

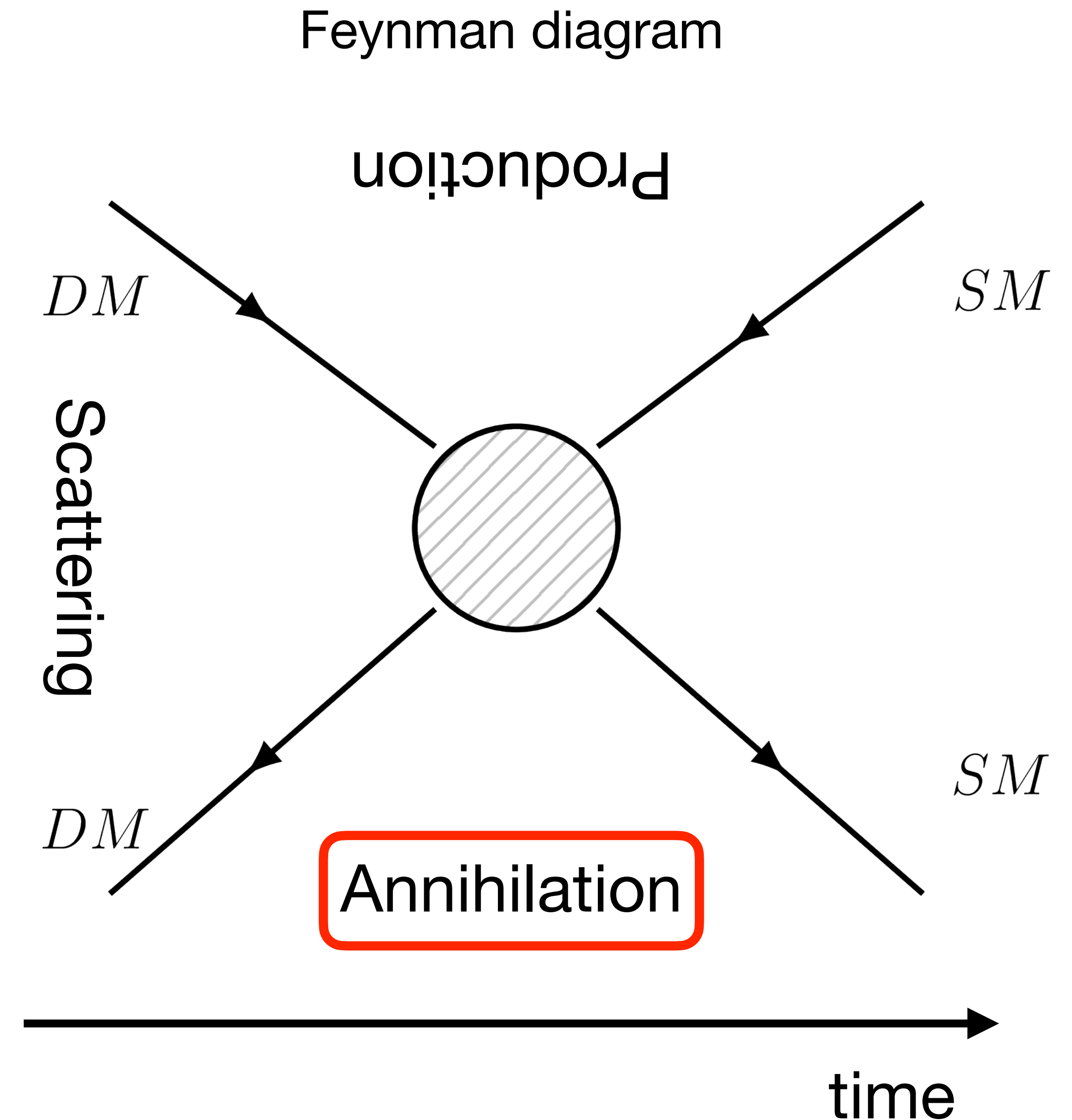
# **CMS Run-2 search for a boosted dark Higgs boson decaying into a bottom quark-antiquark pair**

Erdem Yigit Ertorer  
Carnegie Mellon University

On behalf of the CMS Collaboration

# Dark Matter Searches

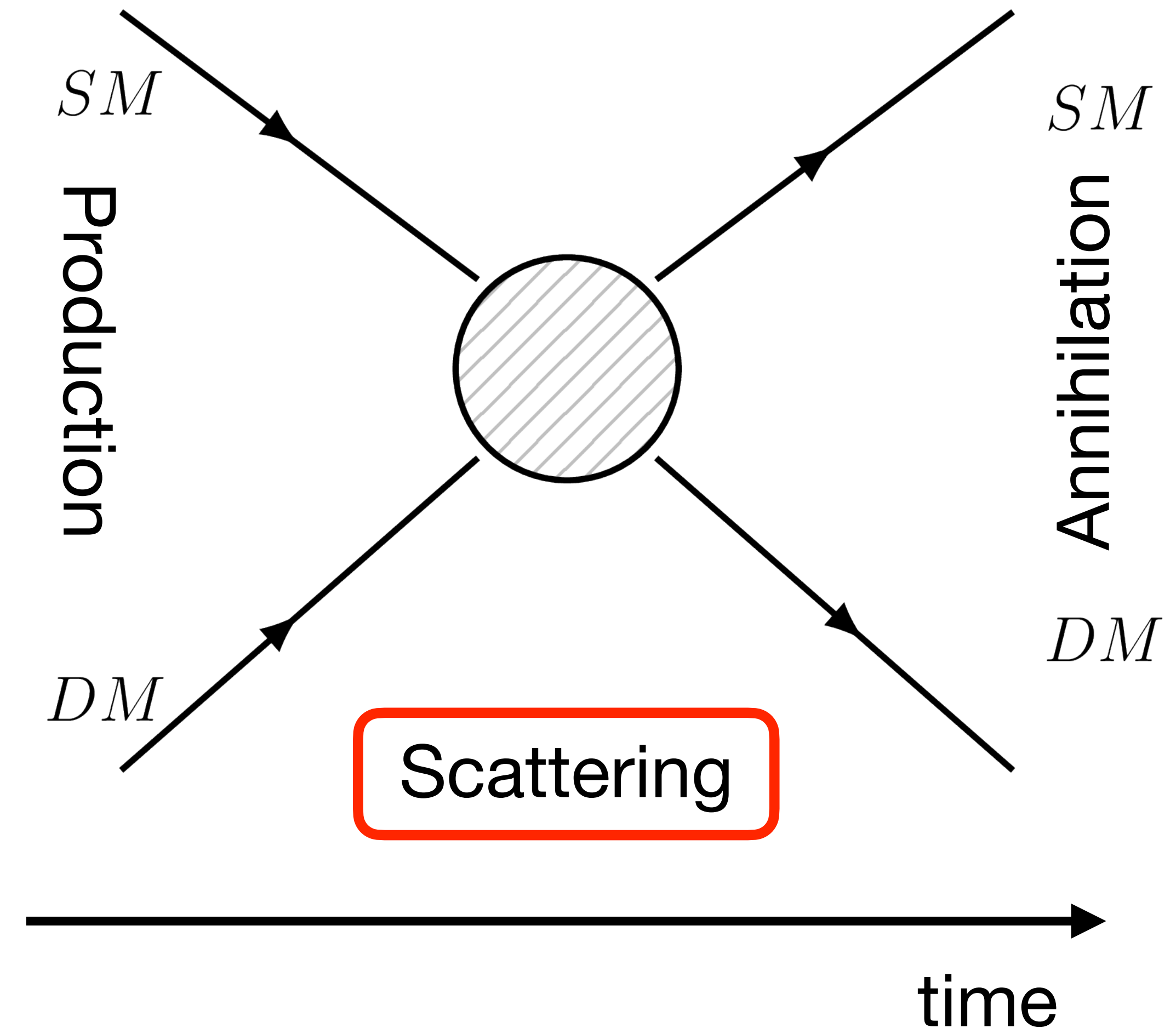
- **Indirect detection:** look for the products of the annihilation of DM particles.
- **Direct detection:** look for the recoil produced when a DM particle scatters against a target.
- **Collider approach:** DM production by colliding SM particles at high energies



# Dark Matter Searches

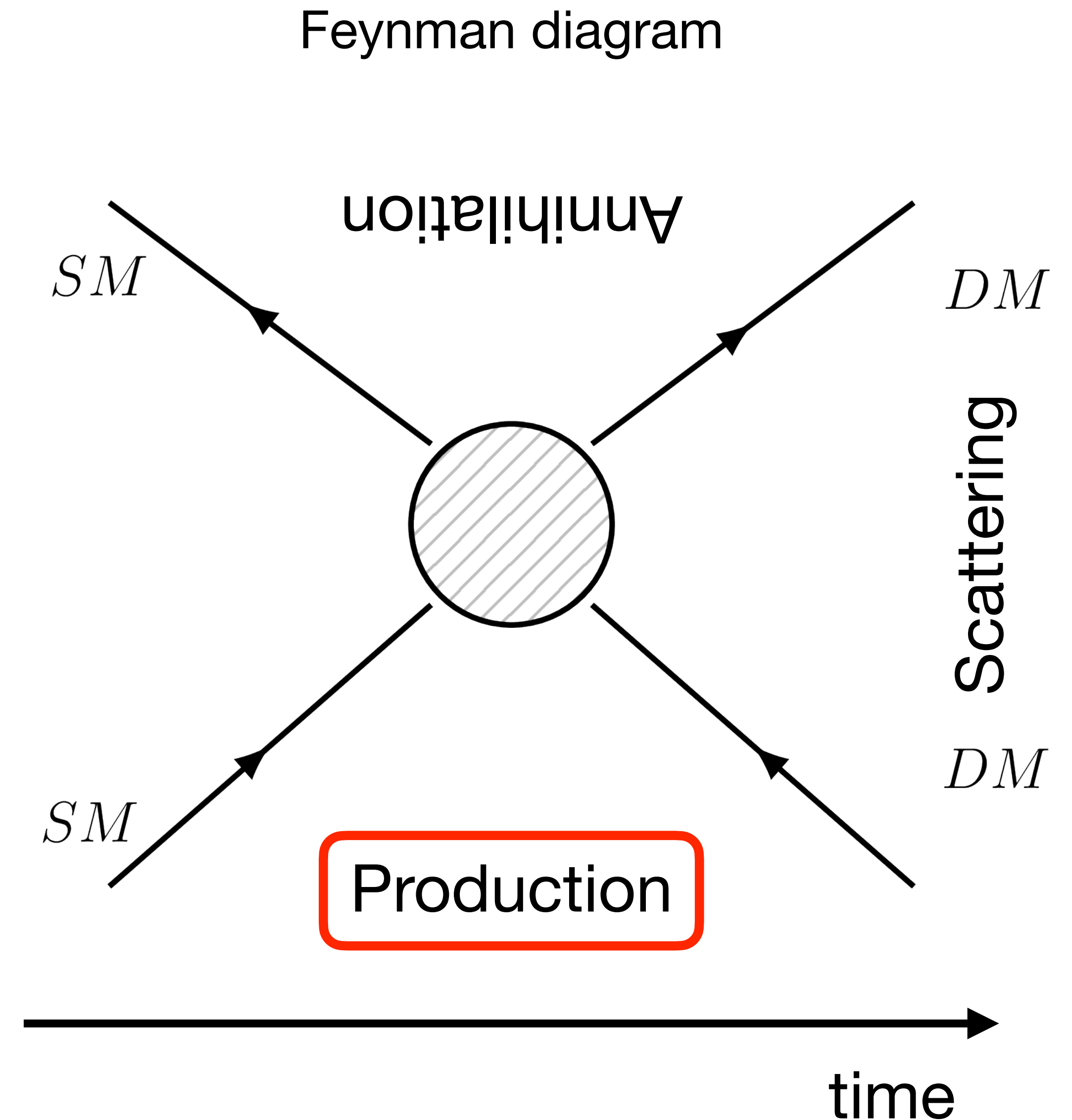
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Feynman diagram



# Dark Matter Searches

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- **Direct detection:** look for the recoil produced when a DM particle scatters against a target.
- **Collider approach:** DM production by colliding SM particles at high energies

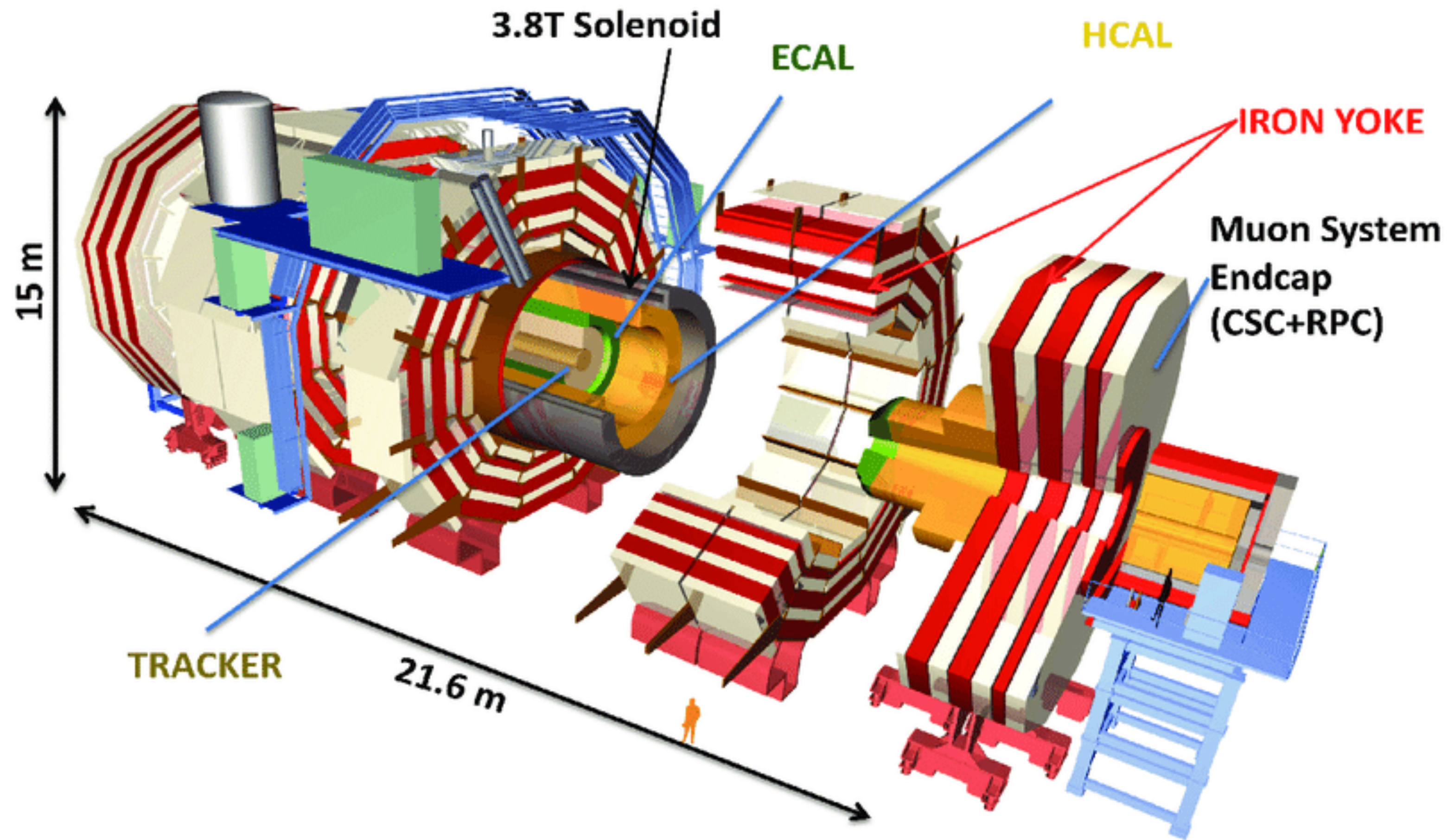


# Large Hadron Collider (LHC)



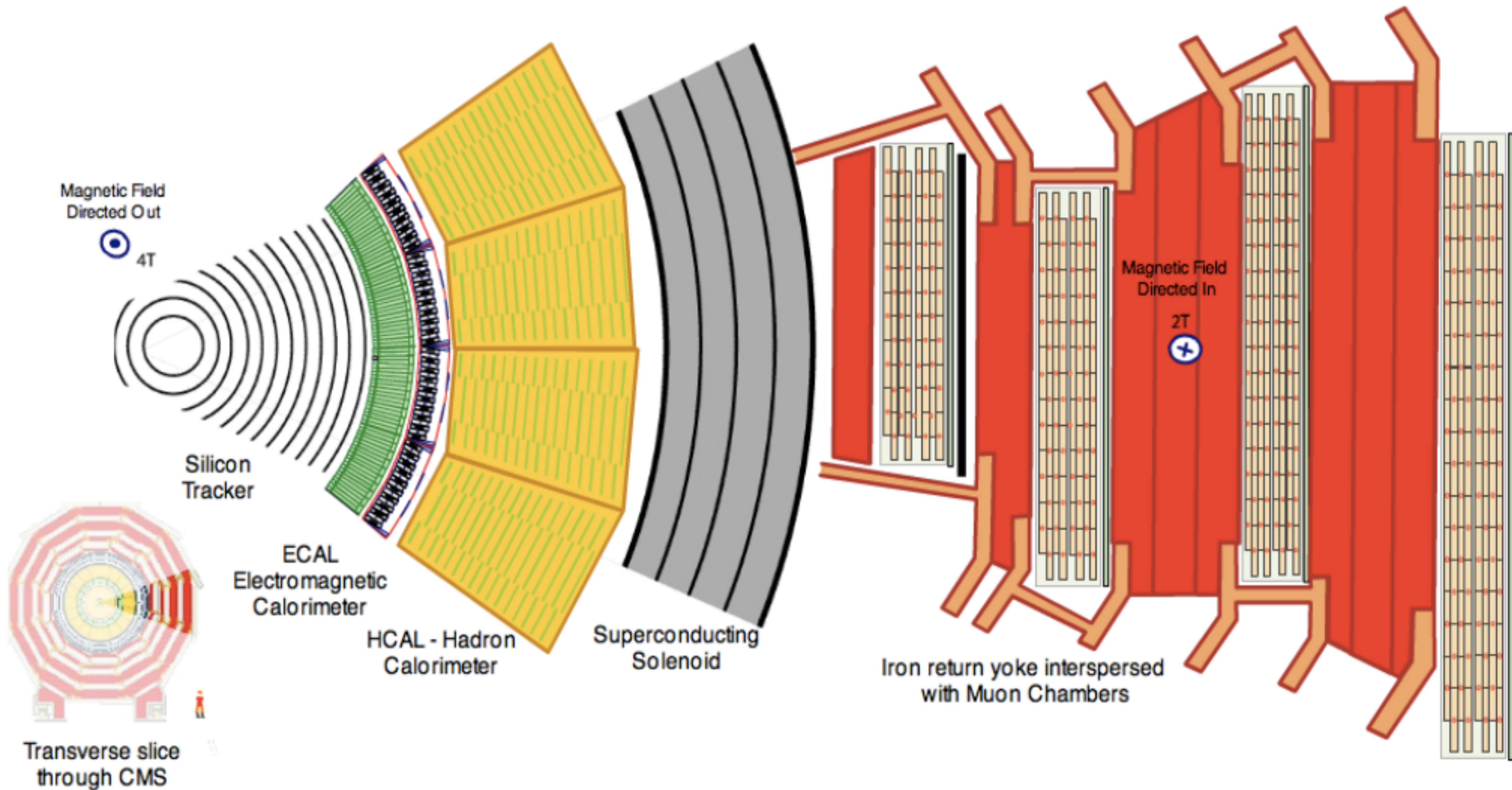
- Most powerful accelerator ever built
- Collides protons, accelerating them at  $\sim$ speed of light
- 27 km in circumference

