Photon Energy Scale Determination and Commissioning with Radiative Z decays

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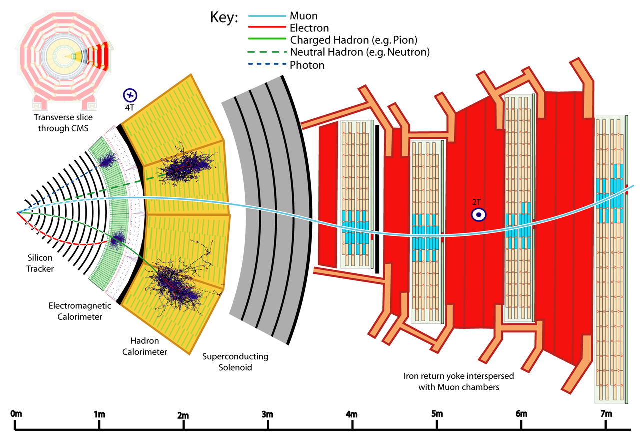
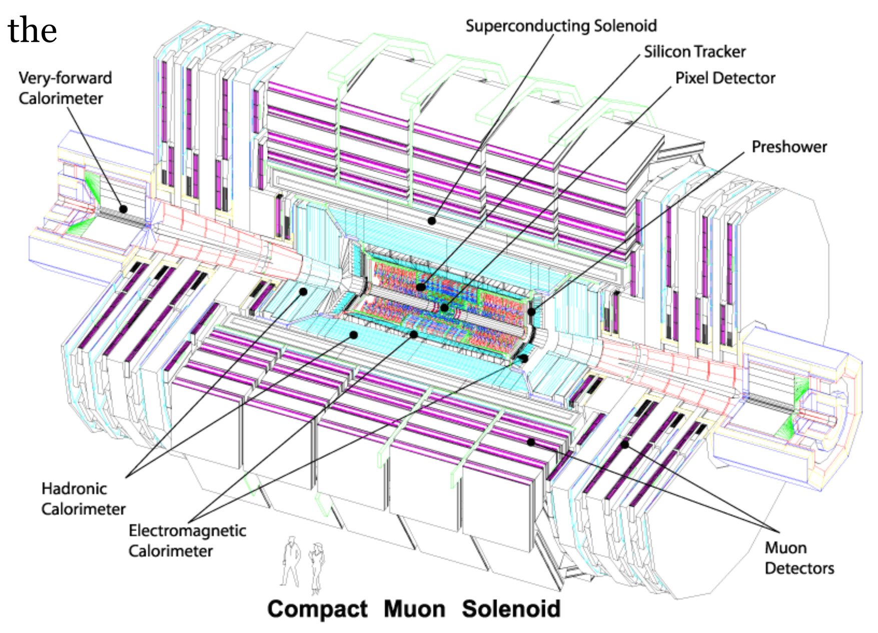
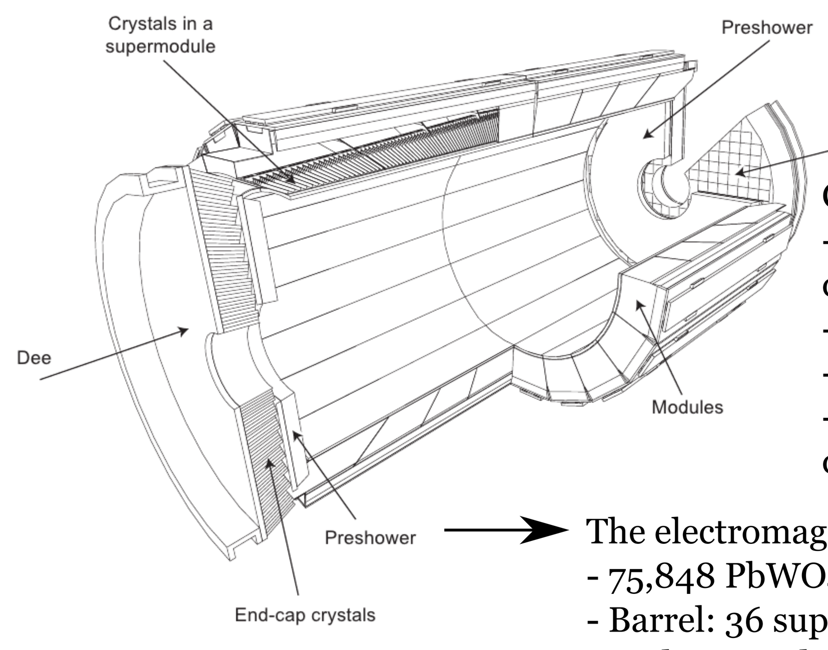
Introduction: CMS and its electromagnetic calorimeter (ECAL)

