CMS measurements of the Higgs, Higgs properties, and BSM searches

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On behalf of the CMS Collaboration

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SantaFeJHF2017:
Santa Fe Jets and Heavy Flavor workshop 2017

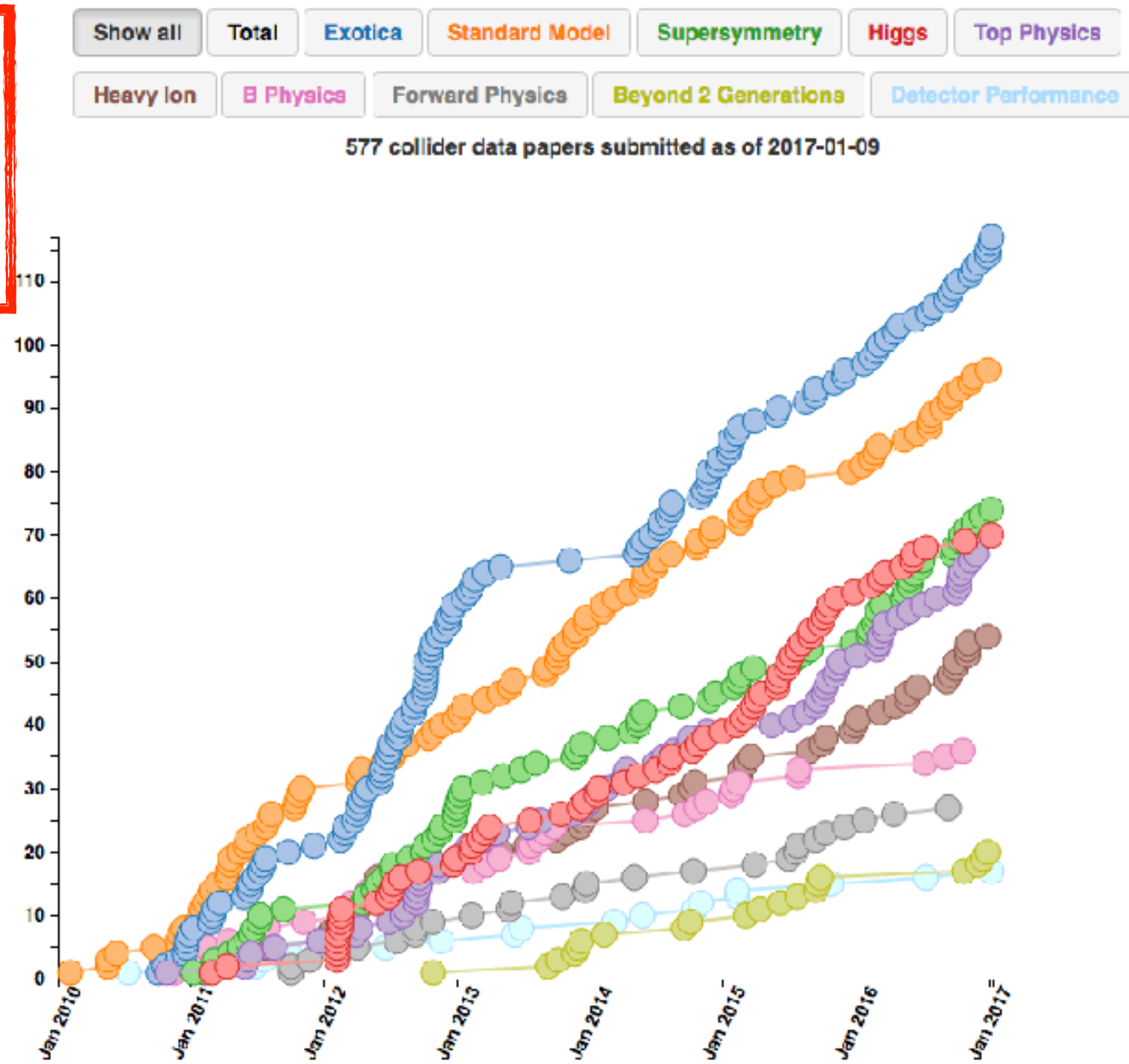
The Large Hadron Collider

- LHC accelerates protons and make them collide at 13 TeV in the center of mass energy

An incredible success

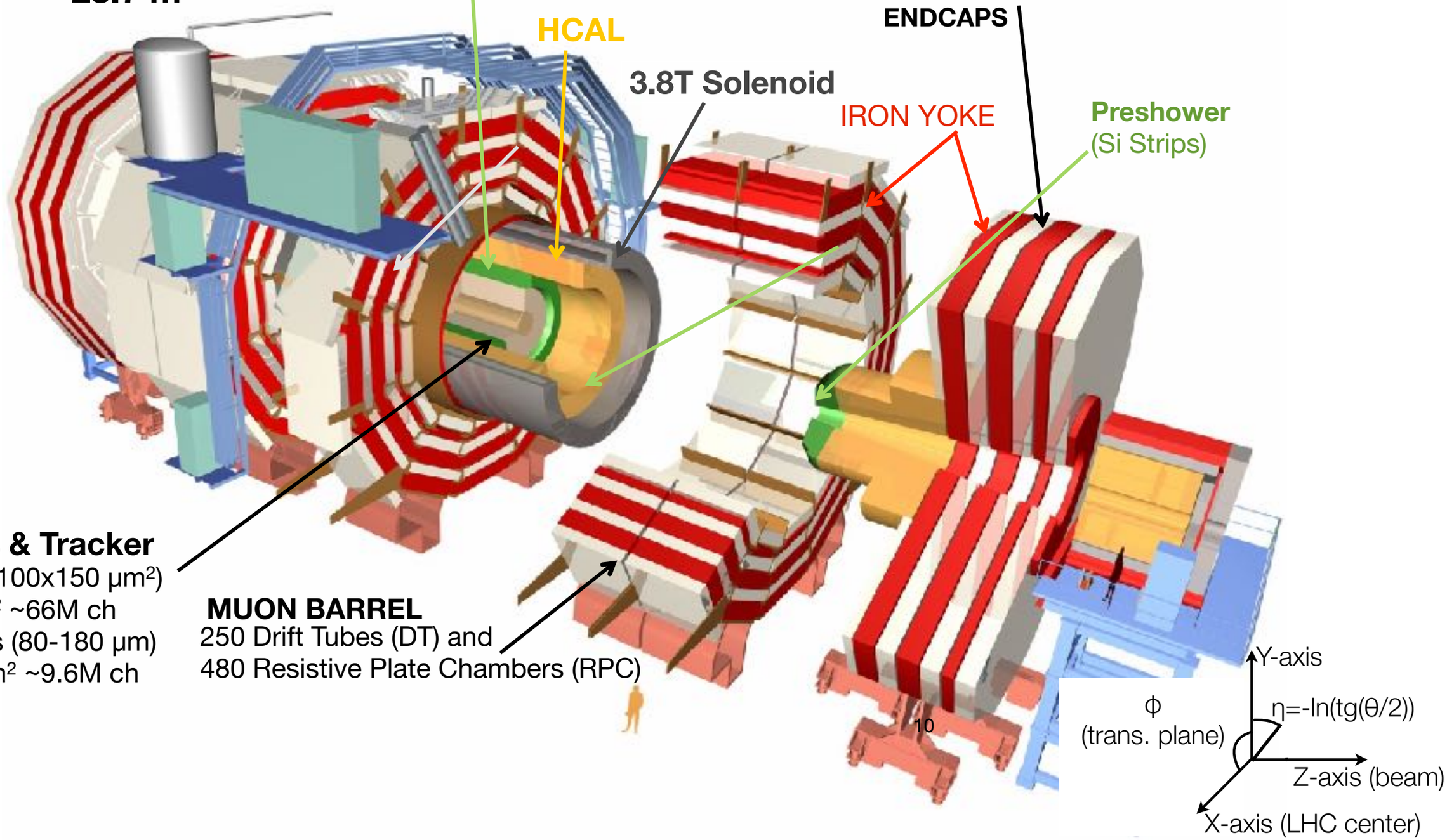
- Almost 600 total publications!
  - → More than 70 on the Higgs
  - → More than 110 on Exotica
  - → More than 20 on 2nd generation searches

- I will try to cover recent results in these topics:
  - → Higgs mass and properties
  - → Extending the Higgs Sector
  - → Dark Matter
  - → Leptoquarks
  - → Gravitons
  - → Long Lived particles
  - → 2nd Generation searches



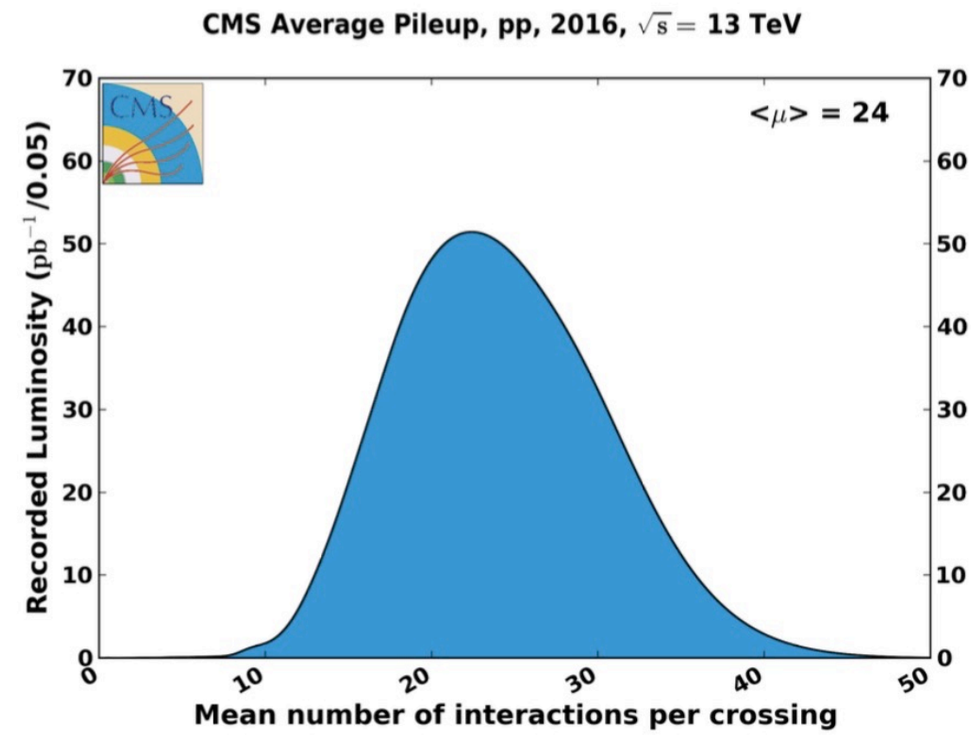
The Compact Muon Solenoid

Total weight	**14000 t**
Diameter	**15 m**
Length	**28.7 m**

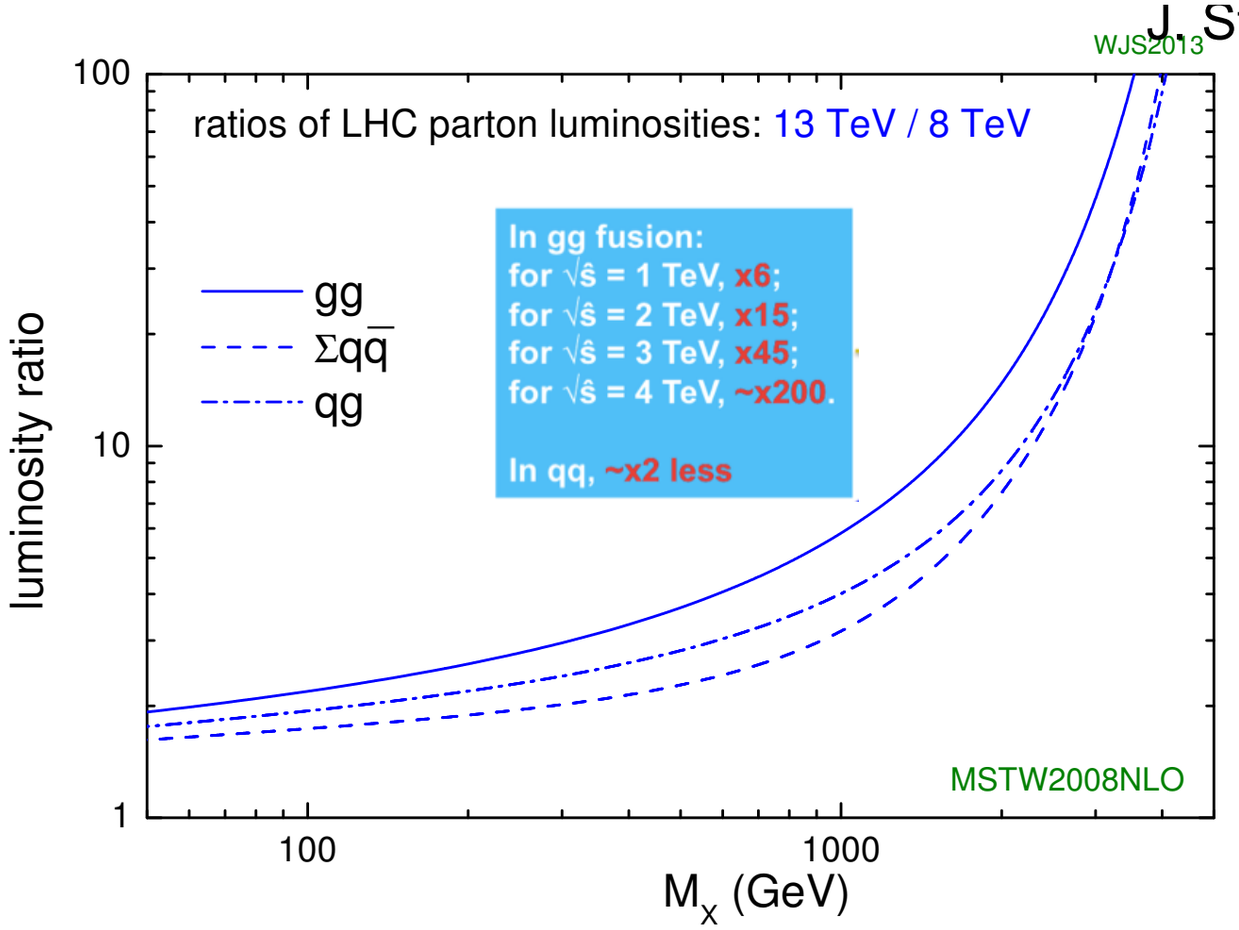


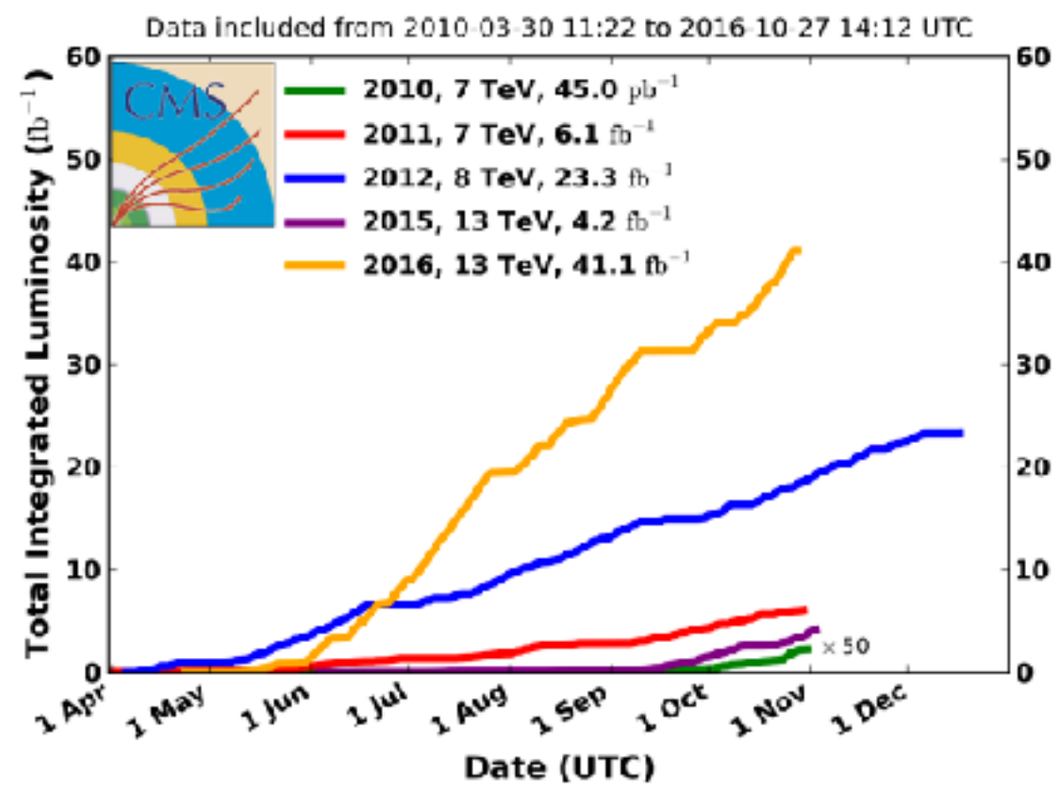
Run II Performance

- Thanks to LHC: 40 fb^{-1} data on 2016
  - → 20 fb^{-1} more than expected
  - → 13 fb^{-1} used for recent public results
  - → Average pileup ~24
- Advantageous ratios of LHC parton luminosities!!



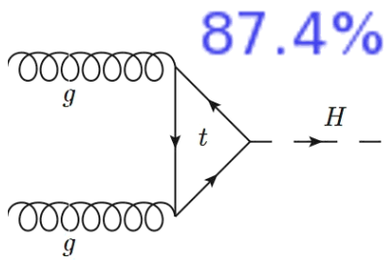
J. Stirling



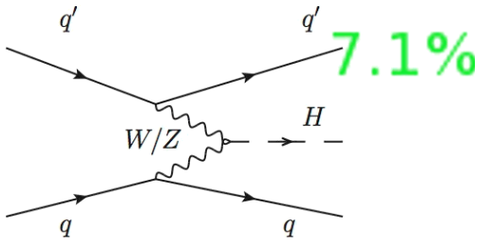


Higgs: Mass and Properties

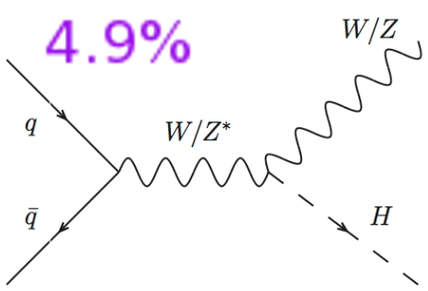
	ggF	VBF	VH	ttH	tH
H→γγ	ATLAS CMS	ATLAS CMS	ATLAS CMS	ATLAS CMS	
H→ZZ	ATLAS CMS	ATLAS CMS	ATLAS CMS	ATLAS CMS	
H→WW	ATLAS CMS	ATLAS CMS	ATLAS CMS	ATLAS CMS	
H→ττ	ATLAS CMS	ATLAS CMS		ATLAS CMS	
H→bb		ATLAS CMS	ATLAS CMS	ATLAS CMS	CMS
H→Zγ	ATLAS CMS	ATLAS CMS			
H→μμ	ATLAS CMS	ATLAS CMS			



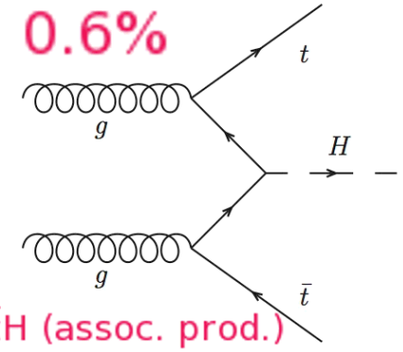
ggH (gluon fusion)



VBF (vector-boson fusion)



VH (assoc. prod.)



$t\bar{t}H$ (assoc. prod.)

= Discovery

ATLAS CMS = Run II analysis

Higgs during Run I

- Run I provided data for discovery and first property measurement
- ATLAS and CMS combined 7 and 8 TeV results in Run1 legacy papers
- Mass measured at 0.2% precision
  → m_H=125.09 ± 0.24 GeV
- Small tension among individual channels
- Angular distribution:
  $J^{PC} = 0^{++}$
- Coupling compatible with SM Higgs

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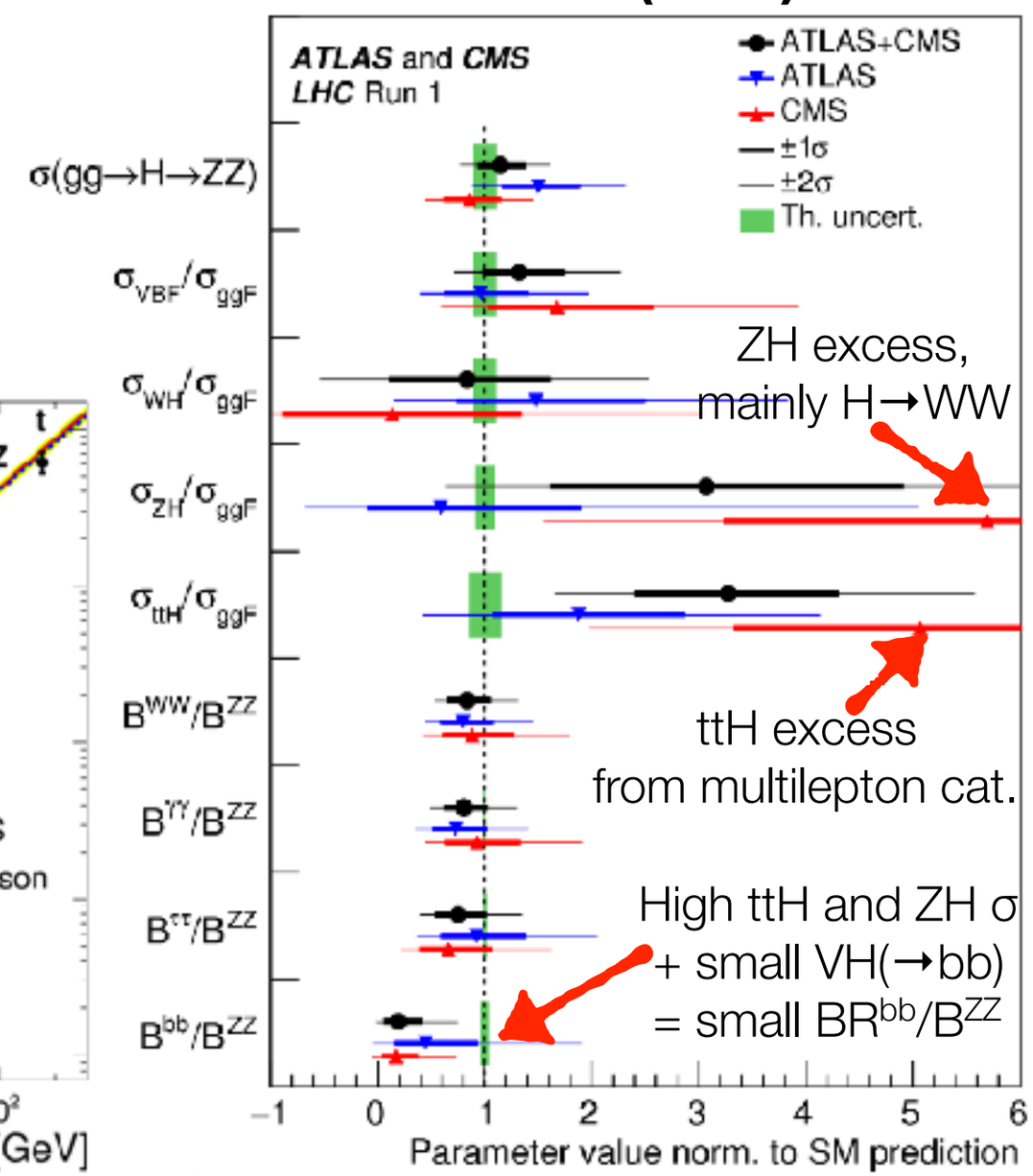

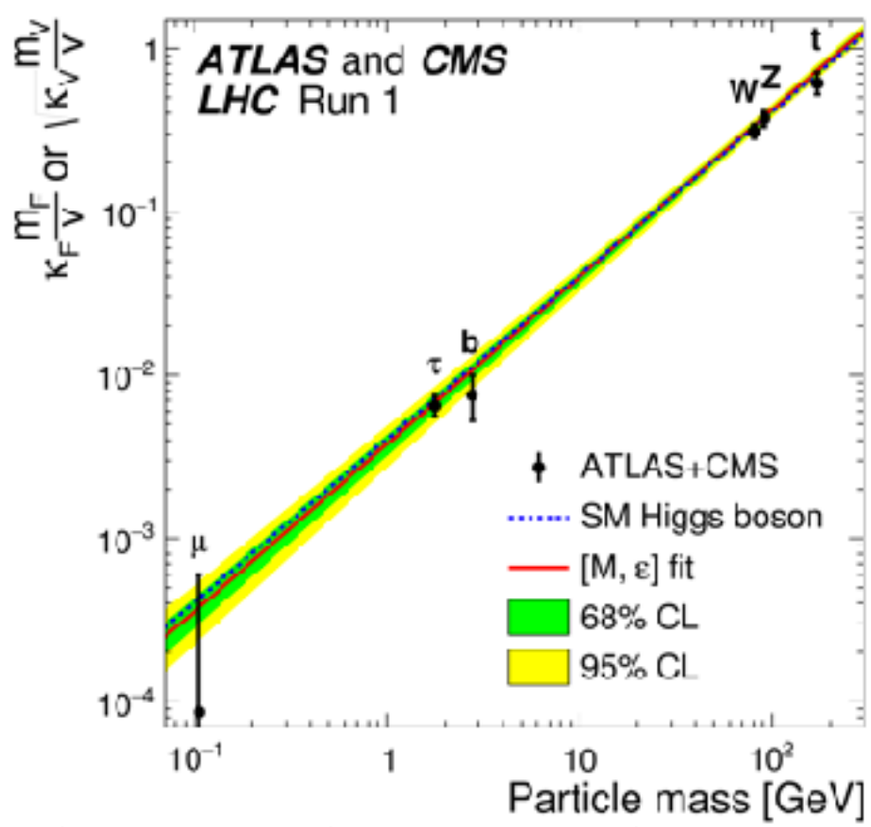

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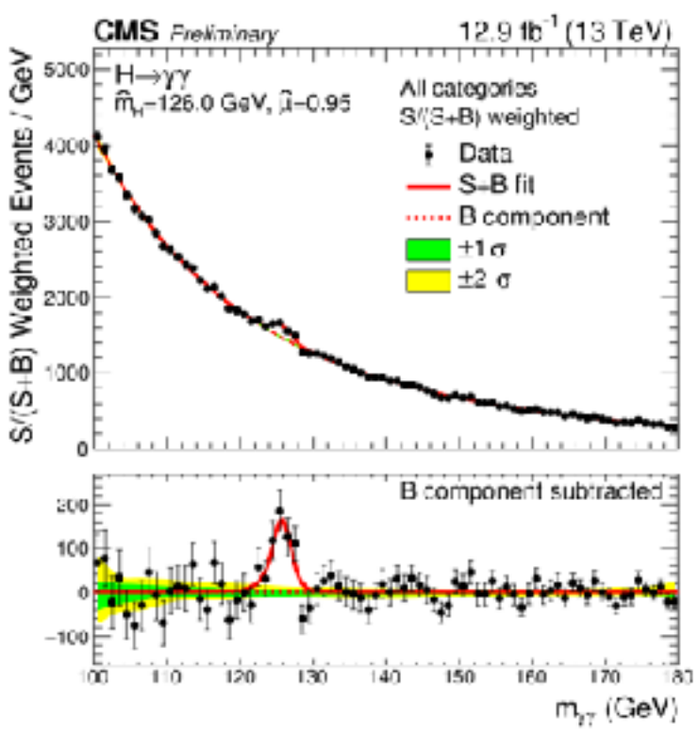
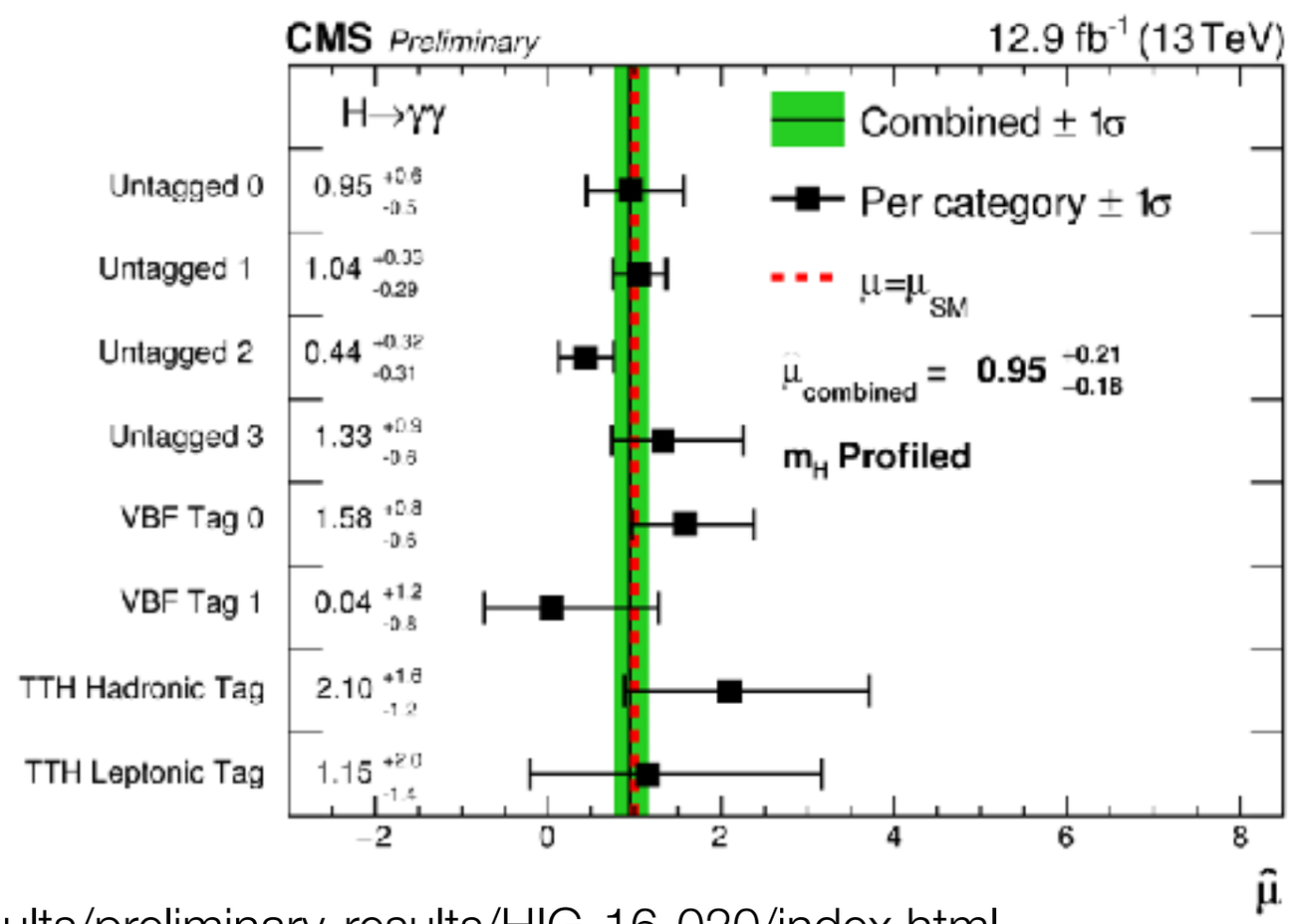
H → γγ

