Status and perspective of Dark Sector searches at ATLAS&CMS

Elena Pompa Pacchi on behalf of the ATLAS and the CMS collaborations

Road trip to dark sectors in ATLAS and CMS is long

Many interesting results!!

Selection of topics driven mostly by personal taste (and representativeness of the field!)

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Dark sectors in a (non-exhaustive) nutshell

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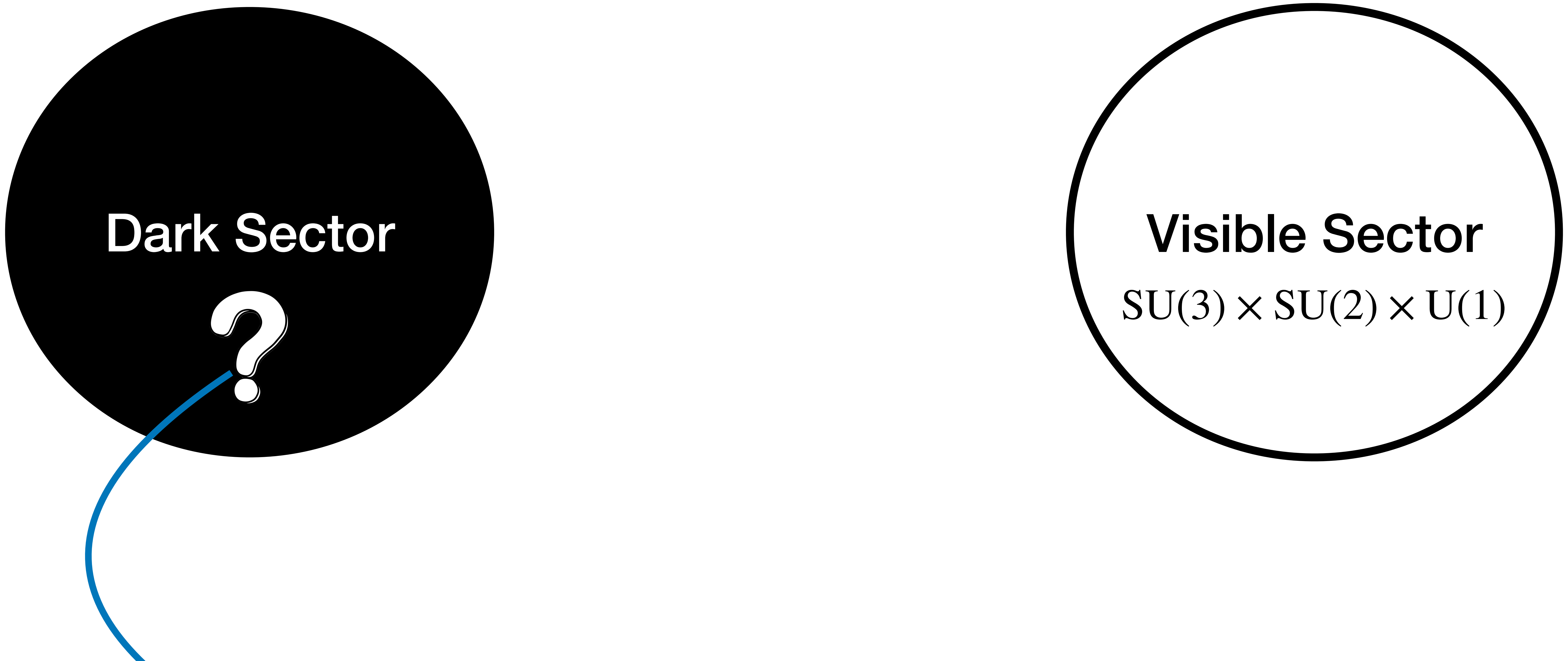

- $U(1)_d$? → dark QED 
- $SU(3)_d$? → dark QCD 

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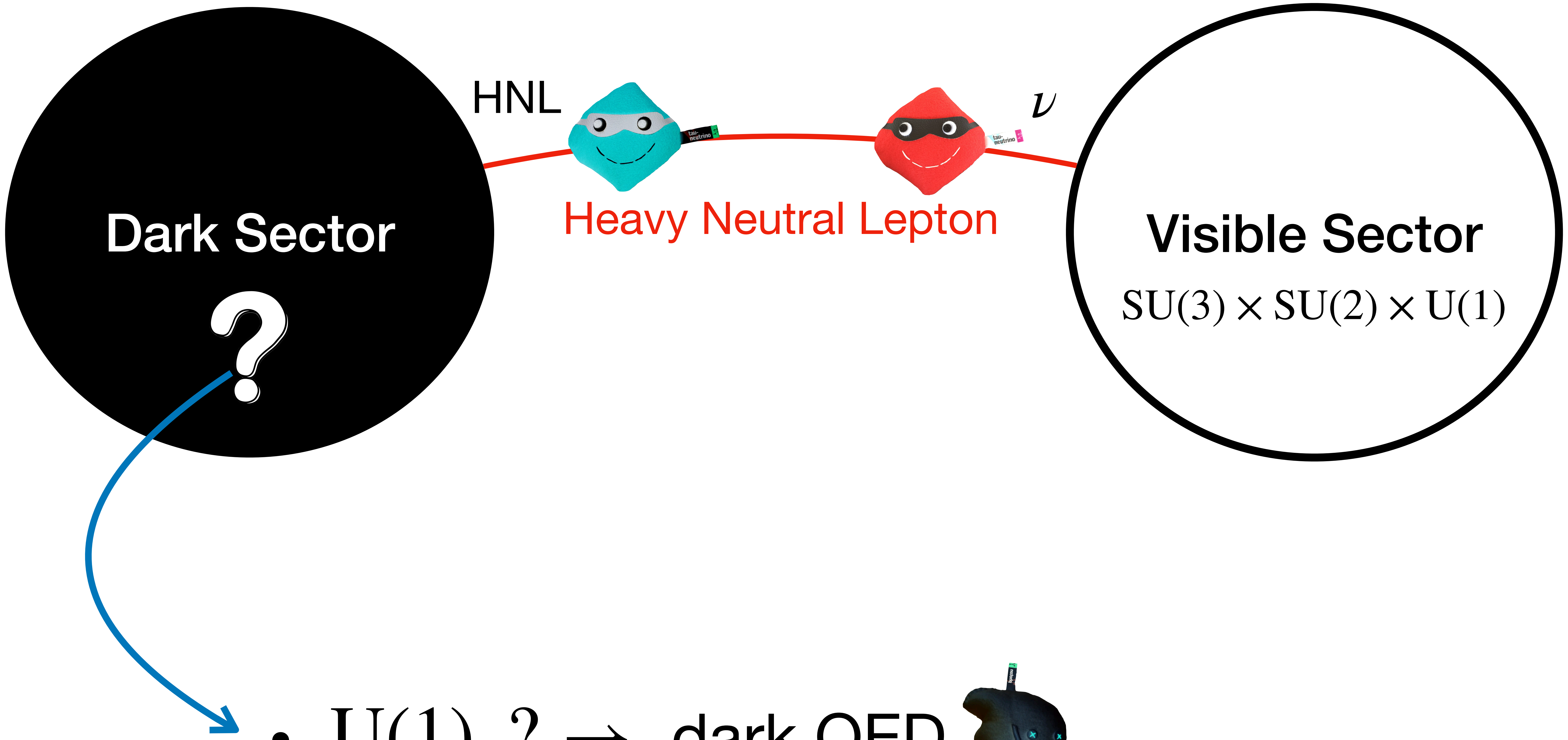

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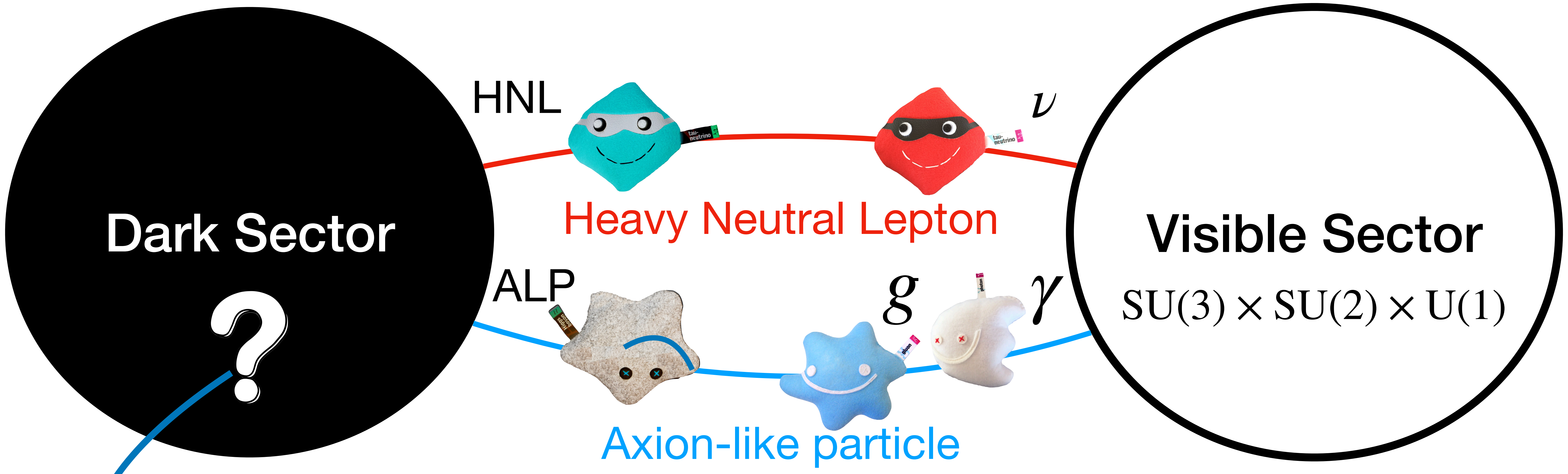

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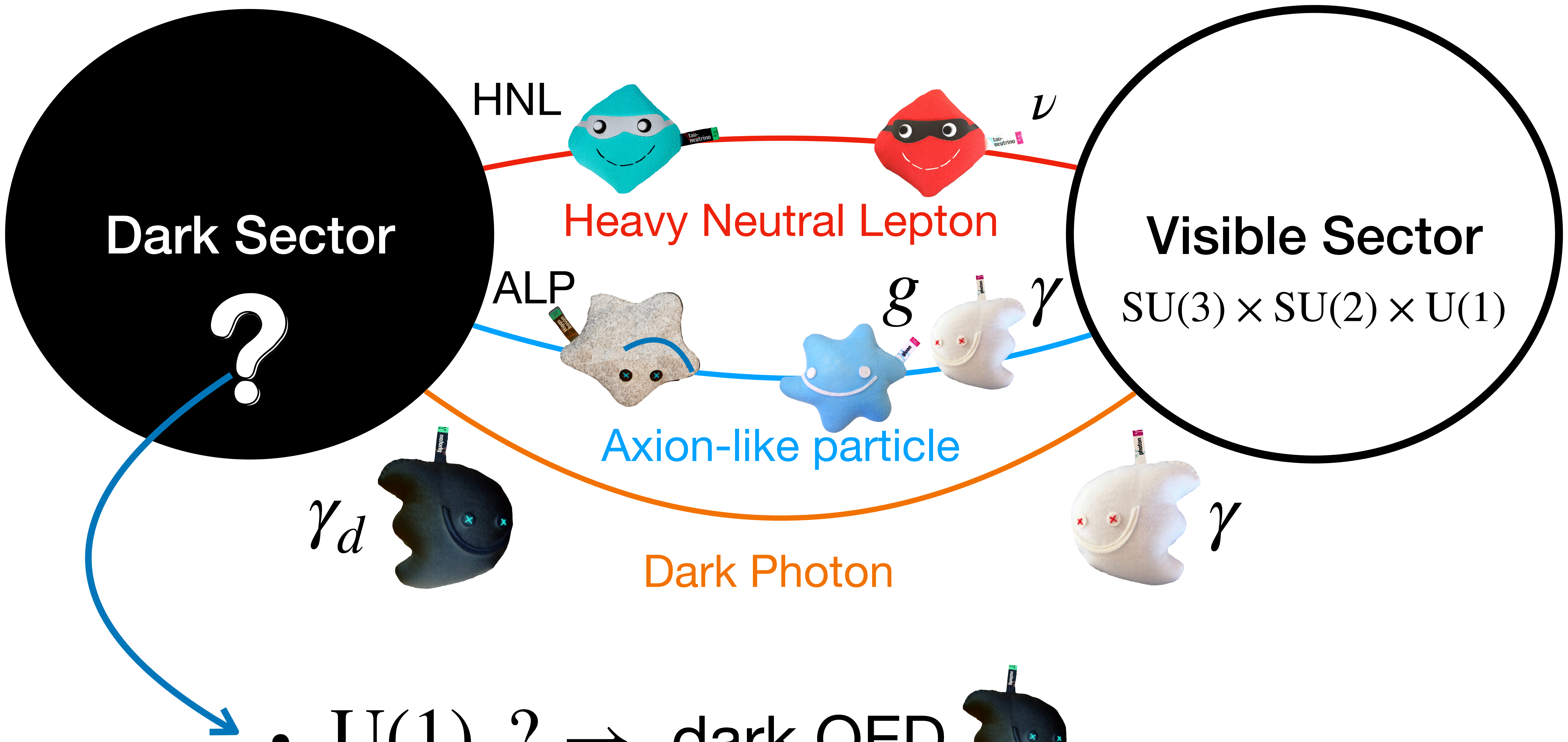

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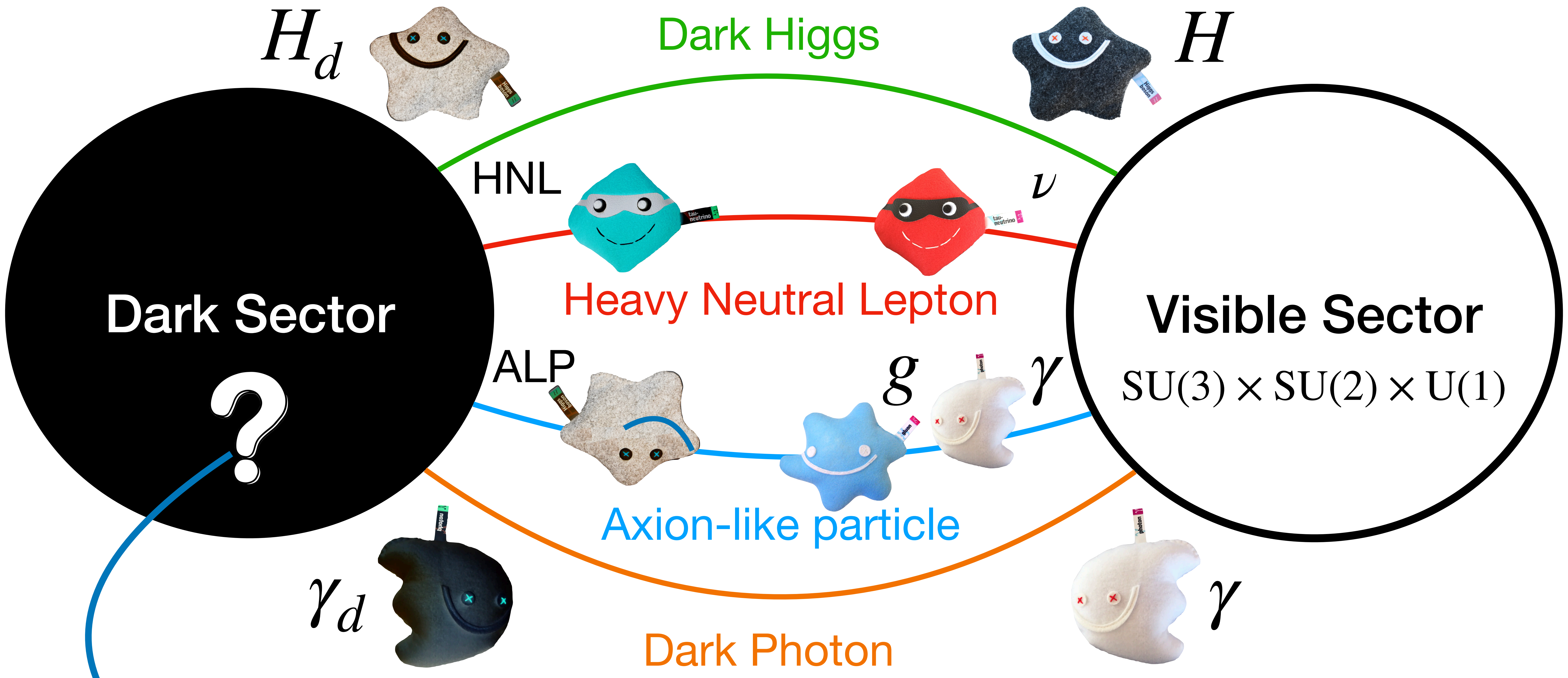

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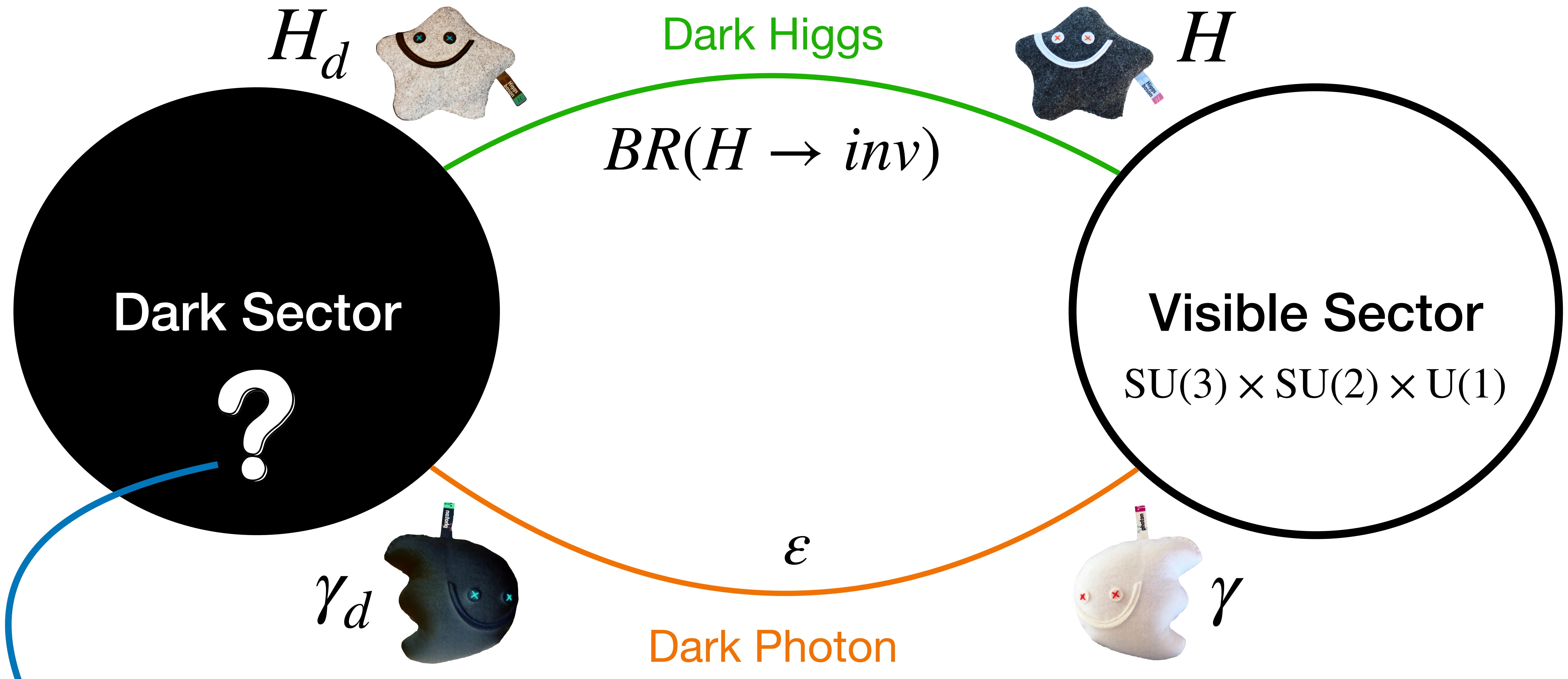
Dark sectors models covered here



- $U(1)_d? \rightarrow$ dark QED $\longrightarrow$ Massive? Massless? Decays to visible? Prompt (large ε)? Displaced (small ε)?

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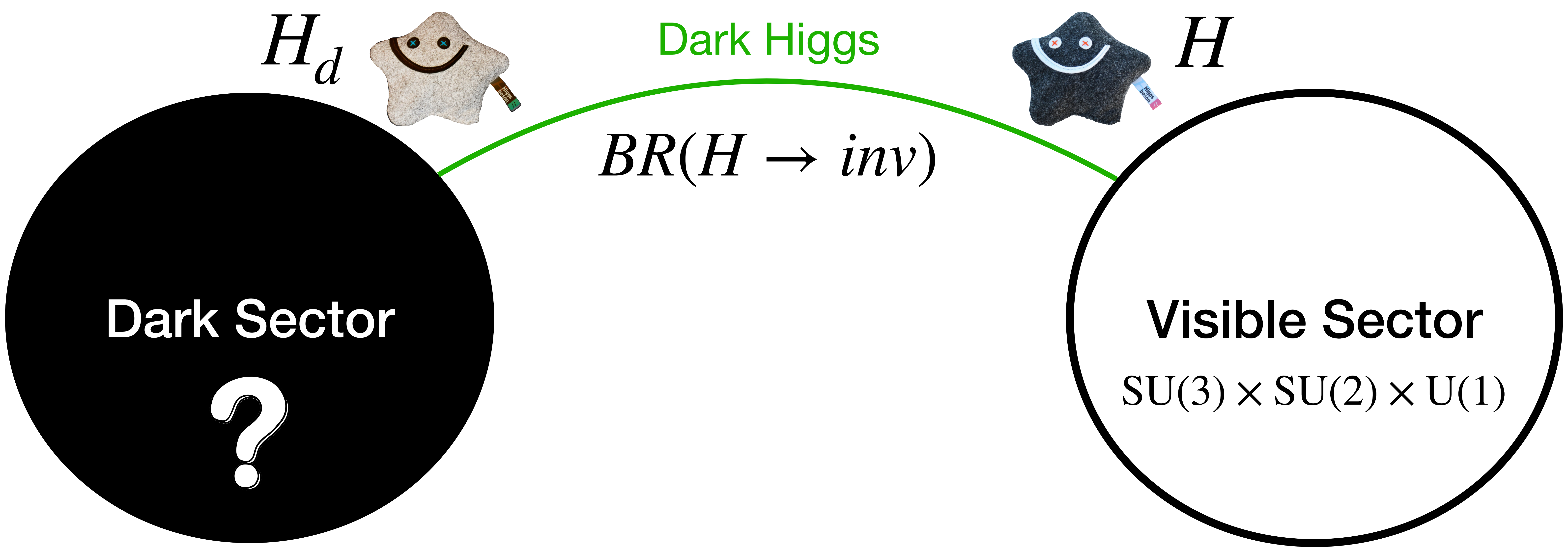

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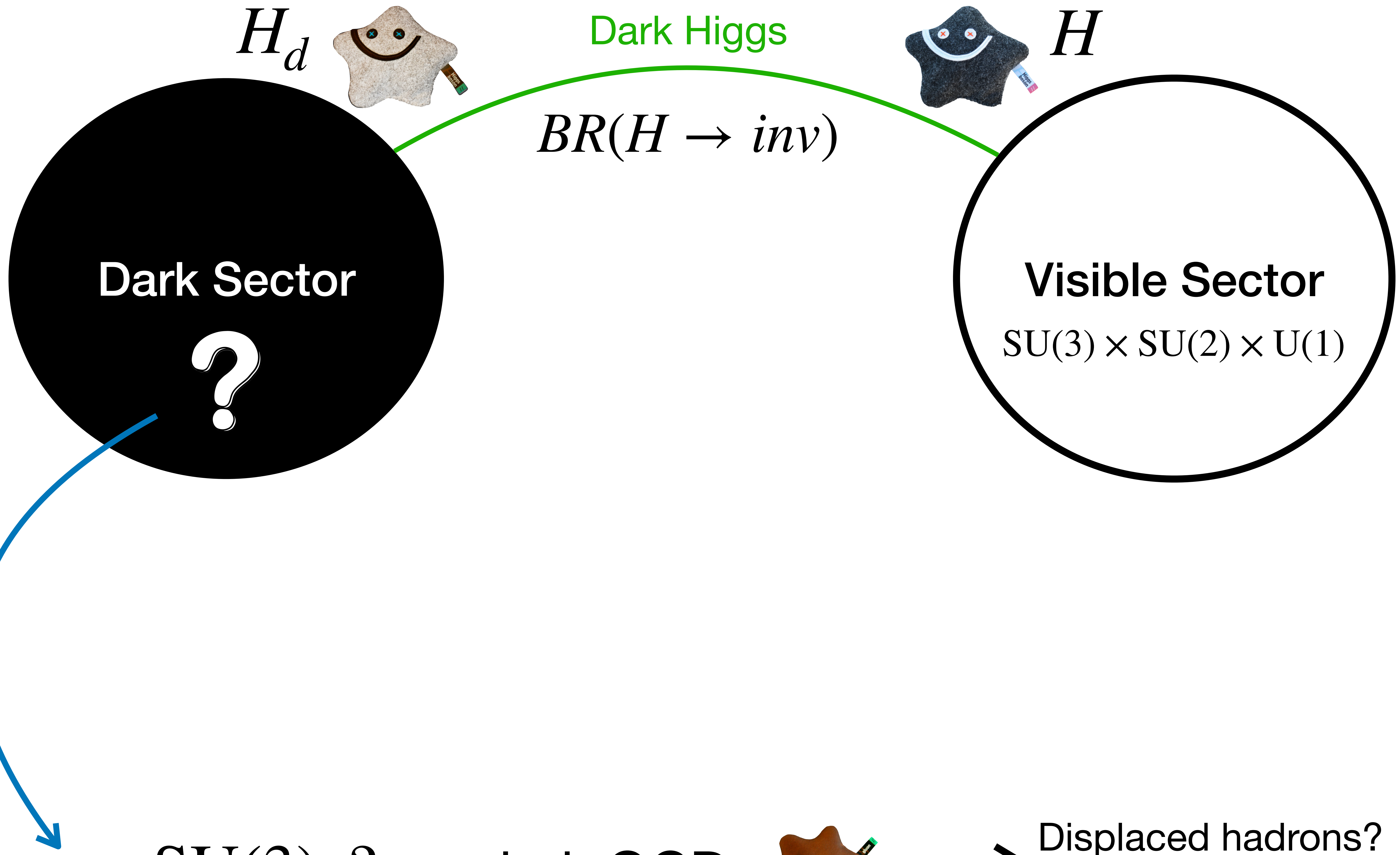
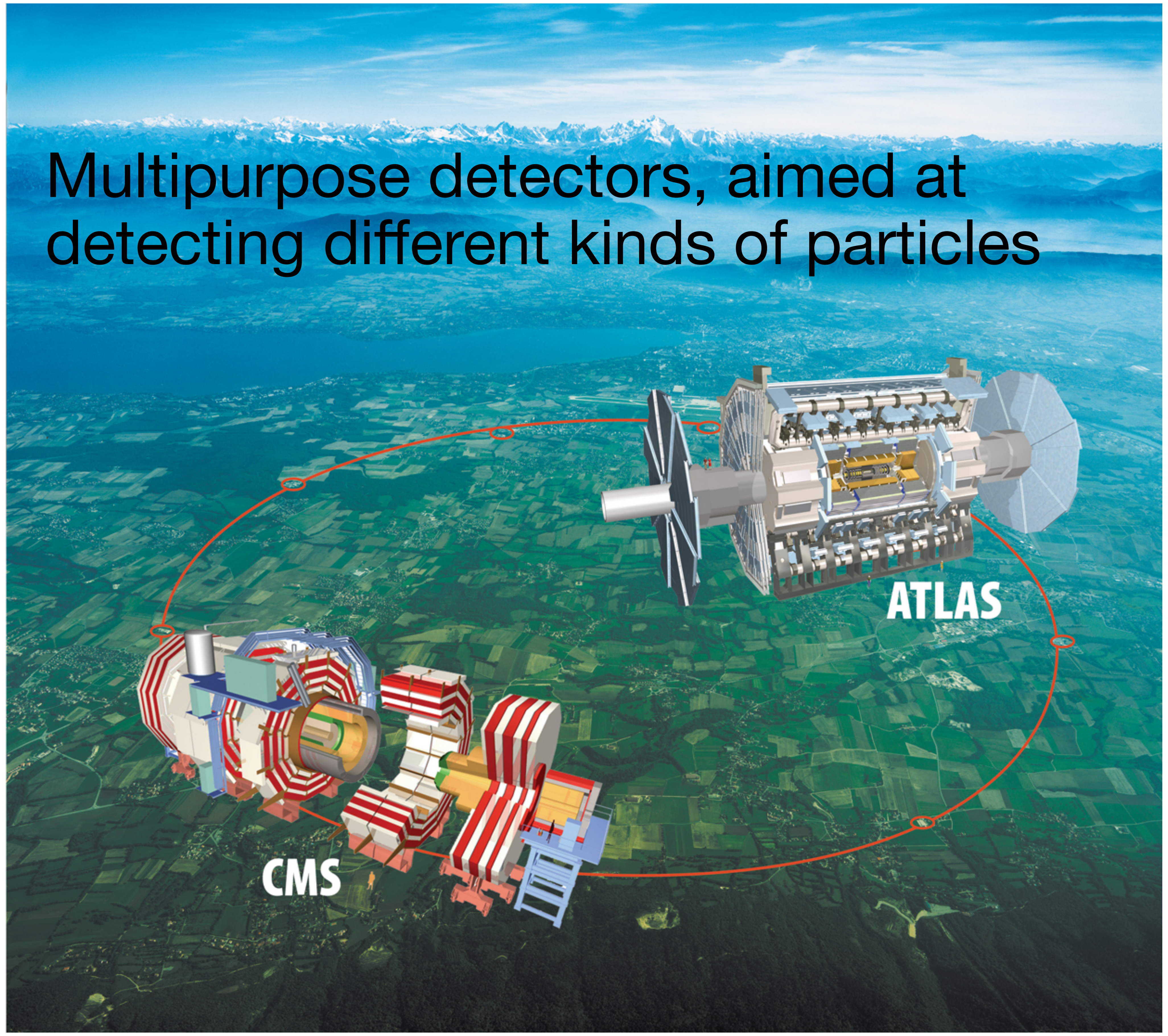


- $SU(3)_d? \to$ dark QCD → Displaced hadrons? Decay back to visible?

ATLAS & CMS @ the LHC



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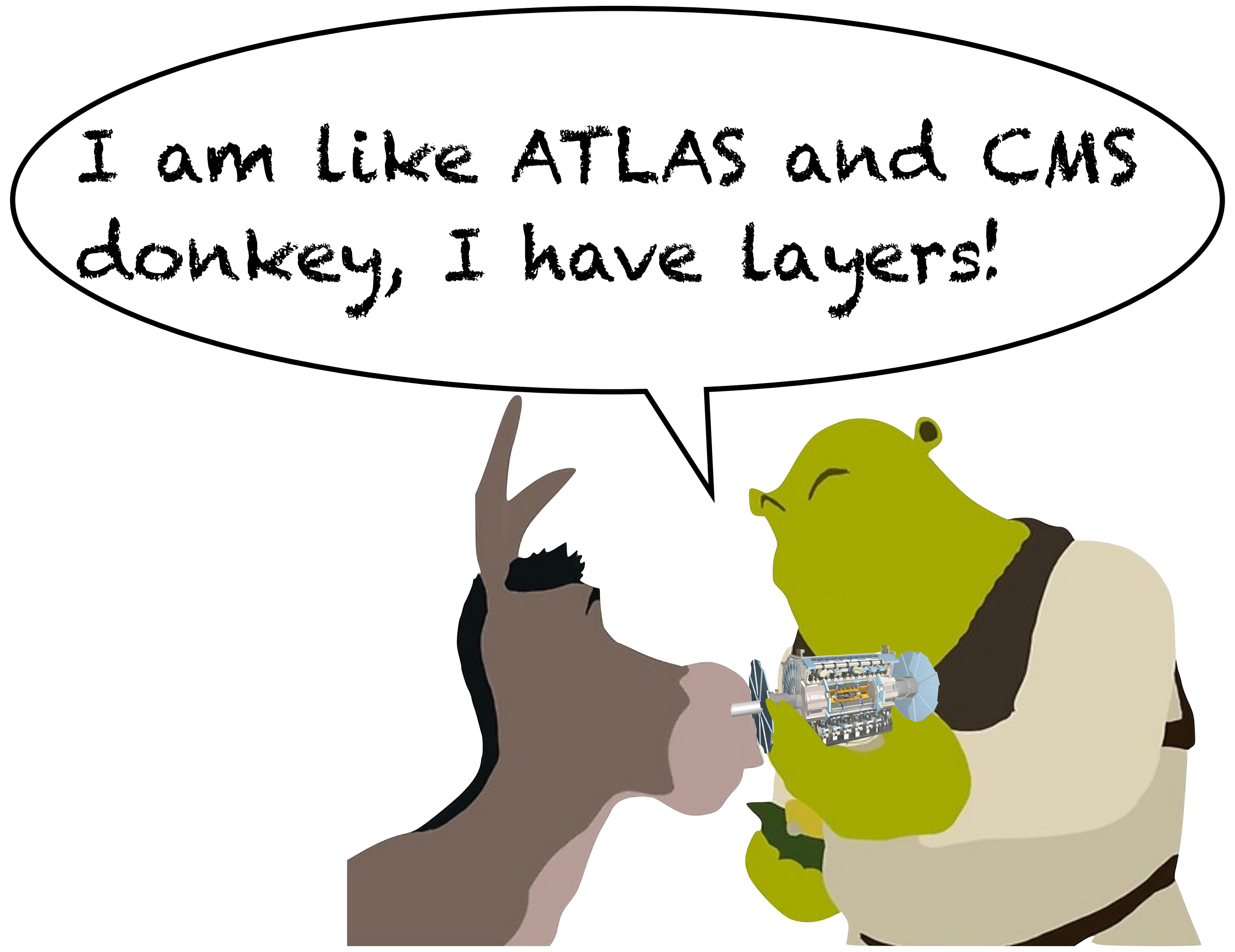
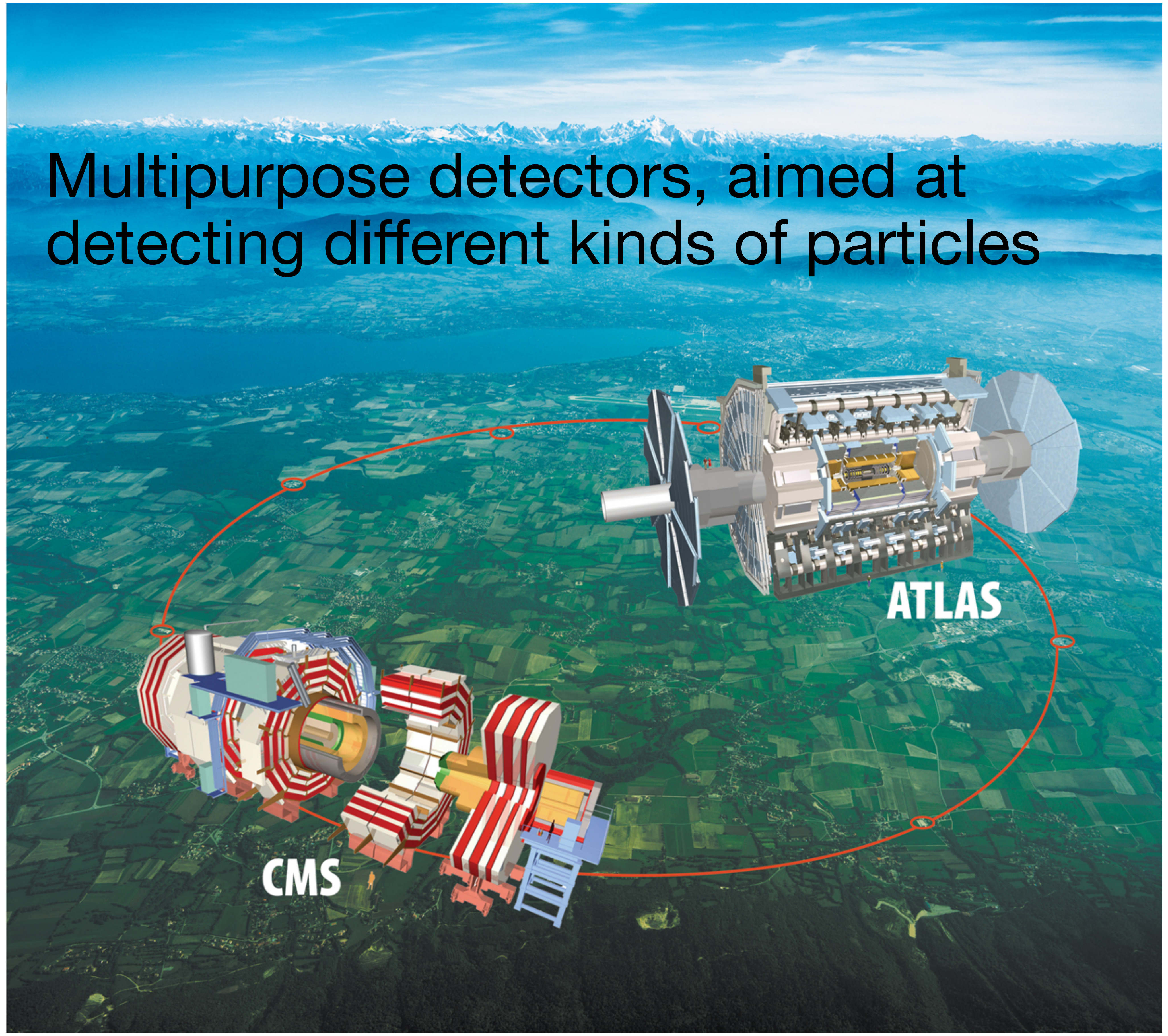