CMS (Compact Muon Solenoid) [1]: one of the two multi-purpose experiments recording collisions produced by the Large Hadron Collider
Main features:
- Superconducting solenoid: 3.8T magnetic field
- Hermetic, compact (14,000 tons ; 28.7m x 15m)
- Muon chambers





Calorimeters within the solenoid coil



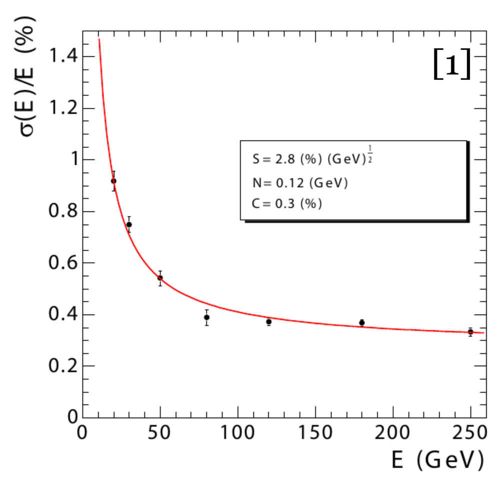
ECAL designed to be fast, compact, radiation-hard, with fine granularity and excellent energy resolution.

Choice of PbWO4:
- size chosen so as to contain an entire EM shower (high density: 8.28 g/cm³ , X0 = 0.89 cm)
- good resolution (homogeneous)
- fast (80% of light emitted in 25ns)
- radiation hard (changes in crystal opacity measured by dedicated laser monitoring system)

→ The electromagnetic calorimeter:
- 75,848 PbWO4 scintillating crystals
- Barrel: 36 supermodules of 1,700 crystals each, light converted by APD
- Endcaps: 4 dees of 3662 crystals each, light converted by VPT

Physics performance: motivation for a dedicated photon standard candle

1) ECAL calibration scheme



The ECAL resolution has been measured in electron test-beams and parametrized as follows:

$$\frac{\sigma(E)}{E} = \frac{2.8\,\%}{\sqrt{E(GeV)}} \oplus \frac{12\,\%}{E(GeV)} \oplus 0.3\,\%$$

The three contributions correspond respectively to the stochastic component (S), the electronic and experimental noise (N), and a constant term (C).

For photons of energy ~100 GeV ($H \to \gamma\gamma$ range), the energy resolution is dominated by the constant term (significant contribution from calibration).

The reconstructed energy of a particle in the ECAL is:

$$E = F \cdot \sum_{cluster\ crystals} G(GeV/ADC) \cdot C_i \cdot A_i$$

Where:
- A_i represents a reconstructed amplitude in ADC counts
- C_i is an intercalibration constant
- G is the global energy scale
- F represents the energy correction (depends on the particle type, energy, and pseudo-rapidity ; contains the cluster energy corrections)

Different physics channels are available to evaluate the different calibration terms: $\pi^0 \to \gamma\gamma$ $\eta \to \gamma\gamma$, $J/\psi \to e^+e^-$, $W^\pm \to e^\pm\nu$, $Z^0 \to e^+e^-$

