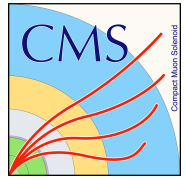


Search for long-lived particles decaying into b-quarks up to the CMS tracking system

Lisa Benato, Melanie Eich, Gregor Kasieczka, Karla Peña

Universität Hamburg

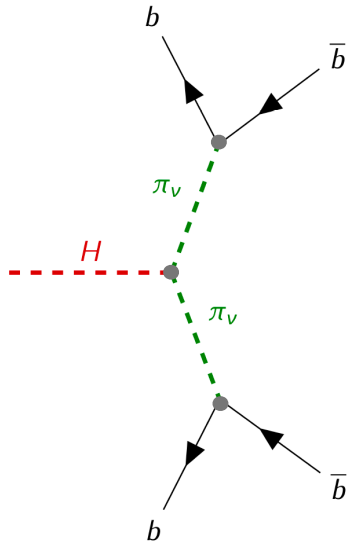
D-CMS Meeting
12 September 2019

Theoretical Overview

- Motivation
  - Hierarchy problem of the SM
  - New coloured particles predicted
- Twin Higgs Model
  - Dark sector, neutral under all SM gauge groups
  - Higgs boson mixing with ist dark partner

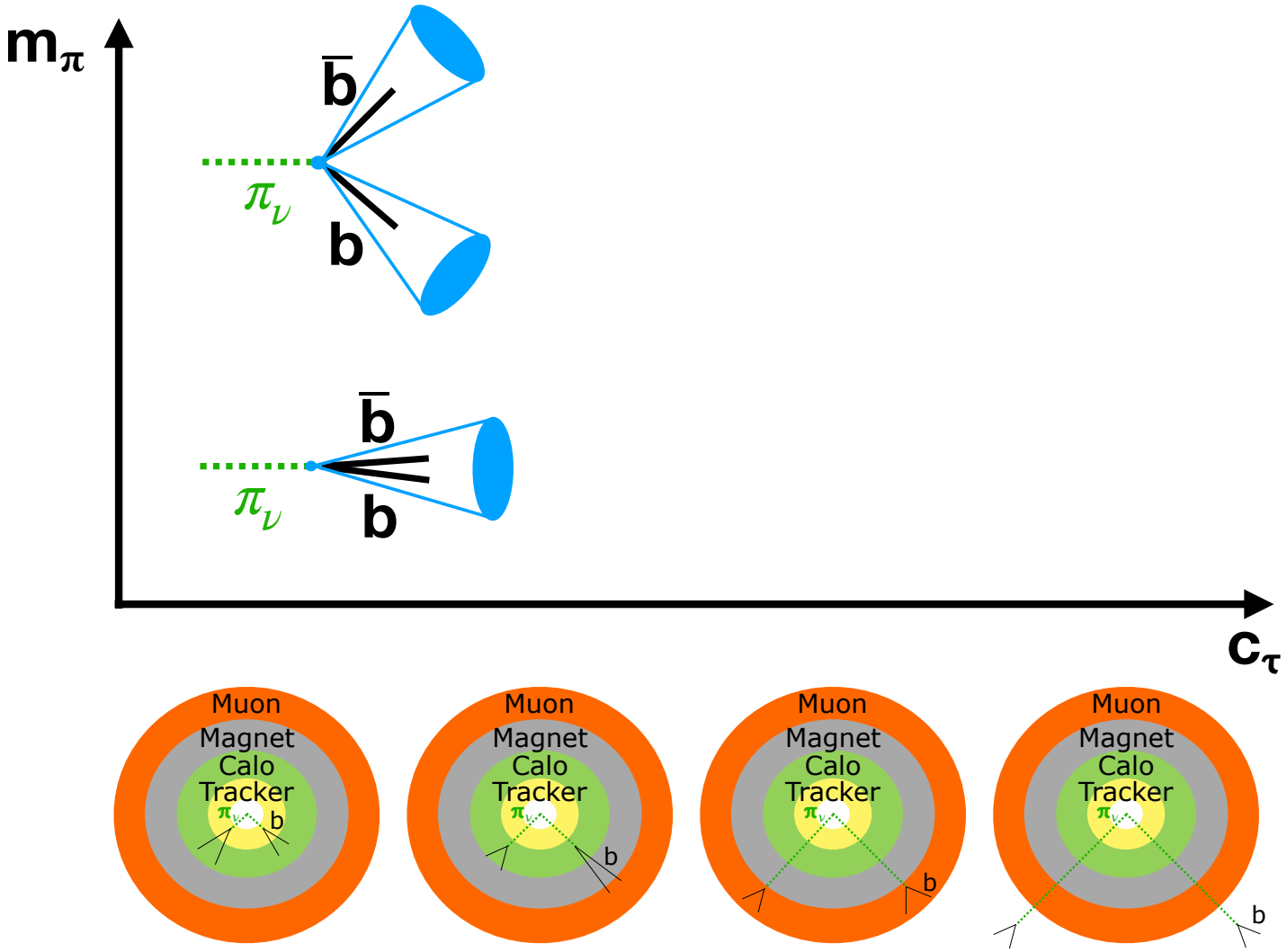
  $\rightarrow$ predicted to decay to dark particles
- Benchmark model
  - Dark neutral scalars π_ν are long-lived

  $\rightarrow$ Travel finite distance in CMS, decay to SM particles (dominantly $b\bar{b}$)
  - Depending on $c\tau$ and m_{π_ν} different experimental signatures



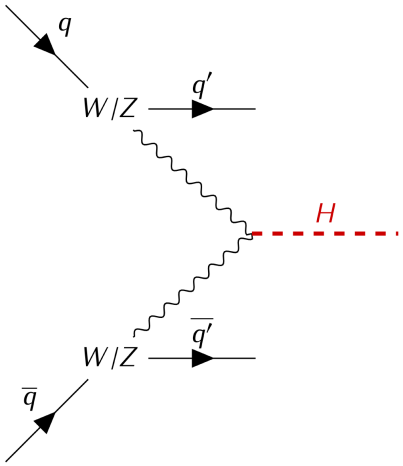
$c\tau$	**Signature**
$< 1\,\text{mm}$	b-quark like
1 mm - 1 m	displaced vertices
1 m - 2 m	trackless jets
up to 5 m	signature in muon chambers

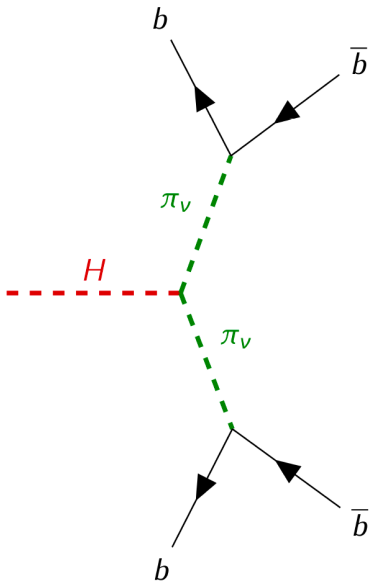
Experimental Signatures



Samples and Reconstruction

- Studies with 2016 CMS simulation
- MC samples
  - Signal samples:
    $m_{\pi_\nu} = 15 - 60\,\text{GeV}$, $c_\tau = 0mm - 10m$
  - Background:
    QCD, W+Jets, DY+Jets, $t\bar{t}$, single top, diboson, SM Higgs
- Vector-Boson Fusion (VBF)
- Trigger
  - VBF
  - jets + b tagging, displaced jets, missing E_T
- Reconstruction = base cut
  - At least two AK4 jets
    $p_T > 15\,\text{GeV}$, $|\eta| < 2.4$
  - Identify VBF jets ($m_jj > 400\,\text{GeV}$, $|\Delta\eta| > 3.0$)
  - $H_T > 100\,\text{GeV}$





