Highlights from LHC

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Prologue

Not a status report

A small selection of interesting results from ATLAS and CMS only

Keeping in mind the organizers' request for reporting deviations!

This talk is based on materials publicly available (by mainly ATLAS & CMS colleagues)

→ Will discuss some results from ATLAS and CMS experiments (personal take)

→ Present personal perspective

Apologies for personal bias for CMS collaboration
& if I have missed mentioning your favourite process

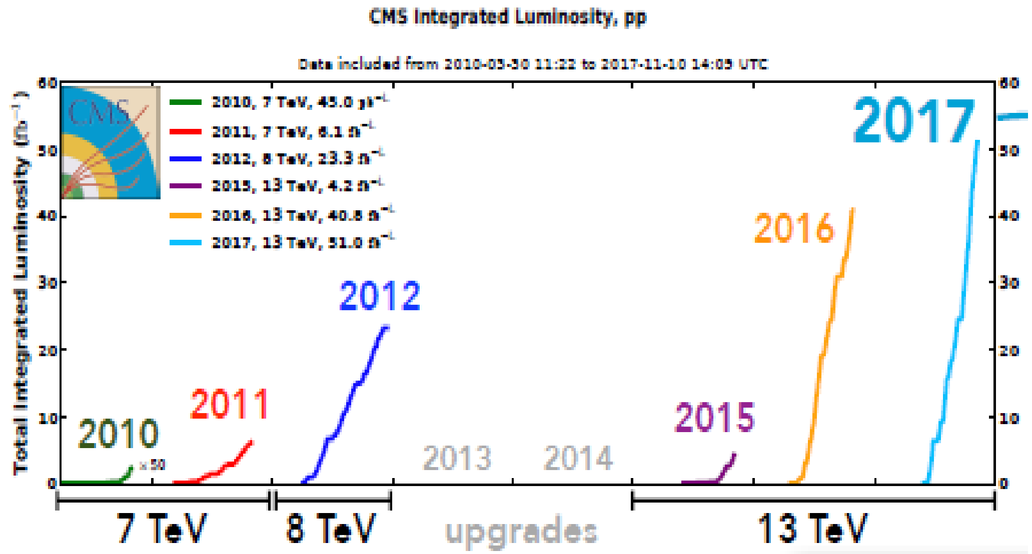
Ode to LHC

proton-proton collisions

Run2: √s = 13 TeV

✓ 2015: $\mathcal{L}$ ~ 4 /fb
✓ 2016: $\mathcal{L}$ ~ 40 /fb

❑ 2017: Highest instantaneous luminosity ever in stable beams
$L = 2.05\times10^{34} cm^{-2}s^{-1}$
➔ $\mathcal{L}$ ~ 50/fb



❑ Also had a brief operation with low luminosity needed for precise measurement of W mass.

❑ **Expect excellent productive operation of LHC in 2018 ➔ expect $\mathcal{L}$ ~ 50 /fb**

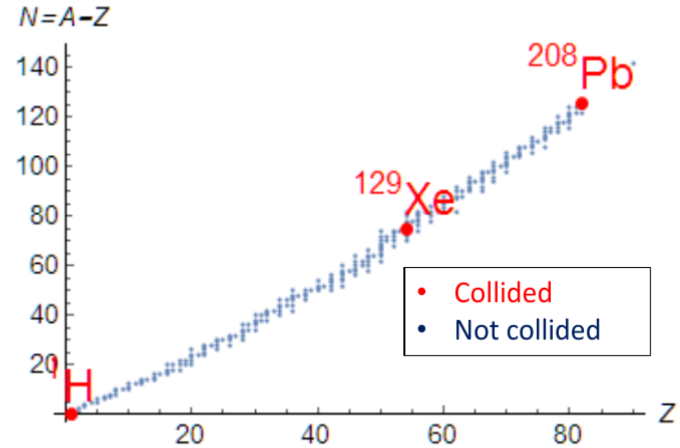
Target of Run2: $\mathcal{L}$ ~ 140 – 150 /fb

Run1: √s = 7 TeV, $\mathcal{L}$ ~ 6 /fb
= 8 TeV, $\mathcal{L}$ ~ 23/fb

Outstanding performance of LHC machine team

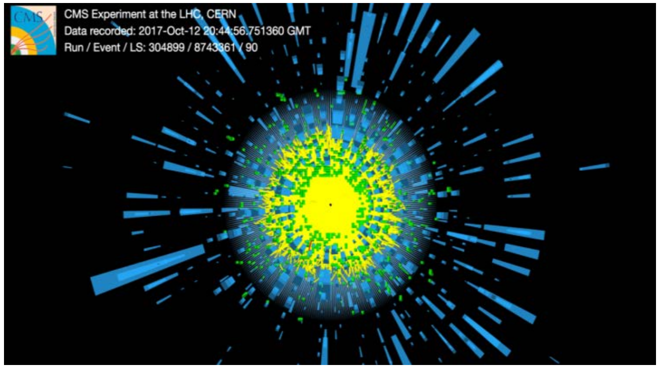
LHC operations in 2017 related to heavy ion studies

Xe-Xe (A=129, Z= 54) collisions :
→ demonstrates the flexibility of the LHC machine



- Fully stripped Xenon beams
- 2.72 TeV per colliding nucleon

- ❑ 300 pb^{-1} in ATLAS and CMS
- ❑ 100 pb^{-1} in LHCb



- **5 TeV pp run: as reference for HI physics data (lead-lead collision)**

→ 2.51 TeV per colliding proton
= energy of each colliding nucleon in Pb-Pb run (13 TeV * 82/ 208)

Big motivations for LHC

1. Discover or rule out existence of Higgs boson: √ done in 2012
2. Probe physics at TeV energy scale
3. ……

What we all know by now:

- Grand success of Standard Model (SM) established from precision data at LEP, Tevatron and LHC results so far

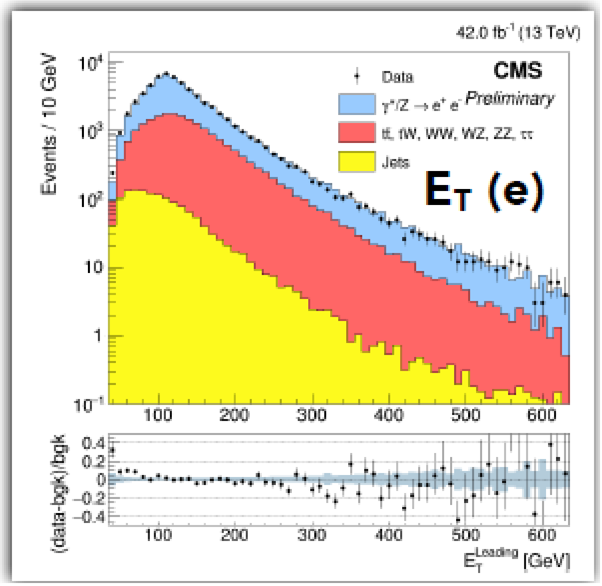
Fundamental discoveries in LHC after ~6 yrs.: Higgs boson (s?)
supersymmety??
extra space dimensions??....

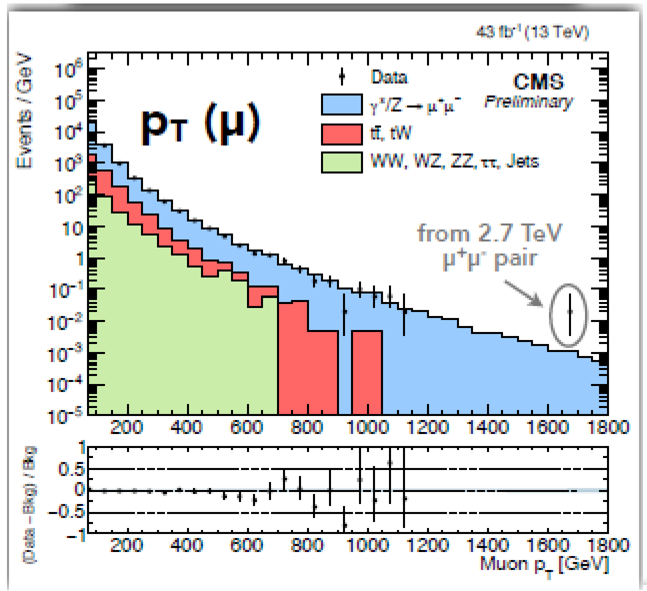
- **Open problems:** mechanism of electroweak symmetry breaking

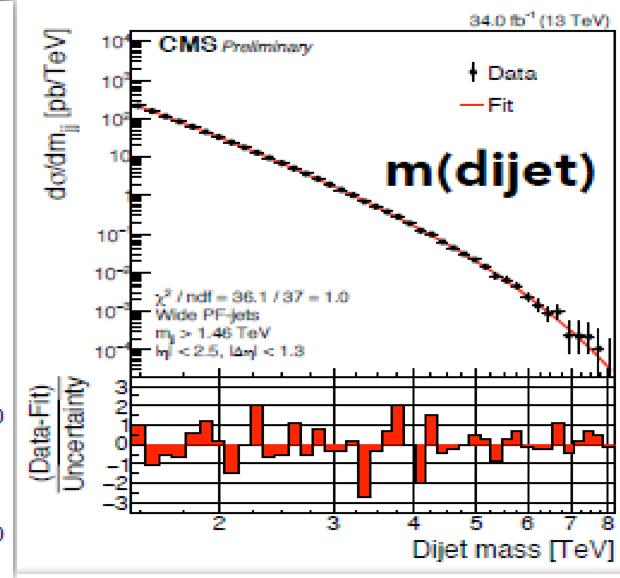
→ possibilities: (i) SM
(ii)SUSY,..,
(iii) Technicolour, Little Higgs, Extra dim.? unification of forces, space-time structure at short distaces

***We do not give up and also LHC is here to stay for a long time*.**

Performance by detectors

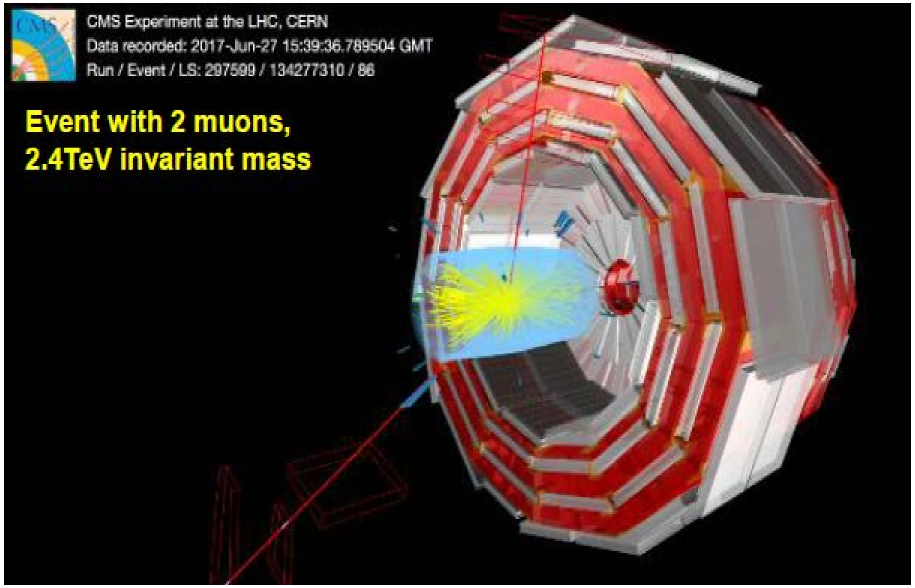




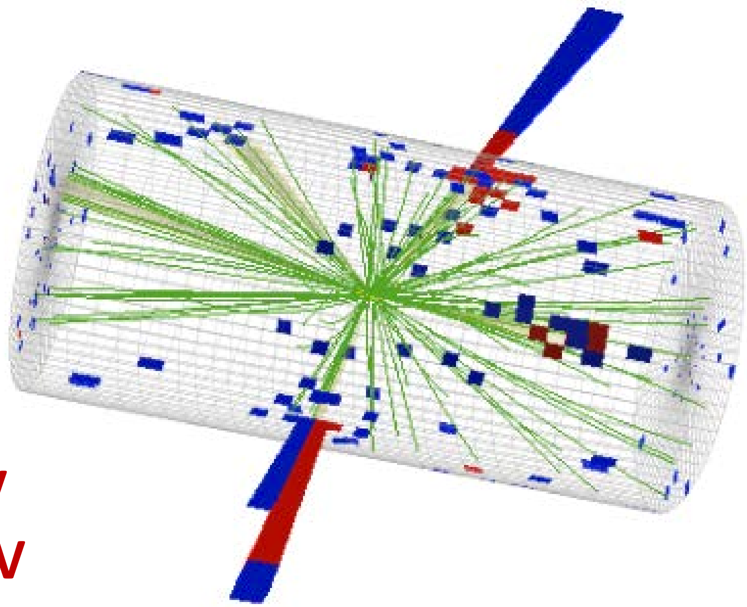


- **Physics highlights presented in this talk is based on data up to 2016 only.**
- **No result as yet from 2017 data**

High p_T physics with ATLAS and CMS



High mass di-muon event in CMS:
$m_{\mu\mu}$ =2.4 TeV



High mass di-jet event in CMS: m_{jj} = 7.7 TeV
ATLAS: m_jj = 9.3 TeV

Though both ATLAS and CMS experiments were designed for high p_T physics, both the experiments are doing extremely well in the area of reasonably low p_T physics

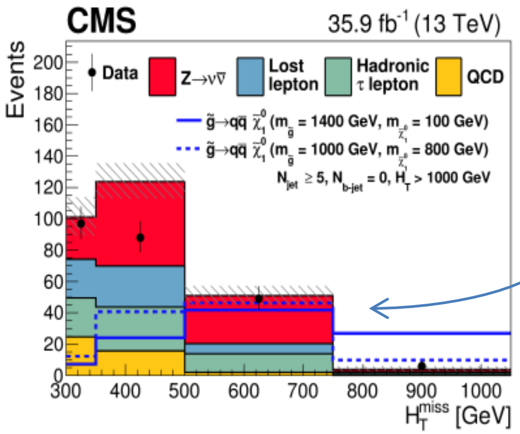
→ will not be covered in this talk ; could be discussed in WG sessions.

Searches for BSM physics

- Cover wide ranges of various final states
- Cover vast range of models
- Experimental searches typically model-independent

→ Look for resonances

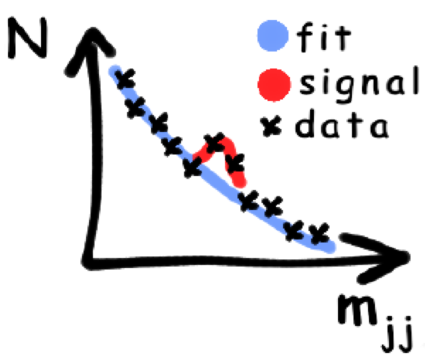
→ Look for excess in the tail of distribution or any disagreement.



Knowing ALL SM contribution is of paramount importance

Note signals could be hiding under the bulk!

Interpret results in simplified model scenario

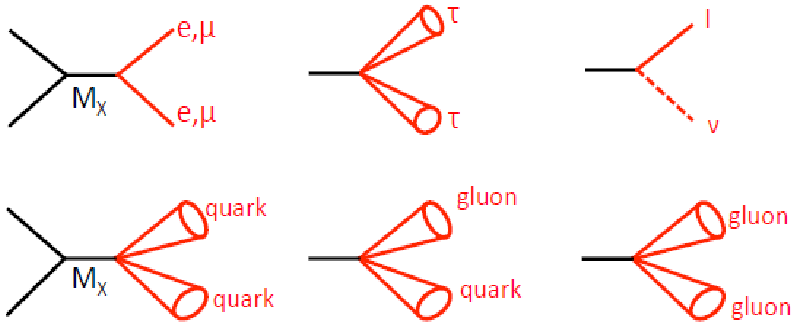


- Bump hunt if X production possible kinematically
- Main issue: estimation of background
- 2 methods: i) parametrise background shape in sideband regions of resonance by analytic expression.
  (ii) data driven method → use control region & transfer factor for signal region

Search for resonances: Run2 strategy

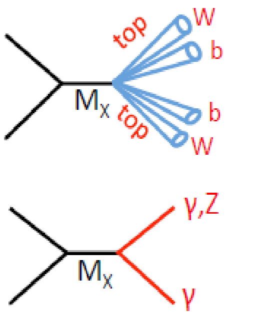
Dilepton

Dijet

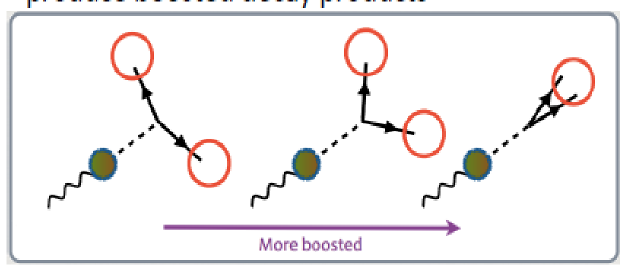


Top

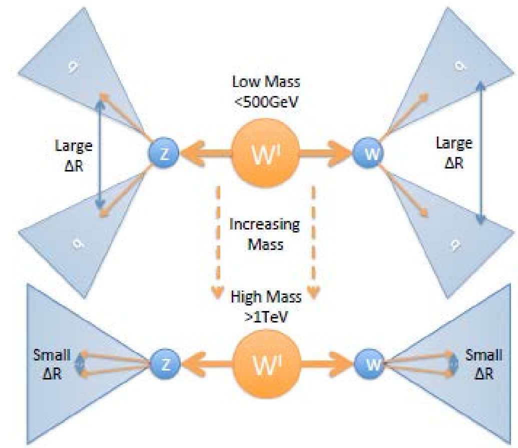
Dibosons



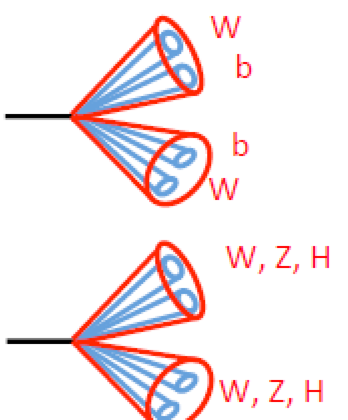
At higher energies and heavier new particles produce boosted decay products



idea credit: S. Rahatlou

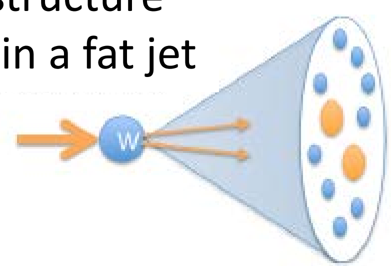


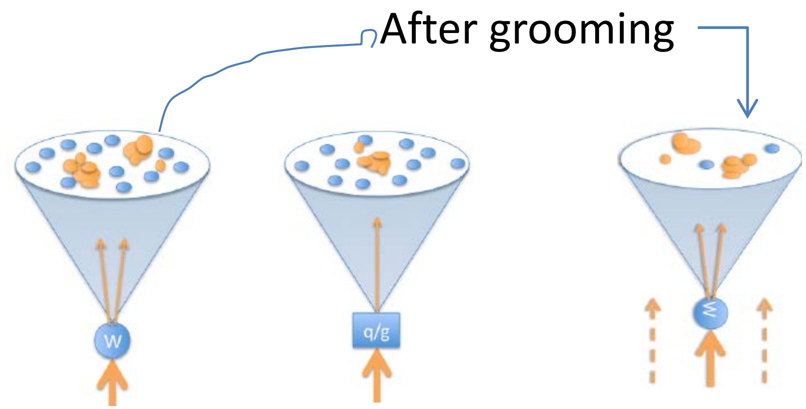
$$\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2} \approx \frac{2m}{p_T}$$



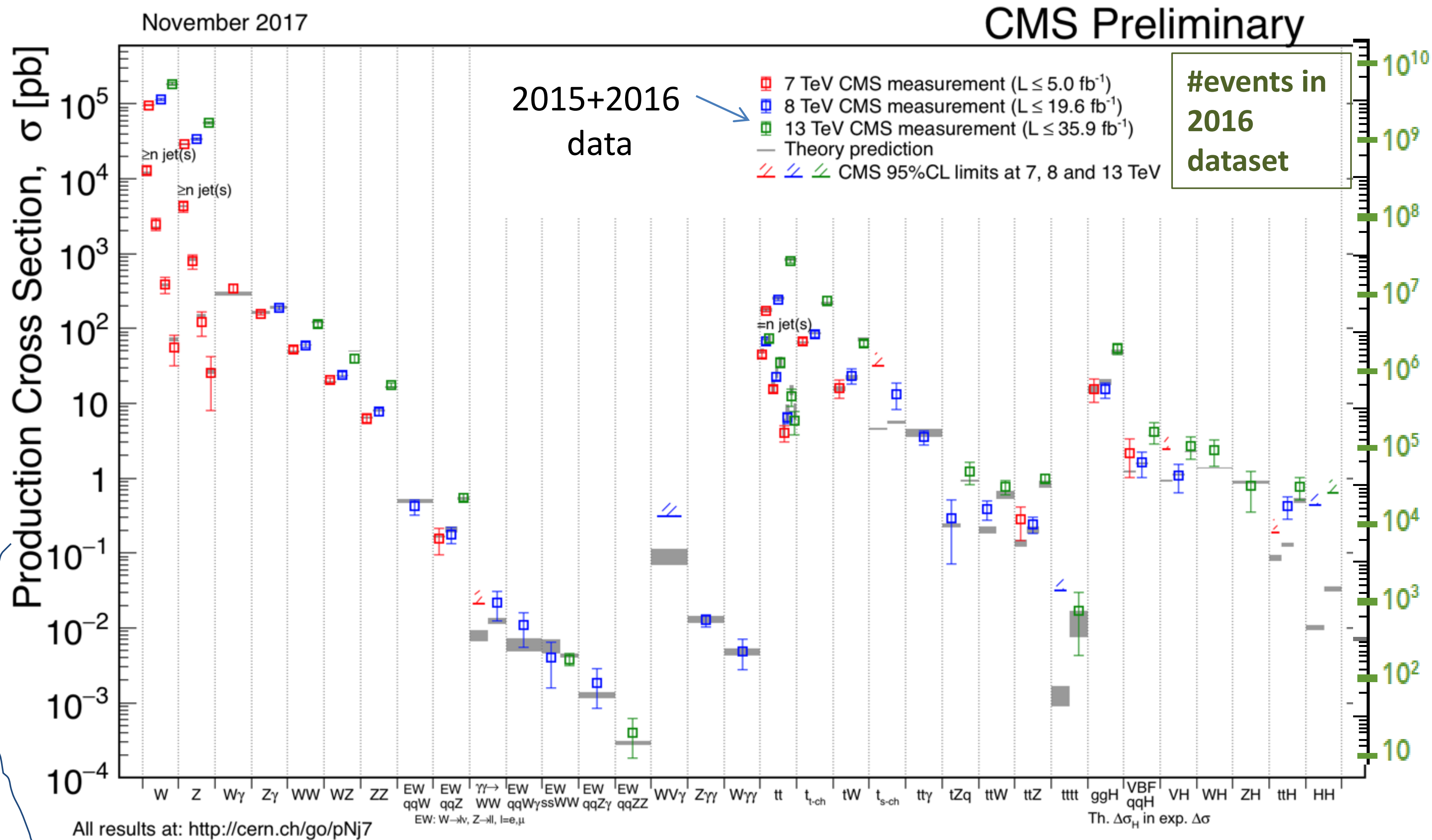
boosted signatures

Substructure within a fat jet





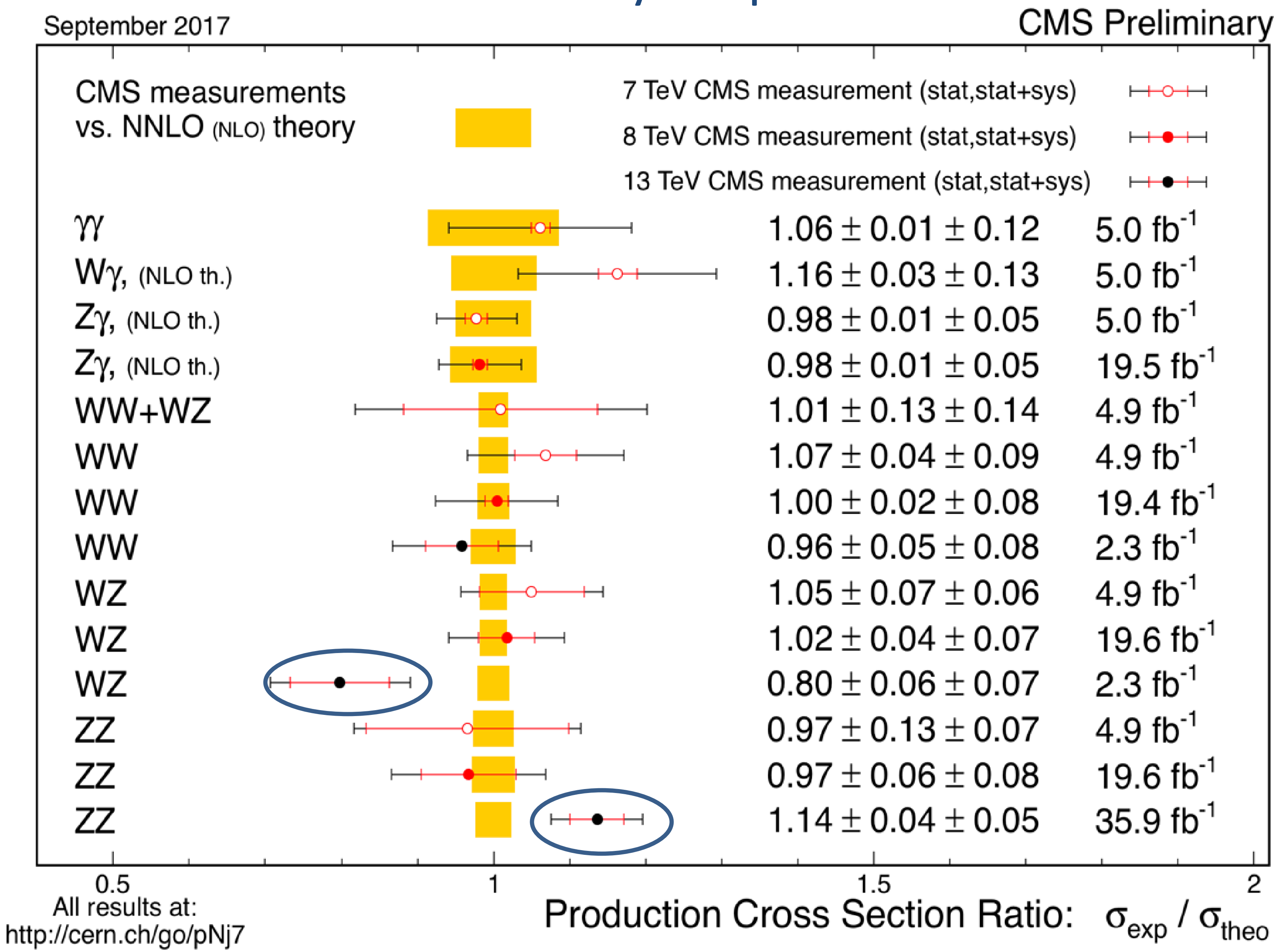
March of Standard Model (Theory?)



