Observation of W and Z candidates with CMS experiment

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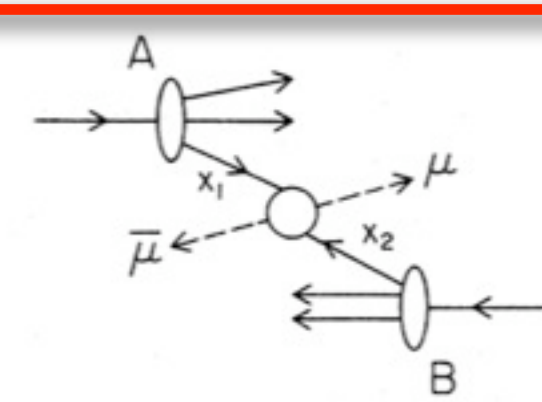
EWK in the LHC era

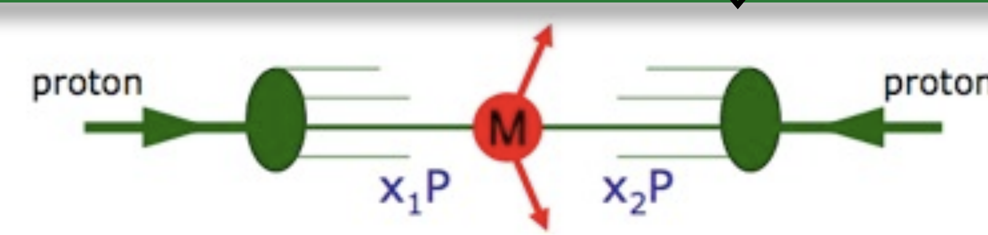
- Production of W,Z bosons is an important process at LHC
  - measurement of M_W, W width, charge and polarization asymmetries
  - W and Z cross-section measurement:
    - background normalization for Higgs, new physics searches
    - luminosity measurement, energy/momentum calibration
  - Parton Density Functions at LHC scale



$Q^2 = x_1 x_2 s$

Drell, Yan,
Phys. Rev. Lett. 25, 316–320 (1970): study of A,B parton structures

- Vector Boson (V) + jets:
  - crucial test of QCD
  - probe for new physics: new physics models predict V+multi-jets productio



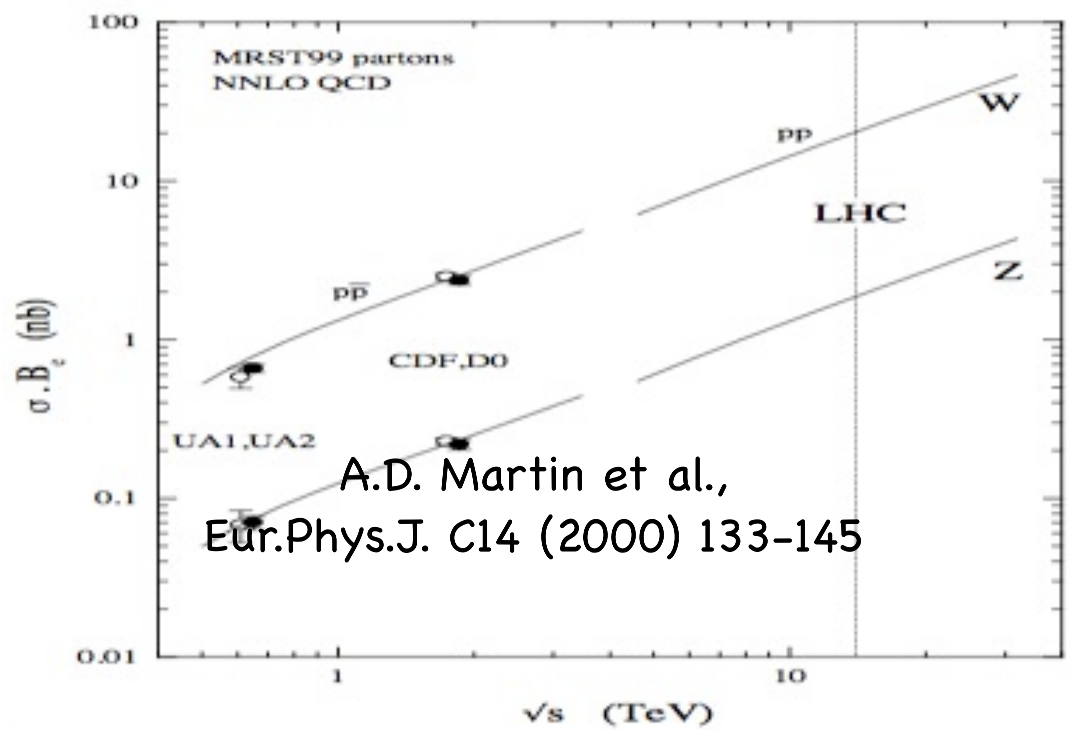
Tevatron, LHC (nowadays): study of quark-gluon scattering to create new particles (W, Z, Z'...)

W, Z production at LHC

- Large cross sections, very precise prediction (2-3% level)

Process ($\sqrt{s}$=7 TeV)	$\sigma_{(CTEQ6.6)}$	PDFs ⊕ α_s uncertainties
W^-	38.0 nb	+1.33 nb -1.39 nb
W^+	56.05	+1.90 nb -1.96 nb
Z^0	28.11	+0.91 nb -0.95 nb

