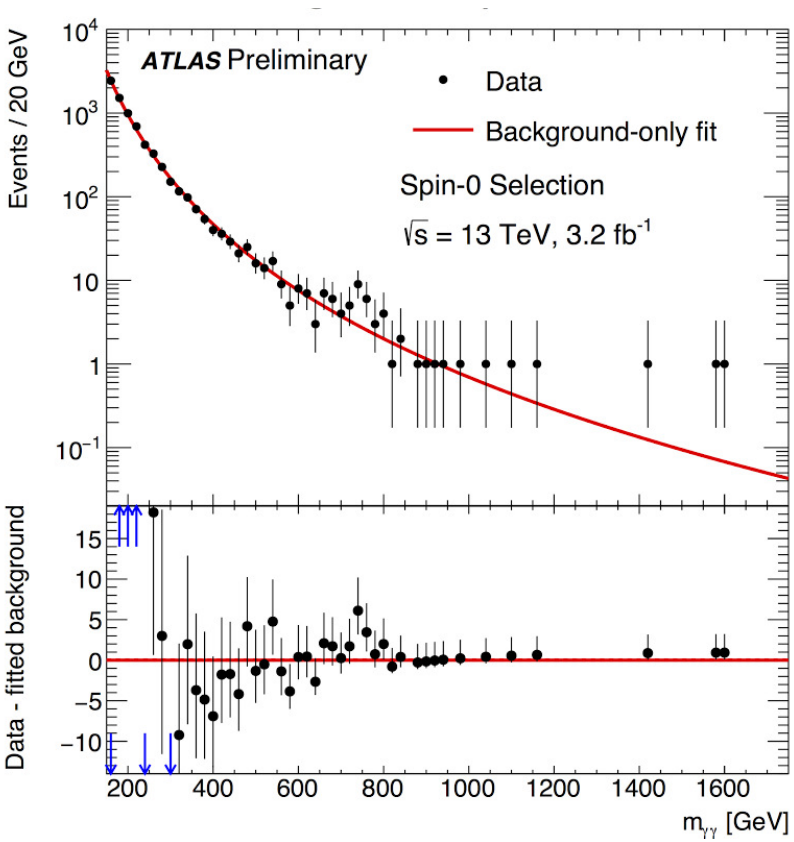
750 GeV diphotons from colorless x-onia

Yael Shadmi
Technion

with **Sho Iwamoto, Gabriel Lee, Robert Ziegler**

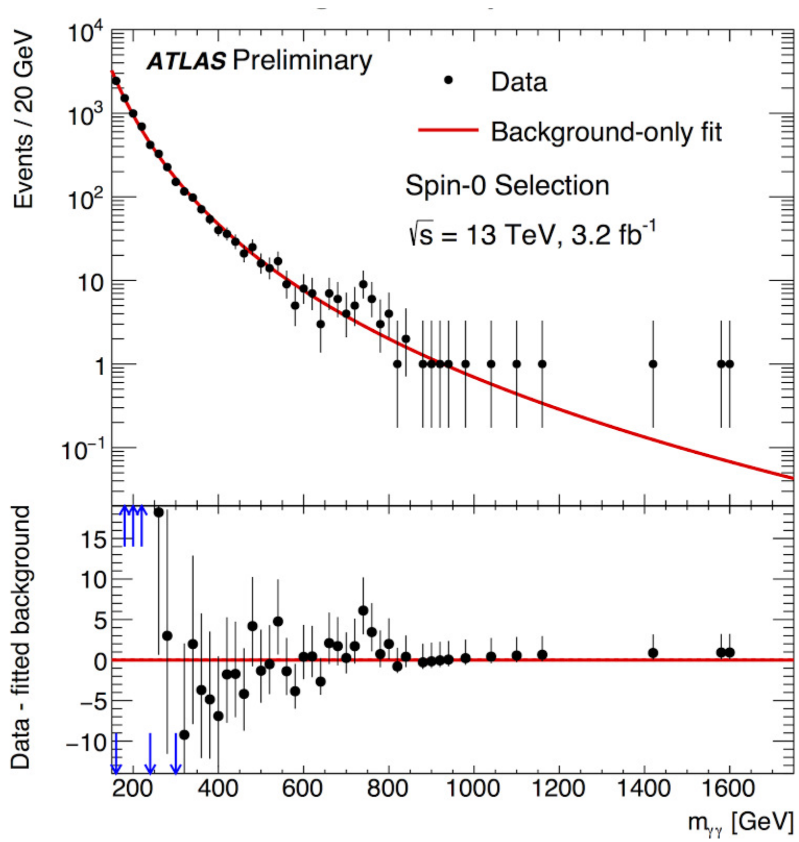


The 750 GeV excess

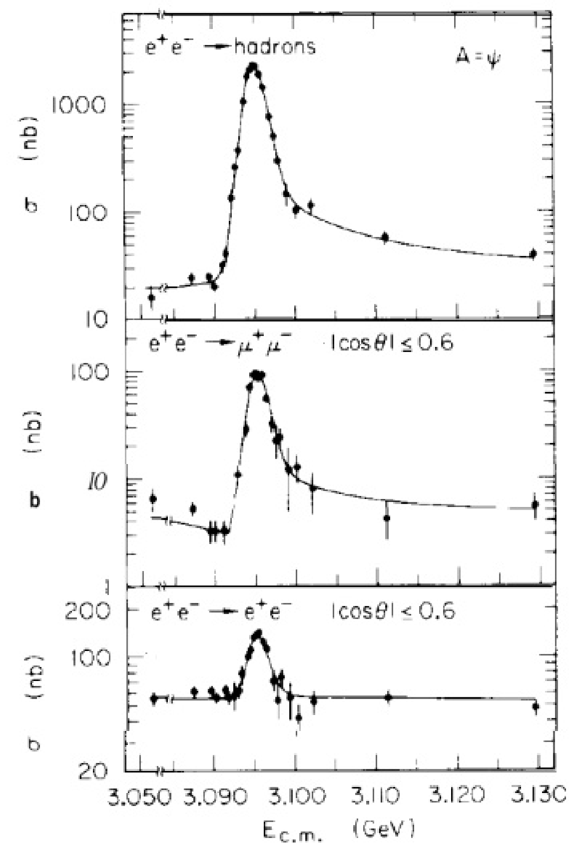
not 750 particle yet

statistics
systematics

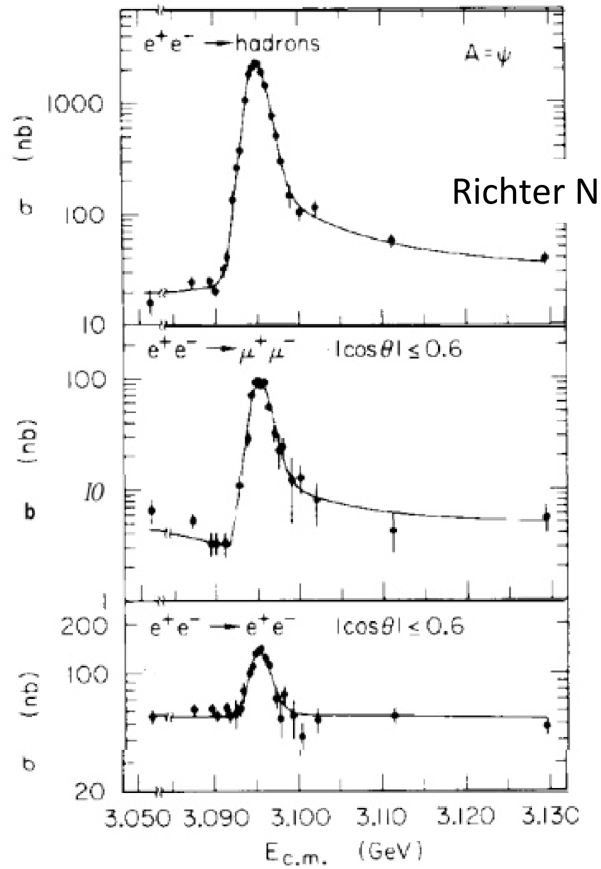
but see squarks, KK modes..
not even excesses..



