Electroweak Results from CMS

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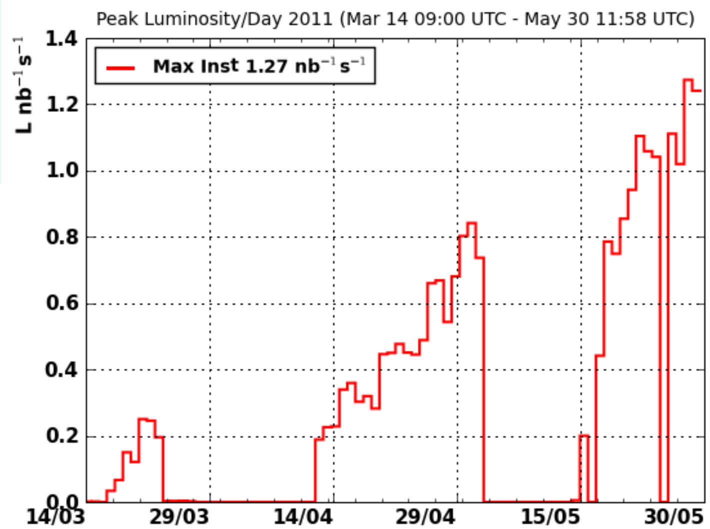
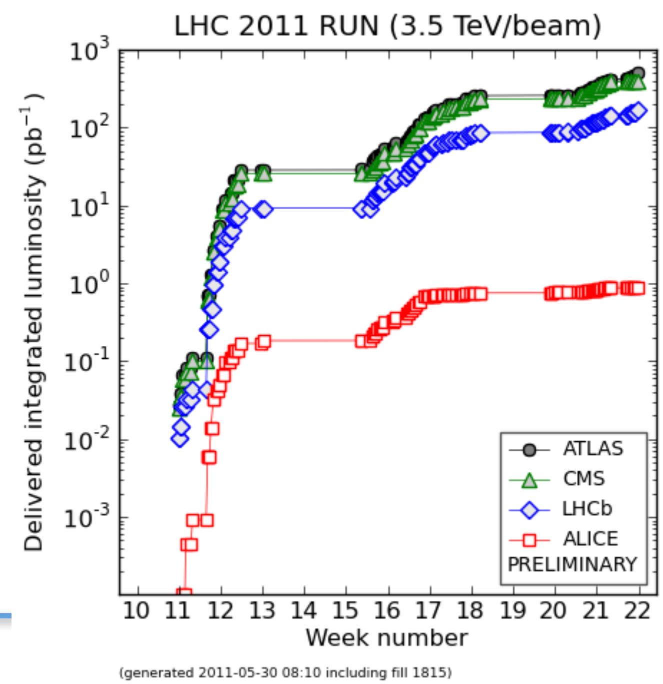
Fermilab 31/05/11

Recent news from 2011

LHC "Official" target:
Deliver at least 1 fb^{-1} per exp at $\sqrt{s}$ = 7 TeV by year end. Likely to get lot more.

- Breaking news: LHC sets new world record luminosity yesterday: **1.27 $10^{33} cm^{-2}s^{-1}$**
  - setting new world record ~every day
  - this exceeded the previous world record of 4.02 $10^{32} cm^{-2}s^{-1}$, which was set by the Tevatron in 2010
- Moving to continuous physics running
  - short technical stop in December, then physics run until end of 2012
- LHC already delivered ~**0.5 fb^{-1} per exp.**



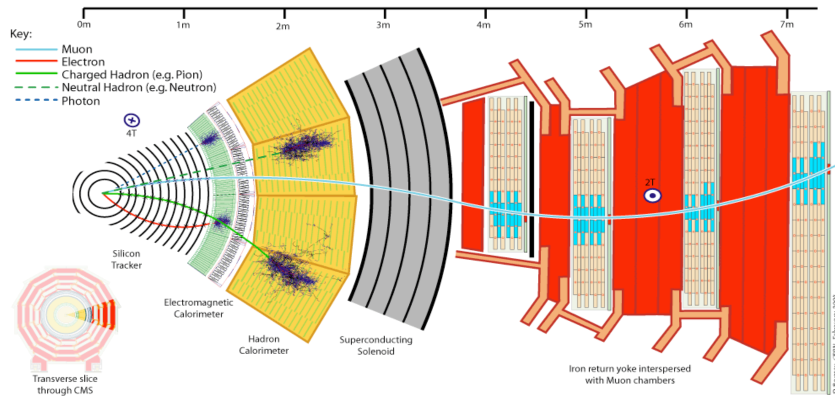


Outline

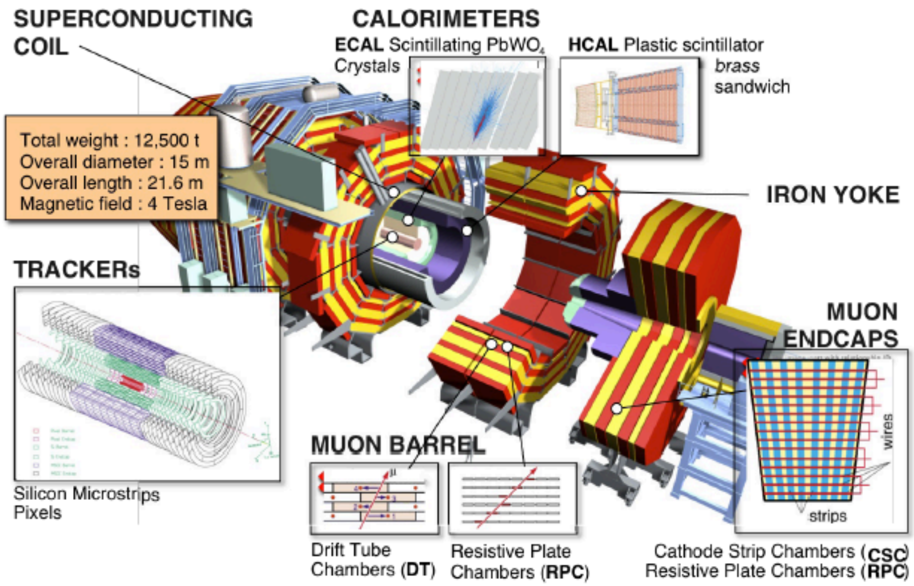
- Introduction
  - CMS in a nutshell
  - Commissioning of CMS physics objects
  - Motivation for EWK@LHC
- CMS plethora of results: already with 2010 data a full physics program
  - Inclusive Z/W cross section
  - Drell-Yan, Z to taus, W asymmetry
  - Associated production with jets, b-jets, gamma, dibosons

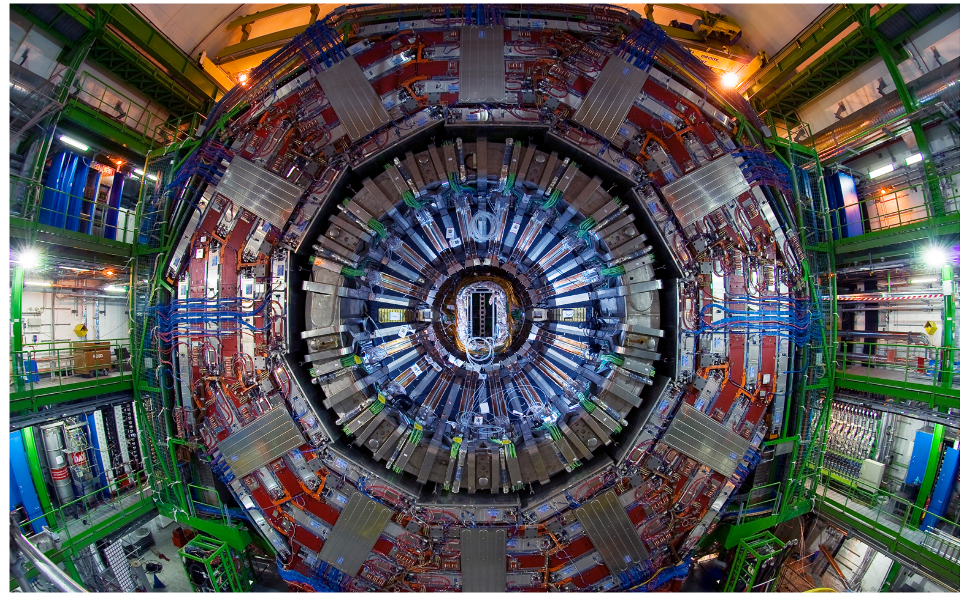
.... and so on!

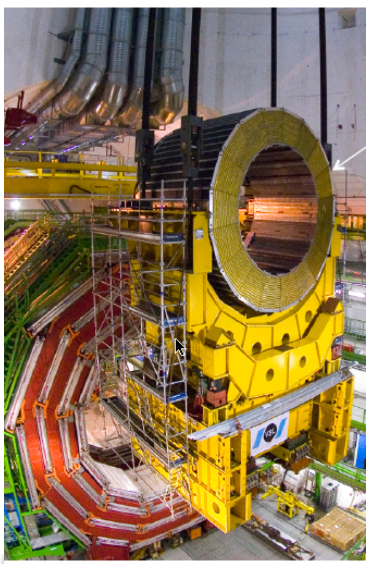
CMS overview



CMS in a nutshell







|η|<2.5 : Tracker

$\sigma/p_T \approx 10^{-4} p_T \oplus 0.005$

|η|<4.9 : EM Calorimeter

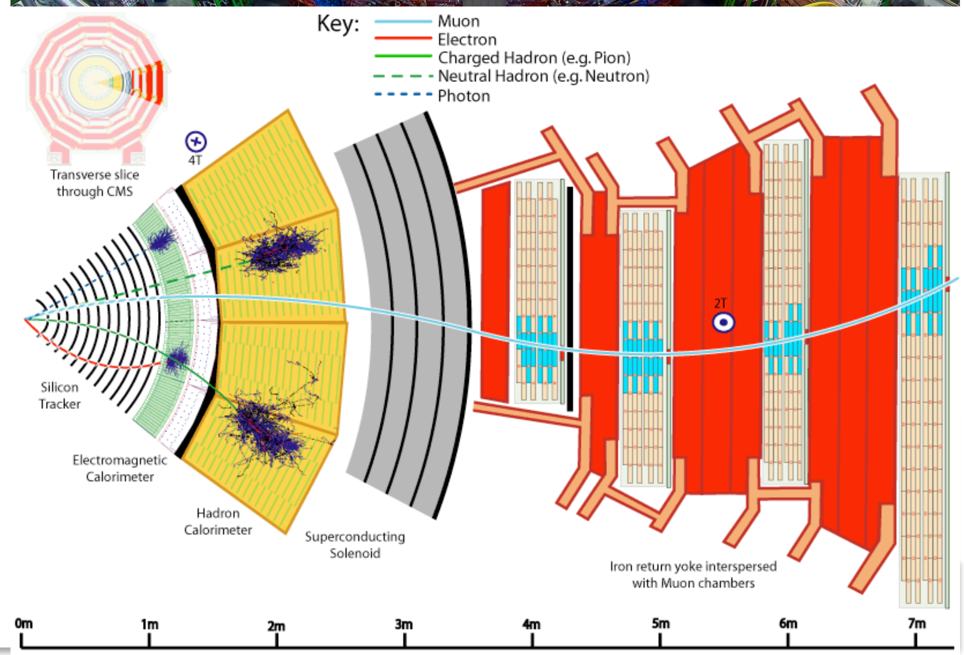
$\sigma/E \approx 0.03/\sqrt{E} + 0.003$

|η|<4.9 : HAD Calorimeter

$\sigma/E \approx 1.0/\sqrt{E} + 0.05$

|η|<2.4 : Muon spectrometer

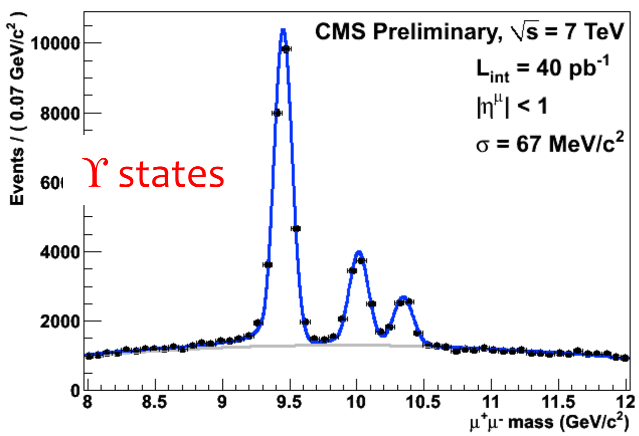
$\sigma/p_T \approx 0.10$ *(1TeV muons)*

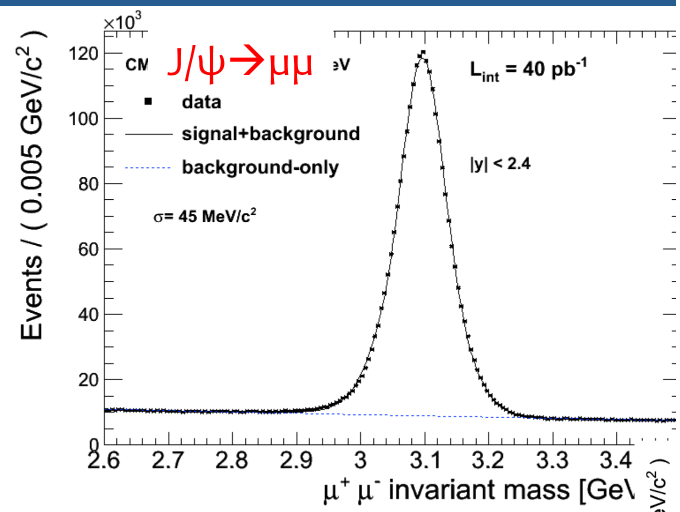


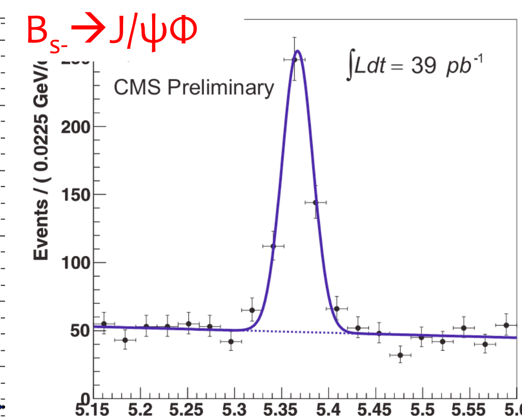
Basic building blocks for any measurement

- Precision electroweak measurement and new physics searches requires excellent performance from the entire detector and several reconstructed "objects"
- Key objects:
  - ☑ Electron, muon, photon, jet
  - ☑ Missing transverse energy (MET)
  - ☑ Tau
  - ☑ b quark-jet tagging (b-tag)
- Ability to reconstruct W, Z, top, W/Z+jets (including heavy flavor), and di-boson events and understand their production rates
- 2010 data has demonstrated excellent performance of CMS in reconstruction of these basic objects
- Performance in data closely matches expectations based on simulations (MC) and sometimes exceeds it