	ID	ECAL	HCAL	MS
p	✓	✓	✓	✗
n	✗	✓	✓	✗
e^-	✓	✓	✗	✗
γ	✗	✓	✗	✗
μ^-	✓	✓	✗	✓



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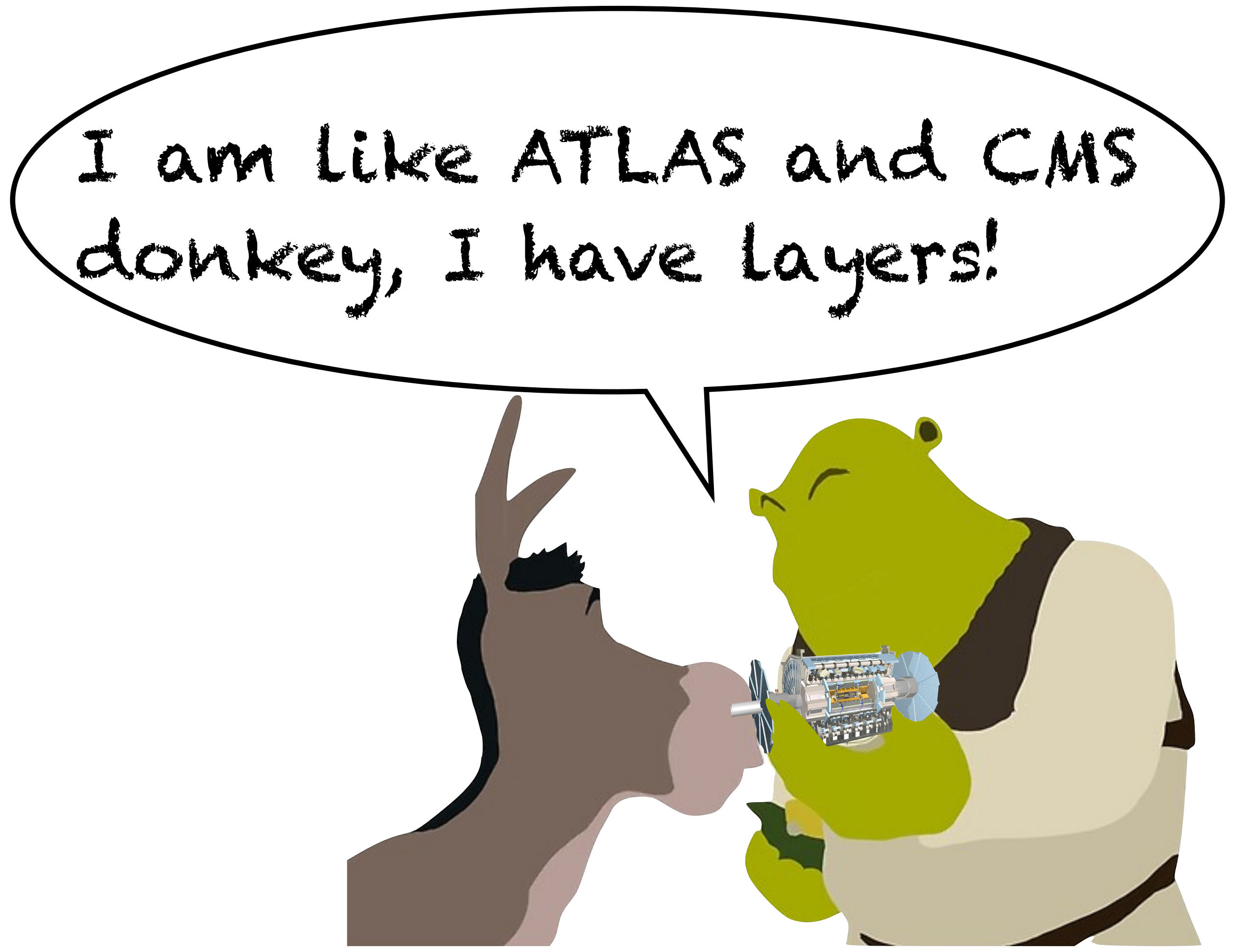

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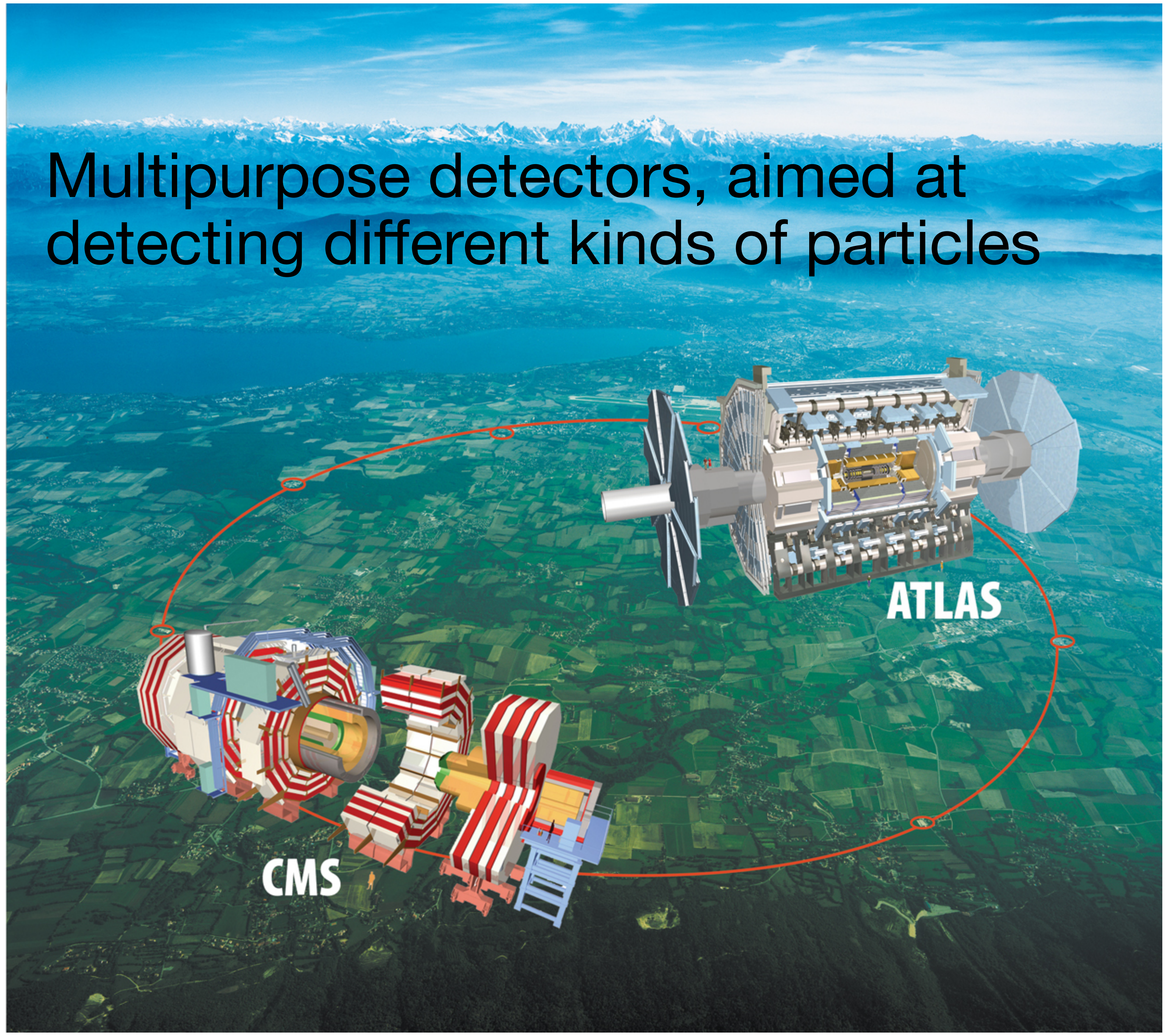
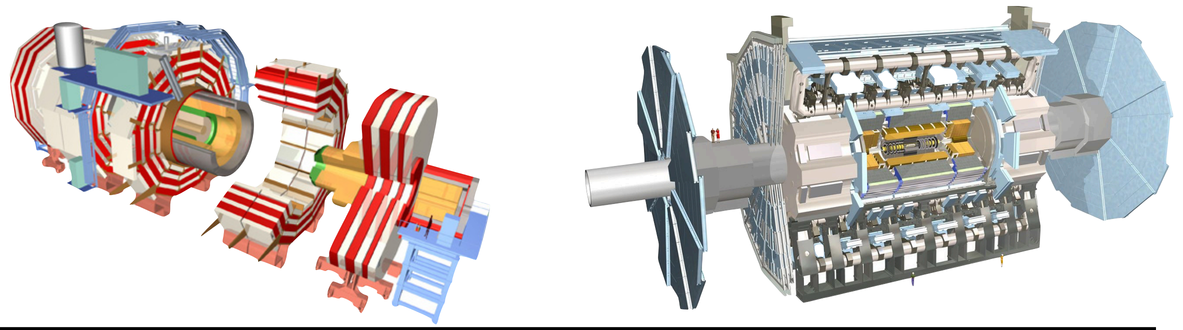
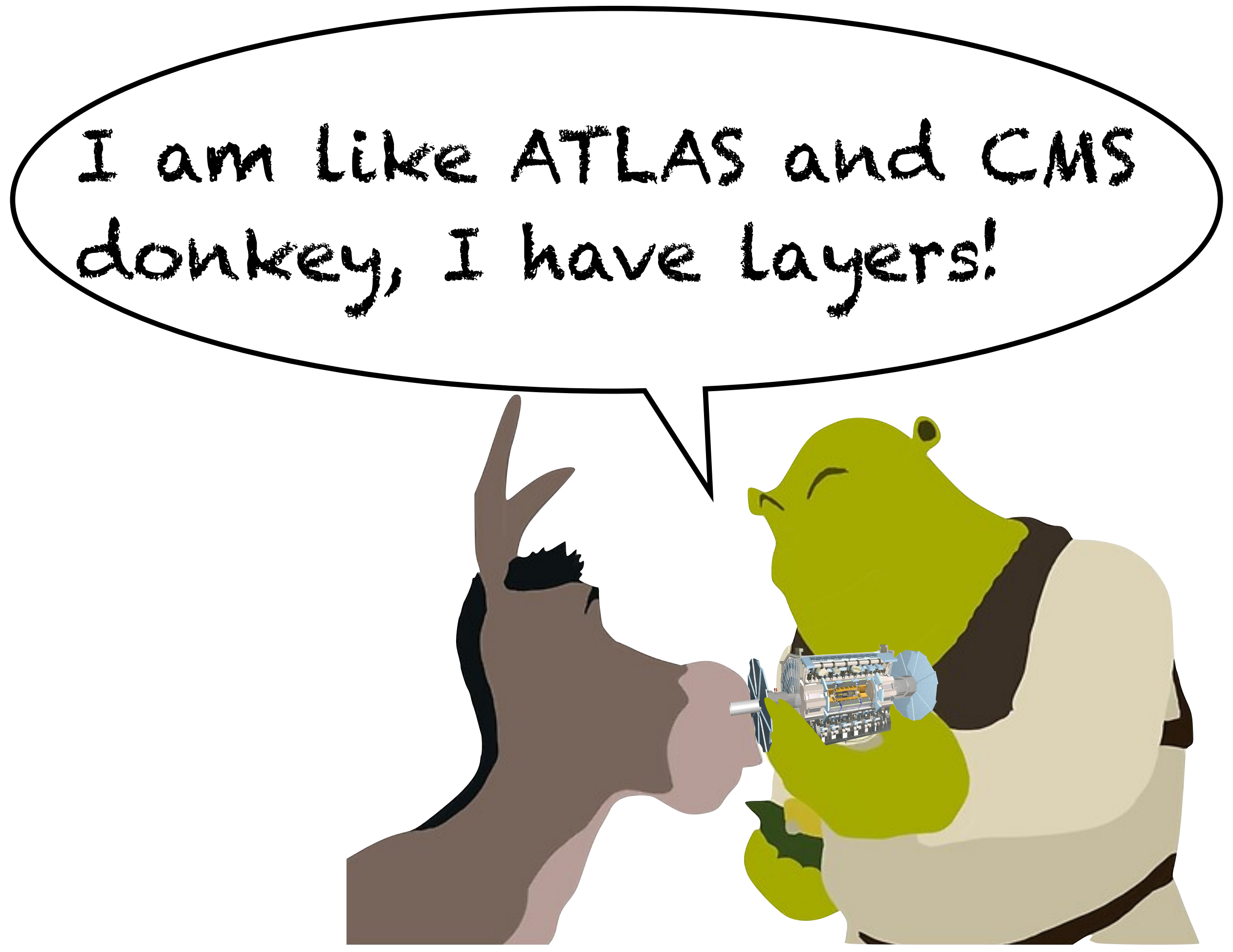


Built to be complementary in performances:



B	Solenoid: 4T	Solenoid: 2T Toroid: 0.5T (barrel) 1T (endcap)
ID	$\sigma/p_T \sim 1.5{\cdot}10^{-4} p_T + 0.005$	$\sigma/p_T \sim 5{\cdot}10^{-4} p_T + 0.01$
ECAL	$\sigma/E \sim 3\,\%/\sqrt{E} + 0.003$	$\sigma/E \sim 10\,\%/\sqrt{E} + 0.007$
HCAL	$\sigma/E \sim 100\,\%/\sqrt{E} + 0.05$	$\sigma/E \sim 50\,\%/\sqrt{E} + 0.03$
Muons	$\sigma/p_T \sim 1\,\%$ @ 50 GeV $\sigma/p_T \sim 10\,\%$ @ 1 TeV	$\sigma/p_T \sim 2\,\%$ @ 50 GeV $\sigma/p_T \sim 10\,\%$ @ 1 TeV

ATLAS & CMS @ the LHC



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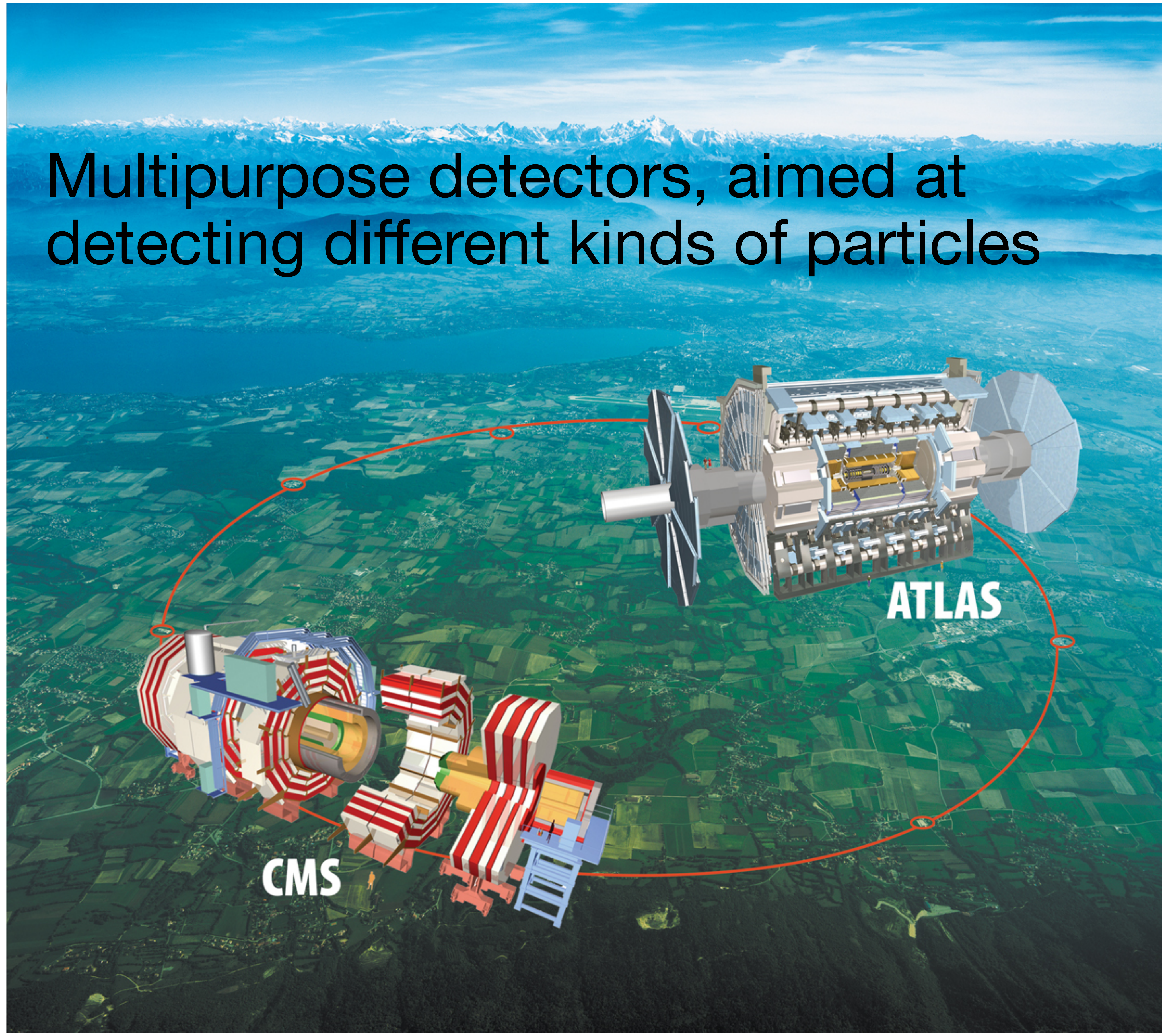

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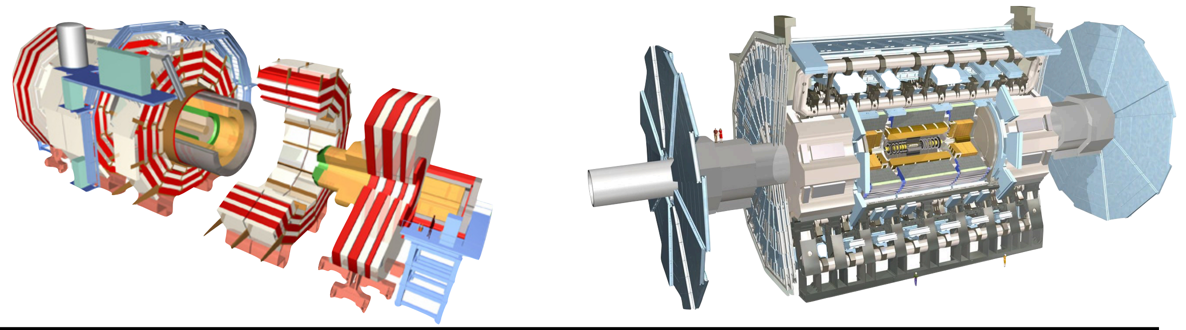

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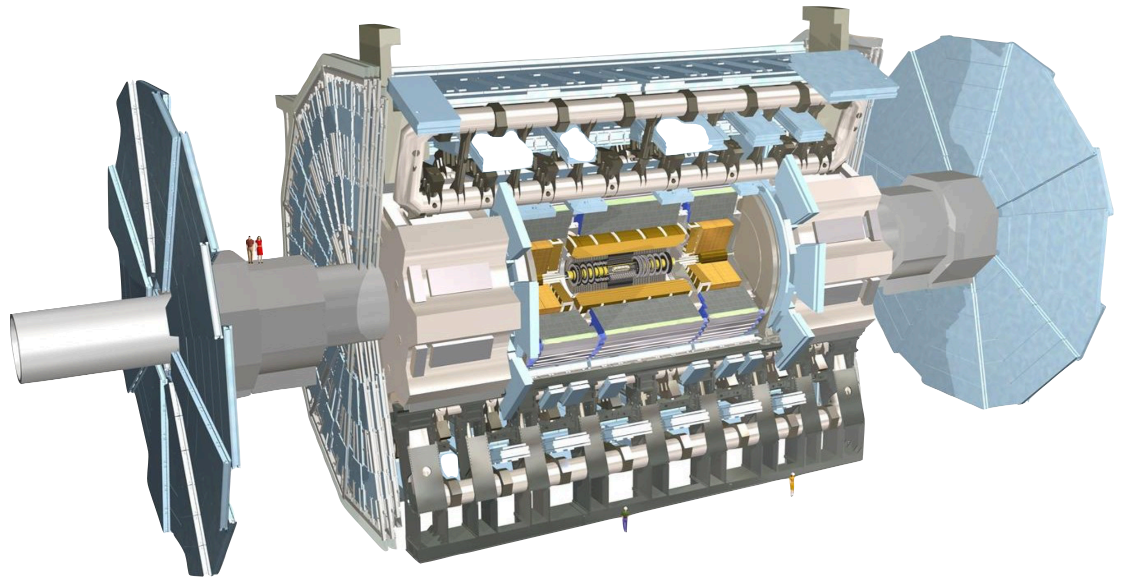
ATLAS larger than CMS →
sensitivity to more displaced objects

Selecting events at ATLAS & CMS @ the LHC

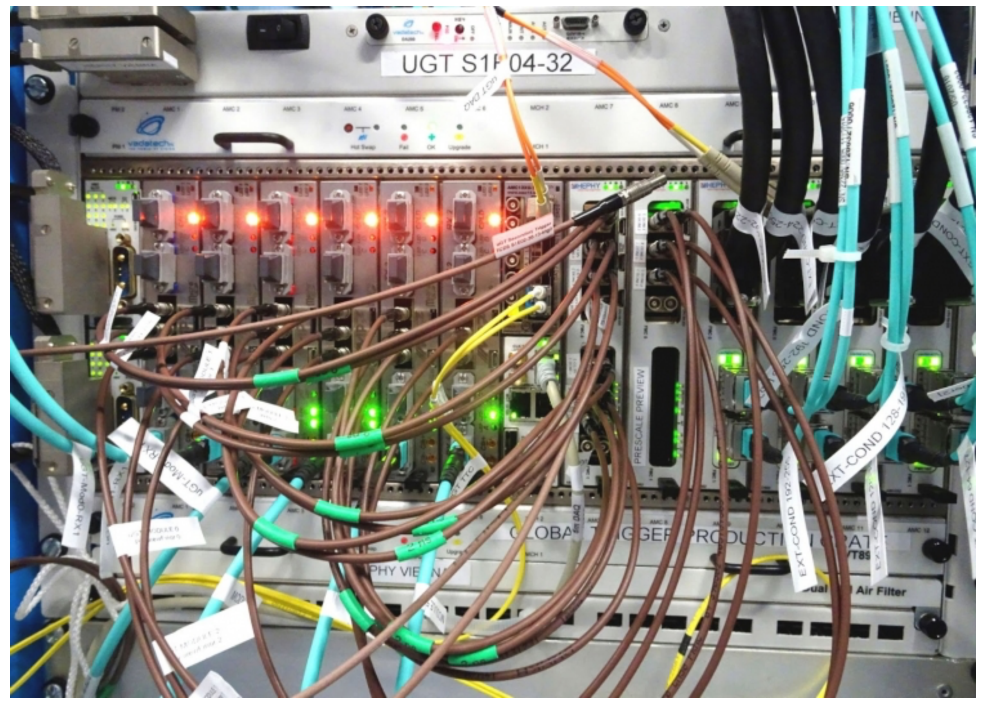
Reconstruction complexity and accuracy



40 MHz

A pp collision per 25 ns

Level 1 (L1) trigger



100 KHz

High Level Trigger (HLT)

1 kHz

Data Storage

Selecting events at ATLAS & CMS @ the LHC

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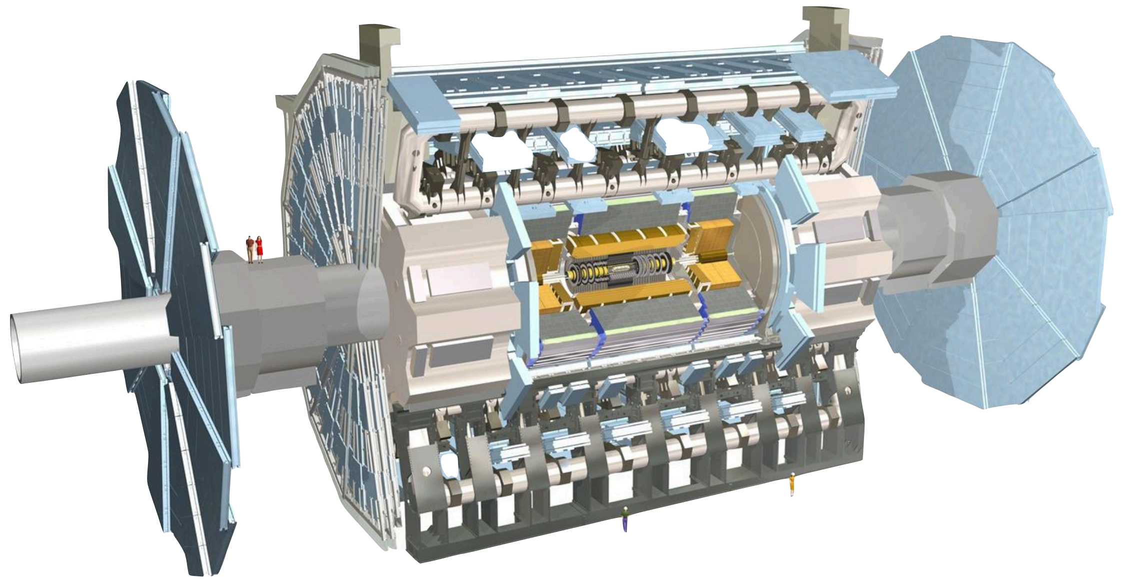

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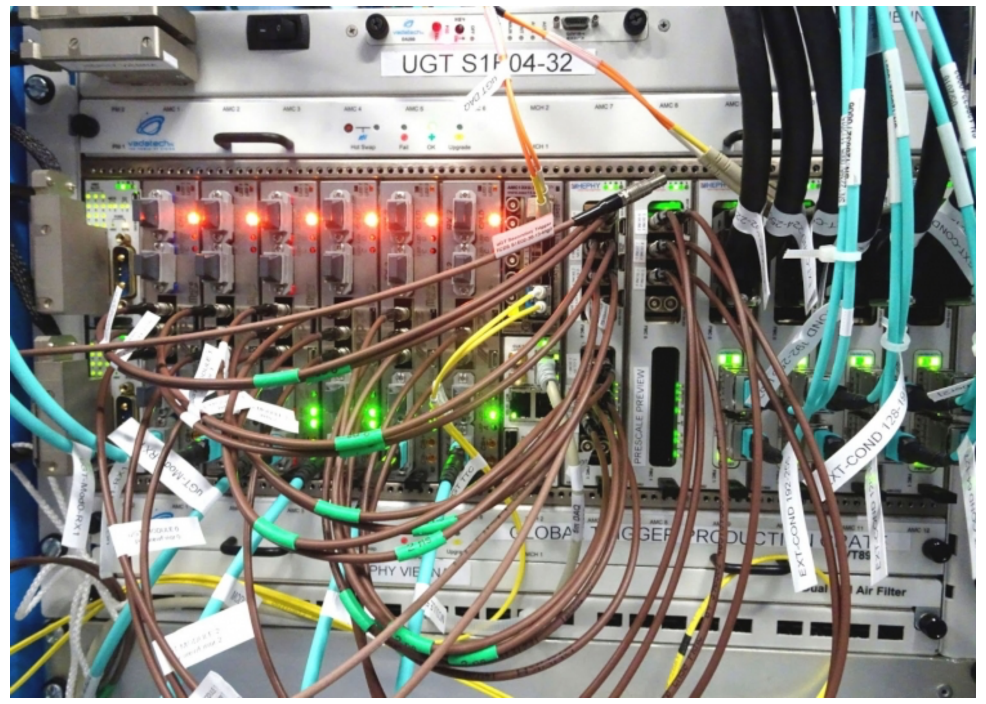

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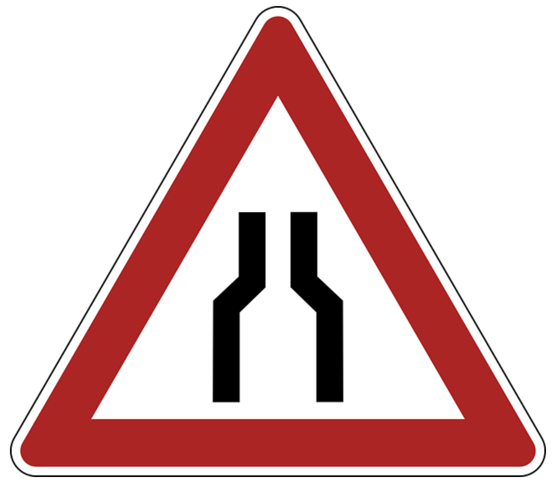
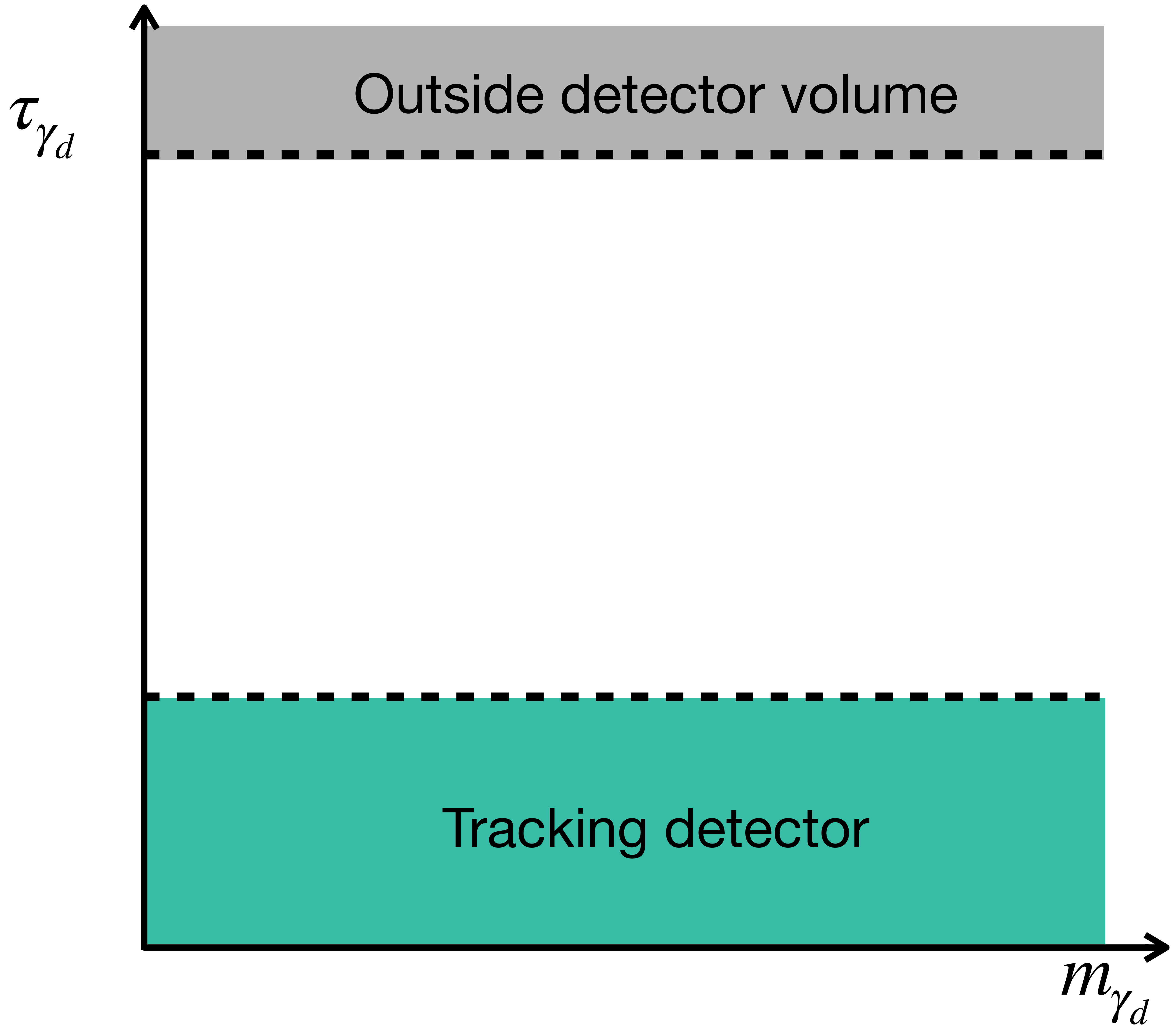


We need to know in advance how interesting events will look like!!


THE PRESENT
(or Run-2 results)

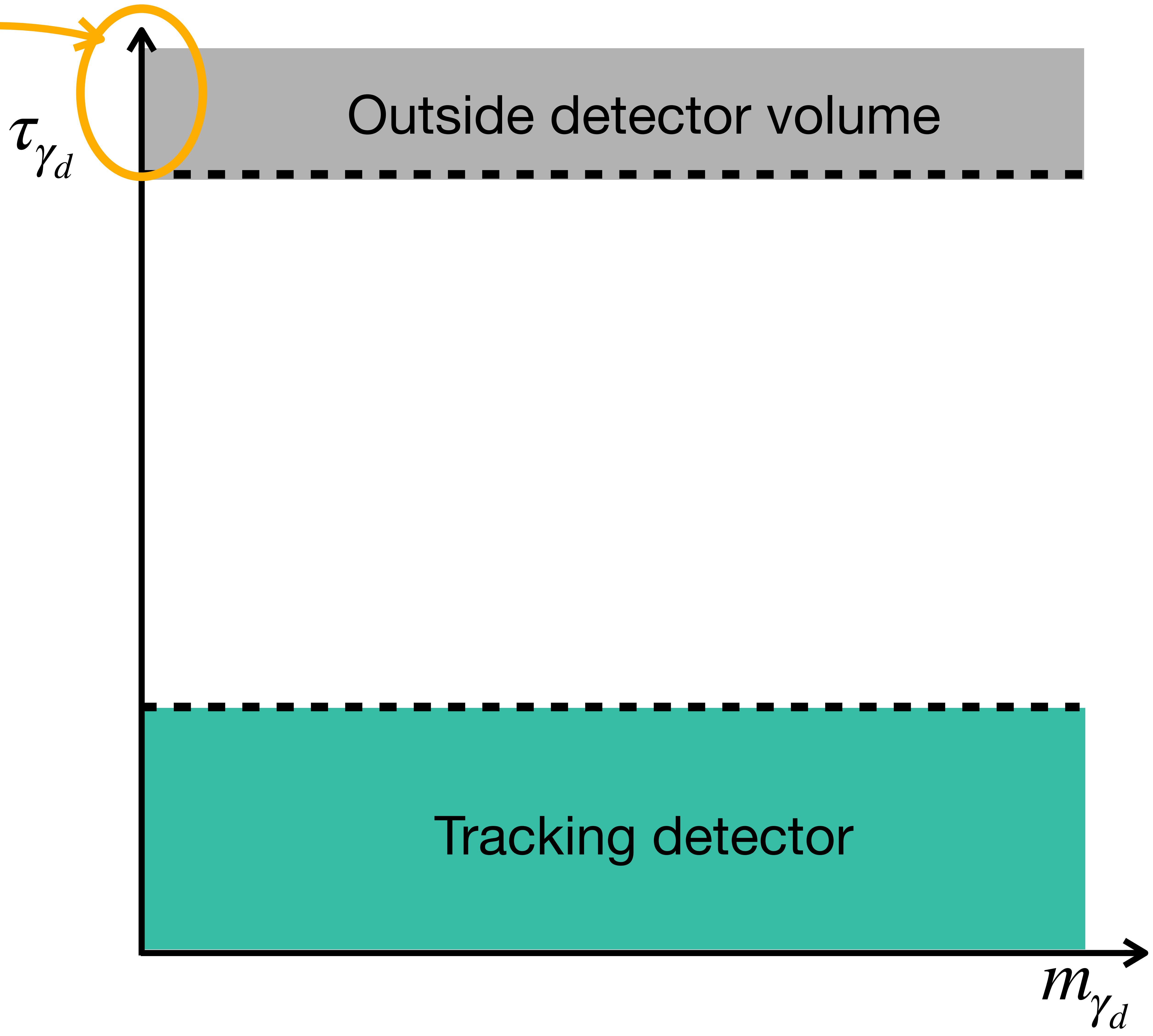
Dark photons and how we look for them



Dark photons and how we look for them

Invisible dark photon:

Massless γ_d or $\alpha_D \gg \alpha\varepsilon^2$



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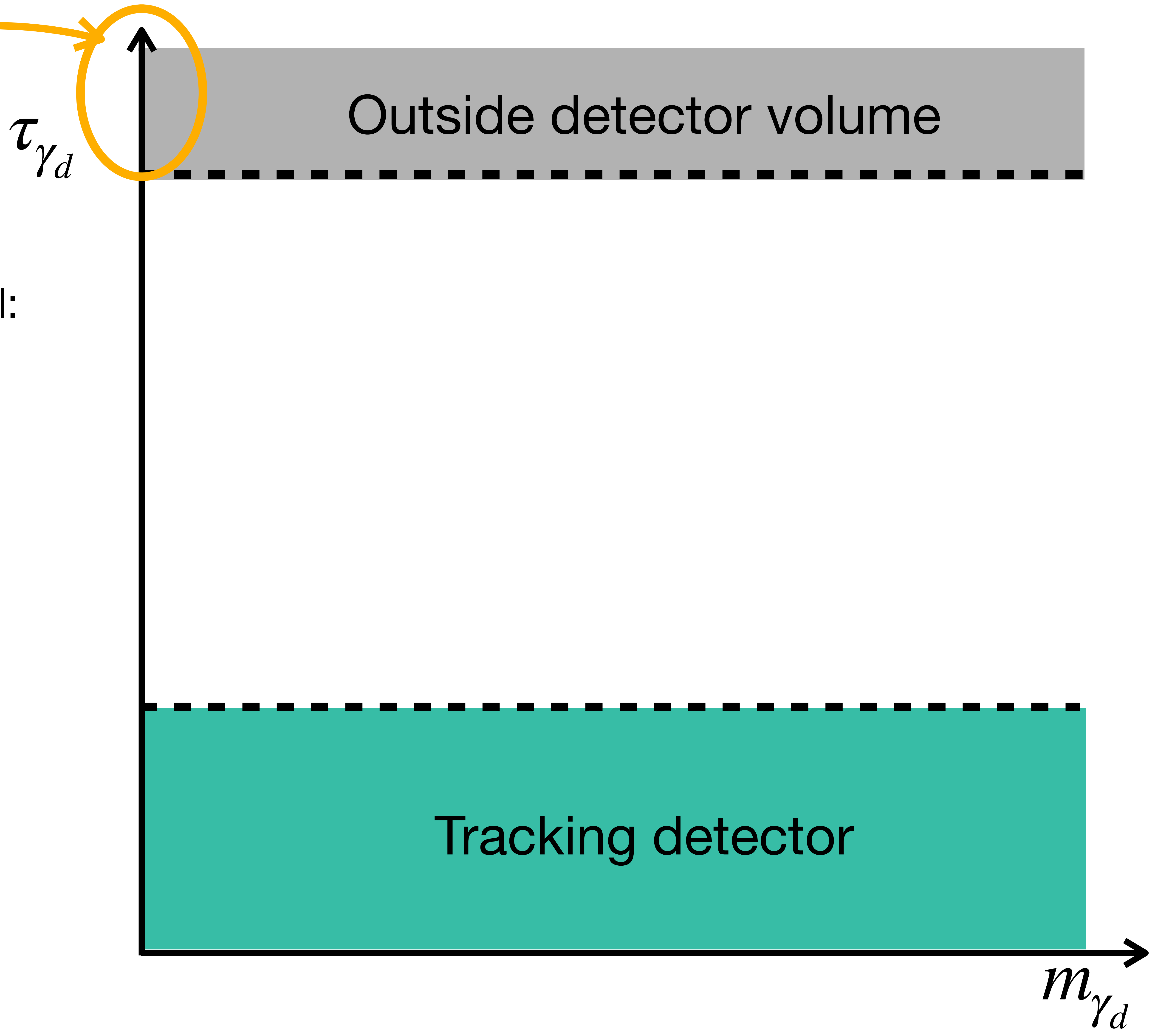
$H \to \gamma\gamma_d$ (Higgs portal)

