Beyond Standard Model Higgs at the LHC

- the more exotic part -

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on behalf of ATLAS and CMS collaborations

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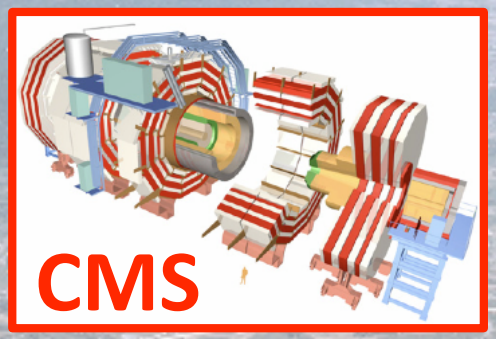
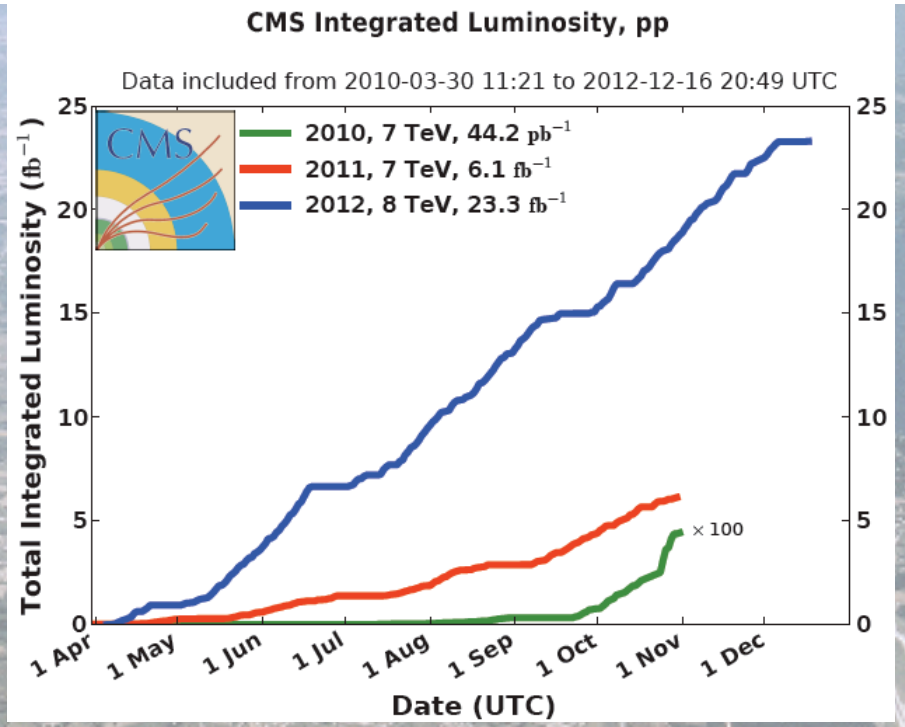




Outline:

- Motivation
- CMS & ATLAS detector
- Higgs Beyond Standard Model:

NMSSM

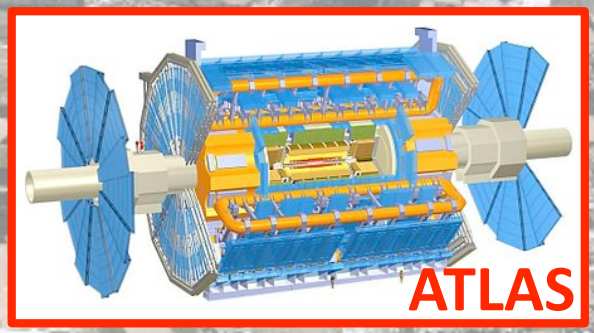
hidden sector

fermiophobic Higgs

SM4

exotic

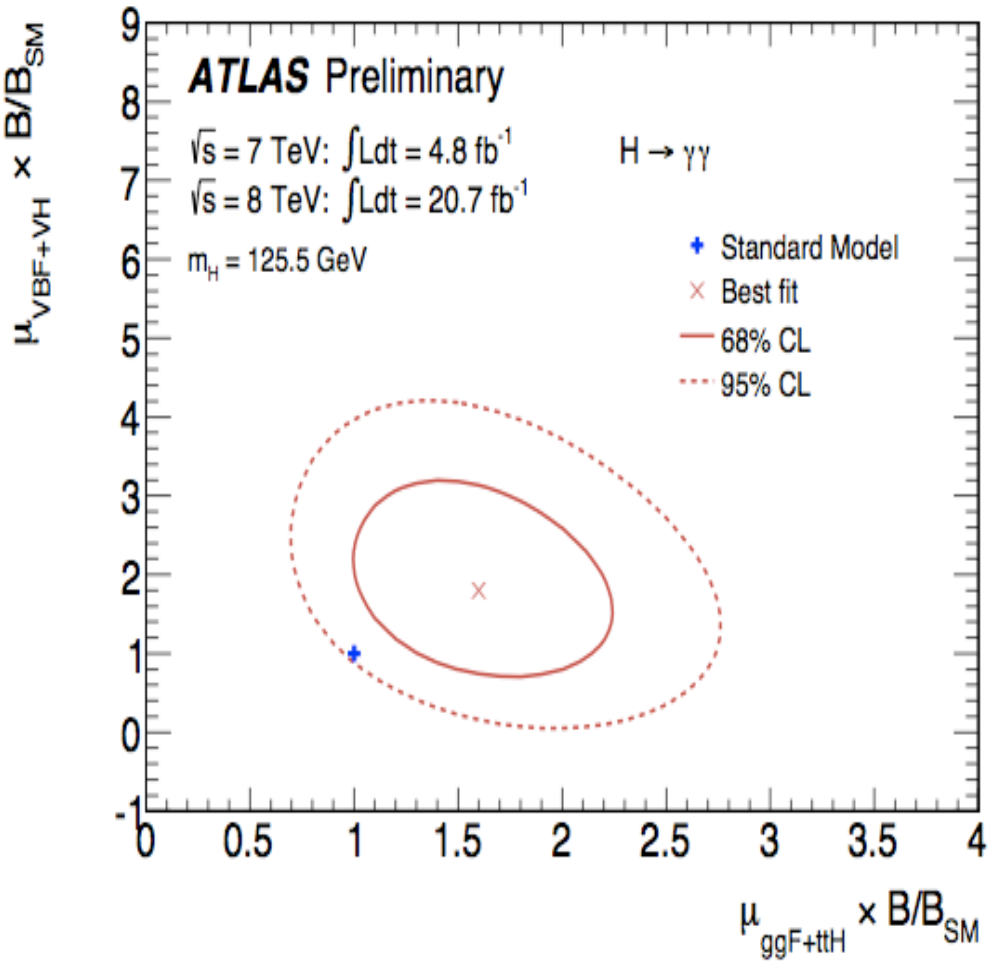
- Higgs rare decays

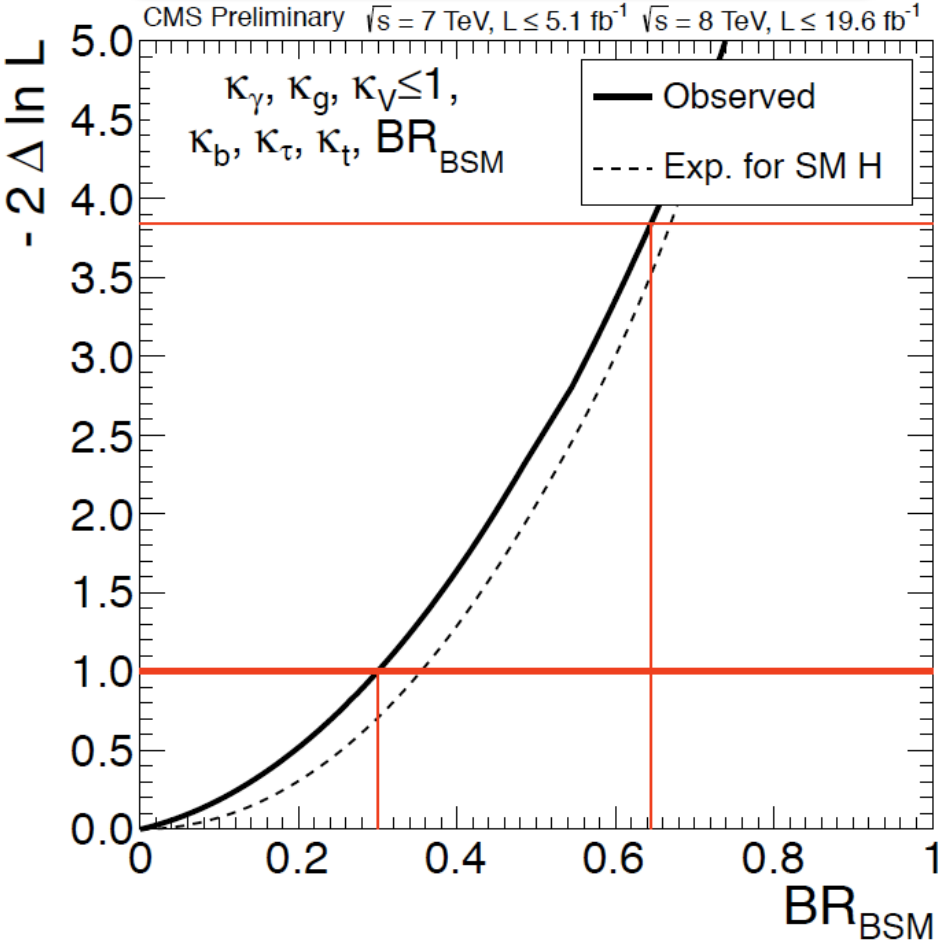


what is driving us

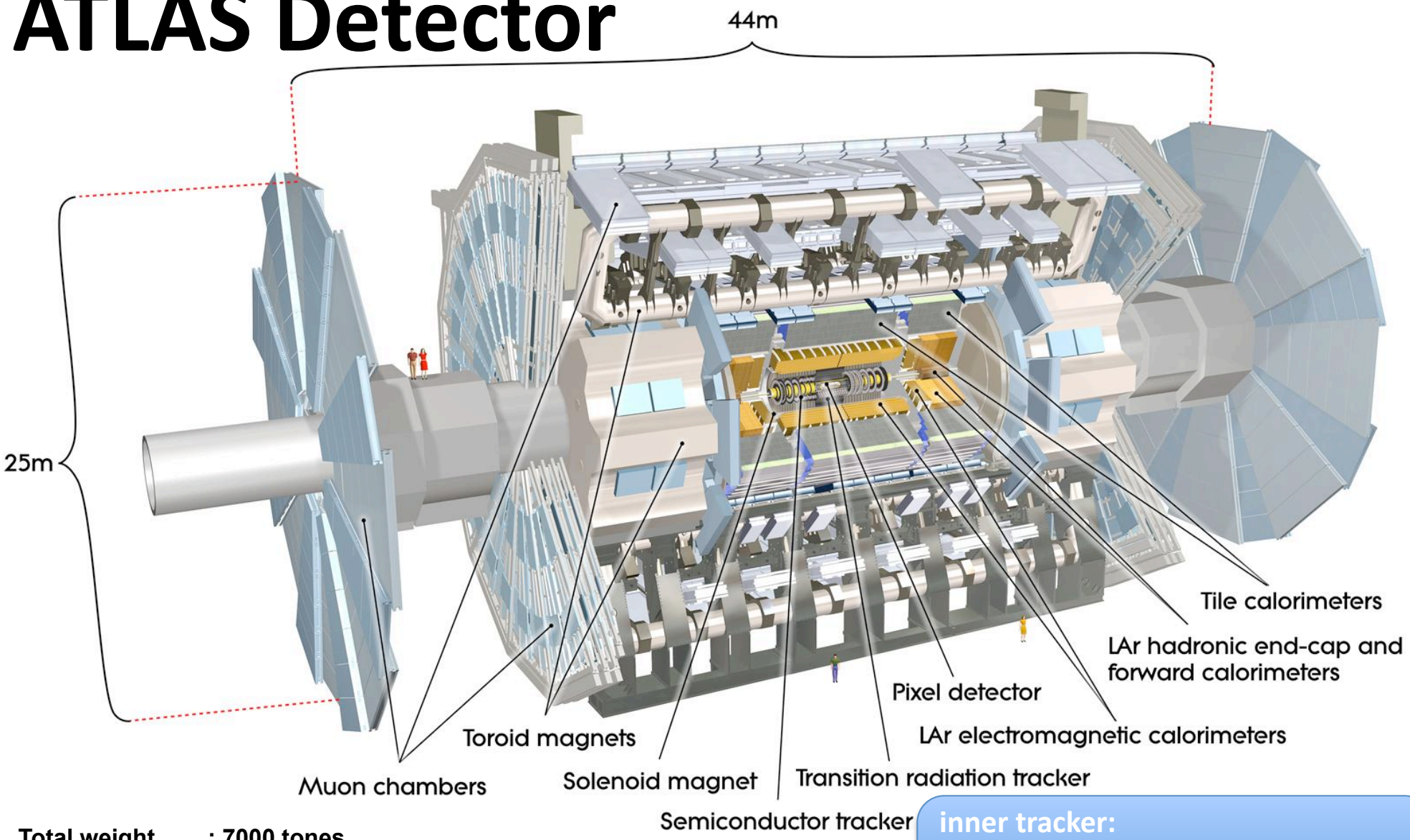
ATLAS combination Moriond'13:
• SM expectation on the 95% CL contour of the best data fit in the signal strength plane (more details in **ATLAS-CONF-2013-014**)

CMS combination Moriond'13:
• $BR_{BSM}=\Gamma_{BSM}/\Gamma_{tot}$ assuming that couplings to the electroweak bosons are bound by the SM expectation ($\kappa_V \leq 1$)
• $0 \leq BR_{BSM} \leq 0.64$ at 95% C.L.
(more details in **CMS-PAS-HIG-13-005**)





ATLAS Detector



Total weight : 7000 tones
Overall diameter : 25.0 m
Overall length : 46.0 m
Magnetic field : 2.0 T

inner tracker:
- **coverage:** $|\eta| < 2.5$, $\eta = -\ln[\theta/2]$
- **transverse momentum resolution:**

$\sigma_{pT}/p_T \approx 0.05\%\ p_T \oplus 1.0\%$

physics objects: electrons

Electrons in ATLAS:
- energy clusters formed within a dedicated ΔηxΔϕ area and matched to a track (e – γ separation)
- track checked for a match to a secondary vertex (e – converted γ separation)
- use **G**auss **S**um **F**unction alg. to account for bremsstrahlung

EM calorimeter:
- **L**iquid **Ar**gon
- high granularity
- longitudinal segmentation

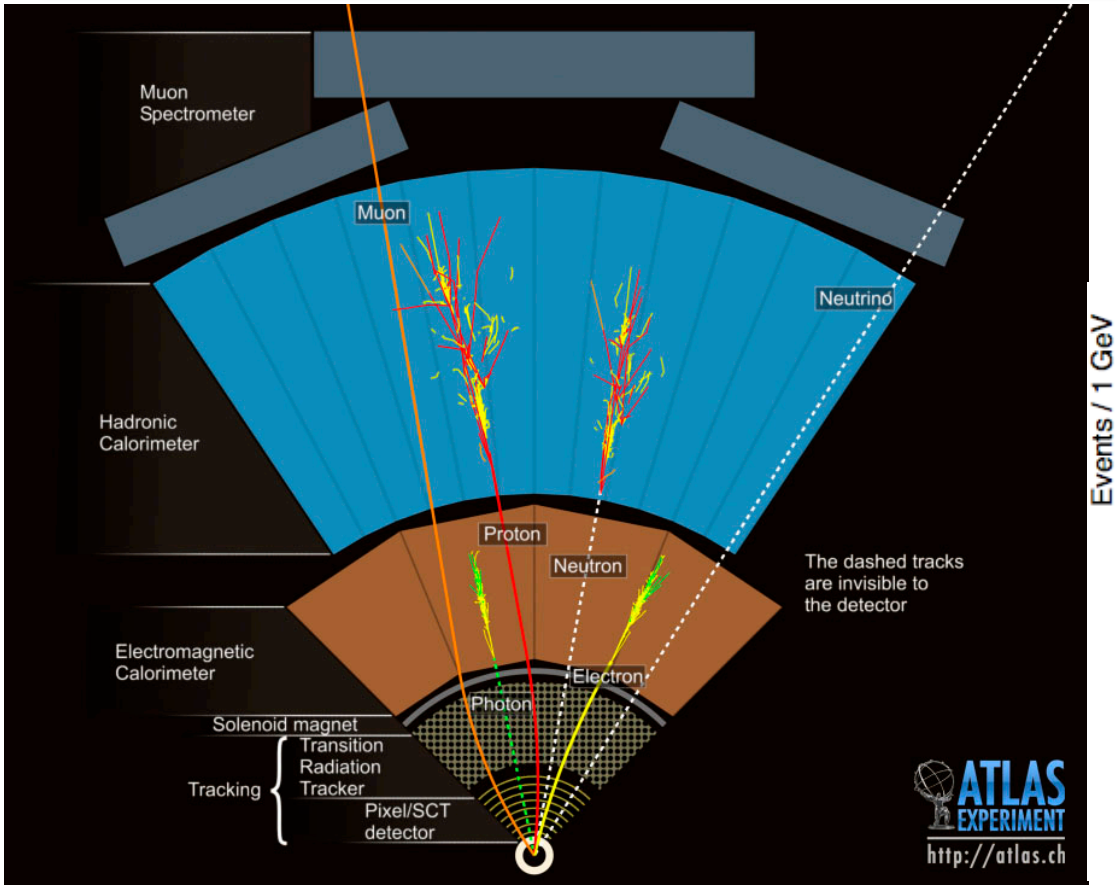
- **energy resolution:**

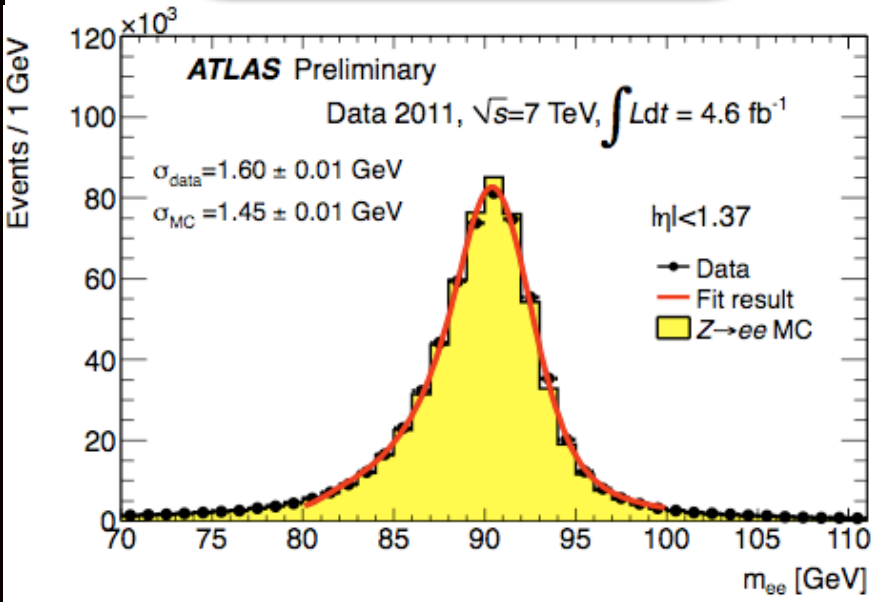
$10\%/\sqrt{E\ /\mathrm{GeV}} \oplus 0.7\%$

- **coverage:**

$|\eta| < 2.5$ (track)

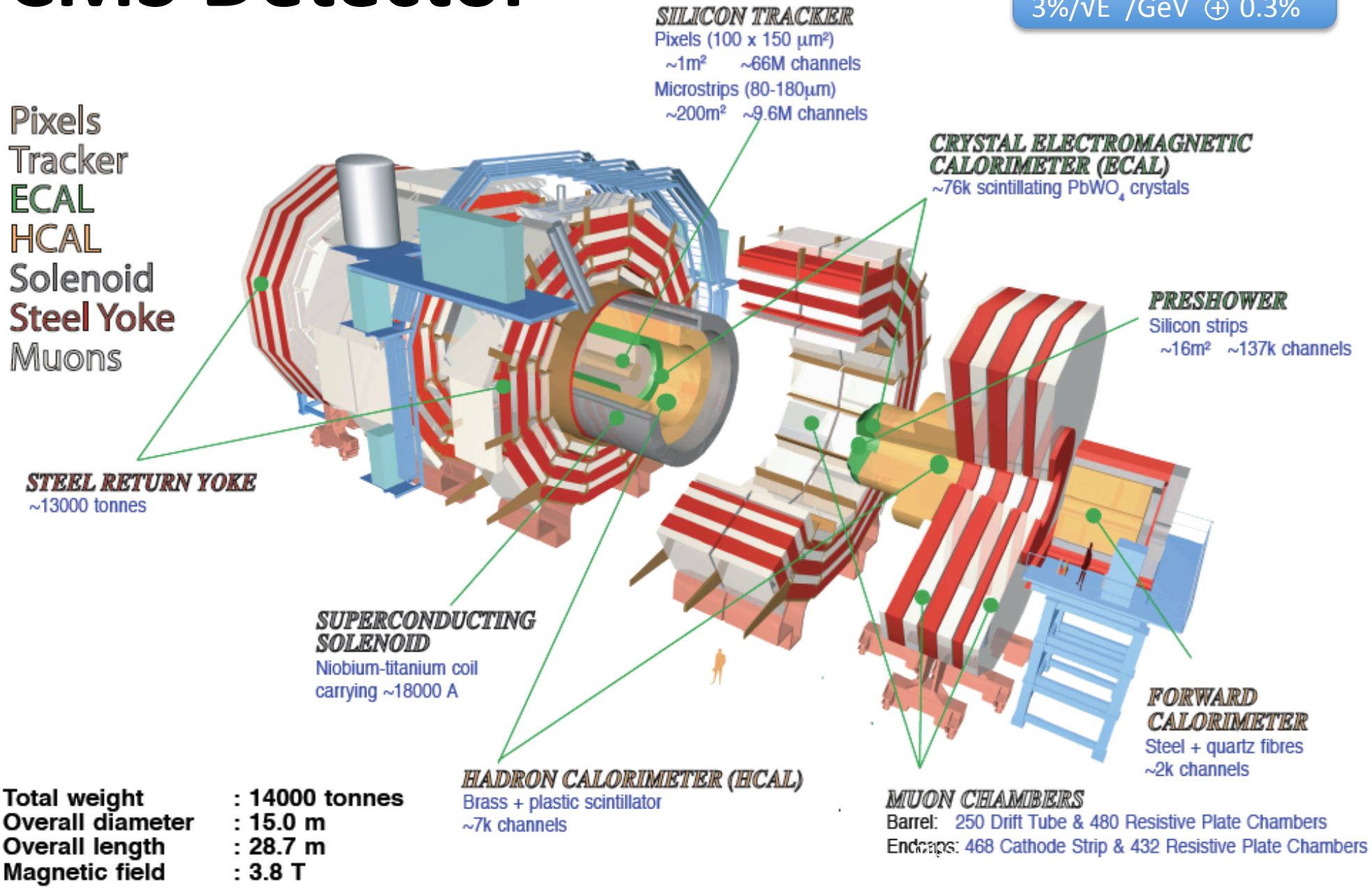
$|\eta| < 4.9$ (cluster shape)





