Search for a heavy gauge boson $W' \to \ell\nu$ at $\sqrt{s} = 7$ TeV

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Penn Seminar
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Low-hanging fruit: W' → eν

- Search for new physics that looks like a carbon copy of SM W in its leptonic decay mode
  - trigger on high-pt electron/muon
  - require sizable missing ET (MET)
- Easy signal in early data
  - few backgrounds, few objects
  - Can even do the search without MET if required
- Theoretically well motivated
- Even with modest 2010 data sets we expected to be competitive with Tevatron

- Good thesis topic for a more senior graduate student!

Theories with new gauge bosons

- Heavy gauge bosons frequently predicted in new physics models

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

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

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

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

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

- We are sensitive in this search to left-handed W'

Previous searches and exclusions

- Direct searches for W' performed at the CDF and D0 experiments at the Tevatron: $\sqrt{s} = 1.96$ TeV
  - $W' \rightarrow e\nu$: $M_{W'} > 1.12$ TeV, CDF with 5.3 fb^{-1}
  - $W' \rightarrow tb$: $M_{W'} > 863$ GeV, D0 with 2.3 fb^{-1}

doi:10.1103/PhysRevD.83.031102

arXiv:1101.0806 [hep-ex]

- Indirect limits (model-dependent)
  - Kaon and B-meson mixing limits in the minimal left-right symmetric model: $M_{WR} > 1.6 – 2.4$ TeV
  - Big bang nucleosynthesis (BBN) limits based on temperature at which the three ν_R's decouple, Tdec:

doi:10.1103/PhysRevD.76.091301

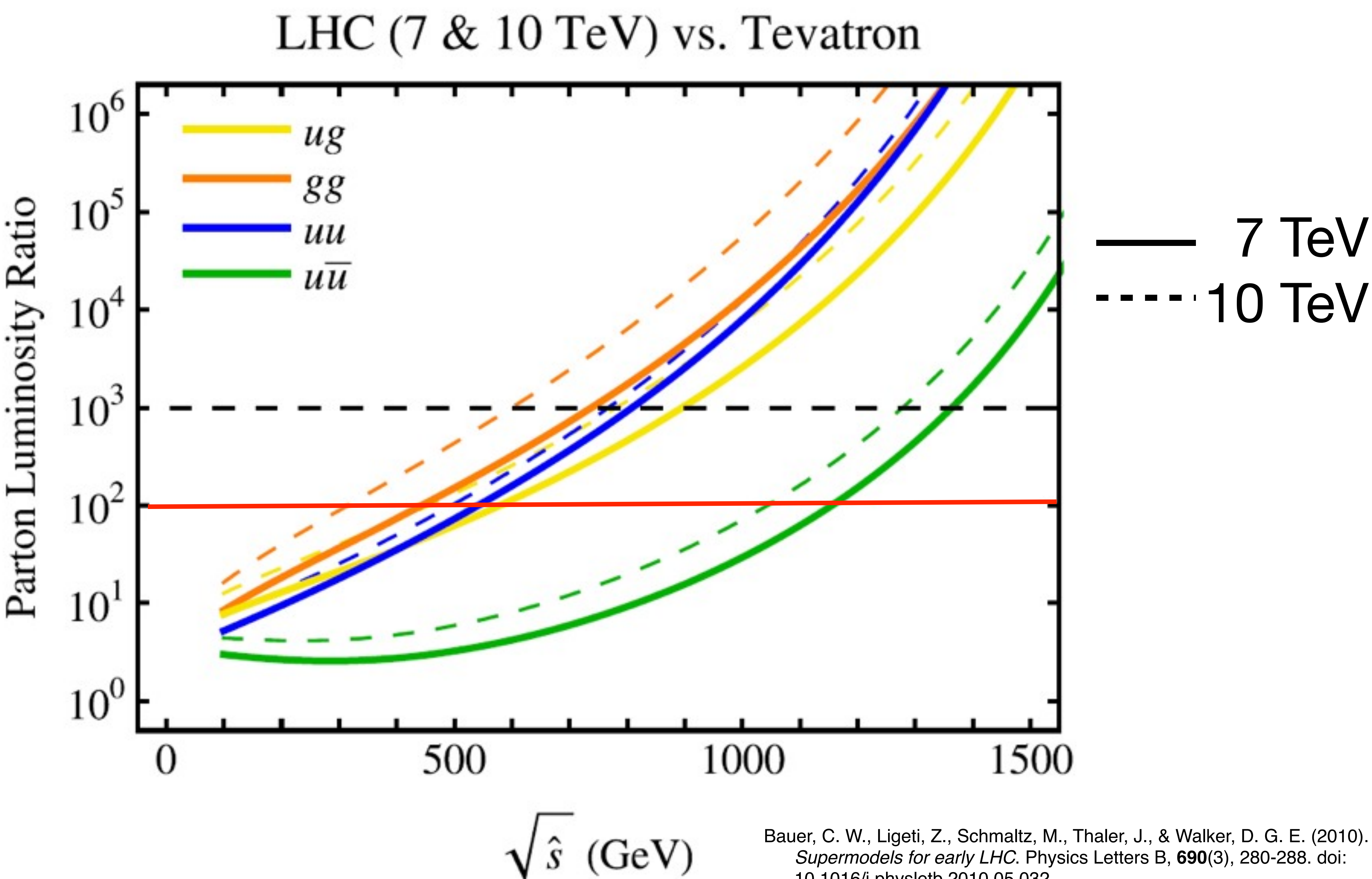
doi:10.1016/j.astropartphys.2005.01.005

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

  - SN 1987A limits on ν_R emission ($M_{\nu R} < 10$ MeV): $M_{WR} > 16$ TeV

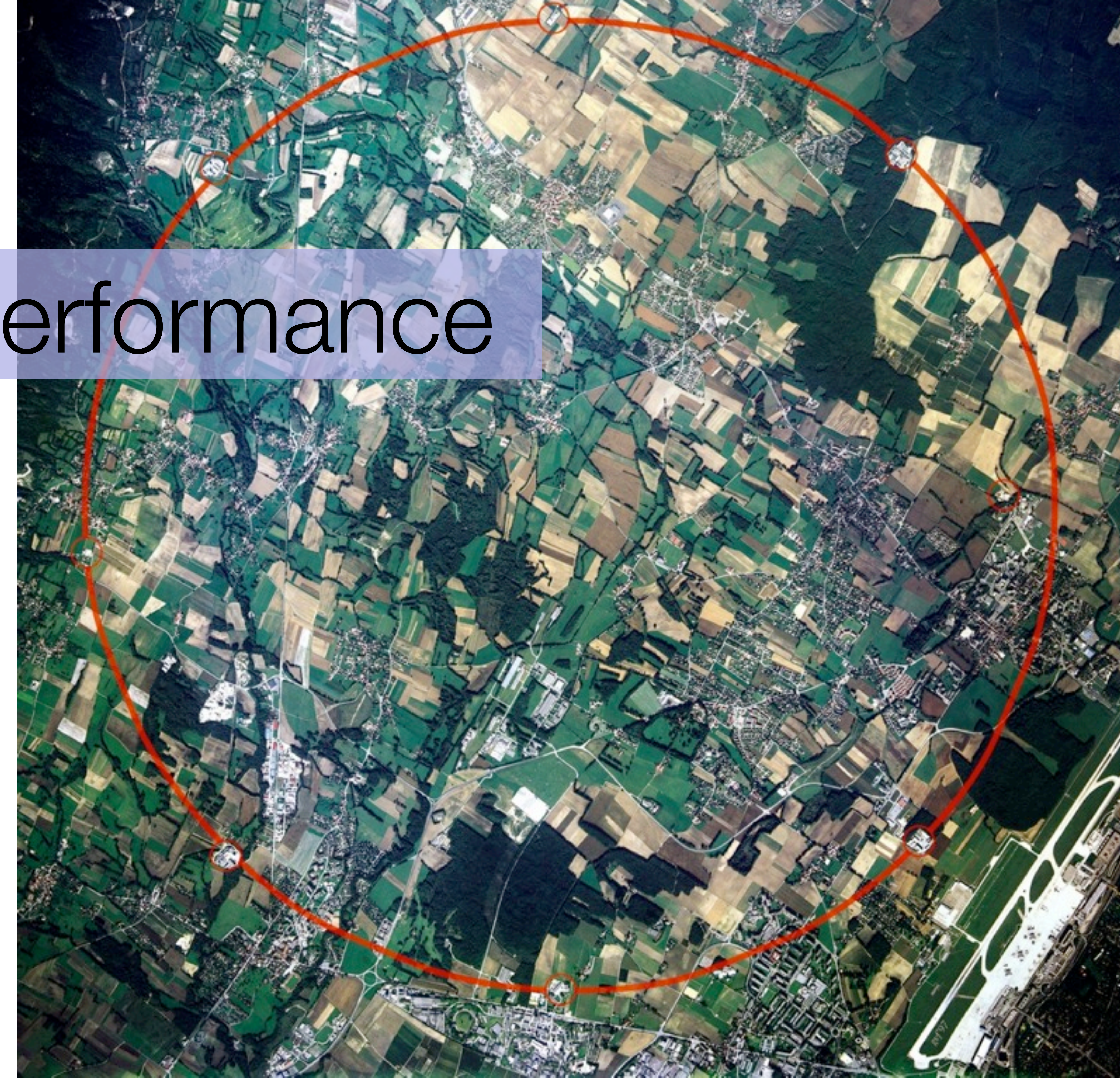
doi:10.1103/PhysRevD.39.1229

Dawn of the LHC Era - little bit goes a long way



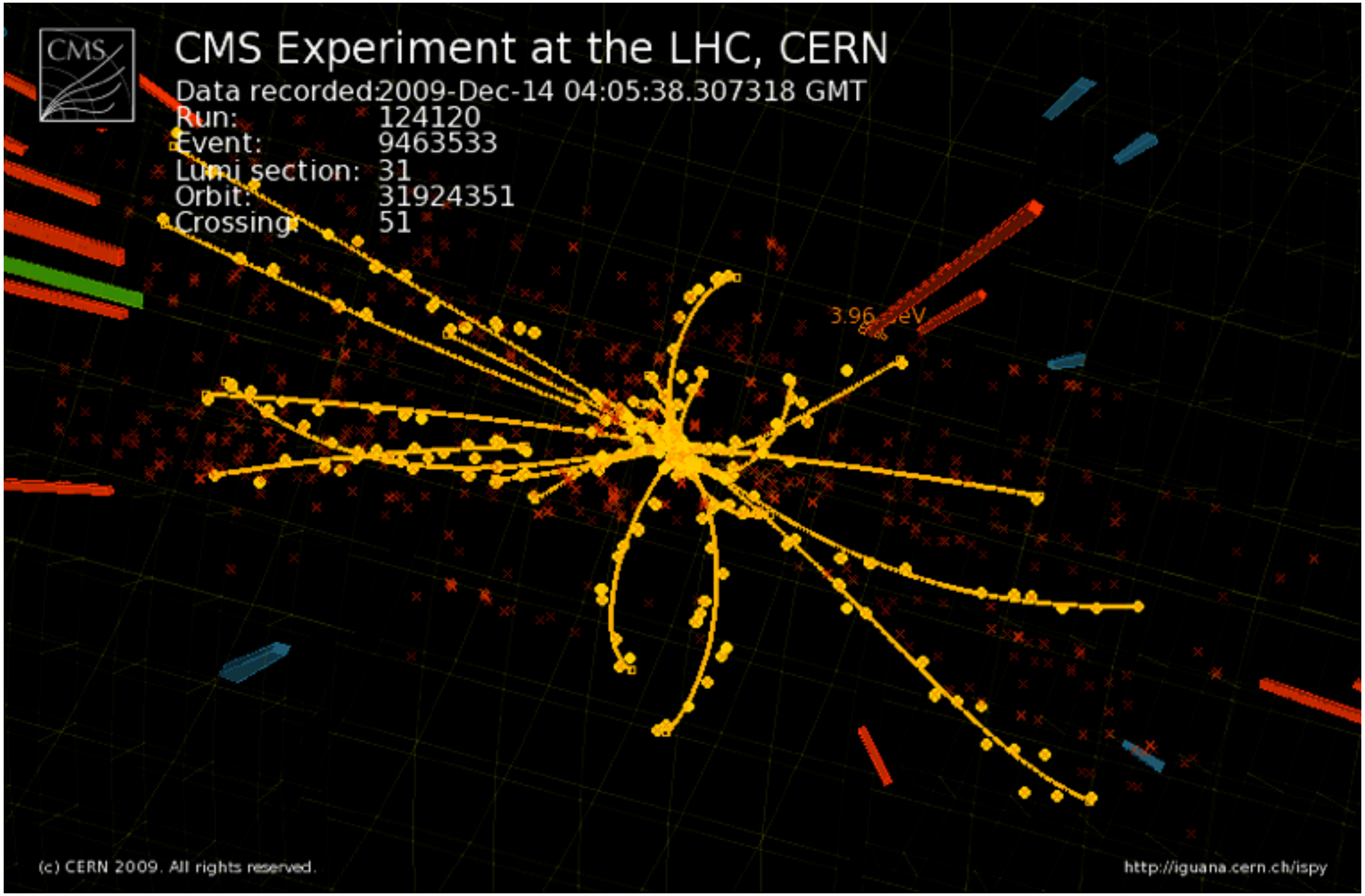
Bauer, C. W., Ligeti, Z., Schmaltz, M., Thaler, J., & Walker, D. G. E. (2010). *Supermodels for early LHC*. Physics Letters B, **690**(3), 280-288. doi: 10.1016/j.physletb.2010.05.032

LHC Performance



History of first run (2009-2010)

- Start at $\sqrt{s}$=900 GeV in November 2009 (injection energy)
- First high-energy collisions @ $\sqrt{s}$= 2.36 TeV on 12/14/2009
- First collisions at $\sqrt{s}$=7 TeV on 3/30/2010
- Delivered 50/pb by end of 2010 (early November) - CMS uses 35/pb



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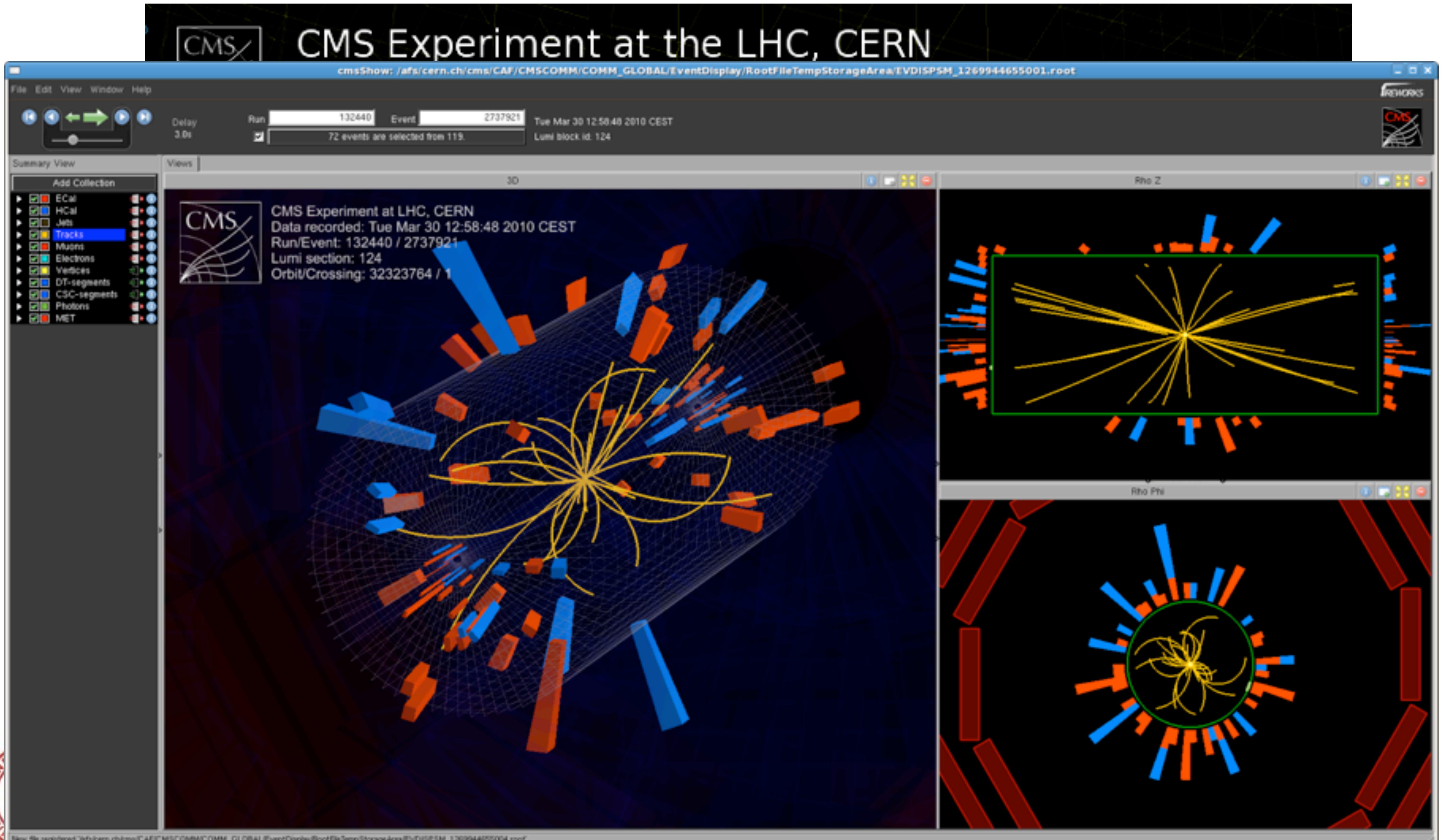

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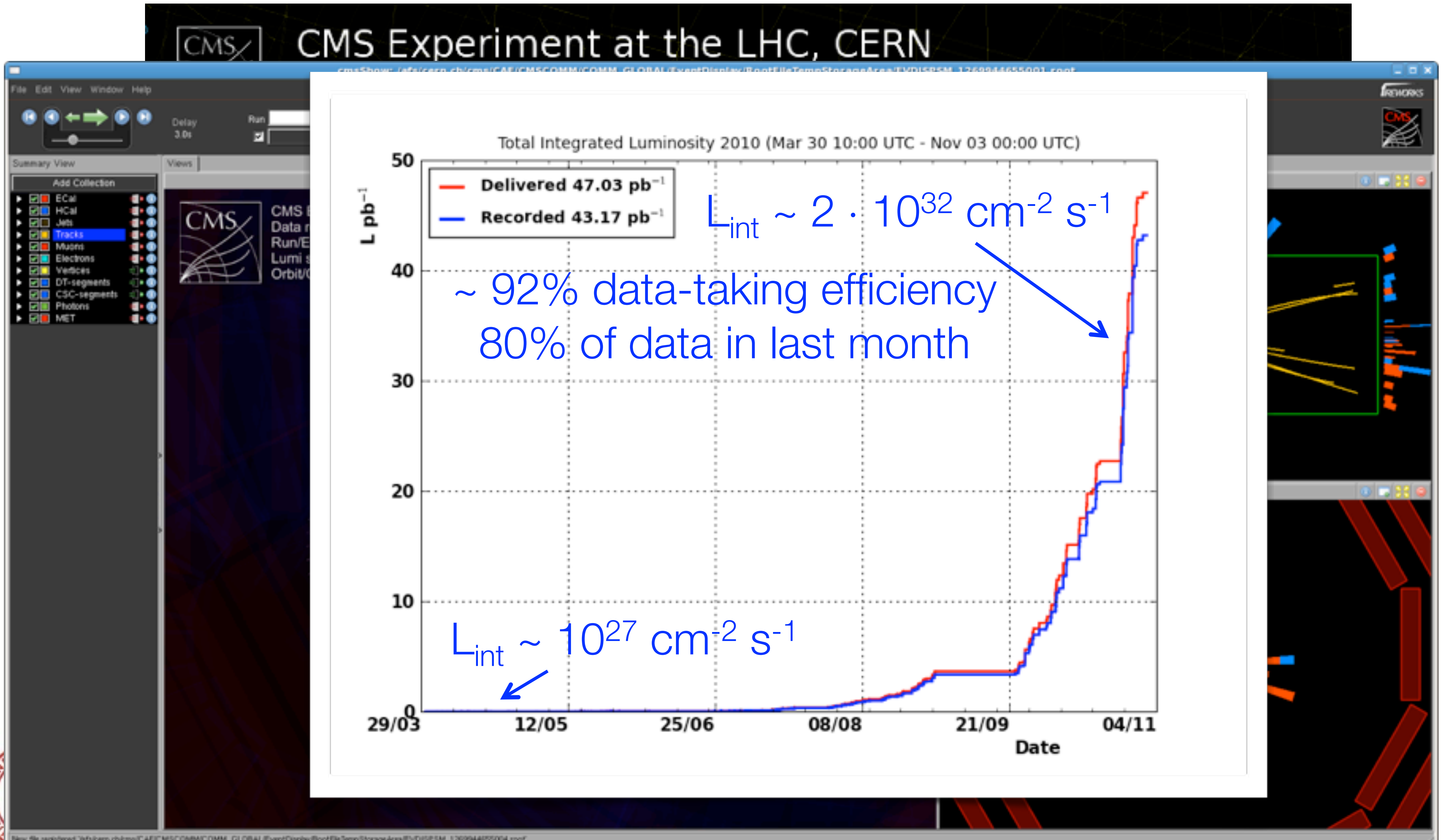

Run plans in 2011-2012 and beyond

- First 2011 collisions with stable beams on March 13, 2011
- Run pp data taking @ 7 TeV through end of 2012 (TC, HI too)
- Official goal: collect 1 fb^{-1} by the end of 2011
  - Inst. luminosities of ~ few · 10^{33} cm^{-2} s^{-1}
  - Pileup already worse than Tevatron at these lumis (10+ interactions/crossing)
- Long shutdown at the end of 2012
- Possibly energy upgrade to $\sqrt{s}$=8 TeV in 2012 run
- No official estimates for integrated lumi goal for 2012

- 15-18 month shut-down starts in 2013

- Run at full energy after this shutdown ($\sqrt{s}$ = 14 TeV)

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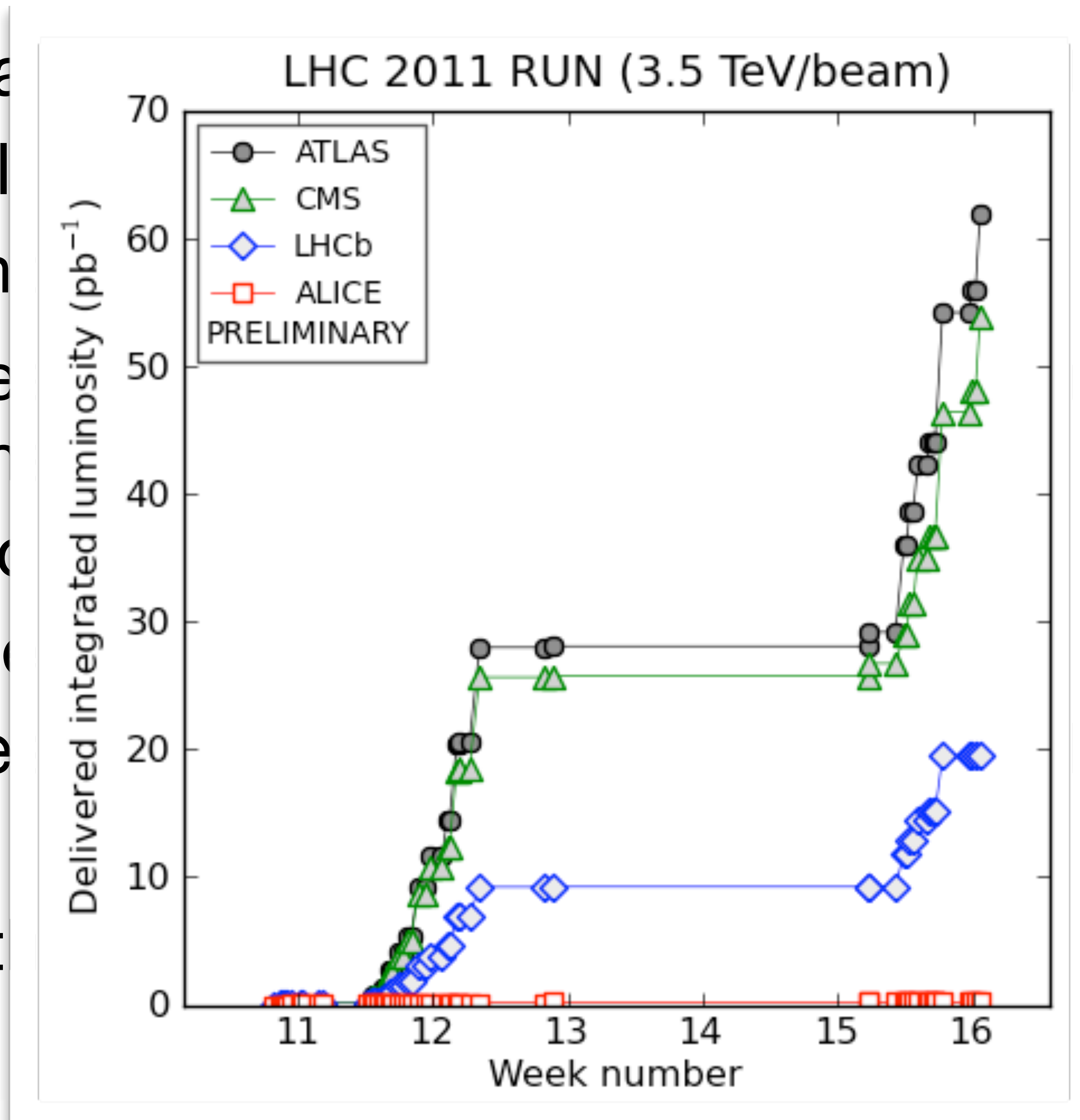

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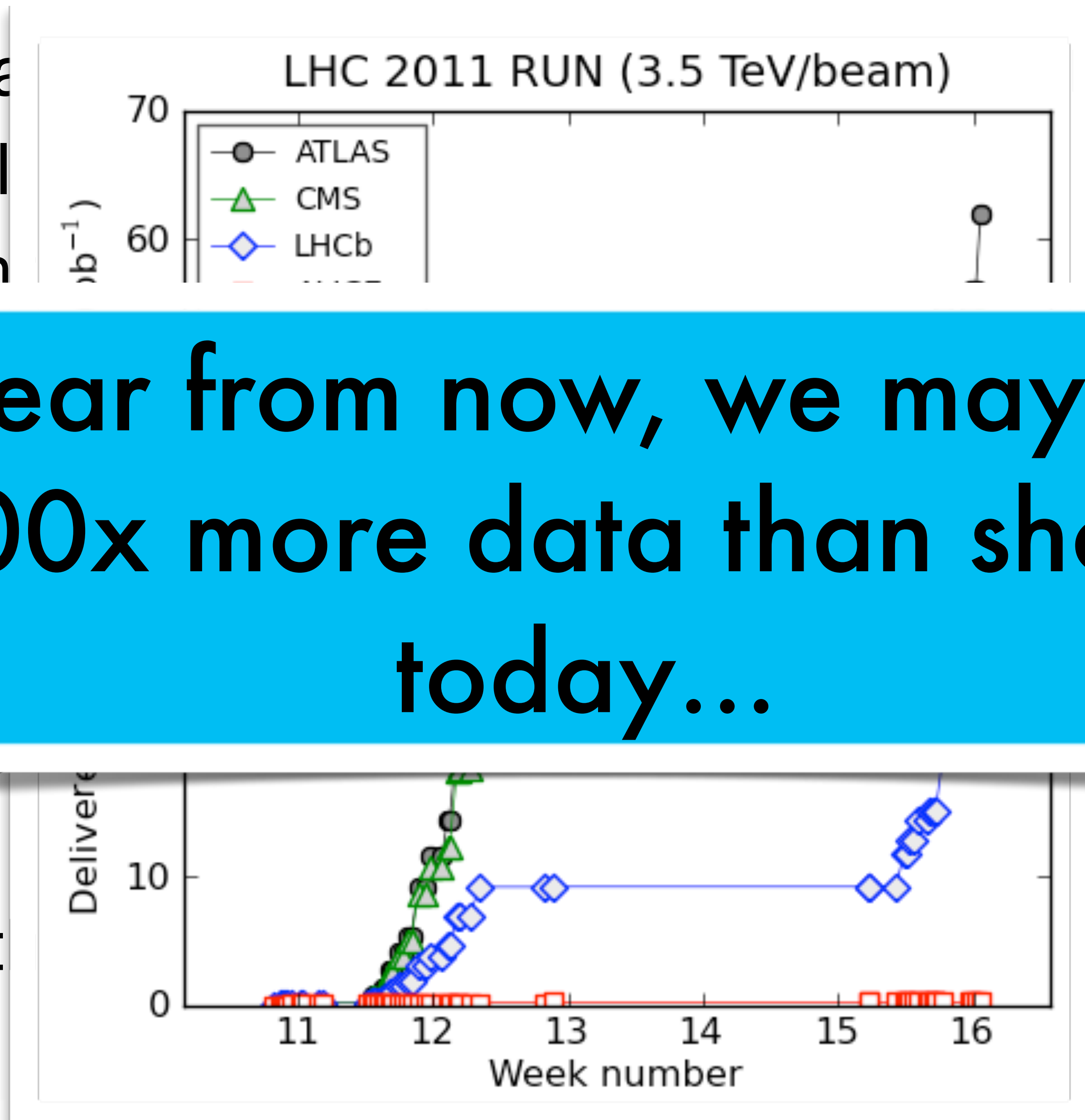
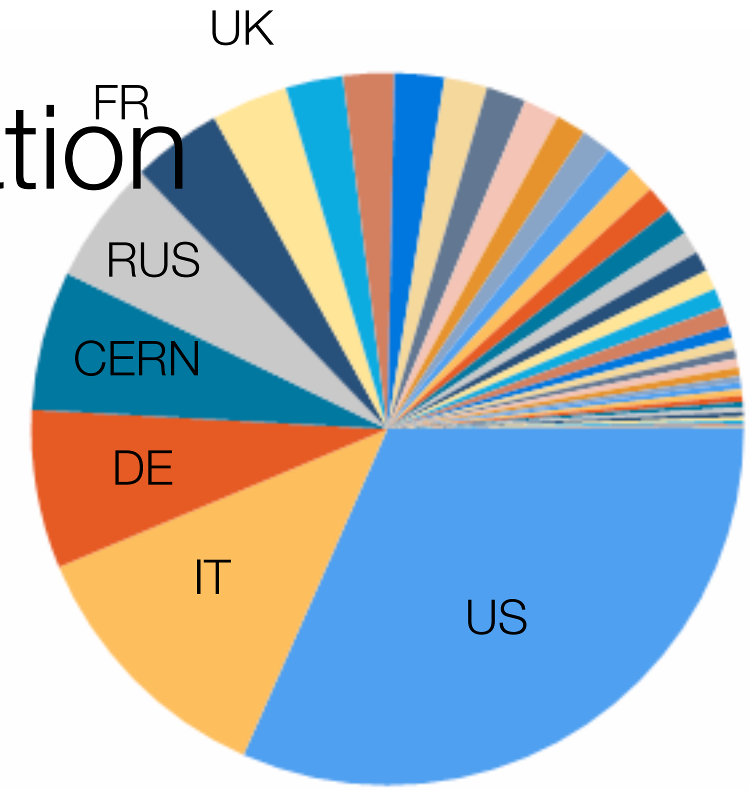


A year from now, we may have 100x more data than shown today...

