What is hiding at 750 GeV?

(

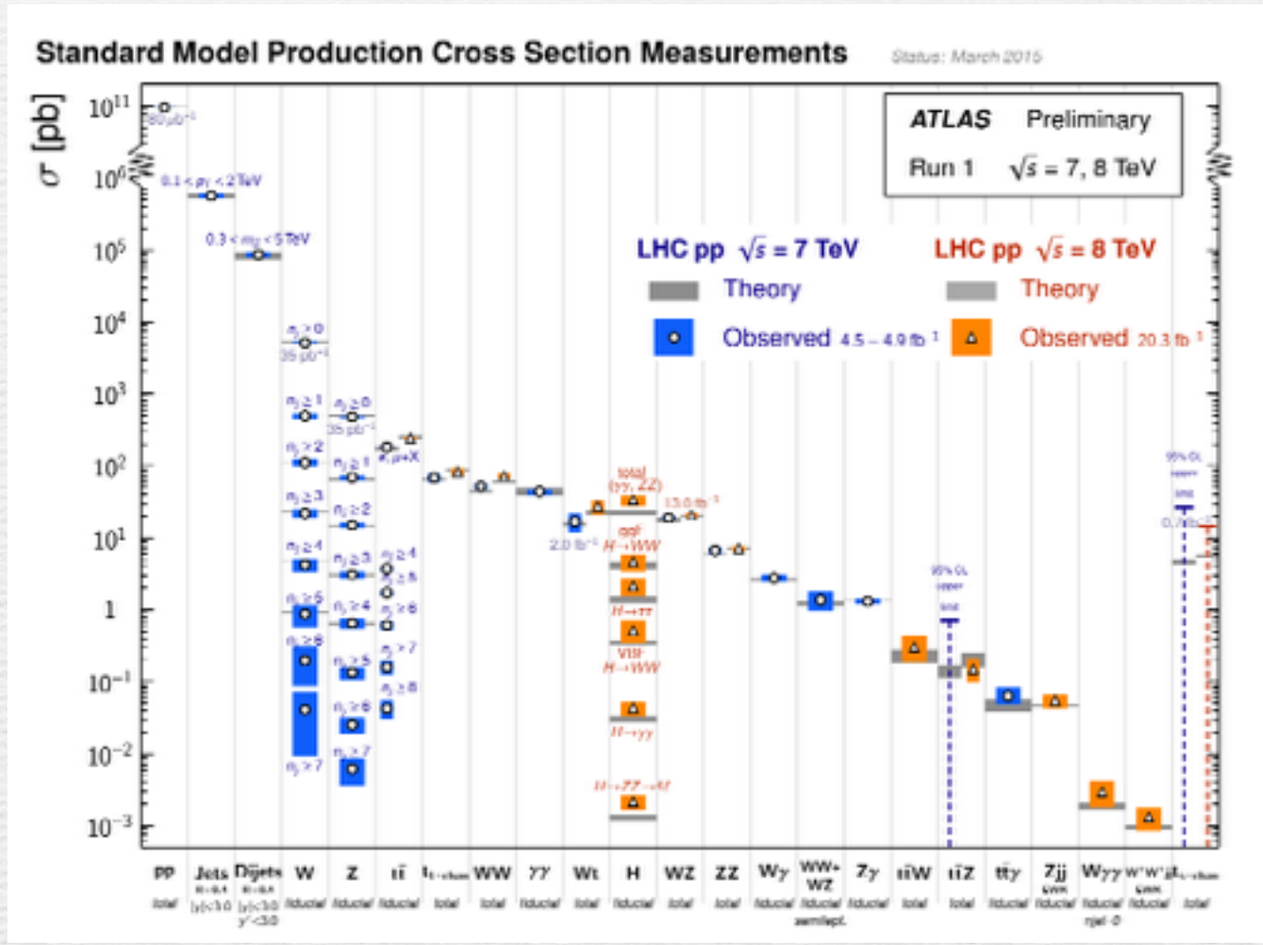
Veronica Sanz (Sussex)

DESY, Hamburg

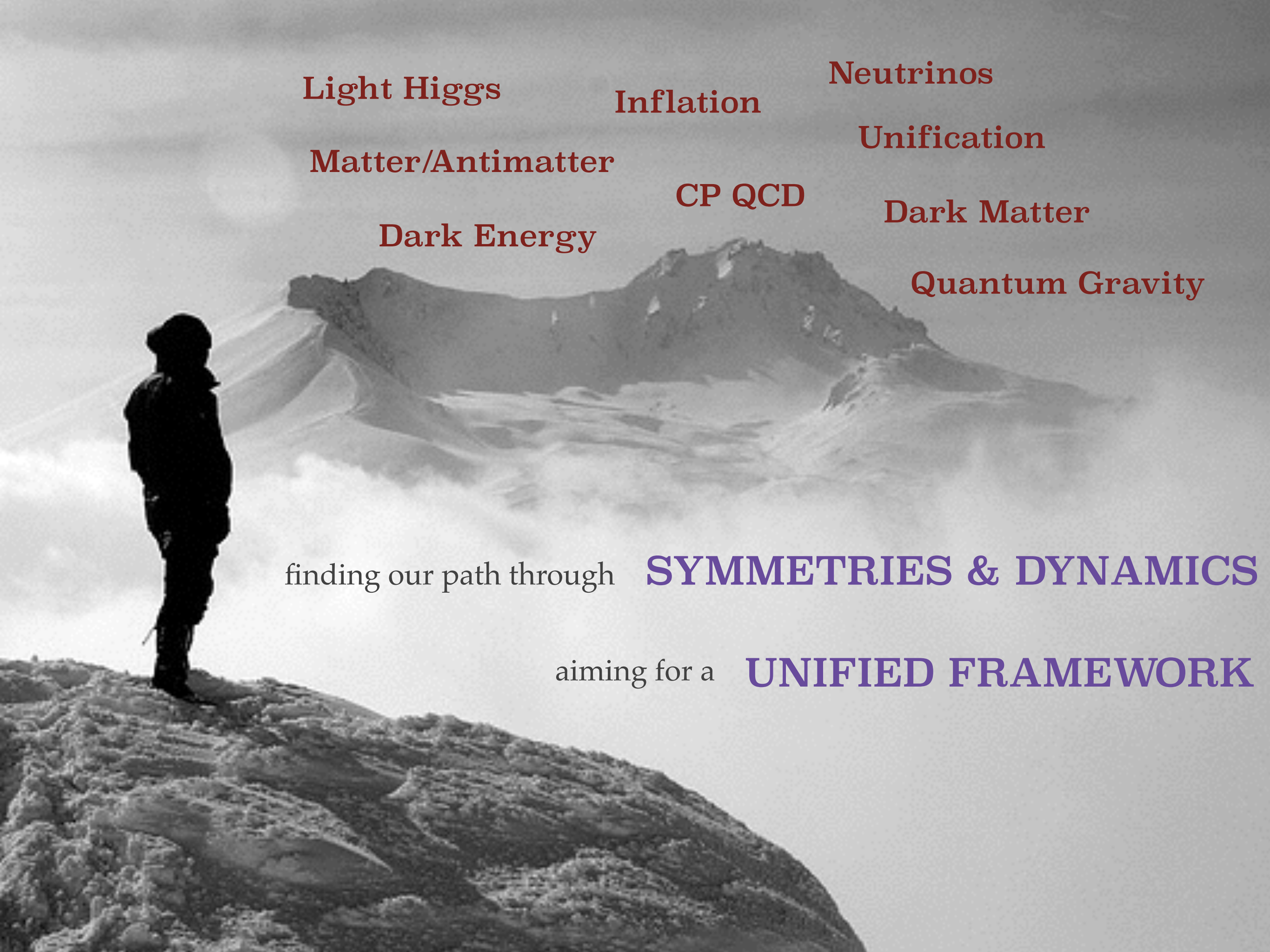
Challenges

Standard Model of Particle Physics

Predictive, successful paradigm being tested to higher and higher precision at the LHC



Based on QFT, symmetries (global/gauge) and consistent ways to break them
Foundation from which we develop theories beyond the SM


Light Higgs
Inflation
Neutrinos
Unification
Matter/Antimatter
CP QCD
Dark Matter
Dark Energy
Quantum Gravity
finding our path through SYMMETRIES & DYNAMICS
aiming for a UNIFIED FRAMEWORK

Example of unified framework: Supersymmetry

Unifies concept of bosons and fermions

Light scalar bosons

Candidates for Dark Matter

Unification of strong/EM/weak forces

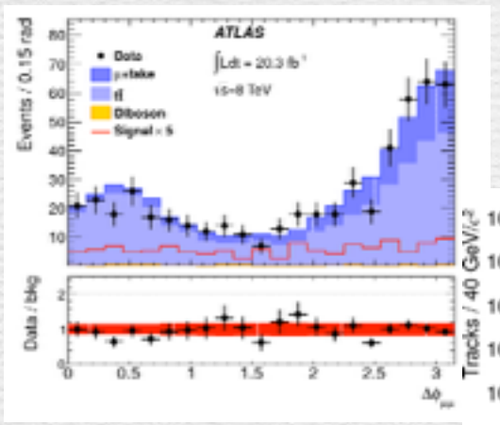
Matter/Antimatter asymmetry

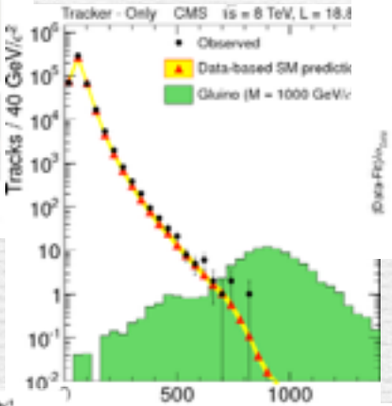
Component of Quantum Gravity

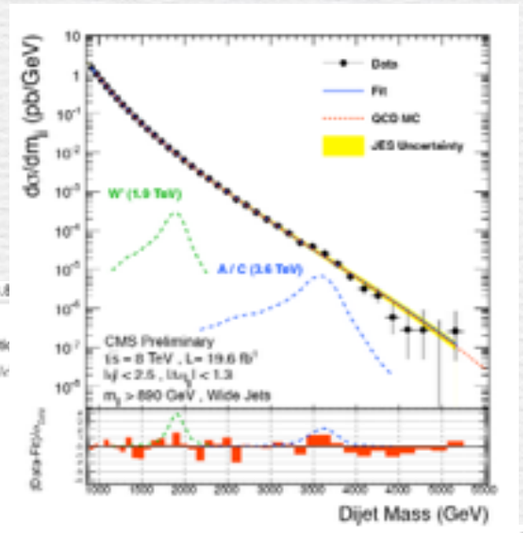
New mechanisms
Inflation, Neutrinos and Dark Energy

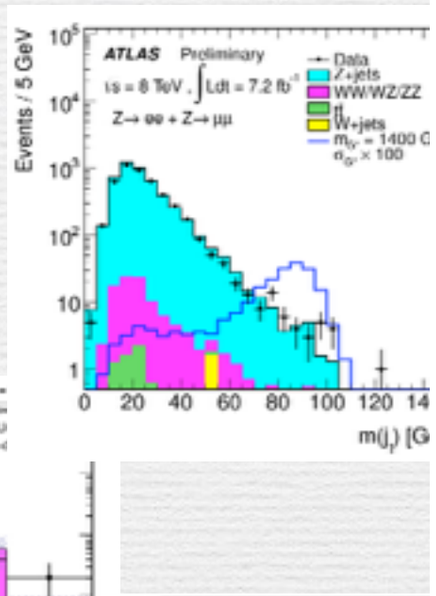
The discovery of SUSY at LHC first step to understand many aspects of Nature

