Search for Dark Matter Produced in Association with a Resonant Bottom-Quark Pair

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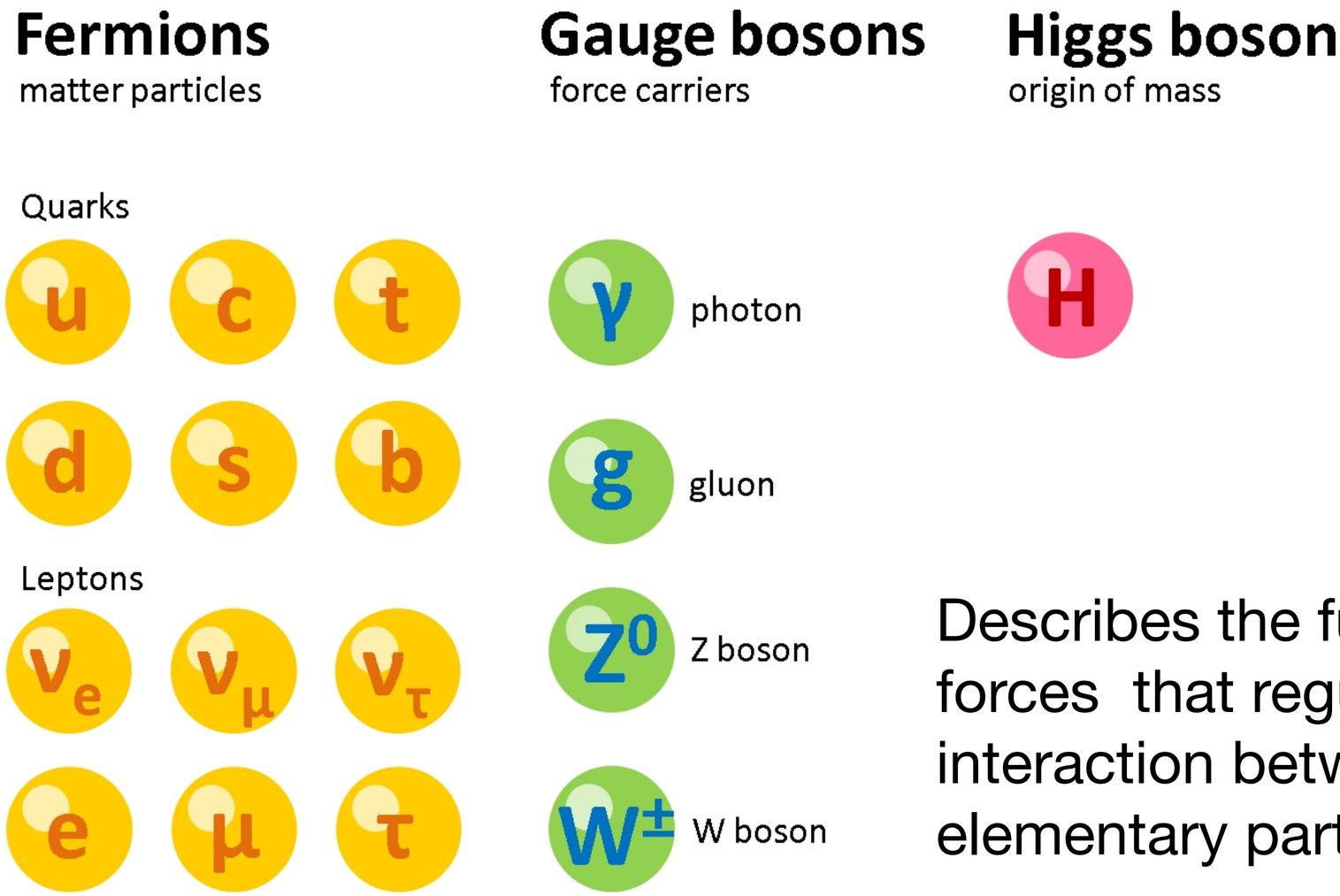
Carnegie Mellon University

On behalf of the CMS Collaboration

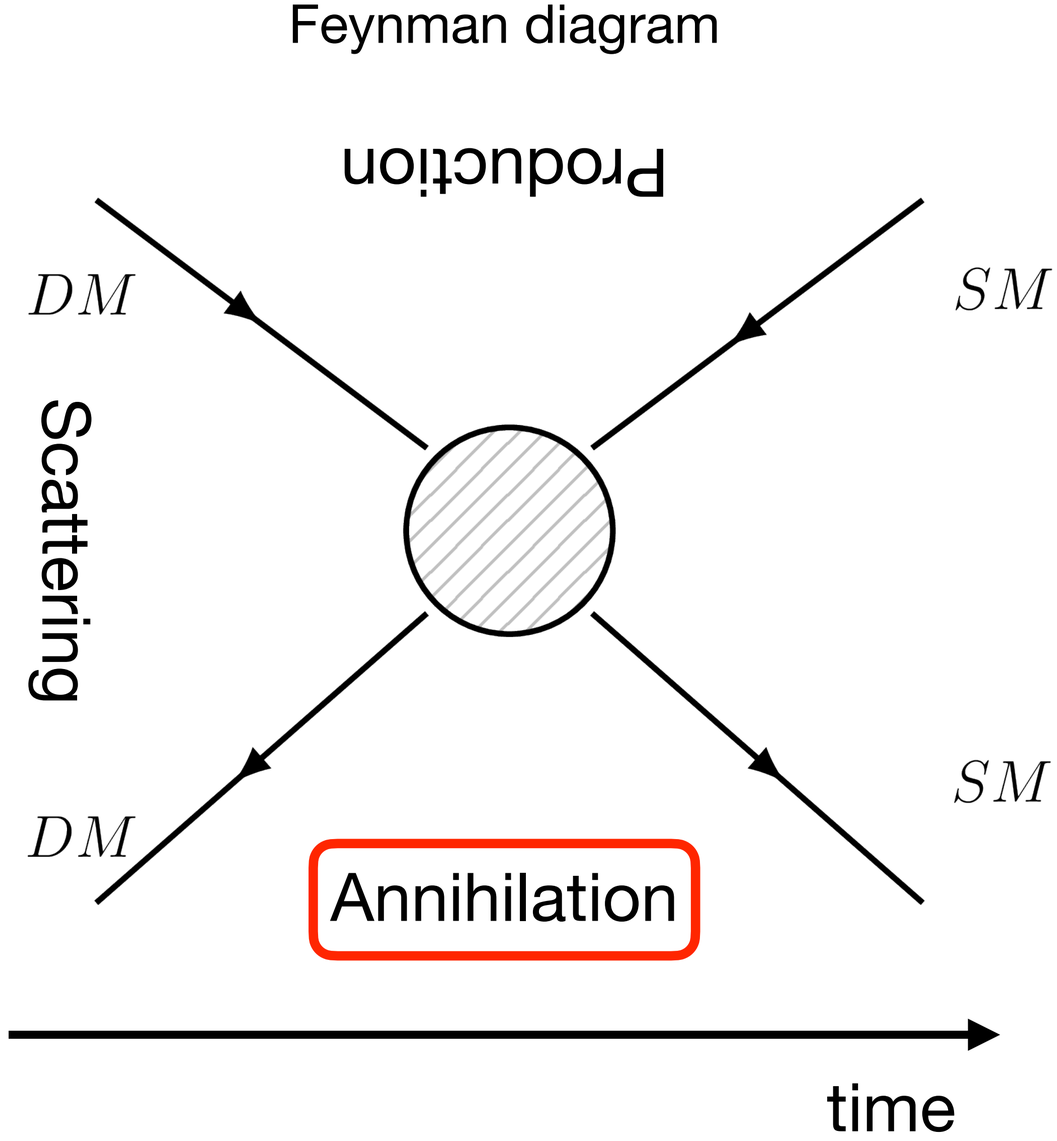
Standard Model (SM)



Describes the fundamental forces that regulate the interaction between elementary particles

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



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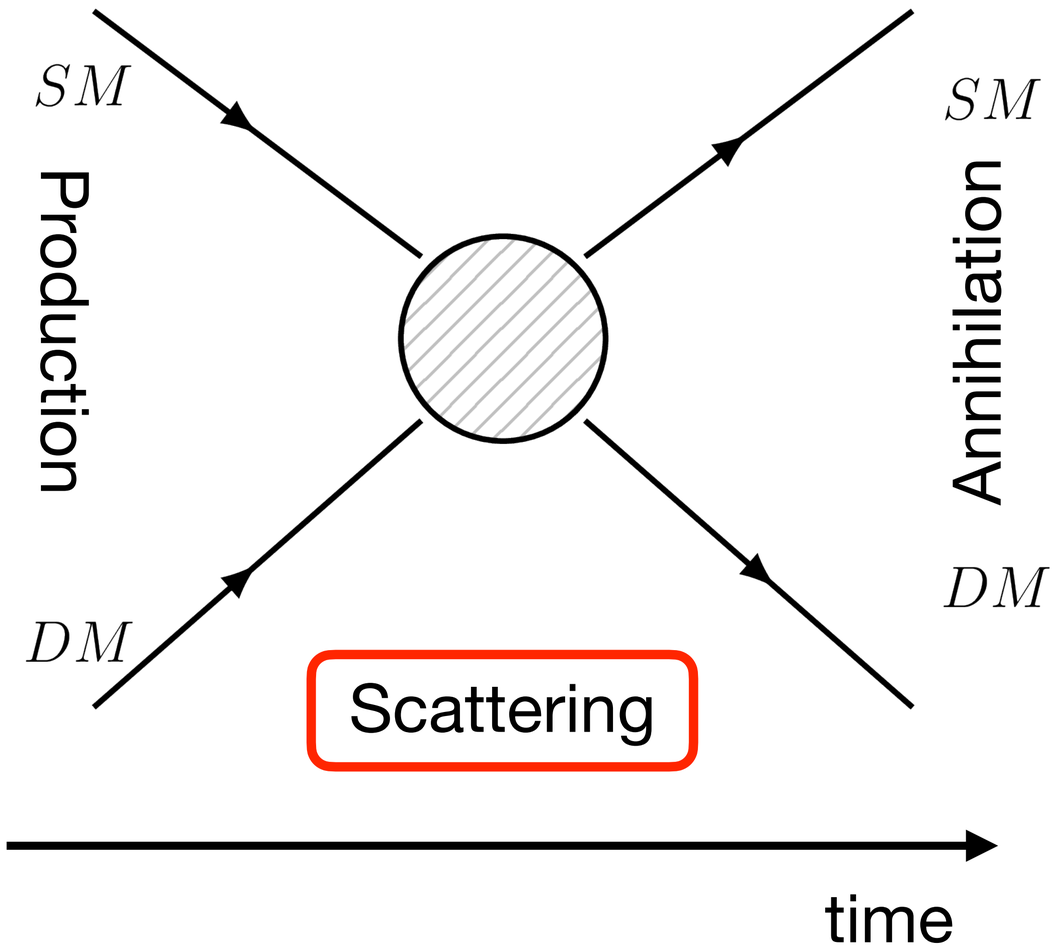
Feynman diagram



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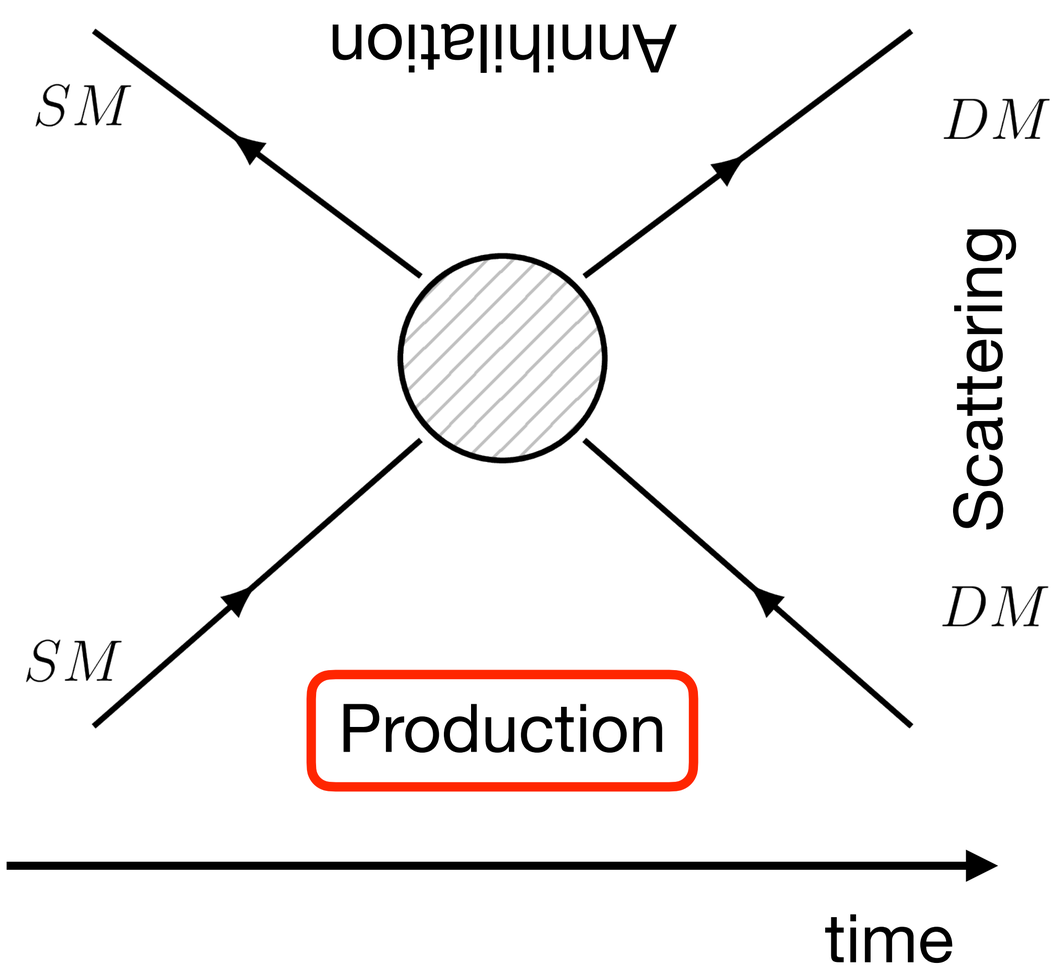
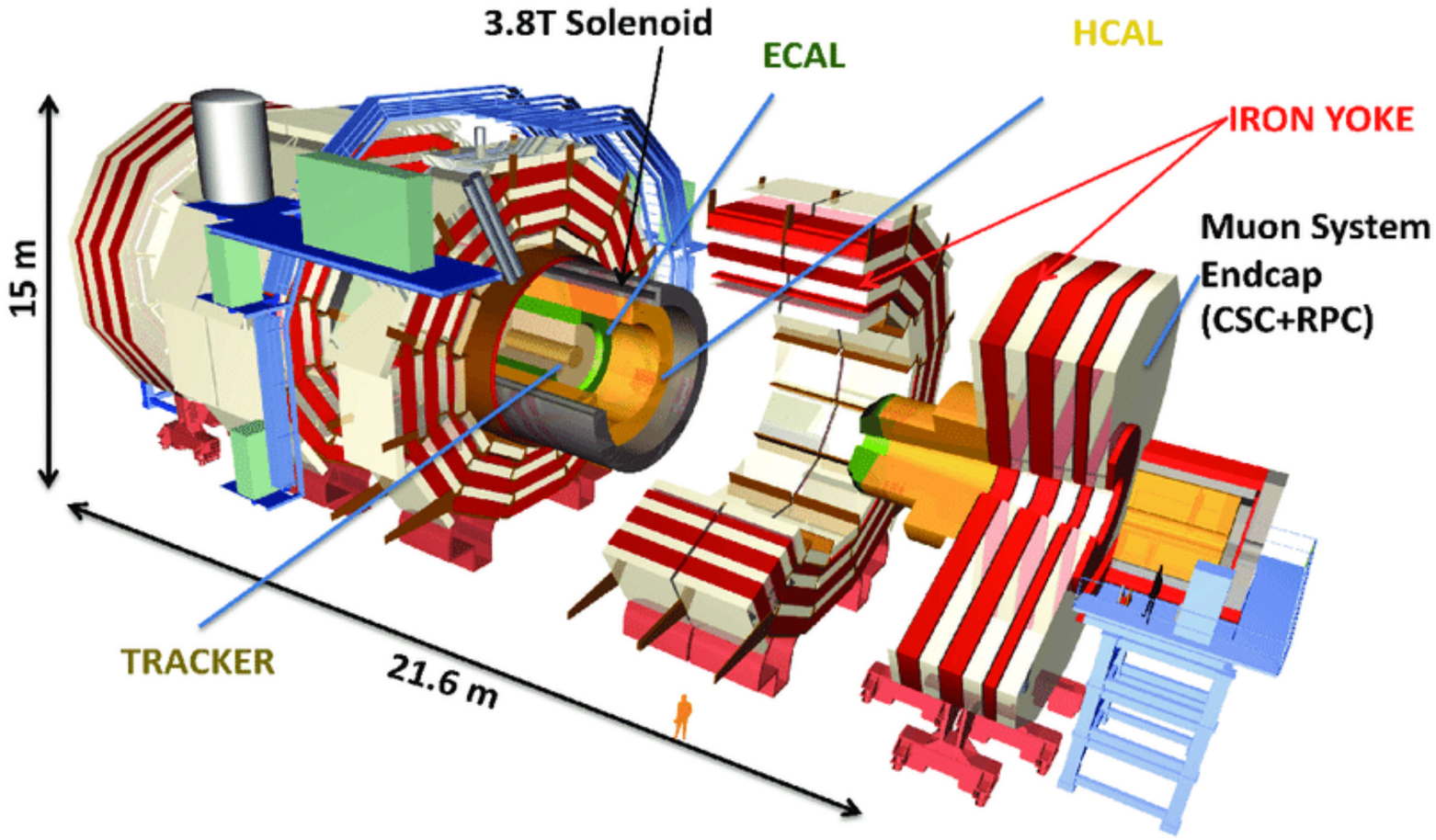


