Physics with Photons at CMS: from the Data Taking to the Higgs Properties

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Overview

1. the LHC Run II data taking for CMS and the electromagnetic calorimeter

2. a study of the Higgs properties in the diphoton decay channel: analysis of the structure of the couplings to gauge bosons W/Z (HVV)

How We Detect Photons: The ECAL Detector in the LHC Run II

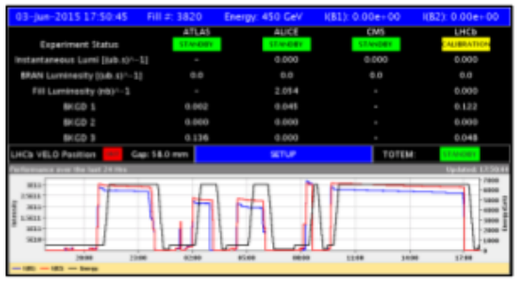
A Few Words About LHC: the Run II

operations restarted in spring after a two-year long shutdown

2015 was a year of commissioning to prepare for:

- higher energy: 13 TeV
- higher luminosity: 1.4×10^{34} $cm^{-2}s^{-1}$

June 3
stable beams: physics!



heavy ion run

Nov. 3
end of proton run

April 5
first circulating beam

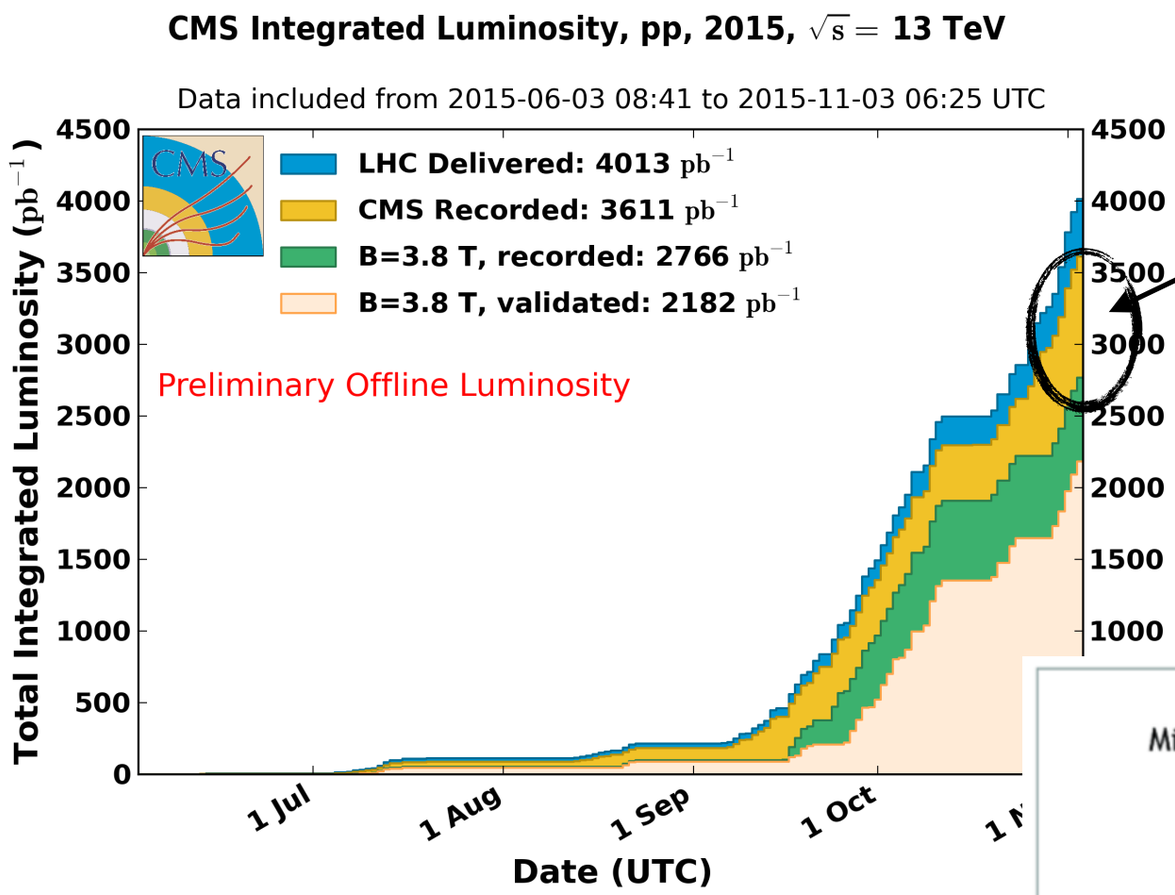
April | May | June | July | August | Sept. | Oct. | Nov.

April 10
first beams at 13 TeV

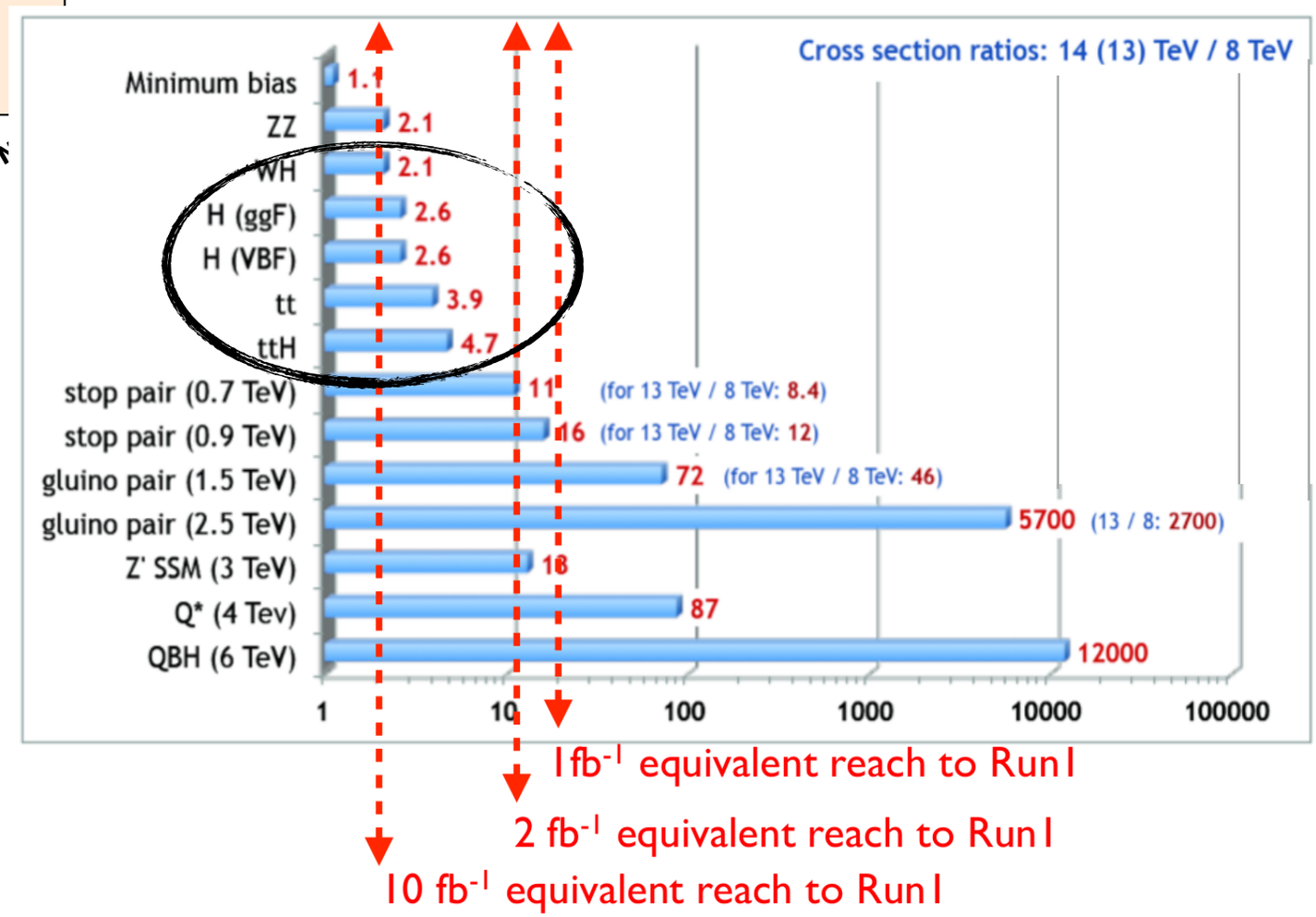
Aug. 3
run at 25ns bunch spacing

luminosity ramp up
data taking for physics

The Run II CMS Dataset



loss of data due to problems with the cryogenic system for the superconductive magnet



