Search for annihilation decays of 4G mesons

Hiroshi Yokoya (NCTSn/NTU)

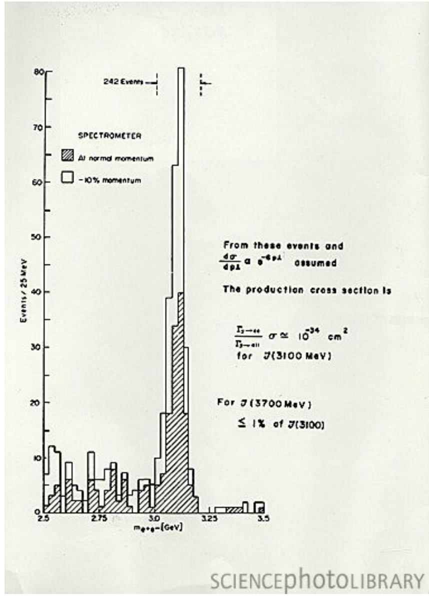
T.Enkhbat, W.S.Hou, HY, Phys.Rev.D84.094013,
(previous talk by T.Enkhbat),
work in progress with J. Alwall,Enkhbat,Hou,HY

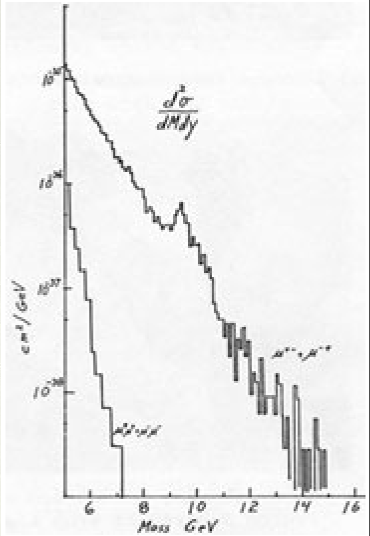
Heavy Quarkonium and Annihilation decay

- charm, bottom quarks :

  J/Ψ, Υ [$^3S_1$] : discovery by dilepton peak,

  (η_c, η_b [$^1S_0$] : Lightest QQ meson)





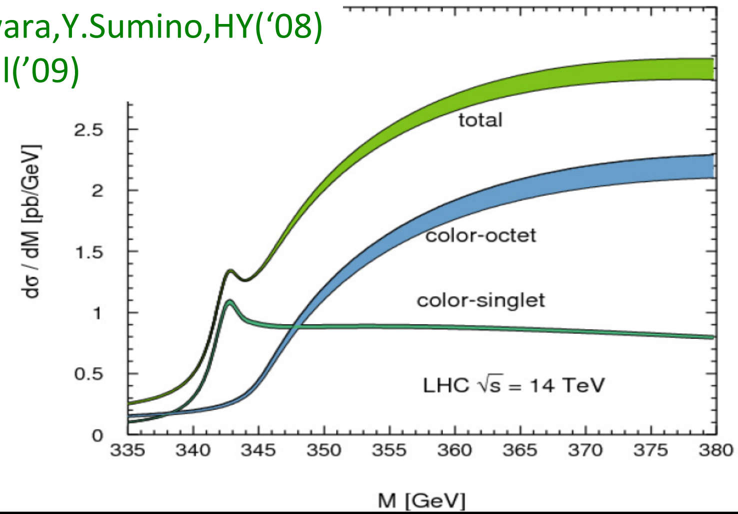
- top quark :

  Unstable bound-state due to the large decay width of the constituent top-quarks

  No hadron, no annihilation decay, but decay by top-quark decay.

  Just as part of “open” production.

K.Hagiwara,Y.Sumino,HY(‘08)
Kiyo etal(’09)



New particle search by dijet, dilepton resonance

- Dijet resonance :