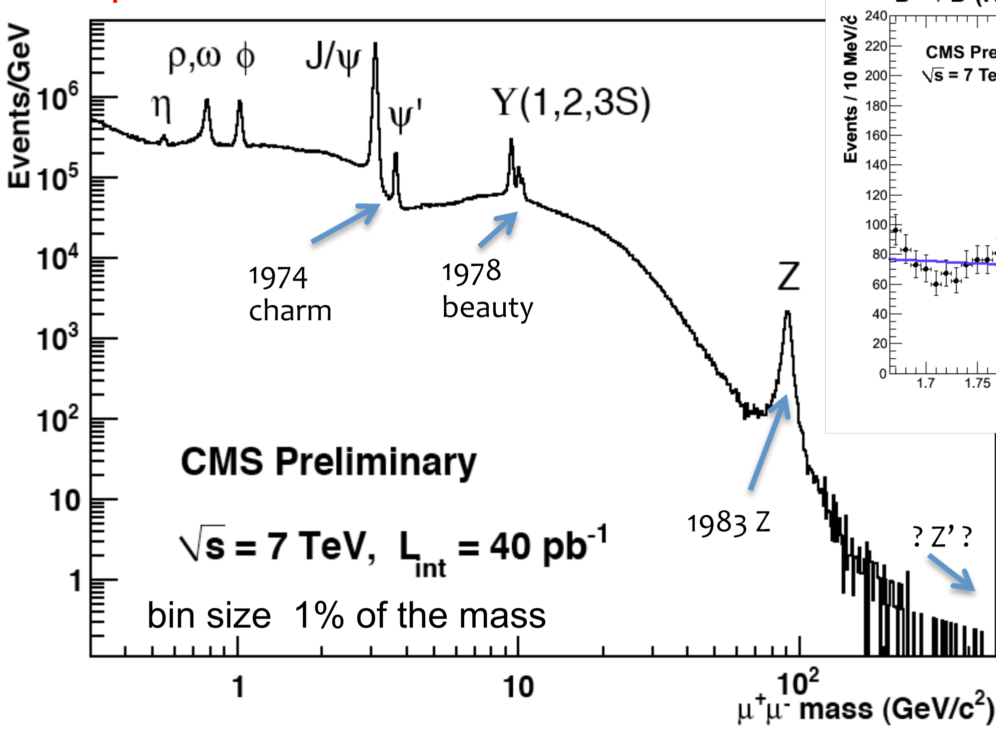
A well calibrated detector

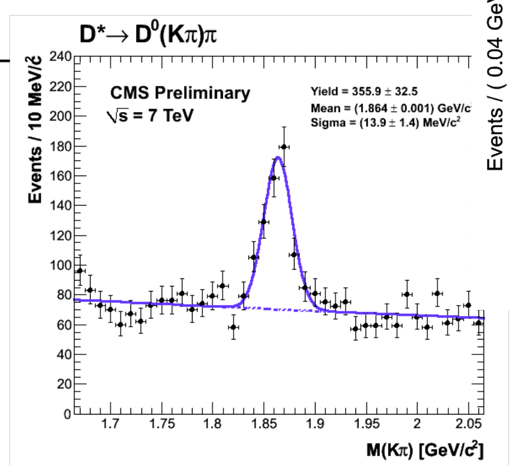


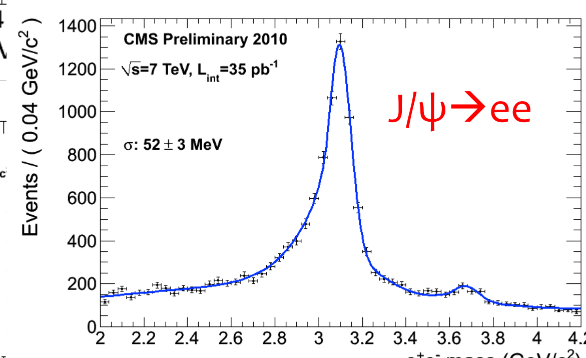


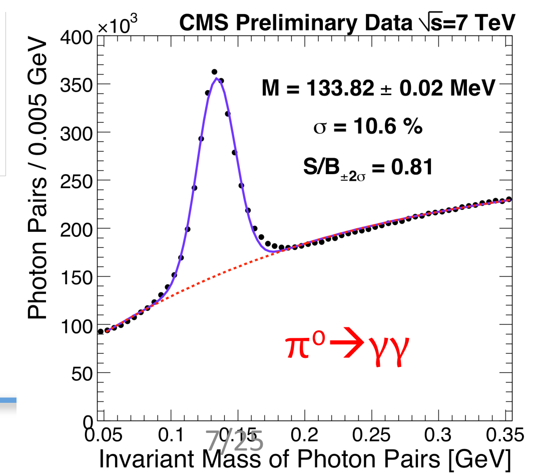


Compact Muon solenoid in action…





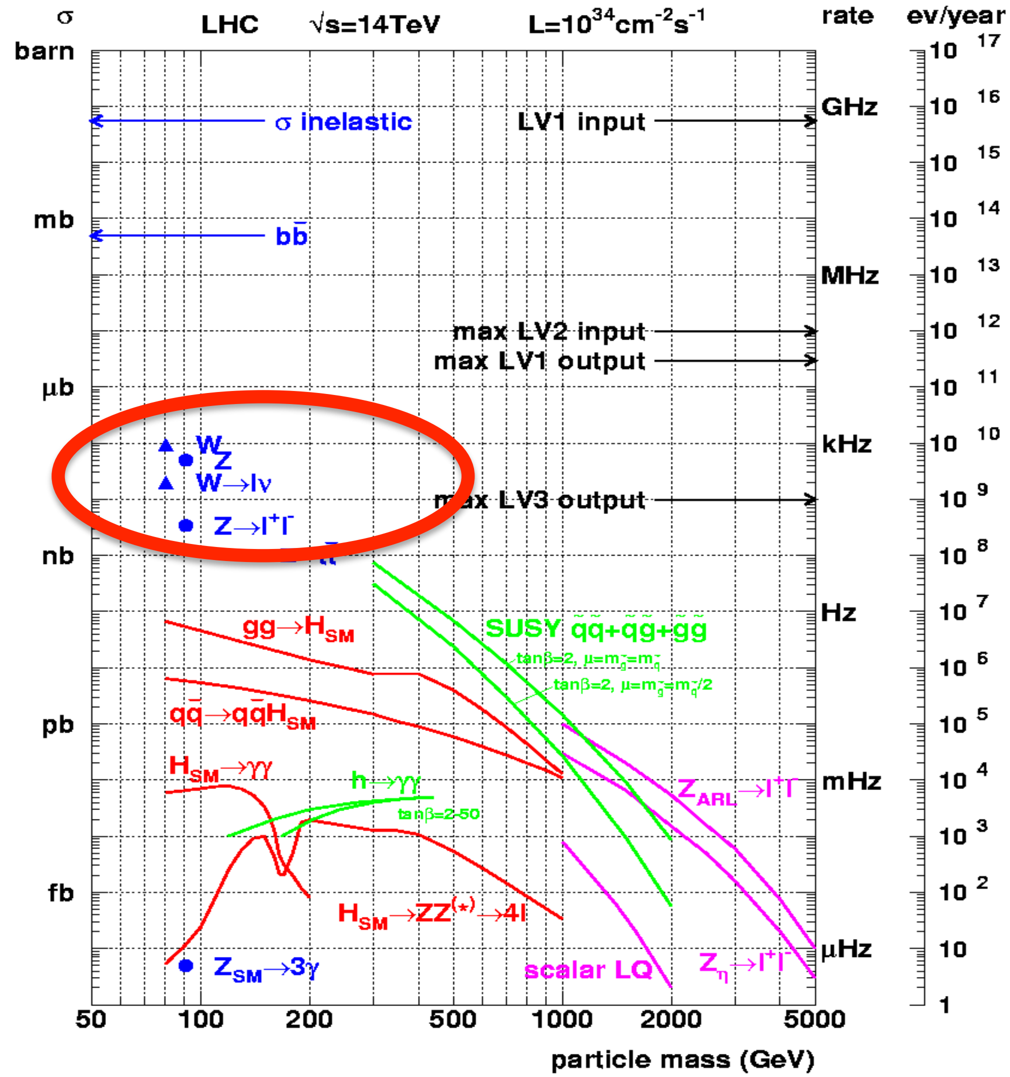




CMS physics objects ok

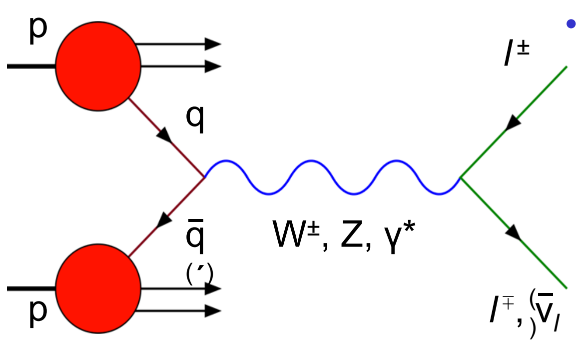
⇓

we can measure EWK processes



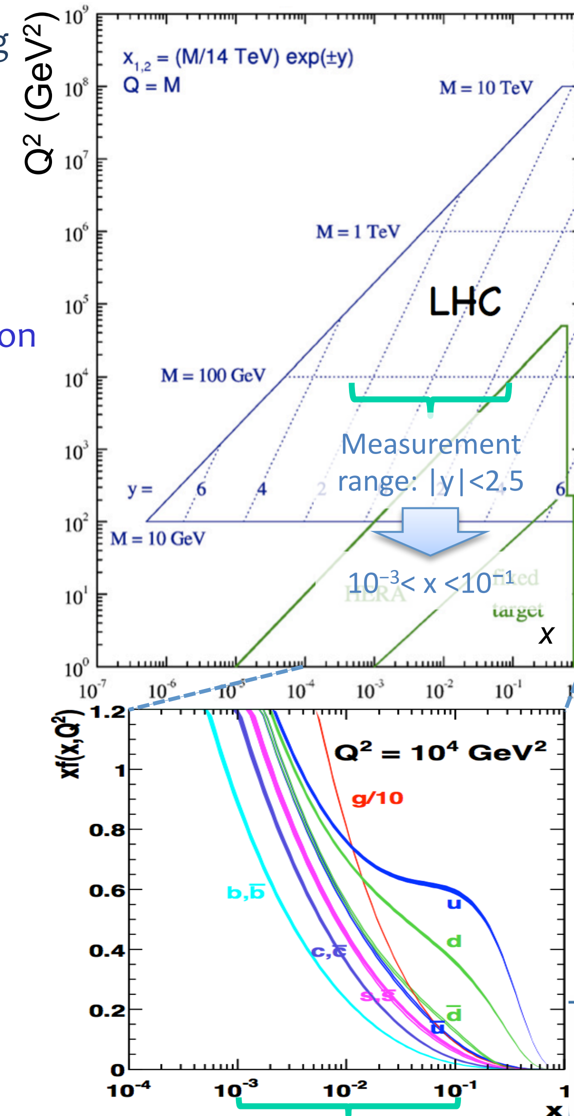
W and Z production at LHC

- W and Z production in pp collisions proceeds mainly form the scattering of a valence quark with a sea anti-quark
- The involved parton fractions are low ($10^{-3} < x < 10^{-1}$) and scattering of a sea quark with a sea anti-quark is also important
- W production is charge asymmetric: $\sigma(W^+)/\sigma(W^-)$~1.43 (< 1.5, as from valence + sea only) in the Standard Model
- W and Z events produce very clean signals and allow to perform precision measurements
  - Large background control samples available in data reduce the need to rely on simulations



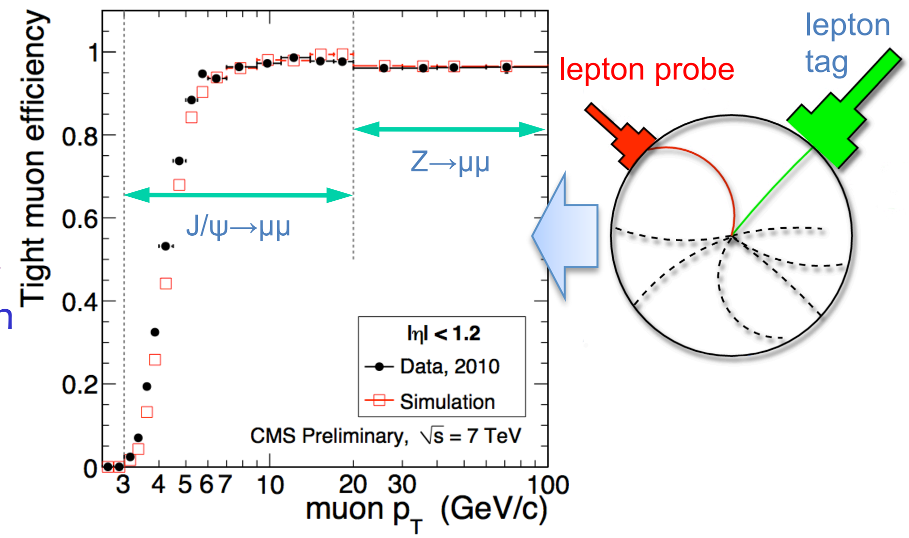
$$Q^2 = m_{W,Z}^2 = x_1 x_2 s$$

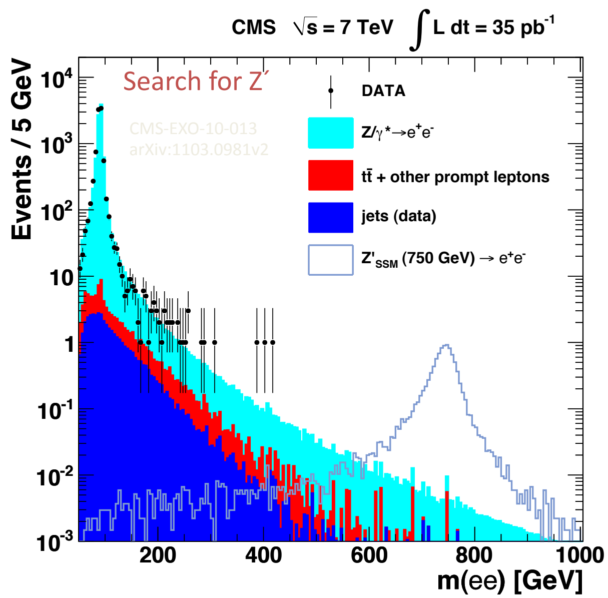
- Accurate theoretical predictions are available
  - POWHEG and MC@NLO for NLO event generators
  - FEWZ, RESBOS, DYNNLO for NNLO cross section and differential distributions
  - Valence and sea PDF uncertainty are sources of uncertainty in theoretical predictions
- Differential distributions are sensitive to PDF

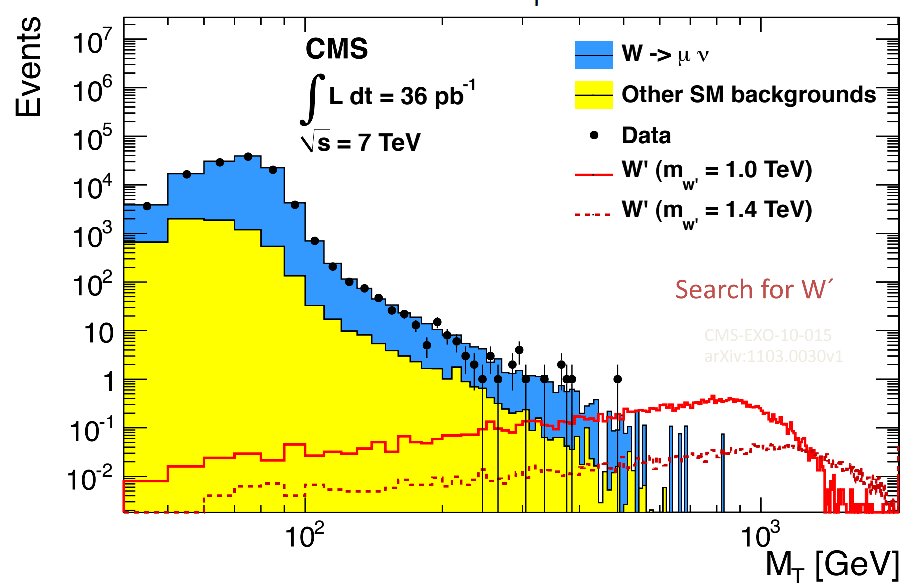


EWK as tool and background

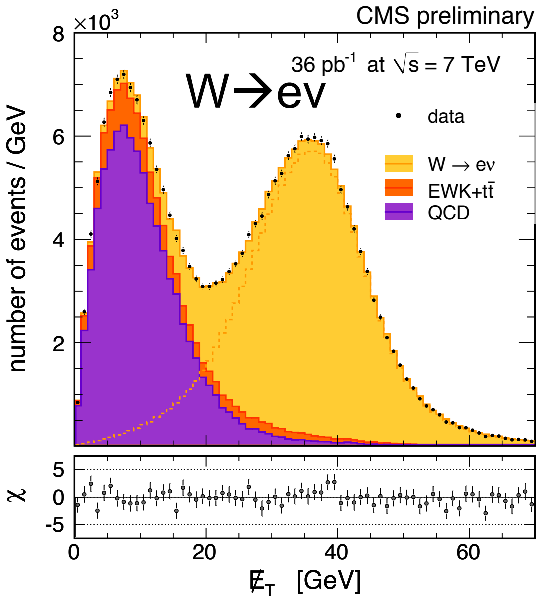
- W and Z are also tools to understand and calibrate the detector
  - Tag and probe method for efficiency measurements
  - Lepton scale and calibration, …
- Many searches have EWK processes as main backgrounds
  - Studying EWK processes means keeping backgrounds under control

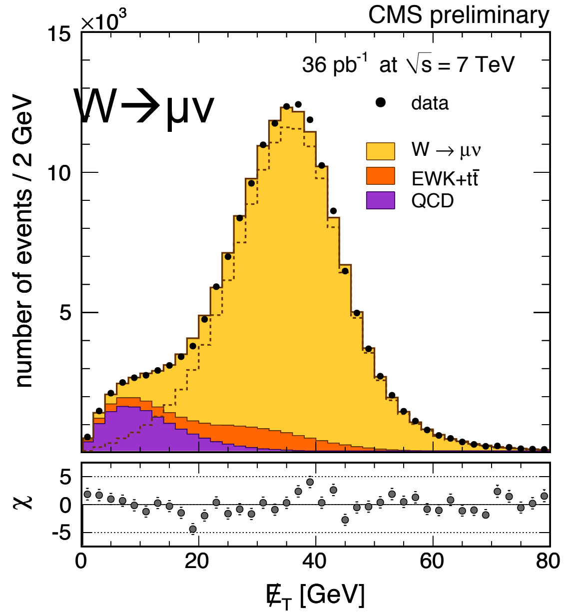






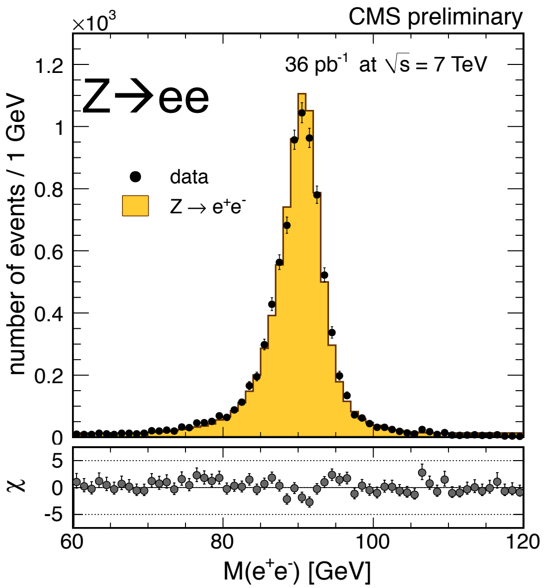
Z/W→ e,μ

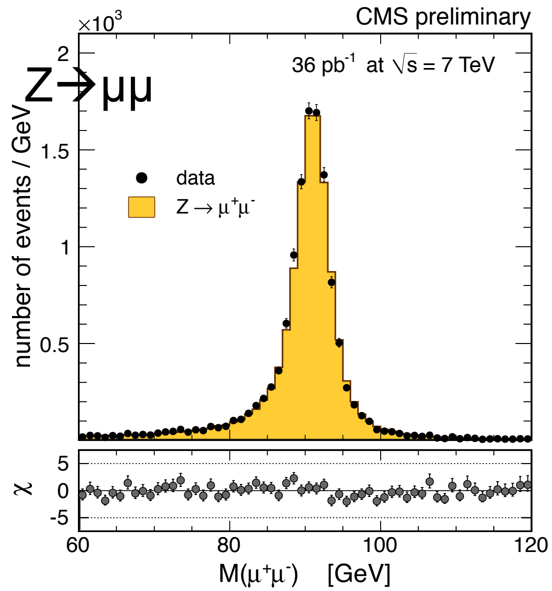




Fully reconstructable, high purity

- MET well understood
  - recoil modeling fine
- Lepton energy scale and resolution well measured
- Tiny experimental errors, luminosity, theory dominate uncertainty





280000 W's

σ x BR = 10.31 ± 0.02 (stat) ± 0.09 (syst) ±0.10 (th.) ± 0.41 (lumi) nb

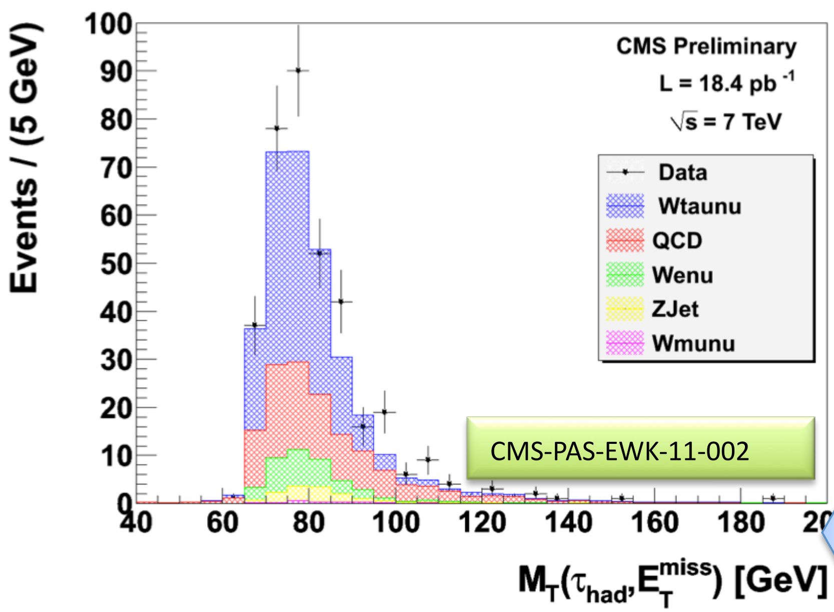
20000 Z's

σ x BR = 0.975 ± 0.007 (stat) ± 0.007 (syst) ± 0.018 (th.) ± 0.039 (lumi) nb

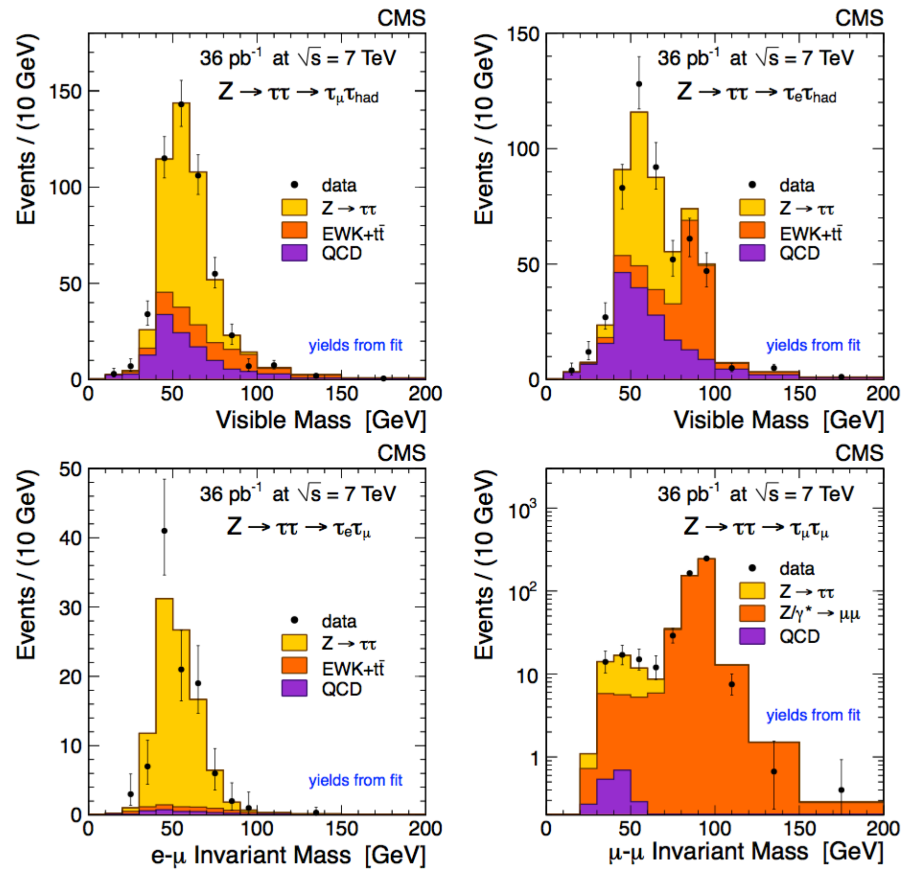
Z→ττ, W→τν

CMS-PAS-EWK-10-013
arXiv:1104.1617

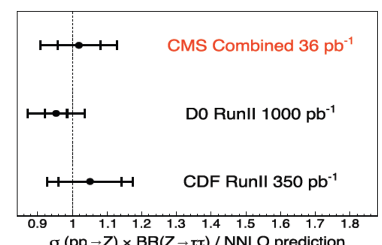
- Benchmark for searches using taus (H⁺→τν, H→ττ, …)
- Particle Flow: combine tracker and calorimeter measurements to determine particle candidates
- Challenging trigger on tau plus missing E_T for W→τν
  - $p_T(\tau) > 20$ GeV, p_T (track)>15 GeV, missing E_T >25 GeV



