Heavy charged gauge boson, W', Search at Hadron Colliders

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Motivation (W' gauge boson)

- **Left-Right Symmetric Model**
  - ✓ Of weak interaction by spontaneous symmetry breaking in the right-handed sector, W' boson obtains its mass
- **Signal Model**
  - ✓ Right-handed neutrino is light and stable.
  - ✓ Coupling of W' to fermions is the same as for W
  - ✓ No mixing between W' and the other gauge bosons.
  - ✓ Decay width of W' scales with its mass.
- **Production and Decay**
  - ✓ W' can be production in both ppbar and pp collisions through qqbar annihilation
  - ✓ Decaying to A lepton-neutrino
  - ✓ Decaying to A quark pair (include tb channel)

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

$\downarrow$ *W'/Z'*

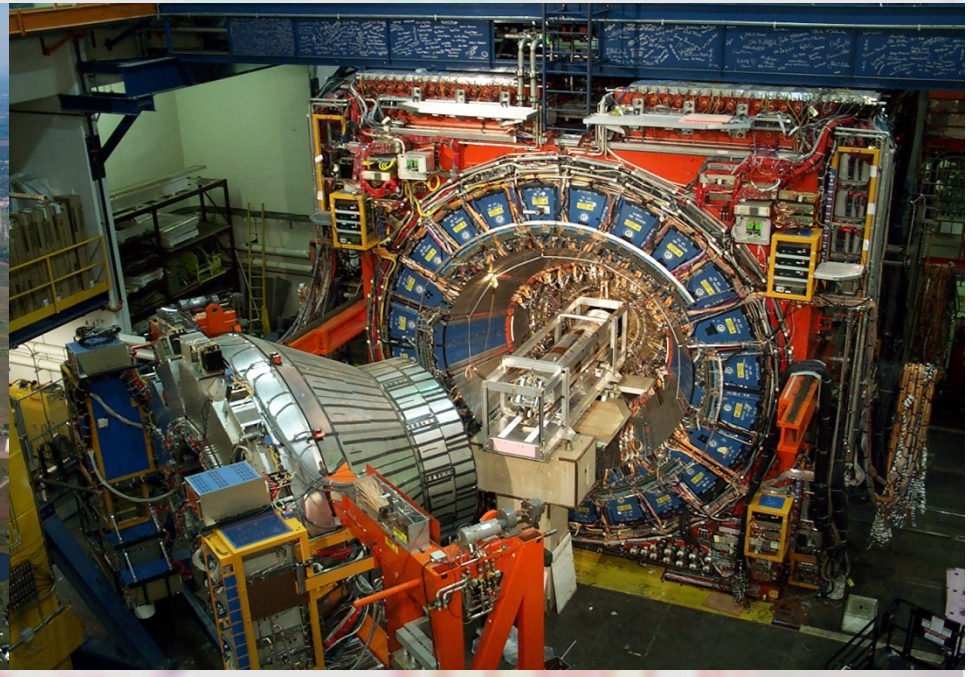
$$SU(2)_L \times U(1)_Y$$

$\downarrow$ *W/Z*

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

- **Result of Search at Hadron Collider Experiments**
  - ✓CDF W' Search (2010)
  - ✓CMS W' Search (2010 and 2011)

CDF W' Search (W' → electron + MET)



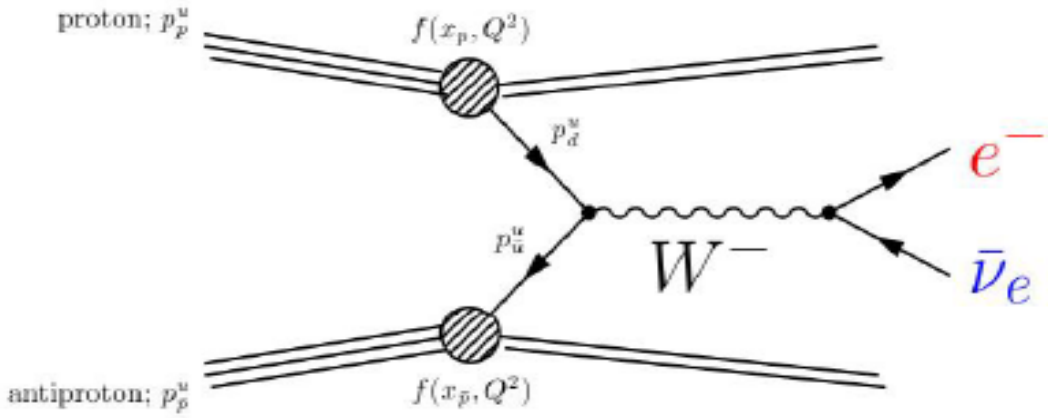
p-pbar Collision at 1.98 TeV with 5.3 fb^{-1} data

Data Samples

- Looking for the excess events over than SM background in high transverse mass region.

- Data : Inclusive High Pt electron sample
  - ✓ 5.3 fb^{-1} (taken in Feb. 2002 ~ Jun. 2009) with good run
  - ✓ Level3 electron trigger path
    - ELECTRON_CENTRAL_18, ELECTRON70_L2_JET, W_NOTRACK
- Background and Signal Samples
  - ➢ PYTHIA MC samples
  - ➢ Multijet Background : from data driven

Event Selection



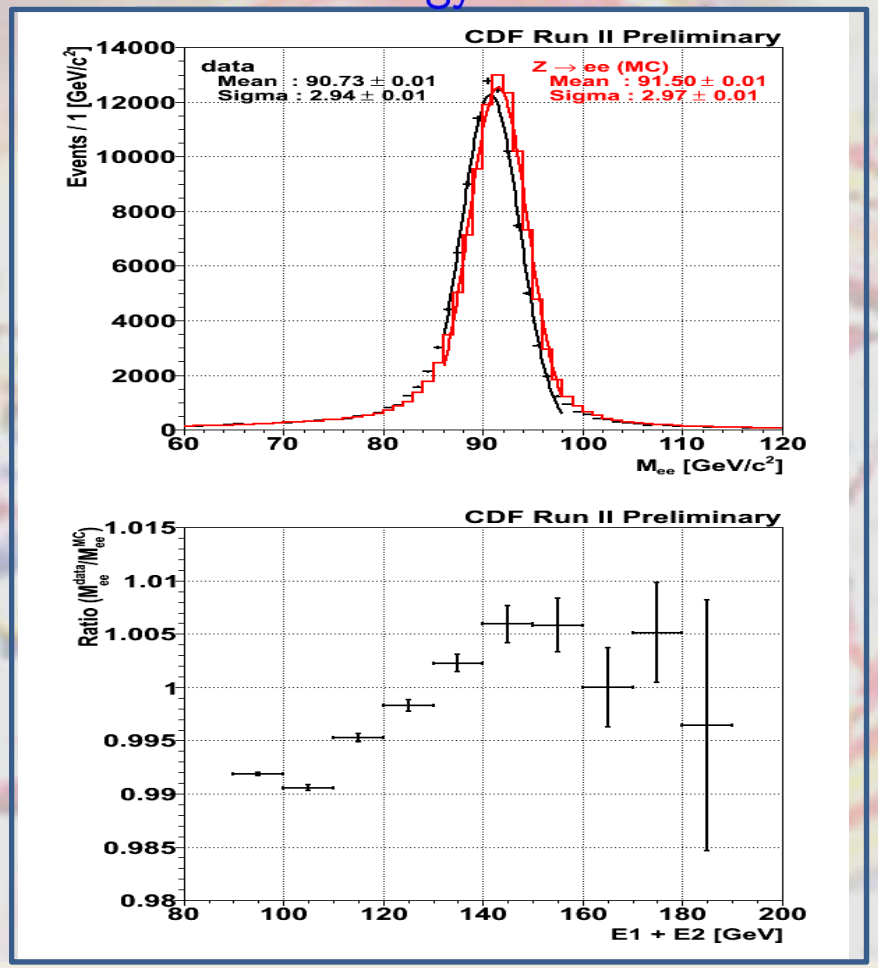
- **Electron**
  - → CEM ($|\eta| < 1.1$)
  - → isolated EM shower
  - → a large of energy fraction deposited in EM
- **Neutrino**
  - → Undetectable
  - → $\not\!\!E_T (\equiv -\sum_i E_T^i \hat{n}_i) > 25$ GeV
  - → correction for jets
- **Event Veto**
  - → dilepton($ee, e\mu$) removal
  - → multijet 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
$Fiducial$	$= 1$
$Conversion$	$\neq 1$

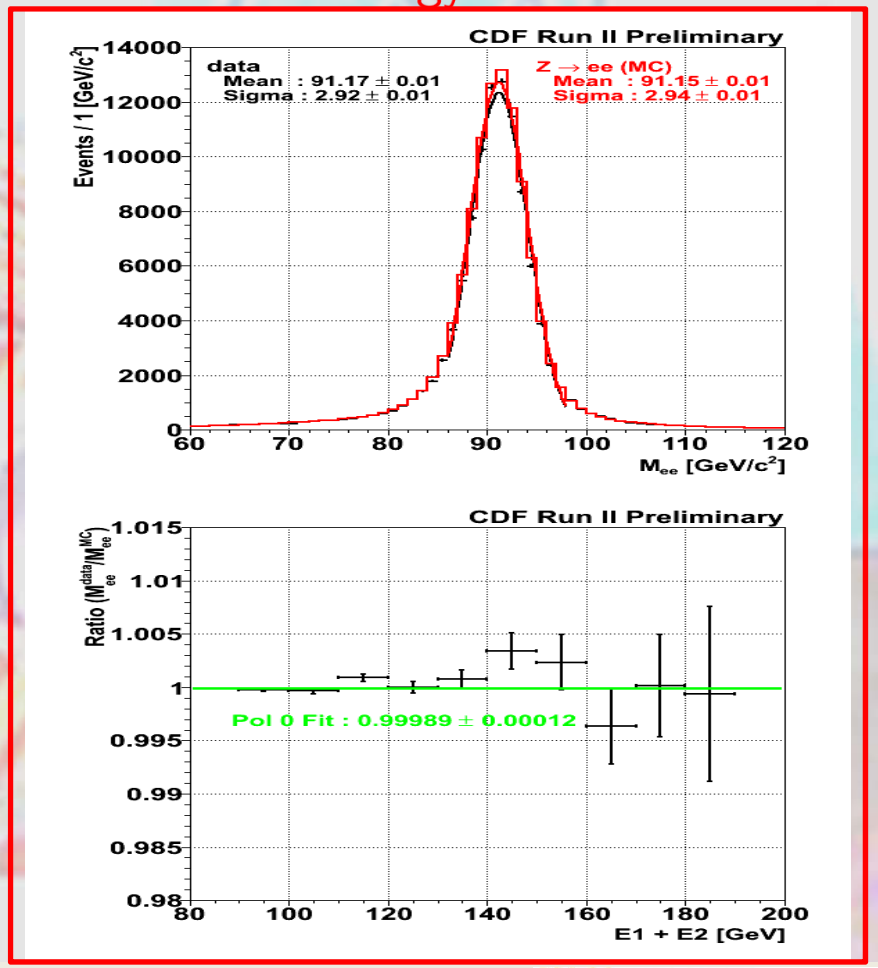
$\not\!\!E_T$ Selection	
$\not\!\!E_T$	> 25 GeV
Jet Selection for $\not\!\!E_T$ Correction	
Corr. Level	5
E_T	> 20 GeV
$\lvert\eta_{Det}\rvert$	2.4
ΔR_{ej}	$(\equiv \sqrt{\Delta\phi_{ej}^2 + \Delta\eta_{ej}^2}) > 0.4$

Electron Energy Correction

- **Using invariant mass of Z to ee sample**
  - before energy correction



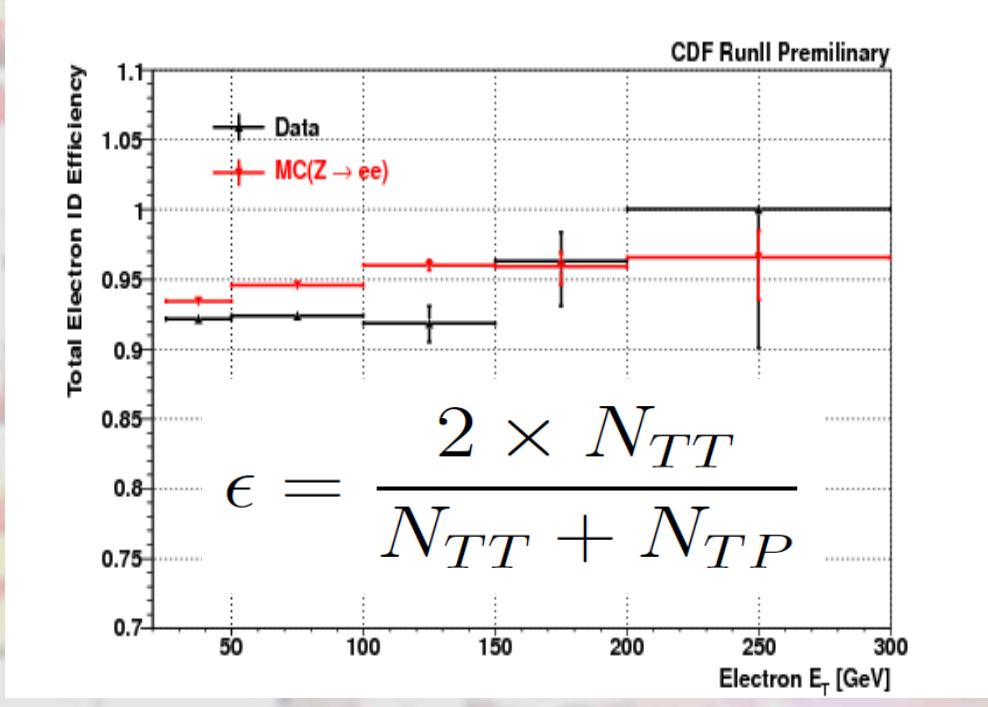
  - after energy correction



Electron Id. Efficiency

- Z →ee Sample used
  - N_{TT} : both electrons passing Tight Cut.
  - N_{TP} : one passing Tight, the other passing Loose Cut
    - Total Efficiency

