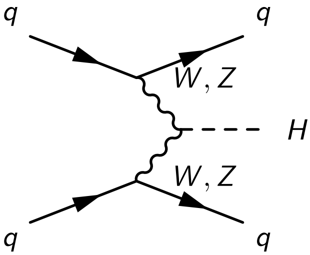
# Searches for invisible decays of the Higgs boson with the CMS detector

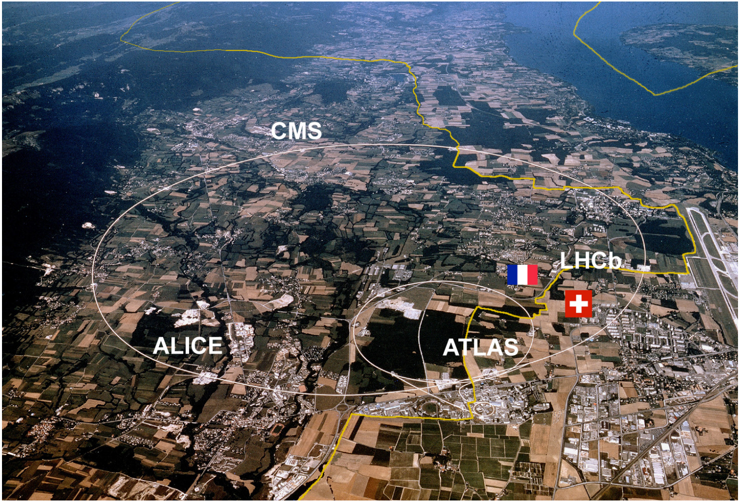
P. Dunne - Imperial College London



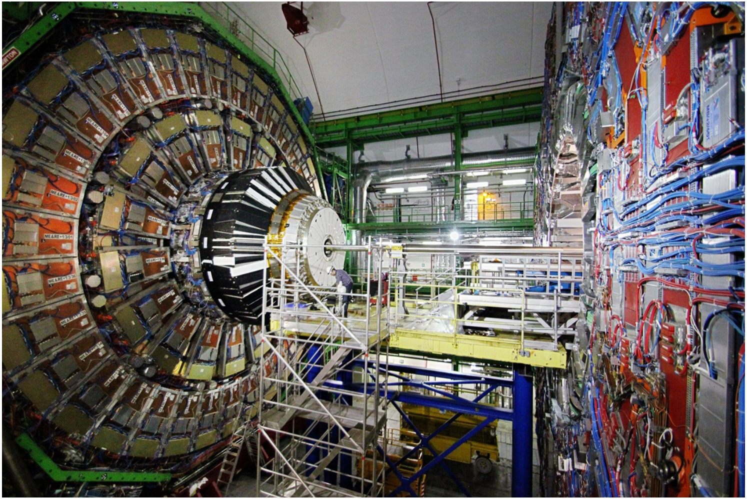
# Introduction

- CMS and the LHC
- Why look for invisibly decaying Higgs bosons?
- How do you look for something invisible?
- What do we see?

