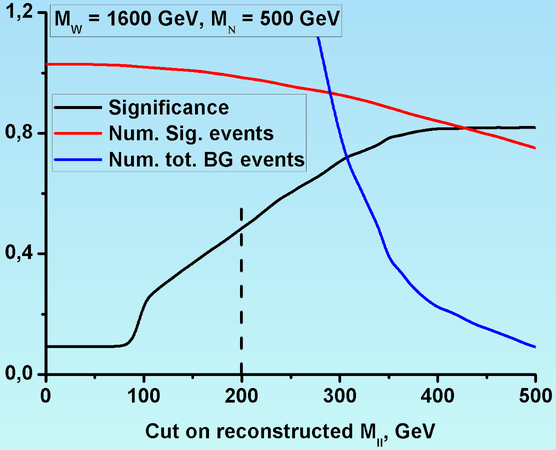
Cuts Optimization



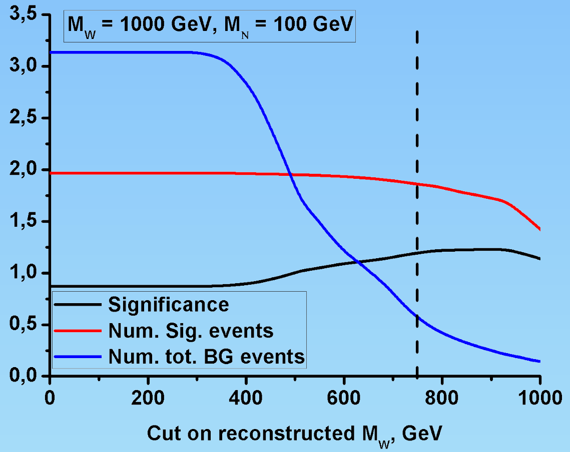
Cuts Optimization

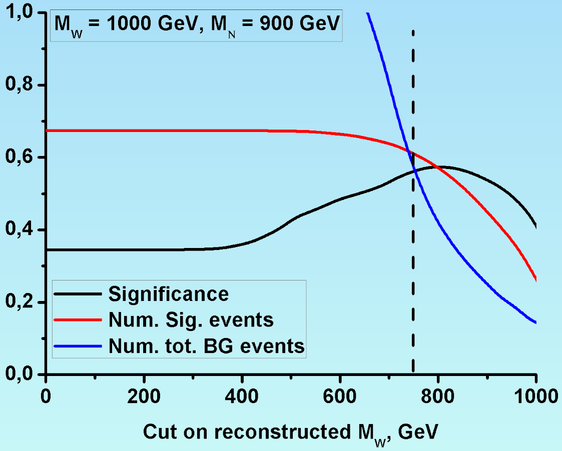


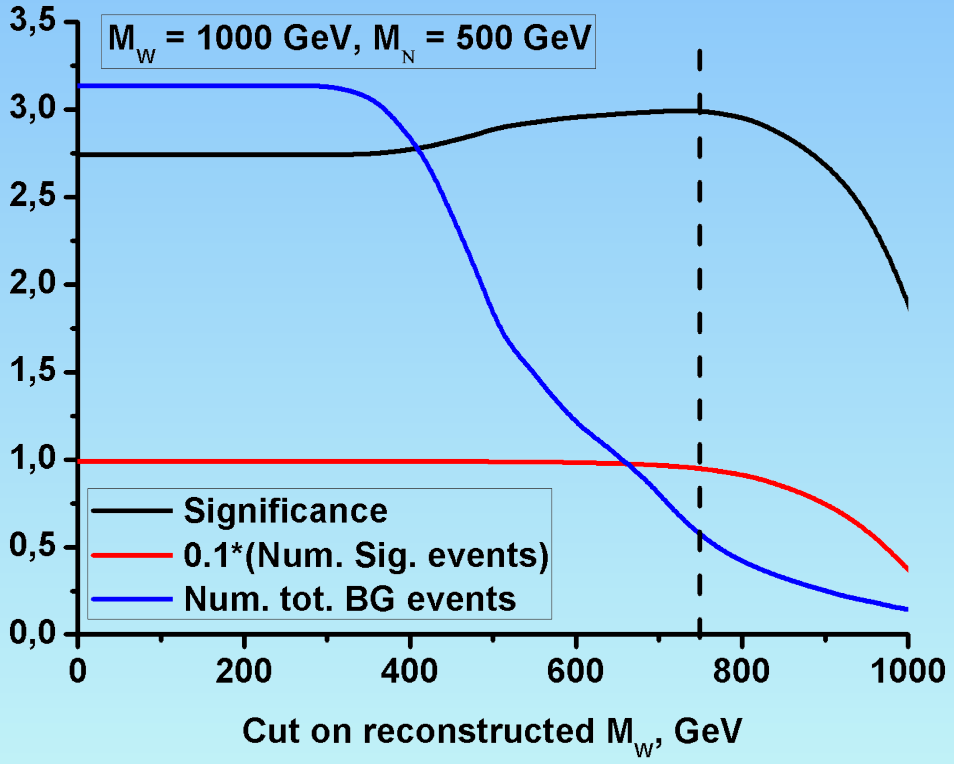




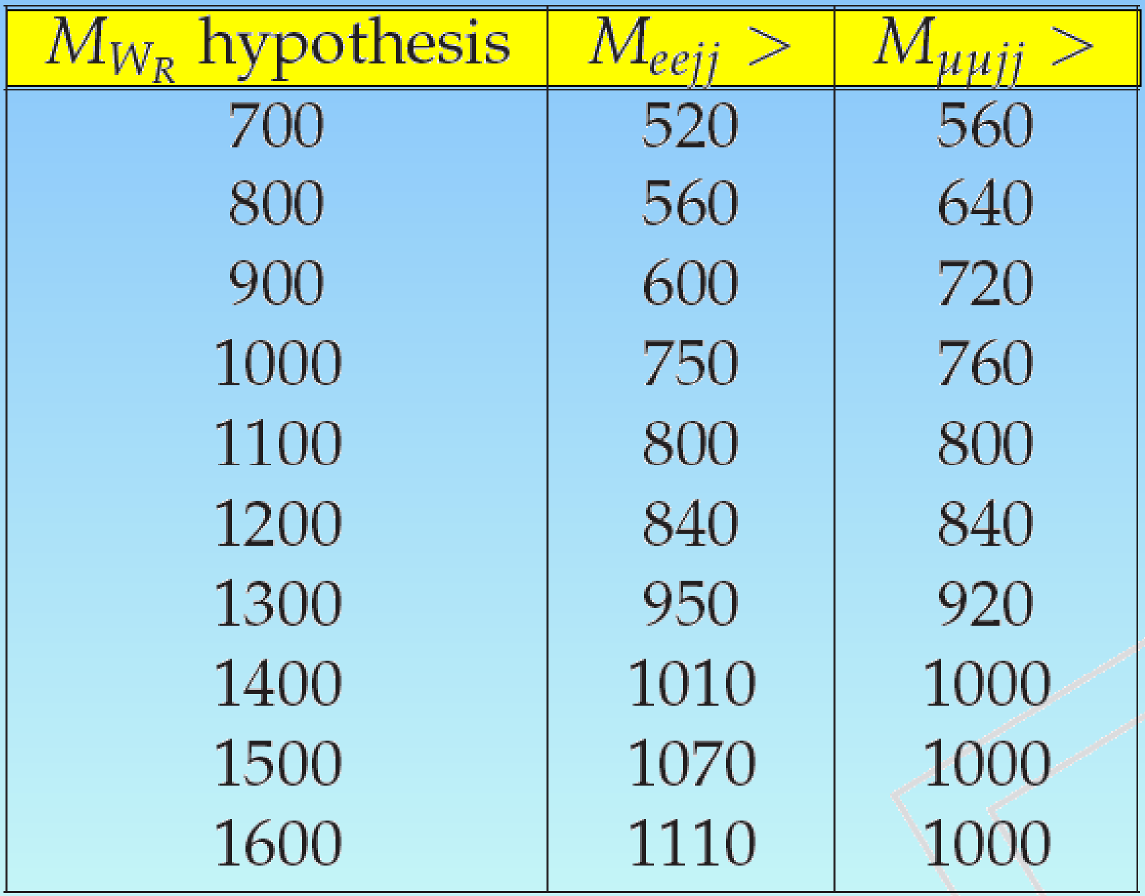
Cuts Optimization







Optimization of M_W cut



M_{W_R} hypothesis	$M_{eejj} >$	$M_{\mu\mu jj} >$
700	520	560
800	560	640
900	600	720
1000	750	760
1100	800	800
1200	840	840
1300	950	920
1400	1010	1000
1500	1070	1000
1600	1110	1000

Signal Efficiency for *Electron* Channel

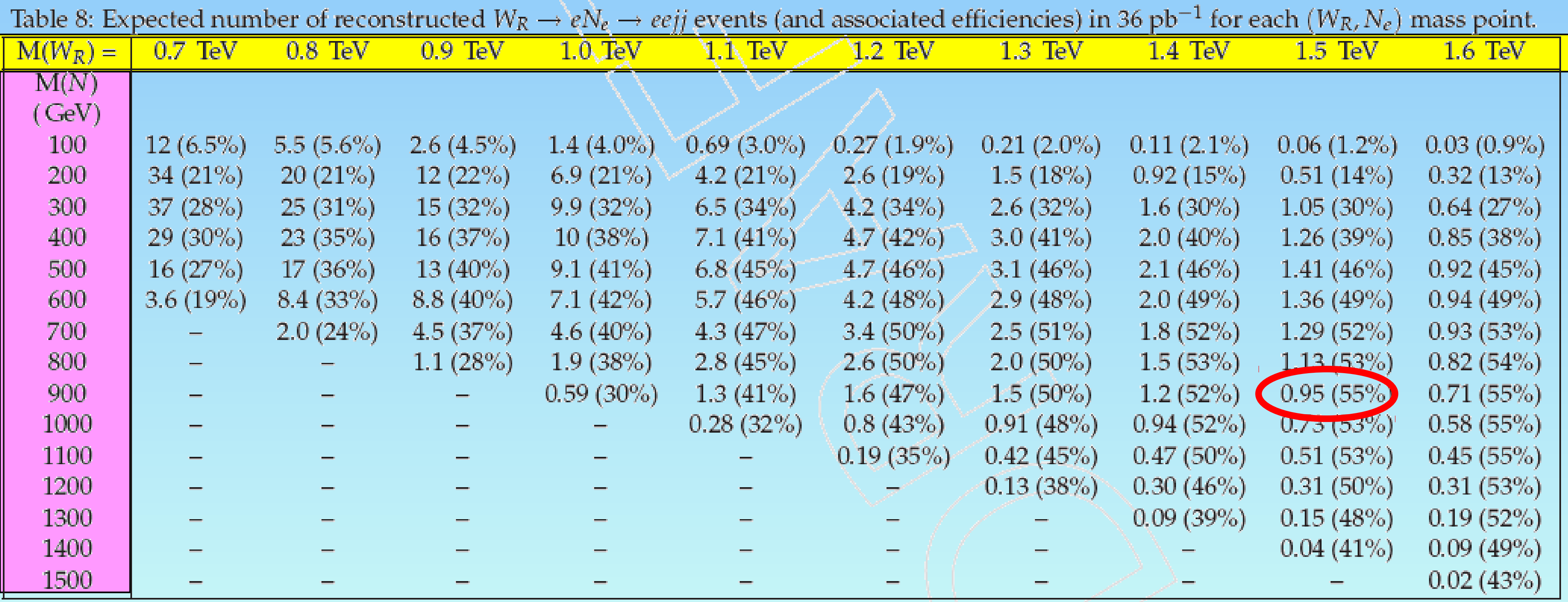


Table 8: Expected number of reconstructed $W_R \to eN_e \to eejj$ events (and associated efficiencies) in 36 pb^{-1} for each (W_R, N_e) mass point.

