CLASHEP 2011

CMS

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CMS-EWK-10-002

Measurements of Inclusive W and Z Cross Sections in pp Collisions at $\sqrt{s} = 7$ TeV

The CMS Collaboration*

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Motivations

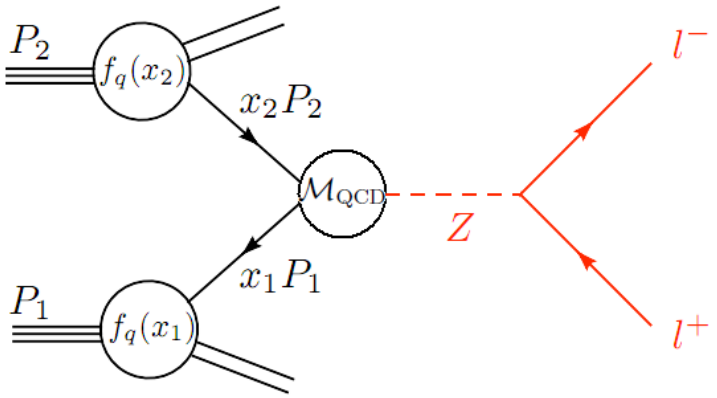
The study of electroweak gauge bosons is an important part of the physics program at the LHC

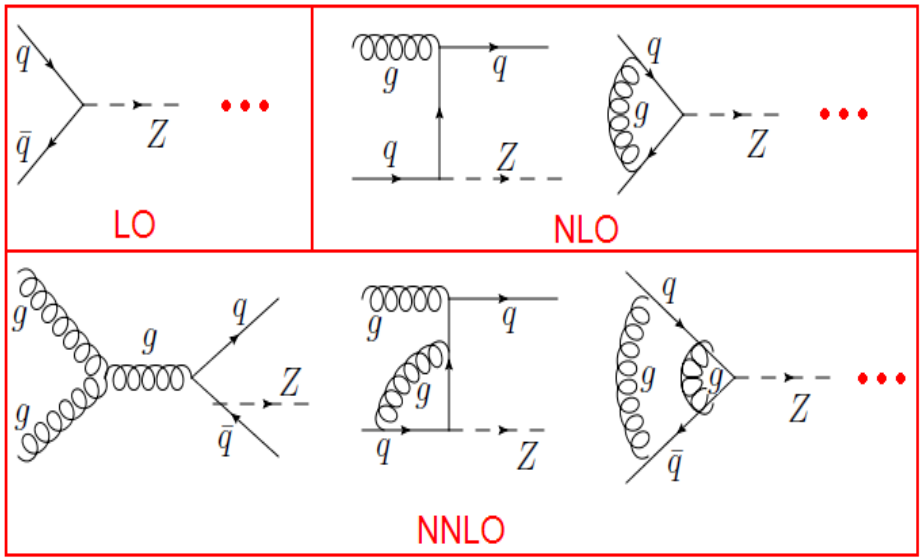
- Determination of the electroweak parameters M_W and $sin^2 \vartheta_W$
- Test of NNLO pQCD calculations at 7 TeV
- Prerequisite for many beyond the standard model physics searches

Measurements provide valuable feedback on the detector performance

- Calibration of the lepton energy / momentum scales
- Uniformity of the electromagnetic calorimeter
- Tracker alignment

Drell-Yan Process





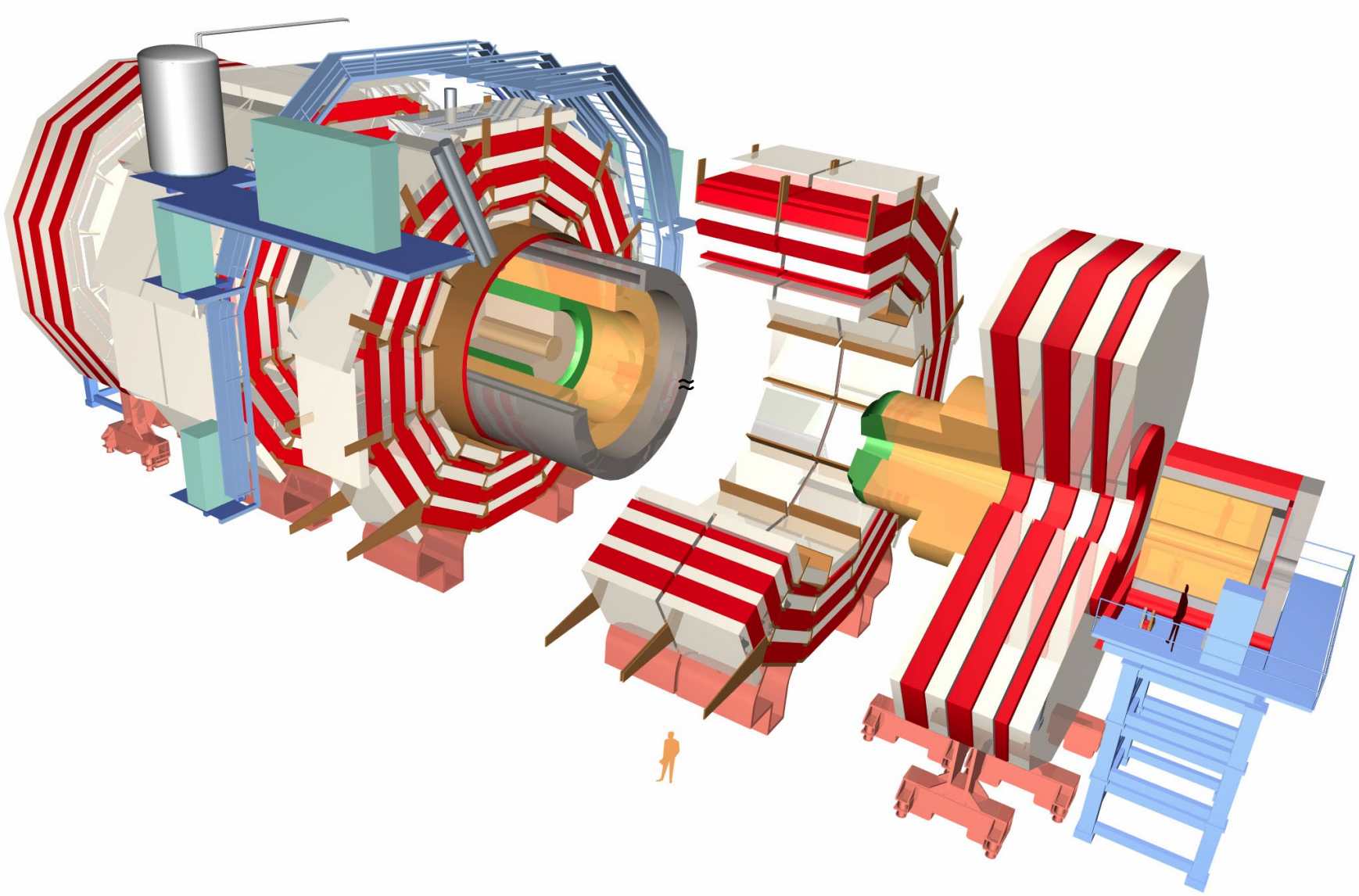
Hadronic cross section (see G. Zanderighi QCD lectures)

$$d\sigma^{Z(W)} = \sum_{i,j} \int dx_1 dx_2 f_i^{h_1}(x_1, \mu_F) f_j^{h_2}(x_2, \mu_F) d\sigma_{ij \to Z(W)+X \to Y}(x_1, x_2, \mu_F, \mu_R)$$