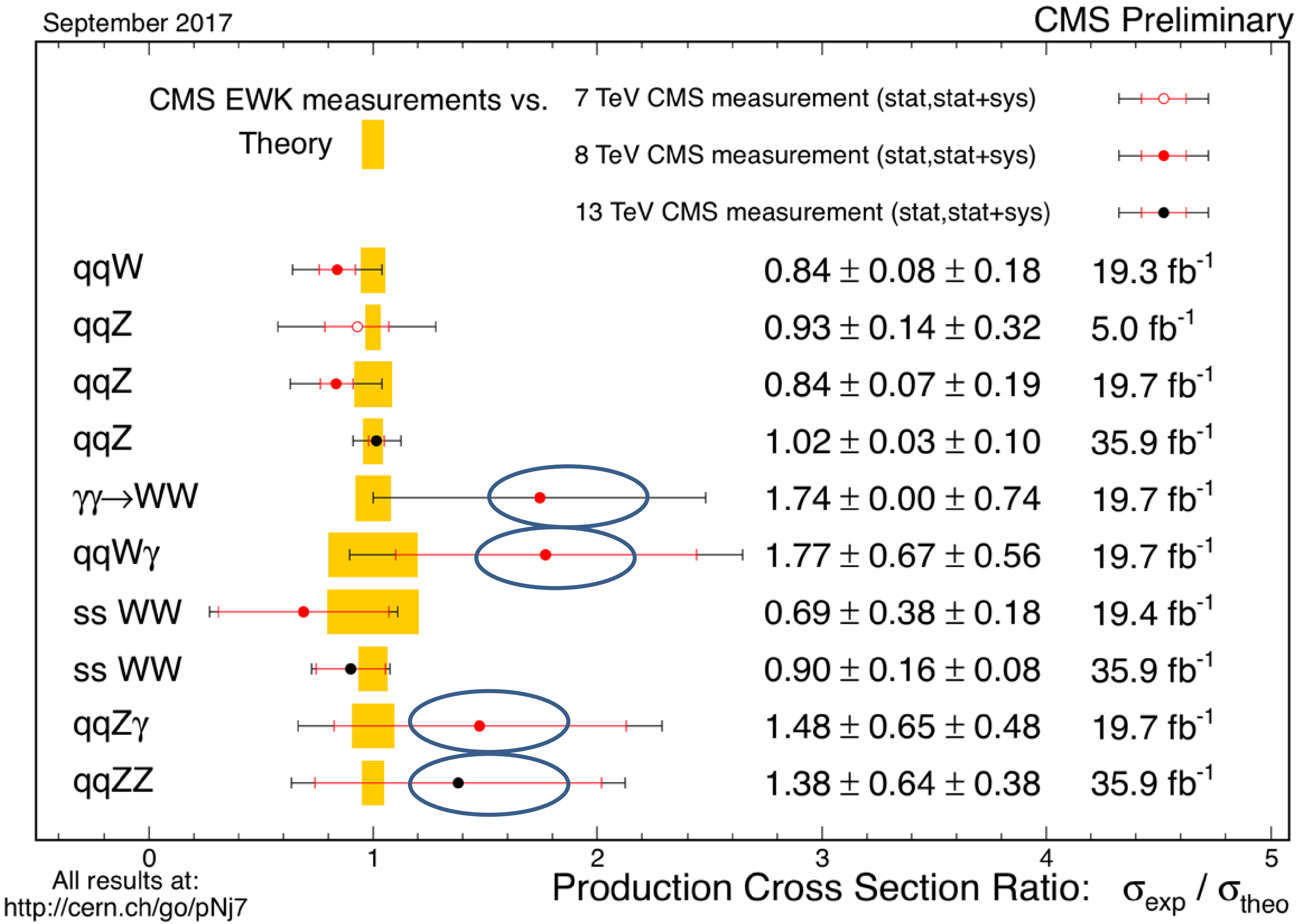
Span of 9 orders of magnitude in cross section!

Diboson productions

Purely weak processes

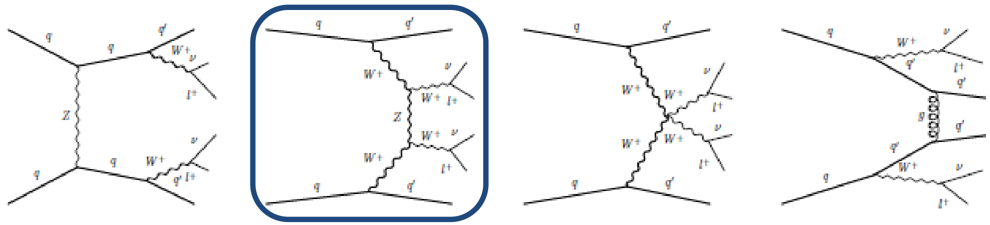


Gauge bosons produced along with quarks

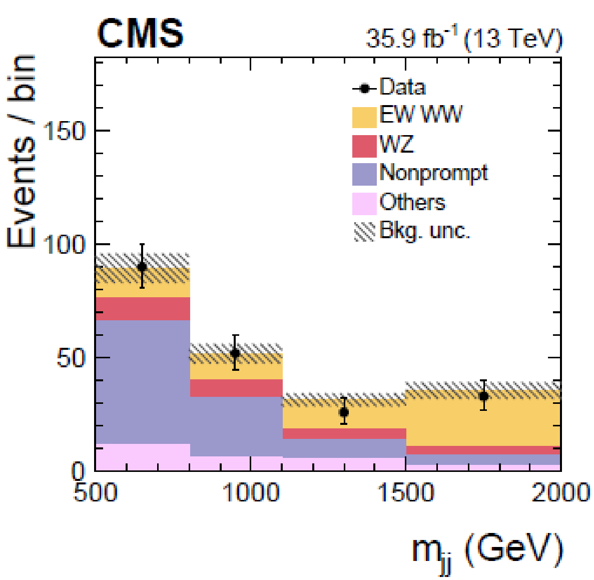


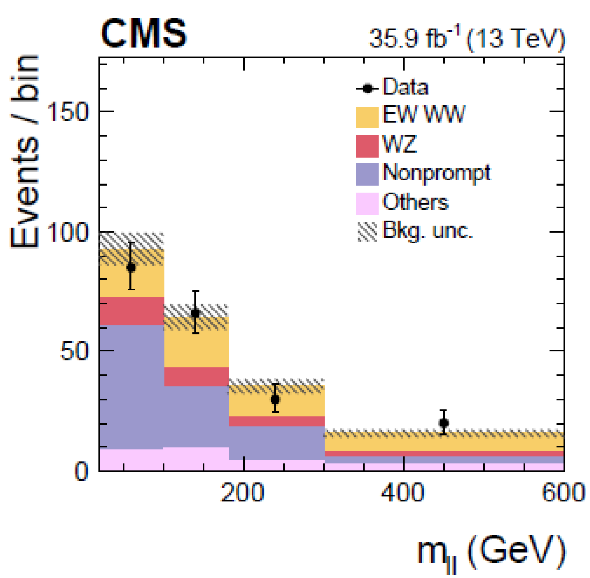
Electroweak production of dibosons

- Single, double, quartic gauge couplings and dominant background



- **First observation of same sign WW**
- Crucial for establishing role of Higgs in weak gauge boson scattering
- **Significance observed (expected) 5.5 (5.7) σ**

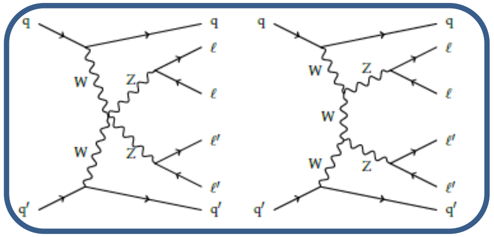




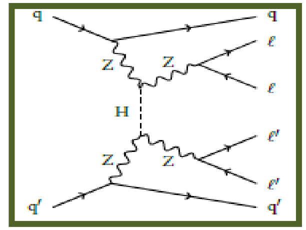
- In agreement with SM
- BSM contribution would enhance high tail of mjj distribution

CMS-PAS SMP-17-004
arXiv:1709.05822

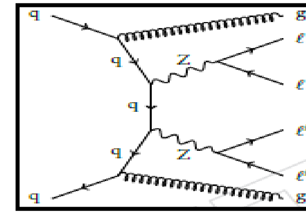
Production of ZZ+2j

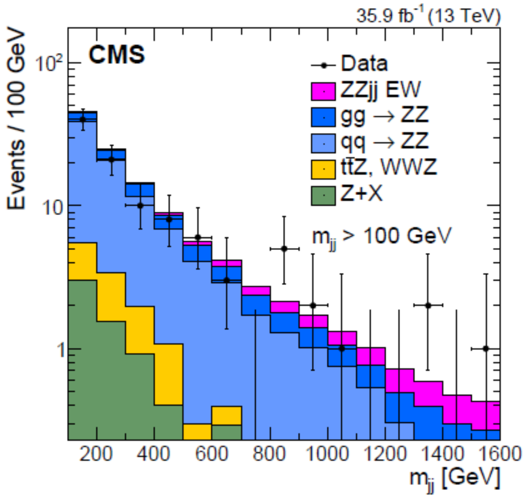


Unitarity of these need this



Must bother about the same final state from QCD!

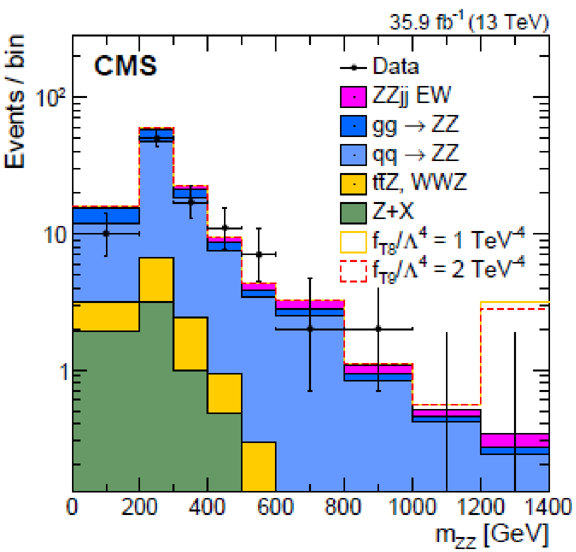




$$\sigma_{EW}(pp \to ZZjj \to \ell\ell\ell'\ell'jj) = 0.40^{+0.21}_{-0.16}\,(\text{stat})\ ^{+0.13}_{-0.09}\,(\text{syst})\ \text{fb}$$

Consistent with SM value: $0.29^{+0.02}_{-0.03}$ fb

Signal strength: $\mu = 1.39^{+0.72}_{-0.57}\,(\text{stat})\ ^{+0.46}_{-0.31}\,(\text{syst}) = 1.39^{+0.86}_{-0.65}$



➔ Constraint on various anomalous Quartic Gauge Couplings

SMP-17-006 to PLB
arXiv: 1708.02812

Measurement of weak mixing angle

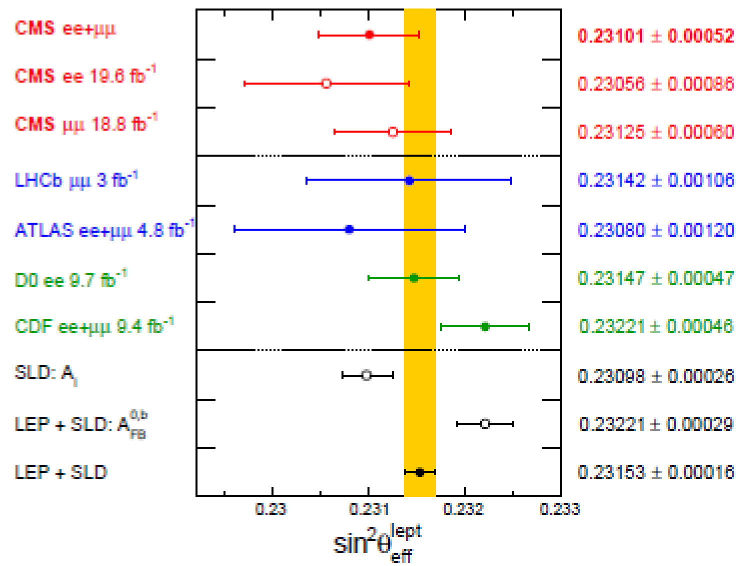
- Exploit forward-backward asymmetry in Z → ee/μμ

$$\frac{d\sigma}{d(\cos\theta^*)} = A(1+\cos^2\theta^*) + B\cos\theta^*$$

ϑ^* : ℓ^- angle in Collins-Soper frame

$$\cos\theta^* = \frac{2(p_1^+ p_2^- - p_1^- p_2^+)}{\sqrt{M^2(M^2+P_T^2)}} \times \frac{P_z}{|P_z|}$$

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}, \qquad v_f = T_3^f - 2Q_f \sin^2\theta_W, \quad a_f = T_3^f,$$



$$\boxed{\sin^2\theta_W = 1 - M_W^2/M_Z^2.} \qquad \boxed{\sin^2\theta_{eff}^f = \kappa_f \sin^2\theta_W}$$

κ_f = electroweak correction

$$\sin^2\theta_{eff}^{lept} = 0.23101 \pm 0.00036(\text{stat}) \pm 0.00018(\text{syst}) \pm 0.00016(\text{theory}) \pm 0.00030(\text{pdf})$$
$$\sin^2\theta_{eff}^{lept} = 0.23101 \pm 0.00052.$$

- **Most precise measurement at LHC**
- Lot of efforts on for improvement

CMS-PAS SMP-16-007

Measurement of W-mass

- One of the fundamental inputs to SM ➔
- Precise measurement crucially constrains the allowed region in m_t- m_H plane

- Based on simultaneous fit of lepton p_T and transverse mass
- Relies on factorization of Drell-Yan differential distribution for reweighting of individual components.

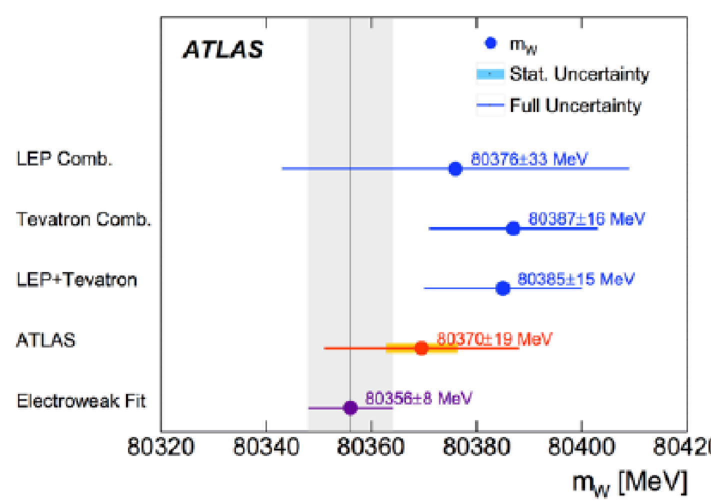
EW QCD

$$\frac{d\sigma}{dp_1\,dp_2} = \left[\frac{d\sigma(m)}{dm}\right]\left[\frac{d\sigma(y)}{dy}\right]\left[\frac{d\sigma(p_T,y)}{dp_T\,dy}\left(\frac{d\sigma(y)}{dy}\right)^{-1}\right]\left[(1+\cos^2\theta)+\sum_{i=0}^{7}A_i(p_T,y)P_i(\cos\theta,\phi)\right]$$

PDFs Angular Coeffs

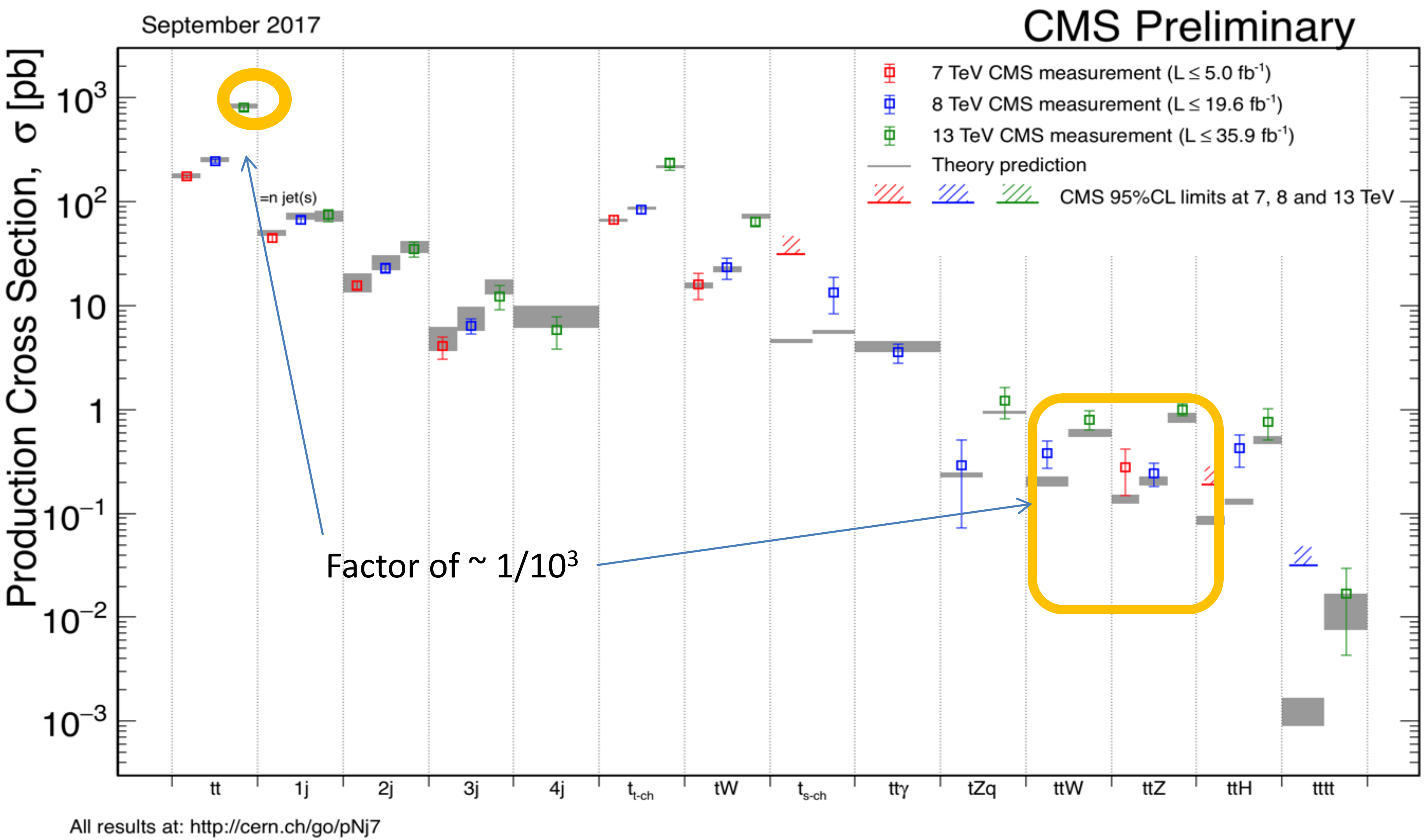
2

- Important inputs for experimental extraction of M_W
  → Parton density function
  → modeling of q_T
  → renormalization and factorization scales
  → accurate calibration of hadronic recoil, lepton p_T
- The challenge ultimately is to reduce *all* systematic uncertainties



ATLAS measurement: total uncertainty = 19 MeV
expt. uncert.: 10.6 MeV, theory uncert. 13.6 MeV

Cross section measurement in top-quark sector



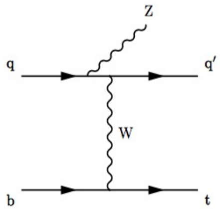
Large energy of ($\sqrt{s}$ = 13 TeV) at LHC opens up possibility for interaction at larger mass scales involving production of multiple heavy particles.

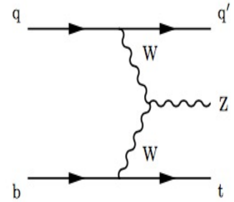
tZq production

CMS-PAS-TOP-16-020

arXiv:1712.02825

ATLAS CONF-2017-052

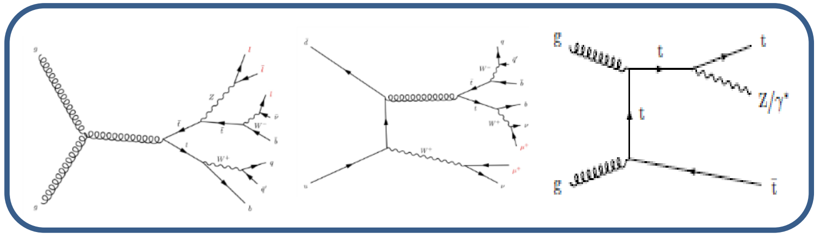


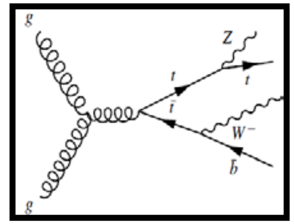


- Rare SM process (~120 fb)
  - SM tZq **probes both tZ and WWZ couplings**
  - SM tZq background for:
    - **FCNC tZ** production,
    - tH final state
  - Study tZq tri-lepton final state:
    - lowest branching fraction (2.2%)
    - high signal to background ratio

- **ATLAS: 5.4σ observed (4.2σ expected)**
- **CMS Evidence: 3.7σ observed (3.1σ expected)**
- **Hint at Run1: 2.4(1.8) σ**

Production of ttW & ttZ

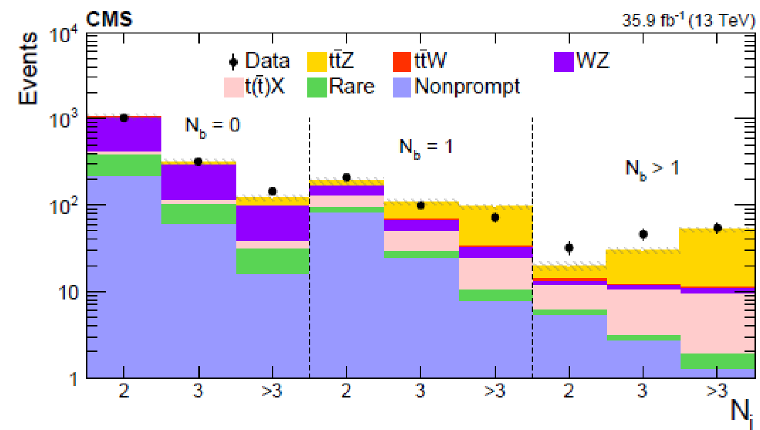




background

CMS arXiv:1711.02547
to JHEP

- Measurement of ttW, ttZ, ttγ couplings: key test of standard model in the gauge sector at TeV energy scale.
- Main background for ttH and many BSM process



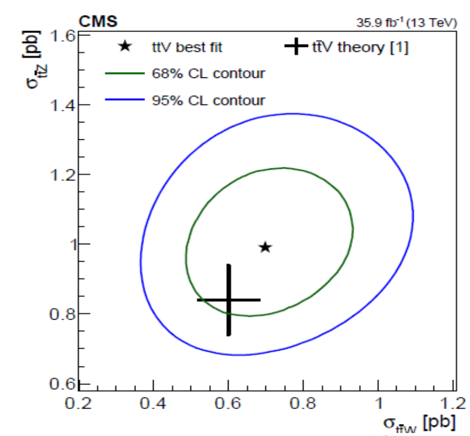
- 3 exclusive analyses:

i) Same sign dilepton pair for ttW (4.8%)

ii) 3 lepton for ttZ (2.8%)

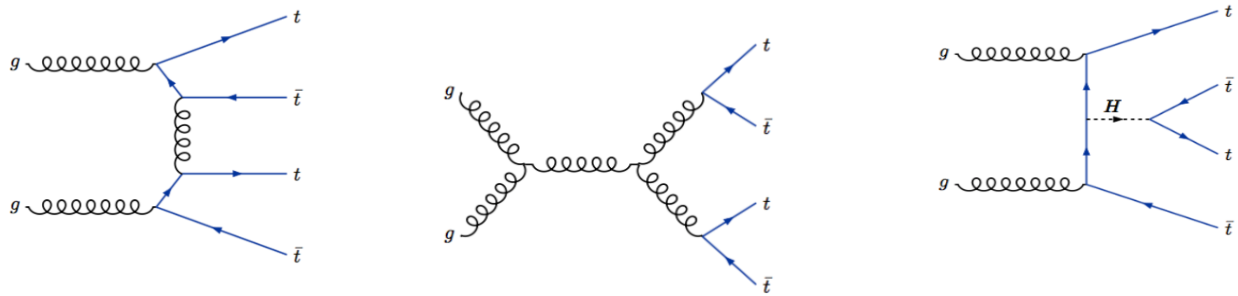
iii) 4 lepton for ttZ (0.5%)

- General good agreement between prediction and data
- **Slight excess (2σ) of events in 3lepton final state in categories N_j = 2, 3 and N_b > 1**



Note: Excess is not in the most sensitive category
Several SUSY analysis has also observed such excess but NOT the ttH analysis

Four top quark production



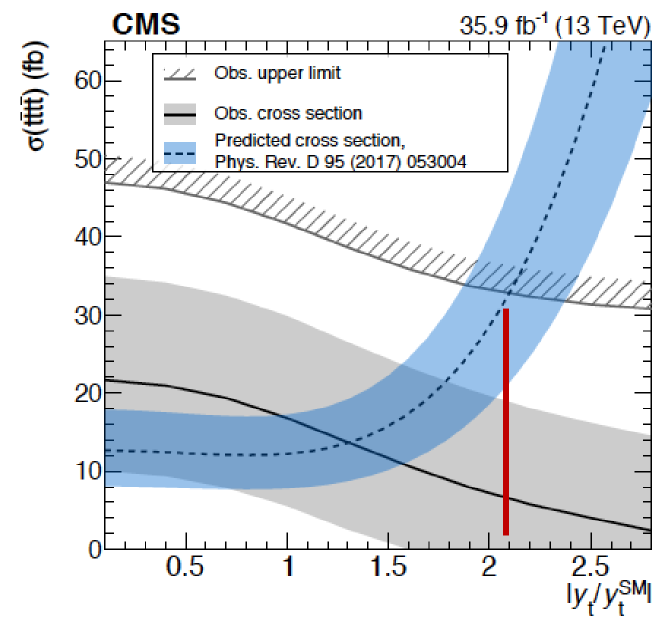
[arXiv:1710.10614 [EPJC]]

- Extremely rare process (~10fb)
  - sensitive to **ttH coupling** and to many to BSM theories
  - Explore same-sign dilepton & multlepton final states

➢ **Significance: 1.6σ observed (1.0σ expected)**

➢ Cross section: 16.0+13.8-11.4 fb (agrees with SM)

➢ **Constrain the Yukawa coupling of the top quark $|y_t/y_t^{SM}|$ <2.1 @ 95% CL**



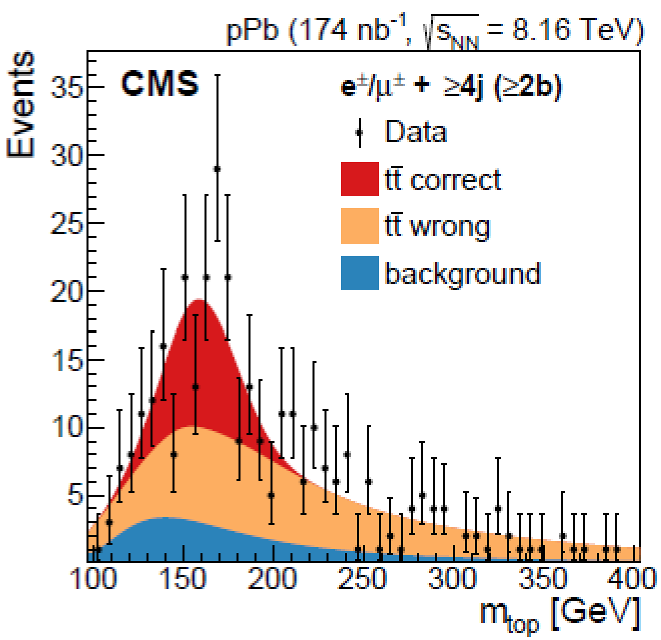
Top production in proton-nucleus collision

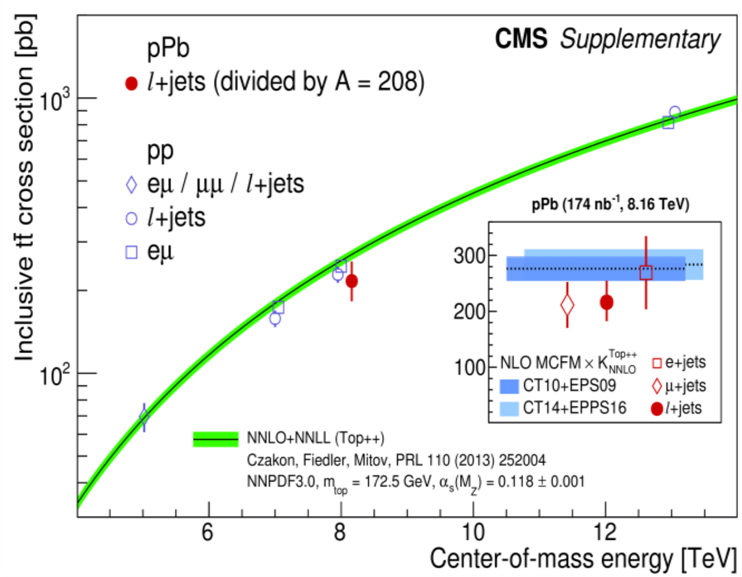
- Novel probe for nuclear densities at high virtuality in high-x region
- Study of top production in HI collision (in hot and dense medium)

→ good handle of space time structure of QGP in nucleus-nucleus collision

→ probes system size dependence of QGP formed

- 1 isolated lepton, 2 non-b jets, 2 b-tagged jets; Fit m_{jj} to W-mass
- **Excess above background matches with NNLO+NNLL accuracy**





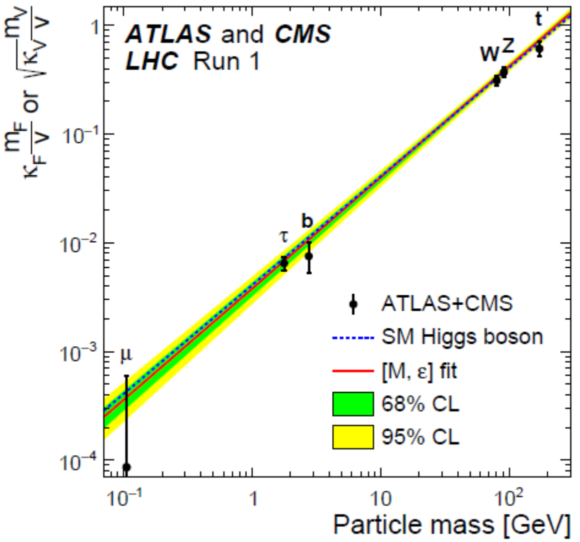
CMS-HIN-17-002
arXiv: 1709.07411

σ (tt) = 45± 8 nb

1st observation

Higgs status: post July, 2012:

- LHC results have presented the first idea about the nature of Higgs boson.