M(W_R) = M(N) (GeV)	0.7 TeV	0.8 TeV	0.9 TeV	1.0 TeV	1.1 TeV	1.2 TeV	1.3 TeV	1.4 TeV	1.5 TeV	1.6 TeV
100	12 (6.5%)	5.5 (5.6%)	2.6 (4.5%)	1.4 (4.0%)	0.69 (3.0%)	0.27 (1.9%)	0.21 (2.0%)	0.11 (2.1%)	0.06 (1.2%)	0.03 (0.9%)
200	34 (21%)	20 (21%)	12 (22%)	6.9 (21%)	4.2 (21%)	2.6 (19%)	1.5 (18%)	0.92 (15%)	0.51 (14%)	0.32 (13%)
300	37 (28%)	25 (31%)	15 (32%)	9.9 (32%)	6.5 (34%)	4.2 (34%)	2.6 (32%)	1.6 (30%)	1.05 (30%)	0.64 (27%)
400	29 (30%)	23 (35%)	16 (37%)	10 (38%)	7.1 (41%)	4.7 (42%)	3.0 (41%)	2.0 (40%)	1.26 (39%)	0.85 (38%)
500	16 (27%)	17 (36%)	13 (40%)	9.1 (41%)	6.8 (45%)	4.7 (46%)	3.1 (46%)	2.1 (46%)	1.41 (46%)	0.92 (45%)
600	3.6 (19%)	8.4 (33%)	8.8 (40%)	7.1 (42%)	5.7 (46%)	4.2 (48%)	2.9 (48%)	2.0 (49%)	1.36 (49%)	0.94 (49%)
700	–	2.0 (24%)	4.5 (37%)	4.6 (40%)	4.3 (47%)	3.4 (50%)	2.5 (51%)	1.8 (52%)	1.29 (52%)	0.93 (53%)
800	–	–	1.1 (28%)	1.9 (38%)	2.8 (45%)	2.6 (50%)	2.0 (50%)	1.5 (53%)	1.13 (53%)	0.82 (54%)
900	–	–	–	0.59 (30%)	1.3 (41%)	1.6 (47%)	1.5 (50%)	1.2 (52%)	0.95 (55%)	0.71 (55%)
1000	–	–	–	–	0.28 (32%)	0.8 (43%)	0.91 (48%)	0.94 (52%)	0.73 (53%)	0.58 (55%)
1100	–	–	–	–	–	0.19 (35%)	0.42 (45%)	0.47 (50%)	0.51 (53%)	0.45 (55%)
1200	–	–	–	–	–	–	0.13 (38%)	0.30 (46%)	0.31 (50%)	0.31 (53%)
1300	–	–	–	–	–	–	–	0.09 (39%)	0.15 (48%)	0.19 (52%)
1400	–	–	–	–	–	–	–	–	0.04 (41%)	0.09 (49%)
1500	–	–	–	–	–	–	–	–	–	0.02 (43%)

Signal Efficiency for *Muon* Channel

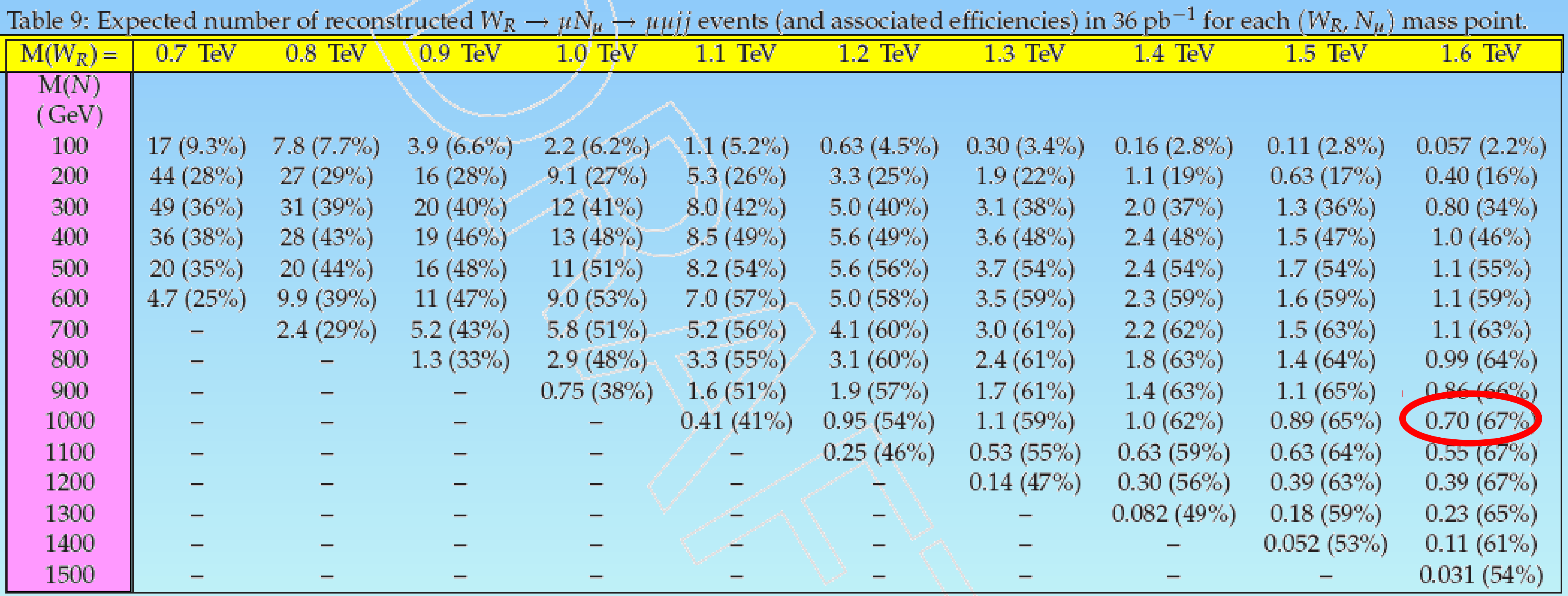
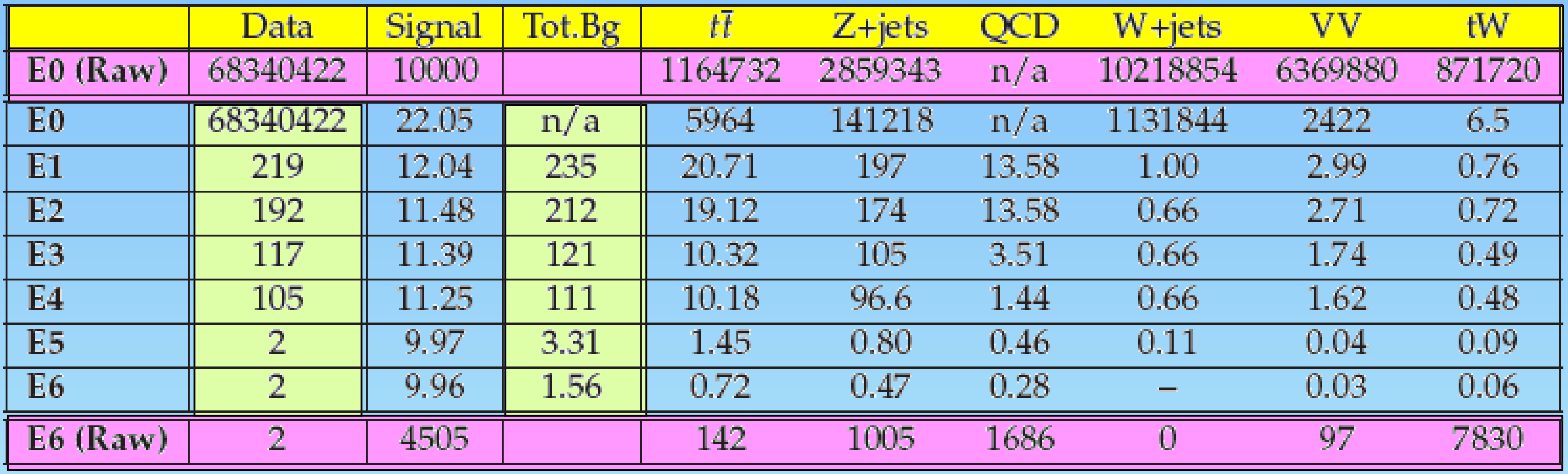


Table 9: Expected number of reconstructed $W_R \rightarrow \mu N_\mu \rightarrow \mu\mu jj$ events (and associated efficiencies) in 36 pb^{-1} for each (W_R, N_μ) mass point.

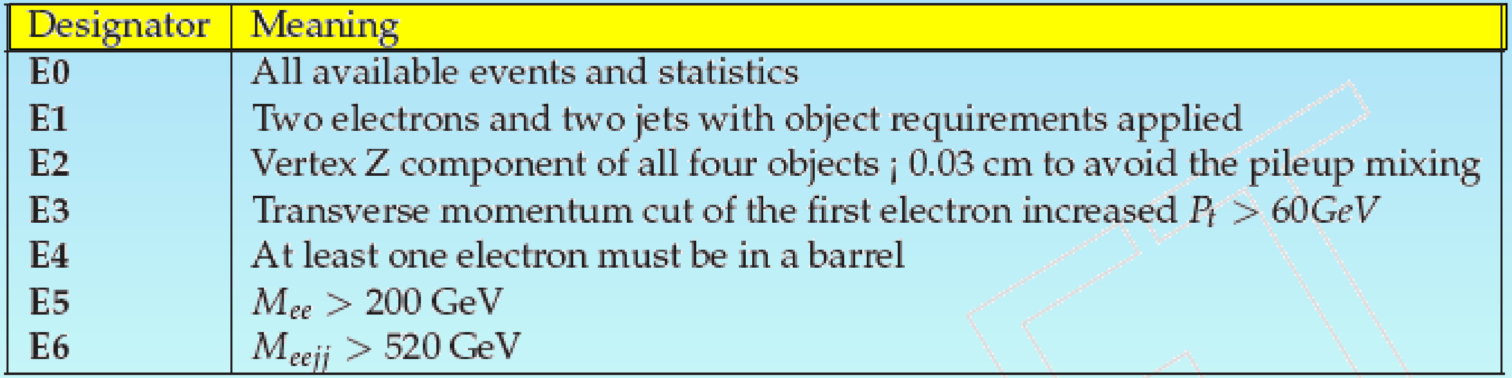
$M(W_R)$ =	0.7 TeV	0.8 TeV	0.9 TeV	1.0 TeV	1.1 TeV	1.2 TeV	1.3 TeV	1.4 TeV	1.5 TeV	1.6 TeV
M(N) (GeV)										
100	17 (9.3%)	7.8 (7.7%)	3.9 (6.6%)	2.2 (6.2%)	1.1 (5.2%)	0.63 (4.5%)	0.30 (3.4%)	0.16 (2.8%)	0.11 (2.8%)	0.057 (2.2%)
200	44 (28%)	27 (29%)	16 (28%)	9.1 (27%)	5.3 (26%)	3.3 (25%)	1.9 (22%)	1.1 (19%)	0.63 (17%)	0.40 (16%)
300	49 (36%)	31 (39%)	20 (40%)	12 (41%)	8.0 (42%)	5.0 (40%)	3.1 (38%)	2.0 (37%)	1.3 (36%)	0.80 (34%)
400	36 (38%)	28 (43%)	19 (46%)	13 (48%)	8.5 (49%)	5.6 (49%)	3.6 (48%)	2.4 (48%)	1.5 (47%)	1.0 (46%)
500	20 (35%)	20 (44%)	16 (48%)	11 (51%)	8.2 (54%)	5.6 (56%)	3.7 (54%)	2.4 (54%)	1.7 (54%)	1.1 (55%)
600	4.7 (25%)	9.9 (39%)	11 (47%)	9.0 (53%)	7.0 (57%)	5.0 (58%)	3.5 (59%)	2.3 (59%)	1.6 (59%)	1.1 (59%)
700	–	2.4 (29%)	5.2 (43%)	5.8 (51%)	5.2 (56%)	4.1 (60%)	3.0 (61%)	2.2 (62%)	1.5 (63%)	1.1 (63%)
800	–	–	1.3 (33%)	2.9 (48%)	3.3 (55%)	3.1 (60%)	2.4 (61%)	1.8 (63%)	1.4 (64%)	0.99 (64%)
900	–	–	–	0.75 (38%)	1.6 (51%)	1.9 (57%)	1.7 (61%)	1.4 (63%)	1.1 (65%)	0.86 (66%)
1000	–	–	–	–	0.41 (41%)	0.95 (54%)	1.1 (59%)	1.0 (62%)	0.89 (65%)	0.70 (67%)
1100	–	–	–	–	–	0.25 (46%)	0.53 (55%)	0.63 (59%)	0.63 (64%)	0.55 (67%)
1200	–	–	–	–	–	–	0.14 (47%)	0.30 (56%)	0.39 (63%)	0.39 (67%)
1300	–	–	–	–	–	–	–	0.082 (49%)	0.18 (59%)	0.23 (65%)
1400	–	–	–	–	–	–	–	–	0.052 (53%)	0.11 (61%)
1500	–	–	–	–	–	–	–	–	–	0.031 (54%)