E_T	$> 25\,\text{GeV}$ $(15\,\text{GeV})$
Track Z_0	$< 6\,\text{cm}$
Track p_T	$> 15\,\text{GeV/c}$
E_{HAD}/E_{EM}	$< 0.055 + 0.00045 \times E$
Isolation E_T	$< 3 + 0.02 \times E_T$
Lshr	< 0.2
E/p	$< 2.5 + 0.015 \times E_T$ for $E_T < 100\,\text{GeV}$ Track $p_T > 25\,\text{GeV/c}$ for $E_T > 100\,\text{GeV}$
CES ΔX	$< 5.0\,\text{cm}$
CES ΔZ	$< 3.0\,\text{cm}$
Fiducial	$== 1$
Conversion	$\neq 1$



Background Estimation

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

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

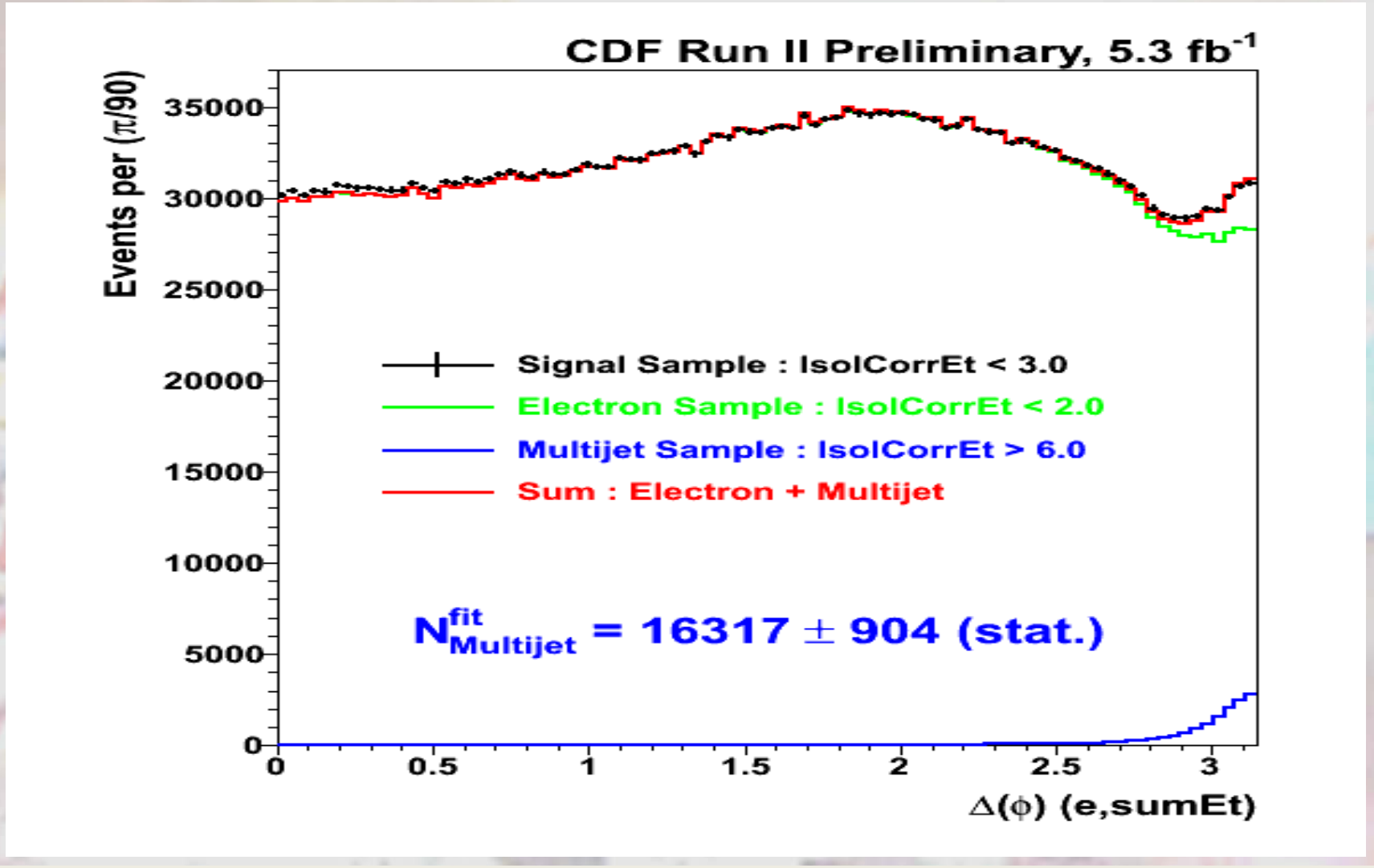
Background	$\epsilon \cdot A$	$\sigma \cdot \mathcal{B}$	$N_{expected}$
$W \to e\nu$	1.96×10^{-1}	2687 ± 54 (NNLO) [15]	2794310
$W \to \tau\nu$	4.13×10^{-3}	2687 ± 54 (NNLO) [15]	58962
$Z/\gamma \to ee$	1.29×10^{-2}	251.3 ± 5 (NNLO) [15]	17190
$Z/\gamma \to \tau\tau$	2.66×10^{-3}	251.3 ± 5 (NNLO) [15]	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

Multijet Background Estimation

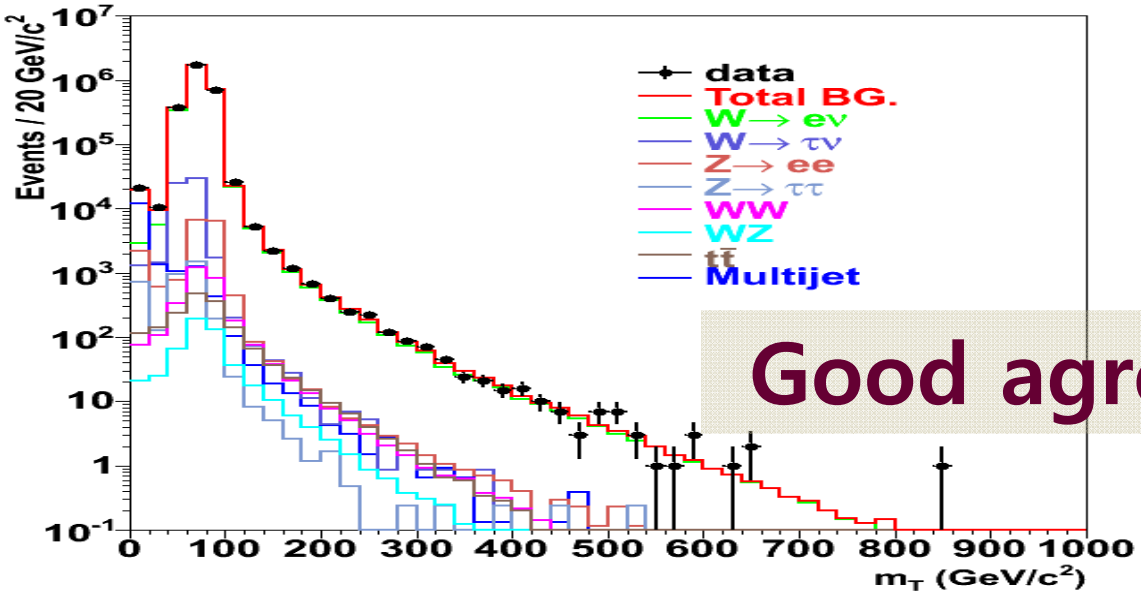
Data-driven method adopted

- Multijet events dominate dijet
  - One jet : mis-id. as electron
  - The other jet : mis-measured and produce MET
- Opening Angle between electron and sumET to be back-to-back
  - Multijet event : to be ~ pi/2
  - Real W event : no correlation in opening angle
- To estimate the Number of Mulijet event
  - Non isolation event (Multijet) + Tight isolation event (Real W)
  - Likelihood Fitting used

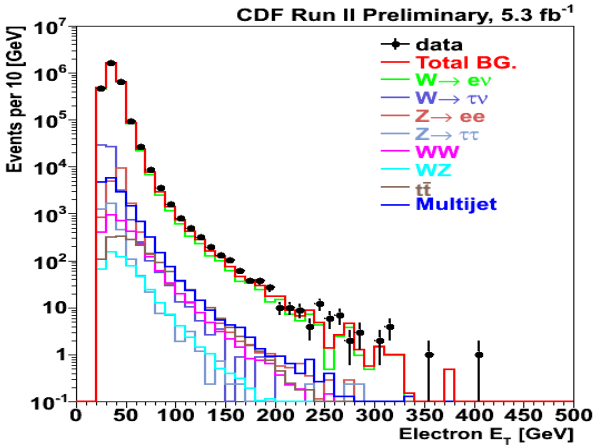
Multijet Background Estimation

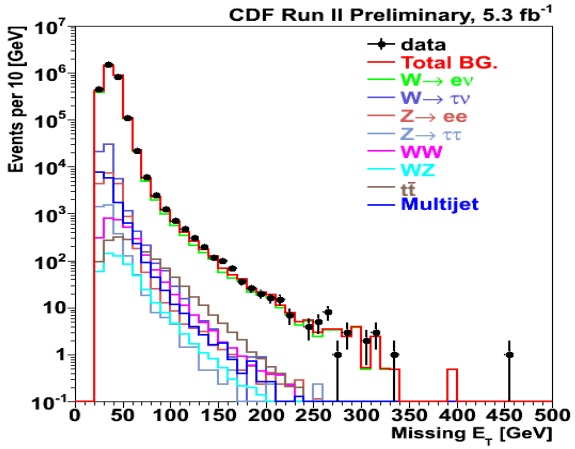


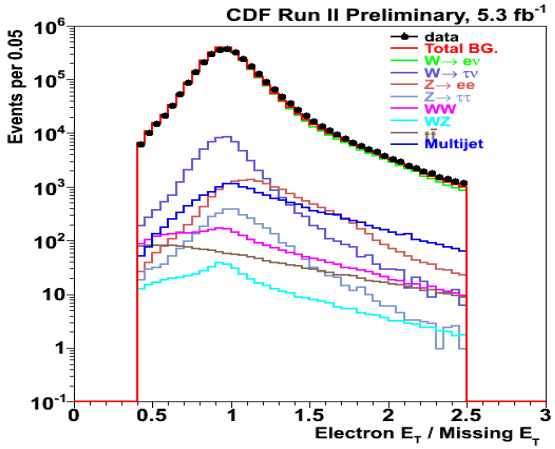
Background and Data Comparisons



Good agreement!!







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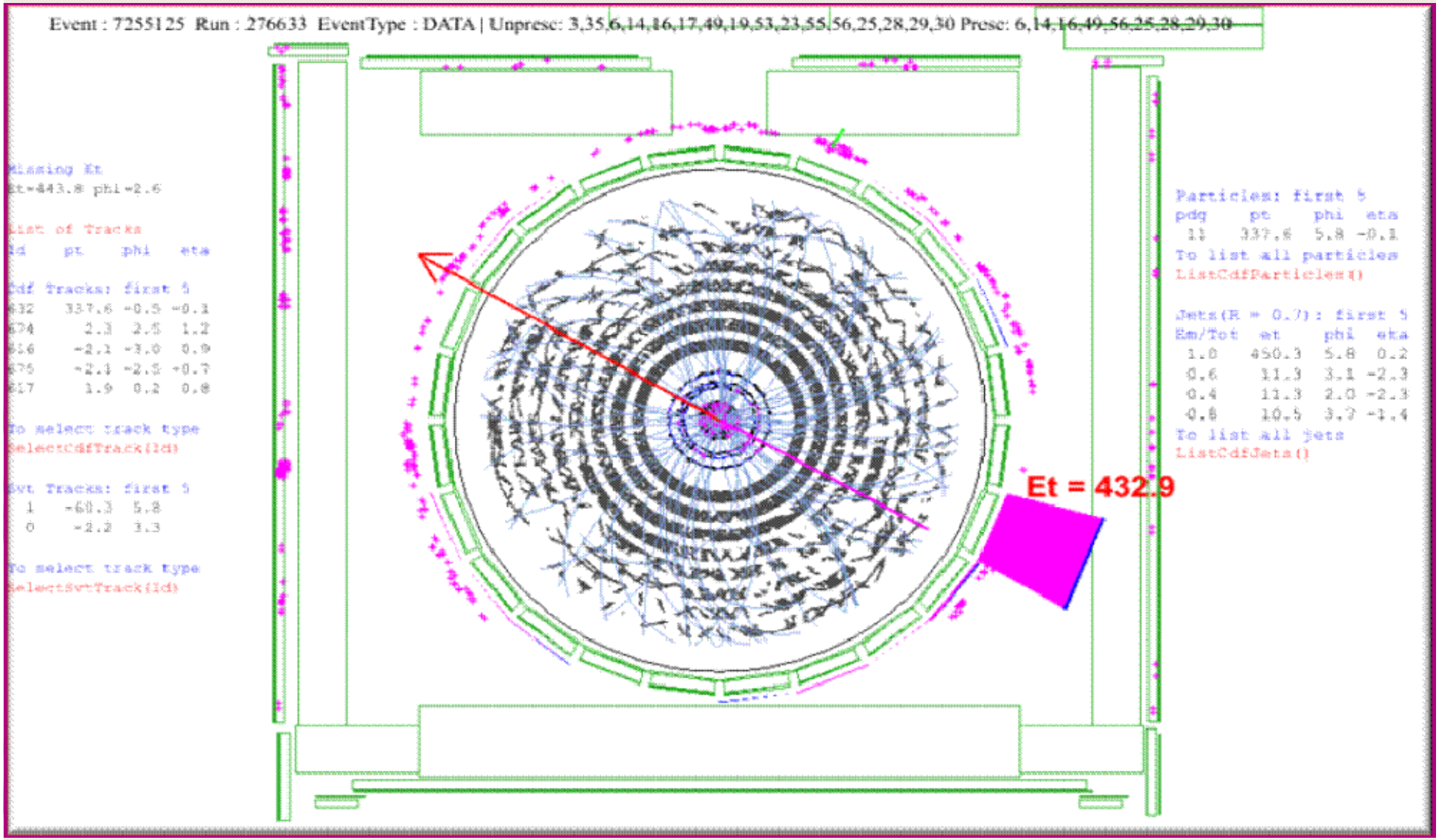
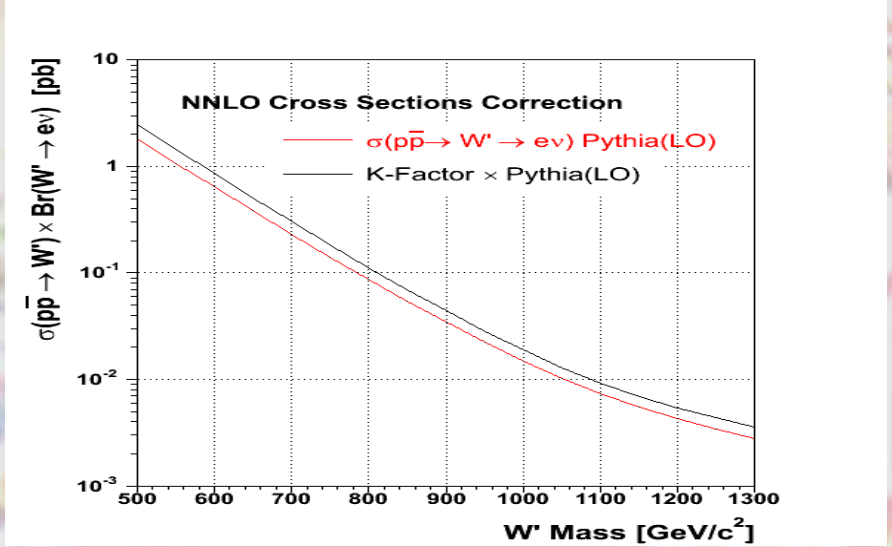
The Highest m_T Event Display