Signature: $\not{E}_T + \gamma$



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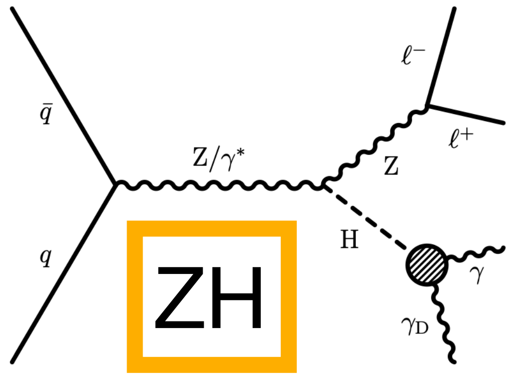
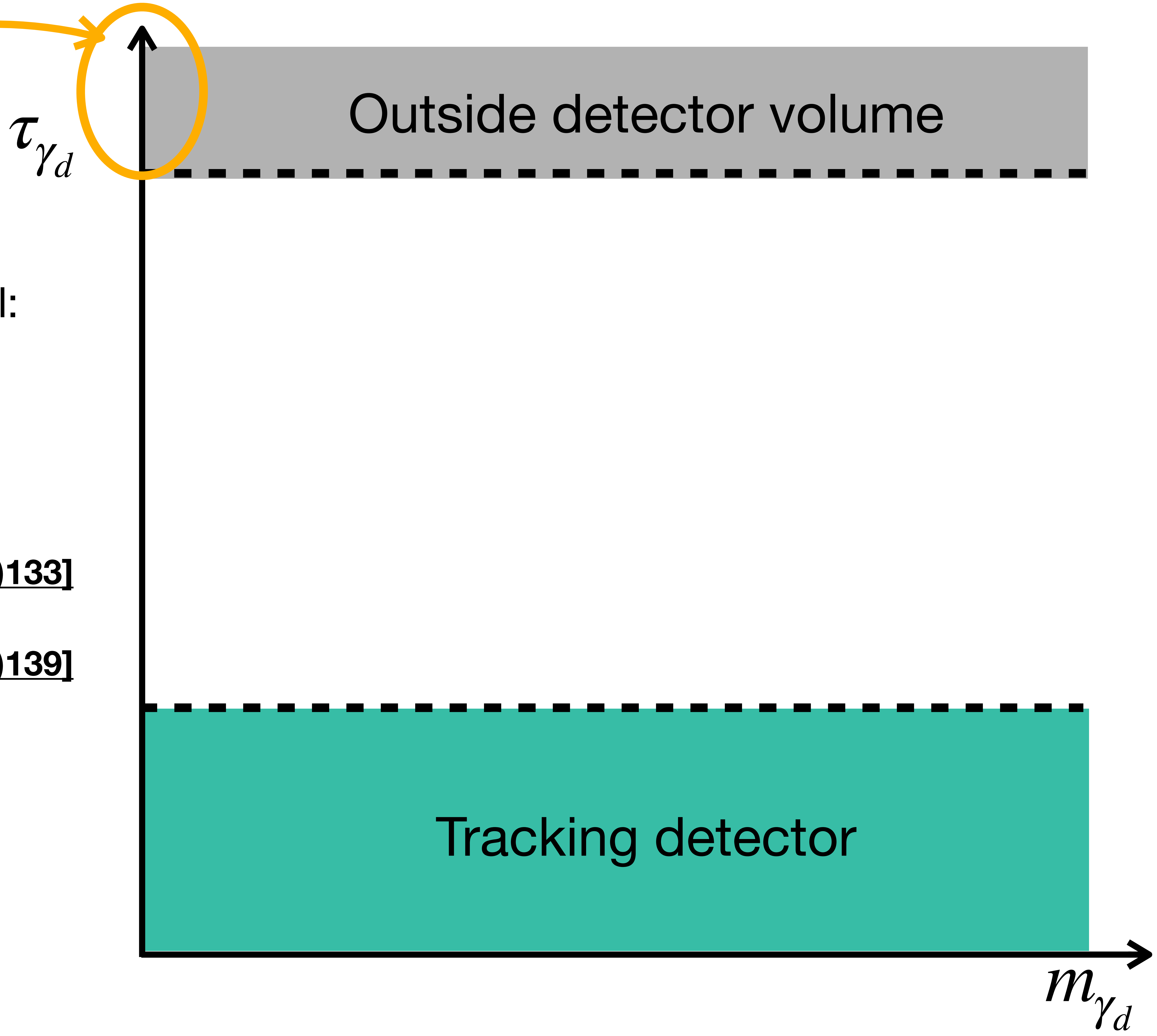


ATLAS [JHEP07(2023)133]

CMS [JHEP10(2019)139]



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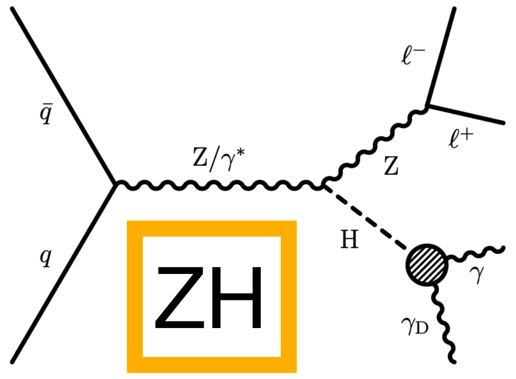

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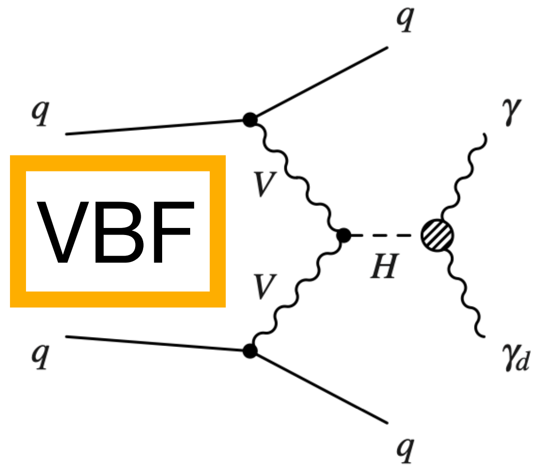
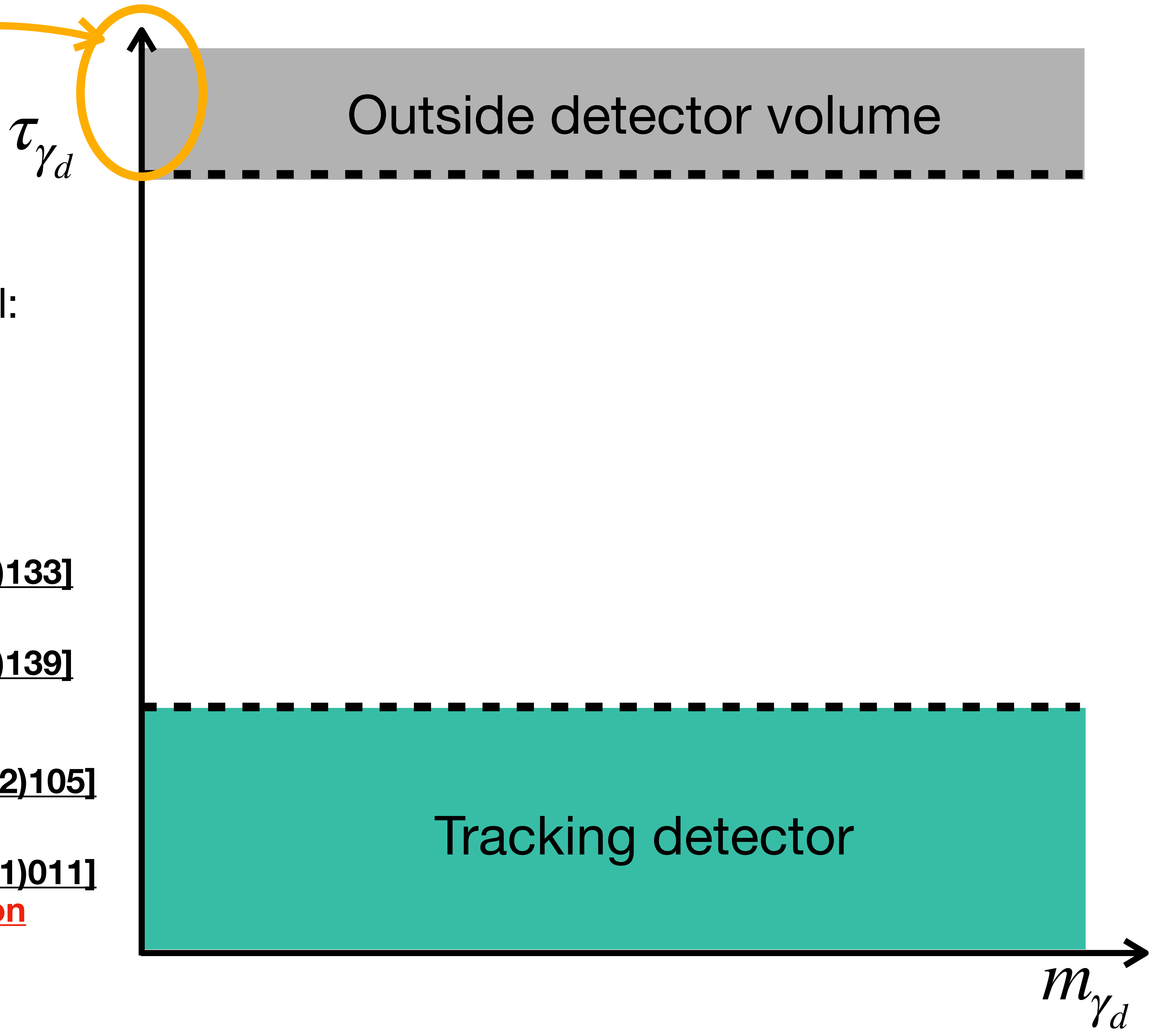


ATLAS [EPJC82(2022)105]

CMS [JHEP03(2021)011]

+ combination



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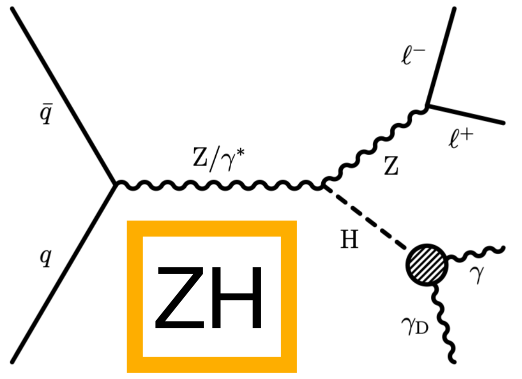

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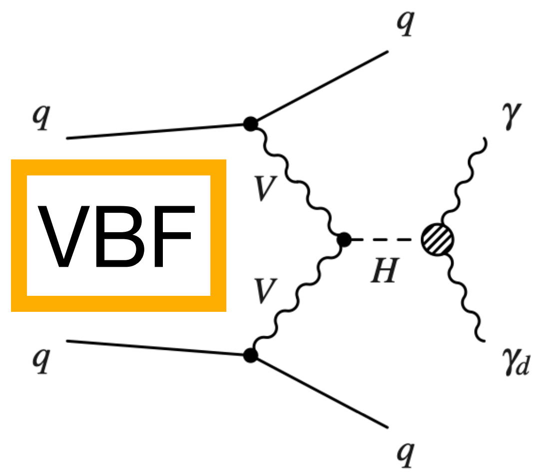

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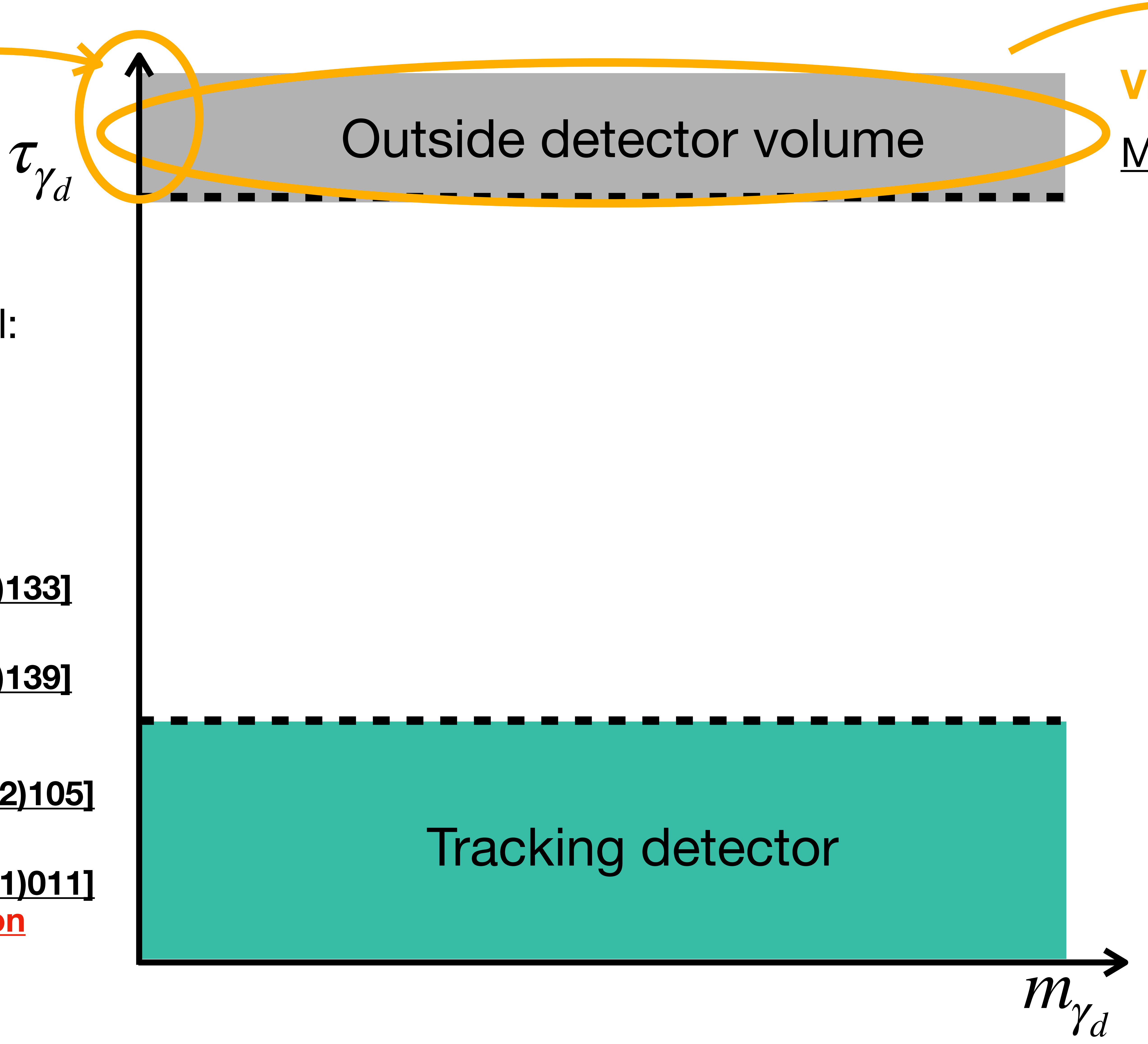

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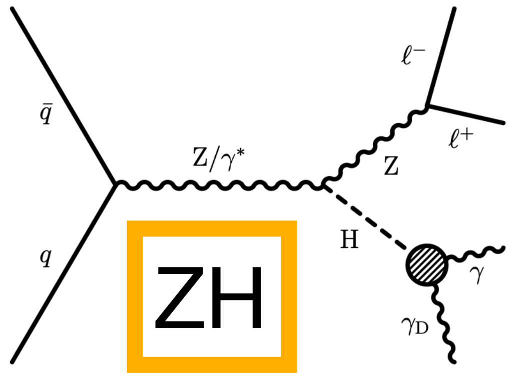

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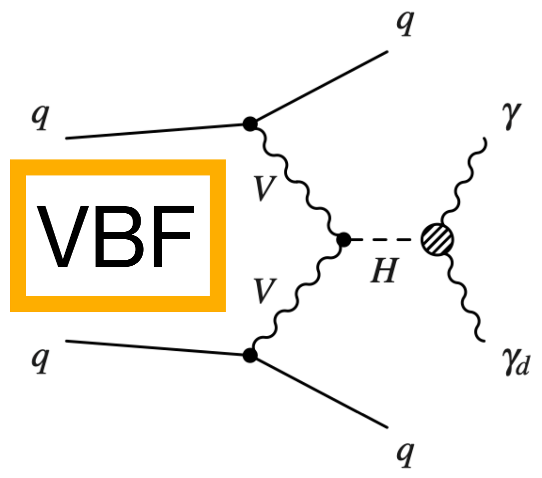

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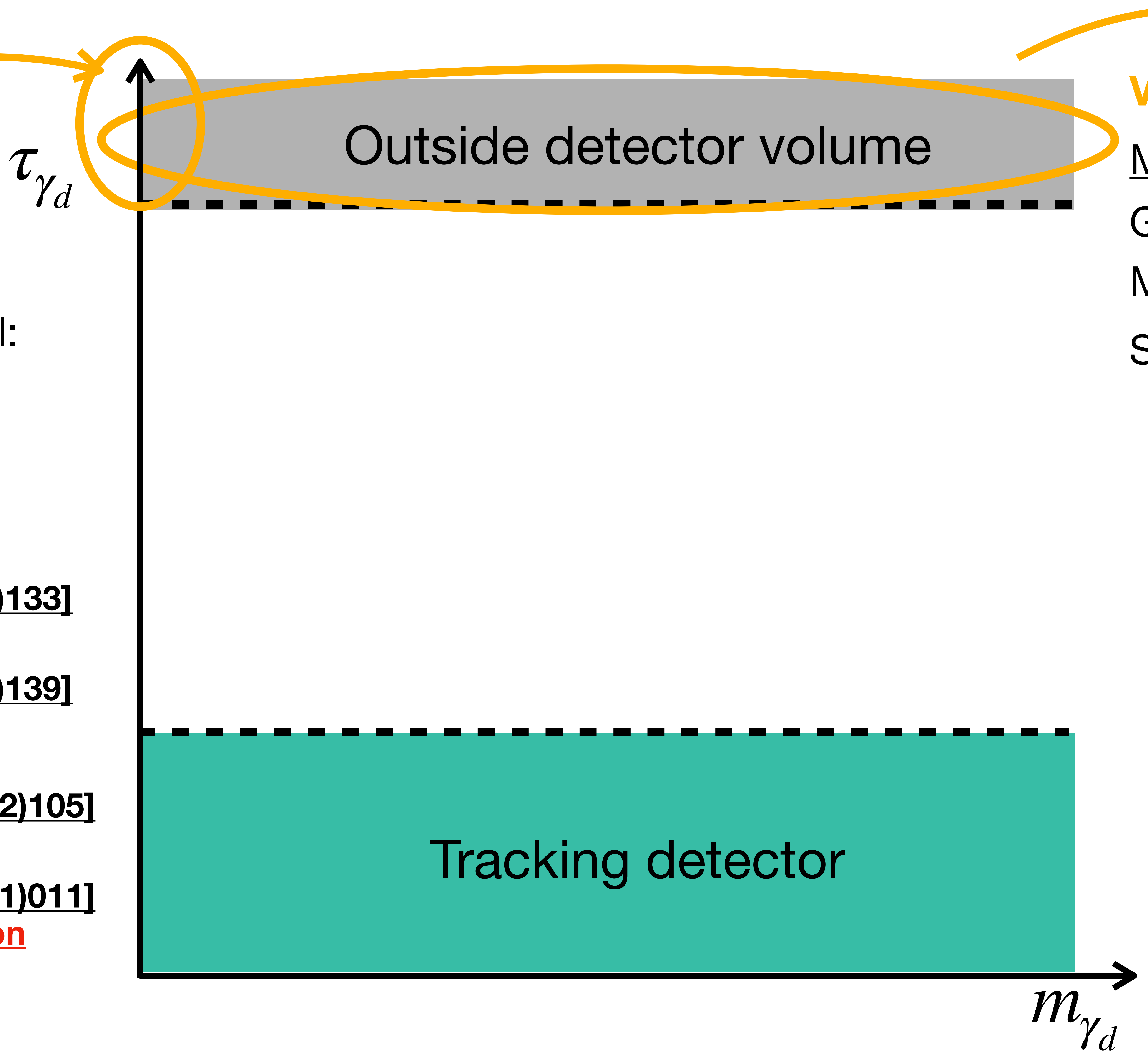

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Monojet (Higgs portal)

Signature: $\not{E}_\mathrm{T} + \mathrm{jets}$

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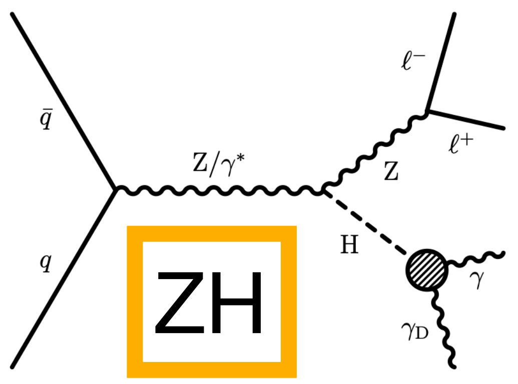

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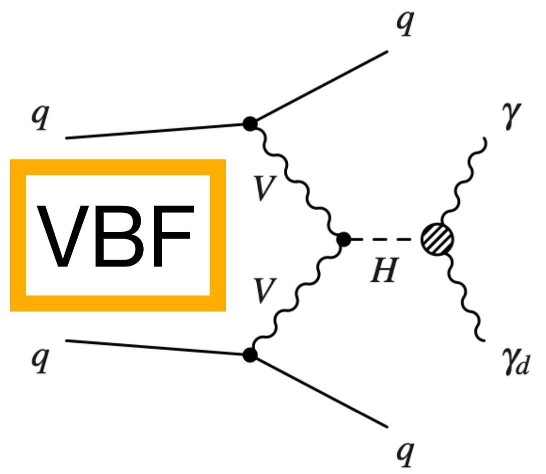

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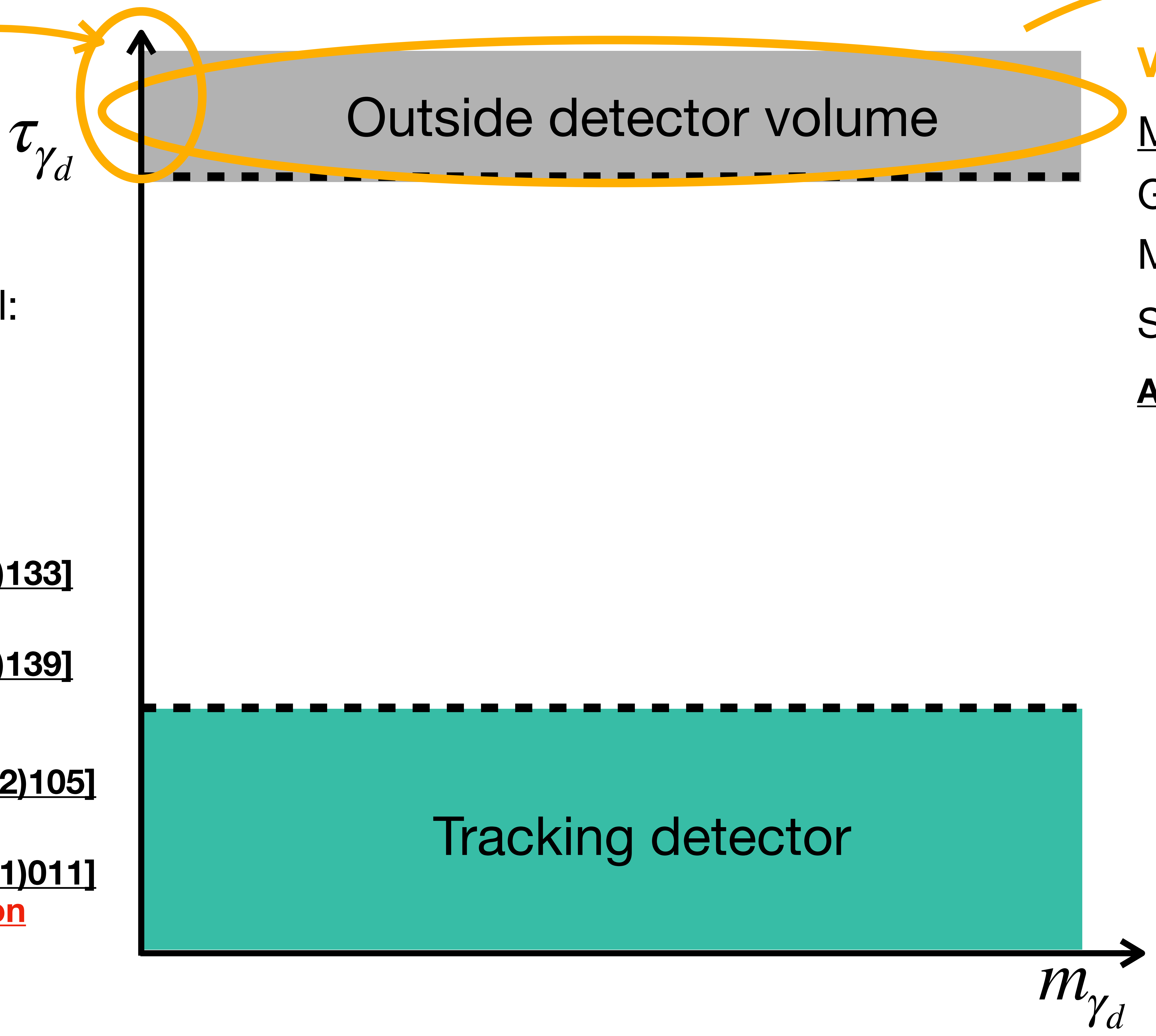

Visible dark photon:

FRVZ

Massive, detector stable γ_d

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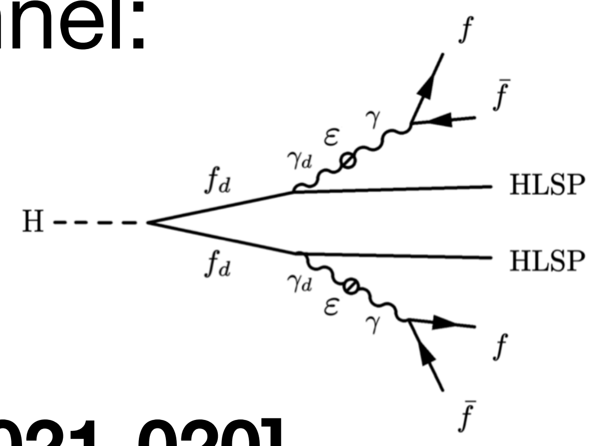

ATLAS [ATL-PHYS-PUB-2021-020]

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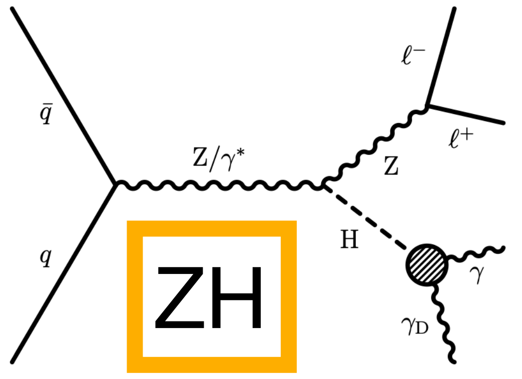

ZH

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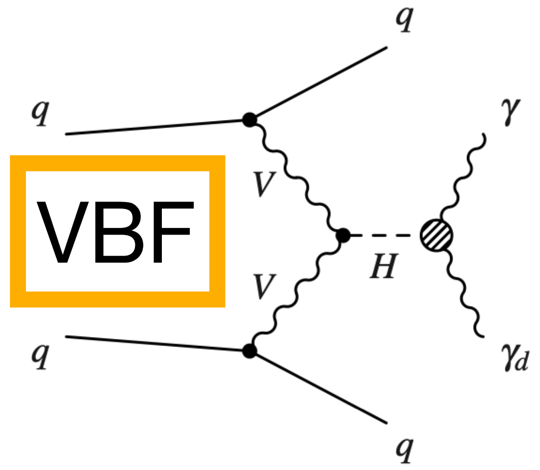

VBF

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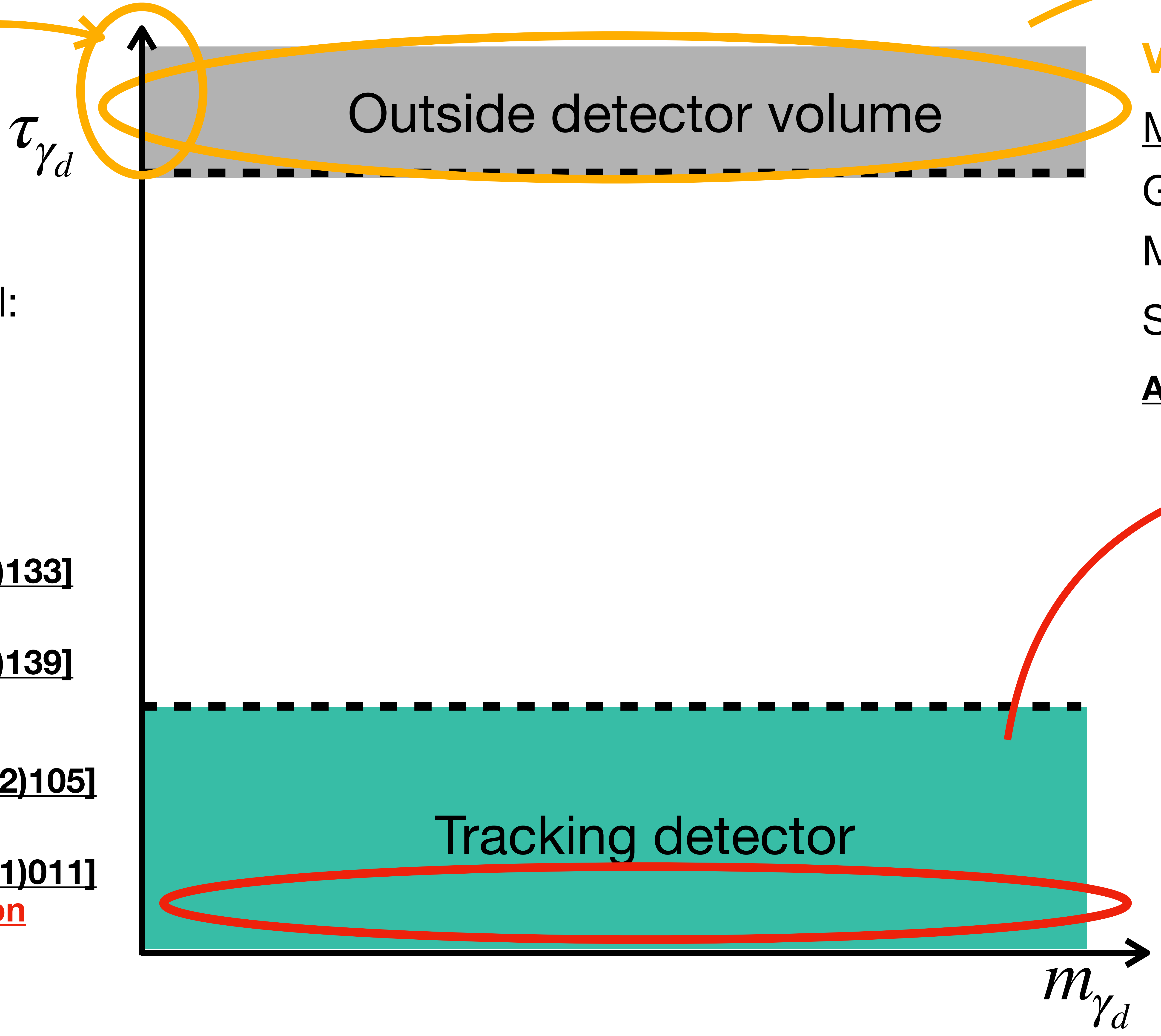

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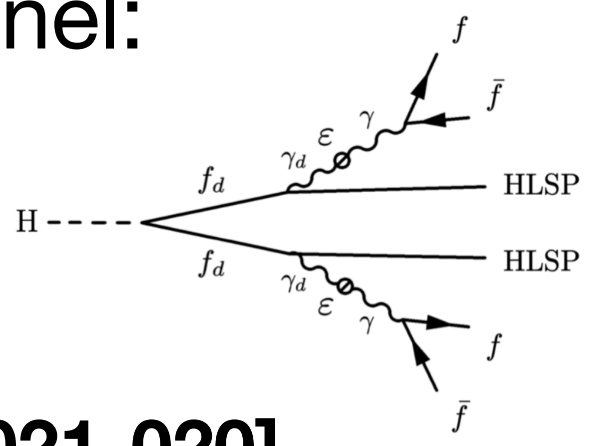
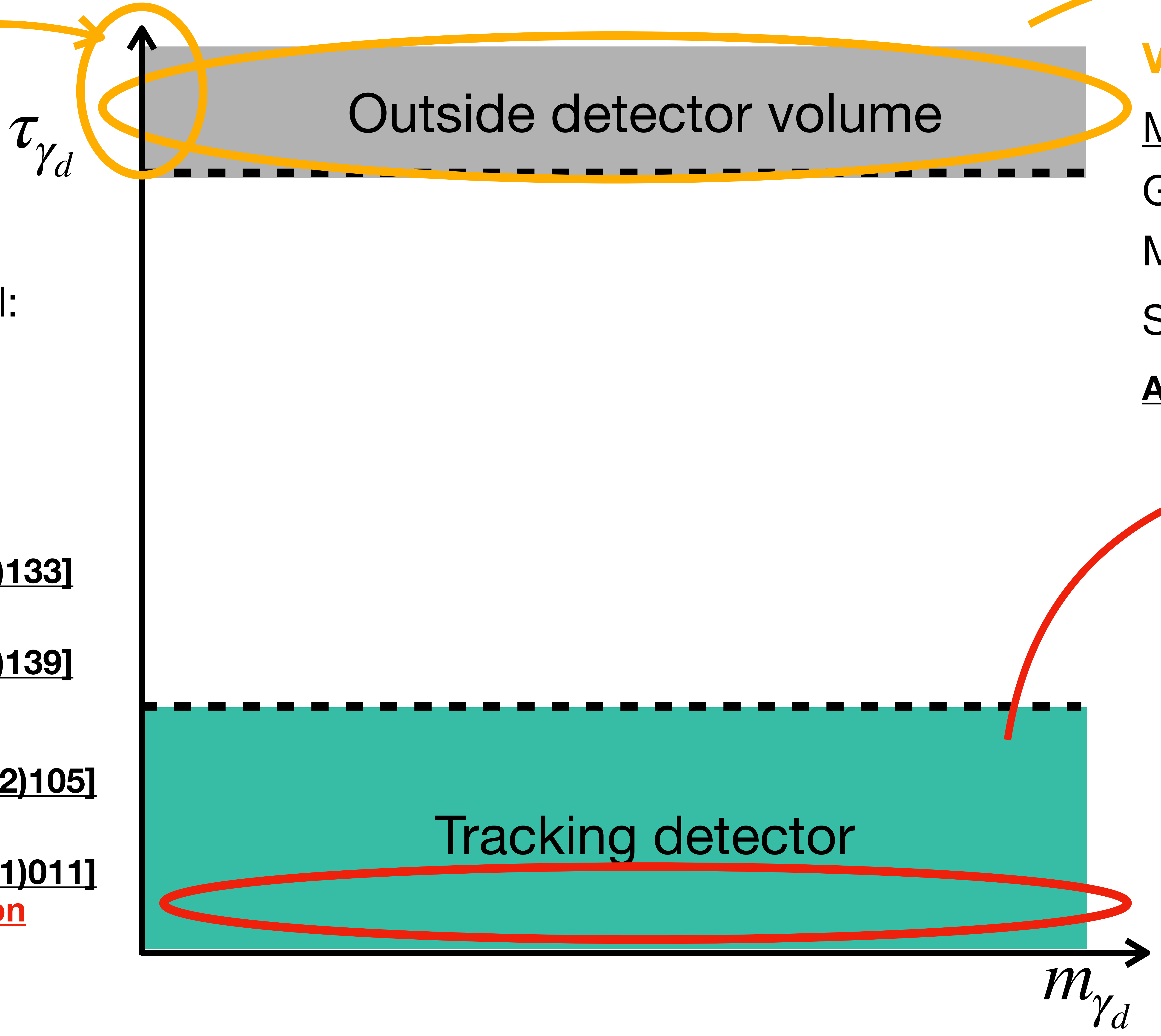


ATLAS [ATL-PHYS-PUB-2021-020]

Prompt dark photon:

- Collimated muon pairs

Dark photons and how we look for them



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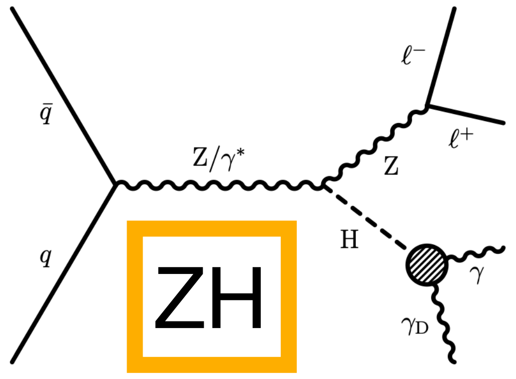

ZH

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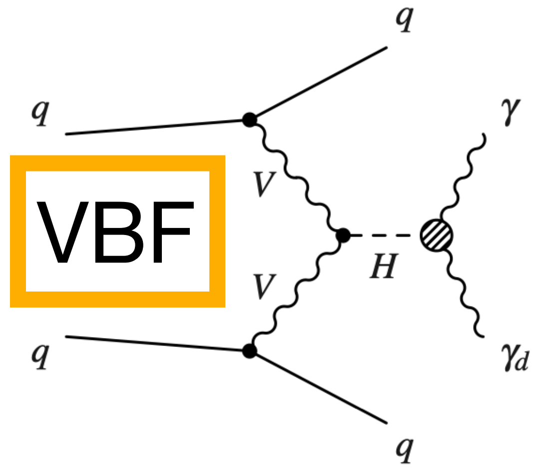

VBF

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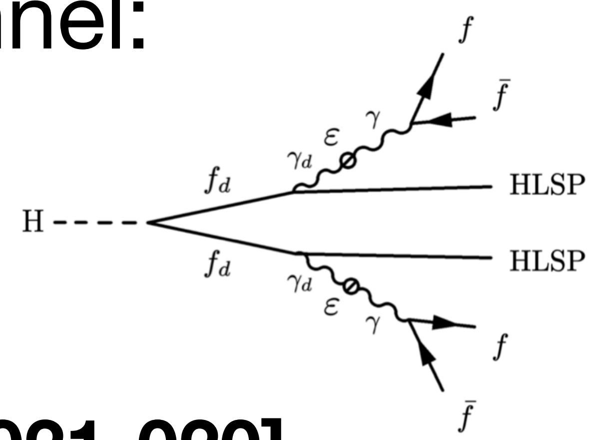

ATLAS [ATL-PHYS-PUB-2021-020]