# Compact Muon Solenoid (CMS)

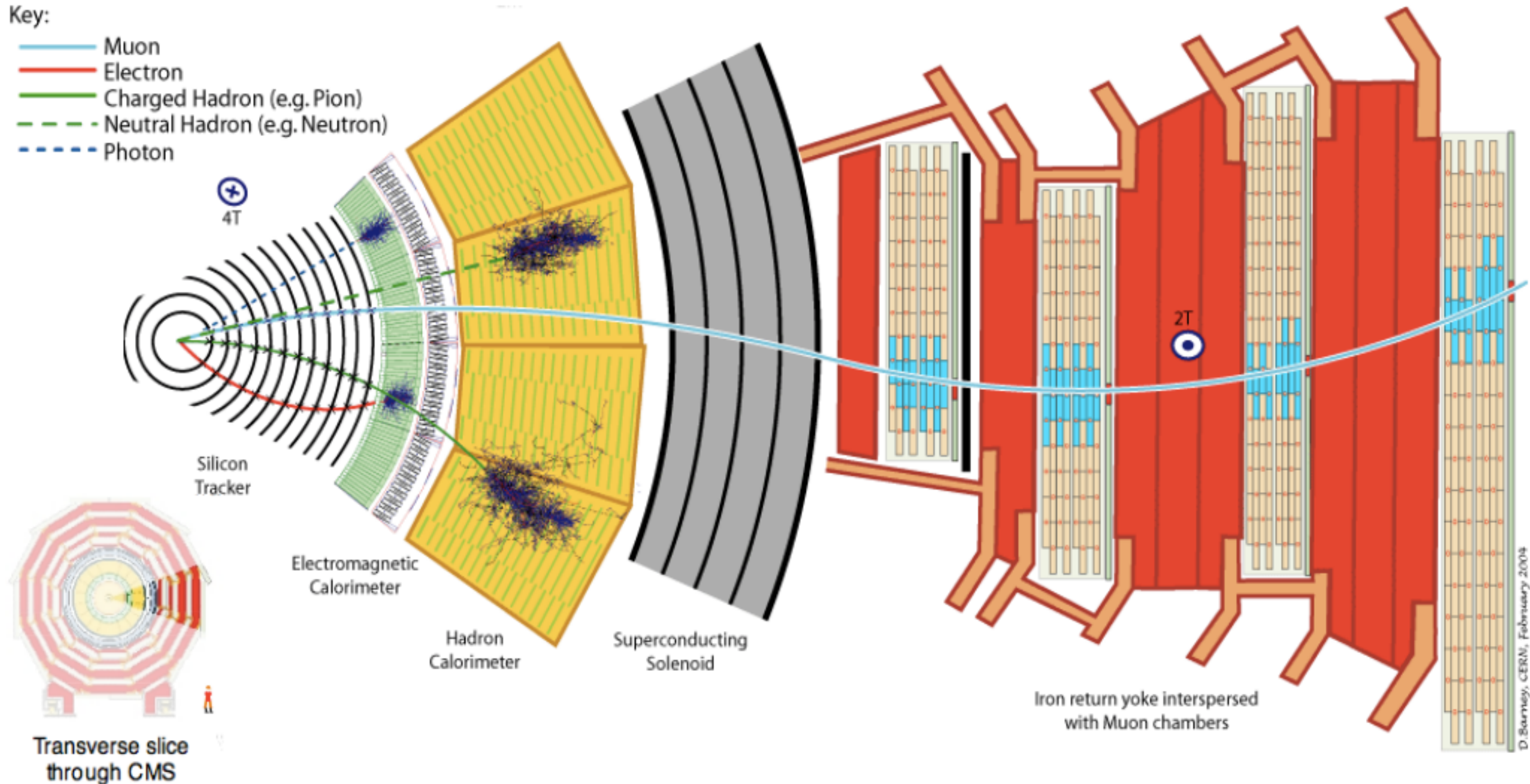


- Very large and complex detector
  - It takes a collaboration of ~3000 physicists all around the world to built it and to operate it

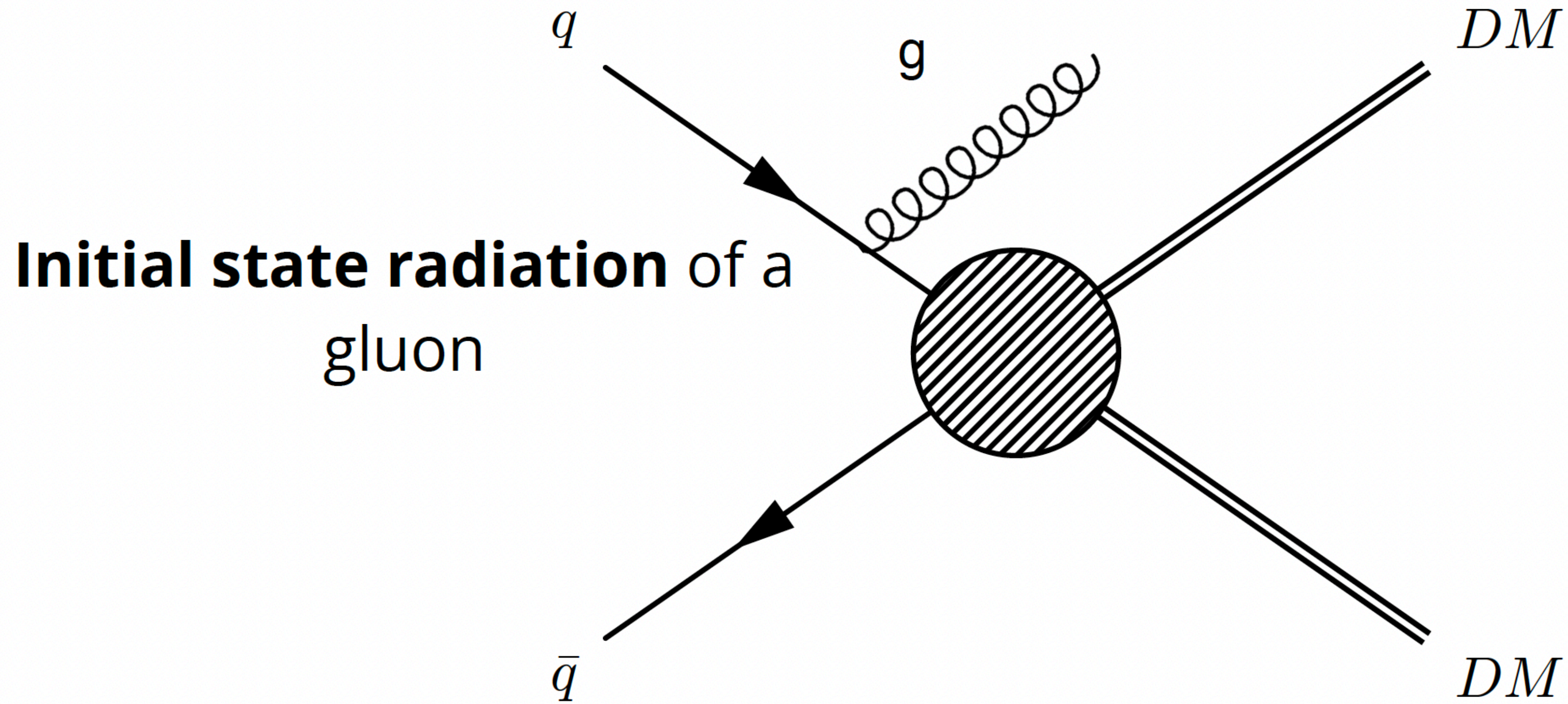
# Compact Muon Solenoid (CMS)



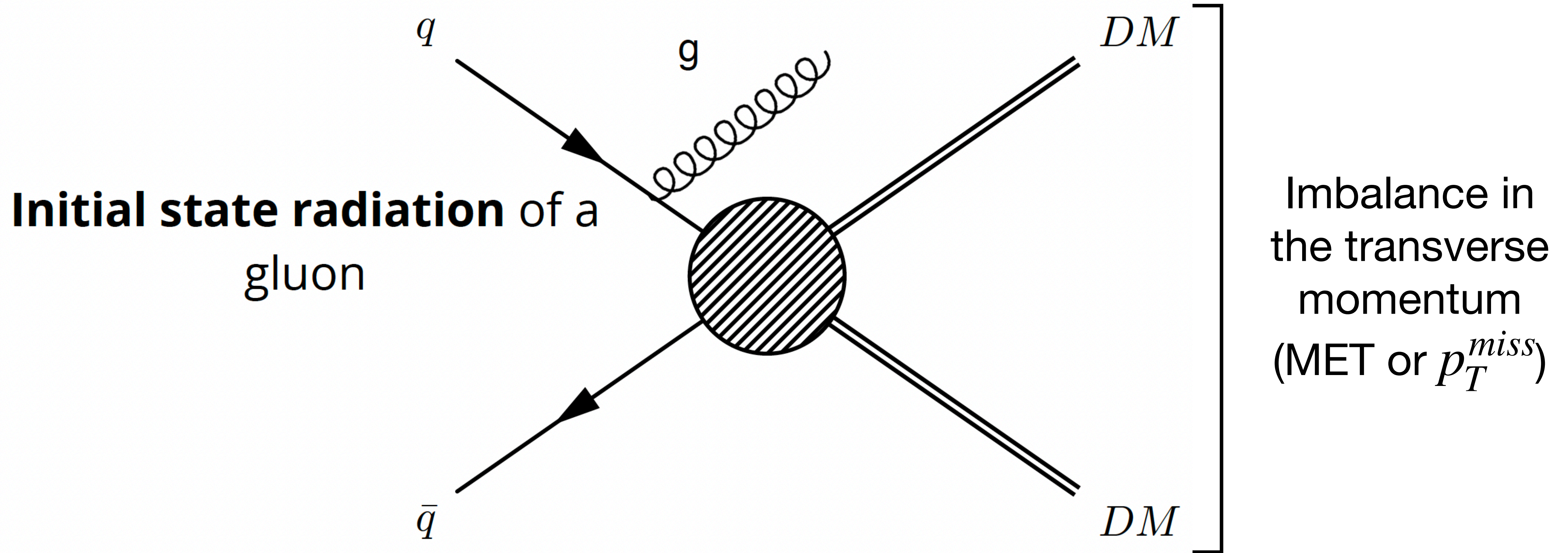
# Compact Muon Solenoid (CMS)



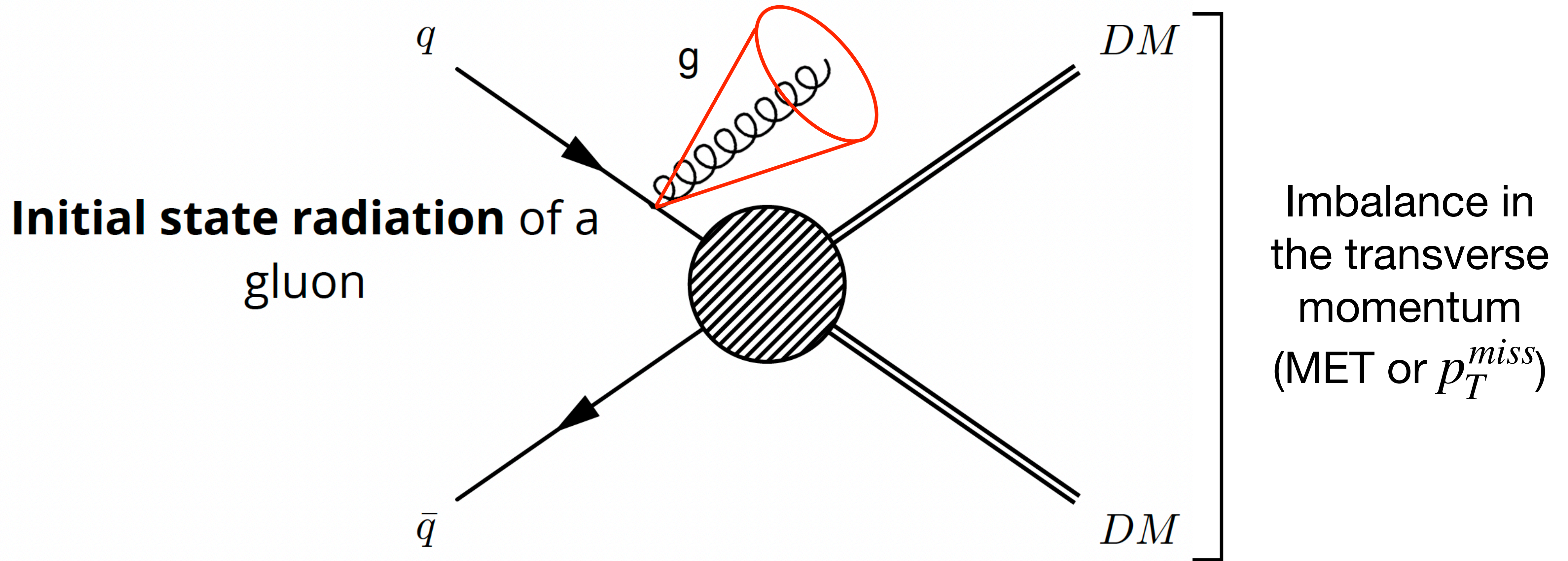
# Dark Matter Manifests as Missing Transverse Momentum



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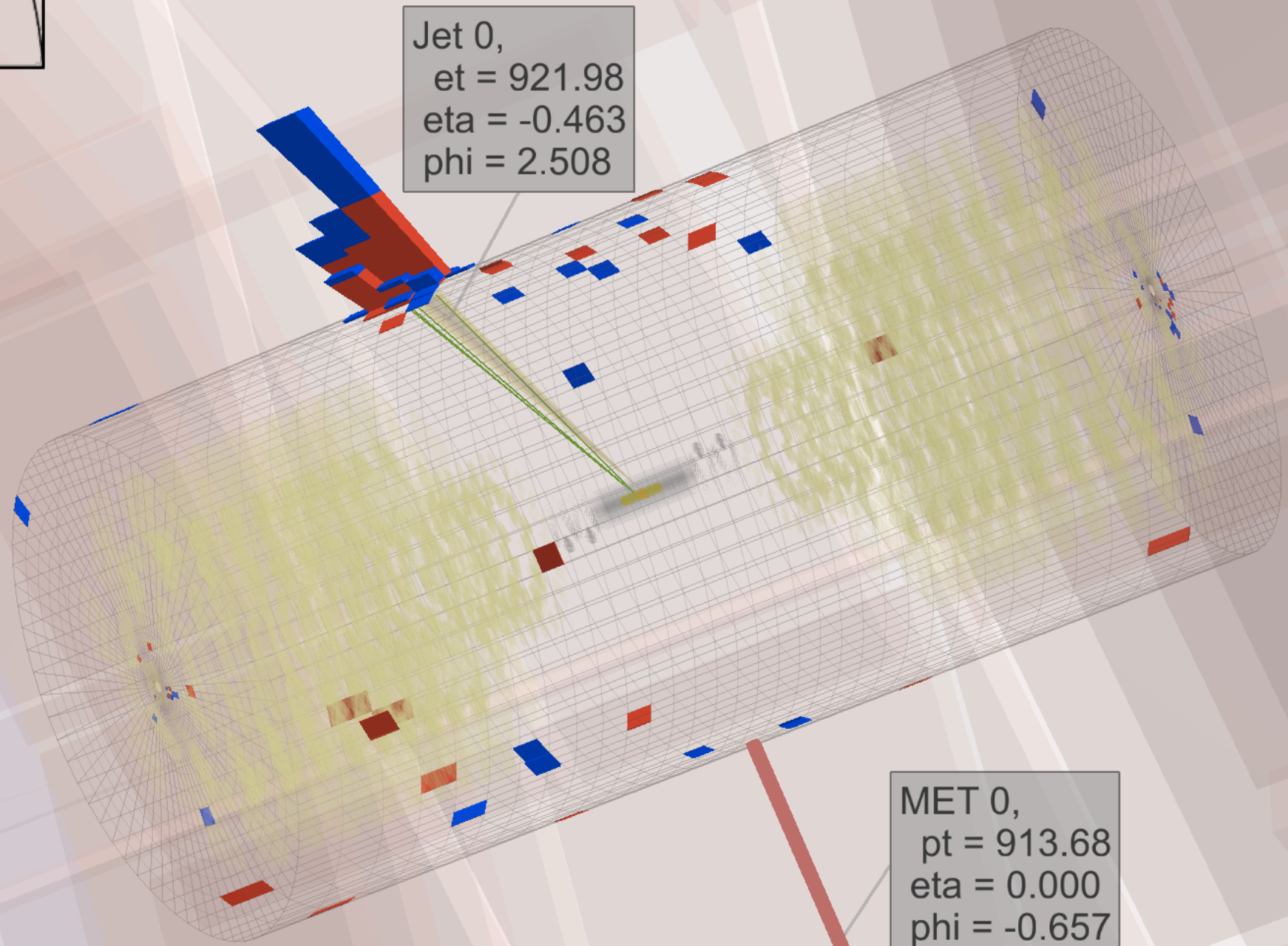
# Dark Matter Manifests as Missing Transverse Momentum



Gives rise to a **mono-jet** signature

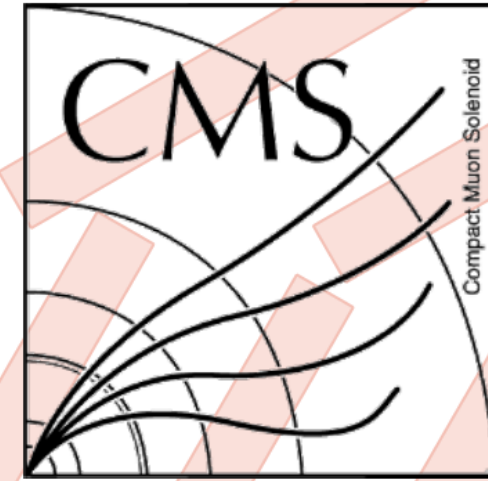


CMS Experiment at LHC, CERN  
Data recorded: Fri Oct 5 20:41:32 2012 CEST  
Run/Event: 204553 / 26729384  
Lumi section: 31