- Clean reconstruction compensate low production
- Interaction point known better than 1 cm → resolution dominated by ECAL
- Large irreducible background… events smartly classified
  → Eight categories to separate categories (VBF/ttH/untagged) and using BDT output
- BDT separate signal from γγ background (using kin. and shower shape variables)
- H → γγ observed with 6.2 σ at 13 TeV
  → μ=0.95 ± 0.20 at m_H=126 GeV





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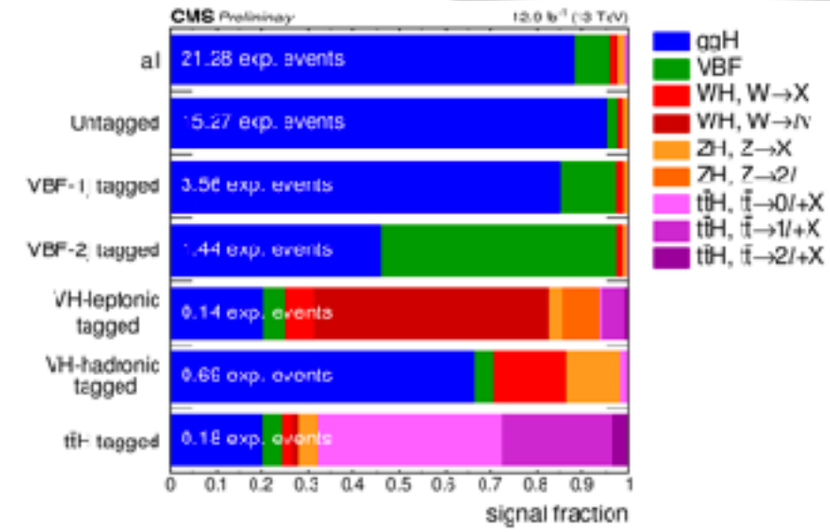
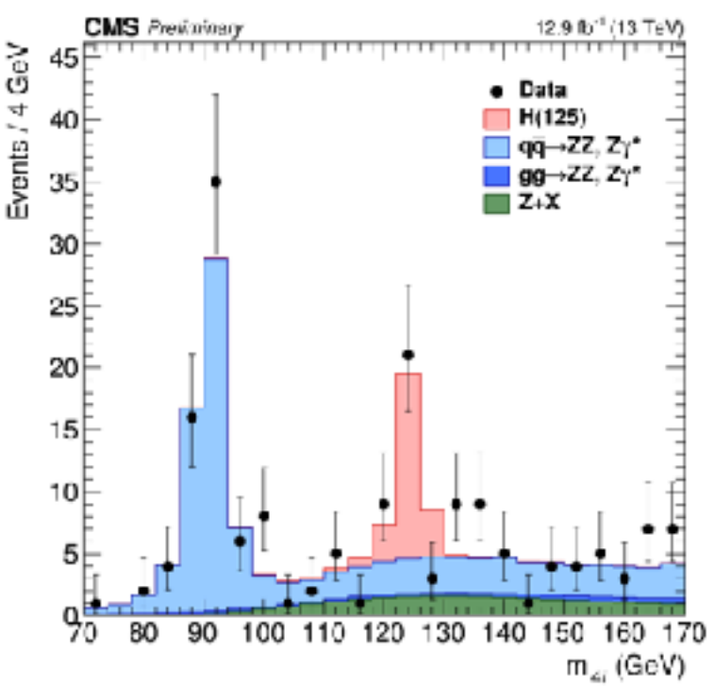
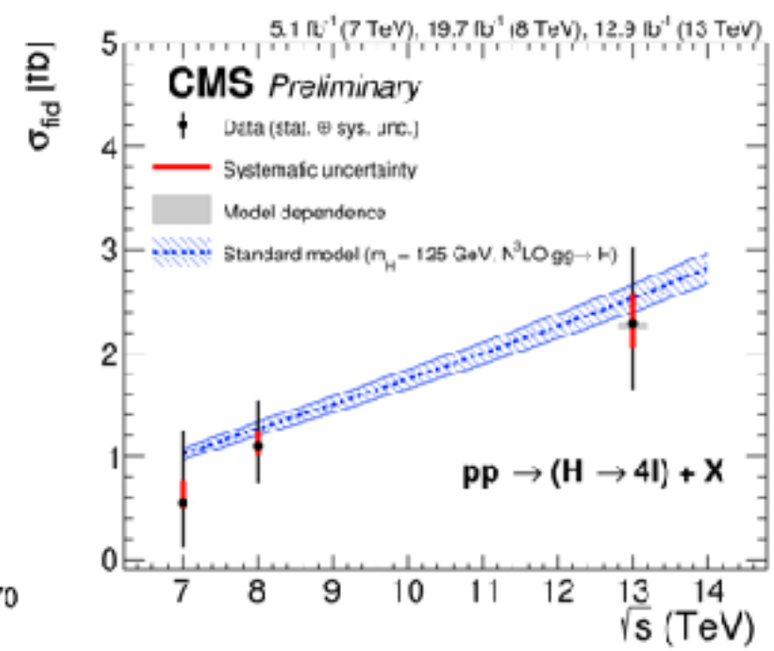
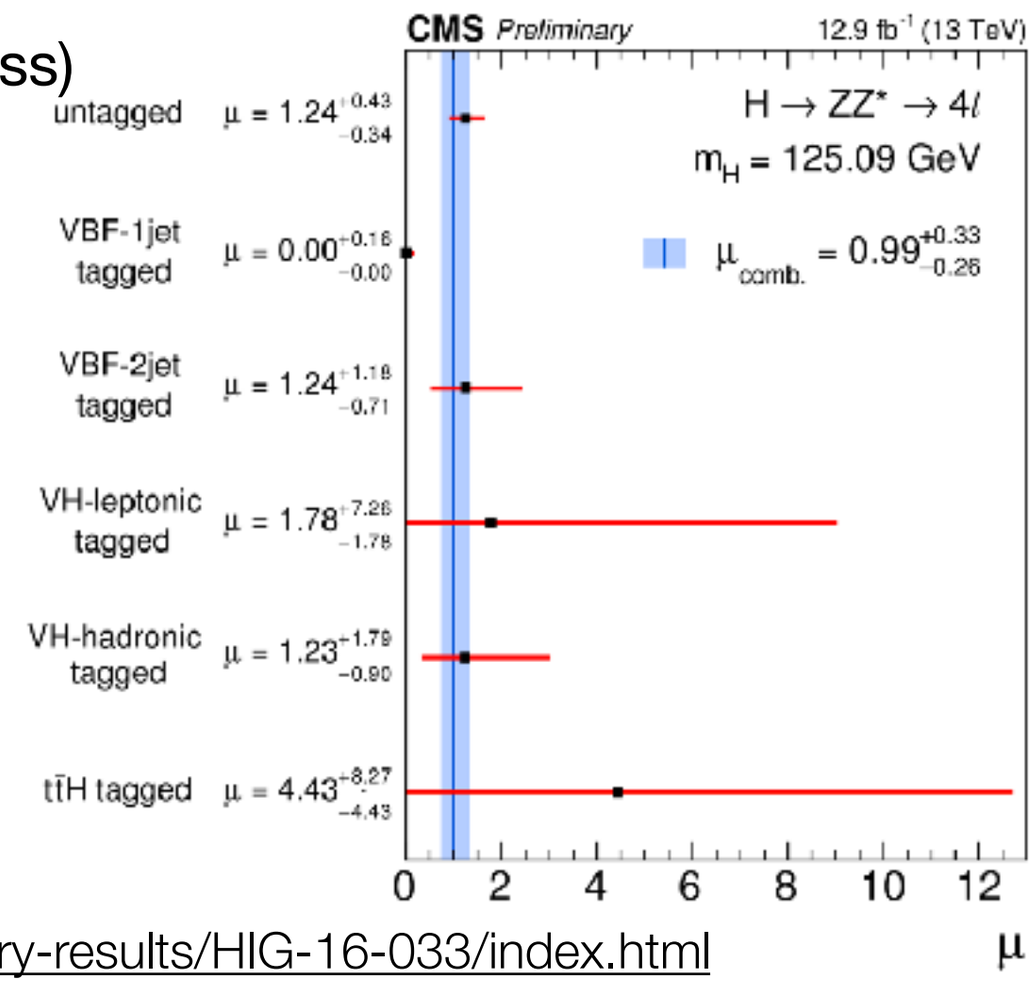
H → ZZ* → 4l

- 6 categories and 3 final states (4μ, 4e, 2e2μ)
  → Untagged, VBF_{1jet}, VBF_{2jet}, VH_{lept}, VH_{hadr}, ttH
- Signal extracted from 2D fit on the m_{4l} and the matrix element discriminant
- Obs. significance: 6.2σ (exp. 6.5σ)
  → $\mu = 0.99^{+0.33}_{-0.26}$ at m_H=125.09 GeV
  → $m_H = 124.50^{+0.48}_{-0.56}$
- High mass search up to 2.5 TeV (no significant excess)
- Width upper limit: Γ_H<41 MeV









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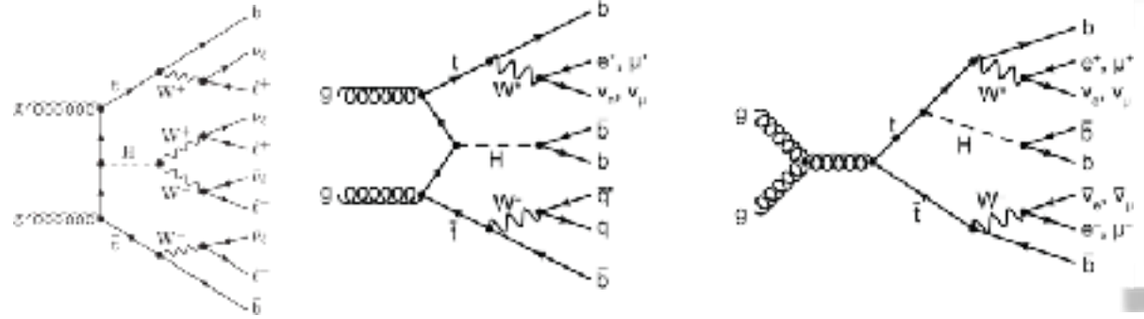
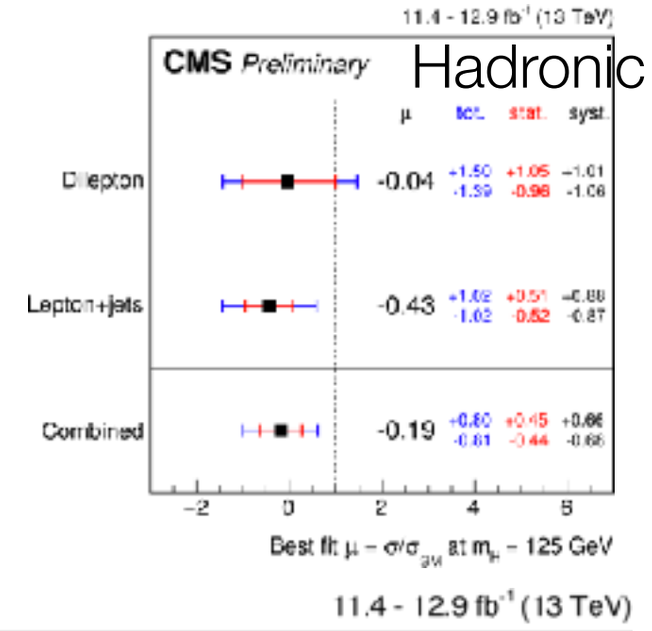
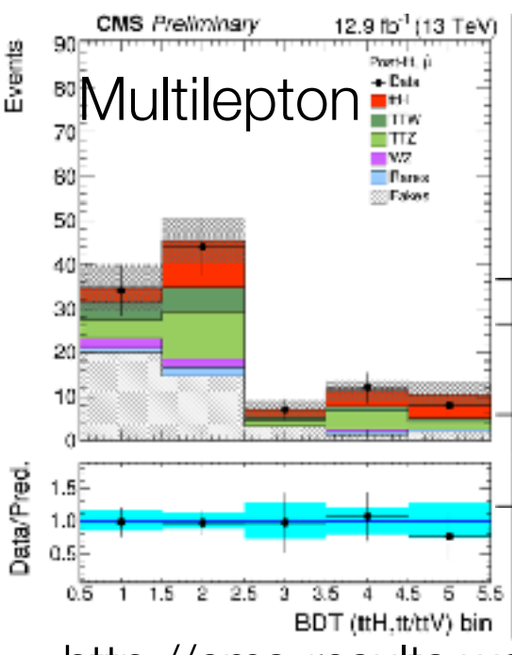
ttH



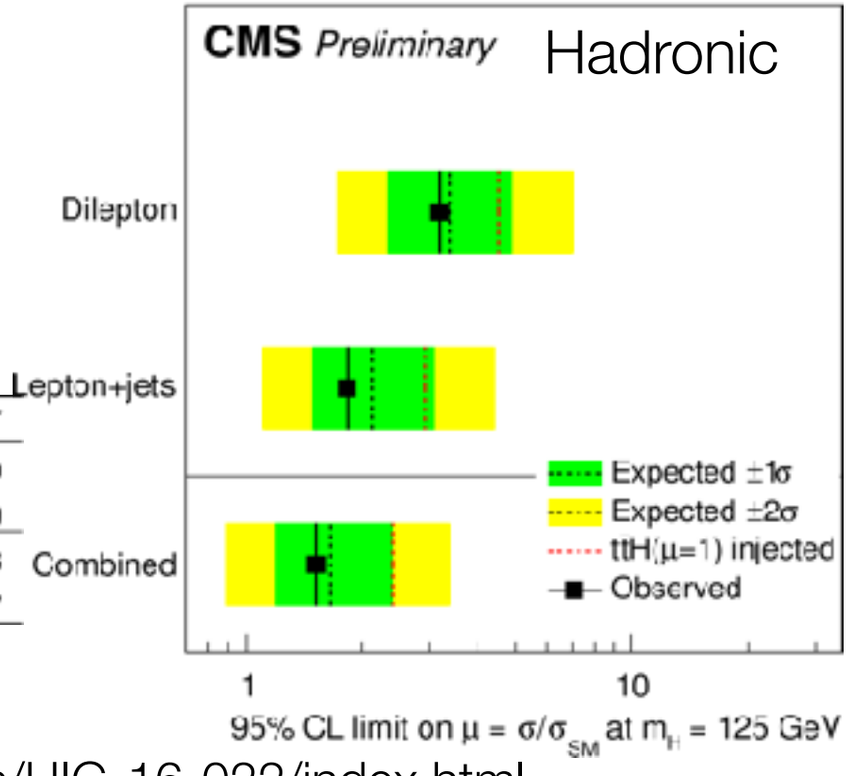
- Two analysis: multilepton and hadronic final states
  - → Multilepton: H → ZZ, WW, ττ into leptons
    (same sign di-leptons: 3 and 4 leptons channel)
    - → Observed significance (B-only): 3.2σ (exp. 1.7σ)
  - → Hadronic: tt → lvqqbb and lvlvbb
    (single lepton and di-lepton channel, sub-divided in N_{bjet})
    - → best fit of $\mu = -0.19^{+0.80}_{-0.81}$ (1.5σ from $\mu_{SM}=1$)
- b-jets from multivariate likelihood discriminant using lifetime and reconstructed secondary vertices (CSV)





Multilepton

Category	Obs. limit	Exp. limit ±1σ	Best fit μ ±1σ
Same-sign dileptons	4.6	$1.7^{+0.9}_{-0.5}$	$2.7^{+1.1}_{-1.0}$
Trileptons	3.7	$2.3^{+1.2}_{-0.7}$	$1.3^{+1.2}_{-1.0}$
Combined categories	3.9	$1.4^{+0.7}_{-0.4}$	$2.3^{+0.9}_{-0.8}$
Combined with 2015 data	3.4	$1.3^{+0.6}_{-0.4}$	$2.0^{+0.8}_{-0.7}$



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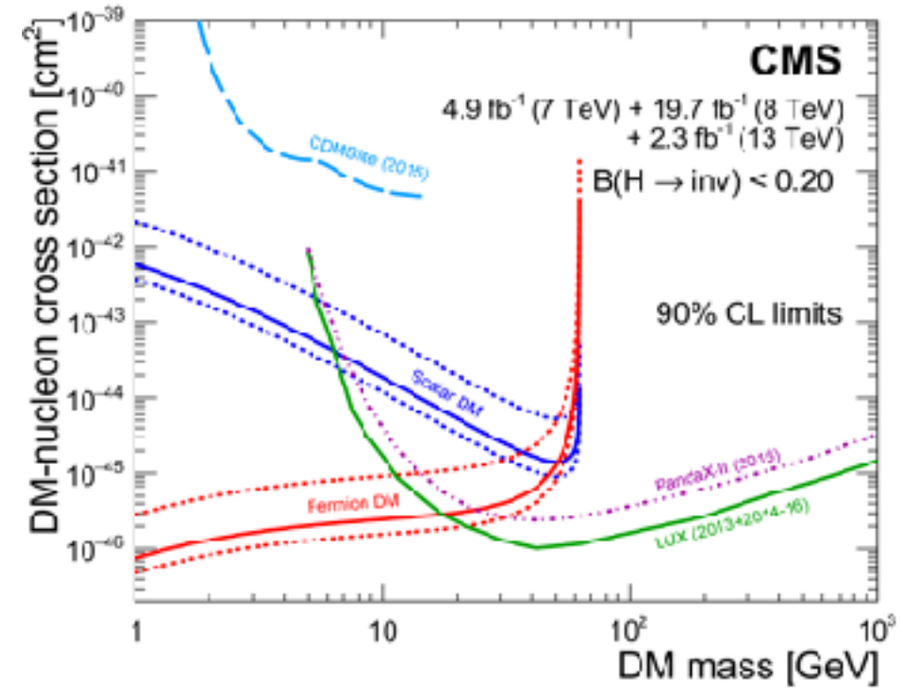
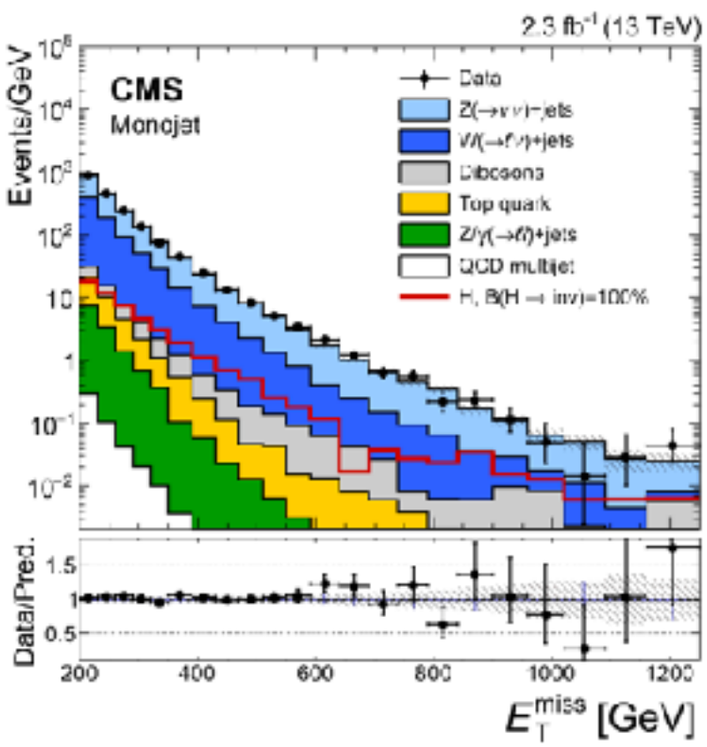
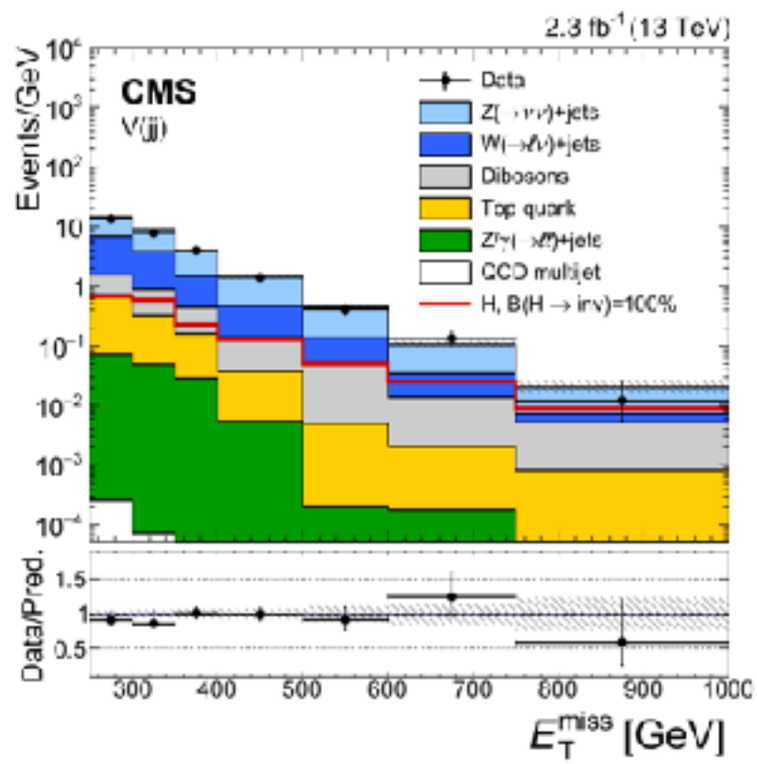
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-16-038/index.html

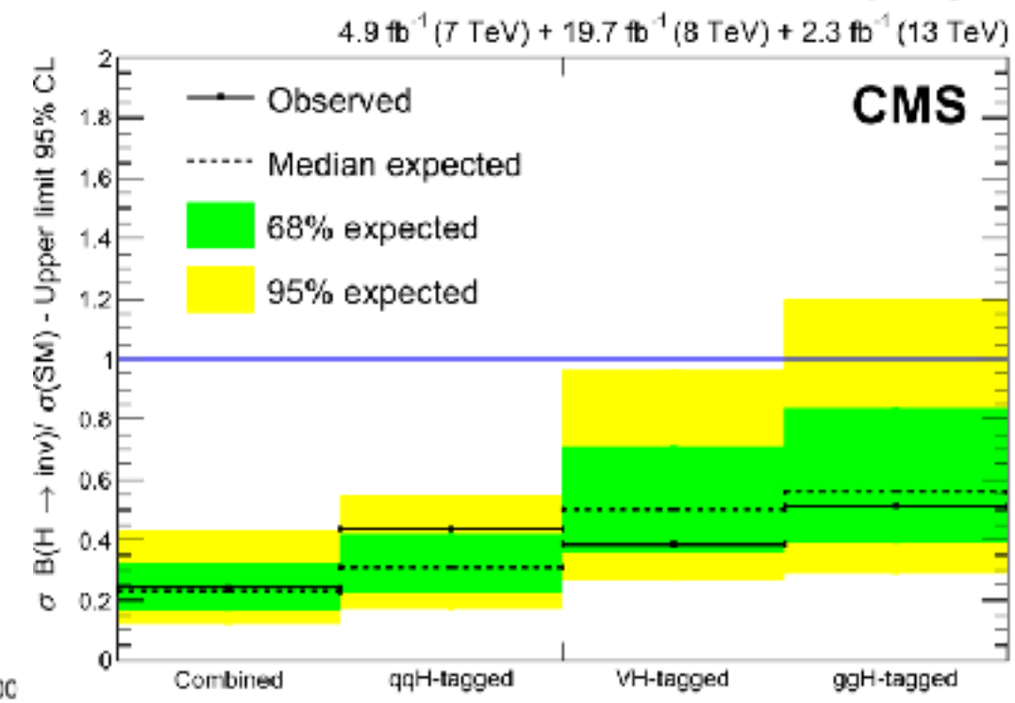
Invisible Higgs Decay

- Categories targeting production modes:
  → Z(ll,bb,jj)H, qqH, V(jj)H, ggH
- Benchmarks models:
  → Neutralinos, Graviscalars, generally Dark Matter
- Z(νν)+jets and W(lν)+jets main backgrounds
- Limits on the spin-independent DM-nucleon σ assuming a scalar or fermion DM particle (f_N parameterizes the Higgs-nucleon coupling)









http://cms-results.web.cern.ch/cms-results/public-results/superseded/HIG-16-016/index.html

Extending the Higgs Sector

Model	Description	Higgs bosons
SM (one doublet of complex scalar fields)	3 d.o.f. give mass to $W^{\pm}$ and Z, Yukawa couplings generate fermion mass	h
SM + real singlet	Used in the context of EWK baryogenesis, DM…	h, H
2HDM (contains a second doublet)	Prerequisite for SUSY, natural in GUT, DM originating from 2HDM	h, H, A, $H^{\pm}$
2HDM + complex singlet (e.g. NMSSM)	Solve the μ-problem in MSSM (where H(125) is unnaturally heavy)	h_1, h_2, h_3, a_1, a_2, $H^{\pm}$
SM + triplet	Natural explanation for small neutrino masses	h, H, A, $H^{\pm}$, $H^{\pm\pm}$