→ Everything seems compatible with SM expectations within uncertainties.

→ Mass 125.09 ± 0.24 GeV known with precision of 0.2%
Spin-parity : $J^p = 0^+$

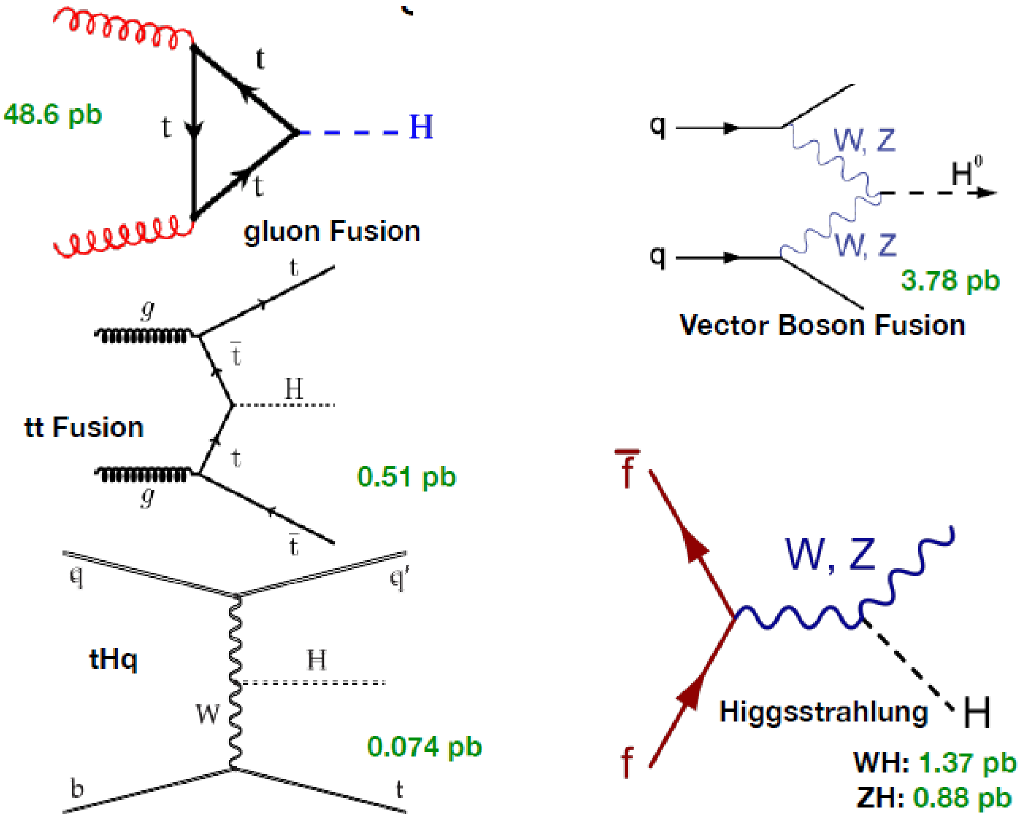
→ H couplings to gauge bosons: ~ 30% accuracy

→ H decays to 3rd generation fermions (bbar, tau-tau) established

- Numerous searches for signatures beyond SM properties or other Higgs bosons → as yet no sign of new physics.

Qn. Is it *THE* Standard Model Higgs or one of the Higgs of beyond Standard Model physics? A.: we have to wait for precision measurements

Higgs production at 13 TeV and main decays



bb - 57% of decays
- **Large branching fraction** but also has a **large background rate**

WW - 21% of decays
- Large number of events, complicated kinematics

gg - 9%

ττ - 6%
- **Accessible with good τ Identification** and Acquisition

cc - 3%

ZZ - 3 %
- Very **pure final state**, low Yield, **discovery channel!**

γγ - 0.2%
- Well parameterized background, **discovery channel!**

Presentation of results after accommodating BSM

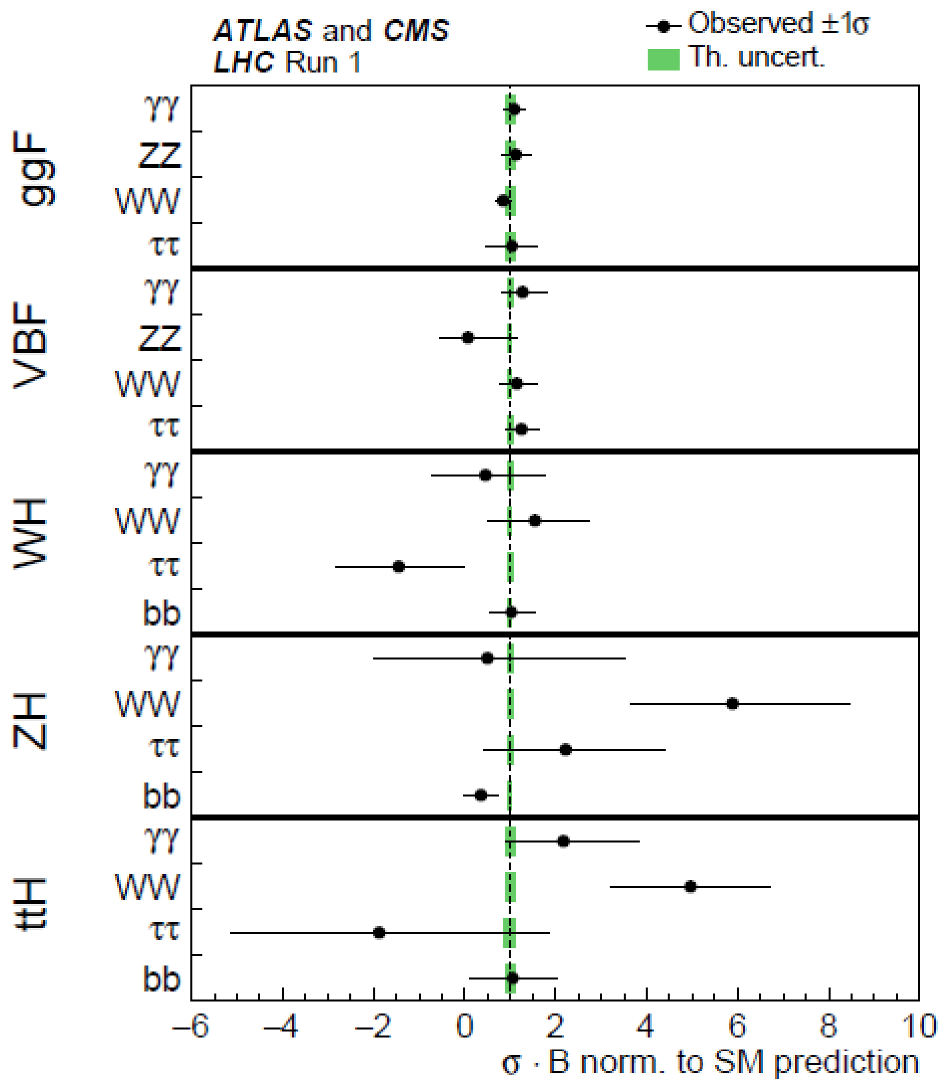
$$\sigma_i \cdot \mathrm{B}^f = \frac{\sigma_i(\vec{\kappa}) \cdot \Gamma^f(\vec{\kappa})}{\Gamma_H},$$

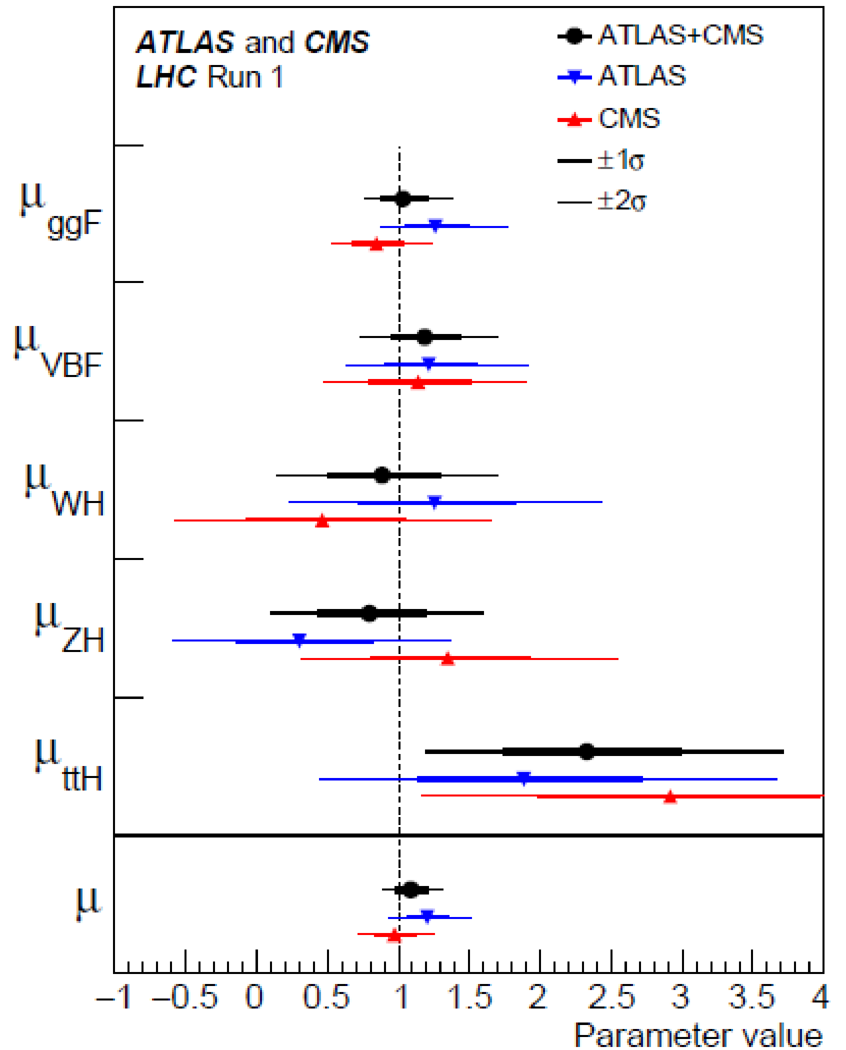
$$\kappa_j^2 = \sigma_j / \sigma_j^{\mathrm{SM}} \quad \text{or} \quad \kappa_j^2 = \Gamma^j / \Gamma^j_{\mathrm{SM}},$$

$$\Gamma_H = \frac{\kappa_H^2 \cdot \Gamma_H^{\mathrm{SM}}}{1 - \mathrm{B}_{\mathrm{BSM}}}$$

Run1 measurements for Higgs

(Production cross section) * (decay branching ratio) compared with SM

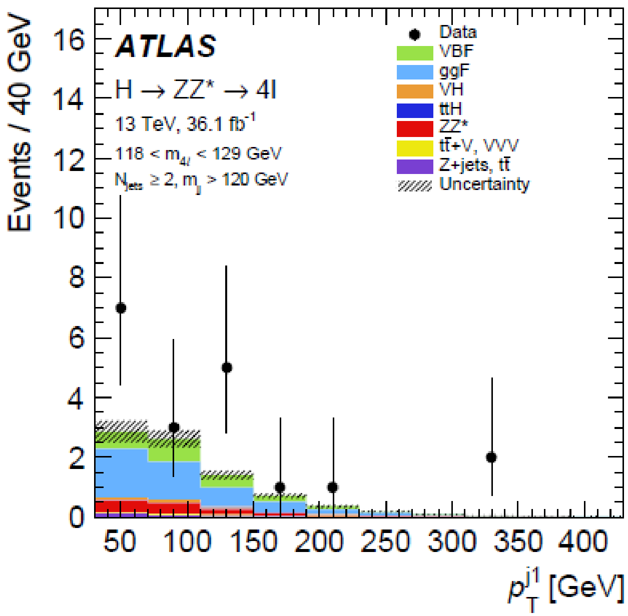


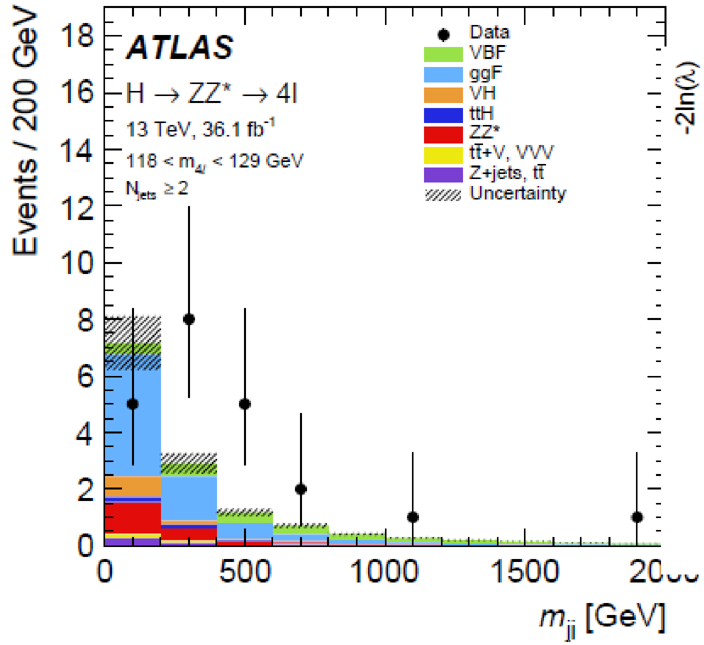


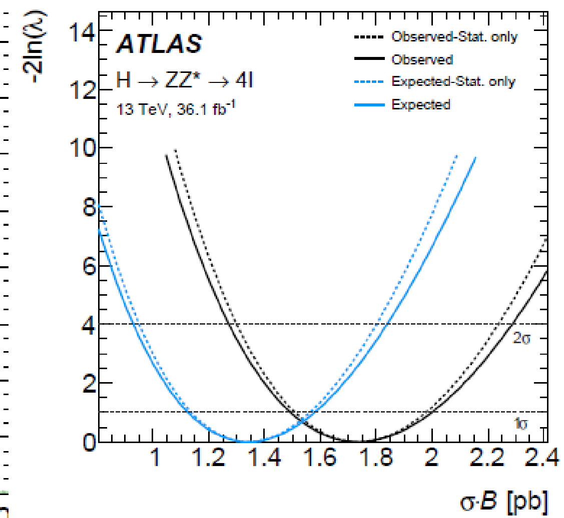
Slight excess in ttH

ATLAS: H → ZZ* → 4l

ATLAS arXiv:1712.02304



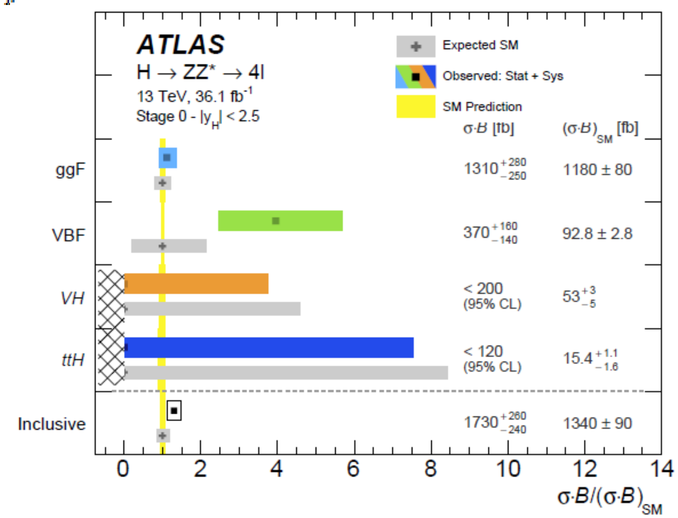




$$\mu = 1.28^{+0.18}_{-0.17}(\text{stat.})^{+0.08}_{-0.06}(\text{exp.})^{+0.08}_{-0.06}(\text{th.}) = 1.28^{+0.21}_{-0.19}$$

- **2σ excess in VBF production mode**
- In both low and high p_T^j categories

- Constrain BSM : CP-even and CP-odd couplings to Z and CP-odd to gluons, using effective Lagrangian .



CMS does not find any excess in same channel: HIG-17-012

H sector: coupling to fermions

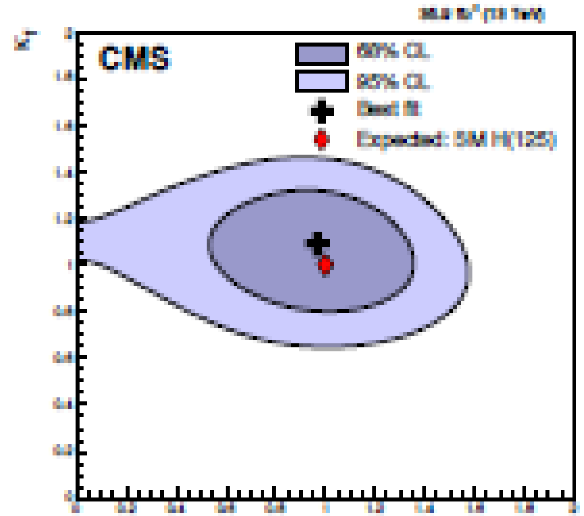
Established H → ττ

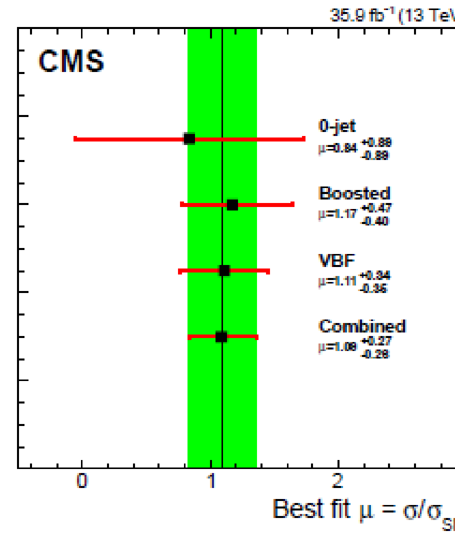
Combined (ATLAS + CMS; 7 + 8 + 13 TeV) **: 5.9 σ significance**

μ = 0.98 ± 0.18

From a single experiment (CMS)
with **4.9 σ significance**

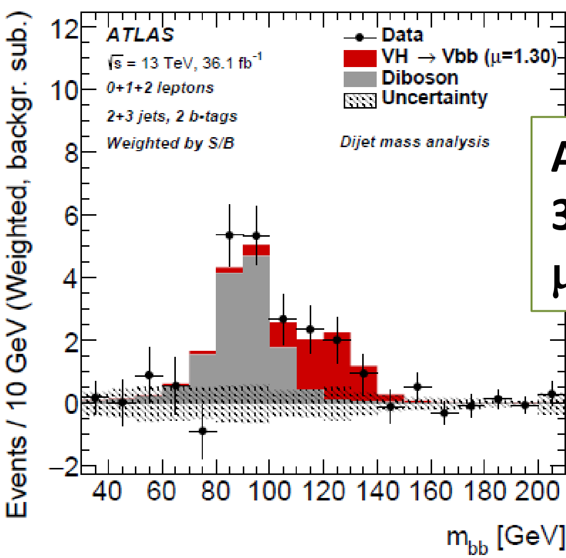
σ*Br(H→ ττ) = 1.09 + 0.27 – 0.26 fb





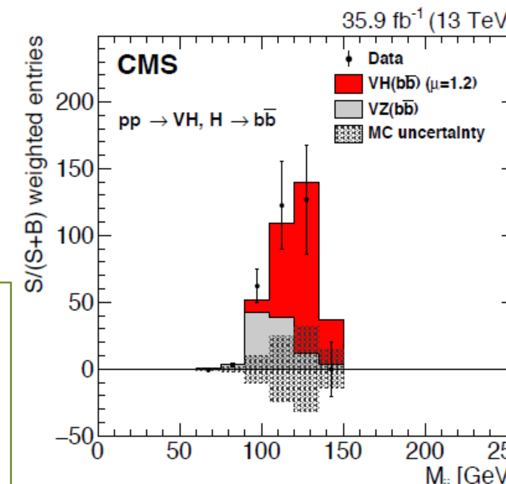
CMS arXiv 1708.00373

Evidence for H → bb



ATLAS
3.5 σ observation
μ = 0.9 +0.31/ – 0.29

CMS
2.8 σ observation
μ = 1.06 +0.31/ – 0.29

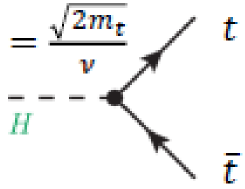


ATLAS arXiv: 1708.03299

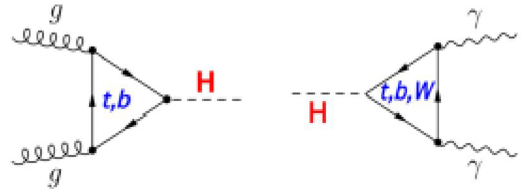
CMS arXiv 1709.07497

ttH measurement

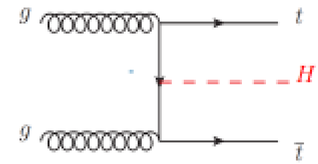
$\lambda_t = \frac{\sqrt{2} m_t}{v}$



Higgs Yukawa coupling
$\lambda_{t \sim 1}$



λ_t measured in ggF production
& $\gamma\gamma$ decay assuming SM in loop

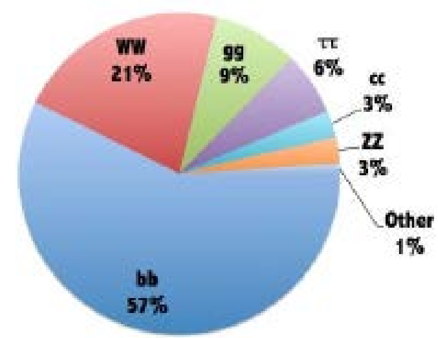


ttH is the best process to measure λ_t

Large Yukawa coupling yt ~
But ttH production rate ~ 1% of ggH
➔ **needs more time for better measurements**

- Experimentally: ttH is a difficult measurement
- Very low cross section ~ 0.5 pb
- Irreducible backgrounds: →ttbb: ~ 15 pb, ttW, ttZ :~ 1.5 pb

H decays



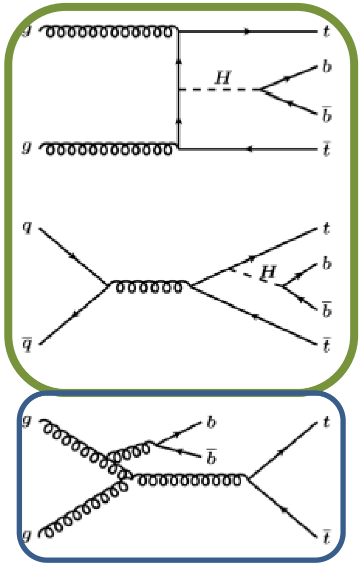
Many final states accessible:
tt→ 1l, 2l, H→ bb, WW, ZZ, ττ, γγ

ttH, ATLAS

ATLAS-CONF-2017-076

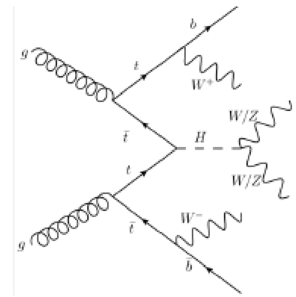
Run1 saw some excess in ttH

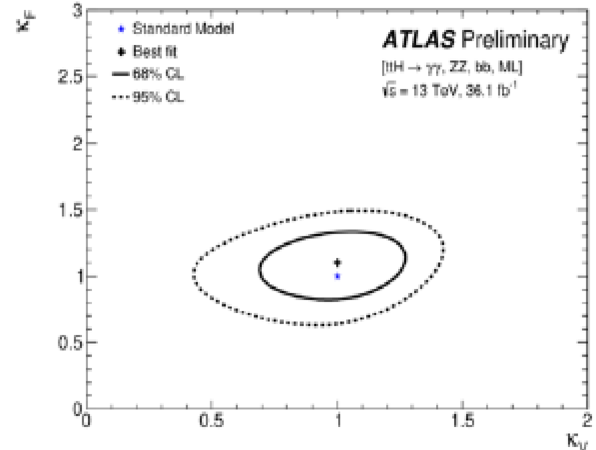
H → bb Use boosted jets

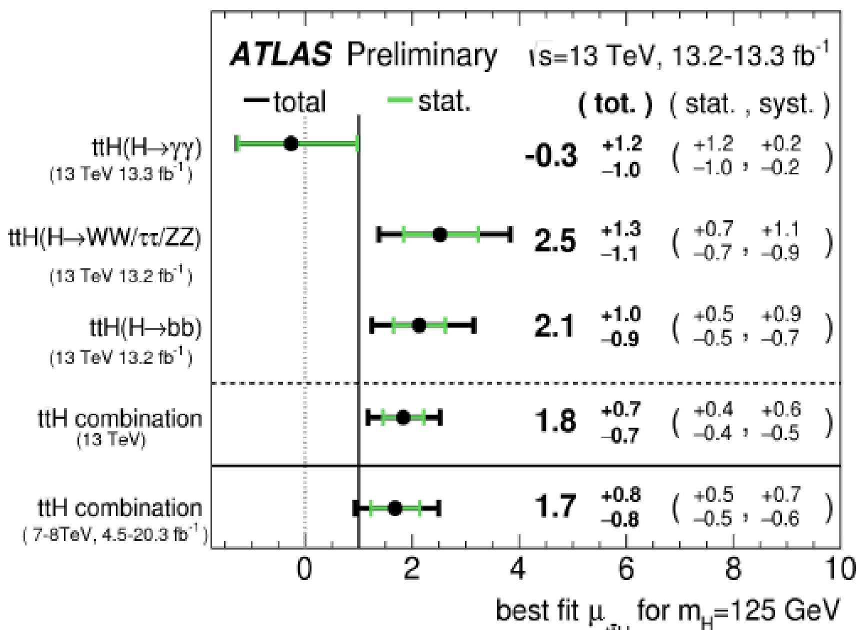


$$\mu = 0.84^{+0.64}_{-0.61}$$

H → WW*/ZZ*/ττ



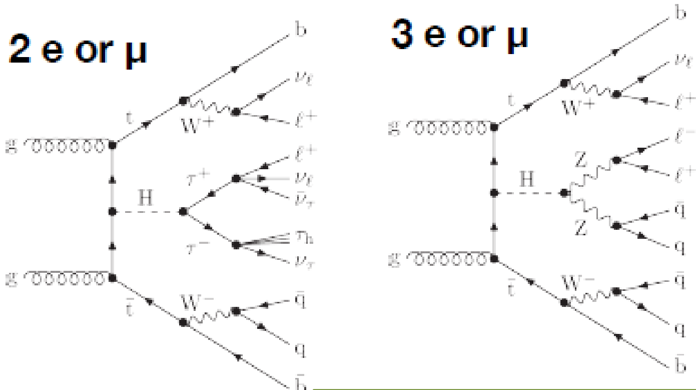




ttH process established with significance of 2.8 (expected 1.8)

ttH,, CMS

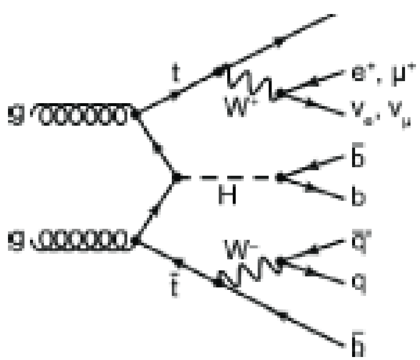
multilepton final states



Category	Observed μ fit $\pm 1\sigma$
Same-sign di-lepton	1.7 (−0.5) (+0.6)
Three lepton	1.0 (−0.7) (+0.8)
Four lepton	0.9 (−1.6) (+2.3)
Combined (2016 data)	1.5 (−0.5) (+0.5)
Combined (2015 data) [42]	0.6 (−1.1) (+1.4)
Combined (2015+2016 data)	1.5 (−0.5) (+0.5)