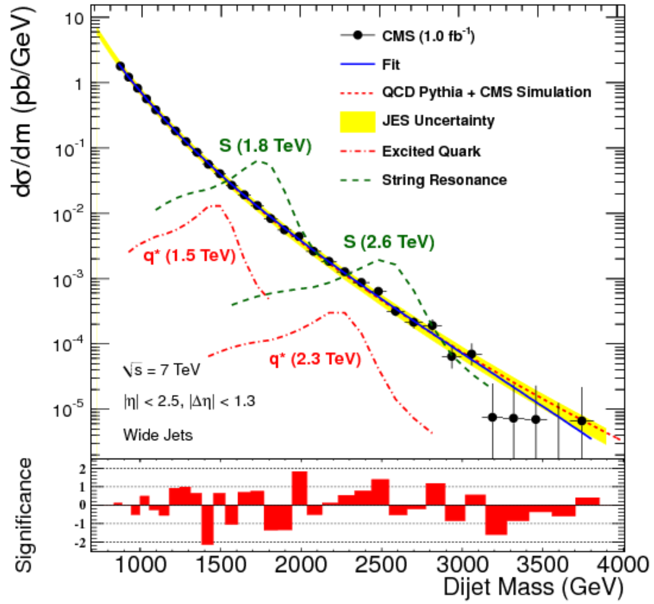
  Z', W', q*, coloron, Axigluon,,,

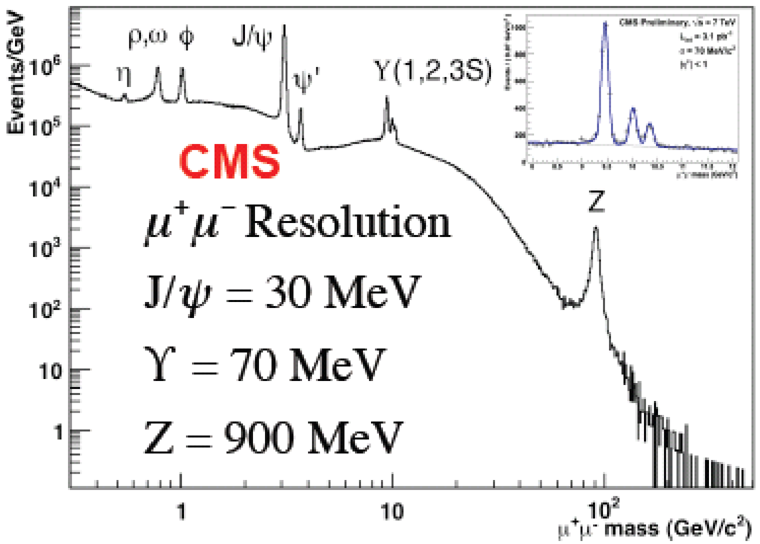
  large cross-section, early search

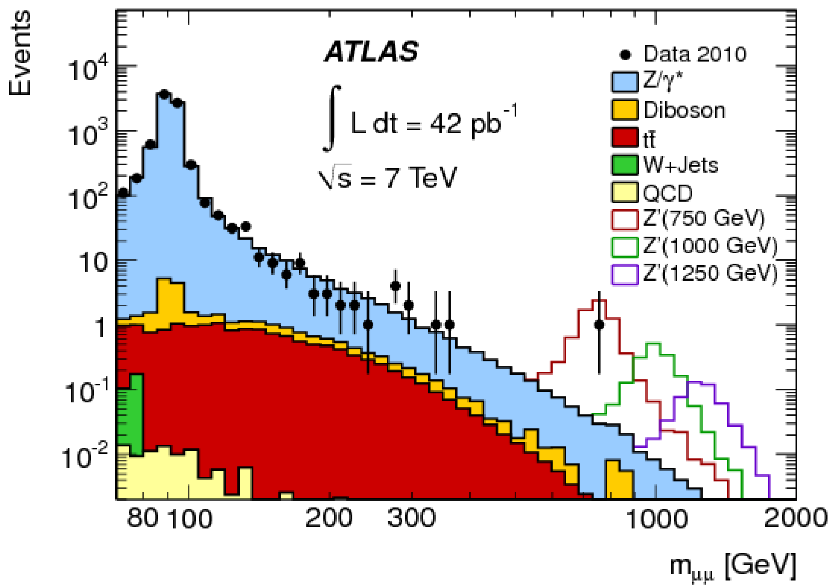
- Dilepton resonance :

  Z',,,

  good mass resolution







Annihilation decay of new particle bound-states

- SUSY, UED, Technicolor,,,

,,, Hagiwara,HY('09), Kauth etal('11), Kats,Schwartz('09), Kahawala,Kats('11)

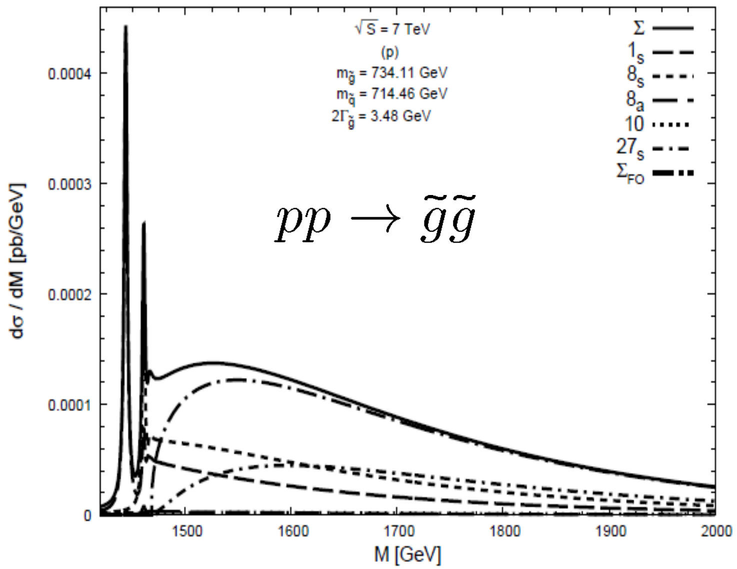
SUSY : gluinonium, squarkonium,,,

UED : KK gluonium,,

,,,

Threshold production is important for production of heavier particles.

Depending on the decay width of the constituents, it can be top-quark-like or quarkonium-like.



- 4^{th} generation quarks (t', b')

Barger etal ('87),,,

EW data -> degenerated doublet -> new Isospin symmetry

Mass limit reaches unitary bound -> binding by Yukawa int.

Yukawa-bound heavy 4G mesons :

Jain etal('92), Ishiwata,Wise('11),
T.Enkhbat,W.S.Hou,HY('11)
previous talk by T.Enkhbat

Our set-up :

SM4
- chiral 4G = t', b' ; degenerated with **m_Q > 500 GeV**
- masses simply given by Yukawa couplings
- Higgs-boson is heavy; m_H > 600 GeV
  (EW precision test, direct search, DEWSB,,,)

Large Yukawa couplings : $$y = \frac{m_Q}{v} > 1$$

$$\alpha_Y \simeq 1 > \alpha_s \simeq 0.1$$

→ possibly bound-states by Yukawa interaction
(even Color-octet)

Yukawa-bound heavy 4G mesons :

- Higgs exchange : suppressed by its mass
- Goldstone-boson exchange : pseudo-scalar exchange, Isospin dependent
- Gluon exchange : subdominant, singlet/octet splitting

States	C, I, S	Higgs	Goldstone	Gluon
$(\pi_1,\ \omega_1)$	$\mathbf{1}$, (1, 0), (0, 1)	$-$	$-$	$-$
$(\pi_8,\ \omega_8)$	$\mathbf{8}$, (1, 0), (0, 1)	$-$	$-$	$+$
$(\eta_1,\ \rho_1)$	$\mathbf{1}$, (0, 1), (0, 1)	$-$	$+$	$-$
$(\eta_8,\ \rho_8)$	$\mathbf{8}$, (0, 1), (0, 1)	$-$	$+$	$+$

$-$:attractive, $+$:repulsive, C :Color, I :Isospin, S :Spin

Expected tight bound-states are :

$\pi_1,\ \pi_8$: Iso-triplet color- singlet/octet pseudoscalar

$\omega_1,\ \omega_8$: Iso-singlet color- singlet/octet vector

Mass ordering : $m_{\pi_1} < m_{\pi_8} \simeq m_{\omega_1} < m_{\omega_8}$

Yukawa-bound heavy 4G mesons :

- GB exchange has γ_5 coupling

  → cannot be described by the static potential

  ⇒ relativistic formalism (Bethe-Salpeter eq.) P.Jain et.al. ('92,'94)

  [hard to solve the system]

- Binding energy could be O(100) GeV even for the color-octet states

  There shall be a turn over from QCD-bound to Yukawa-bound.

K.Ishiwata,M.Wise ('11)

We don't have any solution to the bound-state system,
but assume deep binding, parameterize some parameters,
and perform collider phenomenology.