Displaced-jet Tagging: EXO-16-003 Variables

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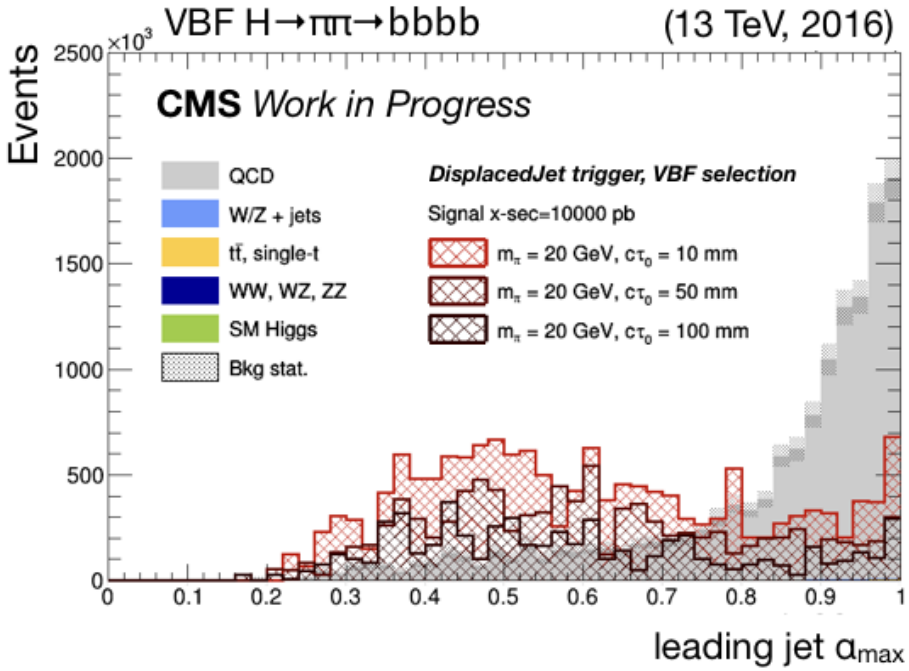
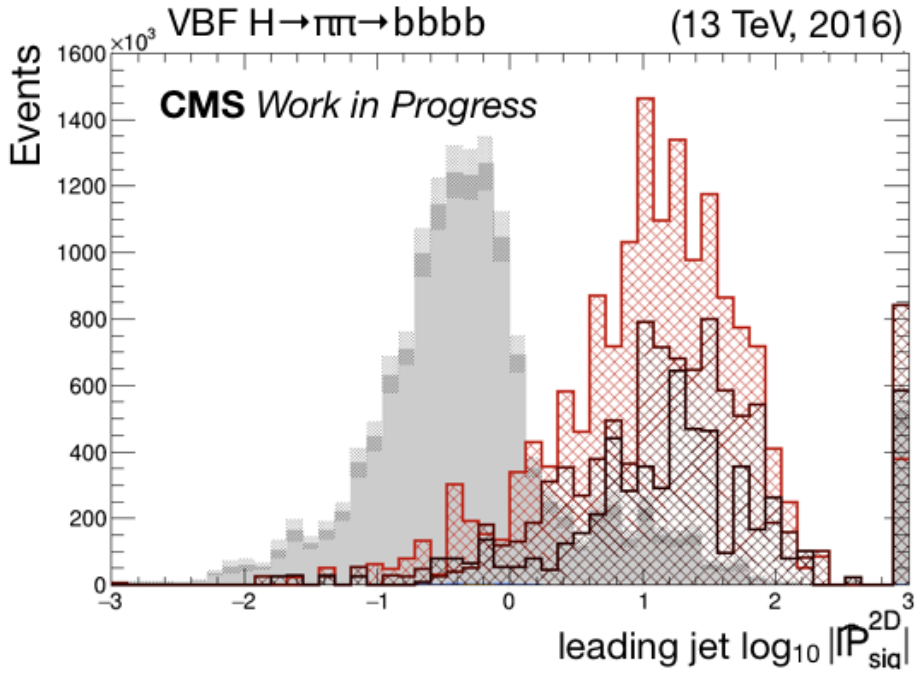
Does the jet origin from the PV?

$$\alpha(\mathrm{PV}) = \frac{\sum_{\mathrm{tracks}\in\mathrm{PV}} p_{\mathrm{T}}^{\mathrm{tracks}}}{\sum_{\mathrm{tracks}} p_{\mathrm{T}}^{\mathrm{tracks}}}$$



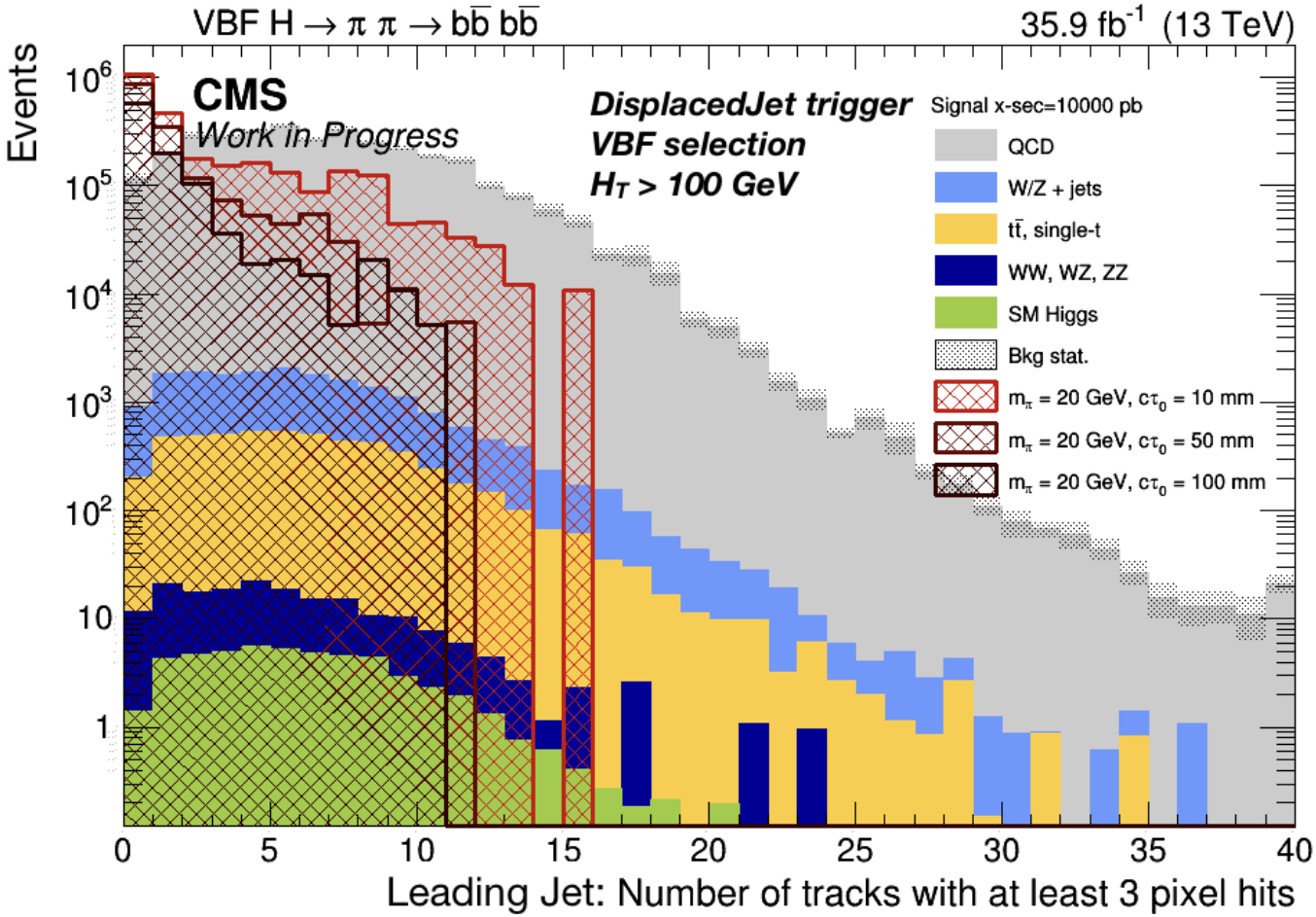
Significance of the transverse impact parameter

