Search for W' in Final States with Electron and Large Missing E_T in CDF and CMS

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Motivation

- **Left-Right Symmetric Model**
  - ✓ Of weak interaction by spontaneous symmetry breaking in the right-handed sector, W′ boson obtains its mass
  - ✓ Assuming that coupling strength and CKM matrix to be same as the Standard Model
  - ✓ Right handed neutrino is light and stable

$$SU(2)_R \times SU(2)_L \times U(1)_{B-L}$$

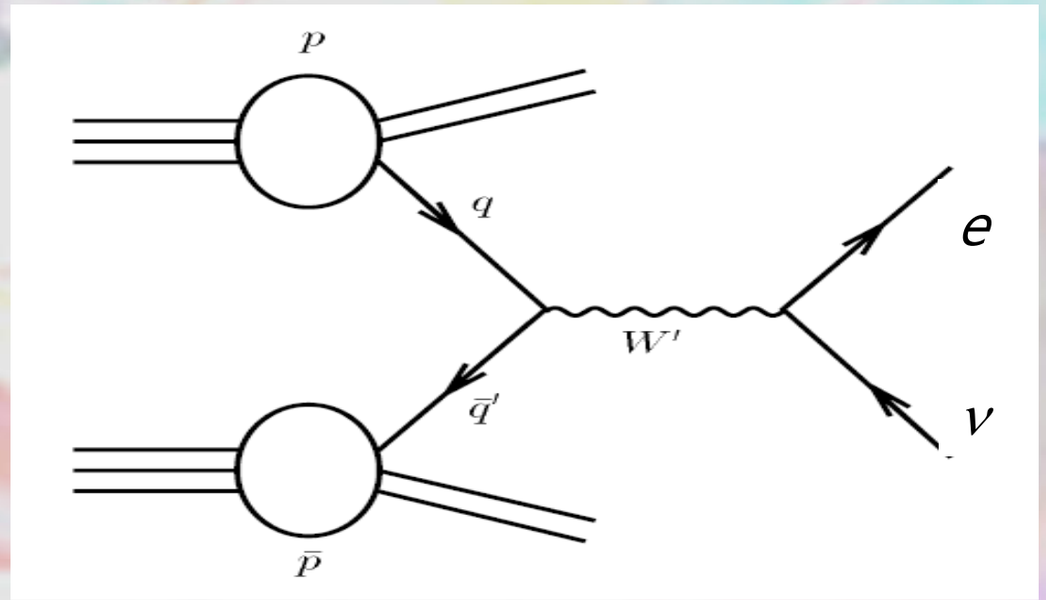
$\downarrow$ *W′/Z′*

$$SU(2)_L \times U(1)_Y$$

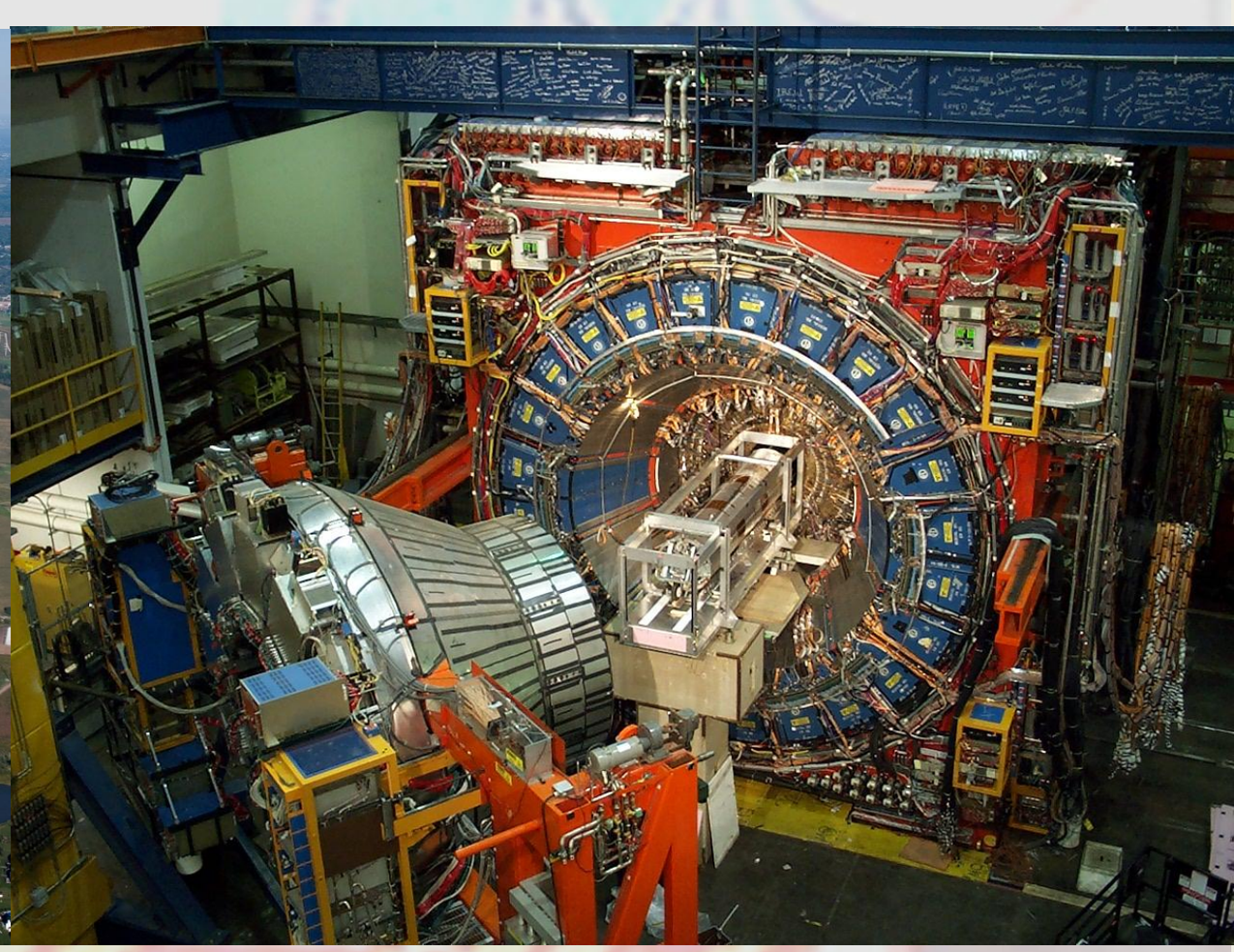
$\downarrow$ *W/Z*

$$U(1)_{EM}$$

- **W′ Production and Decay**
  - ✓ W′ can be produced in both ppbar and pp collisions through qqbar annihilation
  - ✓ Possible decay channels
    - A lepton-neutrino pair
    - A quark pair
    - WZ pair



CDF W' Search



p-pbar Collision at 1.98 TeV with 5.3 fb^{-1} data

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Analysis Procedure

- Analysis procedure
  - ✓ Event Selection (electron+MET in final state)
  - ✓ Background Estimation (MC and QCD multijet)
  - ✓ W' Signal Estimation
  - ✓ M_T Fitting and Limits

- Step

1. TopNtuple(100TB) → WpNtuple (500 GB) : save all events
2. event selection : data vs MC(background & signal)

Electron energy corrections (using Mass of dielectron)

3. multijet bg. estimation : data driven estimate
4. M_T Fitting(binned likelihood)
7. Systematic Studies
8. Limit estimate

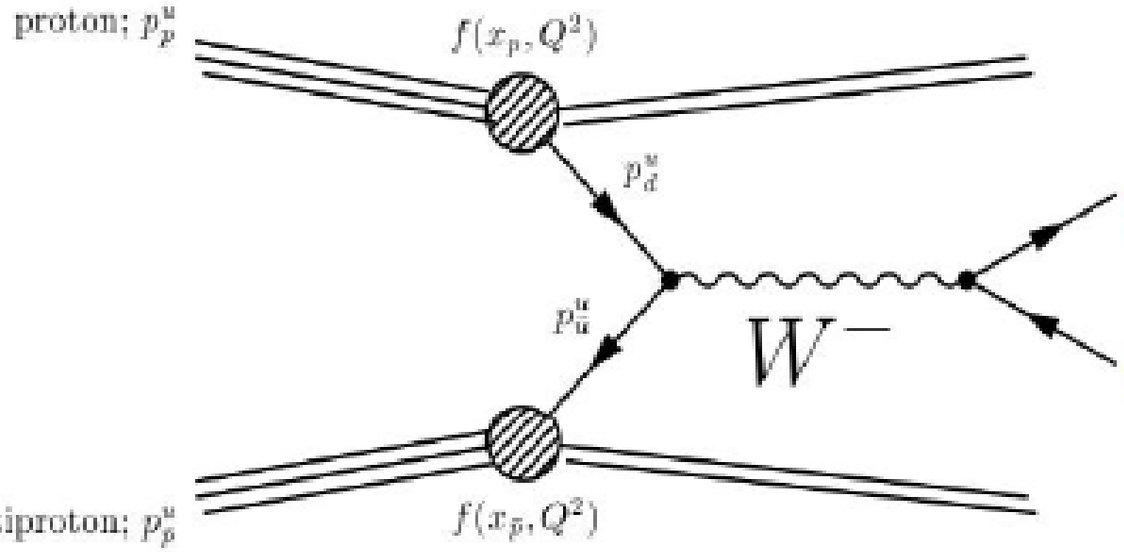
Data Samples

- **Inclusive High Pt electron sample**
  - ✓ 5.3 1 fb^{-1} (up to period25 with goodrun_em_nosi(v31))
  - ✓ Level3 electron trigger path
    - ELECTRON_CENTRAL_18, ELECTRON70_L2_JET, W_NOTRACK
- **Dataset (collision data)**

Period	Run Range	Production ID.	TopNtuple ID
P00	138425 - 186598	bhel0d	bhelkd
P01 ~ P04	190697 - 203799	bhel0h	bhelkh
P05 ~ P10	203819 - 228596	bhel0i	bhelki
P11 ~ P13	228664 - 246231	bhel0j	bhelmj
P14 ~ P17	252836 - 261005	bhel0k	bhelmk
P18 ~ P23	261119 - 274055	bhel0m	bhelmm
P24 ~ P25	274123 - 277511	bhel0m	bhelmm

- **MC backgrounds : official MC sample are generated by EWK group**
- **MC Signal : generated by ourself**

Event Selection



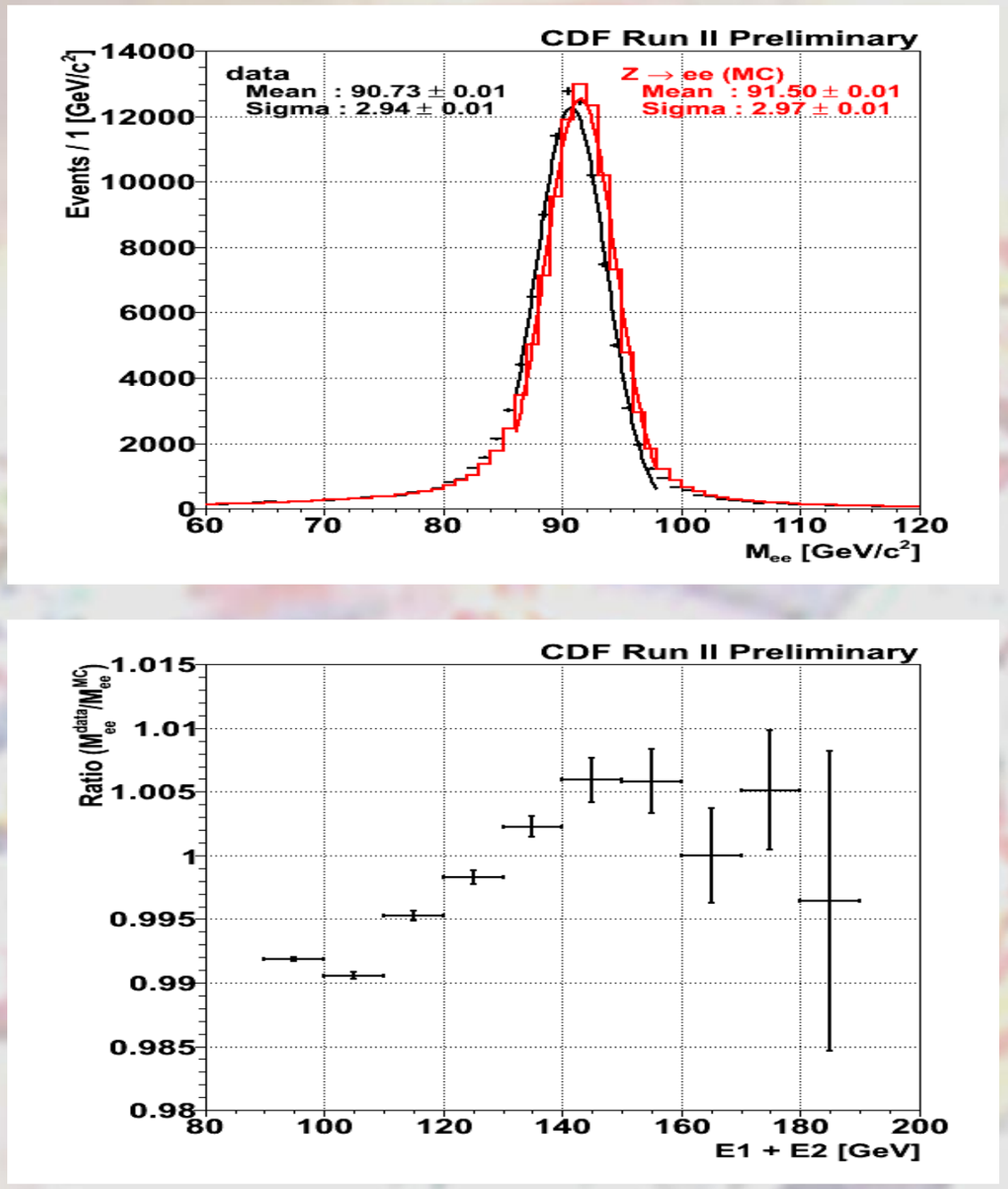
- **Electron**
  - → CEM ($|\eta| < 1.1$)
  - → isolated EM shower
  - → a large of energy fraction deposited in EM
- **Neutrino**
  - → Undetectable
  - → $\not\!\!E_T (\equiv -\sum_i E_T^i \hat{n}_i) > 25$ GeV
  - → correction for jets
- **Event Veto**
  - → dilepton($ee, e\mu$) removal
  - → multijet event reducing ($0.4 < E_T^{ele} / \not\!\!E_T < 2.5$)

Central Electron Id. Cuts	
	cdfnote7527 by Sam Harper, "Very High-Pt Electron Identification"
E_T	> 25 GeV
$Track\ Z_0$	< 60 cm
$Track\ p_T$	> 15 GeV
E_{had}/E_{em}	$< 0.055 + 0.00045 \times E$
$IsolationE_T$	$< 3 + 0.02 \times E_T$ GeV
$Lshr_{track}$	< 0.2
E/p ($E_T < 100$ GeV)	$< 2.5 + 0.015 \times E_T$ GeV
E/p ($E_T > 100$ GeV)	$Track\ p_T > 25$ GeV
$CES\Delta X$	< 5.0 cm
$CES\Delta Z$	< 3.0 cm
$Fiducial$	$= 1$
$Conversion$	$\neq 1$

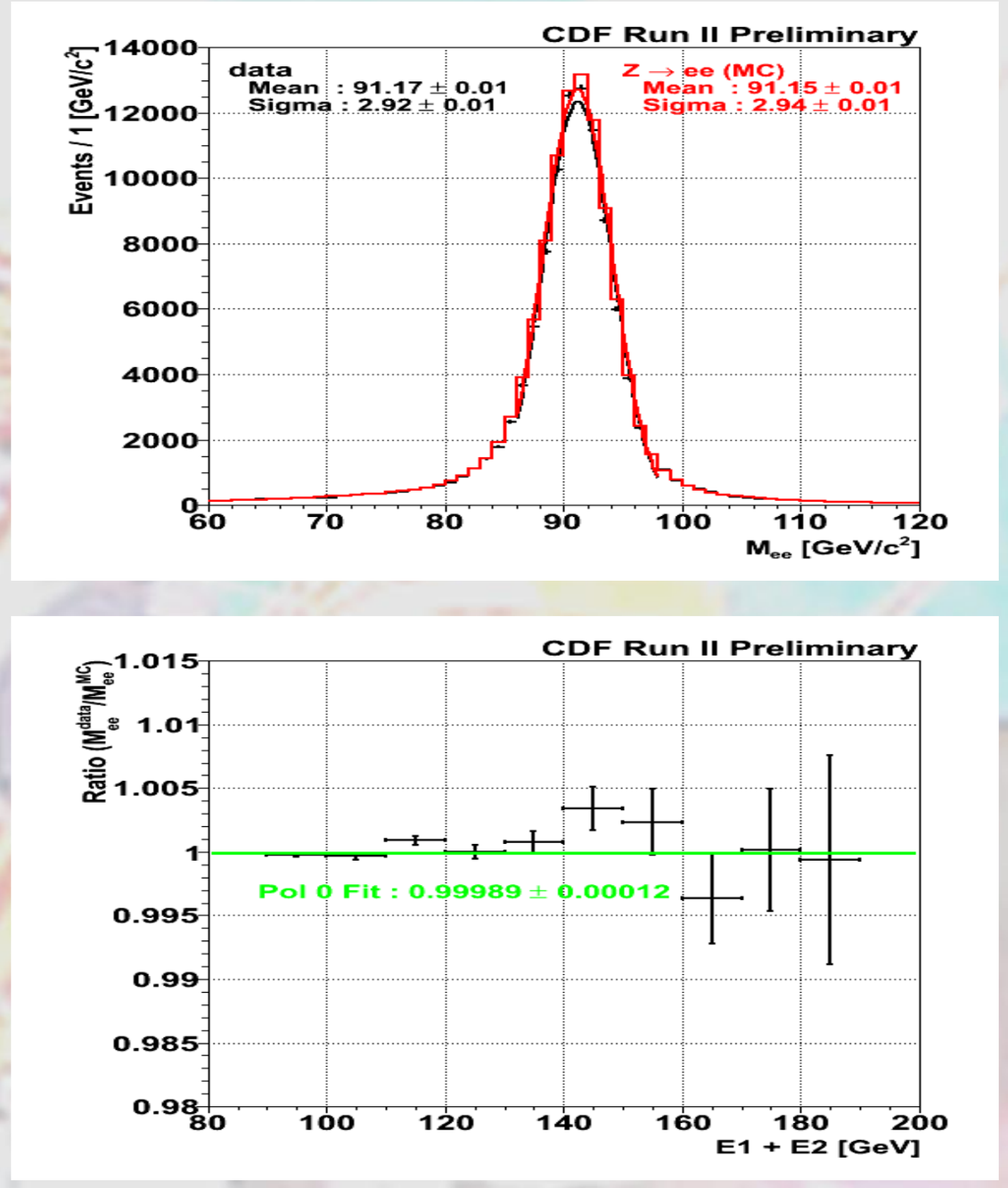
$\not\!\!E_T$ Selection	
$\not\!\!E_T$	> 25 GeV
Jet Selection for $\not\!\!E_T$ Correction	
Corr. Level	5
E_T	> 20 GeV
$\lvert\eta_{Det}\rvert$	2.4
ΔR_{ej}	$(= \sqrt{\Delta\phi_{ej}^2 + \Delta\eta_{ej}^2}) > 0.4$

Electron Energy Correction(Z→ee sample)

- before energy correction



- after energy correction



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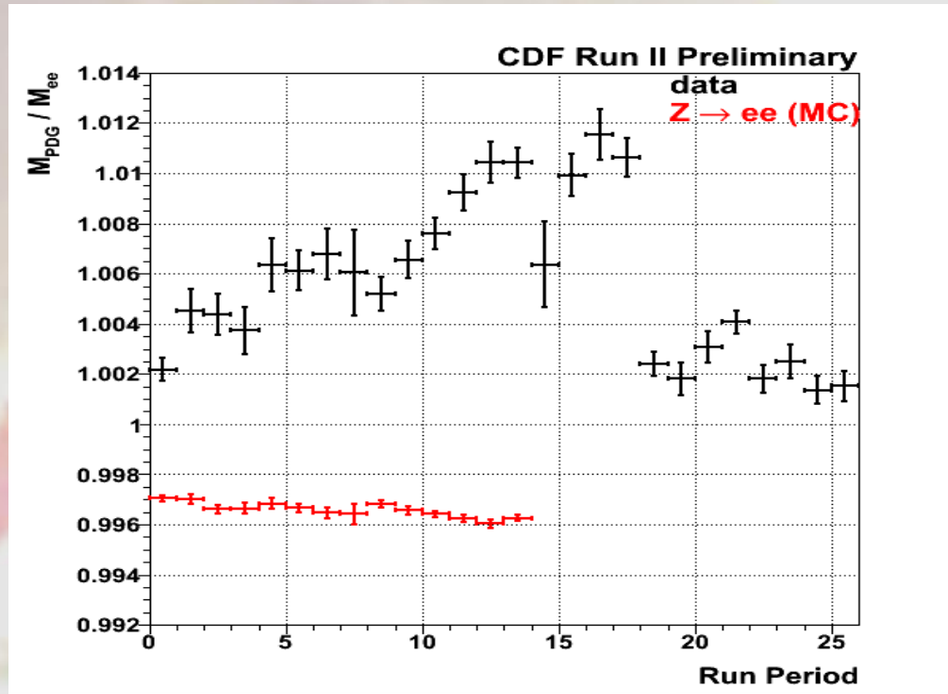
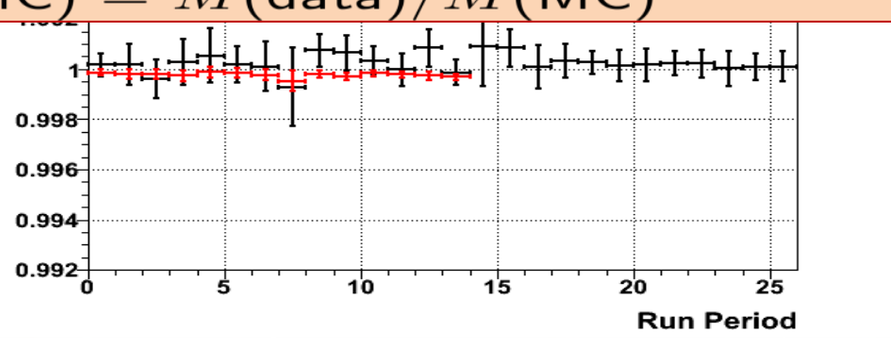
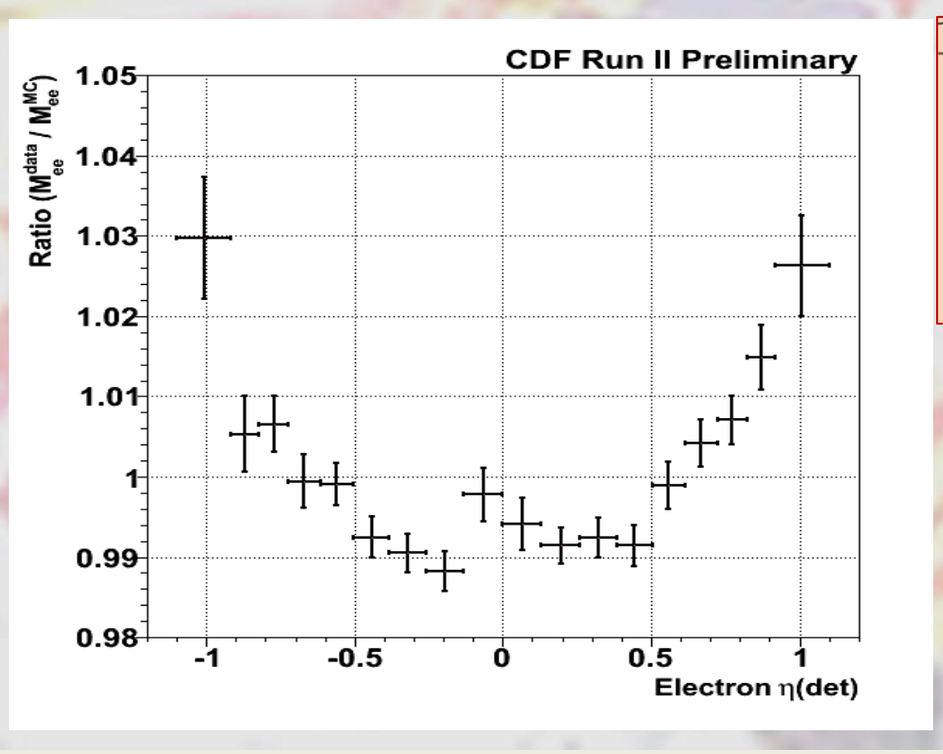
Electron Energy Correction