Large Hadron Collider (LHC)

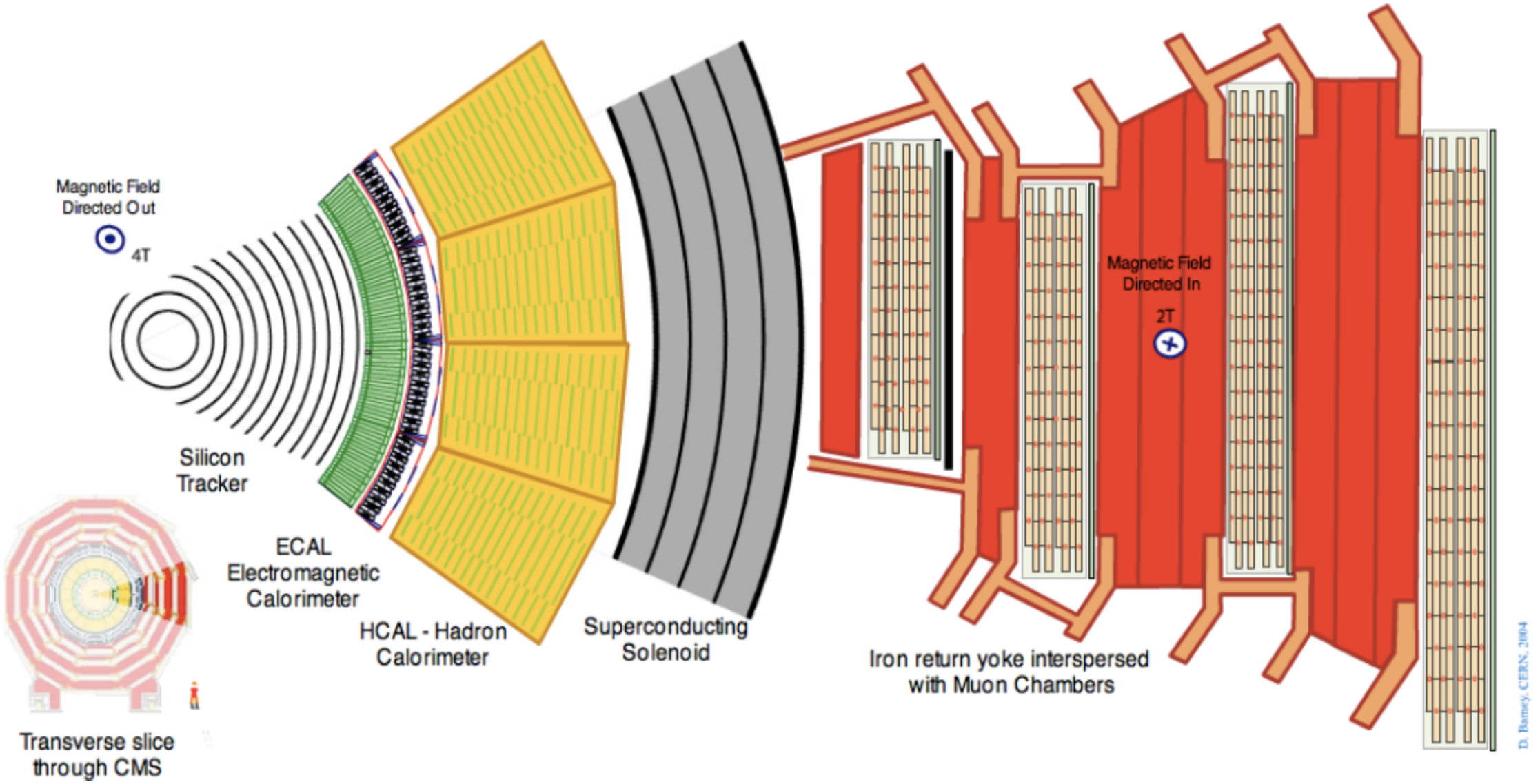
- Most powerful accelerator ever built
- Collides protons, accelerating them at ~speed of light
- 27 km in circumference

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)



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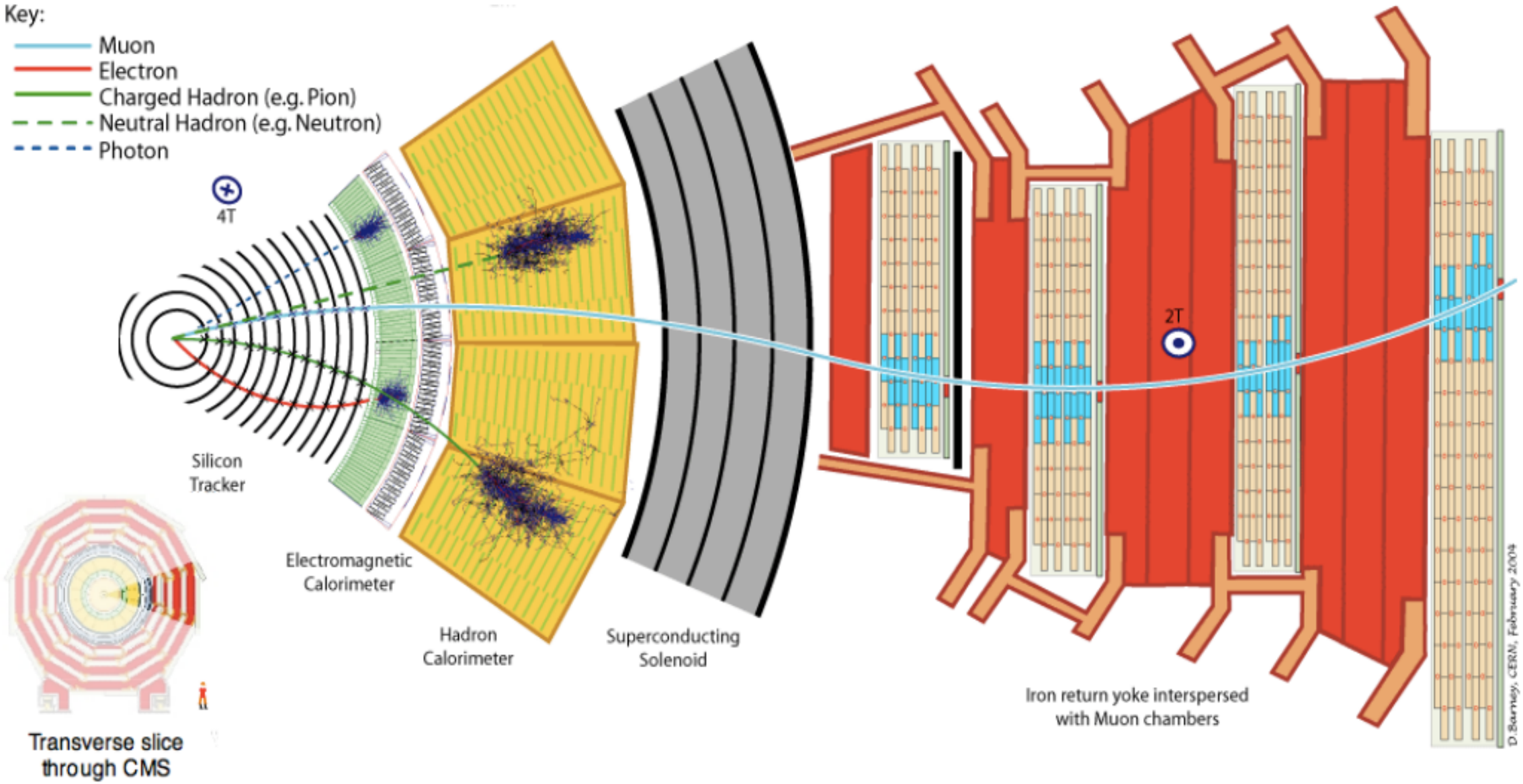
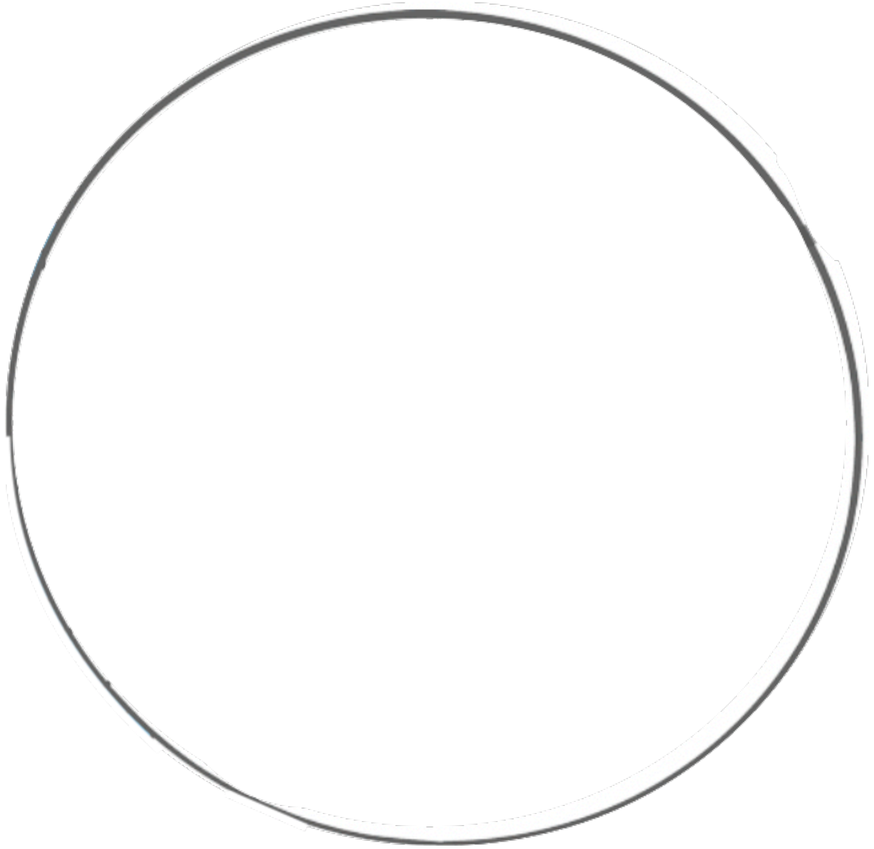


Missing Transverse Momentum ($\mathbf{p_T^{miss}}$)

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

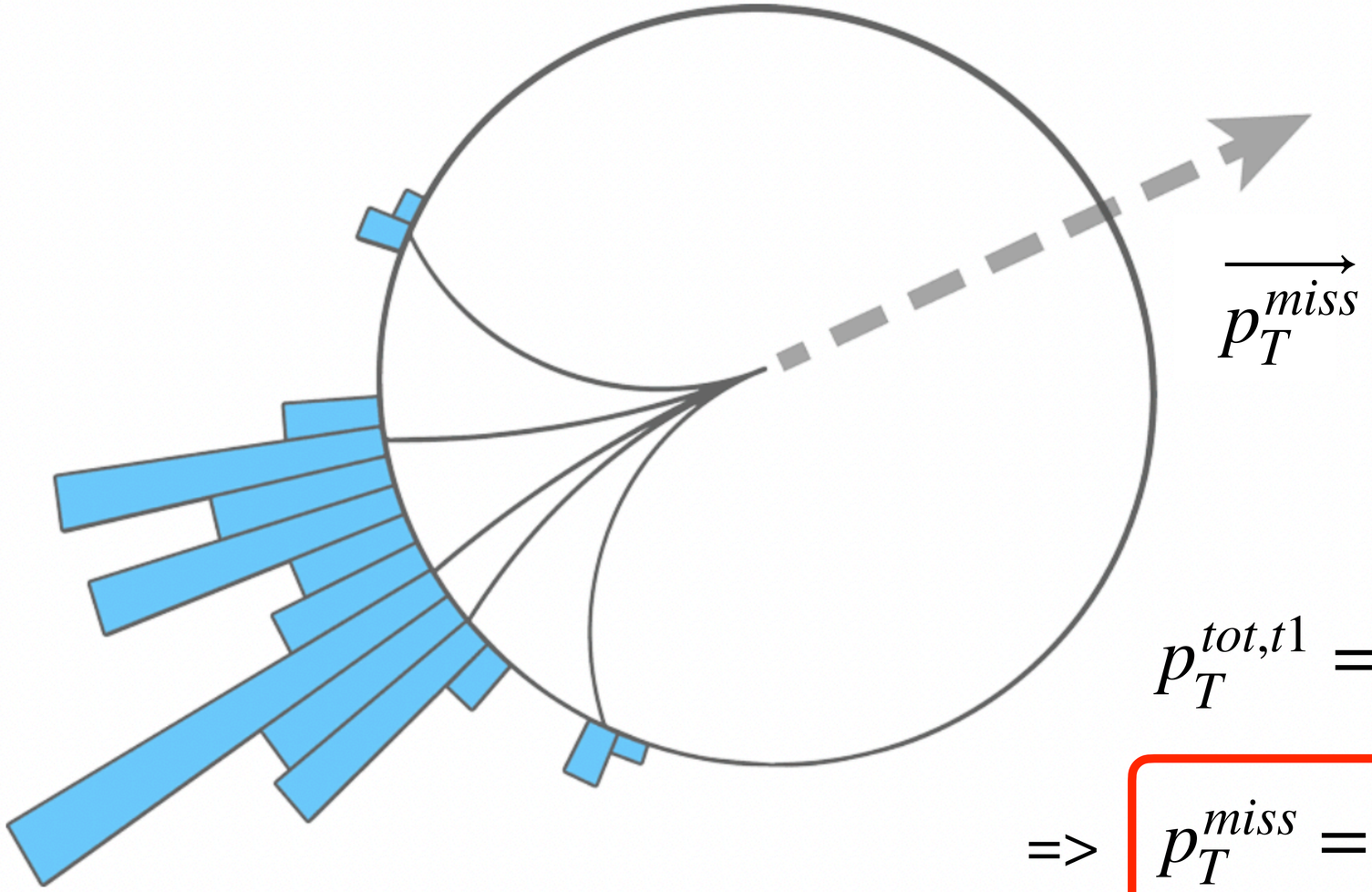
t0: before collision



Missing Transverse Momentum (p_T^{miss})

$$\overrightarrow{p_T^{tot}} = \sum_{\text{All visible particles}} \overrightarrow{p_T} + \overrightarrow{p_T^{miss}}$$

