Summary of Working Group 3: Electroweak and BSM Physics

Kevin Black
Boston University

BOSTON UNIVERSITY

Huge amount of Activity

- 40 talks covering a wide range of LHC searches, LHC measurements, Hera, Babar, NA48, theory…

- Too much to cover in one talk - I will attempt to highlight some results to tell a coherent story in 20 min

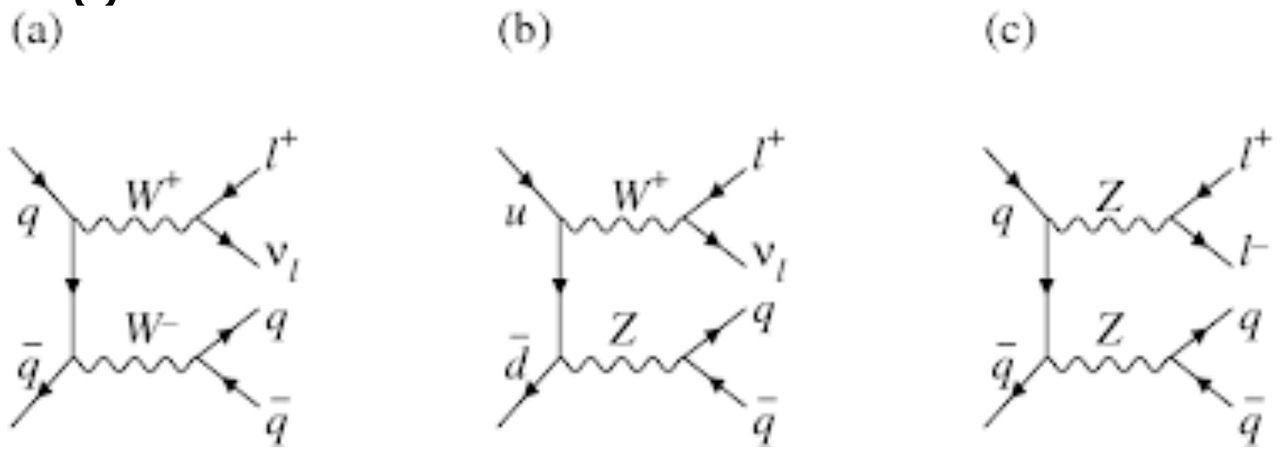
- Disclaimer: All biases on topics covered are mine

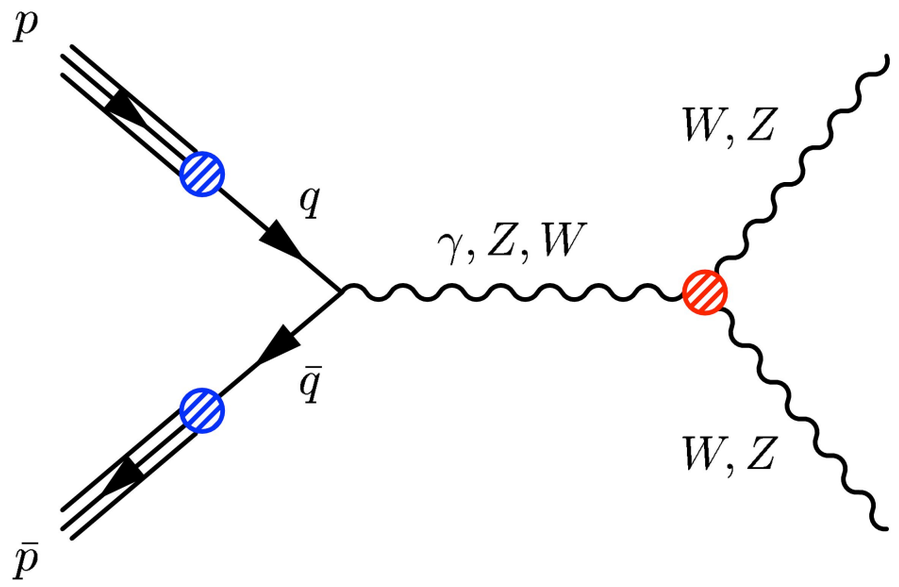
Outline

- Tests of Electroweak sector through precision measurements
- Advances in theory
- Status of the Higgs Boson from Run 1 and first data of Run 2 of the LHC
- Direct Search for BSM Physics

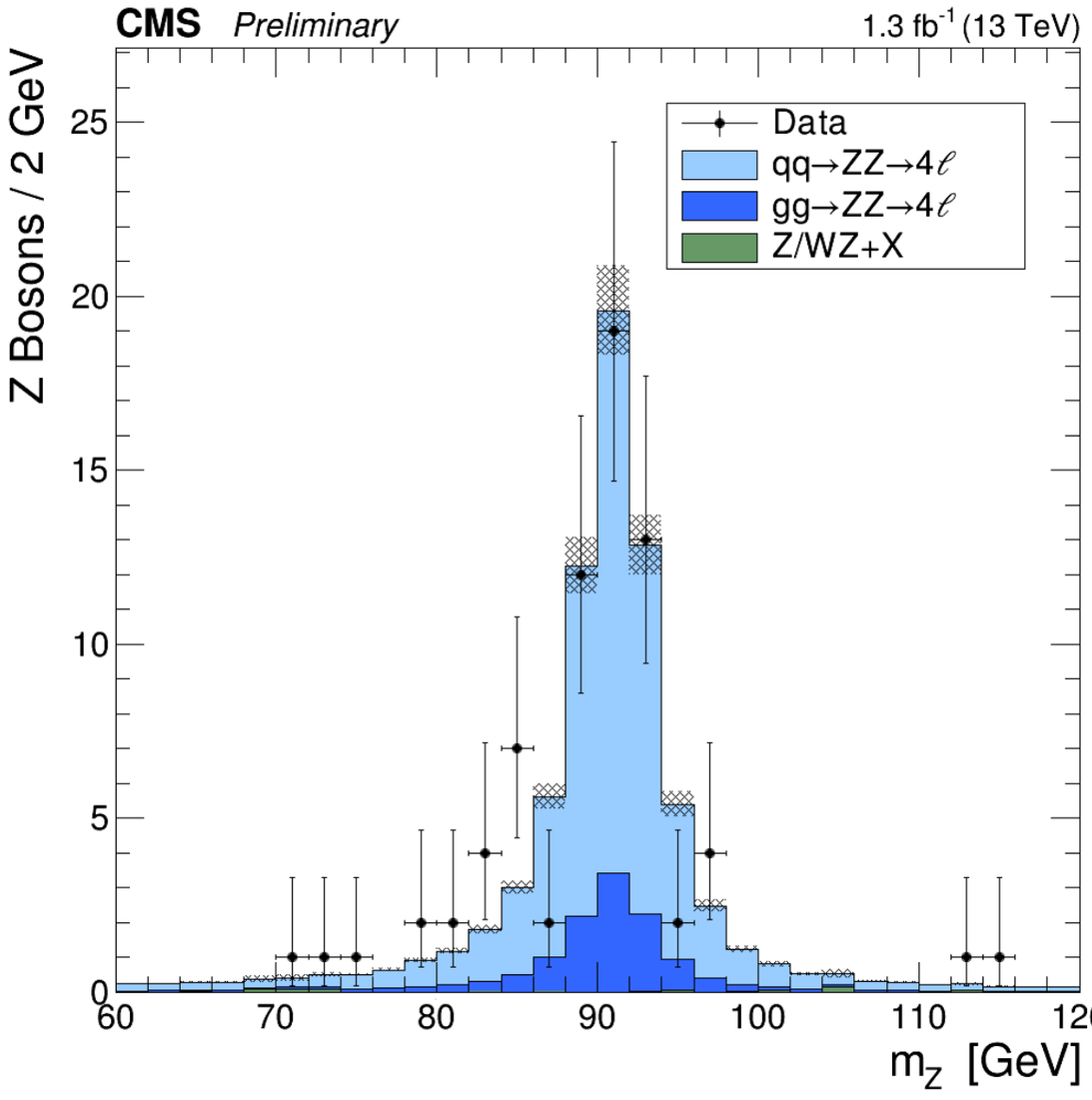
Dibosons

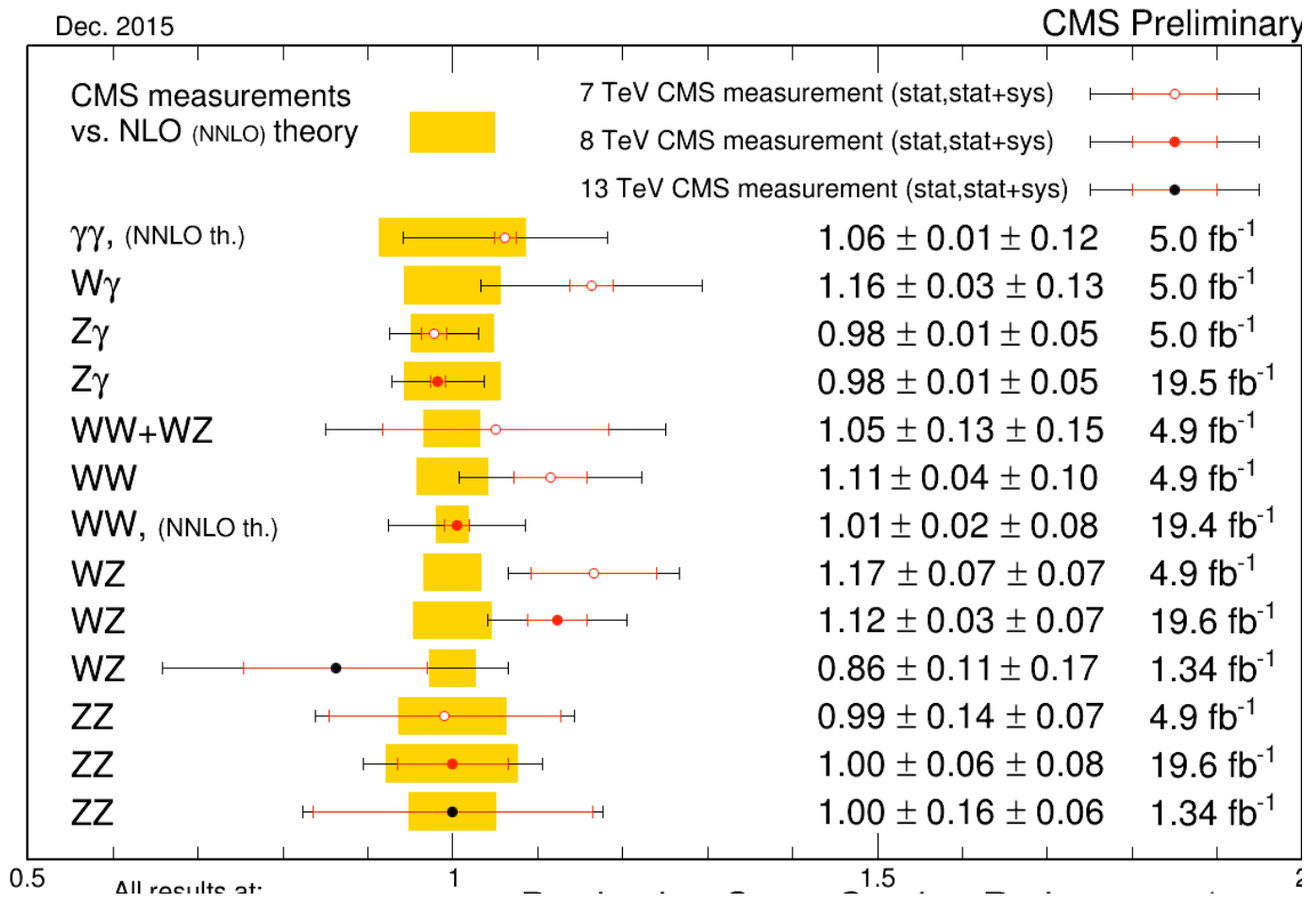
- Test the Electroweak gauge structure
- Test of pQCD
- probe of anomalous triple (aTGCs) and quartic gauge couplings (aQGCs)
- background to Higgs and direct searches for new physics





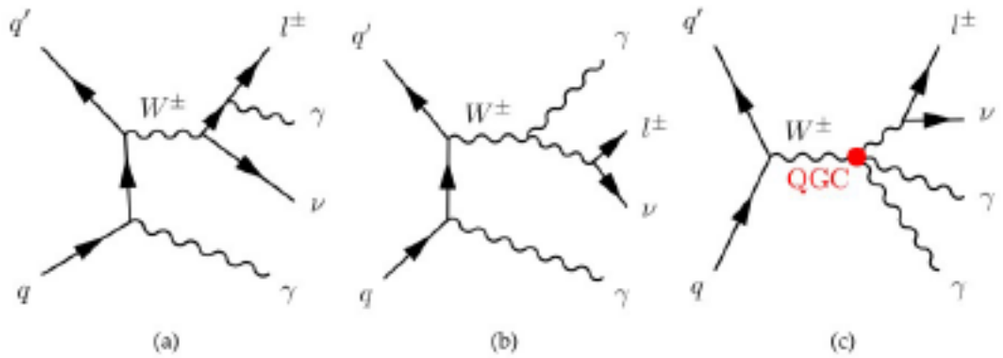
Dibosons

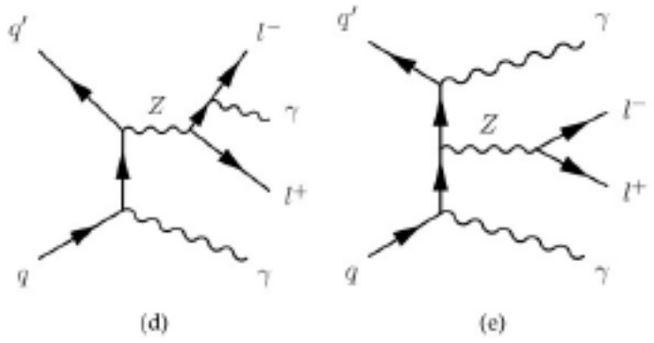

CMS Preliminary
1.3 fb-1 (13 TeV)
Data
qq→ZZ→4ℓ
gg→ZZ→4ℓ
Z/WZ+X
Z Bosons / 2 GeV
mZ [GeV]