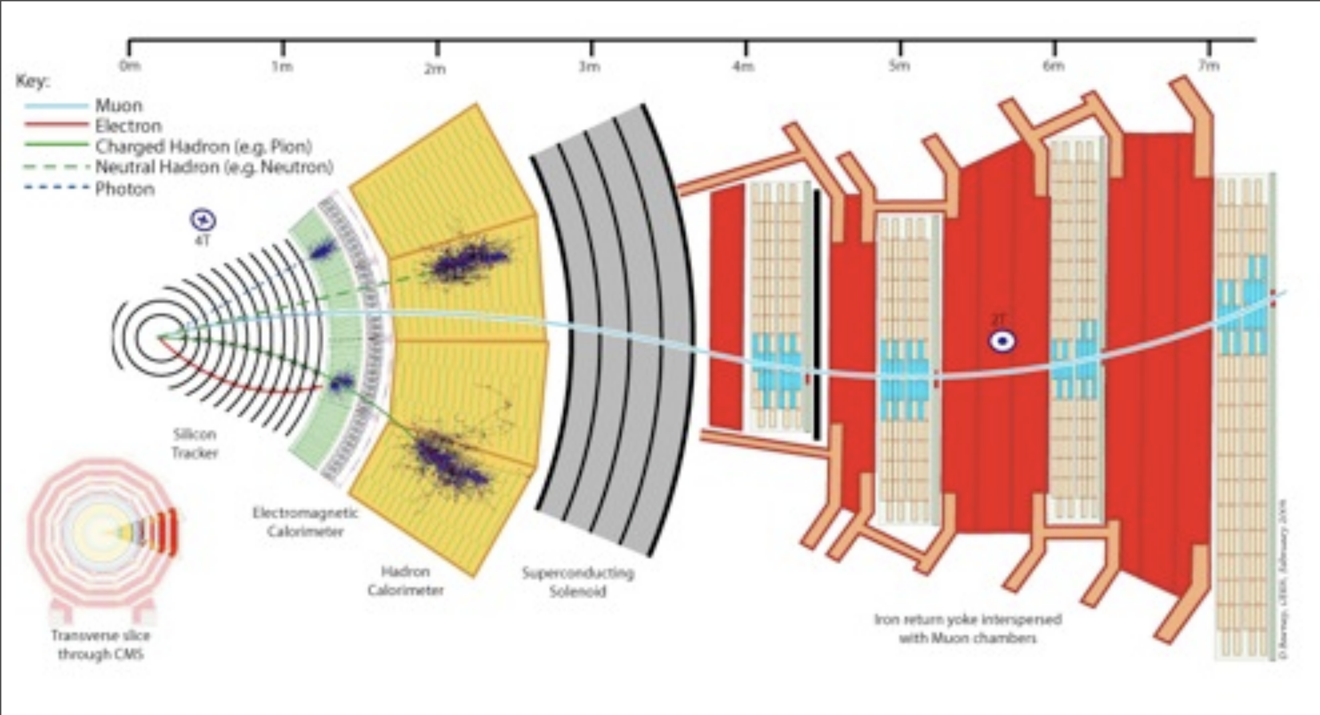
W,Z cross section vs $\sqrt{s}$

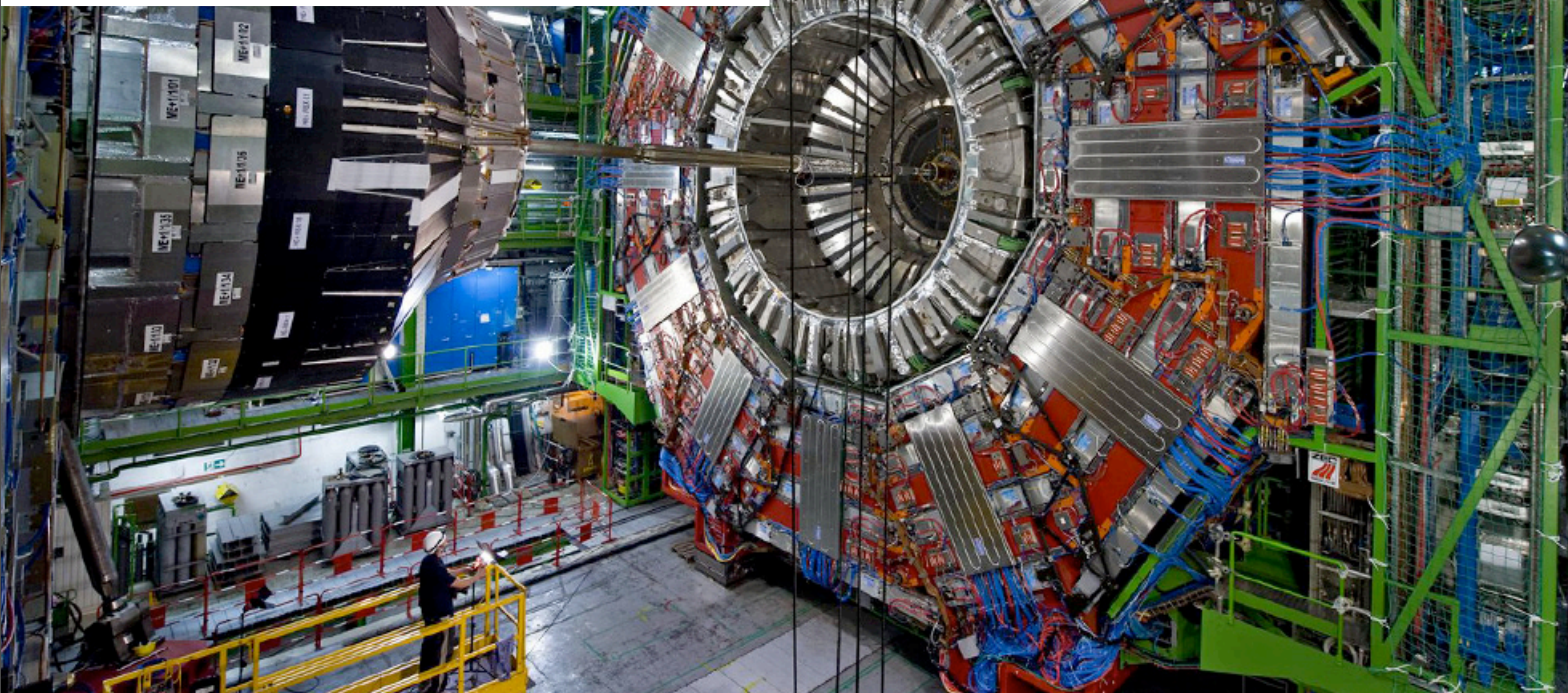


A.D. Martin et al., Eur.Phys.J. C14 (2000) 133-145

- W,Z+jets production:
  - adding an extra jet costs $o(\alpha_s)$ in cross section
    - the scaling is a test of QCD
    - W,Z multi-jet probe new physics contribution
  - LHC can rapidly access high (≥3,4) jet multiplicities

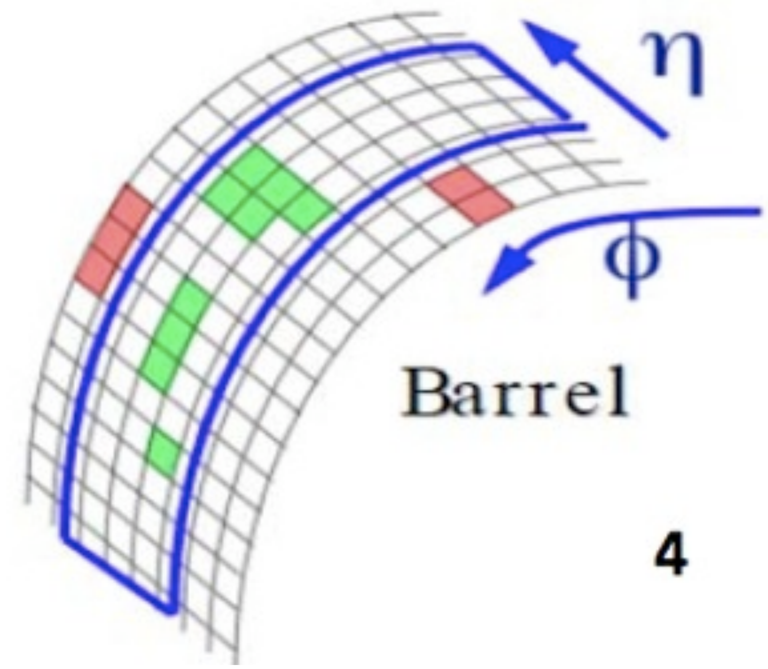
CMS detector at work: the building blocks with 7 TeV data





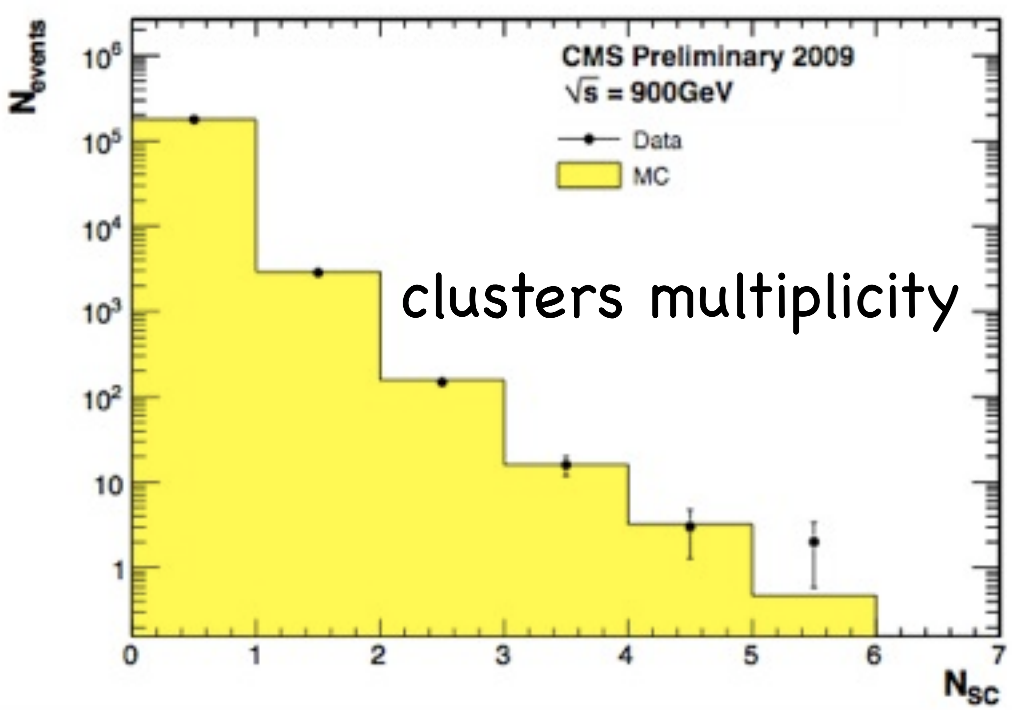
electron ECAL clustering

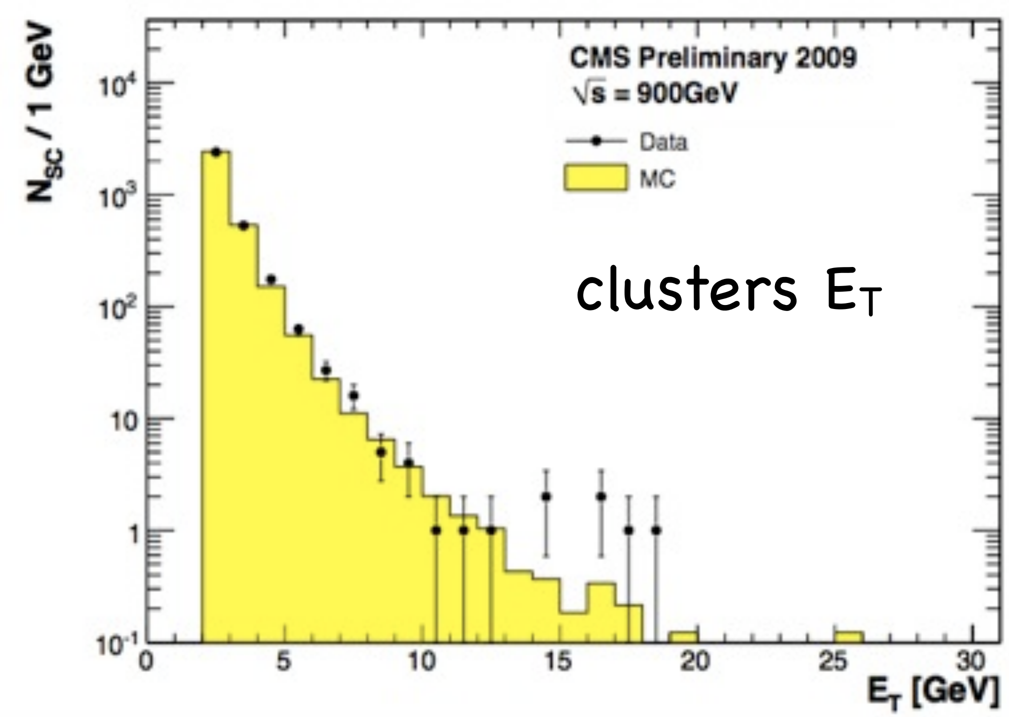
- High granular and precise e.m. calorimeter allows:
  - electron energy measurement through dynamic clustering (collection of bremsstrahlung radiation along Φ)
  - electron-jet separation through cluster shape in η
  - good agreement between data and MC up to the energies reached so far



see P. Musella talk on electron and photons in CMS

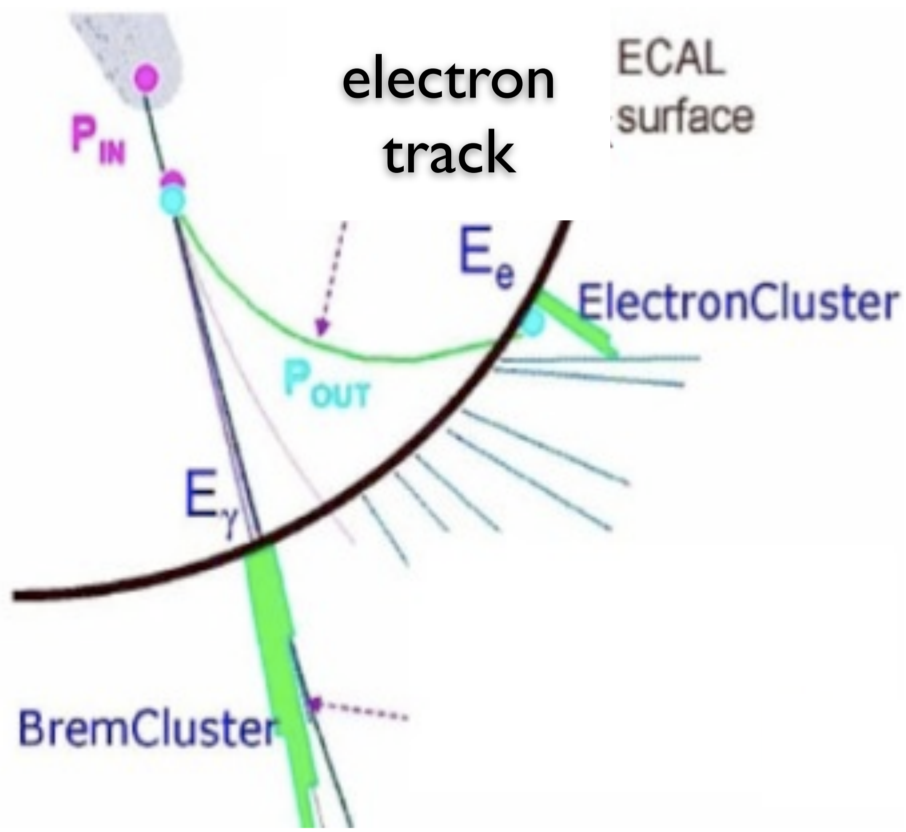
900 GeV
minimum bias events:



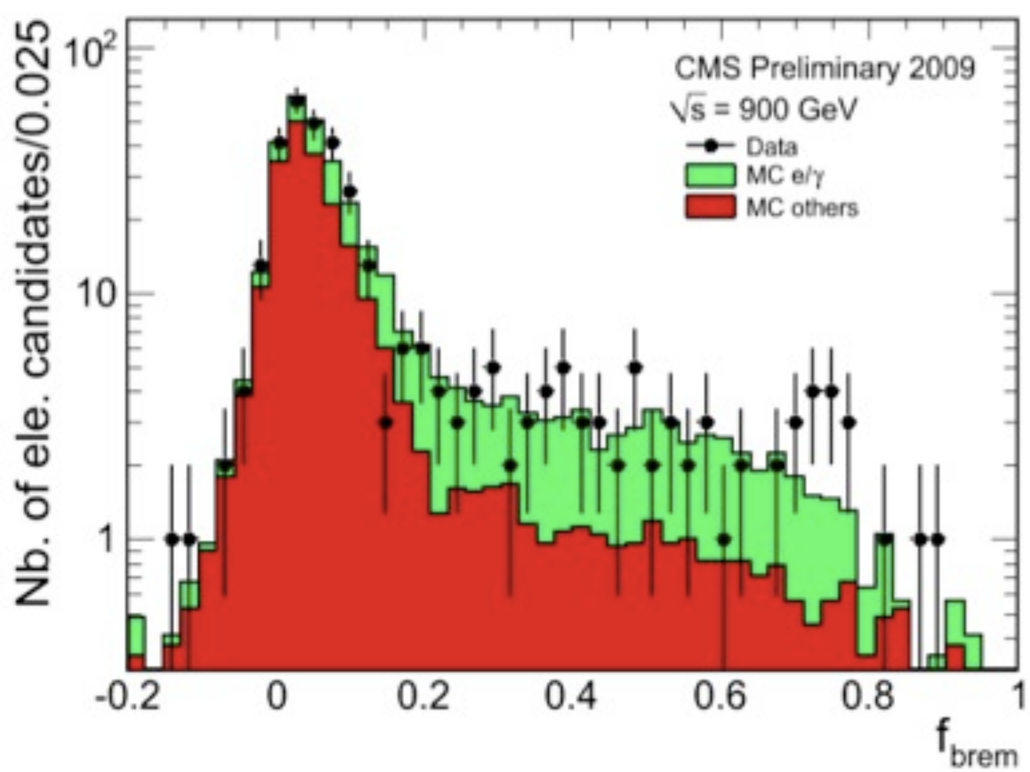


electron tracking

- high granular tracking system allows:
  - electron vertex determination
  - estimation of fraction of energy lost by bremsstrahlung in tracker: f_{brem}
  - precise track-ECAL matching



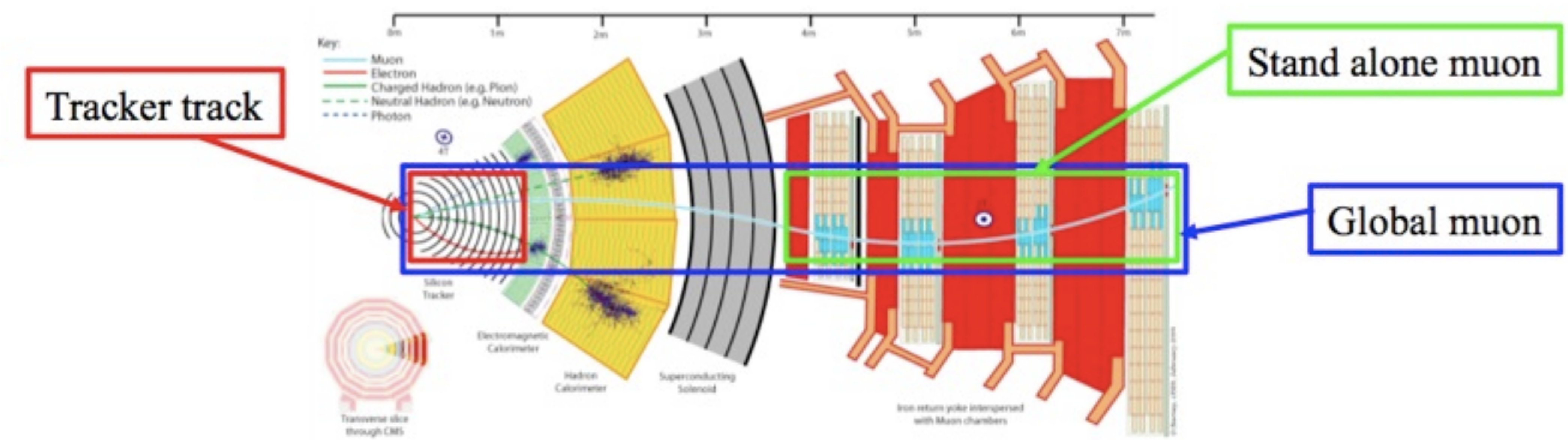
$f_{brem}=(p_{in}-p_{out})/p_{in}$



- 900 GeV / 2.36 TeV / 7 TeV data commissioning:
  from low p_T electrons (mainly from γ conversions)
  to the prompt high p_T ones characteristic of W's and Z's

muon reconstruction

- Three different subsystems to reveal muons: Drift Tubes ($|\eta|<1.2$), Cathode Strip Chambers ($0.9<|\eta|<2.4$) and Resistive Plate Chambers ($|\eta|<1.6$)
- two complementary approaches: “standalone” (outside-in) and “tracker” (inside-out)



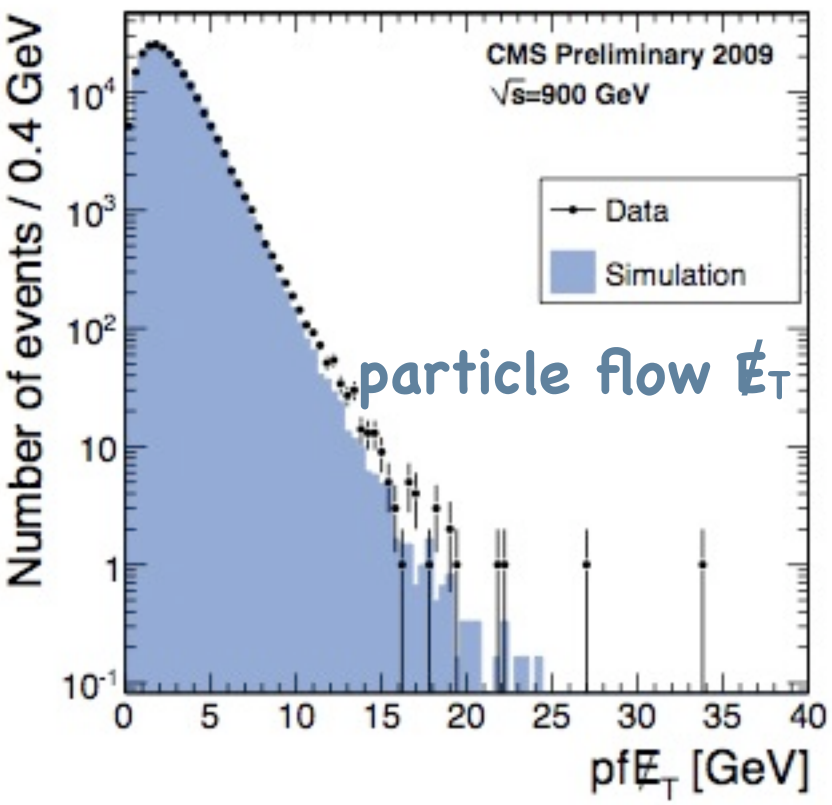
- goals momentum measurement:
  - 1% for $p_T \approx 100$ GeV, 10% for $p_T \approx 1$ TeV
  - good alignment already after the cosmic rays run:
    - resolution($\phi_{\text{Drift Tubes}}$) ≈ 200 μm (close to expected CMS precision)

$\not{E}_T$ commissioning

- ν momentum in W→lν estimated from energy unbalance in the transverse plane
  - main rejection of QCD di-jets and Drell-Yan (no real $\not{E}_T$)
  - necessary for M_W measurement (definition of $m_T(W)$)
- background rejection improves with $\not{E}_T$ resolution
  - three methods exploit increasing number of informations:
    - pure calorimetric, track-corrected, full particle flow

see Daniele Benedetti's talk on
Particle Flow in CMS

  - detector (HCAL+ECAL noises) and beam background noise cleaning applied successfully

