Search for a heavy gauge boson
$W' \to e\,\nu$

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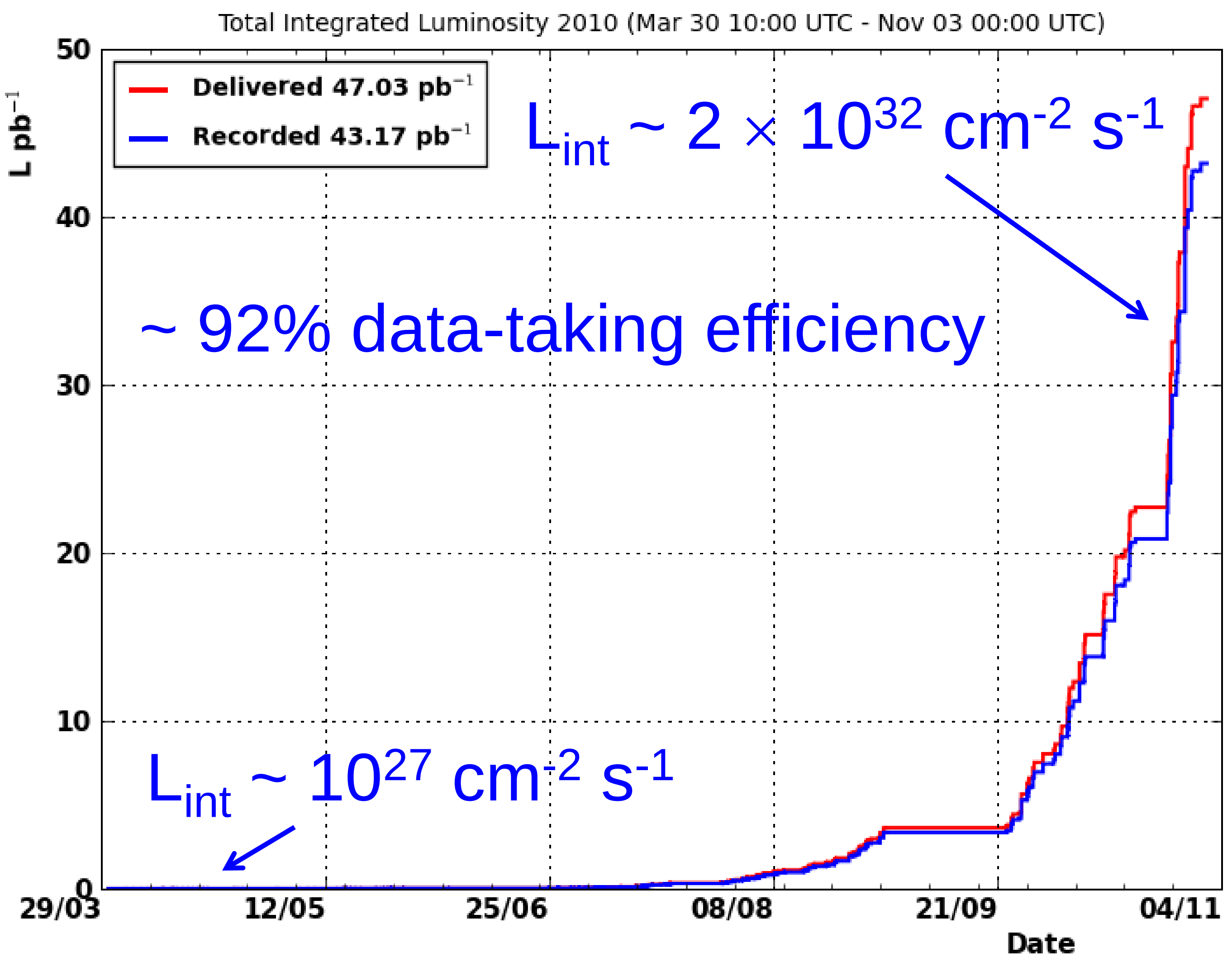
The LHC Machine

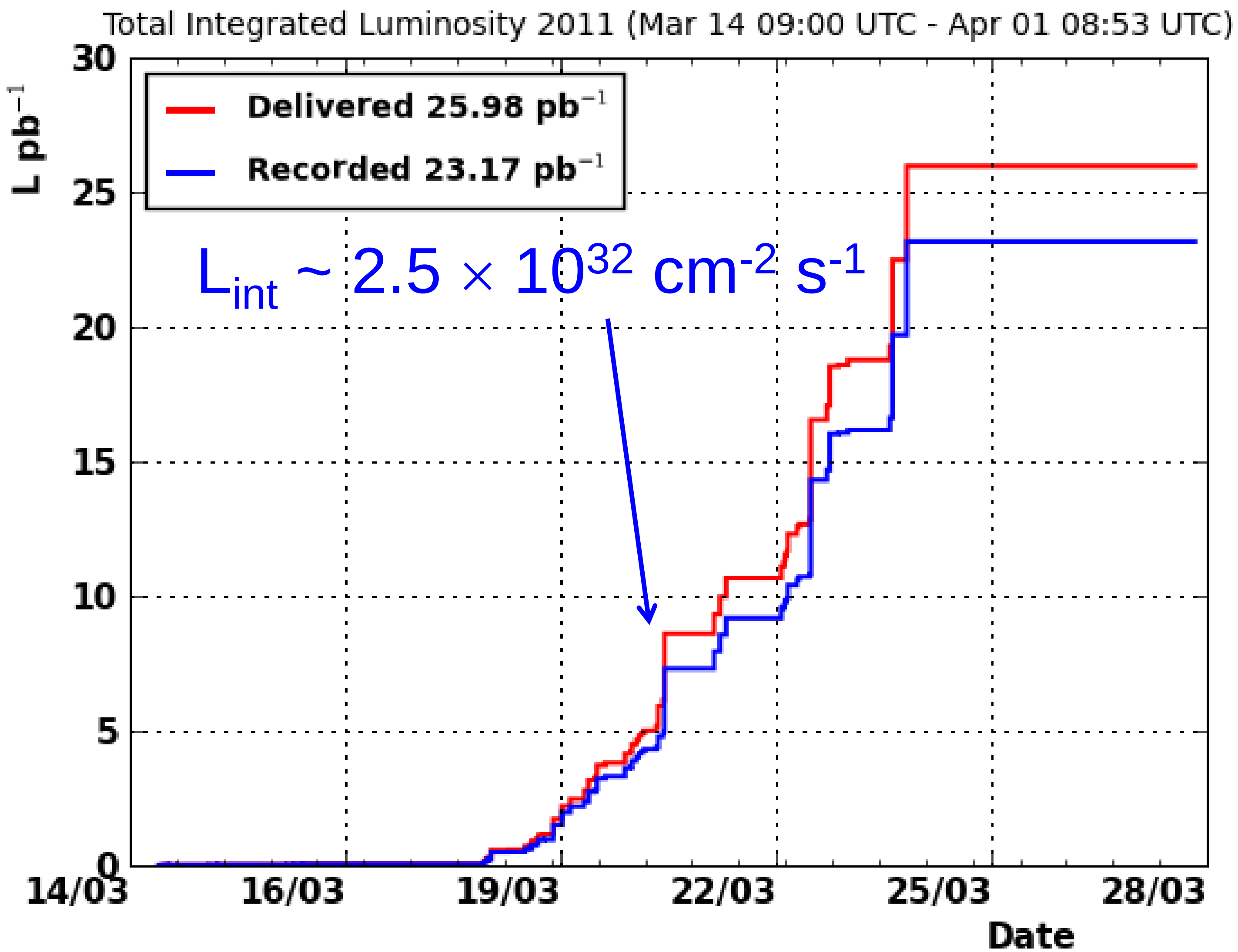
The beginning of the LHC era

- First collisions at 7 TeV confirmed on March 30, 2010
  - There was much jubilation, applause, and champagne
- Data-taking of pp collisions continued until October 31, 2010
- In seven months of data-taking, the LHC delivered ~ 50 pb^{-1}



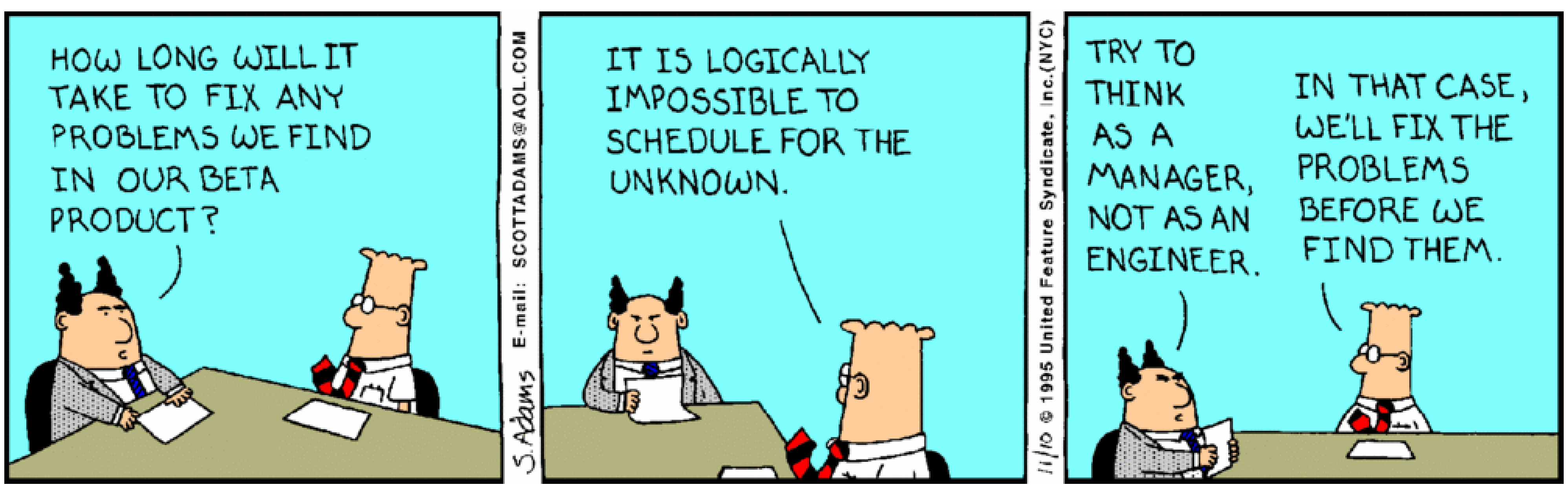
Future LHC plans

- First 2011 collisions with stable beams on March 13, 2011
- Conservatively anticipate collecting 1 fb^{-1} by the end of 2011
  - Realistically, it may be closer 2 – 4 fb^{-1}
  - Should be able to sustain luminosities of ~ few $\times 10^{33}$ $cm^{-2}s^{-1}$



Future LHC plans

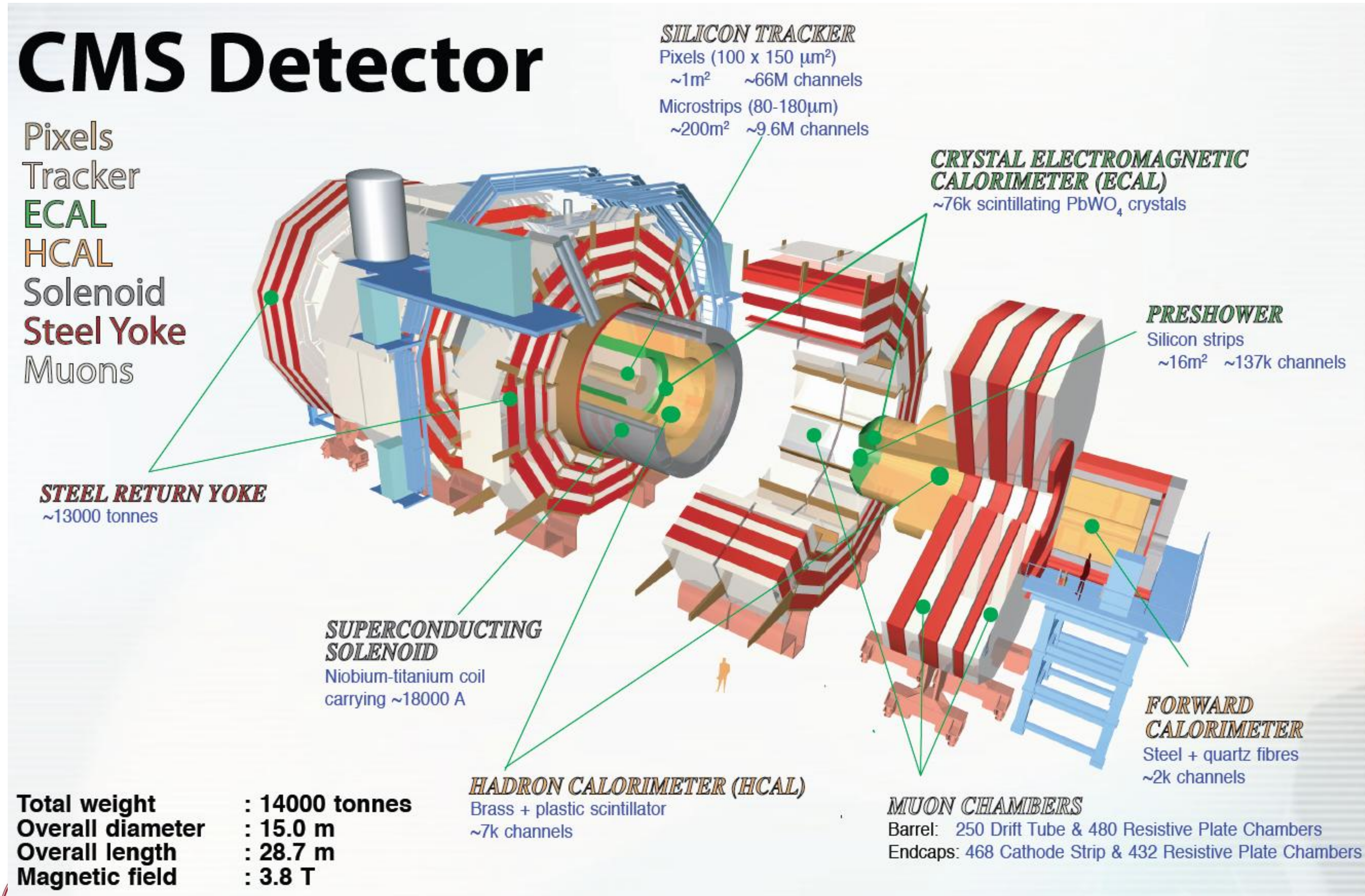
- First 2011 collisions with stable beams on March 13, 2011
- Conservatively anticipate collecting 1 fb^{-1} by the end of 2011
  - Realistically, it may be closer 2 – 4 fb^{-1}
  - Should be able to sustain luminosities of ~ few $\times$ 10^{33} $cm^{-2}s^{-1}$
- Running at 8 TeV center-of-mass in 2012 is still on the table
- Shutdown for ~18 months at the end of November 2012
- Hope is to have 14 TeV collisions around Spring 2014



The CMS Experiment

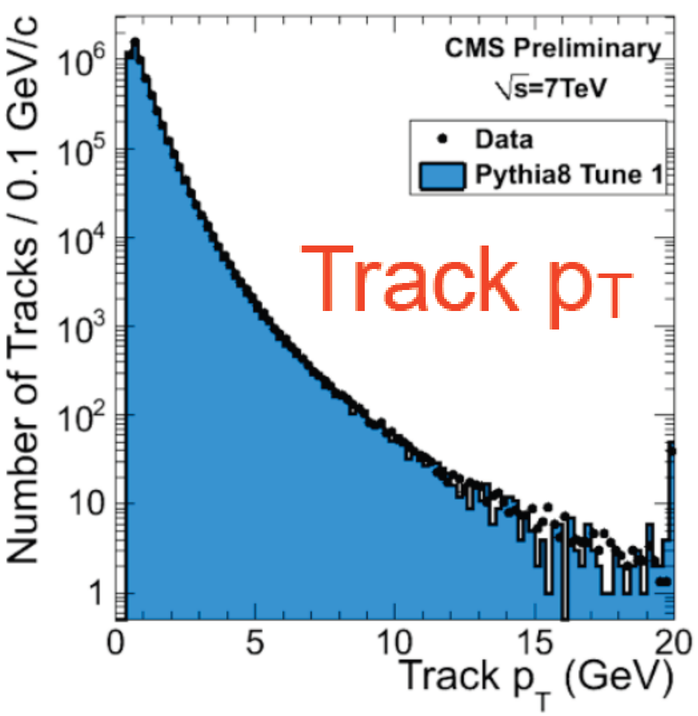
Compact Muon Solenoid collaboration

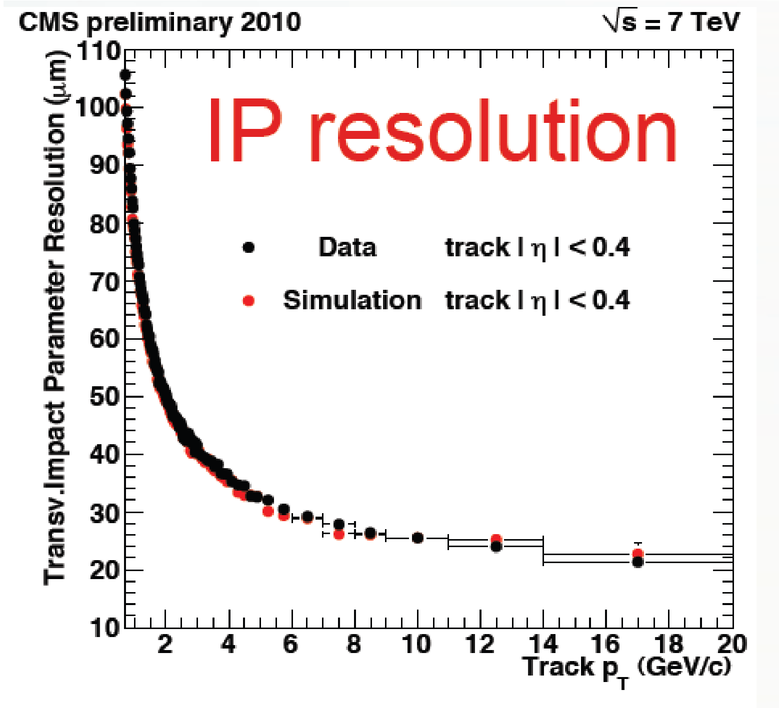
- Experiment has > 3000 scientists and engineers
  - 800 graduate students, 182 institutions, 39 countries

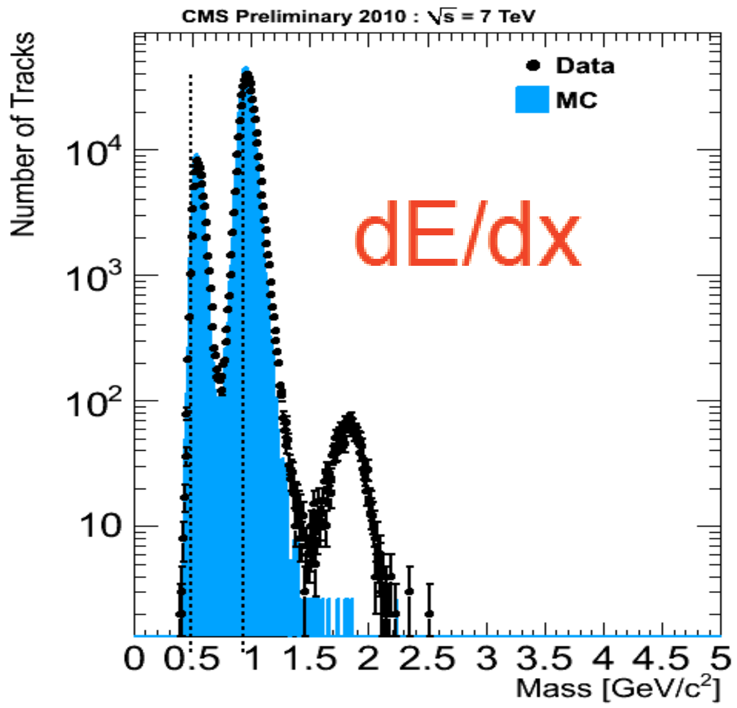

CMS Detector
Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons
SILICON TRACKER
Pixels (100 x 150 μm²)
~1m² ~66M channels
Microstrips (80-180μm)
~200m² ~9.6M channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76k scintillating PbWO4 crystals
PRESHOWER
Silicon strips
~16m² ~137k channels
STEEL RETURN YOKE
~13000 tonnes
SUPERCONDUCTING SOLENOID
Niobium-titanium coil
carrying ~18000 A
FORWARD CALORIMETER
Steel + quartz fibres
~2k channels
HADRON CALORIMETER (HCAL)
Brass + plastic scintillator
~7k channels
MUON CHAMBERS
Barrel: 250 Drift Tube & 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip & 432 Resistive Plate Chambers
Total weight : 14000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

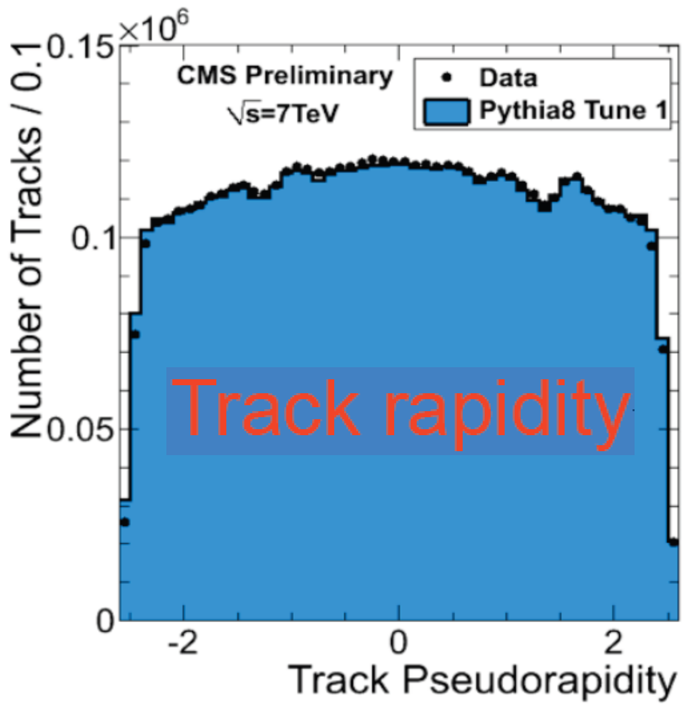
Tracking Performance

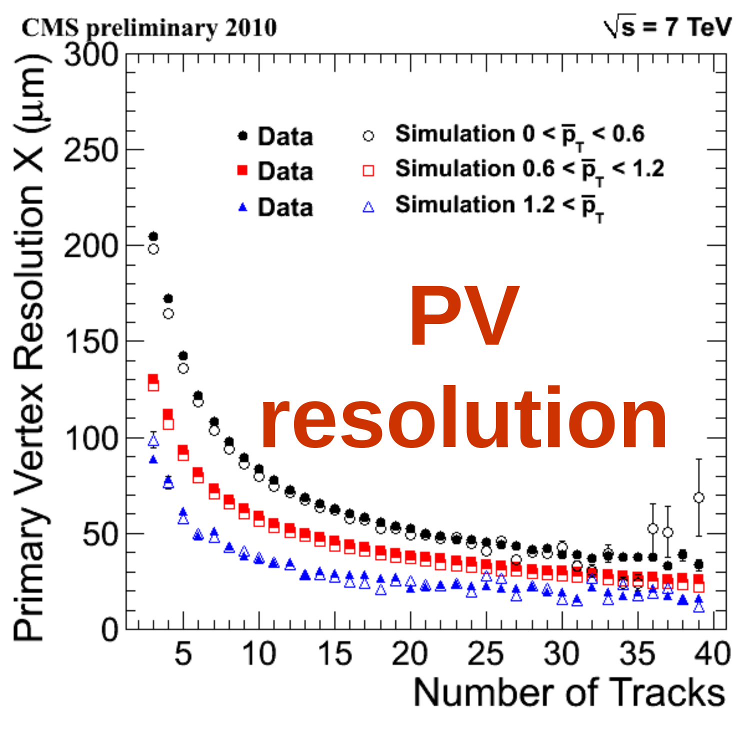
- Tracker > 98% operation, great agreement with simulation