$$\mathrm{IP}_{\mathrm{sig}}^{\mathrm{2D}} = \frac{d_{xy}}{\sigma_{d_{xy}}}$$



Displaced-jet Tagging: Number of Pixel Hits

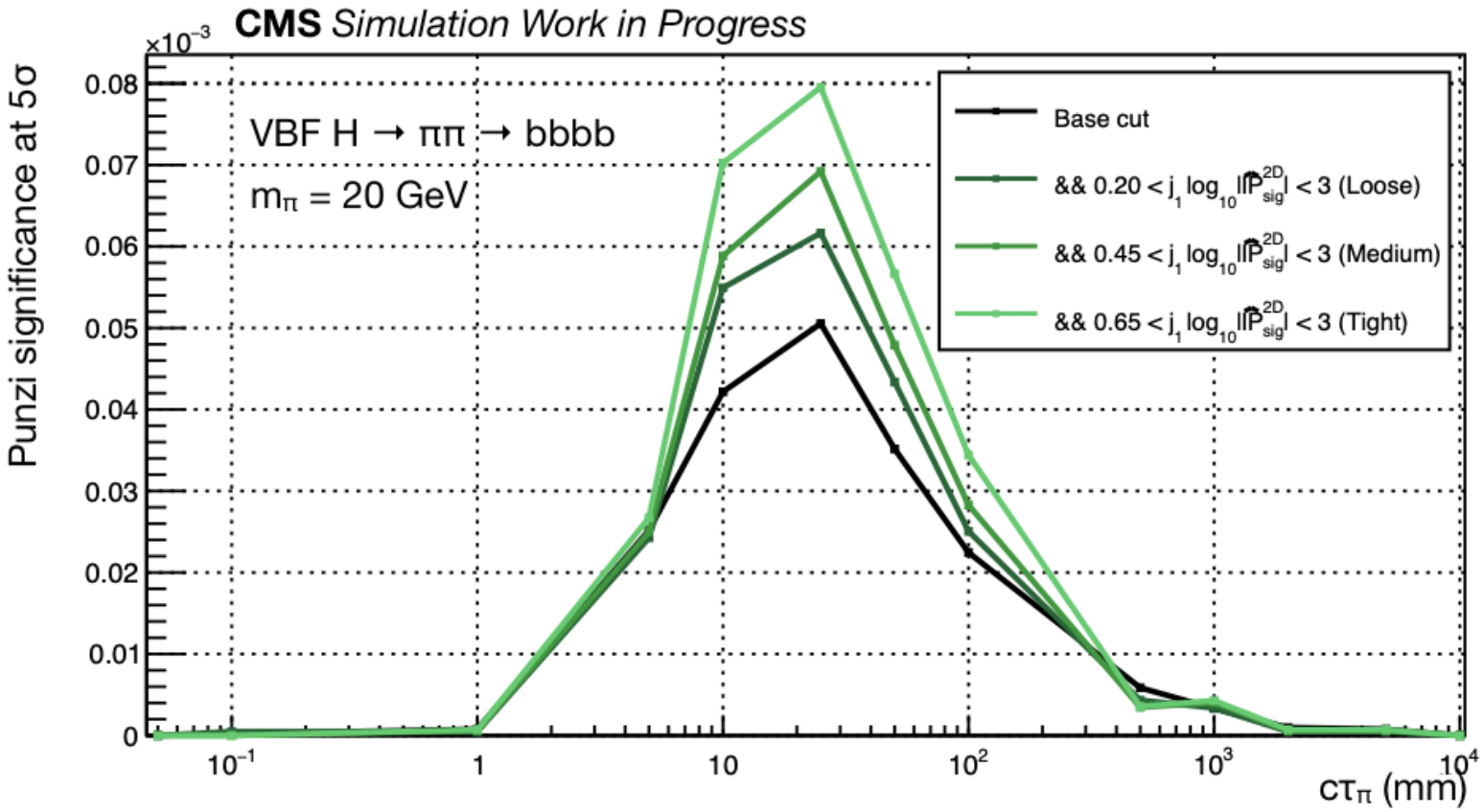
Displaced tracks expected to have no most inner hits
$\rightarrow$ Use number of tracks with $\geq$ 3 pixel hits



Displaced-jet tagging: Punzi Significance

Use Punzi significance as figure of merit:

$$\text{Punzi} = \frac{\epsilon_{\text{signal}}}{\sigma_\alpha/2 + \sqrt{B}}, \text{ with } \sigma_\alpha \text{ corresponding C.L. } \alpha$$