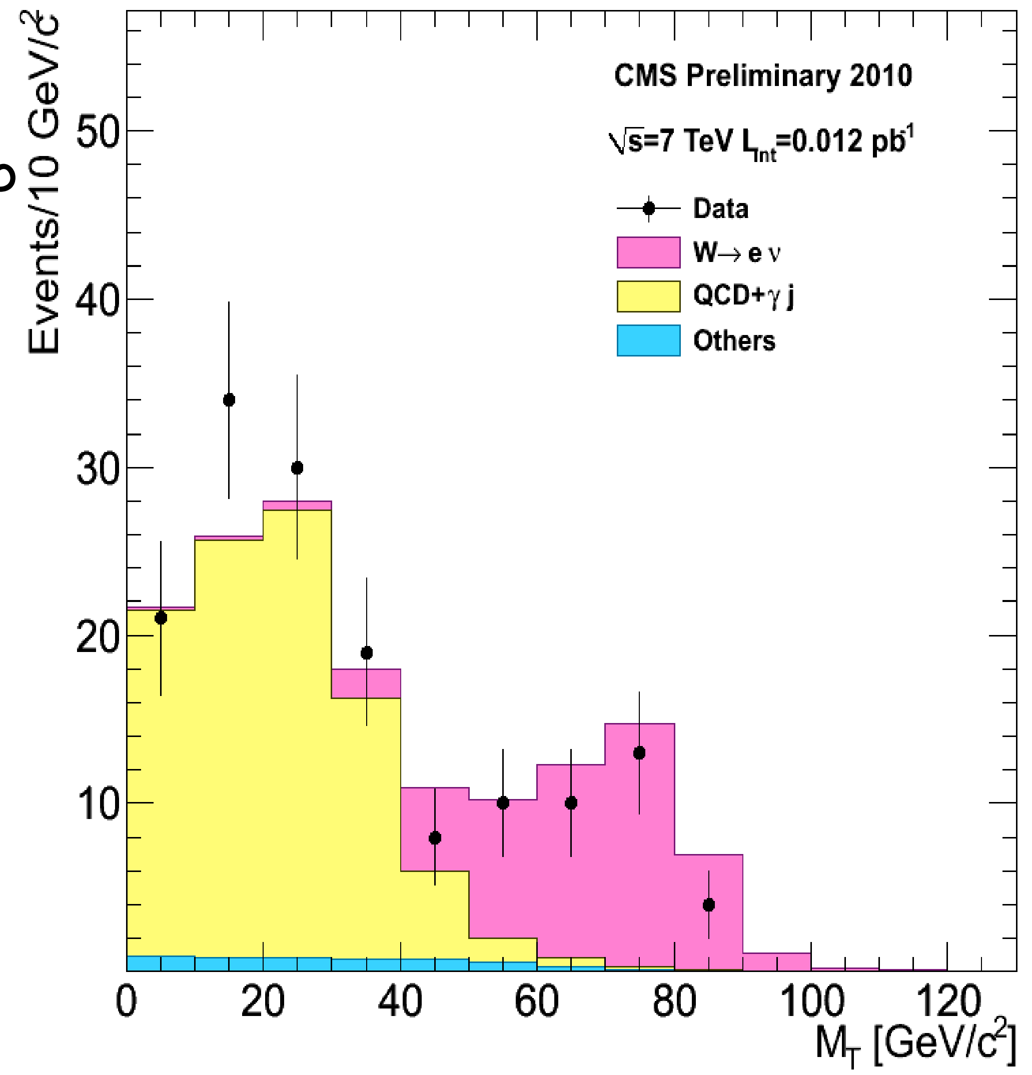


CMS “detectors” at work: looking for candidates

W→eν selection

- Single photon trigger used on first 7 TeV data
- W→eν:
  - electron reconstruction (p_T>20 GeV and $|\eta|$<2.5) and identification (to reject fakes from di-jets):
    - track - ECAL cluster matching: geometrical and E/p
    - cluster shape variables
    - electron isolation (low activity in tracker, ECAL, HCAL around the electron)
  - veto on second electron (to reject Z's)
  - high transverse mass

W→eν
L_{int}=12 nb^{-1}

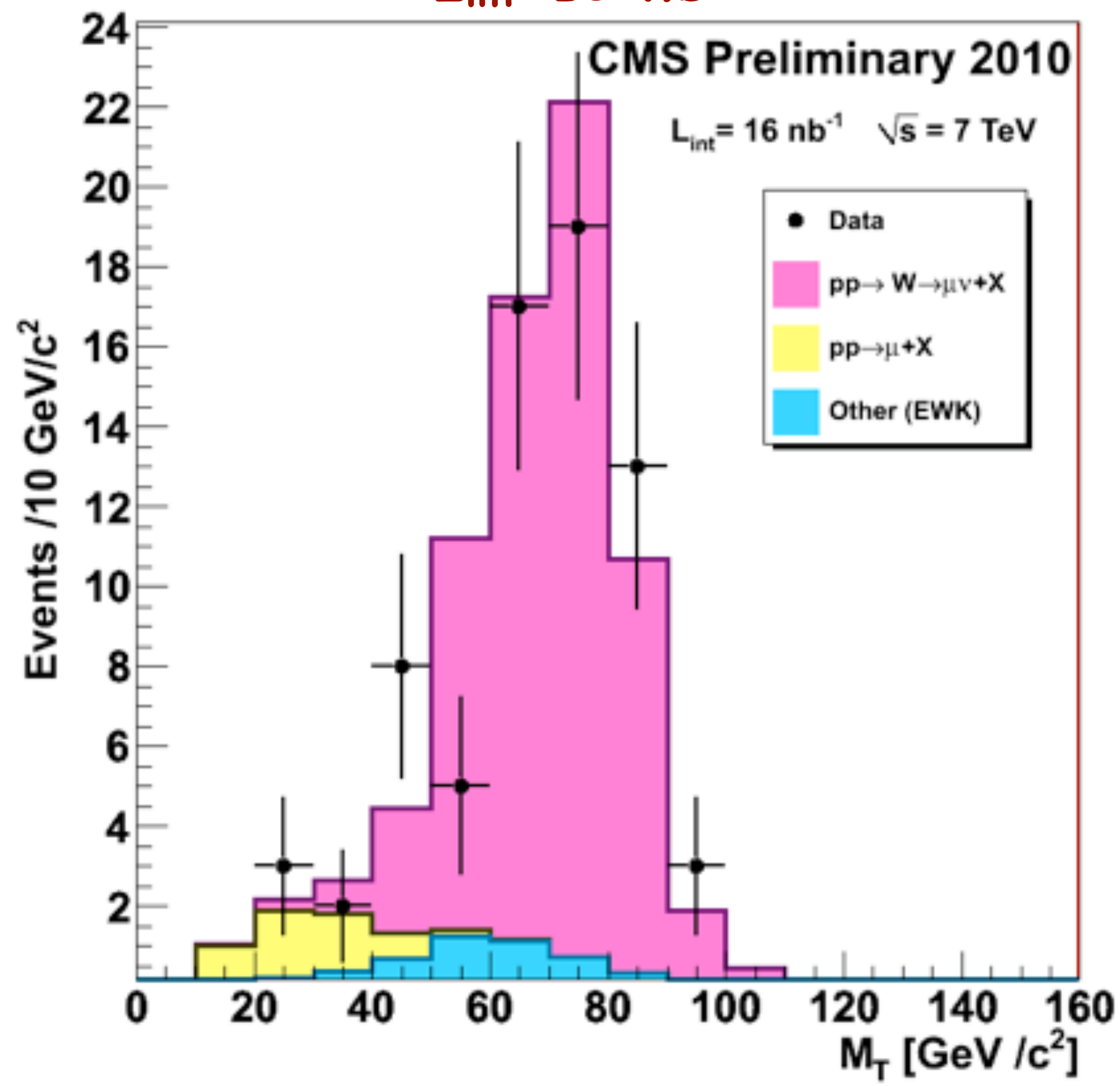


- On 7 TeV data: L_{int}=12 nb^{-1}:
  - 94 W candidates observed
  - 37 signal+background events with m_T>50 GeV (clean signal region)

W→μν selection

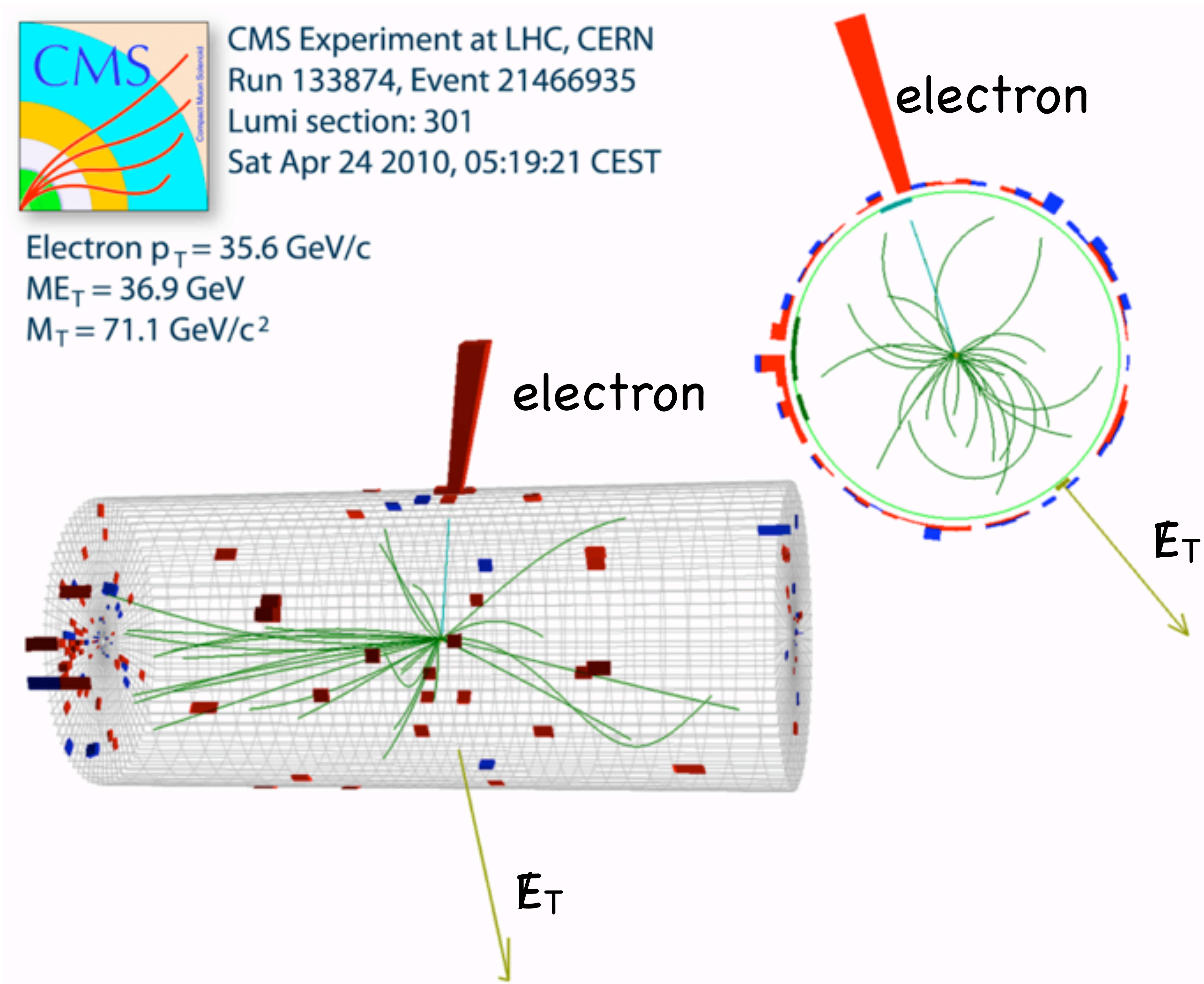
- Single non isolated muon trigger used
- W→μν:
  - exactly one muon (p_T>25 GeV, |η|<2.1) with track quality criteria
  - small transverse impact parameter with beam spot required to reject cosmic muons
  - muon isolation criteria applied
  - m_T(W)>50 GeV to define the signal region
- On 7 TeV data: L_{int}=16 nb^{-1}:
  - 70 events selected
  - 57 signal+background events with m_T>50 GeV (clean signal region)

