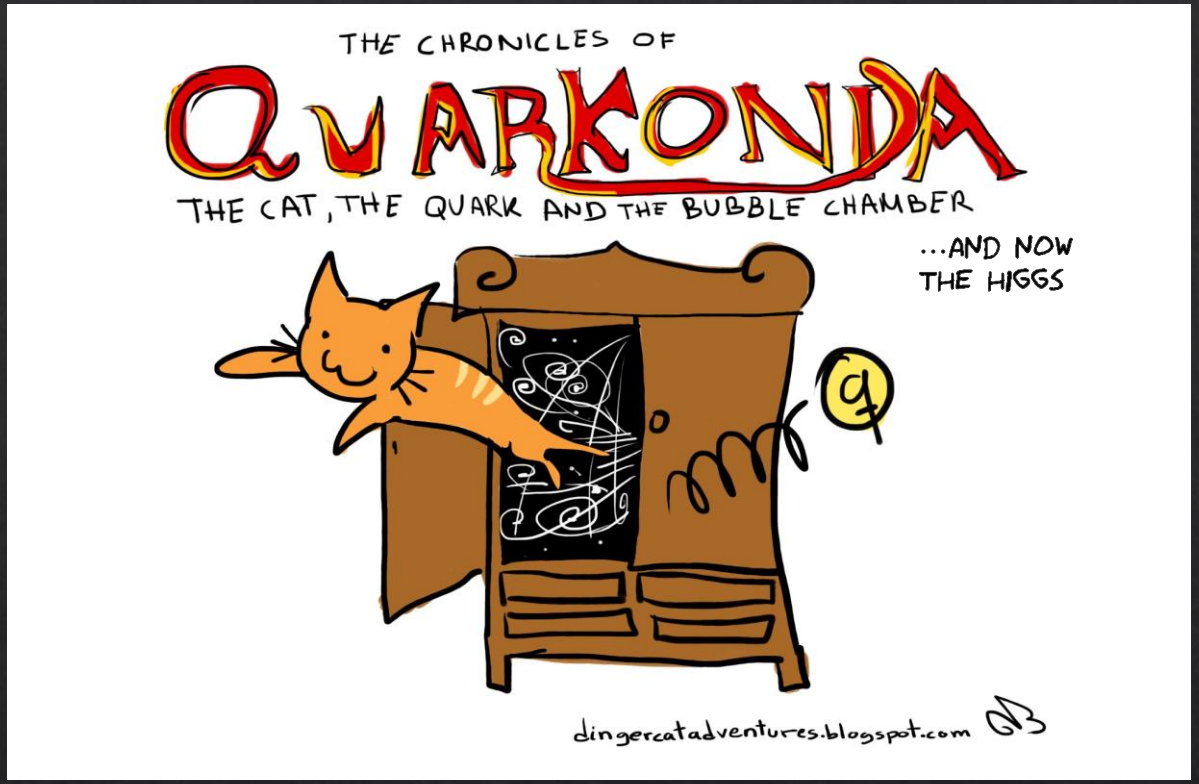
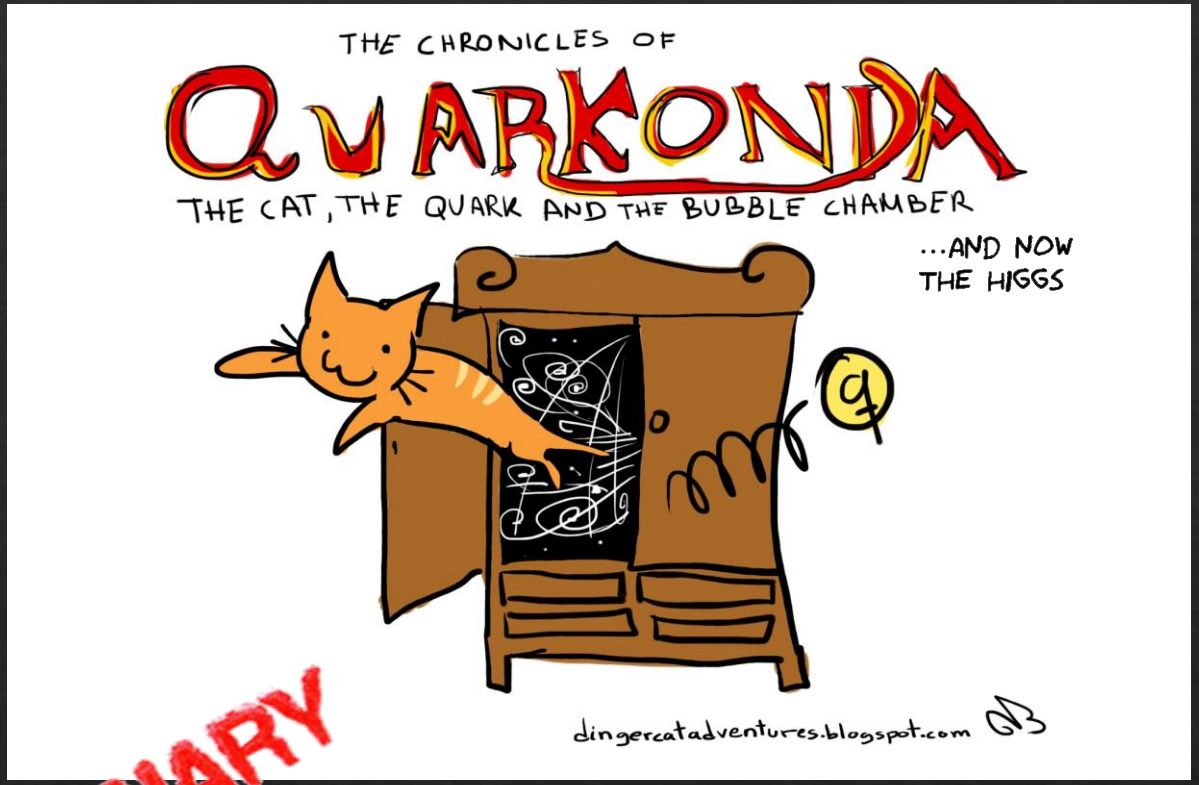