- good photon calibration
- knowledge of photon energy scale
- design resolution

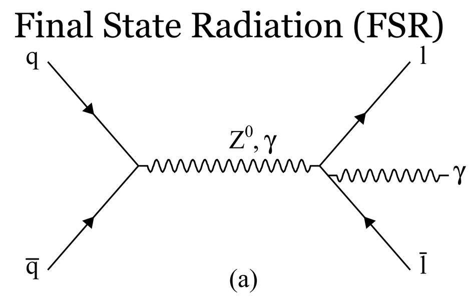
→ required by analyses with photons in the final state (especially crucial for $H \to \gamma\gamma$)

→ photons and electrons behave differently in the ECAL

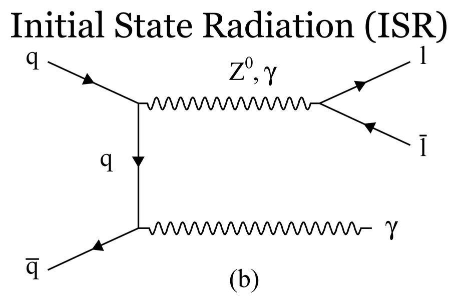
desire for a dedicated standard candle for photons, complementary to $Z^0 \to e^+e^-$

2) Radiative Z^0 decays, process selection strategy

Final State Radiation (FSR)



Initial State Radiation (ISR)



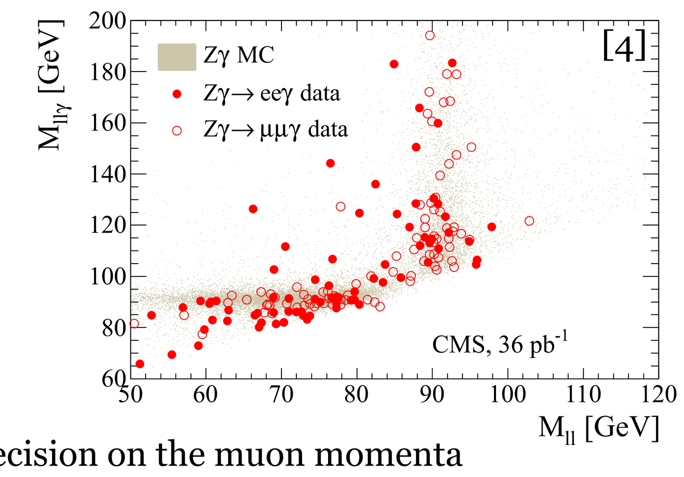
Z decay to muons with Final State Radiation (FSR): one of the muons emits a Bremsstrahlung photon

Z decay to muons
- Z boson properties known with high accuracy
- CMS delivers high precision measurement of muon momentum
- no other particles in ECAL apart from the photon

→ constraint on photon kinematics (three body decay)

purely EWK process: clear and neat signal in hadronic collisions

Selection:
- Standard CMS tight muon ID, without calorimetric isolation
- Dimuon invariant mass requirement (rejection of non-radiative Z decays)
- Loose photon object selection (fiducial cuts only, to keep it as unbiased as possible)
- requirement on maximum angular separation between photon and closest muon to reject ISR
- Three-body invariant mass window



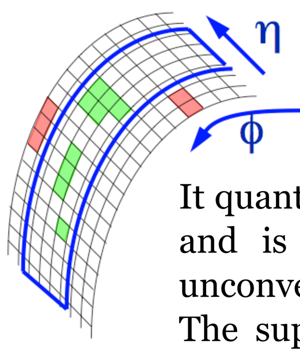
- Source of high-purity photons
- Kinematics are well-constrained by the Z boson mass and the precision on the muon momenta
- steeply falling photon energy spectrum [2]

→ can be used for numerous calibration and measurement purposes

Results

1) Photon Commissioning: R9

SuperCluster



The variable R9 is defined as:

$$R_9 = \frac{E^{3X3}}{E^{SuperCluster}}$$

It quantifies the lateral width of an electromagnetic shower, and is thus widely used to distinguish converted and unconverted photons.
The superclustering algorithms are optimized to give the best photon resolution, thus behave differently if a deposit is thought to belong to a converted photon (threshold on the R9 variable).

