Measurement of W,Z and Top properties with CMS

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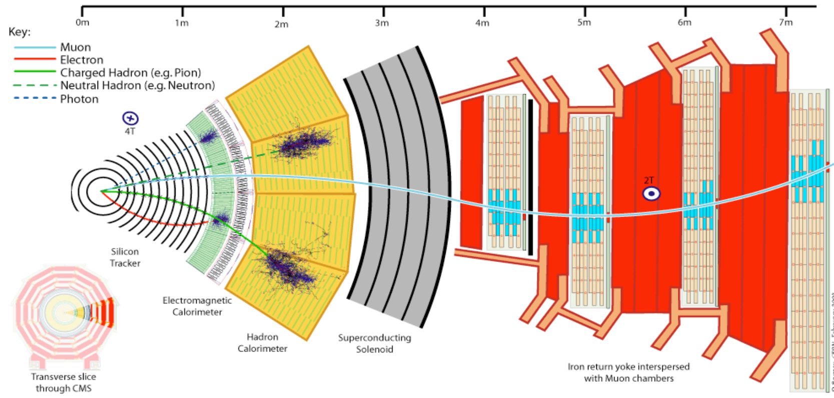
On behalf of CMS experiment

Les Rencontres de Physique de la Vallée d'Aoste,
La Thuile 2011, 3/03/11

Outline

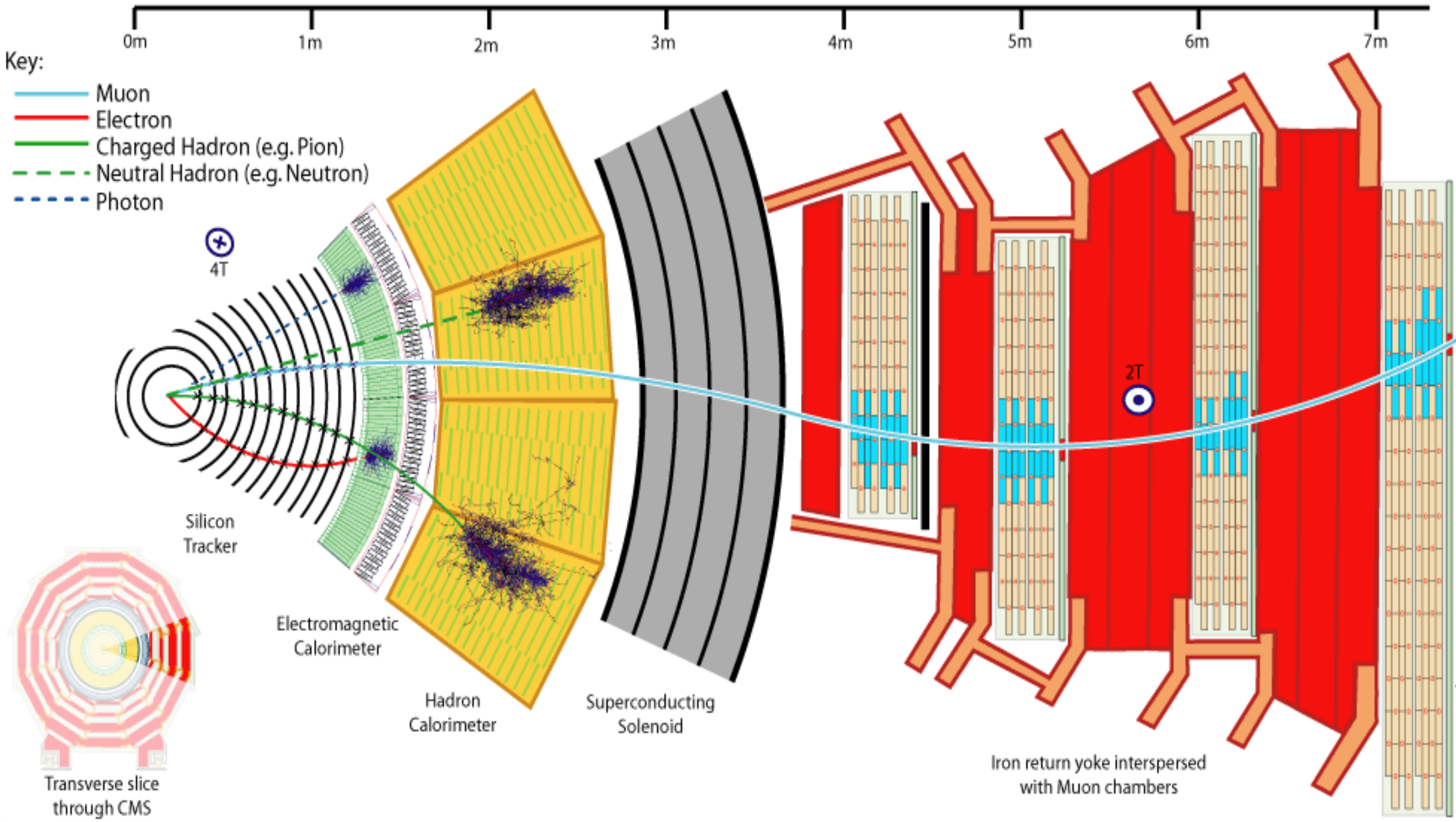
- Muons, electrons, MET, B-tagging in CMS
- W and Z bosons
  - First 7 TeV cross section measurement with ~3pb^{-1}
  - Update plots for ~36pb^{-1} (full 2010 stat)
  - W asymmetry fresh results!
- Top production cross section with ~3pb^{-1}

CMS overview



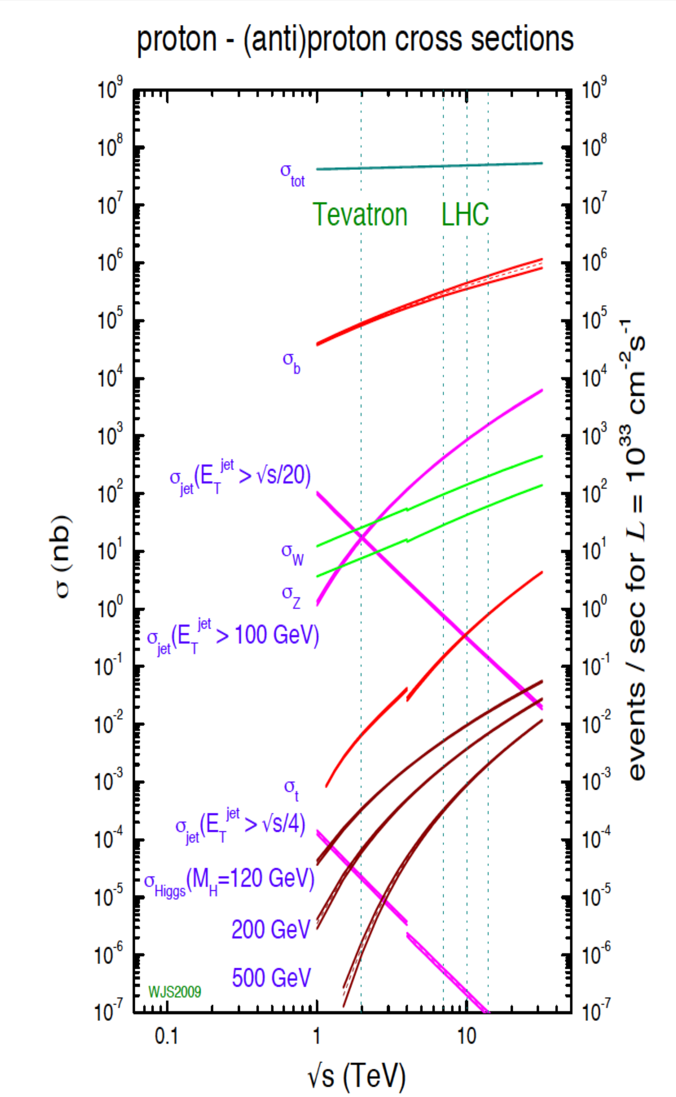
CMS transverse view

- Compact Muon Solenoid



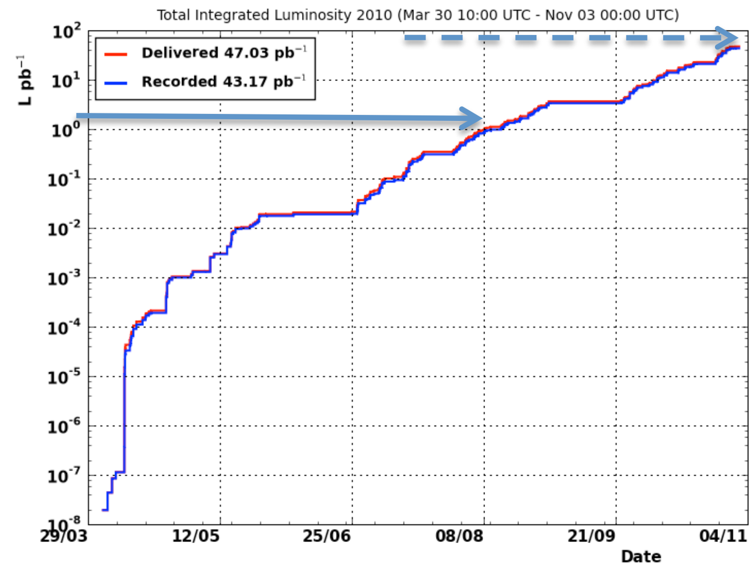
Motivations

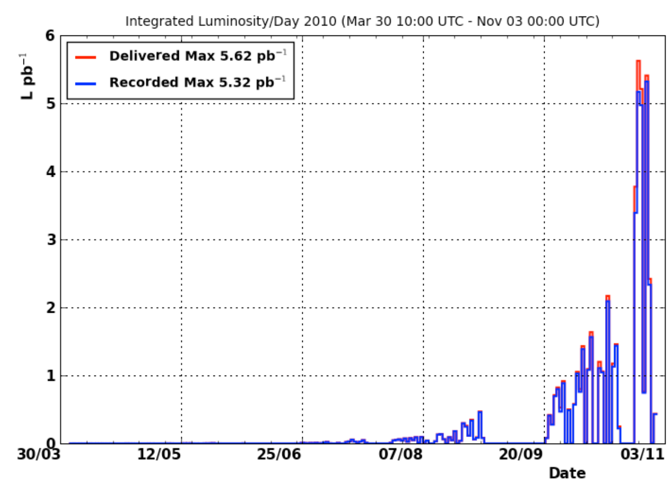
- Well measured by previous experiments
  - Rates : Z/W inclusive cross sections, R(W+/W-), R(W/Z)
  - Production details: differential distributions, associated jets, AFB, etc.
- LHC is a top-factory!
  - Gluon-gluon fusion production
  - new measurement of tt^{bar} x-section, M^{top}, single top, ….
- Yet still educational at the LHC …
  - W/Z Cross sections at √s = 7 TeV
  - Cross section of V+jets
  - New PDF constraints possible
  - Independent luminosity measurements
- "Standard candles" for high-pT analyses
  - Z/W are Calibration and alignment
  - Testbed for analysis techniques
  - Top is a departure point for high-pT BSM physics



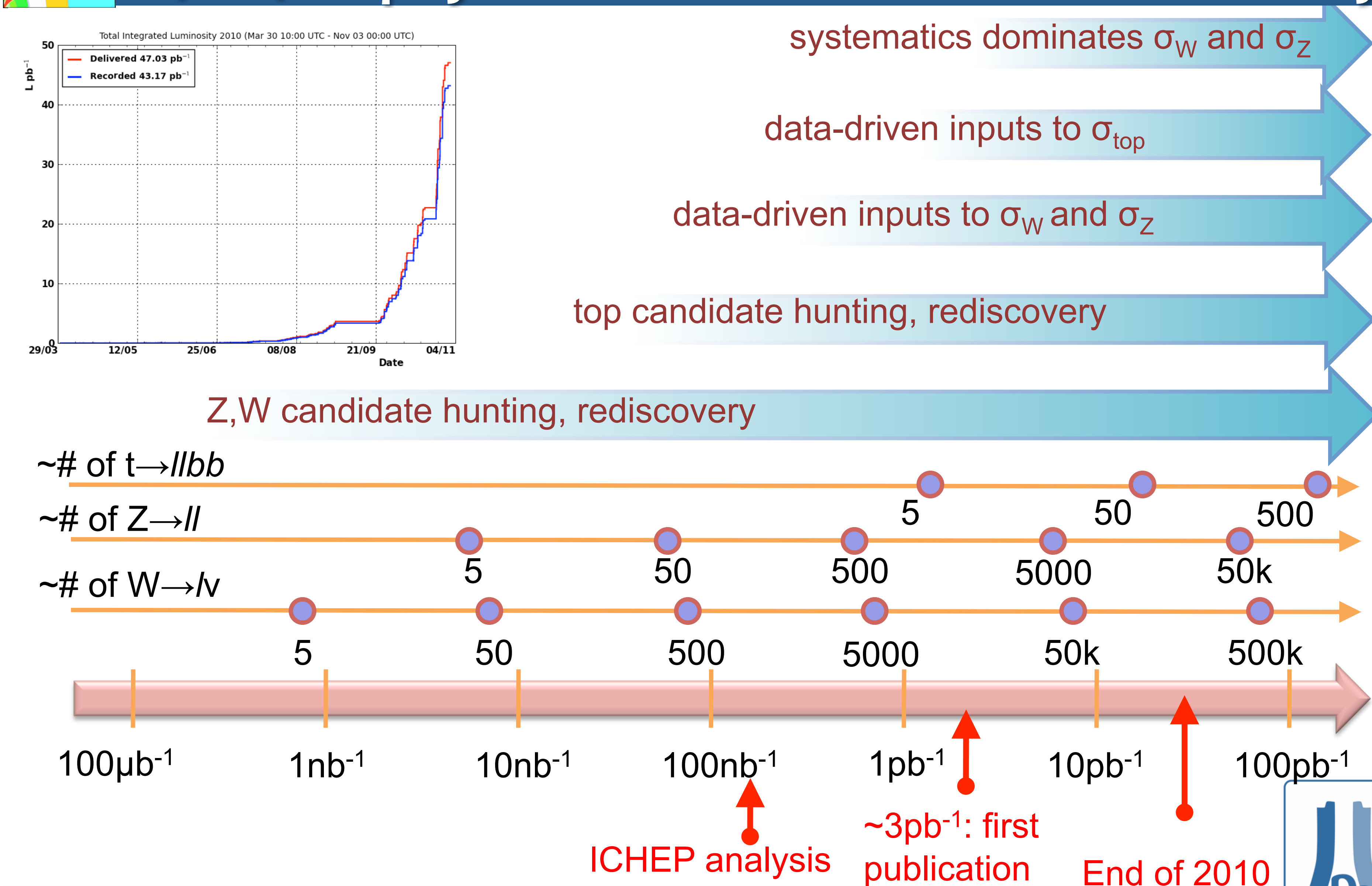
Data & Luminosity

- Mar–Aug: first period(Run2010A) of data taking at $\sqrt{s}$ = 7 TeV
  - First EWK and top measurements shown here performed with ~3 pb^{-1} dataset
- Sep-Nov: second period(Run2010B)
  - It adds up ~40 pb^{-1} of data
  - Analyses updates in the process of approvals these days.
- LHC was on a steep performance curve!
  - Avg efficiency = ~80%
  - Already sufficient data for systematic limited W & Z inclusive measurements