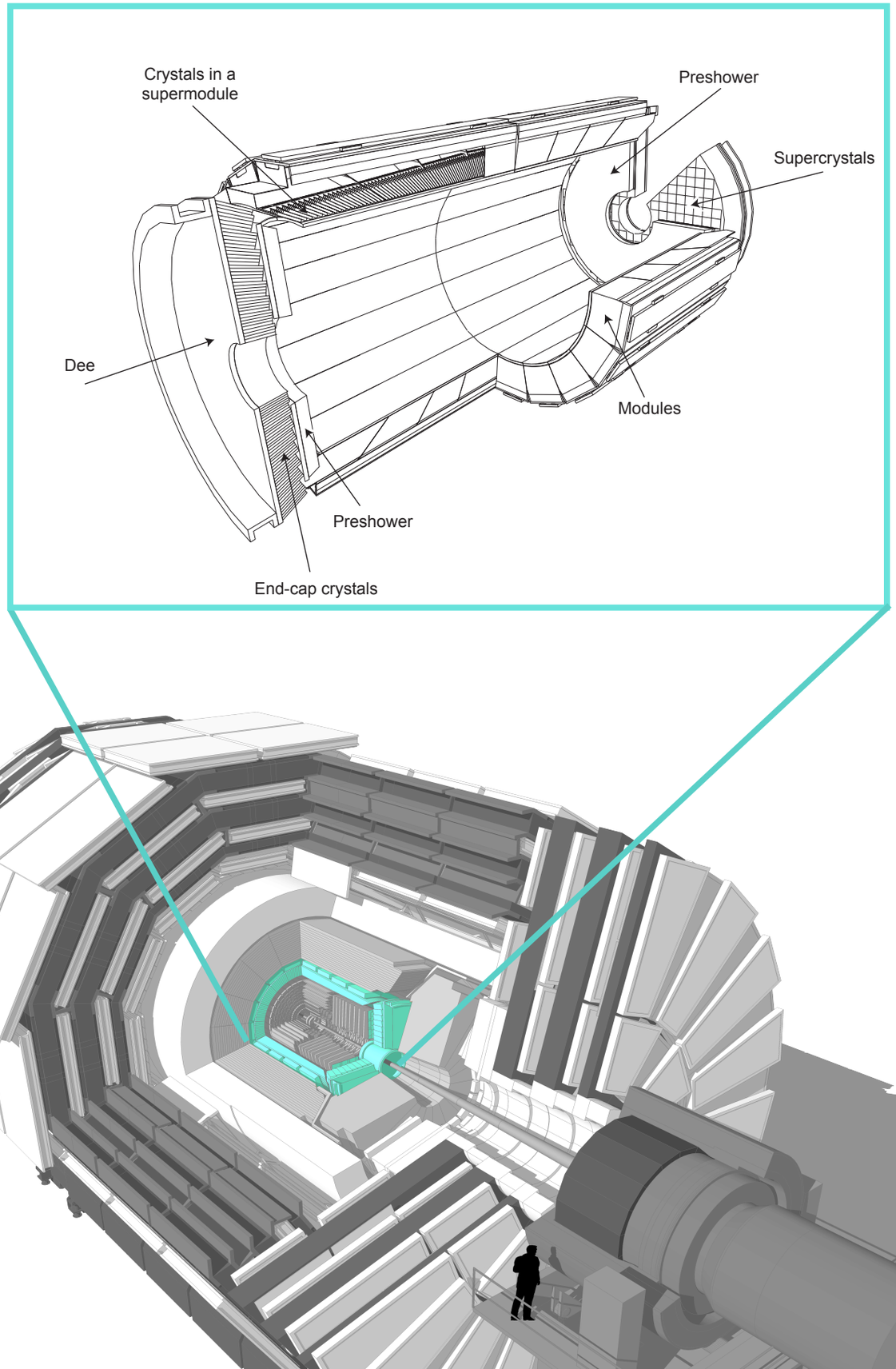
for Higgs studies:

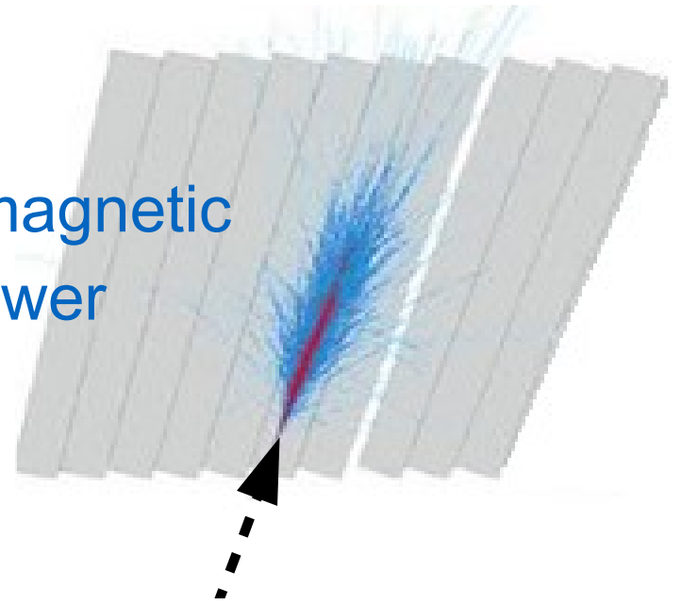
the Higgs production cross section doubles at $\sqrt{s}$ = 13 TeV

still, 2015 datasets are not sufficient for rediscovery

CMS Electromagnetic Calorimeter in a Nutshell

- homogeneous compact hermetic fine grain $PbWO_4$ crystal calorimeter
- designed for excellent energy resolution
- crucial for reconstruction of many physics objects: electrons, photons, jets, missing transverse energy
- crucial for the identification of the Higgs to diphoton decay



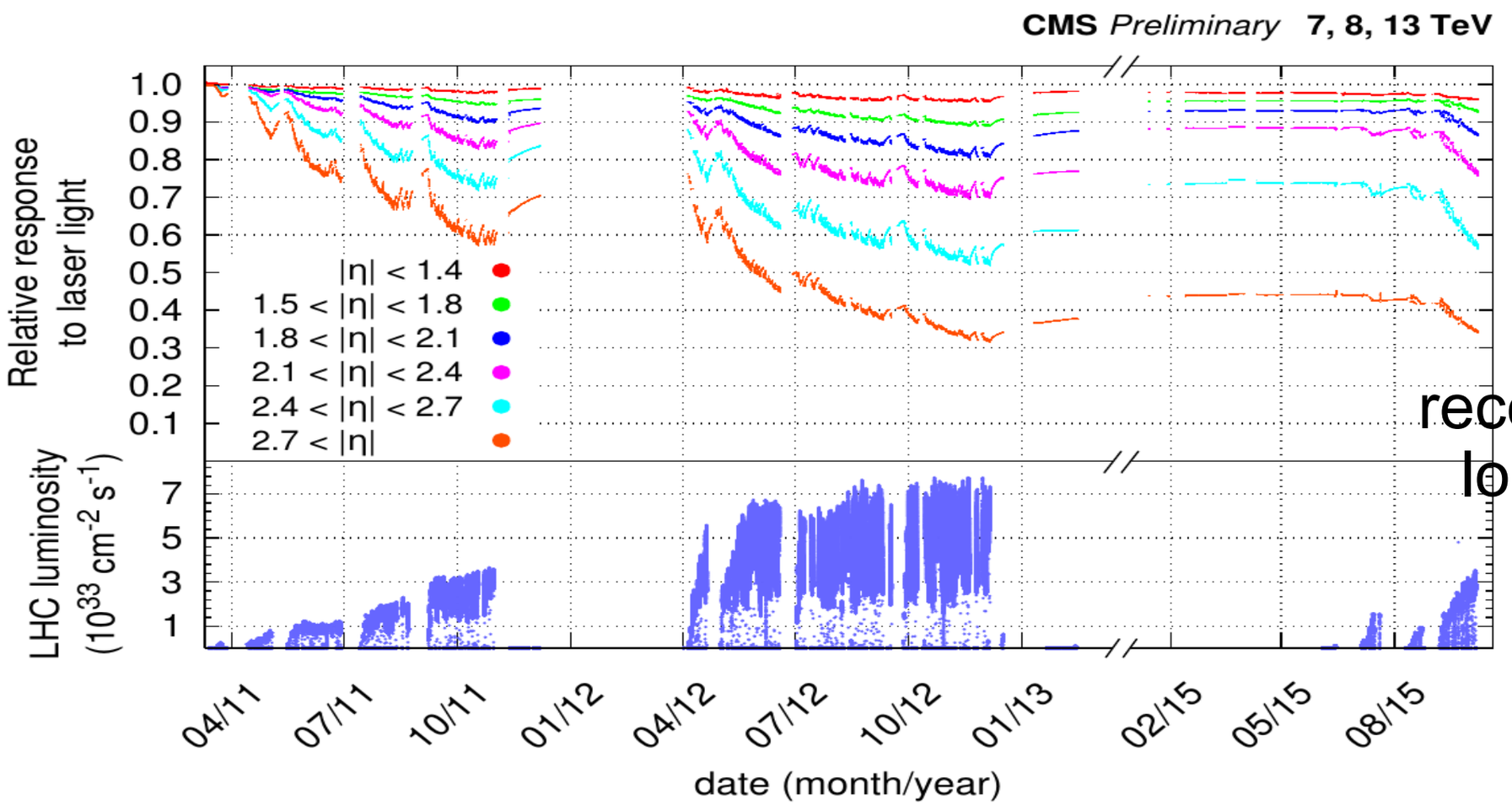


Crystal Response Evolution

- radiation damage, more significant in proximity of the beam (high pseudorapidity region in EE):
  - loss of transparency of crystals (no change in scintillation response)