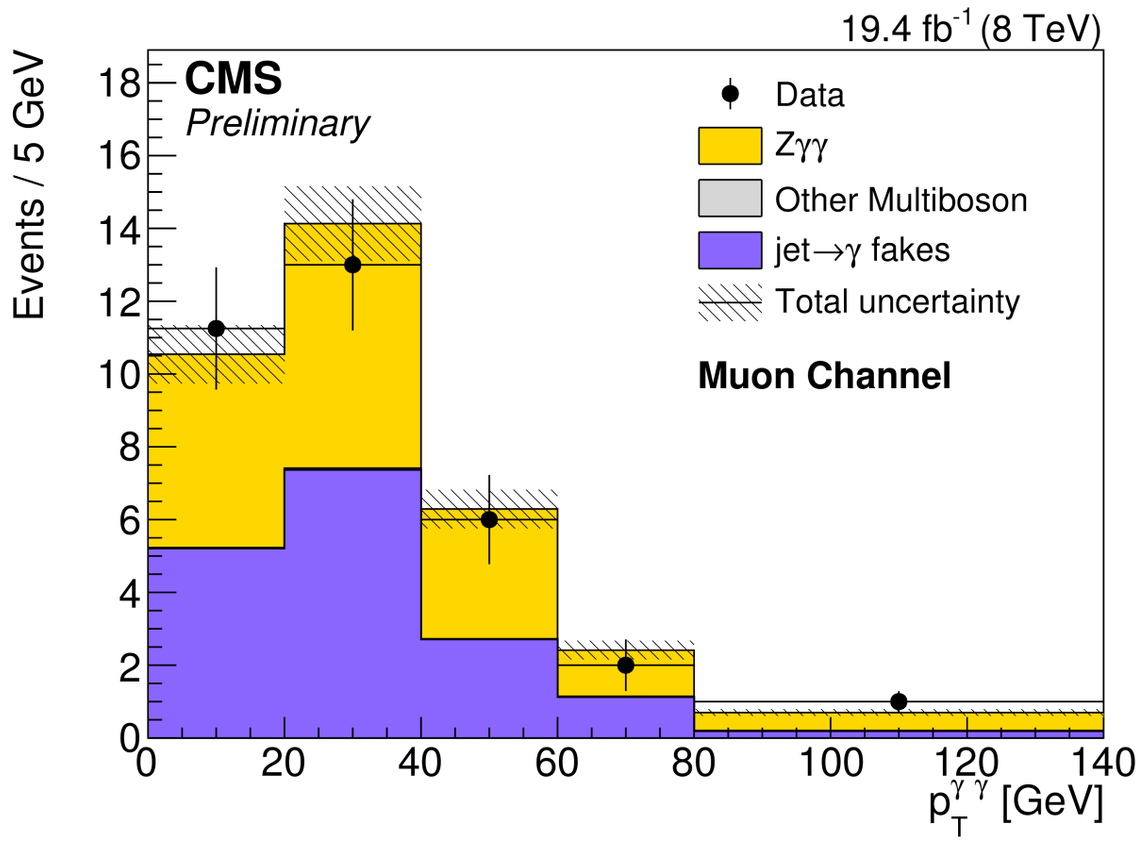

Dec. 2015
CMS Preliminary
CMS measurements
vs. NLO (NNLO) theory
7 TeV CMS measurement (stat,stat+sys)
8 TeV CMS measurement (stat,stat+sys)
13 TeV CMS measurement (stat,stat+sys)
γγ, (NNLO th.) 1.06 ± 0.01 ± 0.12 5.0 fb-1
Wγ 1.16 ± 0.03 ± 0.13 5.0 fb-1
Zγ 0.98 ± 0.01 ± 0.05 5.0 fb-1
Zγ 0.98 ± 0.01 ± 0.05 19.5 fb-1
WW+WZ 1.05 ± 0.13 ± 0.15 4.9 fb-1
WW 1.11 ± 0.04 ± 0.10 4.9 fb-1
WW, (NNLO th.) 1.01 ± 0.02 ± 0.08 19.4 fb-1
WZ 1.17 ± 0.07 ± 0.07 4.9 fb-1
WZ 1.12 ± 0.03 ± 0.07 19.6 fb-1
WZ 0.86 ± 0.11 ± 0.17 1.34 fb-1
ZZ 0.99 ± 0.14 ± 0.07 4.9 fb-1
ZZ 1.00 ± 0.06 ± 0.08 19.6 fb-1
ZZ 1.00 ± 0.16 ± 0.06 1.34 fb-1
All results at:

Jing Li

Observation of multiple boson final states





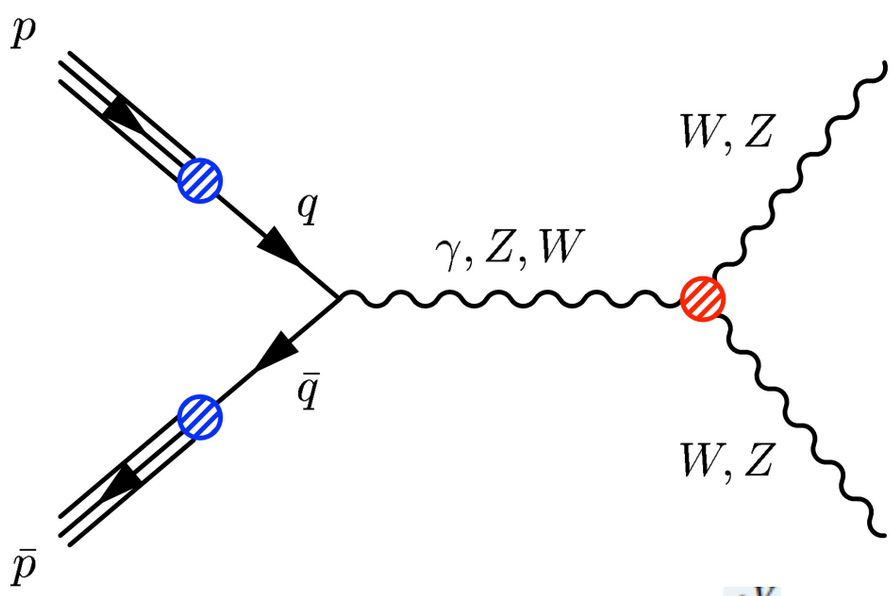


$$\sigma^{\text{fid}}_{\text{W}^{\pm}\gamma\gamma} \cdot \text{BR}\,(\text{W} \to \ell\nu) = 6.0 \pm 1.8\,(\text{stat}) \pm 2.3\,(\text{syst}) \pm 0.2\,(\text{lumi})\,\text{fb}\,.$$

$$\sigma^{\text{fid}}_{\text{Z}\gamma\gamma} \cdot \text{BR}\,(\text{Z} \to \ell\ell) = 12.7 \pm 1.4\,(\text{stat}) \pm 1.8\,(\text{syst}) \pm 0.3\,(\text{lumi})\,\text{fb}$$

Felix Socher

aTGCs
aQGCs



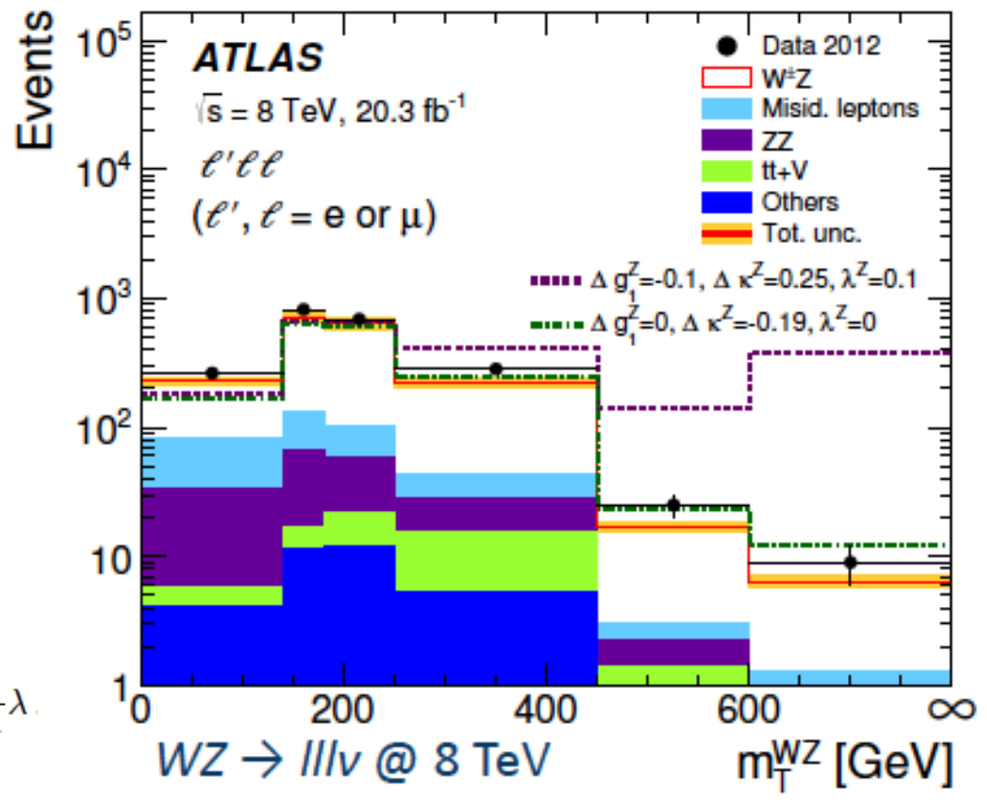
$$\mathcal{L} = ig_{WWV}\left[g_1^V(W^+_{\mu\nu}W^{-\mu} - W^{+\mu}W^-_{\mu\nu})V^\nu + k^V W^+_\mu W^-_\nu V^{\mu\nu} + \frac{\lambda^V}{m_W^2}W^{+\nu}_\mu W^{-\rho}_\nu V^\mu_\rho\right]$$

$$O_{WWW} = \frac{c_{WWW}}{\Lambda^2}\mathrm{Tr}[W_{\mu\nu}W^{\nu\rho}W^\mu_\rho]$$

$$O_W = \frac{c_W}{\Lambda^2}\left(D_\mu\Phi\right)^\dagger W^{\mu\nu}\left(D_\nu\Phi\right)$$

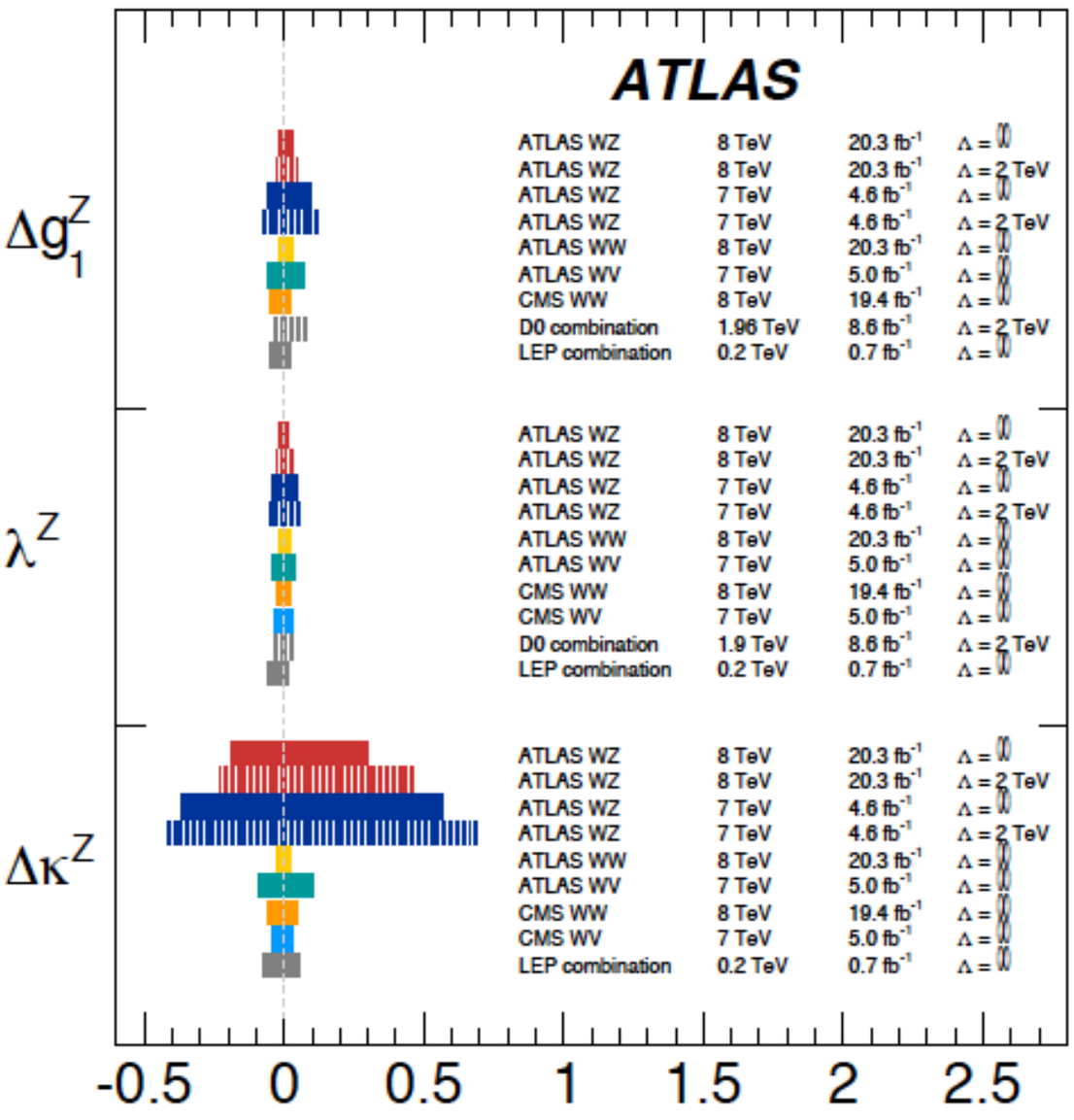
$$O_B = \frac{c_B}{\Lambda^2}\left(D_\mu\Phi\right)B^{\mu\nu}\left(D_\nu\Phi\right)$$