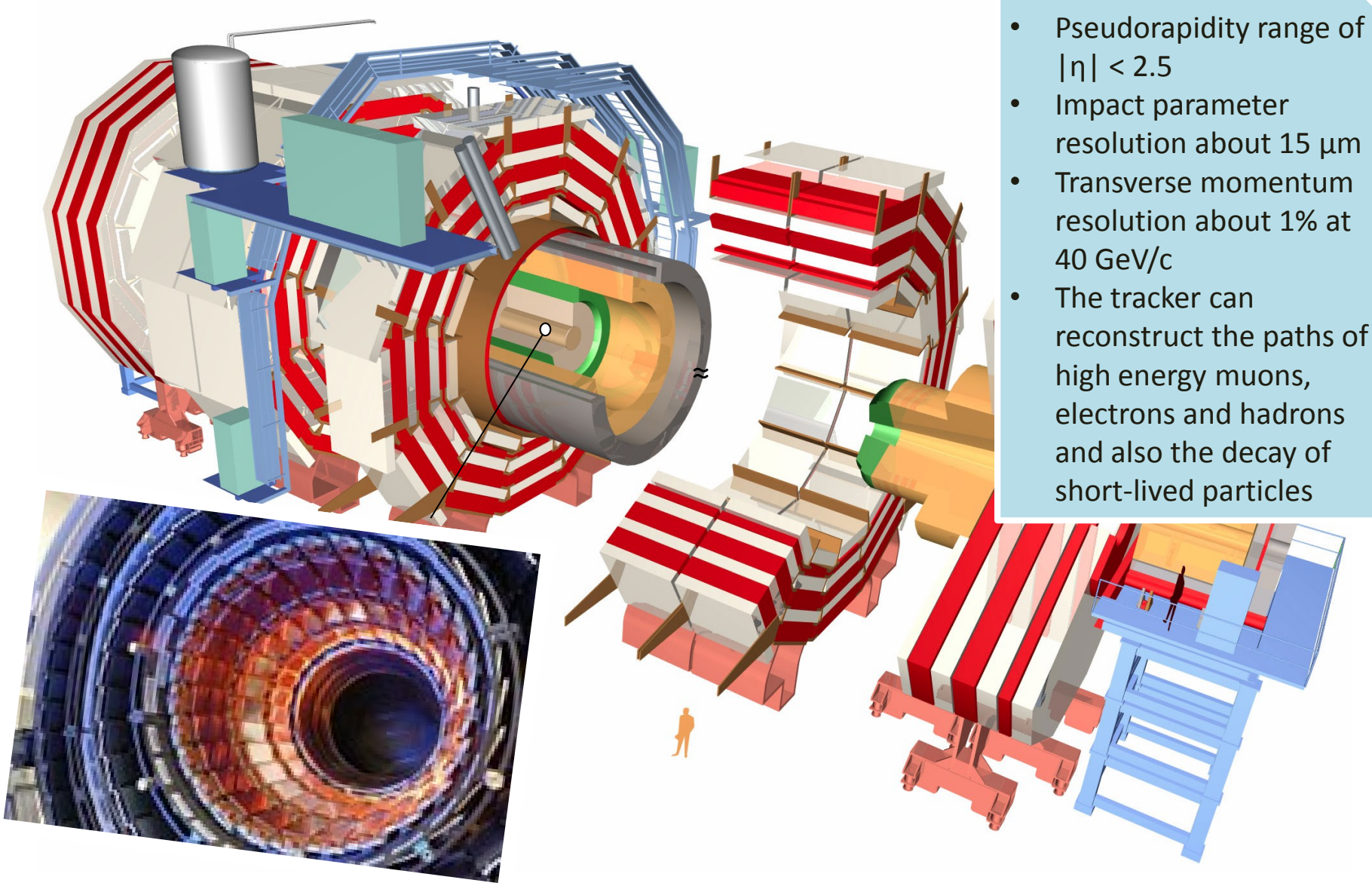
Partonic cross section

$$d\sigma_{ij \to Z+X \to l^+ l^-} = \frac{(2\pi)^4 \delta^{(4)}(x_1 P_1 + x_2 P_2 - \sum_k p_k)}{\phi(x_1 P_1, x_2 P_2)} \left[\frac{H_{\mu\nu} L^{\mu\nu}}{(q^2 - M_Z^2)^2 + M_Z^2 \Gamma_Z^2} \right] dPS$$