monitored by a system of laser lights and corrected for in reconstruction

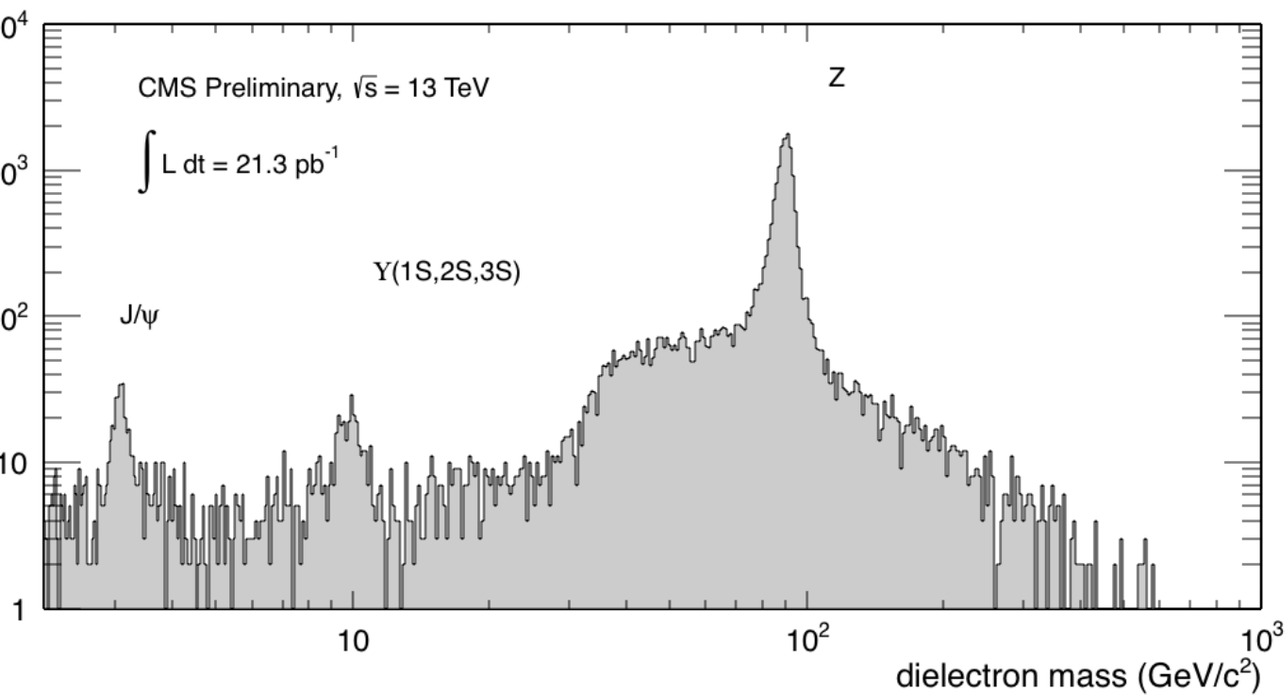
developed at CEA/ Saclay

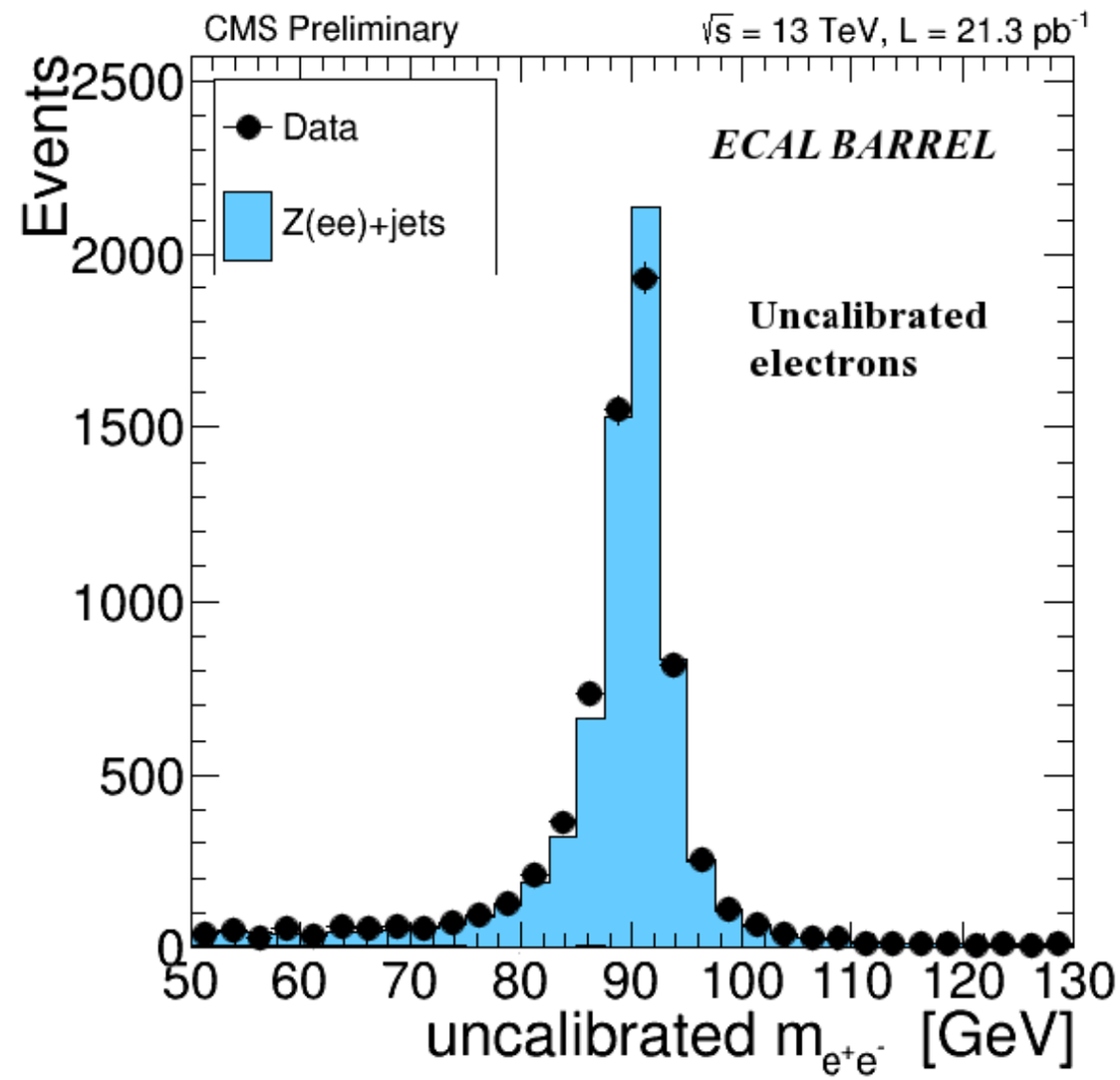


recovery after the long shutdown

Detector Commissioning

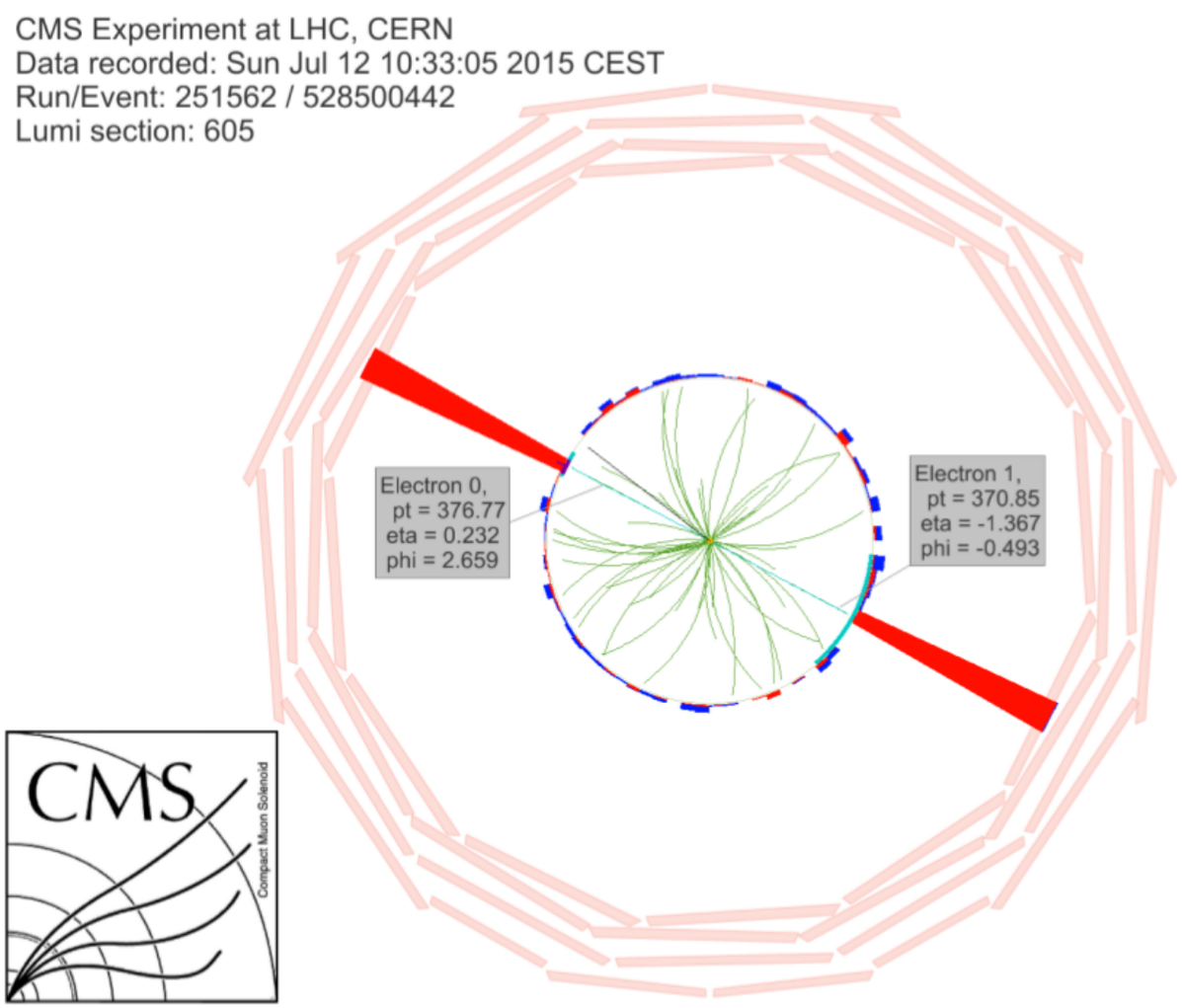
known SM particles serve as "standard candles" to test the performance of the detector