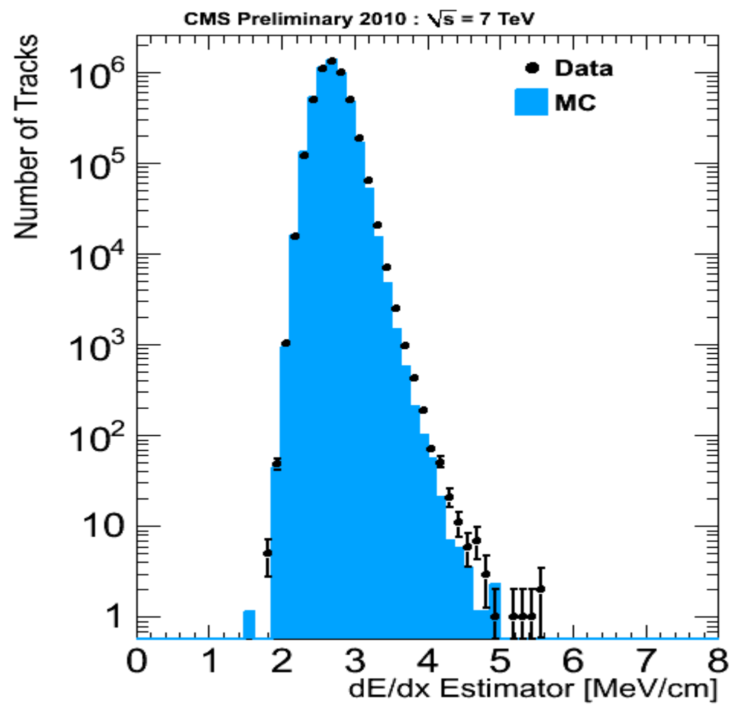




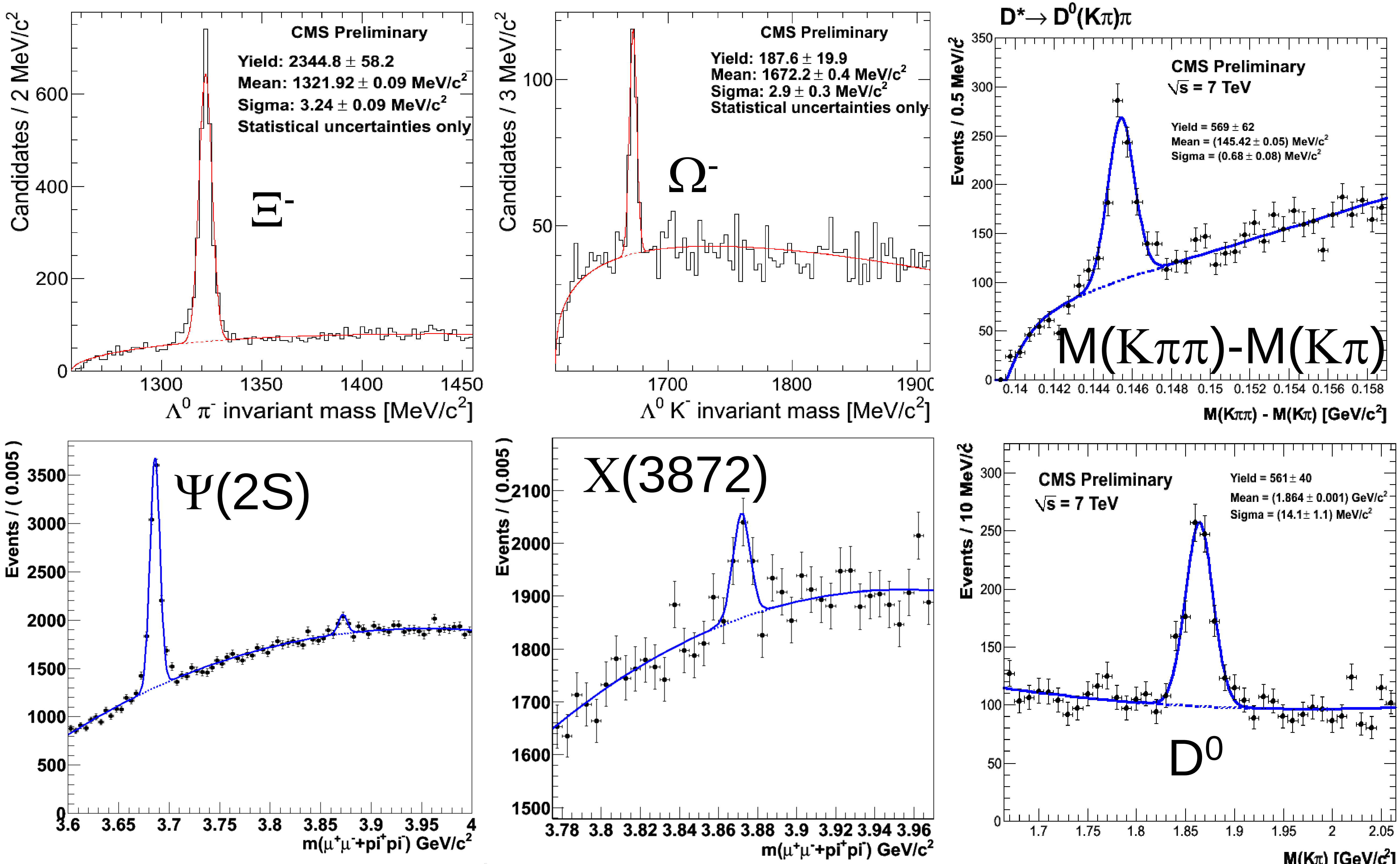








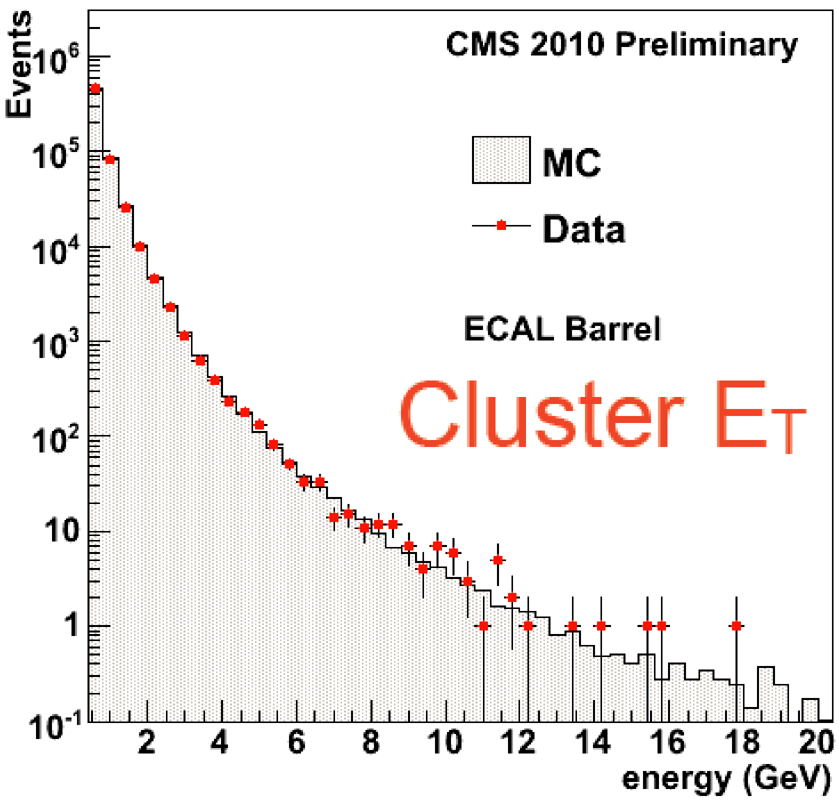
Resonances

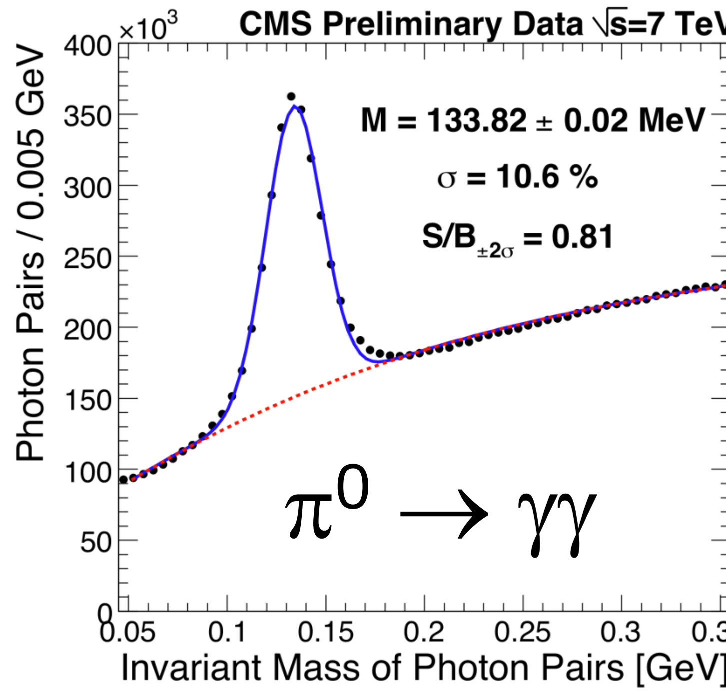


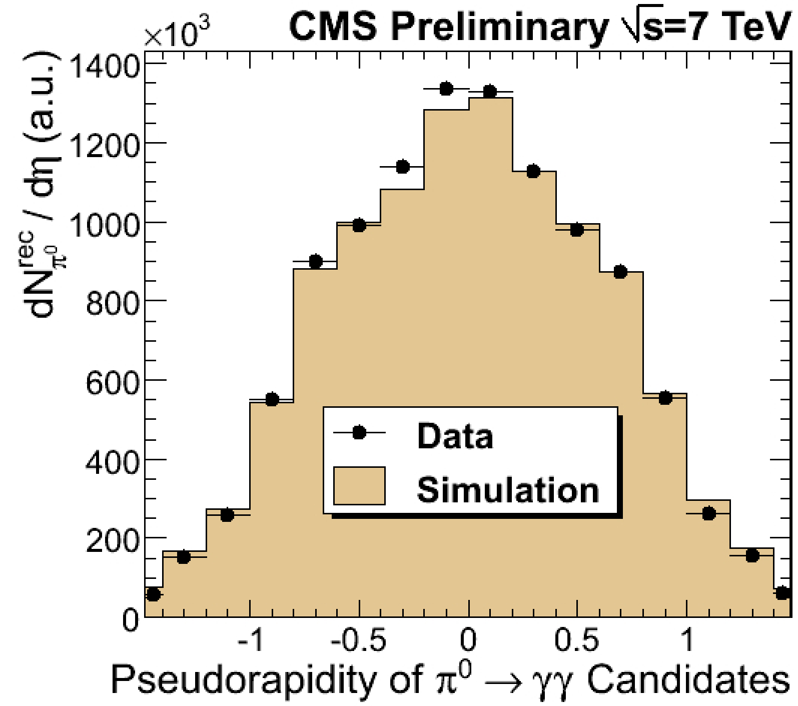
CMS Preliminary
Yield: 2344.8 ± 58.2
Mean: 1321.92 ± 0.09 MeV/c²
Sigma: 3.24 ± 0.09 MeV/c²
Statistical uncertainties only
Ξ⁻
Candidates / 2 MeV/c²
Λ⁰ π⁻ invariant mass [MeV/c²]
CMS Preliminary
Yield: 187.6 ± 19.9
Mean: 1672.2 ± 0.4 MeV/c²
Sigma: 2.9 ± 0.3 MeV/c²
Statistical uncertainties only
Ω⁻
Candidates / 3 MeV/c²
Λ⁰ K⁻ invariant mass [MeV/c²]
D*→ D⁰(Kπ)π
CMS Preliminary
√s = 7 TeV
Yield = 569 ± 62
Mean = (145.42 ± 0.05) MeV/c²
Sigma = (0.68 ± 0.08) MeV/c²
M(Kππ)-M(Kπ)
Events / 0.5 MeV/c²
M(Kππ) - M(Kπ) [GeV/c²]
Ψ(2S)
Events / (0.005)
m(μ⁺μ⁻+pi⁺pi⁻) GeV/c²
X(3872)
Events / (0.005)
m(μ⁺μ⁻+pi⁺pi⁻) GeV/c²
CMS Preliminary
√s = 7 TeV
Yield = 561 ± 40
Mean = (1.864 ± 0.001) GeV/c²
Sigma = (14.1 ± 1.1) MeV/c²
D⁰
Events / 10 MeV/c²
M(Kπ) [GeV/c²]

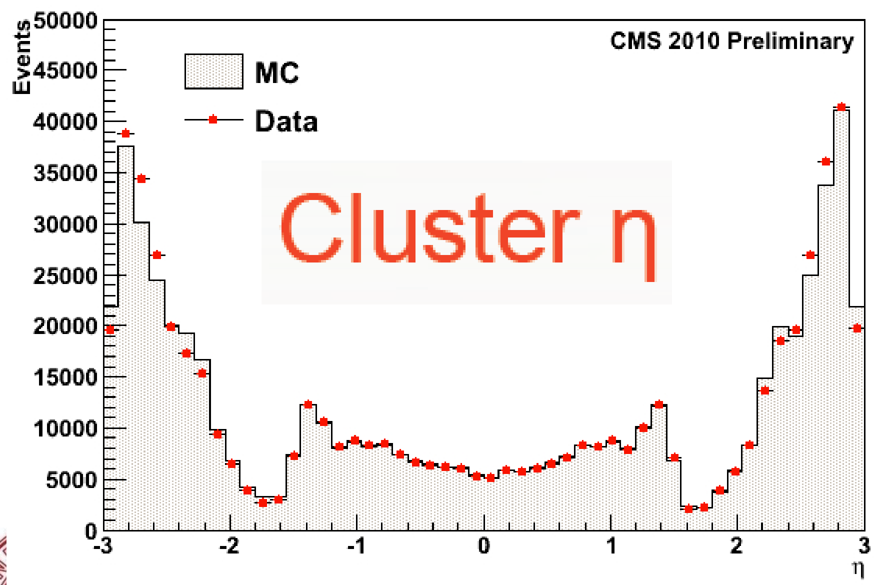
ECAL performance

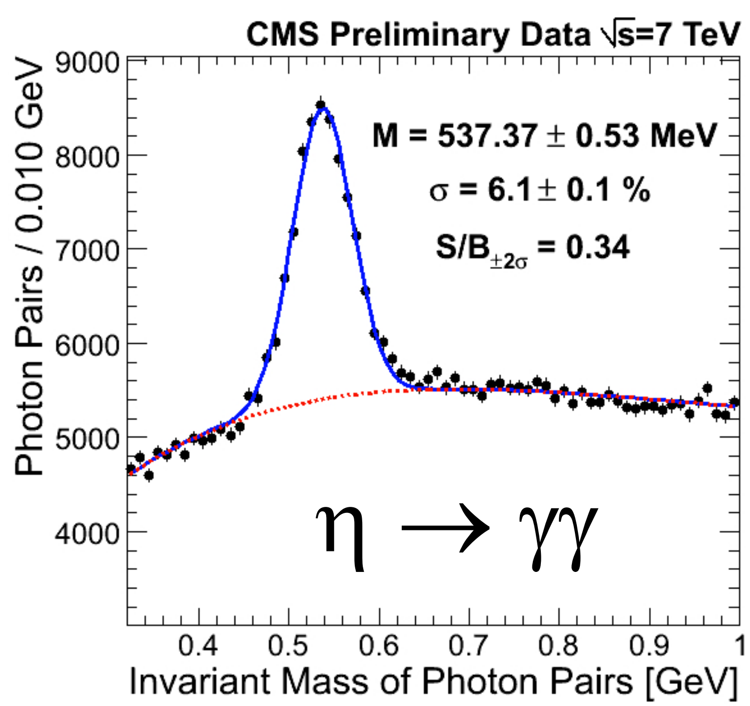
- ECAL nearly 99% operational, with great data / MC agreement