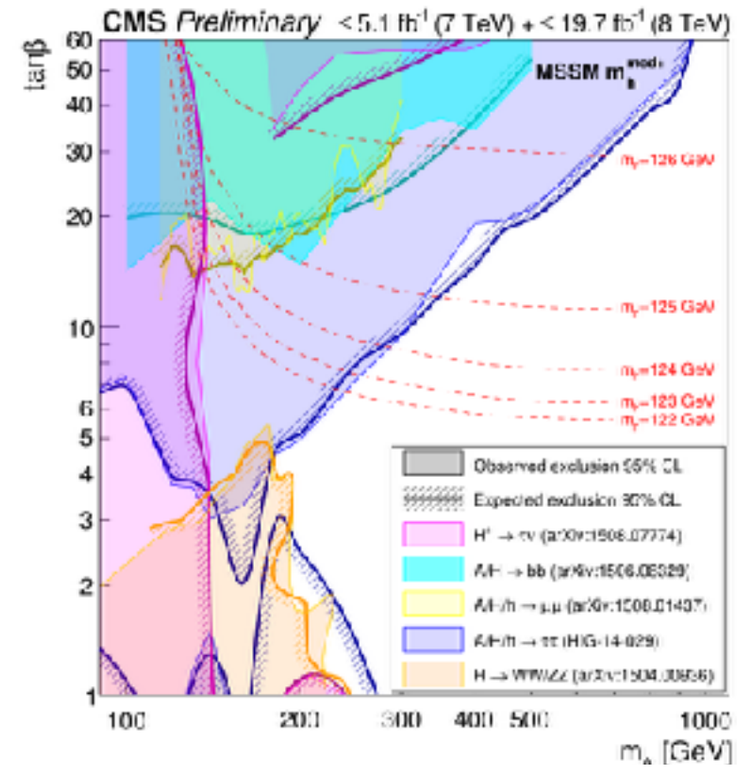
Heavy Higgs searches in Run 1

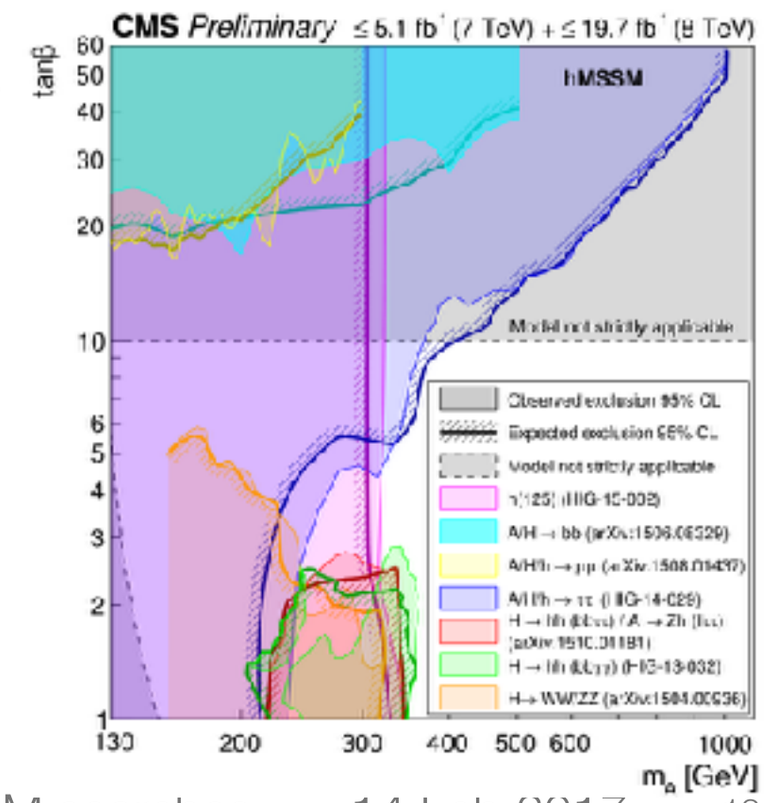
- Exclusion up to tan β ≈ 60 for masses up to m_A=1 TeV. For larger values of tanβ predictions in turn unstable

- Most sensitive search: A/H/h → ττ (unable to separate S and B due to the presence of Z → ττ events with $m_Z \approx m_A$). The strongest exclusion sensitivity for high values of m_A and tanβ

- Supported by the A/H → bb and A/H/h → μμ searches. Note: coupling of the Higgs bosons being proportional to the mass of the final state particle + difficulty to distinguish the signal from the large background from QCD multi-jet (in the case of b-quarks)

- H → WW/ZZ search leads to an exclusion for low values of m_A and tan β, where the H-coupling to vector bosons allows for a significant branching fraction in the m^{mod+}_h





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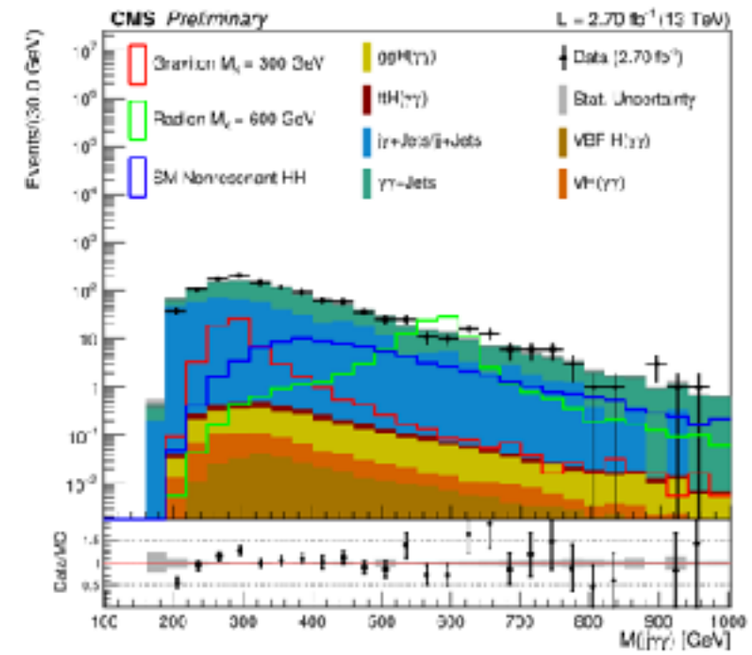
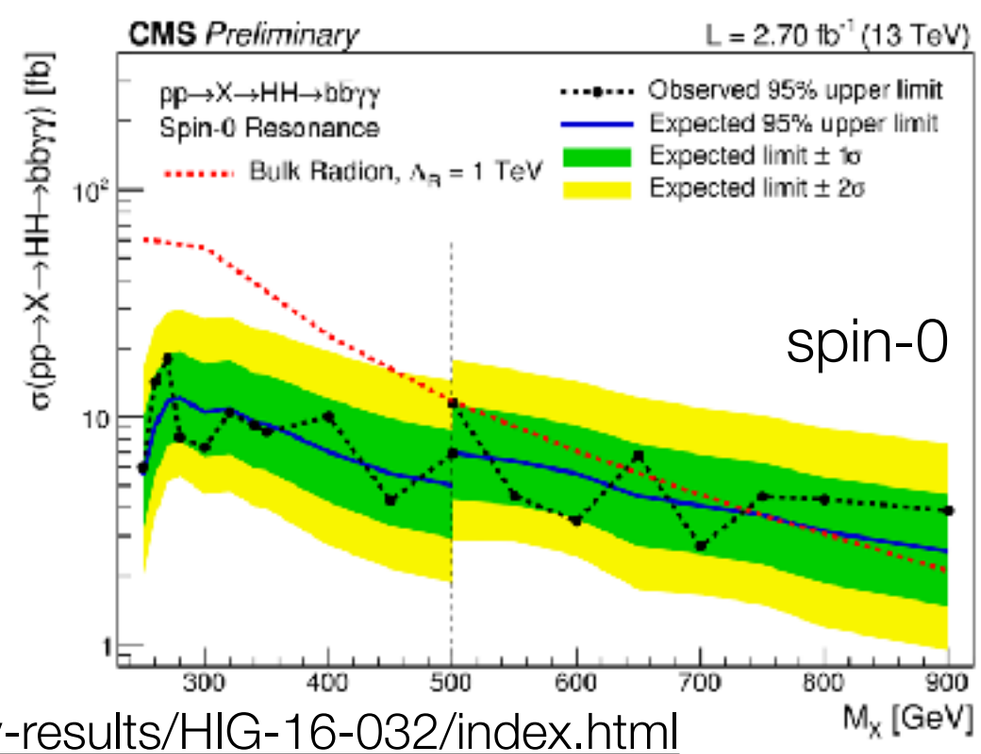
Di-Higgs: bbγγ and bbbb

- HH → bbγγ (resonant and non-resonant)
  - → Signal assume both spin-0 and spin-2 for the resonance (Randall-Sundrum model of Warped Extra Dimensions)
  - → B.R.(HH→bbγγ) = 0.262%
  - → Categories depending on loose-medium-tight CVS disc

- HH → bbbb (resonant)
  - → Data-drive technique for QCD bkg. estimation
  - → Signal into a 2D place $M(j_1j_2)\cdot M(j_3j_4)$
  - → Kinematical selection using the output of a BDT
  - → Upper limits on σ(pp→HH→bbbb)

- b-jets from multivariate likelihood discriminant using lifetime and reconstructed secondary vertices (CSV)





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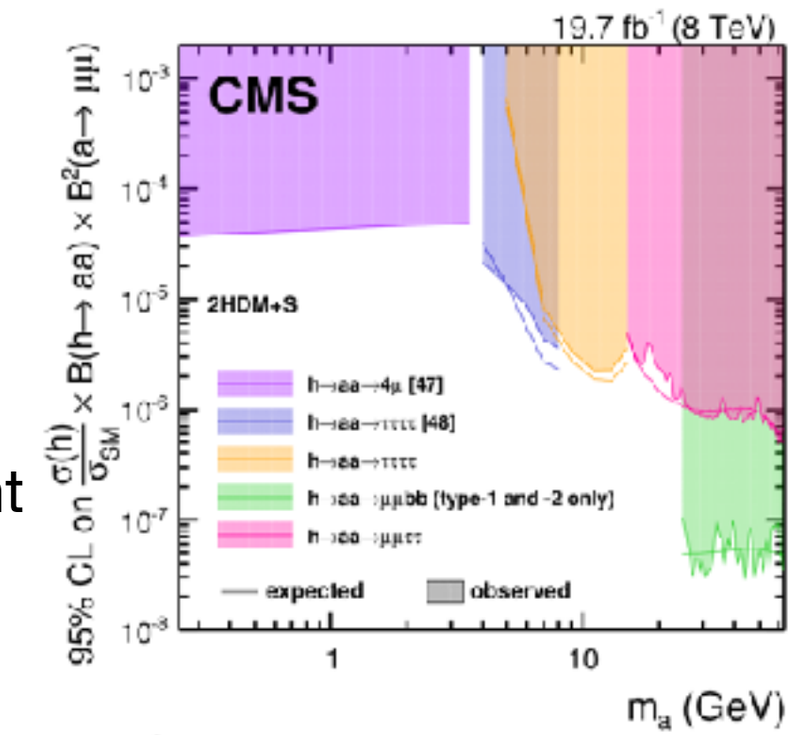
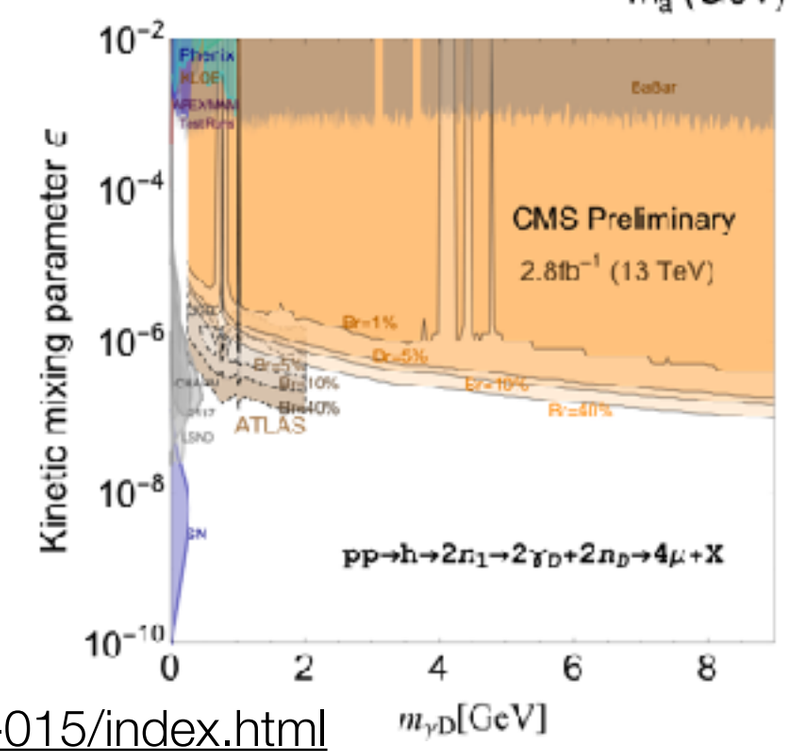
Light bosons searches (and dark susy)

- Light bosons from H decay produce several final states:
  - → Interpreted in terms of 2HDM+S models
  - → Dealing with boosted topologies
  - → Limits as a function of light boson mass (m_a) and tanβ



- BR(a→xx) depends on m_a and several analysis cover different mass ranges

- Alternative benchmark model: dark SUSY:
  $h \to n_1 n_1 \to n_D n_D \gamma_D \gamma_D + X$
  - → Dark photons could have an appreciable life-time before decay
  - → Dark photons are generated with m(γ) in the range 0.25–2.0 GeV and a decay length in the range of 0–20 mm
  - → The limit set in the [m(γ_D),ε] plane.
  - → Nice complementarity with ATLAS analysis



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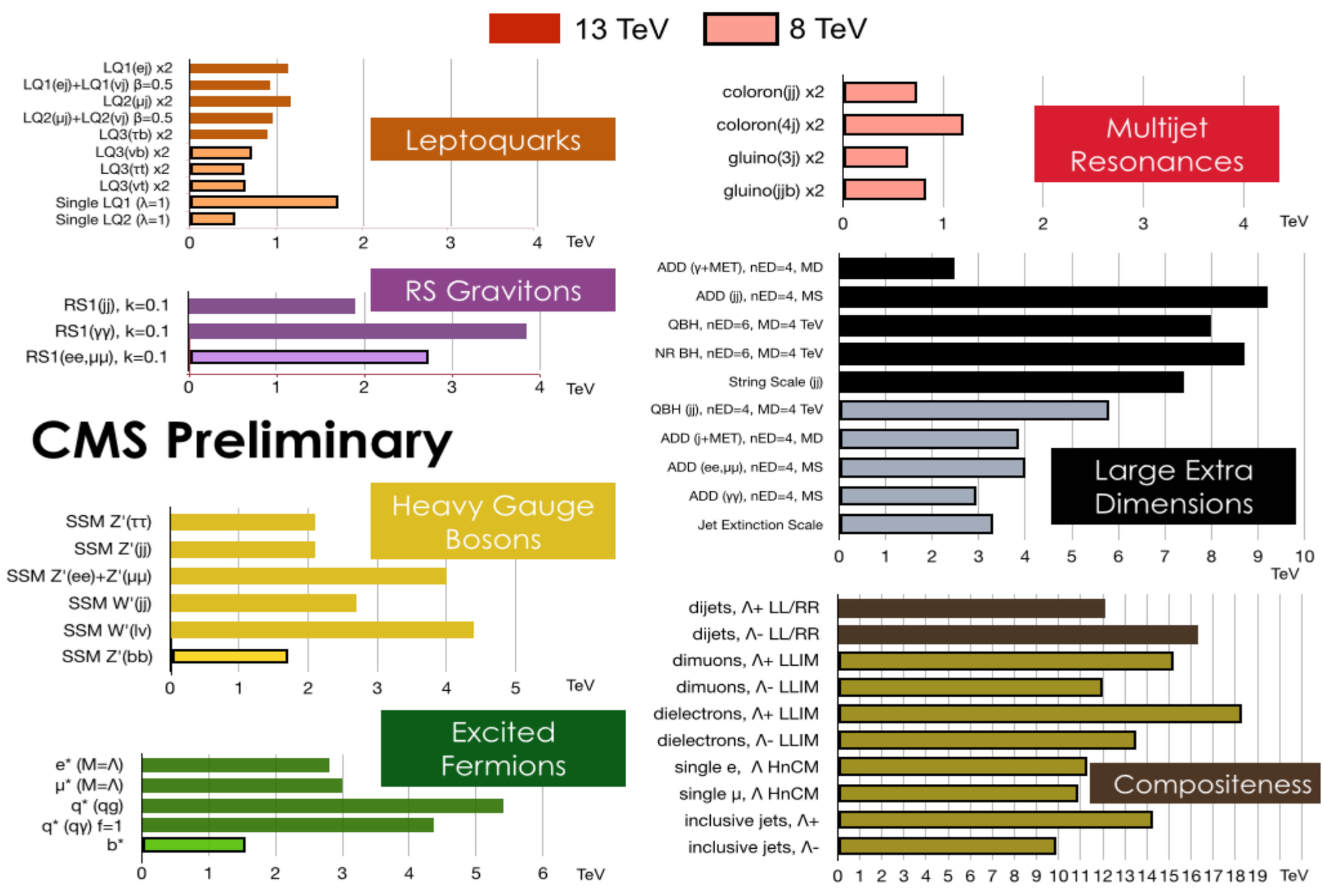
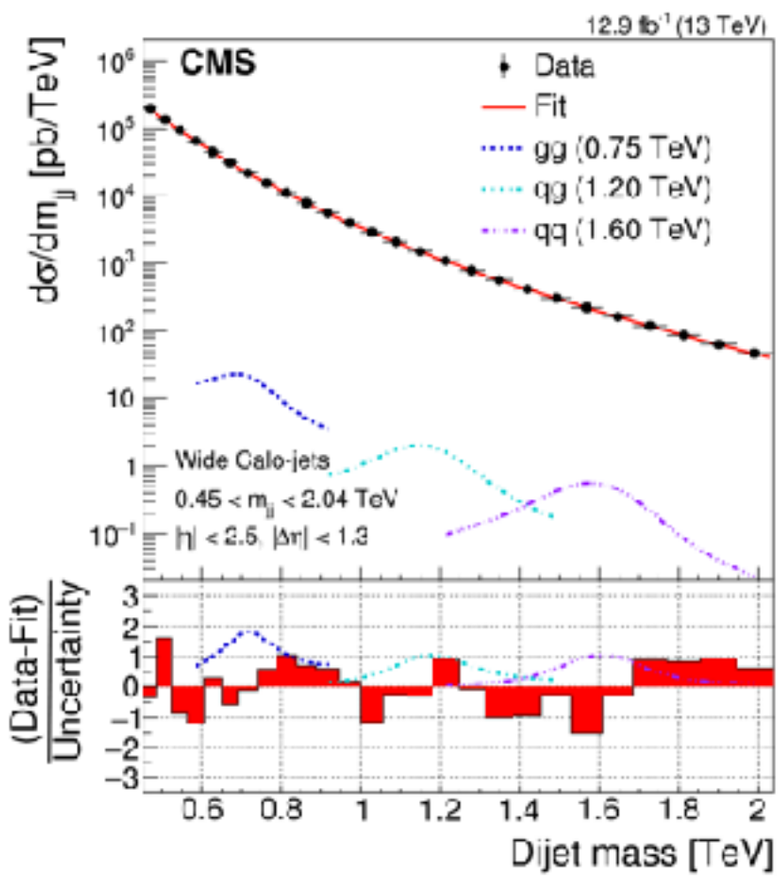
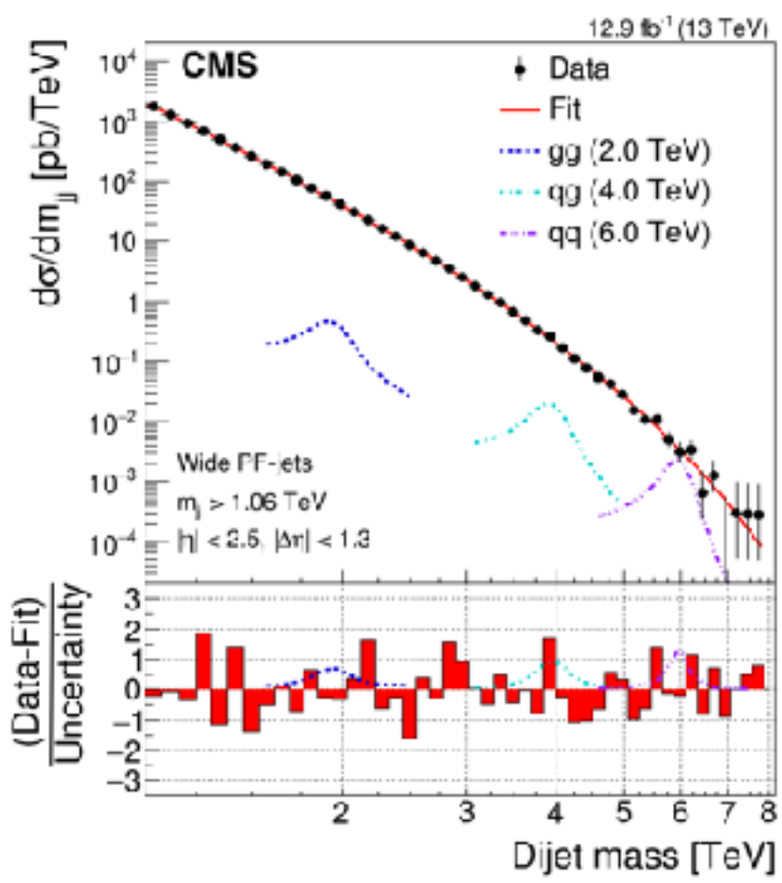
Exotica searches

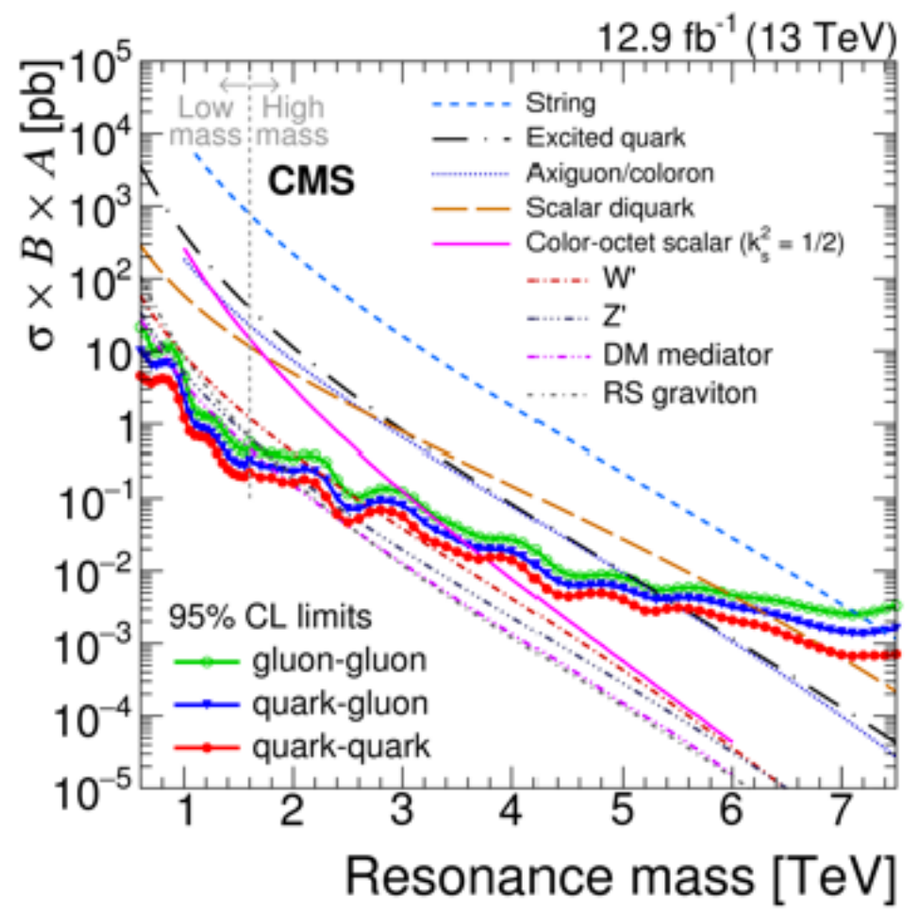


Di-jet search

- Search for narrow resonances decaying to dijet final:
  - → Several benchmark models: string resonances, scalar diquarks, axigluons…
  - → PF-jets reconstructed offline, (the high-mass search). Calo-jets reconstructed by HLT (low-mass search). Spatially close jets: combined into "wide jets"
  - → No evidence, generic upper limits on production σ
- The dijet mass spectra are fit with: $\frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3\ln(x)}}$







http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO-16-032/

Di-photon search

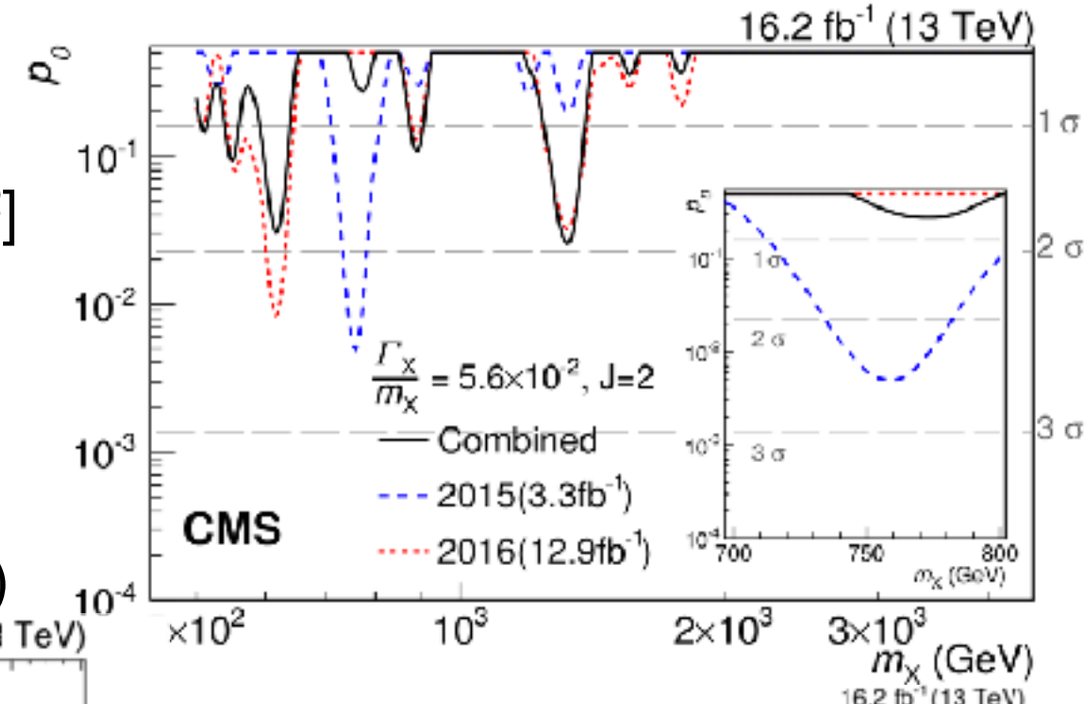
- Search for the resonant high-mass photon pairs (spin-0 and spin-2)
  → $m_X \in [0.5\text{-}4.5]$ TeV and $\Gamma_X/m_X \in [1.4\cdot10^{-4}\text{-}5.6\cdot10^{-2}]$

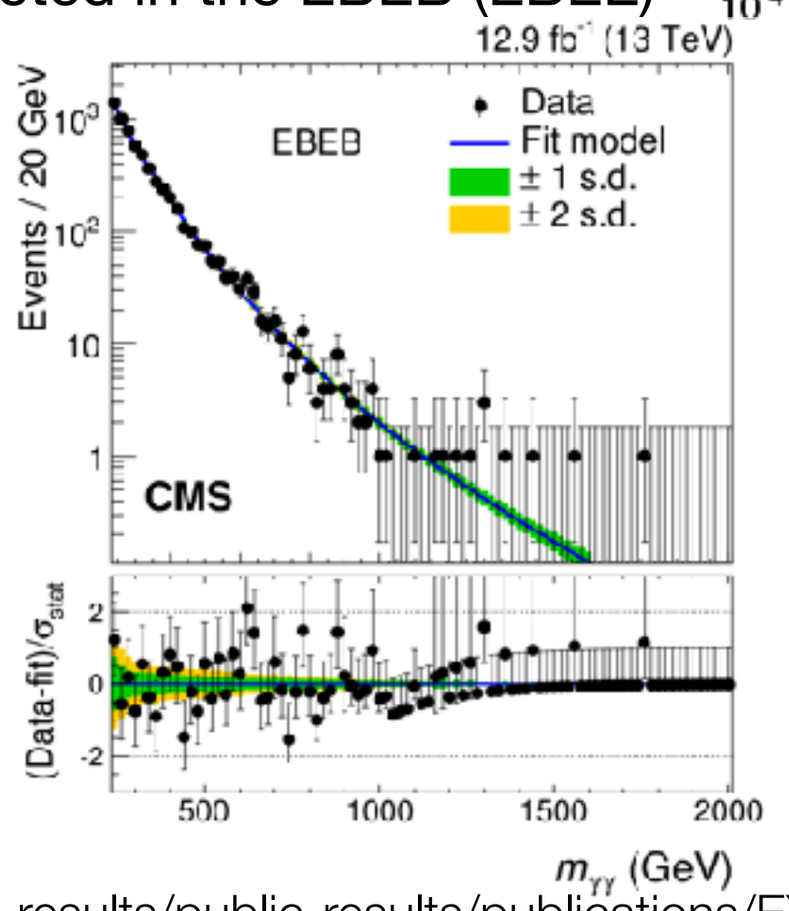
- 2 categories: both γ in the Barrel (EBEB), one in the Endcap (EBEE)