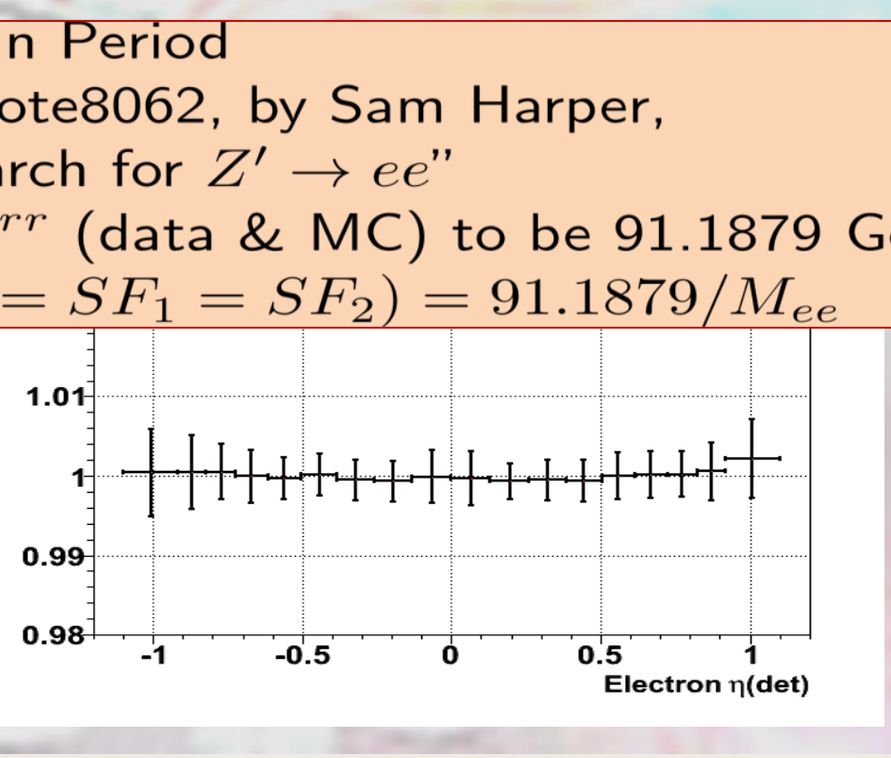


2. SF vs Det. η
   - cdfnote9643, by Jiyeon Han, "$d\sigma/dy$ of Drell-Yan to ee"
   - M_{ee}^{MC} to be same as data
   - $SF_1 = SF_2$: required both electron from same eta region
   - $SF(\text{MC}) = M(\text{data})/M(\text{MC})$





1. SF vs Run Period
   - cdfnote8062, by Sam Harper, "Search for $Z' \to ee$"
   - M_{ee}^{corr} (data & MC) to be 91.1879 GeV/c^2
   - $SF(= SF_1 = SF_2) = 91.1879/M_{ee}$



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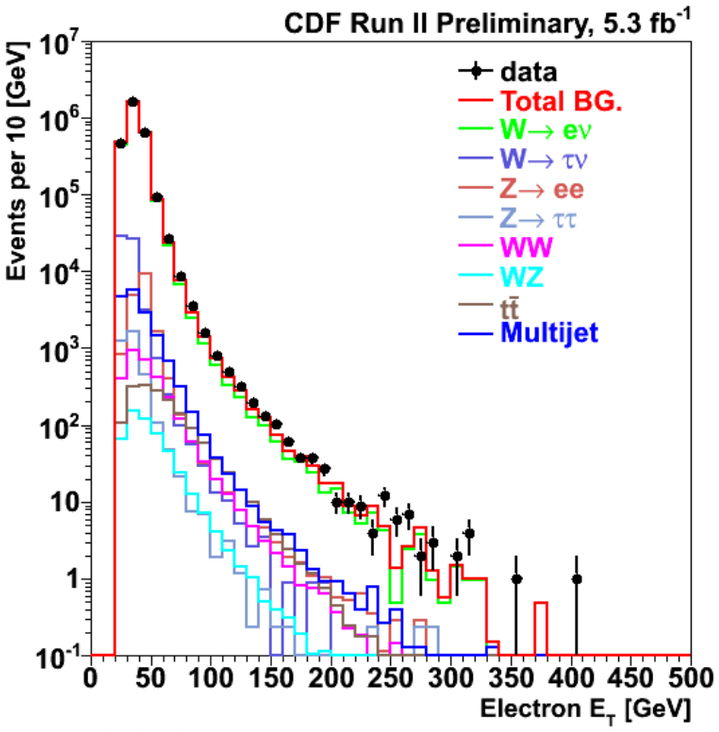
Background Estimation

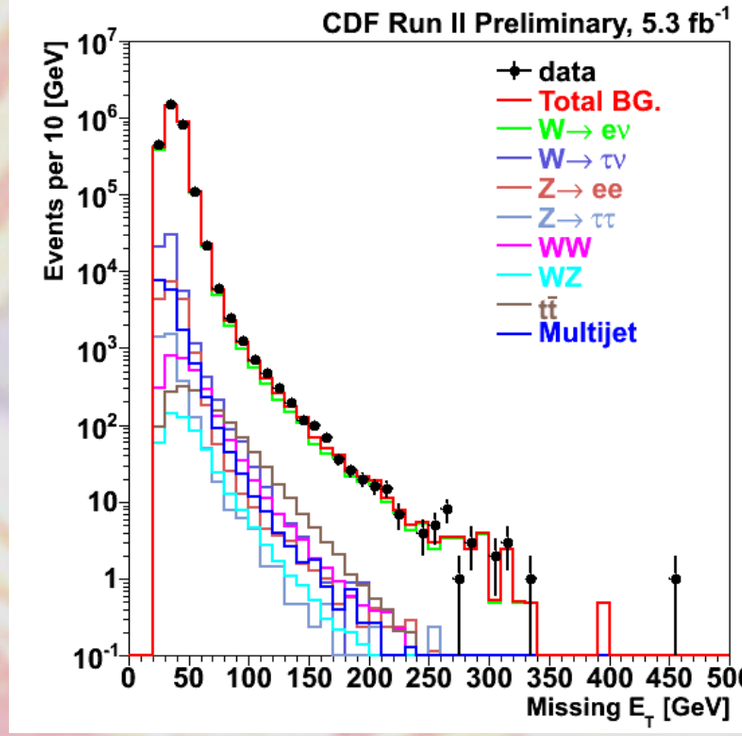
- **MC background :**
  - **W boson : including electron and MET in final states**
  - **Z boson : one electron is mismeasured and then produce as MET**
- **Multijet(QCD) background : data-driven method**

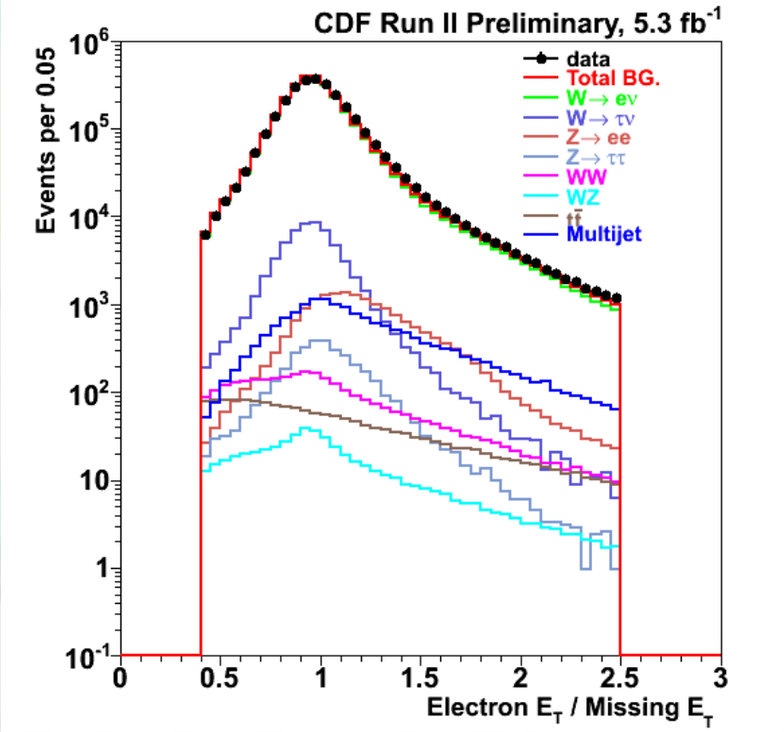
$$N_{expected} = \sigma \bullet Br(pb) \times \varepsilon \bullet A \times \int L\,dt$$

Background	$\epsilon \cdot A$	$\sigma \cdot \mathcal{B}$	$N_{expected}$
$W \to e\nu$	1.96×10^{-1}	2687 ± 54 (NNLO) [15]	2794310
$W \to \tau\nu$	4.13×10^{-3}	2687 ± 54 (NNLO) [15]	58962
$Z/\gamma \to ee$	1.29×10^{-2}	251.3 ± 5 (NNLO) [15]	17190
$Z/\gamma \to \tau\tau$	2.66×10^{-3}	251.3 ± 5 (NNLO) [15]	3548
WW	4.19×10^{-2}	13.25 ± 0.25 (NLO) [16]	2946
WZ	2.47×10^{-2}	3.96 ± 0.06 (NLO) [16]	520
$t\bar{t}$	4.62×10^{-2}	6.7 ± 0.5 (NLO) [17]	1644
Multijet (from DATA)			16317

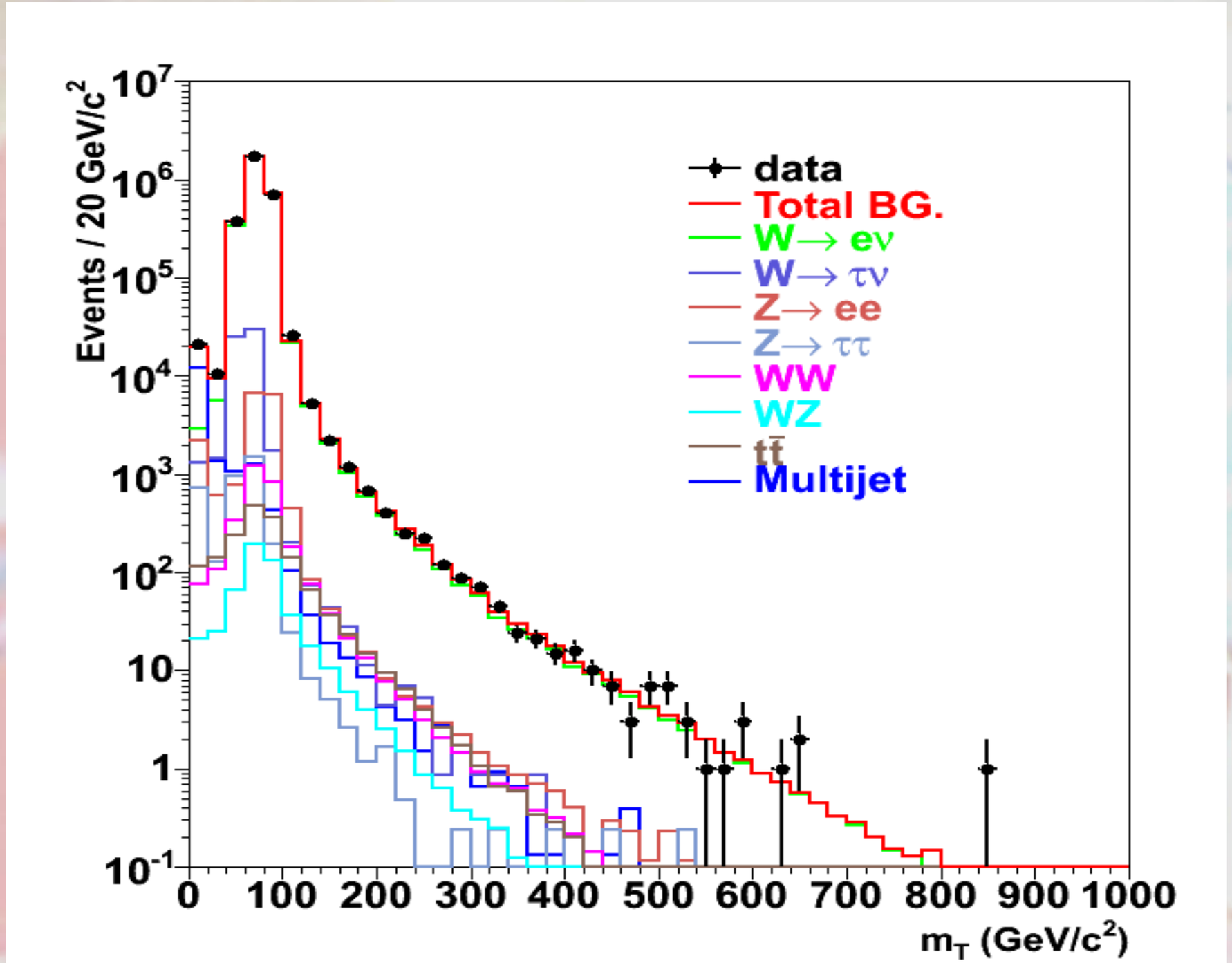
Event Selection : kinematics



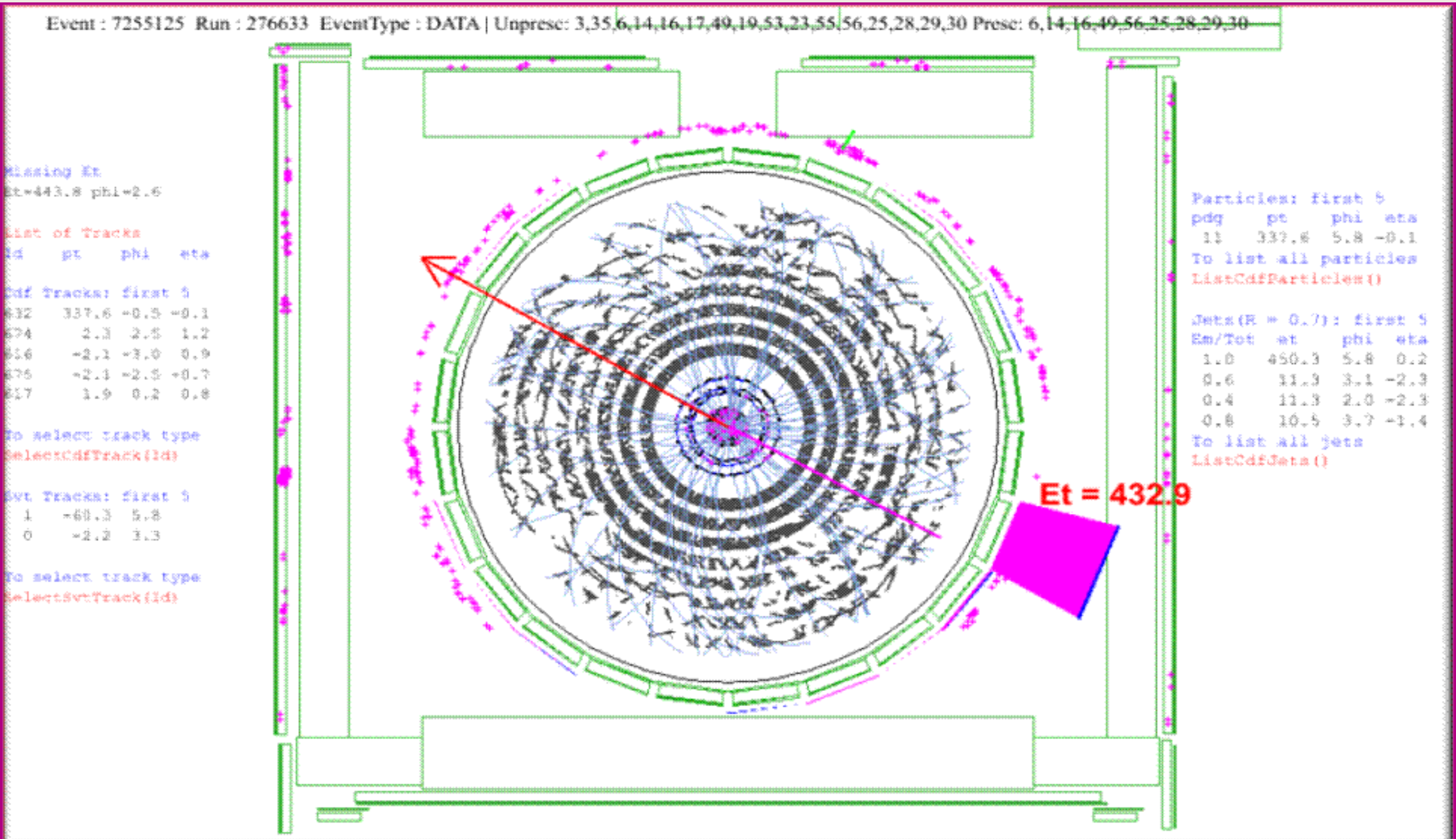




Mt distribution

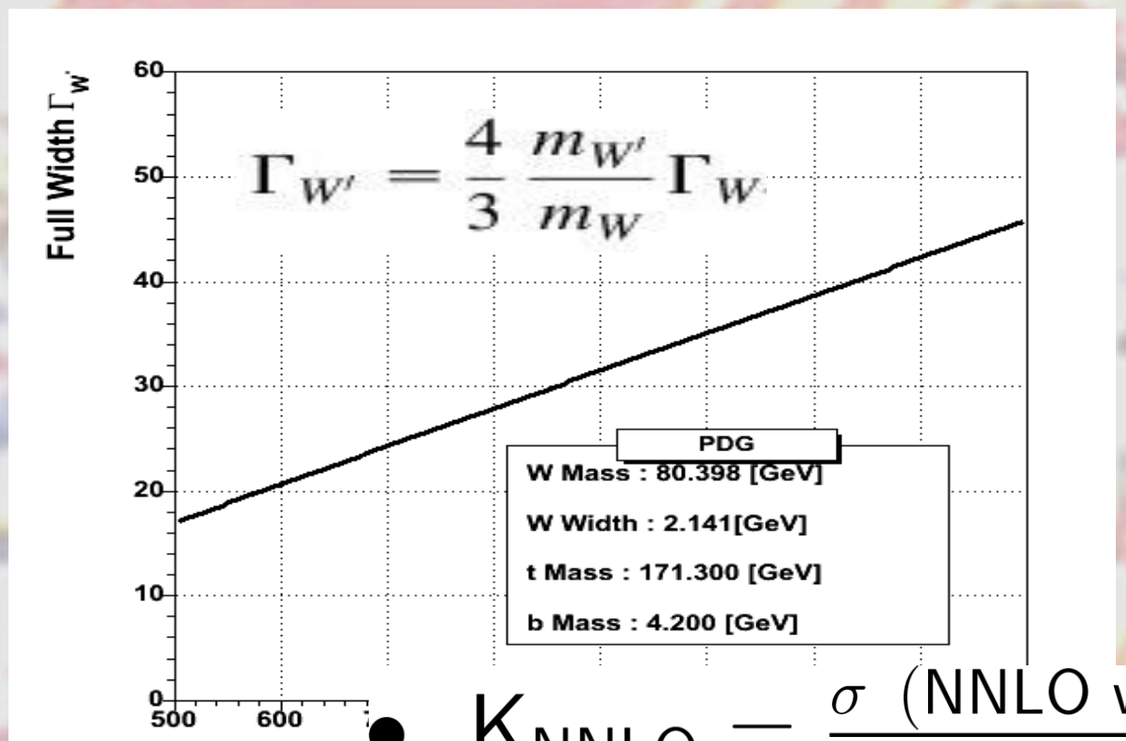


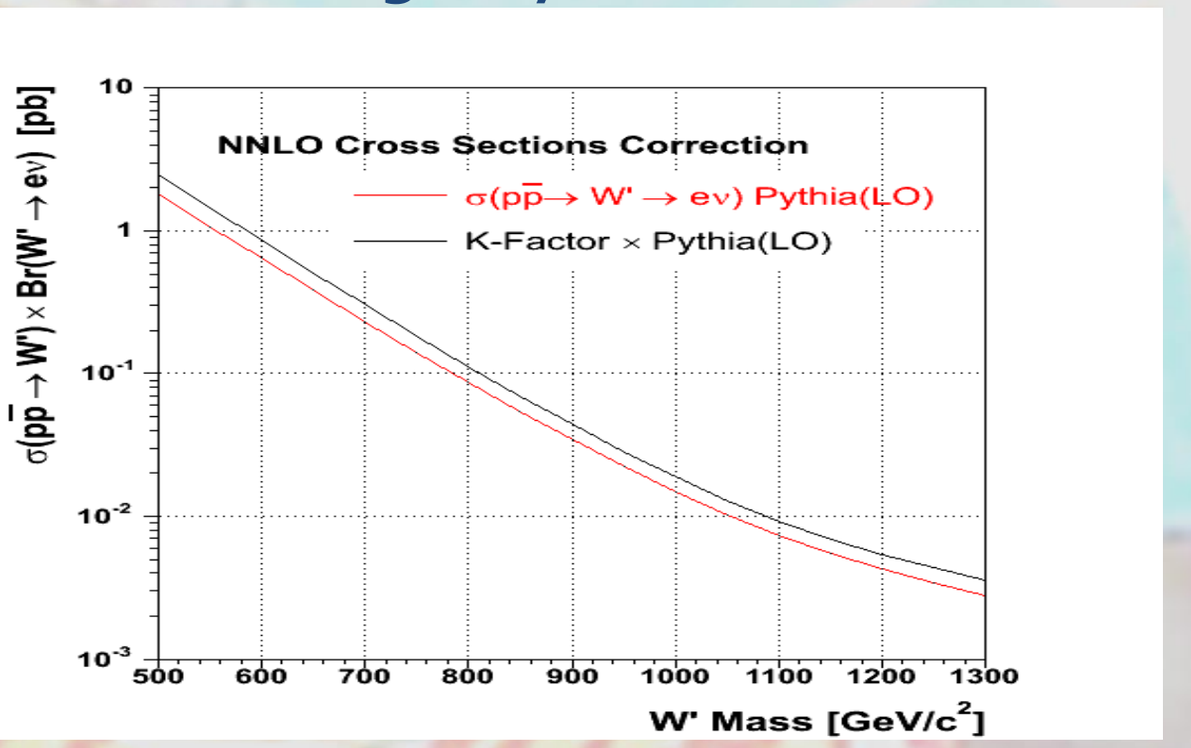
The Highest Mt Event



W′ : MC signal and K-factor

- W′ mass = [500,1300] GeV/c^2, ~50k events for each mass points
  - ✓ PYTHIA with CTEQ5L PDFs
  - ✓ V+A coupling, assuming the right-handed CKM matrix and the strength couplings to be same with SM (manifest letf-right symmetric model)
- Width and x-section



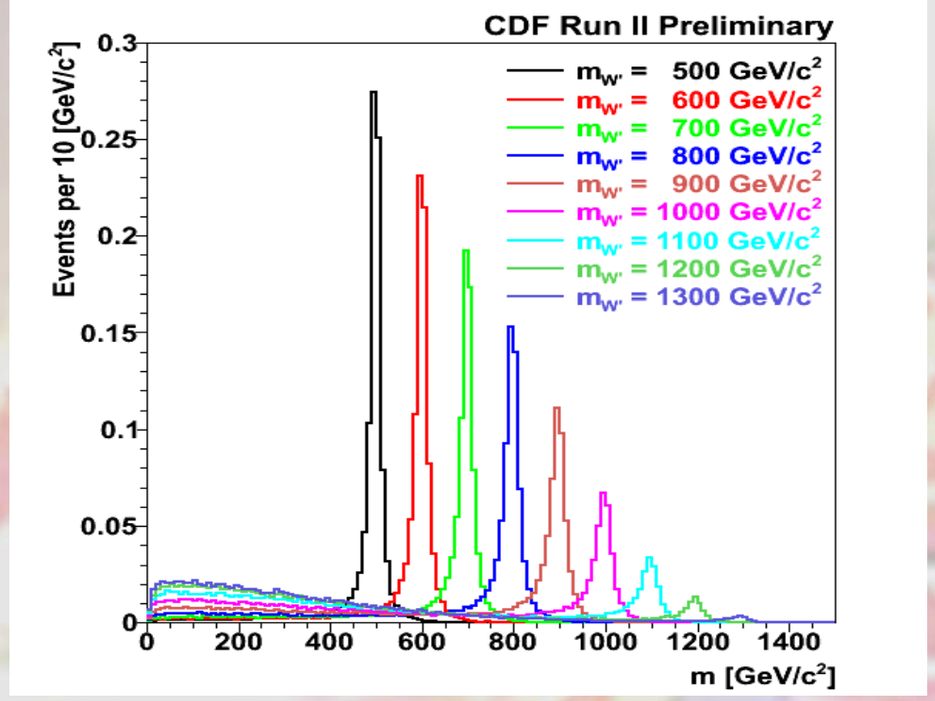


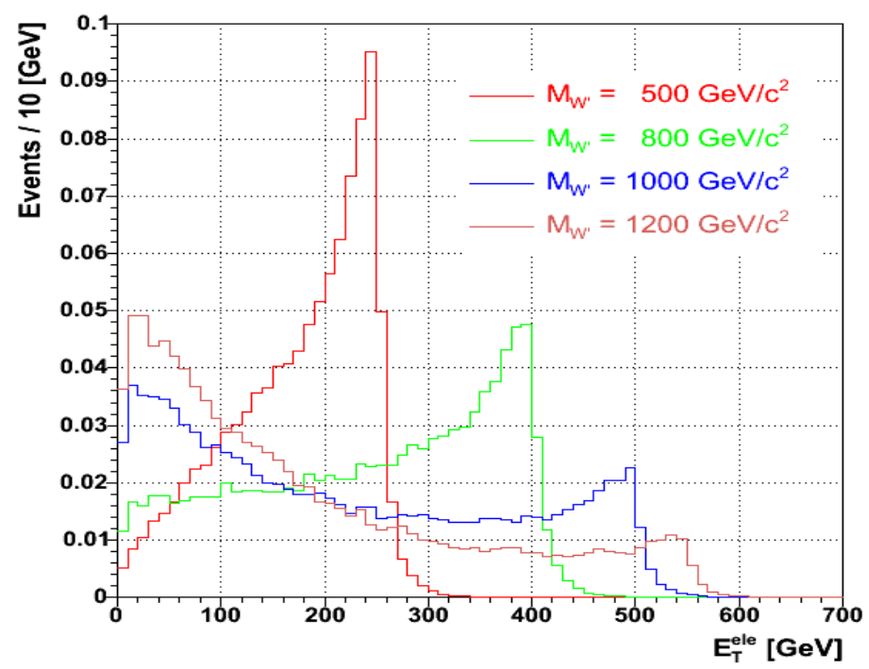
- $K_{NNLO} = \frac{\sigma \text{ (NNLO with CTEQ6.1M PDFs)}}{\sigma \text{ (LO with CTEQ5L PDFs)}}$