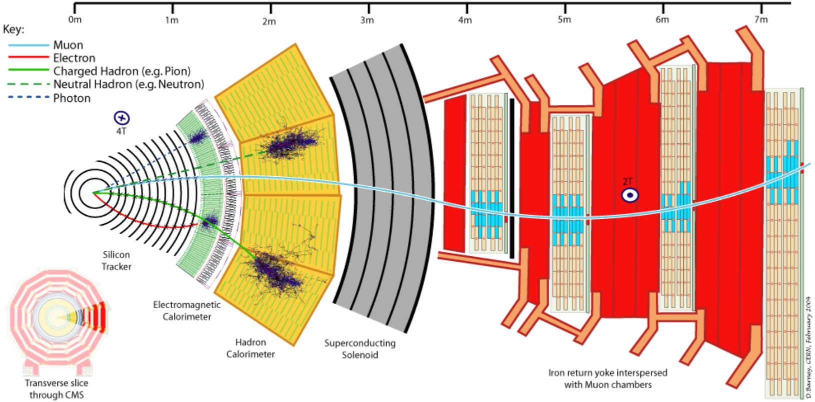
# CMS and the LHC



# CMS

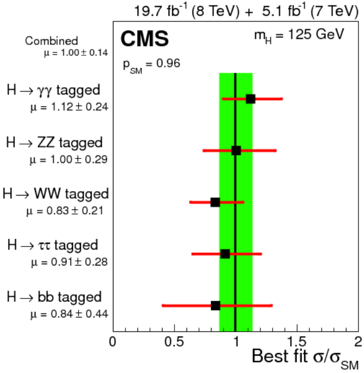


# CMS


0m
1m
2m
3m
4m
5m
6m
7m
Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS
D.Barney, CERN, February 2004

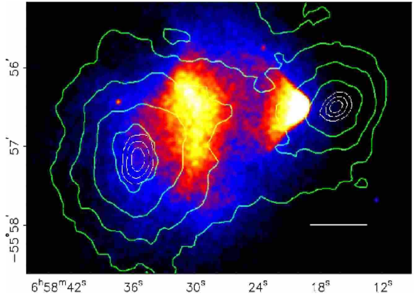
# The Higgs boson

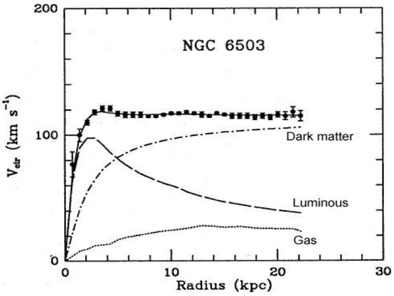
- Explains mass in the Standard model (SM)
  - Every particle with mass interacts with the Higgs
- SM compatible Higgs boson observed at the LHC
  - SM compatible doesn't mean incompatible with other theories



# Dark matter

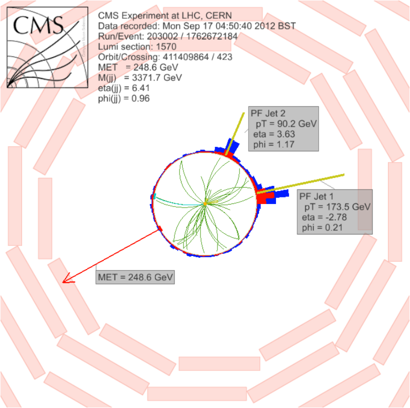
- What do we know?
  - Cold, massive, weakly interacting
- All other massive particles get mass from Higgs coupling
- If dark matter is light enough the Higgs will decay to it
- Look for invisibly decaying Higgs..



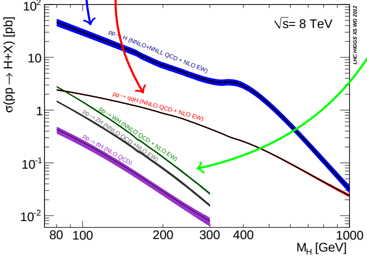
# How do you look for something invisible: Associated production

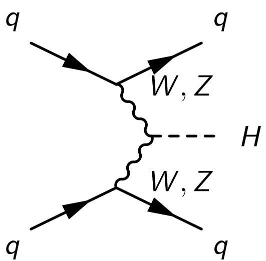
- Higgs not always created alone
- Look for momentum imbalance



# How do you look for something invisible: Associated production

- Three main types of Higgs production at LHC:
  - ggH: high rate, normally no visible products
  - VBF: medium rate, jets+MET final state
  - ZH: low rate, leptons/b jets+MET final state

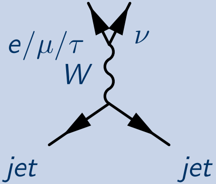


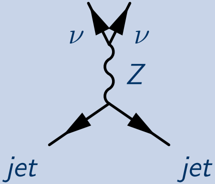
# How do you look for something invisible: VBF strategy