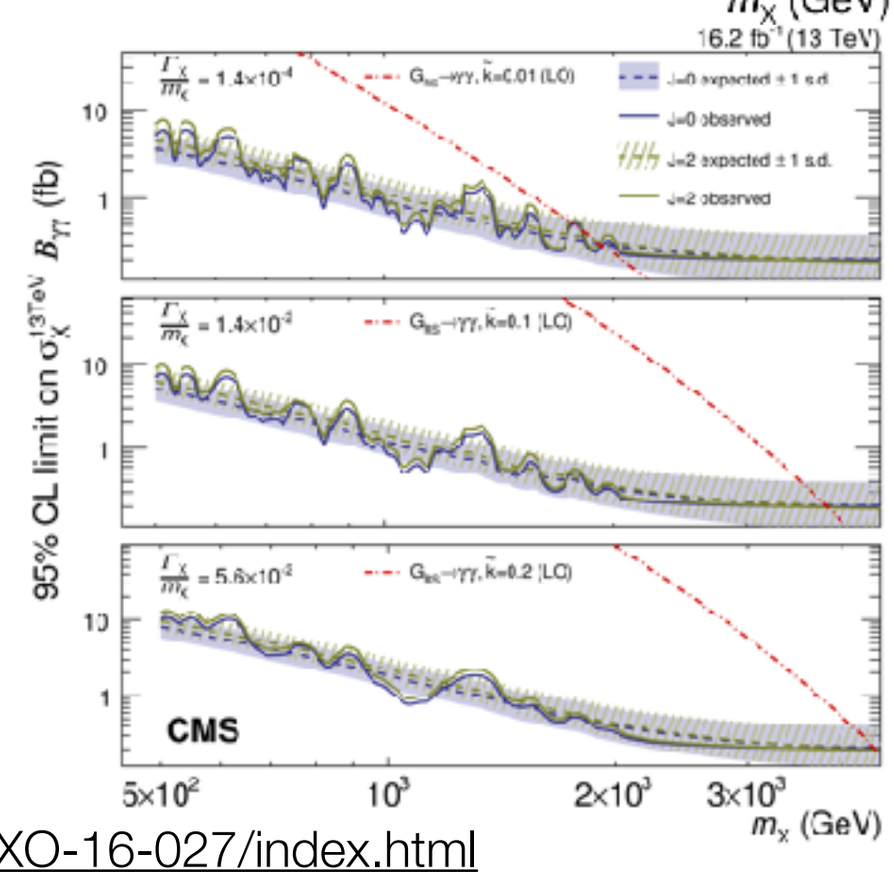
- 6284 (2791) γ-pairs are selected in the EBEB (EBEE)
  → Mass distribution:

$$f(m_{\gamma\gamma}) = m_{\gamma\gamma}^{a+b\,\log(m_{\gamma\gamma})}$$

- Combined results have a p-value smaller than 2σ





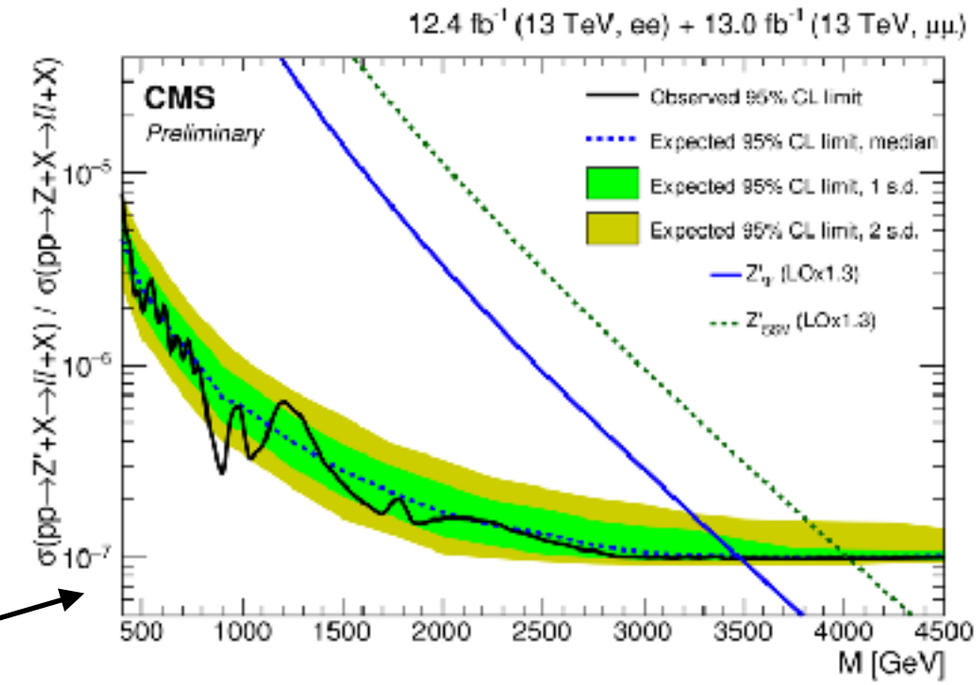


http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO-16-027/index.html

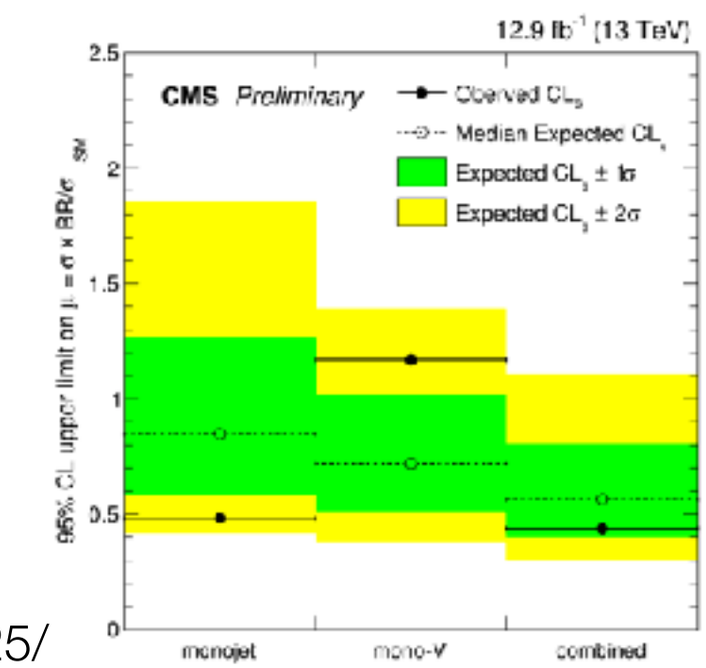
Other X_i+X_j searches

- Search for spin-0 Zγ resonances (hadronic):
  - → Any resonance decaying into γγ or ZZ should also have a Zγ decay fixed by $SU(2)_L$
  - → Depending on mass, we reconstruct two resolved jets, or as a single jet from qq merging

- ee-μμ final state:
  - → Cleaner signature for new physics
  - → Drell-Yan dominant irreducible bkg. (plus photon-induced process, tt, t, tW…)



- E_t^{miss}+X:
  - → Invisible decay of new resonance + g/V (hadronic decay)
  - → Background: mostly Z(νν)/W(lν)+jets
  - → EWK background: from ten exclusive control regions in data



http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO-16-025/

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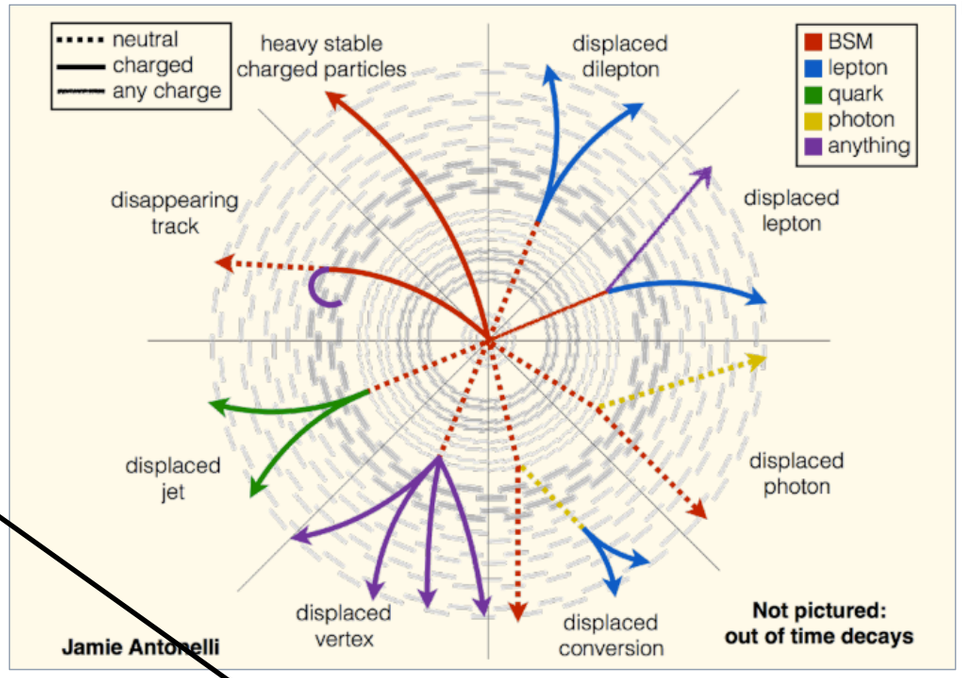
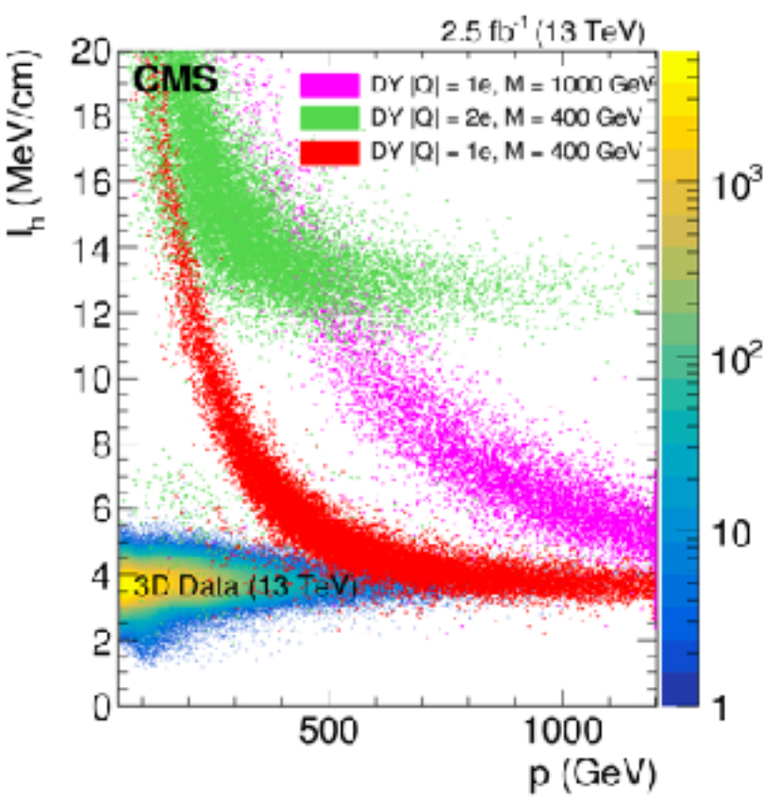
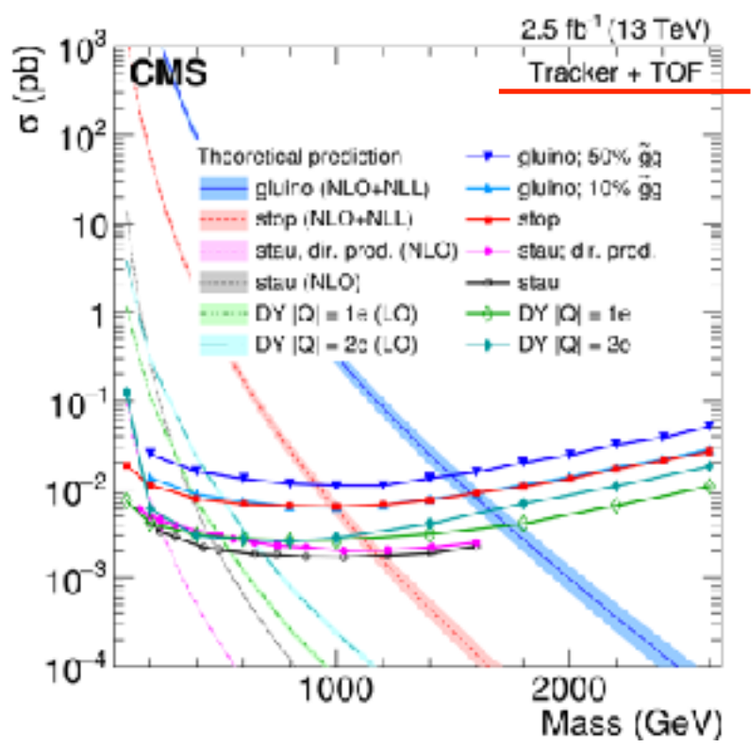
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/EXO-16-037/

Long-lived particles:

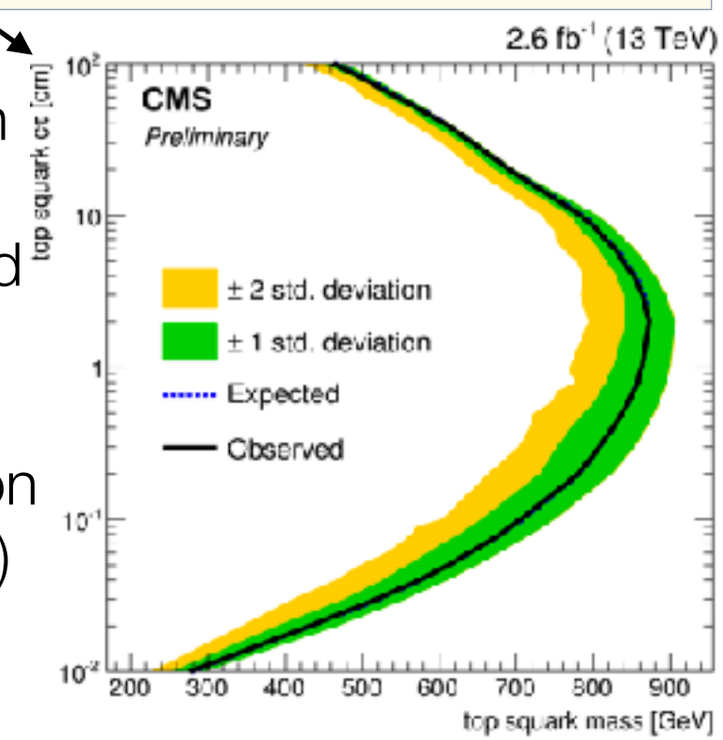
- Broad variety of final states:
  - → Long-lived charged particles
  - → Displaced leptons in the e-μ channel
    - →e/μ with transverse impact parameter ϵ[200μm-10cm]
- I_h discriminator based on dE/dx, from measurement of ionization deposited + time of flight information







Result in term on displaced SUSY (pair production of stops)



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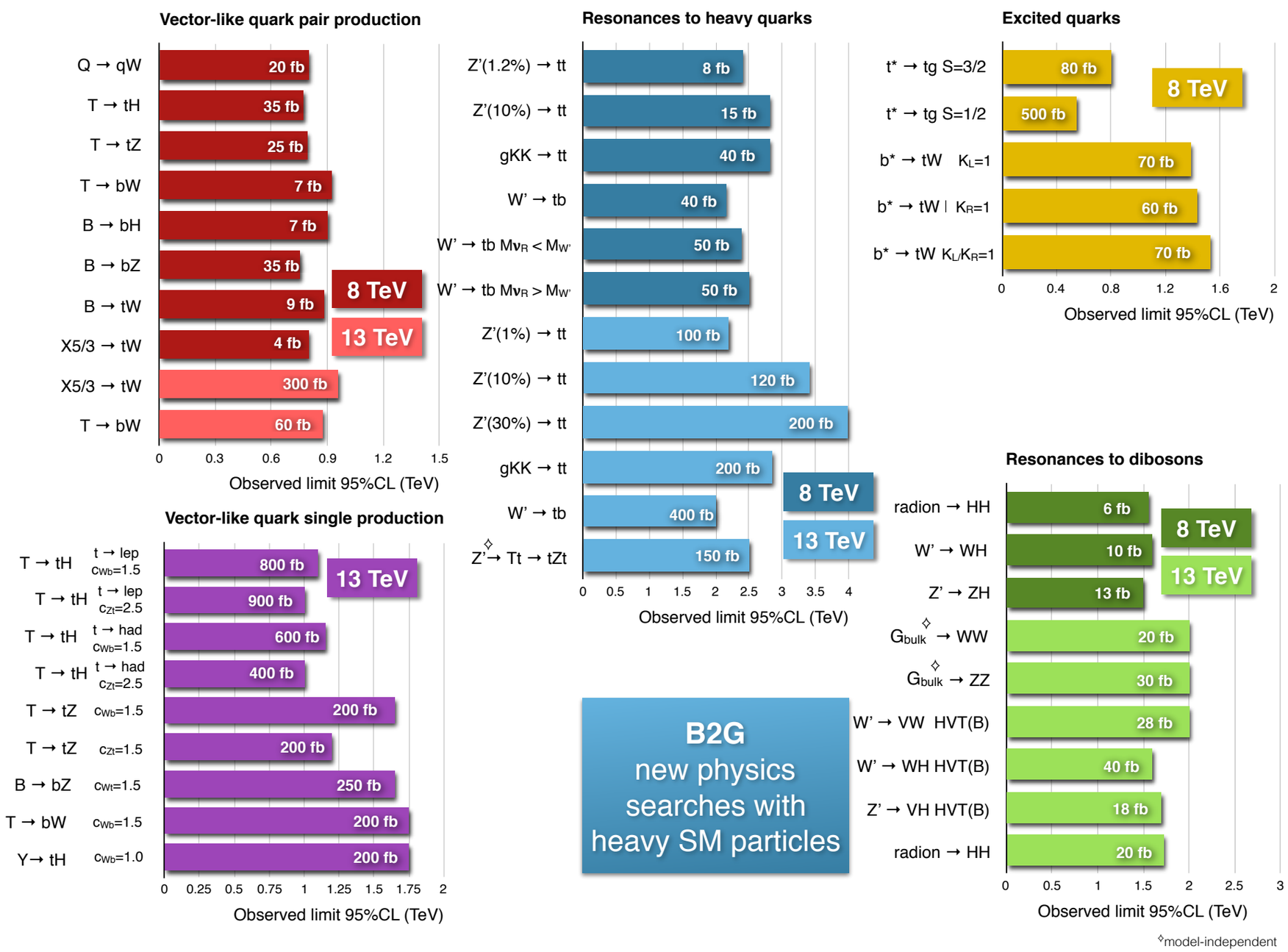
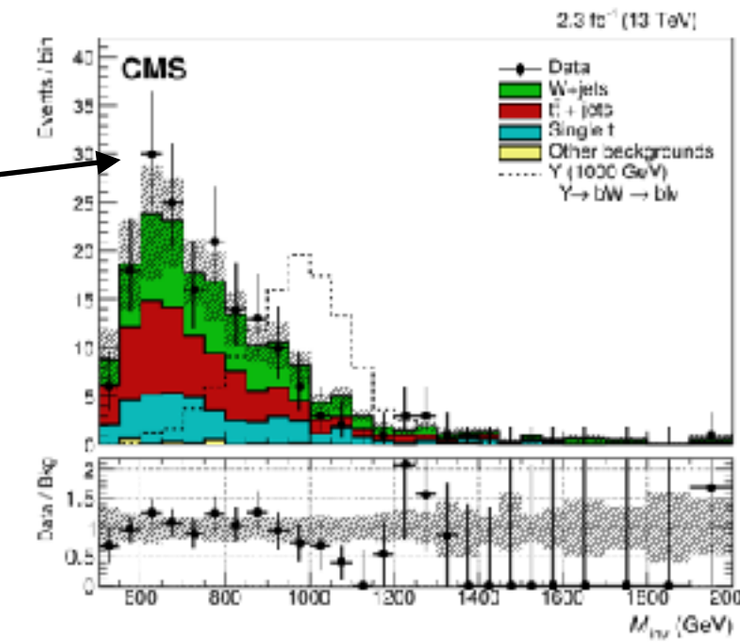
Beyond 2nd generation



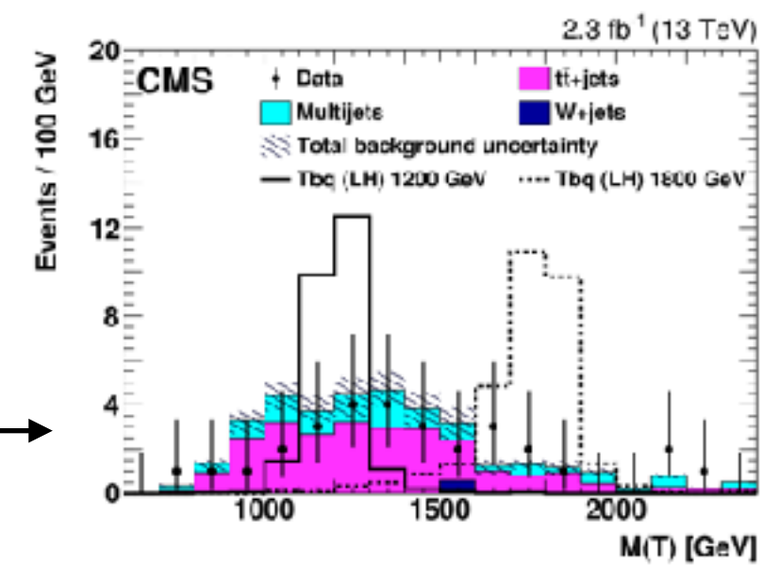
Heavy vector-like quark (VLQ)

- T→Wb (in association with b and a light quark)
  - → Looking for e/μ, b-jet, forward jet, and E_t^{miss}
  - → $P_z(\nu)$ by imposing W mass (allow to compute M_{inv})



- T/B→Z + t/b (in association with b/t and a light quark)
  - → Z decaying to ll (ee or μμ)
  - → 6 categories: 4 for T search, 2 for B search
  - → σ·BR from 1.26-0.13 pb excluded at 95% CL in (0.7-1.7) TeV

- T→Ht: boosted hadronic final states (in association with b/t and a light quark)
  - → For m_T > 1 TeV the tH decay are collimated: two jets
  - → Large hadronic activity: ≥4 AK4 jets, at least one AK8 jet (p_T > 300 GeV), H_T > 1100 GeV (sum of E_T of all jets)
  - → Multijet background estimated using ABCD method
  - → M_T used as final observable
  - → Decay channel also studied using lepton + jet in final state



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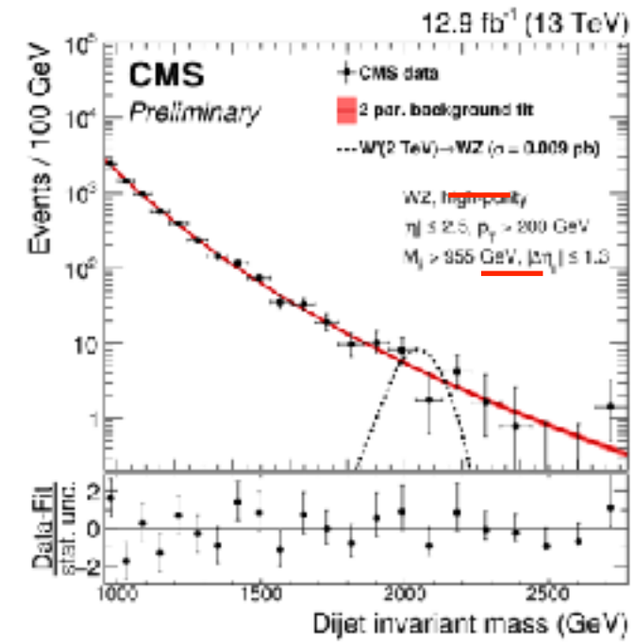
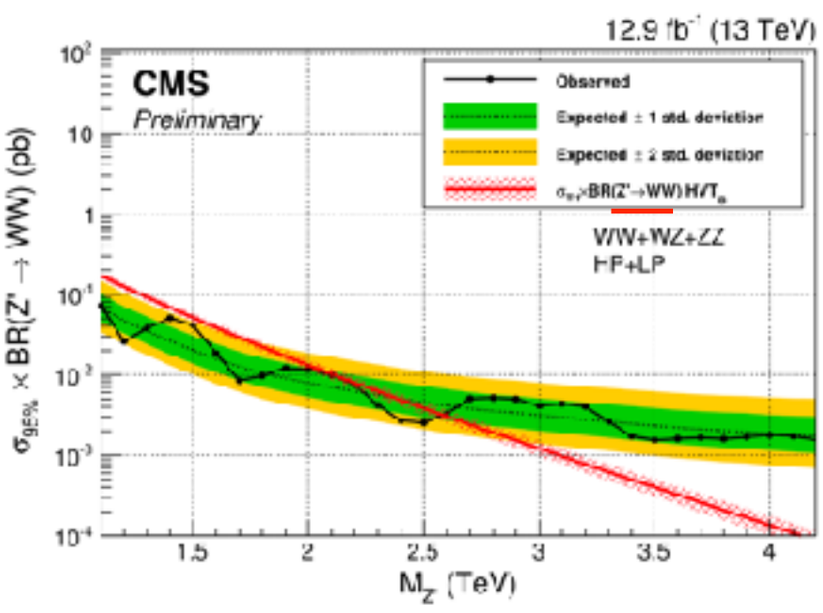
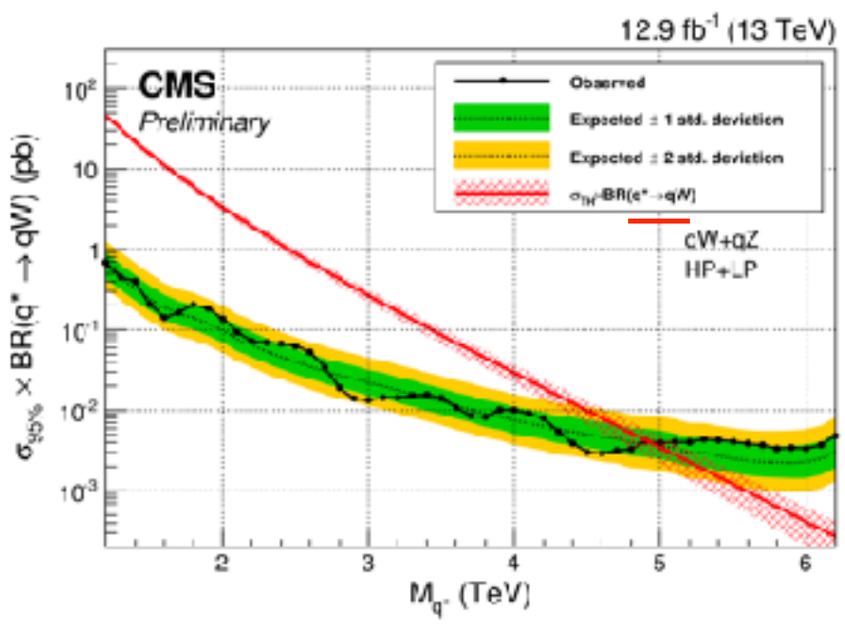
http://cms-results.web.cern.ch/cms-results/public-results/publications/B2G-16-001/index.html
http://cms-results.web.cern.ch/cms-results/public-results/publications/B2G-16-005/index.html

