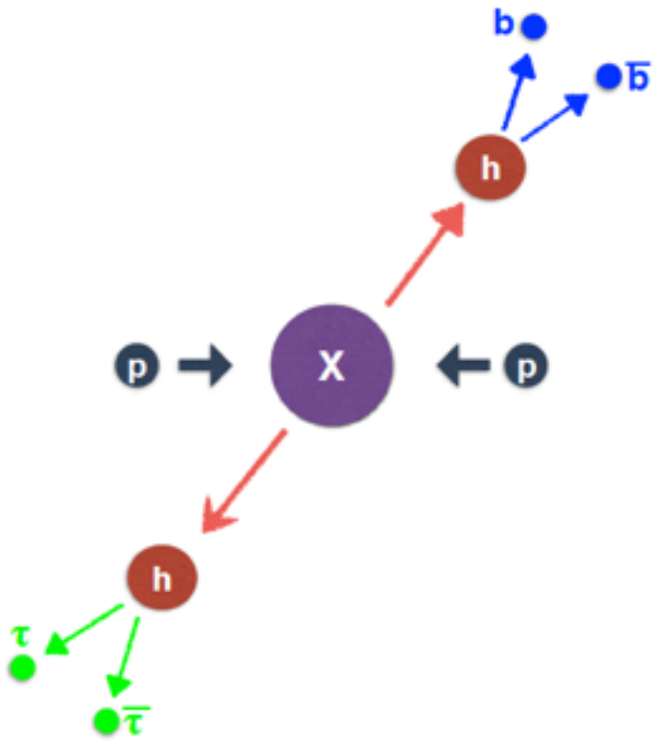
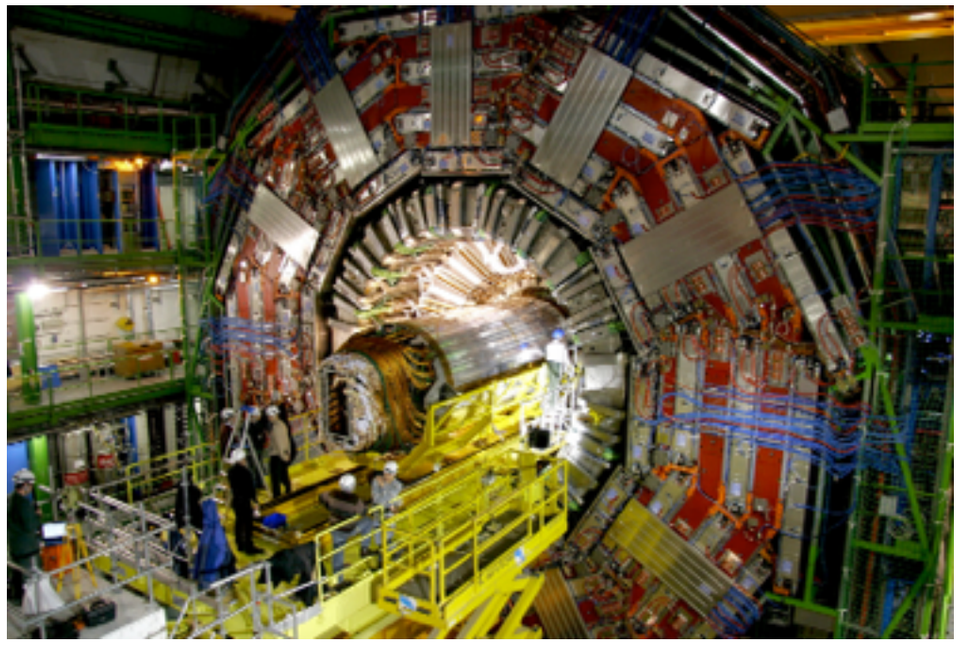
Search for heavy resonances decaying into a pair of Higgs bosons in the $\tau^-\tau^+b\bar{b}$ final state at CMS



Camilla Galloni
University of Zurich

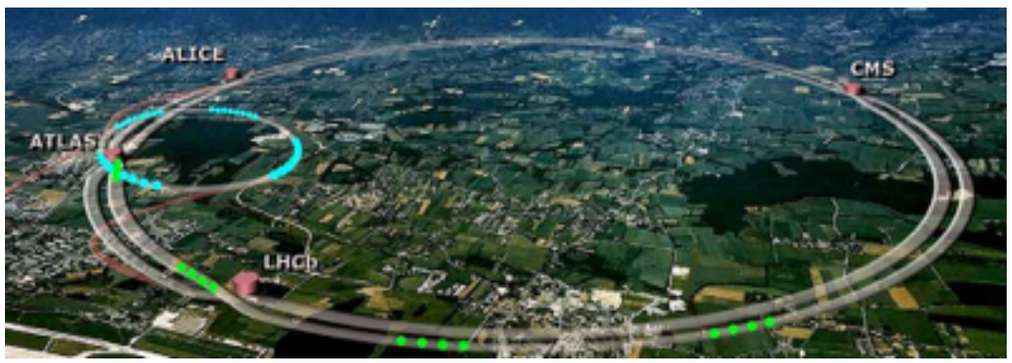
July 2nd 2014



New Physics Scenarios

Outstanding success of LHC physics program at 8 TeV:

- Discovery of the Higgs Boson
- Higgs boson characterization

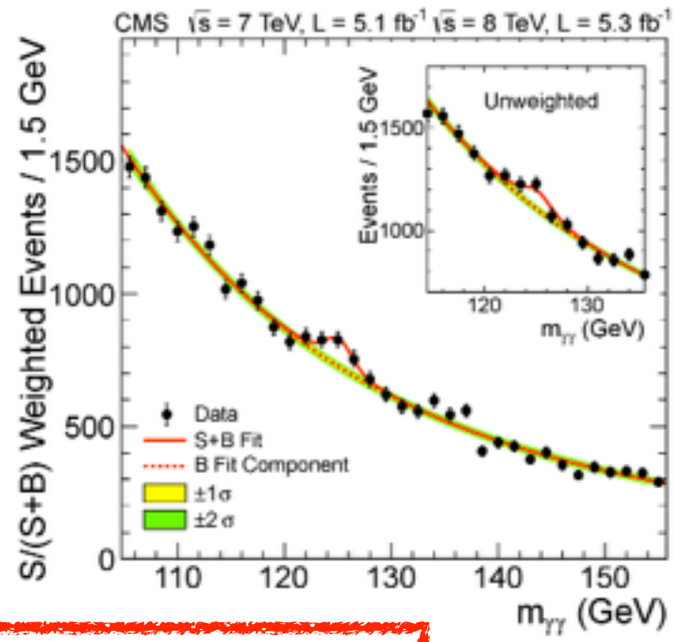


8 TeV → 13 TeV in 2015 accesses new energy frontier

- Beyond the Standard Model searches:
  - Extra Dimensions Models

    Low mass searches (up to 1 TeV)

    High mass searches (1 TeV - 2.5 TeV) → Boosted regime



Higgs Pair Production in NP

- Higgs pair production in the Standard Model has a small cross section, but larger rates are possible in New Physics (NP) Models

- Warped Extra Dimensions scenarios predict:

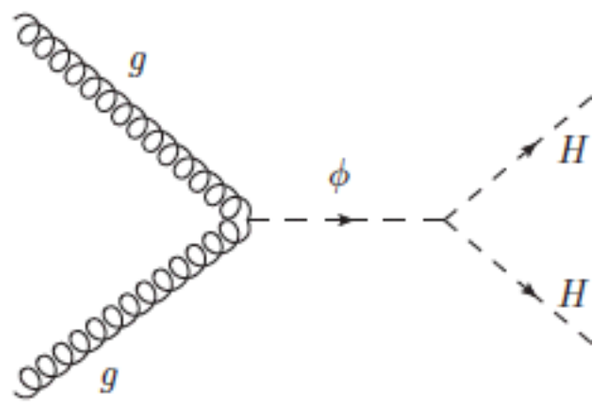
  - Higgs pair production by:

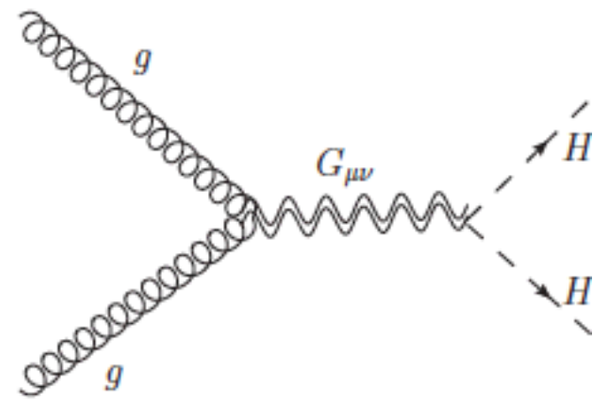
    - spin 2 particle (Kaluza-Klein (KK) Graviton)

    - scalar particle (Radion)

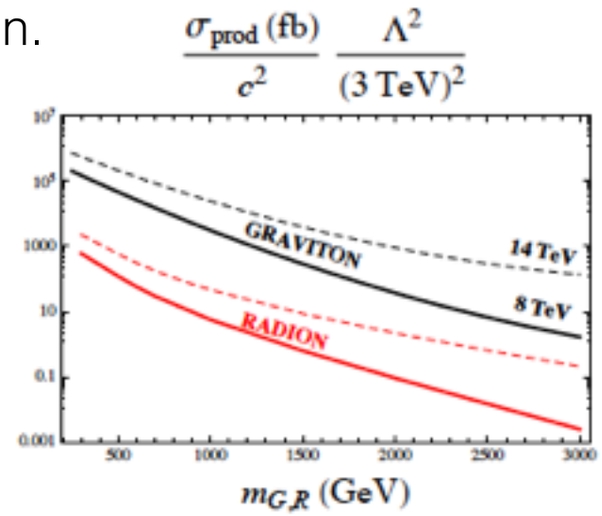
- Explains hierarchy between the Electroweak and the Planck scales

- Non trivial geometry a fifth extra dimension.