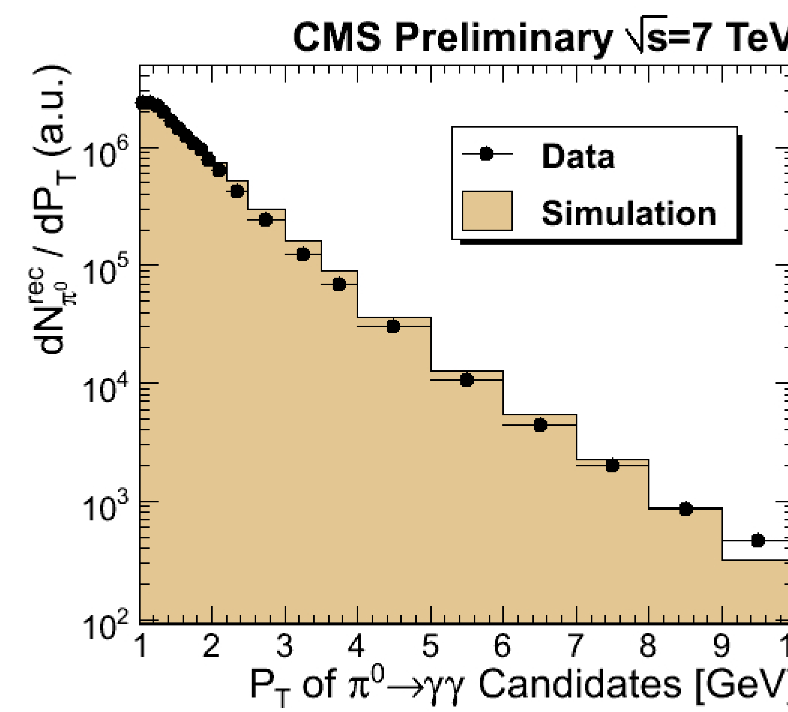




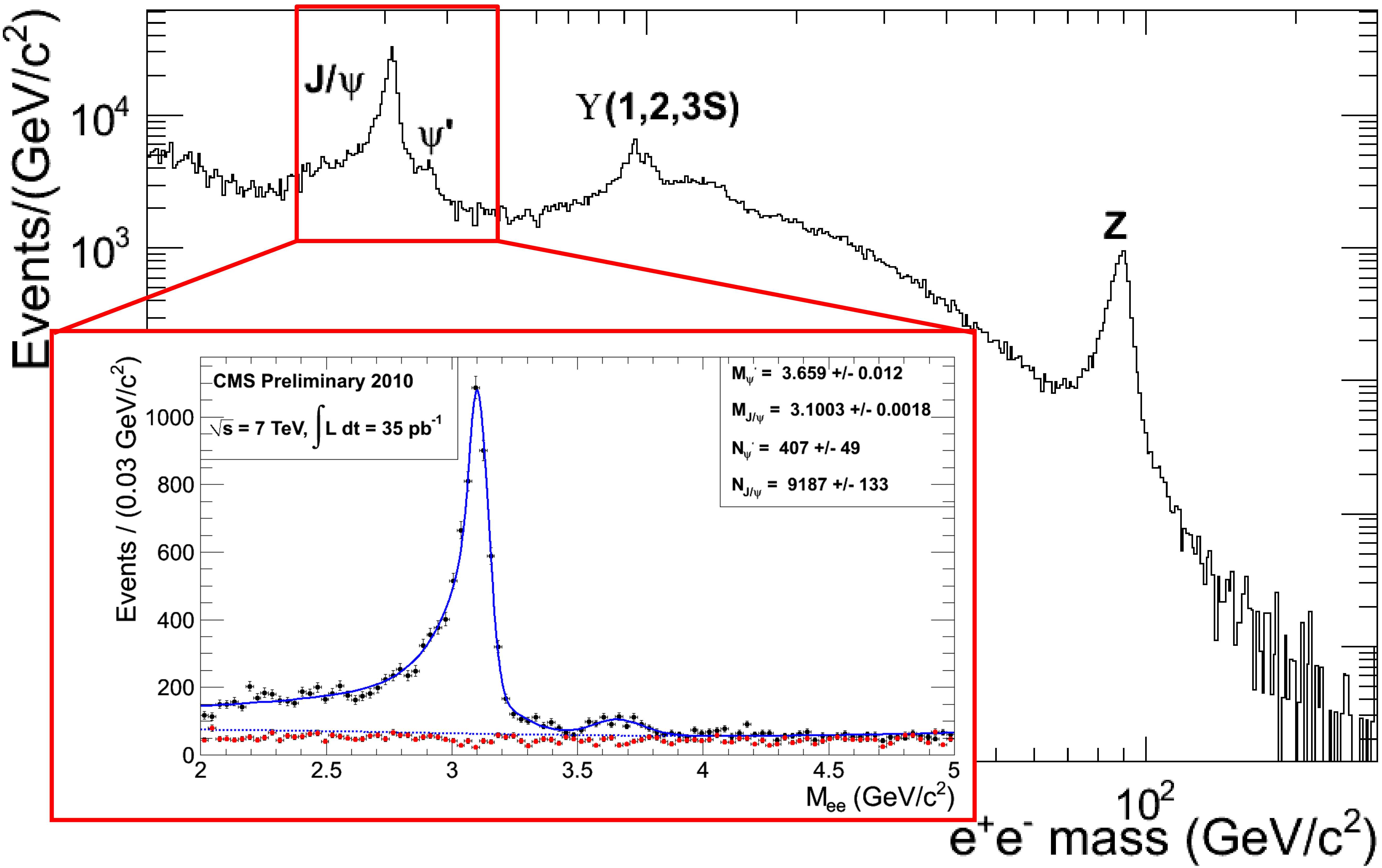




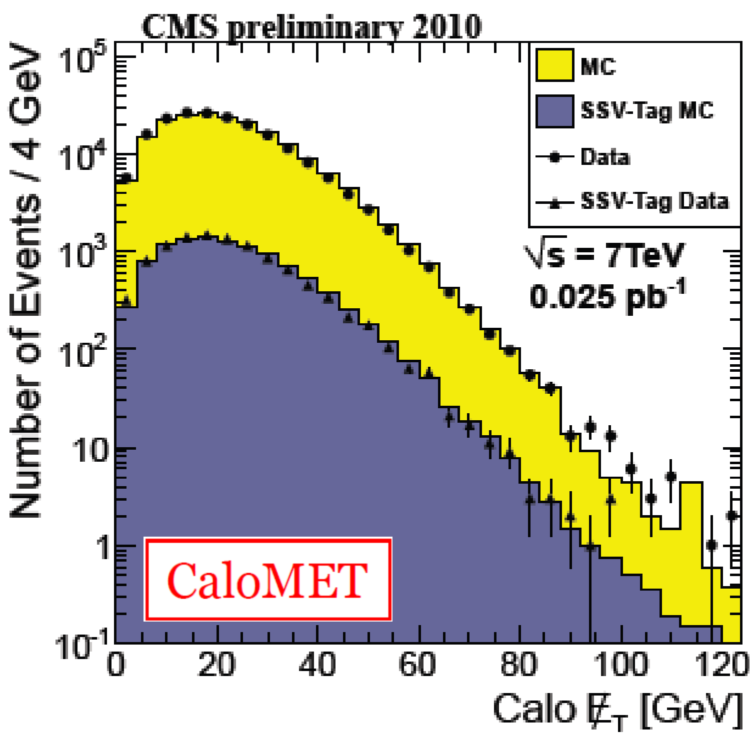


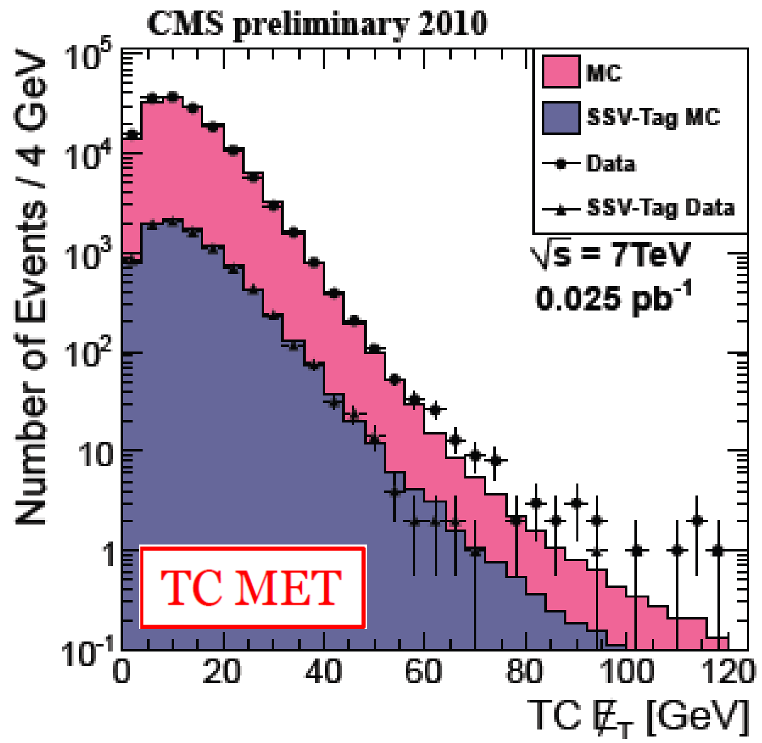


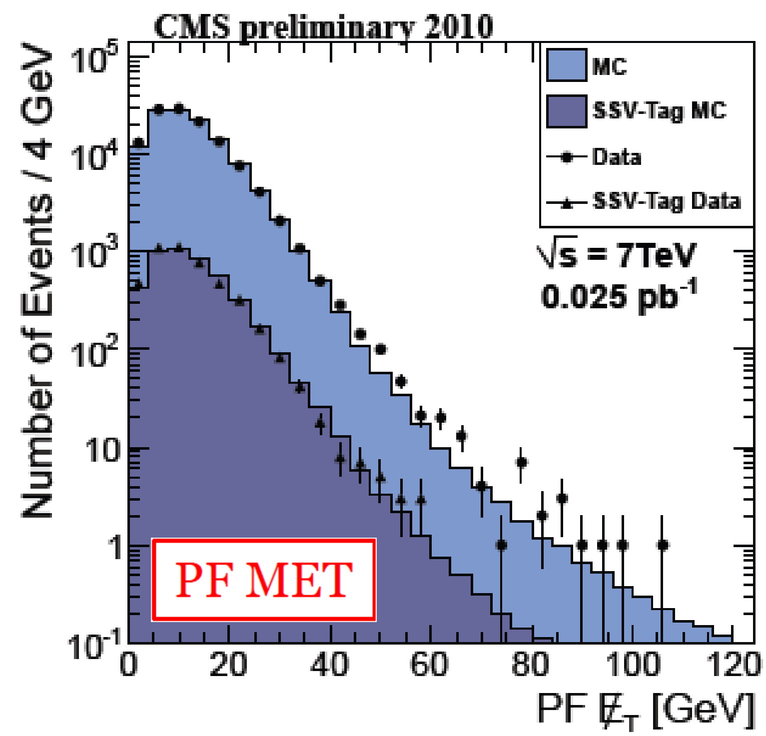
Electron-positron invariant mass

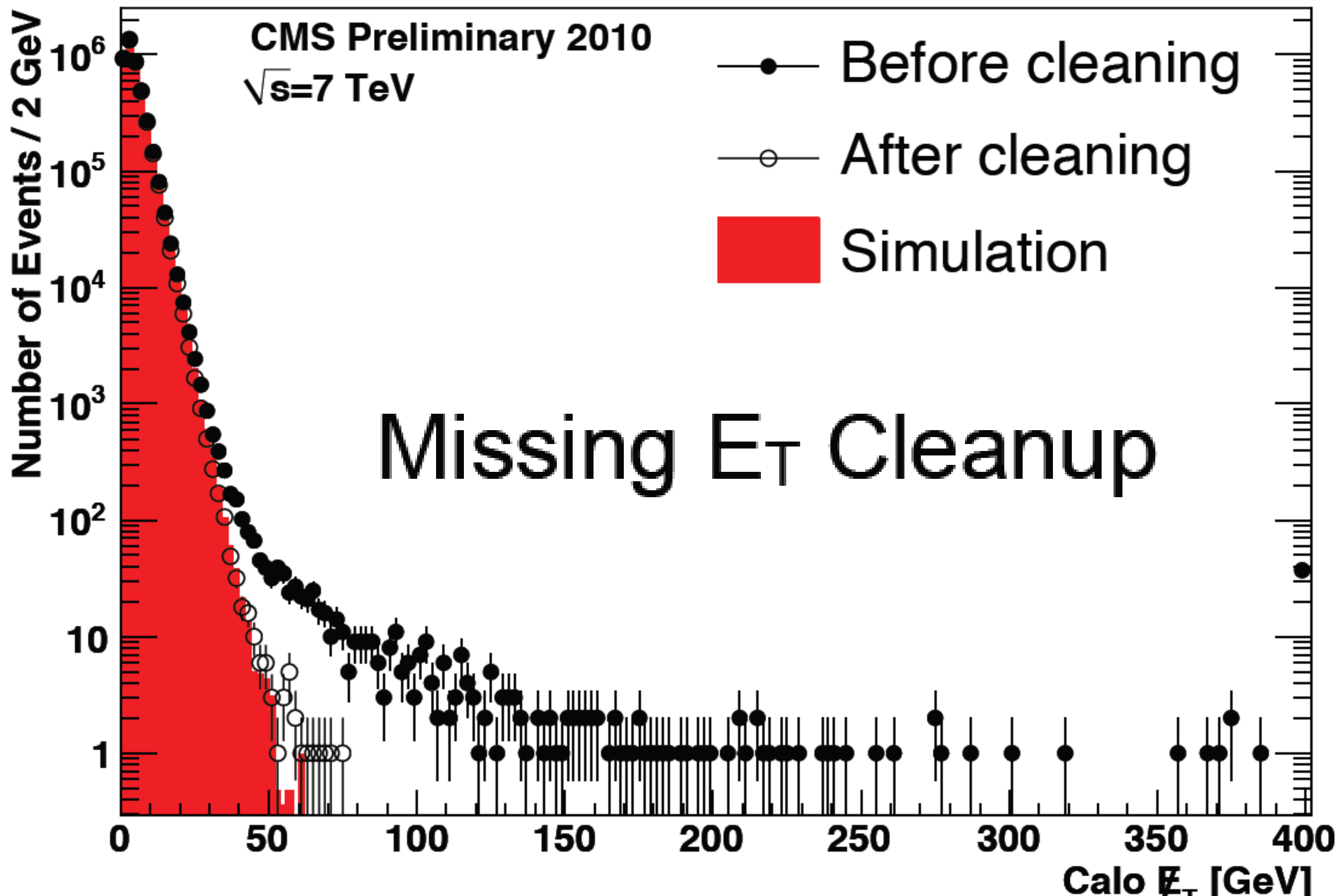


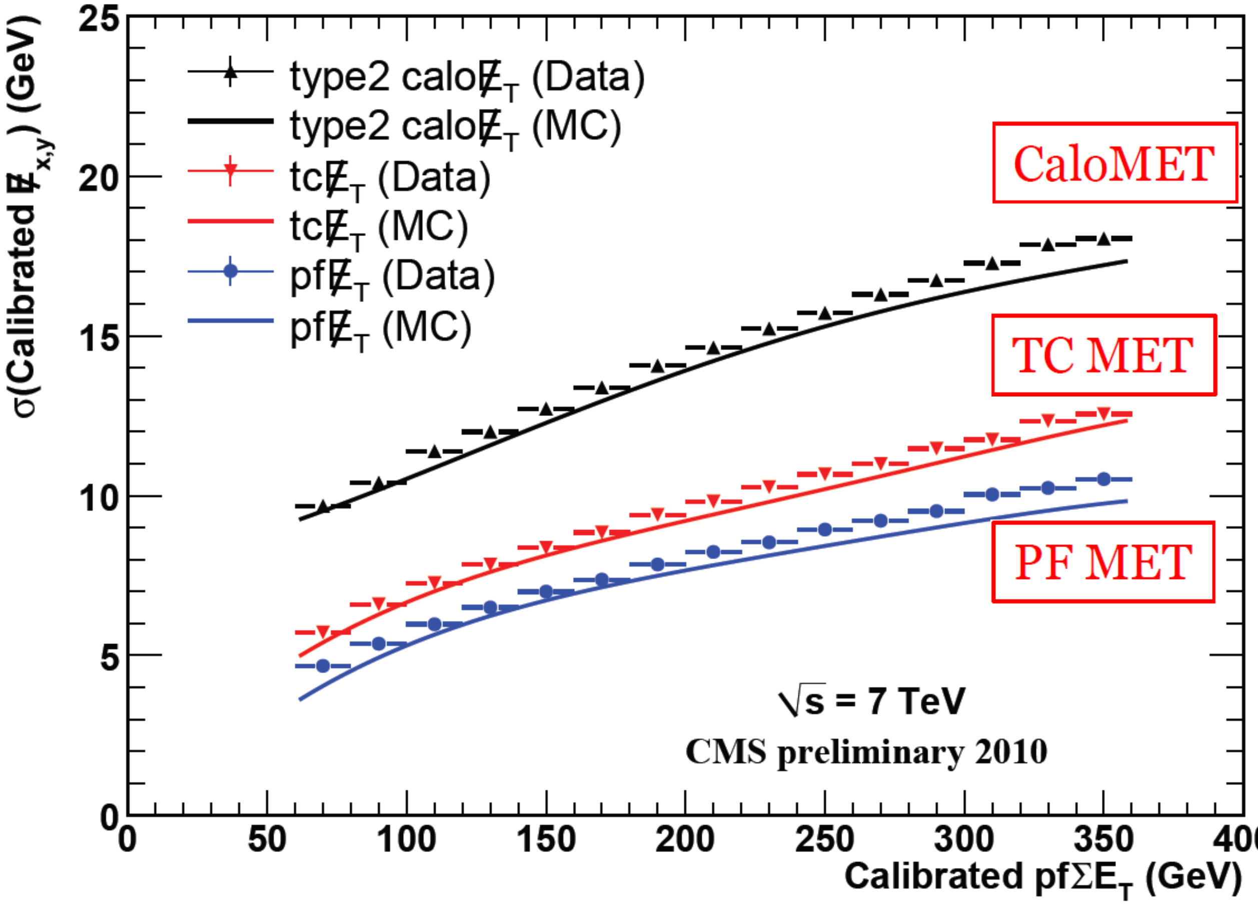
MET performance



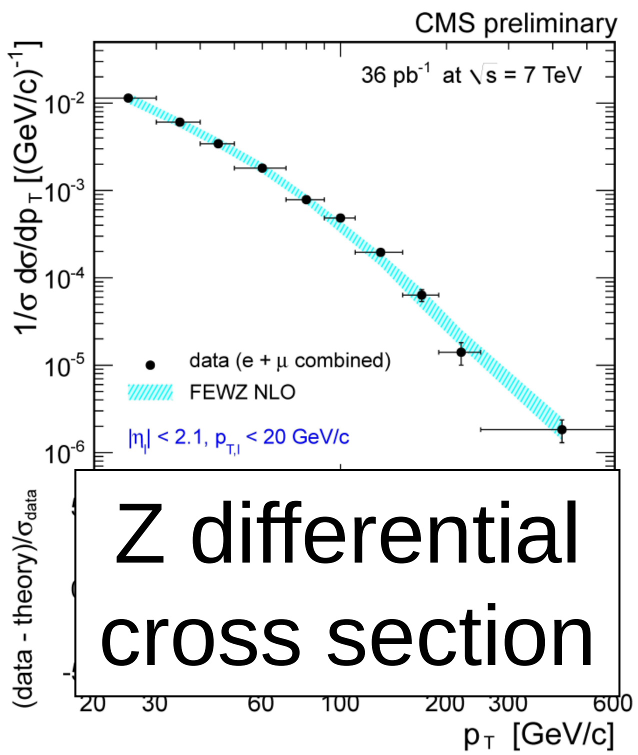


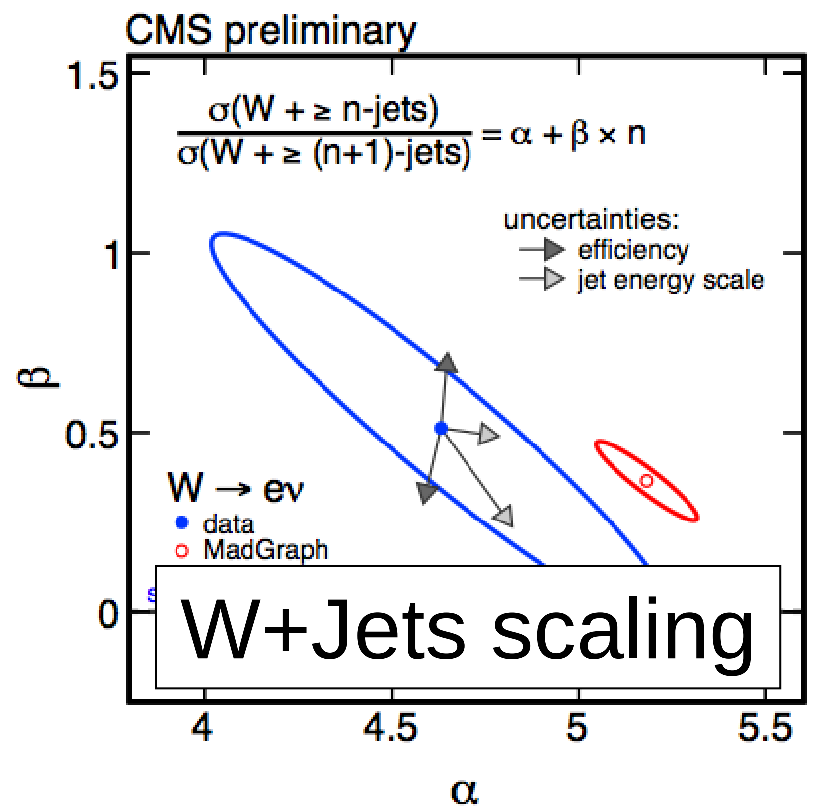


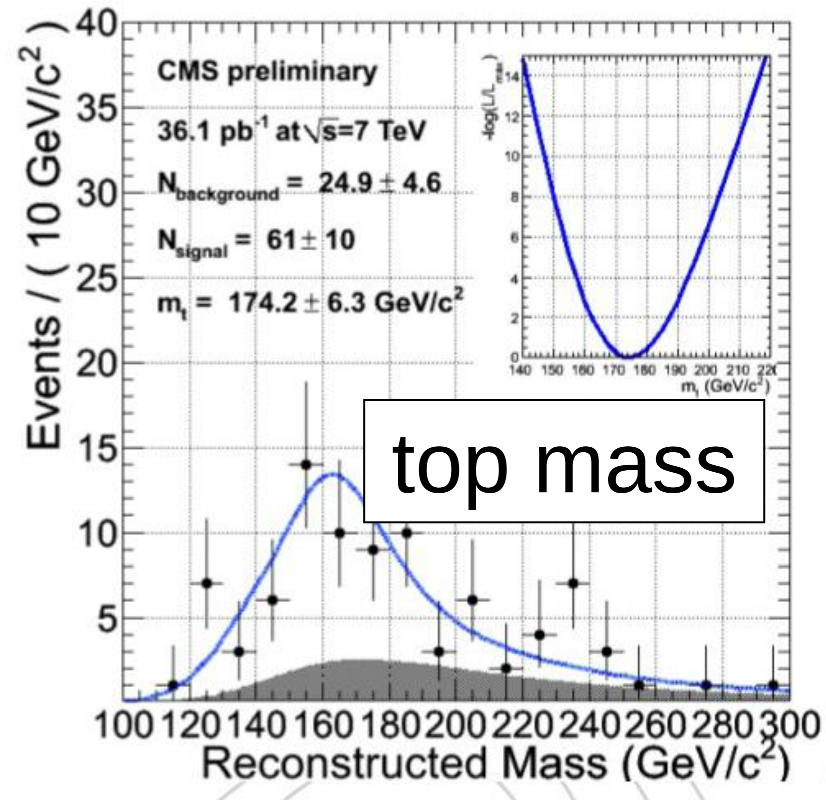


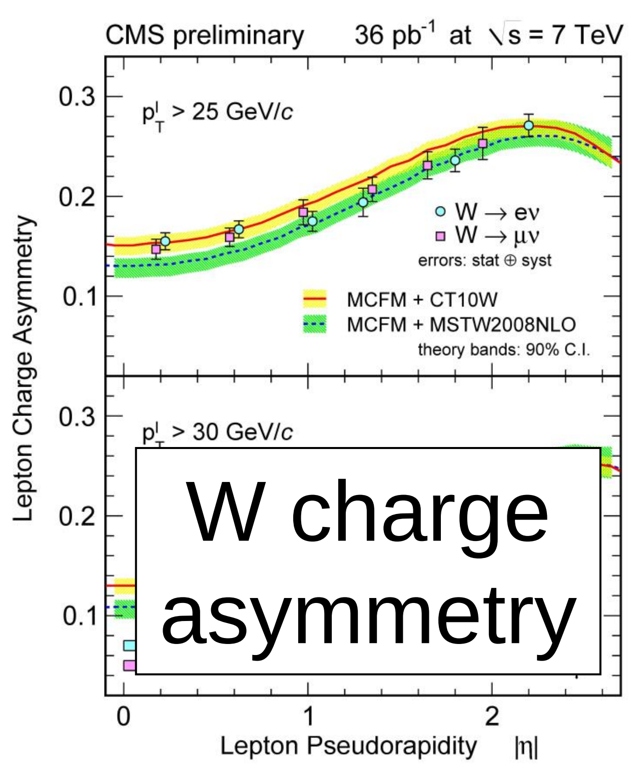


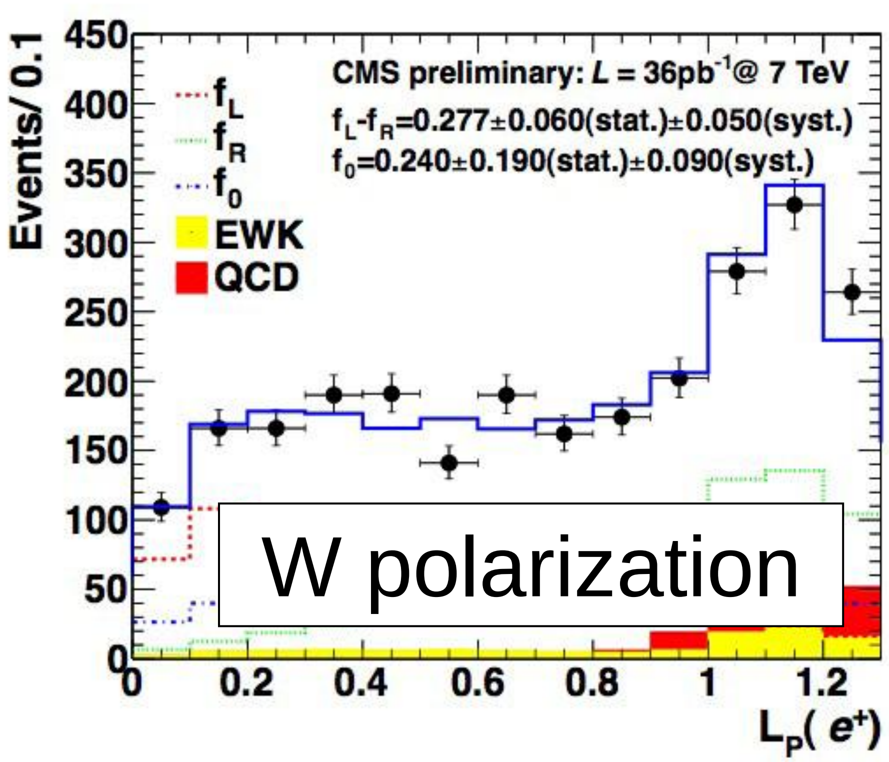
The Standard Model

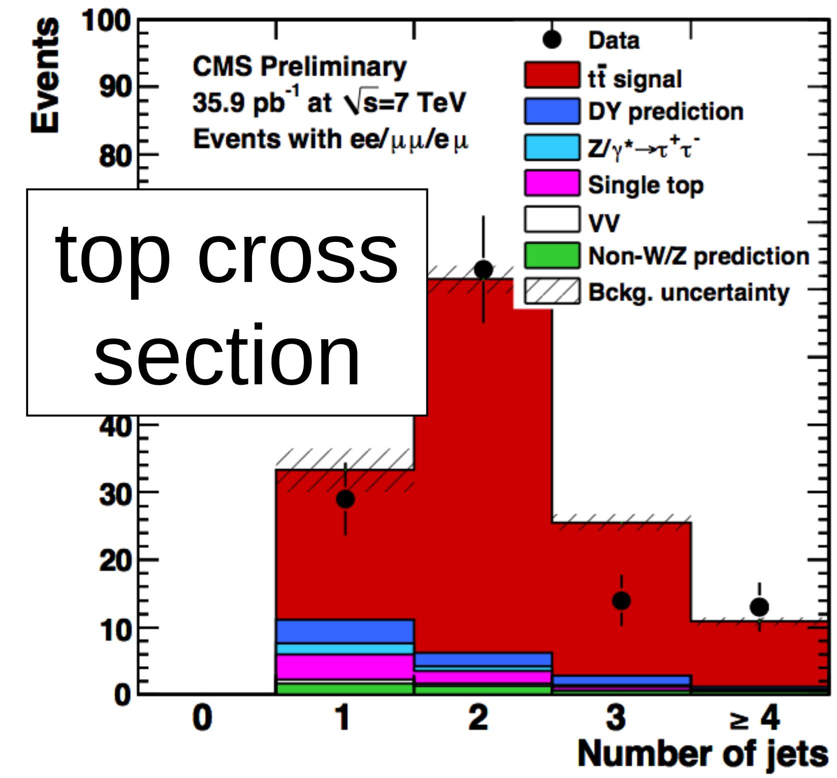












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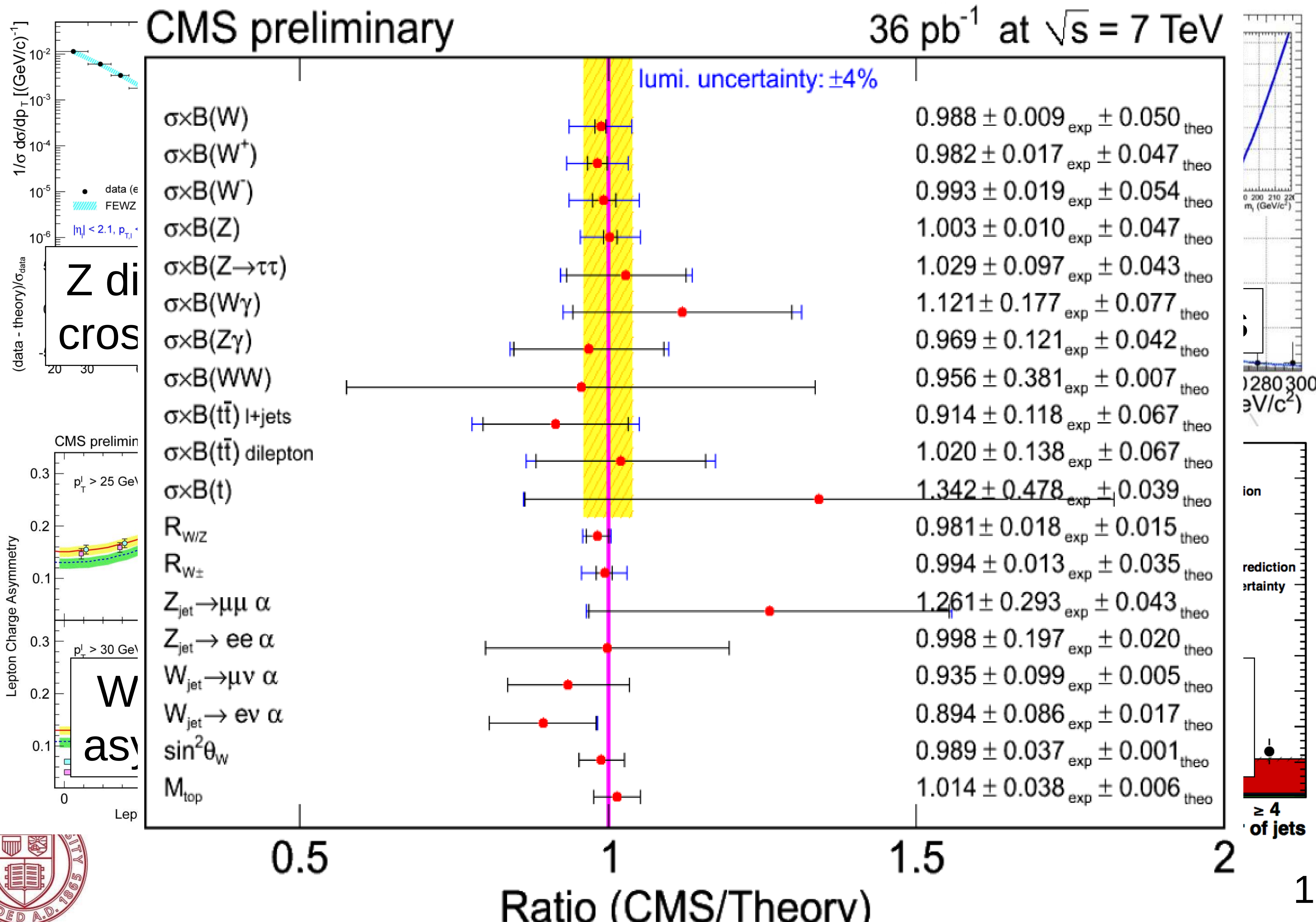
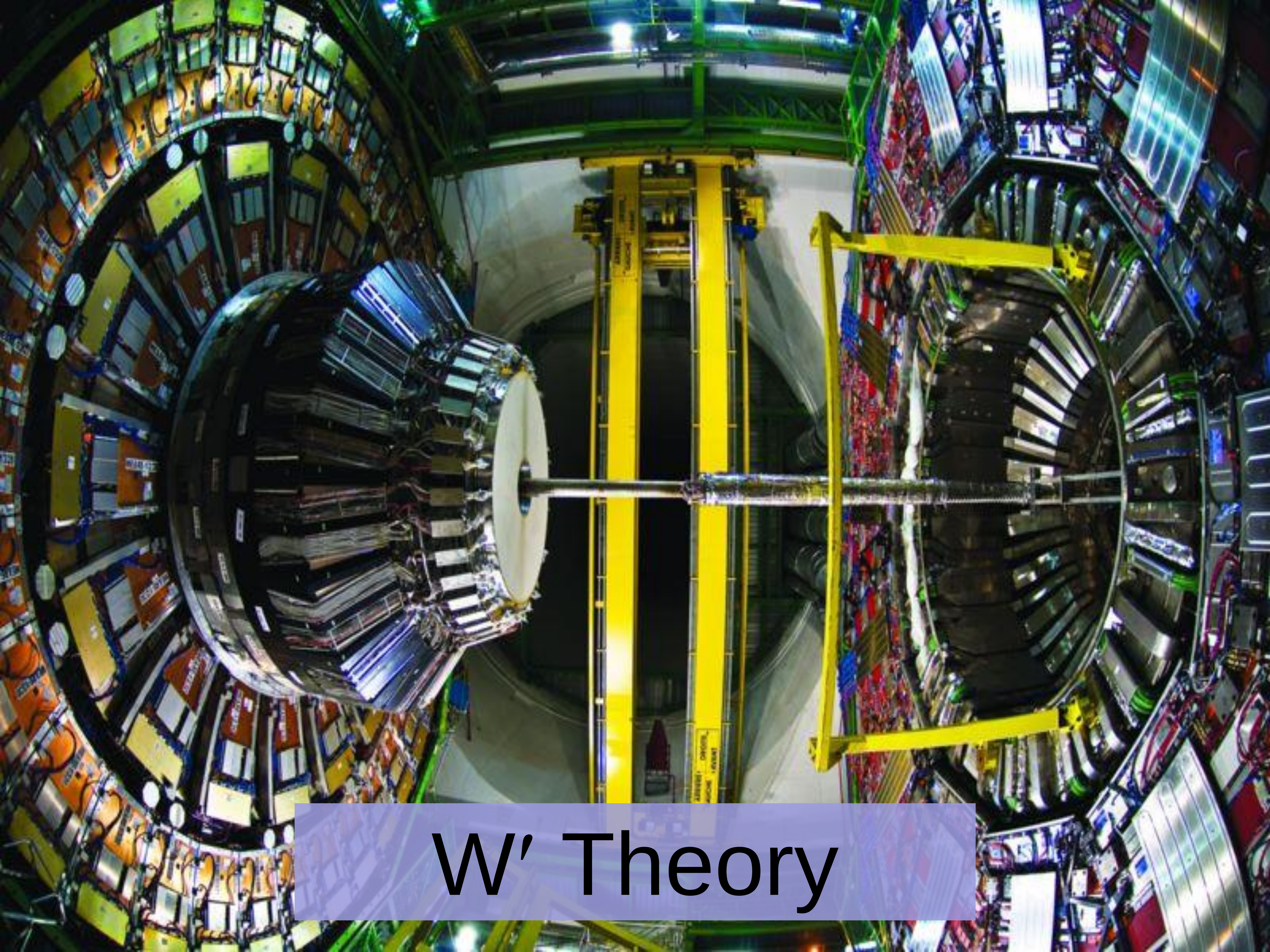




W′ Theory

Theories with new gauge bosons

- Heavier versions of the W boson are found in many theories
- General extensions of the SM gauge group
  - e.g. minimal W'_L model

$$\mathrm{SU(2)_L \times U(1)_Y} \longrightarrow \mathrm{SU(2)_1 \times SU(2)_2 \times U(1)_Y}$$

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

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

- Left-right symmetry of electroweak interactions
  - Extend the SM gauge group to include right-handed interactions

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

Search for heavy gauge bosons

- On the experimental side, we are searching for a W′ that is a massive carbon copy of the Standard Model W boson
  - Useful benchmark to compare between experiments
- Analysis is (relatively) simple and straight-forward
  - Single, high-p_T lepton + nothing else (missing transverse energy)
  - Very little Standard Model background at high transverse mass
- One of the analyses that could lead to an early CMS discovery
  - Excess in single lepton events can arise in other models of new physics, e.g. contact interactions

Previous searches and exclusions

- Direct searches for W′ performed at the CDF and D0 experiments at the Tevatron: $\sqrt{s}$ = 1.96 TeV
  - $W' \to e\nu$: $M_{W'}$ > 1.12 TeV, CDF with 5.3 fb^{-1} doi:10.1103/PhysRevD.83.031102
  - $W' \to tb$: $M_{W'}$ > 863 GeV, D0 with 2.3 fb^{-1} arXiv:1101.0806 [hep-ex]

- Indirect limits are extremely model-dependent, and they are often more stringent than direct searches (with assumptions)
  - Kaon and B-meson mixing limits in the minimal left-right symmetric model: M_{W_R} > 1.6 – 2.4 TeV doi:10.1103/PhysRevD.76.091301
  - Big bang nucleosynthesis (BBN) limits based on temperature at which the three ν_R's decouple, T_{dec}:

$$M_{W_R} > 3.3\,\mathrm{TeV}\left(\frac{T_{dec}}{140\,\mathrm{MeV}}\right)^{3/4}$$

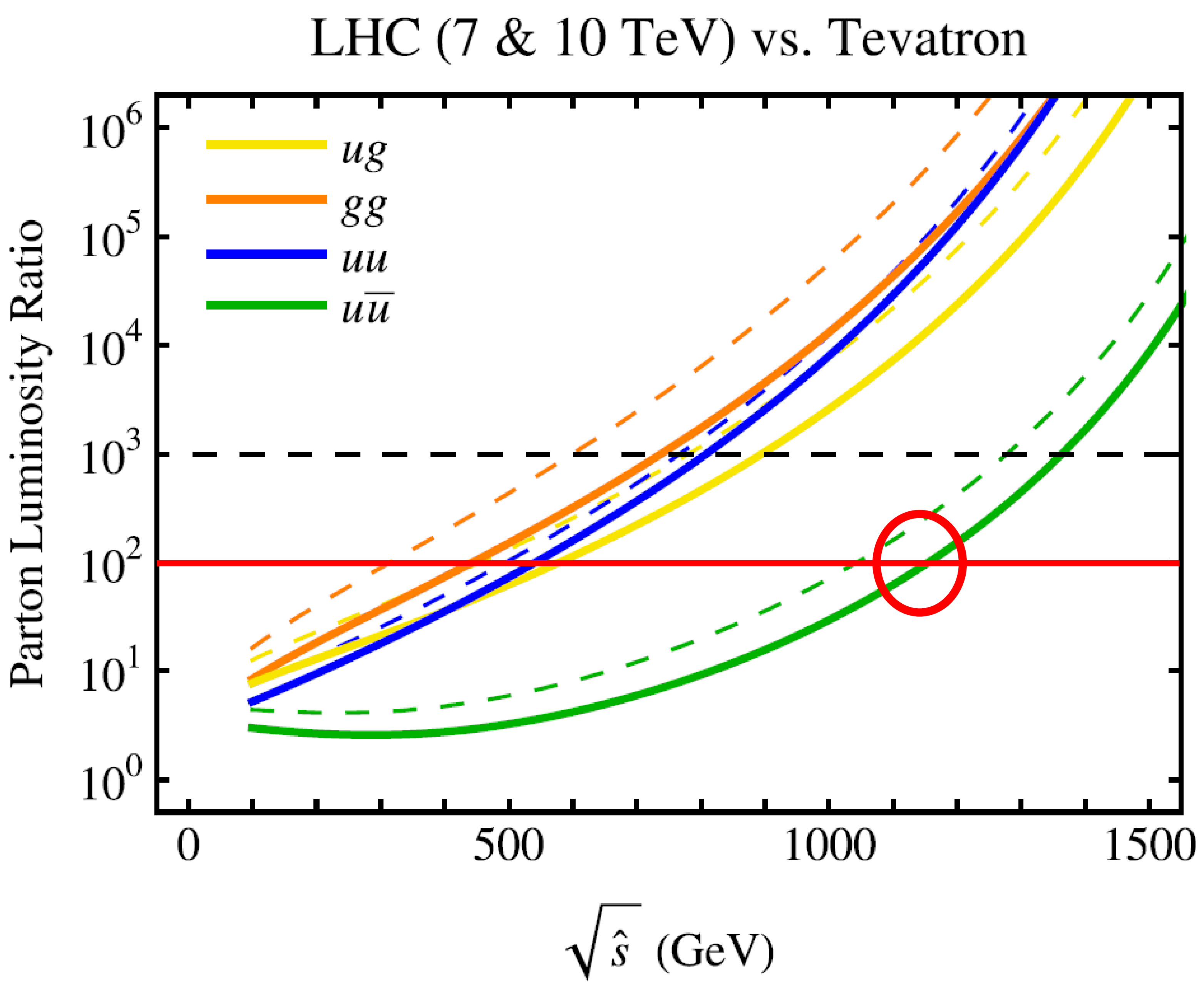
doi:10.1016/j.astropartphys.2005.01.005

  - SN 1987A limits on ν_R emission (M_{ν_R} < 10 MeV): M_{W_R} > 16 TeV

doi:10.1103/PhysRevD.39.1229

How will we surpass the Tevatron searches?