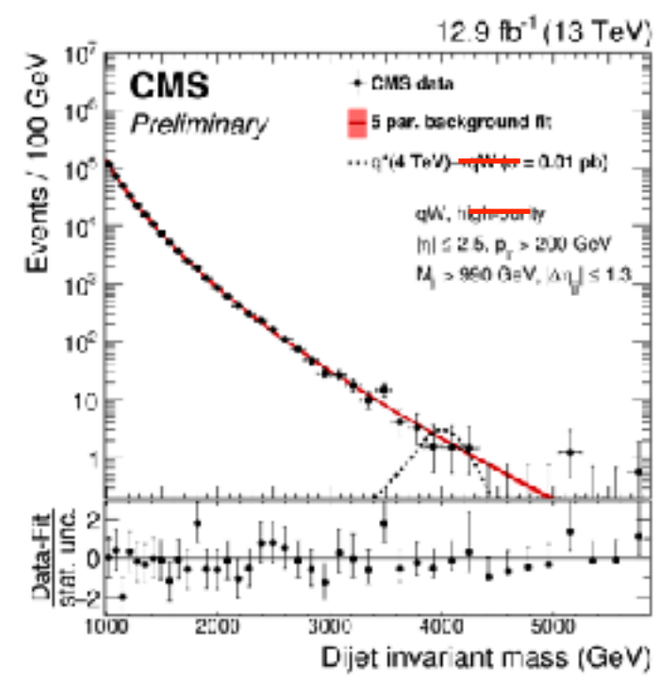
Massive resonances to VV, qV

- Massive resonances to WW, WZ, ZZ, qW and qZ in the dijet final
- Z', W', bulk graviton, excited quark benchmark models (mass of at least 1.1 TeV)
- Trigger based on H_T and jet sub-structure
- W and Z hadronic decay: reconstructed using PF jets with $\Delta R=0.8$ + pileup mitigation + exploitation of jet sub-structure
- QCD described by parametrizable distribution
- Signal described by a double-sided Crystal-Ball
- Most stringent limits on $m(q^*)$ in qV decay and Z' in WW decay. (more results on link below)





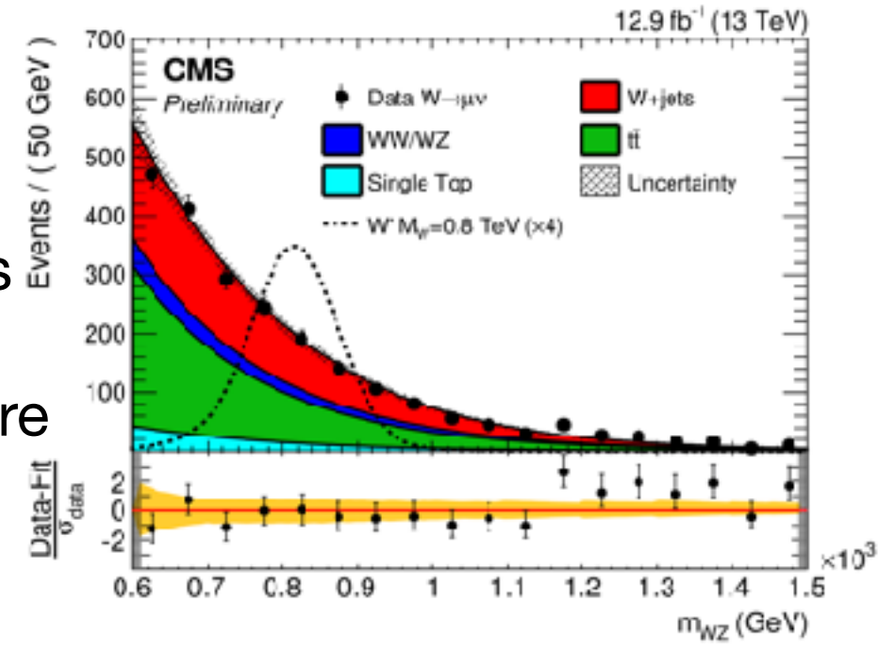


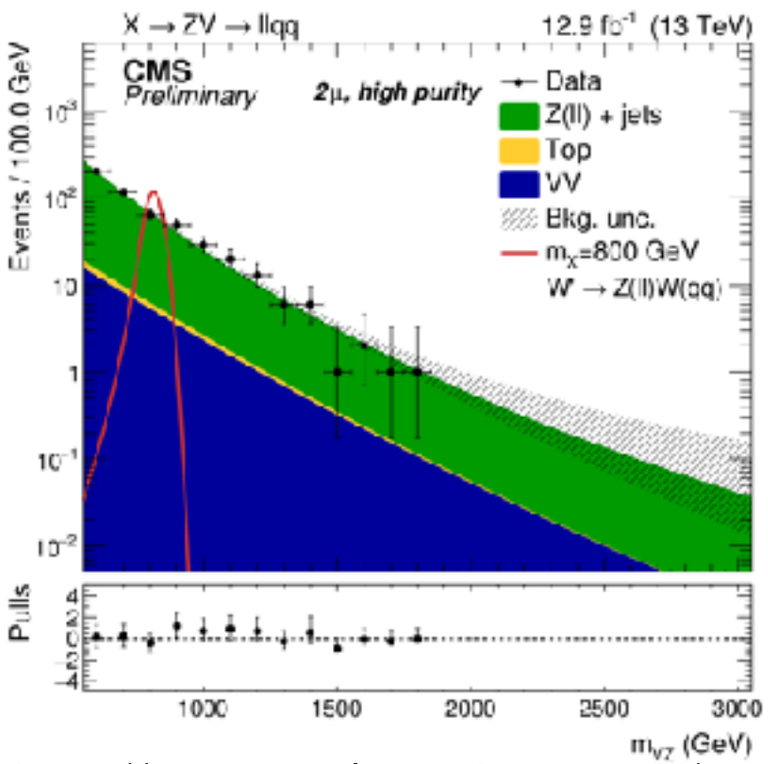


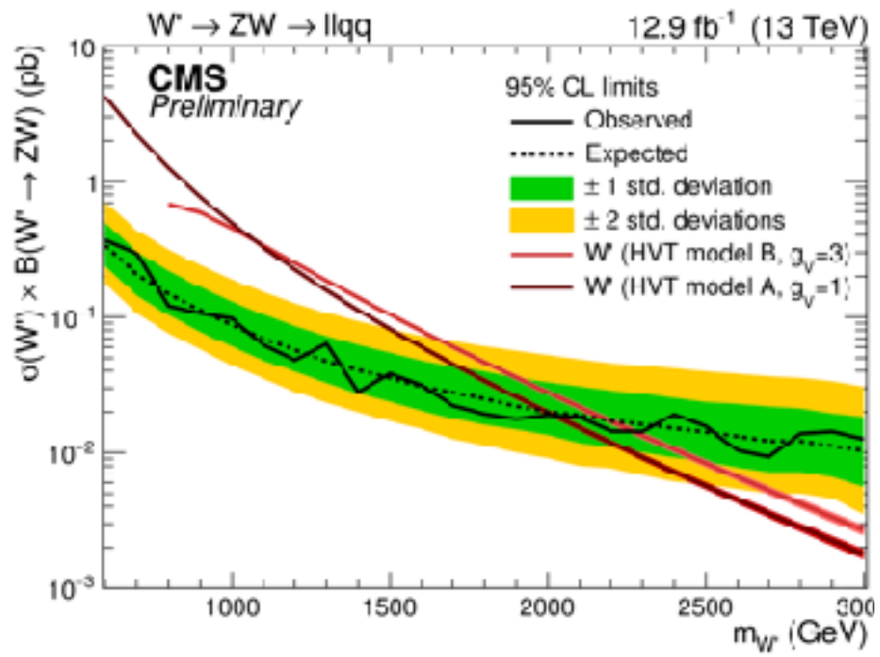
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/B2G-16-021/index.html

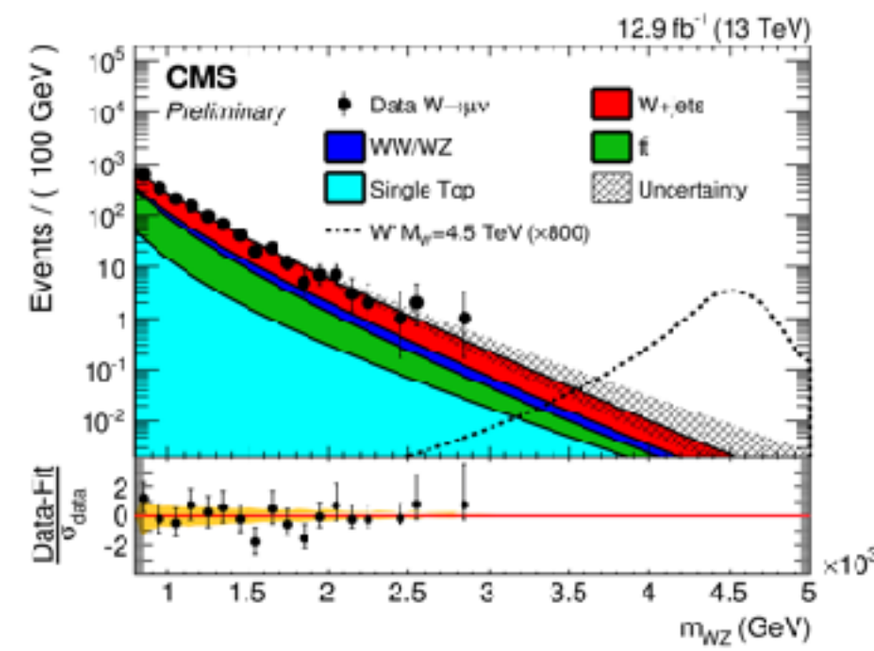
Resonances into lvqq and llqq

- Heavy particles decaying to pairs of bosons
- X→WW/WZ→lvqq:
  - → 2 categories (e and μ)
  - → Limits and interpretation for gravitons and spin-1 bosons
- X→ZW→llqq:
  - → Category depending on lepton flavor and jet sub-structure
  - → Main background: Z+jest and VV (estimated from data)
  - → Limits on the prod σ for spin-1 resonances







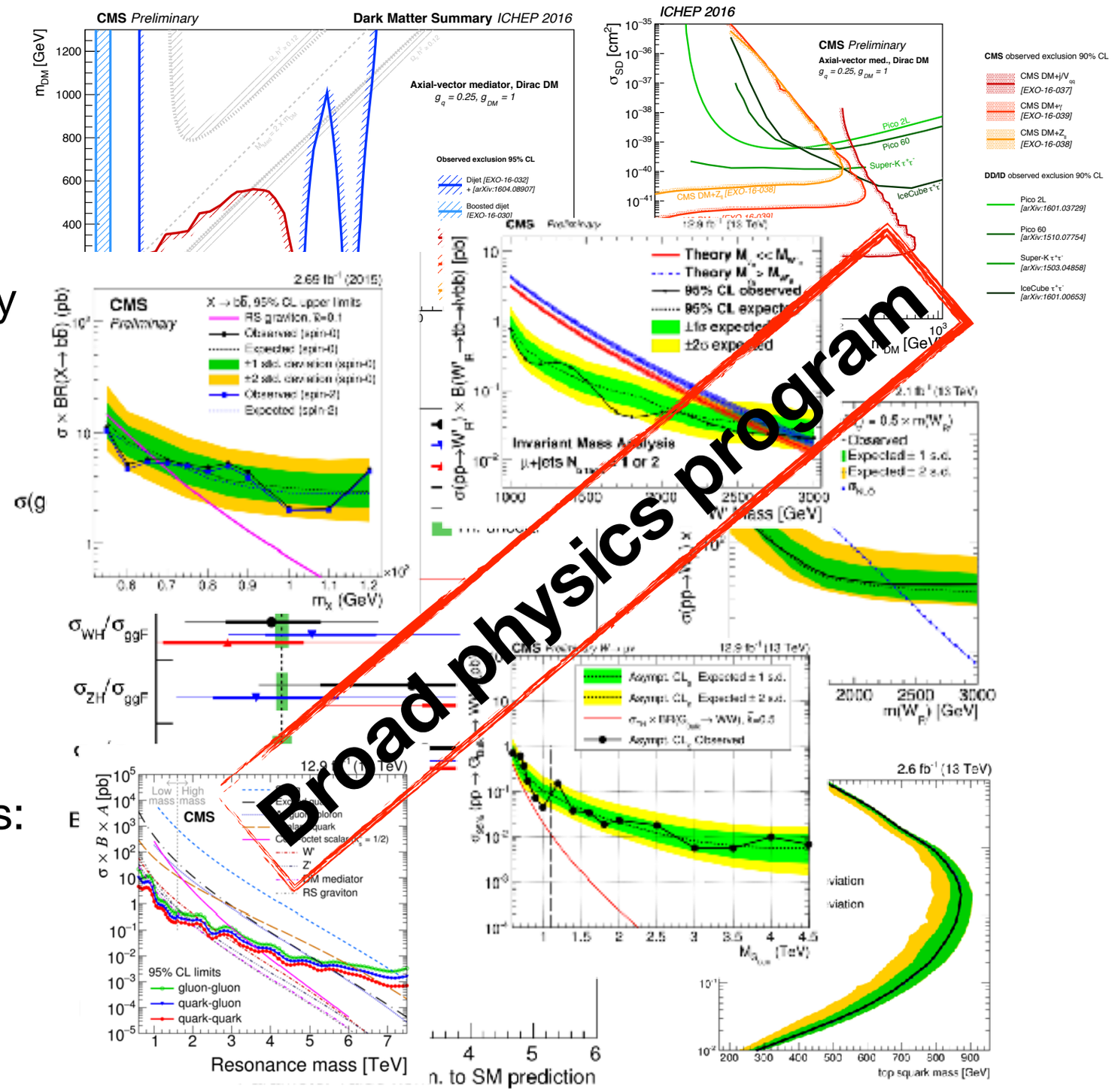


http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/B2G-16-020/index.html

http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/B2G-16-022/index.html

Outlooks

- Large variety of CMS searches:
  - → Nothing found (yet!)
  - → Constrain on various models
- Fundamental to provide a simple way reinterpret CMS results
- CMS has an expanding program:
  - → Boosted topologies
  - → Low-mass searches
  - → Long-lived particles
- CMS keep searching for new physics:
  - → Higher and lower mass
  - → Smaller couplings
  - → Complex final states

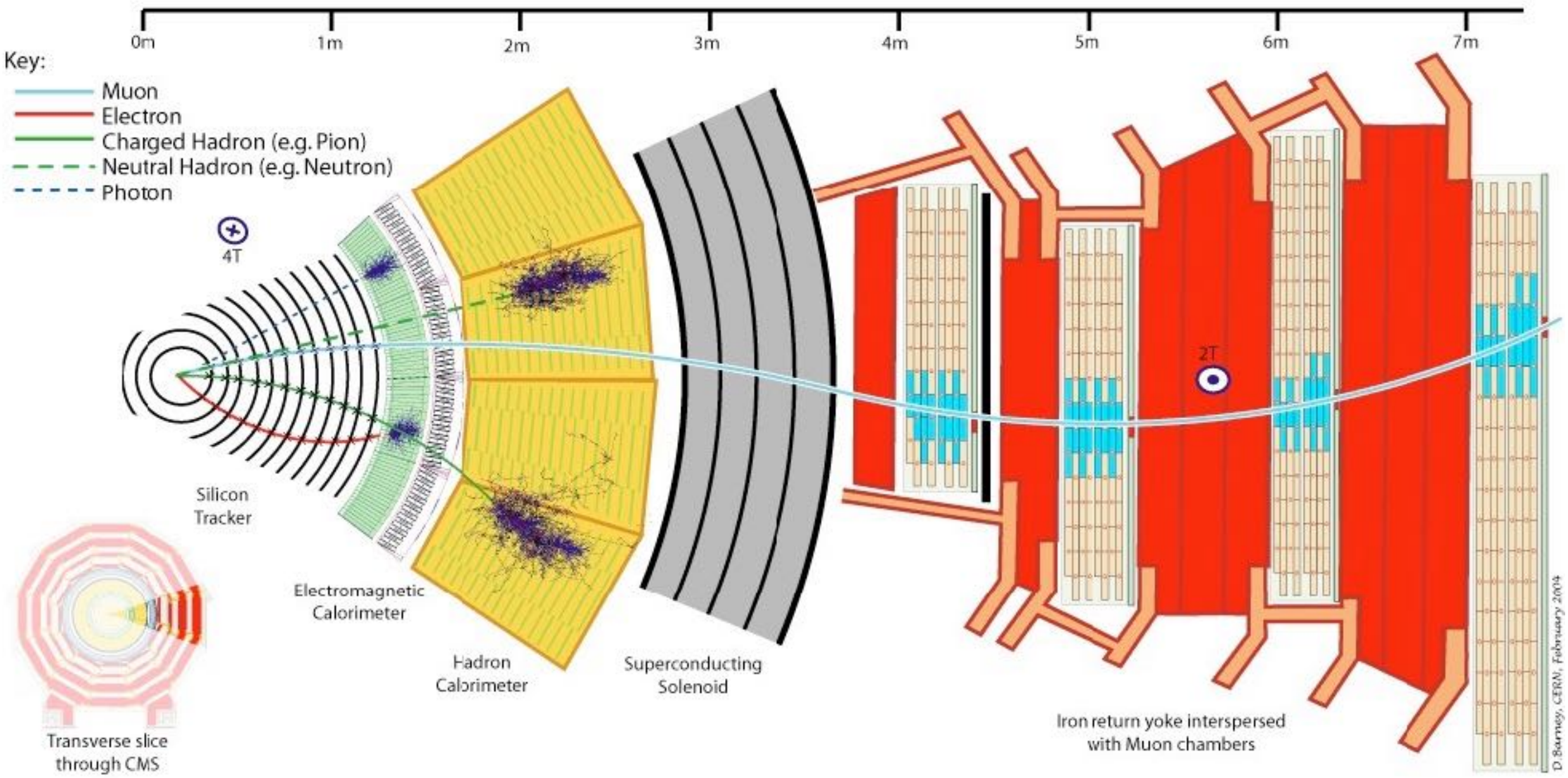


Thanks!

Many: 5000 members,
1900 physicists,
1800 students,
950 eng./ techn.
Global: 200 institutes
from 43 countries

Backup

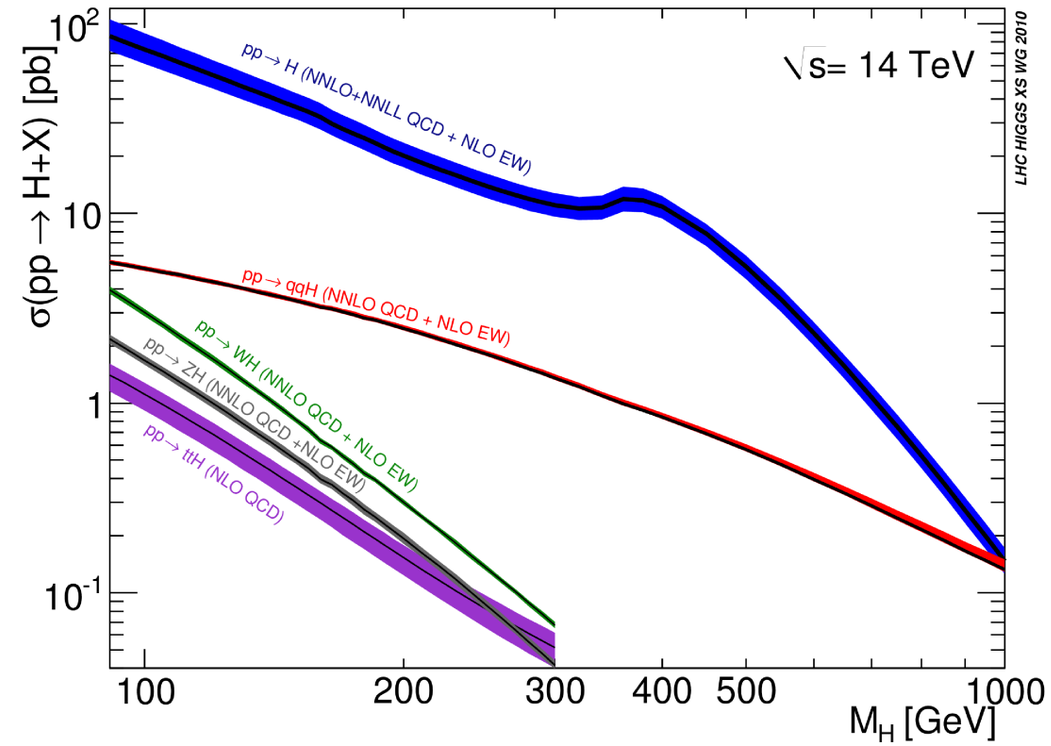
The Compact Muon Solenoid

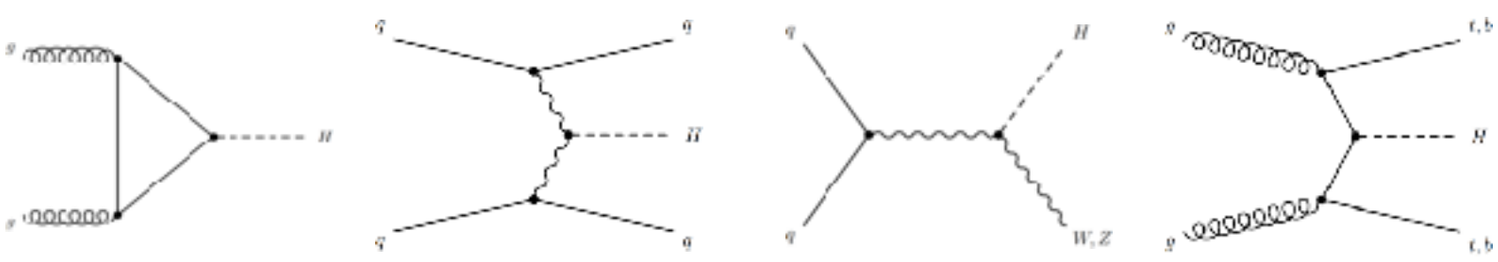


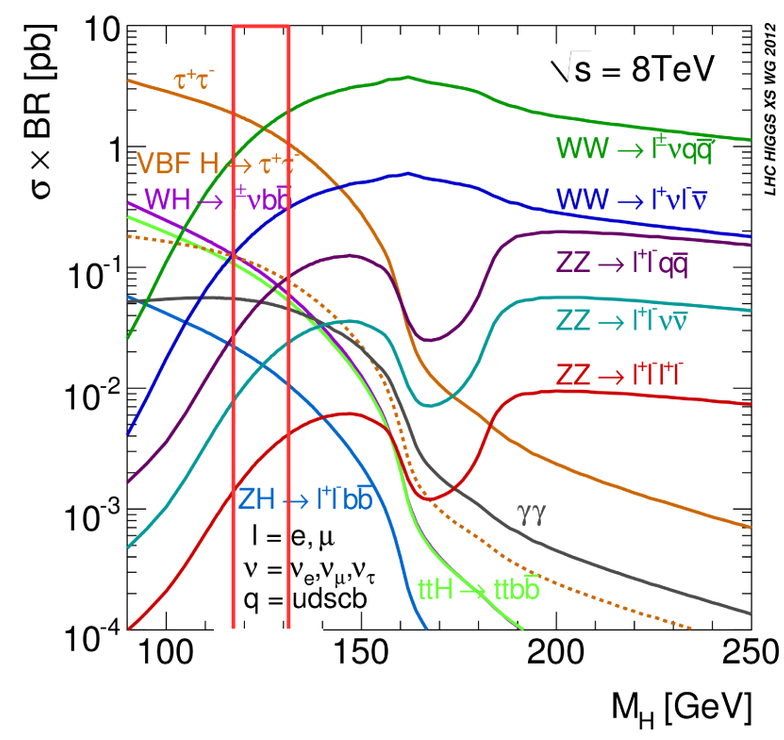
Higgs cross section and B.R.

- From 8 TeV → 13 TeV cross sections increase (for m_H=125 GeV):
  - ggH: 19.3 pb → 43.9 pb [x2.3]
  - VBF: 1.57 pb → 3.75 pb [x2.3]
  - VH: 1.12 pb → 2.25 pb [x2.0]
  - ttH: 0.13 pb → 0.52 pb [x3.9]

- Branching rations (m_H=125 GeV):
  - H → bb: 58%
  - H → ττ: 6.3%
  - H → WW: 21% →2l2v: 0.21%
  - H → ZZ: 2.6% →4l: 0.01%
  - H → γγ: 0.23%





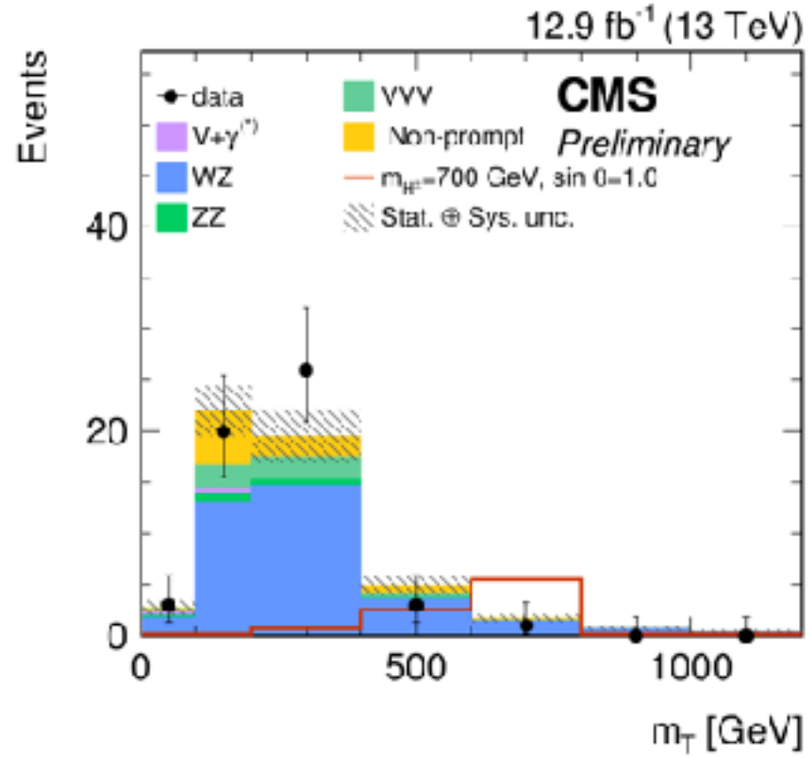


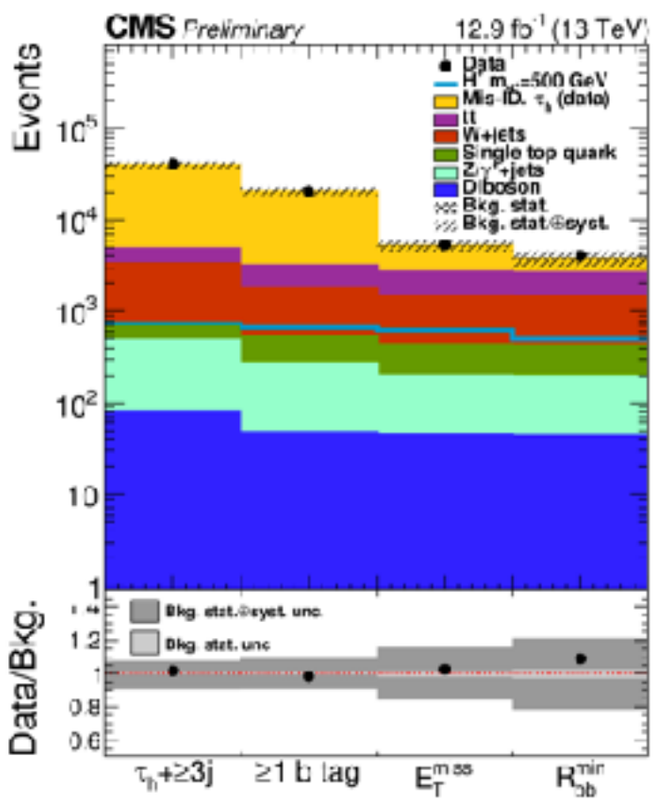
Charged Higgs

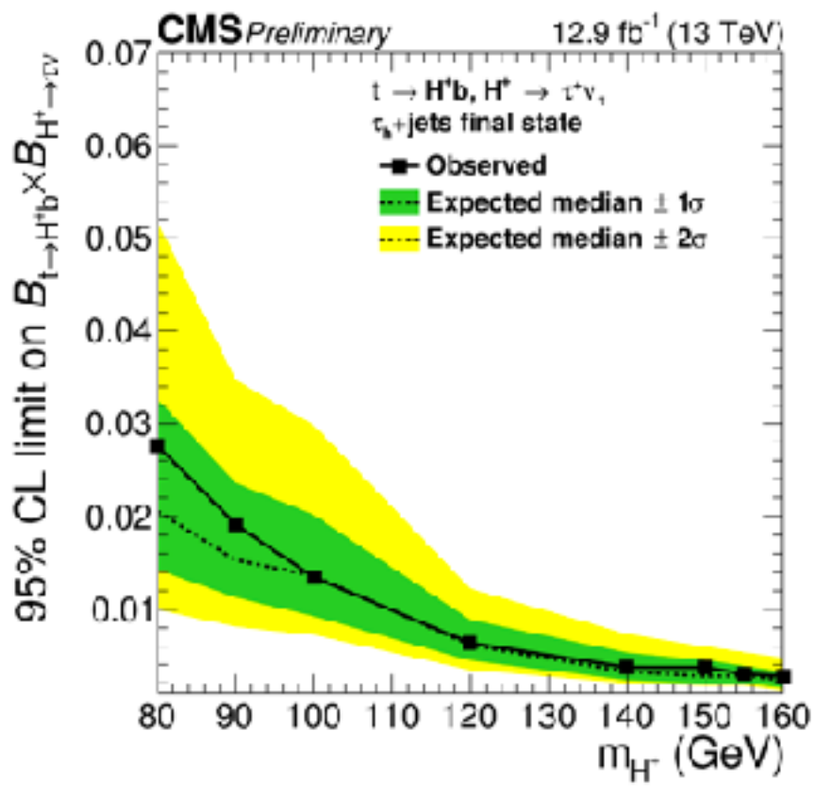
- Charged Higgs bosons appear in many extensions of the SM with at least two Higgs doublets (2HDM are the simplest models)
- $H^{\pm} \rightarrow \tau^{\pm}\nu$ in fully hadronic final state
  → R^{min}_{bb} used to reject multijet events where the MET and τ_h are in a back-to-back:

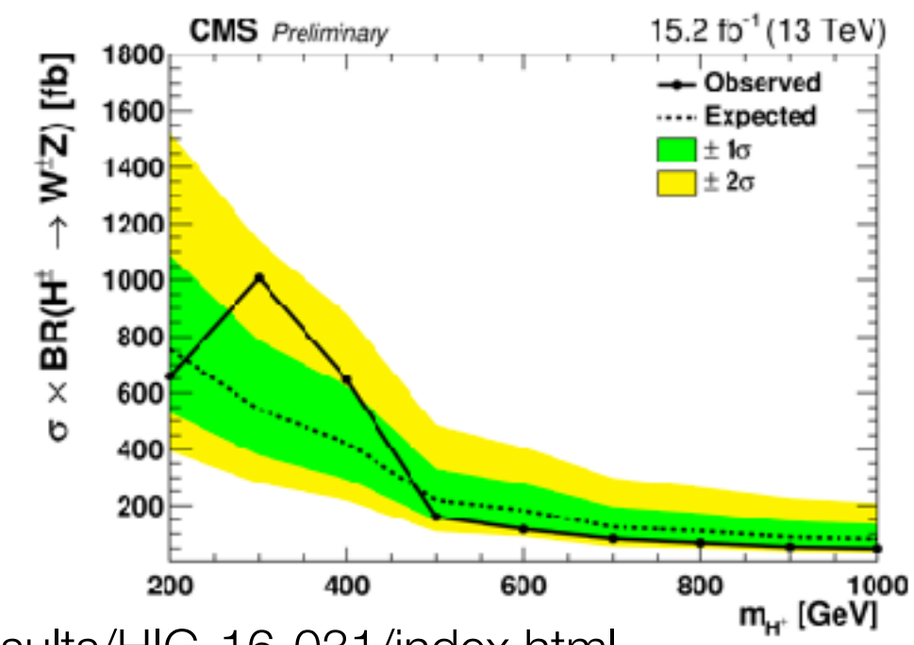
$$R^{\min}_{\mathrm{bb}} = \min_{j \in j_1..j_3} \sqrt{\Delta\phi(\not{E}_T, j)^2 + (\pi - \Delta\phi(\tau^{\mathrm{h}}, \not{E}_T))^2}$$

- $H^{\pm} \rightarrow WZ$ (3 leptons + 2 jets)
  → Background WZ, ZZ, VVV, Zγ, non-prompt lept.