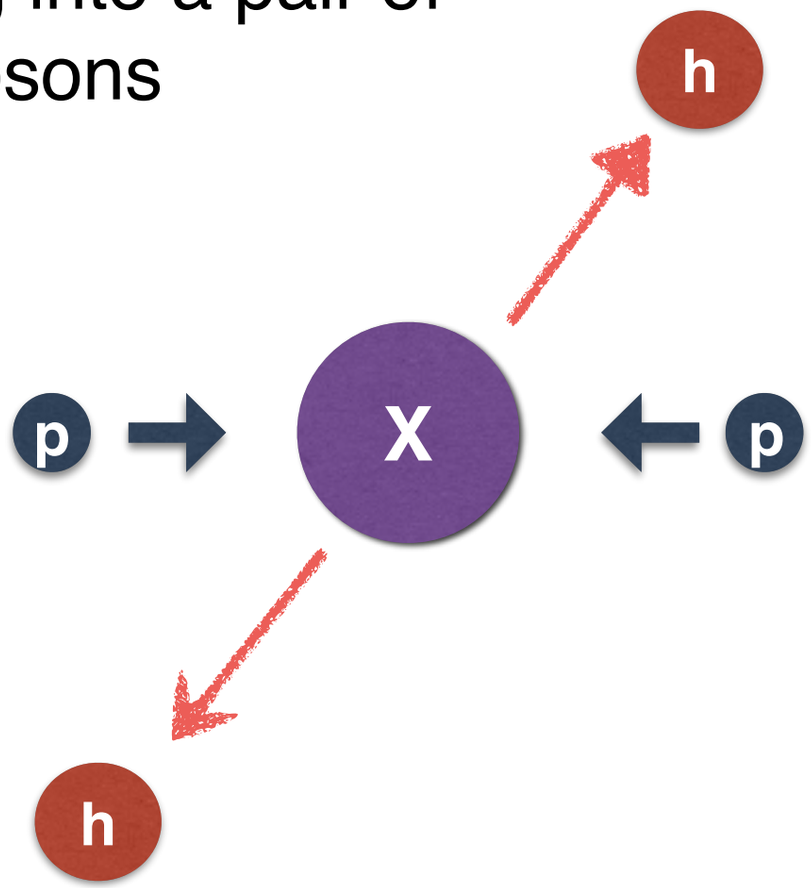


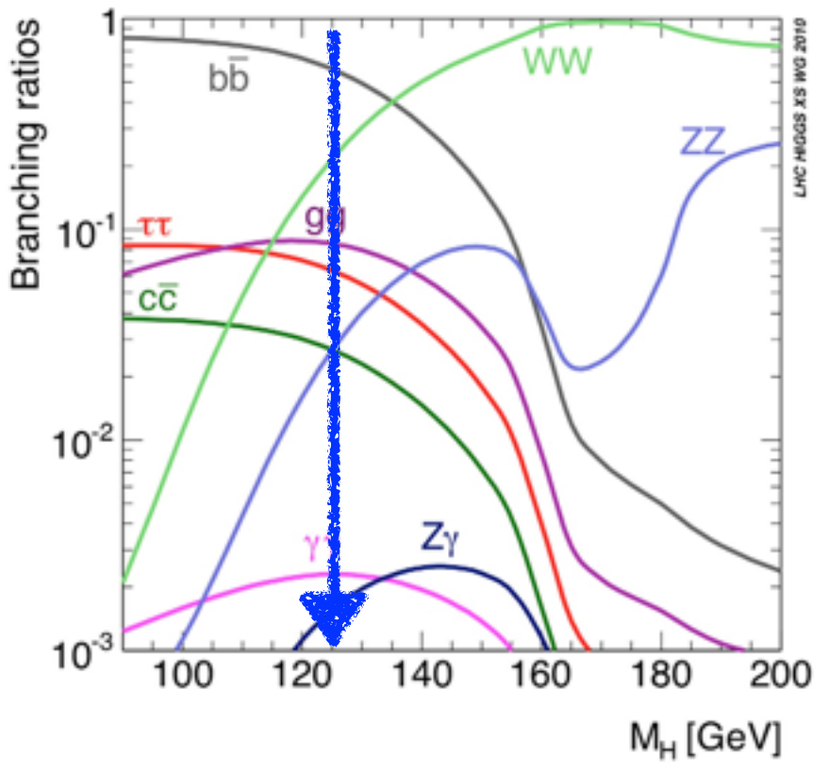
arXiv: 1303.6636



Search strategy

- Radion or Graviton decaying into a pair of Higgs bosons



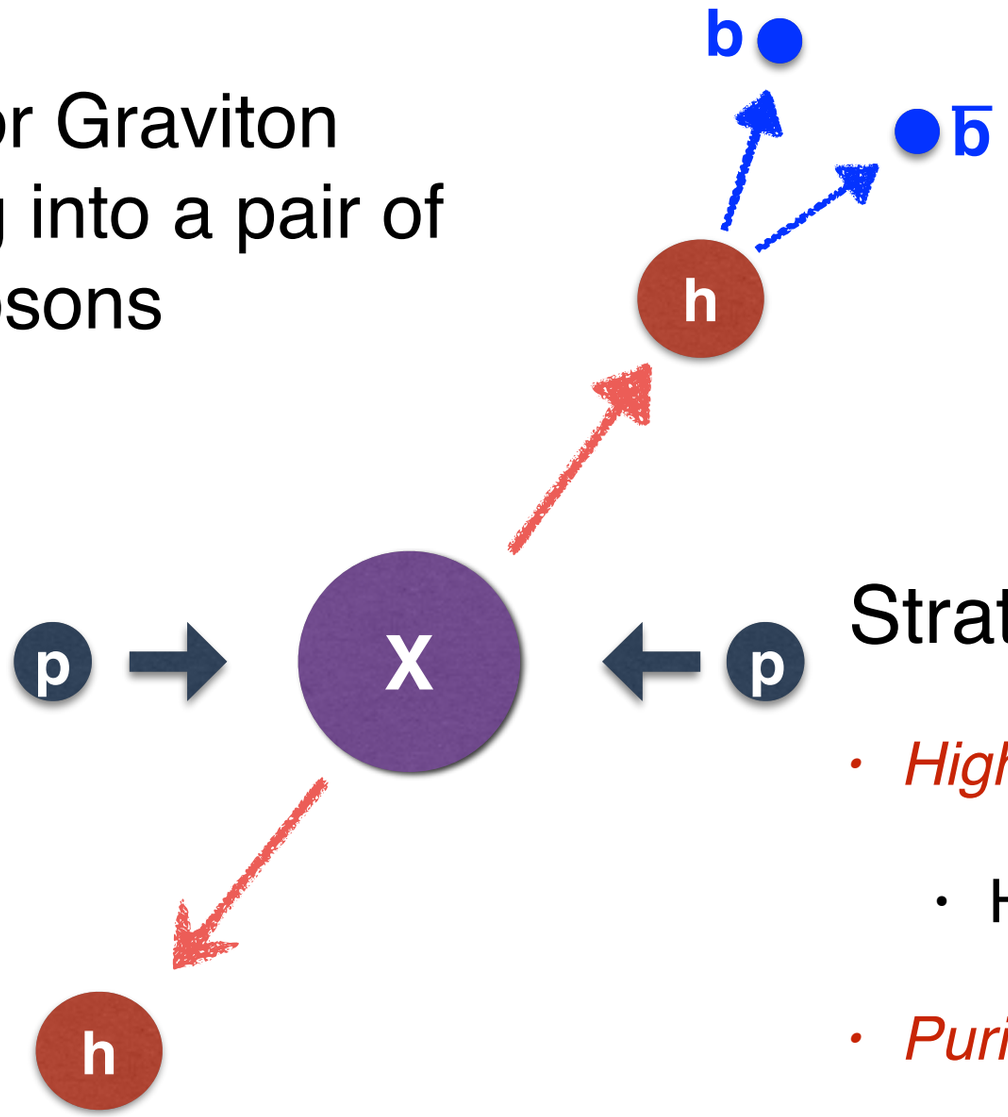


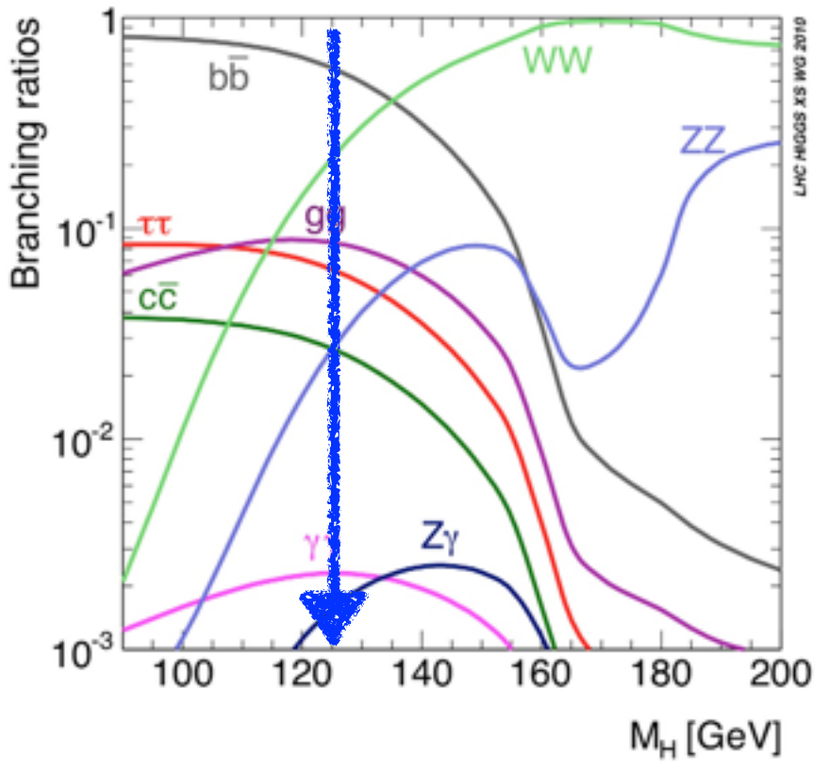
Strategy

- *High statistics*