W→μν
L_{int}=16 nb^{-1}



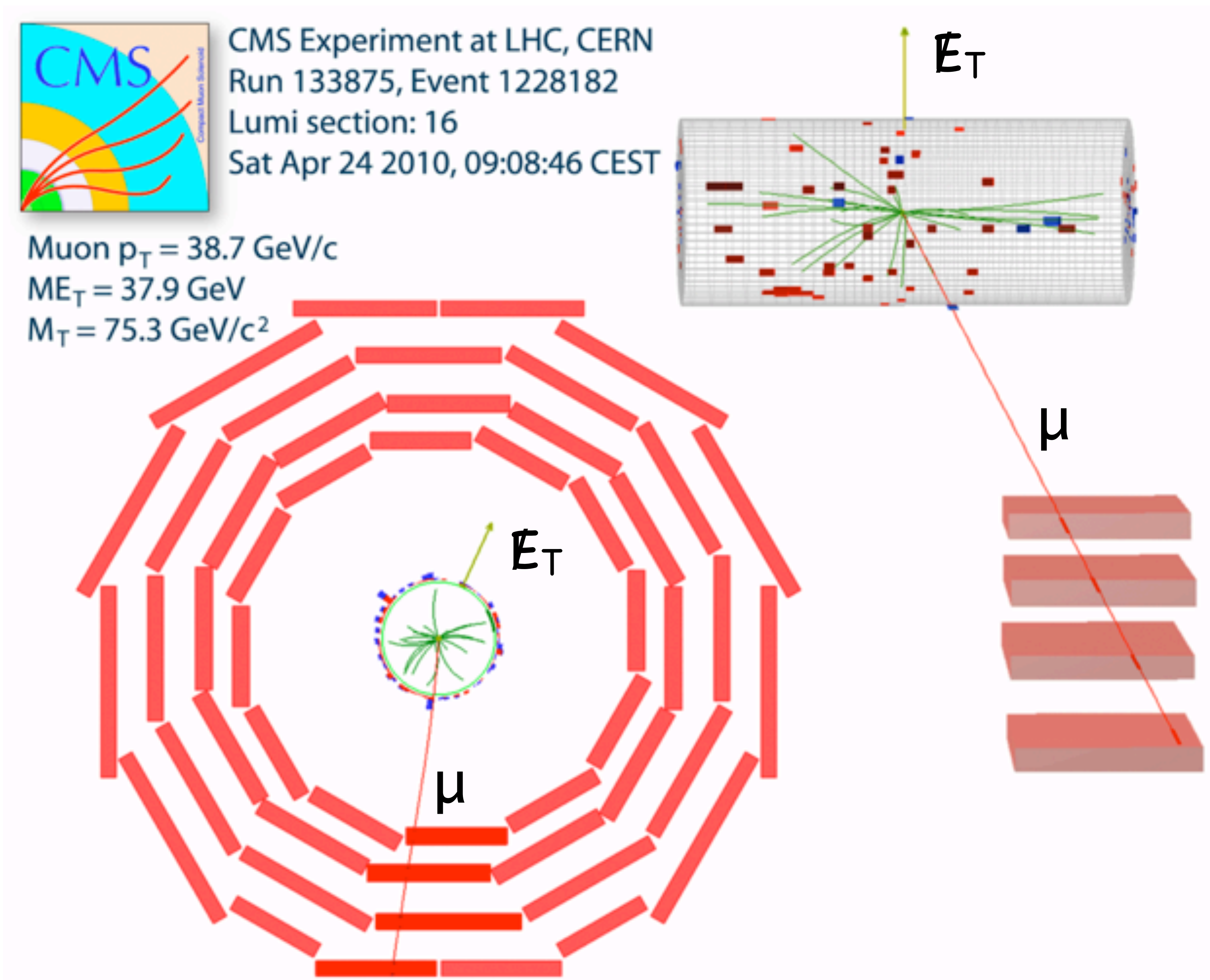
W→eν candidate

- CMS W→eν candidate in 7 TeV data



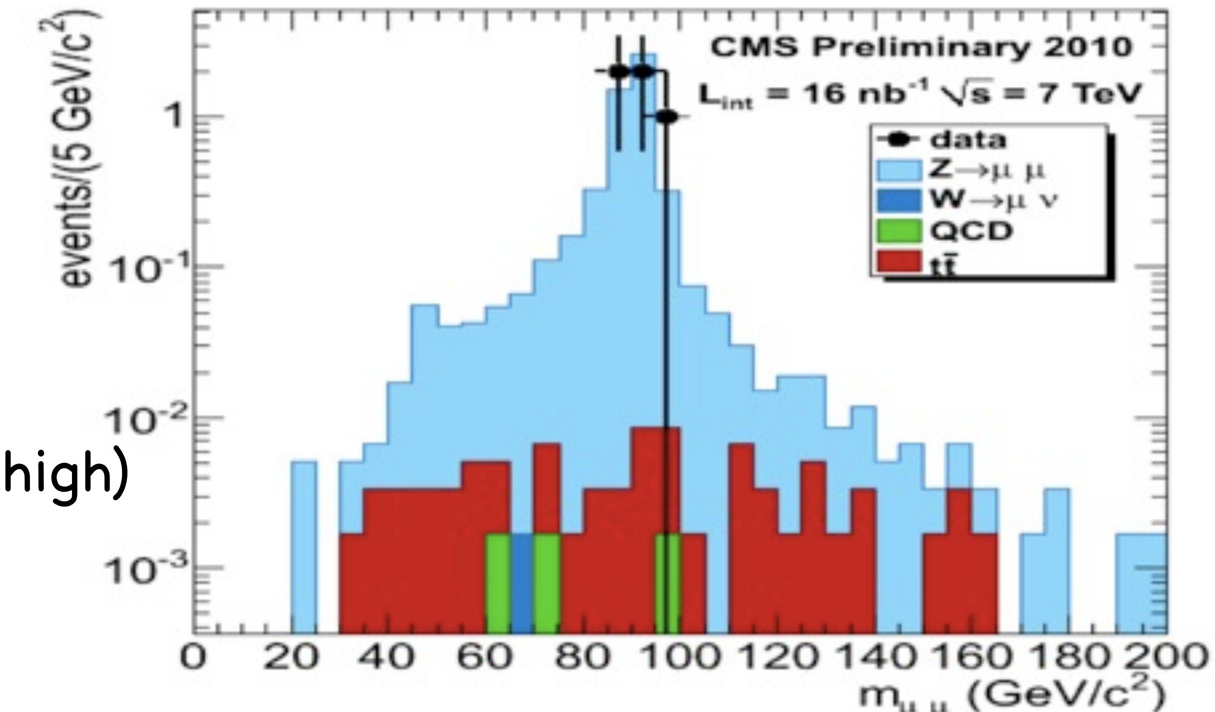
W→μν candidate

- CMS W→μν candidate in 7 TeV data

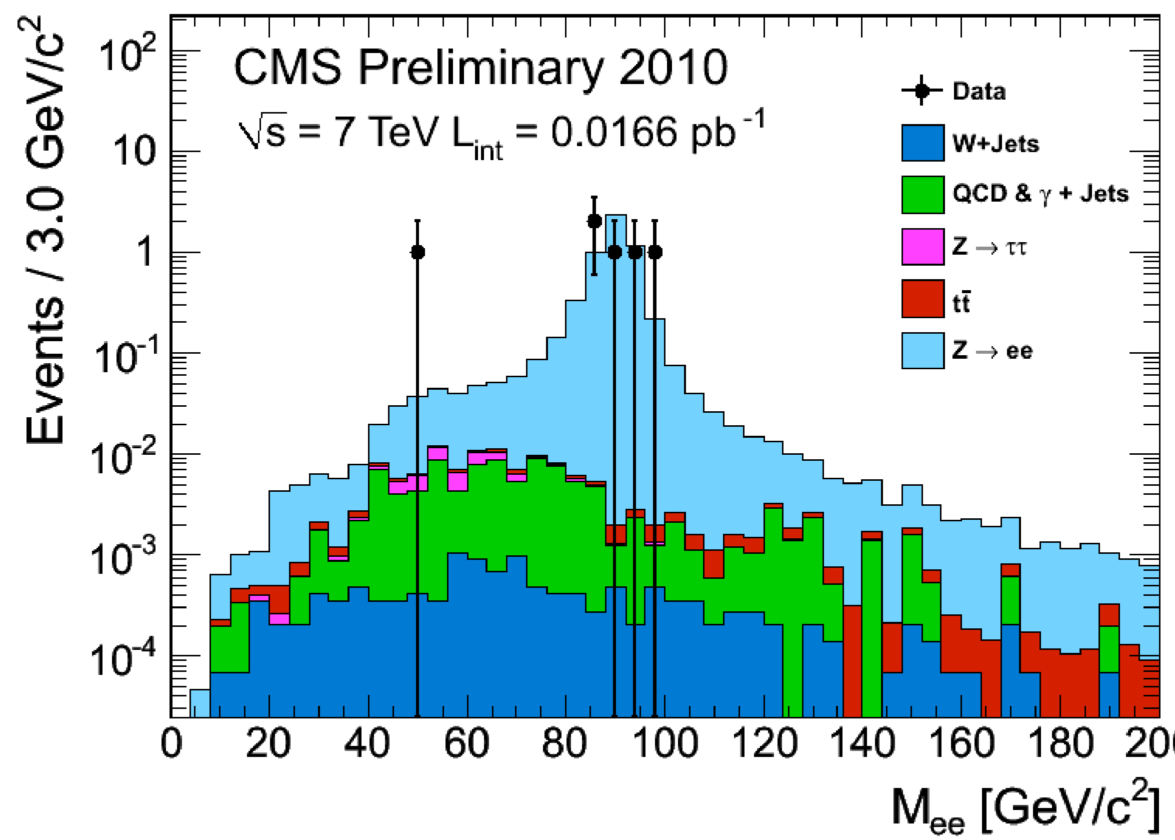


Z→ll (l=e,μ) selection

- Single electron and muon triggers
- $Z \to e^+e^-$:
  - two electrons with $p_T > 20$ GeV and $|\eta| < 2.5$
  - loose electron ID and isolation (keep efficiency high)
  - $70 < m_{ee} < 110$ GeV/c^2