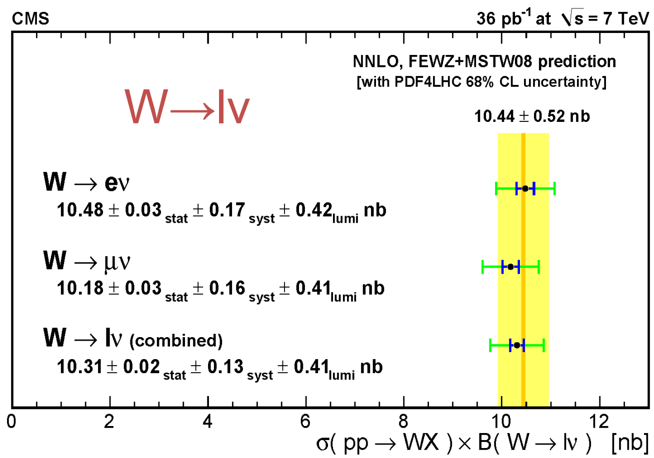
CMS-PAS-EWK-11-002

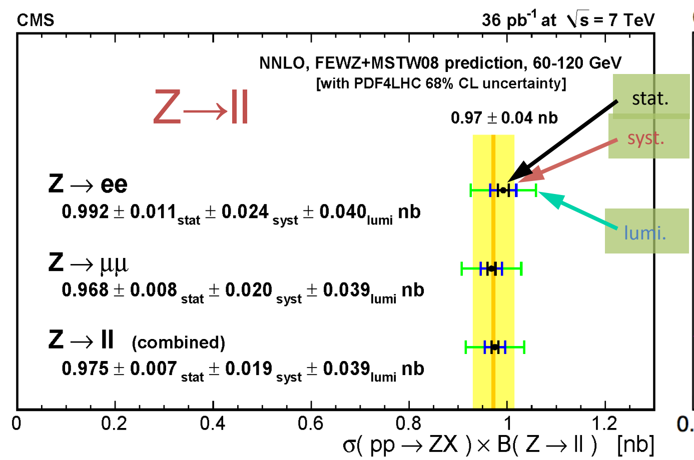


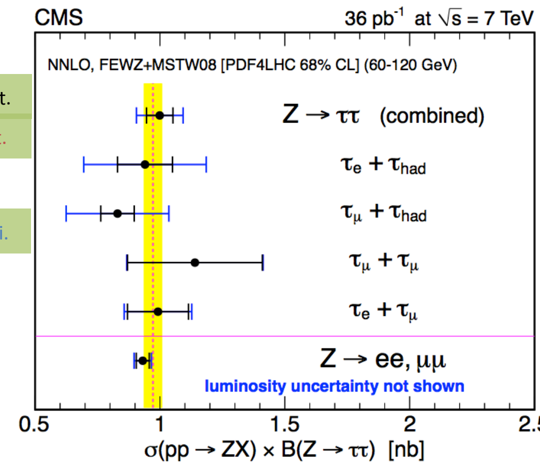
Process	Events
W→τν (sim.)	174 ± 3
EWK (sim.)	46 ± 2
QCD (sideband)	109 ± 6
Data	372

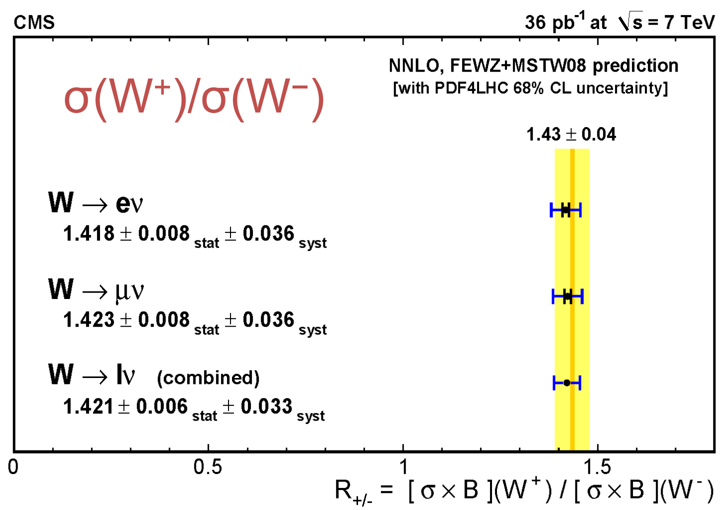


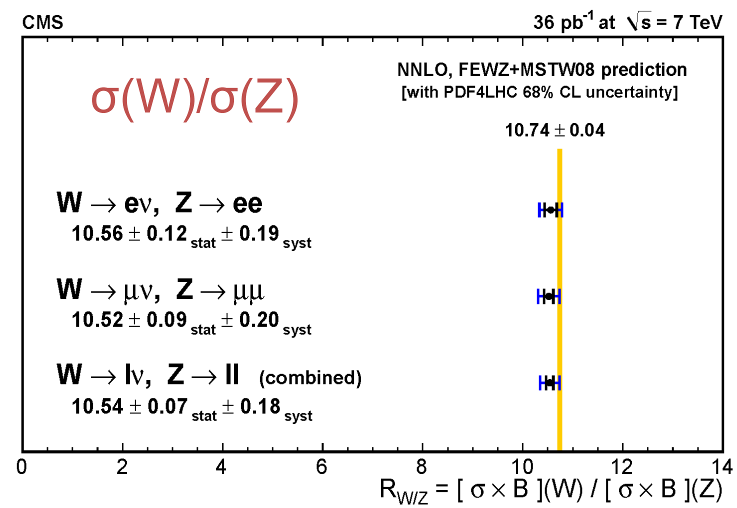
Comparison with theory





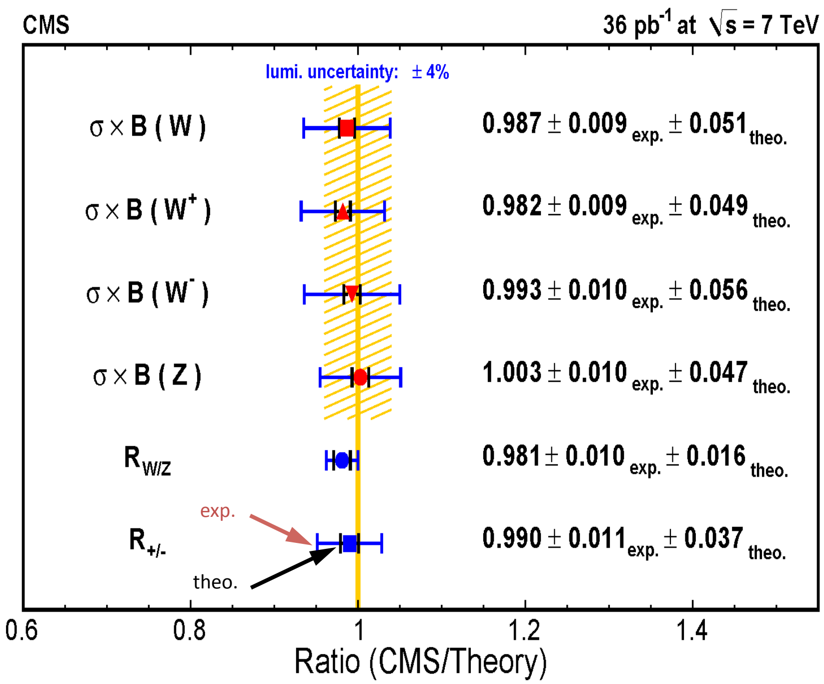


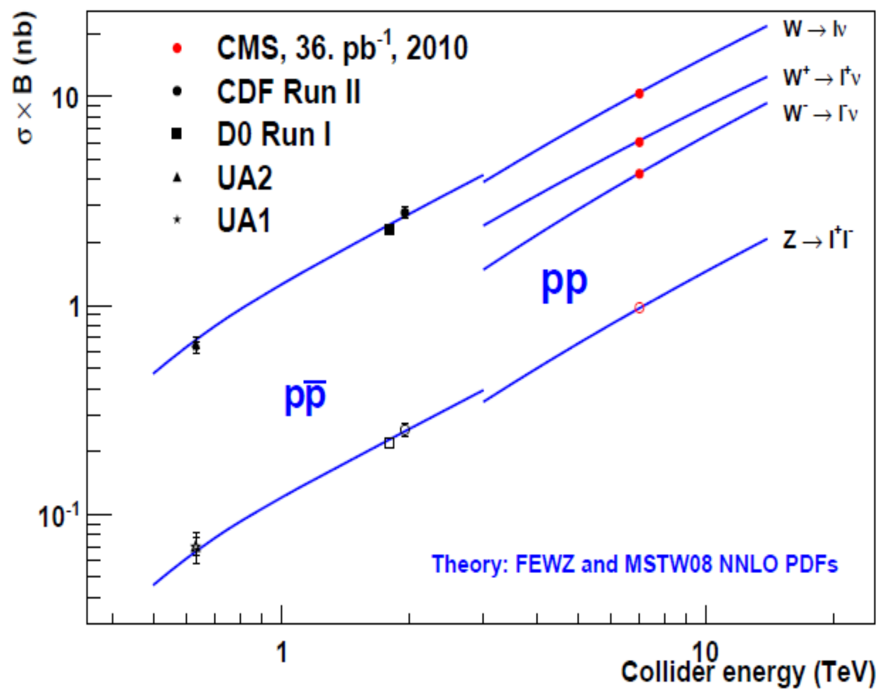




- Ratios are not affected by luminosity uncertainty
- W^+/W^- potentially sensitive to PDF, W/Z has precise prediction

More comparison with theory

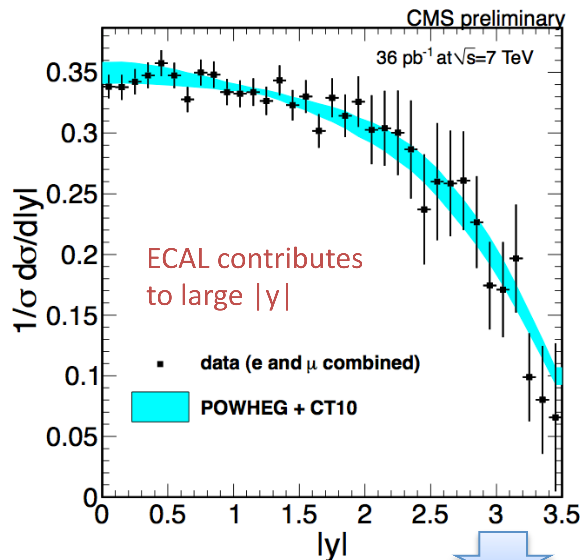




- Good overall agreement with theory predictions at NNLO

Z differential cross section

- Large statistics allows to study differential cross sections vs y and p_T
- compared to theory after an unfolding procedure correcting for resolution and final-state radiation

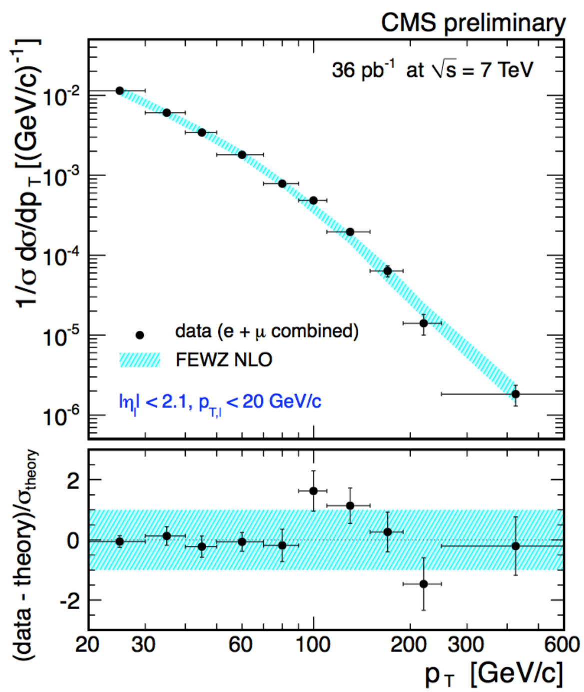


$$x = \frac{m_Z}{\sqrt{s}} e^{\pm y}$$

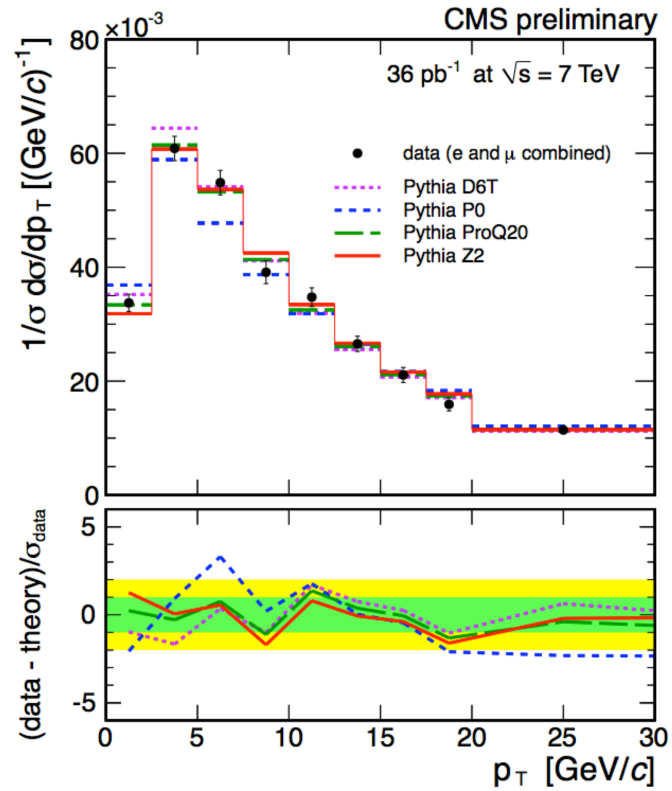
$x < 10^{-3}$

Sensitive to PDF at low x

CMS-PAS-EWK-10-010



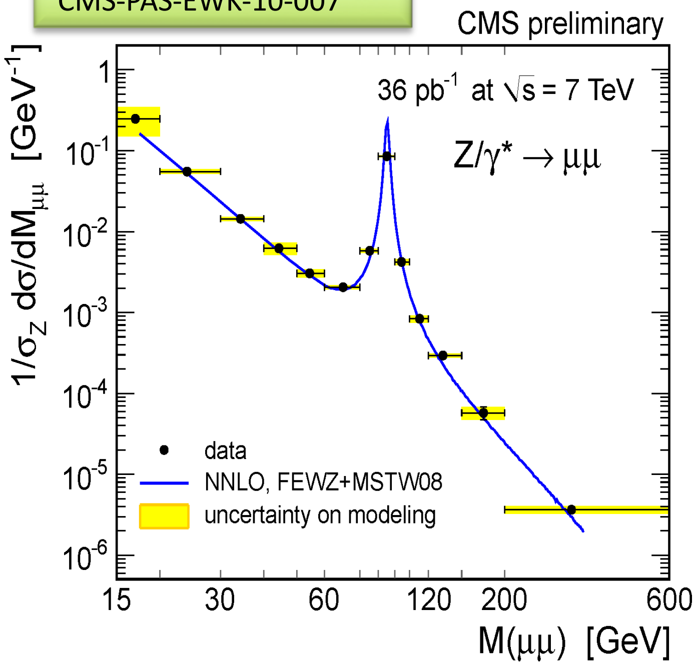
Good agreement with FEWZ prediction (NNLO) at high p_T



Agreement at low p_T requires PYTHIA tuning

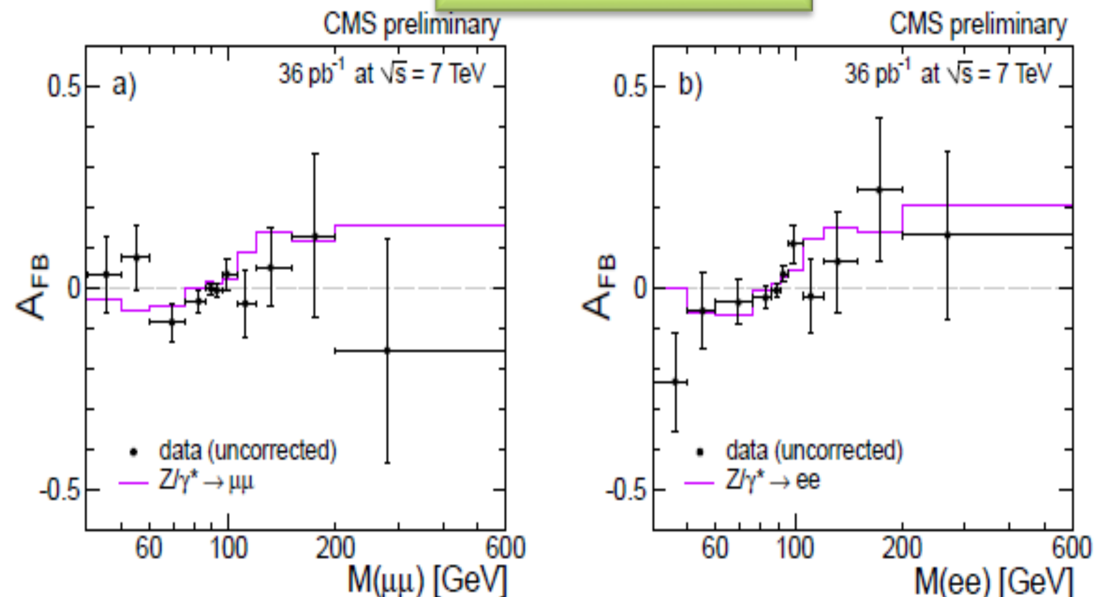
Drell-Yan, $\sin^2\theta_W$

CMS-PAS-EWK-10-007



Unfolded distribution, corrected for acceptance, efficiency and FSR effects (not included in FEWZ)