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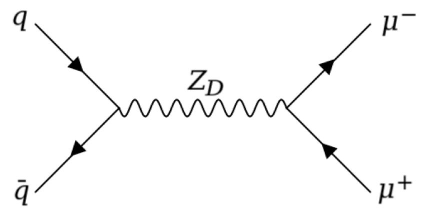
CMS, FRVZ [PLB796(2019)131]

NEW **CMS, CERN-EP-2023-165**



DY

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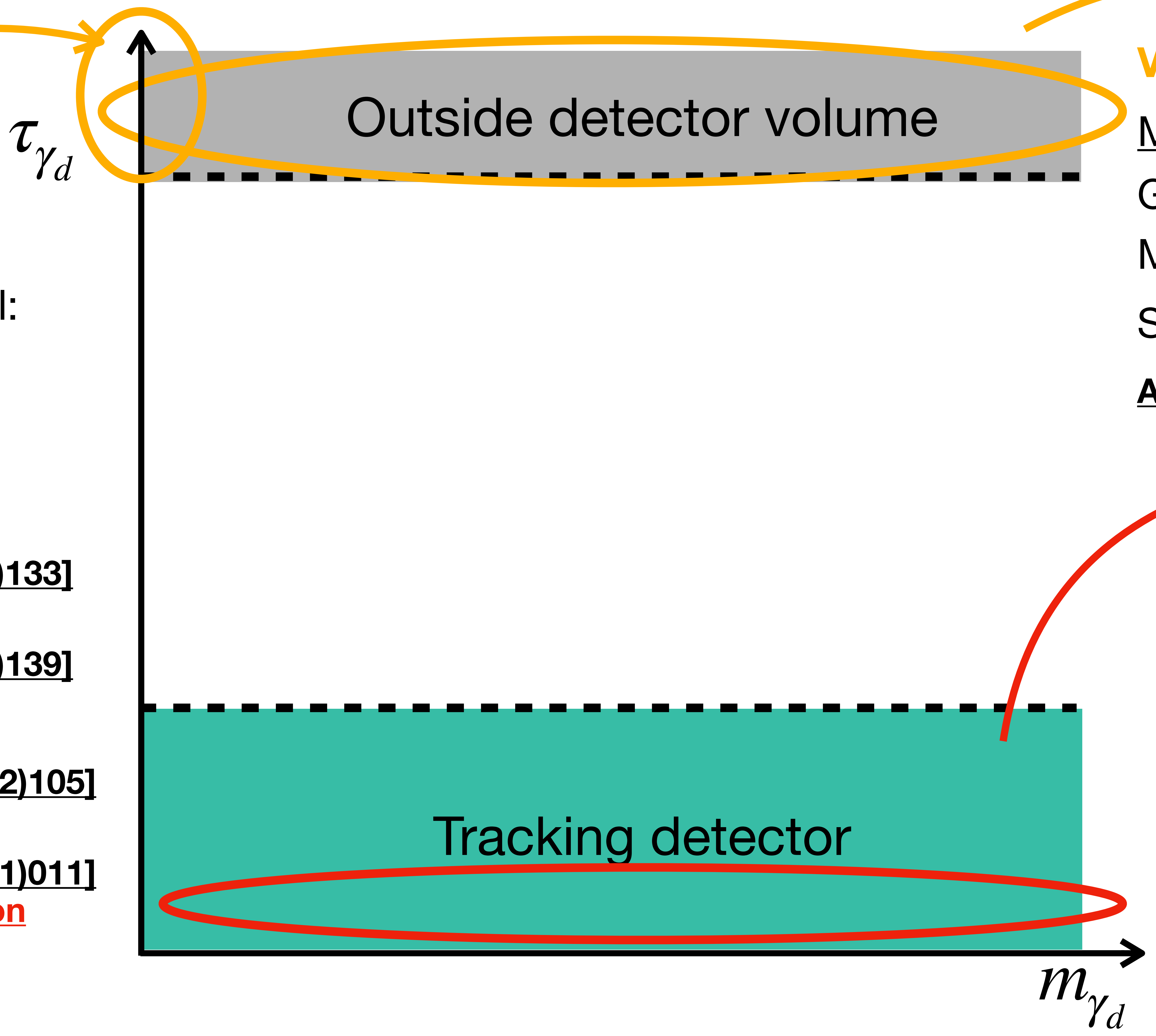

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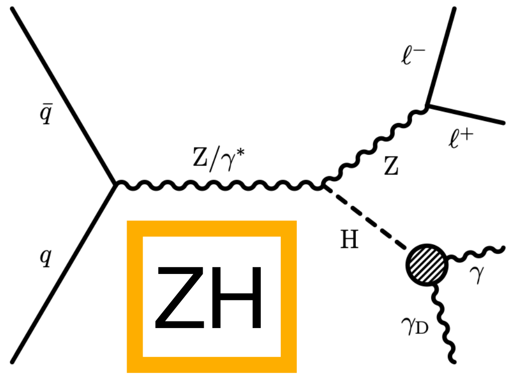
Signature: $E_T\!\!\!\!/ + \gamma$

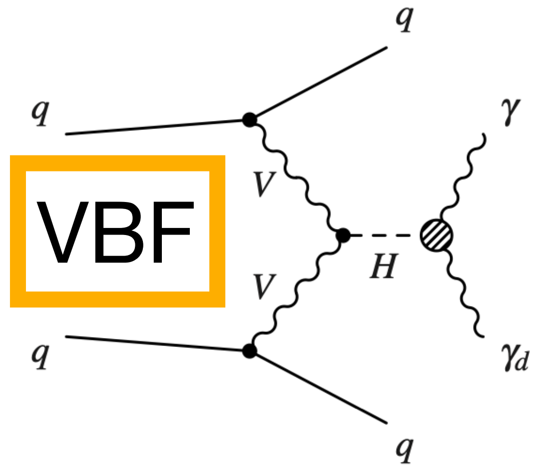
ZH



ATLAS [JHEP07(2023)133]

CMS [JHEP10(2019)139]

VBF



ATLAS [EPJC82(2022)105]

CMS [JHEP03(2021)011]

+ combination

Visible dark photon:

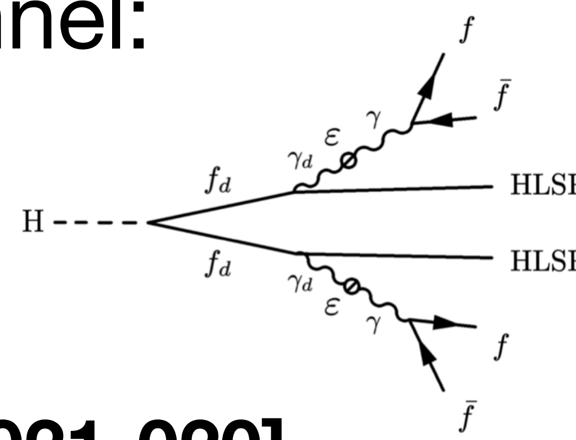
Massive, detector stable γ_d

FRVZ

Golden discovery channel:

Monojet (Higgs portal)

Signature: $E_T\!\!\!\!/ + \text{jets}$



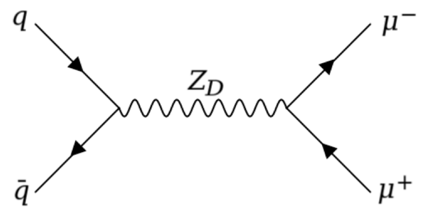
ATLAS [ATL-PHYS-PUB-2021-020]

Prompt dark photon:

- Collimated muon pairs

  CMS, FRVZ [PLB796(2019)131]

  NEW **CMS, CERN-EP-2023-165**

  DY

- Collimated lepton pairs

  ATLAS, FRVZ [JHEP02(2016)062]

Dark photons and how we look for them

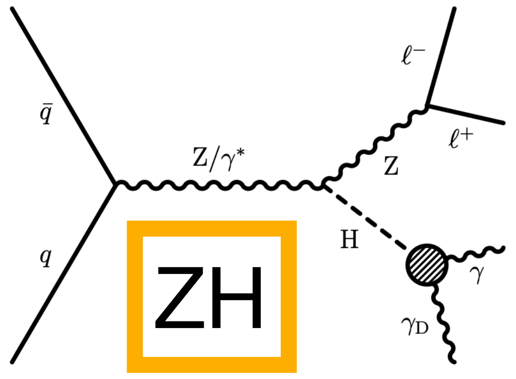
Invisible dark photon:

Massless γ_d or $\alpha_D \gg \alpha\varepsilon^2$

Golden discovery channel:

$H \rightarrow \gamma\gamma_d$ (Higgs portal)

Signature: $E_T\!\!\!\!/ + \gamma$



ATLAS [JHEP07(2023)133]

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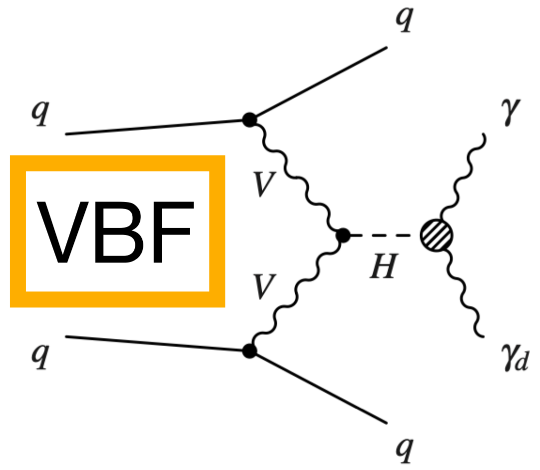

ATLAS [EPJC82(2022)105]

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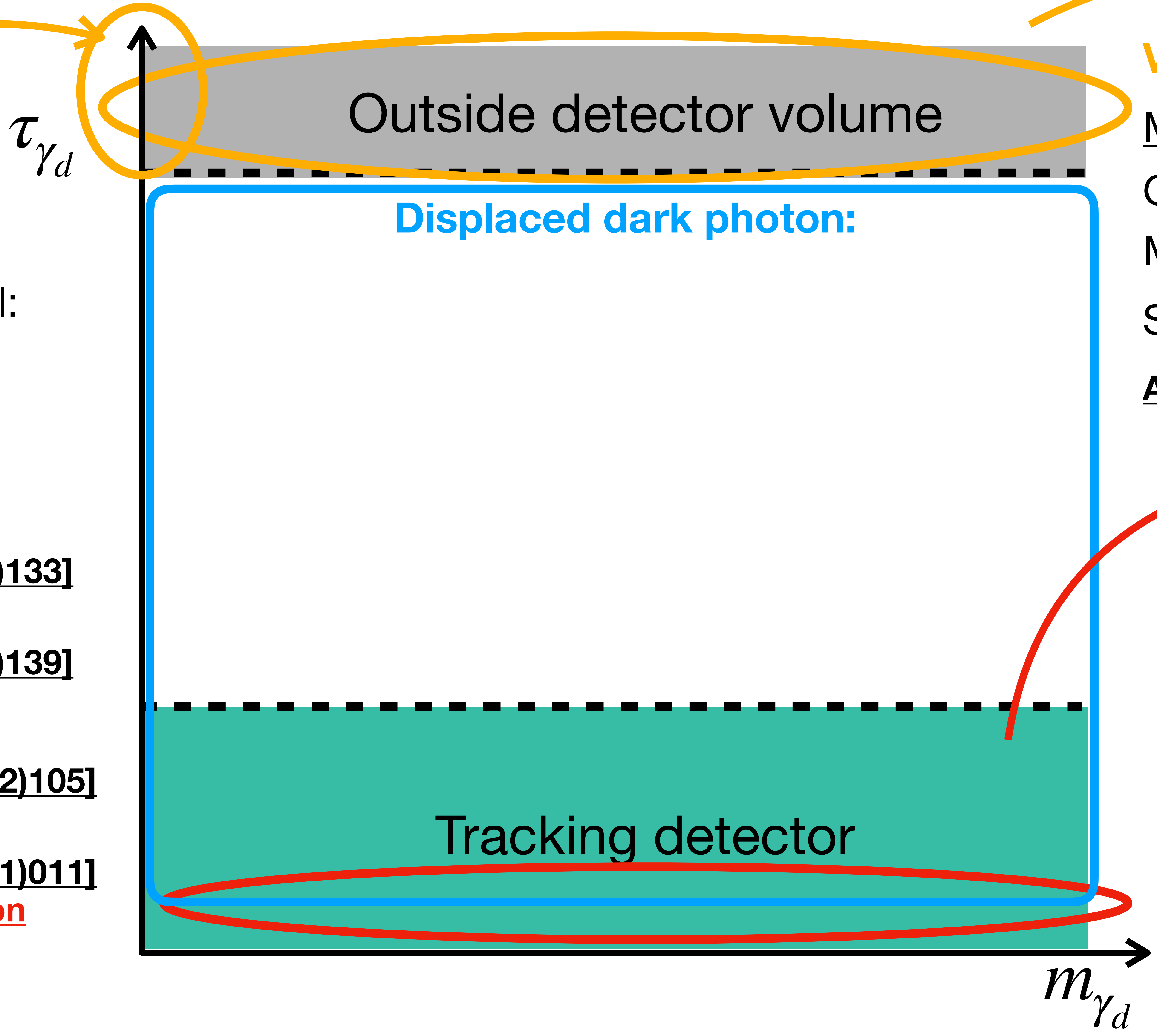

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Massive, detector stable γ_d

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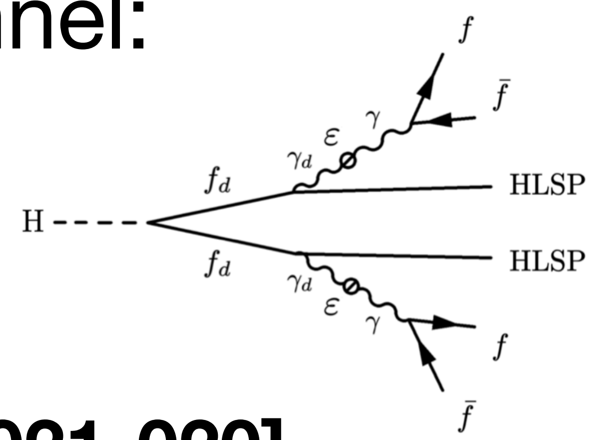

ATLAS [ATL-PHYS-PUB-2021-020]

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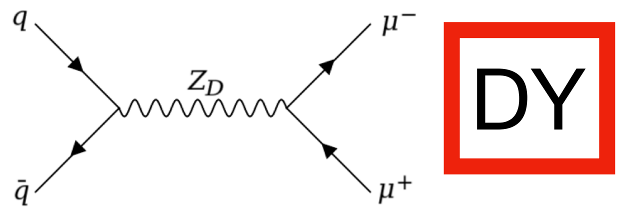
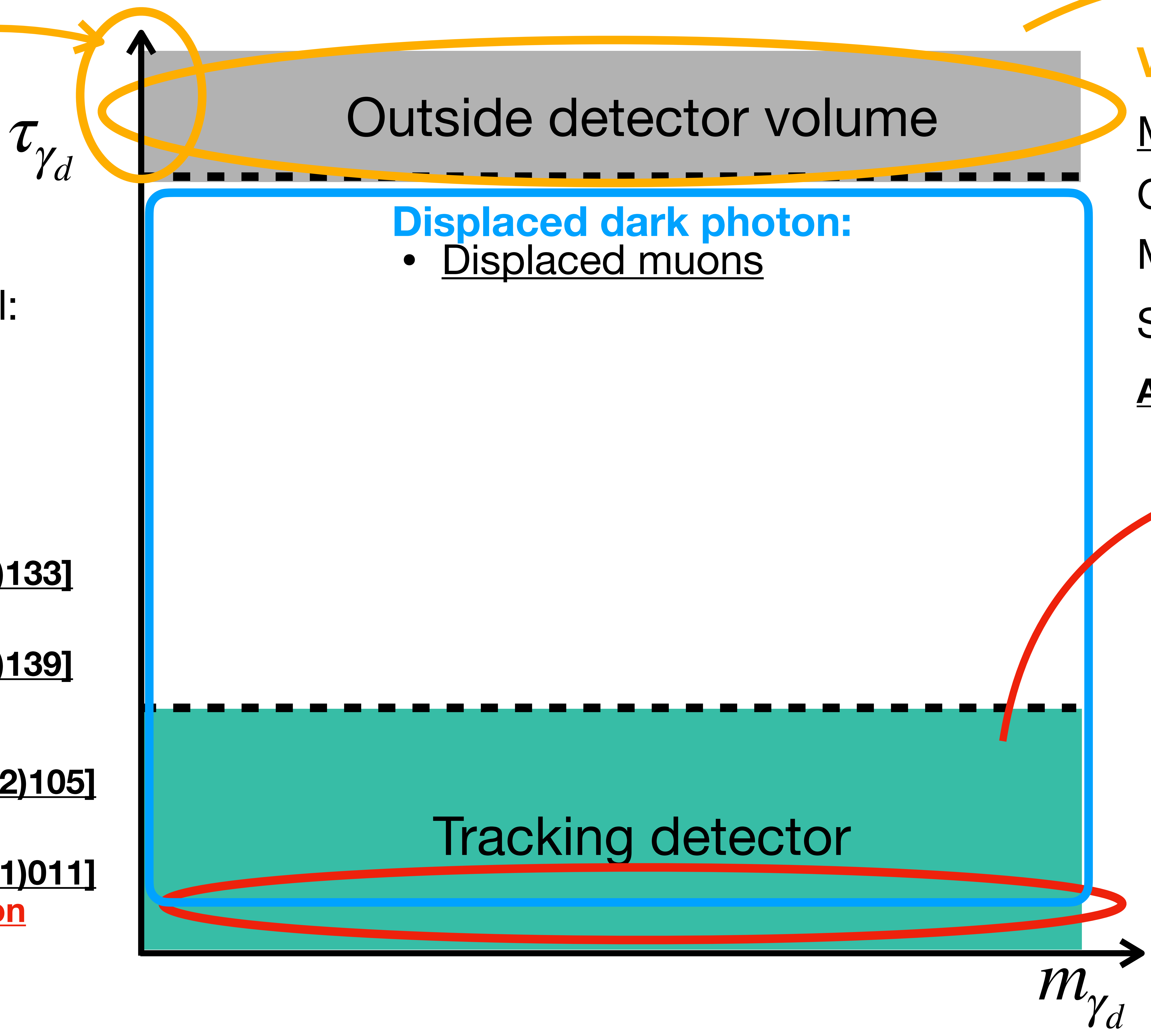
NEW **CMS, CERN-EP-2023-165**



- Collimated lepton pairs

ATLAS, FRVZ [JHEP02(2016)062]

Dark photons and how we look for them



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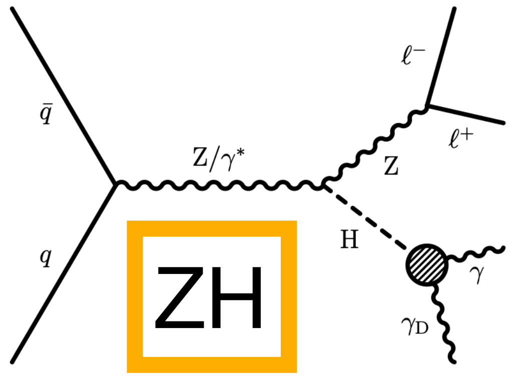

ATLAS [JHEP07(2023)133]

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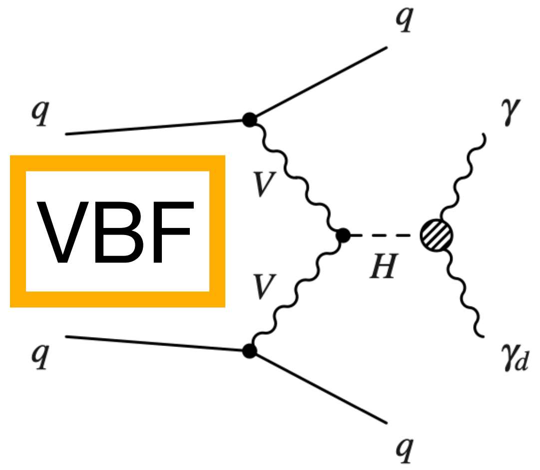

ATLAS [EPJC82(2022)105]

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Visible dark photon:

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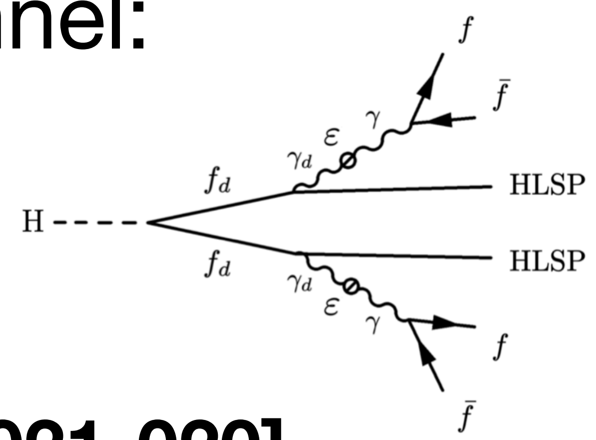

ATLAS [ATL-PHYS-PUB-2021-020]

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CMS, FRVZ [PLB796(2019)131]

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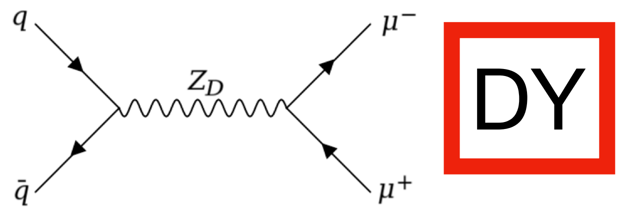

- Collimated lepton pairs

ATLAS, FRVZ [JHEP02(2016)062]

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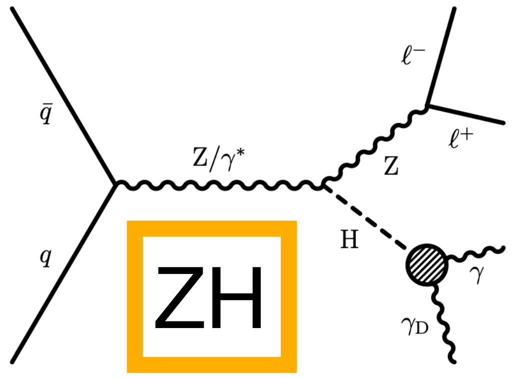
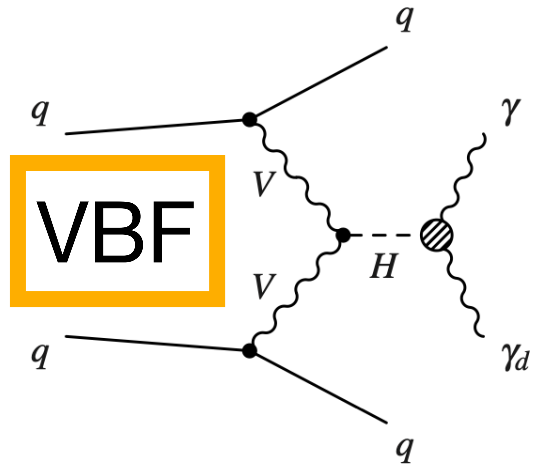


ATLAS [JHEP07(2023)133]

CMS [JHEP10(2019)139]



ATLAS [EPJC82(2022)105]

CMS [JHEP03(2021)011]

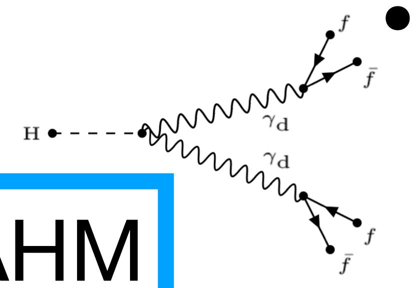
+ combination

τ_{γ_d}

Outside detector volume

Displaced dark photon:

- Displaced muons



CMS, low mass [JHEP04(2022)062]

CMS, high mass [JHEP05(2023)228]

ATLAS, high mass [PRD99(2019)012001]

NEW **CMS, inelastic DM [CERN-EP-2023-083]**

Tracking detector

m_{γ_d}

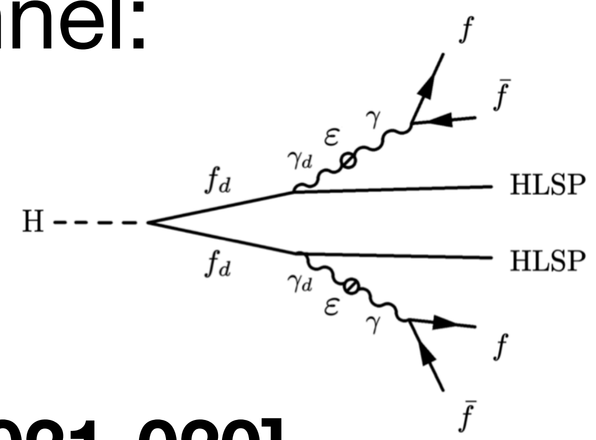
Visible dark photon:

Massive, detector stable γ_d FRVZ

Golden discovery channel:

Monojet (Higgs portal)

Signature: $E\!\!\!/_T + \text{jets}$



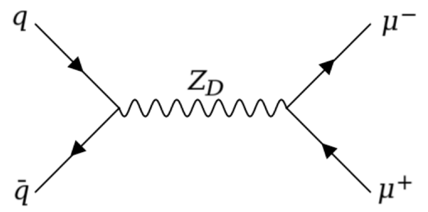
ATLAS [ATL-PHYS-PUB-2021-020]

Prompt dark photon:

- Collimated muon pairs

CMS, FRVZ [PLB796(2019)131]

NEW **CMS, CERN-EP-2023-165**



- Collimated lepton pairs

ATLAS, FRVZ [JHEP02(2016)062]

Dark photons and how we look for them

Invisible dark photon:

Massless γ_d or $\alpha_D \gg \alpha\varepsilon^2$

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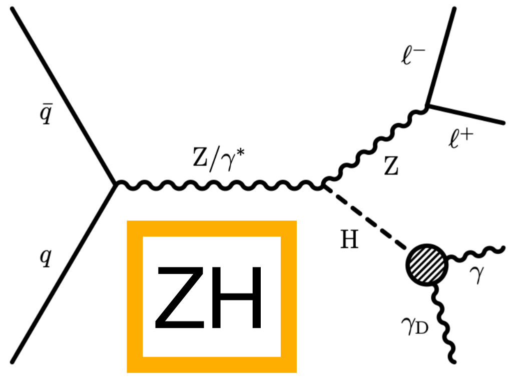
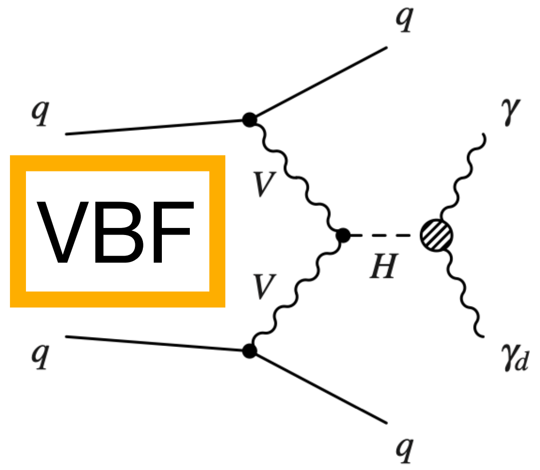
Signature: $E\!\!\!/_T + \gamma$



ZH

ATLAS [JHEP07(2023)133]

CMS [JHEP10(2019)139]



VBF

ATLAS [EPJC82(2022)105]

CMS [JHEP03(2021)011]

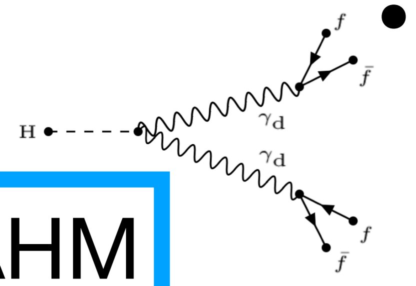
+ combination

τ_{γ_d}

Outside detector volume

Displaced dark photon:

HAHM



- Displaced muons

CMS, low mass [JHEP04(2022)062]

CMS, high mass [JHEP05(2023)228]

ATLAS, high mass [PRD99(2019)012001]

NEW **CMS, inelastic DM [CERN-EP-2023-083]**

- Displaced fermions

Tracking detector

m_{γ_d}

Visible dark photon:

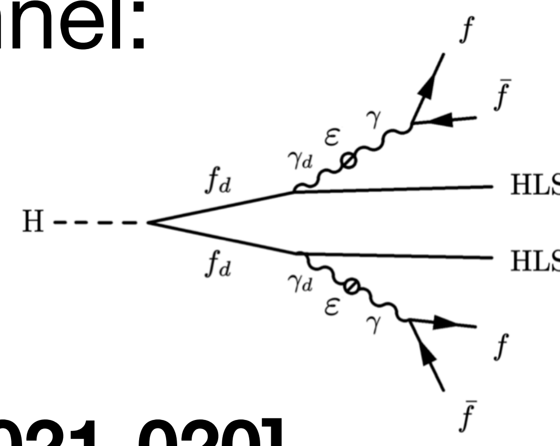
Massive, detector stable γ_d

FRVZ

Golden discovery channel:

Monojet (Higgs portal)

Signature: $E\!\!\!/_T + \text{jets}$



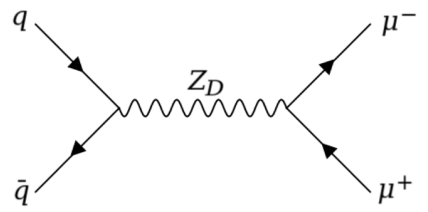
ATLAS [ATL-PHYS-PUB-2021-020]

Prompt dark photon:

- Collimated muon pairs

CMS, FRVZ [PLB796(2019)131]

NEW **CMS, CERN-EP-2023-165**



DY

- Collimated lepton pairs

ATLAS, FRVZ [JHEP02(2016)062]

CMS

ATLAS EXPERIMENT

Dark photons and how we look for them

τ_{γ_d}

Outside detector volume

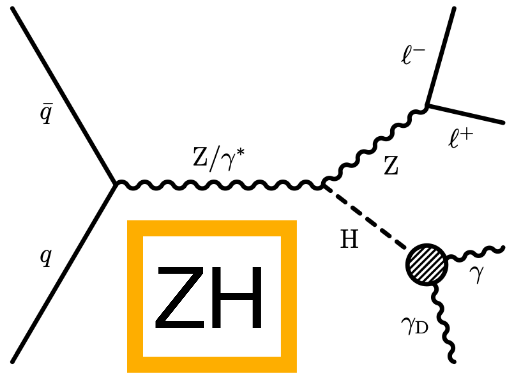
Invisible dark photon:

Massless γ_d or $\alpha_D \gg \alpha\varepsilon^2$

Golden discovery channel:

$H \to \gamma\gamma_d$ (Higgs portal)

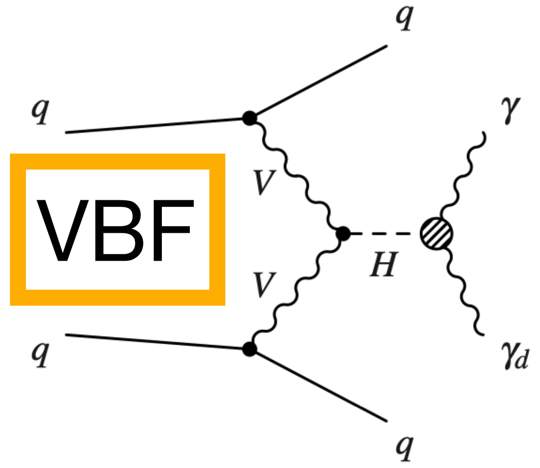
Signature: $E\!\!\!/_T + \gamma$



ZH

ATLAS [JHEP07(2023)133]

CMS [JHEP10(2019)139]



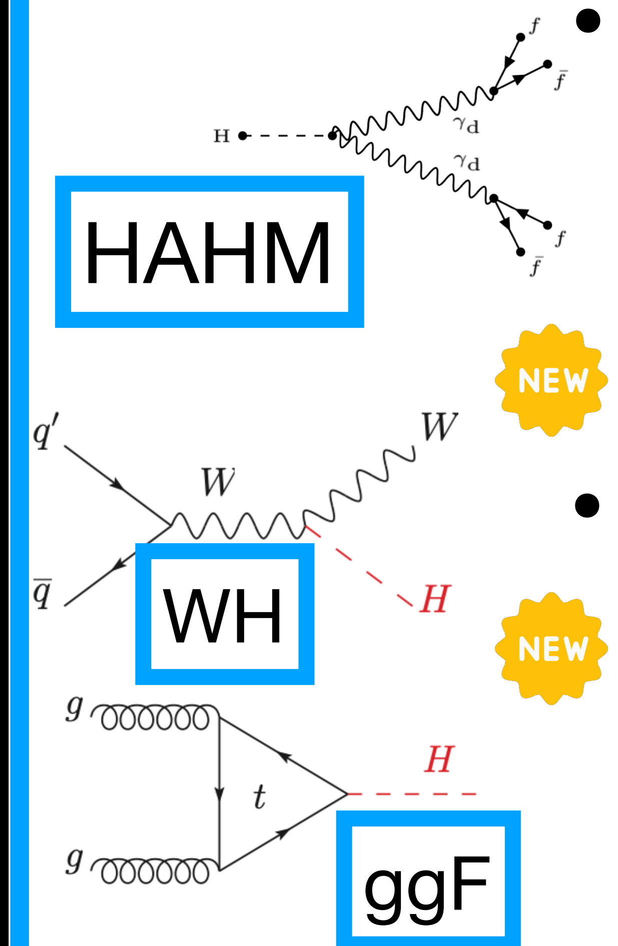
VBF

ATLAS [EPJC82(2022)105]

CMS [JHEP03(2021)011]

+ combination

Displaced dark photon:



HAHM

WH

ggF

- Displaced muons

CMS, low mass [JHEP04(2022)062]

CMS, high mass [JHEP05(2023)228]

ATLAS, high mass [PRD99(2019)012001]

NEW **CMS, inelastic DM [CERN-EP-2023-083]**

- Displaced fermions

NEW **ATLAS, FRVZ, VBF [ATLAS-CONF-2023-051] + combination**

ATLAS, HAHM and FRVZ, ggF and WH [JHEP06(2023)153]

Tracking detector

m_{γ_d}

Visible dark photon:

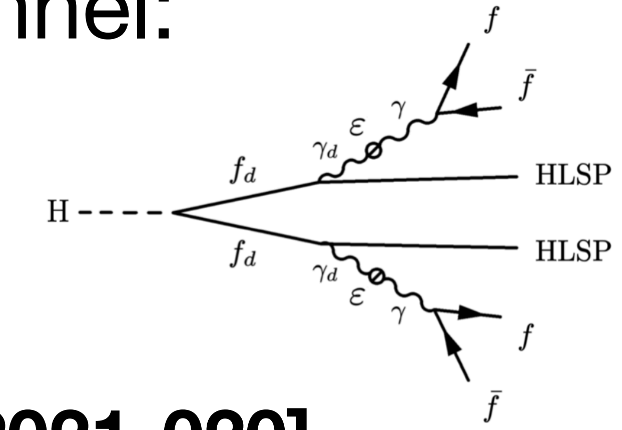
Massive, detector stable γ_d

FRVZ

Golden discovery channel:

Monojet (Higgs portal)

Signature: $E\!\!\!/_T + \text{jets}$



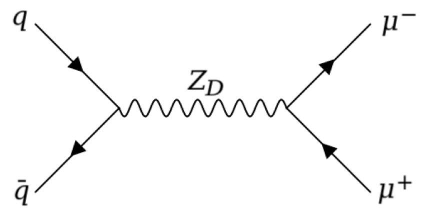
ATLAS [ATL-PHYS-PUB-2021-020]

Prompt dark photon:

- Collimated muon pairs

CMS, FRVZ [PLB796(2019)131]

NEW **CMS, CERN-EP-2023-165**



DY

- Collimated lepton pairs

ATLAS, FRVZ [JHEP02(2016)062]

Dark photons searches covered here

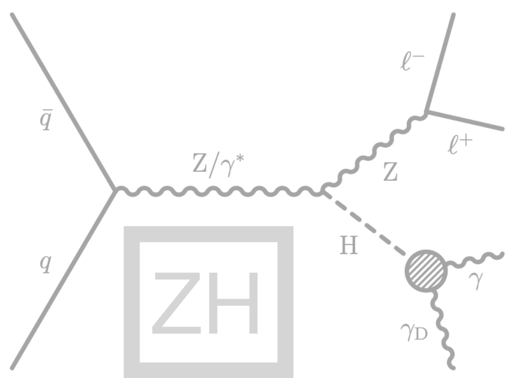
Invisible dark photon:

Massless γ_d

Golden discovery channel:

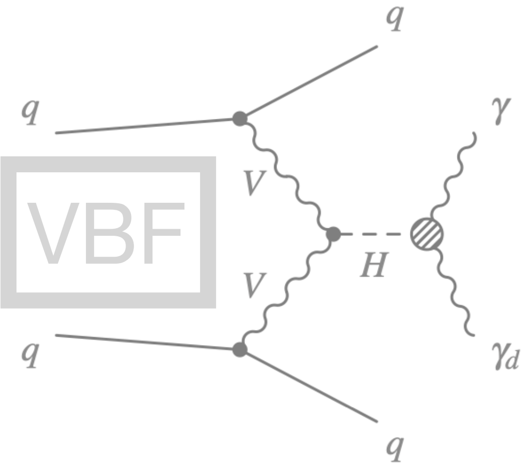
$H \to \gamma\gamma_d$ (Higgs portal)

Signature: $E_T\!\!\!\!/ + \gamma$



ATLAS [JHEP07(2023)133]

CMS [JHEP10(2019)139]



ATLAS [EPJC82(2023)105]

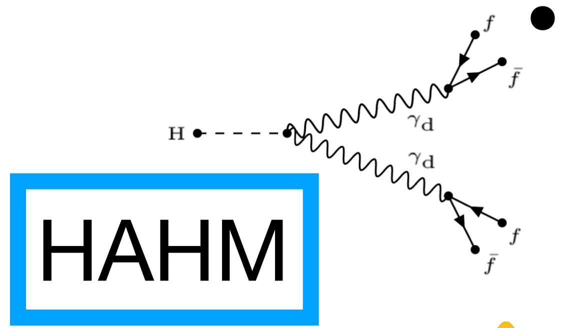
CMS [JHEP03(2021)011] + combination

τ_{γ_d}

Outside detector volume

Displaced dark photon:

- Displaced muons



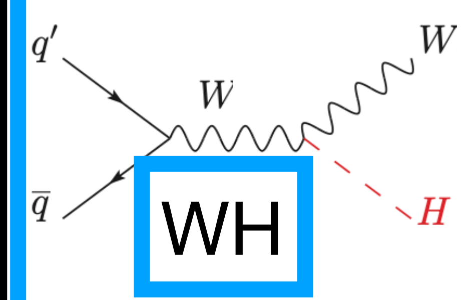
CMS, low mass [JHEP04(2022)062]

CMS, high mass [JHEP05(2023)228]