- *Purity of the signal*

Search strategy

- Radion or Graviton decaying into a pair of Higgs bosons



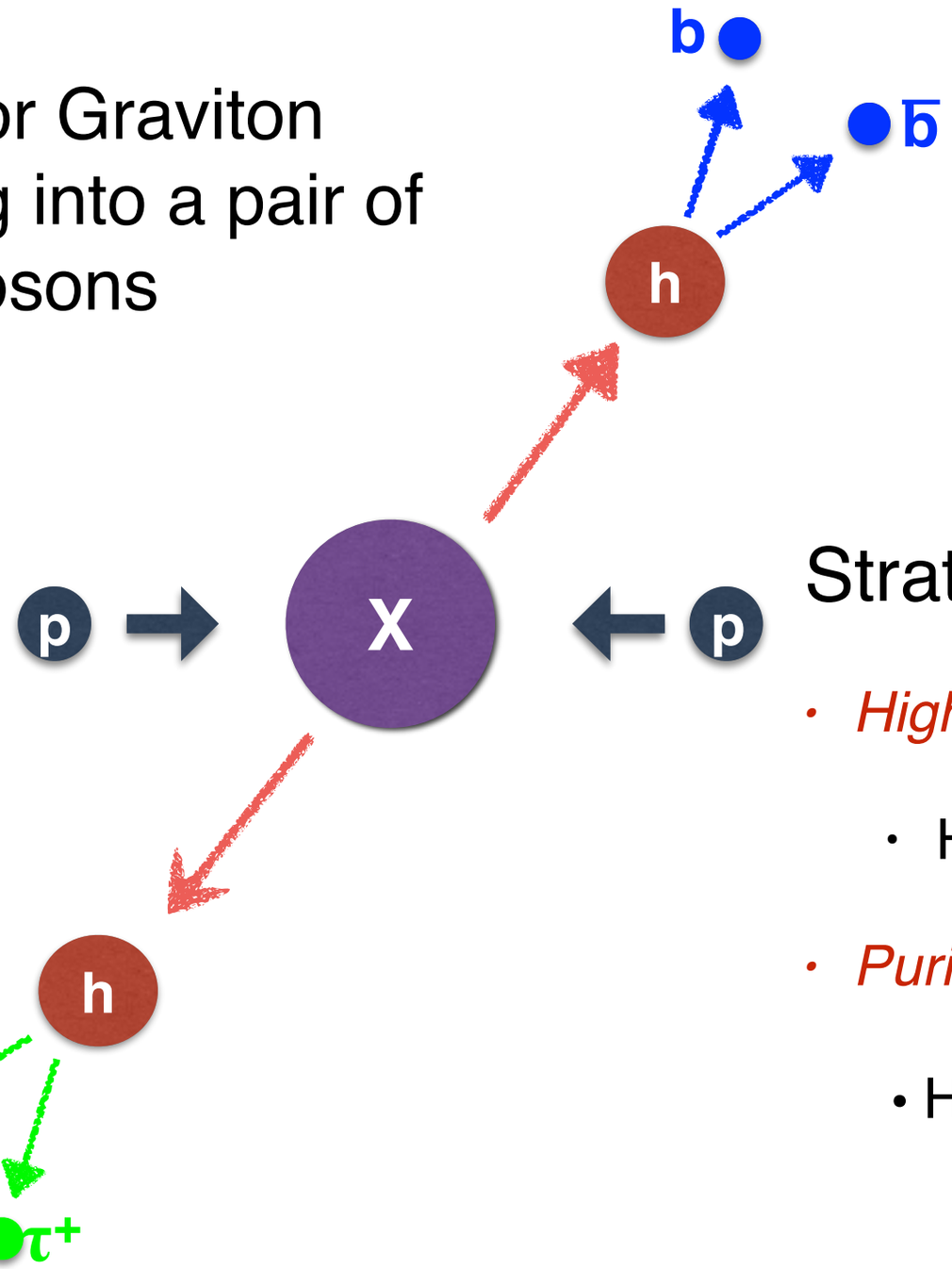


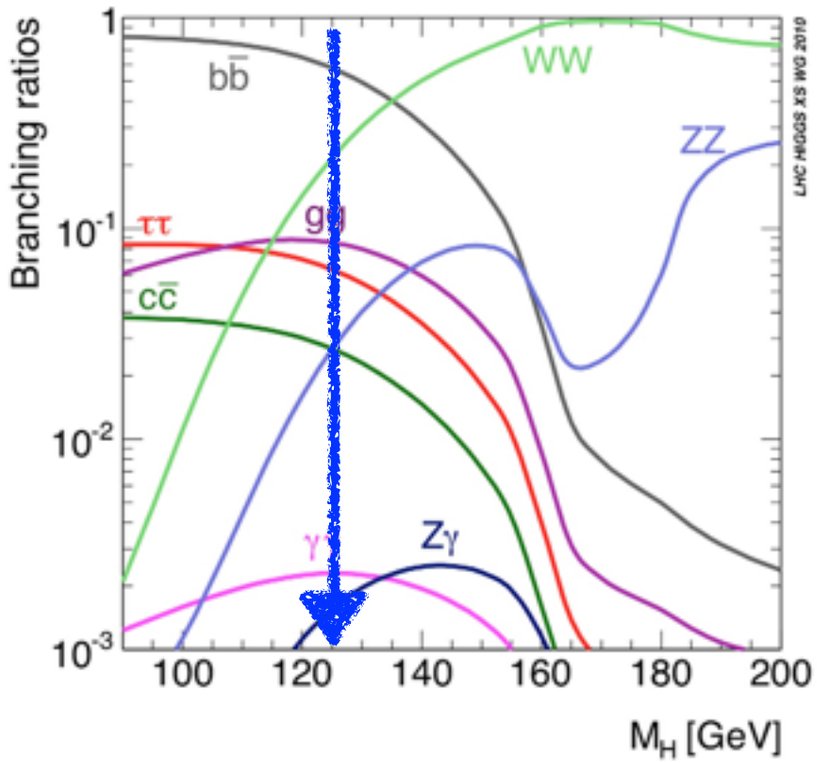
Strategy

- *High statistics*
  - High breaching ratio: $H \to b\bar{b}$(~60%)
- *Purity of the signal*