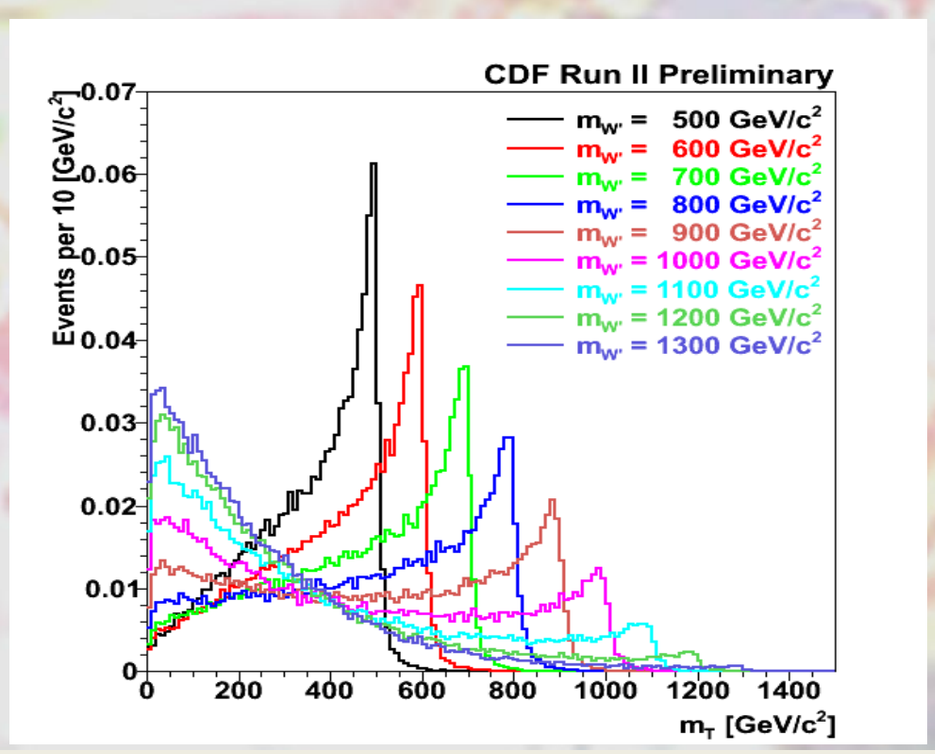
→ calculated using Van Neerver code(2002).

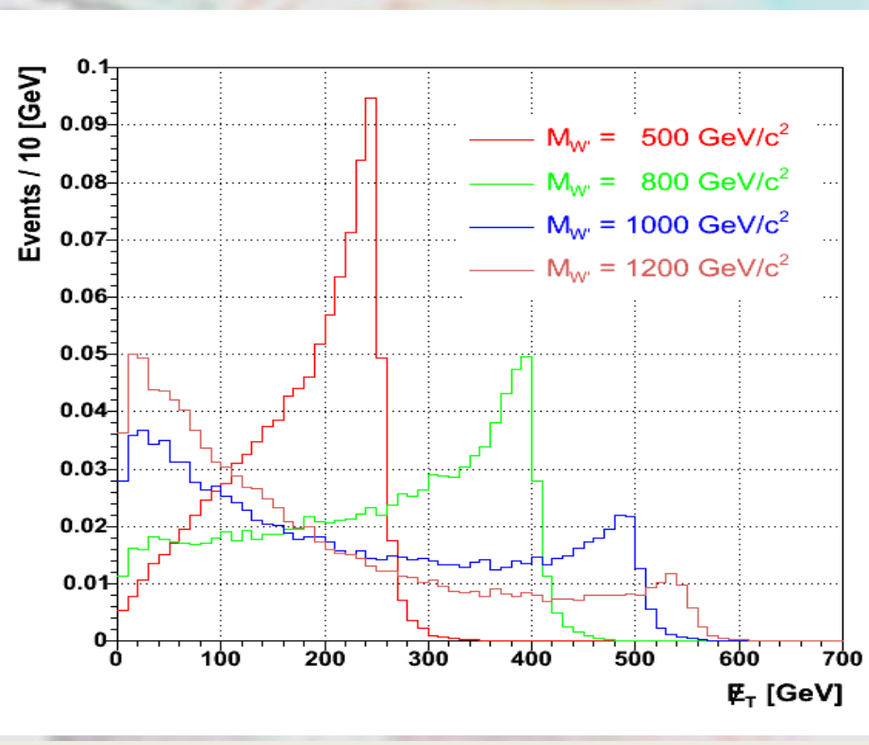
→ R. Hamberg, W.L van Neerven and T. Matsuura, NuCl. Phys. B 359, 343

W’ : kinematic distribution (Gen-Level)









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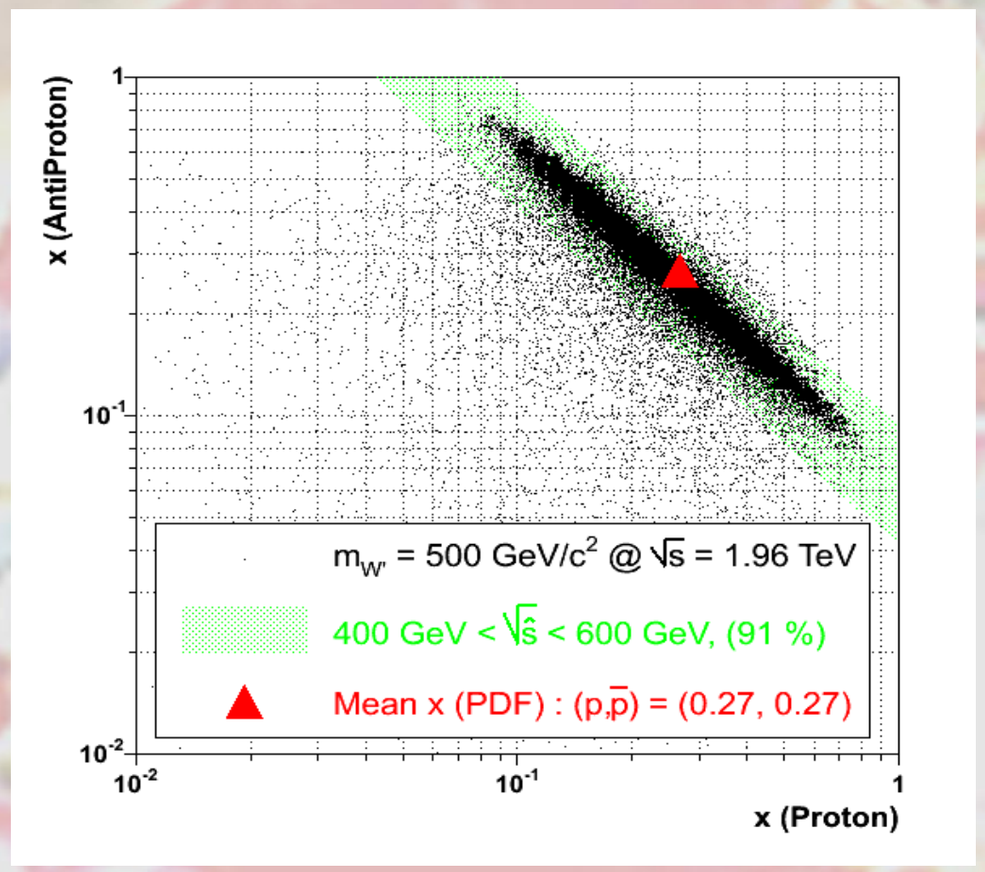
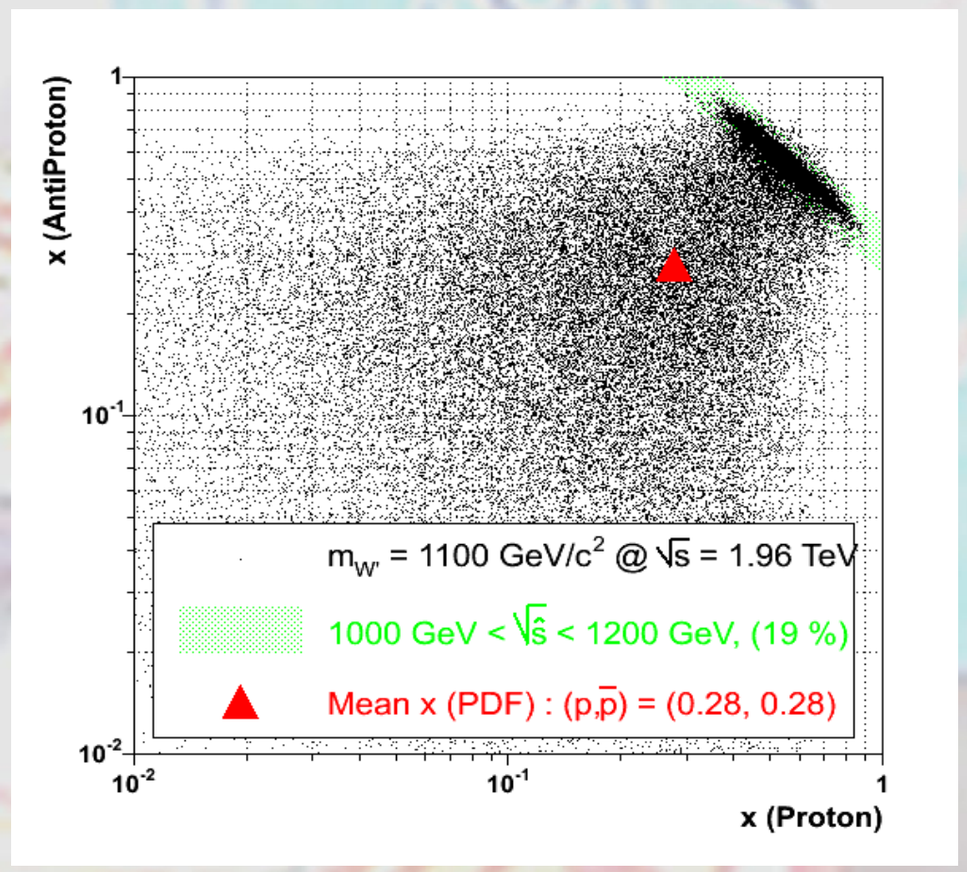
low energy tails in W' MC signal

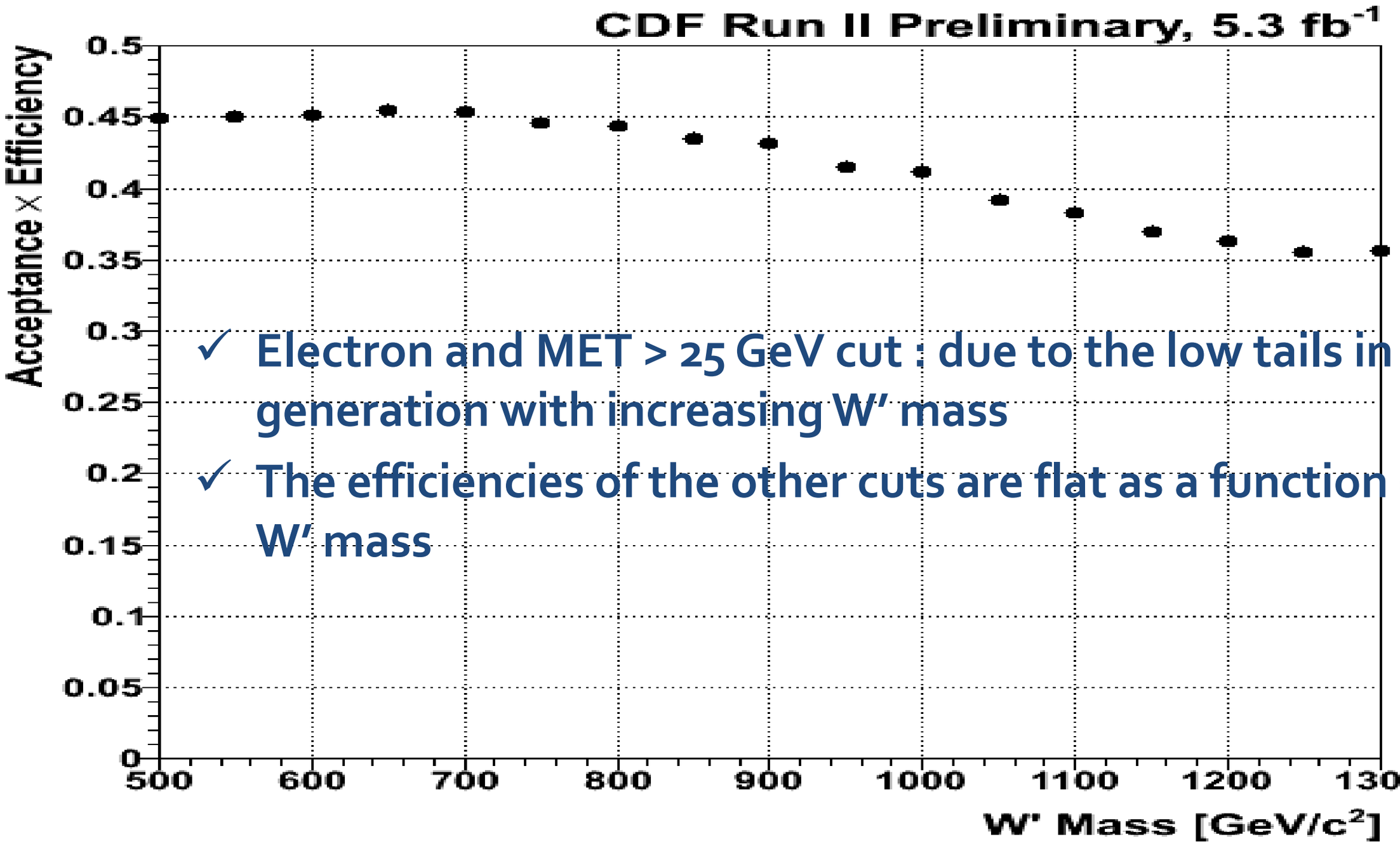
- on-shell-mass production : $\underset{(\sqrt{s})}{p\bar{p}} \xrightarrow[x(\approx x_p \approx x_{\bar{p}})]{PDF} \underset{(\sqrt{\hat{s}})}{q\bar{q}} \rightarrow W' \rightarrow e\nu$
- requried momentum fraction $x = \frac{\sqrt{\hat{s}}}{\sqrt{s}} \approx 0.26, ..., 0.56$ (for $m = 500, \ldots, 1100$)





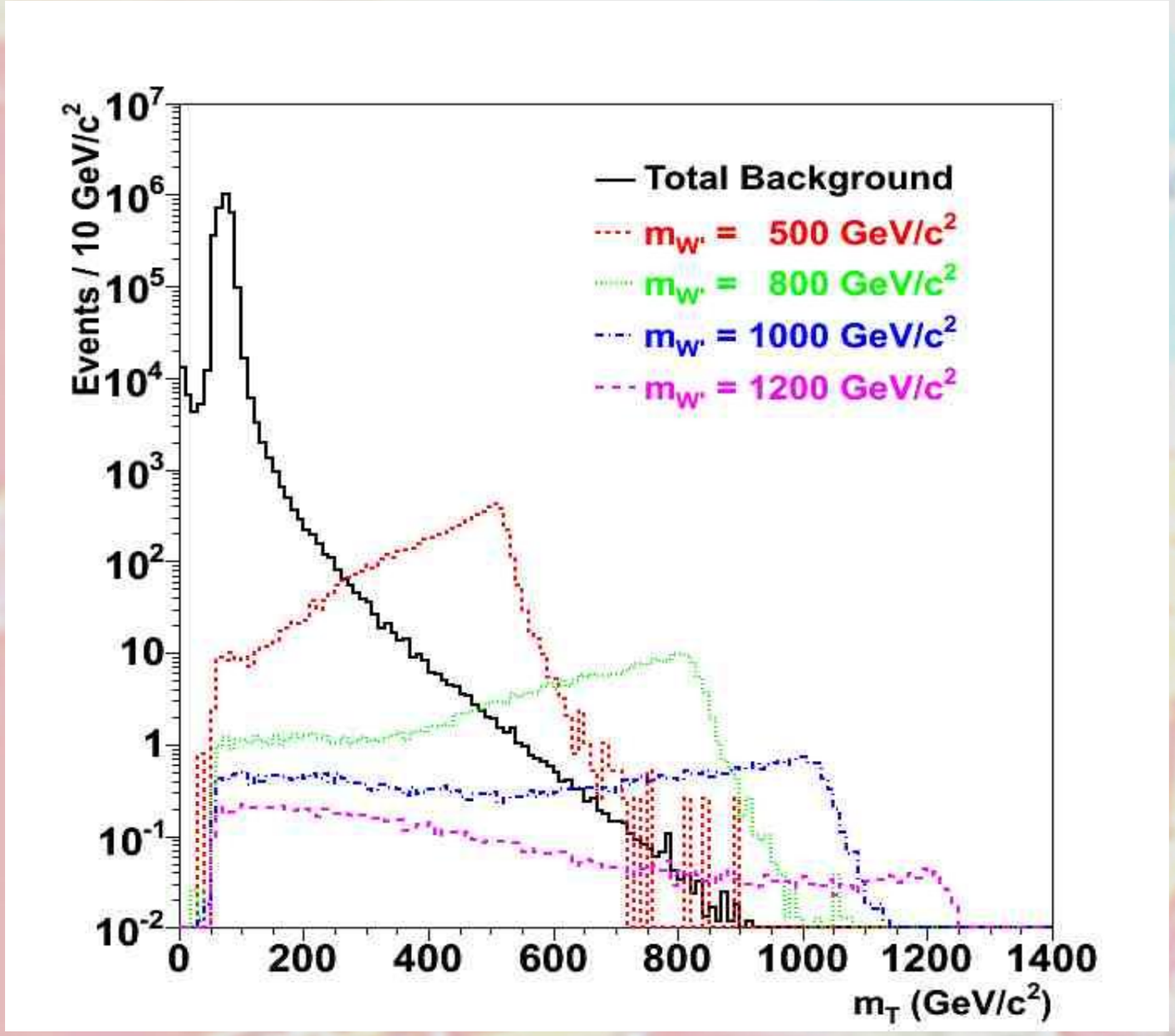
PDF heavily suppress high mass production region due to limitation of parton energy carried by quarks in Tevatron energy [PRL 100, 031804]

W′ MC signal: Event Selection (A X E)



- ✓ Electron and MET > 25 GeV cut : due to the low tails in generation with increasing W′ mass
- ✓ The efficiencies of the other cuts are flat as a function of W′ mass

