Spin-1 particle and the ATLAS Diboson excess

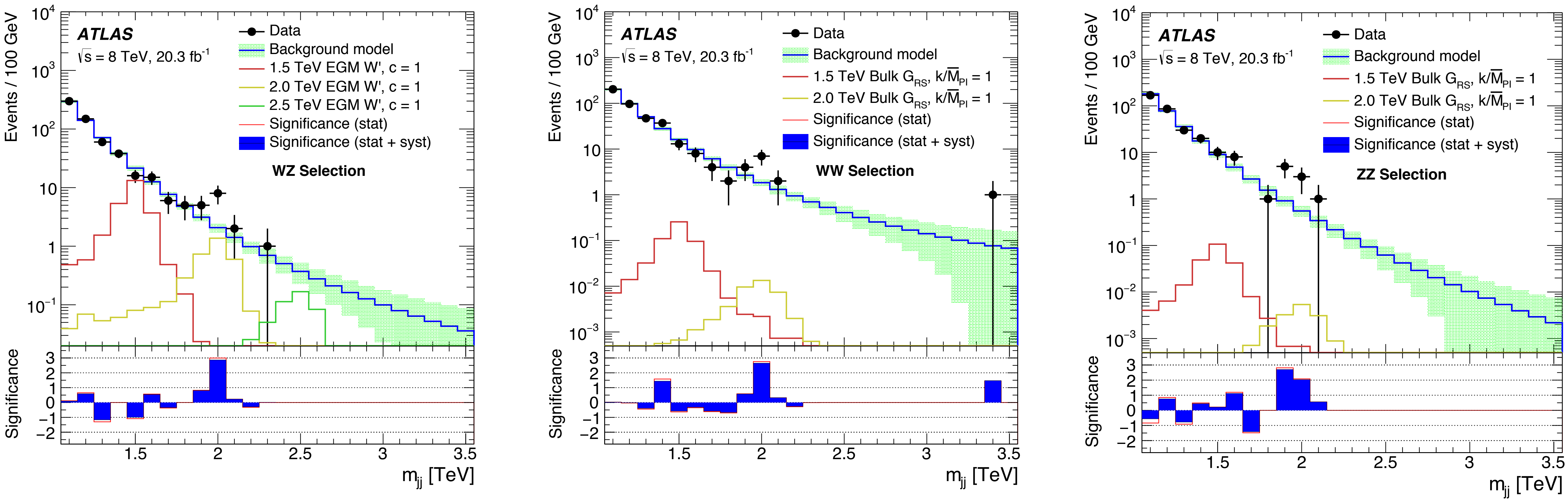
Tomohiro Abe (KEK)

based on the works
1507.01681: **TA, Teppei Kitahara, Mihoko Nojiri**

Kavli-IPMU-Durham-KIAS workshop: New particle searches confronting the first LHC run-2 data
2015.9.9

ATLAS diboson excess

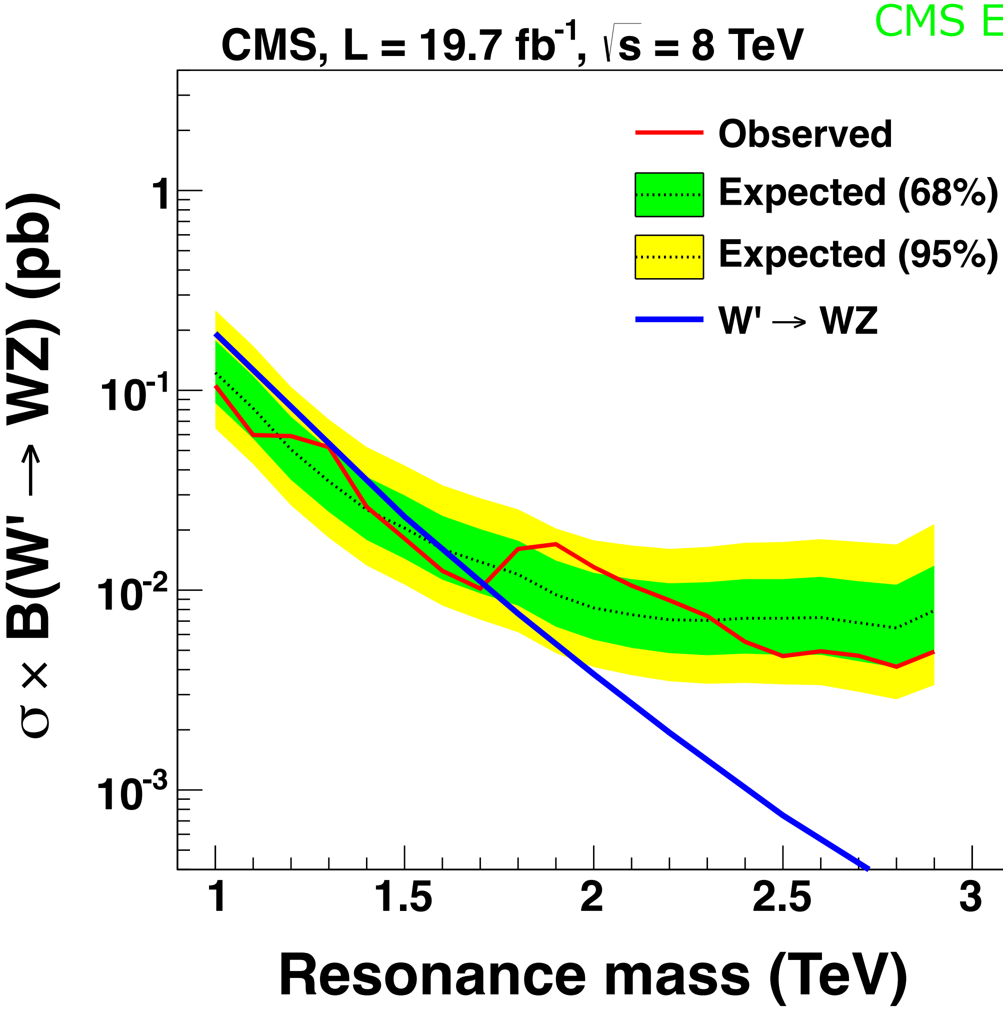
ATLAS EXOT-2013-008



- **pp → X → WZ/WW/ZZ → two fat jets**
  - ★ mass of X ~ 2TeV ?
  - ★ local significance: WZ 3.4σ, WW 2.6σ, ZZ 2.9σ
  - ★ global significance: WZ 2.5σ

No CMS excess in the same process

CMS EXO-12-024



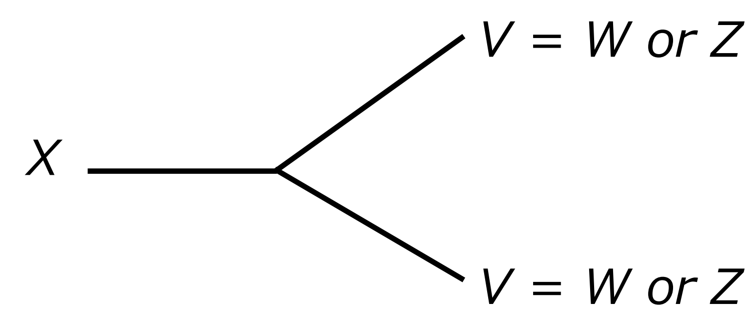
Situation of diboson in each channel

final states	ATLAS	CMS
$VV \to$ jets	excess	no excess
$WZ \to \ell\nu$ $WZ \to$ jets + $\ell\ell$ $WZ \to \ell\nu$ +	no excess	no excess