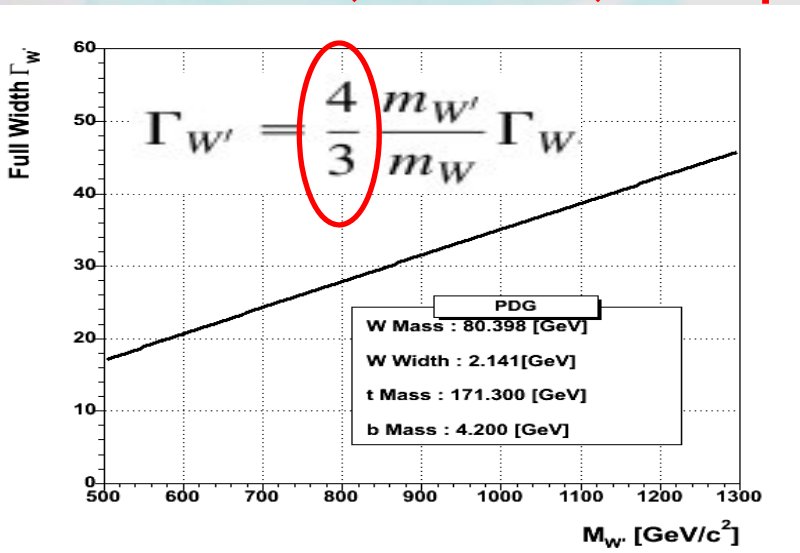


W' Signal : cross-section and width

- W' mass = [500,1300] GeV/c², ~50k events for each mass points
  - ✓ PYTHIA with CTEQ5L PDFs
- Cross-section and width

- W' → tb
- Br(ele.+neu.) : ~ 8.4 %





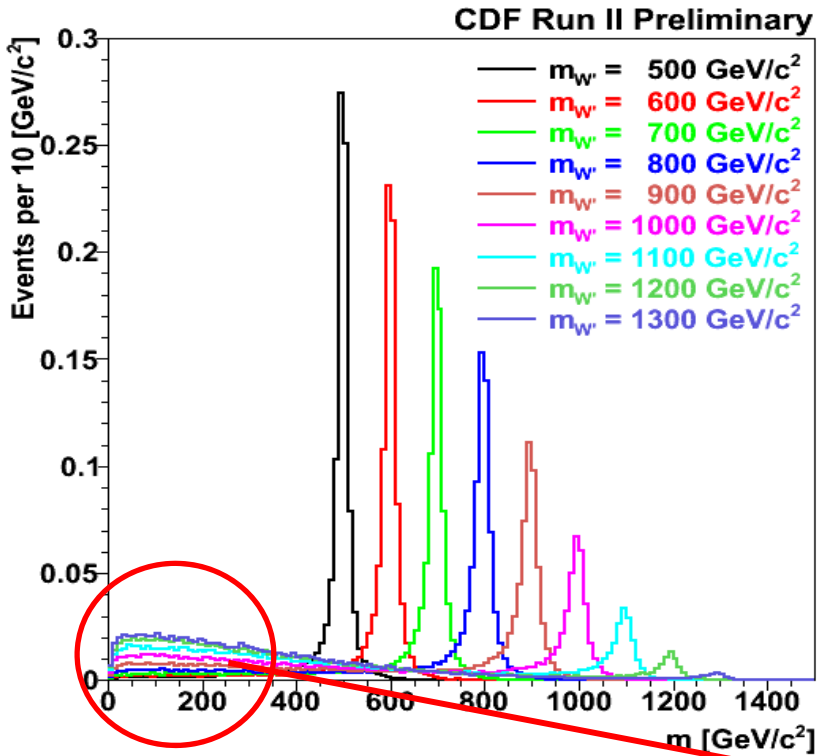
- $K_{NNLO} = \frac{\sigma\ (\text{NNLO with CTEQ6.1M PDFs})}{\sigma\ (\text{LO with CTEQ5L PDFs})}$

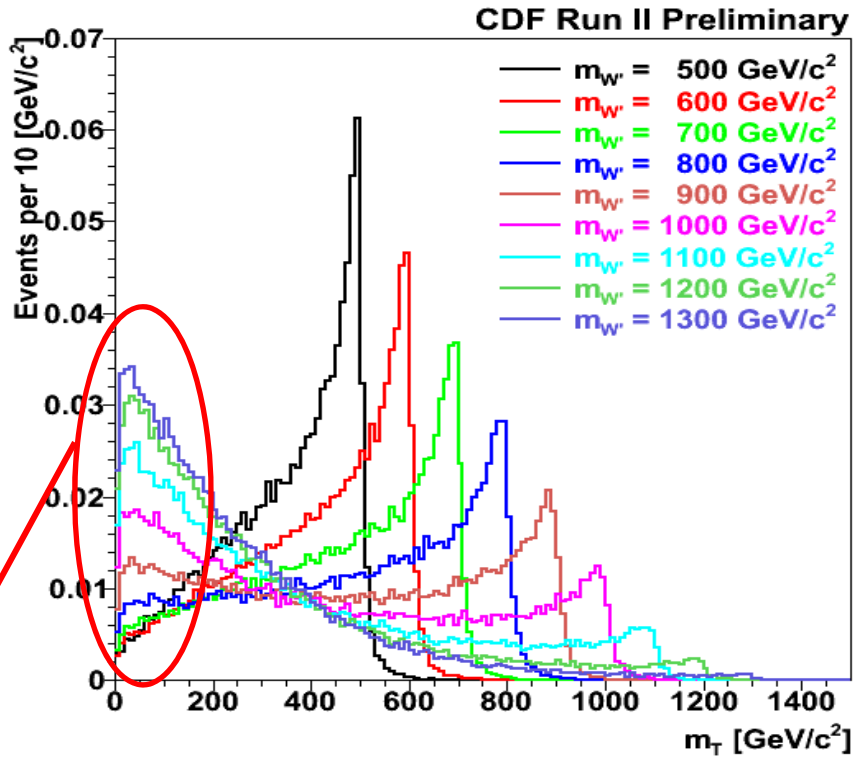
→ calculated using Van Neerver code(2002).

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

W' : generated mass distribution

- Before event selection (from PYTHIA generated information)

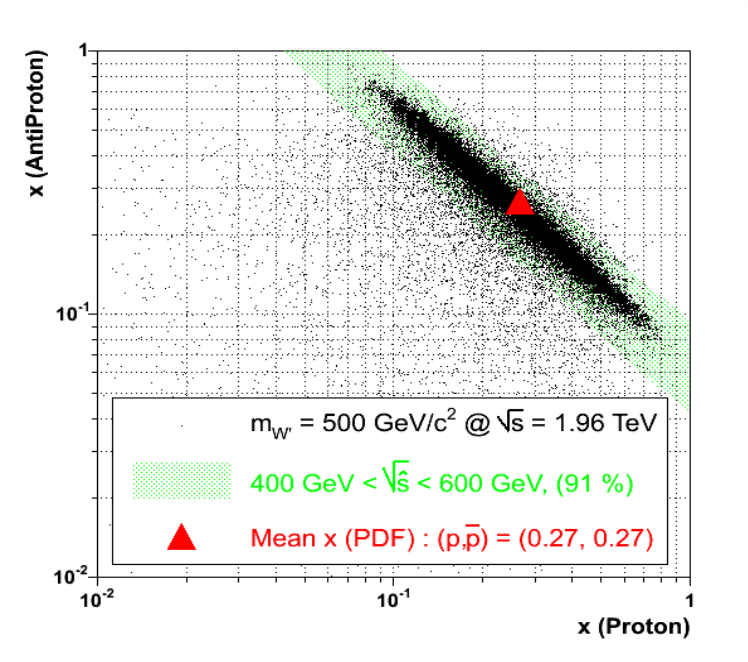


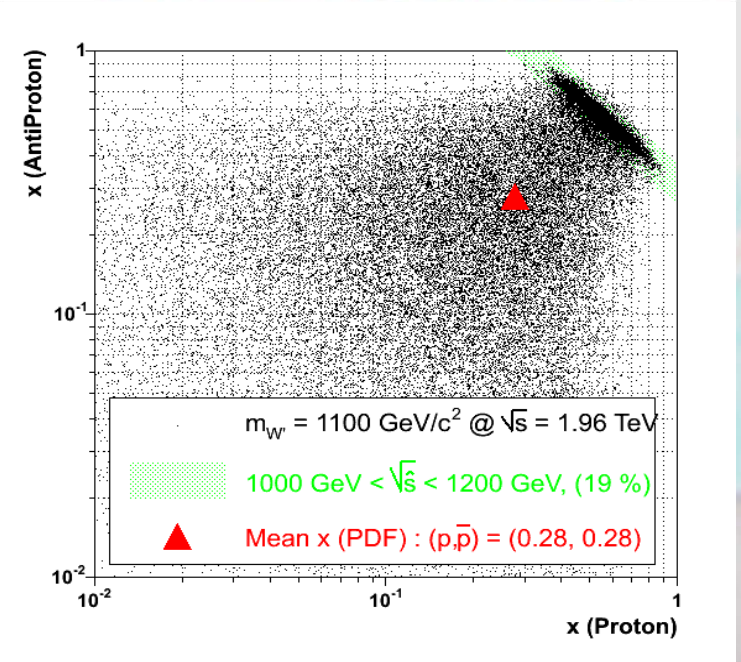


Tails : very heavy W' made large of tail in low mass region

W' : PDF Influence (low tails)