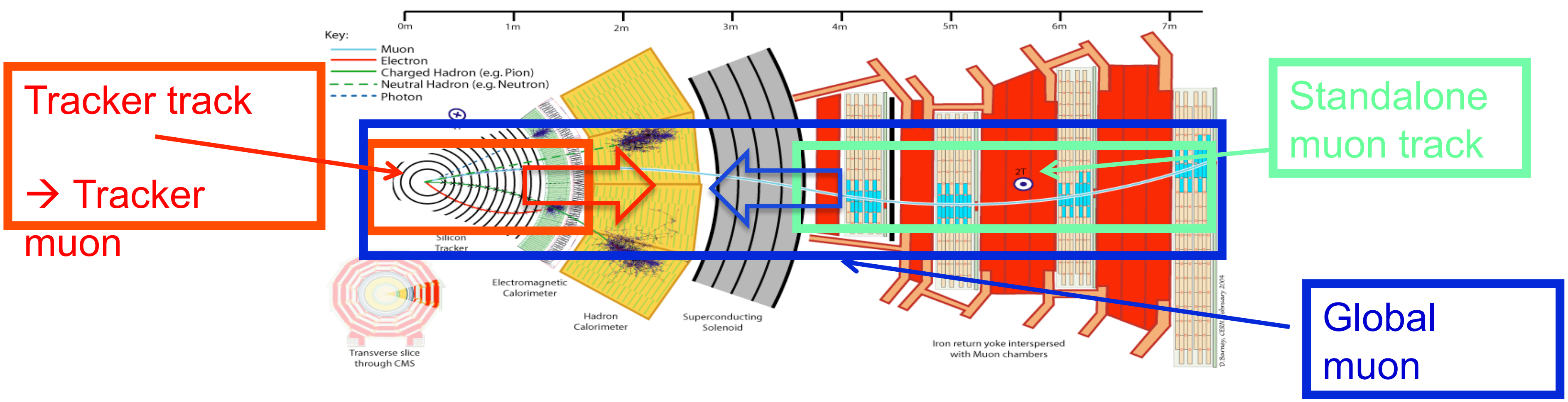


Z/W/top yield versus int. luminosity

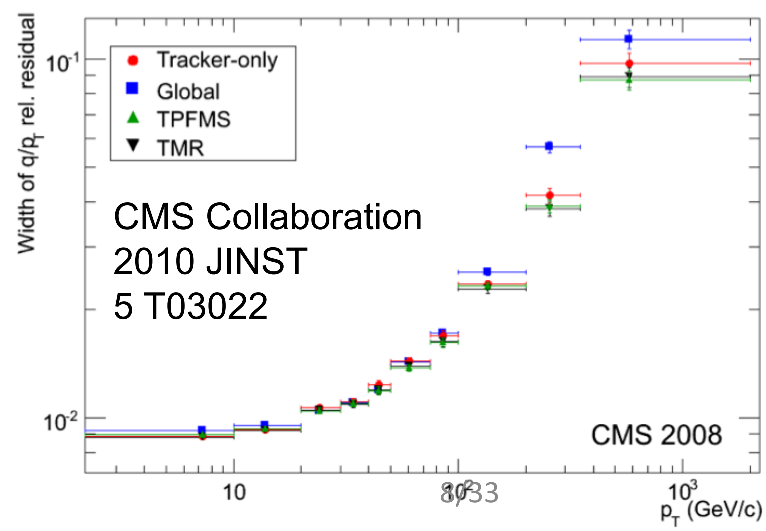


Muon reconstruction

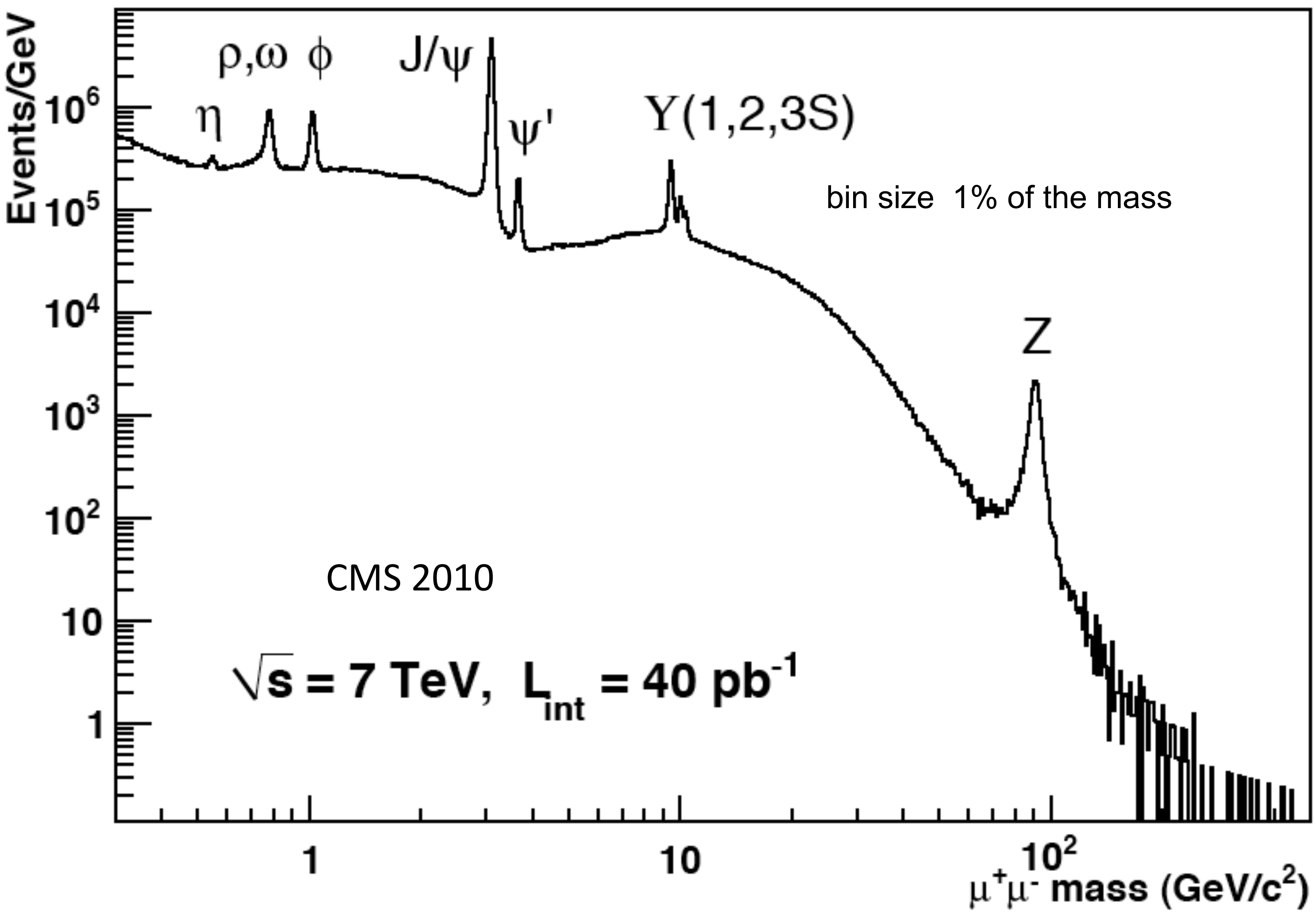
- Three different subsystems to detect muons: Drift Tubes (|η|<1.2), Cathode Strip Chambers (0.9<|η|<2.4) and Resistive Plate Chambers (|η|<1.6)
- two complementary approaches: "global muon" (outside-in) and "tracker" (inside-out)



- 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≈100 GeV, 10% for p_T≈1 TeV
- cosmic rays runs allowed calibration and alignment at the level expected with o(pb^{-1}) of collisions



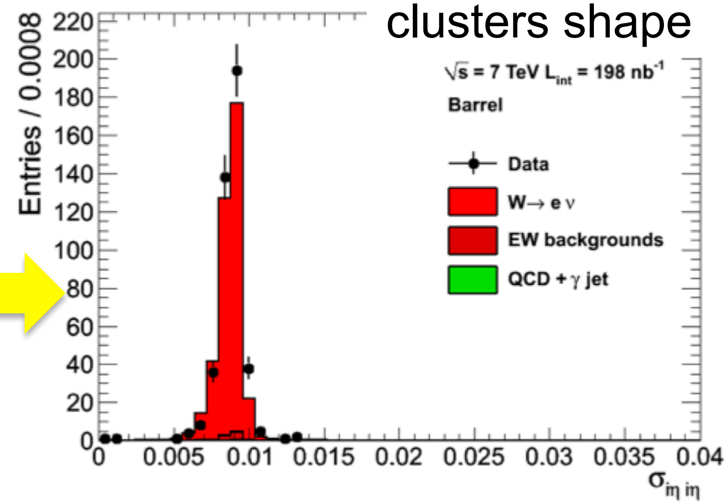
Muons


Events/GeV
η
ρ,ω
ϕ
J/ψ
ψ'
Υ(1,2,3S)
Z
bin size 1% of the mass
CMS 2010
√s = 7 TeV, L_int = 40 pb⁻¹
μ⁺μ⁻ mass (GeV/c²)
1
10
10²
10³
10⁴
10⁵
10⁶

Electron reconstruction

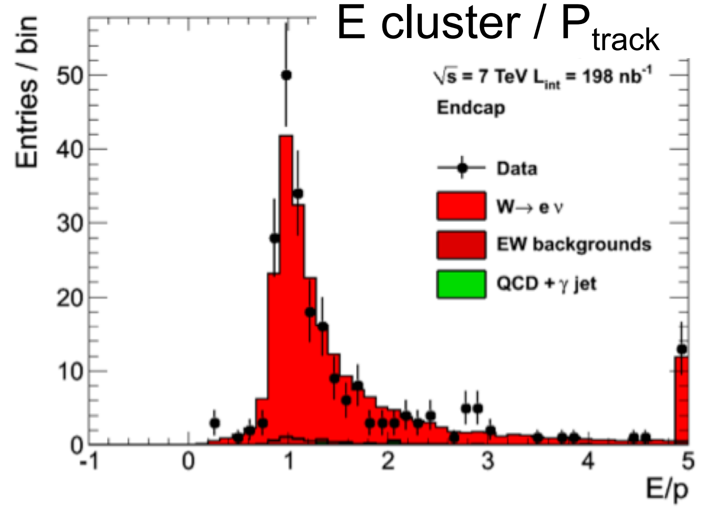
- High granular and precise e.m. calorimetry allows:
  - electron energy measurement through dynamic clustering (collection of bremsstrahlung radiation along Φ)
  - electron-jet separation through cluster shape in η
  - track seeding from clean ECAL clusters
- high granular pixel + Si strips tracking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

clusters shape



CMS-PAS-EGM-10-004

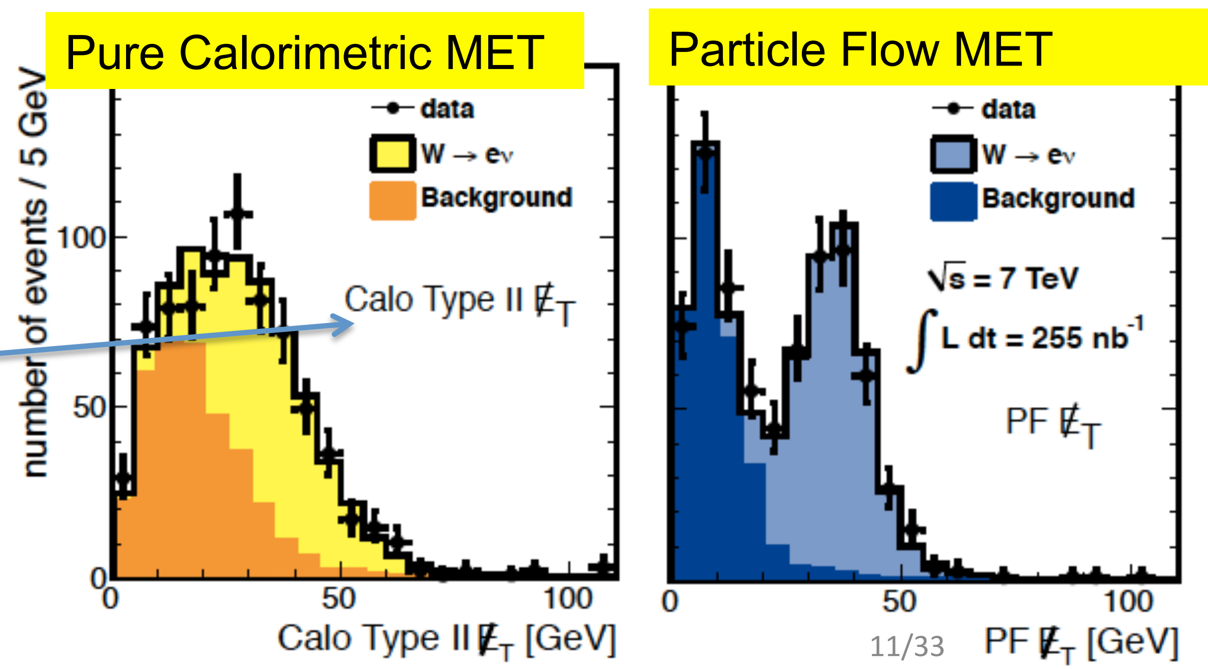
E cluster / P_{track}



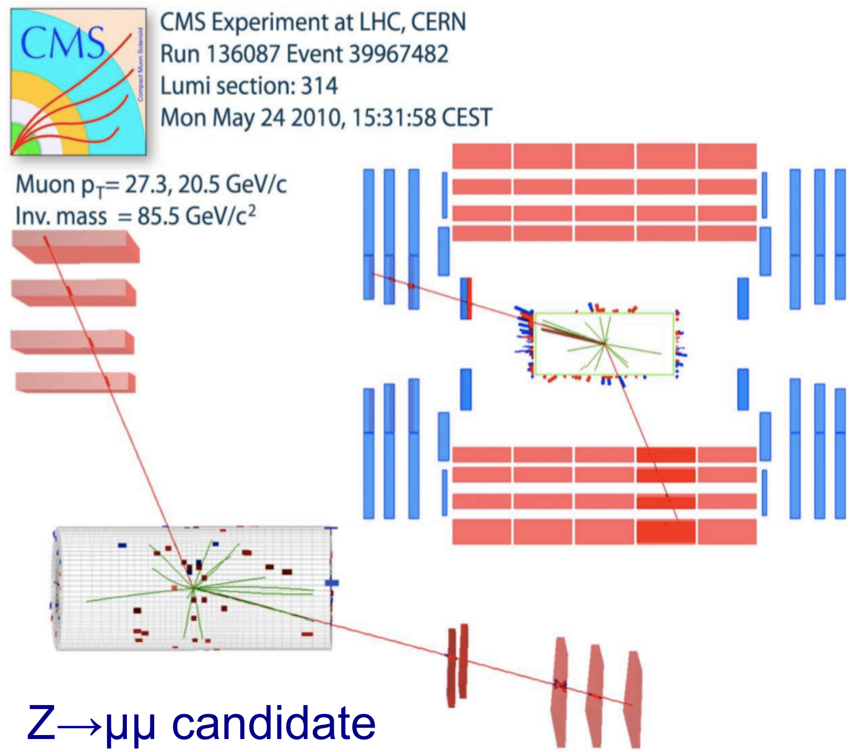
Particle Flow

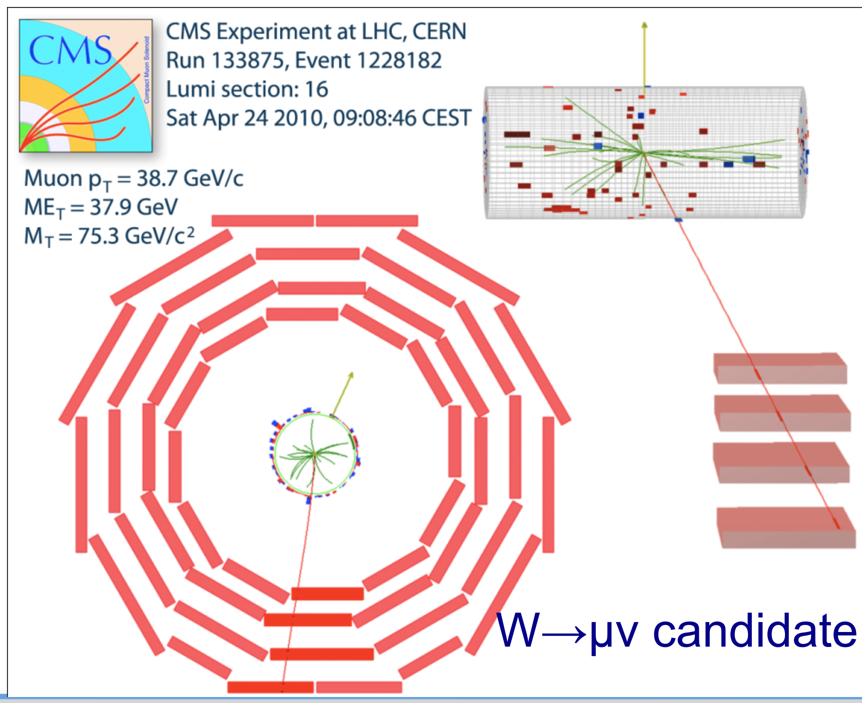
- Particle Flow: Full Event reconstruction
  - Topological matching between charged particle momenta measured with tracker with clusters in calorimeter
  - Corrects for energy loss along trajectories
  - Better precision, full event info
- High-level object: requires holistic detector view
  - Excellent tracker
  - High E/M calorimeter granularity (0.017 × 0.017)
  - Strong magnetic field to separate tracks
- CMS very well suited for P-Flow reconstruction