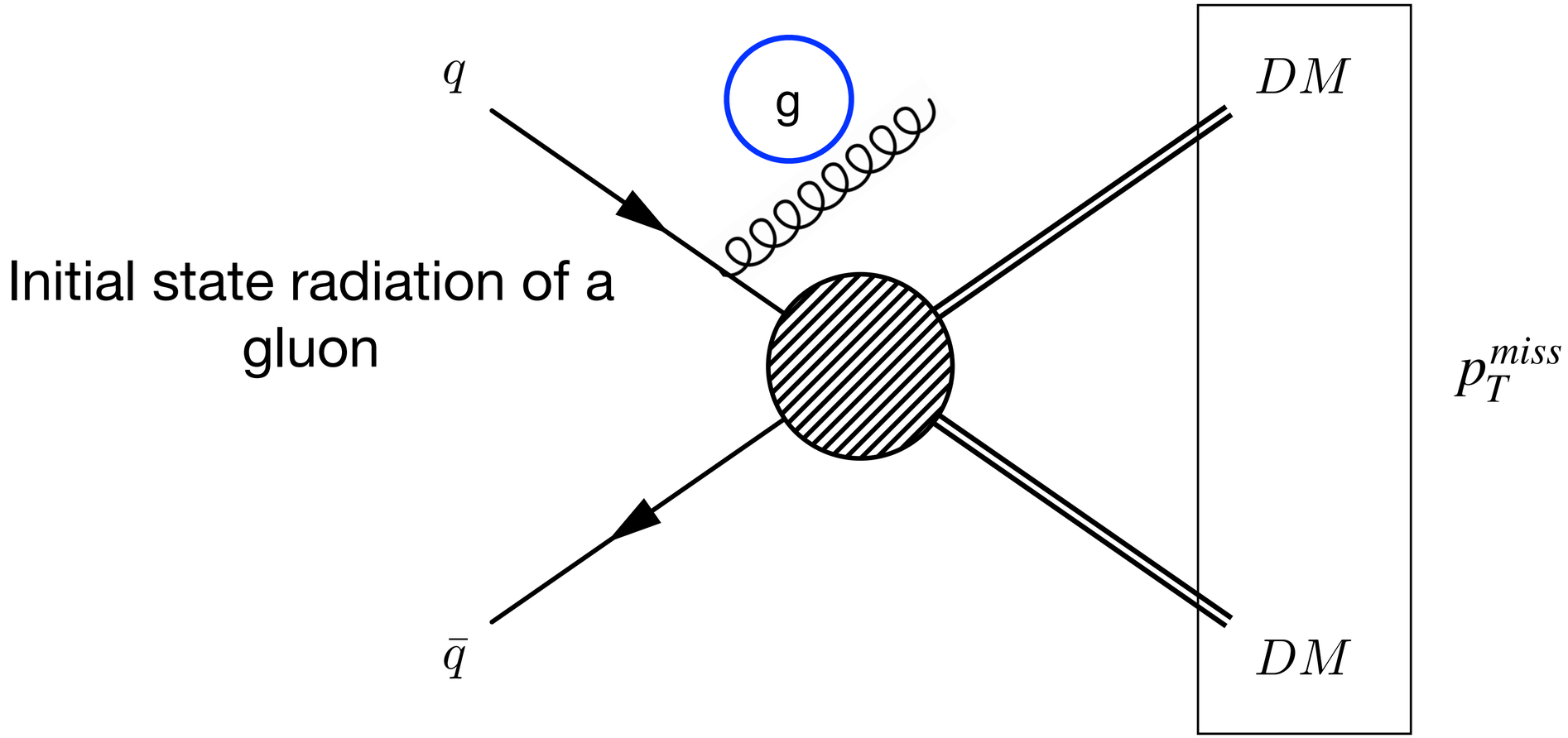
after collision



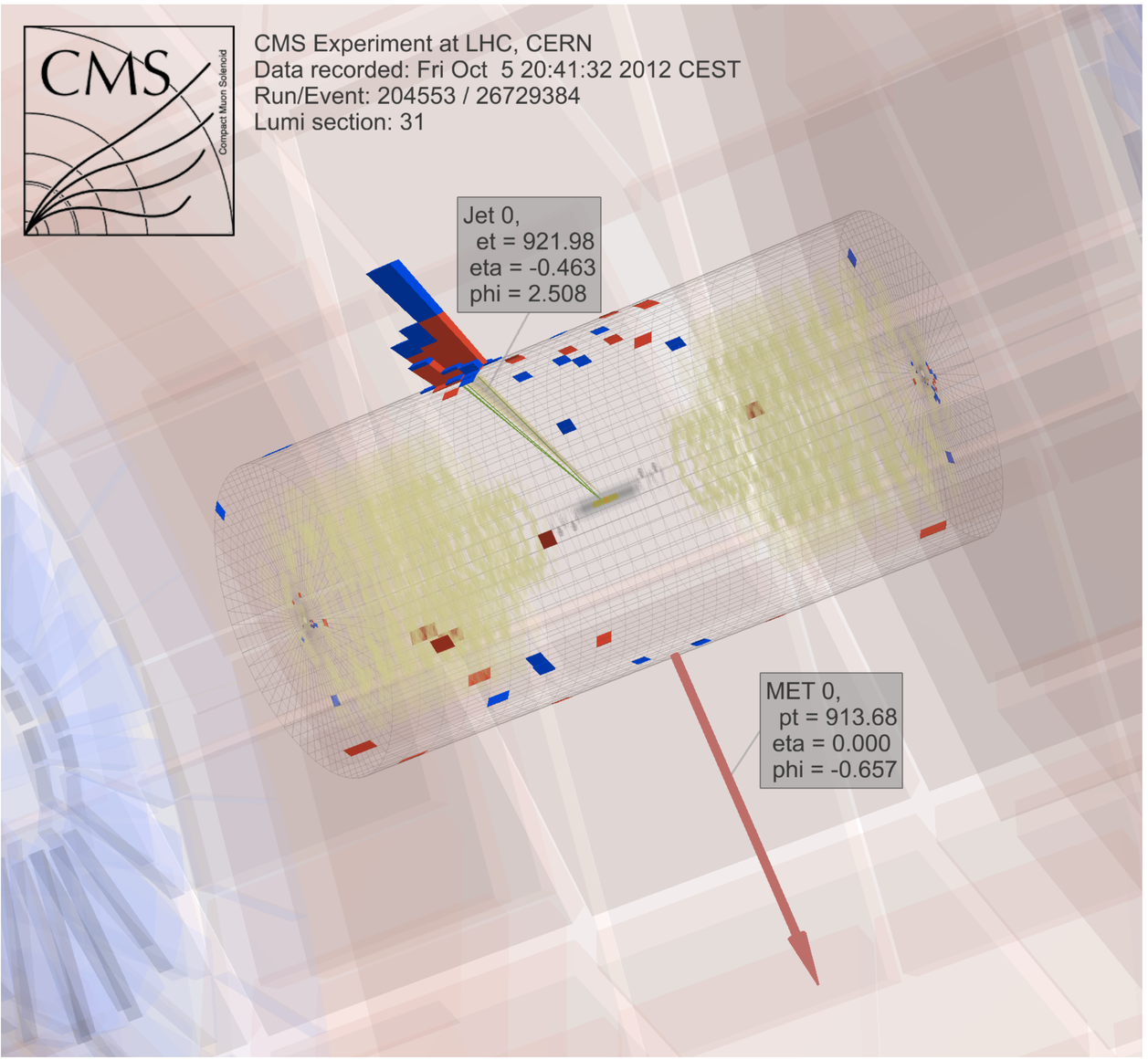
$$p_T^{tot,t1} = p_T^{tot,t0} = 0$$

$$\Rightarrow \quad p_T^{miss} = -\left|\sum \overrightarrow{p_T}\right|$$

Experimental Approach



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


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,
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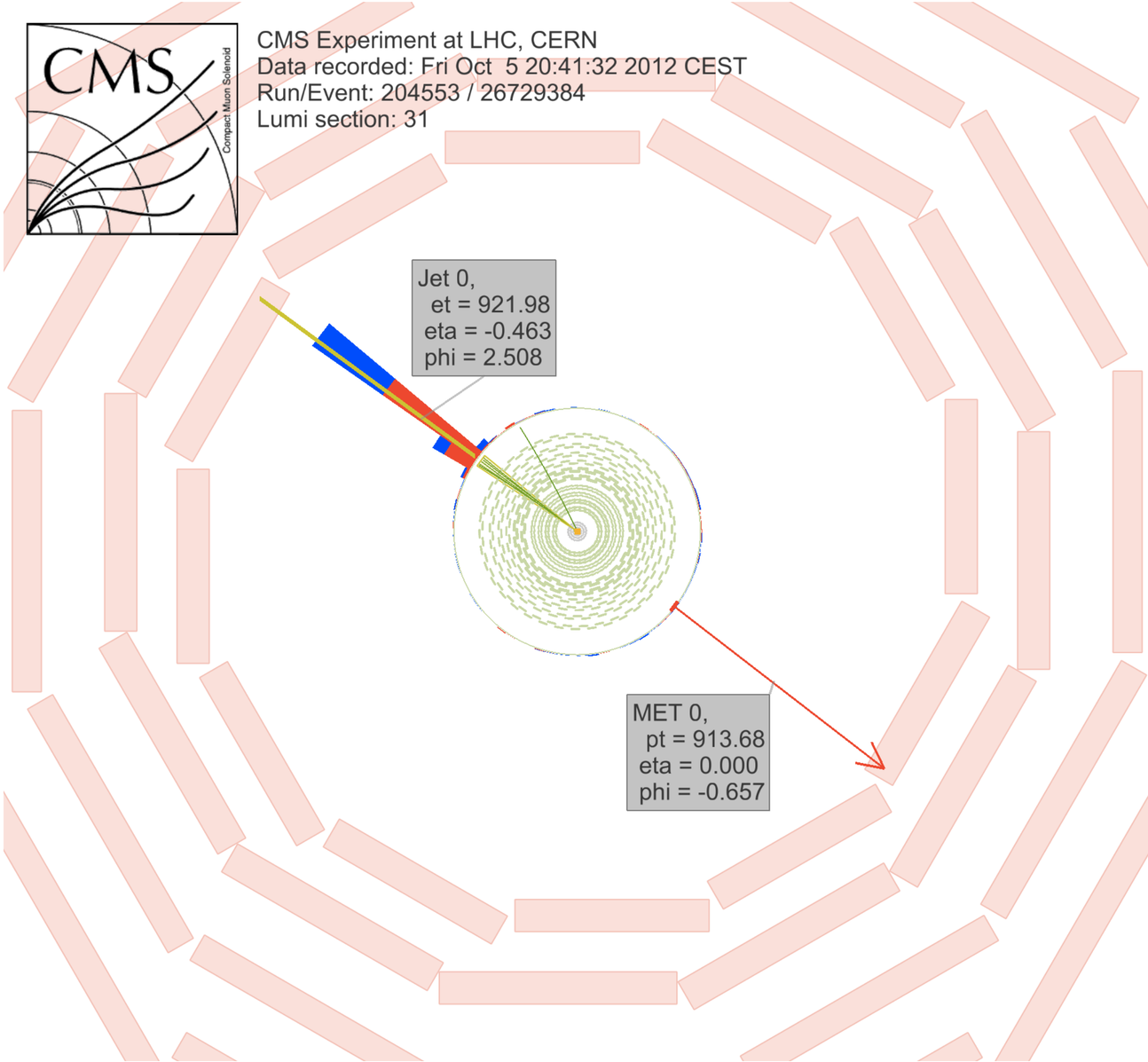
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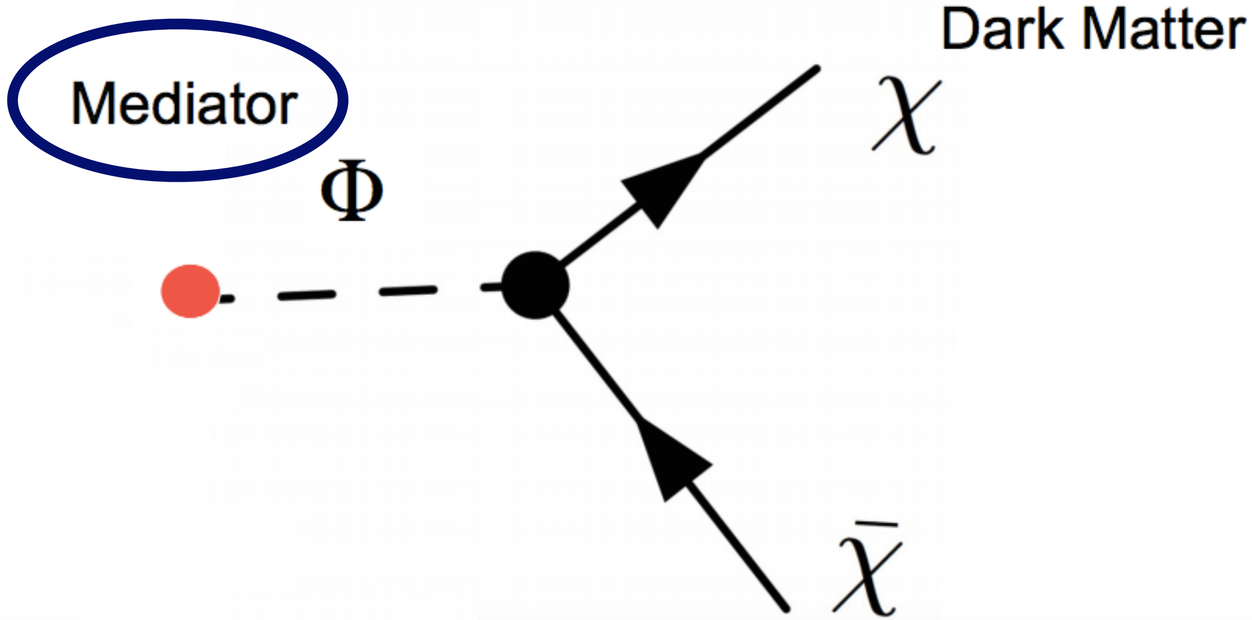
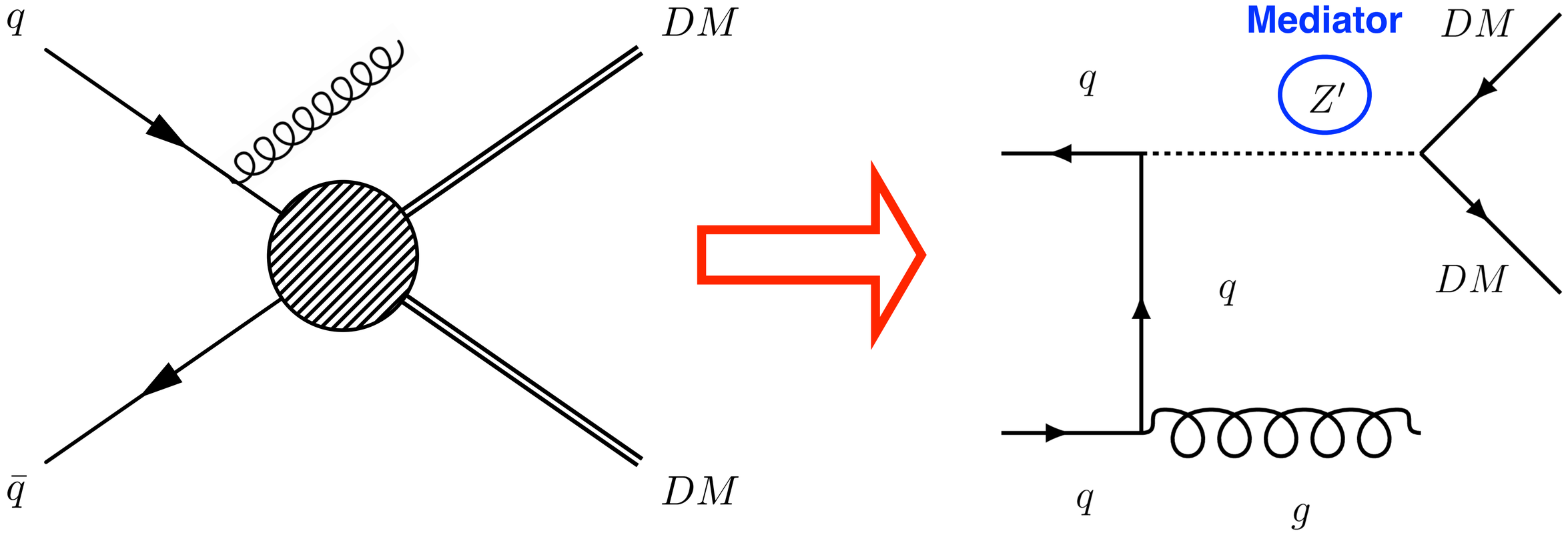
Why at Colliders?