- **Excess is only in pp → VV → jets at the ATLAS**
  - ⋆ logal: WZ 3.4σ, WW 2.6σ, ZZ 2.9σ
  - ⋆ global: WZ 2.5σ
- **Excess might be statistical fluctuation**
- ***But* it is good exercise to consider what kind of BSM can explain the excess**

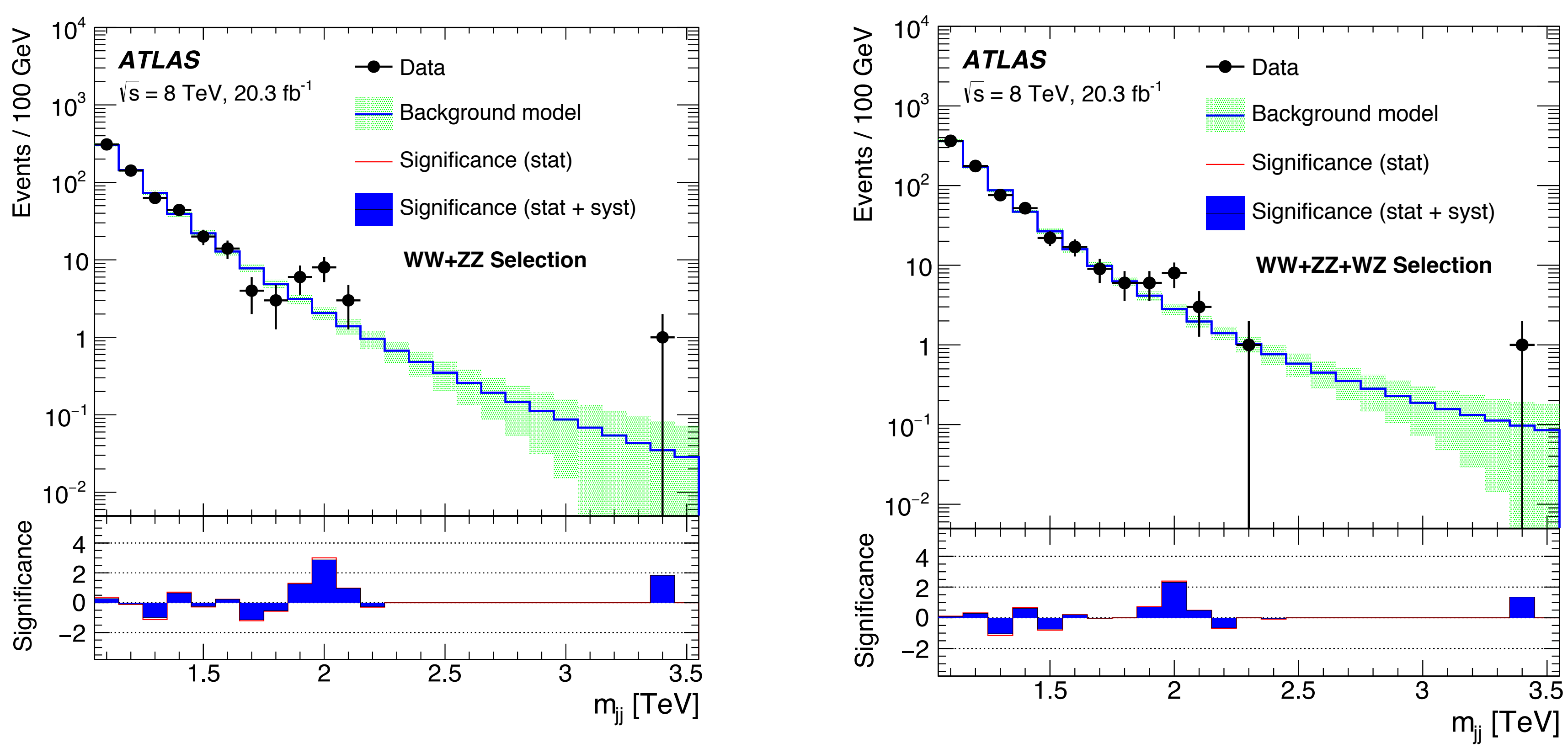
What we know about the excess

- **New particles (*X*) is a boson**
  - ⋆ It decays into *WZ/WW/ZZ*



- ***WZ/WW/ZZ* are not good separated**
  - ⋆ $|m_j - m_V| < 13\mathrm{GeV}$
  - ⋆ one or two channels are enough to be explained

ATLAS EXOT-2013-008



In this talk

- **focus on spin 1 new particle (*W'* and *Z'*)**
  - ⋆ add new SU(2) gauge symmetry
  - ⋆ $W' \to WZ$, $Z' \to WW$
  - ⋆ no ZZ final state
  - ⋆ many models can be constructed (choice of Higgs and fermion sectors)

- **pick up one specific model**
  - ⋆ renormalizable and perturbative model
  - ⋆ (non perturbative model → talk by Dr. Fukano)
  - ⋆ (model independent feature → talk by Mr. Nagai)

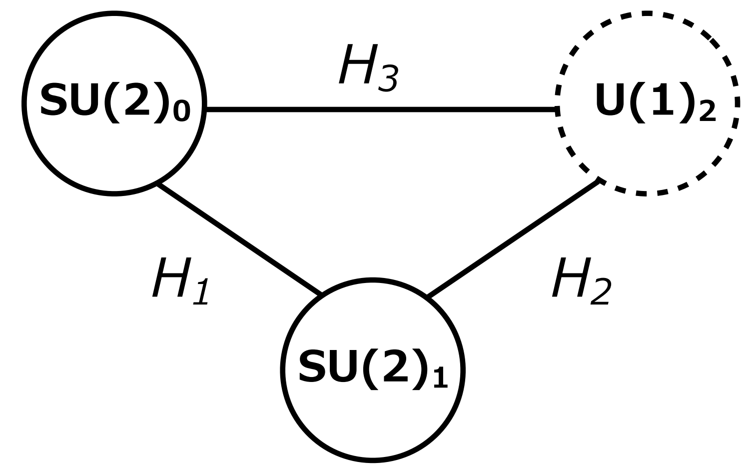
- **discuss prospect for LHC run-2**
  - ⋆ model independent feature of $W' \to WZ \to$ hadrons channel
  - ⋆ (for another channel → talk by Mr. Liew)

model

model setup

TA and Kitano '13

schematic picture (moose notation)