Decay width of 4G quarks :

- The constituent t', b' quarks decay via CKM mixing to lighter quarks

$$\Gamma_{t',b'} \simeq |V_{34}|^2 \frac{G_F m_{t',b'}^3}{8\sqrt{2}\pi}$$

- sizable V_{34} → t', b' de$V_{34} = V_{t'b} = V_{tb'}$e the BS's. (top like)

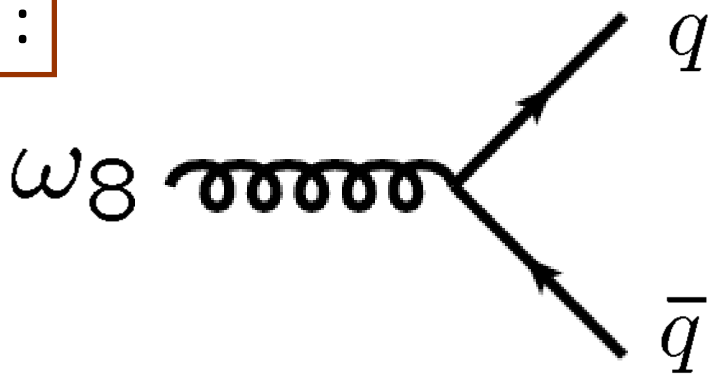
  ~ 0.1 → **Signature similar to open production, hard to distinguish from that**

- small V_{34} → t', b' are rather stable; BS's are narrow and decay by annihilation

  ≤ 0.01

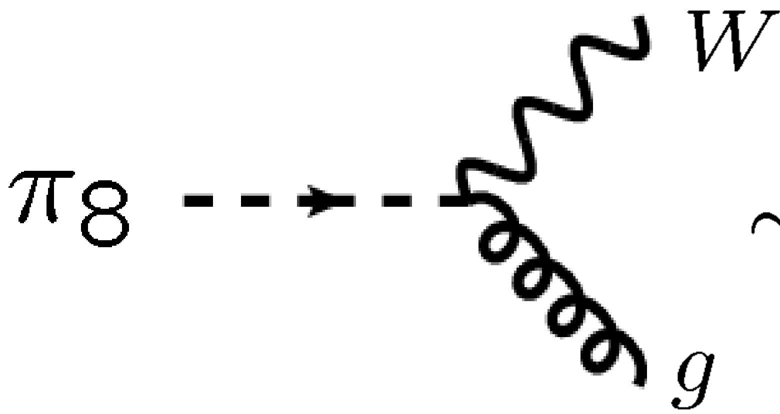
We study the collider signatures in this scenario

Interactions of mesons :



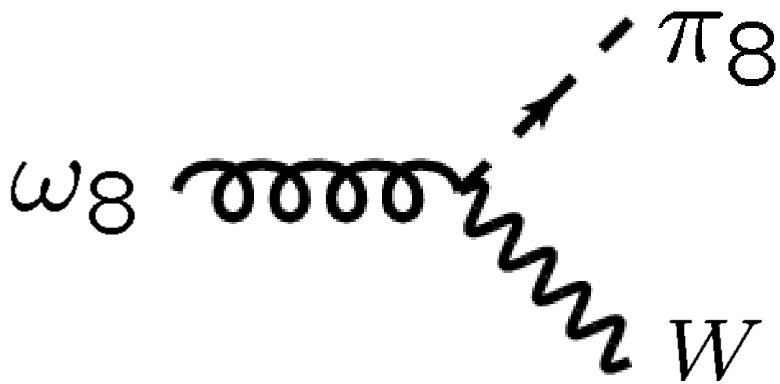
$\sim g_s^2 f_\omega / m_\omega$

f : decay constant
(parameter to be solved,
but unknown to us)



$\sim g_W g_s f_\pi$

- transition of mesons



$\sim g_W$

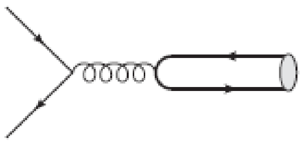
(plus $\omega_8\omega_1 g$, $\omega_1\pi_1 W$)

- Production of 4G mesons at hadron colliders :

$\pi_{1,8}$, ω_1 : pair production by weak interaction

ω_8 : **single production by strong interaction**
(via qqbar annihilation)

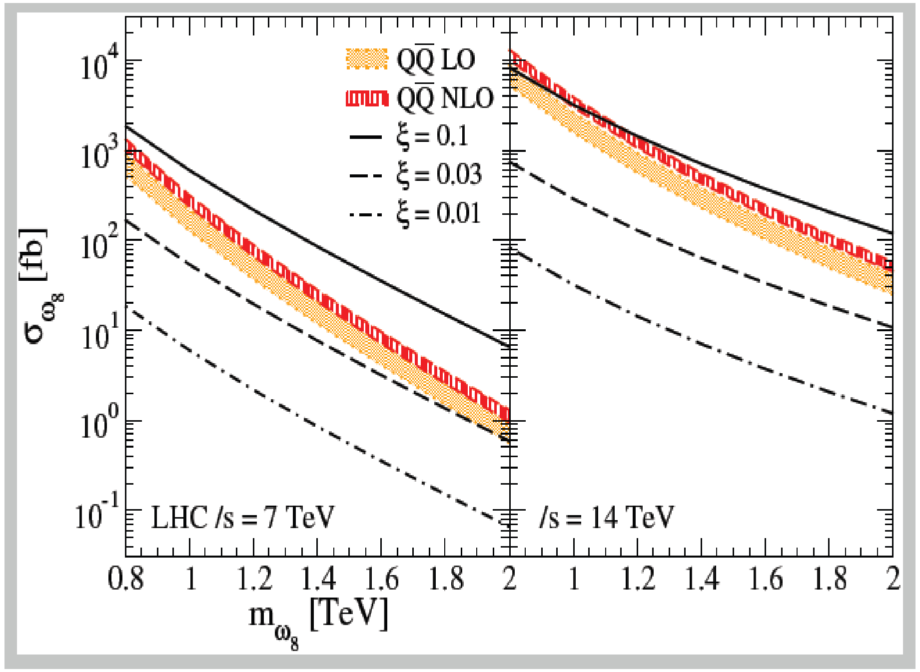
$$\hat{\sigma}_{q\bar{q}\to\omega_8}(\hat{s}) = \frac{32\pi^3\alpha_s^2}{9m_{\omega_8}^2}\xi^2\delta(1 - m_{\omega_8}^2/\hat{s}).$$



$$\xi = f/m$$

$$\langle 0|V^{\mu,a}|\omega_8^b(p)\rangle = \frac{1}{\sqrt{2}}\delta^{ab} f_{\omega_8} m_{\omega_8}\varepsilon^\mu(p),$$

Production cross-section is proportional to the square of the decay constant.