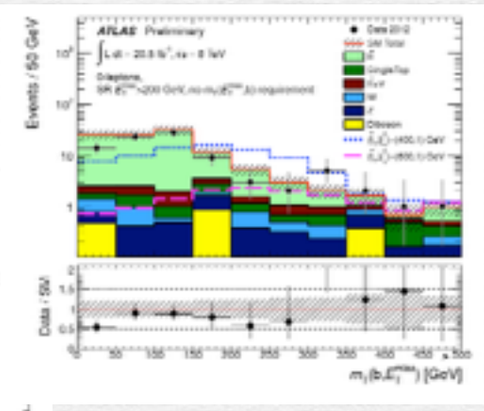
Nature, meanwhile

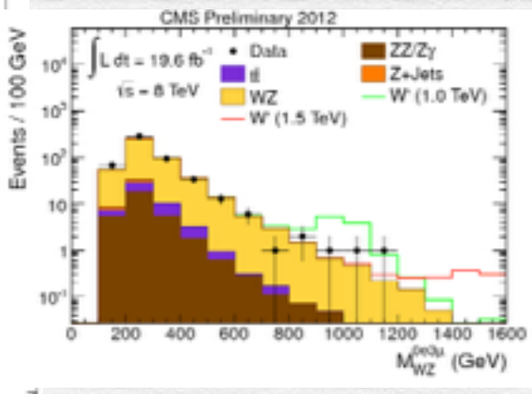


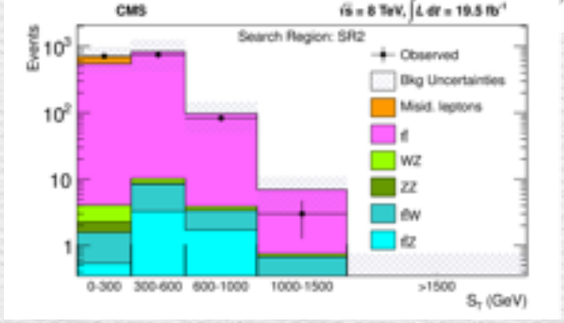


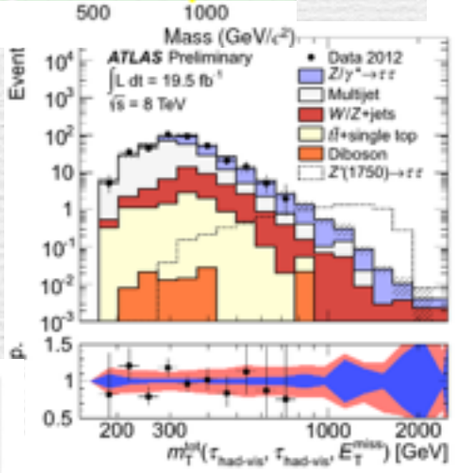


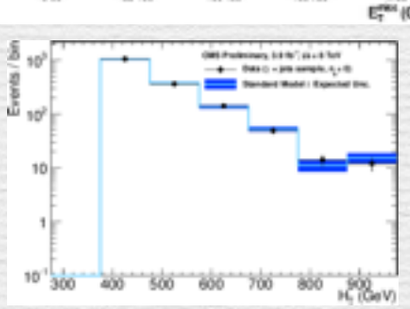


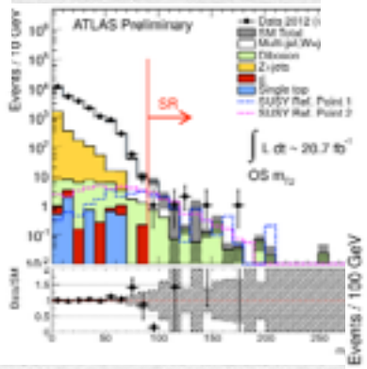


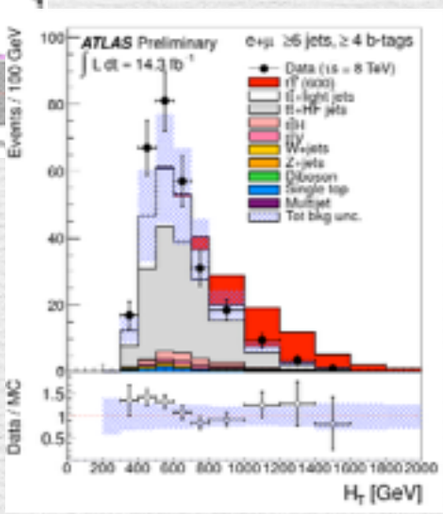


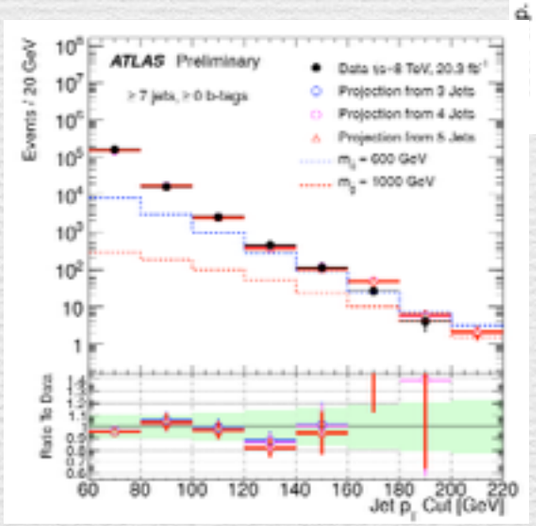


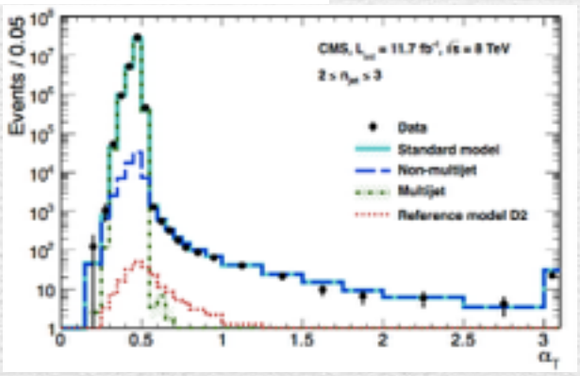


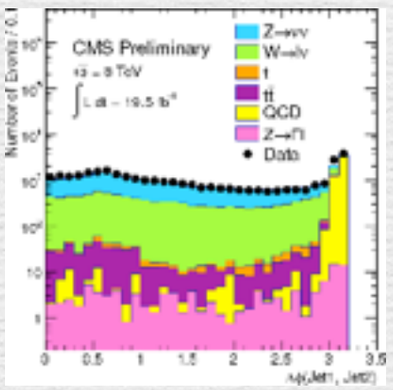




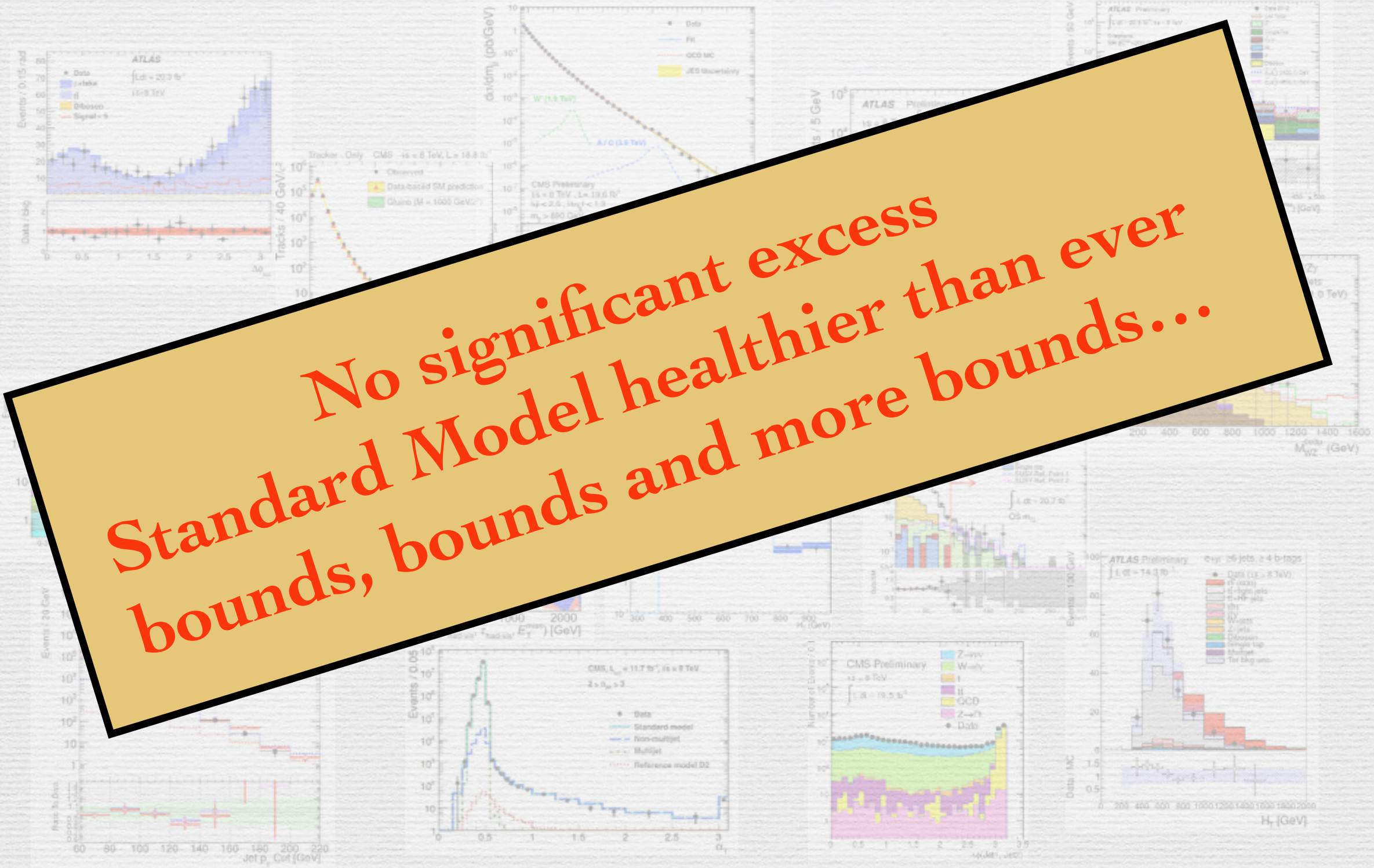








Nature, meanwhile



No significant excess
Standard Model healthier than ever
bounds, bounds and more bounds…

The diphoton excess characteristics

(Theory) Non-trivial
(Experiment) extremely clean

What is it?