The limit setting process in the $H \to \gamma\gamma$ search [5-6] is performed in resolution classes. The uncertainty in class assignment/migration between classes is a source of systematic error and is quantified with $Z^0 \to \mu\mu\gamma$ events.

Source		Uncertainty [6]	
Photon identification efficiency			
	barrel	1.0%	
	endcap	2.5%	
R_9 >0.94 efficiency (results in class migration)	barrel	4%	
	endcap	6.5%	
		$R_9 > 0.94$	$R_9 < 0.94$
Energy resolution ($\Delta\sigma/E_{MC}$)	barrel	0.2%	0.4%
	endcap	0.5%	0.4%
Energy scale ($(E_{data} - E_{MC})/E_{MC}$)	barrel	0.1%	0.4%
	endcap	0.3%	0.4%

2) Photon Identification: lepton veto

For the $H \to \gamma\gamma$ analyses [5-6], the efficiency of photon identification is measured in data using tag-and-probe techniques. $Z^0 \to e^+e^-$ events are used to determine the efficiency of the complete selection with the exception of the electron veto cut.

$Z^0 \to \mu\mu\gamma$ events have been used to measure the efficiency for photons to pass the electron veto, with tag-and-probe techniques with the dimuon system as the tag and the photon candidate as the probe.

[6]

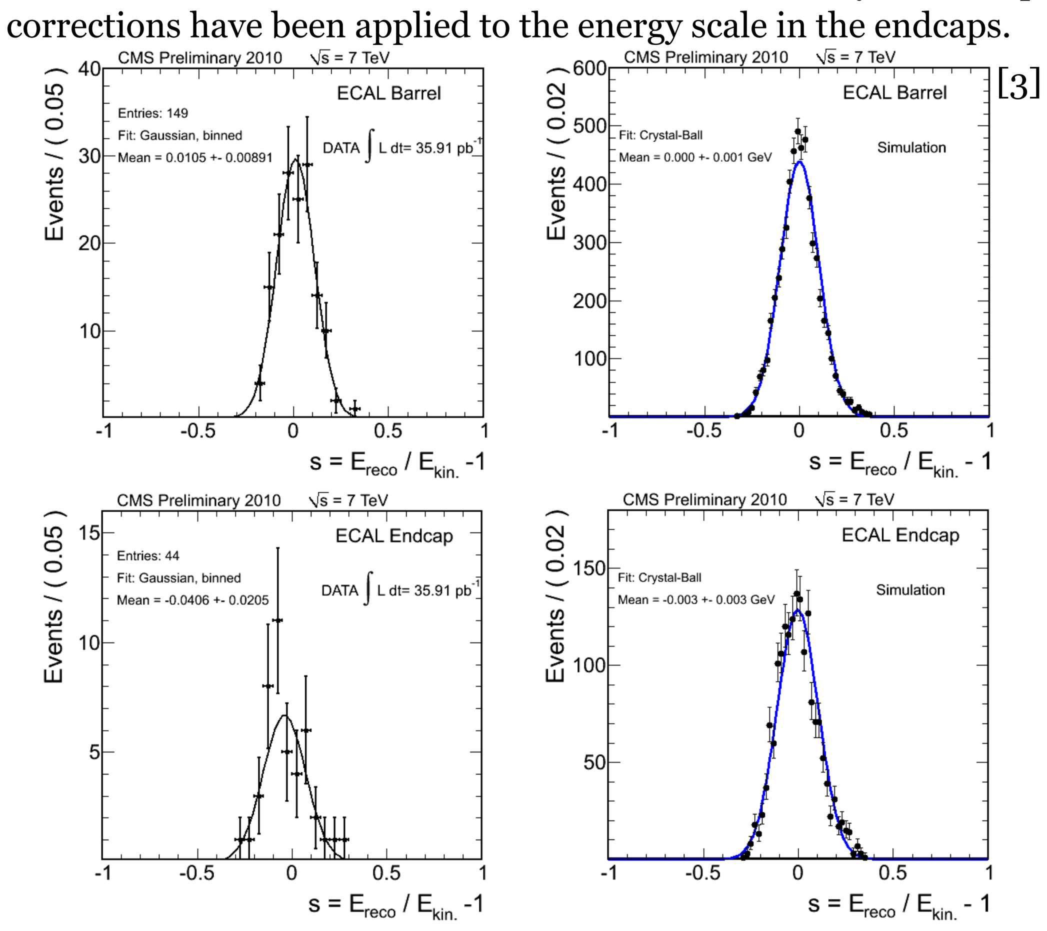
Category	ϵ_{data} (%)	ϵ_{MC} (%)	$\epsilon_{data}/\epsilon_{MC}$
All cuts except electron rejection (from $Z \to ee$)			
1	91.77±0.14	92.43±0.07	0.993±0.002
2	72.67±0.43	71.89±0.08	1.011±0.007
3	80.33±0.47	80.04±0.18	1.004±0.008
4	57.80±1.26	55.09±0.15	1.049±0.025
Electron rejection cut (from $Z \to \mu\mu\gamma$)			
1	$99.78^{+0.13}_{-0.16}$	$99.59^{+0.13}_{-0.17}$	$1.002^{+0.002}_{-0.002}$
2	$98.77^{+0.59}_{-0.73}$	$97.70^{+0.32}_{-0.37}$	$1.011^{+0.007}_{-0.008}$
3	$99.32^{+0.51}_{-1.02}$	$99.29^{+0.30}_{-0.42}$	$1.000^{+0.006}_{-0.011}$
4	$93.0^{+2.1}_{-2.3}$	$93.34^{+0.79}_{-0.86}$	$0.996^{+0.024}_{-0.027}$