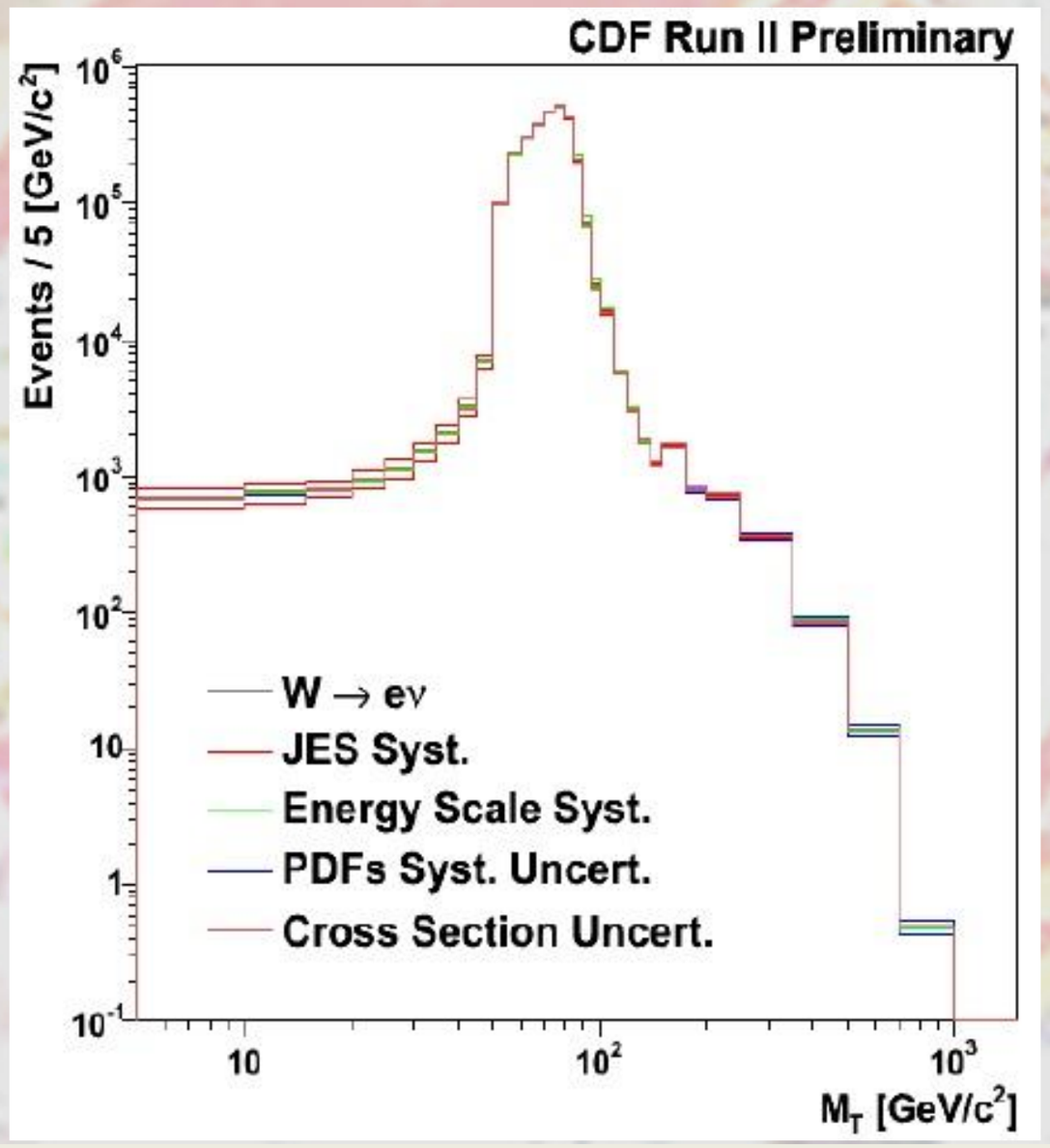
W’ signal and background

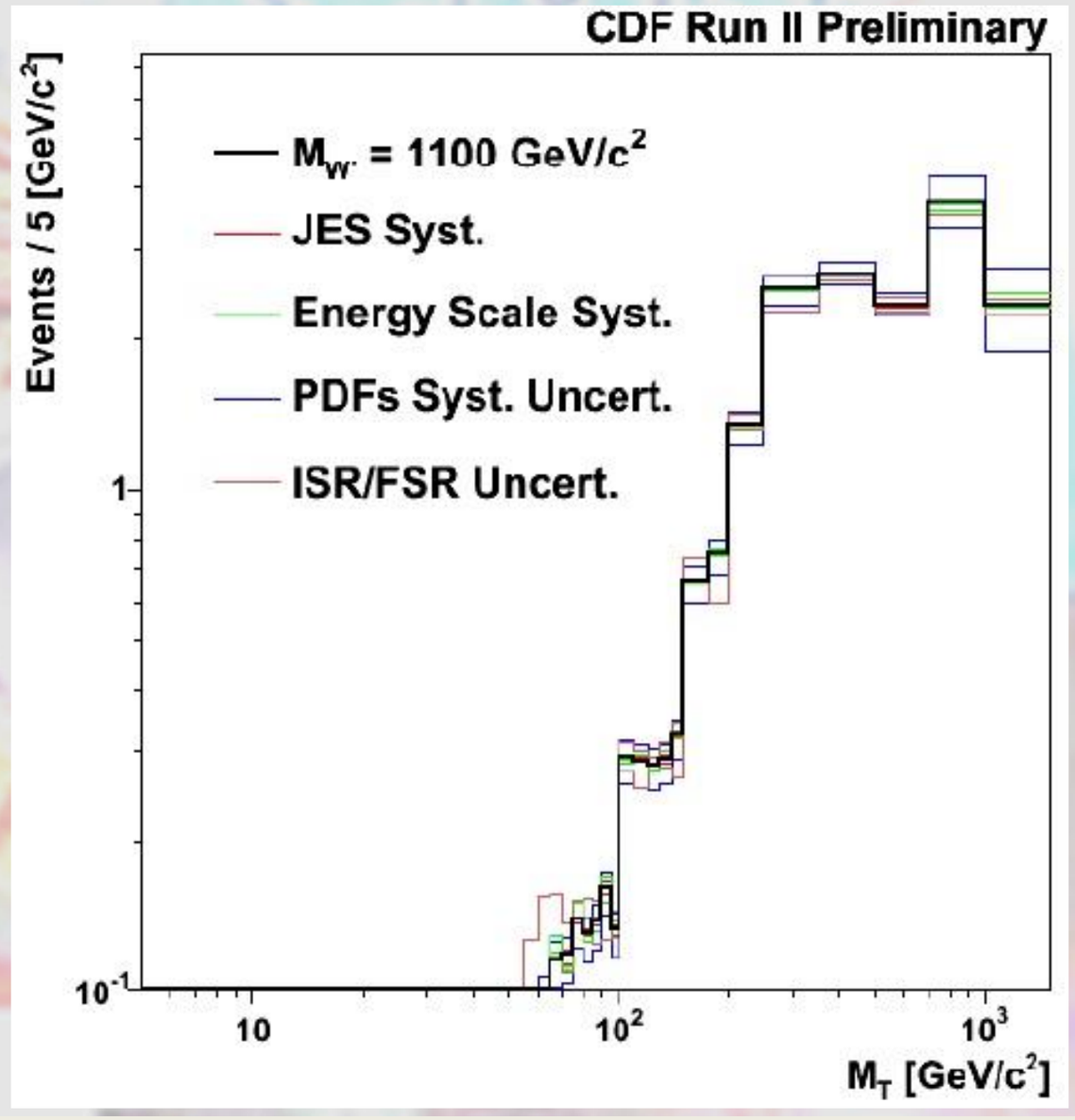


Mt binned likelihood Fitting

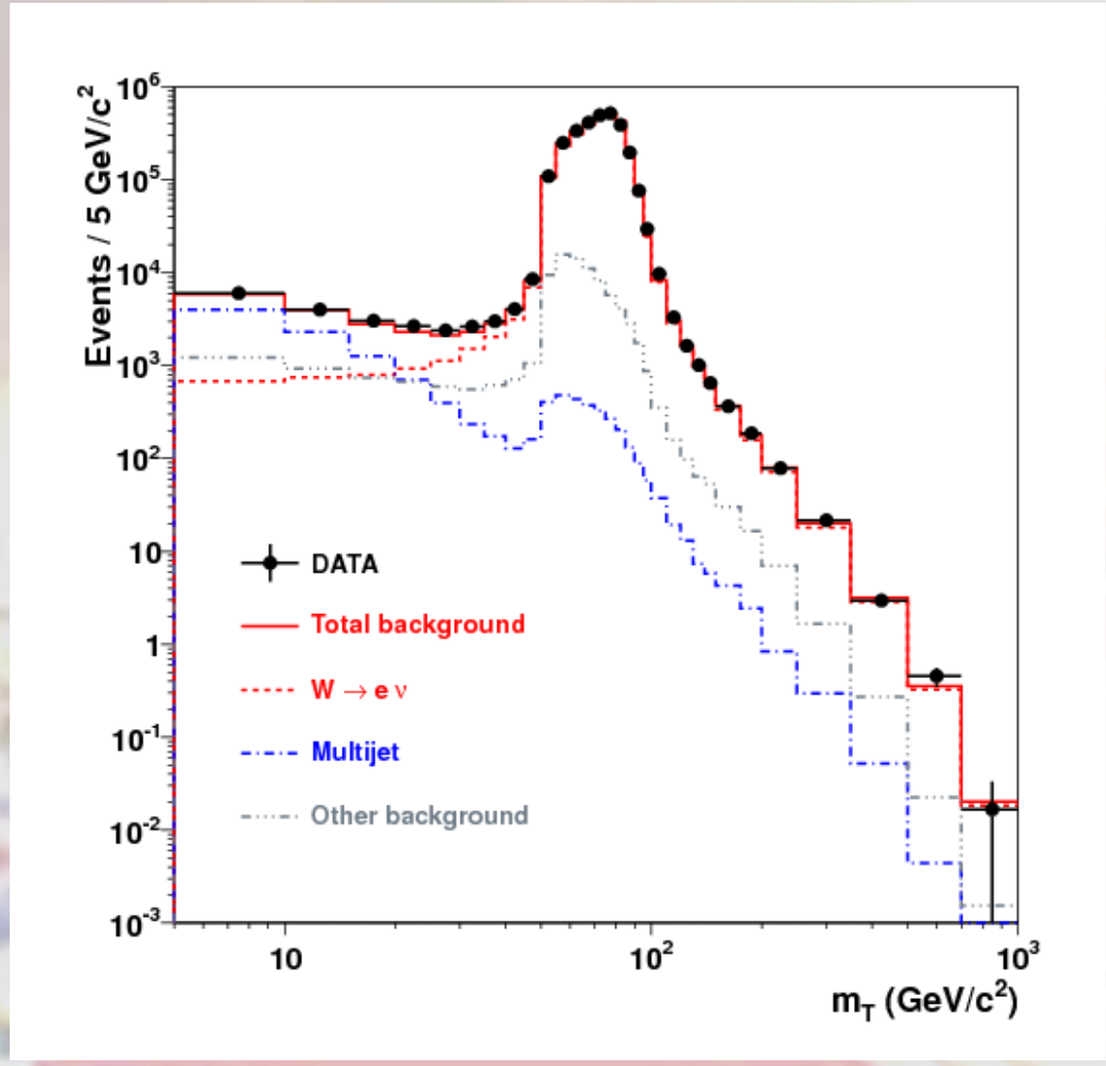
- variable binning (GeV/c^2)

M_T	0,100	100,150	150,200	200,250	250,350	350,500	500,700	700,1000	1000,1500
$width$	5	10	25	50	100	150	200	300	500





Mt Fitting Result



	Events in m_T bins ($\mathrm{GeV/c^2}$)				
	200 - 250	250 - 350	350 - 500	500 - 700	700 - 1000
$W \to e\nu$	711^{+50}_{-50}	359^{+25}_{-25}	85^{+6}_{-6}	13^{+1}_{-1}	$1.1^{+0.1}_{-0.1}$
Multijet	9^{+2}_{-2}	6^{+1}_{-1}	2^{+2}_{-2}	$0.2^{+1.6}_{-0.2}$	$0.01^{+1.10}_{-0.01}$
Other background	70^{+9}_{-6}	33^{+4}_{-3}	8^{+1}_{-1}	$1^{+0.1}_{-0.1}$	$0.09^{+0.01}_{-0.01}$
Total background	790^{+61}_{-58}	398^{+31}_{-30}	94^{+9}_{-8}	14^{+3}_{-1}	$1.2^{+1.2}_{-0.1}$
Data	784	426	88	18	1

- Good agreement between the data and background expectations
  → No statistically significant excess observed for W'

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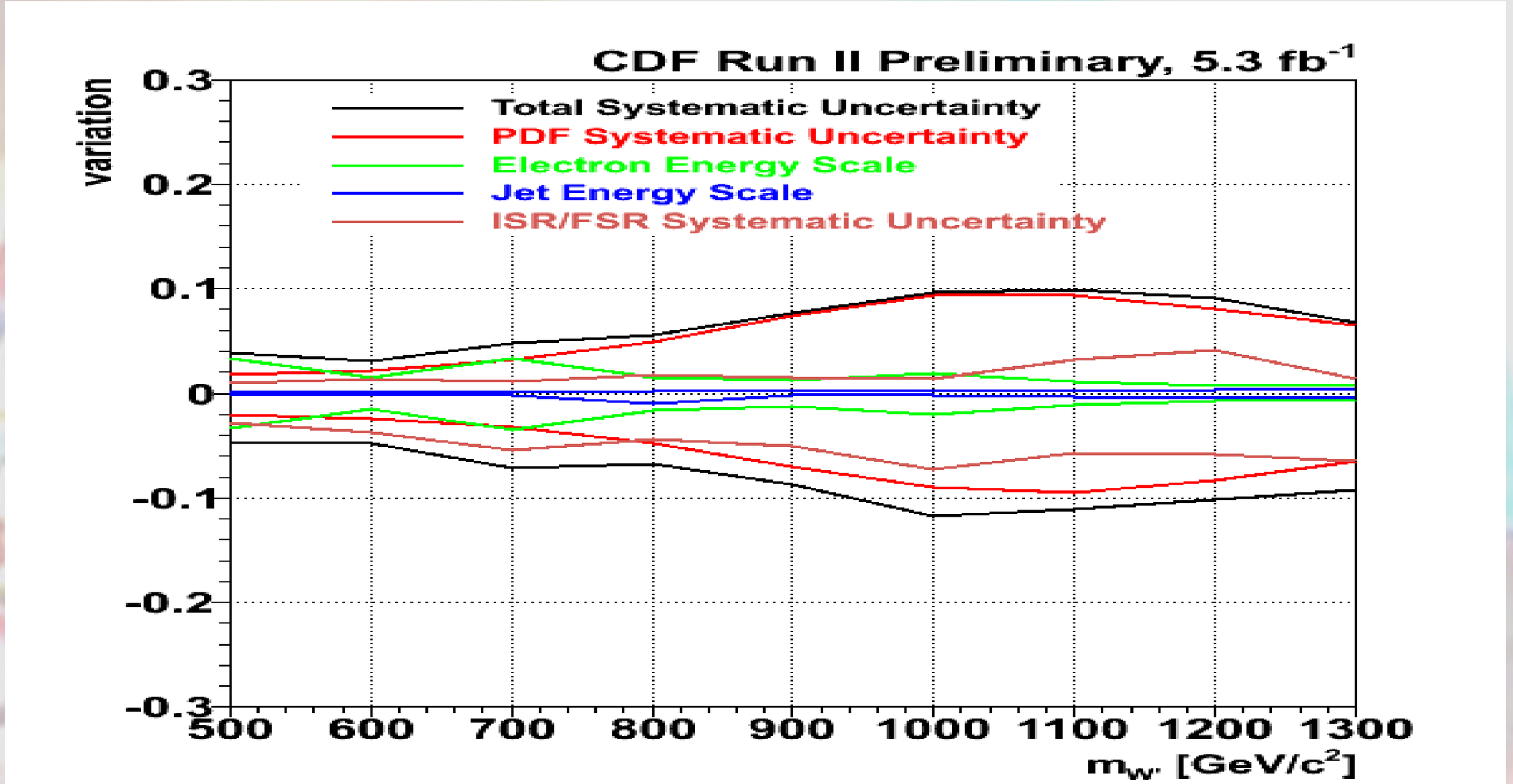
Systematic Uncertainties

- PDF : used reweighting method
  - α_s : difference MRST72 and MRST75
  - MRST : difference between CTEQ5L and MRST72
  - CETQ6M : 20 CETQ6M sets are added in quadrature
  - Total Uncertainty : $\sqrt{\alpha_s^2 + (MAX(CTEQ6M, MRST))^2}$
- ISR/FSR : change Pythia parton shower parameters (joint physics group)
- Electron energy scale : assigned 1.0 % scale
- JES : $\pm 1\sigma$ jet energy scale and recalculate the MET
- Multijet background : change the electron and multijet sample
- MC cross section error :
  - background : theoretical error
  - signal : using PDFs weighting factor

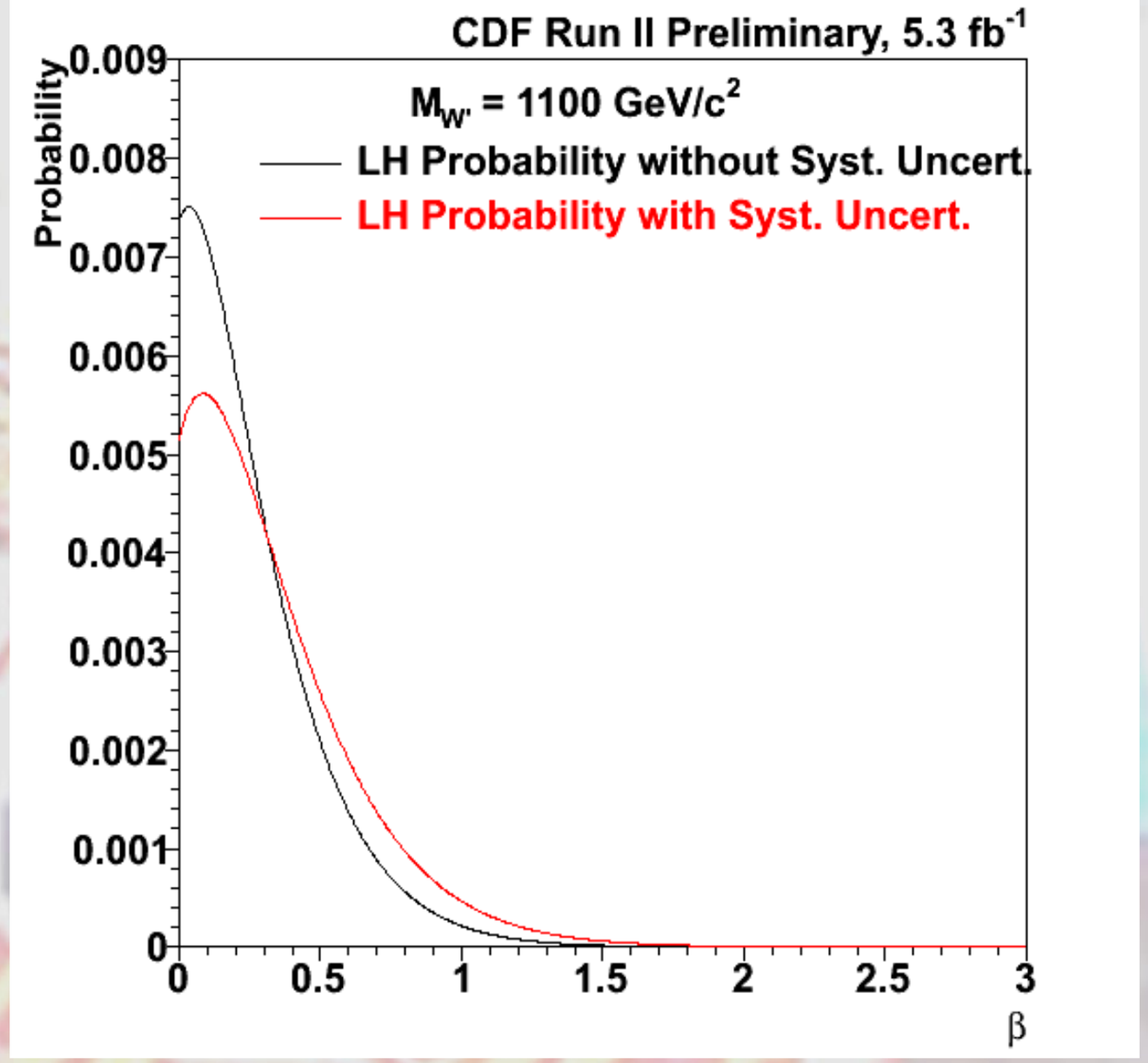
Systematic Uncertainties



Limit Calculation

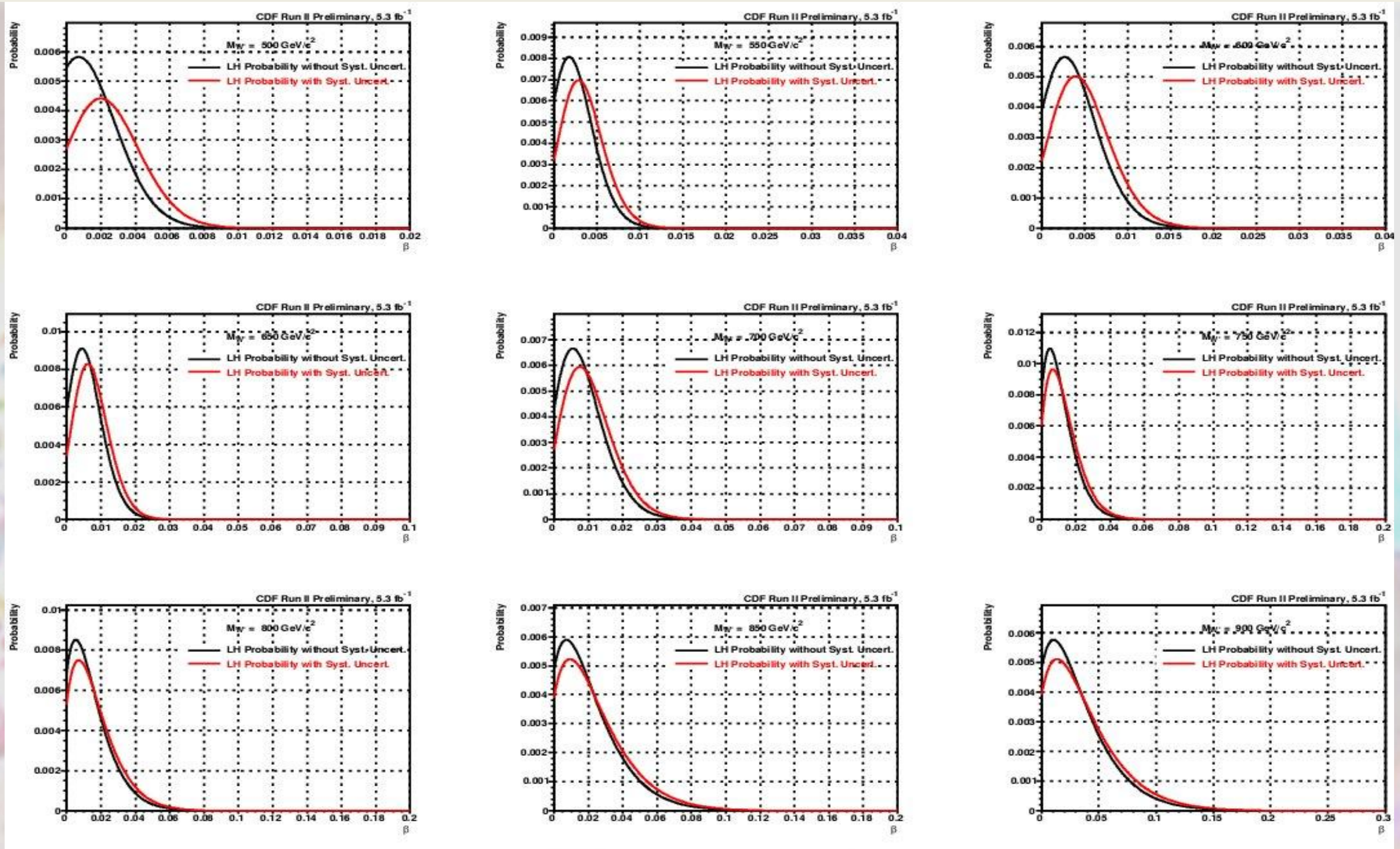
- Used Bayesian approach
- systematic uncertainties incooperated
  - p(beta)
- Extracted the upper limit
  - beta_95
- Observed limit by beta_95

$$0.95 = \frac{\int_0^{\beta_{95}} p(\beta)d\beta}{\int_0^{\infty} p(\beta)d\beta}$$

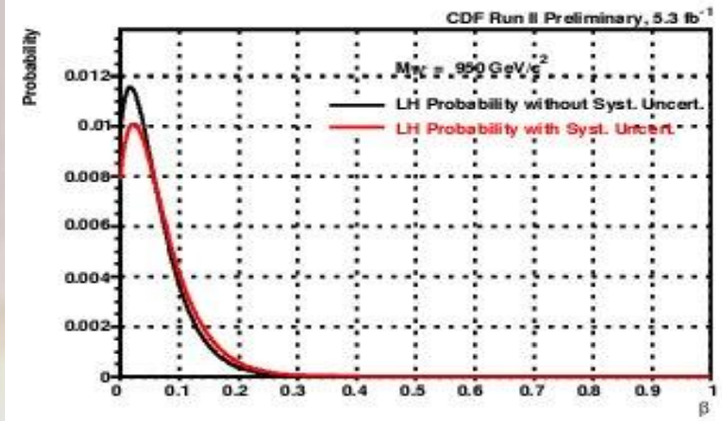


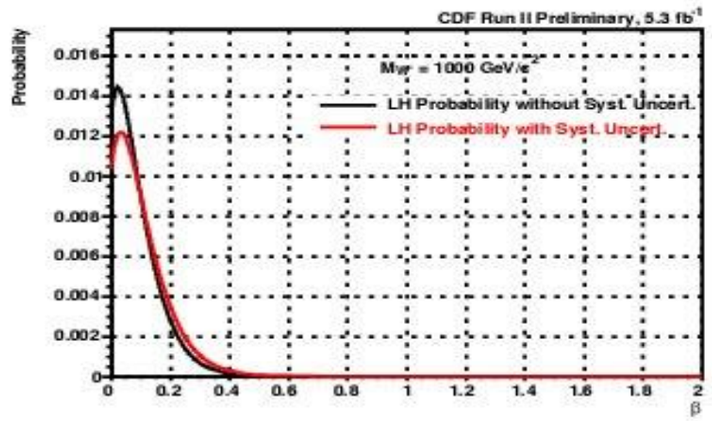
- Expected limit : Pseudo-Experiments with background only

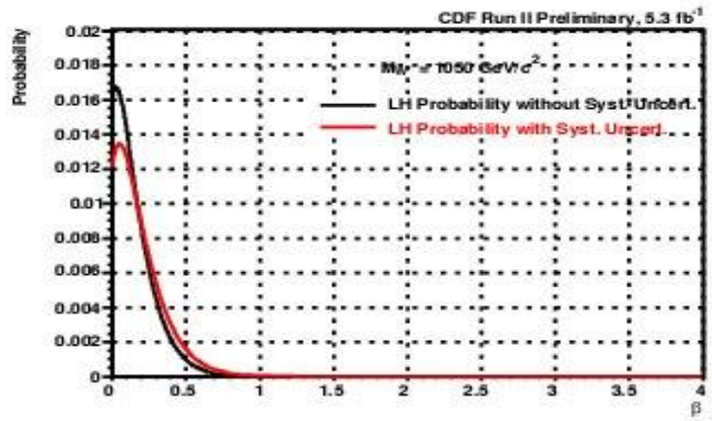
LH Probability with different mass(1)

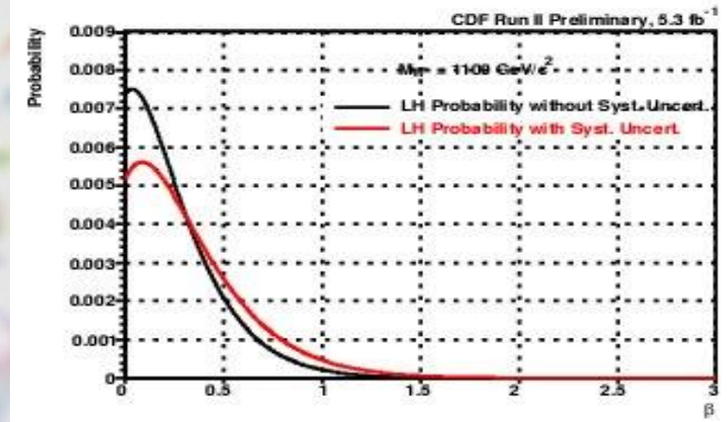


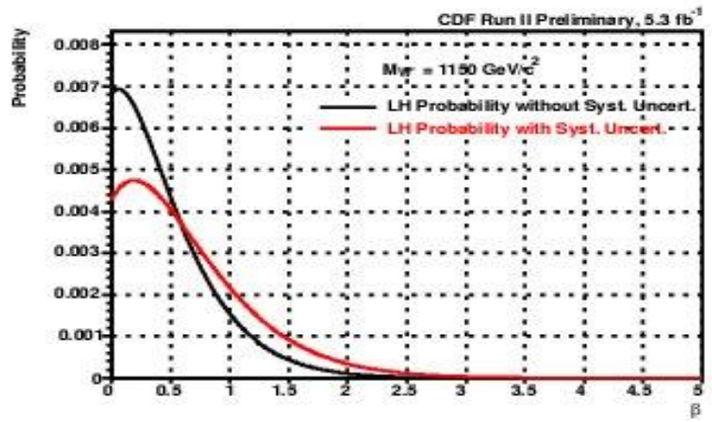
LH Probability (2)