  - QCD ≈ 0.35% of Z, EWK background estimated from MC

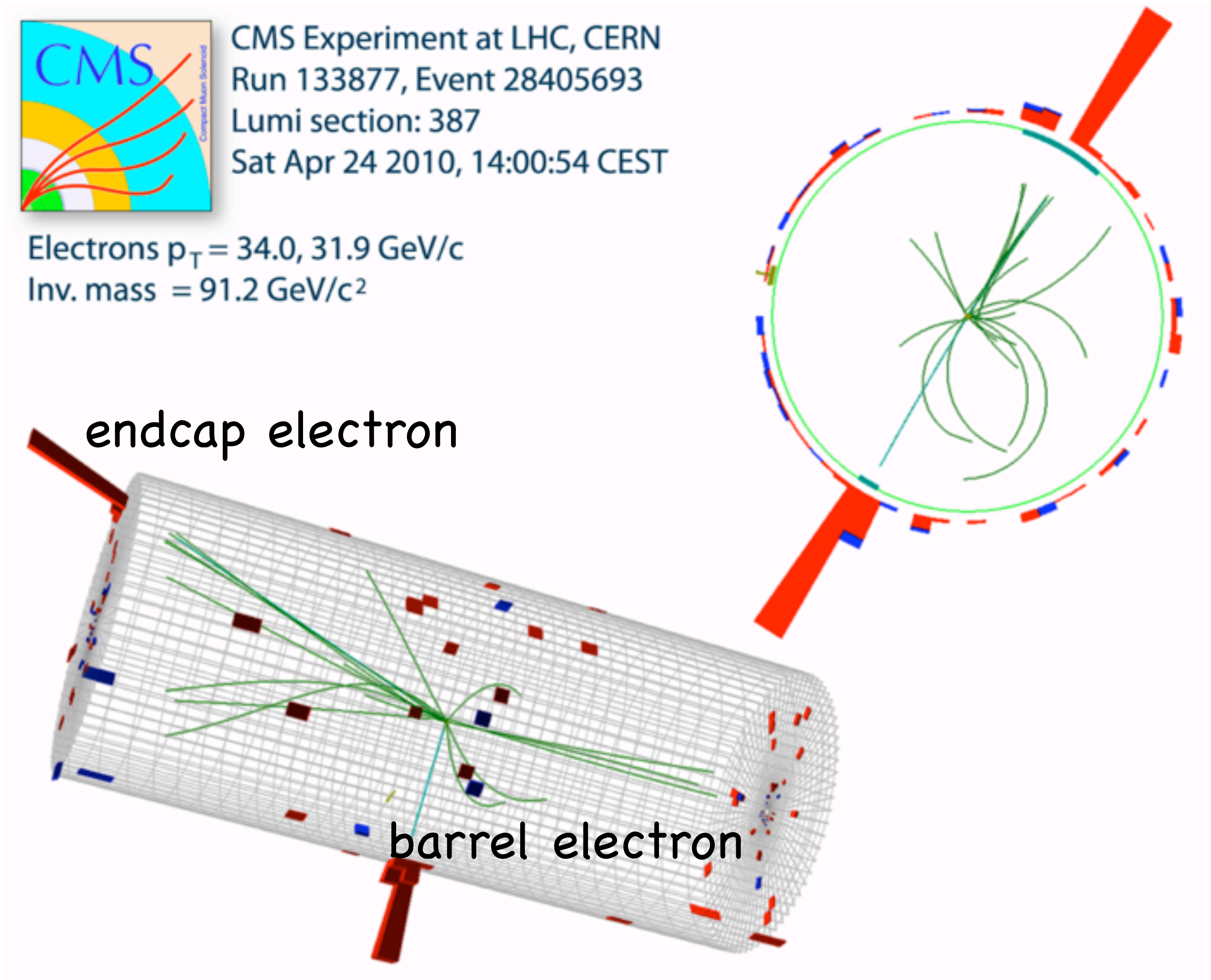


- $Z \to \mu^+\mu^-$:
  - two opposite sign muons with $p_T > 15$ GeV, $|\eta| < 2.0$
  - loose muon isolation in tracker
  - expected cross section uncertainty (statistical) ≈ 2-3% with 5 pb^{-1}



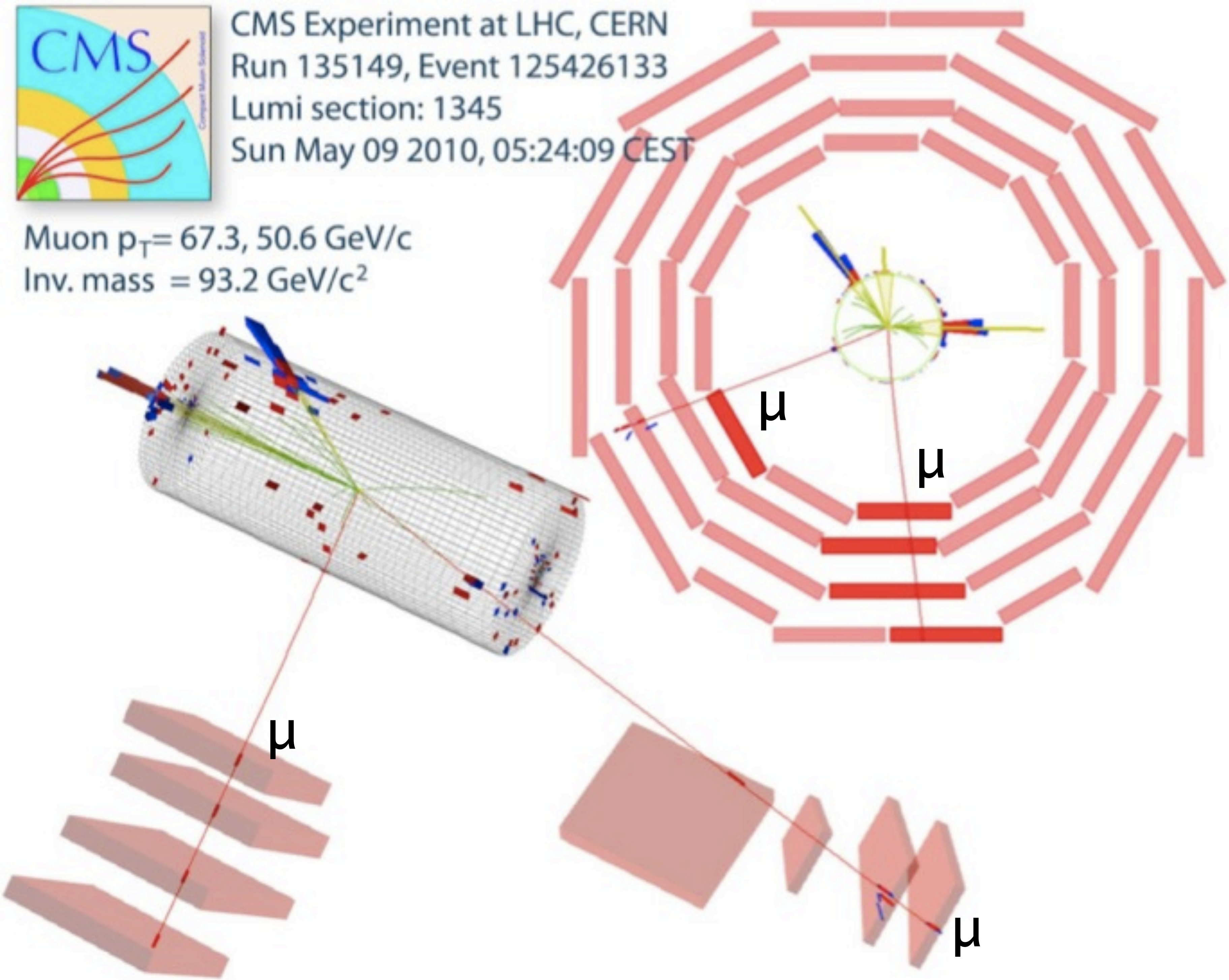
$Z \to e^+e^-$ candidate

- CMS $Z \to e^+e^-$ candidate in 7 TeV data



Z→μ⁺μ⁻ candidate

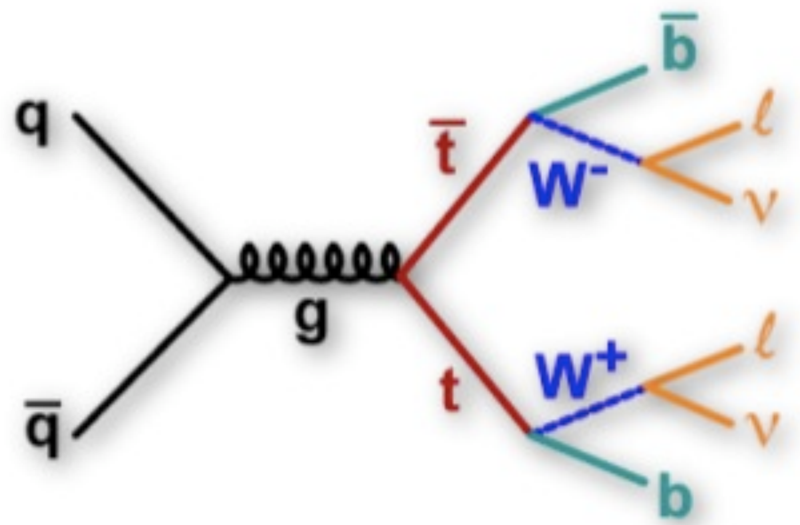
- CMS $Z \rightarrow \mu^+\mu^-$ candidate in 7 TeV data