Compact Muon Solenoid collaboration

- Experiment has > 3000 scientists and engineers
  - 800 graduate students, 182 institutions, 39 countries
- US is largest by country by a wide margin
  - United States (1163, 32%)
  - Italy (443, 12%)
  - Germany (265, 7%)
  - CERN (233, 6%)
  - Russian Federation (207, 6%)
  - France (150, 4.1%)
  - United Kingdom (128, 3.5%)



Collaborators by country of institute

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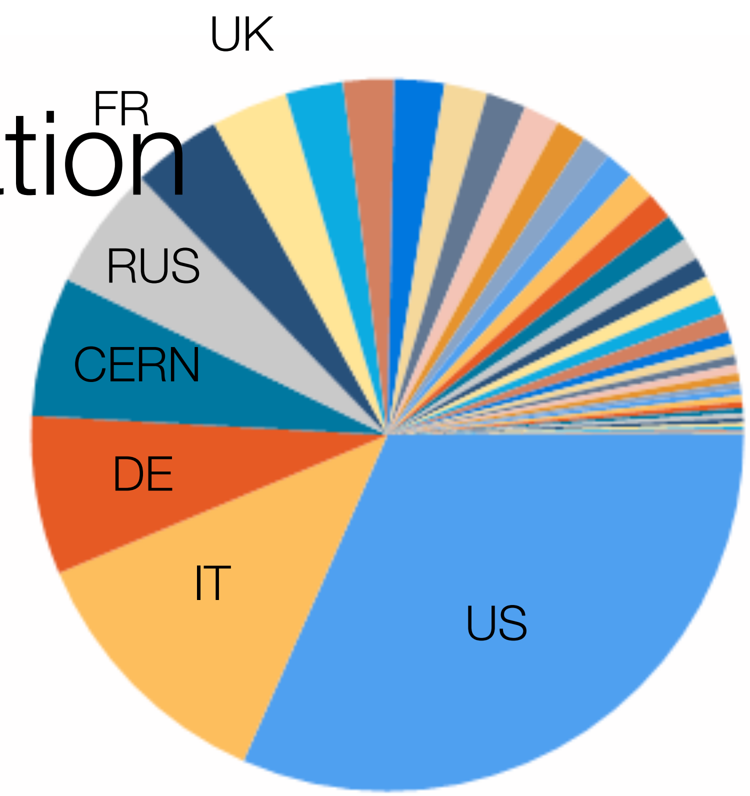

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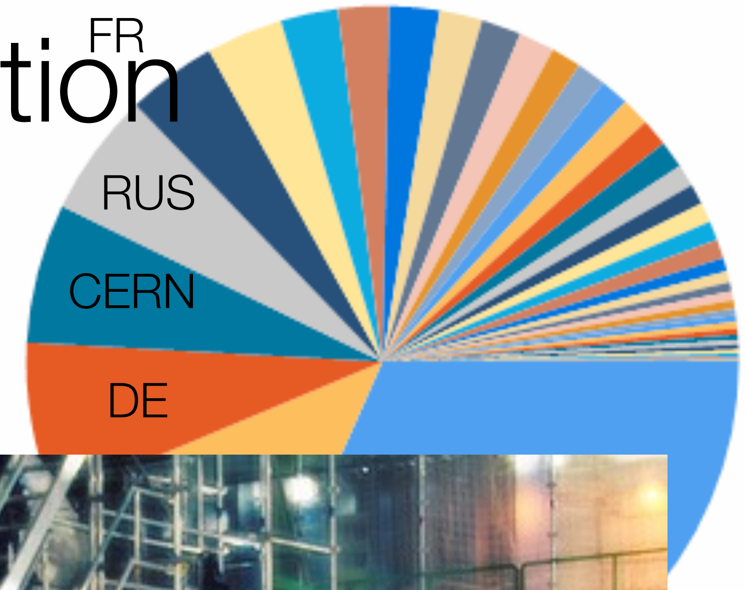

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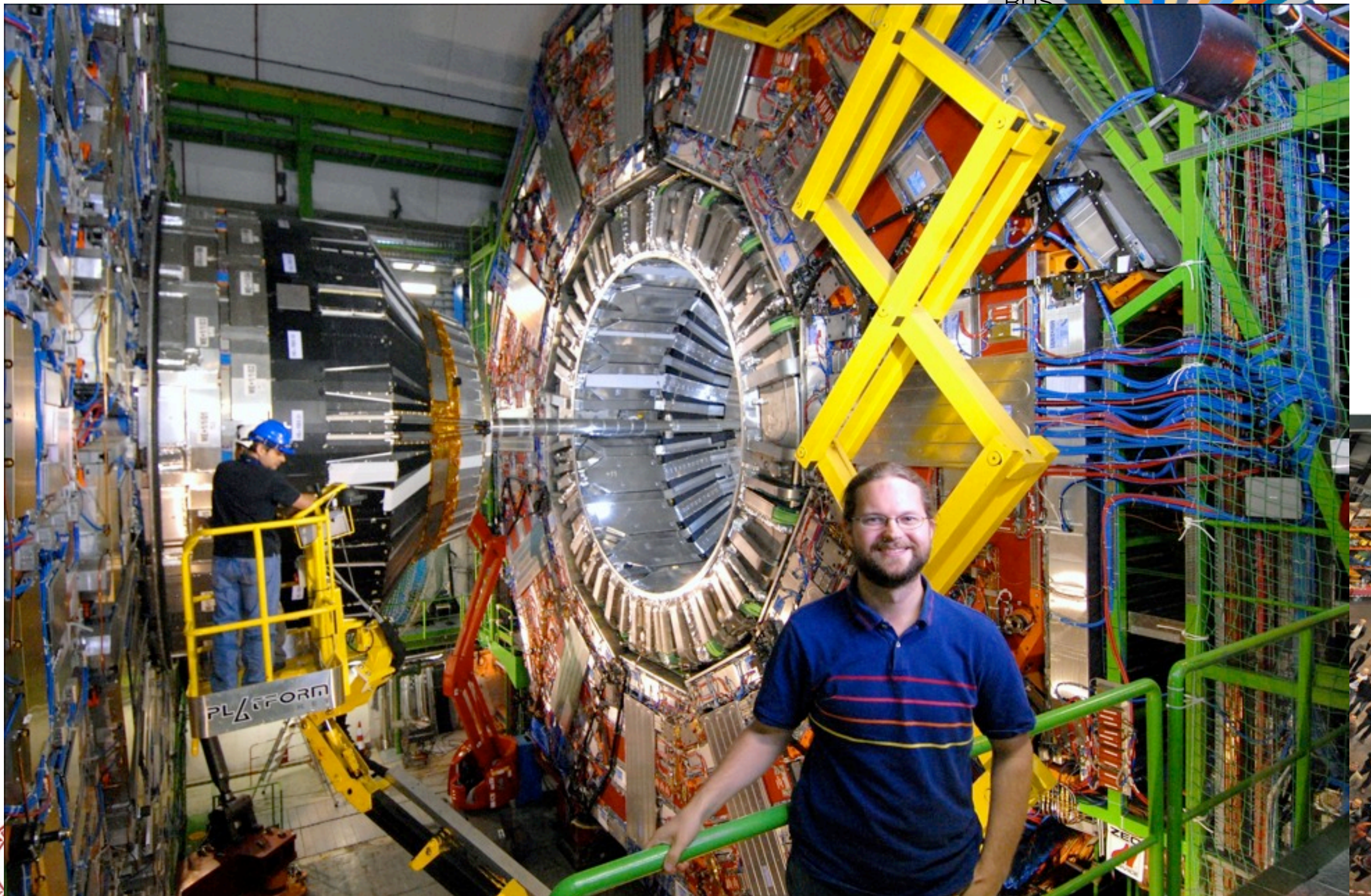

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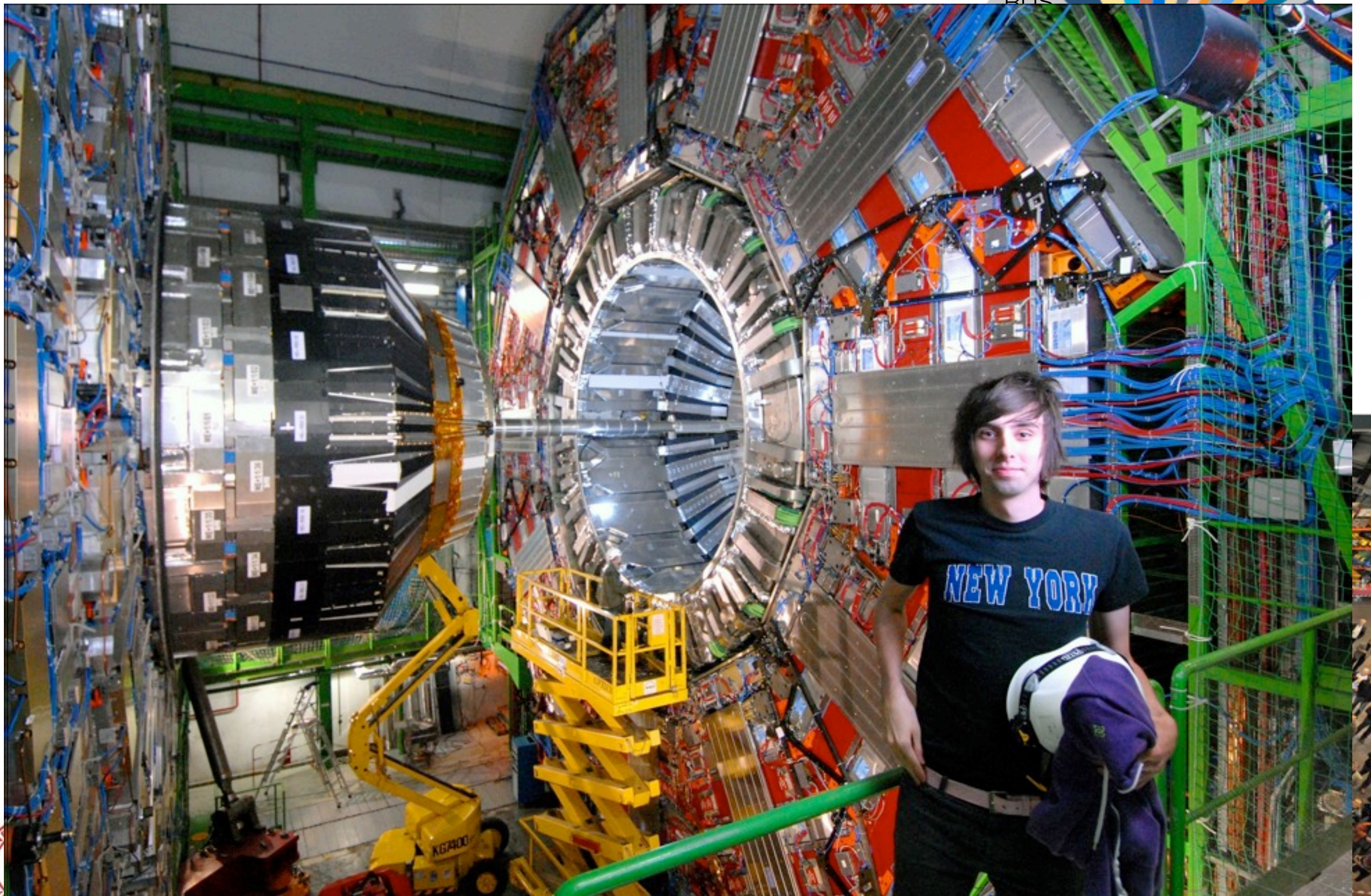
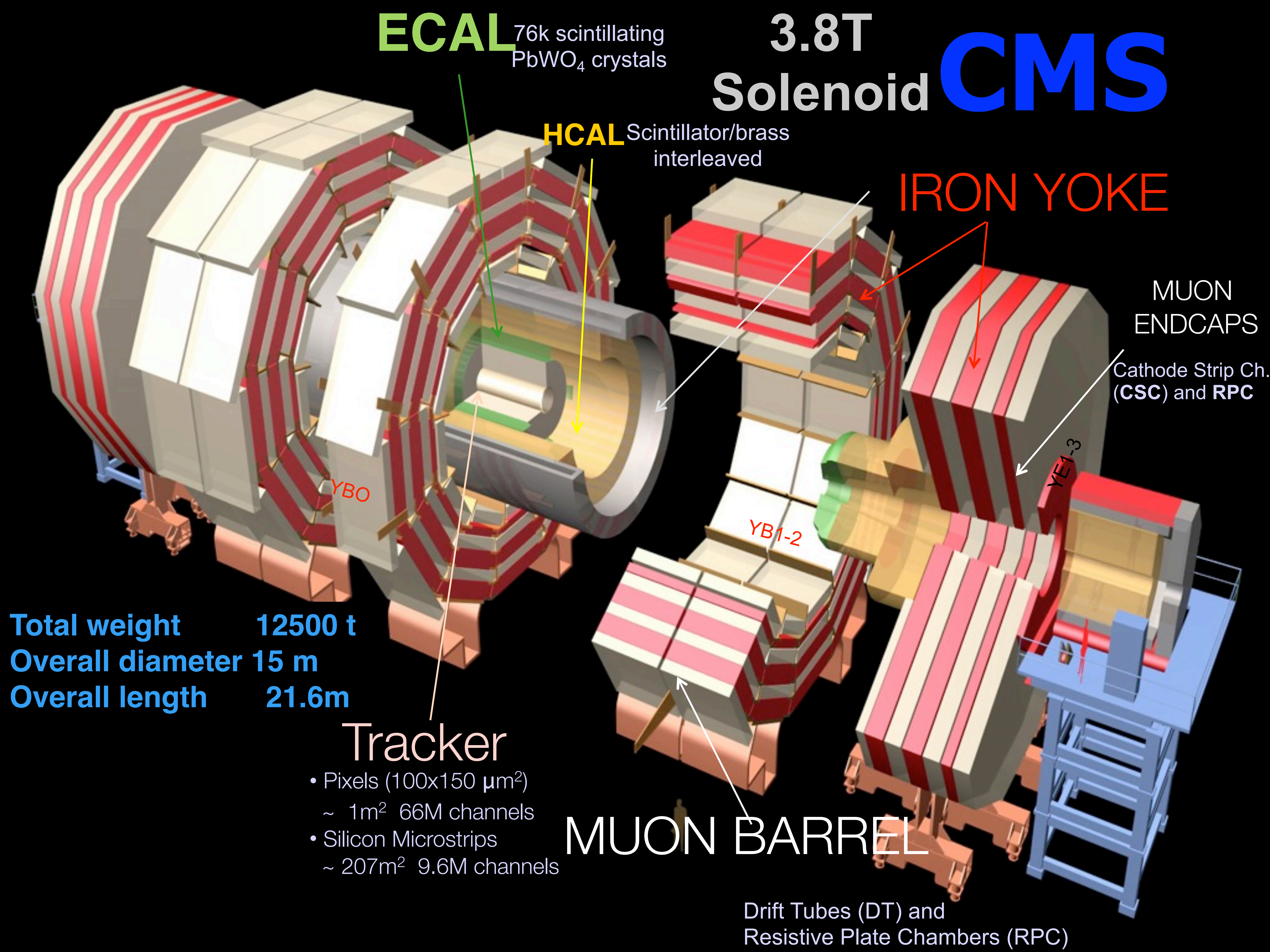
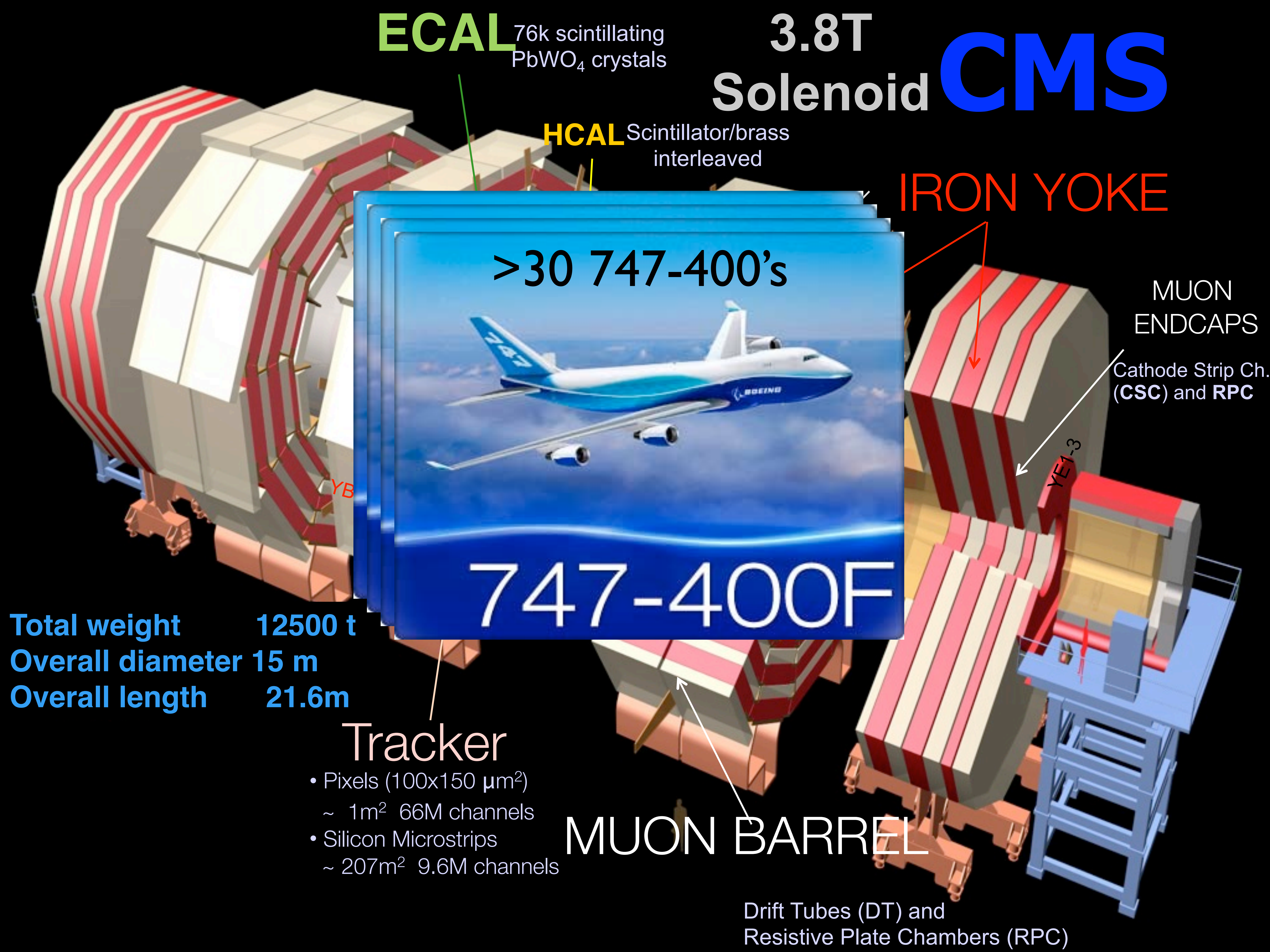




CMS
3.8T Solenoid
ECAL 76k scintillating $PbWO_4$ crystals
HCAL Scintillator/brass interleaved
IRON YOKE
MUON ENDCAPS
Cathode Strip Ch. (**CSC**) and **RPC**
YE1-3
YBO
YB1-2
Total weight 12500 t
Overall diameter 15 m
Overall length 21.6m
Tracker
• Pixels (100x150 μm²)
~ 1m² 66M channels
• Silicon Microstrips
~ 207m² 9.6M channels
MUON BARREL
Drift Tubes (DT) and
Resistive Plate Chambers (RPC)



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CMS detector view

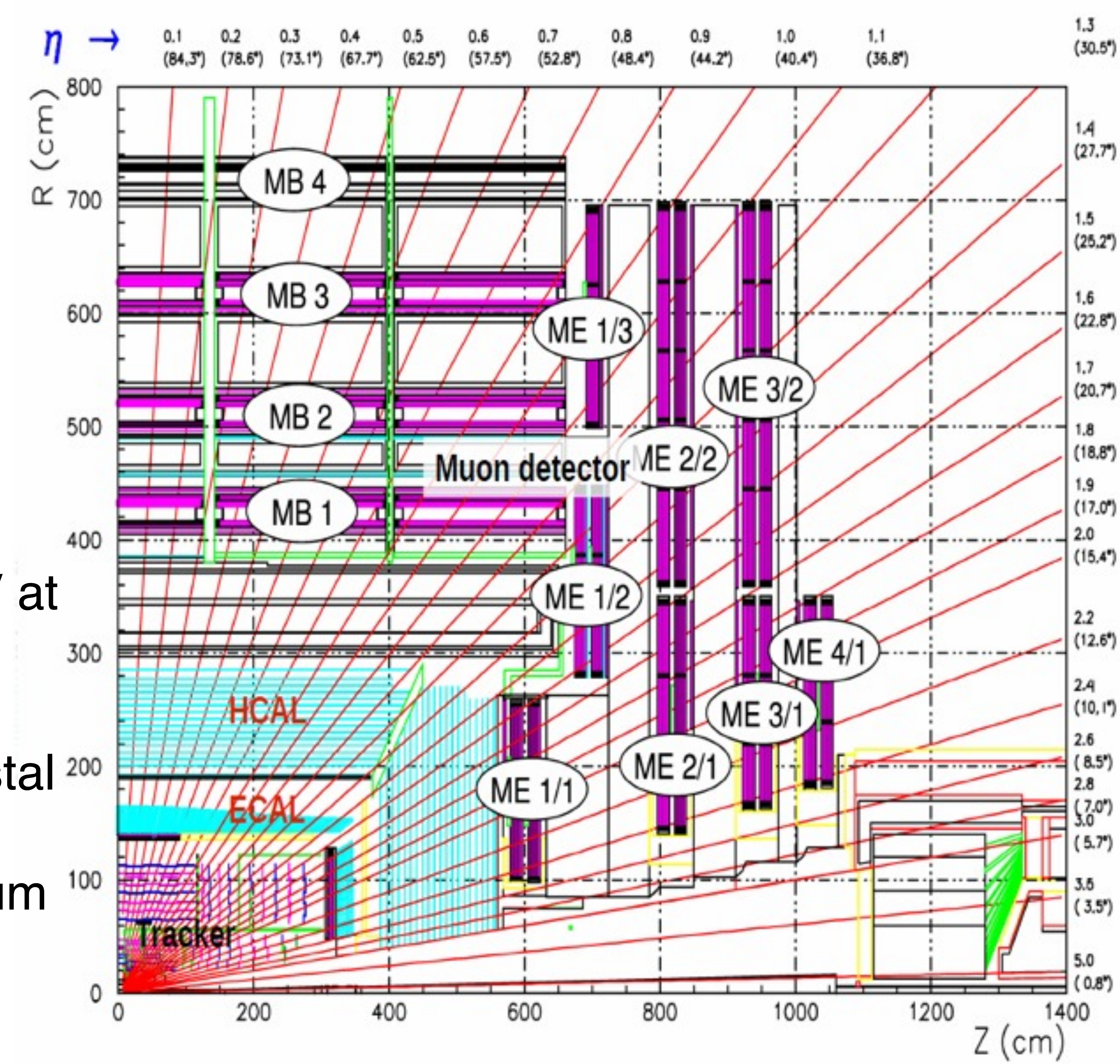
- Tracker coverage |η| < 2.5

- Electron coverage |η| < 2.5
- Hadron coverage |η| < 5.0

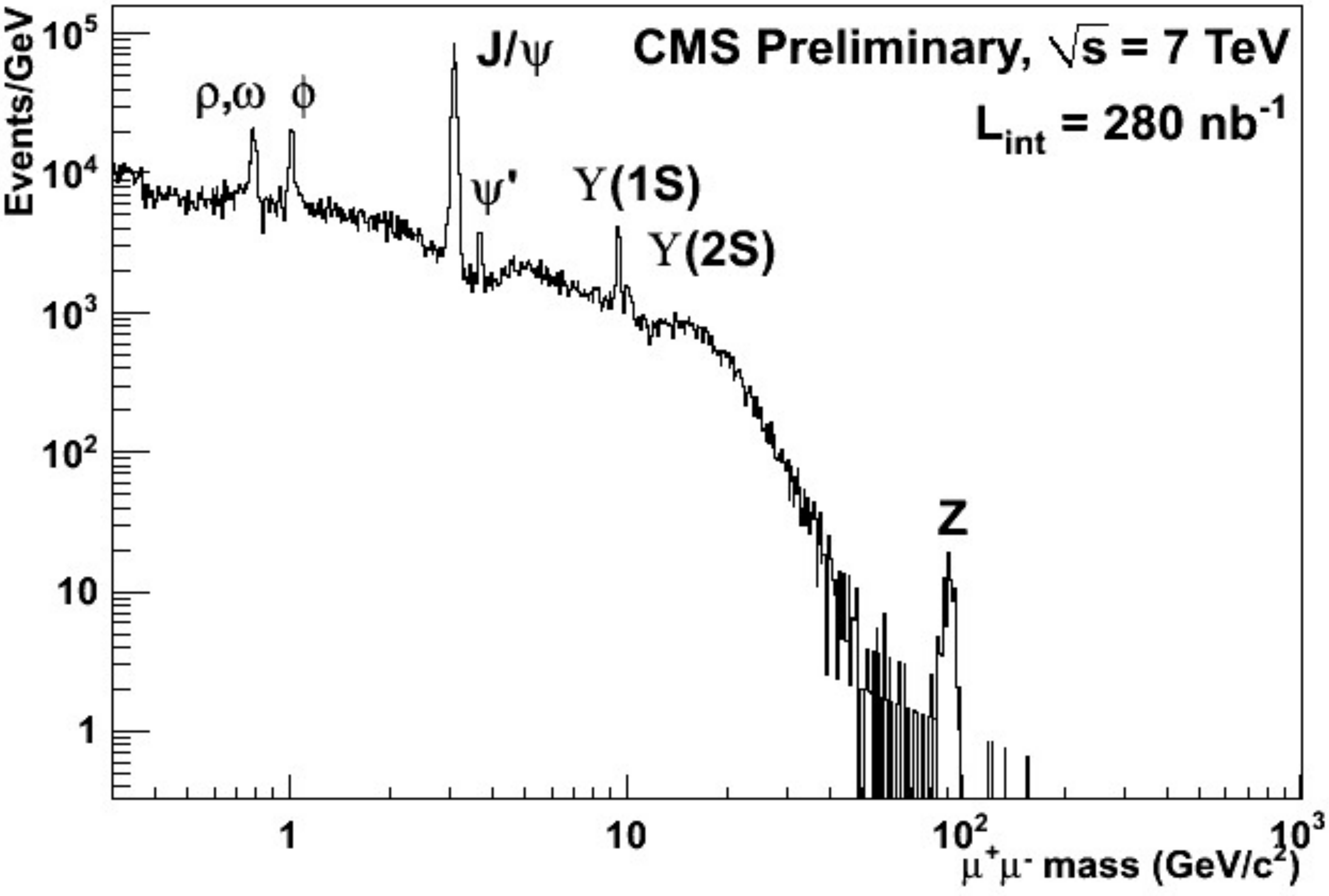
- Muon coverage |η| < 2.4

- Efficient muon (electron) triggering down to 9 (17) GeV at L = 2E32

- 3.8 T solenoid + 76000 crystal ECAL + 200 m² silicon → percent-level lepton momentum resolution at high p_T



putting the μ into CMS



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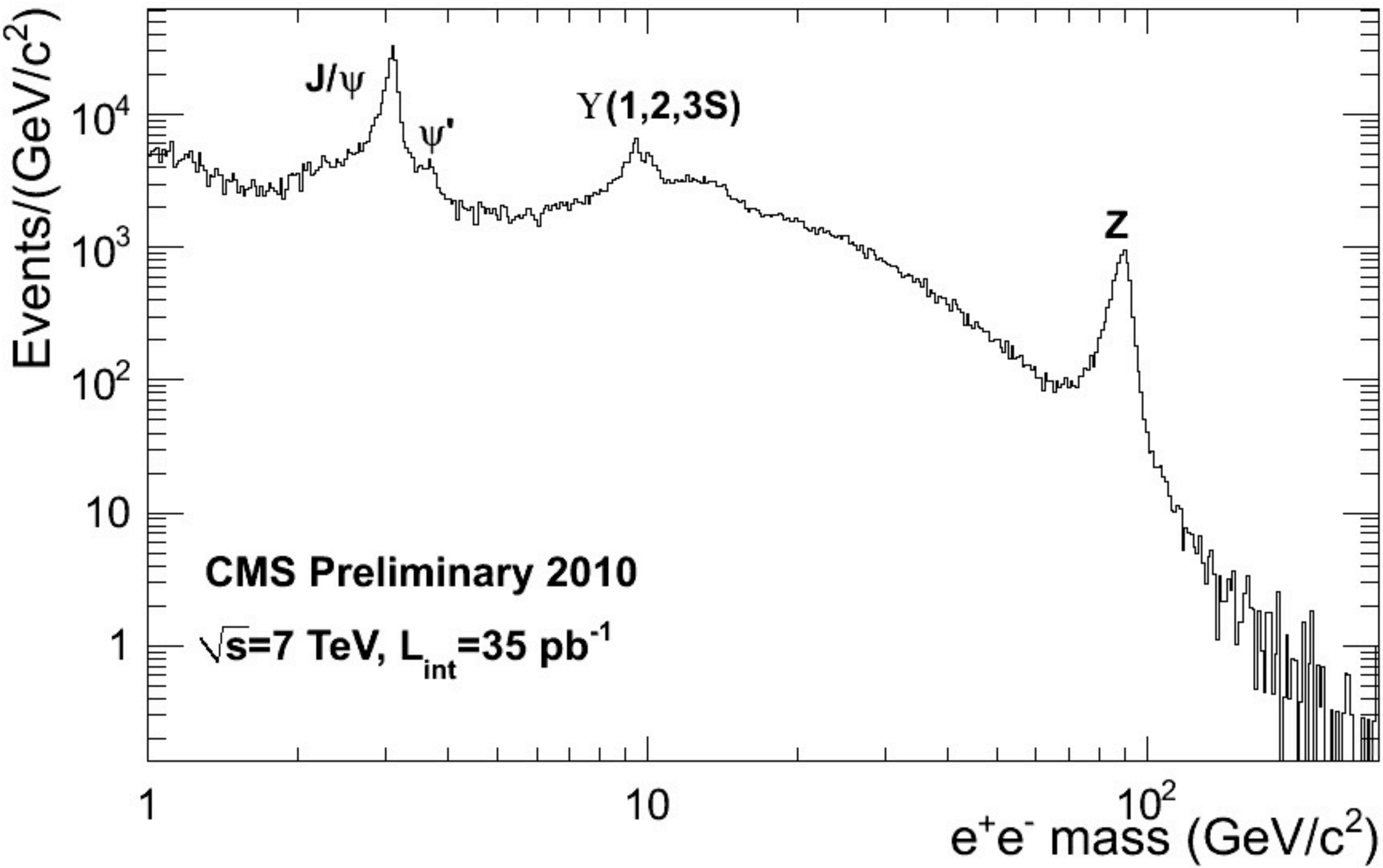

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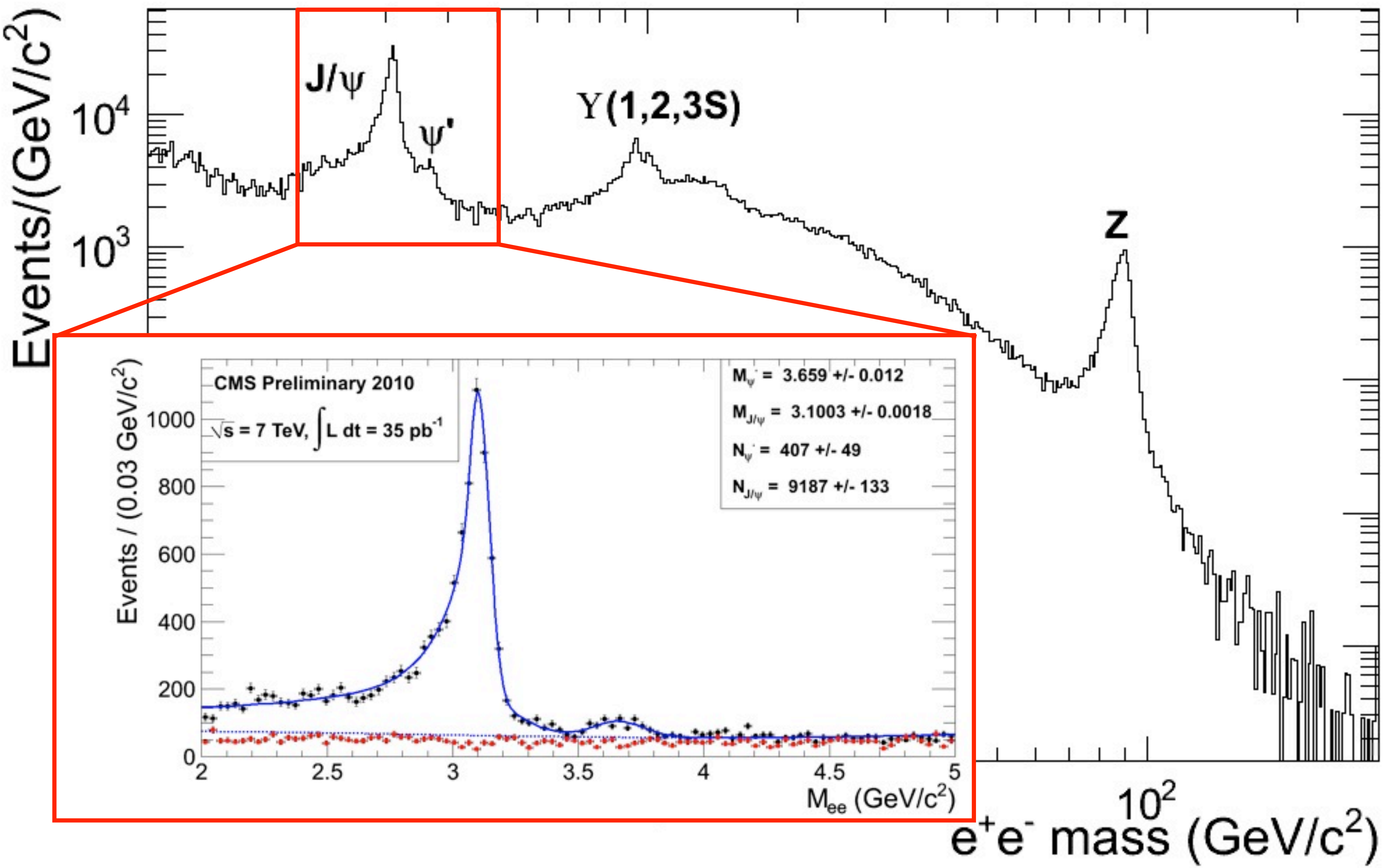
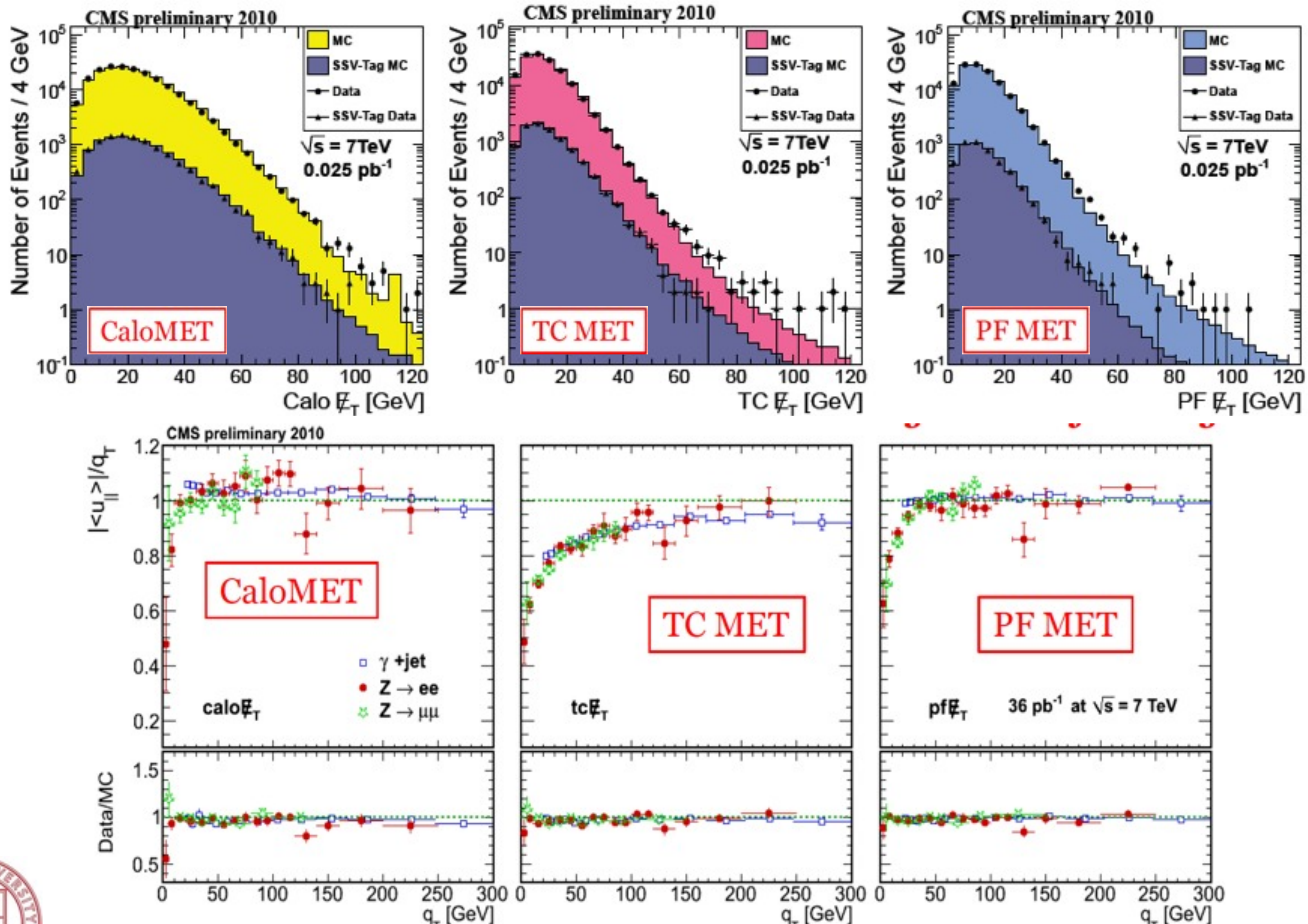