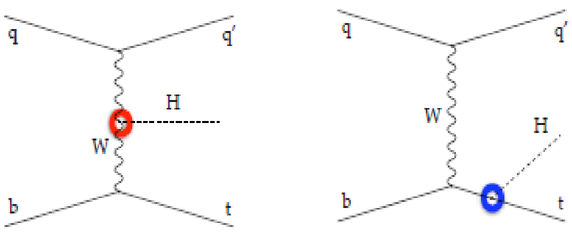
3.3(2.5) σ obs. (exp.)
μ = 1.5 ±0.5 (1.0± 0.4)

H→ bb, ττ



Category	Observed	Expected
3 jets, 2 b-tags	186.0	$114.8^{+52.6}_{-34.1}$
≥ 3 jets, 3 b-tags	104.9	$48.6^{+26.2}_{-15.9}$
≥ 4 jets, 2 b-tags	32.4	$40.1^{+16.8}_{-11.3}$
≥ 4 jets, 3 b-tags	7.4	$10.8^{+5.2}_{-3.3}$
≥ 4 jets, ≥ 4 b-tags	9.1	$12.2^{+7.5}_{-4.3}$
dilepton combined	5.2	$7.7^{+3.6}_{-2.3}$

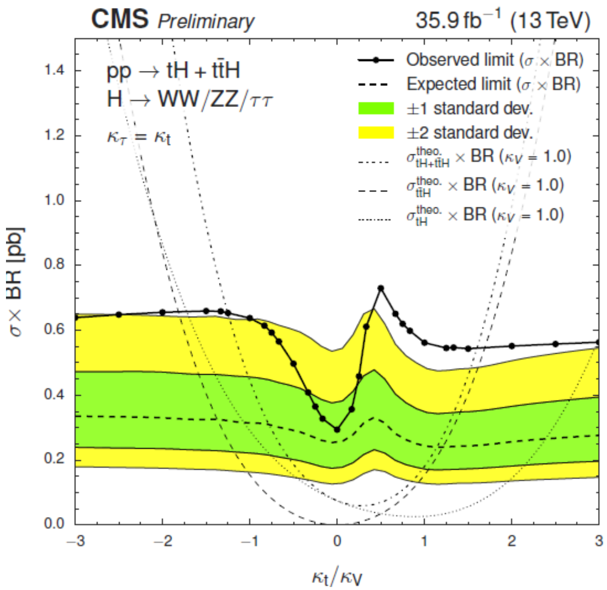
Sign of top-H coupling



- σ(ttH) ~ (coupling)^2
- tHq final state: 2 processes ➔ Interference term reveals the sign of ttH coupling
- SM : destructive coupling leads to small rate ~ 70 fb

→ too small to establish observation with present data

- BSM: large (X 10 SM) enhancement for inverted coupling



- **Obs. (exp.) upper limit on σ = 0.56 (0.24) pb**
- **μ = 1.82± 0.73**
- Event sample dominated by contribution from ttH
- Constraints on κ_f

CMS HIG-17-005

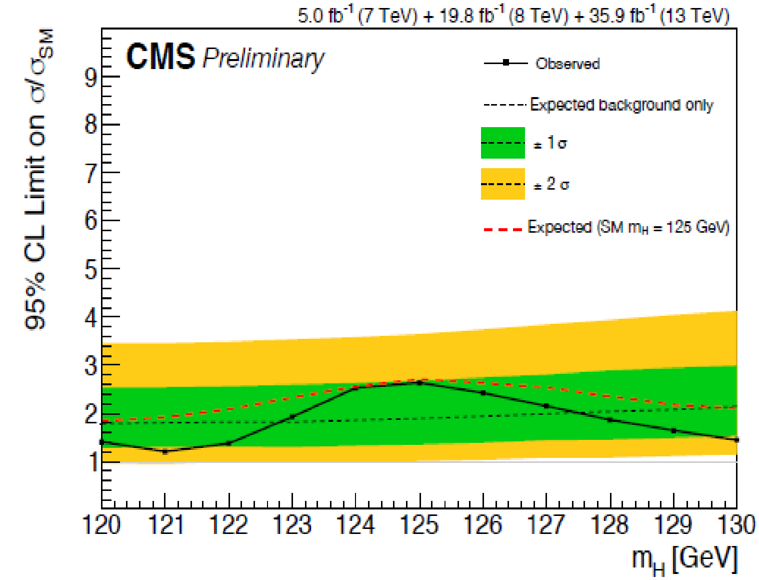
ggH, H →μμ

HIG-17-019

Clean channel, inundated by DY background

SM Branching ratio: $2.2*10^{-4}$, data: $< 5.7*10^{-4}$
CMS: Observed (exp.) rate < 2.64 (1.89) $*\sigma_{SM}$
(by combining 7+8+13 TeV data)

ATLAS: observed (expected): 2.8 (2.9) * σ_{SM}

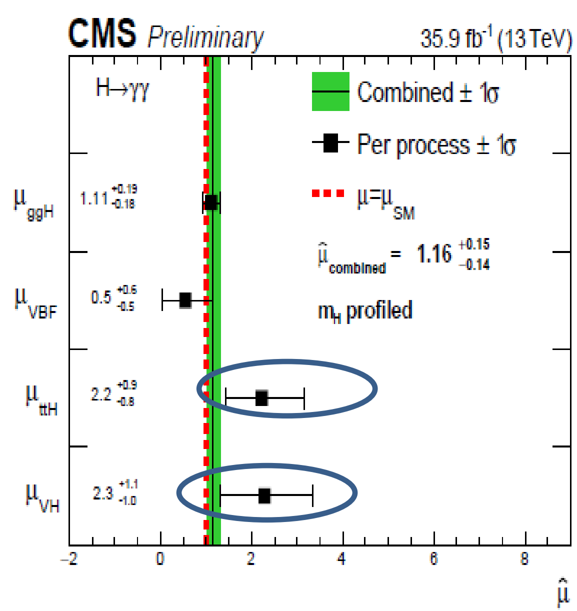


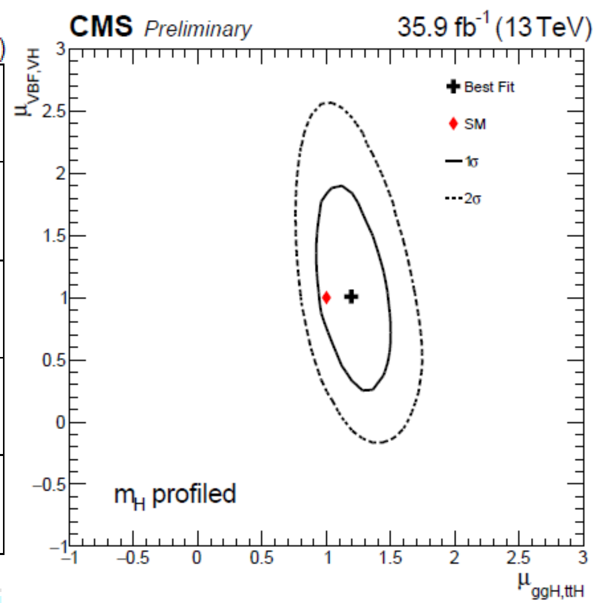
CMS: H →γγ

All categories combined:

$$\widehat{\mu} = 1.16^{+0.15}_{-0.14} = 1.16^{+0.11}_{-0.10}\,(\text{stat.})\,^{+0.09}_{-0.08}\,(\text{syst.})$$

CMS HIG-17-018





Low mass H→$\gamma\gamma$

HIG-17-013

- BSM models like NMSSM, 2HDM accommodates a scalar with mass below 125 GeV
- *LEP data had hints of such a particle*

- Standard H → γγ analysis, but in a challenging region of $m_{\gamma\gamma}$: 70-110 GeV →use $\Delta m_{\gamma\gamma}$ = 100 MeV

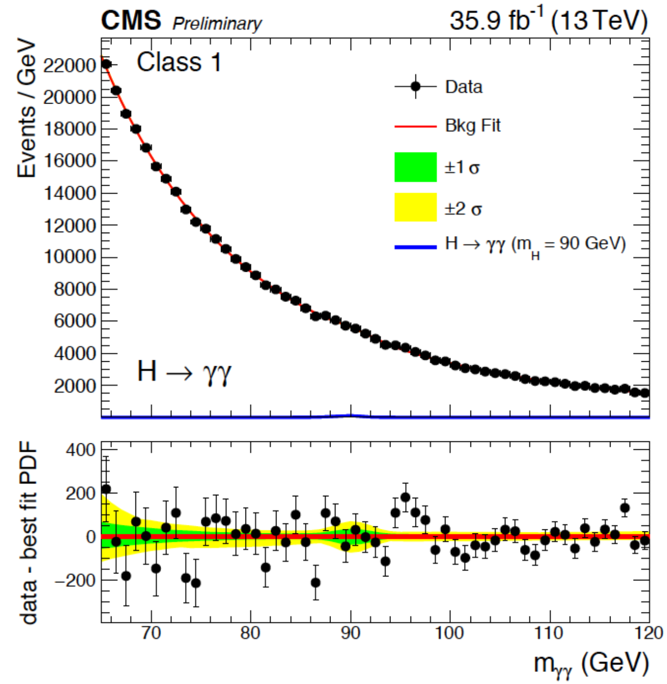
- **Improvement in trigger** led to lowering the search region from 80 GeV (8 TeV) to 70 GeV (13 TeV)

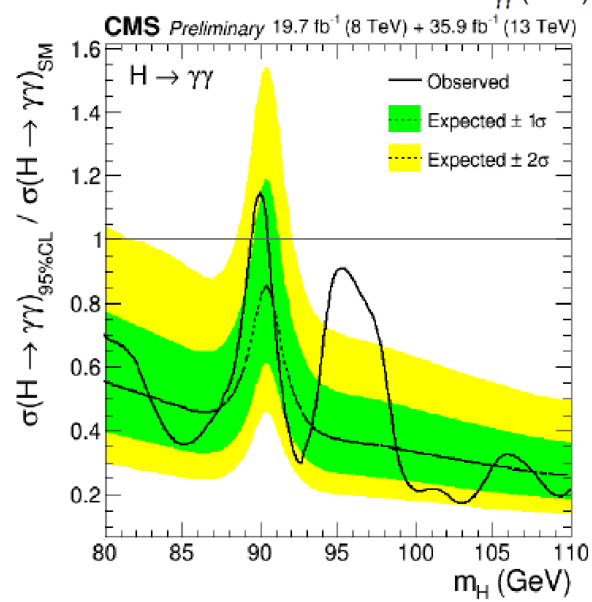
- **Mild excess observed**

13 TeV: ~2.9σ local (1.47σ global) significance @ 95.3 GeV

8 TeV: ~2σ local significance @ 97.6 GeV

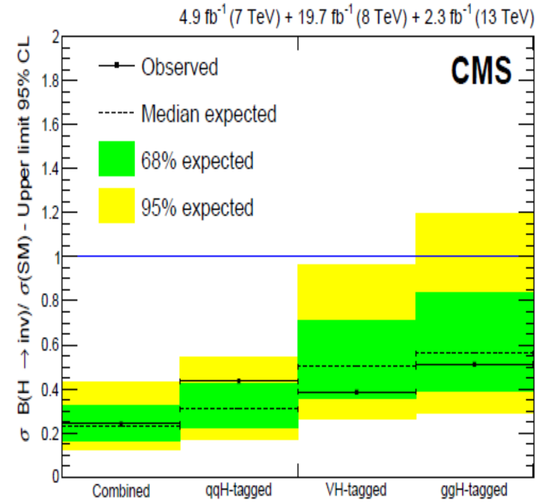
Combined: ~2.8σ local (1.3σ global) significance @95.3 GeV





Need more data to settle

Invisible Higgs



Data volume delivered by LHC ➔ still limited precision
➔ lee way to accommodate H(inv)

Determination of Higgs total decay width provide indirect constraint on invisible decay.

Run1: B_{BSM} < 0.34 @ 95% confidence limit

Direct measurement is more sensitive, allows "direct production" of DM at LHC!

Experimental "tag/identification" : need a "visible" system recoiling against Et(miss)
➔ use all production processes

VBF process more sensitive: Results from 2016 data (36 /fb) coming soon

Z (→ $\ell^+\ell^-$) H(inv): $\mathcal{B}$(H(inv)) = 0.45 (0.40) from shape (MVA) analysis

(i) gg→g+H(inv) and (ii) W/Z(→jets)+H (inv) combined : $\mathcal{B}$(H(inv)) = 0.53

Run1 + Run2 (partial) : **$\mathcal{B}$(H→inv.) < 0.24 (0.23)** at 95% CL, assuming SM production

Interpretation in Higgs-portal model

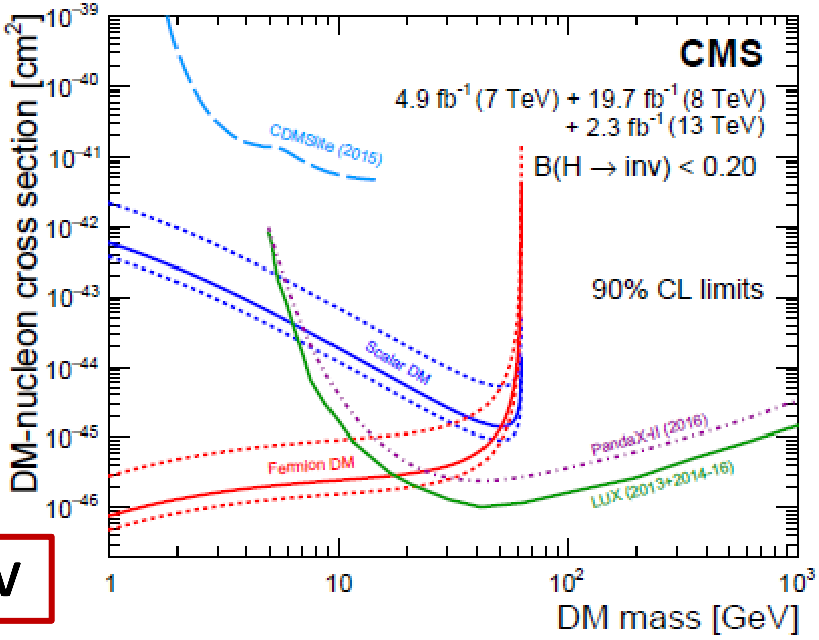
JHEP 02 (2017) 135

- SM particles communicate with dark matter particles via Higgs & tree level coupling ➔ invisible decay of H (produced acc. to SM)
- Interpretation of limit in terms of spin-independent DM-nucleon cross section.
- Assumption: nature of DM particle either scalar or fermion;
  + effective interaction does not depend on spin
- **Use 90% CL to compare with constraints from direct detection ➔ $\mathcal{B}$(H(inv)) < 0.20**

$$\sigma^{\mathrm{SI}}_{\mathrm{S-N}} = \frac{4\Gamma_{\mathrm{inv}}}{m_{\mathrm{H}}^3 v^2 \beta} \frac{m_{\mathrm{N}}^4 f_{\mathrm{N}}^2}{(m_\chi + m_{\mathrm{N}})^2},$$

$$\sigma^{\mathrm{SI}}_{\mathrm{f-N}} = \frac{8\Gamma_{\mathrm{inv}} m_\chi^2}{m_{\mathrm{H}}^5 v^2 \beta^3} \frac{m_{\mathrm{N}}^4 f_{\mathrm{N}}^2}{(m_\chi + m_{\mathrm{N}})^2}$$

f_{N} : nuclear form factor = [0.260, 0.629]



LHC sensitivity for low mass DM below ~ 10 GeV

Double Higgs Production: HH→4b

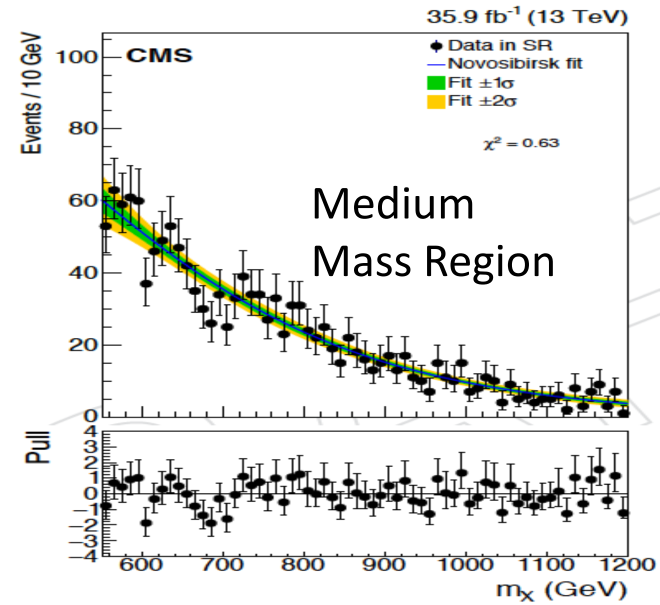
HIG-17-009

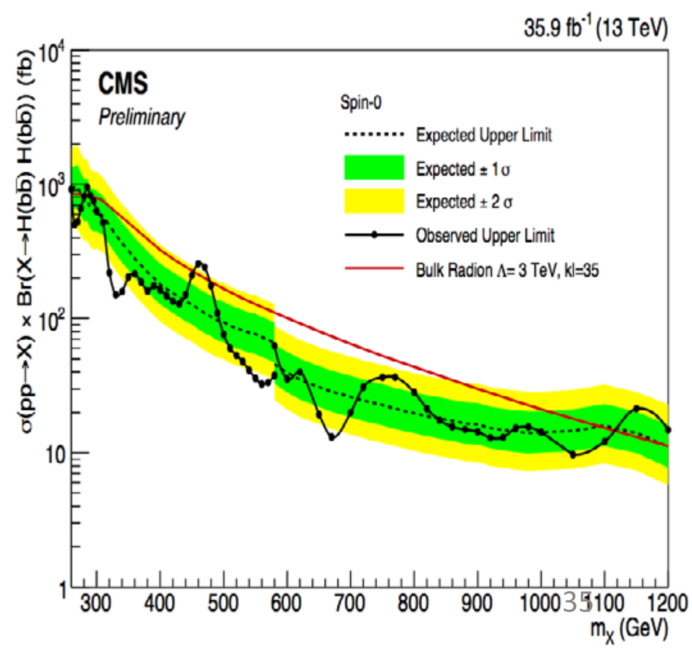
- Gives direct access to its self-coupling & probes the EWSB potential.
- SM: extremely low rate for HH production
- Significantly enhanced in many BSM scenarios
- **Resonant production of new narrow width states: X→HH :** *Identify m_X using resolved b-jets*

→ (N)MSSM (~300-500 GeV),

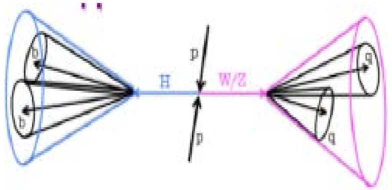
→ Extra dimensions (>500 GeV)

- **Four b quark signature: X→HH→bbbb**
- **Limits on spin 0 & spin 2 (KK-graviton) resonances: 300 < m_X < 1100 GeV (observed)**





V(qq)H(bb) resonances



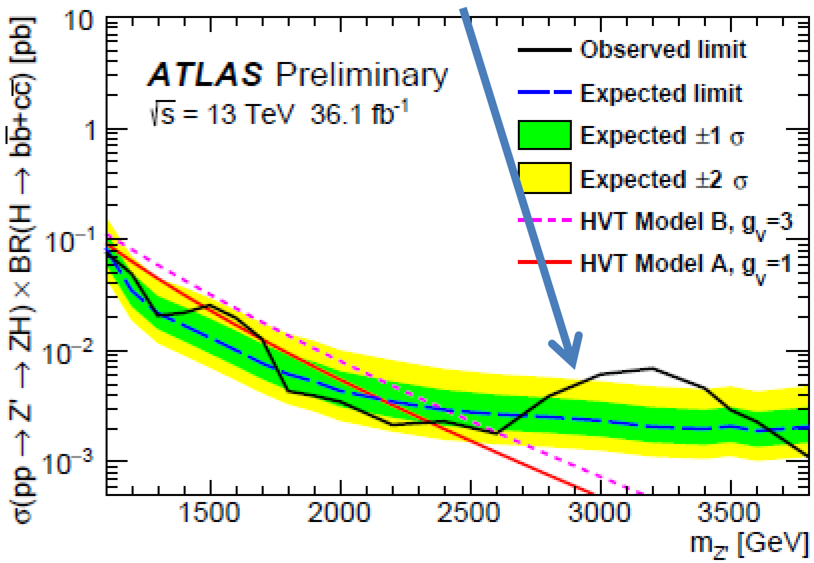
- Motivation: composite Higgs, Little Higgs models , ..
- Interpretation in simplified model: Heavy Vector Triplet

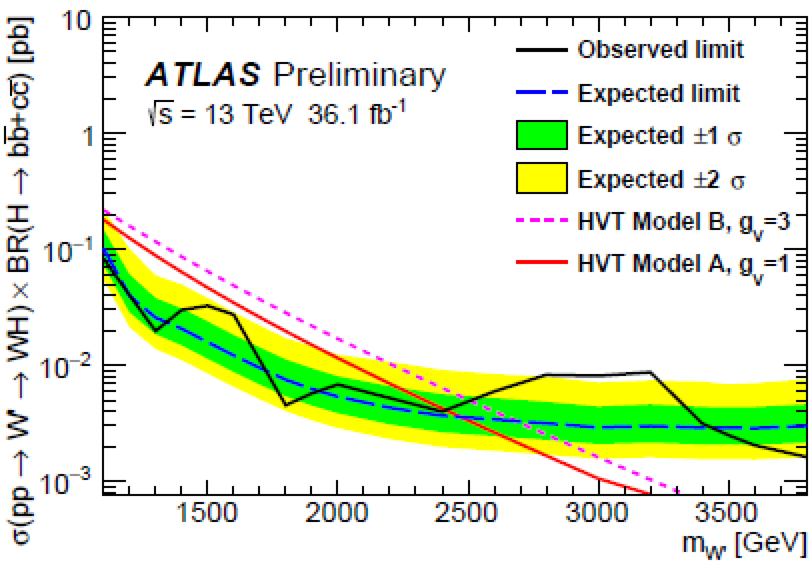
2 varieties: (i) Branching fractions to fermion and gauge couplings are same
(ii) decay to branchings suppressed, as in Little Higgs model

- Trigger on single fat jet (fully efficient for pT> 450 GeV)
- Jet substructure technique on anti-kT R=1 jet to identify V & H

ATLAS-CONF-2017-018

Global significance 2.2 σ





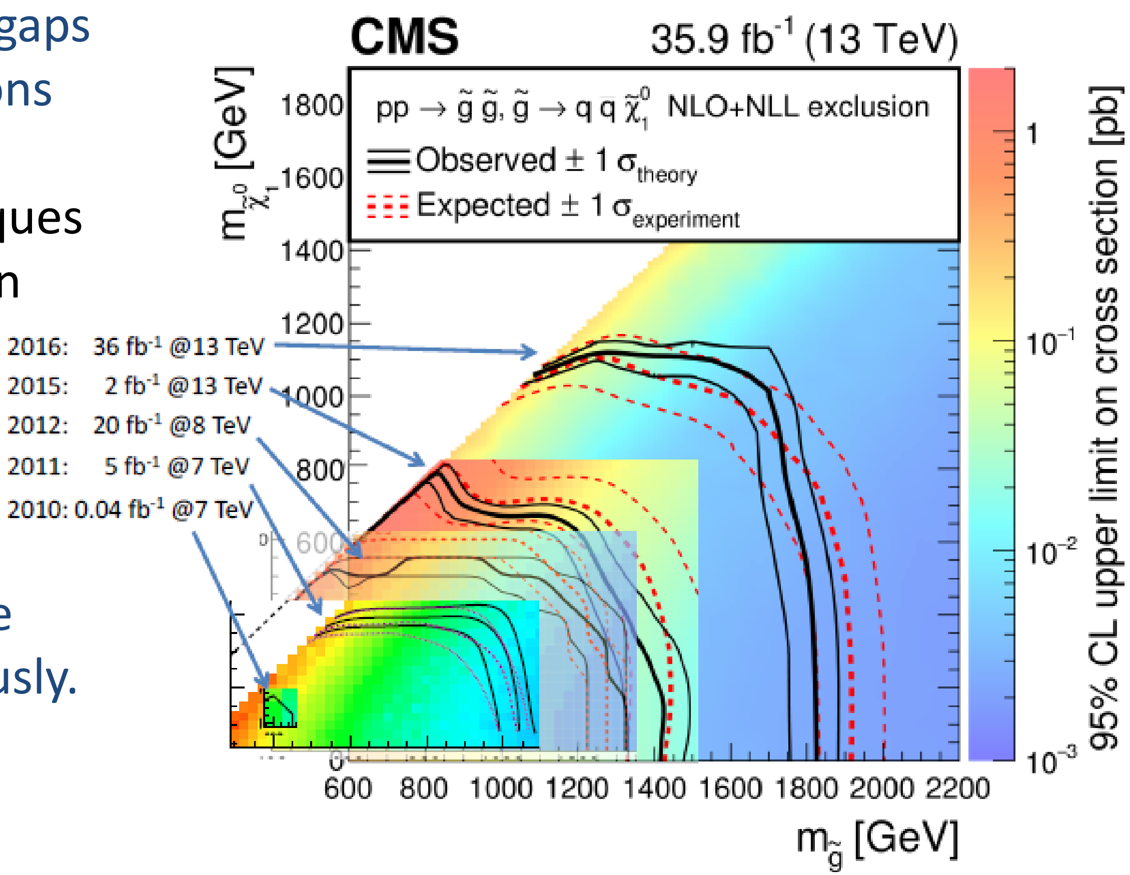
SUSY particle searches

Huge progress in refining strategy for searches:
→ Typically inclusive
but broad searches may leave gaps in sensitivity for difficult regions

→ Sophisticated analysis techniques
→ Robust background estimation

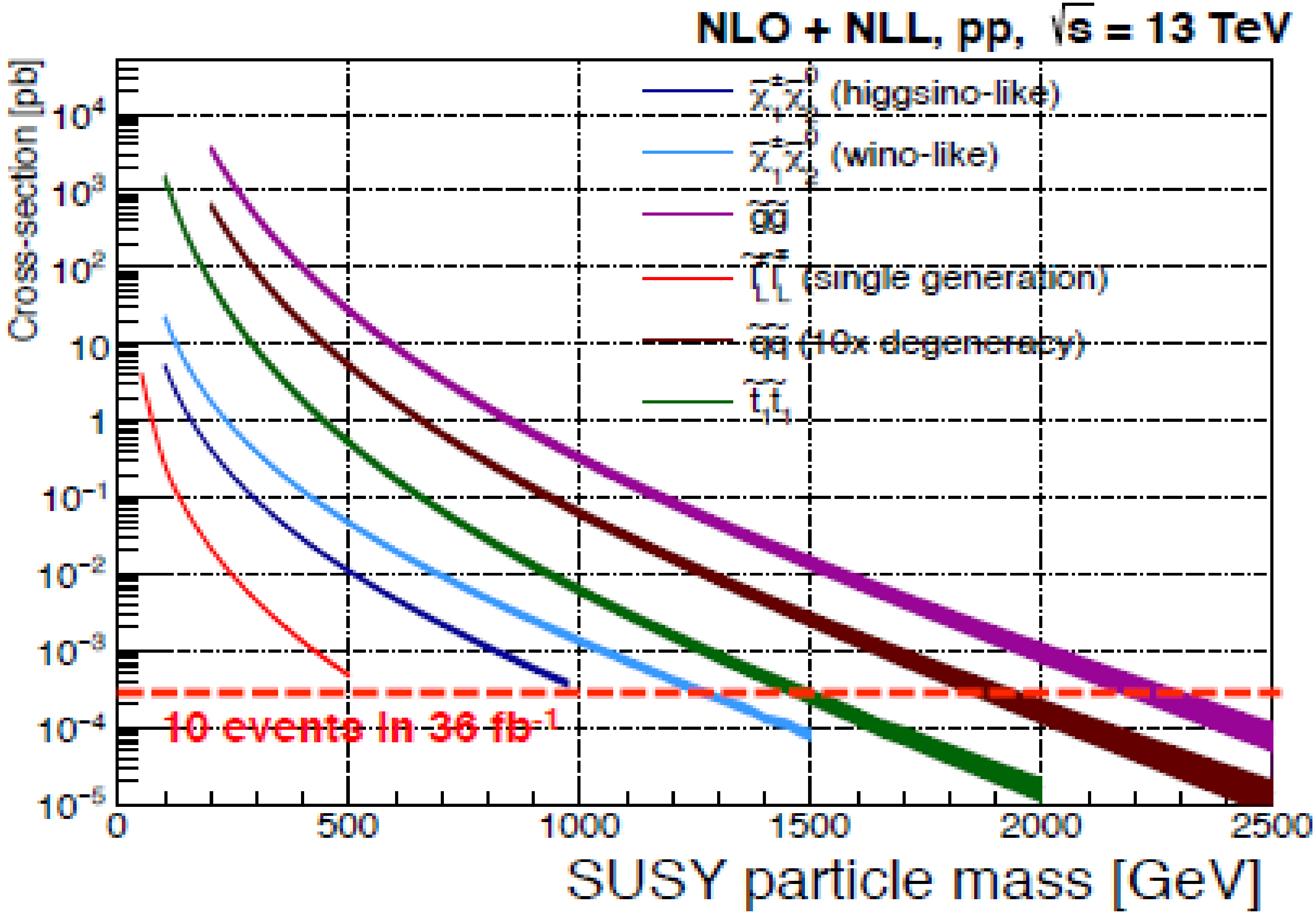
➔ Techniques for comprehensive interpretation evolving continuously.