- 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



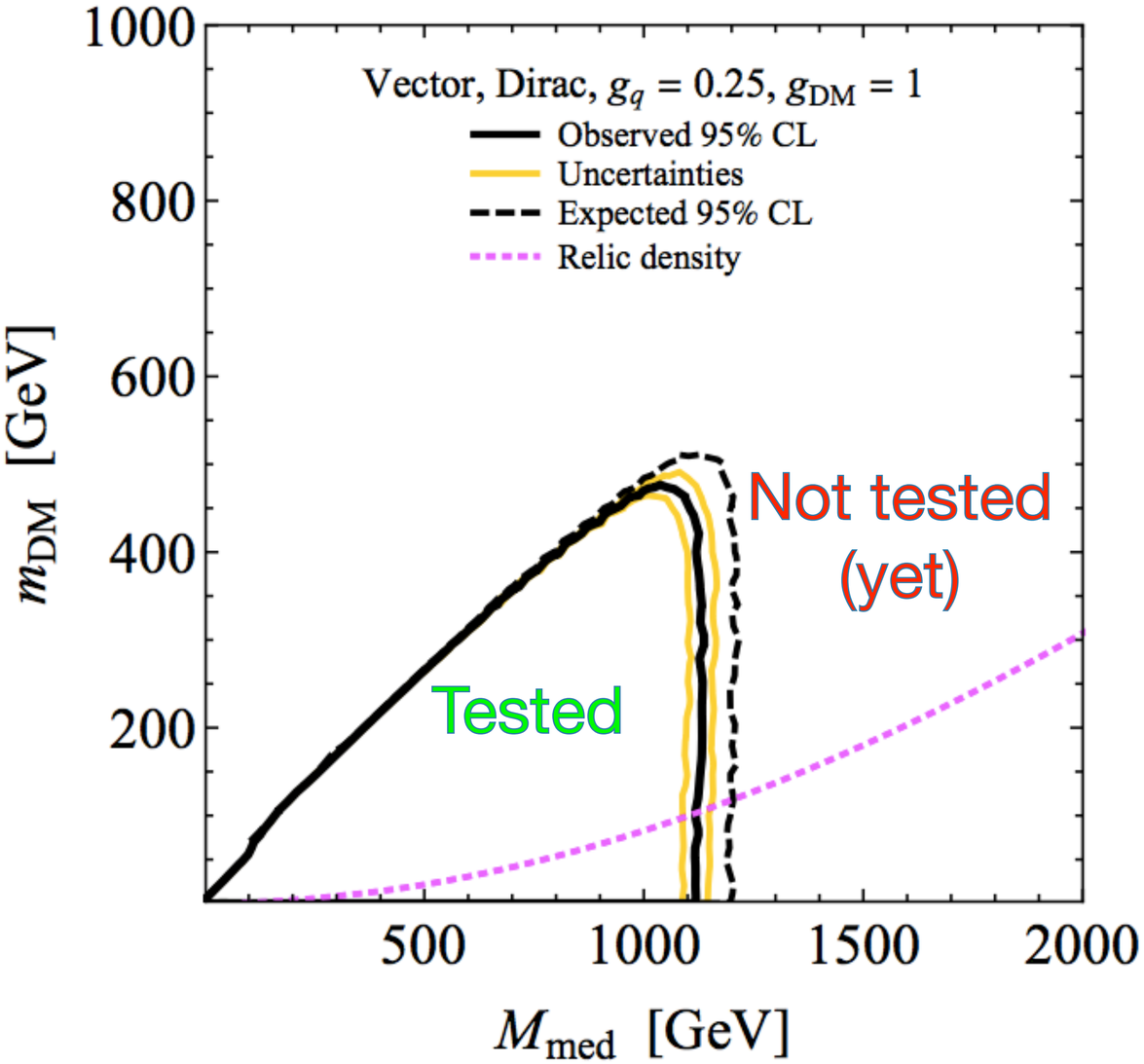
Theoretical Interpretation

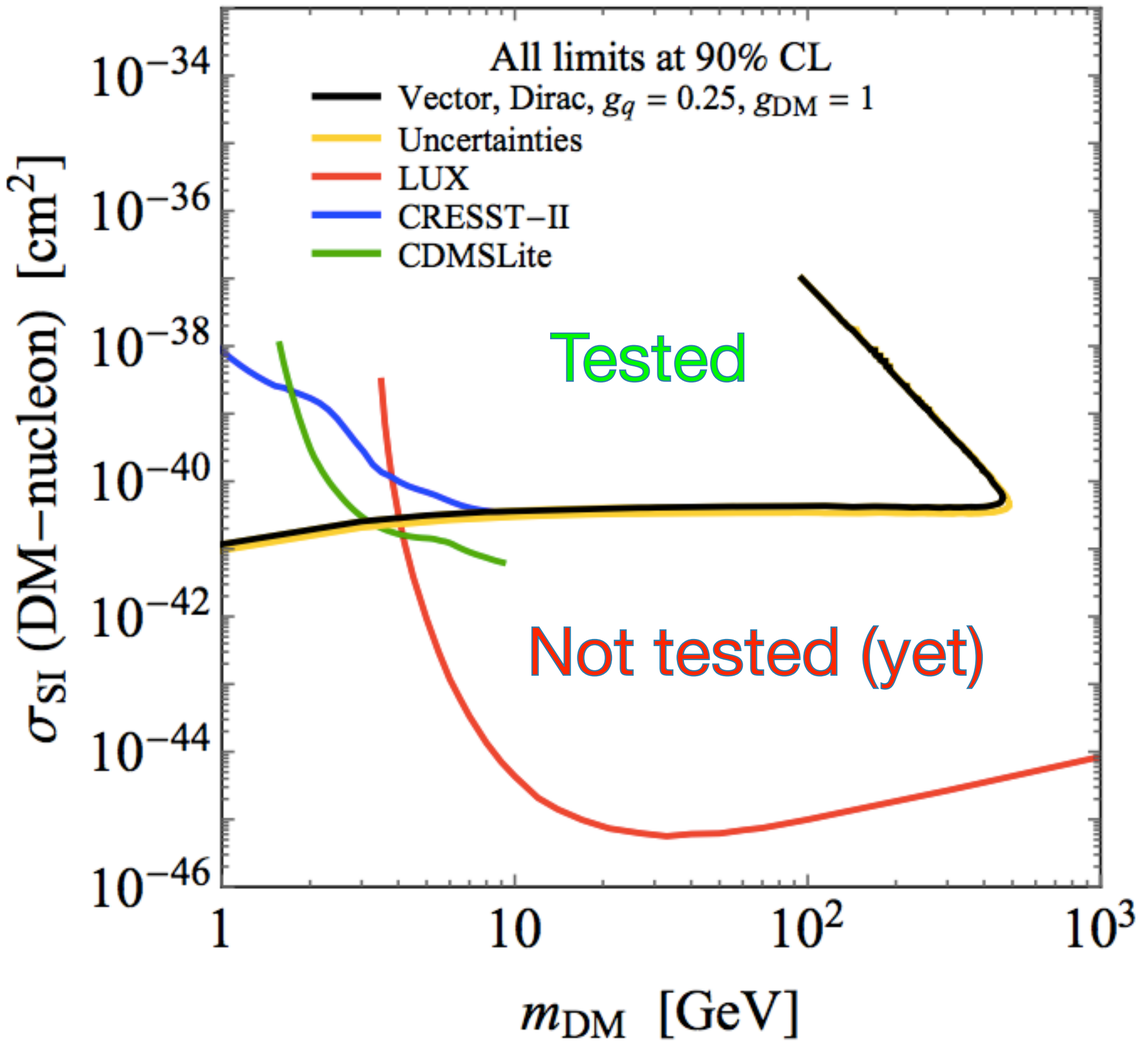


Presentation of Results (Example)

LHC DM WG, arxiv:1603.04156

Recommendations on presenting LHC searches for missing transverse energy signals using simplified s-channel models of dark matter





Our analysis

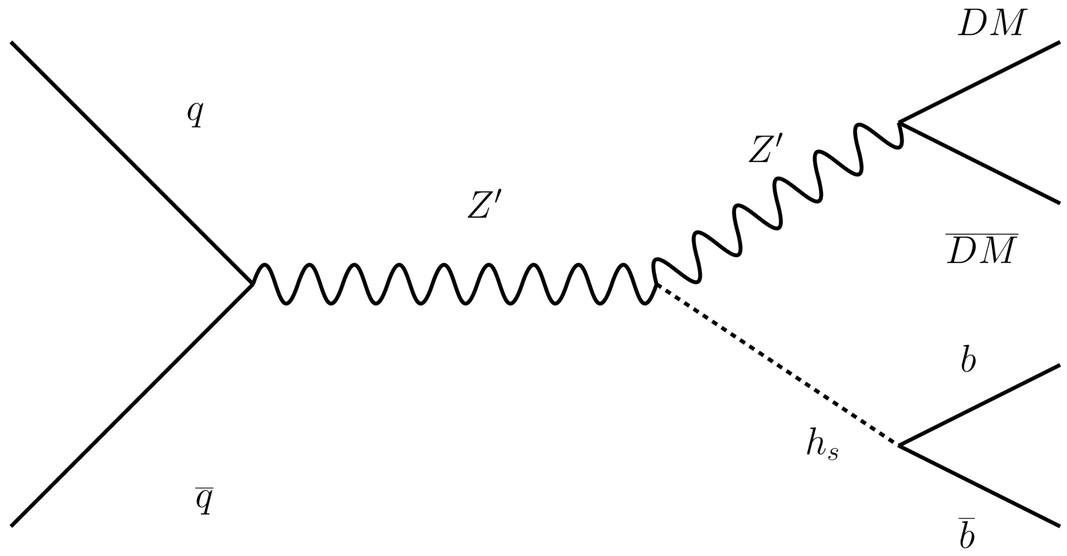
- First search for dark Higgs boson decaying into a b-quark pair in CMS
- Using full Run-2 dataset (138 fb^{-1})
- Still ongoing
  - Pre-approved, going for approval

Dark Higgs Model

https://arxiv.org/abs/1701.08780

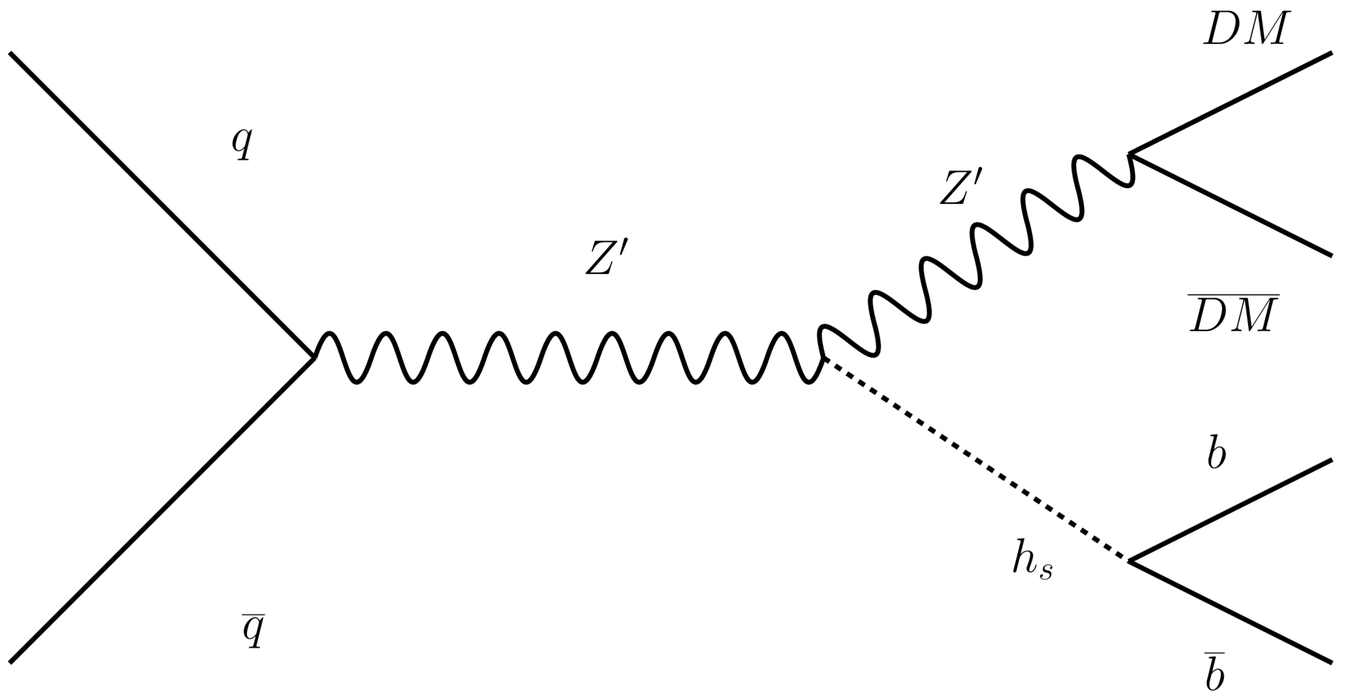
- Dark Higgs (h_s)is the lightest state in the dark sector
  - Does not decay into DM
- Mixes with the SM Higgs
  - Unstable, decays into "$b\bar{b}$"