Missing momentum (MET) performance



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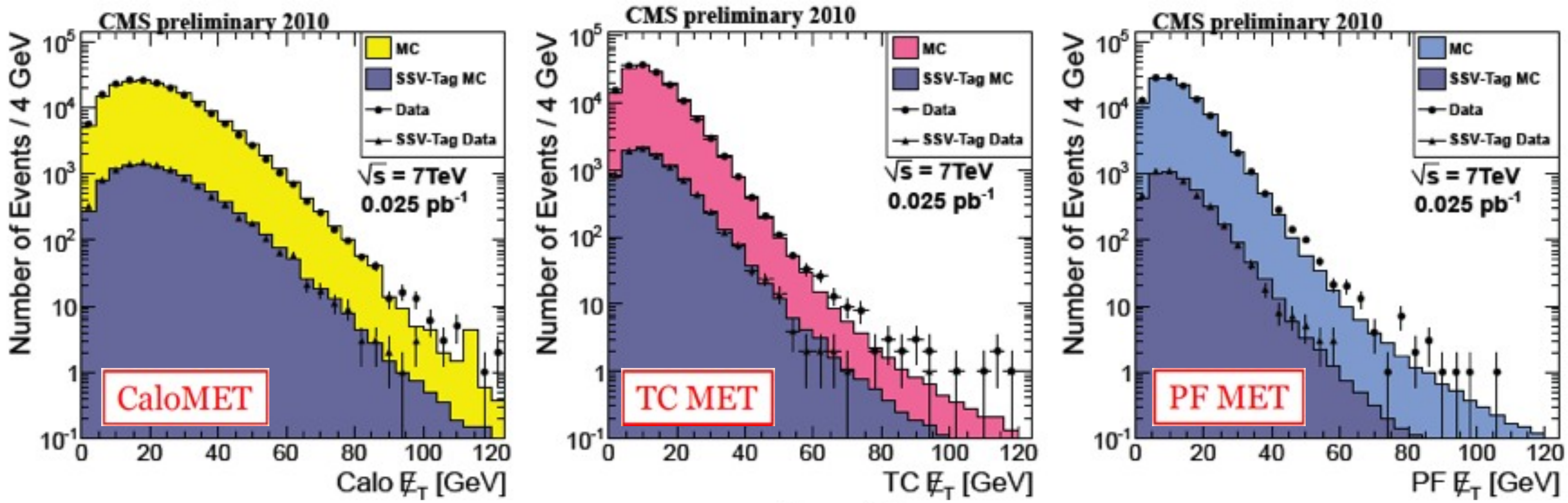
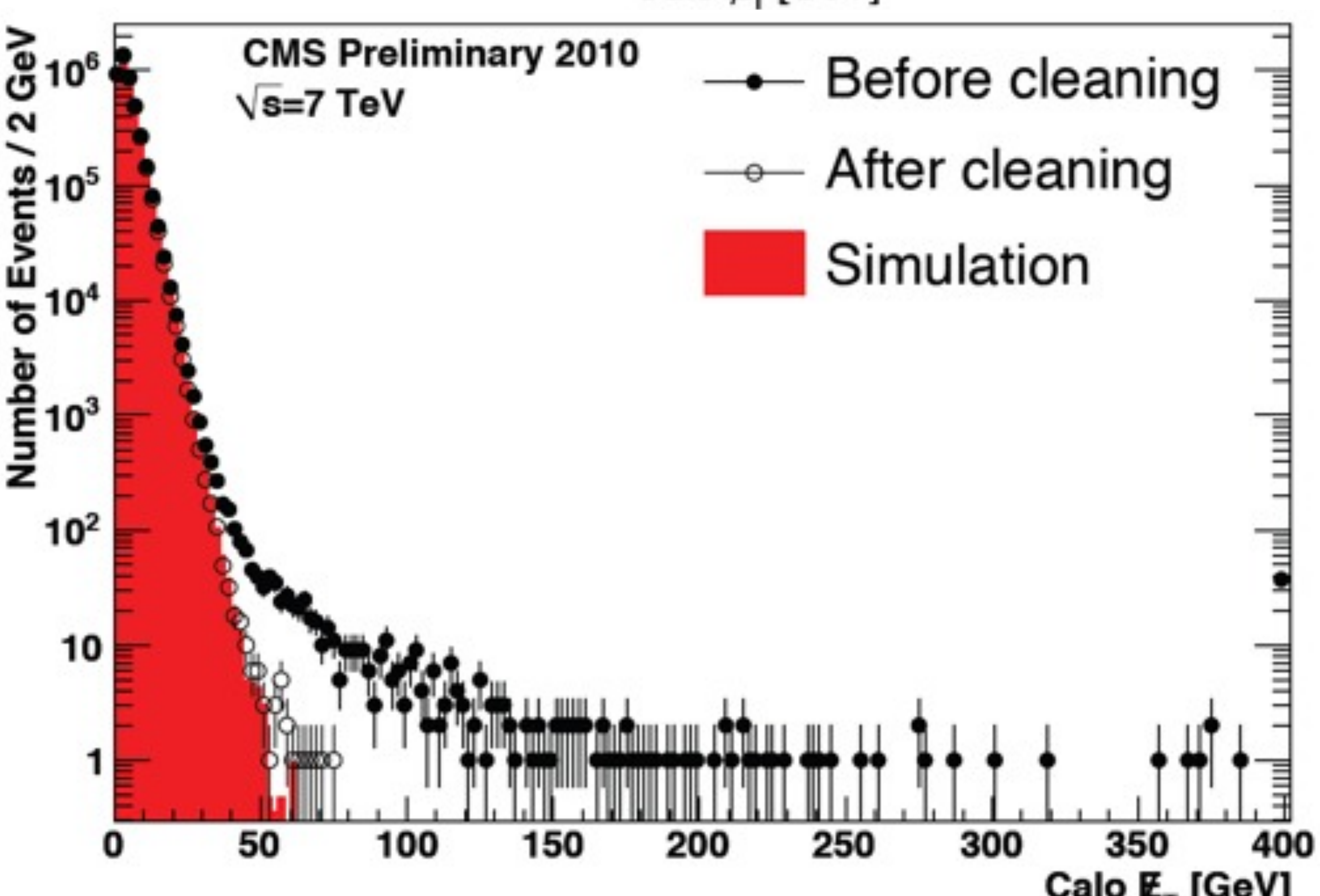
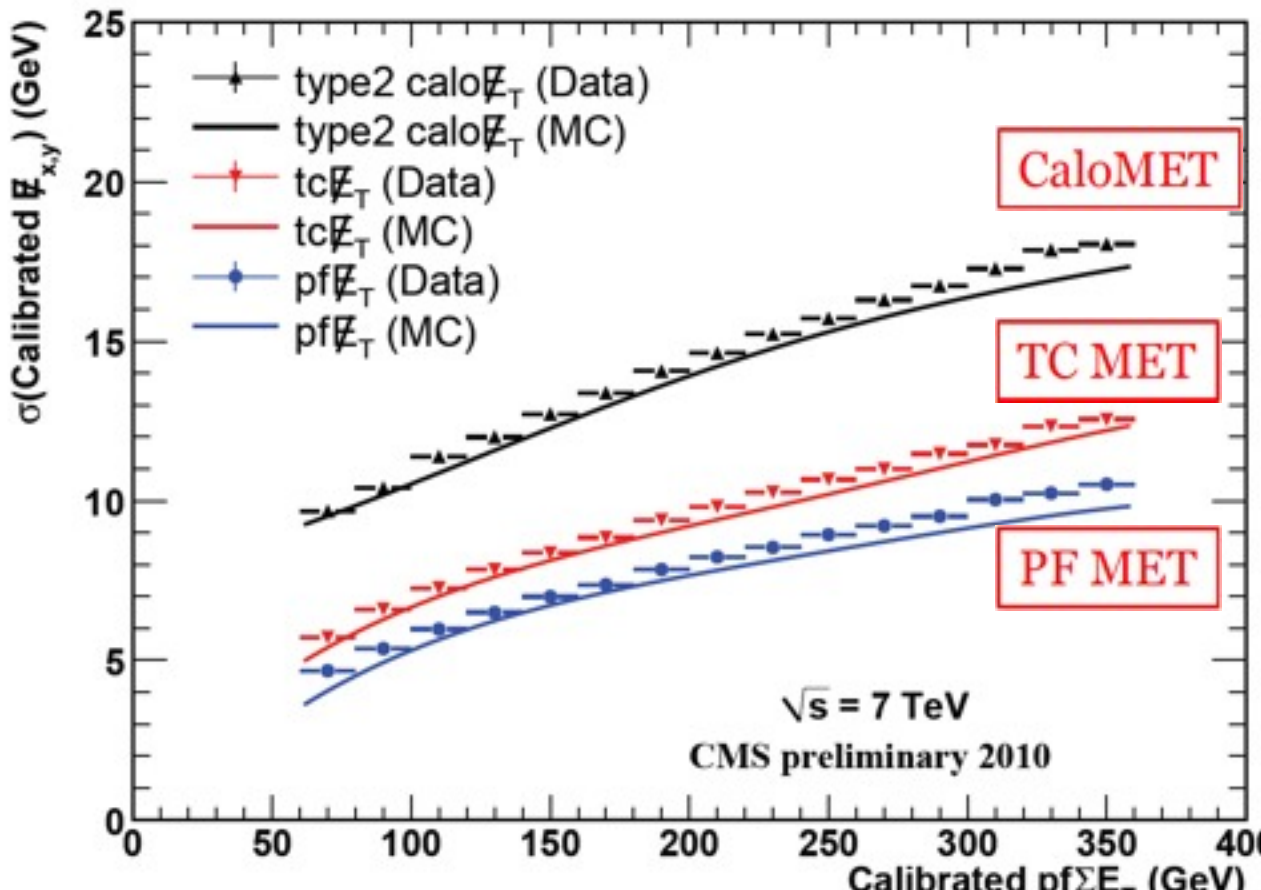






Search Strategy

W′ analysis

- W′ → ℓ ν signature: single, isolated high-p_T lepton + large missing transverse energy

- Performed counting experiment after cutting on transverse mass

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

- Main, irreducible background: Standard Model W → ℓ 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

- Analysis performed with the full 2010 dataset, corresponding to an integrated luminosity of 36.1 pb^{-1}

W’ Reference model

Altarelli, G., Mele, B., & Ruiz-Altaba, M. (1989). *Searching for new heavy vector bosons in ppbar colliders*. Zeitschrift für Physik C Particles and Fields, **45**(1), 109-121.

- 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
  - however decays to tb are allowed when kinematically available
- Decay width of *W* ’ scales with its mass

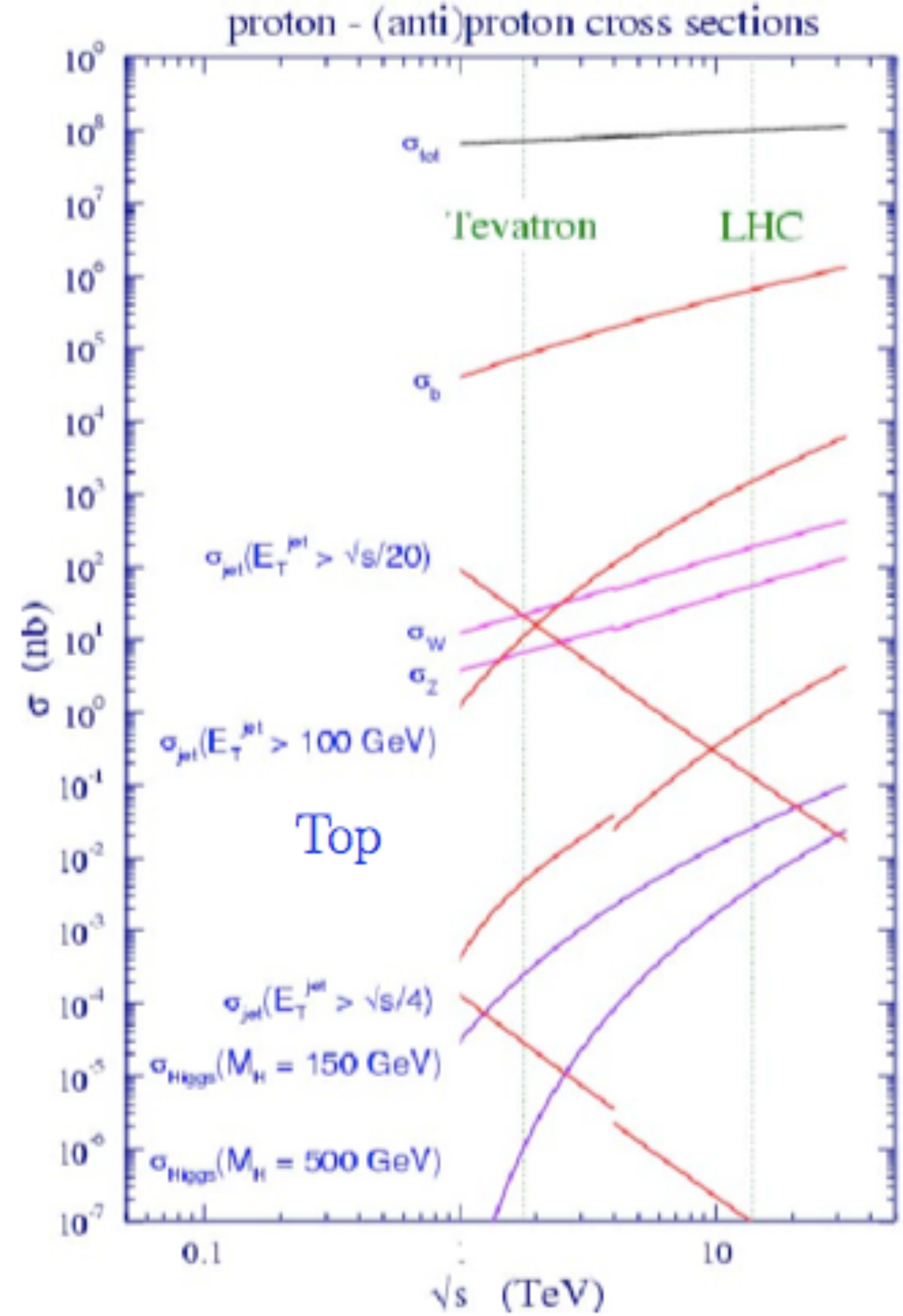
$$\Gamma_{W'} = \frac{4}{3}\frac{M_{W'}}{M_W}\Gamma_W$$

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

- Baseline model for comparison btw exp. (null) results

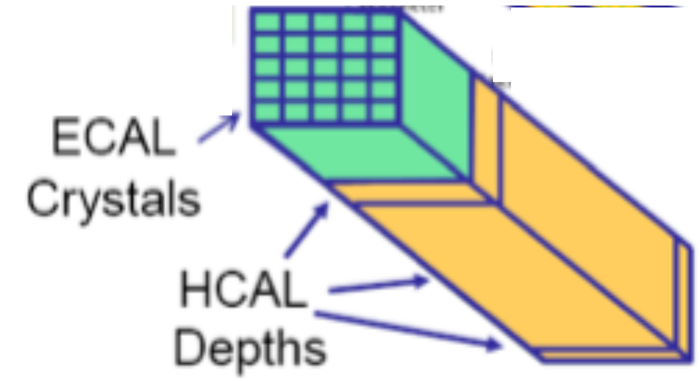
Trigger is simple and robust

- Trigger at LHC is very complex: reject all but 1 in 40,000 events within ms of collision
- Single-object triggers with low momentum cuts usable throughout 2010 run
  - we are still only at few percent of design lumi
  - luxury of early data taking, probably not feasible in 2011+
- Electrons:
  - single electron with loose selection criteria and $15<E_T<22$ GeV
- Muons:
  - single loosely id'd muon with $9<p_T<15$ GeV



How to Select High p_T Electrons

Standard electron ID: single electron trigger. Form clusters of EM energy → combine with pixel hits → search for tracker hits (min 5 hits/track)



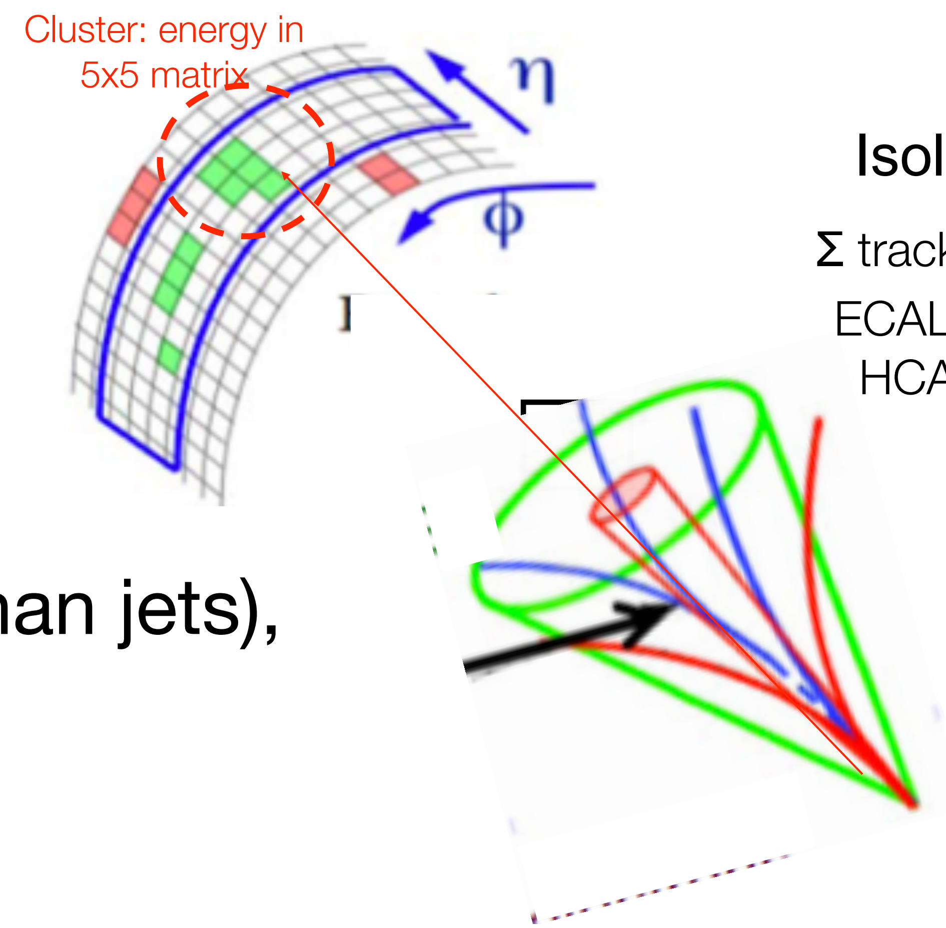
$E_T > 25$ GeV, $|\eta| < 2.5$ (gaps)

Matching in η, φ with a tracker track

Deposits most of its energy in ECAL, very little in HCAL

Shower shape (e^- shower more narrow than jets), characteristic shape in η, Φ, depth (H/E)

Isolation in both calorimeter and tracker

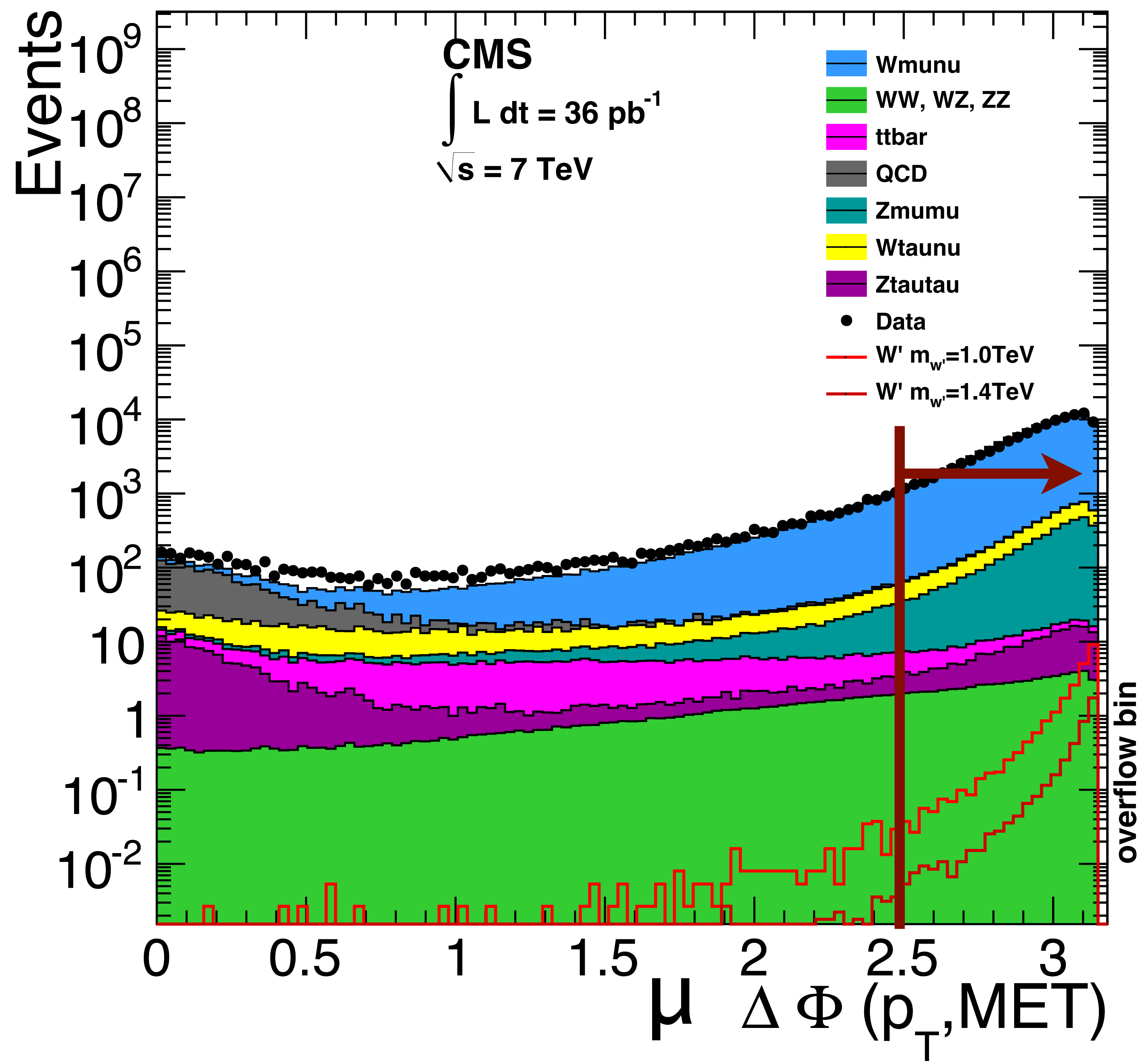


Isolation

Σ tracks p_T, or ECAL hits or HCAL hits

Event selection (e and μ)

- Require single good lepton, primary vertex
  - Isolation in both tracker and calorimeter
  - Rejects fake leptons from punch-through
- Use particle-flow missing E_T to estimate ν momentum in transverse plane
- $0.4 < p_T/MET < 1.5$
  - Select W'-like event topology
  - Effectively a MET cut but sliding with energy of lepton
- $\Delta\Phi(\ell, MET) > 2.5$
  - Reject misreconstructed multi-jet events



Example Background cutflow (W'→eν)

Sample	Preselection	1 Good Ele	$\Delta\phi_{eE_T^{miss}} > 2.5$	$0.4 < \mathrm{E_T^{ele}}/\mathrm{E_T^{miss}} < 1.5$
$W \to e\nu$	- , 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

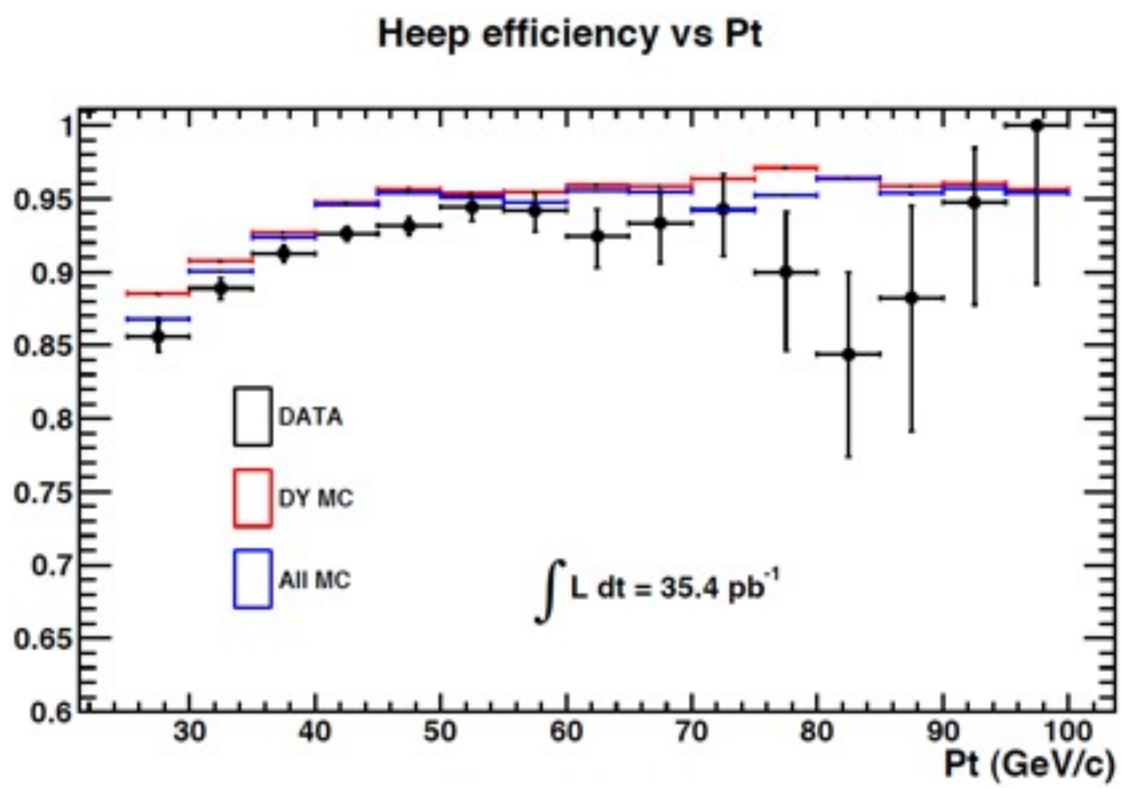
Signal cutflow (W'→eν)

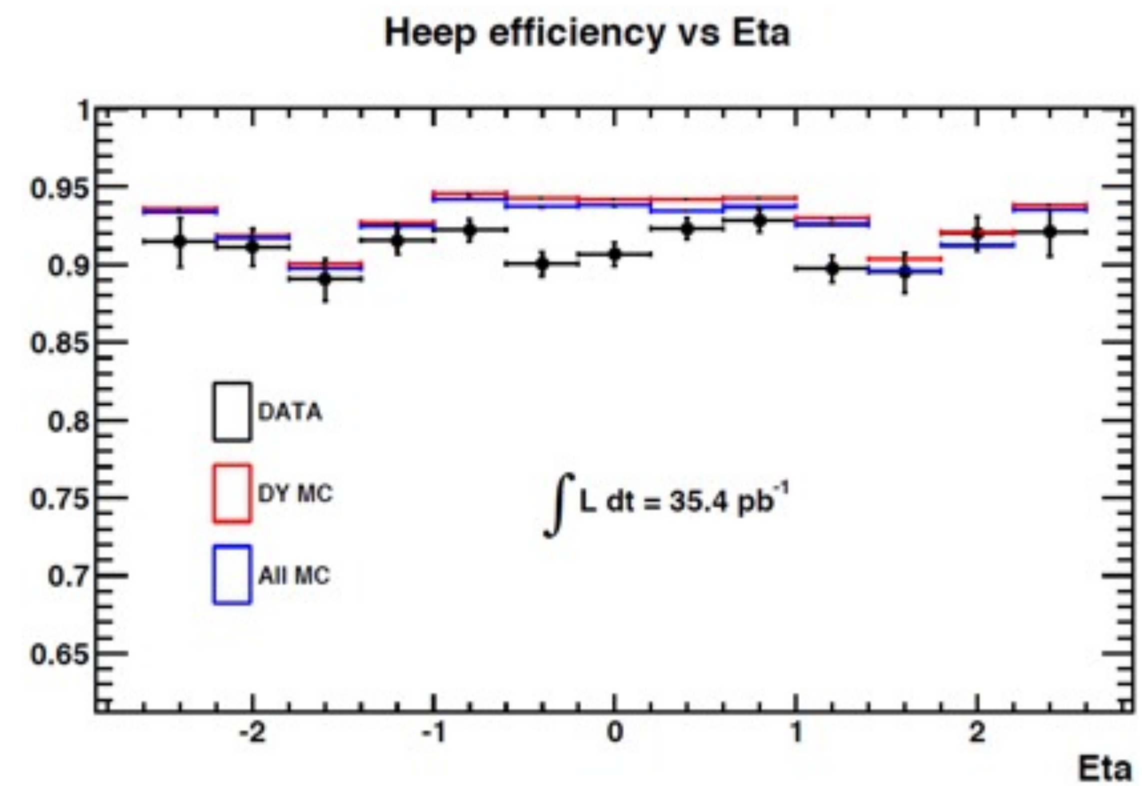
$M_{W'}(\mathrm{TeV}/c^2)$	Preselection	1 Good Ele	$\Delta\phi_{eE_T^{miss}} > 2.5$	$0.4 < \mathrm{E_T^{ele}}/\mathrm{E_T^{miss}} < 1.5$
0.6	- , 88%	80%, 70%	94%, 66%	97%, 64% 191.30
0.7	- , 88%	80%, 70%	95%, 66%	97%, 64% 99.15
0.8	- , 89%	79%, 70%	95%, 66%	97%, 64% 56.46
0.9	- , 90%	79%, 70%	96%, 67%	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

μ efficiencies are generally a bit higher (~80%, μ sel)

High p_T electrons

- Optimize lepton selection for searches for new physics
  - high p_T electrons
  - Efficiency measurements
  - correct for differences between simulation and data





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

Cut and Count, signal and background

- Use transverse mass, calculated from lepton 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
- Electrons: We use a data driven estimate for W and QCD (our dominant backgrounds) for both shape and normalization
  - The other backgrounds are from MC

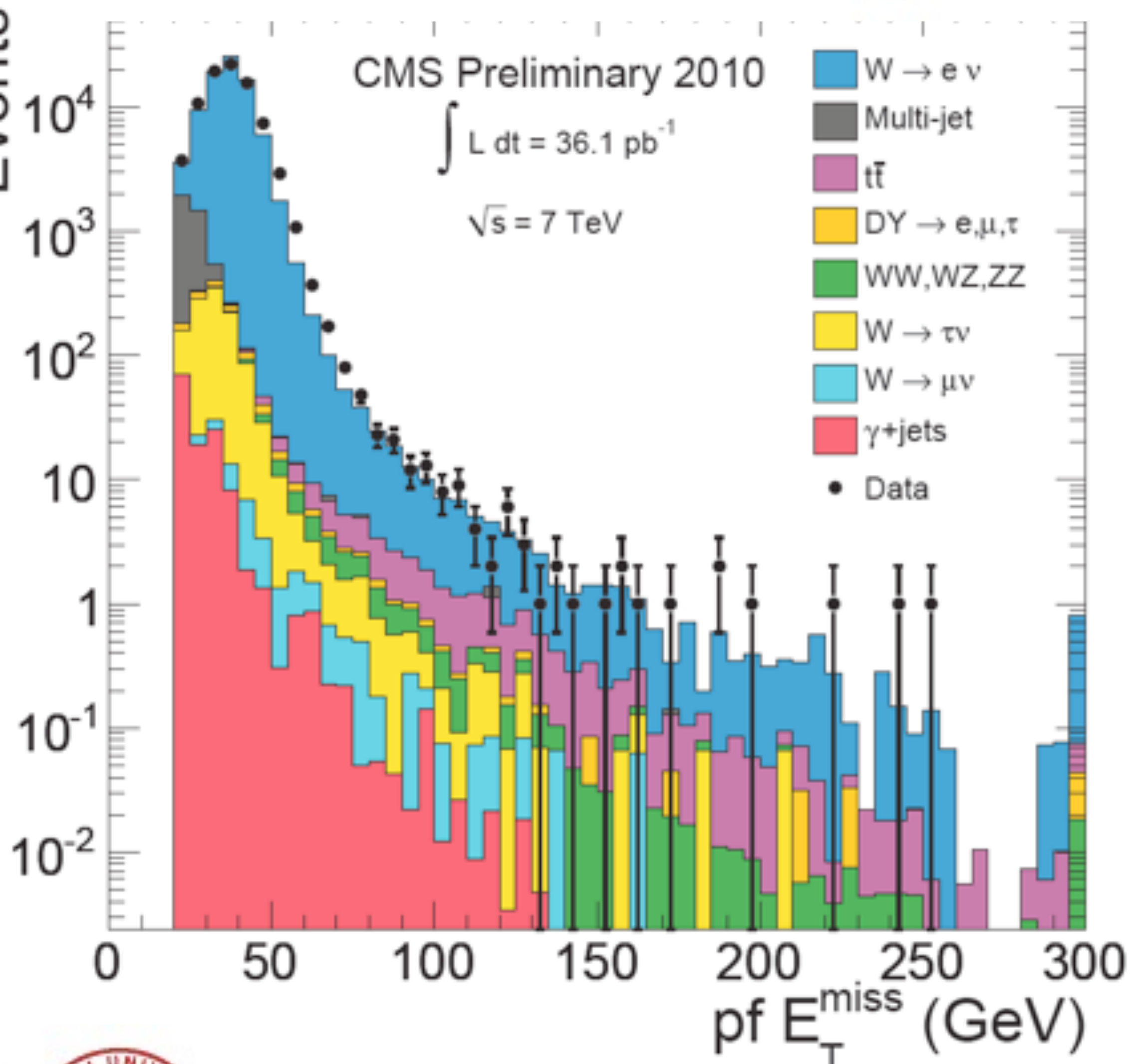
Background	Shape	Normalization
$W \to e\nu$	MC with hadronic recoil correction	fit of $\mathrm{E_T^{ele}}/\mathrm{E_T^{miss}}$
multi-jet	non-isolated electrons from data	fit of $\mathrm{E_T^{ele}}/\mathrm{E_T^{miss}}$
Other backgrounds	MC	MC

- Muons: entirely data-driven background estimate

W shape corrections - hadronic recoil (e and **μ**)

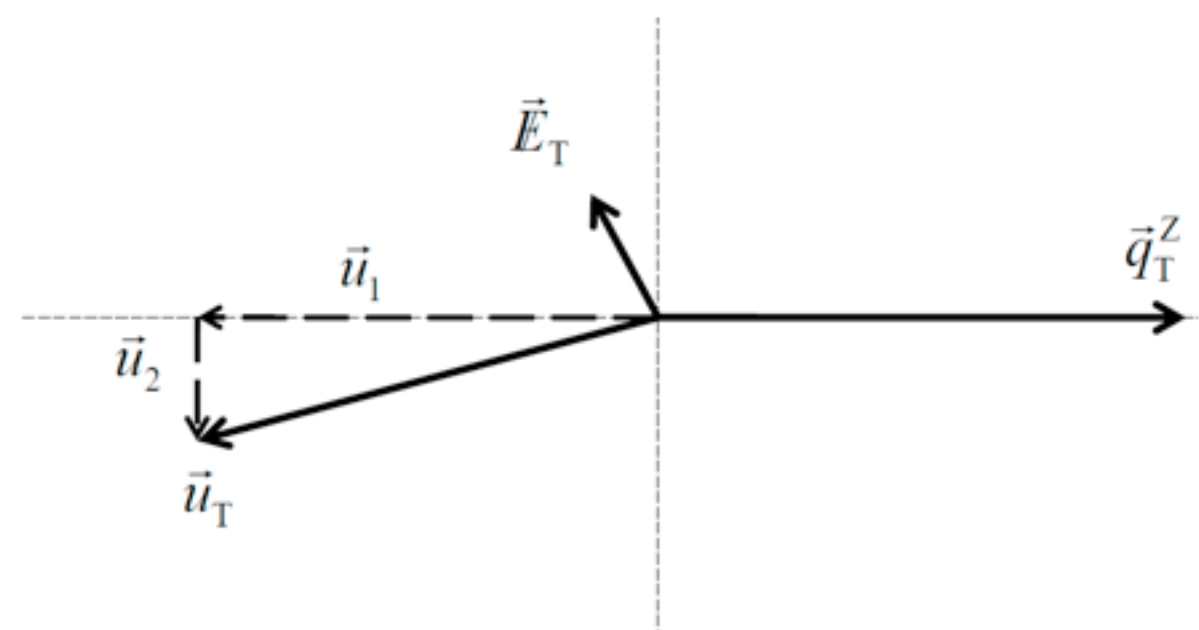
- Poor agreement in missing ET for W→ℓν out of the box
- Apply a correction for calorimeter response and pile-up and underlying event

$$\vec{u}_T = -\vec{E}_T^{miss} - \sum_l \vec{E}_T^l$$



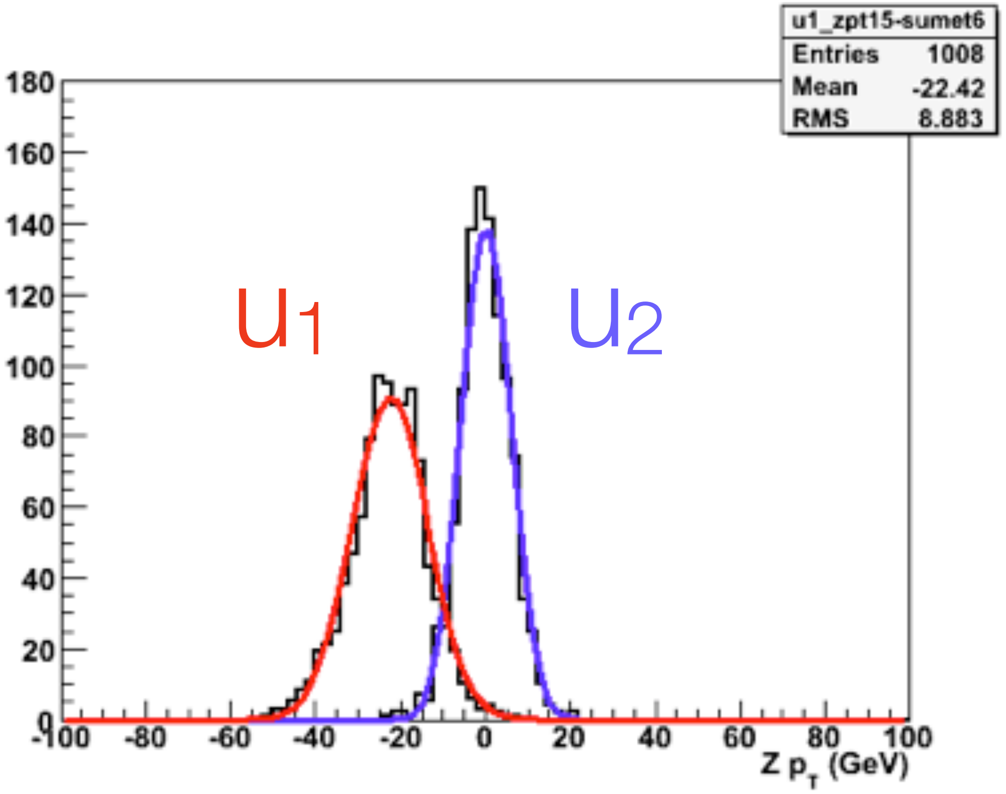
w/o corrections

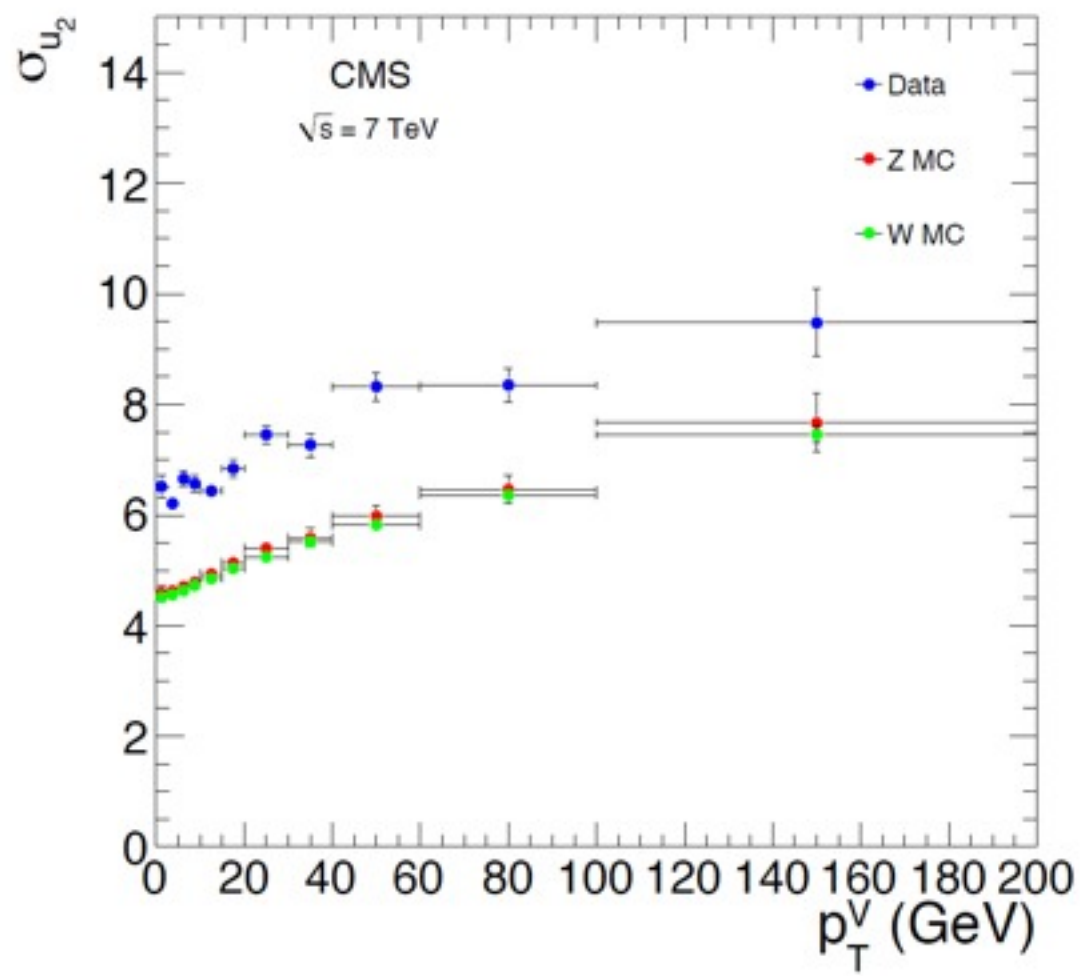
- Address effects with ‘recoil method:’
  - exploit similar Z kinematics to improve the W response with (cleaner) Z data
- Define a vector u: missing ET w/o lepton contribution(s)
- Define u_1 (u_2) as parallel (perpendicular) to axis defined by boson momentum q_T.
- Calculate u_1, u_2 for Z MC, Z data, W MC



Hadronic Recoil, continued

- Model components with Gaussians in boson momentum
  - determine response (mean) and resolution (width) as fcn of boson q_T
  - Determine Z data/MC scale factors to correct W MC response/resolution
- Recalculate MET using MC truth information
  - Correct u: sample truth information as a function of q_T, in both u1 and u2
  - use this corrected u to recalculate MET and then m_T.





