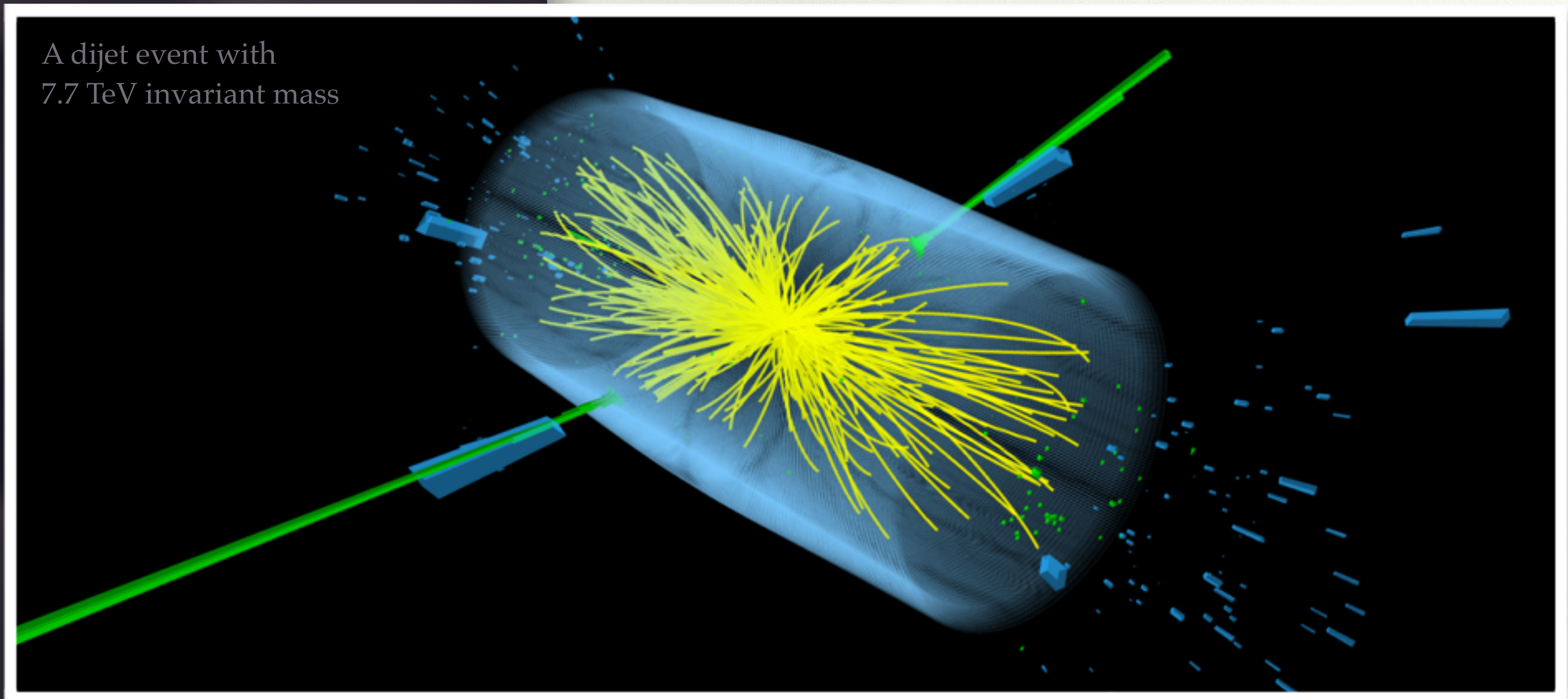


Summary Institute 2016, Xi-Tou, Taiwan

LHC EXPERIMENTAL HIGHLIGHTS

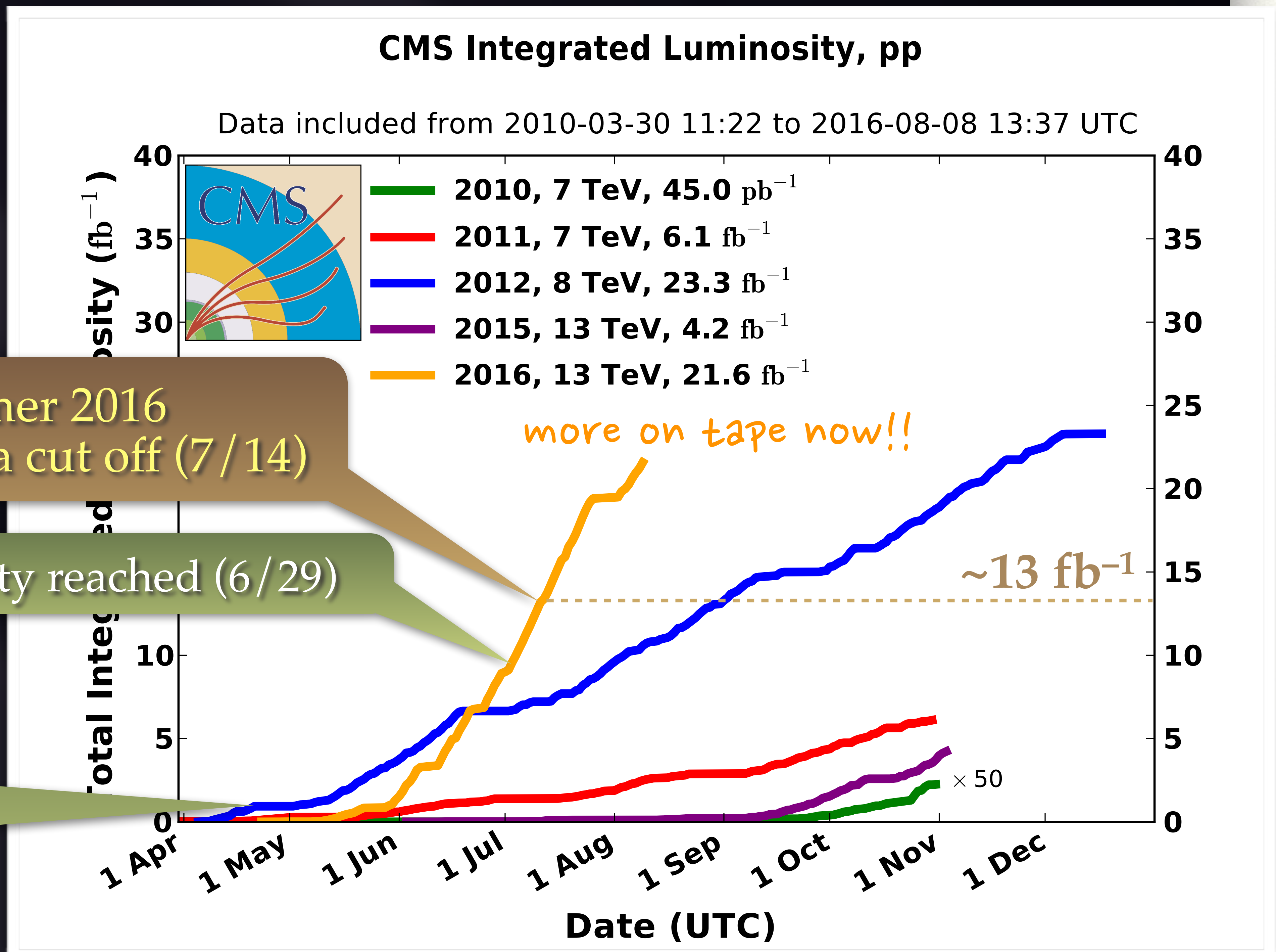
Kai-Feng Chen
National Taiwan University

LHC Status Overview

- *The LHC Run-I was a great success* — a new heavy particle that is consistent with the standard model Higgs boson has been discovered. Many measurements and searches have been performed as well.
- LHC resumed its operation in 2015 with a new center of energy of **13 TeV** and a 50/25 ns bunch spacing.
- The collider has exceeded even the most optimistic performance estimates; **designed peak luminosity reached very recently**.
- Experiments had went through a series of detector and trigger improvements during the previous long shutdown:
  - Sub-detectors operating with active channel fraction higher than the condition in Run-I.
  - Re-commissioning of the physics objects.
  - New challenge of 25 ns operations.

LHC Luminosity

Data comes (very) quick!



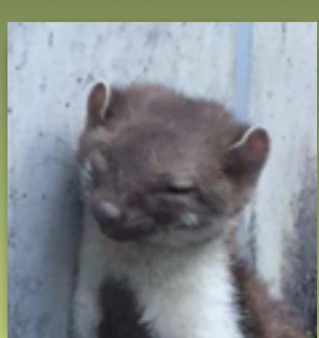
more on tape now!!

~13 fb^{-1}

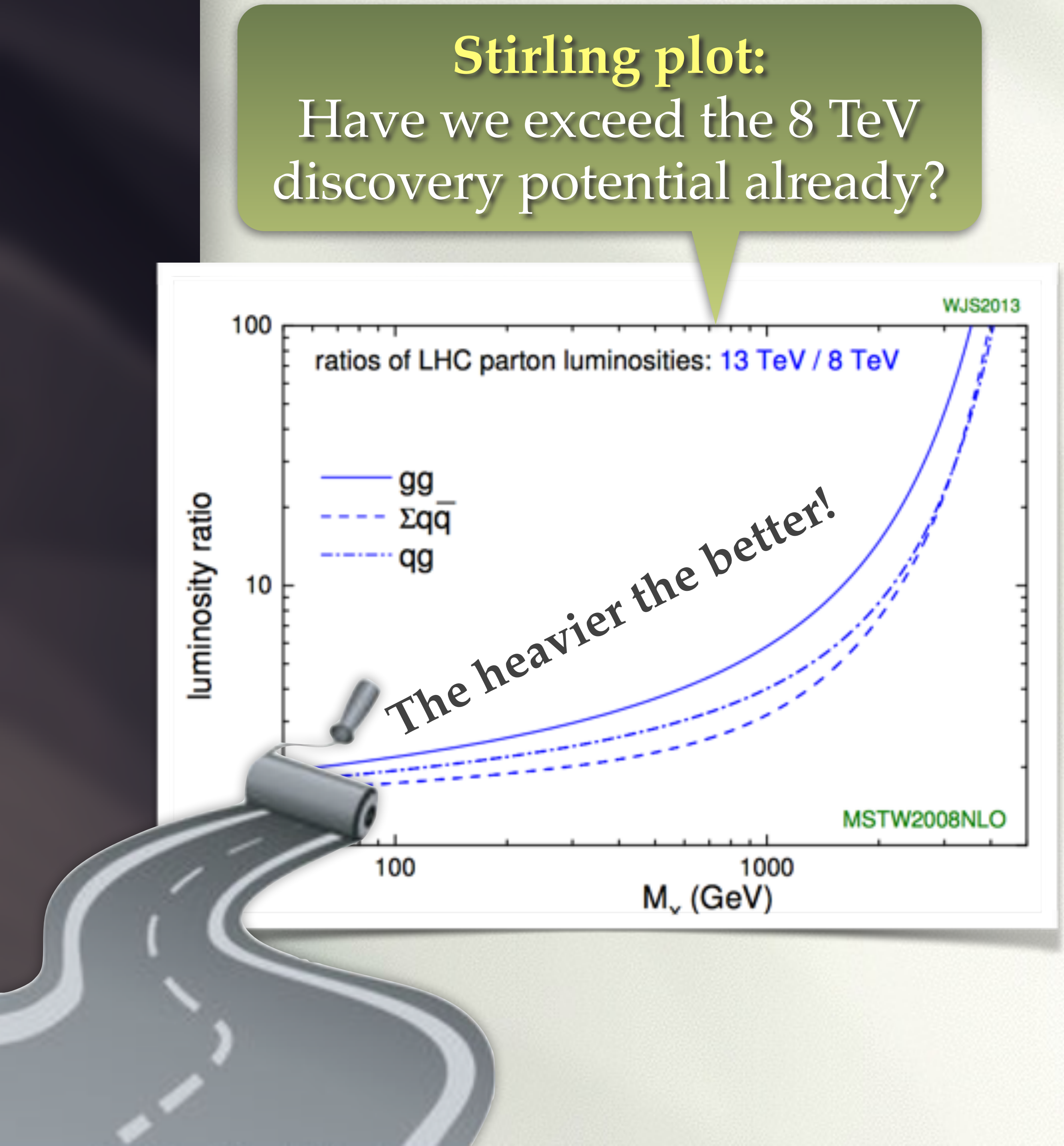
Summer 2016
analysis data cut off (7/14)

Designed luminosity reached (6/29)

Weasel event



Physics Strategies at Run-II

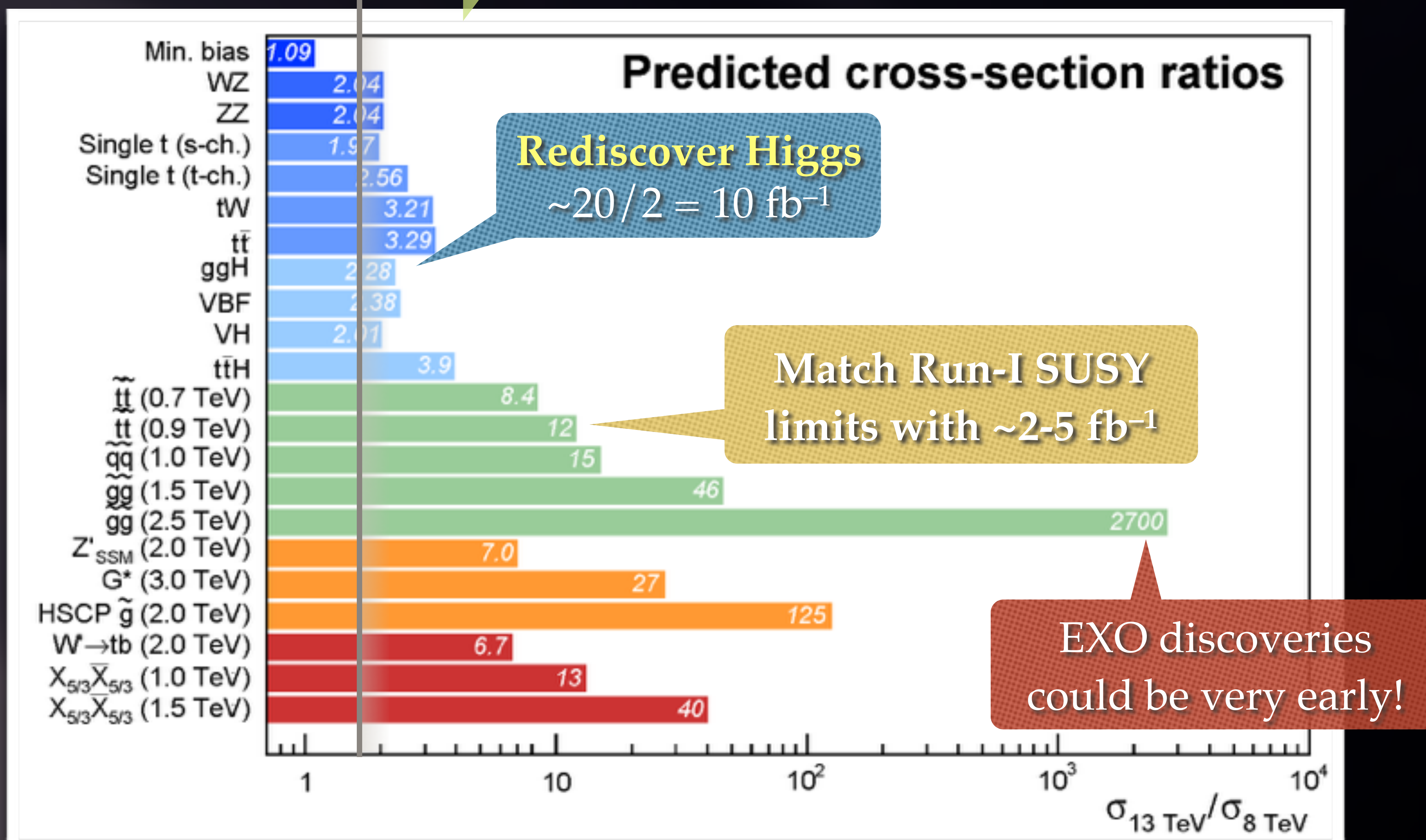


The road is already "well paved"!

- Optimizing in terms of physics potential matched to available luminosity.
- Other than the high mass reach, explore corner of phase space left hidden in the 8 TeV data (low missing E_T, low p_T leptons, long-lived, etc.)
- Precision physics: Monte Carlo tuning, background modeling, and indirect searches.

Discovery Reach: "Boost Factors"

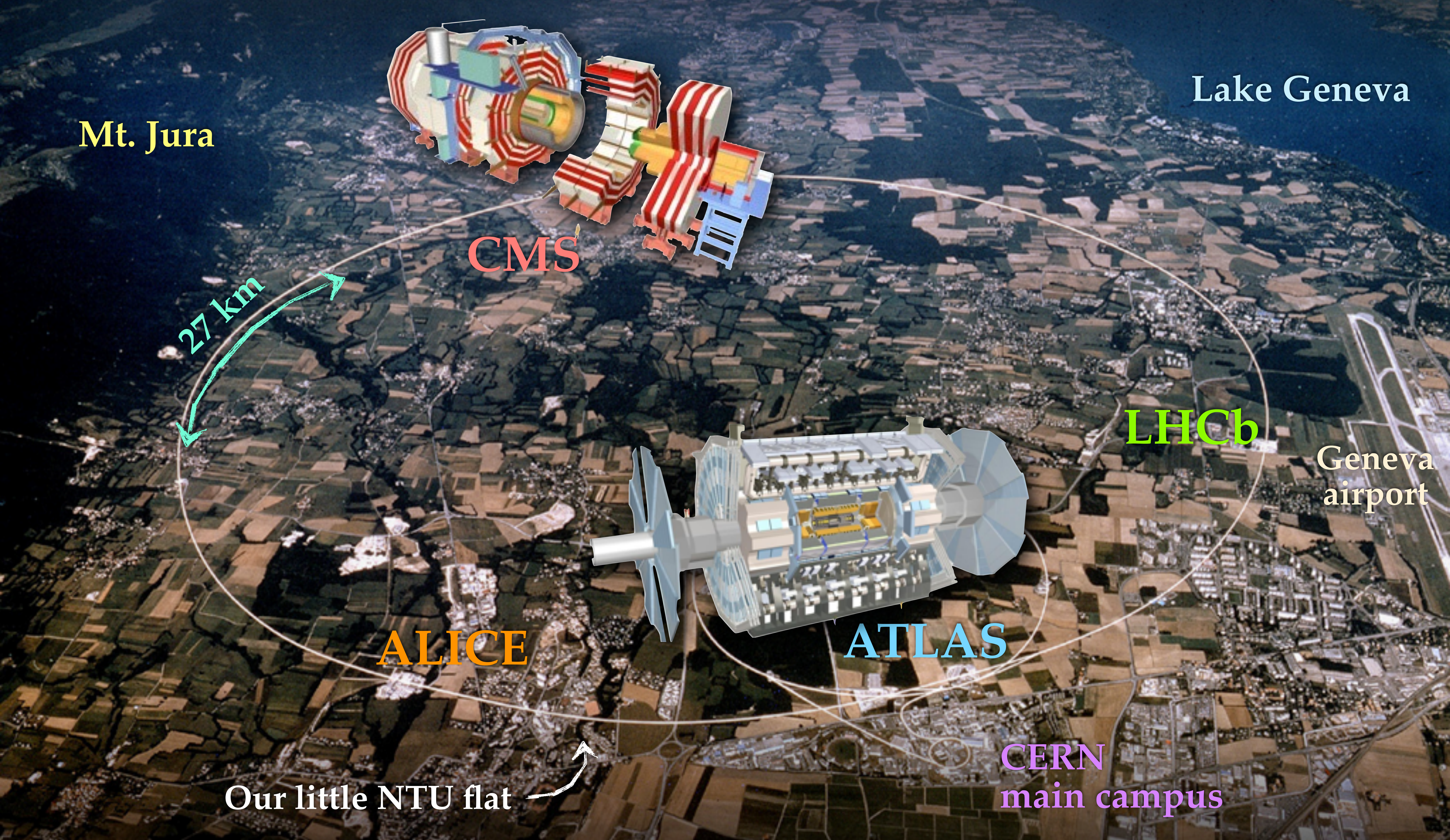
13 fb^{-1} at 13 TeV potentially more sensitive than 8 TeV data for (*almost*) ALL TOPICS!



"Just need to finish the works *(within 2 weeks)*!"

— Nevertheless, the newest results were shown at the ICHEP conference last week.

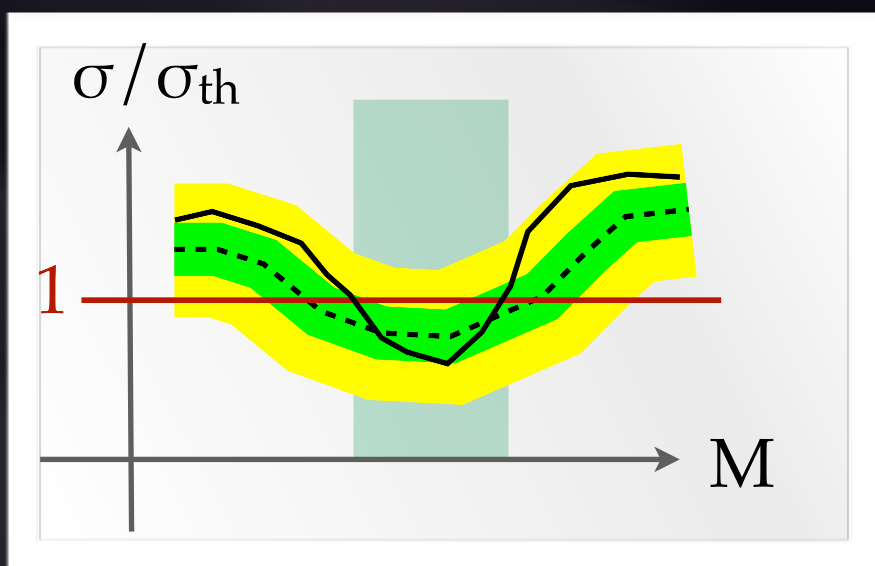
A Friendly Reminder – LHC & Experiments



Going to cover the new results from (mostly) CMS & ATLAS today!

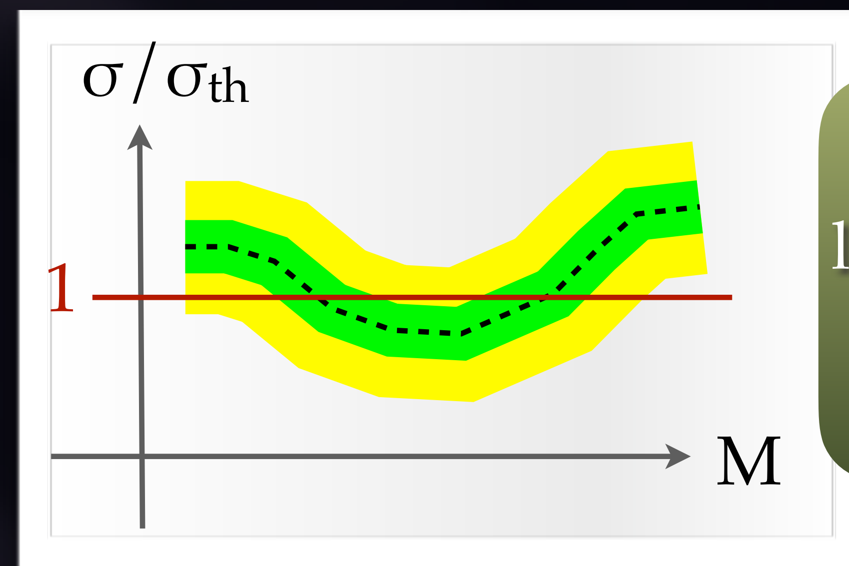
A Friendly Reminder – How to read a Limit plot?

A typical limit plot



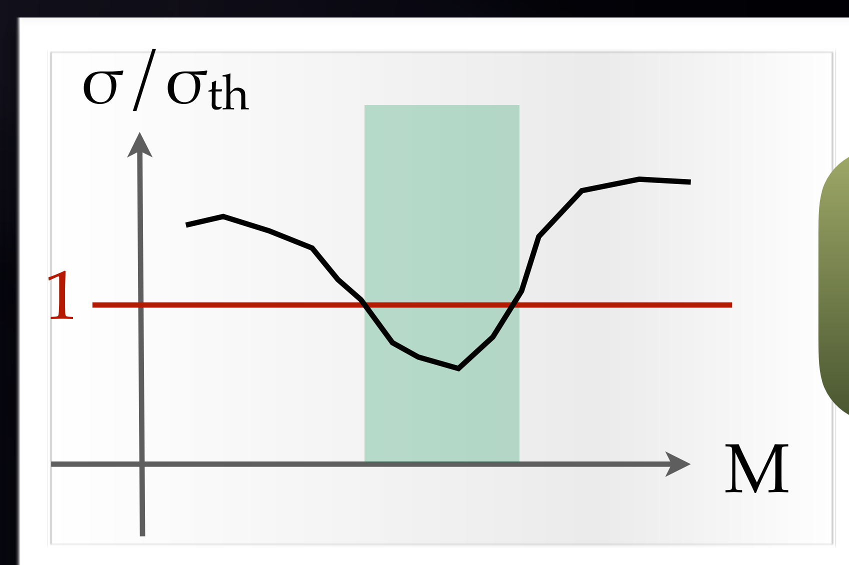
σ/σ_{th} versus M = limit on ratio to the predictions, versus a given mass

=



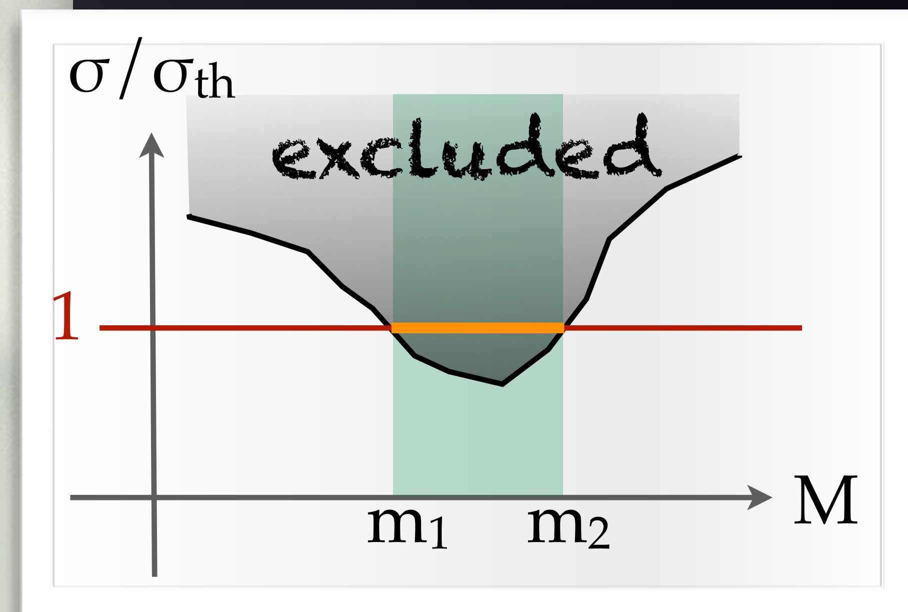
The "expected" limit curve and its uncertainties (±1σ,±2σ bands)

+



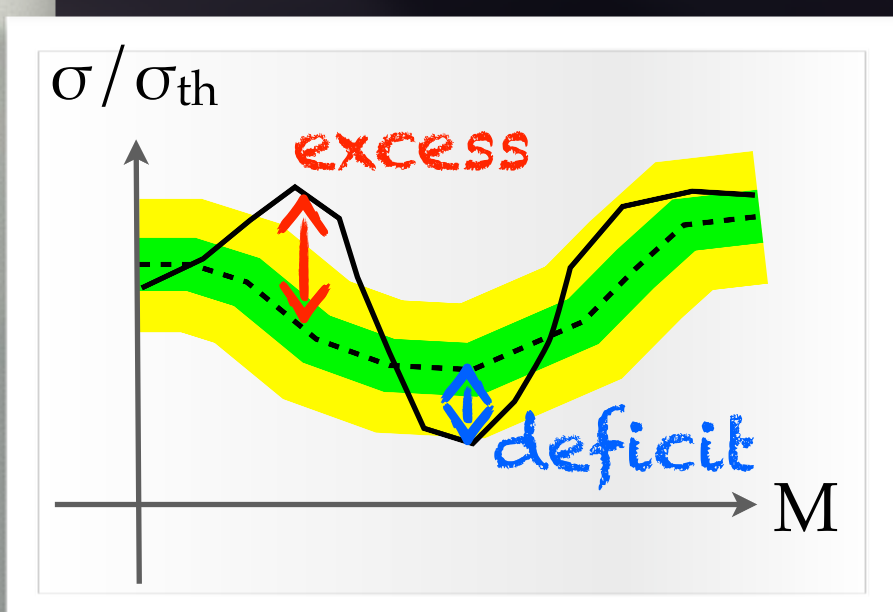
The "observed" limit curve

A Friendly Reminder – How to read a Limit plot?



Comment #1

Any region above the "observed limit" curve is excluded. The **"$\sigma/\sigma_{th} = 1$"** is excluded between m_1 and m_2, indicates a new particle with **$M \in$ [m1,m2] is excluded**.



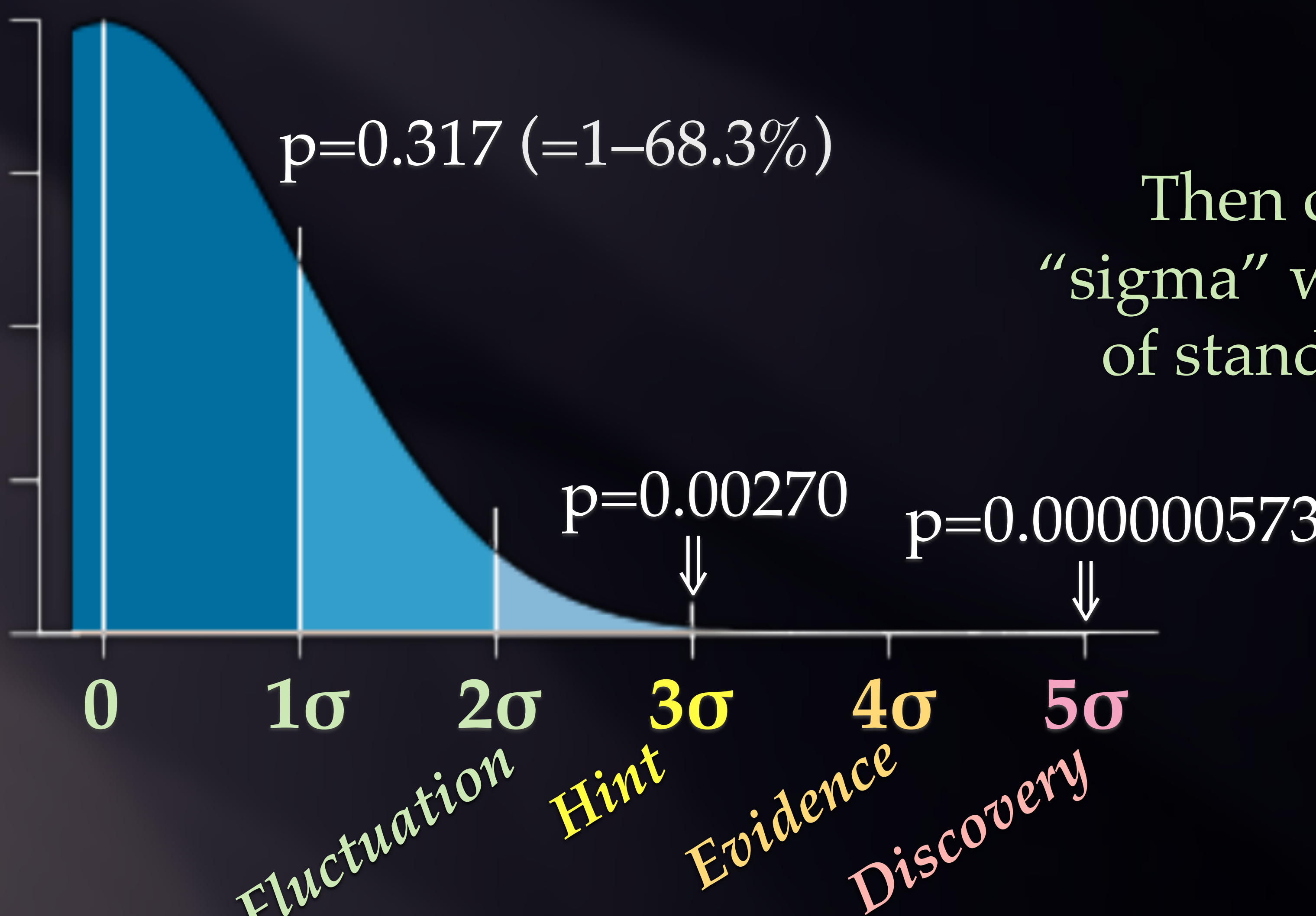
Comment #2

If the "observed limit" is above the "expected limit", one can interpret such behavior as an "excess". But one cannot read the significance (# of σ) from such an exclusion plot.

A Friendly Reminder – Excess benchmarking

The strength of an excess is given by the "p-value", defined by the likelihood that the observed data is actually the fluctuation from a null hypothesis.

(lower p-value = stronger excess; higher p-value = weaker excess.)



Then convert to # of "sigma" with the definition of standard deviations.

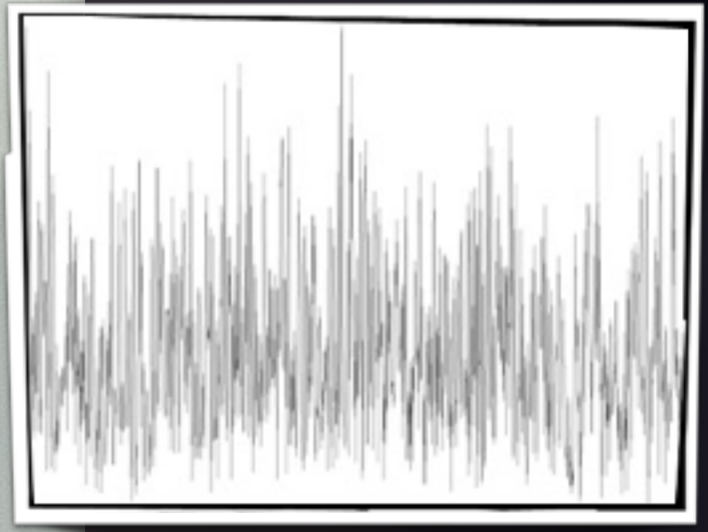
A Friendly Reminder – The Look-Elsewhere Effect

The look-elsewhere effect is a phenomenon, where an apparently statistically significant observation may have actually arisen by chance because of the size of the parameter space to be searched.

– from Wikipedia

Analogy #1

Finding a four-leaved clover in a large clover field is definitely higher than trying to find it in a limited area.



Analogy #2

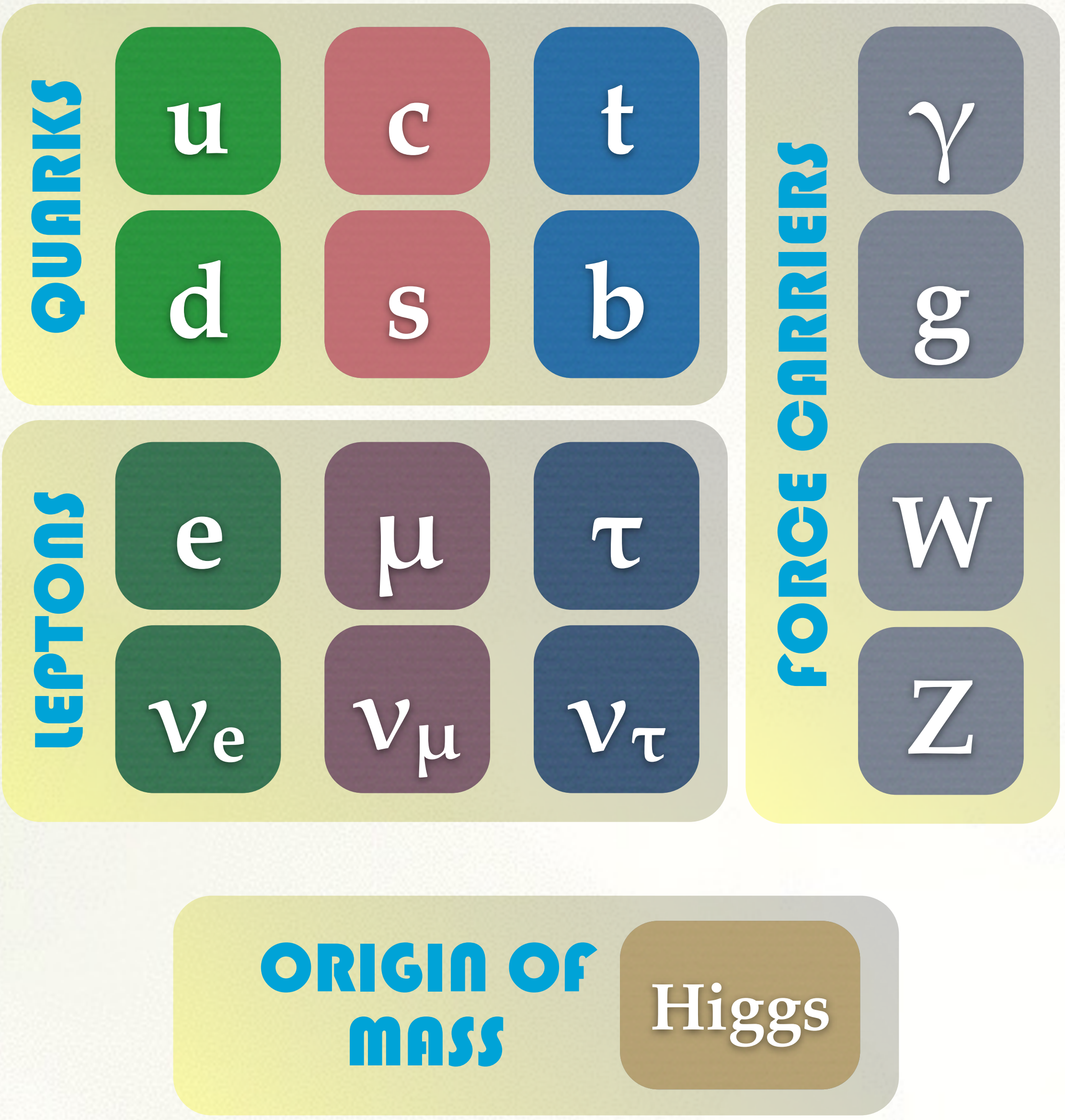
Surely you can find many peaks on a random noise distribution. It is not too difficult to find a single peak with 3σ as well.

In many of the cases we need to "correct" the p-values from **"local"** to **"global"**.

Let's start with the Higgs (pizza)!

Higgs and The Standard Model

- The **Higgs Boson** is an elementary particle predicted to exist by the **Standard Model**. It is the last SM particle that has not yet been fully studied by the experiments.
- The Standard Model describes:
  – How the particles interact;
  – How different particles behave;
  – How the force between particles are manifested.
  – and, **maybe explain the origin of mass**.



The Higgs Mechanism

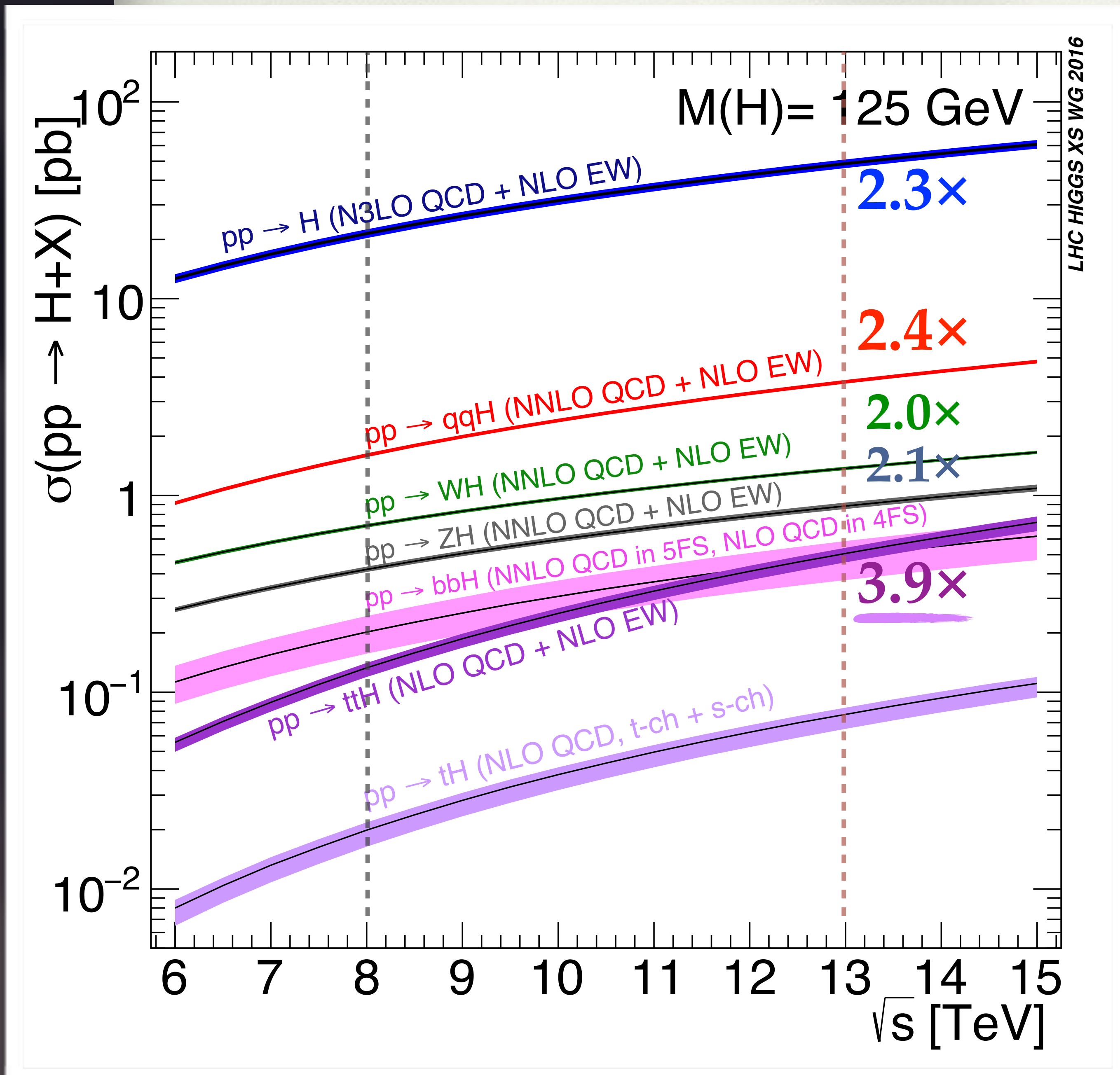
- In the Standard Model, the Spontaneous Symmetry Breaking can be achieved by introducing one complex scalar doublet. This gives 4 degrees of freedom:
  - ➡ 3 give the masses to W^+, W^-, and Z^0 bosons.
  - ➡ **1 left for the Higgs boson.**

- Particles that have mass move through the Higgs field, interacting with the Higgs bosons. Heavier particles interact more with the Higgs field taking on more mass, while massless particles (e.g. photons) have no direct interactions with the Higgs boson.

Higgs Boson @ LHC

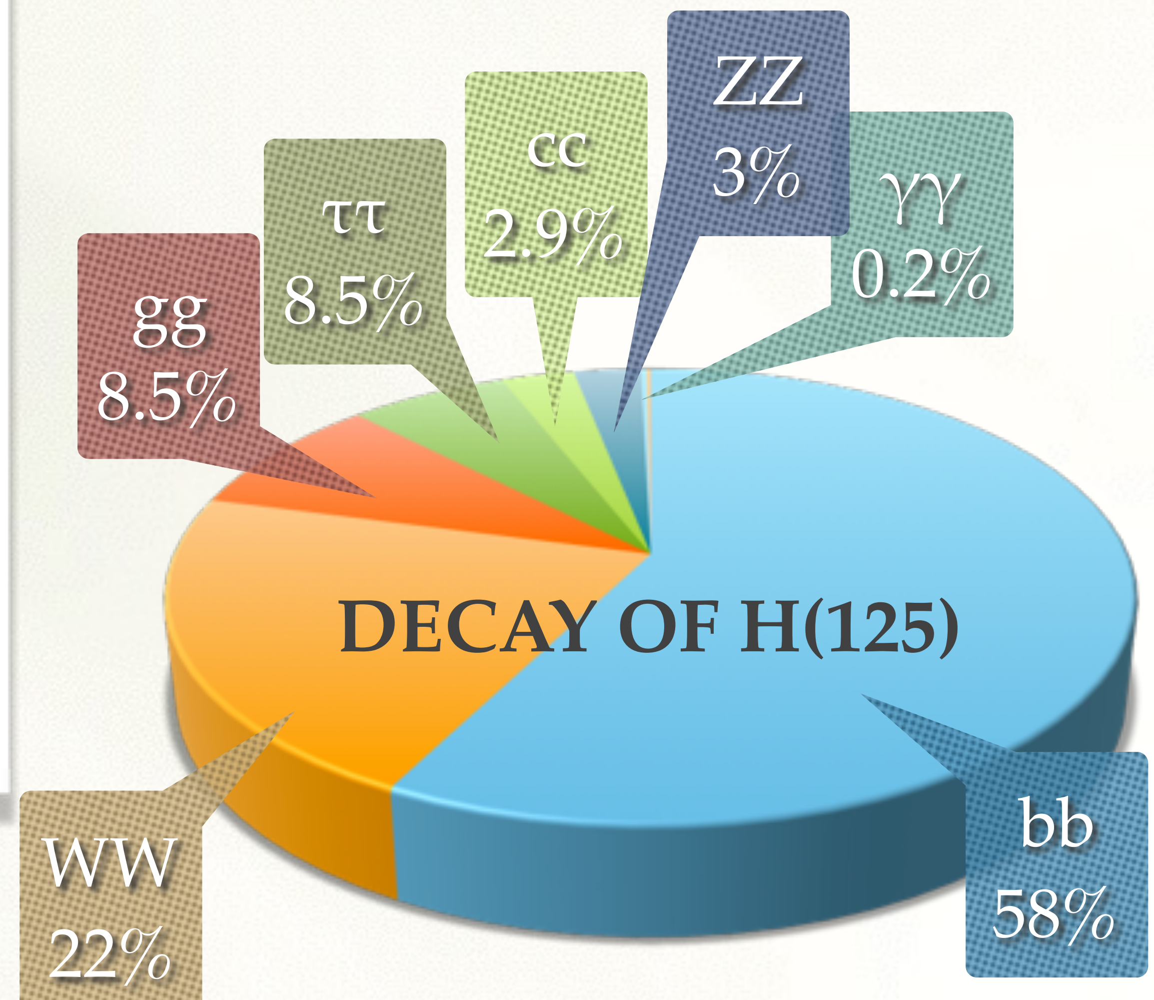
- The first running period of the LHC, Run-I, brought the discovery of the Higgs boson by the CMS and ATLAS experiments.
- ATLAS and CMS have measured nearly all the accessible properties: production, decay rates, mass, and couplings to other SM particles.
- LHC Run-II is now producing an even larger sample of Higgs boson events just available for analysis. These data should be able to produce further precision measurements, and maybe open up new channels to study the interactions of Higgs bosons and SM particles.
- As Higgs joined the particle zoo: now we are in a good position to probe BSM physics associated with the Higgs boson, including anomalous decays, or searching for additional new Higgs bosons.

H(125): Production & Decay



Run-I (2012) → Run-II

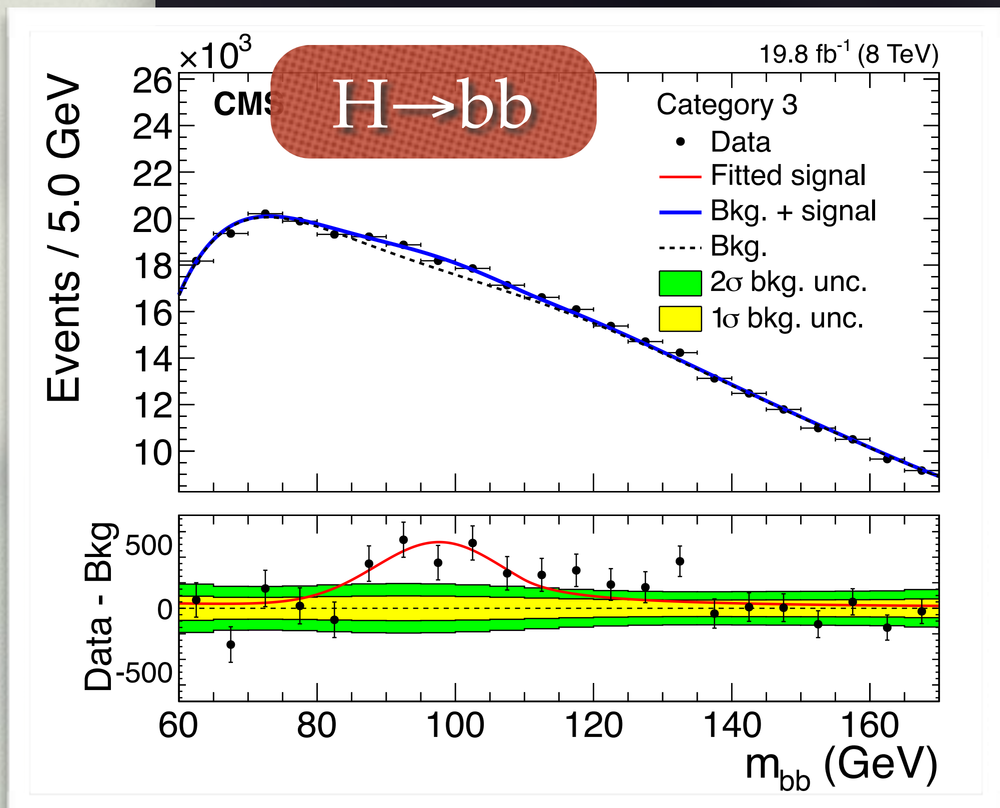
- Analyses depends on the production and decay (and background level).
- Run-II data have a much higher production rate!