=> Relic density set primarily by the $DMDM -> h_s h_s$annihilation channel



Signal MC Samples

https://arxiv.org/abs/1701.08780



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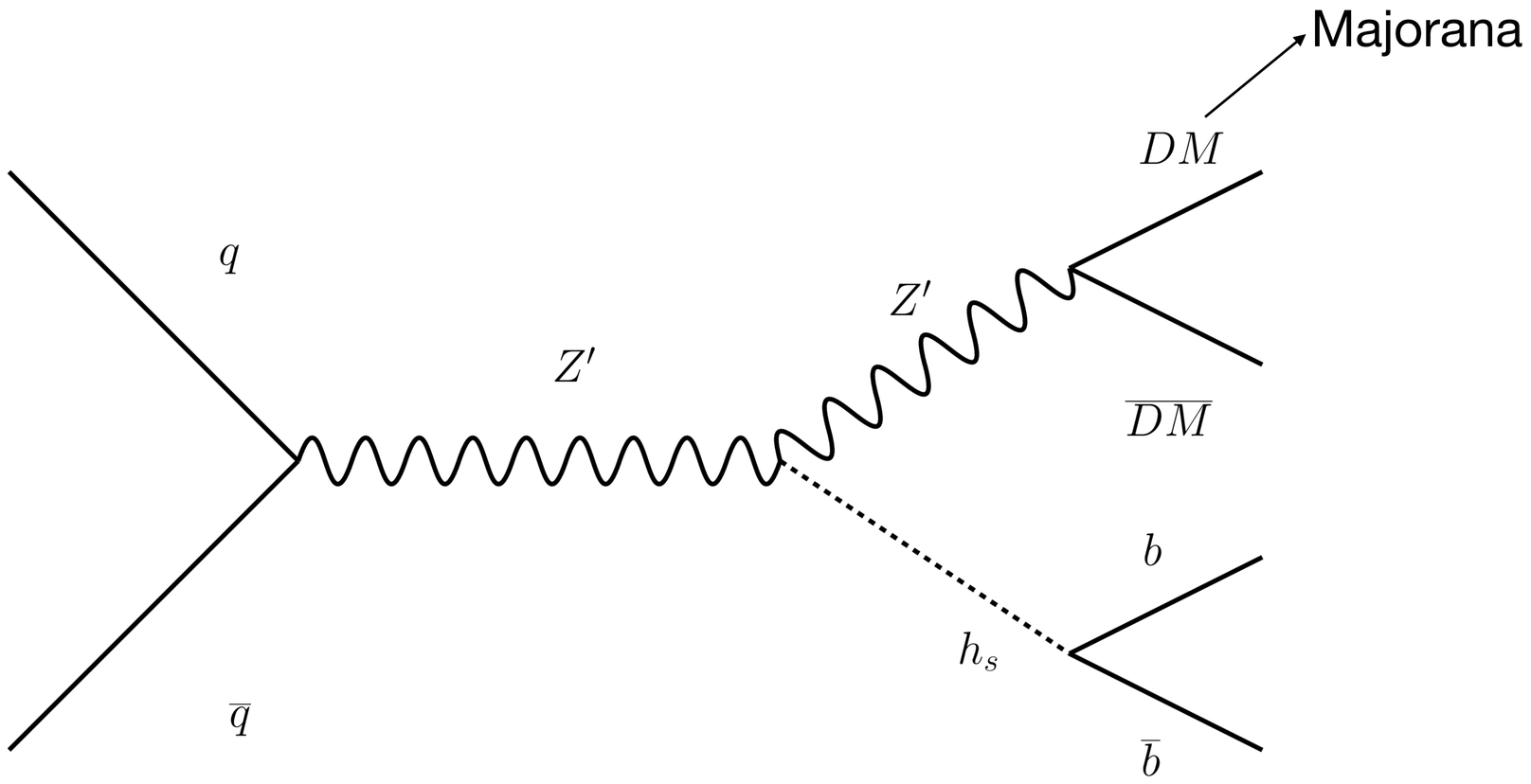

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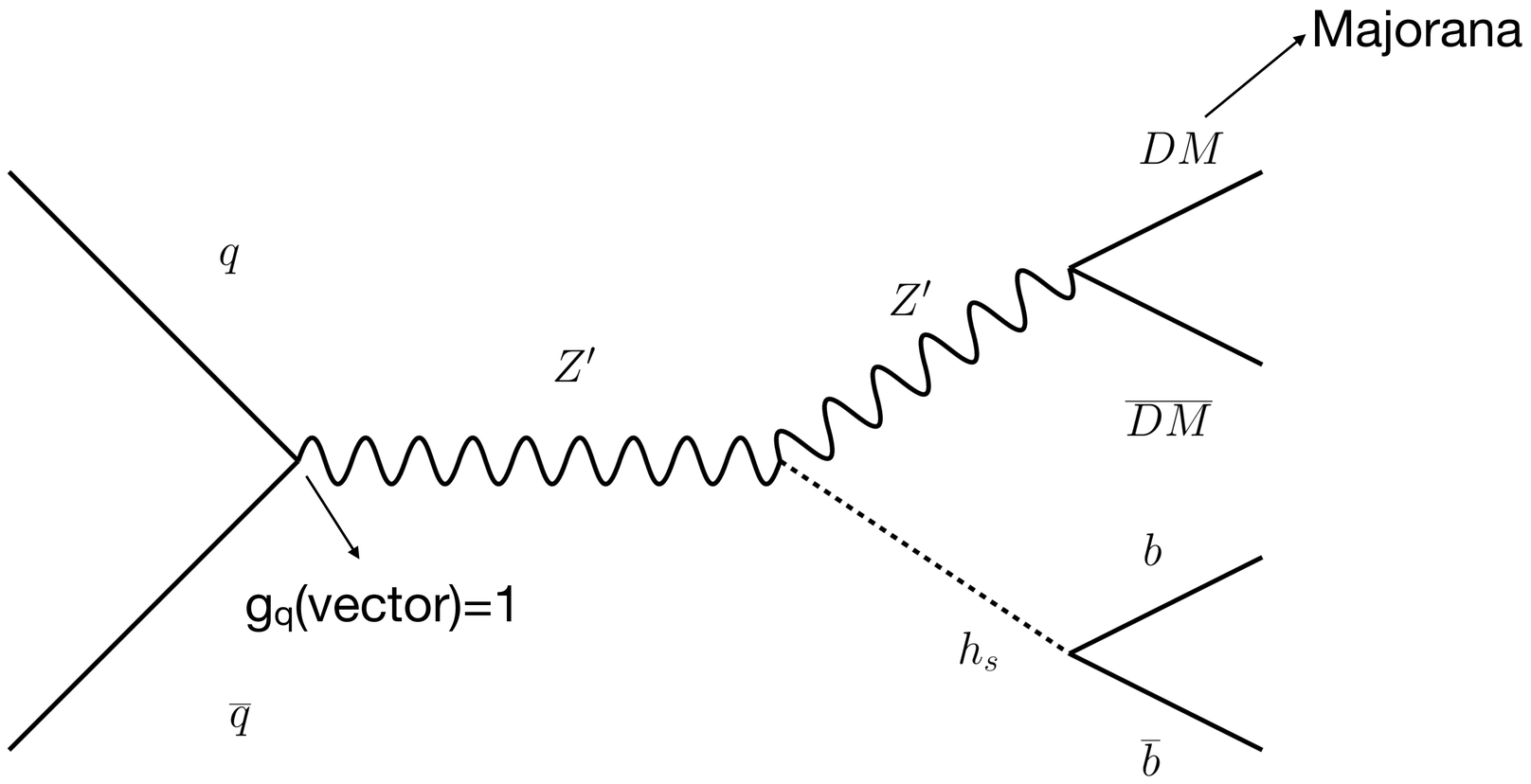

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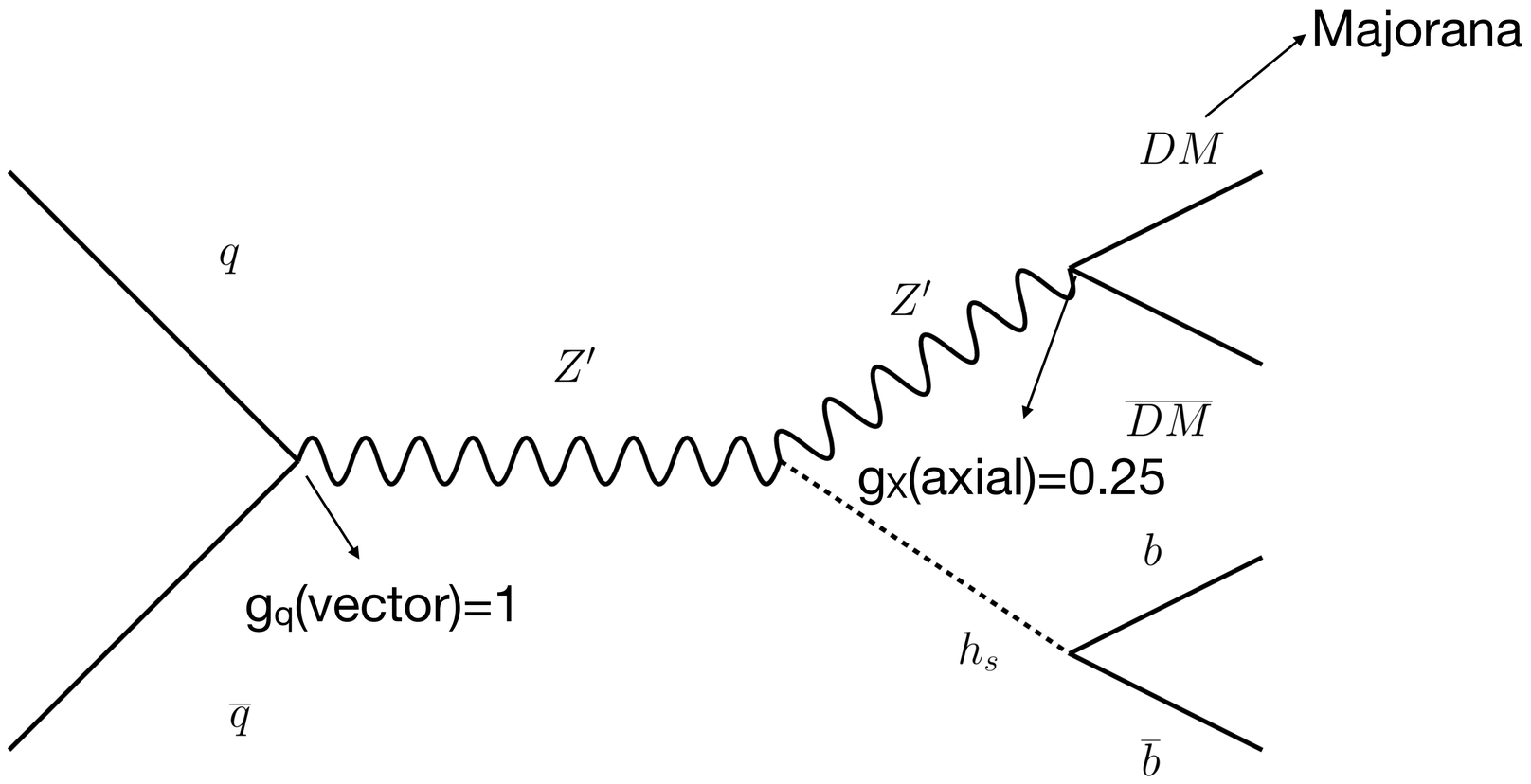

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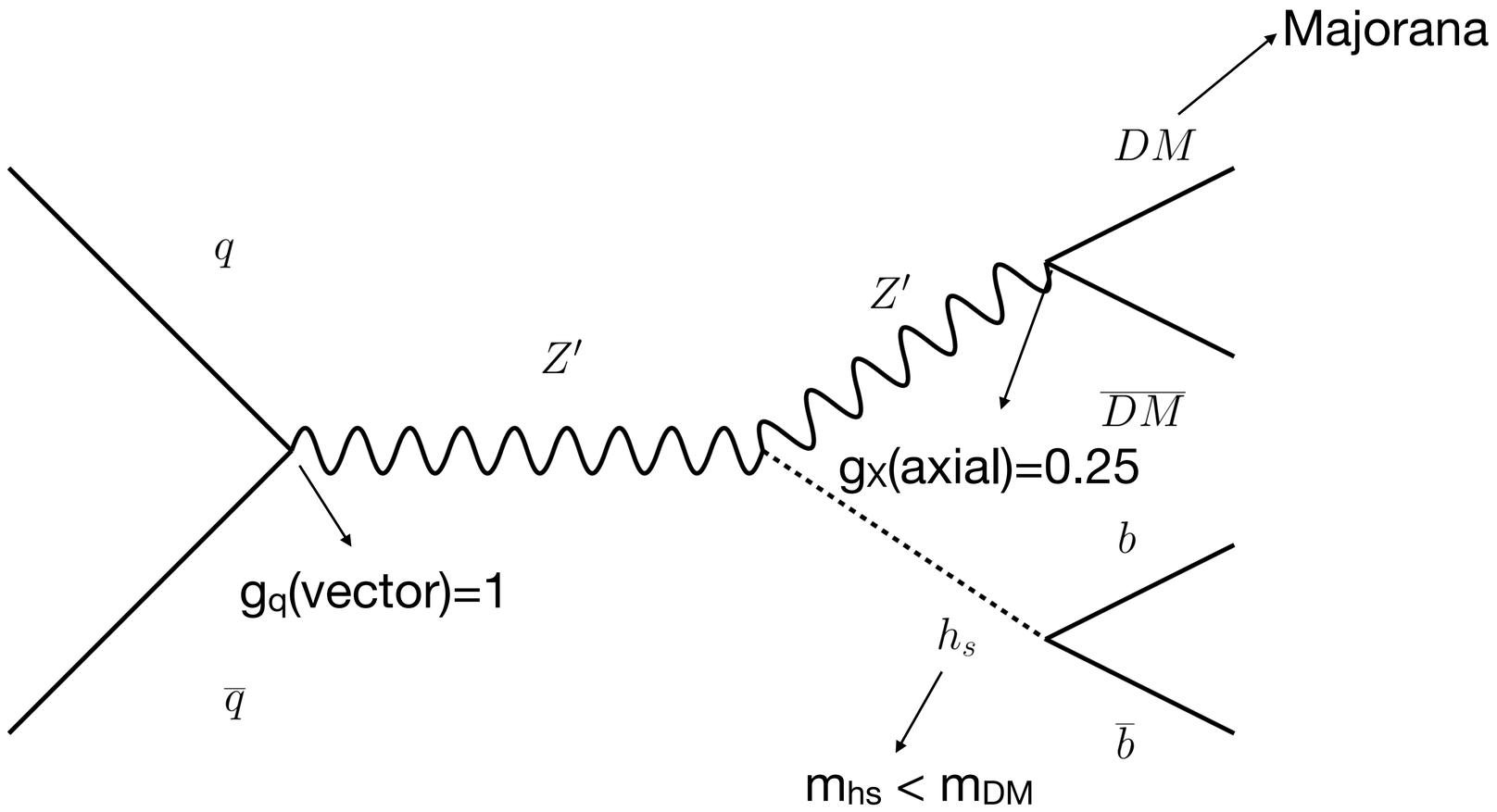