CMS-PAS-EWK-10-011

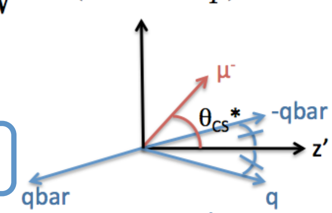


$$\frac{d\sigma}{d\cos\theta} = \frac{3}{8}(1+\cos^2\theta) + A_{\mathrm{FB}}\cos\theta$$

$$\cos\theta^*_{CS} = \frac{2(P_1^+P_2^- - P_1^-P_2^+)}{\sqrt{Q^2(Q^2+Q_T^2)}}$$

Collins-Soper frame adopted[*]

More precise measurement also using y and m^2 of the di-muon pair distributions



$$\sin^2\theta_{\mathrm{eff}} = 0.2287 \pm 0.0077(\mathrm{stat.}) \pm 0.0036(\mathrm{syst.})$$

[*] CS frame: Z rest frame in which the z axis bisects p_1, $-p_2$, p_1 and p_2 being the incoming quark and anti-quark momenta

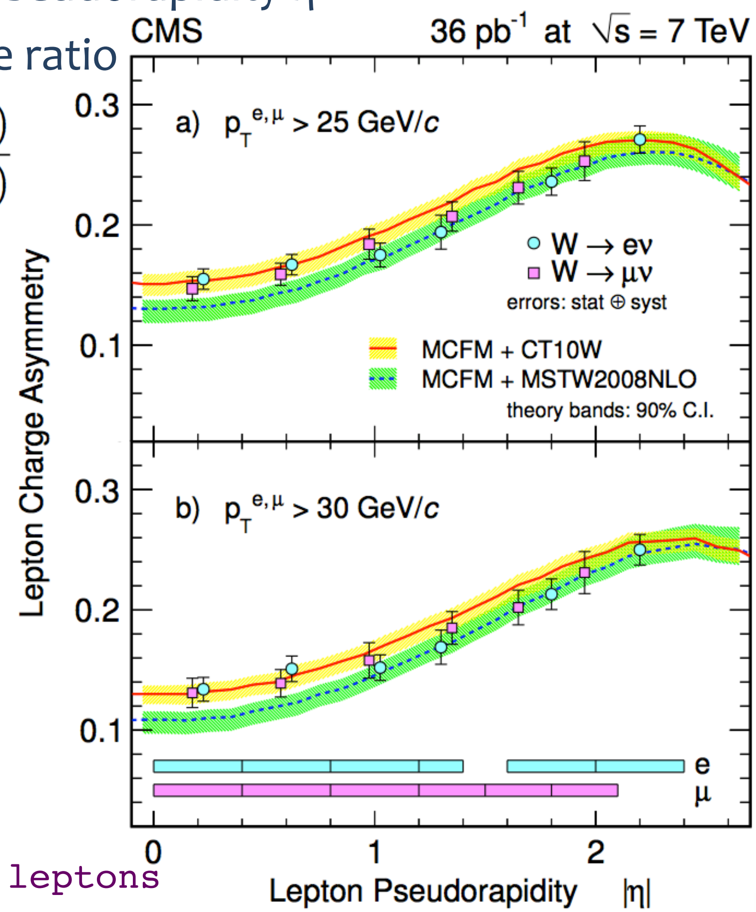
W charge asymmetry

JHEP04 (2011) 050

- W^+/W^- ratio measured as a function of the lepton pseudorapidity η
- Sensitive to PDF; several uncertainties cancel in the ratio

$$\mathcal{A}(\eta) = \frac{d\sigma/d\eta(W^+ \to \ell^+\nu) - d\sigma/d\eta(W^- \to \ell^-\bar{\nu})}{d\sigma/d\eta(W^+ \to \ell^+\nu) + d\sigma/d\eta(W^- \to \ell^-\bar{\nu})}$$

- Similar selection to inclusive cross section analysis
- Two p_T thresholds (25, 30 GeV) to probe different phase space regions
- Charge mis-id: 0.1(barrel)-0.4(endcap)% for electrons, $<10^{-4}$ for muons
- Statistical uncertainty: ~3%
- Systematic uncertainties (~3%) can be improved with increasing size of Drell-Yan data sample
  - Separate efficiency estimates for + and – leptons
  - p_T scale and resolution
  - Background and signal modeling



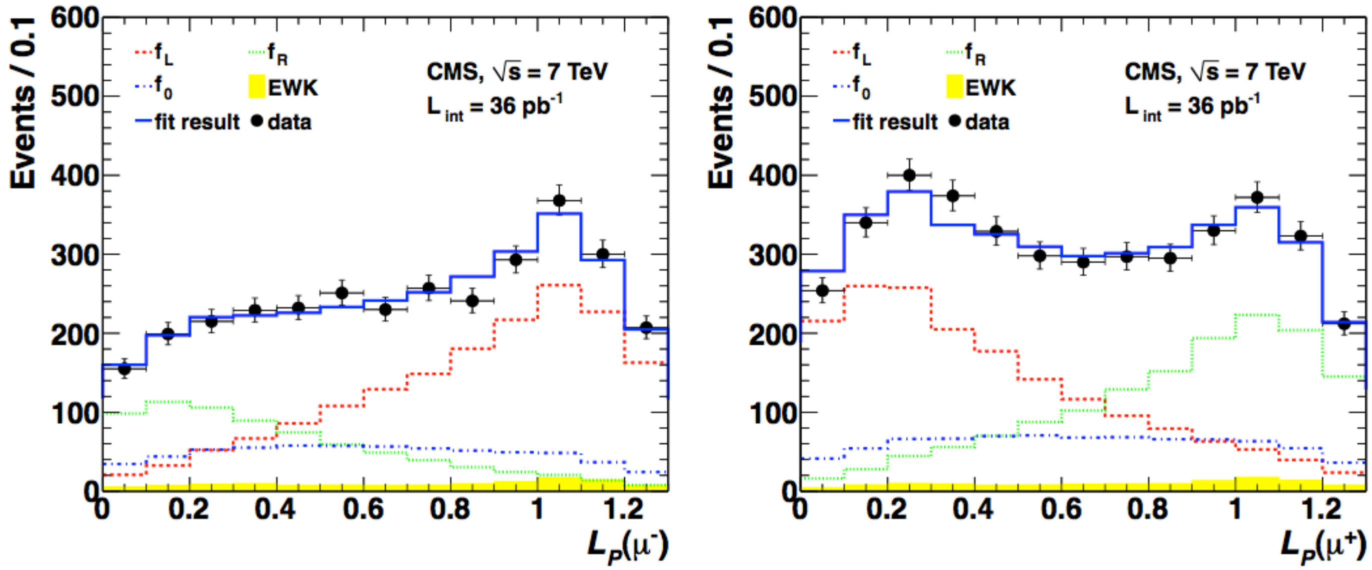
W polarization

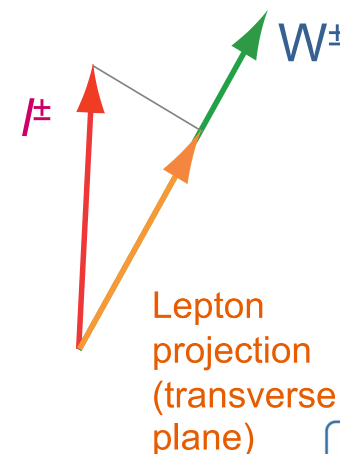
- V-A W-quark coupling imposes L-polarized quarks (for $m_q \approx 0$)
- high W $p_T \Rightarrow$ large W f_L
- Important for searches beyond SM with different W polarization
- Polarization should be measured in the W rest frame:

CMS-PAS-EWK-10-014
arXiv:1104.3829 (→PRL)

$$\frac{d\Gamma}{\Gamma d\cos\theta^*} = \frac{3}{8}\left[f_R(1+\cos\theta^*)^2 + f_L(1-\cos\theta^*)^2\right] + \frac{3}{4} f_0 \sin^2\theta^* \qquad f_R + f_L + f_0 = 1$$

$$L_P = \frac{\vec{p}_T(l)\cdot\vec{p}_T(W)}{|\vec{p}_T(W)|^2} \simeq \frac{1+\cos\theta^*}{2}$$



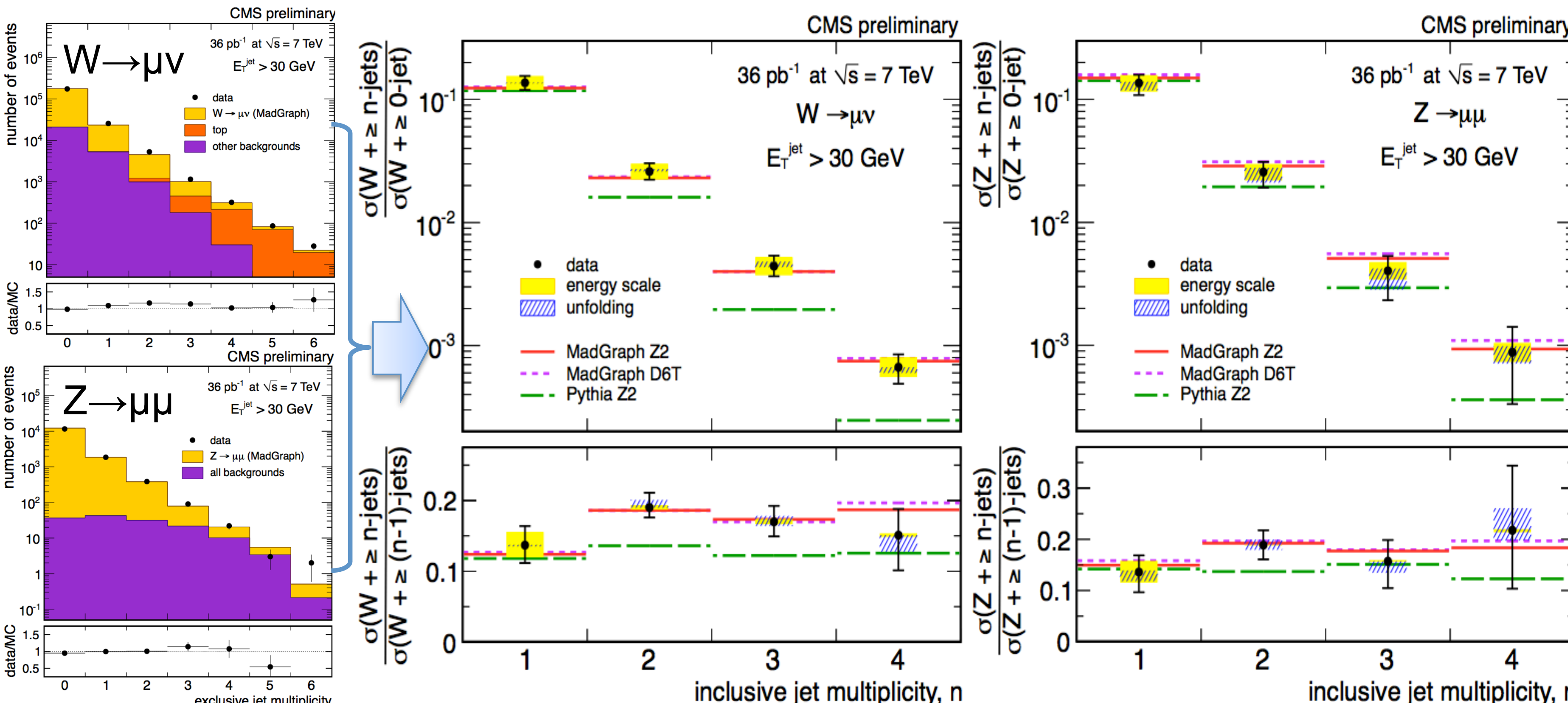


W p_T as lepton plus missing E_T

W, Z + *n* jets

CMS-PAS-EWK-10-012

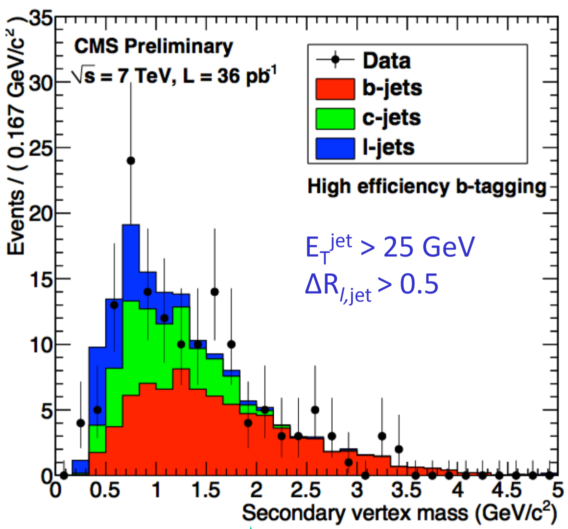
- Important test of perturbative NLO predictions and background to Higgs and many searches
- Systematics dominates, mainly due to energy scale and unfolding for large n
- Agreement with MadGraph, discrepancies with Pythia observed

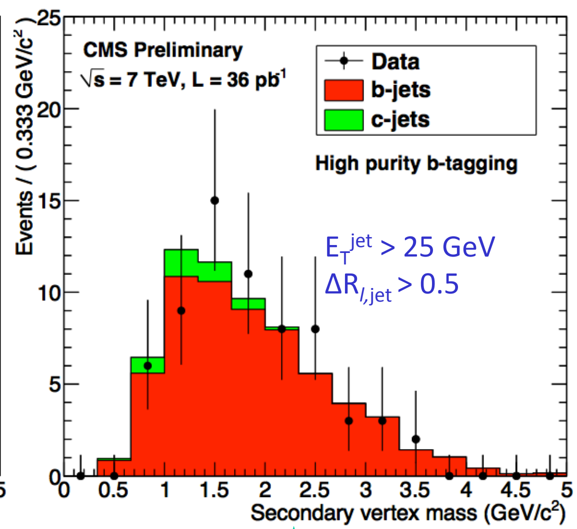


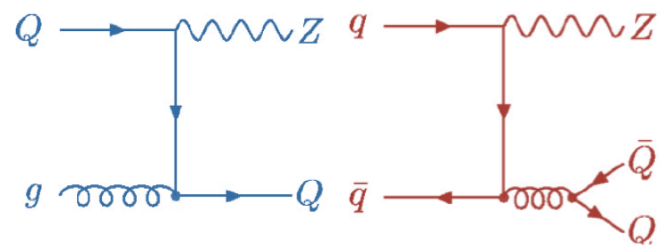
Z+b jets

CMS-PAS-EWK-10-015

- b pair produced from qq, gg scattering, or single b quark at partonic level
- B-tagging purity determined from template fit to the distribution of the invariant mass of tracks associated to the secondary vertex







$$\mathcal{R} = \frac{\sigma(pp \to Z+b+X)}{\sigma(pp \to Z+j+X)}$$

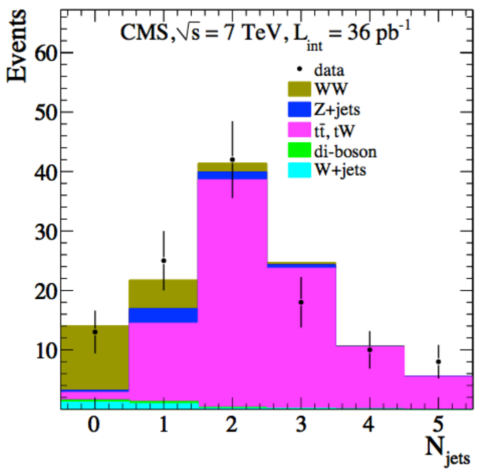
Results are in agreement with theory within uncertainties

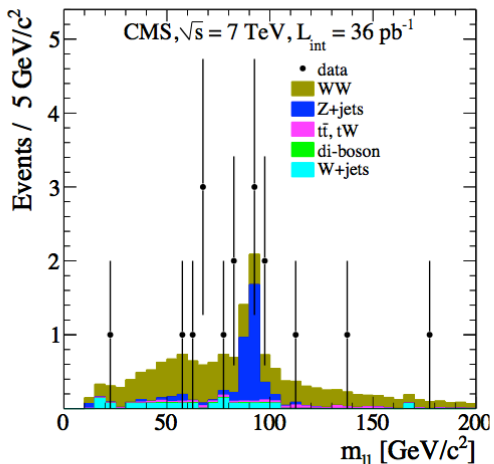
Sample	$\mathcal{R}(Z \to ee)$ (%), $p_T^e > 25$ GeV, $\lvert\eta^e\rvert < 2.5$	$\mathcal{R}(Z \to \mu\mu)$ (%), $p_T^\mu > 20$ GeV, $\lvert\eta^\mu\rvert < 2.1$
Data HE	$4.3 \pm 0.6(stat) \pm 1.1(syst)$	$5.1 \pm 0.6(stat) \pm 1.3(syst)$
Data HP	$5.4 \pm 1.0(stat) \pm 1.2(syst)$	$4.6 \pm 0.8(stat) \pm 1.1(syst)$
MADGRAPH	$5.1 \pm 0.2(stat) \pm 0.2(syst) \pm 0.6(theory)$	$5.3 \pm 0.1(stat) \pm 0.2(syst) \pm 0.6(theory)$
MCFM	$4.3 \pm 0.5(theory)$	$4.7 \pm 0.5(theory)$

WW production

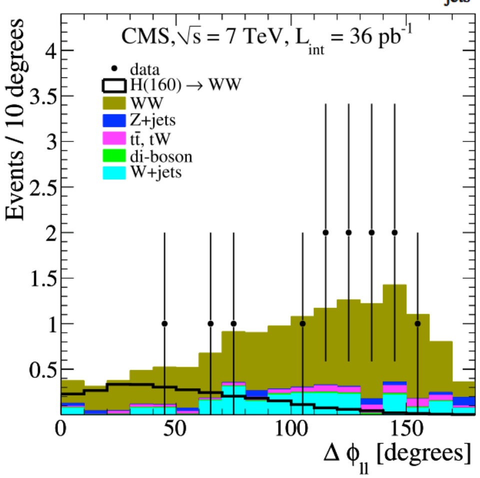
Phys. Lett. B 699 (2011) 25

- Challenging analysis, benchmark for H→WW search
- Limits to anomalous WWγ and WWZ couplings set





- Using W decays to electrons and muons (W→τν signal also included)
- Drell-Yan vetoed (missing E_T required, di-leptons mass far from Z peak)
- Z→ττ suppressed: missing E_T projection transverse to closest leptons > 35 GeV
- Top quark veto using number of jets, also using soft muon and b-tagging veto

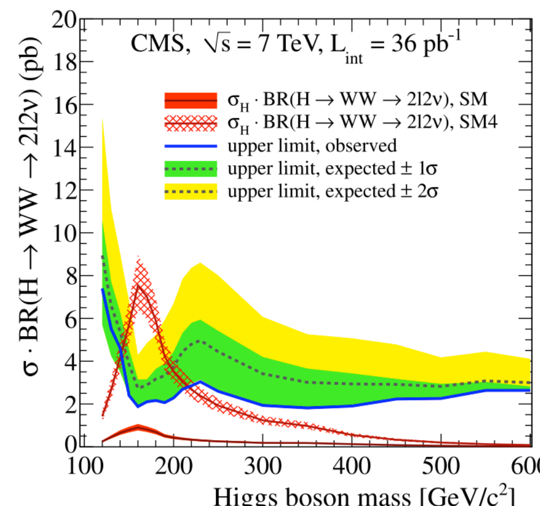


- 13 events selected against a background estimate of 3.3 ± 1.2

σWW = 41.1± 15.3 (stat) ± 5.8 (sys) ± 4.5 (lumi) pb
NLO prediction for SM WW = 43 ± 2 pb

$$\frac{\sigma_{WW}}{\sigma_W} = (4.46 \pm 1.66 \pm 0.64) \cdot 10^{-4}$$

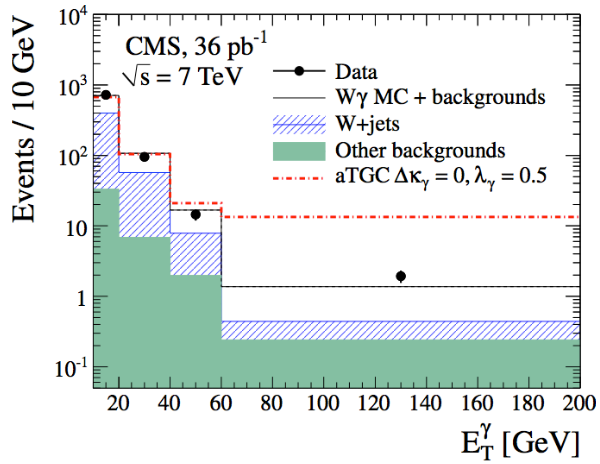
- Search for H→WW and limits to Higgs production with a fourth generation