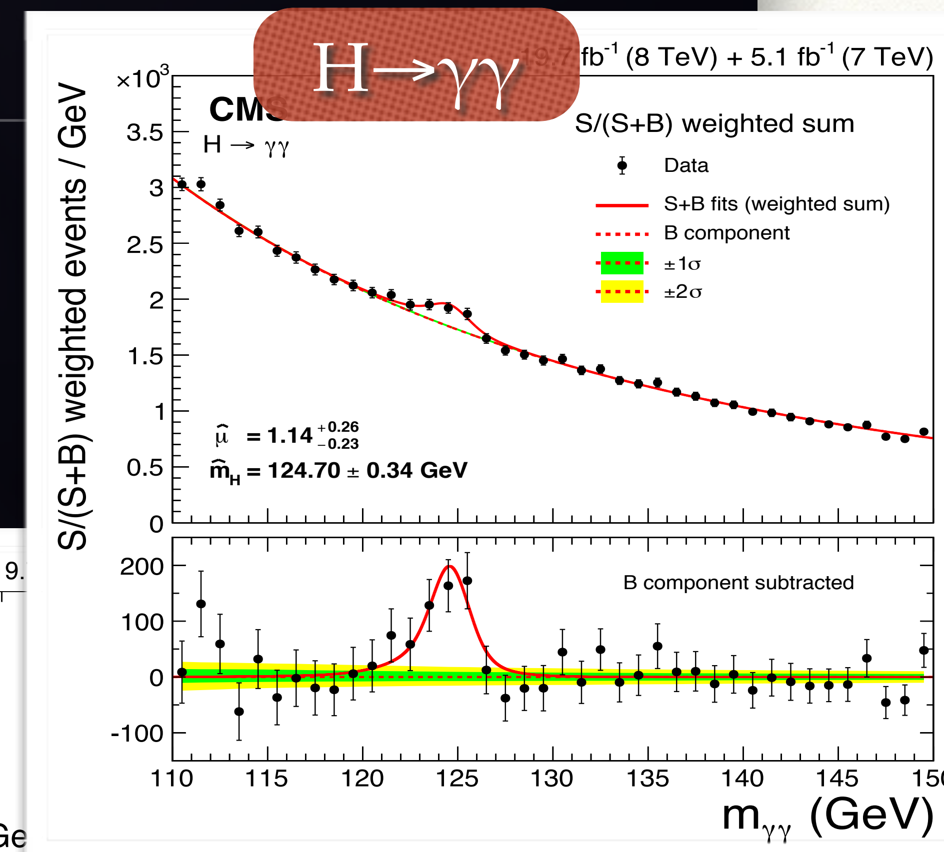


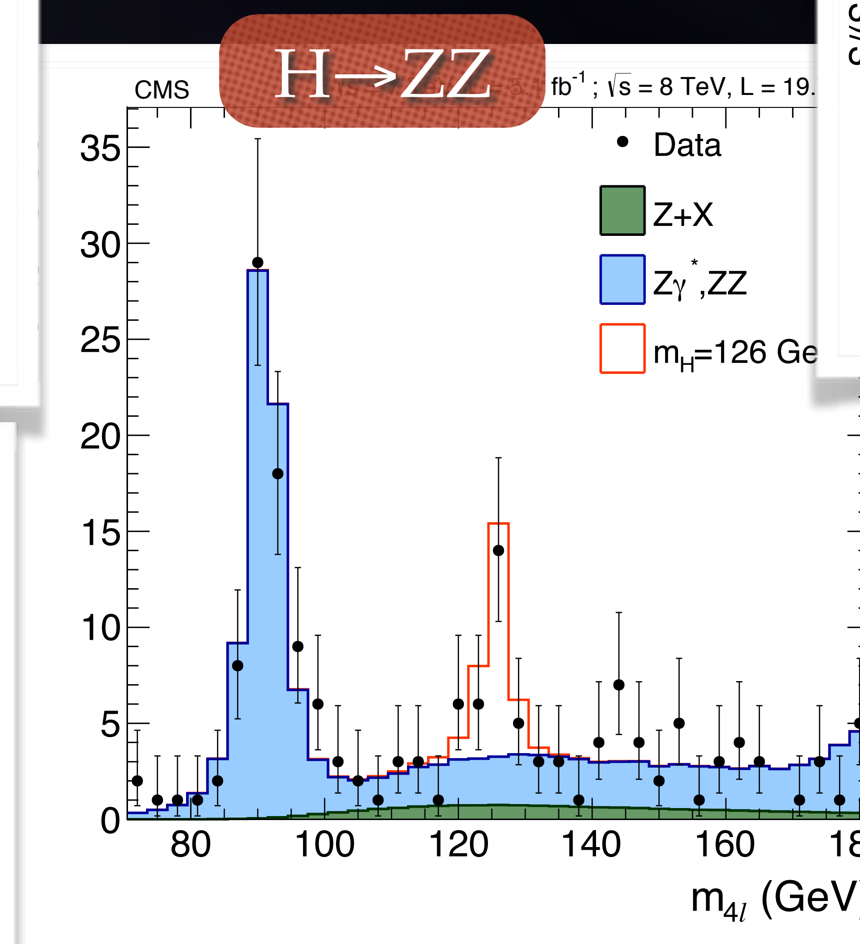
Run-1

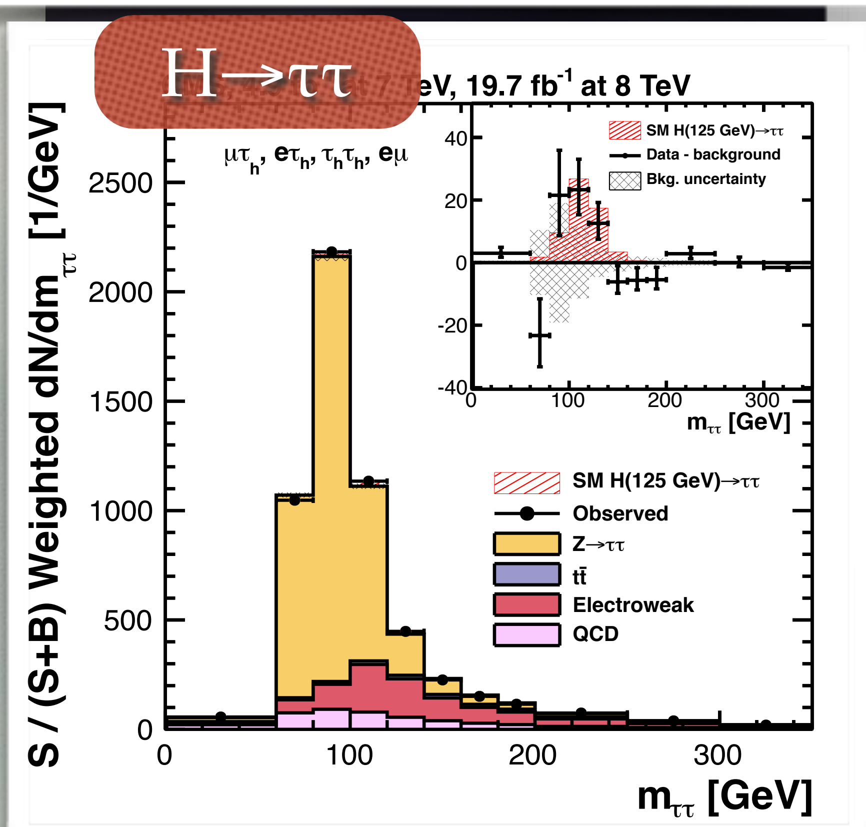
H(125): State of the art

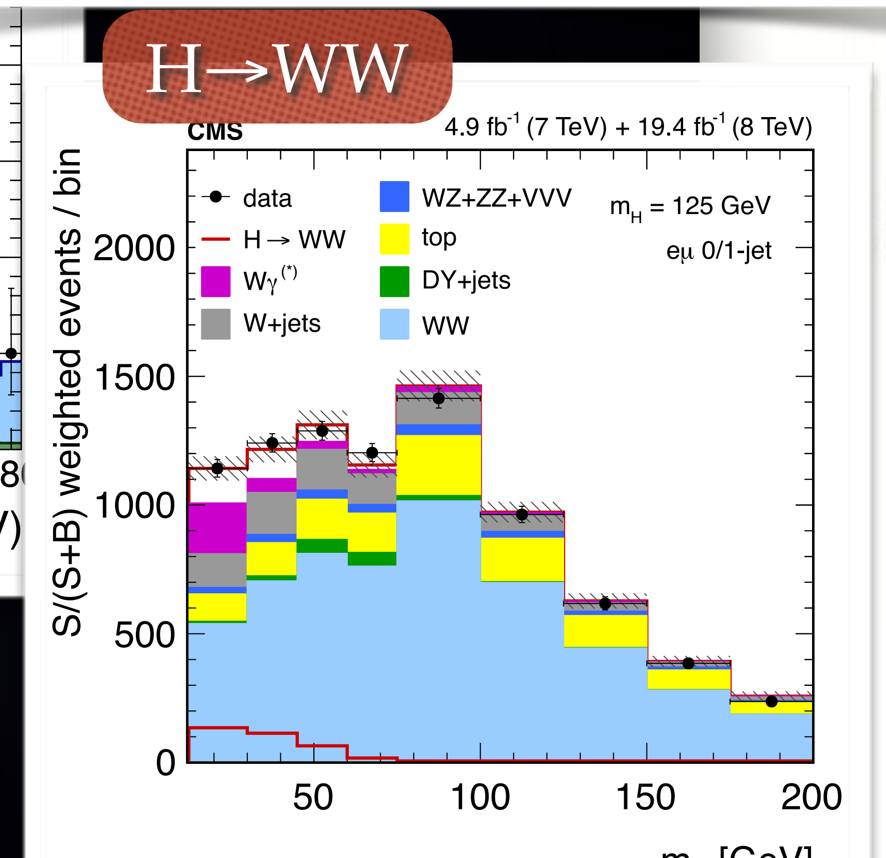
Seen in all major channels.











Run-I

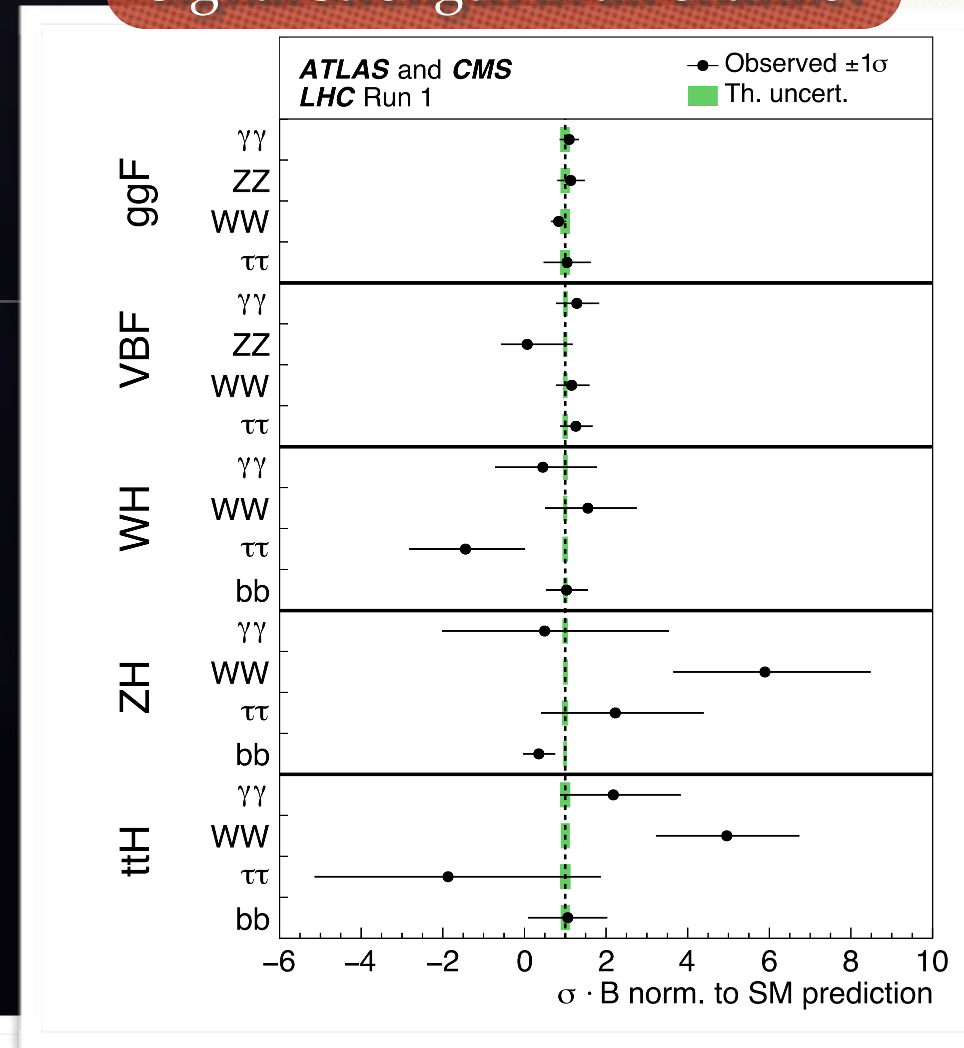
H(125): State of the art

$$M(H) = 125.03^{+0.26}_{-0.27}\,(\text{stat.})^{+0.13}_{-0.15}\,(\text{syst.})\ \text{GeV}$$

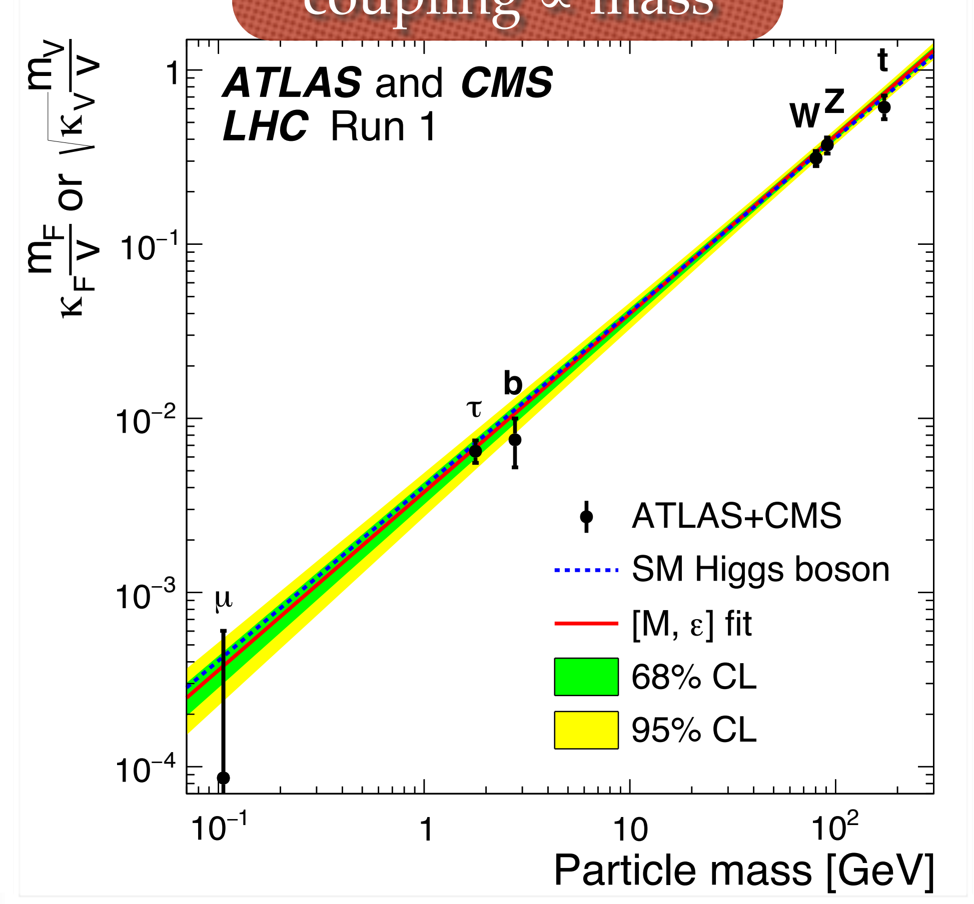
$$\sigma/\sigma_{SM} = 1.00^{+0.14}_{-0.13}$$

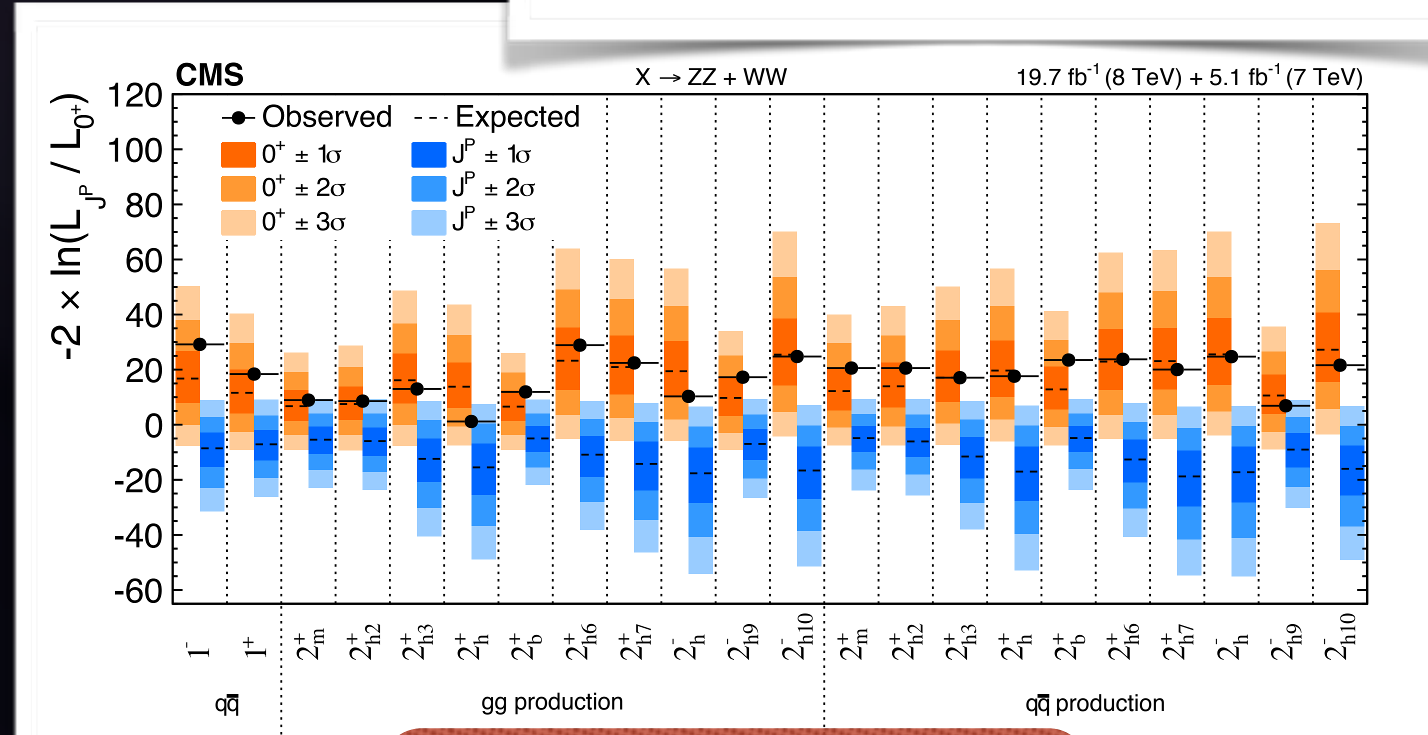
- All measurements are just right!
- ATLAS+CMS legacy paper: PRL 114 (2015) 191803 (mass), arXiv:1606.02266 (couplings)

signal strength in all channel



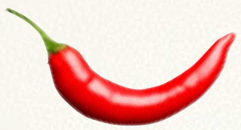
coupling ∝ mass





spin/parity tests passed

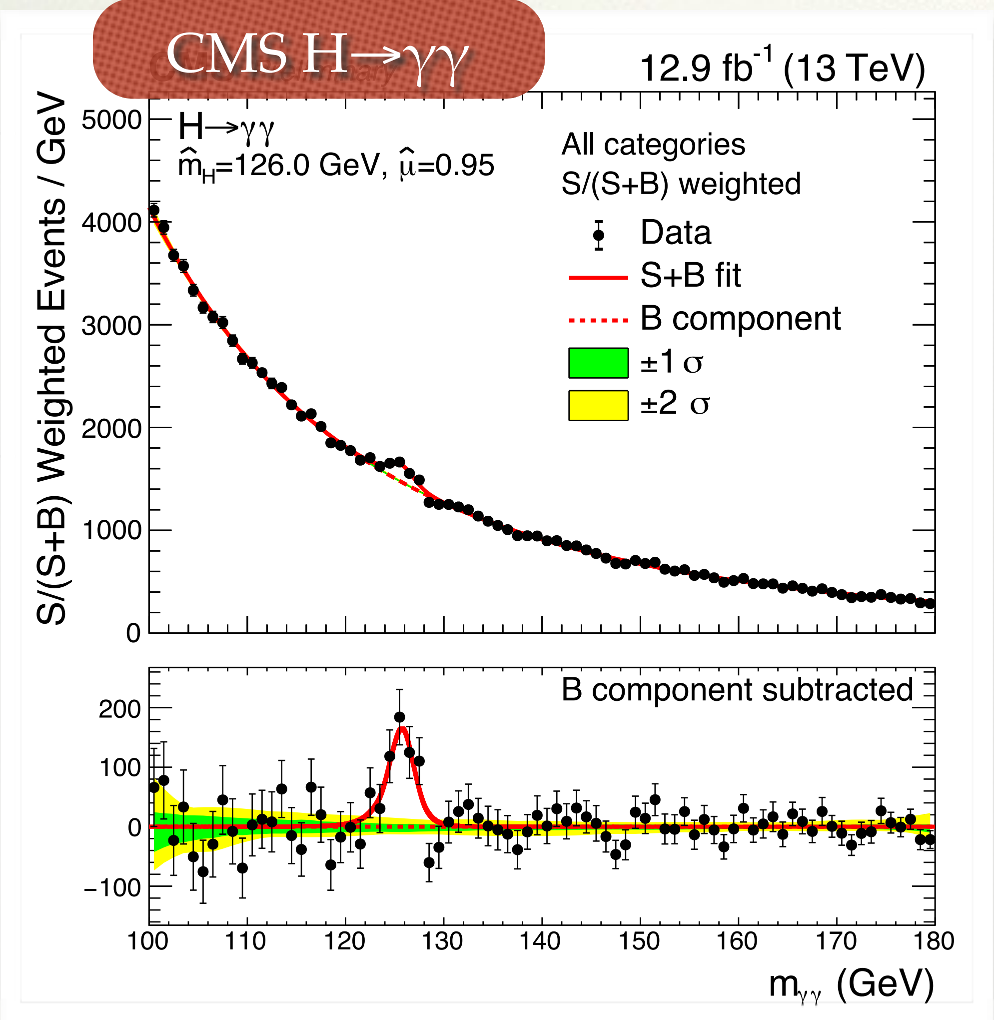
SM Higgs updates @ Run-II

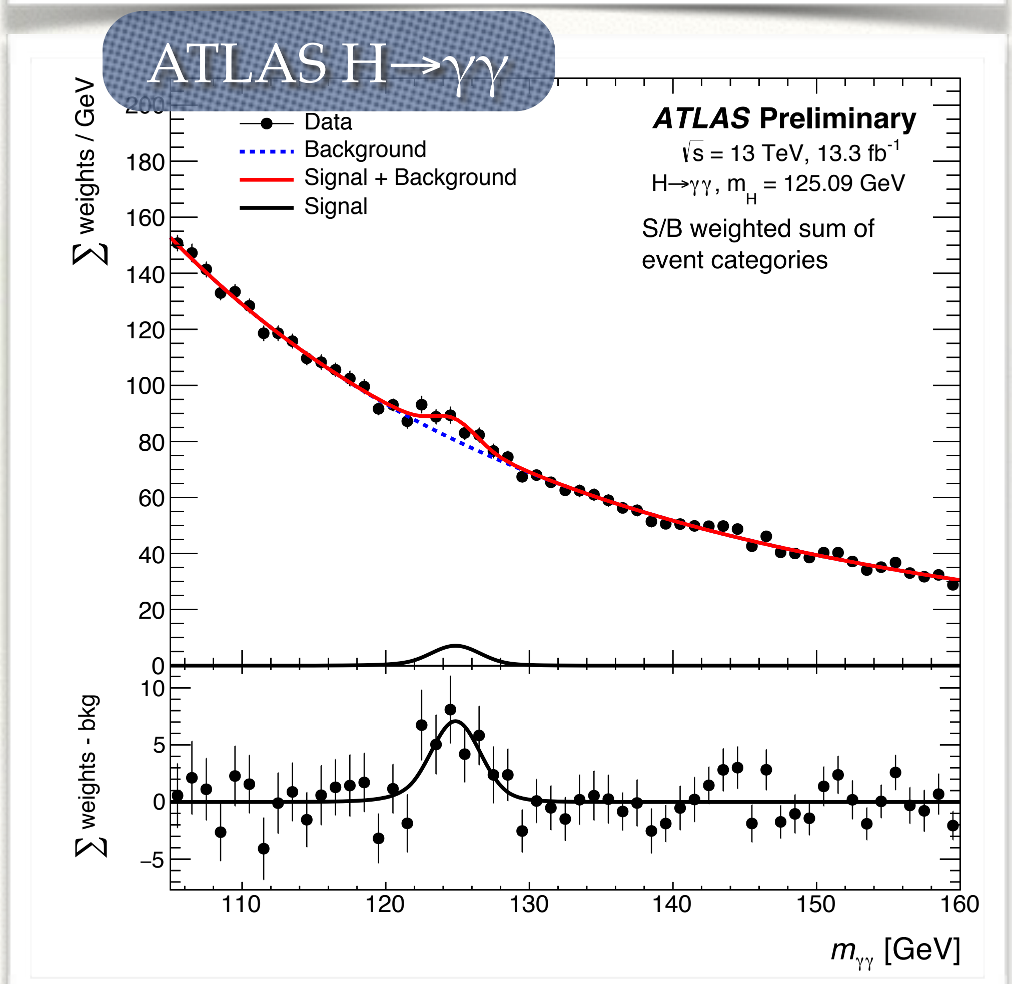
- LHC 2015 (~3 fb^{-1}) and 2016 (~13 fb^{-1}) data sets analyzed.
- More Higgs boson than Run-I has been produced!
- List of **FRESH AND HOT** results covered: 

Channel	Coll.	Lumi.	Reference
$H\to\gamma\gamma$	ATLAS	13.3 fb^{-1}	ATLAS-CONF-2016-067
$H\to\gamma\gamma$	CMS	12.9 fb^{-1}	CMS-HIG-16-020
$H\to ZZ$	ATLAS	14.8 fb^{-1}	ATLAS-CONF-2016-079
$H\to ZZ$	CMS	12.9 fb^{-1}	CMS-HIG-16-033
$H\to\gamma\gamma$ + ZZ	ATLAS		ATLAS-CONF-2016-081
ttH($\to$bb)	ATLAS	13.2 fb^{-1}	ATLAS-CONF-2016-080
ttH($\to$bb)	CMS	2.7 fb^{-1}	CMS-HIG-16-004
ttH(multilep)	ATLAS	13.2 fb^{-1}	ATLAS-CONF-2016-058
ttH(multilep)	CMS	12.9 fb^{-1}	CMS-HIG-16-022
VH ($H\to$bb)	ATLAS	13.2 fb^{-1}	ATLAS-CONF-2016-091
VBF $H\to$bb	ATLAS	12.6 fb^{-1}	ATLAS-CONF-2016-063
VBF $H\to$bb	CMS	2.32 fb^{-1}	CMS-HIG-16-003

H→γγ

- Look for bump on the diphoton invariant mass spectrum.
- Event signature: 2 isolated photons, with additional “tags” for VBF, VH, or ttH productions. Signal extracted with fits to M(γγ).
- Dominant background: QCD diphoton & γ+jet
- Dominant systematics: photon energy scale, resolution, background modeling.



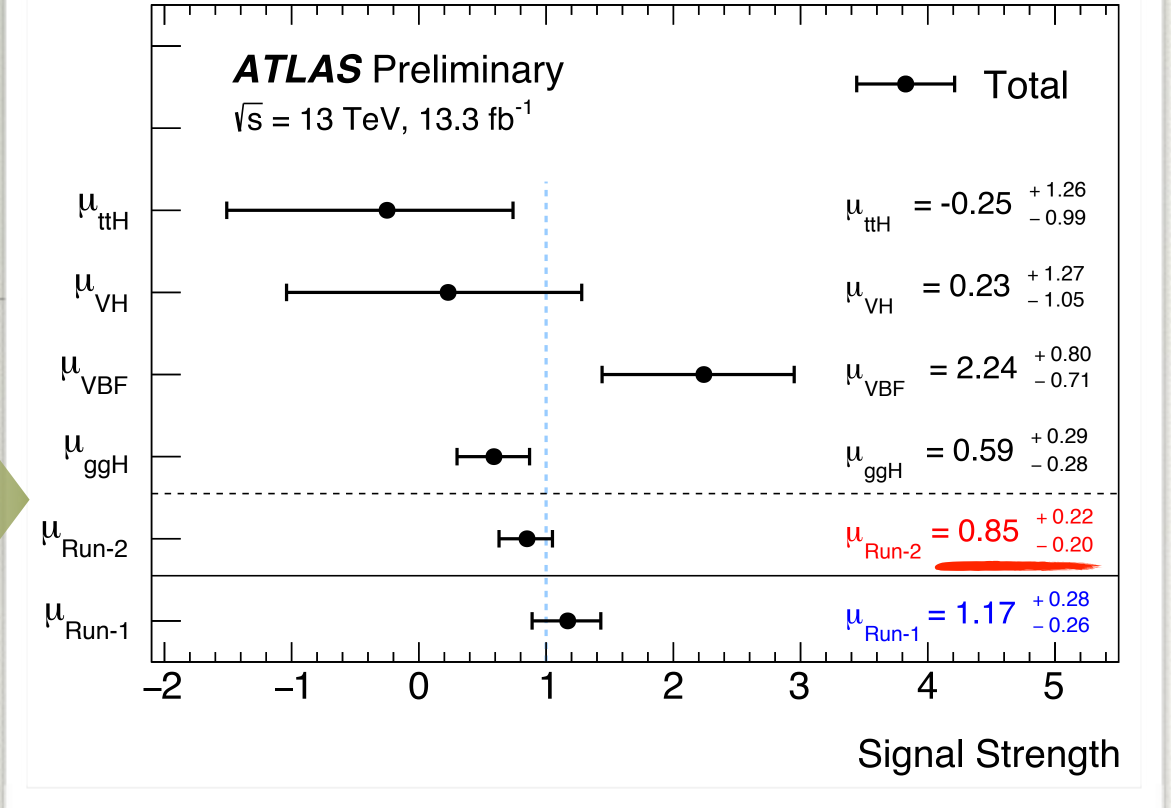


H→γγ

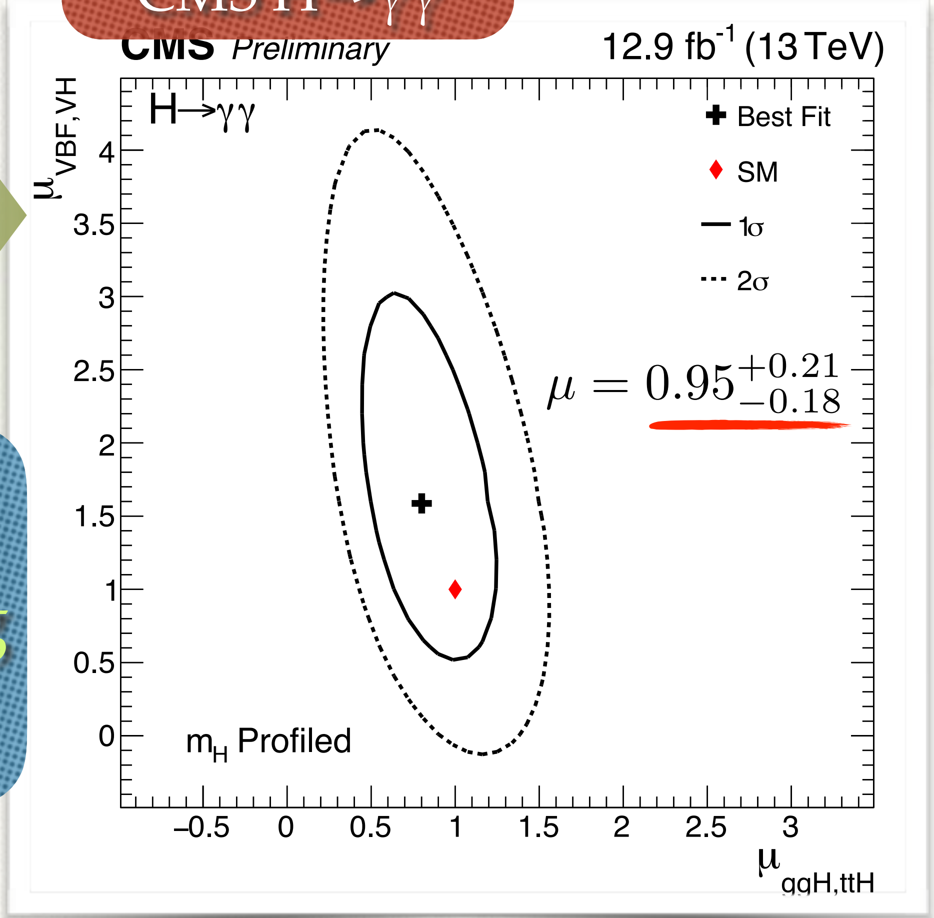
- Production cross section and signal strength:
  - Events are split into orthogonal categories which exploit topological differences between the production processes.
- Extract strength of production processes in a 2-parameter fit:

Compatible with SM predictions.
Reached a better precision comparing to Run-I result already!

ATLAS H→γγ



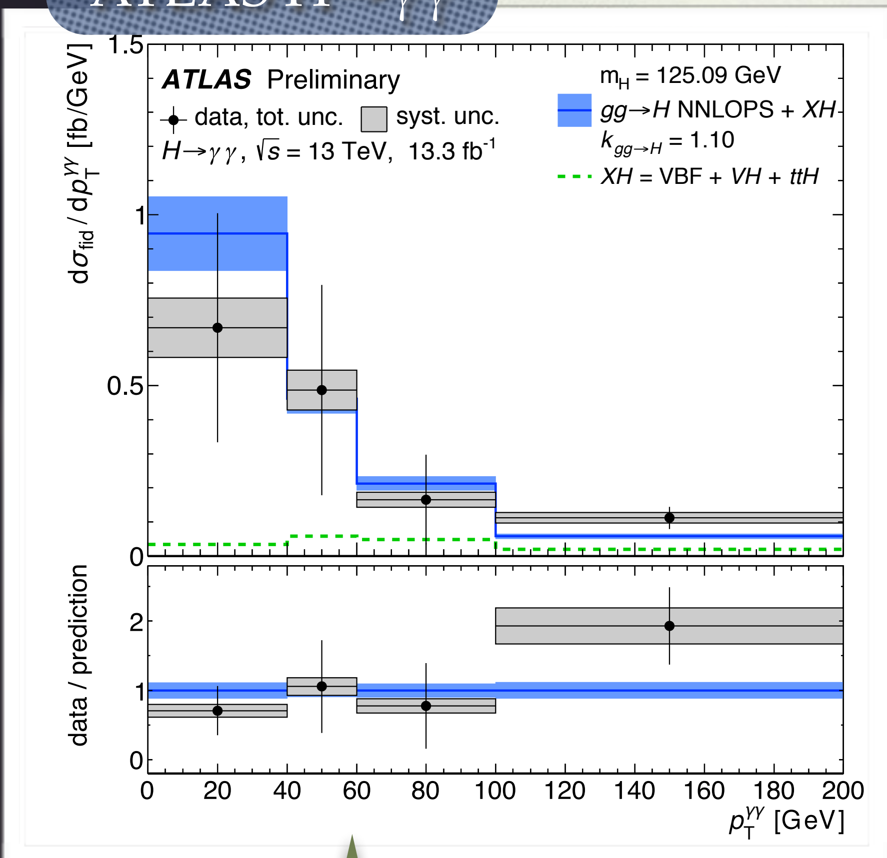
CMS H→γγ

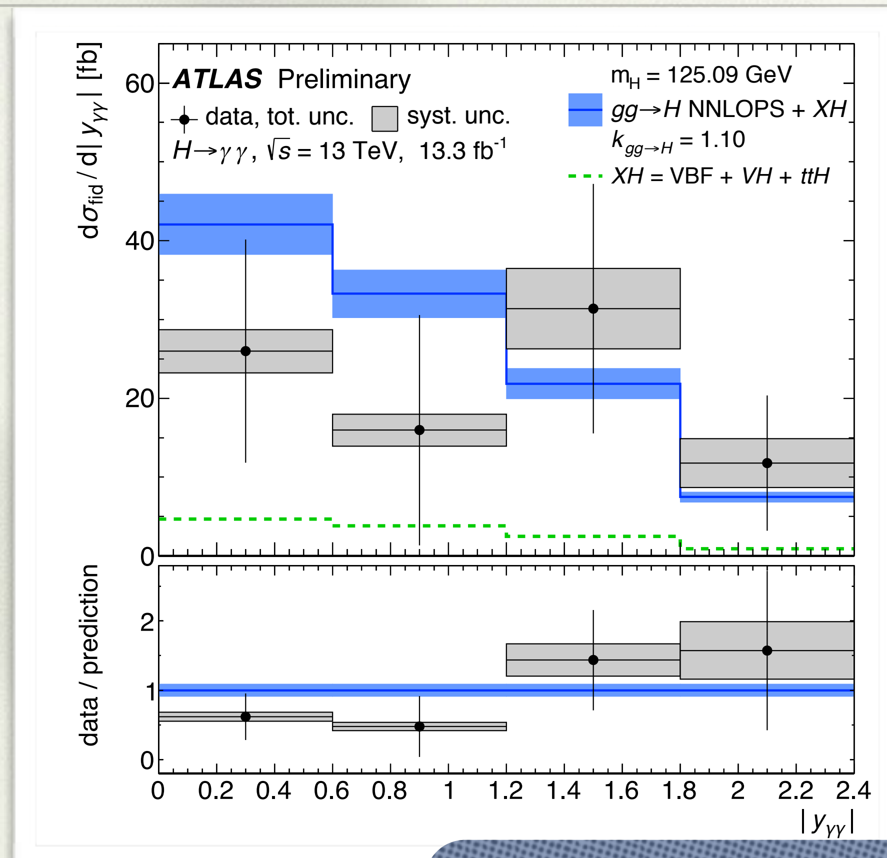


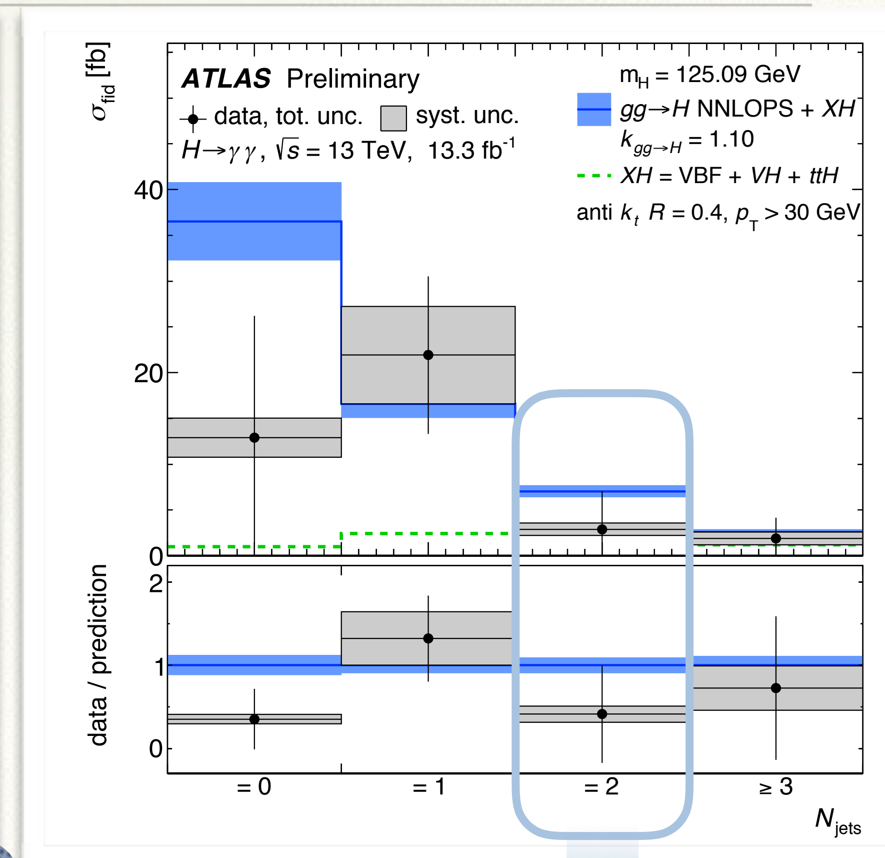
ATLAS-CONF-2016-067
CMS-PAS-HIG-16-020

H→γγ Differential Cross Sections

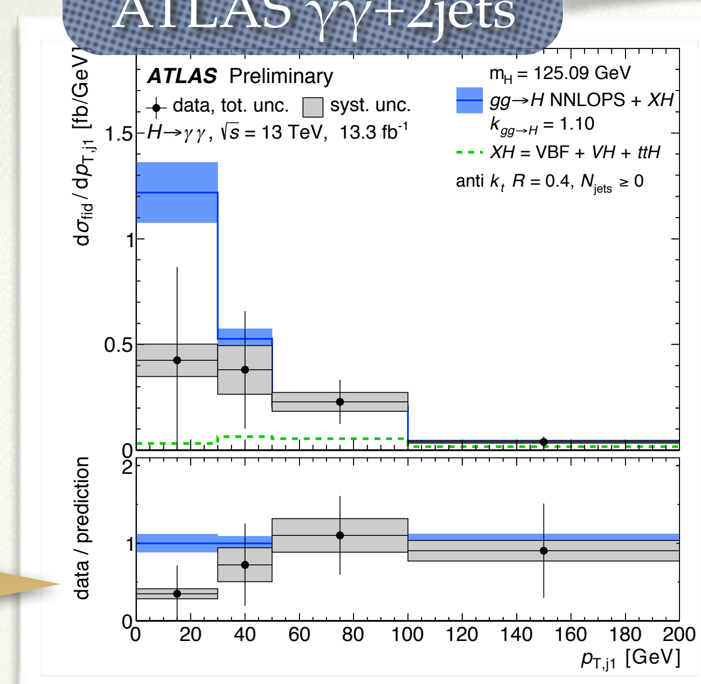
ATLAS H→γγ

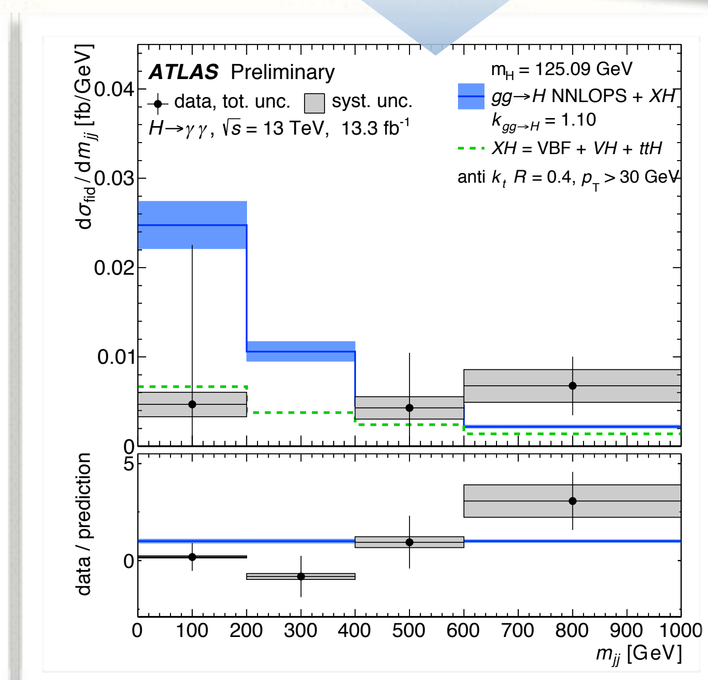






ATLAS γγ+2jets





Time to check not just the total, but also the differential cross sections!

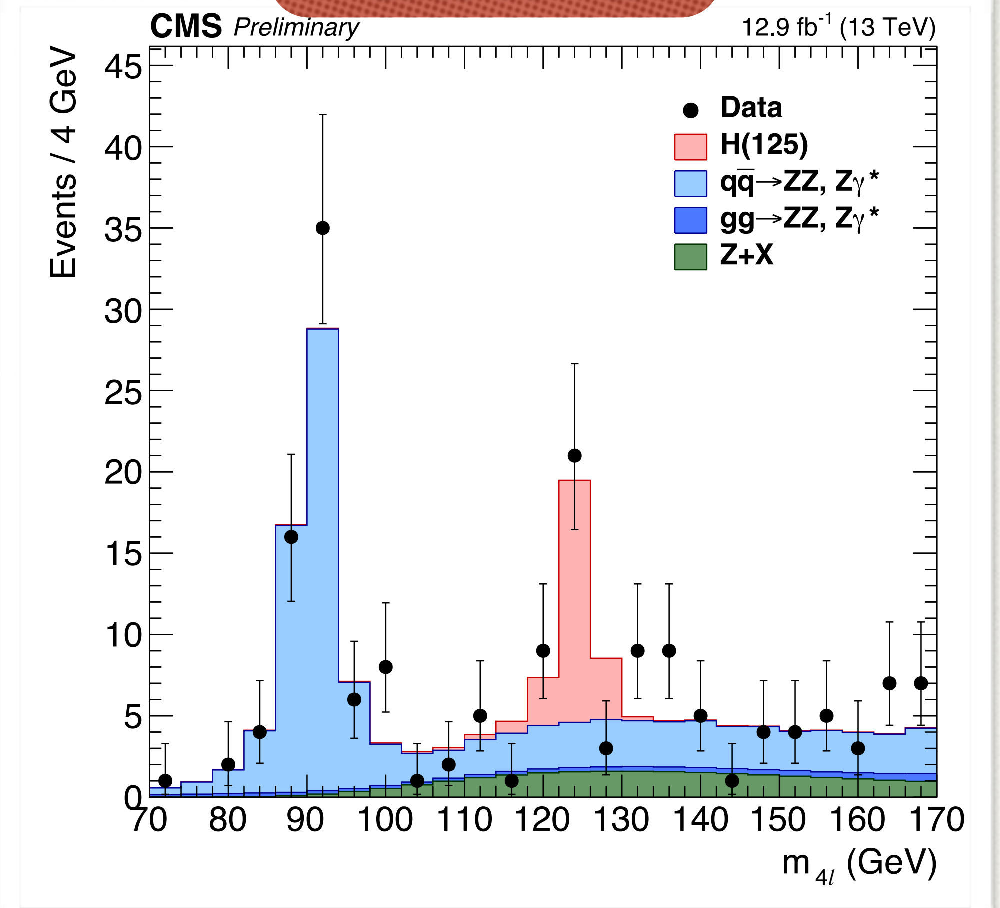
Dijet category: enhanced VBF?

ATLAS-CONF-2016-079
CMS-PAS-HIG-16-033

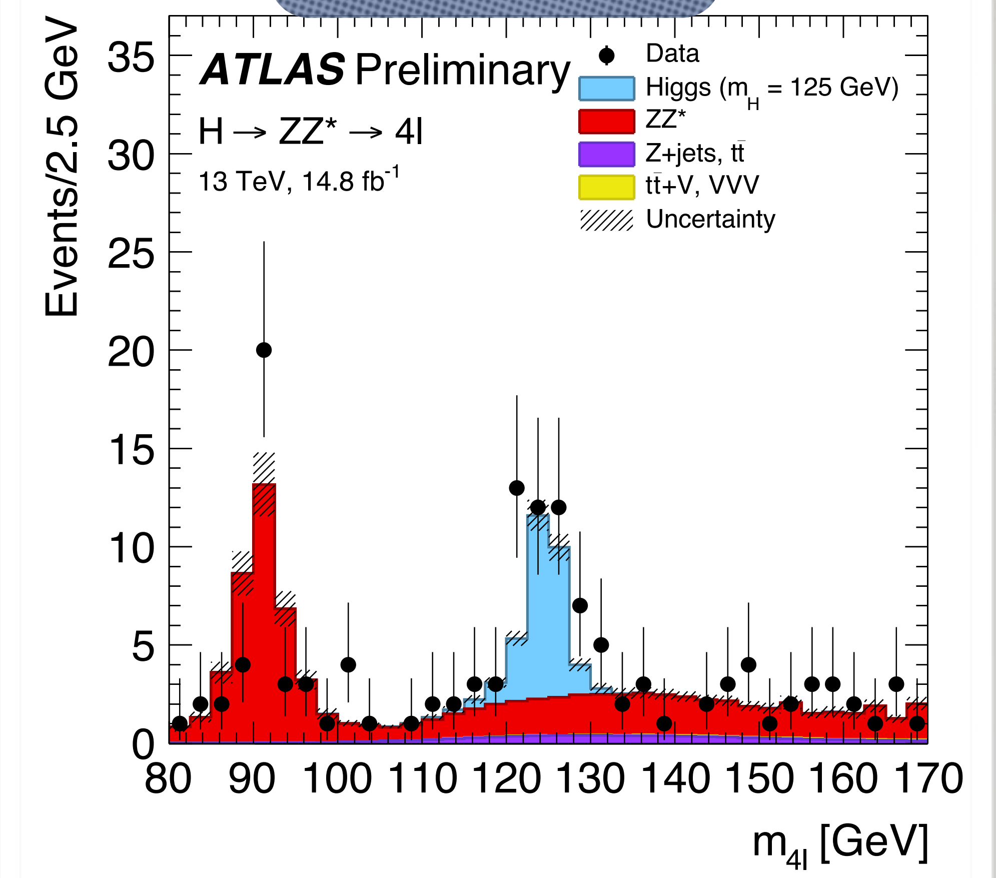
H→ZZ*→4l

- Look for 4 isolated charged leptons, with tags to production processes (ggF, VBF, VH, ttH).
- Very narrow peak on the invariant mass distribution with high S/N ratio. The only background source is the ZZ production.
- Signal extraction with fit to the invariant mass. Kinematic discriminant which includes the spin/parity assumption also used.

CMS H→4l



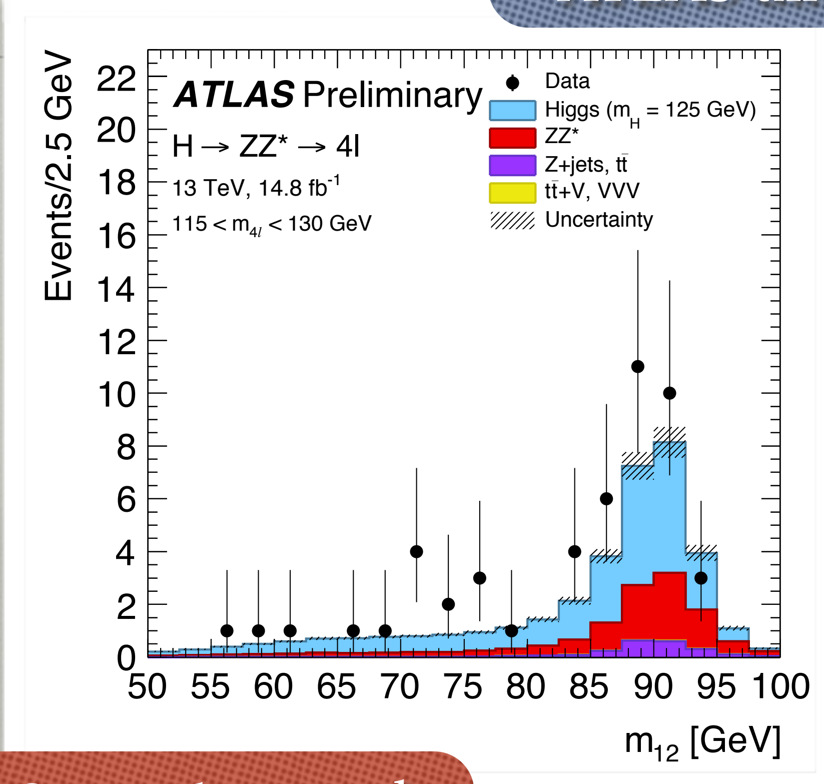
ATLAS H→4l

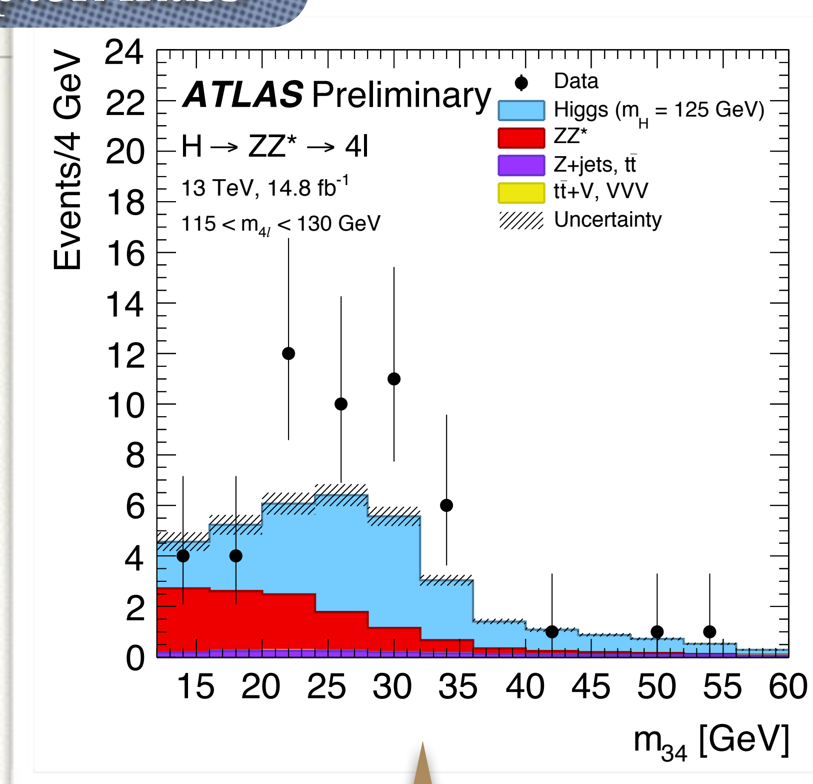


$H \rightarrow ZZ^* \rightarrow 4l$

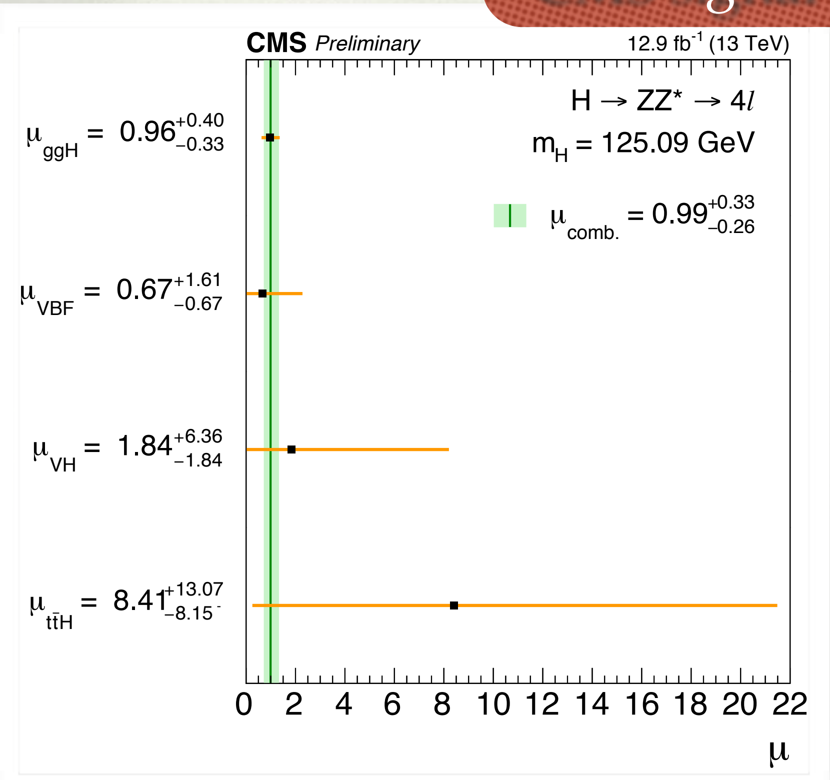
(Very) Compatible with SM predictions, more signals than Run-I data reconstructed!

