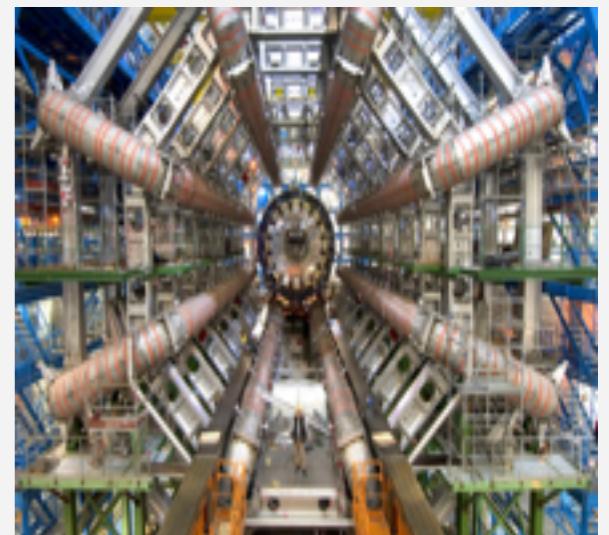
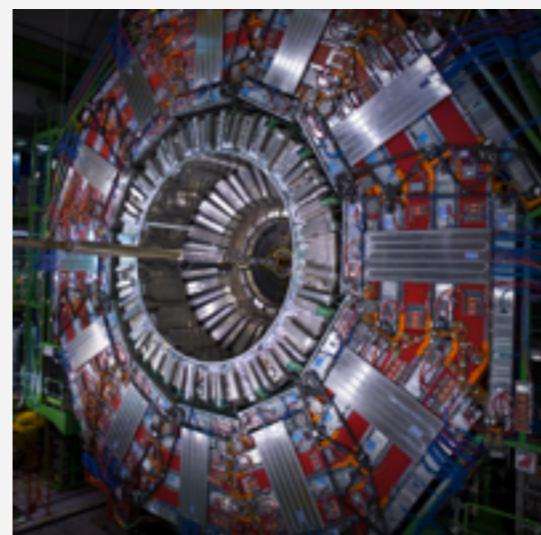
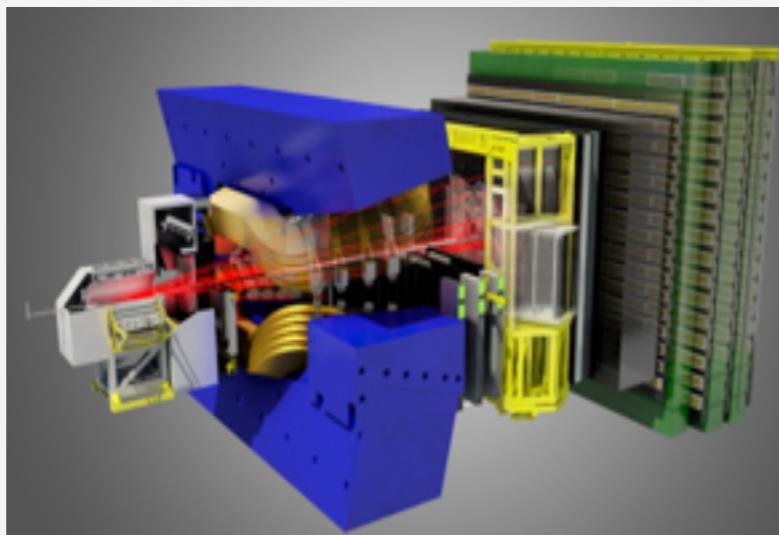
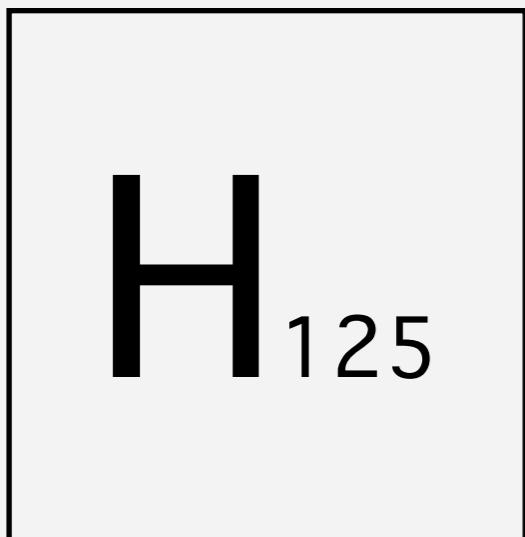


More about Dark Showers: Naturalness & LHC(b) searches

Yuhsin Tsai

University of Maryland

Fermilab, 07/28/2017



What are the forces in the hidden sector?

Standard Model

$U(1)$

$SU(2)_L$

$SU(3)_C$

leptons

quarks

Higgs

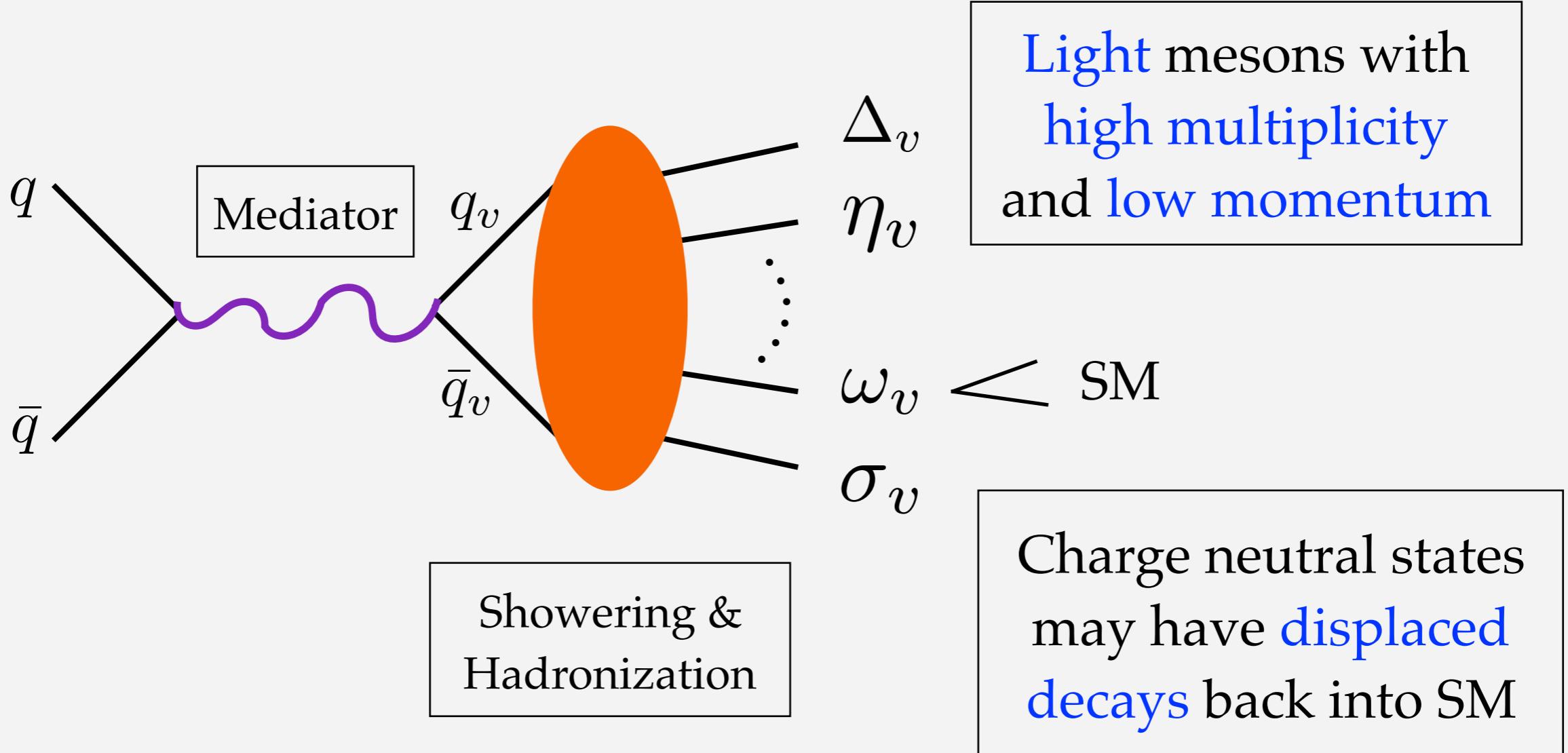
Hidden Sector

confining force ?