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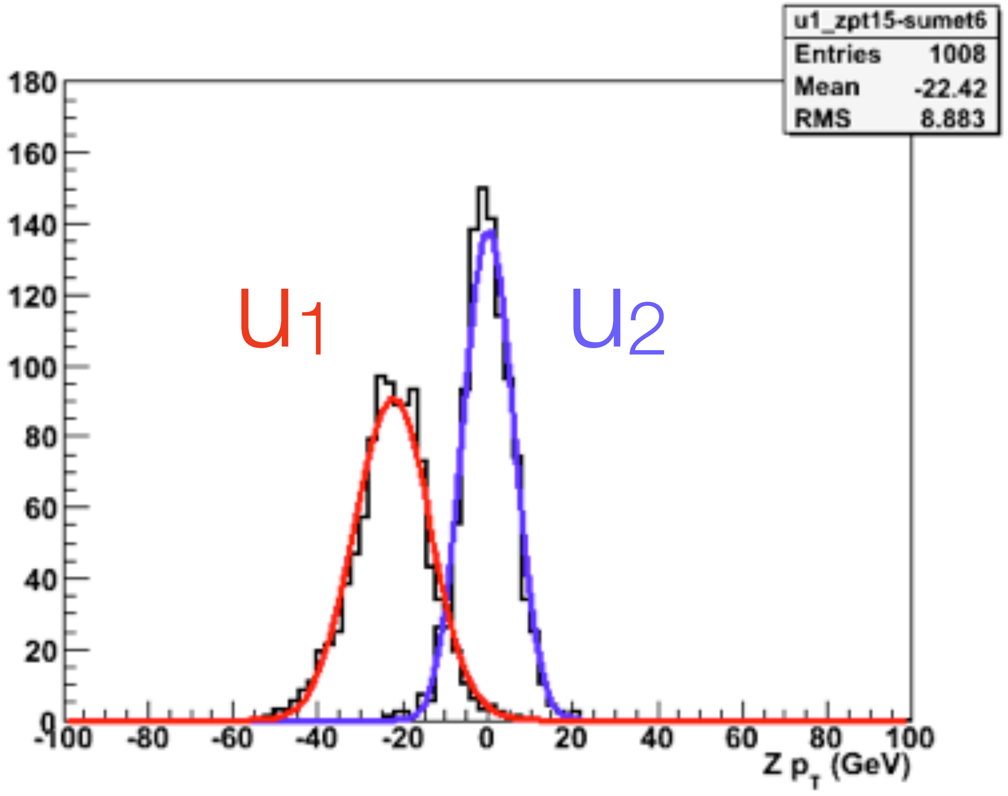
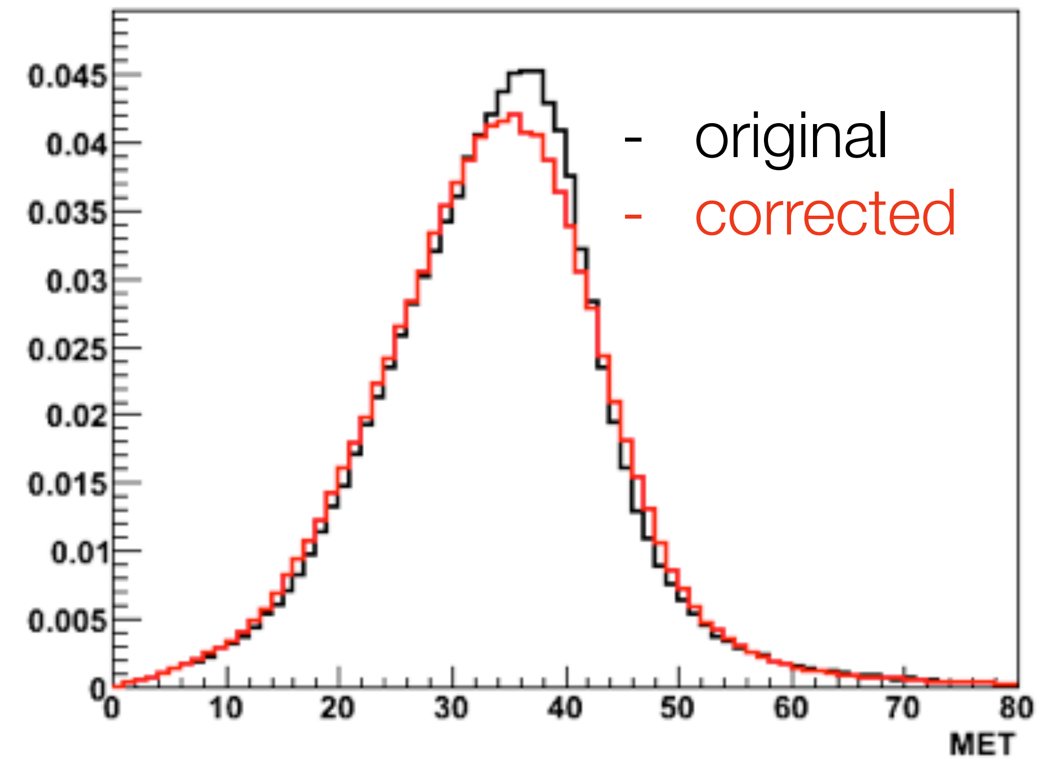
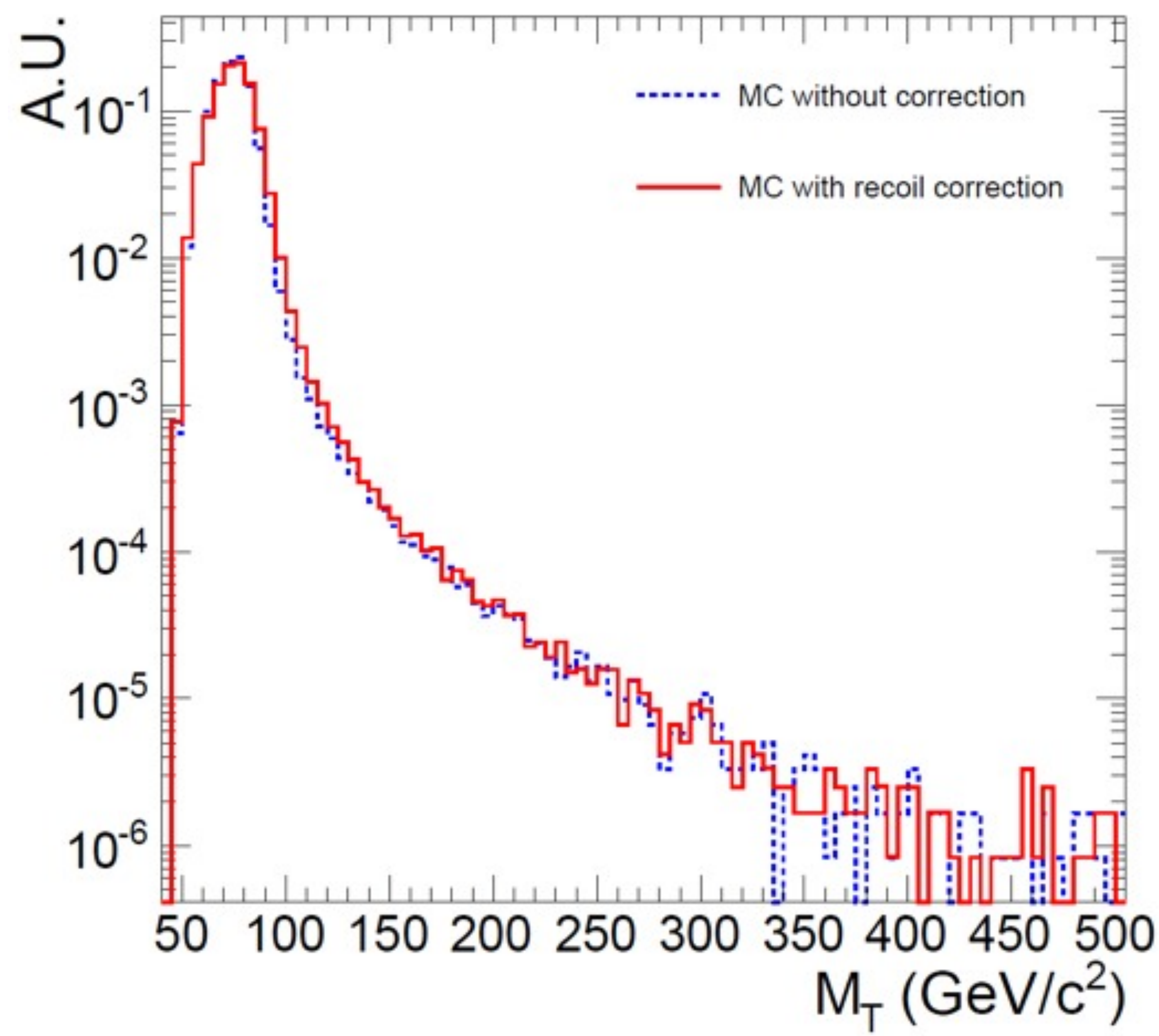
- Recalculate MET using MC truth information
  - Correct u: sample truth information as a function of q_T, in both u1 and u2
  - use this corrected u to recalculate MET and then m_T.





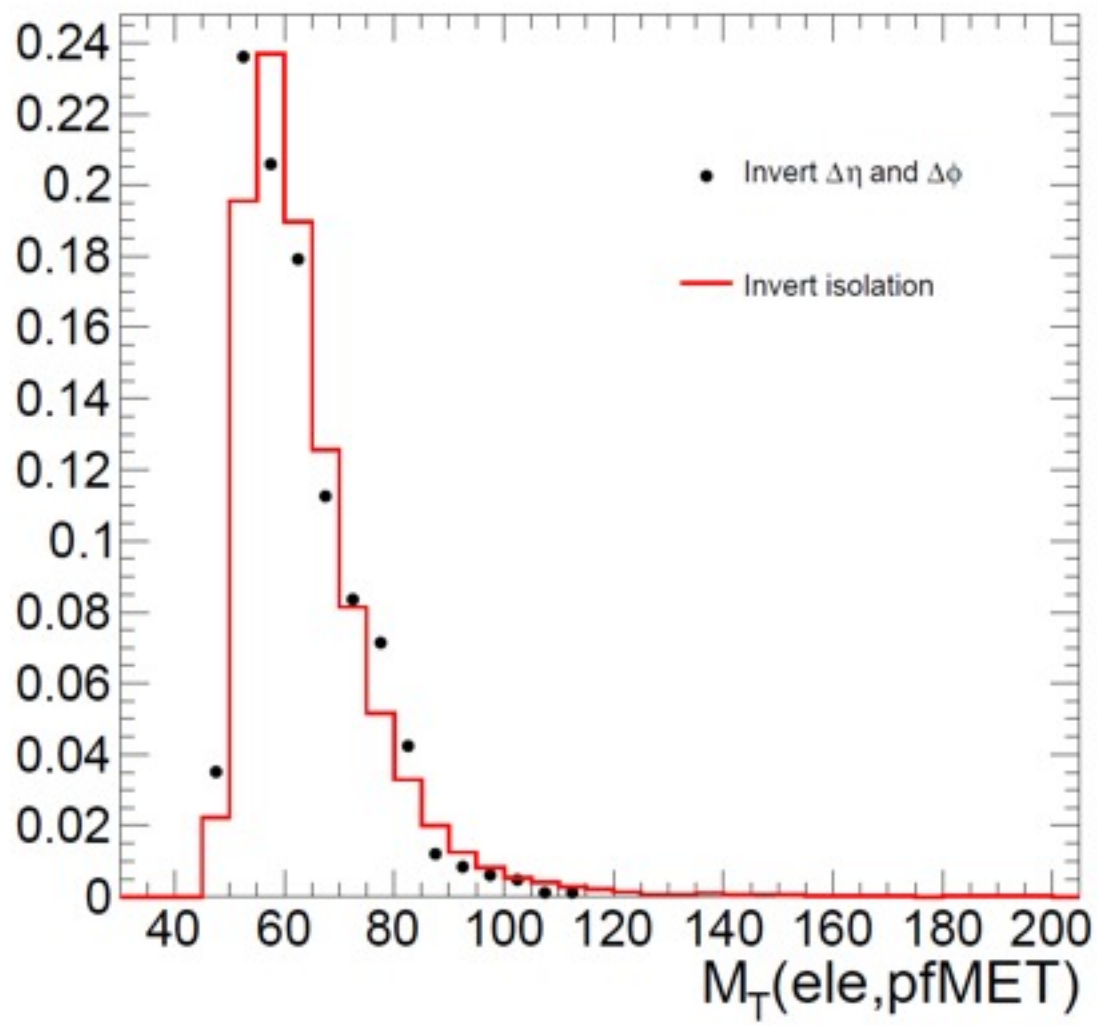
Corrected mass template

- Method gives recoil corrected MET on event-by-event basis
  - Use this MET in our event selections (E_T/MET and $\Delta\varphi$)
  - Use this MET to create transverse mass template for $W \rightarrow e\,\nu$
- Comparing M_T distributions with and without correction, agreement with data improves most for $100 < M_T < 150$ GeV
  - No big changes in the tails
  - Method does not introduce large M_T events



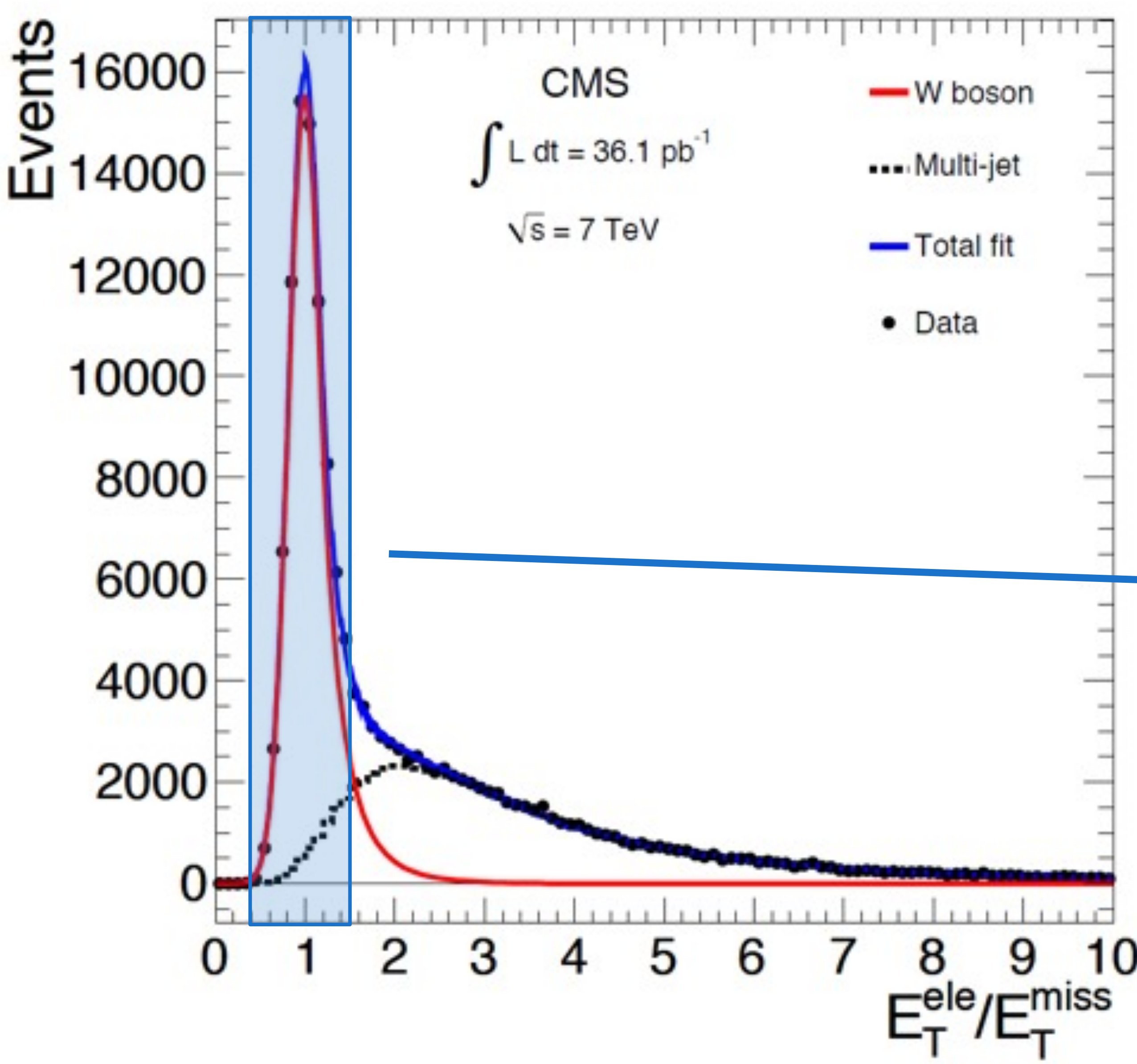
QCD transverse mass template (e only)

- 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 Δη(trk,SC) and Δφ(trk,SC) requirements
  - Decent agreement for orthogonal samples



W and QCD yield extraction (e only)

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



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

Background expectation (e)

- Dominant background is W → eν
- Backgrounds die off quickly as a function of transverse mass

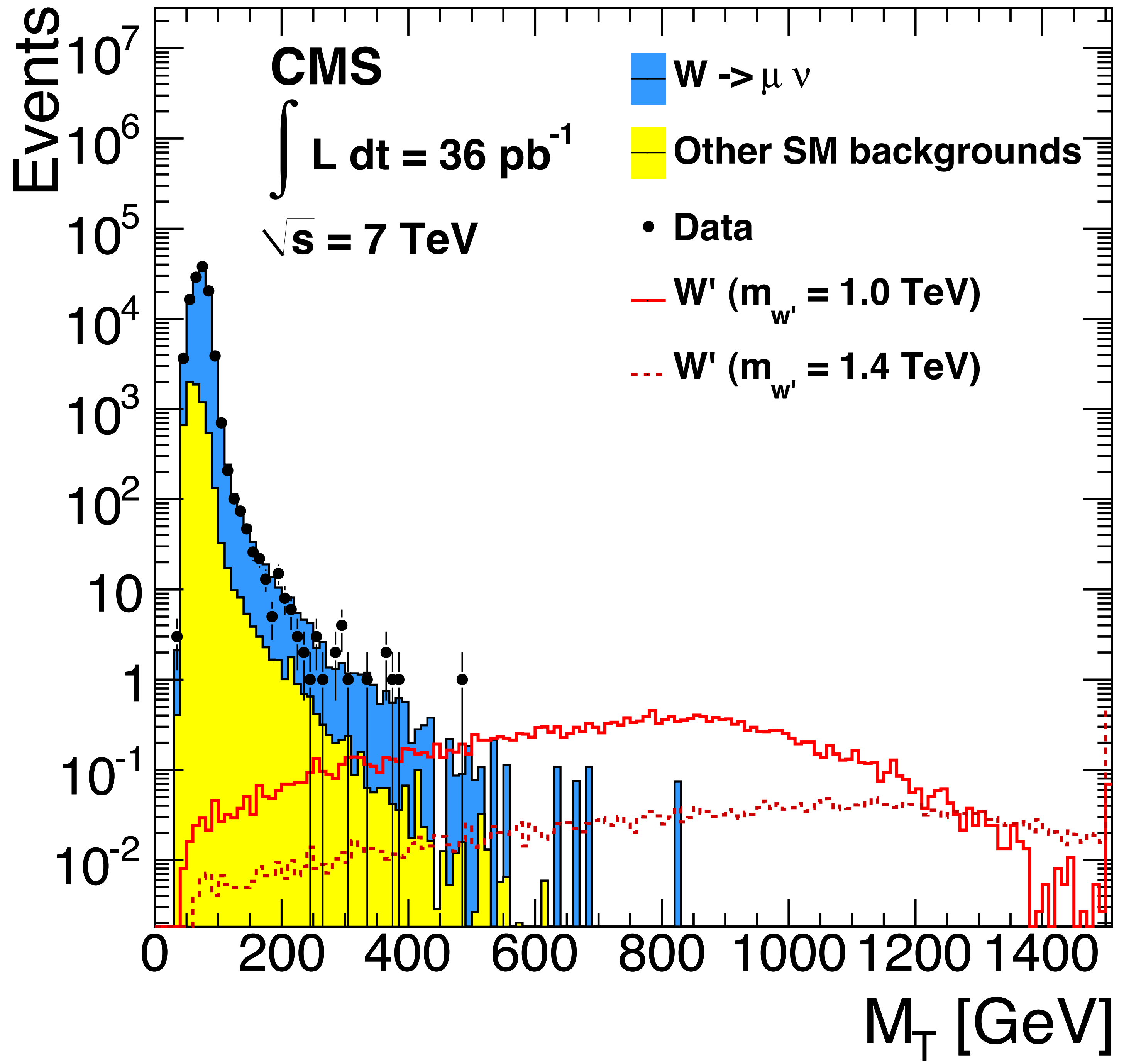
Sample	> 45	> 200	> 300	> 400	> 500	> 600
$W \to e\nu$	75609± 319	33.7±2.7	7.19±0.91	2.52±0.48	0.88±0.28	0.57±0.21
Multi-jet	7083±3546	6.3±3.3	1.64±0.93	0.47±0.33	0.23±0.20	0.23±0.20
$W \to \tau\nu$	1083± 80	1.1±0.3	0.21±0.19	<0.13	<0.08	<0.08
$t\bar{t}$	60± 23	4.1±1.7	0.64±0.29	0.15±0.09	0.03±0.03	0.01±0.02
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

* Other MC bkgs: γ+jets, W→μν, Z/γ* →ℓℓ, WW, WZ, ZZ, single top, Z+γ→νν+γ

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

Muon backgrounds

- Data-driven method for combined (beam-induced) bgd
  - Find “signal-free” region of MT spectrum ($180<M_T<350$ GeV)
  - Fit & use parameters to model background shape, empirical shape
  - Extrapolate to “region of interest” (e.g. $M_T>600$ GeV)
- Estimate # of bgd evens in signal region (w/o relying on MC)



Data-driven background estimate
NB: width of W’ for higher masses

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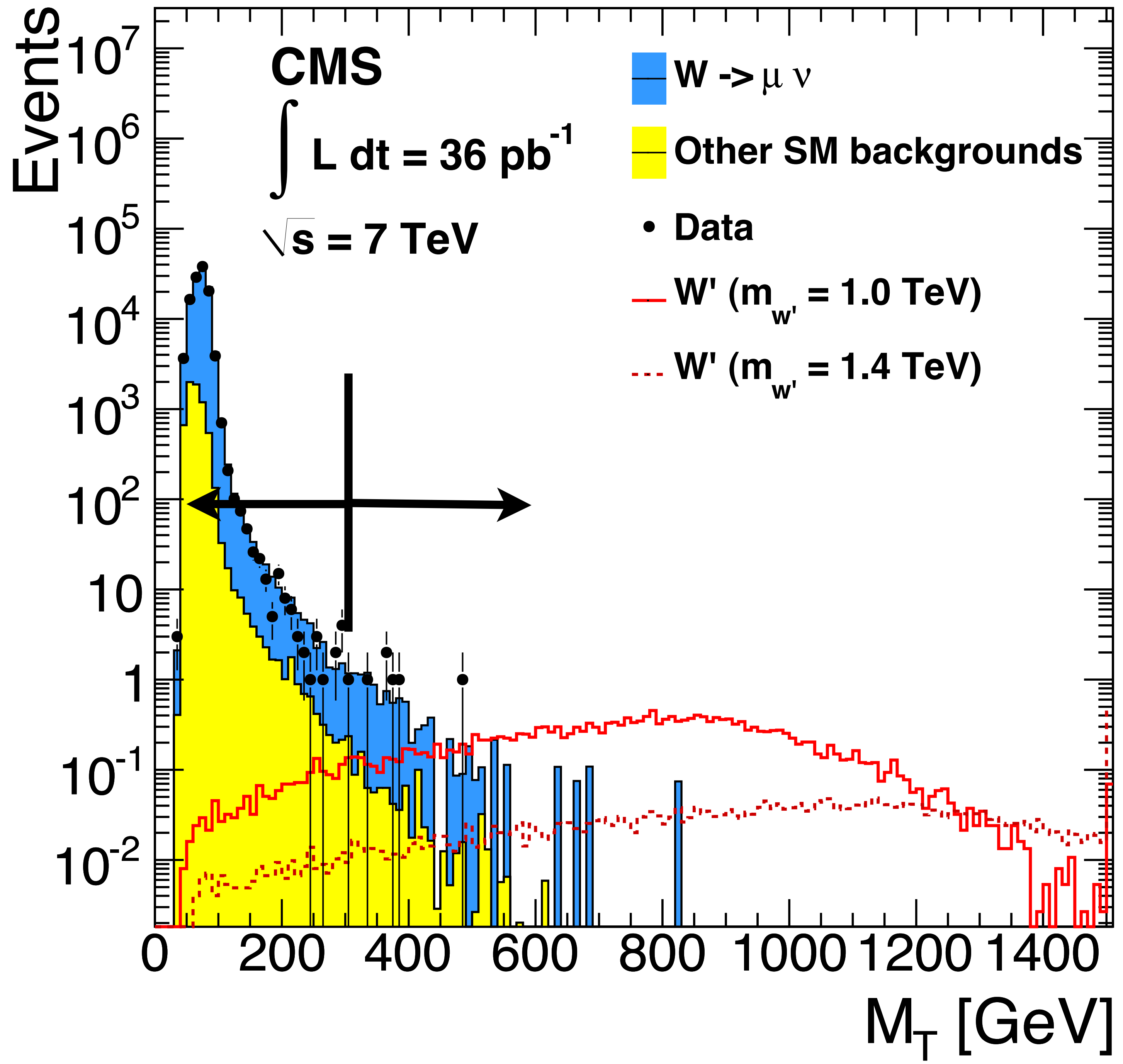

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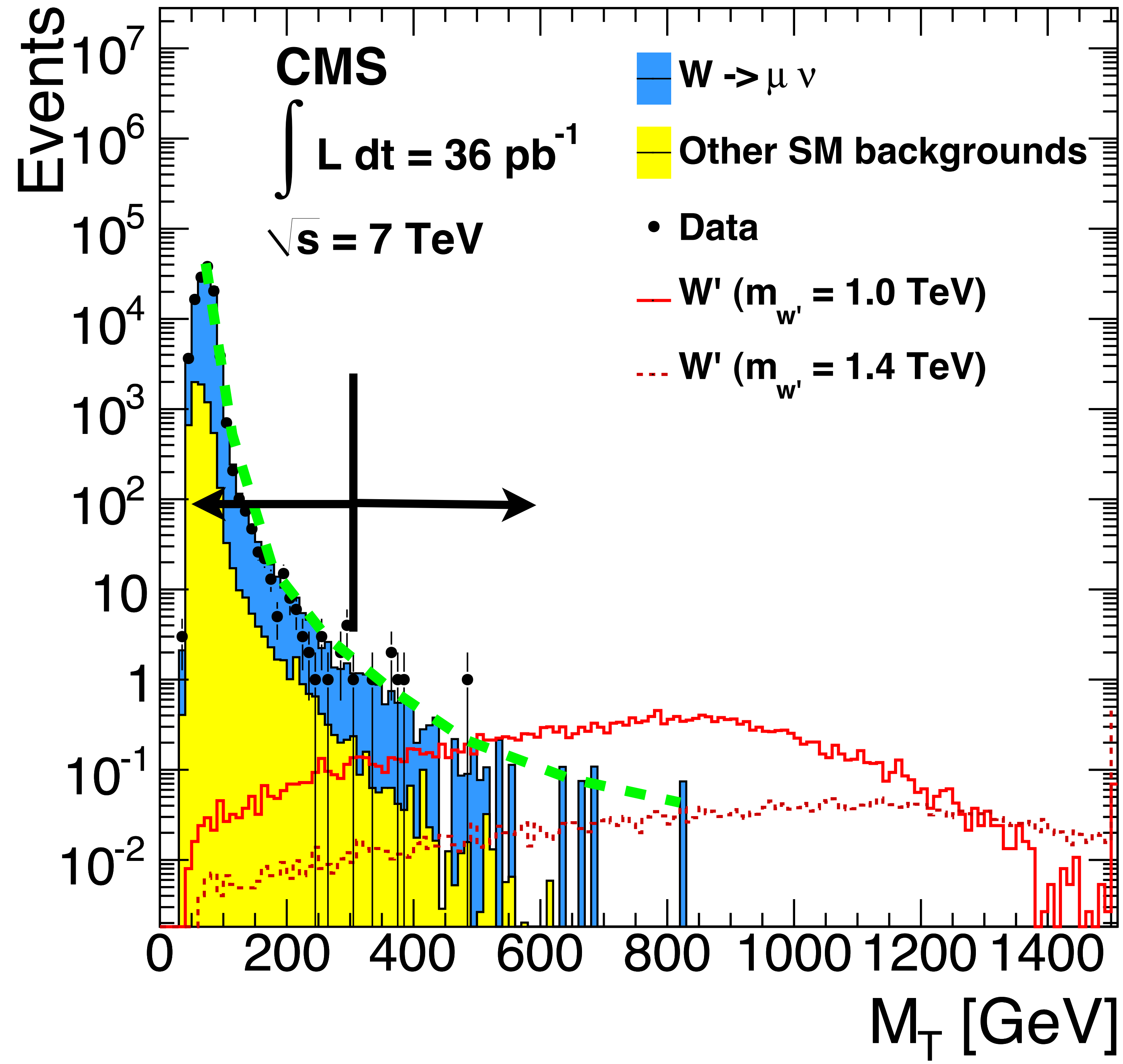
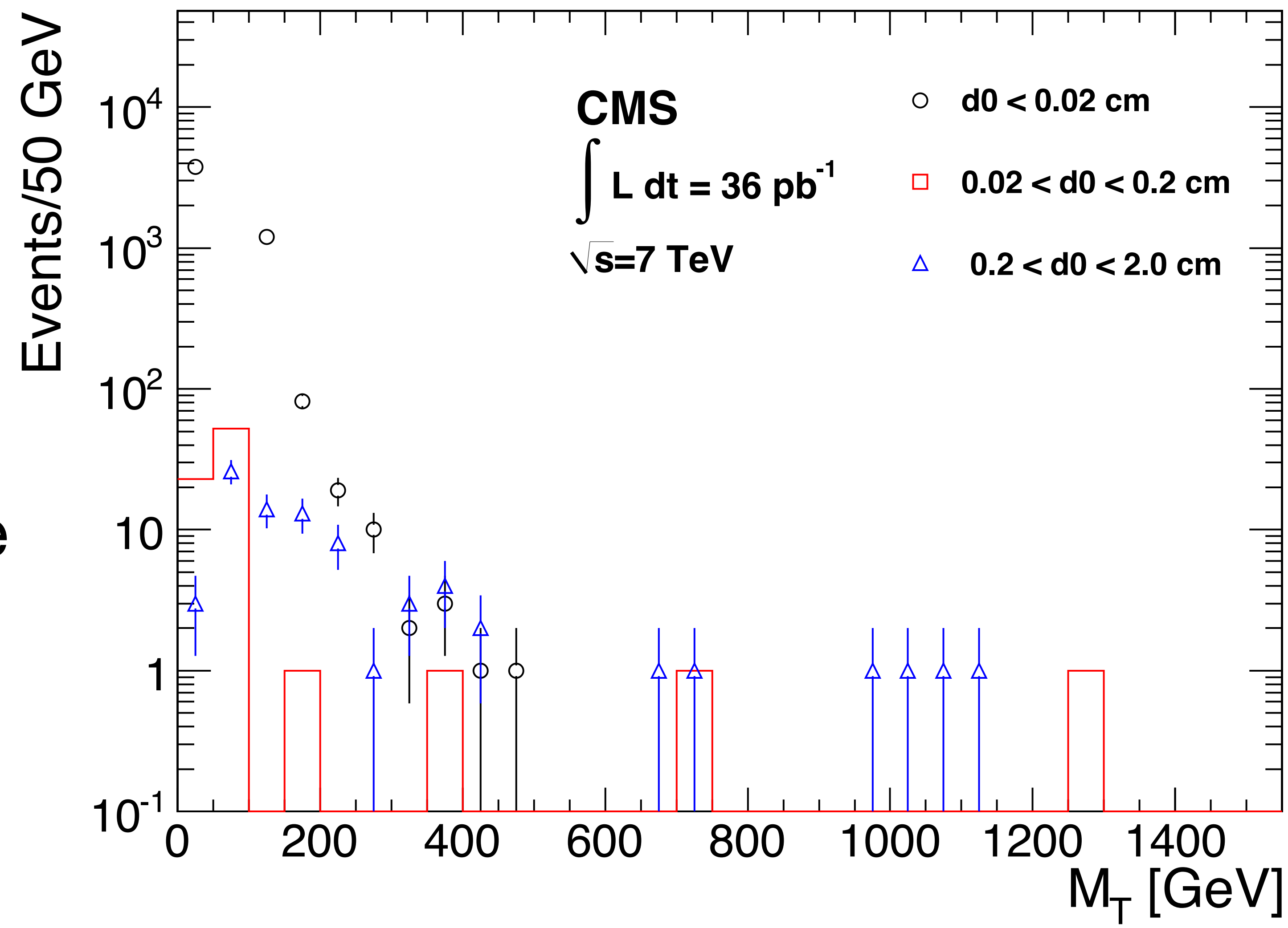