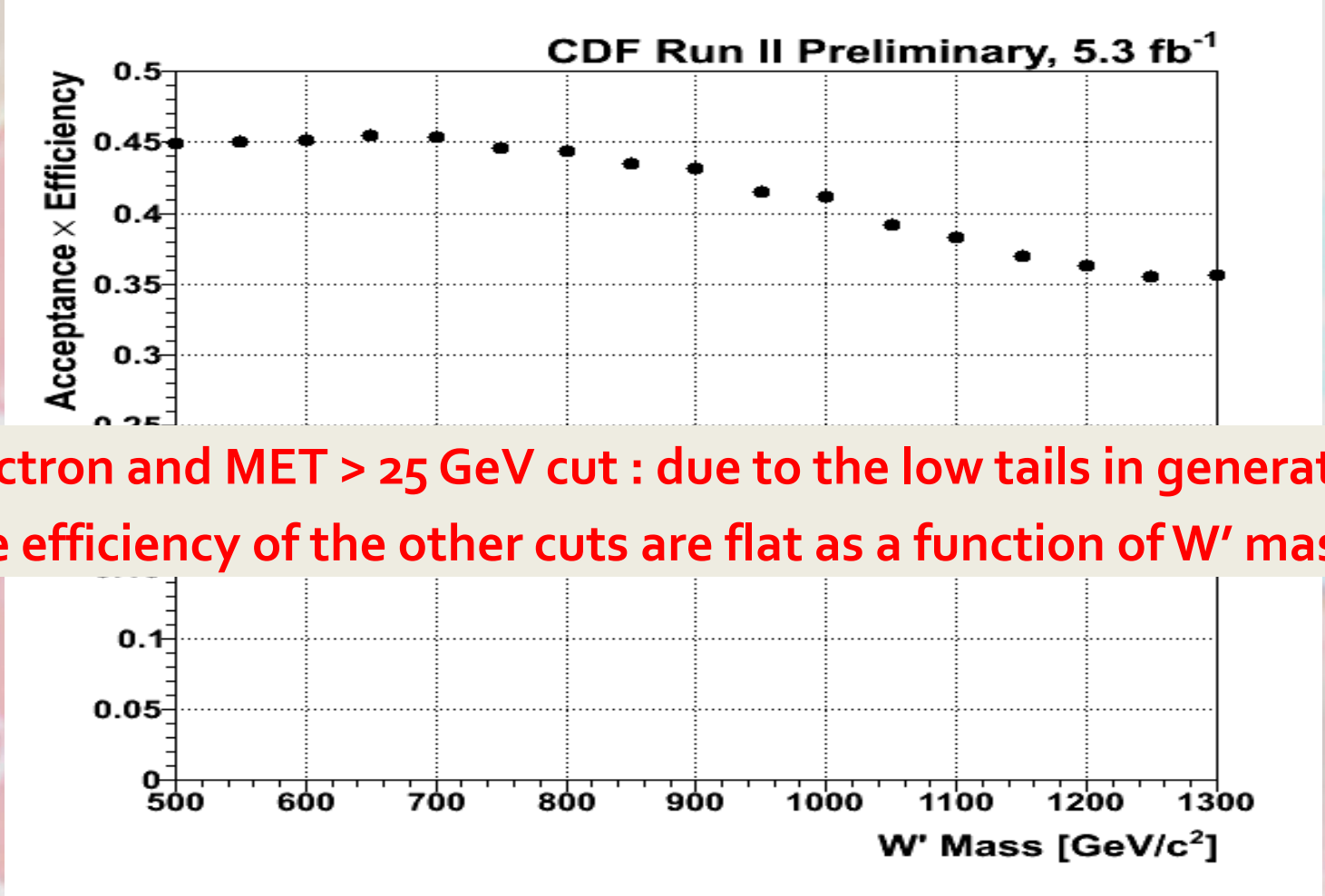
- on-shell-mass production : $\underset{(\sqrt{s})}{p\bar{p}} \xrightarrow[x(\approx x_p \approx x_{\bar{p}})]{PDF} \underset{(\sqrt{\hat{s}})}{q\bar{q}} \rightarrow W' \rightarrow e\nu$
- requried momentum fraction $x = \frac{\sqrt{\hat{s}}}{\sqrt{s}} \approx 0.26, ..., 0.56$ (for $m = 500, \ ... \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





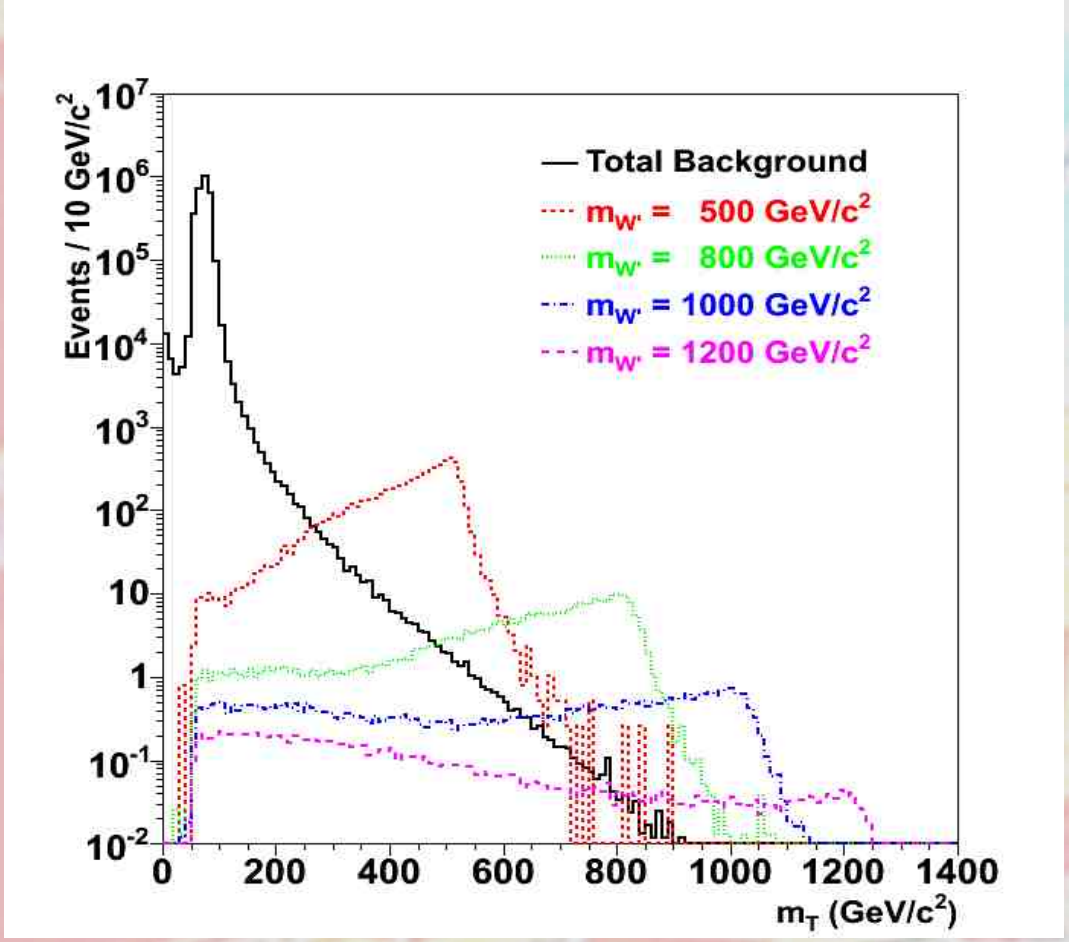
✓ PDF heavily suppress high mass production region due to limitation of parton energy carried by quarks in Tevatron energy and this is also reported by D0 [PRL100, 031804]

W' : MC Acceptance X Efficiency



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

W' signal and background



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

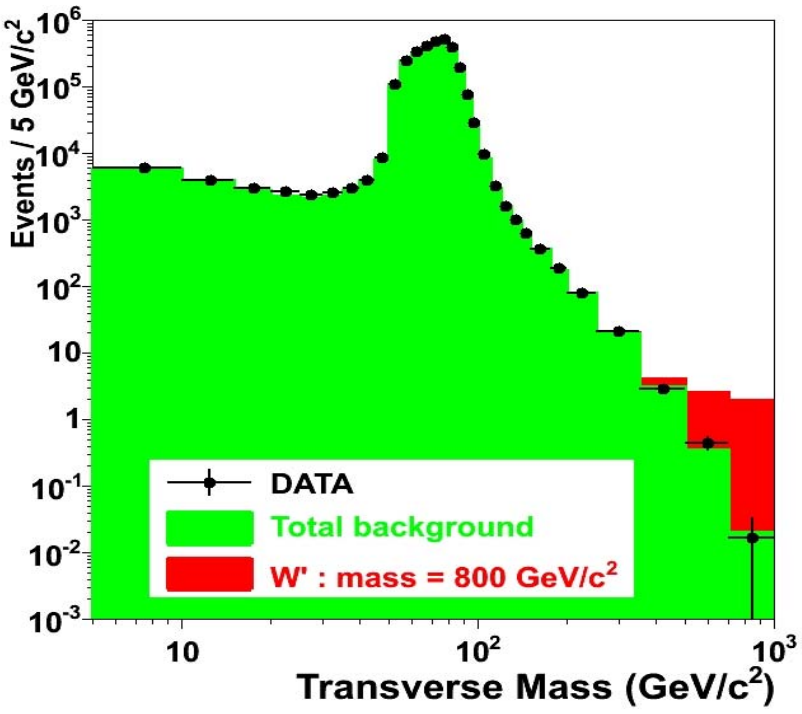
  - **Use Poisson probability with a Gaussian constraining on multijet bg**

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

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

- n_0^j is number of observing events

Mt Fitting Result



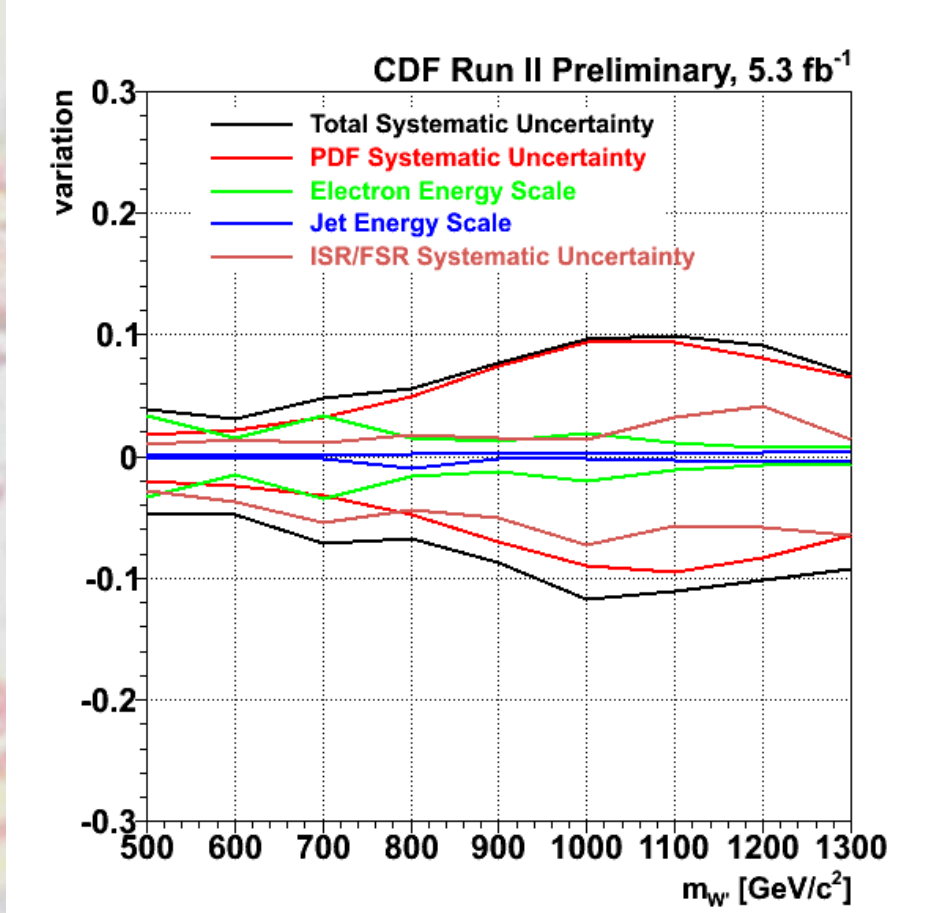
	Events in m_T bins (GeV/c^2)				
	200 - 250	250 - 350	350 - 500	500 - 700	700 - 1000
$W \to e\nu$	711^{+50}_{-50}	359^{+25}_{-25}	85^{+6}_{-6}	13^{+1}_{-1}	$1.1^{+0.1}_{-0.1}$
Multijet	9^{+2}_{-2}	6^{+1}_{-1}	2^{+2}_{-2}	$0.2^{+1.6}_{-0.2}$	$0.01^{+1.10}_{-0.01}$
Other background	70^{+9}_{-6}	33^{+4}_{-3}	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 expectation
  - ✓ No statistically significant excess observed for W' and we set the mass limit for W'

Systematic Uncertainties

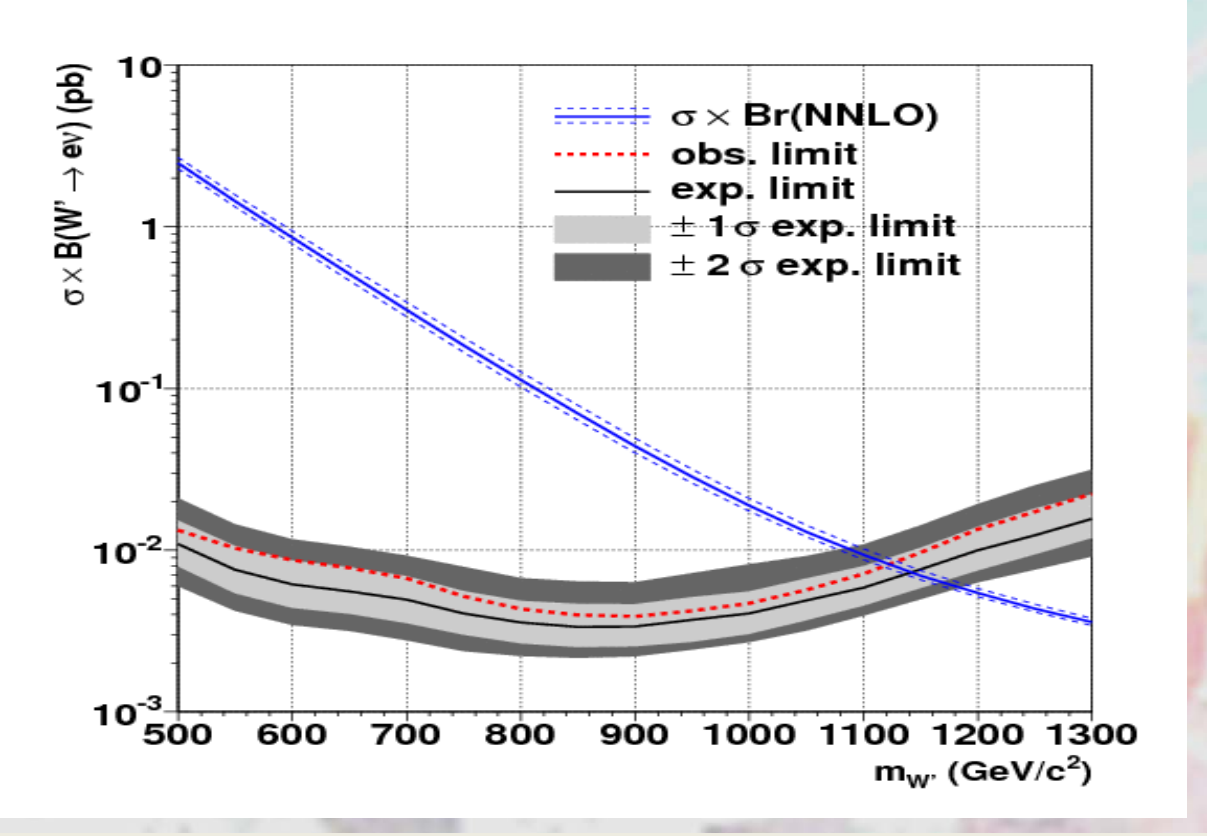
- **PDF :**
  - ✓ weighting method
- **ISR/FSR :**
  - ✓ changing PYTHIA parameters
- **Electron Energy Correction :**
  - ✓ 1% asigned
- **Jet Energy Correction :**
  - ✓ MET is re-corrected with JES $\pm\sigma$
- **Multijet background :**
  - ✓ calculated with variable electron and qcd samples
- **Cross section :**
  - ✓ weighting method