CMS Detector

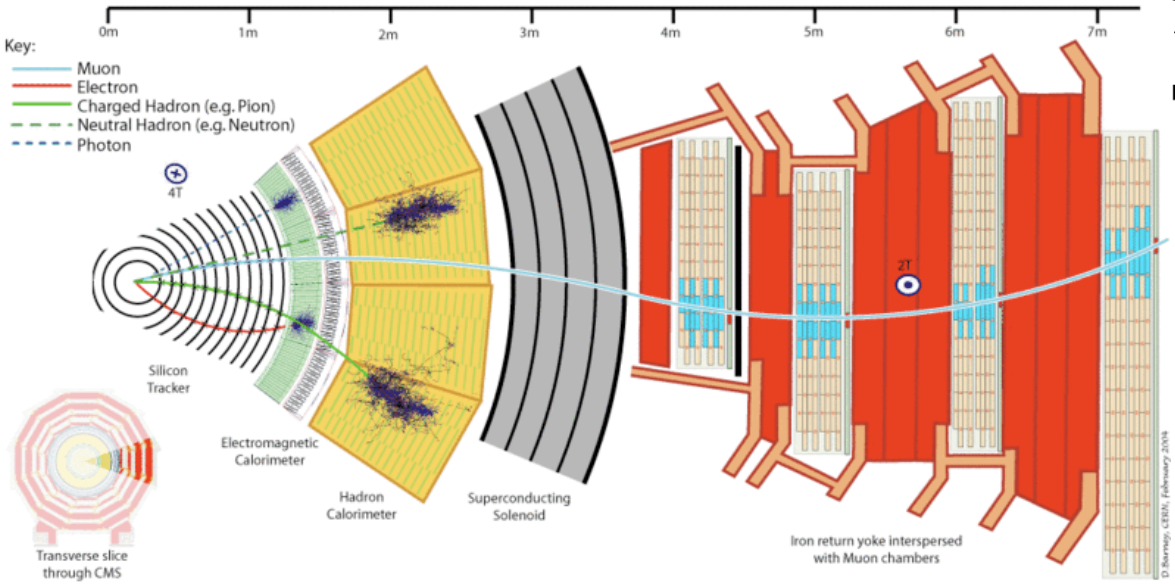
• **energy resolution:**
3%/√E /GeV ⊕ 0.3%

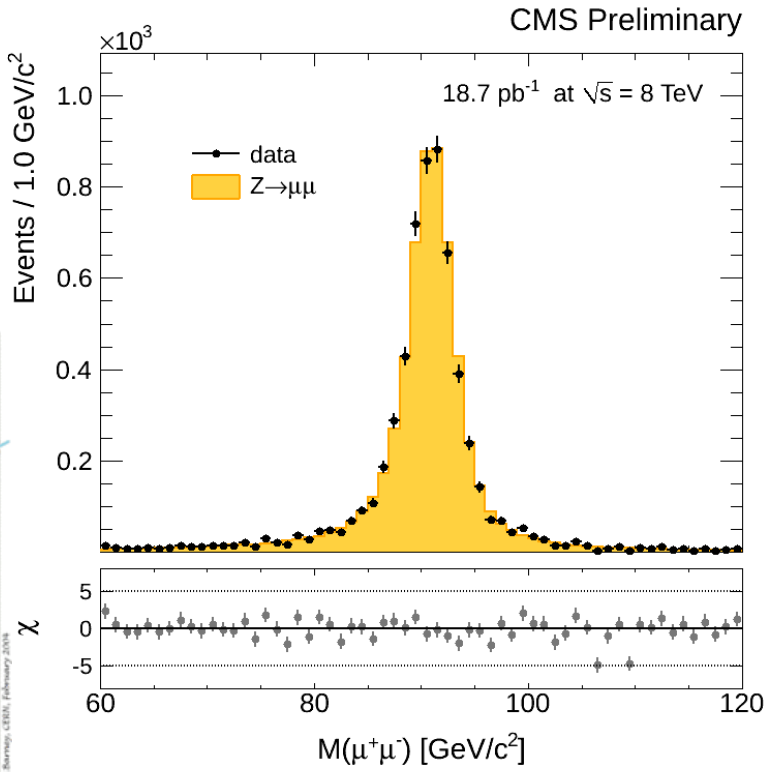


Total weight	**: 14000 tonnes**
Overall diameter	**: 15.0 m**
Overall length	**: 28.7 m**
Magnetic field	**: 3.8 T**

physics objects: muons

Muons in CMS:
track segment reconstructed in the muon chambers matched with track in silicon tracker





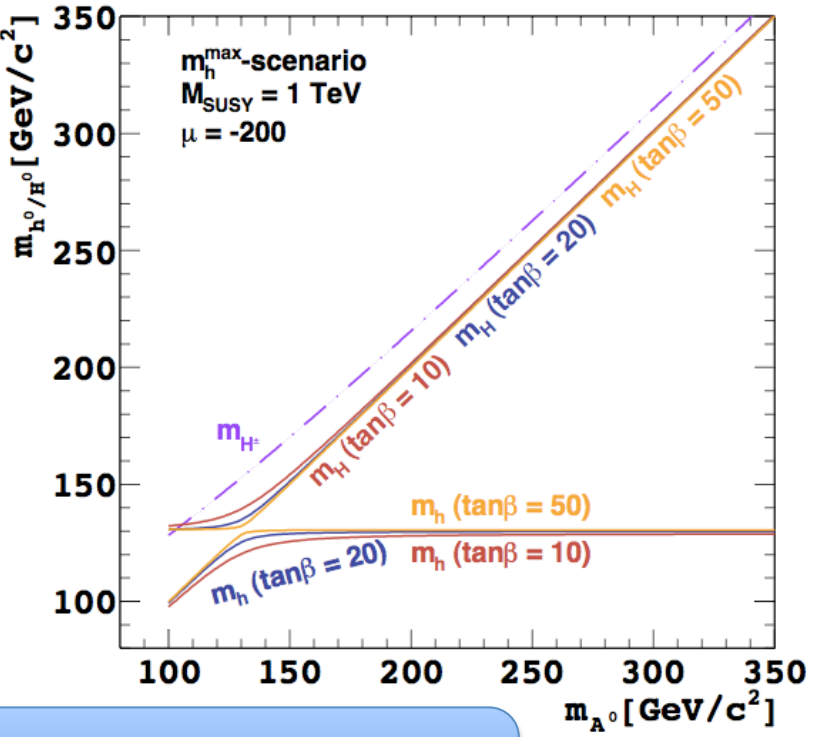
- **coverage:** $|\eta| < 2.4$, $\eta = -\ln[\theta/2]$
- **transverse momentum resolution**:
$\sigma_{p_T}/p_T \approx 0.015\% \, p_T \oplus 0.5\%$

- good agreement between Monte Carlo simulation and data
- there is a reason why we are called CMS ☺

Minimal Supersymmetric SM

MSSM: Φ^0 (h^0, H^0, A^0), $H^\pm$

- Higgs sector can be described by: tanβ and m_A
- $\tan\beta = v_1/v_2$ where v_1 and v_2 are vacuum expectation values



- A^0 (CP odd): m_A
- $H^\pm$: $m_H=(m_A^2+m_W^2)^{1/2}$

- h^0, H^0 (CP even):

$$m_{H,h}=\left\{1/2\left\{m_A^2+m_Z^2 \pm \left[(m_A^2+m_Z^2)^2 - 4m_A^2m_Z^2\cos^2 2\beta\right]^{1/2}\right\}\right\}^{1/2}$$

Relatively recent proposal: m_h mod+ and mod – scenarios
M. Carena *et al.* http://arxiv.org/pdf/1302.7033v1.pdf

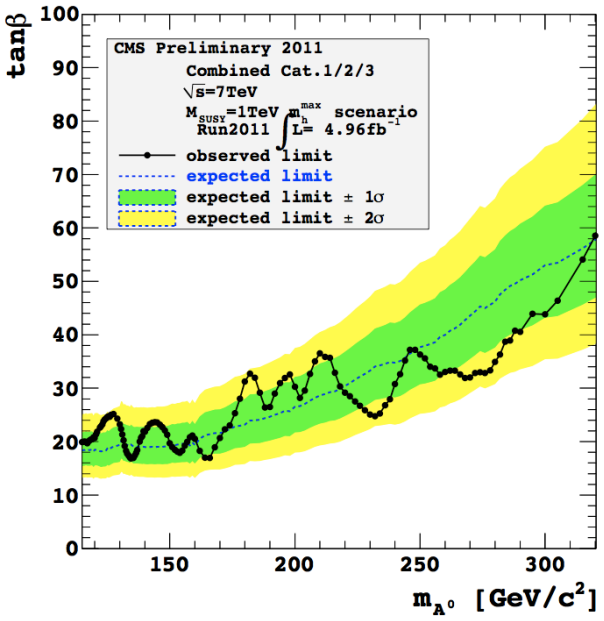
MSSM

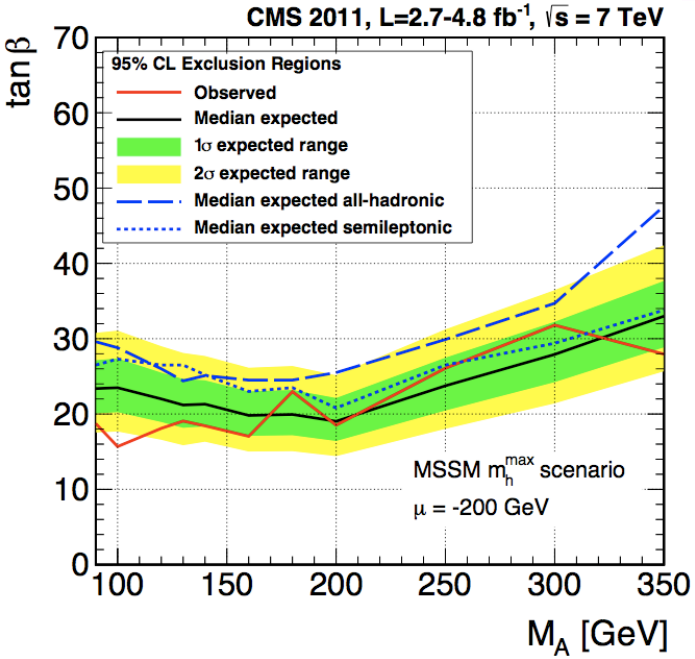
channel: μμ
- even with a BR of ≈10^{-4} good sensitivity is achieved
- best channel for a precise measurement of tanβ

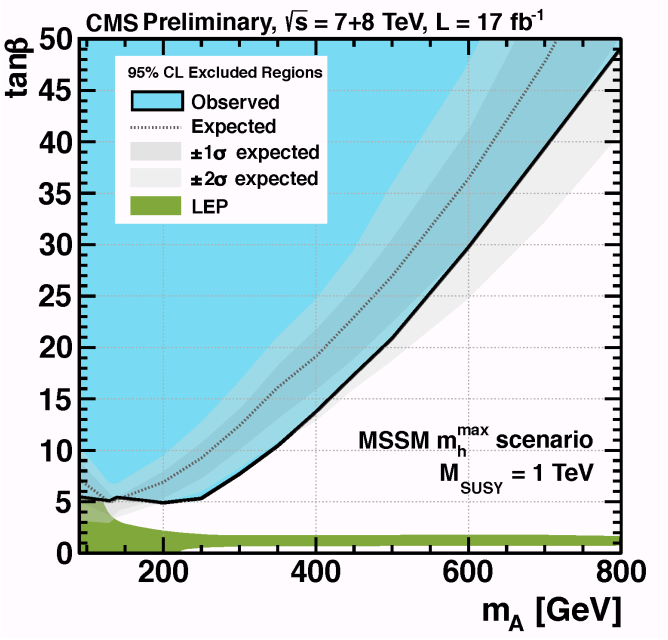
CMS PAS HIG-12-011

channel: bb
- good BR
- challenging background
- more details in **arXiv:1302.2892**

channel: ττ
- better background conditions and ditau mass parameterization
- **CMS PAS HIG-12-050**







- there is an ongoing effort in CMS to combine all analyses and complete the analysis of the √s = 8 TeV data (plan to be ready during summer)

MSSM

channel: μμ
- even with a BR of ≈10^{-4} good sensitivity is achieved
- best channel for a precise measurement of tanβ

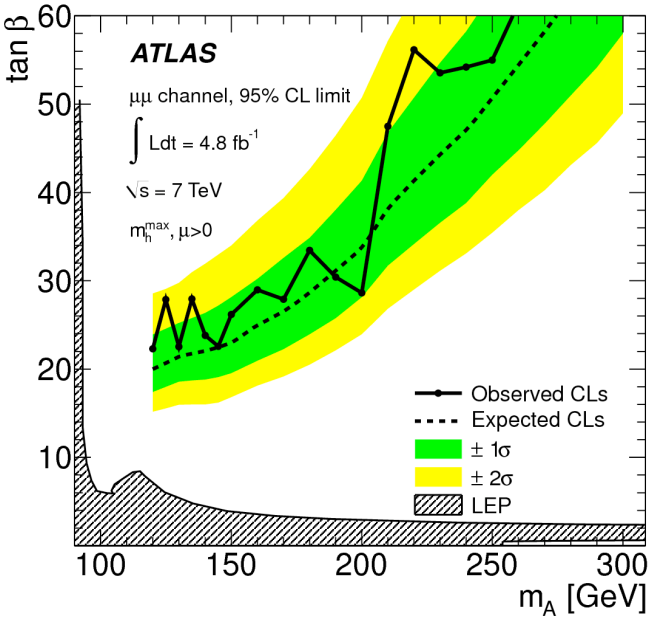
arXiv:1211.6956

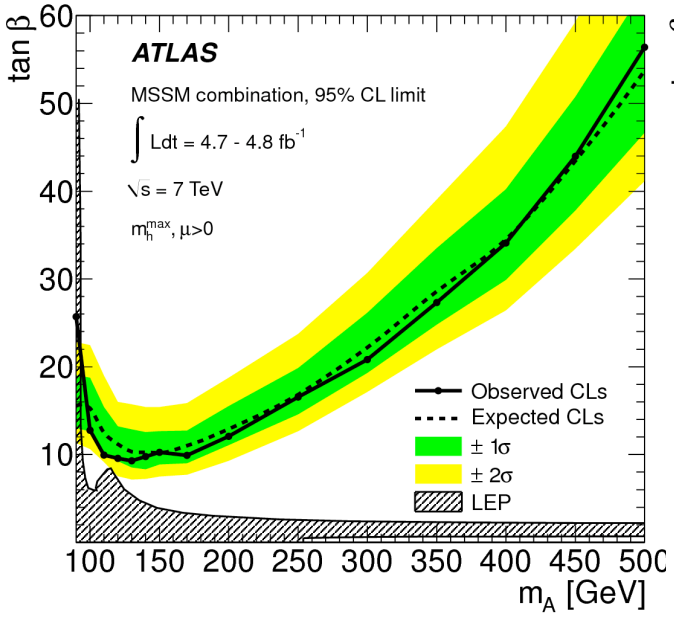
channel: ττ
- better background conditions and ditau mass parameterization

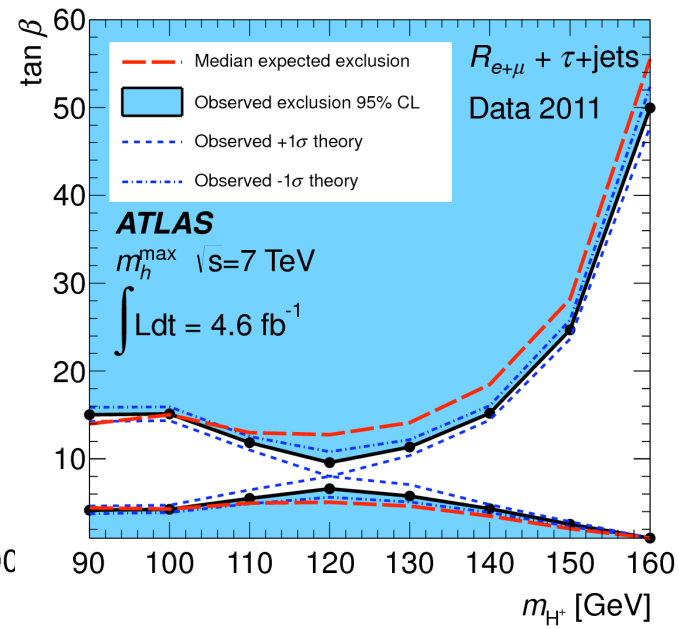
arXiv:1211.6956

Charged Higgs: $H^+ \to \tau^+ \nu_\tau$
- with the Higgs boson produced via $t \to H^+ b$

arXiv:1212.3572



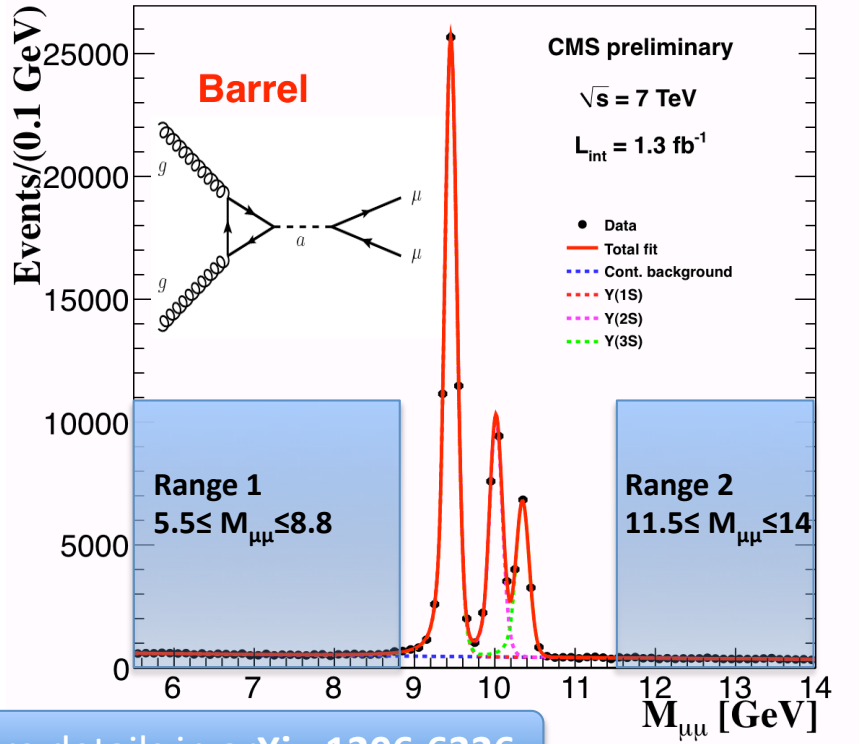




Next-to-MSSM $a_1 \rightarrow \mu^+\mu^-$

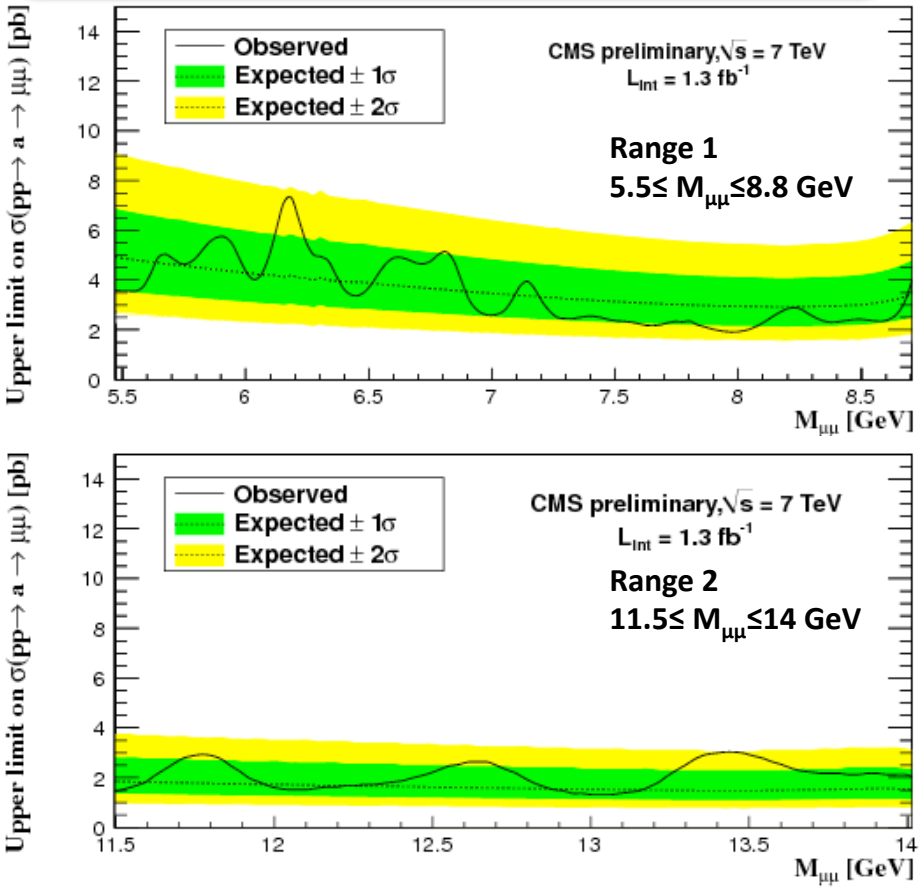
where a_1 is superposition of
- MSSM double pseudoscalar: a_{MSSM}
- additional NMSSM single pseudoscalar: a_S

$a_1 = a_{MSSM} * \cos\theta_A + a_S * \sin\theta_A$
θ_A: mixing angle



more details in **arXiv:1206.6326**

selection:
- dimuon trigger with muons $p_T > 3.5$ GeV, $p_T(\mu\mu) > 6$ GeV and $5.5 \le M_{\mu\mu} \le 14$ GeV
- two isolated and opposite charged muons $p_T > 5.5$ GeV and $|\eta| < 2.4$



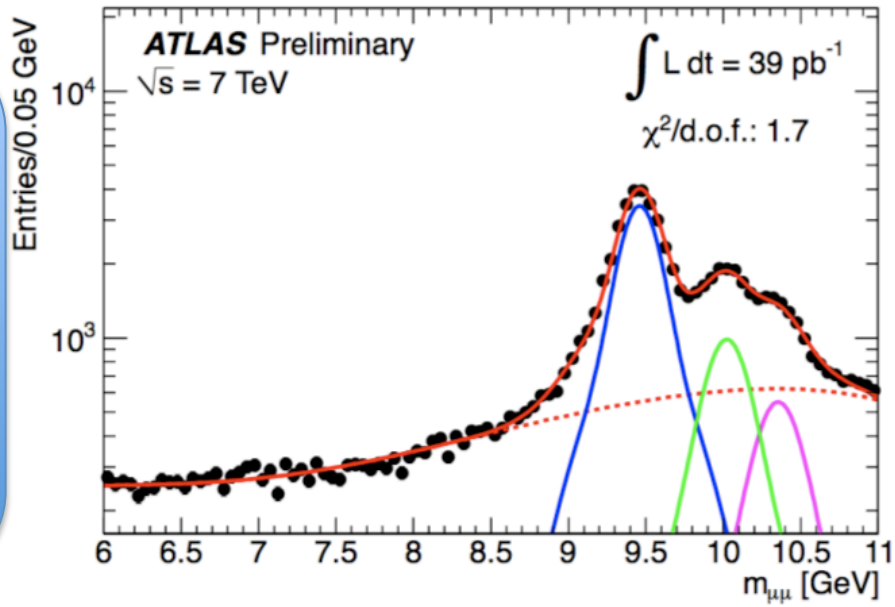
Next-to-**MSSM** $a_1 \rightarrow \mu^+\mu^-$