Displaced-jet Tagging: Limits

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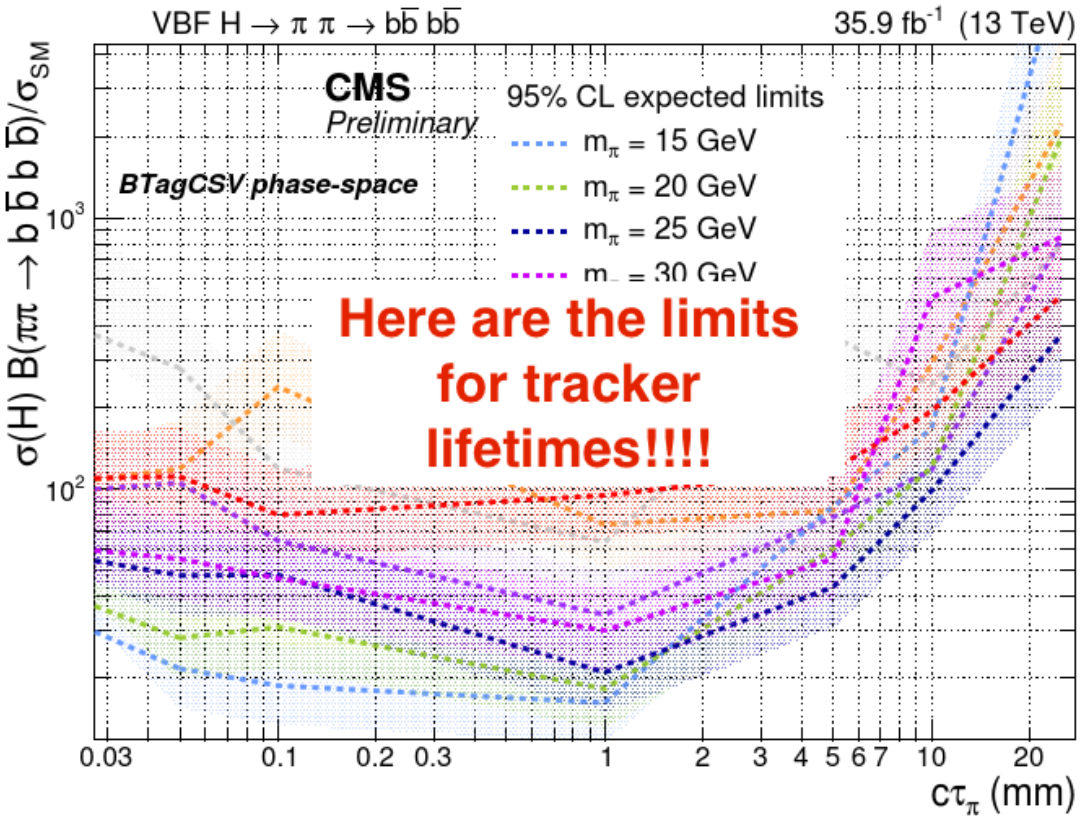
Cuts per event:

- isVBF
- dedicated trigger
- $H_T > 100\,\text{GeV}$
- $1 <$ nCHSJets

Cuts per jet:

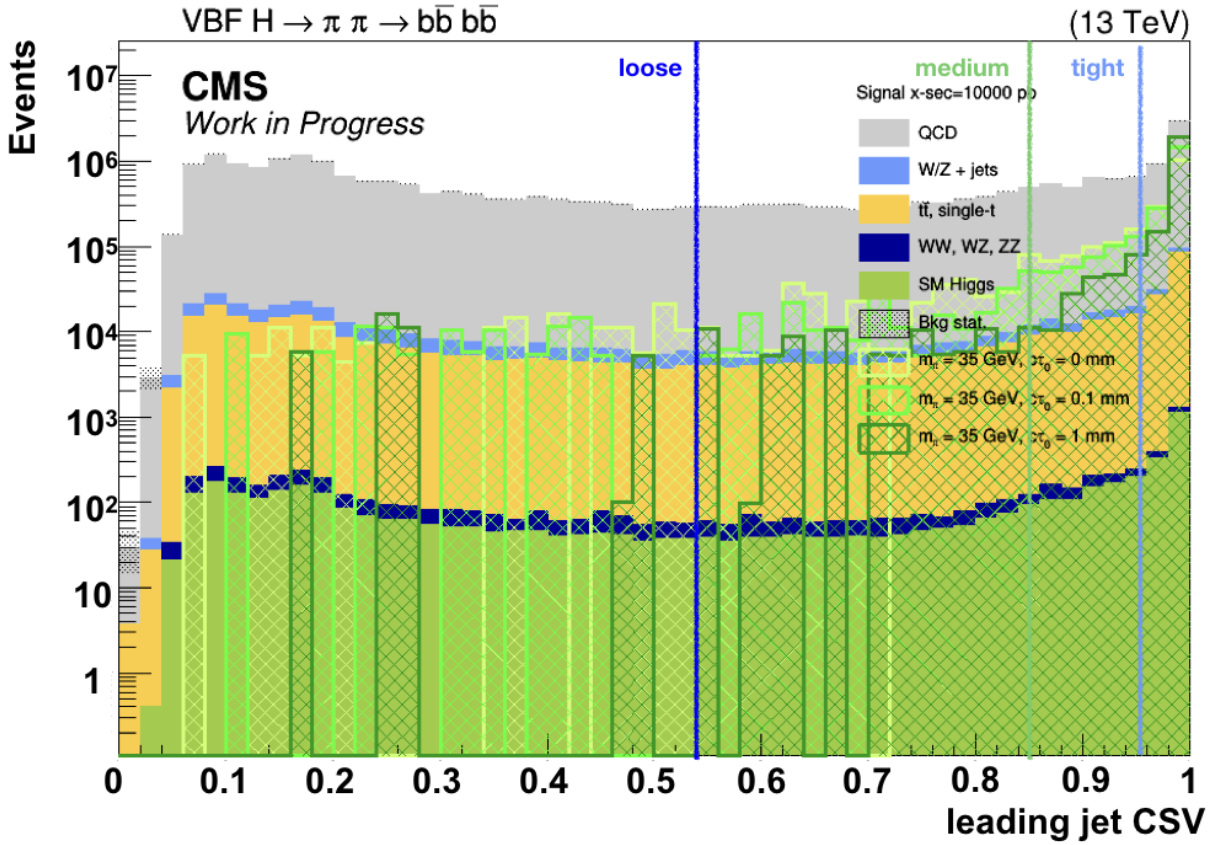
- leading jet: number of tracks with ≥ 3 pixel hits
- subleading jet: $cut < \log_{10}|\text{IP}_{\text{sig}^{2D}}| < cut$