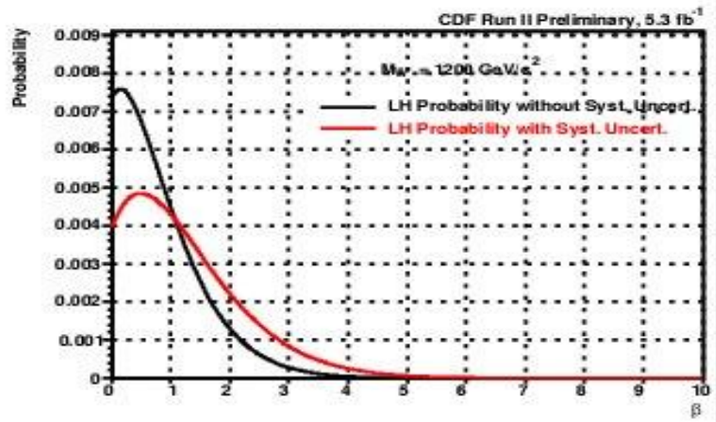


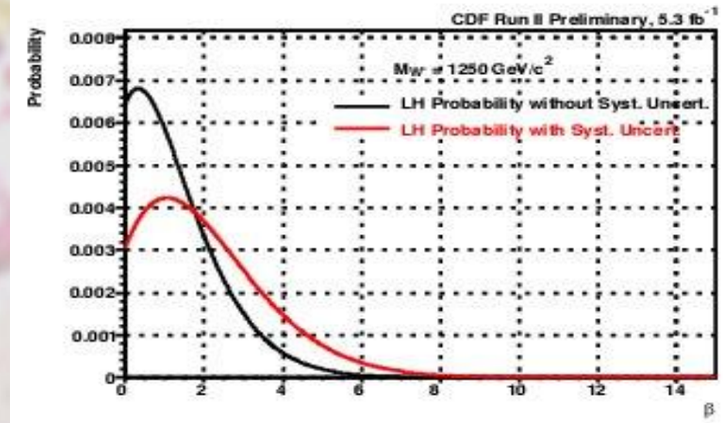


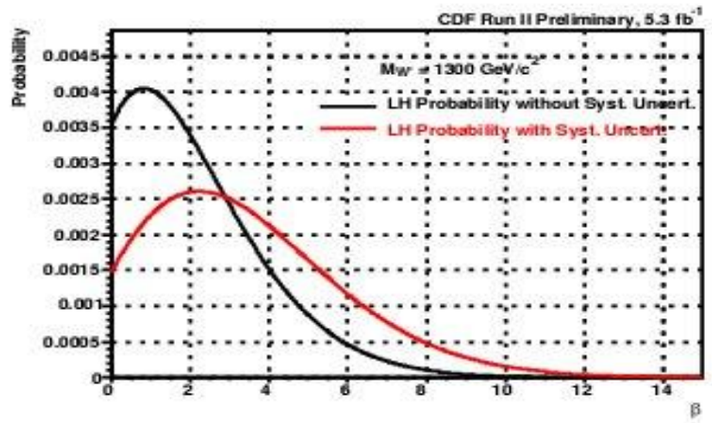






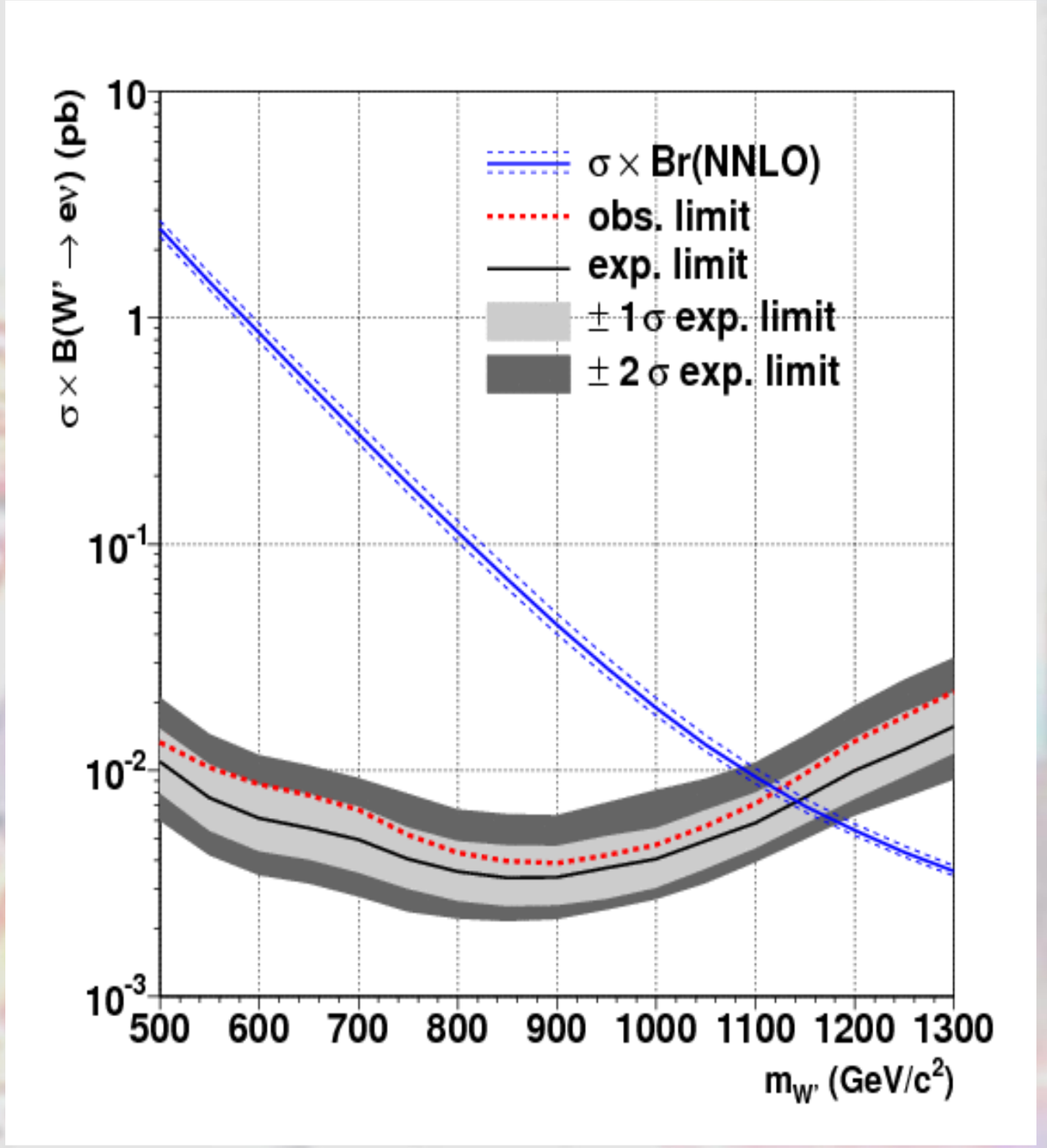






Limits

$m_{W'}$ ($\mathrm{GeV/c^2}$)	N_{exp} (events)	$\beta\left(=\frac{\sigma\cdot\mathcal{B}(W'\to e\nu)}{\sigma\cdot\mathcal{B}(W'\to e\nu)_{LR}}\right)$ Fit ($\times 10^{-2}$)	Upper Limit
500	5828	$0.08^{+0.21}_{-0.08}$	5.38×10^{-3}
550	3407	$0.18^{+0.26}_{-0.18}$	7.16×10^{-3}
600	2037	$0.28^{+0.36}_{-0.28}$	1.01×10^{-2}
650	1218	$0.43^{+0.54}_{-0.43}$	1.52×10^{-2}
700	731	$0.36^{+0.83}_{-0.36}$	2.22×10^{-2}
750	433	$0.15^{+1.07}_{-0.15}$	2.80×10^{-2}
800	263	$0.03^{+1.36}_{-0.03}$	3.82×10^{-2}
850	160	$0.00^{+1.89}_{-0.00}$	5.68×10^{-2}
900	100	$0.00^{+2.80}_{-0.00}$	8.79×10^{-2}
950	62	$0.00^{+4.53}_{-0.00}$	1.49×10^{-1}
1000	41	$0.00^{+6.64}_{-0.00}$	2.48×10^{-1}
1050	27	$0.00^{+10.8}_{-0.00}$	4.36×10^{-1}
1100	19	$0.00^{+17.7}_{-0.00}$	7.62×10^{-1}
1150	14	$0.00^{+32.5}_{-0.00}$	1.39
1200	10	$0.00^{+62.7}_{-0.00}$	2.47
1250	8.1	$0.00^{+114}_{-0.00}$	3.96
1300	6.7	$0.00^{+224}_{-0.00}$	6.24



Summary(CDF W')

- For search results on heavy gauge boson, W' decaying to an electron-neutrino pair, found no statistically significant excess observed in 5.3 fb^{-1} of data
- Set the W' boson mass limit with $m_{W'} > 1.12\ TeV/c^2$ @95% CL ,assuming manifest left-right symmetric model

Phys. Rev. D 83, 031102(R) (2011) [8 pages]

Search for a new heavy gauge boson W' with event signature electron+missing transverse energy in $p\bar{p}$ collisions at $\sqrt{s}$=1.96 TeV

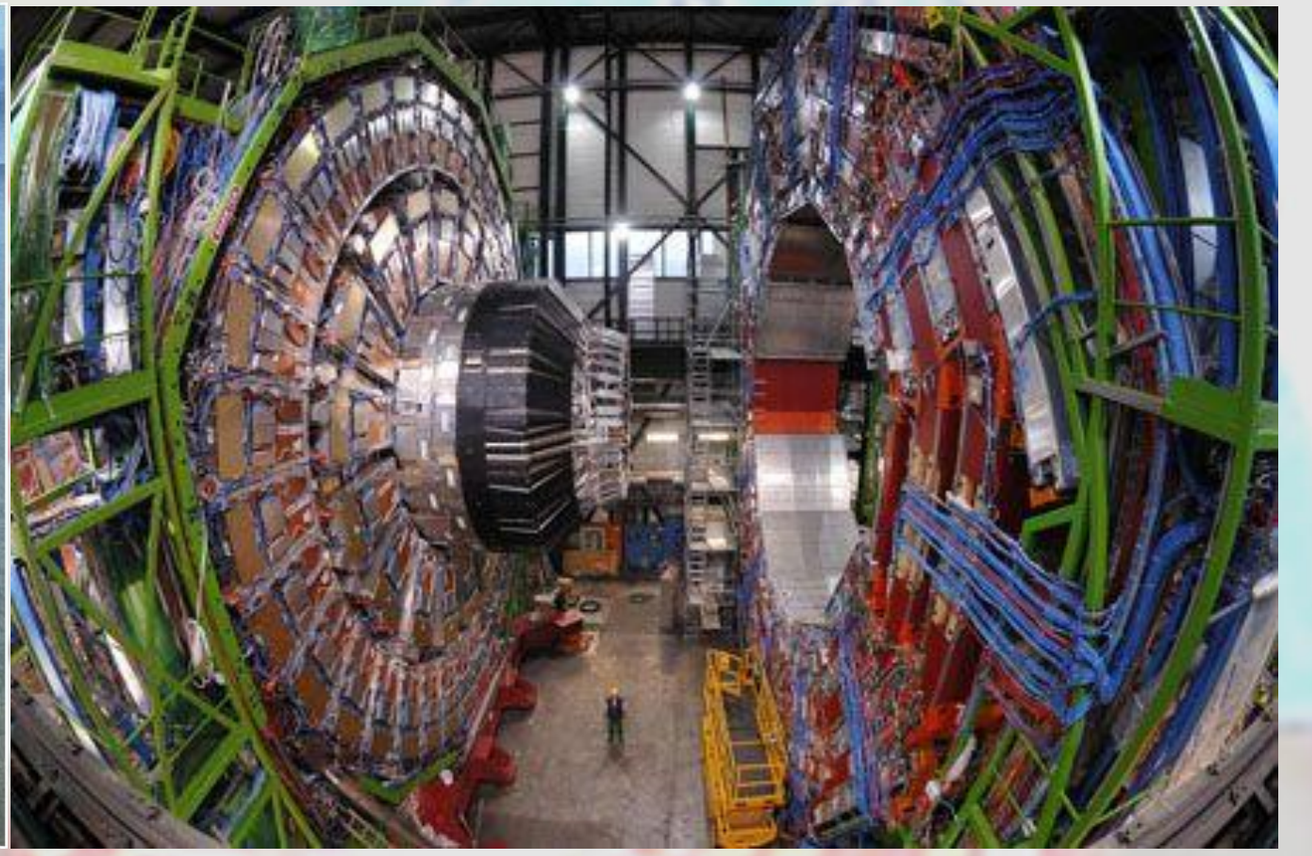
T. Aaltonen *et al.* (CDF Collaboration)
Show All Authors/Affiliations

RAPID Received 23 December 2010; published 3 February 2011

We present a search for a new heavy charged vector boson W' decaying to an electron-neutrino pair in $p\bar{p}$ collisions at a center-of-mass energy of 1.96 TeV. The data were collected with the CDF II detector and correspond to an integrated luminosity of 5.3 fb^{-1}. No significant excess above the standard model expectation is observed and we set upper limits on $\sigma \cdot \mathcal{B}(W' \to e\nu)$. Assuming standard model couplings to fermions and the neutrino from the W' boson decay to be light, we exclude a W' boson with mass less than 1.12 TeV/c^2 at the 95% confidence level.

URL:
http://link.aps.org/doi/10.1103/PhysRevD.83.031102
DOI:
10.1103/PhysRevD.83.031102
PACS:
14.70.Pw, 12.60.Cn, 13.85.Rm

CMS W’ Search



p-p Collision at 7 TeV with 36 pb-1 data

WCU CENTER FOR COLLIDER PHYSICS KNU KYUNGPOOK NATIONAL UNIVERSITY

CMS W' Group(2009-2010)

AN

CMS AN AN-10-314

CMS Analysis Note

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

2010/12/07

Search for a heavy gauge boson W′ in the final states with electrons and large missing E_T in pp collisions at $\sqrt{s}$=7 TeV

Alessio Ghezzi[3], Federico de Guio[3], Kerstin Hoepfner[1], DongHee Kim[4], Simon Knutzen[1], Martina Malberti[3], Philipp Millet[1], Darren Puigh[2], Tommaso Tabarelli de Fatis[3], Sunghyun Chang[4], and Peter Wittich[2]

PAS

CMS AN EXO-10-014

CMS Analysis Note

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

2010/12/07

Search for a heavy gauge boson W′ in final states with electrons and large missing E_T in pp collisions at $\sqrt{s} = 7$ TeV

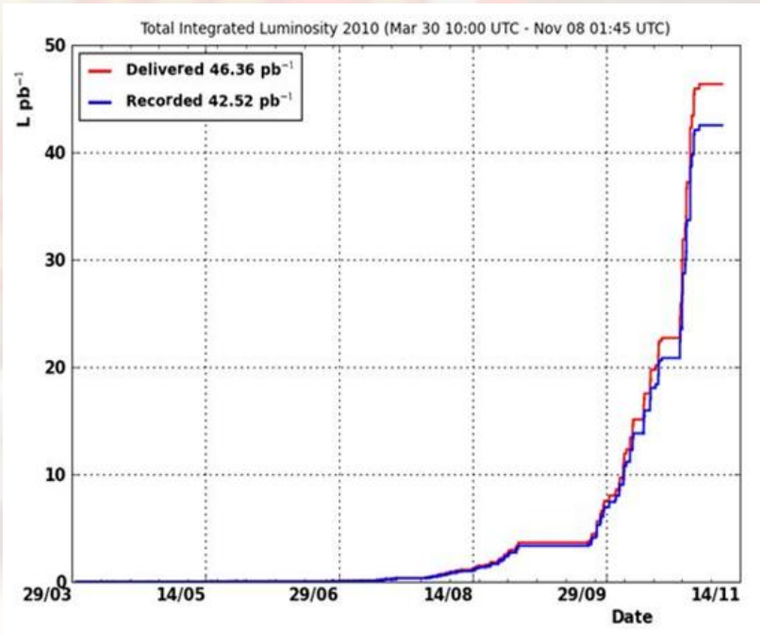
The CMS Collaboration

WCU-경북대, 아헨공대(독일), 코넬대(미국) 밀라노대(이태리)
총 11명

W’ Search Analysis

- W’ → e ν Signature
  : Isolated hight-p_T electron + large missing transverse energy
- Main background : Standard Model W → e ν
- Counting experiment after cutting on transverse mass.

Dataset	Run Range	L(pb-1)
Mar-Sep20 2010 /EG/Run2010A-Nov4ReReco_v1/RECO	136033-144144	3.1
Sep21-Nov14 2010 /Electron/Run2010B-Nov4ReReco_v1/RECO	145726-149442	33.0
Total		36.1



CMS Integrated Luminosity (Mar2010 – Nov2010)

Object Selection

- Preselection
  - Good primary vertex
  - ≥ 1 electron with ET>25 GeV and H/E < 0.1
- MET
  - Uses MET from particle flow algorithm

- electron
  - Single electron High Level Trigger
  - 1 good High p_T electron
  - $\Delta\phi$(electron, MET) > 2.5
  - 0.4 < electronE_T/MET < 1.5

✓ High P_T Electron Selection

Variable	Barrel	Endcap
E_T	> 30 GeV	> 30 GeV
$\|\eta_{sc}\|$	< 1.442	1.560 < $\|\eta_{sc}\|$ < 2.5
isEcalDriven	TRUE	TRUE
$\|\Delta\eta_{in}\|$	< 0.005	< 0.007
$\|\Delta\varphi_{in}\|$	< 0.09	< 0.09
H/E	<0.05	<0.05
$\sigma_{i\eta i\eta}$	n/a	<0.03
E2x5/E5x5	>0.94 OR E^{1x5}/E^{5x5} > 0.83	n/a
EM + Had Depth 1 Isolation	<2+0.03*Et	<2.5 for Et<50 else
		<2.5+0.03*(Et-50)
Had Depth 2 Isolation	n/a	<0.5
Track Isol: Trk Pt	<7.5	<15

High Level Trigger

- HLT path not prescaled
- HLT paths with track requirement have 97% efficiency

HLT path	Run Range	L(pb^{-1})
HLT_Ele10_LW_L1R	135059 - 140041	0.1
HLT_Ele15_SW_L1R	140042 - 141900	0.2
HLT_Ele15_SW_CaloEleId_L1R	141901 - 146427	2.9
HLT_Ele17_SW_CaloEleId_L1R	146428 - 147116	4.4
HLT_Ele27_SW_TightCaloEleIdTrack_L1R_v1	147117 - 148058	9.5
HLT_Ele22_SW_TighterEleId_L1R_v2	148819 - 149064	9.7
HLT_Ele22_SW_TighterEleId_L1R_v3	149065 - 149442	8.1

- Inclusive Electron/Photon paths: H/E < 0.15
- CaloEleId: H/E < 0.15, $\sigma_{i\eta i\eta}$< 0.014 (EB) or 0.035 (EE);
- EleId: CaloEleId plus dEta < 0.01, dPhi < 0.08 (requires track);
- TightCaloEleId: H/E < 0.1, $\sigma_{i\eta i\eta}$ < 0.012 (EB) or 0.032 (EE);
- TightCaloEleIdTrack: H/E < 0.1, $\sigma_{i\eta i\eta}$ < 0.012 (EB) or 0.032 (EE) (requires track)

Background Estimations

- Need to determine both the shape and the normalization of the transverse mass distributions

  -. W : M_T shape from MC, yield from data-driven

  - QCD : Data-Driven Method

  -. The other backgrounds from MC

  (Transverse mass is calculated with E_T of electron and missing E_T)

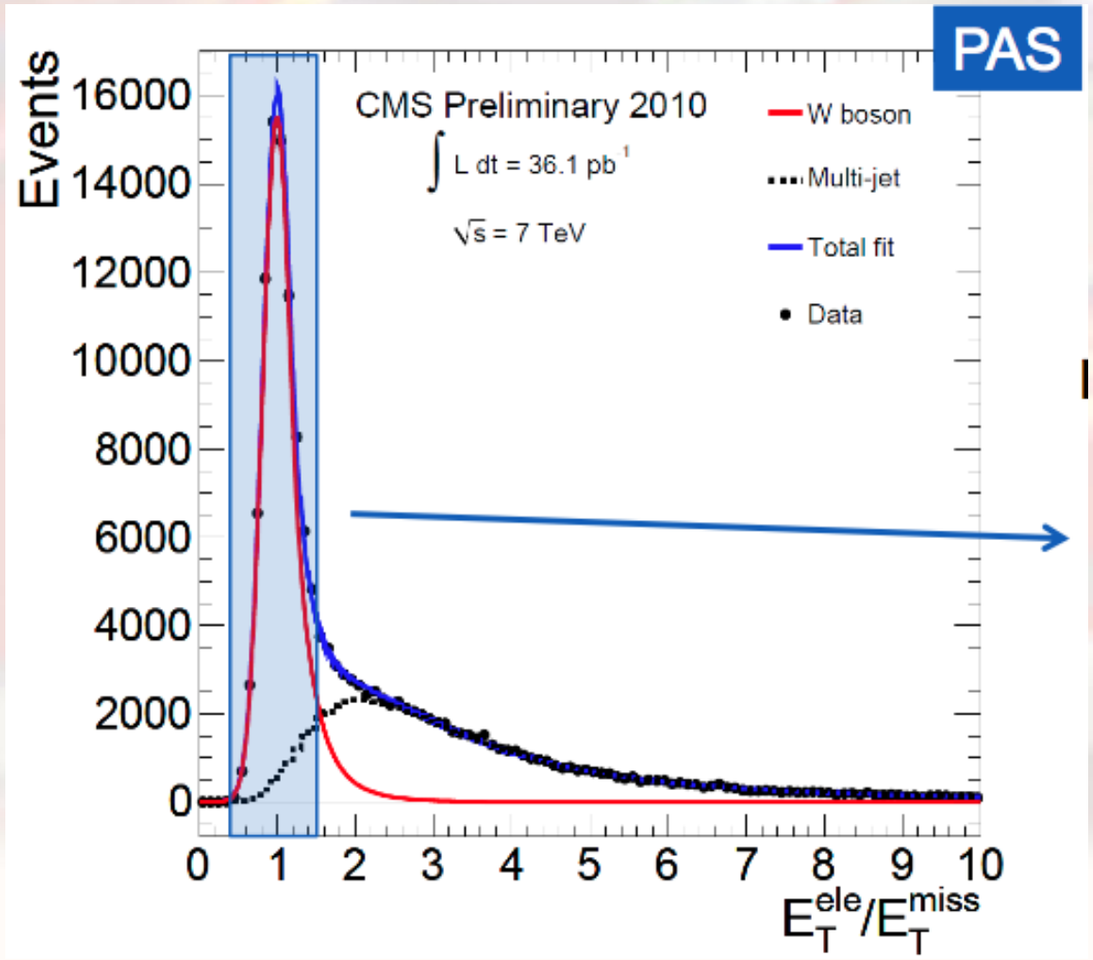
$$M_T = \sqrt{2 \cdot E_T^{ele} \cdot E_T^{miss} \cdot (1 - cos\Delta\phi_{eE_T^{miss}})}$$

Background	Shape	Normalization
W →eν	MC with hadronic recoil correction	fit of E_T^{ele}/E_T^{miss}
multi-jet	non-isolated electrons from DATA	fit of E_T^{ele}/E_T^{miss}
Other backgrounds	MC	MC