MET response with selected W events



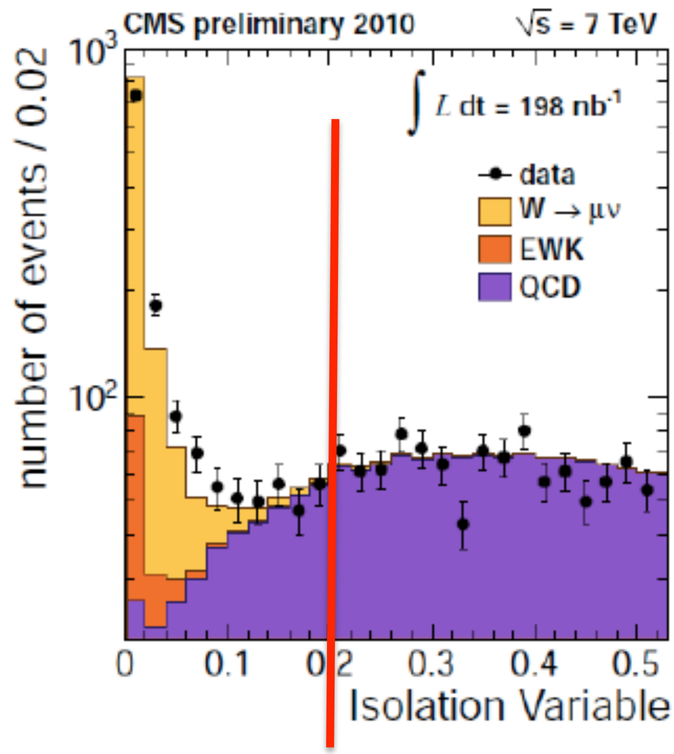
Z→μμ and W→μν inclusive channels





Muon selection

- Kinematics
  - $pT > 20$ GeV, $|\eta| < 2.1$
- Trigger : 9 GeV "open" muon
- Quality Requirements on tracker and muon chamber track
- Both Inside-out & outside-in good track reconstruction
  - Cosmic veto via transverse impact parameter
- Isolation
  - combined relative isolation $(IsoTrk + IsoEcal + IsoHcal)/ p^{T}_{\mu} < 0.15$



Z→μμ cross section

One muon passing full selection, T&P for the efficiencies in [60-120] :

913 candidates collected, 950 (S) + 4 (B) expected (0.4%).

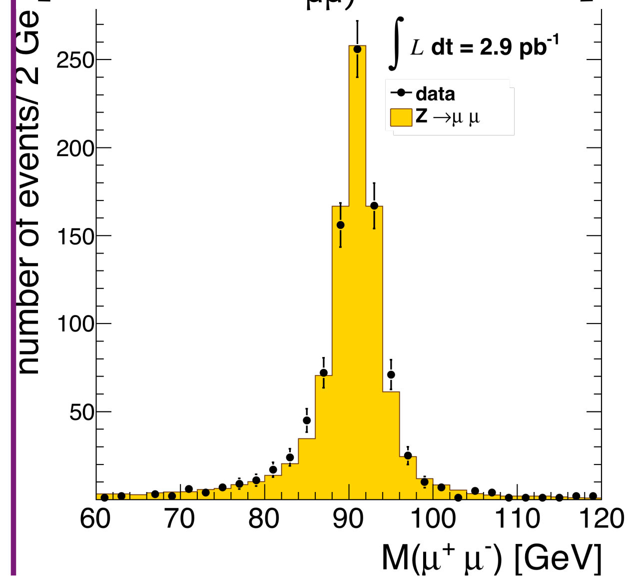
Efficiency	Data	Simulation	Data/Simulation (ρ_{eff})
ϵ_{SA}	(96.4 ± 0.5) %	97.2%	0.992 ± 0.005
ϵ_{TRK}	(99.1 ± 0.4) %	99.3%	0.998 ± 0.003
ϵ_{SEL}	(99.7 ± 0.3) %	99.7%	1.000 ± 0.003
ϵ_{ISO}	(98.5 ± 0.4) %	99.1%	0.994 ± 0.004
ϵ_{TRG}	(88.3 ± 0.8) %	93.2%	0.947 ± 0.009
Net (W)	(82.8 ± 1.0) %	88.7%	0.933 ± 0.012

This is what we need for the W analysis

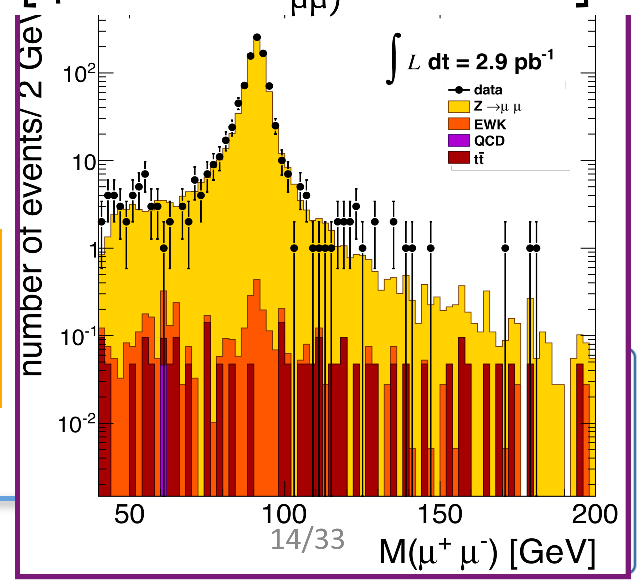
σ (pp→ZX → $\mu^+\mu^-$ X) = 0.924± 0.031 (stat.)nb

compare to σ_{theory} (pp→ZX → $\mu^+\mu^-$ X) = 0.97± 0.04 nb

[60 GeV < $m_{\mu\mu)}$ < 120 GeV]

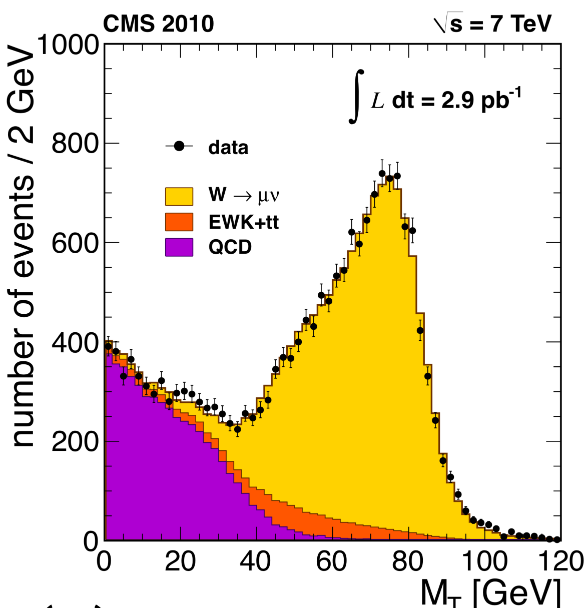


[40 GeV < $m_{\mu\mu)}$ < 200 GeV]

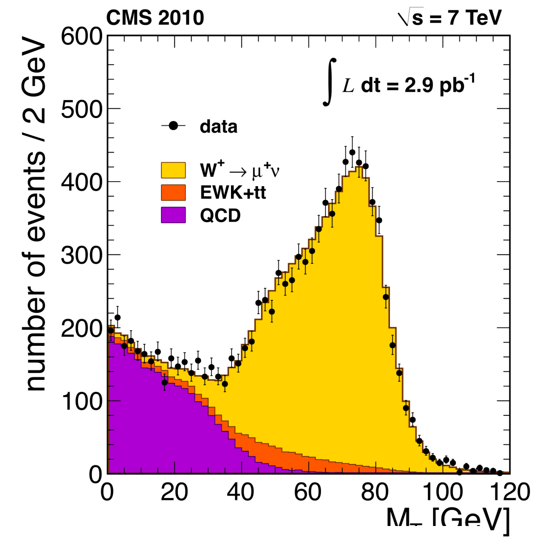


W→μν yields and cross sections

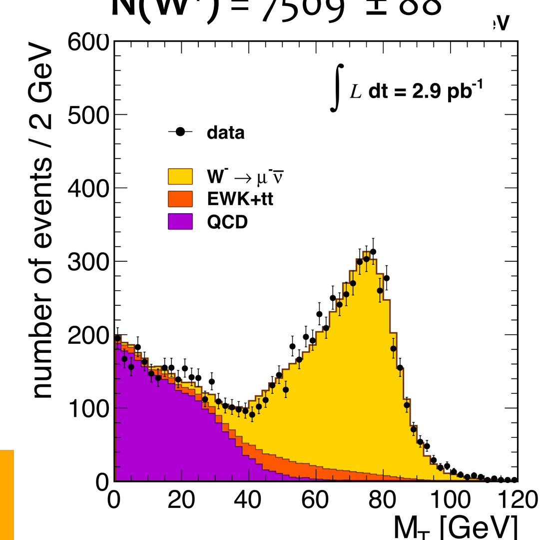
- Event passing the pt>9 trigger path
- One muon passing the full selection with p_T>20 GeV and |η| <2.1
- Reject if a second muon with p_T>10 GeV, Isolated: I^{rel}_{comb} < 0.15
- MET algorithm: Particle Flow
- QCD backgroung from data from anti-isolated sample
- W Signal yield extracted through a Binned Log Likelihood fit to the M_T distribution, with σ(W) as a free parameter. Shape from data.



N(W) = 12370 ±112



N(W⁺) = 7509 ± 88

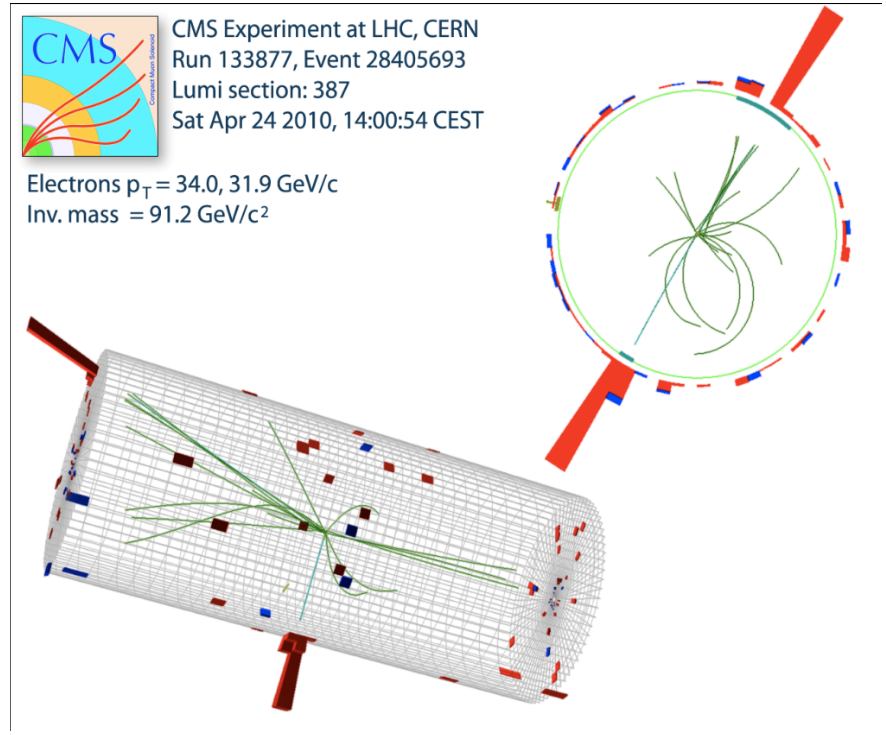


N(W⁻) = 4862 ± 70

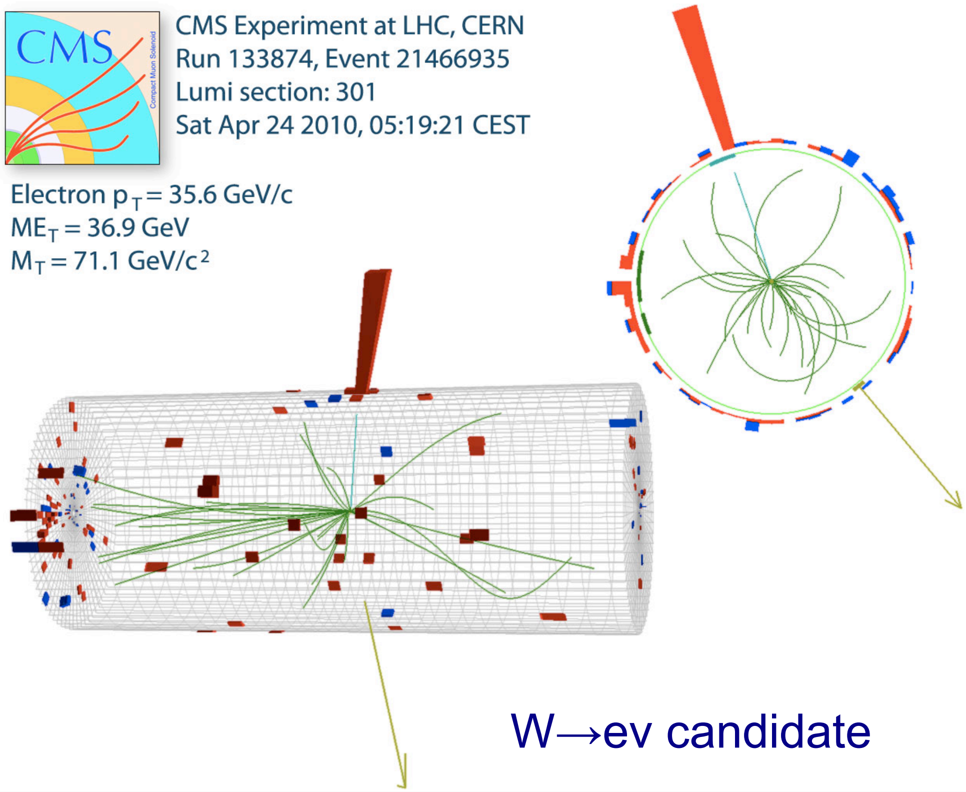
A(W) = 0.4618 ±0.00048
A(W⁺) = 0.4765 ±0.00068
A(W⁻) = 0.4413 ±0.00063
(from POWHEG)
ρ_{eff} = 0.933 ± 0.012 (see slide 14)

σ(pp→W X →μνX) = 9.969 ±0.090 nb
σ(pp→ W⁺ X →μ⁺ν X) = 5.868 ± 0.068 nb
σ(pp→ W⁺ X →μ⁻νX) = 4.101 ± 0.059 nb
σ(W⁺) / σ (W⁻) = 1.431 ± 0.026