# Displaced Quarkonia as a New Physics Probe

Hou Keong (Tim) Lou,

UC Berkeley




PRELIMINARY

# Displaced Quarkonia as a New Physics Probe

Hou Keong (Tim) Lou,

UC Berkeley

# Higgs as a Portal

- Can couple to new sector through $|H|^2 \mathcal{O}_X$
- Lowest dimension $\mathcal{O}_X$:
  - New (pseudo)scalar $\phi^2$
  - New vector through mixing, or fermions
- Leads to Exotic Higgs decay
  - Lifetime of new particles can be naturally long

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- Leads to Exotic Higgs decay
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# Heavy Flavor Decay

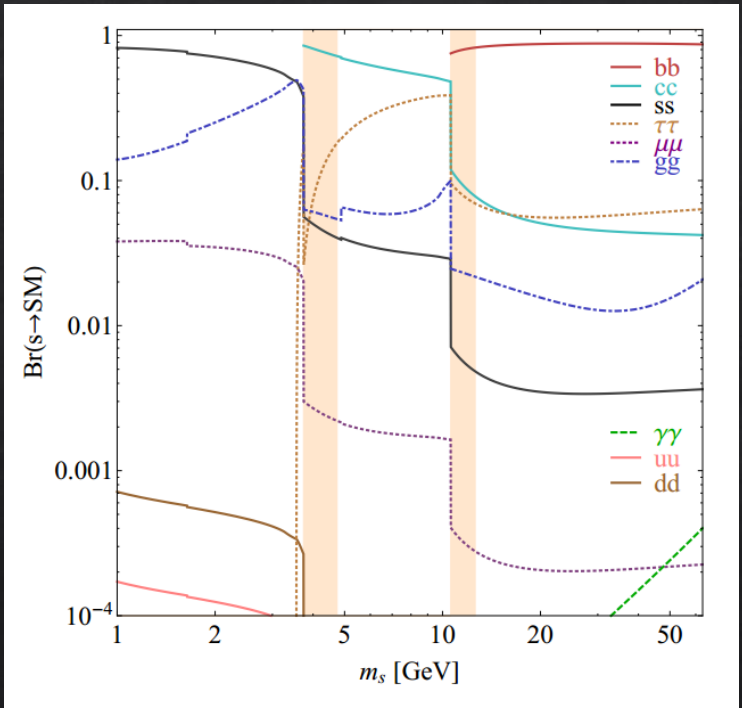
- New particles may decay preferential to heavy fermions:
  - Scalars $\phi$ : mixing with Higgs
  - Pseudoscalar : decay through helicity flip (Hidden Valley)