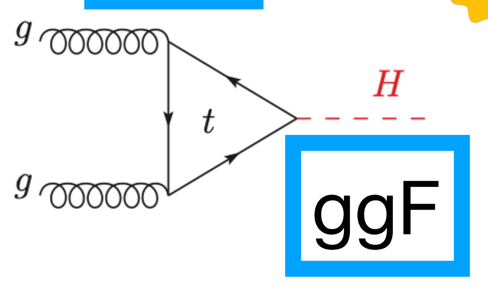
ATLAS, high mass [PRD99(2019)012001]

NEW **CMS, inelastic DM [CERN-EP-2023-083]**

- Displaced fermions



NEW **ATLAS, FRVZ, VBF [ATLAS-CONF-2023-051]** + combination



ATLAS, HAHM and FRVZ, ggF and WH [JHEP06(2023)153]

Tracking detector

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Visible dark photon:

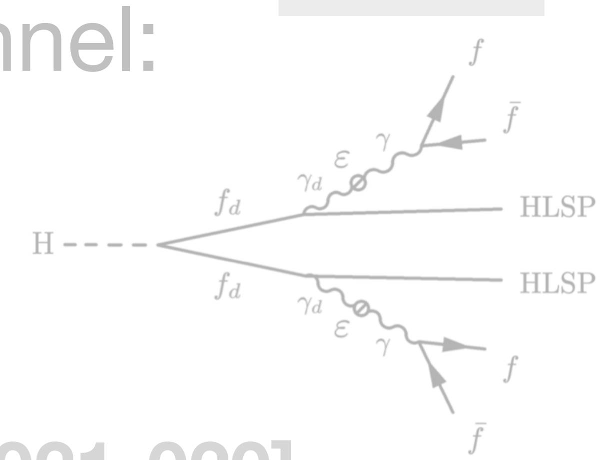
Massive, detector stable γ_d

FRVZ

Golden discovery channel:

Monojet (Higgs portal)

Signature: $E_T\!\!\!\!/ +$ jets



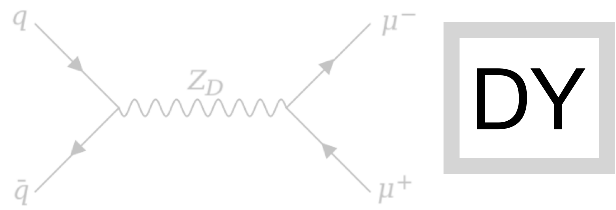
ATLAS [ATL-PHYS-PUB-2021-020]

Prompt dark photon:

- Collimated muon pairs

CMS, FRVZ [PLB796(2019)131]

NEW CMS, CERN-EP-2023-165

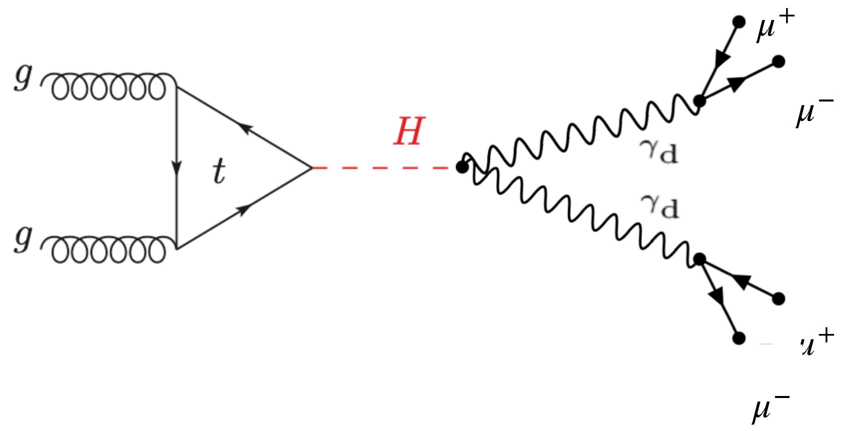


- Collimated lepton pairs

ATLAS, FRVZ [JHEP02(2016)062]

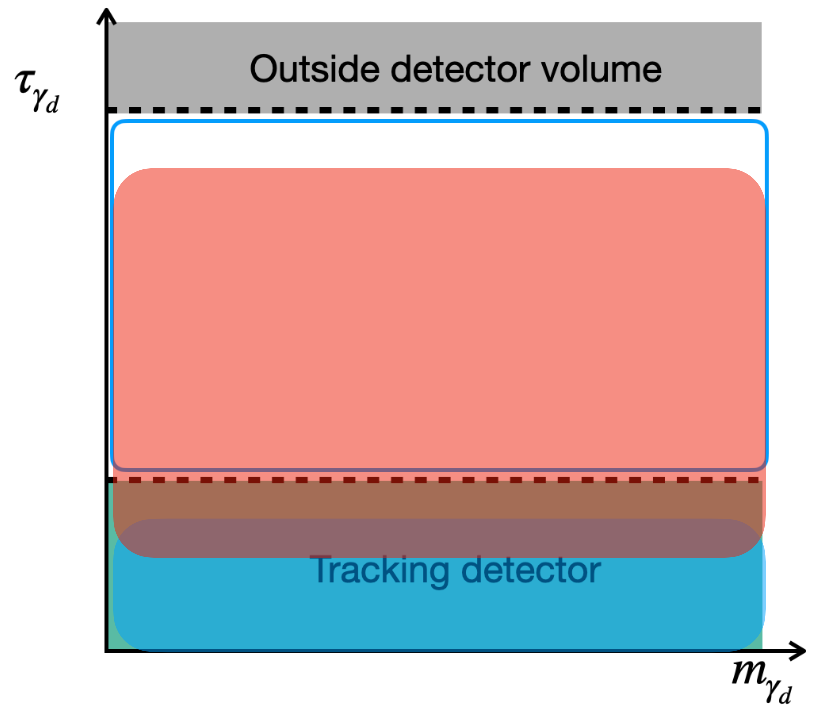
Displaced massive γ_d - displaced muons

ggF produced Higgs boson + HAHM (Higgs + vector portal) =



→ Di-muon pairs:

- Displaced
- Soft
- Collimated



[CMS, low mass [JHEP04(2022)062]](#)

[CMS, high mass [JHEP05(2023)228]](#)

2017-2018 data $(101\text{fb}^{-1}, \sqrt{s} = 13\,\text{TeV})$

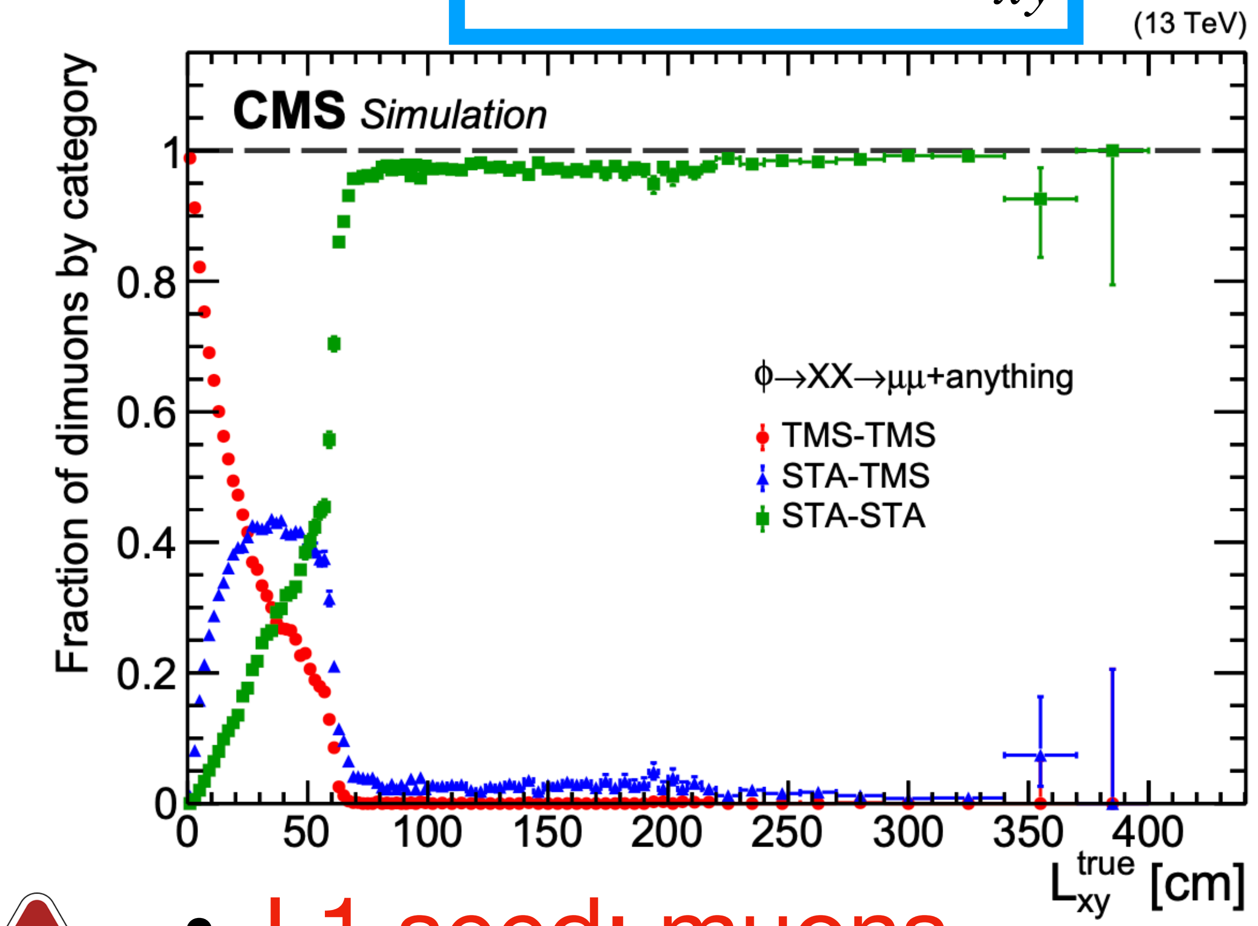
Soft muons → Scouting!

HLT muon trigger p_T threshold decreased (trigger frequency increased to 3kHz), event size reduced to have similar bandwidth wrt standard trigger

- Muon hits in at least 2 layers in the ID required at L1 trigger → loss in efficiency for muons produced after ID
- Reduced info in the event → simpler analysis required

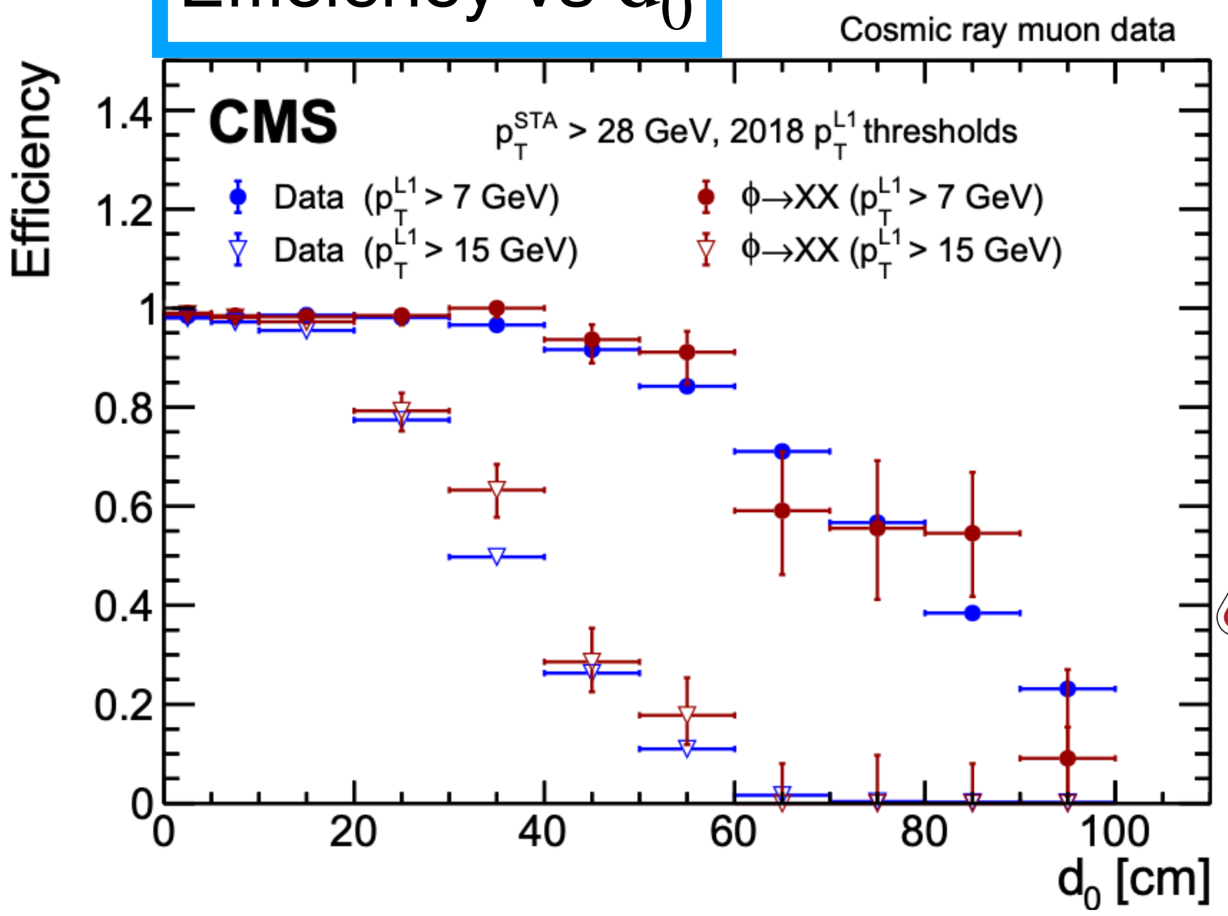
2016+2018 data $(97.6\text{fb}^{-1}, \sqrt{s} = 13\,\text{TeV})$

Muon type vs L_{xy}



Displaced muons → MS only muons used too (no beamspot requirement)

Efficiency vs d_0

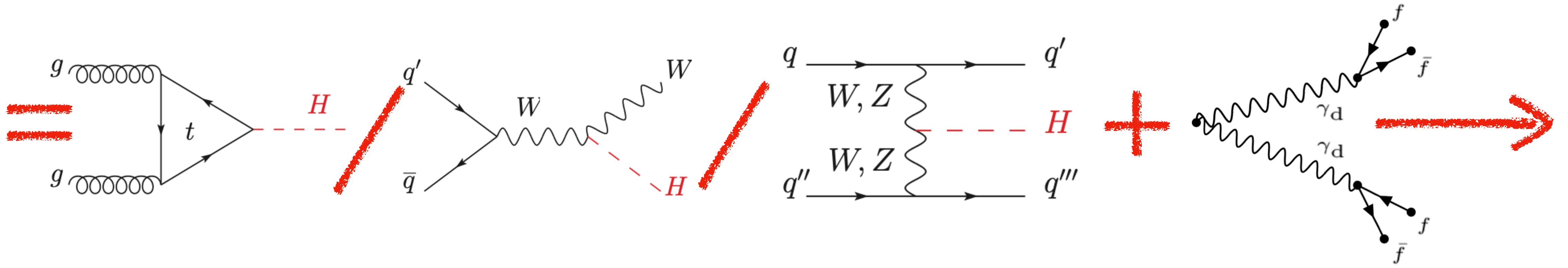


- L1 seed: muons from beam-spot→ efficiency decrease for large d_0

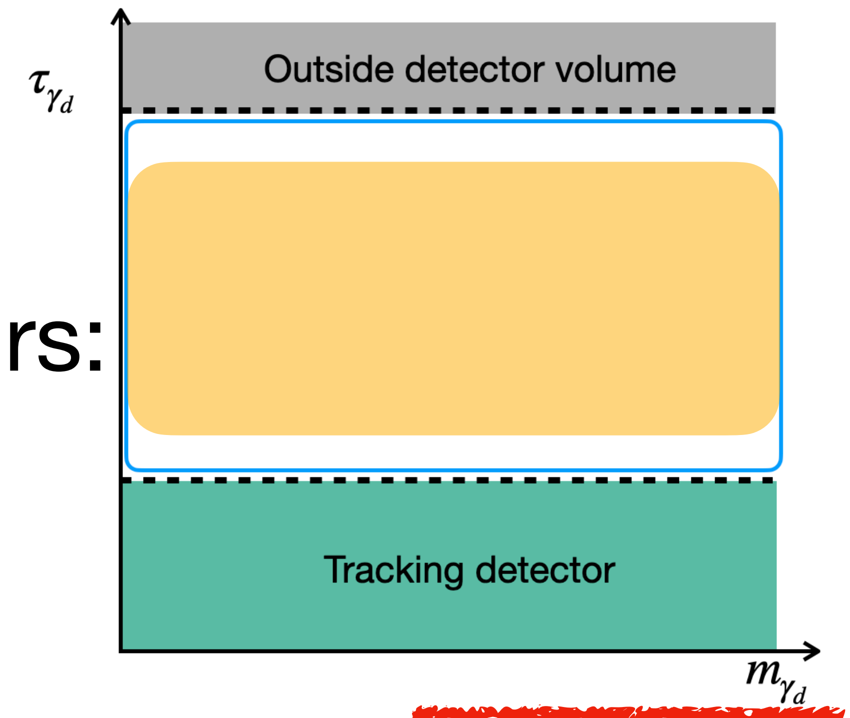
Displaced massive γ_d - displaced fermions

ggF/WH/VBF Higgs boson +
HAHM* (Higgs + vector portal)

*FRVZ was studied as well



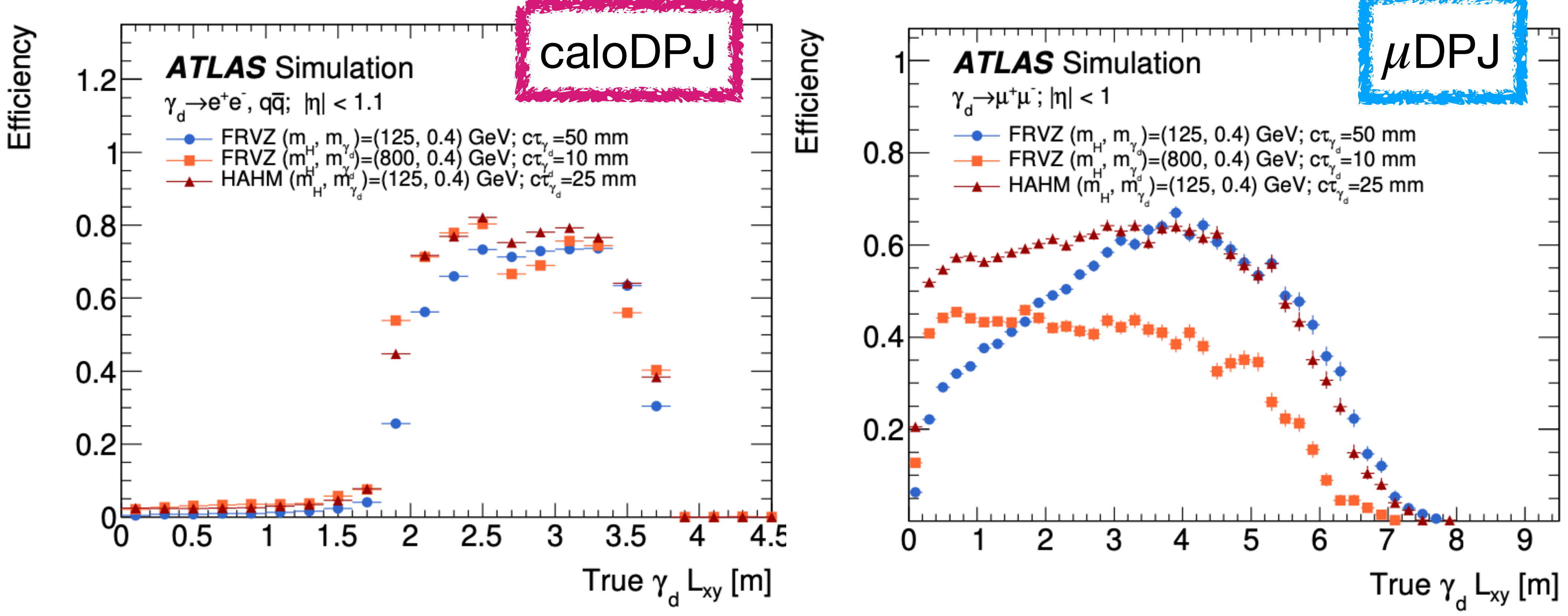
Di-fermion pairs:
- Displaced
- Soft
- Collimated



ATLAS, HAHM and FRVZ, ggF and WH [JHEP06(2023)153] + ATLAS, HAHM and FRVZ, VBF [ATLAS-CONF-2023-051]

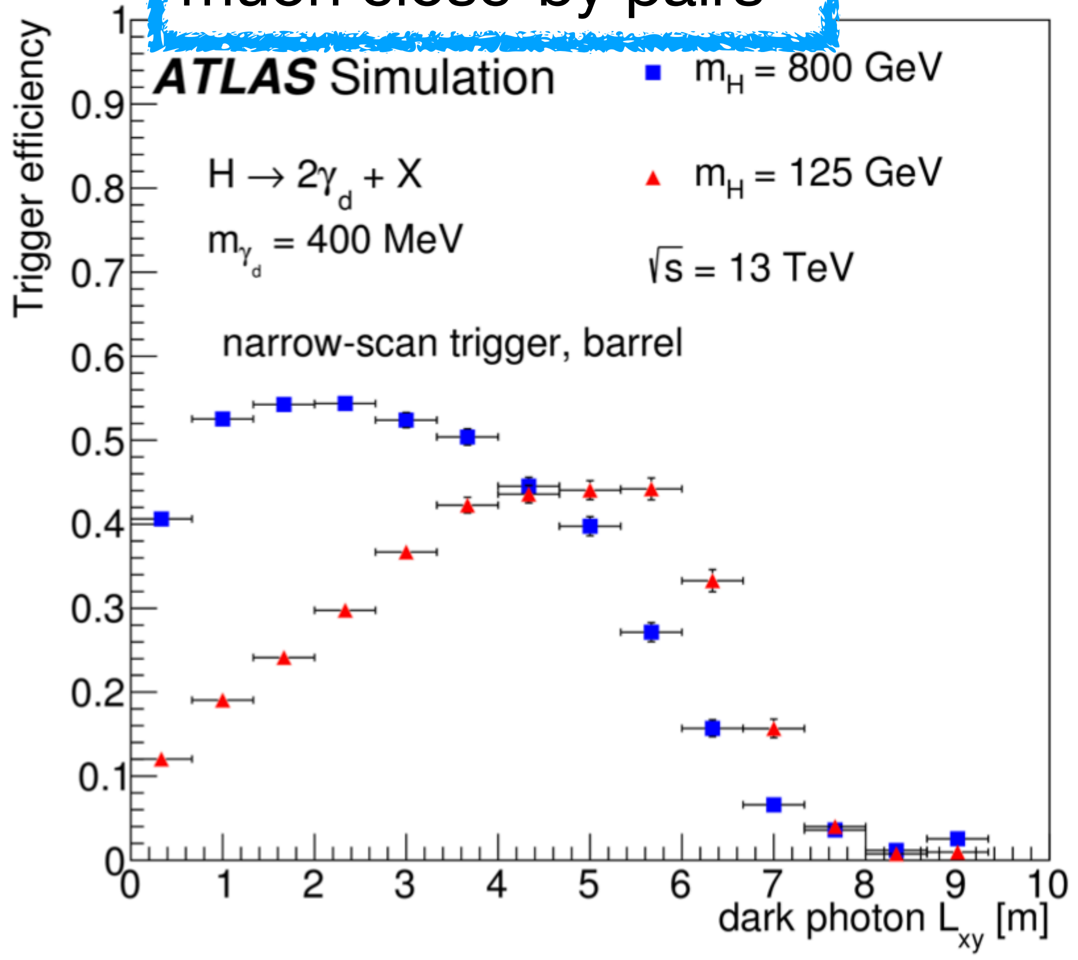
NEW Full Run2 analyses

- Collimated fermions (boosted topology)
  → Reconstruction of jet like structure called Dark Photon Jets (DPJs):
  $\gamma_d \rightarrow q\bar{q}/e^+e^- \rightarrow$ caloDPJ (displaced jets)
  $\gamma_d \rightarrow \mu^+\mu^- \rightarrow$ μDPJ (displaced muons)



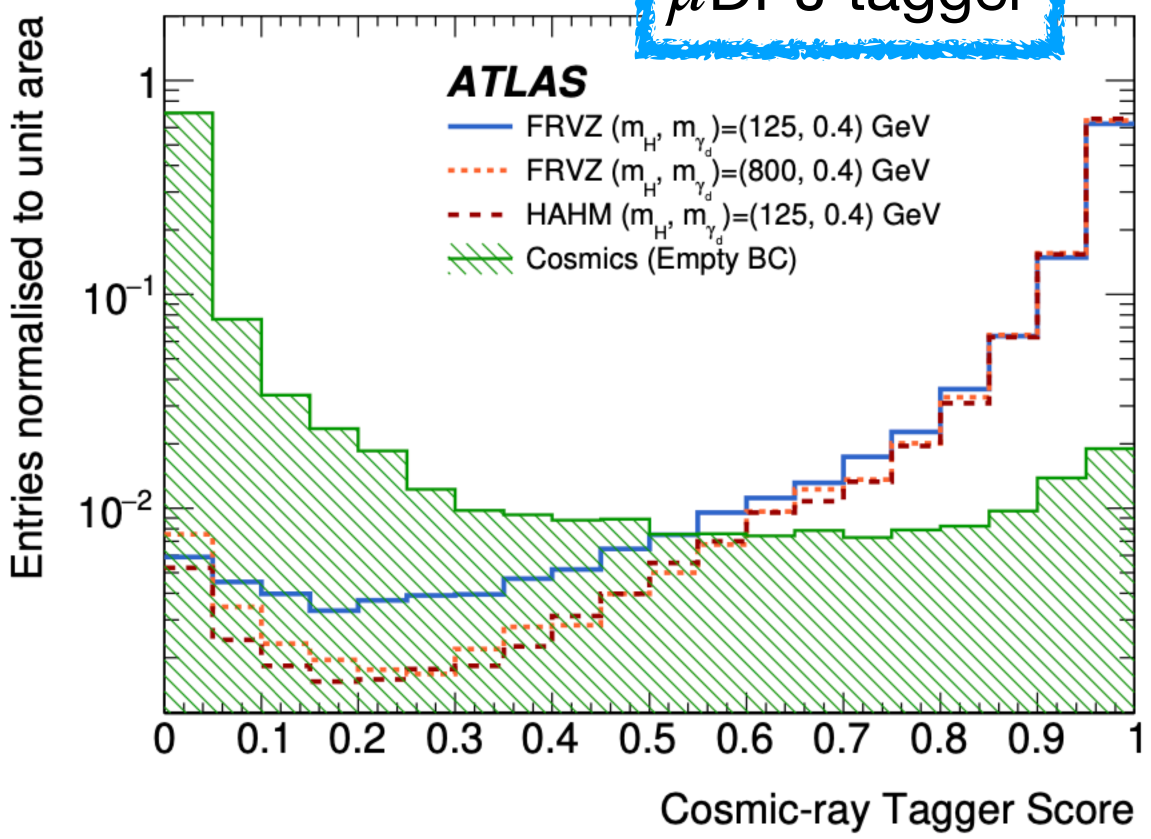
- Displaced fermions
  → Custom triggers looking for displaced (and collimated) objects

Trigger with MS-only muon close-by pairs



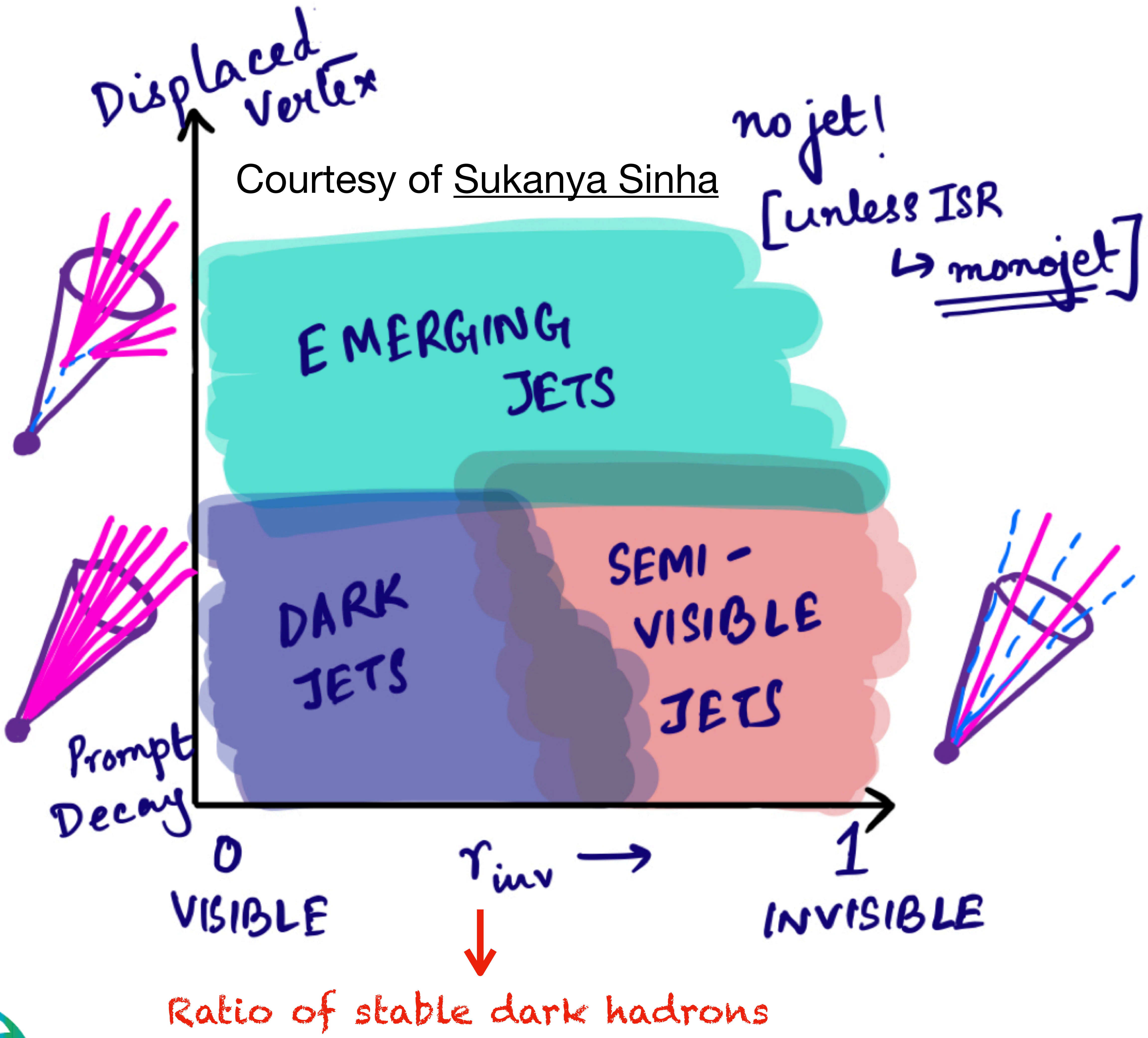
- Exploit ML algorithms (CNN and DNN) to suppress backgrounds

μDPJ tagger



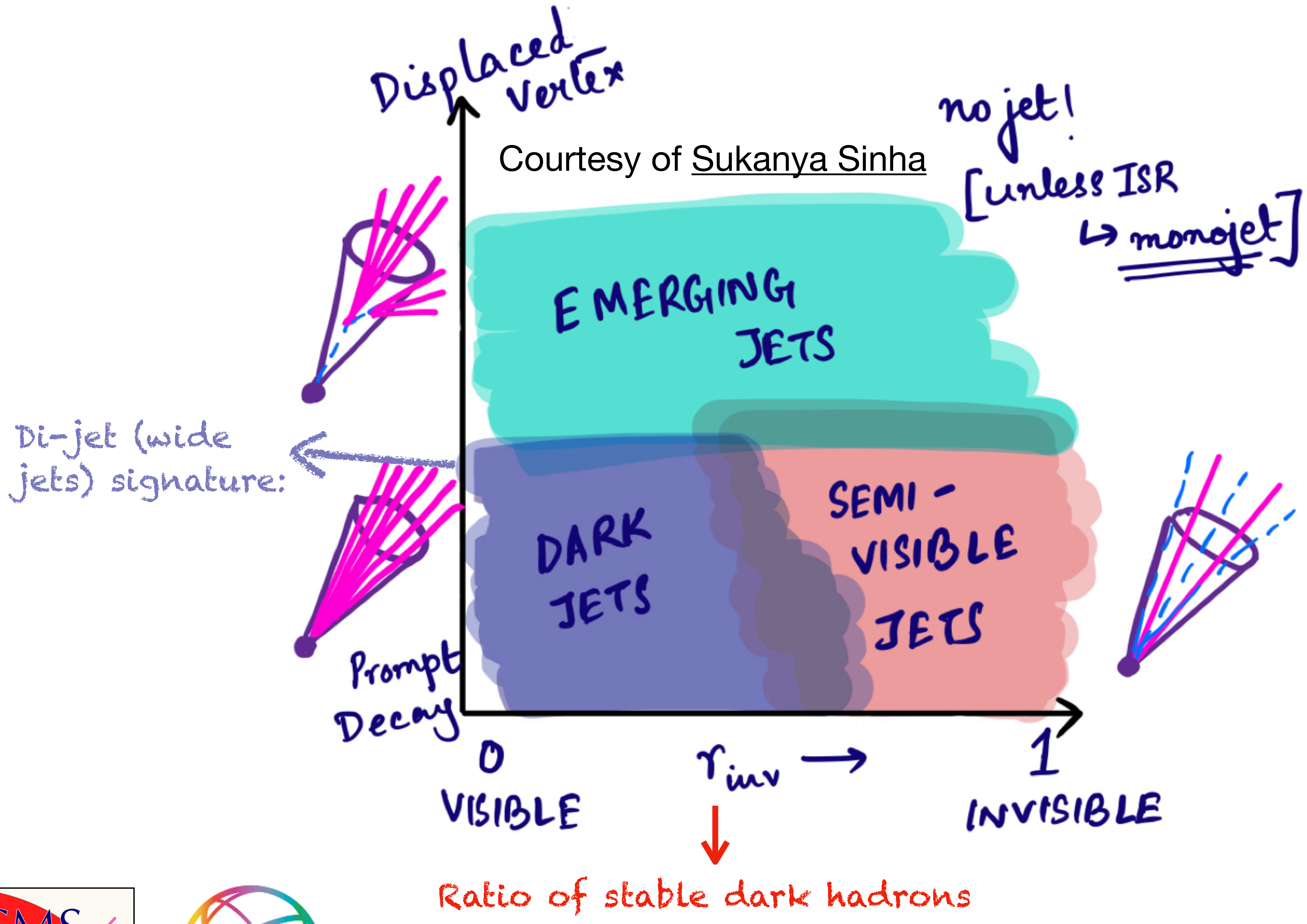
L1 muon trigger seed is limiting:
- Muons from beamspot
- Cannot find too collimated muons