The CMS Detector

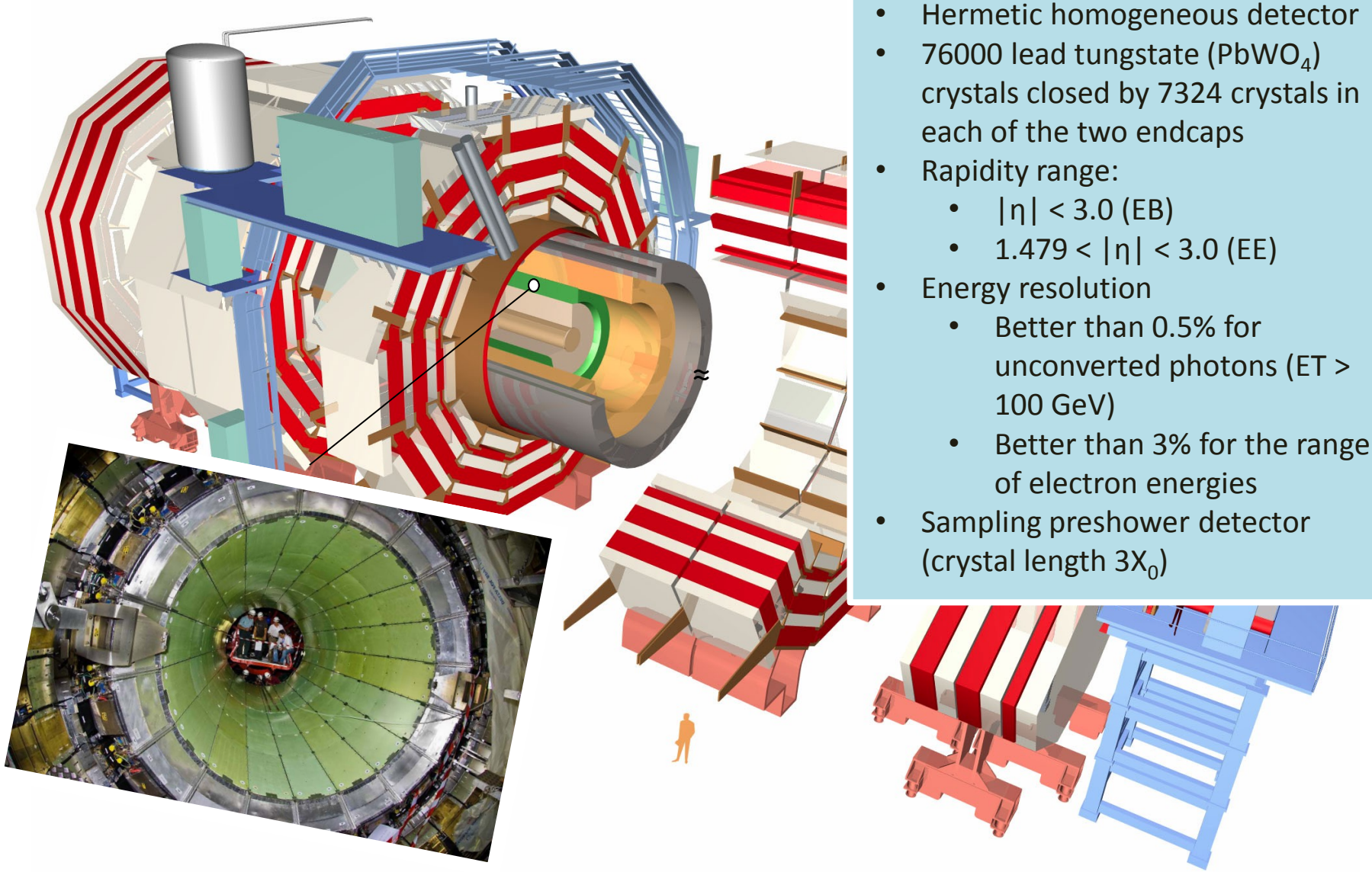


The CMS Detector – Inner Tracker (IT)



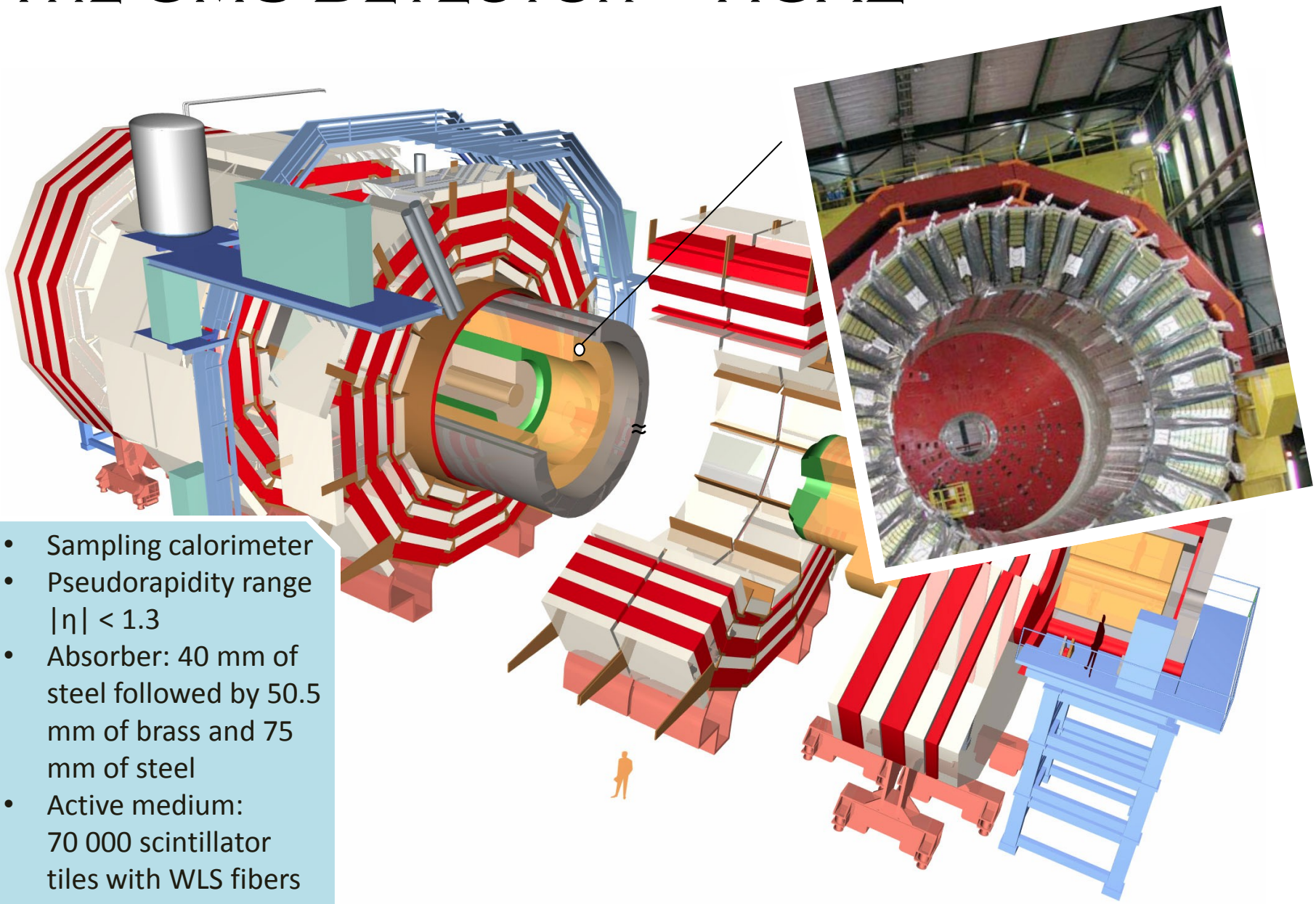
- Pseudorapidity range of $|\eta| < 2.5$
- Impact parameter resolution about 15 µm
- Transverse momentum resolution about 1% at 40 GeV/c
- The tracker can reconstruct the paths of high energy muons, electrons and hadrons and also the decay of short-lived particles