- Transverse mass calculated from electron and MET as follows

W and QCD estimates

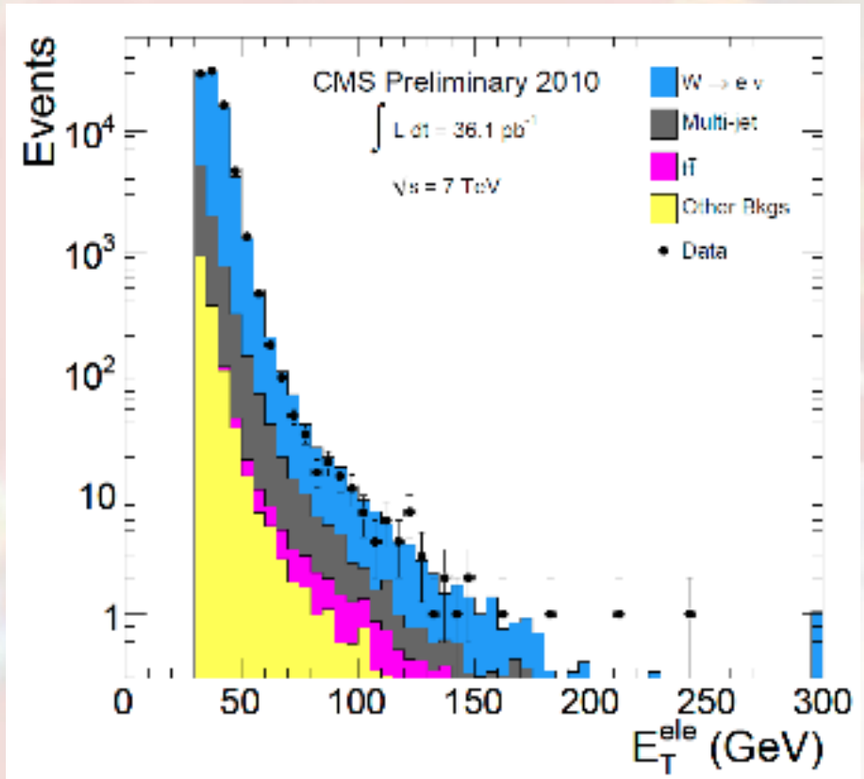
- Use ET/MET distribution (last step of our selection) to normalize W and QCD MT distribution
- Fit data ET/MET distribution with QCD enriched sample (non-iso electrons) and W MC sample with Crystal-Ball function

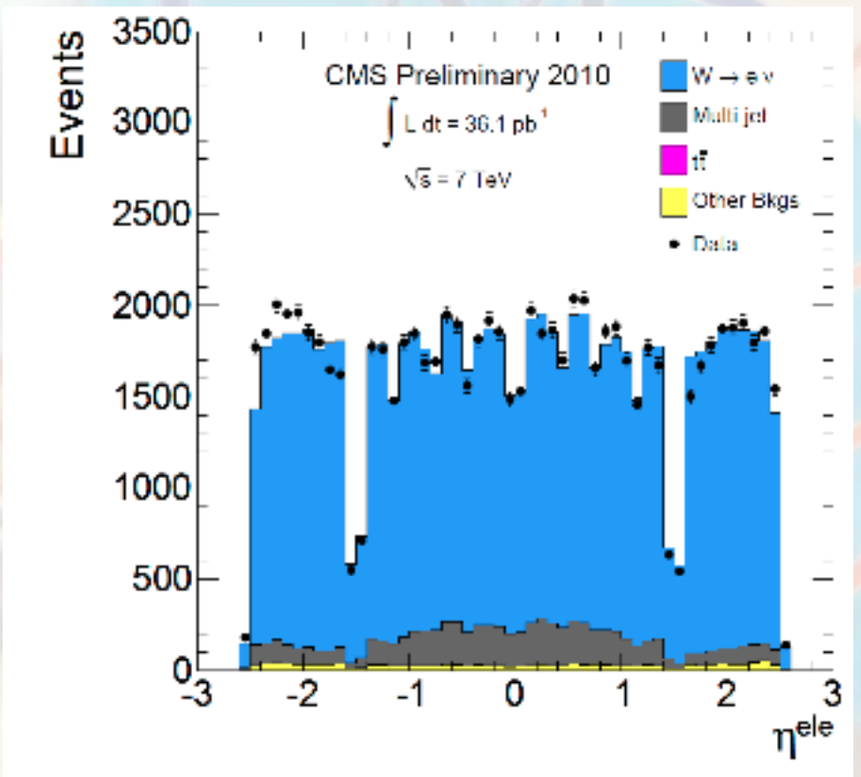


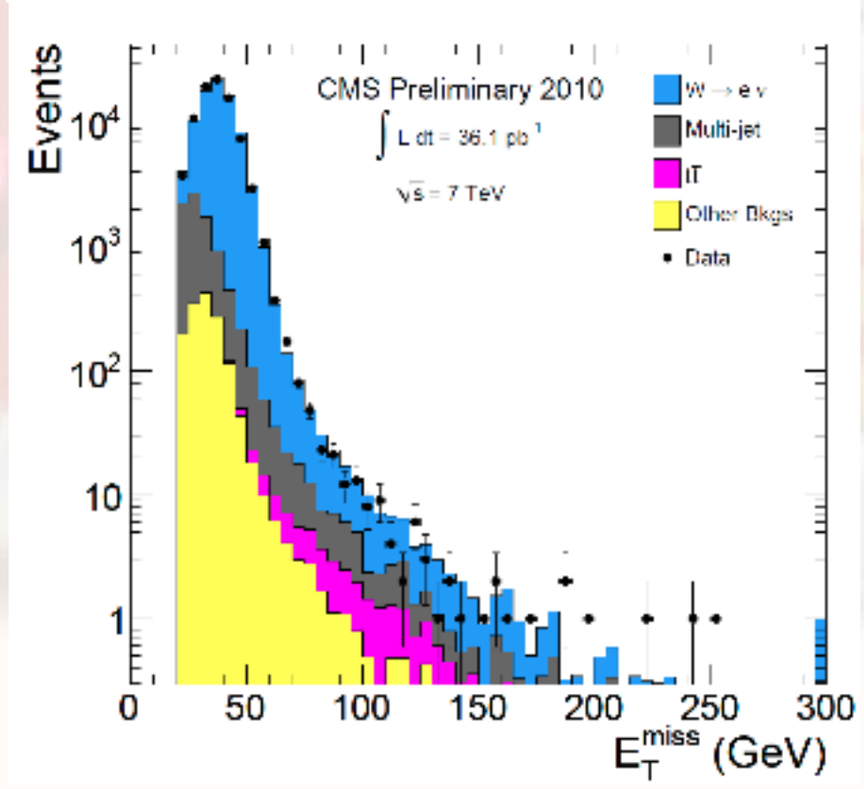
MT distributions normalized to the region 0.4 < ET/MET < 1.5

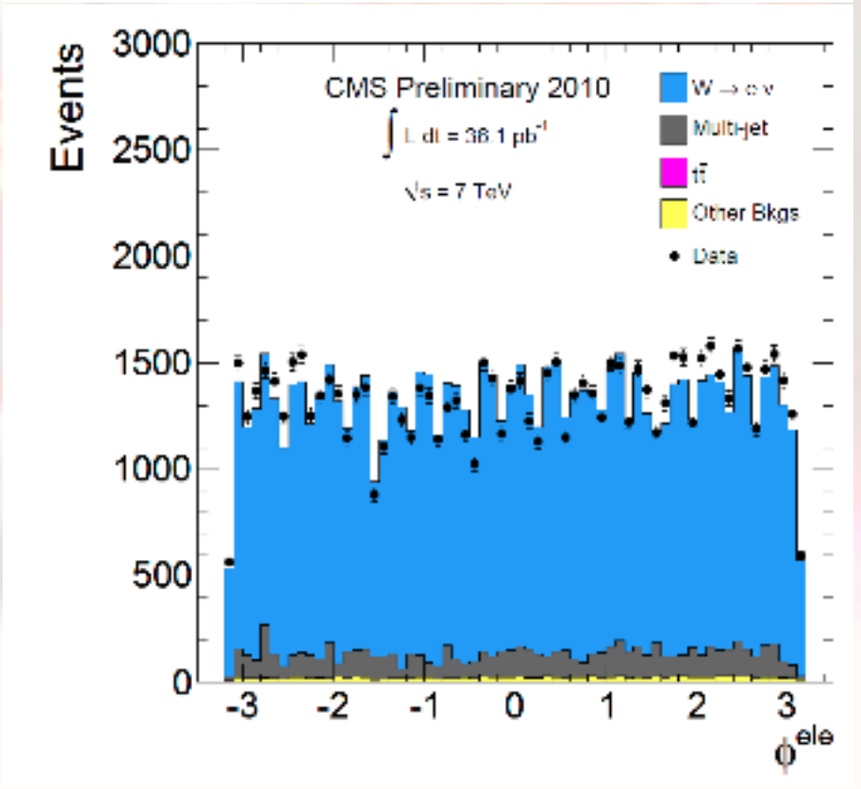
Estimate right amount of QCD/W as backgrounds

Background and data comparisons

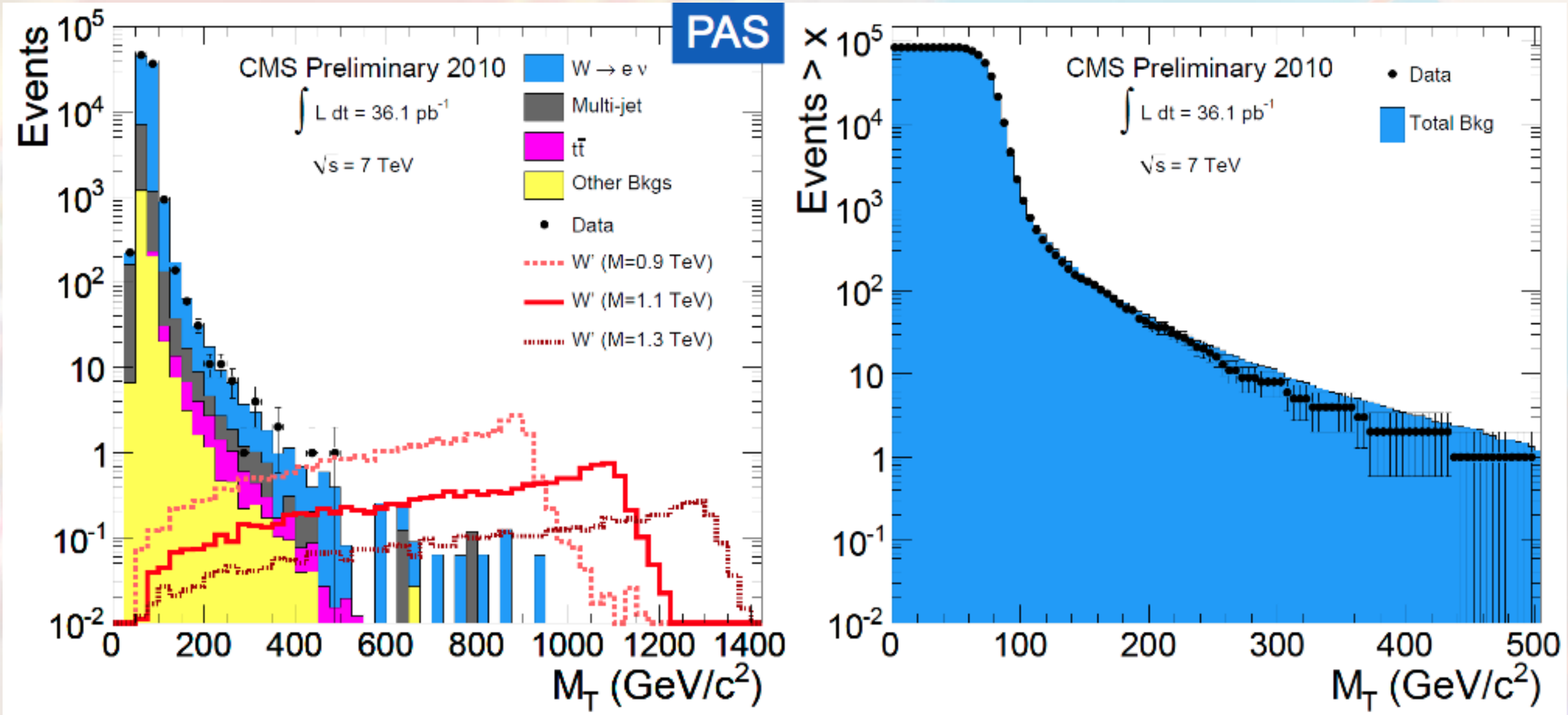








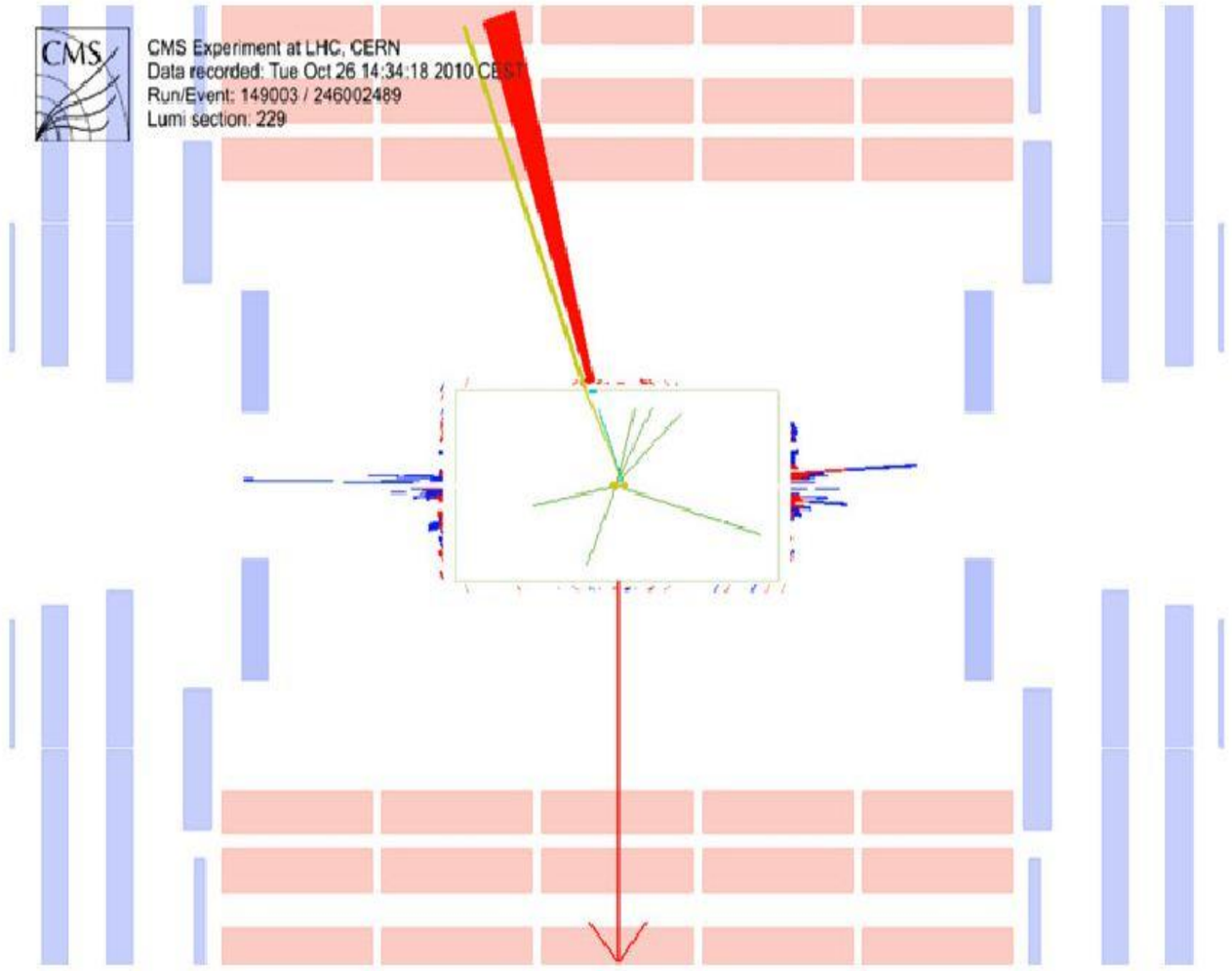
Transverse mass distribution

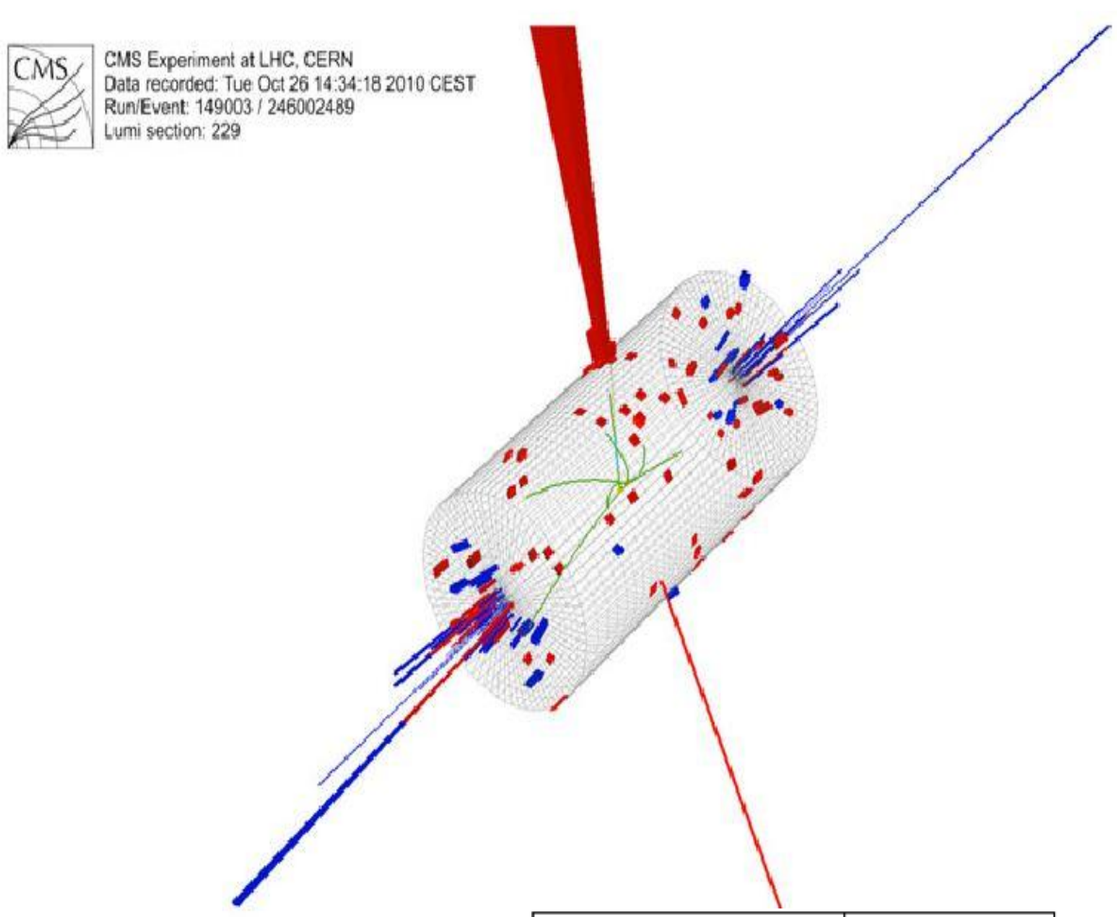


- Good agreement in both background prediction observed in the MT distribution (left) and the cumulative distribution (right)

Highest transverse mass event

$M_T = 493$ GeV





Variable	Value
Run	149003
Lumi section	229
Event number	246002489
Electron E_T	242 GeV
pf $E_{\mathrm{T}}^{\mathrm{miss}}$	241 GeV
Transverse mass	493 GeV

Systematic Uncertainties

Source of systematic error	Uncertainty	Signal	Total Bkg
Integrated luminosity	11%	11%	0.84%
Electron reco efficiency	1.9%	1.9%	0.14%
Electron ID efficiency	1.5%	1.5%	0.11%
Electron energy scale	1%(EB), 3%(EE)	0.4%	9.9%
$E_{\mathrm{T}}^{\mathrm{miss}}$ scale	5%	1.6%	1.4%
$E_{\mathrm{T}}^{\mathrm{miss}}$ resolution	10%	0.9%	0.5%
Cross section		10%	1.1%
Total (lumi not included)		10.5%	28.7%

Final Data and Background Estimation

- Good agreement between data and background prediction
- No excess in data → set a lower-bound on the mass of the W'

Sample	$M_T > 45$ GeV	> 200	> 300	> 400	> 500	> 600
$W \to e\nu$	75609.1± 319.0	33.7± 2.7	7.2± 0.9	2.5± 0.5	0.9± 0.3	0.6± 0.2
multi-jet	7083.4± 3546.1	6.3± 3.3	1.6± 0.9	0.5± 0.3	0.2± 0.2	0.2± 0.2
$t\bar{t}$	59.6± 23.4	4.1± 1.7	0.6± 0.3	0.1± 0.1	0.0± 0.0	0.0± 0.0
$W \to \tau\nu$	1082.9± 79.3	1.1± 0.3	0.2± 0.2	0.0± 0.1	0.0± 0.0	0.0± 0.0
Other bkg	359.1± 72.6	2.0± 0.4	0.6± 0.1	0.2± 0.0	0.1± 0.0	0.0± 0.0
Total bkg	84194.2± 3563.3	47.3± 4.7	10.2± 1.4	3.3± 0.6	1.2± 0.3	0.9± 0.3
Data	84468	38	8	2	0	0

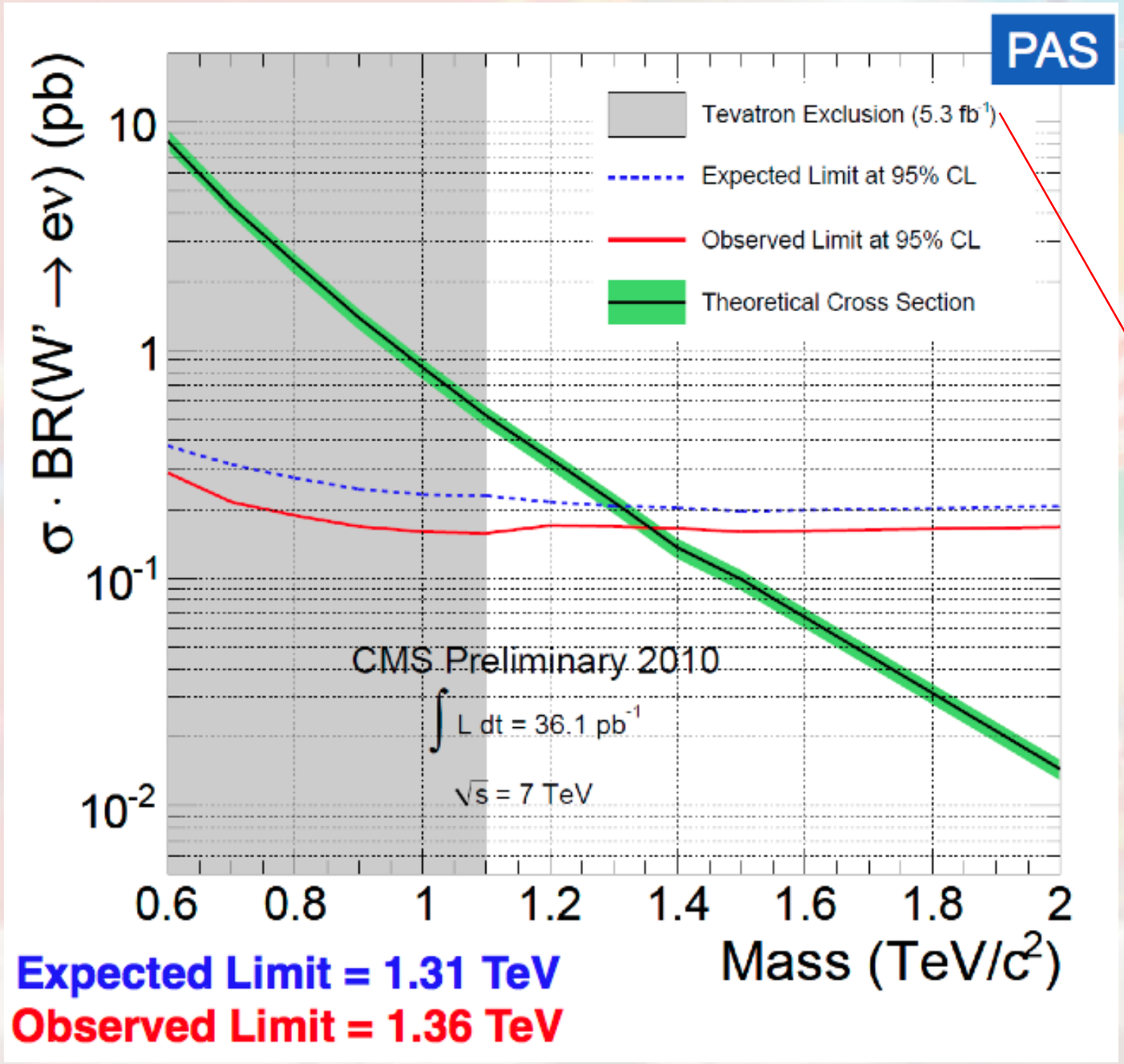
* Other background : gamma+Jet , W→μν, Drell-Yan,WW,WZ,ZZ, single top
* Table includes both statistical and systematic uncertainties added in quadrature (does not include lumi uncertainty)

Setting the Mass Limit

- Cut-and-Count Statistical Method used
- Using Bayesian 95% CL limit calculator to determine expected and observed limits
- For each W' mass point, use MT cut with best expected limit

$M_{W'}$ (TeV/c^2)	$M_T >$ (TeV/c^2)	N_{sig} (Events)	N_{bkg} (Events)	N_{data} (Events)	σ_{theory} (pb)	Exp limit (pb)	Obs limit (pb)
0.6	0.400	129.38 ± 20.16	3.28 ± 0.61	2	8.290	0.379	0.289
0.7	0.500	60.77 ± 9.61	1.21 ± 0.35	0	4.264	0.314	0.215
0.8	0.500	39.54 ± 6.08	1.21 ± 0.35	0	2.426	0.274	0.188
0.9	0.500	25.24 ± 3.85	1.21 ± 0.35	0	1.389	0.246	0.168
1.0	0.500	16.10 ± 2.45	1.21 ± 0.35	0	0.838	0.232	0.159
1.1	0.500	10.06 ± 1.53	1.21 ± 0.35	0	0.516	0.229	0.157
1.2	0.650	6.02 ± 0.92	0.60 ± 0.24	0	0.334	0.215	0.170
1.3	0.675	3.92 ± 0.60	0.51 ± 0.21	0	0.215	0.207	0.168
1.4	0.675	2.52 ± 0.38	0.51 ± 0.21	0	0.136	0.203	0.164
1.5	0.675	1.89 ± 0.29	0.51 ± 0.21	0	0.099	0.196	0.159
2.0	0.675	0.27 ± 0.04	0.51 ± 0.21	0	0.014	0.206	0.167

W' Mass Limit



CDF W' Limit : 1.12 TeV

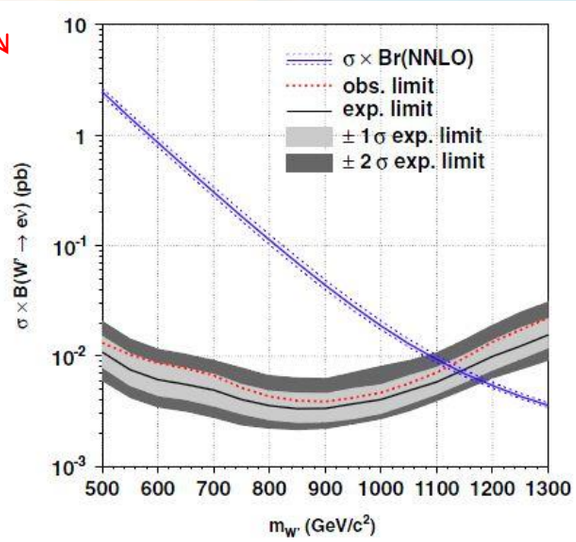


FIG. 3 (color online). The 95% C.L. limits on the cross section times the branching fraction as a function of W' boson mass and the expected limits from the simulated experiments with background only. The black solid lines represent the median expected; the shaded bands indicate the $\pm 1\sigma$ and $\pm 2\sigma$ invervals on the expected limits. The region above the red dashed line (observed limit) is excluded at the 95% C.L. The cross section times the branching fraction assuming the manifest LR symmetric model, $\sigma \cdot \mathcal{B}(W' \rightarrow e\nu)_{\mathrm{LR}}$, is shown along with its uncertainty. The intercept of the cross section limit curve and the lower bound of the theoretical cross section yields $m_{W'} > 1.12\ \mathrm{TeV}/c^2$ at the 95% C.L.