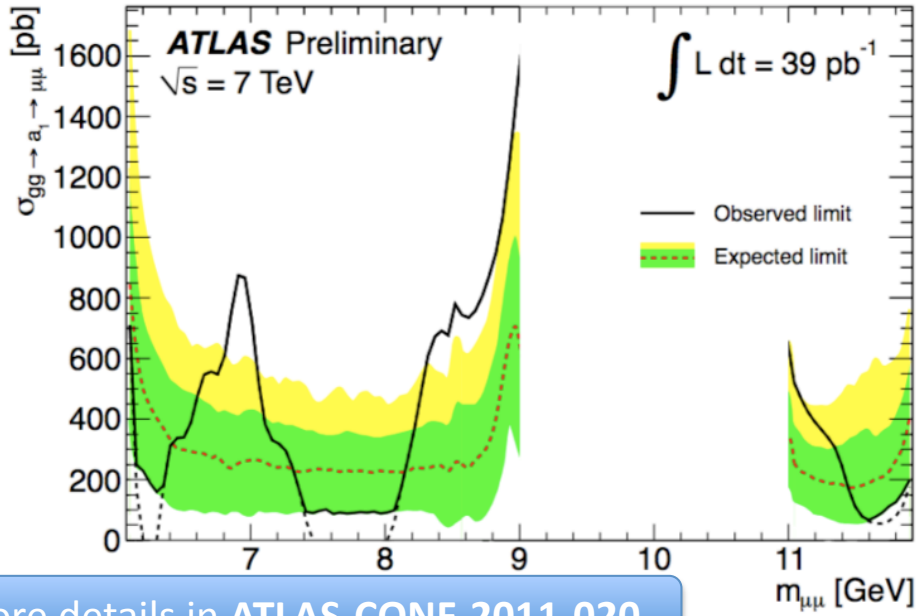
selection:
- dimuon trigger with muons $p_T > 4$ GeV
- two opposite charged muons within $|\eta| < 2.5$
- **Likelihood Ratio** method used to reduce background from muon pairs not coming from the decay of a single particle:

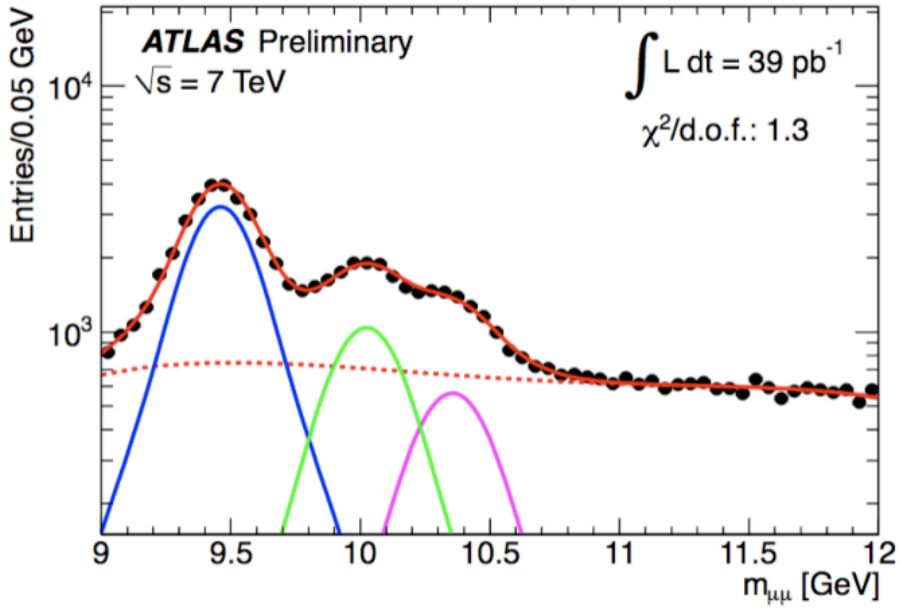
$-\ \chi^2$/ndf of the dimuon vertex fit

$-\ E_T^{cone20}/p_T(\mu_i)$ for each muon

with E_T^{cone20} - calorimetric transverse energy in a cone of size $\Delta R = 0.20$ around muon direction







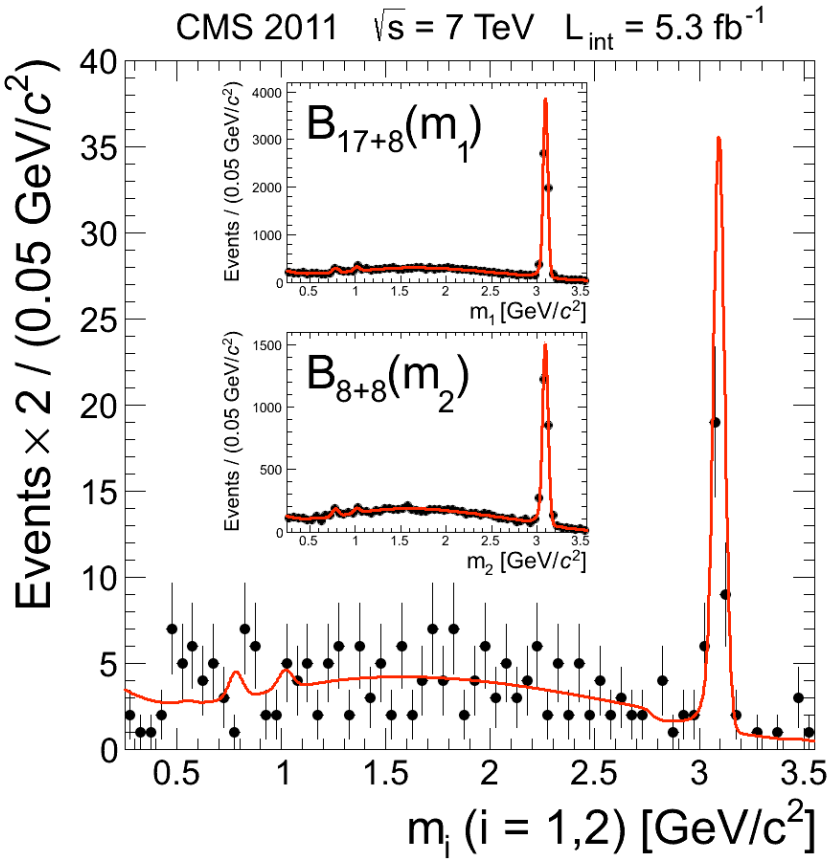
more details in **ATLAS-CONF-2011-020**

Next-to-**MSSM** $h_{1,2} \rightarrow a_1 a_1 \rightarrow 4\mu$

- **NMSSM:** Higgs can decay into an intermediate pair of bosons (a_1)
- CP-even Higgs bosons: h_1, h_2 (one is SM-like Higgs boson)
- CP-odd light Higgs boson: $h_{1,2} \rightarrow 2a_1$
- large BR($a_1 \rightarrow 2\mu$) for $2m_\mu < m_{a1} < 2m_\tau$

- double muon trigger
- at least 4 isolated μ with $p_T > 8$ GeV and $|\eta| < 2.4$, one of them with $p_T > 17$ GeV and $|\eta| < 0.9$
- data driven background estimation
- more details can be found in **arXiv:1210.7619**

- background templates: obtained from bb enriched samples (no isolation criteria for muons)
- m_i: dimuon mass
- B_{17+8} for m_1
- B_{8+8} for m_2
- red curve: predicted bkg. shape model



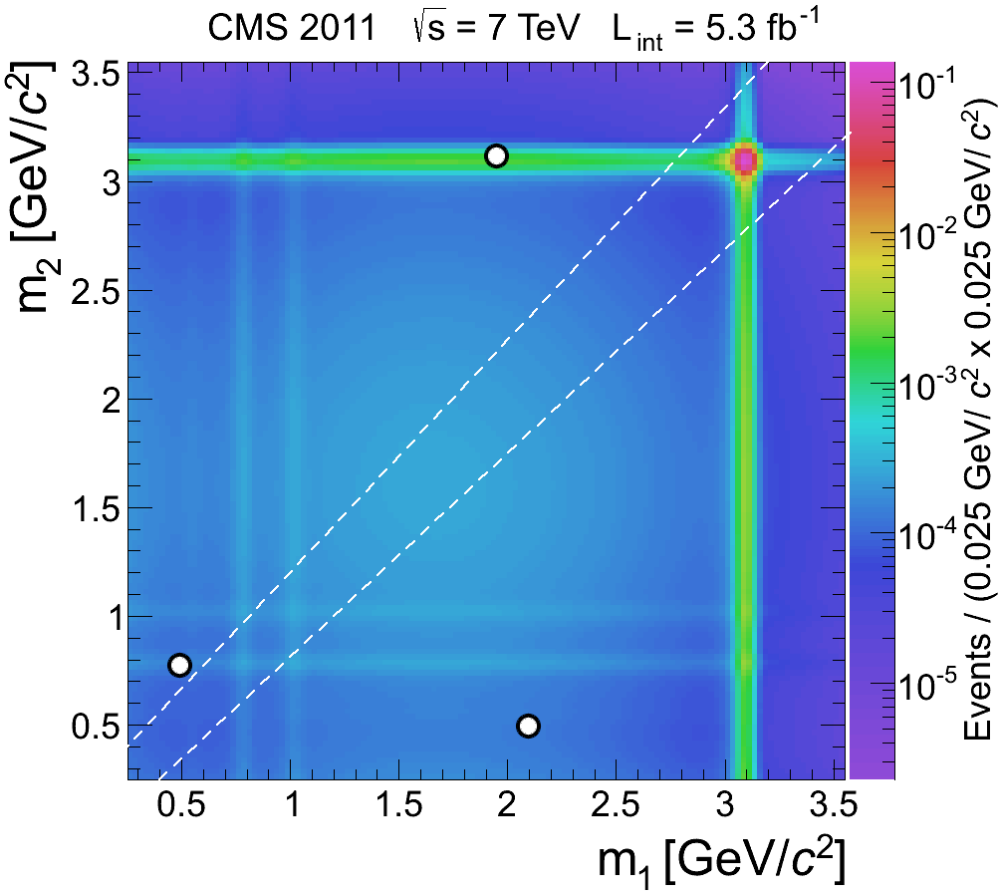
Next-to-**MSSM** $h_{1,2} \rightarrow a_1 a_1 \rightarrow 4\mu$

background expectation:
- sum of bb and direct J/ψ pair production
- including muon isolation
- $m_{1,2} = m_{\mu\mu}$

m_1: a muon with $p_T > 17$ GeV

- **3 events** in the data (empty circles) that all selections except signal requirement:

$m_1 \approx m_2$



interpretations

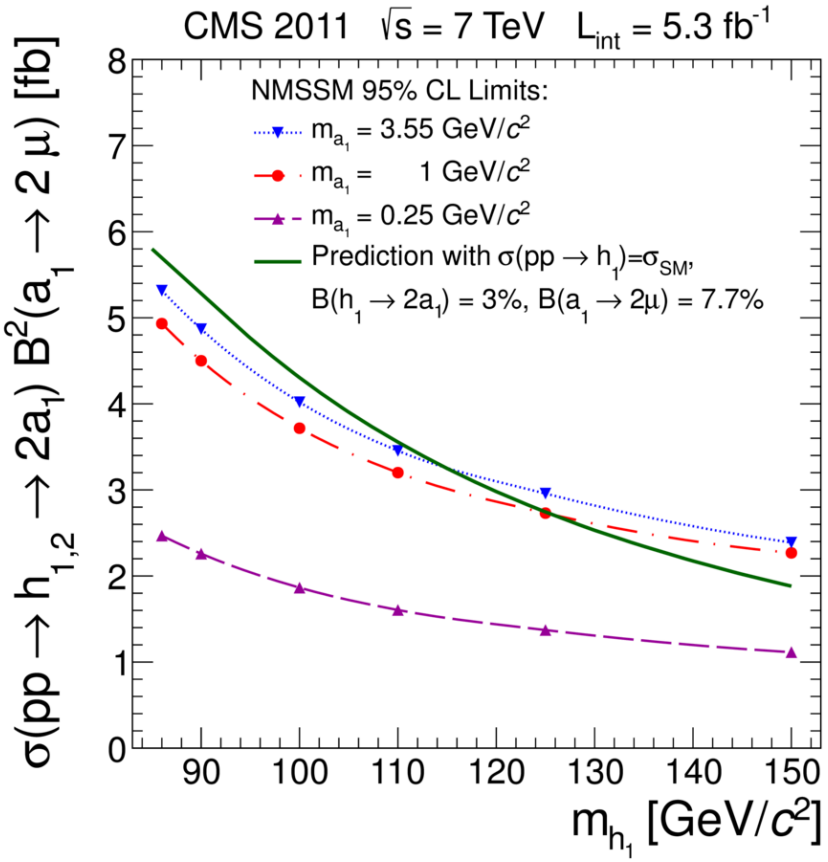
- **NMSSM:**
- CP-odd light Higgs boson: $h_{1,2} \rightarrow 2a_1$
- $2m_\mu < m_{a1} < 2m_\tau$

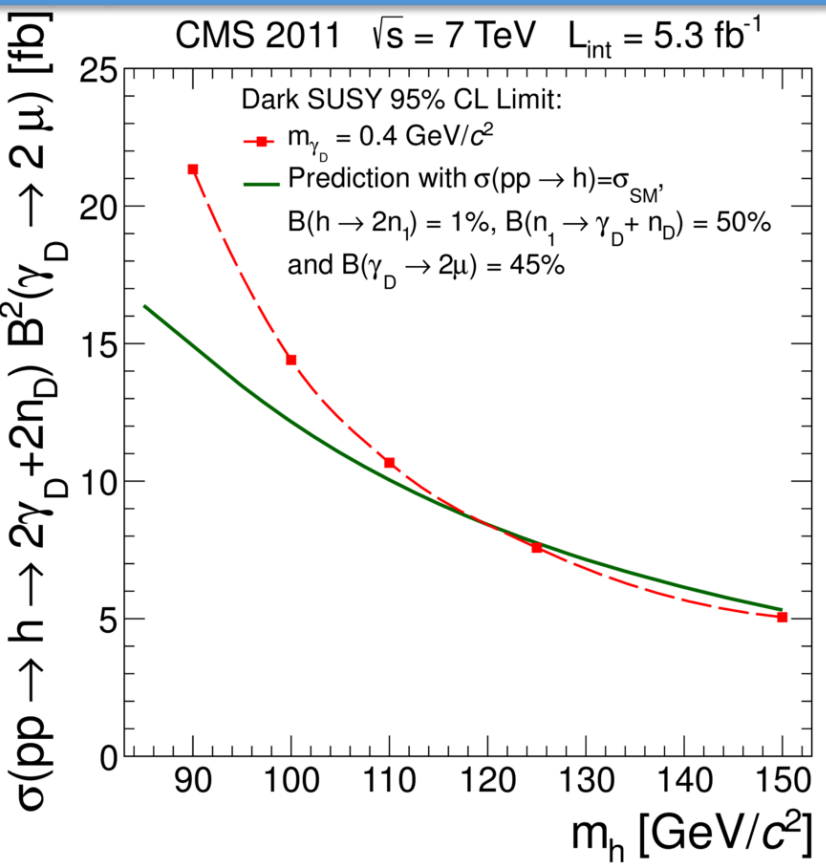
- analysis of 2012 data will be released soon

DARK SUSY:
- lightest neutralino n_1 no longer stable: $n_1 \rightarrow \gamma_D\, n_D$

γ_D – dark photon, n_D – dark fermion

- assumption γ_D decays only in SM particles: $\gamma_D \rightarrow \mu^+\mu^-$ with BR.$\approx$45%





Next-to-**MSSM** $h_{1,2} \rightarrow a_1 a_1 \rightarrow 4\gamma$

event selection:

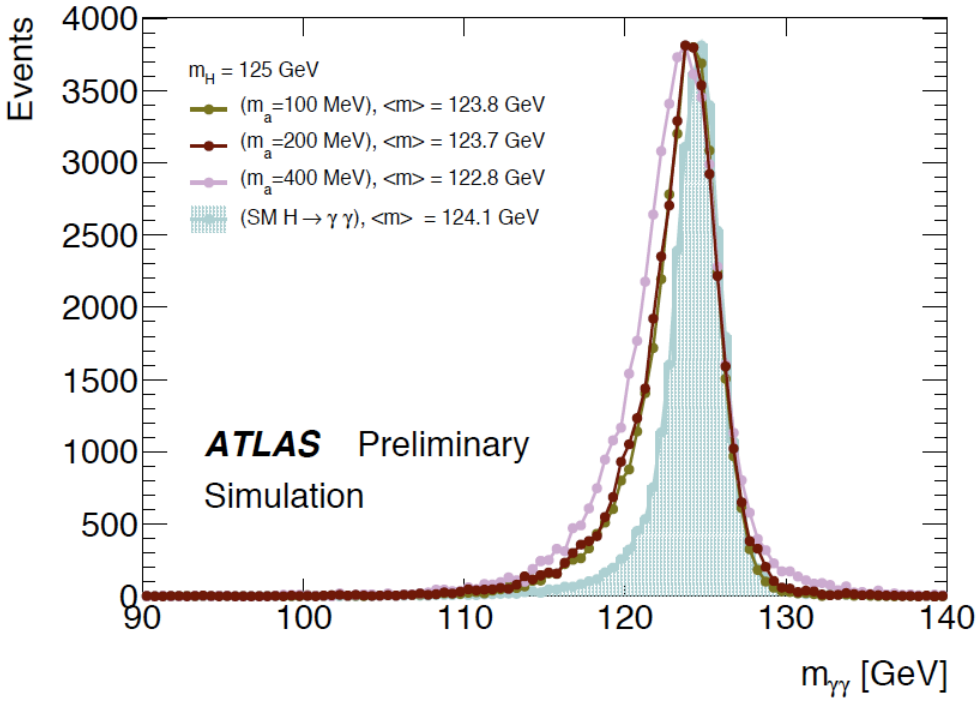
- diphoton trigger with $E_T > 20$ GeV for each leg: lowest efficiency 96% for $m_{a1} = 400$ MeV
- two isolated photons:

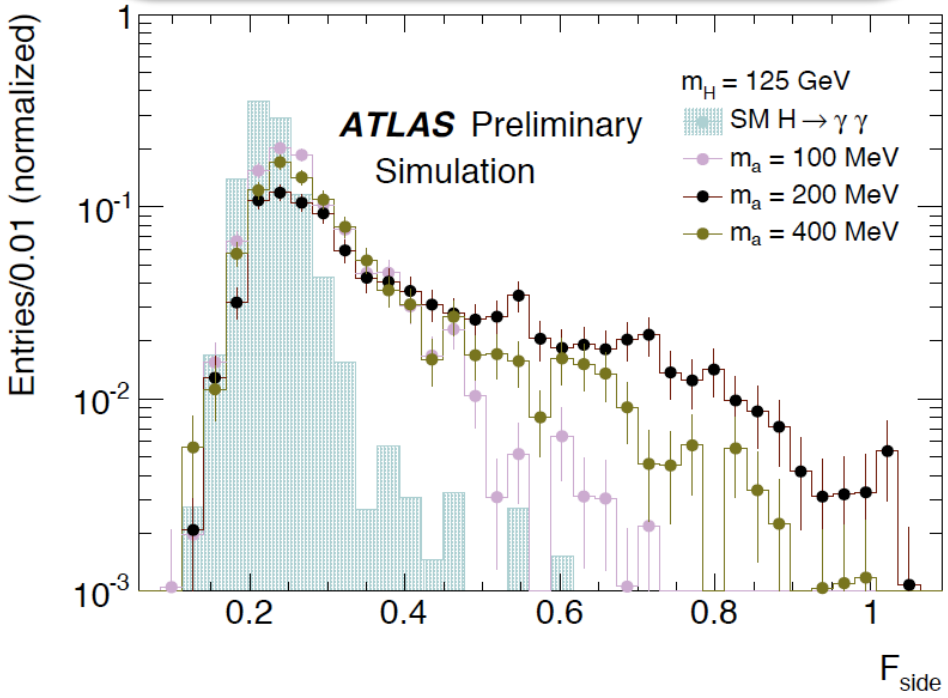
$E_T > 40$ (25) GeV leading γ (sub-leading)

$|\eta| < 1.37$ && $1.52 < |\eta| < 2.37$

- 2 photons from a_1 decay often collimated:
  - identified as single photon

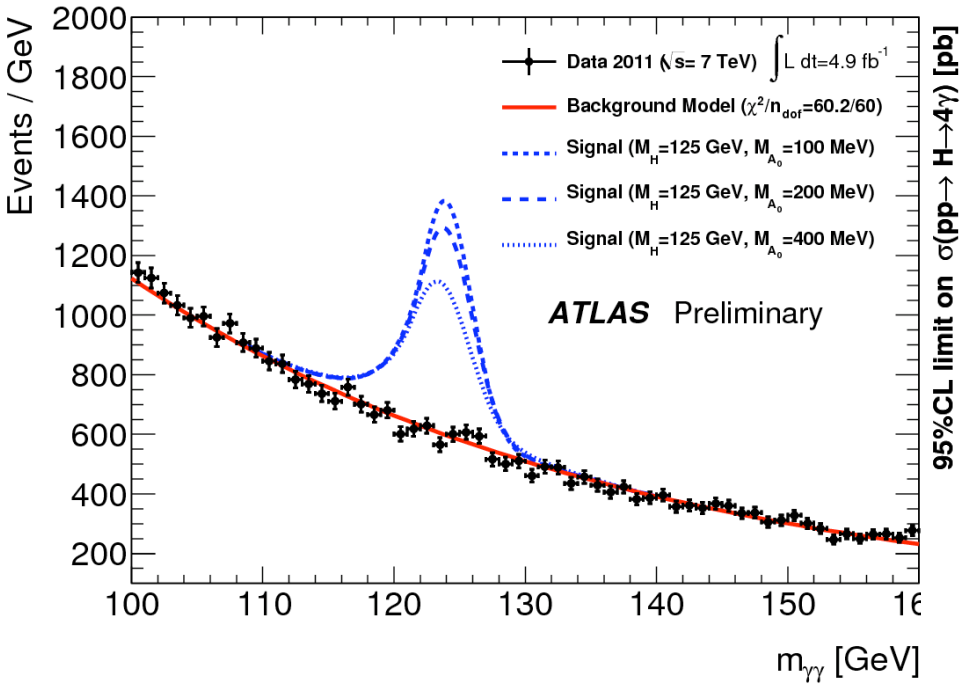
- shower shapes variables:
  - sensitive to overall width in η and ϕ
  - measure properties of inner structure
- F_{side} : energy fraction leaked outside the central core of three cells centered around the most energy in cluster (within 7 cells)



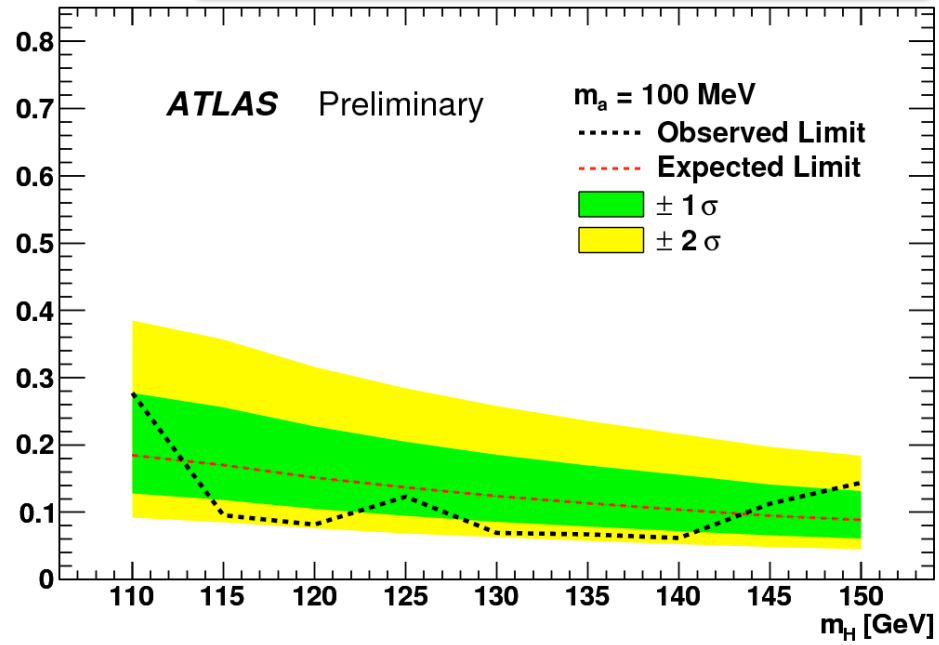


Next-to-**MSSM** $h_{1,2} \rightarrow a_1 a_1 \rightarrow 4\gamma$

- $115 < m_{\gamma\gamma} < 140$ GeV limit on σ x BR ≈ 0.1 pb
- outside above mass range: limit on σ x BR ≈ 0.2 pb