- **$SU(2)_0 \times SU(2)_1 \times U(1)_2 \rightarrow U(1)_{QED}$**

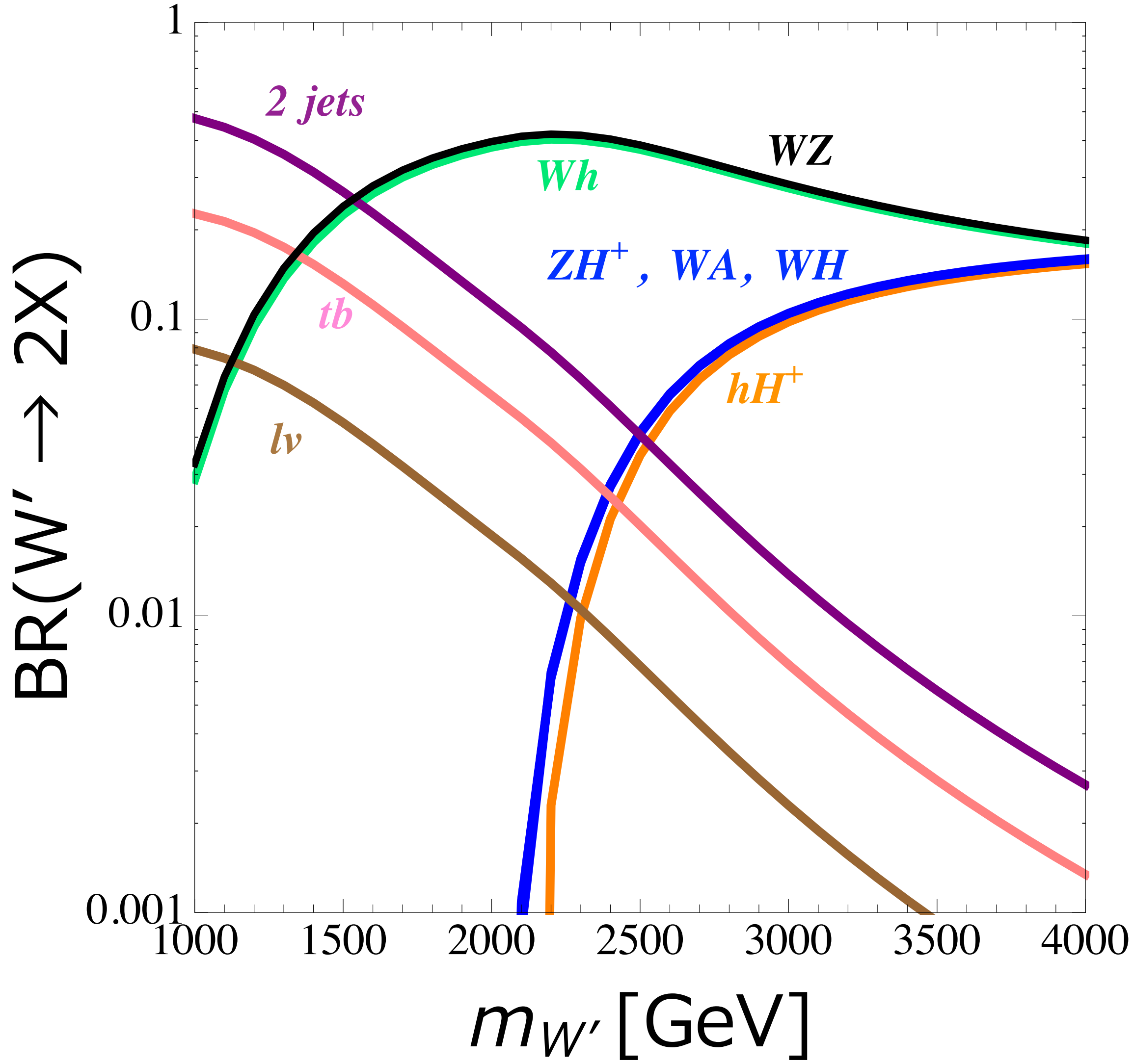
- **three Higgs doublets**
  - ★ H_1 : $SU(2)_0 \times SU(2)_1 \rightarrow SU(2)_v$
  - ★ H_2 : $SU(2)_1 \times U(1)_2 \rightarrow U(1)_v$
  - ★ H_3 : $SU(2)_0 \times U(1)_2 \rightarrow U(1)_v$

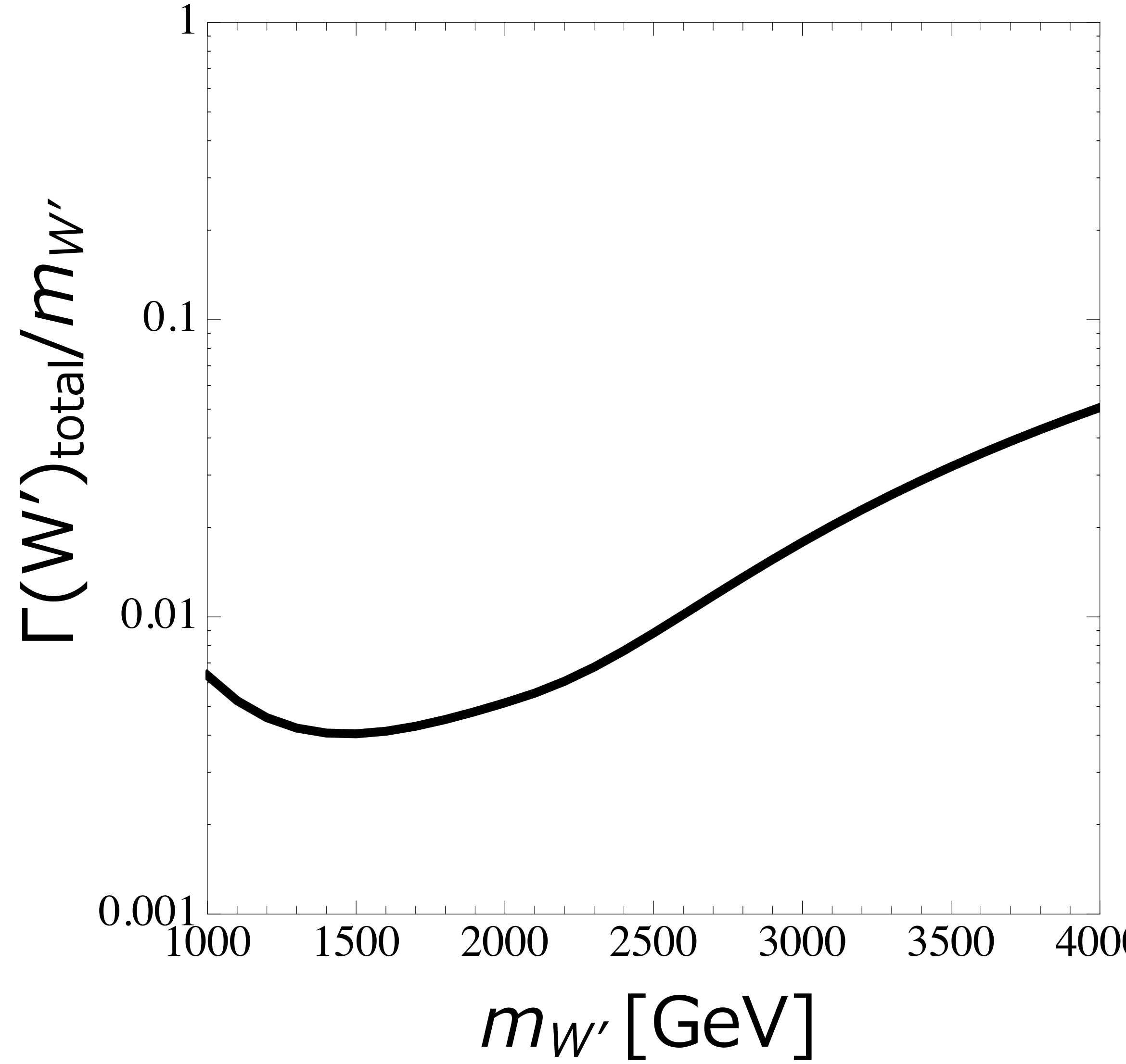
  - ★ 12 reals scalars (6 of them are eaten by gauge boson)
  - ★ 6 physical scalar (3 CP-even + 1 CP-odd + 1 pair of charged Higgs)