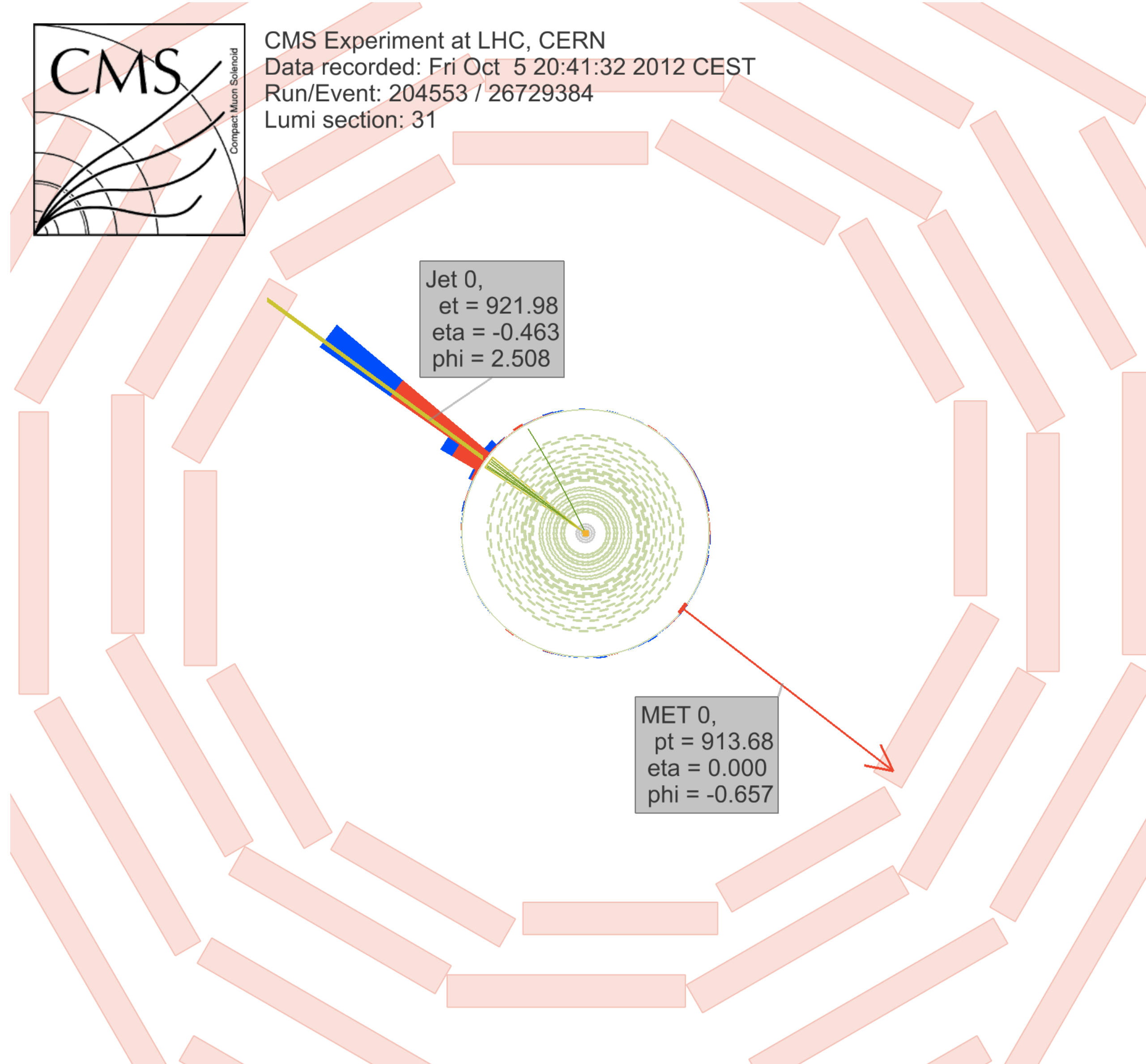


Jet 0,  
et = 921.98  
eta = -0.463  
phi = 2.508

MET 0,  
pt = 913.68  
eta = 0.000  
phi = -0.657



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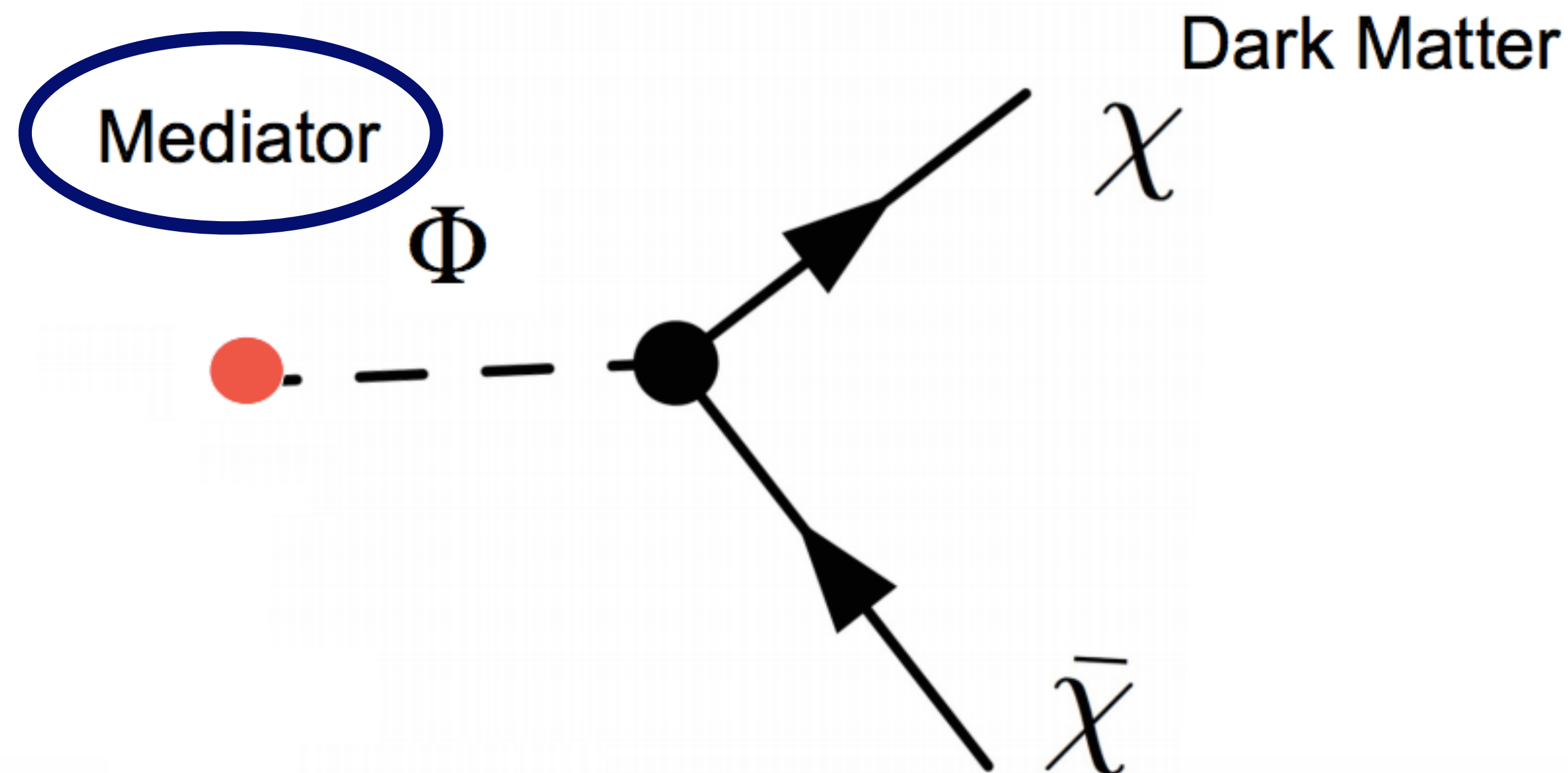


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# Why at Colliders?

- If DM interacts, it does through a mediator
- At colliders, **unique possibility to produce the mediator** and measure its properties
  - $p_T^{miss}$  represents the mediator pT
    - Every  $p_T^{miss}$ -based DM search is essentially a search for the mediator



# Our analysis

- Dark Higgs Model
- SUS-23-013
- Using full Run-2 dataset (138 fb<sup>-1</sup>)
- Public on arXiv, submitted to EPJC

*[Submitted on 22 Apr 2026]*

**Search for dark matter produced in association with a dark Higgs boson decaying into a bottom quark–antiquark pair in proton–proton collisions at  $\sqrt{s} = 13$  TeV**

CMS Collaboration

A search for dark matter produced in association with a dark Higgs boson decaying into a bottom quark–antiquark pair has been performed using proton–proton collision data at a center–of–mass energy of 13 TeV. The search uses data collected with the CMS detector at the CERN LHC during the 2016–2018 data–taking period, corresponding to an integrated luminosity of 138 fb<sup>-1</sup>. The results are interpreted in terms of a theoretical model of dark matter production that, together with a spin–1 gauge boson mediator, predicts the existence of a Higgs–boson–like particle in the dark sector (i.e., a dark Higgs boson). This search focuses on an experimental signature with large missing transverse momentum from dark matter production and a resonant structure in the invariant mass of the bottom quark–antiquark pair from the dark Higgs boson decay. Upper limits at 95% confidence level on the signal strength for dark Higgs boson mass hypotheses below 160 GeV are set. Values of the mediator mass up to 4.5 (2.5) TeV are excluded at 95% confidence level for a dark Higgs boson mass of 50 (150) GeV. This represents the most stringent limits set to date for the dark Higgs boson masses considered in this study.

Comments: Submitted to the European Physical Journal C. All figures and tables can be found at [this http URL](#) (CMS Public Pages)

Subjects: **High Energy Physics – Experiment (hep-ex)**

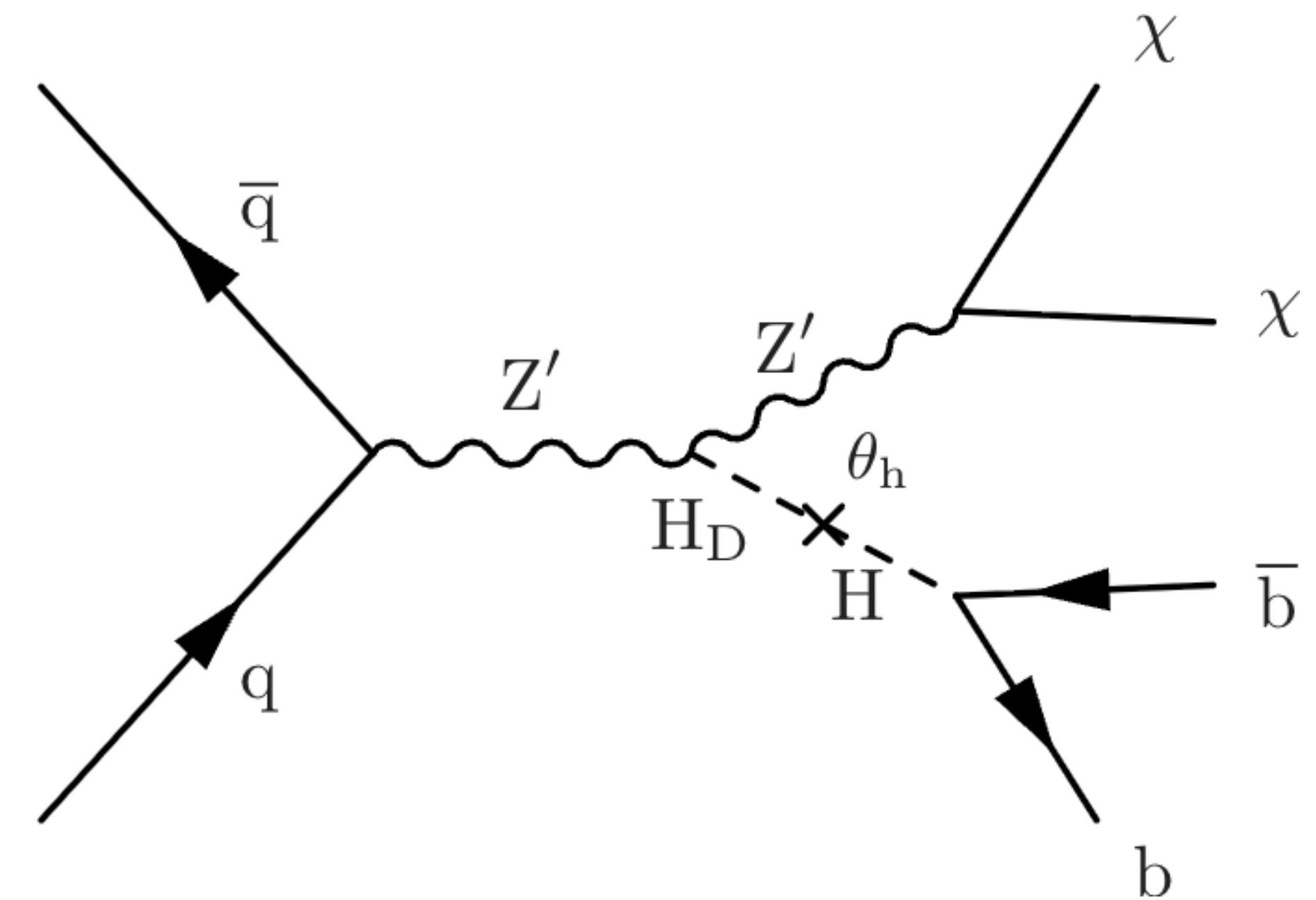
Report number: CMS-SUS-23-013, CERN-EP-2026-087

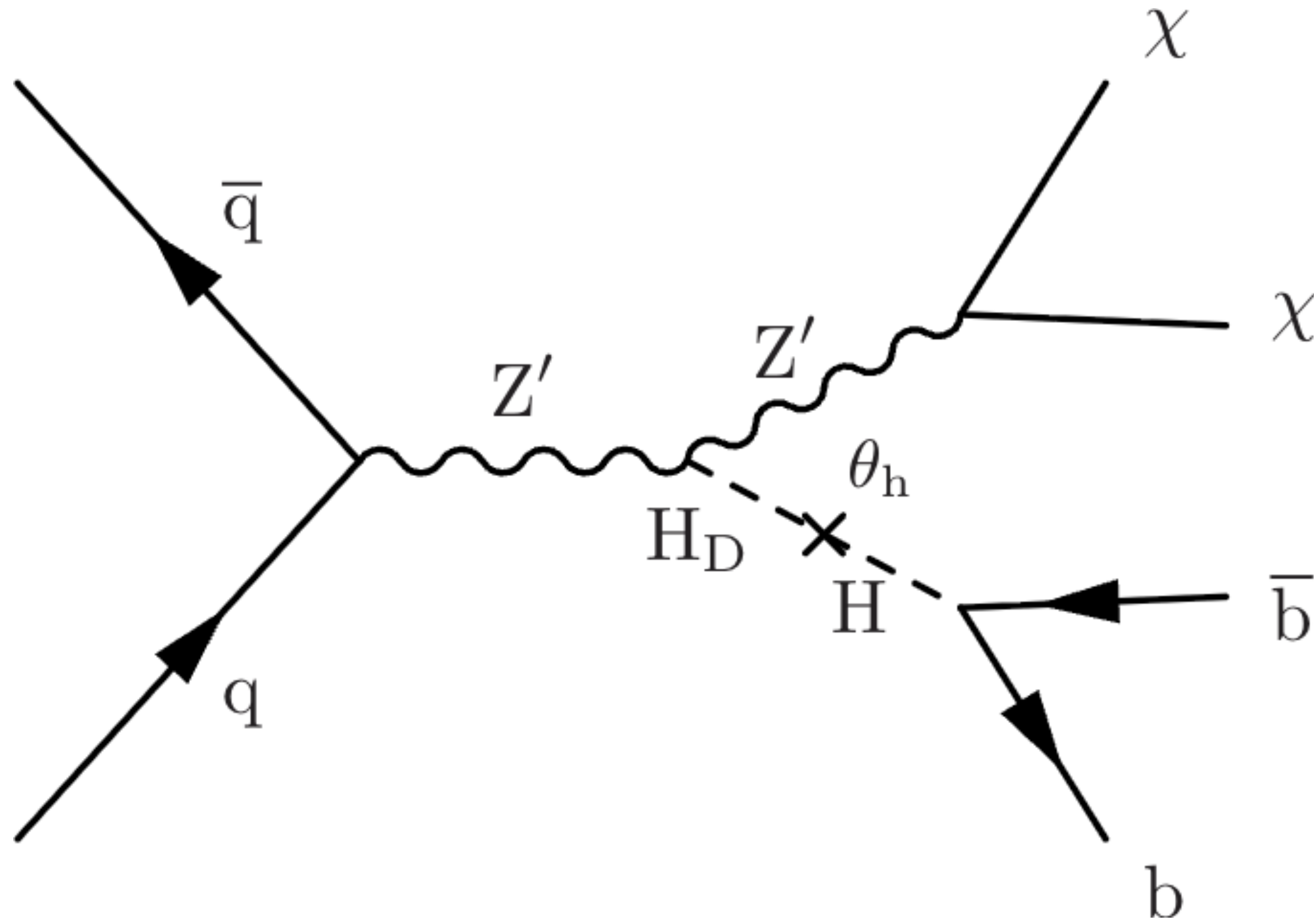
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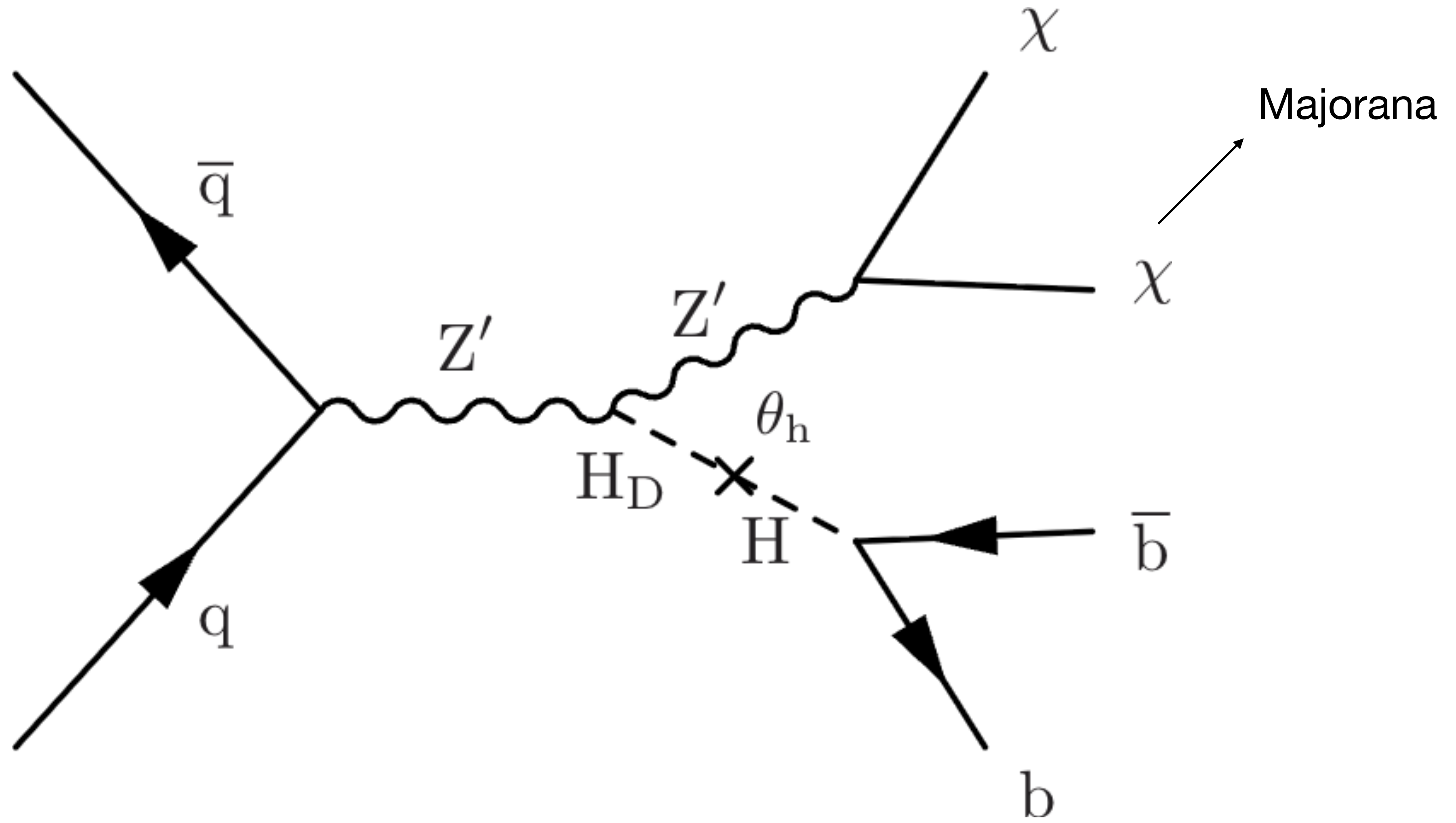
(or [arXiv:2604.20999v1](#) [hep-ex] for this version)

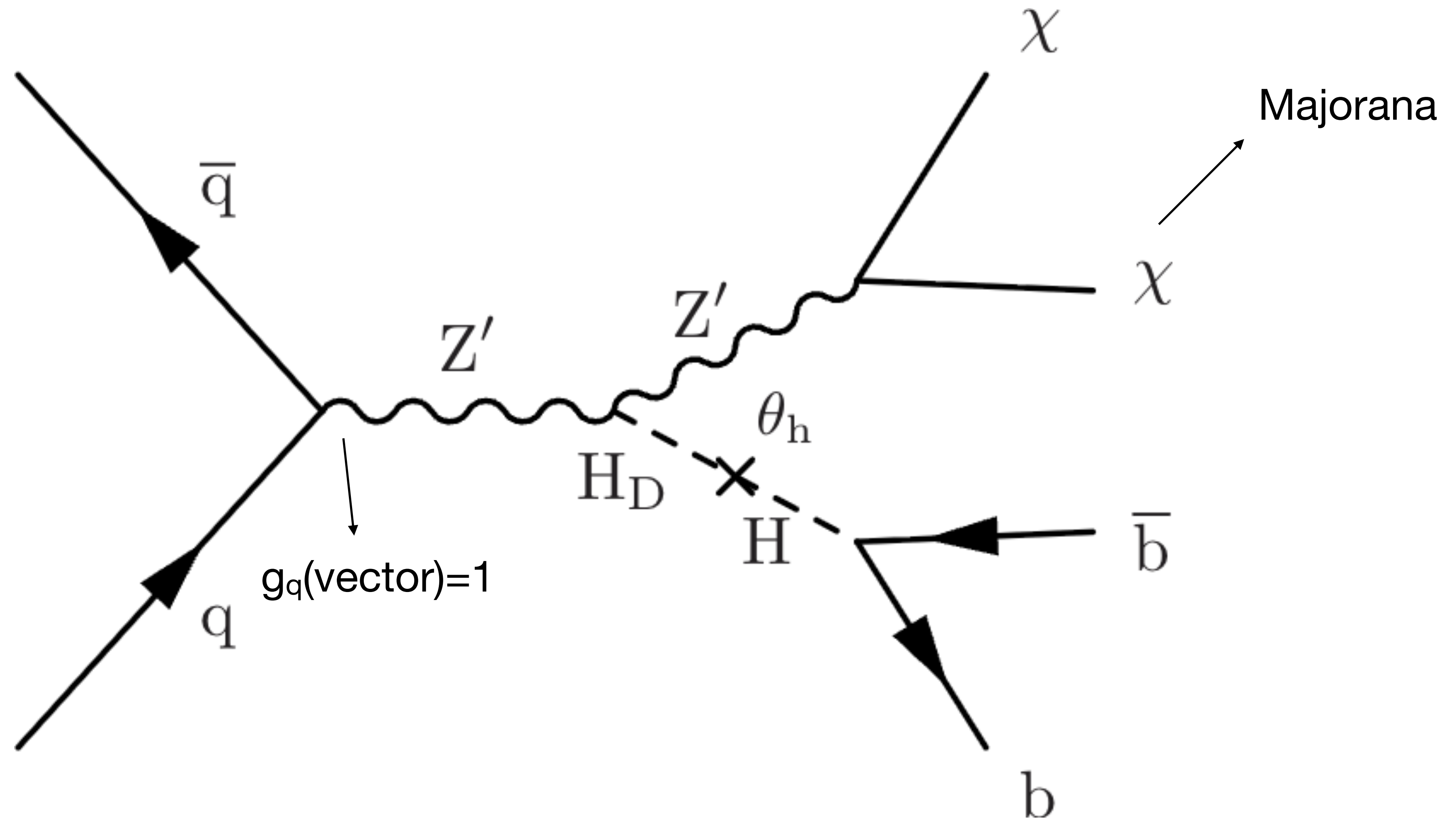
<https://doi.org/10.48550/arXiv.2604.20999> 