- **Total Uncertainties**

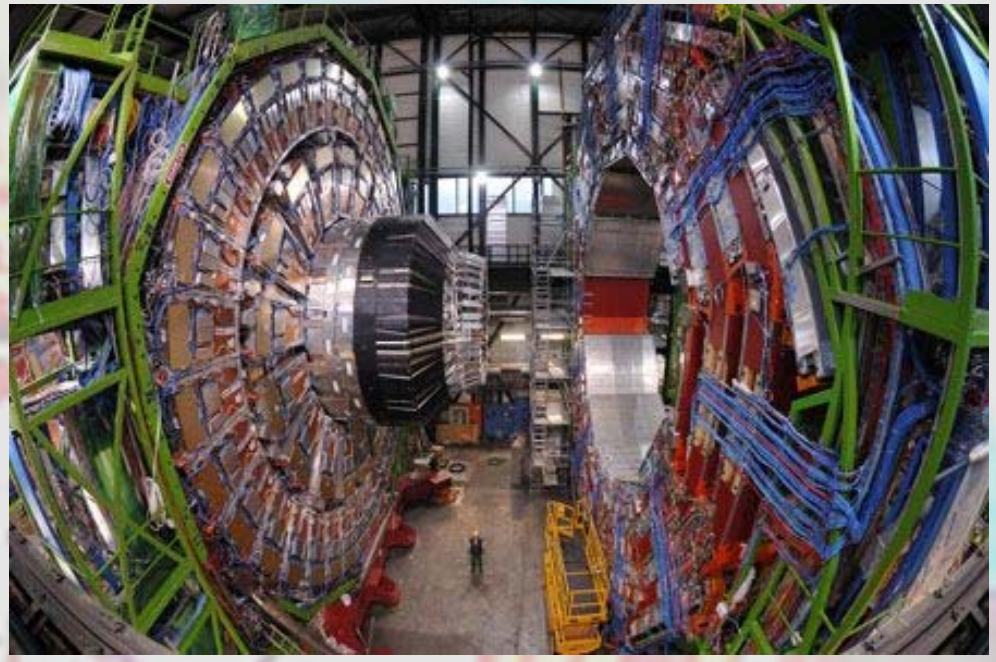


CDF W' → electron + MET : Limits

- Bayesian 95% CL limit calculated
- both the shape and rate systematic uncertainties are incorporated
- 1000 times pseudo experiment is performed for Expected Limits.
  - ✓ Used random generated events from the background expectation.



CMS W' Search



p-p Collision at 7 TeV with 36 pb^{-1} data

(based on : PLB 698, 21 and arXiv:1012.5945)

Event Selection

- **Preselection**
  - ✓ Good primary vertex
  - ✓ At least 1 electron with E_T > 25 GeV and H/E < 0.1
- **Used MET from particle flow algorithm**
- **Single electron trigger path**
- **1 good high p_T electron (HEEP)**
- **Requirement :**

$$\Delta\phi(ele, met) > 2.5,$$

$$0.4 < E_T^{ele} / MET < 1.5$$

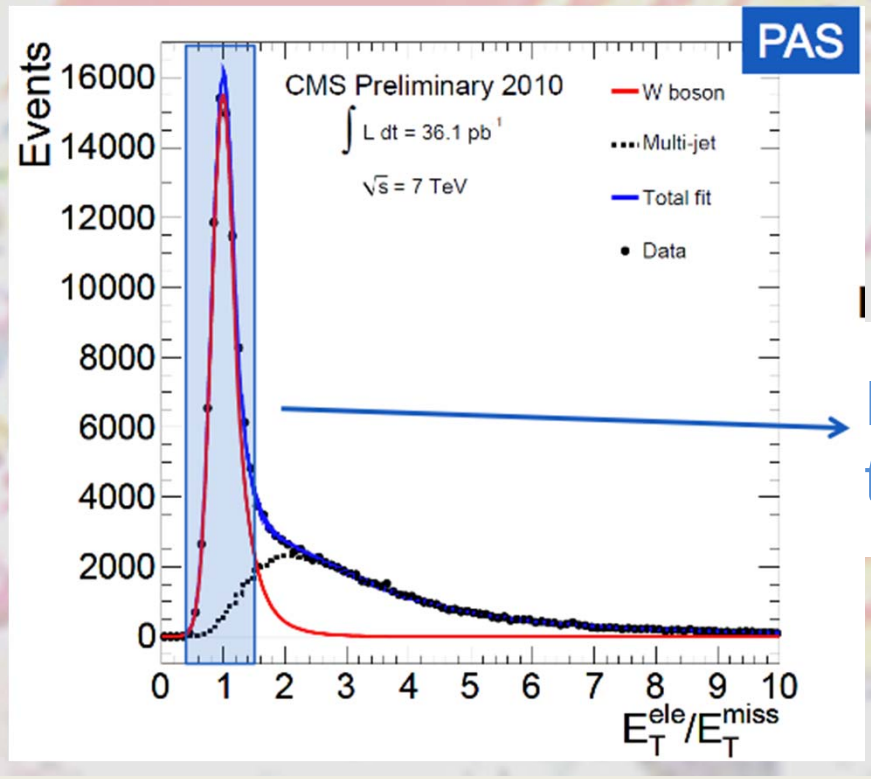
Background Estimation

- **Need to determine both the shape and normalization of the transverse mass.**
  - ✓ **W → ele + neu. : Shape from MC, yield from data-driven (fit of E_T/MET method)**
  - ✓ **QCD multijet : Data-Driven Method**
  - ✓ **The other backgrounds from MC**

background	shape	normalization
W → e + nu	MC	Fit of E_T/MET
multijet	Non-isolated electron from Data	Fit of E_T/MET
Other backgrounds	MC	MC

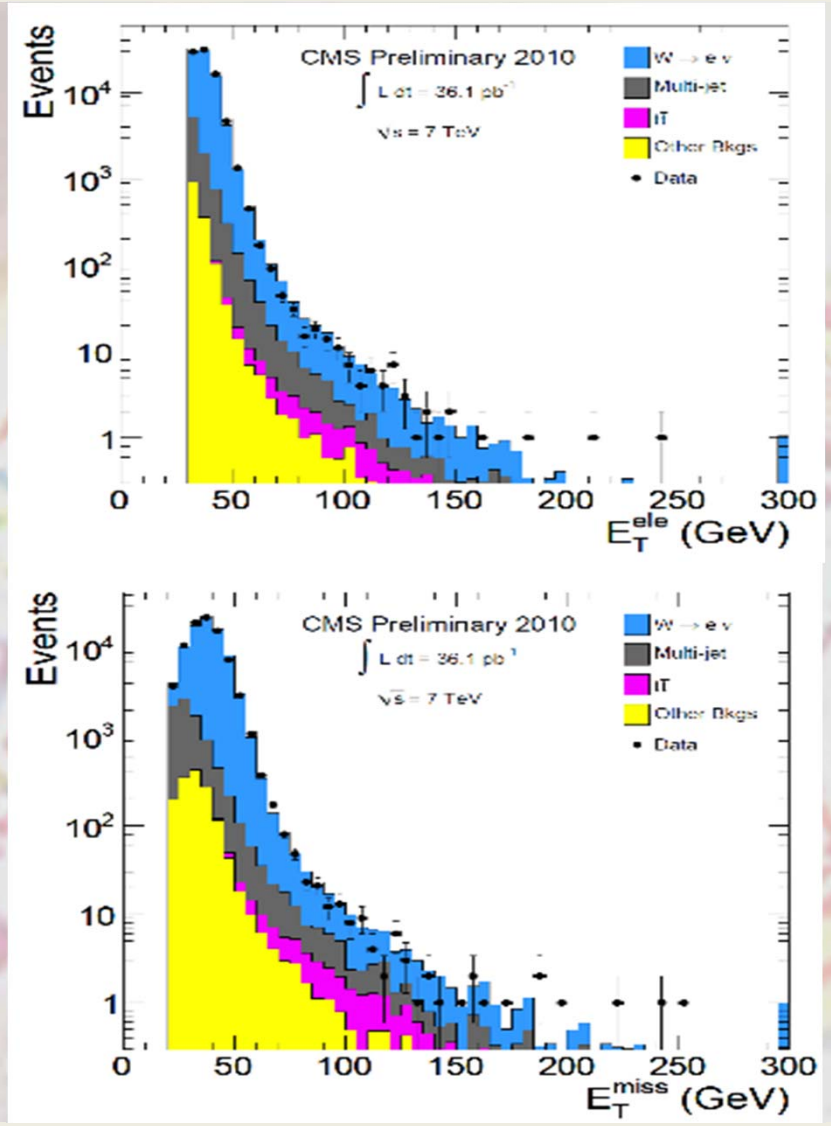
W and QCD Background (Fit of E_T/MET)

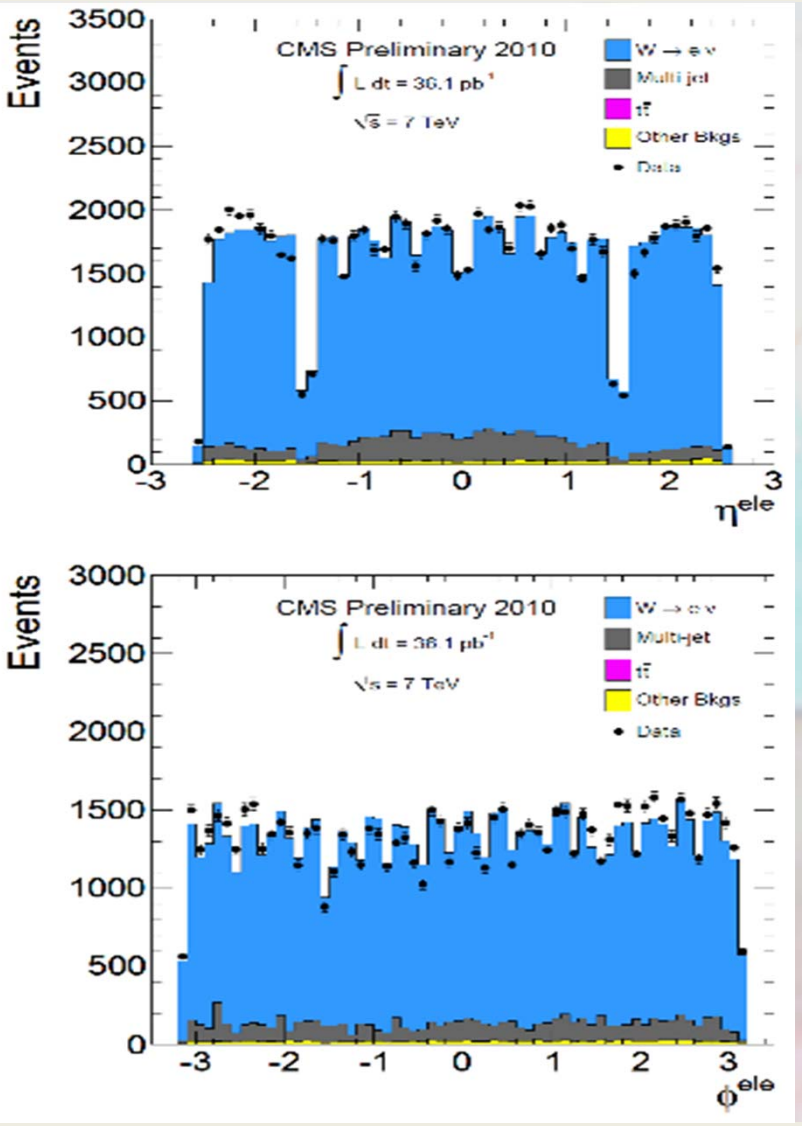
- In two body decay, the energy of the neutrino and electron are expected to be mostly balanced in the transverse plane, and then the ratio of E_T is around 1