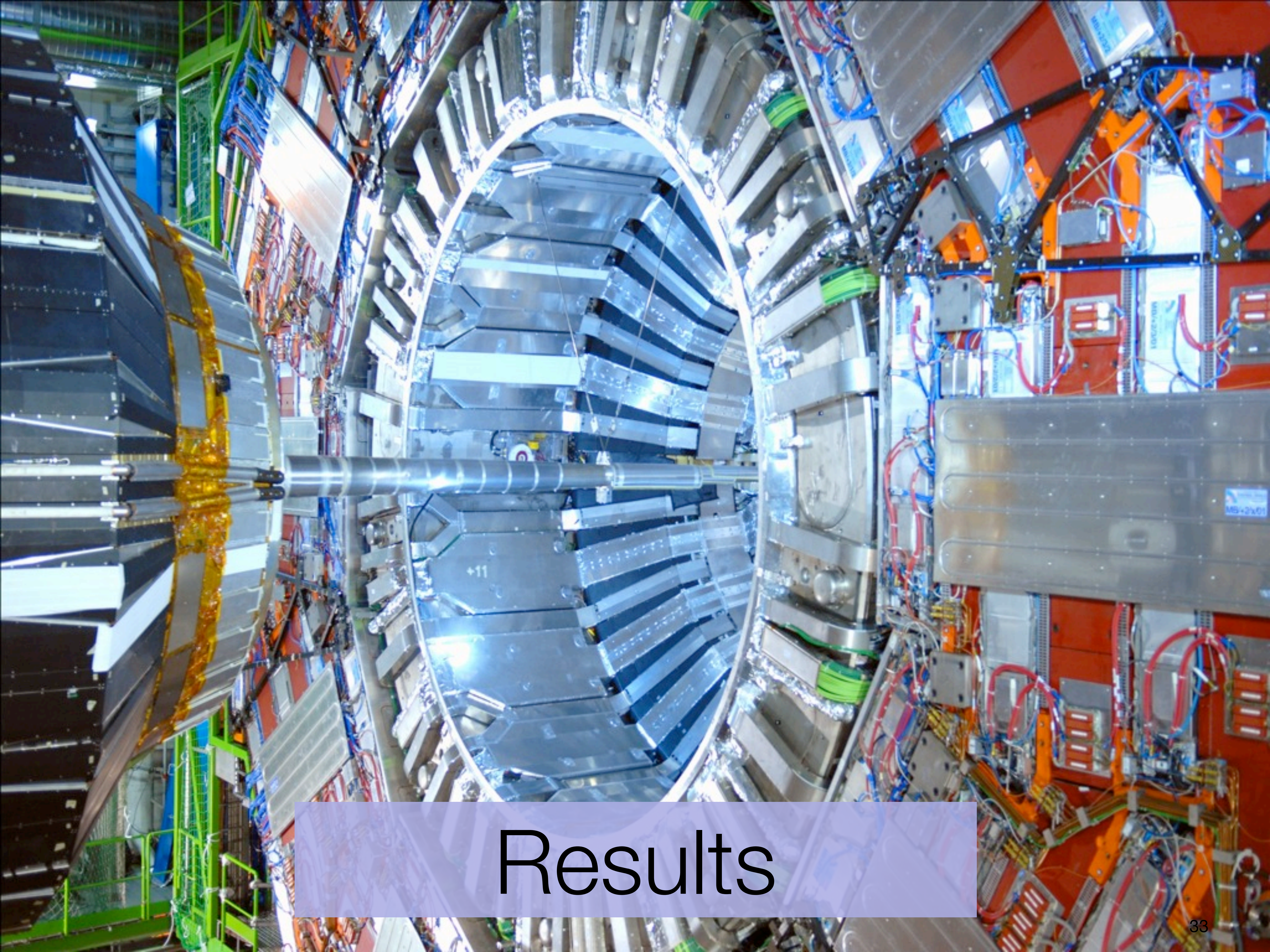
Data-driven background estimate
NB: width of W' for higher masses

Cosmic rays (μ only)

- cosmic ray muons produce large met, large m_T, across detector impinging from above
  - uniform distribution in d_0.
- Large m_T by construction
- suppress this contribution by requiring the muons to originate from the beam pipe
  - $|d_0|<0.02$ cm, tighter than usual cuts (0.2 cm for W,Z σ)

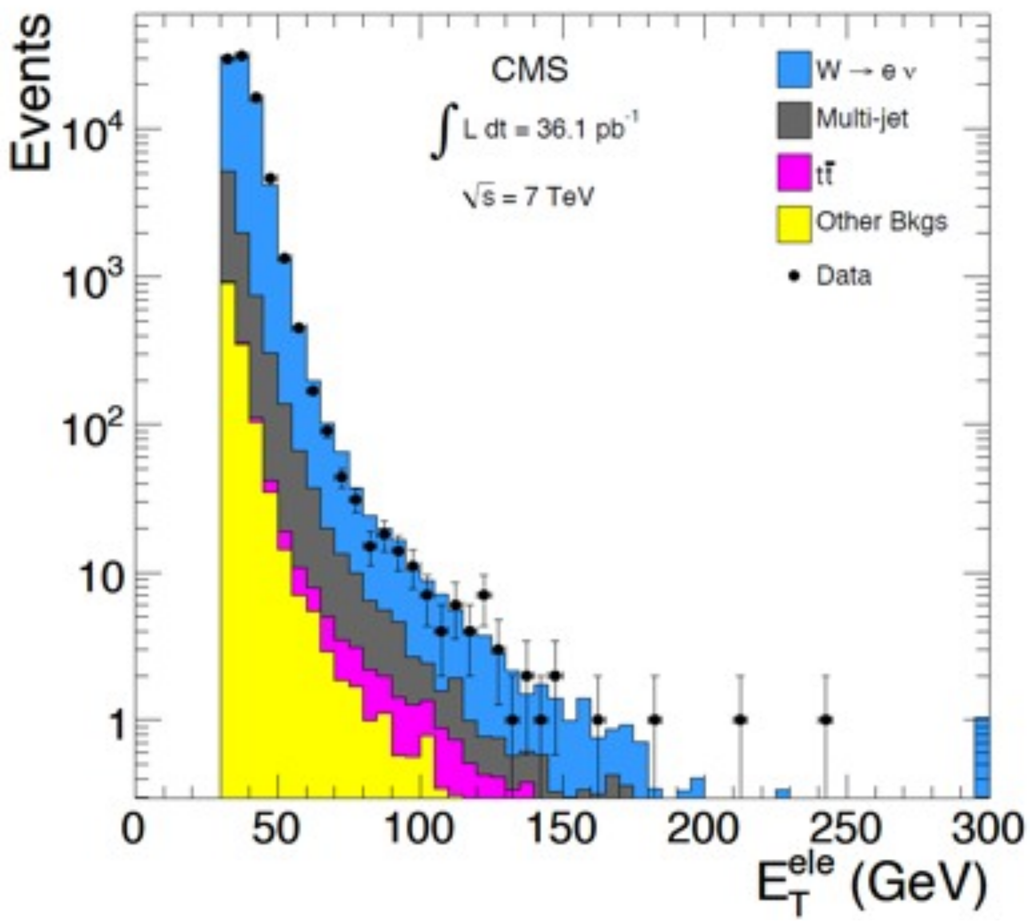


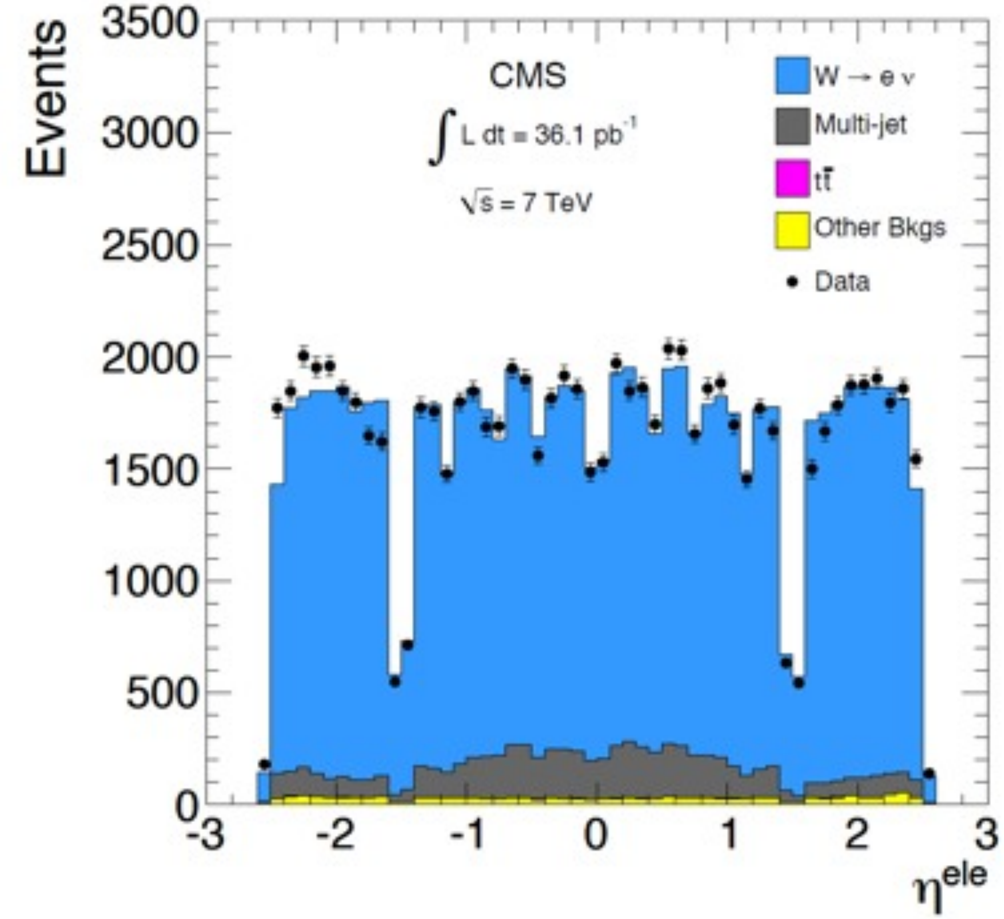
- Estimate residual number of cosmic ray muons left over by looking in Control Region
  - $0.02 < |d_0| < 2$ cm
- Extrapolate into signal region with appropriate m_T shape

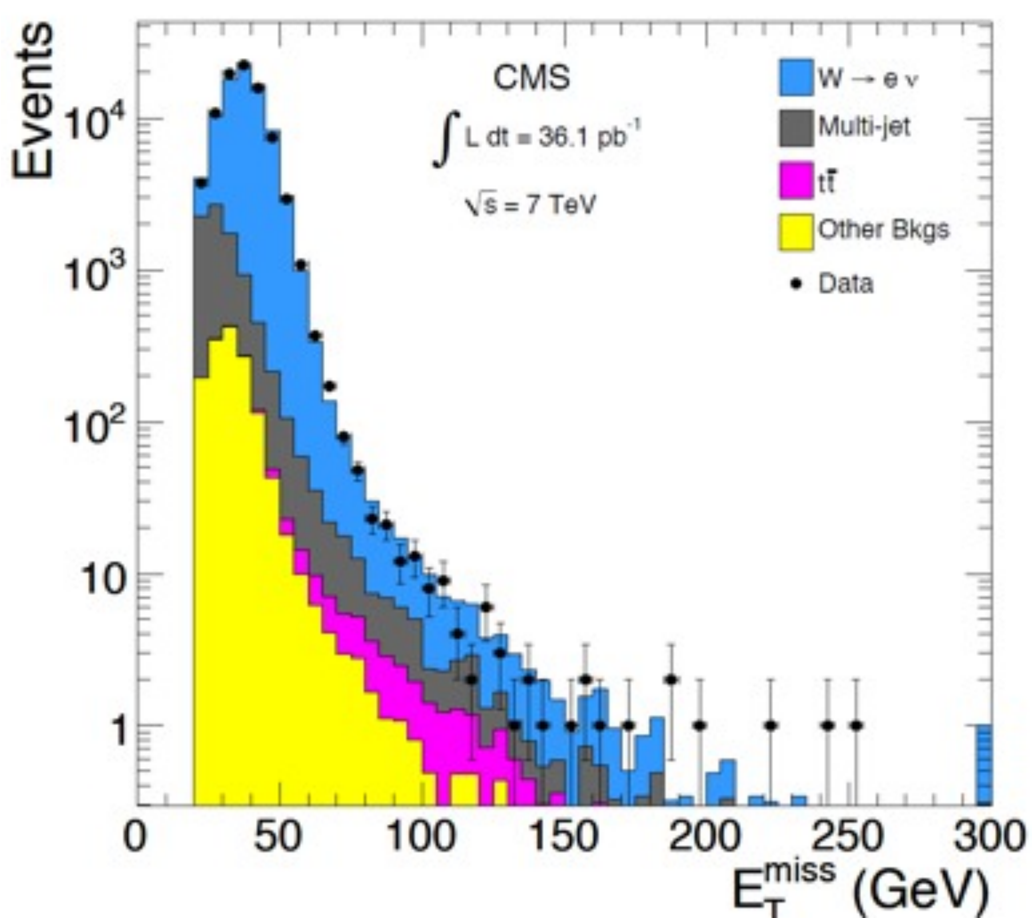


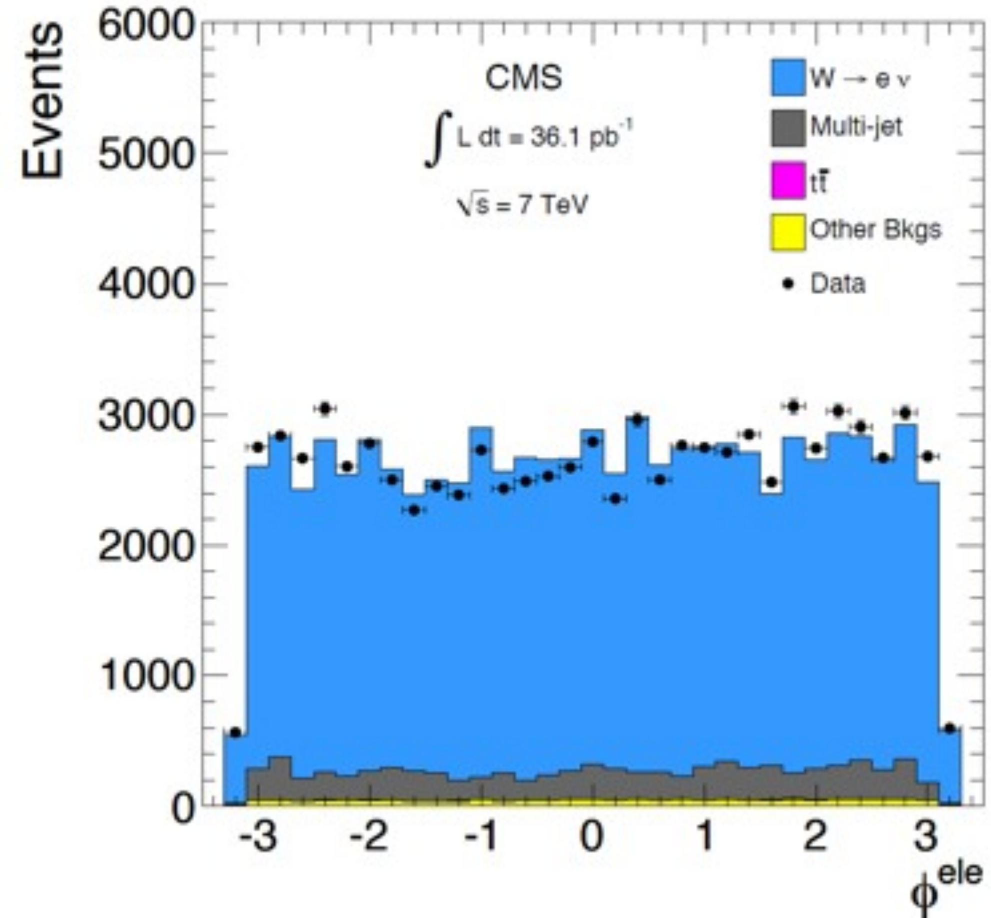
Results

Data: electrons

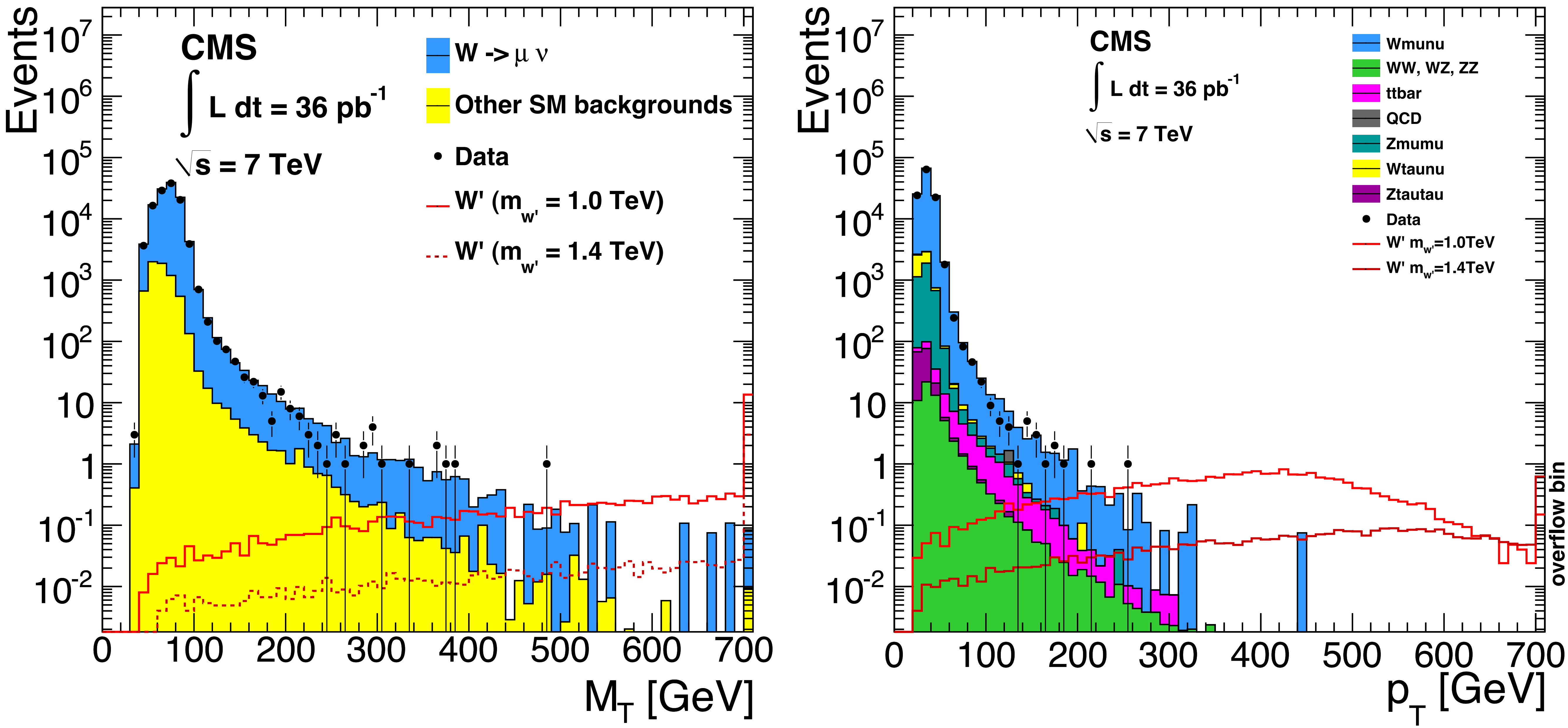






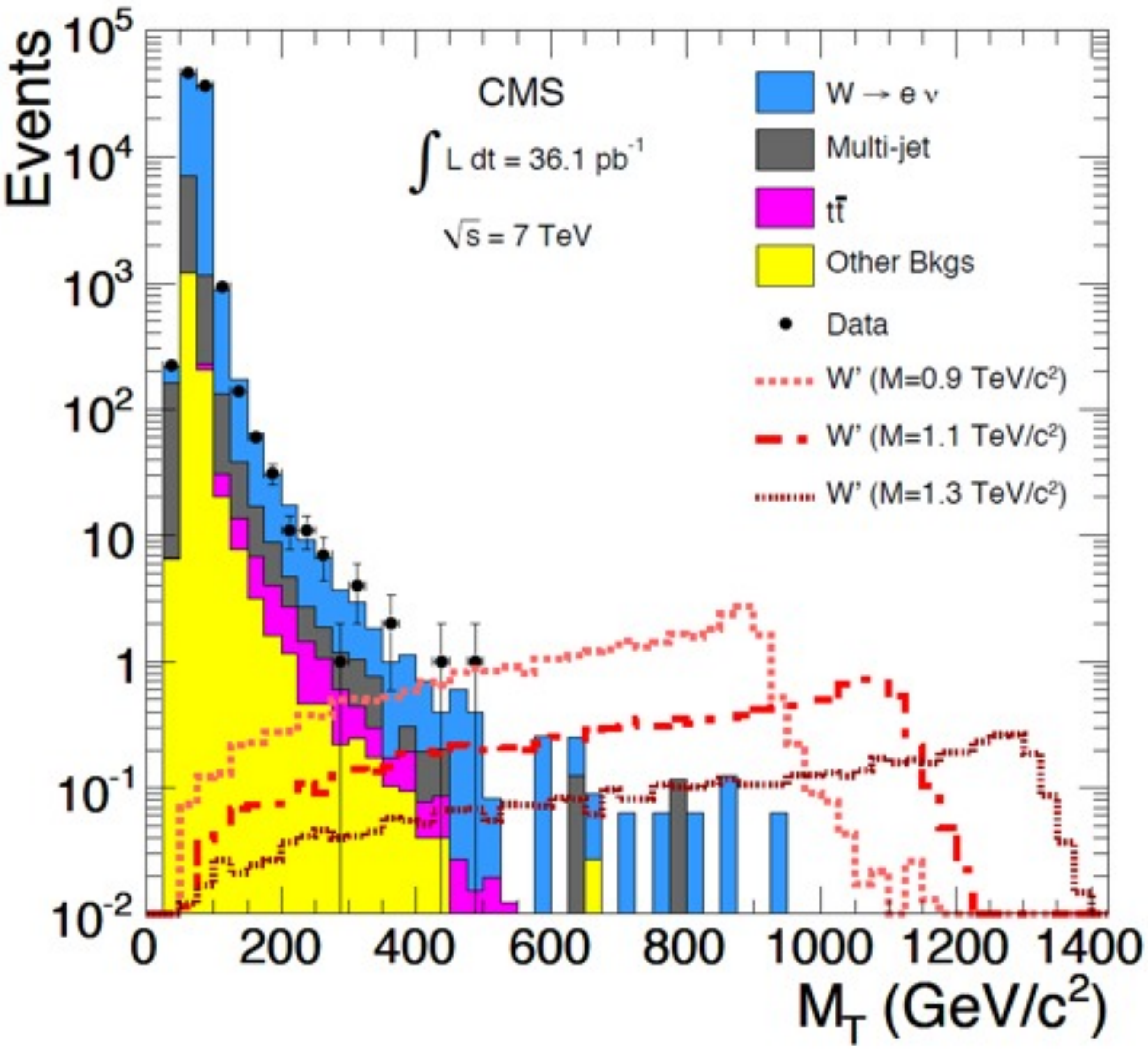


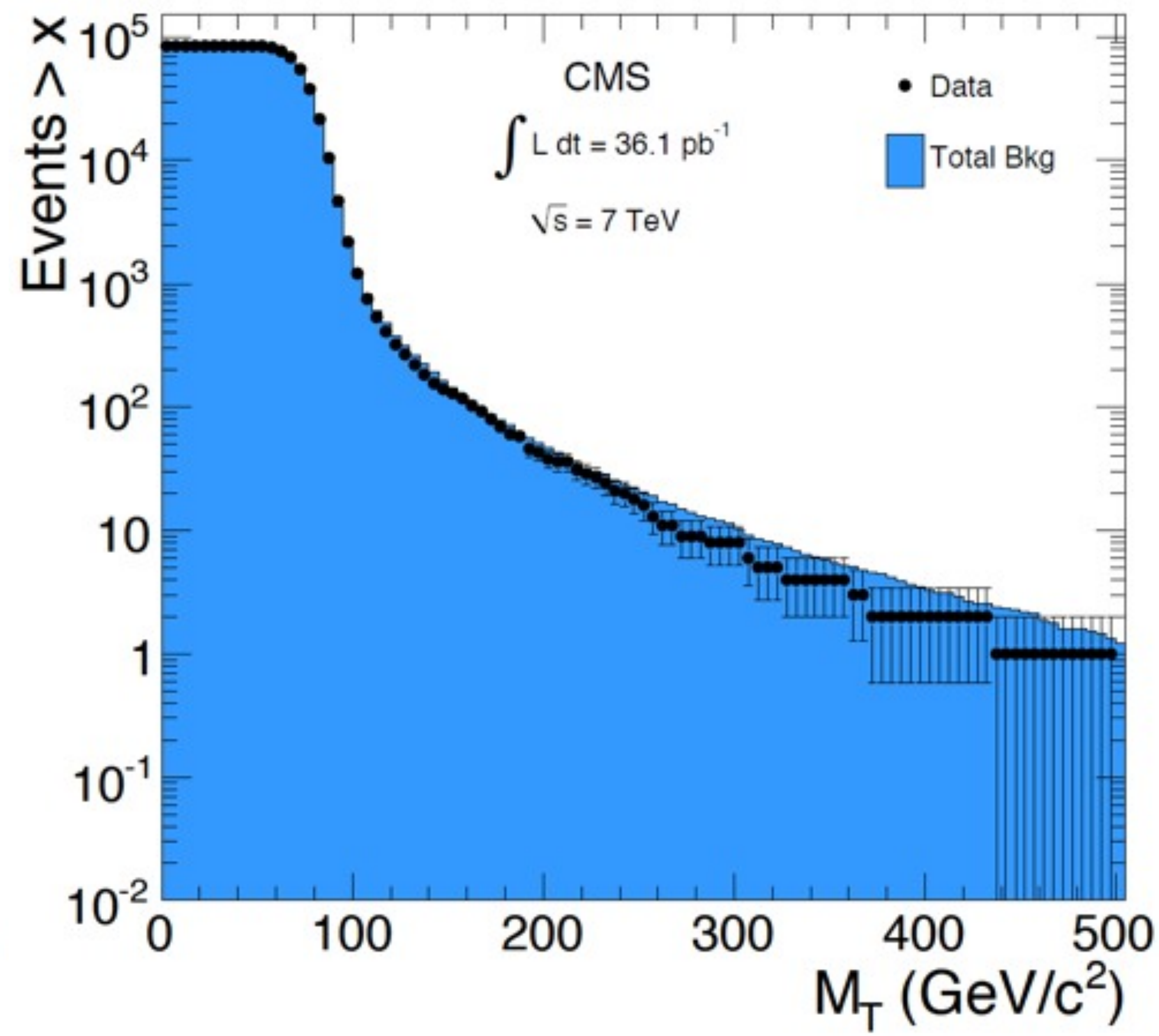
data: μ distributions



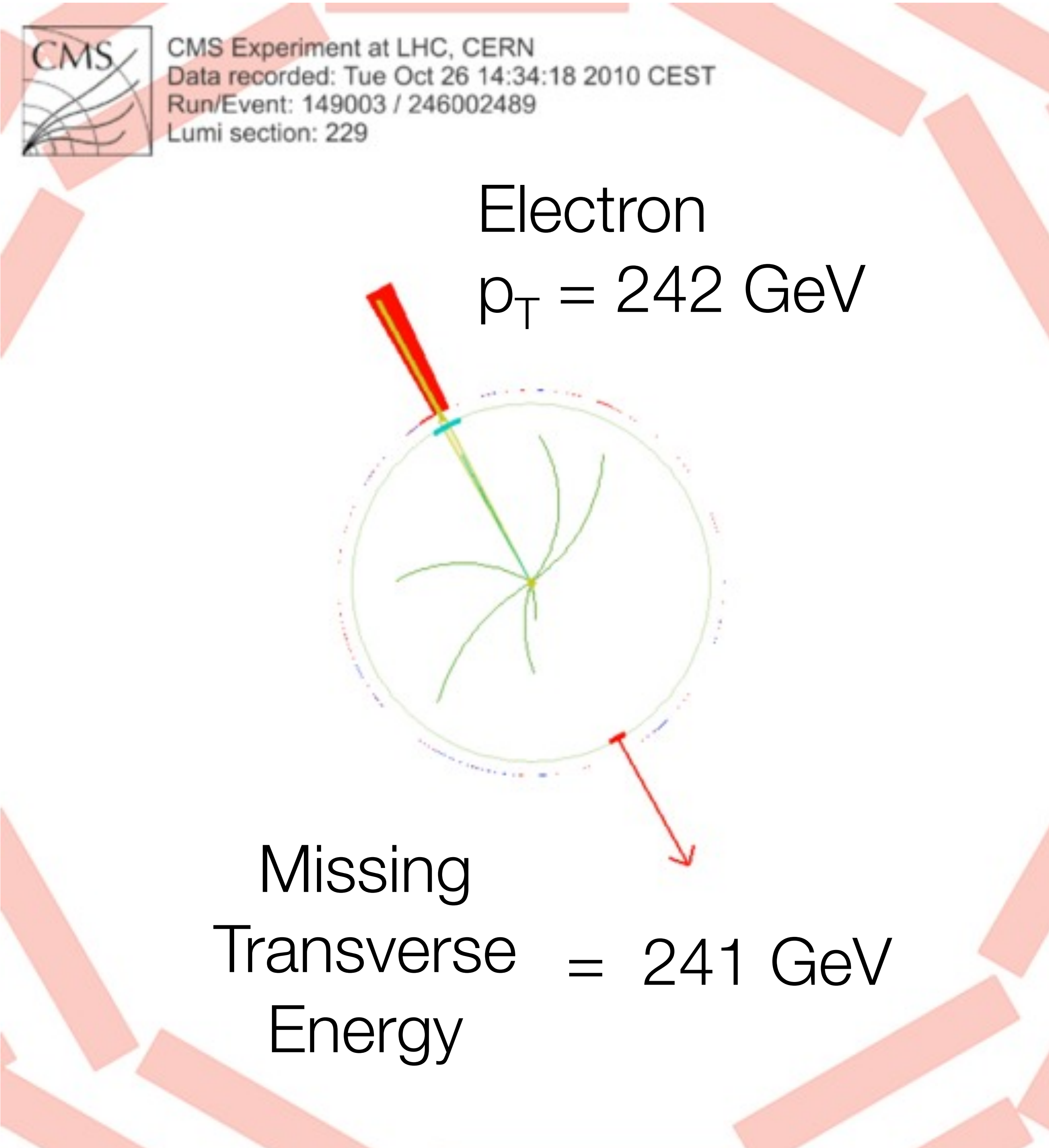
Transverse mass distribution results (ele)

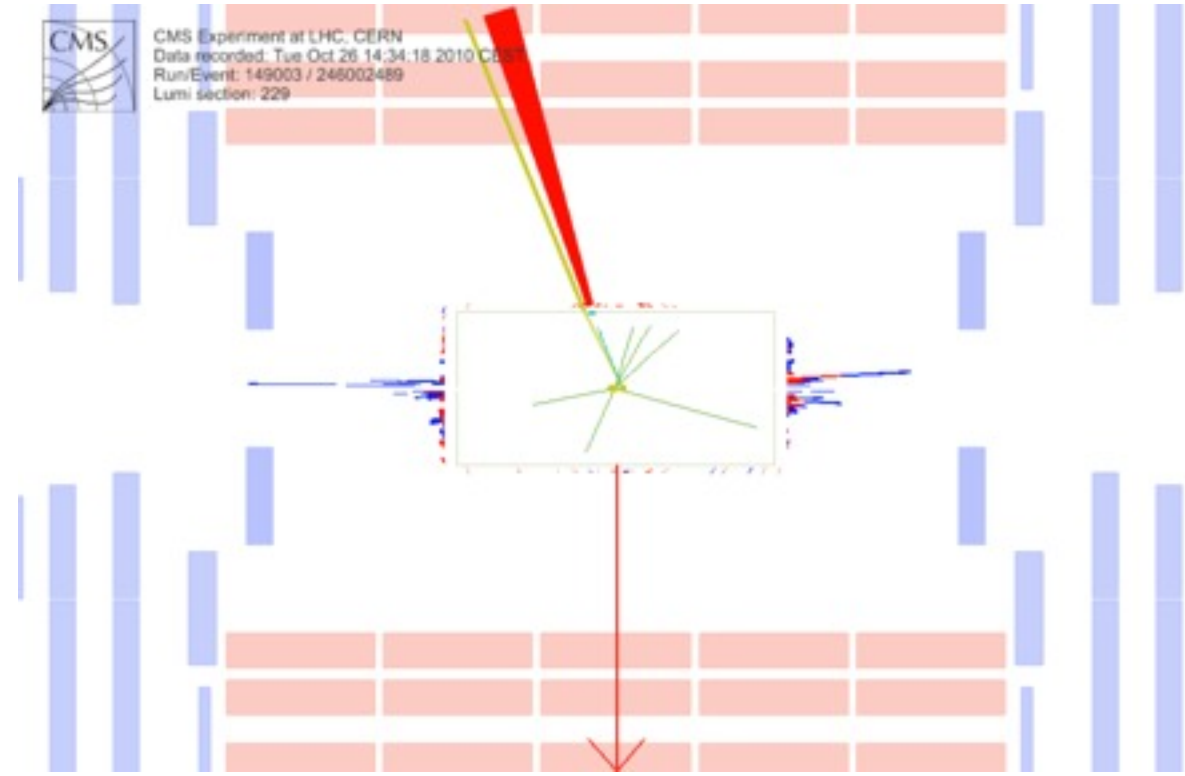
- Good agreement in both background prediction observed in the M_T distribution (left) and the cumulative distribution (right)