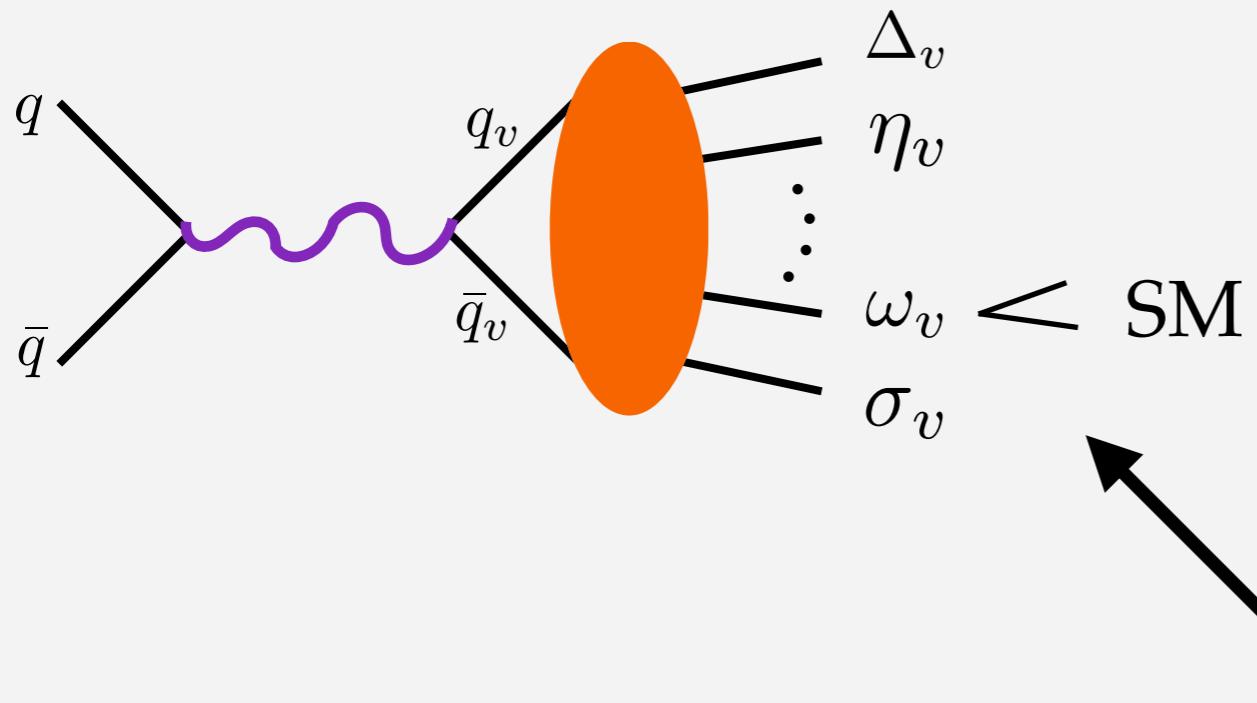
non-confining force ?

Dark showers at collider

M. Strassler and K. Zurek (06')



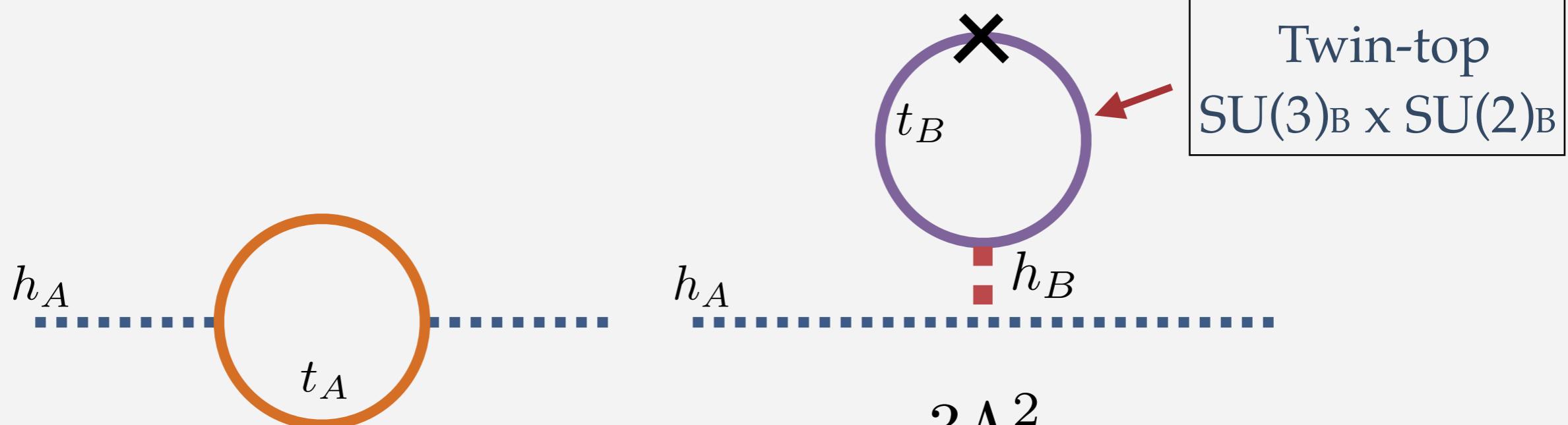
Connection to the Naturalness problem



Twin Higgs model

Chacko, Goh, Harnik 05'

A solution to the little hierarchy problem
without colored partners



$$\delta m_h^2 \approx \frac{3\Lambda^2}{4\pi^2} (y_t^2 - \hat{y}_t^2)$$

SM

Twin

y_t

$y_{\hat{t}}$

SU(3) x SU(2)
gauge couplings

SU(3) x SU(2)
gauge couplings

EWSB scale v

EWSB scale f

Other Yuakwa couplings

\approx

Other Yuakwa couplings

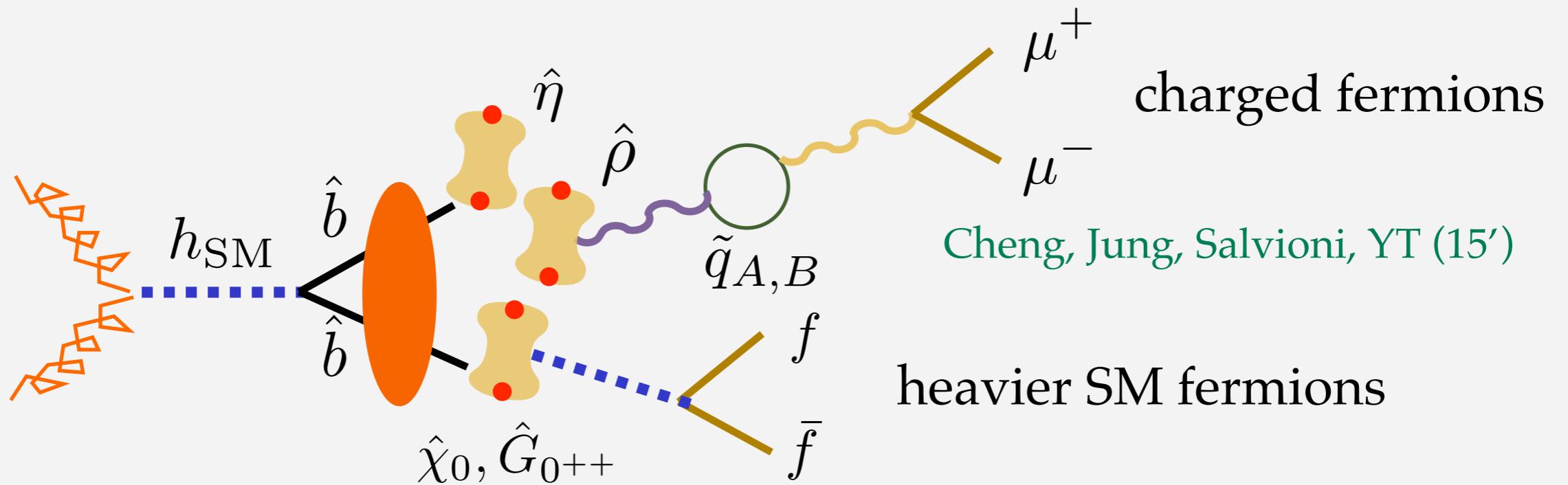
U(1) Y coupling

\approx

U(1) Y coupling

Neutral Naturalness: Twin Higgs model

Chacko, Goh, Harnik (05')