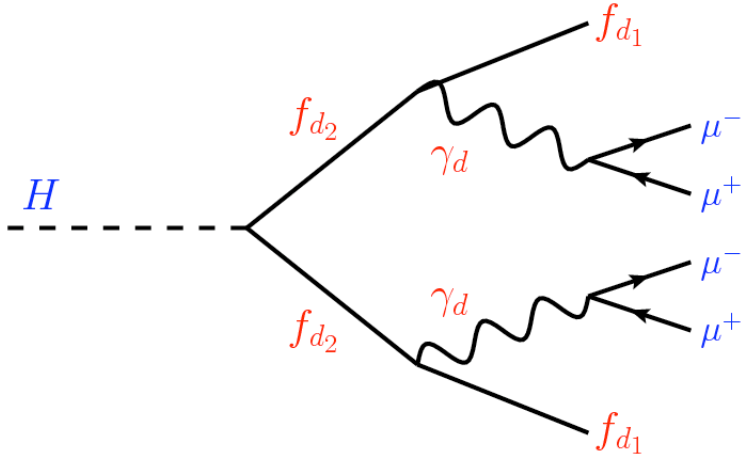
more details in **ATLAS-CONF-2012-079**



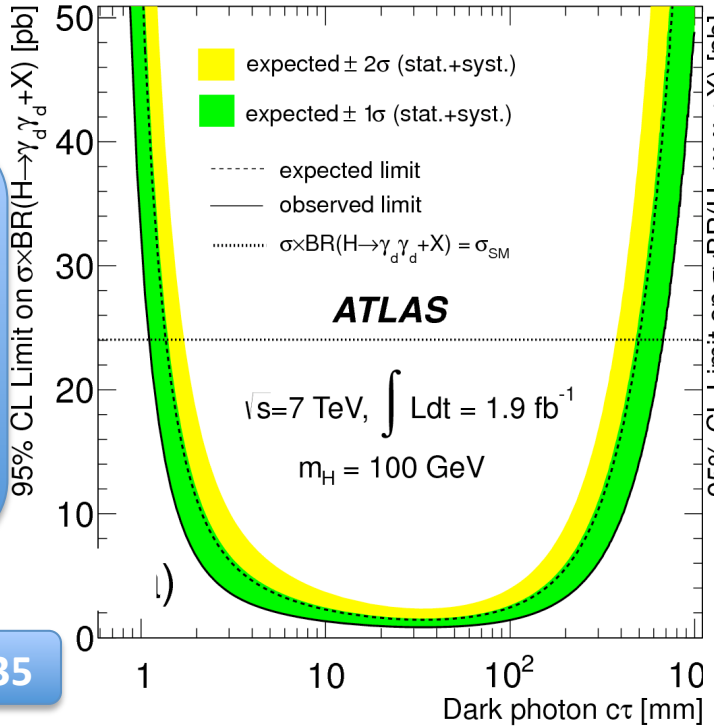
hidden sector: $h \to 2f_{d2}2\gamma_d \to 4\mu\ 2f_{d1}$

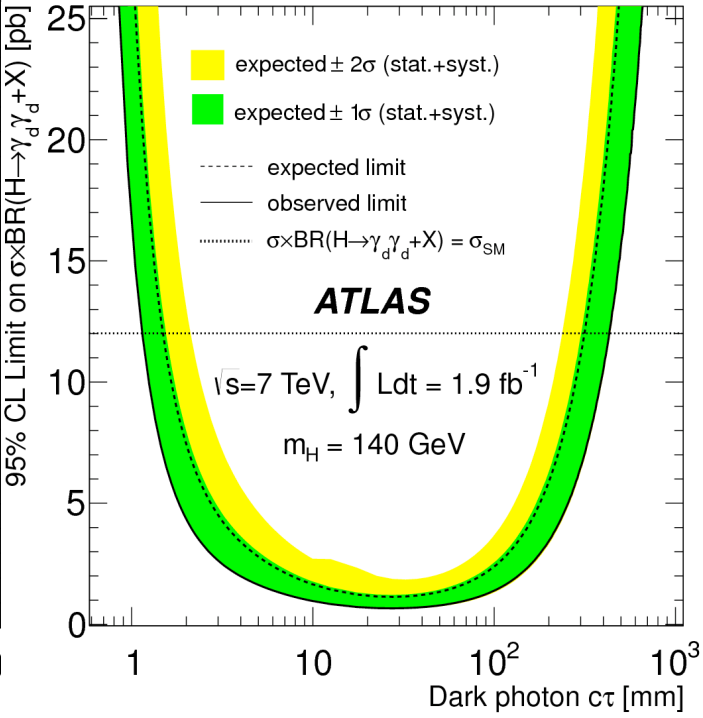
Higgs decays into a new hidden sector of particles
- final state with two sets of collimated muon pairs: *lepton jets*
- event topology: 2μ + 2μ from displaced vertices
- in γ_D decay $\Delta R < 0.1$ for the 2 muons, smaller than L1 granularity

event selection:
- three muons trigger with $p_T > 6$ GeV



excluded cτ:
- **m_H = 100 GeV**
- BR(100%) 1 ≤ cτ ≤ 670 mm
- BR(10%): 5 ≤ cτ ≤ 159 mm
- **m_H = 140 GeV**
- BR(100%): 1 ≤ cτ ≤ 430 mm
- BR(10%): 7 ≤ cτ ≤ 82 mm





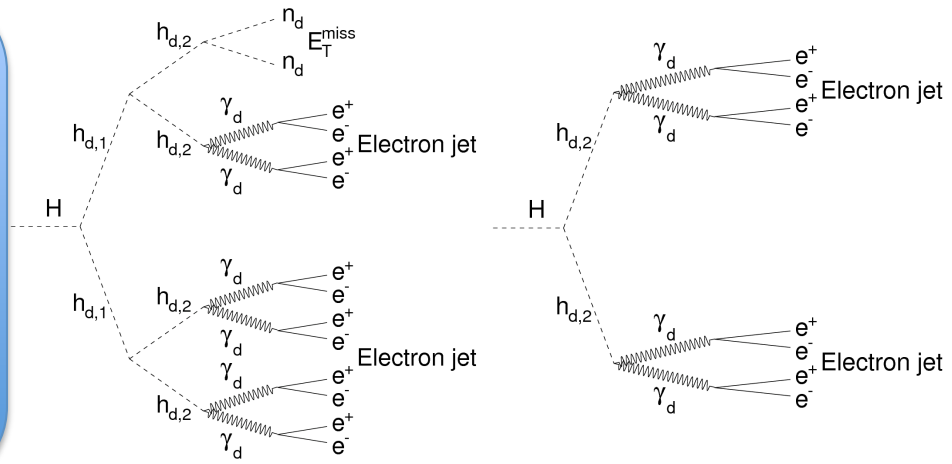
more details in **arXiv:1210.0435**

ATLAS hidden sector: multi e-jets

Higgs decays to hidden-sector particles

- two topologies: 3-step and 2-step cascade
- for γ_D below 210 MeV: $\gamma_D \rightarrow e^+e^-$ BR: 100%
- signal:

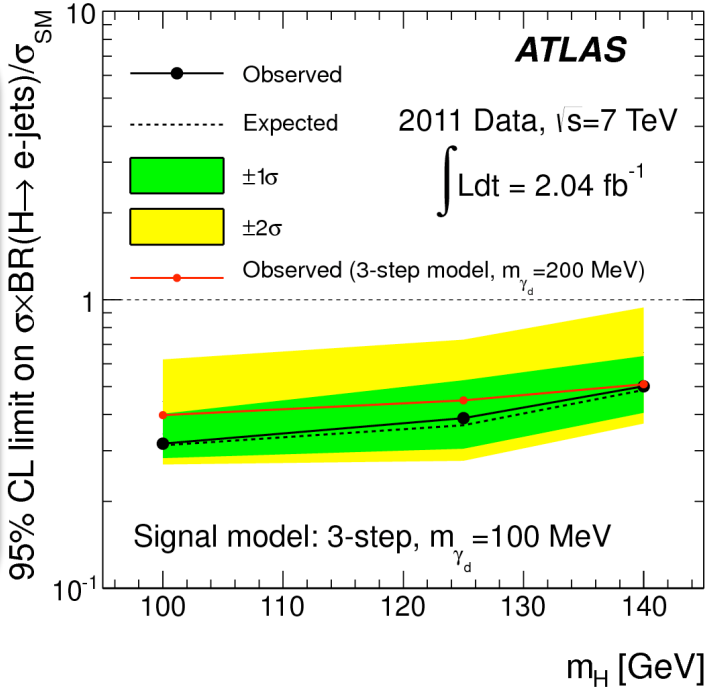
- at least 2 electron-jets with $N_e \geq 4$ each (anti κ_T with R=0.4)
- results robust with respect to masses of $h_{d,1}$, $h_{d,2}$ and n_d if $m \ll m_H$

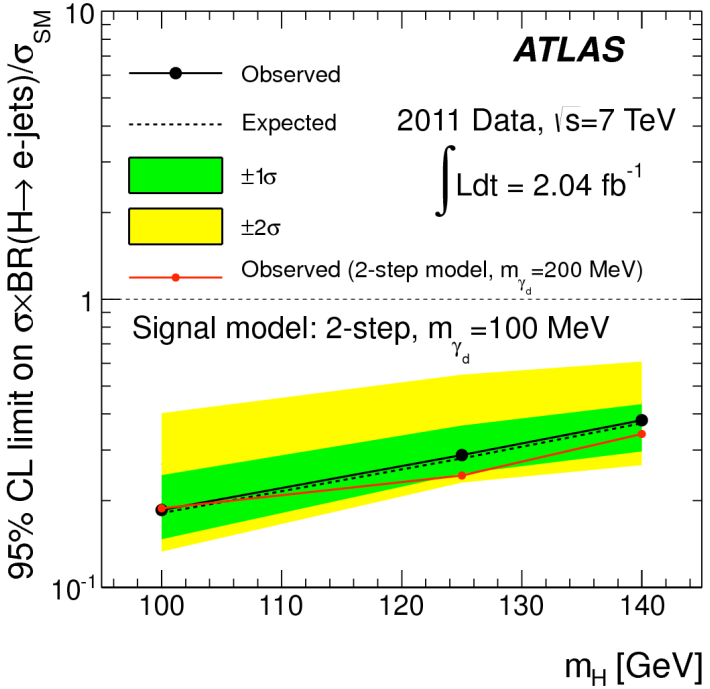


m_H=125GeV
$m_{\gamma d}$=100 MeV

- 3-step model:
$N_{exp.}$=11.3±1.0±0.6
- 2-step model:
$N_{exp.}$=16.2±1.2±0.9

N_{bkg}=0.41±0.29±0.12
N_{data}=1

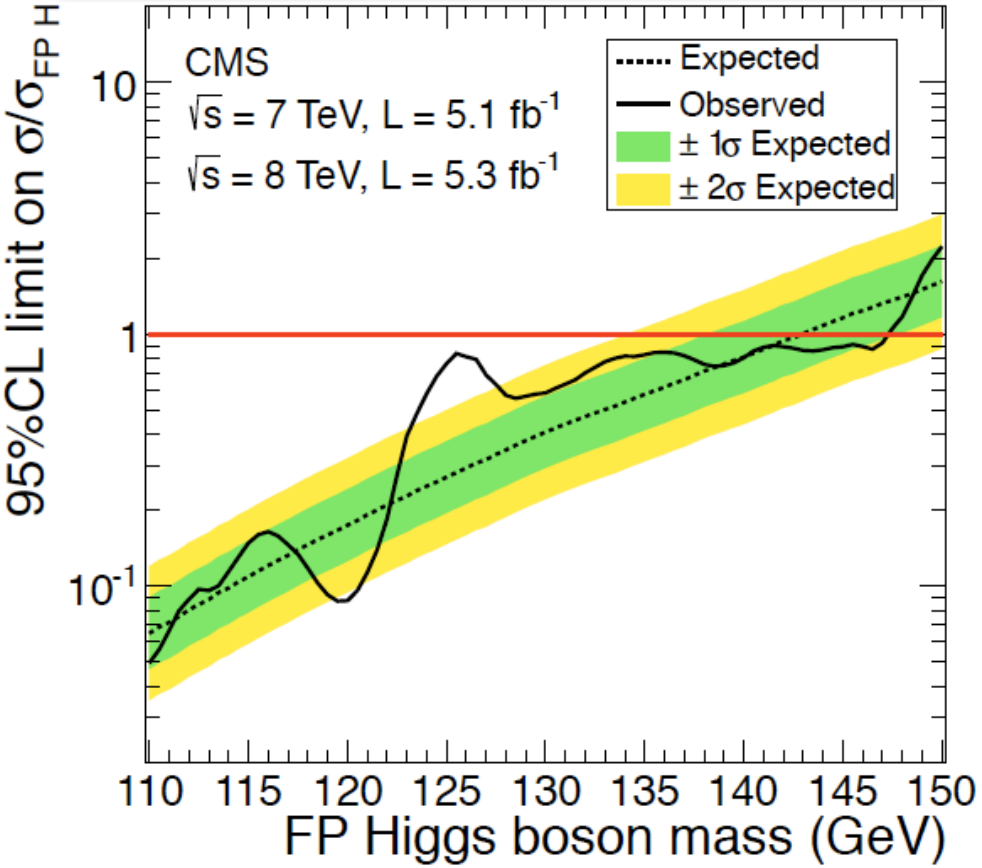


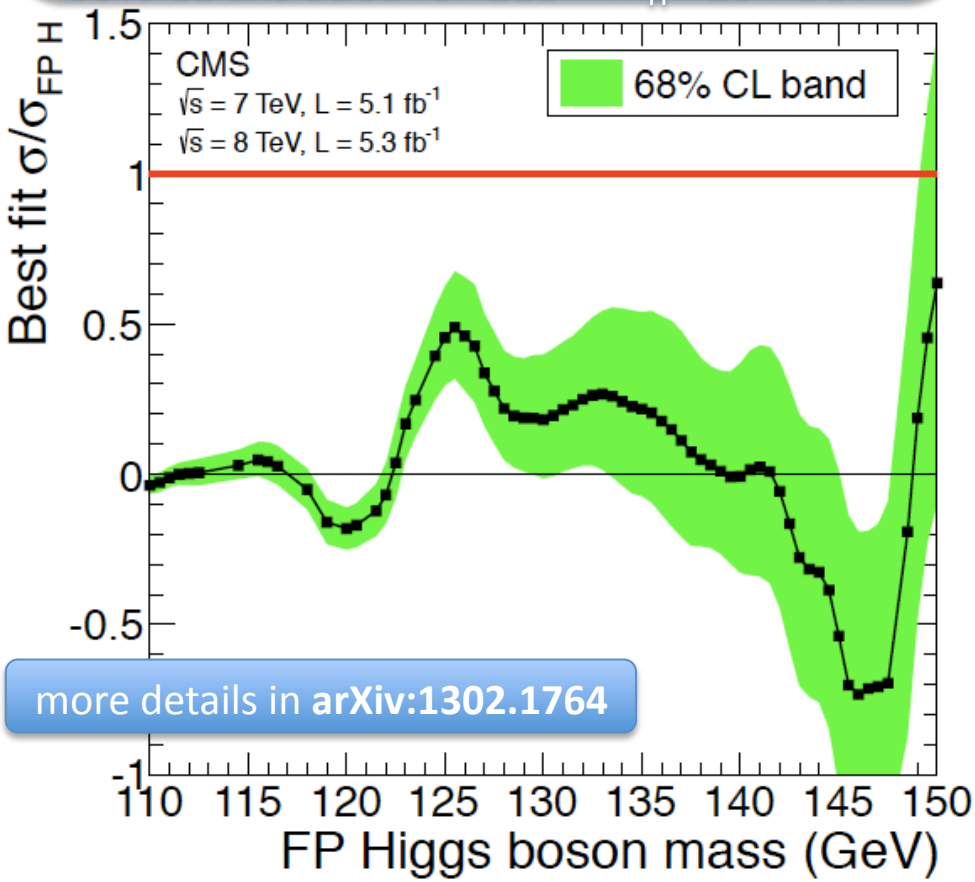


fermiophobic model

- **Higgs boson does not couple to fermions:**
- gluon gluon fusion: negligible
- VBF and VH (V: W, Z): unchanged from SM
- significantly increase of BR for:
H->γγ, H->WW and H->ZZ

- H->γγ increased by an order of magnitude relative to SM for low mass:
- only VBF and VH from H->γγ used
- **limits:**
- 95% CL excluded for 110 < m_H< 147 GeV
- 99% CL excluded for 110 < m_H< 134 GeV





more details in **arXiv:1302.1764**

fermiophobic model

event selection:

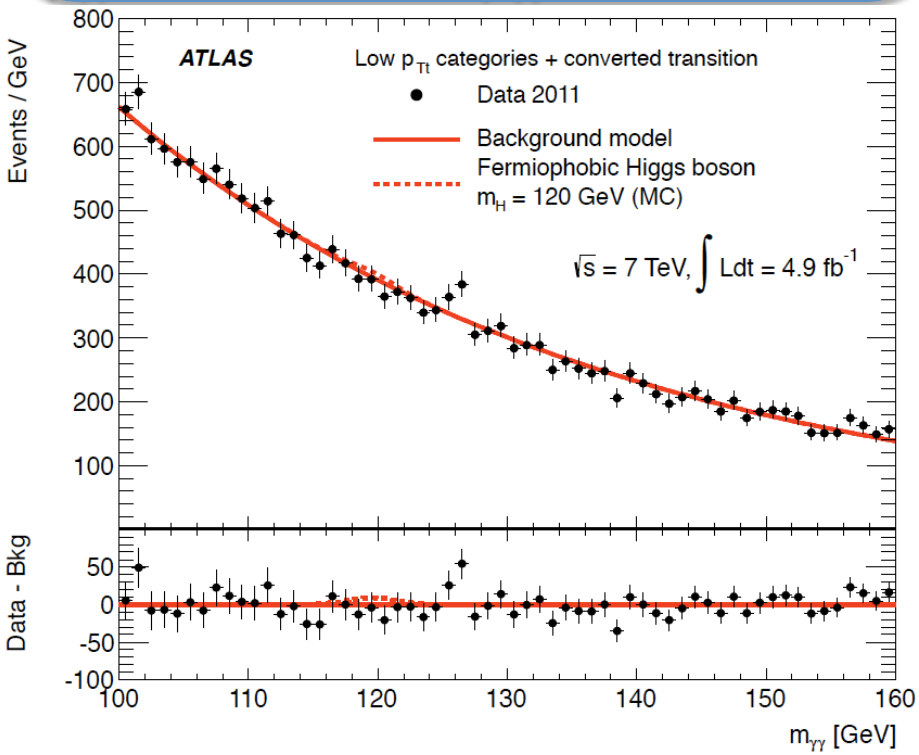
- uses advantage of high p_T of Higgs boson (production mechanism VBF and VH)
- diphoton triggers with E_T> 20 GeV signal efficiency 99%
- two isolated photons:

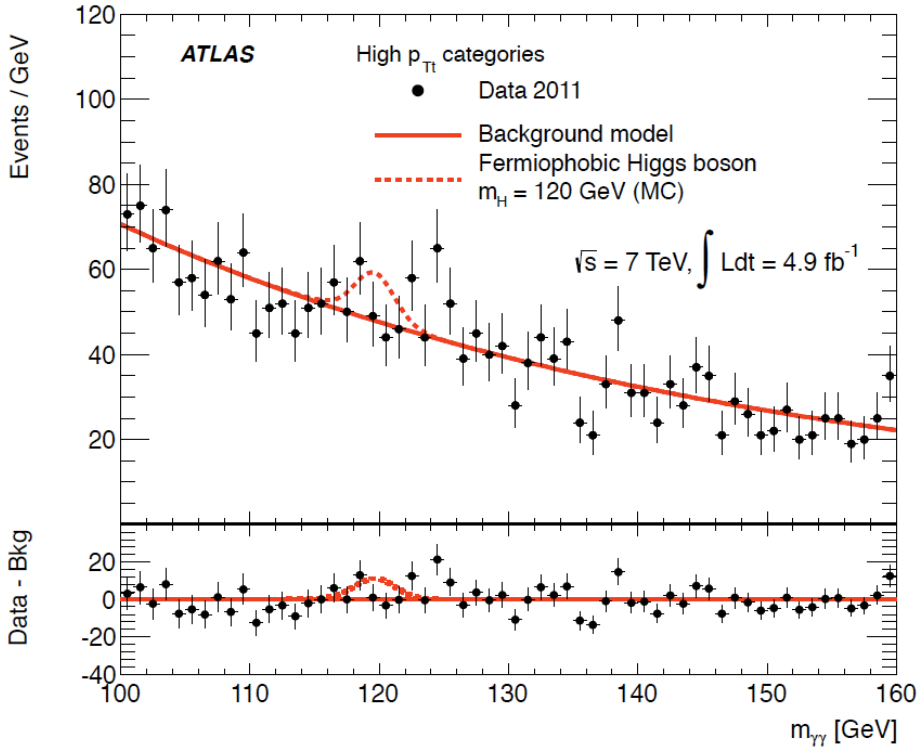
E_T > 40 (25) GeV leading γ (sub-leading)
$|\eta| < 1.37$ && $1.52 < |\eta| < 2.37$

event classification in nine categories:

- impact point on the calorimeter
- photon conversions
- p_{Tt} : diphoton transverse momentum orthogonal to the diphoton thrust-like axis in transverse plane

$$p_{\mathrm{T}t} = |\mathbf{p}_{\mathrm{T}}^{\gamma\gamma} \times \hat{t}| \text{ with } \hat{t} = \frac{\mathbf{p}_{\mathrm{T}}^{\gamma 1} - \mathbf{p}_{\mathrm{T}}^{\gamma 2}}{|\mathbf{p}_{\mathrm{T}}^{\gamma 1} - \mathbf{p}_{\mathrm{T}}^{\gamma 2}|}$$