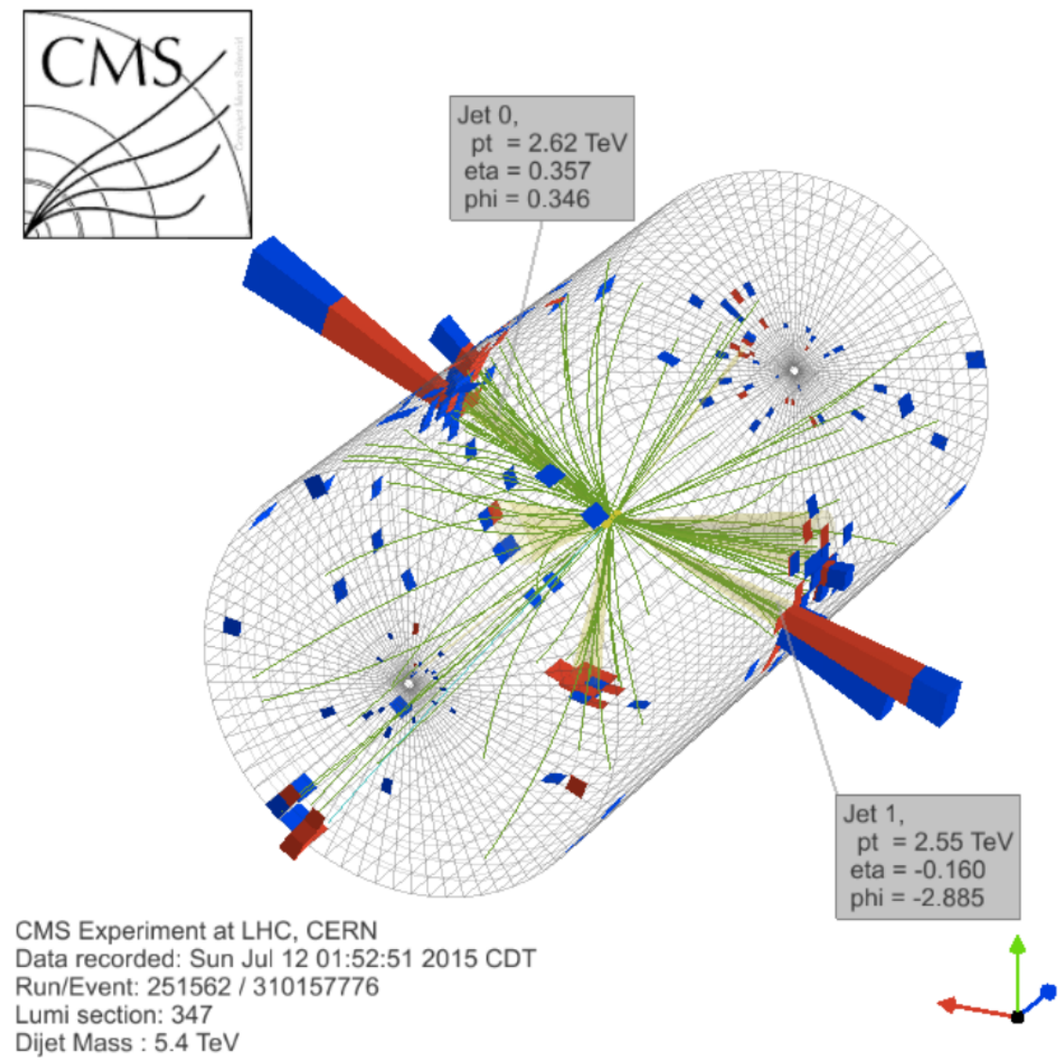


A Couple of Events @ 13 TeV

1 TeV electron-positron pair



5.4 TeV dijet pair



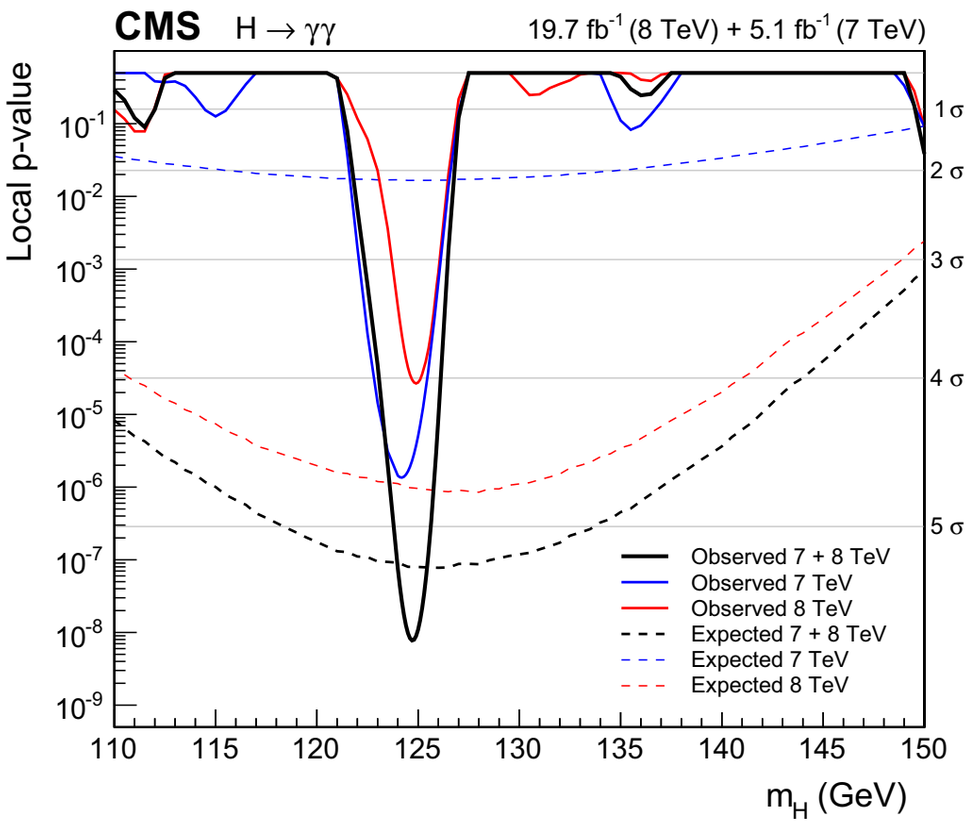
Study of the Higgs Boson Properties in the Diphoton Decay Channel at $\sqrt{s}$ = 8 TeV

The Higgs Studies

- tens of analyses with a common goal: determine the properties of the boson discovered in 2012
- so far all results (signal strength, spin, couplings…) are consistent with the SM predictions
- an update of the studies at a center-of-mass energy of 13 TeV is expected for the end of the year: stay tuned!

diphoton channel has a crucial role:

- excellent mass resolution (thanks to ECAL and reconstruction algorithms)
- low background



http://arxiv.org/abs/1407.0558

The HVV Couplings

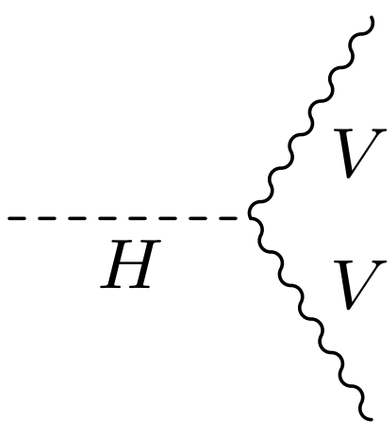
http://arxiv.org/pdf/1309.4819v3.pdf

$$A(\mathrm{HVV}) \sim \left[a_1^{\mathrm{VV}} + \frac{\kappa_1^{\mathrm{VV}} q_{\mathrm{V1}}^2 + \kappa_2^{\mathrm{VV}} q_{\mathrm{V2}}^2}{\left(\Lambda_1^{\mathrm{VV}}\right)^2} \right] m_{\mathrm{V1}}^2 \epsilon_{\mathrm{V1}}^* \epsilon_{\mathrm{V2}}^* + a_2^{\mathrm{VV}} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3^{\mathrm{VV}} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu},$$

SM scalar coupling

pseudoscalar

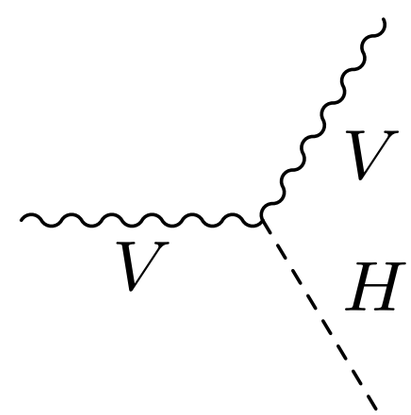
Decay Vertex

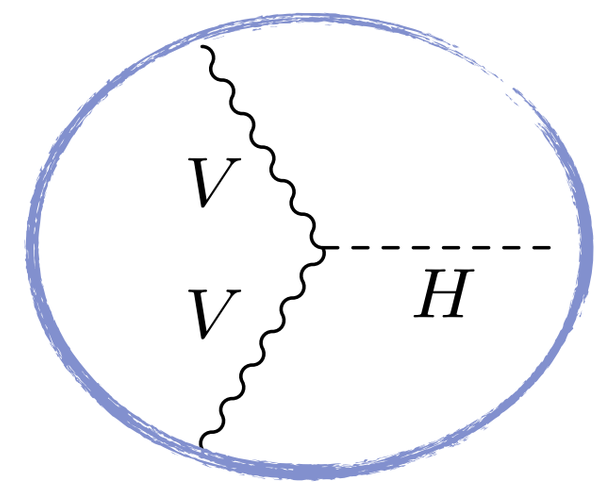


published measurement in H>ZZ /H>WW channels

http://arxiv.org/pdf/1411.3441.pdf

Production Vertex





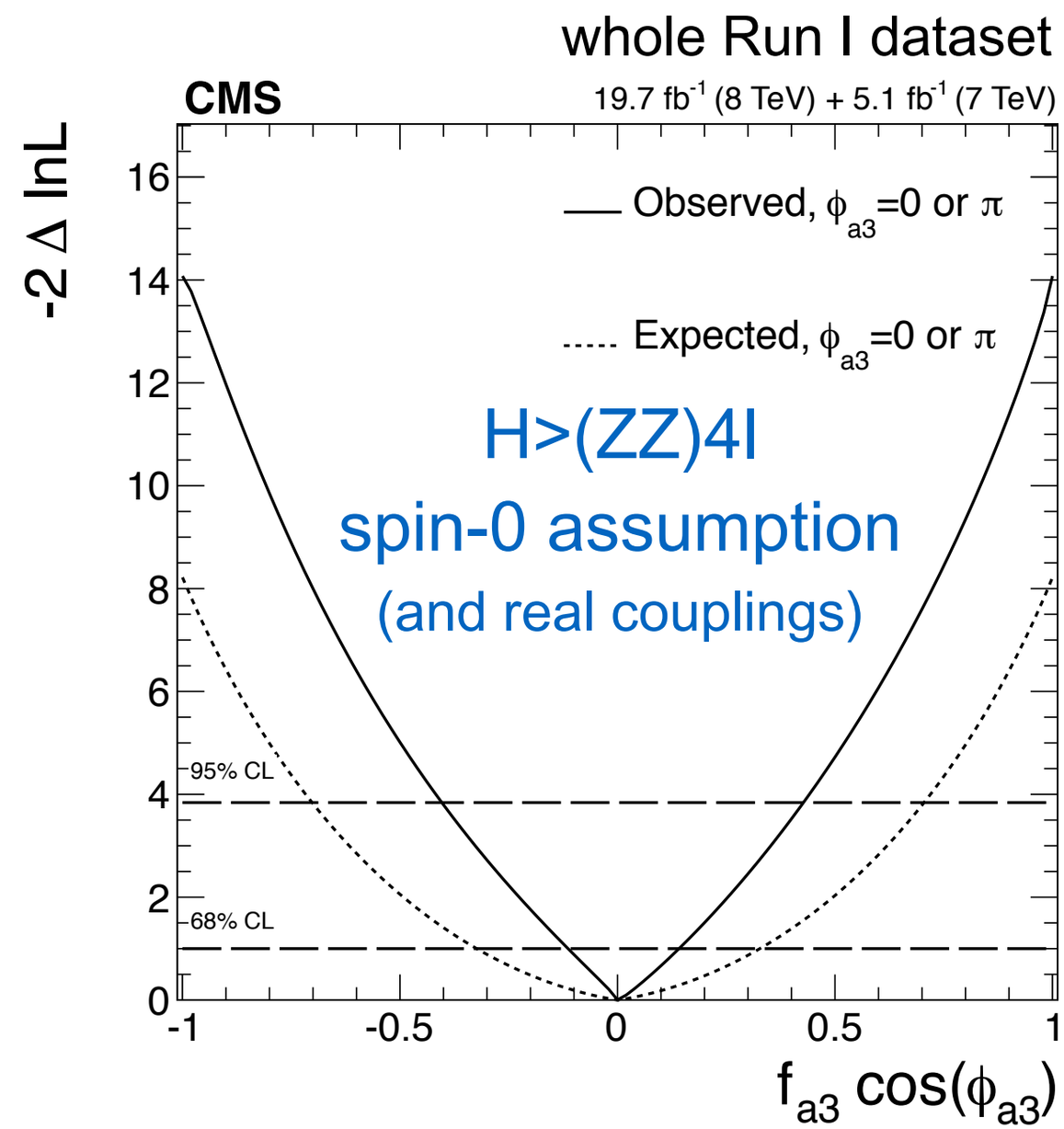
Vector Boson Fusion (VBF)

decay into diphoton

Studies in H>(ZZ)4l and H>(WW)2l2v

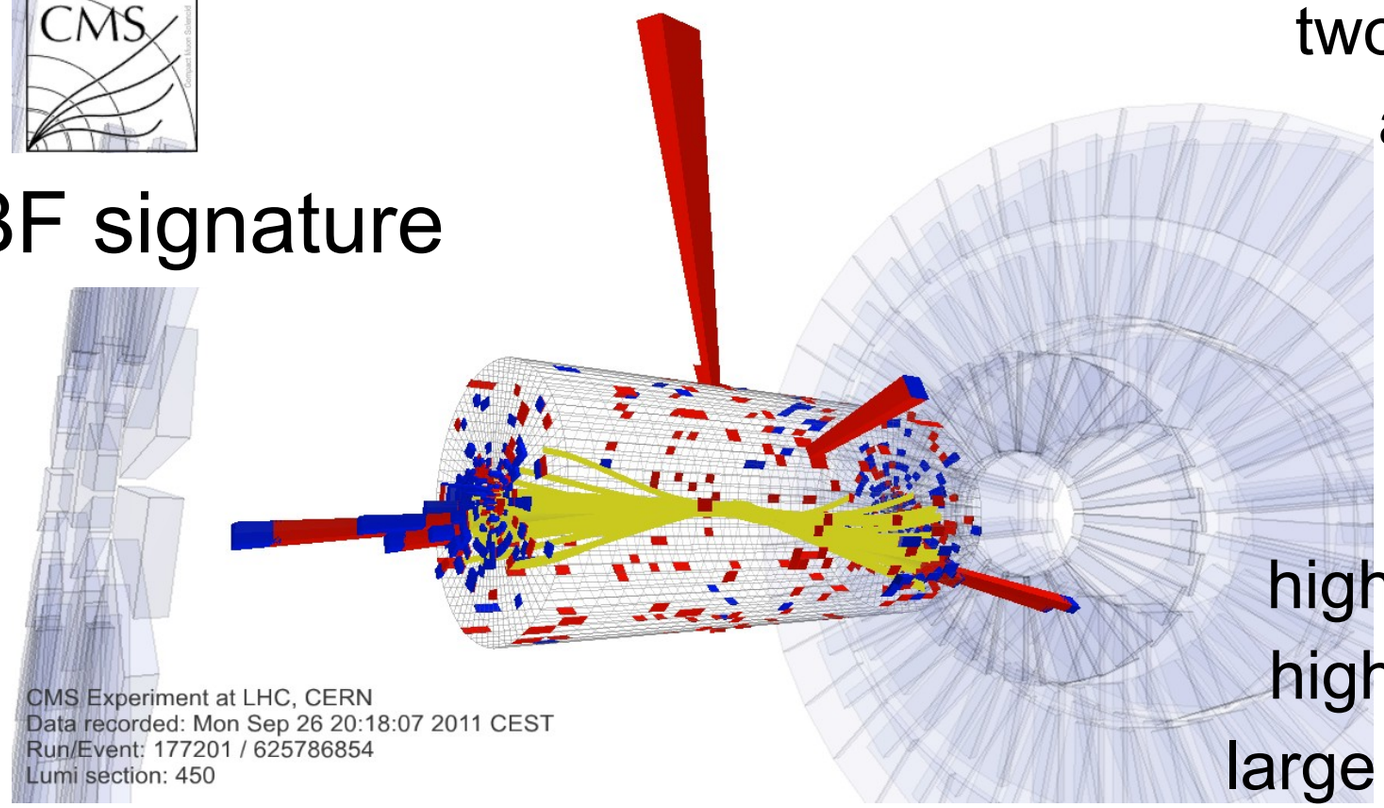
http://arxiv.org/pdf/1411.3441.pdf

- the H>(ZZ)4l channel is the most sensitive, the final state can be fully reconstructed
- maximum likelihood fit to disentangle signal/background and different signal hypotheses
- several theoretical models are considered, and 11 coupling parameters for the spin-0 hypothesis
- all compatible with the SM prediction