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Search for a heavy gauge boson W′ in the final state with an electron and large missing transverse energy in pp collisions at $\sqrt{s} = 7$ TeV ☆

CMS Collaboration *

CERN, Geneva, Switzerland

ARTICLE INFO

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ABSTRACT

A search for a heavy gauge boson W′ has been conducted by the CMS experiment at the LHC in the decay channel with an electron and large transverse energy imbalance $E_{\mathrm{T}}^{\mathrm{miss}}$, using proton–proton collision data corresponding to an integrated luminosity of 36 pb^{-1}. No excess above standard model expectations is seen in the transverse mass distribution of the electron-$E_{\mathrm{T}}^{\mathrm{miss}}$ system. Assuming standard-model-like

2011 W' analysis (by WCU-KNU)

- Data update & monitoring
  - new data is collected , ~1fb^{-1} collected by last June
  - data were minotored every week during last 3 Months
    → No access observed
- Data driven background estimation
  - Trigger includes isolation from 2011 data, new data driven method needs.
  - ttbar : b-tagging method
  - QCD : adopt **opening angle method** as well as E_T/MET fitting method (CB fit)
    (fake electron and the other jet are almost back to back for QCD.)

- A conservative approach on setting mass limit
  - applying **likelihood fitting** to M_T distribution of signal + background.
    (with stat. and systematic uncertainty on background)
  - **pseudo-experiments** will be performed to get 1σ and 2σ band of expected limit.

- PDF uncertainties scheme for CMS provided by KNU
  - effects on selection efficiency,

- Theoretical cross section of W' on NLO, NNLO etc..
  - K factor calculation - code migrates to CMS W' group by KNU

Conclusion

- **Two experiment published W′ mass limit on Feb 2011.**
- **CDF – Tevatron**
  - $M_{W'} > 1.12$ TeV
- **CMS – LHC**
  - $M_{W'} > 1.36$ TeV @ $36pb^{-1}$, 2010 data
  - 2011 data by June.

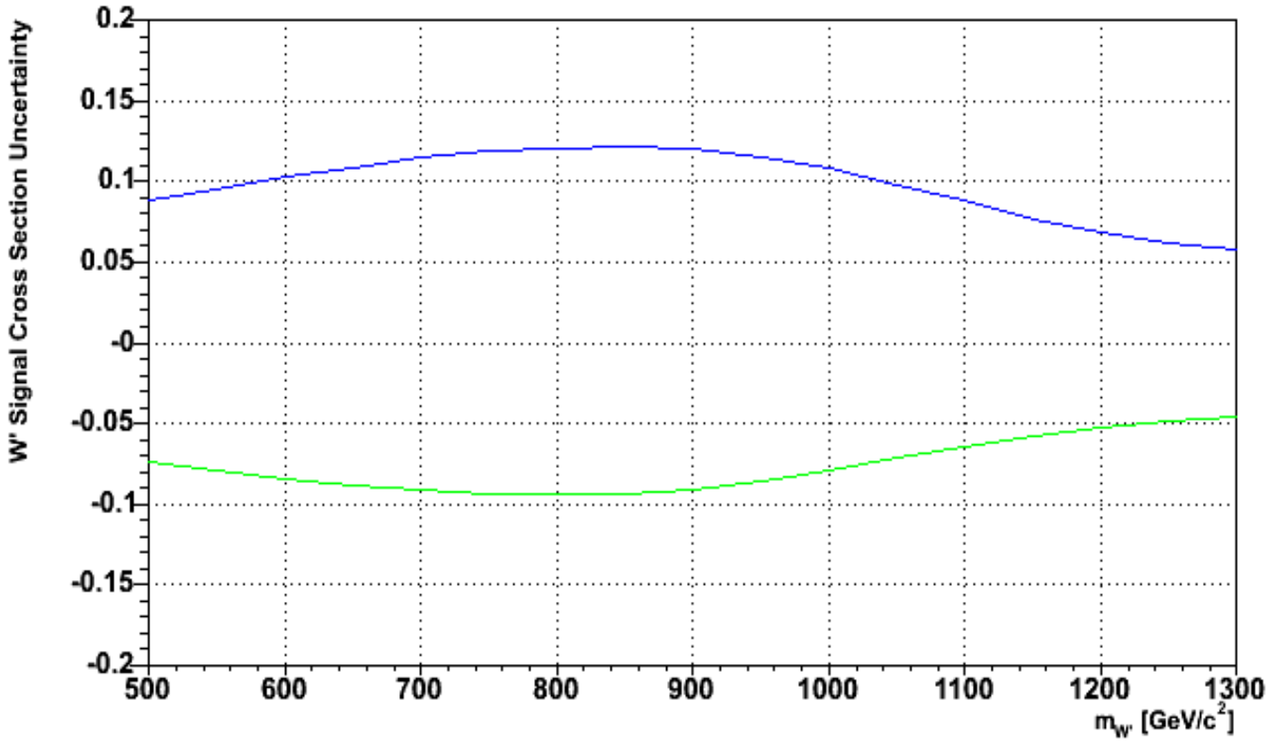
    → Luminosity 1 fb^{-1} .

    → Need to understand background

    → new limit : EPS 2011

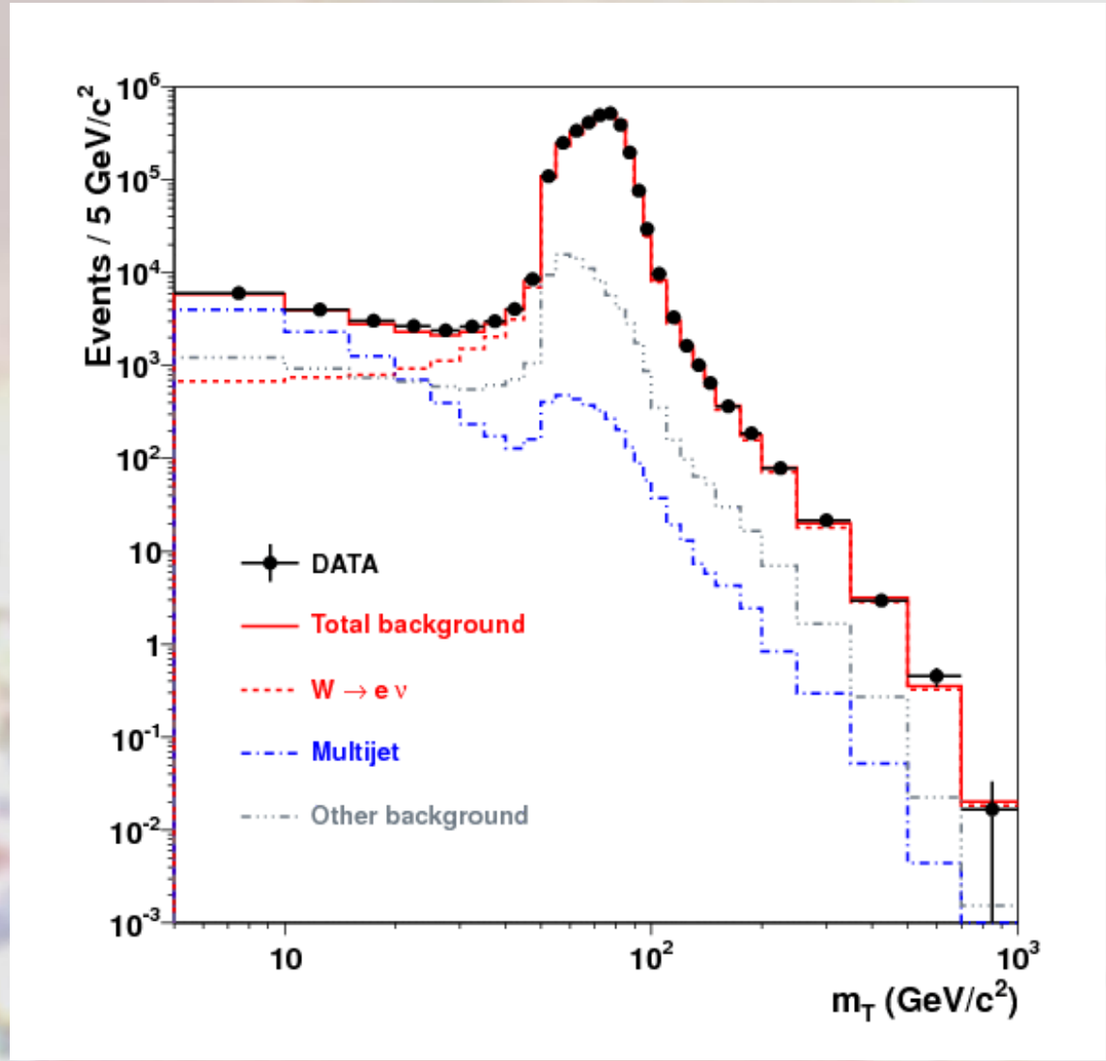
BACKUP

W' Cross-section uncertainty



$$\sigma^{(A)} = \sigma^{(B)} \cdot \frac{1}{N} \sum_{i=1}^{N} w_i(x_1, x_2, Q)$$

Mt Fitting Result



■ Fitting Result :

$\alpha_0 : 0.991 \pm 0.001$

$\alpha_{jet} : 1.134 \pm 0.011$

	Events in m_T bins (GeV/c^2)				
	200 - 250	250 - 350	350 - 500	500 - 700	700 - 1000
$W \to e\nu$	711^{+50}_{-50}	359^{+25}_{-25}	85^{+6}_{-6}	13^{+1}_{-1}	$1.1^{+0.1}_{-0.1}$
Multijet	9^{+2}_{-2}	6^{+1}_{-1}	2^{+2}_{-2}	$0.2^{+1.6}_{-0.2}$	$0.01^{+1.10}_{-0.01}$
Other background	70^{+9}_{-6}	33^{+4}_{-3}	8^{+1}_{-1}	$1^{+0.1}_{-0.1}$	$0.09^{+0.01}_{-0.01}$
Total background	790^{+61}_{-58}	398^{+31}_{-30}	94^{+9}_{-8}	14^{+3}_{-1}	$1.2^{+1.2}_{-0.1}$
Data	784	426	88	18	1

- **Good agreement between the data and background expectations**
  → **No statistically significant excess observed for W'**

Search W' : Mt fitting

- **Search for excess in the m_T dist. over SM backgrounds**
  - **Variable Binned maximum likelihood method**

$$\mu^j = \alpha_0[\sum_{i\neq jet}\mu_i^j + \beta\mu_{sig}^j] + \alpha_{jet}\mu_{jet}^j$$

- α_0, α_{jet}, and β are the parameters
- $\mu_i^j(\mu_{jet}^j)$ is the expected number of background(multijet)
- μ_{sig}^j is the expected number of $W' \to e\nu$ signal

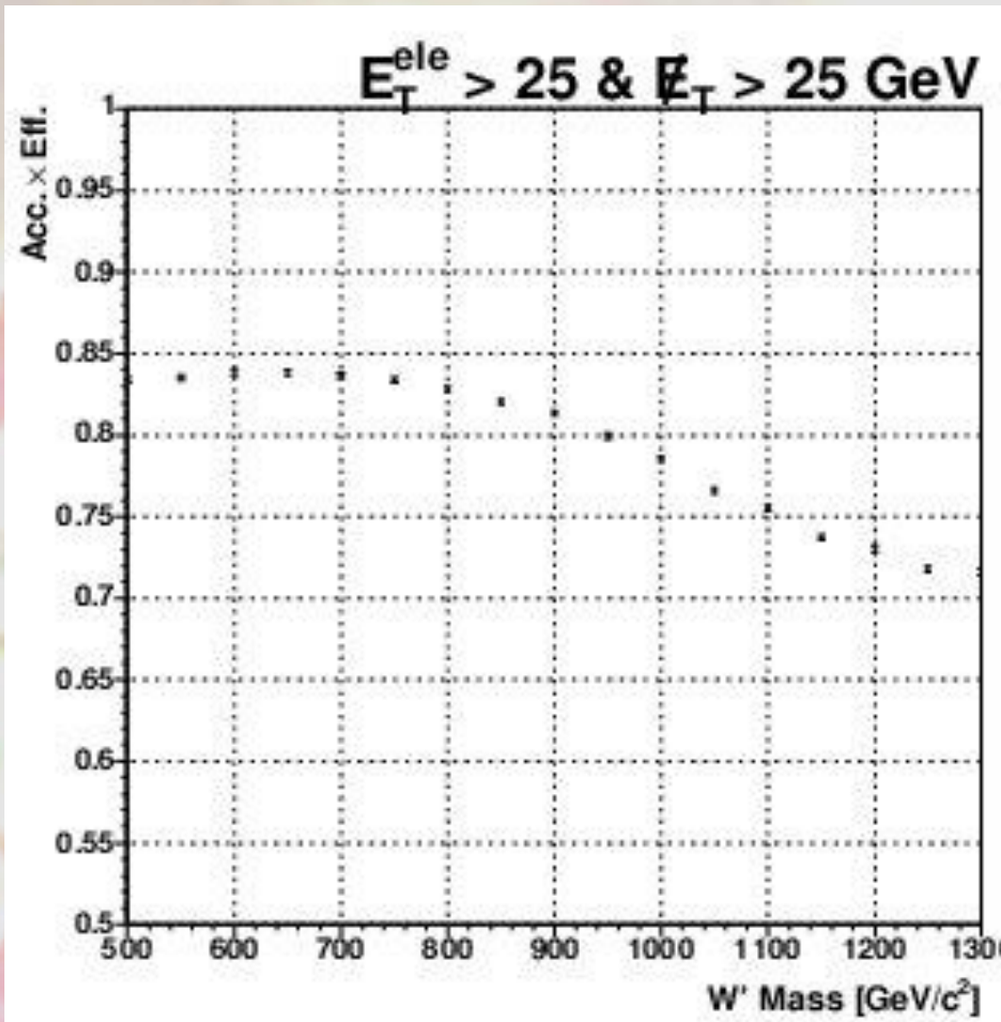
  - **Use Poisson probability with a Gaussian constraining on multijet bg**

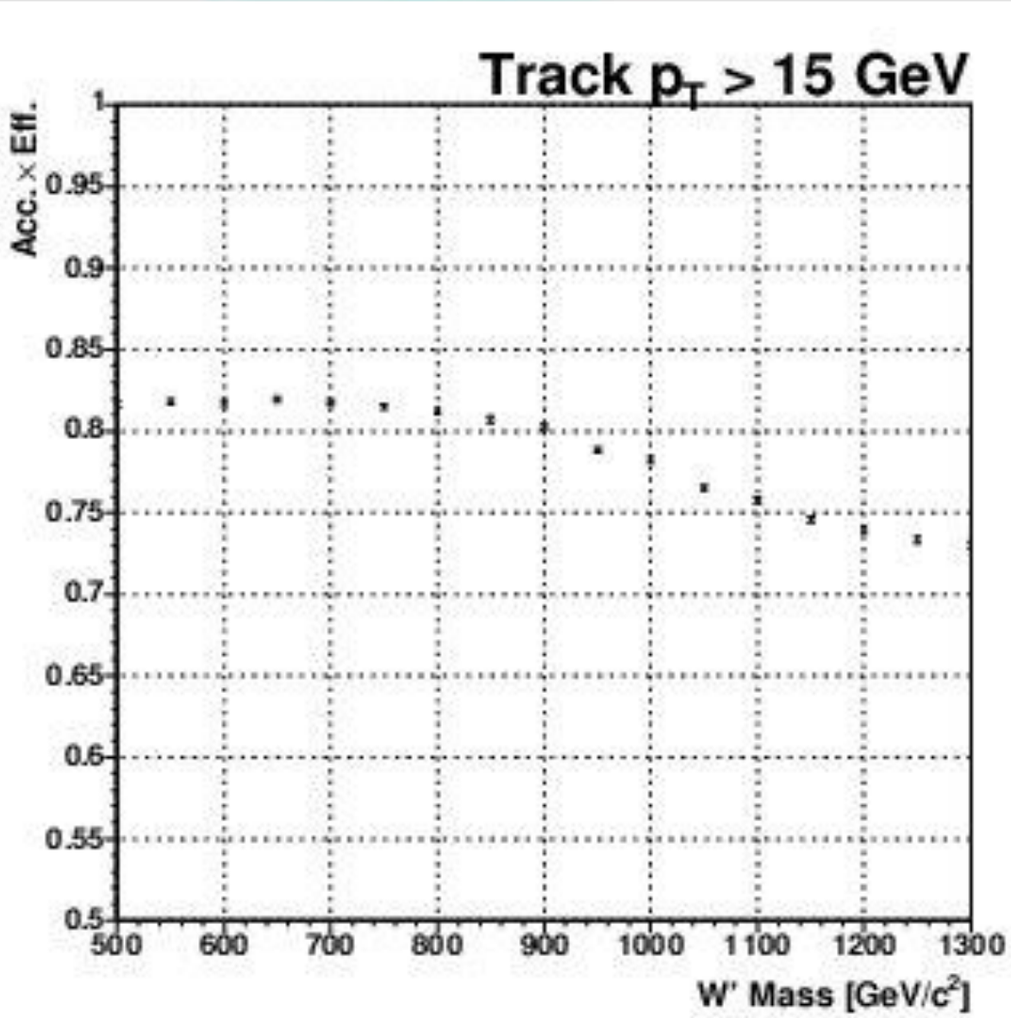
$$p(\alpha_0, \alpha_{jet}, \beta) = \left(\prod_j \frac{\mu_j^{n_o^j} e^{-\mu_j}}{n_o!}\right) \mathcal{G}(\alpha_{jet}, \sigma_{jet}),$$

$$\text{where} \quad \mathcal{G}(\alpha_{jet}, \sigma_{jet}) = \frac{1}{\sqrt{2\pi}\sigma_{jet}} \exp\left(-\frac{1}{2}\left(\frac{\alpha_{jet}-1}{\sigma_{jet}}\right)^2\right)$$

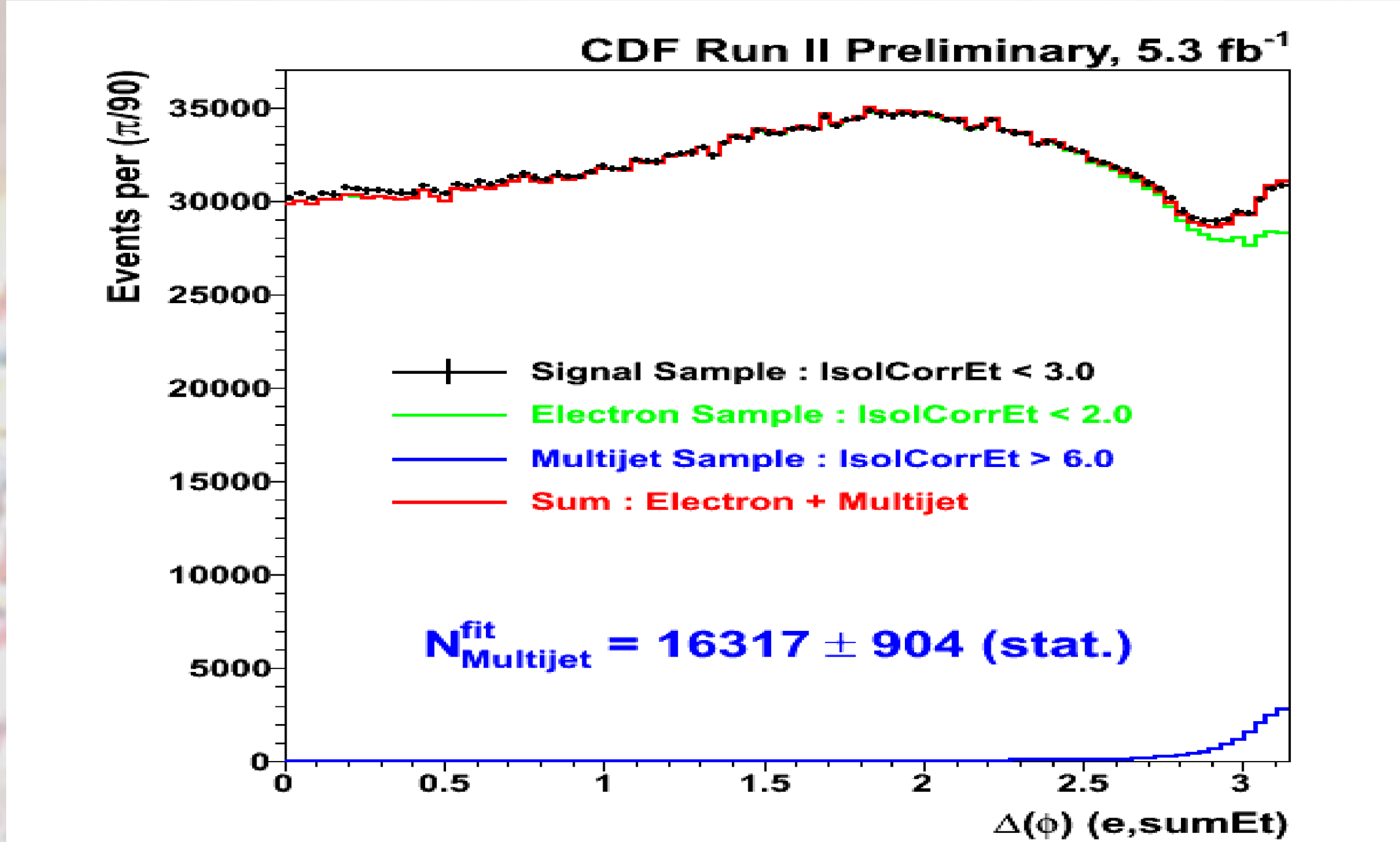
- n_0^j is number of observing events

W' Acceptance x Efficiencies(1)