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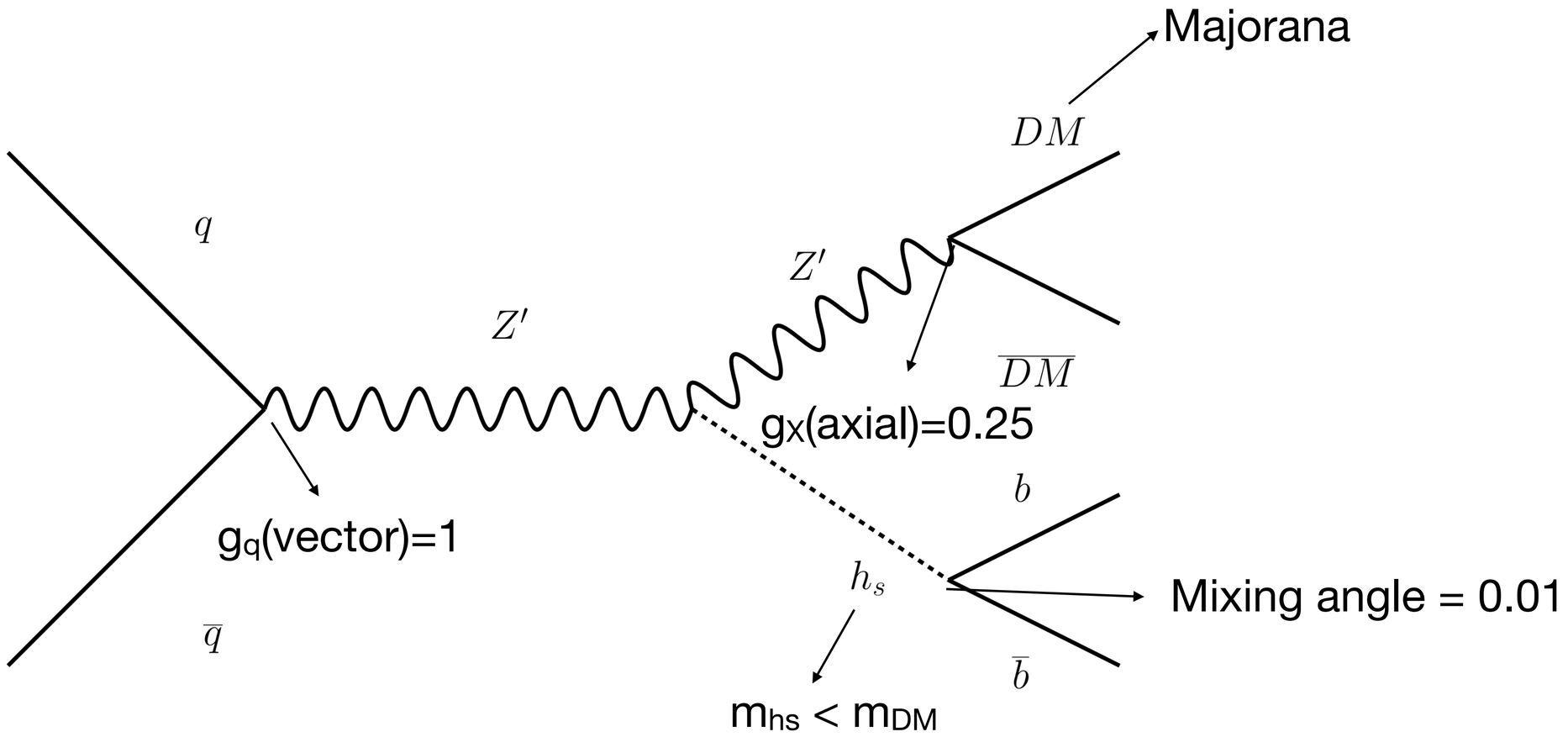

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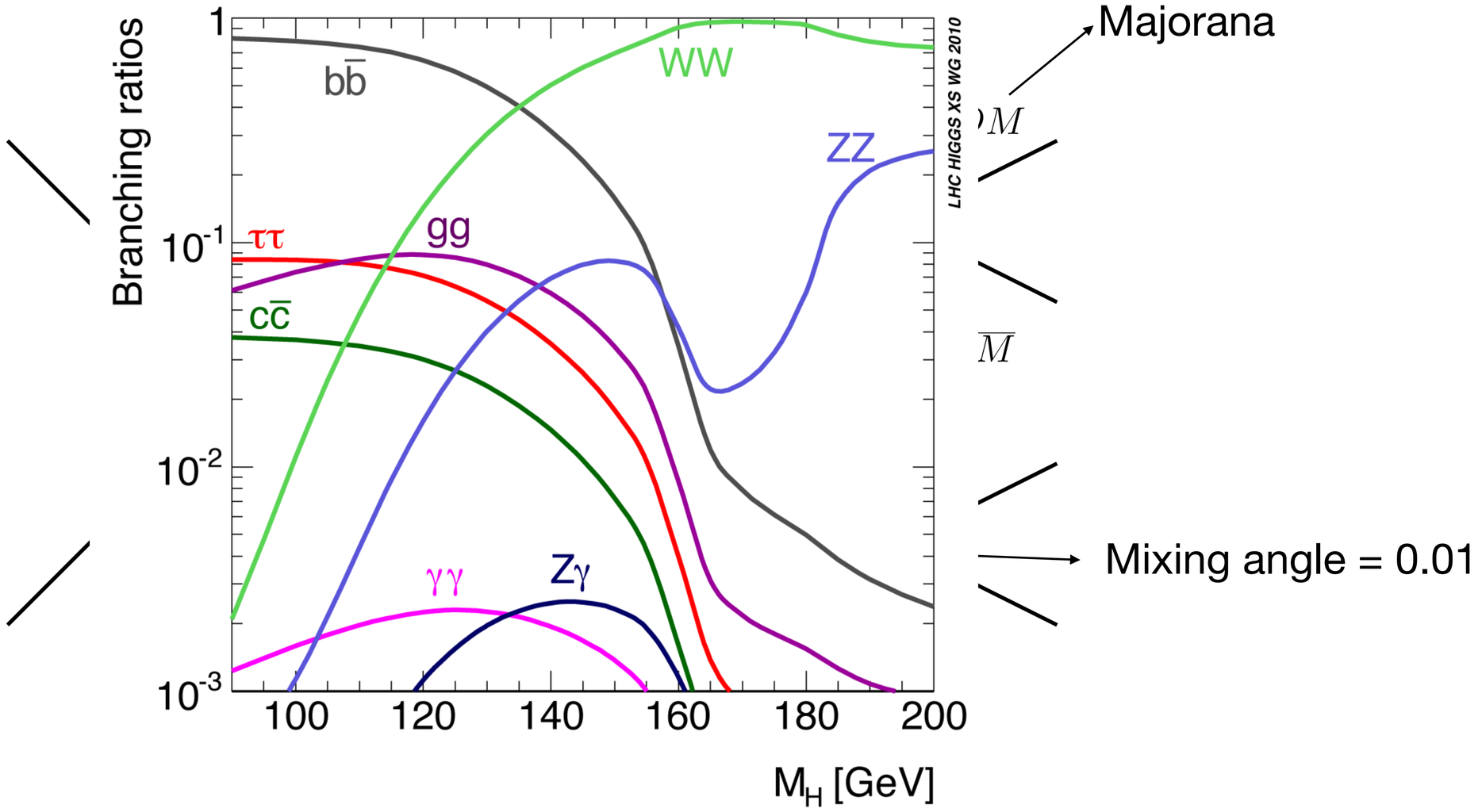

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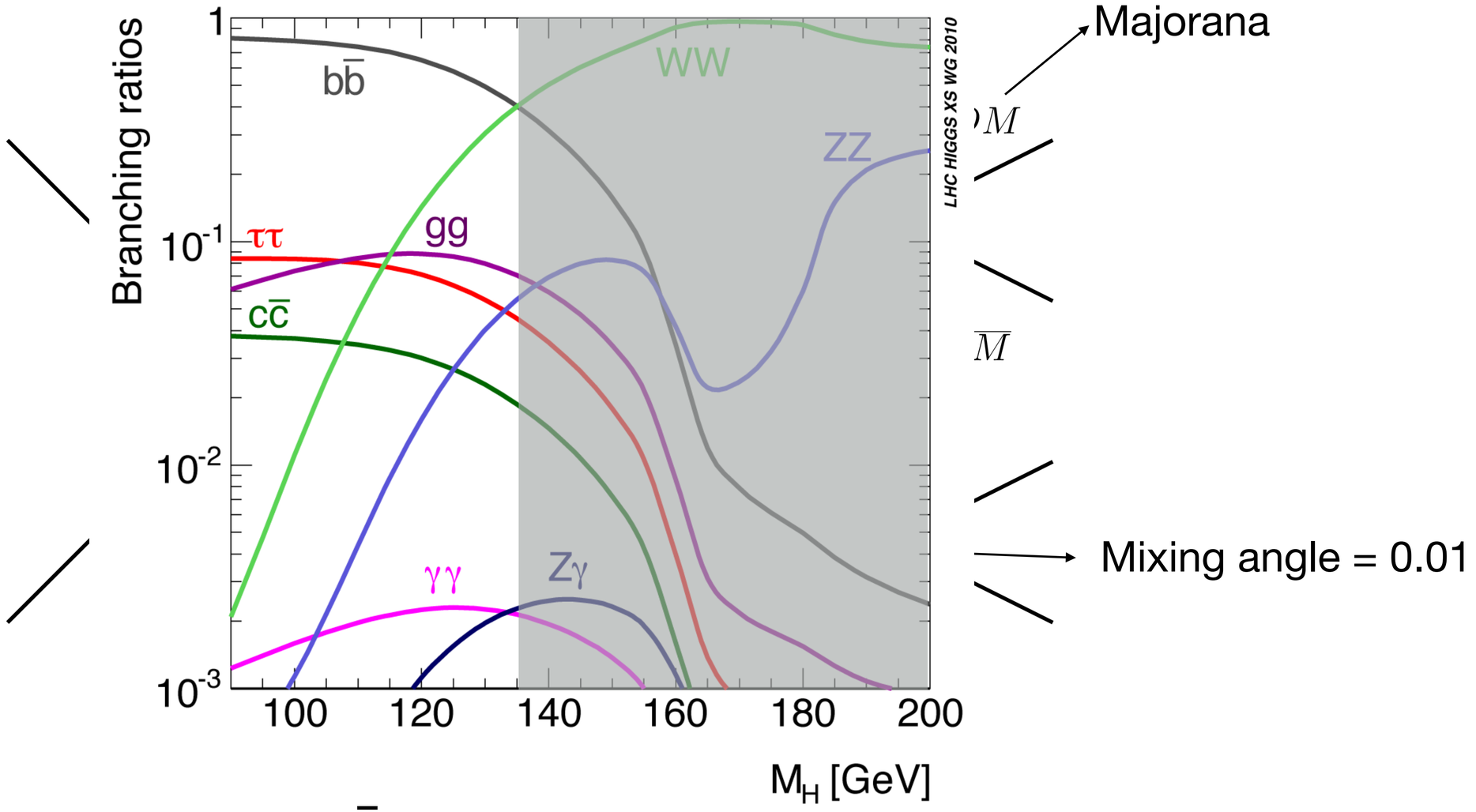

$h_s -> b\bar{b}$ dominates below 135 GeV

Signal MC Samples

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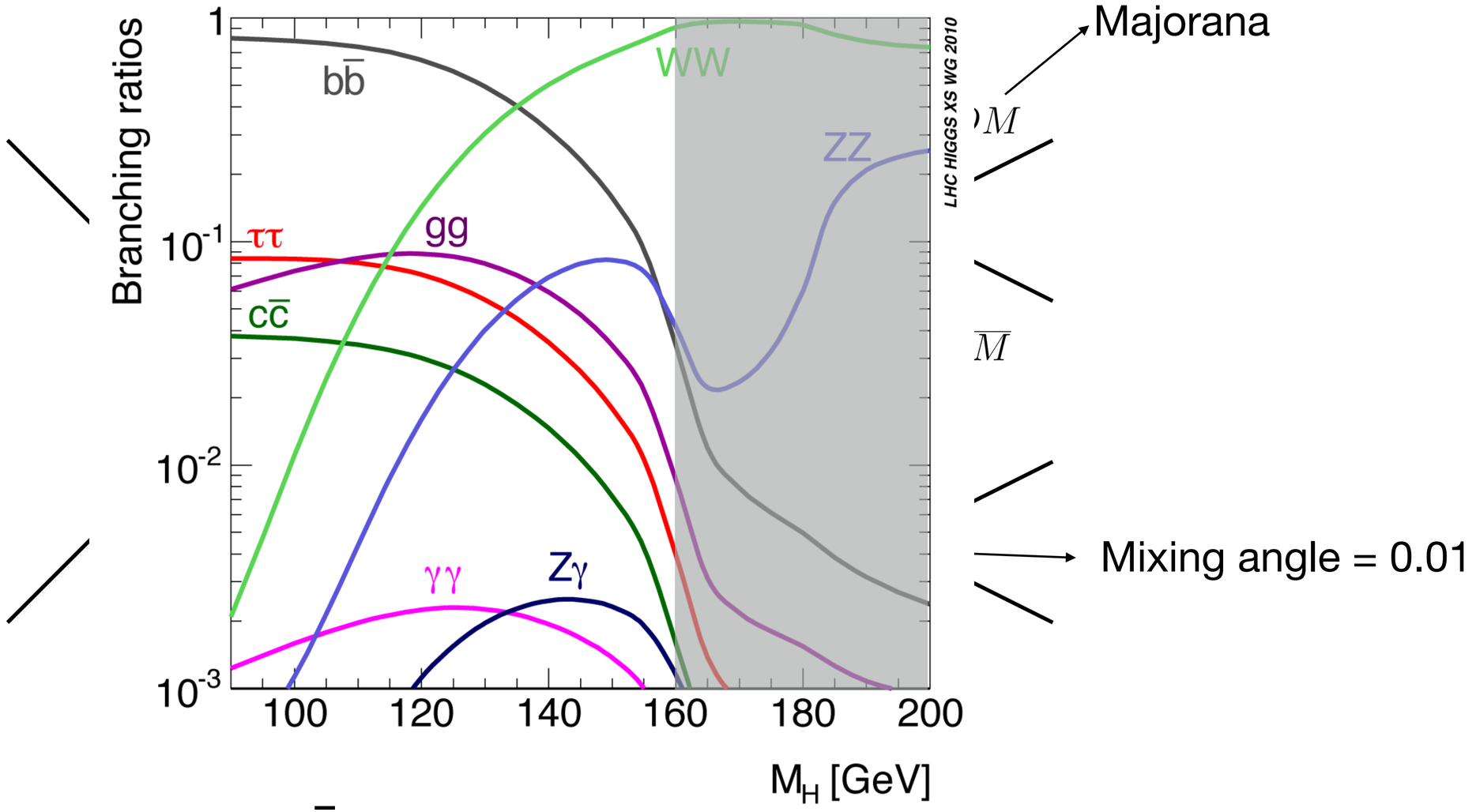
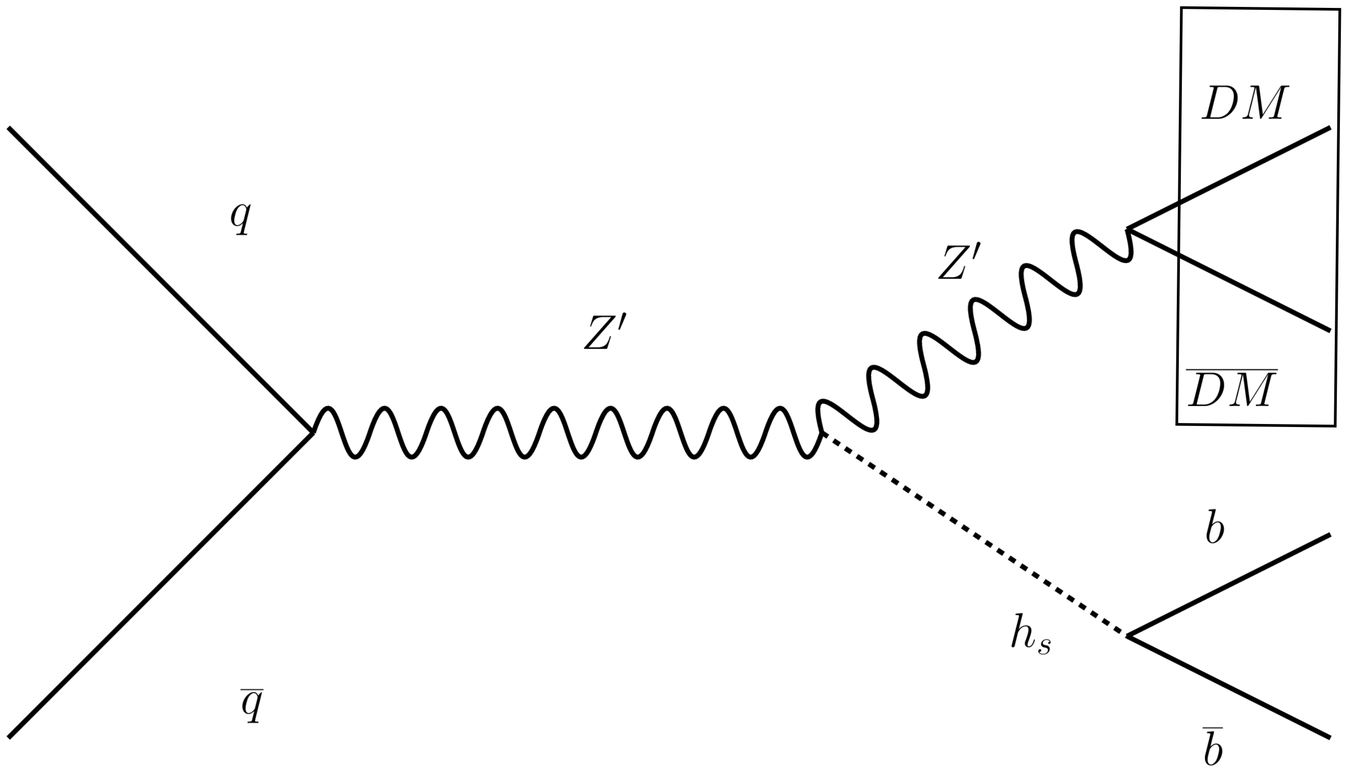
Focus on
$m_{hs} < 160$ GeV