    M. Strassler et. al 0604261
- Decent LHC sensitivity for displaced decay
  - Loses sensitivity at smaller mass and displacement

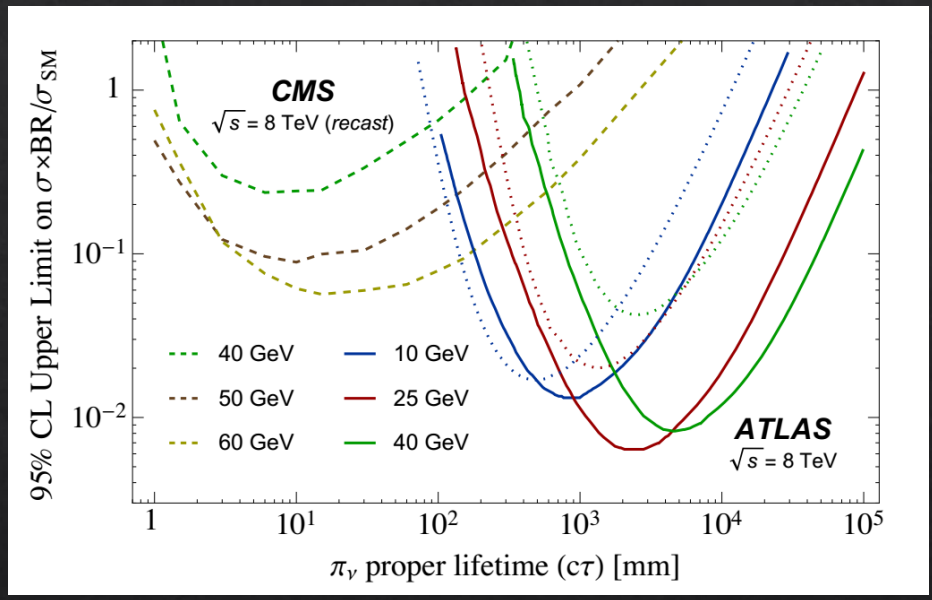
    C. Csaki et. al. 1508.01522, M. Buckley et. al: 1405.2082, V. Halyo el. al, 1308.6213
    ATLAS: 1504.05162, CMS: 1411.6530, LHCb: 1609.03124,
- Can heavy flavor decay lead to quarkonia?
  - Quite Possibly!

# Scalar Decay

C. Csaki et. al. 1508.01522

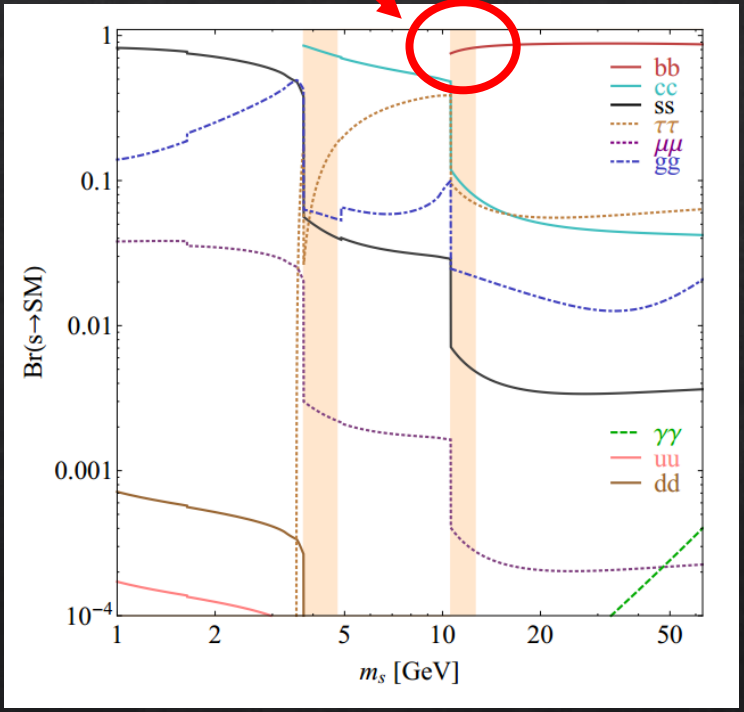



D. Curtin et. al. 1312.4992



# Scalar Decay

What happens here?