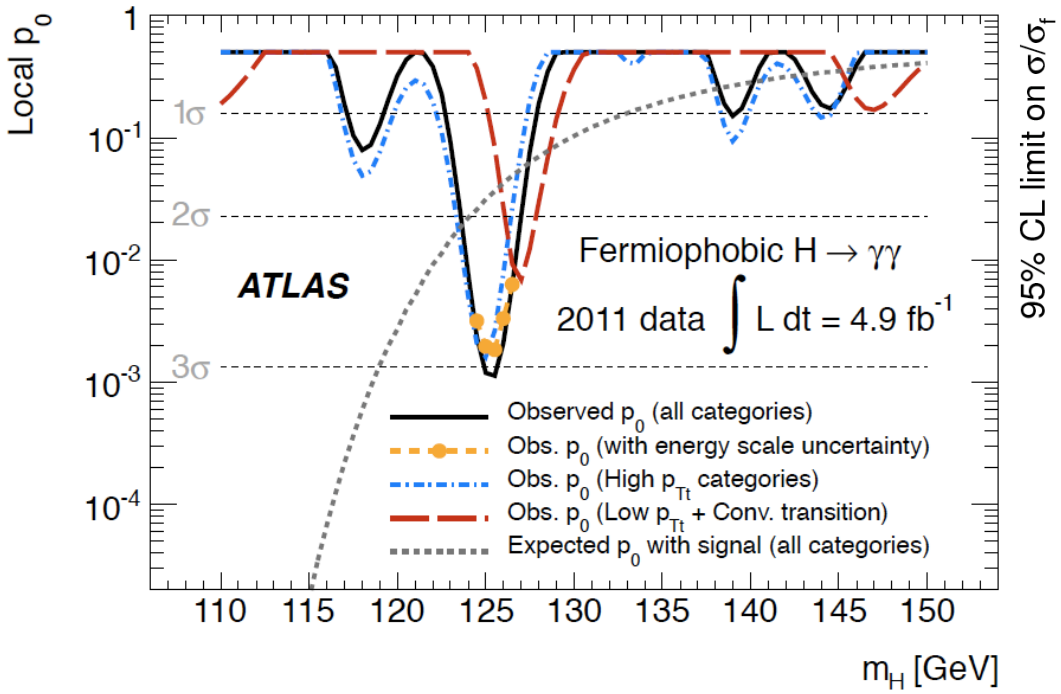


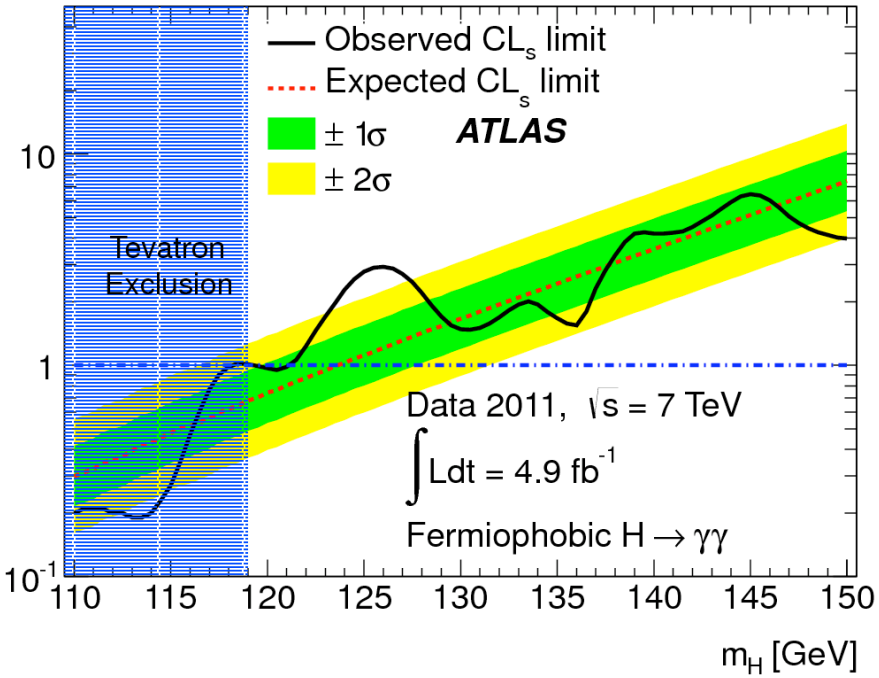


fermiophobic model

- combined p0 value: minimum at 125.5 GeV (3σ)
- including photon energy scale uncertainty: 2.9σ
- considering look-elsewhere effect in 110-150 mass range: 1.6 σ
- SM search with same data set and selection: 1.5 σ (126.5 GeV)
- excluded fermiophobic Higgs boson masses:

110.0 GeV to 118.0 GeV and 119.5 GeV to 121.0 GeV





more details in **arXiv:1205.0701**

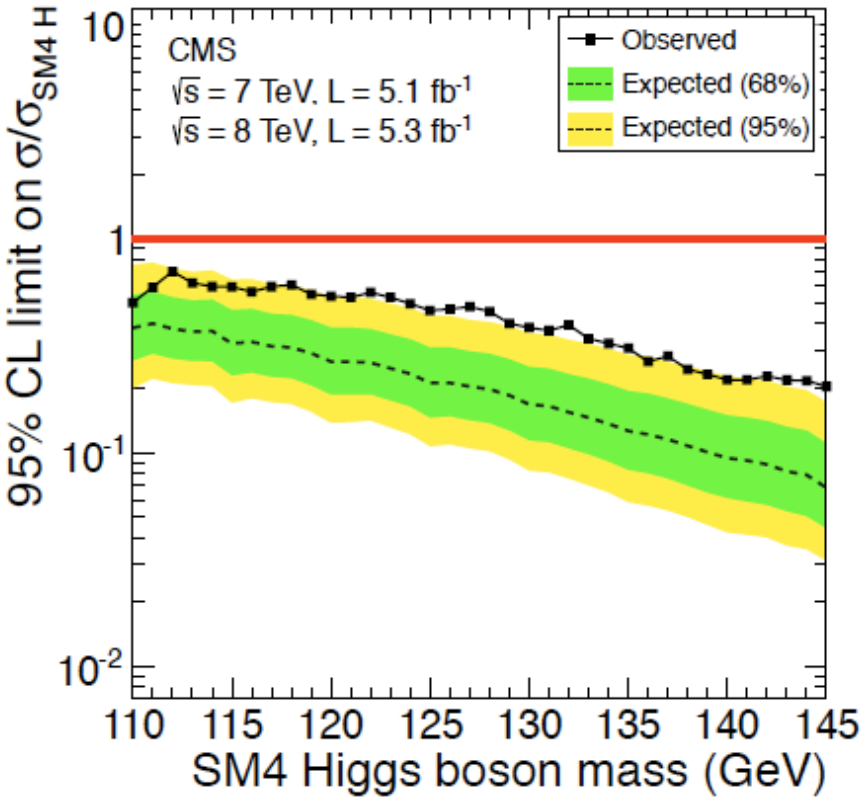
SM 4 generations

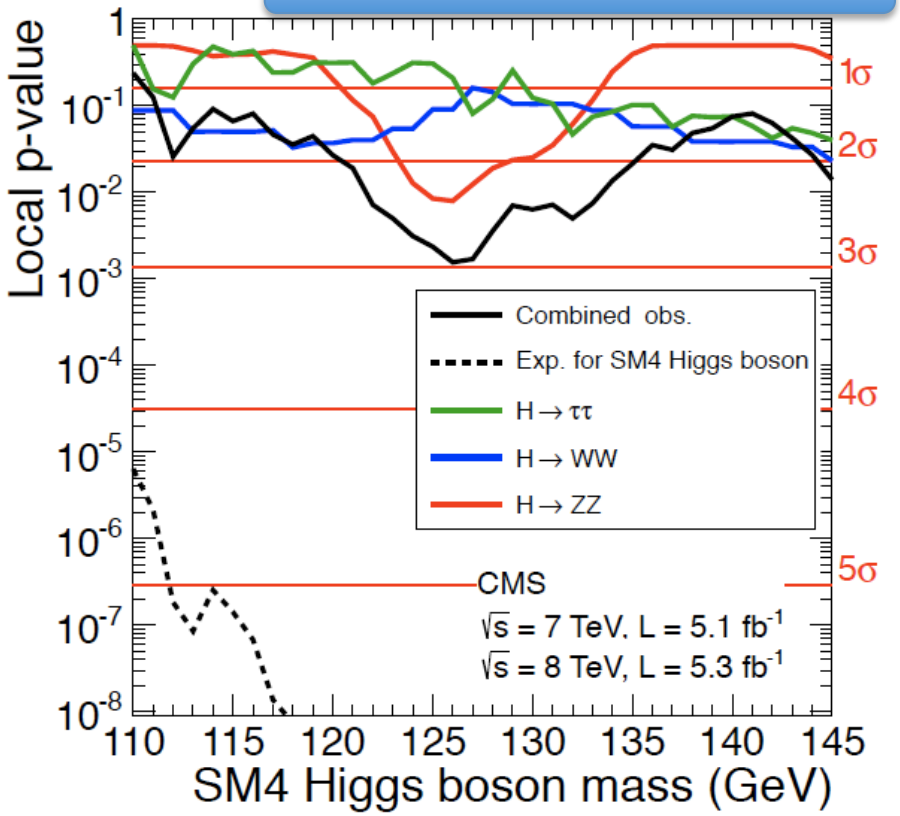
SM4 benchmark:
- $m_{l4} = m_{\nu 4} = m_{d4} = 600$ GeV
- $m_{u4} - m_{d4} = 50 + 10 * \ln(m_H/115)$ GeV

used channels:
- H->ττ : eμ, μμ, $e\tau_{had}$, $\mu\tau_{had}$
- H->WW : 2l 2ν
- H->ZZ : 4l, 2l 2ν and 2l 2q(jets)

sensitivity:
- H->ττ for $m_H < 135$ GeV
- H->ZZ and H->WW for $135 < m_H < 150$ GeV
- H->WW for $150 < m_H < 190$ GeV
- H->ZZ for $m_H > 190$ GeV

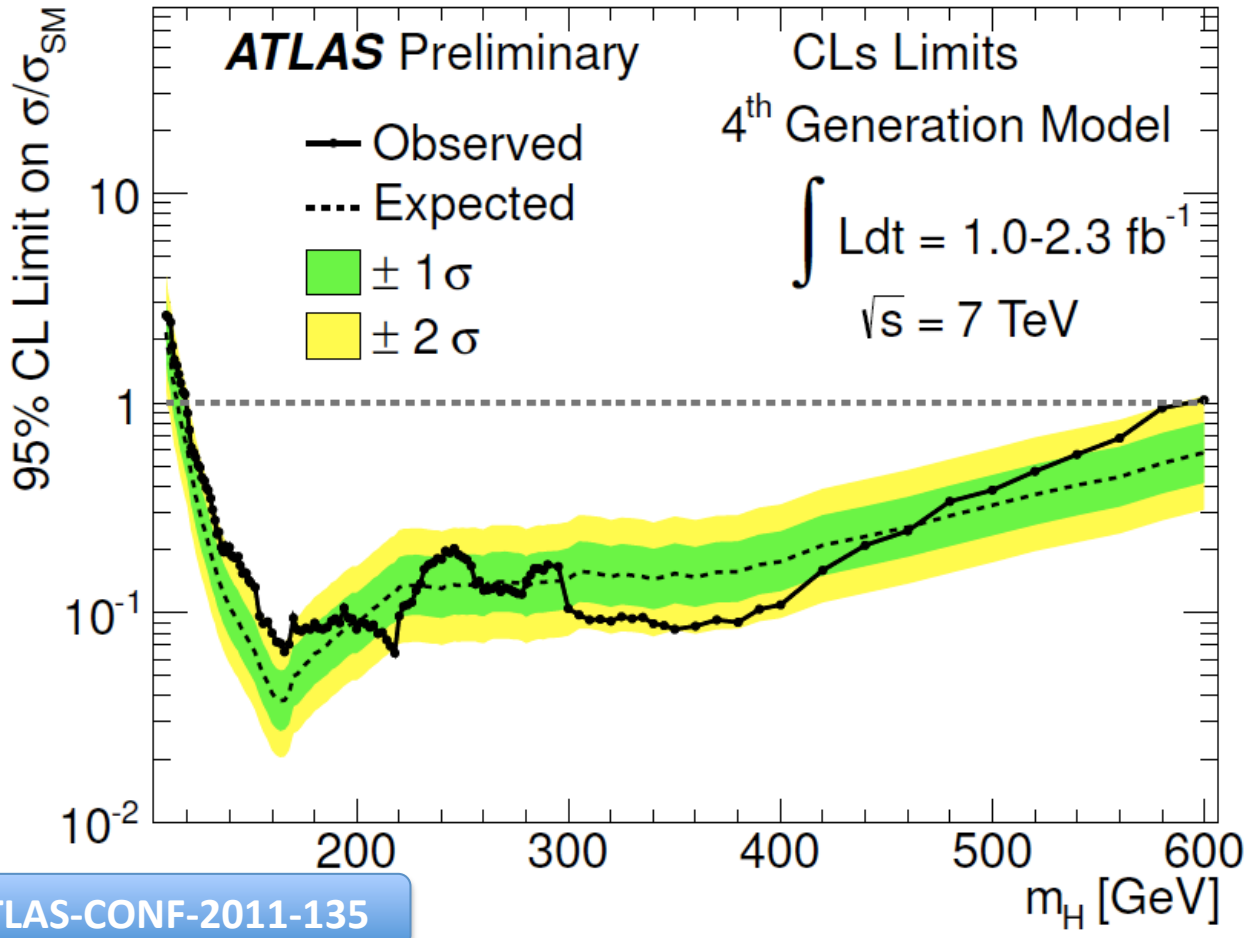
more details in **arXiv:1302.1764**





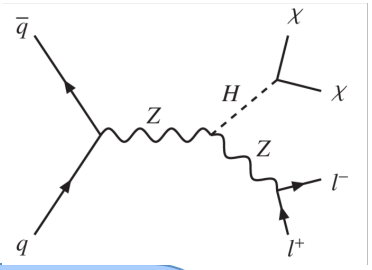
SM 4

• excluded at 95 % CL for Higgs masses between 119 and 593 GeV



more details in **ATLAS-CONF-2011-135**

Z(ll)H decaying invisible



event selection:

- single and double leptons triggers

- signal efficiency:

100% for $Z^0 \to e^+e^-$ and 95% for $Z^0 \to \mu^+\mu^-$

- lepton selection

- two isolated opposite charge leptons with $p_T > 20$ GeV and $|\eta_e| < 2.47$ while $|\eta_\mu| < 2.4$

- $76 < m_{ll} < 106$ GeV

- veto on third lepton with $p_T > 7$ GeV

- topological cuts

- $E_T^{miss} > 90$ GeV

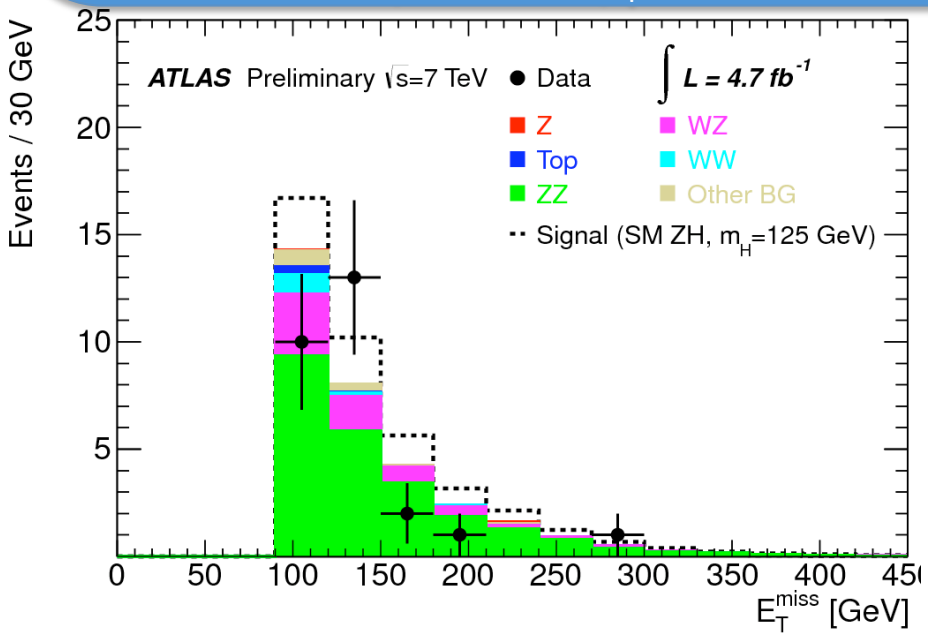
- $\Delta\phi\,(E_T^{miss}, p_T^{miss}) < 0.2$ rad

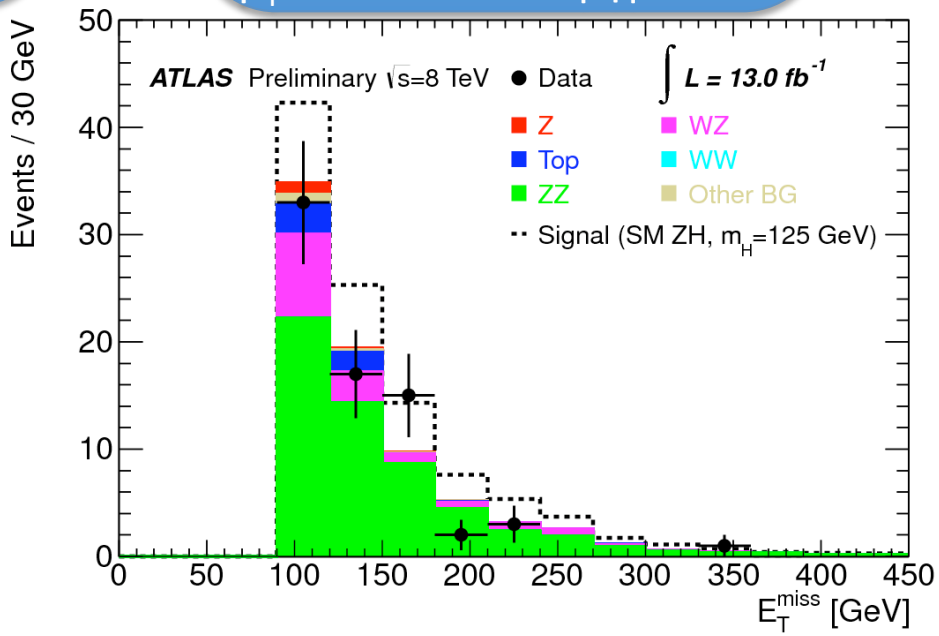
- $\Delta\phi\,(Z_{ll}, E_T^{miss}) > 2.6$ rad

- $\Delta\phi_{ll} < 1.7$ rad

- $|E_T^{miss} - p_T^{ll}|/p_T^{ll} < 0.2$

- no jet with $p_T > 20$ GeV and $|\eta| < 2.5$





Z(ll)H decaying invisible

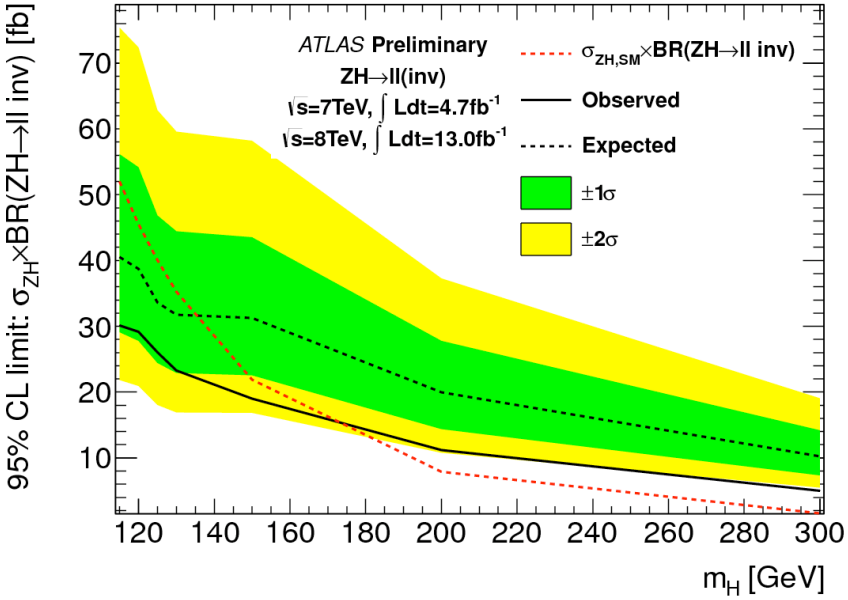
what is invisible?

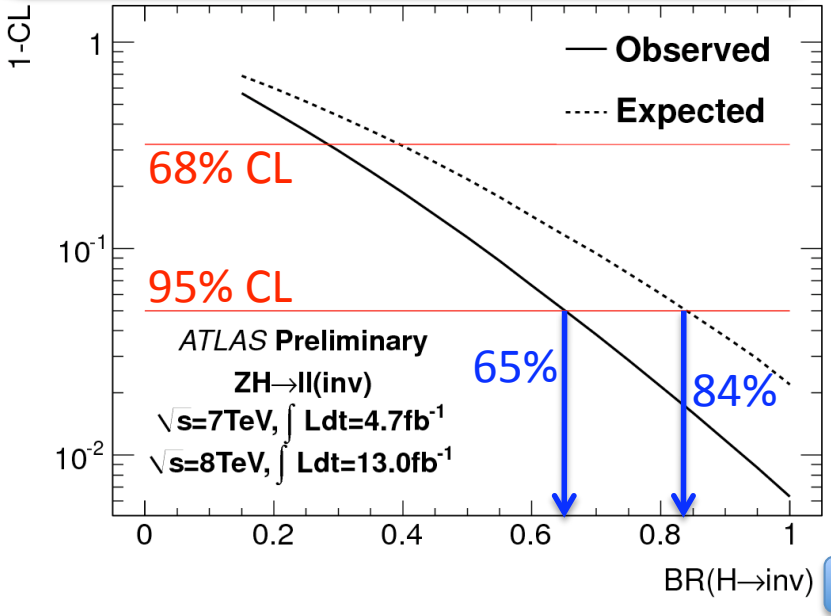
- SM: H->2Z->4ν (SM with BR ~0.1%)
- BSM: Higgs decays into a pair of LSPs
  - Higgs decays/oscillates into graviscalars
  - Higgs decays into dark matter particles

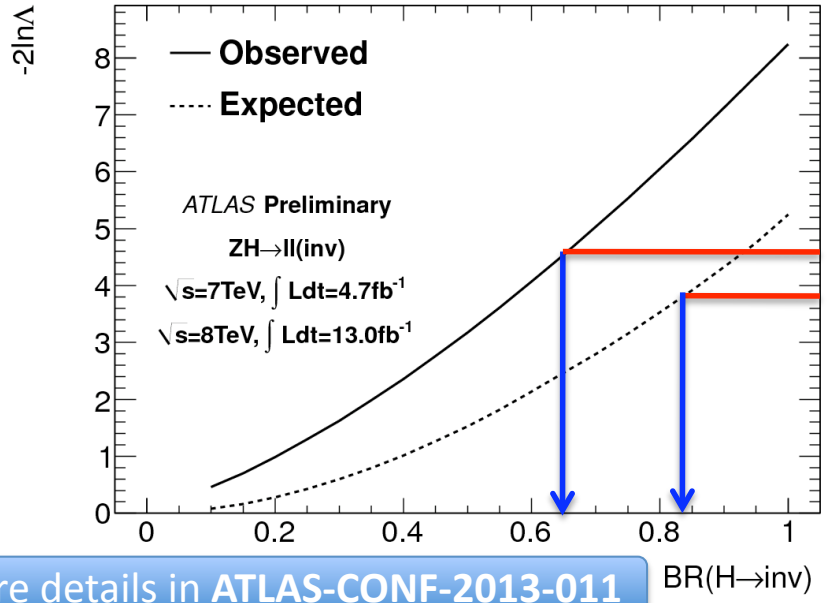
limits:

- on σ_{ZH} x BR(ZH-> ll inv.): no excess observed between 115 and 130 GeV
- on BR(H->inv.):

< 65% observed and < 84% expected







more details in **ATLAS-CONF-2013-011**

exotic intermezzo

what we have seen so far:

- short overview of MSSM
- NMSSM searches for:
- $a_1 \to \mu^+\mu^-$
- $h_{1,2} \to a_1 a_1 \to 4\mu$
- $h_{1,2} \to a_1 a_1 \to 4\gamma$
- dark SUSY:
- $h_{1,2} \to 2n_1 \to 2\gamma_D\, 2n_D \to 4\mu\, 2n_D$
- hidden sector: e- and μ-jets
- fermiophobic model
- SM with 4^{th} generation

what we can still see:

- minimal type II seesaw model:
- $\Phi^{\pm\pm}$
- Higgs boson rare decays:
- $Z^0\gamma$
- few more ideas
- "summviewlook"