The CMS Detector – ECAL (EB + EE)



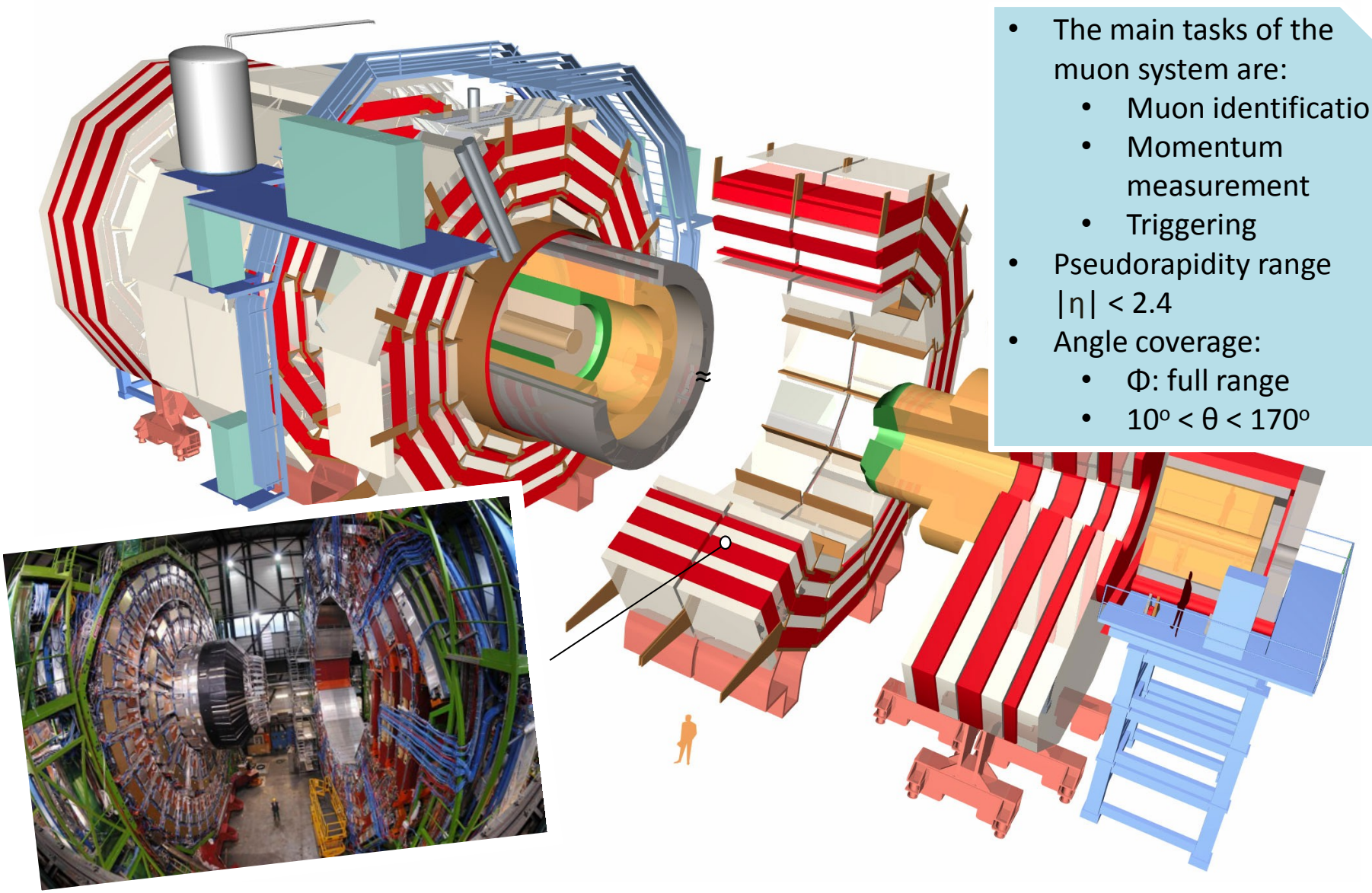
- Hermetic homogeneous detector
- 76000 lead tungstate ($PbWO_4$) crystals closed by 7324 crystals in each of the two endcaps
- Rapidity range:
  - $|\eta| < 3.0$ (EB)
  - $1.479 < |\eta| < 3.0$ (EE)
- Energy resolution
  - Better than 0.5% for unconverted photons (ET > 100 GeV)
  - Better than 3% for the range of electron energies
- Sampling preshower detector (crystal length $3X_0$)

The CMS Detector – HCAL



- Sampling calorimeter
- Pseudorapidity range $|\eta| < 1.3$
- Absorber: 40 mm of steel followed by 50.5 mm of brass and 75 mm of steel
- Active medium: 70 000 scintillator tiles with WLS fibers

The CMS Detector – Muon System



- The main tasks of the muon system are:
  - Muon identification
  - Momentum measurement
  - Triggering
- Pseudorapidity range $|\eta| < 2.4$
- Angle coverage:
  - Φ: full range
  - $10^{o} < \theta < 170^{o}$

Lepton Reconstruction and Identification Missing Transverse Energy

Electrons

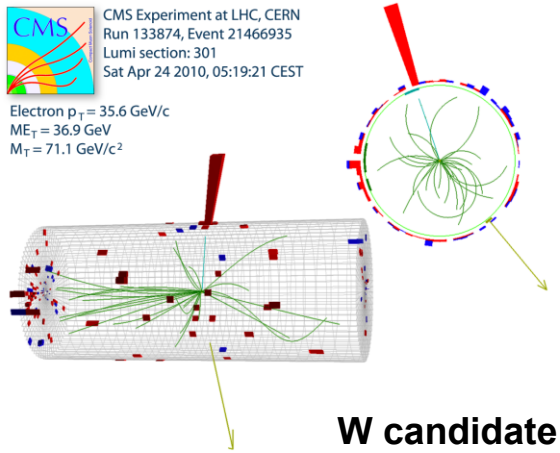
- HLT trigger with cluster E_T threshold > 15 GeV
- Fiducial range $|\eta| < 2.5$, calorimeter crack ($1.44 < |\eta| < 1.57$) removed
- Bremsstrahlung correction
- Shower shape requirements
- Hadronic leakage
- Track-cluster matching
- Require one hit in IT innermost pixel layer
- Calorimeter and track isolation