Dark QCD searches

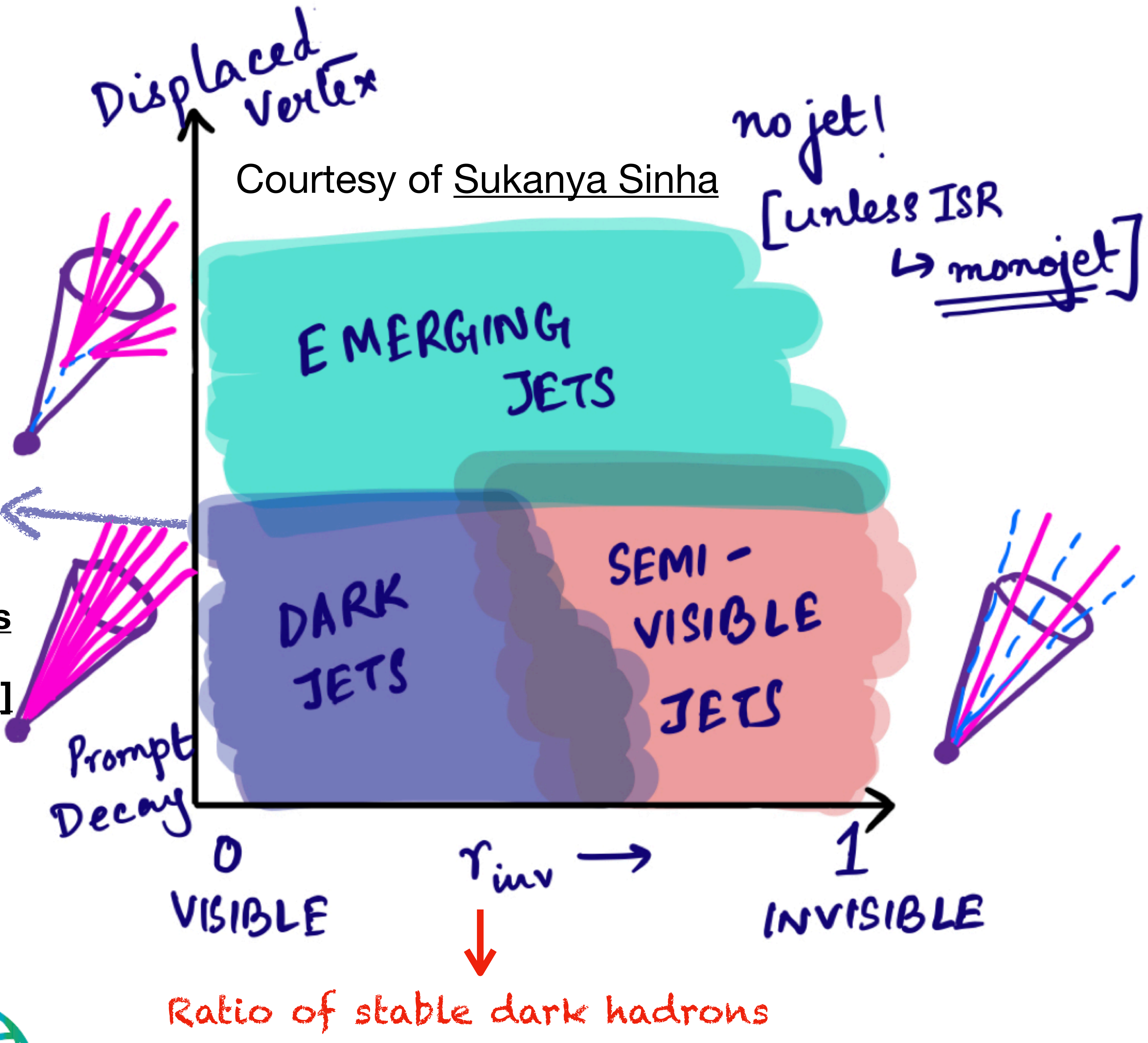


Courtesy of Sukanya Sinha

Dark QCD searches

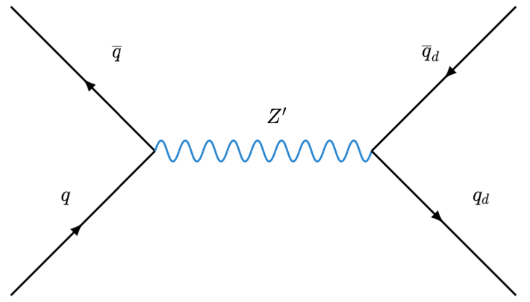


Dark QCD searches



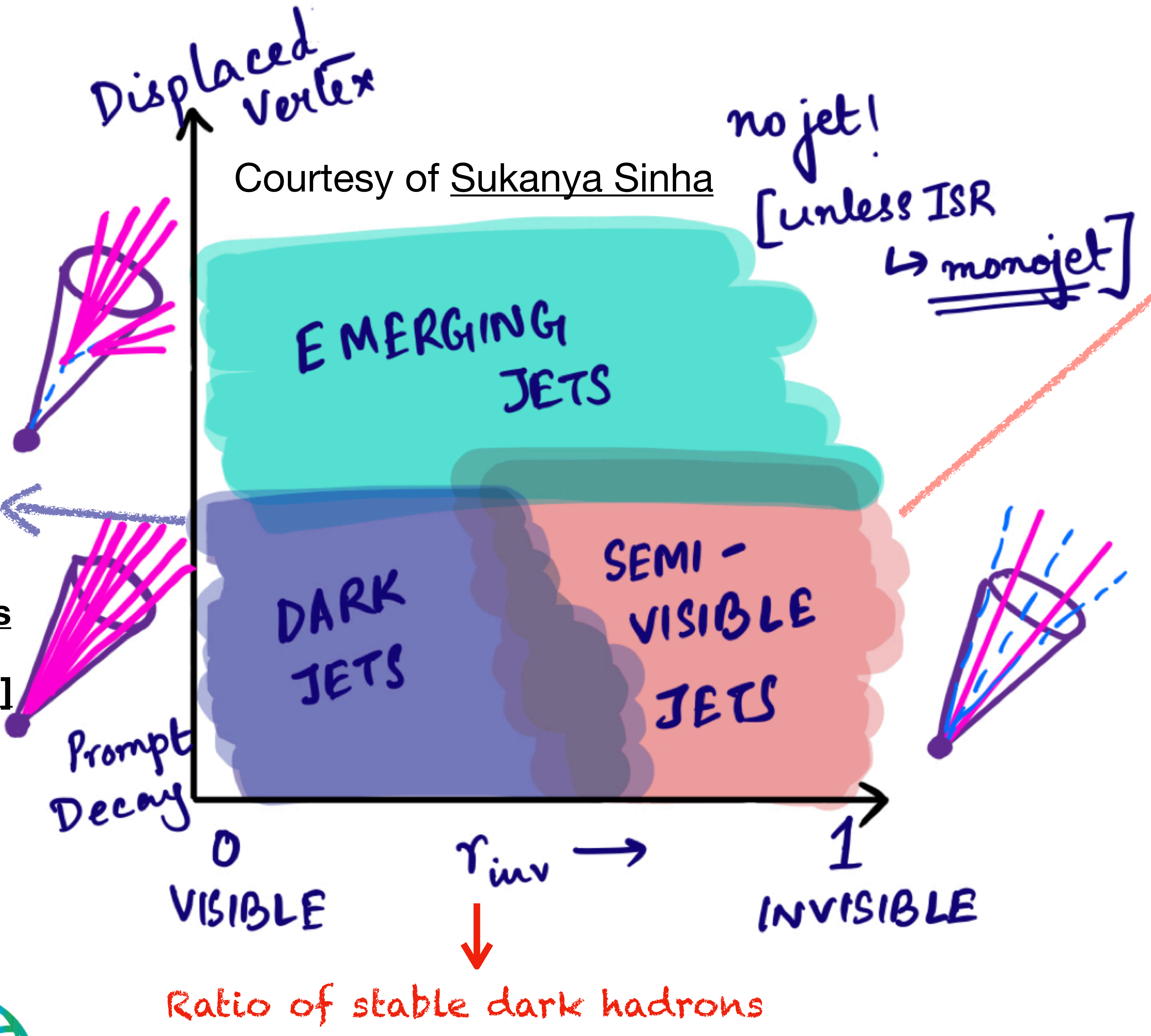
Di-jet (wide jets) signature:

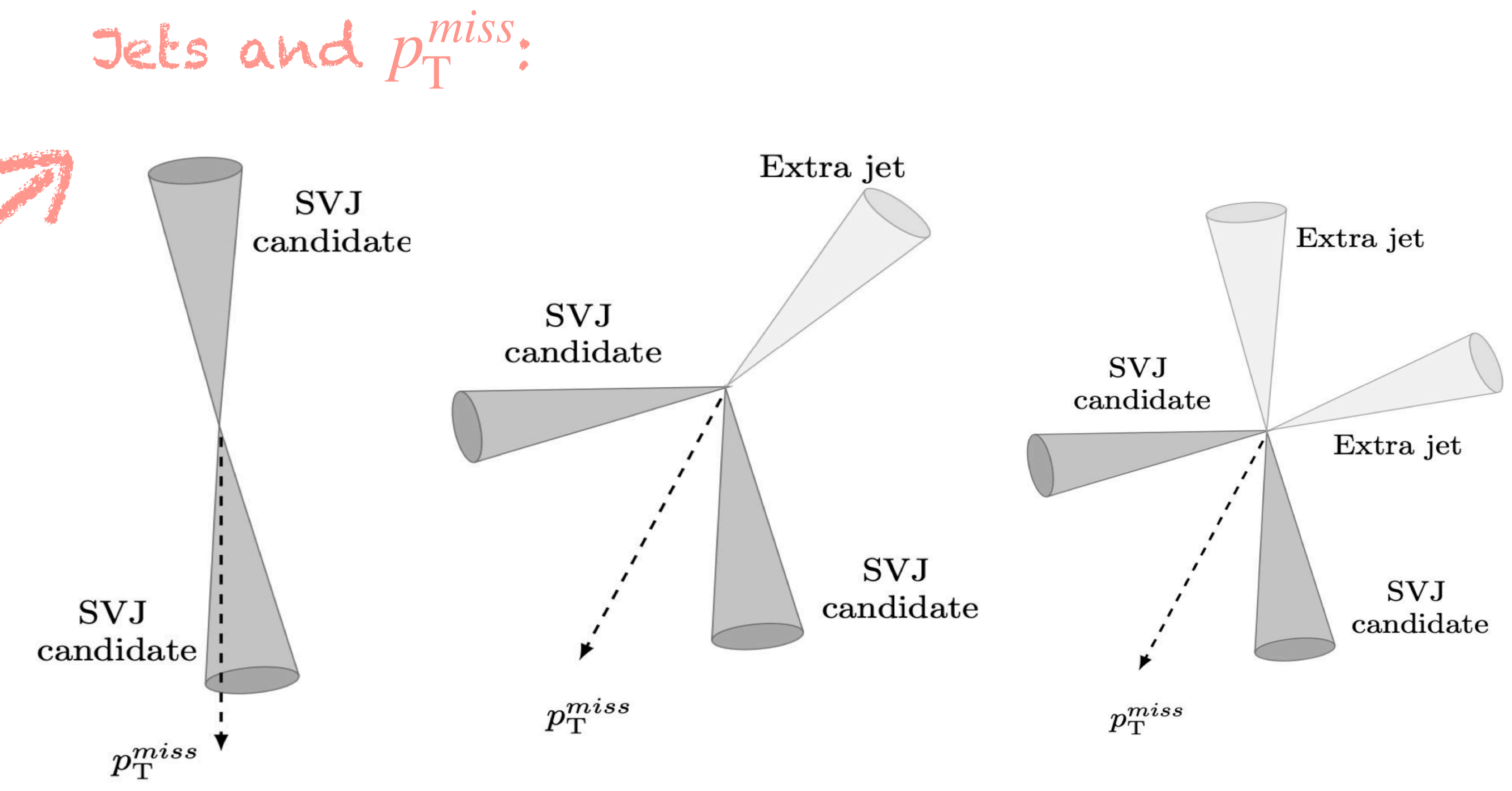
NEW **ATLAS, dark jets [ATLAS-CONF-2023-047]**



Dark QCD searches

Courtesy of Sukanya Sinha





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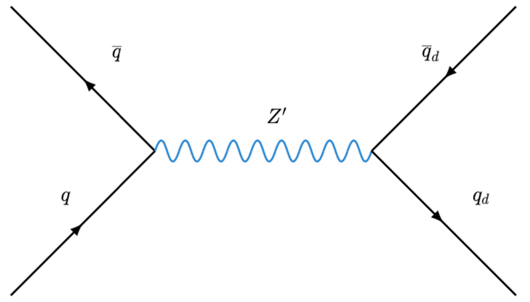
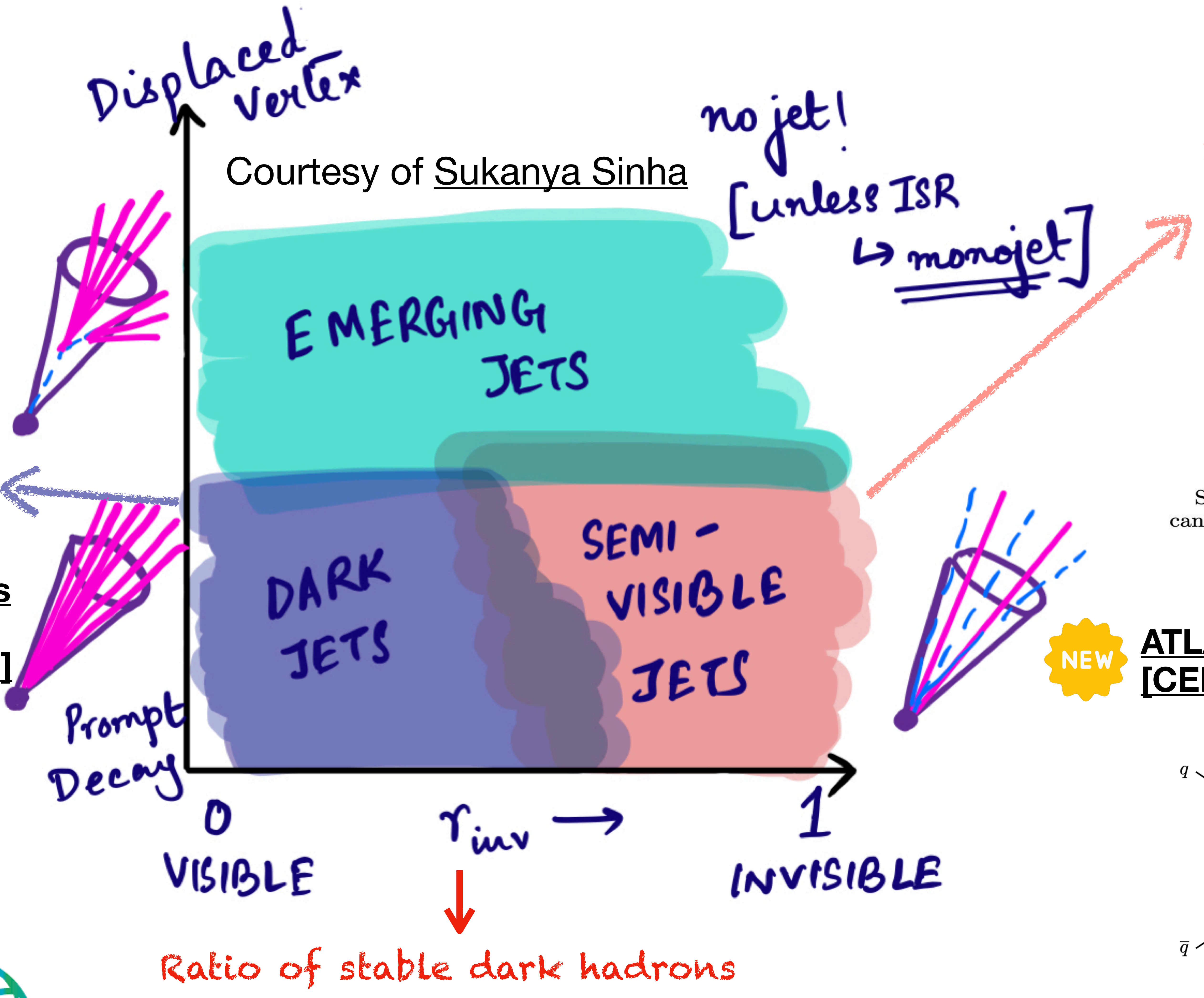


Dark QCD searches



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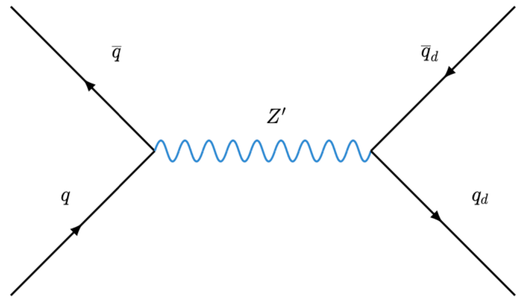
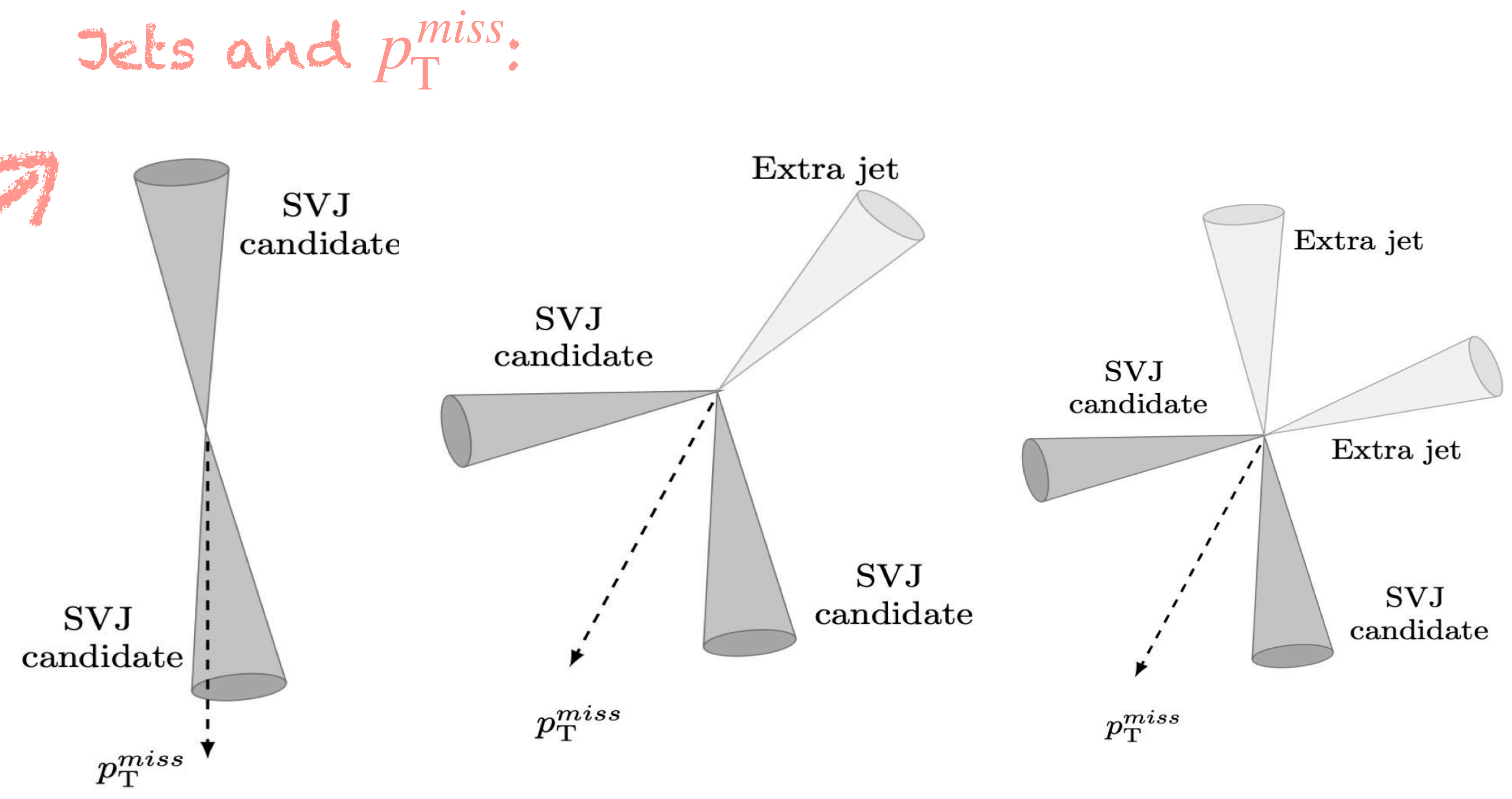
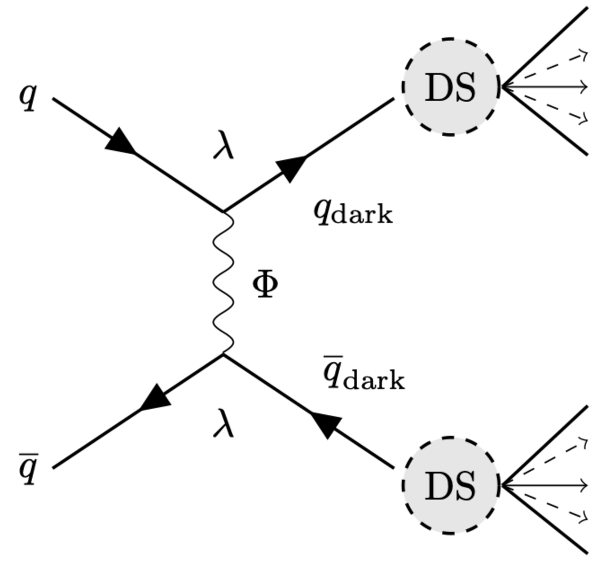
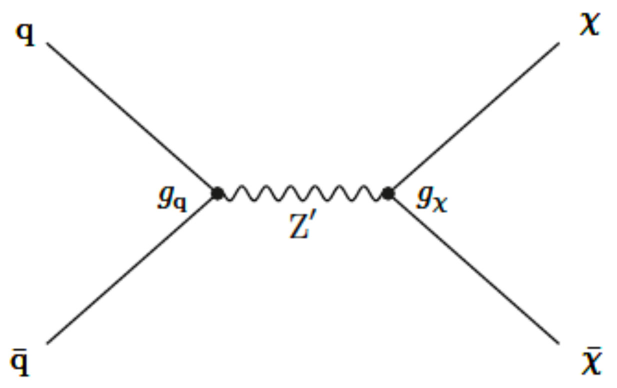




NEW **ATLAS, t-channel [CERN-EP-2023-084]**

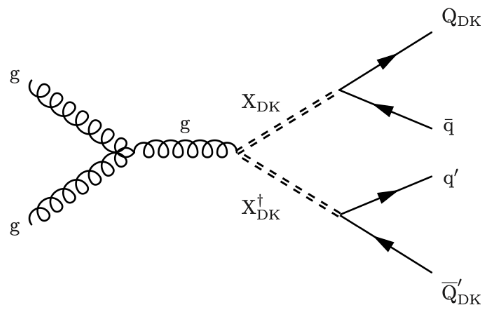


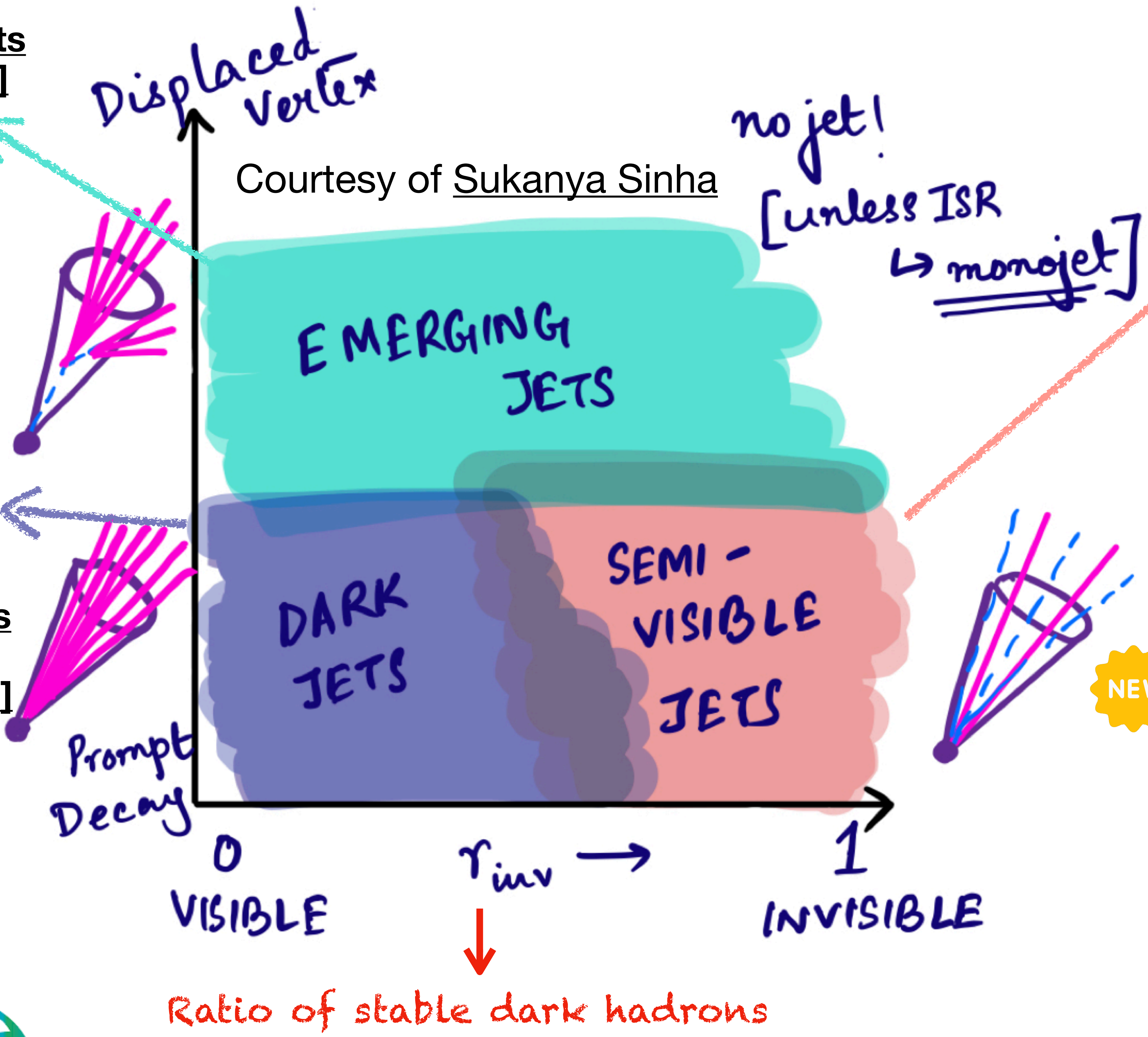
CMS, s-channel [JHEP06(2022)156]



Dark QCD searches

CMS, emerging jets [JHEP02(2019)179]





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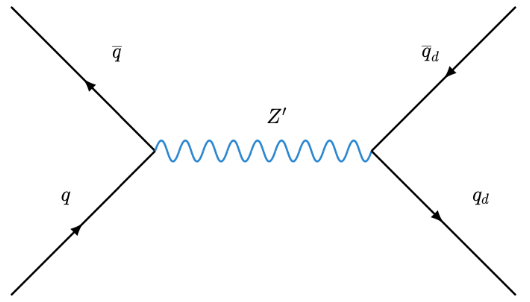

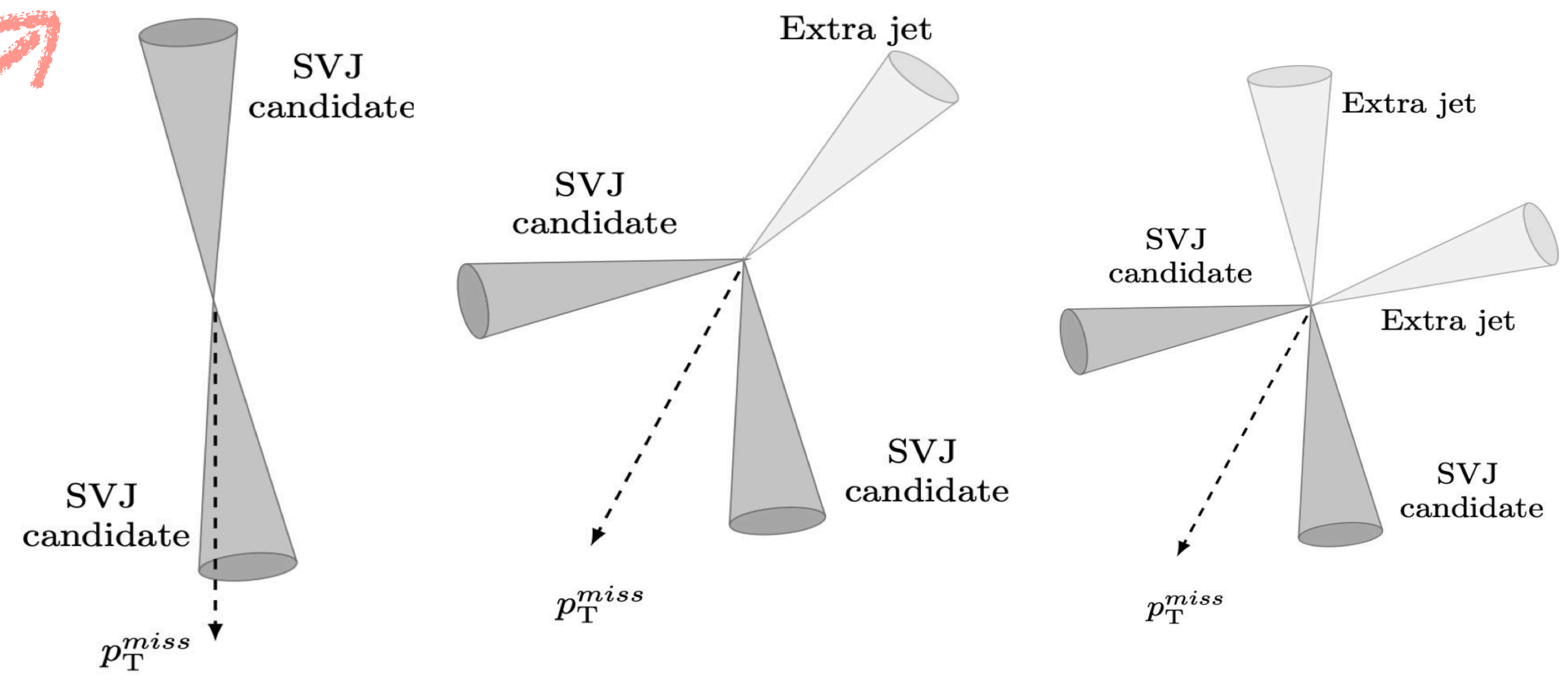

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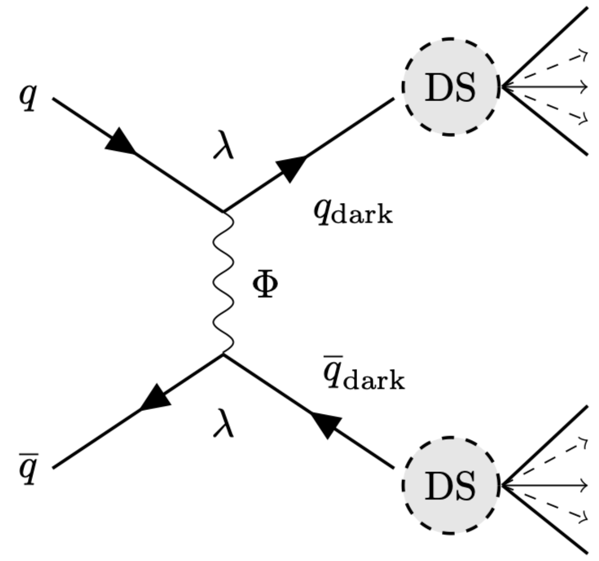
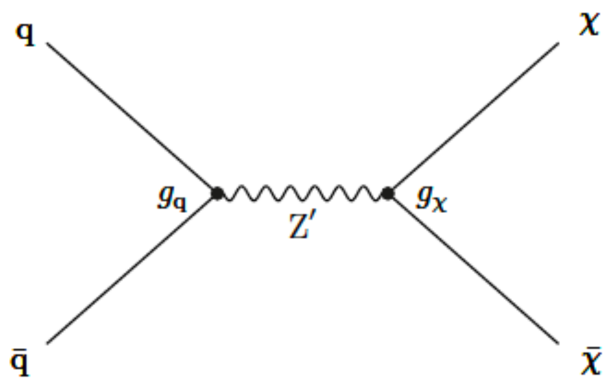
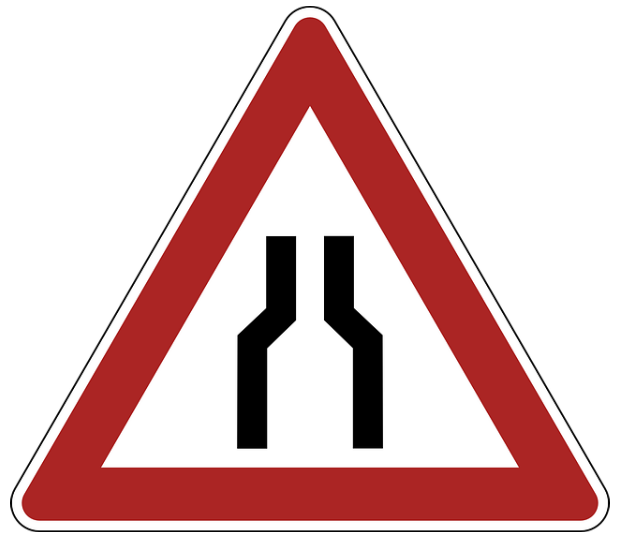


CMS, s-channel [JHEP06(2022)156]

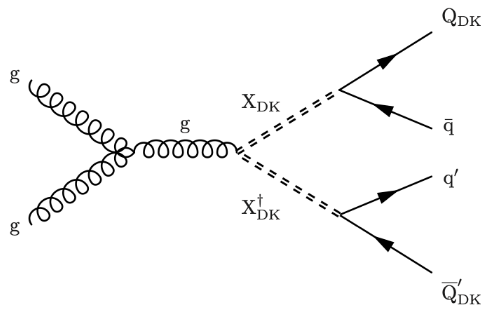


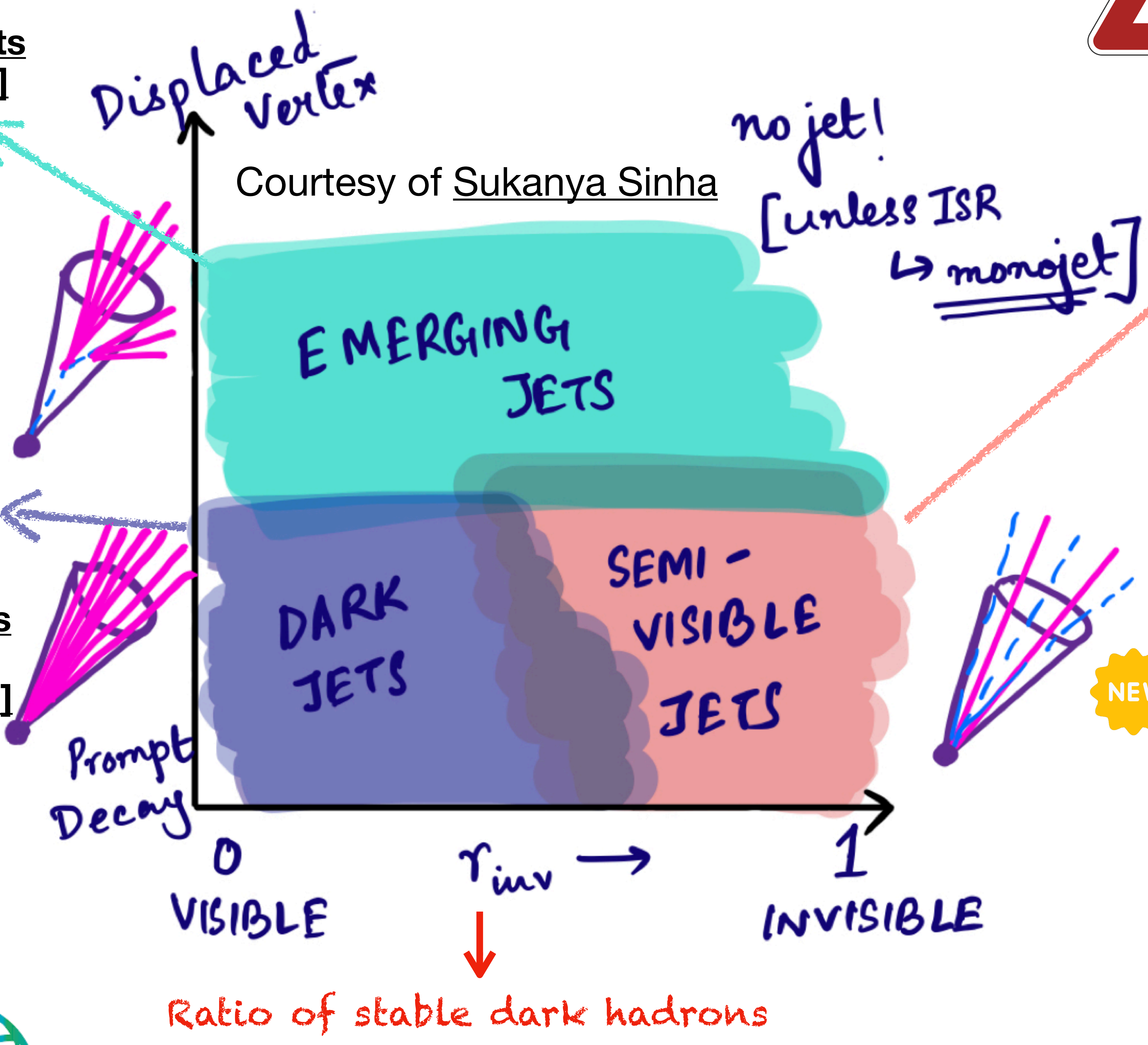
Dark QCD searches



- Modelling! [(YOUNGST@R workshop)]

[CMS, emerging jets [JHEP02(2019)179]]





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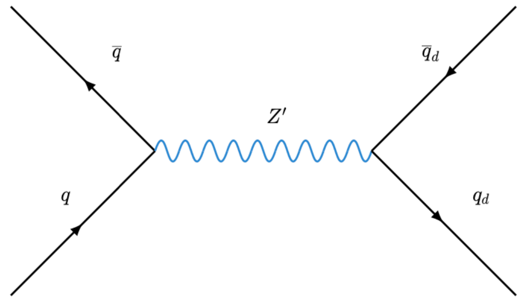
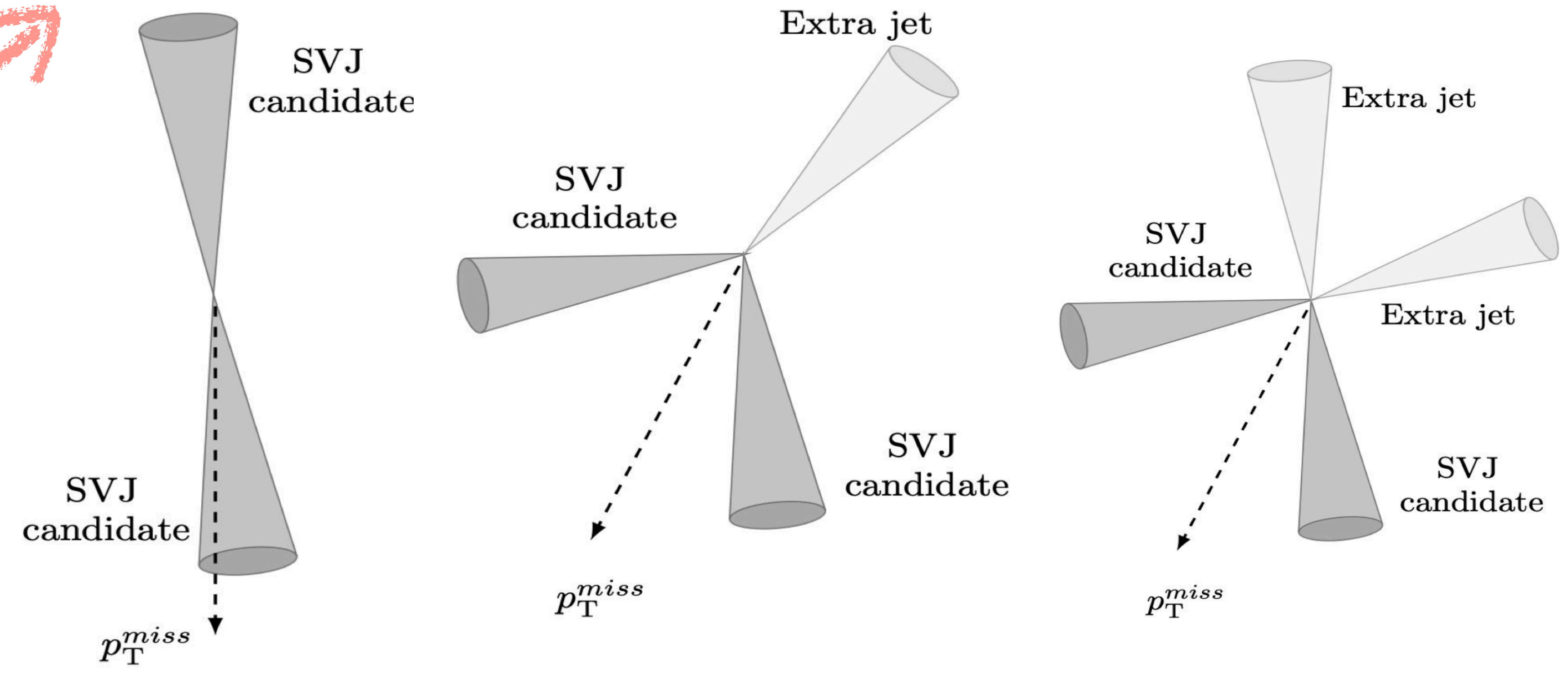
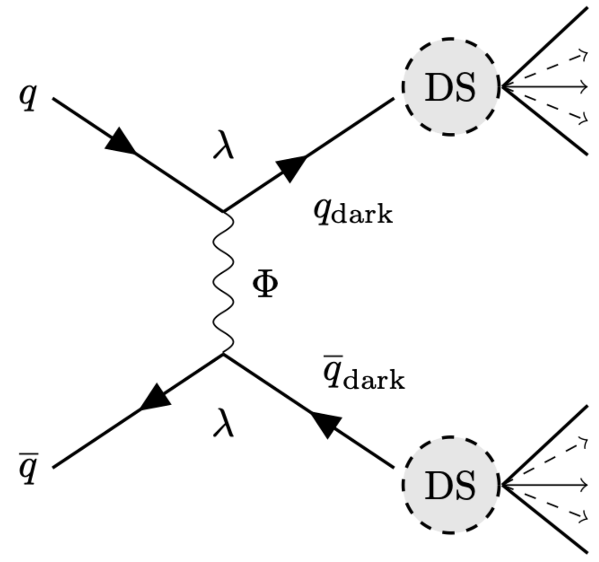