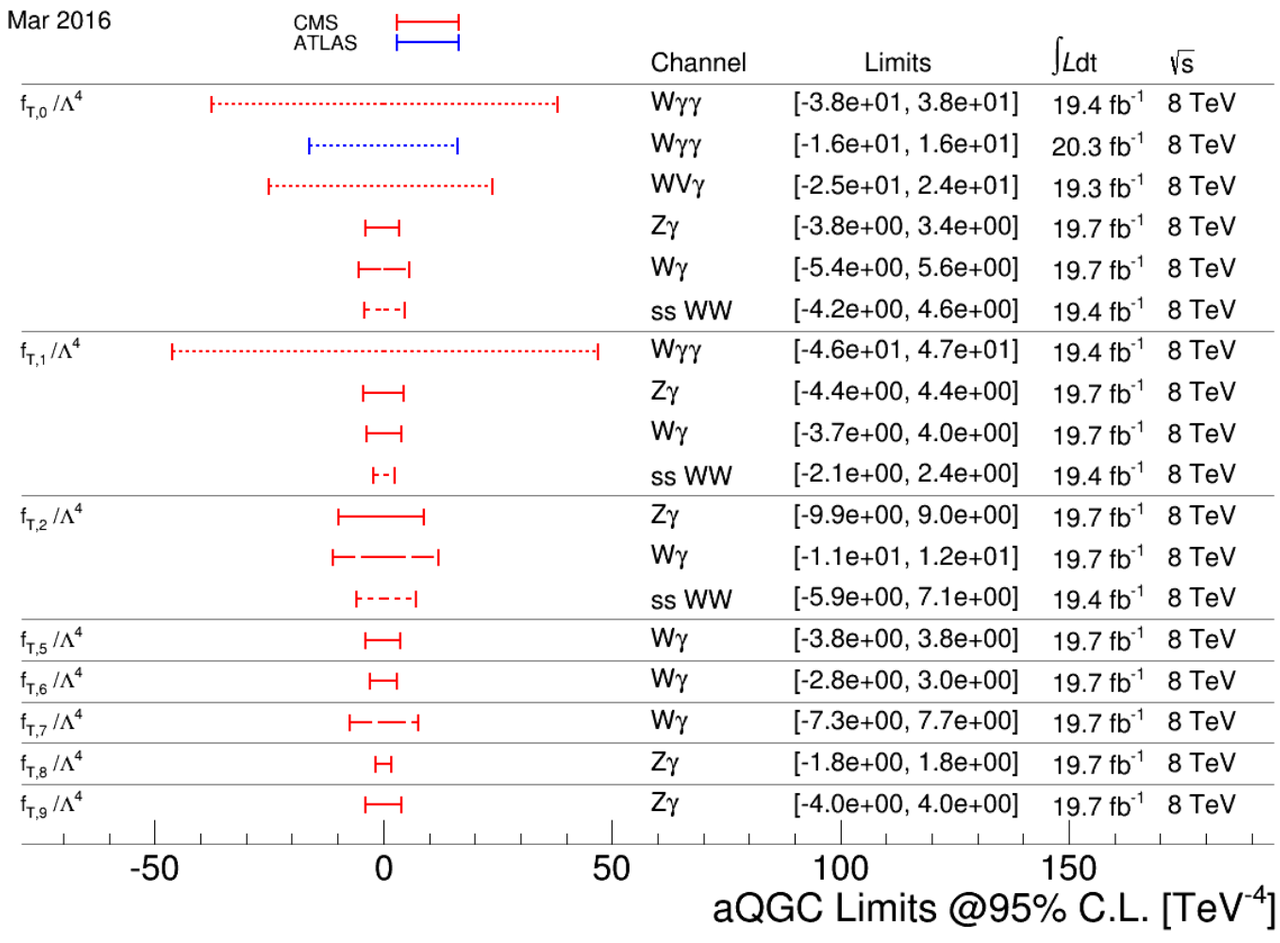
- Along with total cross-sections, measure differential distributions
- aTGCs tend to enhance the tails of the distribution



$$\frac{c_W}{\Lambda^2} = \frac{2}{m_Z^2}\Delta g_1^Z \qquad \frac{c_B}{\Lambda^2} = \frac{2}{m_W^2}\Delta\kappa_\gamma - \frac{2}{m_Z^2}\Delta g_1^Z \qquad \frac{c_{WWW}}{\Lambda^2} = \frac{2}{3g^2m_W^2}\lambda$$

Limits

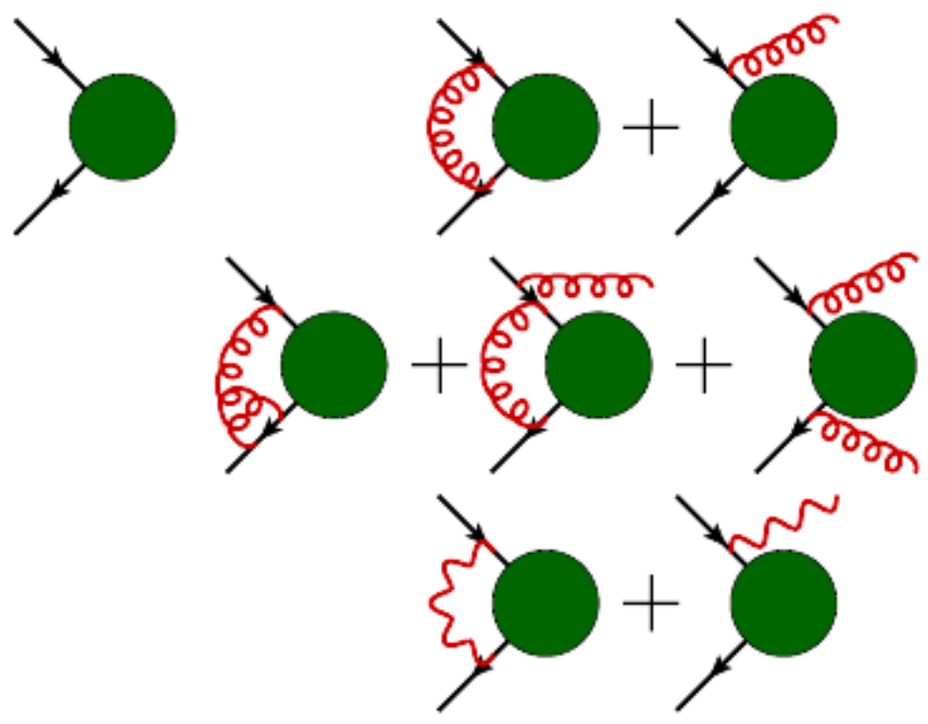

ATLAS
Δg_1^Z
λ^Z
$\Delta\kappa^Z$
ATLAS WZ 8 TeV 20.3 fb-1 Λ = ∞
ATLAS WZ 8 TeV 20.3 fb-1 Λ = 2 TeV
ATLAS WZ 7 TeV 4.6 fb-1 Λ = ∞
ATLAS WZ 7 TeV 4.6 fb-1 Λ = 2 TeV
ATLAS WW 8 TeV 20.3 fb-1 Λ = ∞
ATLAS WV 7 TeV 5.0 fb-1 Λ = ∞
CMS WW 8 TeV 19.4 fb-1 Λ = ∞
CMS WV 7 TeV 5.0 fb-1 Λ = ∞
D0 combination 1.96 TeV 8.6 fb-1 Λ = 2 TeV
D0 combination 1.9 TeV 8.6 fb-1 Λ = 2 TeV
LEP combination 0.2 TeV 0.7 fb-1 Λ = ∞
-0.5 0 0.5 1 1.5 2 2.5


Mar 2016
CMS
ATLAS
Channel Limits ∫Ldt √s
$f_{T,0}/\Lambda^4$ Wγγ [-3.8e+01, 3.8e+01] 19.4 fb-1 8 TeV
Wγγ [-1.6e+01, 1.6e+01] 20.3 fb-1 8 TeV
WVγ [-2.5e+01, 2.4e+01] 19.3 fb-1 8 TeV
Zγ [-3.8e+00, 3.4e+00] 19.7 fb-1 8 TeV
Wγ [-5.4e+00, 5.6e+00] 19.7 fb-1 8 TeV
ss WW [-4.2e+00, 4.6e+00] 19.4 fb-1 8 TeV
$f_{T,1}/\Lambda^4$ Wγγ [-4.6e+01, 4.7e+01] 19.4 fb-1 8 TeV
Zγ [-4.4e+00, 4.4e+00] 19.7 fb-1 8 TeV
Wγ [-3.7e+00, 4.0e+00] 19.7 fb-1 8 TeV
ss WW [-2.1e+00, 2.4e+00] 19.4 fb-1 8 TeV
$f_{T,2}/\Lambda^4$ Zγ [-9.9e+00, 9.0e+00] 19.7 fb-1 8 TeV
Wγ [-1.1e+01, 1.2e+01] 19.7 fb-1 8 TeV
ss WW [-5.9e+00, 7.1e+00] 19.4 fb-1 8 TeV
$f_{T,5}/\Lambda^4$ Wγ [-3.8e+00, 3.8e+00] 19.7 fb-1 8 TeV
$f_{T,6}/\Lambda^4$ Wγ [-2.8e+00, 3.0e+00] 19.7 fb-1 8 TeV
$f_{T,7}/\Lambda^4$ Wγ [-7.3e+00, 7.7e+00] 19.7 fb-1 8 TeV
$f_{T,8}/\Lambda^4$ Zγ [-1.8e+00, 1.8e+00] 19.7 fb-1 8 TeV
$f_{T,9}/\Lambda^4$ Zγ [-4.0e+00, 4.0e+00] 19.7 fb-1 8 TeV
-50 0 50 100 150
aQGC Limits @95% C.L. [TeV-4]

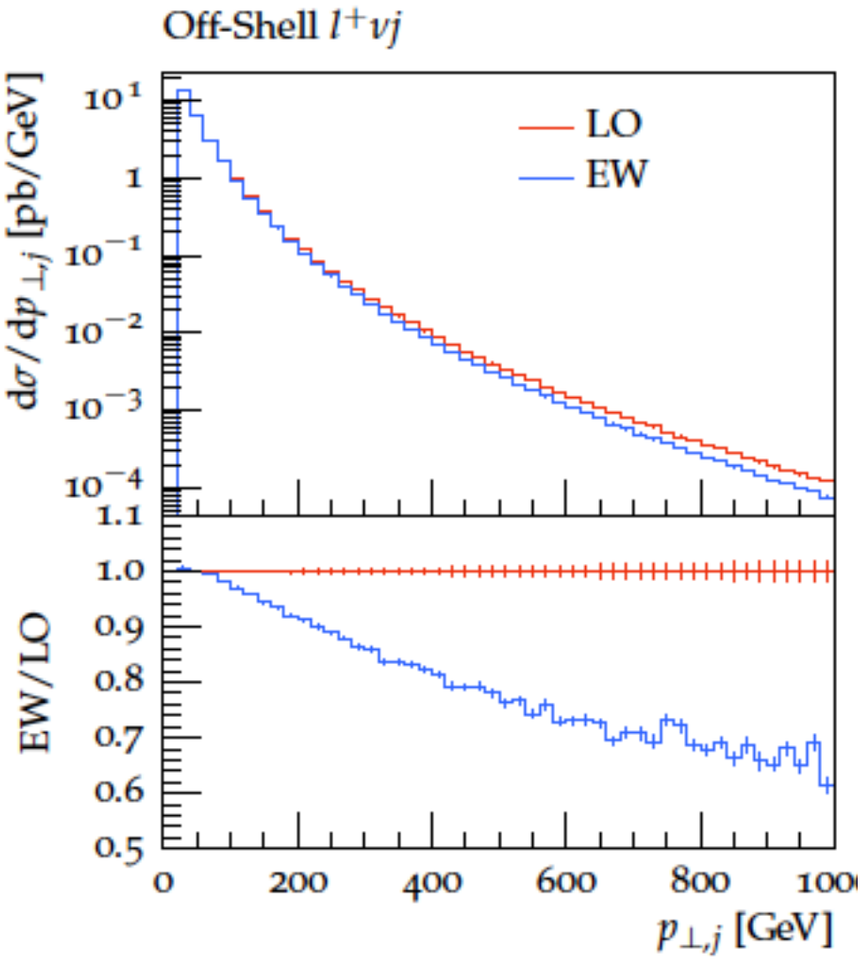
Jennifer Thompson

Tools to understand the SM

- Current Monte Carlo simulations are NLO QCD with a parton shower.
- Extending to NNLO QCD $\longrightarrow$ precision sensitive to EW corrections. ($\mathcal{O}(\alpha_s^2) \sim \mathcal{O}(\alpha)$)