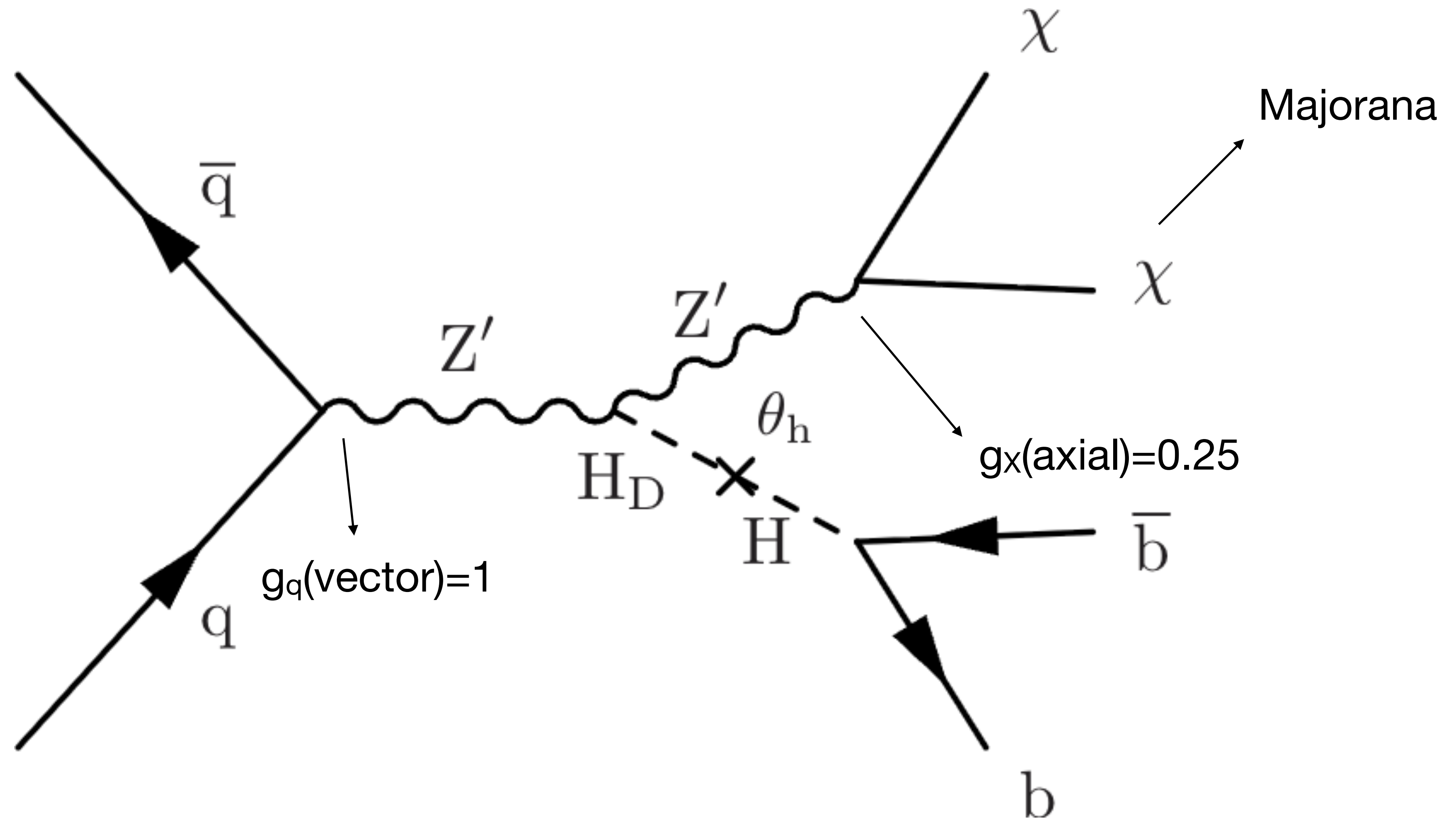
- Dark Higgs ( $H_D$ ) is the lightest state in the dark sector
    - Does not decay into DM
  - Mixes with the SM Higgs
    - Unstable, decays into “ $b\bar{b}$ ”
- $\Rightarrow$  Relic density set primarily by the  $DMDM \rightarrow H_D H_D$  annihilation channel

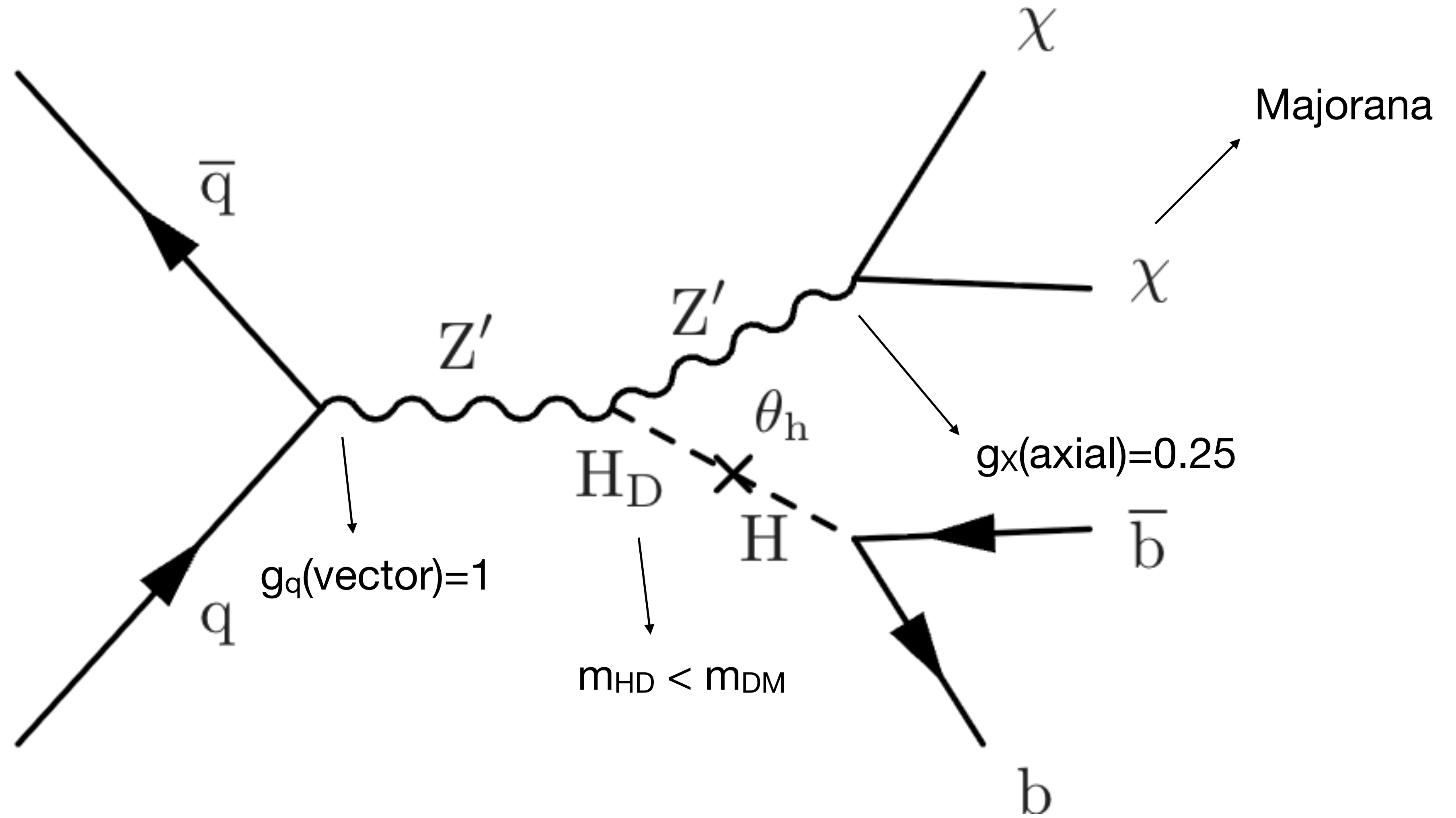


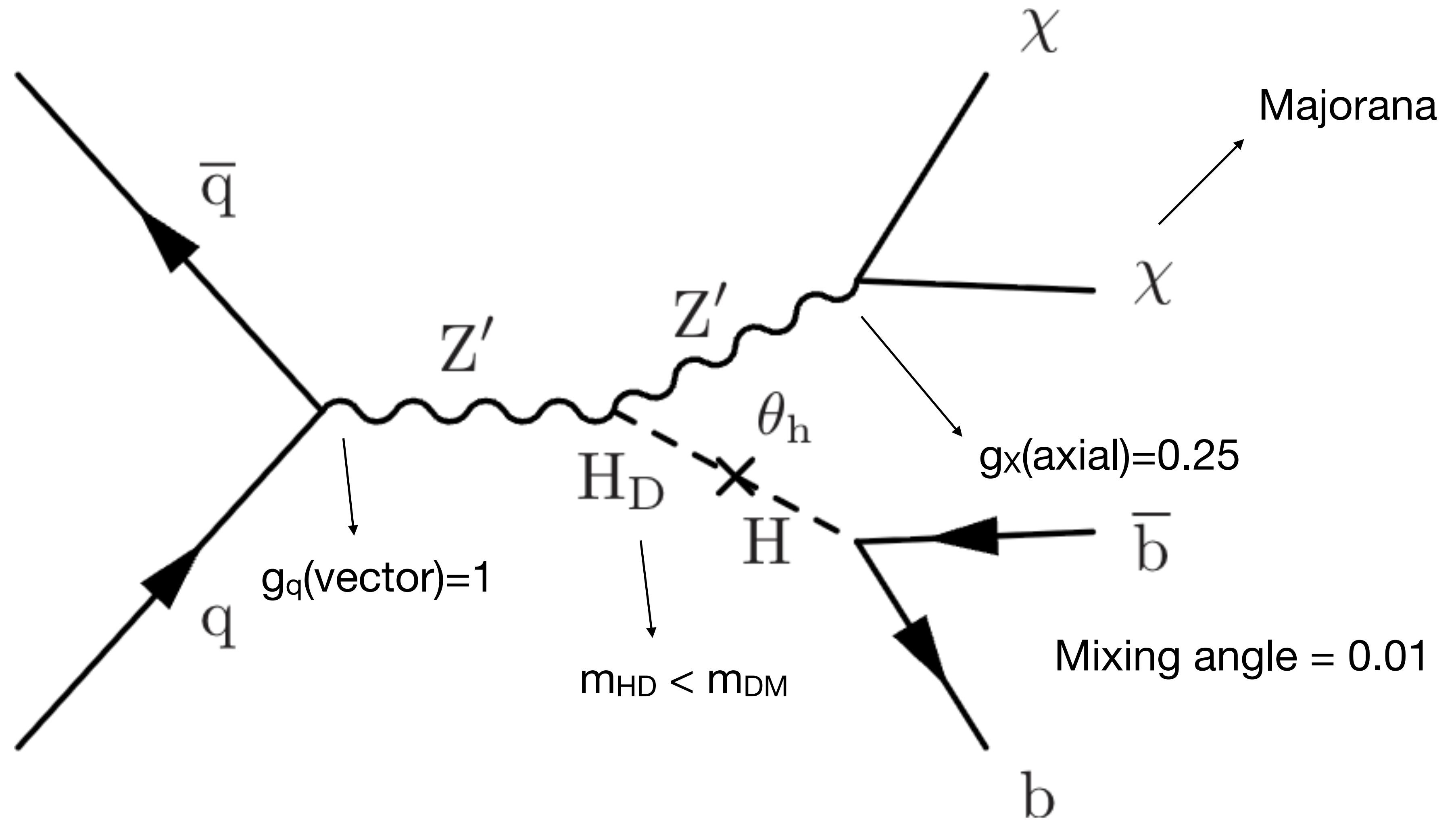




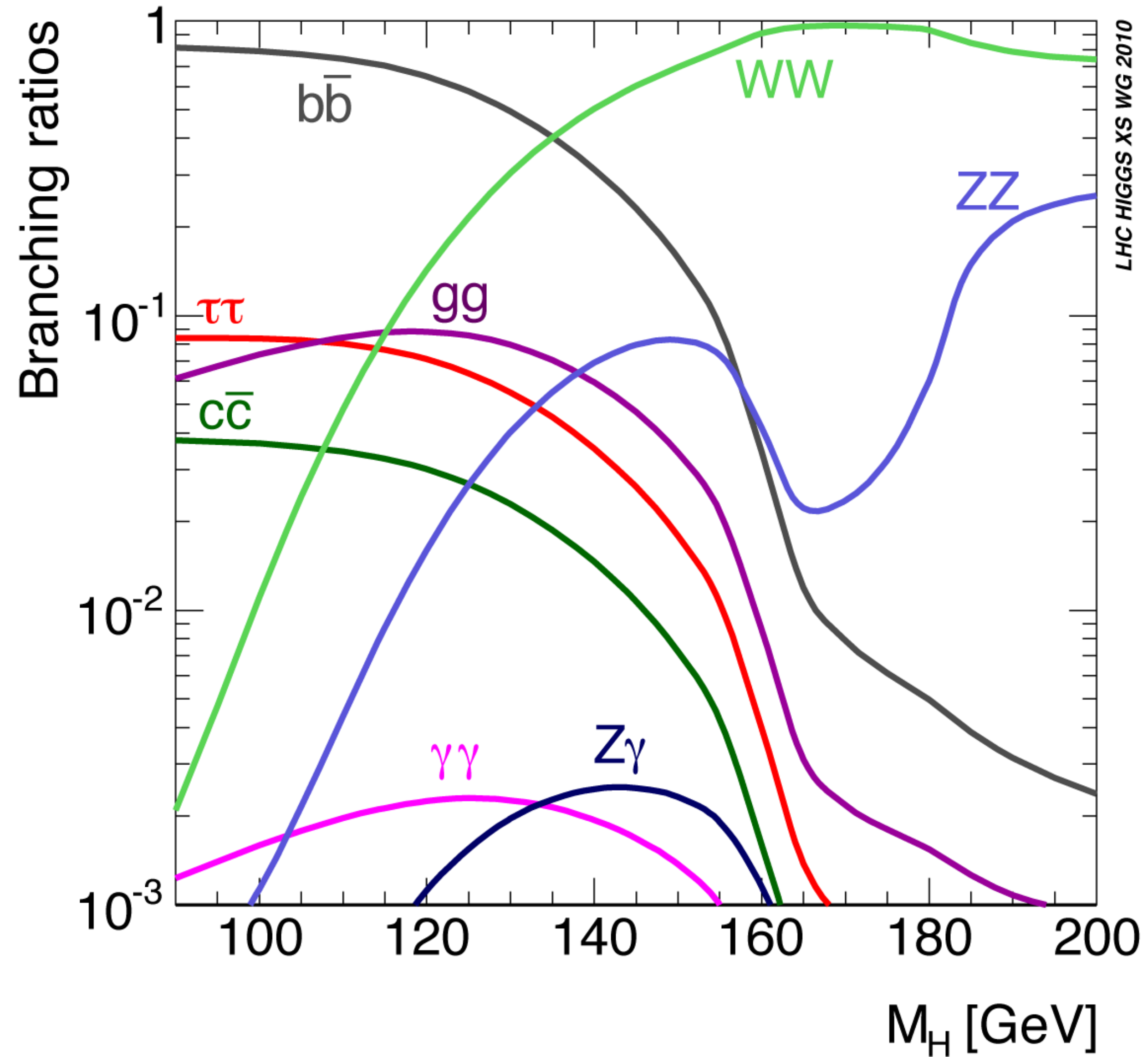




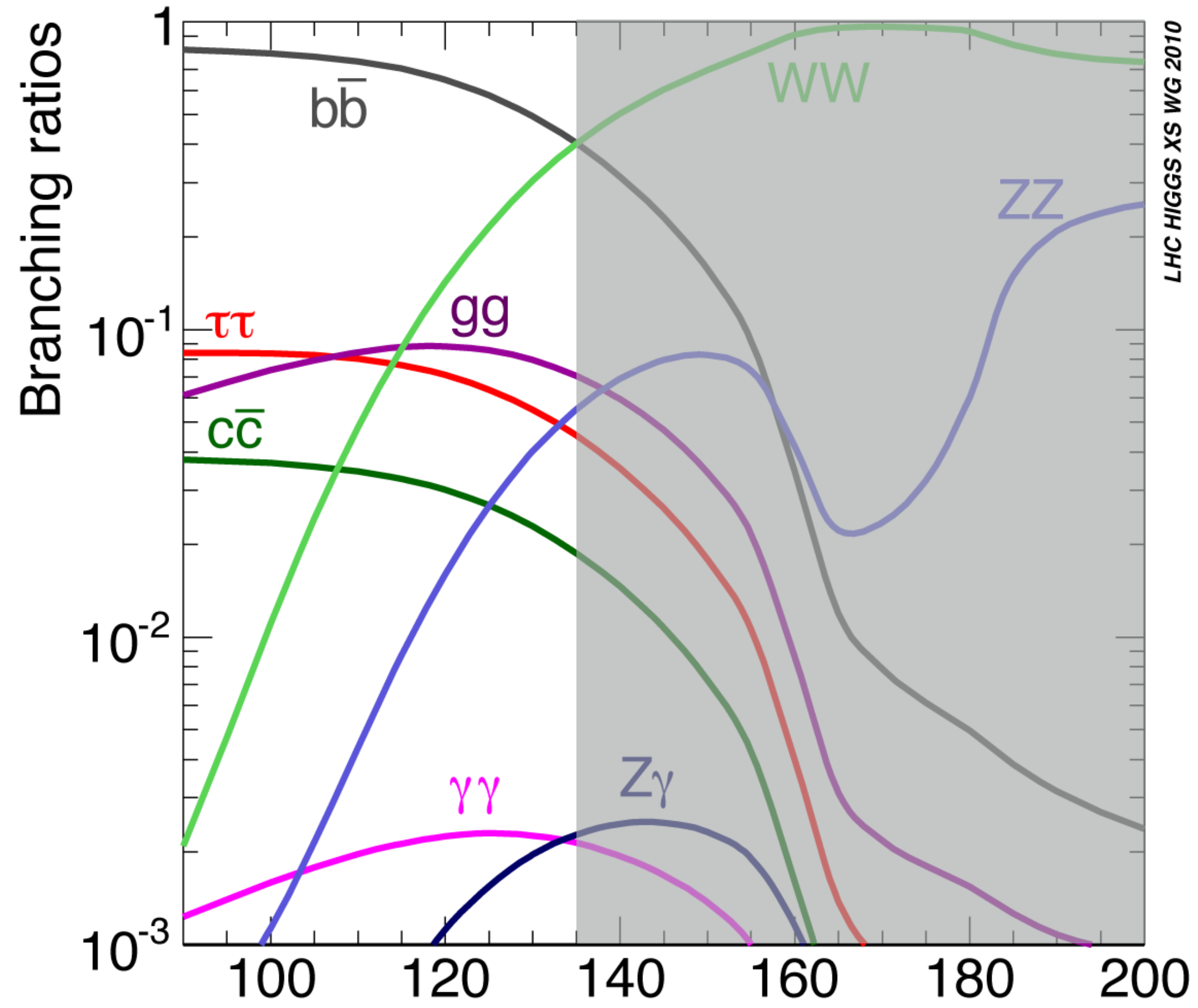




# $H_D$ assumes SM Higgs Branching Ratio



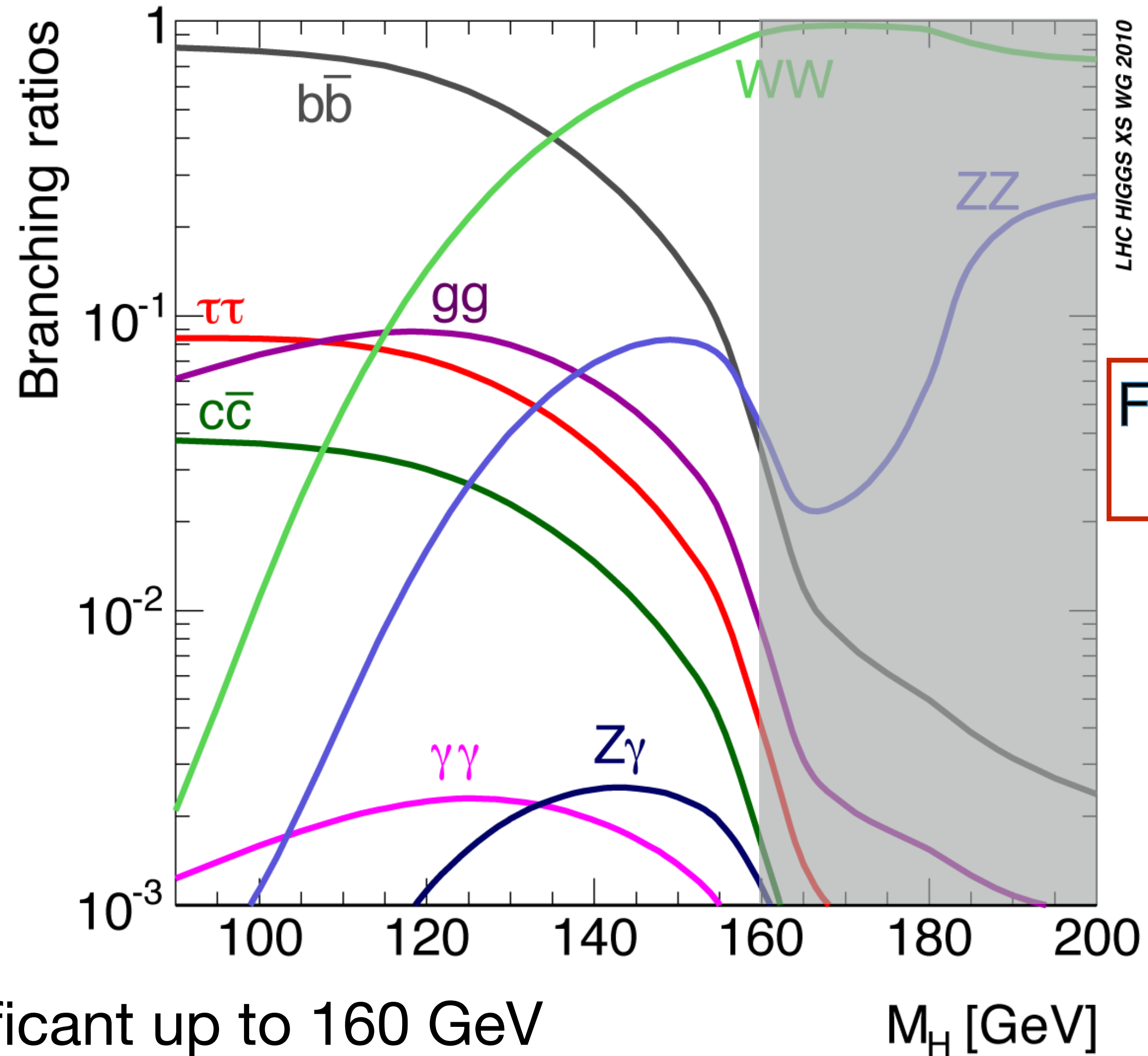
# $H_D$ assumes SM Higgs Branching Ratio