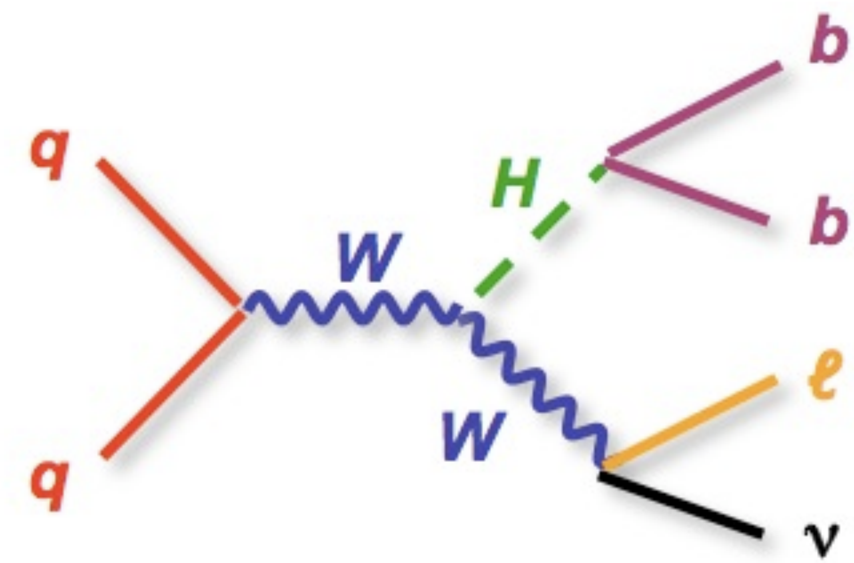


The road to discovery with W and Z... + jets!

W,Z+jets motivations

- W+jets have large cross section at LHC: dominant background for SM measurements: eg. ttbar, Higgs:





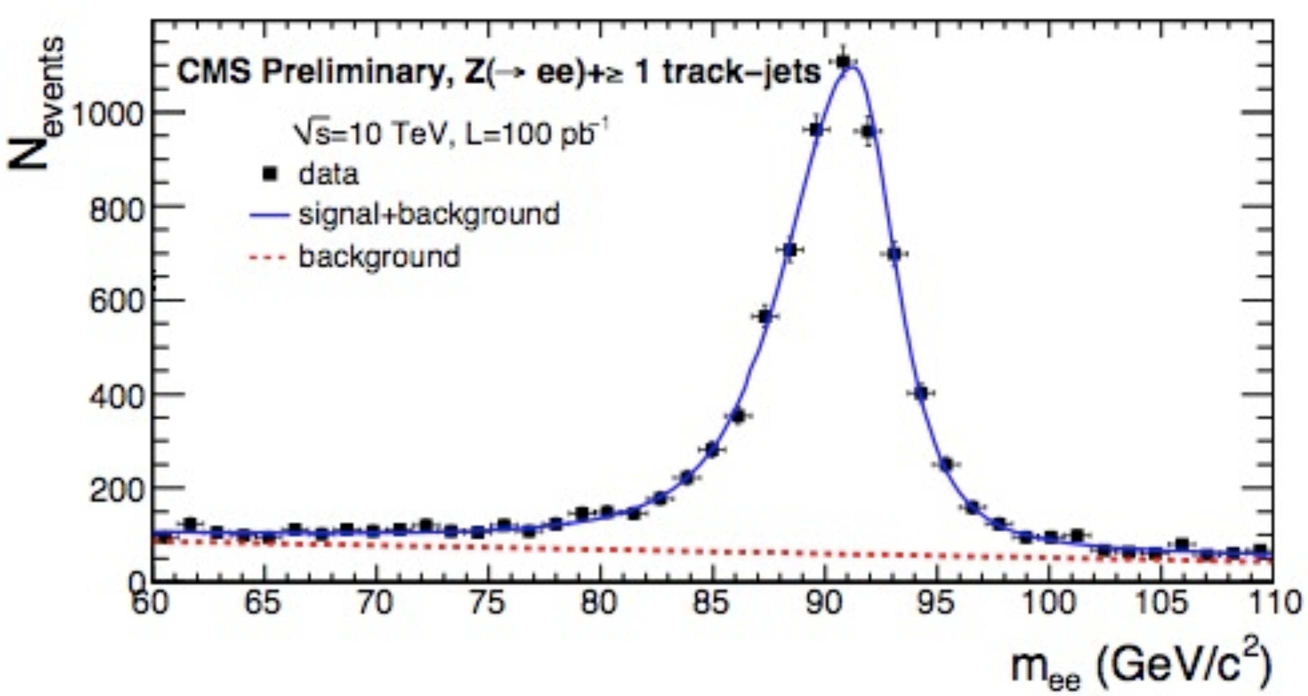
- Z(νν)+jets is a major background for $\not{E}_T$ + jets signatures
- W,Z+jets as a probe for new physics:
  new heavy particles with EWK couplings produce W/Z
  with jets from ISR or FSR
- "Berends Giele" scaling:
  - $\sigma(Z+(n+1)\text{jets})/\sigma(Z+n \text{ jets}) \approx \alpha_s$ (depends on jet definition)
  - if not, new physics?

F.A. Berends et al.:
Nucl. Phys. B357 (1991)32-64

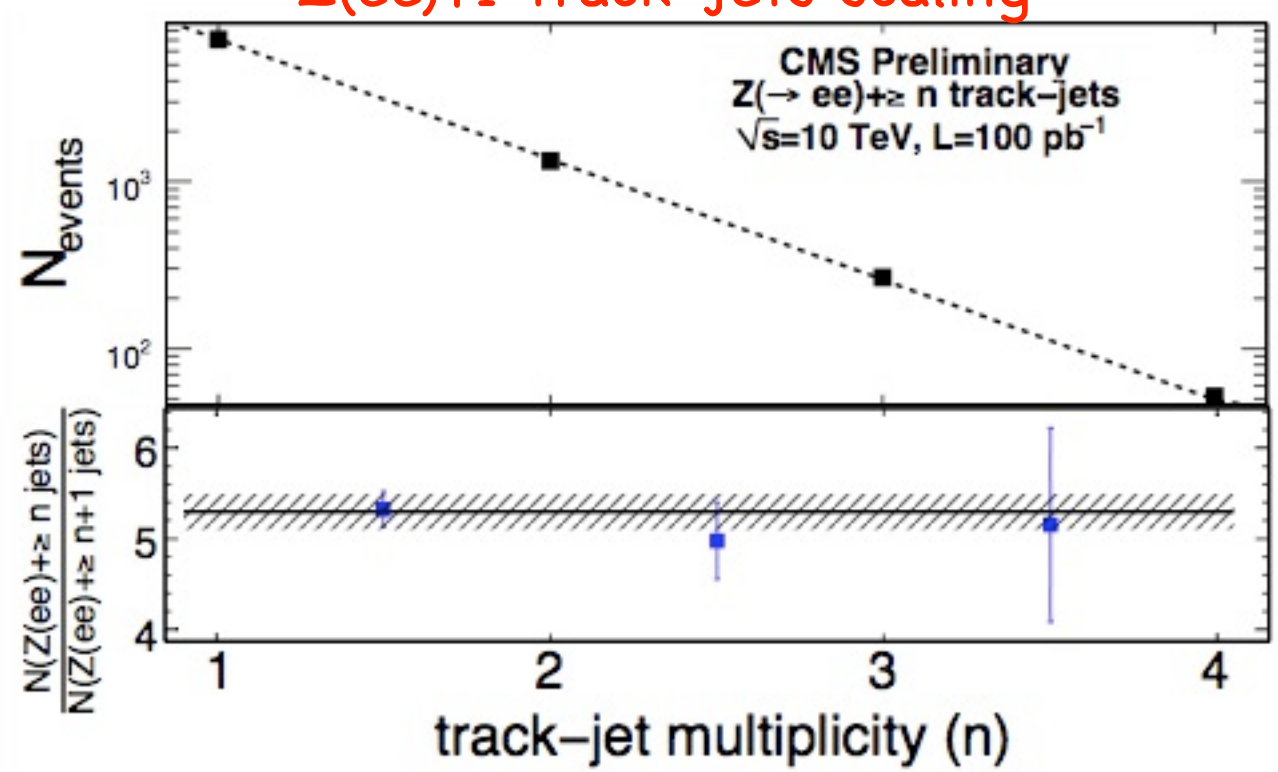
Z+jets expectations

- Z selection similar to inclusive analysis, but as loose as possible
- for jet counting, jets are reconstructed with anti-kT algorithm ($\Delta R=0.5$):
  - using calorimetric towers, tracks, or full particle flow objects
  - probing different phase spaces (p_T, η of jet): ex., track jets with $p_T>15$ GeV/c, $|\eta|<2.4$
- signal yield extracted with likelihood fits to m_{ll} for each multiplicity