Events Flow for Electron Channel



	Data	Signal	Tot.Bg	$t\bar{t}$	Z+jets	QCD	W+jets	VV	tW
E0 (Raw)	68340422	10000		1164732	2859343	n/a	10218854	6369880	871720
E0	68340422	22.05	n/a	5964	141218	n/a	1131844	2422	6.5
E1	219	12.04	235	20.71	197	13.58	1.00	2.99	0.76
E2	192	11.48	212	19.12	174	13.58	0.66	2.71	0.72
E3	117	11.39	121	10.32	105	3.51	0.66	1.74	0.49
E4	105	11.25	111	10.18	96.6	1.44	0.66	1.62	0.48
E5	2	9.97	3.31	1.45	0.80	0.46	0.11	0.04	0.09
E6	2	9.96	1.56	0.72	0.47	0.28	–	0.03	0.06
E6 (Raw)	2	4505		142	1005	1686	0	97	7830

Key:



Designator	Meaning
E0	All available events and statistics
E1	Two electrons and two jets with object requirements applied
E2	Vertex Z component of all four objects ¡ 0.03 cm to avoid the pileup mixing
E3	Transverse momentum cut of the first electron increased $P_t > 60 GeV$
E4	At least one electron must be in a barrel
E5	$M_{ee} > 200$ GeV
E6	$M_{eejj} > 520$ GeV

Events Flow for *Muon* Channel

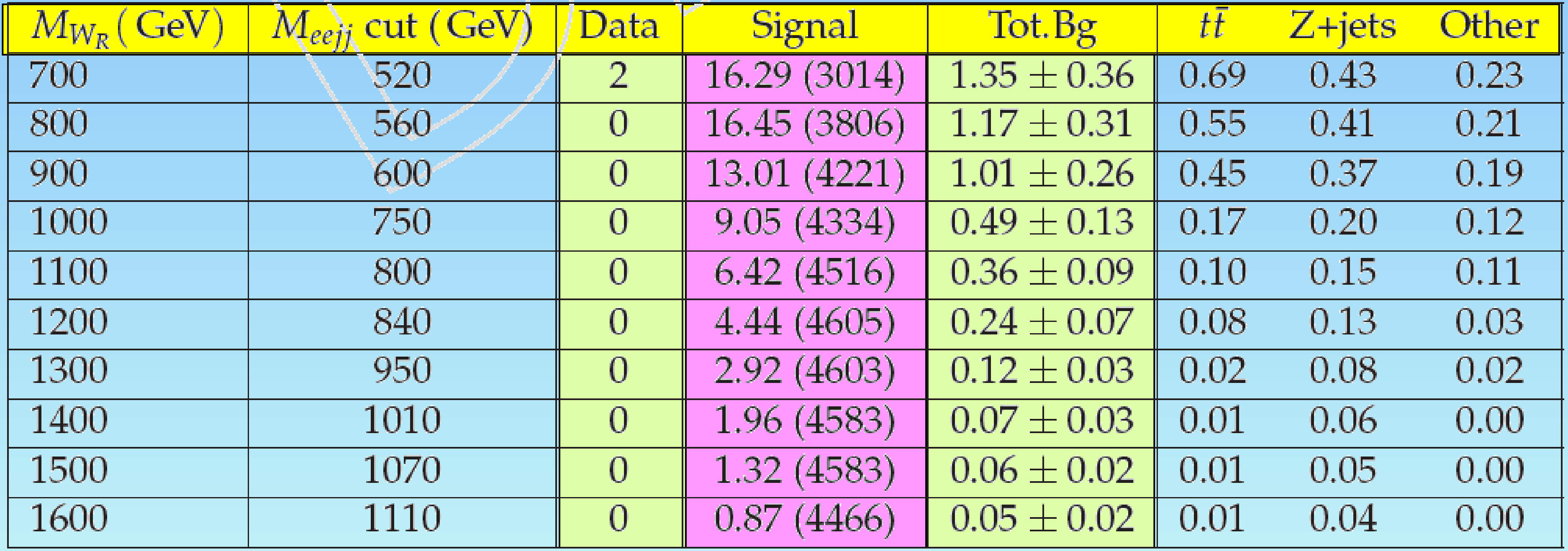
	Data	Signal	Tot.Bg	$t\bar{t}$	Z+jets	QCD	W+jets	VV	tW
M0 (Raw)		10000		1165716	2859343		5021554	6369880	494961
M0		22.4		6036	131165		952579	2425	381
M1	329	13.8	303 ± 54	26	271	1.11	0.14	3.8	0.68
M2	326	13.7	301 ± 54	26	269	1.08	0.14	3.8	0.67
M3	182	13.7	180 ± 32	14	163	0.33	0.12	2.4	0.41
M4	3	12.1	3.4 ± 0.6	1.96	1.31	0.03	0.022	0.062	0.06
M5	1	12.1	1.9 ± 0.3	1.03	0.85	–	0.022	0.037	0.03
M5 (Raw)	1	5397		198	1230	0	2	137	37

Key:

Designator	Meaning
M0	All available events and statistics
M1	Two muons and two jets with object requirements applied
M2	Vertex Z component of all four objects < 0.03 cm to suppress pileup
M3	One muon with $p_{\mathrm{T}} > 60$ GeV/c
M4	$M_{\mu\mu} > 200$ GeV
M5	$M_{\mu\mu jj} > 520$ GeV

Events Flow for Final Cuts

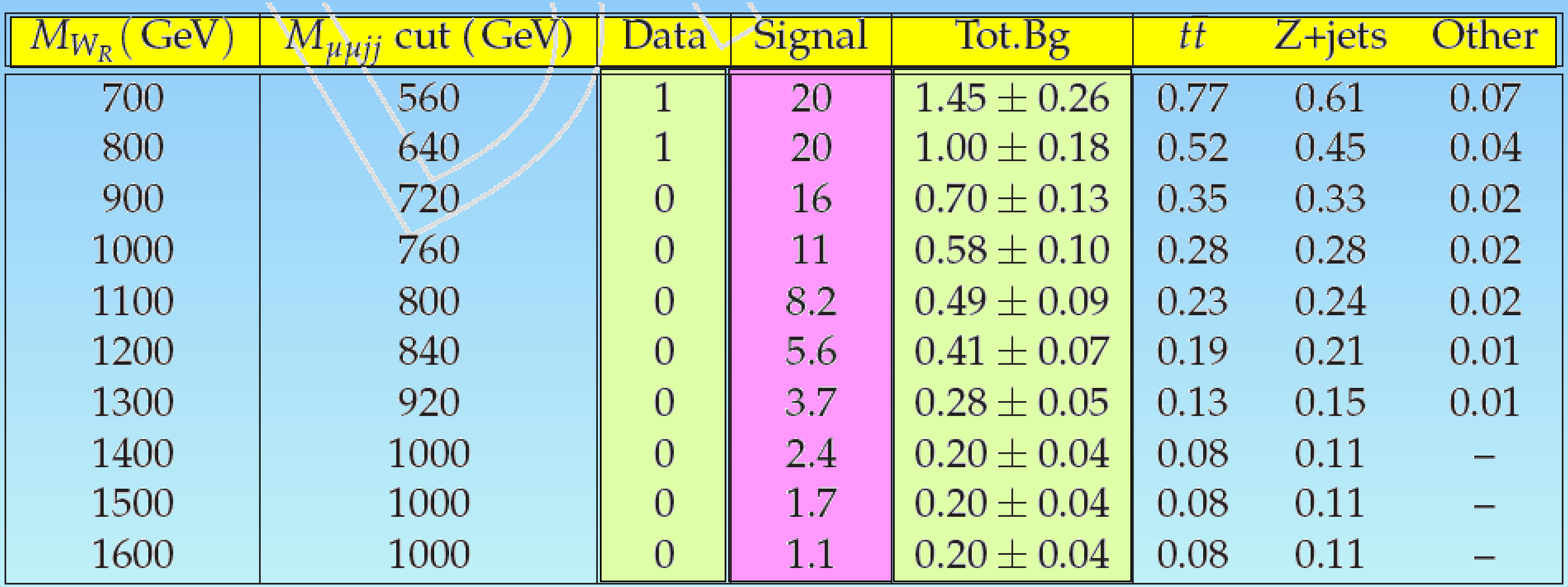
Electron **channel**



M_{W_R} (GeV)	M_{eejj} cut (GeV)	Data	Signal	Tot.Bg	$t\bar{t}$	Z+jets	Other
700	520	2	16.29 (3014)	1.35 ± 0.36	0.69	0.43	0.23
800	560	0	16.45 (3806)	1.17 ± 0.31	0.55	0.41	0.21
900	600	0	13.01 (4221)	1.01 ± 0.26	0.45	0.37	0.19
1000	750	0	9.05 (4334)	0.49 ± 0.13	0.17	0.20	0.12
1100	800	0	6.42 (4516)	0.36 ± 0.09	0.10	0.15	0.11
1200	840	0	4.44 (4605)	0.24 ± 0.07	0.08	0.13	0.03
1300	950	0	2.92 (4603)	0.12 ± 0.03	0.02	0.08	0.02
1400	1010	0	1.96 (4583)	0.07 ± 0.03	0.01	0.06	0.00
1500	1070	0	1.32 (4583)	0.06 ± 0.02	0.01	0.05	0.00
1600	1110	0	0.87 (4466)	0.05 ± 0.02	0.01	0.04	0.00