Evolution of gluino mass search



- **Use Simplified Model Spectrum (SMS) to interpret specific final state**
- New strategies to push beyond: boosted and long-lived signatures

SUSY particle cross sections



sleptons: 0.5 TeV

ewkinos: 1.3 TeV

stops: 1.5 TeV

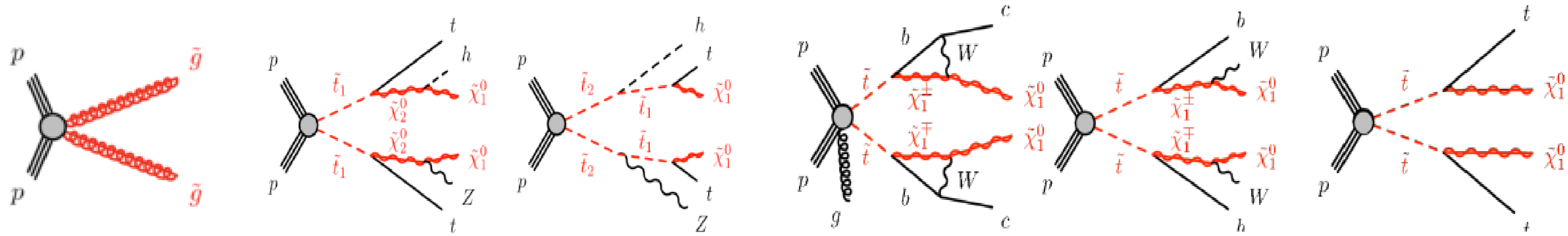
squarks: 1.9 TeV

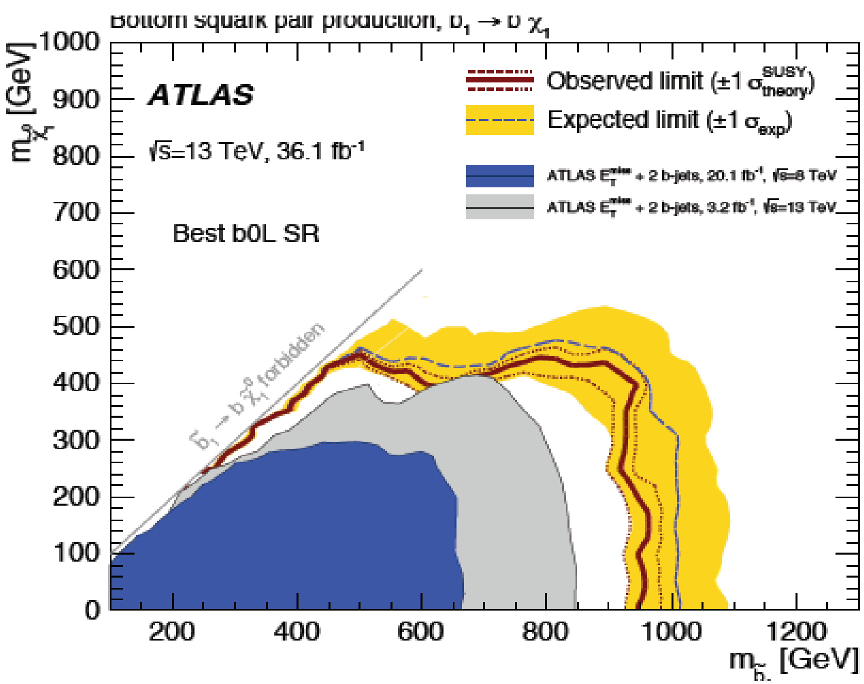
gluinos: 2.3 TeV

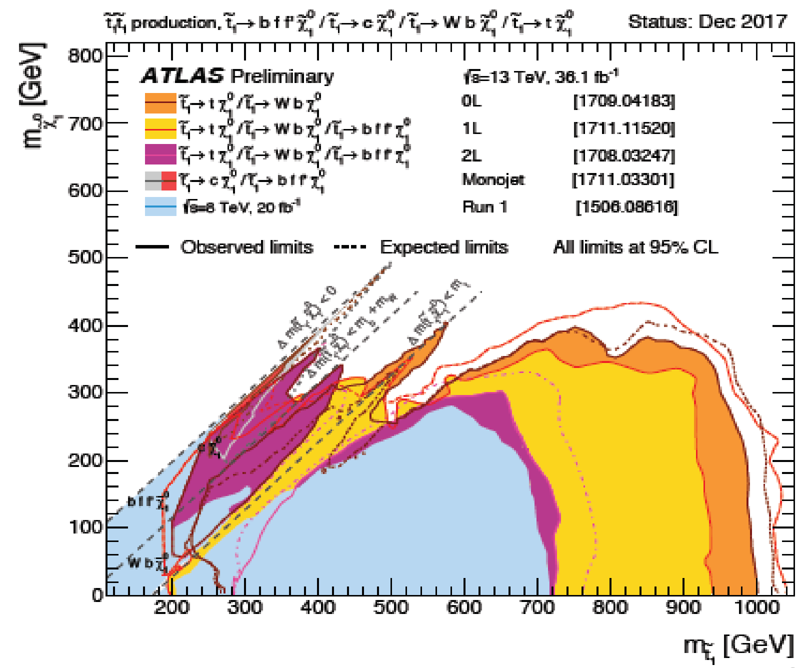
Search for squark, gluino, stop, sbottom

- **Gluinos (squarks) excluded < 2(1.6) TeV**
- **But squarks excluded < 1 TeV , if only one squark is light.**
- **stop > 950 GeV, sbottom > 1.2 TeV**
- **LSP < 1 TeV (800 GeV)**

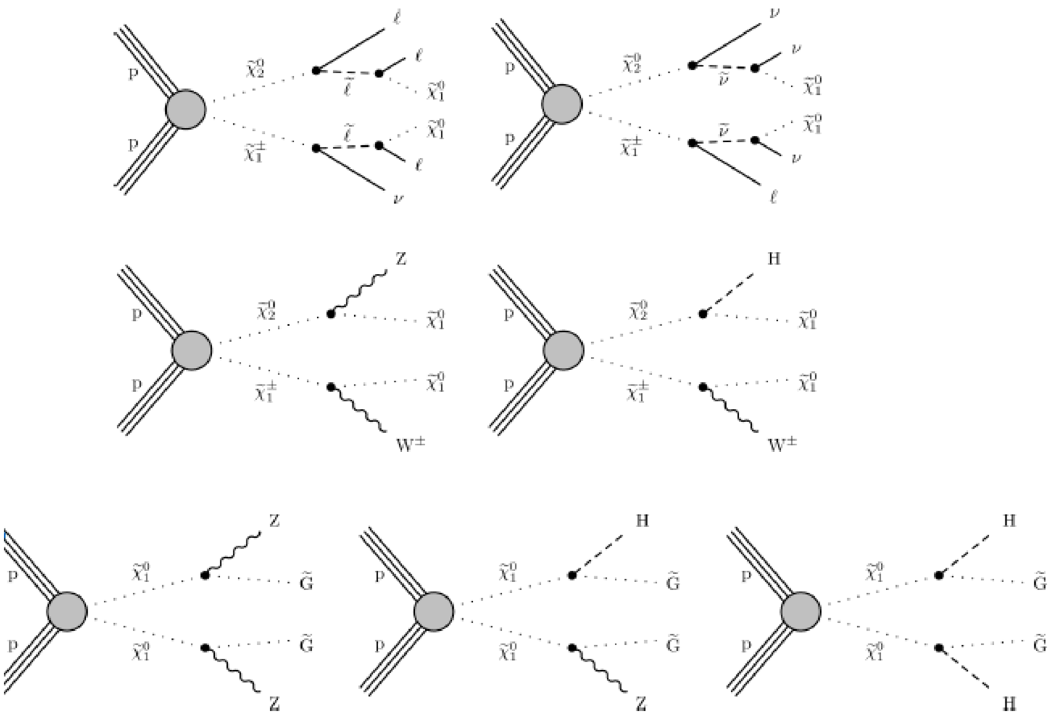
arXiv: 1708.09266



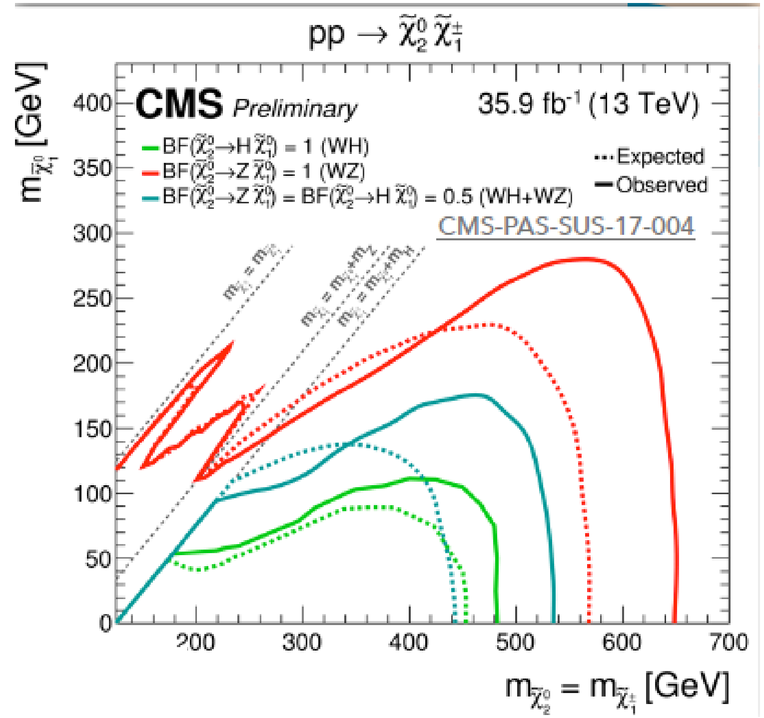




Electroweak production of SUSY particles



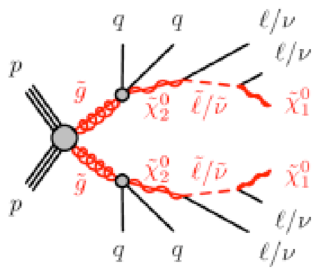
arXiv: 1708.07875

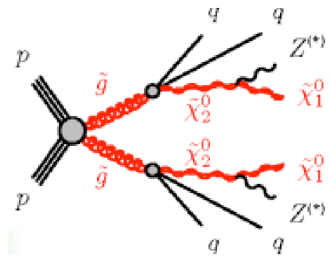


- **Exclude chargino, neutralino below 600 (750) GeV in decay through τ (stau)**
- **exclude masses below 1150 GeV when considering flavour symmetric decays and large mass splitting**
- **Exclude masses up to 650 GeV for various combinations of branching ratios for decays with W/Z/H bosons in final states.**

SUSY search in dilepton final state

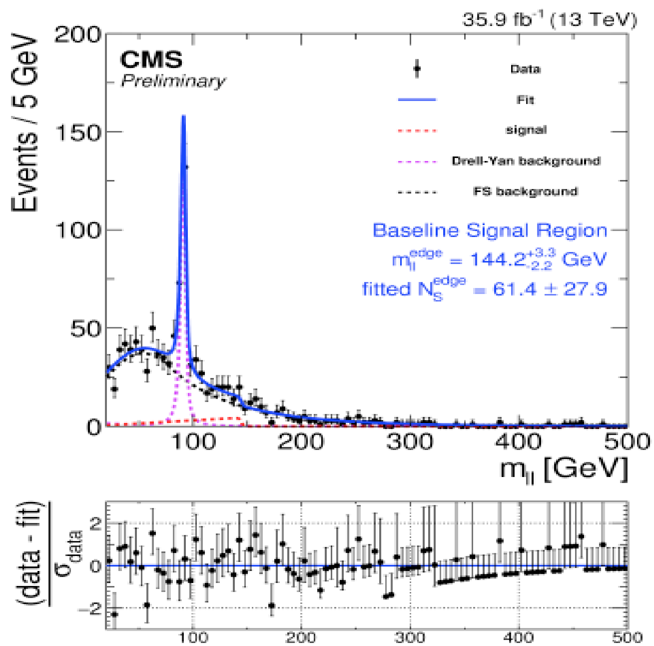
- **Run1 recap: observed excess in m(ll) distribution → ATLAS: on-Z, CMS: off-Z**



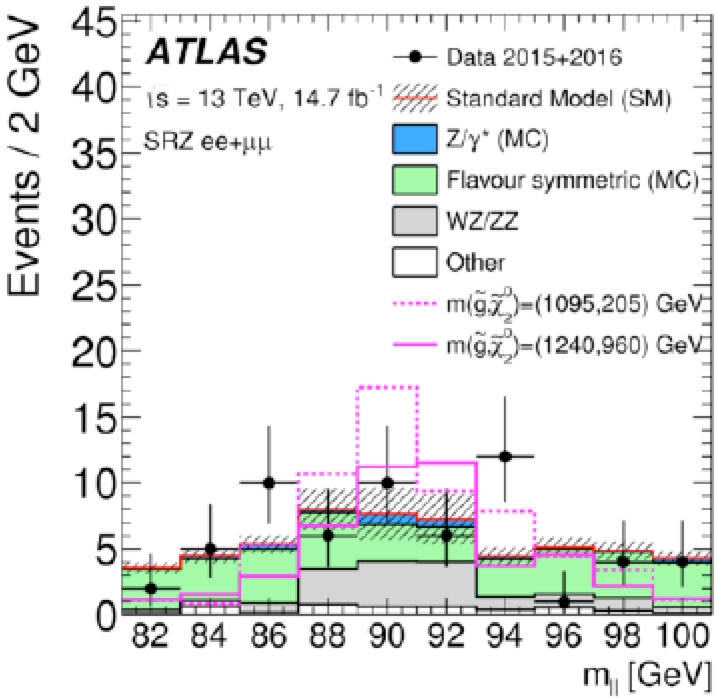


Eur. Phys. J.C75 (2015) 318
JHEP 04 (2015) 124

Run2: 2016 data → no excess observed by either



CMS PAS SUS-16-034



Eur. Phys. J.C77 (2017) 144

Beyond vanilla SUSY

ATLAS CONF-2017-017

CMS arXiv: 1710. 07170

Search for long lived particles

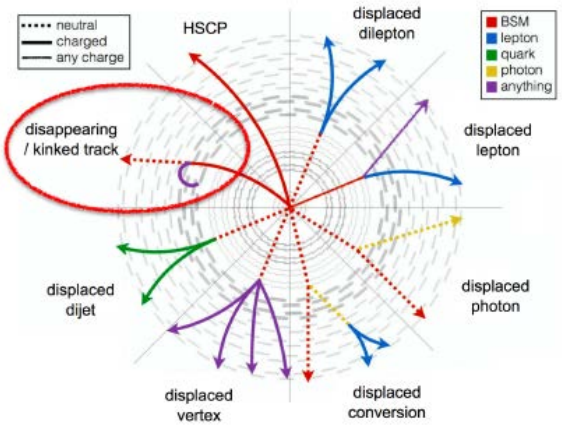
Different topologies possible:

Ex.: Chargino nearly degenerate with a neutralino (wino like LSP)

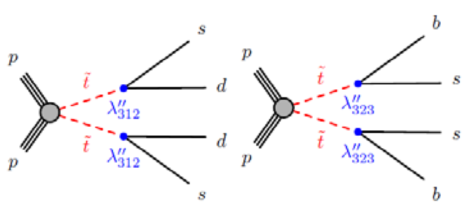
➔ long-lived ➔ disappearing track for Ch. → neu. + pion

typical lifetime ~ 0.2 ns (cτ = 6 cm)

Gluino search may be more sensitive.



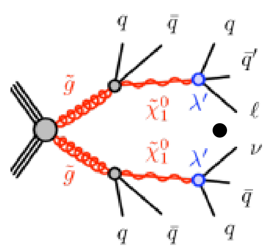
Baryon number violation



Excluded stop mass [100, 470]GeV

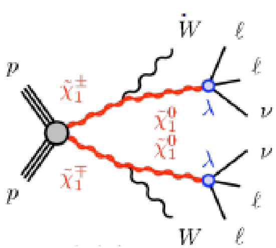
Lepton number violation in LSP decays

JHEP 09 (2017) 88



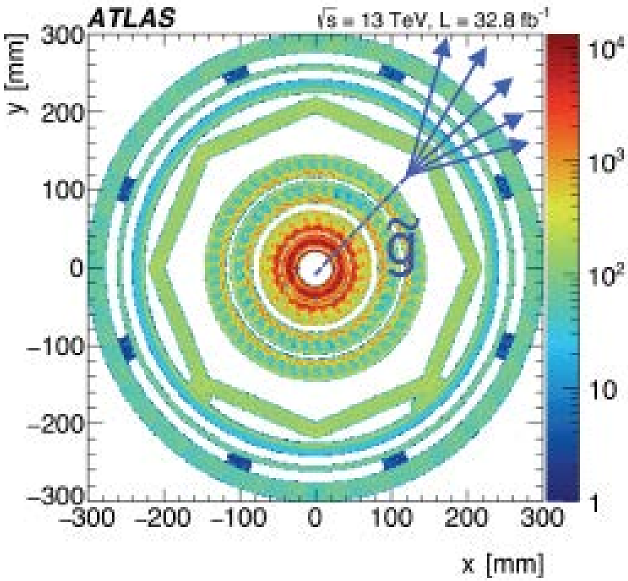
- Exclude gluino masses < 1.8 TeV

ATLAS CONF-2016-075

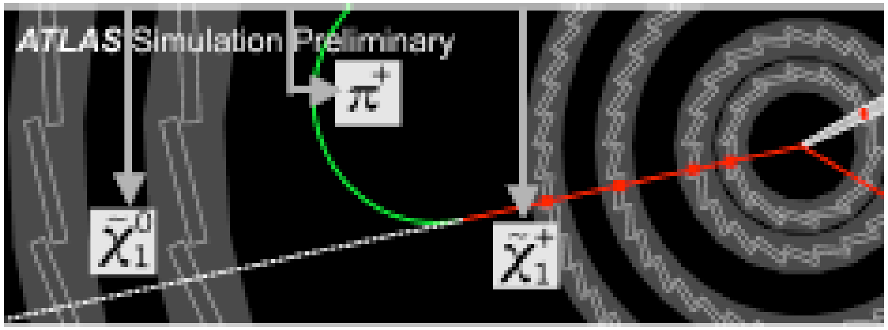


- Exclude chargino, neutralino masses < 1.1 TeV

Search for long lived particles



disappearing track



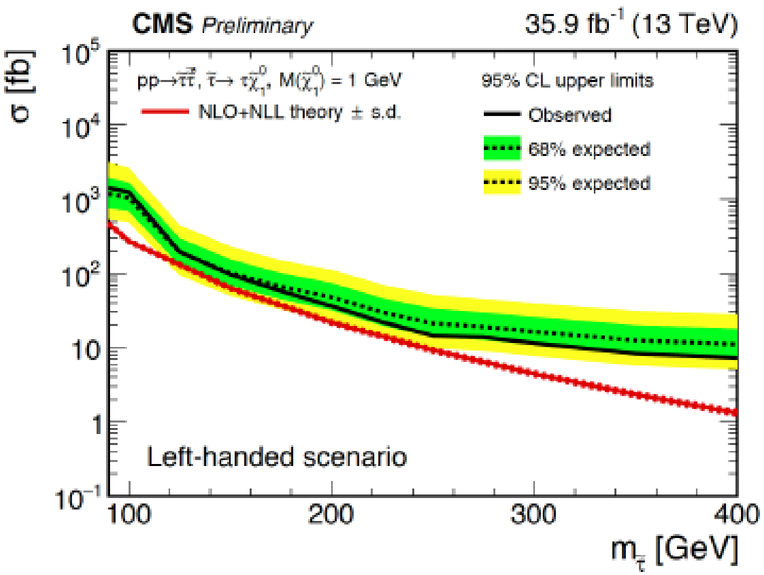
- Signature: Disappearing track + missing energy
- *Need tracking at large radius*

Search	Final State	Sensitivity	References
Direct search for charged LLPs	**disappearing track + E_T^{miss}** + 1 / 4 jets (ISR / gluino decays)	exclude $m(\tilde{\chi}_1^\pm) < 460$ GeV for $\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) = 160$ MeV	1712.02118
Search for LLP decay products	**displaced vertex** (≥5 tracks) **+ E_T^{miss}**	probe 1.8 - 2.4 TeV gluinos with $\tau \sim O(10^{-2})$ - O(10) ns	1710.04901

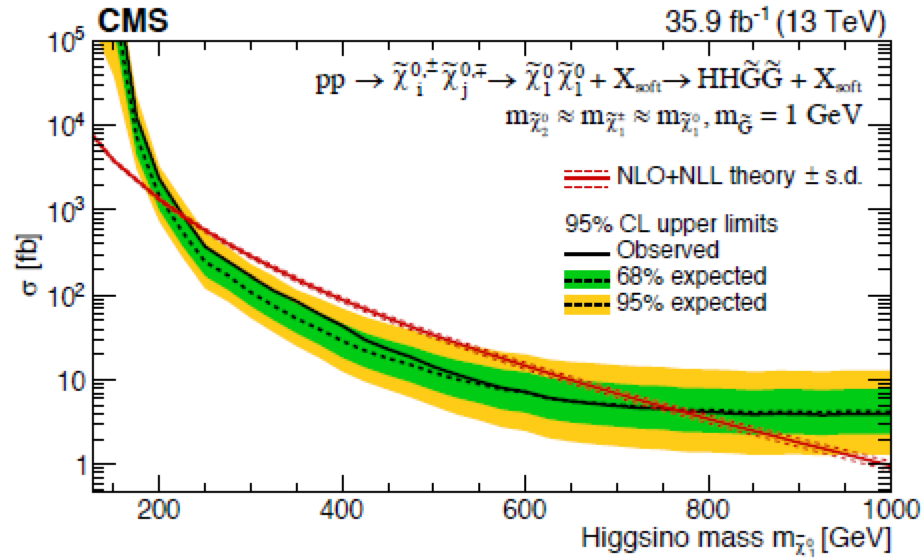
Exclude: pure wino up to 460 GeV

Limits, and limits and limits …..