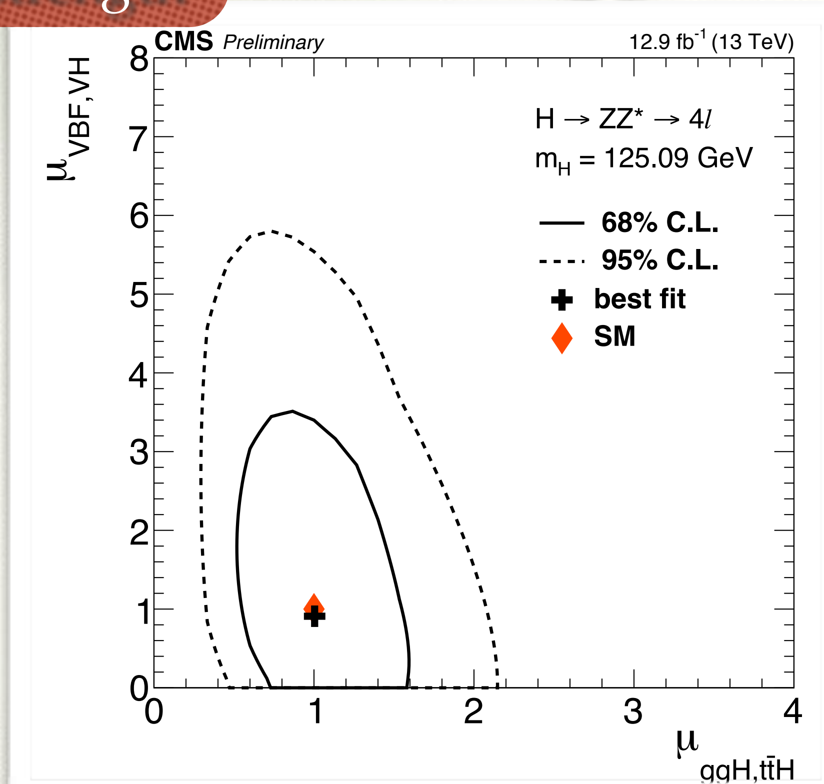
ATLAS dilepton mass





CMS signal strength



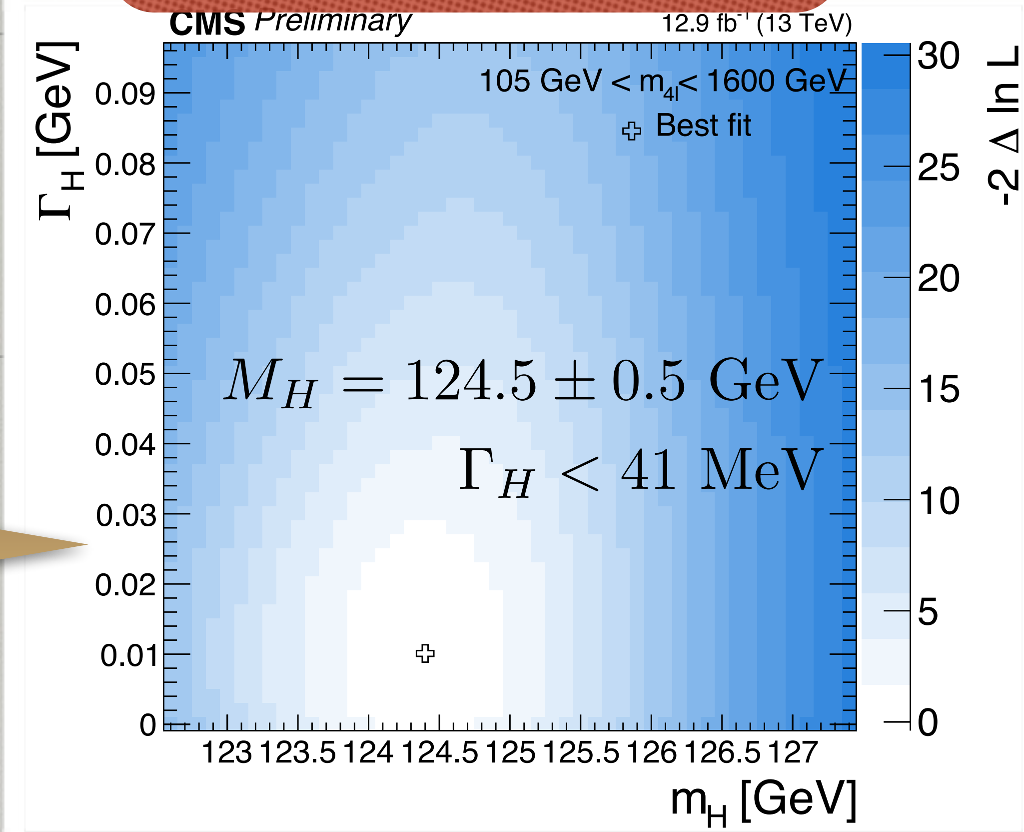


Even the dilepton invariant mass fit the SM quite well.

ATLAS-CONF-2016-079
CMS-PAS-HIG-16-033

$H \to ZZ^* \to 4l$

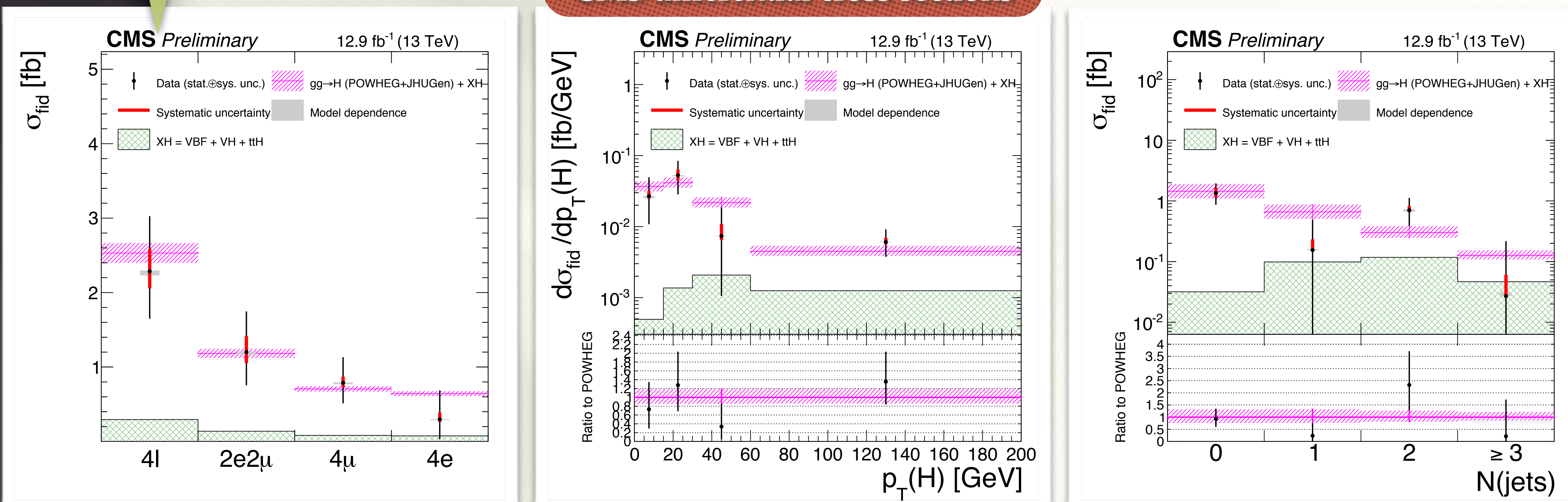
CMS mass & width scan



Scan over M_H & Γ_H

Shows almost perfect matching in lepton flavor / p_T / N(jets).

CMS differential cross sections

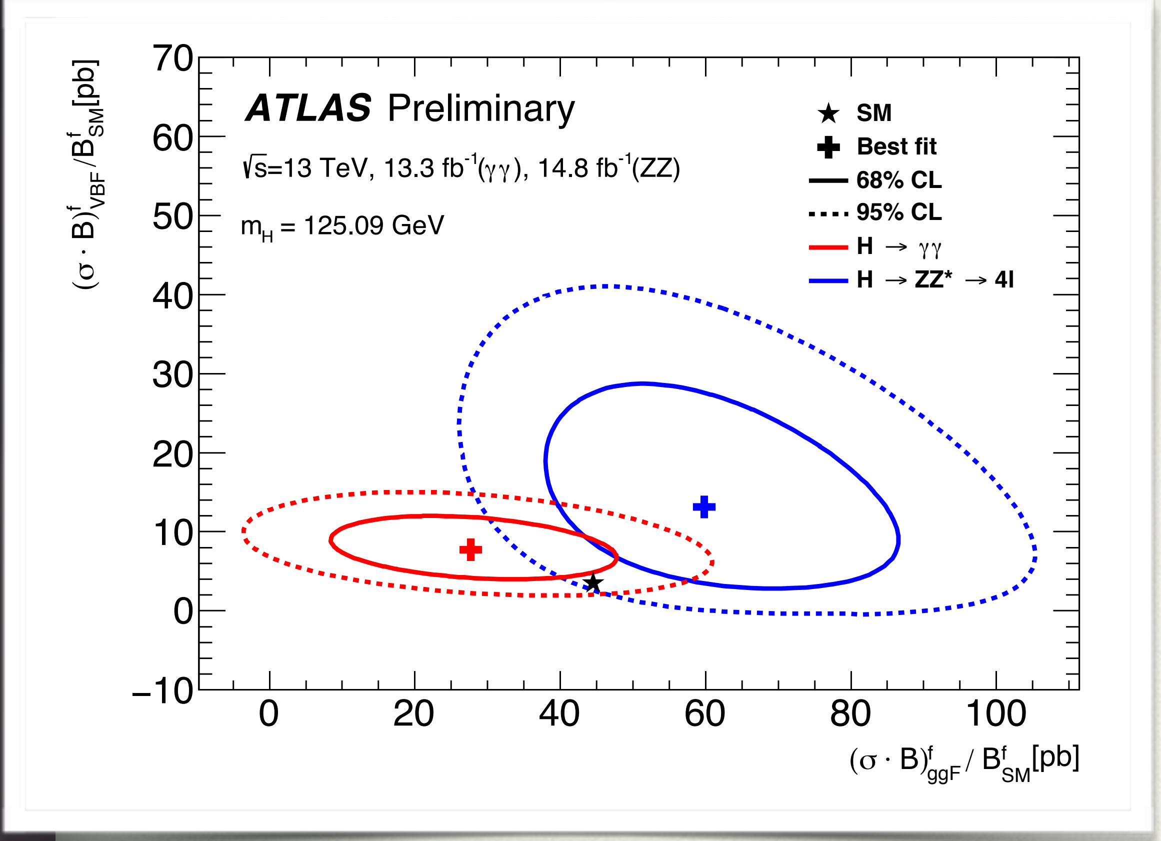


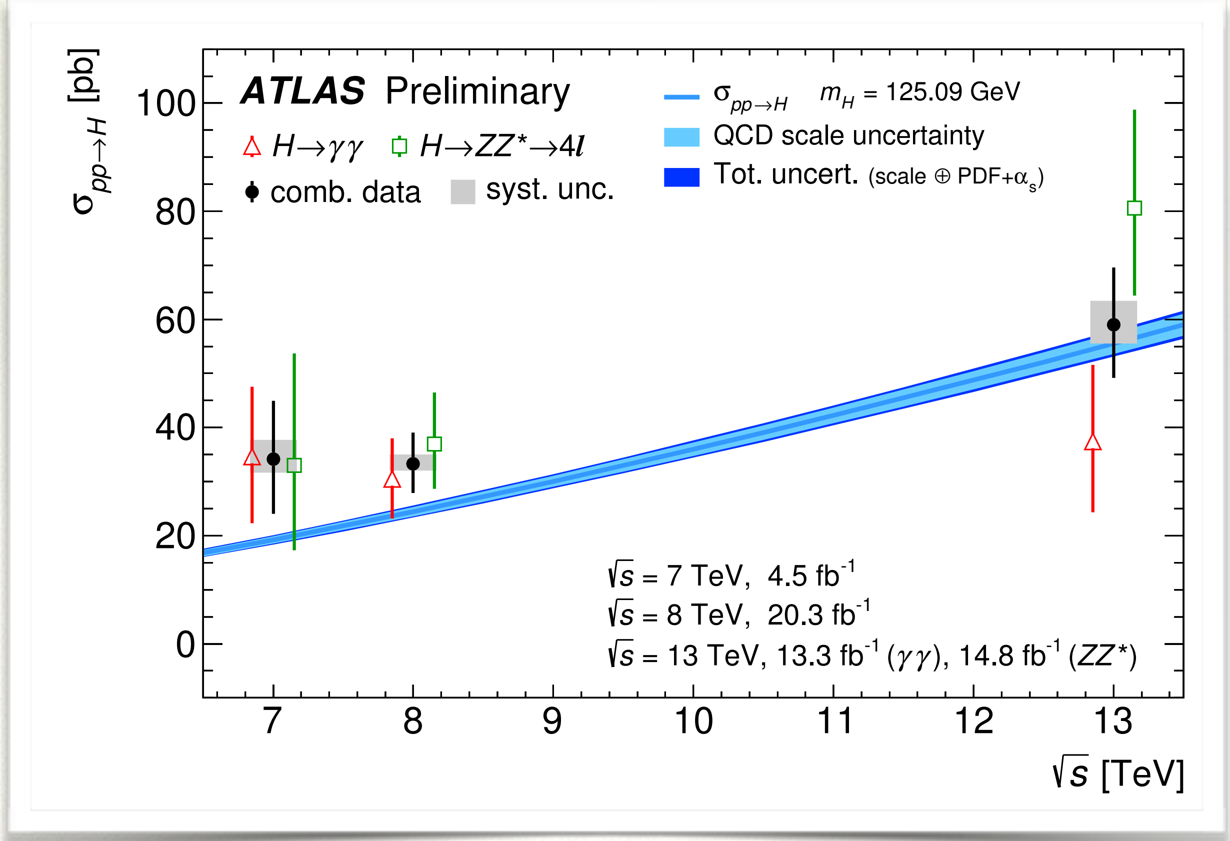
Unfortunately: limited space for BSM→H scenarios!

H→γγ + 4l Combination

- Combining H→γγ and H→ZZ*→4l inclusive samples.
- Higgs production is observed with 10σ significance (8.6σ expected) with 13 TeV data, and in agreement with SM expectation.

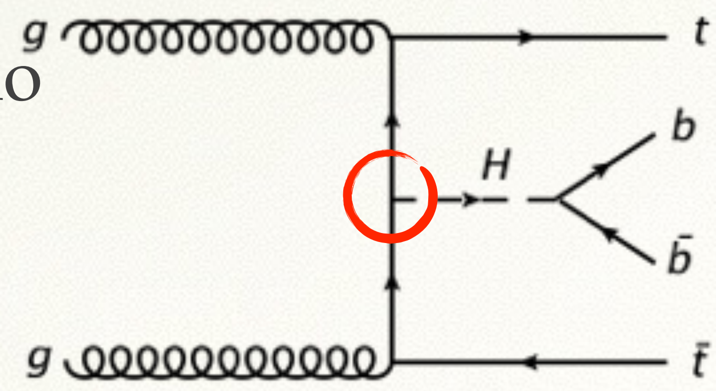
	Measurement	SM Prediction
σ (pb)	$59.0^{+9.7}_{-9.2}(\text{stat.})^{+4.4}_{-3.5}(\text{syst.})$	$55.5^{+2.4}_{-3.4}$
μ	$1.13^{+0.18}_{-0.17}$	1





ttH Production

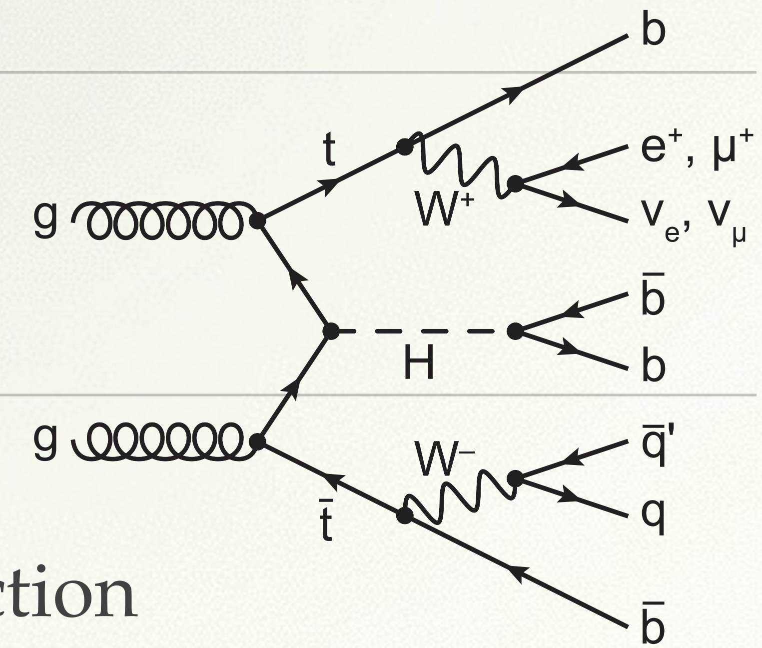
- Probe the top-Higgs coupling at the LHC:
  - through the gluon fusion process, assumes no BSM particles running in the loop
  - through the associated ttH production directly at the tree level.
- Good at Run-II: cross section increases by 3.9x.



Higgs decay	Branching fraction
$H \to bb$	58%
$H \to WW$	22%
$H \to ZZ$	2.6%
$H \to \tau\tau$	6.3%
$H \to \gamma\gamma$	0.23%

- $H \to bb$: reconstruct top pair in all possible channel, with $H \to bb$ in addition.
- $H \to WW$, $H \to ZZ$, $H \to \tau\tau$: Complex multilepton final state, look for 2-4 leptons + 2 jets (and b-tagged jet)
- $H \to \gamma\gamma$: Included in the $H \to \gamma\gamma$ analysis.

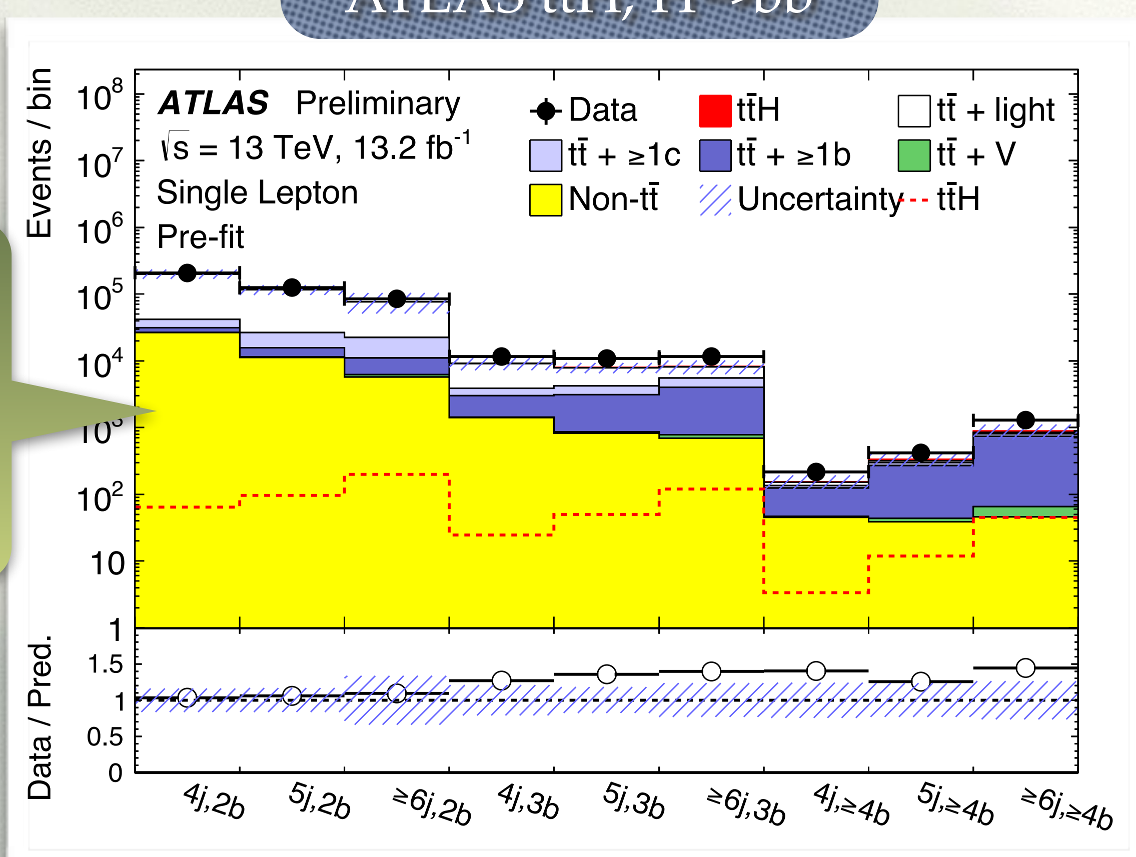
ttH (H→bb)



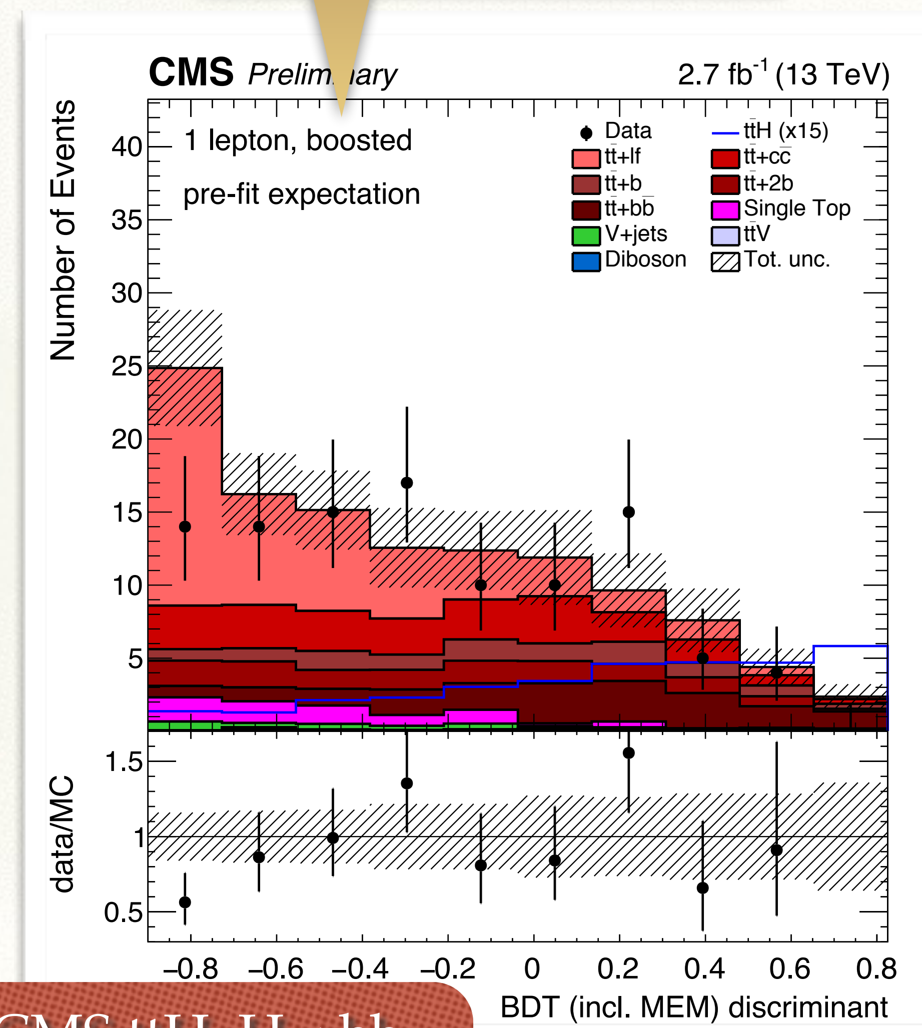
- Strategy: categorize events according to # of leptons and (b-)jets. Background reduction with BDT and matrix elements (MEM).
- Main background is tt+heavy flavor jets.
- Systematics: signal/bkg. modeling.

Also a "boosted" category!

ATLAS ttH, H→bb

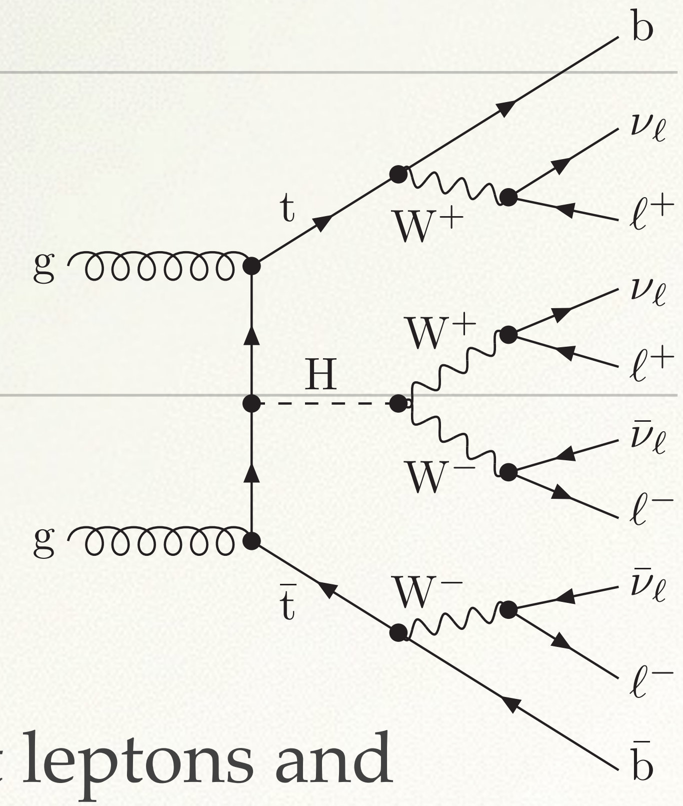


BDT used for each category



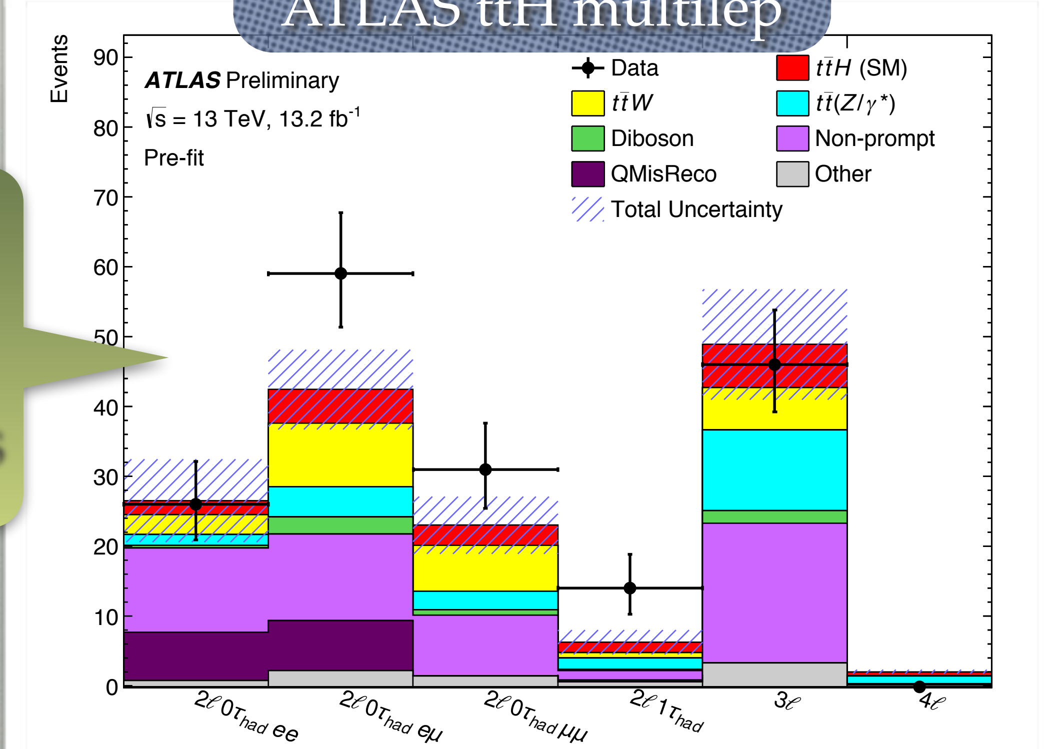
CMS ttH, H→bb

ttH (multilepton)



- Strategy: look for clean signatures and low backgrounds, ie. w/ 2-4 leptons, 2 or more jets, at least one b-tagged jet.
- Main background is contributed by non-prompt leptons and tt+W/Z.
- Main systematics: lepton fake rate studies and non-prompt leptons estimate.

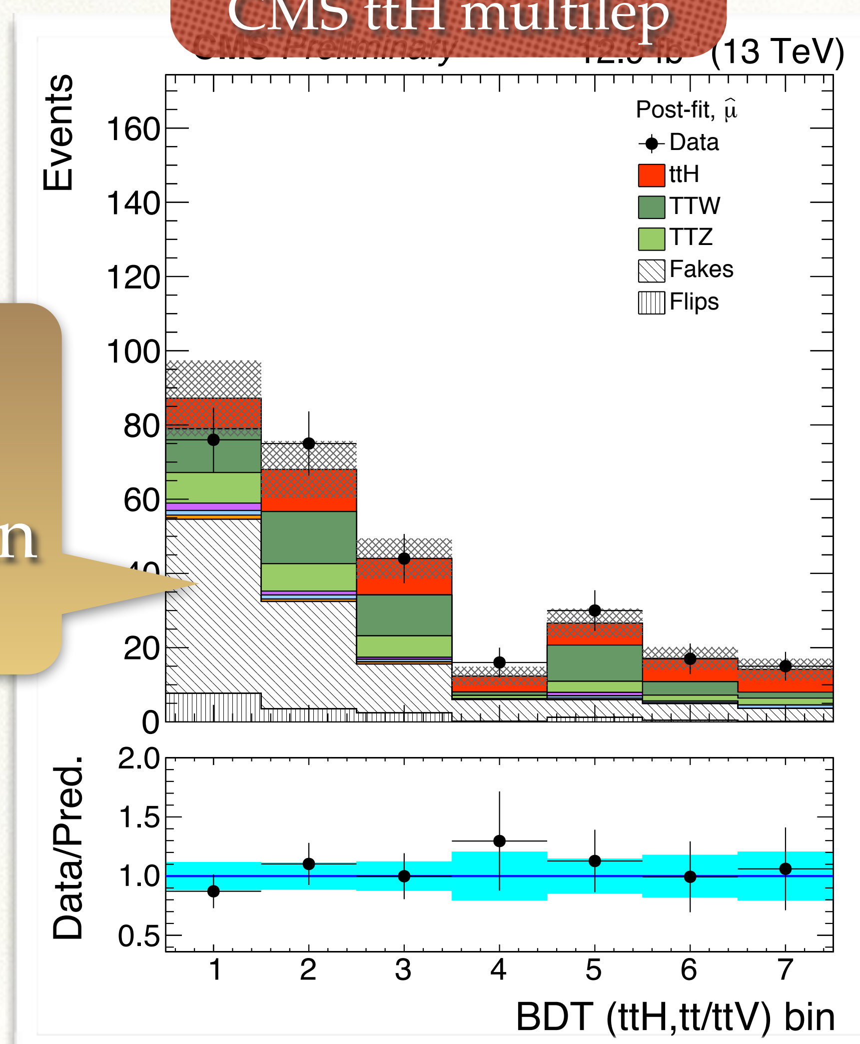
ATLAS ttH multilep



Cut & count analysis

MEM weights included in BDT

CMS ttH multilep

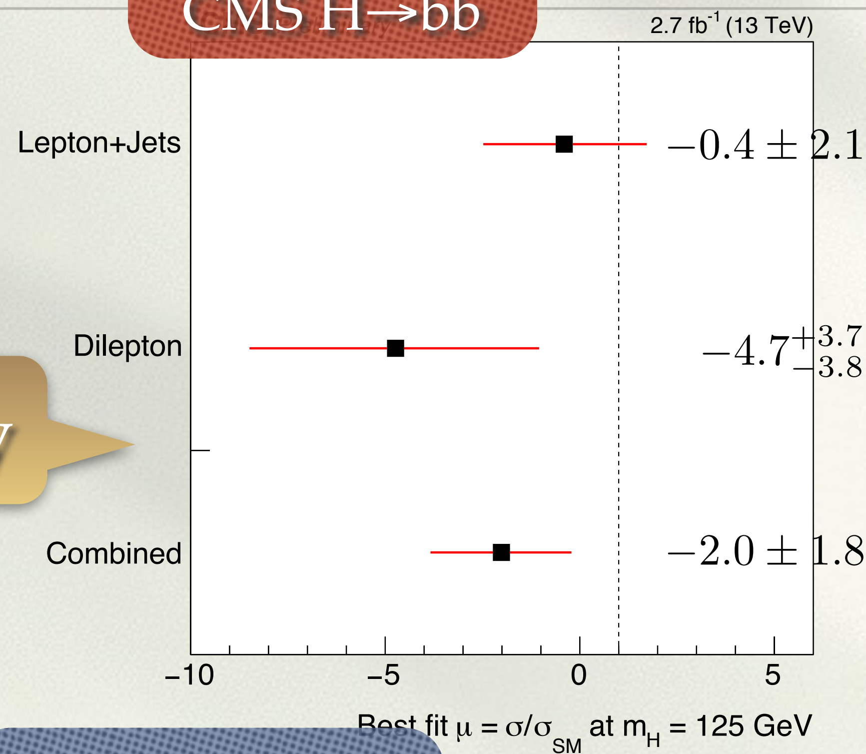


ttH: Best fits

Mild excess ($\mu>1$) in most of the channels.

CMS H→bb

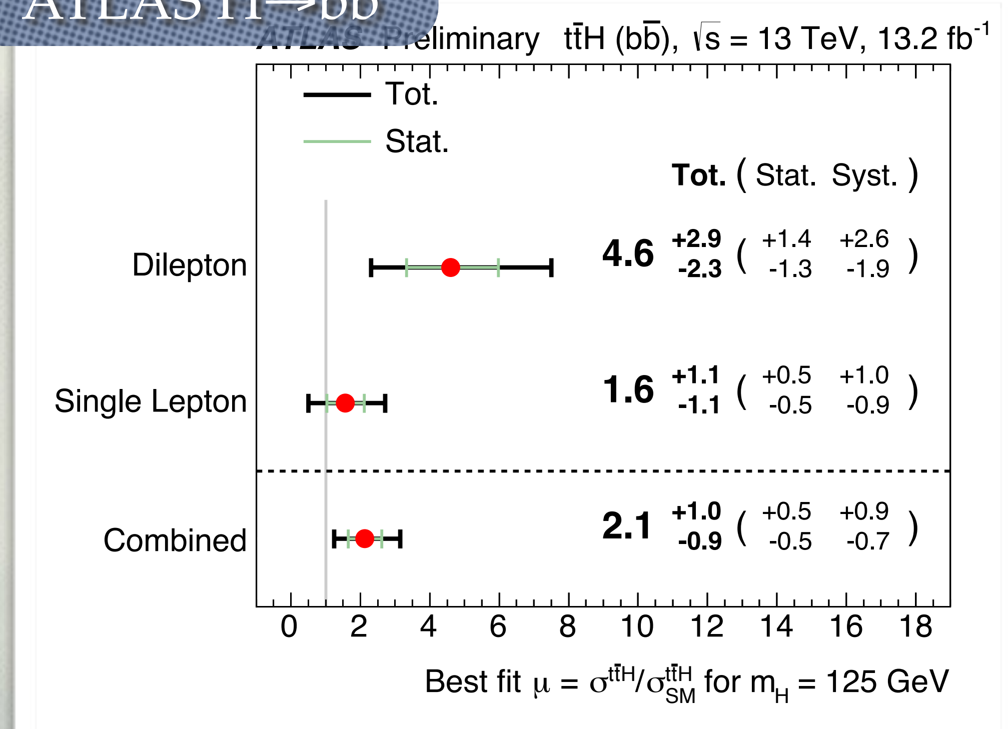
2015 data only



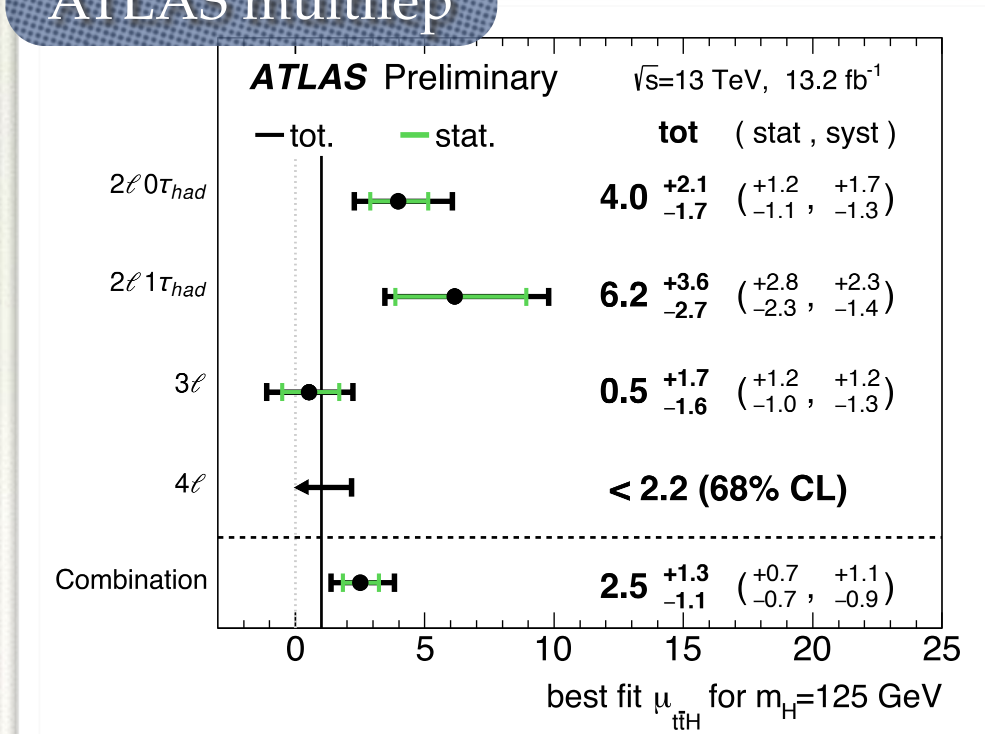
CMS multilep

Category	Best fit μ
same-sign	$2.7^{+1.1}_{-1.0}$
3L	$1.3^{+1.2}_{-1.0}$
combined	$2.3^{+0.9}_{-0.8}$
2015+2016	$2.0^{+0.8}_{-0.7}$

ATLAS H→bb

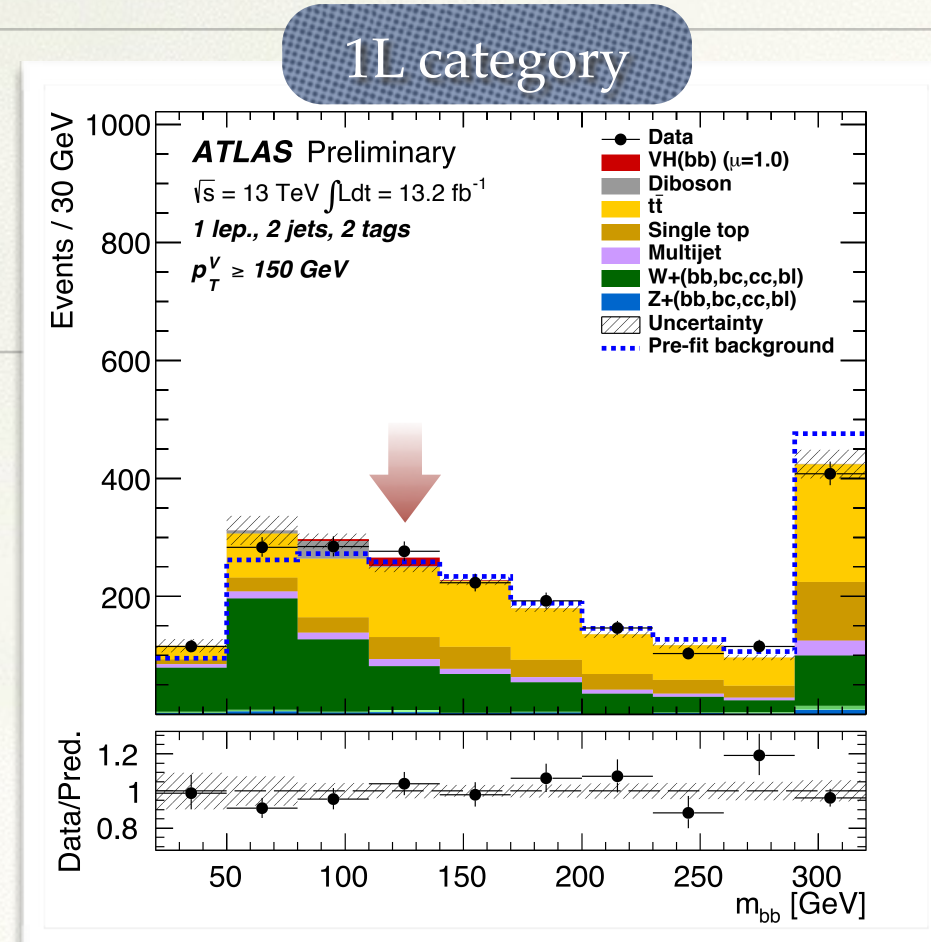


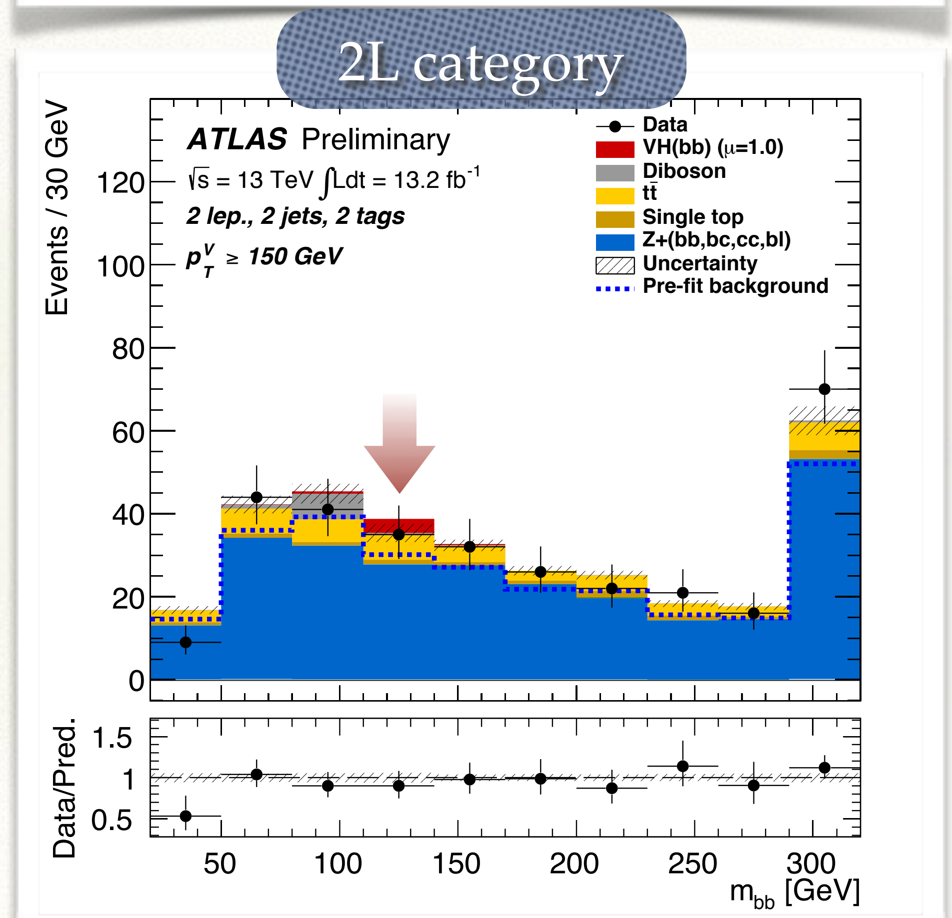
ATLAS multilep

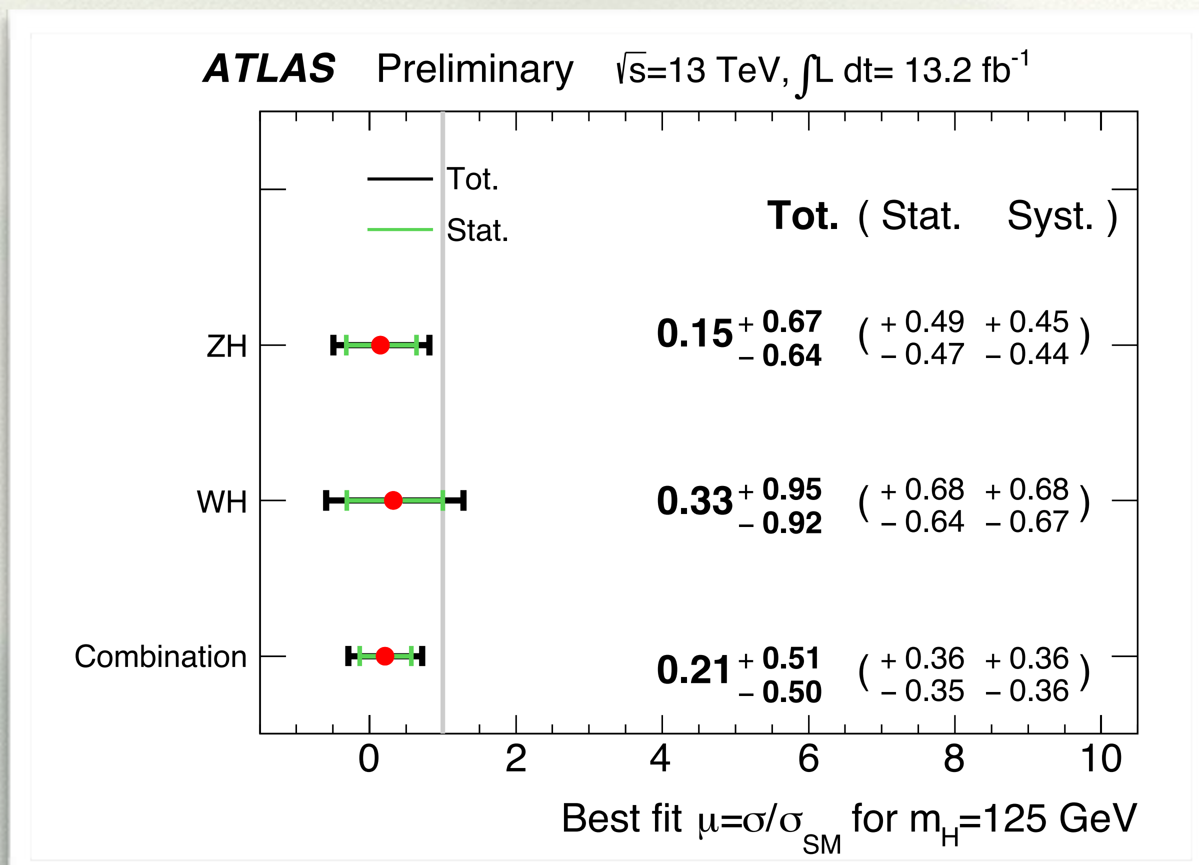


VH (H→bb)

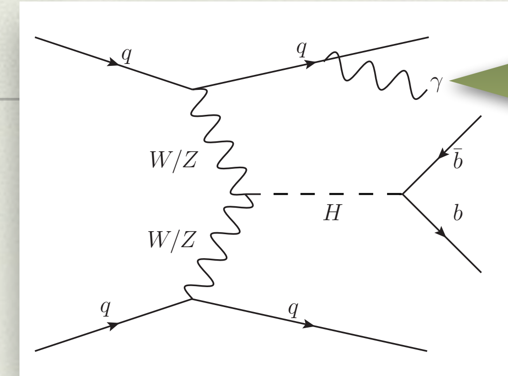
- Strategy: utilize leptonic decays of Z/W events
- Multivariate analysis techniques is required to achieve “working” S/N.
- Main backgrounds: Z+b, top pair







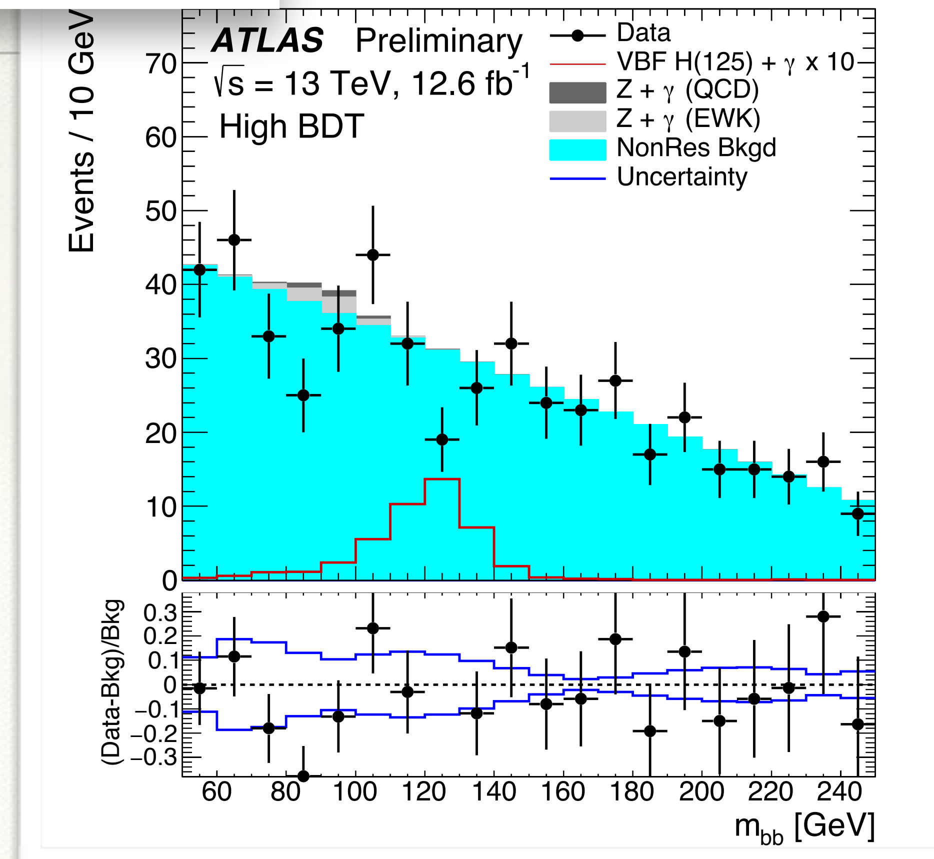
VBF H→bb



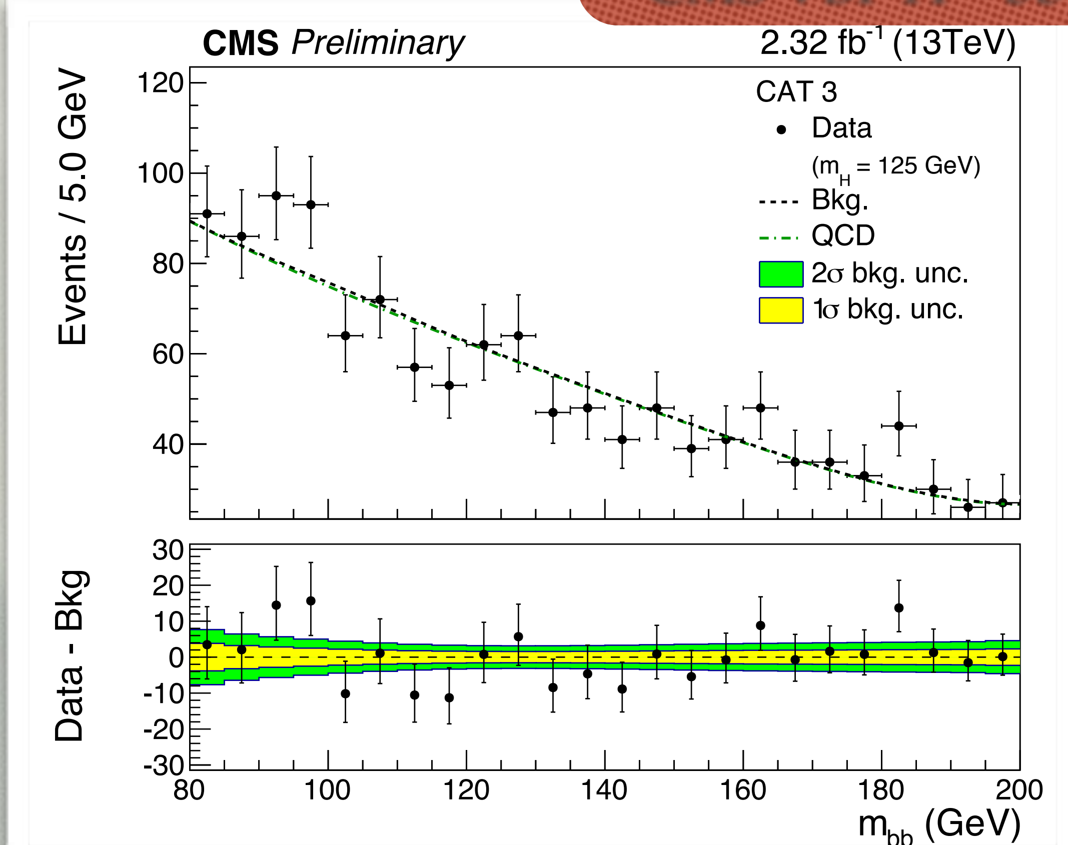
tag addition photon to clean up

- VBF H→bb more difficult (hard to suppress QCD background), but w/ larger production cross section.
- Forward jets are used to trigger and discriminate against the background.
- Signal extracted via a fit to the invariant mass distribution.

ATLAS VBF H→bb



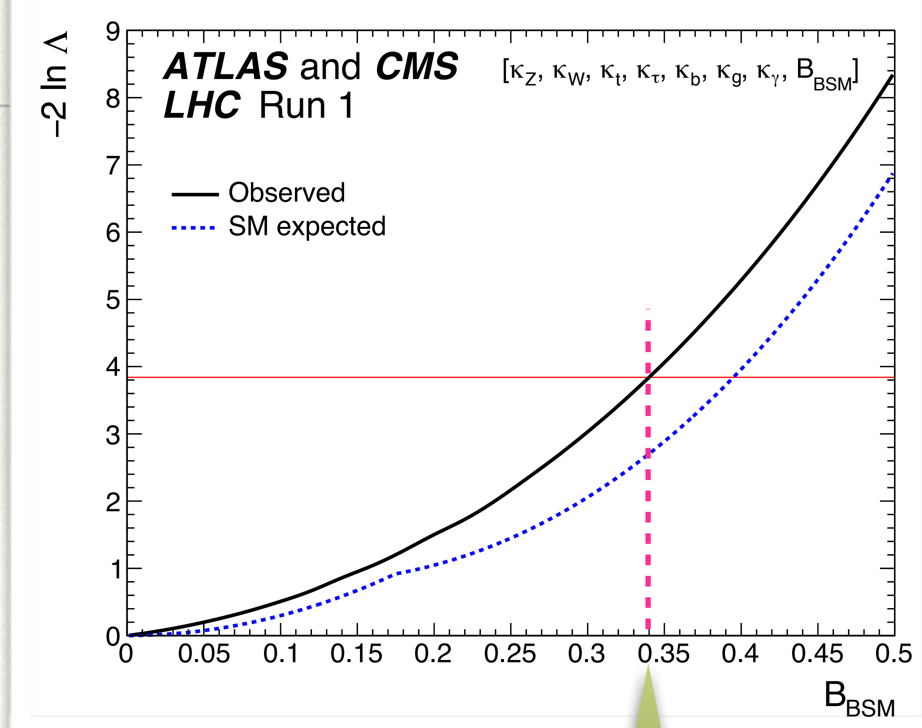
CMS VBF H→bb



	Obs. limit	Best fit μ
CMS (2.3 fb⁻¹)	μ<3.4	$1.3^{+1.2}_{-1.1}$
ATLAS (12.6 fb⁻¹)	μ<4.0	$-3.9^{+2.8}_{-2.7}$

H(125): Exotic Decays

- The observed Higgs is consistent with the SM predictions so far — H(125) becomes a standard object.
- Current constraints still allow for Higgs to couple to new particles or new couplings to particle
  - Higgs to invisible
  - Lepton flavour violating decays
  - Higgs to pseudo-scalars, etc.