- **fermion**
  - ★ ψ_L: $(SU(2)_0, SU(2)_1, U(1)_2)$ =(2, 1, 1/6) or (2, 1, -1/2)
  - ★ ψ_R: $(SU(2)_0, SU(2)_1, U(1)_2)$ =(1, 1, Q_{QED})
  - ★ Yukawa is given by H_3

$$\mathcal{L}^{\text{Yukawa}} = -\bar{Q}^i H_3 \begin{pmatrix} y_u^{ij} & 0 \\ 0 & y_d^{ij} \end{pmatrix} \begin{pmatrix} u_R^j \\ d_R^j \end{pmatrix} + (h.c.) + (\text{lepton sector})$$

W' branching ratio and width

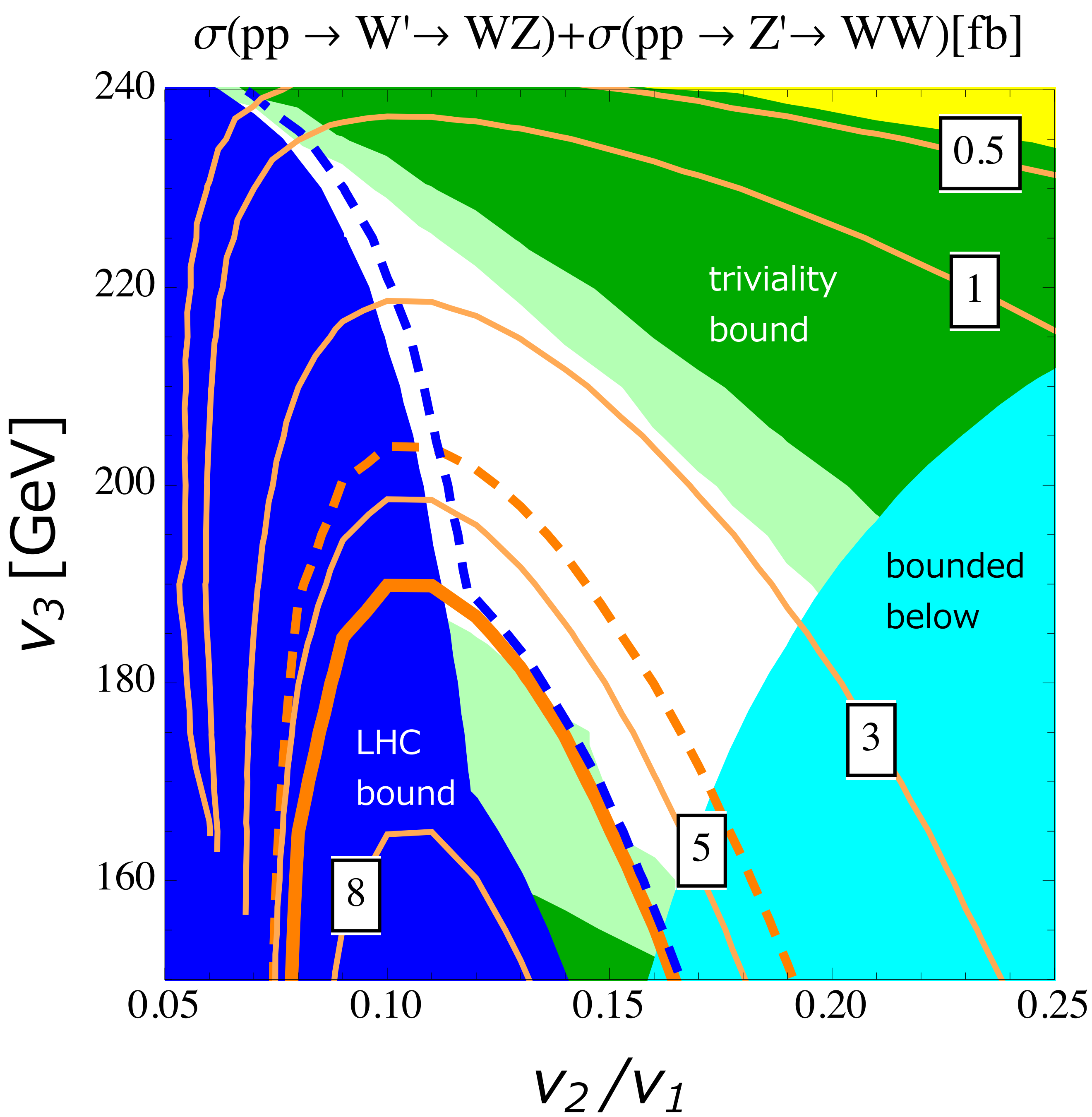




★ $m_H = m_{H'} = m_A = 2$TeV

★ width is narrow (20 GeV for $m_{W'} = 2$TeV)

results



★ colored region is excluded

★ orange lines are σ

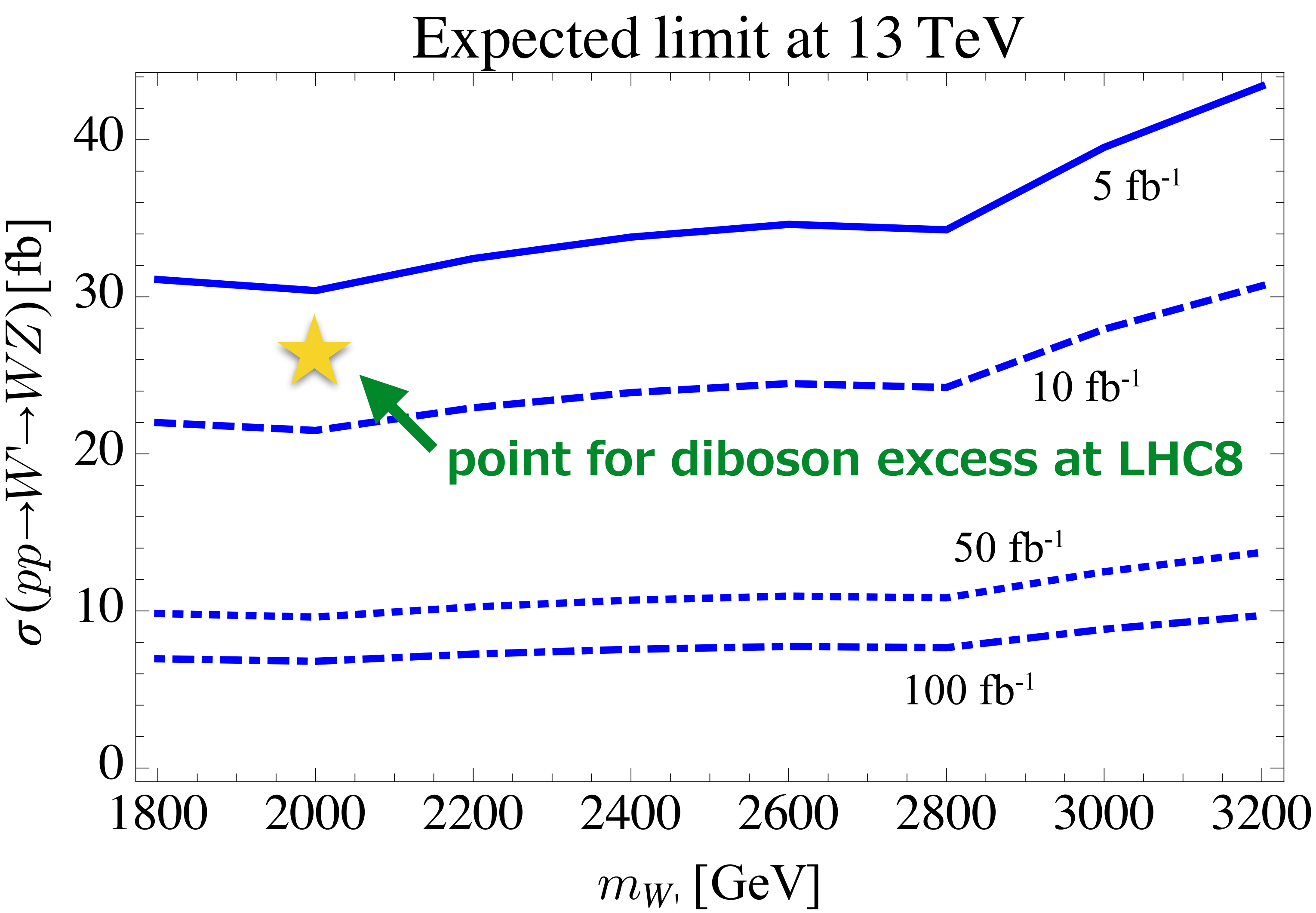
★ σ > 7fb is exclude by W′ → Wh

★ σ = 6fb on bold orange line
(possiblly explain the excess)