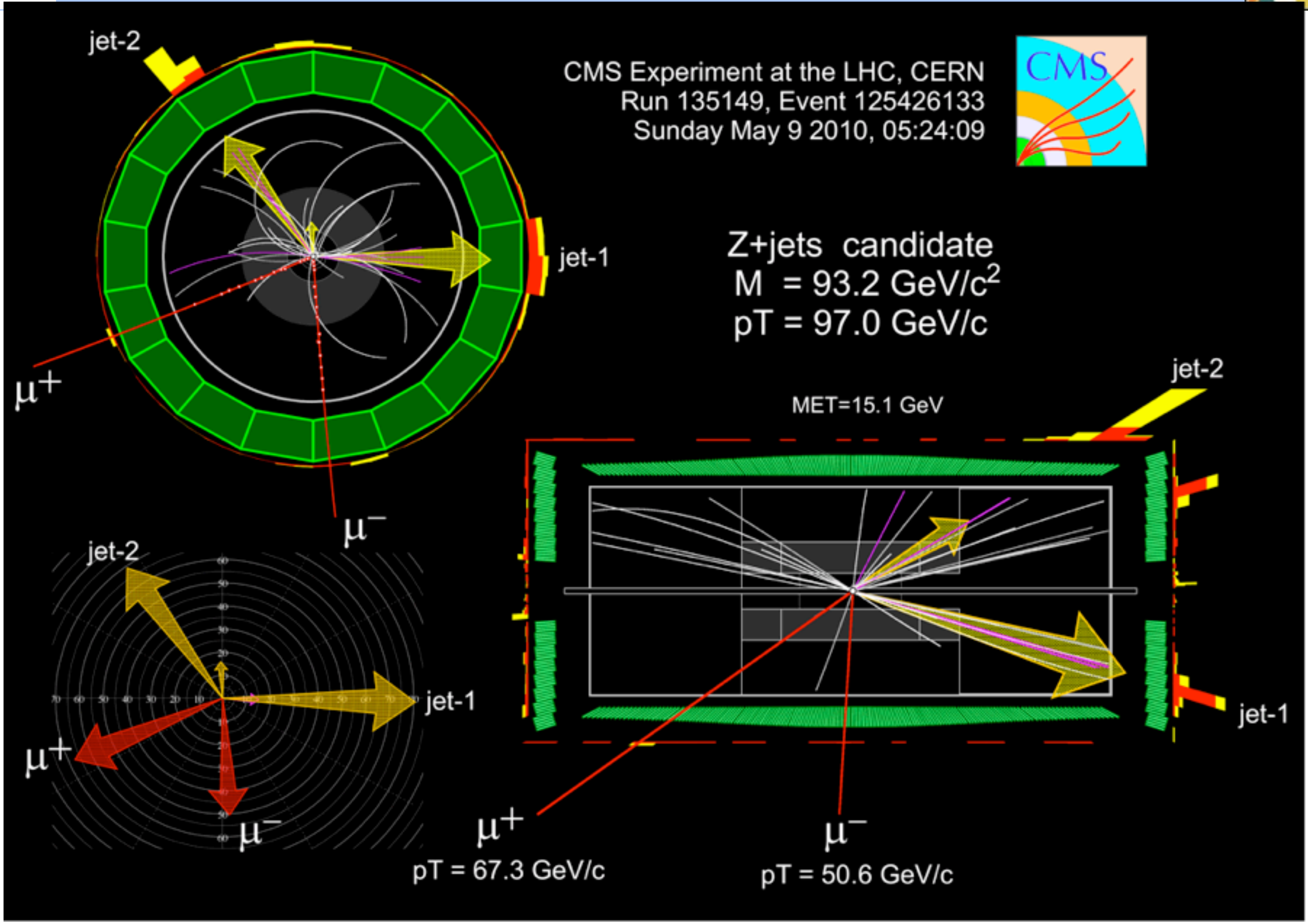
Z(ee)+≥1 track-jet



Z(ee)+1 track-jets scaling

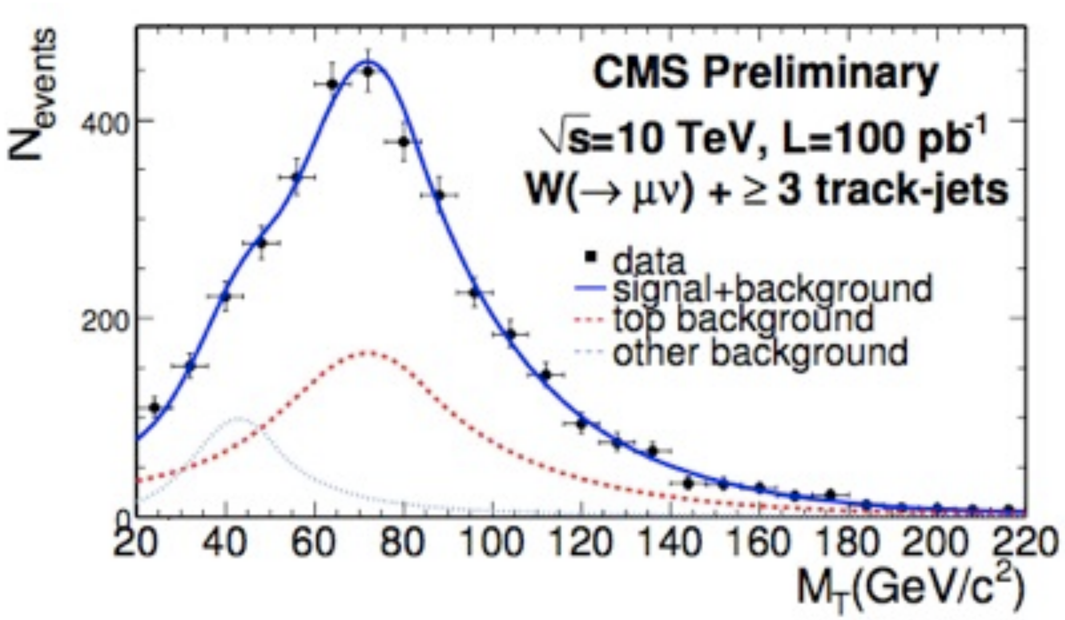


Z+jets candidate

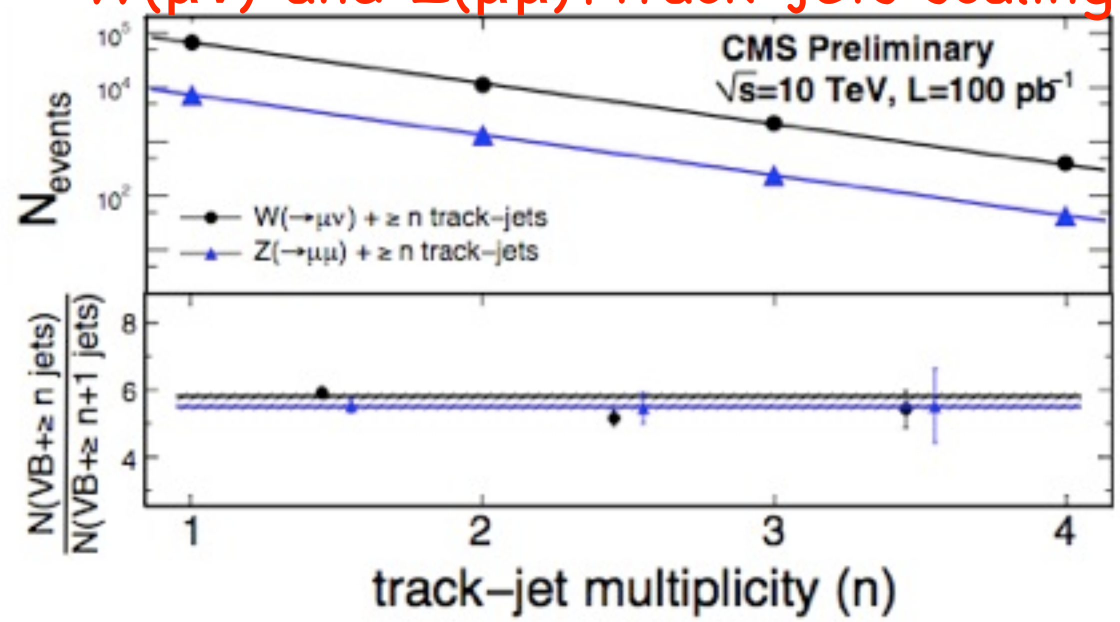


- First measurement can be:
  - dN_W/dn_{jet} as for the Z+jets
  - the double ratio, expected to be 1: $$R = \frac{dN(W+\mathrm{jets})/dn_j}{dN(Z+\mathrm{jets})/dn_j}$$
- W+3,4 jets the most important, but polluted by ttbar events
  - b-tagged jets veto, event shape variables to discriminate W+jets / ttbar events
- likelihood fit to $m_T(W)$ to extract the signal yield on data

W(μν)+≥1 track-jet



W(μν) and Z(μμ)+track-jets scaling



Conclusions

- Observing W and Z bosons at CMS is the starting point for the LHC search program
  - they constitute a measurement per se (EWK constraints)
  - they allow the commissioning of high p_T physics: with o(10 nb^{-1}) CMS already found the first clean W and Z candidates
    - signal and backgrounds scale well with simulations
- With upcoming LHC data at 7 TeV CMS program is:
  - give a first estimate of W and Z cross sections
  - measure integrated W asymmetries
  - measure W+1,2 jets or measure N(W+1-jet)/N(W+0-jet)
- ... and then start looking for the unknowns ...

backup

Jets in first data

- Jet clustering is applied to different detector inputs:
  - calorimetric towers (“**Calo-Jets**”);
  - calorimeter jets with η, p_T corrections from the high granular and precise tracking system (“**Jets-Plus-Tracks**”);
  - clustering of Particle Flow objects (charged hadrons, neutral hadrons, photons): “**PF-Jets**”
- jet energy corrections can be applied to account for non-uniform and non-linear response of calorimeters to jets
- jet counting to test “Berends-Giele” scaling in W,Z+jets can be done on both corrected and un-corrected jets
- first commissioning with 0.9, 2.36 TeV data of di-jets events promising for all three reconstructions