Cheng, Jung, Salvioni, YT (15')

heavier SM fermions

Craig, Katz, Strassler, Sundrum (15')

Curtin, Verhaaren (15')

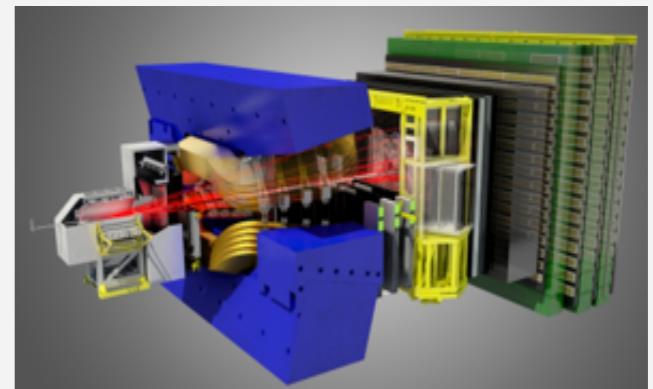
Chacko, Curtin, Verhaaren (15')

We want to look for

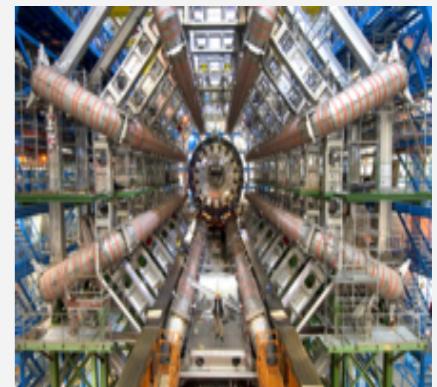
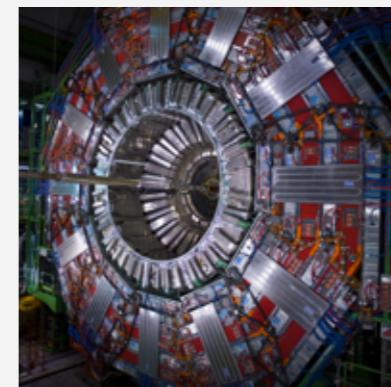
Light & soft DVs with high multiplicity

Two possibilities:

Cleaner environment,
better vertex reconstruction / particle id,
lower pT cut requirement

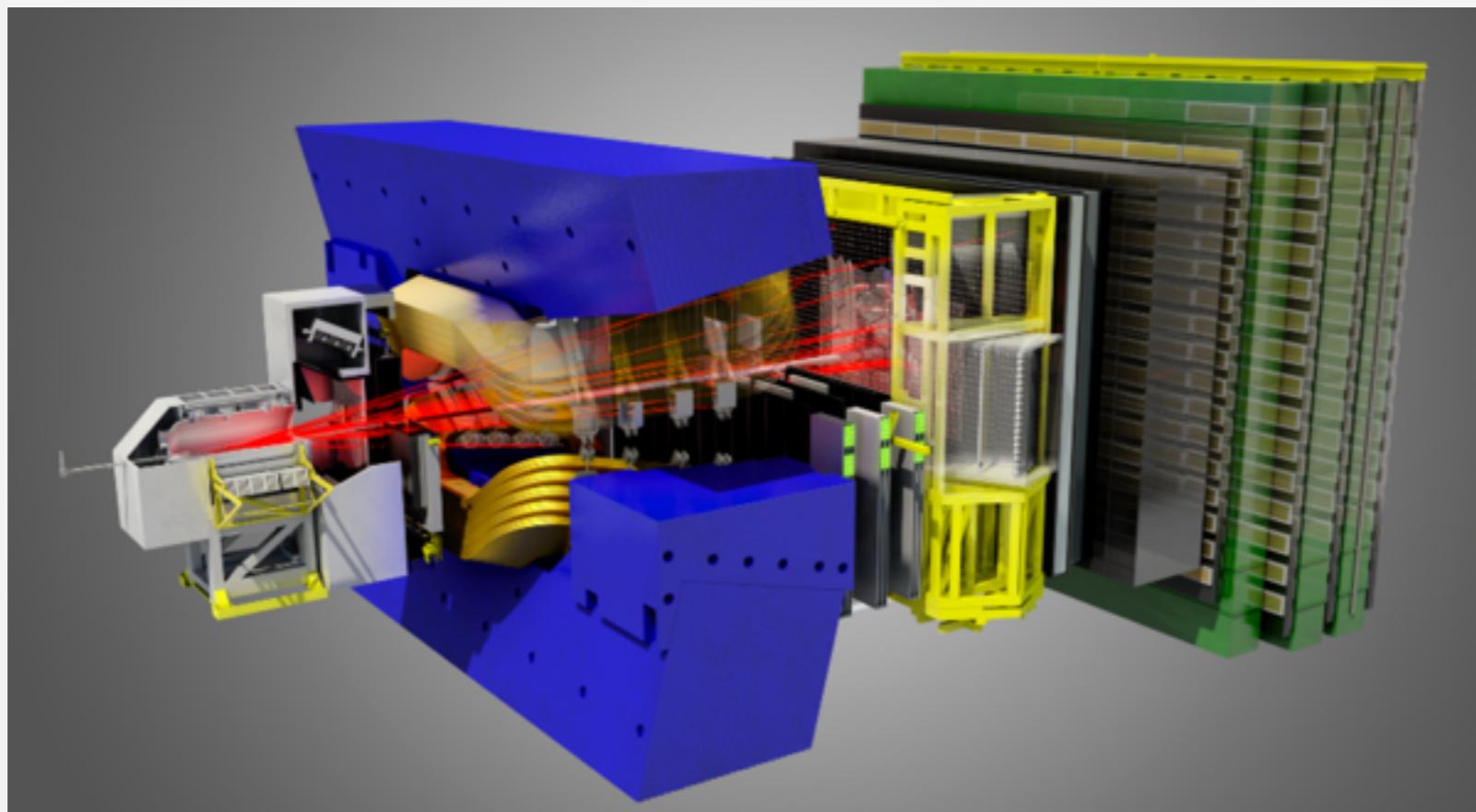


~ 100x more data,
lower pT trigger on multiple final states



Probing dark showers at the LHCb detector

A. Pierce, B. Shakya, YT, Y. Zhao,...hopefully done next week



Existing HV search at LHCb

LLP to jet jet NEW

LHCb-PAPER-2016-065

2 / fb of 7 & 8 TeV data

- No excess found
- Tested the region:
 $m_{\pi} = [25-50]$ GeV, $\tau = [2-500]$ ps
- Example: for $m_{\pi} = 50$ GeV
exclude BR>30% for $\tau = [5-50]$ ps ($c\tau = [1.5-15]$ mm)

$(\sigma/\sigma_{gg \rightarrow gg}) \cdot \mathcal{B}(h^{\pm} \rightarrow \pi_v \bar{\nu}_v)$