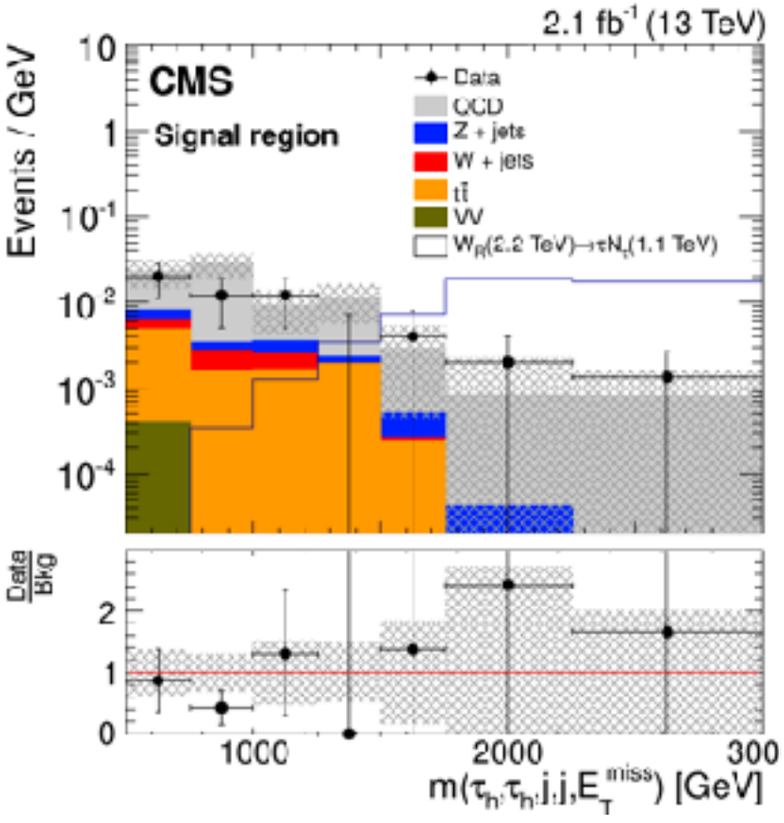


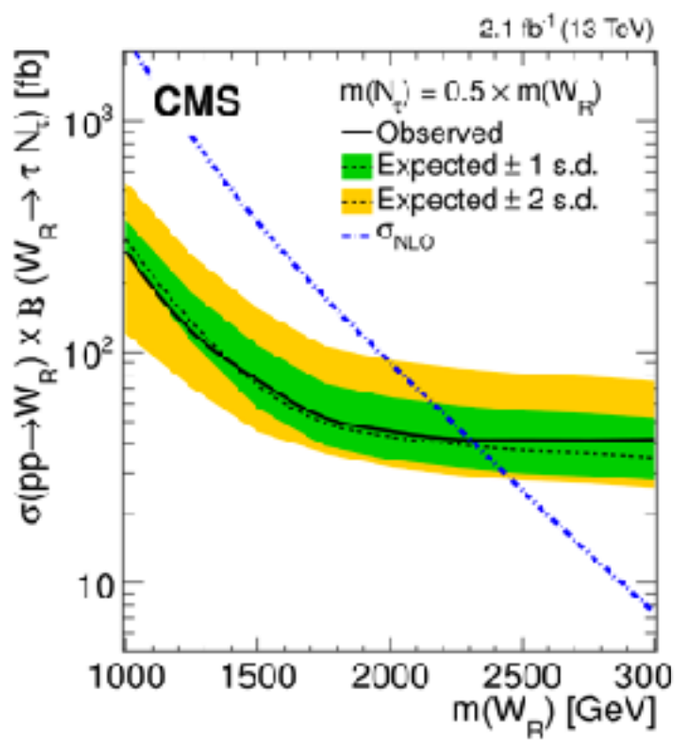


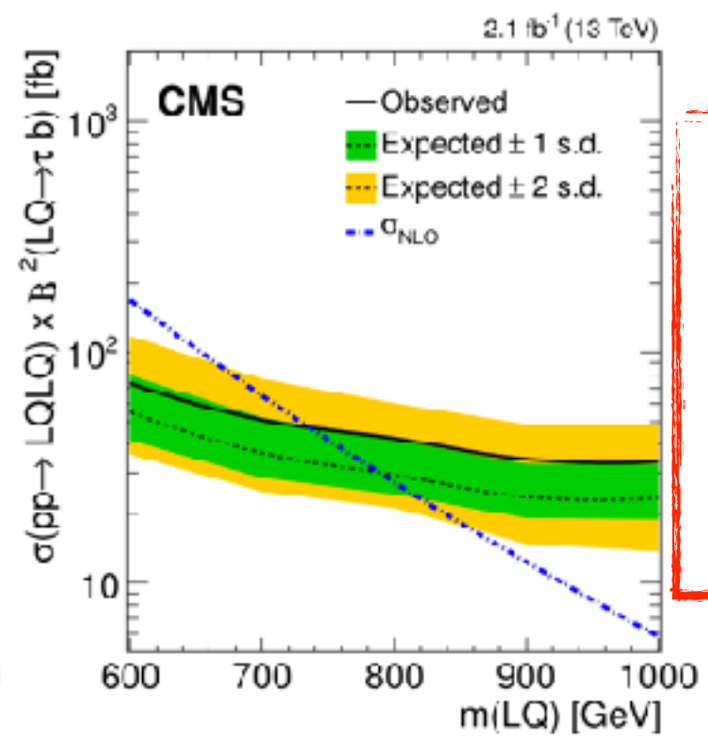
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-16-031/index.html

Di-tau + jets search

- Events: 2 high-p_T τ decaying hadronically + at least two high-p_T jets, and E_T^{miss}
- Search for:
  - → Heavy right-handed neutrinos N_l + and right-handed charged bosons, W_R (arising in a left-right symmetric extension of SM)
    - → m(W_R) boson below 2.35 (1.63) TeV excluded assuming only the Nτ flavor contributes to the W_R the m(Nτ)=0.8 (0.2) times m(W_R)
  - → Pair production of 3rd-generation scalar LQ decaying into ττbb
    - → Masses below 740 GeV are excluded, assuming B.R.(LQ→τb)= 100%







First search at hadron colliders for 3rd-generation LQ!

http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO-16-016/index.html

Heavy Higgs searches in Run 1

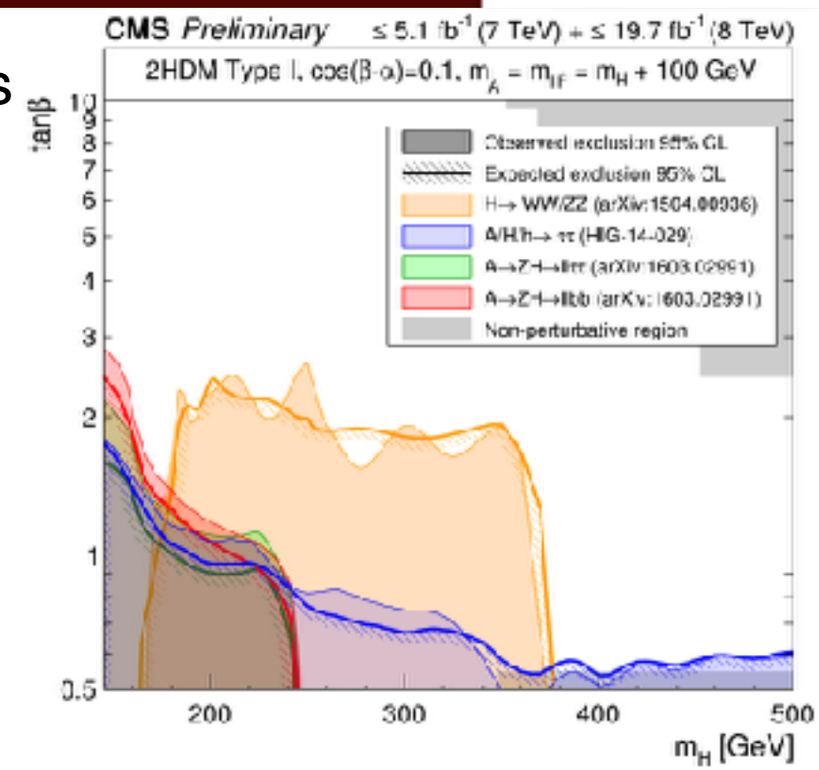
- Several analysis considered:
  - → H → WW/ZZ (145<m<1000 GeV), 55 event categories in WW(2l2ν), WW(2l2q), ZZ(4l), ZZ(2l2ν), ZZ(2l2q).
  - → A/H/h → ττ (90<m<1000 GeV), sensitive variable is $m_{\tau\tau}$. ($\tau_\mu\tau_\mu$, $\tau_e\tau_\mu$, $\tau_\mu\tau_h$, $\tau_e\tau_h$ and $\tau_h\tau_h$) and → μμ (115<m<300 GeV). Most sensitive CMS search to all three neutral Higgs bosons in the MSSM.
  - → $H^\pm$ → τν-tb (τν dominates sensitivity). Divided in low and high mass region.
  - → A/H → bb (100<m<900 GeV). Prod. in assoc. with b-jets. Discriminant variable: invariant mass of the 2 leading b-jets.
  - → A → ZH (140<m<1000 GeV). Z goes into leptons, H into b-quarks or τ. In the llbb final state discriminating variables are m(bb) and m(llbb) (2-dimensional shape analysis). The decay A → ZH is 2HDM specific. In MSSM it is kinematically not allowed (A and H are degenerate in mass, with $m_H \geq m_A$)

- Two ways to obtain limits:
  - → Templates for the full signal prediction for each value in the exclusion plane of the considered scenario (m_A-tanβ for MSSM; m_H-tanβ for 2HDM).
  - → 95% CL limits on σ·Br of a single, narrow-width resonance (except for H → WW ZZ analysis). Limits translated into the exclusion plane.

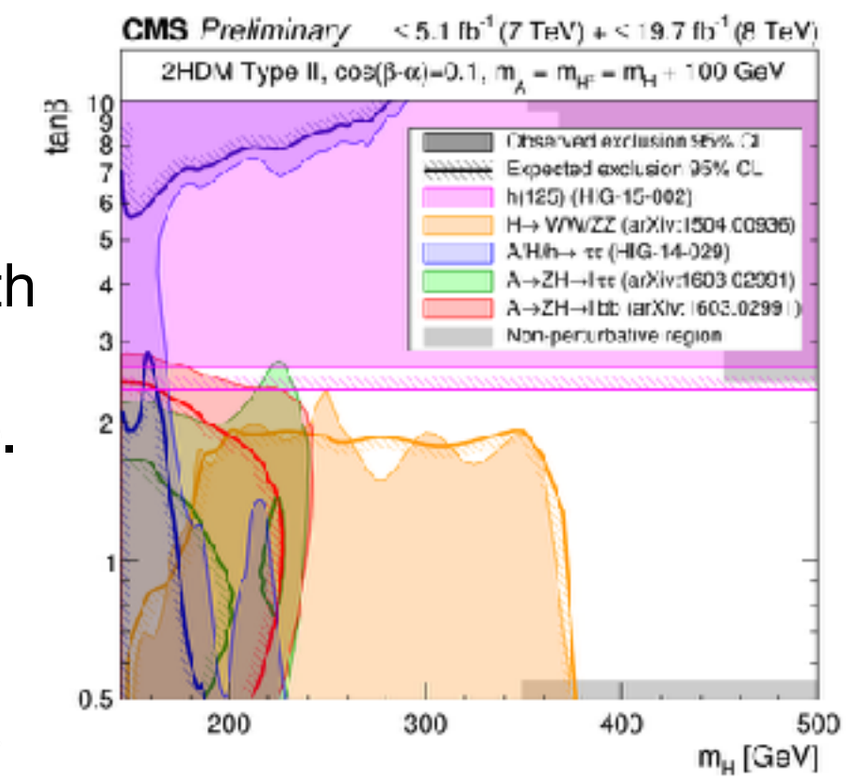
https://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-16-007/

Heavy Higgs searches in Run 1

- By definition the whole parameter space that is displayed is mostly compatible with the constraints imposed by the couplings of the Higgs.
  - → Observed exclusion: transparently filled areas
  - → Expected exclusion: slightly darker shade (with hatching)
  - → The gray shaded areas: non-perturbative or unstable.



- Lower boundary in m_H marks the kinematically allowed region for WW/ZZ. Upper boundary coincides with the opening of the decay into top-quarks.



- A→ZH analysis sharp edge at $m_H \sim 240$ GeV coincides with opening of the decay of the A into top-quarks.
  Final state llbb shows the larger expected exclusion range.

- A/H/h → ττ: for type-I the dominant contribution to the exclusion originates from the production via gluon fusion.

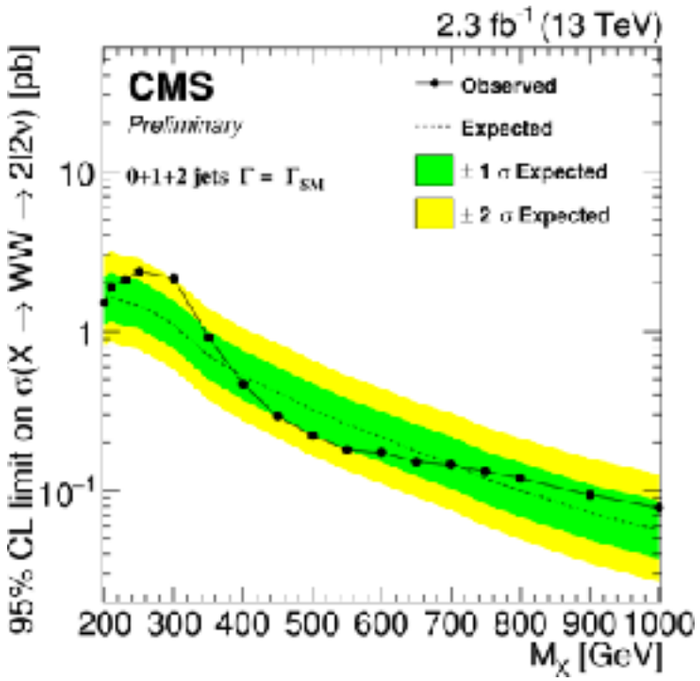
https://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-16-007/

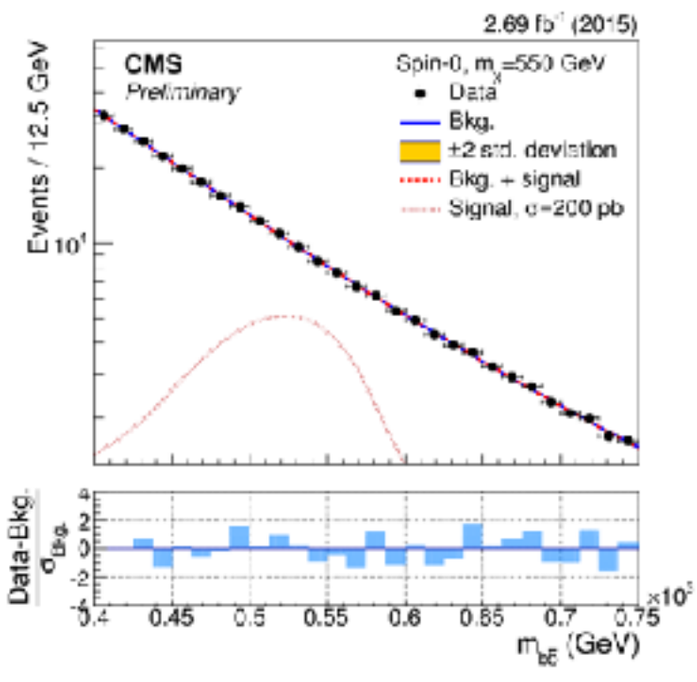
High mass: H→WW and H→bb

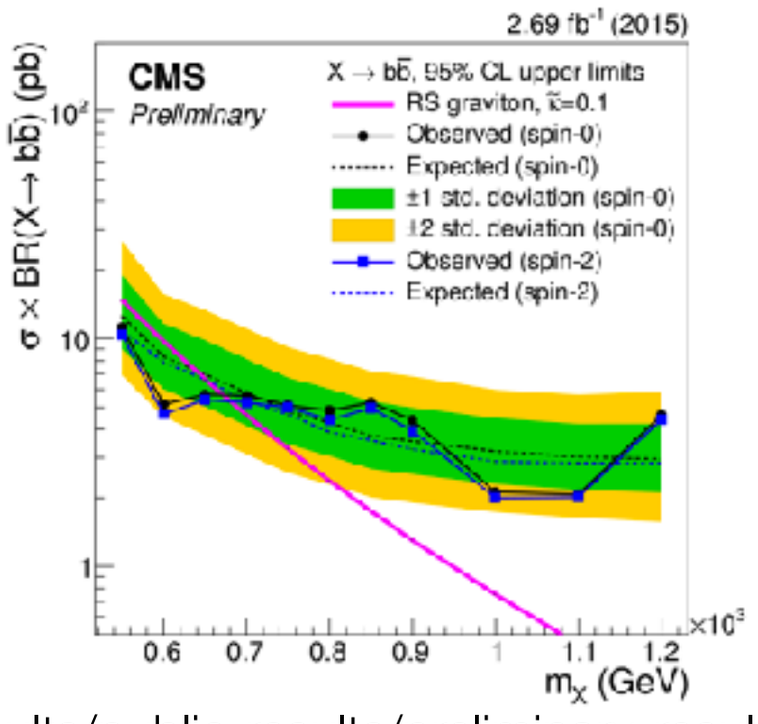
- H → WW (fully leptonic decay):
  - → Main background: WW and tt
  - → 3 categories: 0-jet, 1-jet, VBF
  - → Signal extracted by transverse mass of dilepton+MET

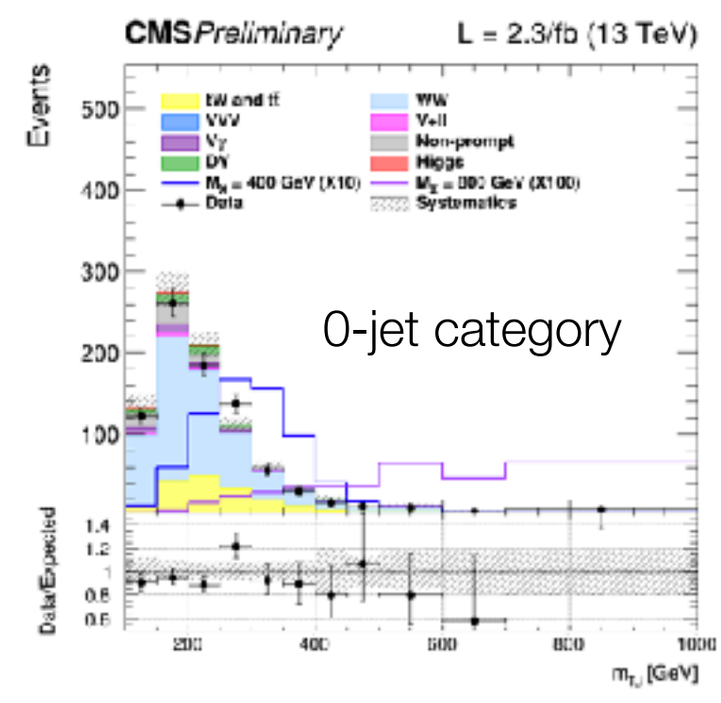
$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\ell\ell} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos \Delta\phi(\ell\ell, \vec{p}_{\mathrm{T}}^{\mathrm{miss}}))}$$

- H → bb:
  - → Signal (spin 0-2) simulated at LO with Pyhtia
  - → Large QCD background (plus tt, single-t)
  - → Final State Radiation need to be included



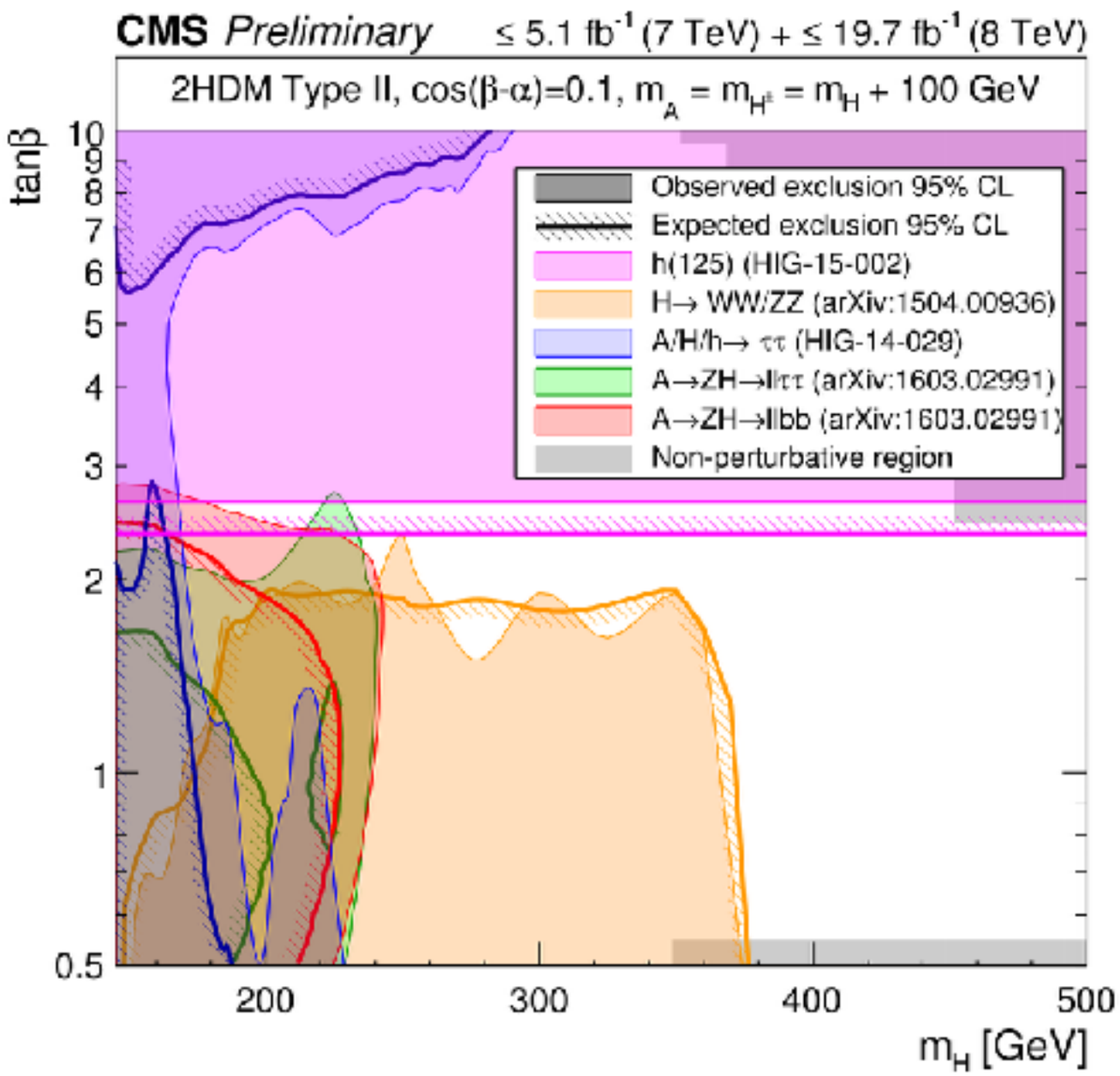


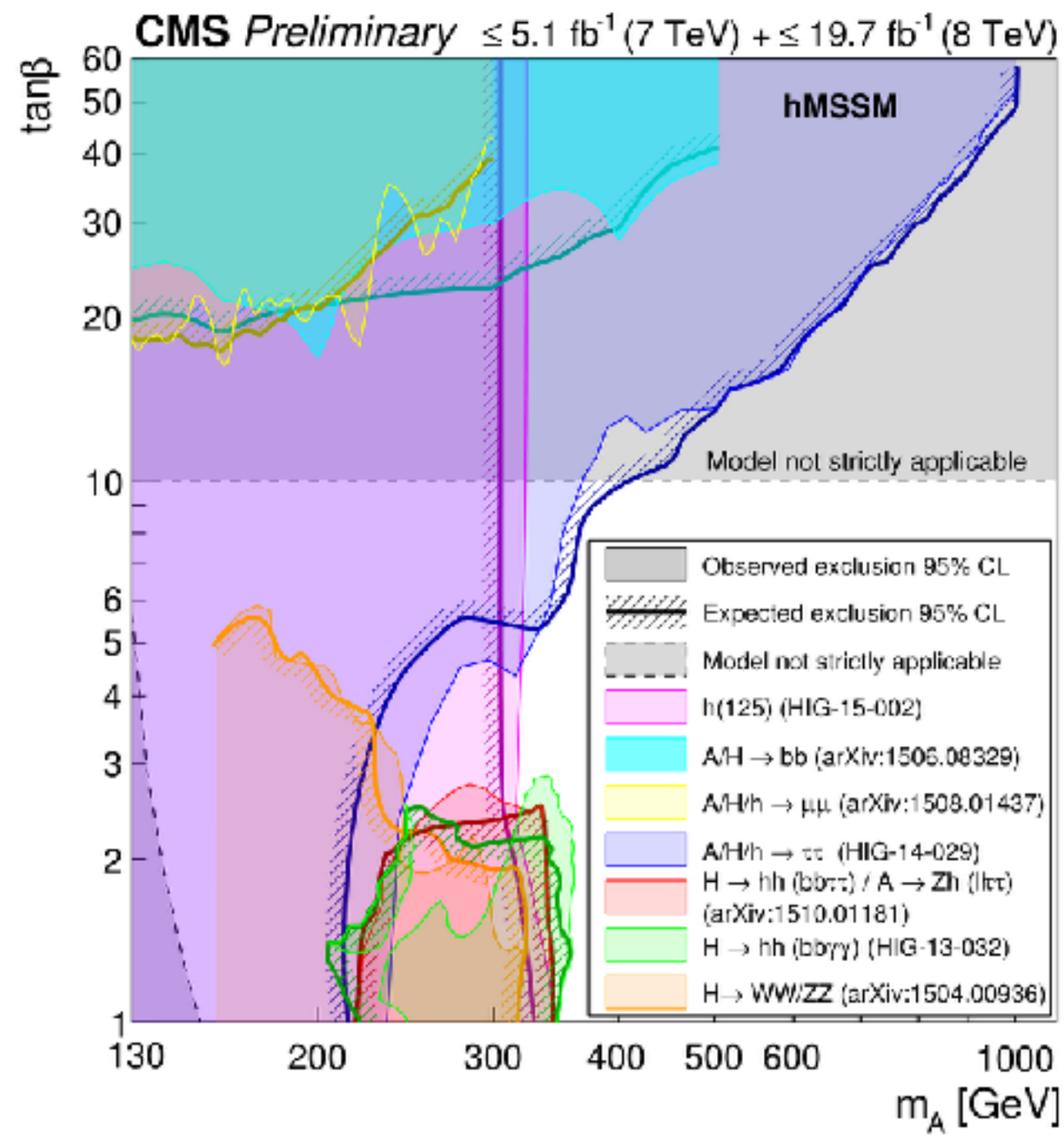




http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-16-025/index.html
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-16-023/index.html