NLO EW with Sherpa



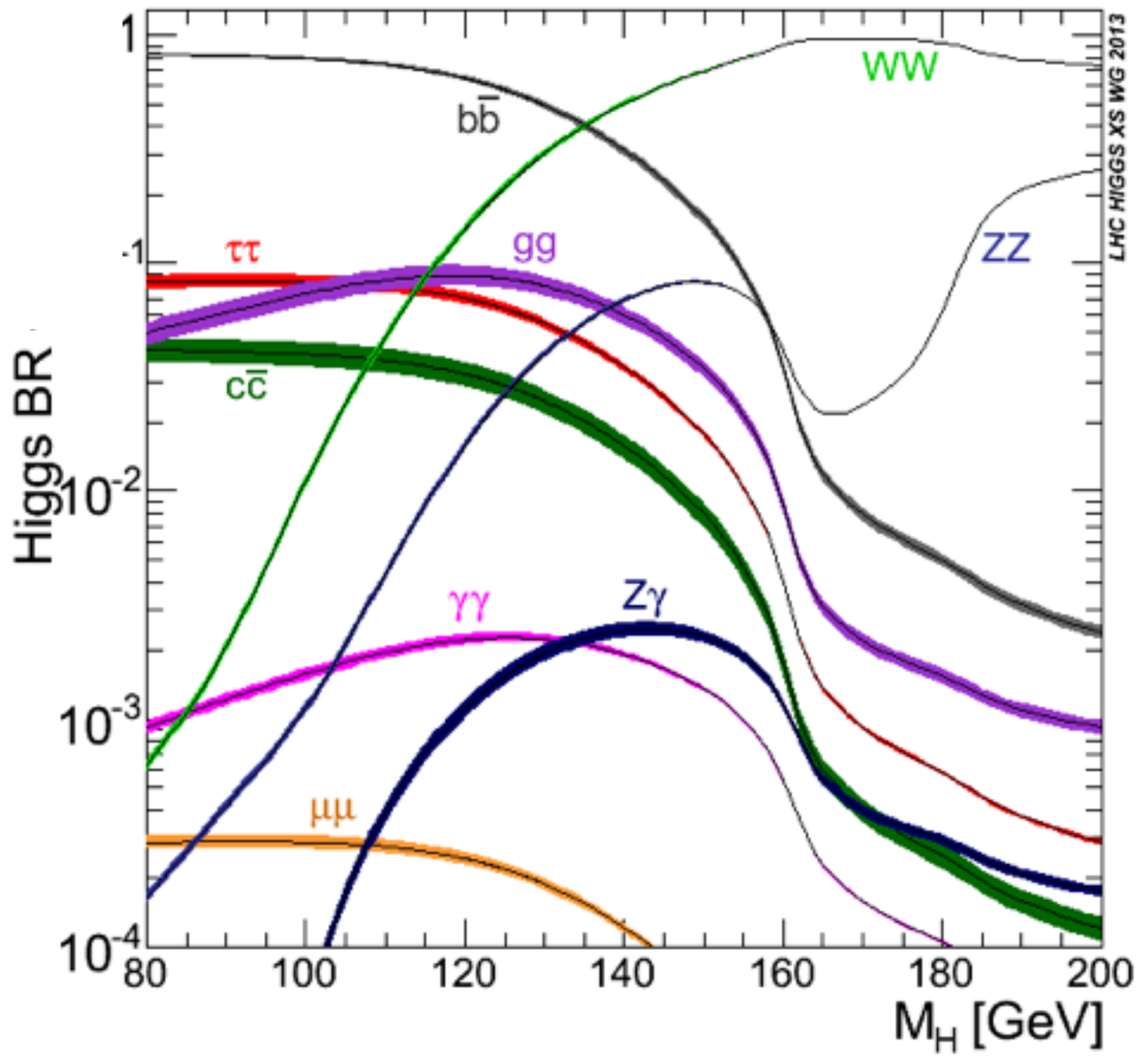
arXiv:1511.08692, arXiv:1505.05704, arXiv:1412.5157

- There is currently an implementation (not public) of full NLO EW computations with SHERPA+OpenLoops
- Currently papers on V+jets
- Current work to also interface to Recola
- Recola generates NLO MEs and will be a loop provider in the interface.
- Aim to automate EW corrections in the same way as NLO QCD corrections.

Off-shell production

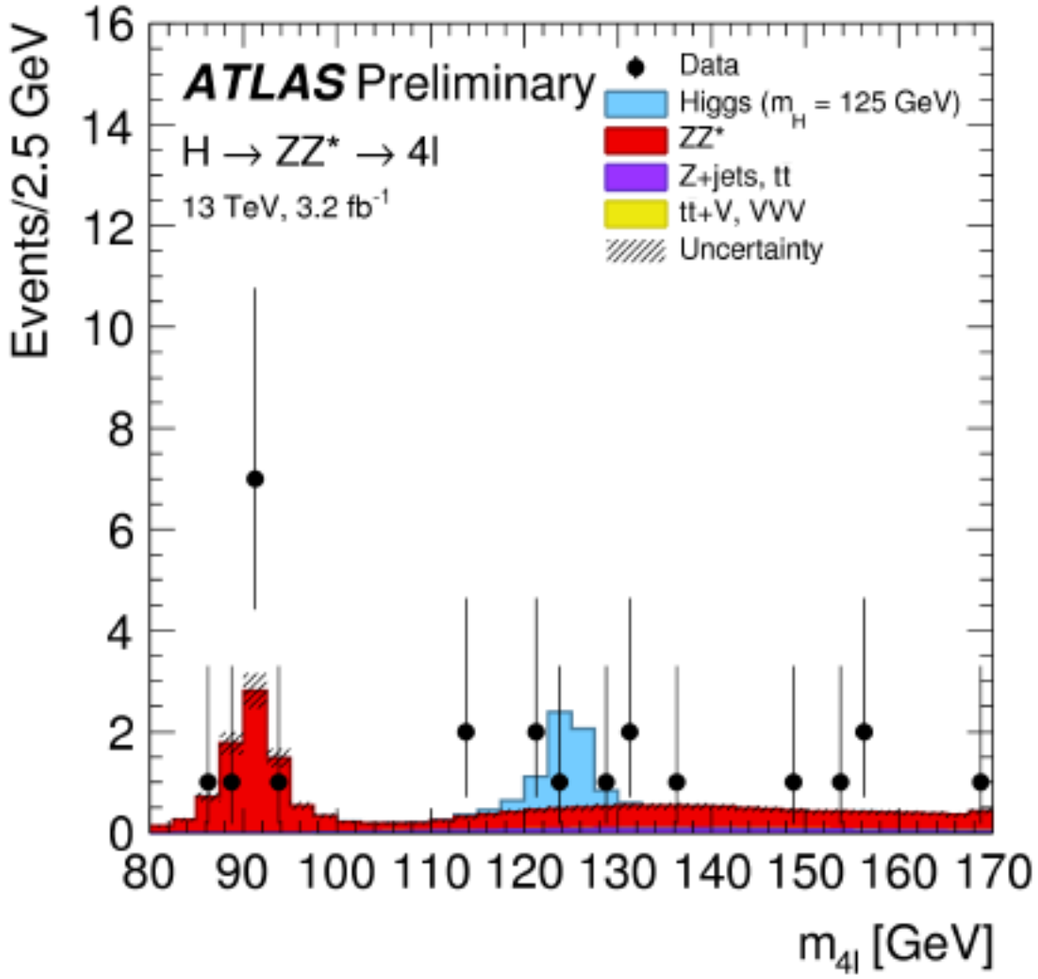
Higgs Status

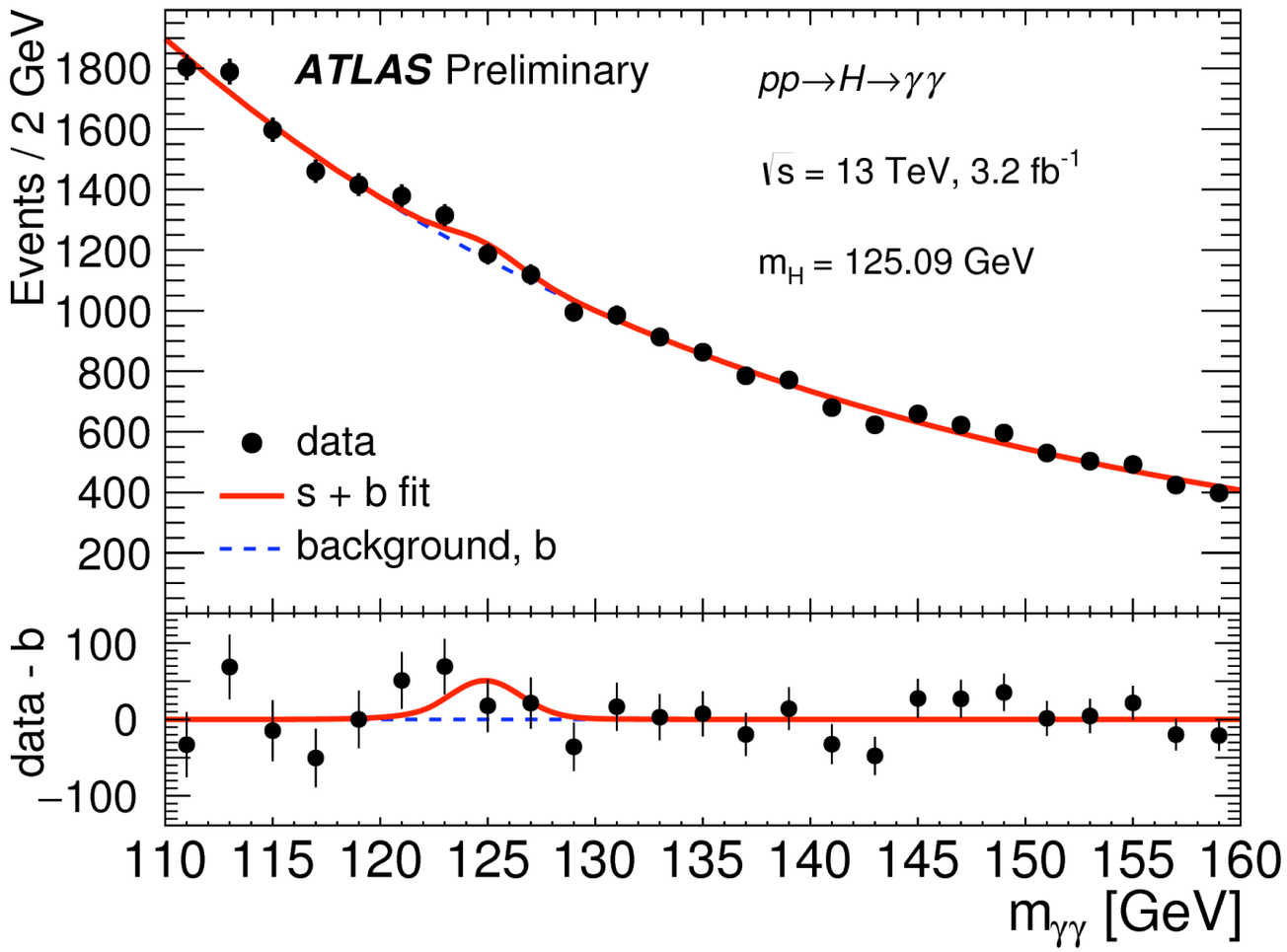
- Search for rare Higgs decays
- Measurement of differential Higgs distributions
- Re-observation of Higgs Boson



Josefina Alconada Verzini

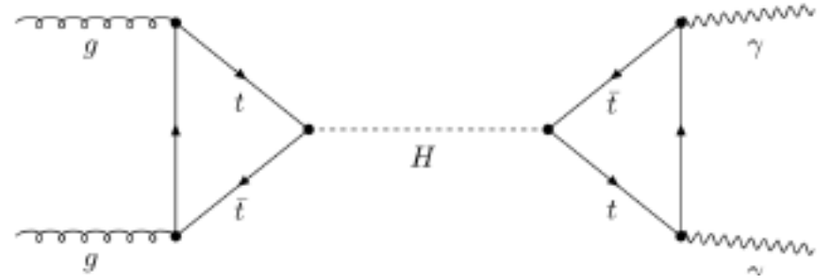
First Higgs data from Run II

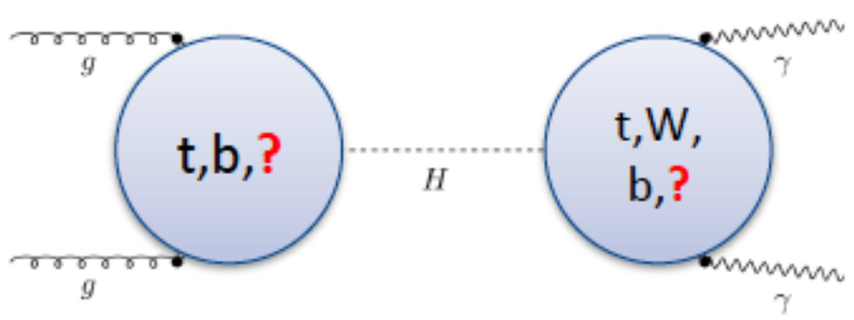




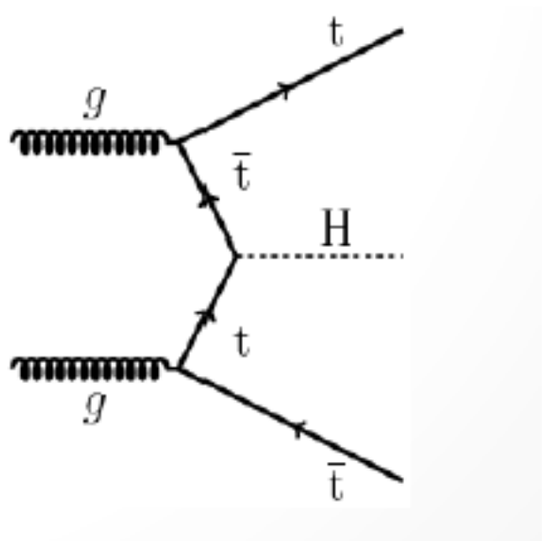
Direct measurement off Higgs to top coupling