LHCb preliminary

lifetime (ps)

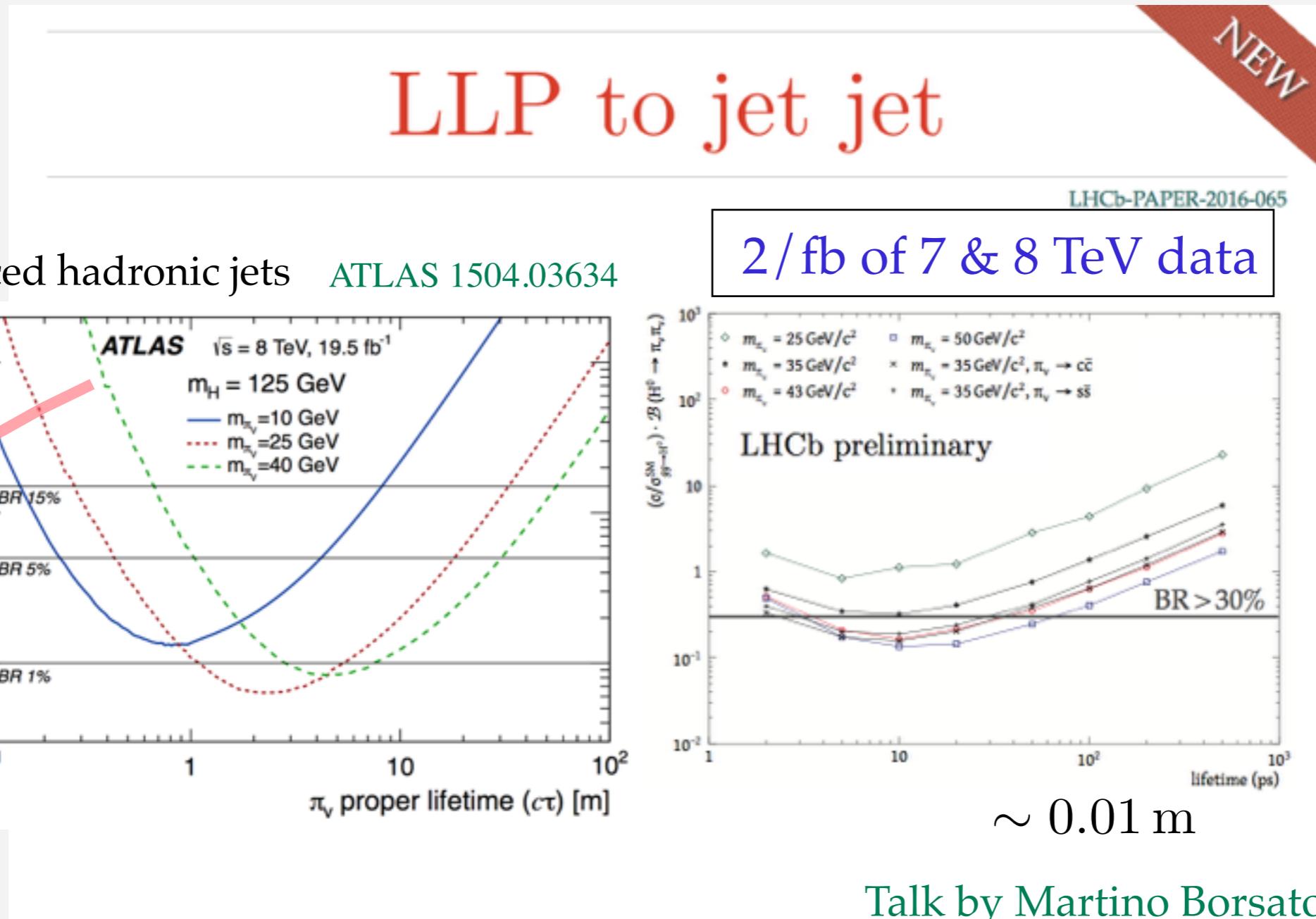
m_{π_v} values: 25, 35, 43 GeV/c² (green circles), 35 GeV/c², $\pi_v \rightarrow c\bar{c}$ (black crosses), 35 GeV/c², $\pi_v \rightarrow s\bar{s}$ (red circles).

BR > 30%

Talk by Martino Borsato

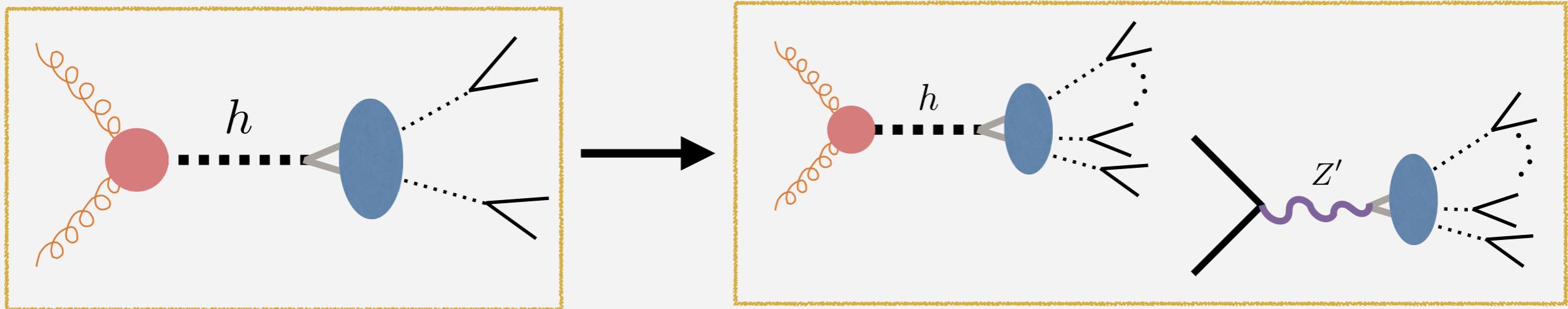
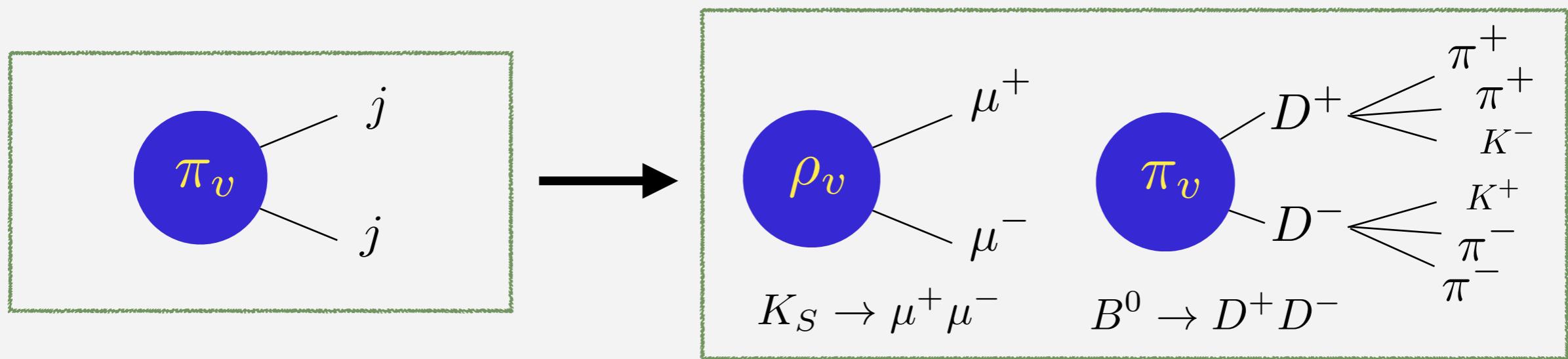
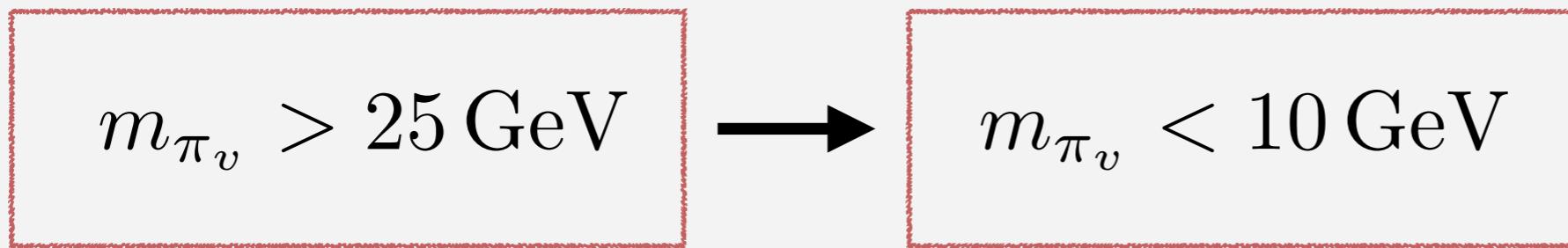
$$m_{\pi_v} > 10 \text{ GeV}$$