Stau production



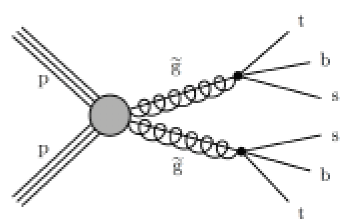
Higgsino search in gauge-mediated scenario

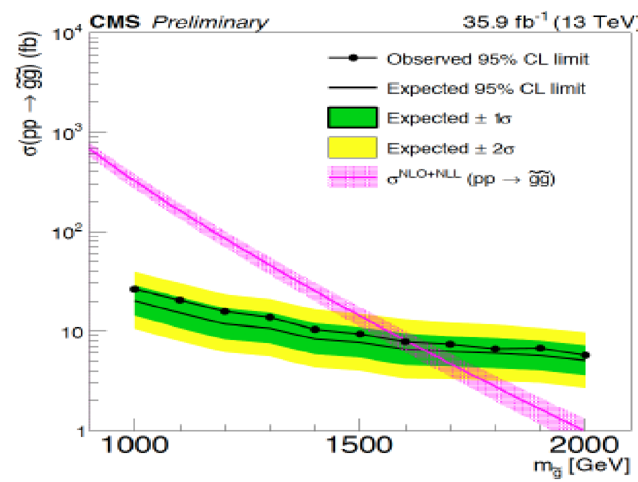


Accumulated data is not yet enough

mass region excluded: 230 to 770 GeV

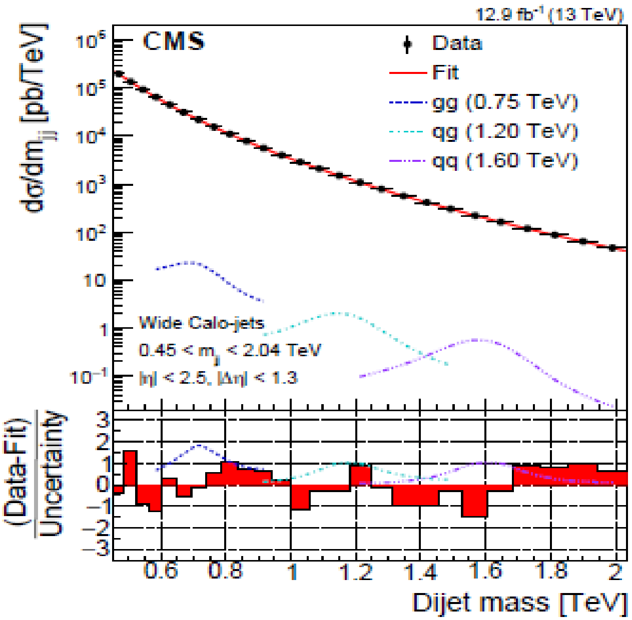
R-parity violation

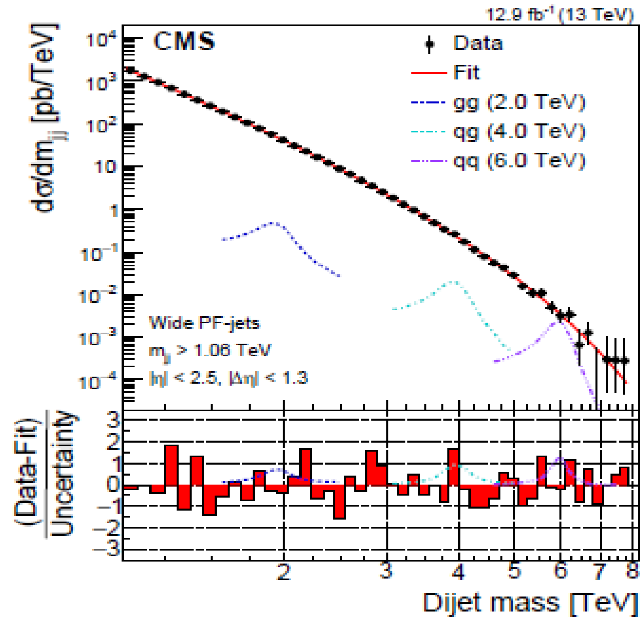




Dijet resonances

- Classic signature with maximal reach ➔ best exclusion limits (@95% CL)





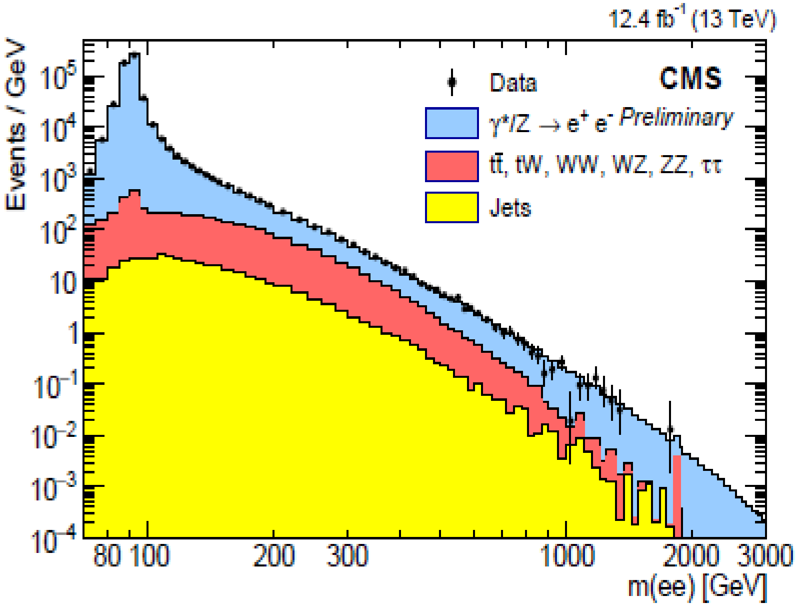
CMS arXiv:1708.9986
CMS PAS: EXO-16-056,
CMS PAS-16-032,
arXiv: 1611.03568

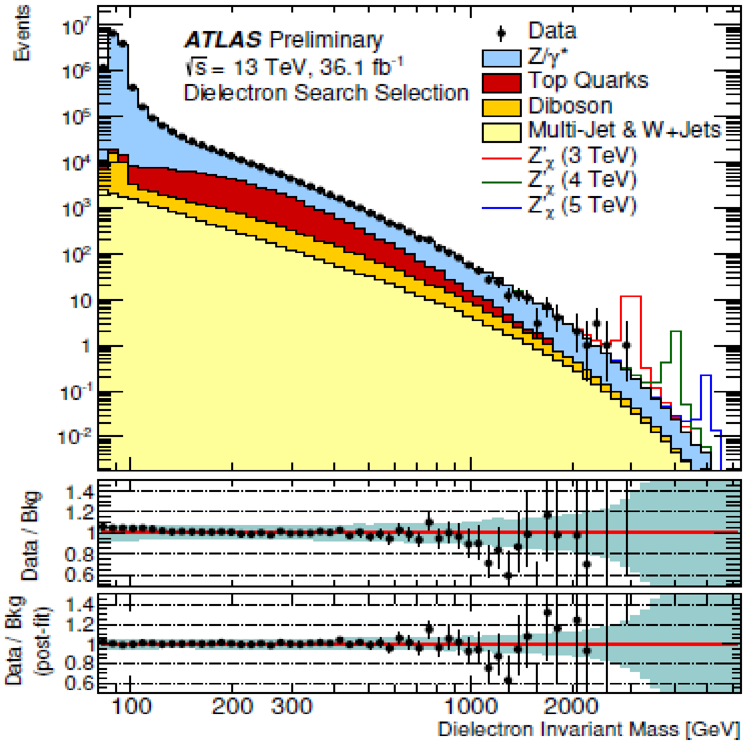
Best limits so far

- Excited quarks $m_{q'}$ > 6.0 TeV (exp.: 5.8 TeV)
- Additional gauge boson m_{W}' > 6.0 TeV (exp.: 5.8 TeV)
- Quantum black hole m_{BH} > 8.9 TeV (exp.: 8.9 TeV)
- Axigluon/colouron > 6.1 TeV (exp.: 6.0 TeV)
- String > 7.7 TeV (exp.: 7.7 TeV)
- RS graviton (k/M_{Pl} = 0.1) > 1.7 TeV (exp.: 2.1 TeV)

Dilepton resonances

- Search for narrow resonances in invariant mass distribution of dileptons above Standard Model background





Best limits:
Z' SSM $m_{Z''} > 4.5$ TeV, sequential gauge bosons
Z' SSM $m_{Z''} > 2.1$ TeV
For models with enhanced coupling to 3rd generation
W' SSM $m_{W''} > 5.11$ TeV
Z' Ψ $m_{Z''} > 3.7$ TeV

ATLAS CONF-2017-027
ATLAS CONF-2017-016
Phys. Lett. B 761 (2016) 372-392

CMS JHEP 02 (2017) 048
CMS PAS-EXO-16-008
CMS arXiv: 1611.06594

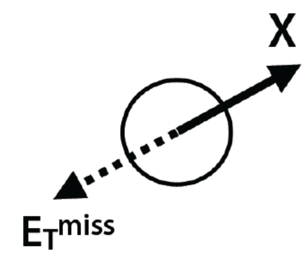
Search for dark matter in mono-X final states

CMS PAS: EXO-16-048

ATLAS CONF-2017-060

- X could be jet, lepton, W, Z, H
- Dark matter may couple to SM particles via a mediator which communicates with SM particles

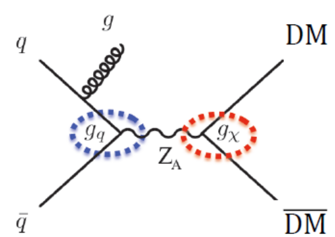
➔ mediator with interaction of type Vector, axial-vector,…



- For vector and axial vector type interaction
- **Excluded DM mass: 400 – 600 GeV, mediator mass 1.6 to 1.8 TeV**

Make it

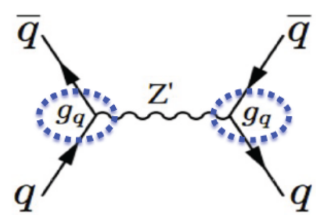
$SM \rightarrow mediator \rightarrow DM$



→Mono-X signature

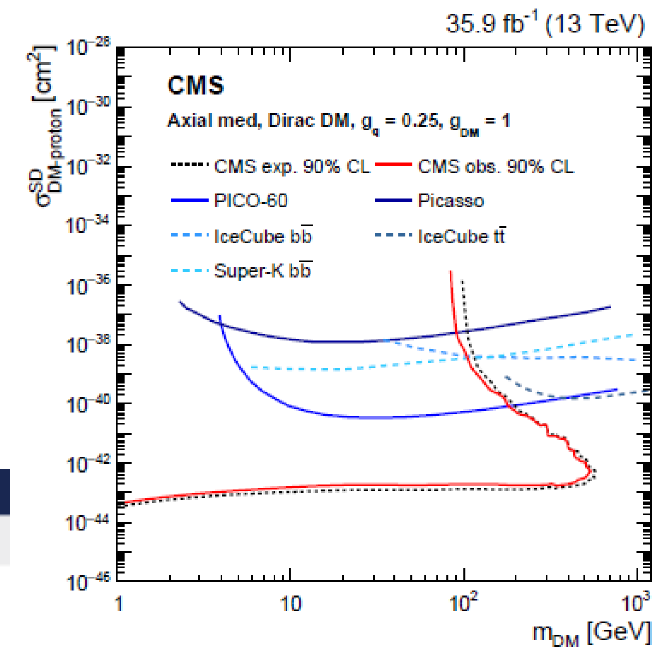
E_T^{miss}+ jet, W/Z/H, γ, …

$SM \rightarrow mediator \rightarrow SM$



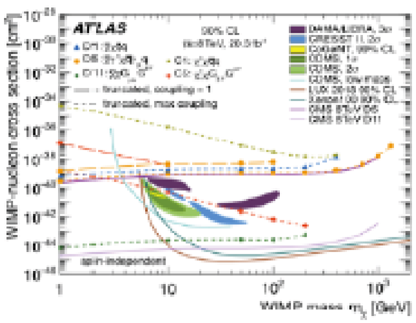
→resonant production

Dijet, ditop, dilepton…..

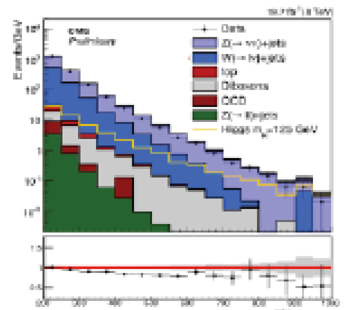


	spin 0		spin 1	
Charge	Q=0 for s-channel			
Lorentz structure	Scalar	$g_q \frac{\phi}{\sqrt{2}} \sum_f y_f \bar{f} f$	Vector	$g_q \sum_q V_\mu \bar{q} \gamma^\mu q$
	Pseudoscalar	$g_q \frac{iA}{\sqrt{2}} \sum_f y_f \bar{f} \gamma^5 f$	Axial-vector	$g_q \sum_q A_\mu \bar{q} \gamma^\mu \gamma^5 q$
Coupling	∝ mass		∝ charge	

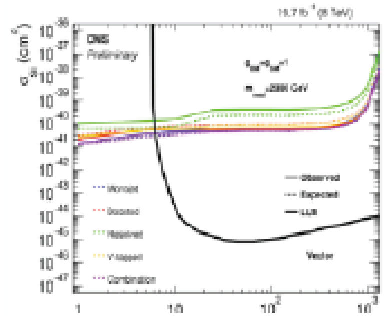
Mono-mania



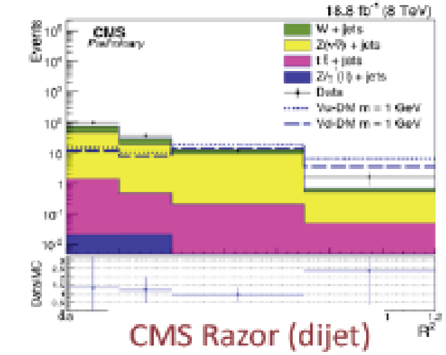
ATLAS Monojet
EPJC (2015) 75:299



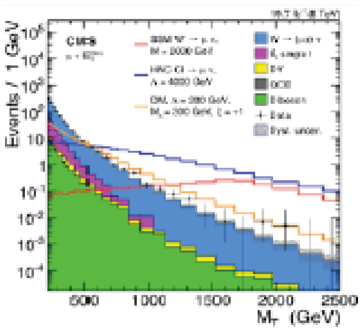
CMS j/V (mono/dijet)
PAS-EXO-12-055



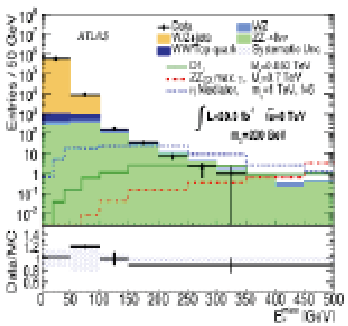
CMS j/V (mono/dijet)
PAS-EXO-12-055



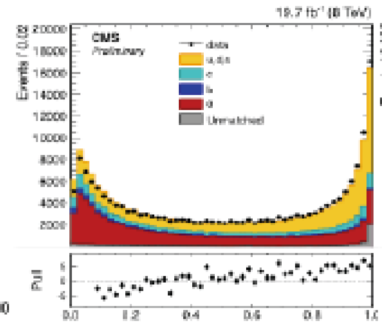
CMS Razor (dijet)
PAS-EXO-14-004



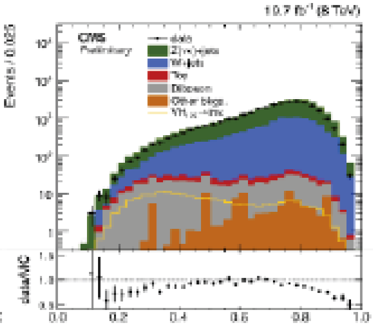
CMS, ATLAS MonoW
PRD 91, 092005, JHEP 09 (2014) 037 (2015)



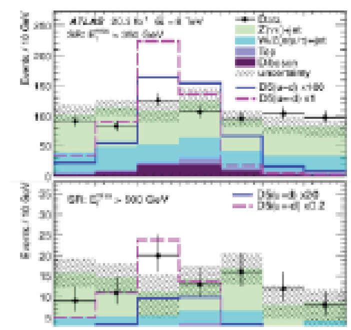
CMS, ATLAS MonoZ
EXO-12-054, PRD 90, 012004 (2014)



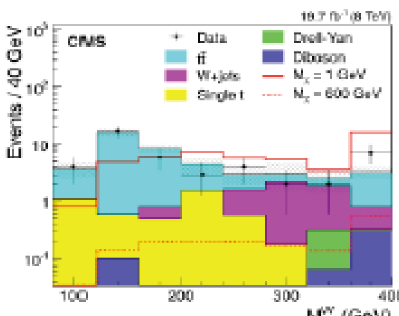
CMS MonoV (resolved)
PAS-EXO-12-005, PAS-JME-14-002



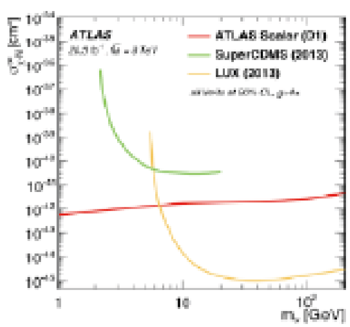
CMS MonoV (boosted)
EXO-12-005/JME-14-002



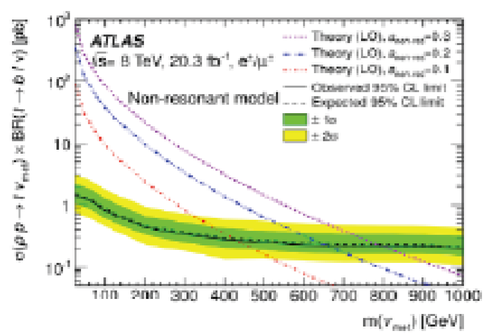
ATLAS MonoV (boosted)
ATLAS, PRL 112, 041802 (2014)



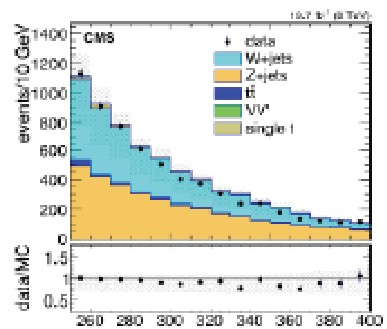
CMS TopPairs
CMS, JHEP 06 (2015) 121



ATLAS TopPairs
ATLAS, EPJC (2015) 75:92



CMS MonoTop
CMS, PRL 114 (2015) 101801



ATLAS MonoTop
ATLAS, JHEP 11 (2014) 118

Retrospect & prospect

- Big ideas are highly constrained by experimental data

- It is not clear if LHC will solve the problem of fine tuning, reveal the nature of dark matter, etc. → no guarantee for a positive answer.

Q.: **What important questions can LHC resolve?**
A.: precision as a requirement: essential to address some of the above.

High-luminosity LHC operation at 14 TeV will provide L ~ 3/ab by 2030 to extract the full potential of this broad-band machine.

➔ HL-LHC as Higgs factory will allow precision measurements of Higgs sector
➔ Rare decay modes of Higgs will be accessible.
➔ Role of Higgs to be established for $W_L W_L$ scattering
➔ Study of Standard Model processes high energies to explore electric dipole moment etc.

Need almost completely new detectors: ATLAS and CMS
→ *Miles to go before we sleep*

Higgs self-coupling

- Measuring the Higgs self-coupling is the key point to prove the electroweak symmetry breaking mechanism
- **Observing two Higgs boson in the event is the only way to probe the self coupling.**
- Accurate measurement may indicate the extension of Higgs sector, if any.

Higgs potential

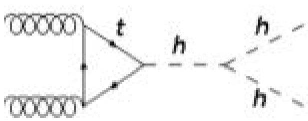
$$V = \lambda v^2 H^2 + \lambda v H^3 + \frac{1}{4}\lambda H^4$$

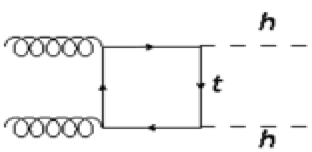
Mass term

Trilinear coupling

Quartic coupling
→difficult to measure

SM: $\lambda = \frac{m_H^2}{2v^2}$ $v \sim 246 GeV$





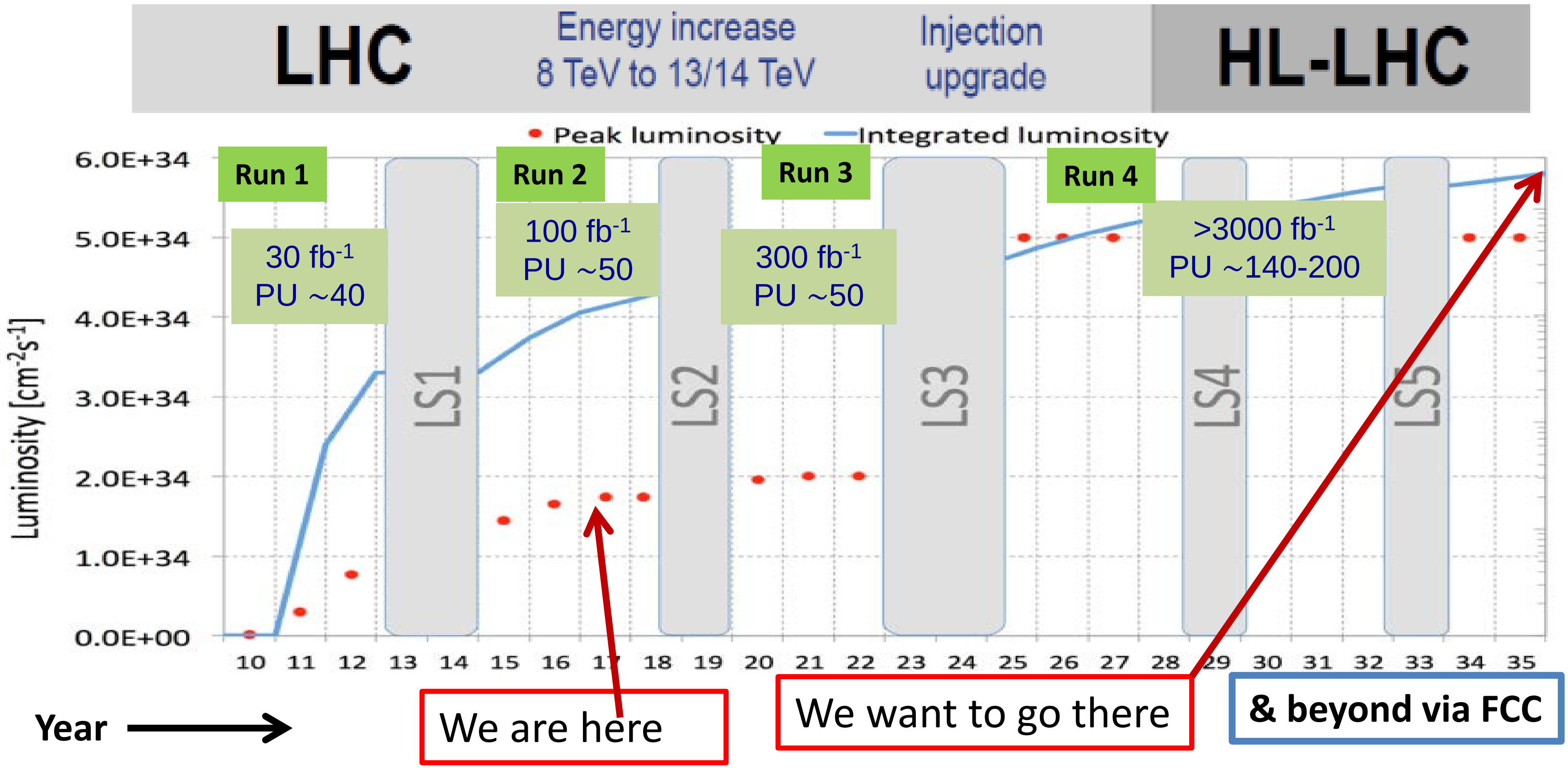
- SM production rate of double Higgs is small,
  signal interfere with background destructively.

→ Enhancement possible through resonant production of H → hh
in MSSM, NMSSM, 2HDM, Higgs portal model etc.

→ Very good prospect for HL-LHC: rate at 14 TeV (NNLO): 40.2 fb

- bbγγ : small rate but relatively clean signature
- bbWW: large rate but large background as well

LHC machine timeline: extraction of full potential is top priority



Run3:
Integrated lumi ≥ 300 /fb by 2022

HL-LHC:

- Lumi-level at 5x design,
- PU=140 / 200
- **integrated lumi nosity: 3000 -5000 /fb**

What will LHC bring, for sure, in future?

Run2: observation of H→ bb	(Yukawa coupling)
Run2/3: observation of ttH process:	(Yukawa coupling)
HL-LHC: observation of H → μμ	(2nd generation Yukawa)
HL-LHC: Higgs width → with 50% accuracy	(BSM constraint)
HL-LHC: H → invisible < 10%	(BSM constraint)
HL-LHC: gg → HH	(Higgs potential)
HL-LHC: Hcc coupling	(2nd generation Yukawa)

- Additionally, X300 sensitivity to rare decays involving new physics.

- Higgs coupling modifier ($\boldsymbol{\kappa}_{\mu}$) to 5% , $H\rightarrow\mu\mu$ signal strength ($\sigma_{meas}/\sigma_{SM}$) to 10%

- Precision measurement of gauge-Higgs couplings across broad kinematics

→ can potentially probe (i) existence of new physics in loops or

(ii) non-fundamental nature of Higgs or

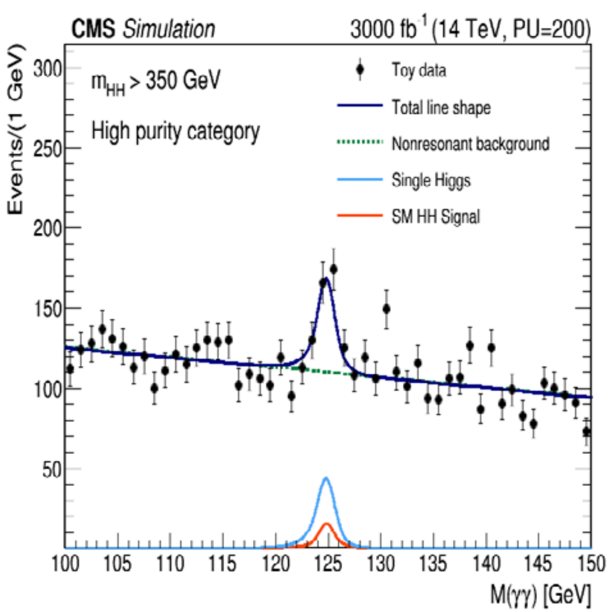
(iii) confirm non-trivial aspects of Higgs sector , including knowledge of H potential.

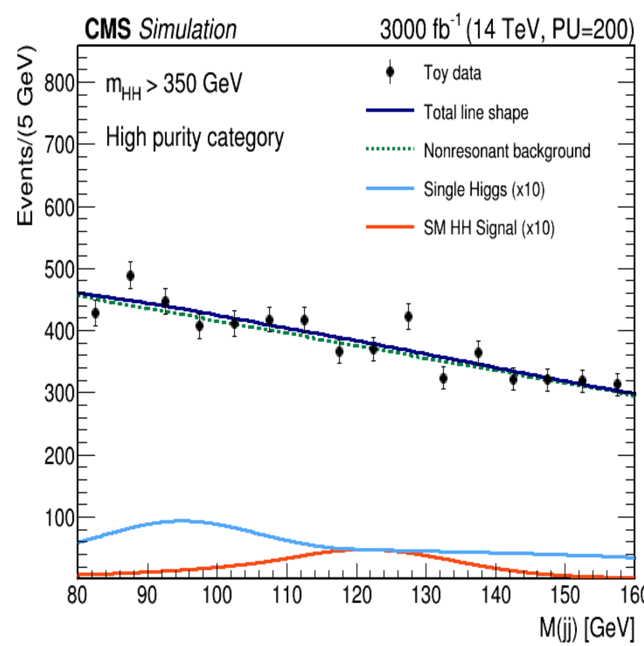
HH → bbγγ at HL-LHC

CMS-PAS-FTR-16-002, 2017

- Updates used in the extrapolation:
  - Di-photon mass resolution (include ECAL ageing after 1000 fb^{-1} of collected data), convoluted with expected gain from regression (as in Run2) and at 200 PU scenario
  - Improvement in b-tagging gives a signal efficiency increase of 15%
- **A significance of 1.9 standard deviations is expected in CMS with 3000 fb^{-1}**
  - Further improvements are anticipated account for improvements that can be gained from precision timing information in ECAL and the tracker

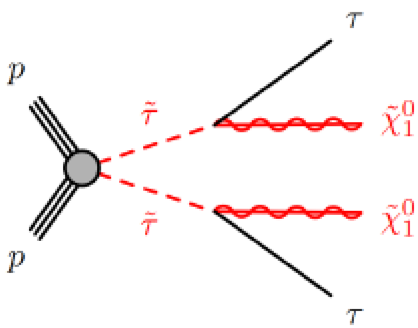
3σ "evidence" of di-Higgs production can be reached by combining all channels in CMS & ATLAS.