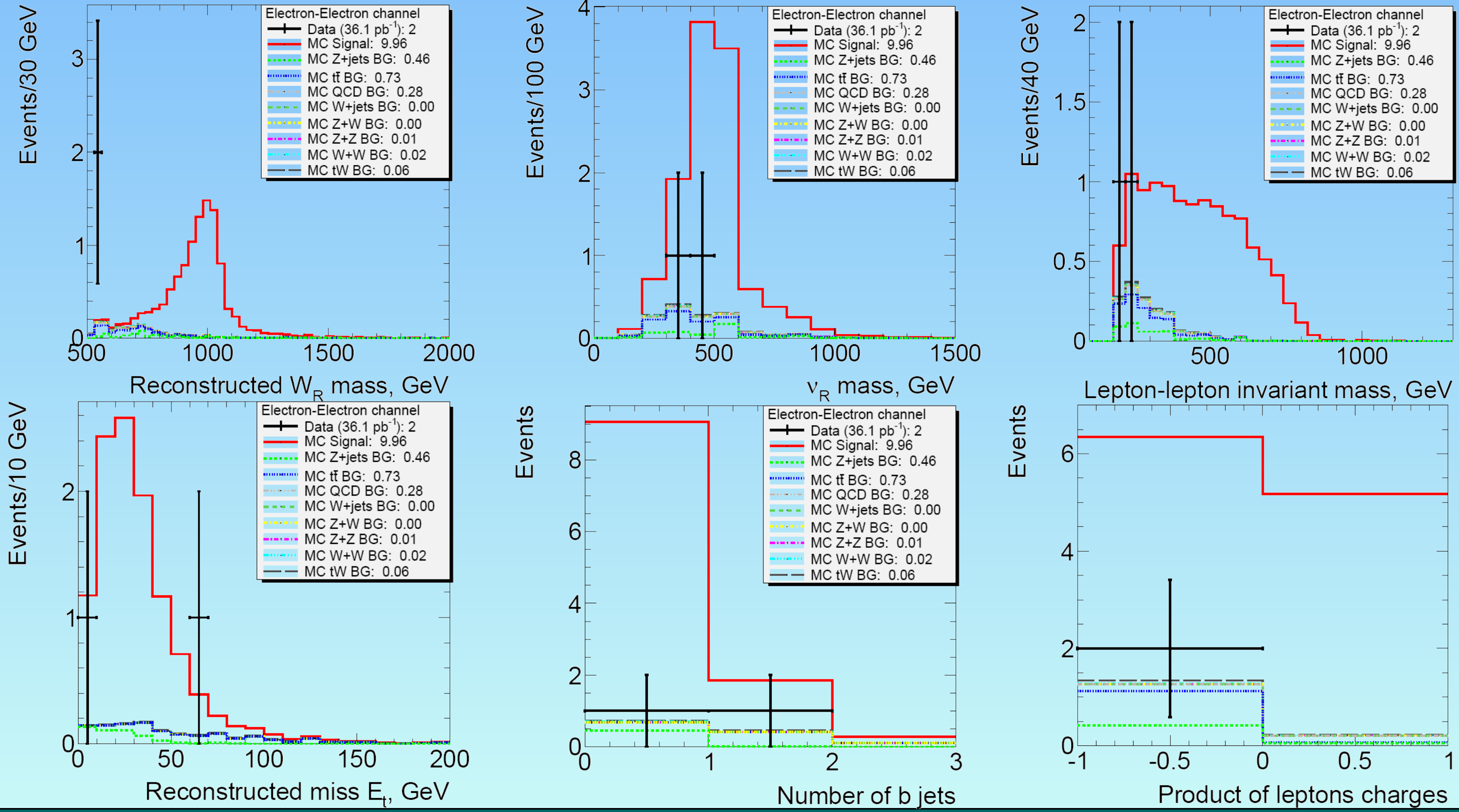
Events Flow for Final Cuts

Muon **channel**

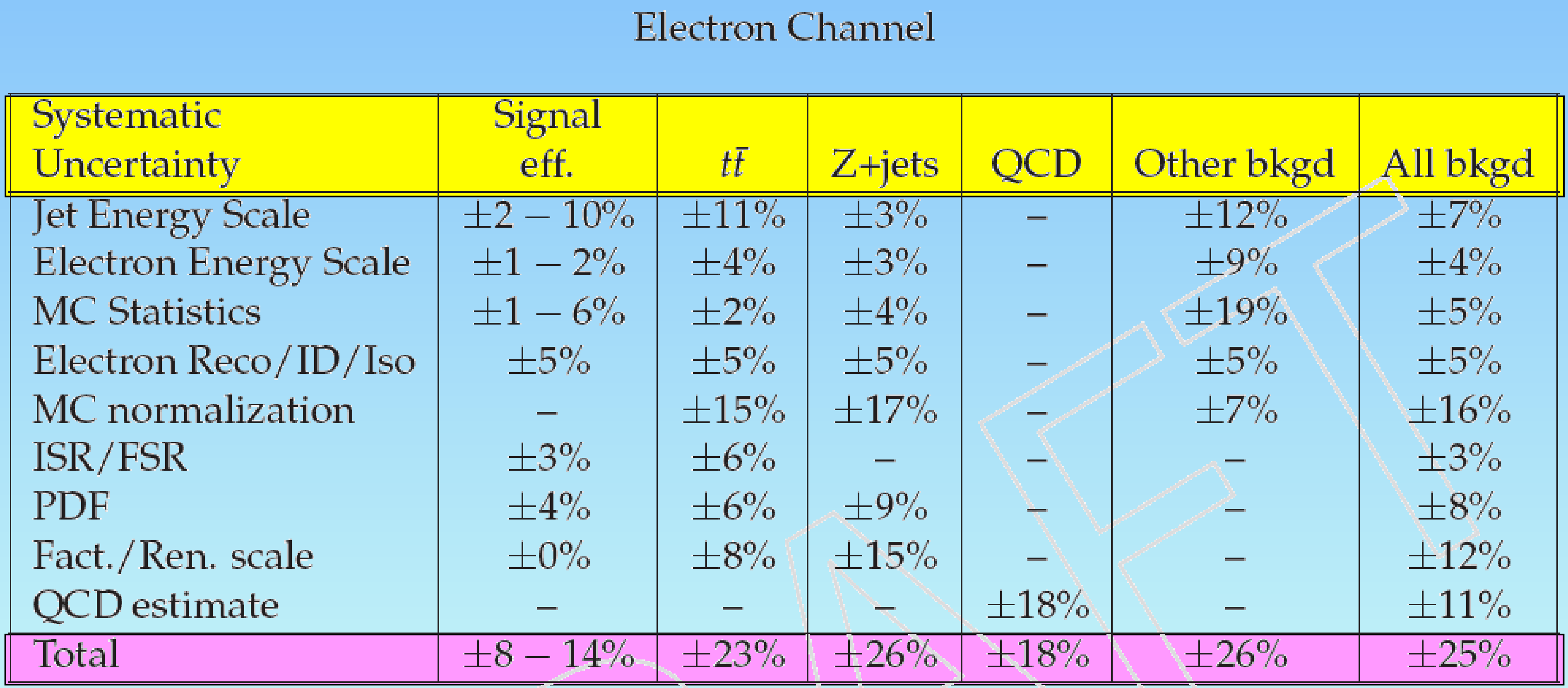


M_{W_R} (GeV)	$M_{\mu\mu jj}$ cut (GeV)	Data	Signal	Tot.Bg	$t\bar{t}$	Z+jets	Other
700	560	1	20	1.45 ± 0.26	0.77	0.61	0.07
800	640	1	20	1.00 ± 0.18	0.52	0.45	0.04
900	720	0	16	0.70 ± 0.13	0.35	0.33	0.02
1000	760	0	11	0.58 ± 0.10	0.28	0.28	0.02
1100	800	0	8.2	0.49 ± 0.09	0.23	0.24	0.02
1200	840	0	5.6	0.41 ± 0.07	0.19	0.21	0.01
1300	920	0	3.7	0.28 ± 0.05	0.13	0.15	0.01
1400	1000	0	2.4	0.20 ± 0.04	0.08	0.11	–
1500	1000	0	1.7	0.20 ± 0.04	0.08	0.11	–
1600	1000	0	1.1	0.20 ± 0.04	0.08	0.11	–

Distributions for *Electron* Channel after M_W=520 GeV



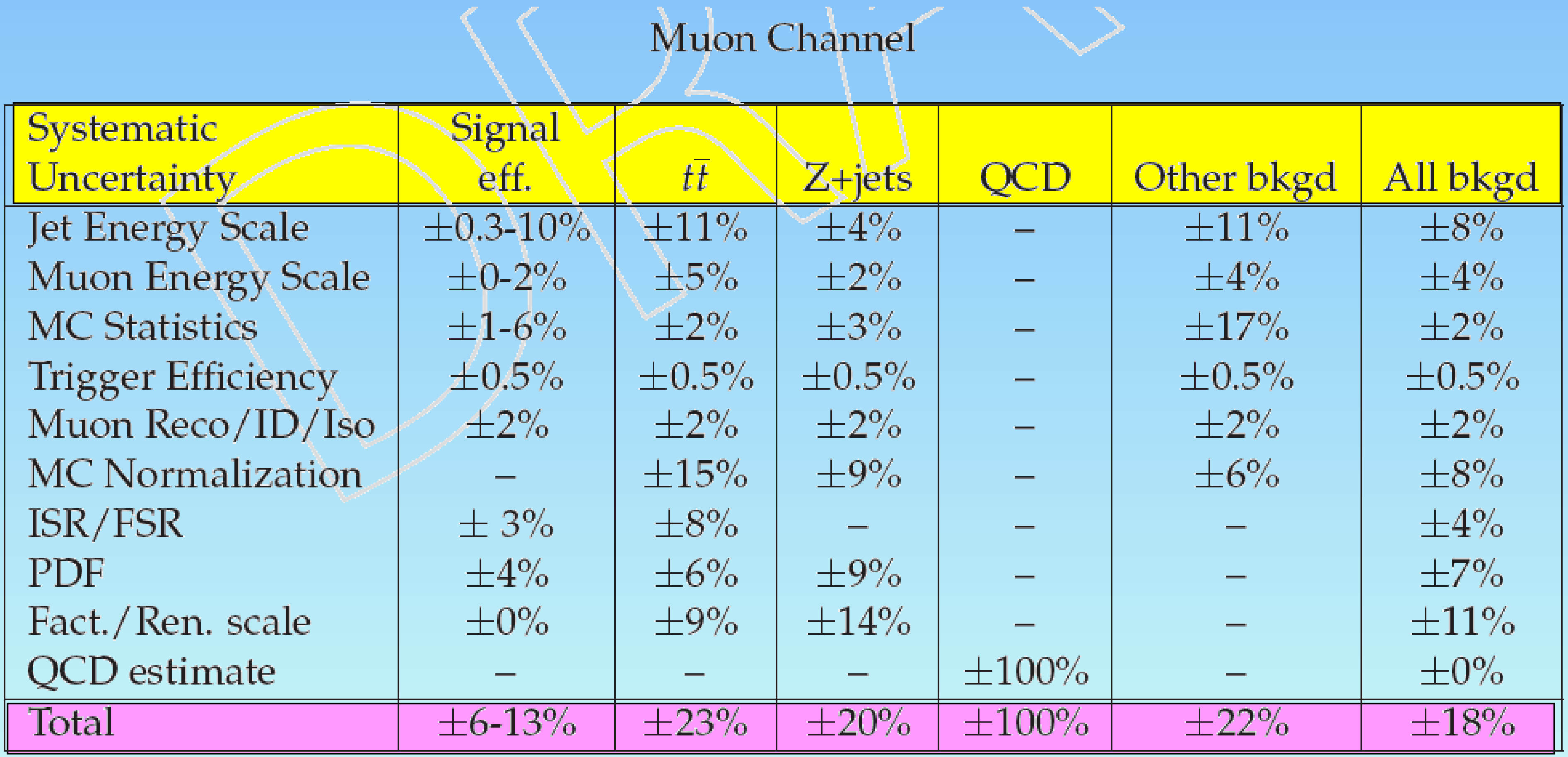
Systematic uncertainties for *Electron* Channel