- Partial decay width, Branching ratio :

$$\Gamma(\omega_8 \to q\bar{q}) = \xi^2 \frac{\pi \alpha_s^2}{3} m_{\omega_8} n_f, \quad \Gamma(\omega_8 \to t\bar{t}) = \xi^2 \frac{\pi \alpha_s^2}{3} m_{\omega_8} \beta_t,$$

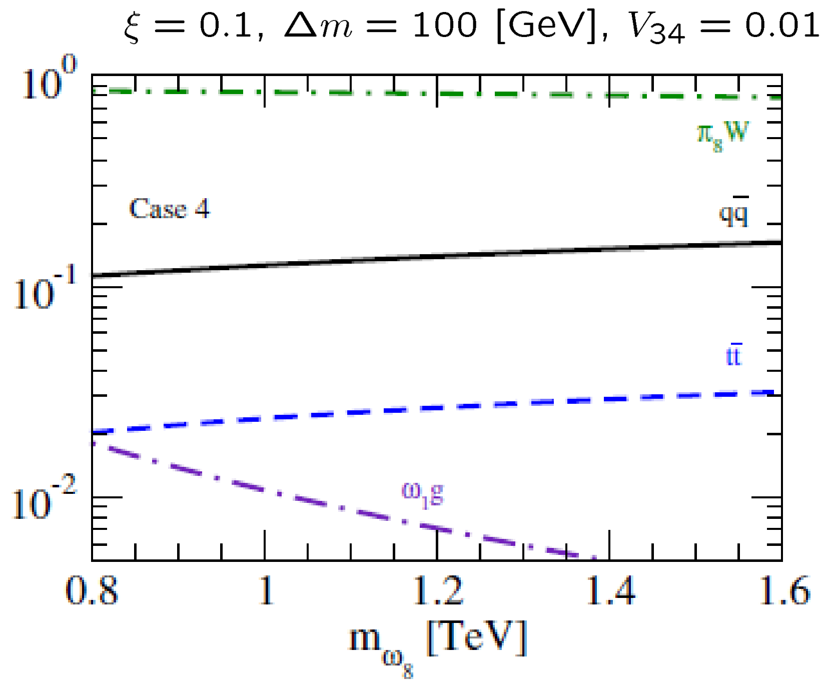
$$\Gamma(\omega_8 \to \pi_8 W) = \frac{G_F m_{\omega_8}^3}{32\sqrt{2}\pi} \frac{m_{\omega_8}}{m_{\pi_8}} W(\hat{m}_{\pi_8}, \hat{m}_W),$$

Large Br(dijet) for large decay constant

Br(tt~) ~ 1/5 * Br(dijet)

$\Gamma(W\pi_8)$ depends on $\Delta m = m_\omega - m_\pi$,

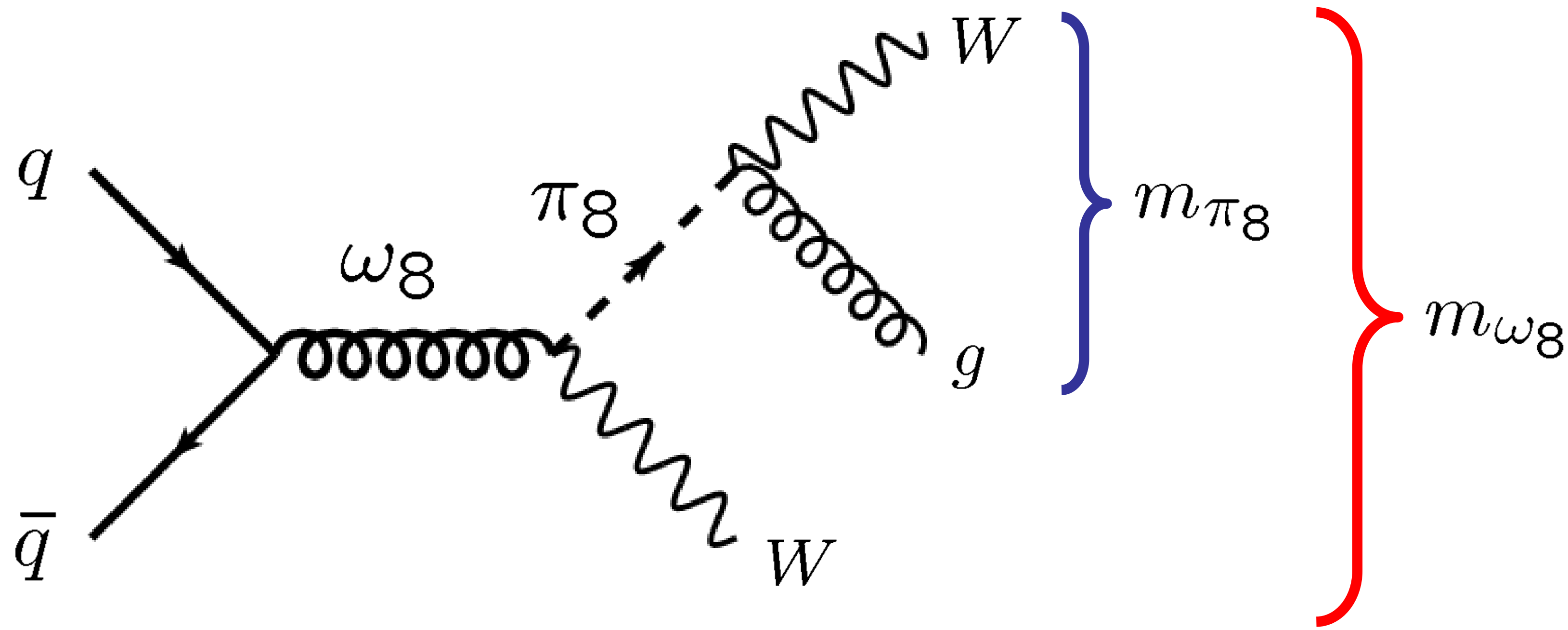
large $Br(W\pi_8)$ for large Δm



- $\pi_8 \to Wg$ decay almost 100%.