- Yukawa coupling by
  - measurement of top mass
  - via production of higgs from loop
- Directly from observation of tth

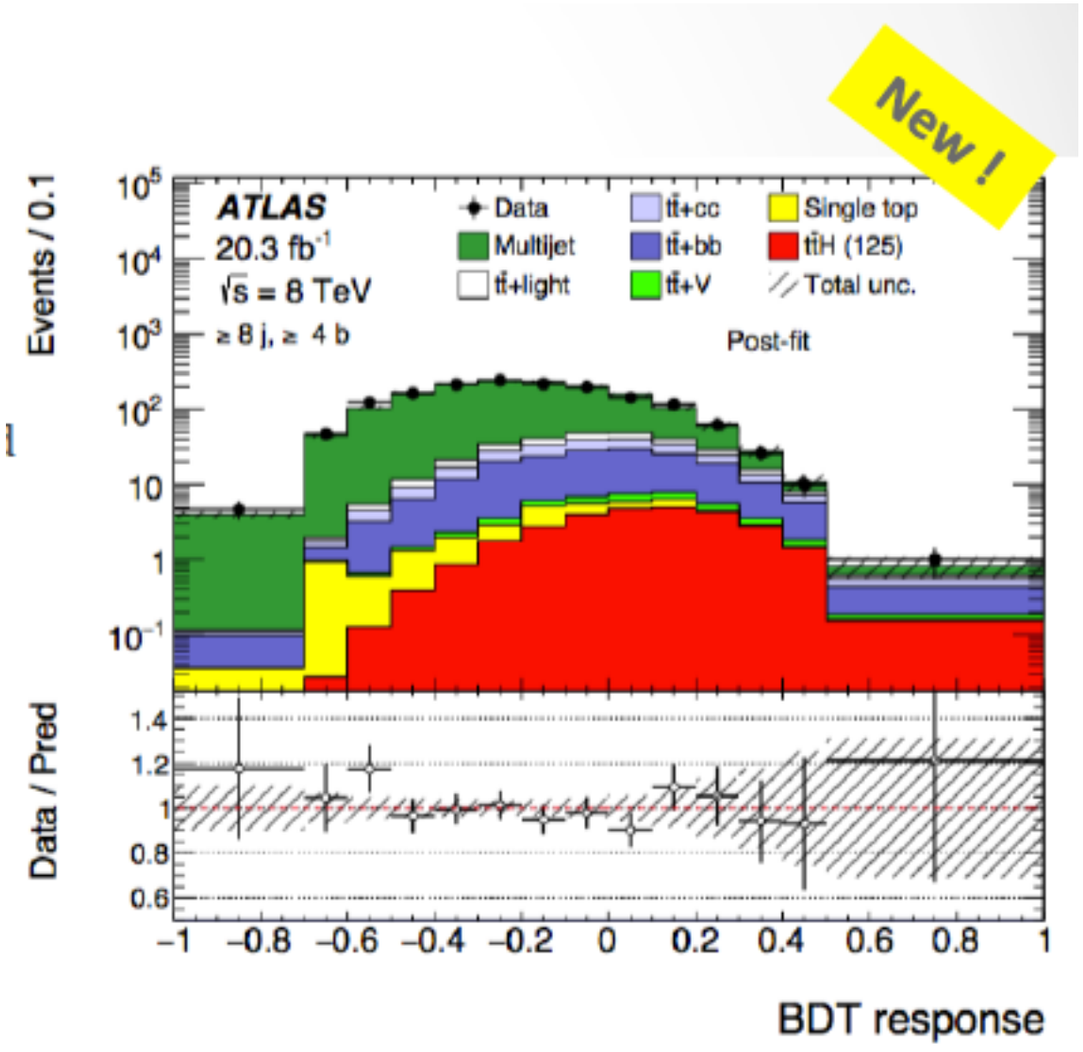


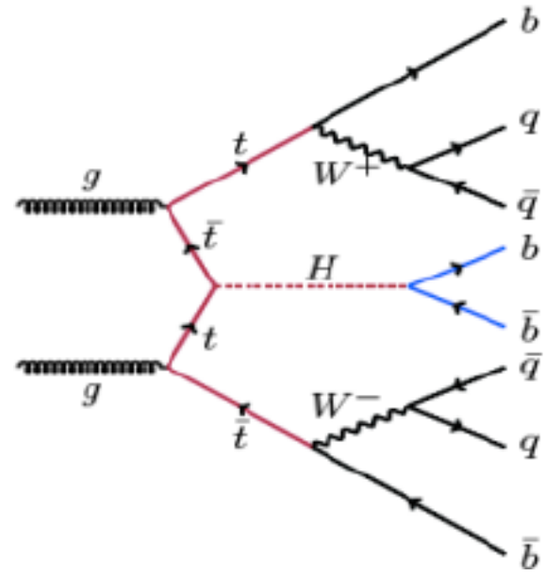


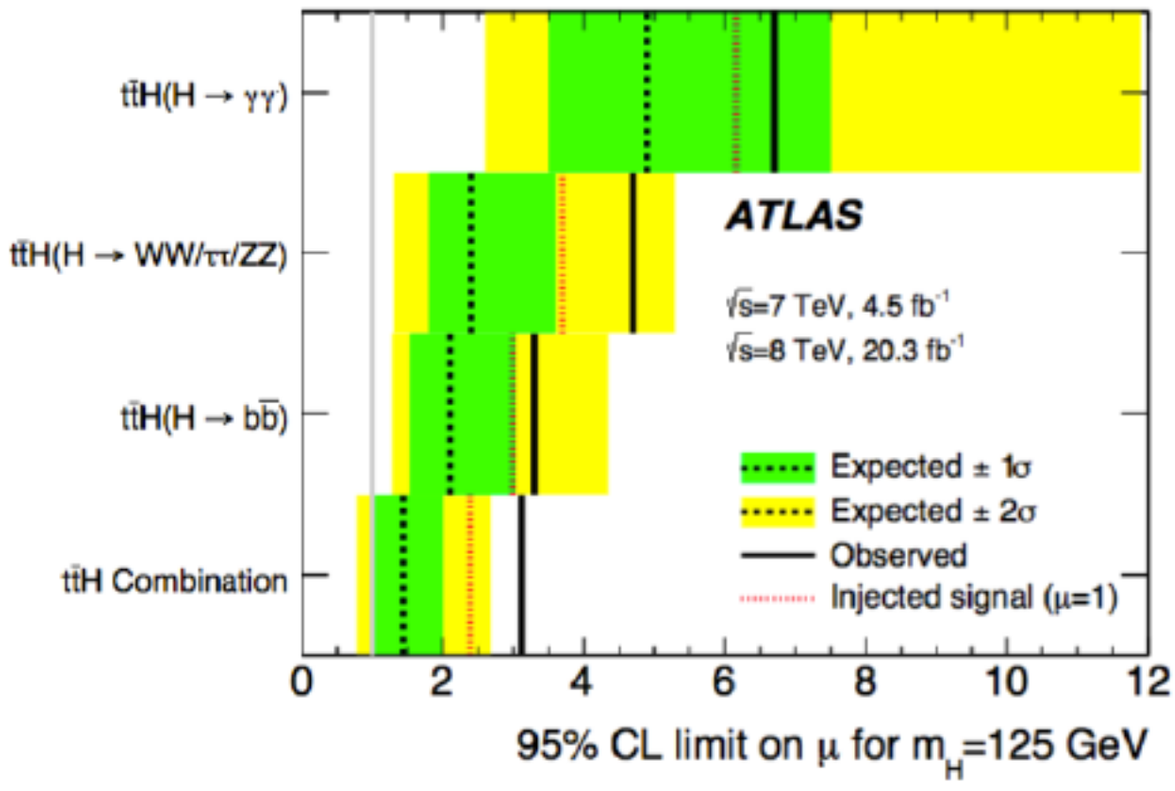
Sensitive to New Physics contributions



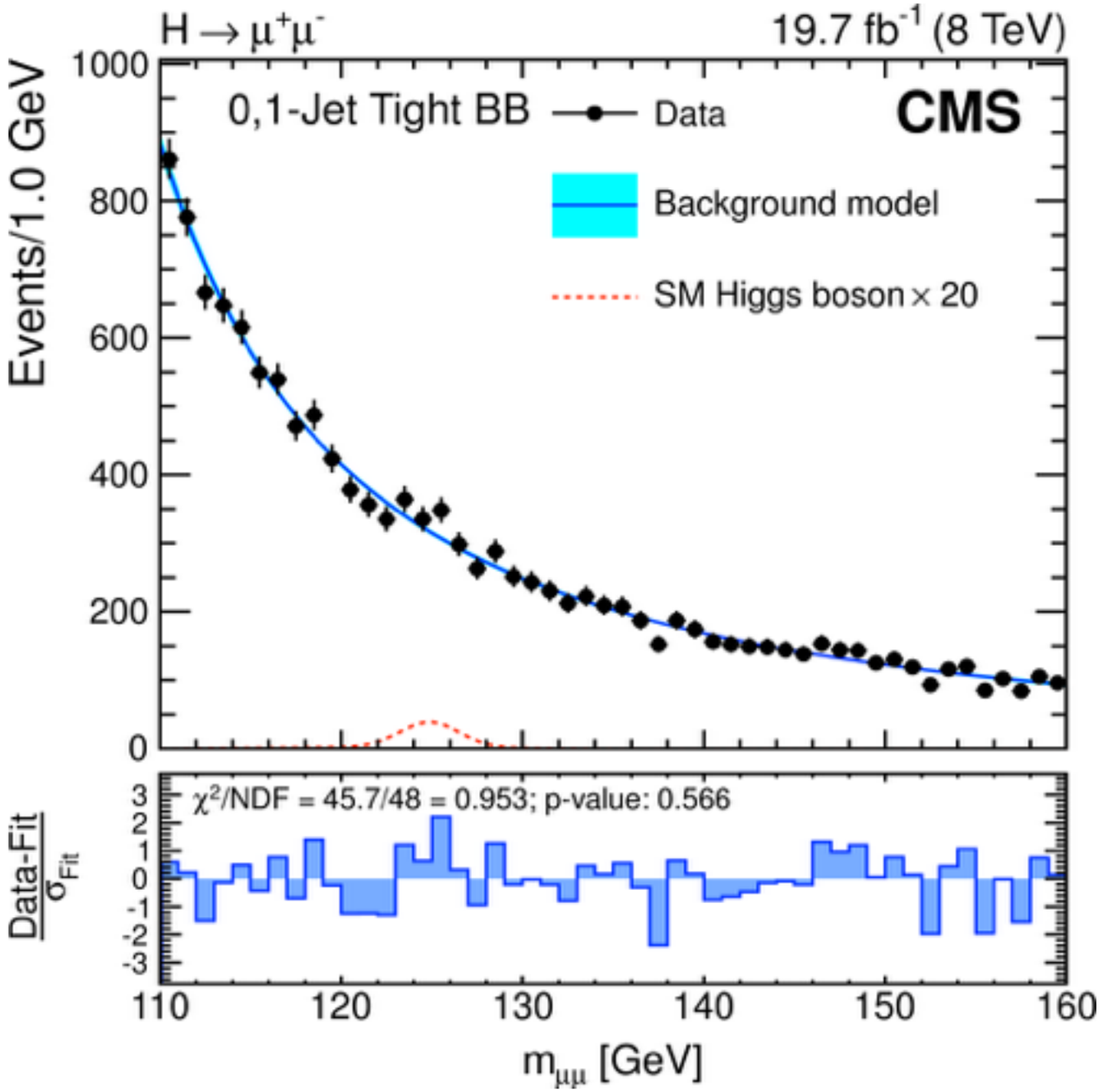
ttH

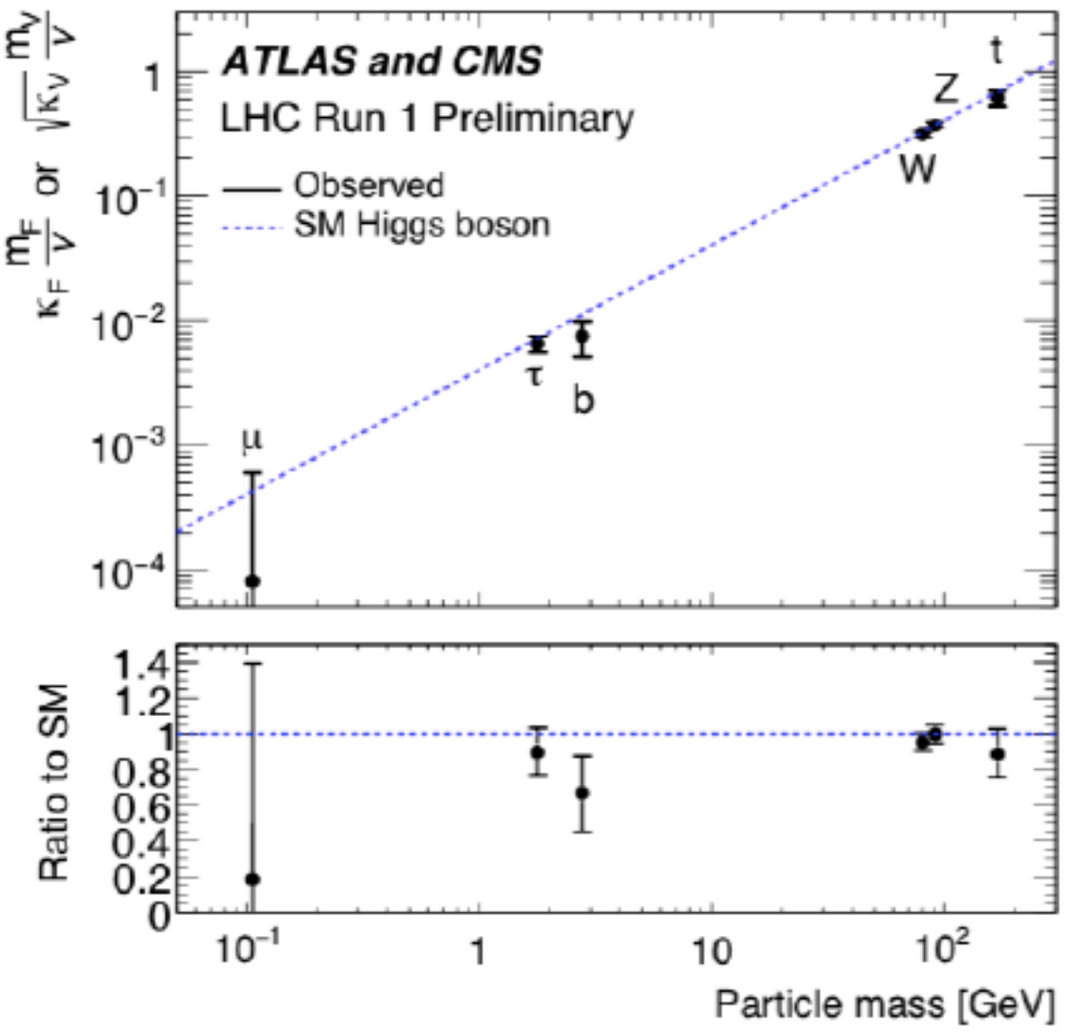

New !
ATLAS
20.3 fb-1
√s = 8 TeV
≥ 8 j, ≥ 4 b
Data
Multijet
tt̄+light
tt̄+cc
tt̄+bb
tt̄+V
Single top
tt̄H (125)
Total unc.
Post-fit
Events / 0.1
Data / Pred
BDT response