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



e+e- → hadrons
A = ψ
e+e- → μ+μ-
|cosθ| ≤ 0.6
e+e- → e+e-
|cosθ| ≤ 0.6
σ (nb)
E c.m. (GeV)



Richter Nobel lecture

The discovery of charmonium

really: The discovery of the charm quark

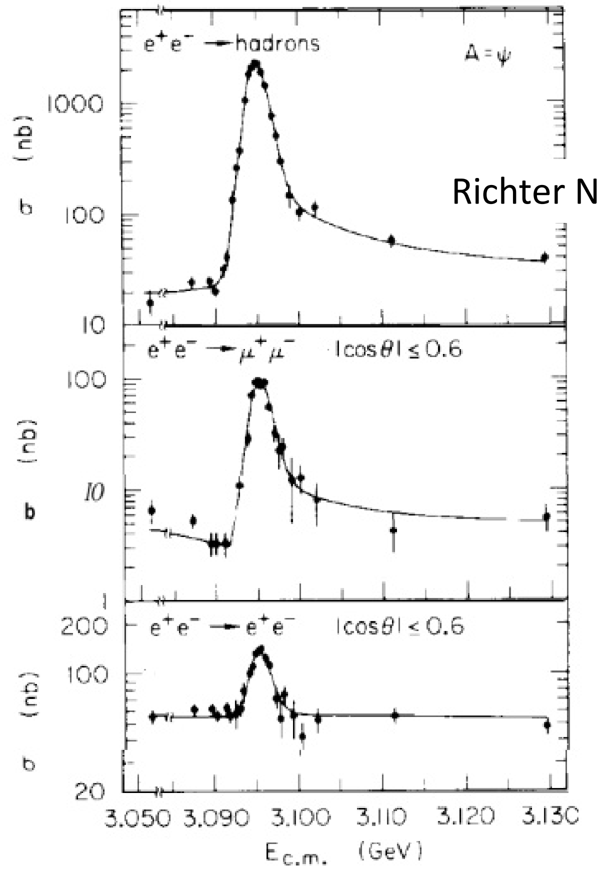
have been looking for new particles:

carrying a new charge/parity?

single production

pair production

2 photons + missing ??