$H_D - > b\bar{b}$  dominates below 135 GeV

$M_H$  [GeV]

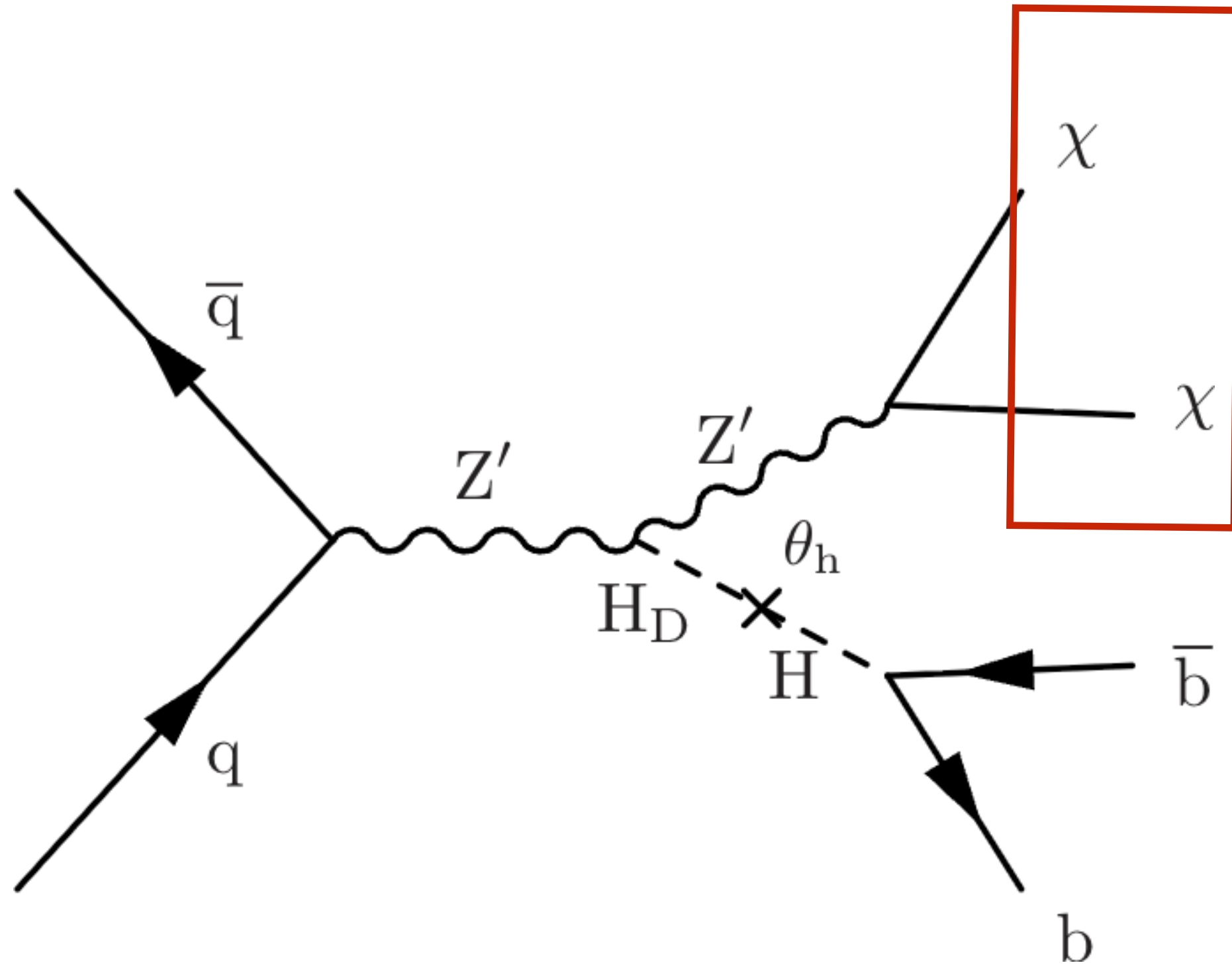
# $H_D$ assumes SM Higgs Branching Ratio

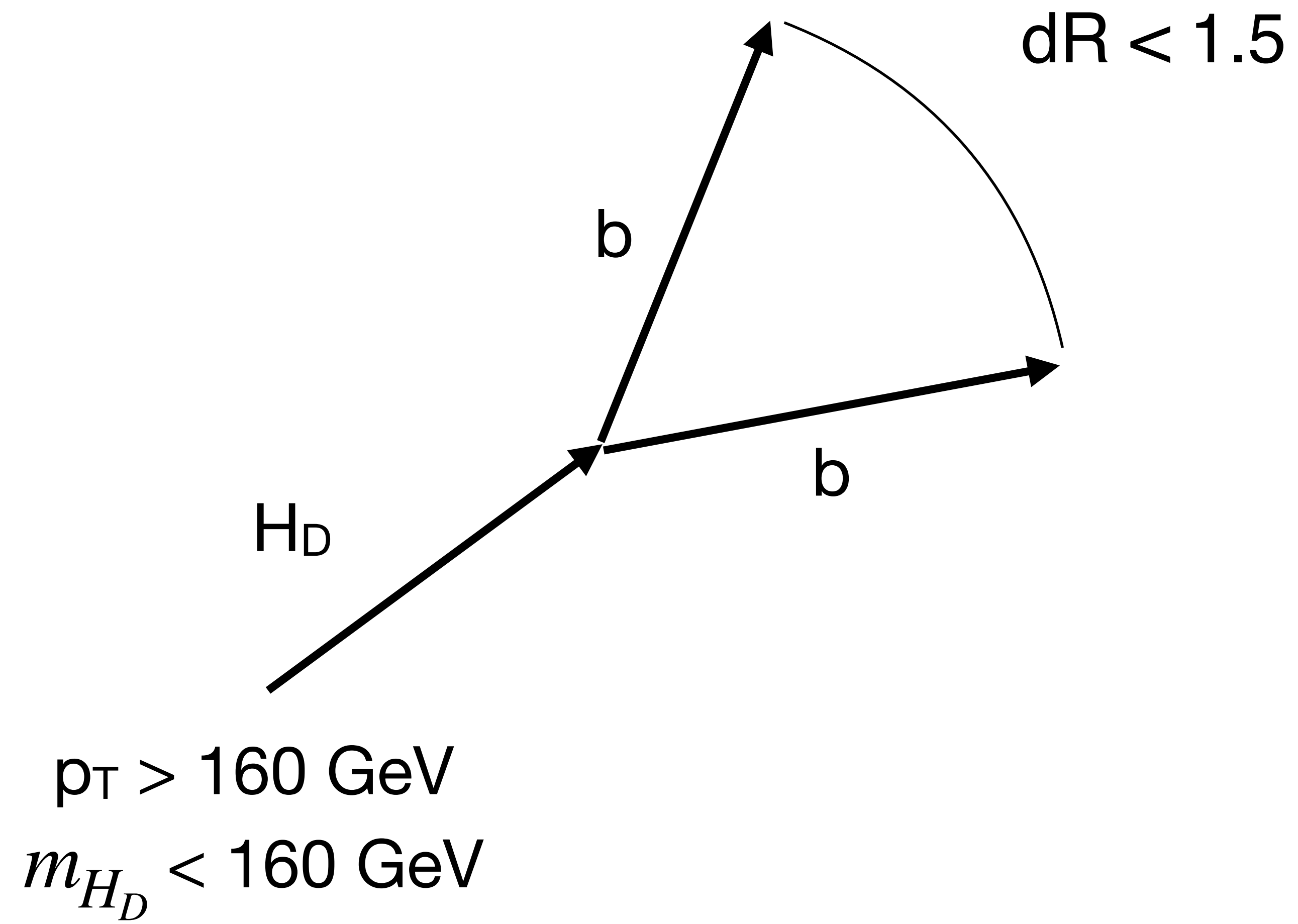


$H_D \rightarrow b\bar{b}$  significant up to 160 GeV

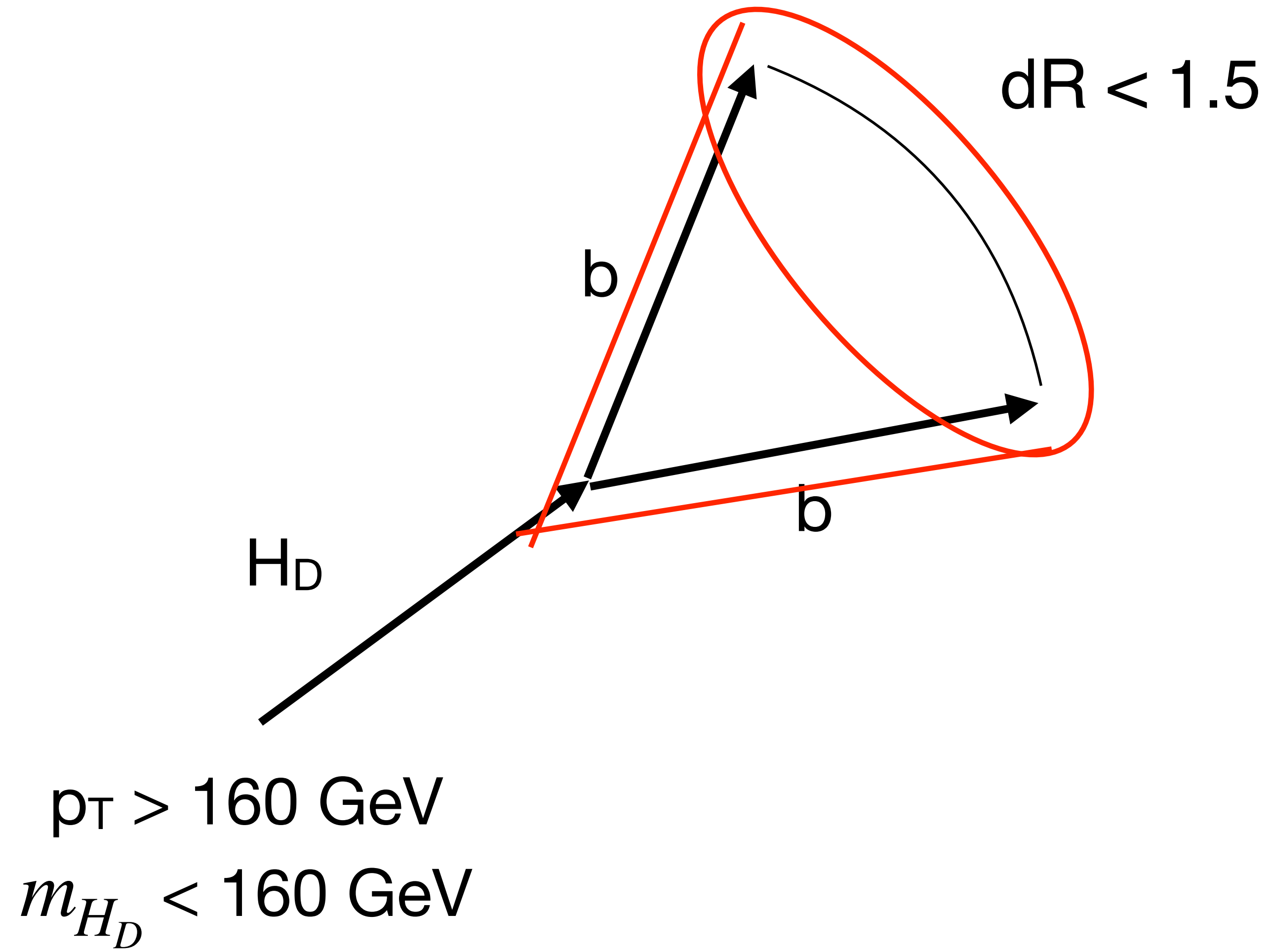
# Event Selection

PFMET > 250 GeV



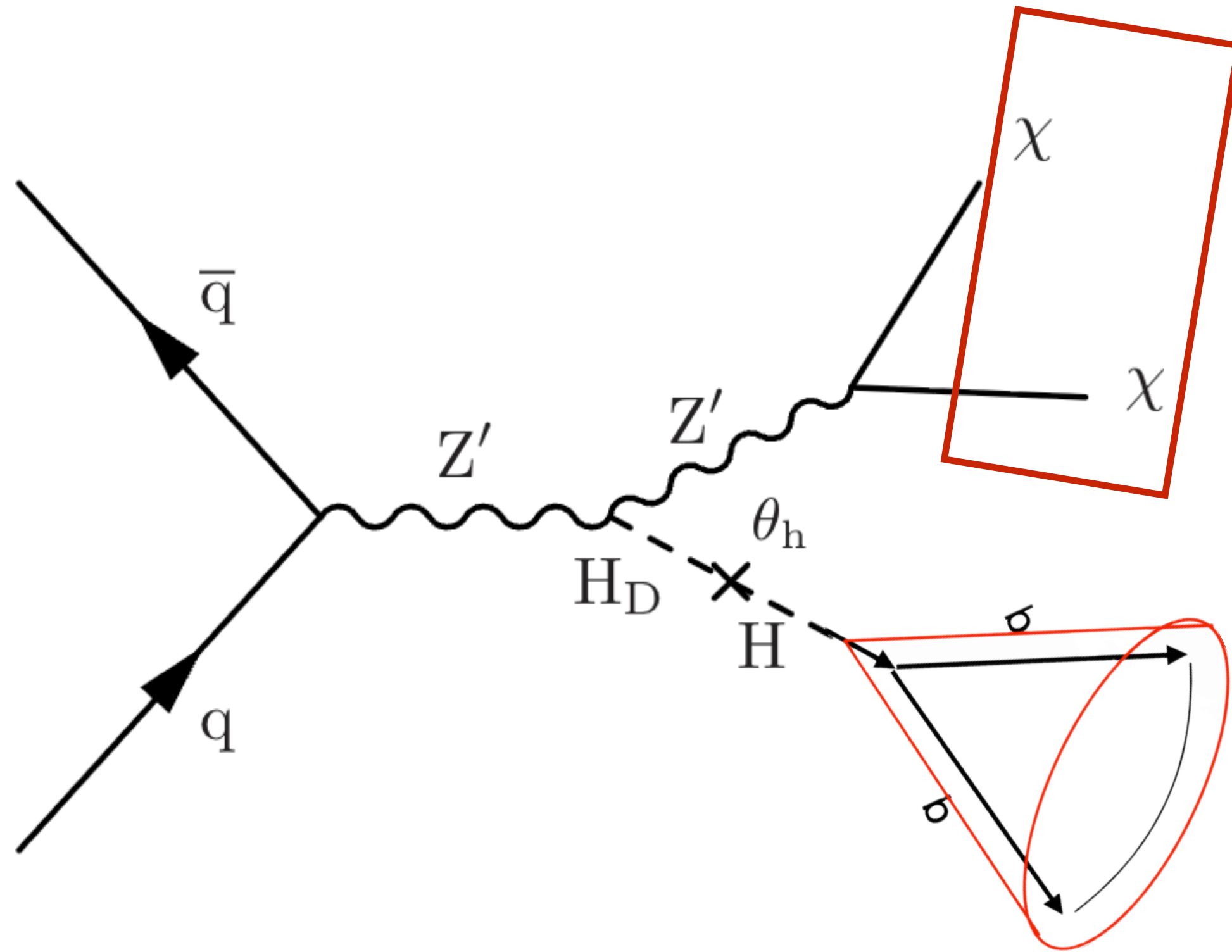


# Large cone jet (AK15)



# Event Selection

PFMET > 250 GeV

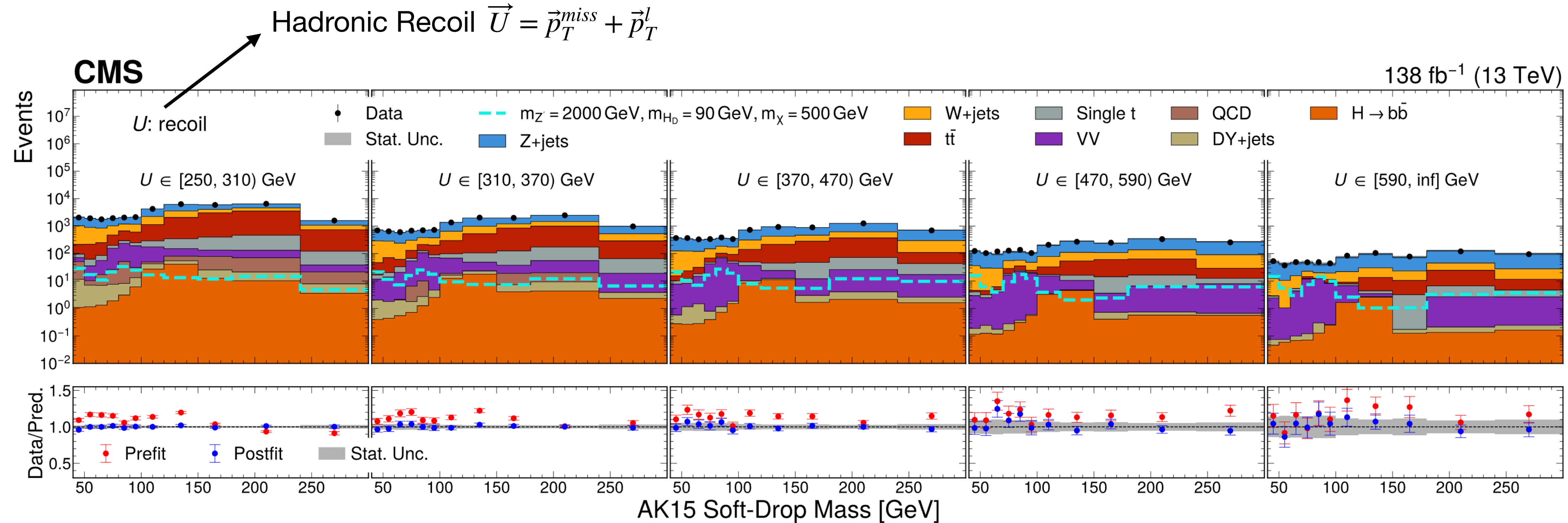


- $\Delta\phi(\text{AK4 jets, PFMET}) > 0.5$
- $\Delta\phi(\text{AK15 jets, PFMET}) > 1.5$
- $\tau/e/\mu/\text{photon veto}$
- Zero b-tagged AK4 jets outside leading AK15 cone