Electron Channel

Systematic Uncertainty	Signal eff.	$t\bar{t}$	Z+jets	QCD	Other bkgd	All bkgd
Jet Energy Scale	±2 – 10%	±11%	±3%	–	±12%	±7%
Electron Energy Scale	±1 – 2%	±4%	±3%	–	±9%	±4%
MC Statistics	±1 – 6%	±2%	±4%	–	±19%	±5%
Electron Reco/ID/Iso	±5%	±5%	±5%	–	±5%	±5%
MC normalization	–	±15%	±17%	–	±7%	±16%
ISR/FSR	±3%	±6%	–	–	–	±3%
PDF	±4%	±6%	±9%	–	–	±8%
Fact./Ren. scale	±0%	±8%	±15%	–	–	±12%
QCD estimate	–	–	–	±18%	–	±11%
Total	±8 – 14%	±23%	±26%	±18%	±26%	±25%

Systematic uncertainties for *Muon* Channel



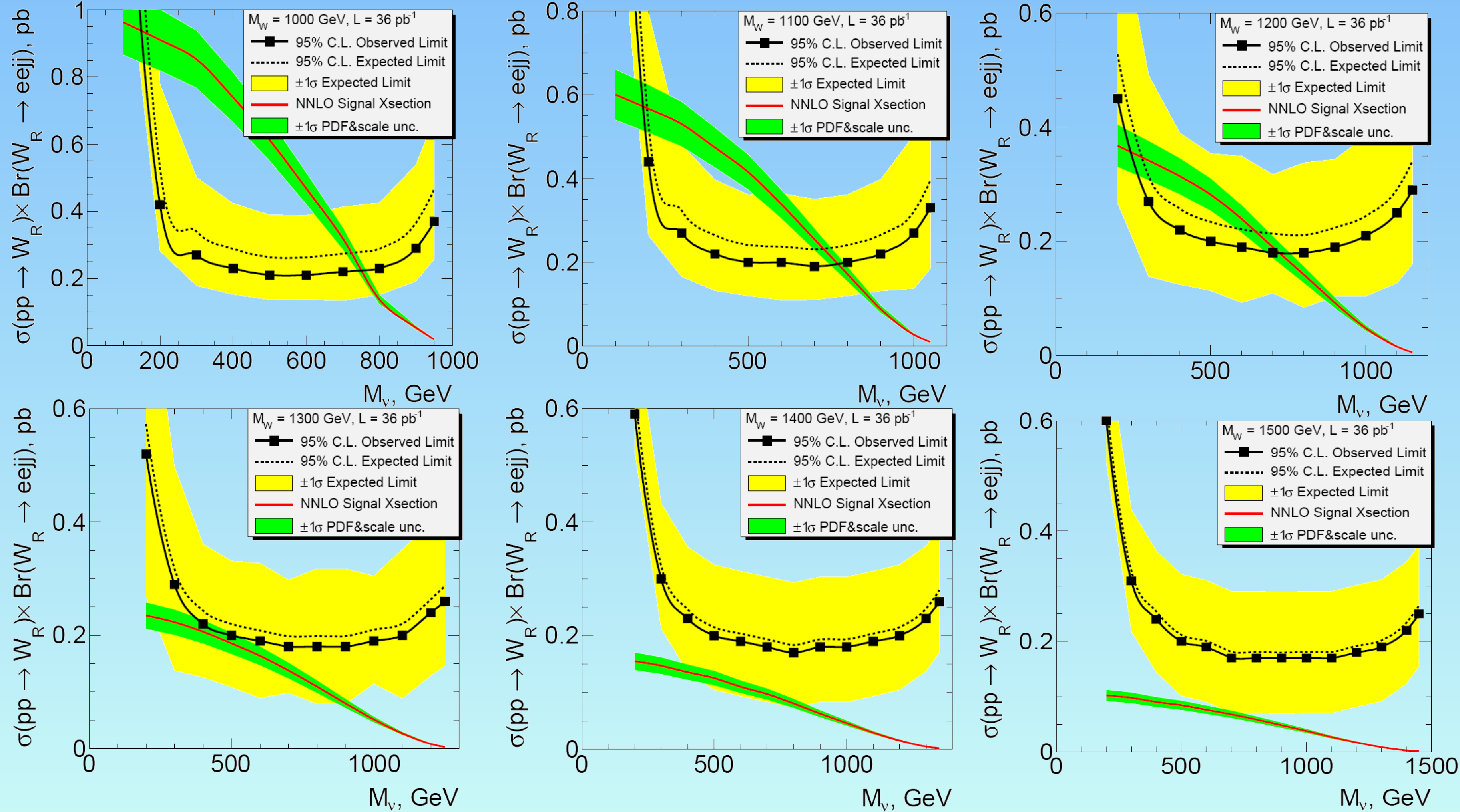
Muon Channel

Systematic Uncertainty	Signal eff.	$t\bar{t}$	Z+jets	QCD	Other bkgd	All bkgd
Jet Energy Scale	±0.3-10%	±11%	±4%	–	±11%	±8%
Muon Energy Scale	±0-2%	±5%	±2%	–	±4%	±4%
MC Statistics	±1-6%	±2%	±3%	–	±17%	±2%
Trigger Efficiency	±0.5%	±0.5%	±0.5%	–	±0.5%	±0.5%
Muon Reco/ID/Iso	±2%	±2%	±2%	–	±2%	±2%
MC Normalization	–	±15%	±9%	–	±6%	±8%
ISR/FSR	± 3%	±8%	–	–	–	±4%
PDF	±4%	±6%	±9%	–	–	±7%
Fact./Ren. scale	±0%	±9%	±14%	–	–	±11%
QCD estimate	–	–	–	±100%	–	±0%
Total	±6-13%	±23%	±20%	±100%	±22%	±18%

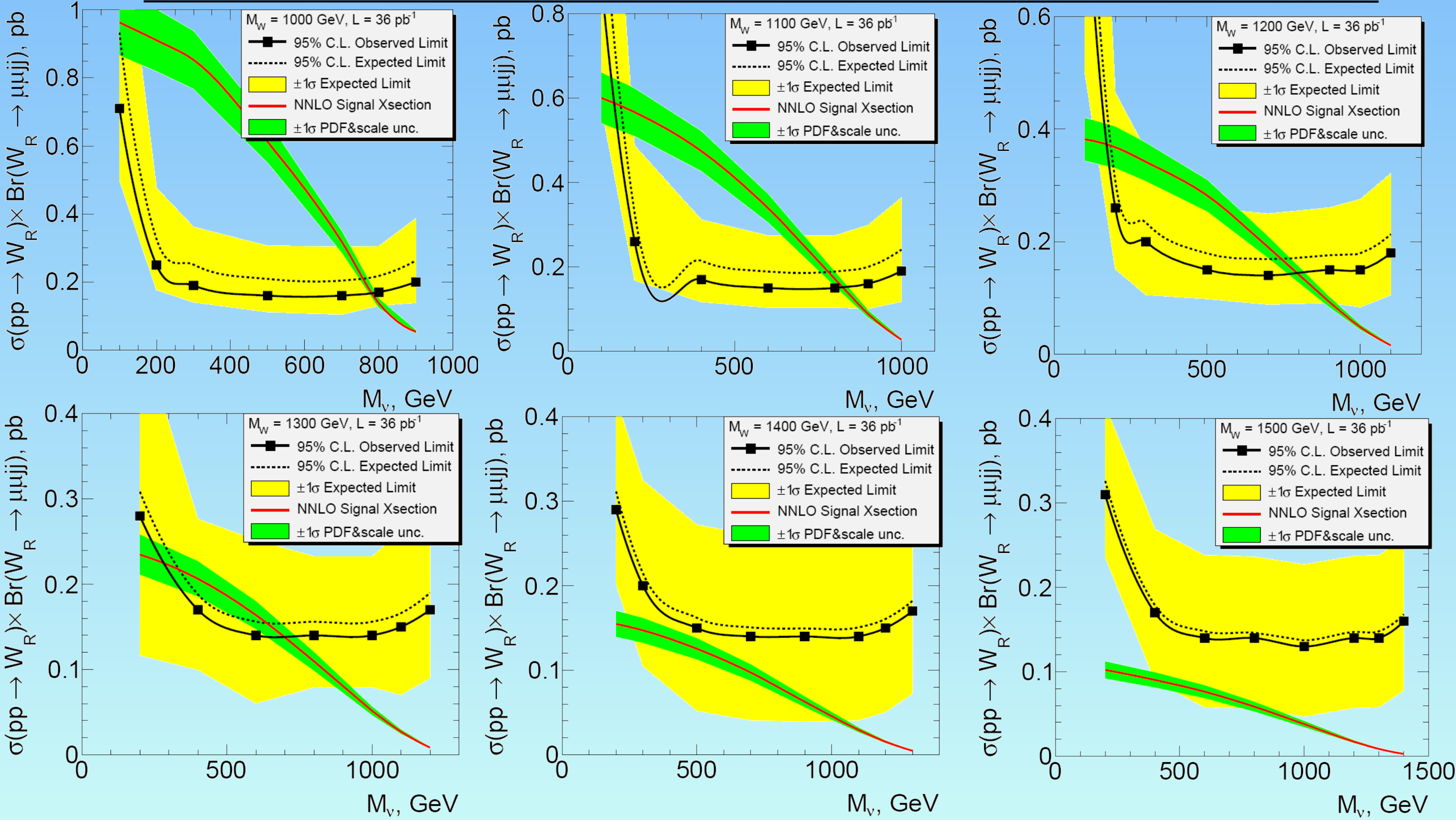
Limits setting

- **Bayesian approach**
- **Signal efficiency and luminosity uncertainties are nuisance parameters with Lognormal distribution**
- **Number of BG events uncertainties are nuisance parameters with Lognormal distribution**