Z→ee and W→eν inclusive channels



Z→ee candidate



W→eν candidate

Electron selection

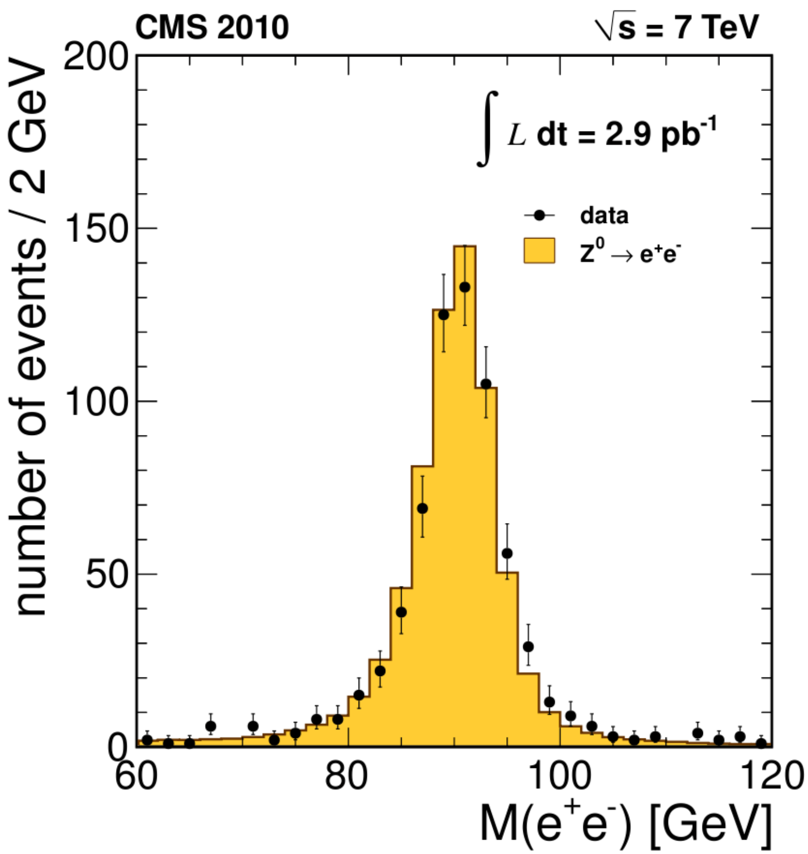
- Kinematic + Geometric Acceptance: fraction of generated events with fiducial ECAL supercluster(s) passing kinematic selection:
  - $|\eta| < 1.44$ or $1.57 < |\eta| < 2.5$
  - SuperCluster $E_T > 20$ GeV
  - Zee: 60 GeV < M_{ee} < 120 GeV
- Electron identification
  - selection on track-cluster matching, shower-shape and H/E. Separate relative track, ECAL and HCAL isolations
  - Additional cleanup cuts for $W \to e\nu$
    - Conversion rejection veto
    - Z veto: reject events with 2nd electron
- Efficiencies determined from Monte Carlo, corrected with data:
  - Data/MC scale factors (ρ) applied to MC efficiencies
  - Tag & Probe used for both Monte Carlo and data efficiencies

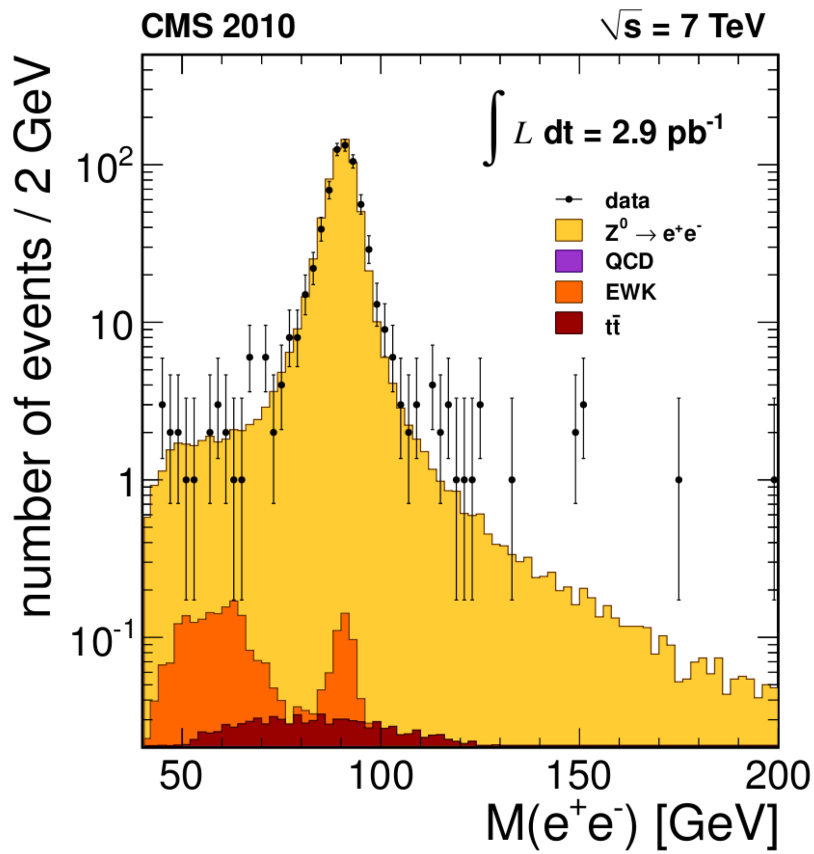
	MC (%)	Data (%)	P(data/MC)
EB	98.50	98.1 ± 1.3	0.996 ± 0.013
EE	97.02	95.7 ± 1.5	0.986 ± 0.016

Z→ee results

electron energy scale corrections applied to data:

σ(Z→ ee) : 0.960 +/- 0.037 [stat] nb

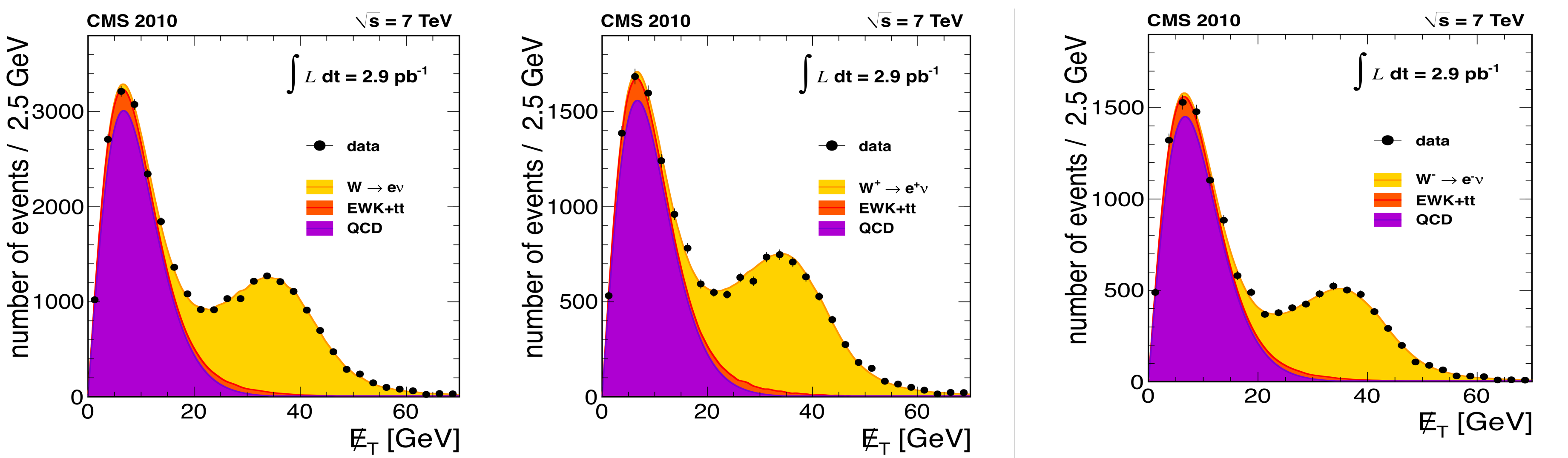




Cross check performed using different electron ID selections

W→eν results

- Apply electron selection, fit to MET distribution
  - Unbinned EML fit with static signal/parametrized background shapes
    - Signal + EWK backgrounds : MC + correction from ZMuMu recoil in data (as the WMuNu case)
    - QCD background : Functional model from Rayleigh distrib.

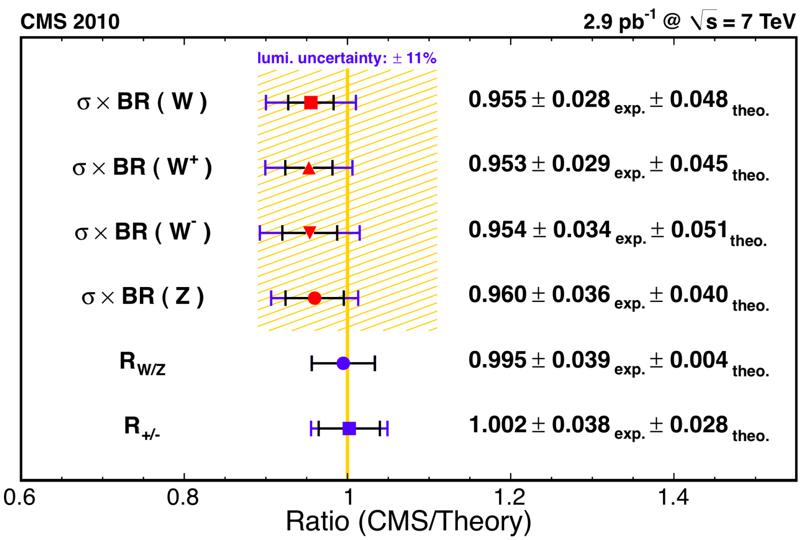


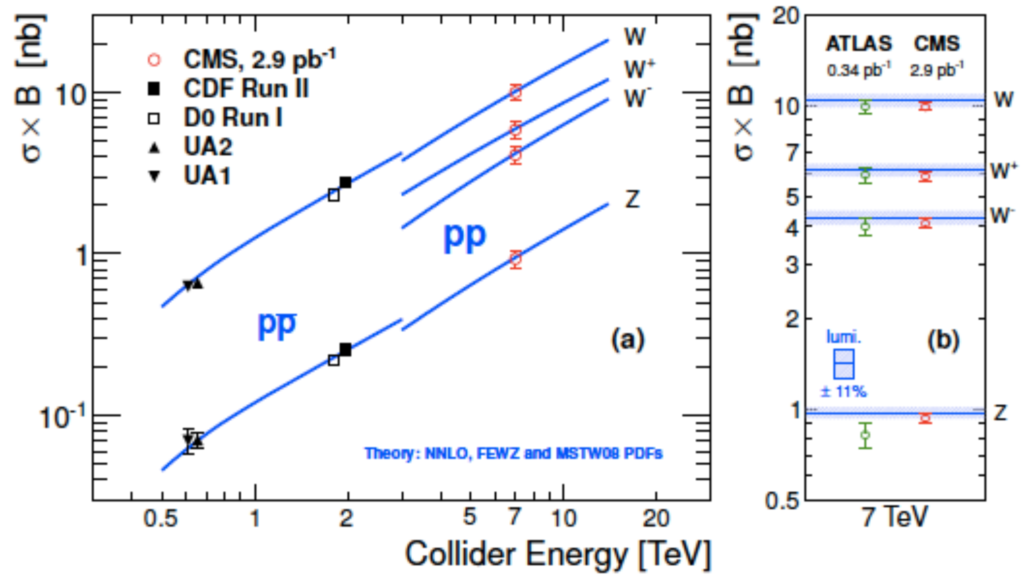
Fit using templates derived from the Z-driven "recoil" method

W = 11789.3 ± 134.4, W^{+} = 7142.2 ± 97.2, W- = 4678.9 ± 79.4

CMS vs theory and ATLAS + systematics

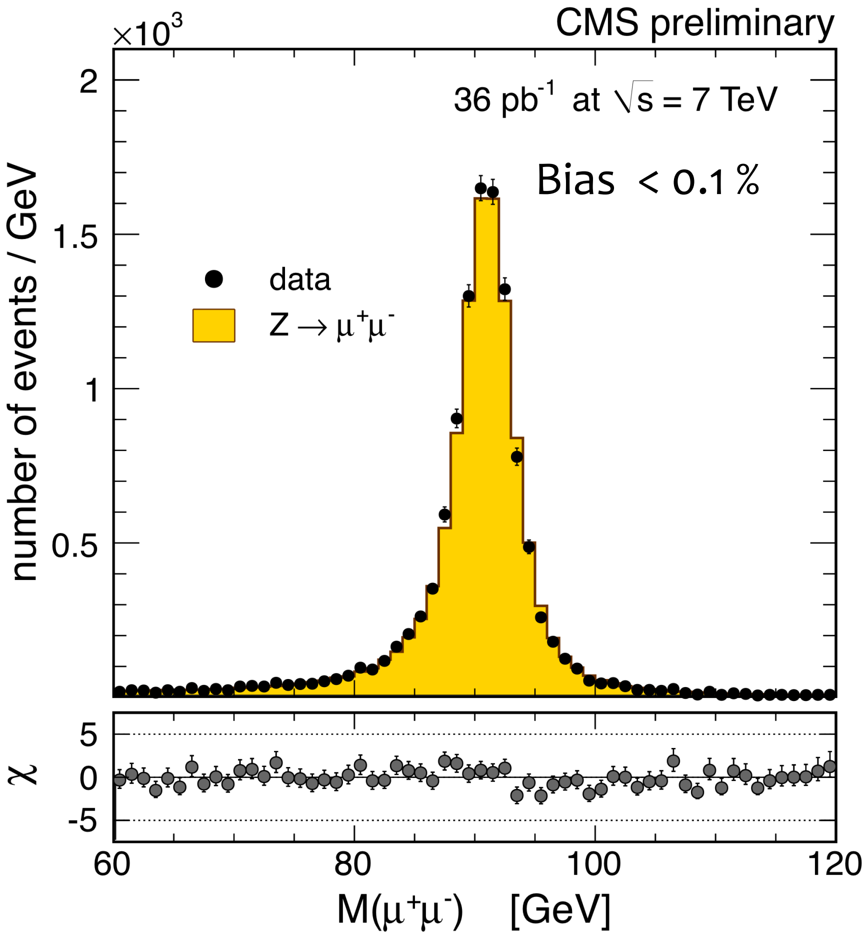
arXiv:1012.2466
J. High Energy Phys. 01 (2011) 080-443

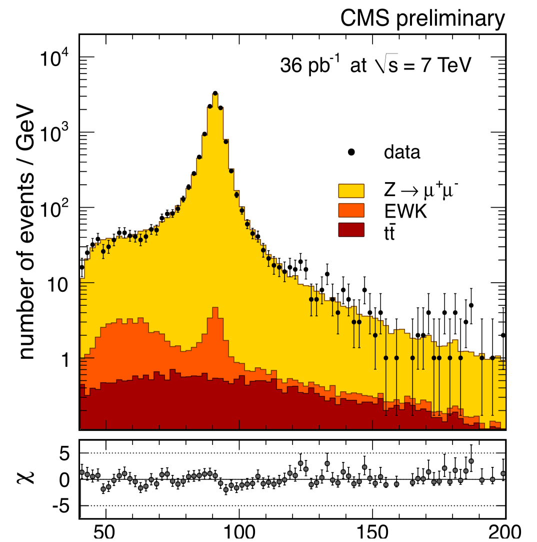


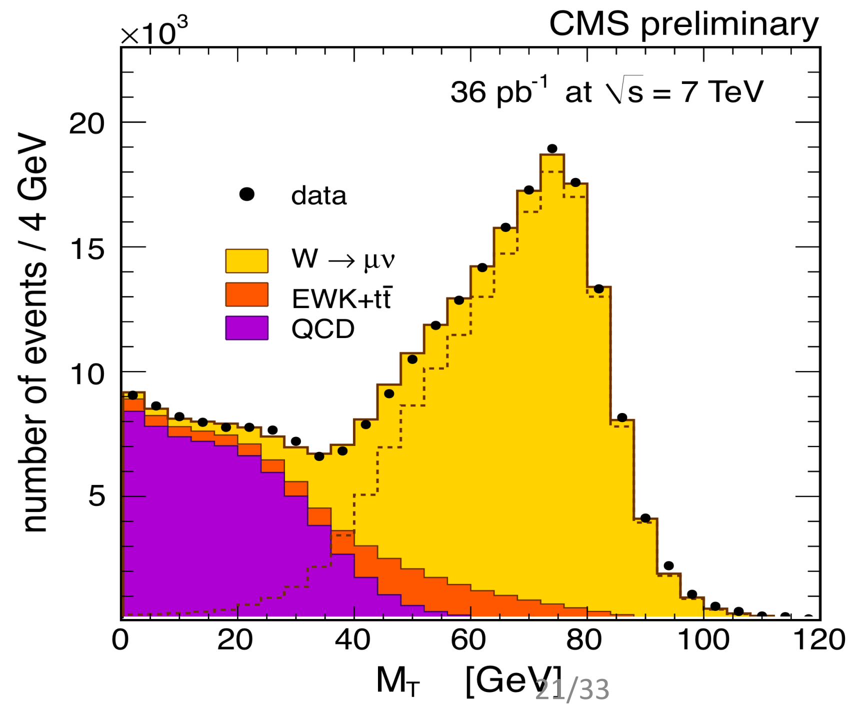


Source	$W \to e\nu$	$W \to \mu\nu$	$Z \to e^+e^-$	$Z \to \mu^+\mu^-$
Lepton reconstruction & identification	3.9	1.5	5.9	0.5
Momentum scale & resolution	2.0	0.3	0.6	0.2
$\not\!\!E_T$ scale & resolution	1.8	0.4	n/a	n/a
Background subtraction/modeling	1.3	2.0	0.1	$0.2 \oplus 1.0$
PDF uncertainty for acceptance	0.8	1.1	1.1	1.2
Other theoretical uncertainties	1.3	1.4	1.3	1.6
Total	5.1	3.1	6.2	2.3