AK15  $p_T > 160$  GeV

$40 \text{ GeV} < \text{AK15 } m_{SD} < 300 \text{ GeV}$

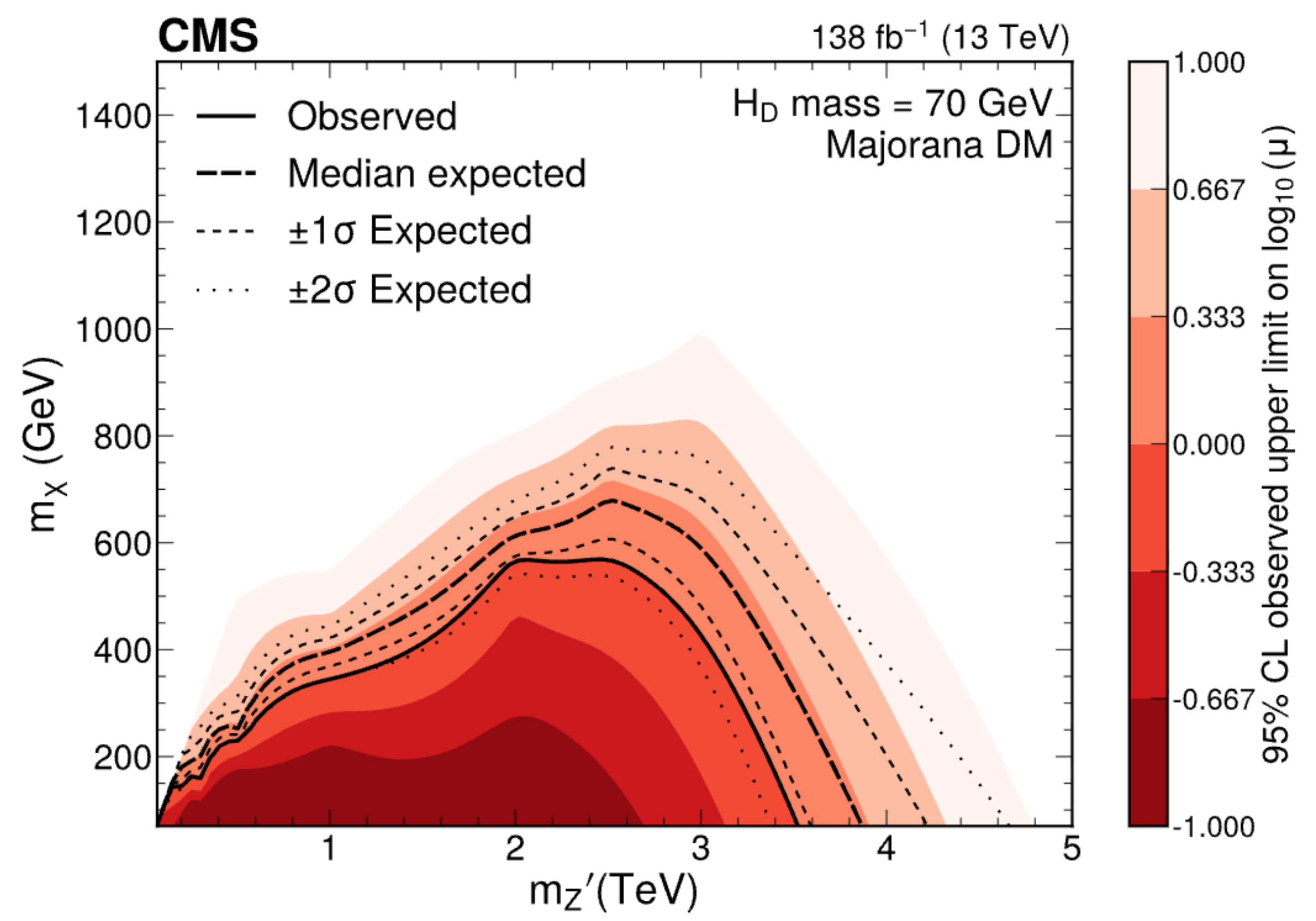
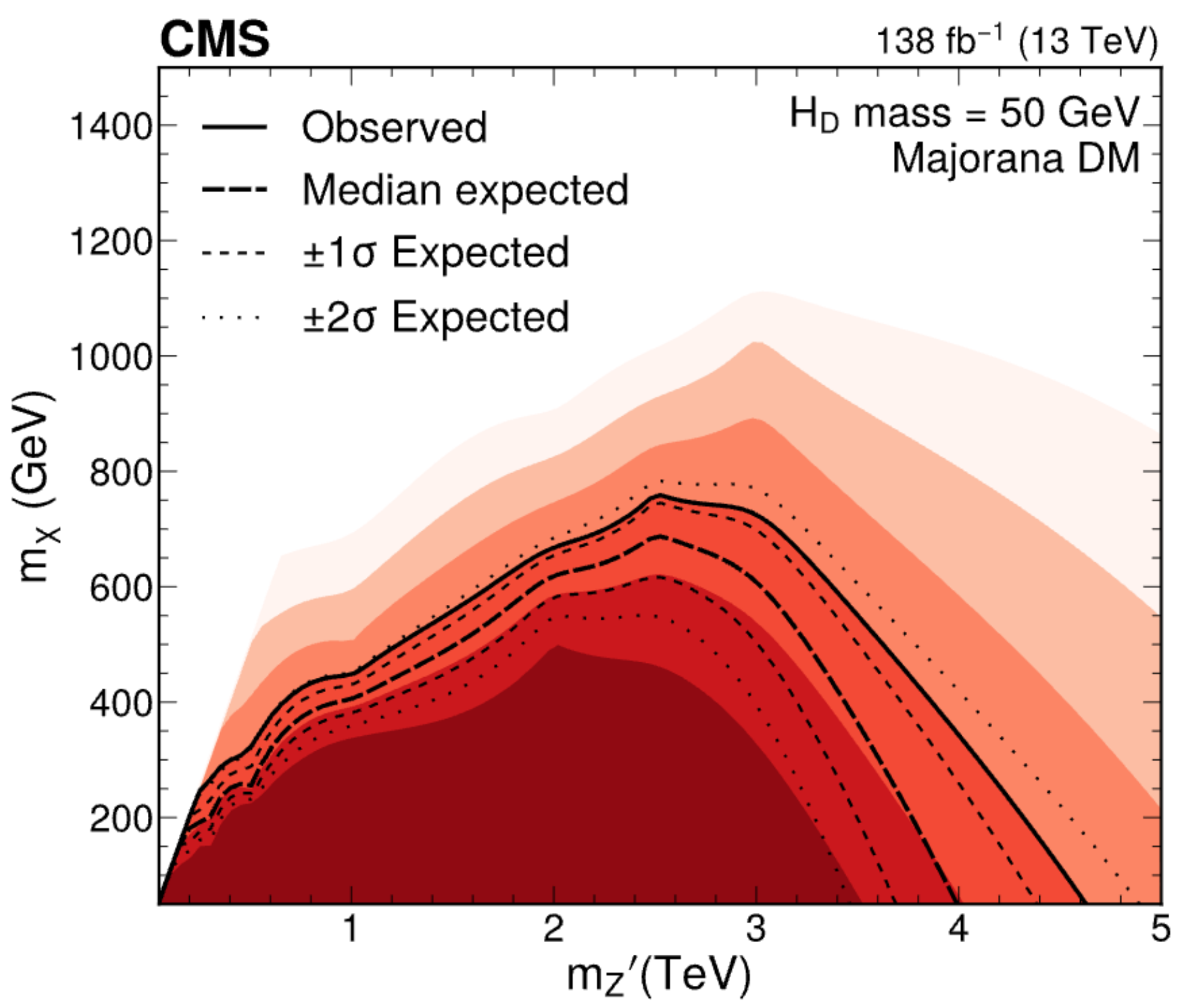
# Results



Postfit  $m_{SD}$  distributions in bins of  $U$  for 2016-2018 combined

# Results

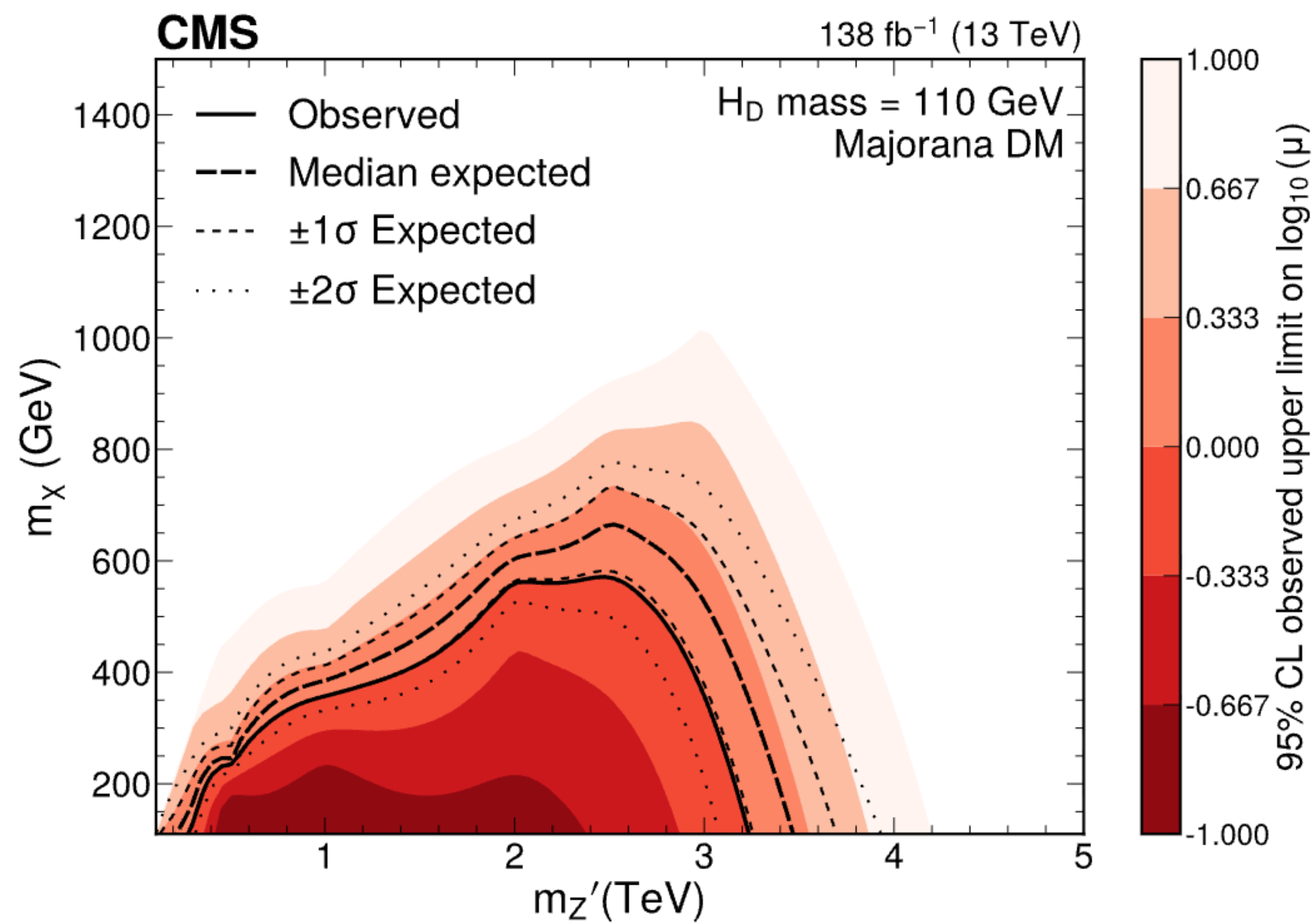
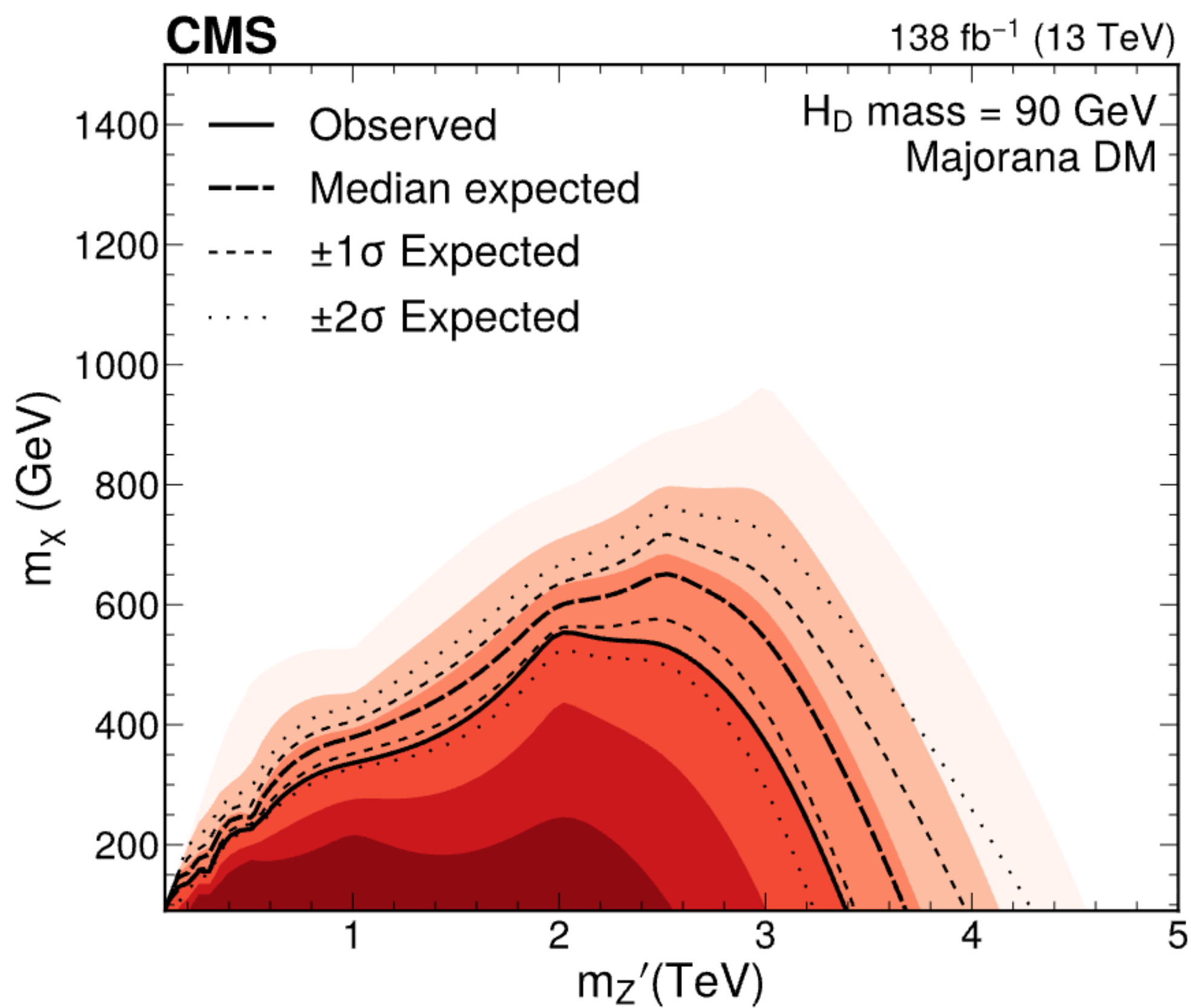
$$\mu = \frac{\sigma}{\sigma_{theo}}$$



Exclusion limits on the signal strength  $\mu$

# Results

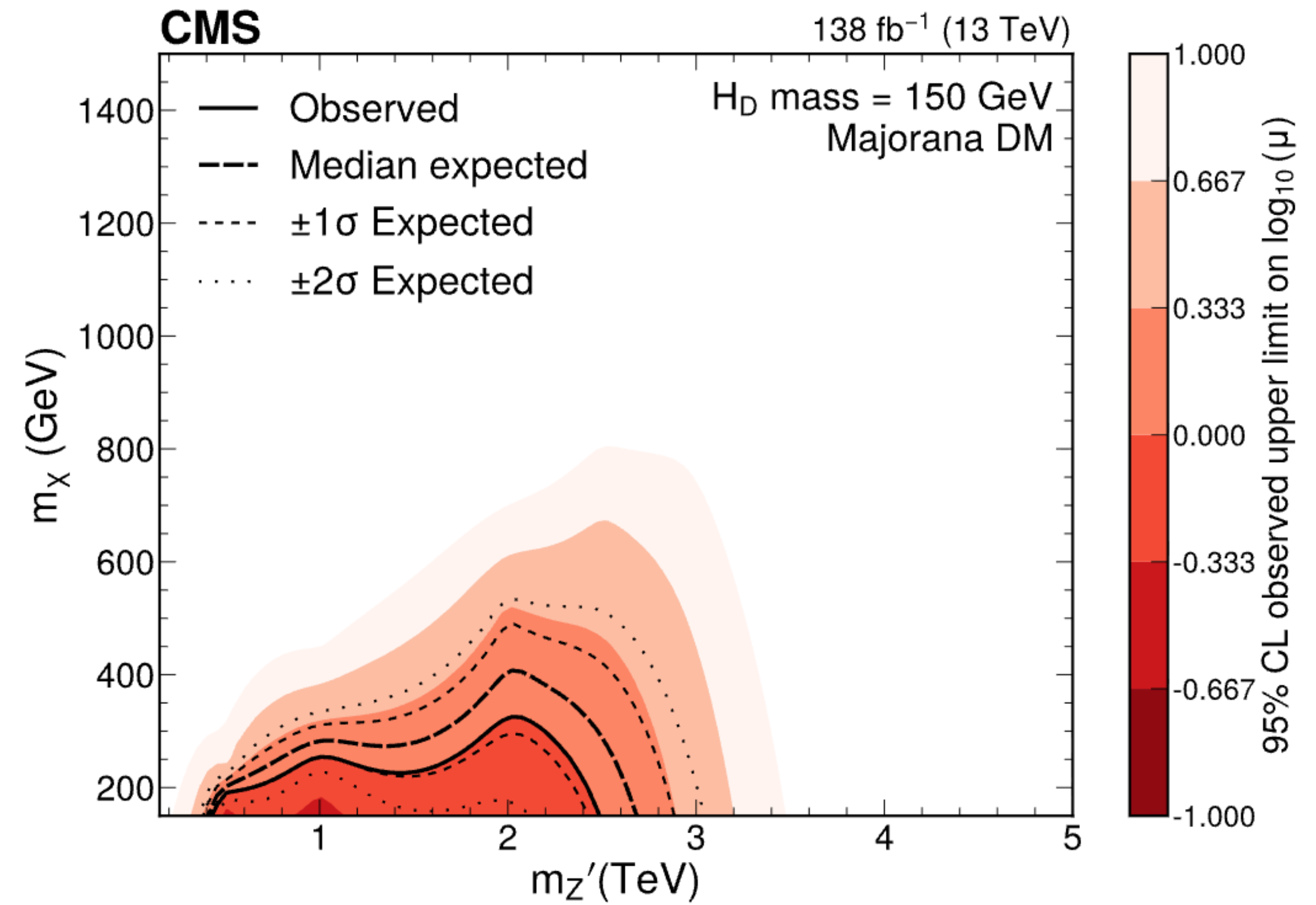
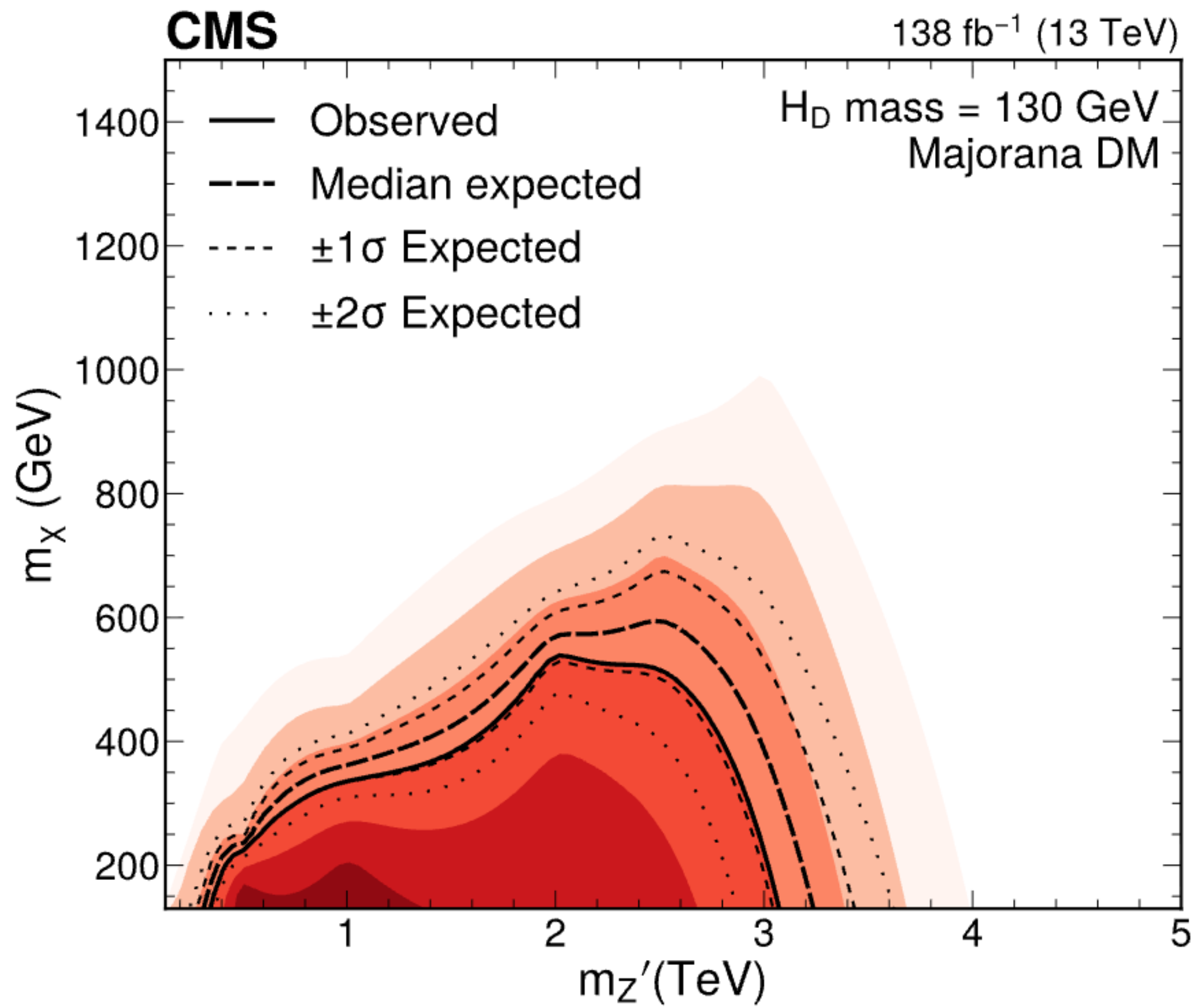
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Exclusion limits on the signal strength  $\mu$