Final State Topology, Event Selection and Backgrounds

VBF signature



two well identified and isolated photons with high p_T

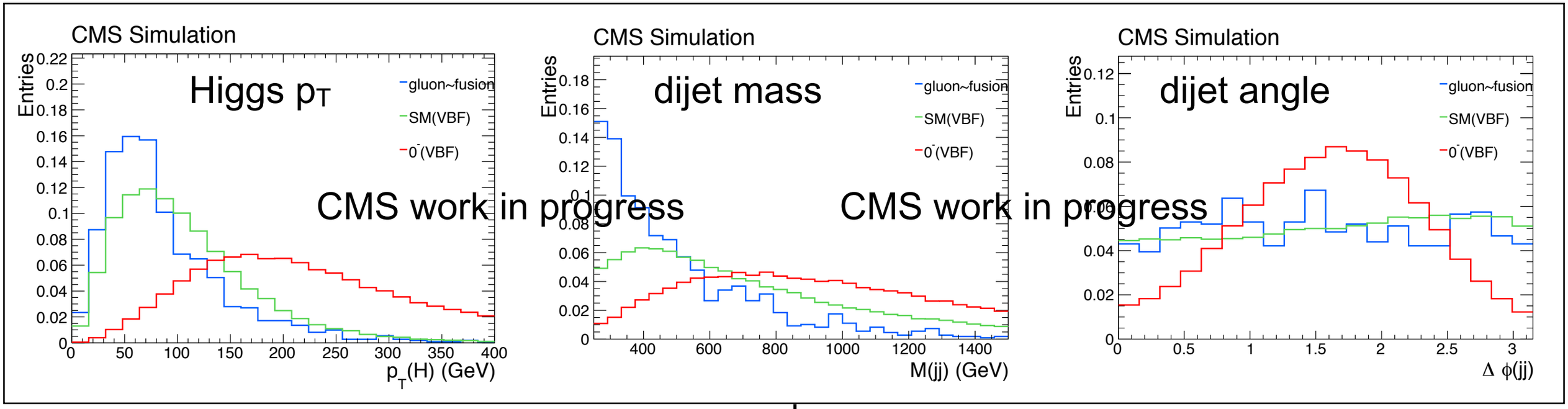
two jets at high pseudorapidity high invariant mass large separation angle

what contributes in the selected event sample:

VBF scalar (0^+)	gluon fusion (ggH)
VBF pseudoscalar (0^-)	QCD background
interference	

A Matrix Element Likelihood Analysis

exploit the event kinematics to disentangle the physics processes

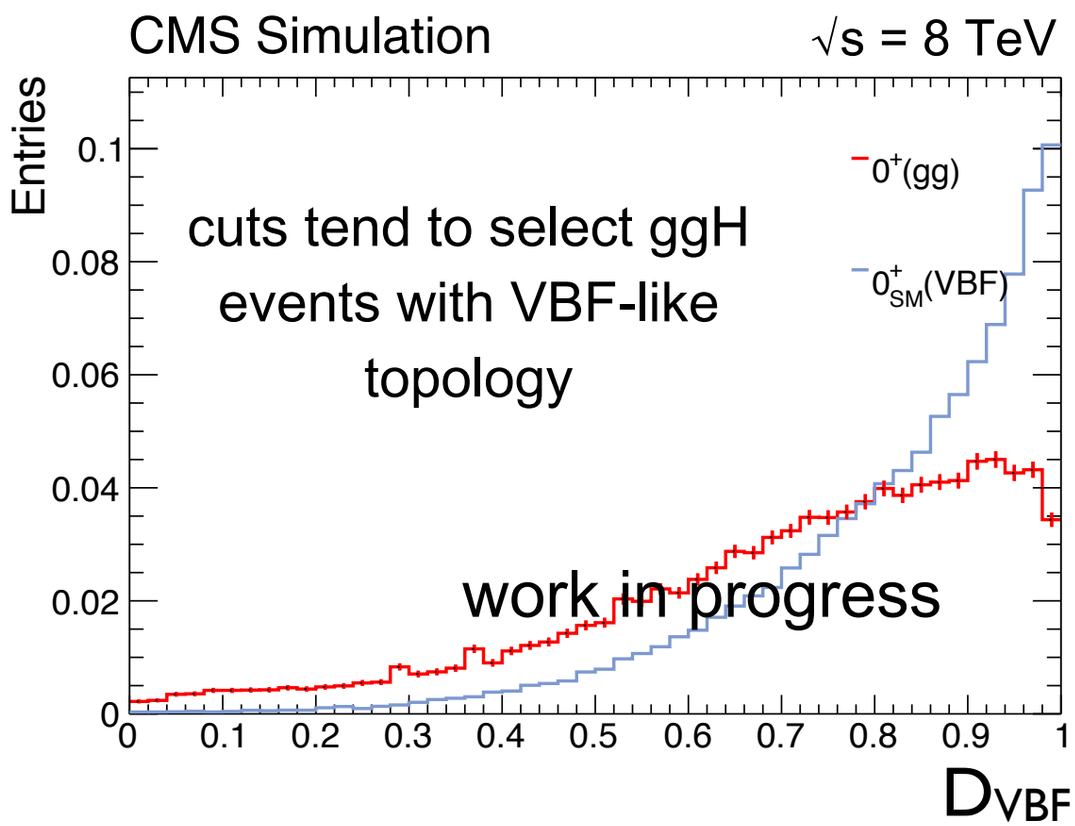


MELA
(Matrix Element
Likelihood Analysis)

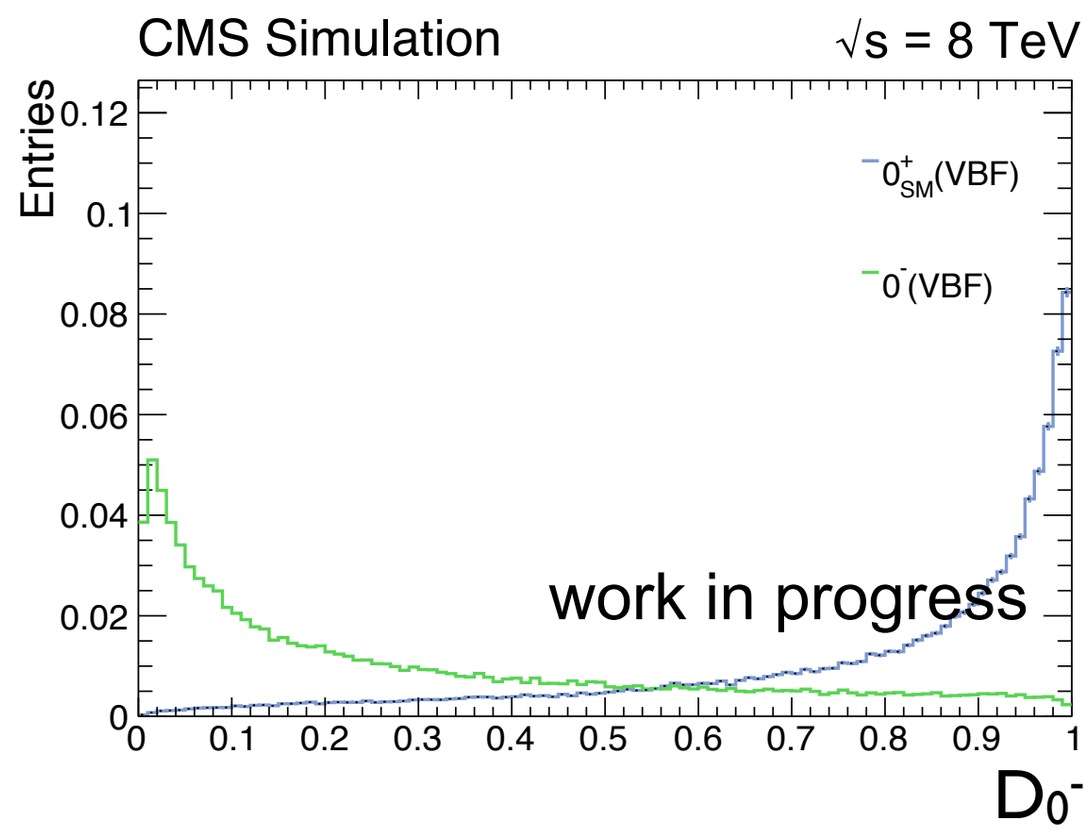
differential cross-sections for the different processes, combined into discriminants