3) Photon Energy Scale measurement

The measured offset of the energy scale is defined as : $s = \frac{E^{\gamma}_{measured}}{E^{\gamma}_{kinematics}} - 1$

This can be written using the three-body decay kinematics, assuming the muon momenta are perfectly measured : $s = \frac{m^2_{\mu\mu\gamma} - m^2_{\mu\mu}}{m^2_{Z^0} - m^2_{\mu\mu}} - 1$

Distributions of s are presented below [3]. The simulation predicts 216 ± 3 events, where 193 events have been selected in data. No crystal transparency loss corrections have been applied to the energy scale in the endcaps.



Photon scale agrees with expectations at the 1% level in EB (1.1% too high) and 3% in EE (3.7% too low) The extracted scale is consistent between three different methods : spread = 1.3% (EB) ; 2% (EE)
This method has been used in V-gamma cross section measurement [4]

Conclusions & Perspectives

The $Z^0 \to \mu\mu\gamma$ channel is the only available Standard Model source of pure high-energy photons. Three current uses of this channel within the CMS collaboration have been presented.

Up to now, photon studies relied mainly on Z decays to electrons to examine in detail photon simulation, reconstruction and selection. With the available statistics recorded by CMS during 2011 (~4.5 /fb), the use of the $Z^0 \to \mu\mu\gamma$ channel will be more effective than $Z^0 \to e^+e^-$. This is of particular importance for $H \to \gamma\gamma$ searches.

References

[1] The CMS experiment at the CERN LHC, CMS Collaboration, J. Instrum. 2 (2008) S08004
[2] CMS Physics Technical Design Report Volume I : Detector Performance and Software, CMS Collaboration, CERN-LHCC-2006-001 ; CMS-TDR-008-1
[3] CMS ECAL 2010 performance results, CMS Collaboration, CMS-DP-2011-008
[4] Measurement of W-gamma and Z-gamma production in pp collisions at sqrt(s) = 7 TeV, CMS Collaboration, Phys. Lett. B701 535-555 (2011). [arXiv:1105.2758 [hep-ex]], CMS-EWK-10-008
[5] Search for a Higgs boson decaying into two photons in the CMS detector, CMS Collaboration, CMS-PAS-HIG-11-010
[6] Search for a Higgs boson decaying into two photons in the CMS detector, CMS Collaboration, CMS-PAS-HIG-11-021

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