Existing HV search at LHCb



LHCb is not quite competitive to ATLAS/CMS searches on [heavy LLP](#)

Idea: LHCb can do better on light DVs



Displaced muon search at LHCb

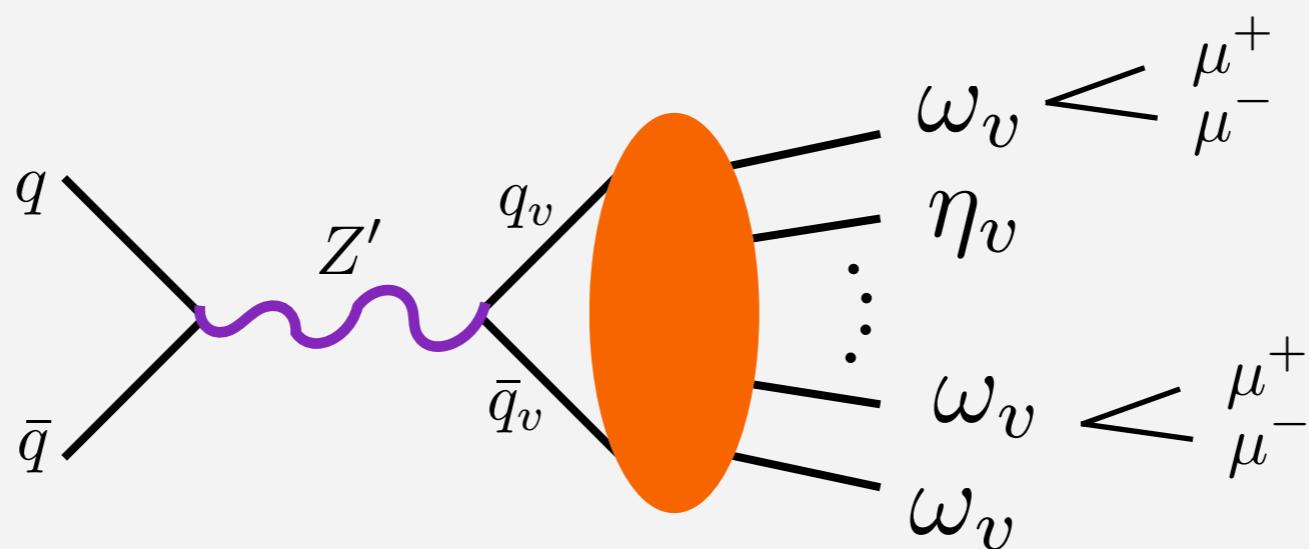
We adopt cuts from the displaced A' analysis

P. Ilten, Y. Soreq, J. Thaler, M. Williams, W. Xue, 1603.08926

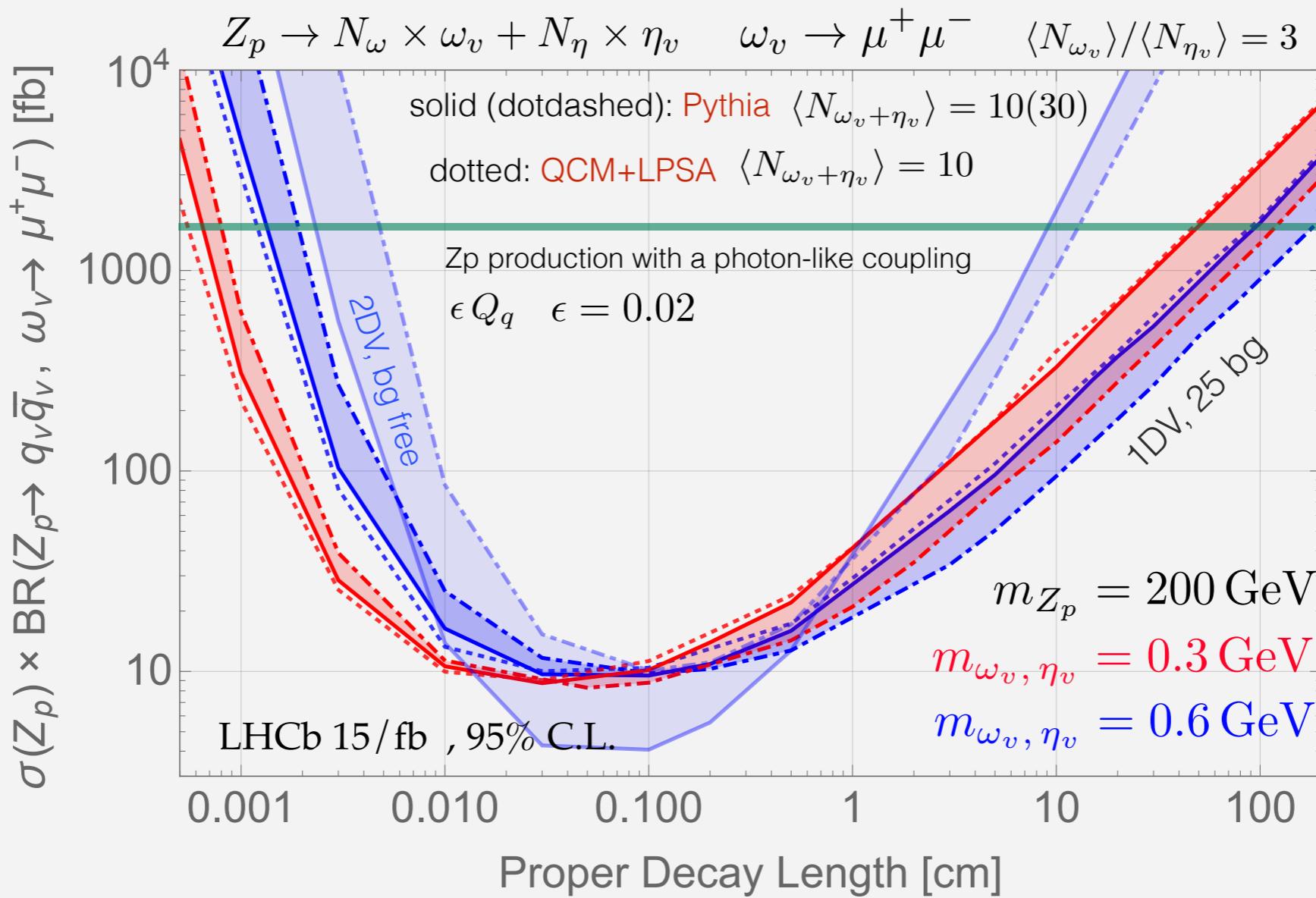
$$\eta(\mu^\pm) \in [2, 5], p(\mu^\pm) > 10 \text{ GeV}, p_T(\mu^\pm) > 0.5 \text{ GeV}$$

$$\text{Muon id efficiency } \epsilon_\mu^2 \approx 0.50$$

$$\eta(\omega_v) \in [2, 5], p_T(\omega_v) > 1 \text{ GeV} \quad \ell_T \in [6 \text{ mm}, 22 \text{ mm}]$$