★ dashed lines are with K-factor (K ~ 1.3) 0711.0749, 1410.4692

prospect for LHC run-2

95% exclusion limit at LHC run-2



- ★ WZ → hadrons
- ★ W' width = 25GeV
- ★ model independent result (as long as width is narrow)

Summary

Summary

- **diboson excess around 2TeV by the ATLAS**
    - ⋆ CMS does not find the excess
    - ⋆ no excess with leptonic decay channel
    - ⋆ nice exercise to consider BSM

- **an example model (W' and Z')**
    - ⋆ renormalizable model
    - ⋆ $\sigma(pp \to V' \to l\nu)$ and $\sigma(pp \to V' \to Vh)$ give strong bound
    - ⋆ $\sigma(pp \to V' \to VV)$ = 6 fb is possible

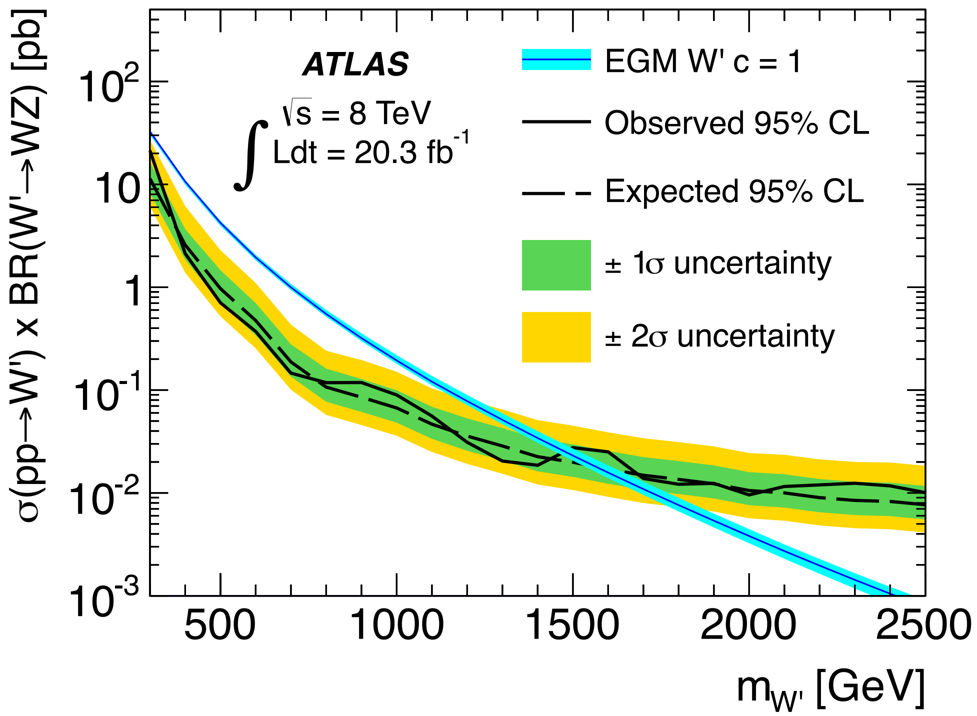
- **prospect for LHC run-2**
    - ⋆ less than 10 fb-1 is enough to exclude the 2TeV excess

Backup slides

Other final states from diboson

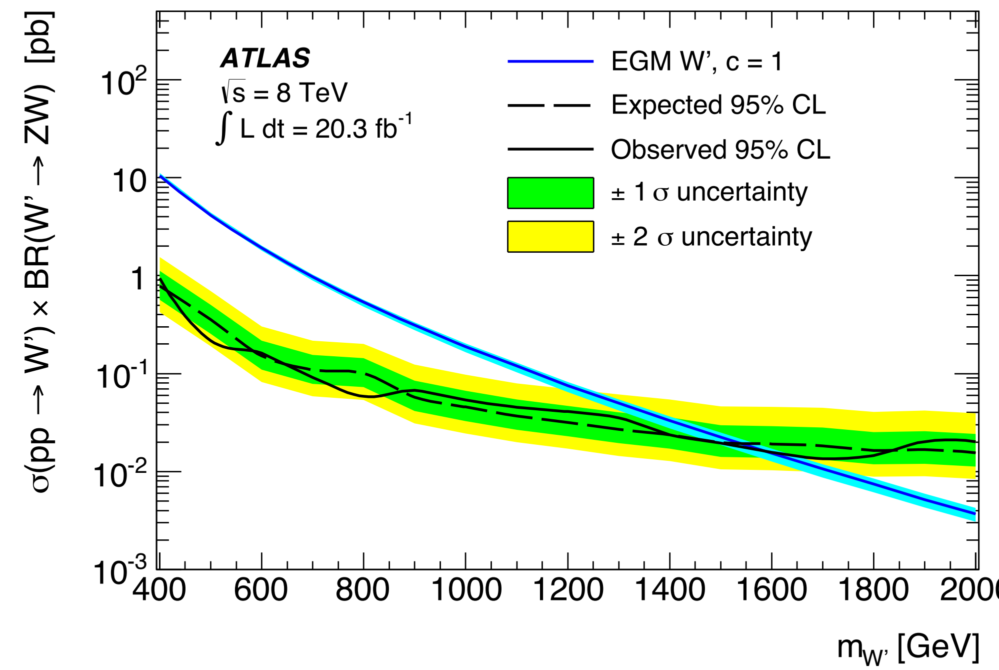
ATLAS EXOT-2013-001

ATLAS(WZ →lv + jets)