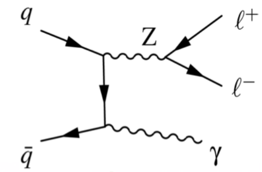


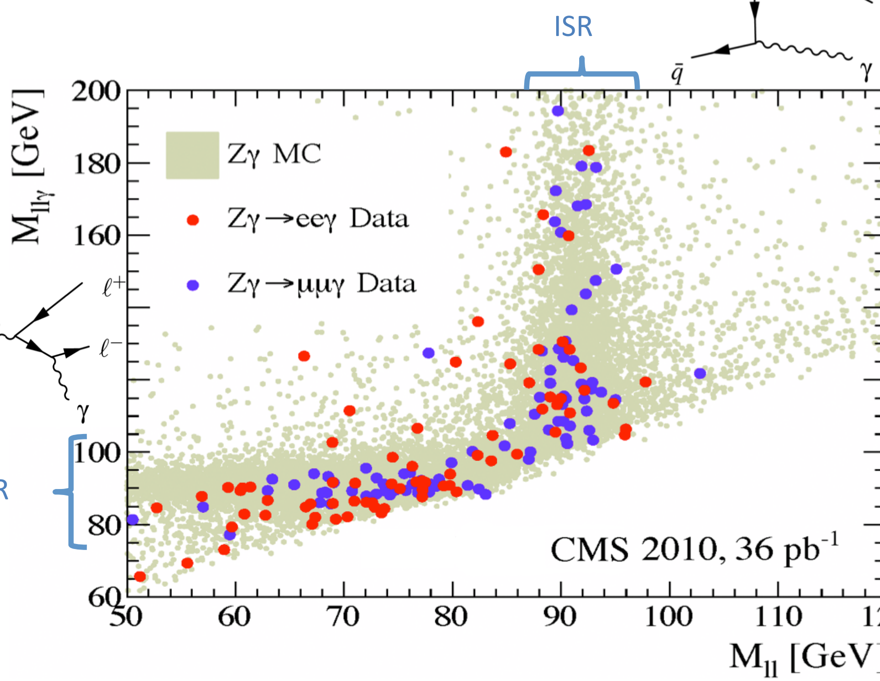
W, Z + γ

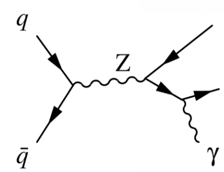
CMS-PAS-EWK-10-008
arXiv:1105.2758

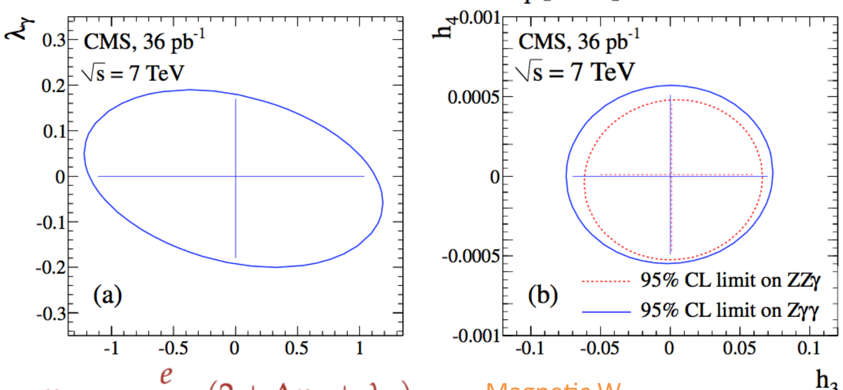
- Final state common to new physics searches, probes triple gauge coupling
- Fake photon estimate is a key task, performed with data-driven methods











$$\sigma(pp \to W\gamma + X) \times \mathcal{B}(W \to \ell\nu) = 56.3 \pm 5.0(\text{stat.}) \pm 5.0(\text{syst.}) \pm 2.3(\text{lumi.})\ \text{pb}$$
$$\sigma(pp \to Z\gamma + X) \times \mathcal{B}(Z \to \ell\ell) = 9.4 \pm 1.0(\text{stat.}) \pm 0.6(\text{syst.}) \pm 0.4(\text{lumi.})\ \text{pb}$$

$E_T^\gamma > 10$ GeV, $\Delta R(\gamma,\ell) > 0.7$

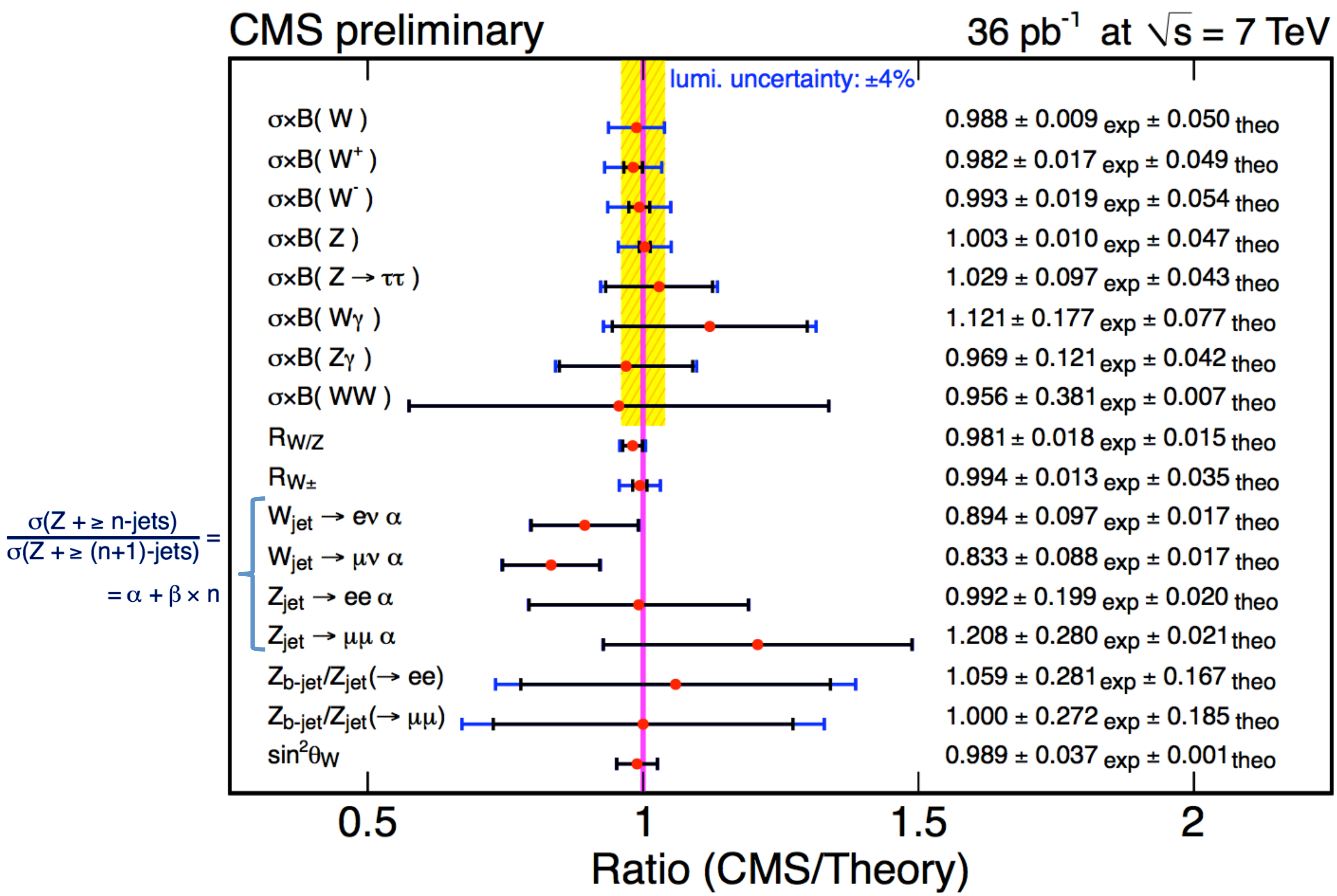
$$\mu_W = \frac{e}{2M_W}(2 + \Delta\kappa_\gamma + \lambda_\gamma)$$

$$Q_W = -\frac{e}{M_W^2}(1 + \Delta\kappa_\gamma - \lambda_\gamma)$$

Magnetic W dipole mom.
Electric W quadrupole mom.

The smallest LHC cross section measured so far!

Summary of CMS EW results



Conclusions

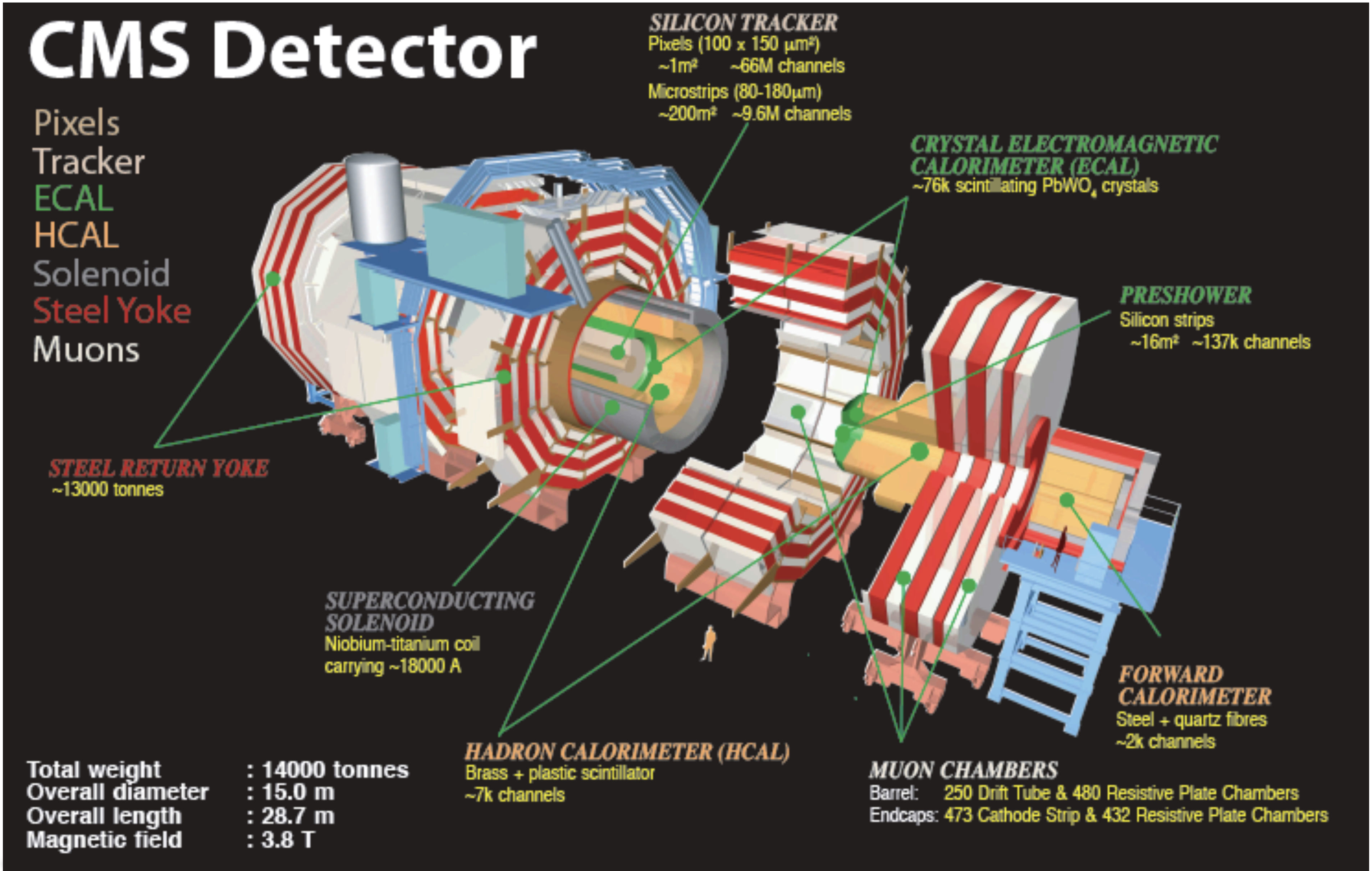
- The LHC Higgs era is upon us
  - Machine is performing spectacularly, and so are ATLAS and CMS
- CMS published lots of papers on the Standard Model EWK searches
  - Already a very good program with 36 pb^{-1} of data collected in 2010.
  - you can imagine what we can do with 0.5 fb
    - Starting probing the Tera scale
    - Both experiments in discovery mode
- We're continuing precision EWK physics and we are ready to start Higgs and new Physics search@LHC

Stay tuned: 2011/12 will be a great biennium for HEP!!!

check here for CMS results:
-- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

BACK-UP

CMS detector



W, Z + n jets

- Berends-Giele scaling:

$$\frac{\sigma(Z + \geq n\text{-jets})}{\sigma(Z + \geq (n+1)\text{-jets})} = \alpha + \beta \times n$$

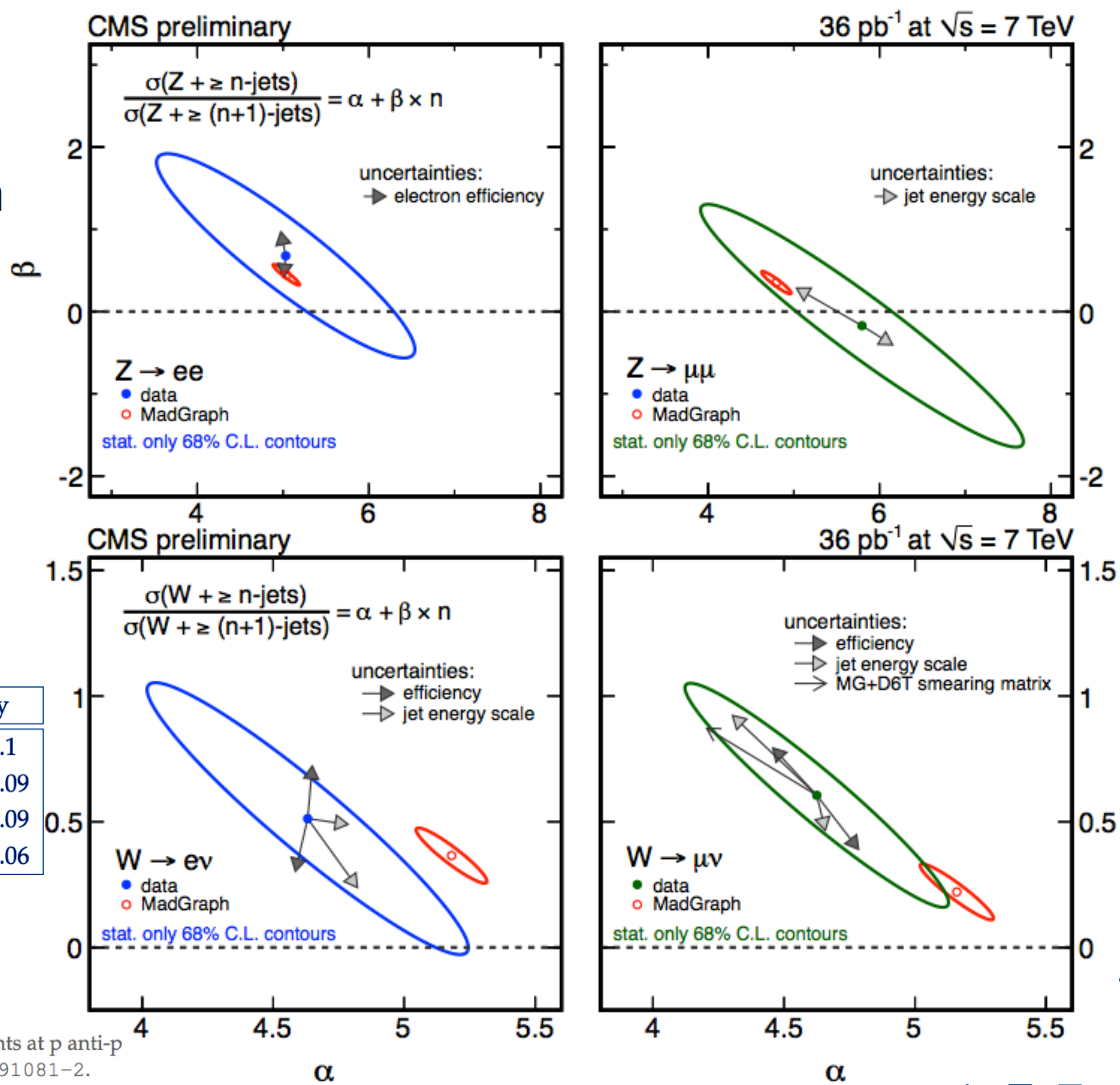
- Expected ~ constant with n

electrons

		data	stat	JES	$\epsilon(\ell)$	Theory
Z	α	5.0	±1.0	$^{+0.1}_{-0.0}$	$^{+0.00}_{-0.06}$	5.04 ± 0.10
	β	0.7	±0.8	$^{+0.08}_{-0.04}$	$^{+0.3}_{-0.6}$	0.45 ± 0.08
W	α	4.6	±0.4	$^{+0.2}_{-0.0}$	$^{-0.05}_{+0.02}$	5.18 ± 0.09
	β	0.5	±0.4	$^{+0.0}_{-0.3}$	±0.2	0.36 ± 0.07

muons

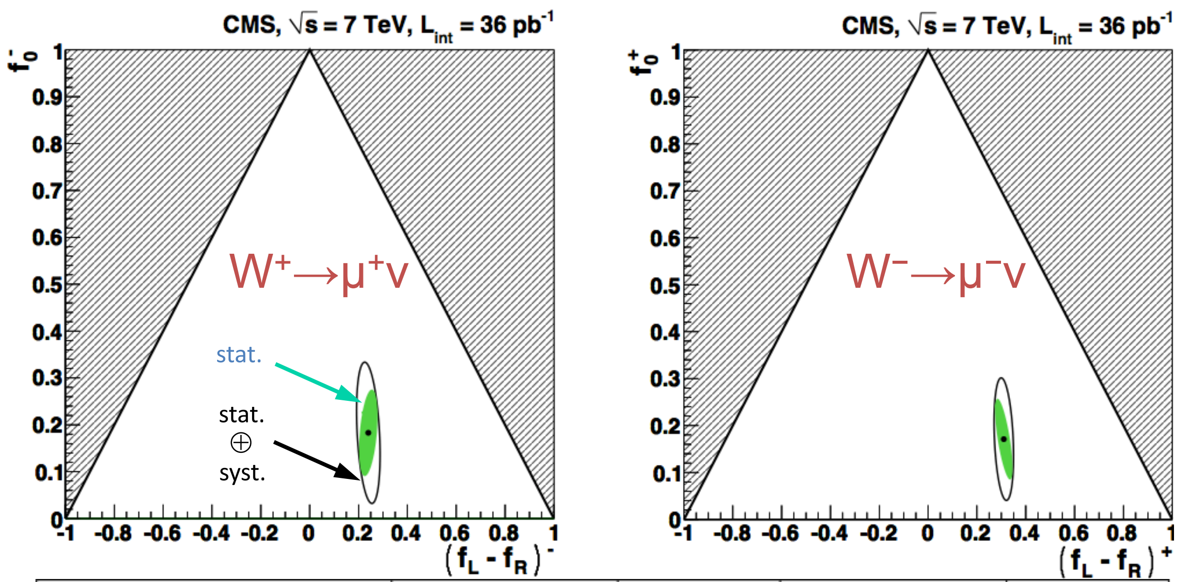
		data	stat	JES MC	$\epsilon(\ell)$	D6T tune	Theory
Z	α	5.8	$\pm$ 1.2	±0.6	±0.1	+0.3	4.8 ± 0.1
	β	-0.2	$\pm$ 1.0	±0.3	±0.1	-0.0	0.35 ± 0.09
W	α	4.3	±0.3	±0.2	±0.2	-0.4	5.16 ± 0.09
	β	0.7	±0.3	±0.2	±0.3	+0.3	0.22 ± 0.06



F. A. Berends, W. T. Giele, H. Kuijf et al., "Multi-jet production in W, Z events at p anti-p colliders", *Phys. Lett.* **B224** (1989) 237. doi:10.1016/0370-2693(89)91081-2.