g
g
t
t̄
t
t̄
H
W+
W−
b
q
q̄
b̄
b
q̄
q
b̄


tt̄H(H → γγ)
tt̄H(H → WW/ττ/ZZ)
tt̄H(H → bb̄)
tt̄H Combination
ATLAS
√s=7 TeV, 4.5 fb-1
√s=8 TeV, 20.3 fb-1
Expected ± 1σ
Expected ± 2σ
Observed
Injected signal (μ=1)
95% CL limit on μ for mH=125 GeV

Search for H to dimuons





Additional Higgs

The model

- Singlet extension:
  simplest extension of the SM Higgs sector
- add an **additional scalar**, singlet under SM gauge groups
  (further reduction of terms: impose additional symmetries)

$\Rightarrow$ potential (H doublet, χ real singlet)

$$\mathbf{V} = -\mathbf{m^2 H^\dagger H} - \mu^2 \chi^2 + \lambda_1 (\mathbf{H^\dagger H})^2 + \lambda_2 \chi^4 + \lambda_3 \mathbf{H^\dagger H} \chi^2,$$

- collider phenomenology studied by many authors: Schabinger, Wells; Patt, Wilzcek; Barger ea; Bhattacharyya ea; Bock ea; Fox ea; Englert ea; Batell ea; Bertolini/ McCullough; ...
- our approach: **minimal:** no hidden sector interactions
- equally: **Singlet acquires VeV**

Current Limits

- SM-like couplings of **light/ heavy** Higgs:
  rescaled by $\sin\alpha$, $\cos\alpha$
- in addition: **new physics channel:** $H \to h\,h$

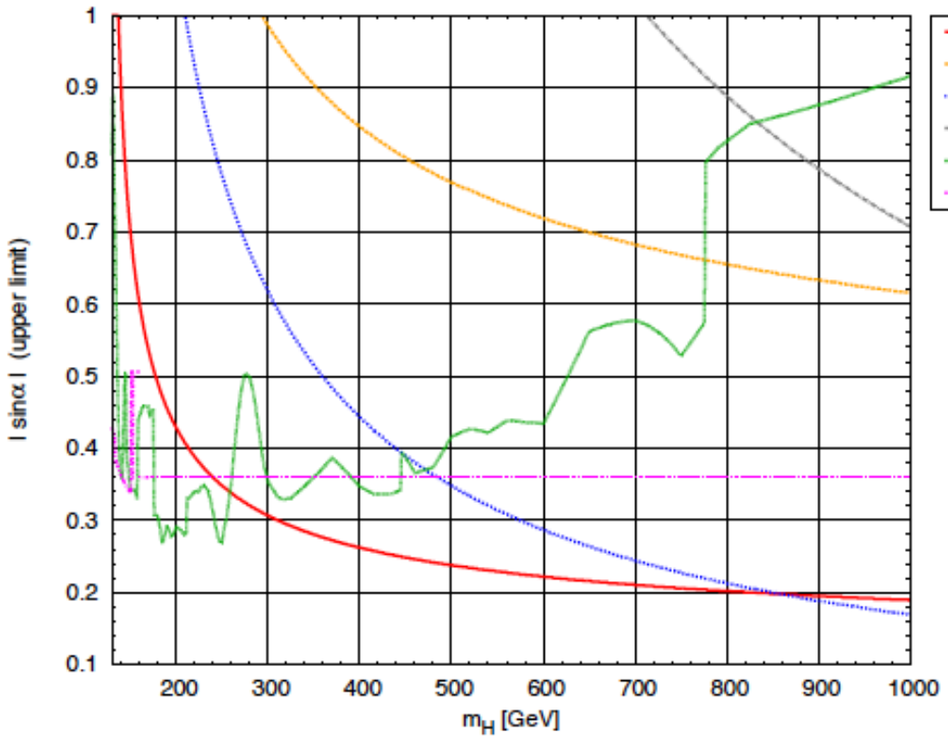
$$\Gamma_{\text{tot}}(H) = \sin^2\alpha\,\Gamma_{\text{SM}}(H) + \Gamma_{H\to h\,h},$$

- **SM like decays** parametrized by

$$\kappa \equiv \frac{\sigma_{\text{BSM}} \times \text{BR}_{\text{BSM}}}{\sigma_{\text{SM}} \times \text{BR}_{\text{SM}}} = \frac{\sin^4\alpha\,\Gamma_{\text{tot,SM}}}{\Gamma_{\text{tot}}}$$

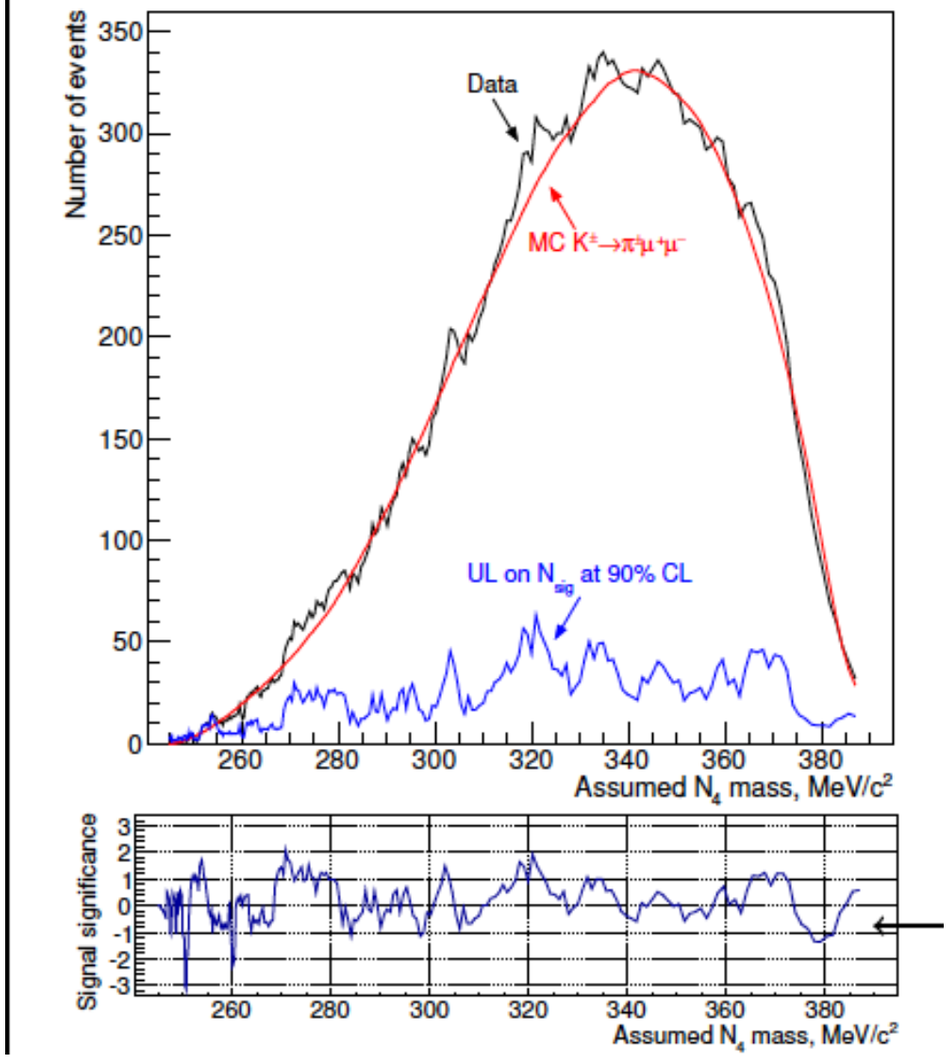
- **new physics channel** parametrized by

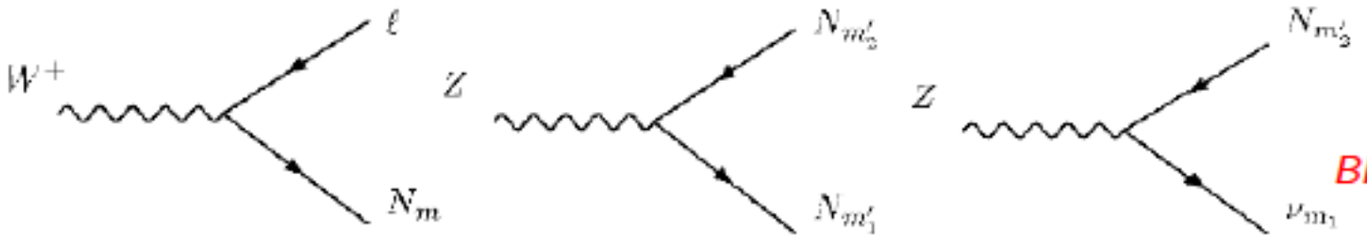
$$\kappa' \equiv \frac{\sigma_{\text{BSM}} \times \text{BR}_{H\to h\,h}}{\sigma_{\text{SM}}} = \frac{\sin^2\alpha\,\Gamma_{H\to h\,h}}{\Gamma_{\text{tot}}}$$



Kaon Decays

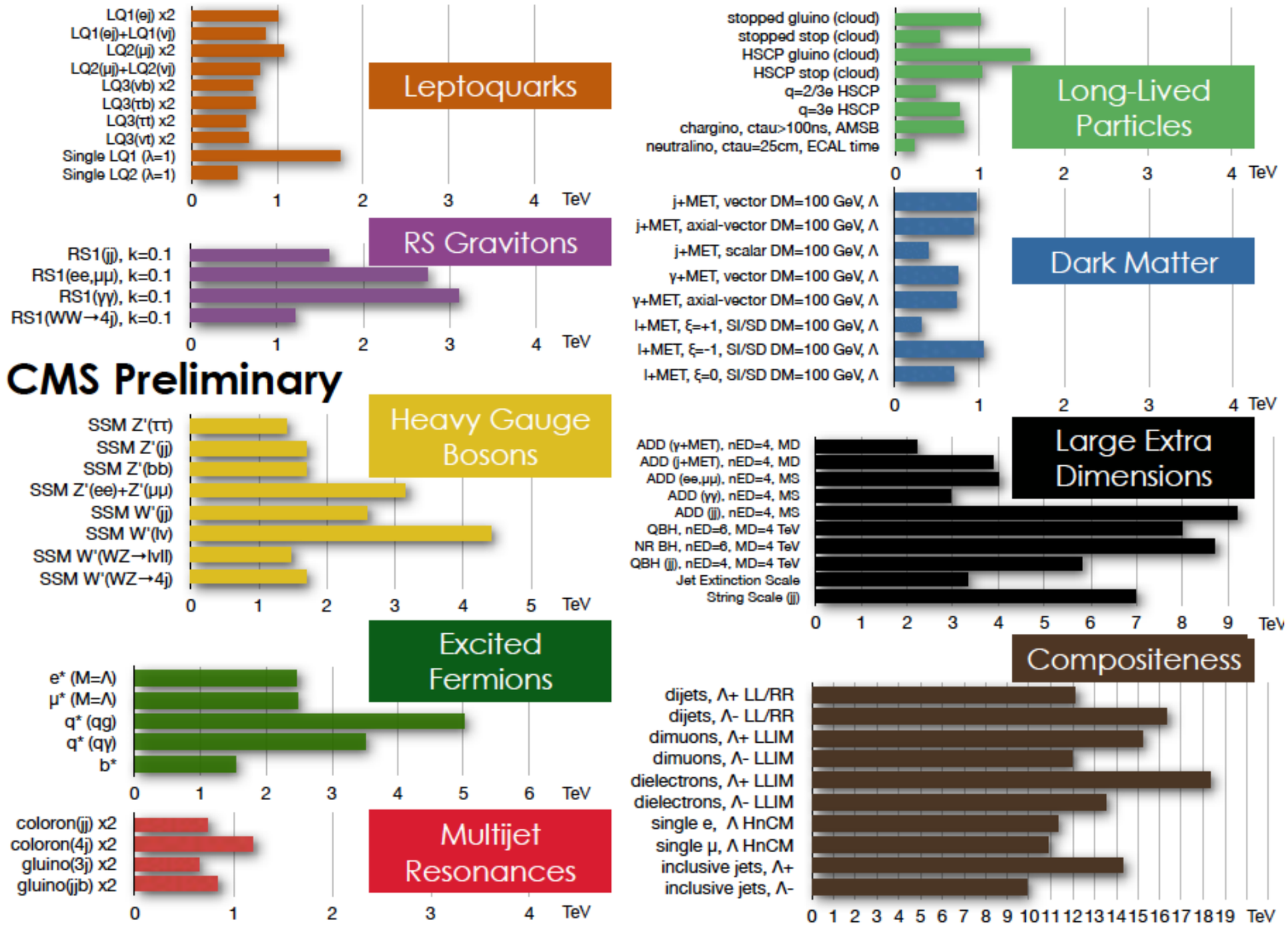
- N_1 - lightest $\mathcal{O}$(keV) $\rightarrow$ Dark Matter candidate
- N_2, N_3 - nearly degenerate (100 MeV - few GeV)
- $N_{2,3}$ production in $K^{\pm}$ decays :
  - $K^{\pm} \rightarrow l^{\pm} N (l = \mu$ this talk), $K^{\pm} \rightarrow \pi^0 l^{\pm} N, \cdots$
- $N_{2,3}$ decays for $m_{2,3} < m_K - m_l$:
  - $N \rightarrow \pi^{\pm} l^{\mp} (l = \mu$ this talk), $N \rightarrow \pi^0 \nu$
  - $N \rightarrow l_1^{\pm} l_2^{\mp} \nu_2$, $N \rightarrow l_1^{\pm} l_2^{\mp} \nu_1$