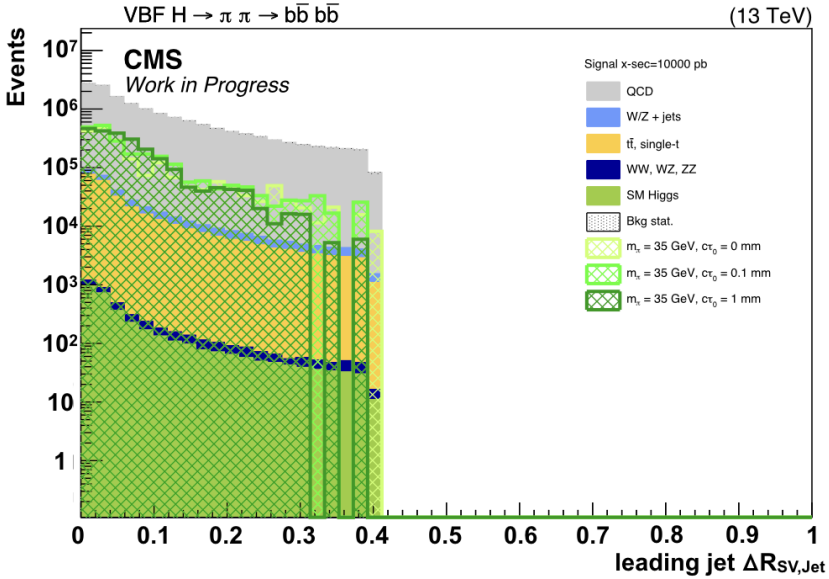
Studies for Shorter Lifetimes

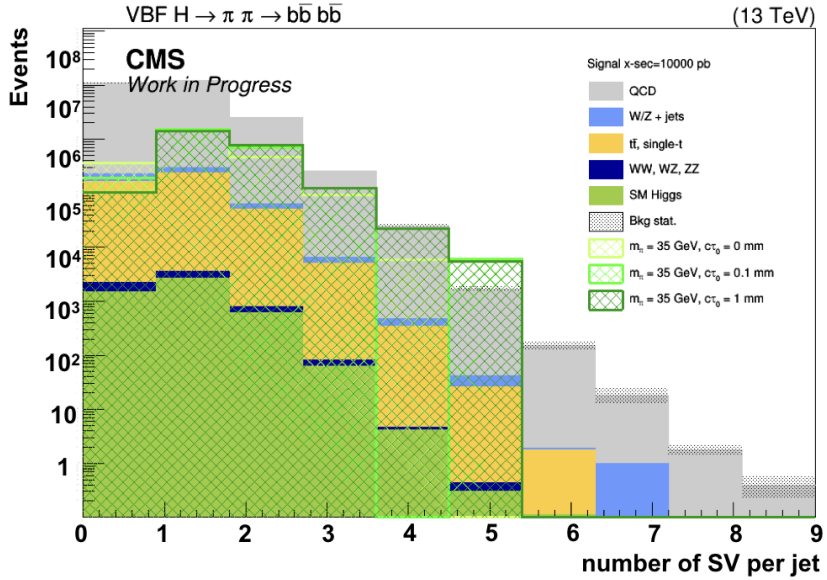
- Signal is b-like
- Harder to find good variables
- What about standard b-tagging?

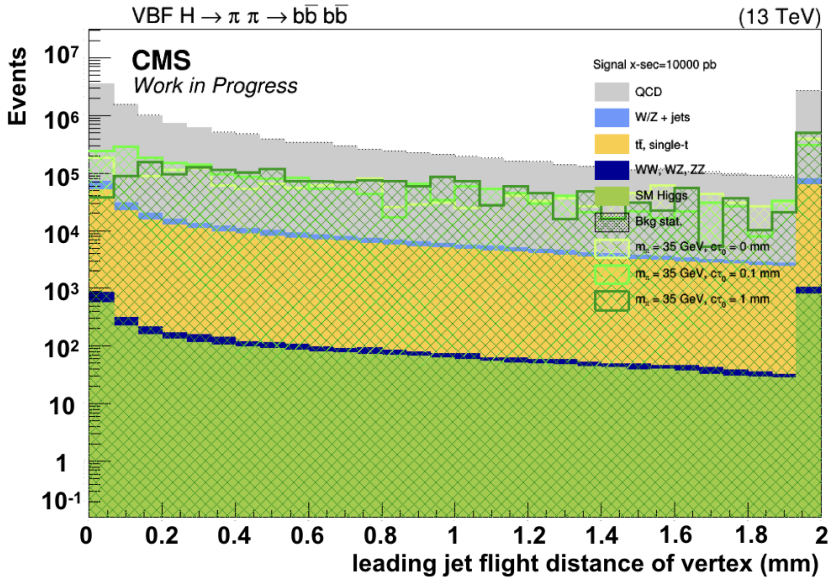
b-tagging: Combined Secondary Vertex (CSV) algorithm



b-tagging Variables







Punzi Significance

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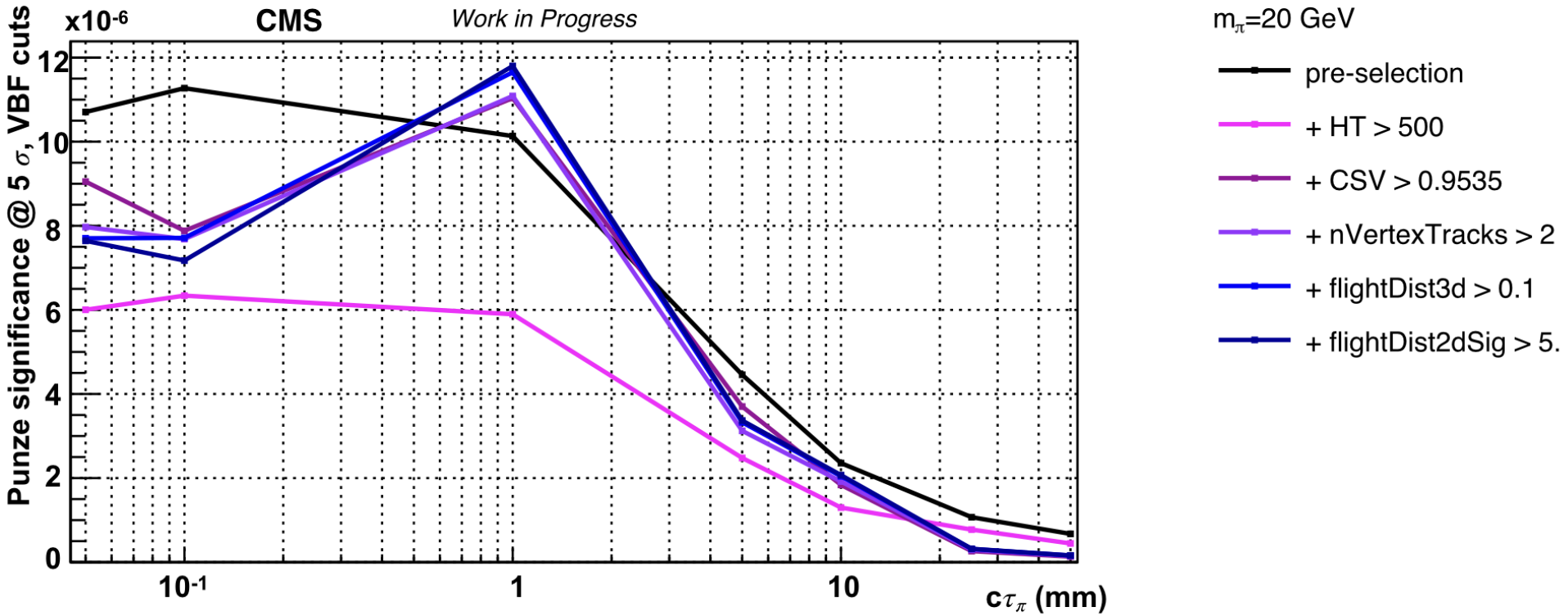