# Results

$$\mu = \frac{\sigma}{\sigma_{theo}}$$

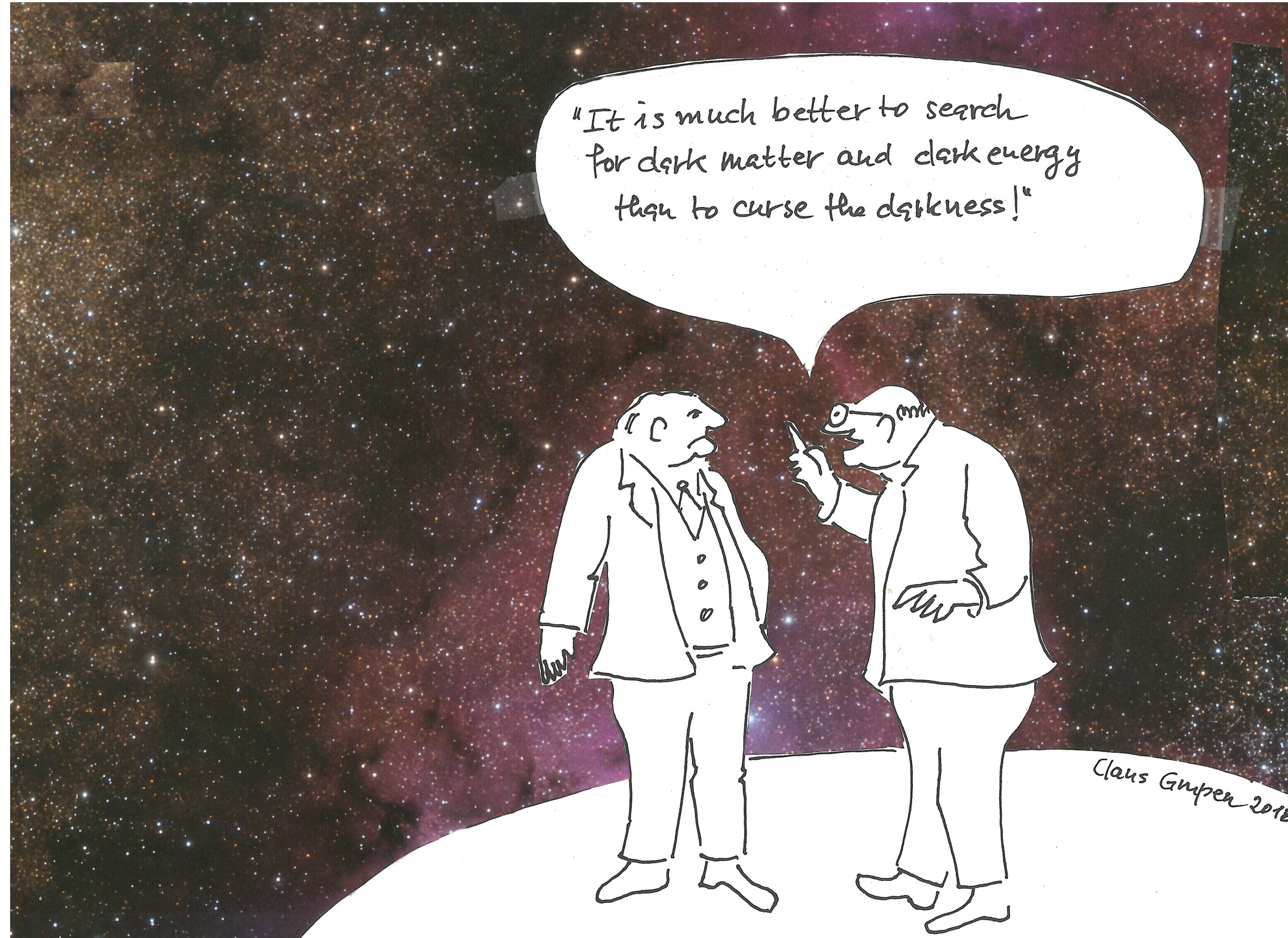


Exclusion limits on the signal strength  $\mu$

# Summary

- **No significant signal is observed** above the expected background
- Used full Run-2 dataset at 138 fb<sup>-1</sup>
- Targeting  $H_D < 160$  GeV
  - $H_D \rightarrow b\bar{b}$  dominates below 135 GeV, significant up to 160 GeV
- Values of  $Z'$  mass up to 4.5 (2.5) TeV are excluded at 95% CL for  $H_D$  mass of 50 (150) GeV
  - **Best limits set to date**
- **Public on [arXiv](#)**, submitted to EPJC

# Thank you!



# Backup: Standard Model (SM)

## Fermions

matter particles

Quarks



Leptons



## Gauge bosons

force carriers



photon



gluon



Z boson



W boson

## Higgs boson

origin of mass

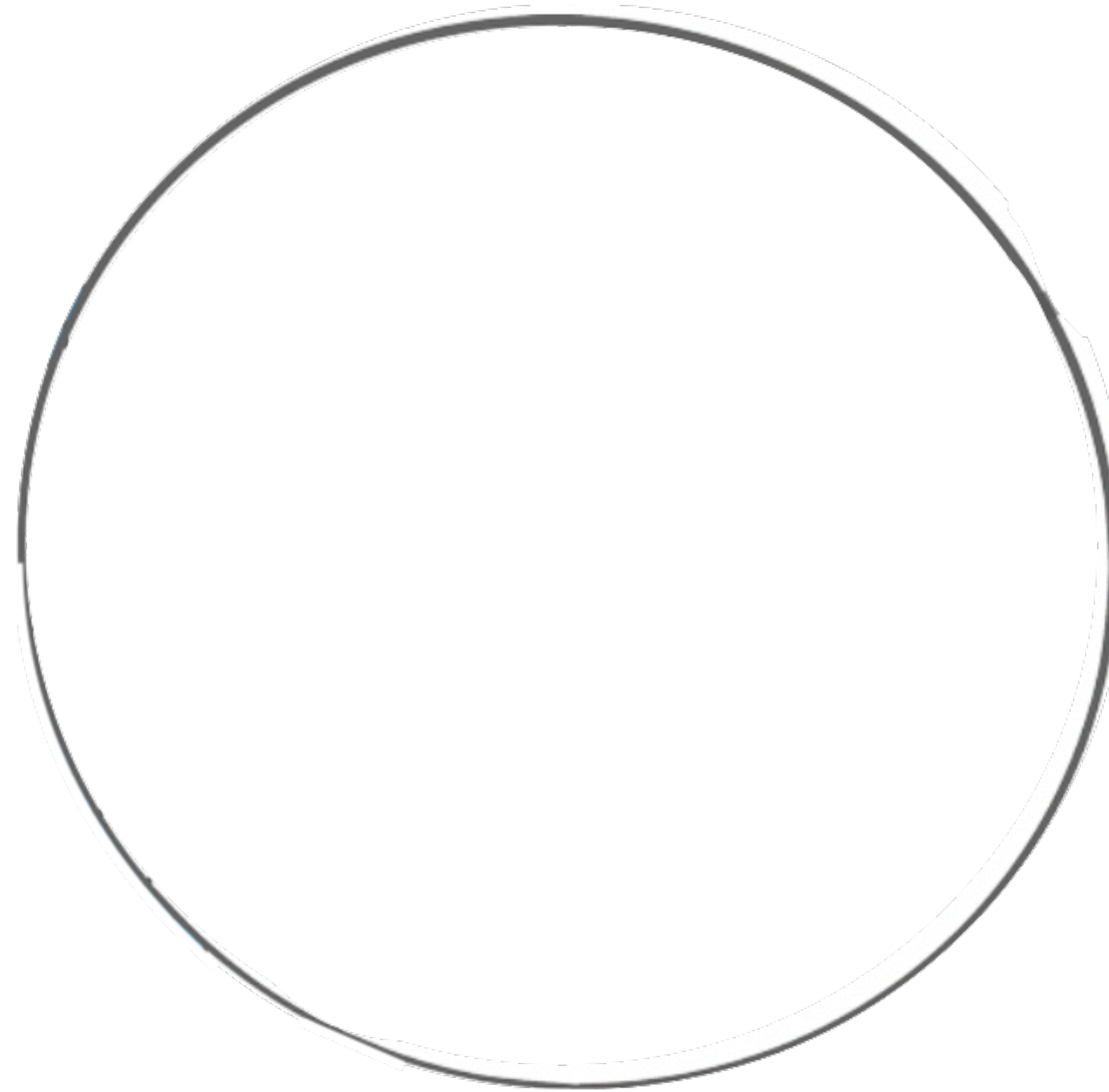


Describes the fundamental forces that regulate the interaction between elementary particles