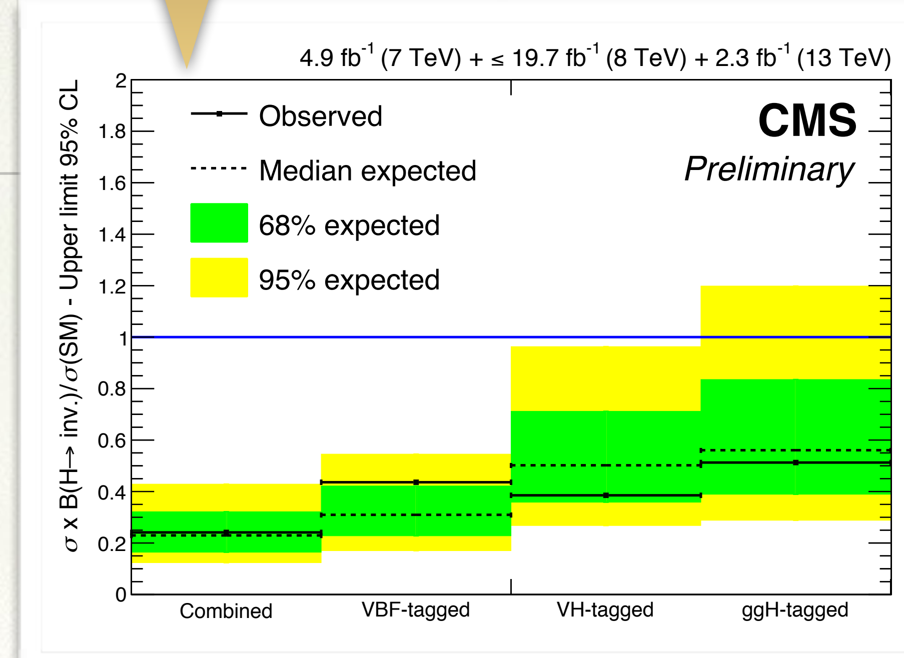
Run-I combination gives an indirect limit: B(BSM)<34%

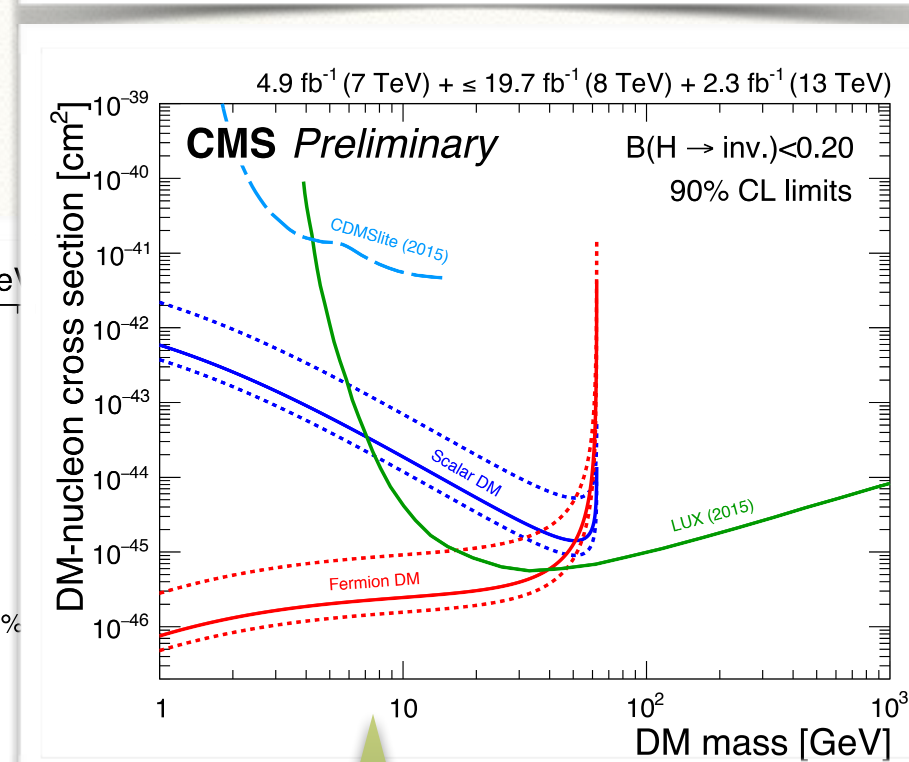
Channel	Coll.	Lumi.	Reference
H→invisible	CMS	Run-I full + Run-II 2.3 fb^{-1}	CMS-HIG-16-016
H→μτ	CMS	2.3 fb^{-1}	CMS-HIG-16-005

H→Invisible

- A combined analysis including full Run-I and 2.3 fb^{-1} from Run-II.
- Search production channels include ggF, VBF, and VH.
- SM production cross section ratios are assumed.

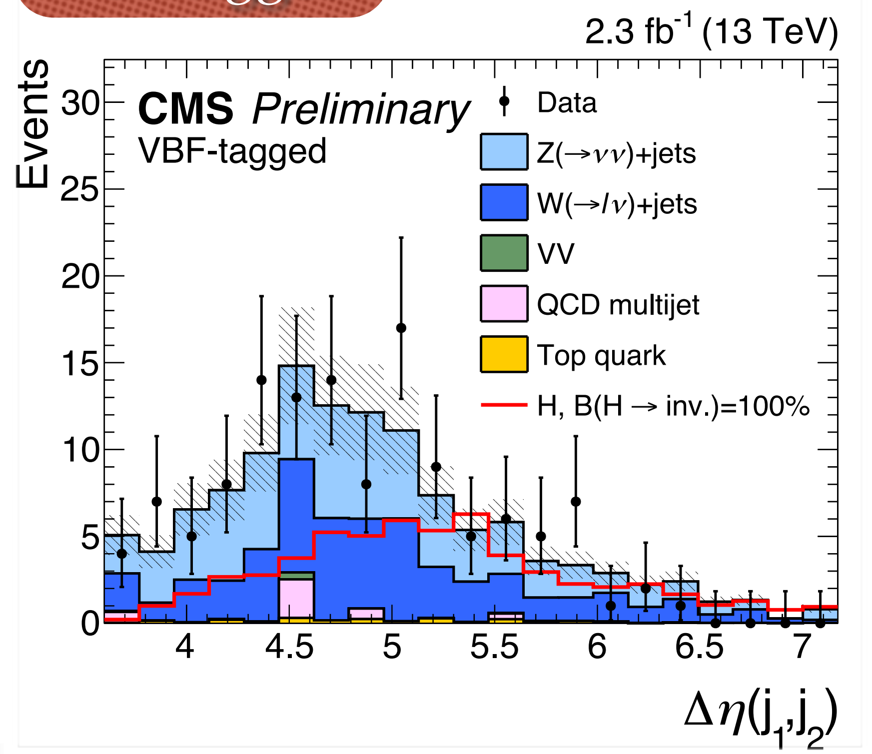
Obs. limit: B(H→Invisible)<24%



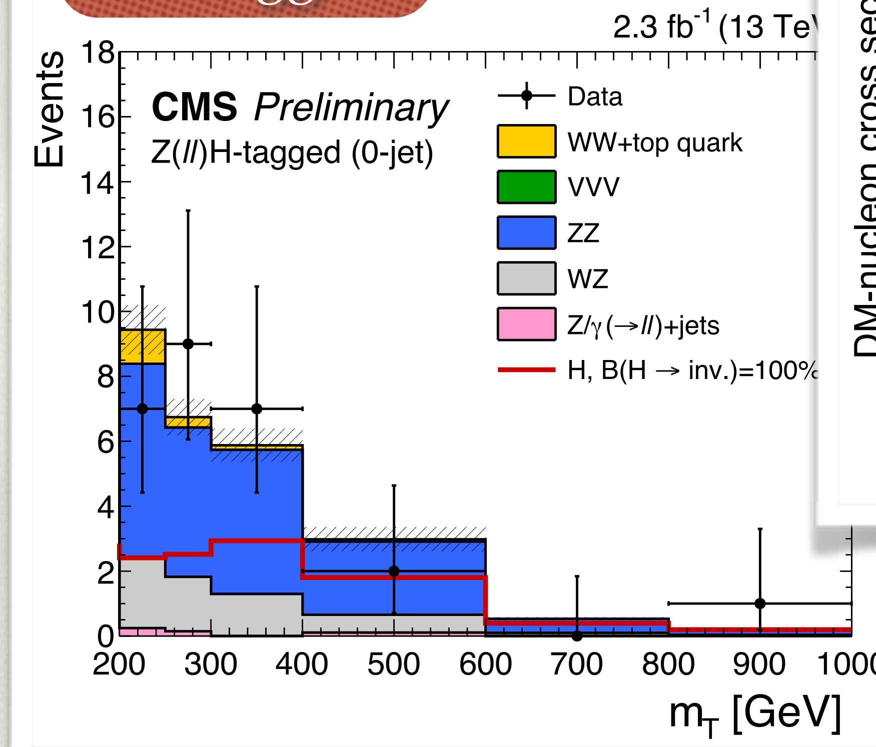


interpreted under Higgs-portal dark matter models

VBF tagged



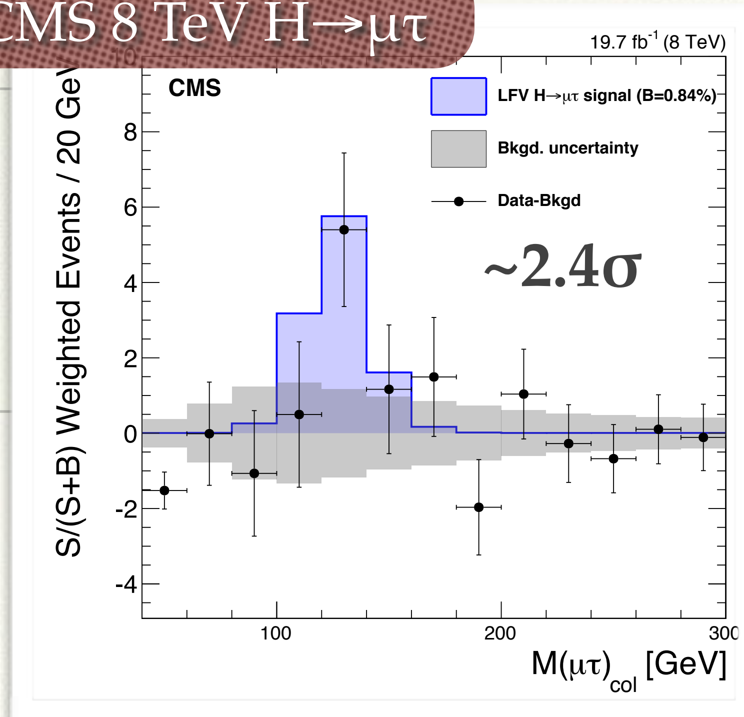
ZH tagged



LFV Higgs Decay

- There were some mild excess (~2.4σ, combining all channels) in the 8 TeV analysis.
- Mandatory to check it with new data w/ exactly the same analysis.

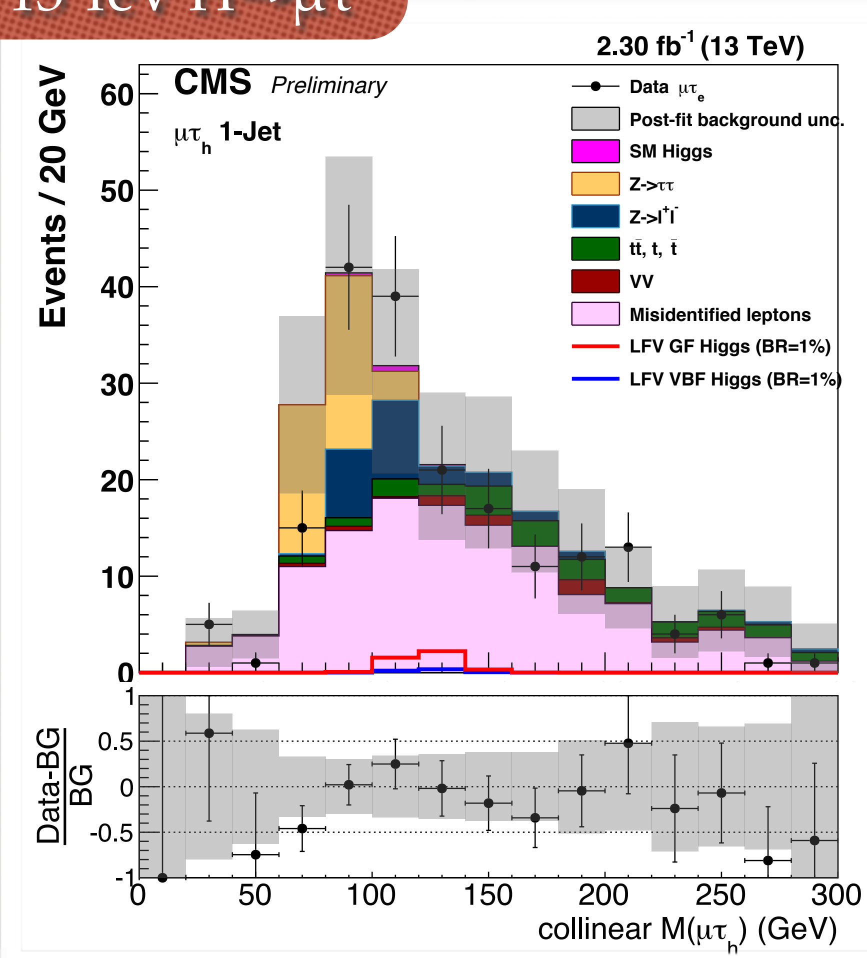
CMS 8 TeV H→μτ

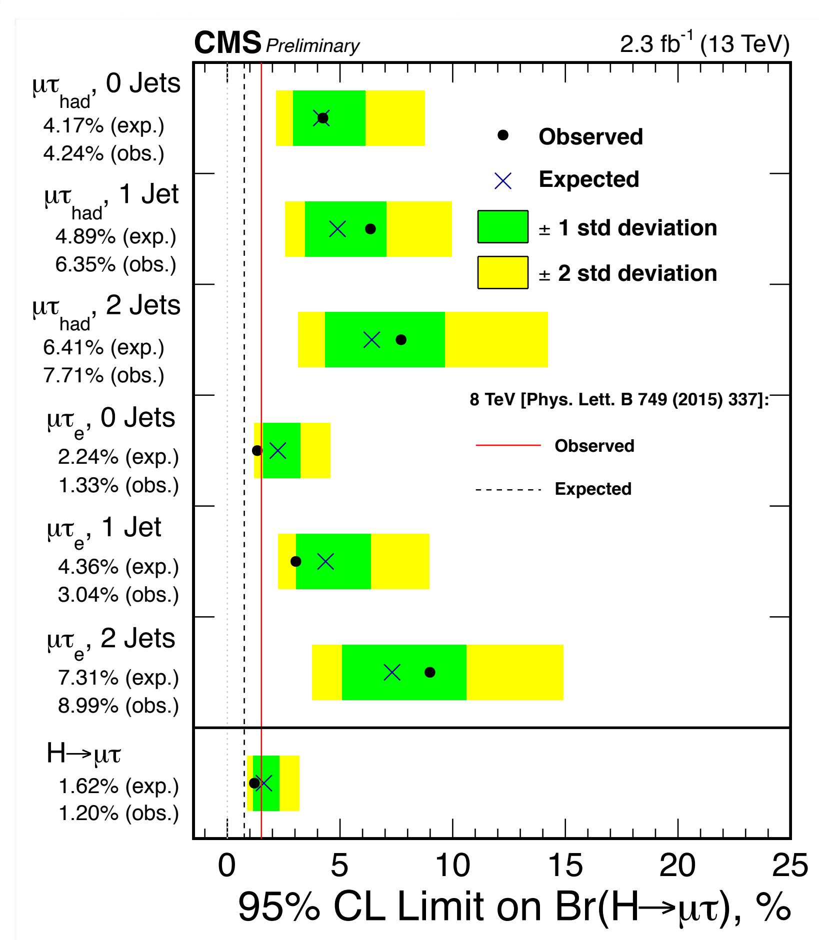


	Limit	Best fit
8 TeV	$<1.51\%$	$0.84^{+0.39}_{-0.37}\%$
13 TeV	$<1.2\%$	$-0.76^{+0.81}_{-0.84}\%$

Negative best fit value; no obvious hint anymore.

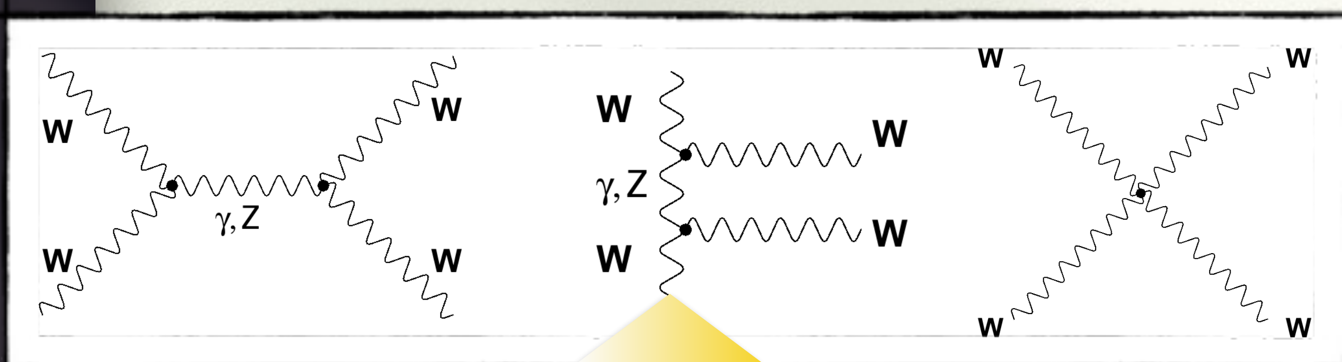
13 TeV H→μτ





From Higgs to Electroweak Physics

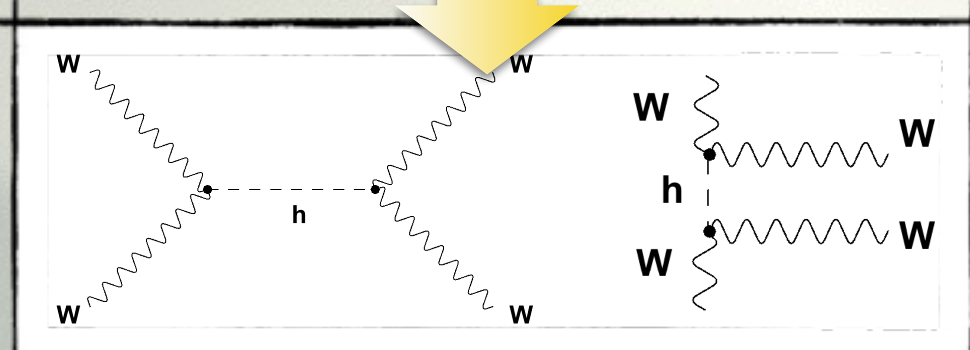
- W bosons is produced in s-channel at LHC; large statistical sample for studying W properties including mass/width.
- Diboson productions should be well-measured. Higgs is required to protect the unitarity in the VV scattering processes:



w/o Higgs, the partial wave amplitudes would be bounded by $\mathcal{M} \sim \frac{s}{m_W^2}$

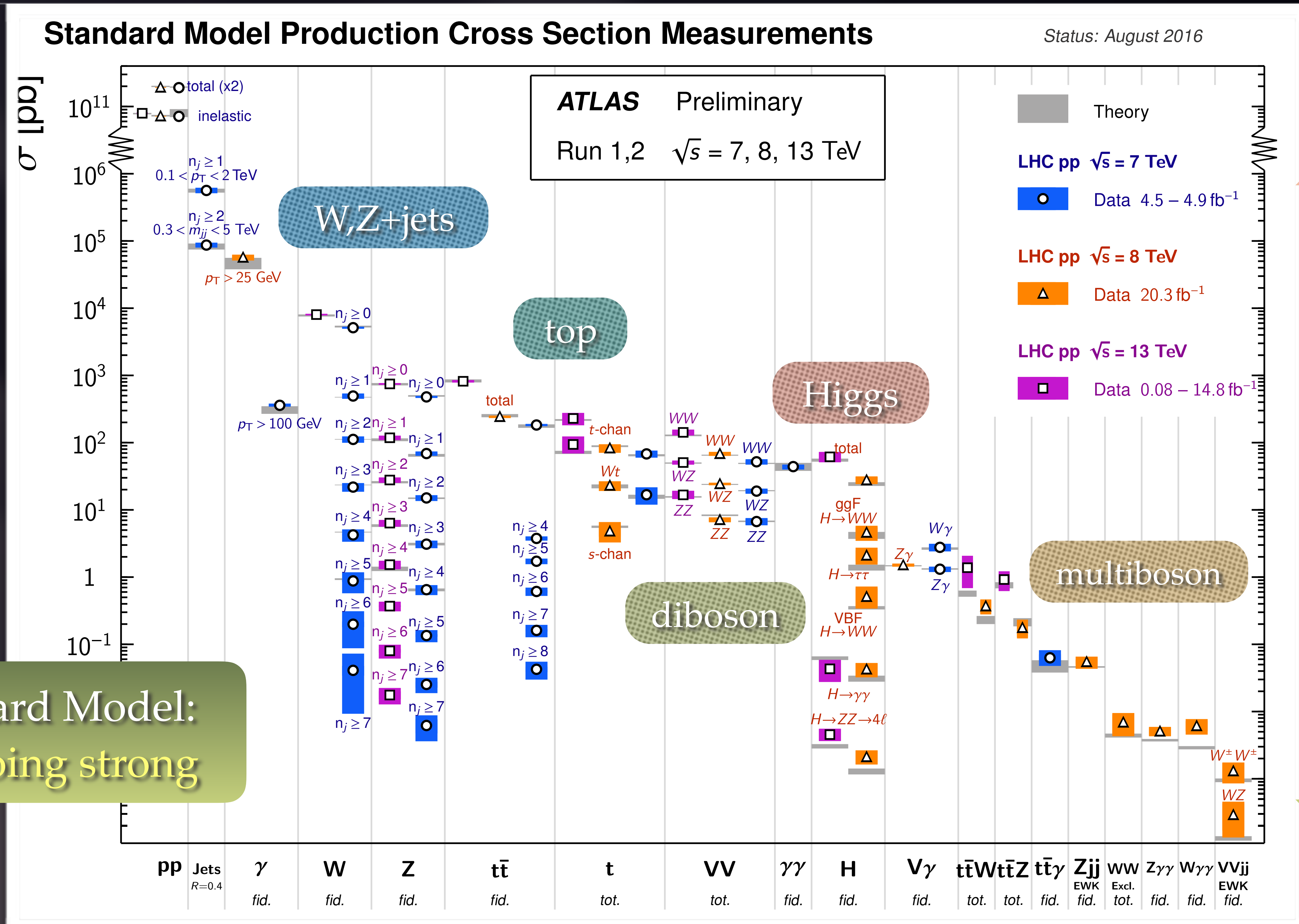
violates unitarity at sufficiently high energy, **s ~ (1.2 TeV)²**

Destructive interference



High mass VV productions are the fundamental probe to the SM and sensitive to the BSM physics!

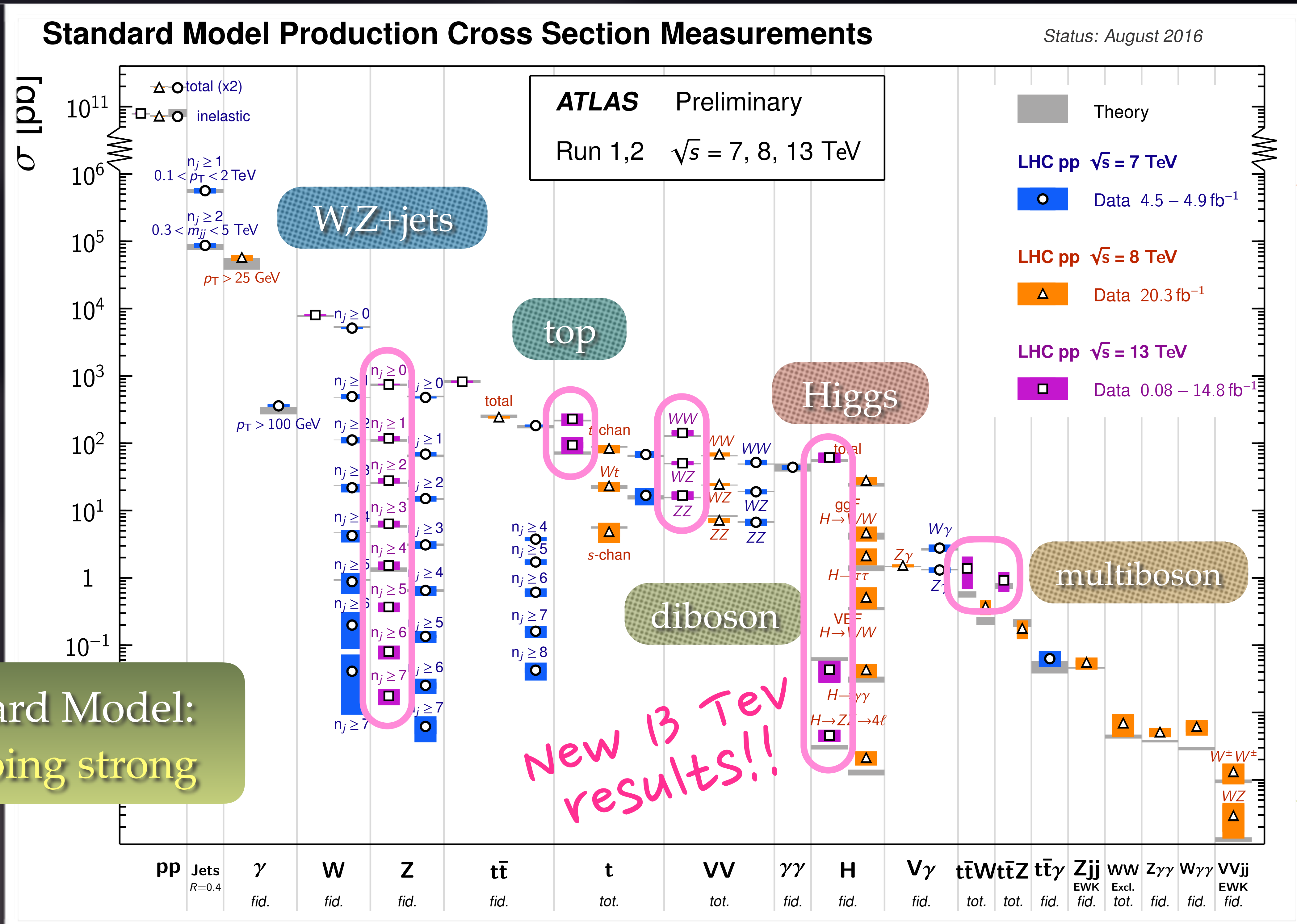
Standard Model: Precision Tests



Standard Model:
still going strong

Exquisite agreement over 6 orders of magnitudes!

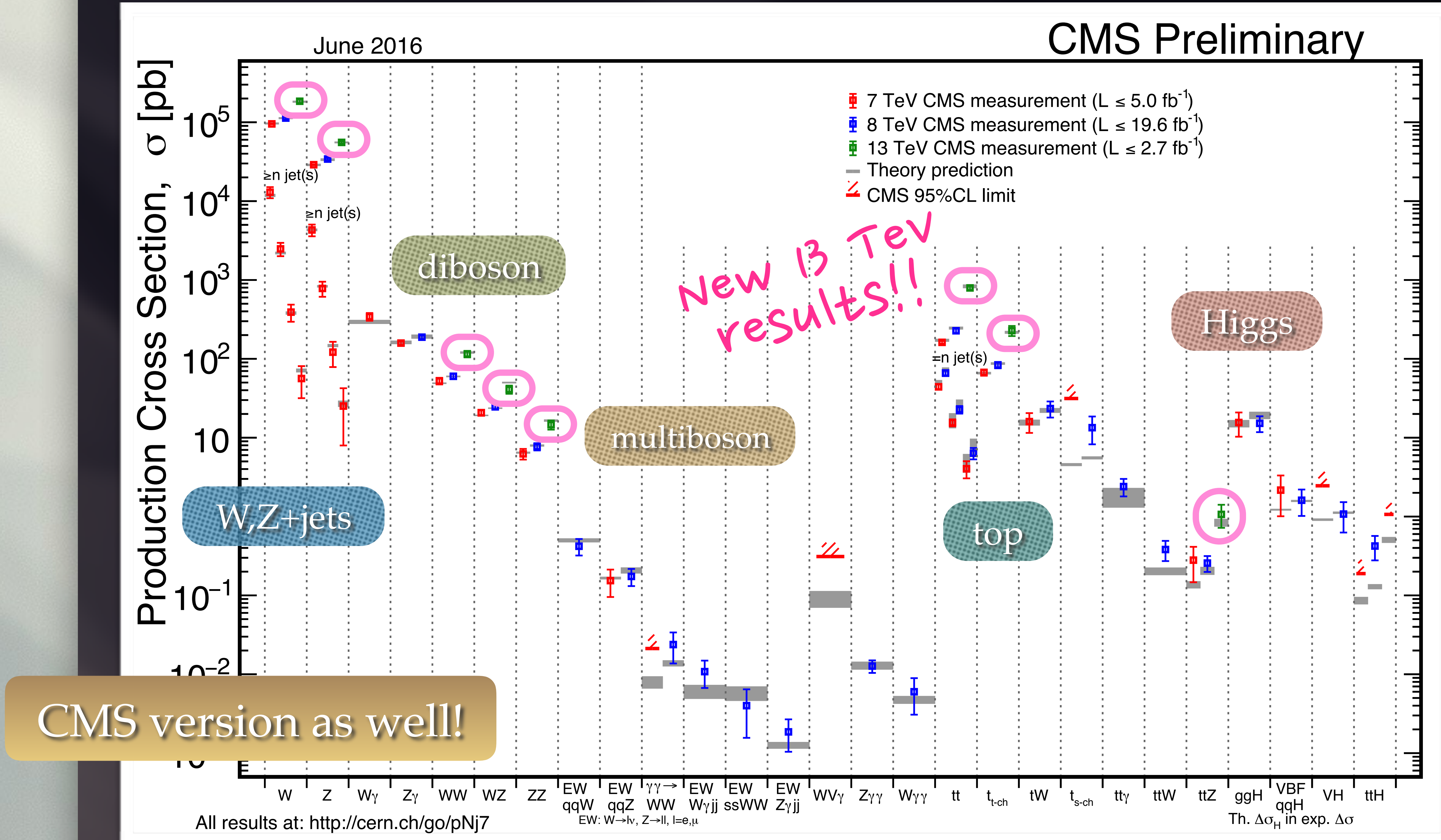
Standard Model: Precision Tests



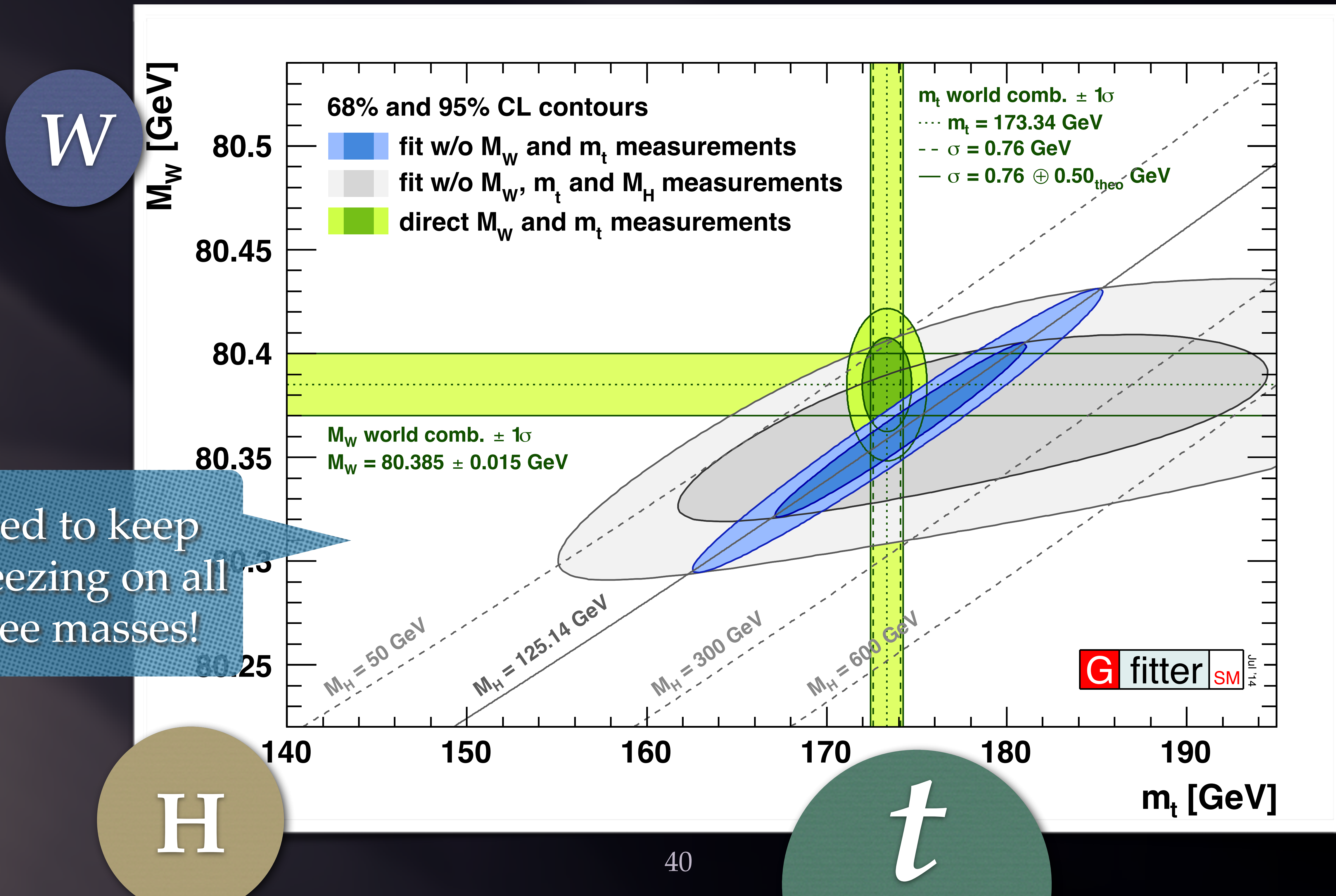
Standard Model: still going strong

Exquisite agreement over 6 orders of magnitudes!

Standard Model: Precision Tests



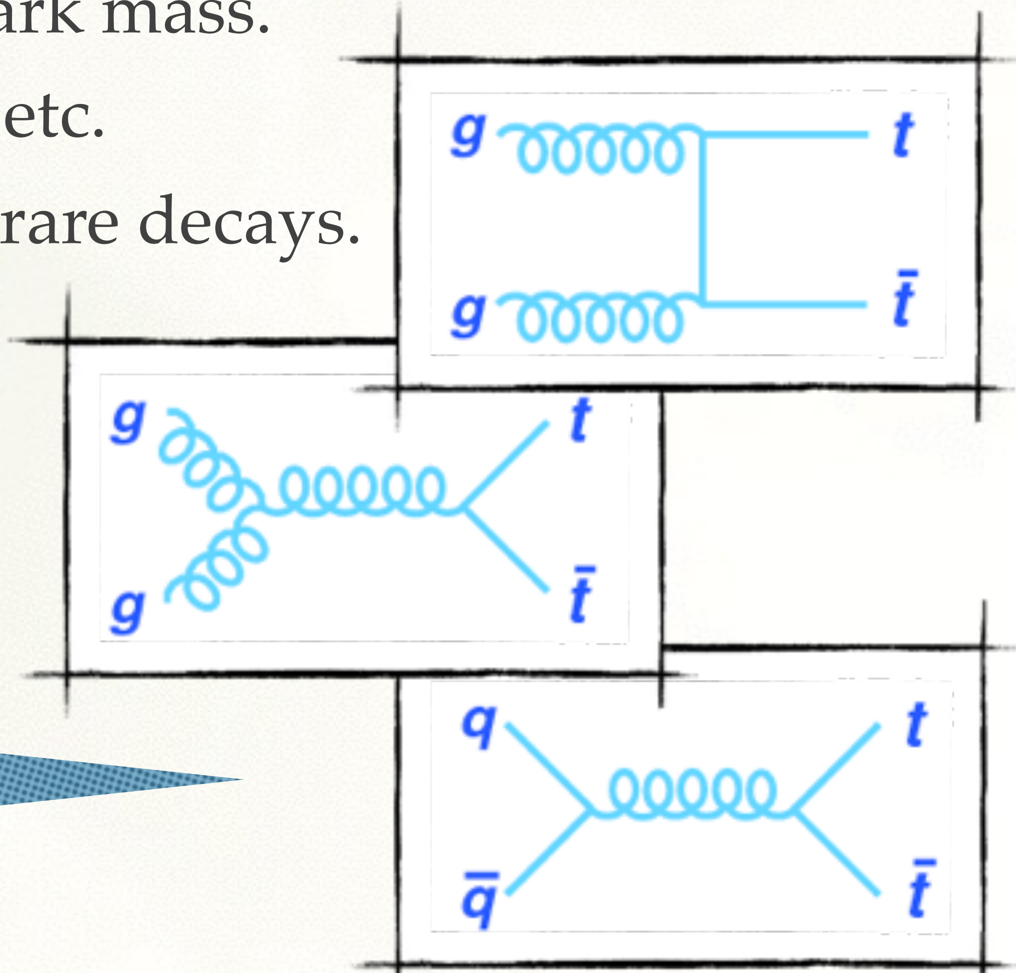
Standard Model: Mission Accomplished?



Need to keep squeezing on all three masses!

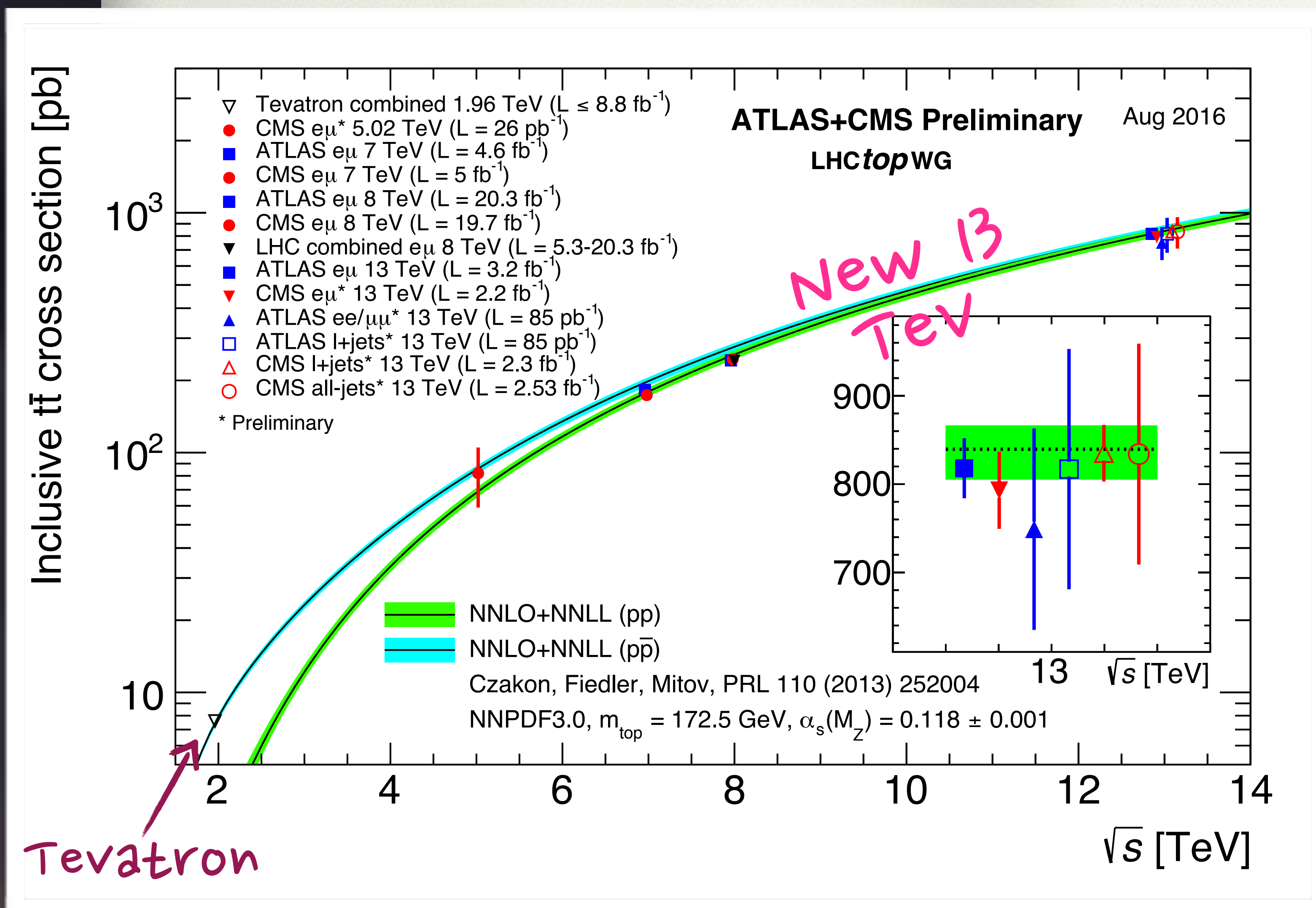
Top Physics at LHC

- **Precision measurement of top cross section.**
  - Top production rate at high center of mass energy.
- **Large top production rate at LHC — A TOP QUARK FACTORY**
  - Use top quark as a calibration source (e.g., a very clean source of b-jet).
  - High precision determination of top quark mass.
  - Test of spin/polarization, asymmetries, etc.
  - Probing electroweak couplings and top rare decays.
- **New physics heavier than the top quark**
  - Heavy new particles decay with (high-p_T) top in the final state.



>30 M top quark pairs have been produced at LHC

Top-pair Production Cross Sections

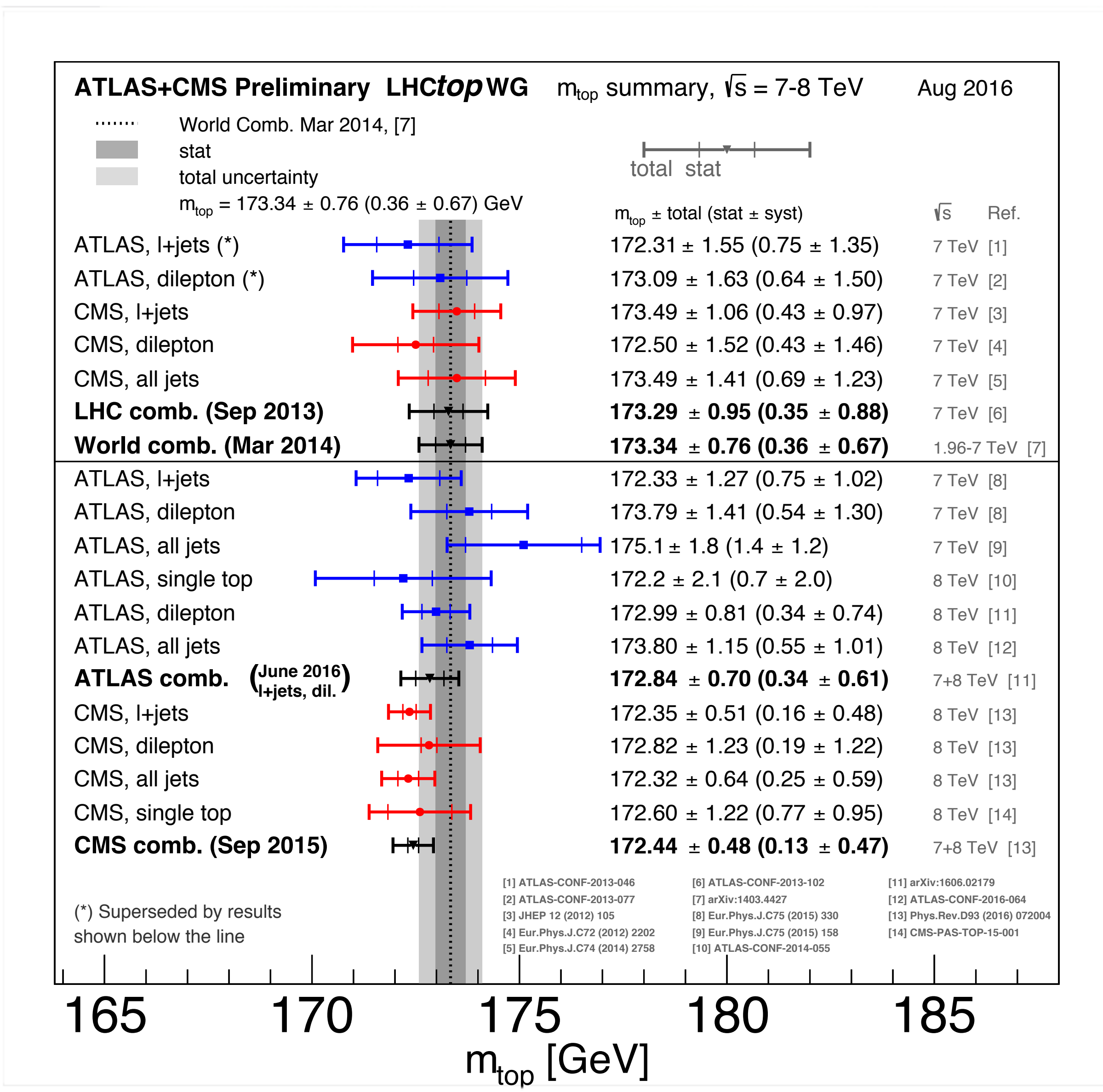


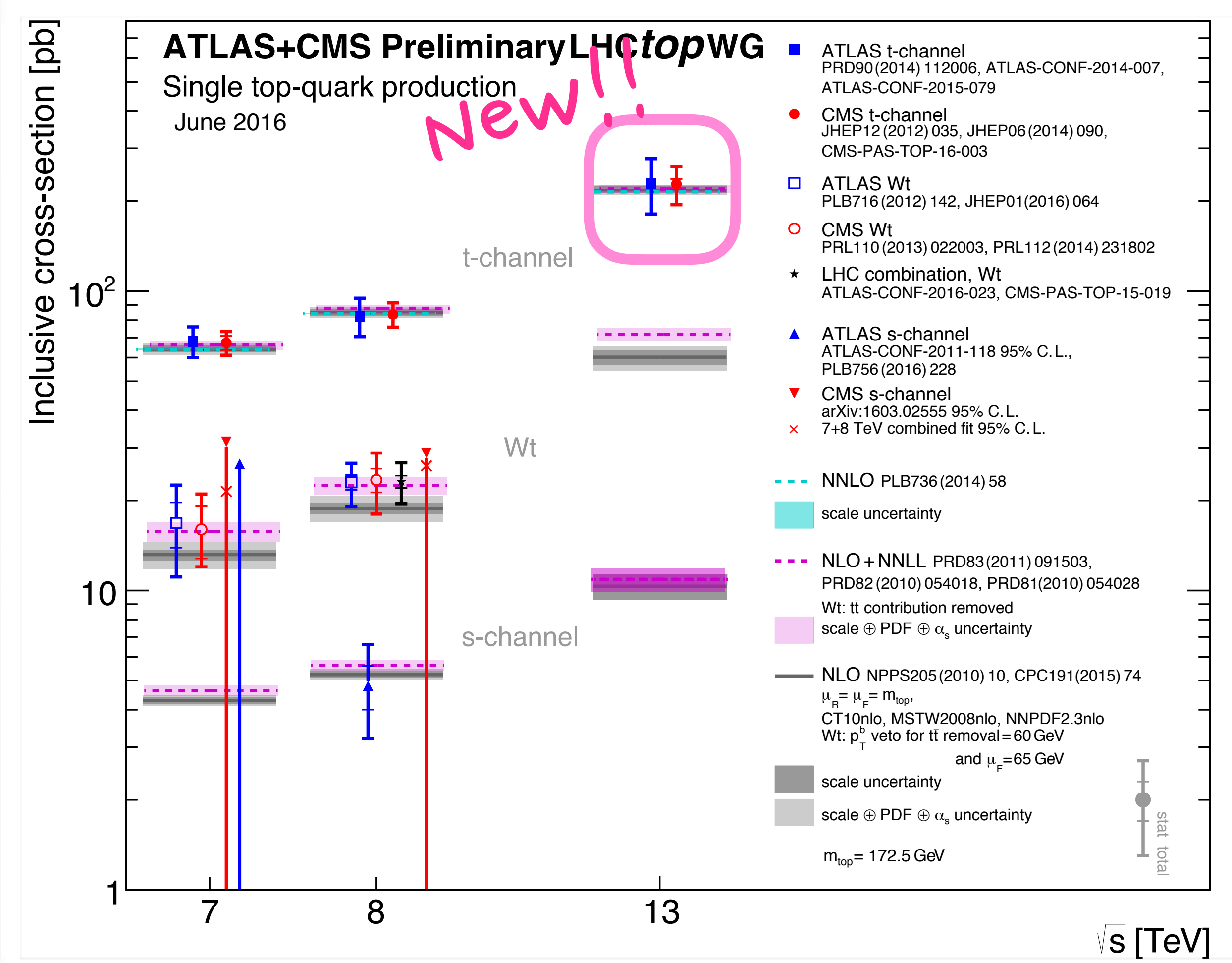
Experimental precisions already reach <4% (8 TeV), comparable to the precision of NNLO+NNLL theoretical calculations ~5%

Start to produce new precision measurements at a new energy of 13 TeV!

Excellent agreement for theoretical predictions and experimental measurements

Top Mass & Single Top Measurement





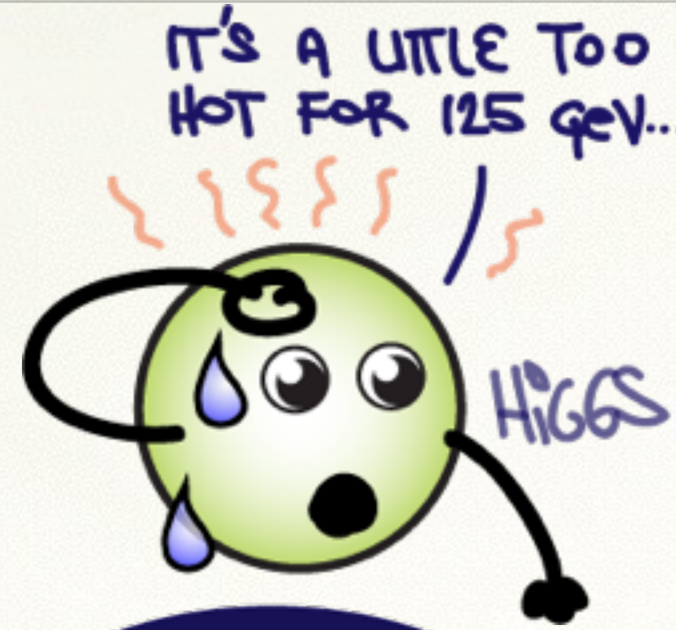
CMS M_{top} = 173.44 ± 0.13 (stat.) ± 0.47 (syst.)

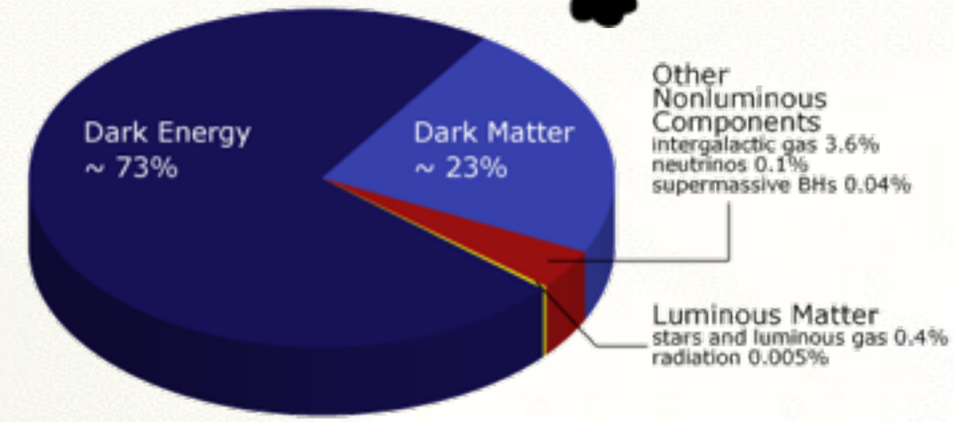
Precision ~0.33%, totally dominant by systematics.

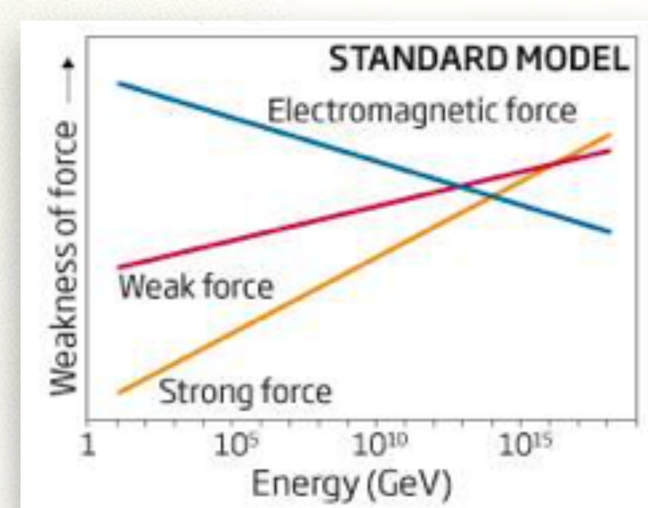
t- and tW-channel have been observed and the measured cross sections are in good agreement with TH predictions. The upper limit for s-channel have been evaluated.

No cracks (yet) in the SM…

- **No cracks, but lots of gaps! Some questions to answer:**
  - **SM just tells us how things work**, but not ***why*** — why 3 families? Mass hierarchy?
  - Lack of mechanism stabilizes the Higgs mass? Fine tuning of parameters to level of $O(10^{-30})$ is required!
  - No connection with gravity; what the hell is the Dark Matter? Dark Energy?
  - No grand unification at the high energy!