An excess in a channel with two photons at an invariant mass of about 750 GeV

Interpretation

scalar, e.g. more Higgses

tensor, e.g. spin-two graviton

What we knew before Dec 2015

Run 1: CMS already a (less significant) excess,
ATLAS did not show above 600 GeV

Dec 2015

excess in both ATLAS and CMS Run2 data

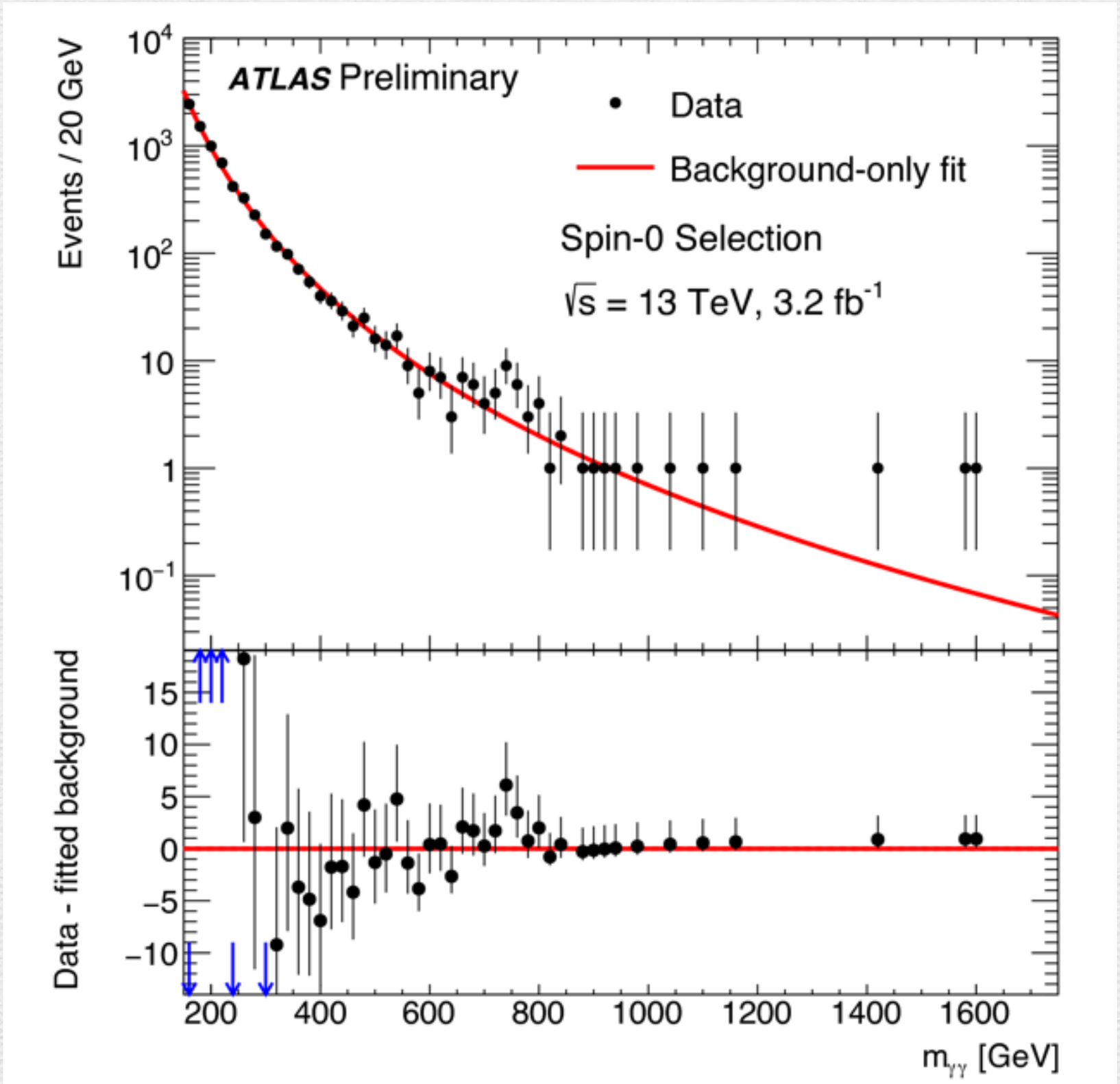
Moriond 2016

ATLAS and CMS results for s=0 & 2
narrow and wide

ATLAS and CMS analysis note public

CMS update including improvements in mass resolution and 0T data-set

By eye

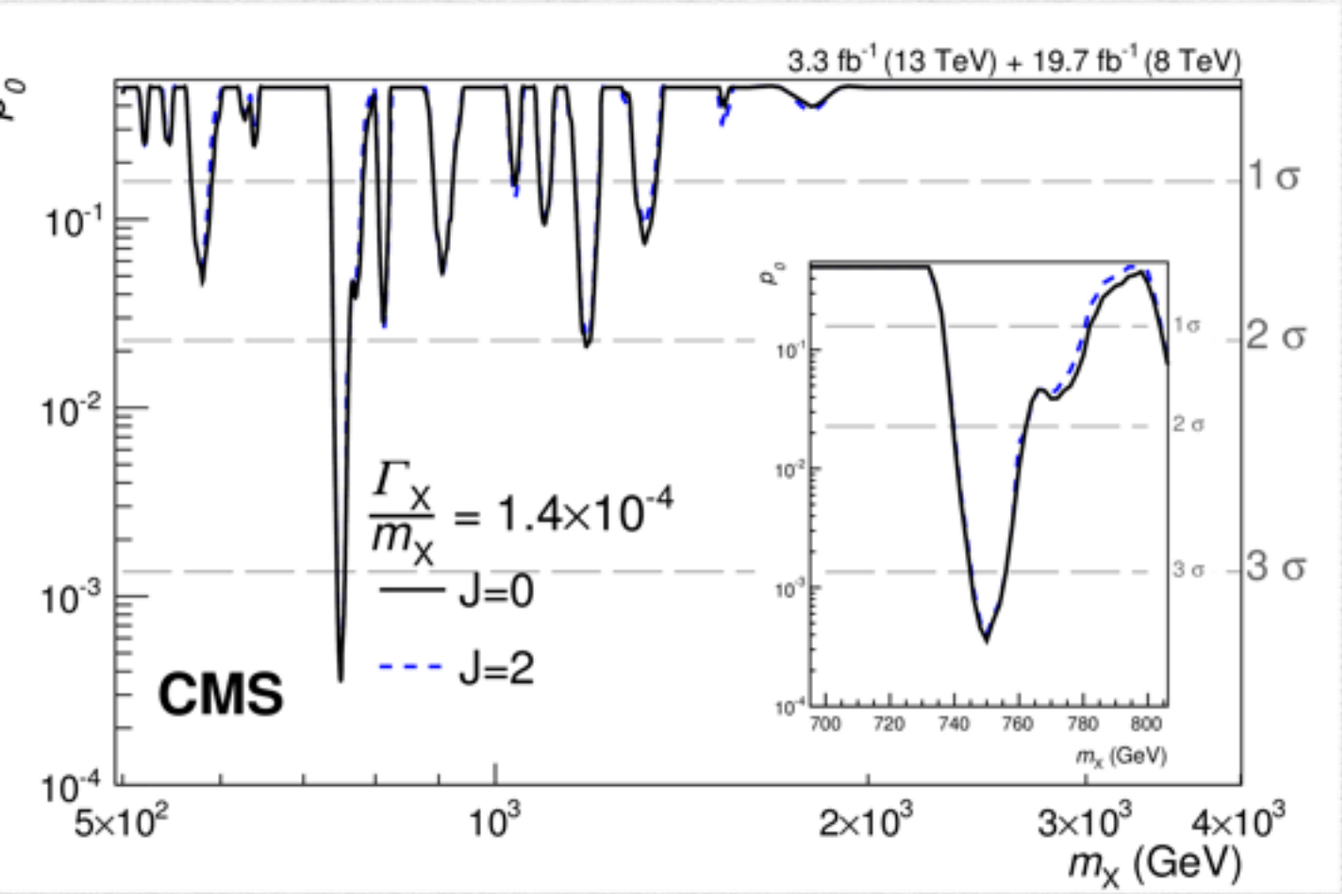

ATLAS Preliminary
Data
Background-only fit
Spin-0 Selection
√s = 13 TeV, 3.2 fb-1
Events / 20 GeV
Data - fitted background
mγγ [GeV]

Significance

ex. interpreted as a gluon-fusion narrow scalar
(similar results for spin-two)

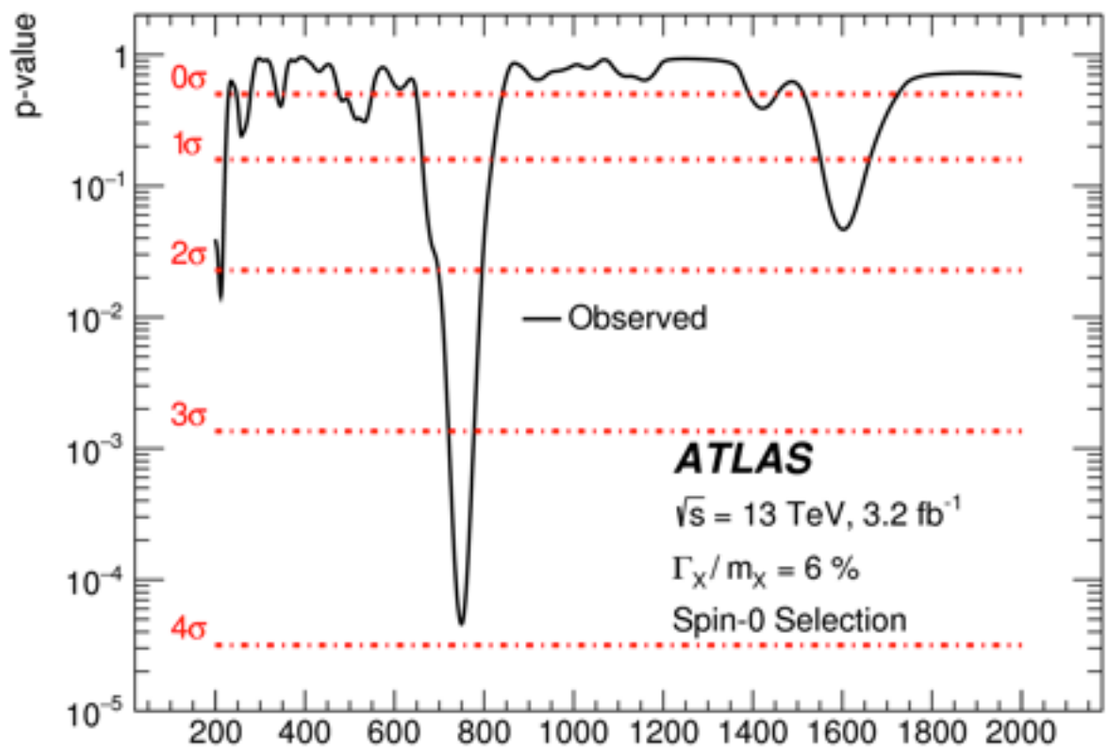
CMS

3.4



ATLAS

3.6

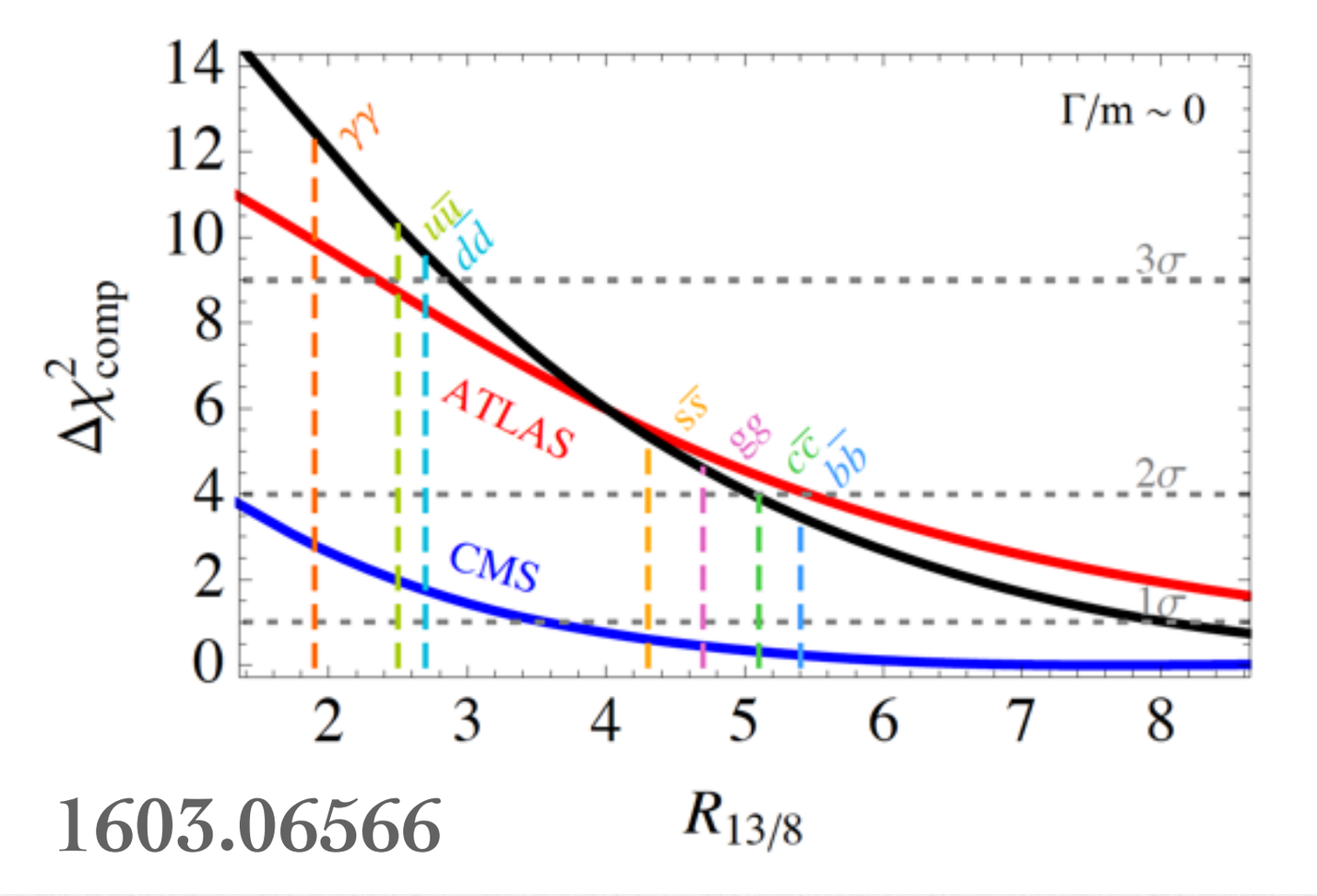


no Run1 combination

(remember LEE should be taken only once)