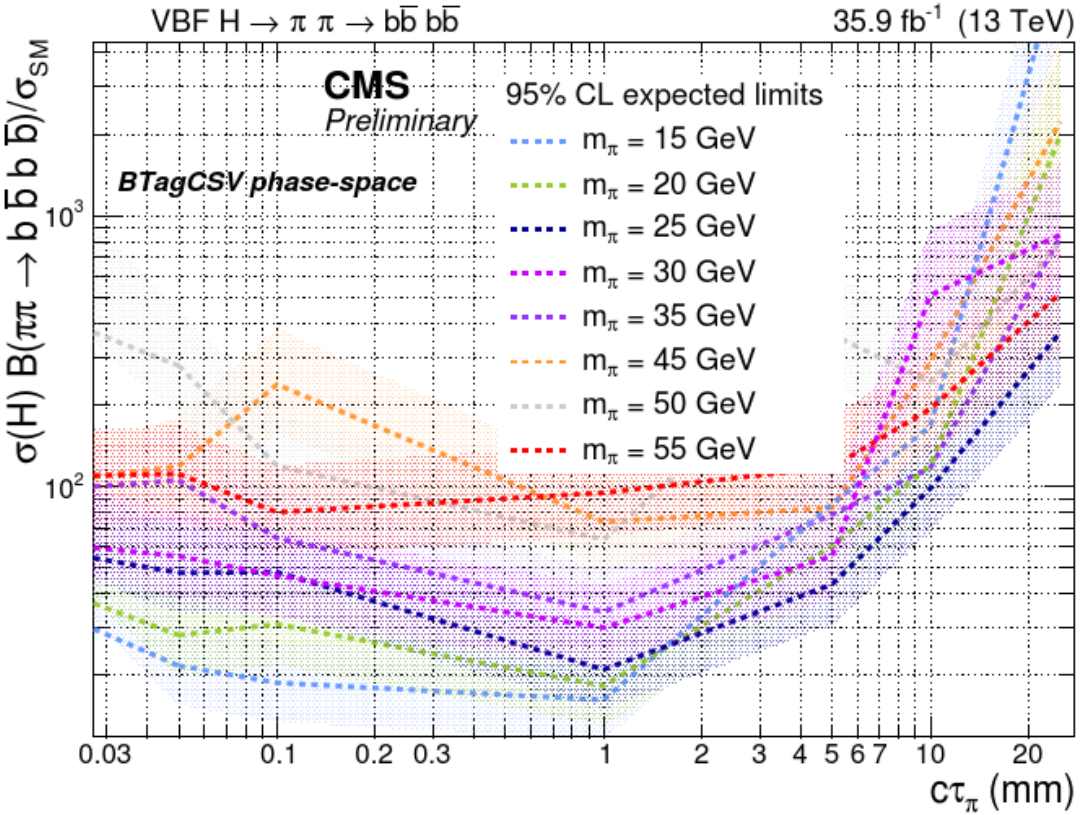
Limits

Cuts per event:

- isVBF
- dedicated trigger
- $H_T > 500\,\text{GeV}$
- $1 <$ nCHSJets < 7
- $70\,\text{GeV} < m_{jj} < 140\,\text{GeV}$

Cuts per jet:

- CSV > 0.9535
- flight distance 3D $> 0.1\,\text{mm}$
- significance flight distance 2D > 5
- tracks per vertex > 2



Perspectives and Summary

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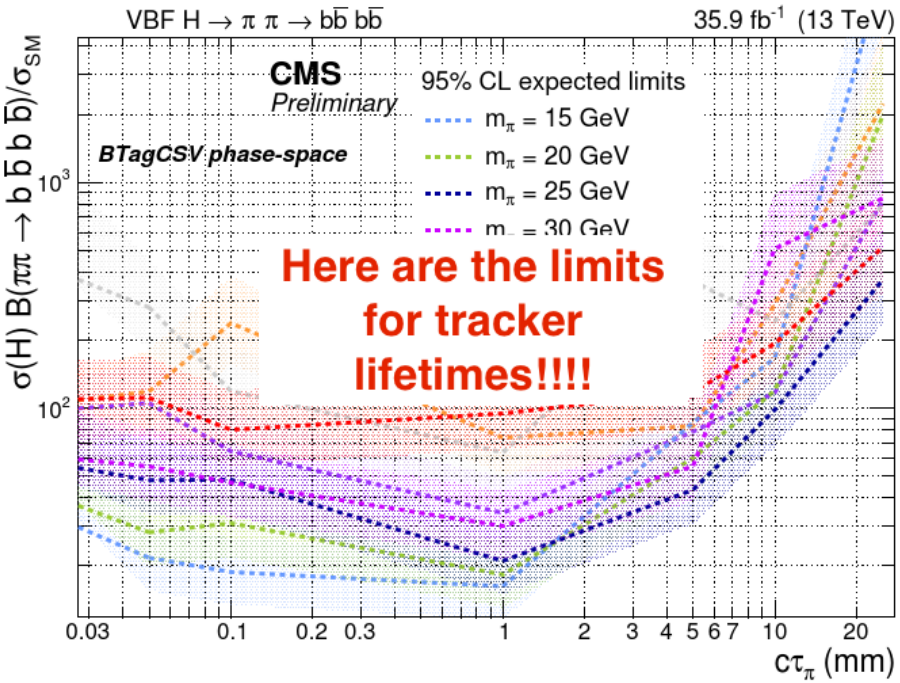
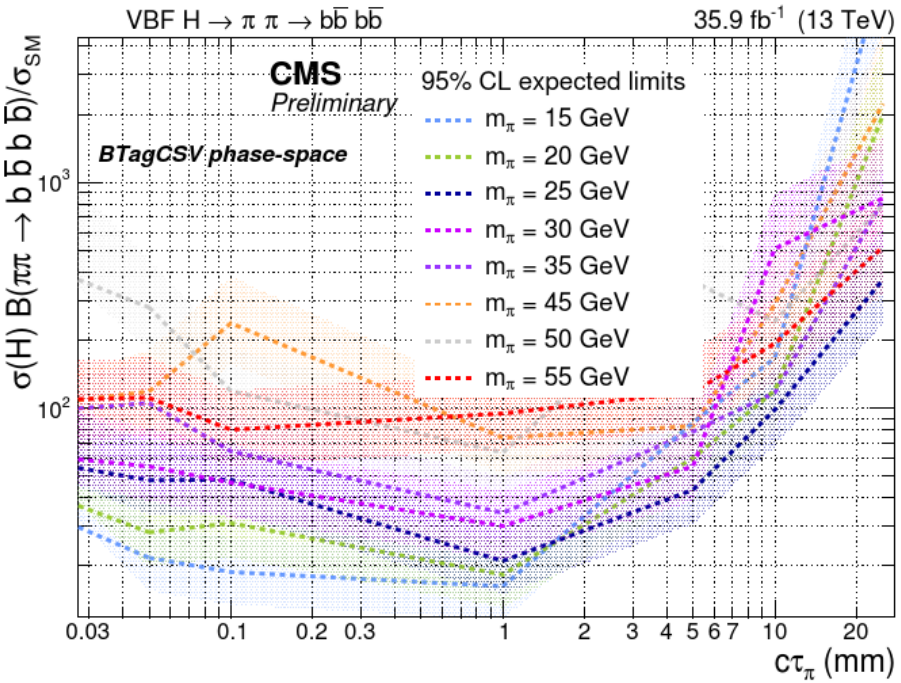
Perspectives

- Variables with discrimination power?
- Efficiency for displaced vertices going down (see talk by Karla Peña)
- Develop deep neural network tagger





Backup

Theoretical Motivation - Overview

- Standard model (SM) not complete e.g. **hierarchy problem** of the Higgs boson mass

→ Extensions to answer questions to the SM

- **Hidden sector**

→ New gauge group
  - No interaction between SM and hidden sector
  - Possible mediator: Higgs boson