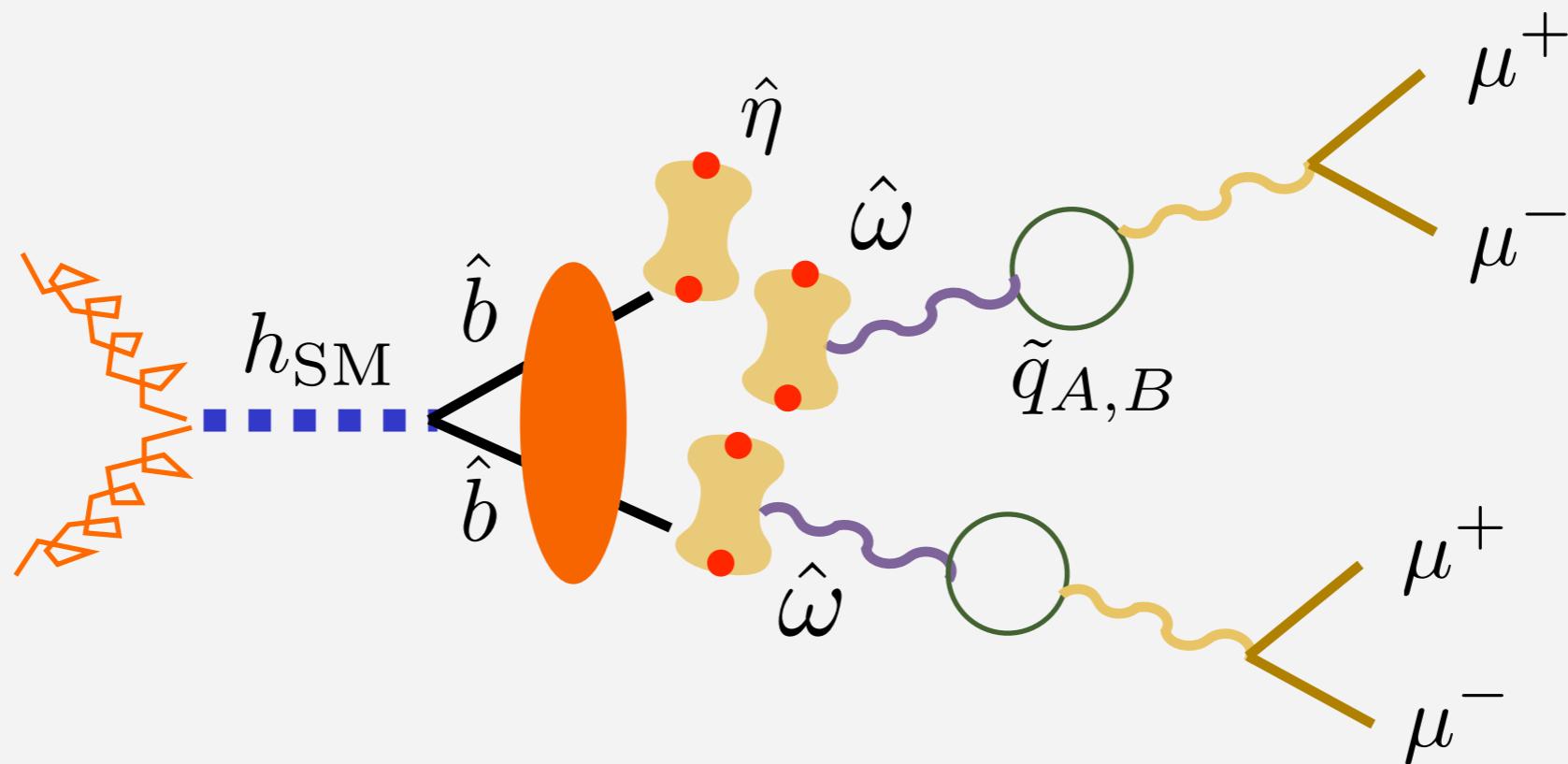


From the displaced muon search

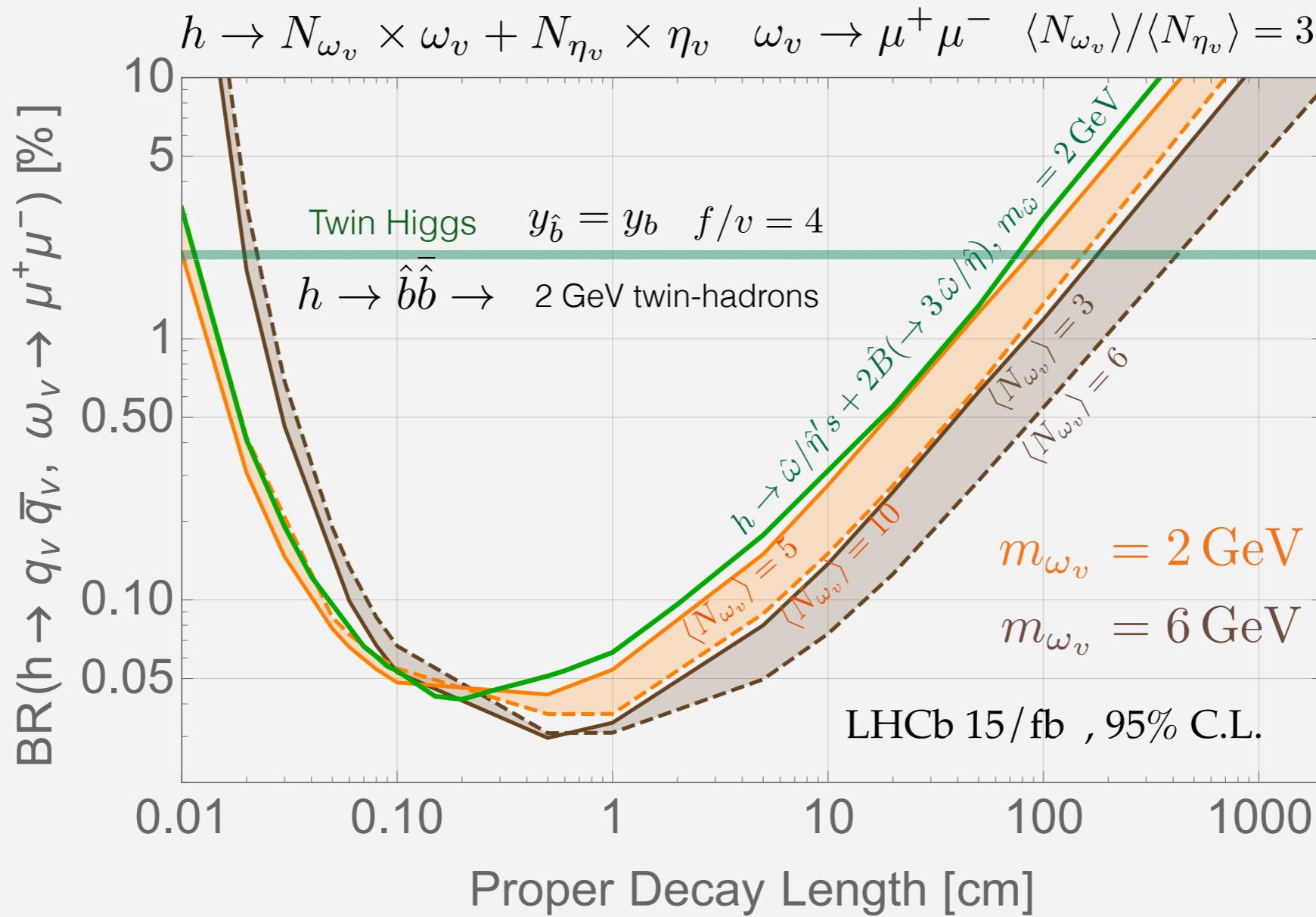


Light twin-meson at the LHCb

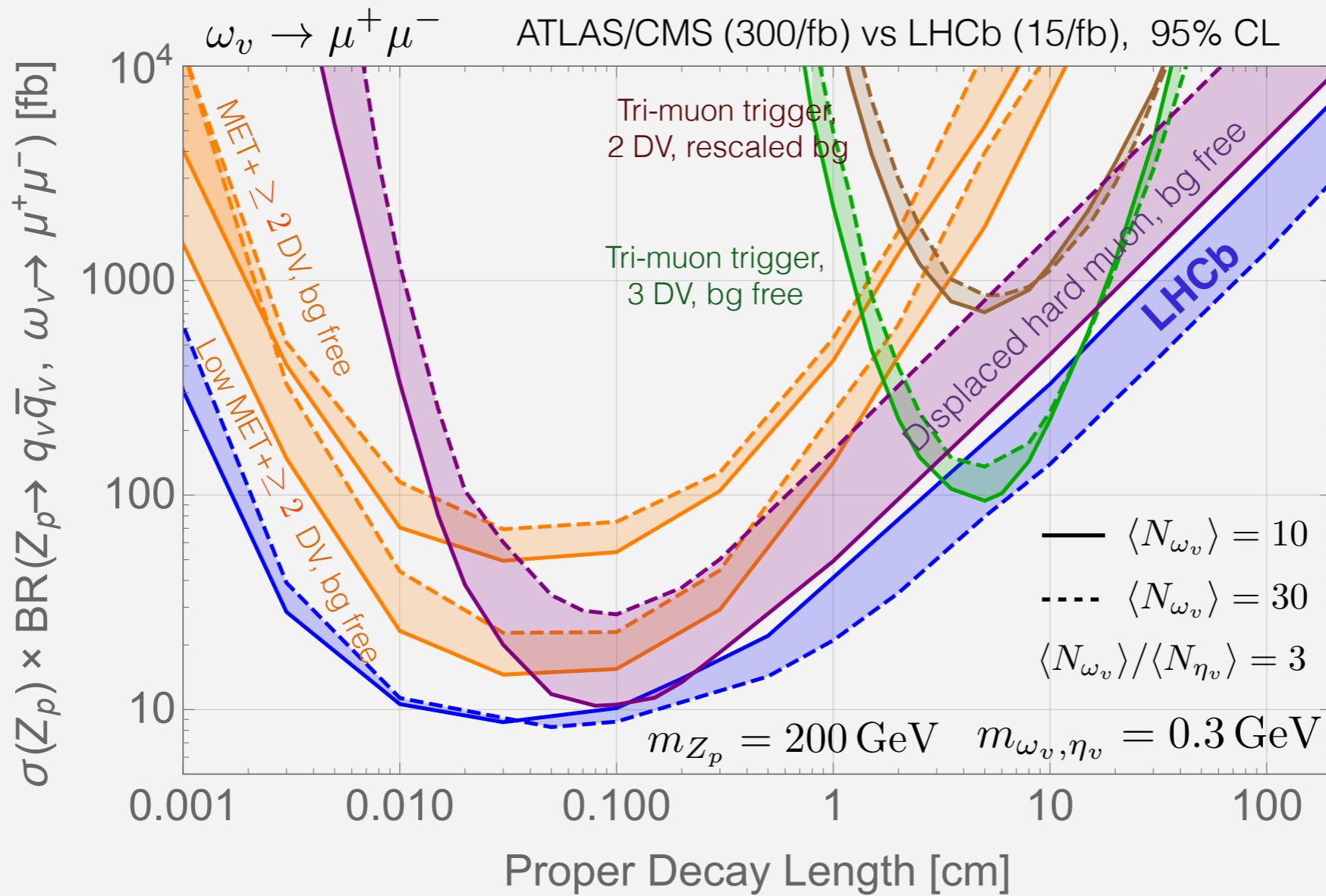