# Backup: Missing Transverse Momentum ( $p_T^{\text{miss}}$ )

$$p_T^{\text{tot}, t_0} = 0$$

$t_0$ : before collision

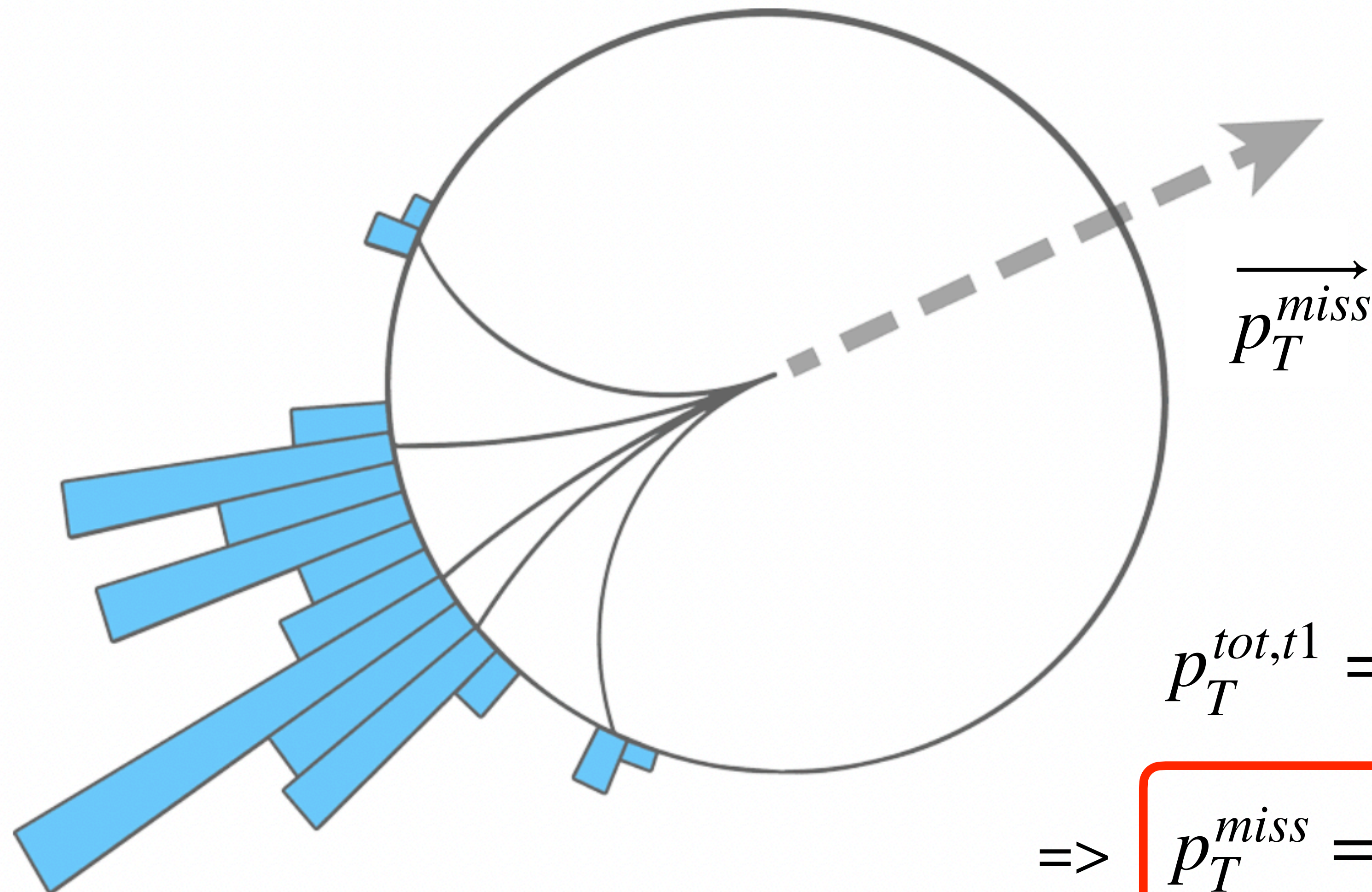


# Backup: Missing Transverse Momentum ( $p_T^{miss}$ )

$$\vec{p}_T^{tot} = \sum \vec{p}_T + \vec{p}_T^{miss}$$

All visible  
particles

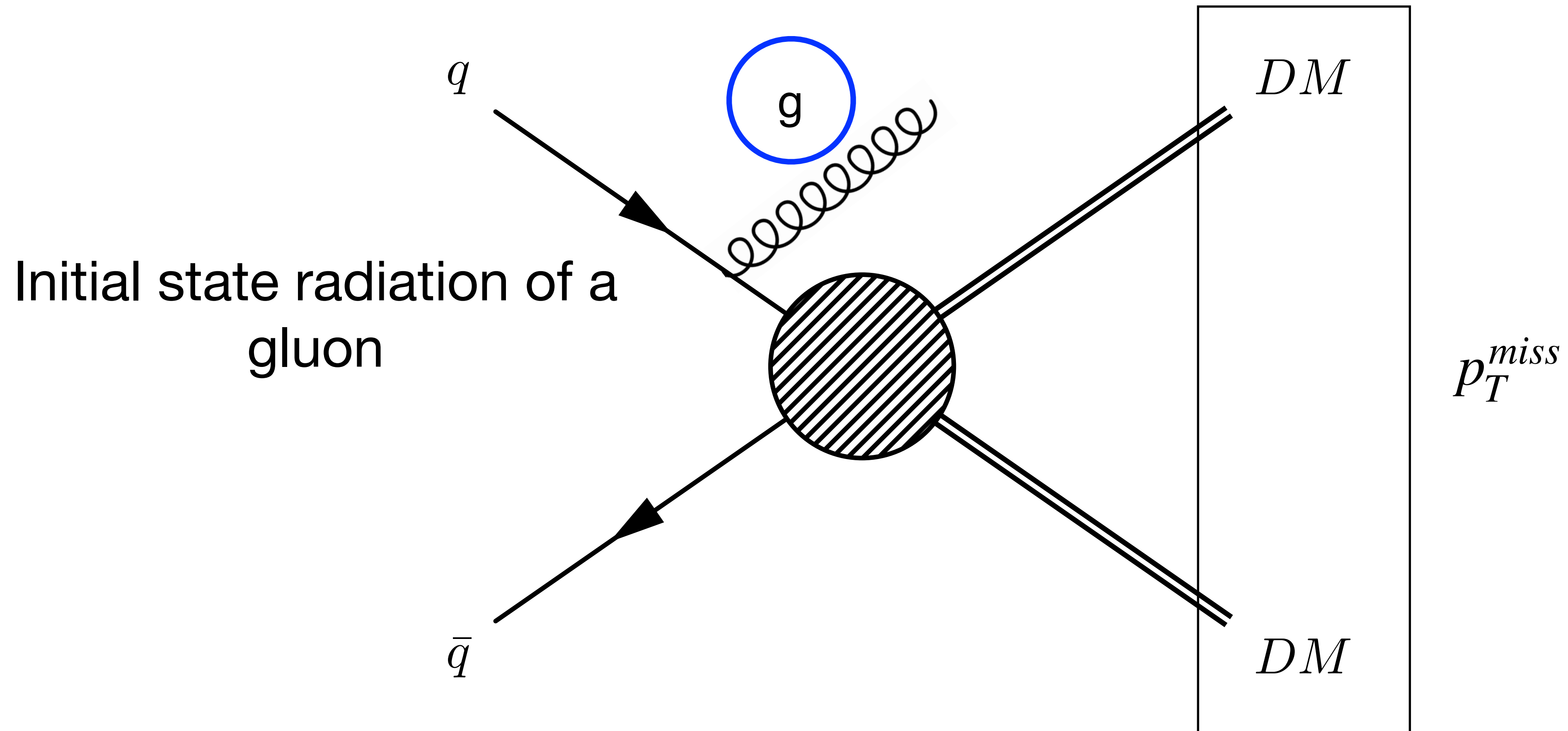
after collision



$$p_T^{tot,t1} = p_T^{tot,t0} = 0$$

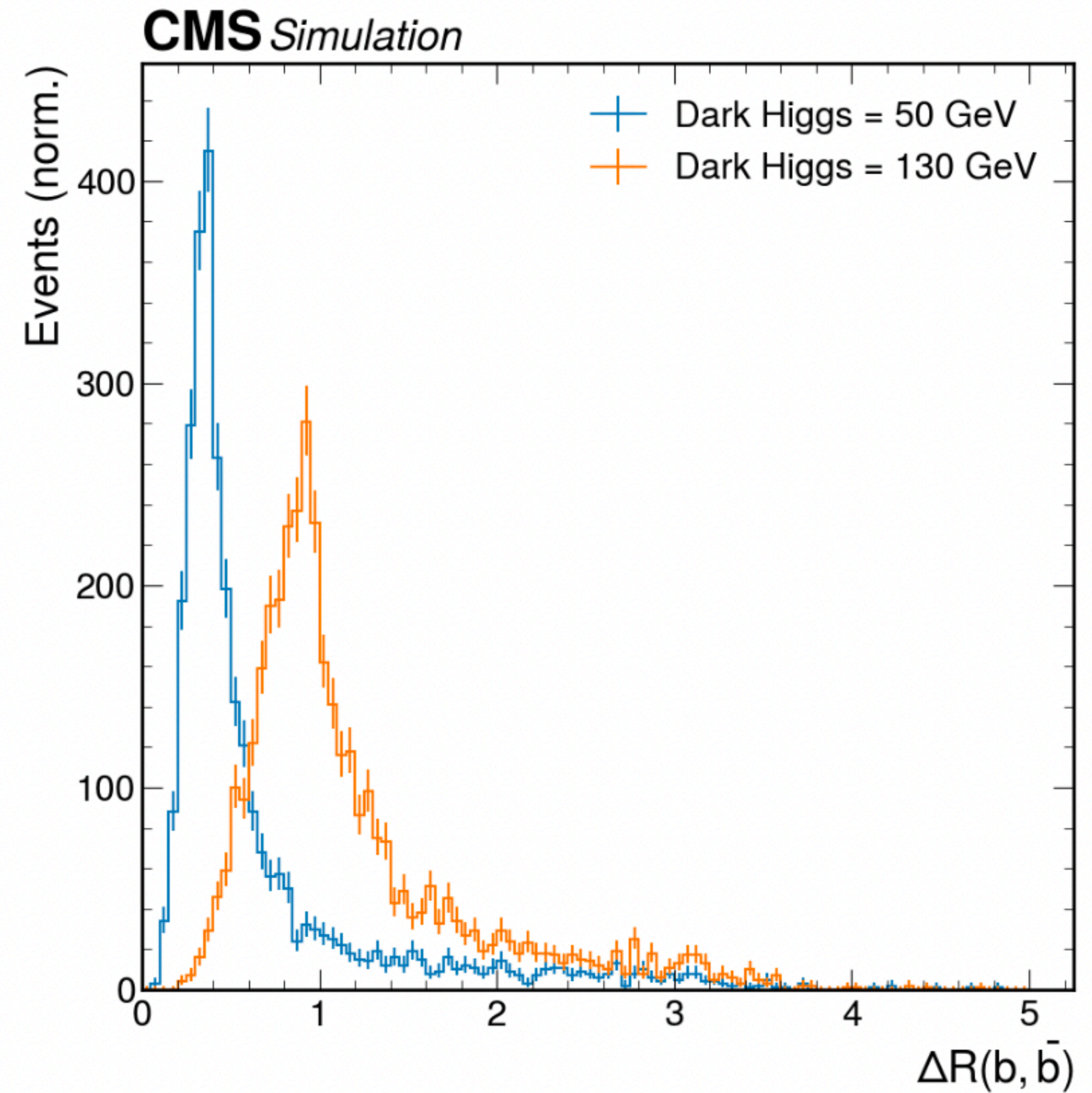
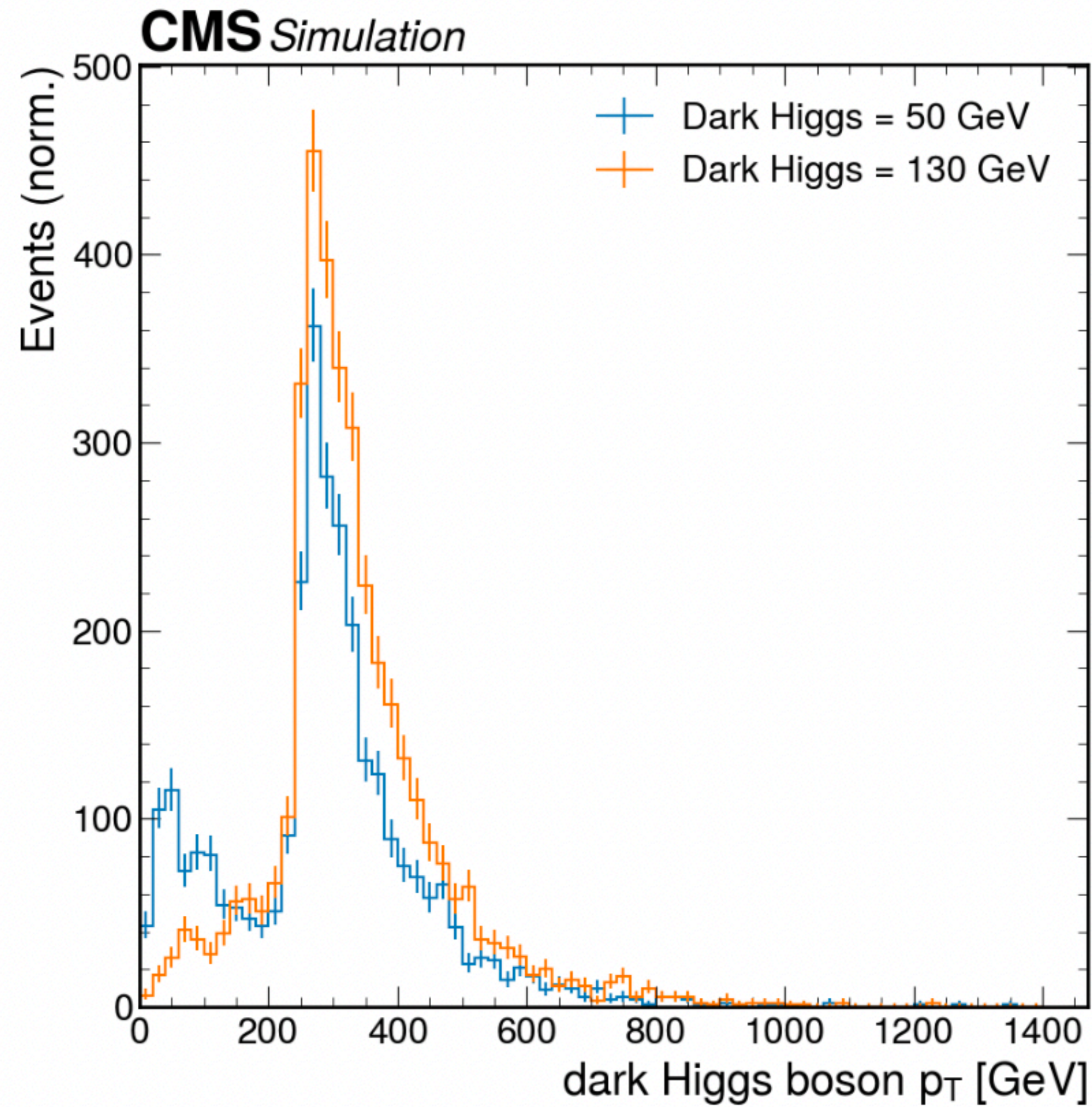
$$\Rightarrow p_T^{miss} = - \left| \sum \vec{p}_T \right|$$

# Backup: Experimental Approach



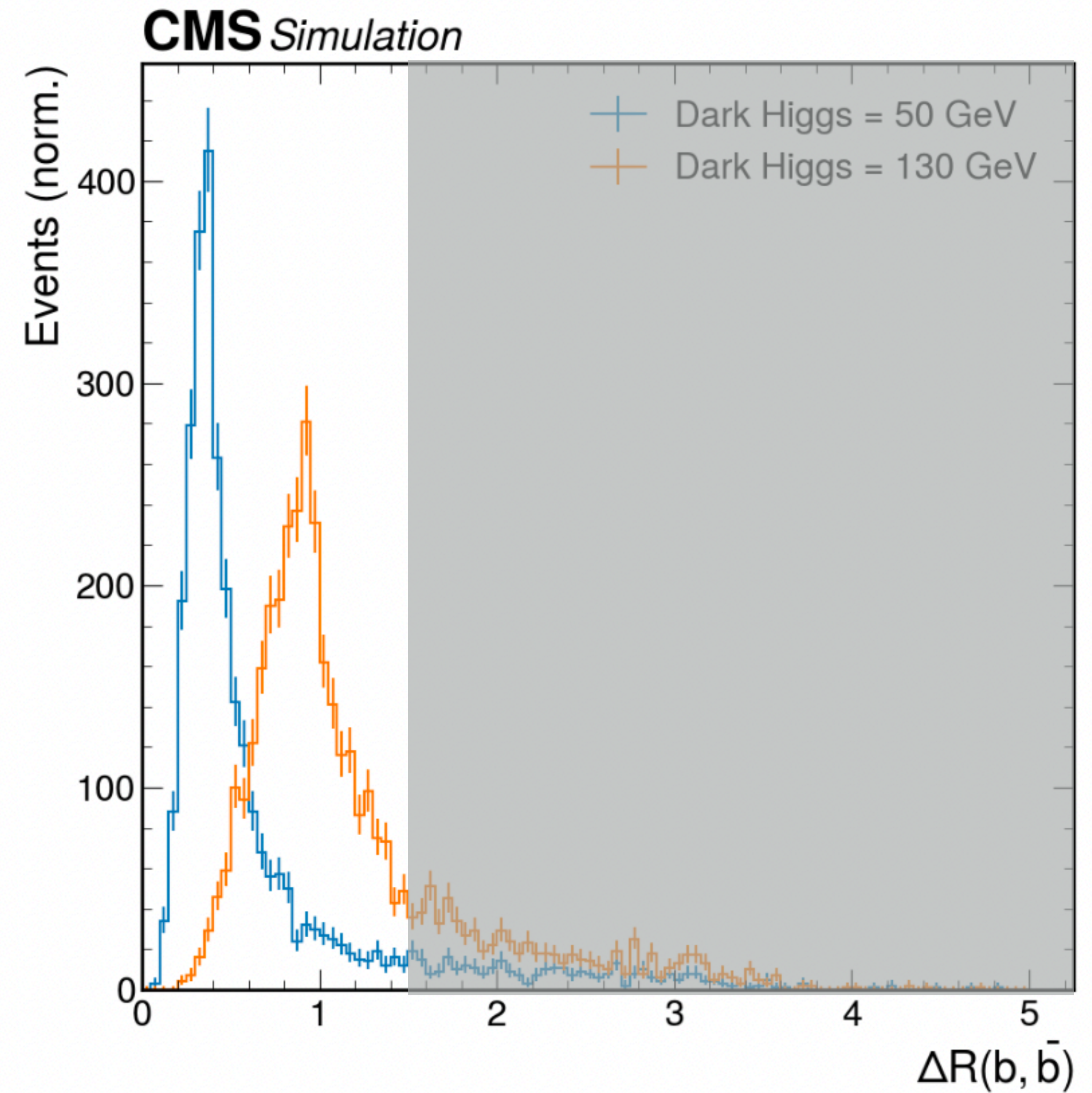
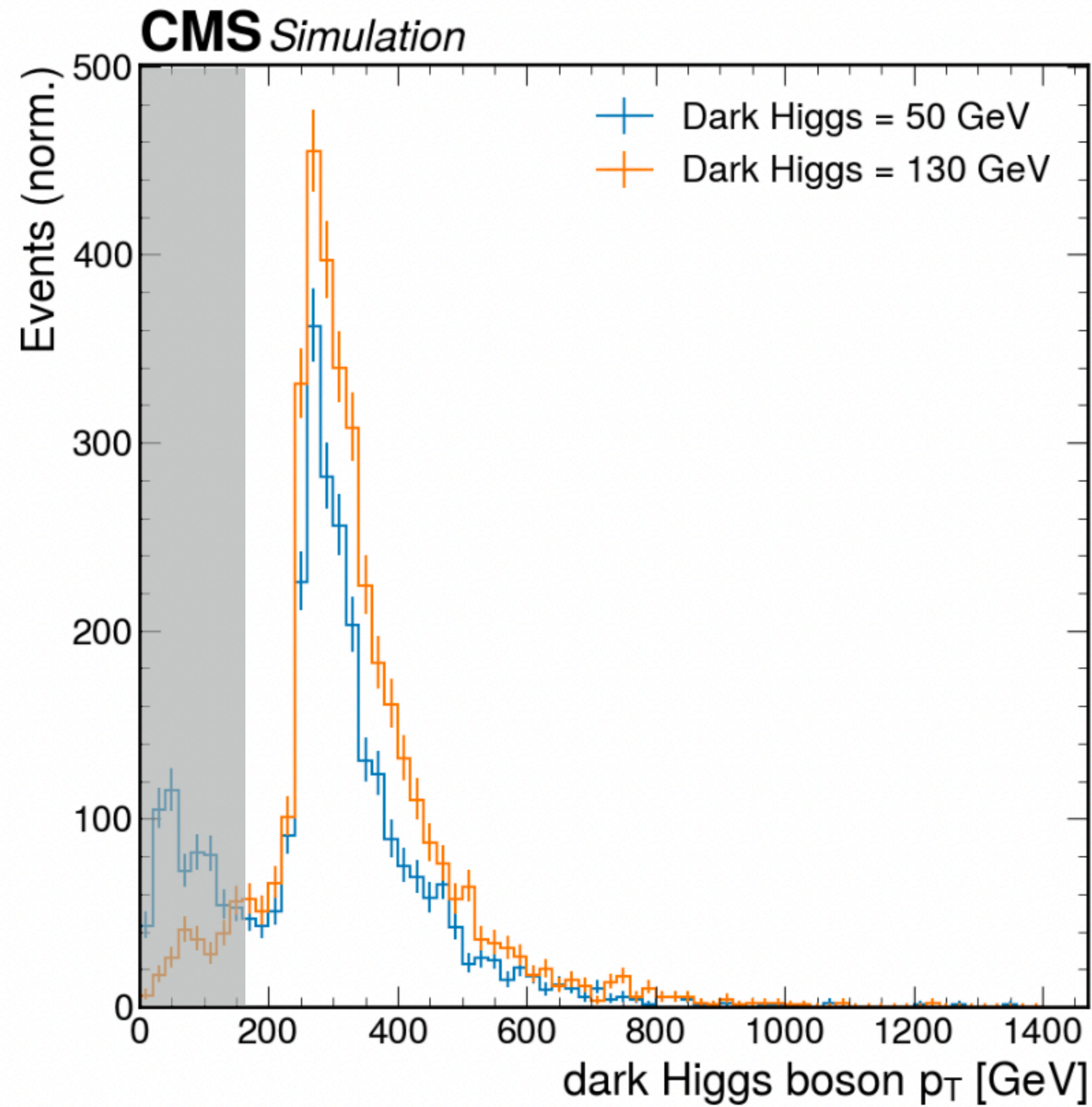
If produced together with a **visible object**, DM manifest itself as  $p_T^{miss}$

# Backup: Event Selection



$p_T(Z') > 250$  GeV

# Backup: Event Selection



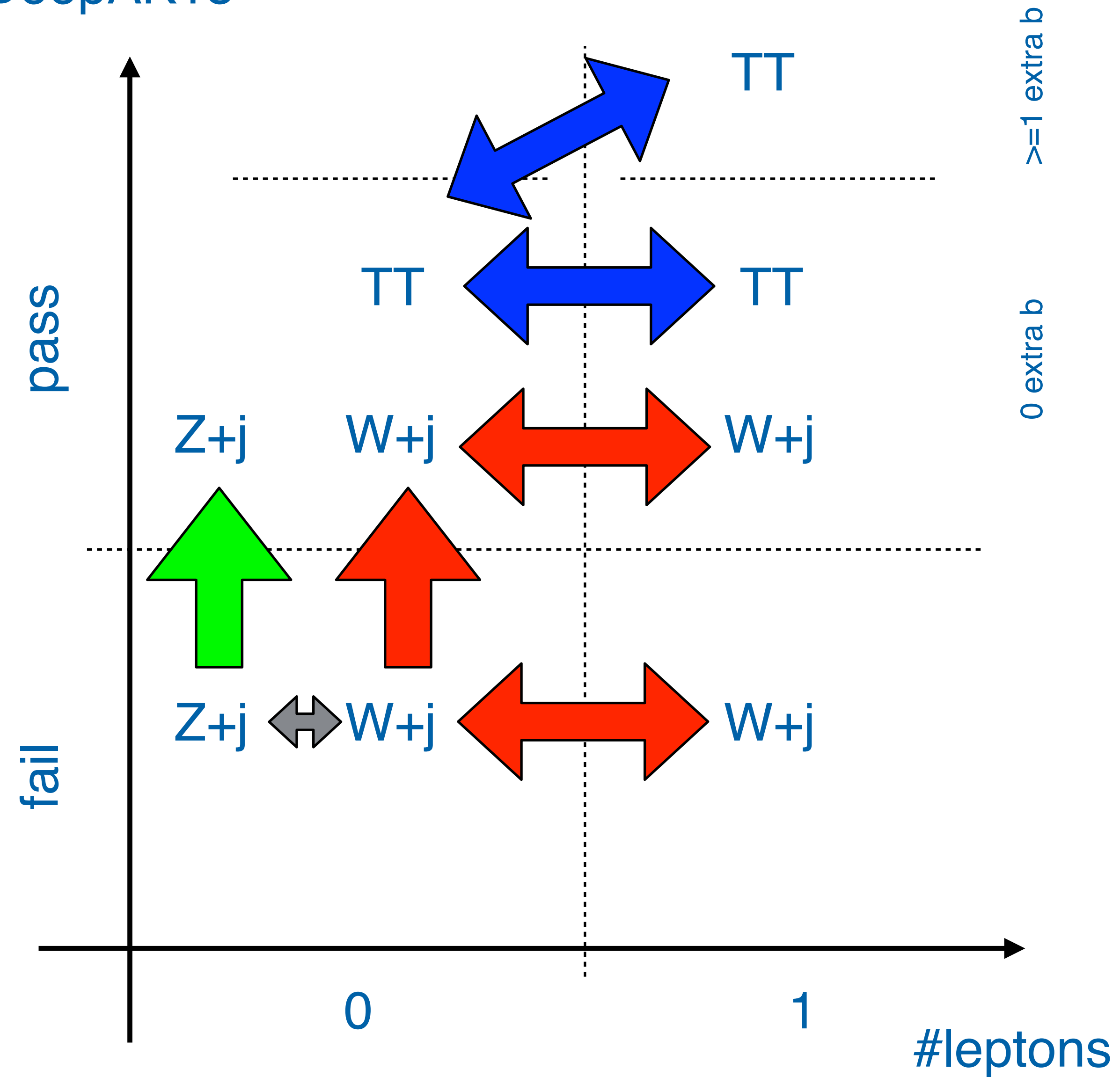
$p_T(Z') > 250$  GeV

# Backup: Event Selection

Selection	SR	ZCR	WMPCR	WEPCR	WMFCR	WEFCR	TTMCR	TTECR
$p_T^{\text{miss}} + H_T^{\text{miss}}$ trigger	✓	✓	✓	×	✓	×	✓	×
Single-electron trigger	×	×	×	✓	×	✓	×	✓
$U > 250 \text{ GeV}$	✓	✓	✓	✓	✓	✓	✓	✓
$ p_T^{\text{miss}}(\text{PF}) - p_T^{\text{miss}}(\text{calo}) /U < 0.5$	✓	✓	✓	✓	✓	✓	✓	✓
AK15 $p_T > 160 \text{ GeV}$	✓	✓	✓	✓	✓	✓	✓	✓
AK15 $m_{\text{SD}} \in [40, 300] \text{ GeV}$	✓	✓	✓	✓	✓	✓	✓	✓
$\min \Delta\phi(\vec{U}, \text{AK4s}) > 0.5$	✓	✓	✓	✓	✓	✓	✓	✓
$\min \Delta\phi(\vec{U}, \text{AK15s}) > 1.5$	✓	✓	✓	✓	✓	✓	✓	✓
$p_T^{\text{miss}} > 100 \text{ GeV}$	×	×	×	✓	×	✓	×	✓
# of muons	0	0	1	0	1	0	1	0
# of electrons	0	0	0	1	0	1	0	1
# of photons	0	0	0	0	0	0	0	0
# of taus	0	0	0	0	0	0	0	0
# of extra b-tagged AK4 jets	0	0	0	0	0	0	$\geq 1$	$\geq 1$
DEEPAK15 requirement	pass	fail	pass	pass	fail	fail	pass	pass

# Backup: Background Model

DeepAK15



# Backup: Uncertainties

Source	Uncertainty
Integrated luminosity	0.6–2%
Pileup	1%
L1 prefiring	1%
$p_T^{\text{miss}}$ trigger efficiency	1–2%
Single-electron trigger efficiency	1%
Muon isolation efficiency	1%
Muon identification efficiency	1%
Electron reconstruction efficiency	1%
Electron identification efficiency	2–3%
Tau veto	3%
Hadronic recoil $U$	5%
Jet energy corrections	4%
DEEPJET efficiency	Shape
DEEPAK15 efficiency	Shape
VV cross section	20%
$H \rightarrow b\bar{b}$ cross section	20%
DY + jets cross section	20%
Single t cross section	10%
$t\bar{t}$ cross section	10%
QCD- $p_T^{\text{miss}}$ normalization	100%
QCD-electron normalization	100%
QCD-muon normalization	100%
Higher-order corrections	Shape
Bin-by-bin event counts	Shape

# Backup: Signal Region Yields

	2016	2017	2018
$H \rightarrow b\bar{b}$	$57.58 \pm 0.34$	$72.03 \pm 0.33$	$83.79 \pm 0.34$
DY + jets	$56.8 \pm 2.2$	$43.3 \pm 2.0$	$37.1 \pm 3.0$
QCD multijet	$93 \pm 26$	$155 \pm 42$	$163 \pm 65$
VV	$718 \pm 18$	$623 \pm 18$	$606 \pm 21$
Single t	$646 \pm 11$	$567 \pm 13$	$615 \pm 13$
$t\bar{t}$	$5487 \pm 200$	$5811 \pm 60$	$6784 \pm 130$
W + jets	$3998 \pm 39$	$2991 \pm 40$	$2827 \pm 50$
Z + jets	$7515 \pm 29$	$7035 \pm 33$	$6979 \pm 39$
Total background	$18571 \pm 210$	$17298 \pm 92$	$18094 \pm 160$
$m_{Z'} = 1000 \text{ GeV}, m_{H_D} = 130 \text{ GeV}, m_{DM} = 150 \text{ GeV}$	$2329 \pm 14$	$2132 \pm 13$	$2337 \pm 16$