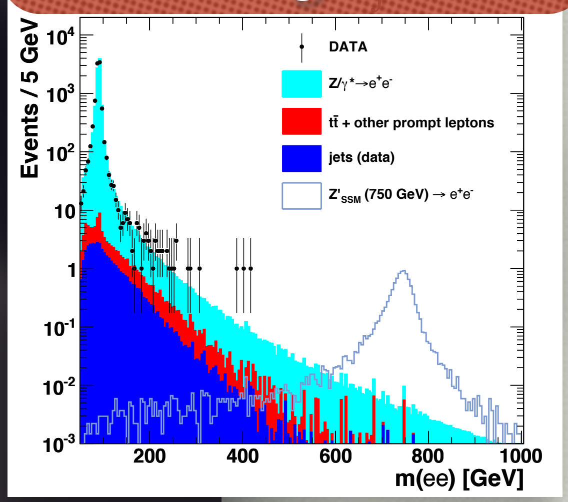




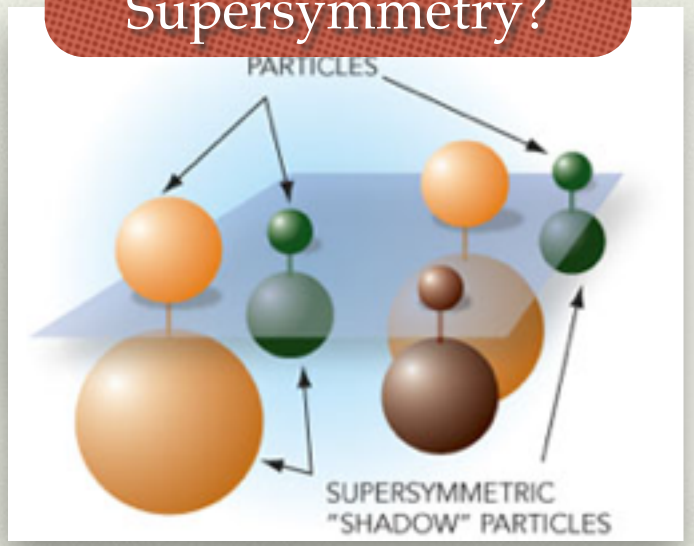
Mandatory to look for *"something beyond"*!

Where is the New Physics?

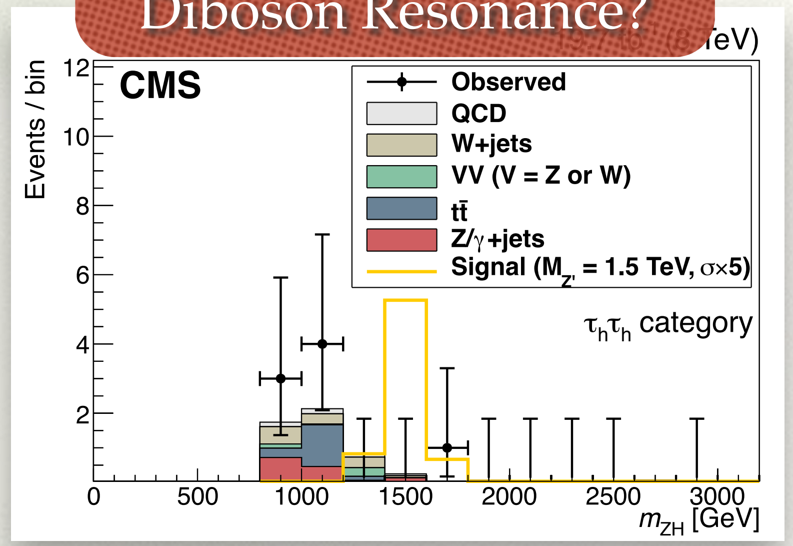
New Gauge Boson?



Supersymmetry?

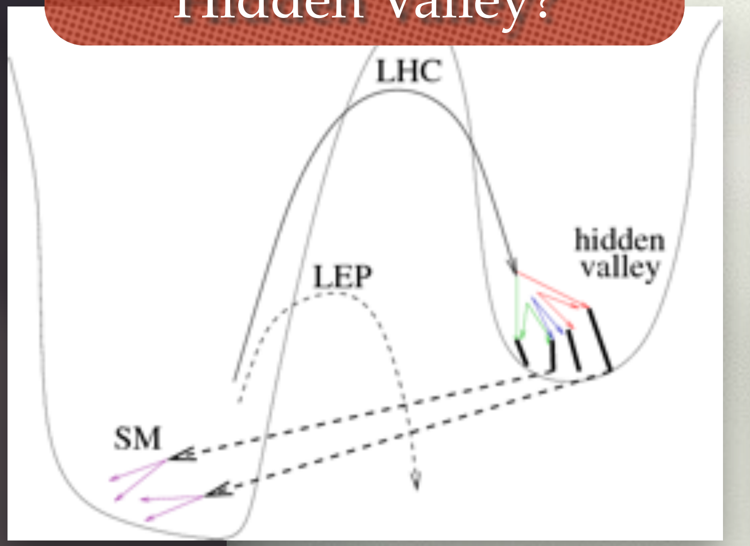


Diboson Resonance?

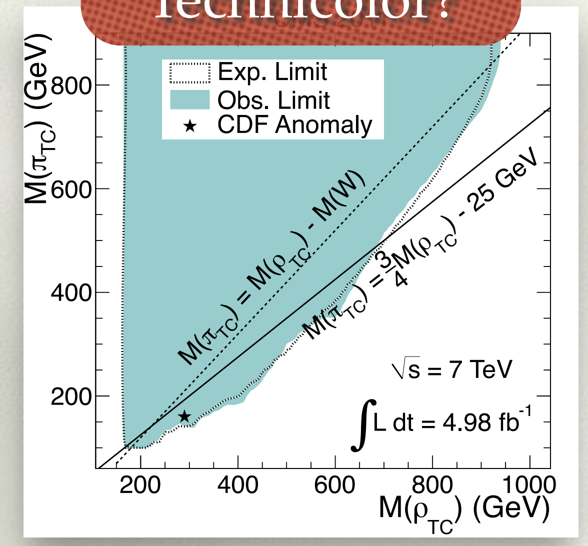


Blackholes?

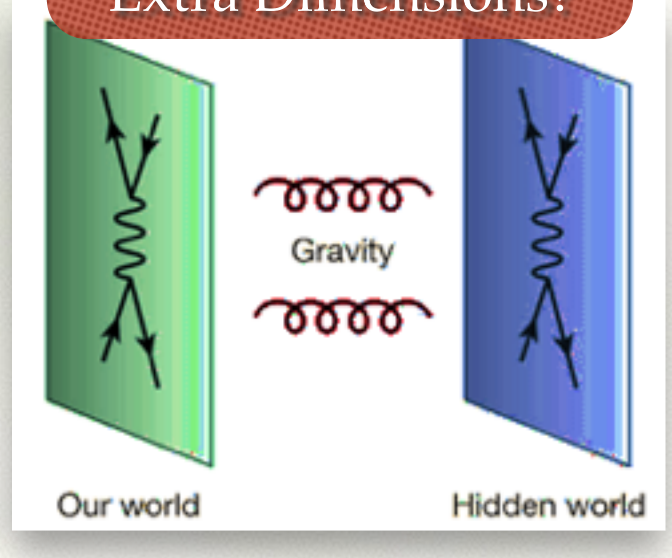
Hidden Valley?



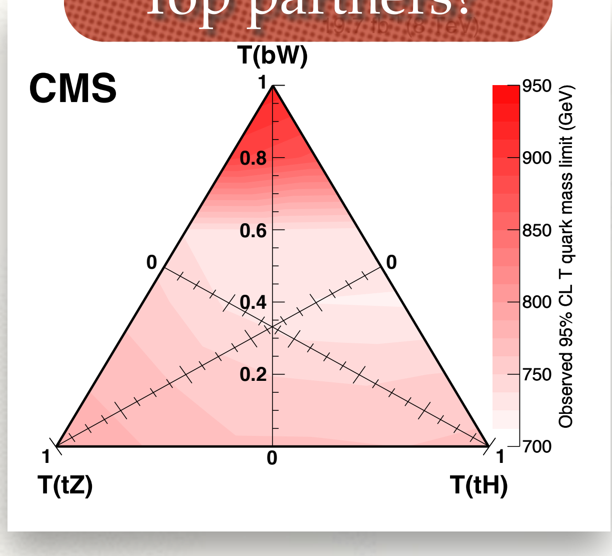
Technicolor?



Extra Dimensions?

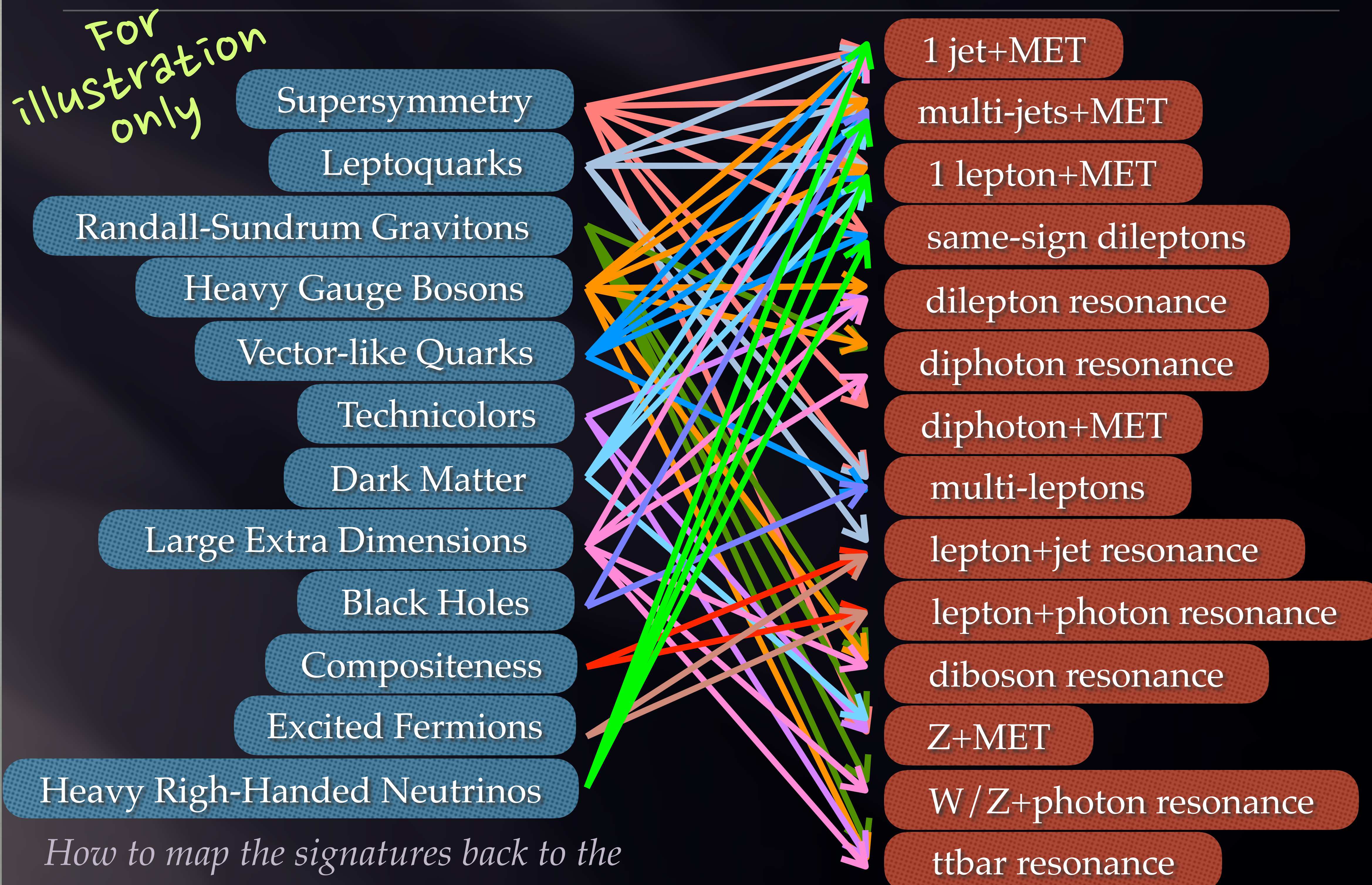


Top partners?



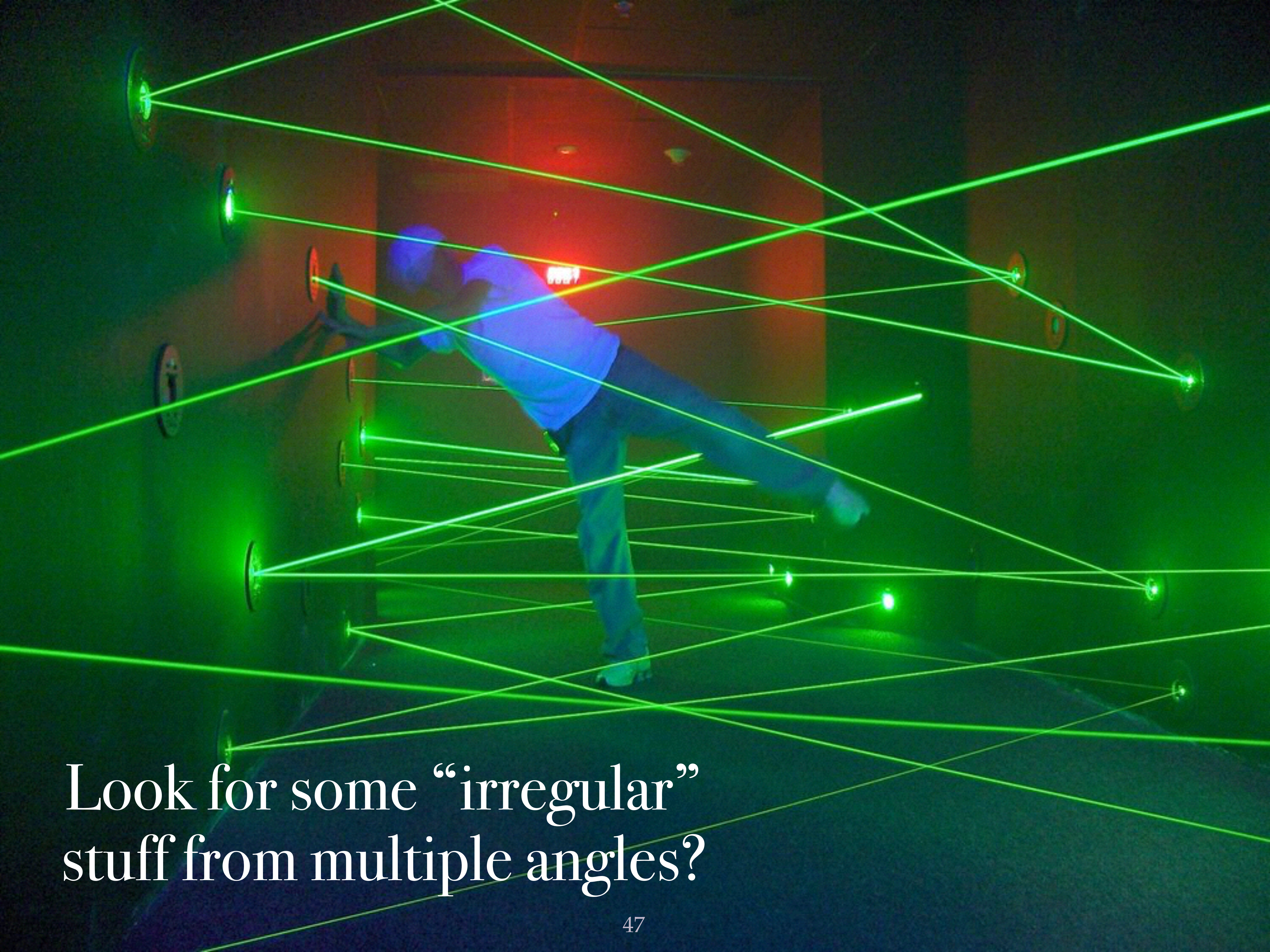
- **Many ideas with a large variety of possible signals!** ***Have to be prepared!***

Signatures of New Physics?

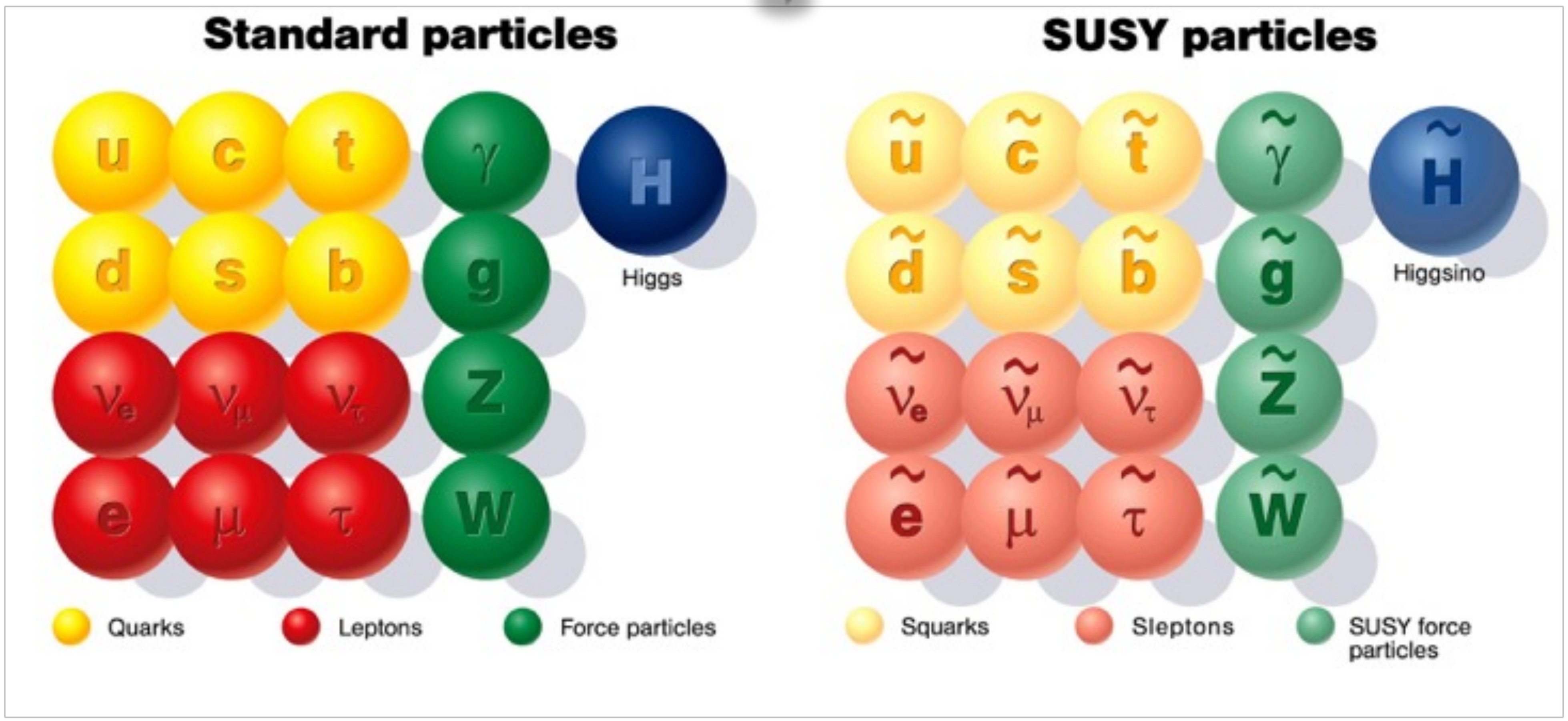


How to map the signatures back to the physics source, it is a difficult question!

……



Look for some "irregular" stuff from multiple angles?

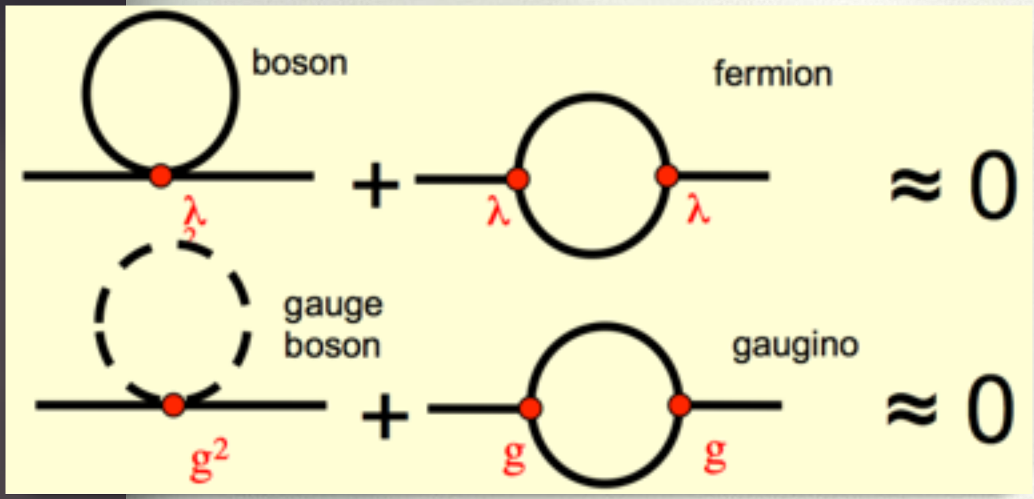


After all these years, and all this data, why are we still obsessed with SUSY?

Not just doubled the particle list!

Why are we obsessed with SUSY?

- It solves/mitigate the hierarchy problem and regularize the Higgs mass (otherwise divergent).
- It "solves" the hierarchy problem and gives us a convenient way to quantify "Natural".
- Given existing constraints, we can still have "natural SUSY" with ~10% fine tuning (*far better than 10^{30} !!*)
- It facilitates Grand Unification and it provides a WIMP Dark Matter candidate.

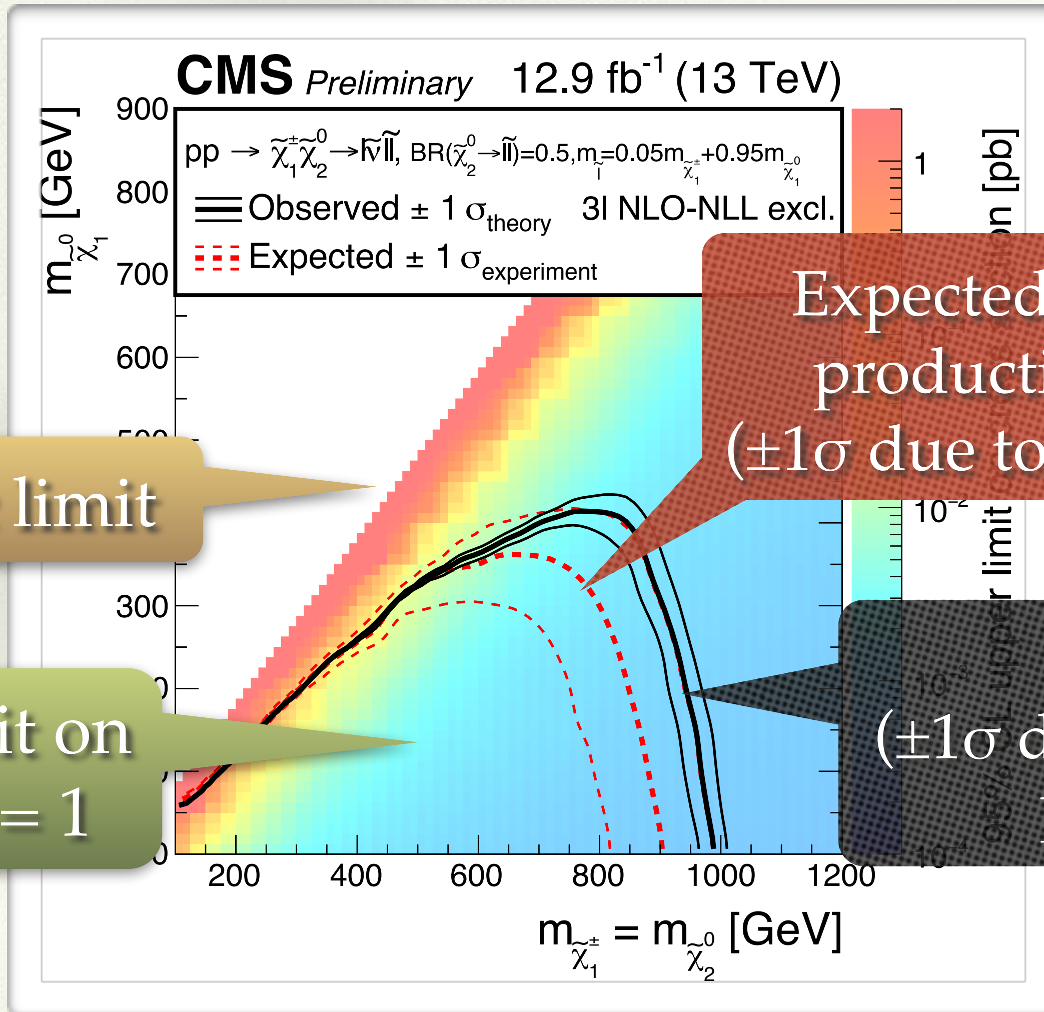


We need a "natural" cancelling term with negative contribution:

$$\delta m_{H_u}^2 = -\frac{3y_t^2}{8\pi^2}(m_{Q_3}^2 + m_{u_3}^2 + |A_t|^2) \ln\left(\frac{\Lambda}{m_{\tilde{t}}}\right)$$

A Friendly Reminder – Simplified Model Spectra

- How to read those (**colorful**?) experimental SUSY results?



Kinematic limit

Map of observed limit on cross section w/ Bf = 1

Expected limit at nominal production cross section (±1σ due to stat & syst uncert.)

Observed limit (±1σ due to variation on total production x-sec)

PRO

closely related to exp. observables;
limited number of parameters;
“easy” to reinterpret
(limit on cross-section)

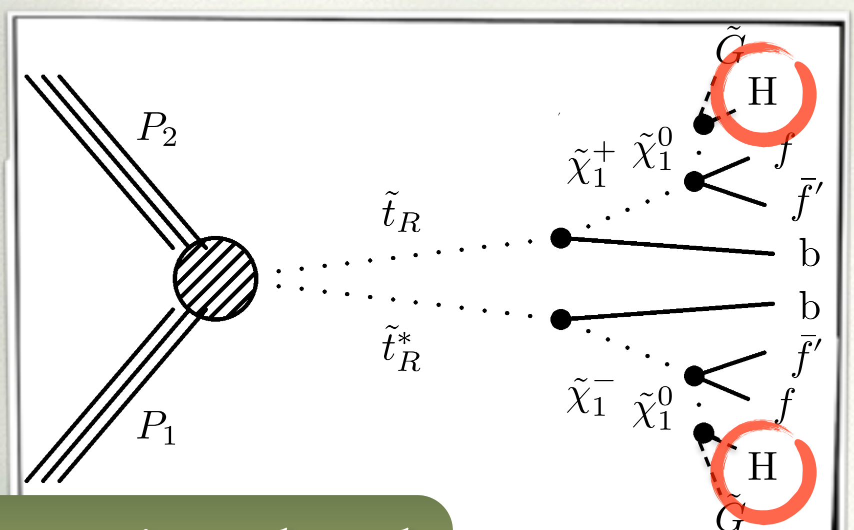
CON

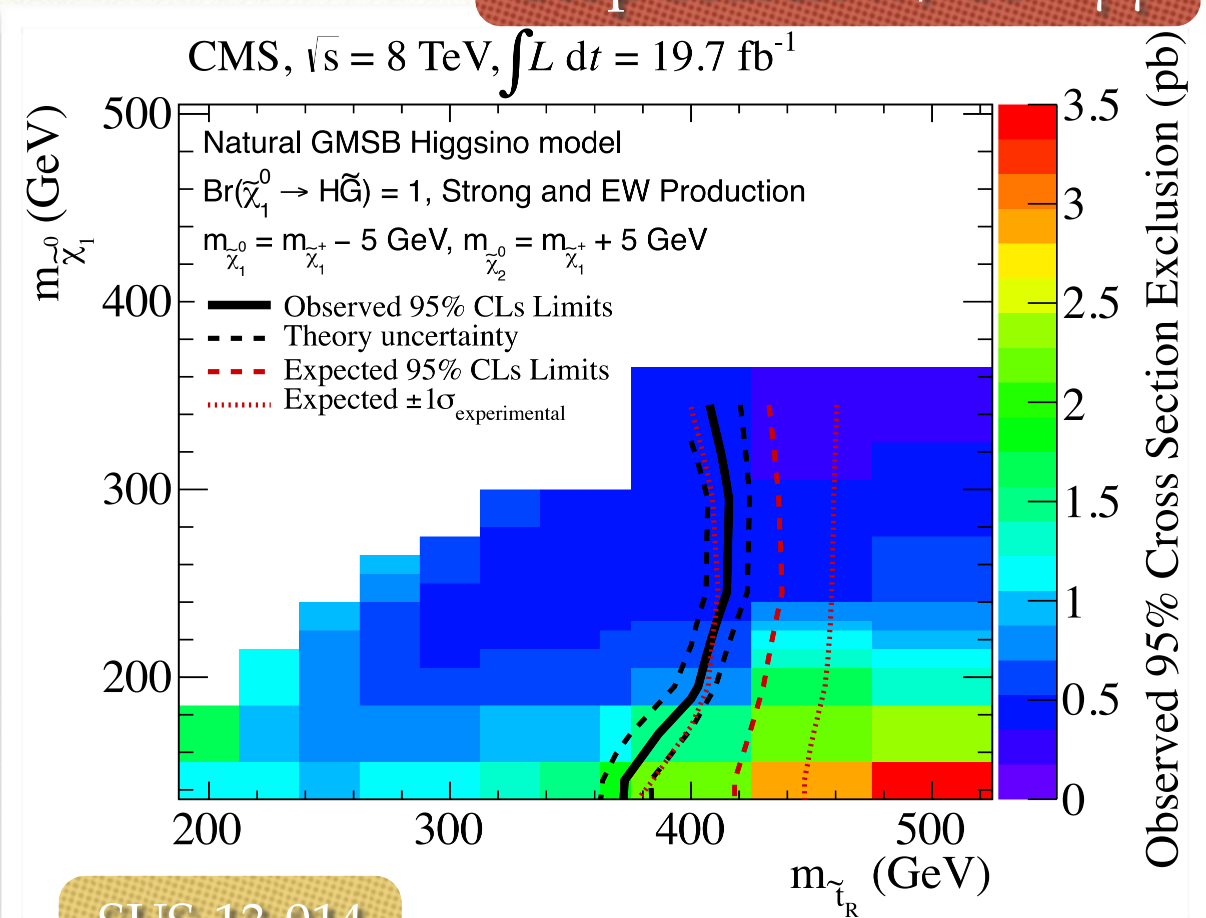
no complete model: missing higher-order corrections;
apply to other (full) models: ignores details of production, spin structure, ...

Where do we stand in SUSY

- SUSY searches were still inconclusive, and the LHC did cut out a large parameter space.
- The 125 GeV Higgs mass disfavoured many models that were on the spot only few years ago: CMSSM, mSUGRA, ….
- No observation of strongly produced sparticles has also deteriorate the faith in "Natural" SUSY.
- But the discovered Higgs give us a also brand new tool for SUSY searches, e.g.

Stop search w/ H→γγ

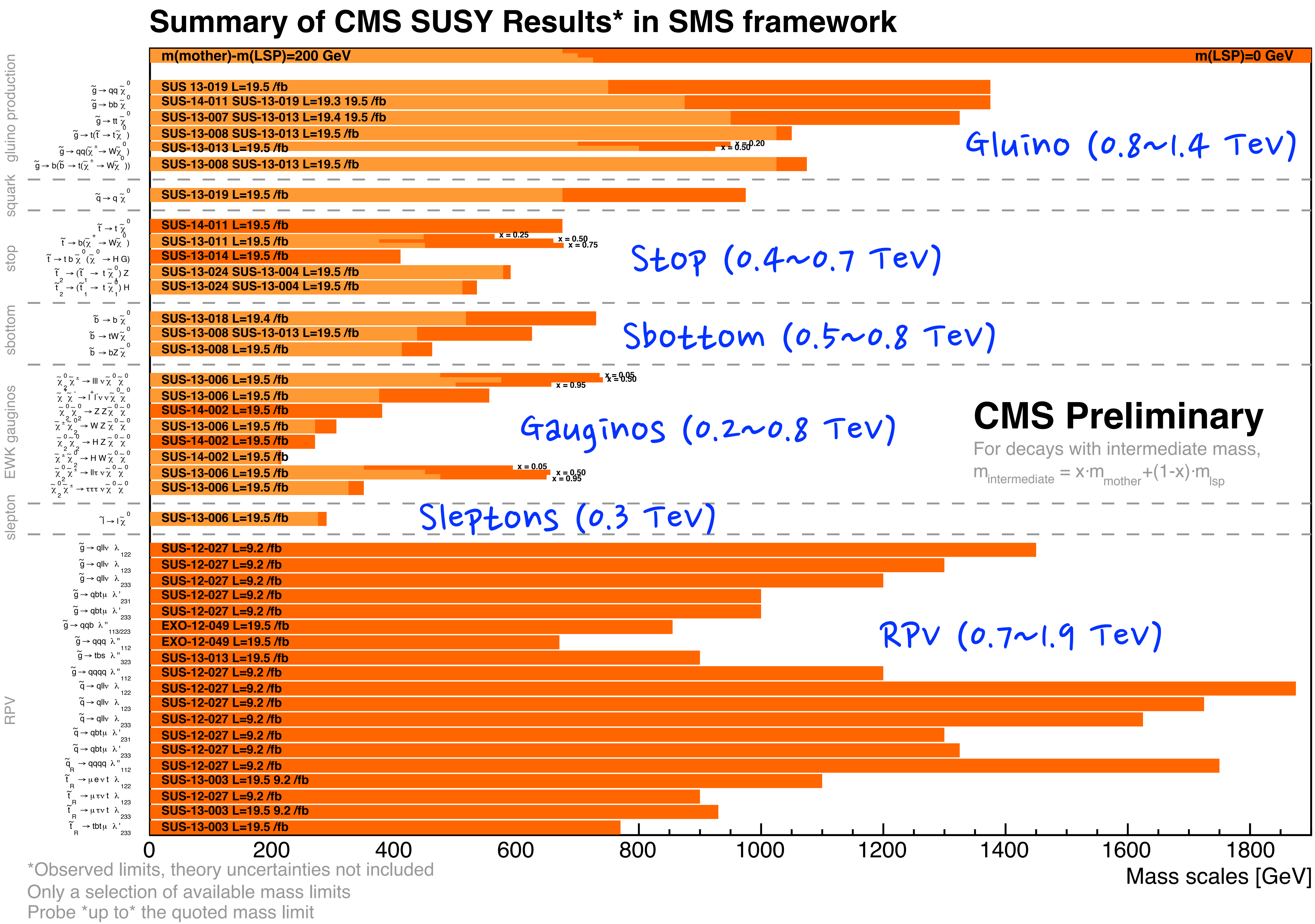




SUS-13-014

To be continued and expanded in Run-II!

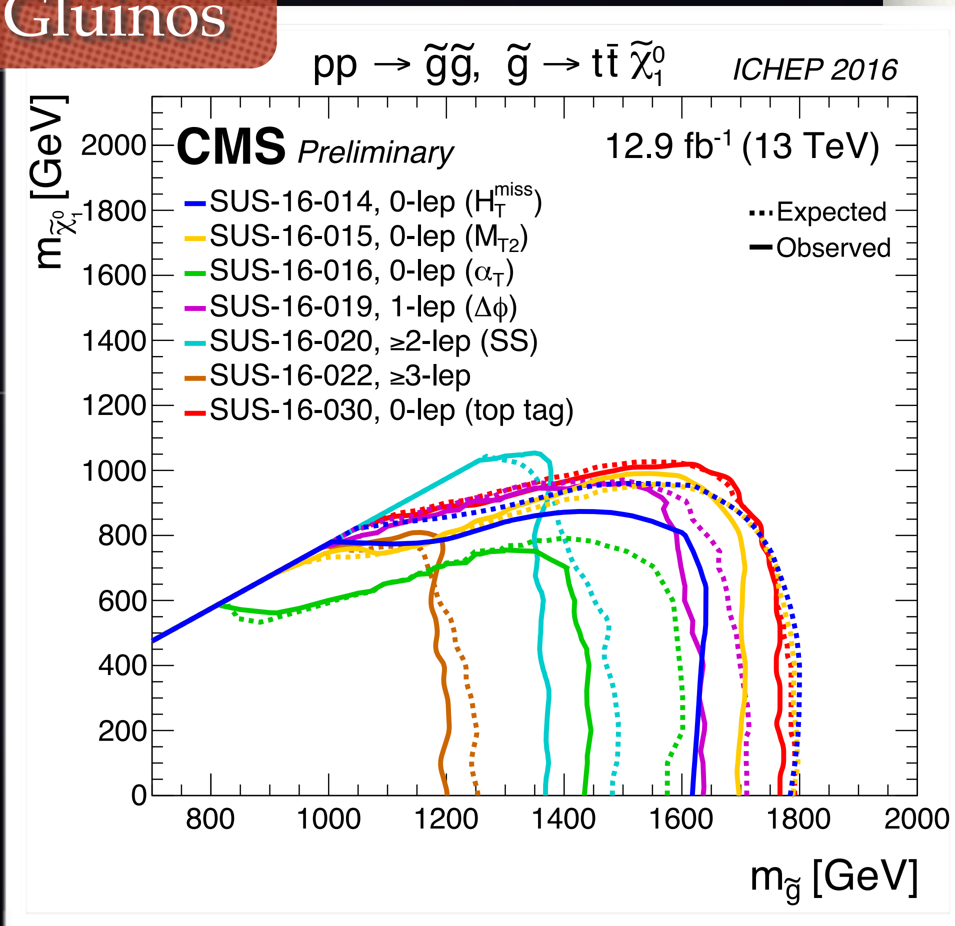
CMS SUSY Summary @ Run-I

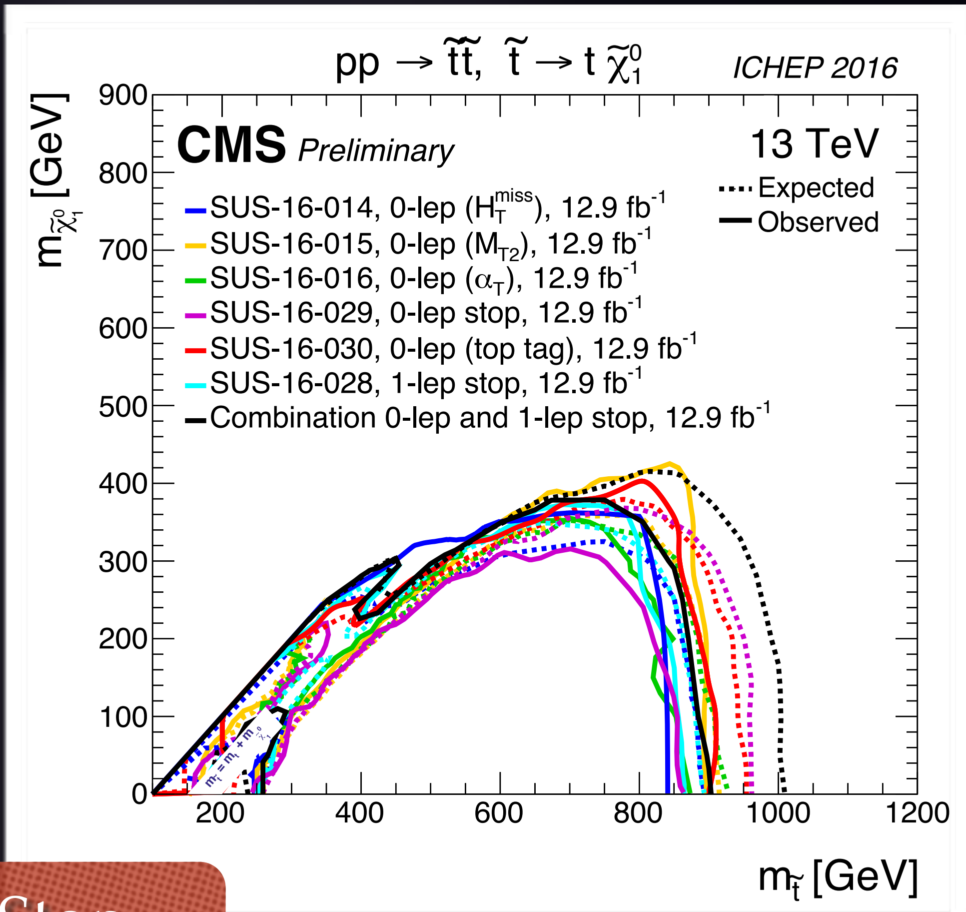


SUSY @ CMS Run-II

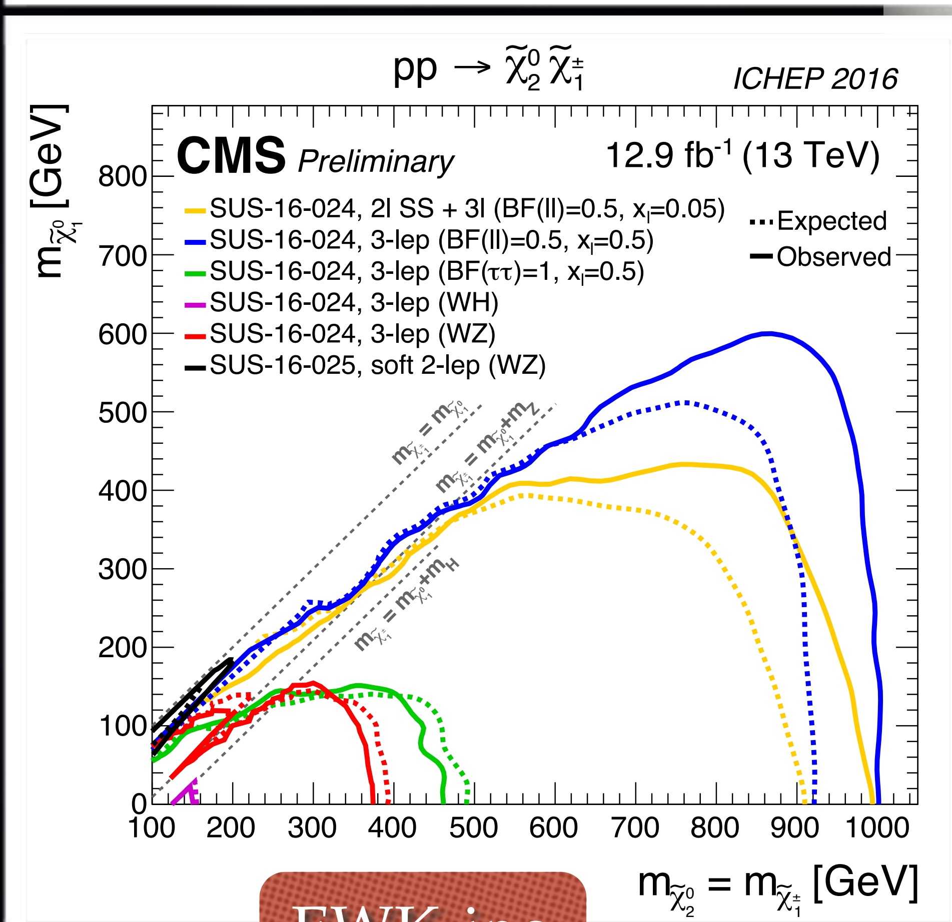
- Limits (in simplified model spectra!) pushed to about 1.8 TeV (gluinos) and 900 GeV (top squarks);
- Limits on EW production even for small mass differences

Gluinos





Stop

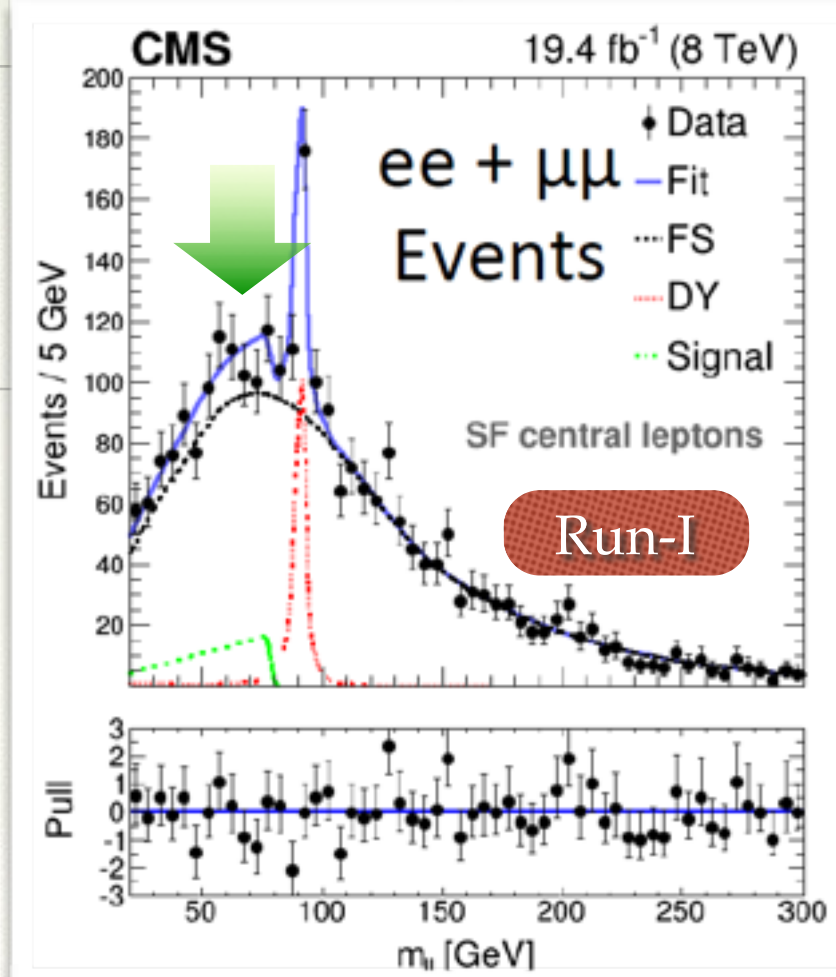


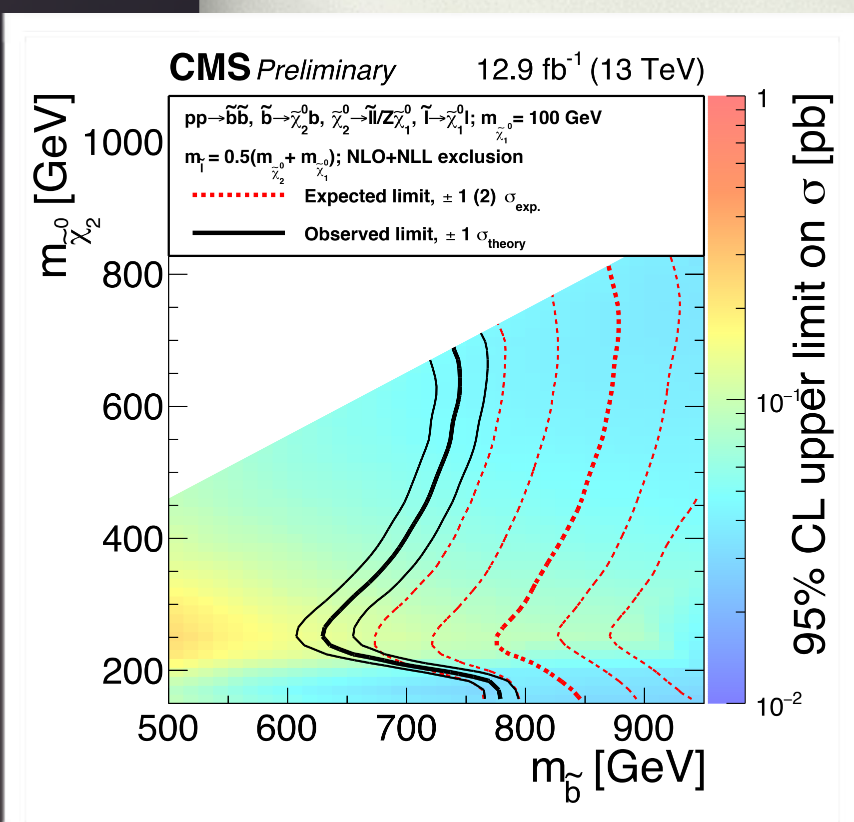
EWK-ino

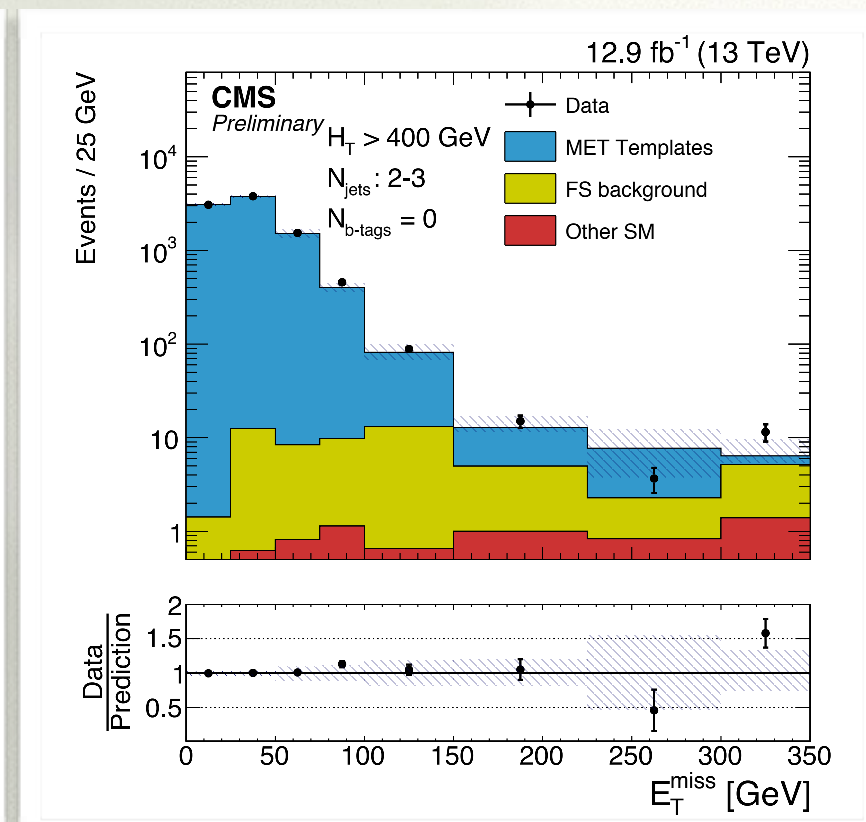
More data are coming — look forward to see the first deviation from the SM?

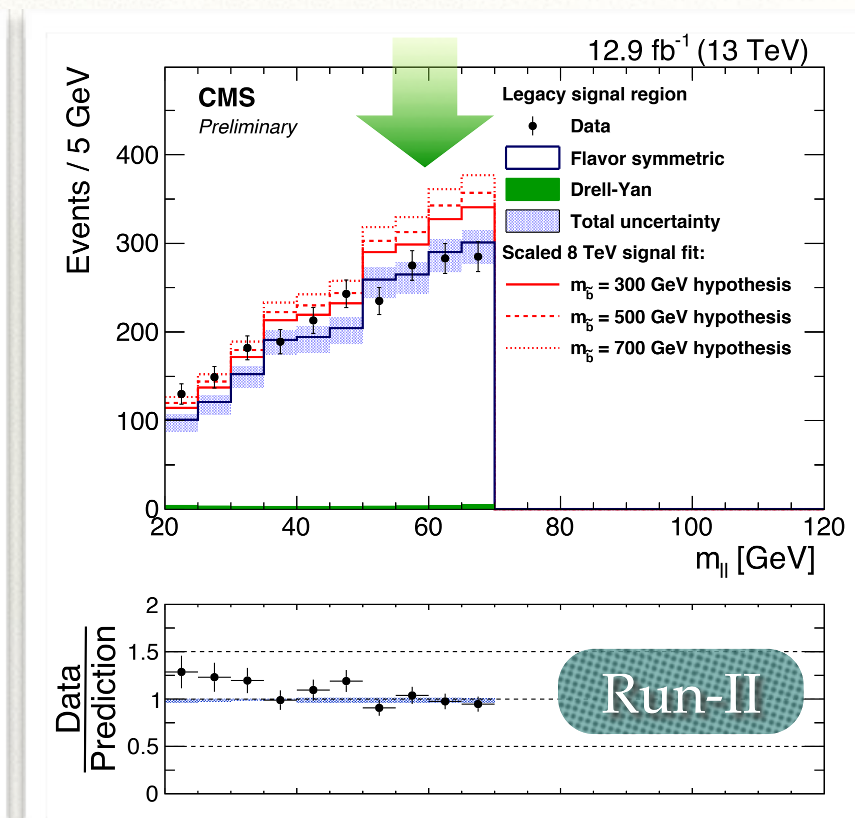
An old hint?

- CMS saw some off-peak excess ("the edge") from the Run-I SUSY analysis
- **No significant signals are observed in Run-II**; the observations in all signal regions are consistent with the expectations from the SM.