Richter Nobel lecture

The discovery of charmonium

really: The discovery of the charm quark

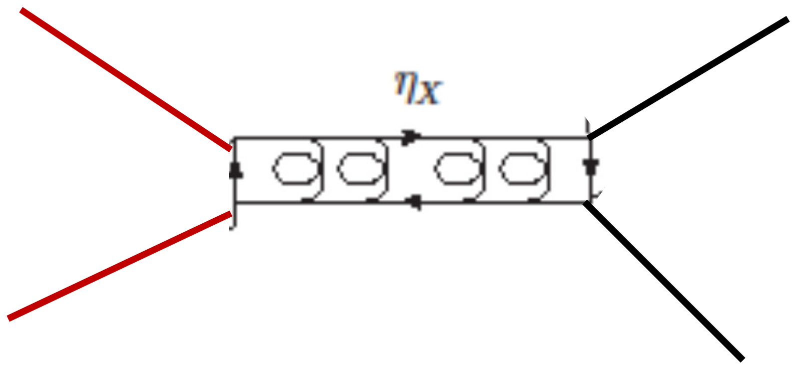
looking for new particles:

carrying a new charge/parity?

single production

pair production

many searches: R-parity, KK-parity..
haven't seen anything
?because their decay rate is suppressed
(``tricky/stealthy" signatures, eg, displaced vertices ..)
small *Γ*: bound state formation is important
diphoton, other SM signatures



$2\Gamma_X \lessapprox \Gamma_{(X\bar{X})}$:   bound state formation important:

otherwise ``X decays before bound state has chance to form”

pair-produced particles X:

$(X\bar{X})$-onia

what is X?

★ Kats Strassler
Han Ichikawa Matsumoto Nojiri Takeuchi
Kamenik Redi
Ko Yu Yuan
Barrie Kobakhidze Liang Talia Wu

<u>pions/quirks:</u>
Nakai Sato Tobioka
Curtin Verhaaren
Harigaya Nomura
Agrawal Fan Heidenreich Reece Strassler
…

[bound states:

even if postulate a 750 GeV fundamental singlet coupling to photons

something needs to generate the coupling:

new charged massive particles at/below TeV

plausibly: bound state threshold production]

what is X?

- j=0, 1/2

- SM charges: couples to photons
- minimally: and ONLY to photons

→ hypercharge Y_X

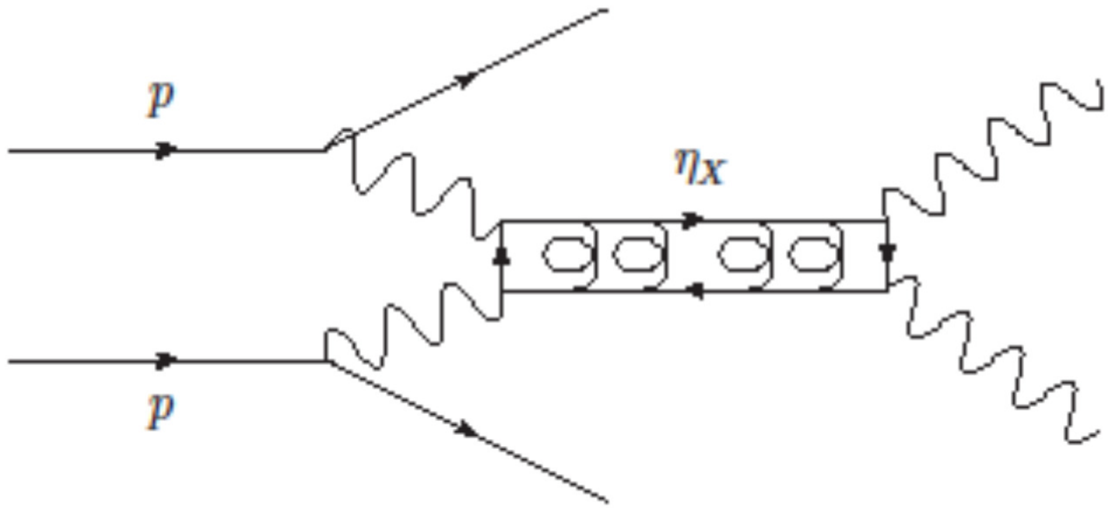
binding force: hidden SU(N)

[EM only: large Y_X more later]

★ Fichet Gersdorff Royon
Csaki Hubisz Terning
Csaki Hubisz Lombardo Terning

so:

X: scalar / (vector-like) fermion pair; SU(N) fundamental; hypercharge Y_X



X: scalar / (vector-like) fermion pair; SU(N) fundamental; hypercharge Y_X

$$\eta = 0^{++}$$

the models: SU(N) x U(1)$_{\text{hypercharge}}$

$$X(N, Y_X) + \bar{X}(\bar{N}, -Y_X)$$

+ variations:

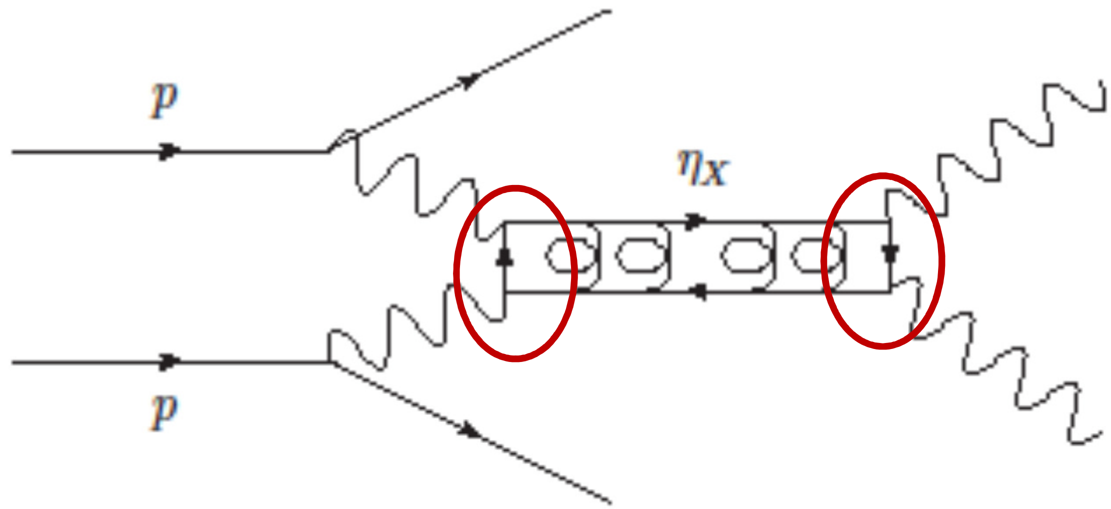
- N_F lighter **hidden** flavors: SM SINGLETS: $S(N, 0) + \bar{S}(\bar{N}, 0)$
- coupling S-X-SM: only for integer Y_X:

  eg, for $Y_X = 2$: $S\bar{X}e^c e^c$ (for fermion X, S)

  $S\bar{X}u^c u^c u^c$ (for fermion X, scalar S)

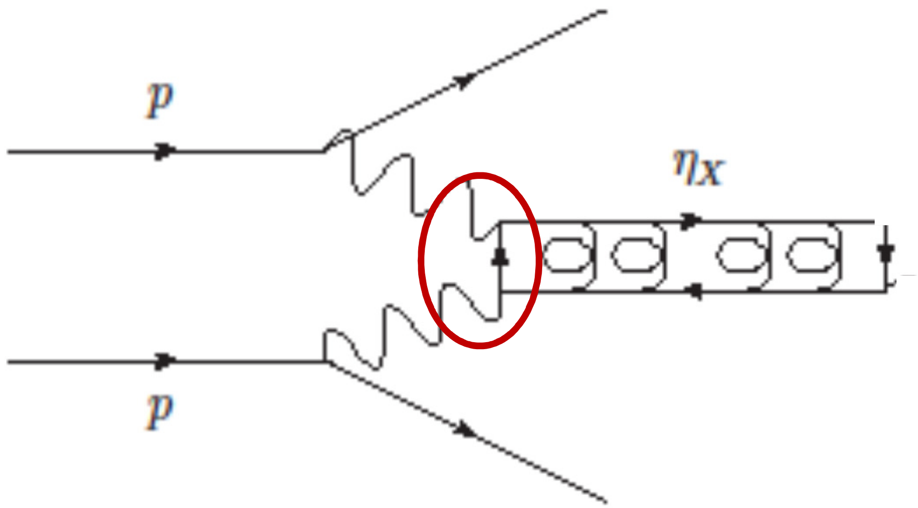
….

LHC production and decay

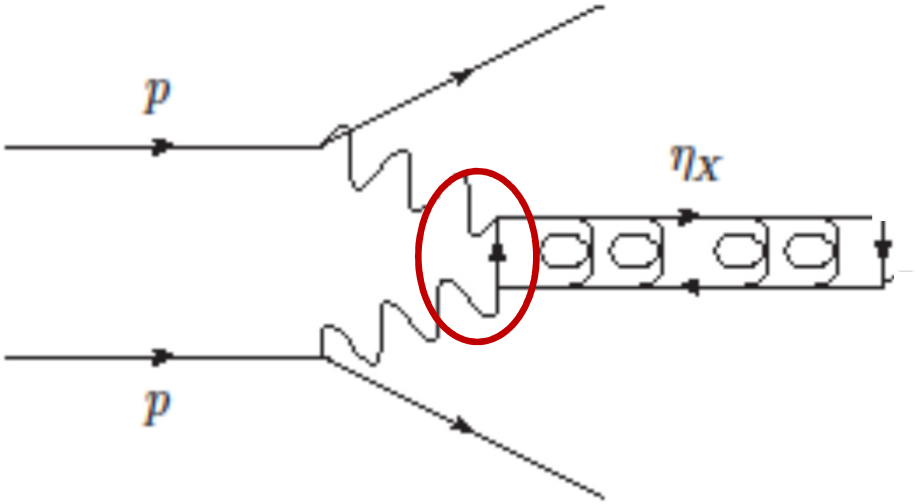


bound state properties:

- here: binding potential = SU(N)+EM
- perturbative or non-perturbative
- independent of initial/final state → cancels out in Br's



$$\sigma(\gamma\gamma \to (X\bar{X})) \ \propto \ \sigma^{free}(\gamma\gamma \to X\bar{X})(\hat{s}) \ |R(0)|^2 \ \delta(\hat{s} - M^2)$$



$$\sigma(\gamma\gamma \to (X\bar{X})) \propto \sigma^{free}(\gamma\gamma \to X\bar{X})(\hat{s})\, |R(0)|^2\, \delta(\hat{s} - M^2)$$

but in BR:

$$\frac{\Gamma(\eta \to \gamma\gamma)}{\Gamma(\eta \to g_h g_h)} = 4\frac{N^2}{N^2-1}\frac{Y_X^4\alpha^2}{\alpha_h^2}$$

R(0) cancels

bound state properties:

SU(N) potential: large distances: confinement: $V \sim \Lambda^2 r$

small distances: Coulomb: $V \sim \alpha / r$

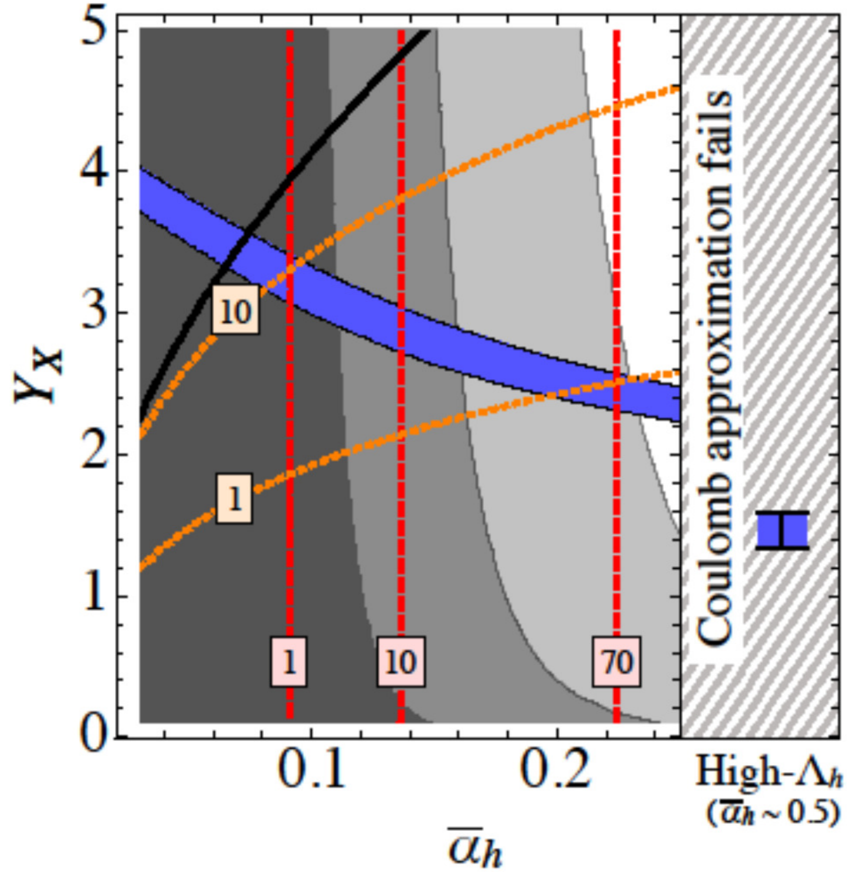
$\alpha_h m_x$ vs Λ

consider first Coulomb: $\Lambda \ll \alpha_h m_x$

$$|R(0)_{n0}|^2 = \frac{C^3 \bar{\alpha}_h^3 m_X^3}{2n^3} \qquad C = \frac{N^2 - 1}{2N}$$