Production

Kick from 8 to 13 TeV
from non-valence quarks or gluons



1603.06566

sizeable cross section & narrow resonance

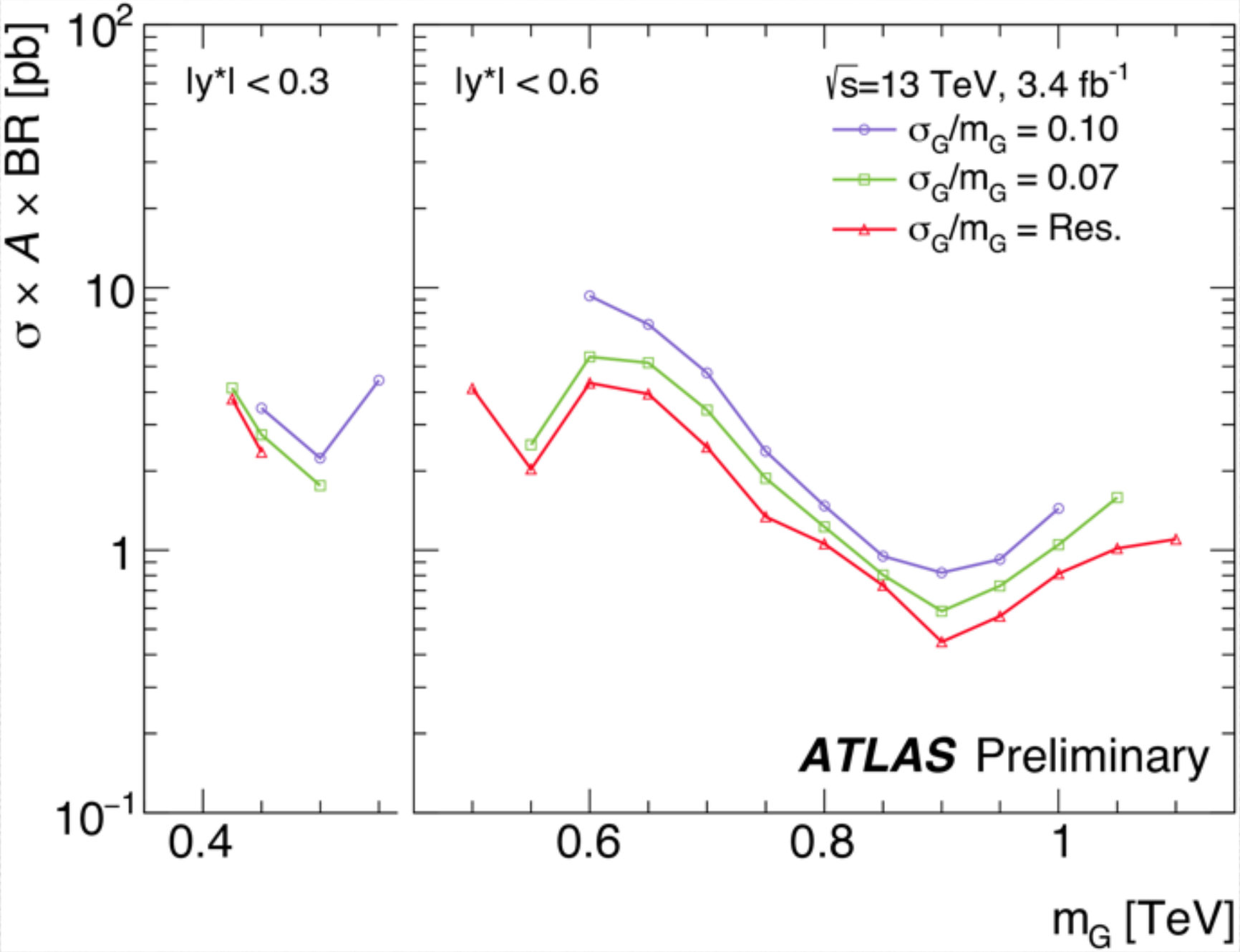
could indicate gluon-initiated

but other productions, incl diphoton still an option

Production

Gluon fusion leads to dijet limits

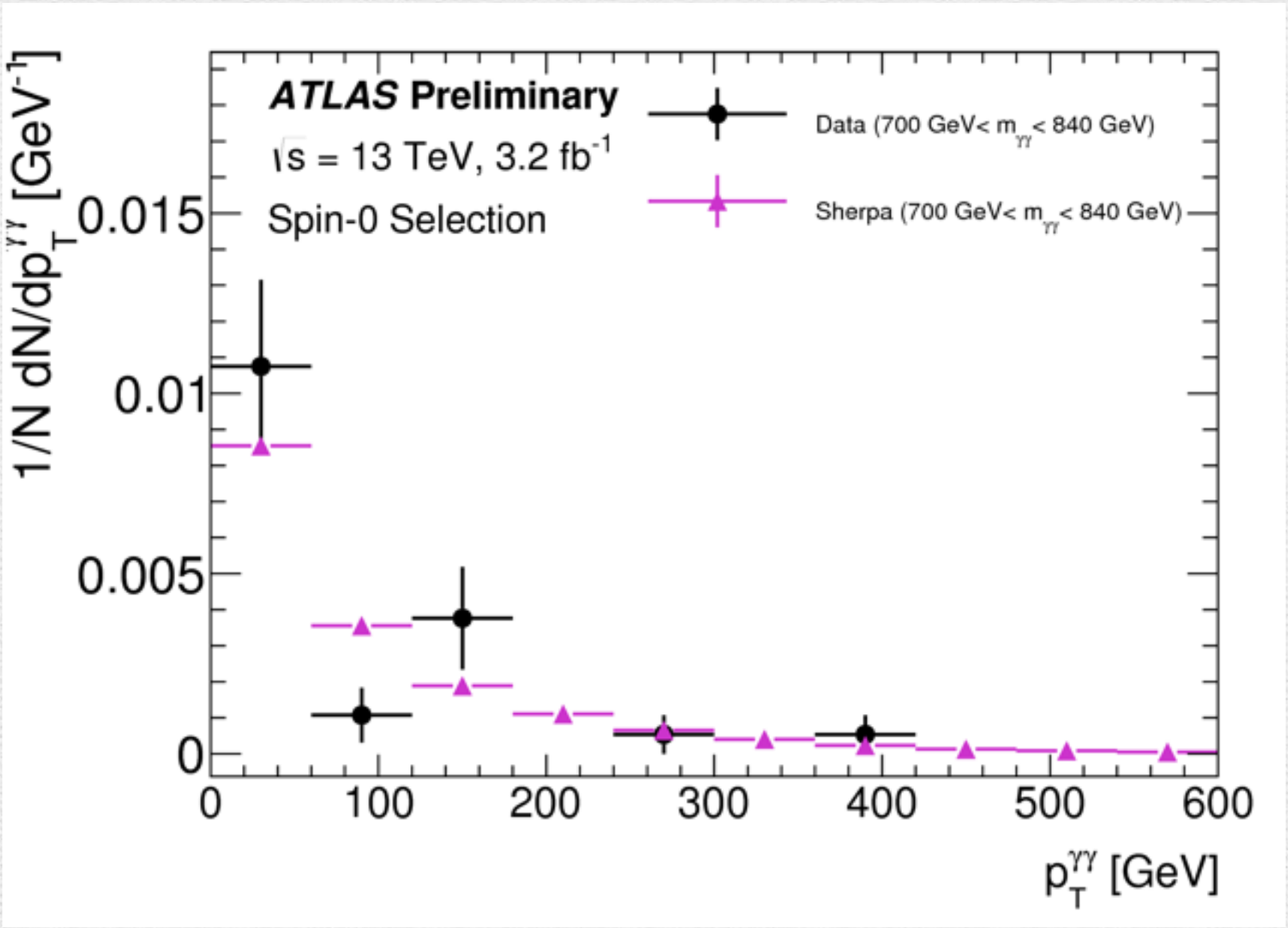
Recent improvements: new analysis at low mjj



Kinematics

Is this signal coming along other objects?

1. It doesn't recoil (much)



Kinematics

Is this signal coming along other objects?

2. No electrons or muons

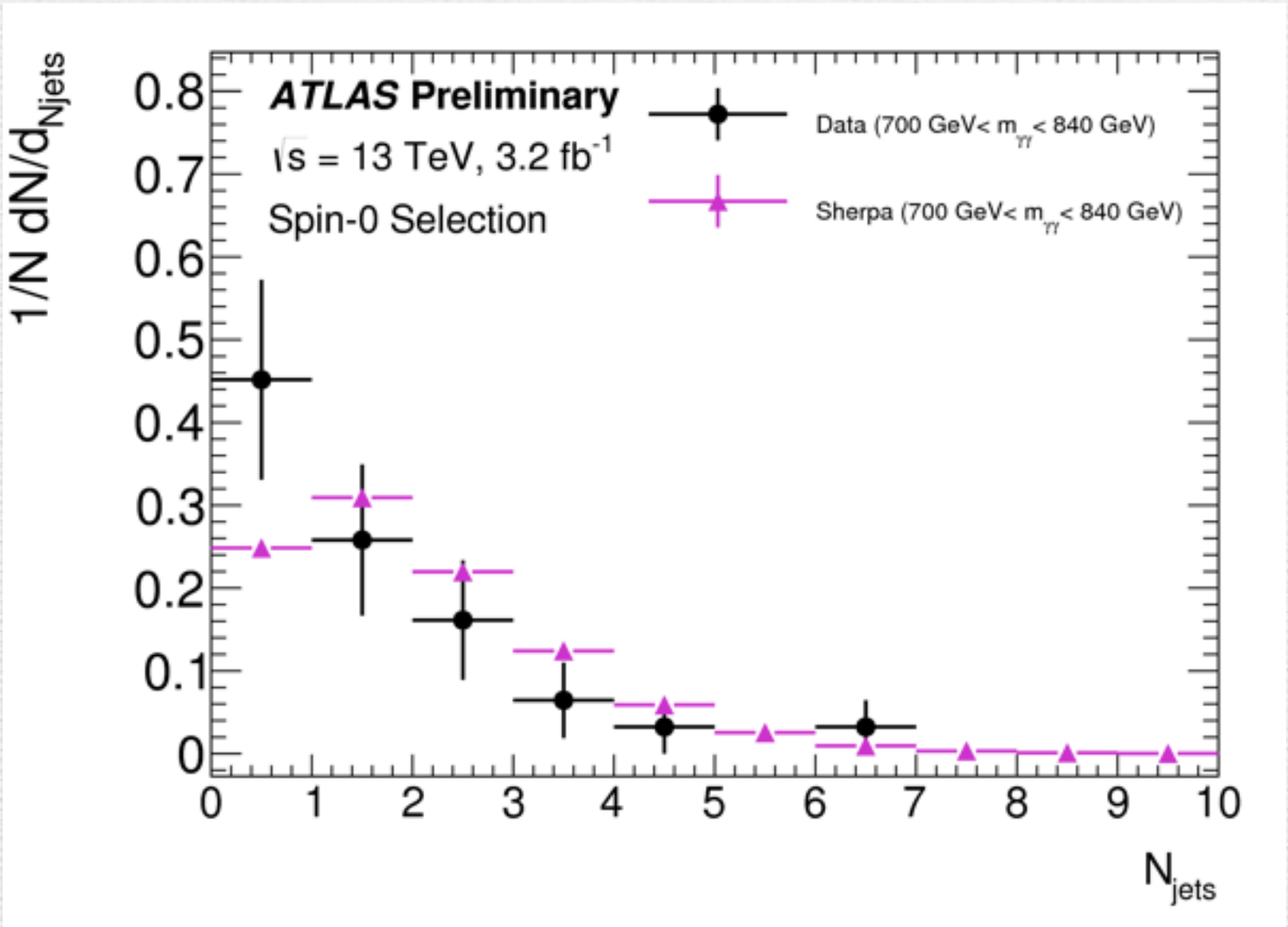
e.g. from ATLAS analysis

"In addition, no electron or muon candidates have been found, with $p_T > 10$ GeV and $|\eta| < 2.$ (electrons) or 2.7 (muons) in the events with invariant masses between 700 GeV and 840 GeV.