ATLAS SUSY Summary

New 13 TeV

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: August 2016

ATLAS Preliminary

$\sqrt{s}$ = 7, 8, 13 TeV

Category	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[fb^{-1}]$	Mass limit ($\sqrt{s}$ = 7, 8 TeV / $\sqrt{s}$ = 13 TeV)		Conditions	Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e, μ/1-2 τ	2-10 jets/3 b	Yes	20.3	$\tilde{q}, \tilde{g}$	1.85 TeV (7, 8 TeV)	m($\tilde{q}$)=m($\tilde{g}$)	1507.05525
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	13.3	$\tilde{q}$	1.35 TeV (13 TeV)	m($\tilde{\chi}_1^0$)<200 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	ATLAS-CONF-2016-078
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	3.2	$\tilde{q}$	608 GeV (13 TeV)	m($\tilde{q}$)-m($\tilde{\chi}_1^0$)<5 GeV	1604.07773
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	13.3	$\tilde{g}$	1.86 TeV (13 TeV)	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2016-078
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^\pm\to qqW^\pm\tilde{\chi}_1^0$	0	2-6 jets	Yes	13.3	$\tilde{g}$	1.83 TeV (13 TeV)	m($\tilde{\chi}_1^0$)<400 GeV, m($\tilde{\chi}^\pm$)=0.5(m($\tilde{\chi}_1^0$)+m($\tilde{g}$))	ATLAS-CONF-2016-078
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq(\ell\ell/\nu\nu)\tilde{\chi}_1^0$	3 e, μ	4 jets	-	13.2	$\tilde{g}$	1.7 TeV (13 TeV)	m($\tilde{\chi}_1^0$)<400 GeV	ATLAS-CONF-2016-037
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqWZ\tilde{\chi}_1^0$	2 e, μ (SS)	0-3 jets	Yes	13.2	$\tilde{g}$	1.6 TeV (13 TeV)	m($\tilde{\chi}_1^0$) <500 GeV	ATLAS-CONF-2016-037
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	3.2	$\tilde{g}$	2.0 TeV (13 TeV)		1607.05979
	GGM (bino NLSP)	2 γ	-	Yes	3.2	$\tilde{g}$	1.65 TeV (13 TeV)	$c\tau$(NLSP)<0.1 mm	1606.09150
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	$\tilde{g}$	1.37 TeV (7, 8 TeV)	m($\tilde{\chi}_1^0$)<950 GeV, $c\tau$(NLSP)<0.1 mm, μ<0	1507.05493
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	13.3	$\tilde{g}$	1.8 TeV (13 TeV)	m($\tilde{\chi}_1^0$)>680 GeV, $c\tau$(NLSP)<0.1 mm, μ>0	ATLAS-CONF-2016-066
	GGM (higgsino NLSP)	2 e, μ (Z)	2 jets	Yes	20.3	$\tilde{g}$	900 GeV (7, 8 TeV)	m(NLSP)>430 GeV	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale	865 GeV (7, 8 TeV)	m($\tilde{G}$)>1.8×10^{-4} eV, m($\tilde{g}$)=m($\tilde{q}$)=1.5 TeV	1502.01518
3rd gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	14.8	$\tilde{g}$	1.89 TeV (13 TeV)	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2016-052
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e, μ	3 b	Yes	14.8	$\tilde{g}$	1.89 TeV (13 TeV)	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2016-052
	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$	1.37 TeV (7, 8 TeV)	m($\tilde{\chi}_1^0$)<300 GeV	1407.0600
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	3.2	$\tilde{b}_1$	840 GeV (13 TeV)	m($\tilde{\chi}_1^0$)<100 GeV	1606.08772
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e, μ (SS)	1 b	Yes	13.2	$\tilde{b}_1$	325-685 GeV (13 TeV)	m($\tilde{\chi}_1^0$)<150 GeV, m($\tilde{\chi}_1^\pm$)= m($\tilde{\chi}_1^0$)+100 GeV	ATLAS-CONF-2016-037
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	0-2 e, μ	1-2 b	Yes	4.7/13.3	$\tilde{t}_1$	117-170 GeV (7, 8 TeV); 200-720 GeV (13 TeV)	m($\tilde{\chi}_1^\pm$) = 2m($\tilde{\chi}_1^0$), m($\tilde{\chi}_1^0$)=55 GeV	1209.2102, ATLAS-CONF-2016-077
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e, μ	0-2 jets/1-2 b	Yes	4.7/13.3	$\tilde{t}_1$	90-198 GeV (7, 8 TeV); 205-850 GeV (13 TeV)	m($\tilde{\chi}_1^0$)=1 GeV	1506.08616, ATLAS-CONF-2016-077
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet	Yes	3.2	$\tilde{t}_1$	90-323 GeV (13 TeV)	m($\tilde{t}_1$)-m($\tilde{\chi}_1^0$)=5 GeV	1604.07773
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e, μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$	150-600 GeV (7, 8 TeV)	m($\tilde{\chi}_1^0$)>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1 + Z$	3 e, μ (Z)	1 b	Yes	13.3	$\tilde{t}_2$	290-700 GeV (13 TeV)	m($\tilde{\chi}_1^0$)<300 GeV	ATLAS-CONF-2016-038
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1 + h$	1 e, μ	6 jets + 2 b	Yes	20.3	$\tilde{t}_2$	320-620 GeV (7, 8 TeV)	m($\tilde{\chi}_1^0$)=0 GeV	1506.08616
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e, μ	0	Yes	20.3	$\tilde{\ell}$	90-335 GeV (7, 8 TeV)	m($\tilde{\chi}_1^0$)=0 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e, μ	0	Yes	20.3	$\tilde{\chi}_1^\pm$	140-475 GeV (7, 8 TeV)	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}_1^\pm$	355 GeV (7, 8 TeV)	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{\tau}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	1407.0350
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e, μ	0	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	715 GeV (7, 8 TeV)	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 e, μ	0-2 jets	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	425 GeV (7, 8 TeV)	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, $\tilde{\ell}$ decoupled	1403.5294, 1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$, $h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e, μ, γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	270 GeV (7, 8 TeV)	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, $\tilde{\ell}$ decoupled	1501.07110
	$\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	4 e, μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$	635 GeV (7, 8 TeV)	m($\tilde{\chi}_2^0$)=m($\tilde{\chi}_3^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell}, \tilde{\nu}$)=0.5(m($\tilde{\chi}_2^0$)+m($\tilde{\chi}_1^0$))	1405.5086
	GGM (wino NLSP) weak prod.	1 $e, \mu + \gamma$	-	Yes	20.3	$\tilde{W}$	115-370 GeV (7, 8 TeV)	$c\tau$<1 mm	1507.05493
	GGM (bino NLSP) weak prod.	2 γ	-	Yes	20.3	$\tilde{W}$	590 GeV (7, 8 TeV)	$c\tau$<1 mm	1507.05493
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^\pm$	270 GeV (7, 8 TeV)	m($\tilde{\chi}_1^\pm$)-m($\tilde{\chi}_1^0$)~160 MeV, $\tau(\tilde{\chi}_1^\pm)$=0.2 ns	1310.3675
	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}_1^\pm$	495 GeV (7, 8 TeV)	m($\tilde{\chi}_1^\pm$)-m($\tilde{\chi}_1^0$)~160 MeV, $\tau(\tilde{\chi}_1^\pm)$<15 ns	1506.05332
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$	850 GeV (7, 8 TeV)	m($\tilde{\chi}_1^0$)=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	3.2	$\tilde{g}$	1.58 TeV (13 TeV)		1606.05129
	Metastable $\tilde{g}$ R-hadron	dE/dx trk	-	-	3.2	$\tilde{g}$	1.57 TeV (13 TeV)	m($\tilde{\chi}_1^0$)=100 GeV, τ>10 ns	1604.04520
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e}, \tilde{\mu})+\tau(e, \mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$	537 GeV (7, 8 TeV)	10<tanβ<50	1411.6795
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$	440 GeV (7, 8 TeV)	1<$\tau(\tilde{\chi}_1^0)$<3 ns, SPS8 model	1409.5542
	$\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}_1^0$	1.0 TeV (7, 8 TeV)	7 <$c\tau(\tilde{\chi}_1^0)$< 740 mm, m($\tilde{g}$)=1.3 TeV	1504.05162
	GGM $\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to Z\tilde{G}$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}_1^0$	1.0 TeV (7, 8 TeV)	6 <$c\tau(\tilde{\chi}_1^0)$< 480 mm, m($\tilde{g}$)=1.1 TeV	1504.05162
RPV	LFV $pp\to\tilde{\nu}_\tau + X$, $\tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu$,$e\tau$,$\mu\tau$	-	-	3.2	$\tilde{\nu}_\tau$	1.9 TeV (13 TeV)	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1607.08079
	Bilinear RPV CMSSM	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{q}, \tilde{g}$	1.45 TeV (7, 8 TeV)	m($\tilde{q}$)=m($\tilde{g}$), $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to ee\nu, e\mu\nu, \mu\mu\nu$	4 e, μ	-	Yes	13.3	$\tilde{\chi}_1^\pm$	1.14 TeV (13 TeV)	m($\tilde{\chi}_1^0$)>400GeV, $\lambda_{12k}\neq 0$ ($k = 1, 2$)	ATLAS-CONF-2016-075
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to\tau\tau\nu_e, e\tau\nu_\tau$	3 $e, \mu + \tau$	-	Yes	20.3	$\tilde{\chi}_1^\pm$	450 GeV (7, 8 TeV)	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^\pm$), $\lambda_{133}\neq 0$	1405.5086
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqq$	0	4-5 large-R jets	-	14.8	$\tilde{g}$	1.08 TeV (13 TeV)	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	0	4-5 large-R jets	-	14.8	$\tilde{g}$	1.55 TeV (13 TeV)	m($\tilde{\chi}_1^0$)=800 GeV	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}$, $\tilde{g}\to\tilde{t}_1 t$, $\tilde{t}_1\to bs$	2 e, μ (SS)	0-3 b	Yes	13.2	$\tilde{g}$	1.3 TeV (13 TeV)	m($\tilde{t}_1$)<750 GeV	ATLAS-CONF-2016-037
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$	0	2 jets + 2 b	-	15.4	$\tilde{t}_1$	410 GeV (13 TeV); 450-510 GeV (13 TeV)		ATLAS-CONF-2016-022, ATLAS-CONF-2016-084
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\ell$	2 e, μ	2 b	-	20.3	$\tilde{t}_1$	0.4-1.0 TeV (7, 8 TeV)	BR($\tilde{t}_1\to be/\mu$)>20%	ATLAS-CONF-2015-015
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$	510 GeV (7, 8 TeV)	m($\tilde{\chi}_1^0$)<200 GeV	1501.01325

10^{-1} — 1 — Mass scale [TeV]

*Only a selection of the available mass limits on new states or phenomena is shown.

Go beyond the SM and SUSY

- While a “natural” solution to the hierarchy problem looks elegant and appealing (with the benefit of adding a potential dark matter candidate), Nature has shown us that exotic solutions might end-up being even more “natural”.
- In fact, there is no compelling argument, apart elegance, to force SUSY solve all of our problems in a single shot.
- Other **“EXOTIC”** models (extra dimensions, new gauge bosons, hidden sectors, unparticles, etc..) might completely change the picture.

You may not be a big fan of exotic models, but you should not miss the exotic fruits in Taiwan!

ATLAS EXO Summary

ATLAS Exotics Searches* - 95% CL Exclusion

Status: August 2016

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 - 20.3)\ \text{fb}^{-1}$ $\sqrt{s} = 8, 13$ TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L} dt[\text{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	–	≥ 1 j	Yes	3.2	M_D 6.58 TeV	$n = 2$	1604.07773
	ADD non-resonant $\ell\ell$	2 e, μ	–	–	20.3	M_S 4.7 TeV	$n = 3$ HLZ	1407.2410
	ADD QBH $\to \ell q$	1 e, μ	1 j	–	20.3	M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD QBH	–	2 j	–	15.7	M_{th} 8.7 TeV	$n = 6$	ATLAS-CONF-2016-069
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \ell\ell$	2 e, μ	–	–	20.3	G_{KK} mass 2.68 TeV	$k/\overline{M}_{Pl} = 0.1$	1405.4123
	RS1 $G_{KK} \to \gamma\gamma$	2 γ	–	–	3.2	G_{KK} mass 3.2 TeV	$k/\overline{M}_{Pl} = 0.1$	1606.03833
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	1 e, μ	1 J	Yes	13.2	G_{KK} mass 1.24 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2016-062
	Bulk RS $G_{KK} \to HH \to bbbb$	–	4 b	–	13.3	G_{KK} mass 360-860 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2016-049
	Bulk RS $g_{KK} \to tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	20.3	g_{KK} mass 2.2 TeV	BR = 0.925	1505.07018
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 4 j	Yes	3.2	KK mass 1.46 TeV	Tier (1,1), BR($A^{(1,1)} \to tt$) = 1	ATLAS-CONF-2016-013
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	–	–	13.3	Z' mass 4.05 TeV		ATLAS-CONF-2016-045
	SSM $Z' \to \tau\tau$	2 τ	–	–	19.5	Z' mass 2.02 TeV		1502.07177
	Leptophobic $Z' \to bb$	–	2 b	–	3.2	Z' mass 1.5 TeV		1603.08791
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	13.3	W' mass 4.74 TeV		ATLAS-CONF-2016-061
	HVT $W' \to WZ \to qq\nu\nu$ model A	0 e, μ	1 J	Yes	13.2	W' mass 2.4 TeV	$g_V = 1$	ATLAS-CONF-2016-082
	HVT $W' \to WZ \to qqqq$ model B	–	2 J	–	15.5	W' mass 3.0 TeV	$g_V = 3$	ATLAS-CONF-2016-055
	HVT $V' \to WH/ZH$ model B	multi-channel			3.2	V' mass 2.31 TeV	$g_V = 3$	1607.05621
	LRSM $W'_R \to tb$	1 e, μ	2 b, 0-1 j	Yes	20.3	W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \to tb$	0 e, μ	≥ 1 b, 1 J	–	20.3	W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	15.7	Λ 19.9 TeV	$\eta_{LL} = -1$	ATLAS-CONF-2016-069
	CI $\ell\ell qq$	2 e, μ	–	–	3.2	Λ 25.2 TeV	$\eta_{LL} = -1$	1607.03669
	CI $uutt$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	20.3	Λ 4.9 TeV	$\lvert C_{RR} \rvert = 1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	0 e, μ	≥ 1 j	Yes	3.2	m_A 1.0 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 250$ GeV	1604.07773
	Axial-vector mediator (Dirac DM)	0 e, μ, 1 γ	1 j	Yes	3.2	m_A 710 GeV	g_q=0.25, g_χ=1.0, $m(\chi) < 150$ GeV	1604.01306
	$ZZ_{\chi\chi}$ EFT (Dirac DM)	0 e, μ	1 J, ≤ 1 j	Yes	3.2	M_* 550 GeV	$m(\chi) < 150$ GeV	ATLAS-CONF-2015-080
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	3.2	LQ mass 1.1 TeV	$\beta = 1$	1605.06035
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	3.2	LQ mass 1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3rd gen	1 e, μ	≥1 b, ≥3 j	Yes	20.3	LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \to Ht + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	T mass 855 GeV	T in (T,B) doublet	1505.04306
	VLQ $YY \to Wb + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	20.3	Y mass 770 GeV	Y in (B,Y) doublet	1505.04306
	VLQ $BB \to Hb + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	B mass 735 GeV	isospin singlet	1505.04306
	VLQ $BB \to Zb + X$	2/≥3 e, μ	≥2/≥1 b	–	20.3	B mass 755 GeV	B in (B,Y) doublet	1409.5500
	VLQ $QQ \to WqWq$	1 e, μ	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
	VLQ $T_{5/3} T_{5/3} \to WtWt$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	3.2	$T_{5/3}$ mass 990 GeV		ATLAS-CONF-2016-032
Excited fermions	Excited quark $q^* \to q\gamma$	1 γ	1 j	–	3.2	q^* mass 4.4 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1512.05910
	Excited quark $q^* \to qg$	–	2 j	–	15.7	q^* mass 5.6 TeV	only u^* and d^*, $\Lambda = m(q^*)$	ATLAS-CONF-2016-069
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	8.8	b^* mass 2.3 TeV		ATLAS-CONF-2016-060
	Excited quark $b^* \to Wt$	1 or 2 e, μ	1 b, 2-0 j	Yes	20.3	b^* mass 1.5 TeV	$f_g = f_L = f_R = 1$	1510.02664
	Excited lepton ℓ^*	3 e, μ	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LSTC $a_T \to W\gamma$	1 e, μ, 1 γ	–	Yes	20.3	a_T mass 960 GeV		1407.8150
	LRSM Majorana ν	2 e, μ	2 j	–	20.3	N^0 mass 2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \to ee$	2 e (SS)	–	–	13.9	$H^{\pm\pm}$ mass 570 GeV	DY production, BR($H_L^{\pm\pm} \to ee$)=1	ATLAS-CONF-2016-051
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	3 e, μ, τ	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, BR($H_L^{\pm\pm} \to \ell\tau$)=1	1411.2921
	Monotop (non-res prod)	1 e, μ	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{non-res} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	multi-charged particle mass 785 GeV	DY production, $\lvert q \rvert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	monopole mass 1.34 TeV	DY production, $\lvert g \rvert = 1 g_D$, spin 1/2	1509.08059

$\sqrt{s}$ = 8 TeV $\sqrt{s}$ = 13 TeV

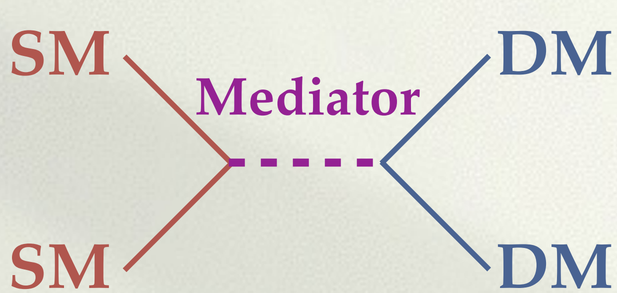
Mass scale [TeV] (10^{-1}, 1, 10)

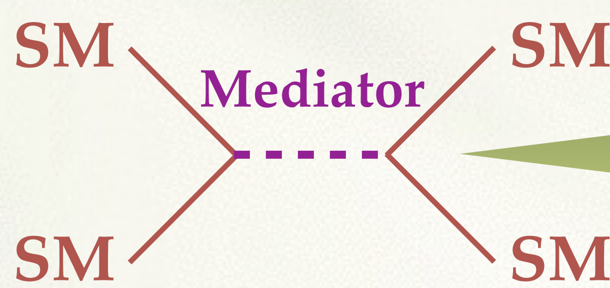
*Only a selection of the available mass limits on new states or phenomena is shown. Lower bounds are specified only when explicitly not excluded.

†Small-radius (large-radius) jets are denoted by the letter j (J).

Case Study: Dark Matter

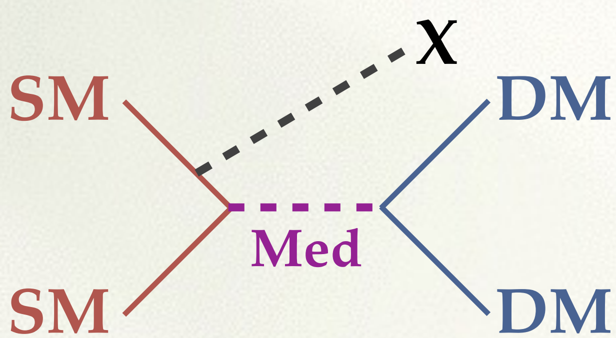
- Searches assuming the DM is a WIMP; interpretation w/ simplified Model.

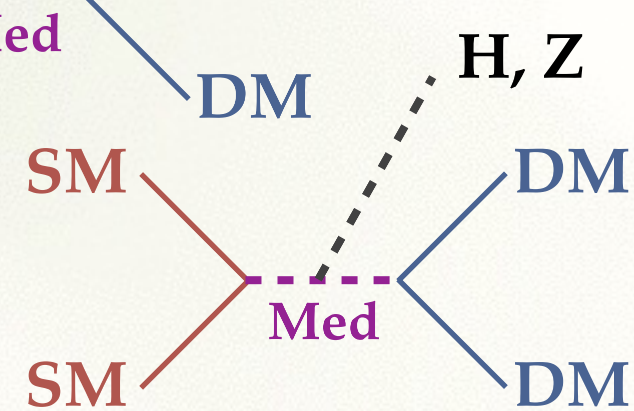




Direct mediator searches contributing to DM interpretations

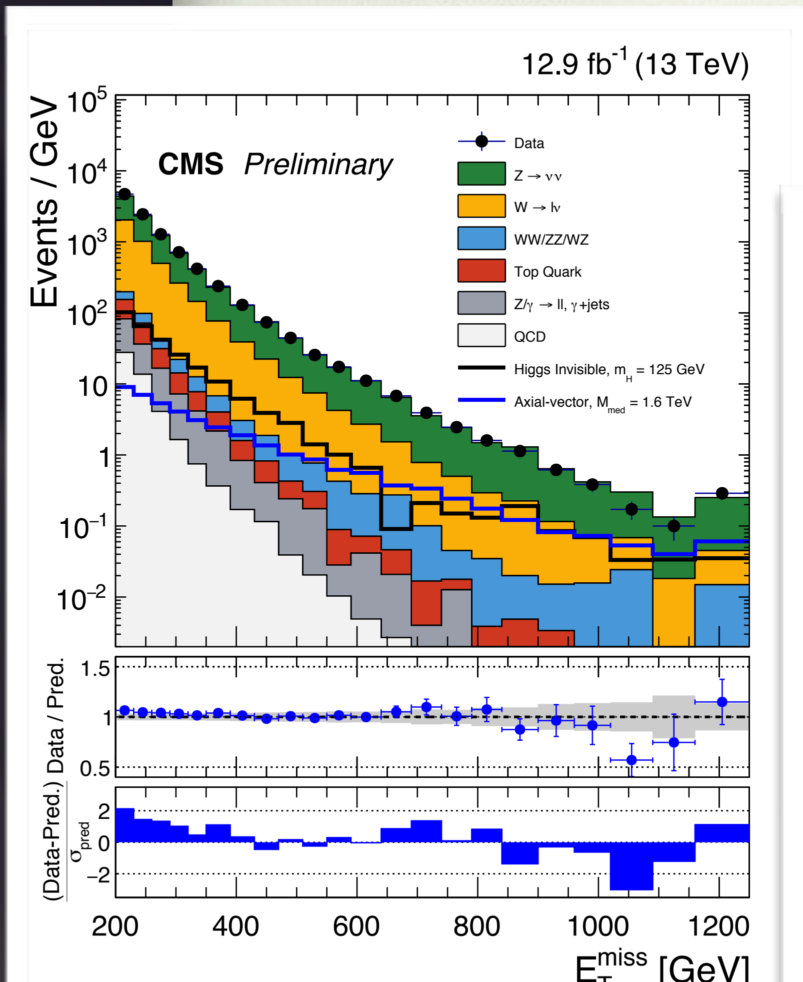
- Look for an unique signature: missing energy + X, ie. the **"Mono-X"** signature.
  - **From ISR,**
    X = jet, b, t, γ, W, Z…
  - **From mixing w/ the mediator**
  - **DM with paired top, bottom quarks**



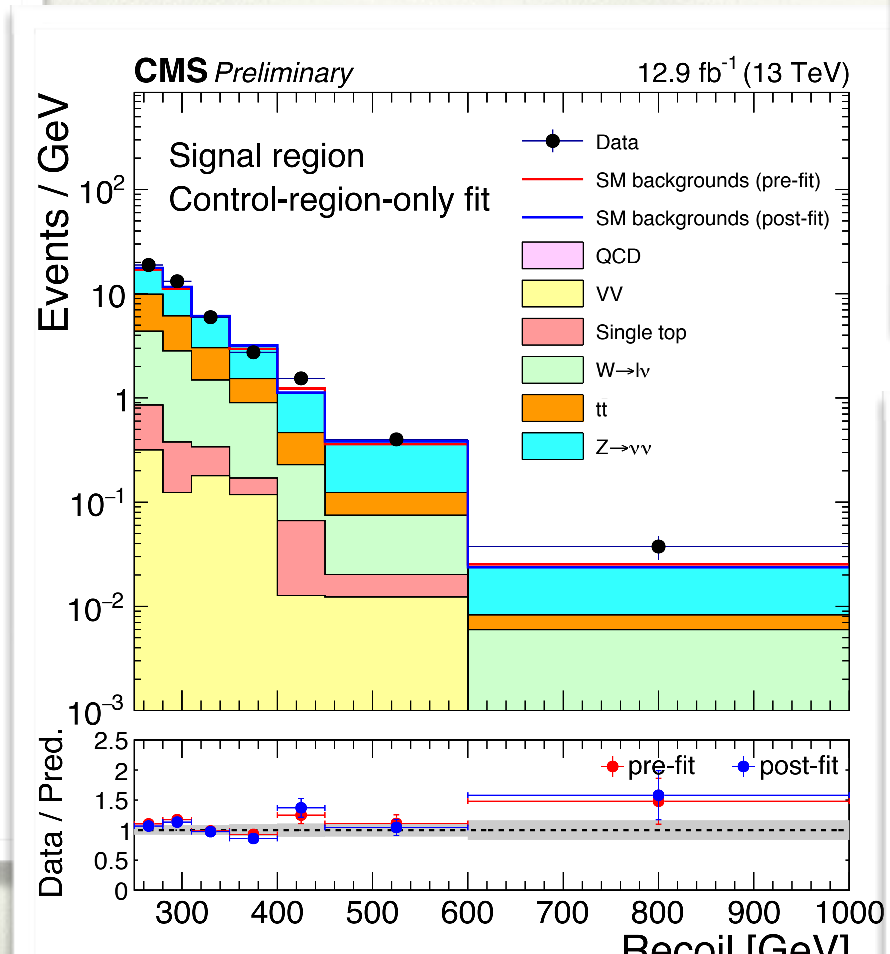


Need something "visible" other than the DM-pair to be detected by the experiment.

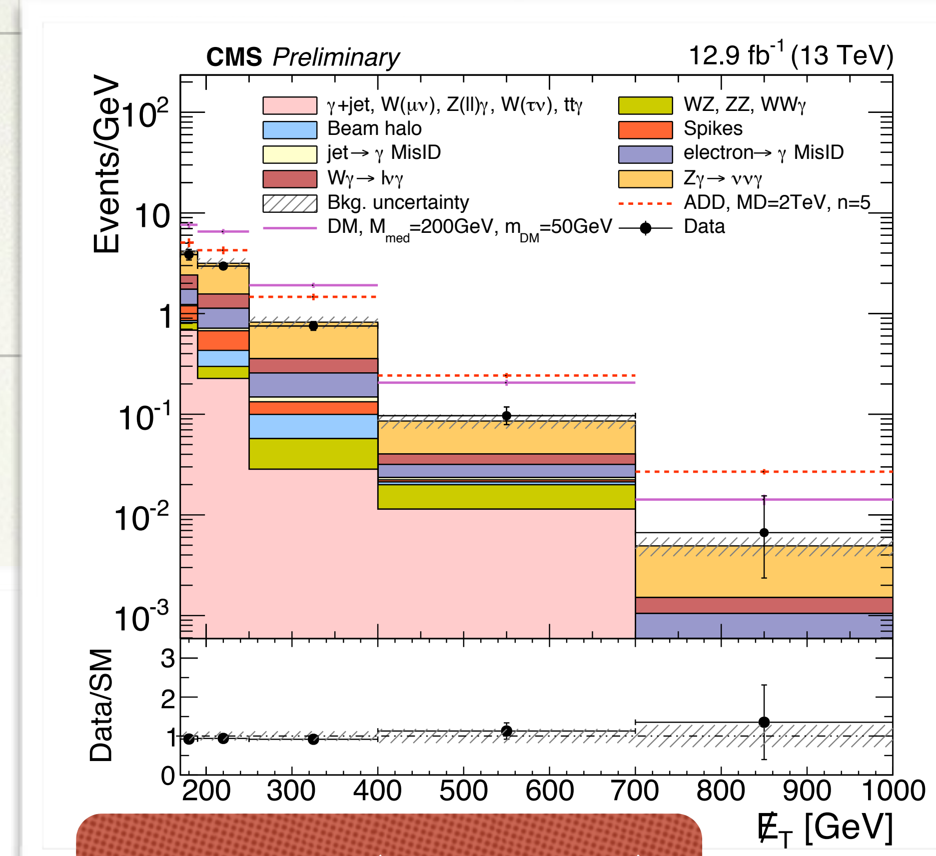
Signal as "Missing"



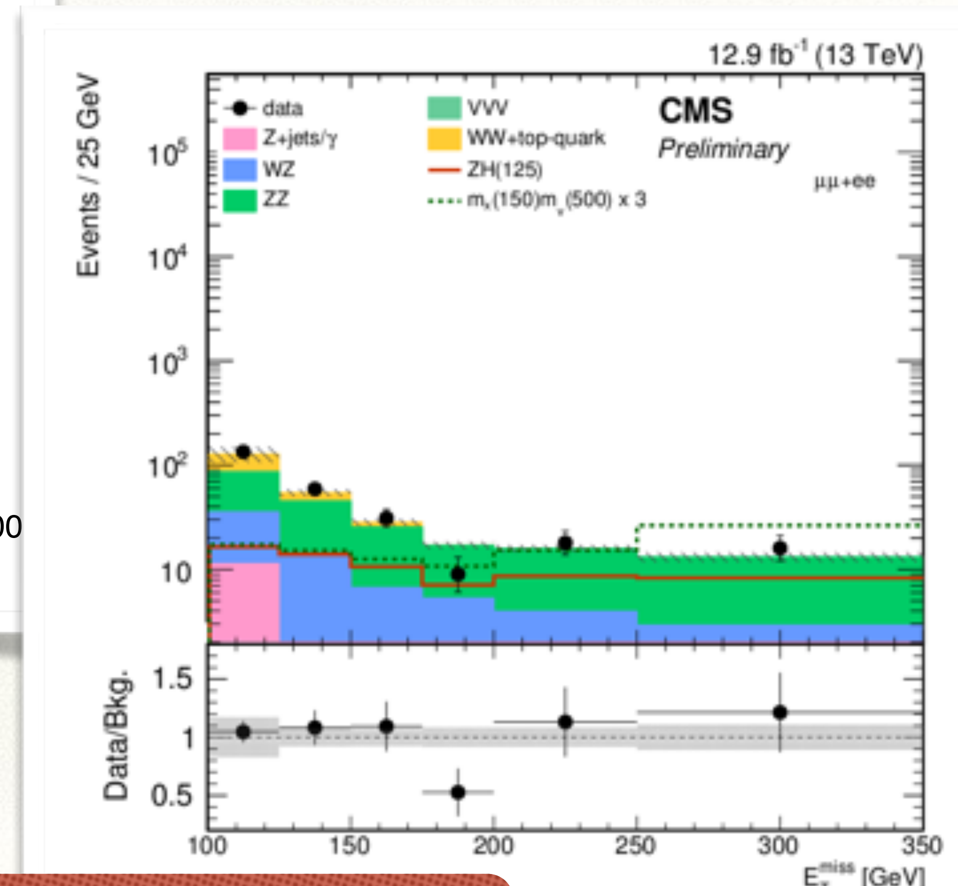
mono-jet (EXO-16-037)



mono-top (EXO-16-040)



mono-γ (EXO-16-039)

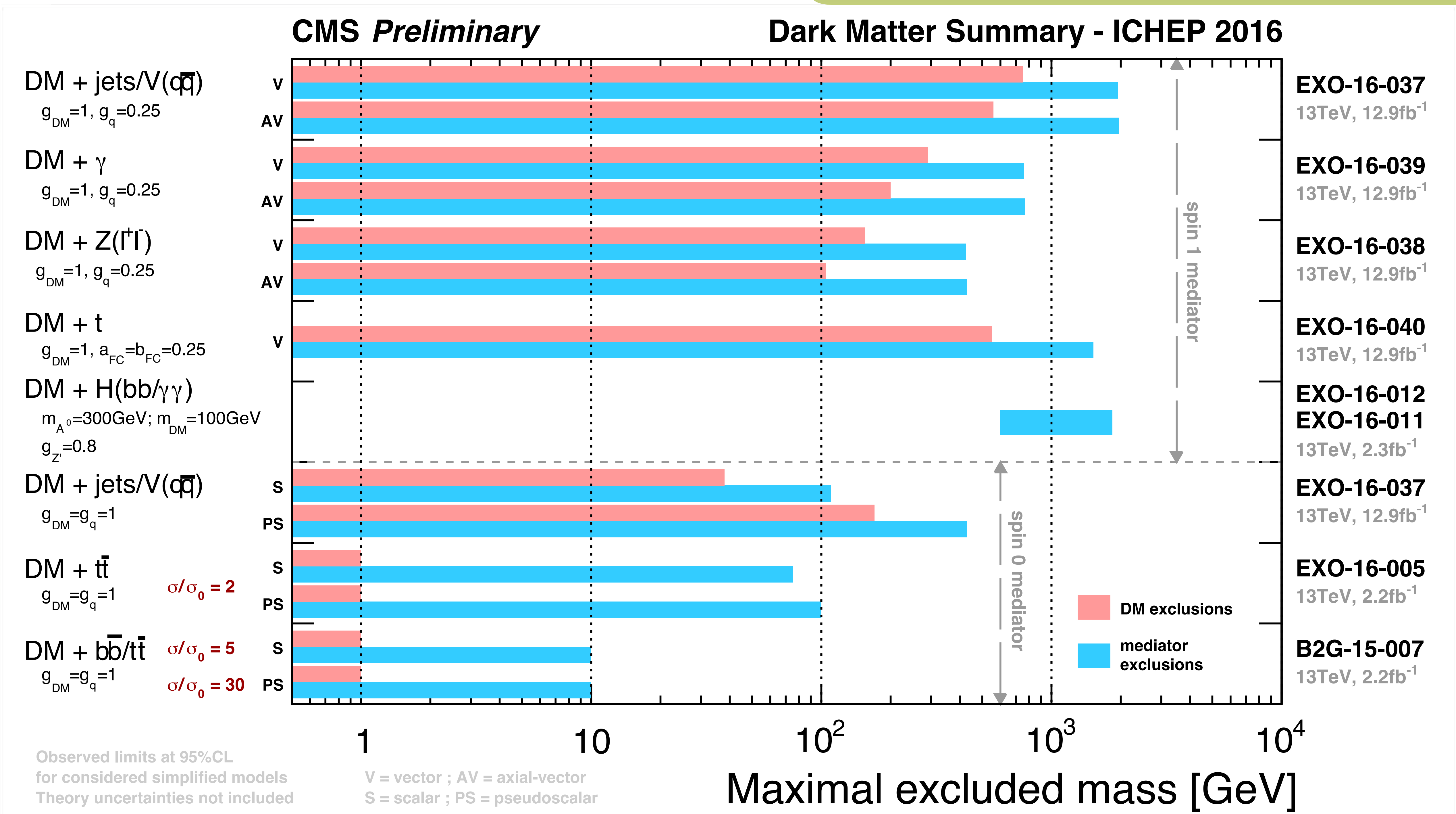


mono-Z (EXO-16-038)

- Many mono-X analyses have been carried out.
- No additional missing energy seen.

DM @ CMS Run-II

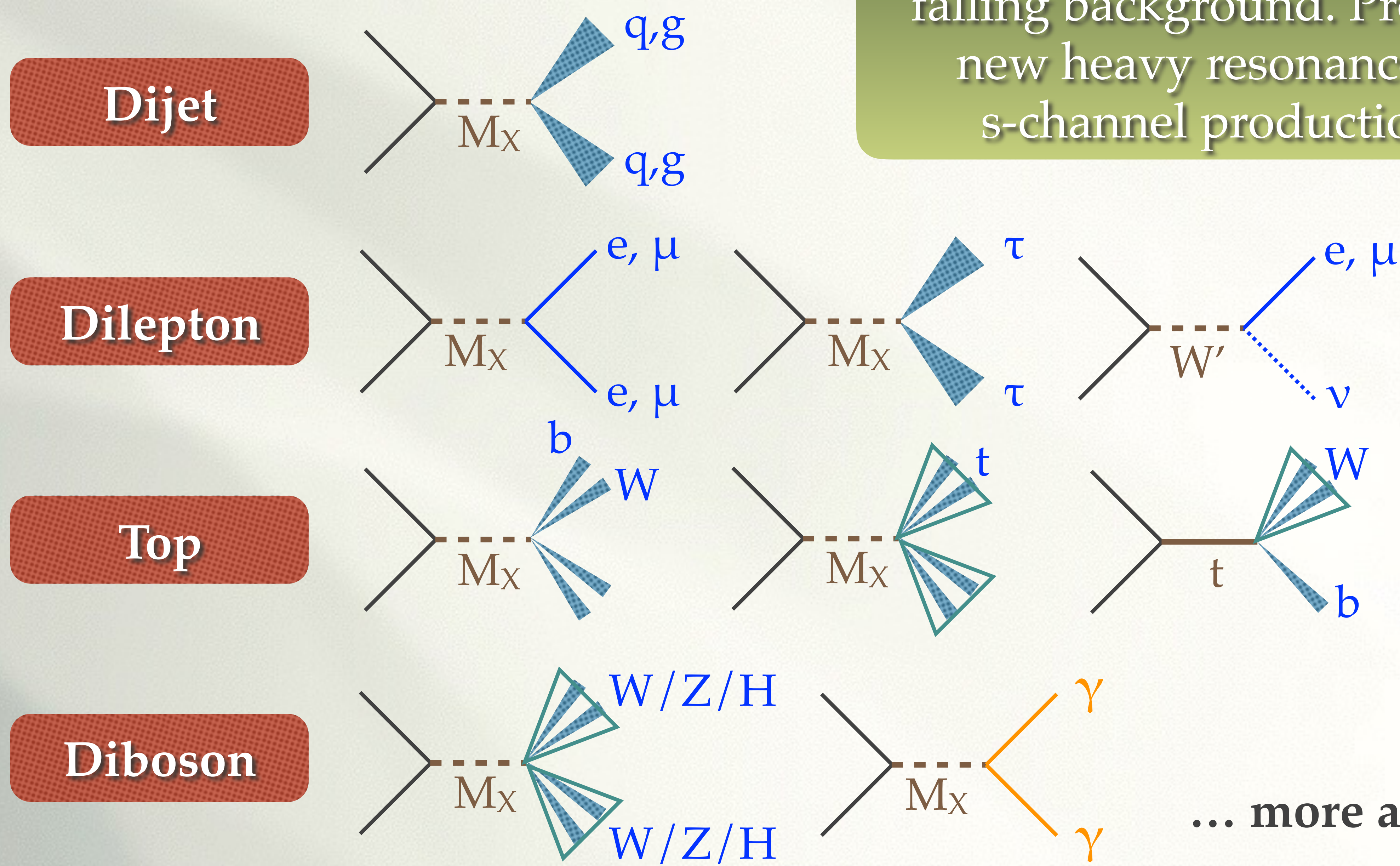
No significant excess observed
DM mass exclusion up to ~750 GeV
Mediator mass exclusion up to ~2 TeV



Search for Heavy Resonances

- The most typical search for new particles!
- Possible signatures:

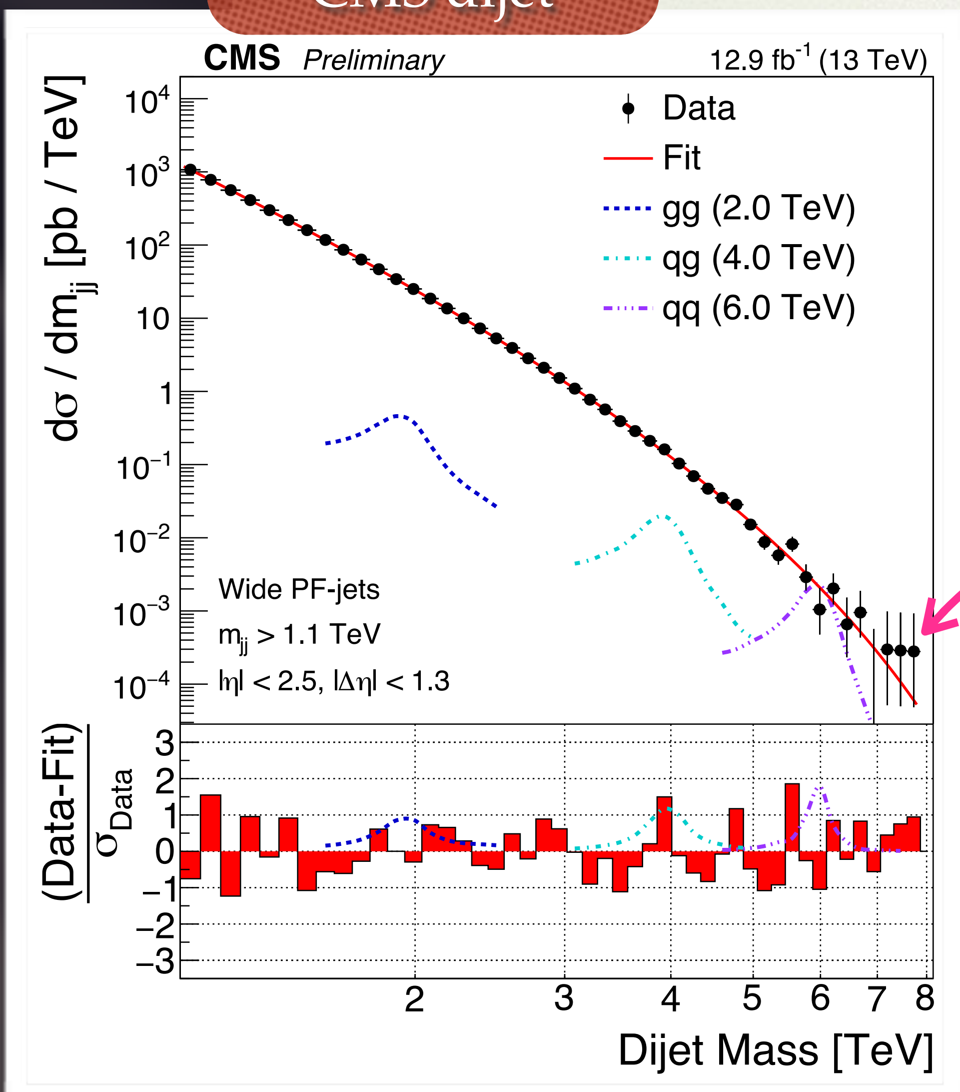
Bump hunt over a smoothly falling background. Probing new heavy resonance in s-channel production.



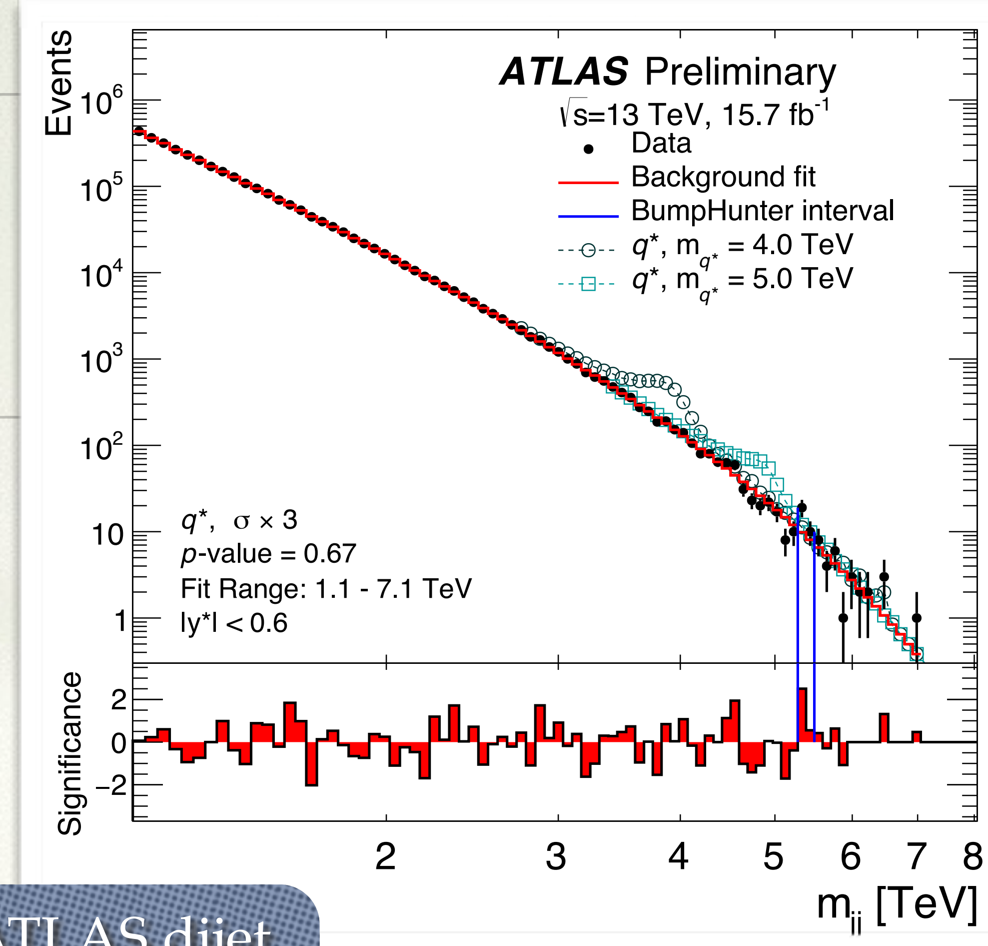
… more and more!

Dijet Resonance

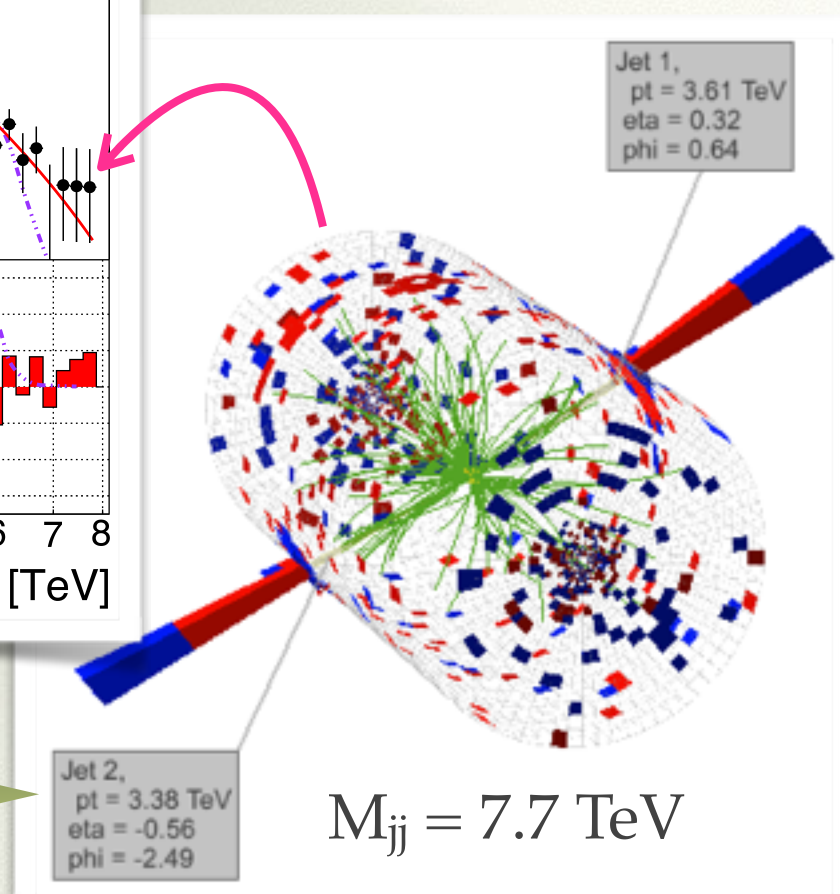
CMS dijet



smooth background only…

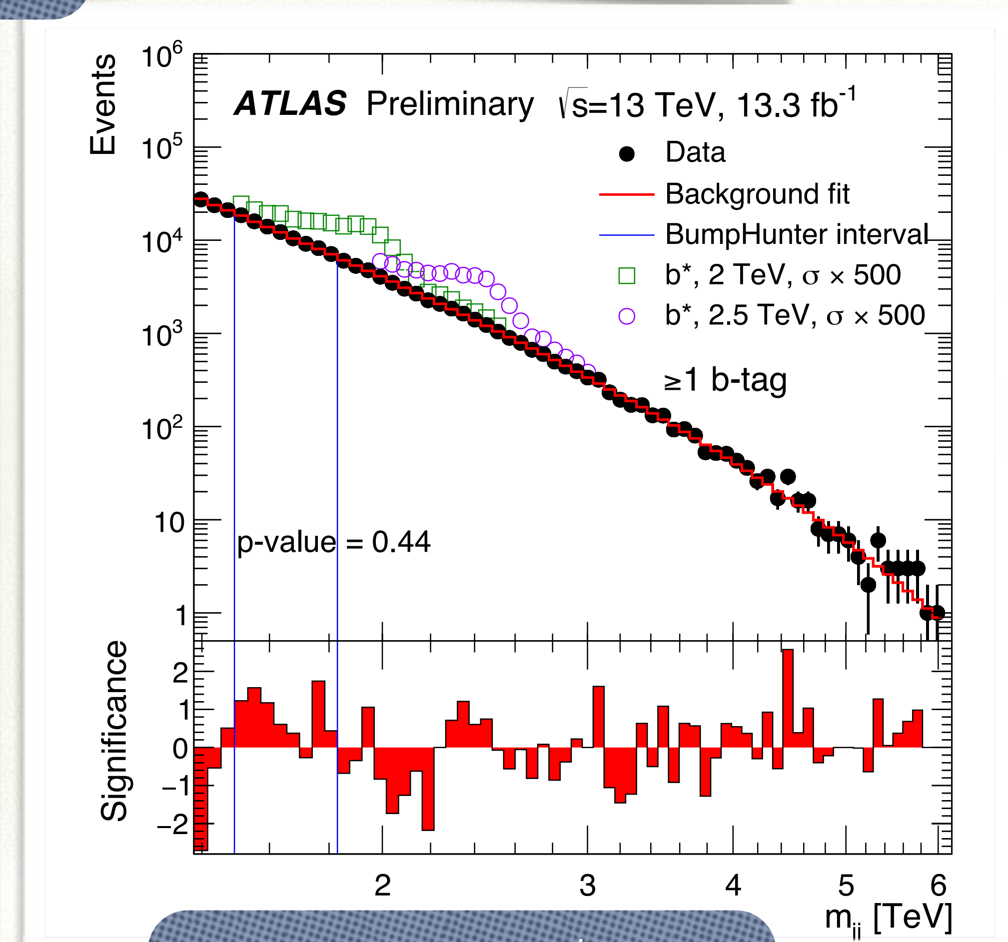


ATLAS dijet



M_{jj} = 7.7 TeV

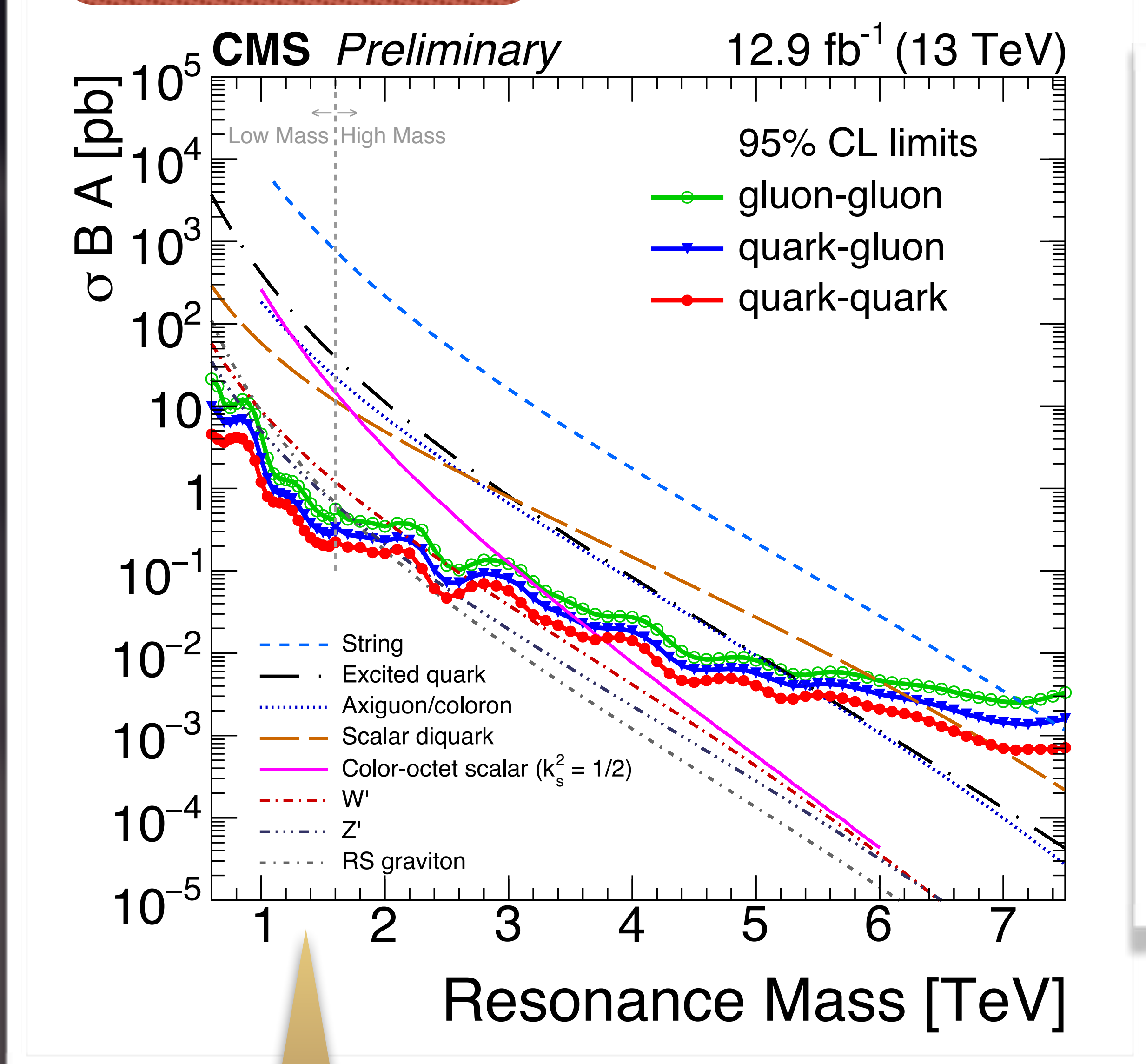
Heaviest event in record!