W polarization (cont.)

- More precise measurement with muons
  - smaller background: ~250 / 14000



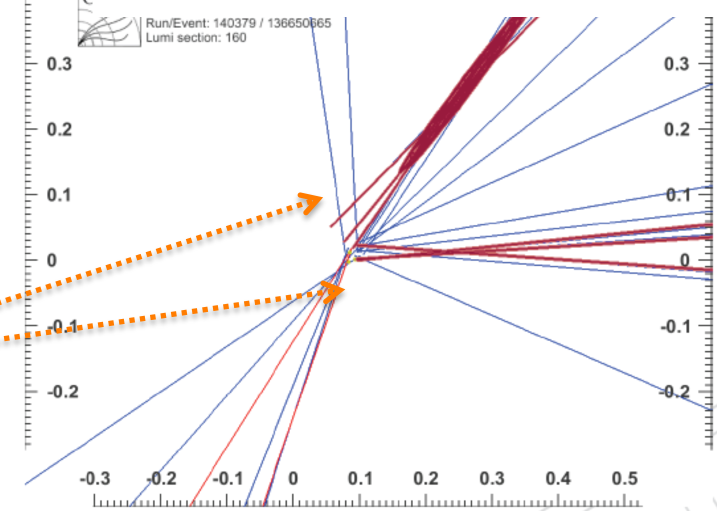
Uncertainty	$(f_L - f_R)^-$	f_0^-	$(f_L - f_R)^+$	f_0^+
	Muon channel			
Recoil energy scale	±0.029	±0.123	±0.011	±0.092
Recoil resolution	±0.012	±0.006	±0.012	±0.004
Muon scale	±0.002	±0.007	±0.004	±0.008
Total uncertainty	±0.031	±0.123	±0.017	±0.099

Remaining objects: MET & btag

- neutrino momentum estimated from energy imbalance in the transverse plane ➔ MET
  - Main rejection of QCD di-jets and Drell-Yan (no real MET)
  - Necessary for M_W measurement (definition of $M_T(W)$) and search for new physics
  - Three methods exploit increasing number of informations:
    - pure calorimetric, track-corrected, full particle flow

- B hadrons have hard fragmentation, long lifetimes (~1ps) and high mass
  - Presence of a displaced vertex

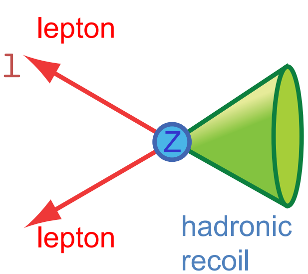
First CMS $t\bar{t}$ candidate

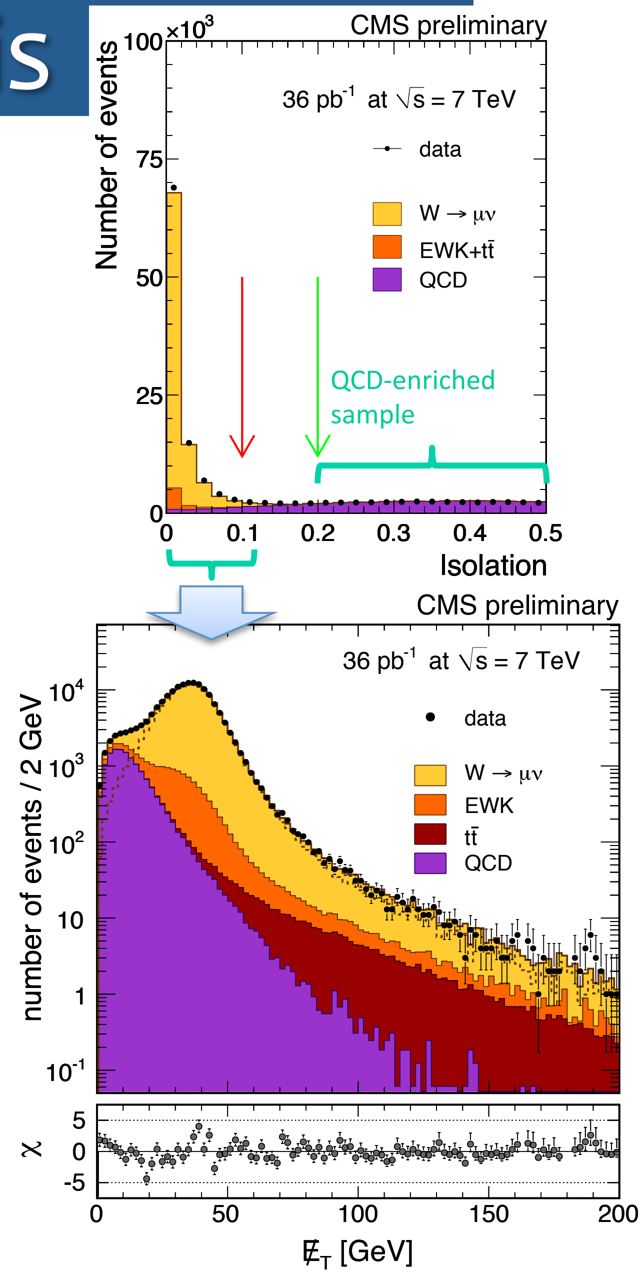


Backup

W→lν analysis

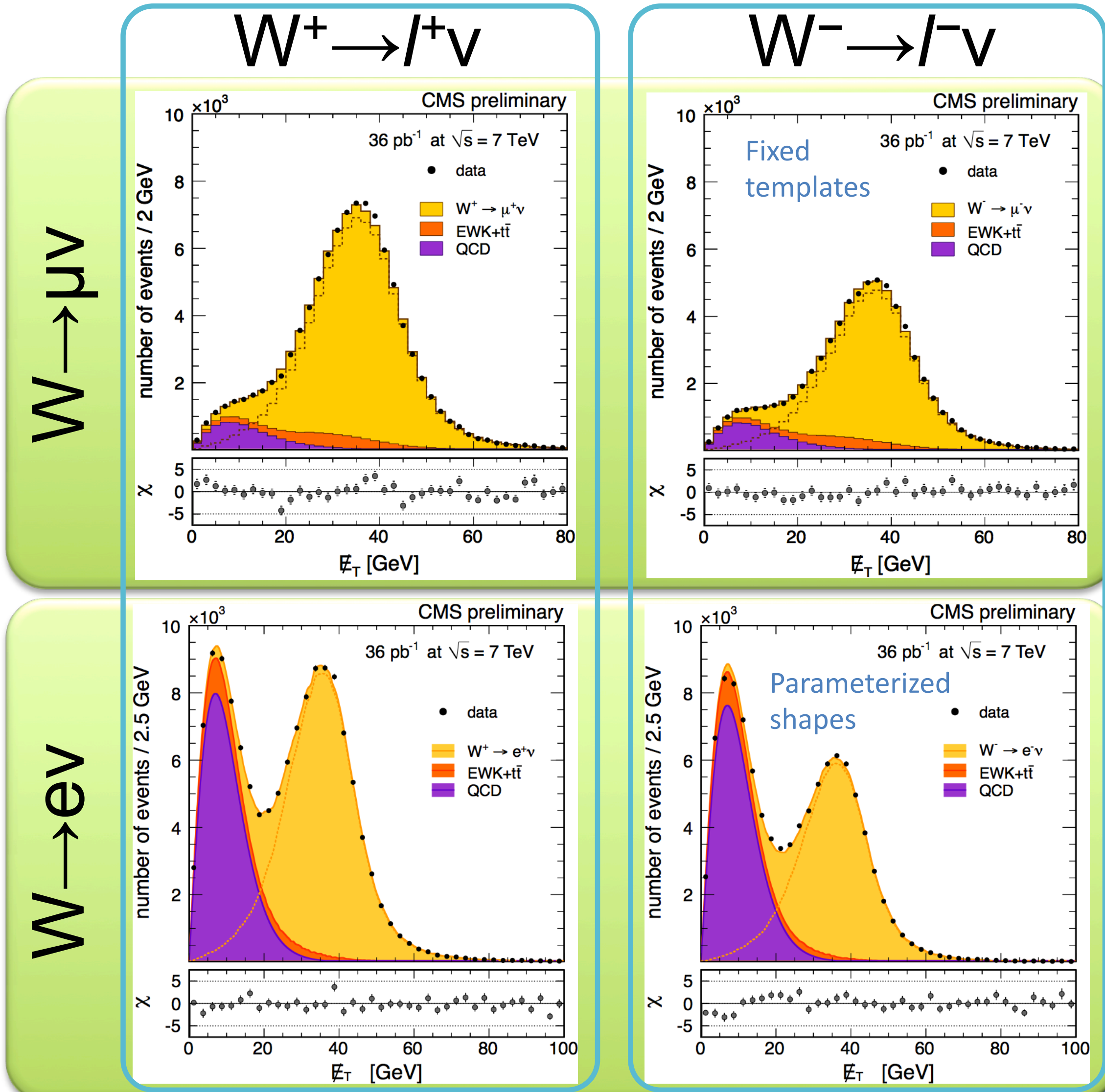
- W event selection is based on:
  - Loose single-lepton trigger
  - Lepton identification cuts, well understood
  - Lepton p_T>25 GeV, η within trigger fiducial volume
  - Isolation: tracker and calorimeter activity within $\Delta R=\sqrt{(\Delta\phi^2+\Delta\eta^2)}<0.3$ normalized to lepton p_T
  - Di-lepton veto (Drell-Yan)
- Signal extraction
  - W yield from fit to missing E_T distribution
    - Parameterized shapes or fixed binned templates
  - QCD shape determined from data inverting lepton id / isolation selections
  - Lepton efficiencies from Z tag and probe as a function of p_T and η
  - Missing E_T studied using Z recoil
  - Momentum scale and resolution studied from $Z\rightarrow l^+l^-$ data





W^+ and W^- production

- Fit separately positive and negative lepton missing E_T spectra to extract $\sigma(W^+)$ and $\sigma(W^-)$
- Alternatively, fit the total yield and ratio to extract $\sigma(W)$ and $\sigma(W^+)/\sigma(W^-)$
- In the ratio several uncertainties cancel



CMS-PAS-EWK-10-005

Systematic uncertainties

- Data-driven methods to determine efficiencies, background and signal shapes allow to reduce experimental uncertainties

$$\sigma \times \mathcal{B} = \frac{N}{A \times \varepsilon \times \mathcal{L}}$$

$$\rho = \frac{\varepsilon_{\mathrm{data}}}{\varepsilon_{\mathrm{sim}}}$$

Uncert. propagated from Z T&P to W p_T/η spectrum

Lumi. uncert.: 4%

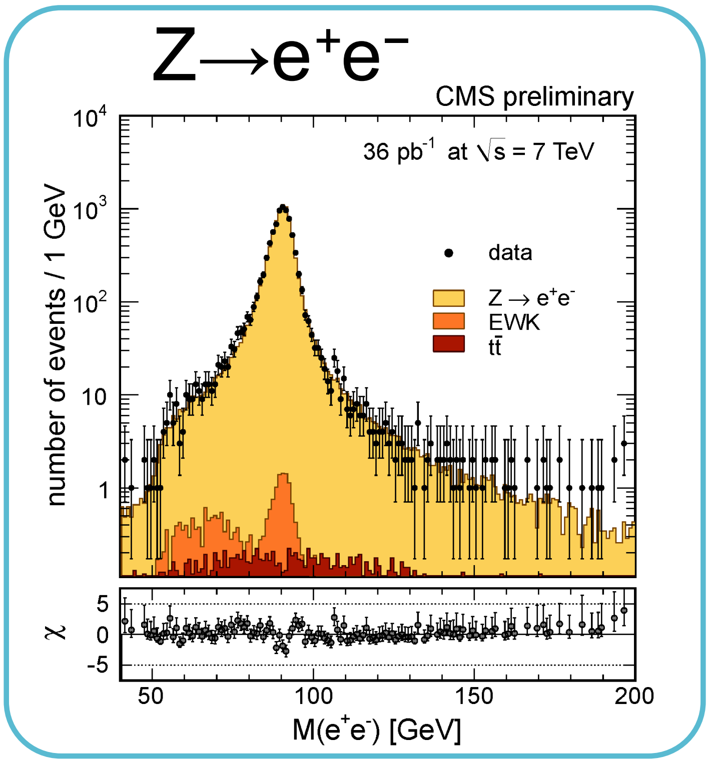
CMS-PAS-EWK-10-004

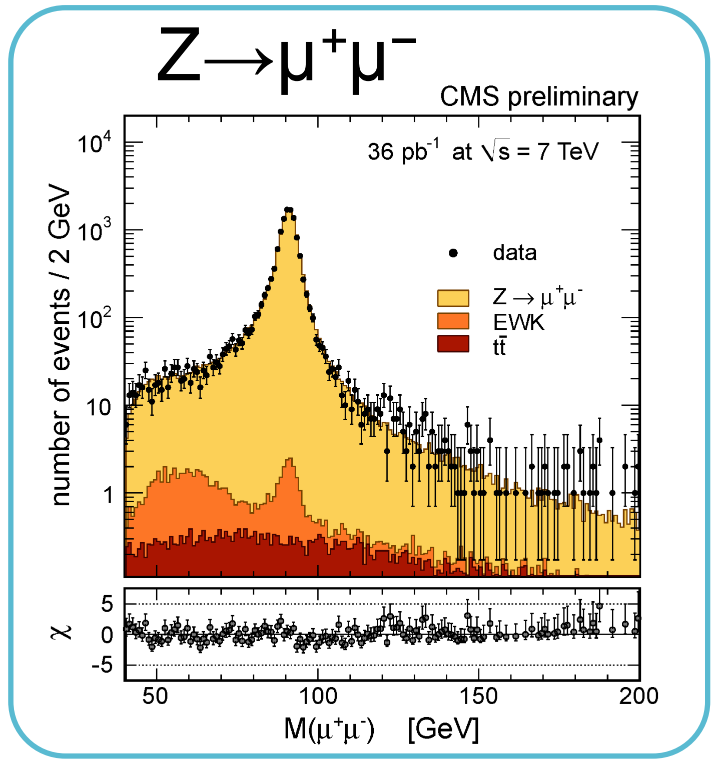
- Theory uncertainties affect acceptance determination:
  - PDF (PDF4LHC: CTEQ, MSTW, NNPDF), Initial-state radiation modeling, higher order effects (ResBos), EWK corrections, Final-state radiation (Horace),

Source	$W \to e\nu$	$W \to \mu\nu$	$Z \to e^+e^-$	$Z \to \mu^+\mu^-$
Lepton reconstruction & identification	1.3	0.9	1.8	n/a
Trigger pre-firing	n/a	0.5	n/a	0.5
Momentum scale & resolution	0.5	0.22	0.12	0.35
$\not\!\!E_T$ scale & resolution	0.3	0.2	n/a	n/a
Background subtraction / modeling	0.35	0.4	0.14	0.28
Total experimental	1.5	1.1	1.8	0.7
PDF uncertainty for acceptance	0.6	0.7	0.9	1.2
Other theoretical uncertainties	0.7	0.8	1.4	1.6
Total theoretical	0.9	1.1	1.7	2.0
Total	1.7	1.6	2.5	2.1

Z→*ll* analysis

- Isolated di-lepton pairs with p_T>20 (μ), 25 GeV (e) and η within trigger fiducial volume. Mass range: 60<m_{ll}<120 GeV
- Yield fitted simultaneously with efficiency using different di-lepton categories (μμ)
- Cut and count analysis using tag & probe efficiencies (ee)



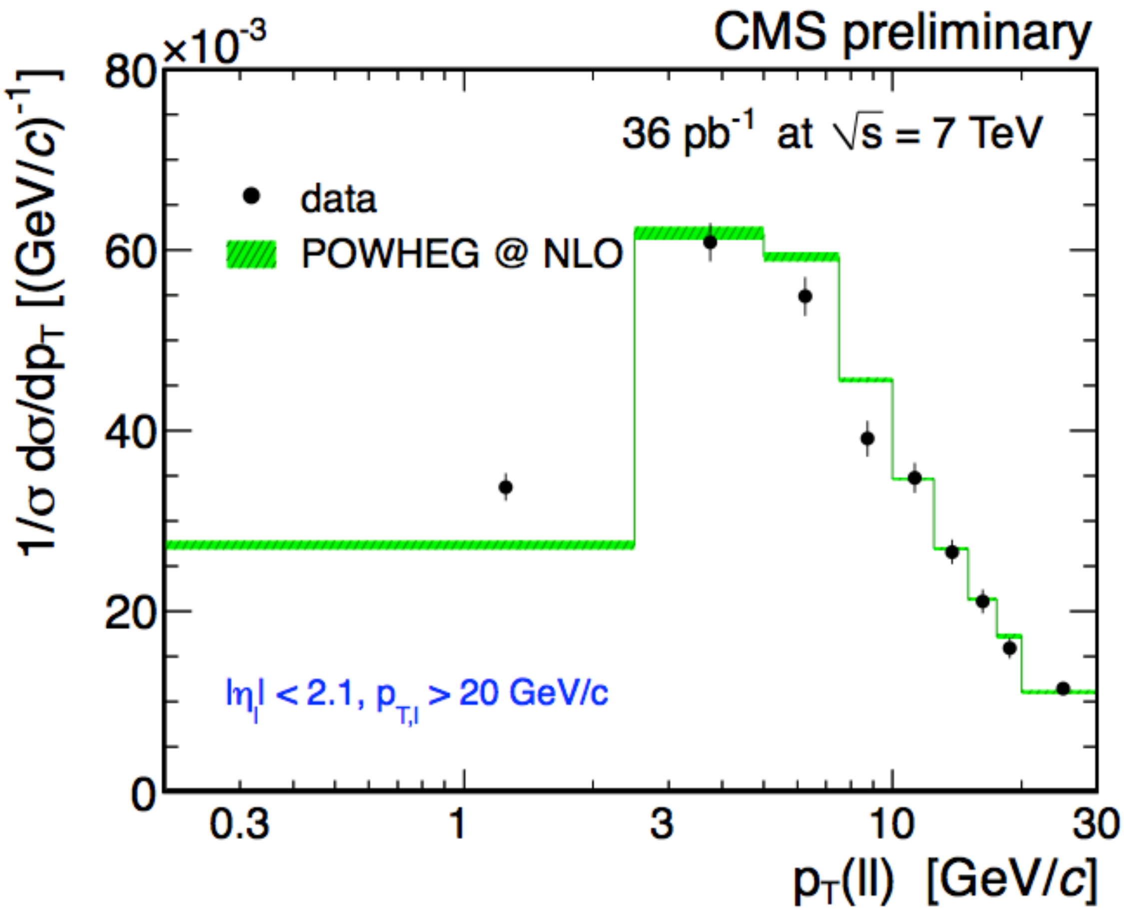


W charge asymmetry systematics

$p_T^\ell > 25\,\mathrm{GeV}/c$												
	Electron Channel						Muon Channel					
$|\eta|$ bin	[0.0, 0.4]	[0.4, 0.8]	[0.8, 1.2]	[1.2, 1.4]	[1.6, 2.0]	[2.0, 2.4]	[0.0, 0.4]	[0.4, 0.8]	[0.8, 1.2]	[1.2, 1.5]	[1.5, 1.8]	[1.8, 2.1]
Charge Misident.	0.02	0.03	0.03	0.08	0.09	0.10	0	0	0	0	0	0
Eff. Ratio	0.70	0.70	0.70	0.70	0.70	0.70	0.59	0.39	0.92	0.72	0.81	1.17
e/μ Scale	0.11	0.09	0.19	0.47	0.40	0.45	0.50	0.48	0.50	0.48	0.50	0.42
Sig. & Bkg. Estim.	0.16	0.19	0.26	0.33	0.25	0.25	0.23	0.29	0.34	0.40	0.53	0.58
Total	0.73	0.73	0.77	0.90	0.85	0.87	0.80	0.68	1.10	0.95	1.08	1.37
$p_T^\ell > 30\,\mathrm{GeV}/c$												
	Electron Channel						Muon Channel					
$|\eta|$ bin	[0.0, 0.4]	[0.4, 0.8]	[0.8, 1.2]	[1.2, 1.4]	[1.6, 2.0]	[2.0, 2.4]	[0.0, 0.4]	[0.4, 0.8]	[0.8, 1.2]	[1.2, 1.5]	[1.5, 1.8]	[1.8, 2.1]
Charge Misident.	0.02	0.02	0.03	0.07	0.08	0.10	0	0	0	0	0	0
Eff. Ratio	0.70	0.70	0.70	0.70	0.70	0.70	0.59	0.39	0.93	0.72	0.82	1.18
e/μ Scale	0.07	0.17	0.26	0.46	0.53	0.55	0.80	0.78	0.83	0.81	0.73	0.77
Sig. & Bkg. Estim.	0.16	0.19	0.26	0.33	0.25	0.25	0.20	0.20	0.27	0.35	0.51	0.56
Total	0.72	0.75	0.79	0.91	0.92	0.93	1.01	0.90	1.27	1.14	1.21	1.52