Search strategy

- Radion or Graviton decaying into a pair of Higgs bosons



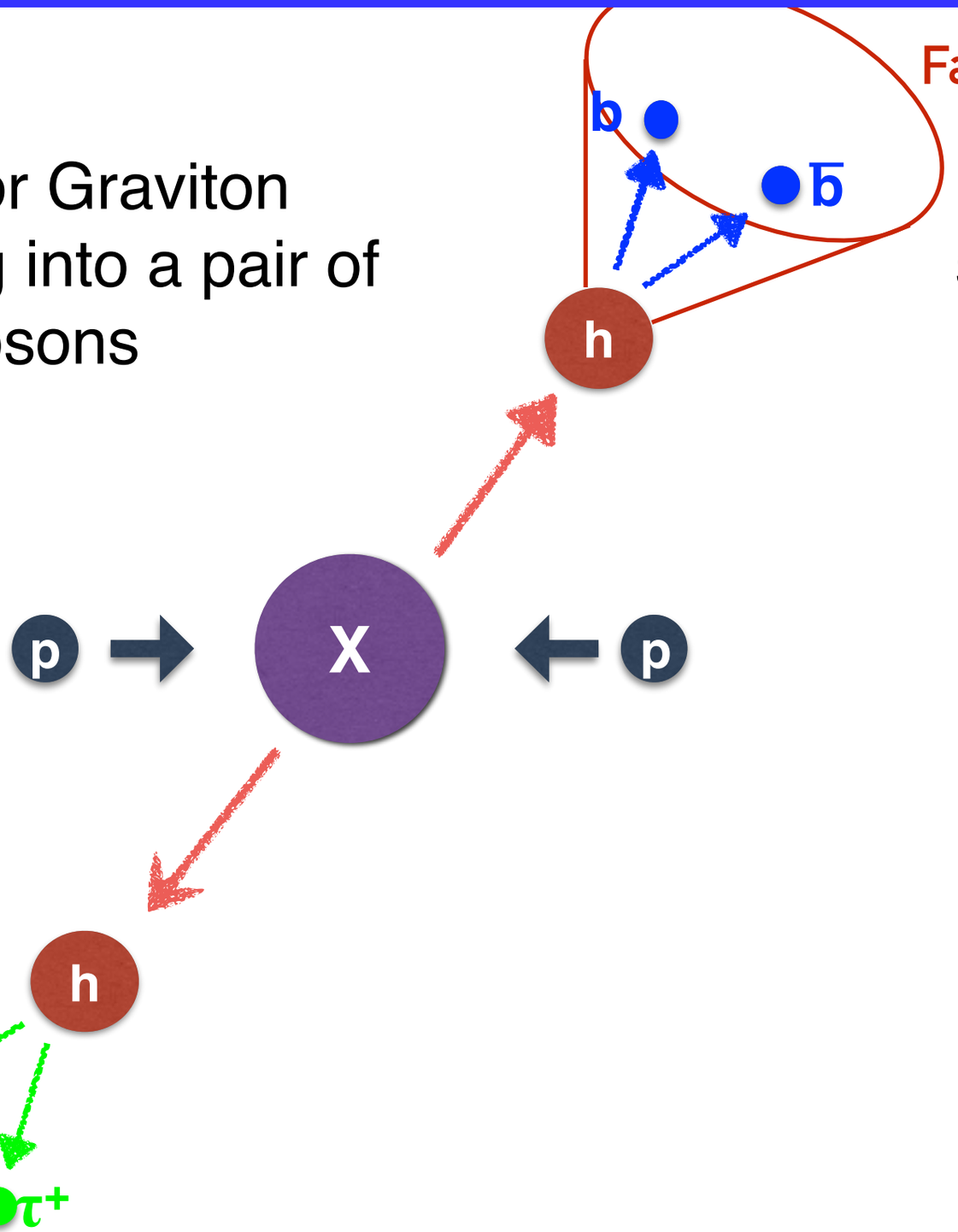


Strategy

- *High statistics*
  - High breaching ratio: $H \to b\bar{b}$(~60%)
- *Purity of the signal*
  - $H \to \tau^-\tau^+$ (~7%)

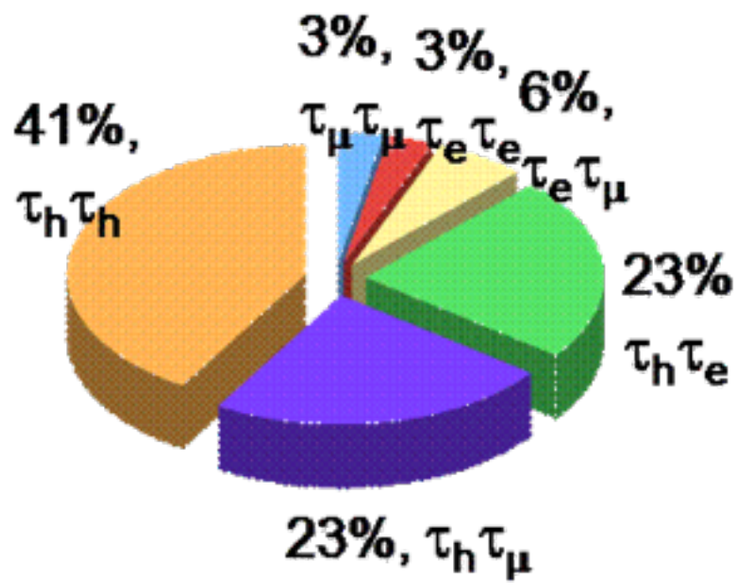
Event Topology

- Radion or Graviton decaying into a pair of Higgs bosons



Six possible final states for H → $\tau\tau$:

- Fully leptonic: μμ, μe , ee
- Semileptonic: τ_hμ , $\tau_h e$
- All hadronic: τ_h τ_h



Object Identification

Particle Flow Algorithm: all the information from the sub detectors are combined to reconstruct all particles produced in the collisions

- charged and neutral hadrons
- photons
- electron
- muons

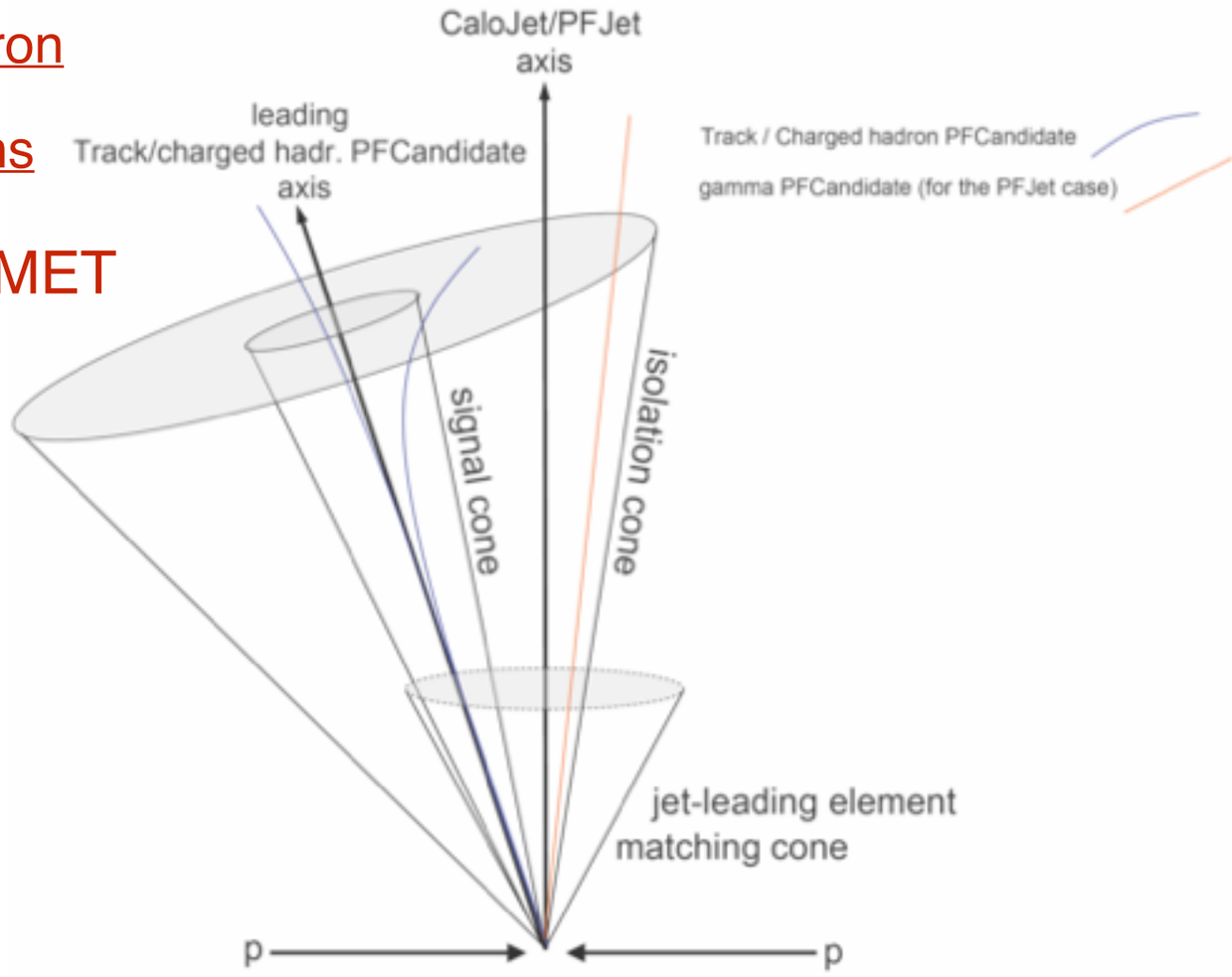
Particles are used to identify jets, taus and MET

- Hadronic taus:

  PF jet

  Cut based and Multivariate Identification discriminants:

  - Decay mode finding: tau lepton decay signature
    - Muon rejection
  - Isolation
    - Electron rejection