Produce dark showers from the exotic Higgs decay



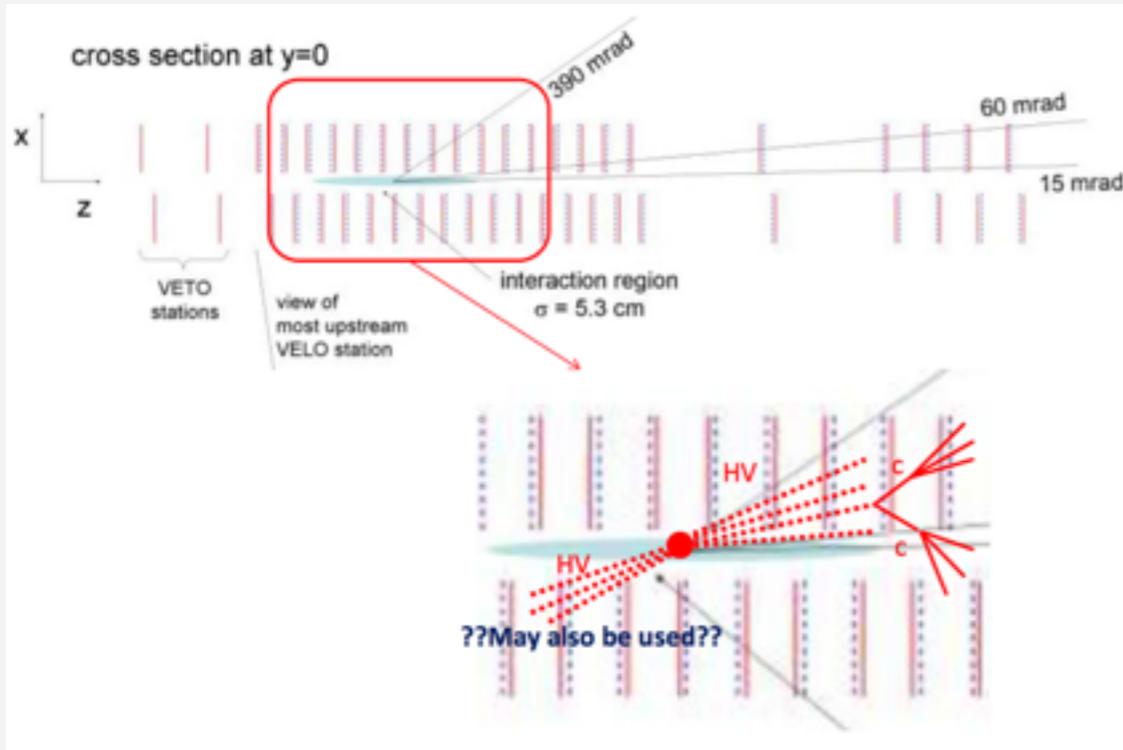
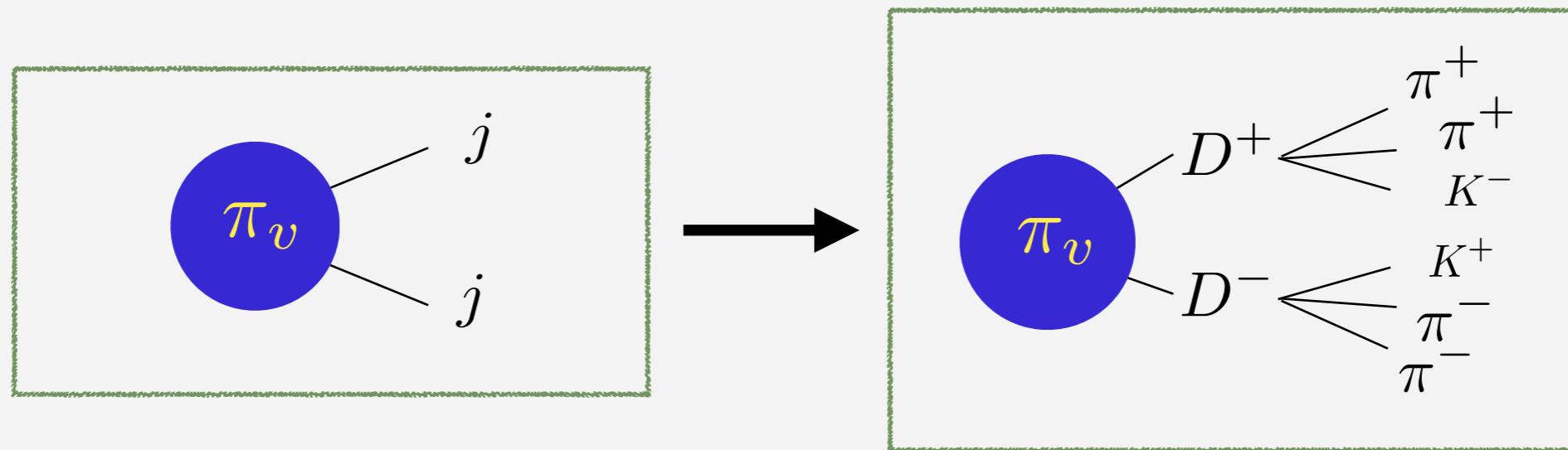
Higgs decay into dark showers