D. Curtin et. al. 1312.4992

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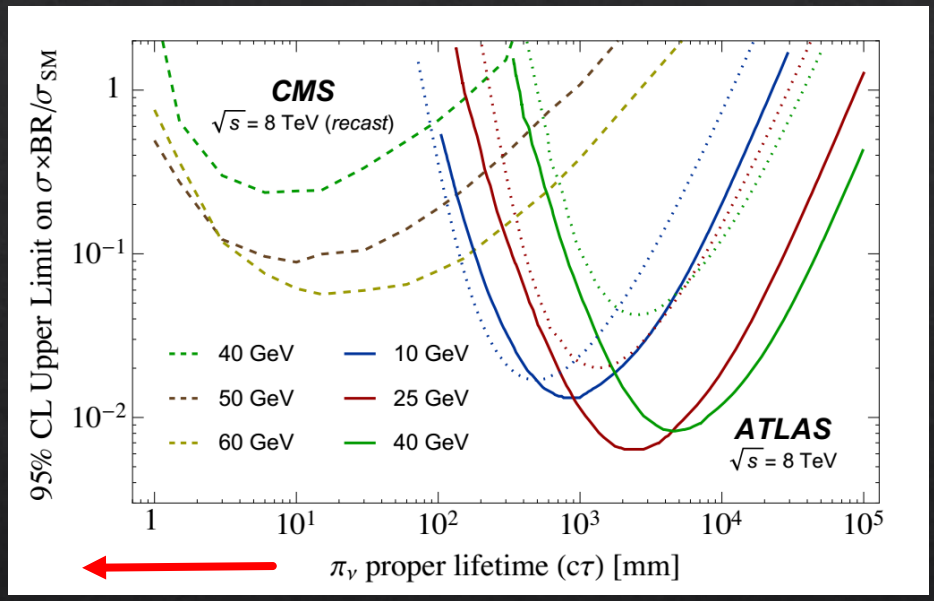
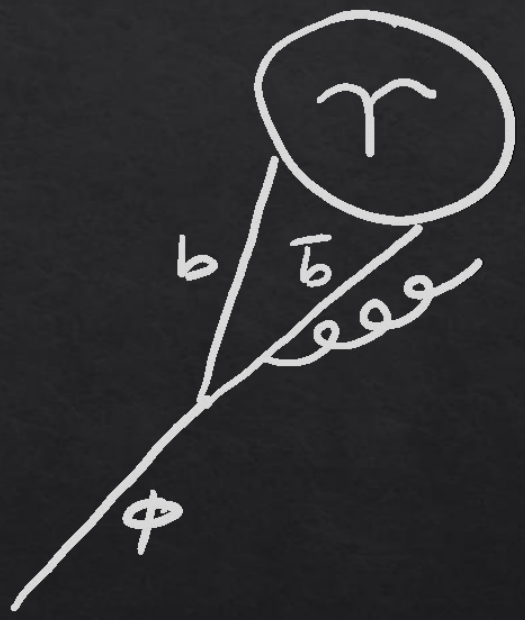



Can we improve lower lifetime regions?

# Signal Topology

- Signal topology: $h \to \phi\phi$,
- Long lived $\phi \to b\bar{b} \to \Upsilon + X$
- $\Upsilon$ decays leptonically into $\mu^+\mu^-$
- Signature: displaced vertices forming a narrow $\Upsilon$ resonance
- Can probe $m_\phi \simeq 10$ GeV and smaller lifetime



# How to make a Quarkonium?

- Color Evaporation Model:
  - $q\overline{q}$ pair below threshold have some chance of making quarkonia

$$\sigma(A \to Q + X) = F_{q\bar{q}\to Q} \int_{2m_q}^{2M} d\sigma_{q\bar{q}}(A \to q\bar{q} + X)$$

- NRQCD:
  - Quarkonia created from $q\overline{q}$ wave-function overlap

$$\sigma(A \to Q + X) = \sum_n \sigma_{q\bar{q}}(A \to q\bar{q} + X) \langle \mathcal{O}_n \rangle$$