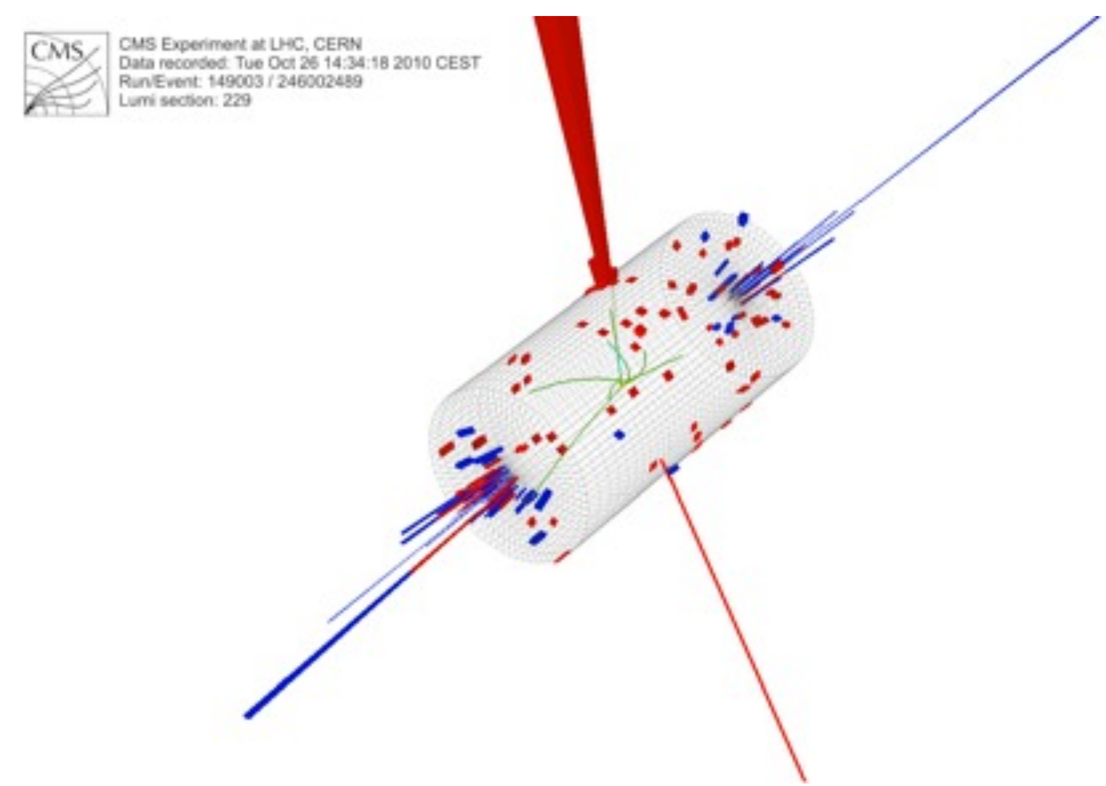




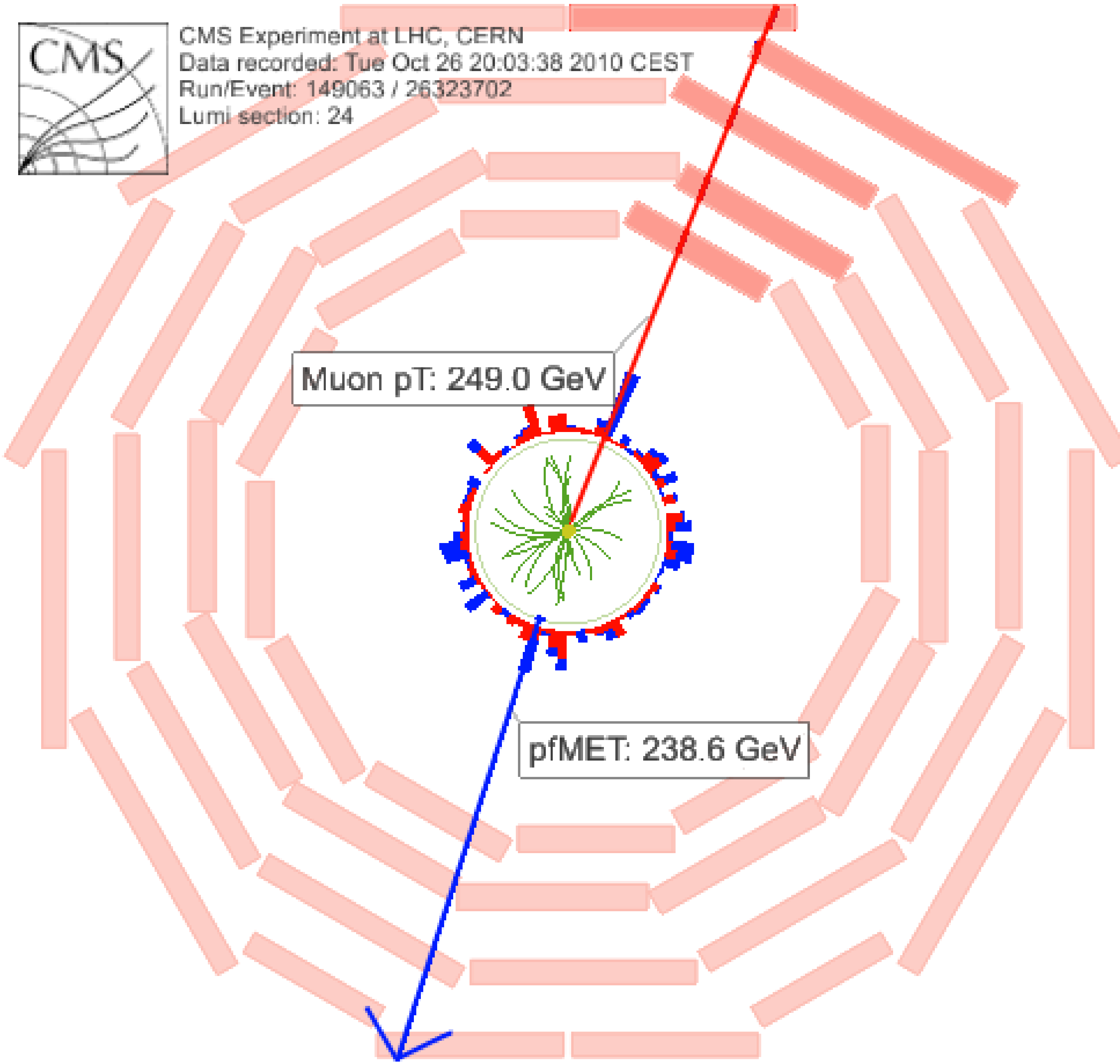
Highest transverse mass event: M_T = 493 GeV



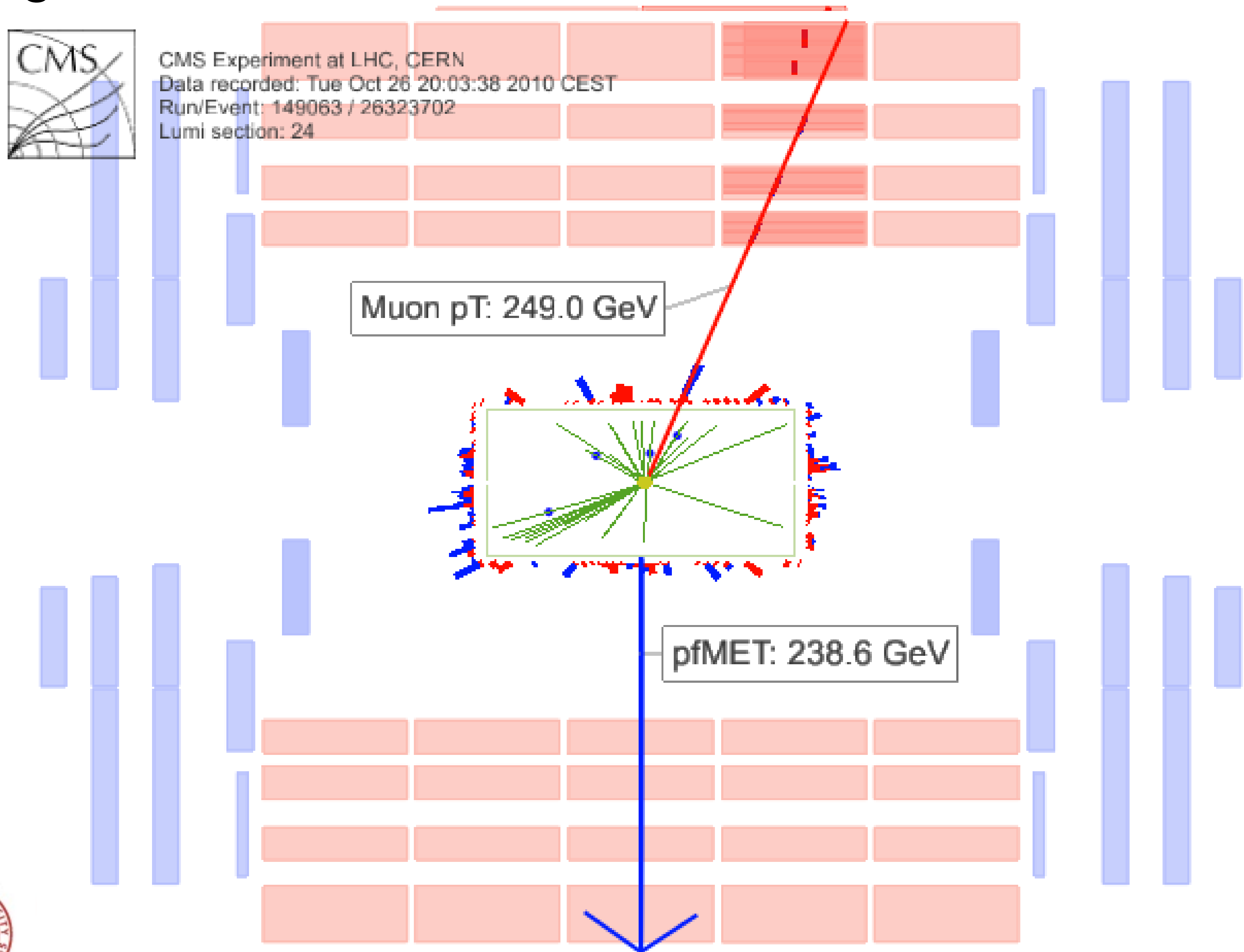




Highest transverse mass muon event, M_T = 487 GeV



Highest transverse mass muon event, M_T = 487 GeV



Systematic uncertainty example (e)

- Values indicate the percent variation on the number of events with M_T > 500 GeV

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 (electron channel example)

- Good agreement between data and background prediction in both channels
- 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)

W' to ℓ ν Results:

σ_t	W' theory cross section
σ_e	expected cross section limit
σ_o	observed cross section limit

Electrons

$M_{W'}$ (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

Muons

$m_{W'}$ (GeV)	M_T (GeV)	N_{sig} (Events)	N_{bkg} (Events)	N_{data} (Events)	$\sigma \cdot BR$ (pb)	Expected limit (pb)	Observed limit (pb)
600	390	152 ± 16	2.54 ± 0.68	1	8.290	0.308	0.212
700	450	78 ± 8	1.54 ± 0.41	1	4.264	0.267	0.227
800	470	49 ± 5	1.33 ± 0.35	1	2.426	0.236	0.212
900	500	29 ± 3	1.09 ± 0.29	0	1.389	0.216	0.150
1000	530	18 ± 1.9	0.91 ± 0.23	0	0.849	0.204	0.147
1100	590	11 ± 1.2	0.65 ± 0.16	0	0.516	0.193	0.151
1200	610	7.1 ± 0.7	0.59 ± 0.15	0	0.334	0.188	0.150
1300	630	4.7 ± 0.5	0.54 ± 0.13	0	0.214	0.180	0.146
1400	630	3.0 ± 0.3	0.54 ± 0.13	0	0.141	0.175	0.139
1500	680	2.1 ± 0.2	0.42 ± 0.10	0	0.094	0.175	0.146
2000	690	0.29 ± 0.03	0.40 ± 0.10	0	0.014	0.185	0.153

W' to ℓ ν Results:

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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

Muons

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1200	610	7.1 ± 0.7	0.59 ± 0.15	0	0.334	0.188	0.150
1300	630	4.7 ± 0.5	0.54 ± 0.13	0	0.214	0.180	0.146
1400	630	3.0 ± 0.3	0.54 ± 0.13	0	0.141	0.175	0.139
1500	680	2.1 ± 0.2	0.42 ± 0.10	0	0.094	0.175	0.146
2000	690	0.29± 0.03	0.40 ± 0.10	0	0.014	0.185	0.153

W' to ℓ ν Results:

σ_t	W' theory cross section
σ_e	expected cross section limit
σ_o	observed cross section limit

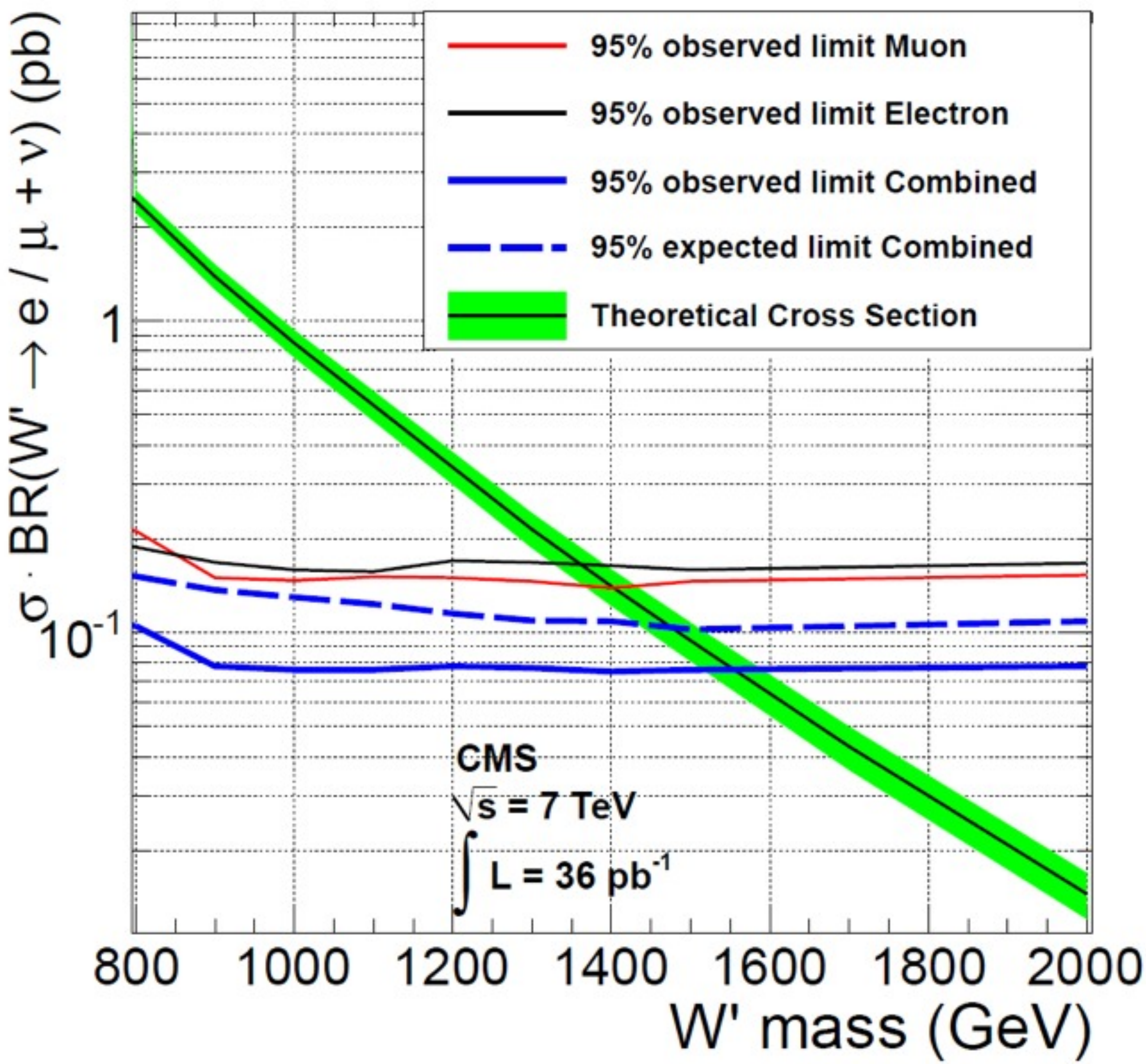
Electrons

$M_{W'}$ (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

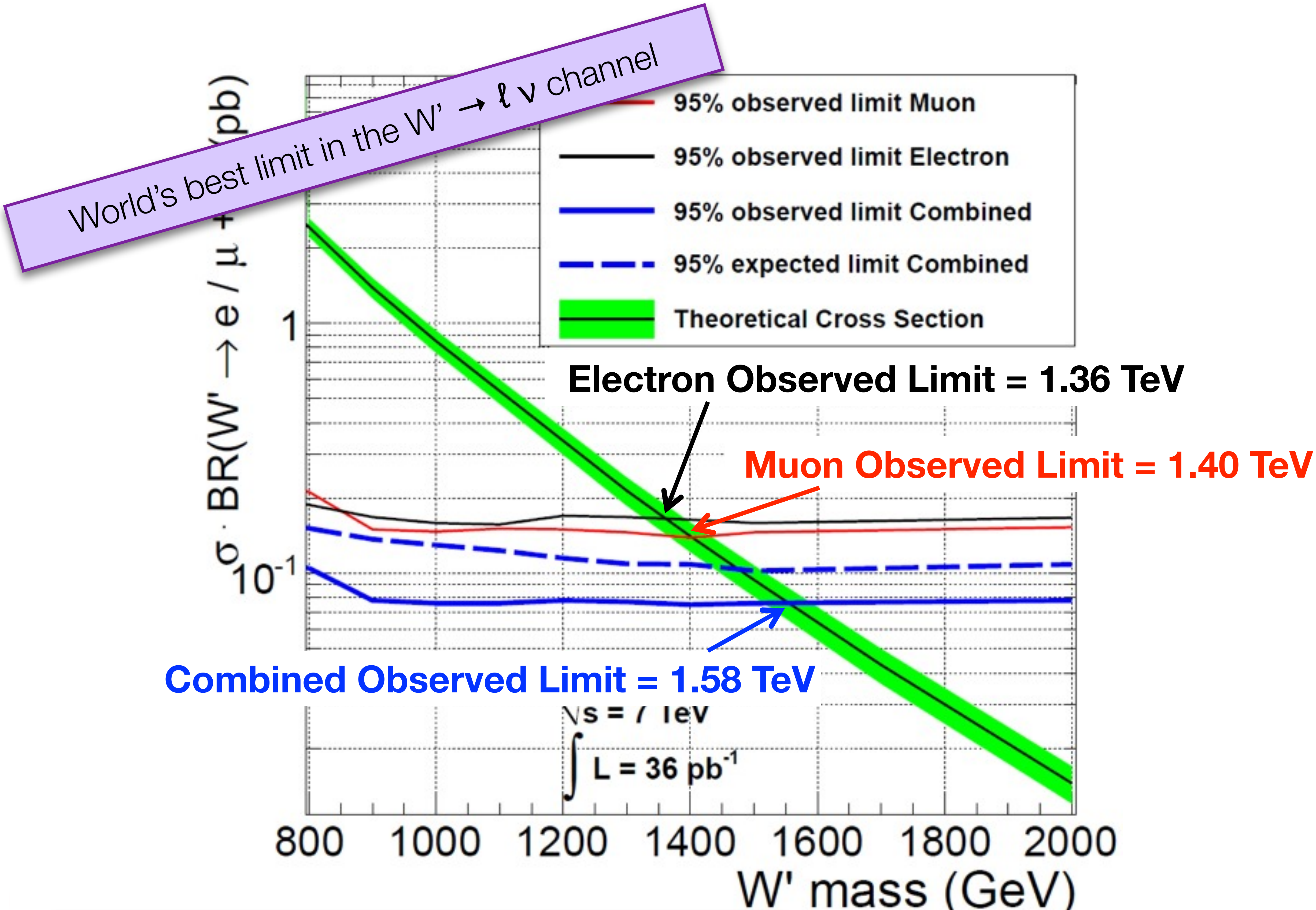
Muons

$m_{W'}$ (GeV)	M_T (GeV)	N_{sig} (Events)	N_{bkg} (Events)	N_{data} (Events)	$\sigma \cdot BR$ (pb)	Expected limit (pb)	Observed limit (pb)
600	390	152 ± 16	2.54 ± 0.68	1	8.290	0.308	0.212
700	450	78 ± 8	1.54 ± 0.41	1	4.264	0.267	0.227
800	470	49 ± 5	1.33 ± 0.35	1	2.426	0.236	0.212
900	500	29 ± 3	1.09 ± 0.29	0	1.389	0.216	0.150
1000	530	18 ± 1.9	0.91 ± 0.23	0	0.849	0.204	0.147
1100	590	11 ± 1.2	0.65 ± 0.16	0	0.516	0.193	0.151
1200	610	7.1 ± 0.7	0.59 ± 0.15	0	0.334	0.188	0.150
1300	630	4.7 ± 0.5	0.54 ± 0.13	0	0.214	0.180	0.146
1400	630	3.0 ± 0.3	0.54 ± 0.13	0	0.141	0.175	0.139
1500	680	2.1 ± 0.2	0.42 ± 0.10	0	0.094	0.175	0.146
2000	690	0.29± 0.03	0.40 ± 0.10	0	0.014	0.185	0.153

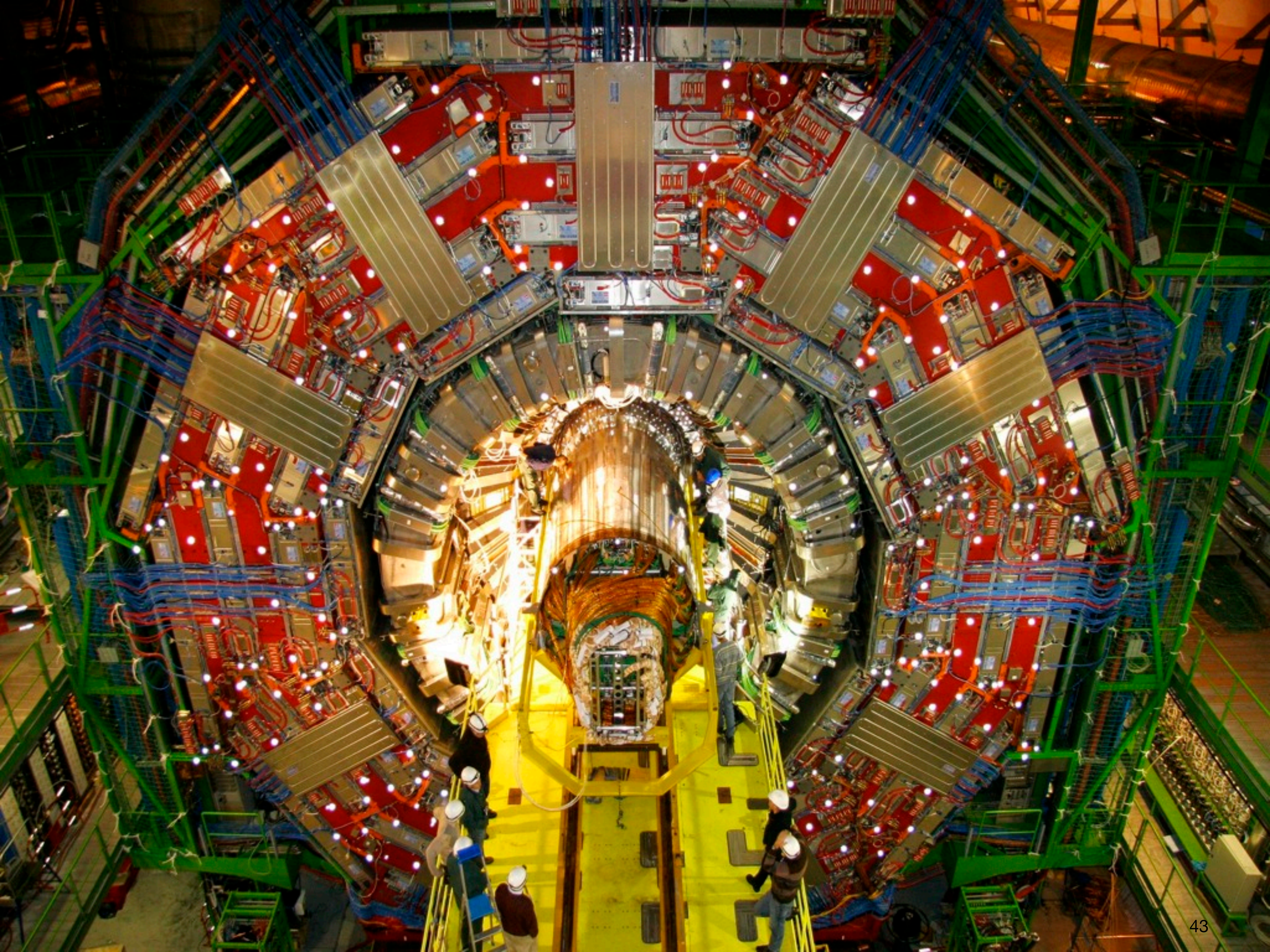
Combined limit for electron and muon channels



Combined limit for electron and muon channels

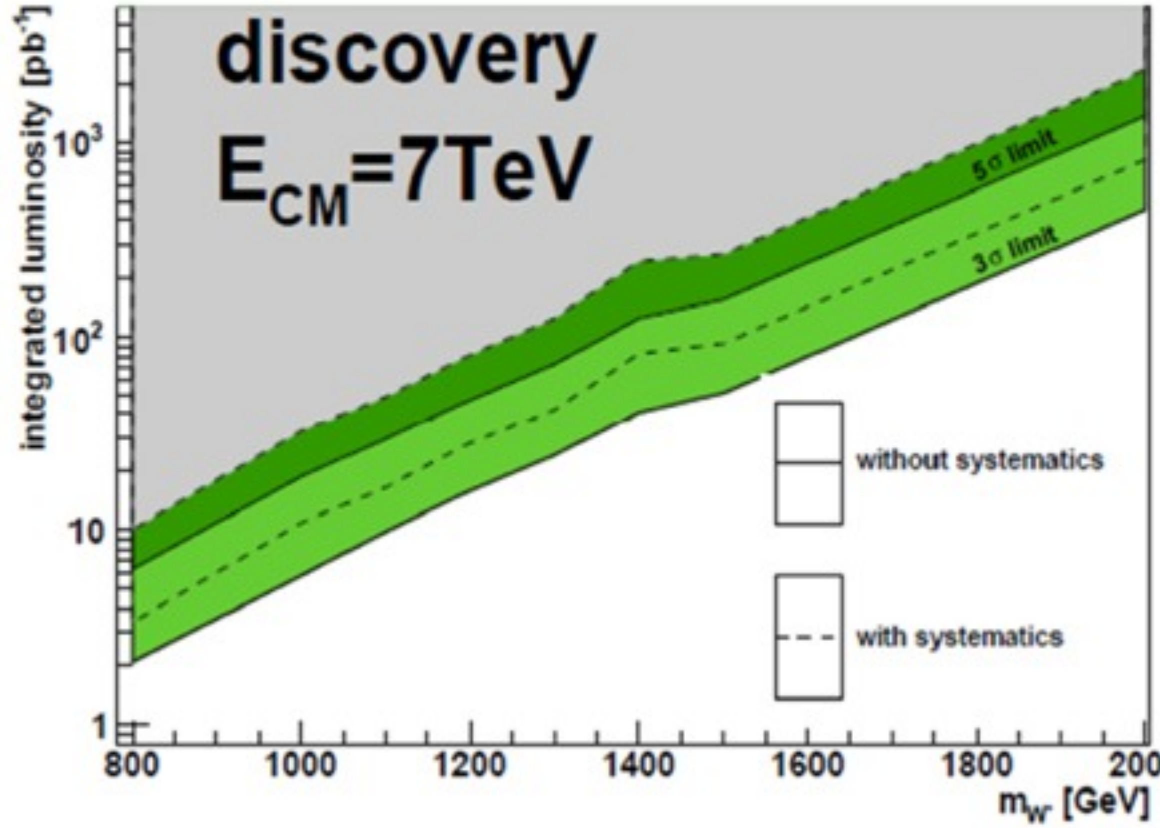


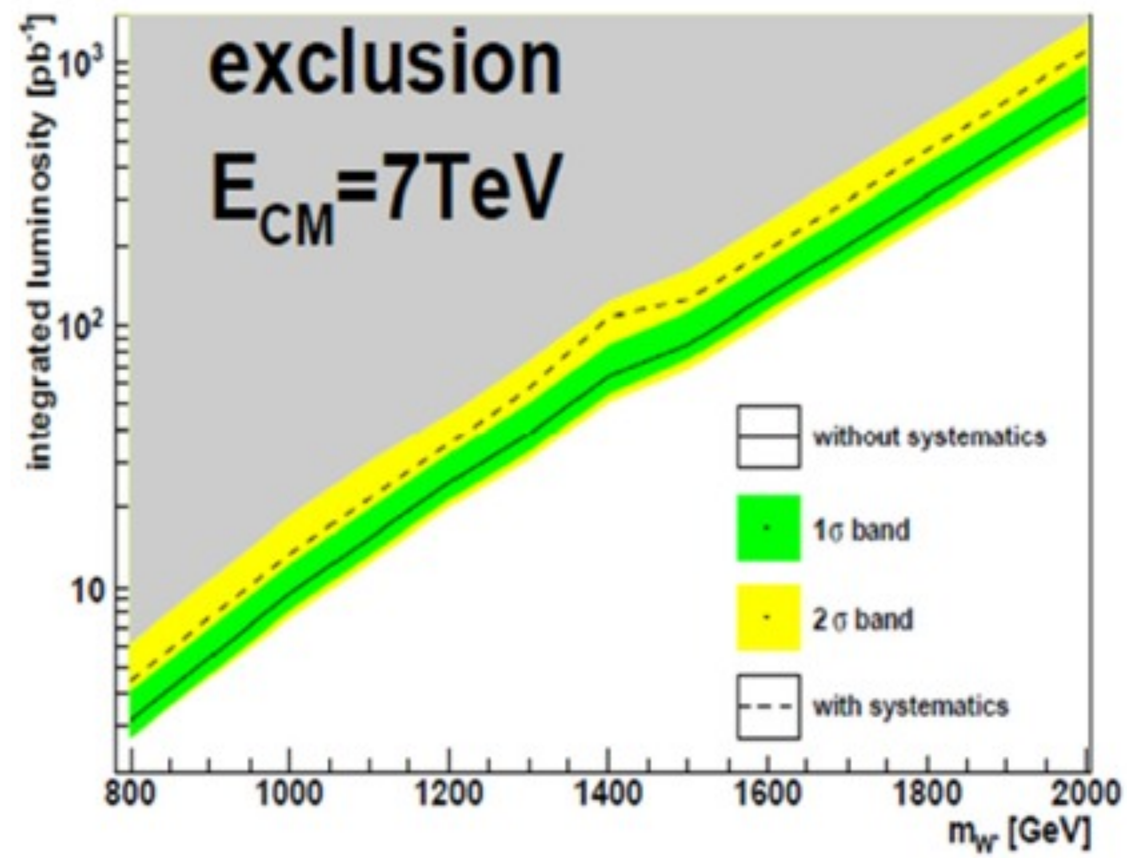
cf ATLAS limit (arXiv:1103.1391v2): 1.49 TeV



Future plans for W' searche

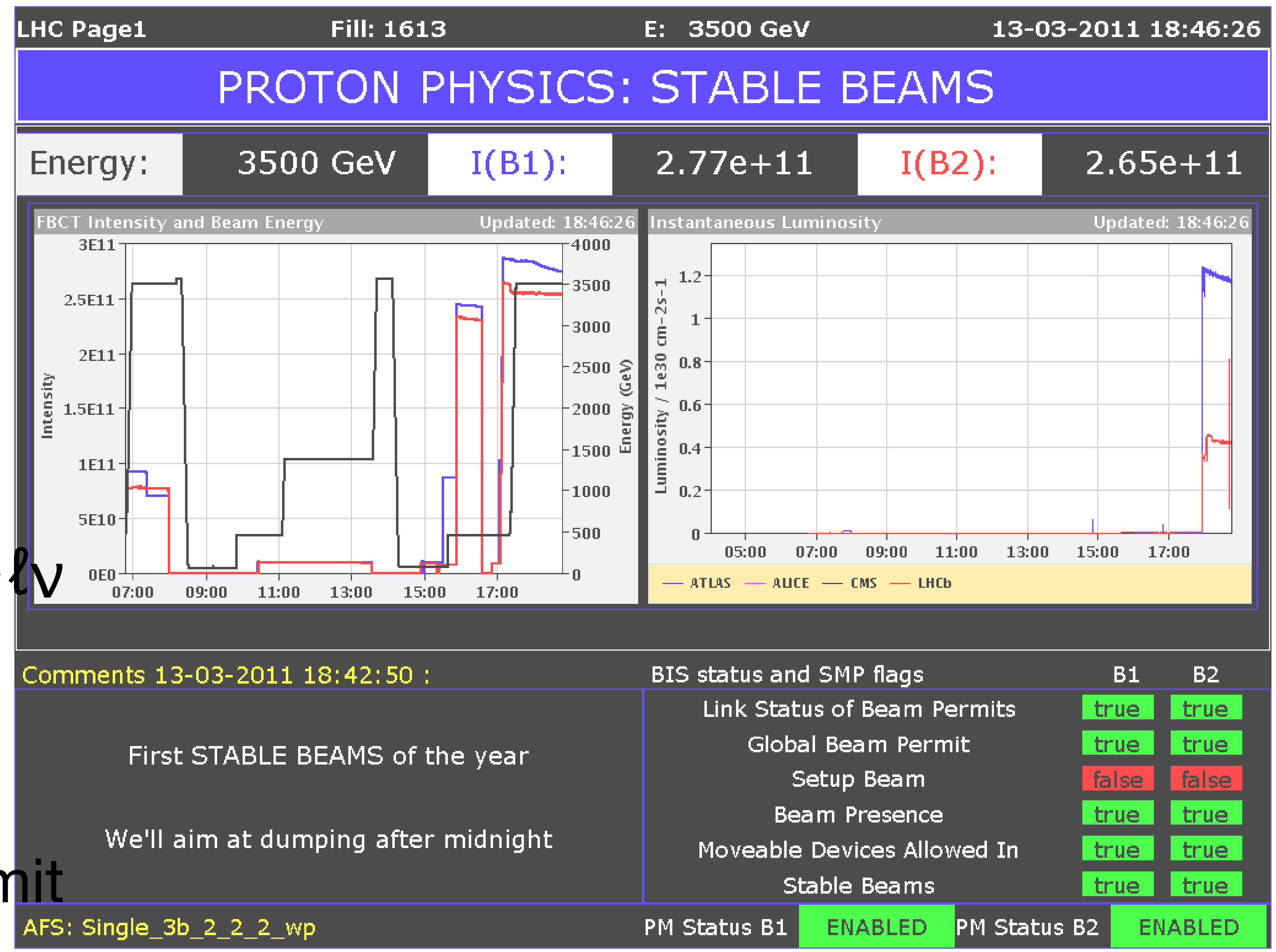
- Include other search channels
  - $W' \rightarrow \ell\nu$ (ℓ = e, μ, τ)
  - $W' \rightarrow tb$
  - $W' \rightarrow WZ$
  - $W' \rightarrow \ell N_R \rightarrow \ell\ell jj$
- New challenges in this run
  - Multiple interactions per crossing
  - High-luminosity triggering
  - High-p_T object reconstruction
- But a lot of possibilities with large data samples (1/fb ++)





Summary

- The LHC era has begun!
    - CMS detector is performing exceptionally
- Already exploring new territory, even with tiny data sets
- We performed a search for $W' \to \ell\nu$ with 36.1 pb^{-1} of 2010 data
- Combining electron and muon channels: $M_{W'} > 1.58$ TeV
    - Most stringent direct search limit in the world
- with more than 30 times as much data in near future, great chance for something exciting at LHC in 2011/2012 run
    - Keep paying attention!