Z →μμ/W→μν 2010 dataset

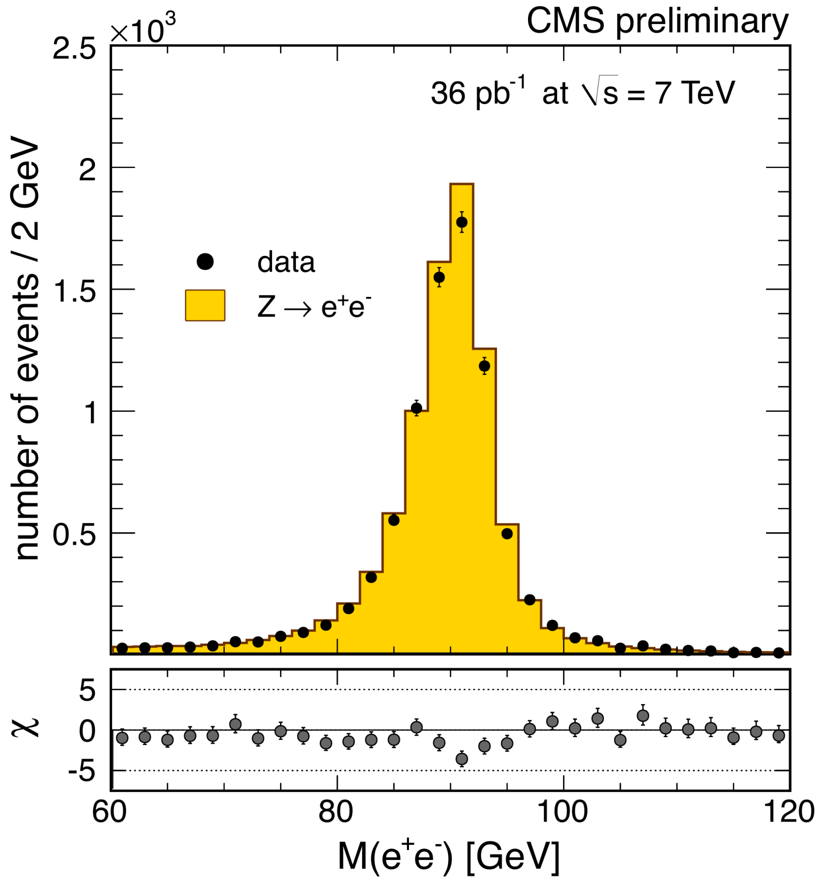


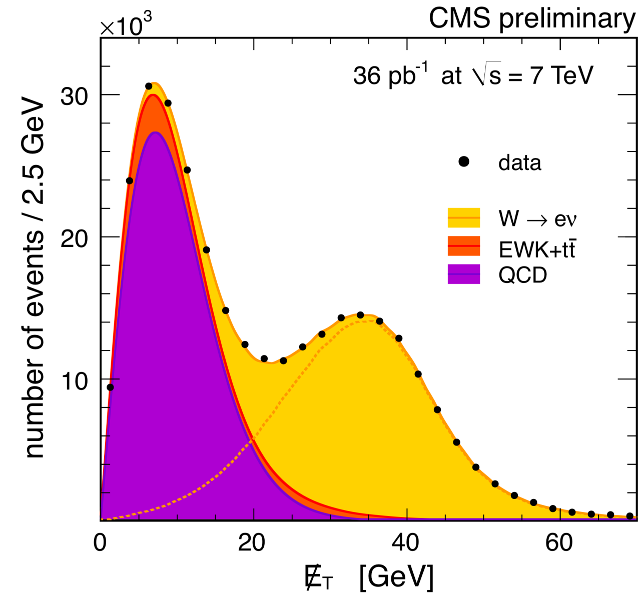


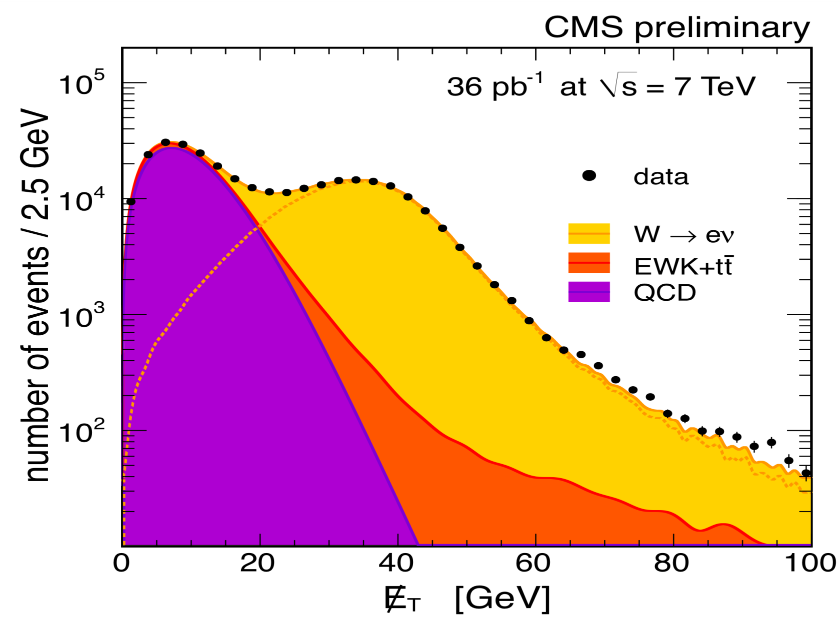


Rates consistent with SM prediction

Z →ee/W→eν 2010 dataset







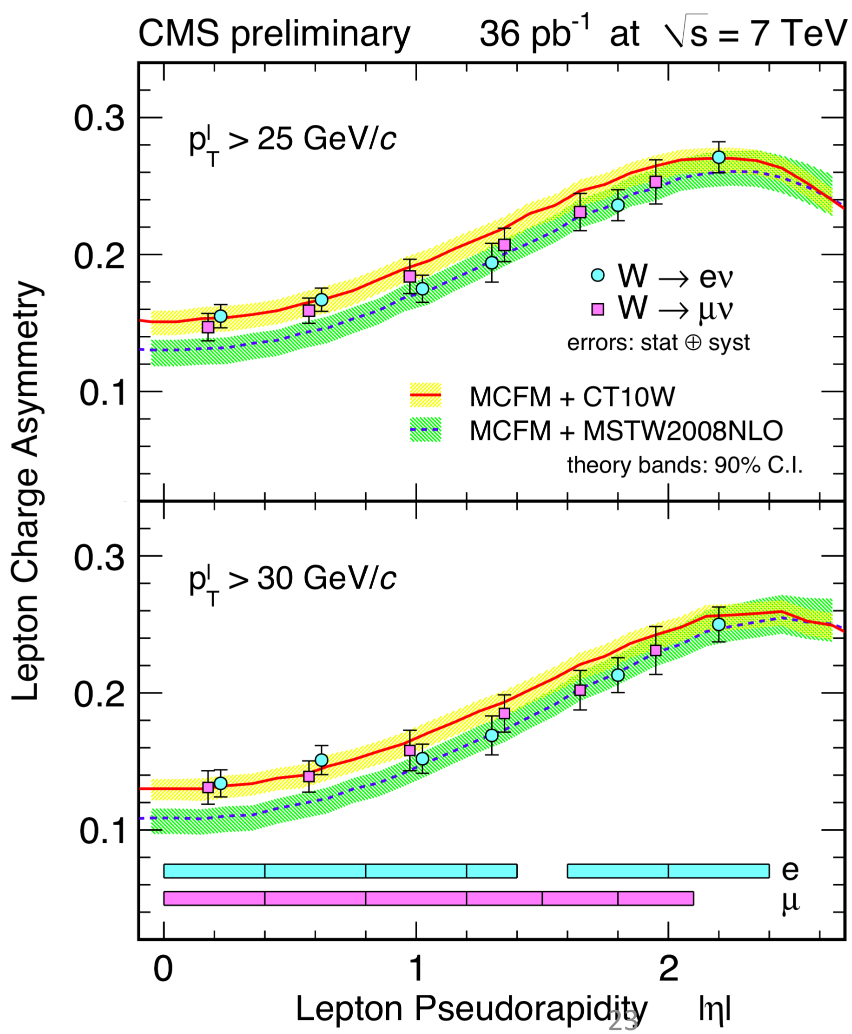
Rates consistent with SM prediction

W asymmetry

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

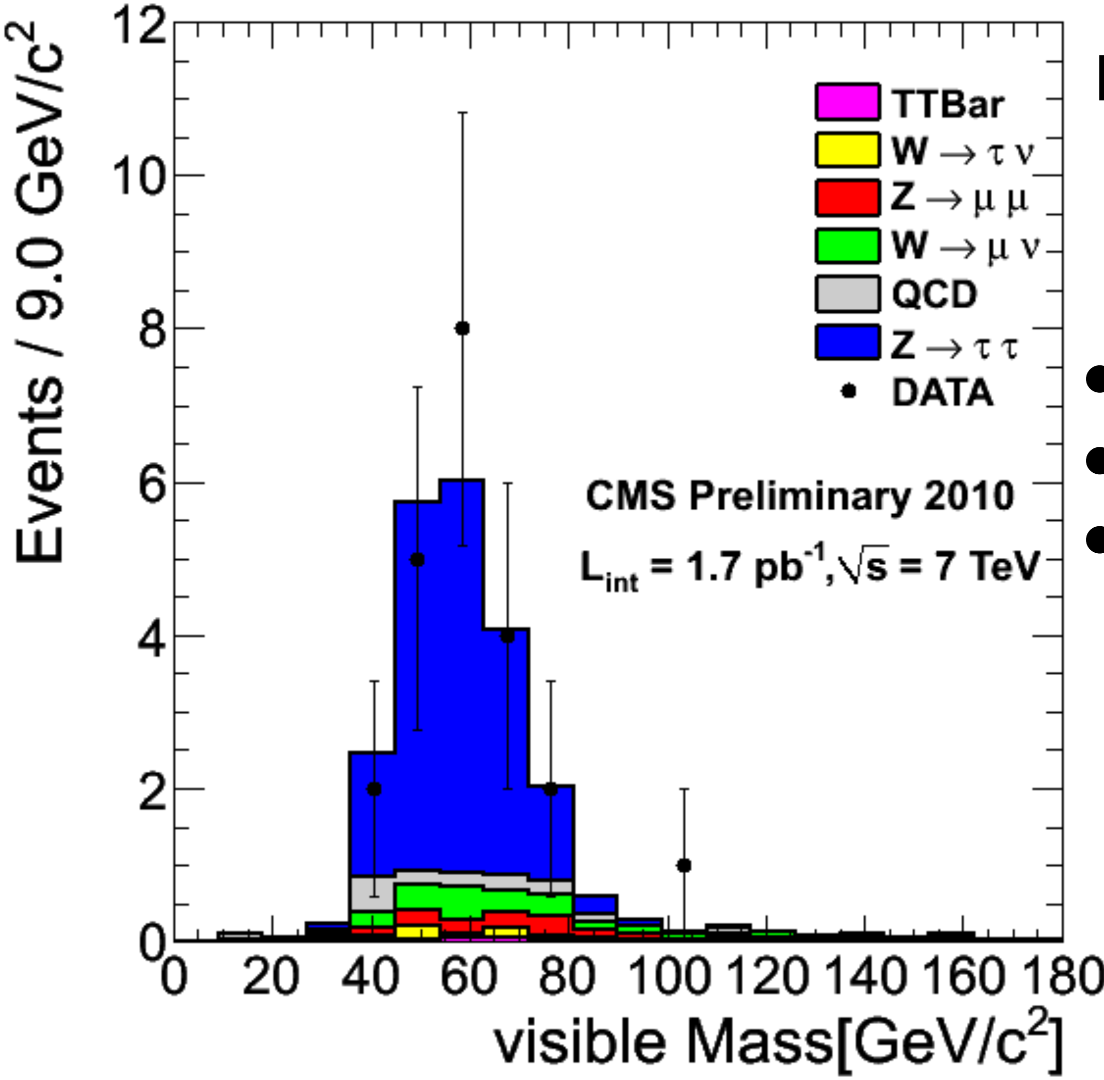
CMS PAS EWK 10 -006

- In pp collisions, more W^+ are expected than W^- due to the excess of *u* quarks wrt *d* quarks.
- Asymmetry is a function of η since *u* quarks carry higher fraction of proton momentum.
- An asymmetry measurement could be used explore the proton structure (PDF) or to measure contribution of new physics.
- Start costraining PDF models



Z → ττ

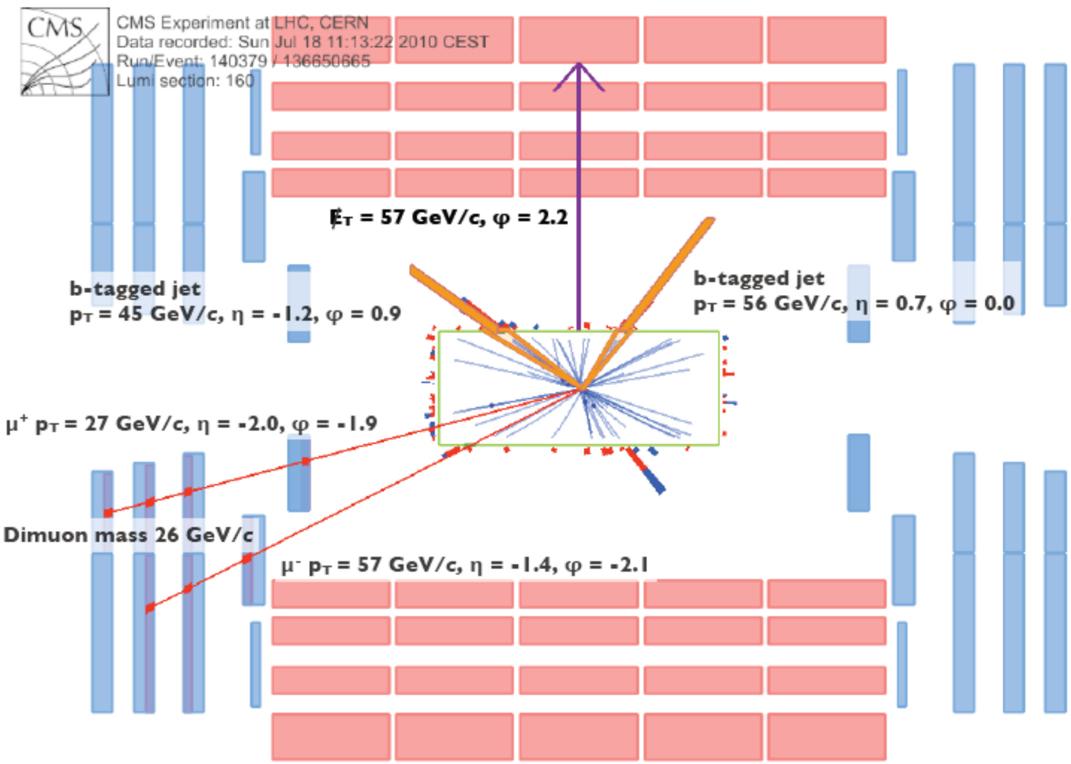
CMS PFT-10-004 PAS

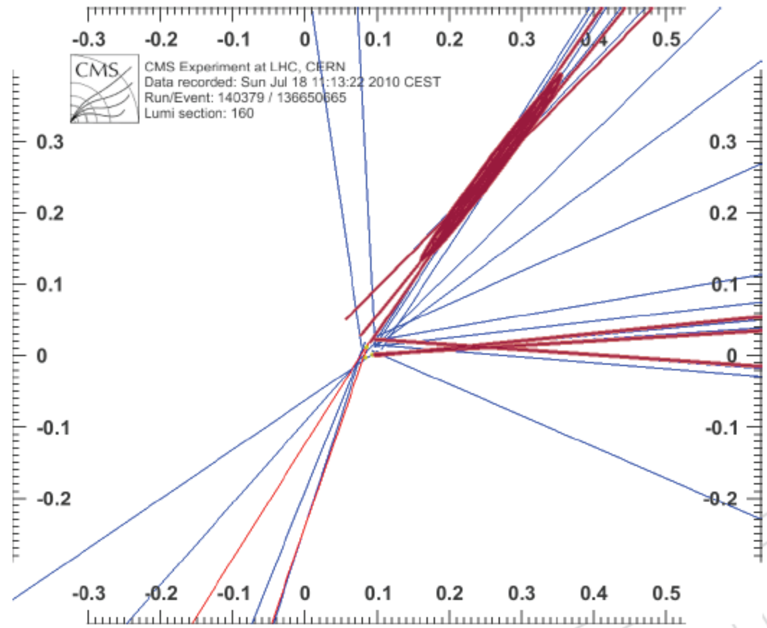


First step to H->ττ….