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Implemented in Pythia8

- NRQCD:
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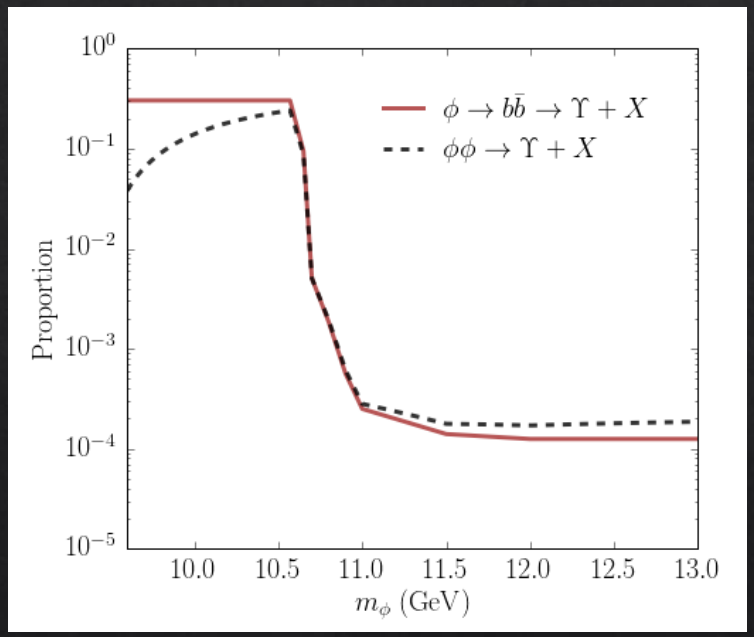
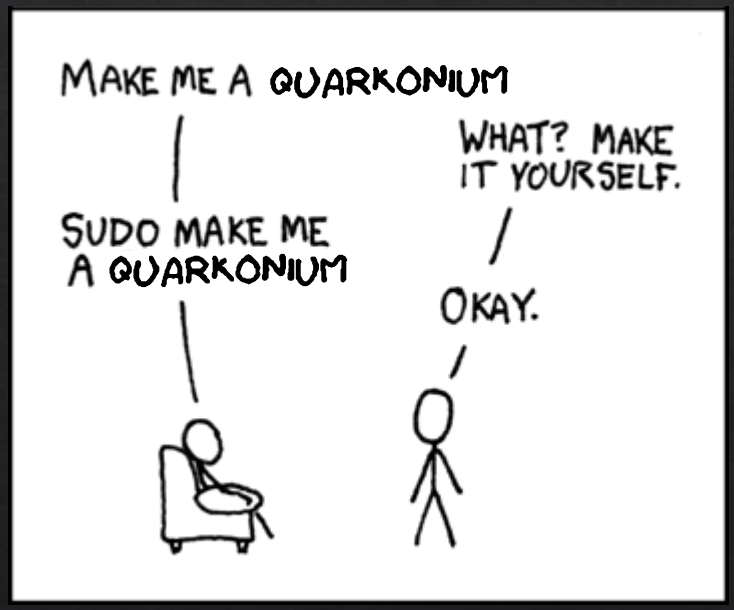
$$\sigma(A \to Q + X) = \sum_n \sigma_{q\bar{q}}(A \to q\bar{q} + X) \langle \mathcal{O}_n \rangle$$

# Pythia8:~$ make me a quarkonium_

- Need to re-sum gluon emissions and include fragmentations:
  - Pythia8 comes to the rescue!




modified from xkcd.com

# What can Quarkonia do for you?

- Dedicated data scouting trigger!

- Many important exclusive Higgs decay involving quarkonia:
  - $h \to \Upsilon + \gamma/Z$
  - $h \to J/\psi + \gamma/Z$

See earlier talks, some recent work:
G. Bodwin et. al. 1306.5770, G. Isidori et.al. 1305.0663,
S. Alte et.al. 1609.06310, D. Gao, 1406.7102,
V. Kartvelishvili el. al, 0810.0953… many others