Upper Limits for *Electron* Channel

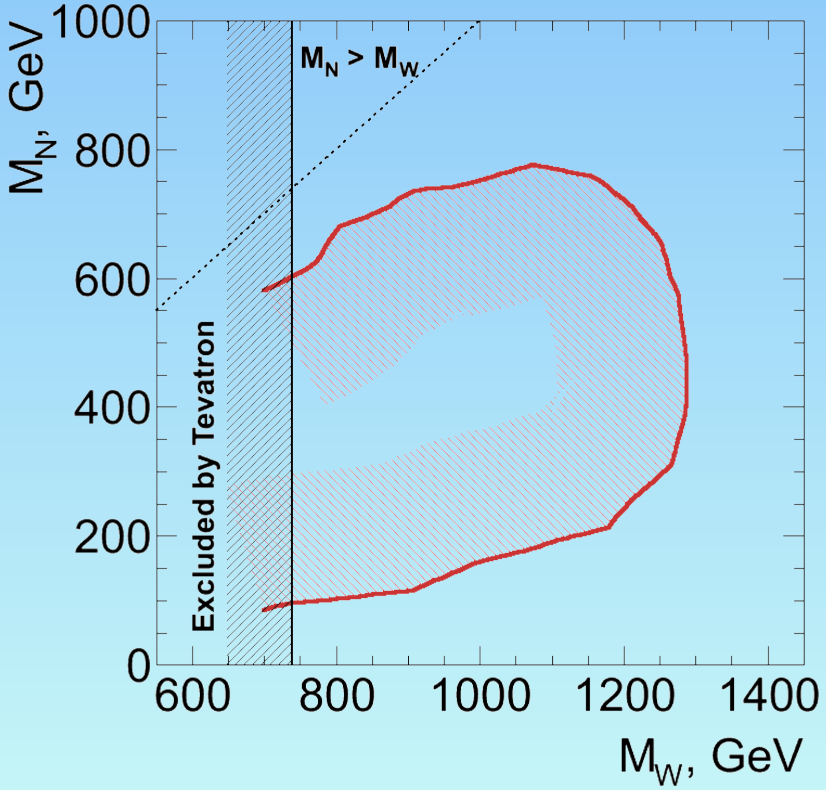


Upper Limits for *Muon* Channel

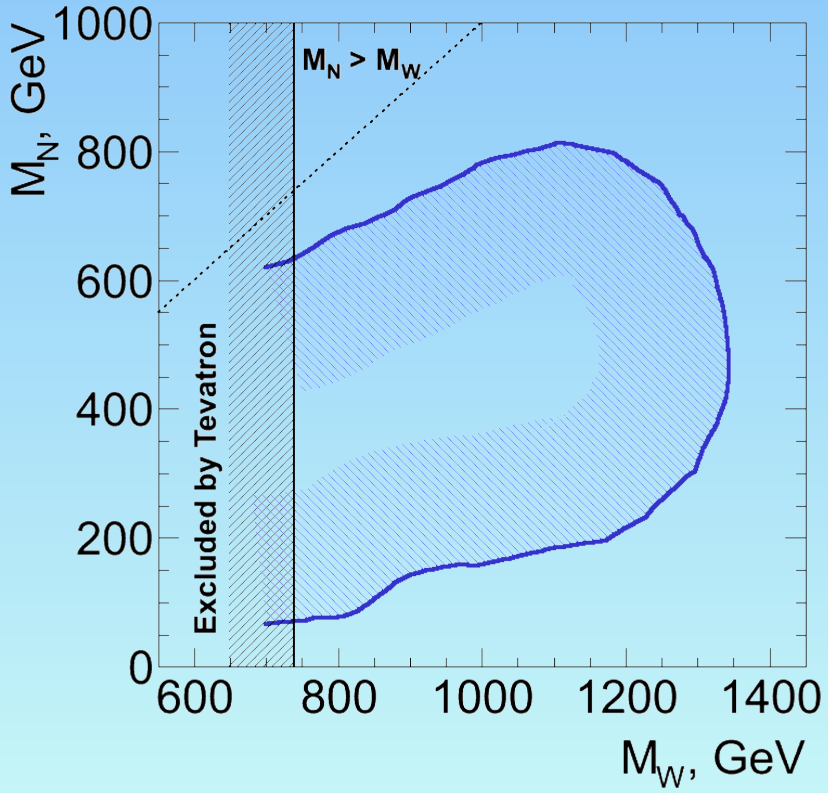


95% Exclusion mass region

Electron channel



Muon channel



Summary

- **36.1/pb of data analysed;**
- **BGs have been investigated;**
- **Selection cuts have been optimized;**
- **Systematic has been estimated;**
- **No candidates after all selections have been observed;**
- **Upper limits have been obtained;**
- **New mass region has been excluded.**

Backup

QCD BG, *Muon* Channel

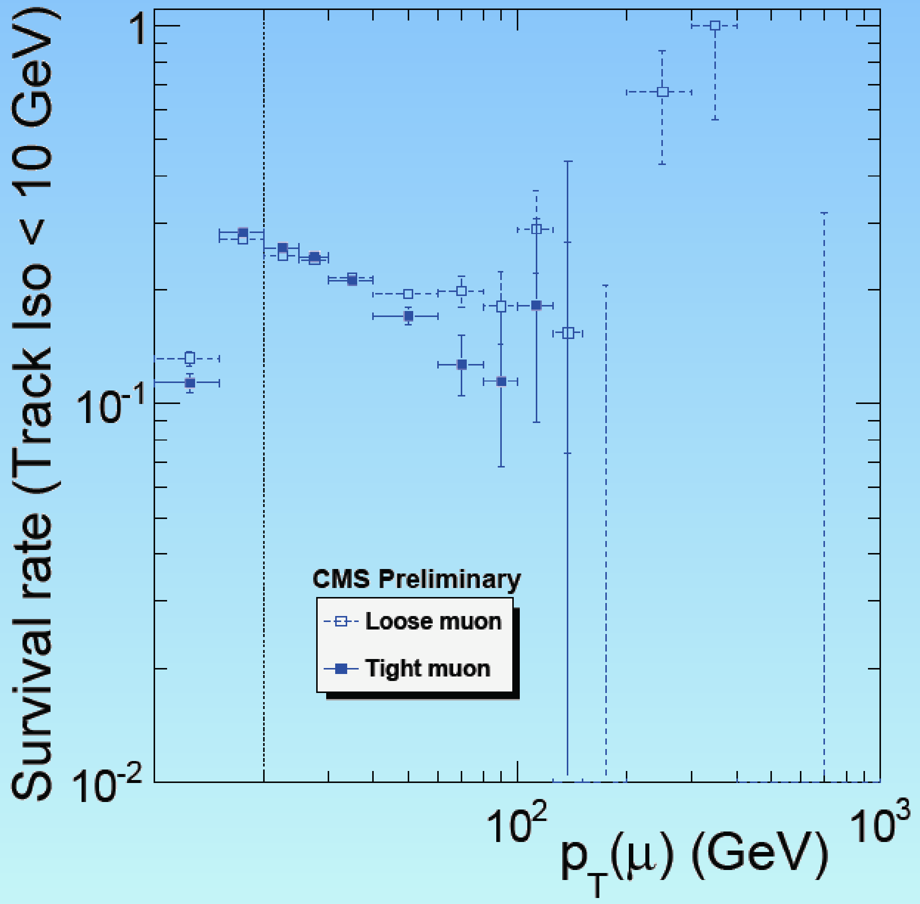
1st Step: Extract a di-jet sample from data...

- With a back-to-back jet / muon pair in each event;
- Muon must pass either VBTF loose or tight;
- Jet must pass LOOSE PURE09 ID, $p_t > 10$ GeV;
- To purify the sample, reject events if any of these apply:
  - (Calo) MET > 20 GeV;
  - Less than 10 GeV in ECAL in the muon's vicinity;
  - Any jet with $p_t > 20$ GeV outside μ–jet axis;
  - 2nd loose quality muon found that:
    - Has relative isolation < 0.15;
    - Forms dimuon invariant mass within Z-peak or
    - Is found inside the selected jet with at least 75% of jet p_t.

QCD BG, *Muon* Channel

2nd Step: determine a fake rate

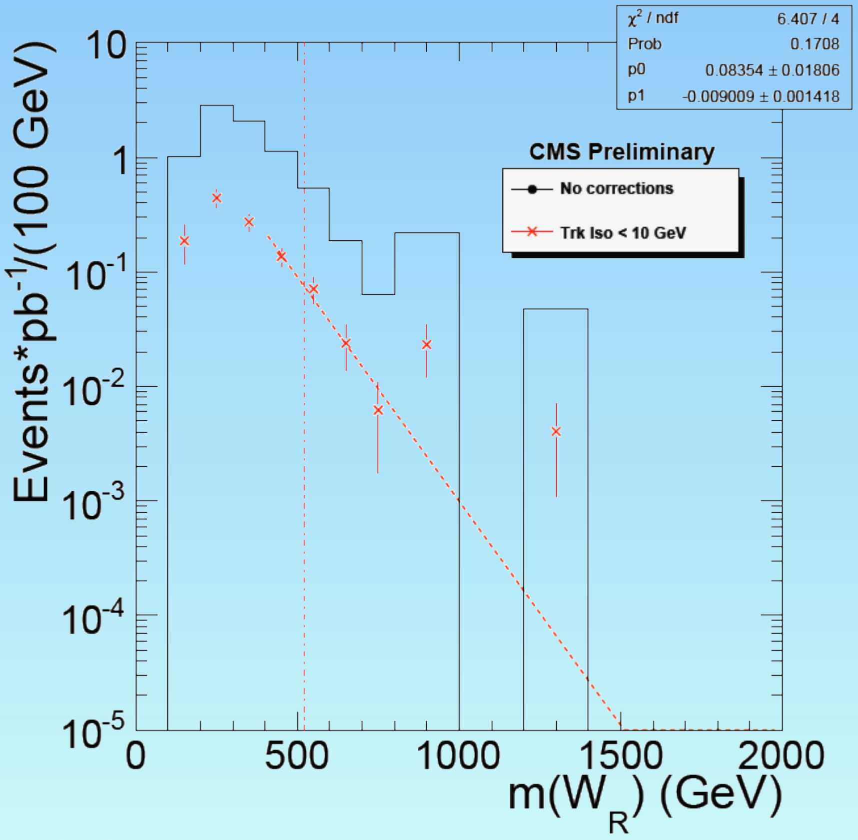
- **determine rate at which these muons pass the absolute track isolation criterion as a function of muon quality (loose or tight)**



QCD BG, *Muon* Channel

3rd Step: determine a background rate

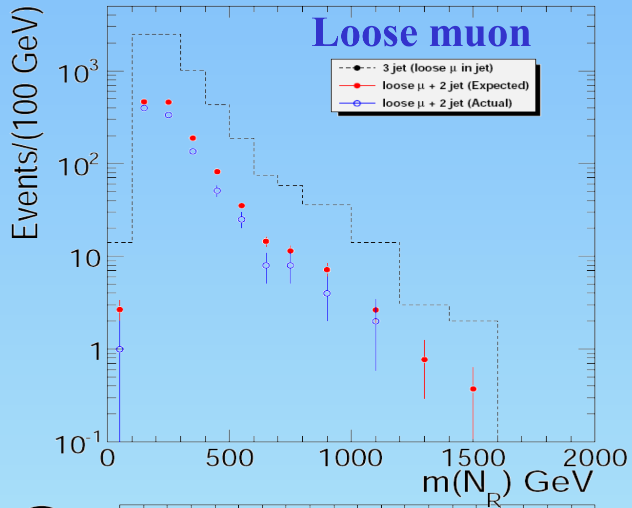
- Duplicate the μμjj object selection, except require both μ's to be inside a jet;
- Weight the muon according to rate determined previously;
- Generate $M_{\mu\mu jj}$ distribution;
- M_{ll} > 200 GeV removes 99% of QCD background;
- Plot shows events before mass cut.