Systematic uncertainties (%)

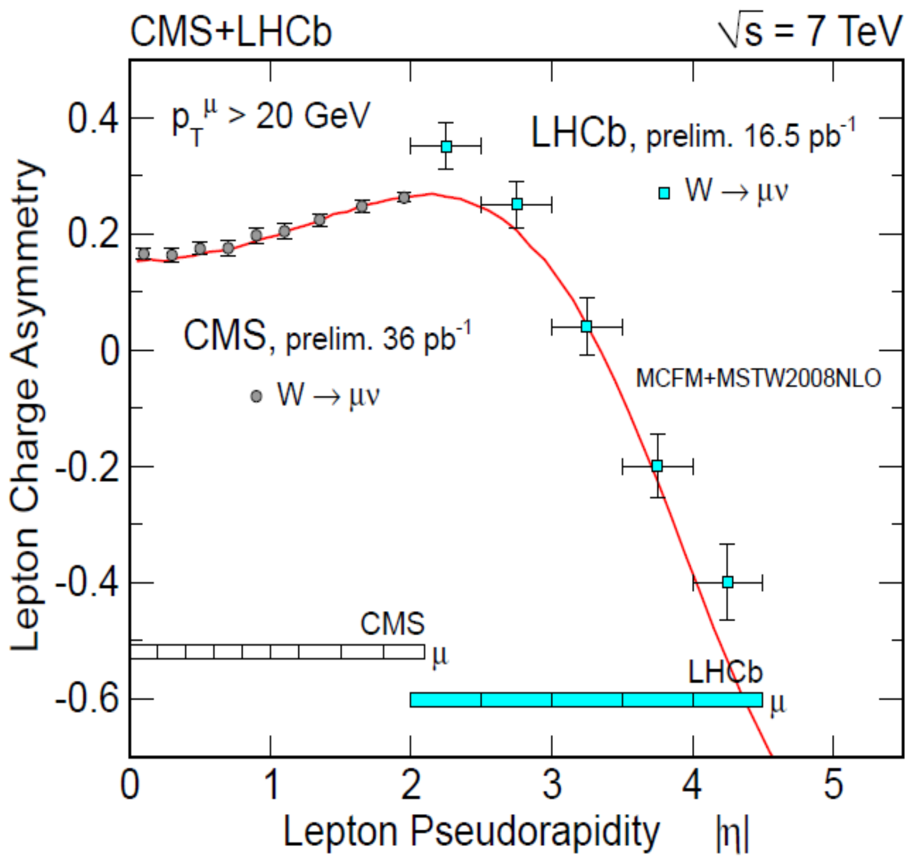
Z differential cross section



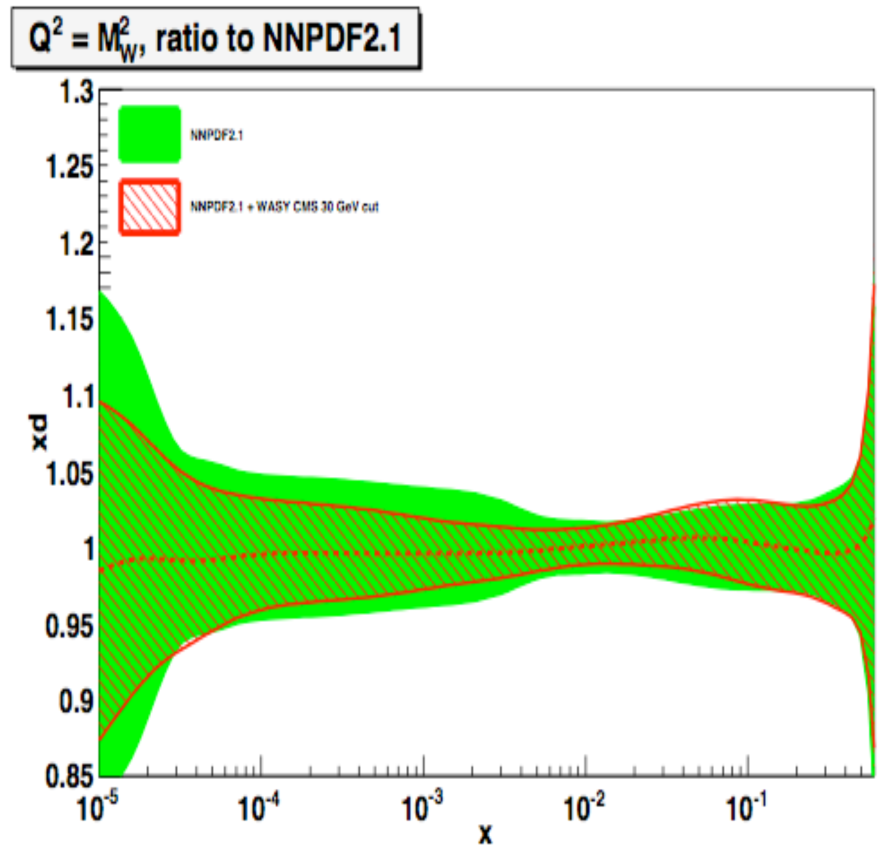
Disagreement w.r.t. POWHEG is significant in some bins

Non-perturbative effects dominate at low p_T, and are part of the 'tune' of the underlying model

CMS ad LHCb measurements



CMS complementary w.r.t. LHCb

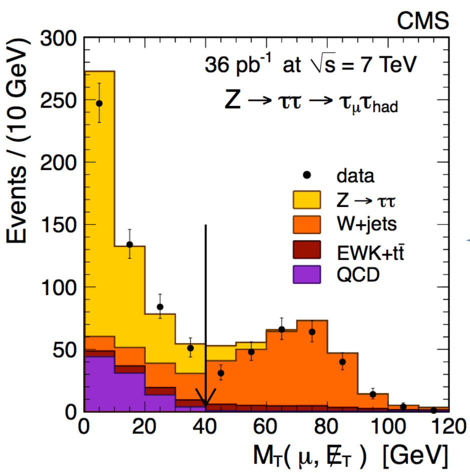


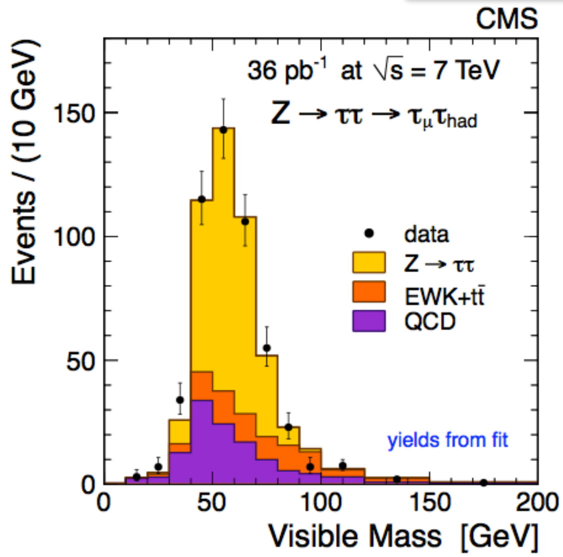
CMS results already improve d,u,d,u,s quark PDFs by >40% in the range $10^{-3} < x < 10^{-2}$!!!

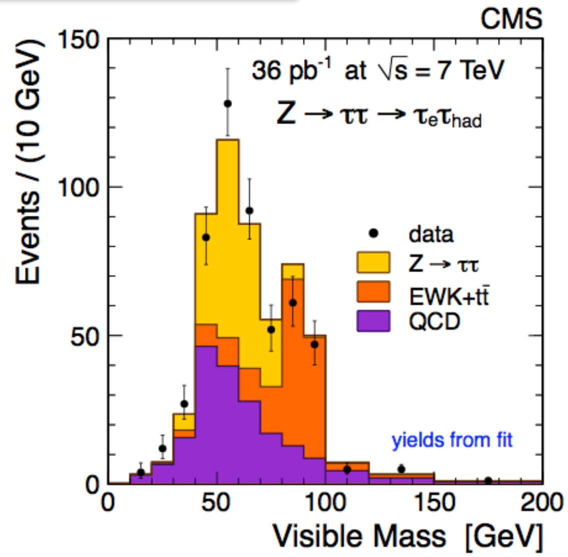
$Z \rightarrow \tau\tau$

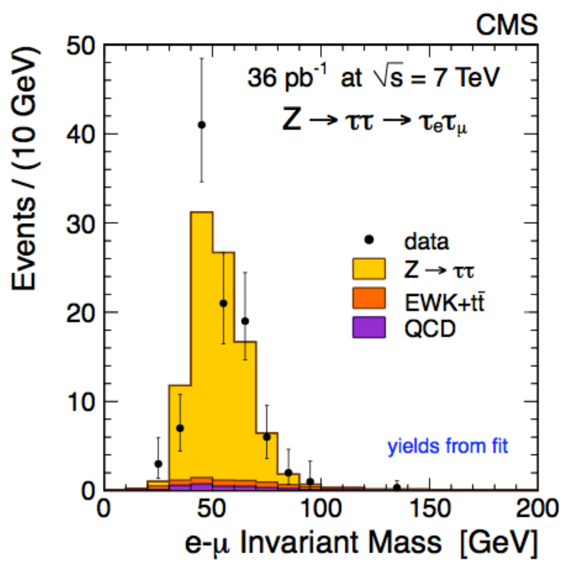
CMS-PAS-EWK-10-013
arXiv:1104.1617

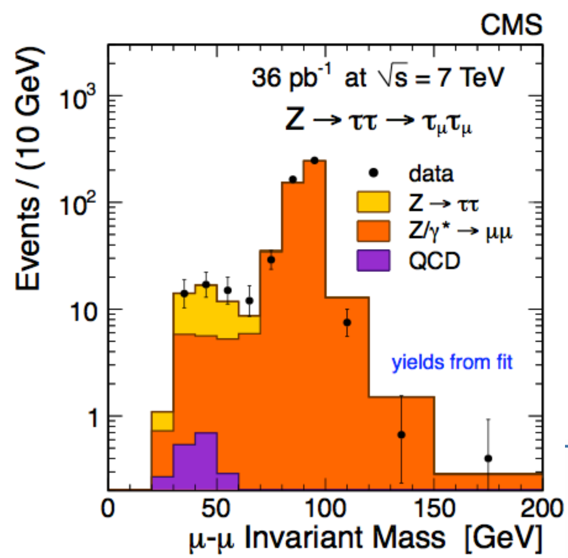
- Benchmark for searches using taus ($H^+ \rightarrow \tau\nu$, $H \rightarrow \tau\tau$, …)
- Particle Flow: combine tracker and calorimeter measurements to determine particle candidates
- $p_T(l)$>15 GeV, p_T(had)>20 GeV
- M_T(l, miss. E_T)<40 GeV (lep+had)
- Missing E_T < 50 GeV(lep+lep) to suppress W+jets
- Main systematic: tau id eff. in hadronic mode (23%), determined from data







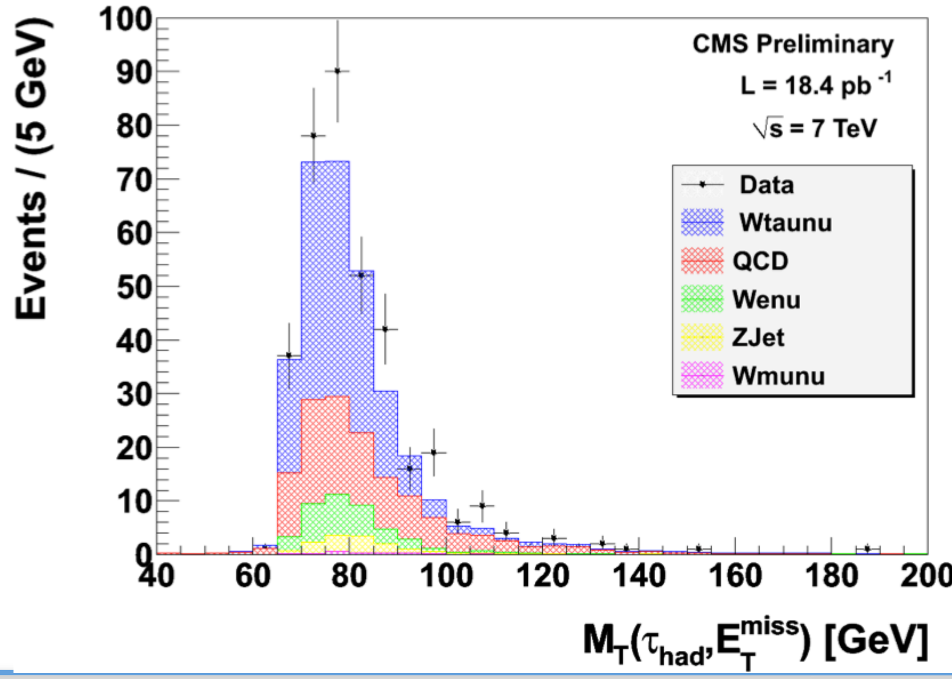




W→τν

CMS-PAS-EWK-11-002

- Events triggered a single tau plus missing E_T
  - challenging, especially as luminosity increases
  - Trigger cuts: p_T (τ) > 20 GeV, p_T (track)>15 GeV, missing E_T >25 GeV
- QCD estimate from control regions
  - p_T(τ) / Σp_T(all jets) cut inversion

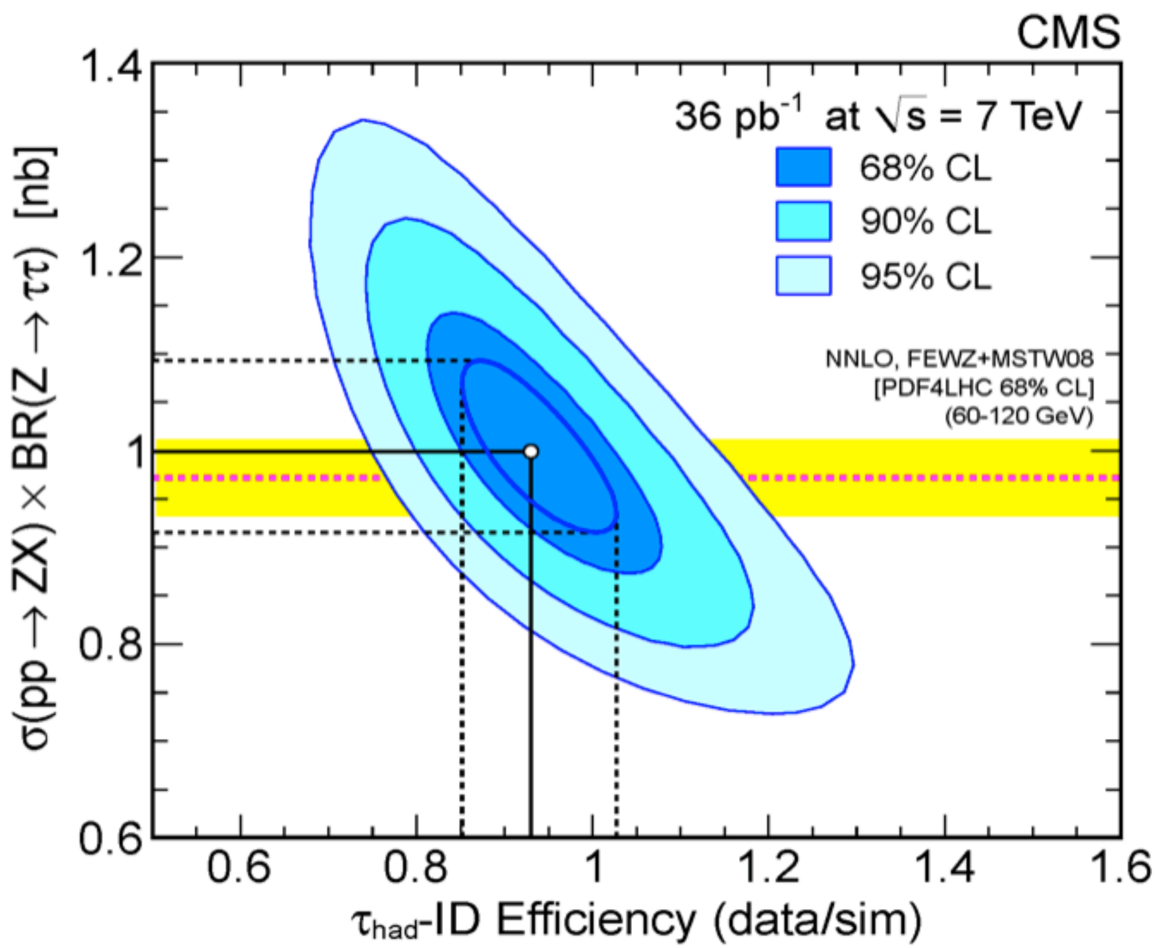


Selection:
- p_T(τ) > 30GeV, tightened as offline cut
- Tau isolated from other particle-flow particles
- p_T(τ) / Σp_T(all jets) > 0.65
- Missing E_T > 35 GeV