- Ratio of parton luminosities for 7 TeV LHC compared to the 1.96 TeV Tevatron exceeds the inverse ratio of luminosities (~100 = 5 fb^{-1}/50 pb^{-1}) for masses above 1150 GeV



doi:10.1016/j.physletb.2010.05.032

Search Strategy

W′ analysis

- W′ $\rightarrow$ e ν signature: single, isolated high-p_T electron + large missing transverse energy
- Performed counting experiment after cutting on transverse mass
- Main, irreducible background: Standard Model W $\rightarrow$ e ν
  - An off-peak W (W*) is really just a heavy W (same as W′)
  - Cannot differentiate between W* and W′ on event-by-event basis
  - However, the two have very different kinematics
- Analysis performed with the full 2010 dataset, corresponding to an integrated luminosity of 36.1 pb^{-1}

The usual suspect signal model

- Neutrino is light and stable
- 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′ $\rightarrow$ 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

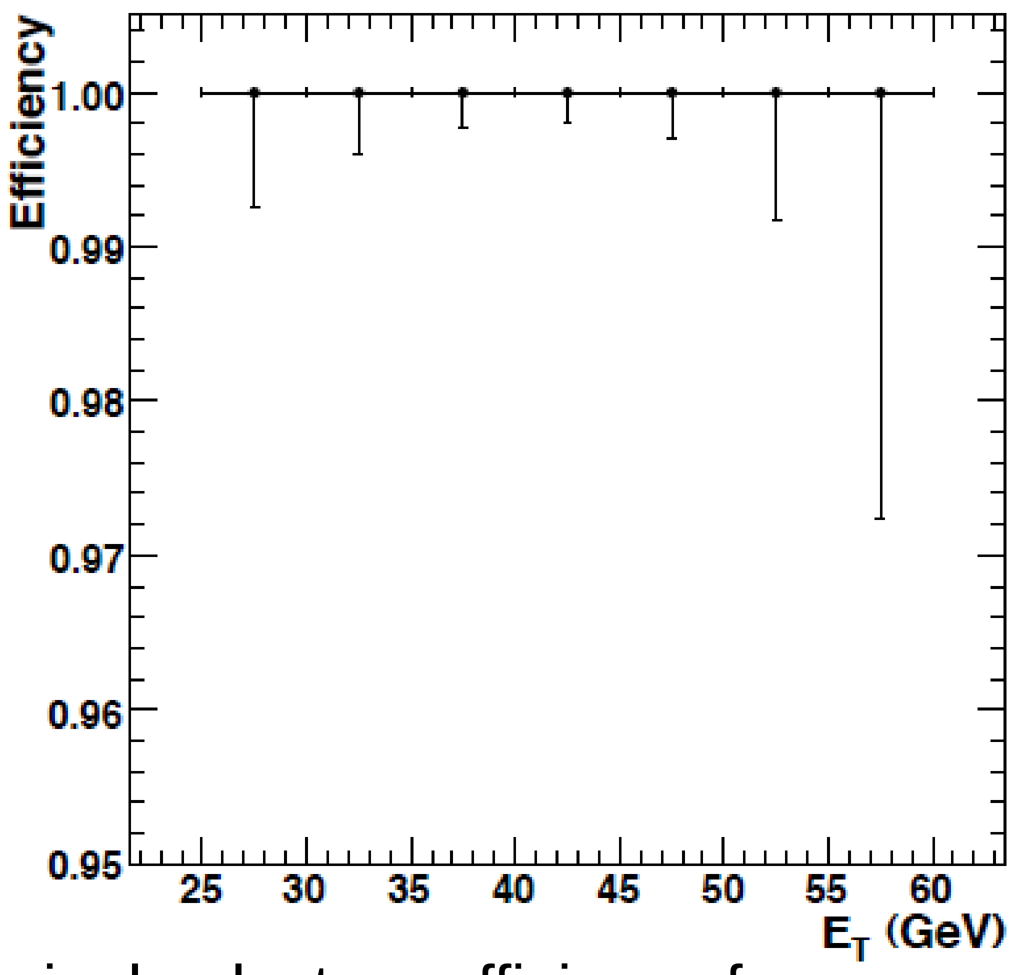
Selection cuts

- Pre-selection to remove uninteresting events for this analysis
  - Good primary vertex
  - $\geq$ 1 reconstructed electron with E_T > 25 GeV and H/E < 0.1

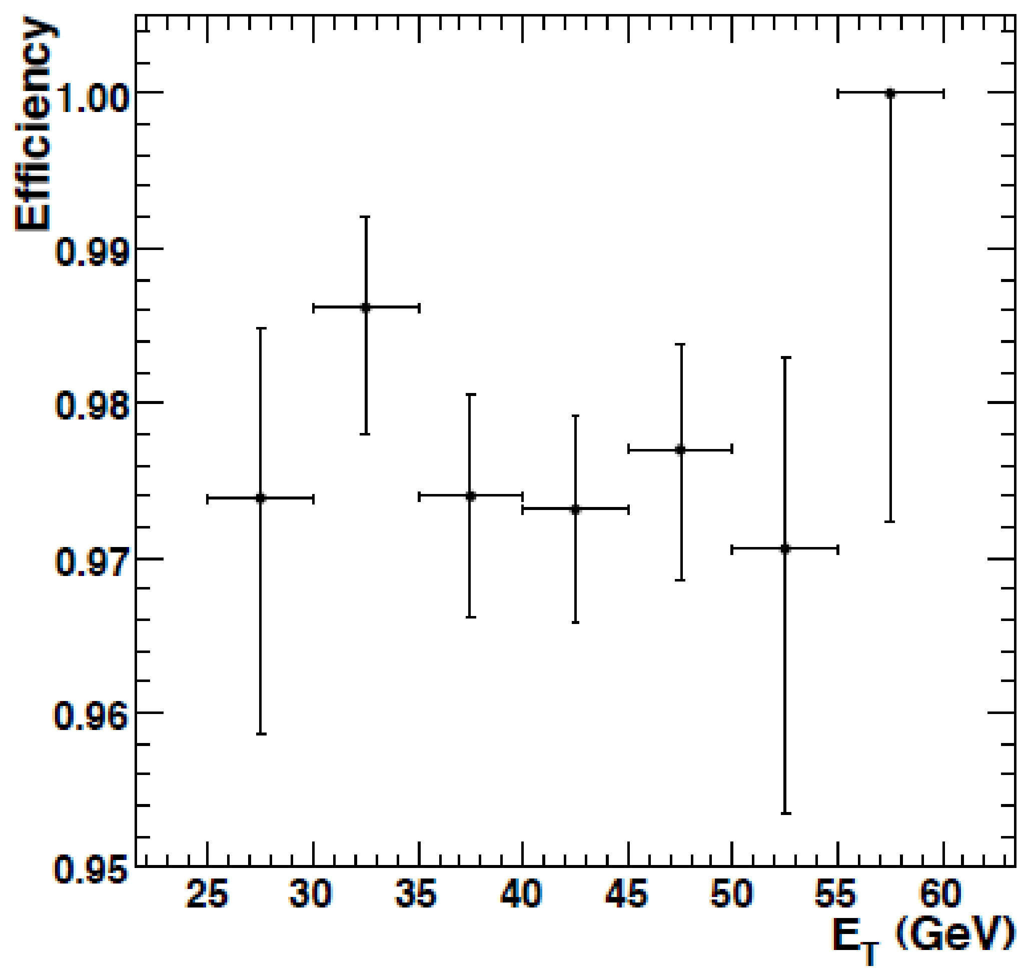
- Selection designed to improve signal-to-background ratio while keeping signal efficiency high
  - Passes unprescaled single electron trigger
  - Only one good quality electron
  - Kinematic cuts

Trigger

- Due to rapidly evolving beam conditions, we needed to use a collection of single electron triggers with several thresholds
  - Bulk of data were collected with electron threshold of $E_T > 22$ GeV
- Inefficiency of software trigger (HLT) primarily from online track requirement



single electron efficiency for L1 (hardware) trigger

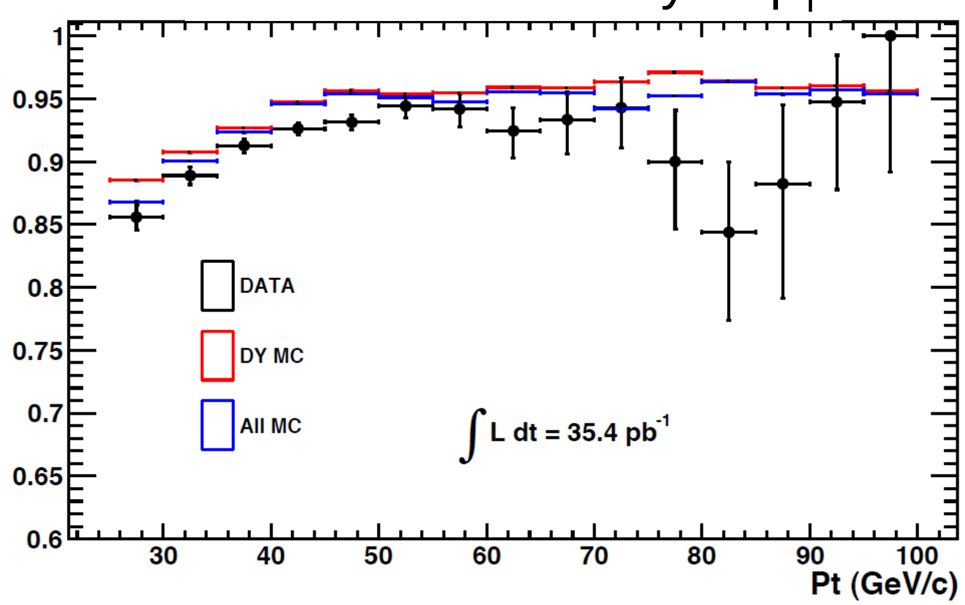


single electron efficiency for HLT (software) trigger

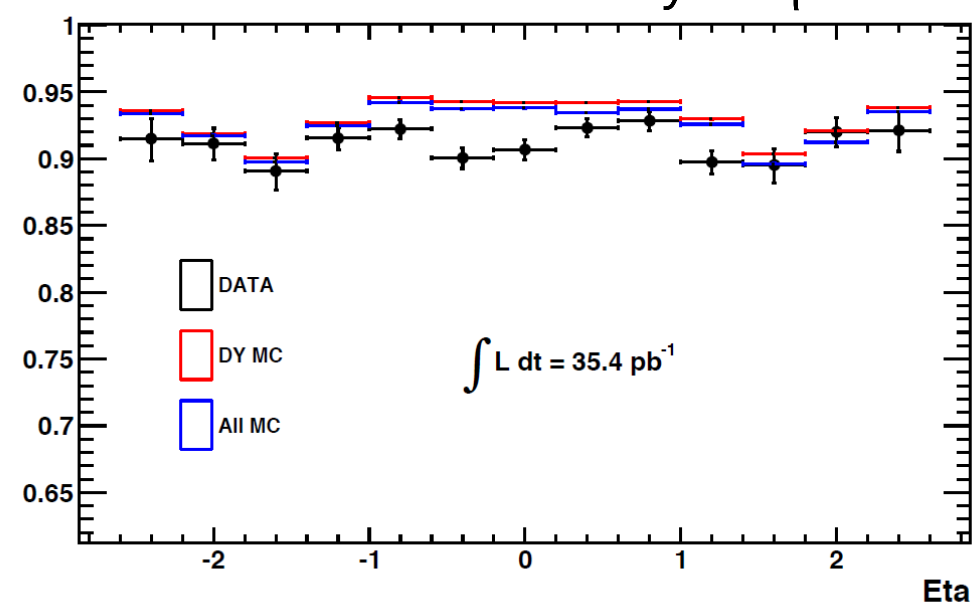
Electron selection

Variable	Barrel	Endcap
E_T	> 30 GeV	> 30 GeV
η_{SC}	$\|\eta\| < 1.442$	$1.560 < \|\eta\| < 2.5$
isEcalDriven	true	true
$\Delta\eta_{in}$	$\|\Delta\eta_{in}\| < 0.005$	$\|\Delta\eta_{in}\| < 0.007$
$\Delta\phi_{in}$	$\|\Delta\phi_{in}\| < 0.09$	$\|\Delta\phi_{in}\| < 0.09$
H/E	< 0.05	< 0.05
$\sigma_{i\eta i\eta}$	n/a	< 0.03
$E^{2\times5}/E^{5\times5}$	> 0.94 OR $E^{1\times5}/E^{5\times5} > 0.83$	n/a
EM + Had Depth 1 Isolation	$< 2 + 0.03\times E_T$	< 2.5 for $E_T < 50$ else $< 2.5 + 0.03 \times (E_T - 50)$
Had Depth 2 Isolation	n/a	< 0.5
Track Isol: Track p_T	< 7.5	< 15

electron id efficiency vs p_T



electron id efficiency vs η



Darren Puigh

MET and electron balance

- Energy imbalance due to missing neutrino accounted for using particle flow technique
  - Particle flow reconstructs complete list of particles in event
    - e.g. muons, electrons, photons, charged and neutral hadrons
  - Missing transverse energy (MET) is the negative vector sum of the energy of all particles projected on the transverse plane

- Electron and neutrino balanced in transverse plane in both direction and magnitude
  - $\Delta\phi$(electron,MET) > 2.5 radians (back-to-back)
  - $0.4 < E_T^{ele}/MET < 1.5$

Background cutflow (from MC)

Sample	Preselection	1 Good Ele	$\Delta\phi_{eE_T^{miss}} > 2.5$	$0.4 < \mathrm{E}_\mathrm{T}^{ele}/\mathrm{E}_\mathrm{T}^{miss} < 1.5$
$W \to e\nu$	- , 47%	64%, 30%	85%, 26%	87%, 23% 84846.78
Multi-jet	- , $1 \cdot 10^{-3}$%	1 %, $2 \cdot 10^{-5}$%	38%, $8 \cdot 10^{-6}$%	3%, $2 \cdot 10^{-7}$% 3282.35
$t\bar{t}$	- , 27%	37%, 10%	19%, 2%	54%, 1% 59.62
DY $\to e, \mu, \tau$	- , 15%	47%, 7%	32%, 2%	4%, 0% 150.94
WW, WZ, ZZ	- , 15%	49%, 8%	41%, 3%	59%, 2% 44.24
$W \to \tau\nu$	- , 2%	27%, 0.6%	60%, 0.4%	77%, 0.3% 1082.89
$W \to \mu\nu$	- , 0.3%	5%, $2 \cdot 10^{-2}$%	54%, $9 \cdot 10^{-3}$%	81%, $7 \cdot 10^{-3}$% 27.29
γ+jets	- , $6 \cdot 10^{-3}$%	19%, $1 \cdot 10^{-3}$%	41%, $5 \cdot 10^{-4}$%	1%, $5 \cdot 10^{-6}$% 136.60

efficiency relative to previous cut

total efficiency

Signal cutflow

$\geq$ 64% efficient

$M_{W'}$(TeV/c^2)	Preselection	1 Good Ele	$\Delta\phi_{eE_T^{miss}} > 2.5$	$0.4 < \mathrm{E_T^{ele}}/\mathrm{E_T^{miss}} < 1.5$
0.6	- , 88%	80%, 70%	94%, 66%	97%, 64% 191.30
0.7	- , 88%	80%, 70%	95%, 66%	97%, 64% 99.15
0.8	- , 89%	79%, 70%	95%, 66%	97%, 64% 56.46
0.9	- , 90%	79%, 70%	96%, 67%	98%, 66% 32.92
1.0	- , 90%	79%, 71%	95%, 67%	98%, 66% 19.96
1.1	- , 89%	79%, 70%	96%, 67%	98%, 66% 12.21
1.2	- , 90%	79%, 71%	96%, 69%	98%, 67% 8.13
1.3	- , 89%	79%, 70%	96%, 68%	98%, 66% 5.16
1.4	- , 89%	79%, 70%	96%, 67%	98%, 66% 3.24
1.5	- , 89%	79%, 71%	96%, 68%	98%, 67% 2.39
2.0	- , 88%	78%, 69%	96%, 66%	98%, 65% 0.34

* Generated with Pythia, NNLO k-factor (van Neerven)

Transverse mass as test statistic

- Use transverse mass, calculated from electron and MET, as test statistic

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

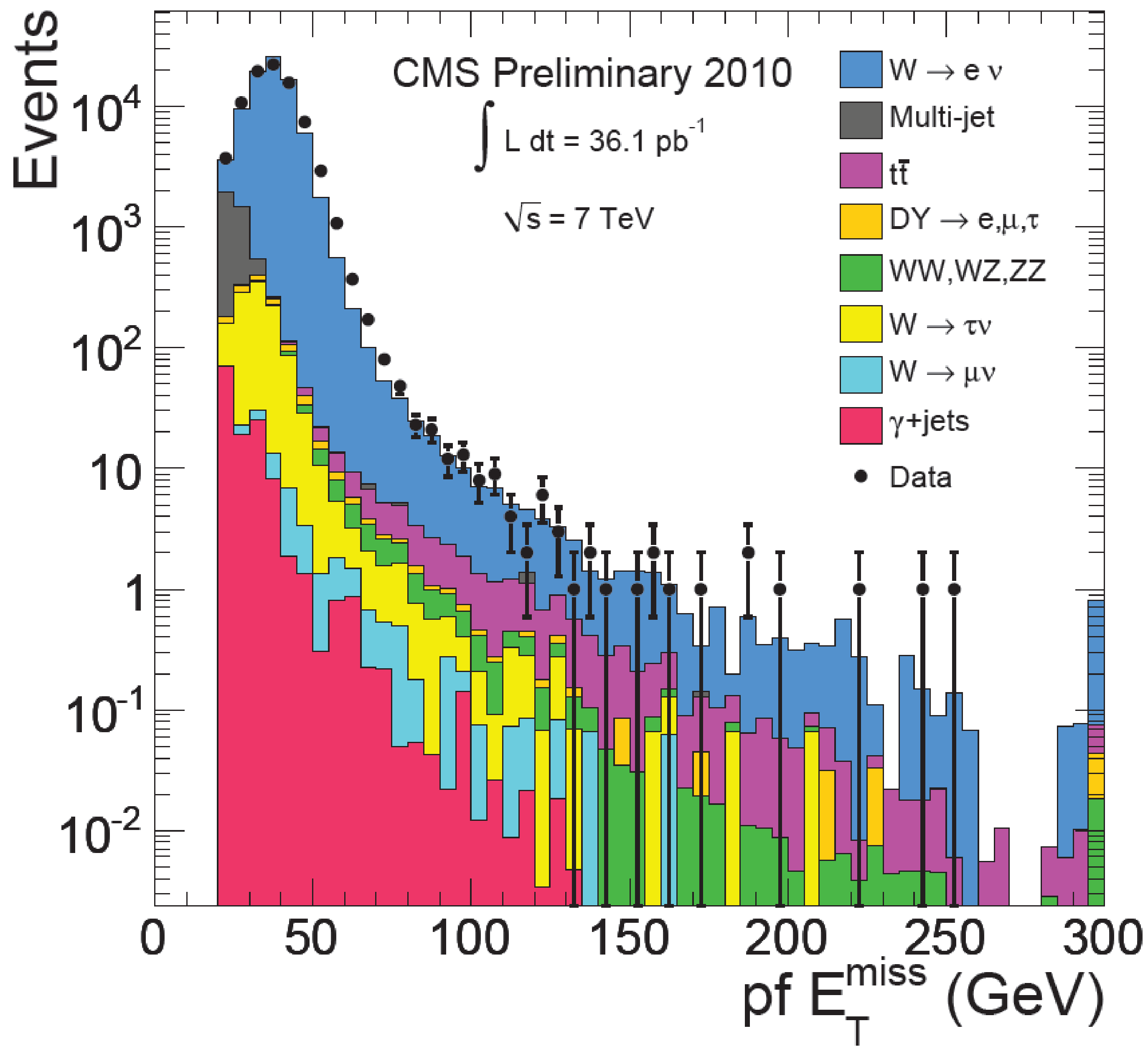
- Need to determine both the shape and the normalization of the transverse mass distributions for our backgrounds
- We use a data driven estimate for W and QCD (our dominant backgrounds) for both shape and normalization
  - The other backgrounds are from MC

Background	Shape	Normalization
$W \to e\nu$	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

Other MC bkgs: γ+jets, $W\to\tau\nu$, $W\to\mu\nu$, $Z/\gamma^*\to\ell\ell$, WW, WZ, ZZ, $t\bar{t}$, single top, $Z+\gamma\to\nu\nu+\gamma$

Calibrating the MC

- The response and the resolution of the calorimeters is different between data and simulation
  - Arises due to detector effects not fully modeled, e.g. pile-up



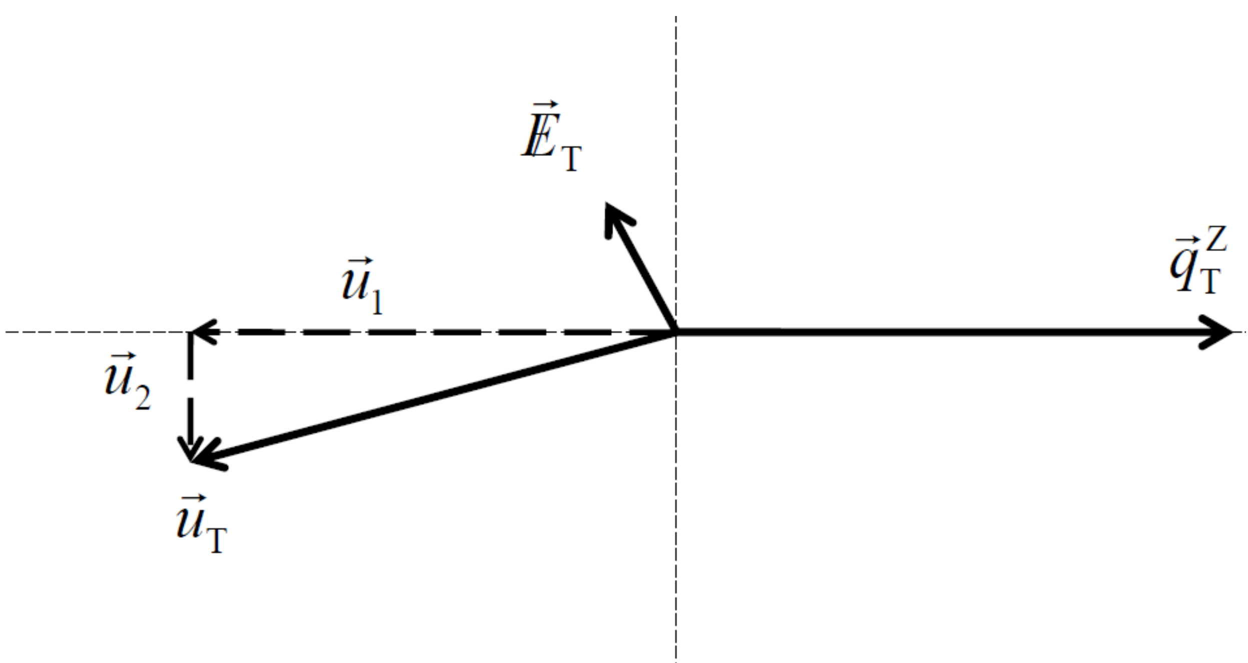
Calibrating the MC

- The response and the resolution of the calorimeters is different between data and simulation
  - Arises due to detector effects not fully modeled, e.g. pile-up
- Z boson used to calibrate the detector simulation
  - Presents a clean signature and provides a standard candle
- Hadronic recoil from MET compared with boson p_T from leptons
  - Recoil due to hard radiation (jets), soft radiation (unclustered energy), and the underlying event