Future searches @ ATLAS/CMS



LLP decay into quarks



Search based on the
geometry of tracks

Displace decay into D-mesons

| | | |
|----------|--|---|
| Consider | $D^\pm \rightarrow K^\mp \pi^\pm \pi^\pm$ (9.5% Br) | $D^0 \rightarrow K^- 2\pi^+ \pi^-$ (8% Br) |
|----------|--|---|

2 reconstructed D-mesons

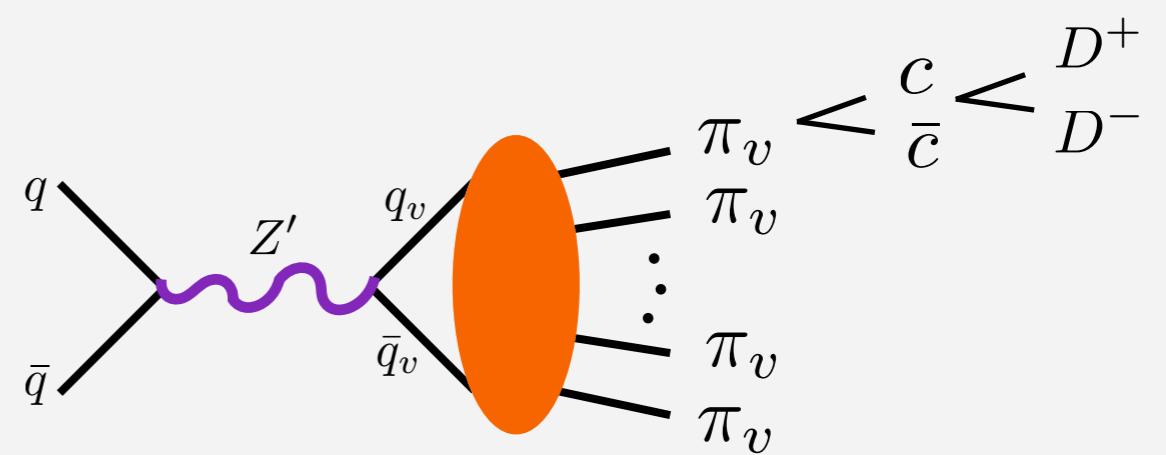
(based on $B^0 \rightarrow D^+ D^-$ search)

1608.06620

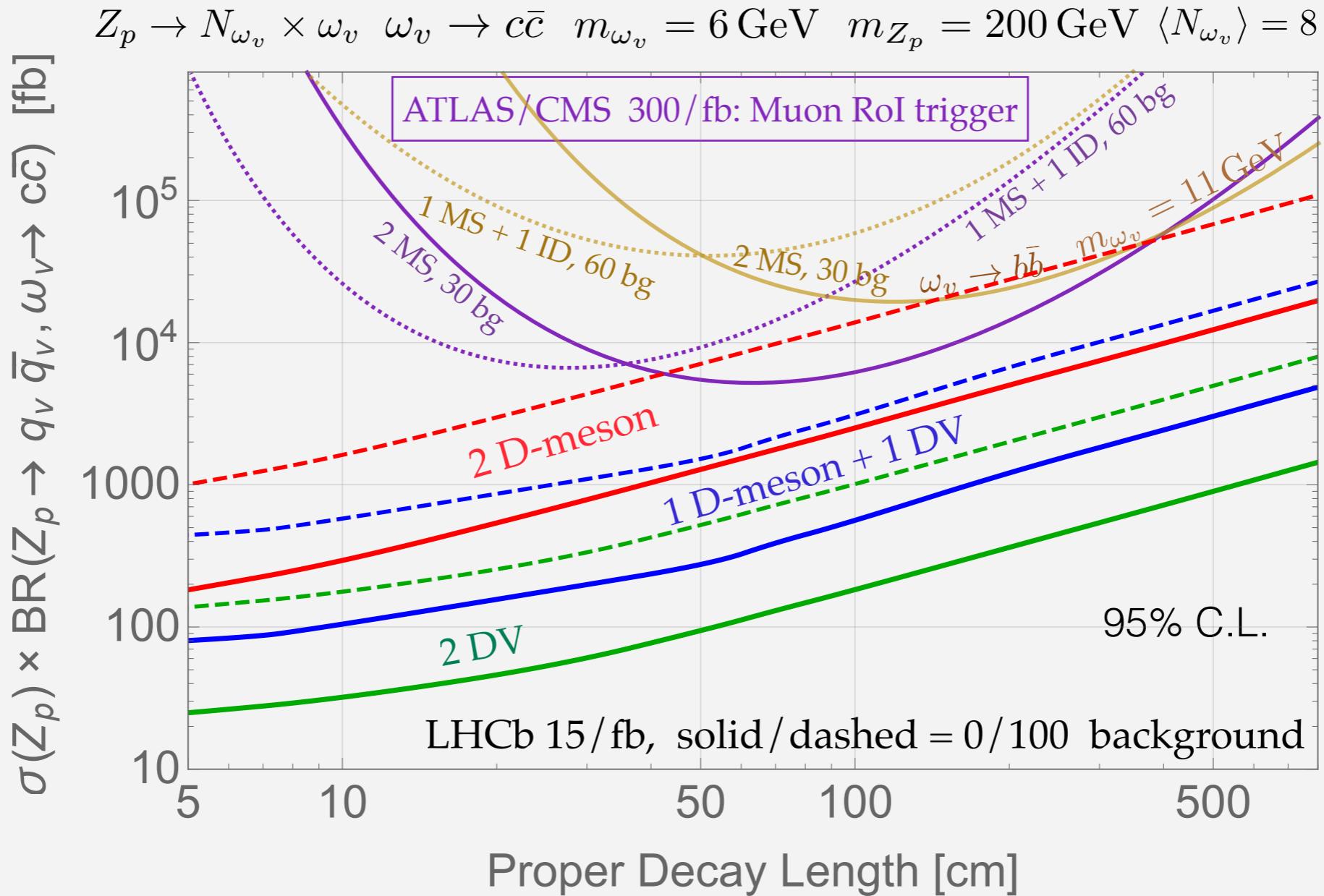
track pT > 0.1 GeV, D-meson HT > 1.8 GeV
 DV p > 10 GeV, total D-meson pT > 5 GeV
 $\ell > 10c\tau_D$

1 D-meson + 1 DV (>= 3 tracks)

2 DV (>= 3 tracks)



HV decay into D-mesons



~90% of B-meson decay contains D's, bound on HV > bb is similar

Summary and outlook

- A confining hidden sector can do important things, such as solving the hierarchy problem
- Dark showers can produce dark mesons with high multiplicity, low mass, soft energy, and long decay lifetime
- LHCb is a good place to look for low mass displaced decays
- ATLAS/CMS: high multiplicity soft muon trigger will be very useful