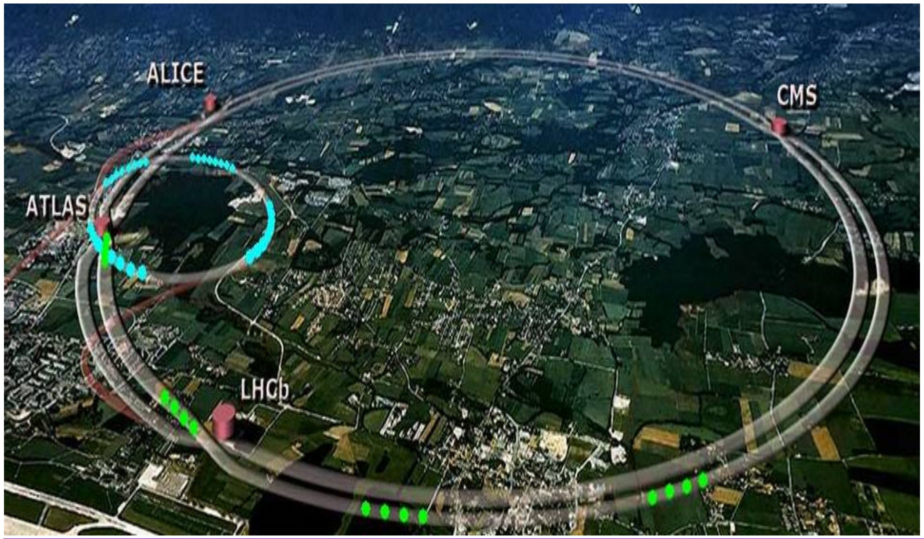
Process	Events
W→τν (sim.)	174 ± 3
EWK (sim.)	46 ± 2
QCD (sideband)	109 ± 6
Data	372

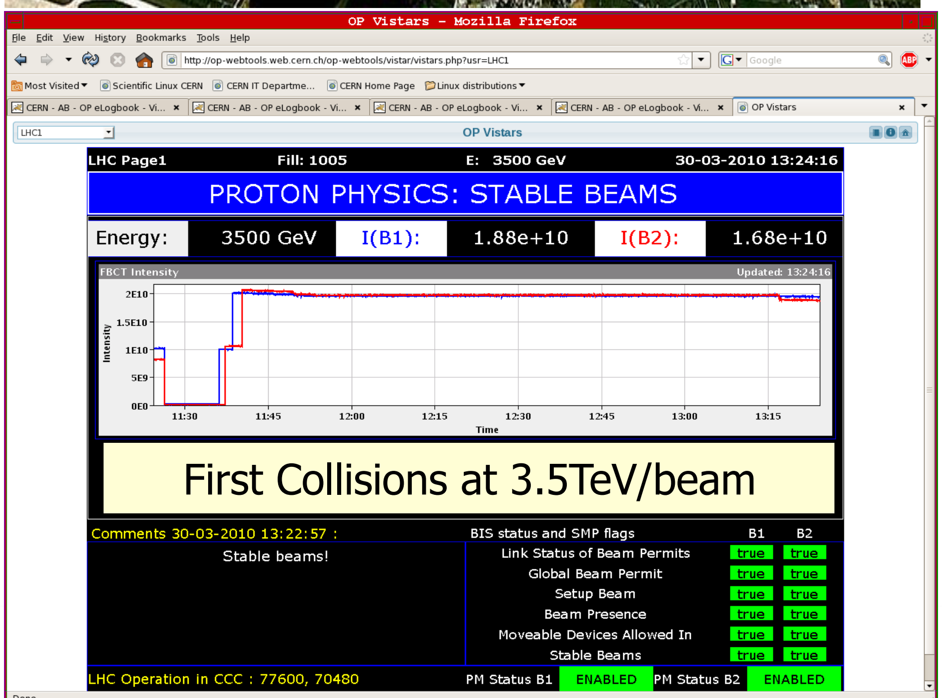
Z→ττ

- Simultaneous fit of tau id and cross section



The LHC machine





Circumference (km)	26.7
Number of superconducting Dipoles	1232
Length of Dipole (m)	14.3
Dipole Field Strength (Tesla)	8.4
Operating Temperature (K)	1.9
Current in dipole sc coils (A)	13000
Beam Intensity (A)	0.5
Beam Stored Energy (MJoules)	362
Number of particles per bunch	1.15×10^{11}
Number of bunches per beam	2808
Crossing angle (mrad)	285
Bunch length (cm)	7.55
Norm transverse emittance (mm rad)	3.75
Beta function at IP 1,2,5,8 (m)	0.55,10,0.55,10

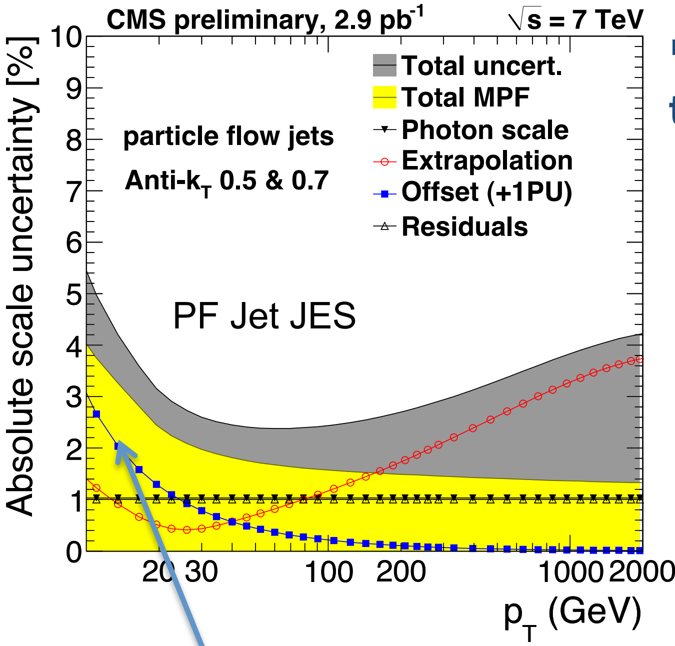
$$L = \frac{N_b^2 n_b f_{rev} \gamma_r}{4\pi \varepsilon_n \beta *} F$$

N_b = number of proton per bunch
n_b = number of bunches

f_{rev} = rotation frequency (~ 11Hz)
F = crossing angle factor

Rms transverse beam size $= \sqrt{\varepsilon\ \beta / \gamma}$
ε_n = renorm. transverse emittance
$\beta *$ = optics at beam crossing (m)
γ_r = relativistic factor

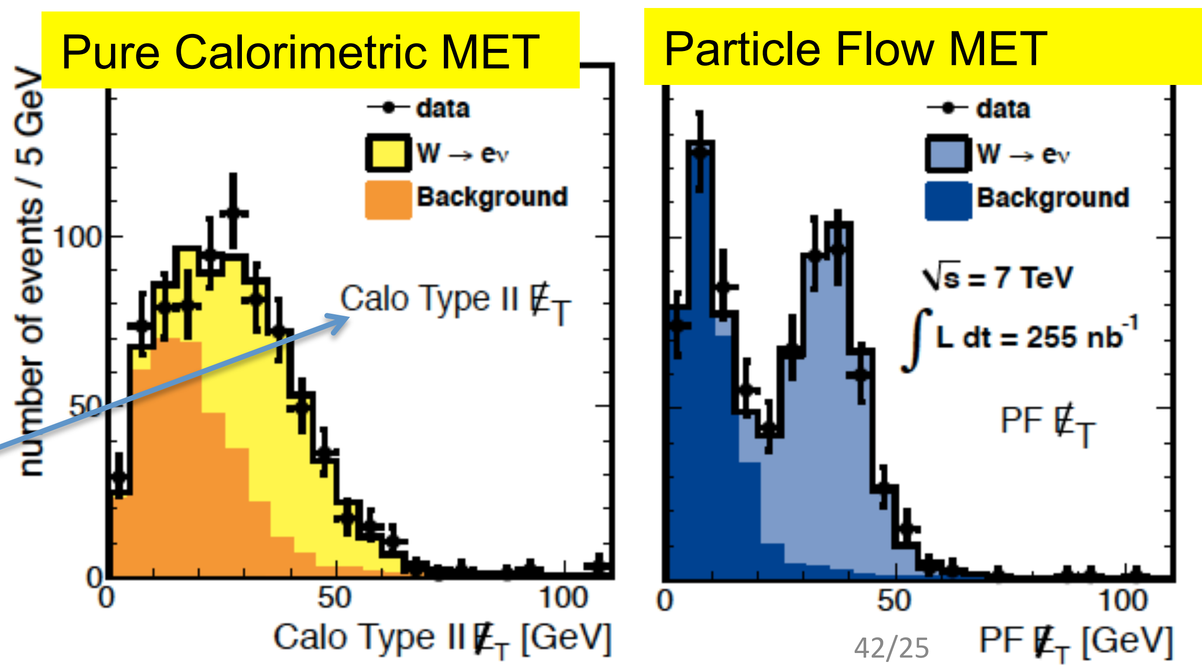
Jets and MET



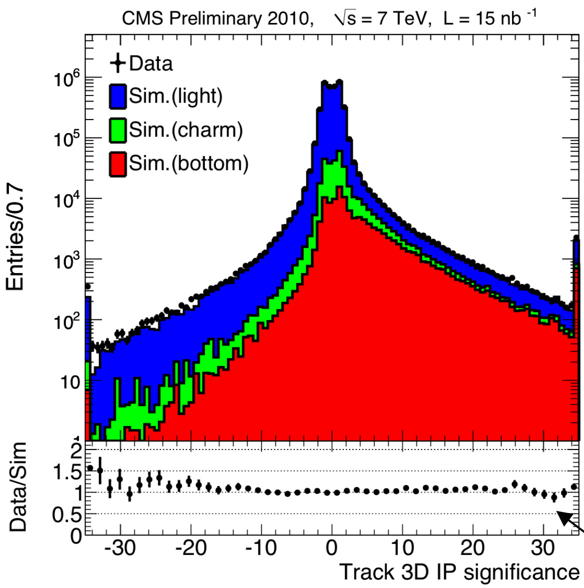
- Jet and Missing ET reconstruction uses **Particle Flow (PF) technique:**
  - All tracks/energy deposits sorted into charged/ neutral hadron, electron, photon, or muon candidates
  - Resulting set of corrected particles input to jet clustering, MET determination, HT, MT, etc.
  - Significant improvement over traditional "CaloJets" for ~low-medium pT jets with tracker coverage

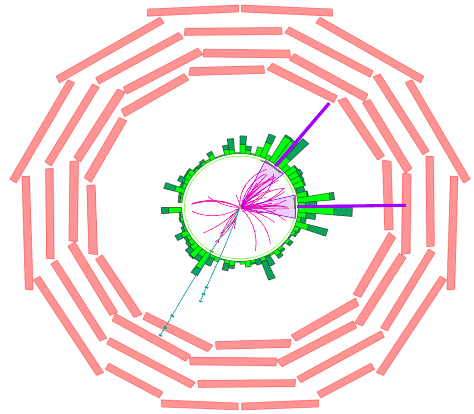
- **Anti-kT clustering with R=0.5 used** everywhere here
  - JES of PF jets known to 3-4%
  - high PU JEC evaluation carried on now

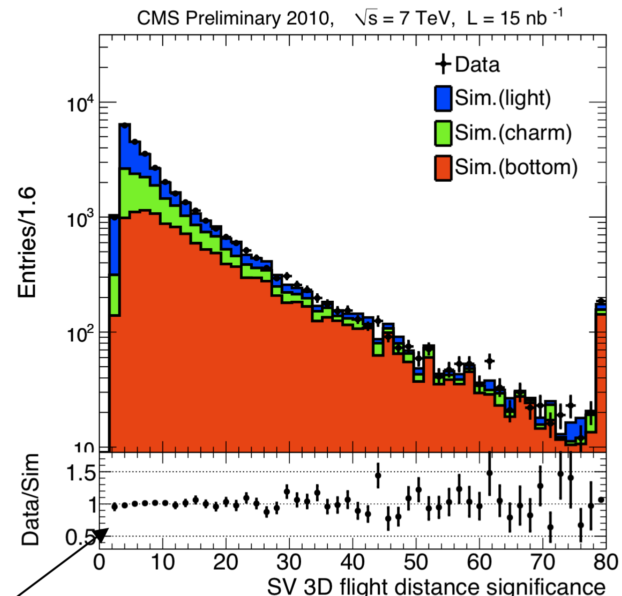
MET response with selected W events



Data-MC comparison for b-tagging observables



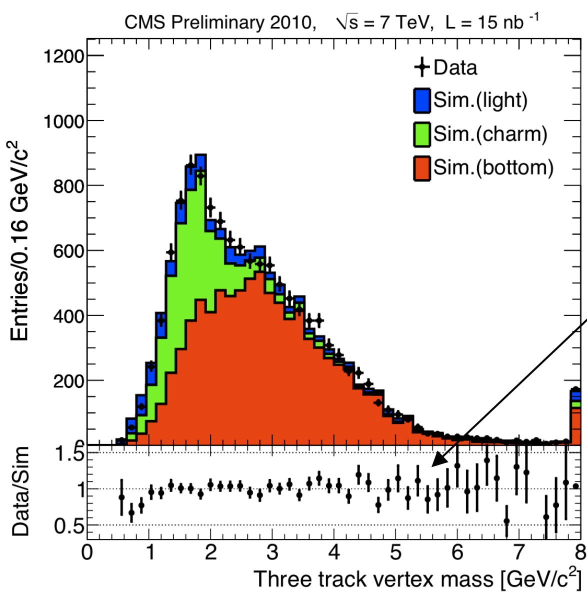


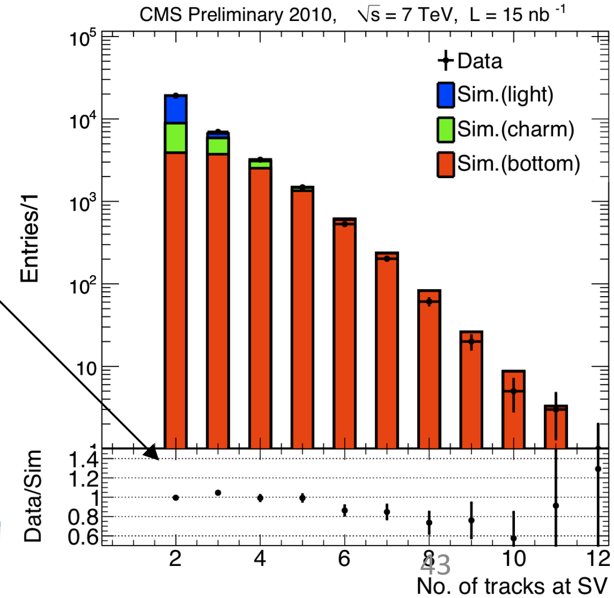


Minimum bias:

DATA/MC ratio is close to 1 for all observables

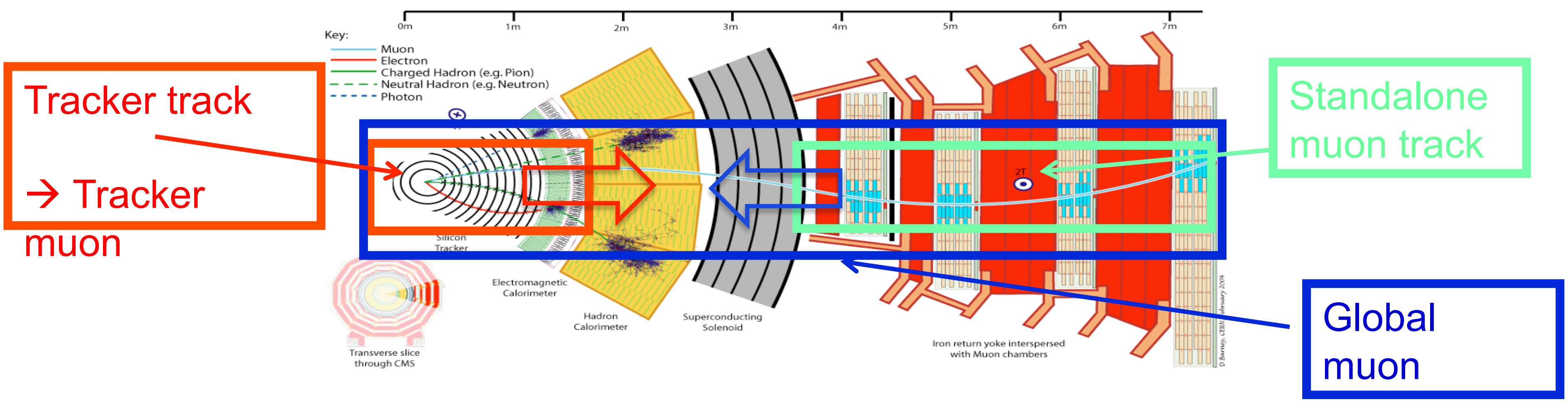
B-tag can be used immediately at least for supporting ckecks!



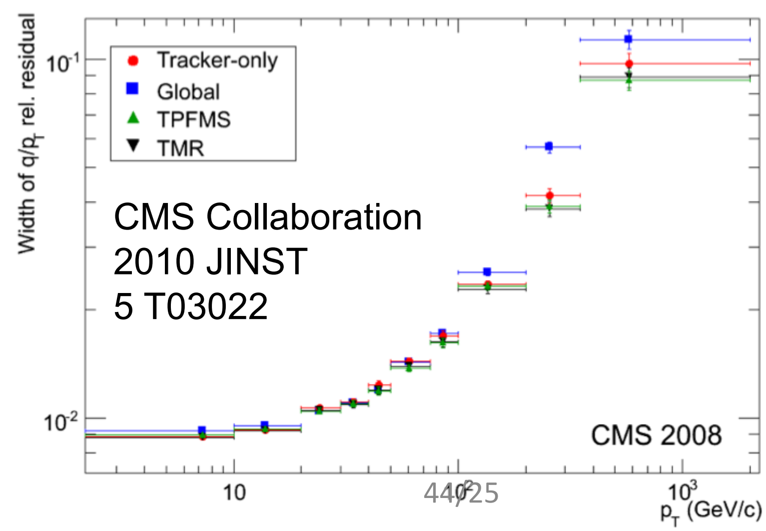


Muon reconstruction

- Three different subsystems to detect muons: Drift Tubes (|η|<1.2), Cathode Strip Chambers (0.9<|η|<2.4) and Resistive Plate Chambers (|η|<1.6)
- two complementary approaches: "global muon" (outside-in) and "tracker" (inside-out)



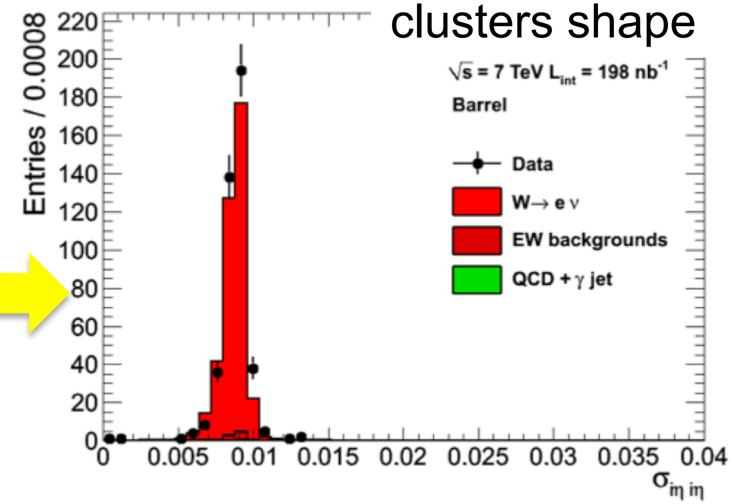
- A similar approach is followed for the trigger:
  - `L1 muon uses only standalone track info`
  - `L2 adds calorimetric inputs`
  - `L3 muon add also tracker hits`
- goals: momentum measurement:
  - 1% for $p_T \approx 100$ GeV, 10% for $p_T \approx 1$ TeV
- cosmic rays runs allowed calibration and alignment at the level expected with o(pb^{-1}) of collisions



Electron reconstruction

- High granular and precise e.m. calorimetry allows:
  - electron energy measurement through dynamic clustering (collection of bremsstrahlung radiation along Φ)
  - electron-jet separation through cluster shape in η
  - track seeding from clean ECAL clusters
- high granular pixel + Si strips tracking system allows:
  - track pattern modeling with "Gaussian Sum Filter"
  - track seeding, complementary to ECAL seeding
  - precise track-ECAL matching

clusters shape



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E cluster / P_{track}