- Mu Pt > 15 GeV/c
- Rel Comb Iso < 0.1
- Tau Pt > 20 GeV/c

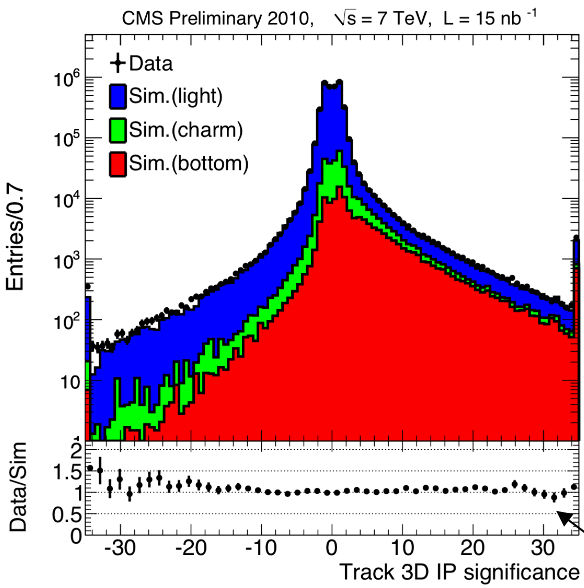
TOP

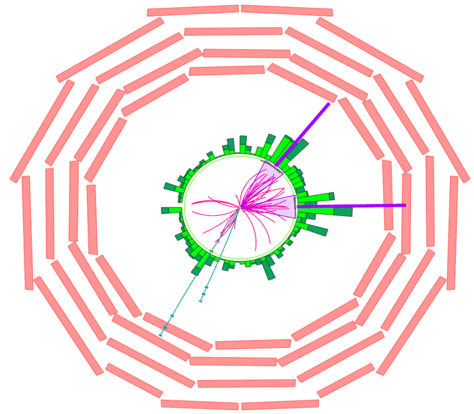


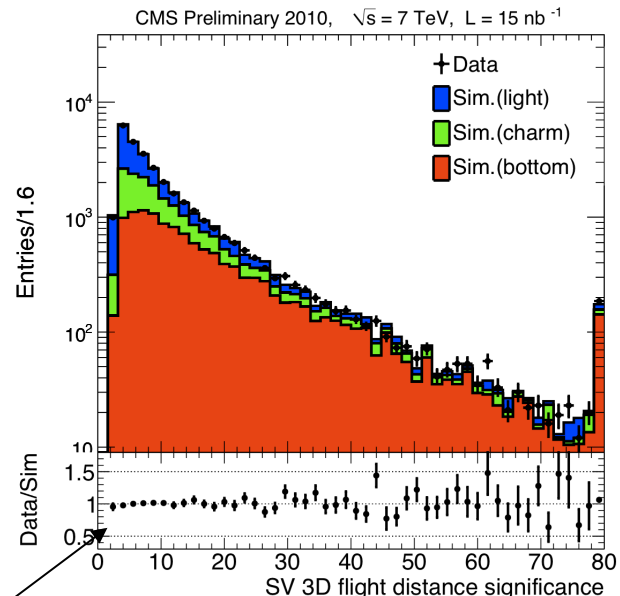


Candidate tt→WbWb→lνb lνb with 2 muons (far from Z peak), 2 jets and large missing energy; muons and jets belong to the same primary vertex; clear secondary vertices in jets

Data-MC comparison for b-tagging observables

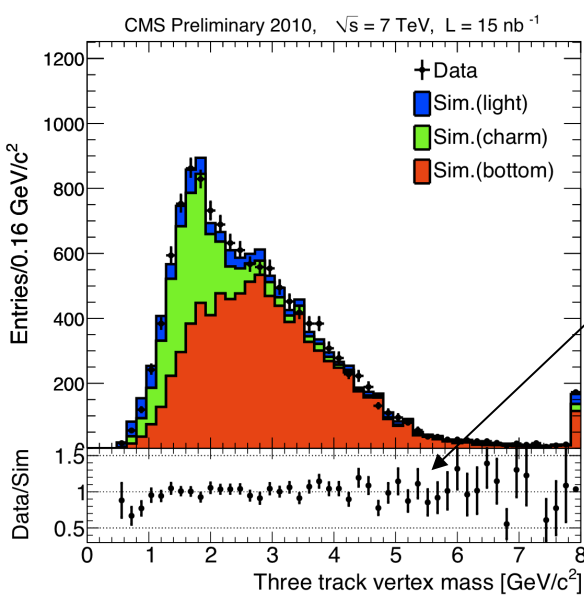


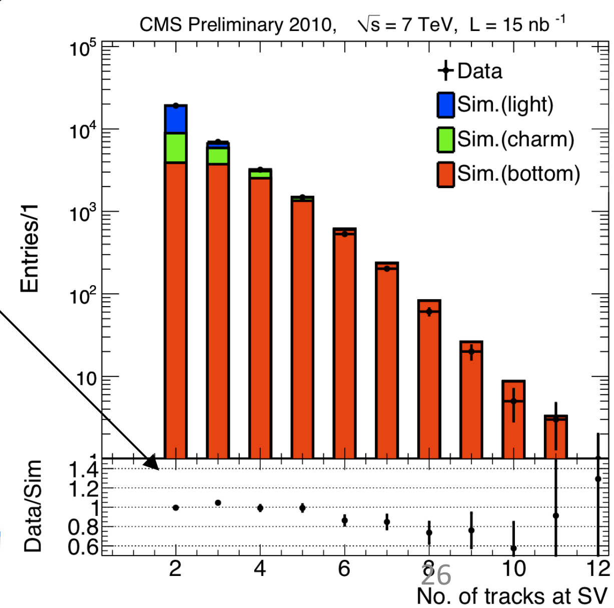




DATA/MC ratio is close to 1 for all observables

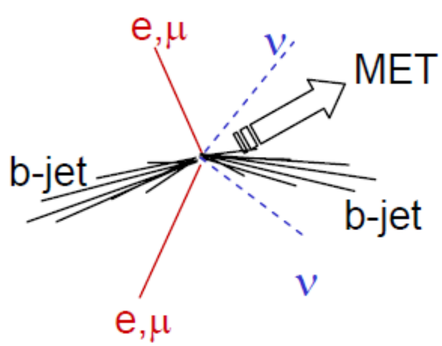
B-tag can be used immediately at least for supporting ckecks!



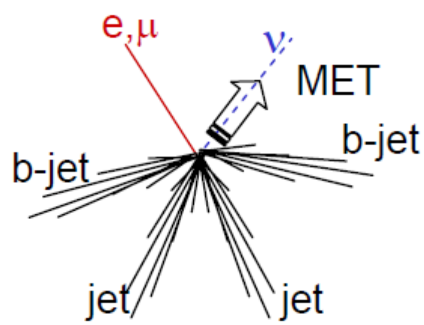


tt^{bar} overview: selection criteria

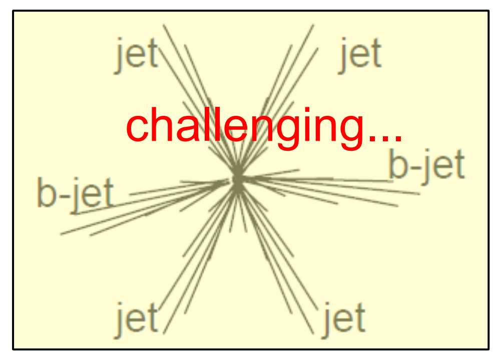
- Dileptons
  - 2m || 2e || em, isolated
  - At least 2 central jets
  - Z veto in 2m and 2e
  - High MET
  - B-tagging for supporting results
- Lepton+jets
  - 1m || 1e, isolated
  - At least 4 central jets
  - High MET
  - Alternative analyses w/ and w/o b-tagging



dileptons
(BR~5%)



lepton + jets
(BR~30%)



all hadronic
(BR~46%)

$t\text{-}t^{bar}$ cross section in the di-leptonic channel with 3.1 pb^{-1}

Full selection applied: Z-Veto, |M(ll)-M(Z)|>15 GeV
MET >30 (20) GeV in ee,mm, (em); N(jets)≥2

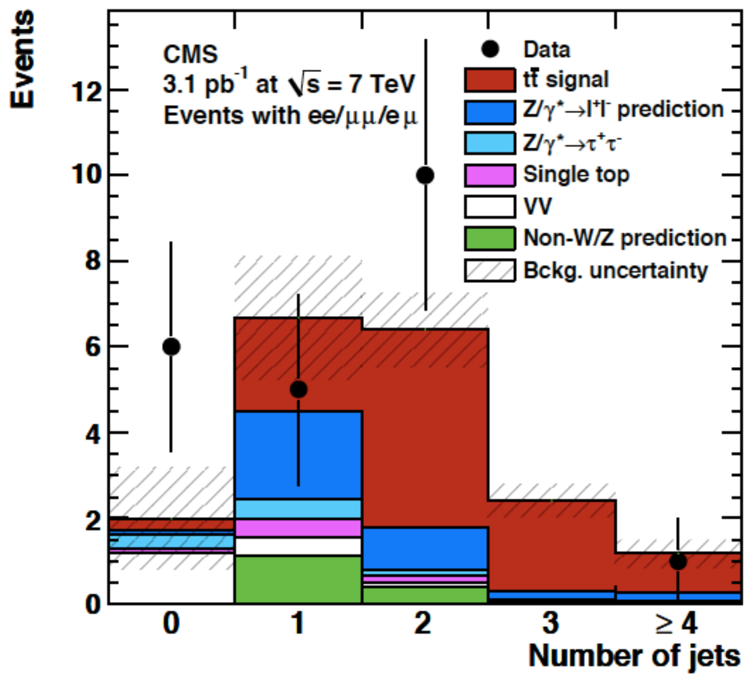
arXiv:1010.5994
Phys. Lett. B 695 (2011) 424-443
L= 3.1 pb^{-1}

Source	Number of events
Expected $t\bar{t}$	7.7 ± 1.5
Dibosons (VV)	0.13 ± 0.07
Single top (tW)	0.25 ± 0.13
Drell-Yan $Z/\gamma^{\star} \to \tau^{+}\tau^{-}$	0.18 ± 0.09
Drell-Yan $Z/\gamma^{\star} \to e^{+}e^{-}, \mu^{+}\mu^{-}$	$1.4 \pm 0.5 \pm 0.5$
Events with non-W/Z leptons	$0.1 \pm 0.5 \pm 0.3$
Total backgrounds	2.1 ± 1.0
Expected total, including $t\bar{t}$	9.8 ± 1.8
Data	11

Background estimation:

- Diboson, single-top and Z->ττ prediction taken from MC
- Drell Yan and Events with non-W/Z leptons from data
  - Extrapolation of the rate outside the Z mass (see back-up)
  - Jet-triggered control sample enriched by two-leptons with loose lepton identification cuts (see back-up)

$t\bar{t}$ dileptonic: results of full selection



- All dileptonic channels combined
- In this plot: backgrounds from data-driven estimates, apart from single top and VV, taken from MC scaled to NLO
- Hashed lines: background uncertainties

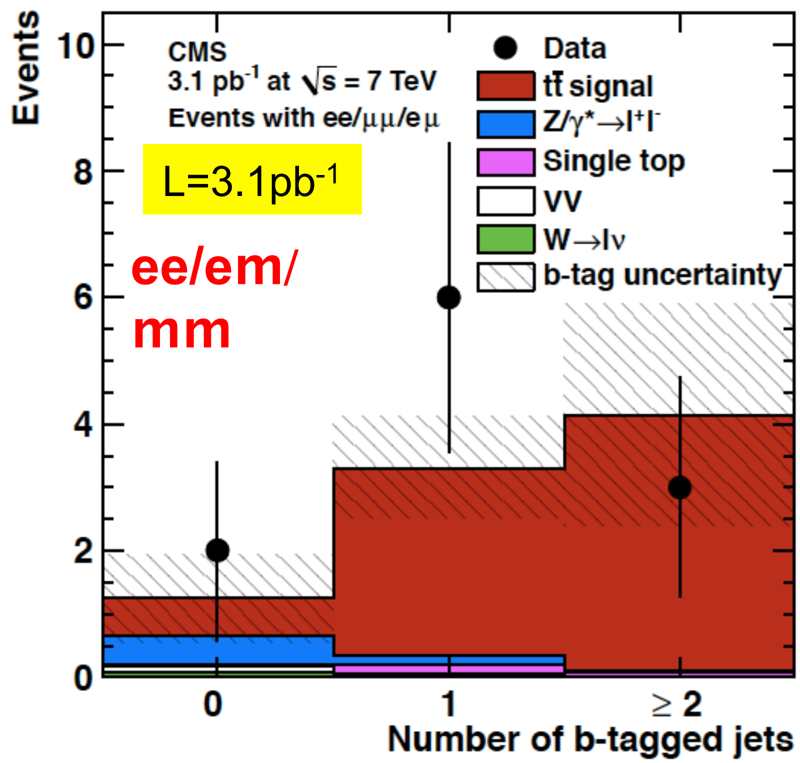
Compare with NLO expectation:
$157.5^{+23.2}_{-24.4}$ pb
from MCFM, with M_t=172.5 GeV, uncertainty from scale variations, PDF (MSTW, CTEQ, NNPDF), α_S (PDF4LHC prescriptions)

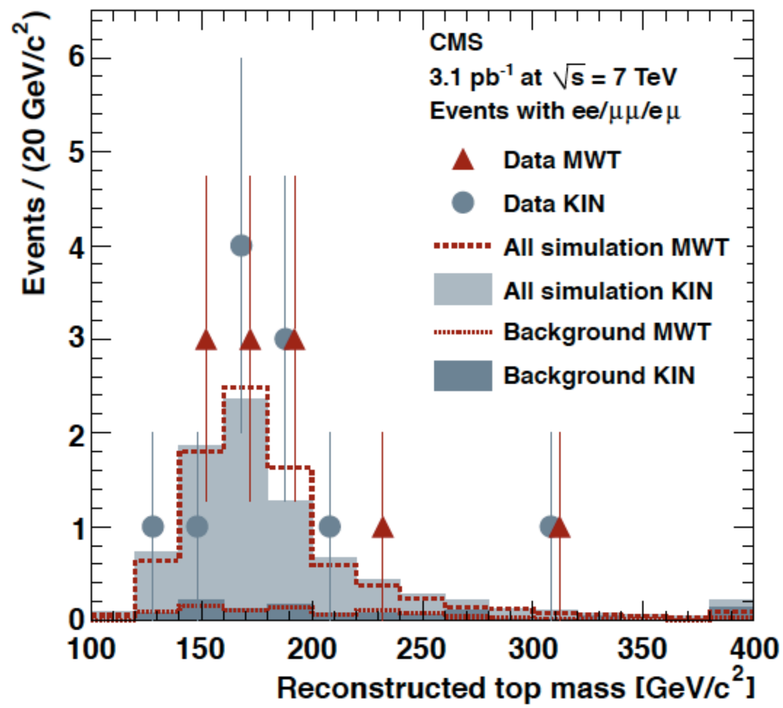
Experimental systematics of 11% mainly due to the uncertainties in the bkg method subtraction