Muons

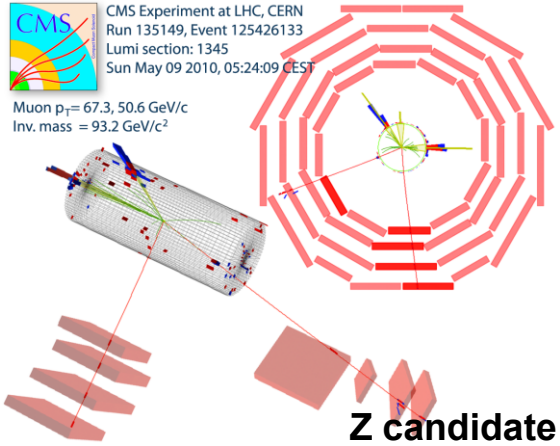
- HLT trigger with combined muon track $p_T > 9$ GeV
- Fiducial range $|\eta| < 2.1$
- Global muons (stand alone + tracker muon)
- Signal in at least 2 muon stations
- Track-fit quality requirement
- IP < 2 mm from nominal beam axis (rejection of cosmic backgrounds)
- Calorimeter and track isolation

Missing transverse energy

- Combination of reconstructed objects according to particle type (particle flow techniques, see J. Alcaraz's lecture)
- Calorimeter noise removal



W candidate



Z candidate

Cross Section Measurement

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

$\mathcal{N}$ = number of signal events	$\mathcal{A}$ = fiducial and kinematic acceptance	ε = selection efficiency for events in acceptance	$\mathcal{L}$ = integrated luminosity

Lepton Selection Efficiencies

Efficiencies for lepton reconstruction, identification, isolation and trigger are obtained from data with a "Tag-and-Probe" (T&P) method

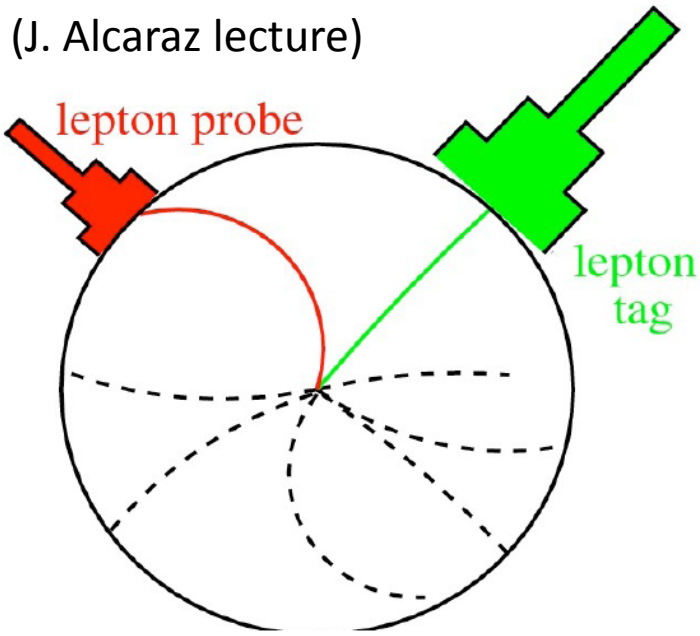
Methodology:

- Two lepton candidates:
  1) The "Tag" ➔ tight ID and ISO requirements
  2) The "Probe" ➔ selection criteria depending on the efficiency being measured

➢ See J. Alcaraz's lecture

Correction factors are obtained as the ratio of the efficiencies from simulation and data

(J. Alcaraz lecture)



Lepton Selection Efficiencies

$$\varepsilon_{sel} = \varepsilon_{rec} \cdot \varepsilon_{iso} \cdot \varepsilon_{tr}$$

W Boson Selection

Electron Selection

- 1 electron: $E_T > 20$ GeV
- Veto if second loose lepton: $E_T > 20$ GeV
- Signal shape from MC
- QCD modelled using Rayleigh distribution

Muon Selection

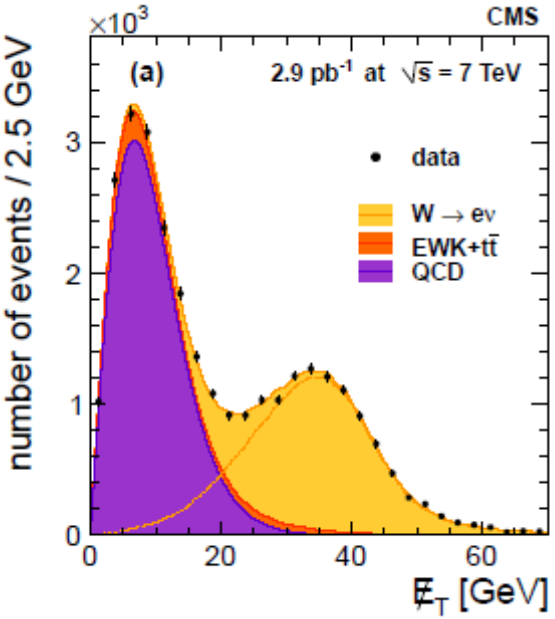
- 1 muon $p_T > 20$ GeV
- Veto if second muon: $p_T > 10$GeV
- Signal and EWK background from simulation
- QCD shape from inverted isolation region

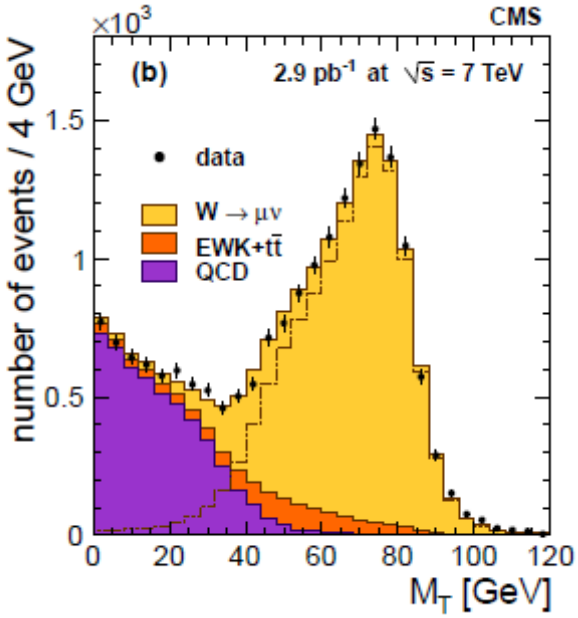
Main backgrounds

- QCD suppressed by lepton isolation
- Drell-Yan suppressed by second lepton veto

Signal extraction

- Electron Channel: Extracted from unbinned maximum likelihood fit
- Muon Channel: Extracted from binned maximum likelihood fit





- Rayleigh distribution:

$$f(\not{E}_T) = \not{E}_T \times \exp\left(-\frac{\not{E}_T^2}{2(\sigma_0 + \sigma_1 \not{E}_T)^2}\right)$$

- Transverse Mass:

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

Z Boson Selection

Electron Selection

- 2 electron: $E_T > 20$ GeV
- Invariant mass: $(60 < M < 120)$ GeV
- Z mass peak shift correction