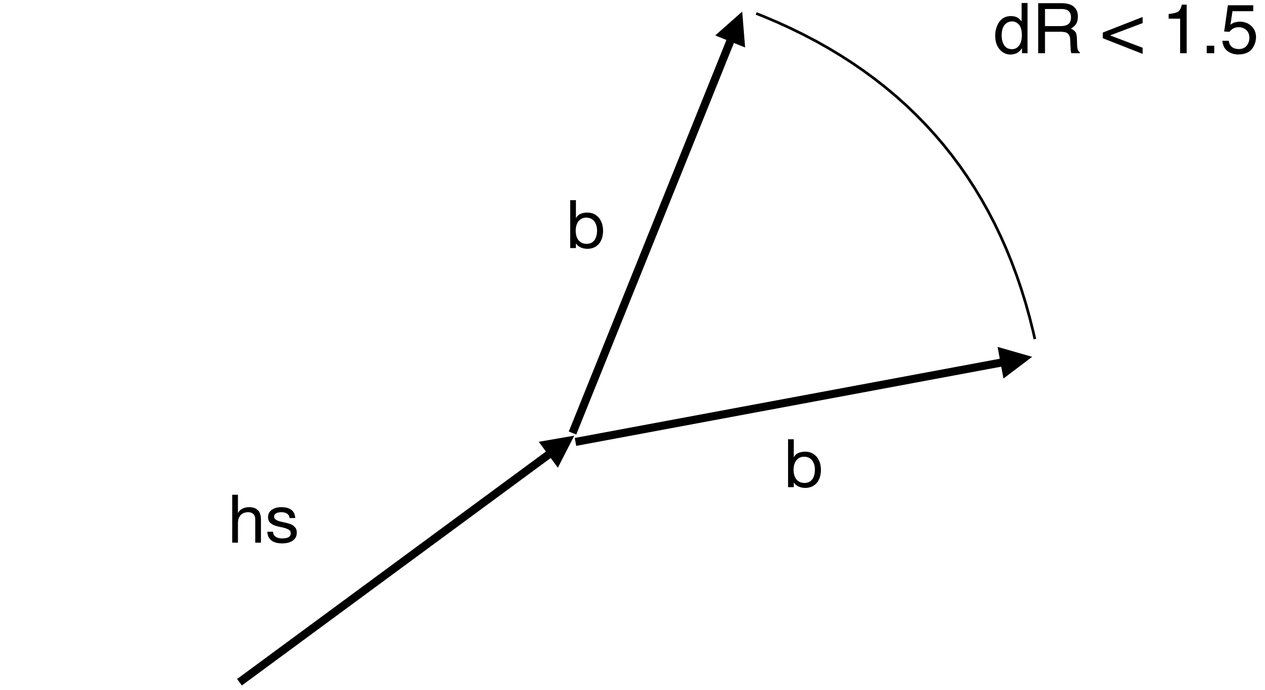


$h_s -> b\bar{b}$ still significant below 160 GeV

Event Selection

PFMET > 250 GeV

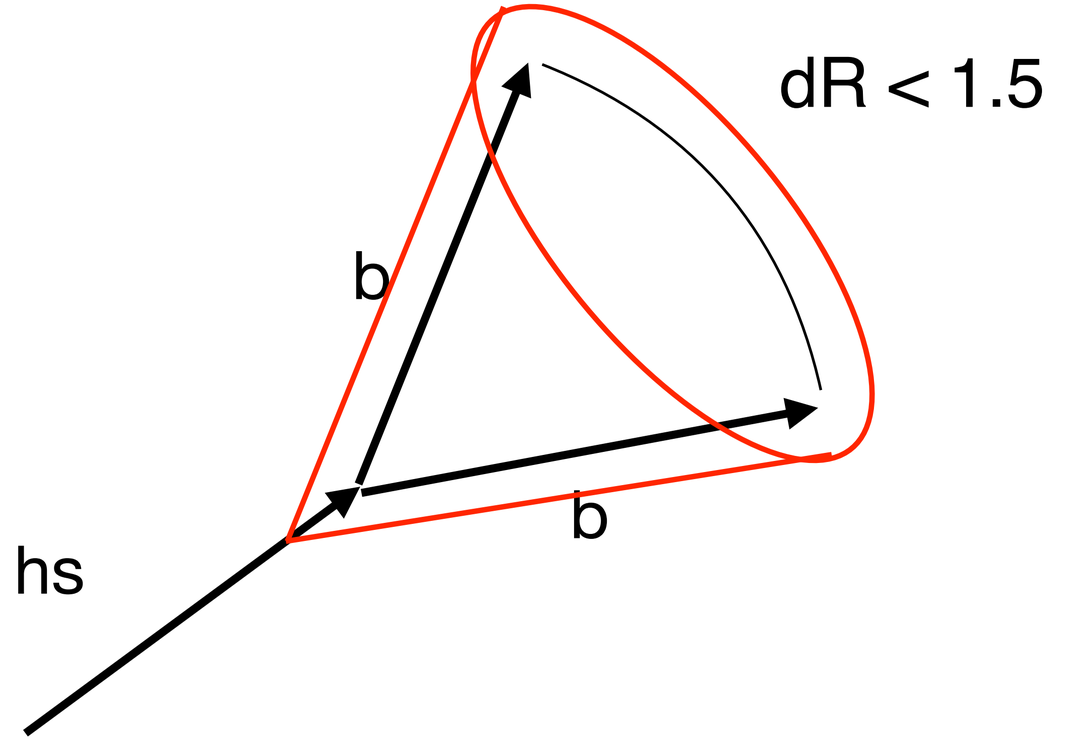




pT > 160 GeV

m_{h_s} < 160 GeV

AK15 jet

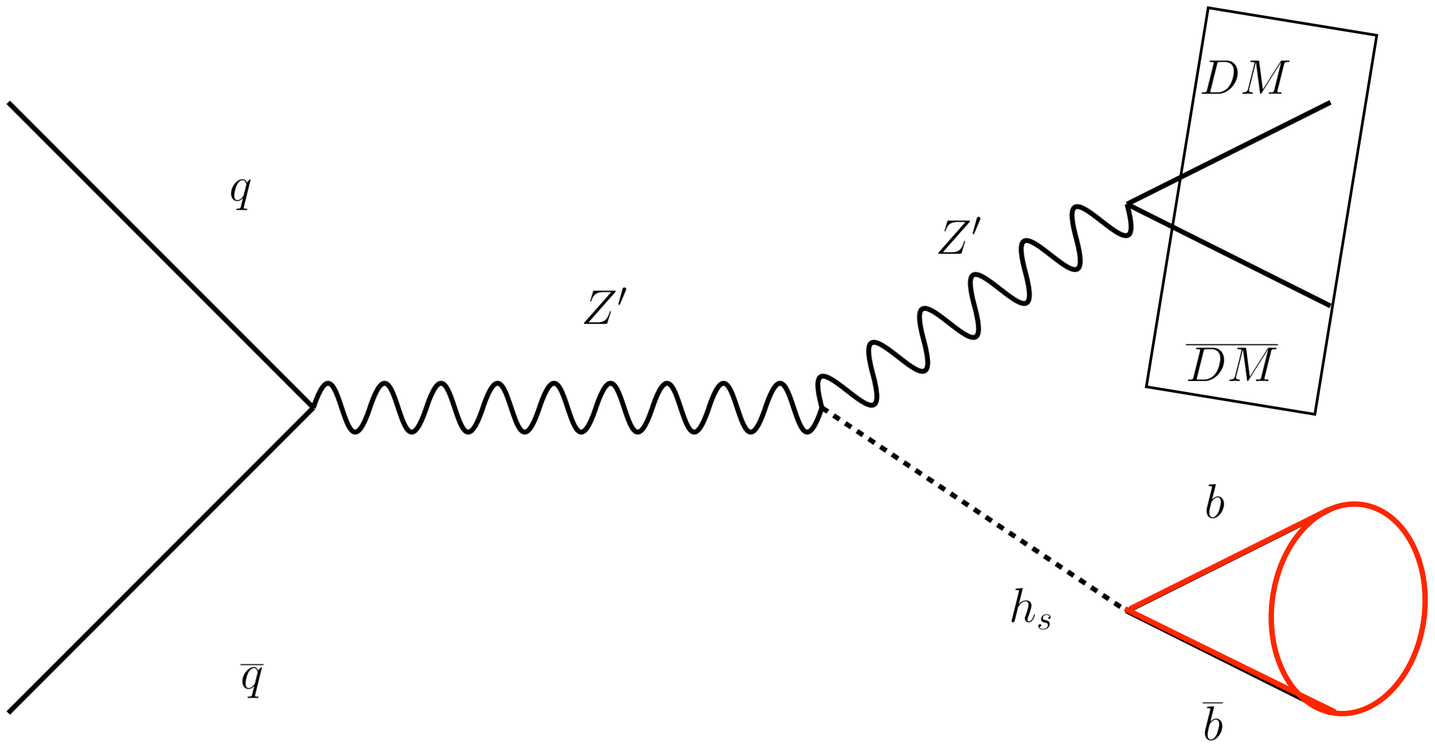


pT > 160 GeV

m_{h_s} < 160 GeV

Event Selection

PFMET > 250 GeV



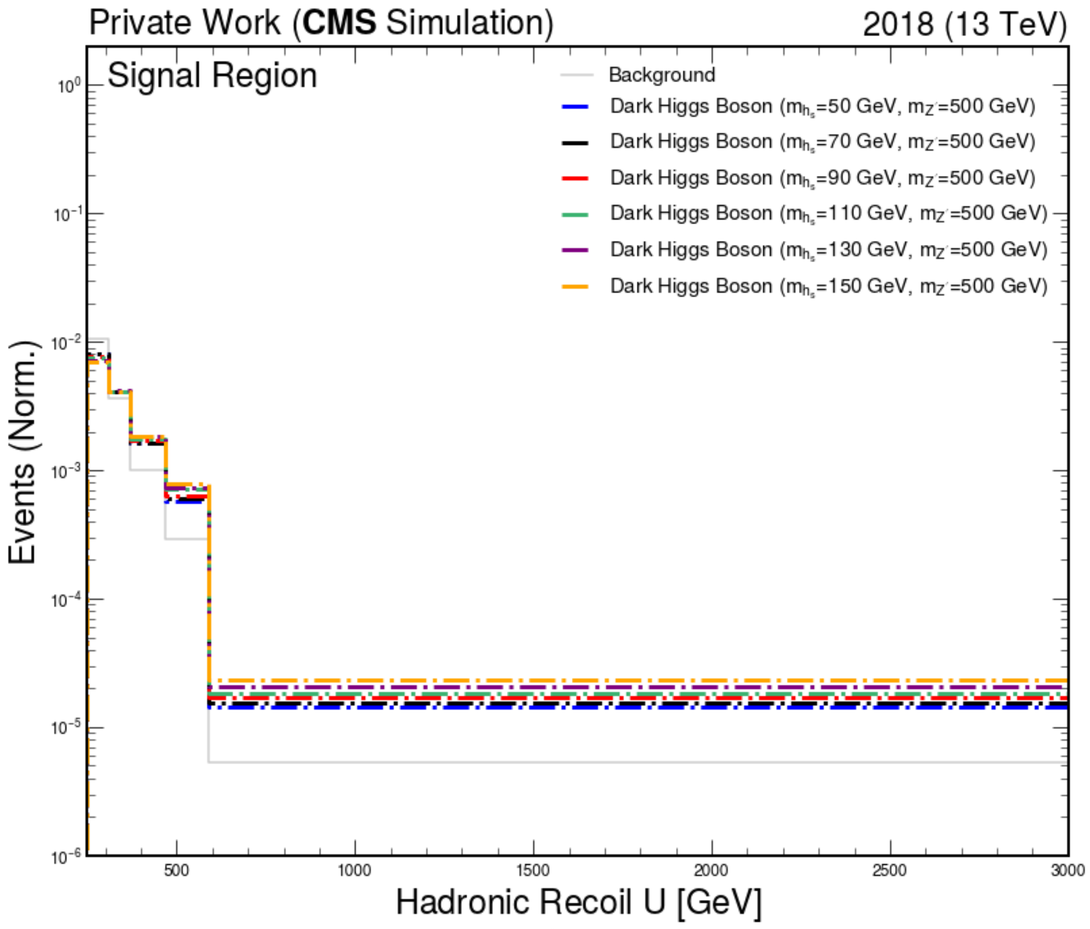
- Δϕ(AK4 jets, PFMET) > 0.5
- Δϕ(AK15 jets, PFMET) > 1.5
- τ/e/mu/photon veto
- Zero b-tagged AK4 jets outside leading AK15 cone