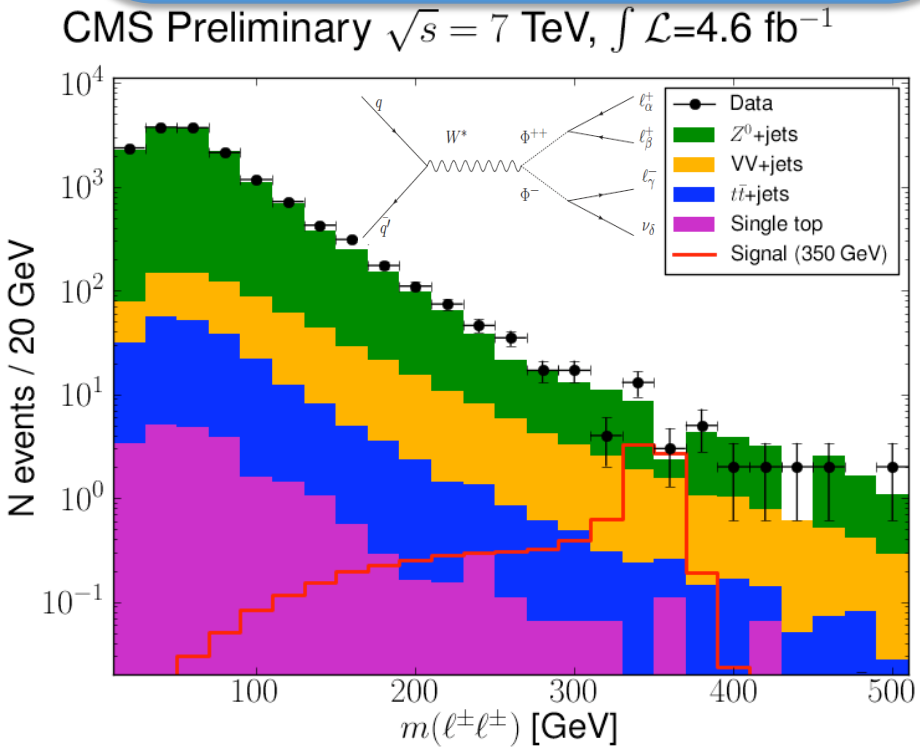
double charged Higgs

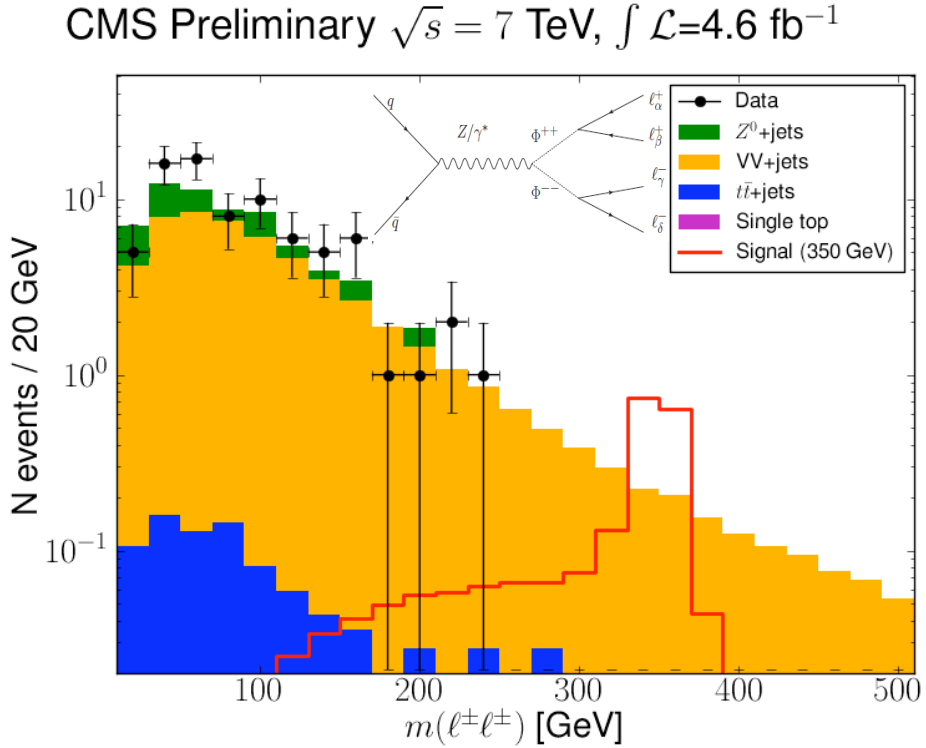
minimal type II seesaw model:

- an additional scalar field, triplet under $SU(2)_L$: Φ^{++}, Φ^{+} and Φ^{0} with $U(1)_Y$ hypercharge Y = 2
- test neutrino mass generation
- production processes:
  - $\Phi^{++}\Phi^{--}$ pair
  - $\Phi^{++}\Phi^{-}$ associated production

selection:

- Σp_T leptons as function of m_Φ
- Z^0 veto
- missing energy in transverse plane
- $\Delta\phi$ for $\ell^{\pm}\ell^{\pm}$
- data driven methods to estimate bkg.: side bands, ABCD (4τ and 3τ final state)





double charged Higgs

- BP1: a massless neutrino, normal mass hierarchies
- BP2: a massless neutrino, inverted mass hierarchies
- BP3: degenerate neutrino mass spectrum (0.2 eV)
- BP4: Φ^{++} with equal BR to each lepton generation.

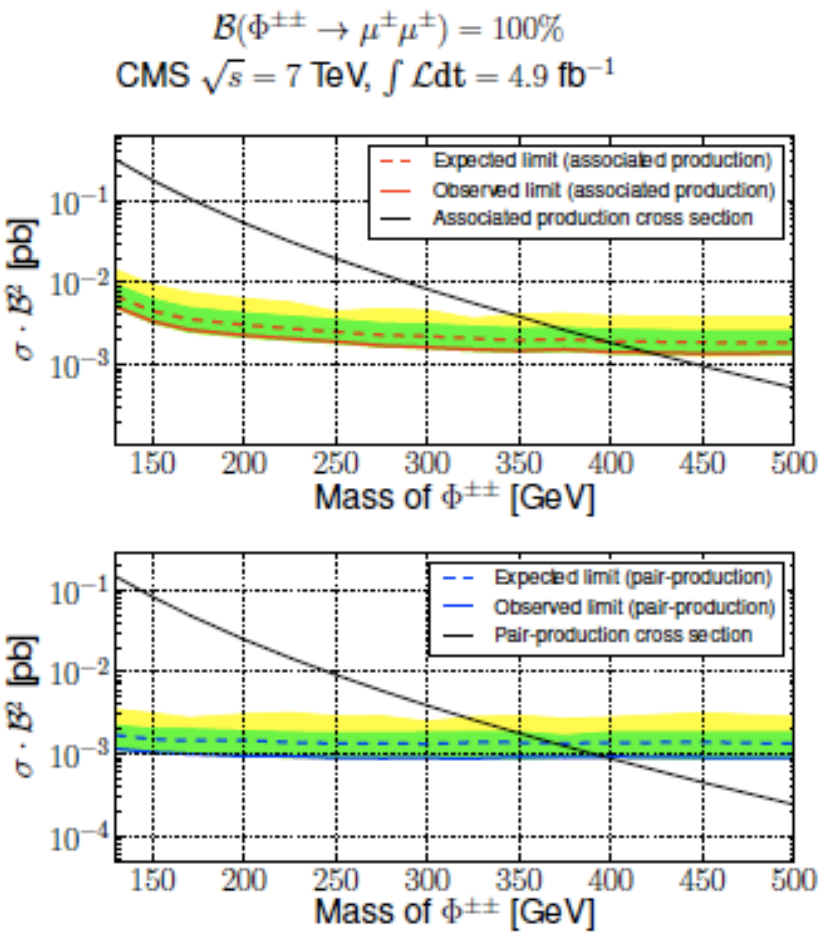
Branching fractions of Φ^{++} for the 4 benchmark points

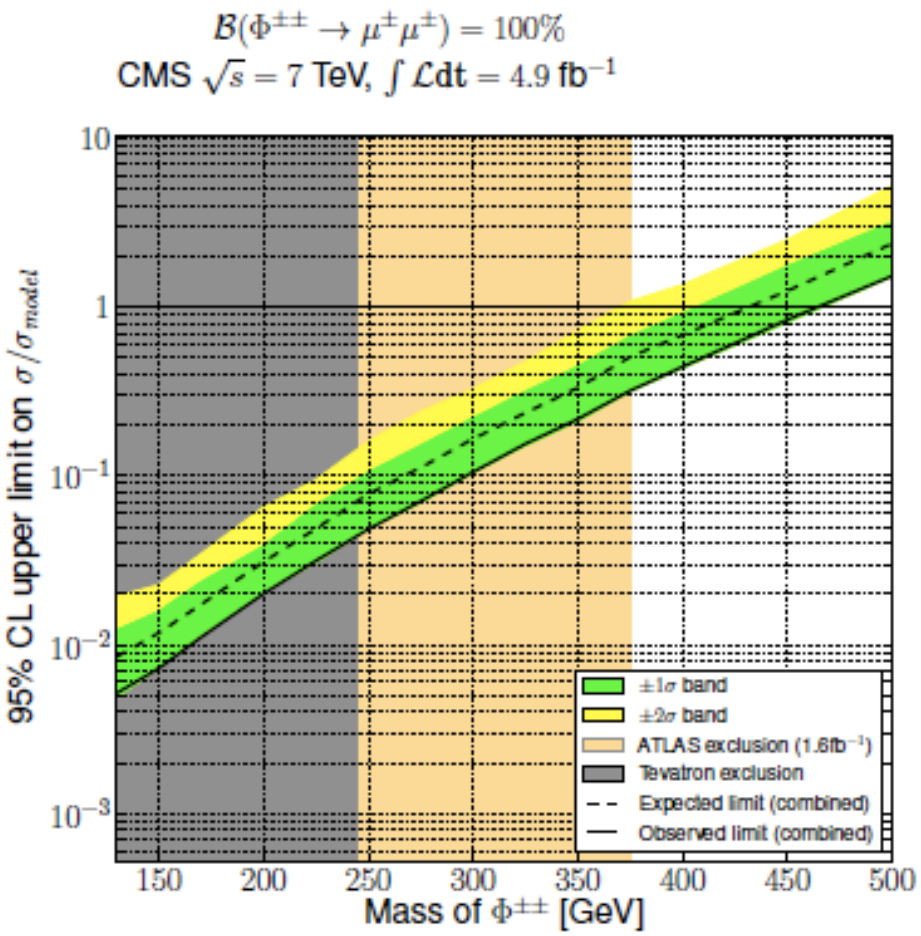
Benchmark point	ee	$e\mu$	$e\tau$	$\mu\mu$	$\mu\tau$	$\tau\tau$
BP1	0	0.01	0.01	0.30	0.38	0.30
BP2	1/2	0	0	1/8	1/4	1/8
BP3	1/3	0	0	1/3	0	1/3
BP4	1/6	1/6	1/6	1/6	1/6	1/6

observed limits:

Benchmark point	Combined 95% CL limit [GeV]	95% CL limit for pair production only [GeV]
$\mathcal{B}(\Phi^{++} \to e^+e^+) = 100\%$	444	382
$\mathcal{B}(\Phi^{++} \to e^+\mu^+) = 100\%$	453	391
$\mathcal{B}(\Phi^{++} \to e^+\tau^+) = 100\%$	373	293
$\mathcal{B}(\Phi^{++} \to \mu^+\mu^+) = 100\%$	459	395
$\mathcal{B}(\Phi^{++} \to \mu^+\tau^+) = 100\%$	375	300
$\mathcal{B}(\Phi^{++} \to \tau^+\tau^+) = 100\%$	204	169
BP1	383	333
BP2	408	359
BP3	403	355
BP4	400	353

double charged Higgs





- **limits calculated also for**

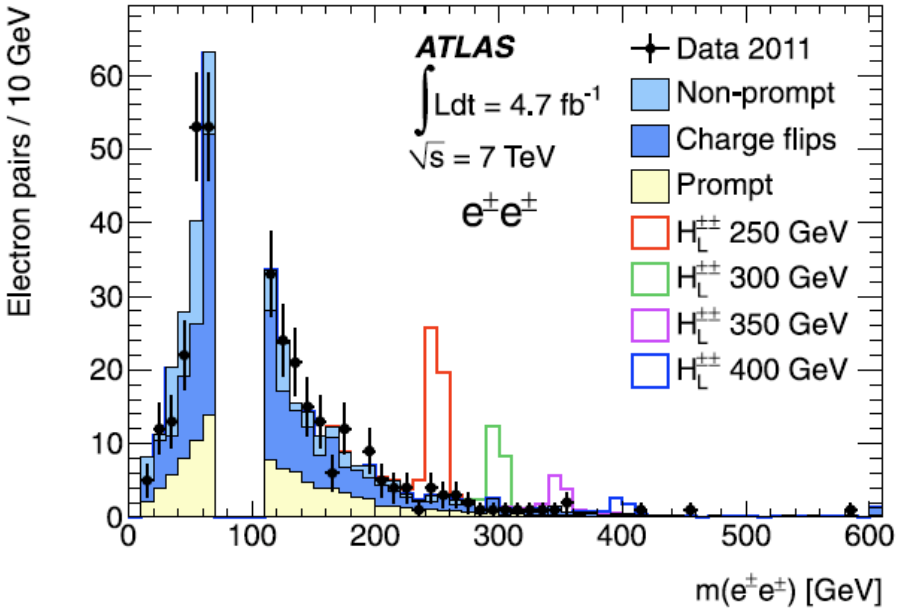
$\Phi^{\pm\pm} \to e^{\pm}e^{\pm}$, $\Phi^{\pm\pm} \to e^{\pm}\mu^{\pm}$,
$\Phi^{\pm\pm} \to e^{\pm}\tau^{\pm}$, $\Phi^{\pm\pm} \to \mu^{\pm}\tau^{\pm}$, $\Phi^{\pm\pm} \to \tau^{\pm}\tau^{\pm}$

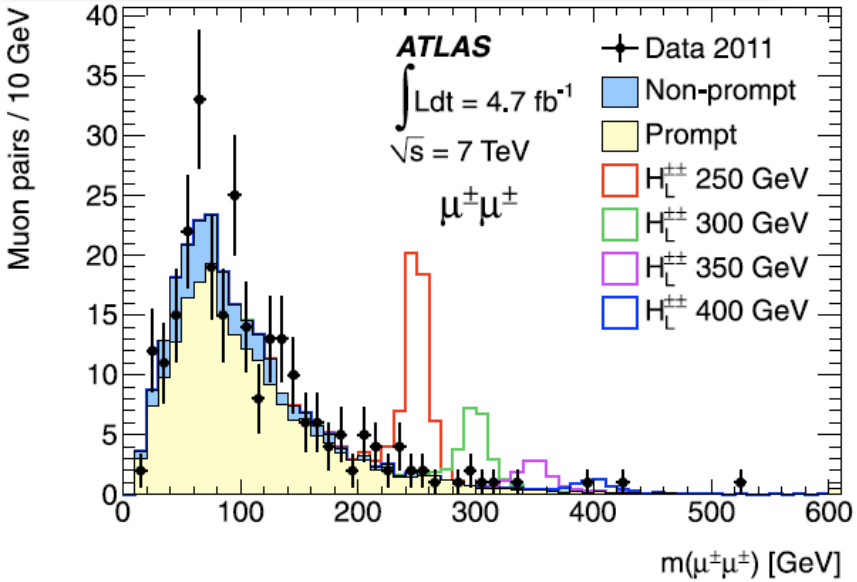
more details in **arXiv:1207.2666**

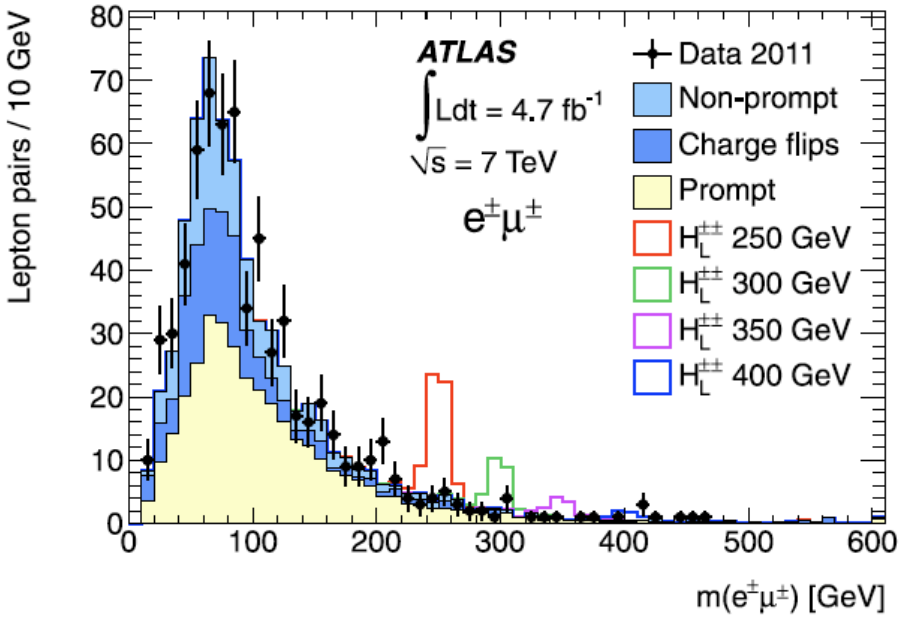
double charged Higgs

- **final states:** $e^{\pm}e^{\pm}$, $e^{\pm}\mu^{\pm}$, $\mu^{\pm}\mu^{\pm}$
  - only $H^{\pm\pm}$ prompt decays: $c\tau < 10\ \mu m$

- **event selection:**
  - single lepton triggers with $p_T > 18$ (20 & 22) GeV for μ (e)
  - leading p_T lepton with $p_T > 25$ GeV, while next-to-leading lepton with $p_T > 20$ GeV
  - $m_{ll} > 15$ GeV and for $e^{\pm}e^{\pm}$ $70 < m_{ll} < 110$ GeV excluded due to charge misidentification

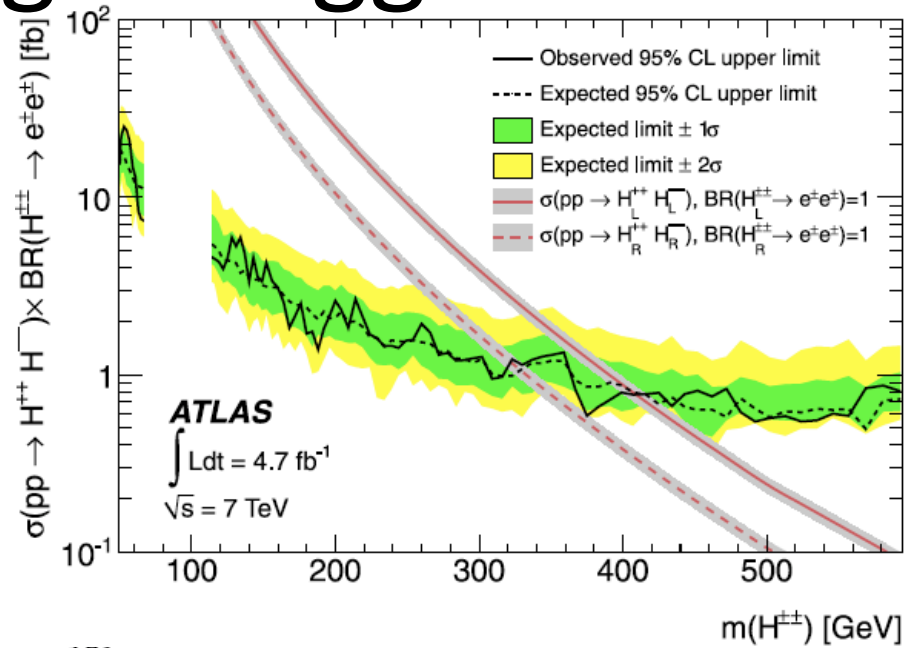


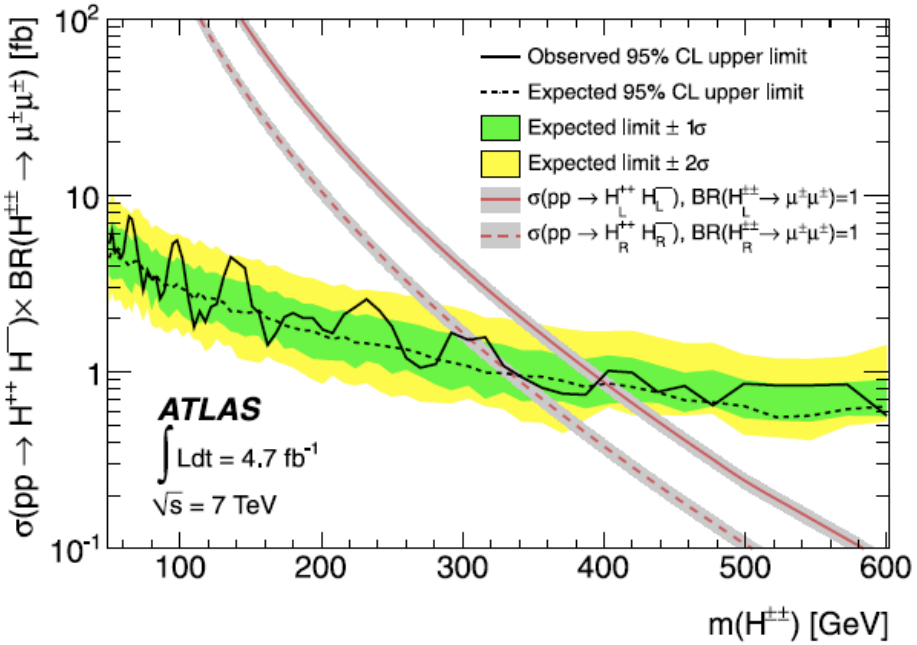


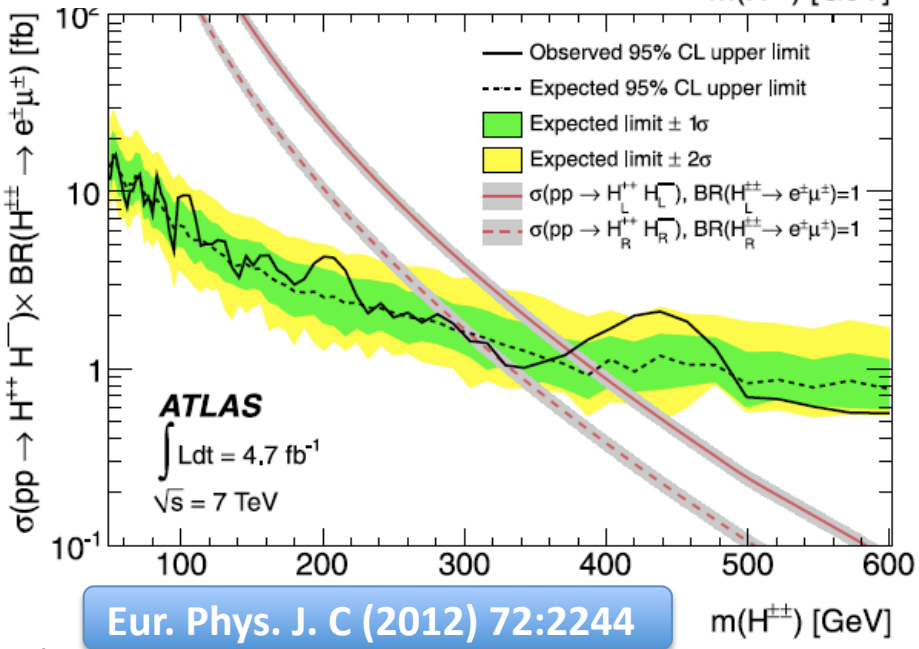


double charged Higgs

- couples to either left- or right-handed fermions
- in left-right asymmetric models the two cases are distinguished: $H_L^{\pm\pm}$ and $H_R^{\pm\pm}$
- $\sigma(H_L^{++}H_L^{--})/\sigma(H_R^{++}H_R^{--}) \approx 2.5$ (due to different couplings to Z boson)