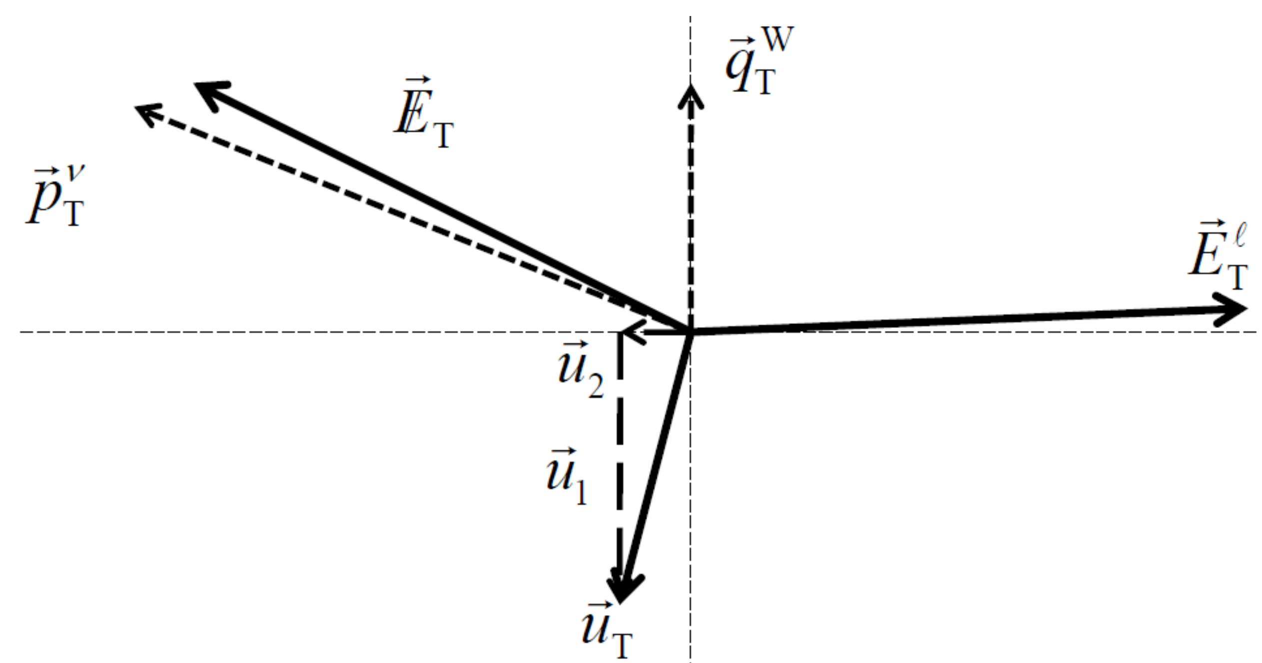
Hadronic recoil

- Estimate the parallel (u_1) and transverse (u_2) component of the hadronic recoil (u_T) in MC and DATA using $Z \rightarrow ee$ events
  - u_1 is dominated by calorimeter response to energy deposits
  - u_2 is dominated by the ambient calorimeter noise

$$\vec{u}_T = -\vec{E}_T^{miss} - \sum_l \vec{E}_T^l \qquad \vec{u}_T = \vec{u}_1 + \vec{u}_2$$



Z boson events



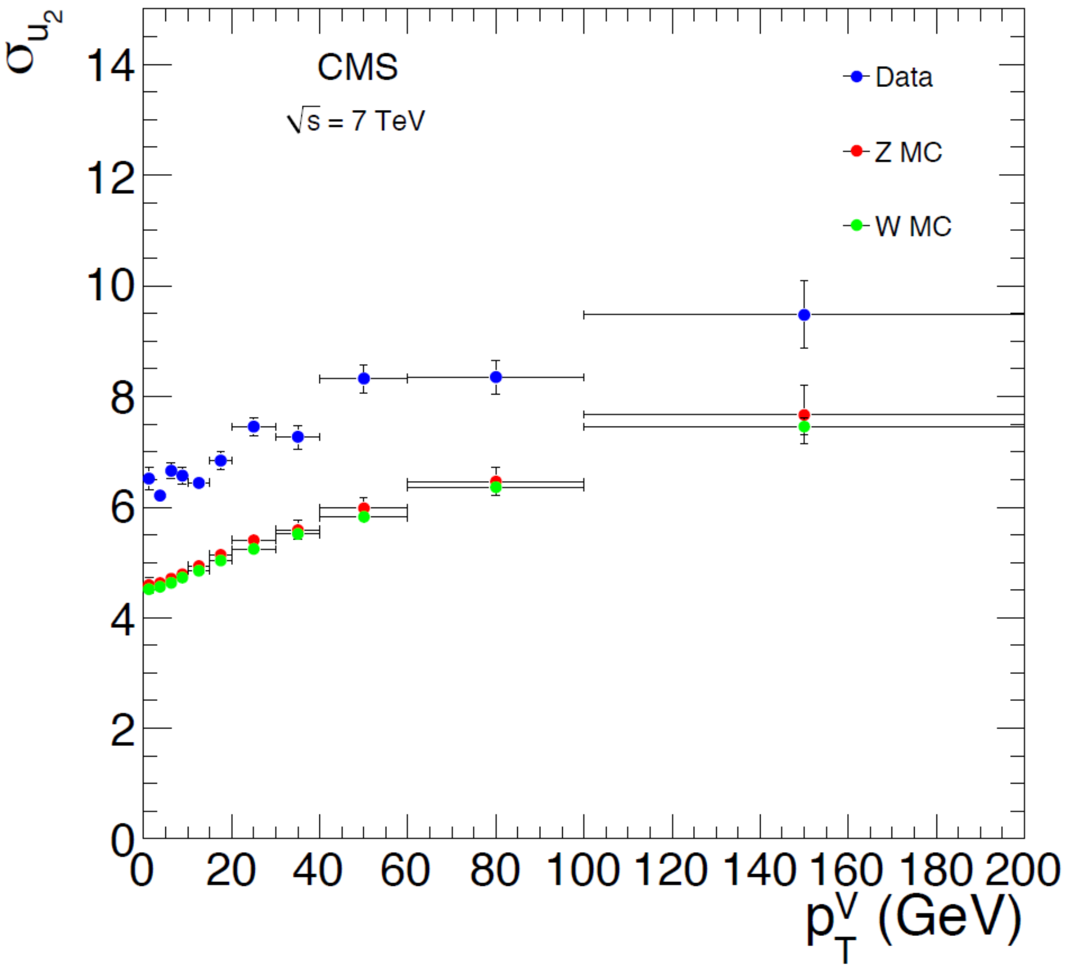
W boson events

Recoil correction to MET

- We exploit the similarities between the hadronic recoil of W and Z bosons to construct a recoil corrected MET for W boson events

$$u_i = Gauss(f_{u_i}(p_T^W), \sigma_{u_i}(p_T^W))$$

Model components with Gaussians in boson p_T



- Transverse momentum of W found using generator level information
  - We have access to this as we are correcting the MC shape

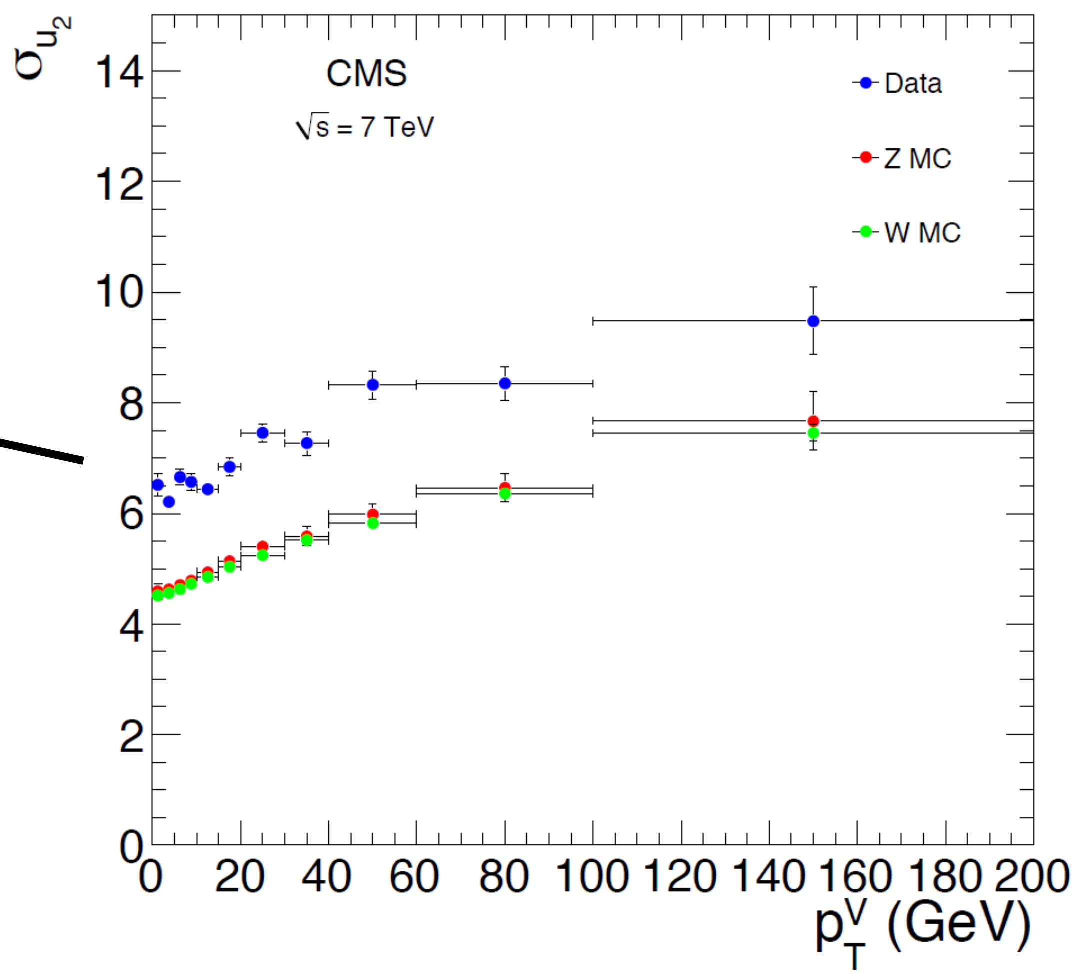
Recoil correction to MET

- We exploit the similarities between the hadronic recoil of W and Z bosons to construct a recoil corrected MET for W boson events

$$u_i = Gauss(f_{u_i}(p_T^W), \sigma_{u_i}(p_T^W))$$

$$\sigma_{u_i}(p_T^W) = \frac{\sigma_{u_i}^{Zdata}(p_T^W)}{\sigma_{u_i}^{Zmc}(p_T^W)} \cdot \sigma_{u_i}^{Wmc}(p_T^W)$$

Determine Z data/MC scale factors to correct W MC response and resolution event-by-event



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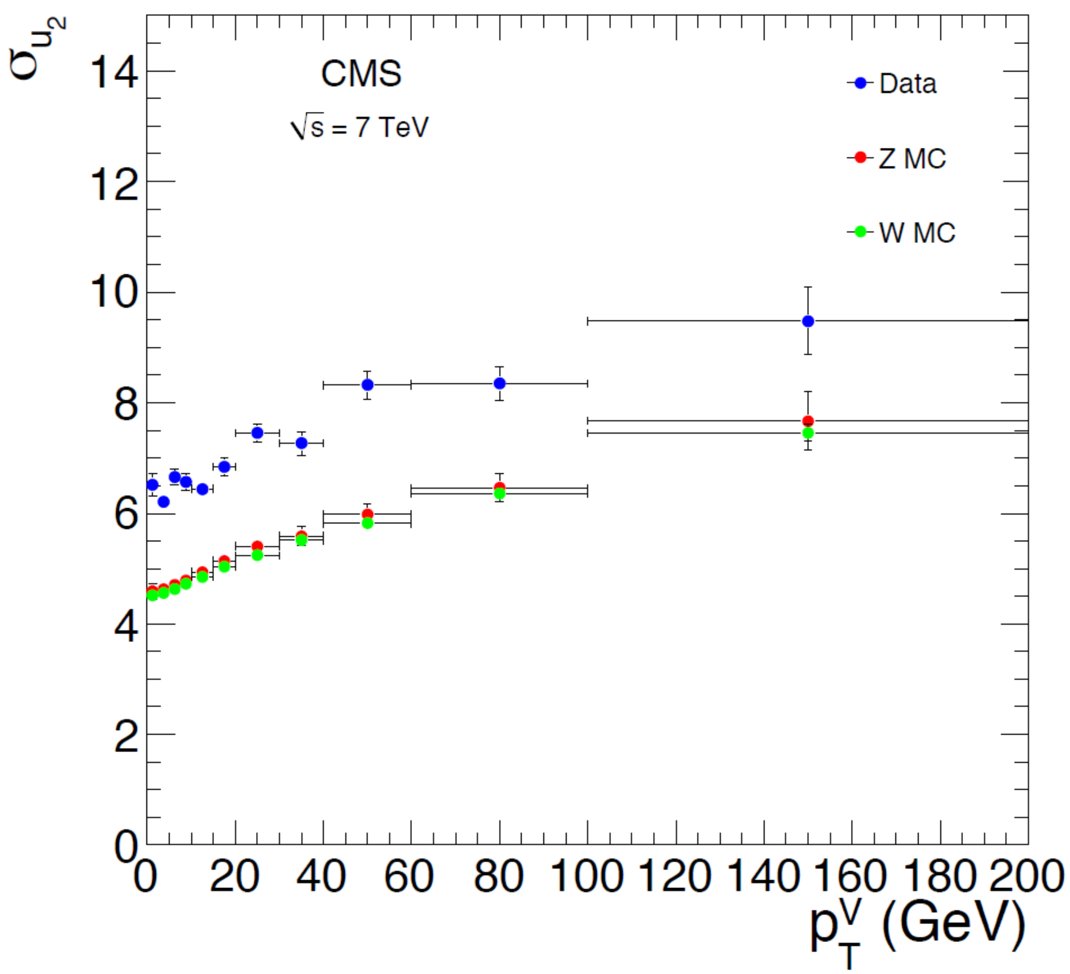
$$\vec{u}_T = \vec{u}_1 + \vec{u}_2$$

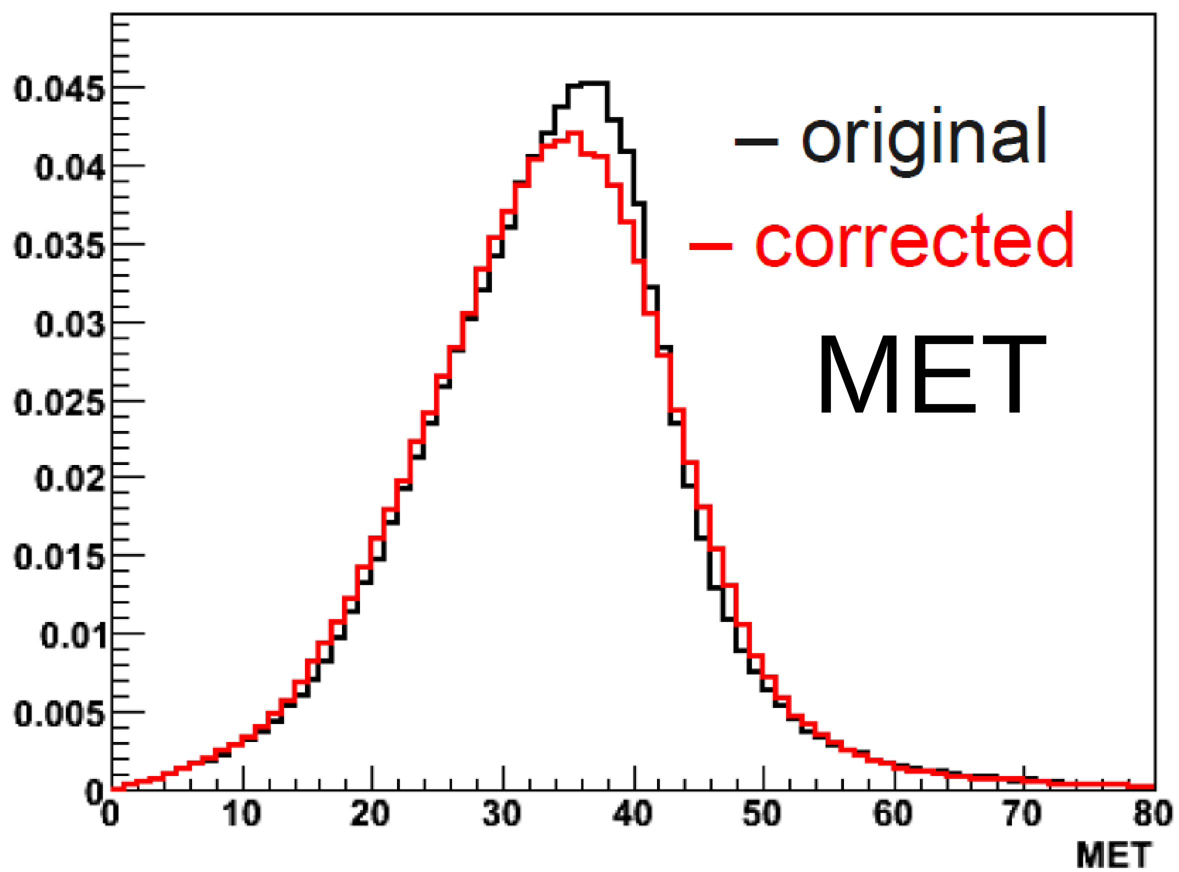
$$\vec{E}_T^{miss,corr} = -\vec{u}_T - \vec{E}_T^{ele}$$



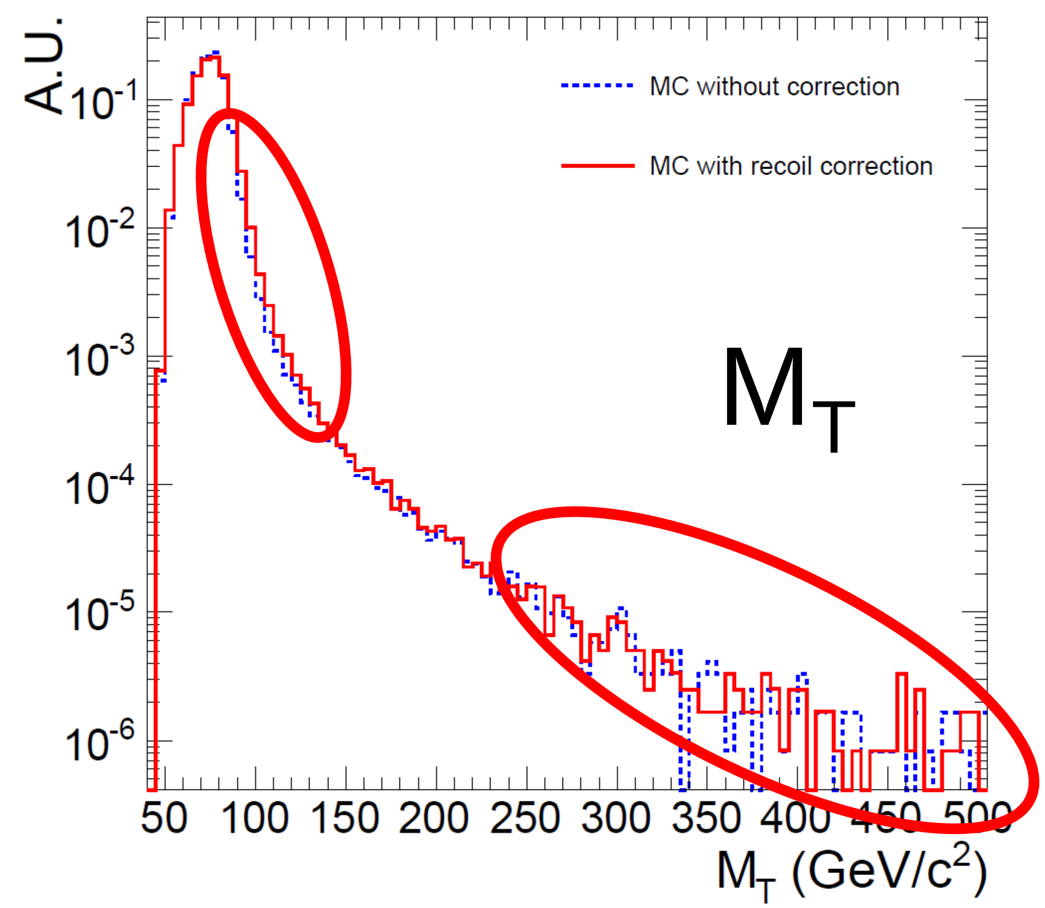
- Transverse momentum of W found using generator level information
  - We have access to this as we are correcting the MC shape

$W \to e\nu$ transverse mass template

- Method gives recoil-corrected MET on event-by-event basis
  - Use this MET in our event selections (E_T^{ele}/MET and $\Delta\phi$)
  - Use this MET to create transverse mass template for $W \to e\,\nu$
- Comparing M_T distributions with and without correction, agreement with data improves most for $100 < M_T < 150$ GeV
  - Fairly good agreement in tails $\to$ method does not introduce large M_T events

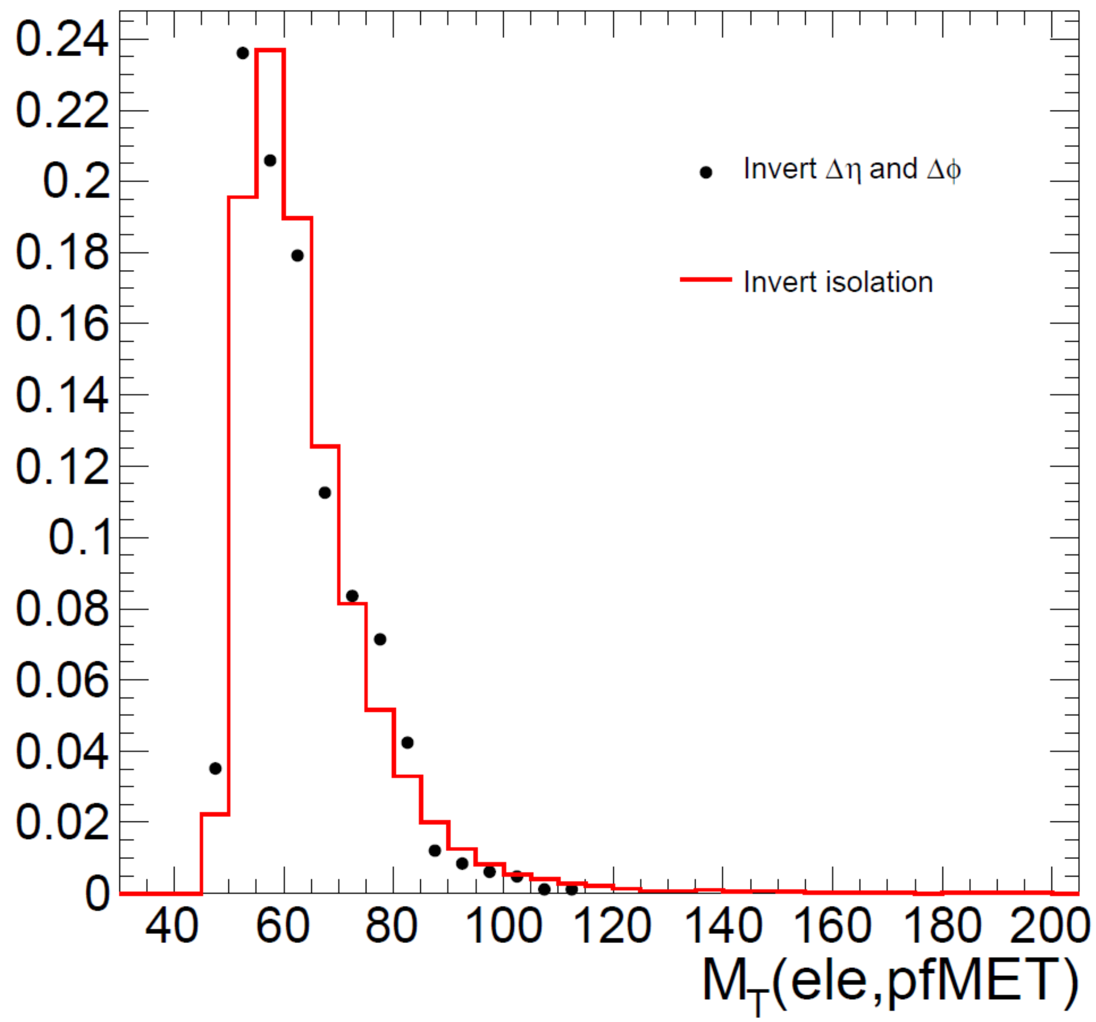


Darren Puigh



QCD transverse mass template

- Use M_T distribution from non-isolated electrons as our template
  - Sample enriched in multi-jet events
- As a check, we compare this to the template obtained from instead inverting the $\Delta\eta$(trk,SC) and $\Delta\phi$(trk,SC) requirements
  - Decent agreement for orthogonal samples



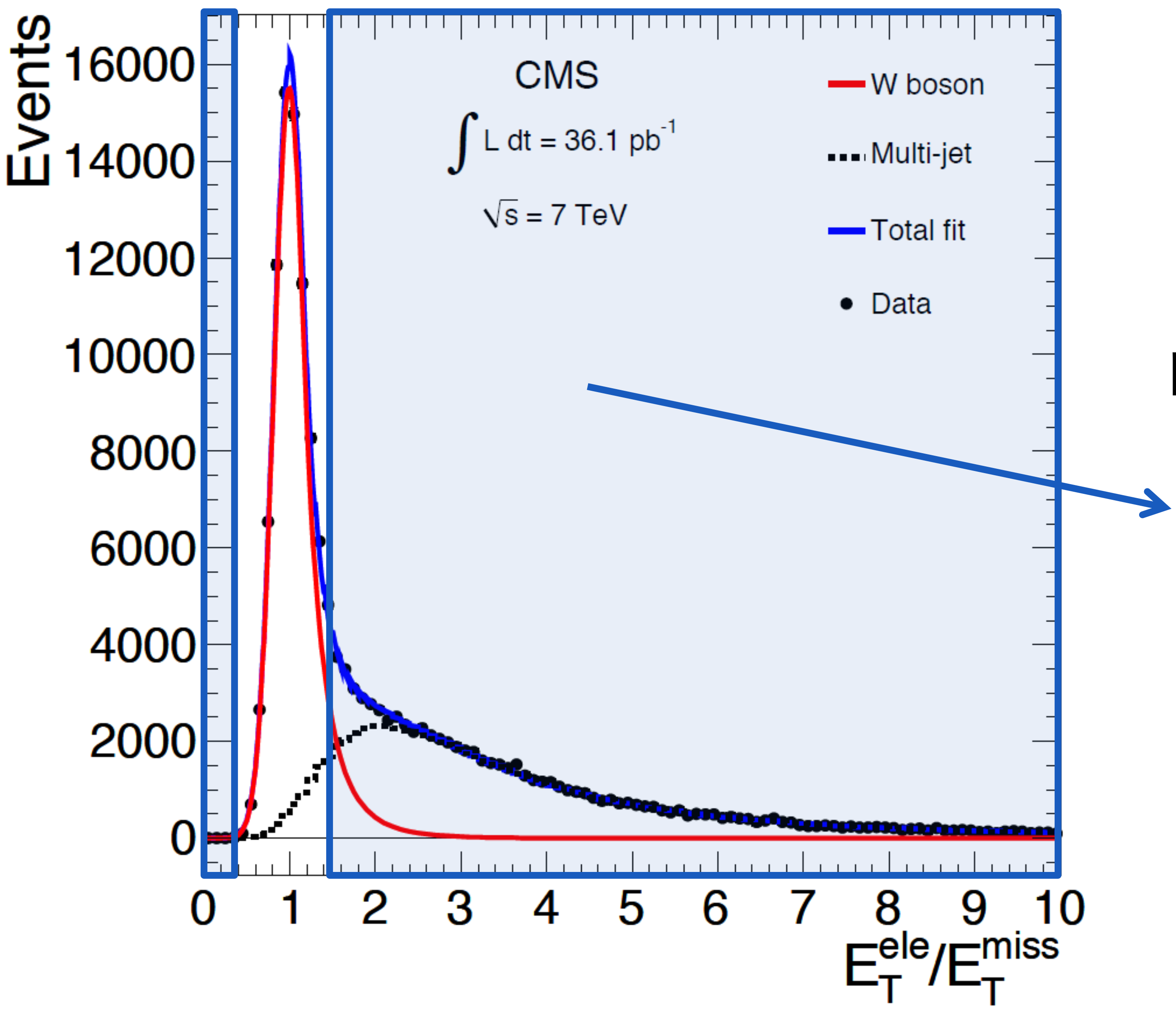
QCD transverse mass template

- Use M_T distribution from non-isolated electrons as our template
  - Sample enriched in multi-jet events
- As a check, we compare this to the template obtained from instead inverting the $\Delta\eta$(trk,SC) and $\Delta\phi$(trk,SC) requirements
  - Decent agreement for orthogonal samples
- Comparing the number of predicted QCD events in different M_T bins, we again see good agreement (within uncertainty)