Thus, the collider signatures are

$$\begin{cases} pp \to \omega_8 \to q\bar{q}(t\bar{t}) & \text{[dijet, ttbar]} \\ pp \to \omega_8 \to \pi_8 W \to WgW & \end{cases}$$



"hard W + hard gluon + soft W"

WWg signature :

Decay of W's and collider signatures

- Hard W : $(p_T^W \sim m_{\pi_8}/2)$

  hadronic decay → seen as one-jet, subjet structure

  leptonic decay → high-p_T lepton + missing E_T (aligned)

- Soft W : $(p_T^W \sim \mathcal{O}(m_{\omega_8} - m_{\pi_8}))$

  lepton+missing or dijet in central region

Dilepton : difficult to reconstruct masses

Lepton + jets : both mass reconstructable

All hadrons : large QCD BG

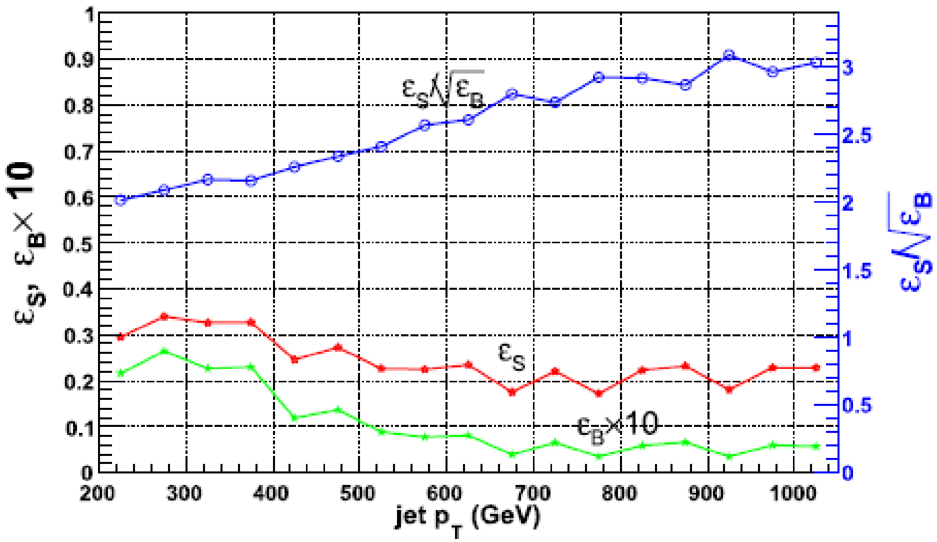
W-jet tagging :

Y.Cui,Z.Han,M.Schwartz('11)

by finding subjet structure in rather larger radius jet.

Better significance for higher p_T W can be achieved.

$$\epsilon_S \sim 20\% \sim 30\%$$
$$\epsilon_B \sim 1\% \sim 2\%$$



Reduce W+jets background significantly.

→ The most promising signature should be $(Wg)W \to (jj)\ell v$ where one of the jets is W-tagged.

In our simulation, we use R=1.0 anti-k_T jet and assume ε_S=0.3, ε_B=0.015.

WWg signature :

Selection cuts : (universal cut for any M_{jj}, and scan a bump)

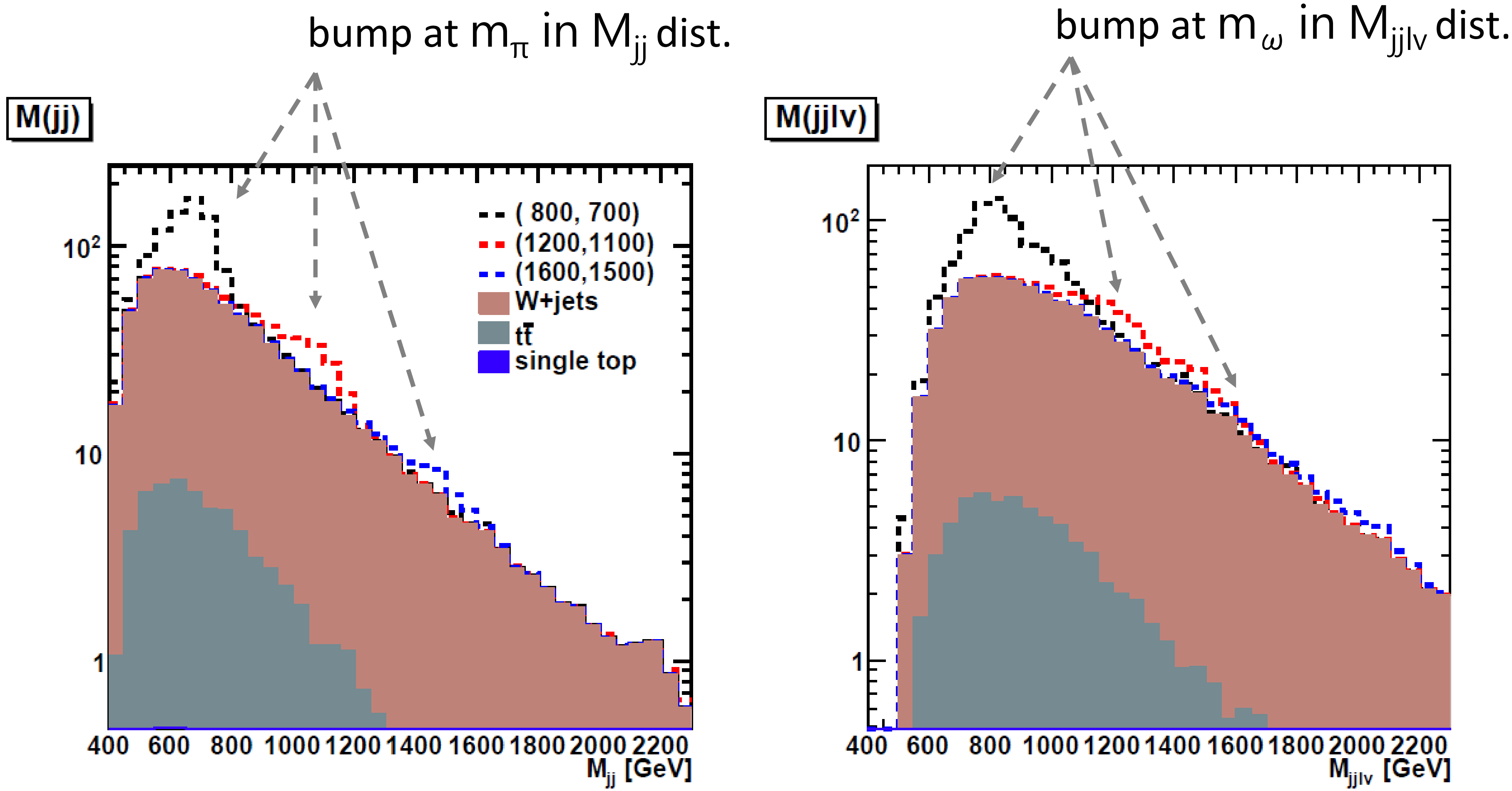
- Two high-p_T jets (p_T > 200 GeV, one W-jet tagged)
- One isolated lepton + missing E_T
- leptonic W momentum is solved by solving neutrino long. mom. with on-shell W-mass condition.