Boosted regime

Final decay products very collimated

→ Particle identification

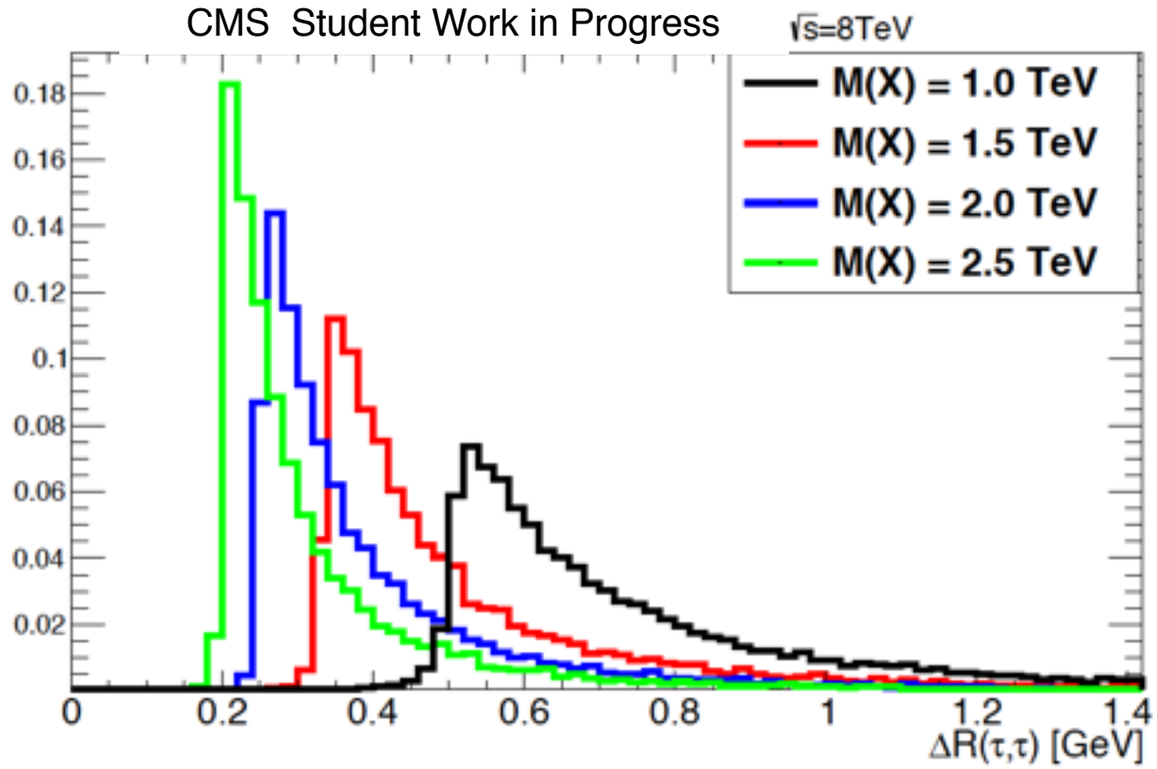
↓

New algorithms have been developed

- hadronic tau reconstruction
- lepton isolation

↓

Jet " lepton cleaning" procedure
& Standard Identification

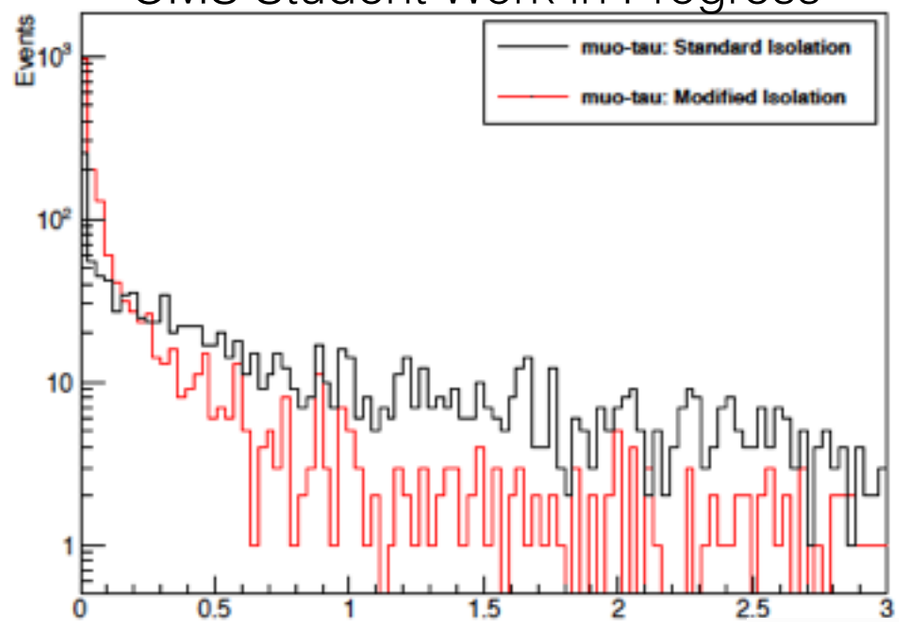


Lepton Isolation

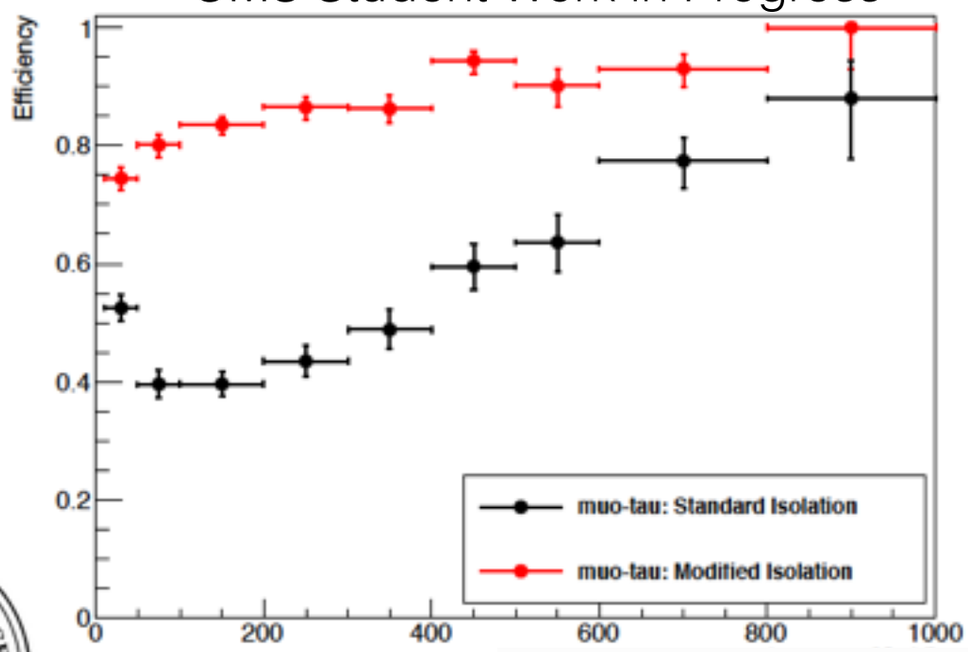
New algorithm for lepton isolation:

- hadronic tau in the lepton isolation cone
- tau is fully identified (IDs)
- the PF constituents removed from the lepton isolation deposits