Discriminants: Signal Hypotheses

VBF/gluon fusion



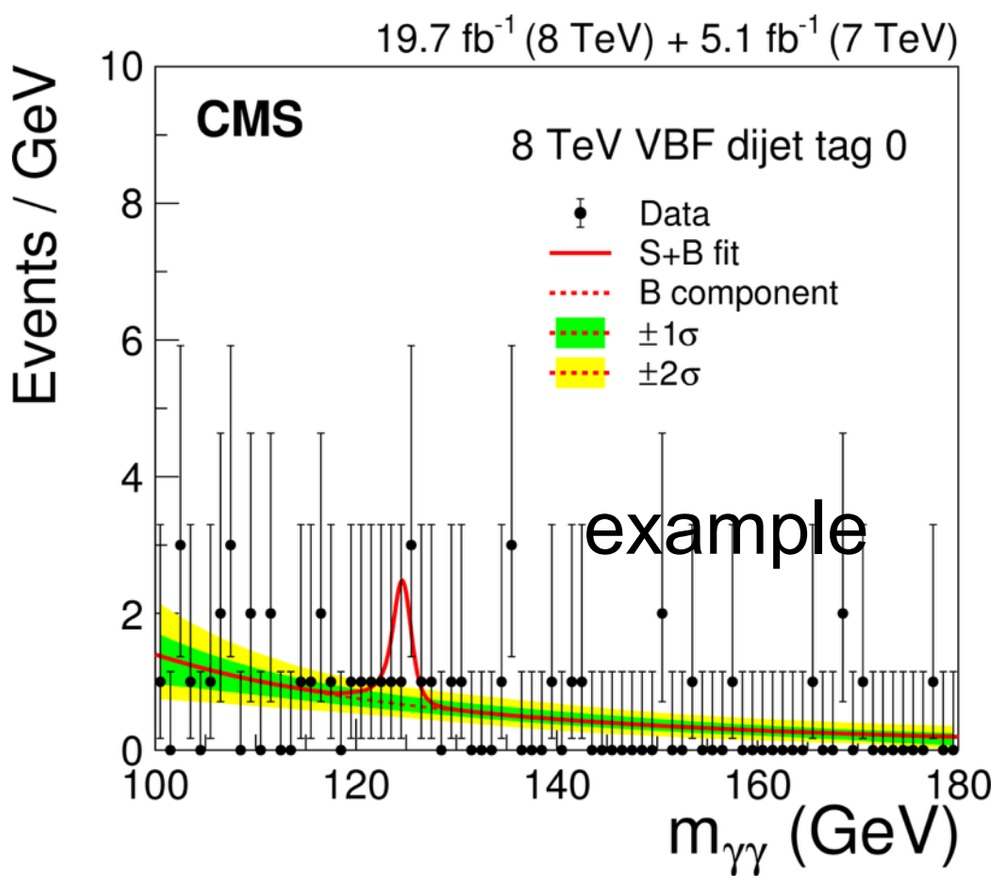
scalar/pseudoscalar



identification of a set of regions of the discriminant space dominated by one process

Discriminants: Signal/Background

- the diphoton invariant mass is the most effective variable
- ▸ simultaneous maximum likelihood fit of the diphoton mass spectrum in all regions together
- ▸ determine the best-fit value of the coupling parameters