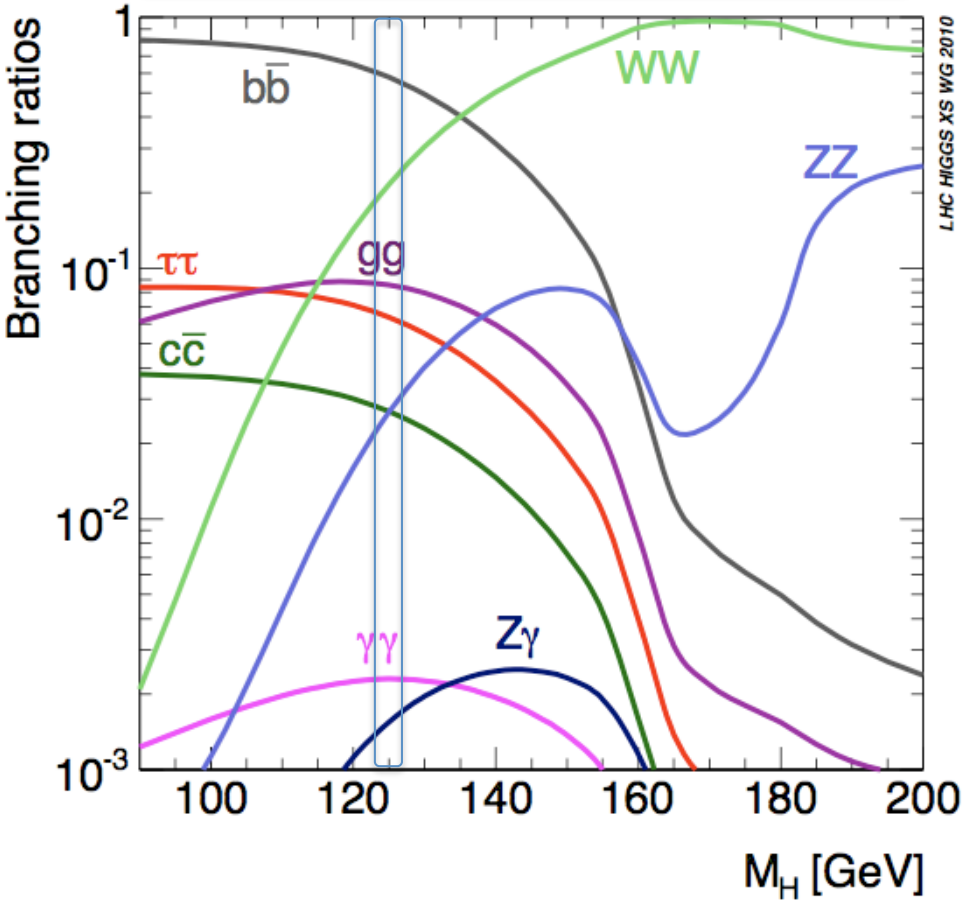


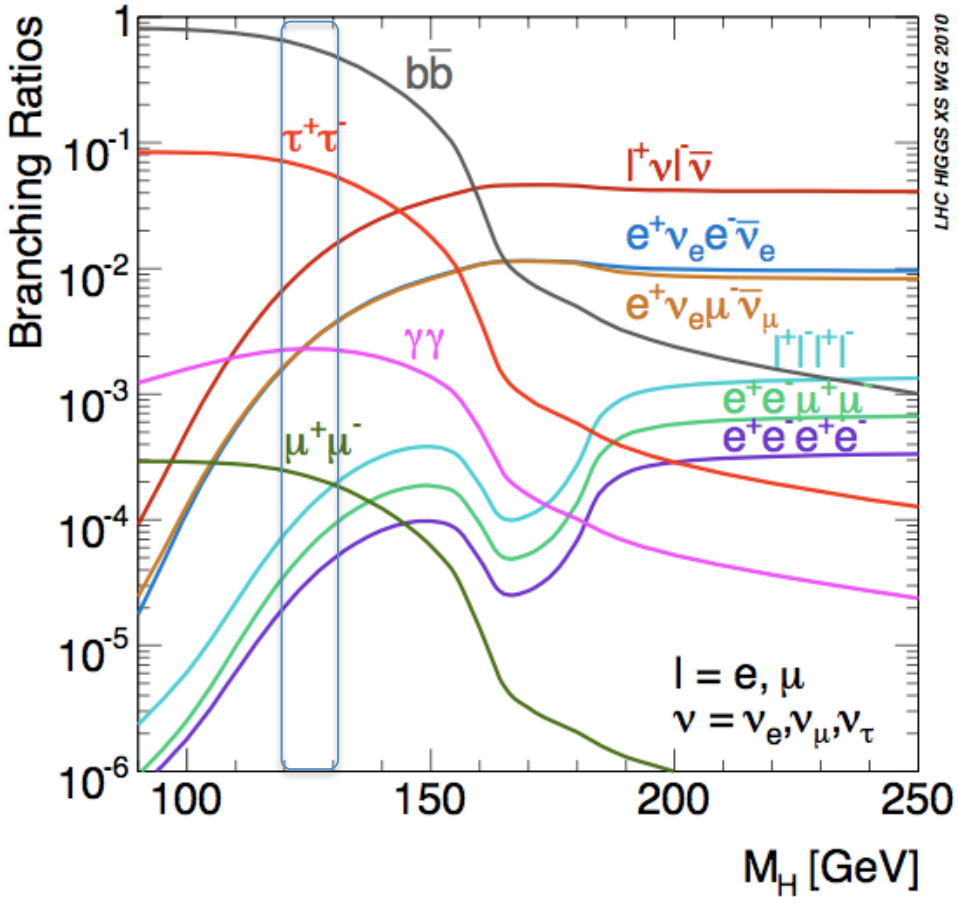
Eur. Phys. J. C (2012) 72:2244

Higgs rare decays:

for m_H = 125.5 GeV everything below
predicted BR(H^0->$\gamma\gamma$):
2.28 ± 0.11 * 10^{-3}

- BR(H^0->$Z^0\gamma$): 1.58± 0.14 * 10^{-3}
- BR(H^0->$\mu^+\mu^-$): 2.17± 0.13 * 10^{-4}
- BR(H^0->e^+e^-): ≈5 * 10^{-9}





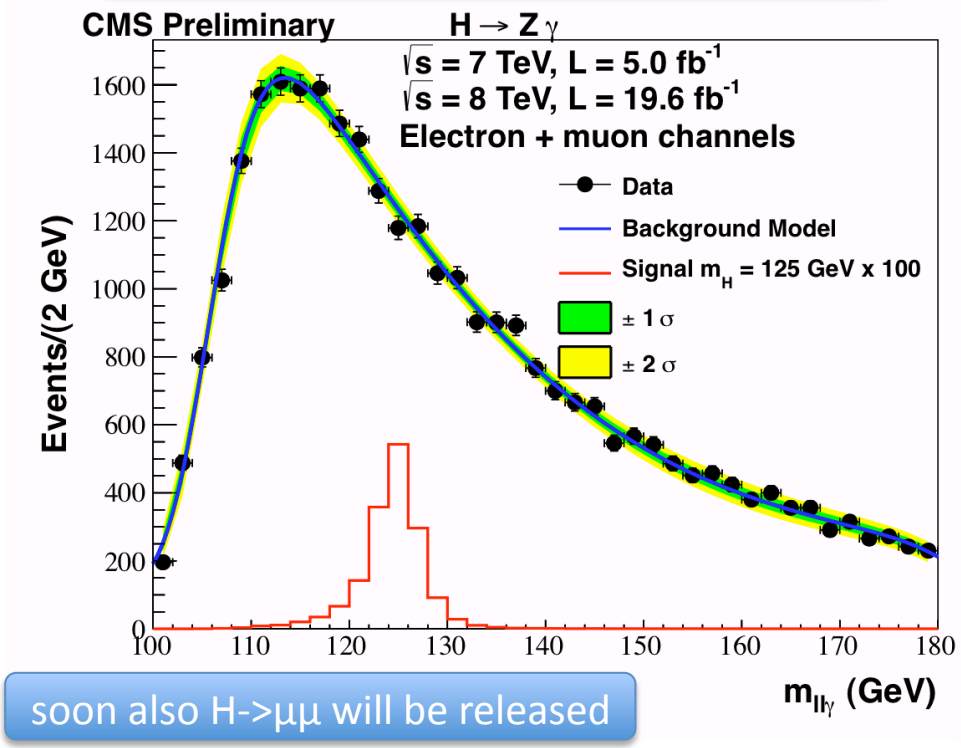
more details at https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CERNYellowReportPageBR2

Higgs rare decays: $Z^0\gamma$

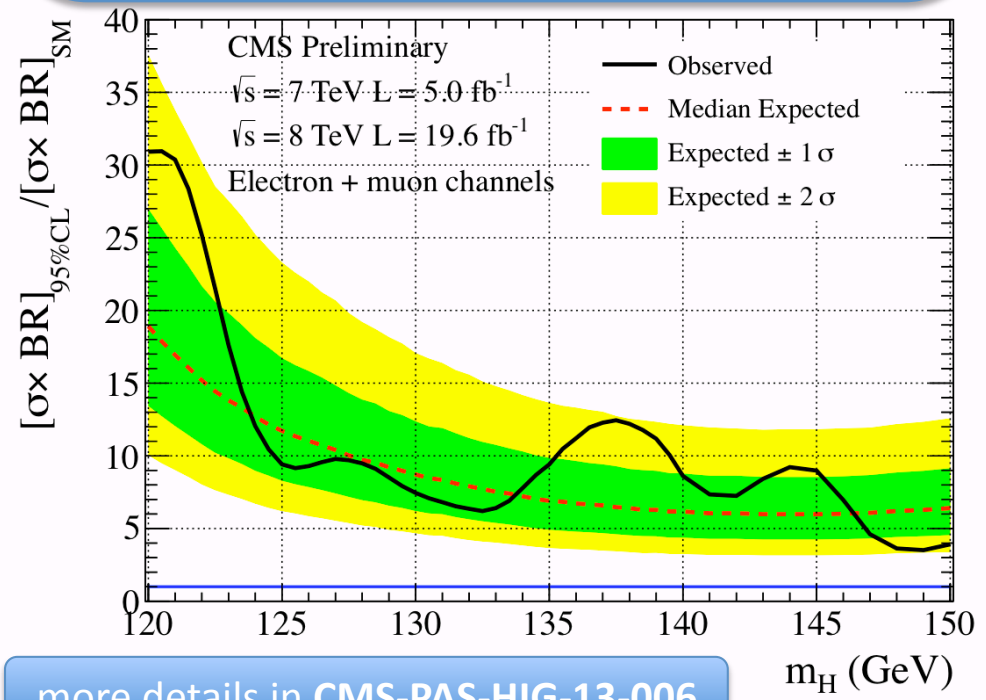
selection:
- dilepton triggers
- two opposite charge, same flavor and isolated leptons with $p_T > 20$ (10) GeV and $|\eta|<2.4$ (2.5) for μ (e)
- isolated photon $p_T > 15$ GeV & $|\eta|<2.5$

event classes:
- both leptons and γ in barrel region:
  - c1: high R_9 (best S/B)
  - c2: low R_9

  with R_9: ΣE of 3x3 ECAL crystals around most energetic one
- c3: one lepton in endcap, γ in barrel region
- c4: both leptons and γ in endcap region



soon also H->μμ will be released



more details in **CMS-PAS-HIG-13-006**

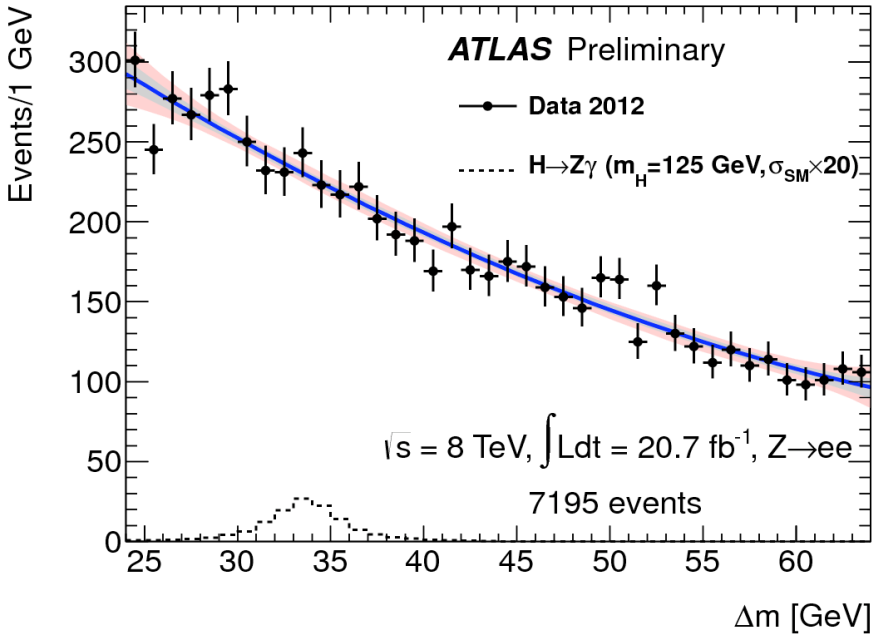
Higgs rare decays: $Z^0\gamma$

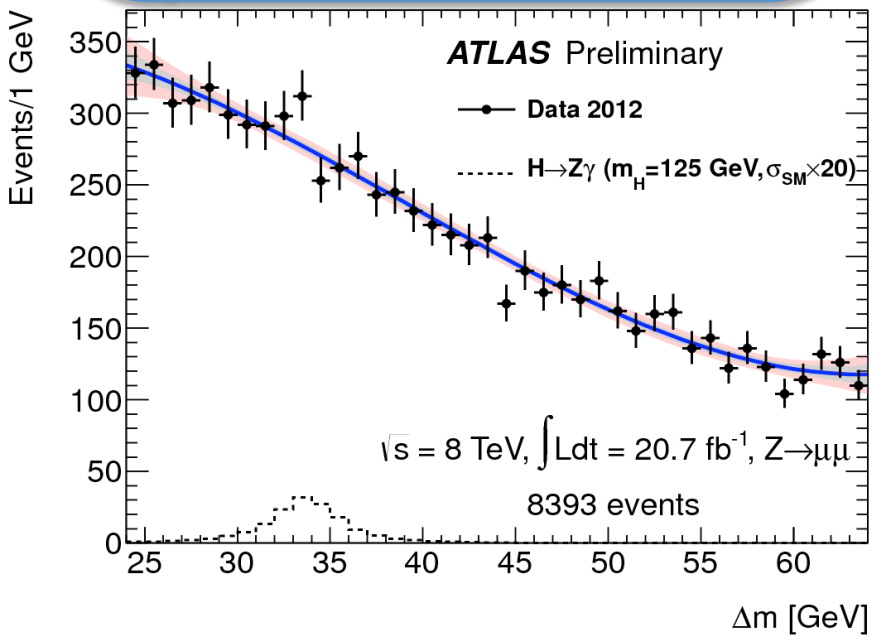
event selection:

- single- or double-lepton triggers
  - efficiency: 99% eeγ and 92% μμγ
  (reduced geometric acceptance for muon triggers $|\eta| < 1.05$)

- muons:
  $p_T > 10$ GeV and $|\eta| < 2.7$ spectrometer
  $p_T > 15$ GeV and $|\eta| < 0.1$ calorimeters

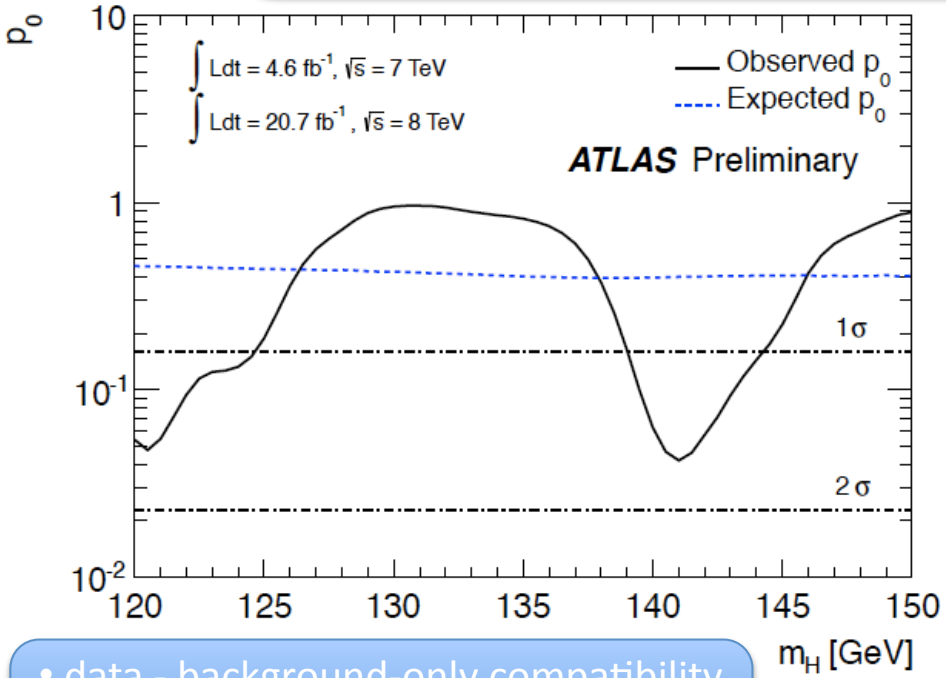
- electrons:
  $p_T > 10$ GeV and $|\eta| < 2.47$
- photon:
  $E_T > 15$ GeV and
  $|\eta| < 1.37$ or $1.52 < |\eta| < 2.37$
  $\Delta R > 0.3$ with respect to e and μ
- $m_{ll\gamma}$ corrections:
  - η^γ & E_T^γ recalculated from PV and γ impact point in the calorimeter
  - m_Z constraint kinematic fit

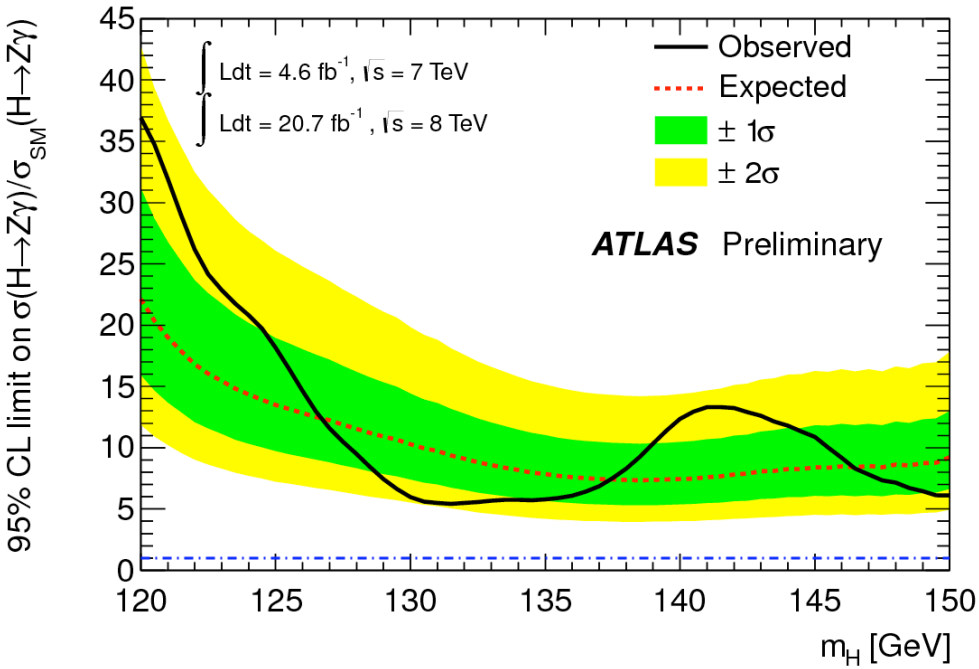




Higgs rare decays: $Z^0\gamma$

- expected p_0 between 0.40 and 0.46 for $120 < m_H < 150$ GeV (≈0.25 σ)
  - p_0 = 0.443 (0.14 σ) for m_H = 125 GeV
- observed p_0 compatible with background only:
  - smallest p_0: 0.042 (1.61 σ) for a mass of 141 GeV.
  - p_0 = 0.188 (0.89 σ) for m_H = 125 GeV
- expected and observed limits for m_H = 125 GeV: 13.5 and 18.2 x SM





- data - background-only compatibility hypothesis quantified by *p*-value of μ = 0 hypothesis: p_0

more details in **ATLAS-CONF-2013-009**

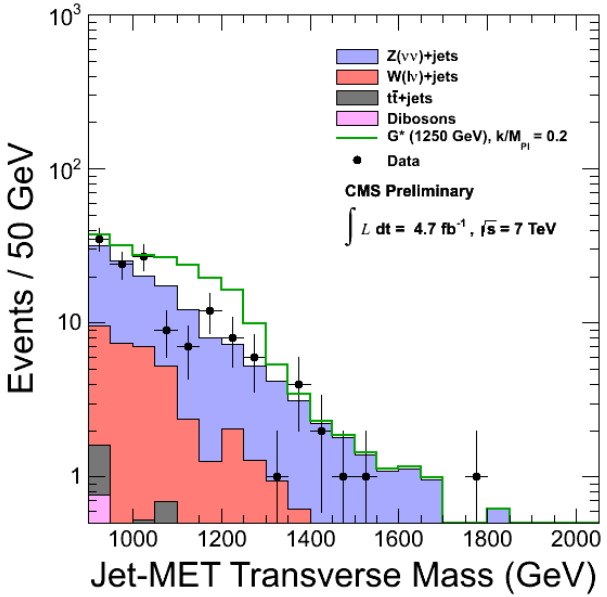
CMS from exotic searches: Graviton

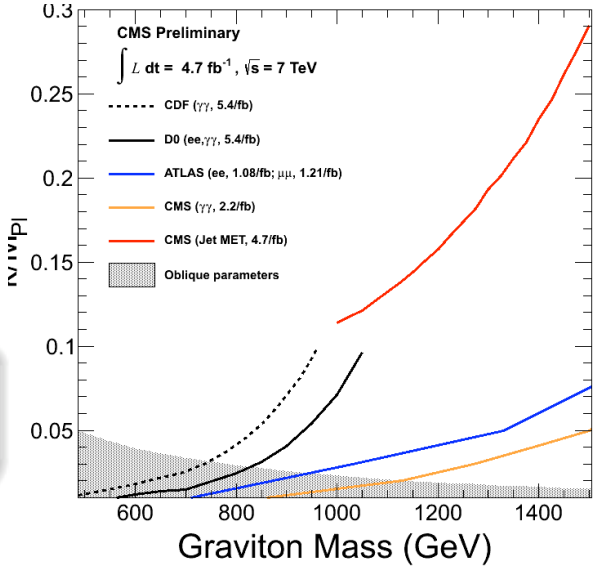
- Models:
  - graviton propagates in the extra dimension, leading to a Kaluza-Klein tower of states
  - parameters: M_G and k/M_{Pl} (ratio of the 5d curvature to reduced Plack mass)
- final state:
  $G^* \rightarrow Z^0 Z^0 \rightarrow q\bar{q}\nu\bar{\nu}$
  $M_T^G = \sqrt{2 p_T^{jet} E_T^{miss} (1 - \cos\Delta\varphi(jet, E_T^{miss}))}$
- Background Contributions:
  - $Z^0 + nq \rightarrow \nu\bar{\nu} + njets$, $W + nq \rightarrow \ell\nu + njets$
  - $t\bar{t}$, WW, WZ, ZZ

- Event Selection:
  - only 2 jets with $\Delta\varphi > 2.8$ (veto QCD)
  - leading jet $p_T > 200$ GeV/c and $m_j > 70$ GeV/c^2
  - $E_T^{miss} > 300$ GeV and $M_T^G > 900$ GeV/c^2
  - veto on isolated e or μ (veto $W \rightarrow \ell\nu$)

Limits at 95% C.L. for $M_G \in (1000; 1500)$ GeV/c^2

- σ in range 0.047 to 0.021 pb; k/M_{Pl} in range 0.11 to 0.29



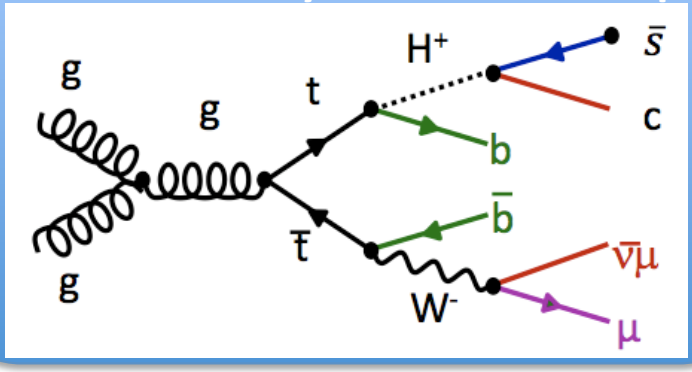


• similar analysis is now performed in CMS, but with: G*->H^0H^0-> bb γγ - soon results to be released

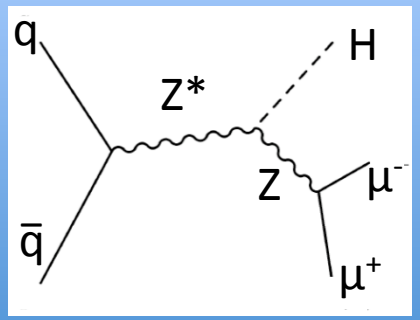
more details in **CMS PAS** EXO-11-061

going for even more exotic

$H^+ \rightarrow c\bar{s}$:
dominant decay channel for tan β <1



ZH with H inv.