AK15 p_T > 160 GeV

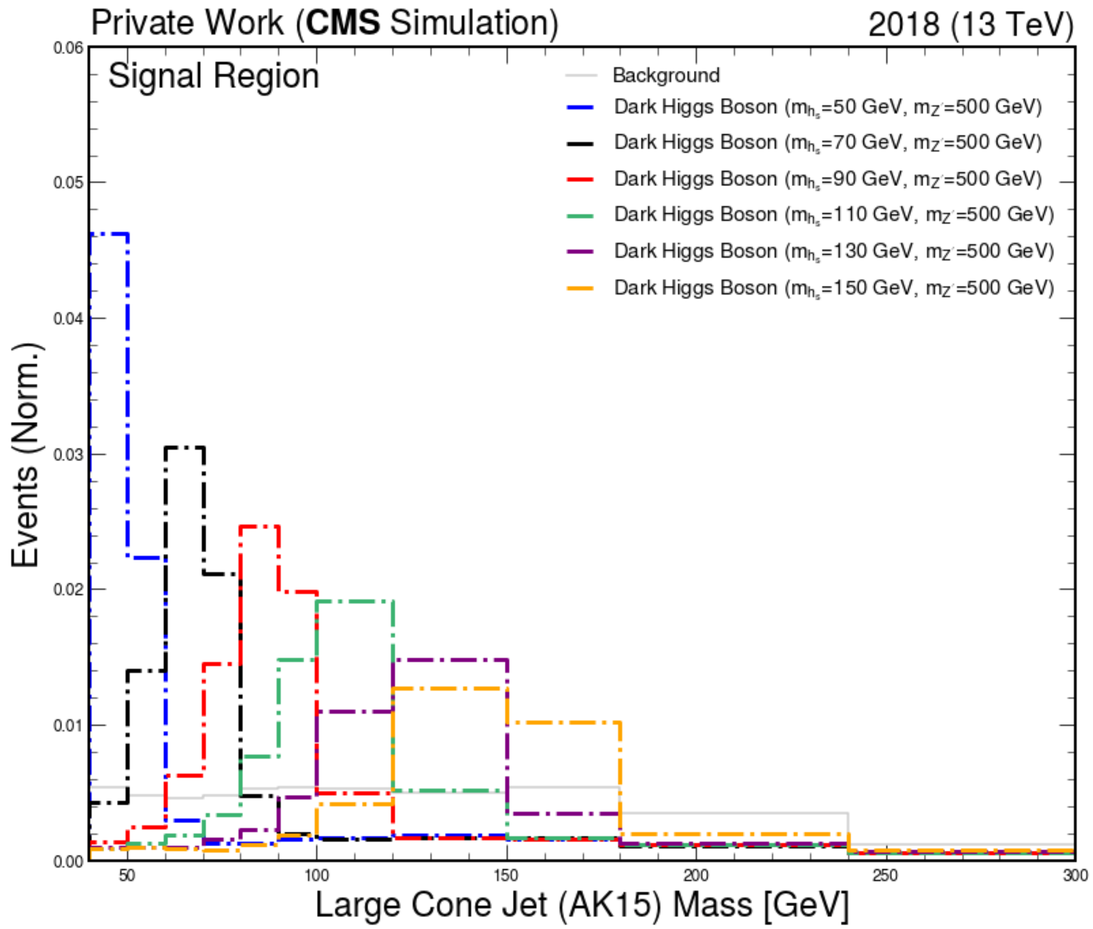
40 GeV < AK15 m_{SD} < 300 GeV

DeepAK15 > WP (90% signal eff)

Features of the Signal



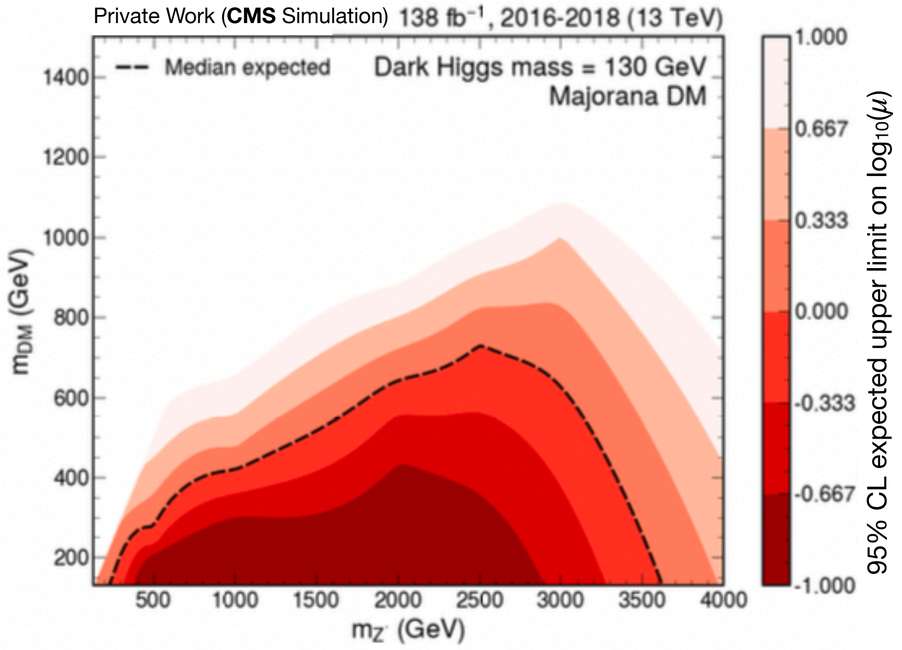
Recoil $\overrightarrow{U} = \vec{p}_T^{\,miss} + \vec{p}_T^{\,\ell}$

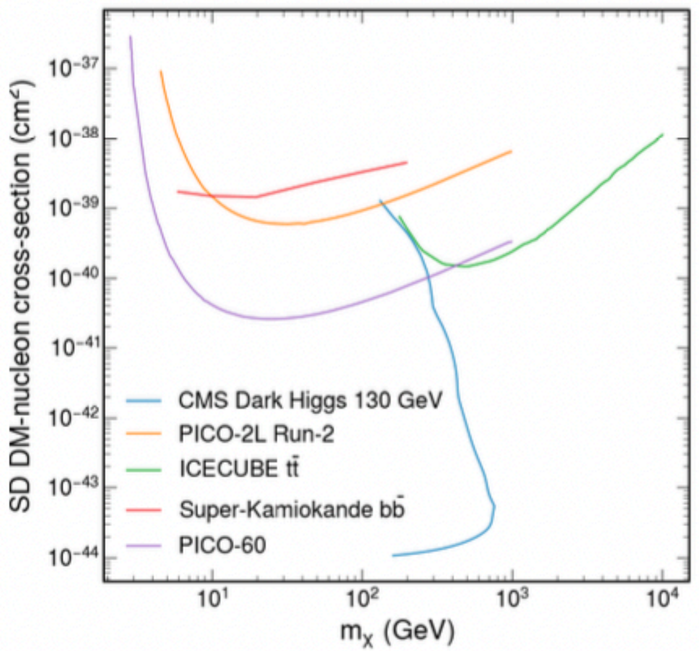


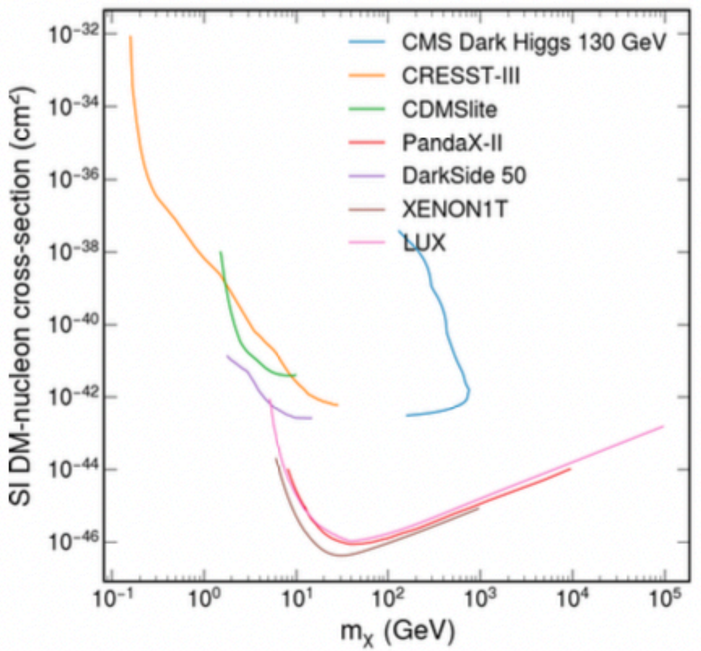
Signal Region Yields

	2016	2017	2018
H$\to b\bar{b}$	57.6 ± 0.3	72.0 ± 0.3	83.8 ± 0.3
Z($\to \ell\ell$)+jets	56.8 ± 2.2	43.3 ± 2.0	37.1 ± 3.0
QCD multijet	93.3 ± 25.8	154.9 ± 41.7	163.2 ± 64.6
Diboson	718.0 ± 17.5	623.4 ± 17.8	606.4 ± 20.8
Single t	646.0 ± 10.9	567.4 ± 12.5	614.6 ± 12.8
$t\bar{t}$	5486.5 ± 199.7	5810.7 ± 60.0	6784.2 ± 133.7
W($\to \ell\nu$)+jets	3997.8 ± 38.5	2991.0 ± 40.2	2826.6 ± 50.5
Z($\to \nu\nu$)+jets	7514.8 ± 29.2	7035.2 ± 33.3	6978.5 ± 38.8
Total expected	18570.7 ± 208.1	17297.9 ± 92.4	18094.2 ± 163.4
$M_Z1000\_M_{h_s}130\_M_{dm}150$	684.8 ± 4.1	626.7 ± 3.9	687.2 ± 4.6
$M_Z1000\_M_{h_s}130\_M_{dm}500$	$(381.6 \pm 2.1)\times10^{-4}$	$(357.6 \pm 2.0)\times10^{-4}$	$(399.6 \pm 2.4)\times10^{-4}$
$M_Z1000\_M_{h_s}130\_M_{dm}1000$	$(1341.2 \pm 6.7)\times10^{-8}$	$(1005.9 \pm 6.7)\times10^{-8}$	$(1341.2 \pm 10.1)\times10^{-8}$

Expected Results







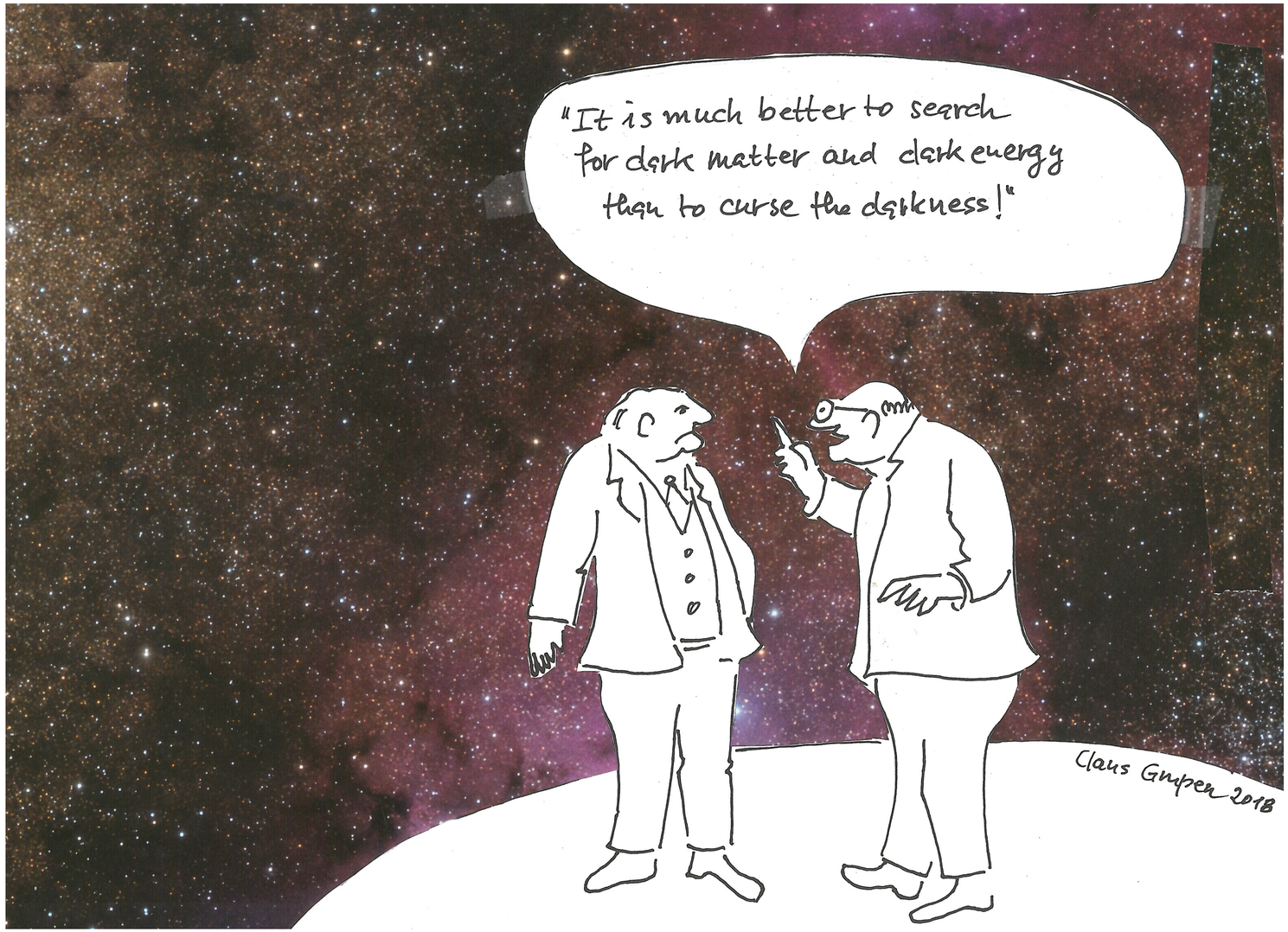
$$\mu_{n\chi} = m_n m_{\mathrm{DM}}/(m_n + m_{\mathrm{DM}})$$

$$\sigma_{\mathrm{SI}} \simeq 6.9 \times 10^{-41}\ \mathrm{cm}^2 \cdot \left(\frac{g_q g_{\mathrm{DM}}}{0.25}\right)^2 \left(\frac{1\,\mathrm{TeV}}{M_{\mathrm{med}}}\right)^4 \left(\frac{\mu_{n\chi}}{1\,\mathrm{GeV}}\right)^2$$

Summary

- Dark matter is an exciting topic
  - One of the most important open questions in modern physics
  - It is interdisciplinary by construction
- The LHC has a crucial role in the dark matter quest
  - And entire physics program has been built
  - Multiple searches testing different hypotheses in the same broad theoretical framework
    - With similar search strategies and experimental techniques
- Our analysis is the first search for dark Higgs boson decaying into a b-quark pair in CMS
  - Using full Run-2 dataset at 138 fb^{-1}

Thank you!


"It is much better to search for dark matter and dark energy than to curse the darkness!"
Claus Gnuper 2018