| Trigger Selection for Data Parking |
| --- |
| $\mu^+\mu^-$ : $p_T(\mu\mu)$>5 GeV, $\lvert y(\mu\mu)<2.5\rvert$, $\Delta R<2$ , $m_{\mu\mu} \approx m_{\Psi'} \to$ [3.35,4.05] GeV |
| $\mu^+\mu^-$ : $p_T(\mu\mu)$>8 GeV, $\lvert y(\mu\mu)<2.5\rvert$, $\Delta R<2$ , $m_{\mu\mu} \approx m_{J/\Psi} \to$ [2.8,3.35] GeV |
| $\mu^+\mu^-$ : $p_T(\mu\mu)$>5 GeV, $\lvert y(\mu\mu)<2.5\rvert$, $\Delta R<2$ , $m_{\mu\mu} \approx m_{\Upsilon} \to$ [8.5,11.5] GeV |
| $\mu^+\mu^-$ : $p_T(\mu)$>3.5 GeV, $\lvert \eta(\mu)<2.2\rvert$, $p_T(\mu\mu)$>6.9 GeV, displaced vertex wrt beam, $m_{\mu\mu}$ = [1.0,4.8] GeV |

CMS data-scouting triggers

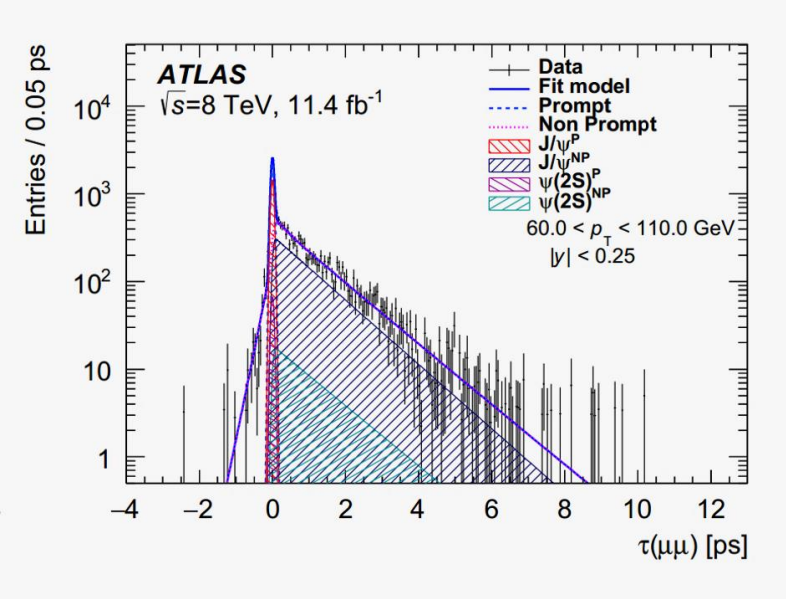
# What can Quarkonia do for you?

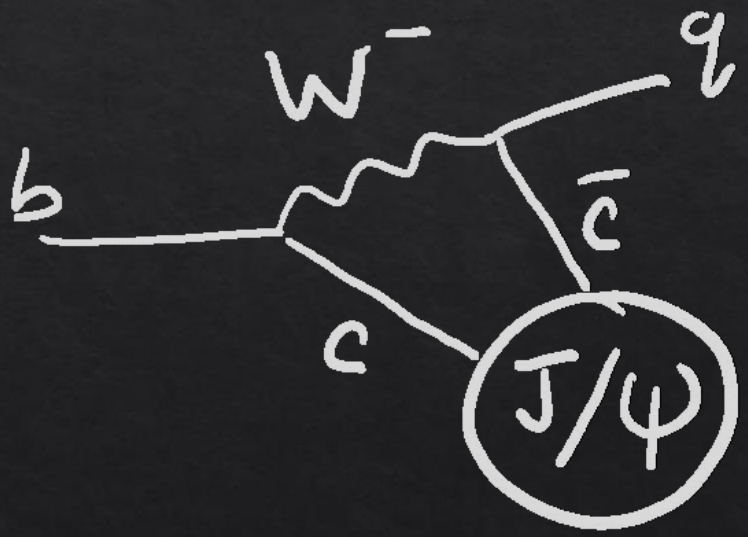
- $\Upsilon$ :
  - from QCD (prompt)
  - Branching to $\mu^+\mu^-$: 2.4%
- $J/\psi$ (perfect control sample):
  - from QCD (prompt)
  - from $b$-decays (displaced)
  - Branching to $\mu^+\mu^-$ : 6.0%