- Select events with two quark jets and missing momentum
- Main backgrounds: $W \rightarrow \ell\nu / Z \rightarrow \nu\nu$+jets, QCD
  - Veto events with leptons present
  - QCD hard to model so use tight selection to remove
  - Estimate remaining backgrounds

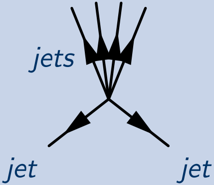
**W+jets**




**Z+jets**



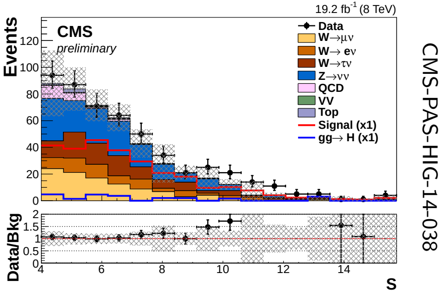

**QCD - multijets**

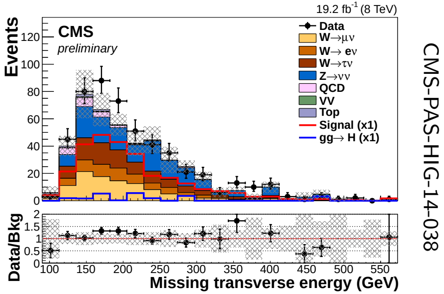


# What do we see?

| | |
|---|---|
| Total background | $439.7 \pm 41.0(stat.) \pm 55.8(syst.)$ |
| VBF H(inv.) assuming B(H→inv)=100% | $273.4 \pm 31.2(syst.)$ |
| ggF H(inv.) assuming B(H→inv)=100% | $22.6 \pm 15.6(syst.)$ |
| Observed data | 508 |

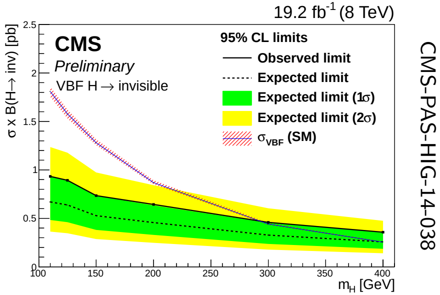
- No significant excess seen

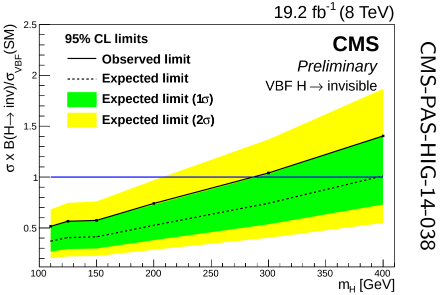


# What do we see?

- Lack of excess rules out some values of invisible decay rate
  - VBF alone limits $B(H \rightarrow inv)$ for $m_H$=125 GeV to less than 57%
- Combining with other searches the limit is less than 47%