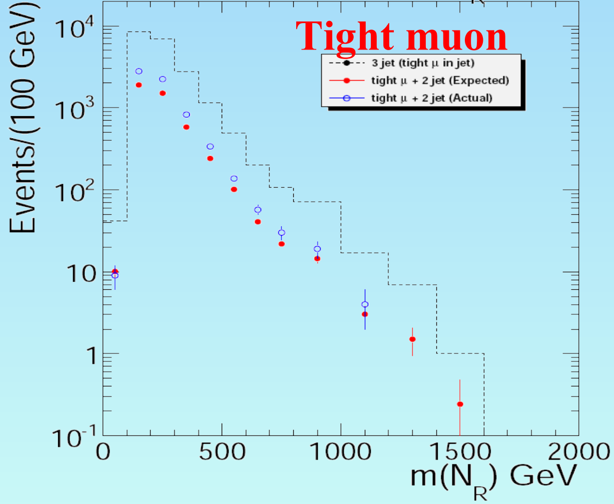


QCD BG, *Muon* Channel

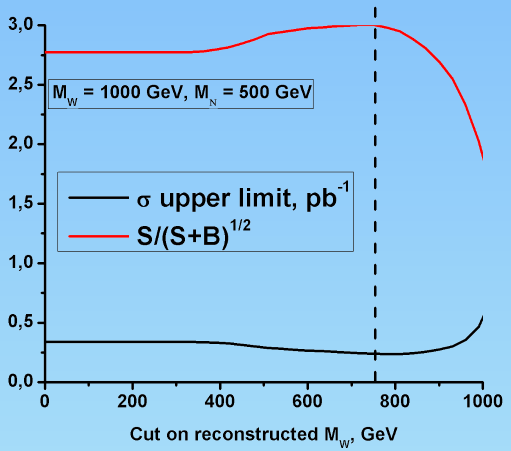
Closure Test using three jet sample:

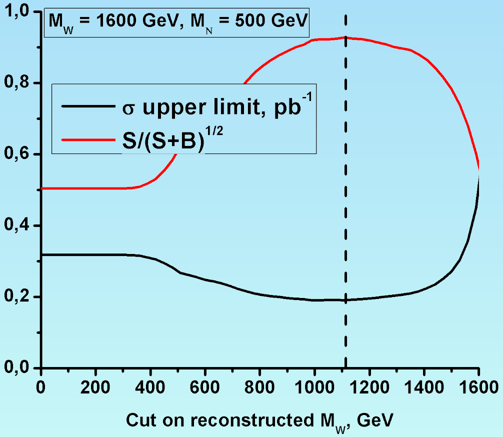
- Require *MET* < 20 GeV to reduce contribution from W+jets
- Find muon (in jet) of tight or loose quality
- Apply usual requirements on other two jets, compute N_R mass
- Scale distribution by muon weight
- Compare expectations to isolated muon + 2 jet sample
- Loose muon: 1266 expected from 3 jet sample, 964 seen
- Tight muon: 4412 expected, 6442 seen
- Assume 100% uncertainty on QCD estimate
- Roughly double the discrepancy seen for tight muon