# $J/\psi$ as a calibration

- (non-)Prompt $J/\psi$, has been well measured at the LHC

ATLAS: 1412.03567 LHCb: 1304.6977
CMS: 1111.4193 ALICE: 1205.5880



# Signal Benchmark

- $m_\phi = 11$ GeV
- One $\phi$ decays into:
  - $\Upsilon + \pi\pi$
- The other $\phi$ decays into:
  - 20% $\tau^+\tau^-$
  - 80% QCD ($c\bar{c}$)
- Trigger (~60% efficient):
  - $p_{T,\Upsilon} > 5$ GeV, $|y_\Upsilon| < 2.5$, $\Delta R(\mu^+\mu^-) < 2$
- Preselection:
  - One jet $\Delta R > 0.5$ from $\Upsilon$ with $p_T > 30$ GeV
  - $p_{T,\Upsilon} > 20$ GeV

# Kinematics

## Higgs Mass

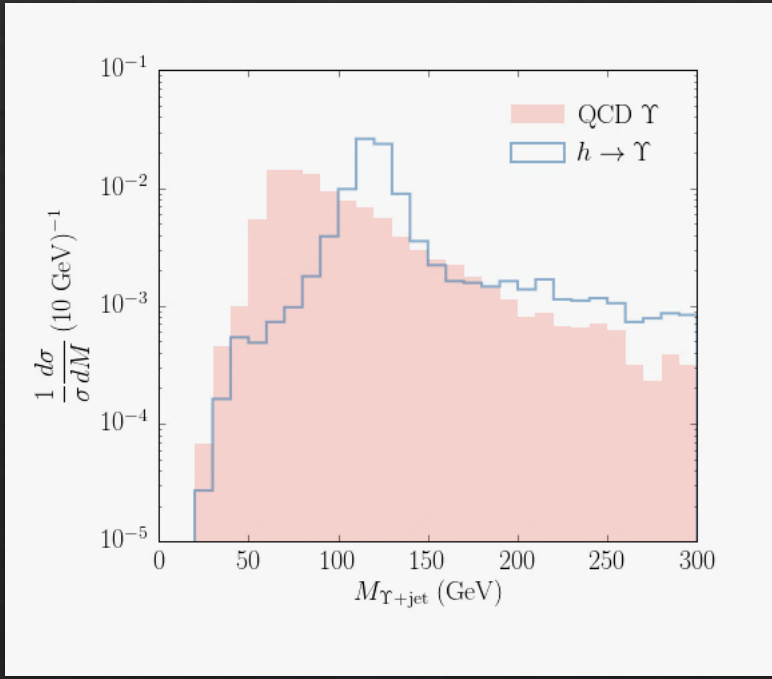
- Light $\phi$ leads to collimated decay products
- $\Upsilon$ + jet close to Higgs mass
- May be combined with displaced vertices for a 2D fit

## Displaced Vertices

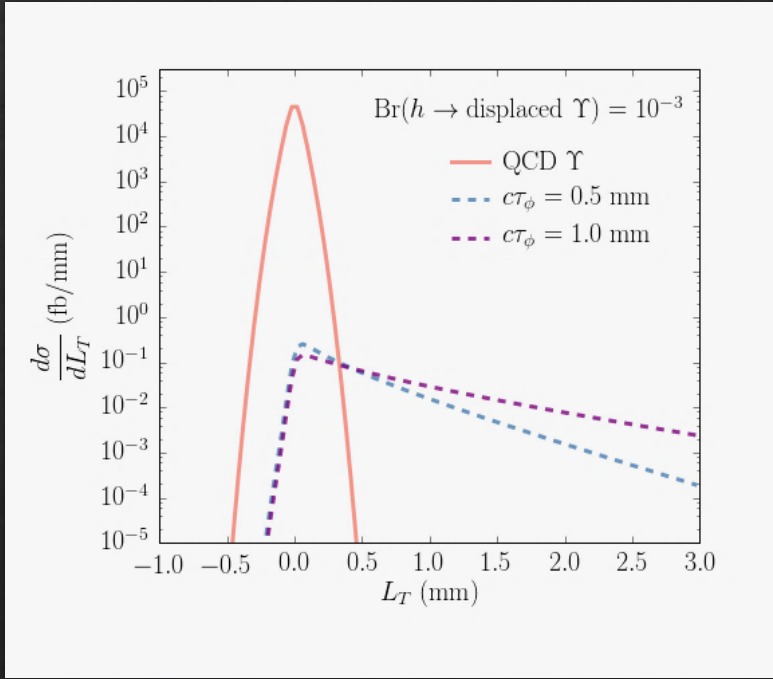
- Transverse displacement
  - $L_T = \left(\frac{m}{p_T}\right)\vec{L} \cdot \vec{p}_T$
- Resolution ~ $.15\left(\frac{m}{p_T}\right)$ mm