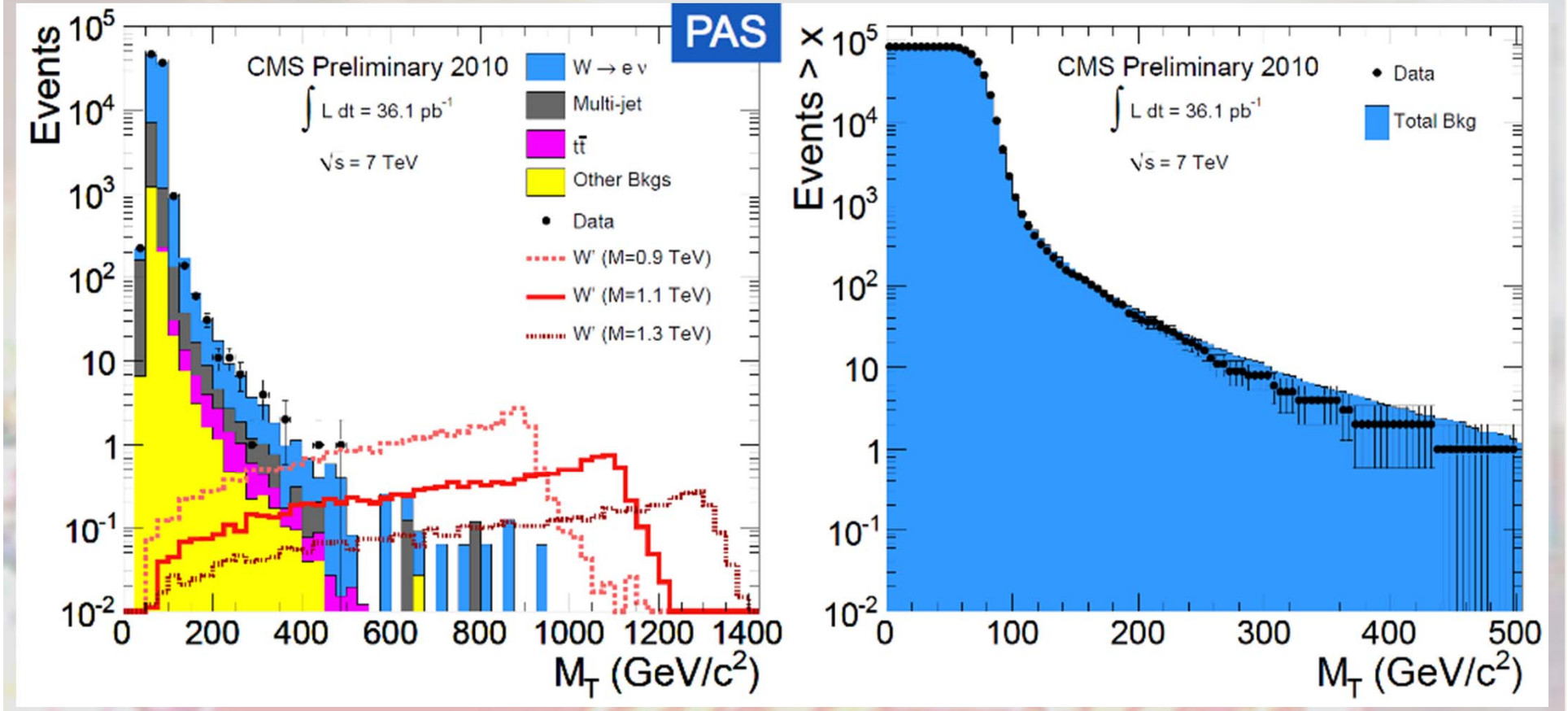
MT distributions normalized to the region $0.4 < E_T/MET < 1.5$

Background and Data Comparisons





Transverse Mass distributions



Good agreement in both background prediction and observed data in the M_T distribution(left) and the cumulative distribution(right)

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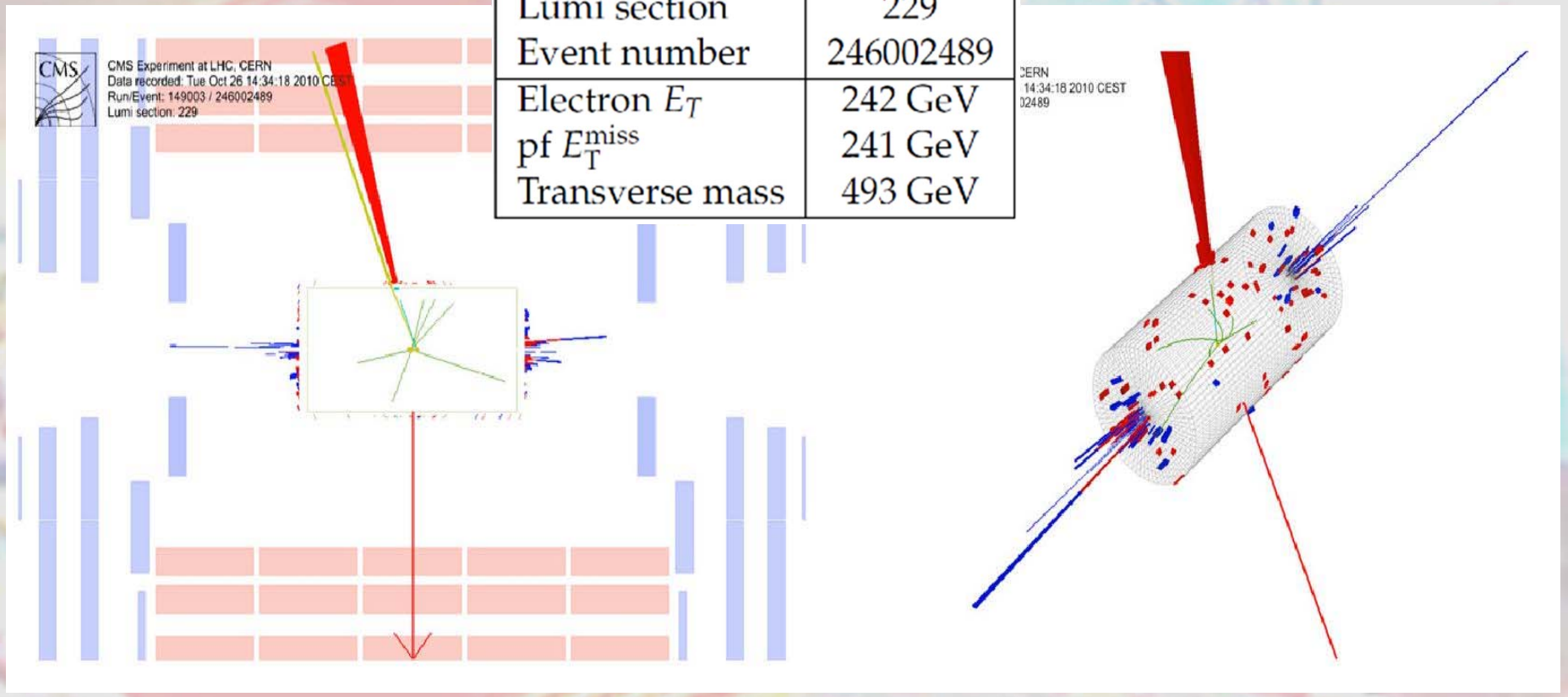
The highest M_T Event Display

Variable	Value
Run	149003
Lumi section	229
Event number	246002489
Electron E_T	242 GeV
pf E_T^{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%

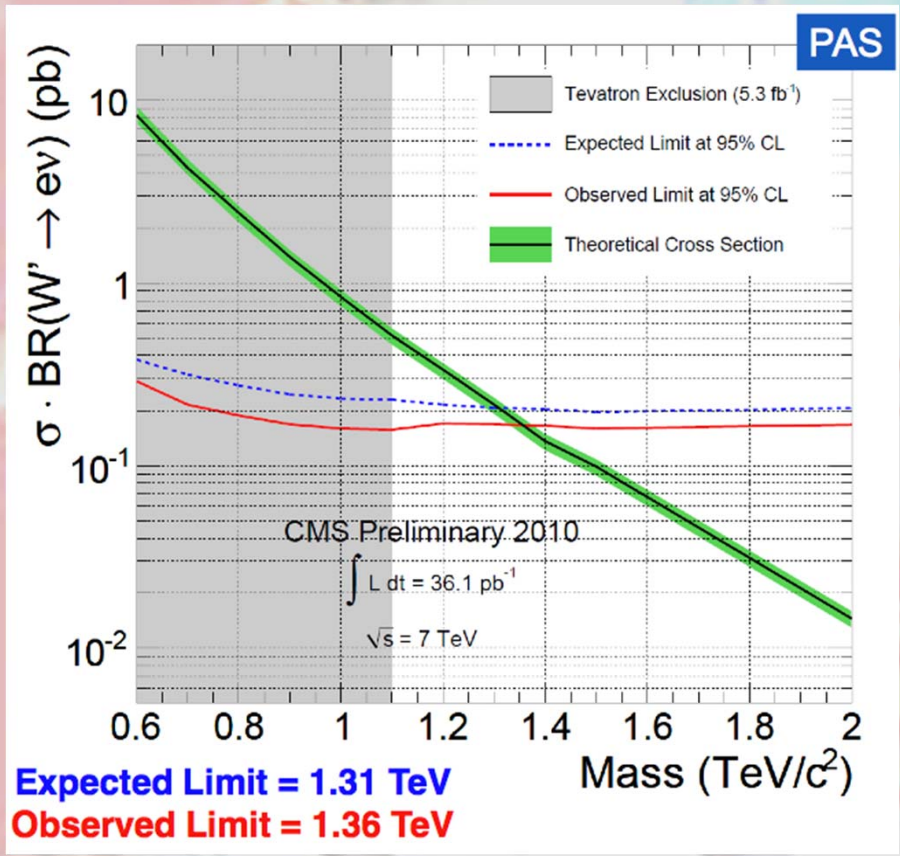
Number of Event

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

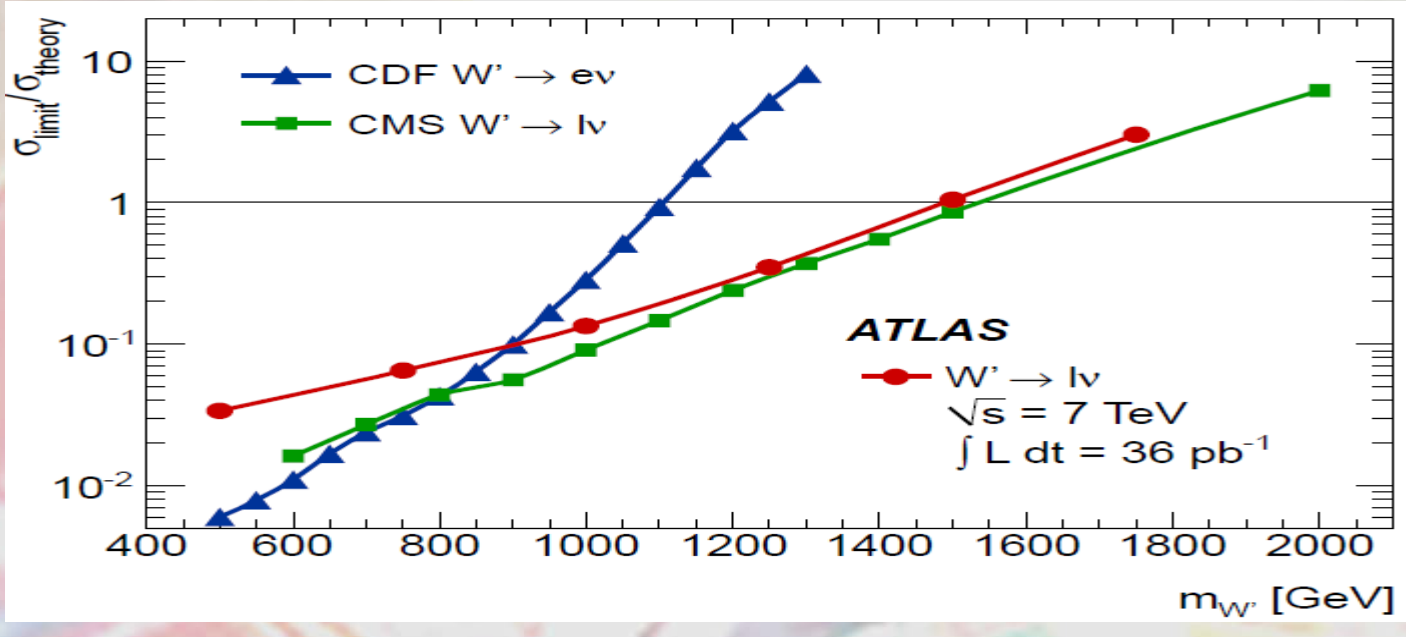
* Other background : gamma+Jet , W→μν, Drell-Yan,WW,WZ,ZZ, single top
* Table includes both statistical and systematic uncertainties added in quadrature (does not include lumi uncertainty)

CMS W' → ele+MET : Limits

- Bayesian 95% CL limit calculator.
- Cut-and-Count Method, cut point (> 0.5 TeV)from the best expected limit.