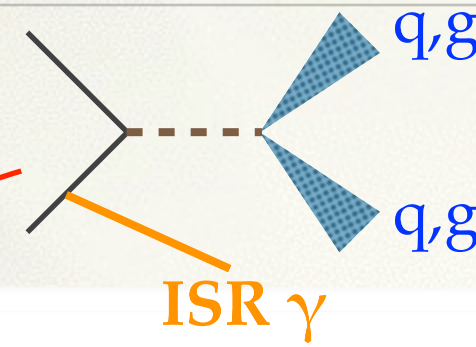
ATLAS dijet w/ b-tag

Dijet Resonance: Limits

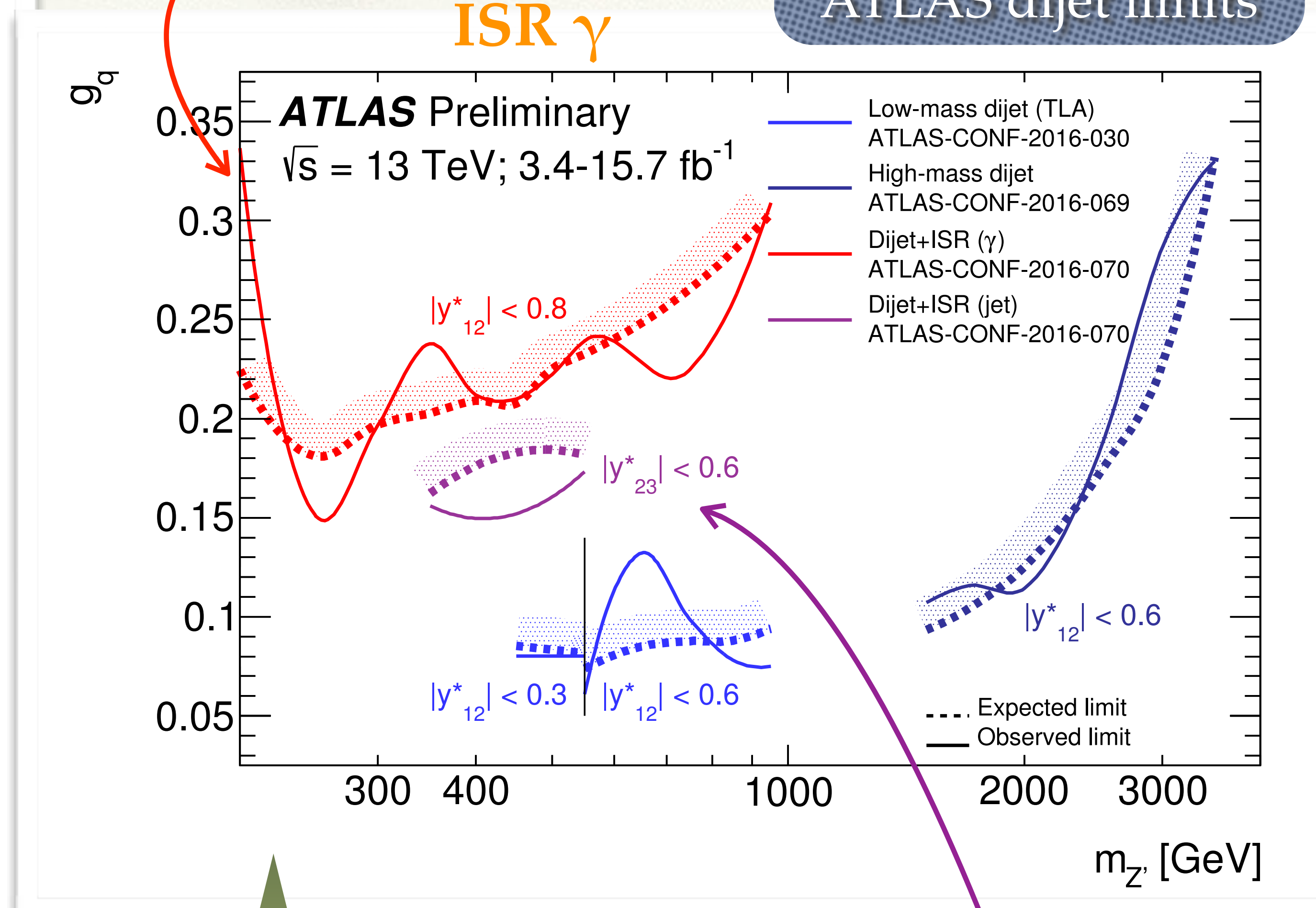
CMS dijet limits



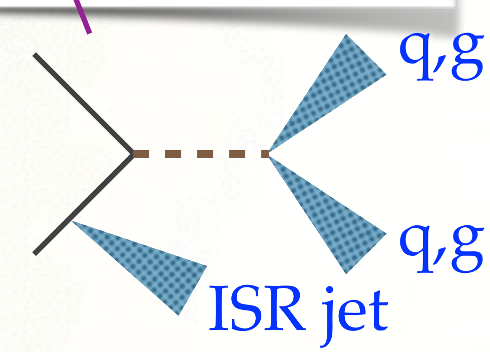
Different models!



ATLAS dijet limits

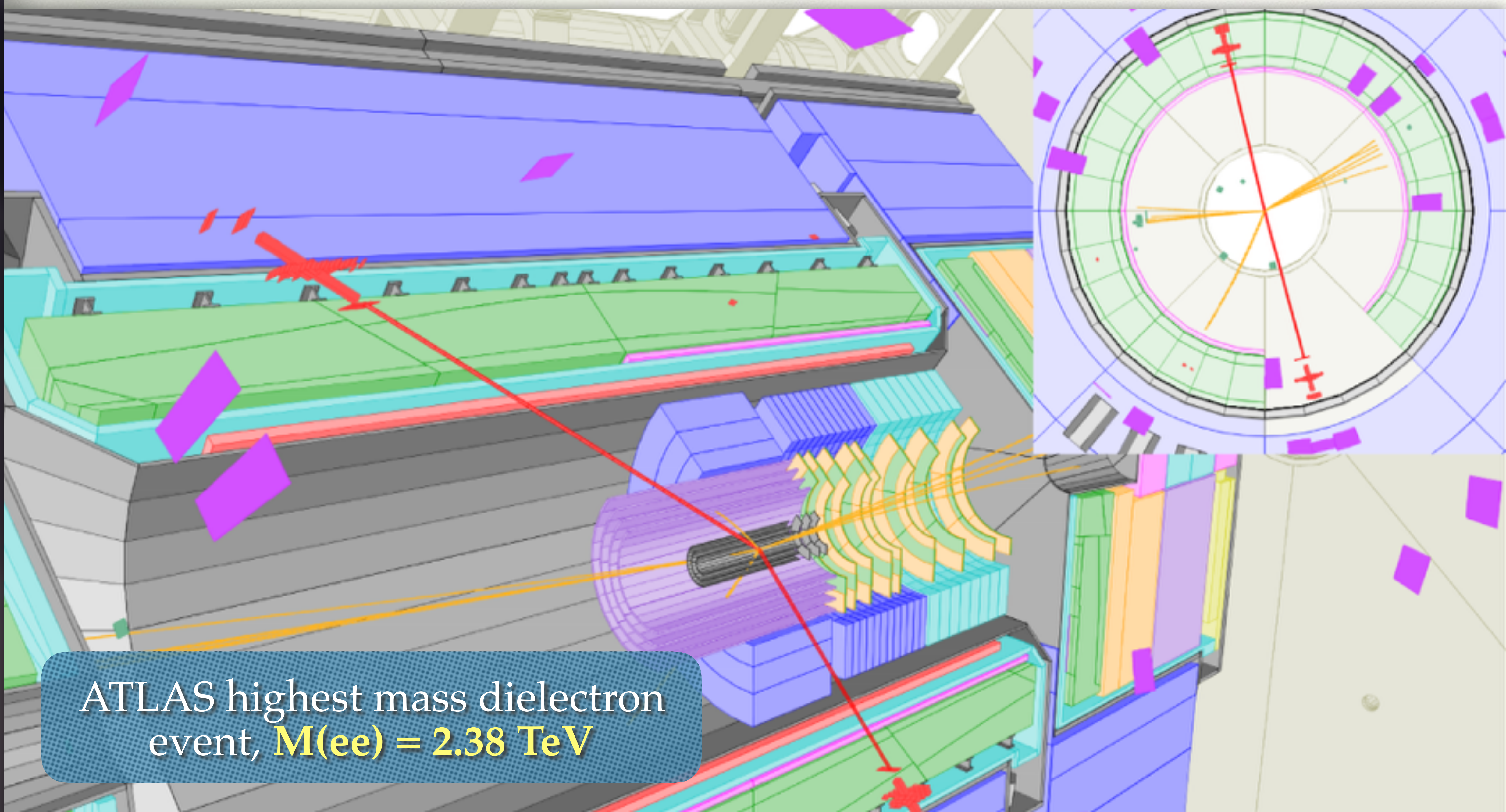


bounds in the Dark matter mass-coupling plane from dijet searches



Dilepton Resonance

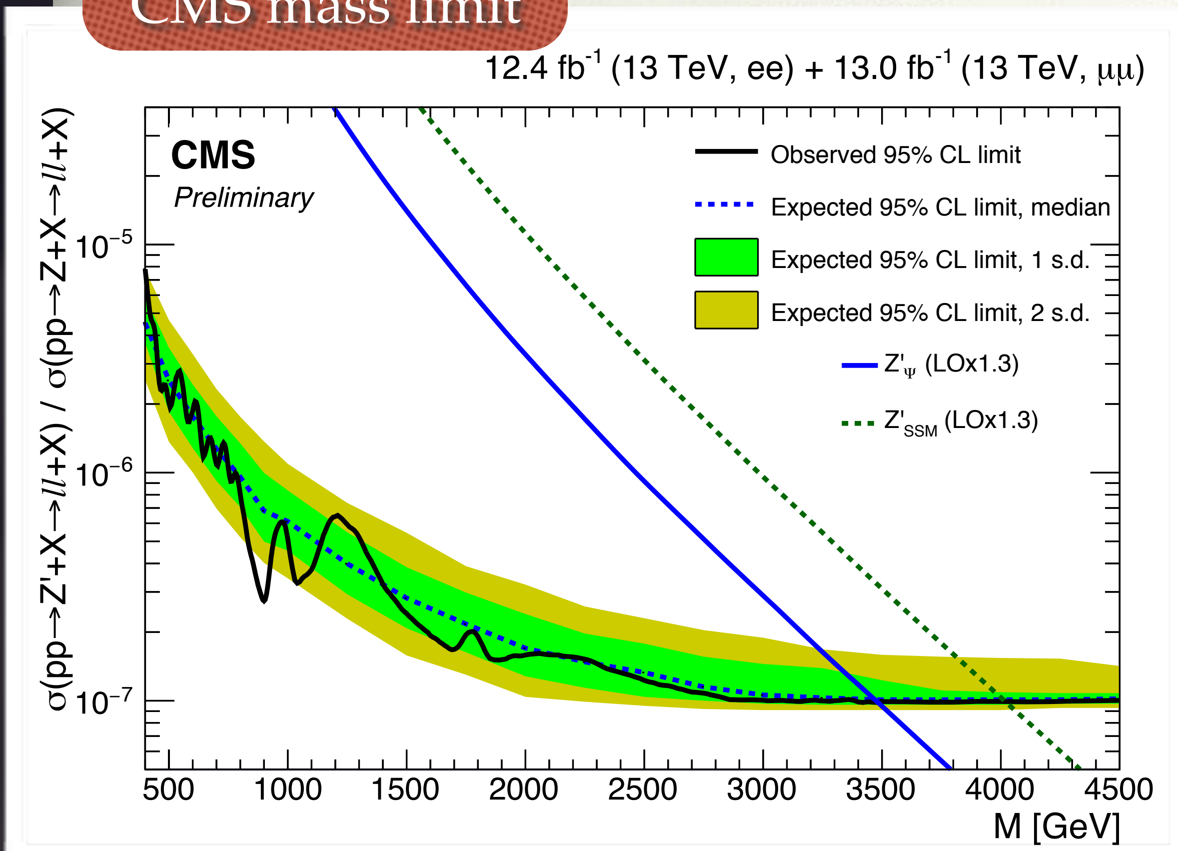
- Search for localized excess in the mass spectra of dimuon and dielectron events. Very clean signature with very low background at high mass.



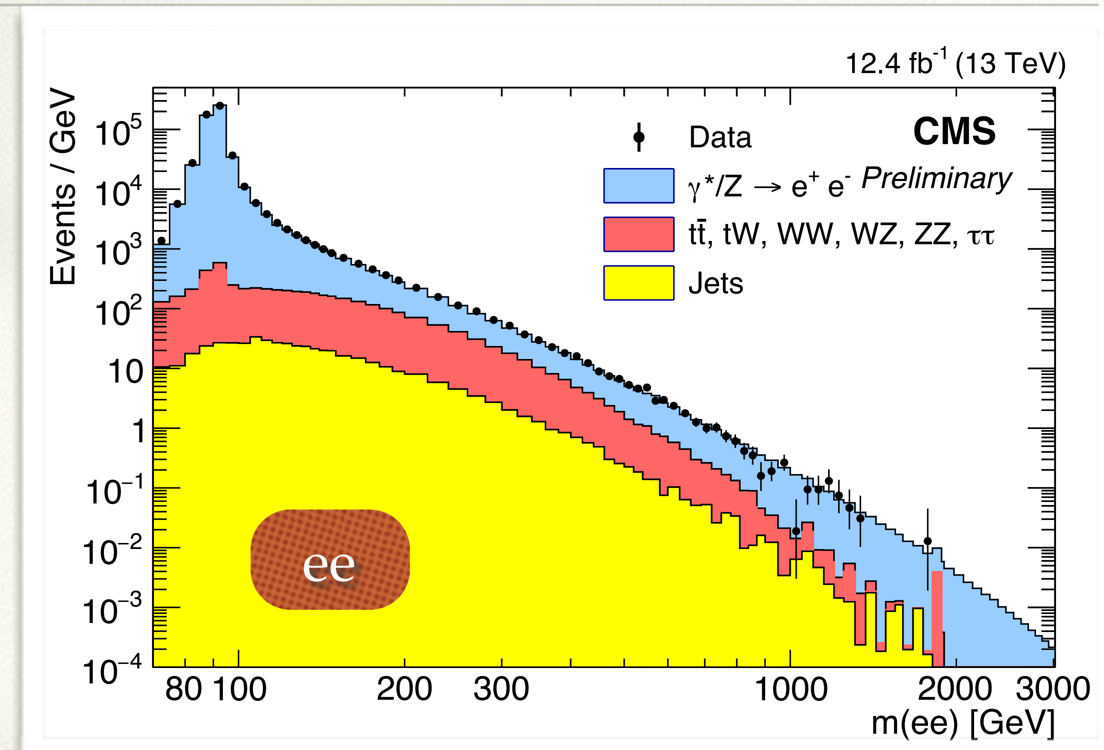
CMS Dilepton Resonances

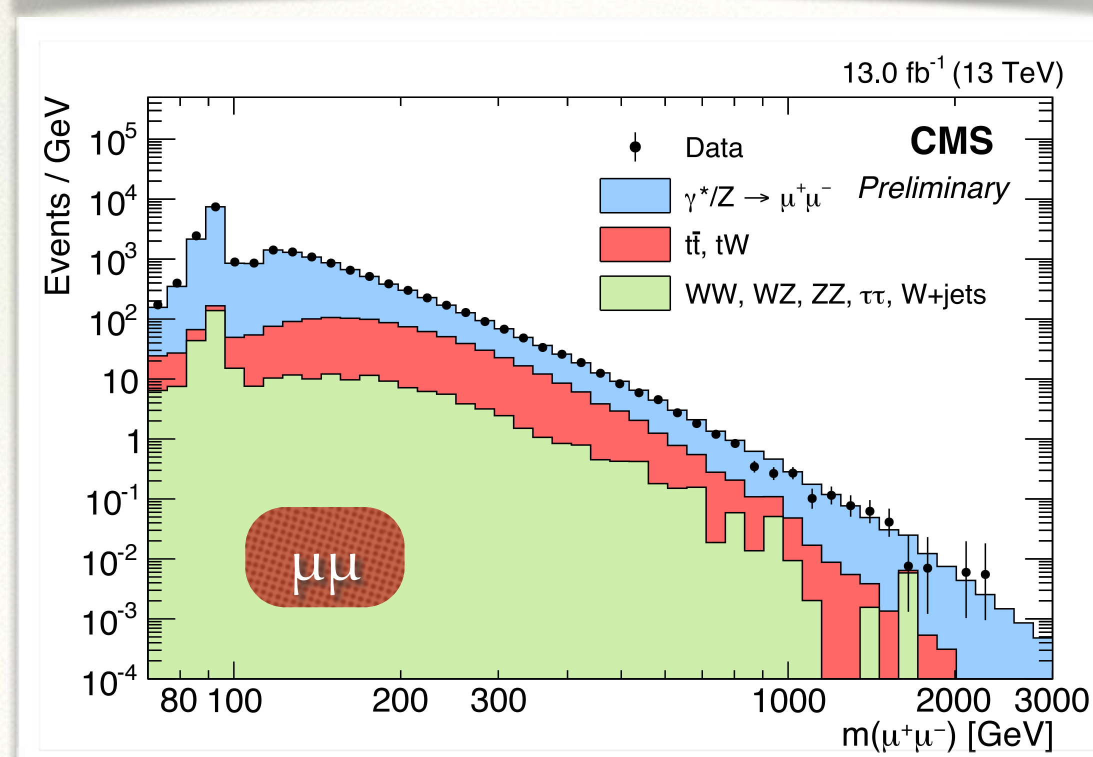
- No significant deviations from the SM.

CMS mass limit

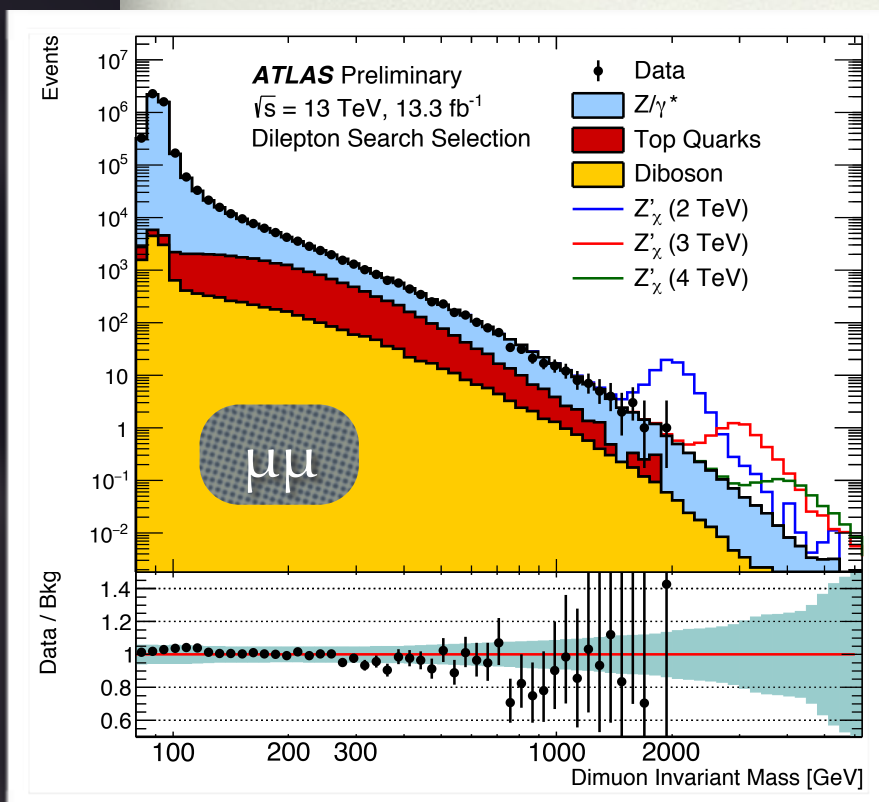


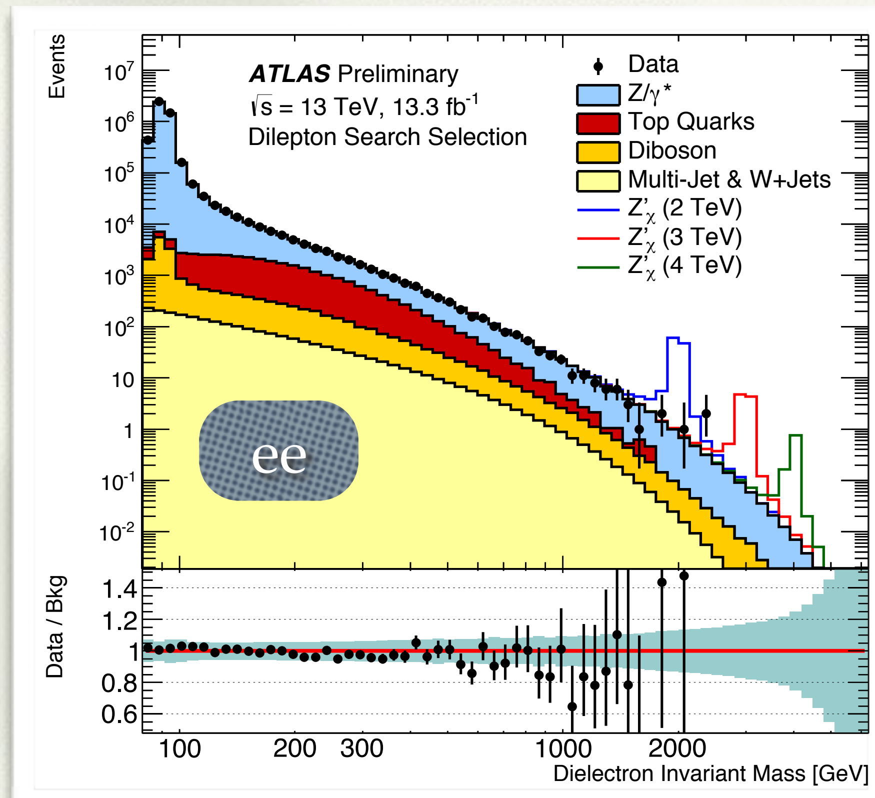
Model	Width	Obs. limit
Z'_{SSM}	3.0%	4.0 TeV
Z'_ψ	0.6%	3.5 TeV





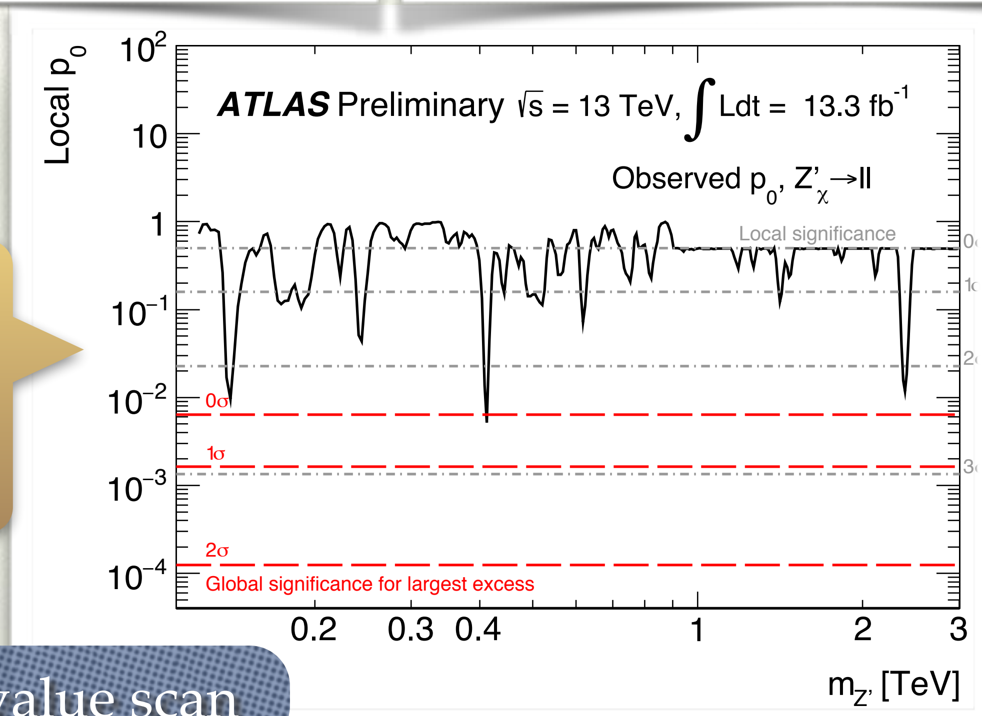
ATLAS Dilepton Resonances





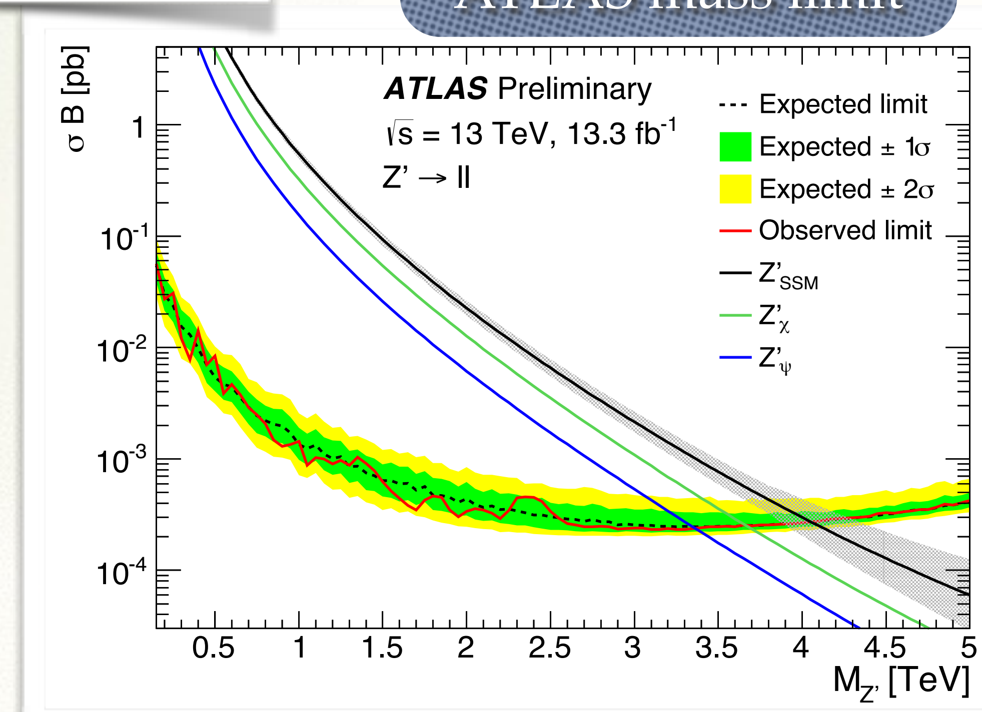
Model	Width	Obs. limit
Z'_{SSM}	3.0%	4.05 TeV
Z'_{χ}	1.2%	3.66 TeV
Z'_{ψ}	0.5%	3.36 TeV

Maximum local p-value ~2.6σ; but only 0.2σ global



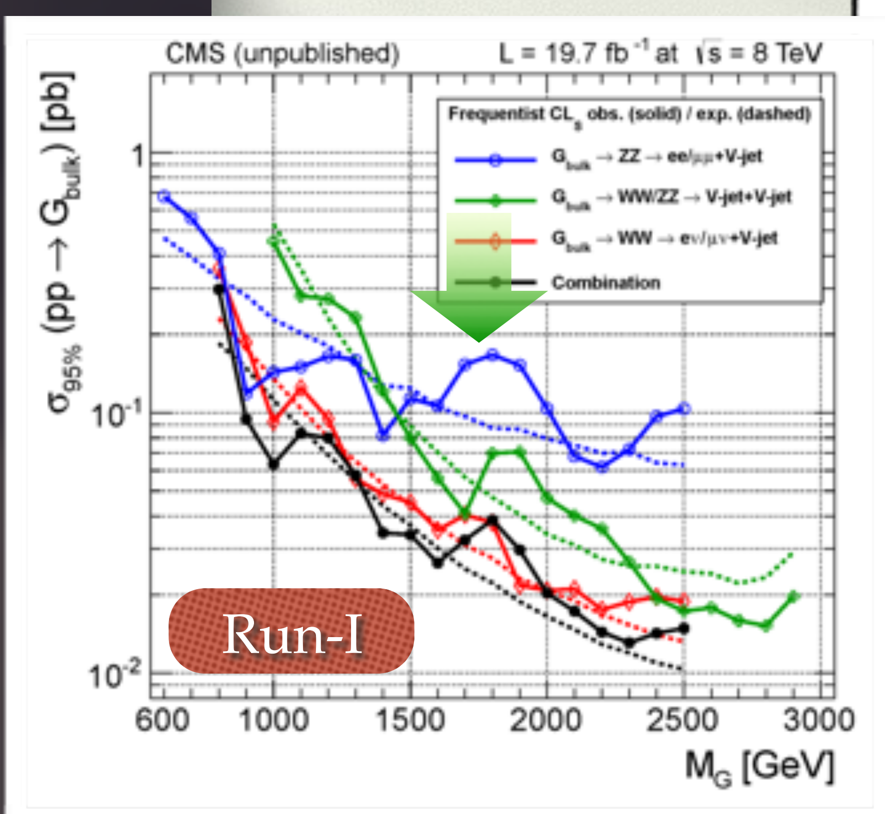
p-value scan

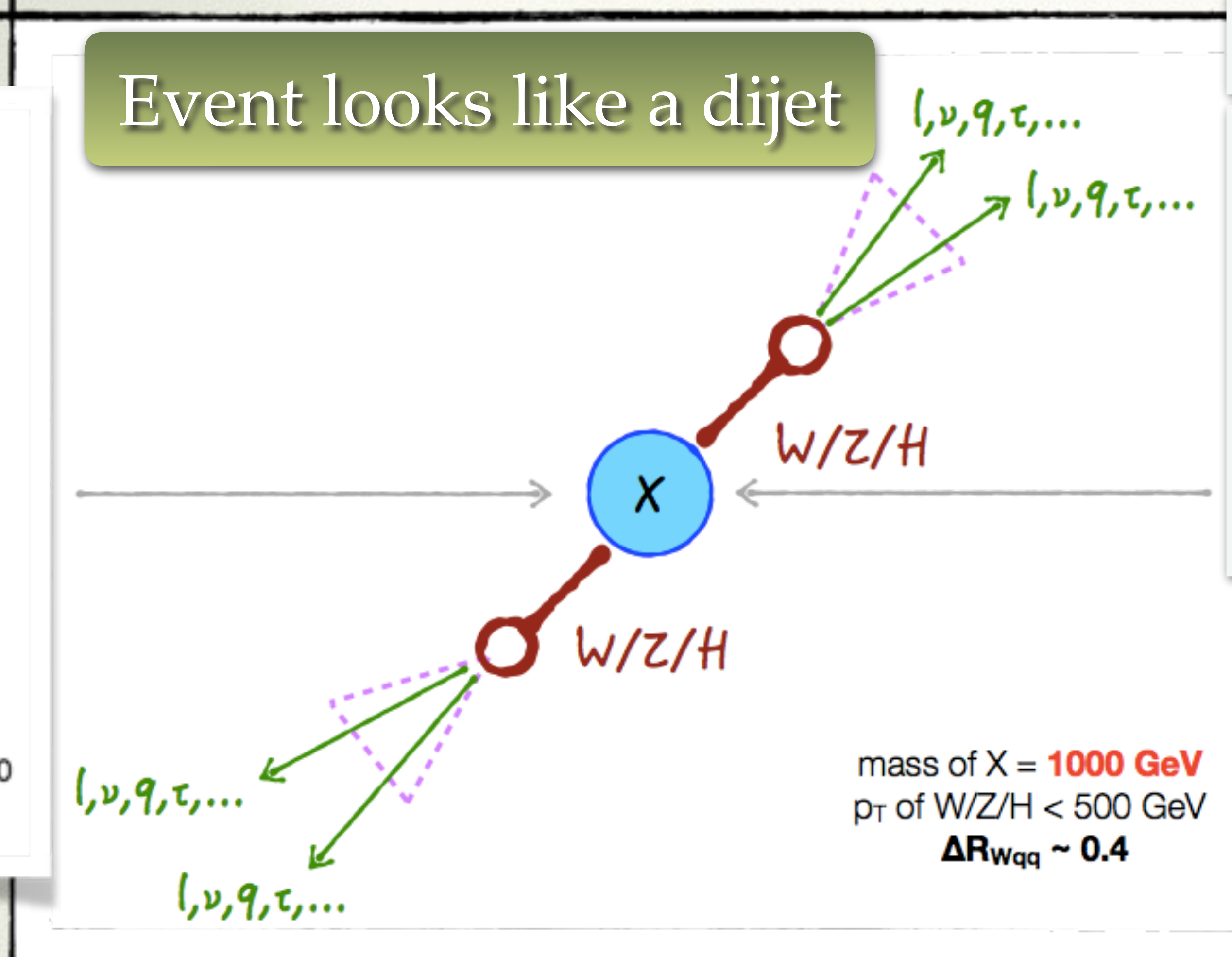
ATLAS mass limit

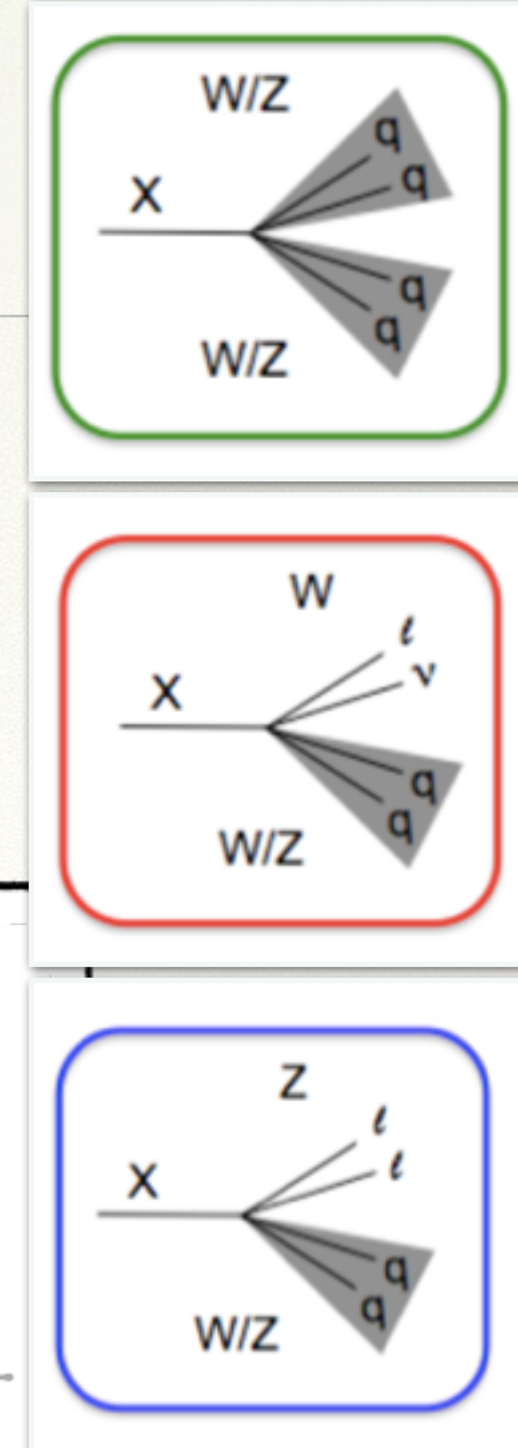


Diboson Resonances

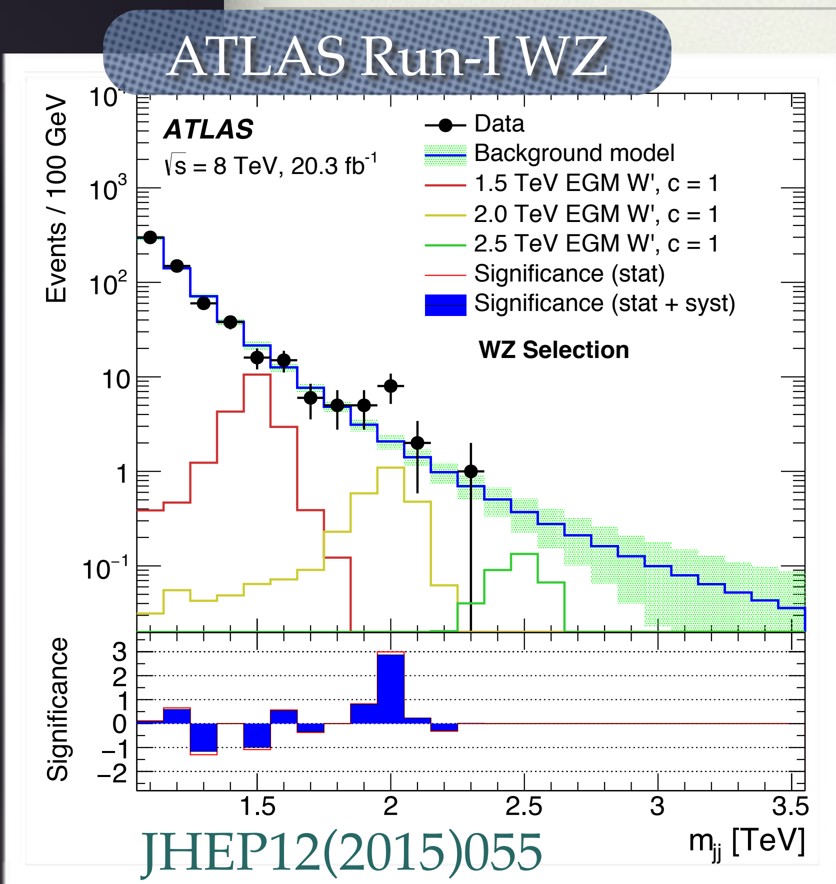
- Above $\mathbf{M_X \approx 1}$ **TeV** hadronic decay products of W / Z and Higgs are reconstructed as a single jet object.
- Below 1 TeV the tagging efficiency is reduced.
- Run-I: ATLAS & CMS >2σ excess near 1.8-2.0 TeV.



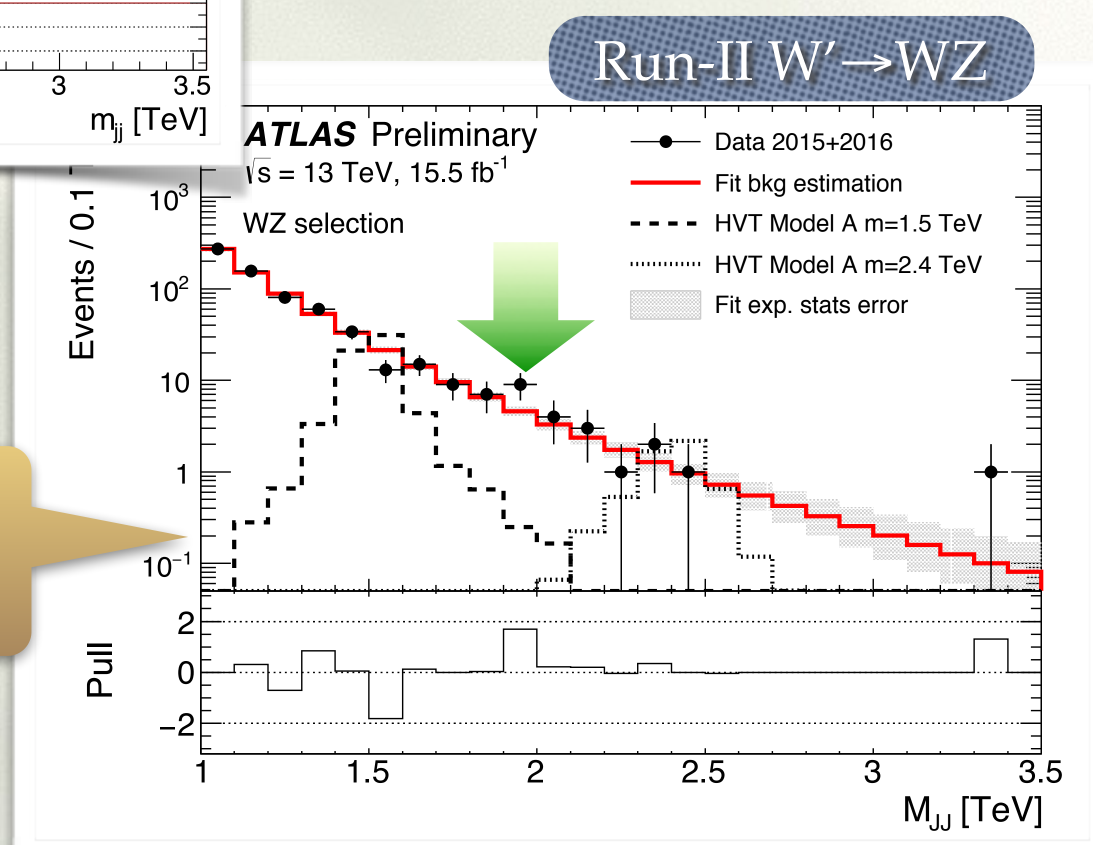




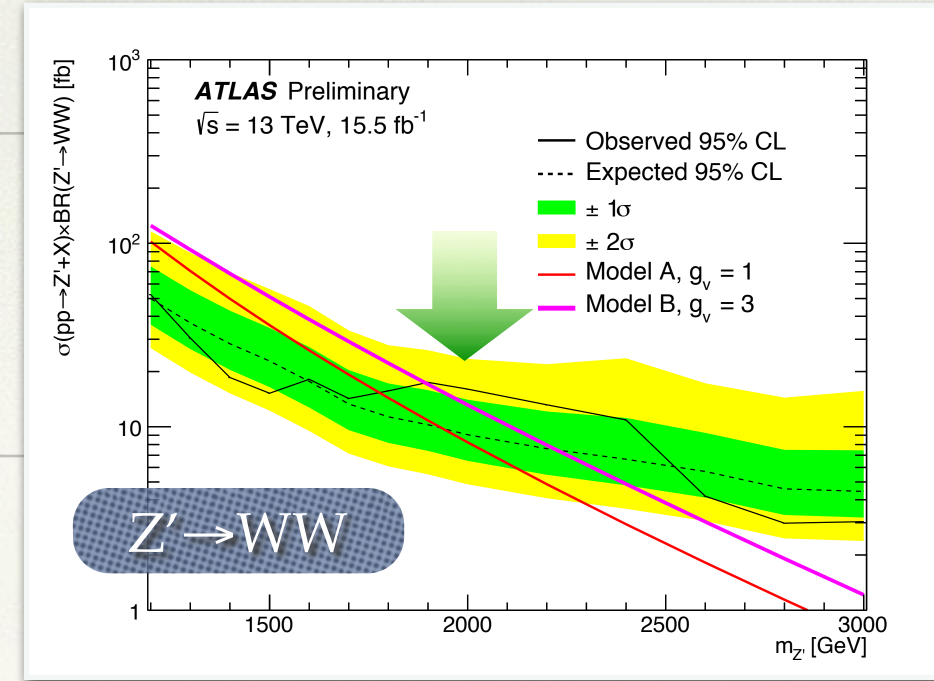
ATLAS Diboson Res.

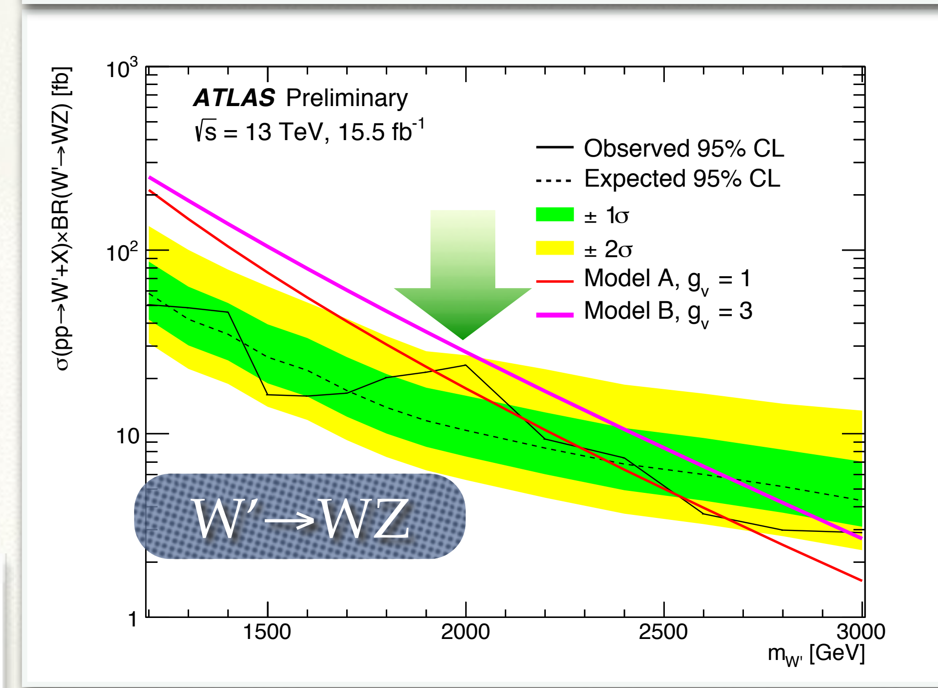


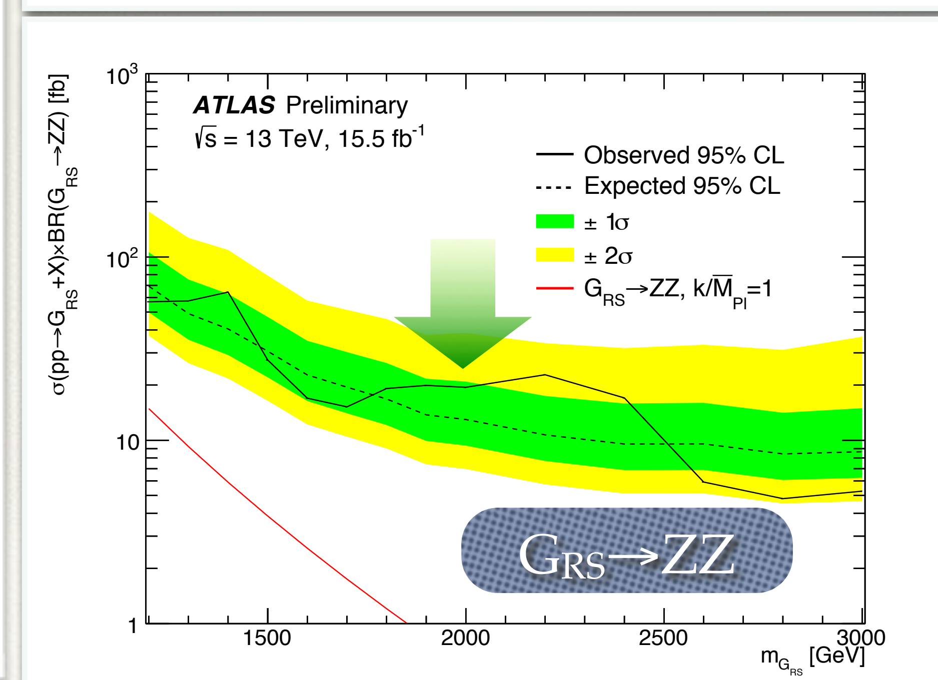
- Run-I excess:
  - M = 2 TeV
  - 3.4σ local significance (2.9σ global)



<2σ local significance now

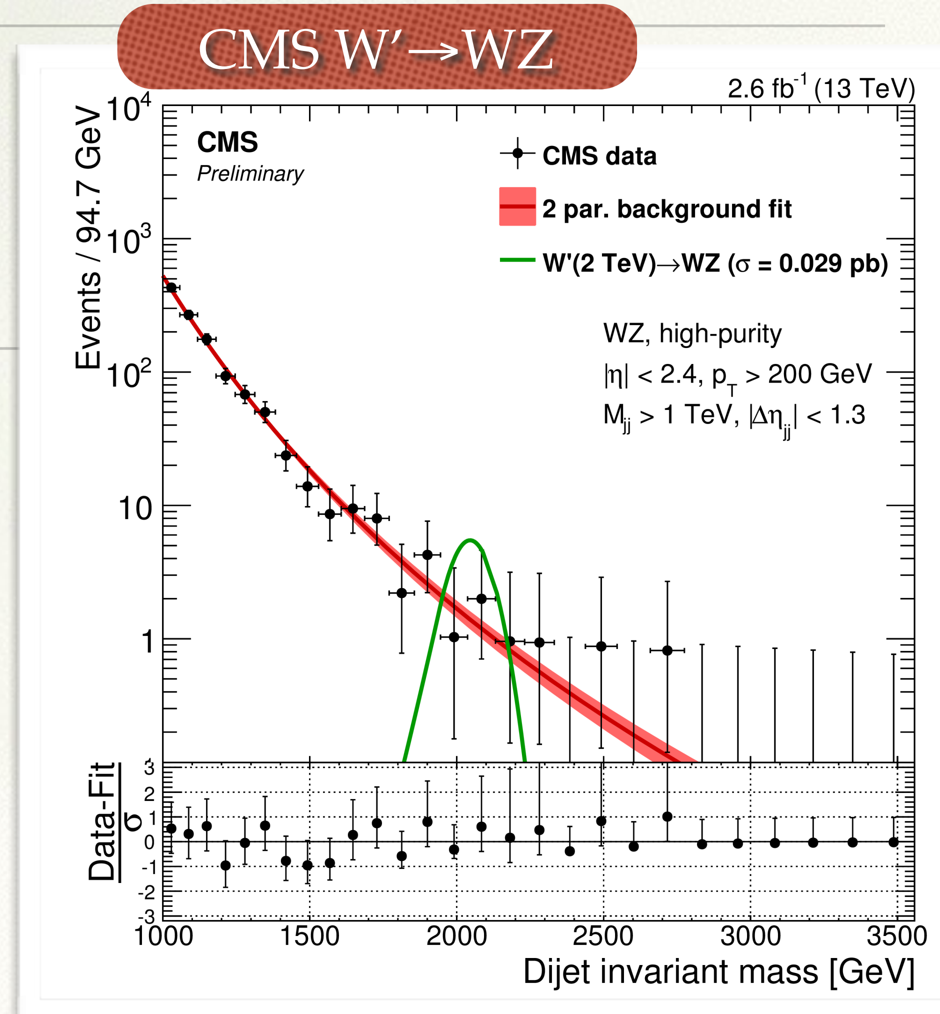


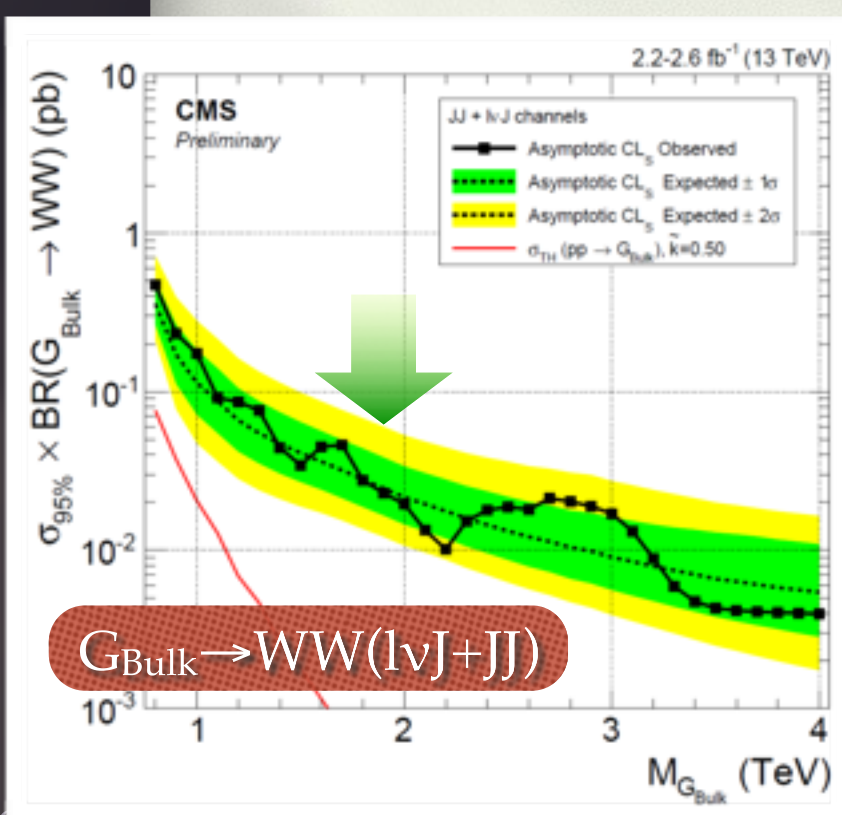


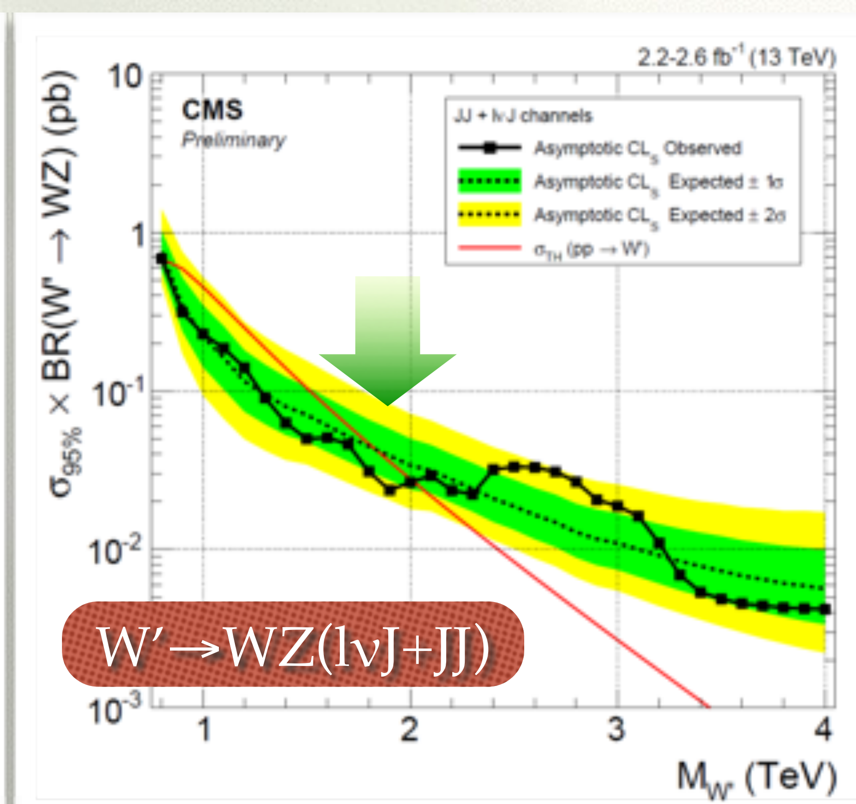


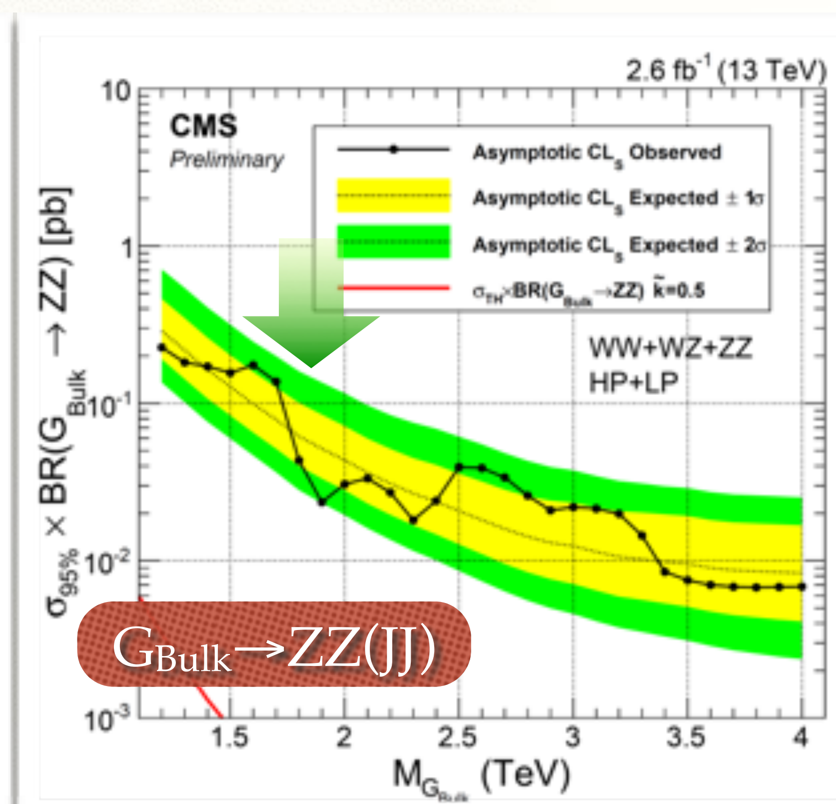
CMS Diboson Res.