Kinematics

Is this signal coming along other objects?

3. No high-pT jets

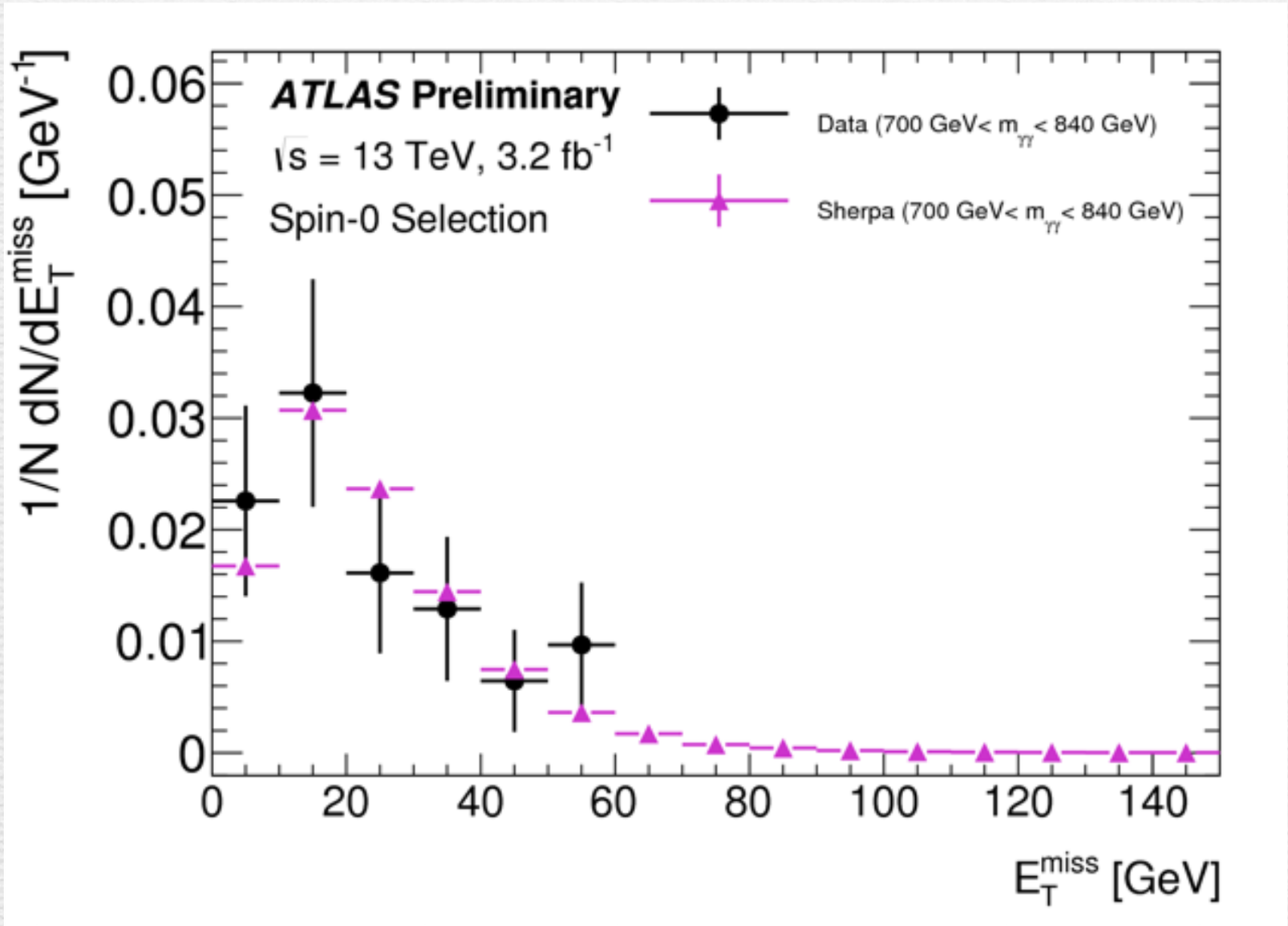


jet anti-kT 0.4
pT> 25, eta< 4.4

Kinematics

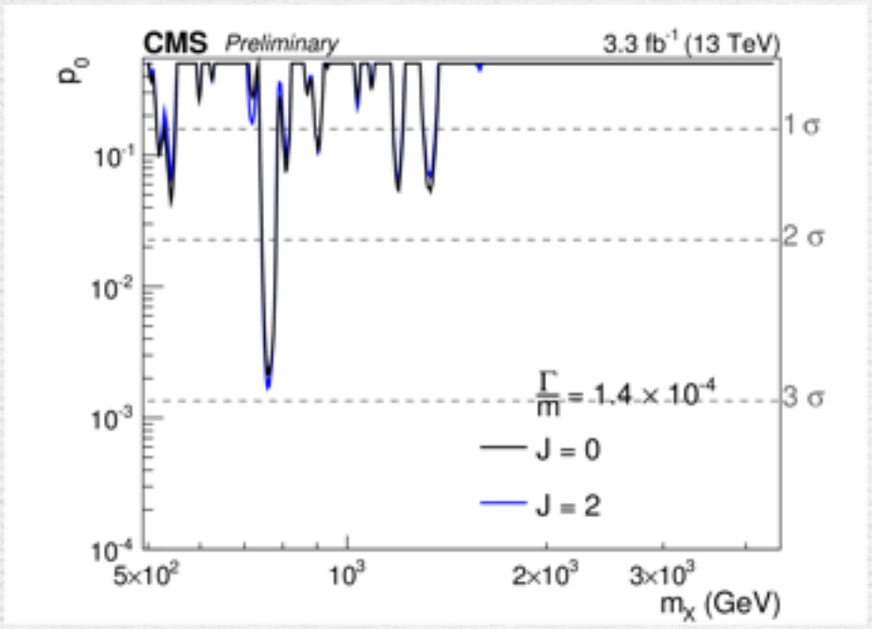
Is this signal coming along other objects?

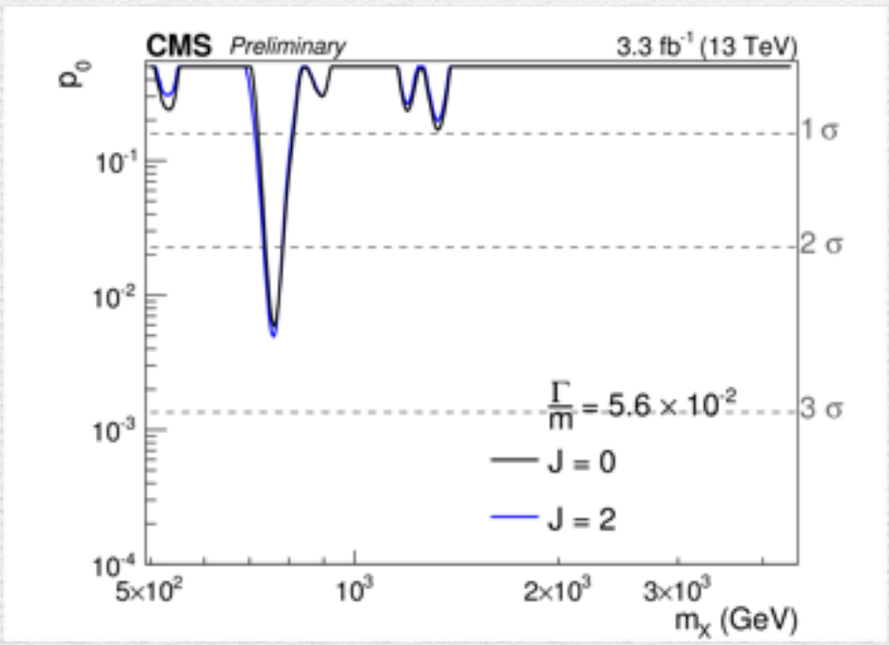
4. No MET



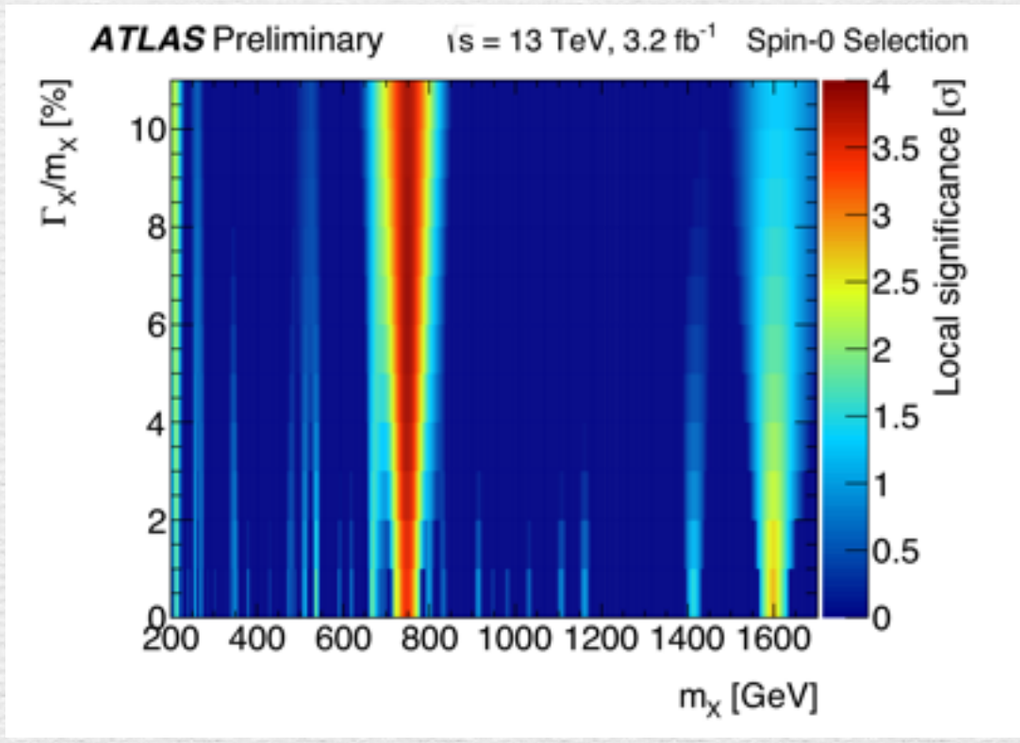
Kinematics
Narrow or wide?