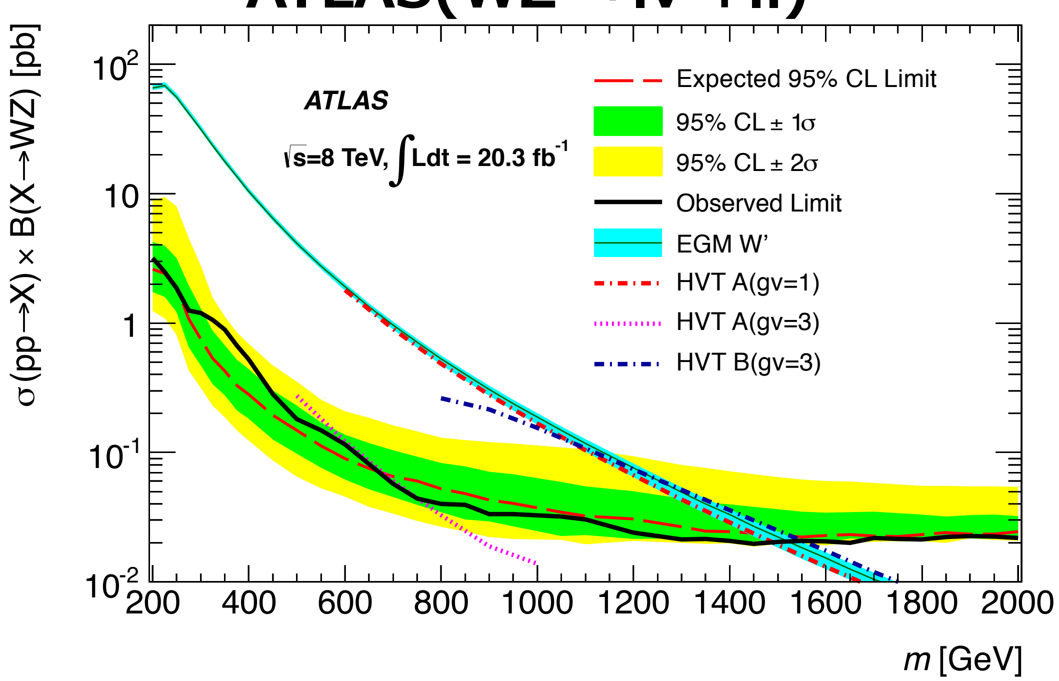
ATLAS EXOT-2013-006

ATLAS(WZ → jets + leptons)



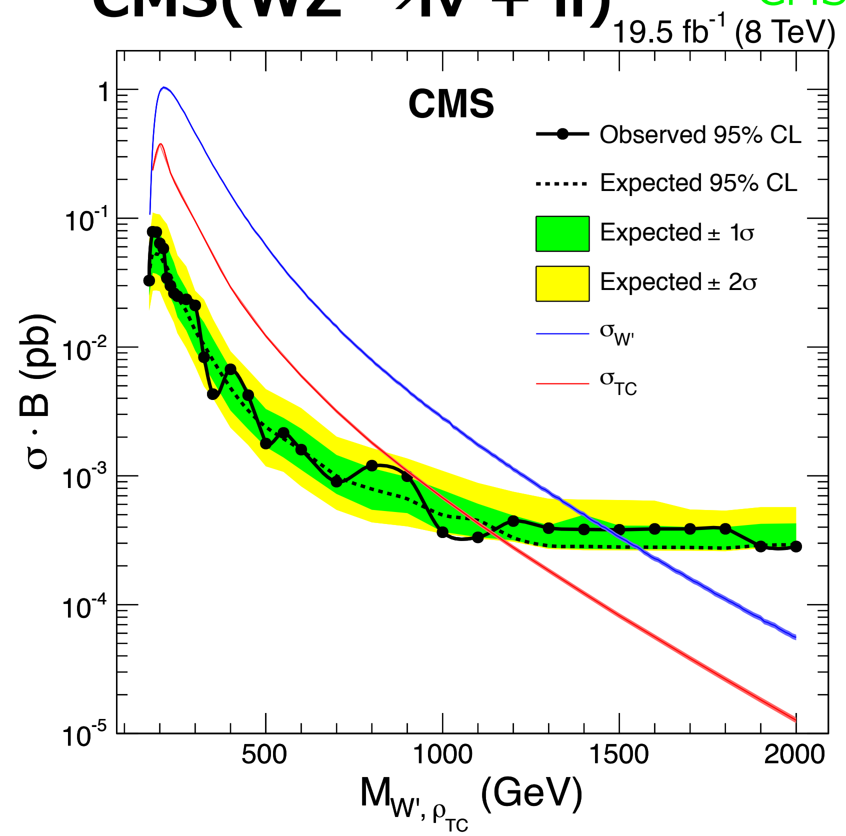
ATLAS EXOT-2013-007

ATLAS(WZ →lv +ll)



CMS(WZ →lv + ll)

CMS EXO-12-025



Works in market (more than 30 papers)

- **Spin 0 ($S \to WW$, $S \to ZZ$)**

  1507.02483, 1507.03553, 1507.04431, 1507.05028, 1507.05310, 1507.06312, 1508.04814, 1508.05632

- **Spin 1 ($W' \to WZ$, $Z' \to WW$)**

  1506.03751, 1506.03931, 1506.04392, 1506.05994, 1506.06064, 1506.06736, 1506.06767, 1506.07511, 1506.08688, 1507.00013, 1507.00268, 1507.00900, 1507.01185, 1507.01638, 1507.01681, 1507.01914, 1507.01914, 1507.01923, 1507.02483, 1507.03098, 1507.03428, 1507.03553, 1507.03940, 1507.04431, 1507.05028, 1507.05299, 1507.05310, 1507.06018, 1507.06312, 1507.07102, 1507.07406, 1507.07557, 1507.08273, 1508.00174, 1508.02277, 1508.03544, 1508.04129, 1508.05940

- **Spin 2**

  1507.03553, 1507.06312, 1508.04814

- **others (tri-boson can mimic diboson signal)**

  1506.06739

Monte Carlo part

What we did in MC part

- **Monte Carlo**
  - ★ QCD dijet as BG (1.73 10^6 ~ 5fb-1, E_{CM} > 1TeV, pT>400GeV, sqrt[s] =13TeV) by PYTHIA8.205
  - ★ signal (pp $\rightarrow$ W′ $\rightarrow$ WZ) $m_{W'}$ = 1.8TeV to 3.2 TeV, width =25GeV
  - ★ Tune 4C for fragmentation and hadronization
  - ★ detector simulator DeLPHES3 is modified using FastJet3
  - ★ cuts: same as the cuts used by ATLAS
- **Our MC result**
  - ★ we checked signal distributions agree with the ATLAS result (8TeV)
  - ★ we found # of back ground is twice of the ATLAS result (8TeV)
  - ★ we scale our BG 1/2 for 13TeV analysis