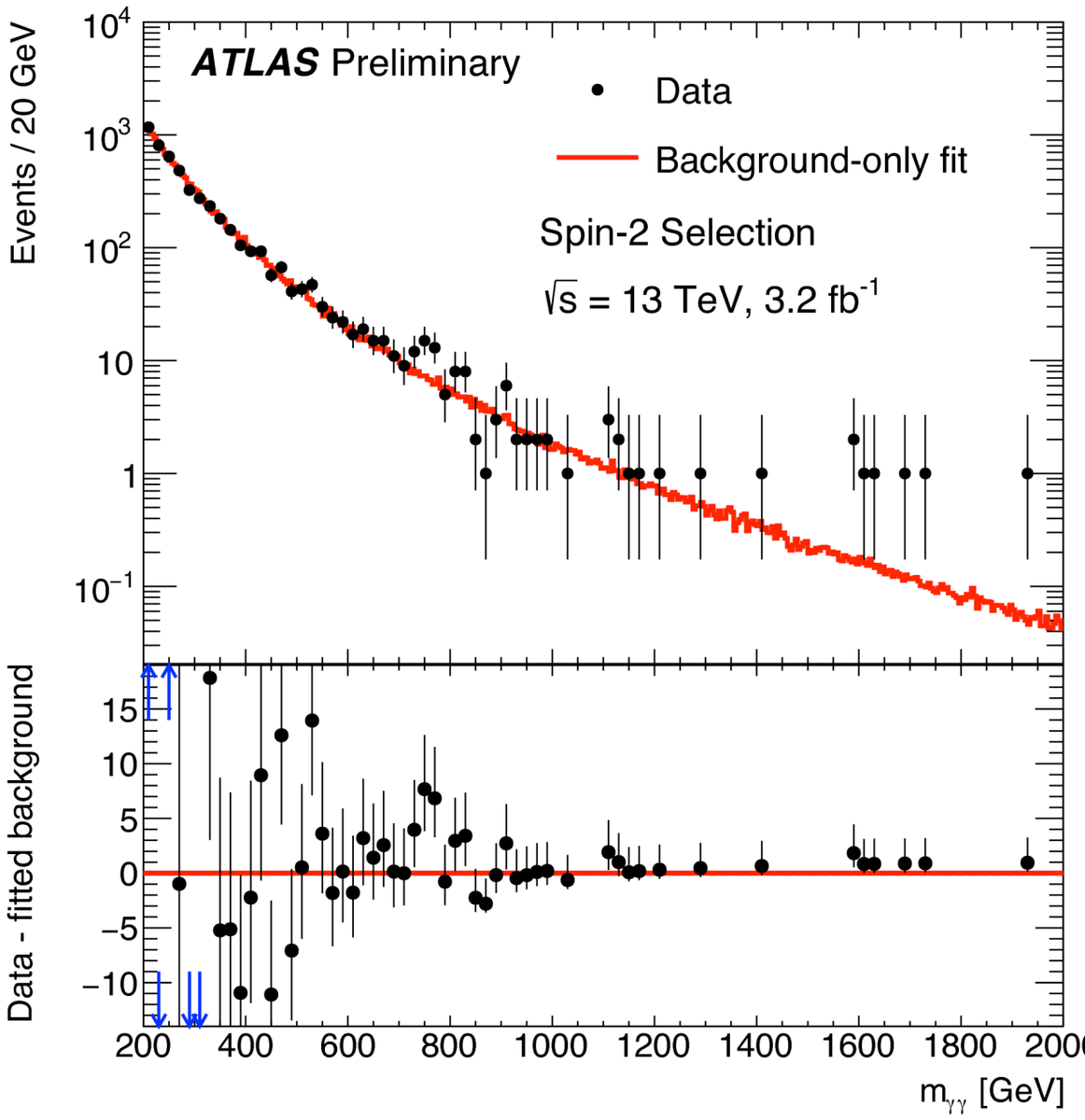


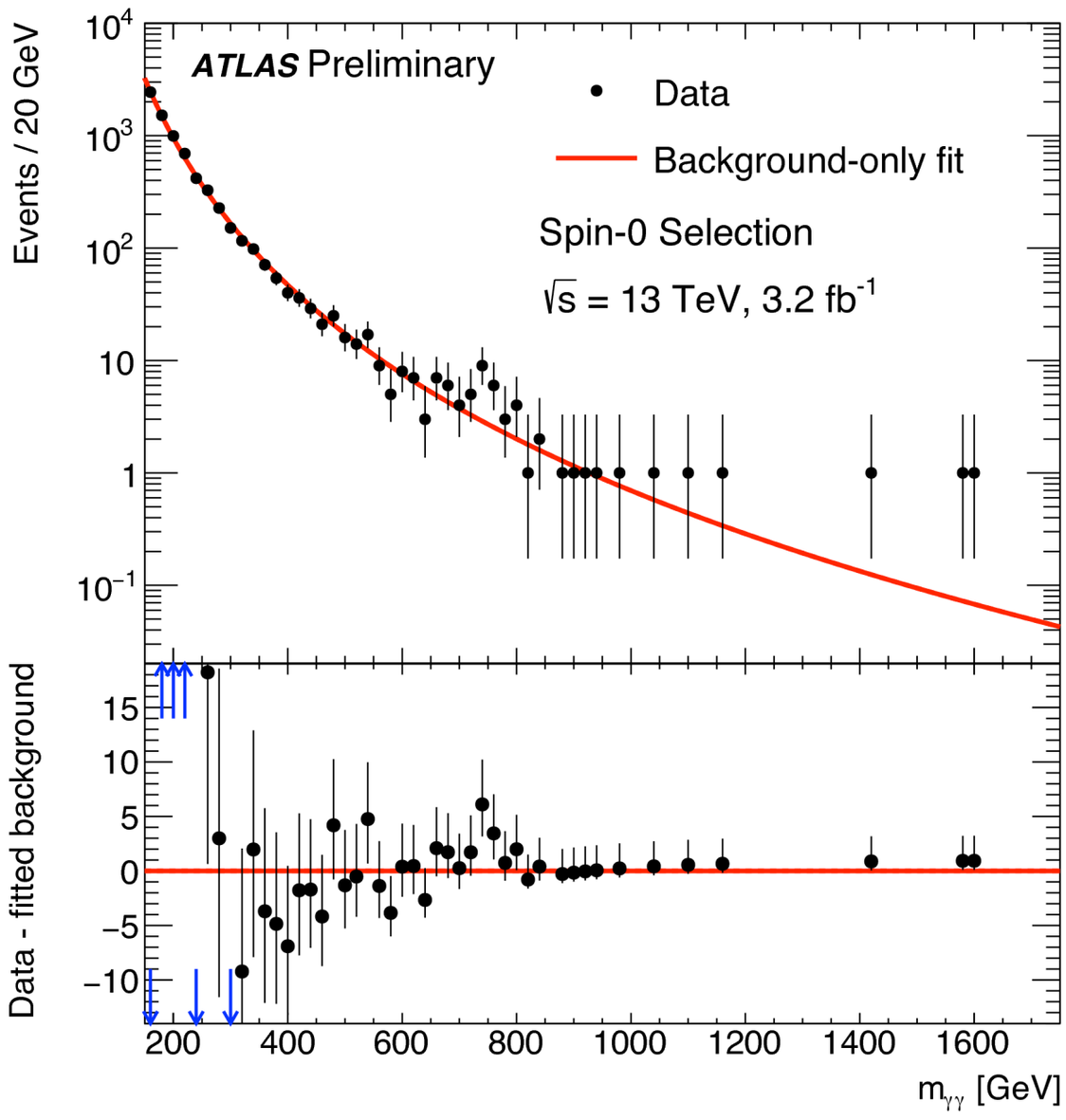
$BR(K^{\pm} \rightarrow \mu^{\pm} N) \times BR(N \rightarrow \pi^{\mp} \mu^{\pm}) \sim |U_{\mu 4}|^4$

Searches


Leptoquarks
LQ1(ej) x2
LQ1(ej)+LQ1(vj)
LQ2(μj) x2
LQ2(μj)+LQ2(vj)
LQ3(vb) x2
LQ3(τb) x2
LQ3(τt) x2
LQ3(vt) x2
Single LQ1 (λ=1)
Single LQ2 (λ=1)
0 1 2 3 4 TeV
RS Gravitons
RS1(jj), k=0.1
RS1(ee,μμ), k=0.1
RS1(γγ), k=0.1
RS1(WW→4j), k=0.1
0 1 2 3 4 TeV
CMS Preliminary
Heavy Gauge Bosons
SSM Z'(ττ)
SSM Z'(jj)
SSM Z'(bb)
SSM Z'(ee)+Z'(μμ)
SSM W'(jj)
SSM W'(lv)
SSM W'(WZ→lvll)
SSM W'(WZ→4j)
0 1 2 3 4 5 TeV
Excited Fermions
e* (M=Λ)
μ* (M=Λ)
q* (qg)
q* (qγ)
b*
0 1 2 3 4 5 6 TeV
Multijet Resonances
coloron(jj) x2
coloron(4j) x2
gluino(3j) x2
gluino(jjb) x2
0 1 2 3 4 TeV
Long-Lived Particles
stopped gluino (cloud)
stopped stop (cloud)
HSCP gluino (cloud)
HSCP stop (cloud)
q=2/3e HSCP
q=3e HSCP
chargino, ctau>100ns, AMSB
neutralino, ctau=25cm, ECAL time
0 1 2 3 4 TeV
Dark Matter
j+MET, vector DM=100 GeV, Λ
j+MET, axial-vector DM=100 GeV, Λ
j+MET, scalar DM=100 GeV, Λ
γ+MET, vector DM=100 GeV, Λ
γ+MET, axial-vector DM=100 GeV, Λ
l+MET, ξ=+1, SI/SD DM=100 GeV, Λ
l+MET, ξ=-1, SI/SD DM=100 GeV, Λ
l+MET, ξ=0, SI/SD DM=100 GeV, Λ
0 1 2 3 4 TeV
Large Extra Dimensions
ADD (γ+MET), nED=4, MD
ADD (j+MET), nED=4, MD
ADD (ee,μμ), nED=4, MS
ADD (γγ), nED=4, MS
ADD (jj), nED=4, MS
QBH, nED=6, MD=4 TeV
NR BH, nED=6, MD=4 TeV
QBH (jj), nED=4, MD=4 TeV
Jet Extinction Scale
String Scale (jj)
0 1 2 3 4 5 6 7 8 9 TeV
Compositeness
dijets, Λ+ LL/RR
dijets, Λ- LL/RR
dimuons, Λ+ LLIM
dimuons, Λ- LLIM
dielectrons, Λ+ LLIM
dielectrons, Λ- LLIM
single e, Λ HnCM
single μ, Λ HnCM
inclusive jets, Λ+
inclusive jets, Λ-
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 TeV
CMS Exotica Physics Group Summary – Dec Jamboree, 2015