M_T range	inverted isolation prediction	inverted track/SC matching prediction
(25, 50)	79 ± 40	76 ± 38
(50, 75)	2900 ± 1500	1800 ± 890
(75, 100)	440 ± 220	300 ± 150
(100, 125)	55 ± 28	15.8 ± 7.9
(125, 150)	13.4 ± 6.8	0.0 ± 0.0

Sideband examination

- Use E_T^{ele}/MET distribution (last step of our selection) to normalize W and QCD M_T templates
  - Fit data E_T^{ele}/MET distribution with QCD template (non-iso electrons) and W template (CB function), other backgrounds from MC



M_T distributions normalized to template area in the region

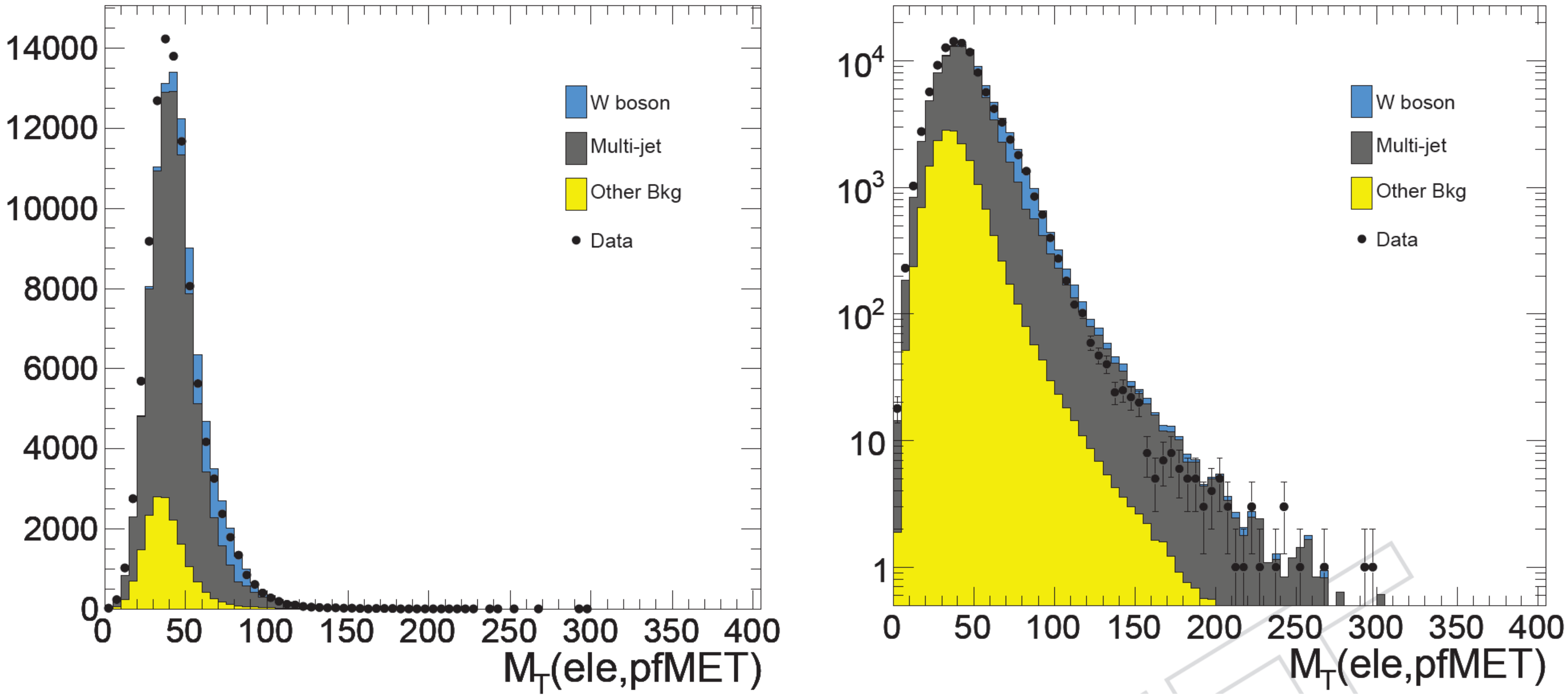
E_T^{ele}/MET < 0.4

or

E_T^{ele}/MET > 1.5

Sideband examination

- Using our background estimation technique, we look at events that fail the E_T^{ele}/MET cut
  - As expected, QCD dominates in this region
- Although agreement is not perfect, shape and normalization are reasonable and covered by the background uncertainty



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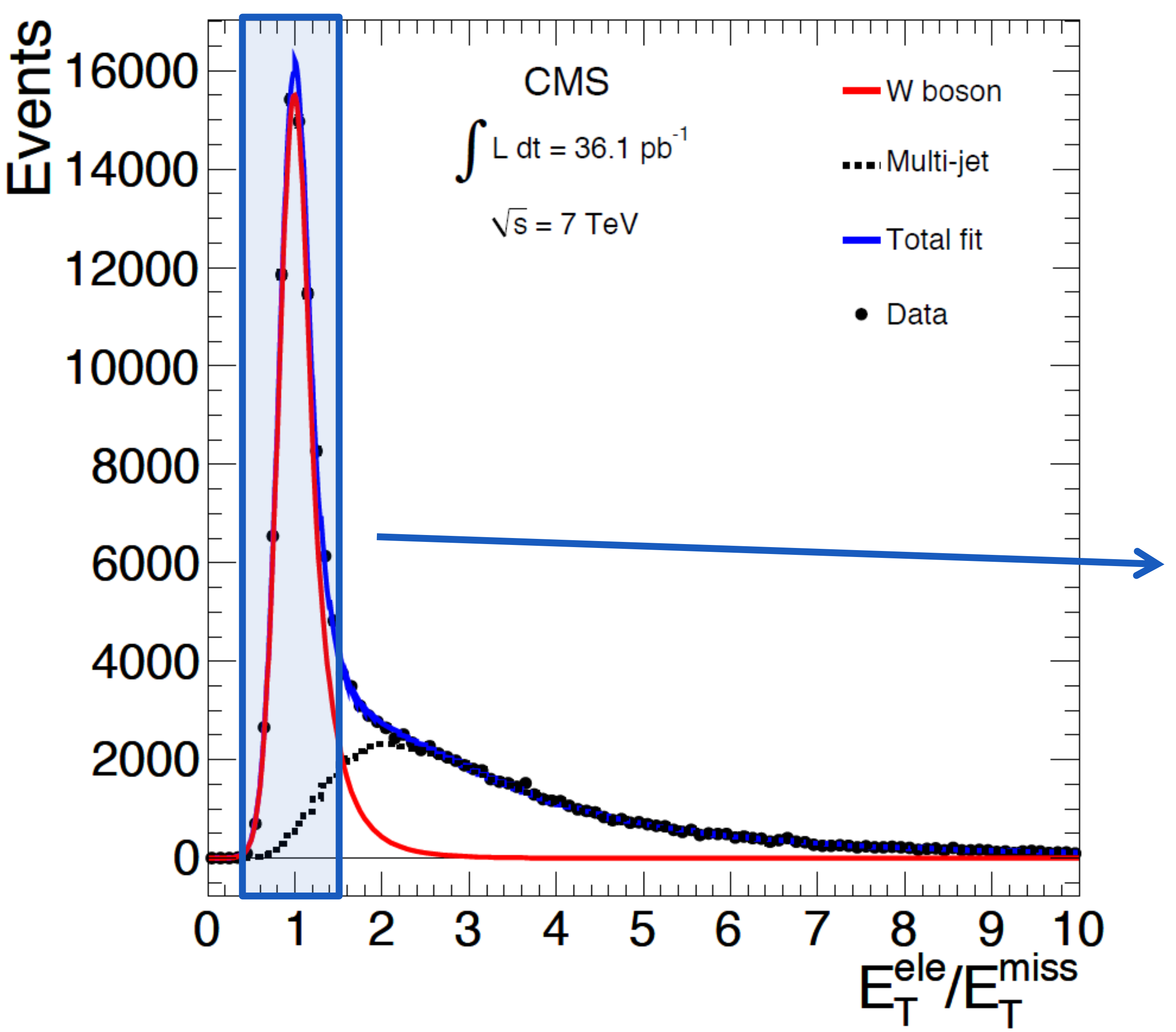
W and QCD yield extraction

- Use E_T^{ele}/MET distribution (last step of our selection) to normalize W and QCD M_T templates
  - Fit data E_T^{ele}/MET distribution with QCD template (non-iso electrons) and W template (CB function), other backgrounds from MC



M_T distributions normalized to template area in the region $0.4 < E_T^{ele}/MET < 1.5$

Darren Puigh

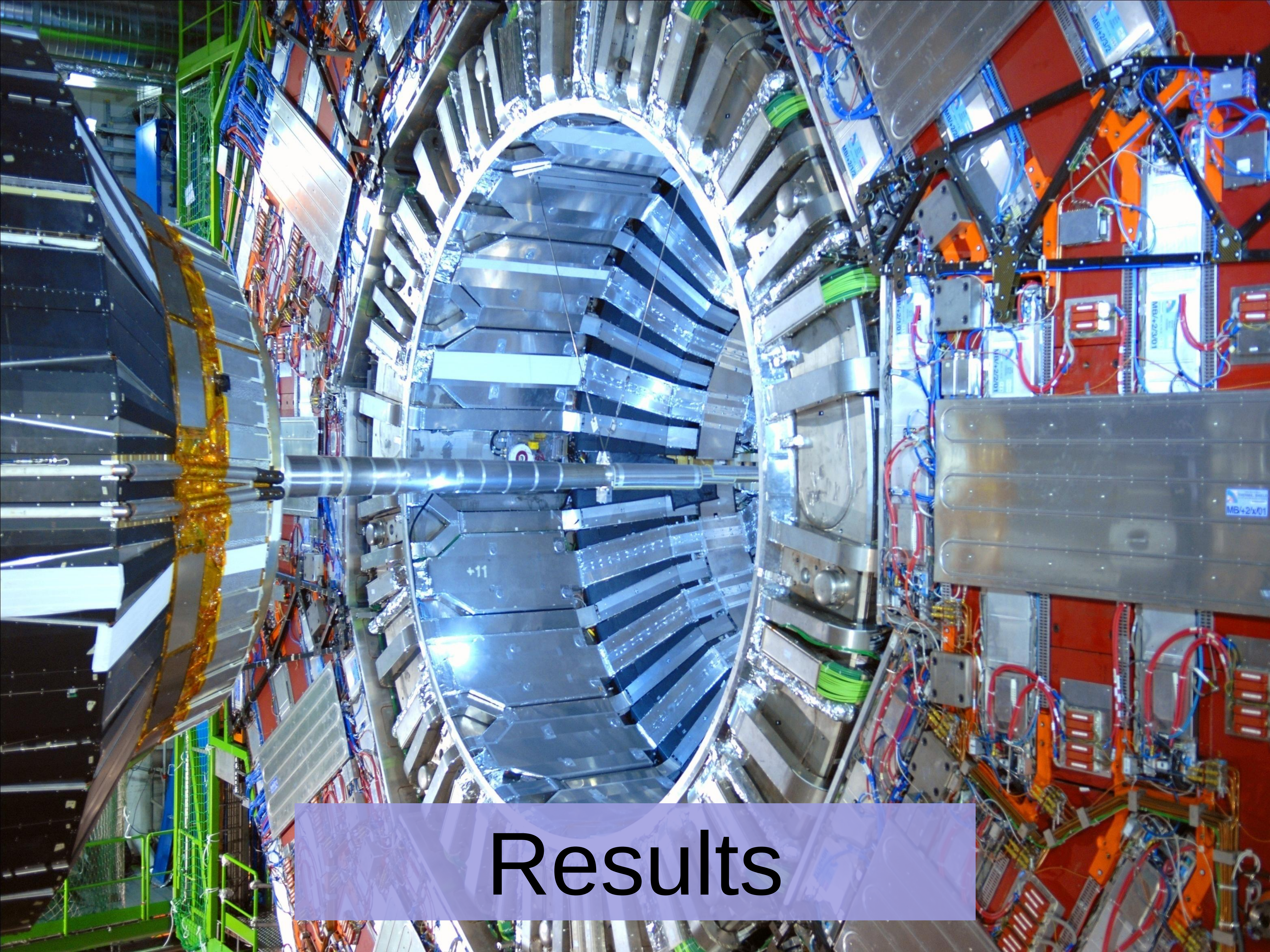
Background expectation

- Full data-driven estimate
- Dominant background is $W \rightarrow e\nu$
- Backgrounds die off quickly as a function of transverse mass

Sample	> 45	> 200	> 300	> 400	> 500	> 600
$W \rightarrow e\nu$	75609 ± 319	33.7 ± 2.7	7.19 ± 0.91	2.52 ± 0.48	0.88 ± 0.28	0.57 ± 0.21
Multi-jet	7083 ± 3546	6.3 ± 3.3	1.64 ± 0.93	0.47 ± 0.33	0.23 ± 0.20	0.23 ± 0.20
$W \rightarrow \tau\nu$	1083 ± 80	1.1 ± 0.3	0.21 ± 0.19	<0.13	<0.08	<0.08
$t\bar{t}$	60 ± 23	4.1 ± 1.7	0.64 ± 0.29	0.15 ± 0.09	0.03 ± 0.03	0.01 ± 0.02
Other bkg	359 ± 73	2.0 ± 0.4	0.56 ± 0.14	0.15 ± 0.05	0.06 ± 0.03	0.04 ± 0.03
Total bkg	84194 ± 3563	47.2 ± 4.7	10.24 ± 1.35	3.29 ± 0.61	1.21 ± 0.35	0.85 ± 0.30

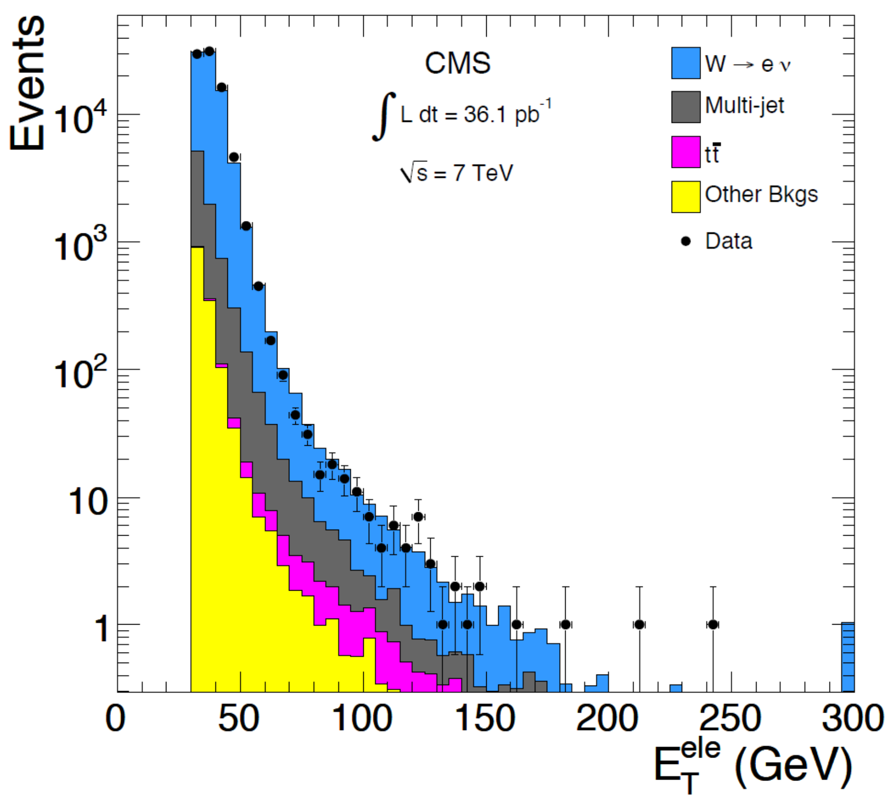
* Other MC bkgs: γ+jets, $W \rightarrow \mu\nu$, $Z/\gamma^* \rightarrow \ell\ell$, WW, WZ, ZZ, single top, $Z+\gamma \rightarrow \nu\nu+\gamma$

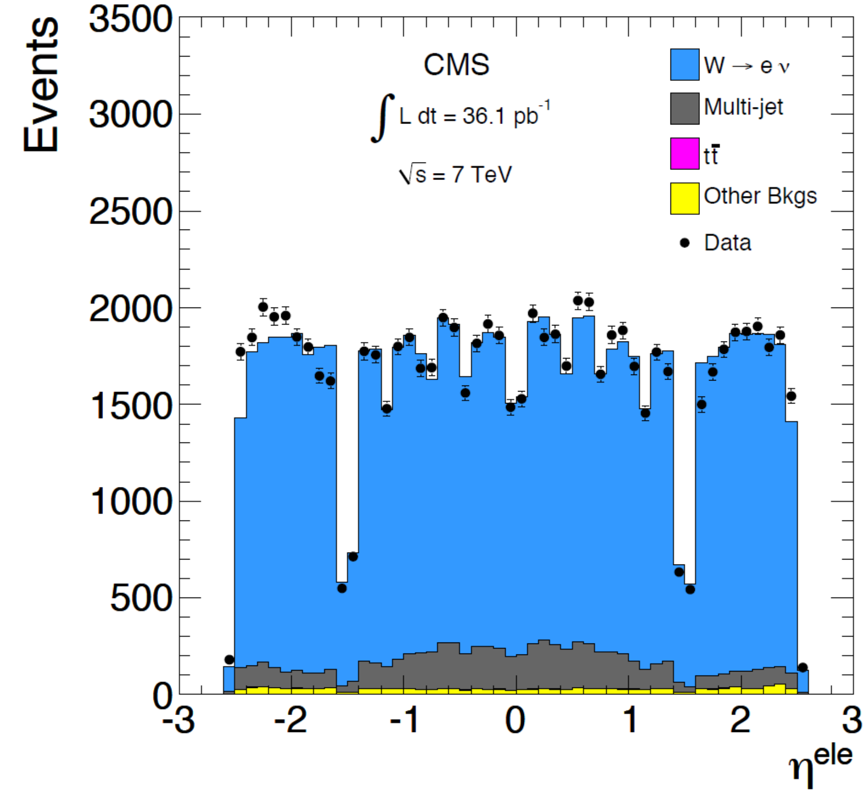
** Table includes both statistical and systematic uncertainties added in quadrature (does not include luminosity uncertainty)