$\sigma(pp \rightarrow t\bar{t}) = 194 \pm 72(\mathrm{stat.}) \pm 24(\mathrm{syst.}) \pm 21(\mathrm{lumi.})$ pb

Supporting plots ;-)

arXiv:1010.5994
Phys. Lett. B 695 (2011) 424-443

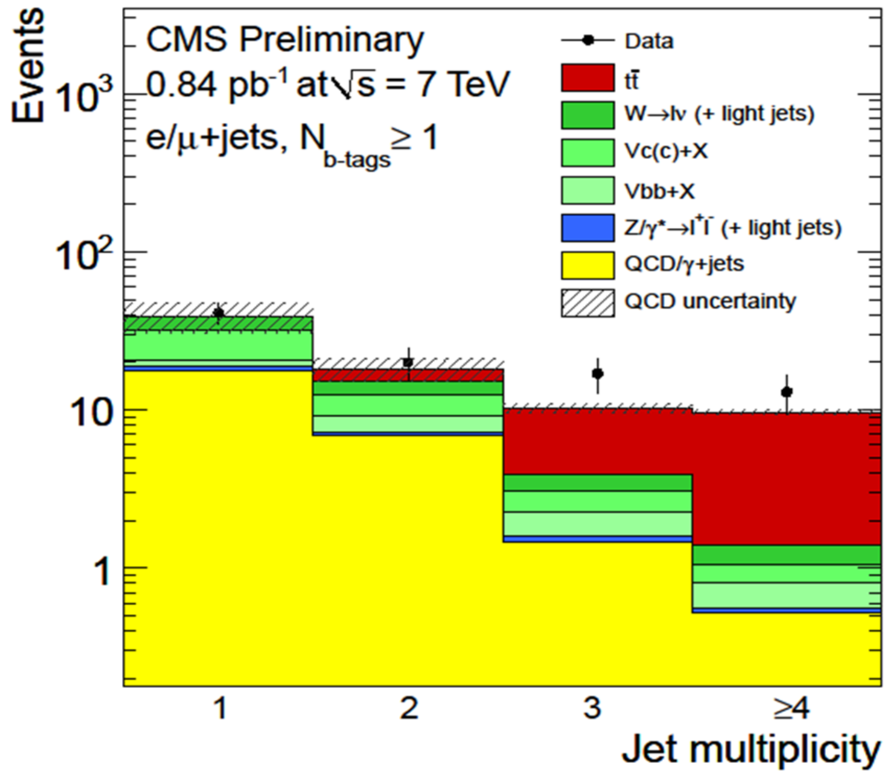




- two different methods to start "verifying" the top mass obtained from data (see back-up)

t-tbar : lepton+jets

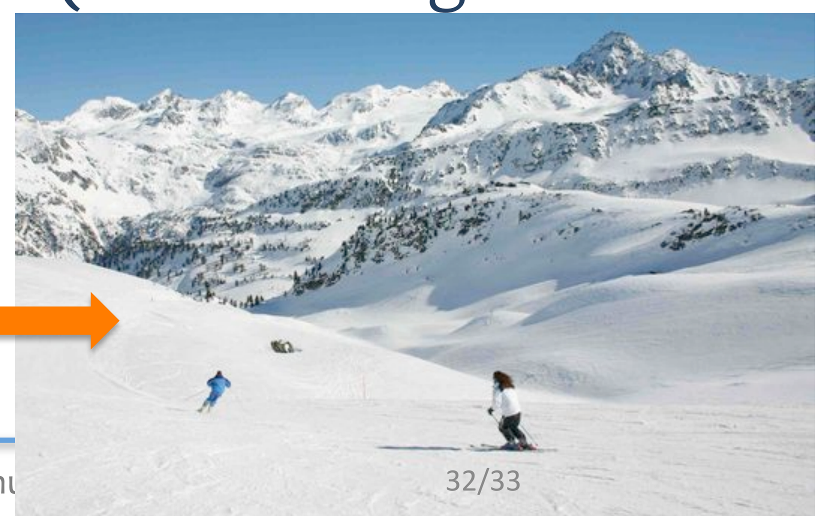
- Using 0.84pb^{-1} and requiring at least 1 secondary vertex tagger with ≥2 tracks;
  - ~50% efficiency
  - ~1% fake rate
- N(jets)≥3
  - 30 signal candidates over a predicted background of 5.3
- tt rate consistent with NLO cross section
  - Up to experimental (JES, b-tagging) and theoretical (scale, PDF, HF modeling, …) uncertainties.



Conclusions

- Overview of first W and Z production cross-section measurements
  - First 7 TeV p-p collision cross section measurement with ~3pb^{-1} and update plots for ~36pb^{-1} (full 2010 stat)
- Top production cross section with ~3pb^{-1}
- CMS can do precision measurements in EWK and Top field, and demonstrates the physics objects and analysis are ok to start searches (see Henning Flacher tomorrow talk)

Many results to come soon for Moriond, so I encourage you to stay here also the next 2 weeks!



BACK-UP

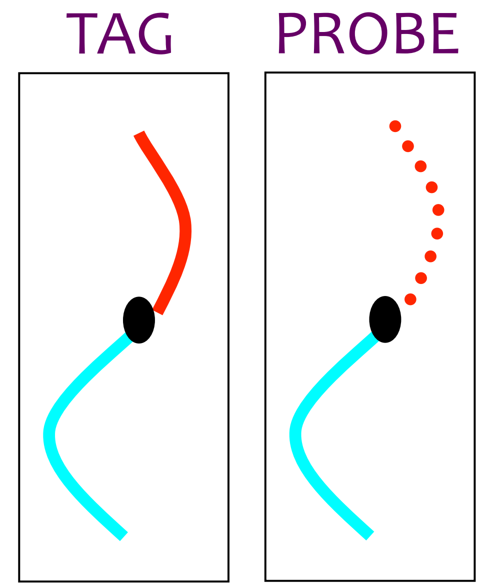
ZMuMu Event Selection

- One muon fulfilling the muon selection, with $p_T > 20$ GeV and $|\eta| < 2.1$
- A second muon, with opposite charge, with $p_T > 20$ GeV and $|\eta| < 2.1$
- Signal region: $m_{\mu\mu} \subset [60, 120]$ GeV
- Signal Yield and Muon efficiencies are determined simultaneously
- An example: Let´s take a single condition to define a good muon → a single efficiency (eff.)
  - Category 1 (T_PP): TagMuon and PassingProbeMuon

    $N_{T\_PP} = N_{MuMu} \times eff^2$
  - Category 2 (T_FP): TagMuon and FailingProbeMuon

    $N_{T\_FP} = 2 \times N_{MuMu} \times eff \times (1-eff)$

  Solving for N_{MuMu} and eff:



$eff = 2 \times N_{T\_PP} / (2 \times N_{T\_PP} + N_{T\_FP})$

$= nPassingProbes / nProbes$

$N_{MuMu} = N_{T\_PP} / eff^2$

Generalizing for several efficiencies and formulating the problem in terms of a fit, errors and correlations between N_{MuMu} and eff´s are automatically taken into account

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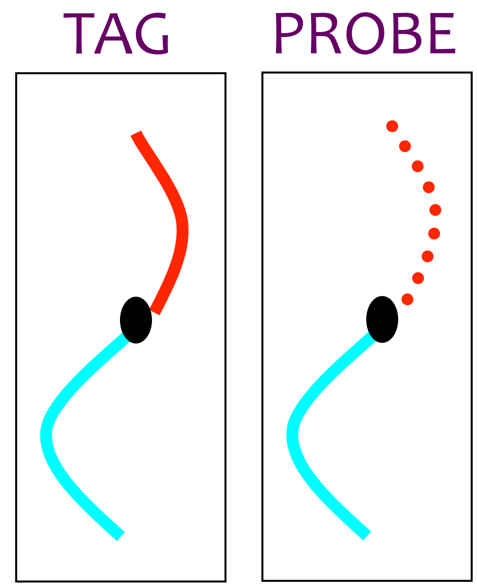
  Solving for N_{MuMu} and eff:



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$= nPassingProbes / nProbes$

$N_{MuMu} = N_{T\_PP} / eff^2$

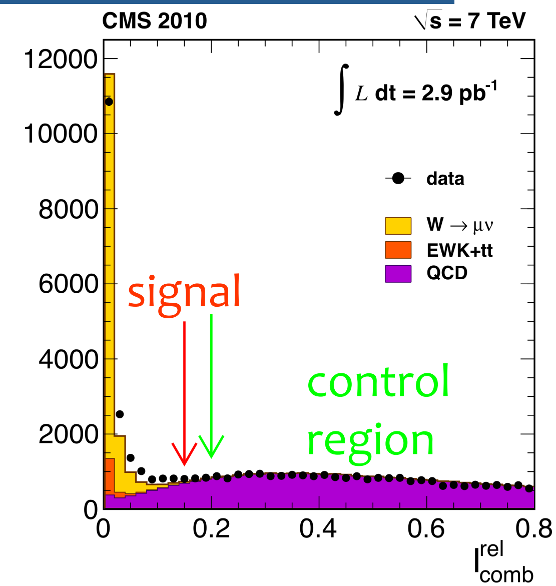
Generalizing for several efficiencies and formulating the problem in terms of a fit, errors and correlations between N_{MuMu} and eff´s are automatically taken into account

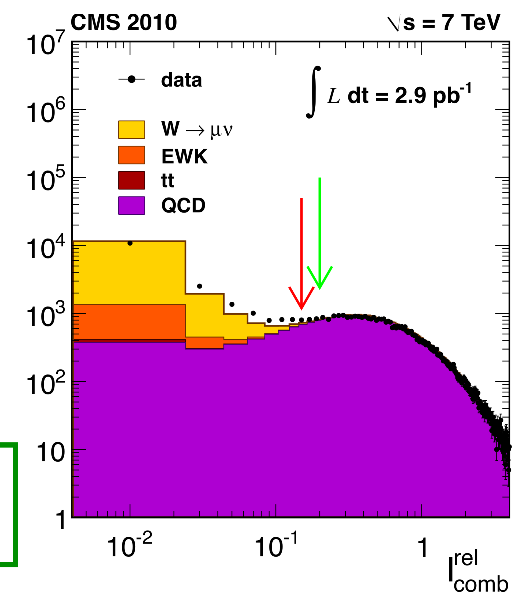
WMuNu Event selection

- Event passing the pt>9 trigger path
- One muon passing the full selection with p_T>20 GeV and $|\eta|$ <2.1
- Reject if a second muon with p_T>10 GeV
- Isolated: I^{rel}_{comb} < 0.15
- MET algorithm: Particle Flow
- W Signal yield extracted through a Binned Log Likelihood fit to the M_T distribution, with σ(W) as a free parameter. Shape from data.

$$M_T = \sqrt{2p_T(\mu)\not{E}_T(1-\cos(\Delta\phi_{\mu,\not{E}_T}))}$$

$\Delta\phi_{\mu,\not{E}_T}$ Angle between the muon and MET



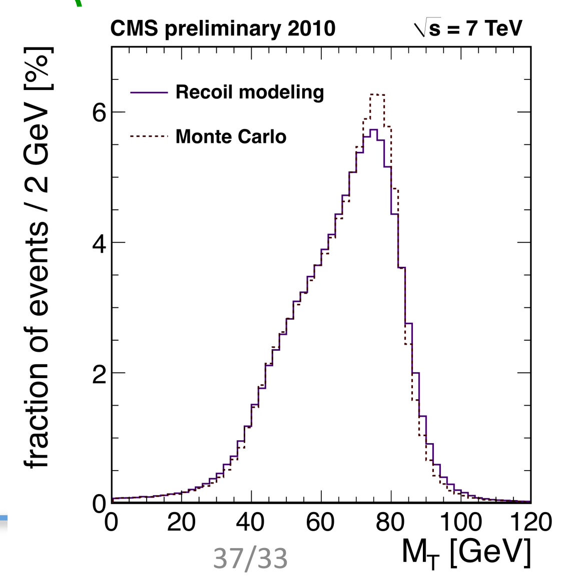


W signal and Bkg templates

- Main backgrounds arise from:
  - QCD (b decays mainly, plus decays in flight), at low M_T. Determined in the fit. Shape derived from the data (inversion of isolation cut).
  - Electroweak processes: $Z \rightarrow \mu\mu$, $Z \rightarrow \tau\tau$, $W \rightarrow \tau\nu$, tt-bar, Dibosons (WW, WZ, ZZ). Normalized to the signal contribution. Shape derived from MC

$$N(M_T) = \{\underbrace{\sigma_W \times [\mathcal{A}_W(M_T)}_{W} + \underbrace{K \times \mathcal{A}_{EWK}(M_T)]}_{EWK} + \underbrace{\mathcal{F}_{QCD}\mathcal{T}(M_T)\}}_{QCD} \times \mathcal{L}_{int}$$

  - Signal shape derived correcting the simulation template:
    - use di-lepton system in ZMuMu events to reconstruct the recoil to the Z boson $\vec{u}_T \equiv -(\vec{q}_T + \vec{E}_T)$



Additional Information from Z→ee

- Charge misidentification data/MC scale factor
  - Fit for mis-ID fraction (ω) in SS/OS Z data

$$N_{sig}^{os} = \left[(1-\omega)^2 + \omega^2\right] N_{sig}$$
$$N_{sig}^{ss} = 2\omega(1-\omega) N_{sig}$$

  - Assume OS is background free, fixed signal template + exp for SS

- Energy Scale scale factor
  - Fit for shift of the Z peak, unfold corresponding energy scale corrections
  - Check of application of corrections to MC succeeds

	WP95 EB	WP95 EE	WP80 EB	WP80 EE
E-scale	1.0115 ± 0.0025	1.0292 ± 0.0040	1.0116 ± 0.0031	1.0120 ± 0.0057

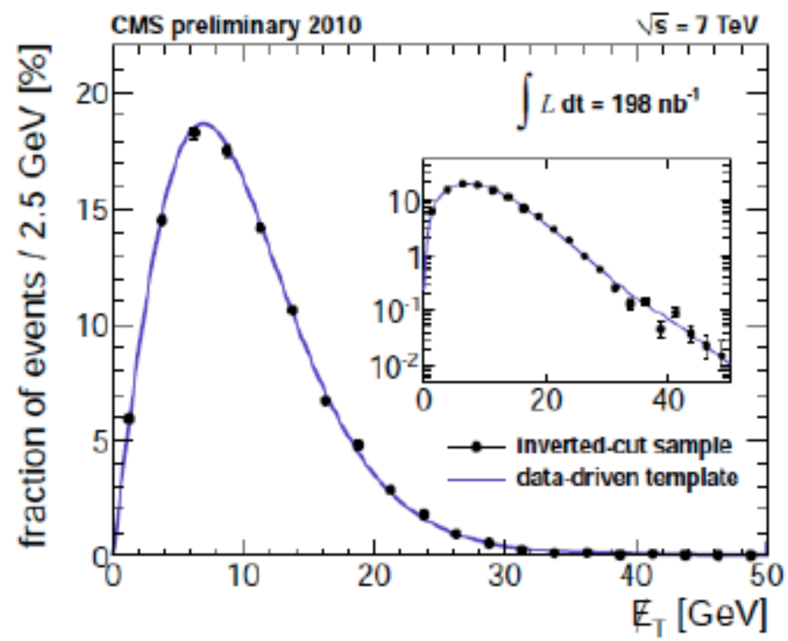
  - Scale corrections applied to data for Zee but MC for W MET
    - ρ in table above defined as MC/data