  → Higgs Portal

Theoretical Motivation - Twin Higgs Model

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- **Twin Higgs model**

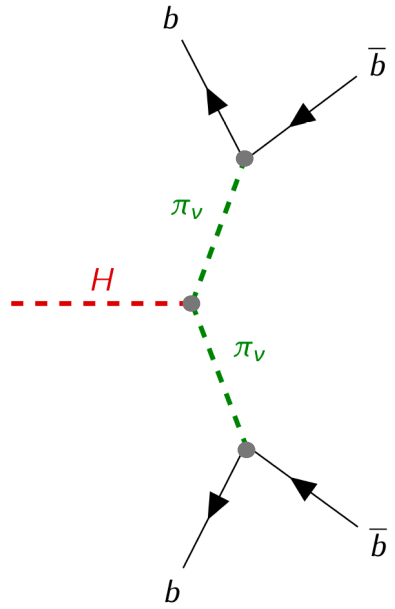
→ Mirror symmetry between SM and hidden sector

→ Mixing of SM Higgs boson with dark partner

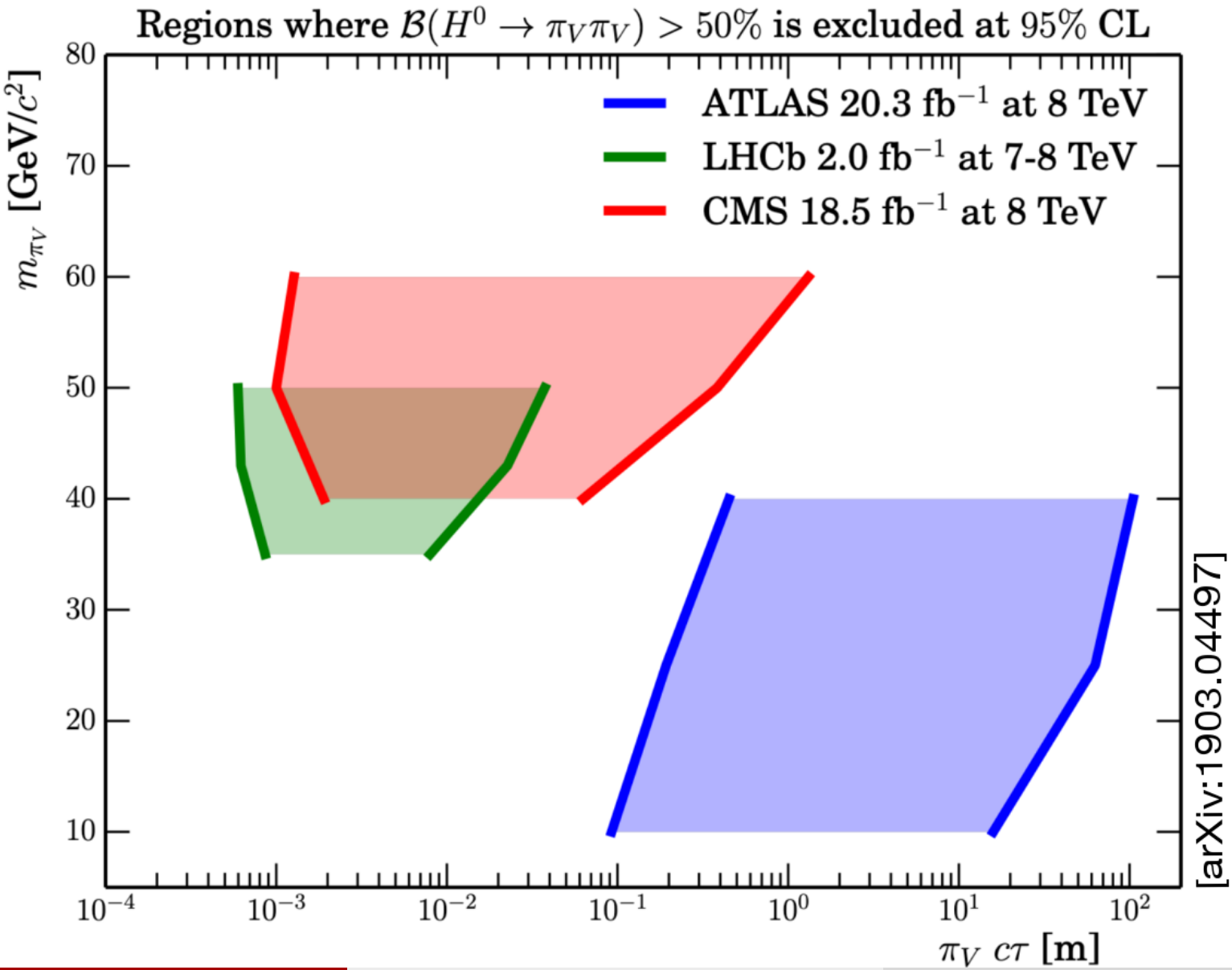
→ Prediction of electrically neutral scalars π_ν

→ Decay to pair of fermions via virtual Higgs boson

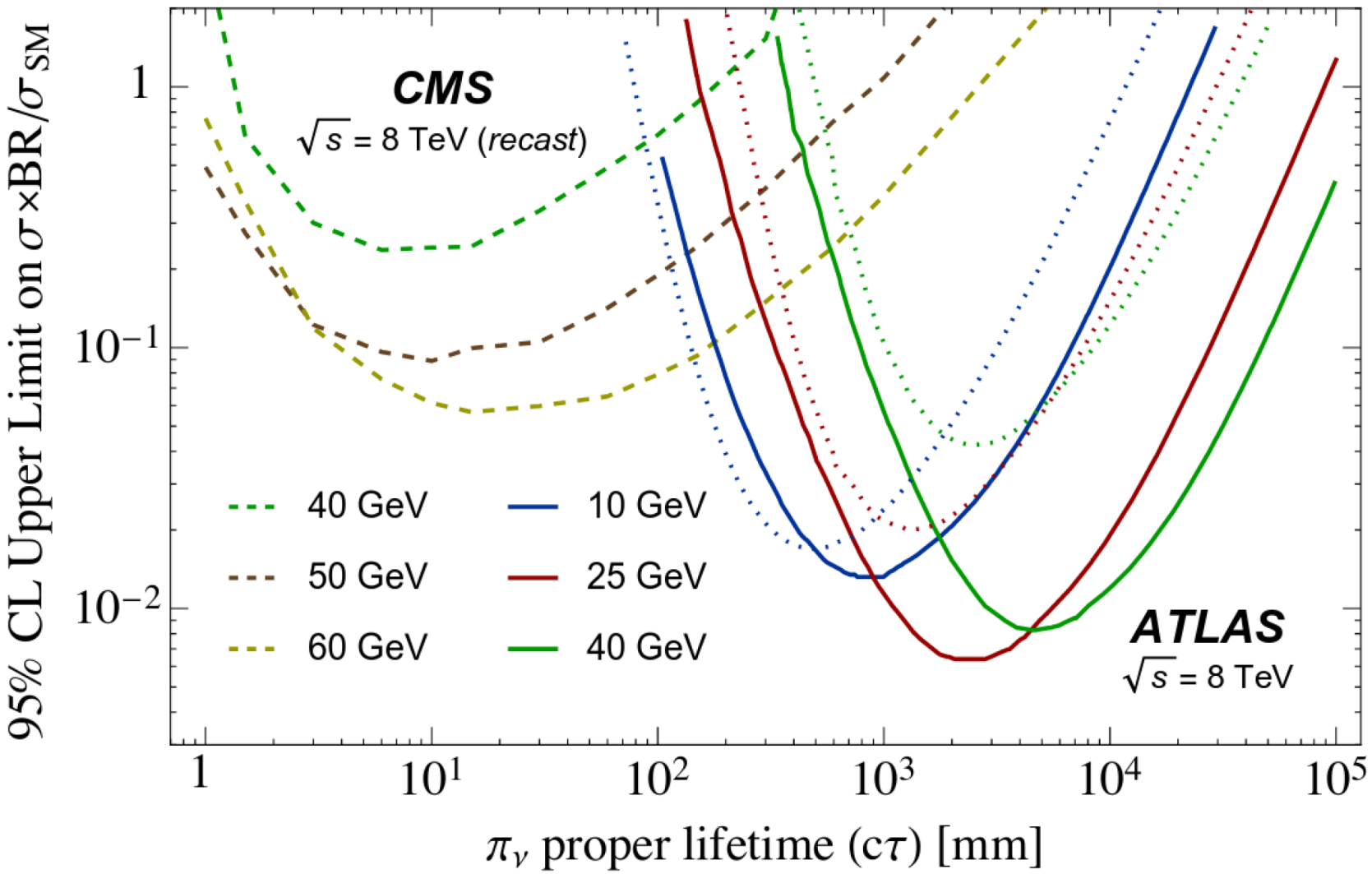
  - Dominant decay is $b\bar{b}$
  - Lifetime and mass depending on theoretical parameters