More on our model

model parameters

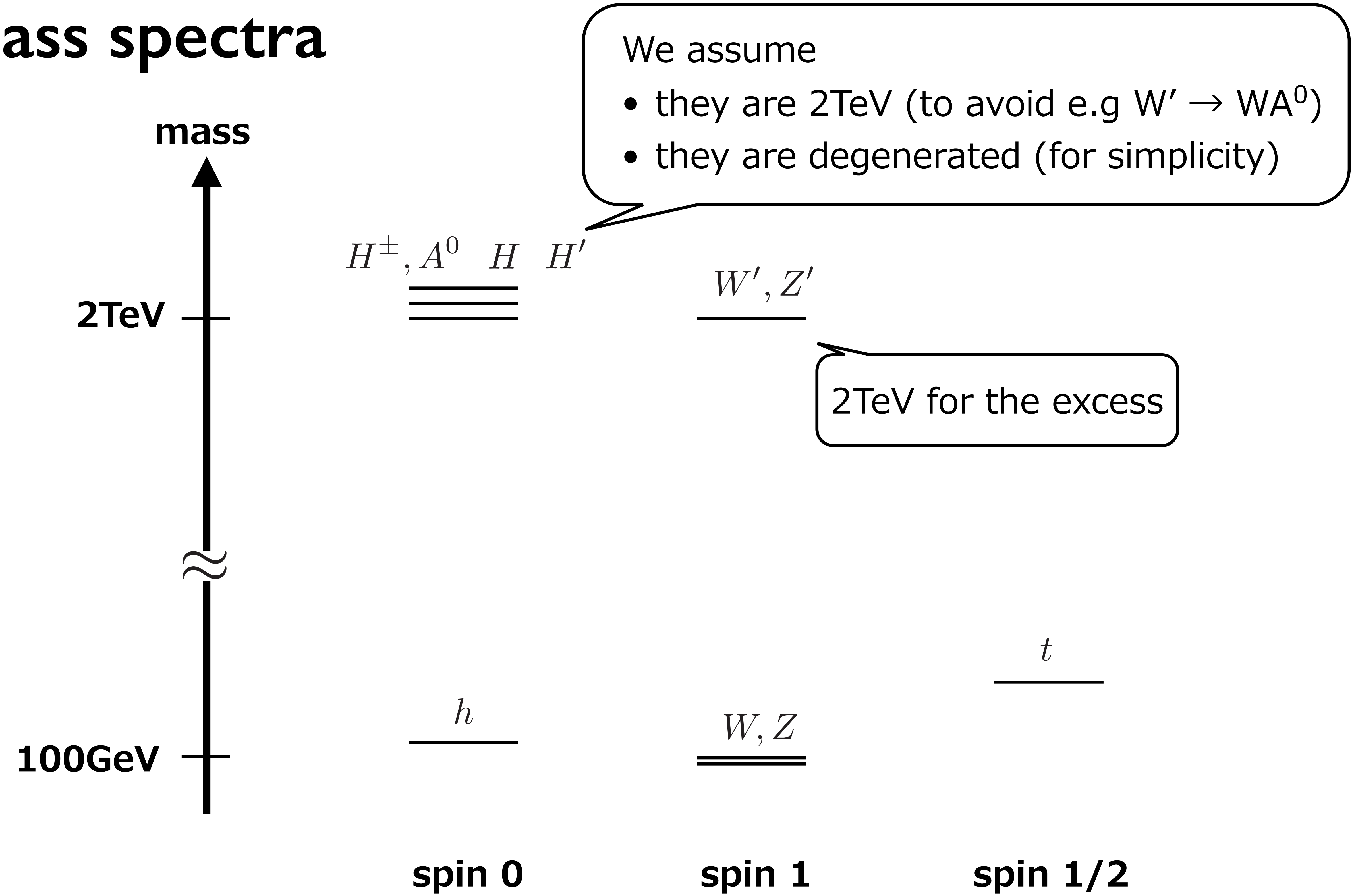
- **4 masses:** $m_{Z'}$, m_H, $m_{H'}$, m_A
  - ⋆ $m_{Z'}$ = 2TeV (for the excess)
  - ⋆ $m_H = m_{H'} = m_A$ = 2TeV (for simplicity)

- **3 couplings:** κ_F, κ_Z, $g_{WW'H'}$
  - ⋆ $\kappa_F = 1$, $\kappa_Z \sim 1$, $g_{WW'H'} = 0$

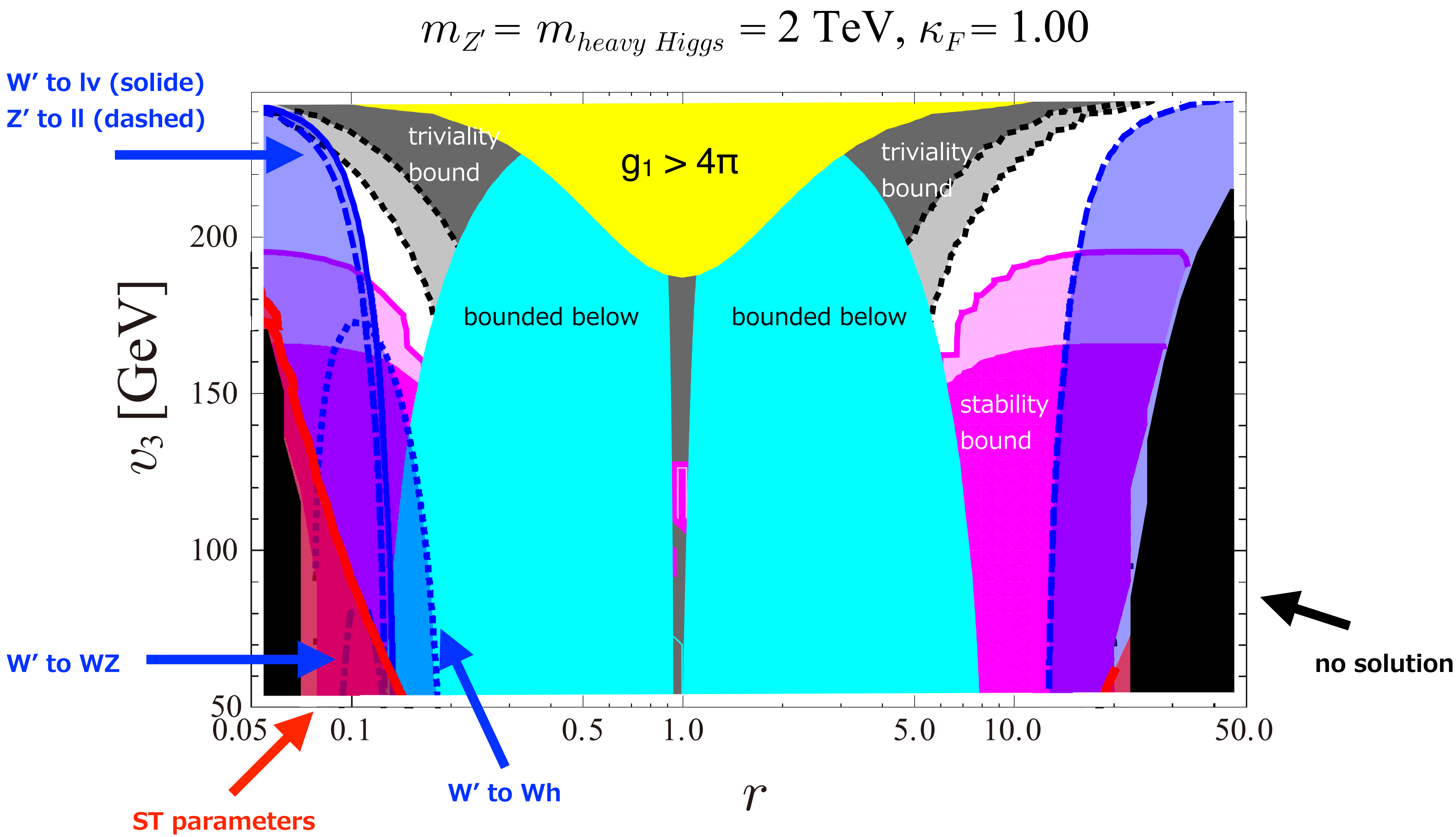
($\kappa_F = g_{hff}/g_{hff}^{SM}$, $\kappa_Z = g_{hZZ}/g_{hZZ}^{SM}$)

- **2 others VEVs:** r, v_3 ($r = v_2/v_1$)
  - ⋆ we treat them as free parameter in our analysis