CMS
prefers narrow





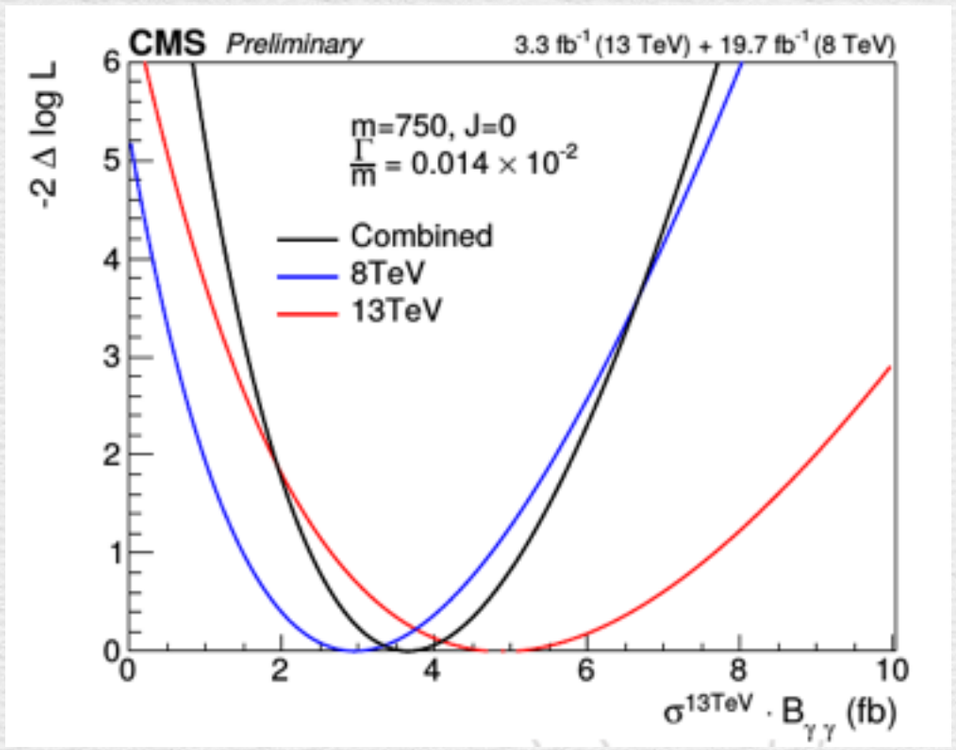
ATLAS
slight preference wide
(0.3 sigma)

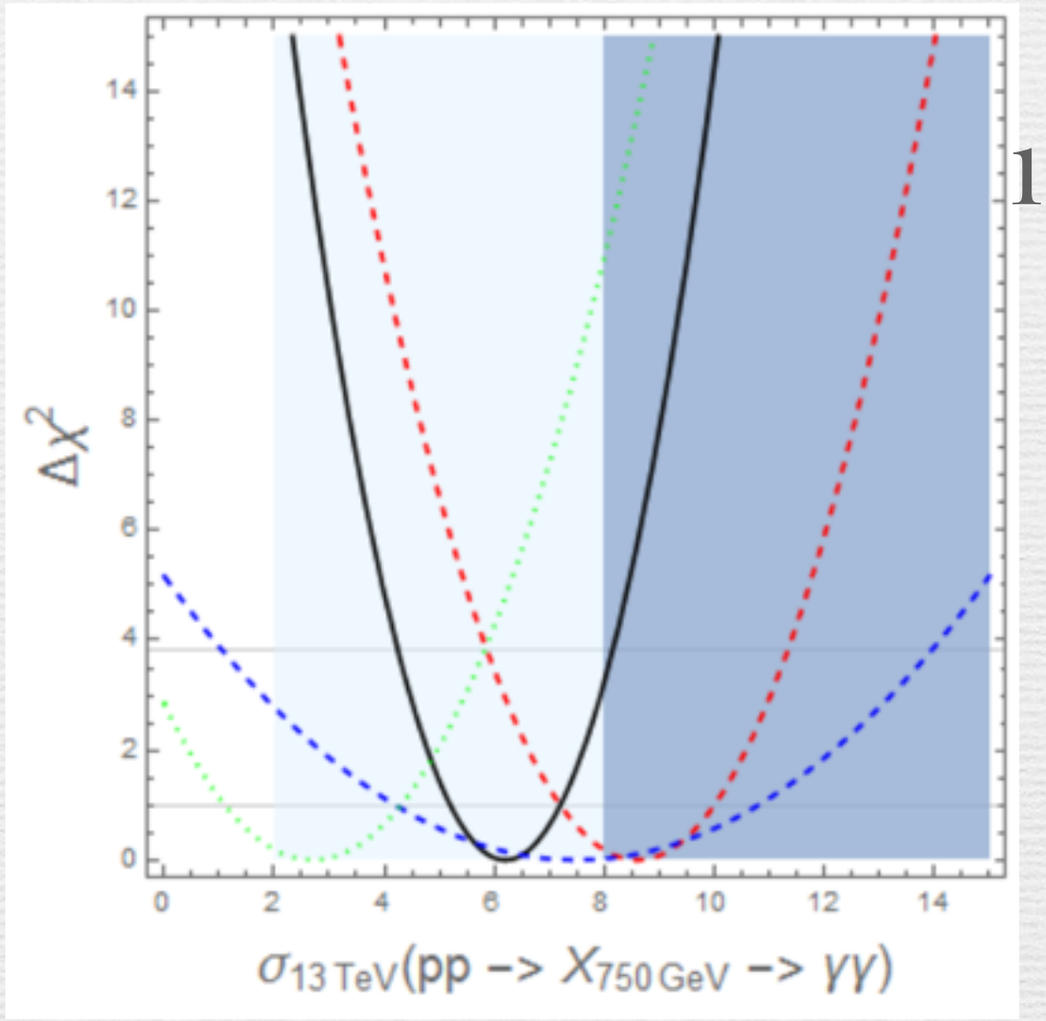


overall
no preference for wide

Signal strength

compatibility? Run1 vs Run 2
and CMS vs ATLAS





1512.05327

CMS1

CMS2

ATLAS2

theorists combination in Dec

6.2 ± 1.0 (fb) (local)

Other final states

light Higgs into diphotons is not like the 750 GeV

Higgs below the threshold of WW, ZZ
suppressed BRs

A heavy resonance in two photons?
it couples to SM gauge interactions we expect
WW, ZZ and Zgamma (and hh)

diphotons means there must be at least one non-zero
BR(Z-gamma) and/or BR(ZZ)

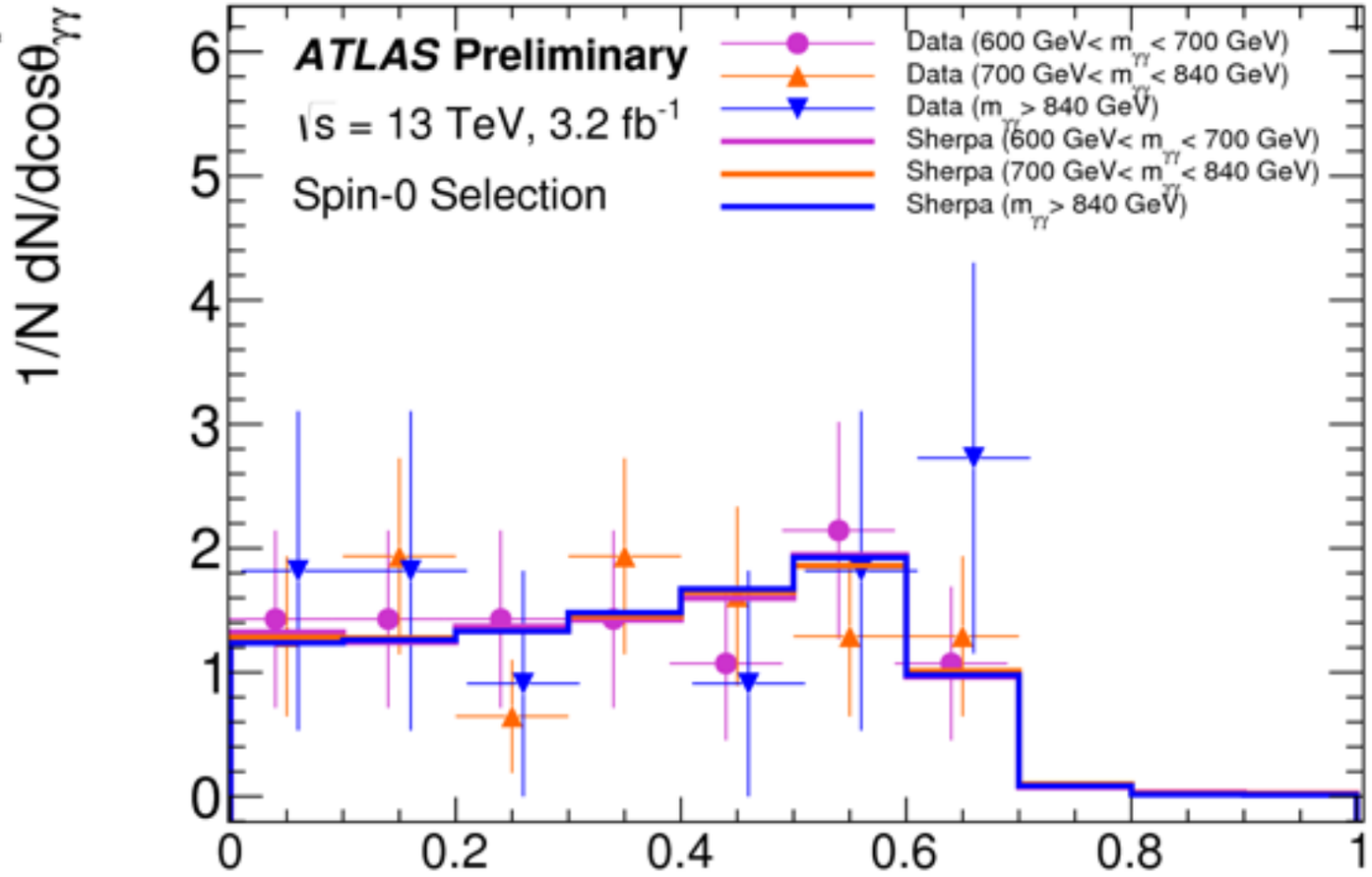
$$g_{\gamma\gamma} = c_1\alpha_1 c_W^2 + c_2\alpha_2 s_W^2$$

non-zero coupling to photons

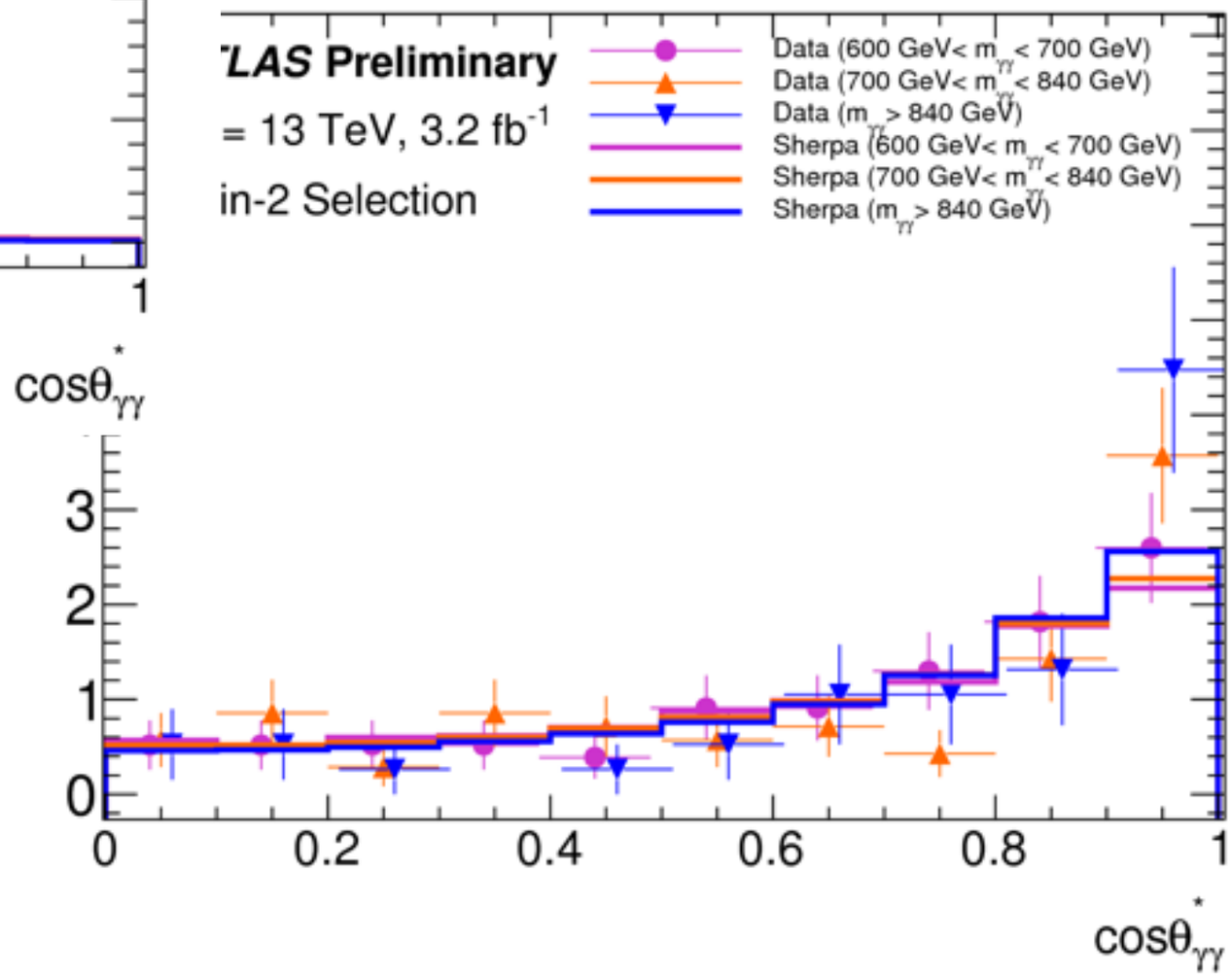
$$g_{z\gamma} = (c_1\alpha_1 - c_2\alpha_2)s_{2W}$$
$$g_{zz} = c_1\alpha_1 s_W^2 + c_2\alpha_2 c_W^2$$