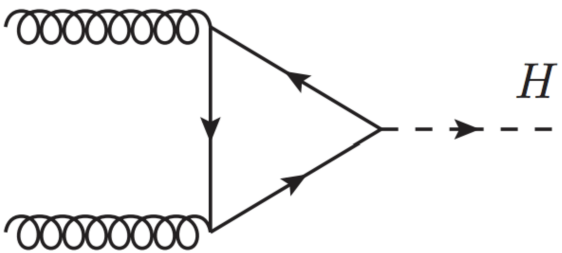
Previous Analyses



Limits 8 TeV

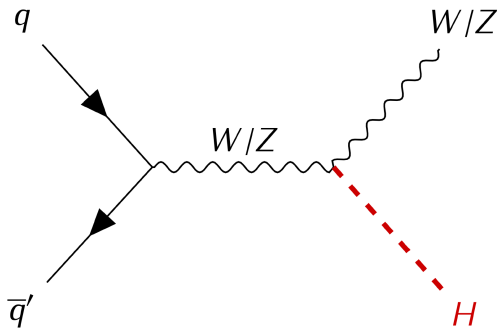

CMS
$\sqrt{s}$ = 8 TeV (recast)
40 GeV
50 GeV
60 GeV
10 GeV
25 GeV
40 GeV
ATLAS
$\sqrt{s}$ = 8 TeV
95% CL Upper Limit on $\sigma \times BR/\sigma_{SM}$
π_ν proper lifetime (cτ) [mm]
1
10^{-1}
10^{-2}
1
10^1
10^2
10^3
10^4
10^5

Production Mechanism



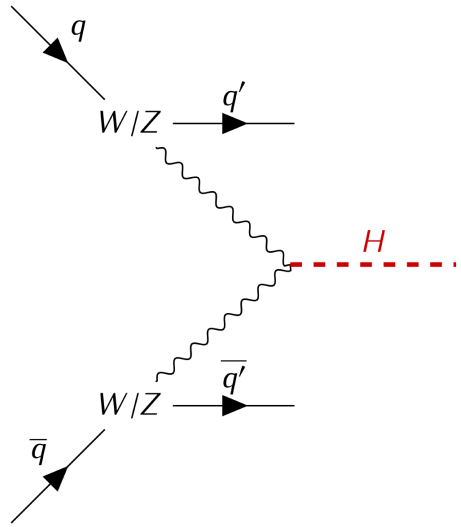
ggH production:

No additional decay,
trigger difficult



VH associated production:

W/Z decay into leptons
or jets



VBF production:

forward jets

$\rightarrow$ Possible triggers for associated production mechanisms
First studies with 2016 data and private MC samples,
$m_{\pi_\nu} = [15, 60]\,\text{GeV}$, $c\tau = [0, 10.000]\,\text{mm}$

Trigger list

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BTagCSV

HLT_DoubleJet90_Double30_TripleBTagCSV_p087_v
HLT_DoubleJetsC112_DoubleBTagCSV_p014_DoublePFJetsC112MaxDeta1p6
HLT_DoubleJetsC112_DoubleBTagCSV_p026_DoublePFJetsC172_v
HLT_QuadJet45_TripleBTagCSV_p087_v
HLT_QuadPFJet_BTagCSV_p016_p11_VBF_Mqq240_v
HLT_QuadPFJet_BTagCSV_p016_VBF_Mqq500_v

DisplacedJet

HLT_HT350_DisplacedDijet40_DisplacedTrack_v
HLT_HT350_DisplacedDijet80_DisplacedTrack_v
HLT_HT350_DisplacedDijet80_Tight_DisplacedTrack_v
HLT_HT650_DisplacedDijet80_Inclusive_v
HLT_HT750_DisplacedDijet80_Inclusive_v
HLT_VBF_DisplacedJet40_DisplacedTrack_2TrackIP2DSig5_v
HLT_VBF_DisplacedJet40_DisplacedTrack_v
HLT_VBF_DisplacedJet40_VTightID_DisplacedTrack_v

Trigger list - continuing

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DisplacedJet

HLT_VBF_DisplacedJet40_VVTightID_DisplacedTrack_v
HLT_VBF_DisplacedJet40_VVTightID_Hadronic_v

MET

HLT_CaloMHTNoPU90_PFMET90_PFMHT90_IDTight_BTagCSV_p067_v
HLT_MET200_v, HLT_MET250_v
HLT_MET75_IsoTrk50_v
HLT_MET90_IsoTrk50_v
HLT_MonoCentralPFJet80_PFMETNoMu110_PFMHTNoMu110_IDTight_v
HLT_MonoCentralPFJet80_PFMETNoMu120_PFMHTNoMu120_IDTight_v
HLT_PFMET110_PFMHT110_IDTight_v
HLT_PFMET120_PFMHT120_IDTight_v
HLT_PFMET170_HBHECleaned_v
HLT_PFMET300_v
HLT_PFMETNoMu110_PFMHTNoMu110_IDTight_v
HLT_PFMETNoMu120_PFMHTNoMu120_IDTight_v

Number of Expected Events - Cross Sections

$$N_{events} = \mathcal{L} \times \sigma_{production} \times \mathcal{B}(H \to \pi_\nu \pi_\nu b\bar{b}b\bar{b}) \times \epsilon_{trigger} \epsilon_{fiducialcut}$$

- $\sigma \times \mathcal{B}(W^+H \to l^+\nu H) = 5.893 \times 10^{-2}\,\text{pb}$
- $\sigma \times \mathcal{B}(W^-H \to l^-\nu H) = 9.426 \times 10^{-2}\,\text{pb}$
- $\sigma \times \mathcal{B}(ZH \to llH) = 2.982 \times 10^{-2}\,\text{pb}$
- $\sigma \times \mathcal{B}(VBFH) = 3.782\,\text{pb}$
- $\mathcal{L} \approx 36\,\text{fb}^{-1}$