# Kinematics

90 GeV $< M_{\Upsilon+\text{jet}} <$ 150 GeV

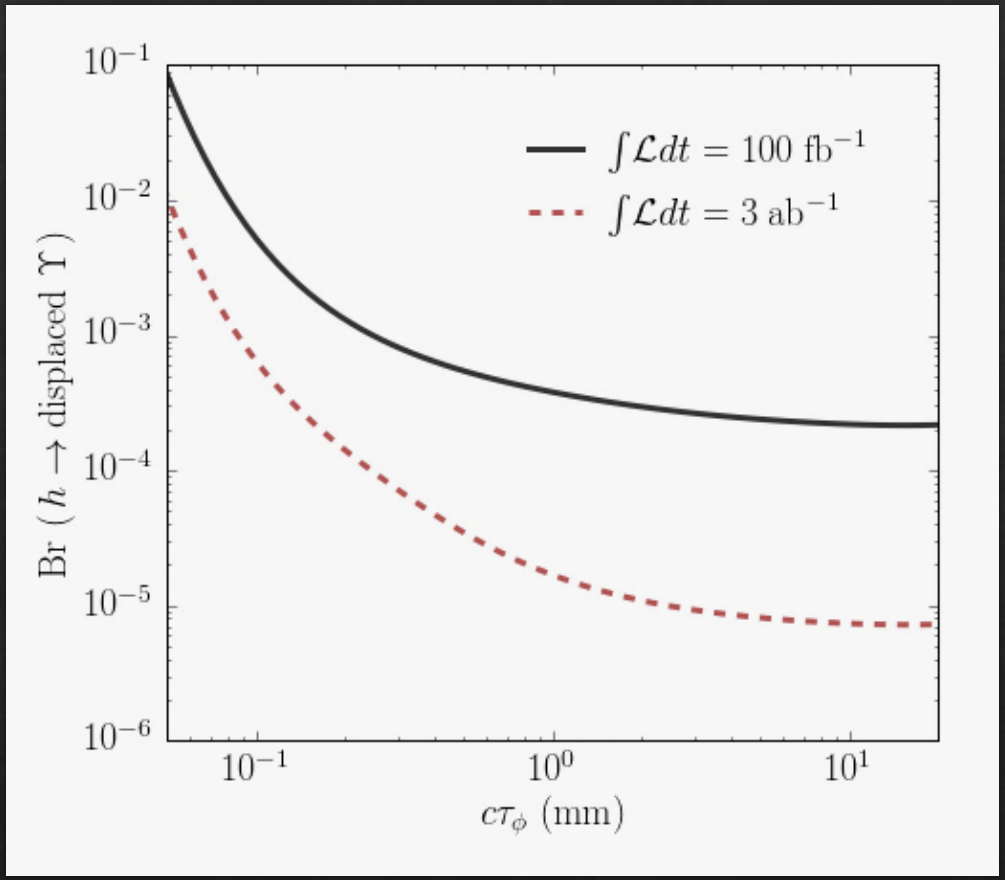



No background $L_T > 0.5$ mm



# Expected 95% Exclusion Limits

- Simple $\chi^2$ fit
- Sensitive to mm displacement
- Limits statistics limited
- May be improved significantly
  - exploit $\tau^+\tau^-$



# Conclusion

- New physics could lead to displaced quarkonia in Higgs decay
- Existing dedicated trigger and clean leptonic decays lead to simple and effective search strategies
- $J/\psi$ can be used as a calibration, allowing data-driven background for robust limits
- Can probe $m_\phi \simeq 10$ GeV and $c\tau$ down to mm

# Future Directions?

- Accurate $\Upsilon$ production rate at threshold is needed
- LHCb may yield good limits at small displacement
- $h \to \Upsilon + \tau^+\tau^-$ channel may be exploited
- $J/\psi$ can be used to tag $b$-quark, which may also be helpful in new physics searches (already done for $t\bar{t}$ studies)