expected yields in all regions (SM) in 8 TeV

data sample: ~ 10 events from VBF

~ 5 events from ggH

estimated sensitivity comparable with existing public results

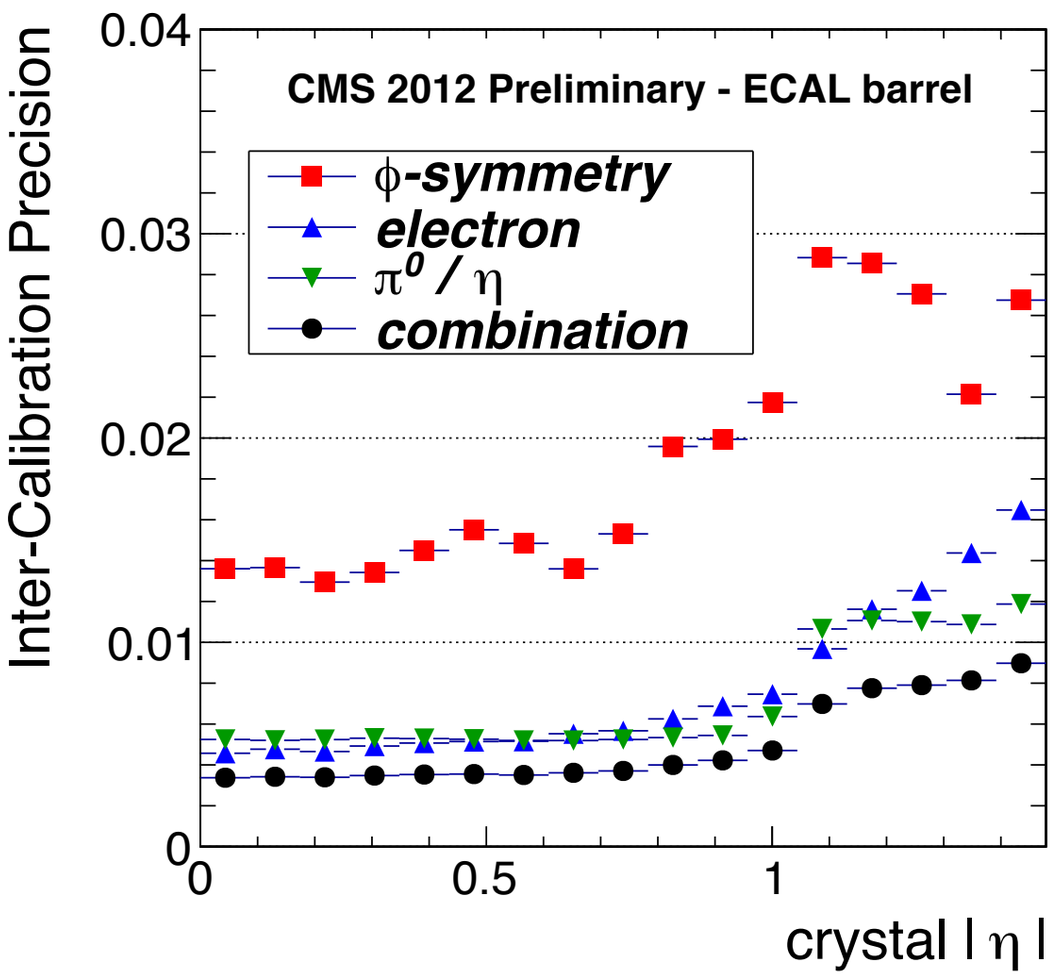
Conclusions

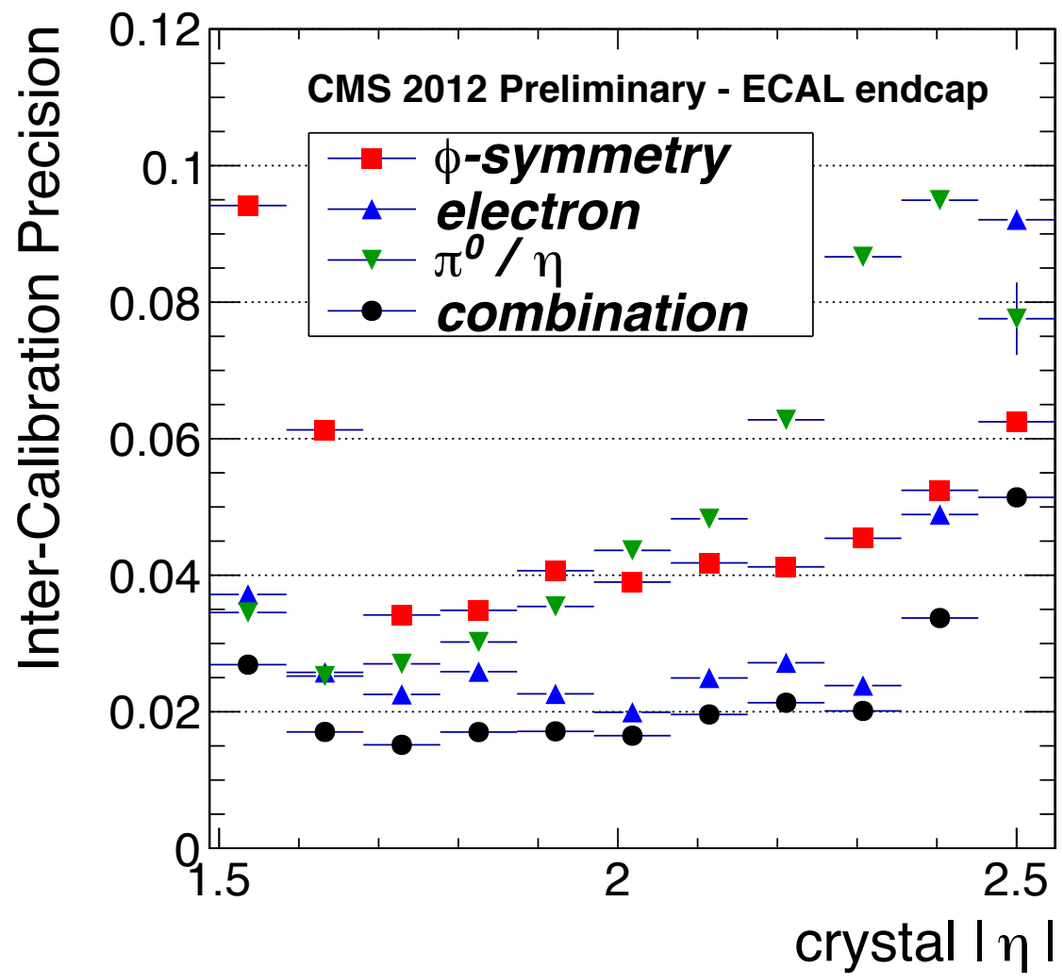
- the first year of the LHC Run II at higher center-of-mass energy is concluded
- all CMS subdetectors have been recommissioned to operate in the new conditions, including ECAL, in which CEA/Saclay is strongly involved
- the Run II data are not sufficient yet for a Higgs rediscovery, but large datasets are expected for 2016. first results with the available luminosity will be delivered by the end of the year
- a measurement of the anomalous HVV couplings in the diphoton channel has been designed using Run I datasets
- the sensitivity seems promising, comparable with that of the published analyses in other channels (not approved by the collaboration yet)

Thanks!

Backup

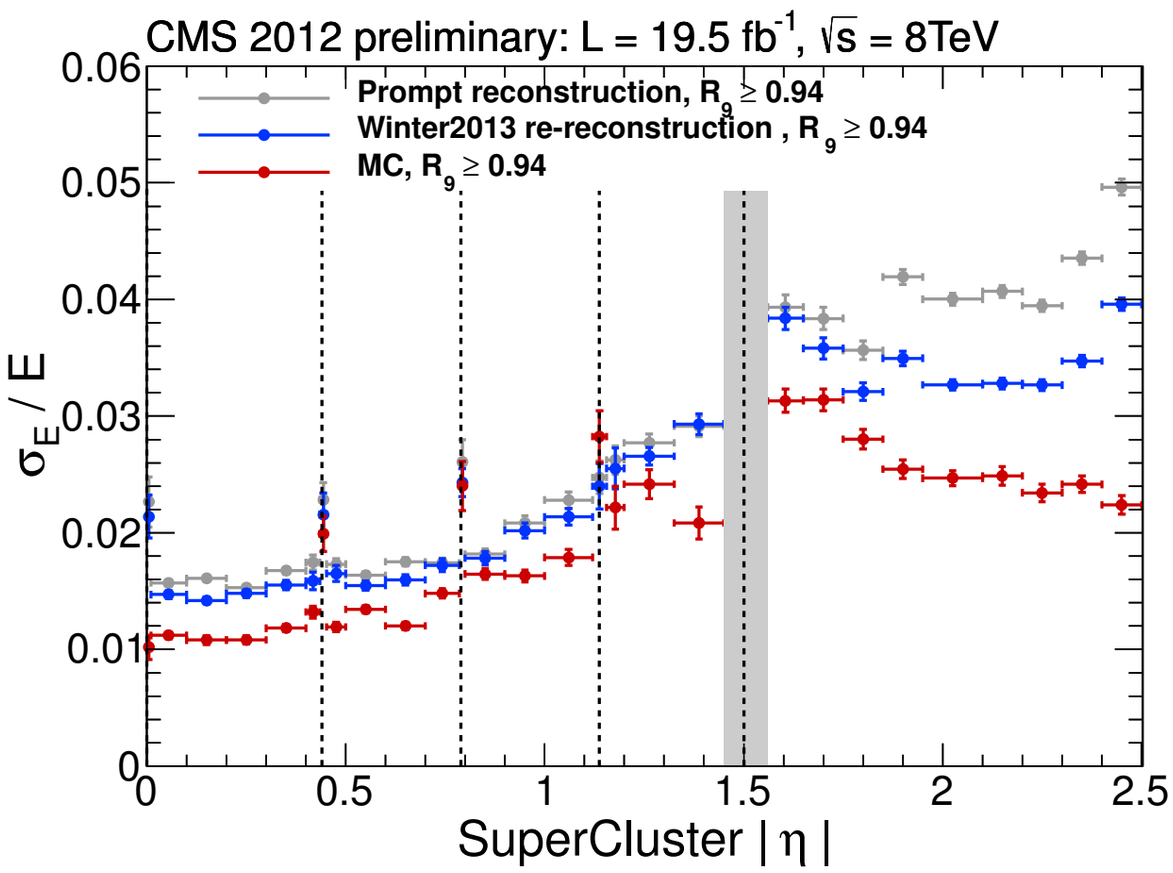
ECAL Intercalibration

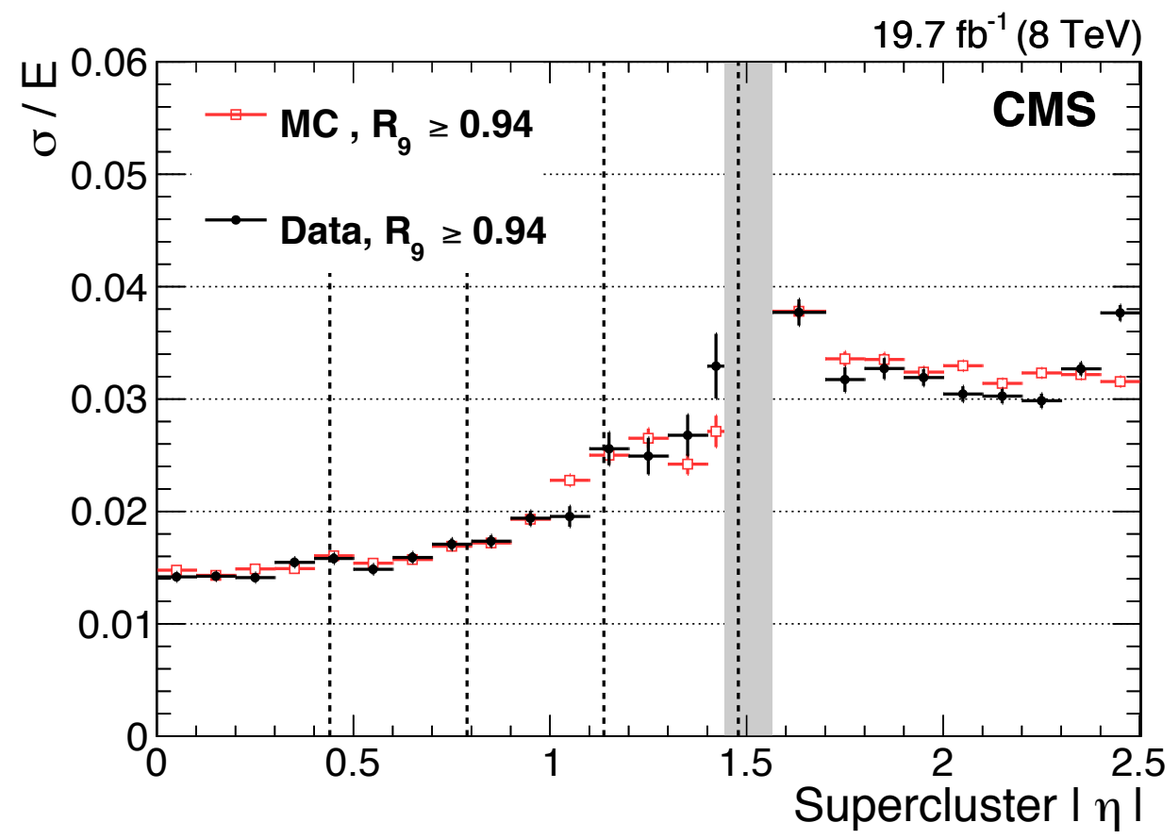




Electron Energy Resolution

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





tuned simulation
(addition of Gaussian smearing)

ECAL Local Reconstruction

multifit method

$$\chi^2 = \sum_{i=1}^{N} \frac{\left(\sum_{j=1}^{M} \mathcal{A}_j p_{ij} - S_i\right)^2}{\sigma_{S_i}^2}$$

amplitudes extracted by minimising the X^2

i runs over the pulses

weight method

$$\hat{\mathcal{A}} = \sum_{i=1}^{N} w_i \times S_i$$

i runs over the samples in one pulse