Jets and p_T^{miss}:



NEW **[ATLAS, t-channel [CERN-EP-2023-084]]**



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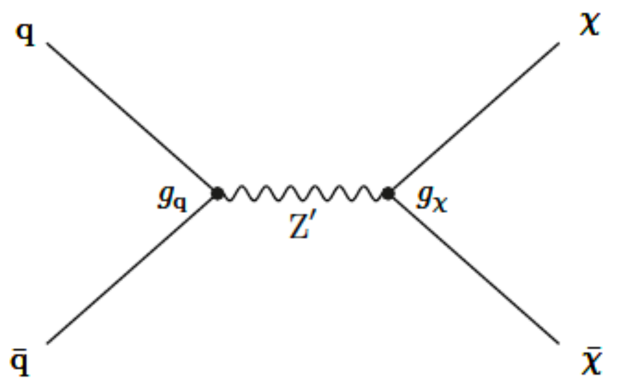
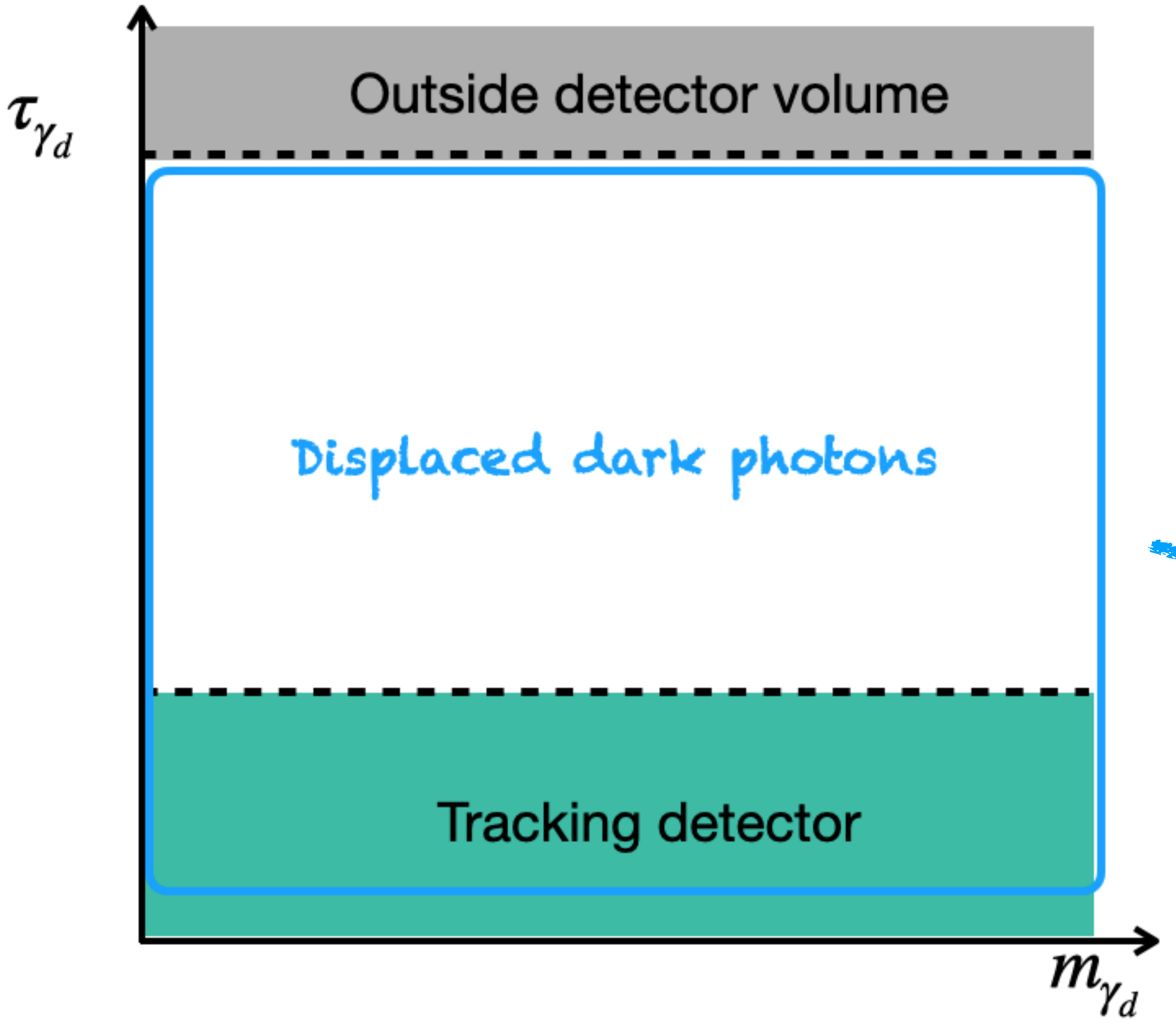
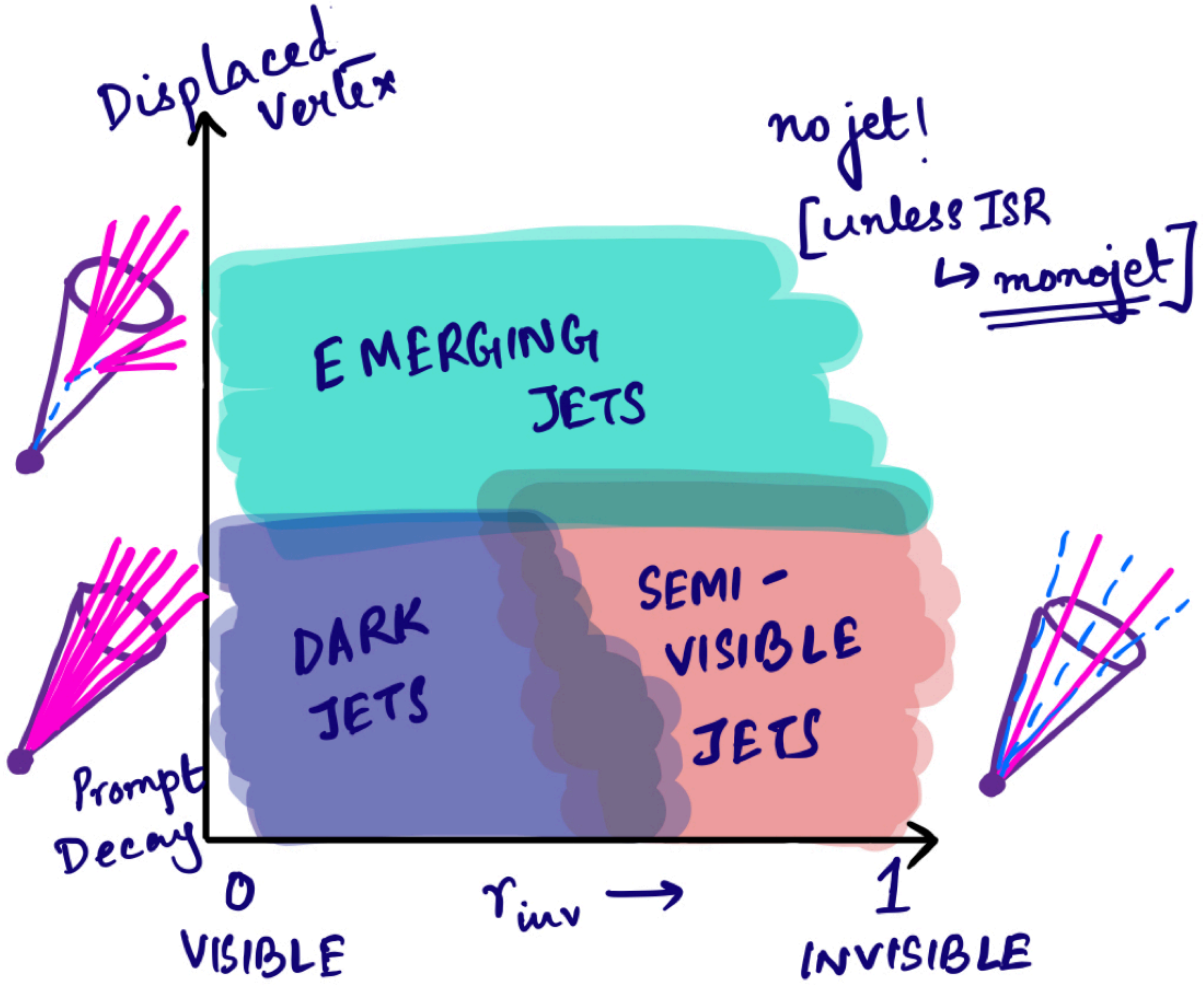


The challenges



- Triggers not optimised for soft, collimated, non pointing objects!

Yesterday's offline reconstruction = today's online one?



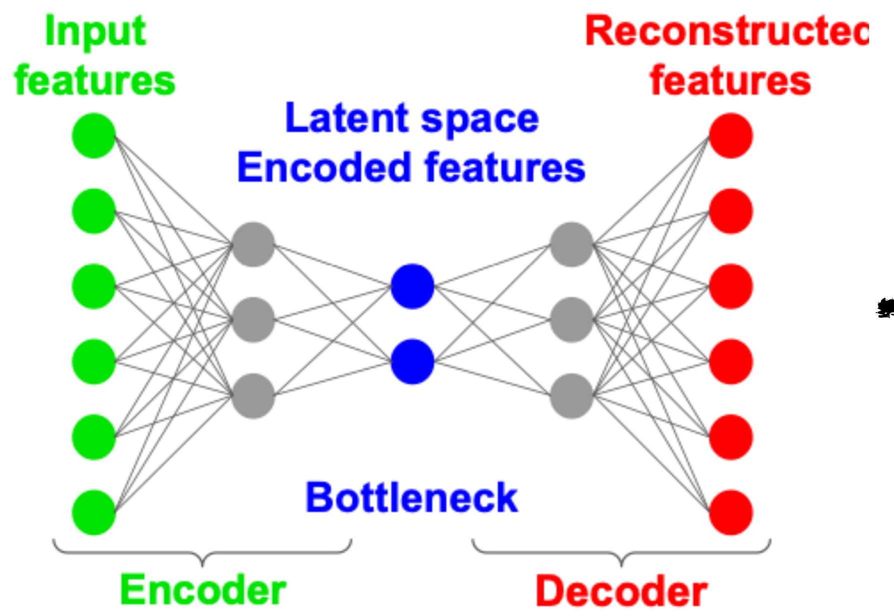
- Modelling!

Model independent searches?

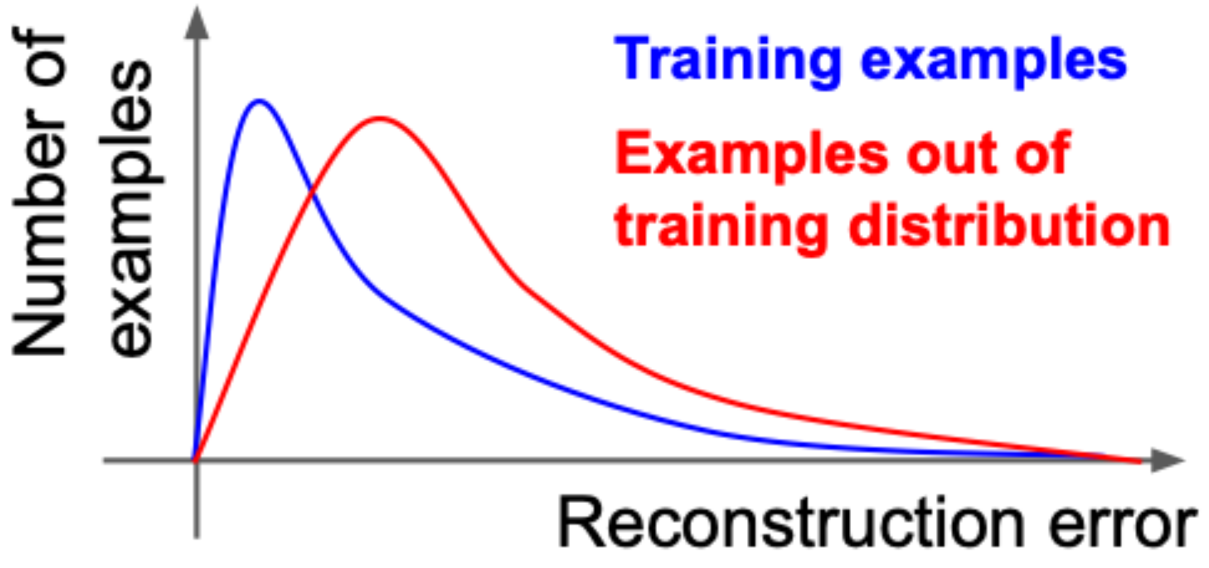

THE FUTURE
(is now?)

Model independent dark QCD serches: Auto Encoders (AE) for semi-visible jets

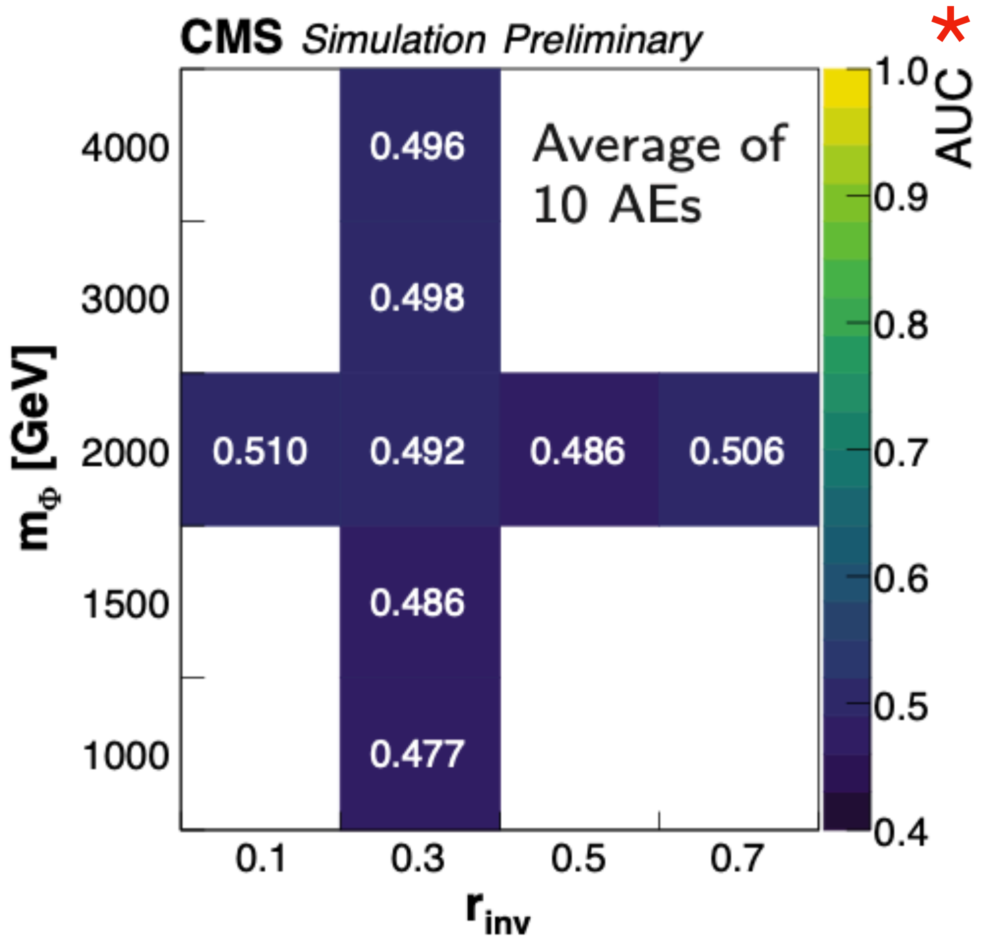
AE learns to reconstruct with small error examples provided



Examples different from input → large reconstruction error

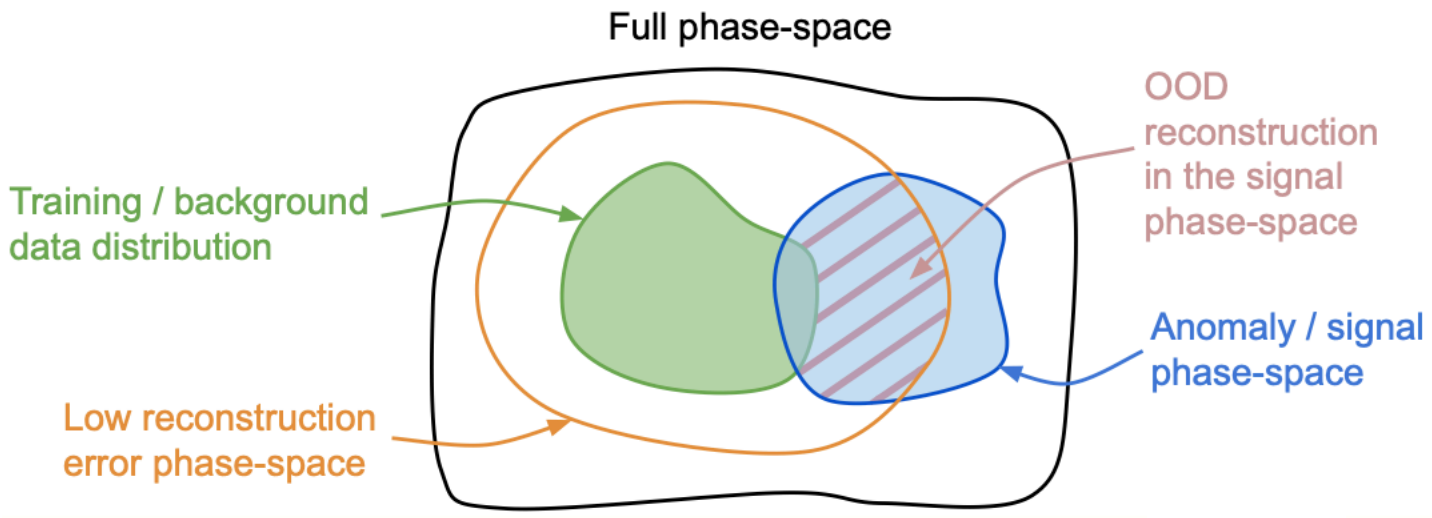


Training on top-jets, testing on semi-visible jets

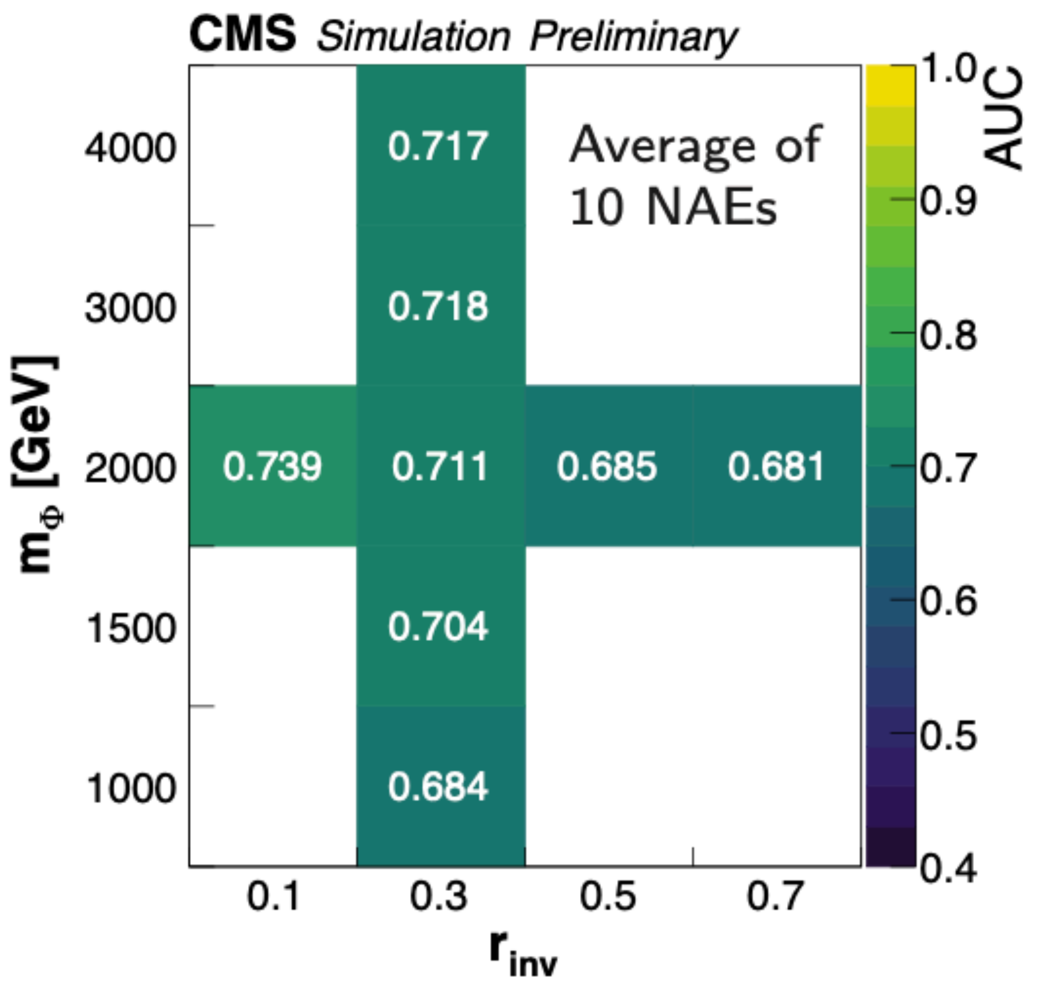


→ random classifier, AUC ~ 0.5

Standard AE generalises reconstruction in close-by phase space wrt to the input → if anomalous events are there, low reconstruction error as well → poor discrimination



Normalised AE (NAE) learn probability distribution of input → anomalous events correctly identified



*AUC = Area Under the Curve of the ROC curve, the larger, the more the AE is discriminating between S and B

Model independent dark QCD serches: Auto Encoders (AE) for semi-visible jets

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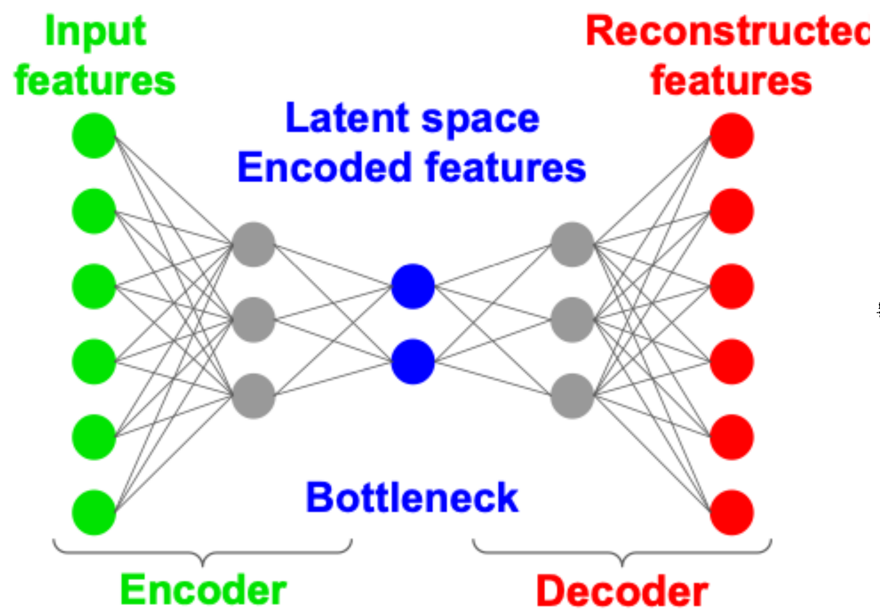
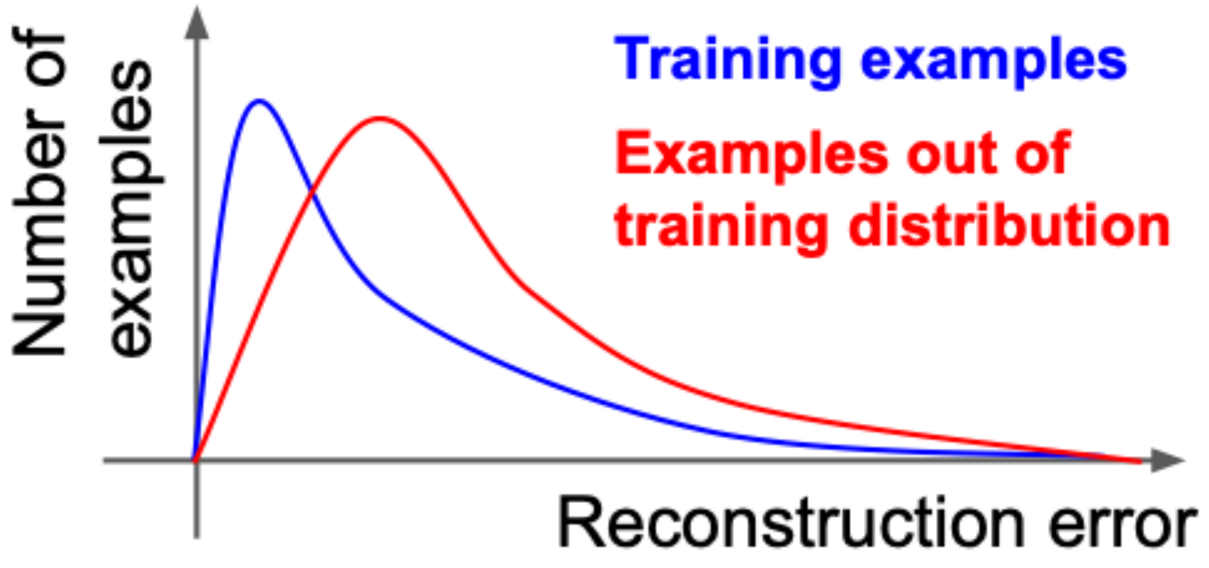


Examples different from input → large reconstruction error



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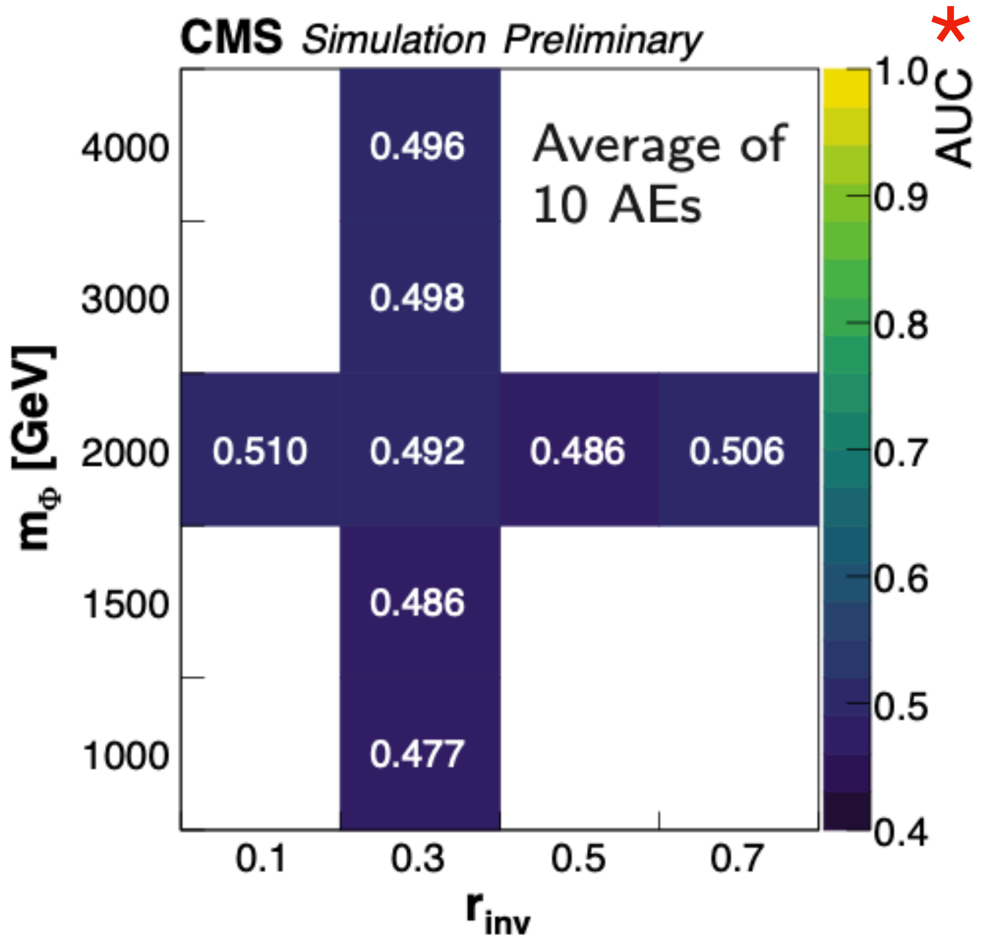

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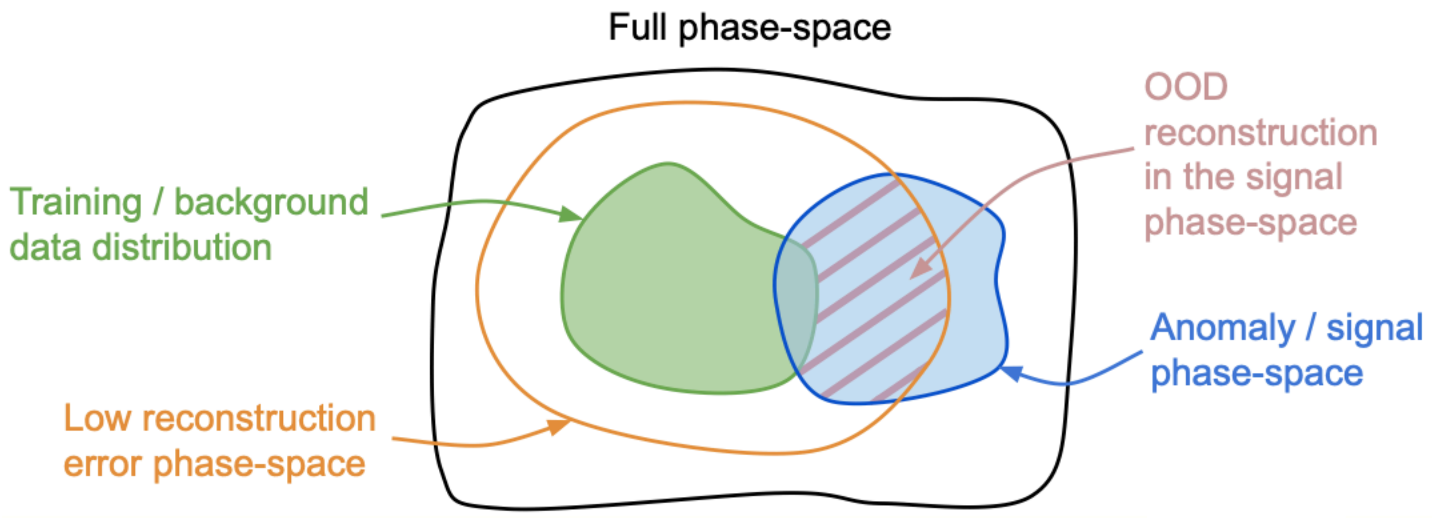

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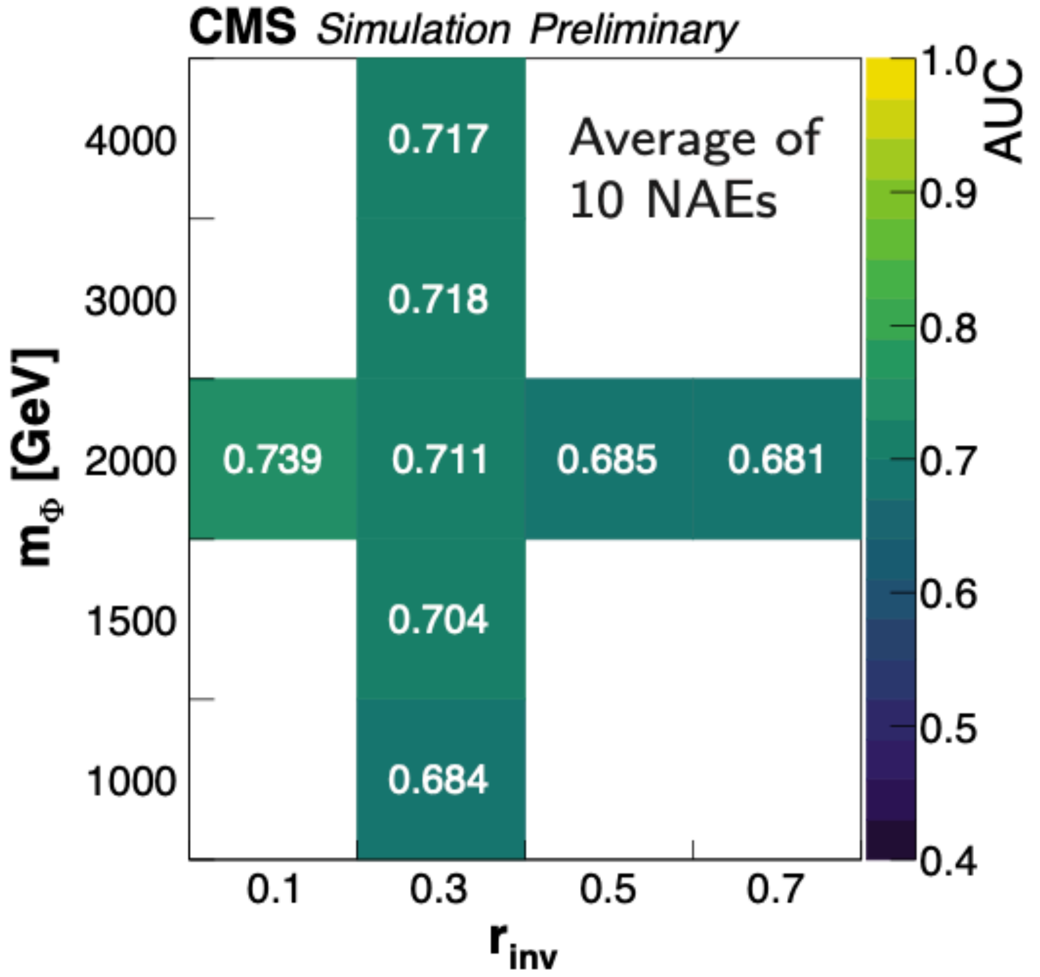

To know more…

CMS performance note [CMS DP -2023/071]

EPS 2023 proceeding

EPS 2023 poster

*AUC = Area Under the Curve of the ROC curve, the larger, the more the AE is discriminating between S and B

Triggering displaced, non-pointing, soft objects

Muons searches limited by:

- Soft muons → high L1 p_T thresholds
- Displaced muons → L1 muons pointing to the beamspot assumption
- Collimated muons → only one can be trigger seed

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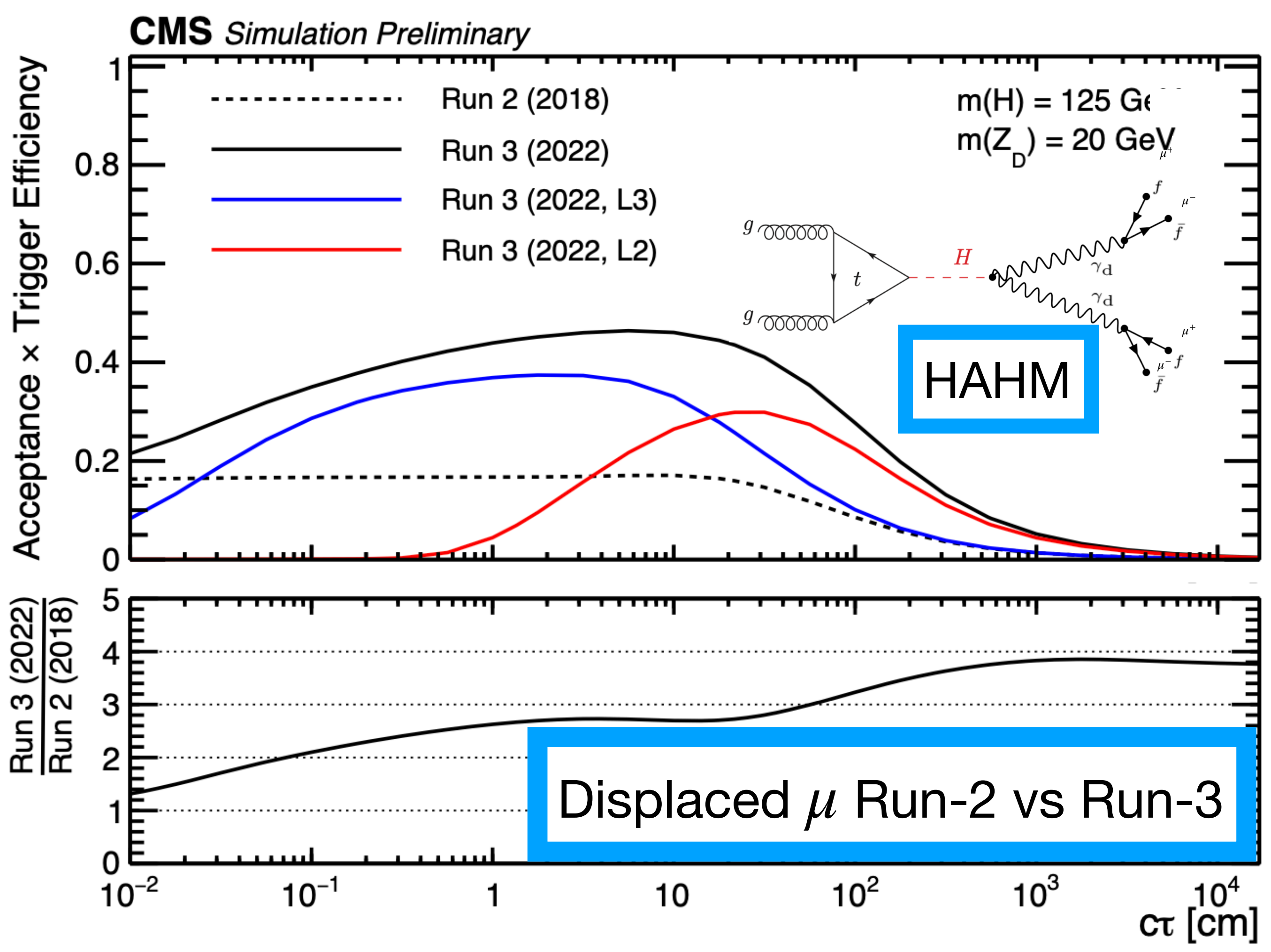
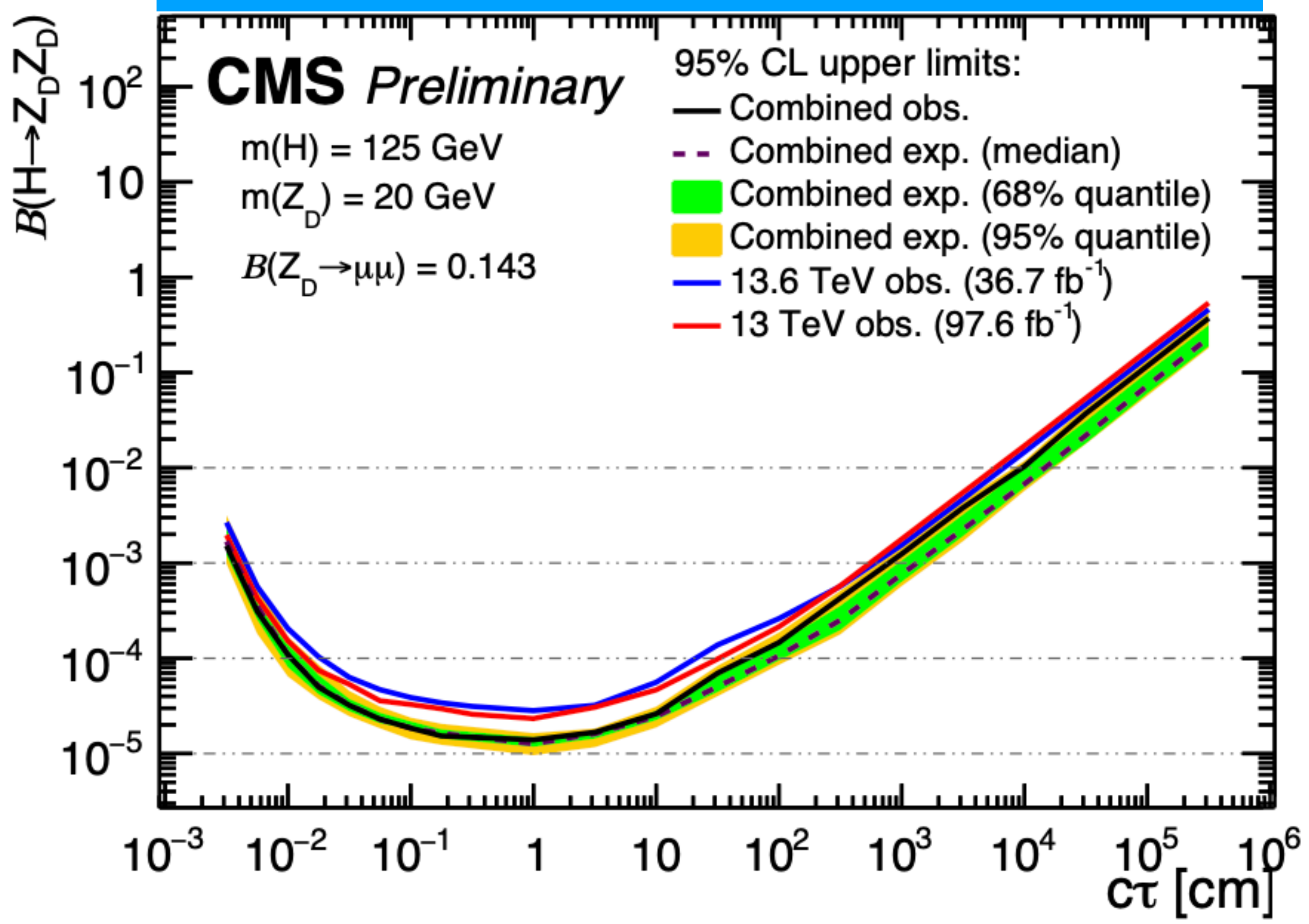
NEW CMS loosened first two → New result for displaced muons: [**CMS PAS EXO-23-014**]



Run-3 CMS displaced μ exclusion



→ 2022 Run-3 competitive sensitivity wrt Run-2 (but 1/3 of data!!)