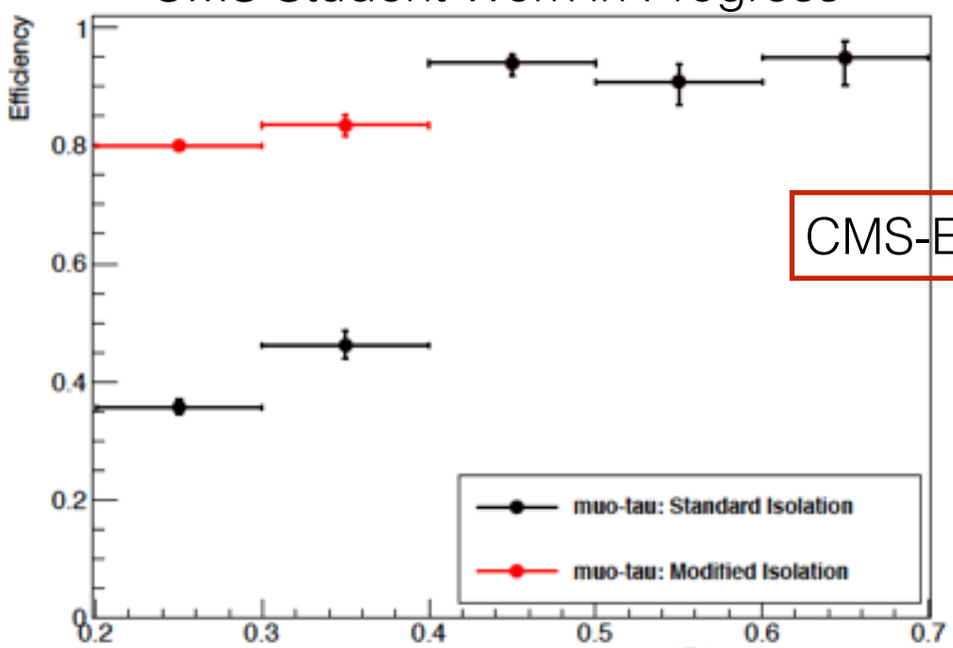
CMS Student Work in Progress



CMS Student Work in Progress



CMS Student Work in Progress

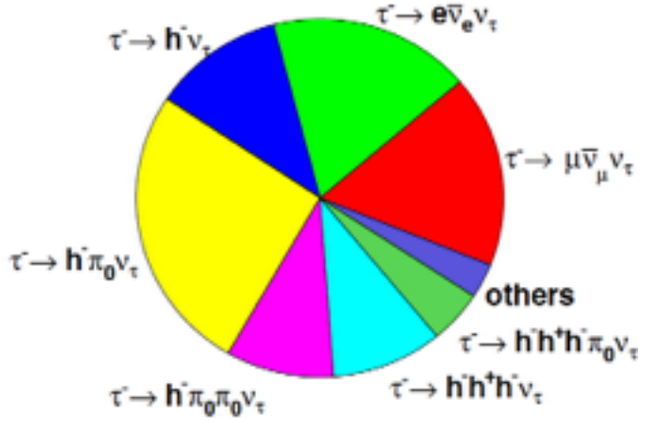


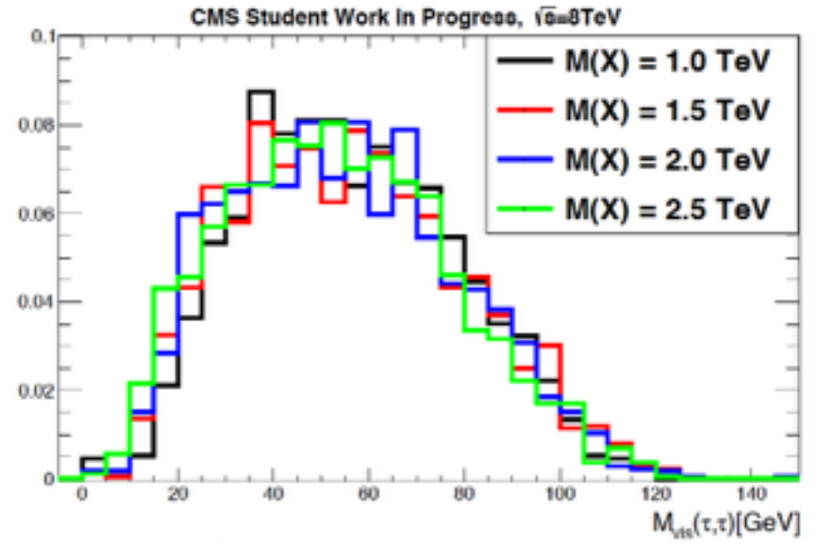
CMS-EXO-13-007

H $\rightarrow \tau\tau$ reconstruction

Neutrinos in the final state

→ Challenge in kinematics reconstruction

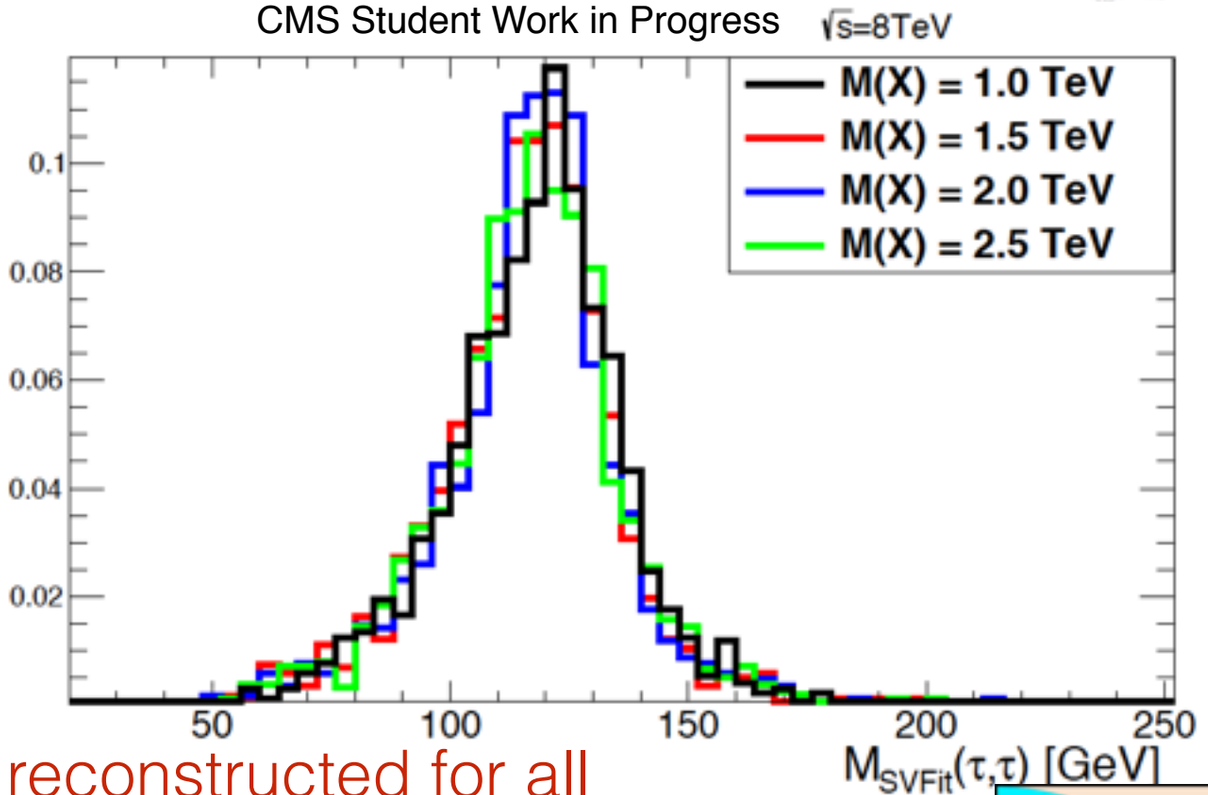




SVFit tool: algorithm for taus invariant system reconstruction

arXiv:1401.5041

- Probability model:
  - measured METx and METy
  - the tau decay visibile kinematics
  - the MET resolution
- Marginalized likelihood function on an event-by-event basis



Higgs mass reconstructed for all the resonance masses

Conclusions

- Searching for physics BSM predicting HH resonances, e.g. Composite Higgs or Extra Dimension models

  - Heavy resonances ⇒ highly boosted H bosons

    - First time we look for such high mass resonances in Higgs pairs

- Jets with merged tau leptons or b quark pairs are most common for Higgs decays, but experimentally very challenging

- Algorithms have been developed for the physics object and the event reconstruction

Analysis of 8 TeV data well underway!

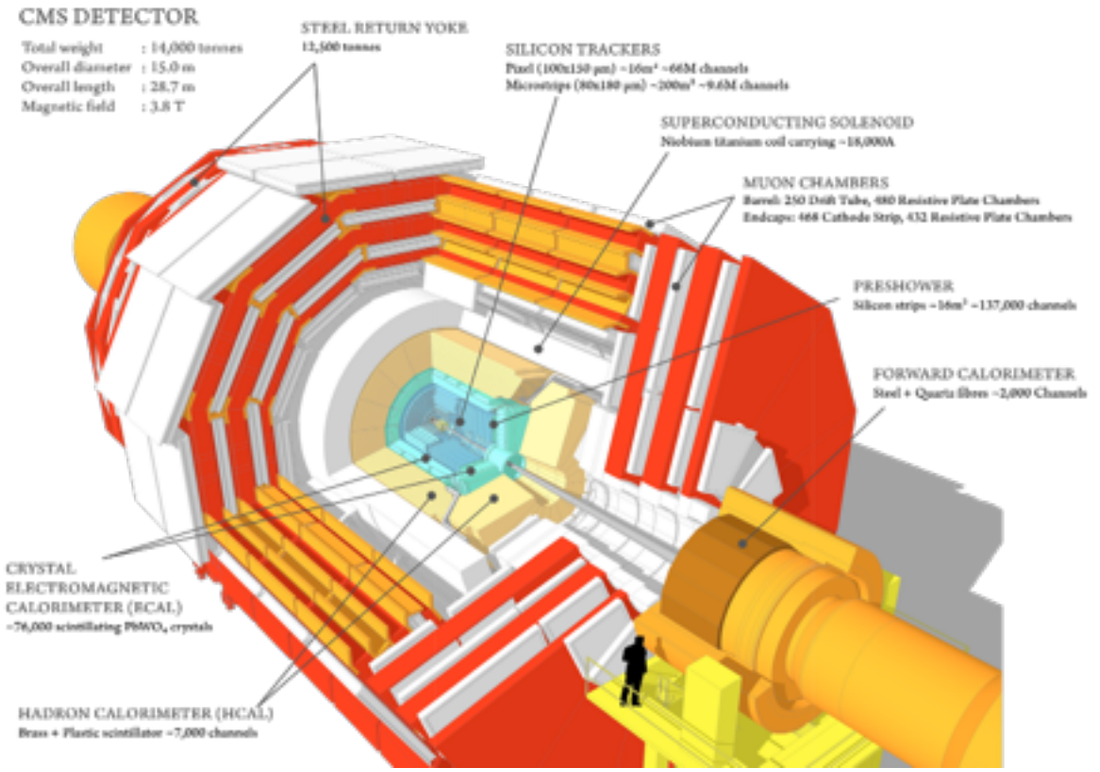
Stay tuned for the next run at 13/14 TeV!