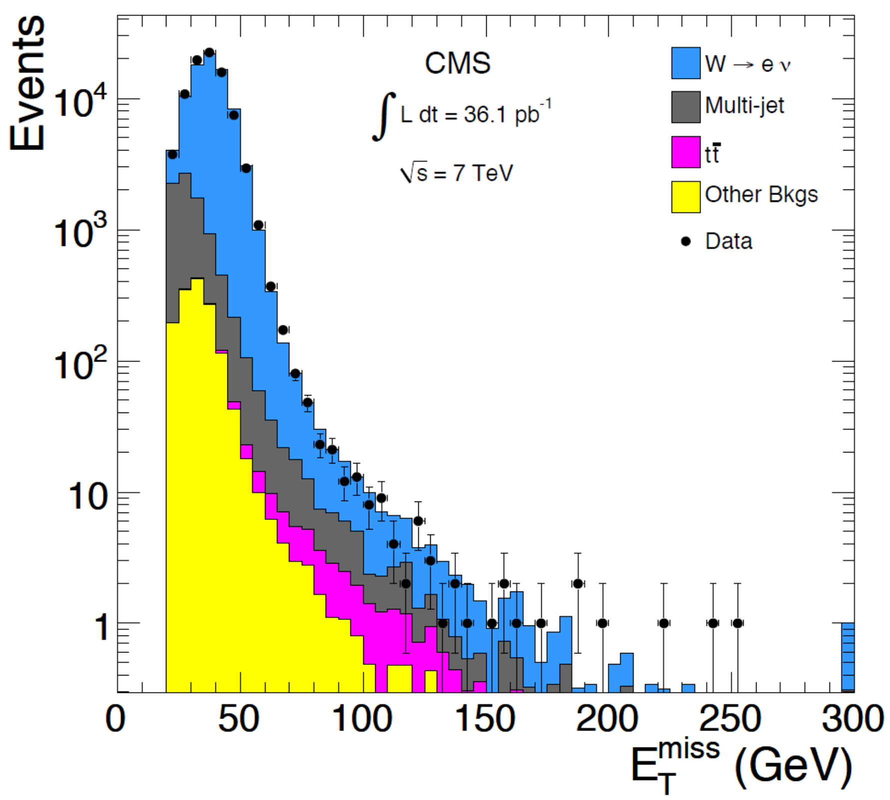


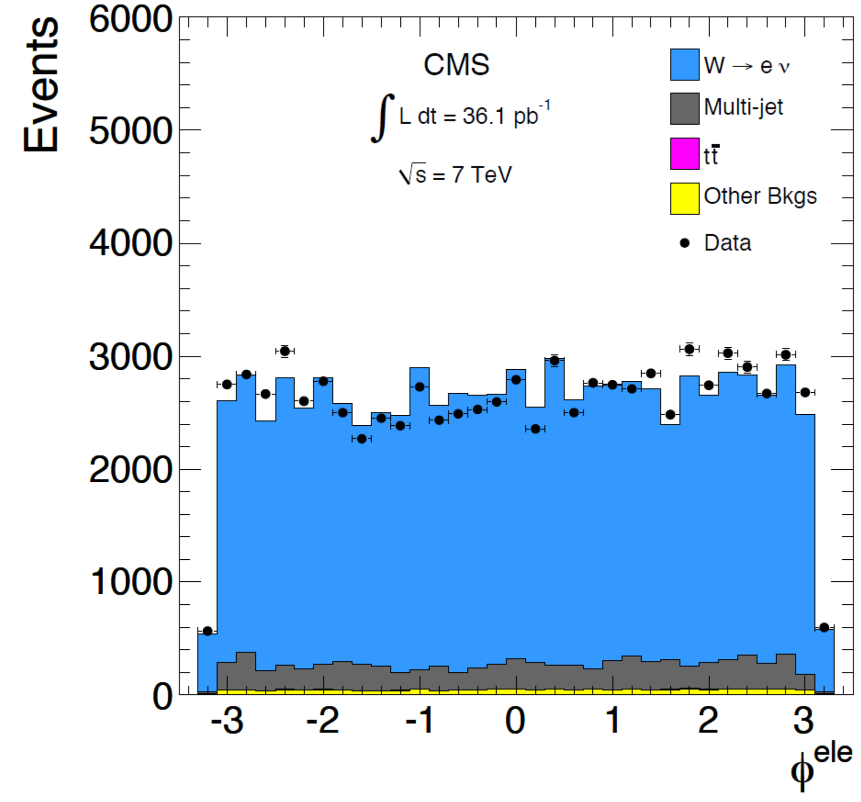
Results

Background and data comparisons



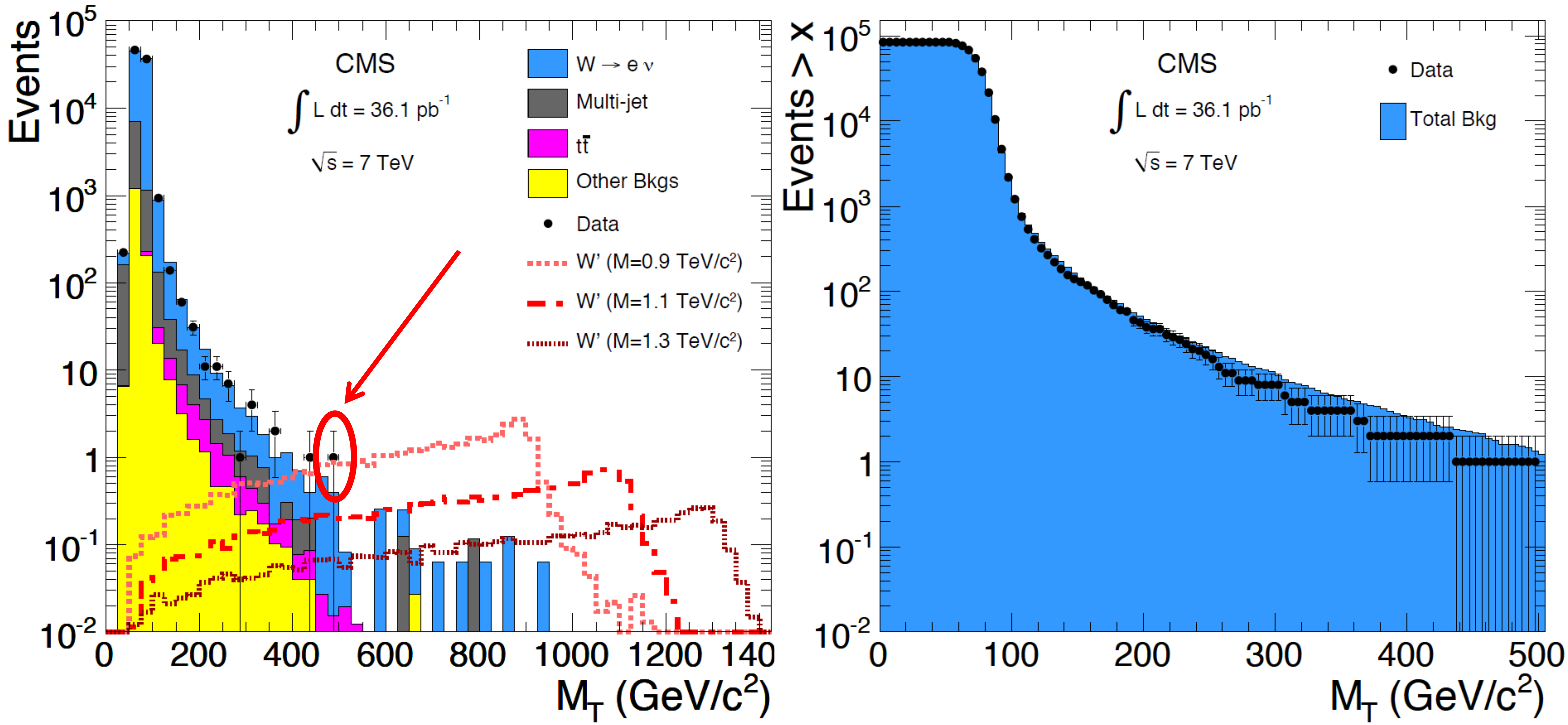




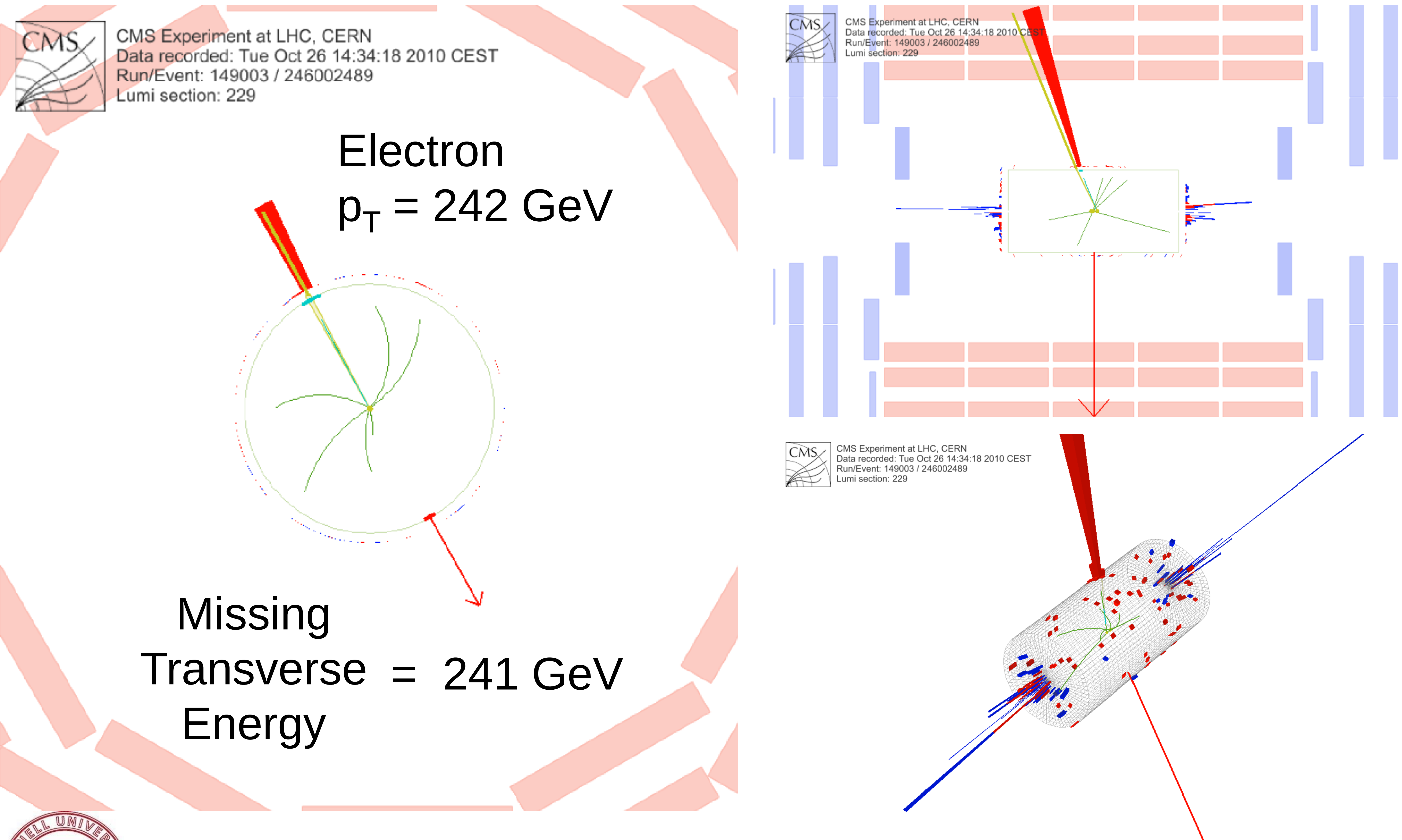


Transverse mass distribution results

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



Highest transverse mass event: M_T = 493 GeV



Systematic uncertainty

- Values indicate the percent variation on the number of events with M_T > 500 GeV
  - Electron reconstruction efficiency uncertainty from W/Z cross section measurement
  - Electron identification efficiency uncertainty from W′ and Z′ searches

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_T^{miss} scale	5%	1.6%	1.4%
E_T^{miss} resolution	10%	0.9%	0.5%
Cross section		10%	1.1%
Total (lumi not included)		10.5%	10.1%

Data

- Good agreement between data and background prediction
- As we do not see an excess in data, we can set a lower-bound on the mass of the W′ boson for our model

Sample	> 45	> 200	> 300	> 400	> 500	> 600
$W \to e\nu$	75609 ± 319	33.7 ± 2.7	7.19 ± 0.91	2.52 ± 0.48	0.88 ± 0.28	0.57 ± 0.21
Multi-jet	7083 ± 3546	6.3 ± 3.3	1.64 ± 0.93	0.47 ± 0.33	0.23 ± 0.20	0.23 ± 0.20
$W \to \tau\nu$	1083 ± 80	1.1 ± 0.3	0.21 ± 0.19	<0.13	<0.08	<0.08
$t\bar{t}$	60 ± 23	4.1 ± 1.7	0.64 ± 0.29	0.15 ± 0.09	0.03 ± 0.03	0.01 ± 0.02
Other bkg	359 ± 73	2.0 ± 0.4	0.56 ± 0.14	0.15 ± 0.05	0.06 ± 0.03	0.04 ± 0.03
Total bkg	84194 ± 3563	47.2 ± 4.7	10.24 ± 1.35	3.29 ± 0.61	1.21 ± 0.35	0.85 ± 0.30
Data	84468	38	8	2	0	0

* Other MC bkgs: γ+jets, $W \to \mu\nu$, $Z/\gamma^* \to \ell\ell$, WW, WZ, ZZ, single top, $Z+\gamma \to \nu\nu+\gamma$

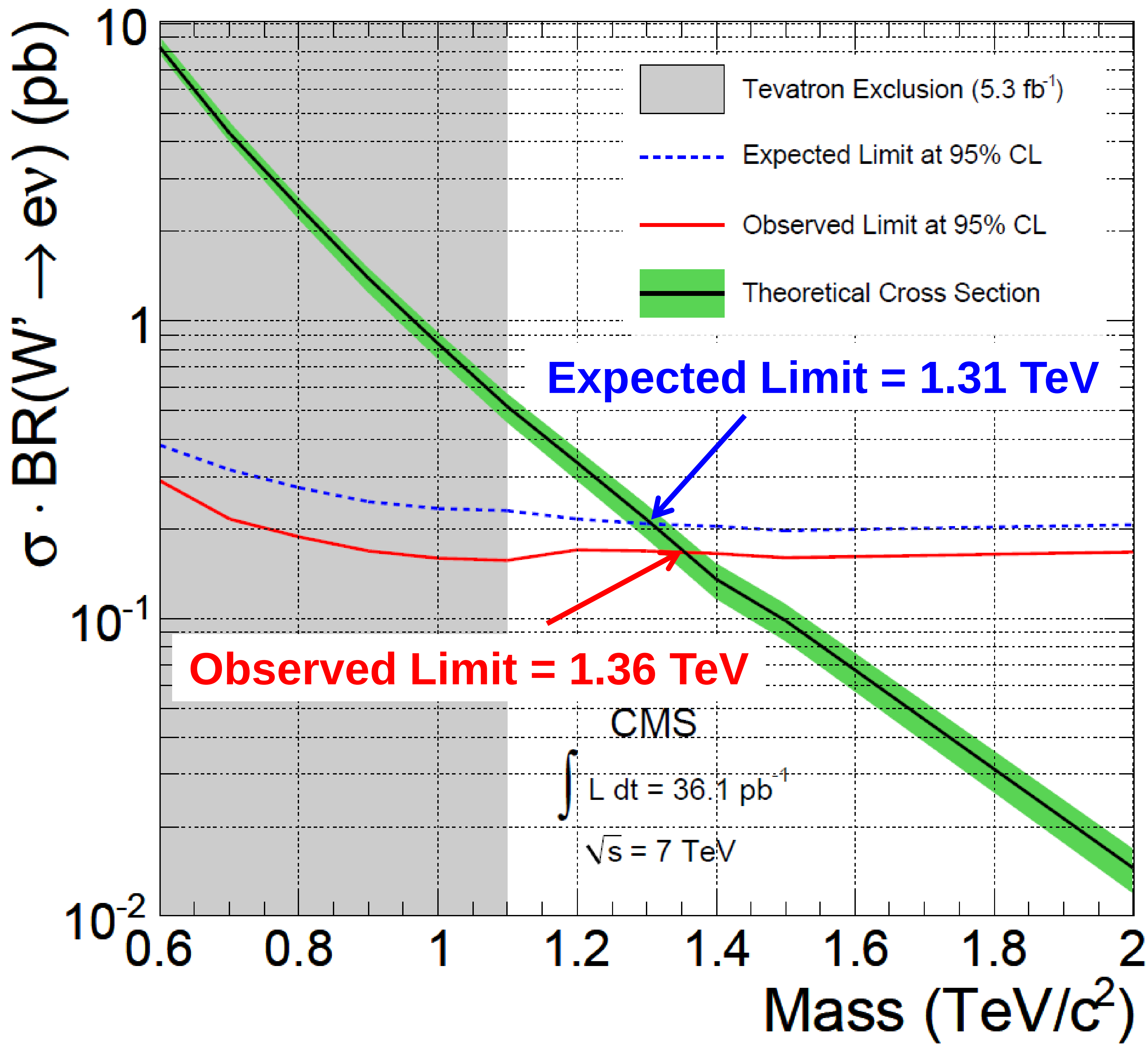
** Table includes both statistical and systematic uncertainties added in quadrature (does not include luminosity uncertainty)

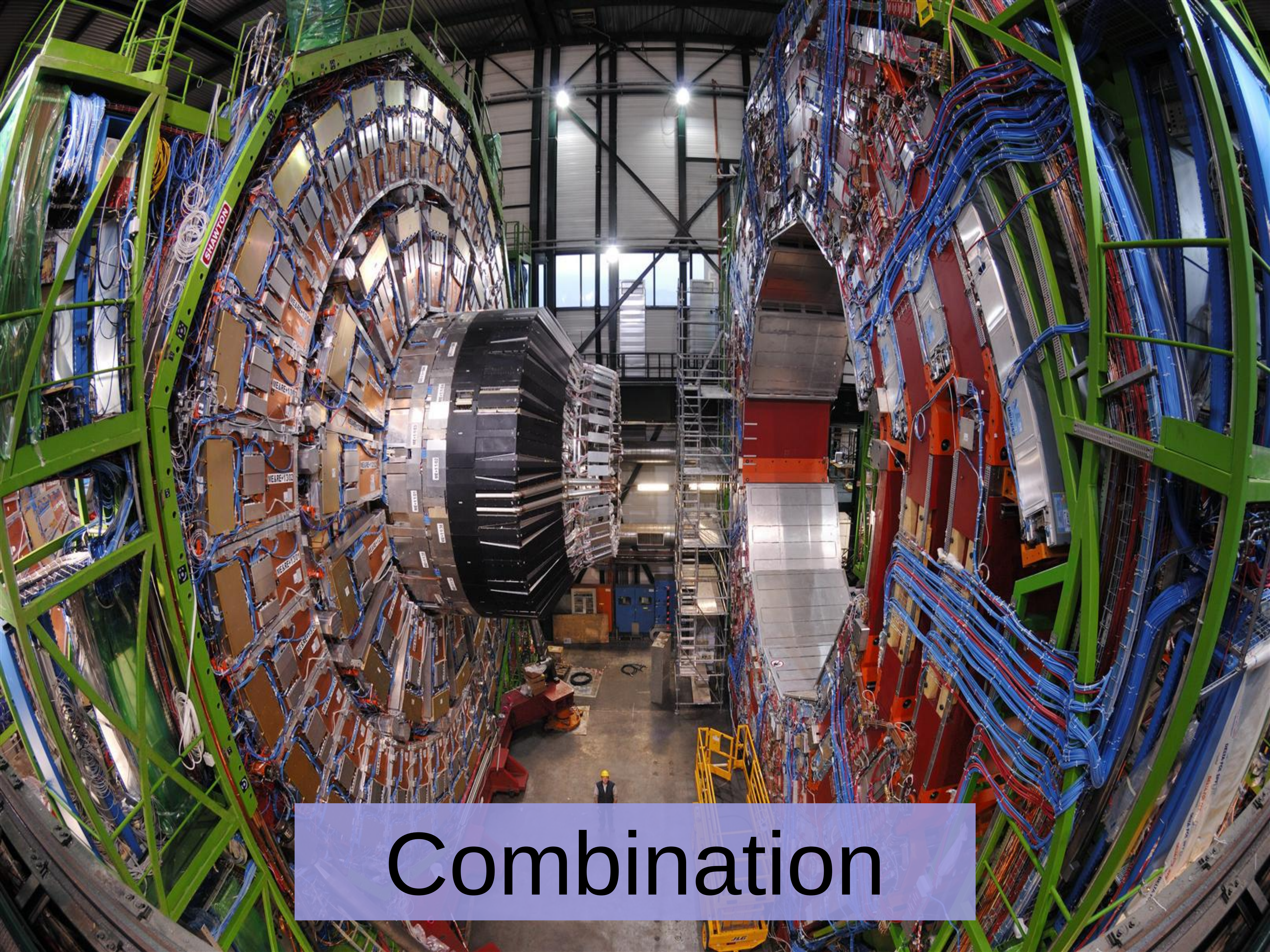
Cut-and-count statistical method

- Using Bayesian 95% CL limit calculator, described elsewhere, to determine expected and observed limits
  - Flat prior assumed for signal cross section
  - Log-normal distribution for integration over nuisance parameters
- For each W′ mass point, use M_T cut with best *expected* limit

$M_{W'}$ (TeV/c^2)	min M_T (TeV/c^2)	n_s	n_b	n_d	σ_t (pb)	σ_e (pb)	σ_o (pb)
0.6	0.400	129.38 ± 20.16	3.29 ± 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

Exclude W′ with masses below 1.36 TeV at 95% CL

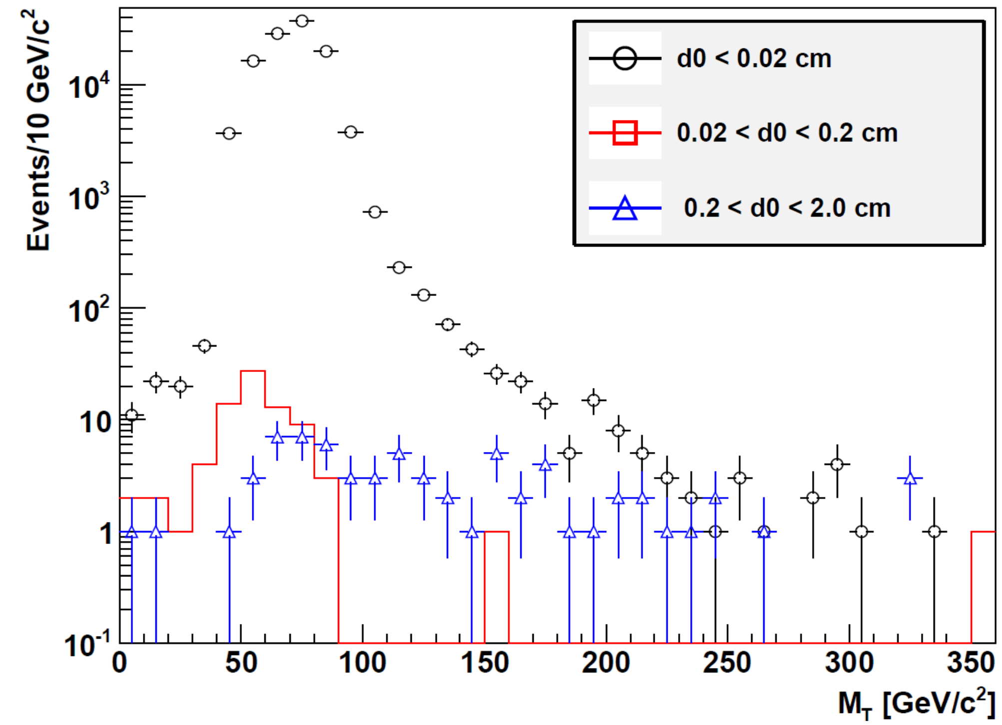


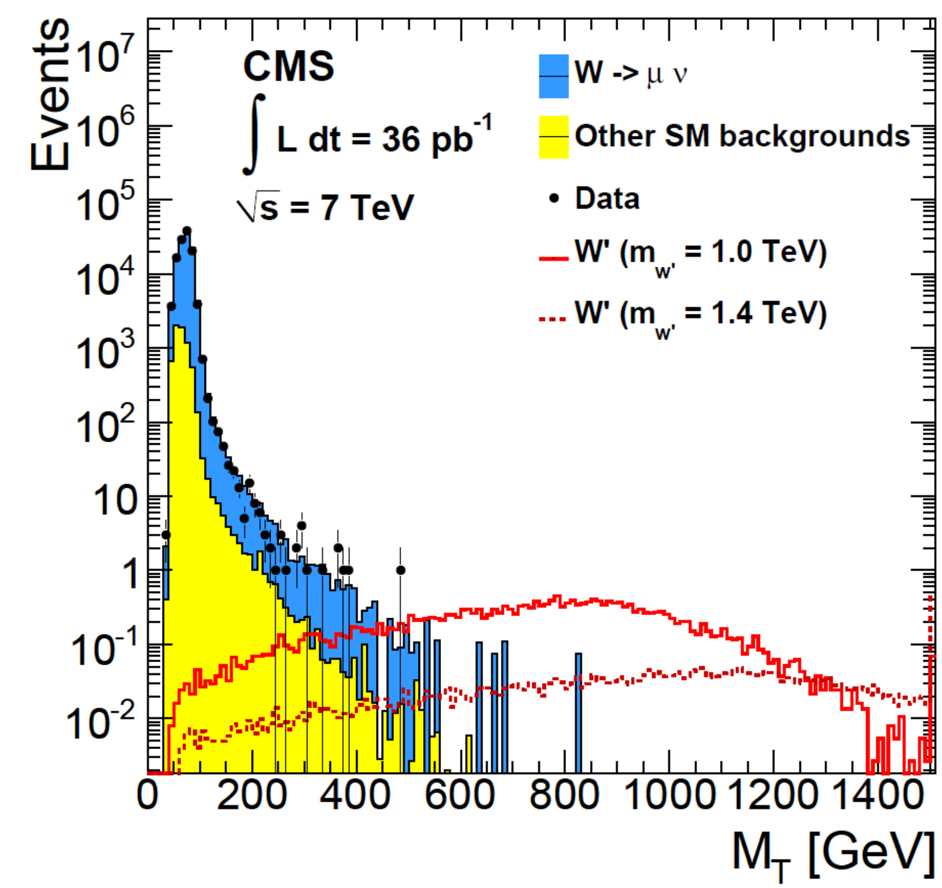


Combination

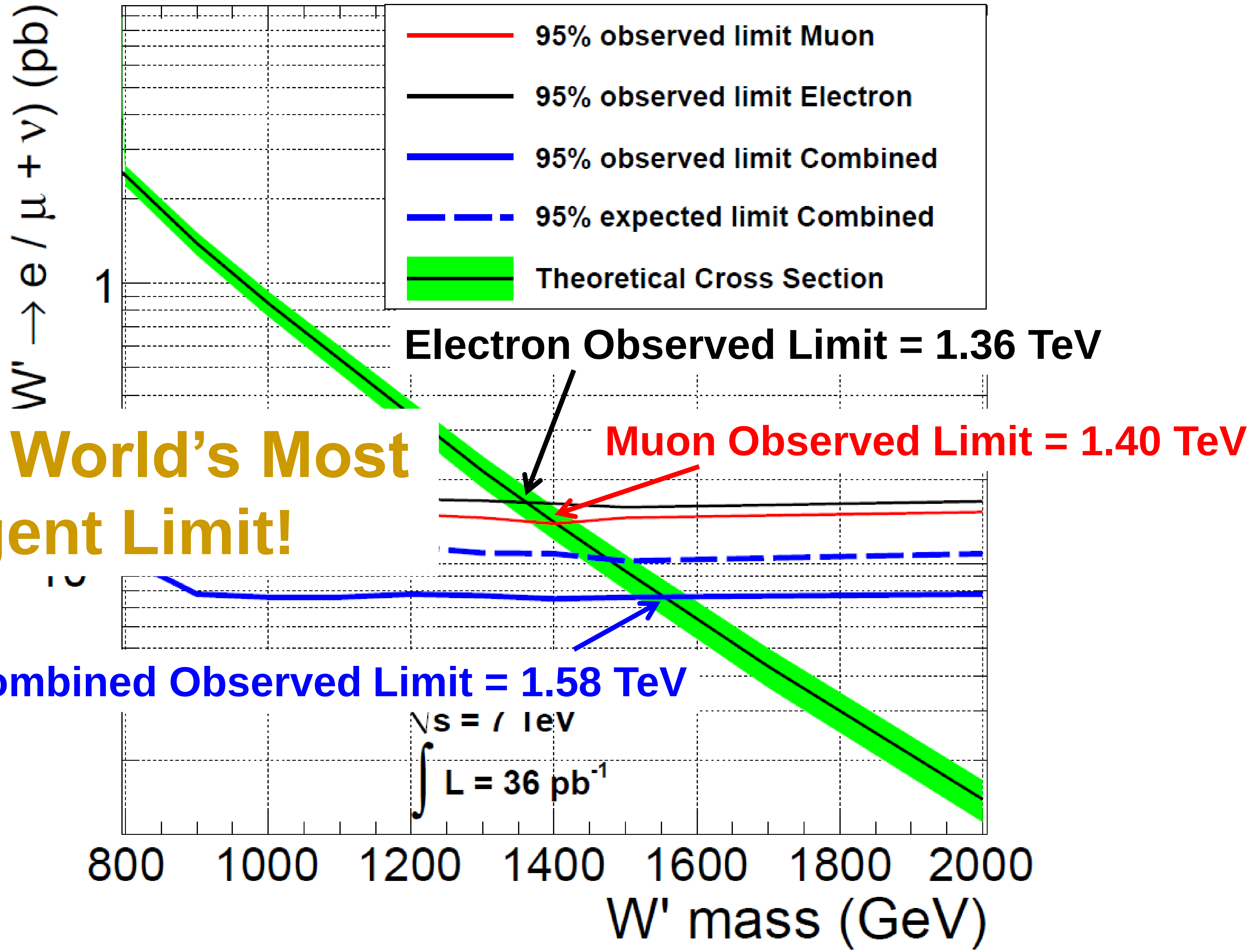
Combining with the muon channel

- Need to determine contamination from cosmic-ray background
- No excess beyond the Standard Model found in $W' \rightarrow \mu\nu$ search
  - Combine e and μ channels
- Straightforward extension of the implemented Bayesian upper limit given assumptions:
  - Identical branching ratios to e, μ
  - Uncertainty on lumi fully correlated
  - Uncertainties on signal efficiency and background fully uncorrelated
    - Assuming full correlation gives same limit

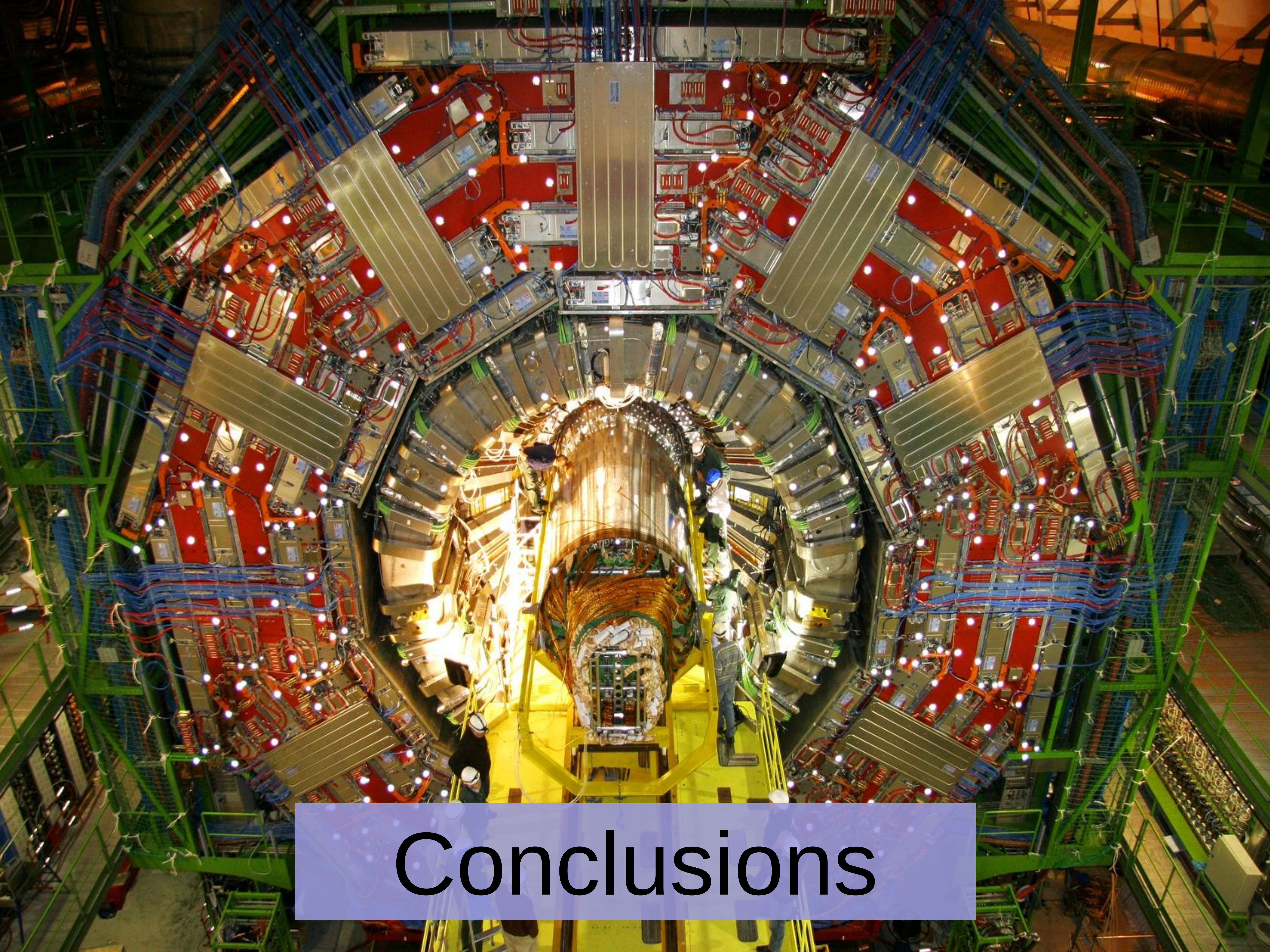




Combined limit for electron and muon channels



Currently World's Most Stringent Limit!