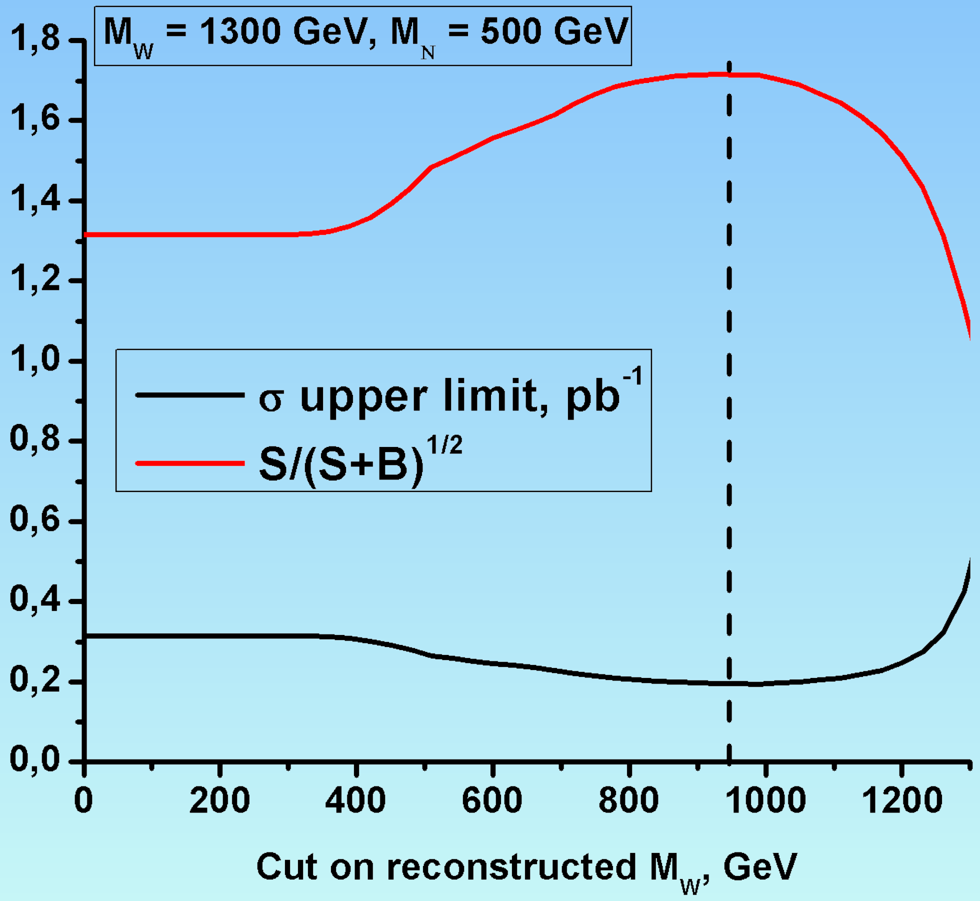




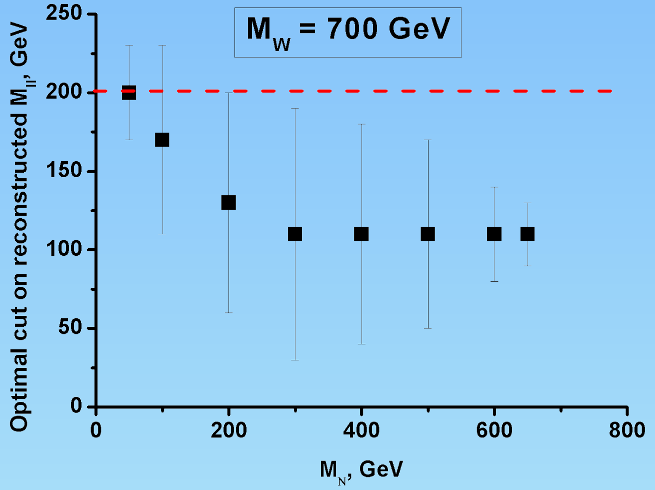
Cuts Optimization via Exp. Limit

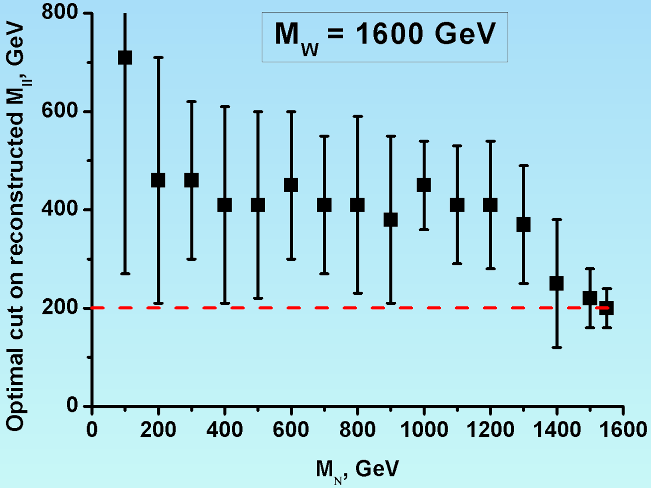


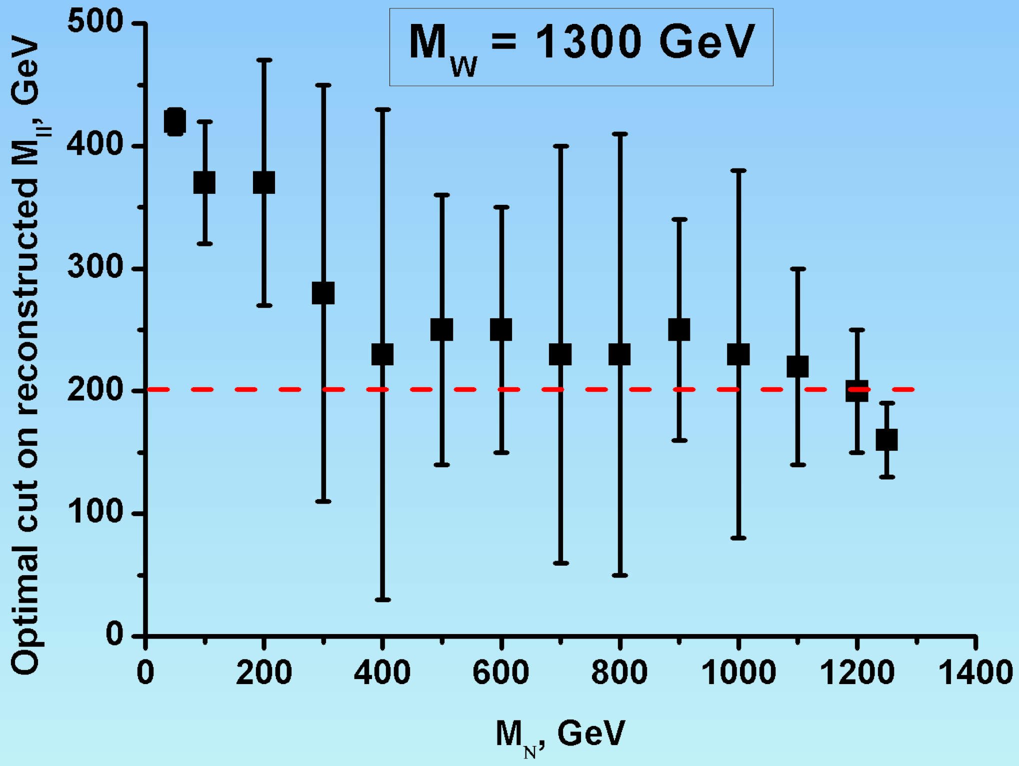




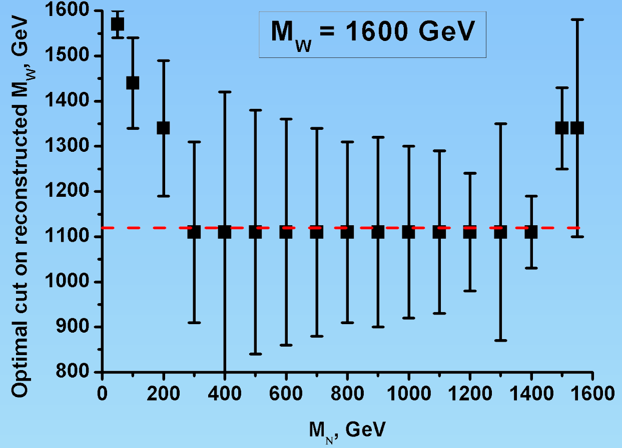
M_{ll} Cut Optimization

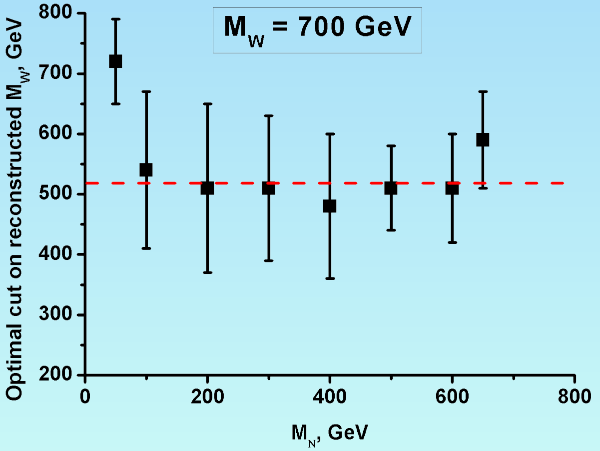


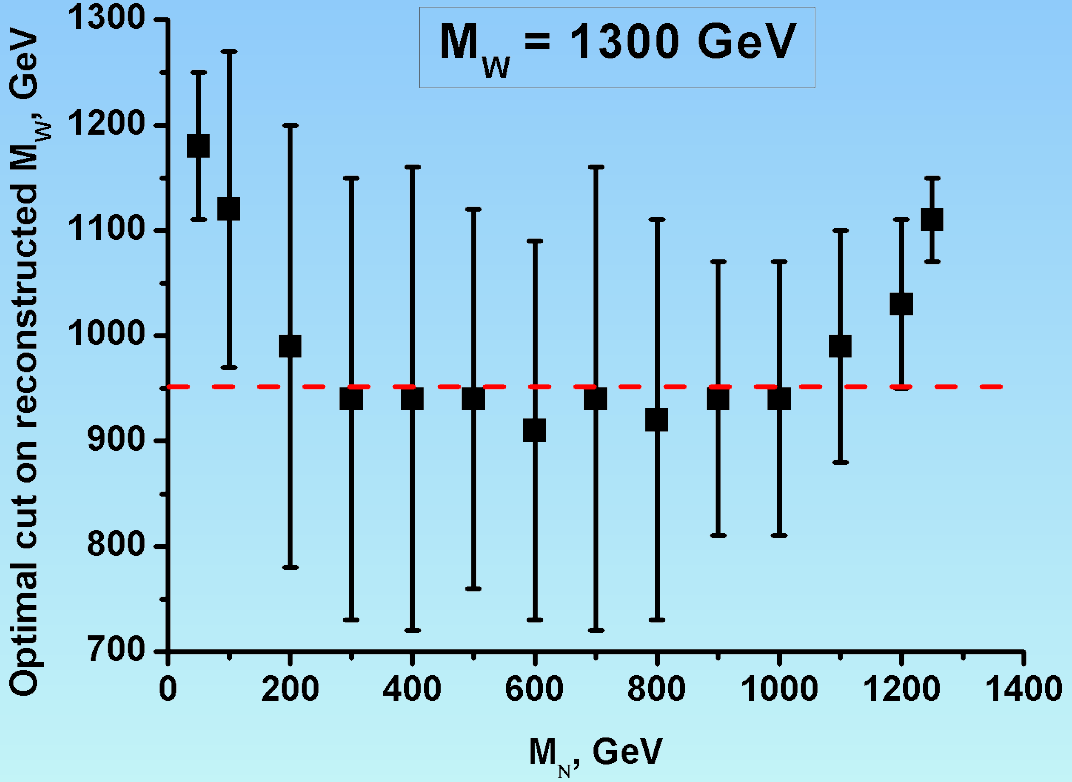




M_W Cut Optimization







PDF uncertainties

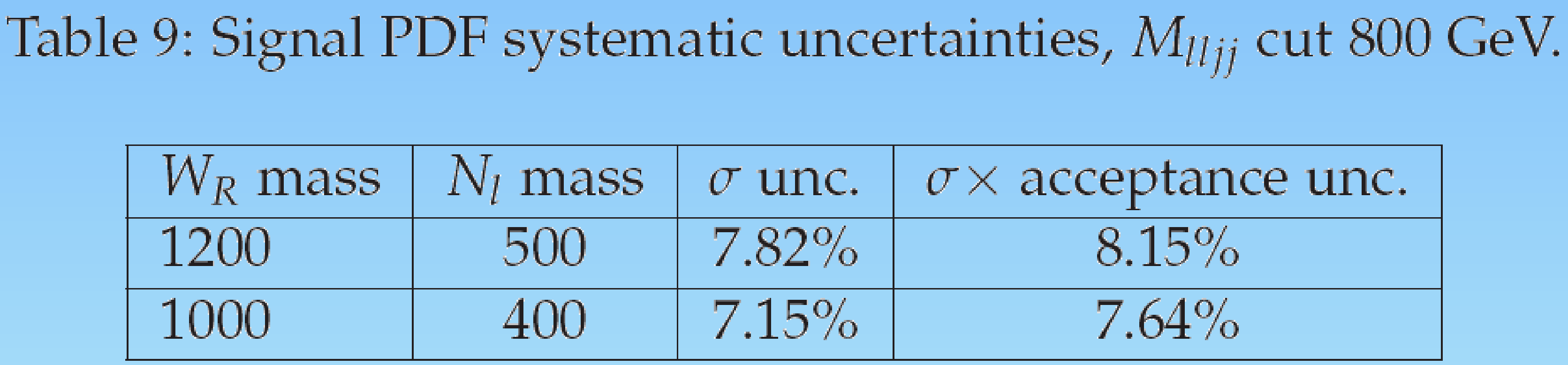


Table 9: Signal PDF systematic uncertainties, M_{lljj} cut 800 GeV.

W_R mass	N_l mass	σ unc.	$\sigma \times$ acceptance unc.
1200	500	7.82%	8.15%
1000	400	7.15%	7.64%

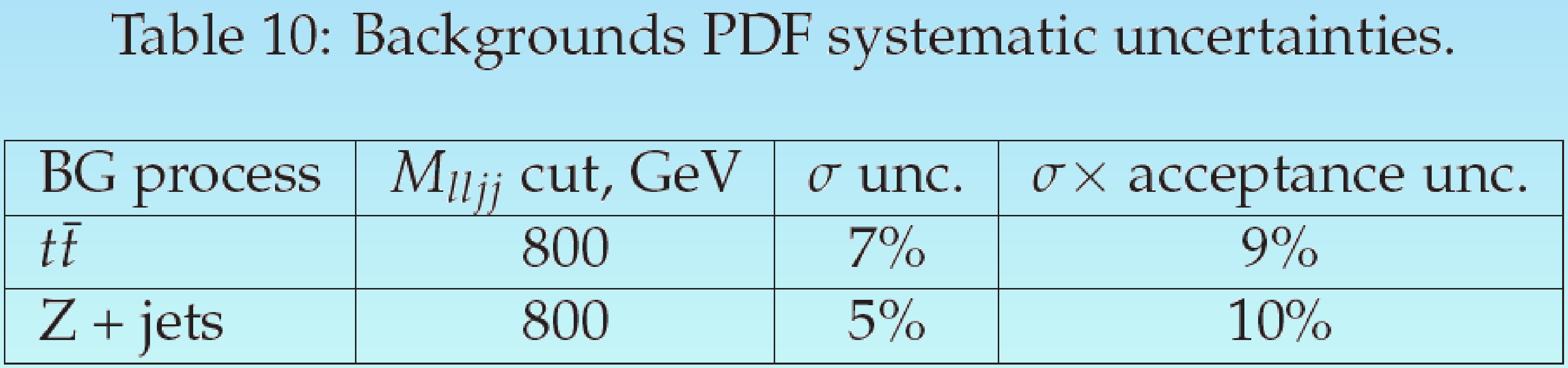


Table 10: Backgrounds PDF systematic uncertainties.

BG process	M_{lljj} cut, GeV	σ unc.	$\sigma \times$ acceptance unc.
$t\bar{t}$	800	7%	9%
$Z + \text{jets}$	800	5%	10%

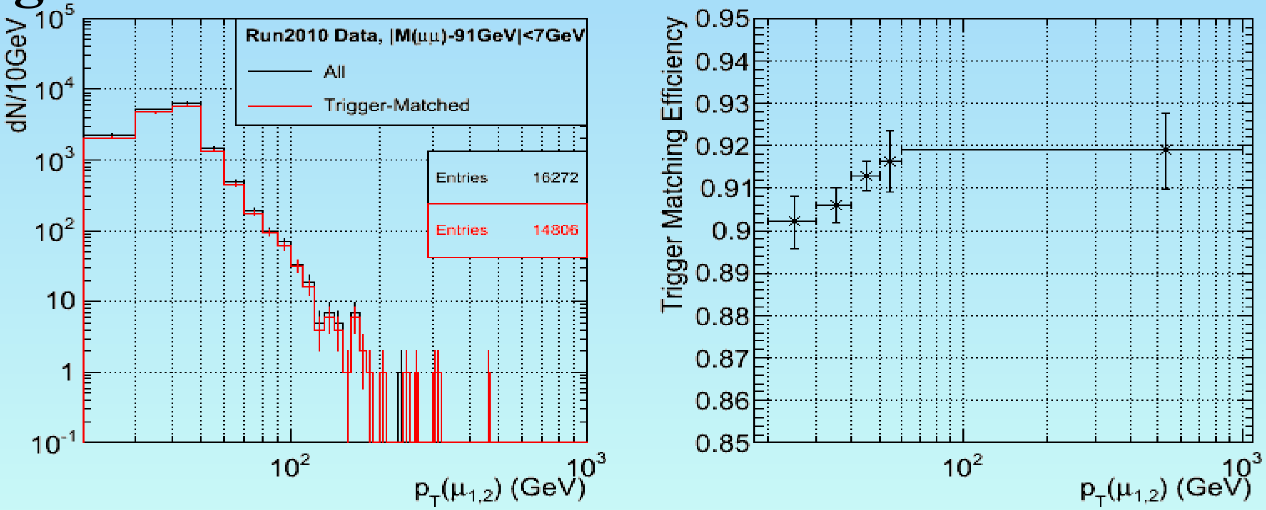
Bayesian Approach

$$0.95 = \int_0^{\sigma_{\mathrm{UL}}} d\sigma \int_0^{\infty} dL \int_0^{\infty} db \int_0^{1} d\epsilon \, g(\epsilon) h(L) f(b) \left(\frac{e^{-(b+L\sigma\epsilon)}(b+L\sigma\epsilon)^k}{k!} \right)$$

$$P = \frac{e^{-(b+L\sigma\epsilon)}(b+L\sigma\epsilon)^k}{k!}$$

Muon Trigger Efficiency

- **Trigger efficiency studied within Z-peak window in data**
- **Tag-and-probe to determine rate of trigger matching for the probe muon as a function of p_t, "trigineff(p_t)"**
- **trigineff(p_t) *simulated* for all MC samples**
- **Trigger efficiency uncertainty systematic determined by varying the probability of failing trigger match up and down by 1-sigma.**



Template

Template