Background :

- W+jets (MG5, matched with 2,3 jets ME)
- tt~ (MG5, matched with 0,1 jets ME)

Results : LHC /s=8 [TeV] and L=20 [fb^{-1}]

Signal with $\xi(=f/m)=0.1$ and $\Delta m=100$ [GeV]

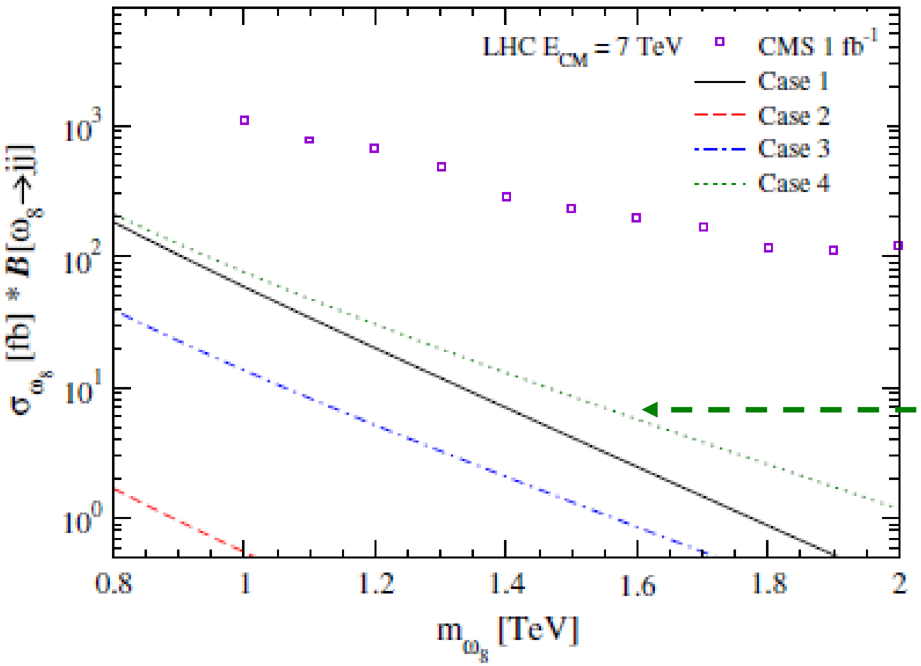


Dijet signature :

Upper bound of the dijet resonance cross-section

→ upper bound for the decay constant for given Δm

(Both the production cross-section and
the dijet Br depend on the decay constant.)