E-channel signal extraction strategy

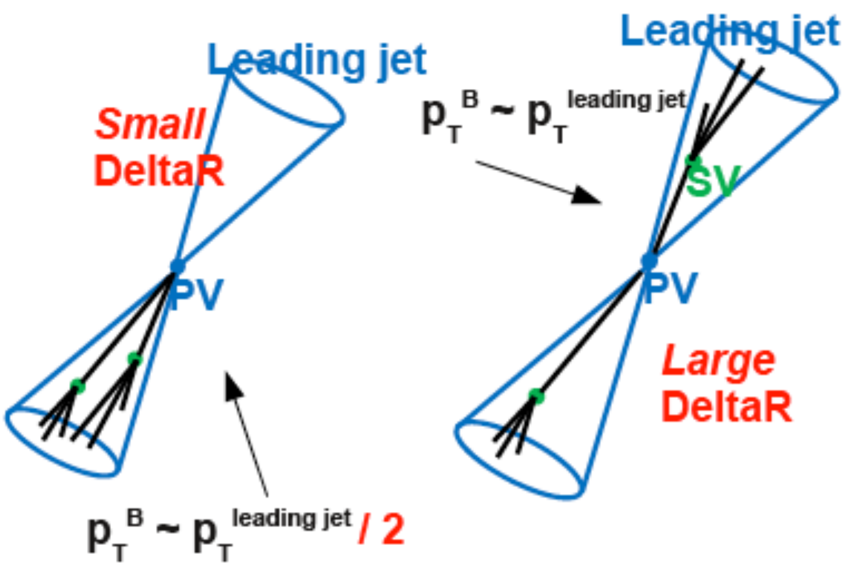
- W – "hybrid" MET fit
  - Unbinned ELM fit with static signal / parametrized background shapes
  - Signal + EWK backgrounds : POWHEG
  - QCD background : Rayleigh distribution
    - Functional form from first principles

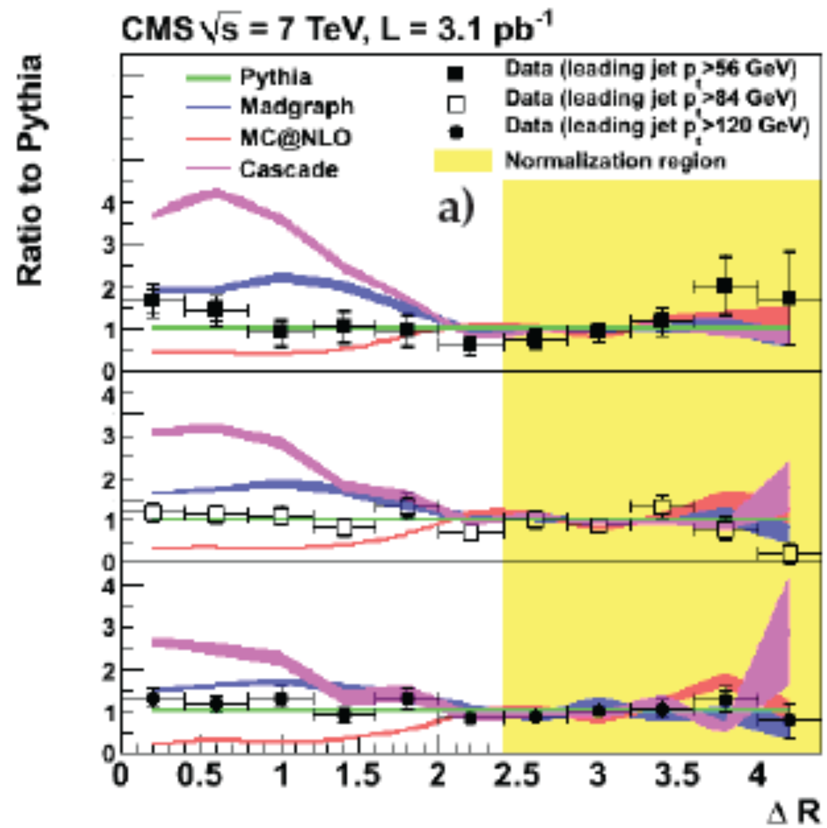
$$f(x) = Cx \exp\left(-\frac{x^2}{2(\sigma_0 + x\sigma_1)^2}\right)$$

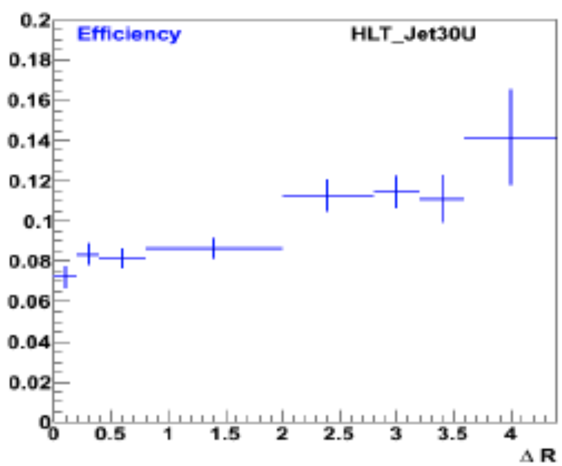
    - Tail parameter σ1 for ΣET dependence
    - σ_1 fixed to value found in anti-selected
- Z – Simple counting
  - Again, negligible background in 198 nb^{-1}
  - Estimate both Electroweak and QCD background from MC



Capability to reconstruct 2 vertices in the same jet







Angular Correlation between the two b hadrons

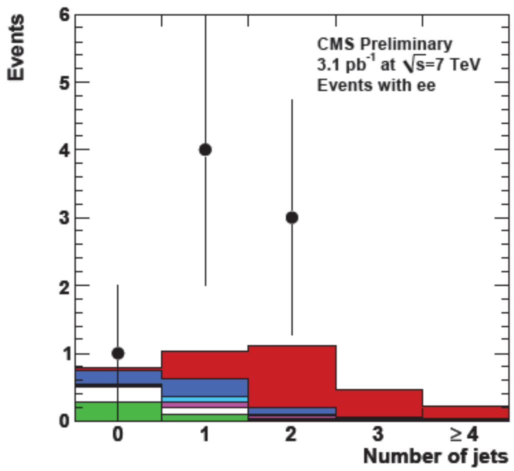
ttbar : leptons and jets

- Muon:
  - global + tracker muon;
  - $|d_0|$ <0.02 ; P_T >20;
  - Relative isolation < 0.05
- Electron:
  - spike removal; EE misalignment correction; Veto conversion; simple cut based WP90;
  - Relative isolation < 0.1
- Jets:
  - antiKT5 JPT or PFlow
  - P_T > 30 ; |h| < 2.5
  - b-tag requirement: trackCounting, SSV etc.

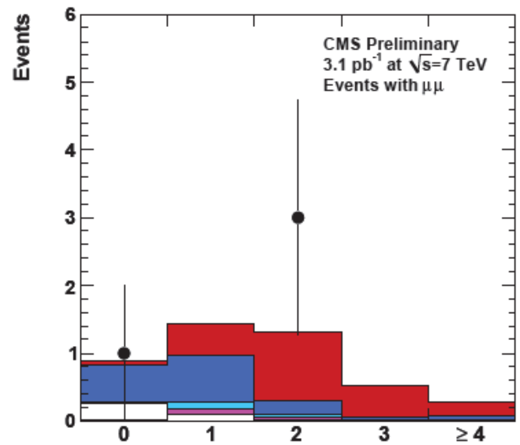
RelIso = (trackIso + HCalIso + ECalIso)/P_T

ttbar dileptonic: Jet multiplicity

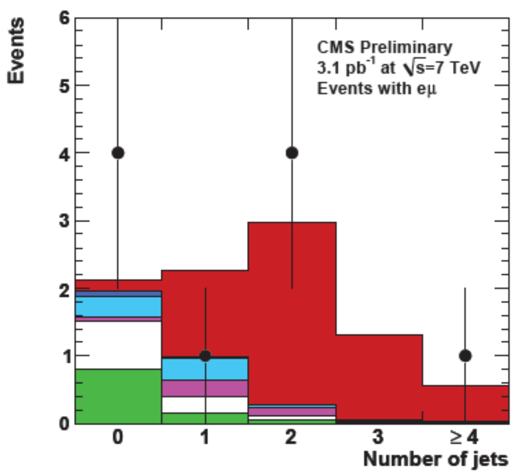
ee



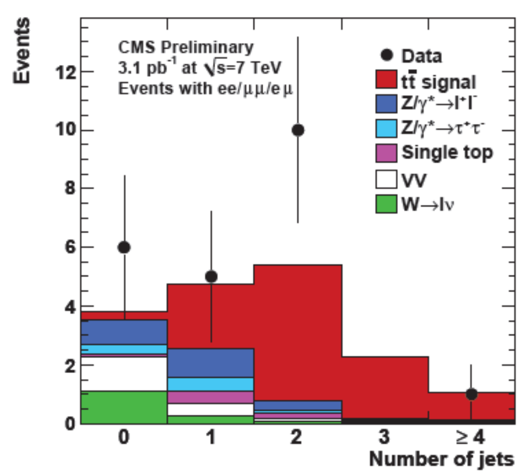
mm



em



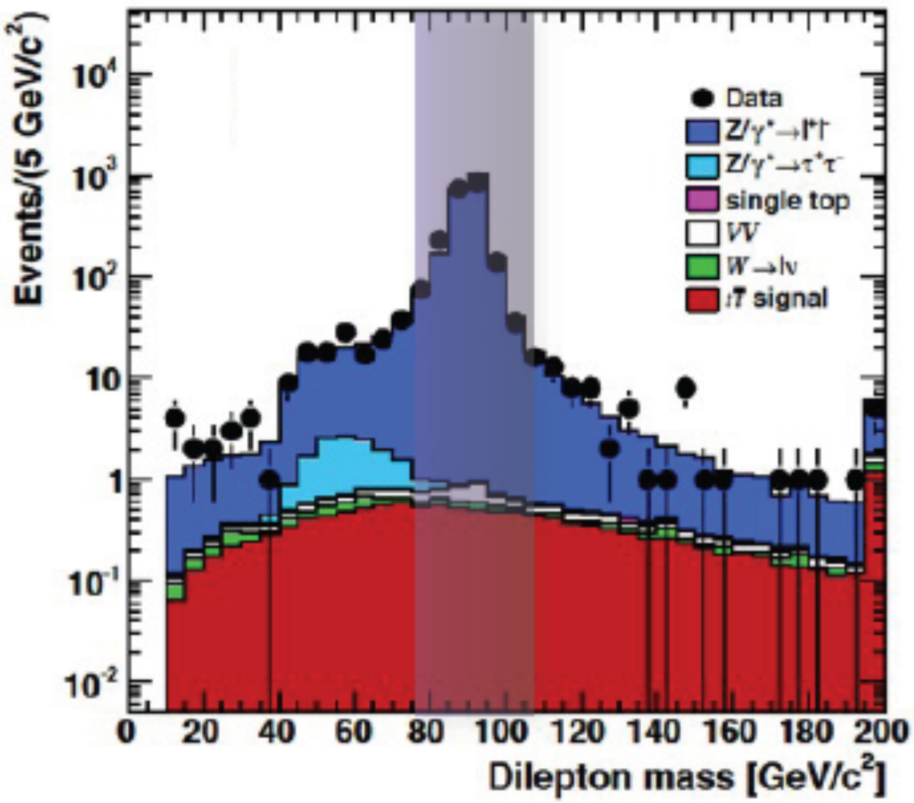
All



- After requiring n jets ≥ 2:

Process	ee	$\mu\mu$	$e\mu$	all
Dilepton $t\bar{t}$	1.50	1.68	4.48	7.65
VV	0.03	0.03	0.08	0.13
Single top - tW	0.05	0.05	0.15	0.25
Drell-Yan $\tau\tau$	0.04	0.07	0.07	0.18
Drell-Yan $ee, \mu\mu$	0.14	0.28	0.01	0.43
Non-dilepton $t\bar{t}$	0.05	0.01	0.09	0.15
W+jets	0.03	< 0.01	0.06	0.09
Total simulated	1.8	2.1	4.9	8.9
Data	3	3	5	11

ttbar dileptonic: background estimation for g/Z $\to \ell\ell$



- Take $Z \to \ell\ell$ in the region vetoed by the cuts
- Extract the number of events in the signal region using the MC $M_{\ell\ell}$ shape
- The number of non Drell-Yan events in the vetoed region is estimated from the *em* signal channel

$$N_{out}^{e^+e^-} = N_{out/in}^{e^+e^-}(N_{in}^{e^+e^-} - 0.5 N_{in}^{e^\pm\mu^\mp} k_{ee})$$

$$k_{ee} = \sqrt{\frac{N_{out}^{e^+e^-,loose}}{N_{out}^{\mu^+\mu^-,loose}}}$$

$$R_{out/in} = N_{DYMC}^{out} / N_{DYMC}^{in}$$

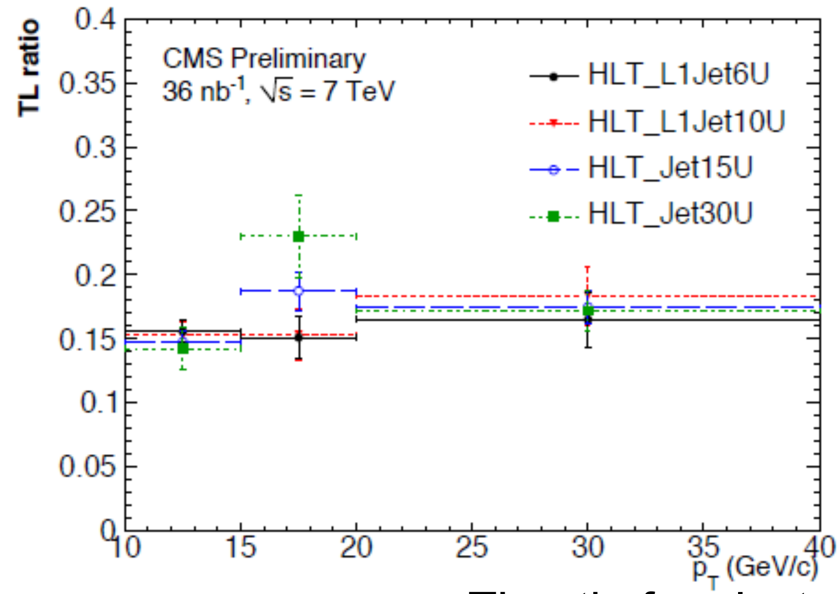
ttbar dileptonic: background estimation for W jets/QCD

- MC estimates of events with fake/ non-prompt leptons depend crucially on the detector simulation

$$N_{nn}^{QCD} = \sum_{i,j} \frac{TL_i TL_j}{(1-TL_i)(1-TL_j)} N_{nn}^{ij}$$

$$N_{nn}^{WJets} = \sum_{i,j} \frac{TL_i}{(1-TL_i)} N_{\overline{nn}}^{ij}$$

- We extract them from data:
  - We define a "Fakeable Object" (FO), with similar but looser selection than our muon / electron candidates
  - We define a scale factor, Tight-to-Loose (TL) ratio, in h, p_T bins
  - We derive TL from a jet-triggered sample requiring an offline jet passing some threshold



TL ratio for electrons

ttbar dileptonic: top mass with Matrix Weighting Technique (MWT)

- 2leptons and 2 b-jets: For every lepton-jet permutation and top mass hypothesis:
  - constrain the p_T of top and anti-top by ellipses in the p_x-p_y plane
  - Up to 4 intersections →up to 4 solutions for the momenta (Dalitz & Goldstein, PRD 45, 1531 (1992))
- Iterate over top mass values from 0 to 400 GeV/c^2
  - use CTEQ6.1M to get weight
  - for each value, take the two leading jets in the event
  - smear 100 times for MC, 1000 times for data
  - Add the weights for all solutions for each value of m_{top}.
- For each event, take the value of the top mass with the highest sum of weights:

$$W = f(x) \cdot f(\bar{x}) \cdot p(E^*|m_{top}) \cdot p(\bar{E}^*|m_{top})$$

- Details in CMS AN-259/10

ttbar dileptonic: top mass with Full Kinematic Reconstruction (KIN)

- 2 leptons and 2 jets: for each lepton-jet permutation solve the kinematic equations with numerical techniques 10^4 times
  - To solve the equations extract randomly Pz from gaussian distribution(MC)
  - Smear the original Jet energy / MET scale
  - After varying the jet energy scales of the two jets correct the missing energy accordingly
  - Accept solutions for which $|m_{t1} - m_{t2}| < 3\ GeV/c^2$

- Select lepton-jet combination which yields more valid solutions

- Rank multiple solutions using M_{tt} : soft value chosen.

- Details in CMS AN-198/10