Multijet Background Estimation



Multijet Background Estimation

Data-driven method adopted

- QCD events dominate dijet
  - one jet : mis-id as electron
  - the other jet : mis-measured and produce $\not\!\!E_T$

- Opening Angle between electron and sumE_T to be back-to-back
  - sum$E_T = (\sum \vec{E}_T^{towers}) - \vec{E}_T^{e}$
  - QCD Event : ϕ(electron,sumE_T) $\rightsquigarrow 180°$
  - Real $W \to e\nu$ Event : no correlation in Opening Angle

- To estimate the Number of QCD Events,

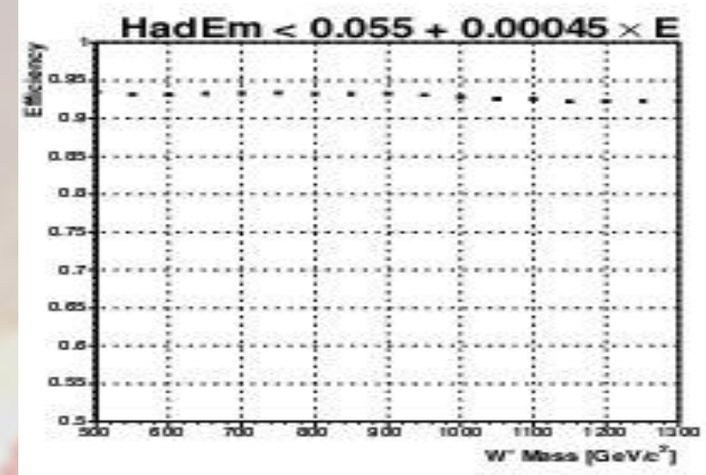
  → we made Electron and QCD enriched sample

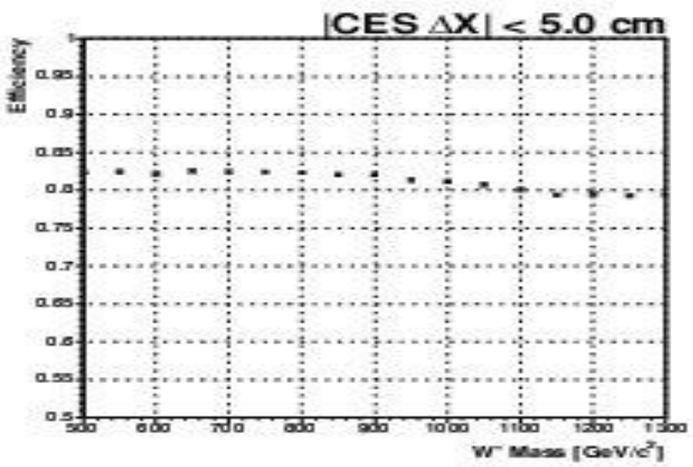
$$IsolCorrE_T = (IsolFrac - 0.02) \times E_T$$

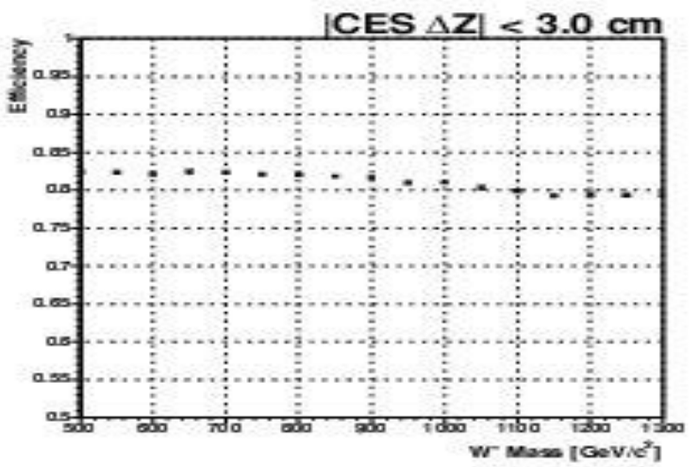
  - Electron enriched sample : $IsolCorrE_T < 1.0$ (subtracted $Z \to ee$)
  - Signal sample : $IsolCorrE_T < 3.0$
  - QCD enriched sample : $IsolCorrE_T > 6.0$ (subtracted $W \to e\nu, Z \to ee$)

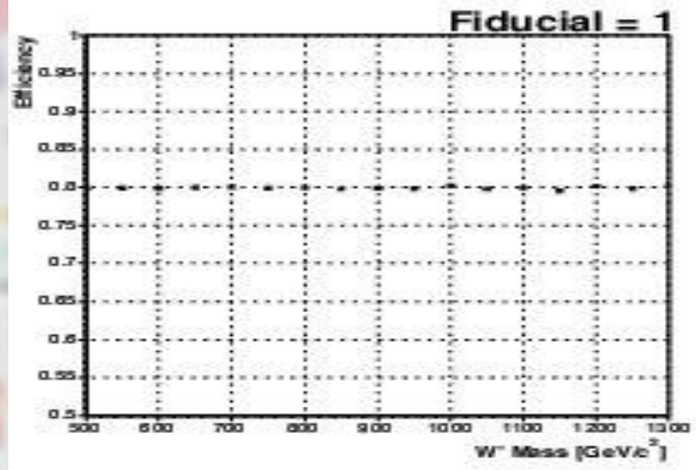
  → Likelihood fitting in Angular Distribution$[\pi/2, \pi]$

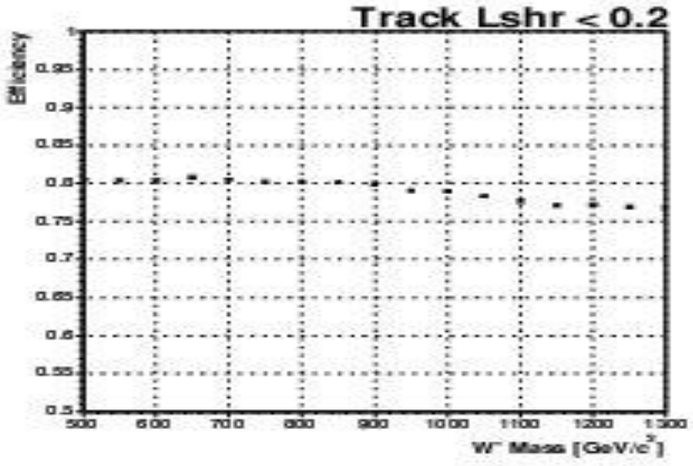
W' Acceptance x Efficiencies (2)

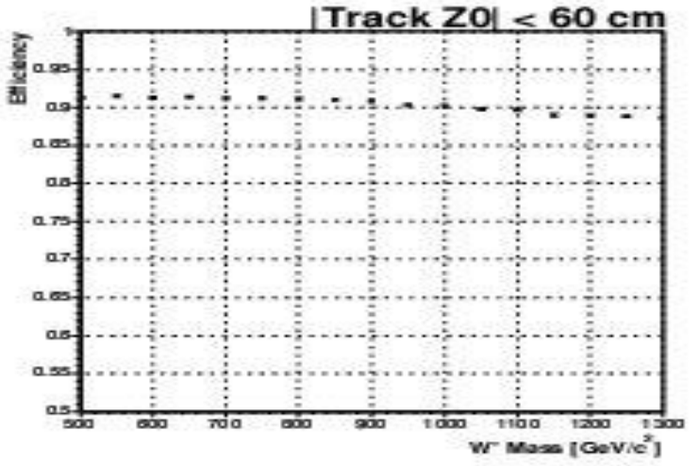


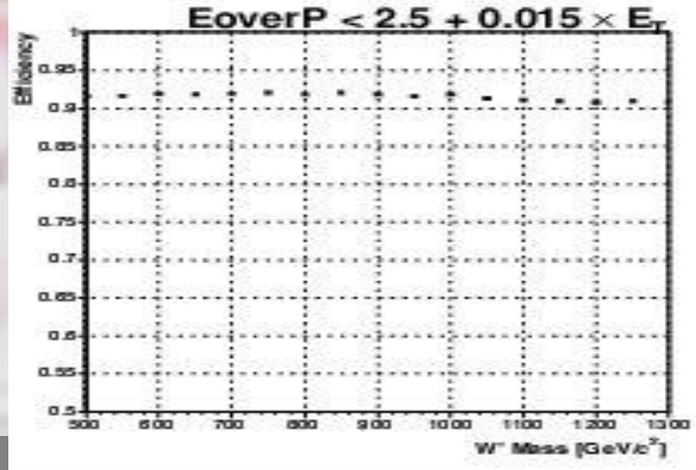


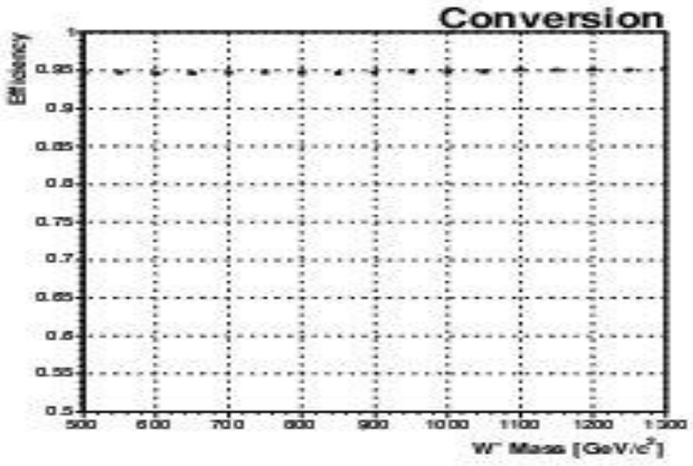


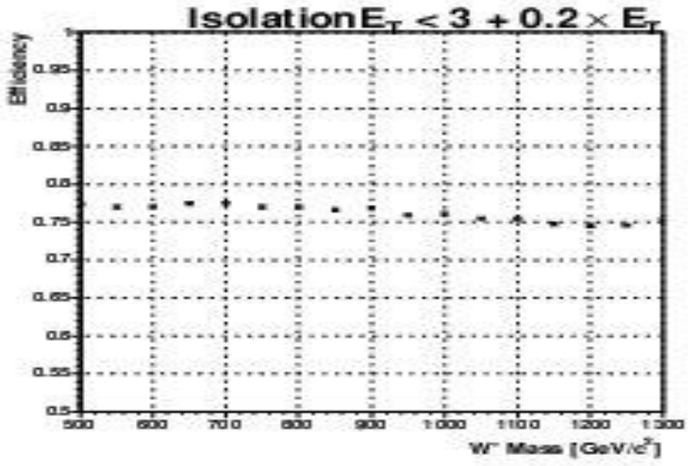












Theoretical Motivation

- Heavier versions of the W boson are found in many theories.
- Left-right symmetry of electroweak interactions
  - Extend the Standard Model gauge group to include right-handed interactions

$$SU(2)_L \times U(1)_Y \rightarrow SU(2)_R \times SU(2)_L \times U(1)_{B\text{-}L}$$

- Extra dimensions
  - Kaluza-Klein(KK) tower of heavy copies of all SM fields
    - n = KK excitation mode
    - R = size of extra dimension

$$M^2_{W_n} \sim \frac{n^2}{R^2} + M^2_{W_0}$$

- General extensions of the SM gauge group
  - e.g Little Higgs models

Signal Model

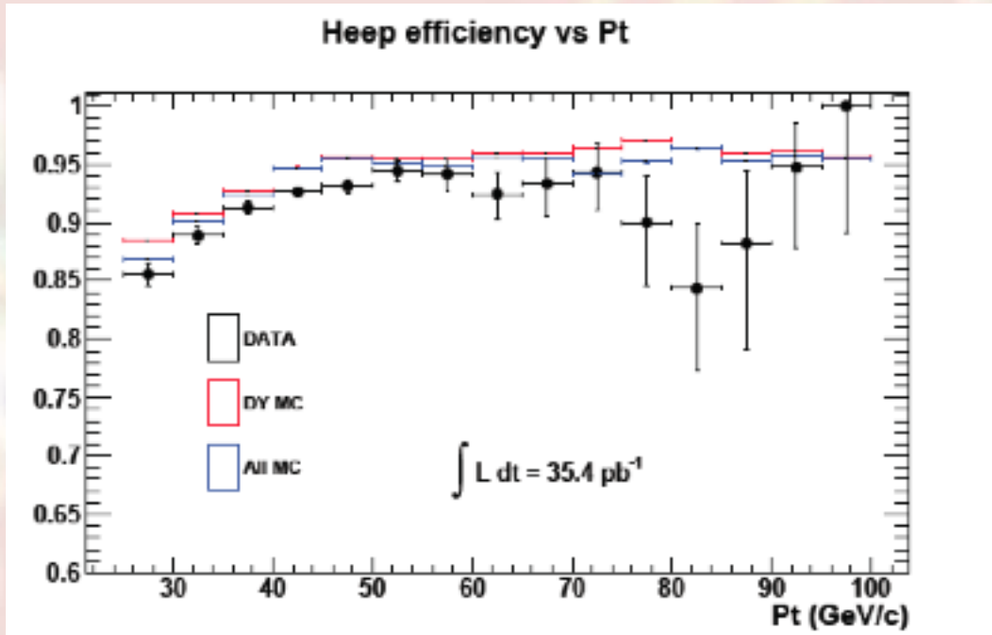
- Neutrino is light and stable
  - Important in the context of the left-right symmetric model (ν_R)
- Coupling of W’ to fermions is the same as for W.
  - CKM matrix is the same as well.
- No mixing between W’ and other gauge bosons .
  - Excludes mixing between W’ and either W or Z'.
- Decay channels W’→ WW, WZ and ZZ are suppressed .
  - Occurs in many extended gauge models.
- Decay width of W’ scales with its mass.

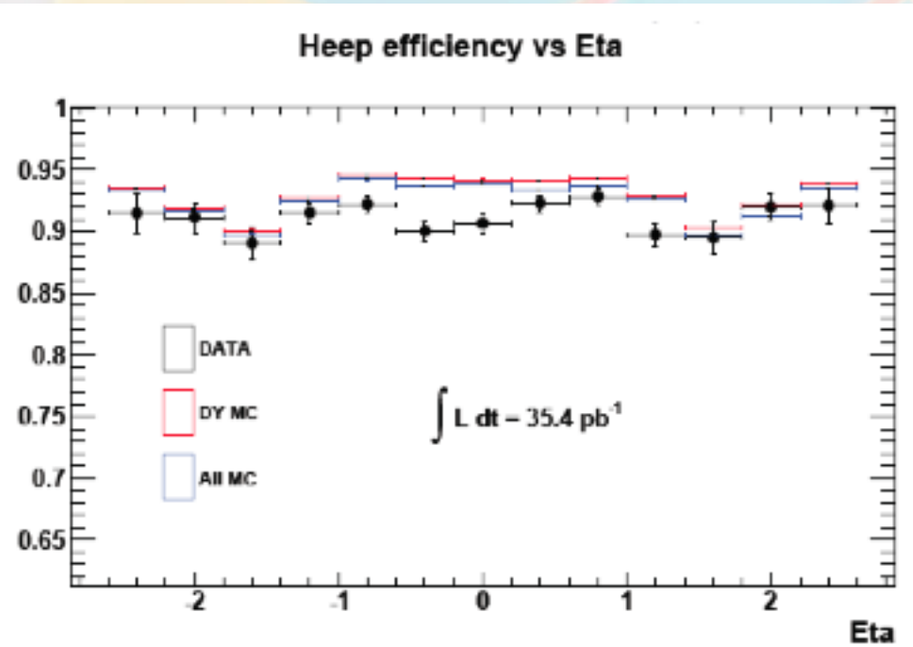
$$\Gamma_{W'} = \frac{4}{3}\frac{M_{W'}}{M_W}\Gamma_W$$

- Additional generations of fermions (if exist) are too heavy to be produced.

Data/MC Scaling

- Scale factor from the efficiencies of both data and MC

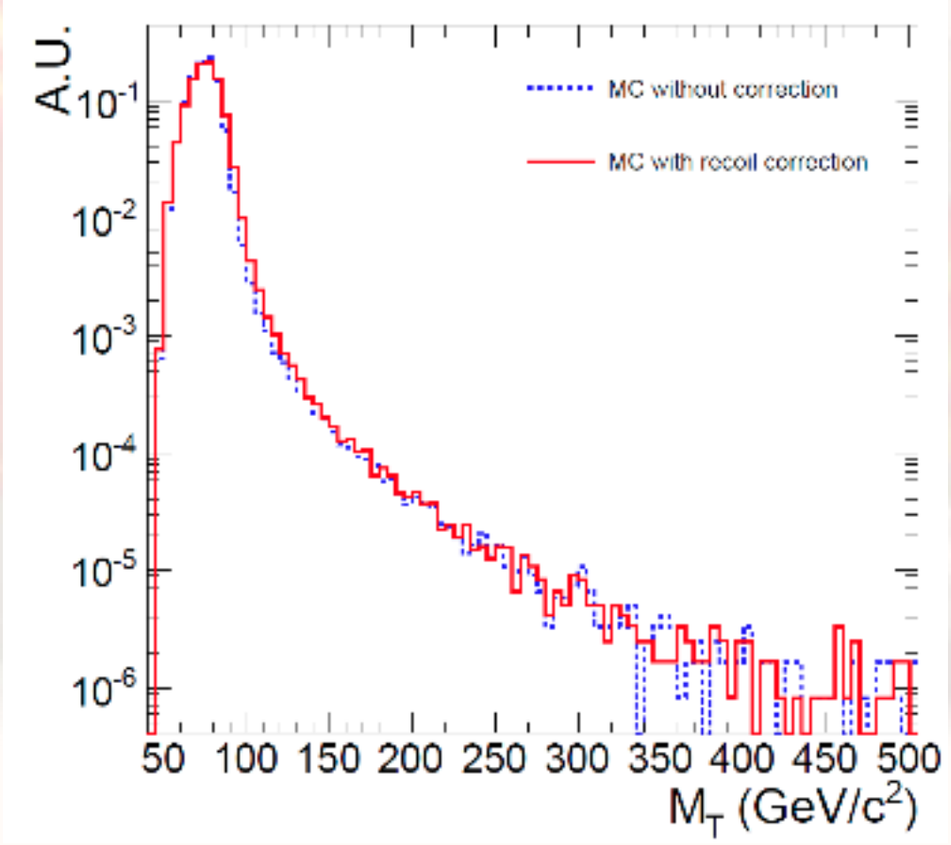




	HEEP Eff.(Barrel)	HEEP Eff.(Endcaps)
Drell-Yan	93.9% ± 0.0%	91.6% ± 0.1%
Drell-Yan +BG	93.5% ± 0.0%	91.2% ± 0.1%
Data	91.4% ± 0.3%	90.6% ± 0.6%
Scale factor	**0.978 ± 0.003(stat.) ± 0.002(syst.)**	**0.994 ± 0.006(stat.) ± 0.002(syst.)**

W →eν transverse mass distribution

- Method gives recoil corrected MET on event-by-event basis
  - Use this MET in our event selections (ET/MET and Δϕ)
  - Use this MET to create transverse mass template for W →eν
- Comparing MT distributions with and without correction, agreement with data improves most for 100 < MT < 150 GeV



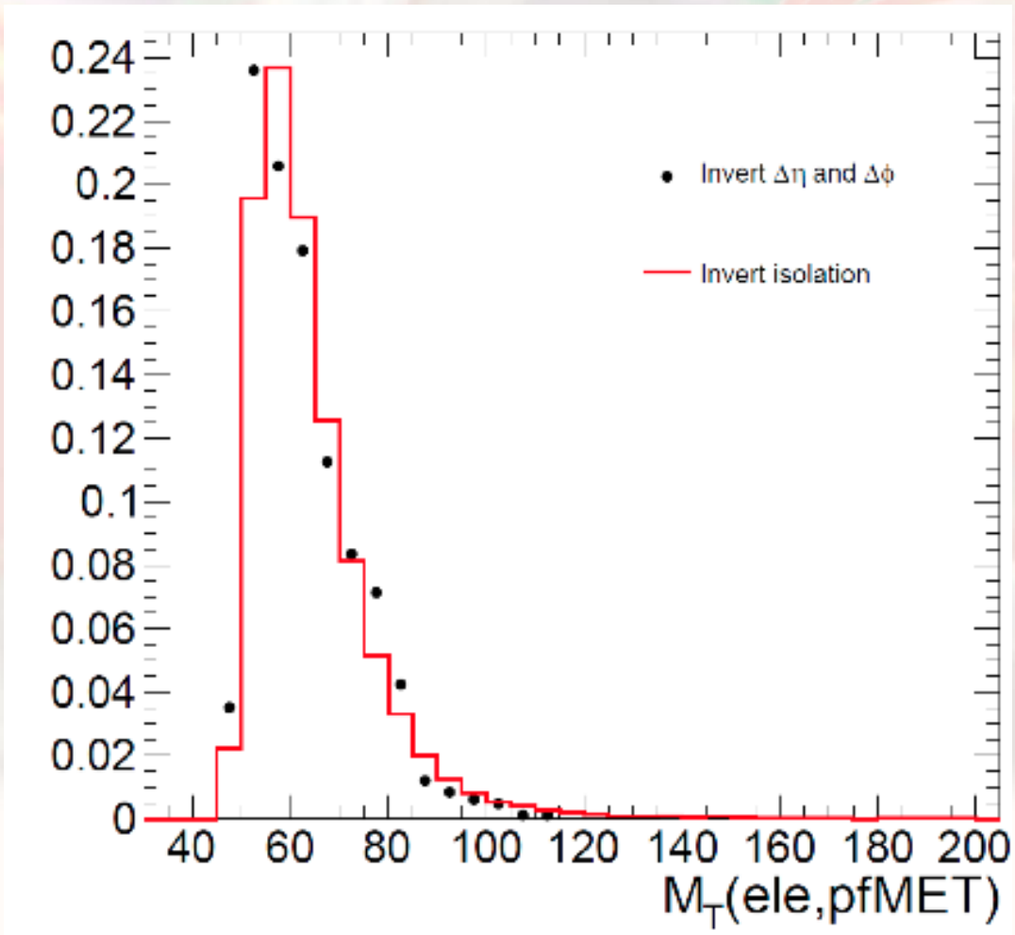
Cross-check of QCD enriched sample

- Use data from non-isolated electrons

  -. Sample enriched in multi-jet events

- we compare this to the distribution obtained from I nstead inverting the $\Delta\eta$(trk,SC) and $\Delta\phi$(trk,SC) requirements

  -. Decent agreement between two samples



CDF and CMS competition

CDF와 CMS의 W′ 논문 출판 경쟁

◆ CDF 5.3 fb^{-1} w/ 2 TeV p-pbar comparable with CMS ~ 35 pb^{-1} w/ 7 TeV p-p
◆ involved in W' analysis in both CDF(KNU only) and CMS(KNU, Aahen, Cornell, Milano)

- 2010년 3월 LHC 7 TeV에서 데이터 획득 시작 (계획 200 pb^{-1} 2010, 1 fb^{-1} 2011)
- 6월 8일(CMS run coordinator e-mail) LHC 가속기 문제 등으로 금년 기껏해야 10 pb^{-1} 정도 획득할 것으로 예상
- CMS 파리에서의 ICHEP 학술회의에서 100 nb^{-1} 정도의 데이터 분석 결과 발표
- 본 그룹 CDF에서 5.3 fb^{-1} 데이터로 W′ 탐색 계속 수행 중(약 2년간)
- 2010년 9월 9일 W′ 데이터 분석 결과 인증받음. (M > 1.1 TeV)
- 2010년 9월 20일: CDF내 W′ 탐색 논문심사위원회 결성
- 9월말부터 LHC running이 심상치 않음
- 일주일에 5 pb^{-1}의 데이터를 획득하여 10월말까지 ~ 40 pb^{-1} 획득
- 10월 중순부터 출판 경쟁이 시작됨
- 동시에 CMS W′ 탐색의 같은 멤버로서 이상한 동거가 시작됨
- CDF논문심사위원회 및 대표에게 위급성 긴급 타진(8차례 국제전화)
- CDF W′ sensitivity를 높이기 위한 피나는 노력이 이루어짐
- W mass high tail 설명으로 질량 하한선이 상향 조정될 것임.
- CDF실험 대표의 직권으로 단계별 심사를 대폭 줄임
- 결국 2010년 12월 23일 CDF 논문 PRL에 제출
- CMS는 동년 12월 29일에 Physics Letter B에 제출
- APS 편집장이 CDF W′ 논문 심사 기간을 심사위원에게 1주일 만 부여
- CDF 논문 Physical Review D Rapid Communication에 2011년 2월 3일 출판됨
- CMS 논문 2011년 2월 27일 출판됨.
- 이는 CDF 사상 처음 있는 일임. 그만큼 LHC의 경쟁력이 큼.(에너지)
- 이 일로 인해 CDF의 논문 제출을 위한 제반 규정이 바뀜