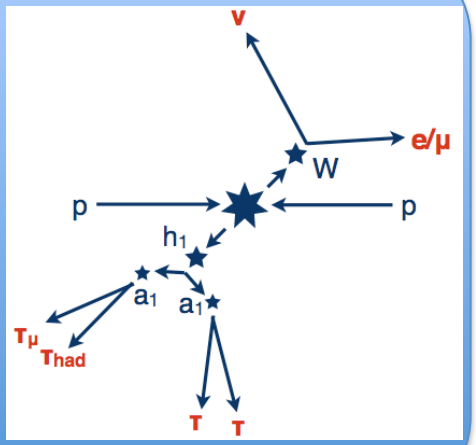


- Higgs decaying to Dark Matter candidates
- MSSM h^0 decaying to LSP
- extra-dimension Higgs decaying to neutrinos

dedicated new group in CMS:
Higgs Exotic
- Radion/Graviton→hh→γγbb
- h→μτ and h→eτ (LFV)
- heavy H→hh
- VBF with H inv.
- …

NMSSM: $h \rightarrow a_1 a_1 \rightarrow \tau_\mu \tau_h + X$

- τ_h reconstruction to be re-thought due to the boost from a_1
- together with final state topologies as 4τ, 2τ2b and 4γ will complete the NMSSM picture



"summary over view out look"

- short overview of MSSM
- NMSSM searches for:
- $a_1 \to \mu^+\mu^-$
- $h_{1,2} \to a_1 a_1 \to 4\mu$
- $h_{1,2} \to a_1 a_1 \to 4\gamma$
- dark SUSY:
- $h_{1,2} \to 2n_1 \to 2\gamma_D\, 2n_D \to 4\mu\, 2n_D$
- hidden sector: e- and μ-jets
- fermiophobic model
- SM with 4^{th} generation
- minimal type II seesaw model: $\Phi^{\pm\pm}$
- Higgs boson rare decays: $Z^0\gamma$
- few more ideas

- **at the end of the day we did a good job, but not yet perfect**
- **MSSM:** we need more statistics and new channels for $\tan\beta < 10$ (even < 1) and to go away from m_h max scenario
- **NMSSM:** there is a wide campaign to try to close its phase space too, more analyses to come in the next months
- **re-adjust exotic model searches** to incorporate the discovered Higgs

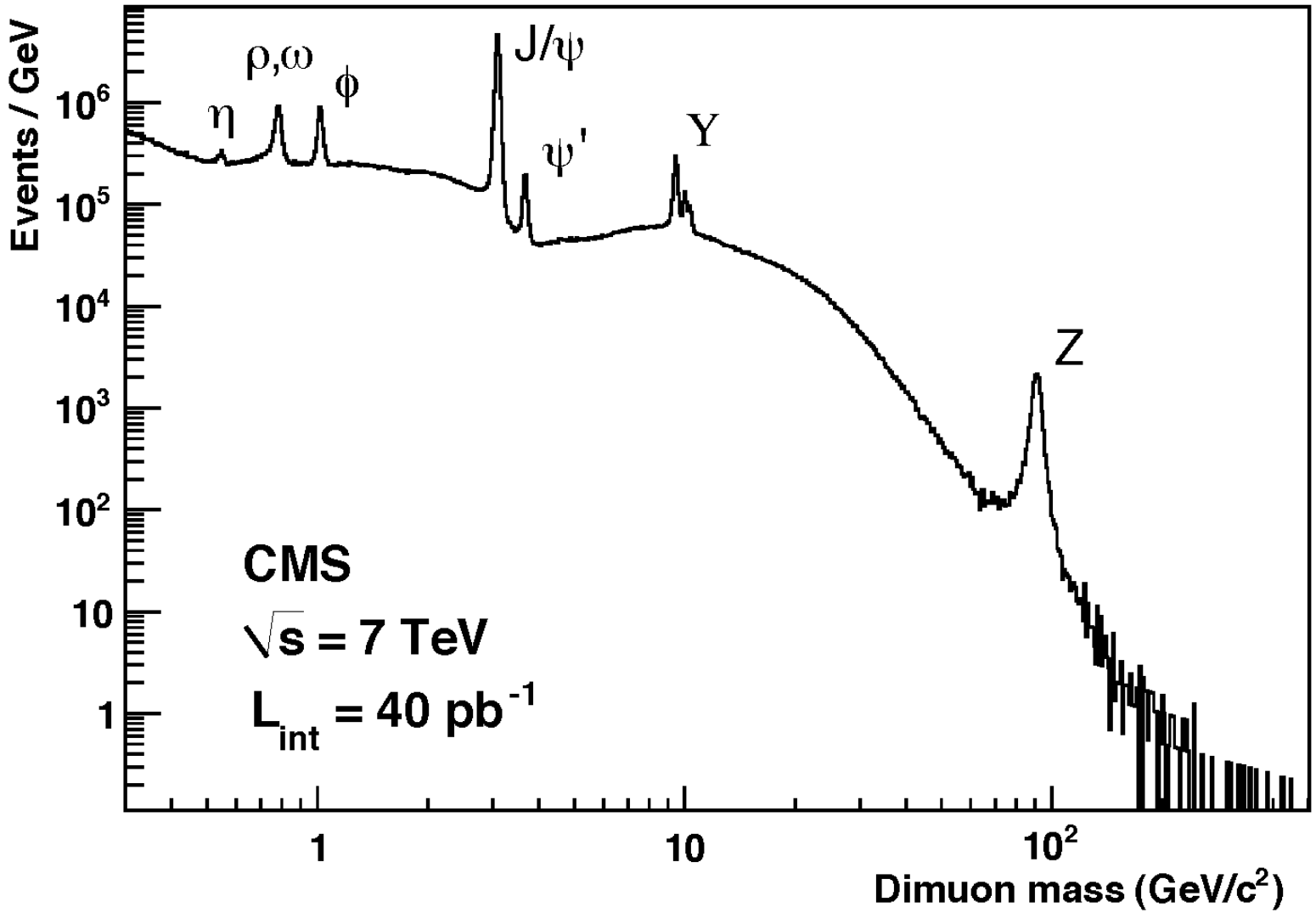
- we need to **push further the limits in the invisible spectrum** of Higgs decays, **because**

- **combination of the CMS results presented at Moriond sets limits at $0 \le BR_{BSM} \le 0.64$ at 95% C.L (CMS)**
- **SM expectation on 95% CL contour of best data fit in signal strength plane (ATLAS)**

as long as there is a corner not looked at, we don't give up!

back-up

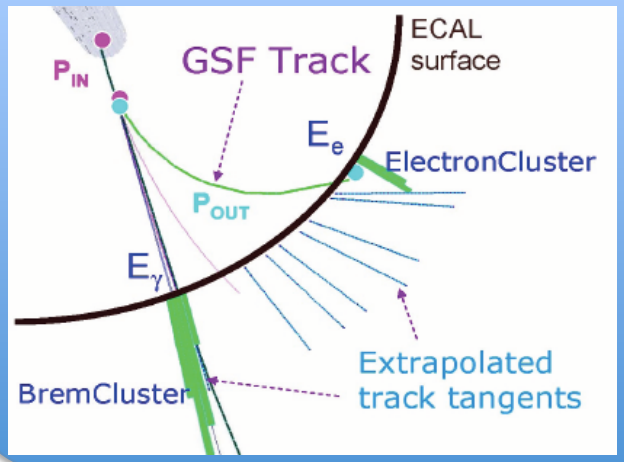
dimuon spectrum



we can reconstruct dimuon resonances from η to Z and beyond…

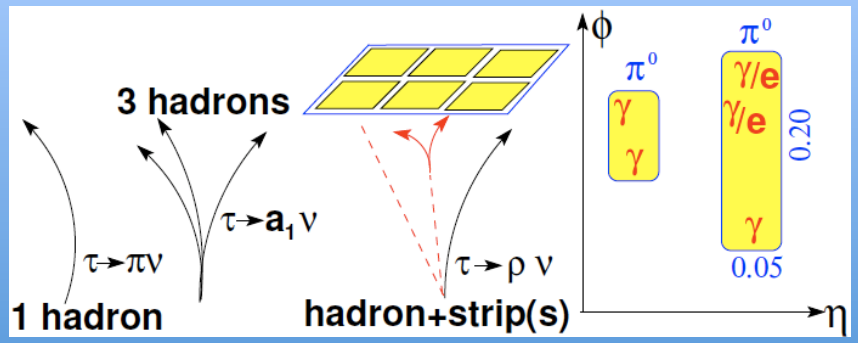
physics objects: e, τ, jets and E_T^{miss}

electron



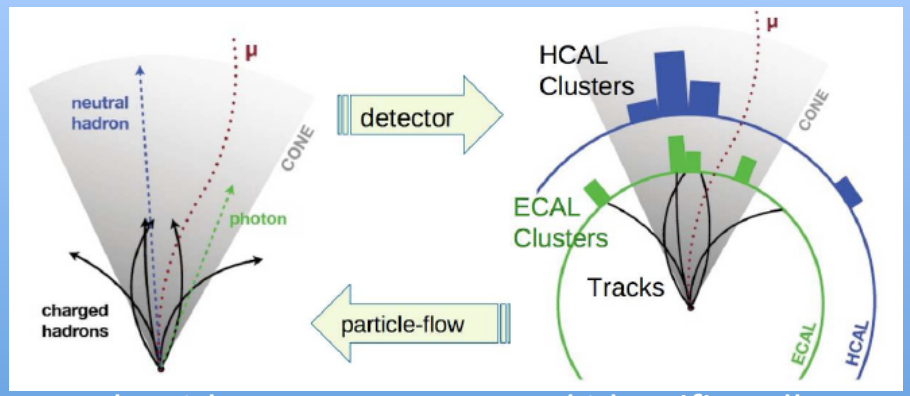
- Gauss Sum Function
- **coverage:** $|\eta| < 1.442$ & $1.556 < |\eta| < 2.5$
- **energy resolution:** $3\%/\sqrt{E\ /\mathrm{GeV}}$

τ lepton: hadronic decays

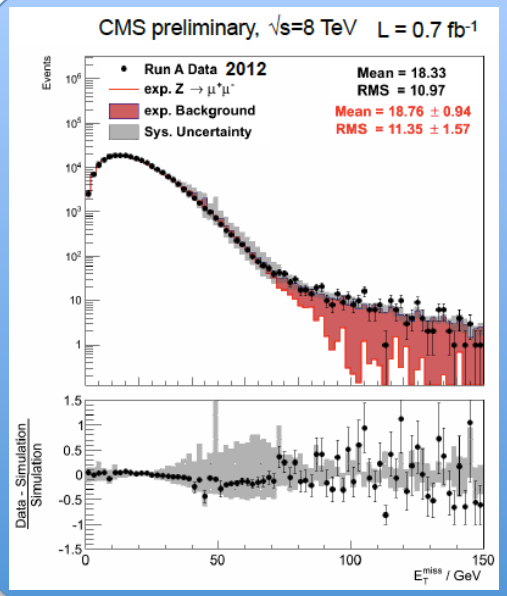


- **coverage:** $|\eta| < 2.3$
- **energy scale:** < 3 %

Particle Flow Jets in CMS:



- PF algorithm reconstructs and identifies all stable particles within the detector
- builds jets with the *anti*-k_T alg. which are infrared & collinear safe



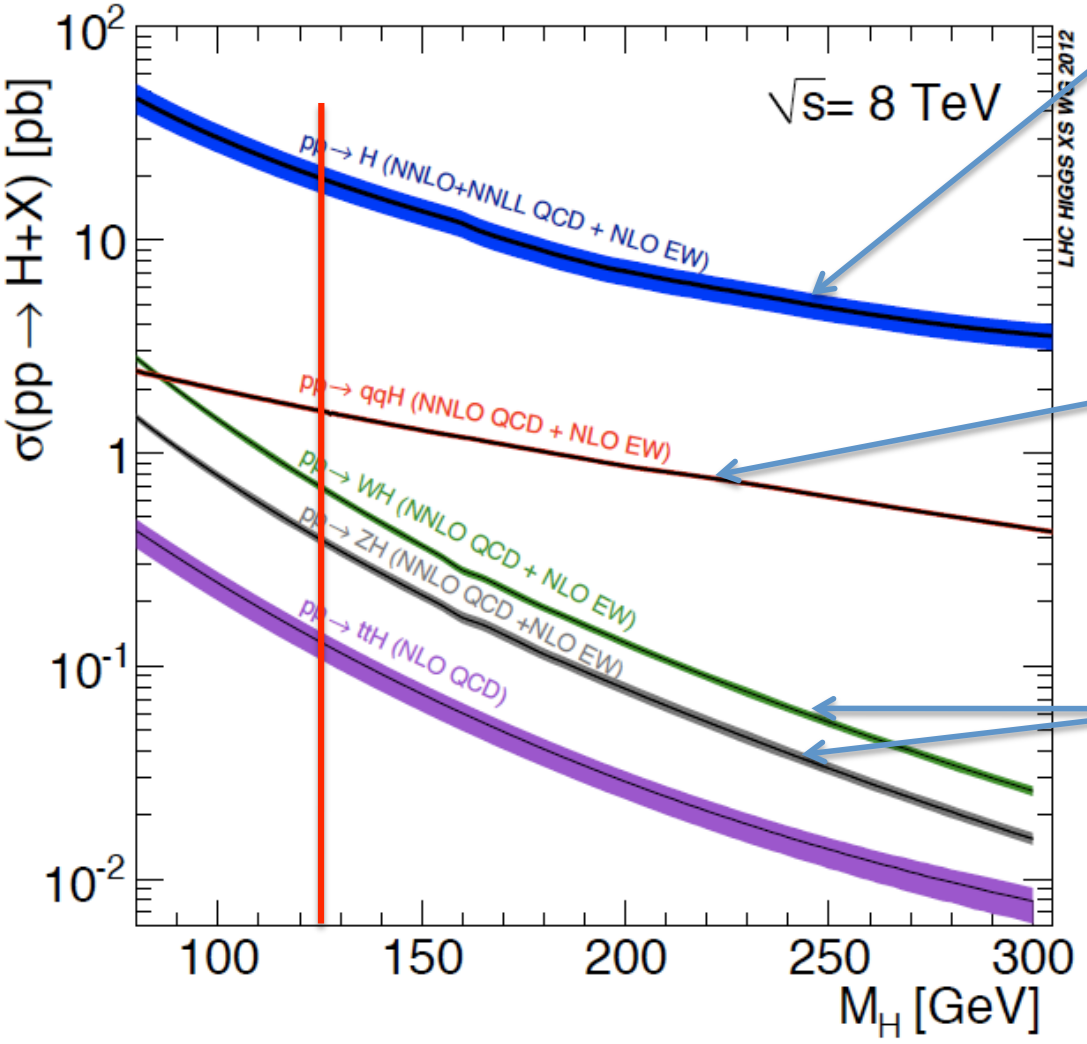
Missing Energy in Transverse plane

E_T^{miss}

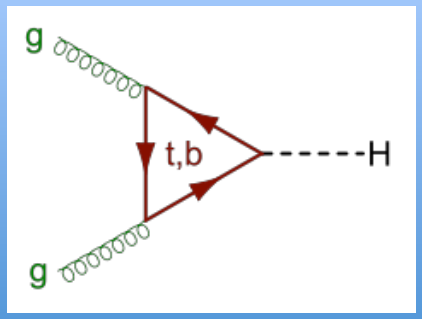
- **in CMS:** negative vector sum of all particle candidates reconstructed with the PF algorithm

SM production channels

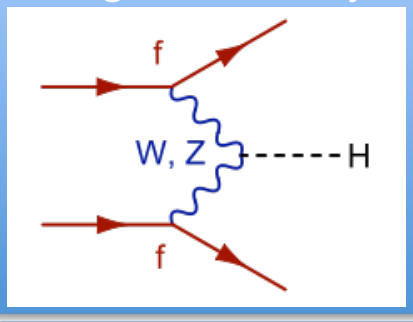
• cross-section expectations for $\sqrt{s}$ = 8 TeV



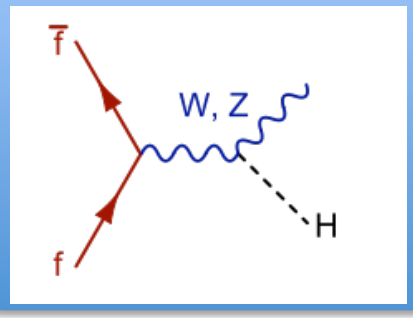
• gluon-gluon fusion



• VBF production
(2 energetic forward jets)



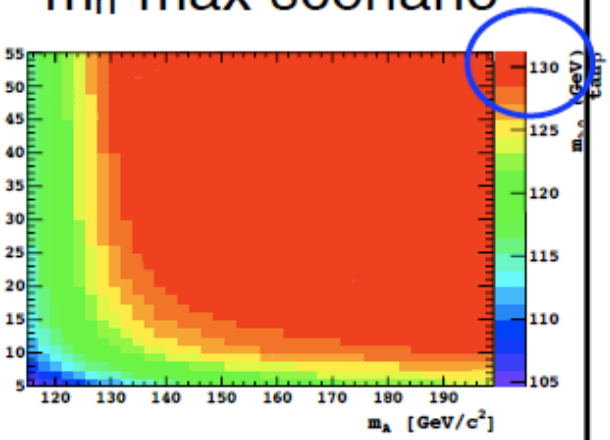
• associated production
(additional W or Z boson)



produced with FeynHiggs

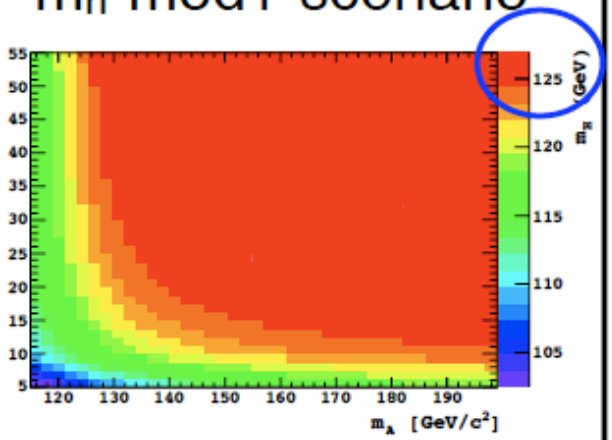
MSSM modified scenarios

m_h-max scenario



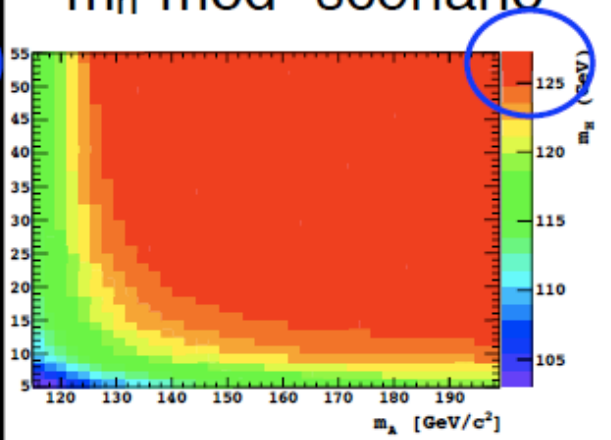
$$
\begin{aligned}
m_t &= 173.2 \text{ GeV}, \\
M_{\text{SUSY}} &= 1000 \text{ GeV}, \\
\mu &= 200 \text{ GeV}, \\
M_2 &= 200 \text{ GeV}, \\
X_t^{\text{OS}} &= 2\, M_{\text{SUSY}} \text{ (FD calculation)}, \\
X_t^{\overline{\text{MS}}} &= \sqrt{6}\, M_{\text{SUSY}} \text{ (RG calculation)}, \\
A_b &= A_t = A_t, \\
m_{\tilde{g}} &= 1500 \text{ GeV}, \\
M_{\tilde{l}_3} &= 1000 \text{ GeV} .
\end{aligned}
$$

m_h-mod+ scenario



$$
\begin{aligned}
m_t &= 173.2 \text{ GeV}, \\
M_{\text{SUSY}} &= 1000 \text{ GeV}, \\
\mu &= 200 \text{ GeV}, \\
M_2 &= 200 \text{ GeV}, \\
X_t^{\text{OS}} &= 1.5\, M_{\text{SUSY}} \text{ (FD calculation)}, \\
X_t^{\overline{\text{MS}}} &= 1.6\, M_{\text{SUSY}} \text{ (RG calculation)}, \\
A_b &= A_t = A_t, \\
m_{\tilde{g}} &= 1500 \text{ GeV}, \\
M_{\tilde{l}_3} &= 1000 \text{ GeV} .
\end{aligned}
$$

m_h-mod- scenario



$$
\begin{aligned}
m_t &= 173.2 \text{ GeV}, \\
M_{\text{SUSY}} &= 1000 \text{ GeV}, \\
\mu &= 200 \text{ GeV}, \\
M_2 &= 200 \text{ GeV}, \\
X_t^{\text{OS}} &= -1.9\, M_{\text{SUSY}} \text{ (FD calculation)}, \\
X_t^{\overline{\text{MS}}} &= -2.2\, M_{\text{SUSY}} \text{ (RG calculation)}, \\
A_b &= A_t = A_t, \\
m_{\tilde{g}} &= 1500 \text{ GeV}, \\
M_{\tilde{l}_3} &= 1000 \text{ GeV} .
\end{aligned}
$$

Gianni Masetti

M. Carena *et al.* http://arxiv.org/pdf/1302.7033v1.pdf