The diphoton excess





Diphoton

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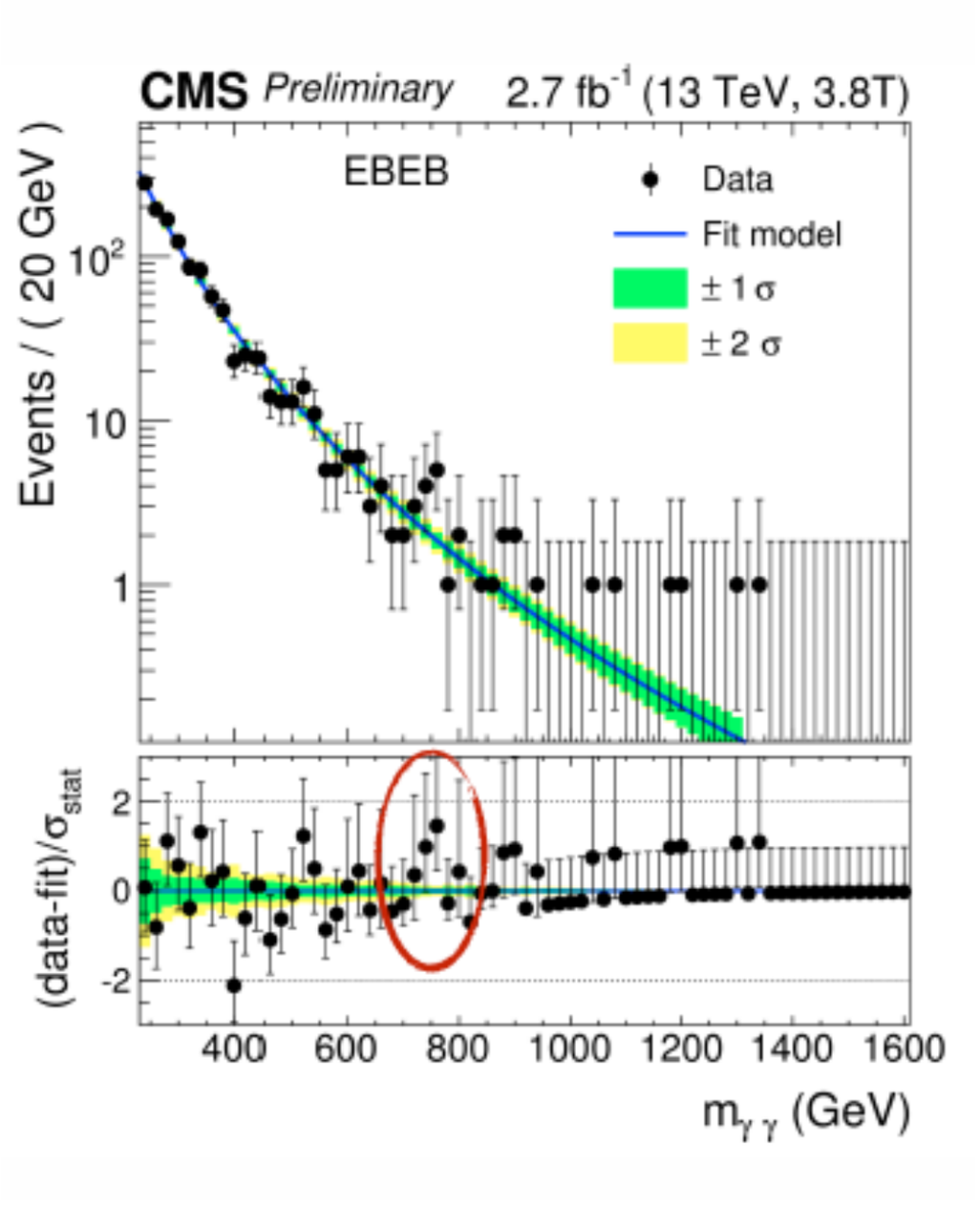
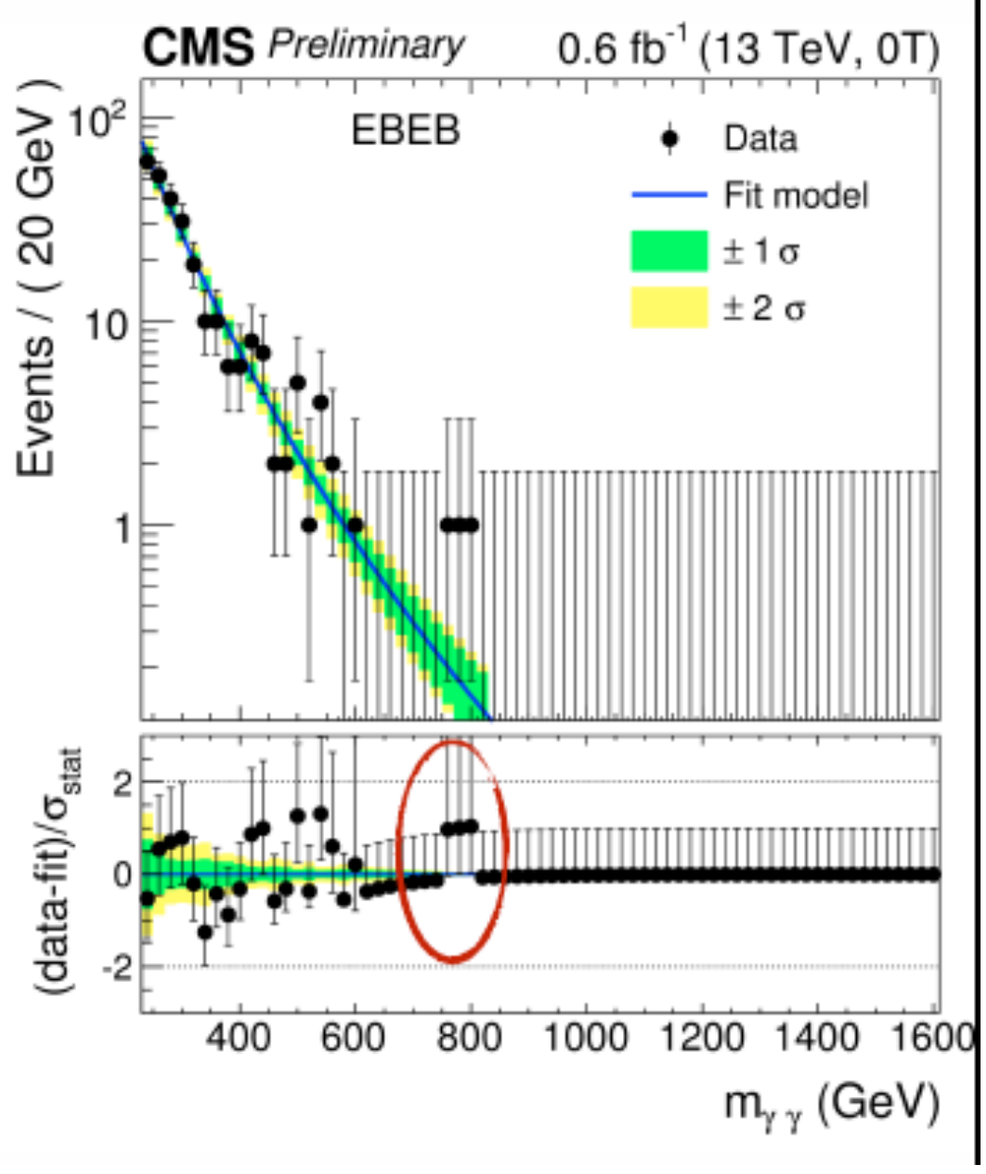
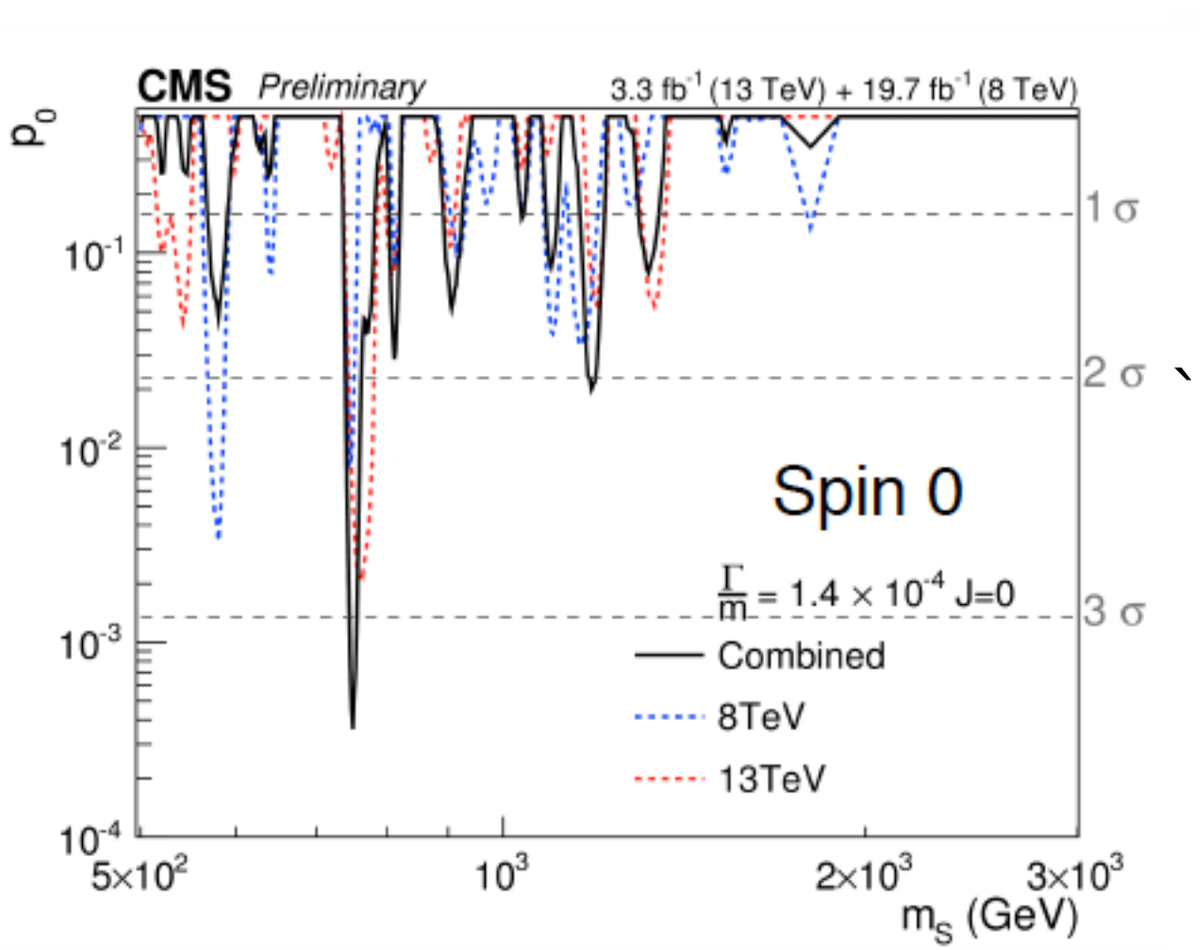
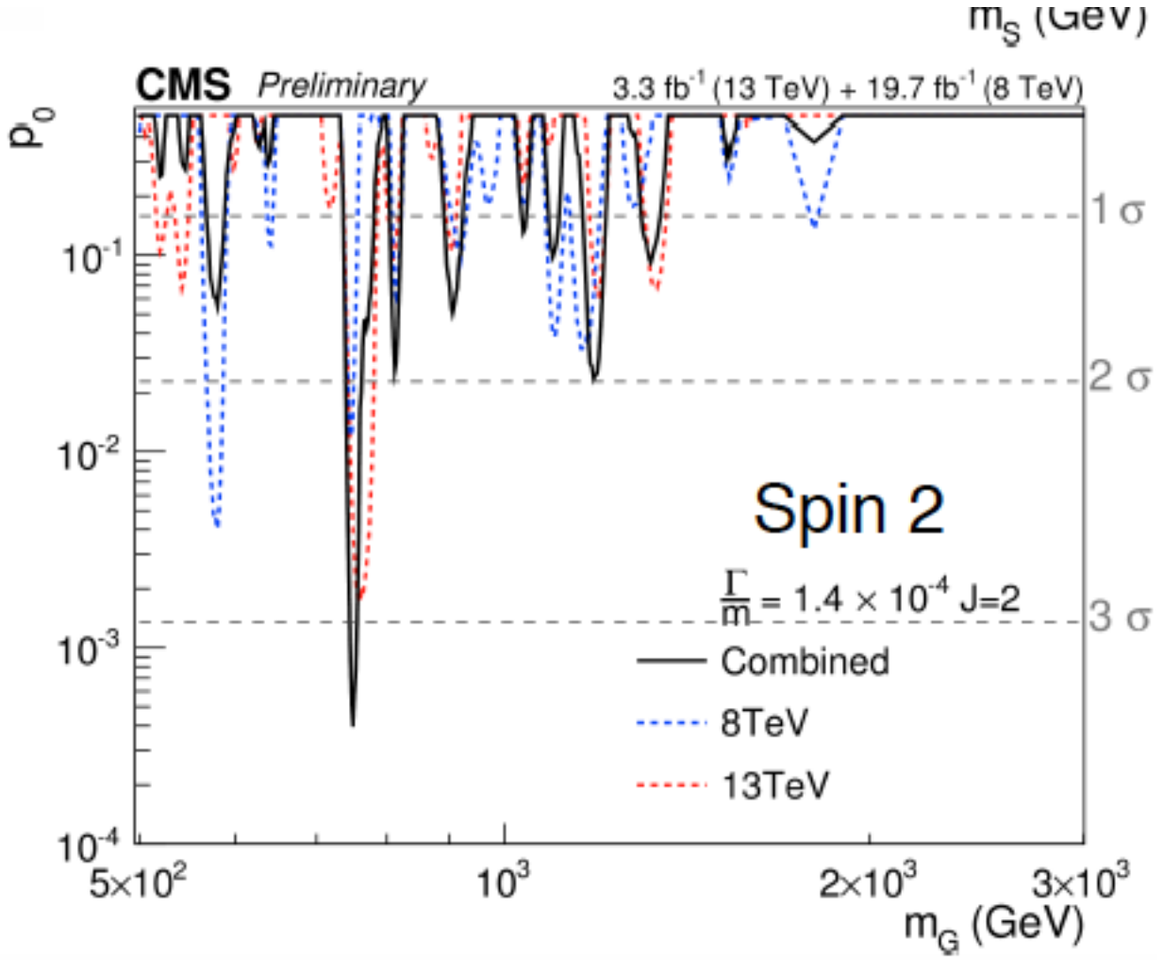




Significance





CMS:Local significance ~3.4, global 1.6

ATLAS: Local ~3.9, global 2.0

slight different numbers for Spin 0 / 2

Milena Quittnat