coupling to ZZ and/or Zphoton

Spin

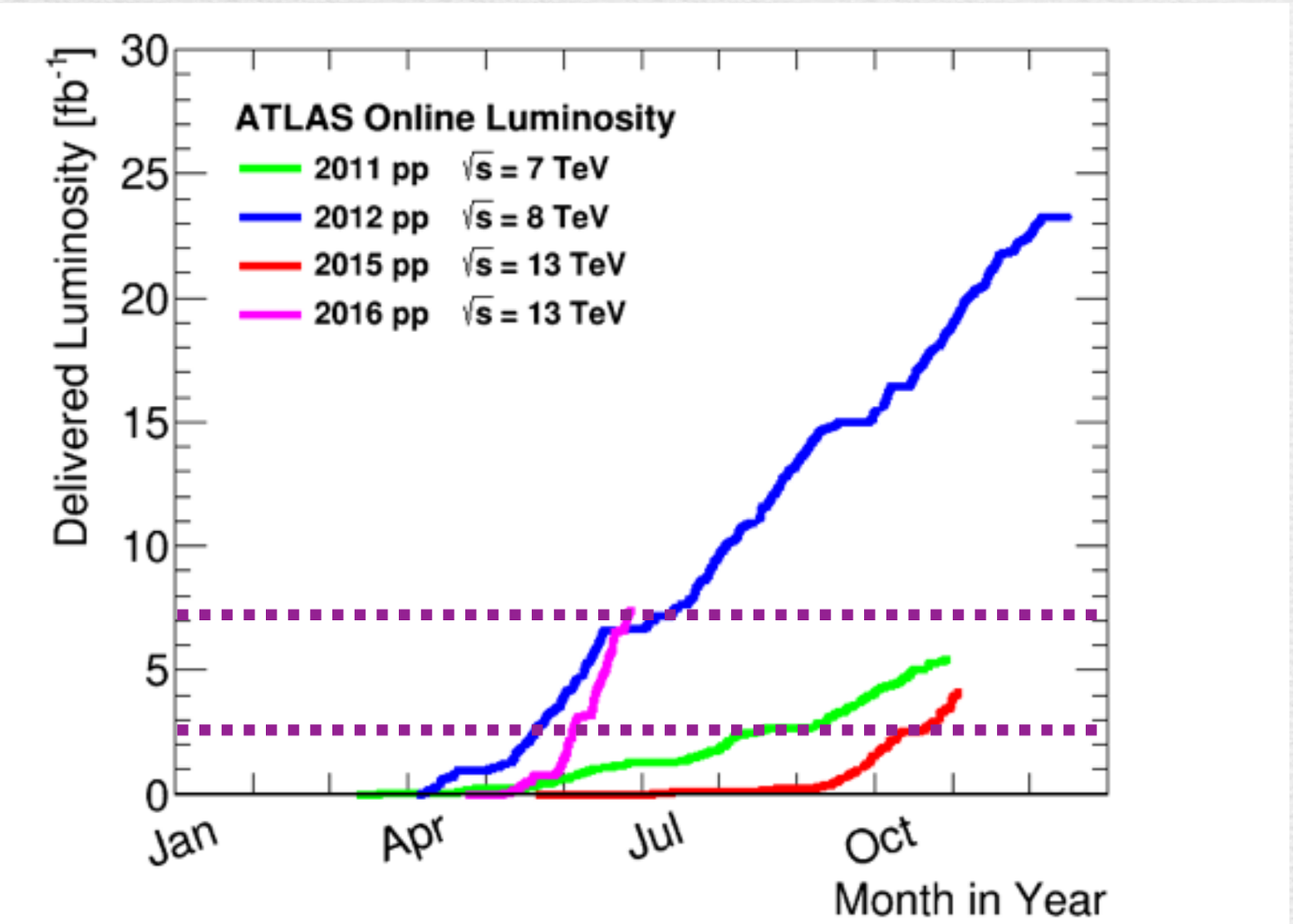


spin-0 vs spin-2
both compatible



Rumours

based on 2.6 ifb: negative results?



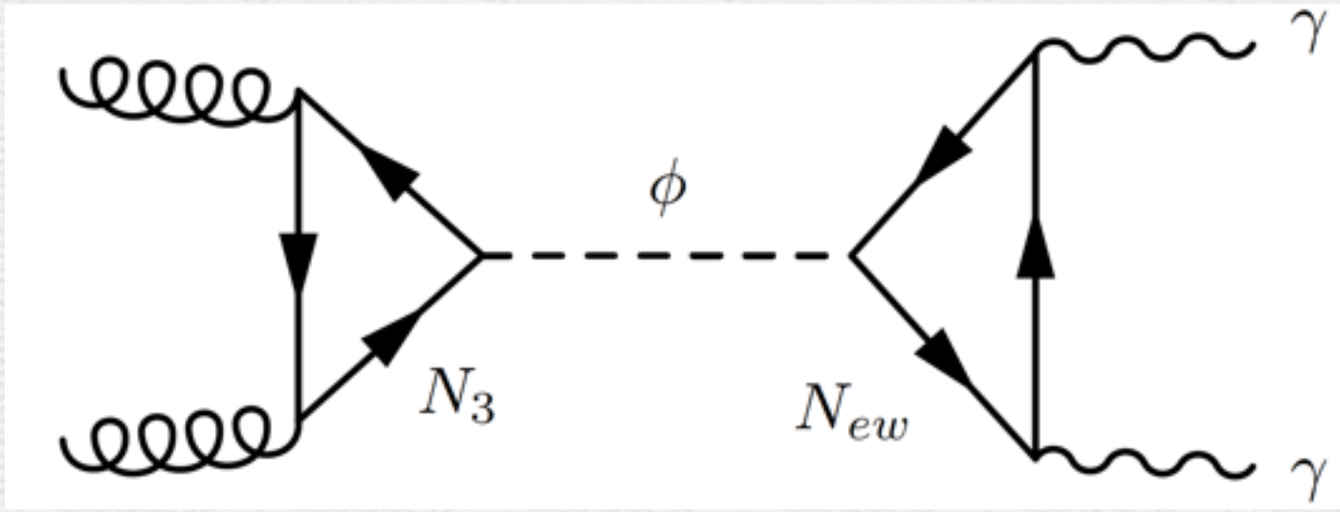
Today: ~6.5 ifb recorded
follow-up in ICHEP

Models for the diphoton

Many papers written
Some model-independent,
most model-building

What is it, if anything?

maybe a scalar coupled to vector-like fermions?



SUSY, Composite scalar?

likely to be seen it in other channels with vector bosons
WW, ZZ, Z-photon
compatible with diphoton first

Spin

J=0

A new scalar

Would this be the end of anthropics?

and a reinforcement of naturalness?

Higgs and naturalness: new states below TeV

Spin

J=0

A new scalar

Hooray SUSY!?

MSSM or NMSSM
compatibility with other
searches, dof,
perturbativity and tuning

non-minimal SUSY
(e.g. MRSSM)
or threshold effects

Spin

J=0

A new scalar

Hooray SUSY!?

MSSM or NMSSM
compatibility with other
searches, dof,
perturbativity and tuning

non-minimal SUSY
(e.g. MRSSM)
or threshold effects

Composite dynamics?

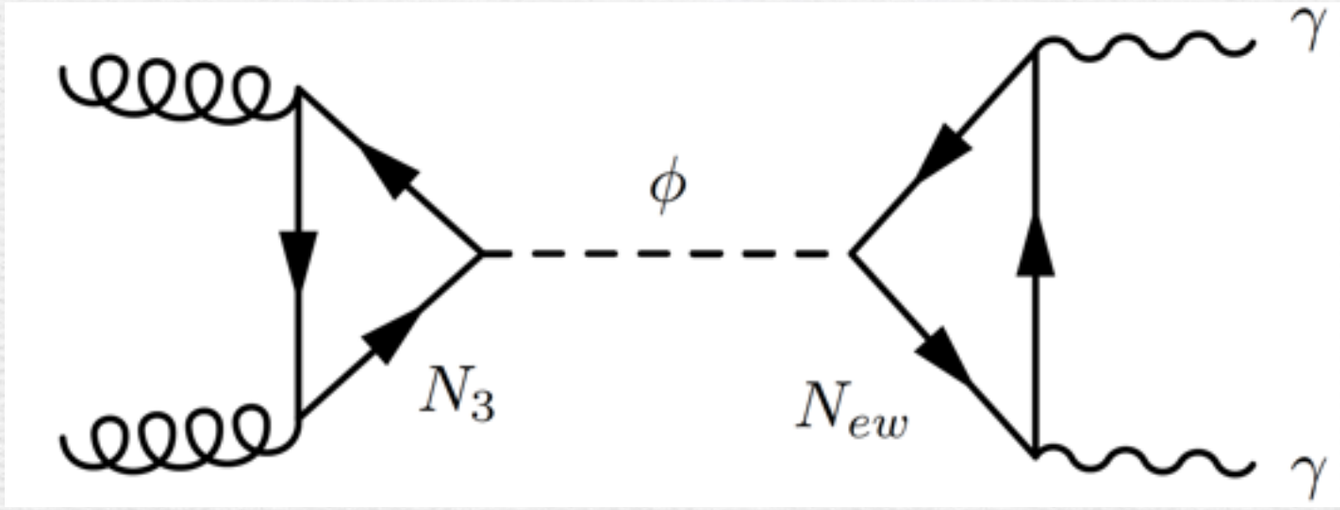
glueball of new strong force
or a pseudo-Goldstone boson

strong dynamics
lack of control

link to Composite Higgs

Model-building example for J=0

No, VS, Setford.1512.05700



Another scalar, related to the composite nature of the Higgs
a new scale close to the TeV, new dof to explain the strength

A scenario:

See-saw Composite Higgs

VS and Setford.1508.06133

motivation:

alternative to the top-partner EWSB

assume sequential breaking at scales F1, F2

F_1

F_2

f_1

f_2

spontaneous

2 sets of GBs

explicit

pGBs

$$V^{1/4} \sim \frac{g}{4\pi} F = f$$

if mixing allowed

see-saw mechanism

$$V_{mix} = \frac{\mu^2}{2} H^\dagger h + h.c.$$

$$\begin{pmatrix} m_1^2 & \mu^2/2 \\ \mu^2/2 & m_2^2 \end{pmatrix}$$

See-saw Composite Higgs

VS and Setford.1508.06133

explicit example:

$$\mathcal{G} \to \mathcal{H}_1 \to \mathcal{H}_2 = SO(6) \to SO(5) \to SO(4)$$

$$\langle \Sigma_1 \rangle = (0,0,0,0,0,F_1)^T \,, \quad \langle \Sigma_2 \rangle = (0,0,0,0,F_2)^T$$

$$\Sigma_1 = \exp(i(X^a H^a + X^5 \eta)/F_1)\langle \Sigma_1 \rangle$$

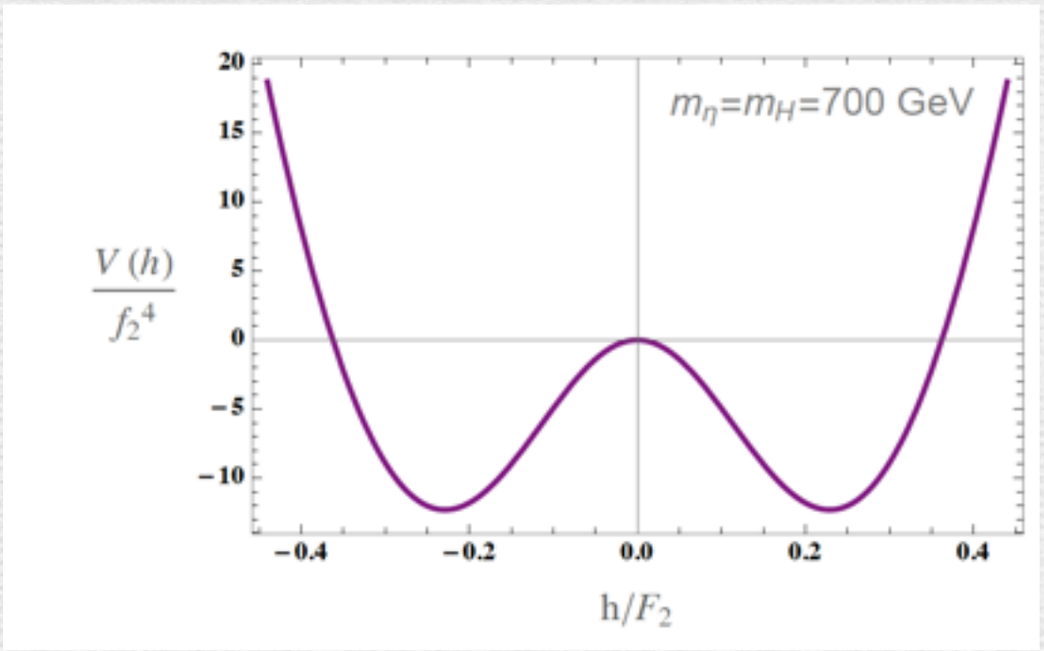
$$\Sigma_2 = \exp(i\tilde{X}^a h^a/F_2)\langle \Sigma_2 \rangle$$

F_1

F_2

f_1

f_2



potential terms

size

origin

from Yukawa and gauge explicit breaking

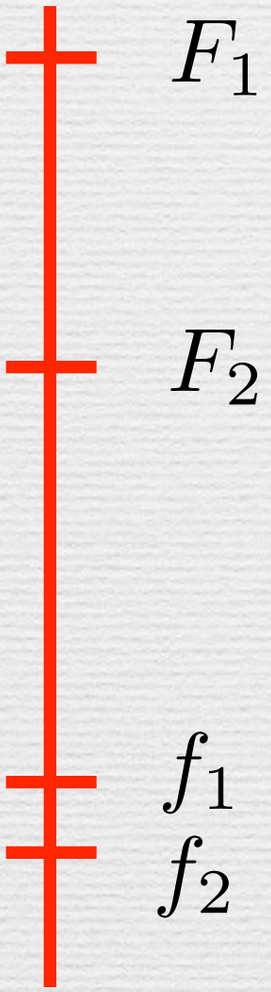
==> new DOF

See-saw Composite Higgs for the diphoton

No, VS, Setford.1512.05700

candidates:

new fermions generating the CW, also generating signal



	c_1	c_2	$g_{\eta\gamma\gamma}$
$\langle\eta\rangle = 0$	$-\frac{y_\eta N_{ew}}{2M_\Psi}$	$\frac{y_\eta N_{ew}}{2M_\Psi}$	0
$\langle\eta\rangle \neq 0$	$(\frac{1}{2}+4\,X^2)\,\frac{-N_{ew}y_\eta^2\langle\eta\rangle}{M_\Psi^2}$	$\frac{-N_{ew}y_\eta^2}{2}\,\frac{\langle\eta\rangle}{M_\Psi^2}$	$-\frac{N_{ew}y_\eta^2\langle\eta\rangle\alpha}{M_\Psi^2}(1+4X^2)$

e.g. 4 of SO(5), |X| = 1/2

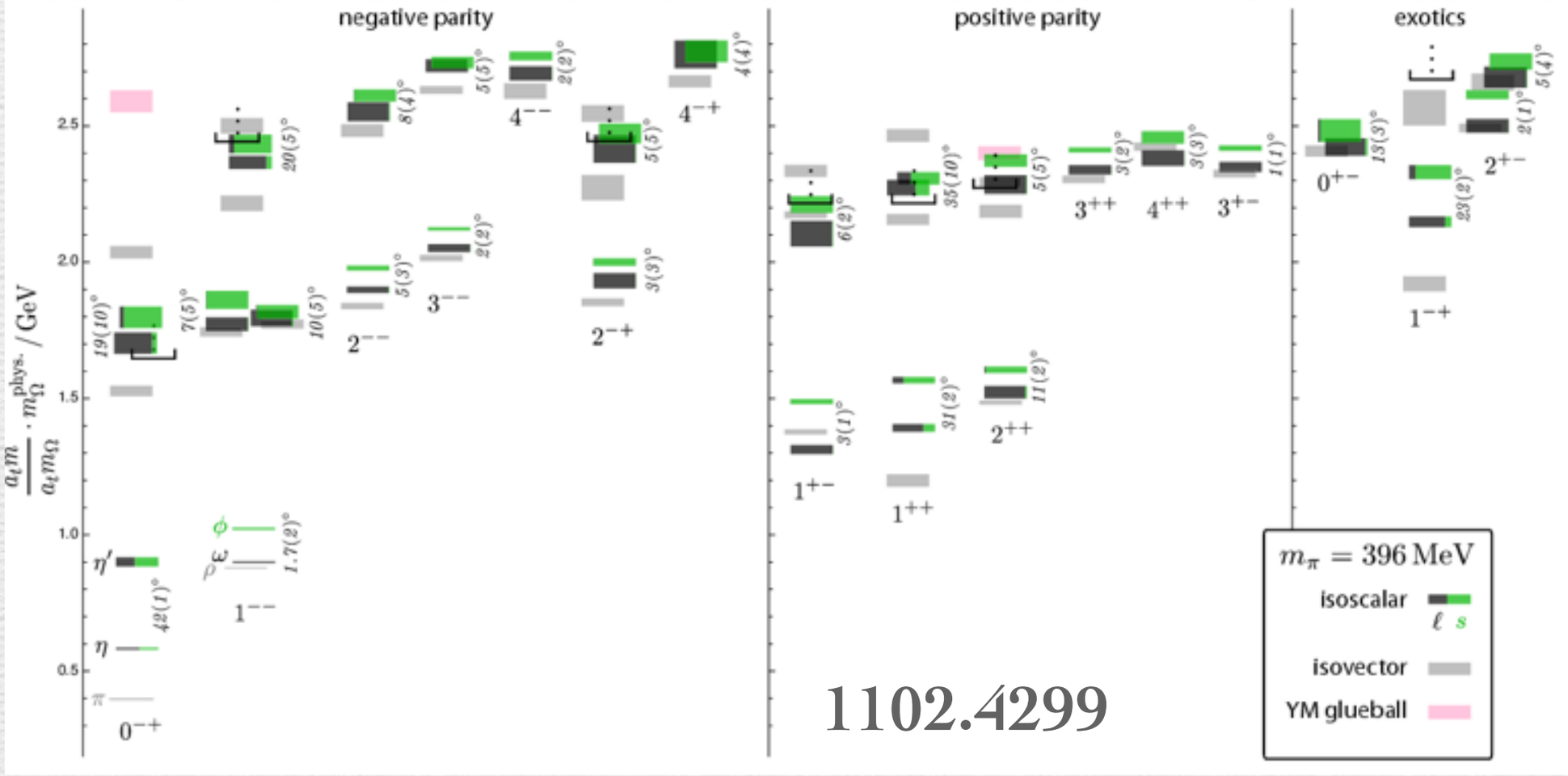
explain the signal, but also address other BSM:
DM candidate (neutral fermion)
with eta the DM mediator, and new hopes for baryogenesis (spontaneous CPV)

Spin

J=2

A kind of massive graviton or
glueball of new strong force

Important hurdle is EWPTs



1102.4299

Spin

J=2

A kind of massive graviton or
glueball of new strong force

Important hurdle is EWPTs

Experimental interpretations neglect this problem,
theorists using AdS/CFT to find models

recent progress, additional kinetic terms
suffering from

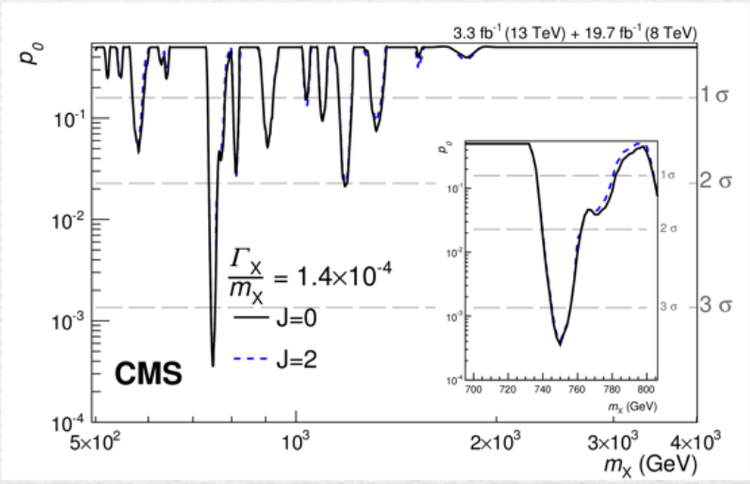
1603.06980, 1603.08250

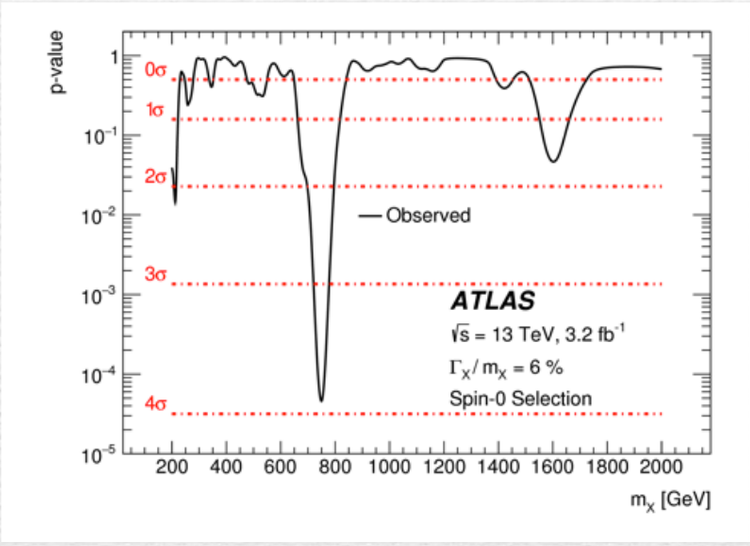
In composite Higgs:

Dillon, VS. 1603.09550

Conclusions

- Two excesses at roughly 3.5 sigma on same location in mass at 750 GeV and cross section 5 fb reduces each to about 2 sigma (double-counting)
- Width and spin still TBD. Excess doesn't come with high-pT objects. Most compatible with gluon-fusion
- Models of spin-zero: composite scalars or non-standard SUSY
- Models of spin-two: non-standard AdS/CFT techniques required. radion-ghost, beyond gravity duals?





Whatever is hiding, making sense of naturalness, Dark Universe and model-building techniques is a challenge for theorists.
Now, wait and see August 8th ICHEP