Muon Selection

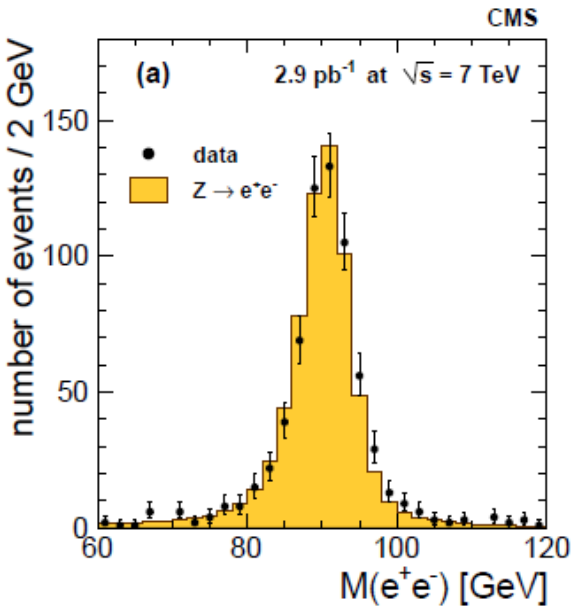
- Invariant mass: $(60 < M < 120)$ GeV
- Tag muon must satisfy isolation and identification criteria
- At least one muon must fulfill trigger requirement

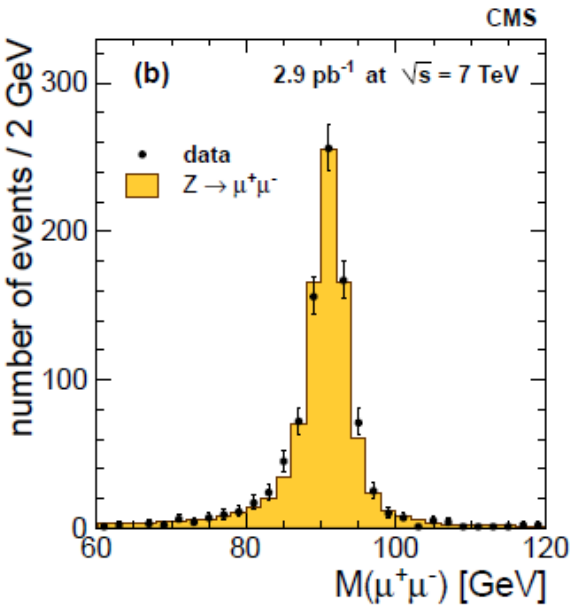
Main backgrounds

- Almost negligible
- Electron: QCD estimated from data
- Muon: QCD background shape from polynomial and exponential function, EW estimated from simulation

Signal extraction

- Electron Channel: Extracted by counting selected events and small bkg correction
- Muon Channel: Extracted from likelihood fits to mass spectra