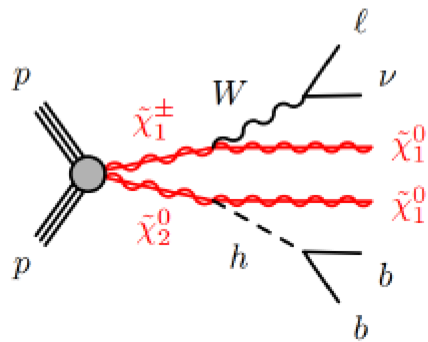


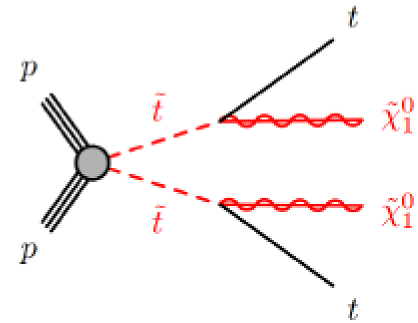


Prospect of SUSY searches at HL-LHC

- A large number of SUSY scenarios need large integrated luminosity



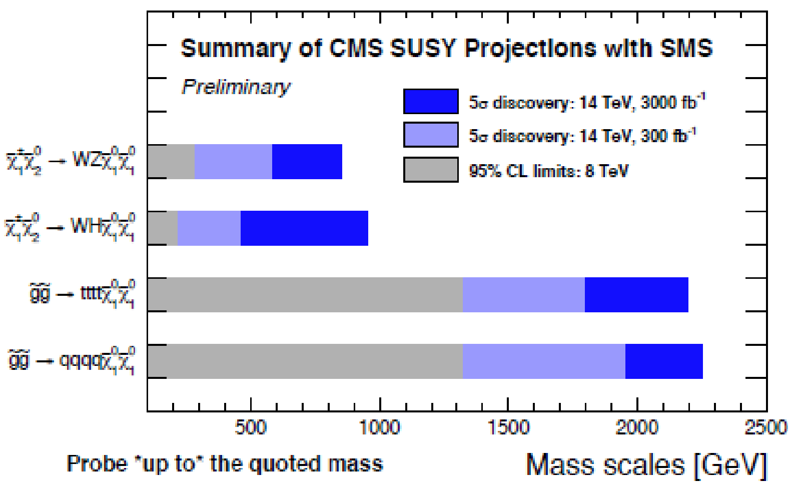




Direct staus
- Discovery up to ~ 500 GeV

Electroweak SUSY with Higgs
- Discovery up to ~ 800 geV

Hidden stops
- Discovery up to ~ 500 GeV



- Discovery potential extended by several hundred GeV for pair produced squarks, gluinos

- Gain more for chargino-neutralino production → Discovery reach up to 850 GeV with 3/ab

- Di-stau production: discovery ~ 520 GeV with 3/ab

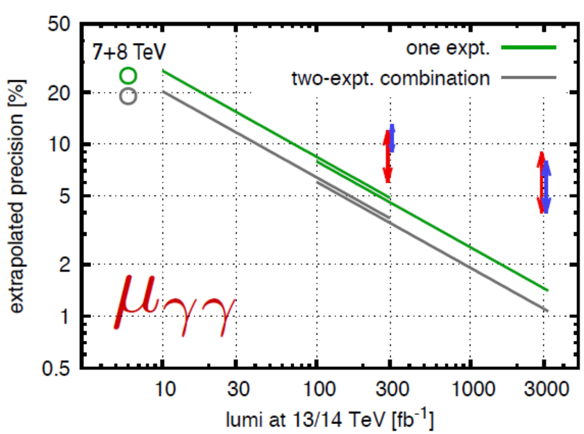
CMS PAS SUS-14-012
ATLAS PHYS-PUB-2014-010

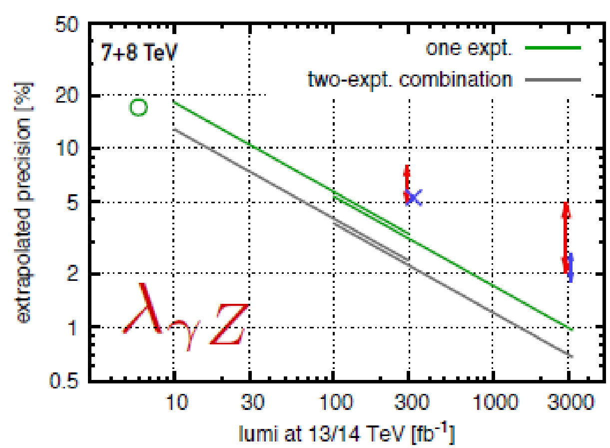
What is needed other than luminosity?

- **Note LHC has delivered only ~ 1% of total data to be delivered by 2030s.**
- Study of H→ μμ is in purely experimental domain
- But in some cases like measurement of Hcc, or triple Higgs coupling precision in both theory and experiment are essential

Naïve extrapolation of Run1 results, based on integrated luminosity and σ (ATLAS + CMS combined) ➔ need to aim for accuracy better than $\mathcal{O}$(1%), to be able to benefit from the high statistics data of HL-LHC.

- **Search for BSM has turned out to be a marathon, though we expected to be a sprint until a few years back!**

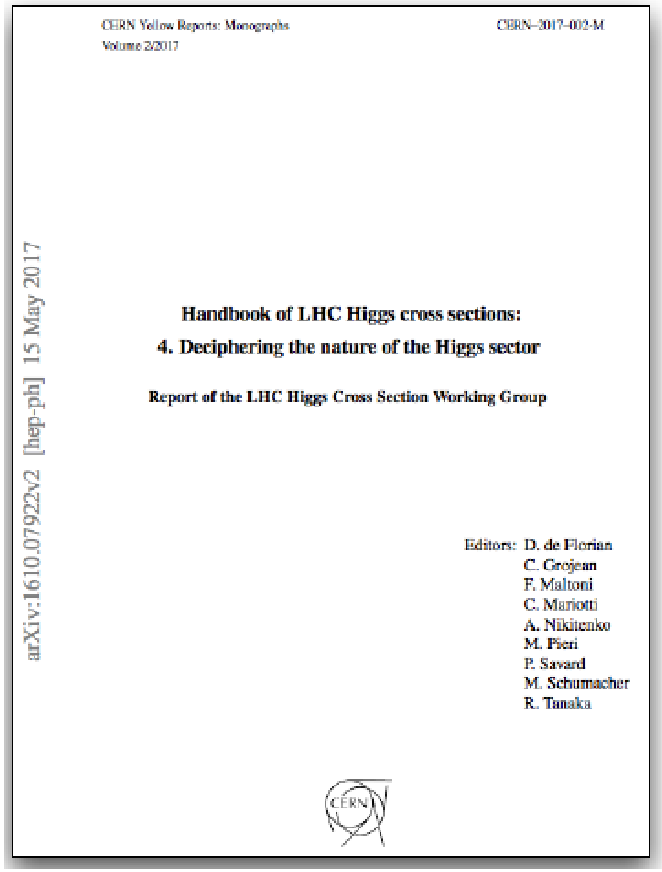




Exploitation of potential for HL-LHC needs synergy in all communities.

Thought/provocations in the context of this workshop

The holy books in LHC community



CERN Yellow Reports: Monographs
Volume 2/2017

CERN–2017–002-M

arXiv:1610.07922v2 [hep-ph] 15 May 2017

Handbook of LHC Higgs cross sections:
4. Deciphering the nature of the Higgs sector

Report of the LHC Higgs Cross Section Working Group

Editors: D. de Florian
C. Grojean
F. Maltoni
C. Mariotti
A. Nikitenko
M. Pieri
P. Savard
M. Schumacher
R. Tanaka

- Great collaboration between experimental & theoretical communities has made the LHC community highly vibrant compared to the activities of a single type
  ➔ **More credibility of LHC related studies**

- How can we be more part of CERN activities related to LHC?
  -- Lot of working groups formed under broad categorization: Higgs, SM, FSQ , ..
  -- Regular publication of yellow reports as the guidance to both experiment and theory communities.

- *New activities recently started for studying the potential of high luminosity LHC.*

- **-- lot of opportunities for substantial contribution and visibility**

Example: industry for SM processes

- **Calculating the rates with precision pays in the long run**; eg. W, Z, t, H
- **Higher order corrections enhance the cross section and also modify kinematics in final state → both equally important for BSM searches**
- Higgs cross section correct to α_s^2 (N2LO) in 2013
- N3LO in 2016, involving more than 10k diagrams → sophisticated tools have made the required time to result reasonably small
- Drell-Yan, inclusive top pair processes are all equally crucial
- Note N4LO (in α_s) estimate for ggH may not be forthcoming in a while improvements in electroweak corrections start to become significant at high energies.
- Improvement in PDF (N3LO) highly desirable in near future?
- At higher energies multiple heavy particles are produced even at tree level : need to know their rates

Conclusion

- Current era of LHC is marked by triumph of SM Higgs
- SM will continue to rule strong even after BSM appears eventually

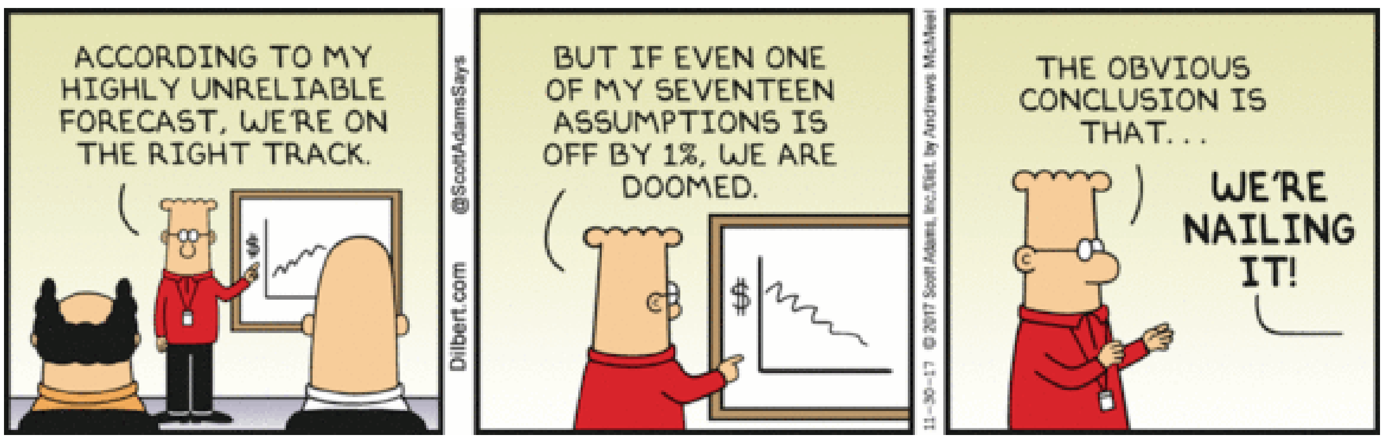
- **Investing efforts in SM related works, even partly, will be prudent IMHO.**

Extensive search for new physics

→ Continuing benchmark studies and exploring new strategies

→ By now the era of large jumps in energy or luminosity is over.

→ A lot more needs to be done by consolidation and widening the strategies.



Thank you!

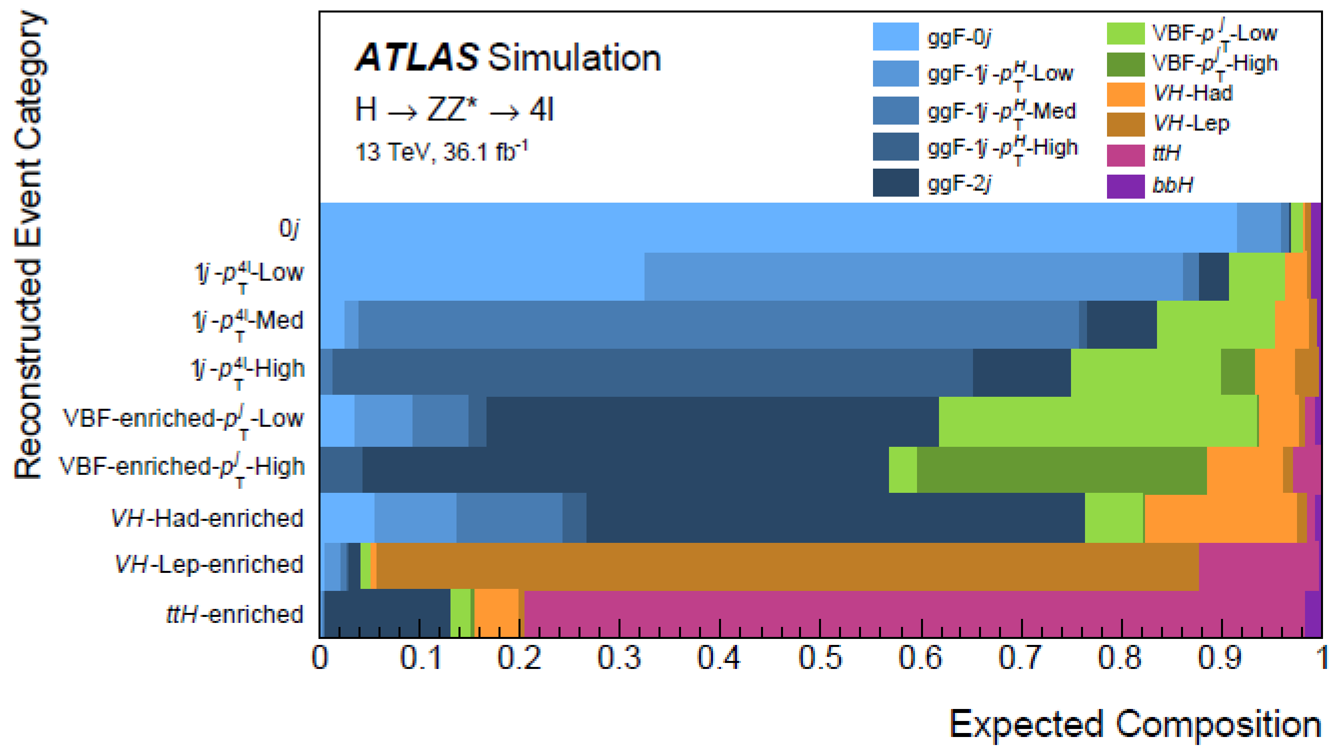
backup

ATLAS: H→ ZZ* → 4l

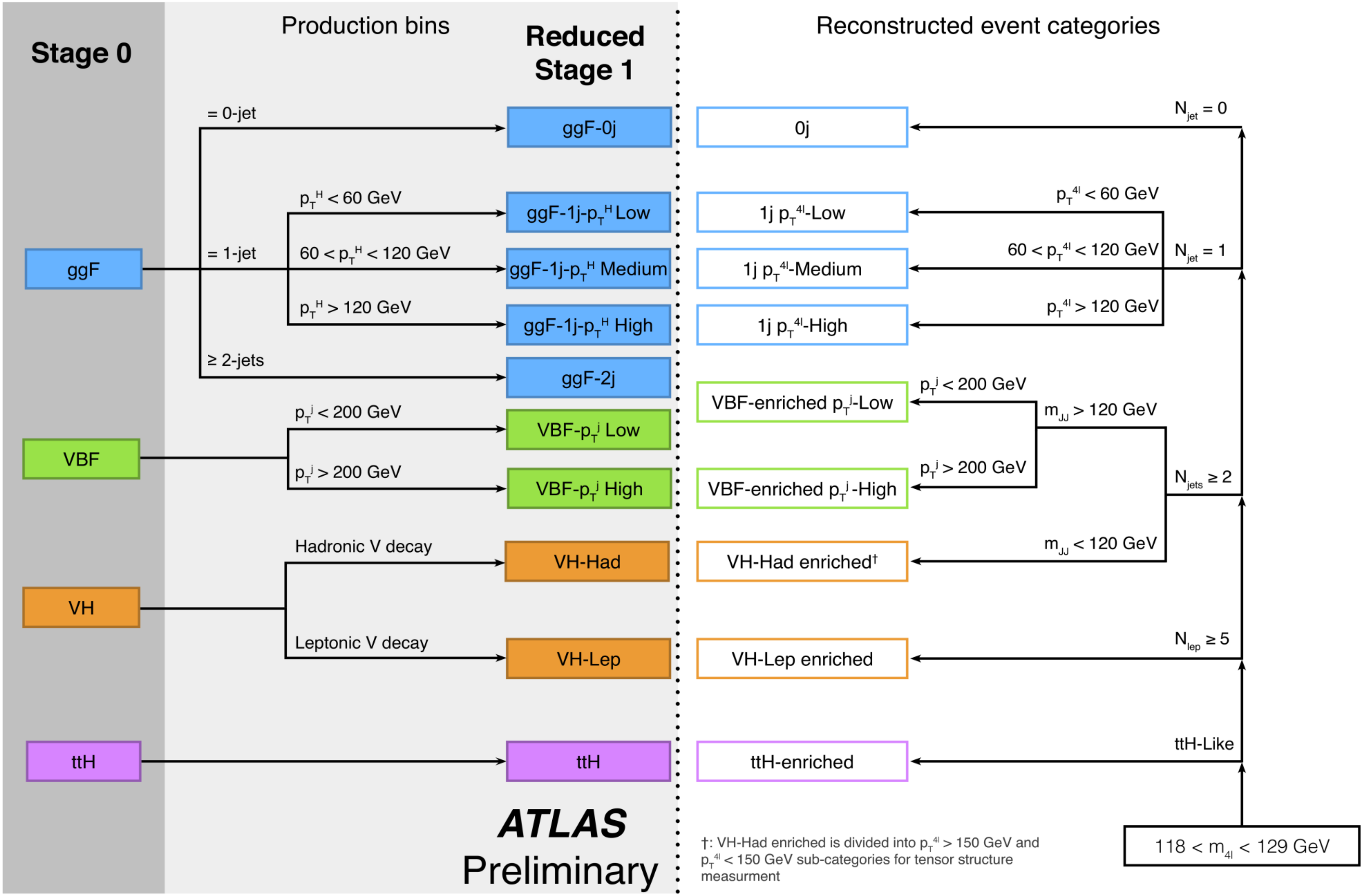
Study tensor stricture of Higgs coupling to vector bosons in terms of effective coupling

$$\mathcal{L}_0^V = \left\{ \kappa_{\rm SM} \left[\frac{1}{2} g_{HZZ} Z_\mu Z^\mu + g_{HWW} W_\mu^+ W^{-\mu} \right] \right.$$
$$- \frac{1}{4} \left[\kappa_{Hgg} g_{Hgg} G_{\mu\nu}^a G^{a,\mu\nu} + \tan\alpha \kappa_{Agg} g_{Agg} G_{\mu\nu}^a \tilde{G}^{a,\mu\nu} \right]$$
$$- \frac{1}{4} \frac{1}{\Lambda} \left[\kappa_{HZZ} Z_{\mu\nu} Z^{\mu\nu} + \tan\alpha \kappa_{AZZ} Z_{\mu\nu} \tilde{Z}^{\mu\nu} \right]$$
$$- \frac{1}{2} \frac{1}{\Lambda} \left[\kappa_{HWW} W_{\mu\nu}^+ W^{-\mu\nu} + \tan \right.$$

Signal composition in different categories



ATLAS definition of phase-space regions in Higgs analyses



$$(\sigma \cdot BR)(i \to H \to f) = \frac{\sigma_i \cdot \Gamma_f}{\Gamma_H}$$

i = production mode ; f = decay channel ; Γ_H = total width = sum of all partial widths

The signal yield in category k, $n_{signal}(k)$ is computed as:

$$n_{\text{signal}}(k) = \mathcal{L}(k) \times \sum_i \sum_f \left\{\sigma_i \times A_i^f(k) \times \varepsilon_i^f(k) \times \text{BR}^f\right\},$$

$$= \mathcal{L}(k) \times \sum_i \sum_f \mu_i \mu^f \left\{\sigma_i^{\text{SM}} \times A_i^f(k) \times \varepsilon_i^f(k) \times \text{BR}_{\text{SM}}^f\right\}$$

$$\mu_i = \frac{\sigma_i}{\sigma_i^{\text{SM}}} \quad \text{and} \quad \mu^f = \frac{\text{BR}^f}{\text{BR}_{\text{SM}}^f}.$$

Luminosity

production/decay modifiers

Acceptance

Efficiency

Parametrization defined by the LHC Higgs cross section working group

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWG

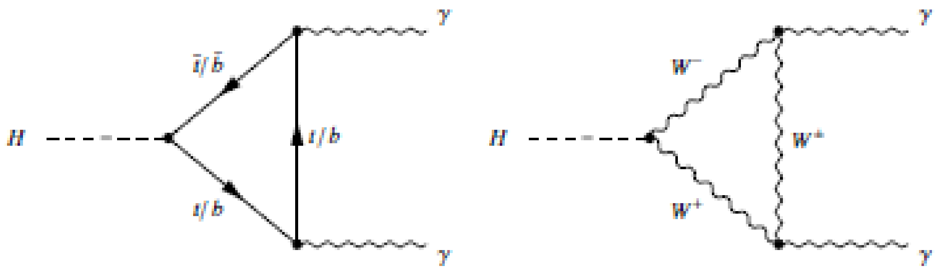
Coupling modifiers: "k-framework" (kappa-framework) = multipliers at amplitude level introduced to parametrise possible deviation from SM. They are defined as

$$\kappa_j^2 = \sigma_j / \sigma_j^{\mathrm{SM}} \quad \text{or} \quad \kappa_j^2 = \Gamma^j / \Gamma^j_{\mathrm{SM}}$$

$$\kappa_H^2 = \sum_j \mathrm{BR}^j_{\mathrm{SM}} \kappa_j^2 \qquad \Gamma_{\mathrm{H}} = \frac{\kappa_H^2 \cdot \Gamma_H^{\mathrm{SM}}}{1 - \mathrm{BR}_{\mathrm{BSM}}}$$

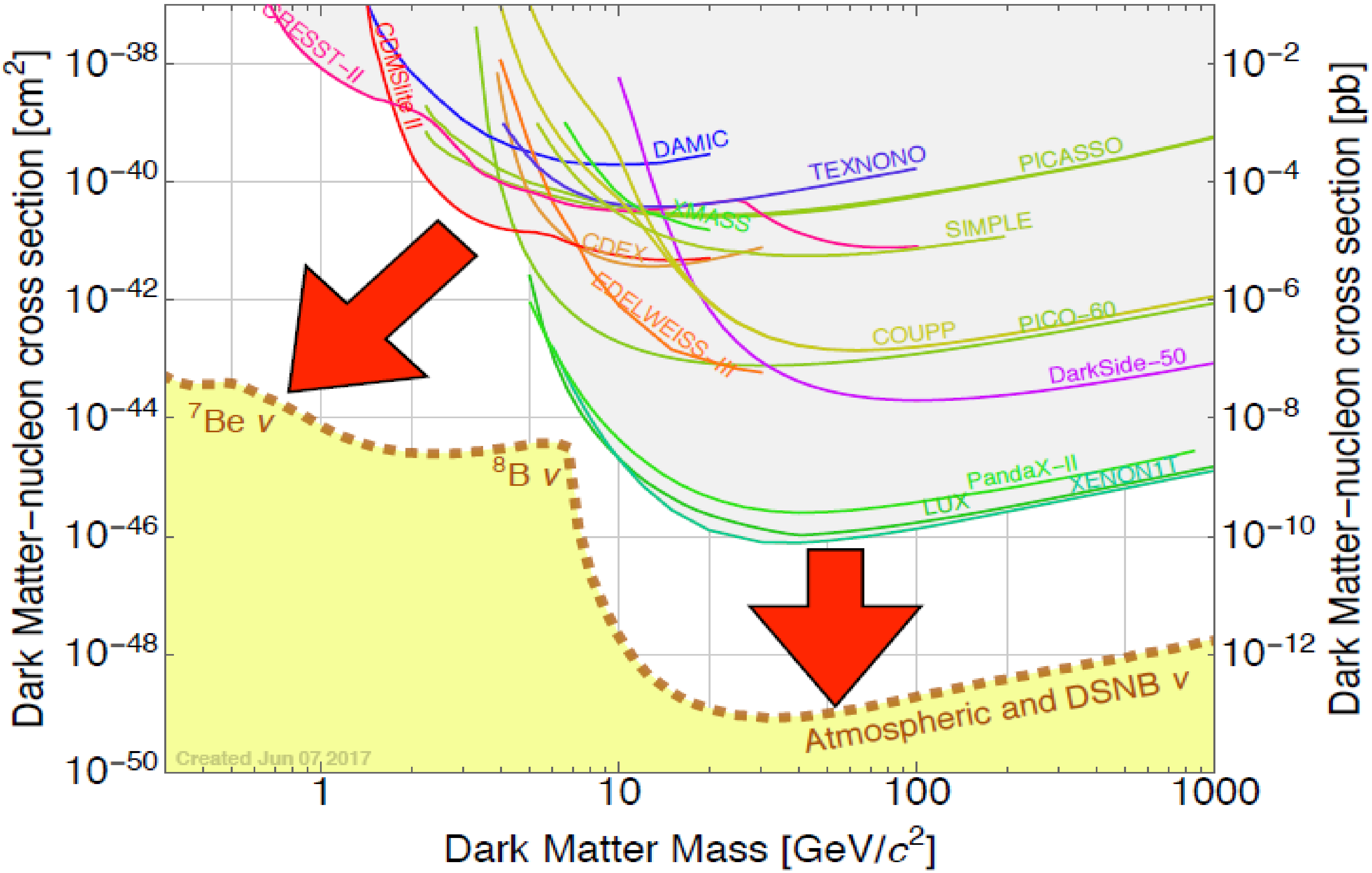
Sensitive to interference effect in loops

e.g. negative interference between:



Production	Loops	Interference	Effective scaling factor	Resolved scaling factor
$\sigma(ggF)$	✓	t–b	κ_g^2	$1.06 \cdot \kappa_t^2 + 0.01 \cdot \kappa_b^2 - 0.07 \cdot \kappa$ [illegible]
$\sigma(VBF)$	–	–		$0.74 \cdot \kappa_W^2 + 0.26 \cdot \kappa_Z^2$
$\sigma(WH)$	–	–		κ_W^2
$\sigma(qq/qg \rightarrow ZH)$	–	–		κ_Z^2
$\sigma(gg \rightarrow ZH)$	✓	t–Z		$2.27 \cdot \kappa_Z^2 + 0.37 \cdot \kappa_t^2 - 1.64 \cdot \kappa_Z \kappa_t$
$\sigma(ttH)$	–	–		κ_t^2
$\sigma(gb \rightarrow tHW)$	–	t–W		$1.84 \cdot \kappa_t^2 + 1.57 \cdot \kappa_W^2 - 2.41 \cdot \kappa_t \kappa_W$
$\sigma(qq/qb \rightarrow tHq)$	–	t–W		$3.40 \cdot \kappa_t^2 + 3.56 \cdot \kappa_W^2 - 5.96 \cdot \kappa_t \kappa_W$
$\sigma(bbH)$	–	–		κ_b^2
Partial decay width				
Γ^{ZZ}	–	–		κ_Z^2
Γ^{WW}	–	–		κ_W^2
$\Gamma^{\gamma\gamma}$	✓	t–W	κ_γ^2	$1.59 \cdot \kappa_W^2 + 0.07 \cdot \kappa_t^2 - 0.66 \cdot \kappa_W \kappa_t$
$\Gamma^{\tau\tau}$	–	–		κ_τ^2
Γ^{bb}	–	–		κ_b^2
$\Gamma^{\mu\mu}$	–	–		κ_μ^2
Total width ($B_{BSM} = 0$)				
Γ_H	✓	–	κ_H^2	$0.57 \cdot \kappa_b^2 + 0.22 \cdot \kappa_W^2 + 0.09 \cdot \kappa_g^2 +$ $0.06 \cdot \kappa_\tau^2 + 0.03 \cdot \kappa_Z^2 + 0.03 \cdot \kappa_c^2 +$ $0.0023 \cdot \kappa_\gamma^2 + 0.0016 \cdot \kappa_{(Z\gamma)}^2 +$ $0.0001 \cdot \kappa_s^2 + 0.00022 \cdot \kappa_\mu^2$

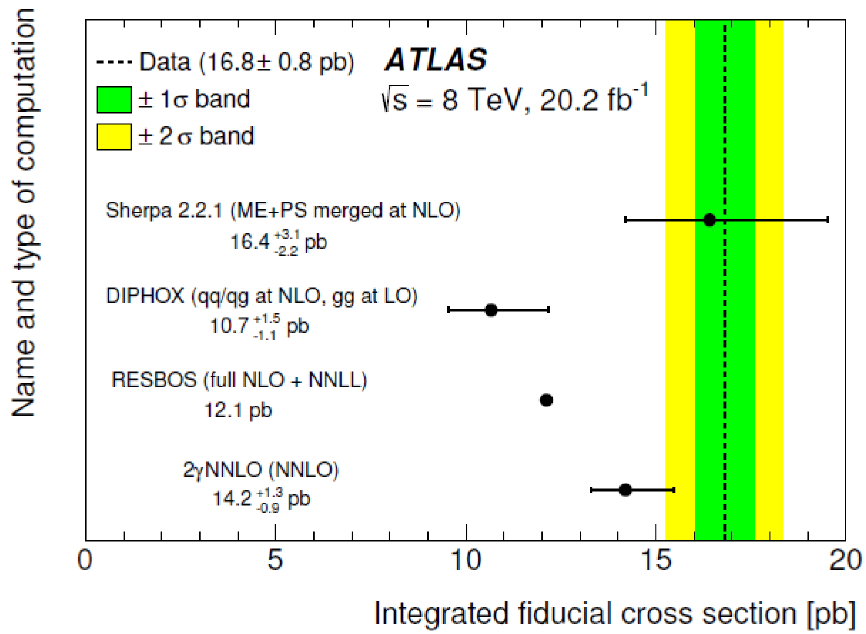
CERN-PH-2016-100

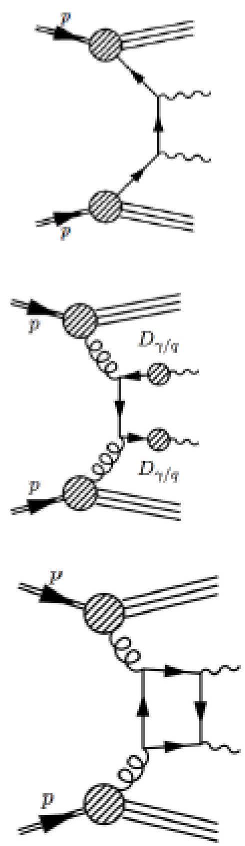


"Make It" - WIMP production searches LHC
"Break It" - WIMP Annihilation searches - astrophysical gamma-ray searches
"Shake It" - Direct DM searches underground

Diphoton differential cross section

ATLAS arXiv;1704.03839





Fiducial cross section and differential distributions compared to several fixed-order and ME+PS generators

Search for new physics

- Countably infinite number of models for physics beyond standard model has been proposed during last 30 years.
- LHC experiments are keeping no stone unturned.