W' Limits (2010)



- ✓ $m_{W'} > 1.12\ TeV/c^2$ (5.3 fb^{-1}@CDF; W' → electron + neutrino) [PRD.83.031102]
- ✓ $m_{W'} > 1.49\ TeV/c^2$ (36 pb^{-1}@ATLAS; W' → electron/muon + neutrino) [**arXiv:1103.1391**]
- ✓ $m_{W'} > 1.58\ TeV/c^2$ (36 pb^{-1}@CMS; W' → electron/muon + neutrino) [PLB 698, 21]

CMS (1.1fb^{-1} ;2011) : ele + MET

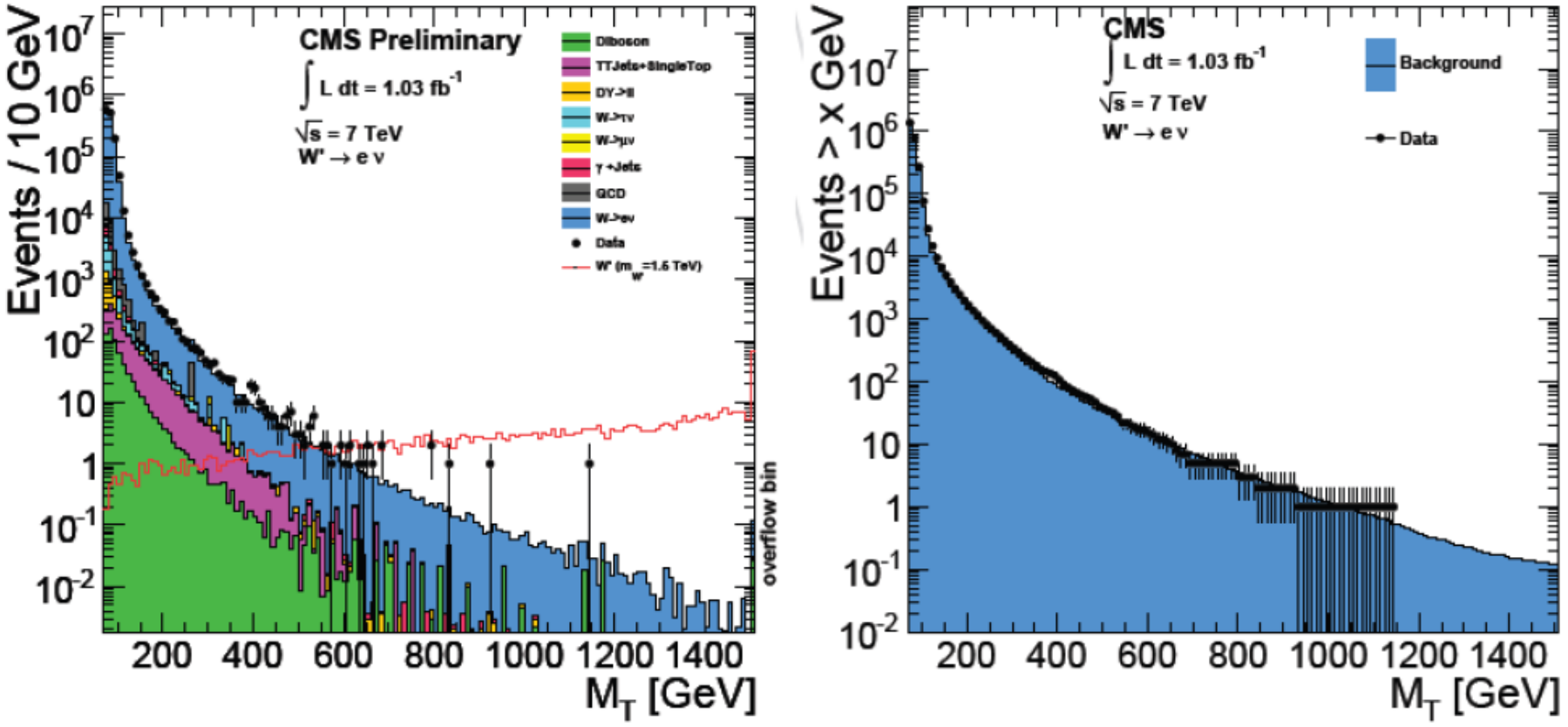


Figure 2: Transverse mass distribution (left) and cumulative distribution (right) for the electron channel.

CMS (1.1fb^{-1} ;2011) : muon + MET

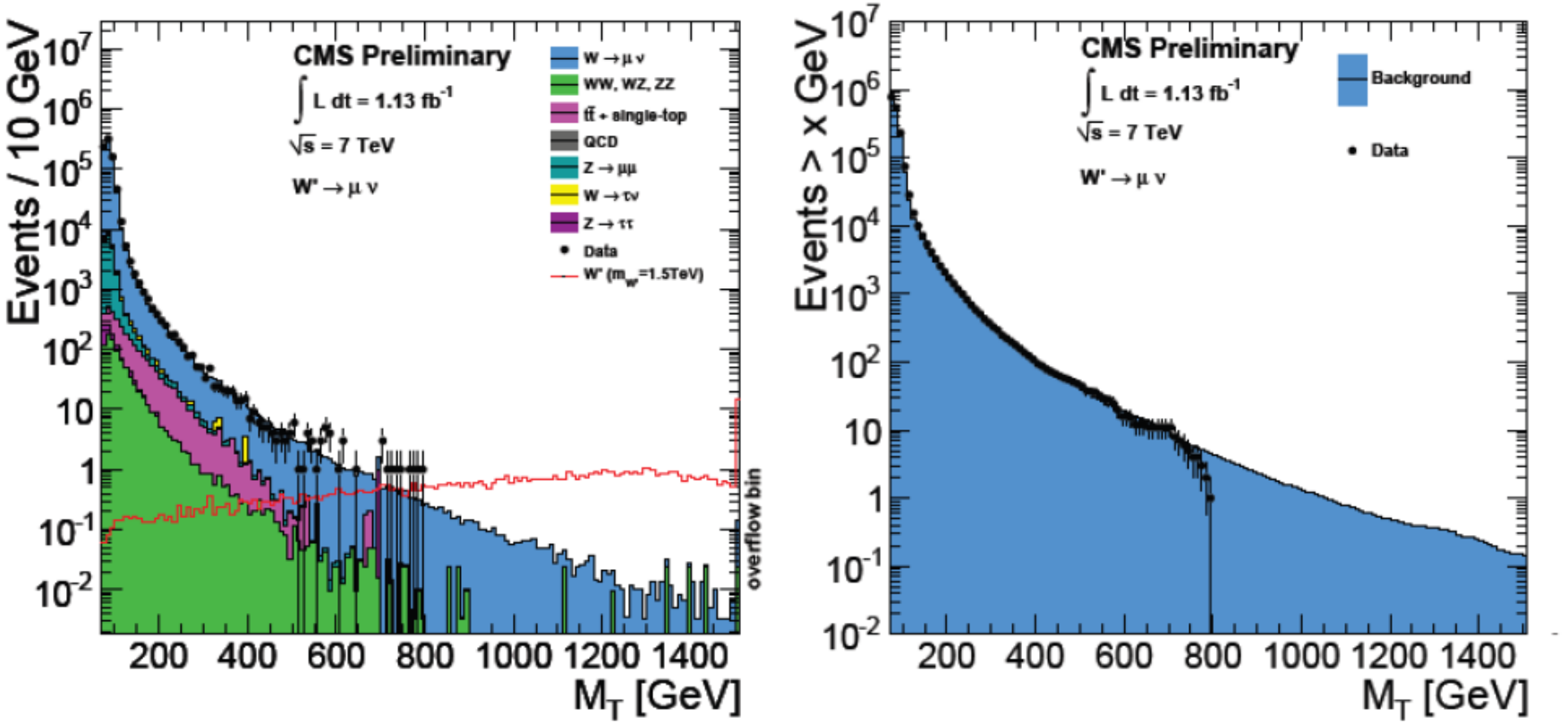
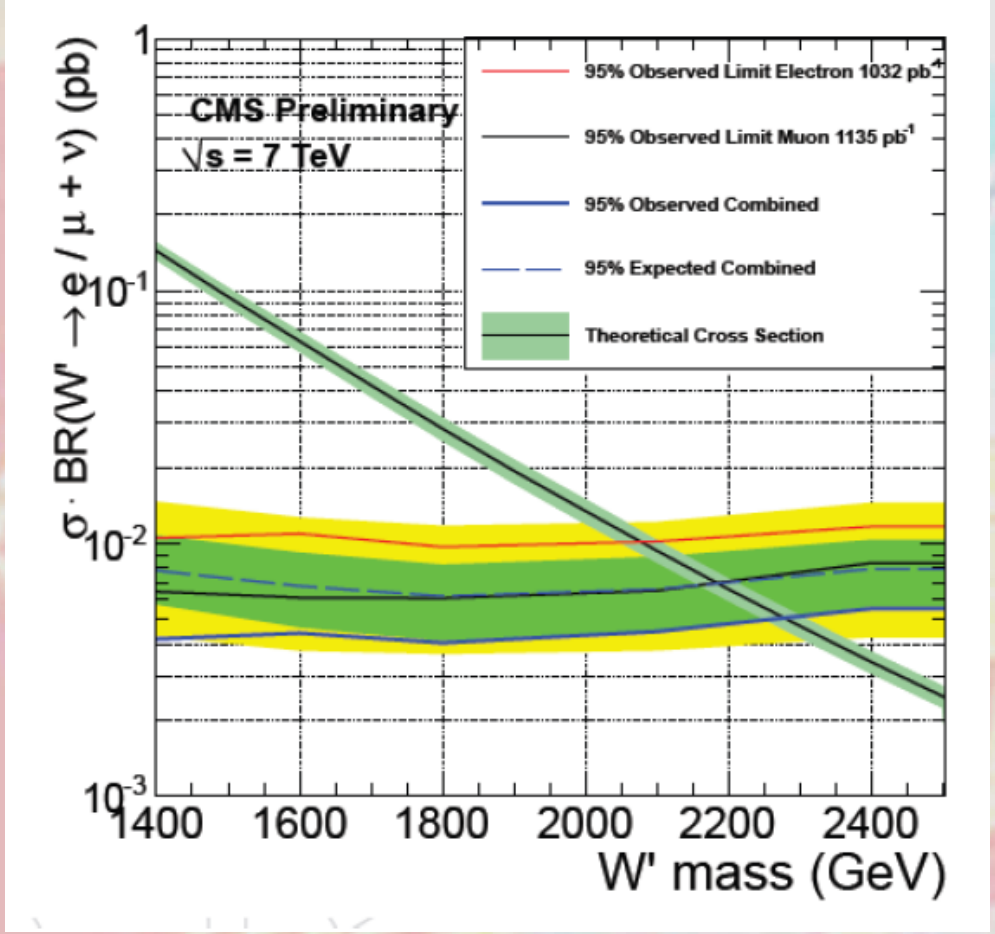


Figure 3: Transverse mass distribution (left) and cumulative distribution (right) for the muon channel.

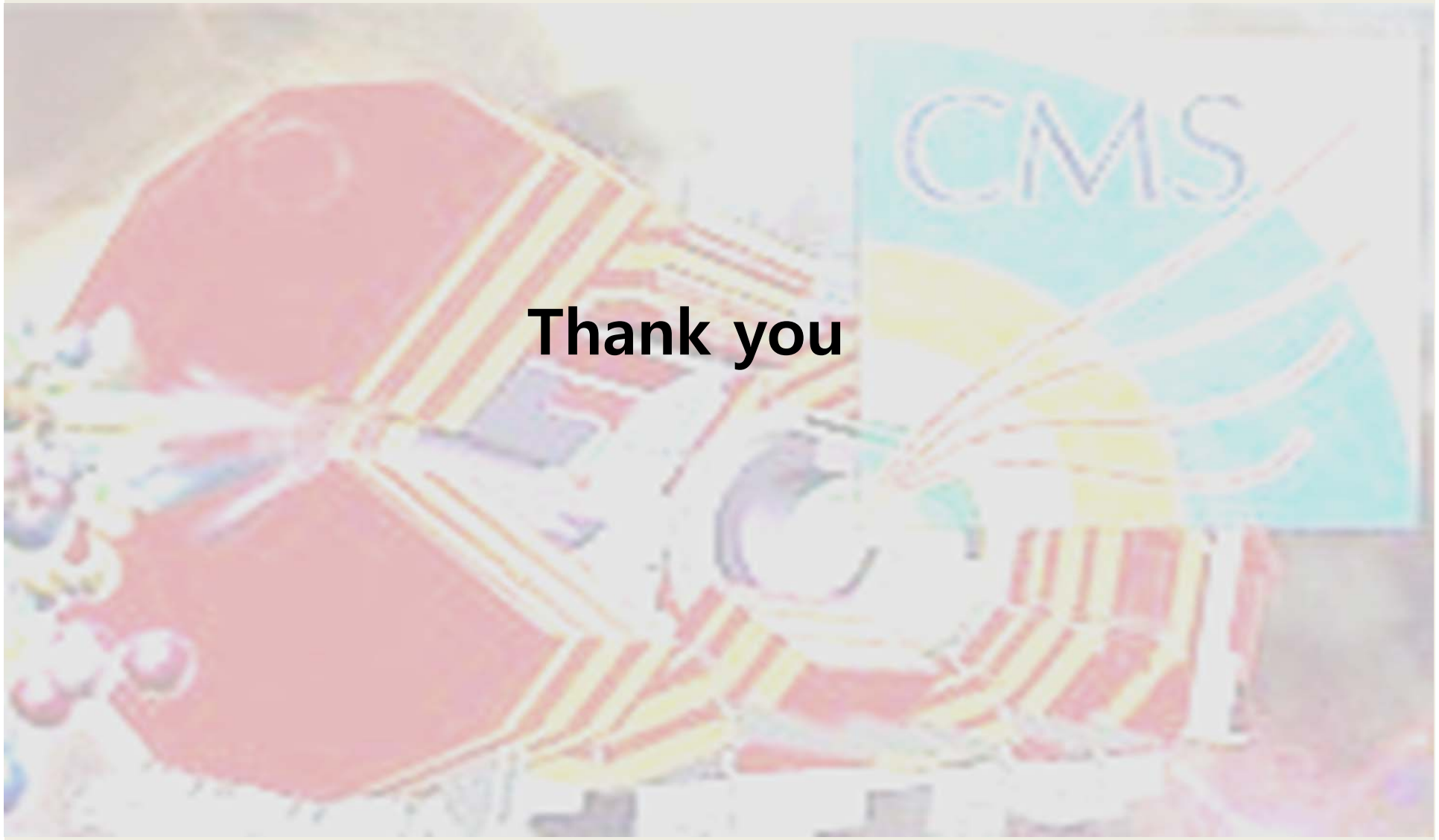
W' Mass Limits : CMS ($1.1fb^{-1}$;EPS2011)