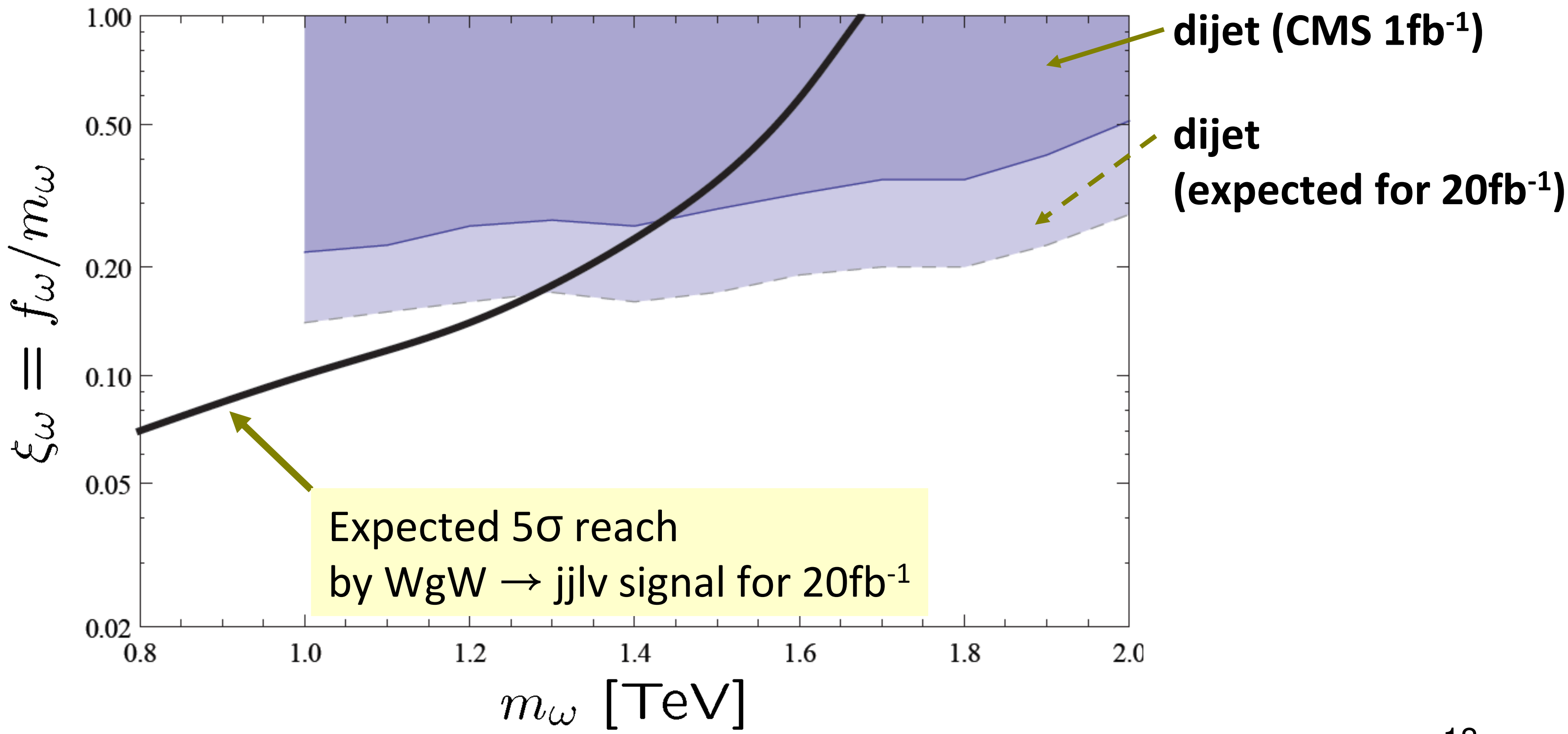


CMS 1fb^{-1} data

$\xi = 0.1,$
$\Delta m = 100$ [GeV],
$V_{34} \to 0.$

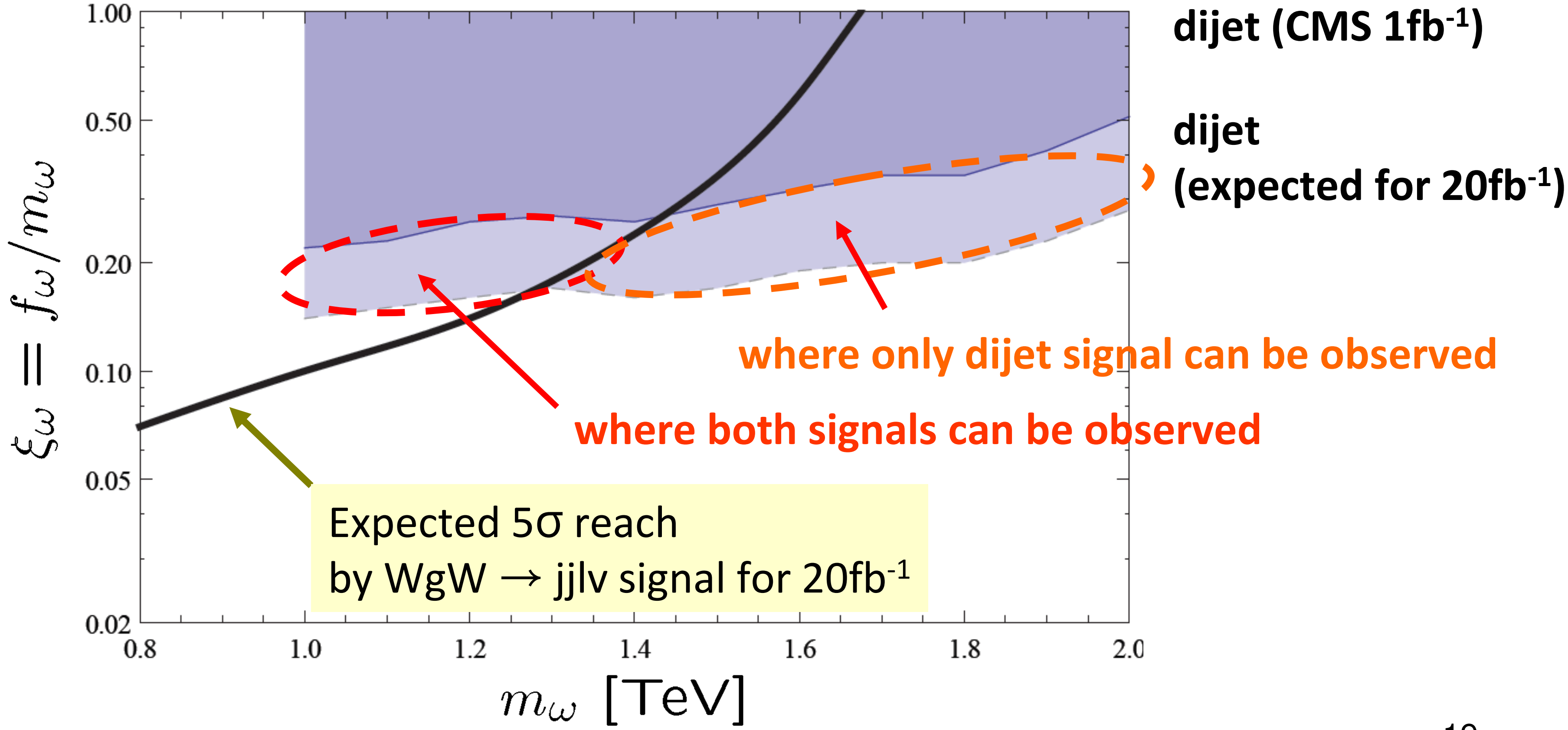
Constraining/determining the parameters

fixed $\Delta m = m_\omega - m_\pi = 100$ GeV



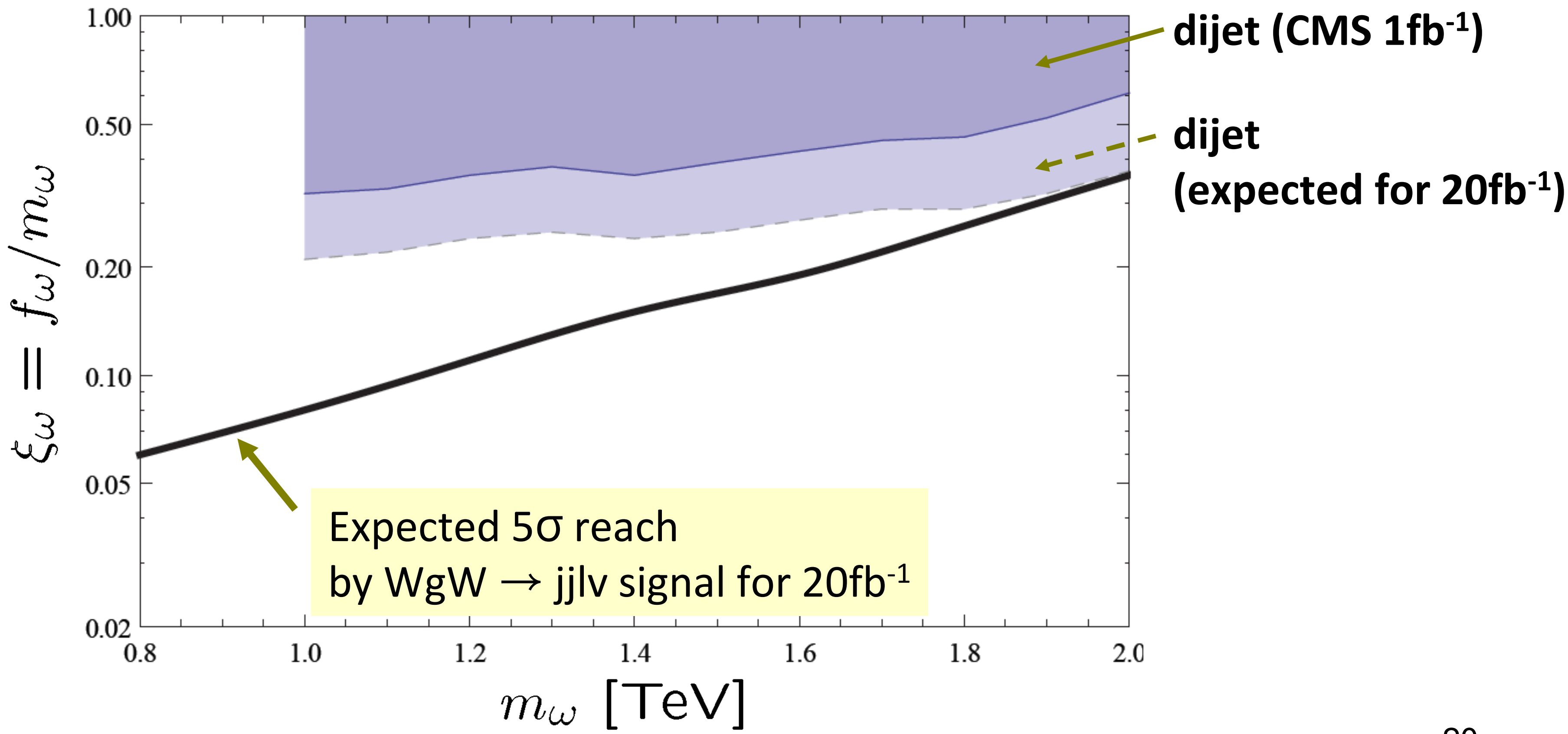
Constraining/determining the parameters

fixed $\Delta m = m_\omega - m_\pi = 100$ GeV



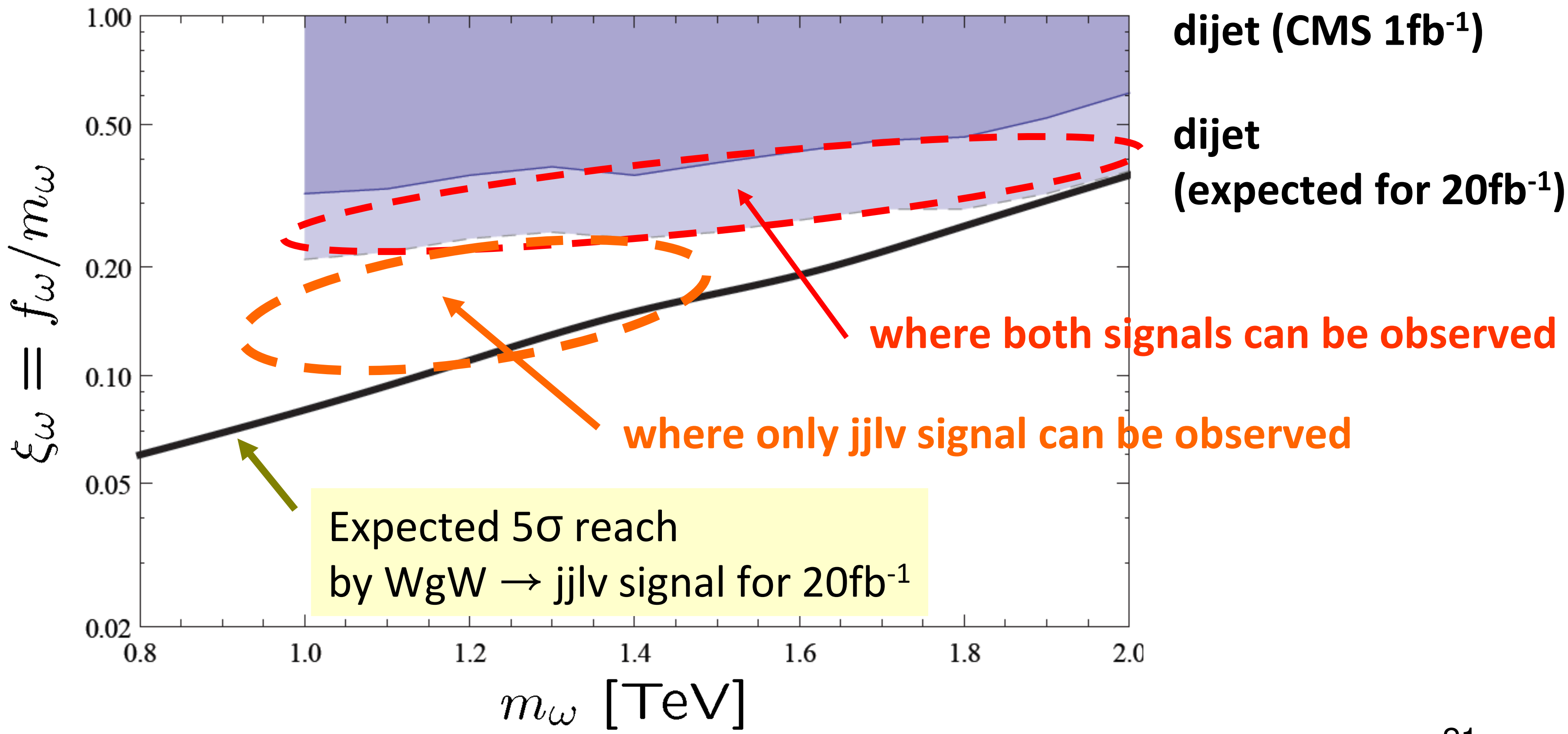
Constraining/determining the parameters

fixed $\Delta m = m_\omega - m_\pi = 200$ GeV



Constraining/determining the parameters

fixed $\Delta m = m_\omega - m_\pi = 200$ GeV



Summary :

- 4G quarks, if exist, can form relativistic boundstates by Yukawa int. Heavy Isospin and Goldstone-boso exchange force cause quite characteristic spectrum of the 4G mesons ($\omega_{1,8}$, $\pi_{1,8}$ states).

- We study the search for the annihilation decay of the 4G mesons.
  ω_8 production is most attractive production process.
  Collider signals are dijet resonance and (Wg)W > (jj)lv signal with jj and jjlv resonances, whrere one of the hard jets is W-tagged.

- LHC early data (2011,2012) can constrain the parameters (mass spectrum, decay constant), which have to be theoretically investigated, or find peaks.