- Broad categorization:

→ Supersymmetry
→ Dark matter
→ Long-lived particles
→ New heavy resonances

- Searches are tuned on specific final states

→ inclusive single/double (opposite sign, same sign) or multiple leptons
→ fully hadronic
→ b-tagged jets
→ Fat jets with substructures

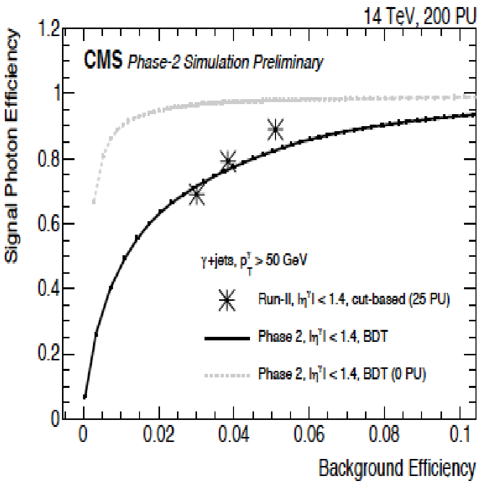
- Consider only SM processes as backgrounds in any search

→ Lie in the tail of distributions: difficult to determine from simulations
→ Use control regions in data and transfer factors to signal region

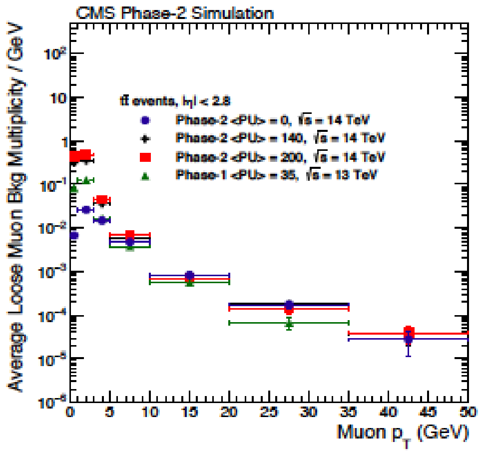
Detector performance at HL-LHC (Phase II upgraded CMS detector

Motto: at least maintain current performance of physics objects

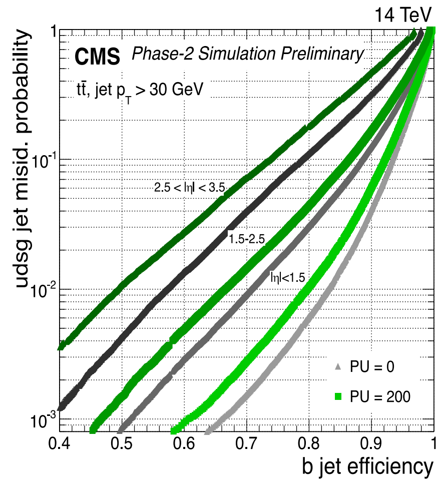
Photon ID



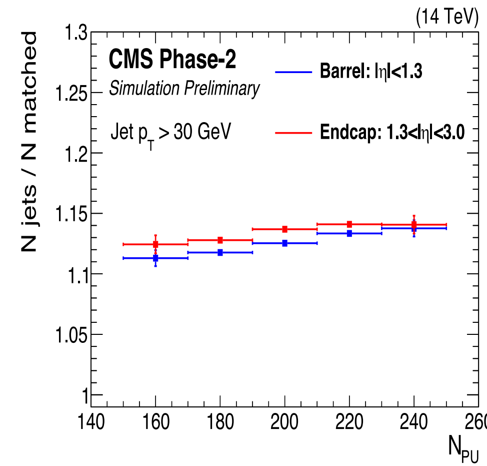
Muon ID



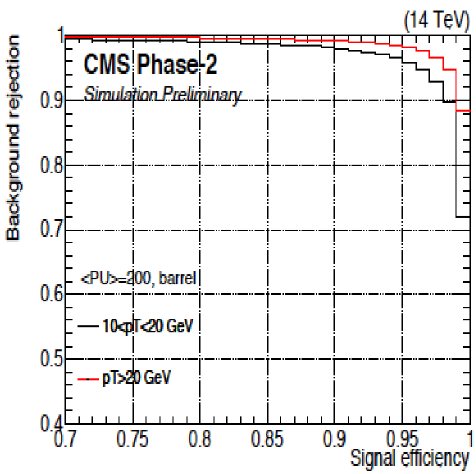
b-tagging



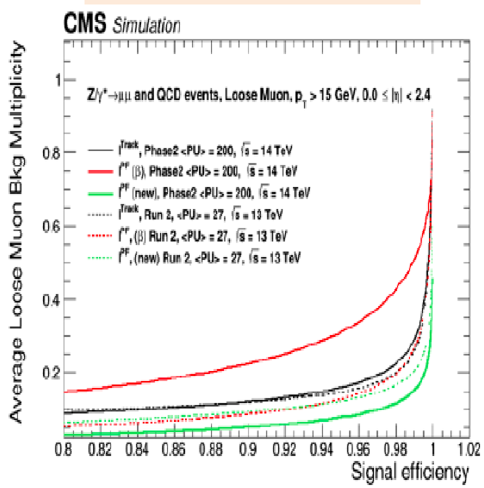
Pile up jet rate



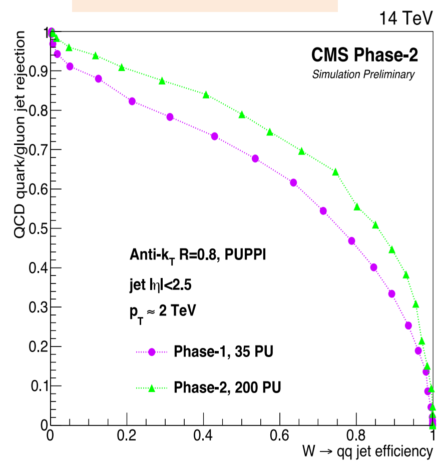
Electron ID



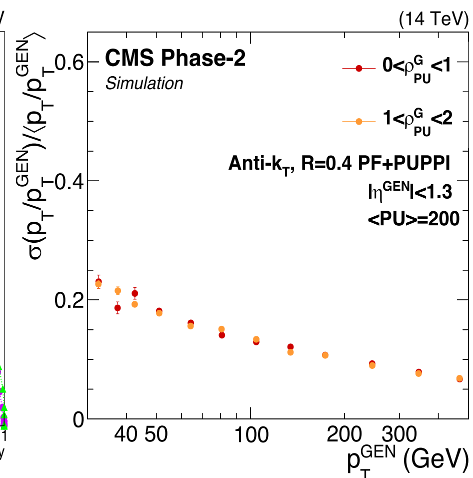
Muon isolation



Boosted W



Jet Energy Resolution

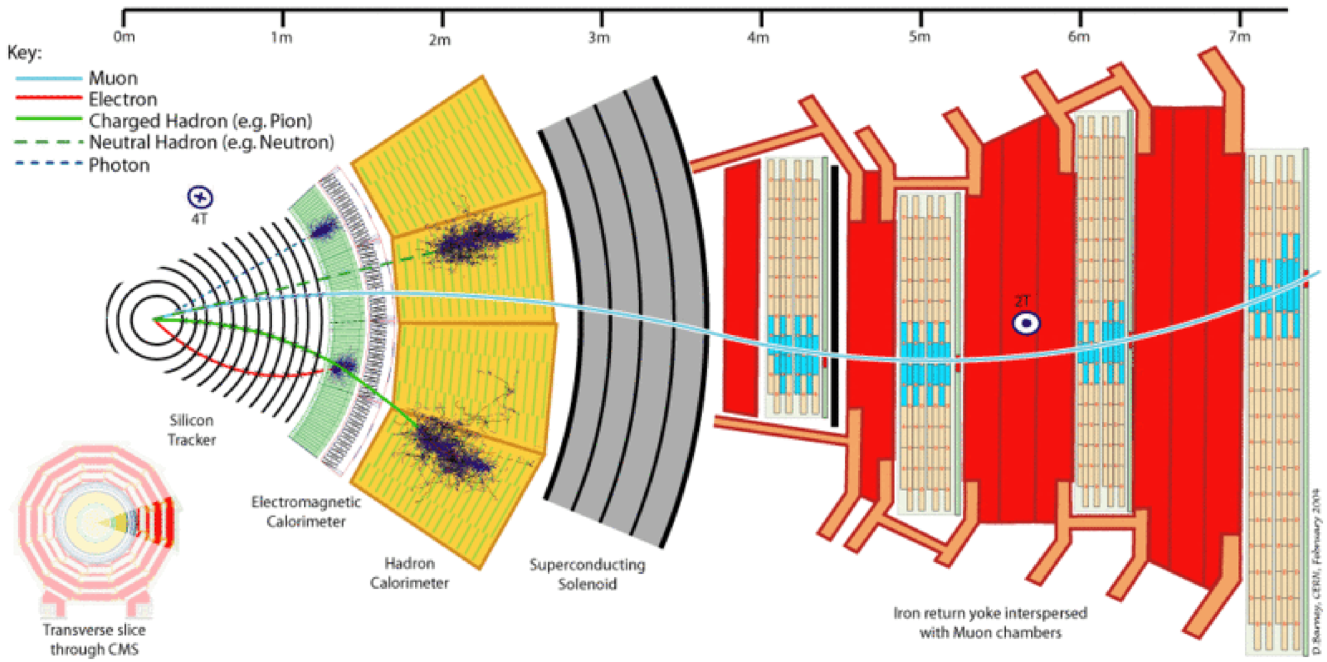


Electron positron collider at LHC?

- Strip Pb ions partially to get 1S e- knocked out and collide with proton
- CM energy =120 GeV ~ HERA range of DIS
- Boost of CM frame wrt lab: y = 4.4
- Accessible Q2 < few GeV2
- CMS very forward detector is capable for triggering on 1 GeV electron.

- Central acceptance of $|\eta|<3$ ideal
- Covered kinamtcs:
- Bjorken x over 5 orders of magnitude
- Q^2 over 3 orders in perturbative region

Transverse slice of CMS detector



- Particle flow reconstruction algorithm

➔ Utilise info from all parts of detector to reconstruct individual final state particles(γ, e, μ), jets, missing Et .

- Anti-kt (Cambridge-aachen) jet clustering , R=0.4 (0.8)
- b-jet: combined secondary vertex
- Hadronically decaying τ: sum of all pT within cone of R=0.3 should be <5 GeV

Coupling modifiers

$$\sigma_i \cdot \mathrm{B}^f = \frac{\sigma_i(\vec{\kappa}) \cdot \Gamma^f(\vec{\kappa})}{\Gamma_H}$$

If couplings are modified

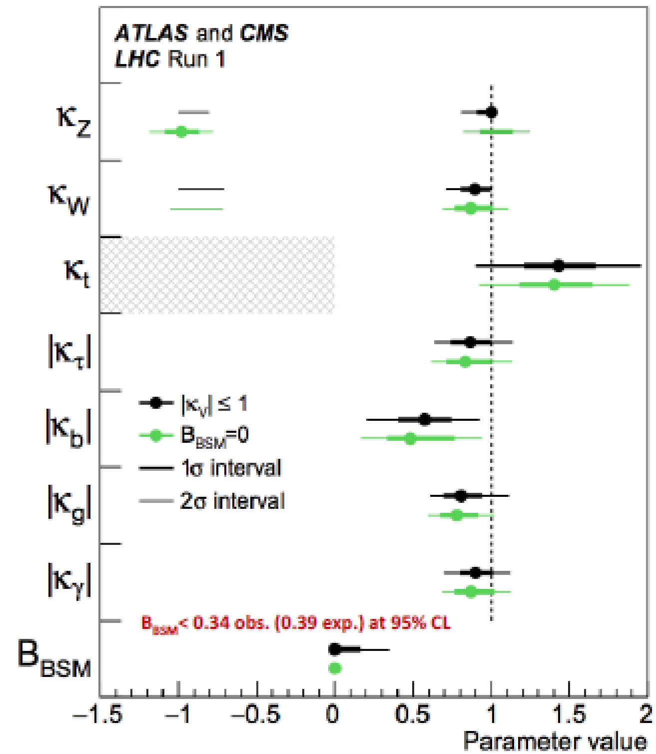
$$\kappa_H^2 = \sum_j \mathrm{B}_{\mathrm{SM}}^j \kappa_j^2$$

$$\kappa_j^2 = \sigma_j / \sigma_j^{\mathrm{SM}} \quad \text{or} \quad \kappa_j^2 = \Gamma^j / \Gamma_{\mathrm{SM}}^j$$

If only SM decays are allowed.

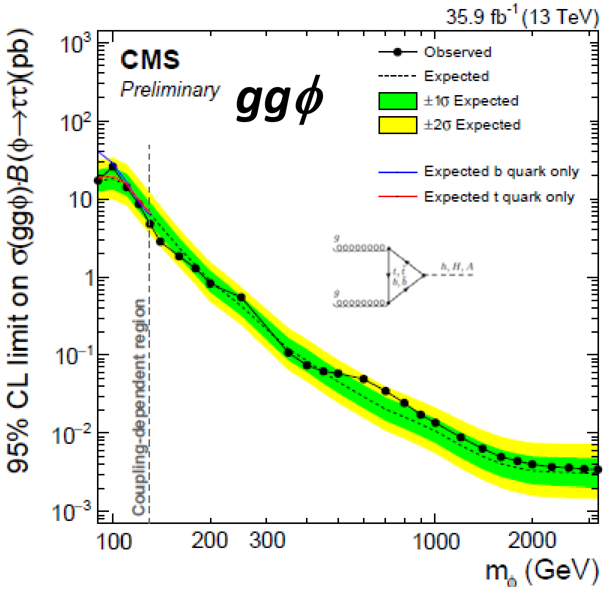
$$\kappa_H^2 = \Gamma_H / \Gamma_H^{\mathrm{SM}}$$

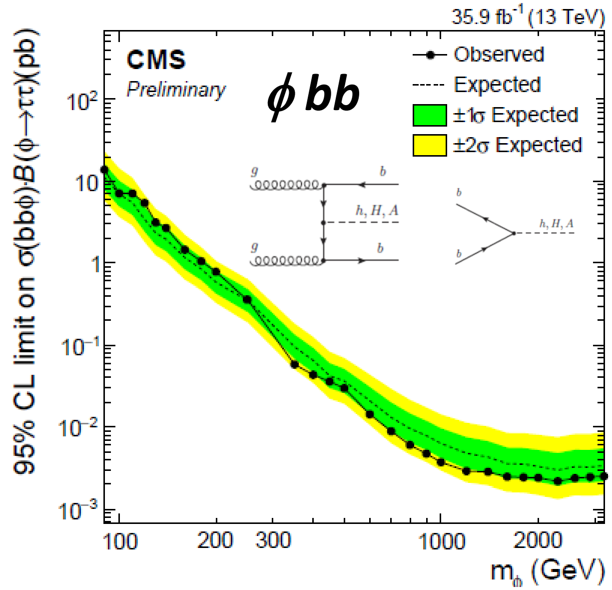
$$\Gamma_H = \frac{\kappa_H^2 \cdot \Gamma_H^{\mathrm{SM}}}{1 - \mathrm{B}_{\mathrm{BSM}}}$$

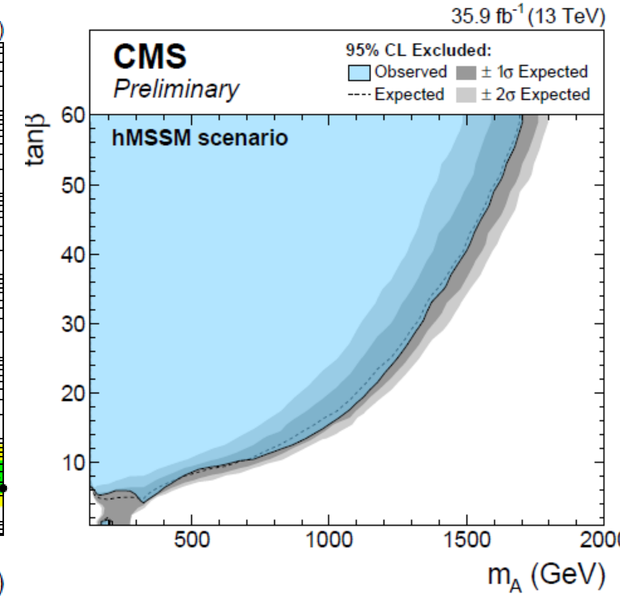


arXiv.: 1606.02266

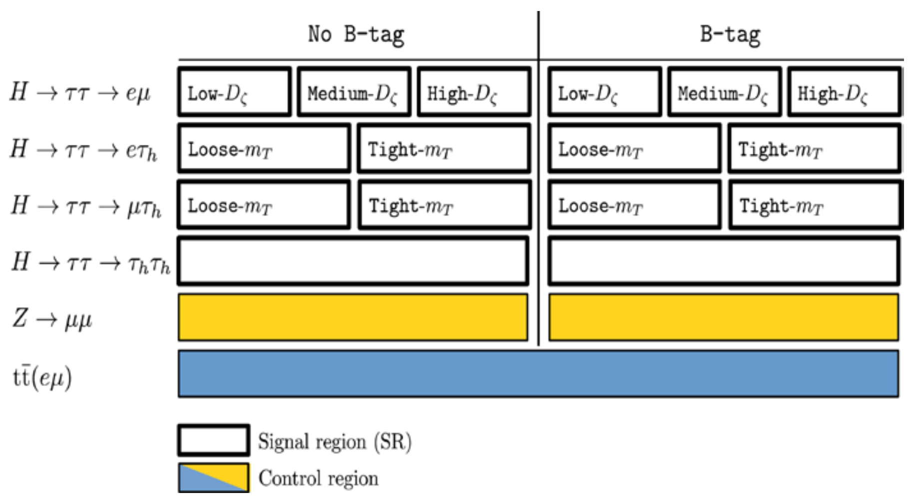
CMS : MSSM H → ττ







Event categories

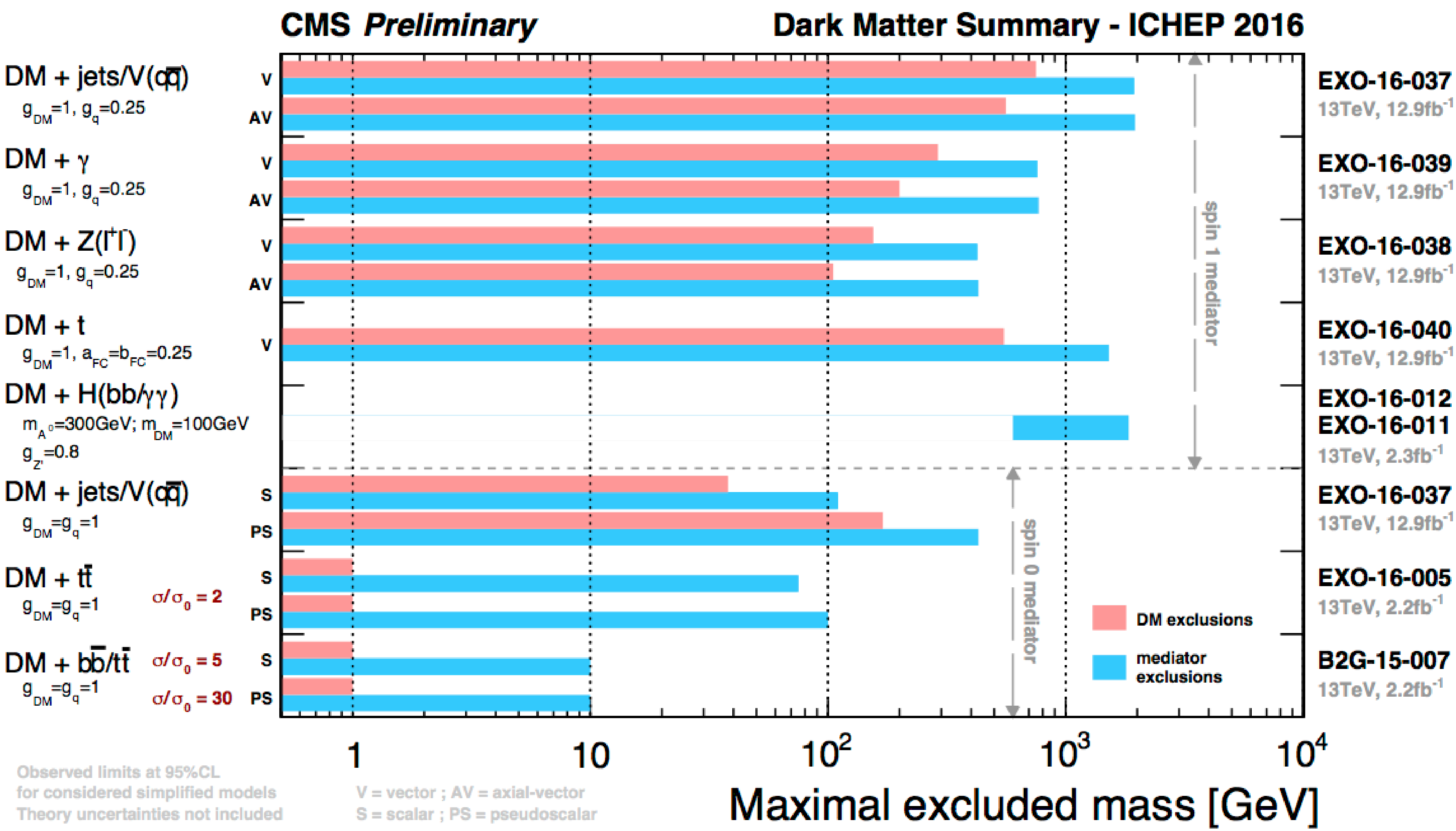


Excluded: $m_A < 250$ GeV for $\tan\beta > 6$

$m_A > 1.6$ TeV for $\tan\beta > 60$

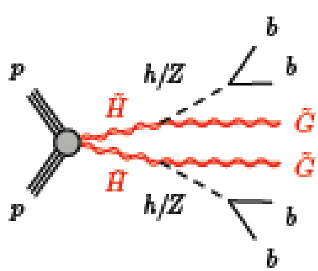
Data allows low values of $\tan\beta$ in hMSSM

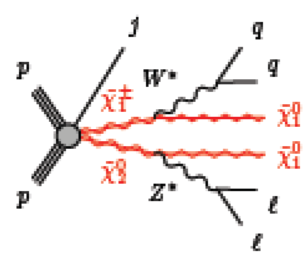
CMS PAS-HIG-17-020


CMS Preliminary
Dark Matter Summary - ICHEP 2016
DM + jets/V(qq̄)
g_DM=1, g_q=0.25
V
AV
EXO-16-037
13TeV, 12.9fb-1
DM + γ
g_DM=1, g_q=0.25
V
AV
EXO-16-039
13TeV, 12.9fb-1
DM + Z(l+l-)
g_DM=1, g_q=0.25
V
AV
EXO-16-038
13TeV, 12.9fb-1
DM + t
g_DM=1, a_FC=b_FC=0.25
V
EXO-16-040
13TeV, 12.9fb-1
DM + H(bb/γγ)
m_A0=300GeV; m_DM=100GeV
g_Z'=0.8
EXO-16-012
EXO-16-011
13TeV, 2.3fb-1
spin 1 mediator
DM + jets/V(qq̄)
g_DM=g_q=1
S
PS
EXO-16-037
13TeV, 12.9fb-1
DM + tt̄
g_DM=g_q=1
σ/σ0 = 2
S
PS
EXO-16-005
13TeV, 2.2fb-1
DM + bb̄/tt̄
g_DM=g_q=1
σ/σ0 = 5
σ/σ0 = 30
S
PS
B2G-15-007
13TeV, 2.2fb-1
spin 0 mediator
DM exclusions
mediator exclusions
1
10
10^2
10^3
10^4
Maximal excluded mass [GeV]
Observed limits at 95%CL
for considered simplified models
Theory uncertainties not included
V = vector ; AV = axial-vector
S = scalar ; PS = pseudoscalar

R-parity conserving electro-weakino production

Search	Final State	Limits	References
ewkino 2ℓ / 3ℓ	2/3 leptons + MET	max. reach $m_{N2/C1}$ ~ 1150 GeV (light sleptons), $m_{N2/C1}$ ~ 580 GeV (no light sleptons)	ATLAS-CONF-2017-039
ewkino 2τ_{had}	2τ_{had} + MET	$m_{N2/C1}$ ~ 580 GeV (light staus)	1708.07875
ewkino 4ℓ [13 fb^{-1}]	4ℓ ($\leq 2\tau_{had}$) + (MET or m_{eff})	probe up to 1.1 TeV RPV winos	ATLAS-CONF-2016-075
compressed higgsino LSPs	soft e^+e^- / $\mu^+\mu^-$ + jet(s) + MET	μ > 100 (130) GeV for $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$ = 3 (5) GeV	SUSY-2016-25
compressed slepton NLSPs	soft $\ell^+\ell^-$ + jet(s) + MET	$m_{\tilde{\ell}}$ > 70 (180) GeV for $\Delta m(\tilde{\ell}, \tilde{\chi}_1^0)$ = 1 (5) GeV	
GMSB higgsino NLSPs	4b + MET	exclude μ between 130-230 GeV and 290-880 GeV for BF($\tilde{h} \rightarrow h\,\tilde{G}$) = 1	ATLAS-CONF-2017-081
ultra-compressed higgsinos	disappearing track + jet + MET	exclude charged higgsinos up to 152 GeV	ATL-PHYS-PUB-2017-019 (reinterpretation of 1712.02118)
GMSB with photons	γ / $\gamma\gamma$ + MET	probe up to 1.2 TeV charginos/neutralinos	ATLAS-CONF-2017-080





- Multiple possibilities considered.
- No luck in any
- Stau production rate too low
  → need more data

- Chargino, neutralino decays
  → via slepton
  → W, Z, H in the final state

- Production in GMSB

Possible due to abundance of LHC data

Search for 3rd generation SUSY particles

Search	Final State	Max Mass Reach [GeV]	References
sbottom	2 b-jets + MET	950 GeV (stop) 860 GeV (sbottom)	1708.09266
stop 0L	0ℓ + b-jets + MET	950 GeV	1709.04183
stop 1ℓ with DM+HF	1ℓ + jets + MET	950 GeV	1711.11520
stop 2ℓ	2ℓ + MET (+ jets)	720 GeV	1708.03247
stops with Z/h	1 / 2 / 3ℓ+ b-jets + MET	870 GeV	JHEP08 (2017) 006
stop→stau	2ℓ + MET (+ jets)	1160 GeV	ATLAS-CONF-2017-079