$M_{W'} > 2.27$ TeV

Summary

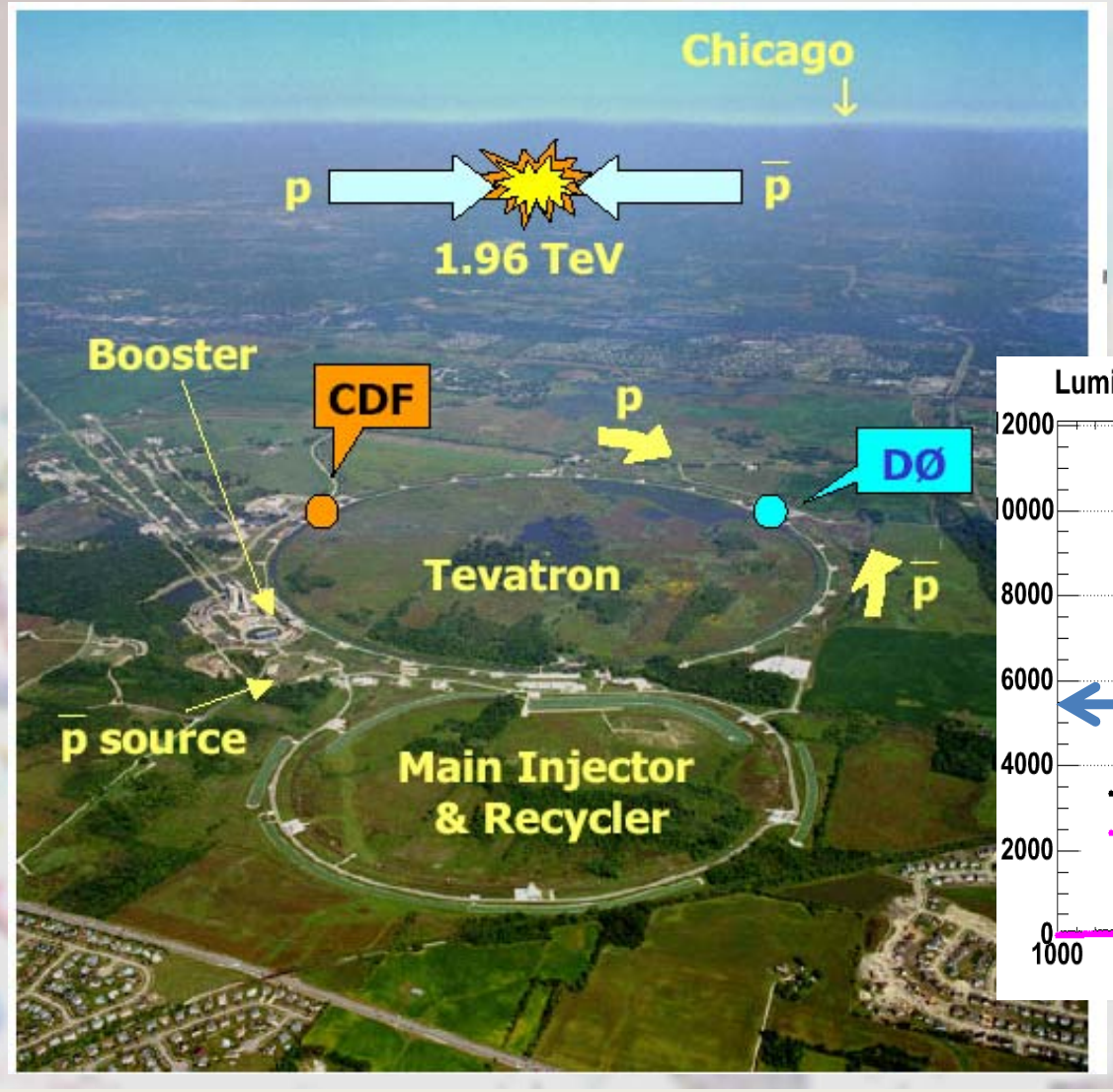
- Search for W' : performed at Tevatron and LHC experiments
- No excess above SM background expectations is observed in collision data distributions
- $M_{W'} > 2.27$ TeV/c^2 for ℓ+MET channel @CMS(1.1fb^{-1})
- Search for W' is ongoing at LHC (CMS and ATLAS)
  - ✓ W' to electron + neutrino
  - ✓ W' to muon + neutrino
  - ✓ W' to top + bottom
  - ✓ W' to WZ



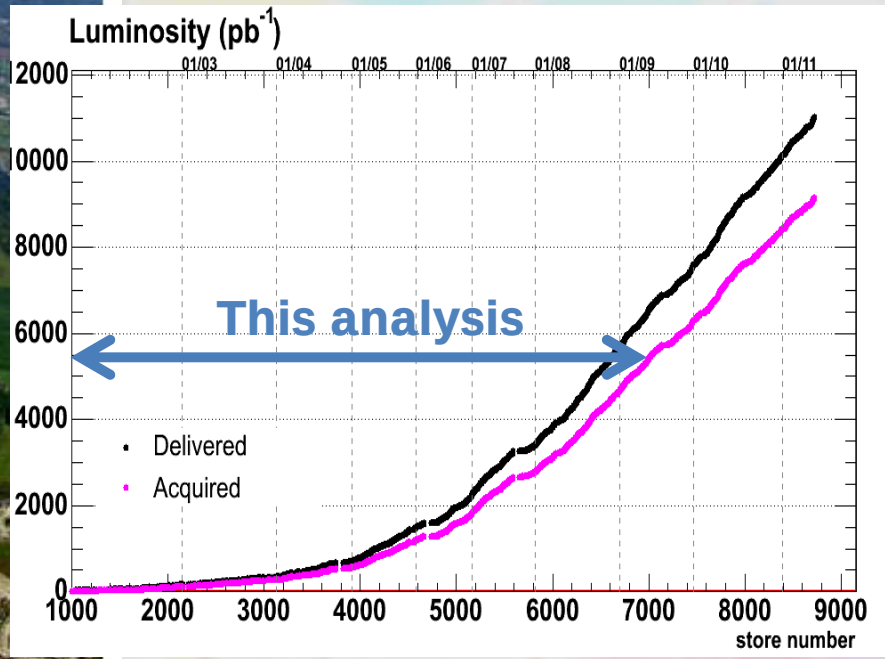
Thank you

backup

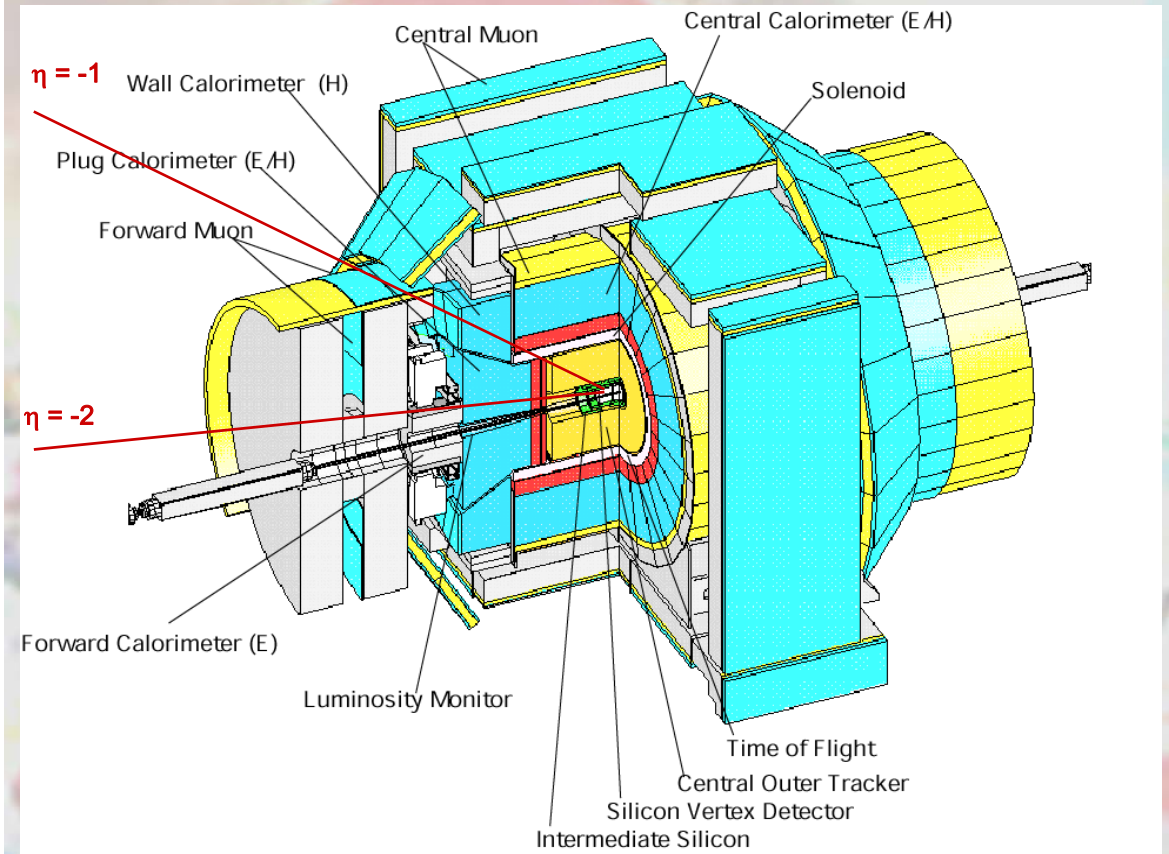
Tevatron



- Proton-antiProton colliding with center of mass 1.96 TeV



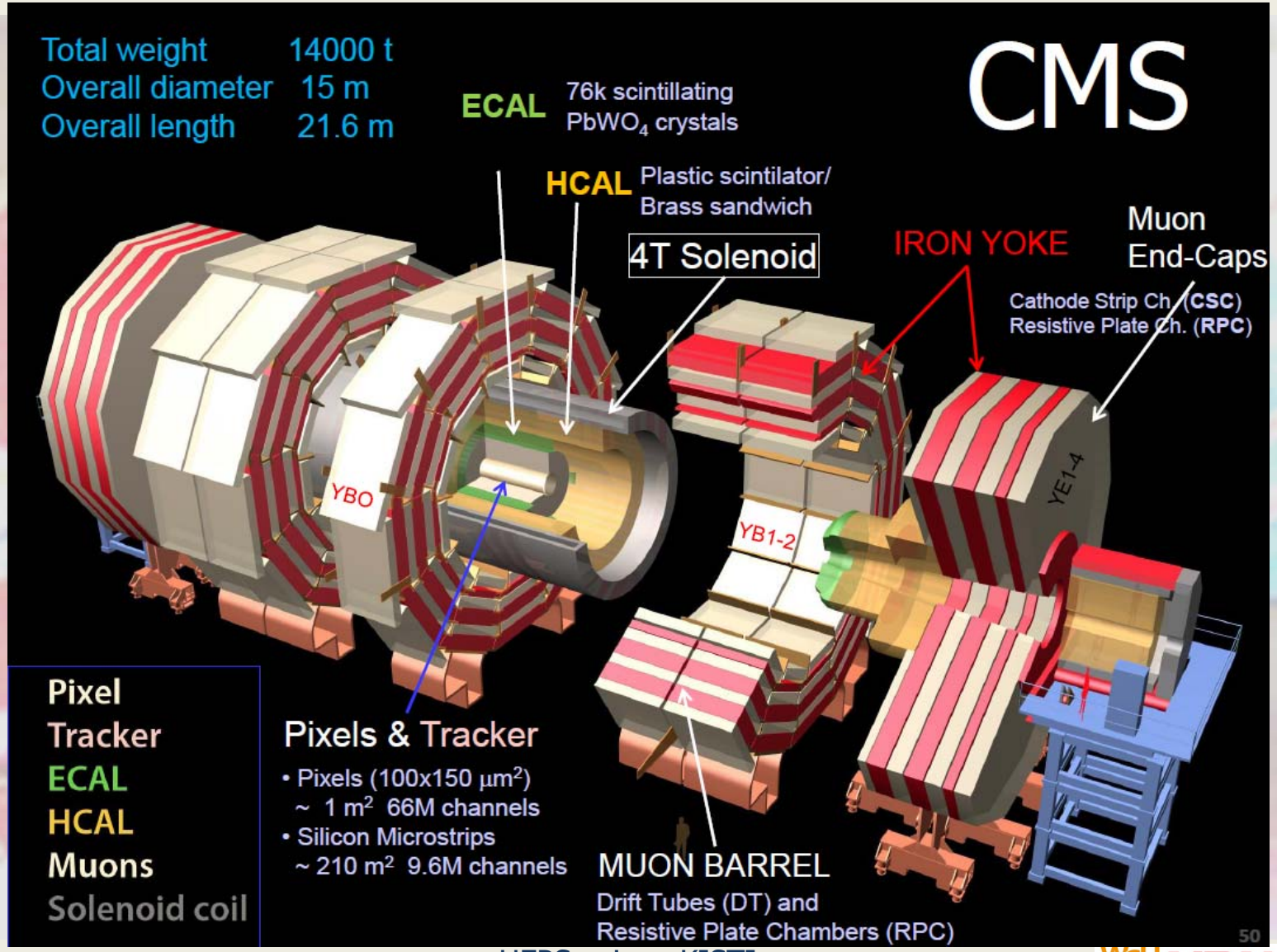
CDF Detector



- Tracking System
  - ✓ Silicon Detector
  - ✓ Central Outer Tracker
  - ✓ 1.4 T B-field
- Calorimeter
  - ✓ ElectroMagnetic
  - ✓ Hadron
- Muon Detection

- Trigger System
  - ✓ Level3 (25000/300/100 Hz)
  - ✓ High p_T Lepton
  - ✓ Missing E_T
  - ✓ Jets

CMS Detector



Summary