- Studies at Run-II :
  - Repeat the searches using most sensitive channels: lν-Jet, Jet-Jet.
  - **Analysis categorized in dijet mass** for optimal sensitivity to WW/WZ/ZZ signals.
  - **No excess observed in the region of interest so far.**



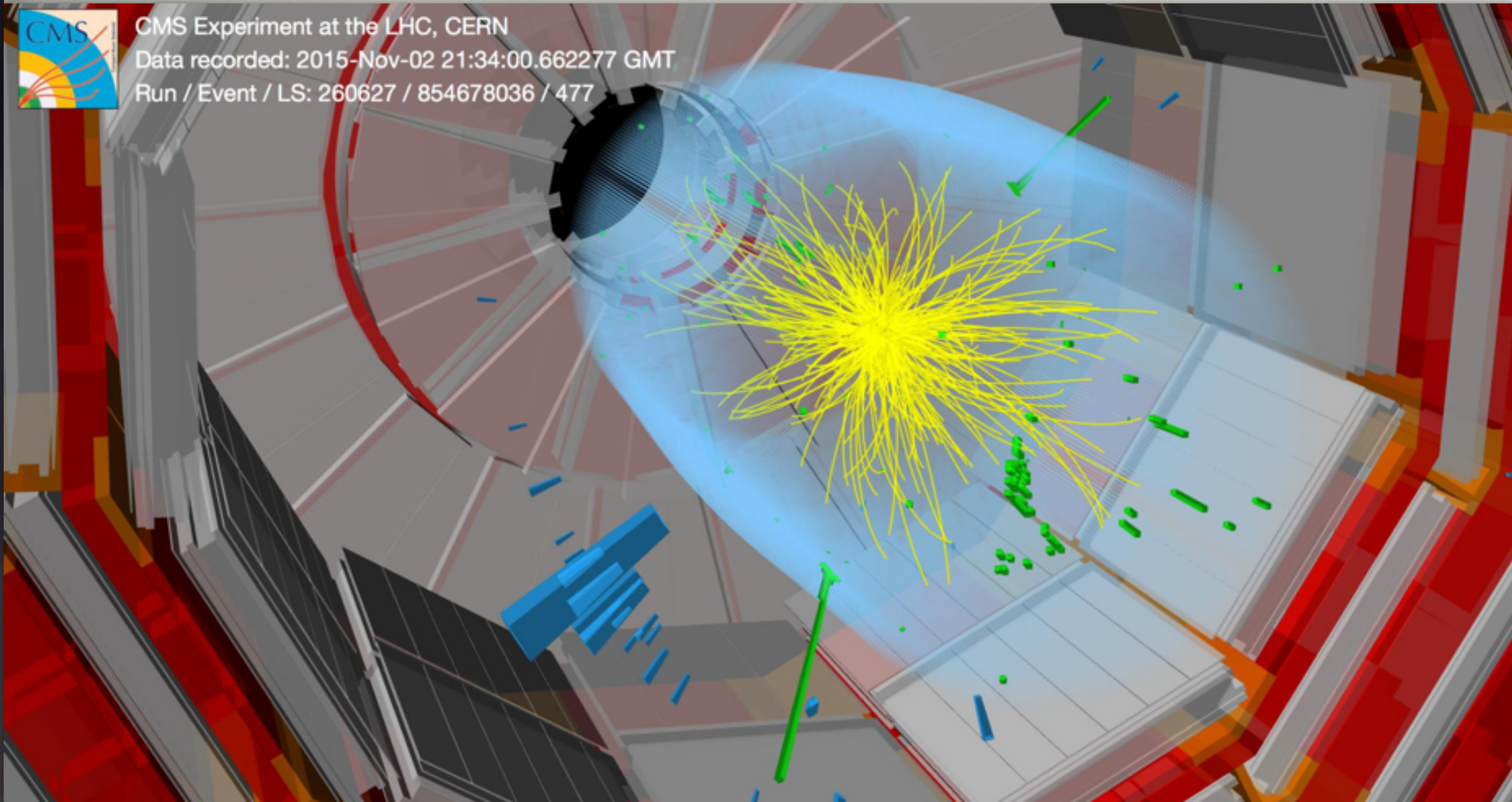






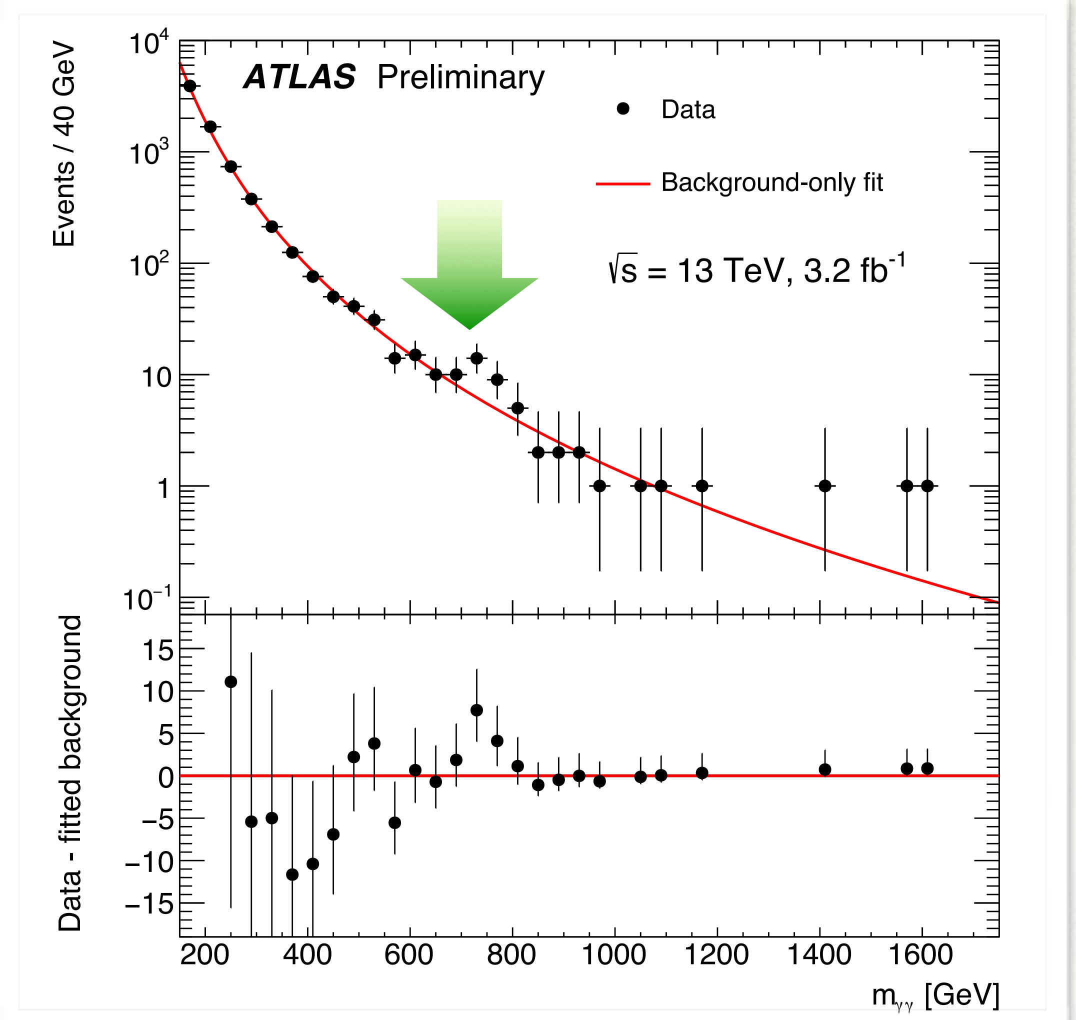
Diphoton Resonances

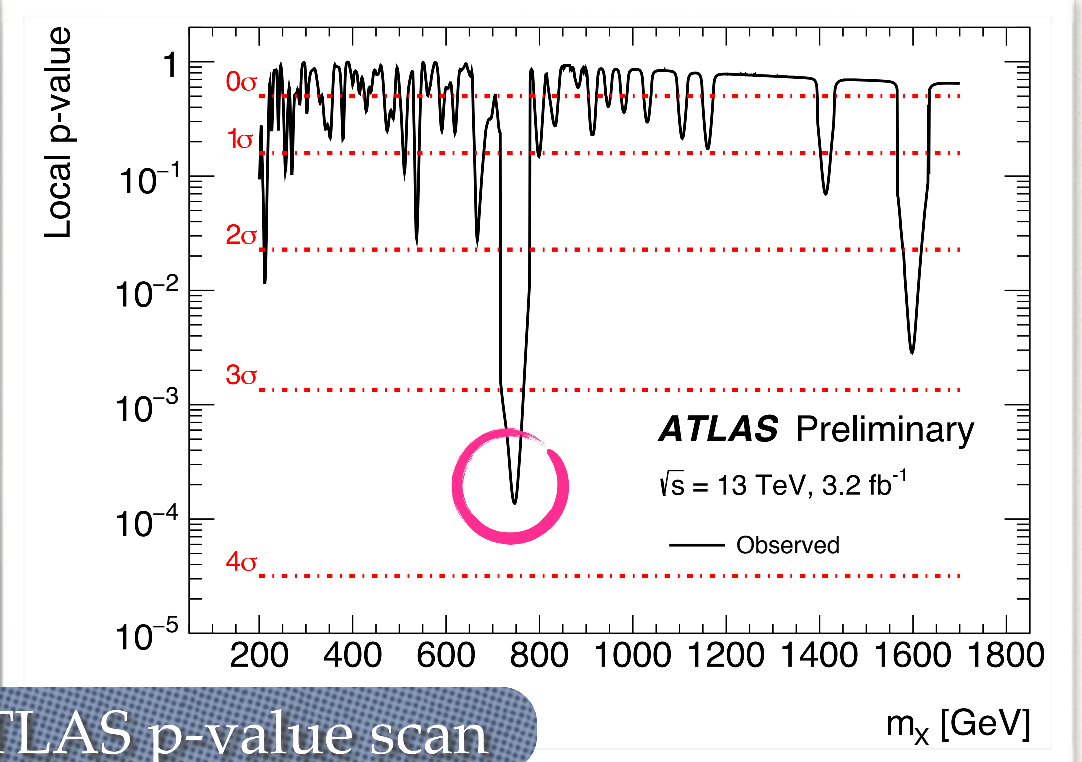
- Inclusive search for diphoton resonance — optimized for a spin-2 resonance as motivated by Extra Dimensions models.



ATLAS Diphoton Res. @ 2015

- Inclusive search for diphoton resonance, optimized for a scalar resonance.
- 2 high-pT isolated photons selected.
- Parameterized background with a functional form.
- With narrow width search, **maximum local significance of 3.9σ found at 750 GeV (2.1σ global)**.





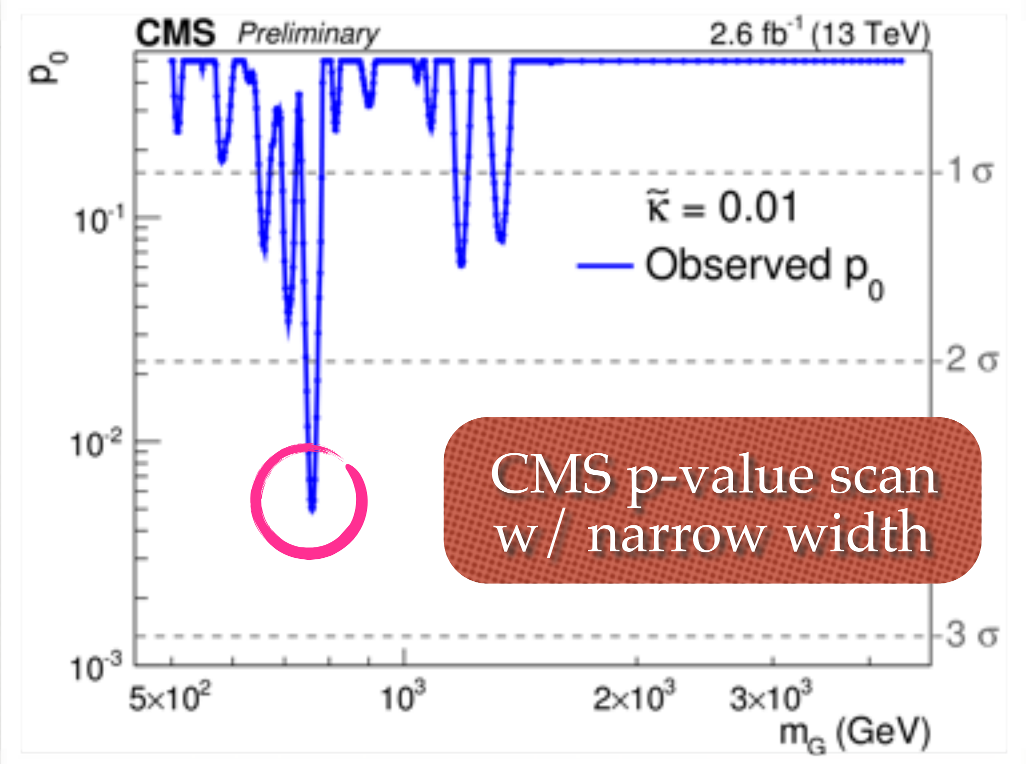
ATLAS p-value scan

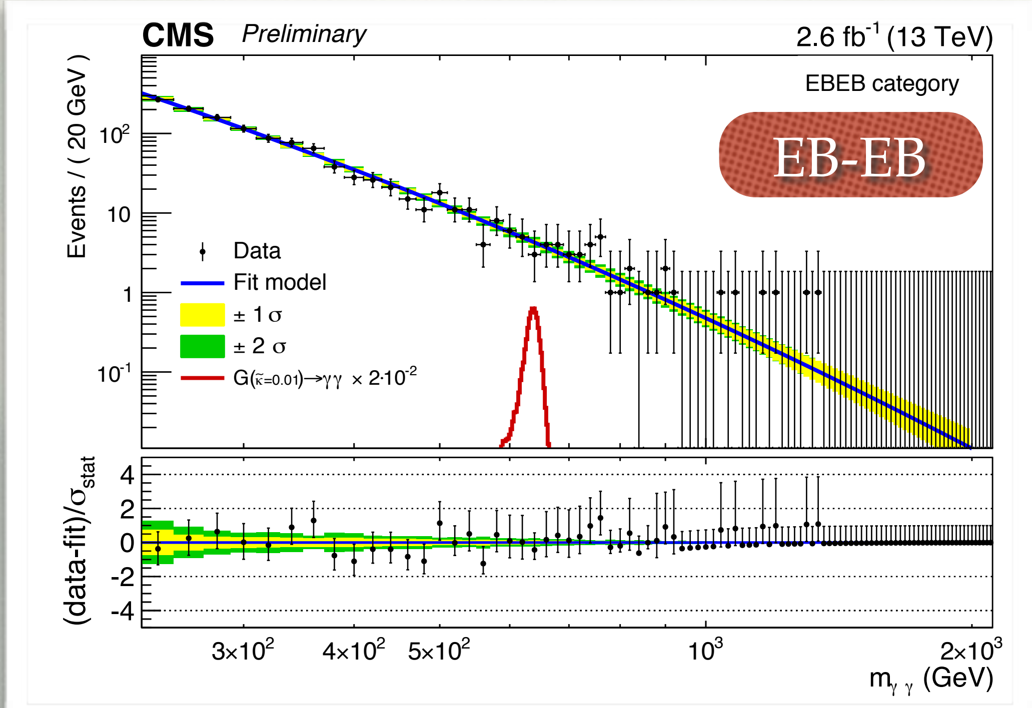
Striking result shown at the 2015 end of year jamboree

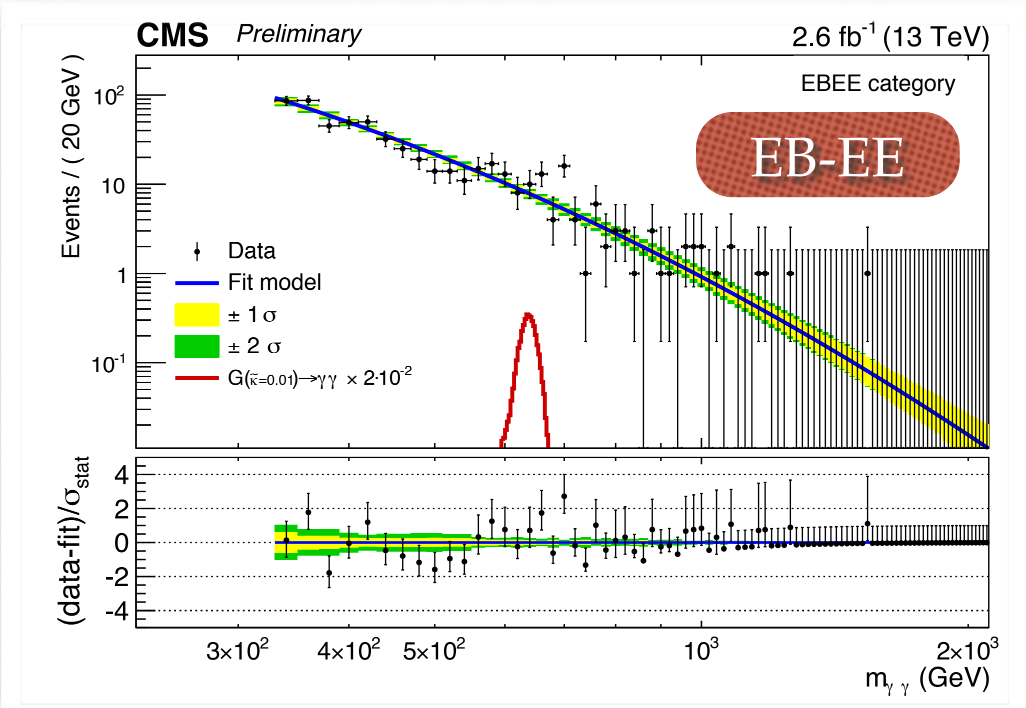
(w/ minor updates afterwards)

CMS Diphoton Res. @ 2015

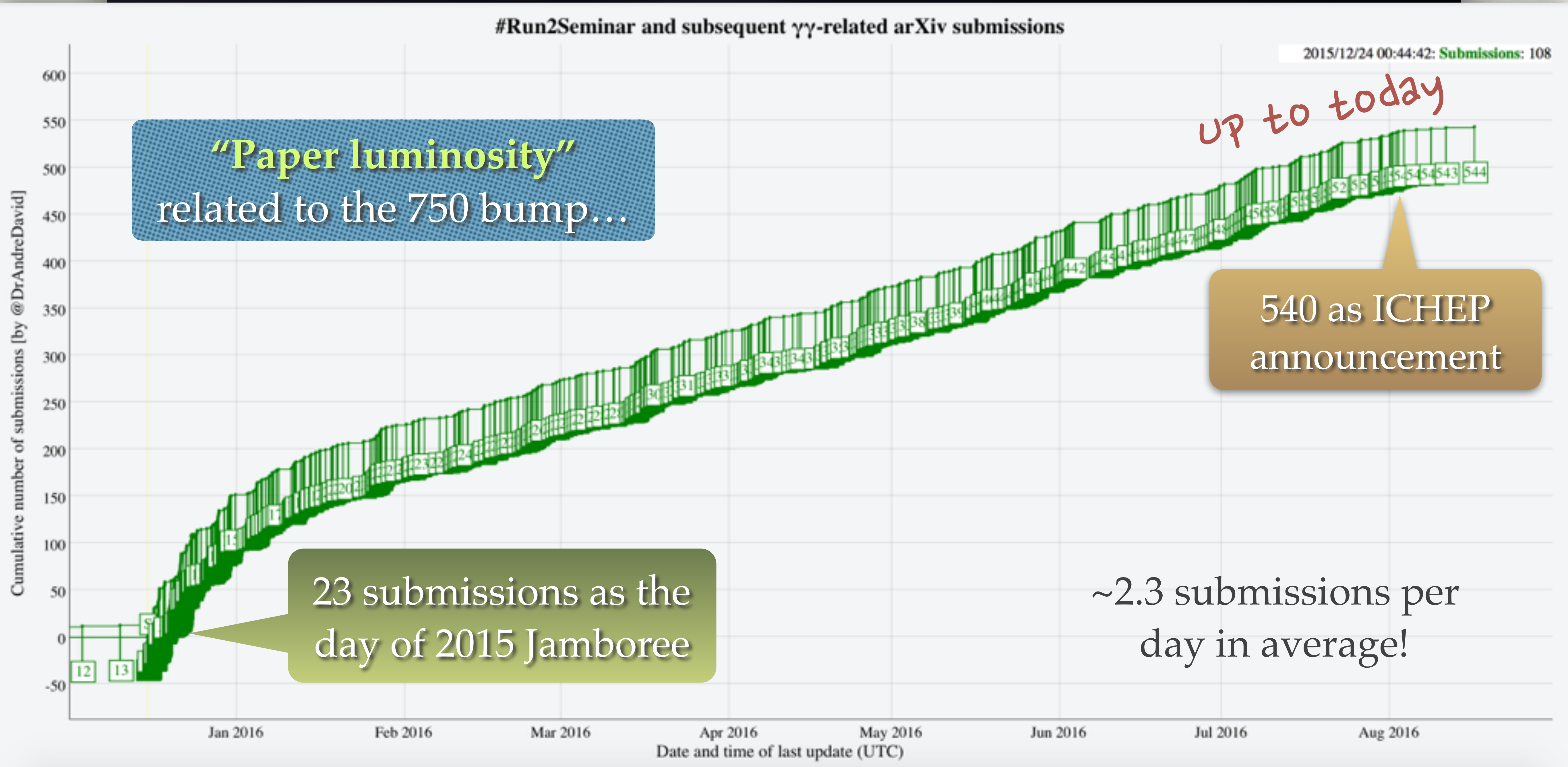
- Simple kinematic selection and categorization in the analysis:
  - events categorized in Barrel-Barrel (EB-EB) and Barrel-Endcap (EB-EE)
- Statistical interpretation based on the m spectrum for the search of diphoton resonances.
- **Maximum local significance: 2.6σ at 760 GeV (1.2σ global)**







The X(750) Saga



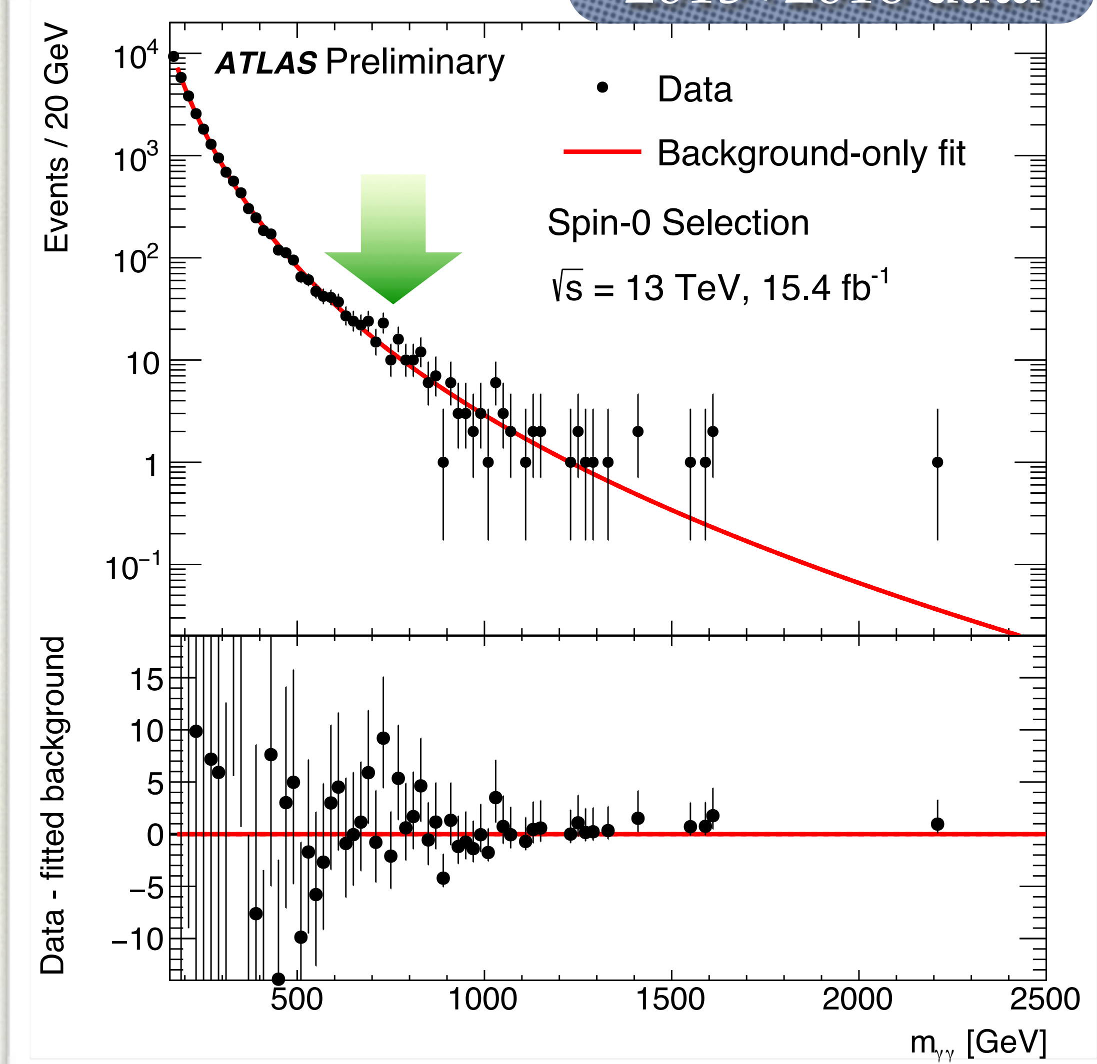
By A. David: http://jsfiddle.net/adavid/bk2tmc2m/show/

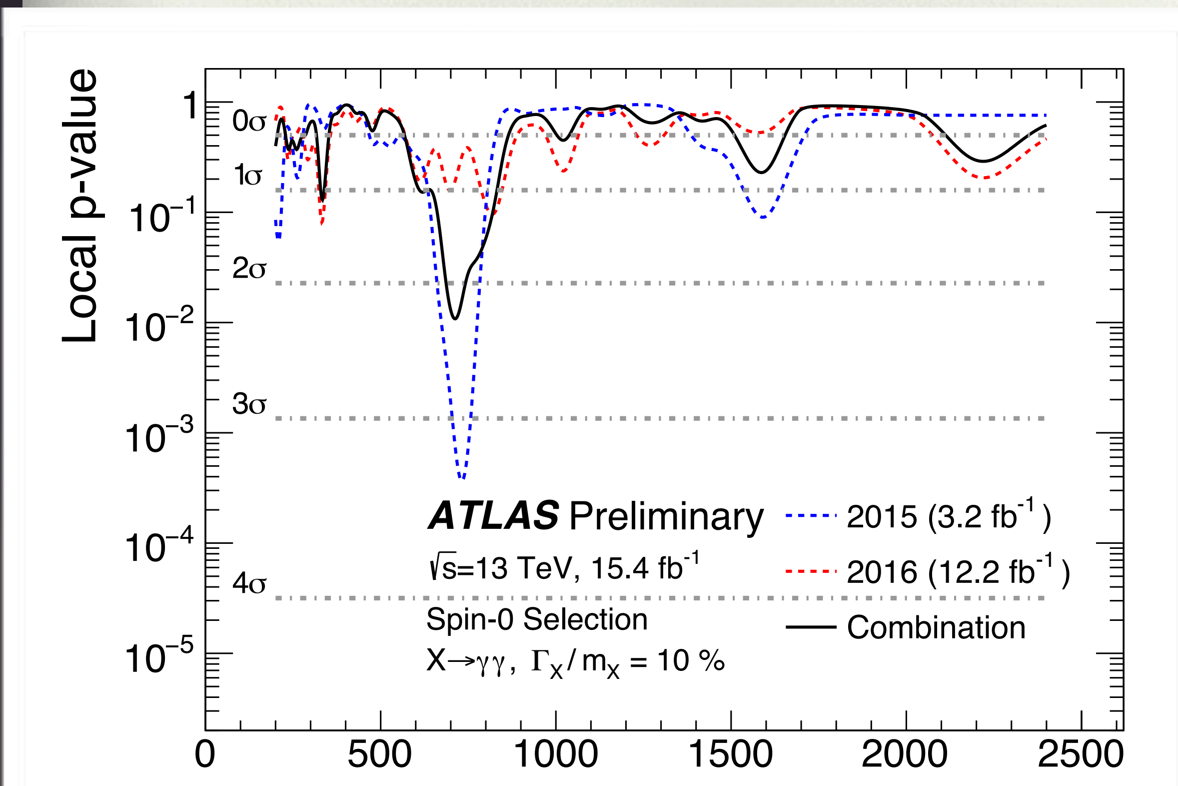
“We are just very hungry…of something new!”

ATLAS Update @ ICHEP

- 2016 data: no clustering around 730-750 GeV with 3.8x more data.
- 2016 data consistent with 2015 at the 2.7σ level
- **Appears that the 2015 excess was a statistical fluctuation.**

2015+2016 data





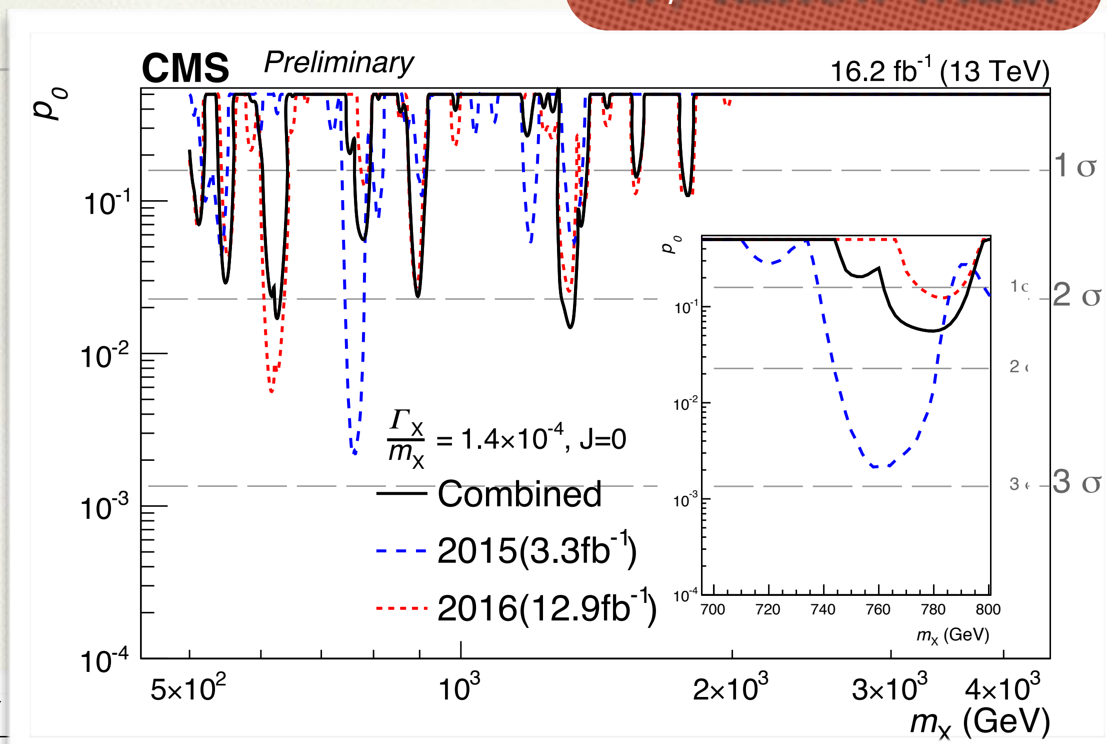
ATLAS p-value scan

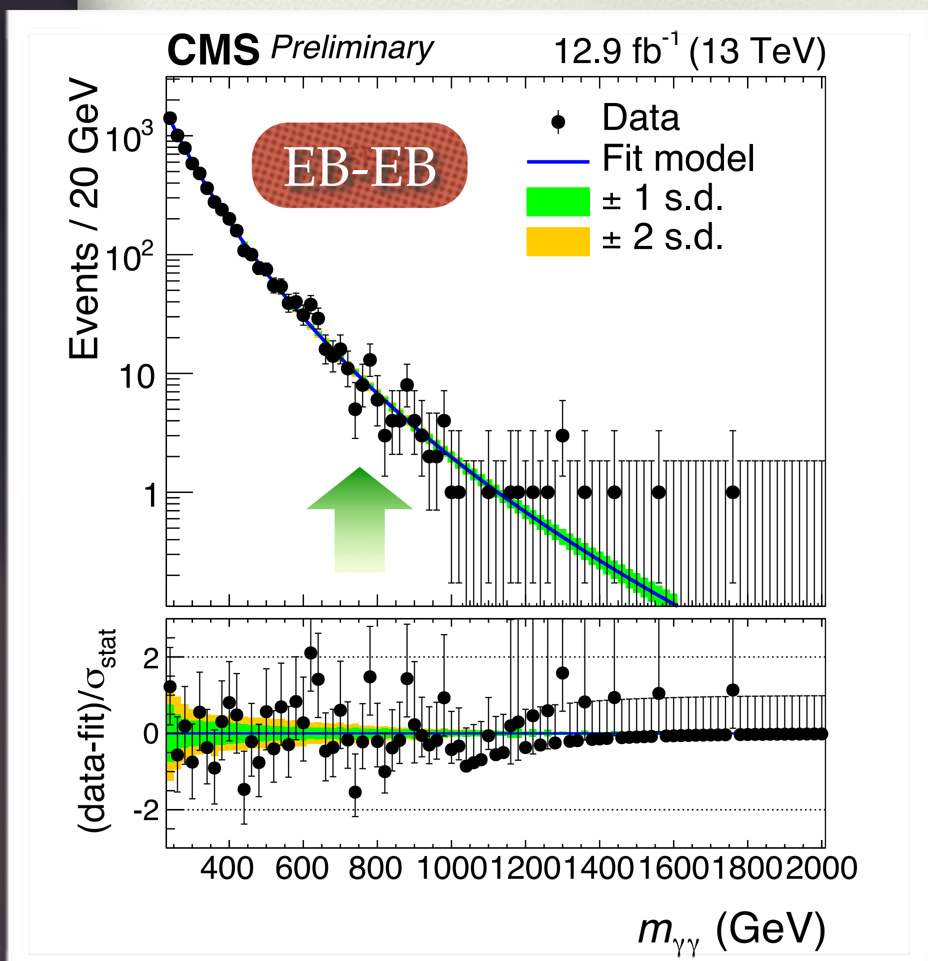
Combining 2015+2016 data
Small excess at 710 GeV (Γ/m~10%)
Local significance 1.4σ, global <1σ

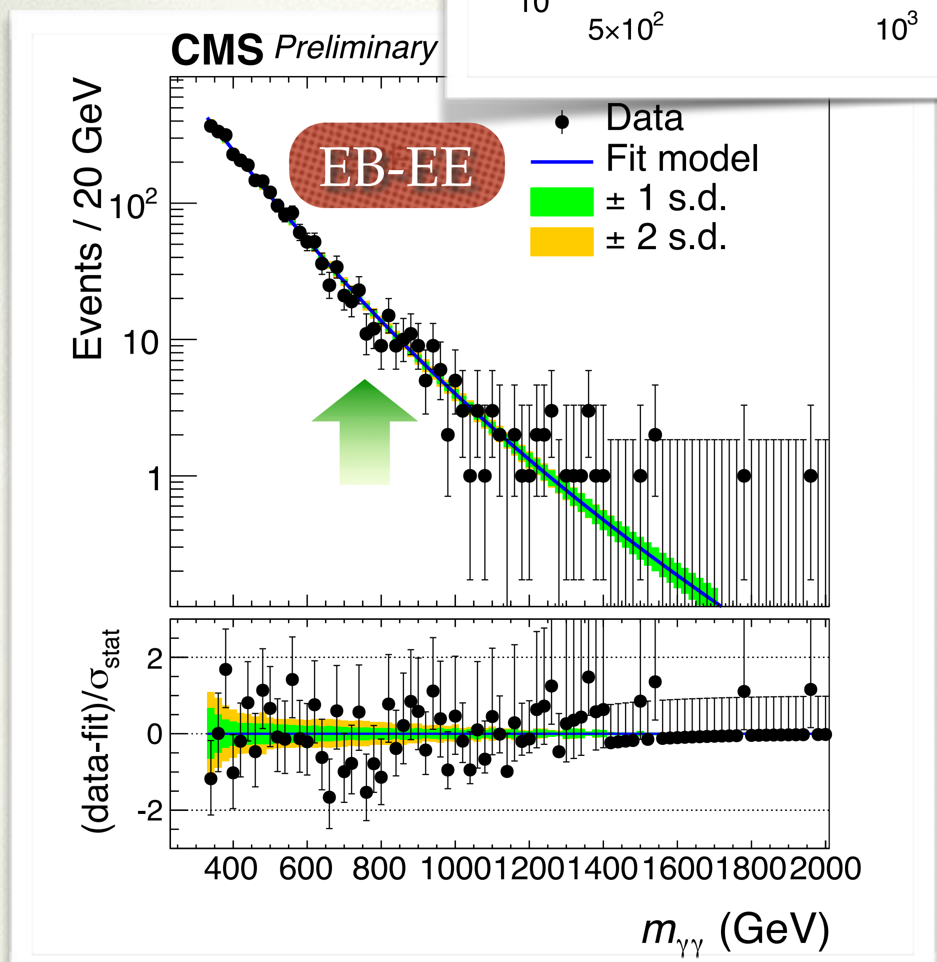
CMS Update @ ICHEP

- Data consistent with SM expectations.
- Modest excess presented based on 2015 (+ 8TeV) data in the region around **750 GeV not confirmed by the new data**

CMS p-value scan w/ narrow width





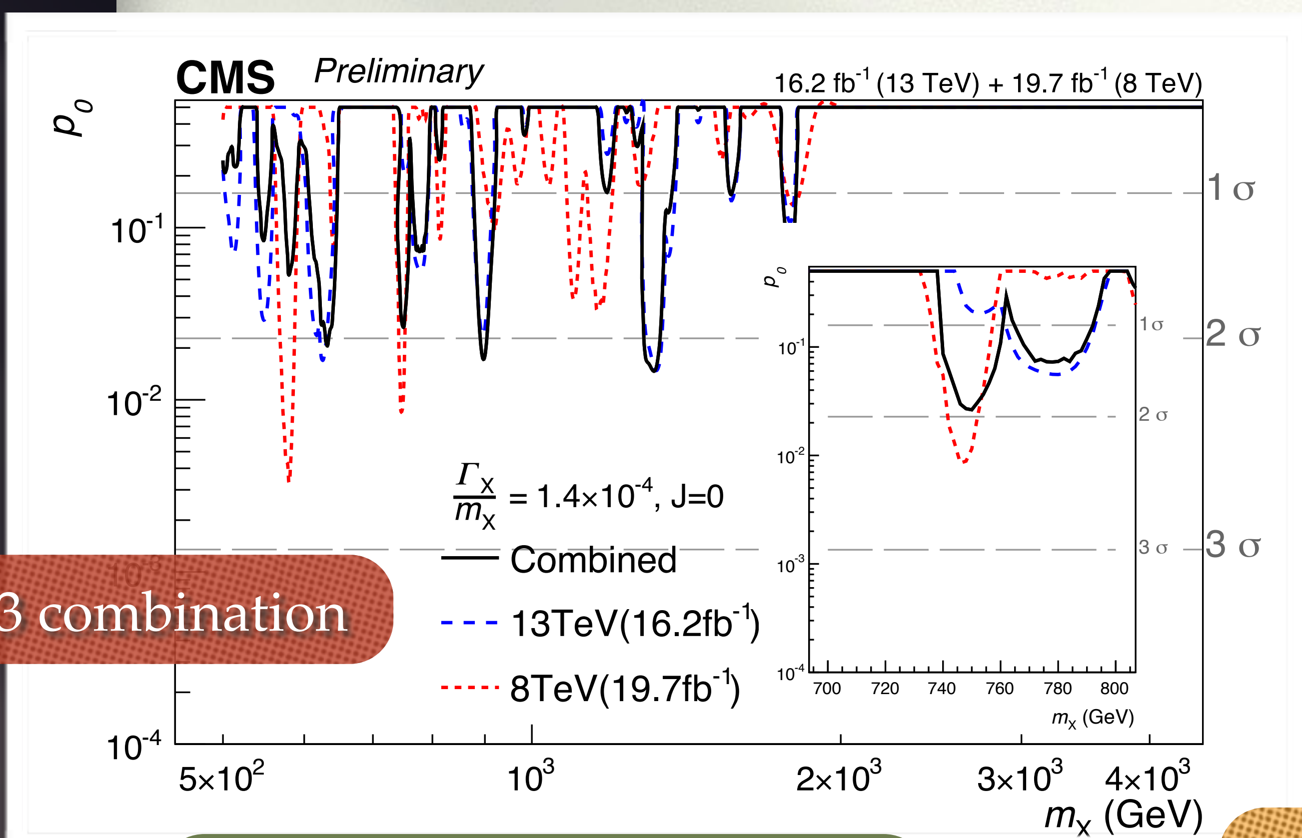


Local significance
2.9σ in 2015 data
⇓
<1σ in 2015+2016

CMS Update @ ICHEP

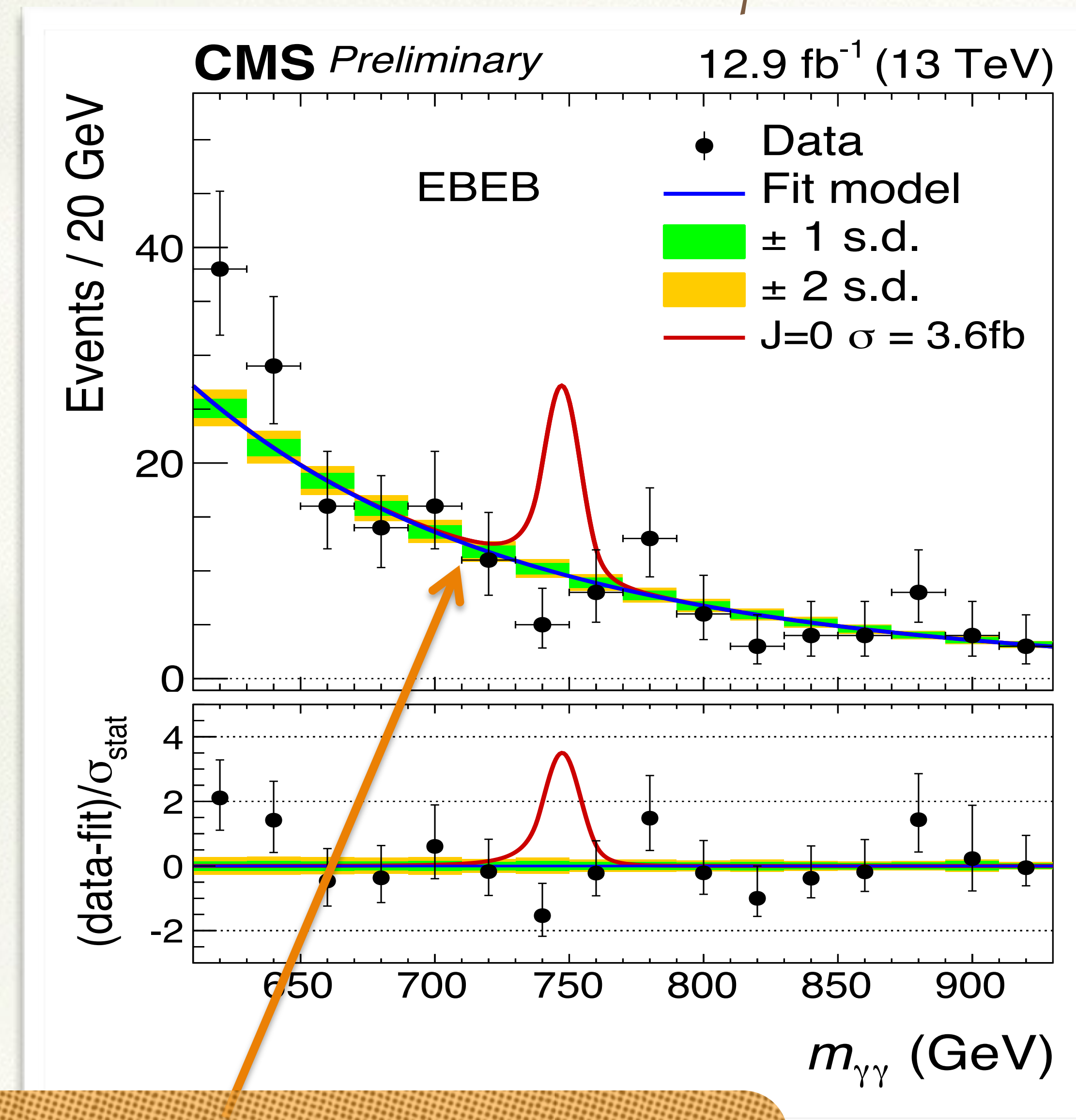
- Compatibility of data tested with a likelihood ratio:
  - 13TeV data only: 2.7σ
  - 8TeV+13TeV data: 2.4σ

Basically we found a hole rather than a peak…



8+13 combination

Local significance <2σ in 2012+2015+2016



A signal with cross-section as the largest excess in 2015+8TeV would look like this

X(750): A lesson in statistics

- In fact, we do know the "global" significance is not very high (maximum ~2σ), even in the best setup since the end of 2015 jamboree announcement. A 2σ excess can disappear easily.
- A 3.9σ "local" significance is nothing more than an entertaining "hint".
- This exactly the reason why we have set the condition of discovery to 5σ (+ cross check experiment!).
- No needs of over-reaction here.

3 mins before the "official death of X(750)"

This is exactly what we need to do…

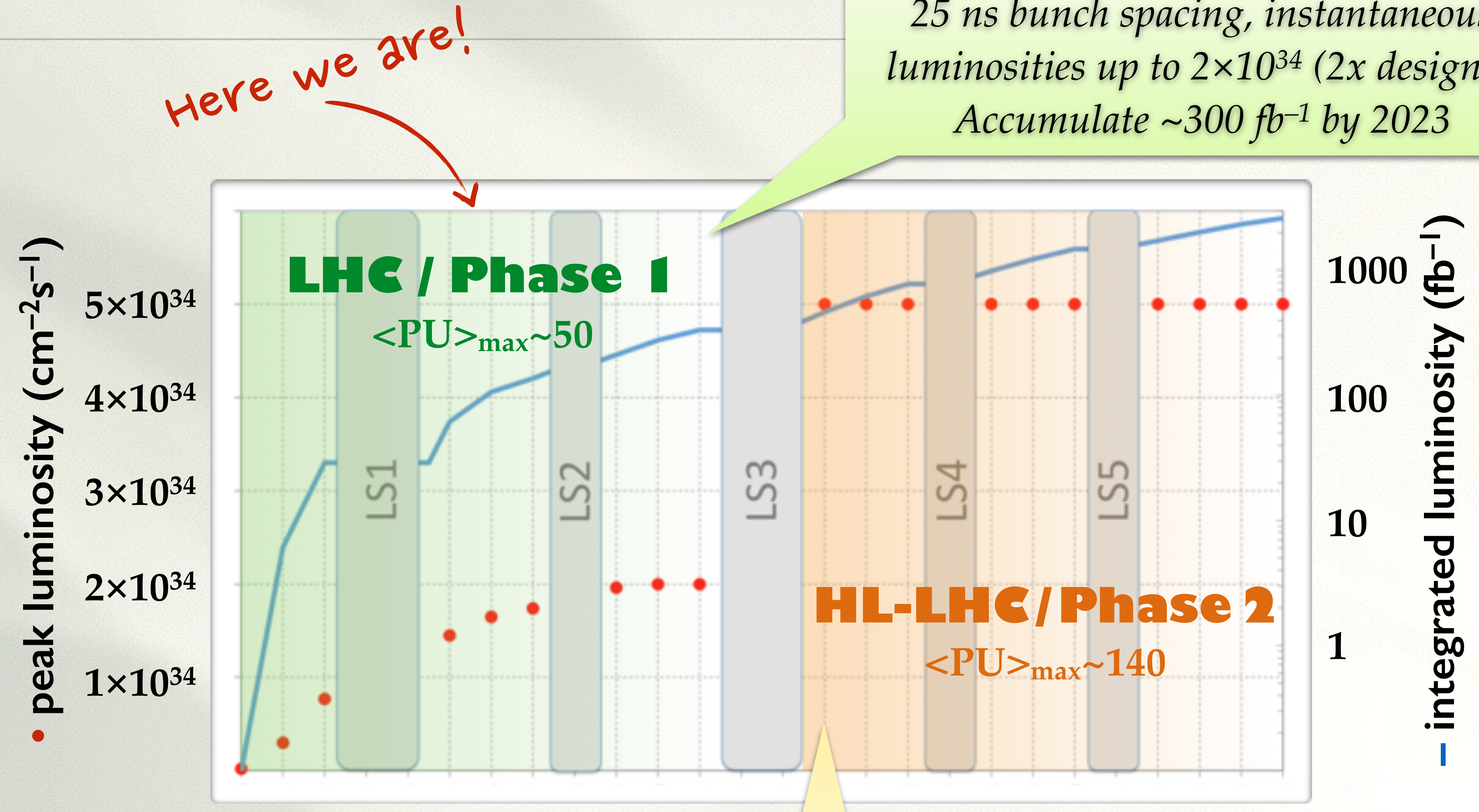
Summary

- We have quickly went though the major new results from CMS and ATLAS experiments.
- The data took at LHC Run-II 13 TeV already have a better sensitivity than Run-I data.
- The Higgs boson has been confirmed with the new data set. The Standard Model is still going strong(er).
- All other hints / excesses found in Run-I or early Run-II fade away with higher statistics.
- Much more data are coming, sooner than our original expectations! Just work hard and keep our fingers crossed.

Toward the Future

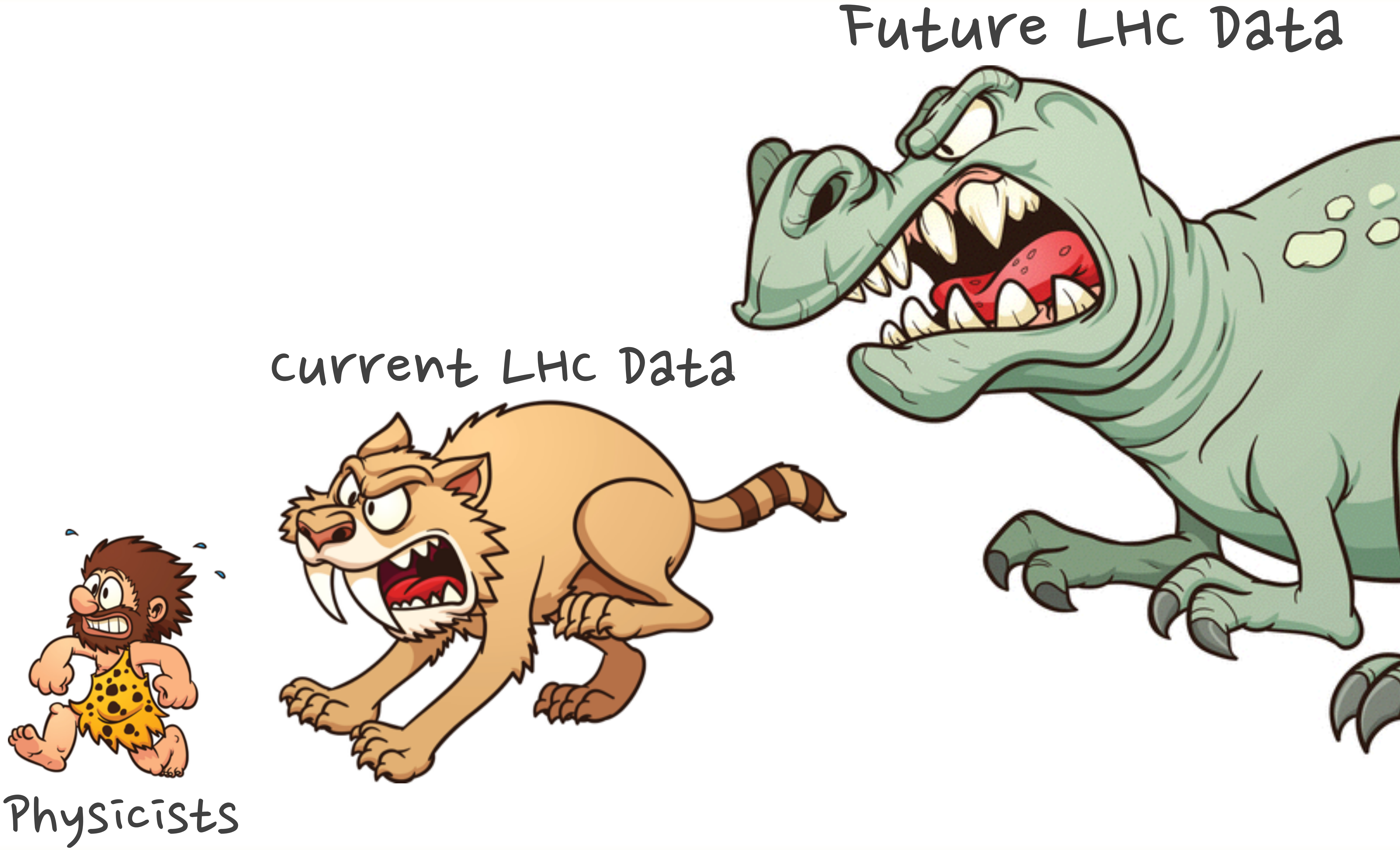
LHC operation up to LS3 (2023)

25 ns bunch spacing, instantaneous luminosities up to 2×10^{34} (2x design!). Accumulate ~300 fb^{-1} by 2023



HL-LHC operation beyond LS3 (2025+)

New low-β triplets and crab-cavities to optimize the bunch overlap at the interaction region. Level the instantaneous luminosity at 5×10^{34} from a potential peak value of 2×10^{35}. Deliver ~250 fb^{-1} per year for 10 years of operation, accumulate up to 3000 fb^{-1}.



Experimental data are not our pets anymore…

Backup Slides