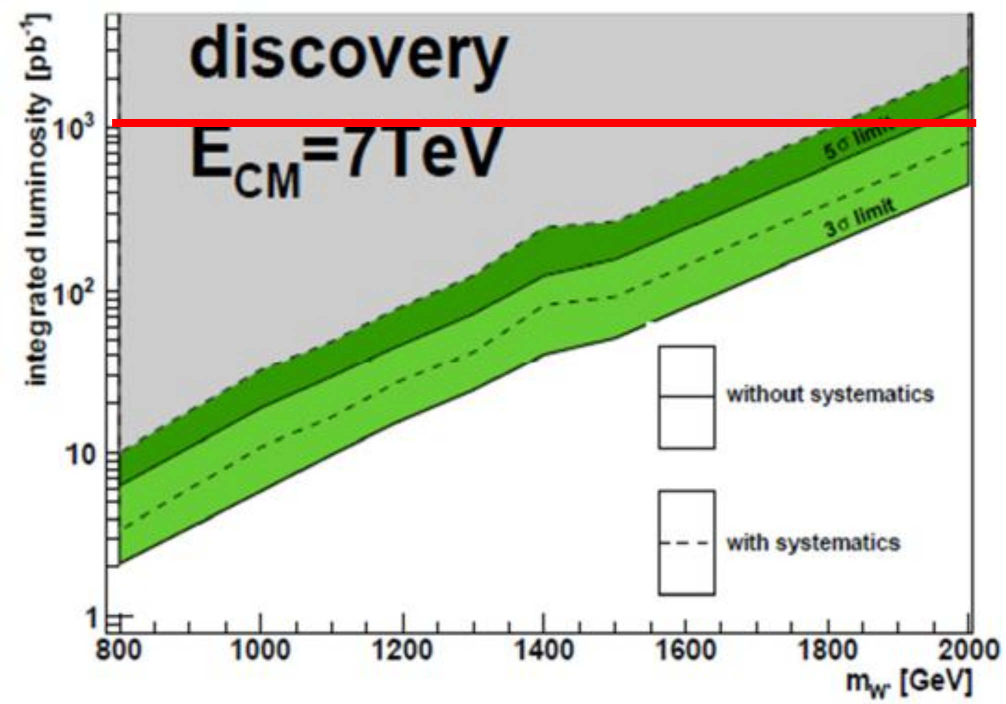


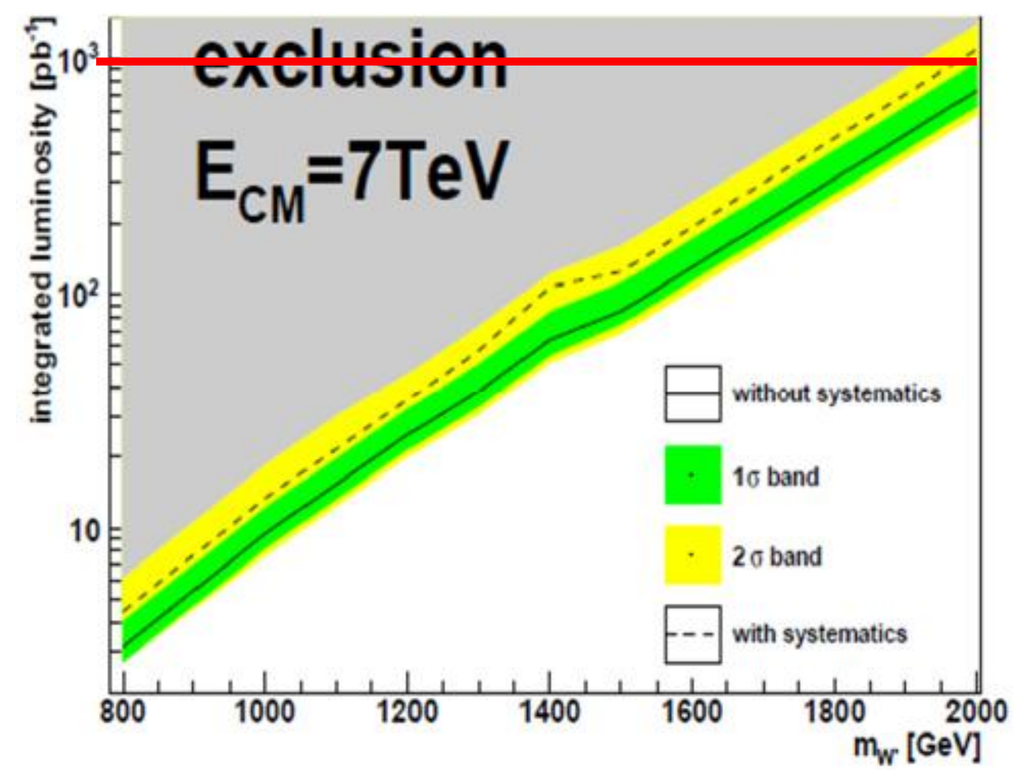
Conclusions

Future plans for W′

with ~ 1 fb^{-1}, $O(M_{W'}) > 2$ TeV

- Focus on *discovery*
- Include several search channels
  - $W' \to \ell\nu$ ($l = e, \mu, \tau$)
  - $W' \to tb$
  - $W' \to WZ$
  - $W' \to \ell N_R \to \ell \ell j j$
- Prepare for the difficulties of the next two years of running
  - Multiple interactions per crossing
  - High-luminosity triggering
  - High-p_T object reconstruction
  - Statistical analysis tools





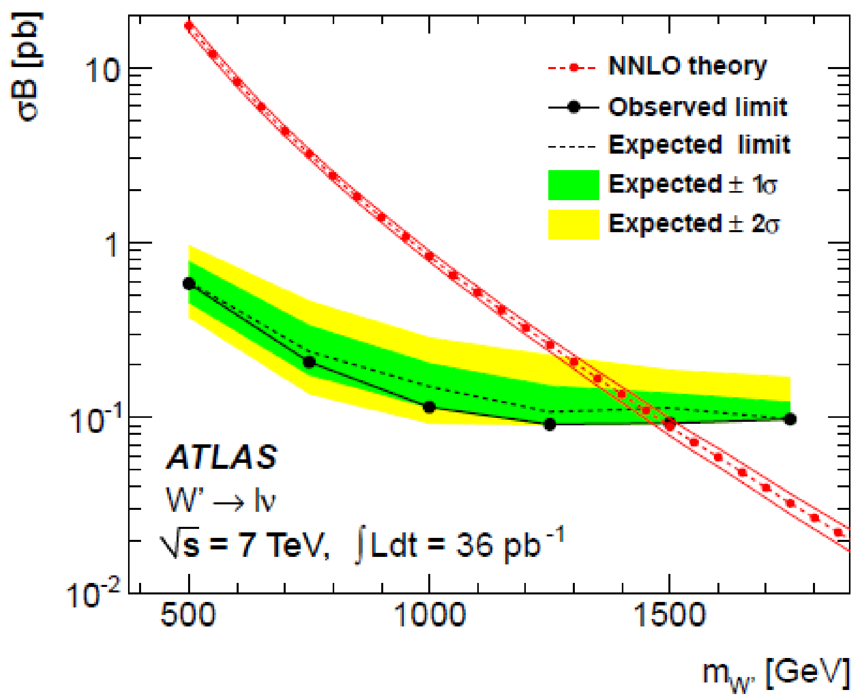
Summary

- The LHC era has begun!
  - The CMS and ATLAS detectors are performing exceptionally
- We performed a search for $W' \rightarrow e\,\nu$ with 36.1 pb^{-1} of certified CMS 2010 data
- Using a Bayesian technique, we exclude the existence of a W' boson with masses below 1.36 TeV with a confidence of 95% in the electron channel
- Combining electron and muon channels: $M_{W'} > 1.58$ TeV
  - Most stringent direct search limit in the world
- The 2011 – 2012 run will provide a unique discovery possibility for LHC experiments

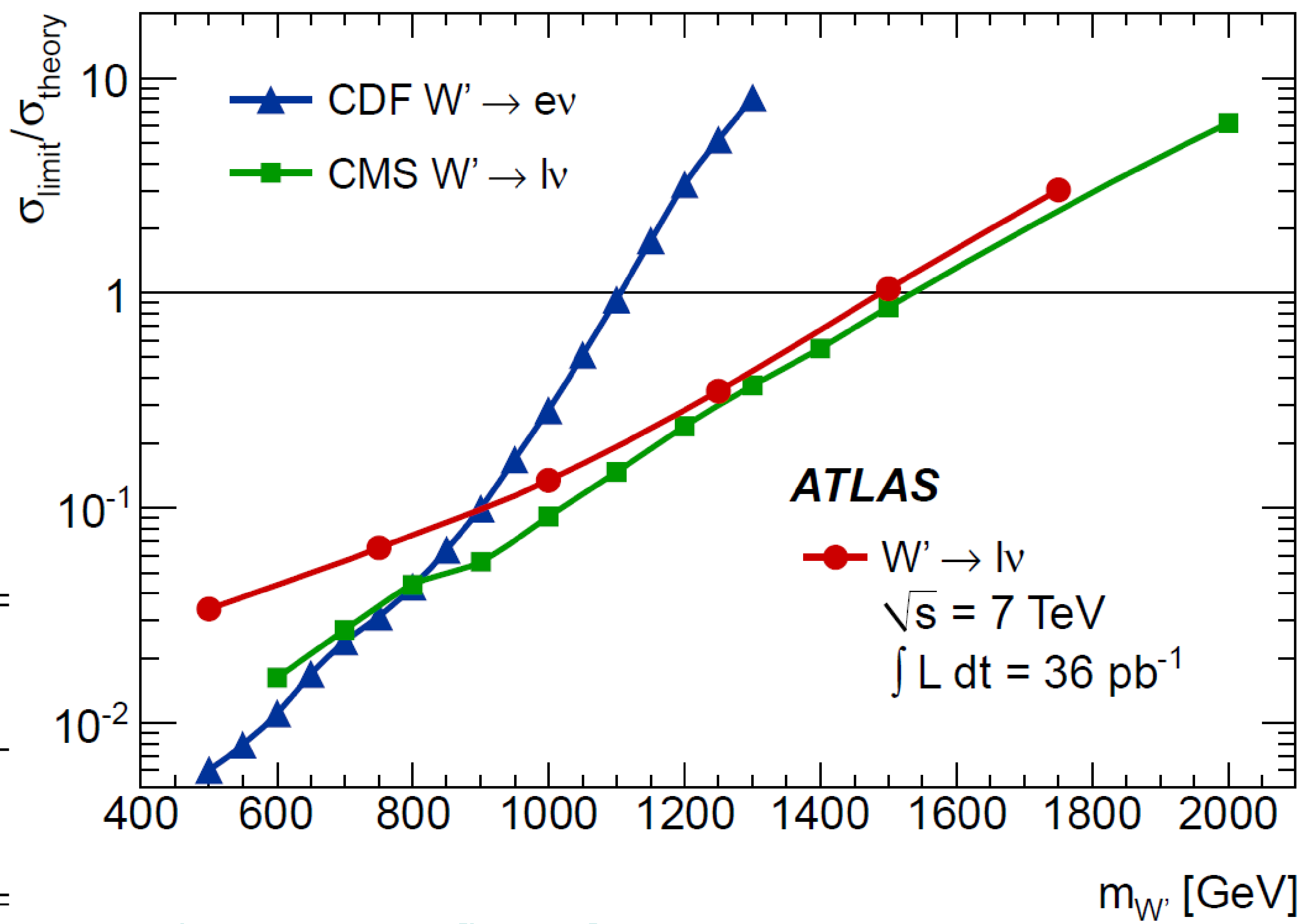
Backup Slides

ATLAS limit

- Biggest difference between CMS and ATLAS is lepton acceptance
  - ATLAS: electrons with $|\eta_e| < 2.4$, muons with $|\eta_\mu| < 1.05$
  - CMS: electrons with $|\eta_e| < 2.5$, muons with $|\eta_\mu| < 2.10$



	Mass limit [GeV]			
	W'		W^*	
decay	Exp.	Obs.	Exp.	Obs.
$e\nu$	1370	1370	1390	1390
$\mu\nu$	1210	1290	1100	1210
both	1450	1490	1440	1470



arXiv:1103.1391v1 [hep-ex]

Left- and right-handed W′ constraints

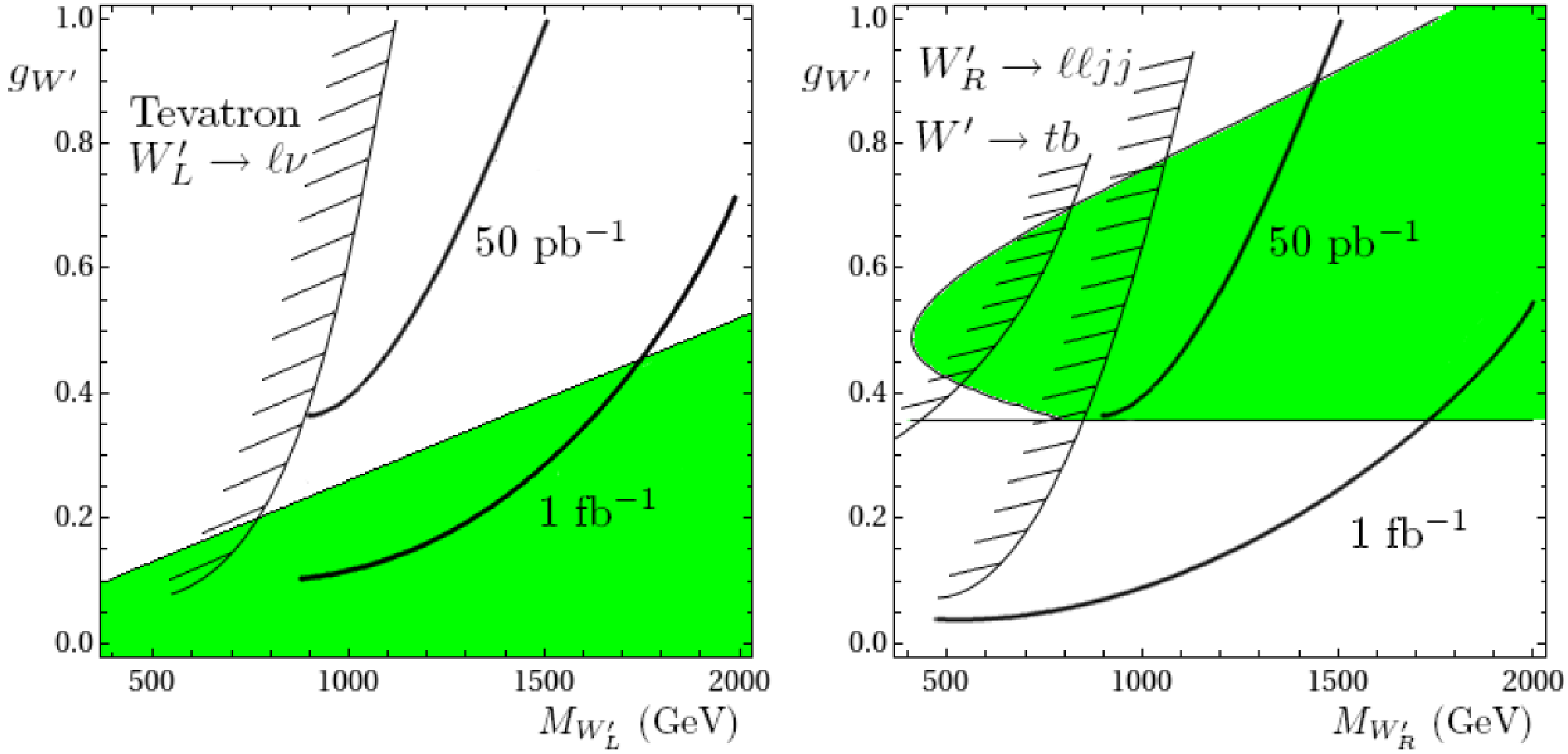


Figure 1: Experimental constraints and LHC reach for the left-handed (left) and right-handed (right) W prime as functions of the simplified model parameters $M_{W'}$ and $g_{W'}$. The plots show limits from direct searches at the Tevatron (hashed contours), the region favored by electroweak precision fits at 95 % C.L. (green/gray region), and the LHC reach at $\sqrt{s} = 7$ TeV for 50 pb^{-1} and 1 fb^{-1} of integrated luminosity.

arXiv:1011.5918 [hep-ph]

High energy electrons

		$1.56 < \|\eta\| < 1.80$	$1.80 < \|\eta\| < 2.20$	$2.20 < \|\eta\| < 2.50$
Data	nb. el.	493	2011	1520
	Δ	0.01 ± 0.02	-0.02 ± 0.01	0.01 ± 0.01
Drell-Yan MC	nb. el.	620	1981	1422
	Δ	0.01 ± 0.00	0.03 ± 0.00	0.01 ± 0.00

Table 8: For three $|\eta|$ bins in the ECAL endcap, number of electrons with $p_t > 25$ GeV/c and $E > 100$ GeV with mass $M_{ee} > 40$ GeV/c^2, selected using the HEEP criteria, and value of the Δ variable, both for data (luminosity of 35 pb^{-1}), and for Drell-Yan Monte Carlo simulation.

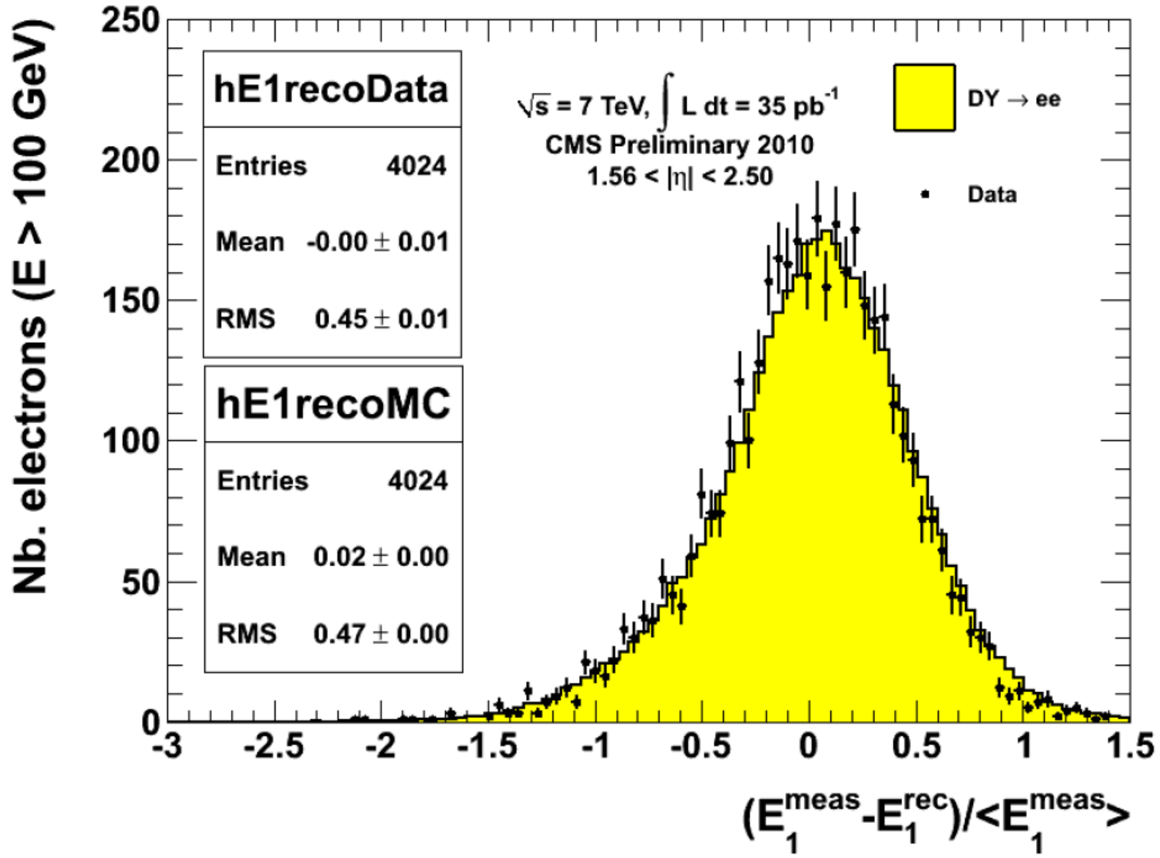
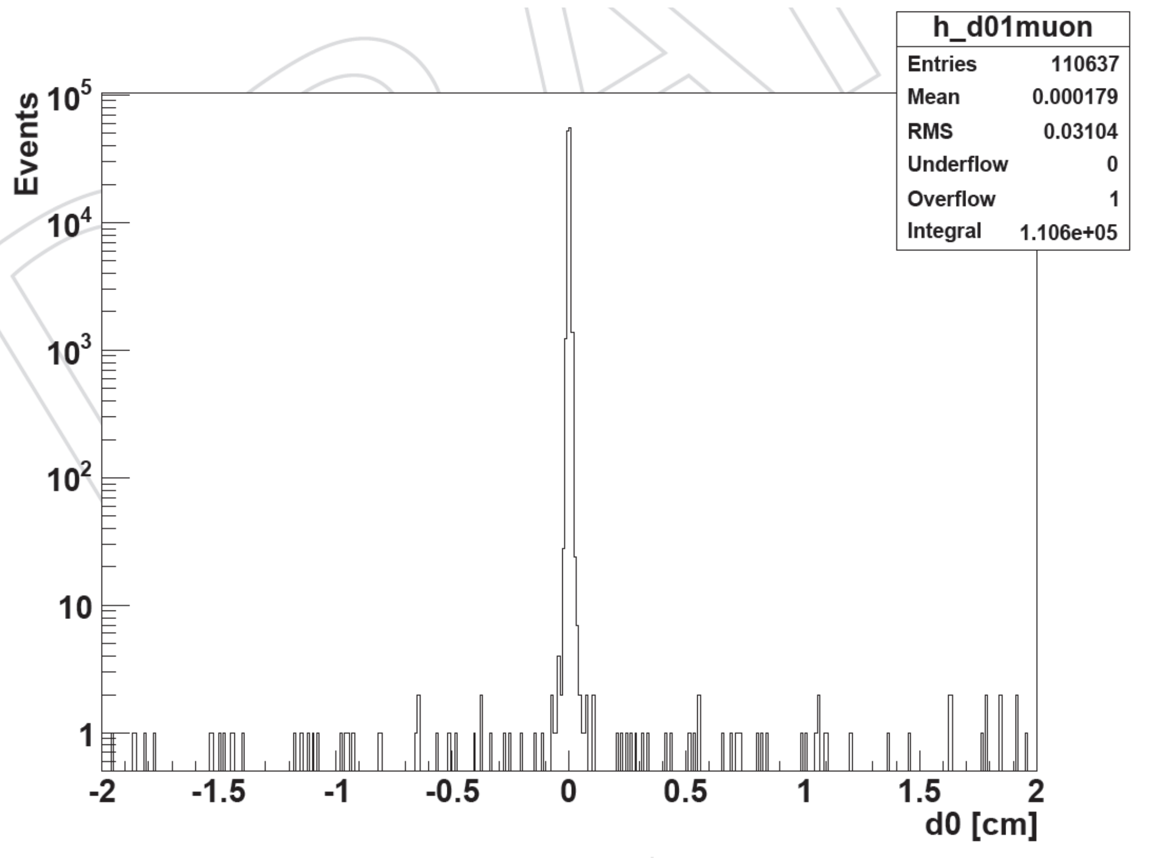


Figure 20: Distribution of the fractional difference between the measured energy (E_1^{meas}) and the energy reconstructed with the method described in this section (E_1^{rec}), for $E > 100$ GeV in the ECAL endcap.

Cosmic ray background in muon channel

- Cut on impact parameter to remove cosmics: $d_0 < 0.02$ cm
- Assuming cosmic background is flat in d_0, count the number of events, N, with $0.02 < d_0 < 2.00$ cm
  - Cosmic ray background = $0.02/(2.00-0.02) \times N$

M_T [GeV/c^2] range	Collision background	Cosmic background	Total background
$180 < M_T < 350$	54.7 ± 7.3	0.19 ± 0.04	54.9 ± 7.3
$M_T > 350$	3.6 ± 1.0	0.15 ± 0.04	3.8 ± 1.0
$M_T > 400$	2.2 ± 0.6	0.10 ± 0.03	2.3 ± 0.6
$M_T > 500$	1.0 ± 0.3	0.08 ± 0.03	1.1 ± 0.3
$M_T > 600$	0.54 ± 0.15	0.08 ± 0.03	0.62 ± 0.15



Systematic uncertainty

- Values indicate the percent variation on the number of events with M_T > 200 GeV
  - Electron reconstruction efficiency uncertainty found as part of W/Z cross section measurement
  - Electron identification efficiency uncertainty found as part of the W′ and Z′ searches

Source of systematic error	Uncertainty	Signal	MC Bkg	$W \rightarrow e\nu$	Multi-jet
Integrated luminosity	11%	11%	11%	-	-
Electron reco efficiency	1.9%	1.9%	1.9%	-	-
Electron ID efficiency	1.5%	1.5%	1.5%	-	-
Electron energy scale	1%(EB), 3%(EE)	0.0%	0.7%	20%	50%
E_T^{miss} scale	5%	2.0%	5.7%		conser-
E_T^{miss} resolution	10%	0.3%	2.2%	11%	vative
Cross section		10%	29%	-	-
Total (lumi not included)		10.5%	29.7%	22%	50%

Bayesian upper limit calculator

- We use a Bayesian tool to calculate the expected and observed 95% CL upper limits

flat signal prior

$$p(\sigma|n,\epsilon,\mathcal{L},b) = \frac{p(n|\sigma,\epsilon,\mathcal{L},b)\pi(\sigma)}{\int p(n|\sigma,\epsilon,\mathcal{L},b)\pi(\sigma)d\sigma}$$

$$p(n|\sigma,\epsilon,\mathcal{L},b) = \int\int\int P(n|\sigma,\epsilon',\mathcal{L}',b')g(\epsilon')h(\mathcal{L}')f(b')d\epsilon' d\mathcal{L}' db'$$

Poisson

Log-normal distributions to describe uncertainties

$$P(n|\sigma,\epsilon,\mathcal{L},b) = \frac{(b+\mathcal{L}\epsilon\sigma)^n}{n!}e^{-(b+\mathcal{L}\epsilon\sigma)}$$

$$\int_0^{\sigma^{95}(n)} p(\sigma|n,\epsilon,\mathcal{L},b)d\sigma = 0.95$$

Expected limit

$$<\sigma^{95}> = \sum_{k=0}^{\infty} \sigma^{95}(k) \cdot P(k|\sigma=0,\epsilon,\mathcal{L},b)$$

n = Number of observed events

b = Expected number of background

$\mathcal{L}$ = Integrated luminosity

ϵ = Acceptance $\times$ efficiency