$$\bar{\alpha} = \alpha(1/\text{Bohr radius}) \sim \alpha(\alpha m_X)$$

SU(3); fermion X; $N_F = 0$



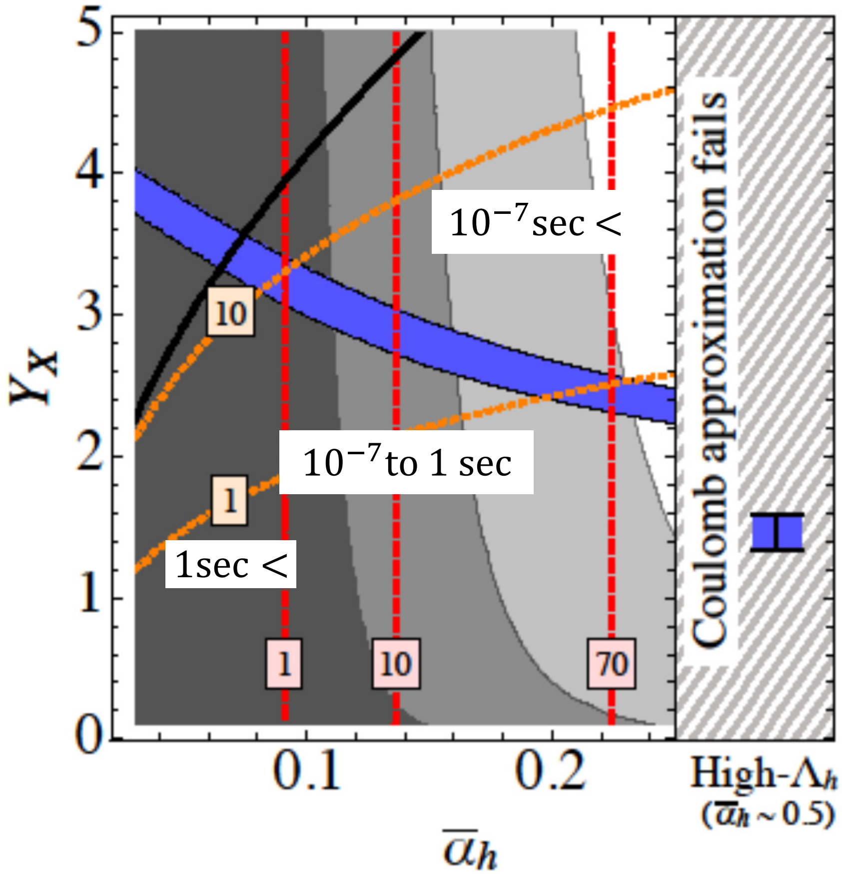
eta to diphoton signal: 3-6 fb

------- $\Gamma(\eta \to \gamma\gamma)/\Gamma(\eta \to g_h g_h)$

------- glueball masses

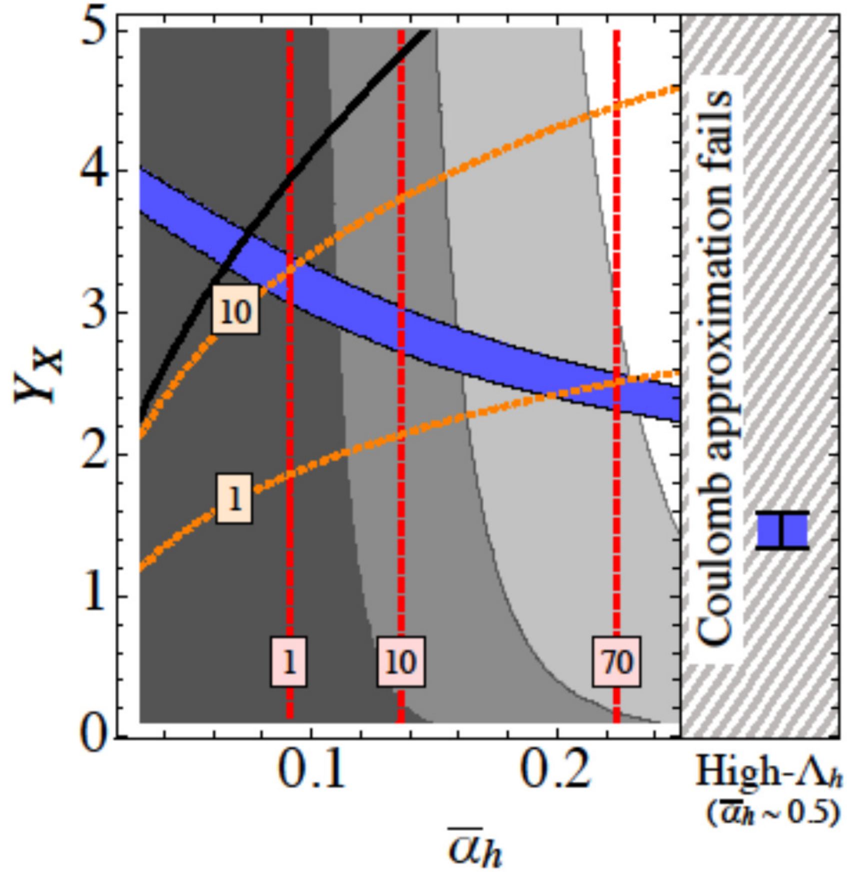
-------- EM=SU(N)

SU(3); fermion X; $N_F = 0$



glueball lifetime
(decays to two photons)

SU(3); fermion X; $N_F = 0$

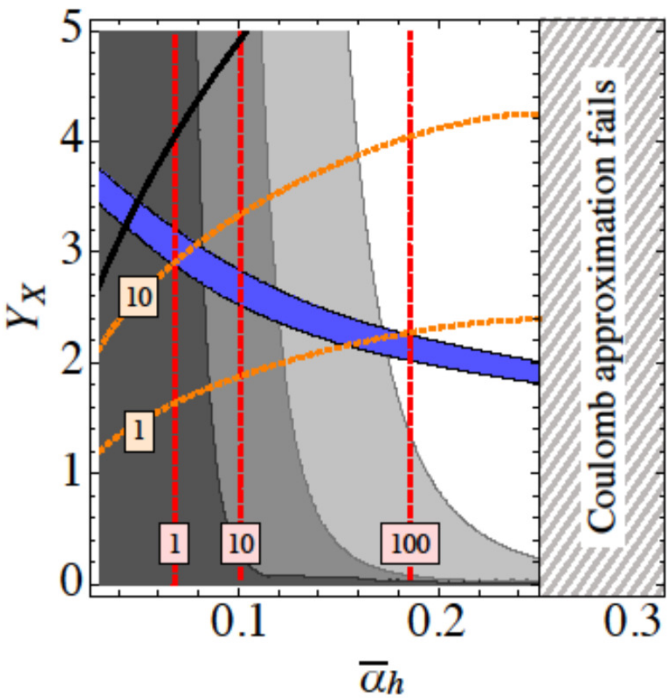


scalar X:

blue region would (barely) move up

$$Y_X \sim \sigma^{1/8}$$

SU(4); fermion X; $N_F = 0$



smaller hypercharge

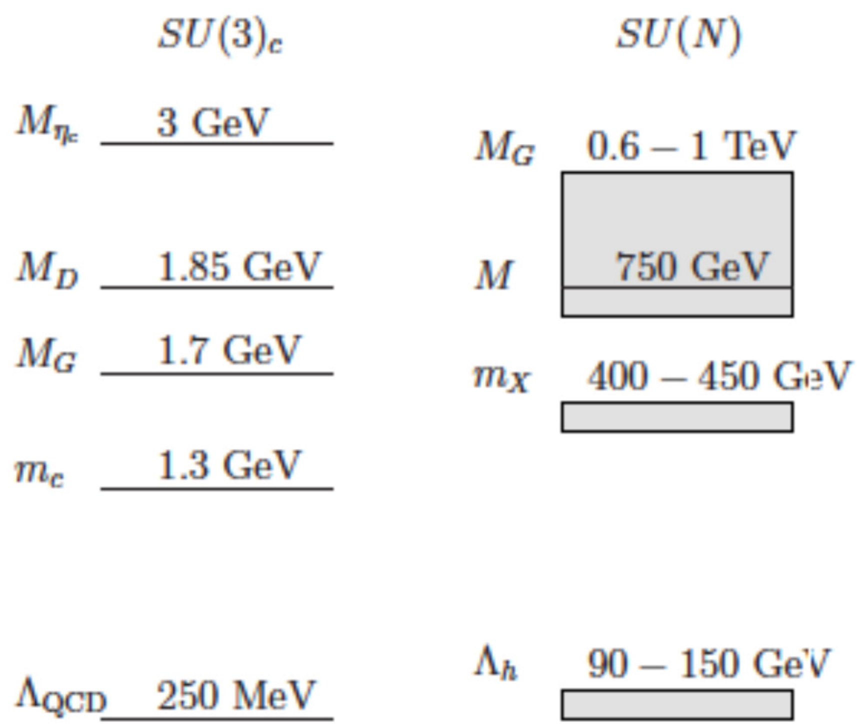
beyond Coulomb?

potential models (eg Cornell potential)

lattice

or: **use charmonium:**

with N_F=0:

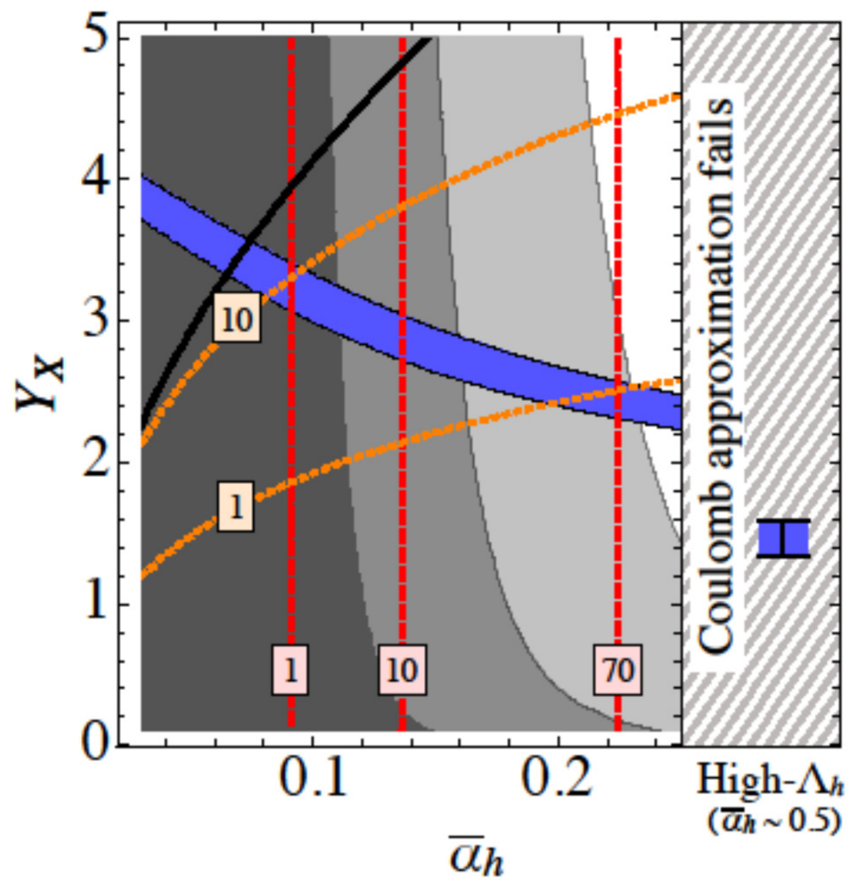


beyond Coulomb?

or: **use charmonium:**

$$\Gamma(\eta \to g_h g_h) \to 0$$

$$\frac{\Gamma(\eta \to \gamma\gamma)}{M} = \frac{Y_X^4}{q_c^4} \frac{\Gamma(\eta_C \to \gamma\gamma)}{M_{\eta_C}}$$



other LHC signatures?