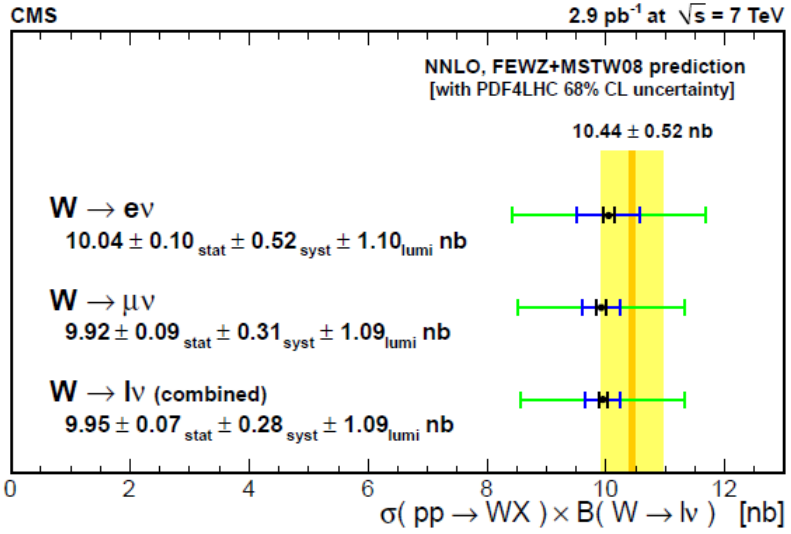


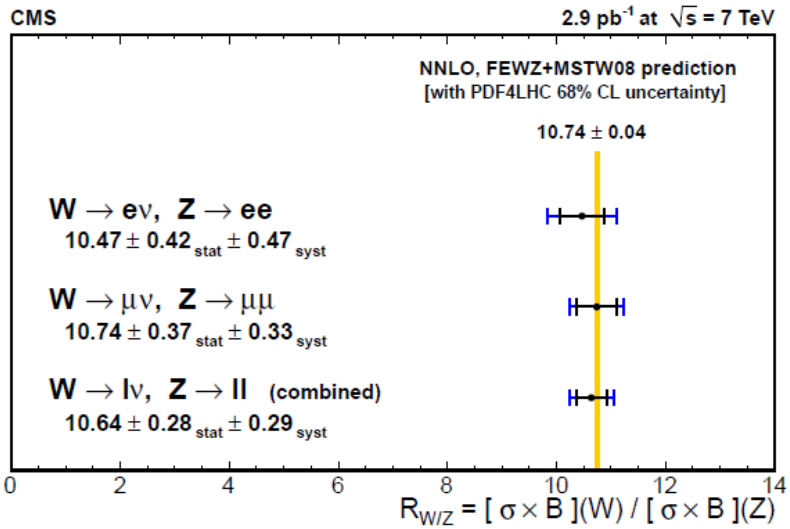


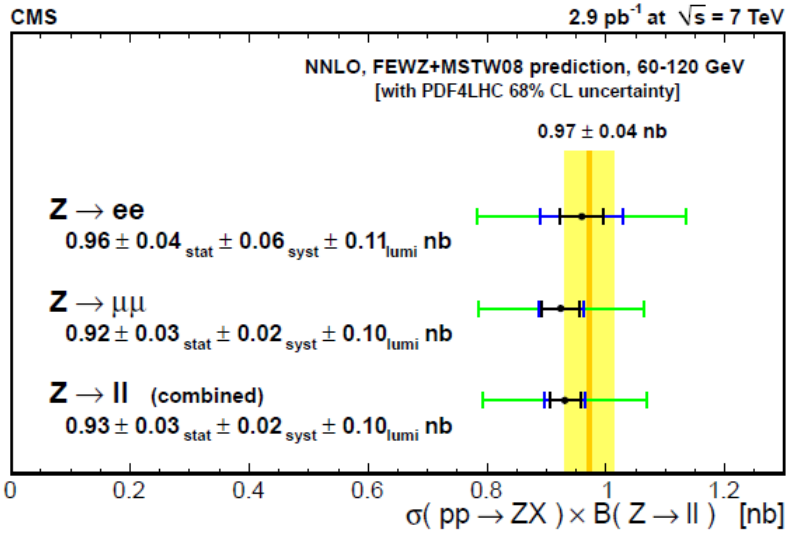
Systematics Uncertainties

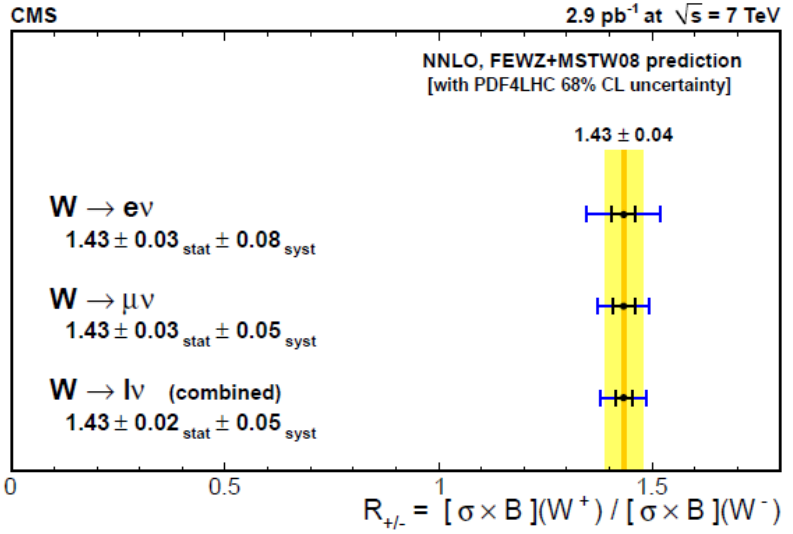
Integrated Luminosity	• **11 % in all channels (now is 4%!)**
Lepton reconstruction & identification efficiencies	• Uncertainties from "tag & probe" measurements on data (≤ 5.9%)
Momentum scale & resolution	• Corrections from observed shift of the Z-mass peak (≤ 2.0%)
Missing transverse energy scale & resolution (W channel)	• Uncertainties from data / simulation comparisons (≤ 1.8%)
Background subtraction / modeling	• Uncertainties from comparison of different background estimation techniques (≤ 2.0%)
PDF uncertainty for acceptance	• Event reweighting according to different PDF set assumptions (≤ 1.2%)
Theoretical Uncertainties	• Initial / final state radiation, renormalization and factorization scale assumptions (≤ 1.6%)

Results: σ x B for W and Z

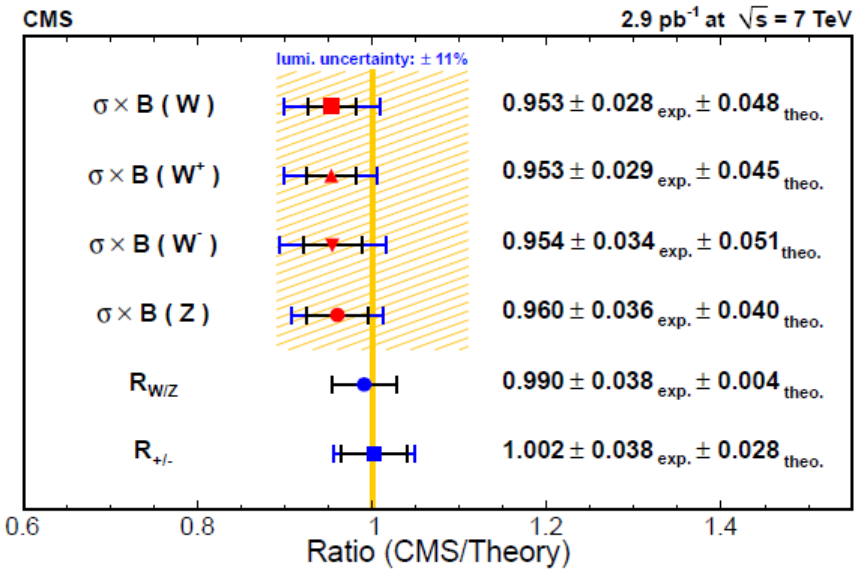


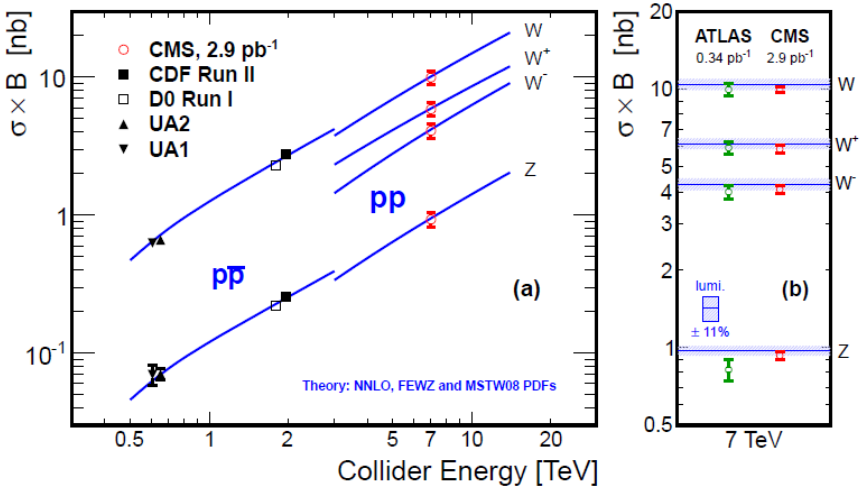






Comparing Results with Theory





Measurement agrees with theoretical predictions

Luminosity uncertainty shown by yellow area

Results from ATLAS and CMS are consistent

σ x B increases with energy

Conclusion

Inclusive W and Z boson production cross section is consistent with the theoretical results

Compatible measurements in the electron and muon channels

The experimental uncertainties are smaller than the theoretical ones

With larger amount of data and a better understanding of the CMS detector, it is expected that systematic and statistical uncertainties will decrease

Thank you!

Thank you!