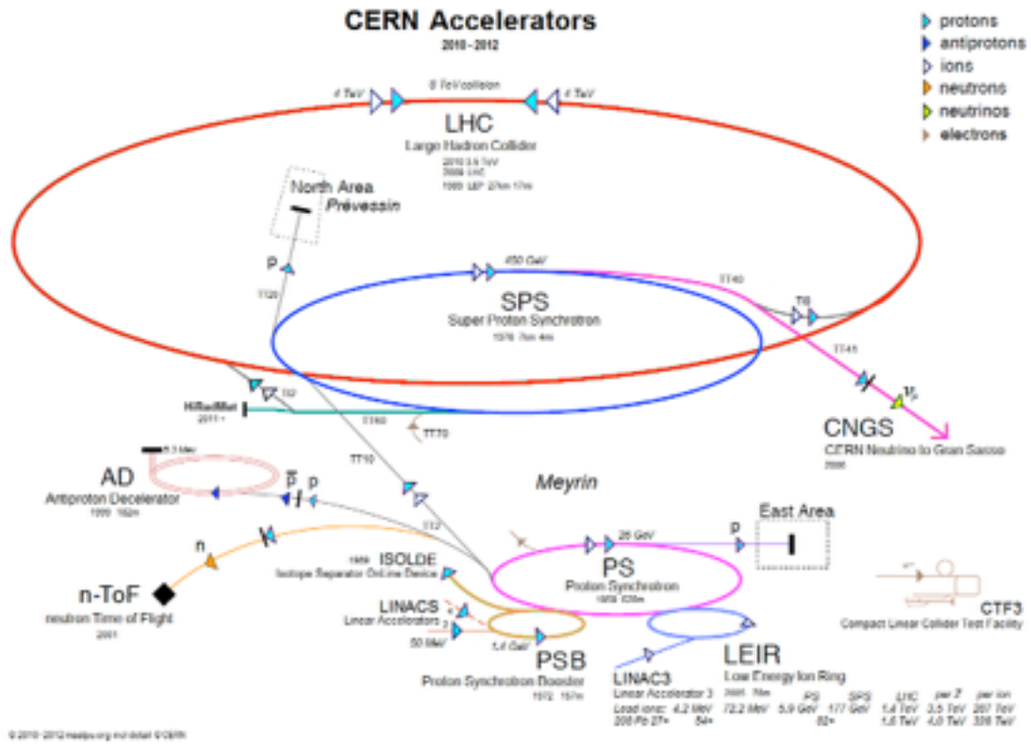
Thanks for your attention!

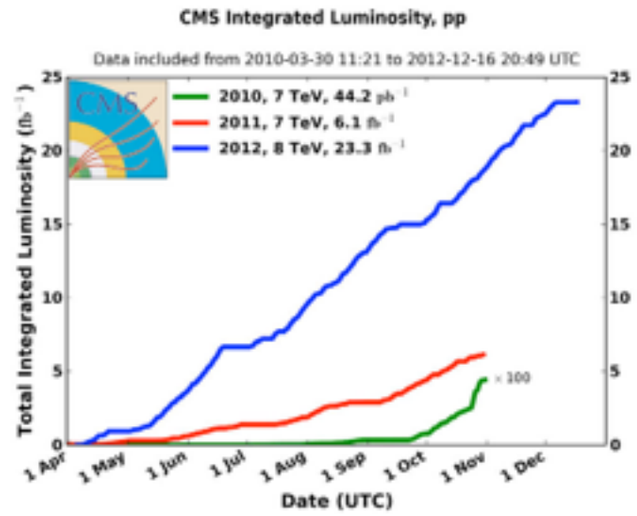
Back up

LHC and CMS

- Heavy particles production require high energy.
- LHC 8 TeV of energy in the center of mass reference frame
- CMS detector for particle identification







Higgs Pair Production

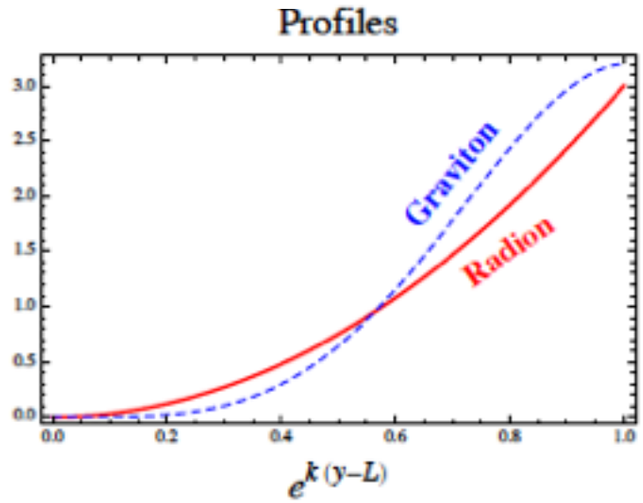
arXiv: 1303.6636

- Metric due to the fifth extra dimension

$$ds^2 = e^{-2ky}\eta_{\mu\nu}dx^\mu dx^\nu - dy^2$$

$$g_{\mu\nu} = e^{-2ky}\eta_{\mu\nu} \rightarrow e^{-2(ky+F(x,y))}\left(\eta_{\mu\nu} + G_{\mu\nu}(x,y)\right)$$

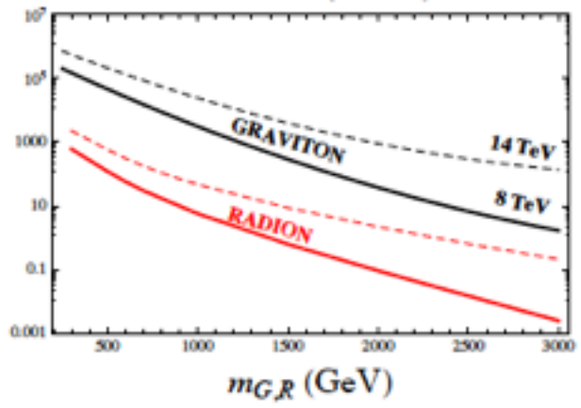
$$F(x,y) \propto e^{2ky}\,\phi(x) \qquad G^{(1)}_{\mu\nu}(x,y) \propto e^{2ky}\,J_2\left(e^{2ky}\frac{m_G}{k}\right)G^{(1)}_{\mu\nu}(x)$$

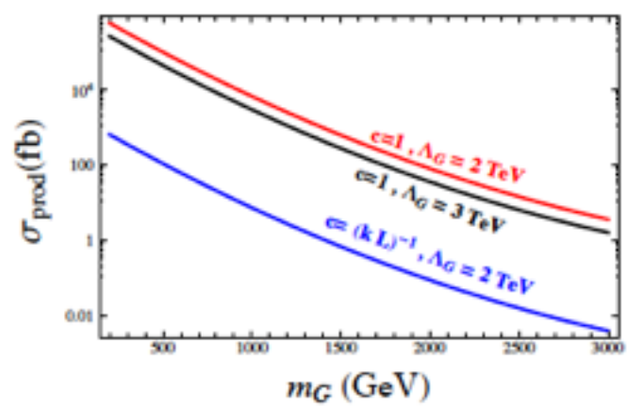


- Localization of the fields

- Coupling to SM fields

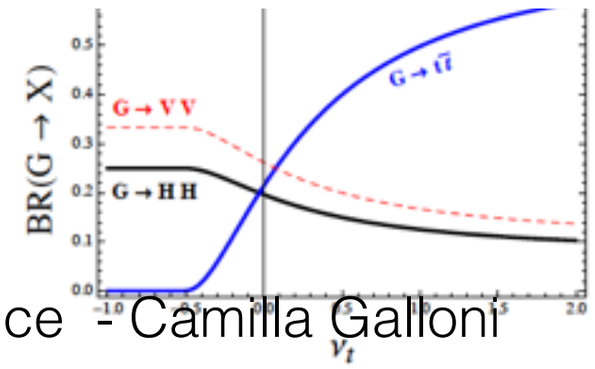
$$\mathcal{L} = -\frac{c_i}{\Lambda_G}G^{\mu\nu(1)}\,T^i_{\mu\nu} - \frac{d_i}{\Lambda_\phi}\phi\,T^{\mu i}_{\mu}$$