Heavy Higgs searches in Run 1

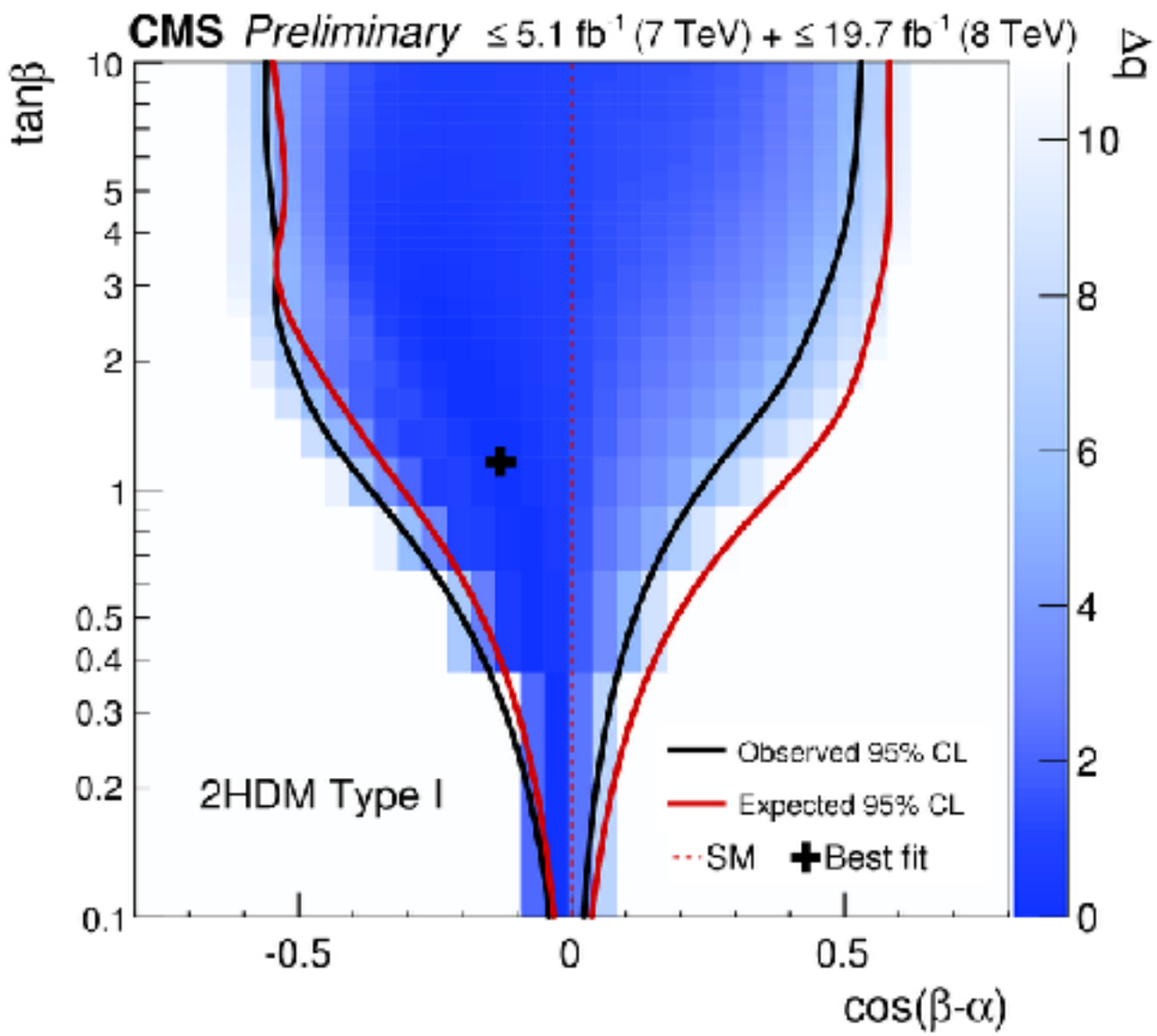


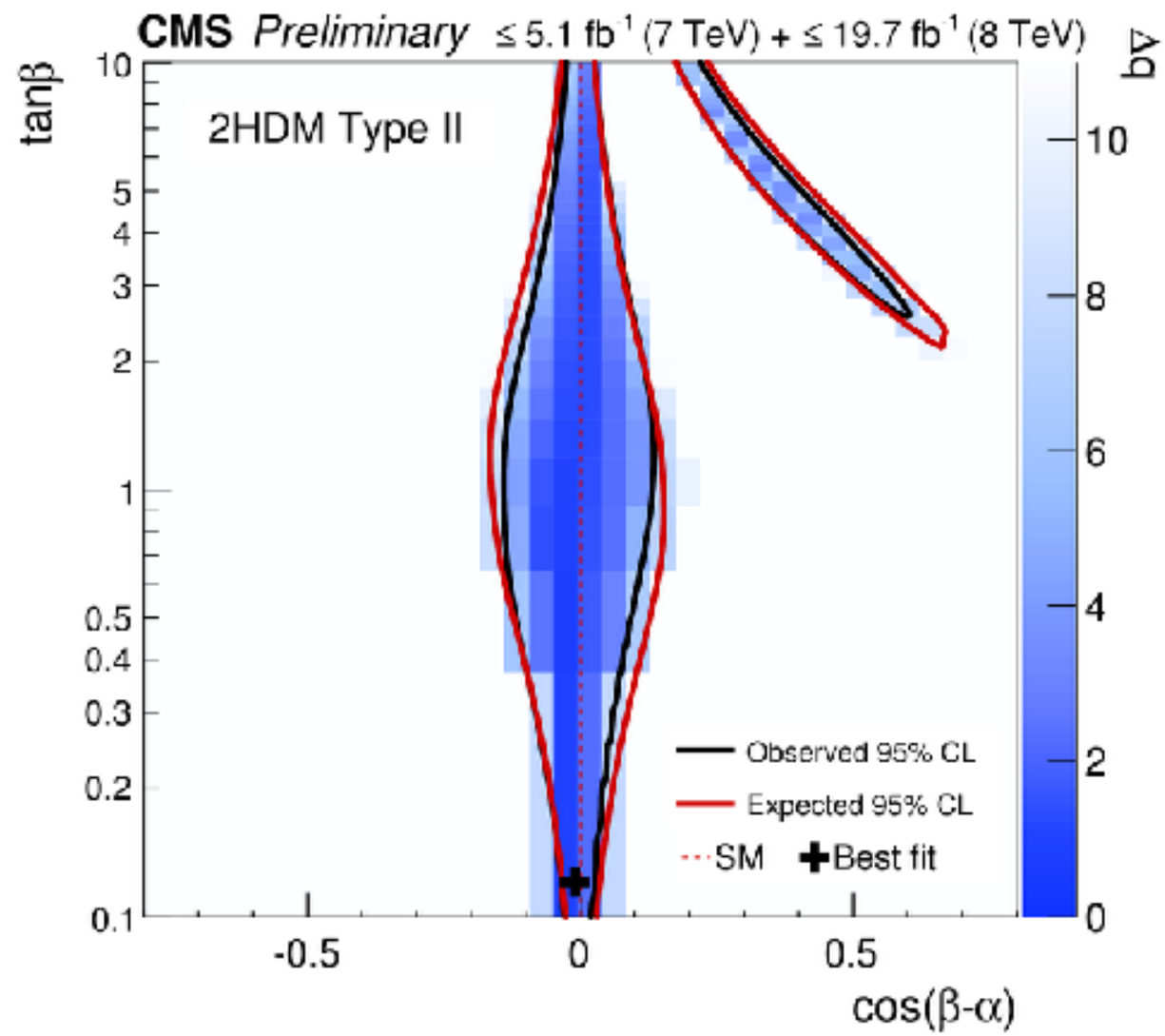


Constrain from h(125) observation

- 2HDM is constrained from H(125) properties:
  Preventing FCNC leave only two free parameters in the Higgs sector
  → tanβ: ration of vev's associated with the doublets
  → α: mixing between the fields associated with the doublets

$$q(\lambda_{du}, \lambda_{Vu}, \kappa_{uu}) = -2\ln\left(\frac{\mathcal{L}(\text{data}|\lambda_{du}, \lambda_{Vu}, \kappa_{uu})}{\mathcal{L}(\text{data}|\hat{\lambda}_{du}, \hat{\lambda}_{Vu}, \hat{\kappa}_{uu})}\right)$$

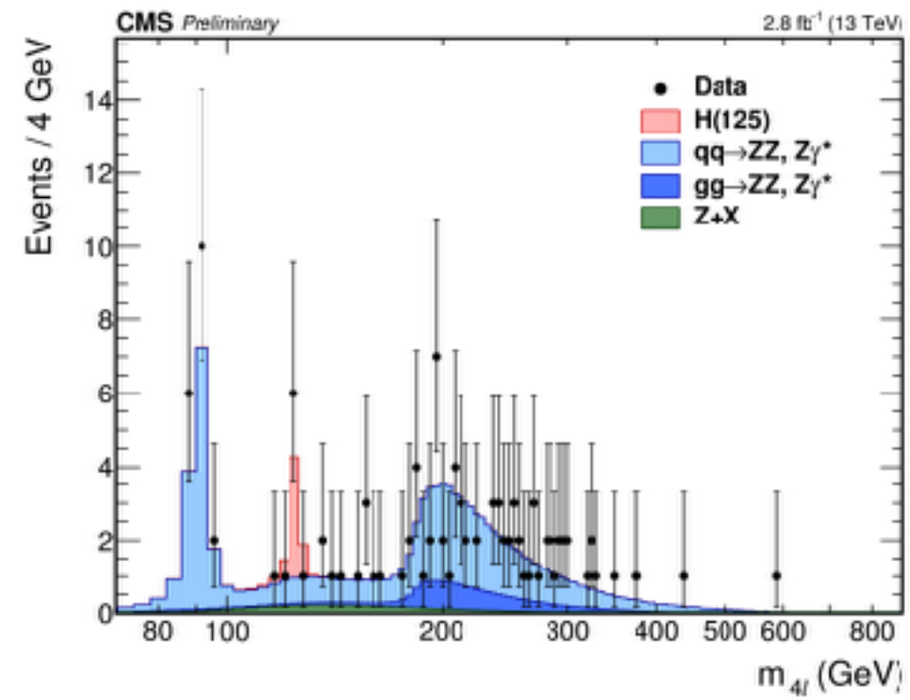




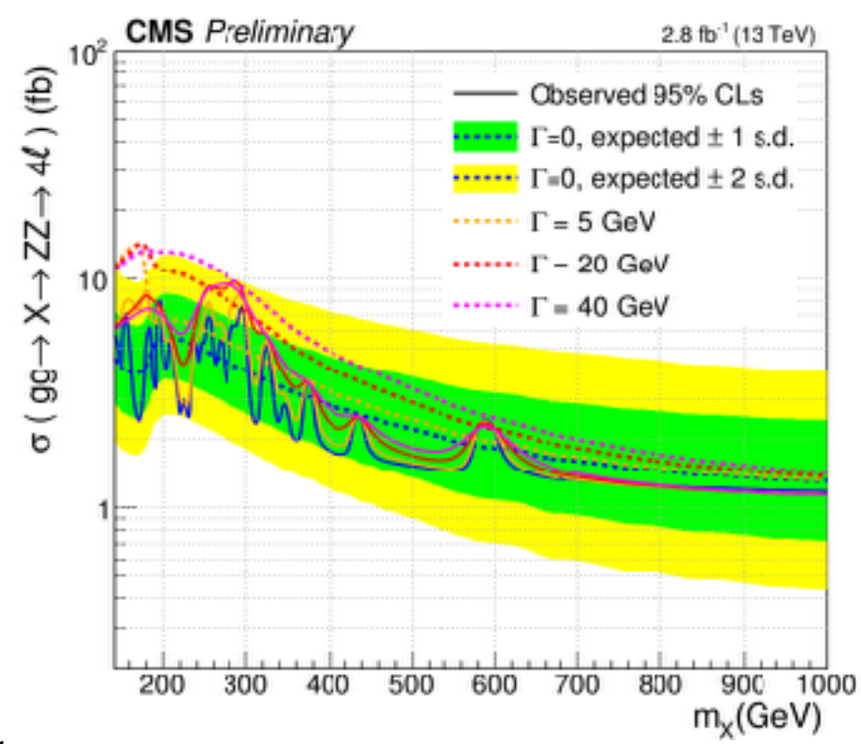
H→ZZ→4l @13 TeV

- Signal:
  - → H → ZZ → 4l (l = e,μ): analysis measures both SM-H and limits on additional resonances.
  - → Significance for SM-H: 2.5σ

- Backgrounds:
  - → ZZ (irreducible): estimated by simulation
  - → Z+jets, tt, Zγ + jets, WW+jets, WZ + jets (reducible): estimated by two independent control regions



- Search for add. narrow resonance, width less than 1% of m_H (dominated by the resolution)
  - → Acceptance and efficiency modeled using gluon fusion production for masses 120 - 850 GeV



- Few systematic uncertainties treated as shape (EWK correction). Fit to derive a 95% on σ × BR

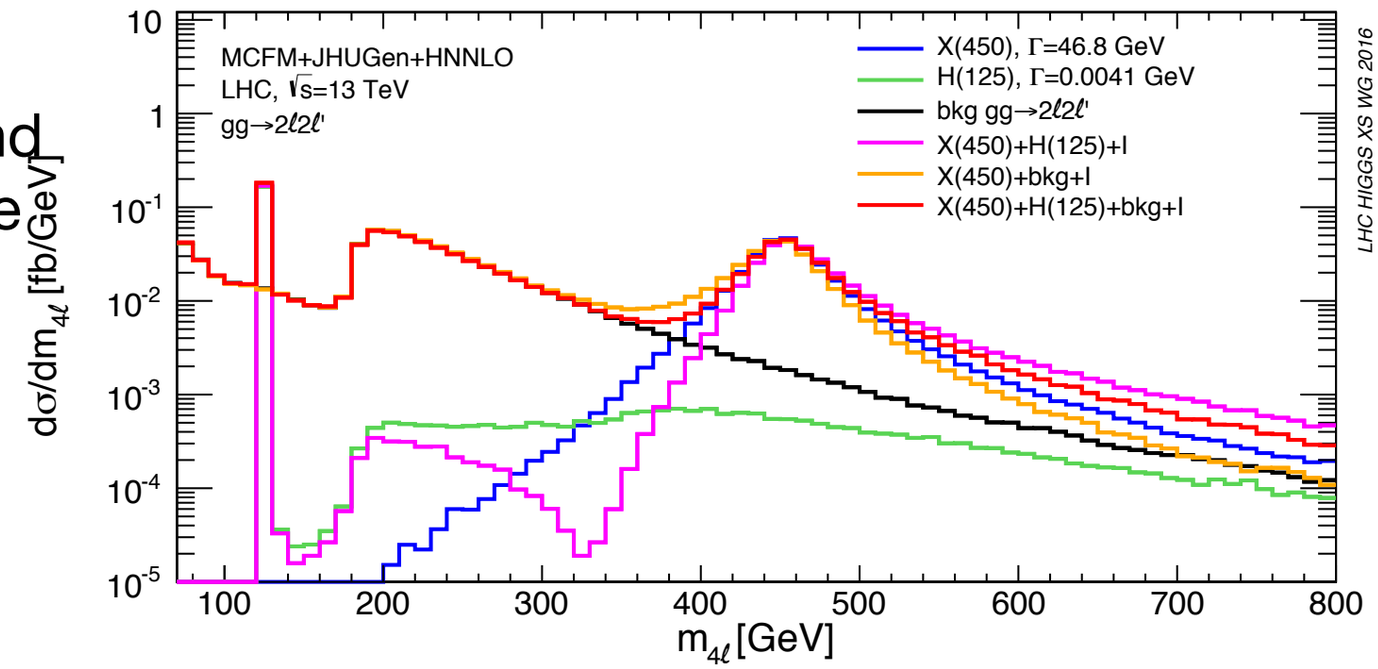
https://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-15-004

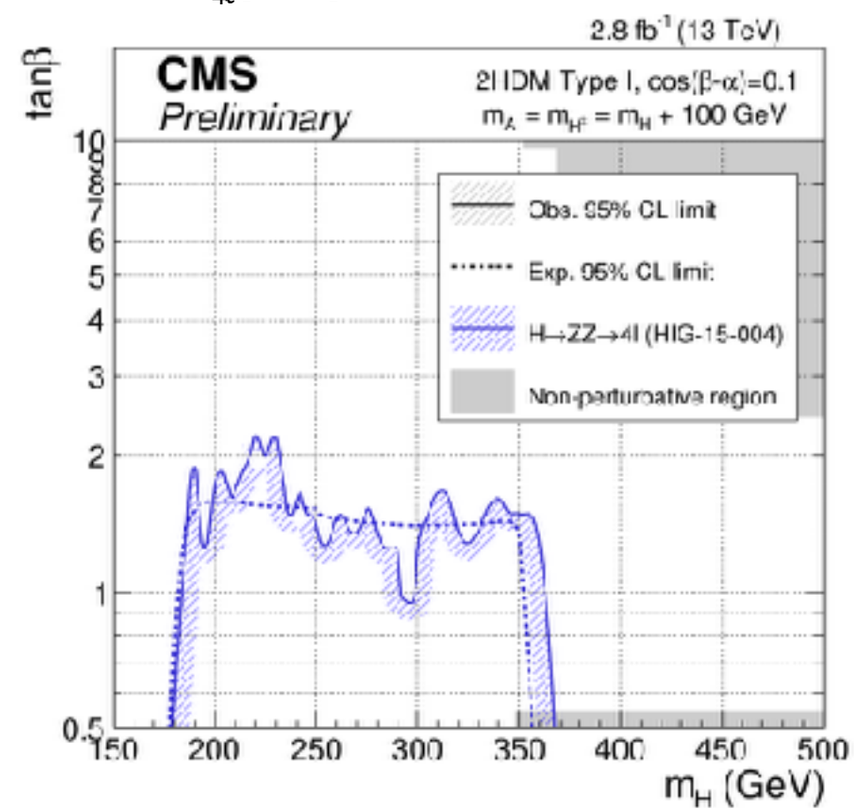
H→ZZ→4l @13 TeV

- Search for any resonance is of high priority. Recent hints of an excess around $m_{\gamma\gamma} \sim 750$ GeV make this task even more urgent.

- Production mechanism at high mass is predominantly gluon fusion with substantial contribution from VBF (here only gluon fusion).

- Treated as one process in gg-fusion:
  - → $P(m_{4l}, m_X, \Gamma_X, \sigma_X)$ for the gg →bkg + H(125)*+ X(mX) → 4l allows inclusion of interference, including off-shell tail of H(125)
  - → m_H, Γ_H, m_X, Γ_X are also included as general parameters of the model
  - → Limits at the 95% CL on $\sigma \cdot Br$ for several values of Γ_X

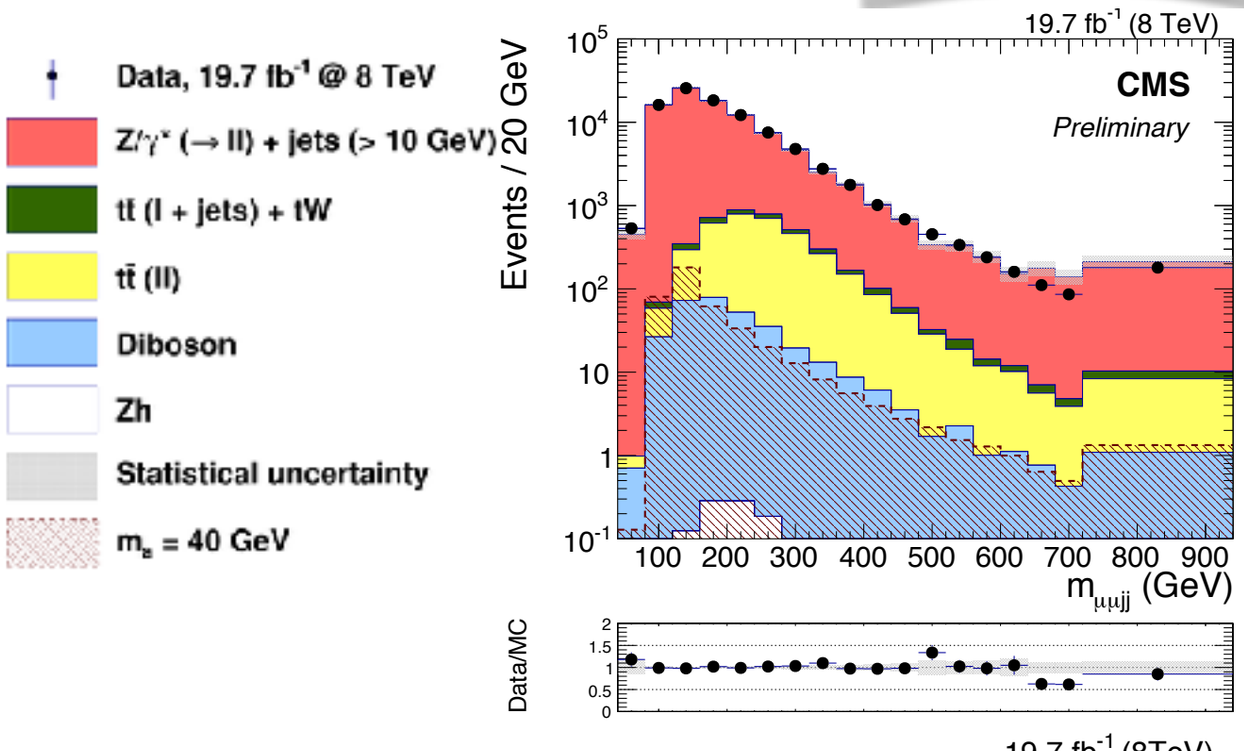




https://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-15-004

H(125) → aa → μμbb

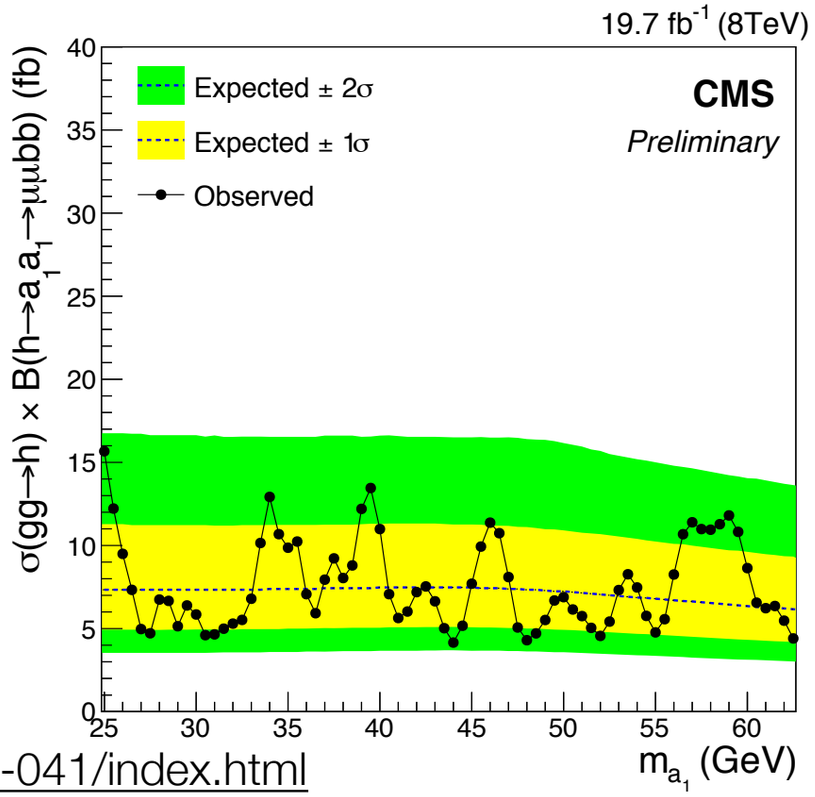
- Signal:
  - → SM Higgs decaying to 2 light bosons a (foreseen by in NMSSM or 2HDM)
  - → Only the gluon fusion production mechanism considered
  - → Here: m(a) ~ [25,65] GeV



- Selection:
  - → 2 muons with p_T > 24 and 9 GeV
  - → 2 jets with p_T >15 GeV (b-tagged)
  - → |m(μμbb)-125| < 25 GeV

- Main background:
  - → Z + jets, tt

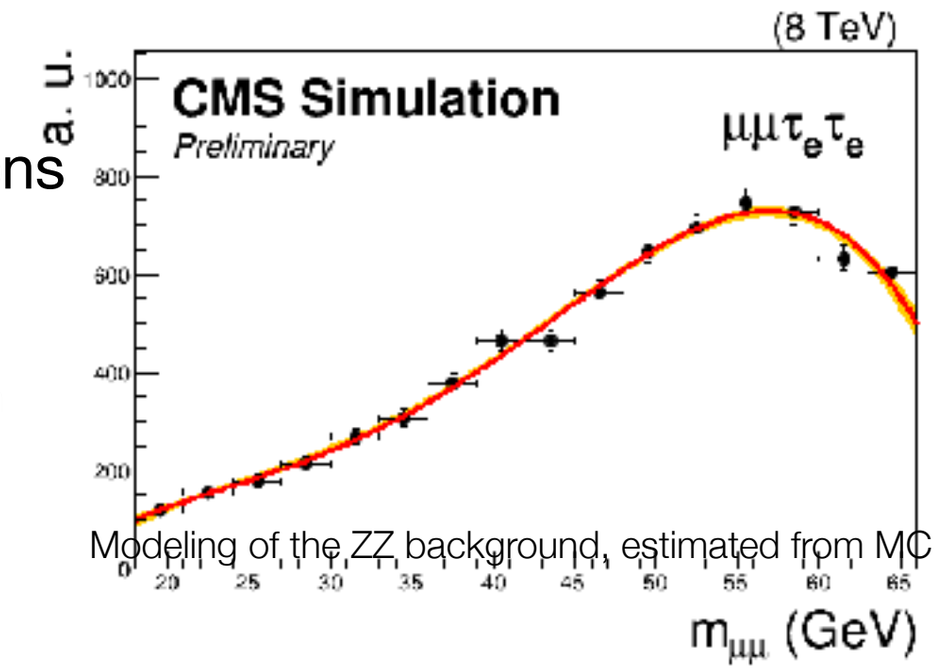
- Sensitivity extracted using a fit to m(μμ) distribution:
  - → Limits on the production rate times B.R.