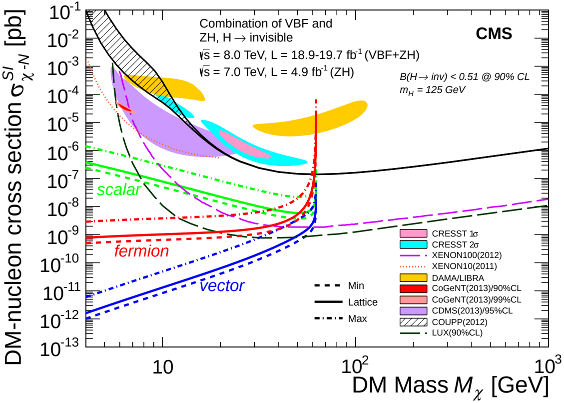



# What does this mean for dark matter?

- Invisible decay rate corresponds to DM interaction rate

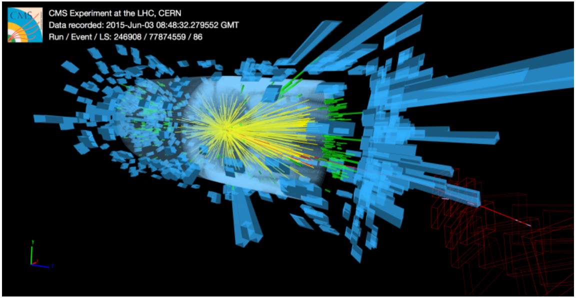
$$\sigma^{SI}_{S-N} = \frac{4\Gamma_{inv}}{m_H^3 v^2 \beta} \frac{m_N^4 f_N^2}{(M_\chi + m_N)^2}$$

- Use invisible limit to constrain DM



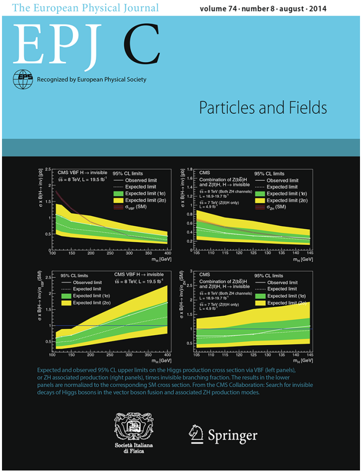
# Summary

- The Higgs discovery is only the beginning
- We have already placed tight constraints on Higgs-dark matter interactions
- LHC Run II will allow us to be even more sensitive



# The Higgs Boson

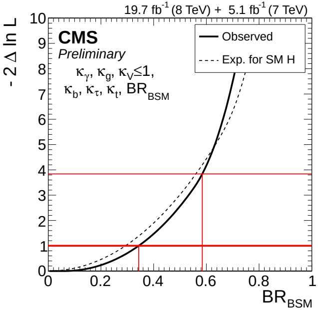
# What do I do?


The European Physical Journal
volume 74 · number 8 · august · 2014
EPJ C
Recognized by European Physical Society
Particles and Fields
CMS VBF H → invisible
95% CL limits
Observed limit
Expected limit
Expected limit (1σ)
Expected limit (2σ)
CMS
Combination of Z(bb̄)H and Z(ll)H, H → invisible
Expected and observed 95% CL upper limits on the Higgs production cross section via VBF (left panels), or ZH associated production (right panels), times invisible branching fraction. The results in the lower panels are normalized to the corresponding SM cross section. From the CMS Collaboration: Search for invisible decays of Higgs bosons in the vector boson fusion and associated ZH production modes.
Società Italiana di Fisica
Springer

# Why Higgs to Invisible?

## Experimental motivation

- Current measurements of the 125 GeV Higgs boson are compatible with Standard Model (SM) expectations
  - large uncertainties can still accommodate significant beyond the SM (BSM) properties
- Additional Higgs bosons with exotic decays are not excluded




CMS-PAS-HIG-14-009

## Theoretical motivation

- Many BSM theories predict Higgs boson decays to invisible final states:
  - e.g. SUSY, extra dimensions, fourth-generation neutrinos
- These final state particles are often dark matter candidates

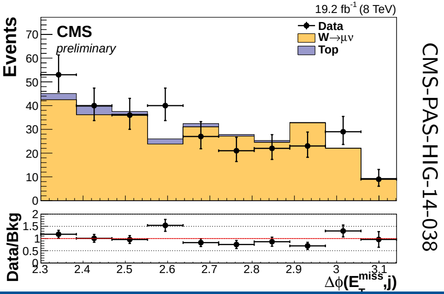
# VBF: background estimation

- All major backgrounds have data driven normalisation

$$N^{sig}_{bkg} = \frac{(N^{control}_{obs} - N^{control}_{other\ bkgs})}{N^{control}_{MC}} \cdot N^{sig}_{MC}$$

- Most backgrounds from missed lepton or misreconstructed jet
  - use control region where object is reconstructed

$W \to \mu\nu$ control region




$Z \to \nu\nu$ control region