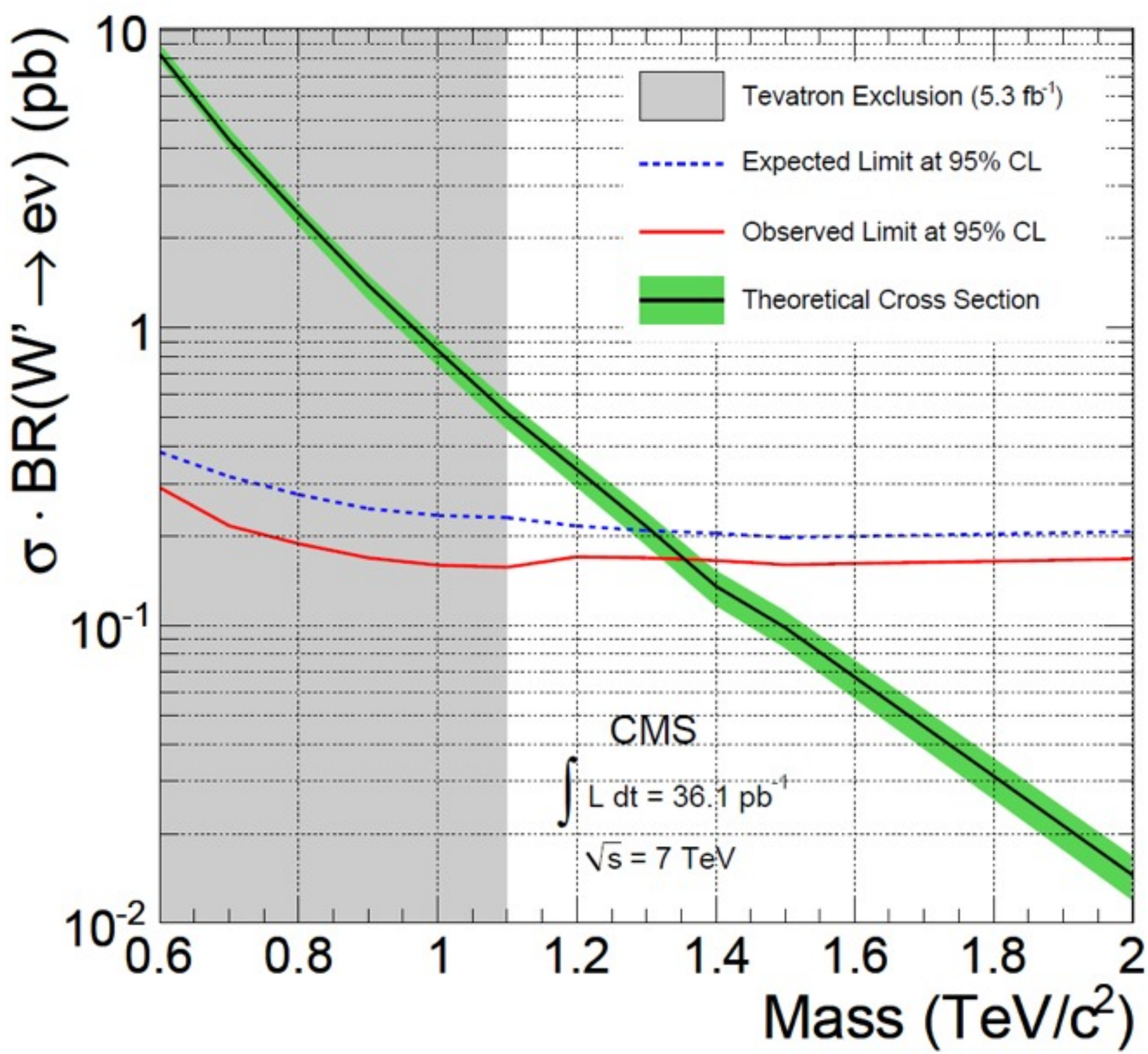


Higgs Discovery at CMS?

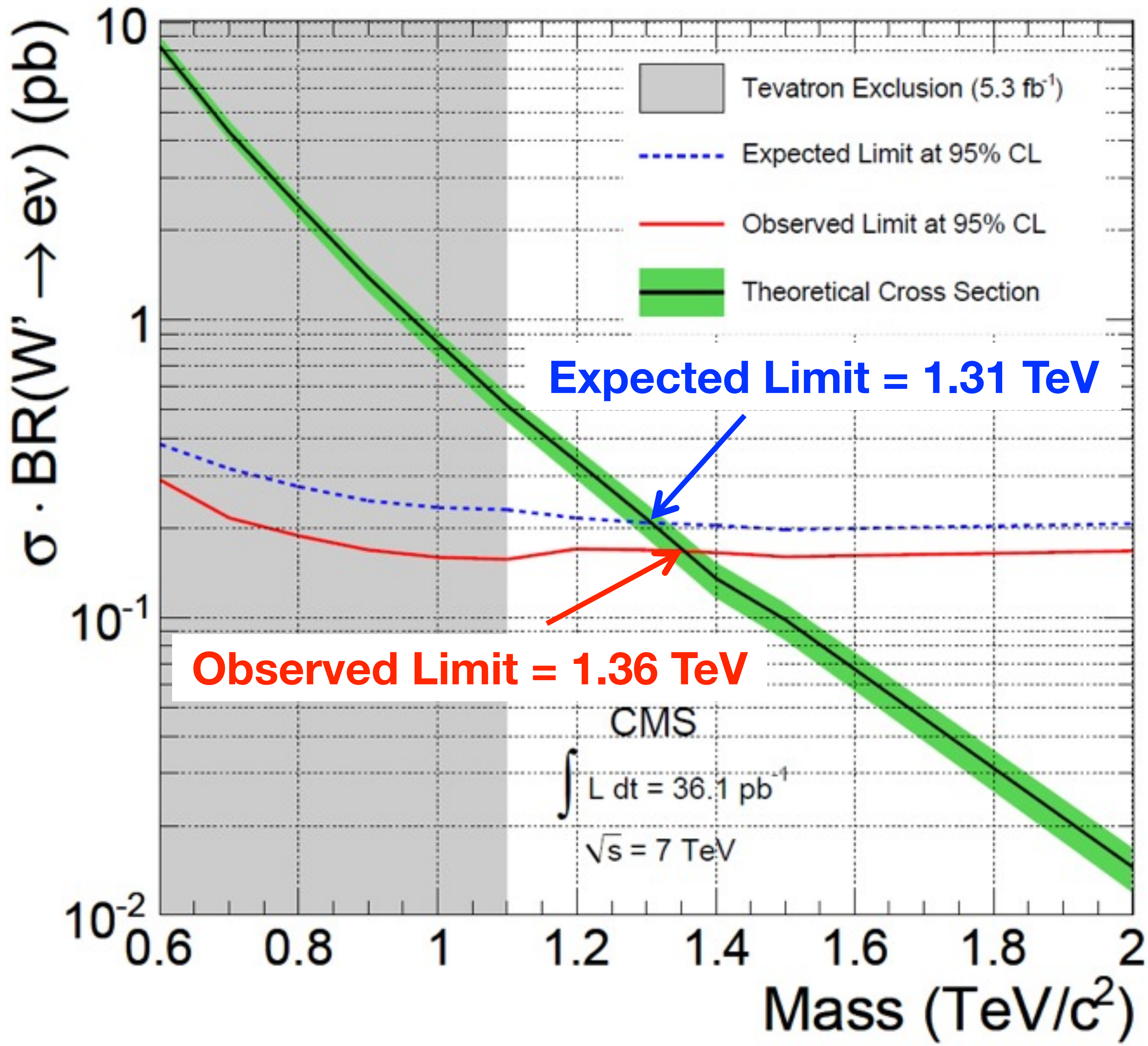
Peter Higgs visiting CMS…

Backup Slides

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

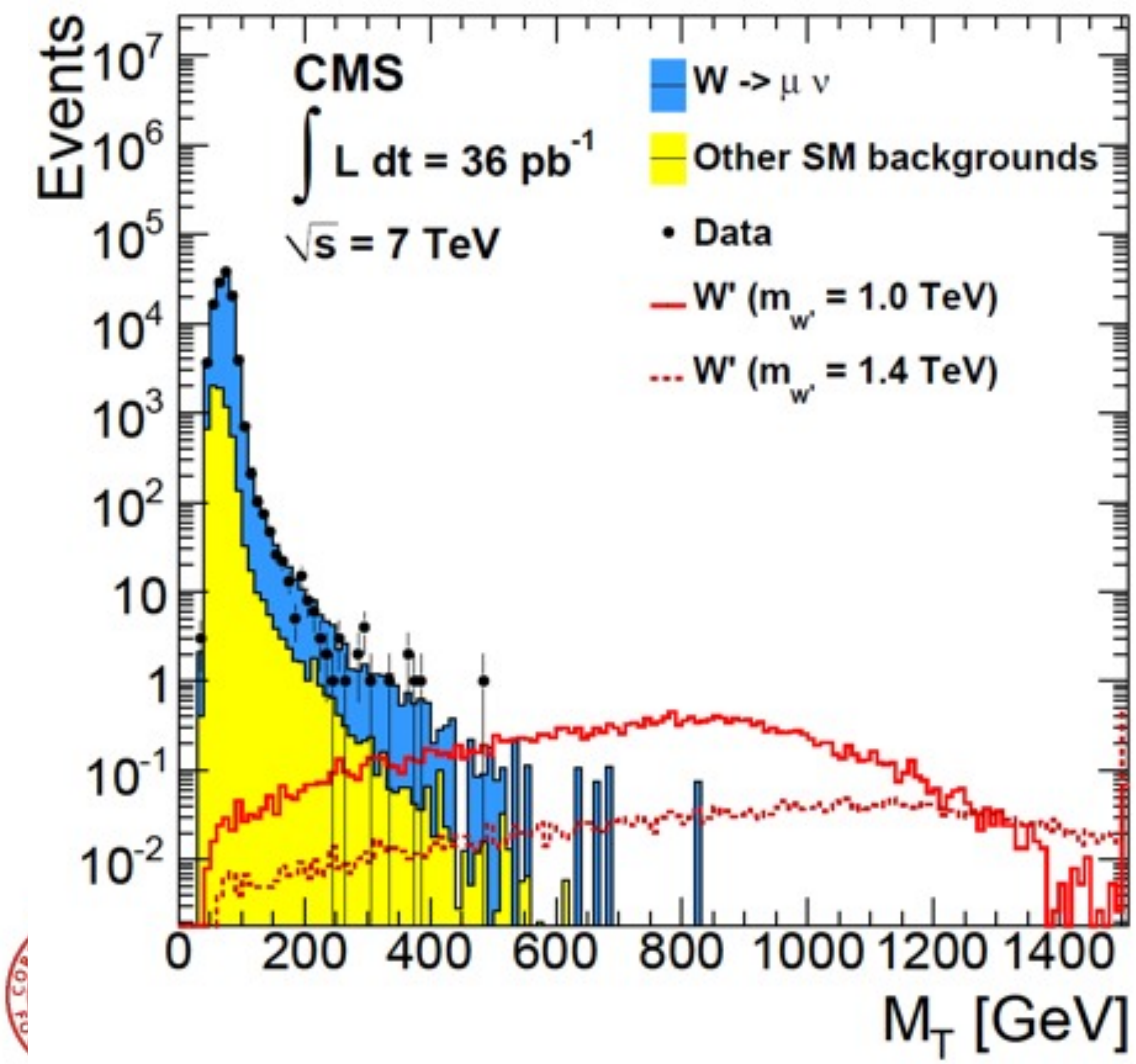


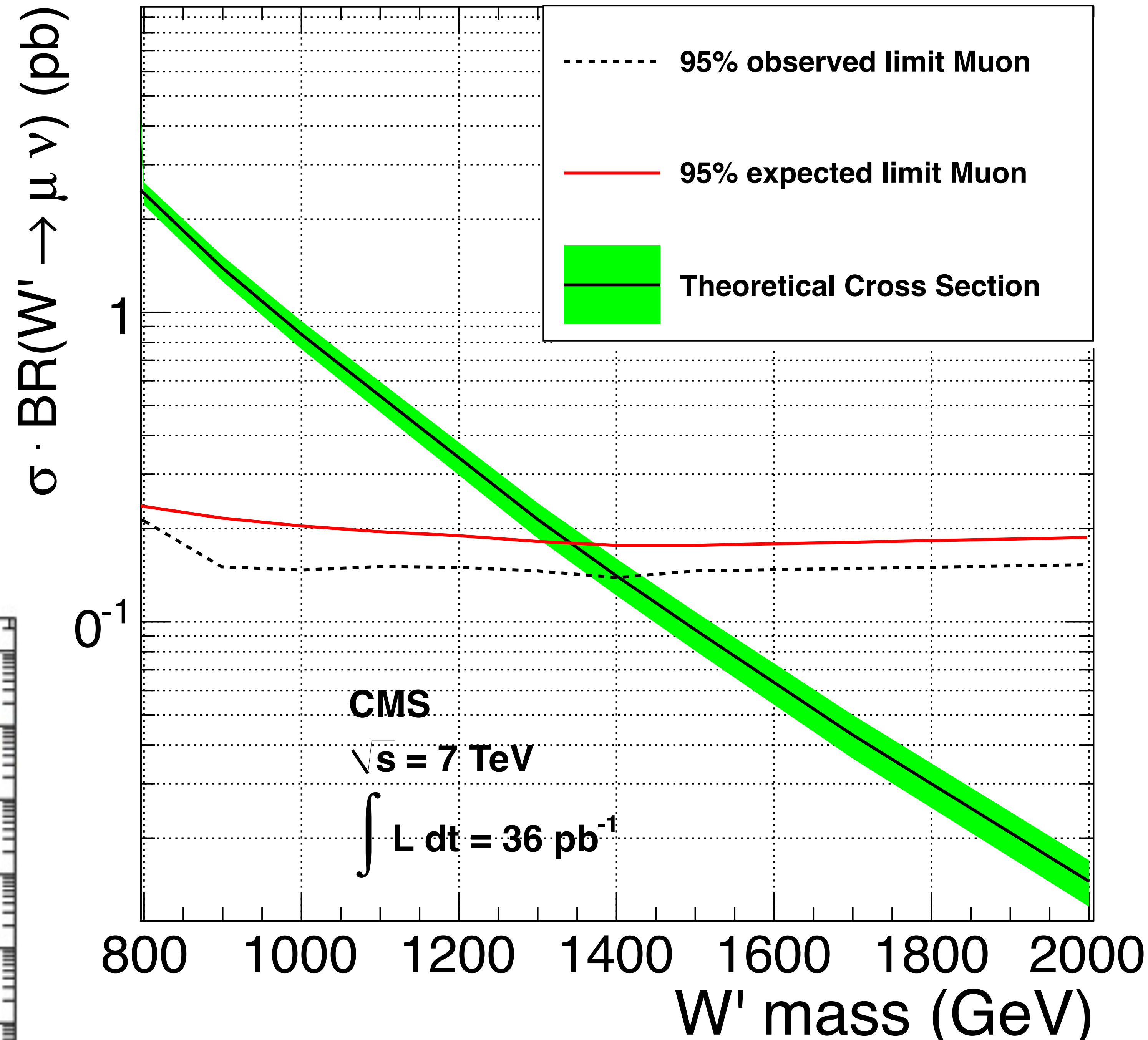
Exclude W′ with masses below 1.36 TeV at 95% CL



Muon Limit alone

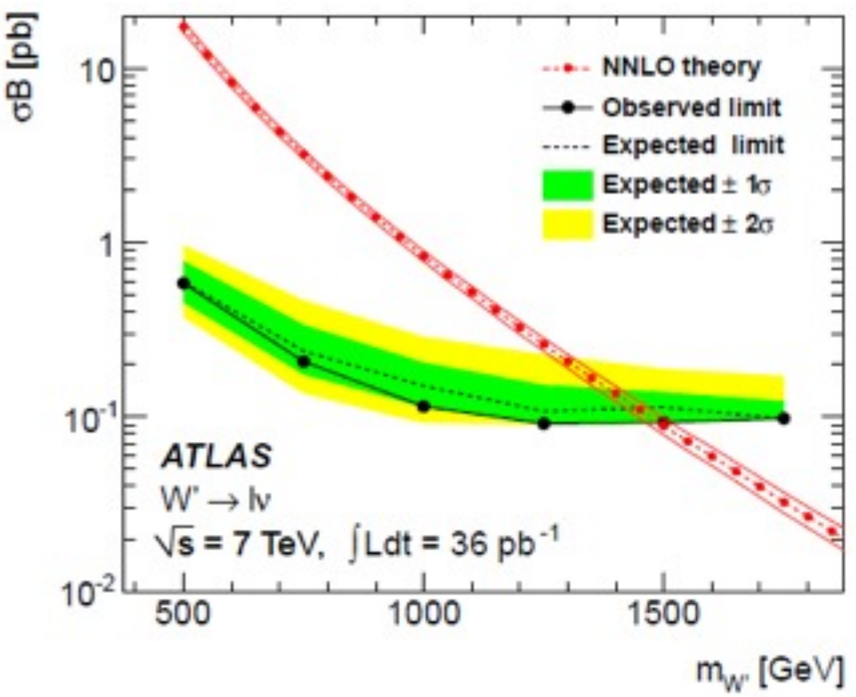
- Got a bit lucky (expected limit around 1.35 TeV, observed is 1.40 TeV)
- No events seen in high MT region



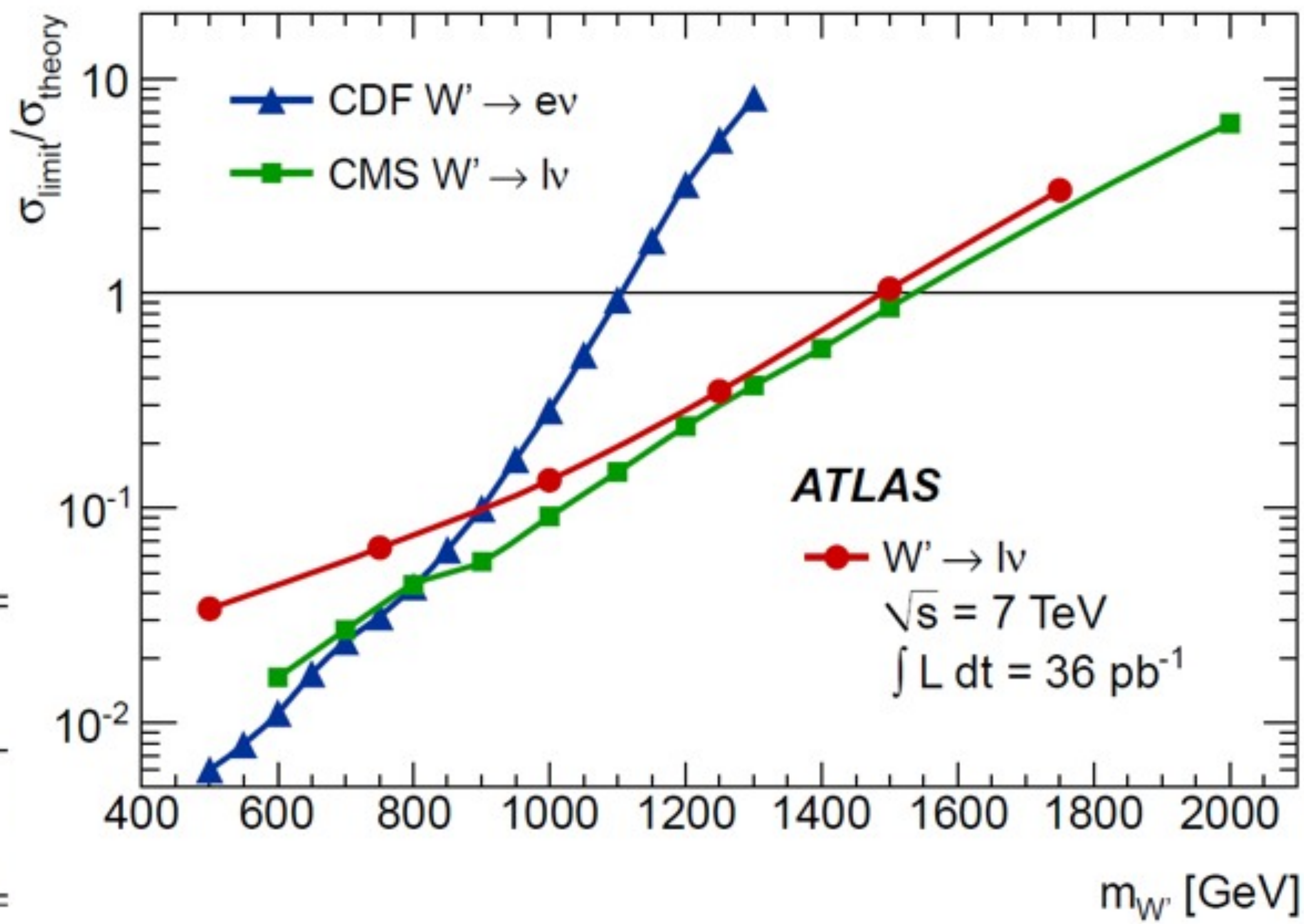


ATLAS limit

- 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 $|\eta_\mu| < 2.10$



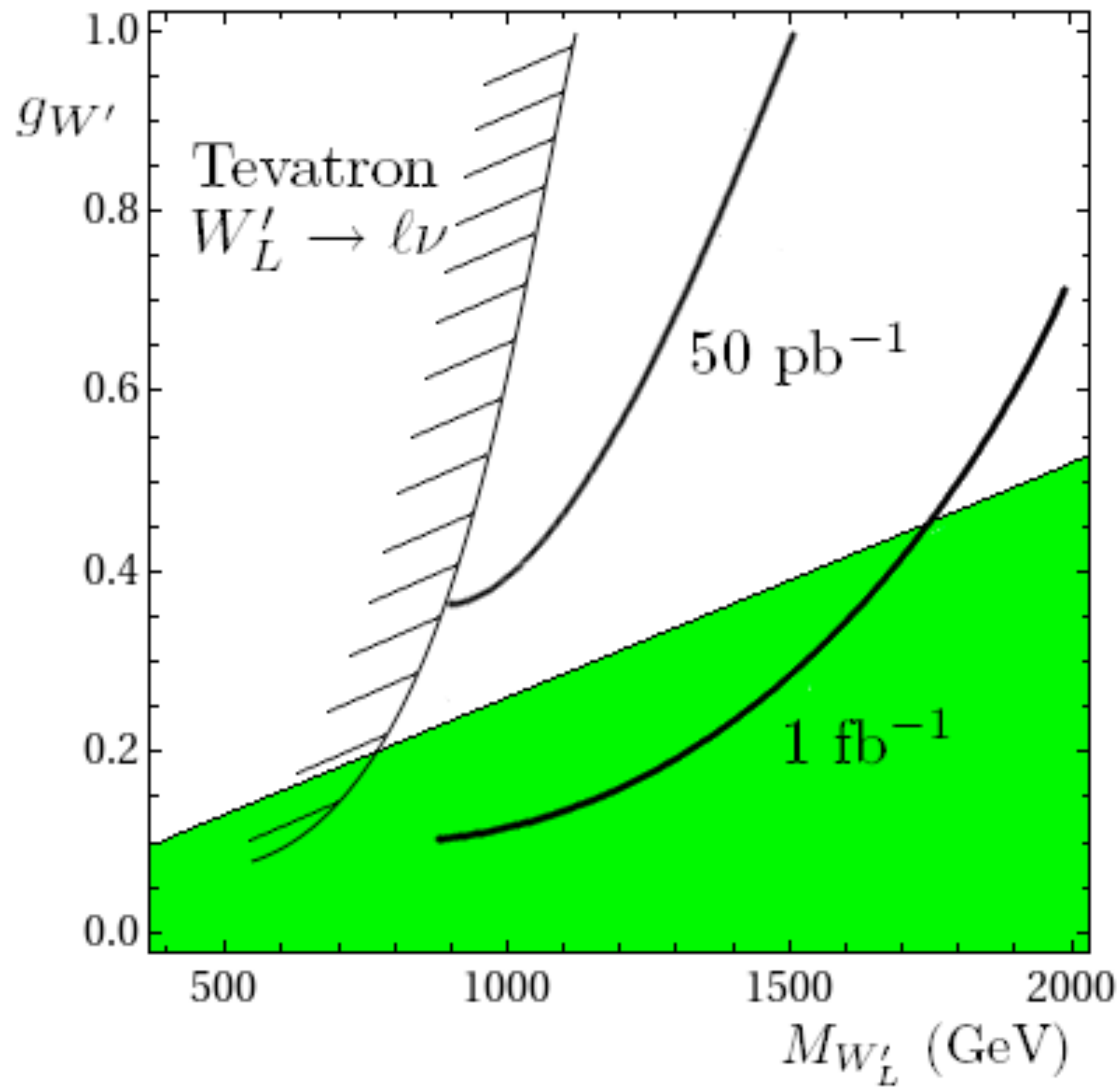
	Mass limit [GeV]			
	W'		W^*	
decay	Exp.	Obs.	Exp.	Obs.
$e\nu$	1370	1370	1390	1390
$\mu\nu$	1210	1290	1100	1210
both	1450	1490	1440	1470



arXiv:1103.1391v1 [hep-ex]

Indirect Limits on $W'_L \to \ell\nu$

- Simple model for W':
  - $SU(2)_1 \times SU(2)_2 \times U(1)_Y$.
- Limits presented have $g_1 = g_2$ (sequential W')
- Green: Precision EWK preferred
- Claim: LHC not competitive beyond Tevatron until 10/fb (green region)



Schmaltz, M., & Spethmann, C. *Two Simple W' Models for the Early LHC.* arXiv:1011.5918v2

Systematic uncertainty

- Values indicate the percent variation on the number of events with M_T > 200 GeV
  - Electron reco efficiency uncertainty from EWK group
    - CMS AN-10-264, EWK-10-002
  - HEEP efficiency uncertainty from HPTE group
    - CMS AN-10-318

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

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

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

n	$=$	Number of observed events
b	$=$	Expected number of background
$\mathcal{L}$	$=$	Integrated luminosity
ϵ	$=$	Acceptance $\times$ efficiency

Expected limit

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

Trigger efficiency

CMS-AN-318-v6

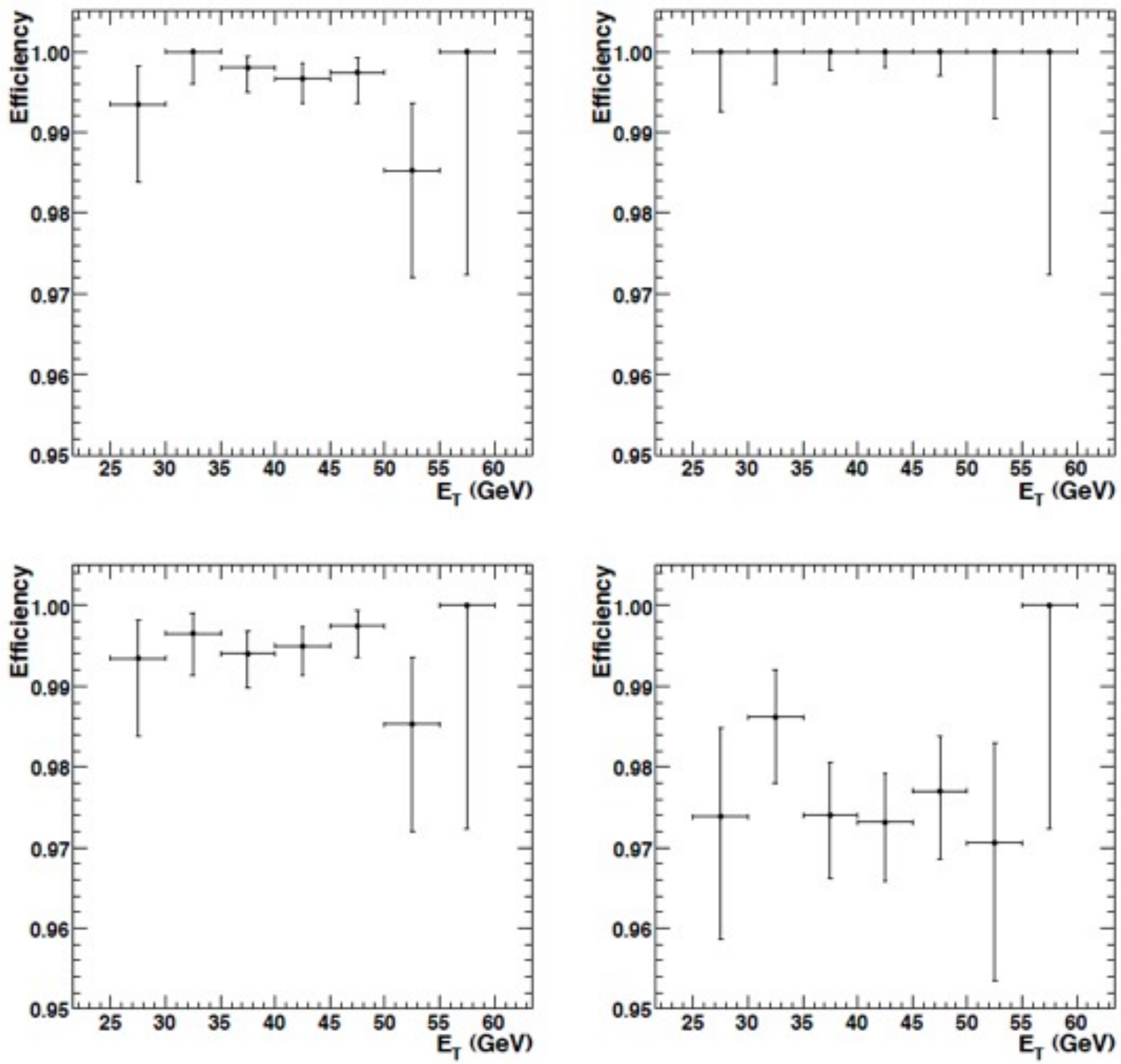


Figure 1: The trigger efficiencies for single L1 seeded photon trigger (top left), the L1 unseeded second leg of the double photon trigger (top right), single electron without EleId trigger (bottom left) and single electron with EleId (bottom right) trigger vs E_T. Electrons are required to pass the HEEP selection and invariant mass in the range 70-110 GeV/c^2 with second HEEP electron passing the HLT_Ele32_SW_TightEleId_v2 trigger. The E_T is the offline electron E_T and the online threshold is 22 GeV. This is done for the run-range 146426-147119 (4.4 pb^{-1})

High energy electrons

CMS-AN-318-v6

		$1.56 < \|\eta\| < 1.80$	$1.80 < \|\eta\| < 2.20$	$2.20 < \|\eta\| < 2.50$
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.

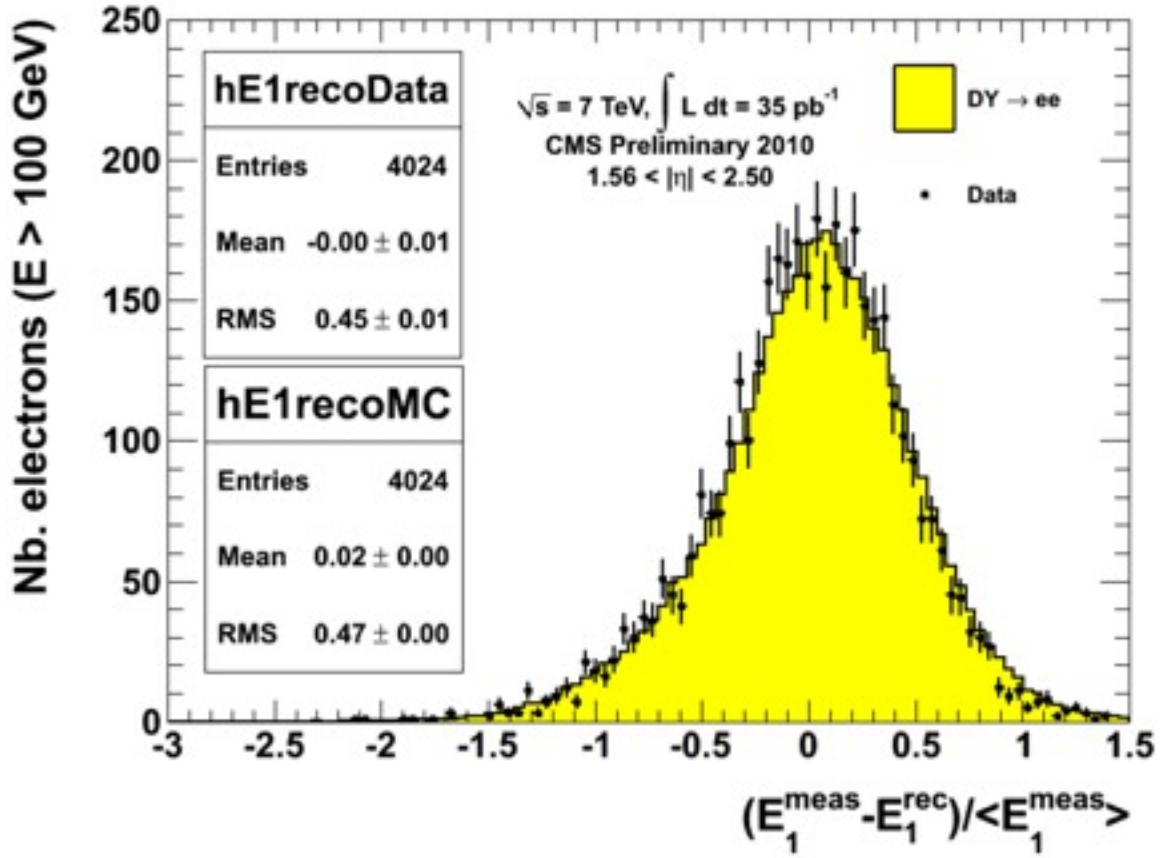
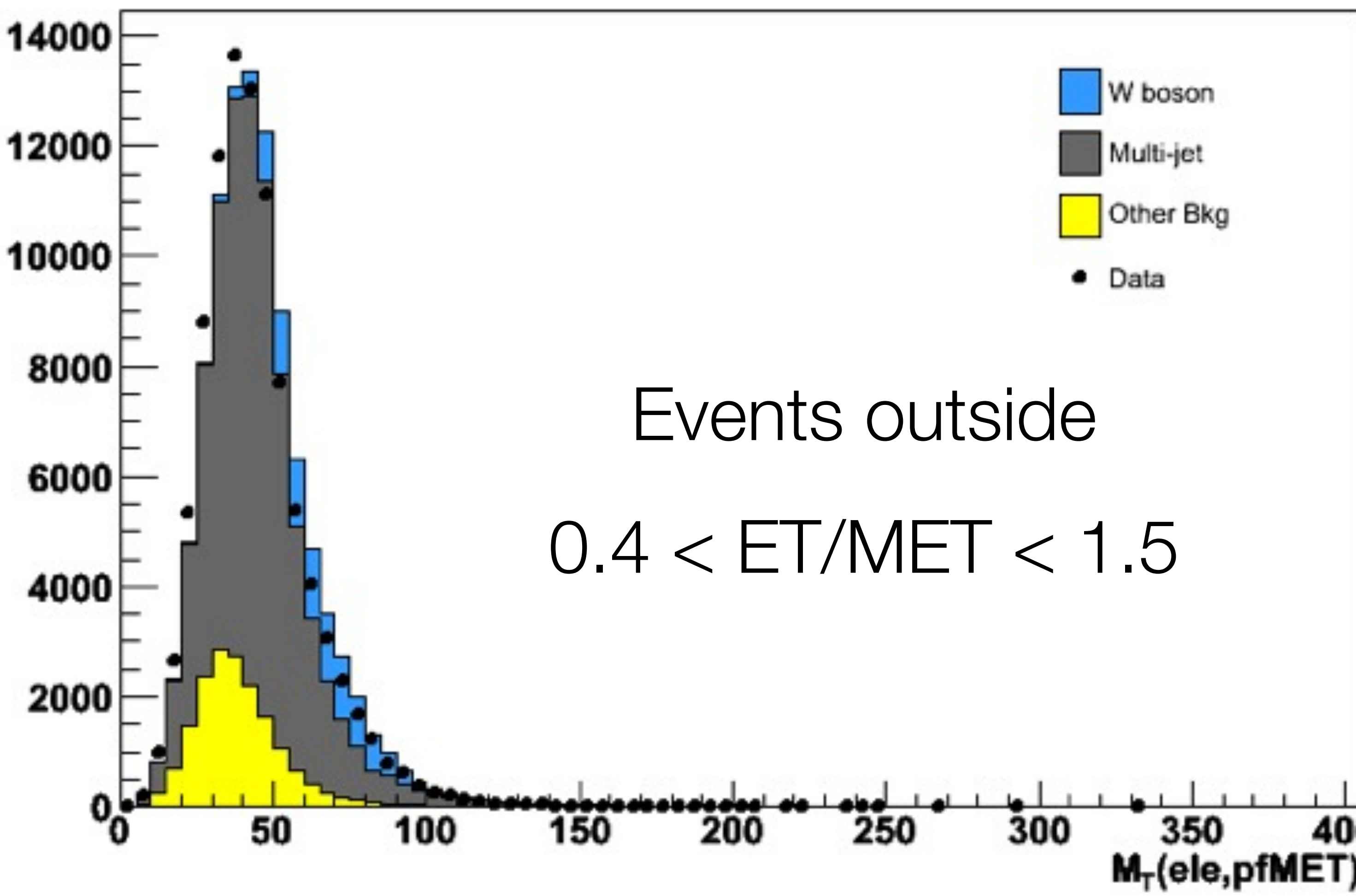


Figure 20: Distribution of the fractional difference between the measured energy (E_1^{meas}) and the energy reconstructed with the method described in this section (E_1^{rec}), for $E > 100$ GeV in the ECAL endcap.