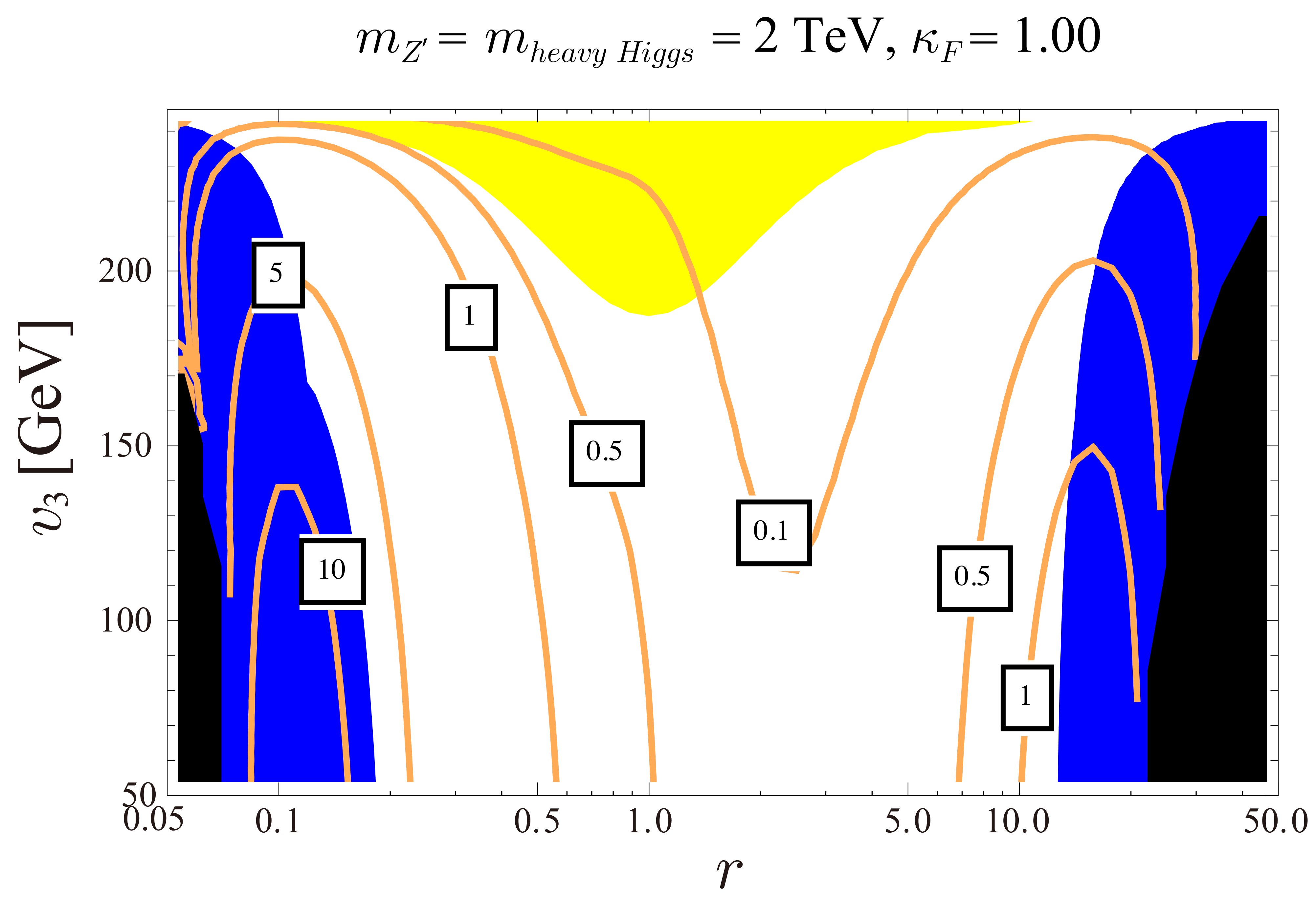
mass spectra



constraint on (r, v_3)-plane

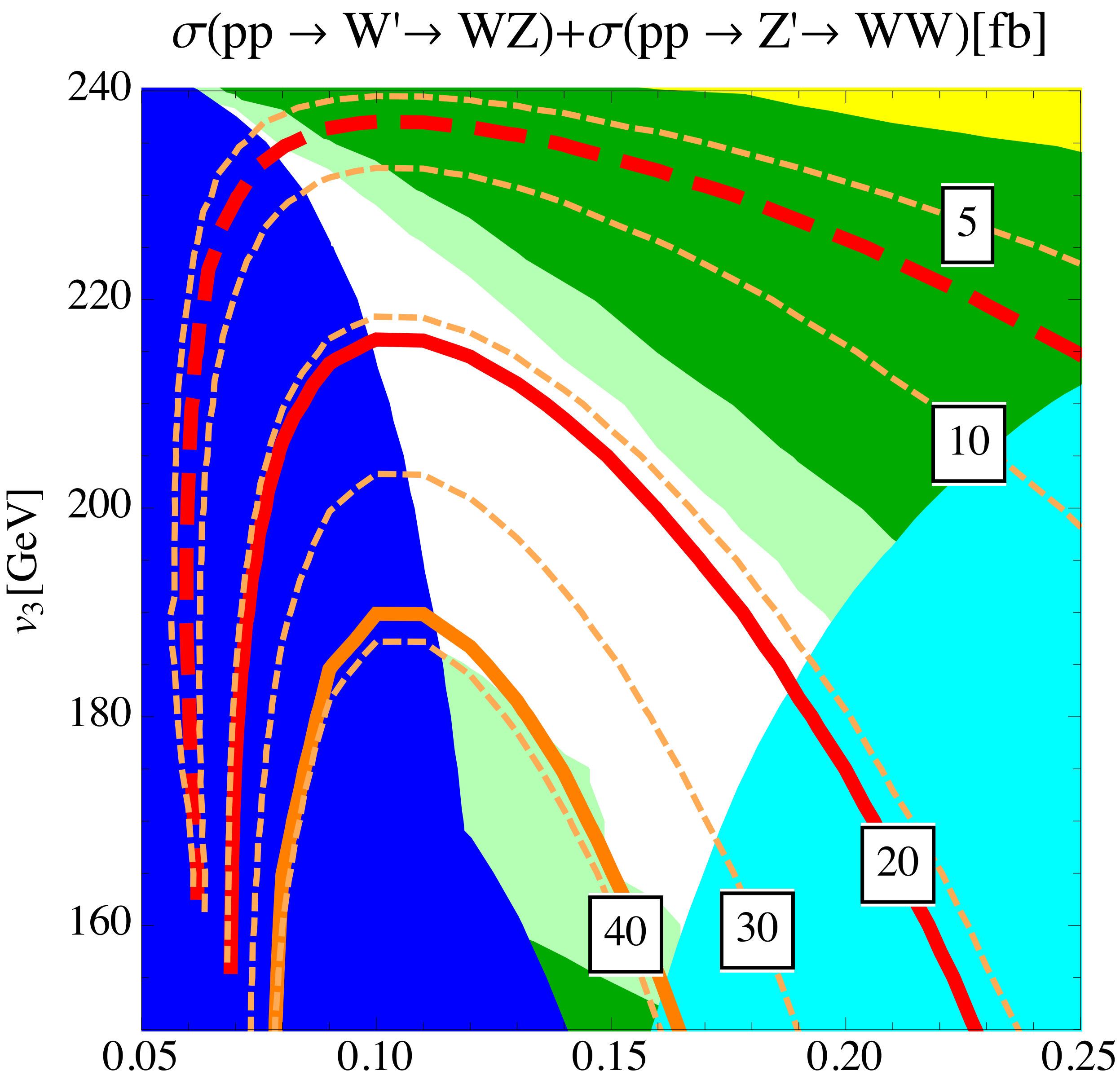


$\sigma(pp \to W' \to WZ) + \sigma(pp \to Z' \to WW)$ [fb]



★ σ > 5fb for small *r* region

95% exclusion limit at 13TeV



- ★ colored region is excluded

- ★ orange lines: σ
- ★ bold orange line: σ=6fb at 8TeV
- ★ Red lines: 95% exclusion limit at 10 fb^{-1}
- ★ Red dashed lines: 95% exclusion limit at 100 fb^{-1}