- $N_F = 0$: continuum quirk-pair production
  annihilate to diphotons (or hidden gluons)
  or: relax to ground state (eta):
  → 750 GeV diphoton + soft photons
  or 750 GeV diphoton + (hidden → lower mass diphotons,
  displaced?)

- $N_F > 0$: X hadronizes with S and hadron decays (→ leptons/jets)

depends on details of hidden sector

for fermion X: upsilon (J=1) production:

much smaller width: $\Upsilon \to g_h g_h g_h$

$+ \; g_h g_h V, \quad \mathrm{VVV} \qquad \mathrm{V} = \gamma, Z$

+ q qbar, ***e+e-, mu+mu-*** ...

$+\eta\gamma$ **(another source of eta)**

→ Drell-Yan production

constrained by 8 TeV $\sigma(pp \to \Upsilon \to \mu\mu) \leq 1.2\ \mathrm{fb}$

→ $N_F = 0$ models excluded for $\bar{\alpha} > 0.2$

→ charmonium point: need large $\Gamma(\Upsilon \to G_0 \gamma)$

$\sim 10 \times g_h g_h \gamma$ 2-body vs 3 body ??

eta vs upsilon:

sensitive to details of hidden sector:

- large N_F : Br(Υ to hidden) goes up → Br(Υ to *l+l-*) goes down
  (running between Bohr radius and m_X)
- if X decays (to S+SM) with $\boldsymbol{\Gamma}_X \sim \boldsymbol{\Gamma}_\Upsilon$ $(\ll \boldsymbol{\Gamma}_\eta)$: upsilon production goes down; eta roughly unchanged
- hidden photon (mediating upsilon decays to light hidden flavors)

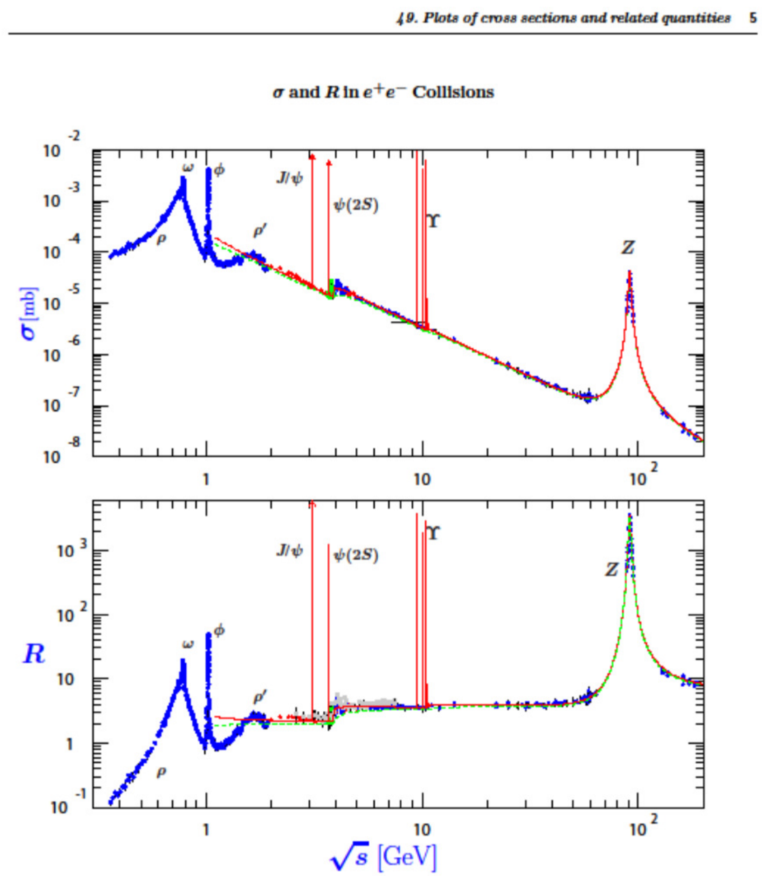
- and of course: scalar X: J=1 suppressed

To conclude:

- lots of photons.. not many jets
- lots of interesting signatures: 750 diphotons + other (soft) photons, missing energy
- 4 photons from glueball decay (2 glueballs; each decaying to 2 photons)
- depending on model*: l+l-* from upsilon at least 1fb (also 2 jets)

- can tolerate large Br(hidden) just as in colored (QCD) production:

$$\sigma(pp \to \eta \to \gamma\gamma) \sim \Gamma(QCD)\frac{\Gamma(\gamma\gamma)}{\Gamma(QCD)}$$


49. Plots of cross sections and related quantities 5
σ and R in e+e− Collisions
σ [mb]
R
J/ψ
ψ(2S)
Υ
Z
ω
φ
ρ
ρ′
√s [GeV]

thank you!