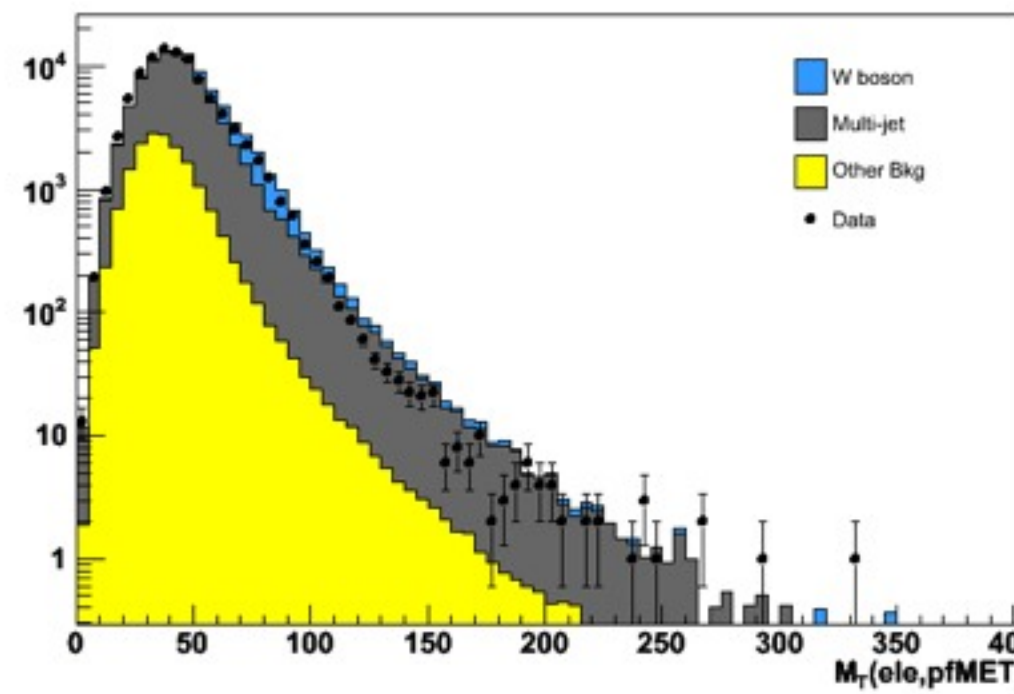
Electrons not selected (Sideband Examination)



ARC question:

1) Sideband examination. Do your background estimation techniques adequately predict any of the following:

b) Events failing either the delta phi or <u>ET/MET</u> cuts.



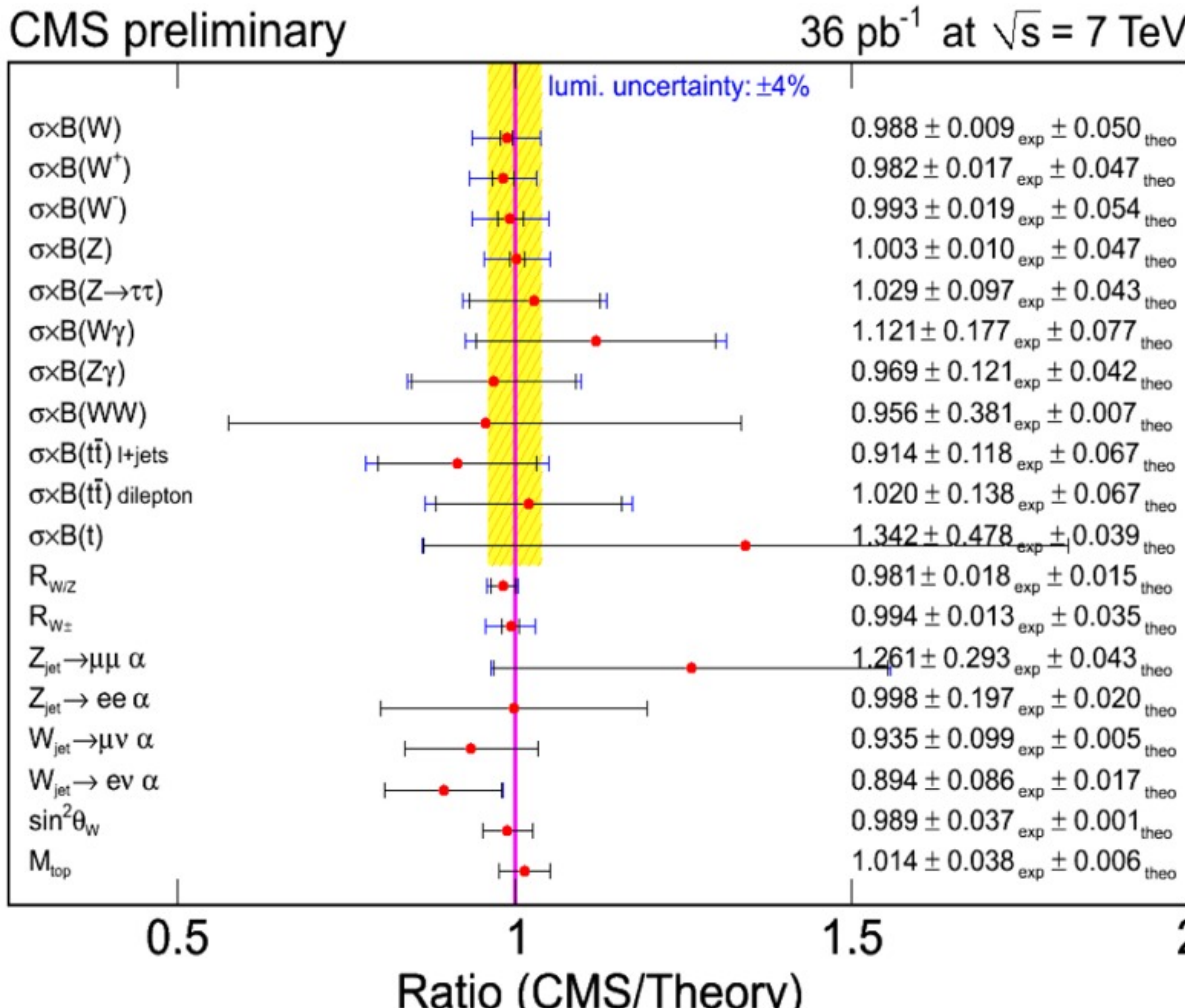
Using our background estimation technique, the plots shows MT for events that fail ET/MET cut and sit <u>outside</u> the range 0.4 < ET/MET < 1.5

As expected, this region is QCD dominated

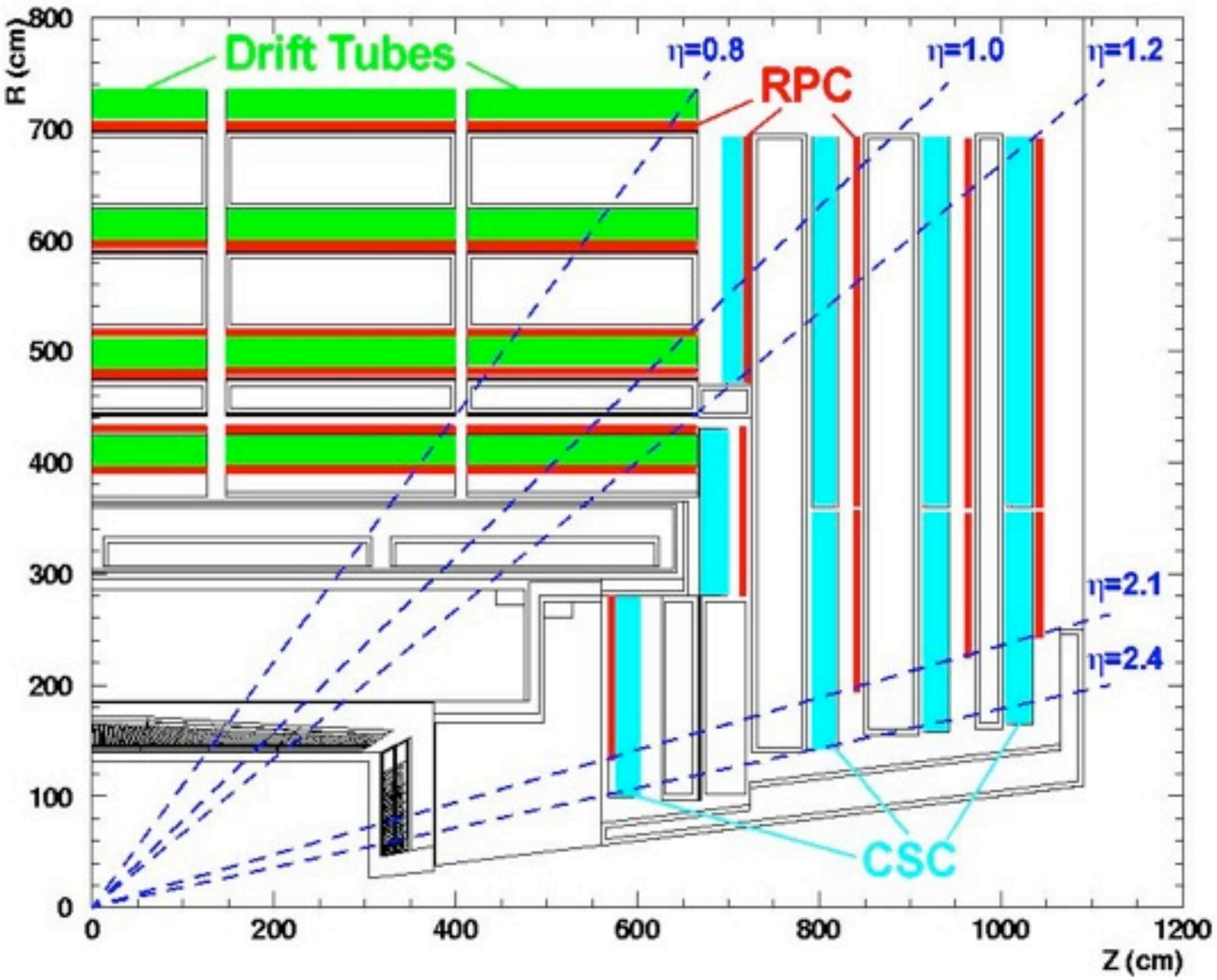
Although agreement isn't perfect, shape and the normalization are reasonable

CMS EWK and top measurements at a glance

CMS EWK and top measurements at a glance



CMS Muon System



Muon Barrel ($0 < |\eta| < 1.2$)

- ➡ 5 barrel wheels, iron return yoke for the solenoid magnet
- ➡ Almost no B-field at chamber positions
- ➡ 250 Drift Tube (DT) Chambers
- ➡ 480 Resistive Plate Chambers (RPC)

Forward Muon ($0.9 < |\eta| < 2.4$)

- ➡ Arranged in 2 x 3 disks
- ➡ 4 muon stations in 2/3 rings
- ➡ Inhomogenous field with B<1.2 T
- ➡ 250 Cathode Strip Chambers (CSC)
- ➡ 483 Resistive Plate Chambers (RPC)

Momentum resolution up to ~100 GeV limited by multiple scattering in the iron, $\Delta p/p$~10%@100 GeV (μ system only)

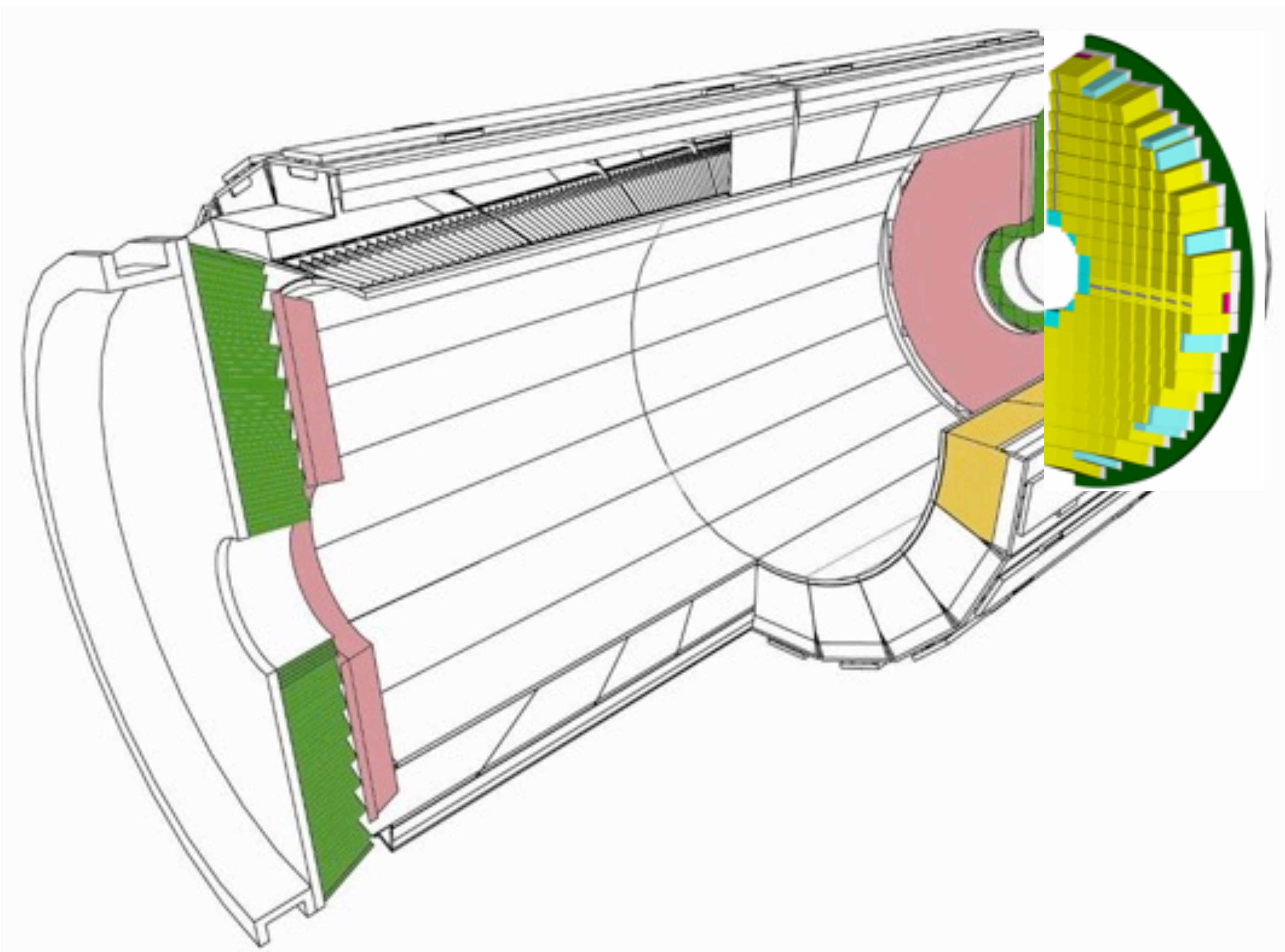
Combination with high resolution silicon tracker →few %

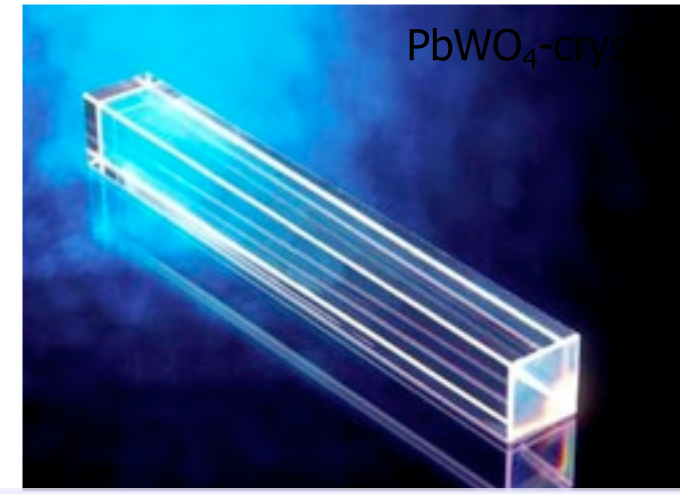
For p_μ~O(TeV), muon system resolution is dominating →$\Delta p/p$~10%

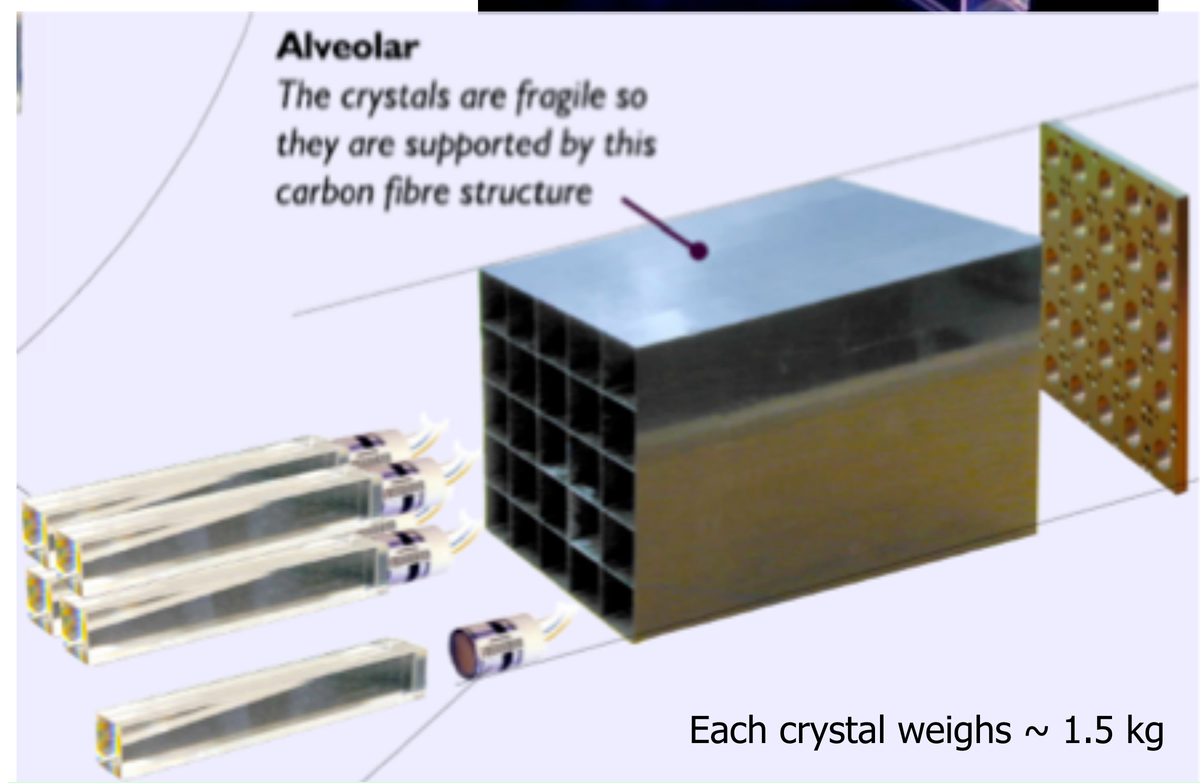
CMS Electromagnetic Calorimeter

Fully active ECAL, made of $PbWO_4$ crystals (CMS development)

Arranged in 36 barrel supermodules (61200 crystals, 67.4t) and 4 end-cap D's (14648 crystals, 22.9t)







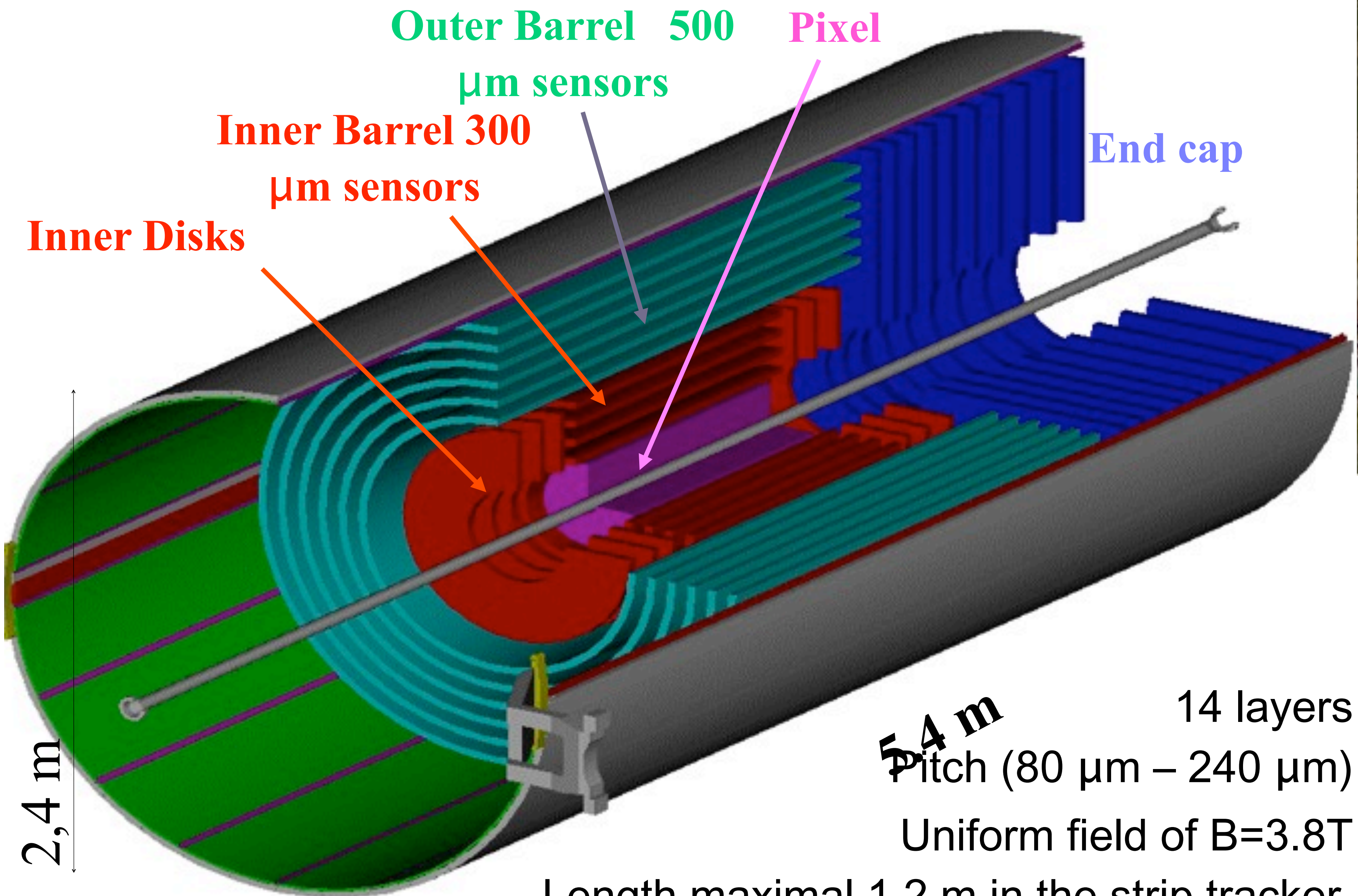
$$\frac{\sigma_E}{E} \cong \frac{0.01}{\sqrt{E[GeV]}} \oplus 0.005 \oplus \frac{0.2}{E[GeV]}$$

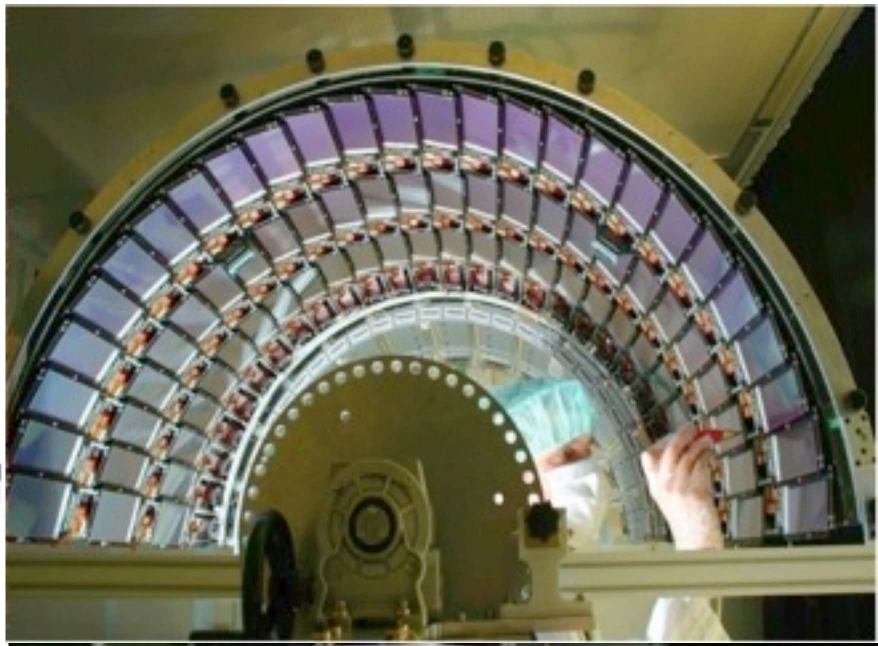
Operating at B=3.8T

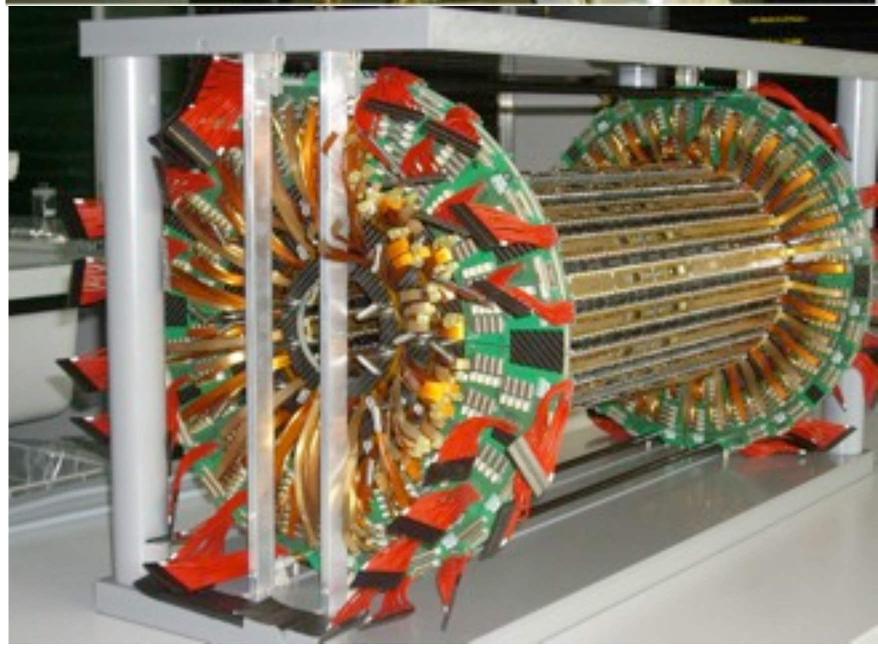
Temperature stabilized to mK for light output

Laser system for calibration (crystals darken from radiation)

CMS Tracker (Strips & Pixels)







14 layers

Pitch (80 µm – 240 µm)

Uniform field of B=3.8T

Length maximal 1.2 m in the strip tracker, seeded by the pixel

Goal: Reconstruction of

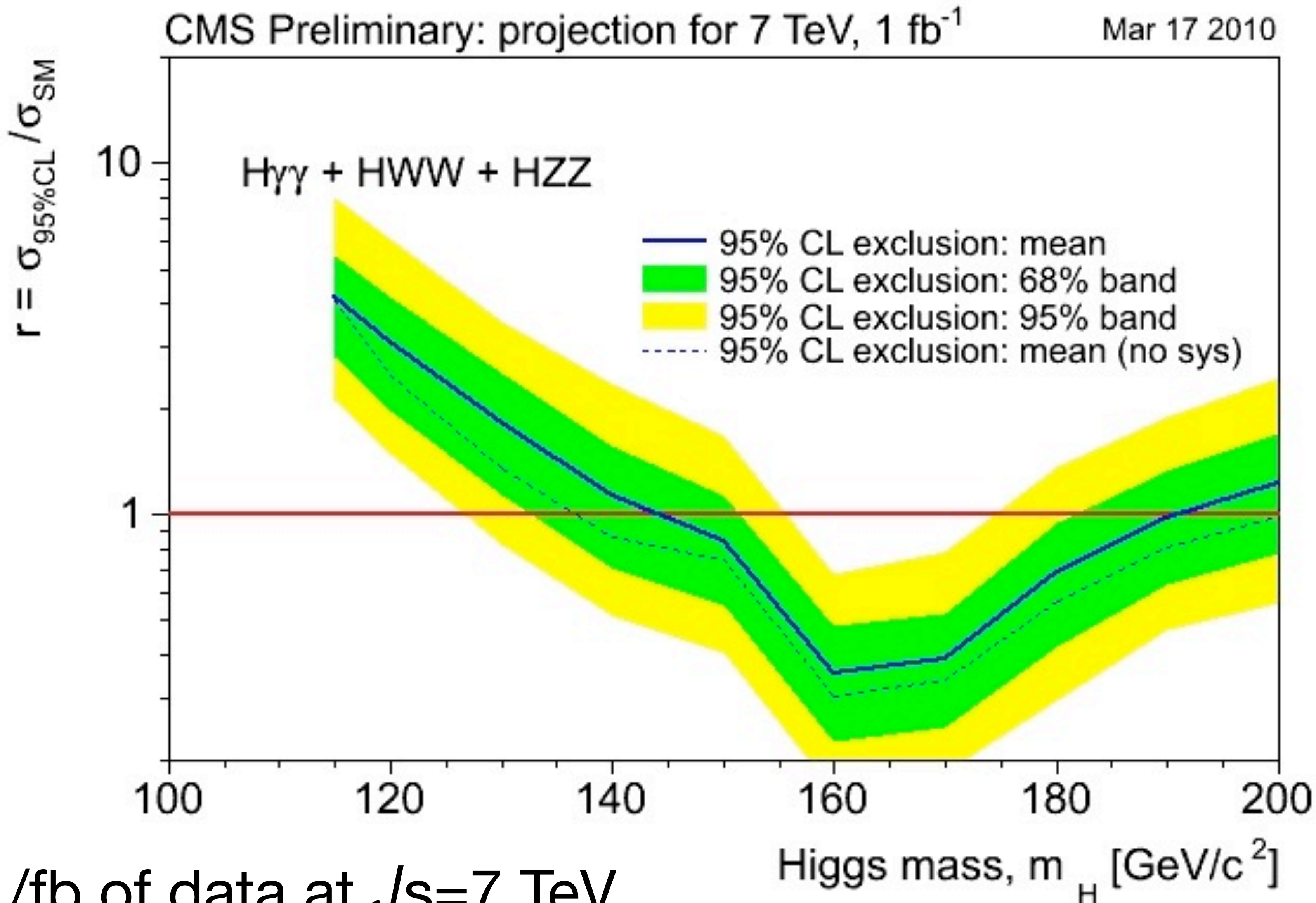
isolated tracks with ε > 0.95

high p_T tracks within jets with ε > 0.9

Requires

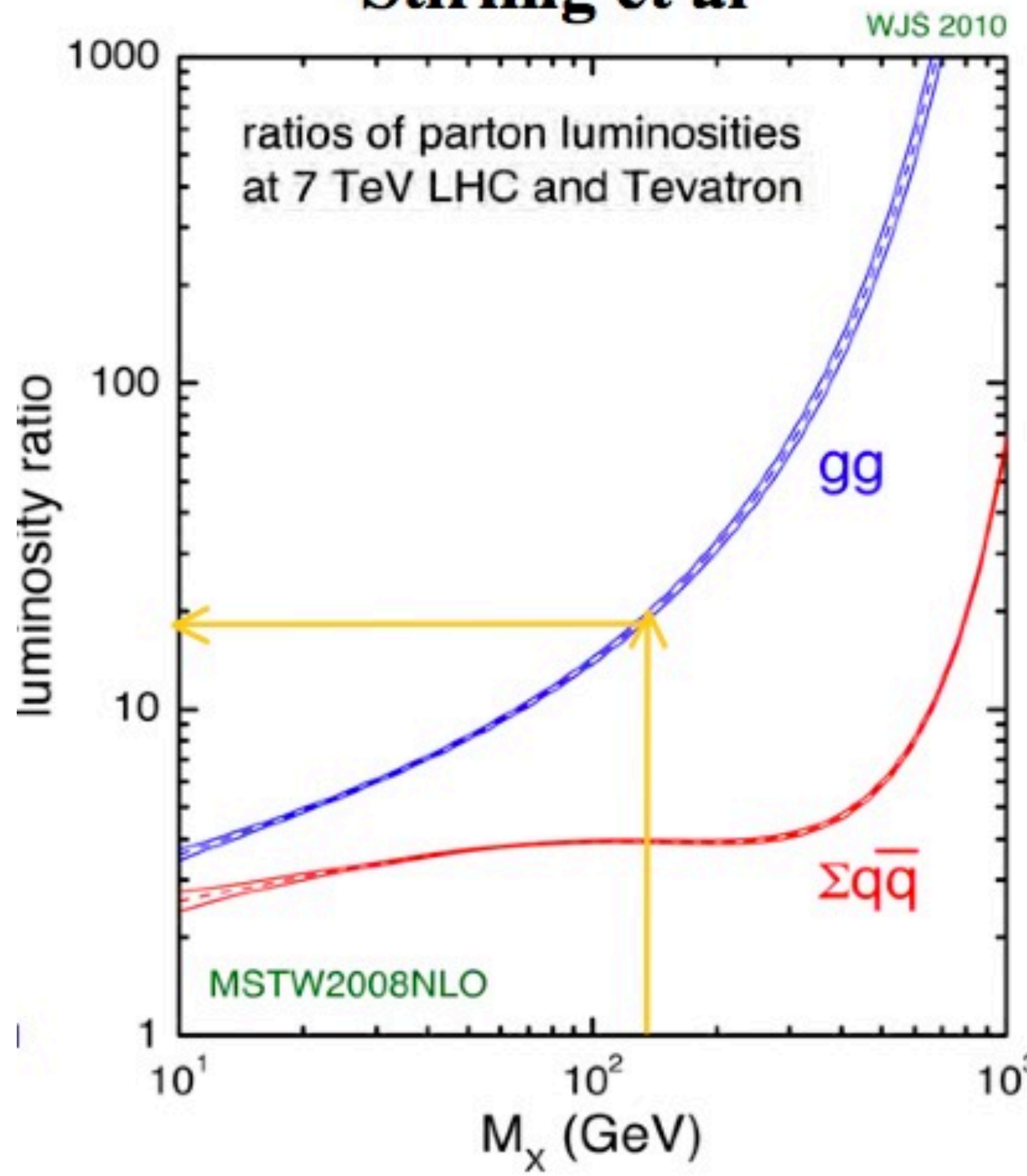
$$\frac{\delta p}{p} = \left(\frac{\text{pitch}}{100\ \mu m}\right) \times \frac{1.2\ m}{L} \times \frac{p}{\text{TeV}}$$
$$= 1.2\ \%\ \text{ at } 100\ \text{GeV}$$

Standard Model Higgs Boson Searches



- Estimated reach with 1/fb of data at $\sqrt{s}$=7 TeV
- Obtained by scaling 14 TeV studies to current COM energy
- Strong limits in range where H → WW dominates
  - Can exclude SM Higgs in this range
- No sensitivity outside this range for 1/fb
  - Does not appreciably improve if you do naive CMS+ATLAS combo

Stirling et al



CMS Jets and Missing ET

Most all of the Jet and Missing ET reconstruction here uses **Particle Flow** (PF) technique:

All tracks/energy deposits sorted into charged/neutral hadron, electron, photon, or muon candidates

Resulting set of corrected particles input to jet clustering, MET determination, HT, MT, etc.

Significant improvement over traditional "CaloJets" for ~low-medium ET jets with tracker coverage

Anti-kT clustering with R=0.5 used everywhere here

JES of PF jets known to 3-4%
PF MET FWHM in dijets ~10 GeV