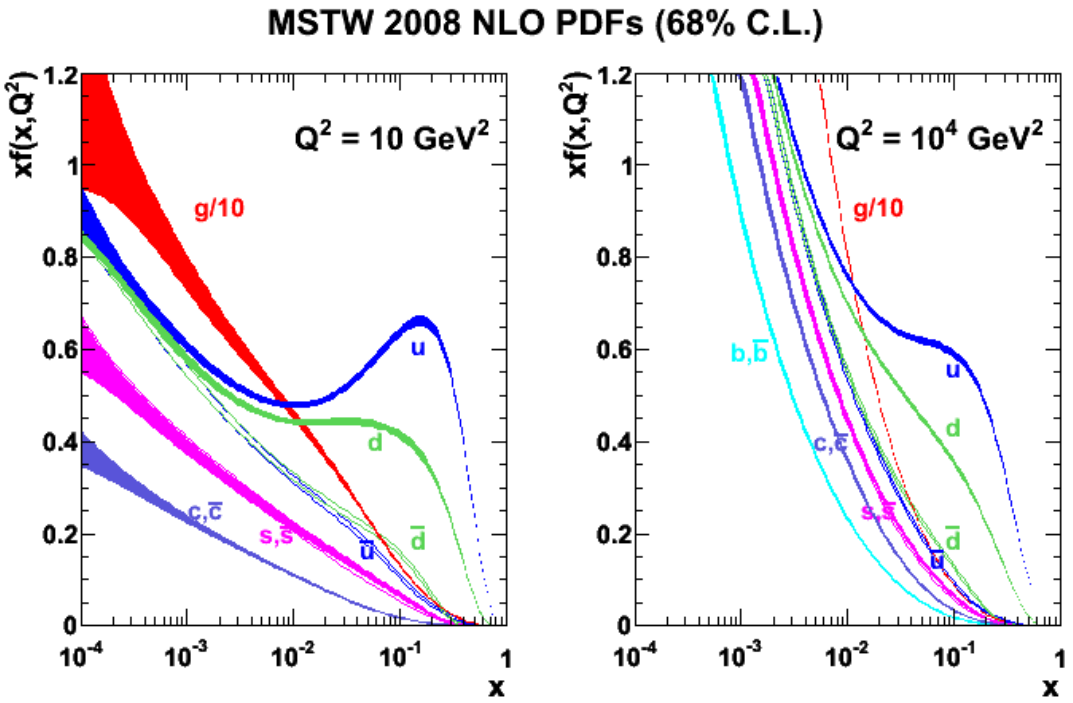
BACKUP SLIDES

Some Comments

$$d\sigma_{ij\to Z+X\to l^+l^-} = \frac{(2\pi)^4\delta^{(4)}(x_1P_1 + x_2P_2 - \sum_k p_k)}{\phi(x_1P_1, x_2P_2)} \left[\frac{\blacksquare}{(q^2 - M_Z^2)^2 + \bullet} \right] dPS$$

Information related to the QCD contribution to the partonic cross section is encoded in tensor H, while leptonic interaction is related with tensor L.

Takes into account the finite width of the intermediate particle



Computation performed with FEWZ plus MSTW 2008 PDFs

Systematics Uncertainties

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

Lepton Isolation

Isolation Variables:

$$I^{rel}_{ECAL} = \frac{\sum E_T(ECAL)}{p^{\ell}_T} \qquad I^{rel}_{HCAL} = \frac{\sum E_T(HCAL)}{p^{\ell}_T} \qquad I^{rel}_{track} = \frac{\sum E_T(track)}{p^{\ell}_T}$$

Where $E_T = E\ sin(\theta)$ and the sum is computed in a region around the lepton candidate fulfilling the condition:

$$\sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.3$$

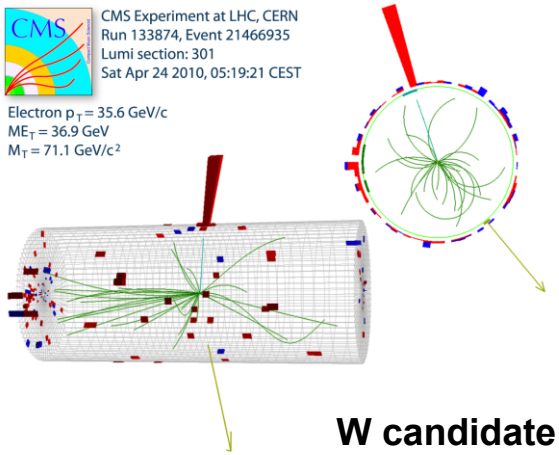
Excluding the energy deposit and momentum of the lepton candidate. We also define a combined isolation variable:

$$I^{rel}_{comb} = I^{rel}_{ECAL} + I^{rel}_{HCAL} + I^{rel}_{track}$$

Electron Reconstruction and Identification

Offline Reconstruction of High-E_T electrons

- ECAL clusters energy > 20 GeV
- Match to reconstructed track in silicon tracker (IT)
- $|\eta| < 1.44$ (EB clusters)
- $1.57 < |\eta| < 2.50$ (EE clusters)
- Reconstruction algorithm (accounts for Brem)

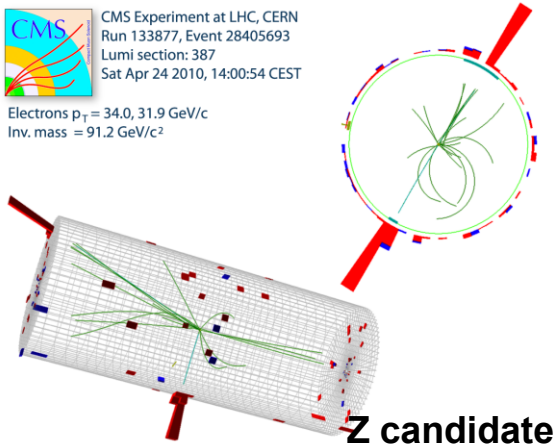


W candidate

Background Suppression

- Match HCAL energy in a cone ($\Delta R < 0.15$) around ECAL cluster
- Require ONE hit in IT innermost pixel layer
- Demand electron isolation:
  - EB region: $I^{rel}_{trk} < 0.09$ $I^{rel}_{ECAL} < 0.07$ $I^{rel}_{HCAL} < 0.10$
  - EE region: $I^{rel}_{trk} < 0.04$ $I^{rel}_{ECAL} < 0.05$ $I^{rel}_{HCAL} < 0.025$

Electron Candidate > 20 GeV ECAL clusters + momentum direction of associated track



Z candidate

Muon Reconstruction and Isolation

The main contamination is from

- Hadronic jets
- Real leptons from decays
- Cosmic rays

Online

- L1 muon trigger
- Reconstructed muon candidate in inner tracker and muon chambers
- HLT pT > 9 GeV for muon in range |η| < 2.1

Offline

- Global muons (stand alone + tracker muon)
- Signal in at least 2 muon stations
- Rejection of cosmic BG: IP < 2 mm from nominal beam axis
- $I^{\mathrm{rel}}_{\mathrm{comb}} < 0.15$