https://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-14-041/index.html

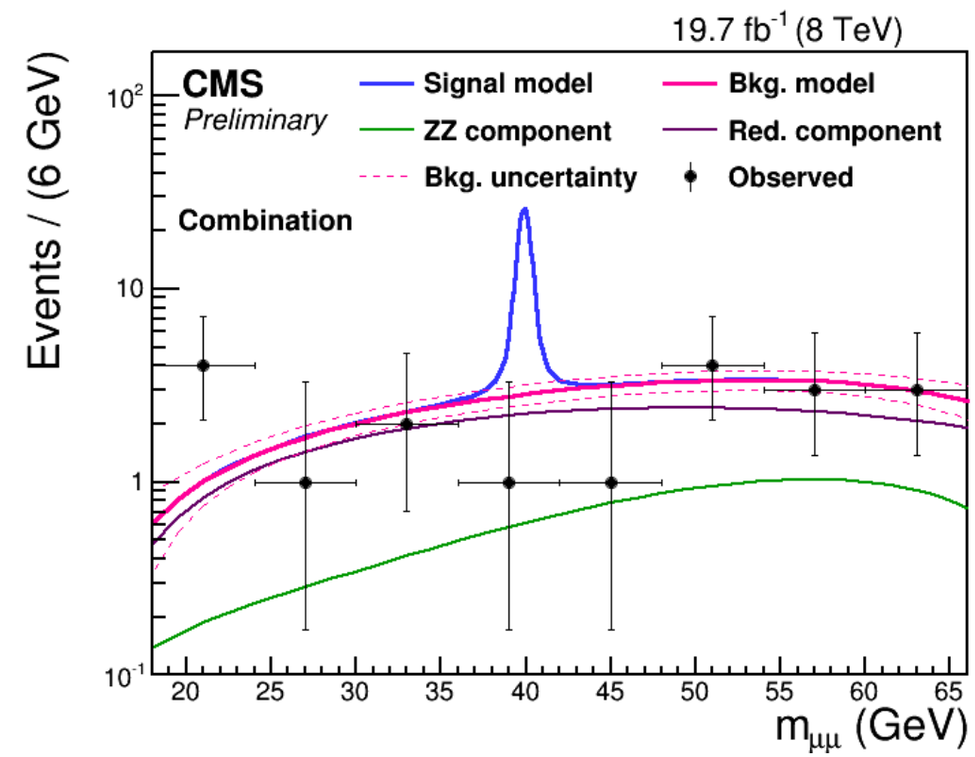
H(125) → aa → μμττ

- Signal:
  - → SM Higgs decaying to 2 light pseudoscalar bosons (foreseen by 2HDM or 2HDM+S)
  - → m_a ~ [20,63] GeV
  - → Considering: $\mu\mu\tau_e\tau_h$, $\mu\mu\tau_\mu\tau_h$, $\mu\mu\tau_\mu\tau_e$, $\mu\mu\tau_e\tau_e$, $\mu\mu\tau_h\tau_h$ ($\mu\mu\tau_\mu\tau_\mu$: ambiguities in pairing muons)



Modeling of the ZZ background, estimated from MC

- Selection:
  - → Two μ with p_T > 18/9 GeV
  - → p_T > 5,7,15 GeV for τ_μ, τ_e and τ_h
  - → |m(μμττ)-125| < 25 GeV
  - → |m(μμ)-m(ττ)| < 0.8 m(μμ)



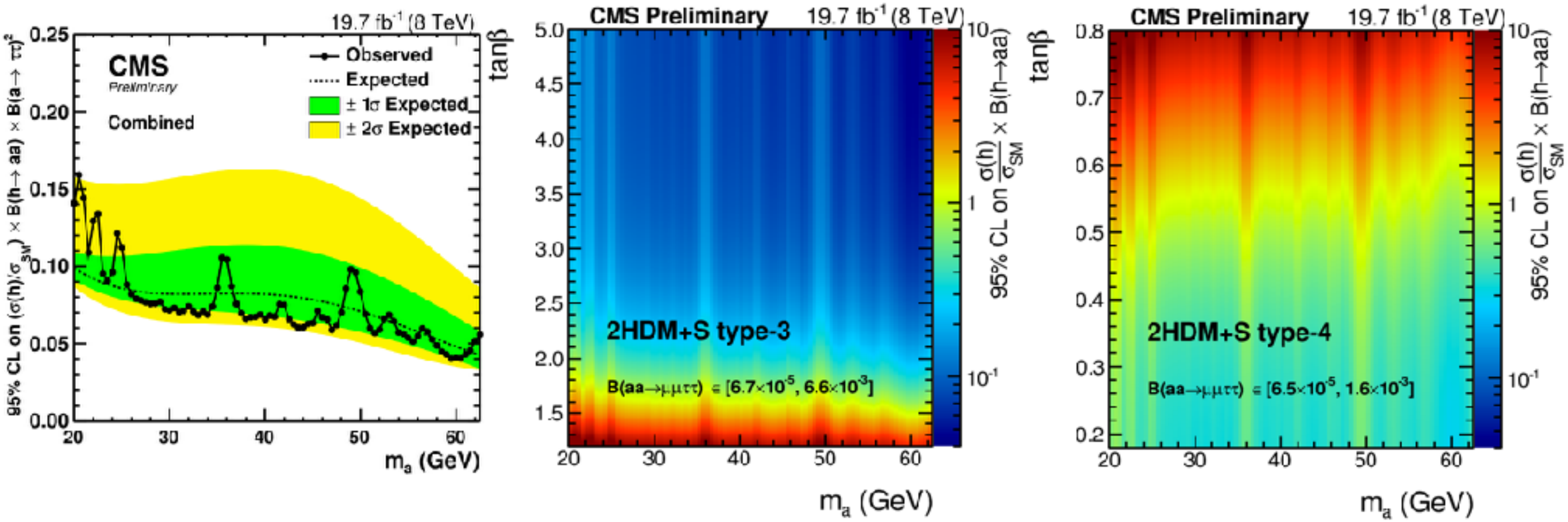
- Main background:
  - → Irreducible ZZ production
  - → Reducible processes with at least one jet misidentified (Z+jets and WZ+jets).

https://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-15-011/index.html

H(125) → aa → μμττ

- Upper limits on h→aa production relative to the SM h production, scaled by B(a → ττ)^2
  - → Data comparable with background-only hypothesis (No excess exceed 2σ glob. significance)
  - → Set 95% C.L. upper limits on signal event rate
  - → Limits in the context of 2 HDM+S models

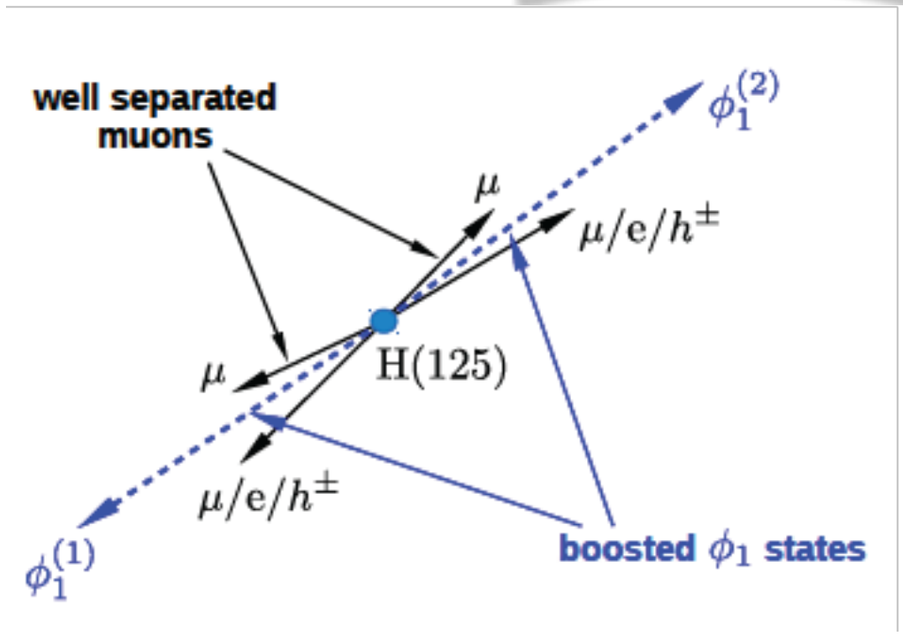
$$\frac{\Gamma(a \to \mu\mu)}{\Gamma(a \to \tau\tau)} = \frac{m_\mu^2\sqrt{1-(2m_\mu/m_a)^2}}{m_\tau^2\sqrt{1-(2m_\tau/m_a)^2}}$$



https://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-15-011/index.html

H(125) → aa → ττττ

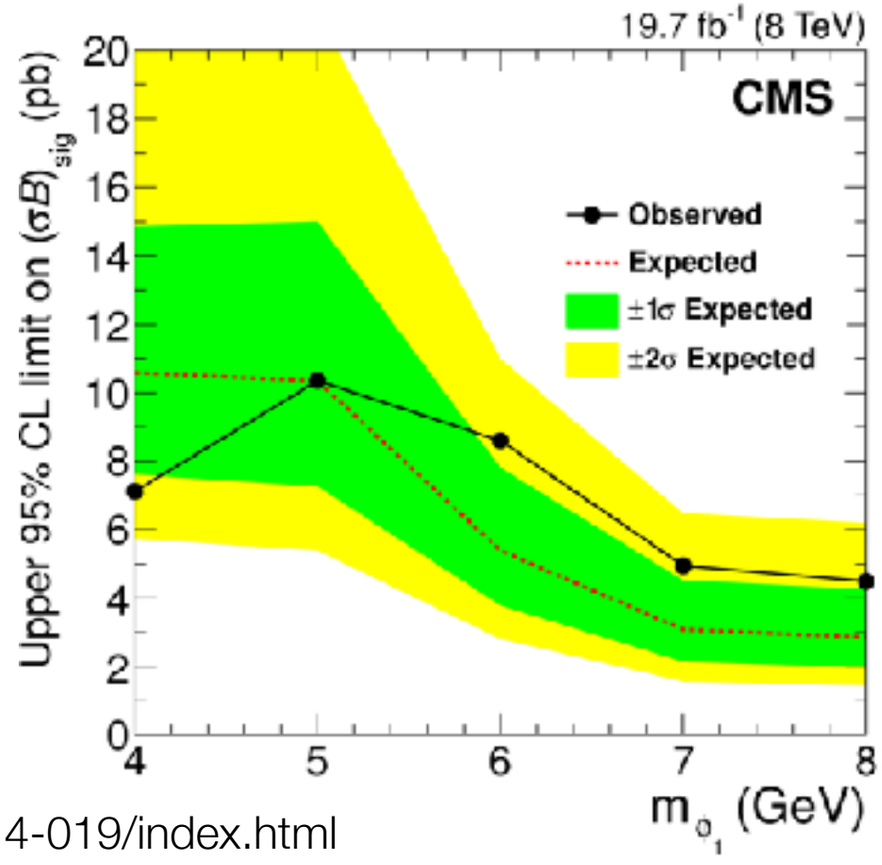
- Signal:
  - → SM-Higgs decaying into 2 light bosons Φ_1 (=a_1,h_1) (foreseen by NMSSM)
  - → SM-H corresponds to:
    - → h_2 and decays into $h_2 \to 2h_1$
    - → h_2 and decays into $h_2 \to 2a_1$ ($2m_\tau < m(a_1) < 2m_b$)
    - → h_1 and decays into $h_1 \to 2a_1$



- Selection:
  - → One τ goes to μ and other to one-prong mode
  - → Two same sign μ with p_T>17/10 GeV and |η|<2.1
  - → One opp. sign track with p_T>2.5 GeV and |η|<2.4

- Main background: QCD multijet events

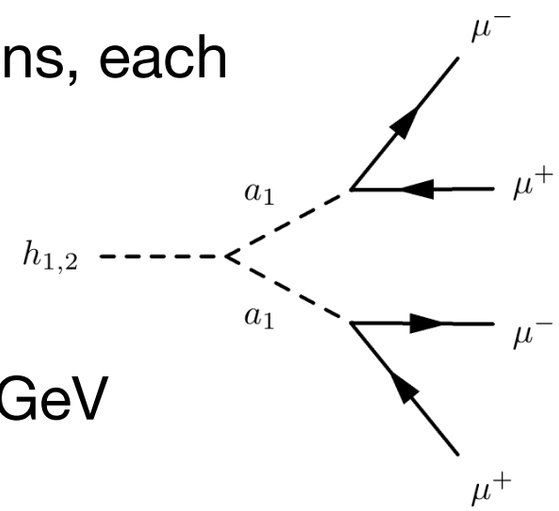
- 95% C.L. upper limit set on the production rate of signal events

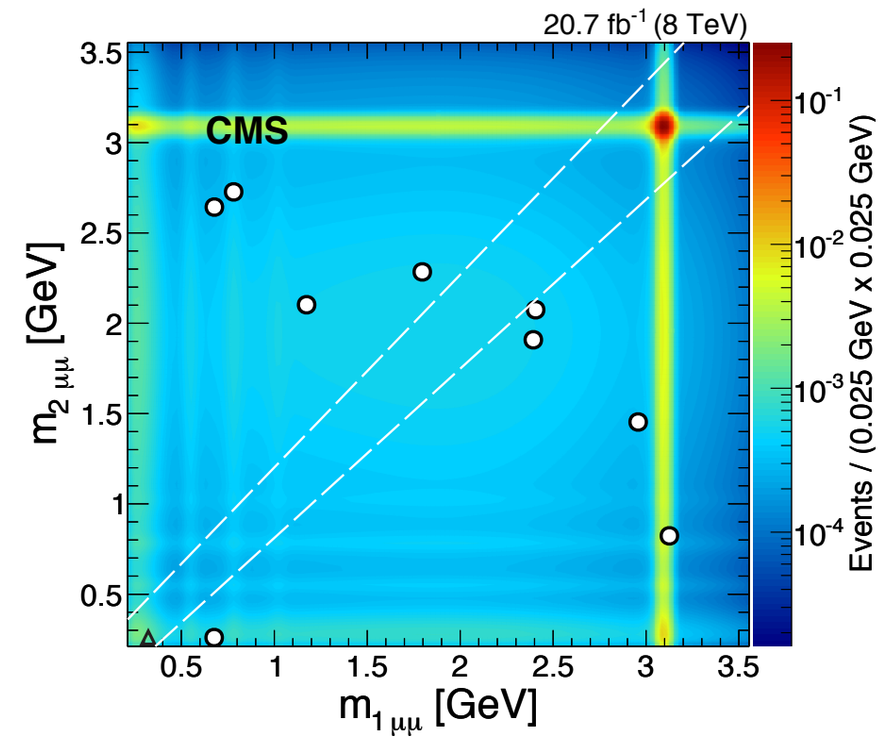


https://cms-results.web.cern.ch/cms-results/public-results/publications/HIG-14-019/index.html

Search for H→aa→μμμμ

- Signal:
  → Pair production of new light bosons, each decaying into a pair of muons

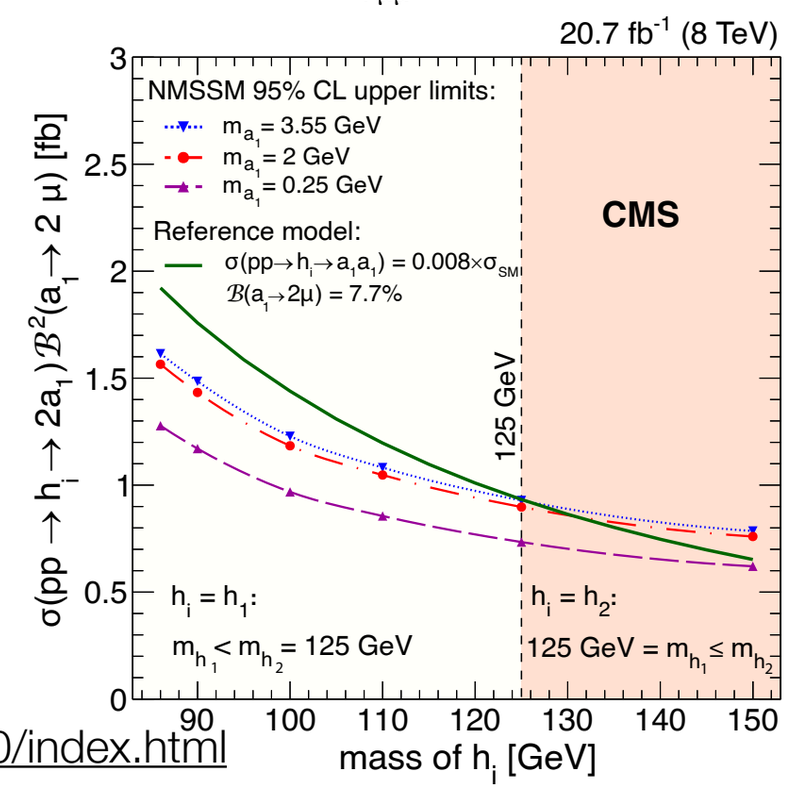




- Selection:
  → P_{T1}>17 GeV; $|\eta_1|$ <0.9; $P_{T2,3,4}$ > 8 GeV
  → $|z_{1\mu\mu} - z_{2\mu\mu}|$ < 1 mm

- Main background:
  → $b\bar{b}$, double J/Ψ (SPS and DPS)

- Excess searched on the diagonal:
  $|m_{1\mu\mu} - m_{2\mu\mu}| < 0.13$ GeV + $0.065(m_{1\mu\mu} + m_{2\mu\mu})/2$
  → Model independent search, benchmark model is NMSSM
  → Assume SM-like production σ for $h_{1,2}$ to simplify interpretation



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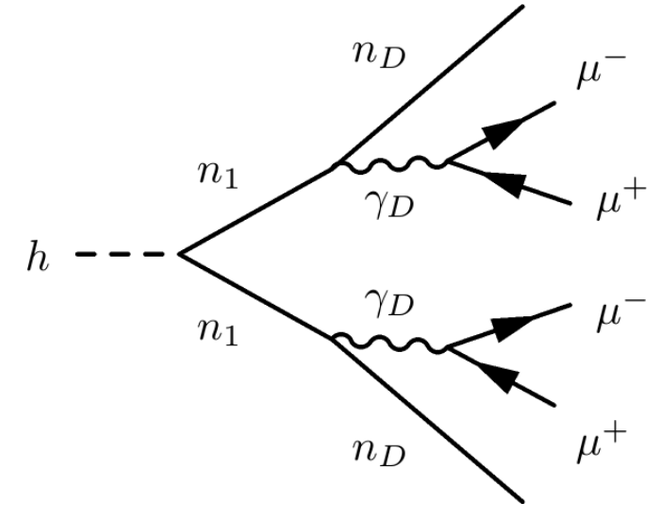
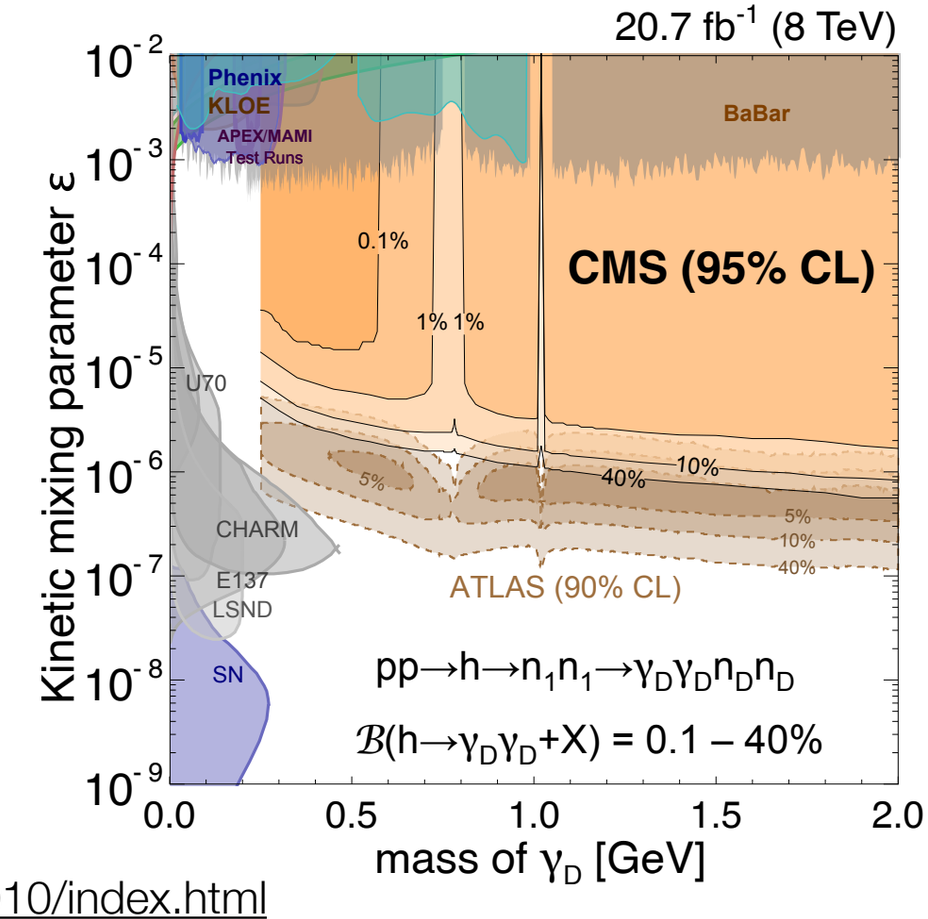
Search for H→aa→μμμμ

- Additional Benchmark: Dark SUSY
  $h \rightarrow n_1 n_1 \rightarrow n_D n_D \gamma_D \gamma_D + X$
  - → Dark photons could have an appreciable life-time before decay
  - → Dark photons are generated with m(γ) in the range 0.25–2.0 GeV and a decay length in the range of 0–20 mm



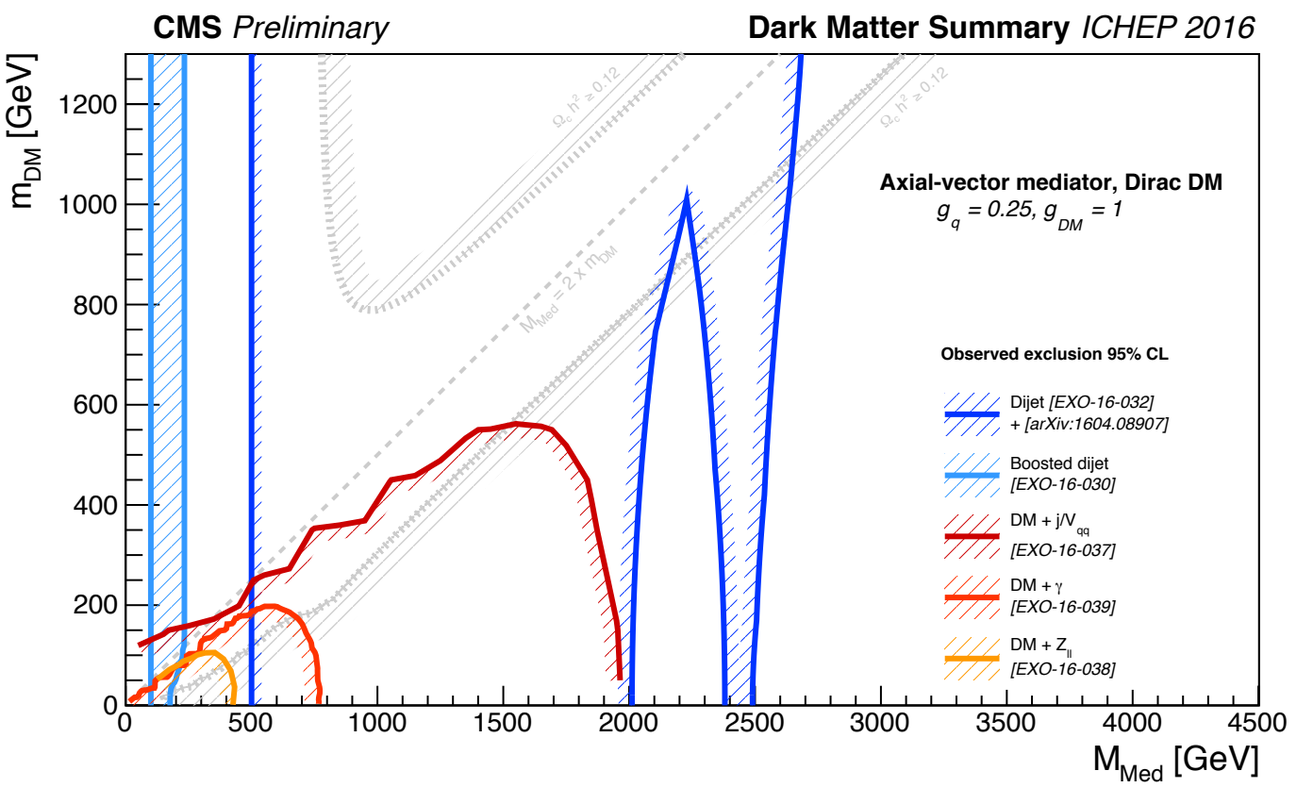
- 95% CL limit on H boson production σ·B.R.
  - → The limit set in the [m(γ_D),ε] plane.
  - → Implies model dependence when comparing to low energy results
  - → Nice complementarity with ATLAS analysis searching for decays far from the interaction point

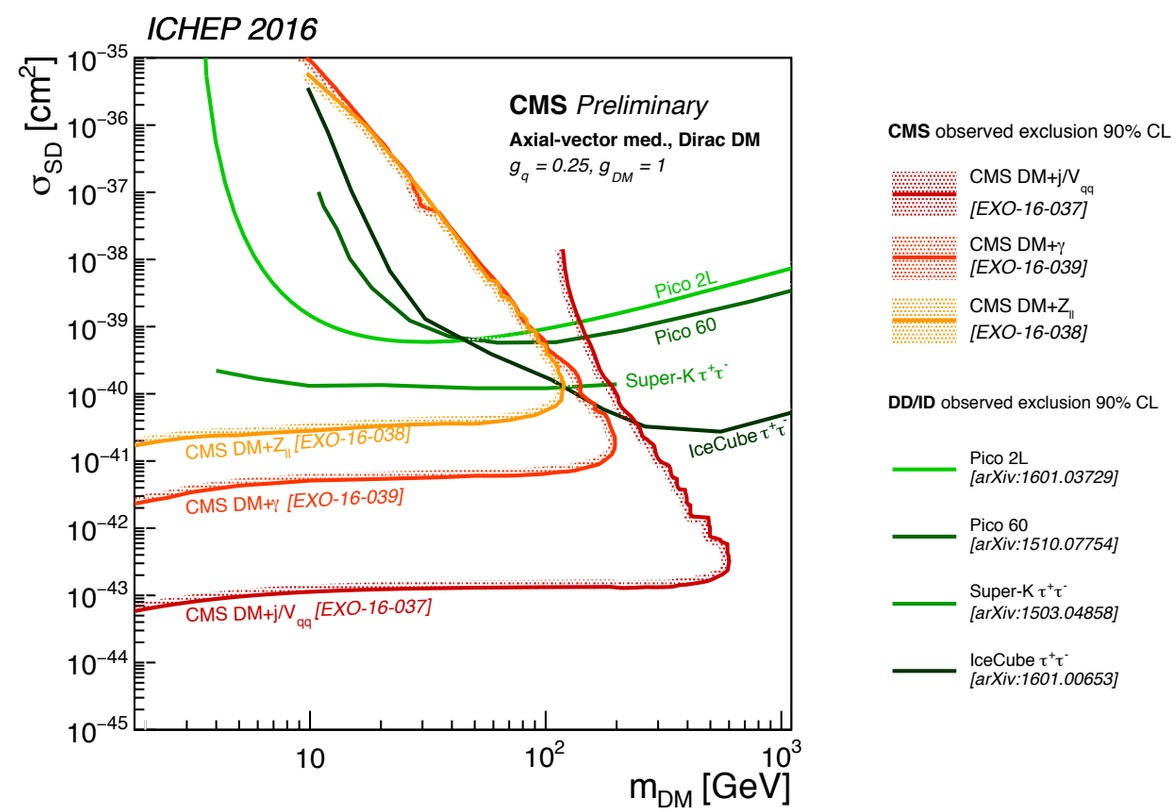


https://cms-results.web.cern.ch/cms-results/public-results/publications/HIG-13-010/index.html

Dark Matter Summary plots

- Searches di-jet and E_T^{miss} based in leptophobic Axial Vector model
- Exclusions computed for universal quark coupling g_q=0.25 and for a DM coupling of g_{DM}=1
- Limits are shown at 90% CL. The CMS contour in the SD plane is for an Axial Vector mediator, Dirac DM (g_q = 0.25, g_{DM} = 1)





- Exclusion depends on the chosen coupling and model scenario
  → Exclusion regions not applicable to other choices of coupling values or model

https://cds.cern.ch/record/2208044