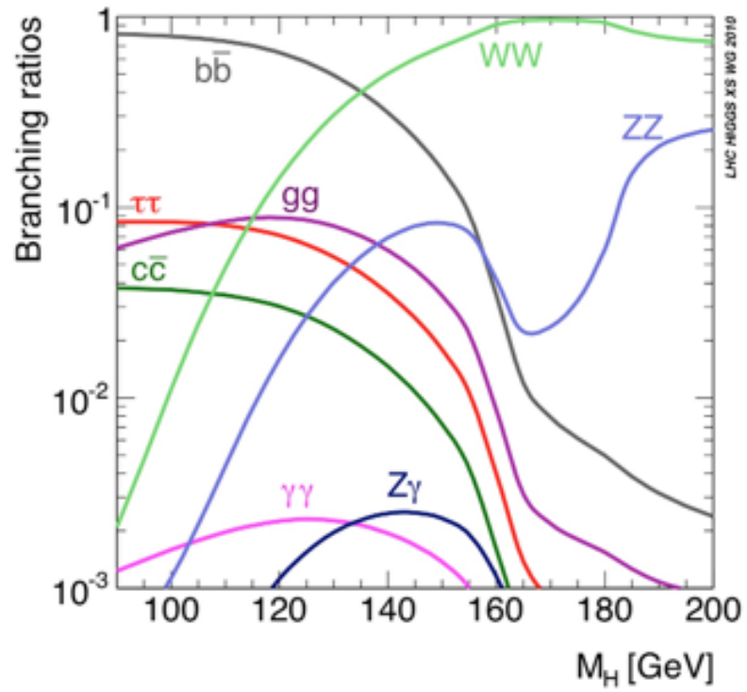
RS1 scenario: $c_H =$ all the other $c_i \simeq \mathcal{O}(1)$

Bulk RS scenario: $c_H \simeq c_{Z,W,t} \simeq \mathcal{O}(1) \simeq (kL)\,c_{\gamma,g} \gg c_{u,d,\ell\ldots}$



Search strategy

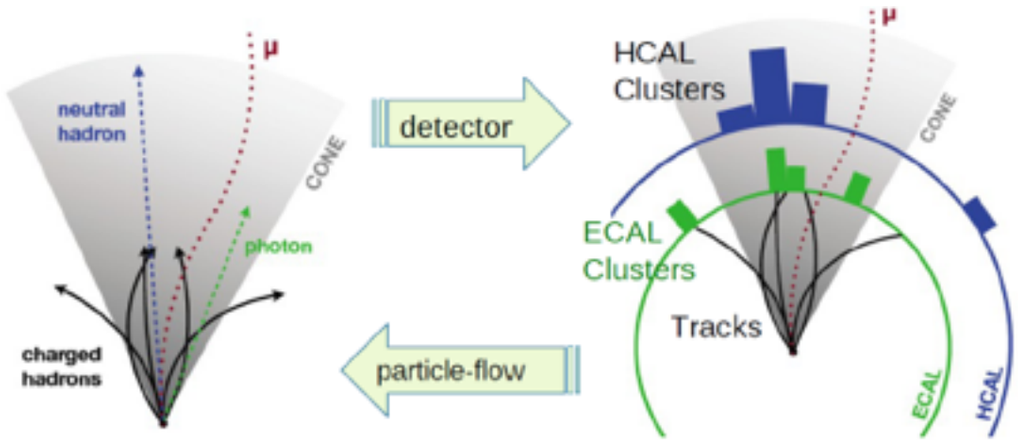
- Radion or Graviton decay into a pair of Higgs bosons
- Channel HH-> $\tau\tau bb$
  - *High breaching ratio*
  - *The presence of tau leptons can help discriminate against QCD Multi-jet background.*
- Many possible final states depending on the tau lepton decay mode:
  - Fully leptonic: $\tau\rightarrow\mu\nu\nu$, $\tau\rightarrow e\nu\nu$
  - Semileptonic: $\tau\rightarrow\mu\nu\nu$, $\tau\rightarrow h\nu$
  - All hadronic: $\tau\rightarrow h\nu$



Decay channel	BR(%)
τ	17.36
	17.85
τ	11.6
τ	26.0
τ	9.5
τ	9.8
τ	4.8
others	3.1

PF particle Identification

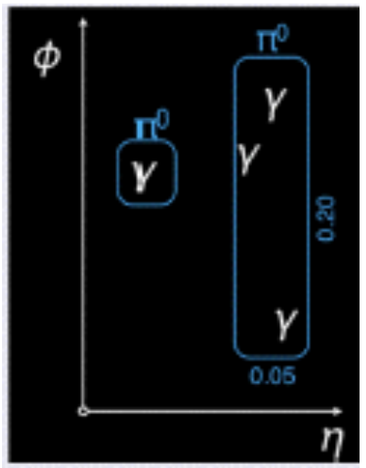
- Particle Flow: all the information from the sub detectors are combined to reconstruct all particles in the collisions
- Particles are identified in mutually exclusive categories: charged and neutral hadrons, photons, electron and muons.
- Particles are used to identify jets, tau and MET



- Algorithms have been developed to reconstruct the tau hadron decay:
  - HPS

PF Tau Identification

- Starting from a PF Jet, special attention is given to photon conversion in the tracker, since the bending of electron positron can broaden the photon signature in the ϕ



- A strip of $\Delta\eta = 0.05$ and $\Delta\phi = 0.2$ is centered around the most energetic electromagnetic particle in the jet

- Other electromagnetic particles in the strip are considered and added to the four momentum.

- Strips with p_T > 1 GeV/c are combined to the hadrons to reconstruct the Tau hadronic decay mode

Strips and hadrons ($\pi^{\pm}$, $K^{\pm}$) are combined to reconstruct the main decay topologies:

- **Single hadron (for $h^-\nu_\tau$ and $h^-\pi^0\nu_\tau$);**
- **One hadron + 1 or 2 strips (for $h^-\pi^0\nu_\tau$);**
- **Three hadrons (for $h^-h^+h^-\nu_\tau$).**

The other decay modes are reconstructed via the previous topologies.

- All hadrons and strips have to be within a cone of $\Delta R = (2.8 \text{ GeV/c}) / p_T^{(\text{Tau\_h})}$

- The tau 4-vector has to be in a cone of $\Delta R = 0.1$ from the Jet axis

- The mass of the composite system has to be compatible with $\rho(770 \text{ MeV})$ (2 hadrons) or a_1 (>=3 hadrons 1200 MeV)

Searches at low mass (<1TeV)

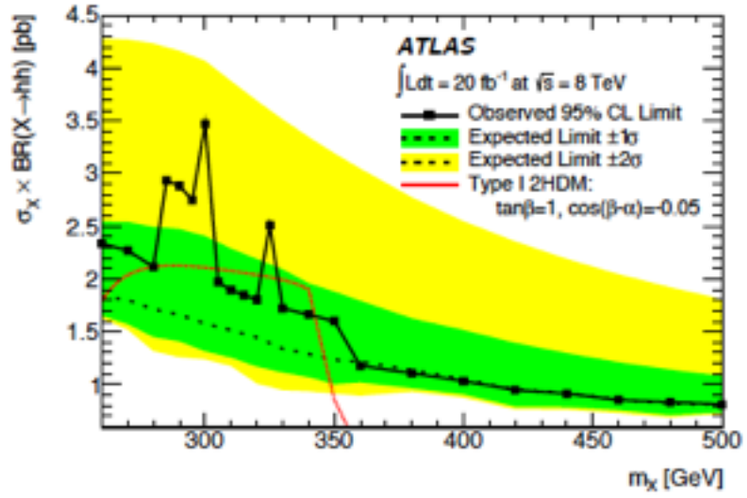
CMS (CMS PAS HIG-13-032):

hh ->gamma gamma bb final state.
The search for a new particle X is performed in the range 260 < mX < 1100 GeV.
Upper limits at 95%confidence-level are extracted on new particles production cross-section.
WED Radion is observed (expected) to be excluded with masses below 0.97 TeV (0.88 TeV).

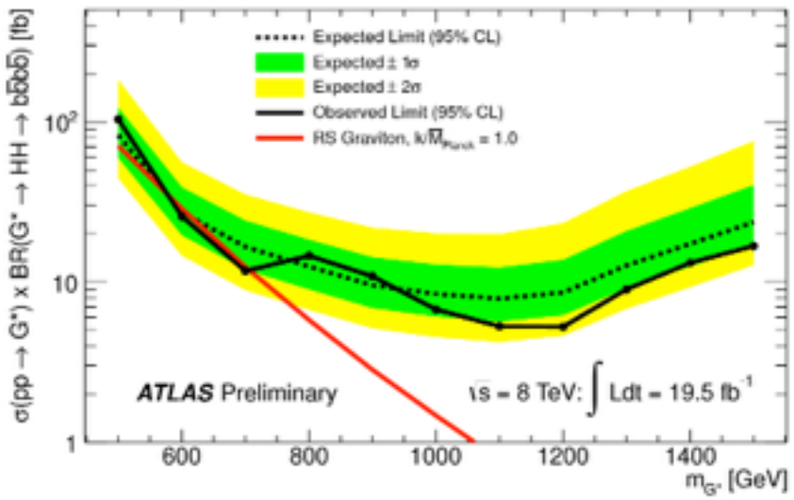
ATLAS(arXiv:1406.5053):
hh ->gamma gamma bb final state.
A 95% confidence level upper limit on the cross section times branching ratio of non-resonant production is set at 2.2 pb, while the expected limit is 1.0 pb.
The corresponding limit observed for a narrow resonance ranges between 0.8 and 3.5 pb as a function of its mass.

ATLAS (ATLAS-CONF-2014-005):
G*->hh ->bbbb final state.

arXiv:1406.5053



ATLAS-CONF-2014-005



CMS PAS HIG-13-032