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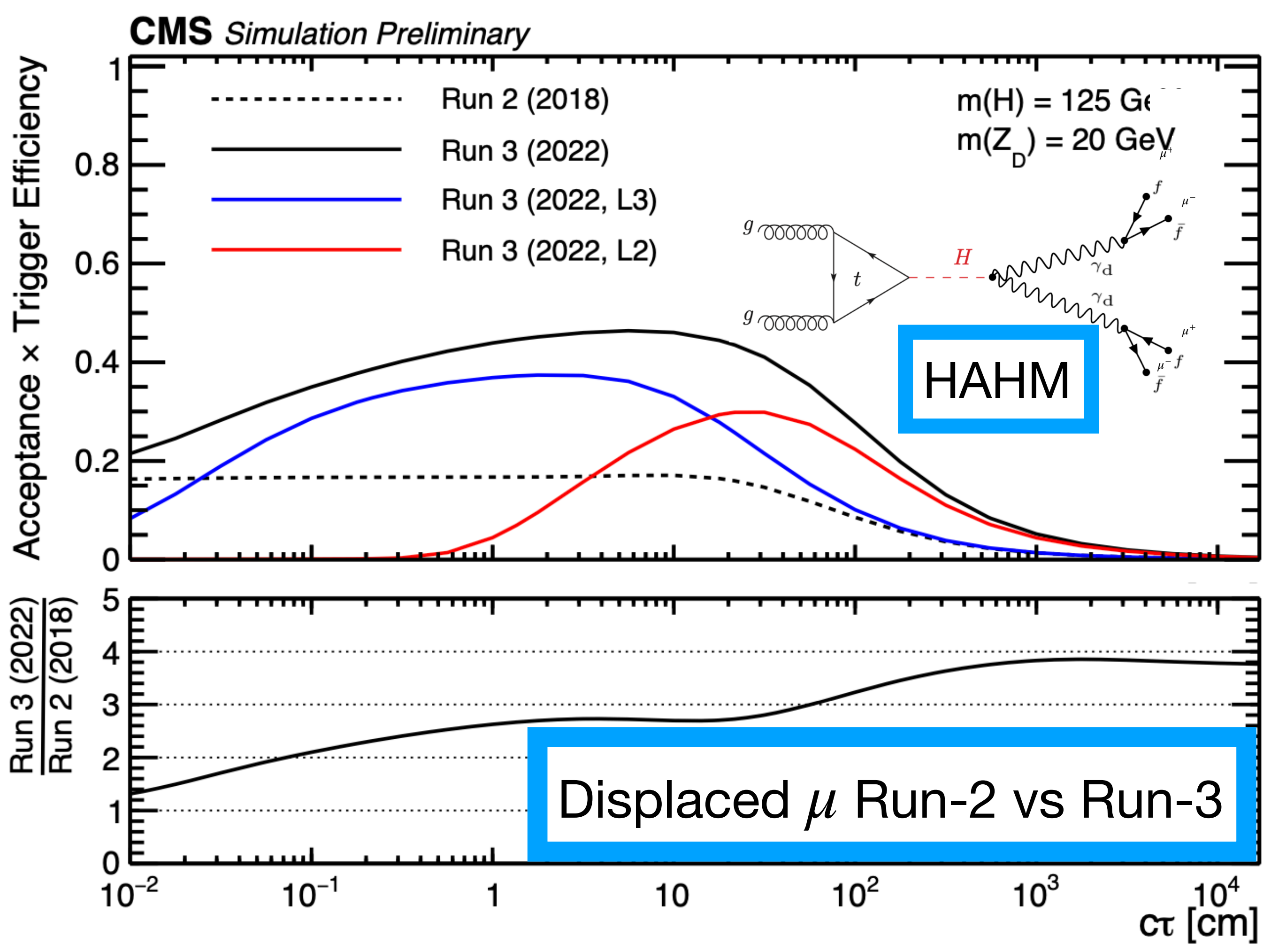

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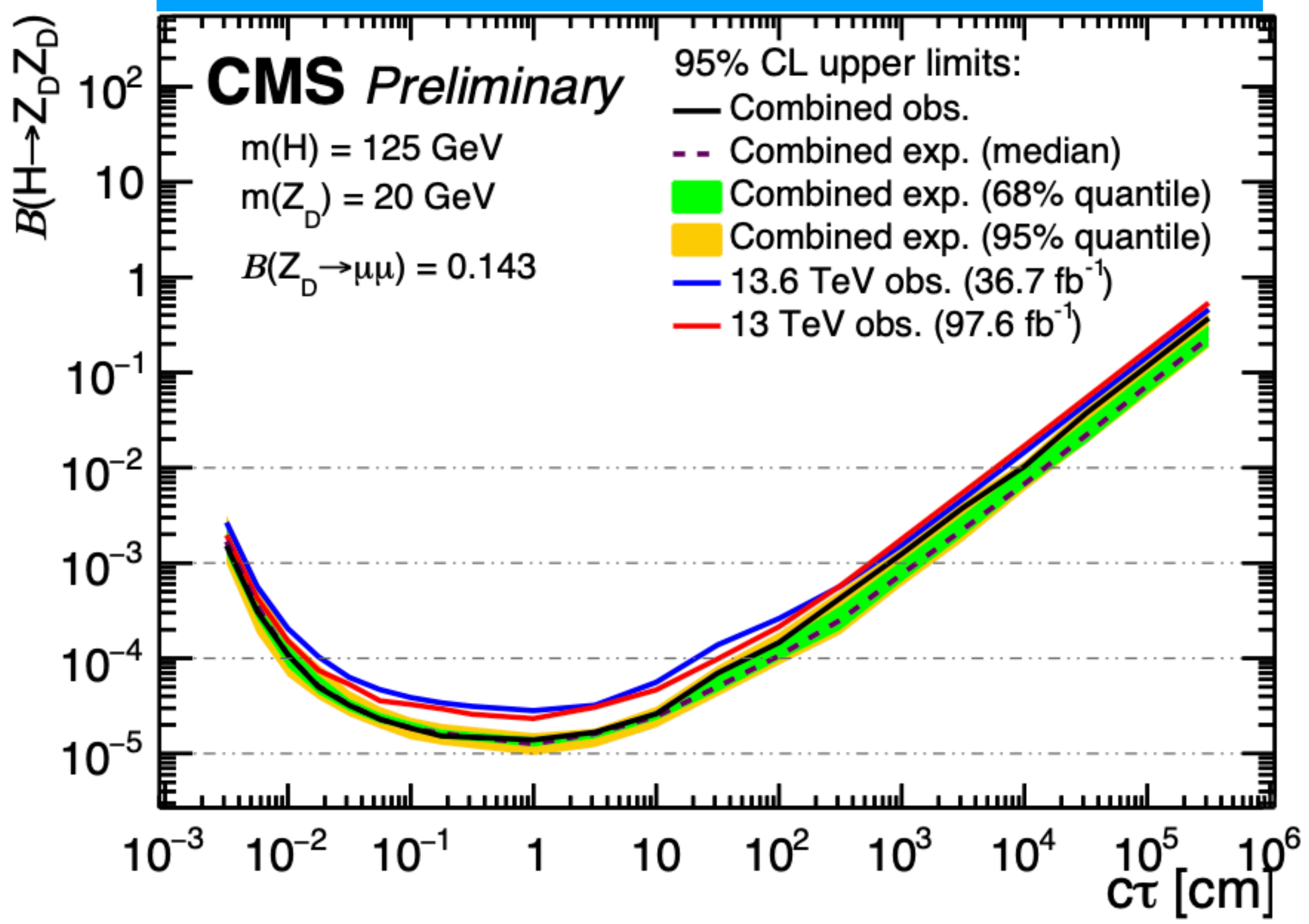


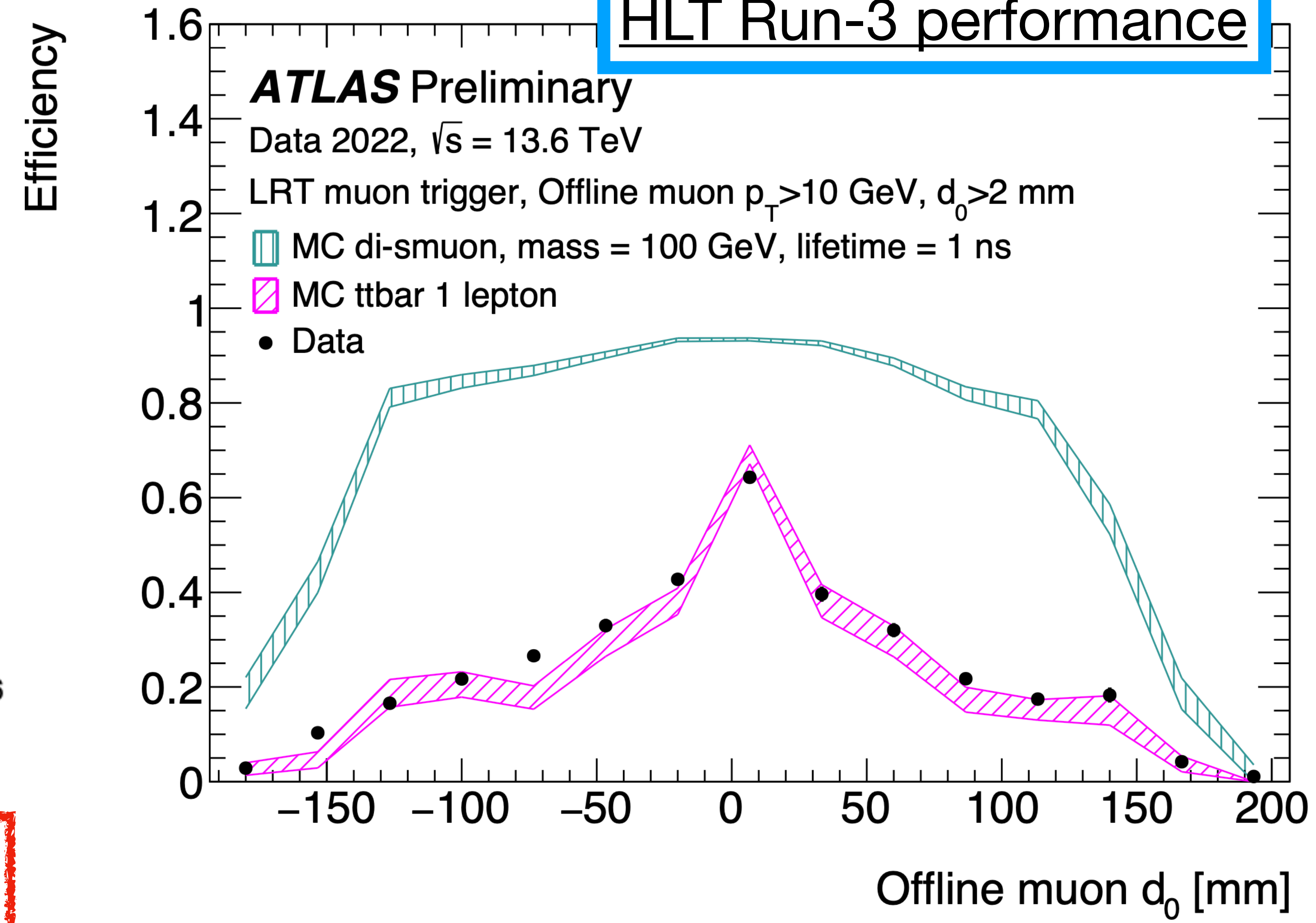
2022 Run-3 competitive sensitivity wrt Run-2 (but 1/3 of data!!)

In ATLAS standard tracking: $|d_0| < 10\,\mathrm{mm}$ → displaced tracks suppressed! ⇒ Large Radius Tracking (LRT): $|d_0| < 300\,\mathrm{mm}$ and $|z_0| < 500\,\mathrm{mm}$

In Run-2 LRT was run only on 10% of data (computation time too long)

In Run-3 already **running at the HLT level**, expected **sizeable sensitivity** for displaced scenarios! NEW

HLT Run-3 performance



Conclusion

Dark Sectors are challenging search candidates → different parameters, very different signatures

→ unconventional final states, pushing detector capabilities!

Extensively studied during Run-2, many challenges were identified, some already overcame in Run-3

Exciting prospects for the future!

We are here!

Additional material

All ATLAS public results

All CMS public results

LHCP2023: HNLs searches in ATLAS & CMS

LHCP2023: ALPs sarches in ATLAS, CMS, LHCb

Dark Higgs H_d:

CMS: $H_d \to W^+W^-$ (fully and semi-leptonic) [CERN-EP-2023-216]

ATLAS: $H_d \to W^+W^-$ (semi-leptonic) [JHEP07(2023)116]

ATLAS: $H_d \to VV$ (fully hadronic) [PRL.126.121802]

LHC Dark Matter Working Group (LHC DM WG) → Dark Matter Models for Run 3

May 13-17 CERN

15th International workshop of Identification of Dark Matter

July 8-12 L'Aquila

Past conferences about DM searches:

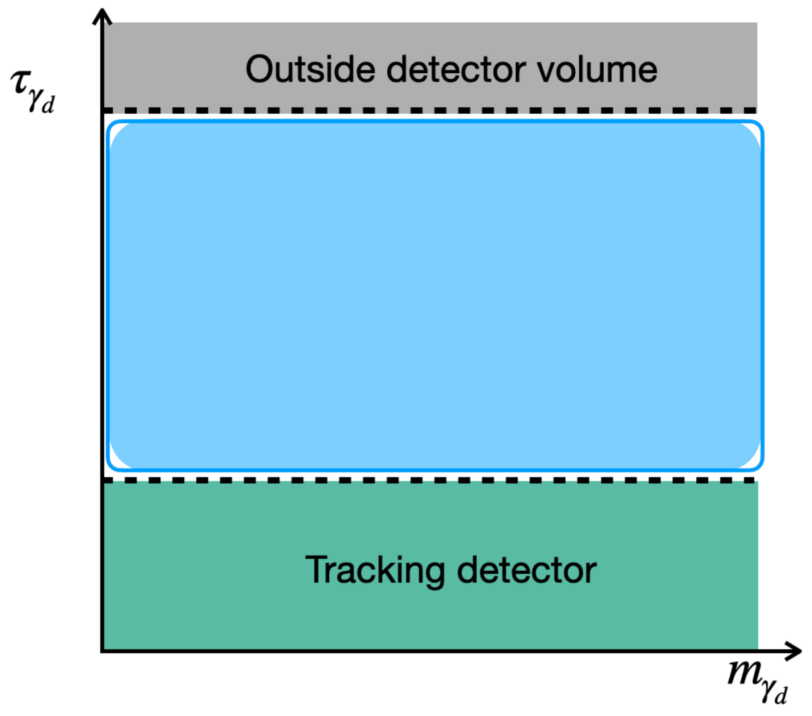
Dark Matter 2023 Conference

Dark Matter UCLA 2023

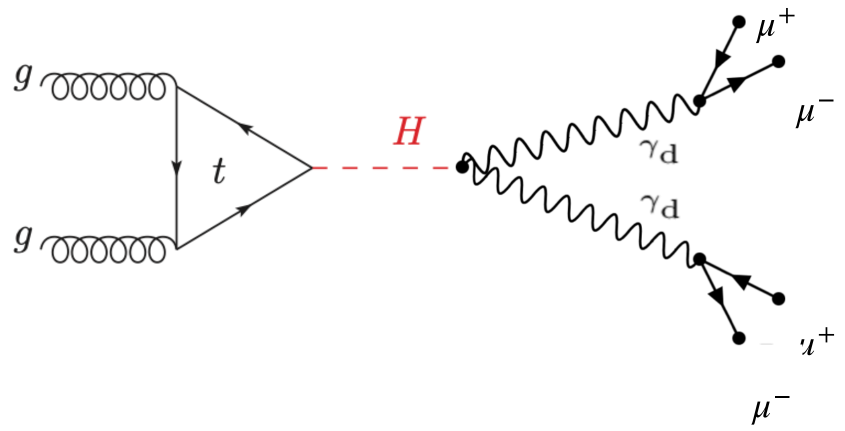
Light Dark World 2023

Backup

Displaced massive γ_d - displaced muons

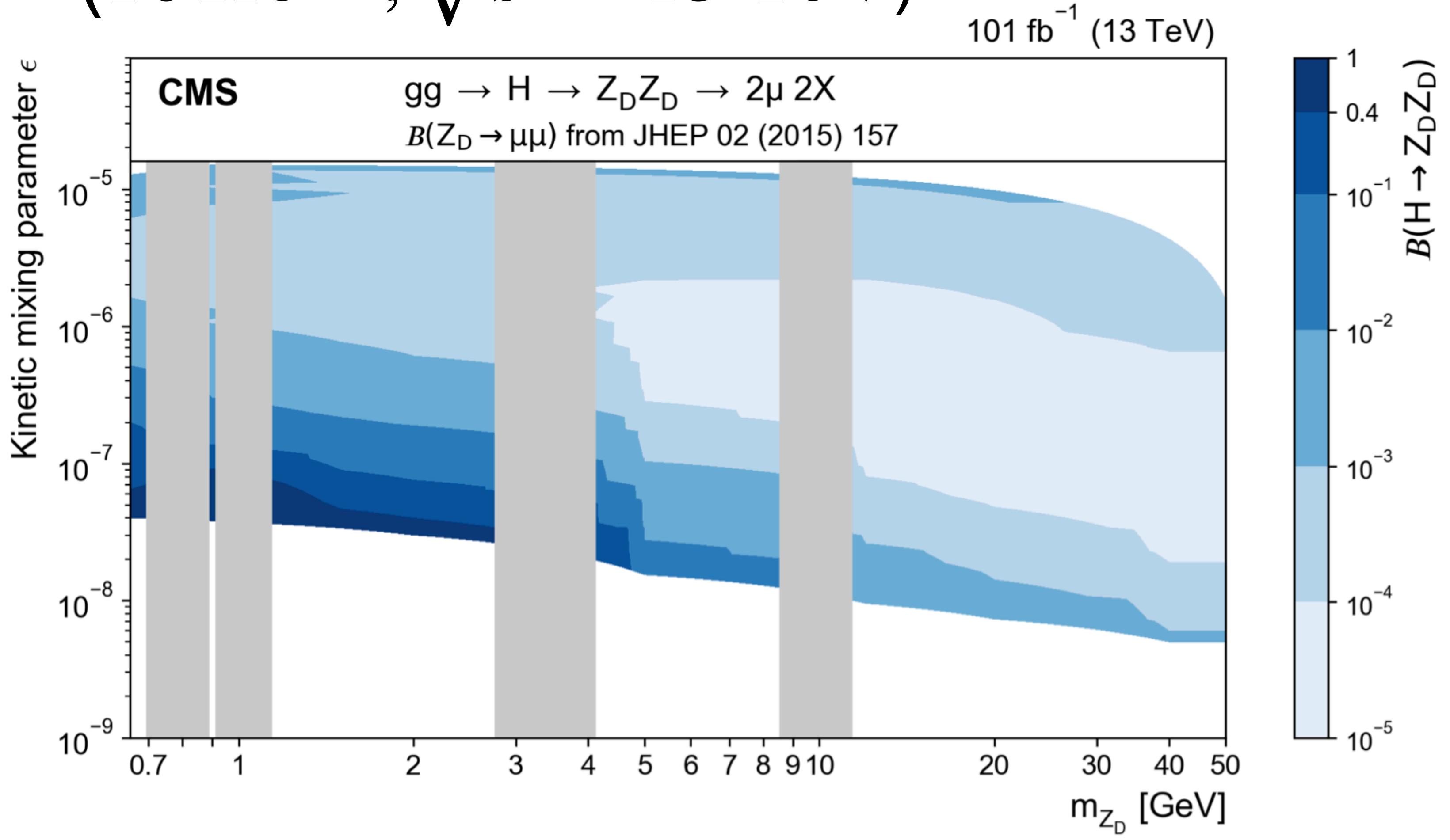


ggF produced Higgs boson + HAHM (Higgs + vector portal) =

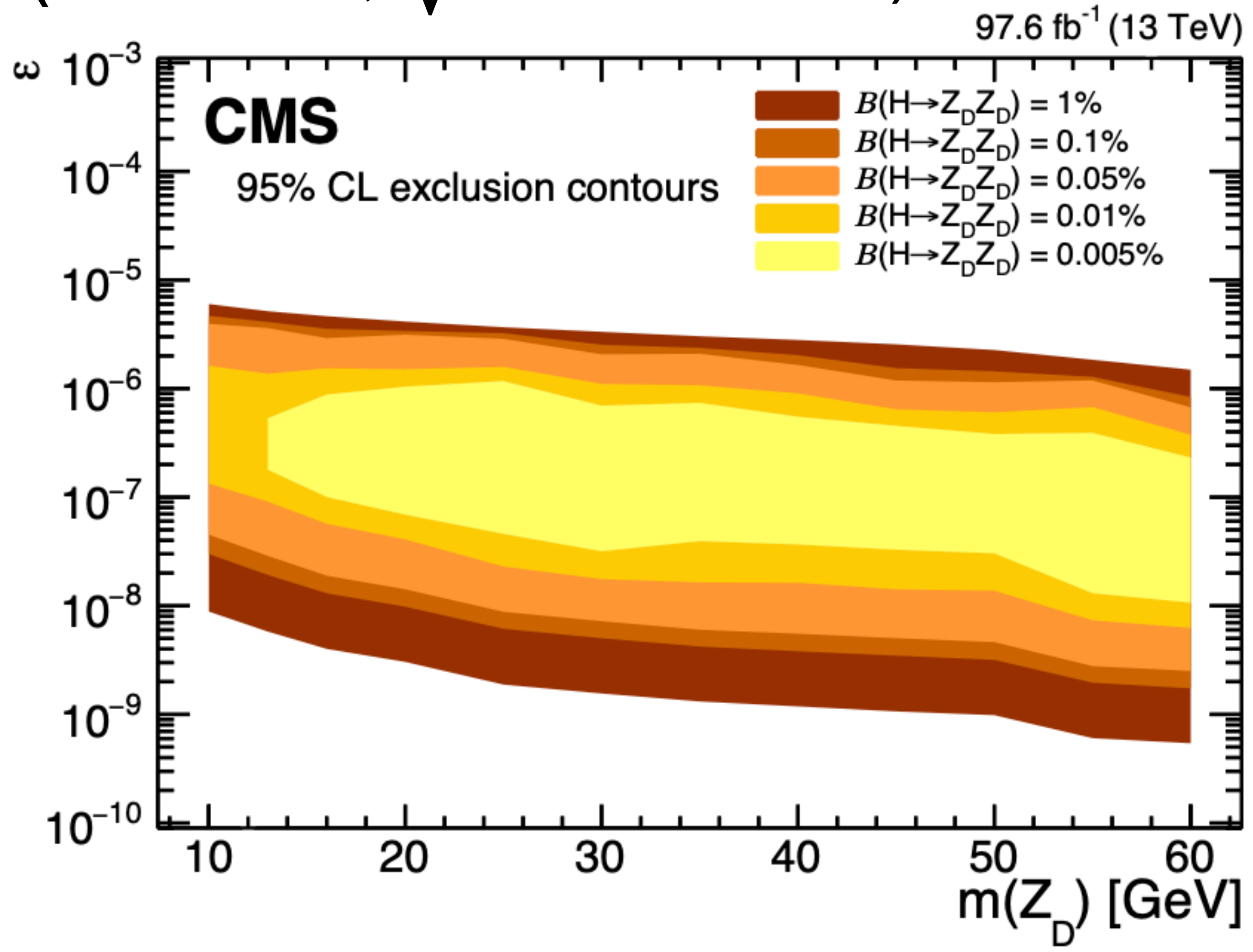


→ Collimated displaced opposite signed di-muon vertices!

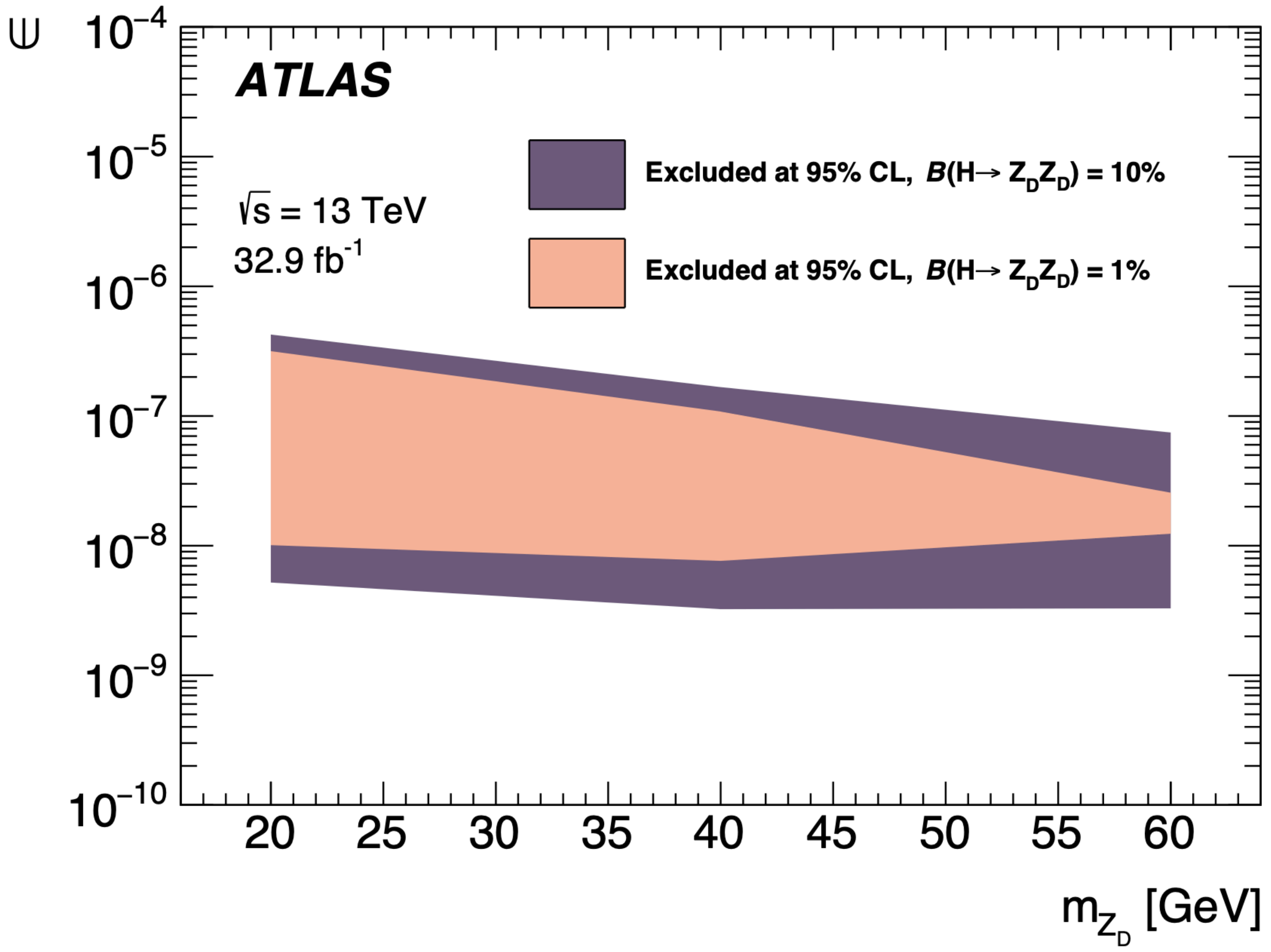
CMS, low mass [JHEP04(2022)062]	CMS, high mass [JHEP05(2023)228]	ATLAS, high mass [PRD99(2019)012001]
2017-2018 data $(101\text{fb}^{-1}, \sqrt{s} = 13\text{ TeV})$	2016+2018 data $(97.6\text{fb}^{-1}, \sqrt{s} = 13\text{ TeV})$	2016 data $(32.9\text{fb}^{-1}, \sqrt{s} = 13\text{ TeV})$



Exclusions up to $BR(H \to 2\gamma_d) = 10^{-5}$ for $m_{\gamma_d} \in [0.7,50]$ GeV and $\varepsilon \in [10^{-5},10^{-8}]$



Exclusions up to $BR(H \to 2\gamma_d) = 5 \times 10^{-3}$ for $m_{\gamma_d} \in [10,60]$ GeV and $\varepsilon \in [10^{-5},10^{-9}]$



Exclusions up to $BR(H \to 2\gamma_d) = 0.1$ for $m_{\gamma_d} \in [20,60]$ GeV and $\varepsilon \in [7 \times 10^{-6}, 8 \times 10^{-8}]$

Displaced massive γ_d - displaced muons

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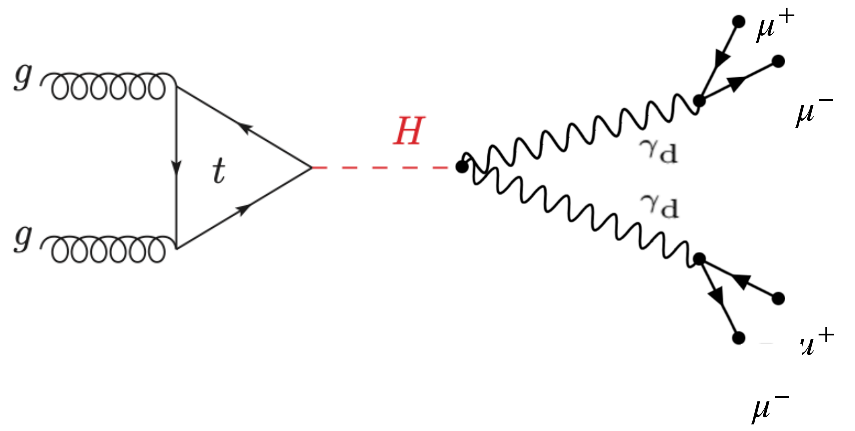

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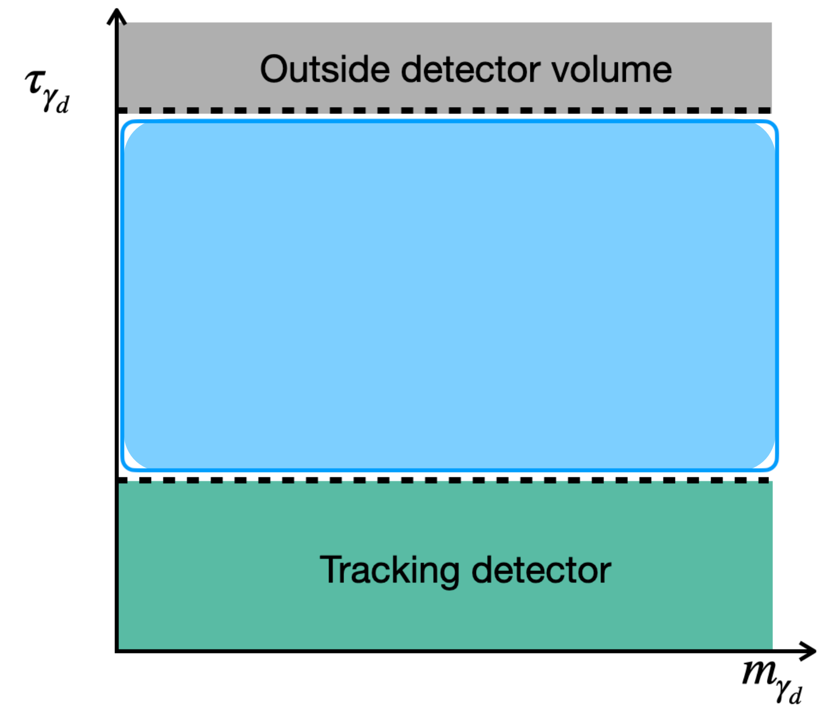

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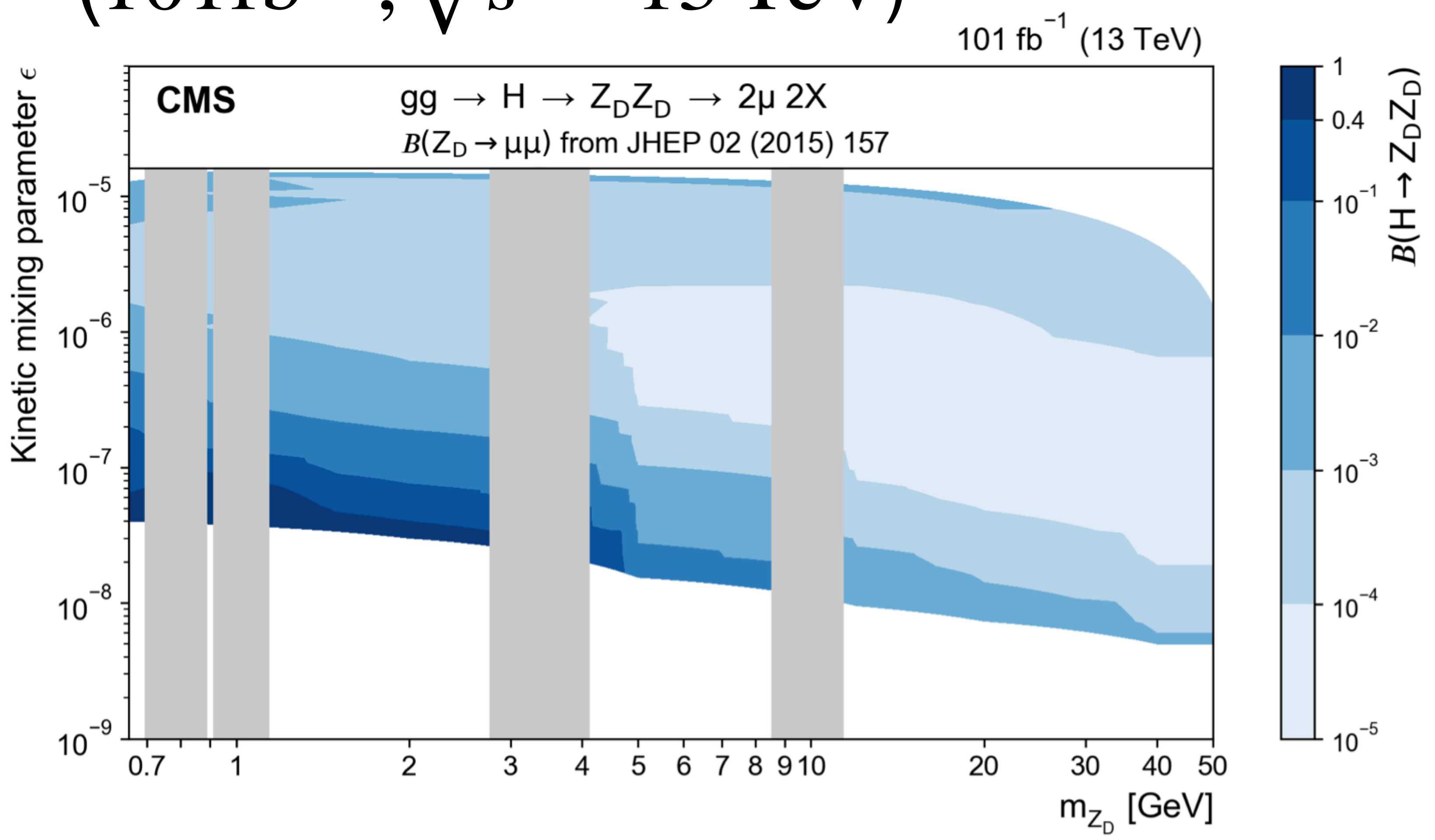

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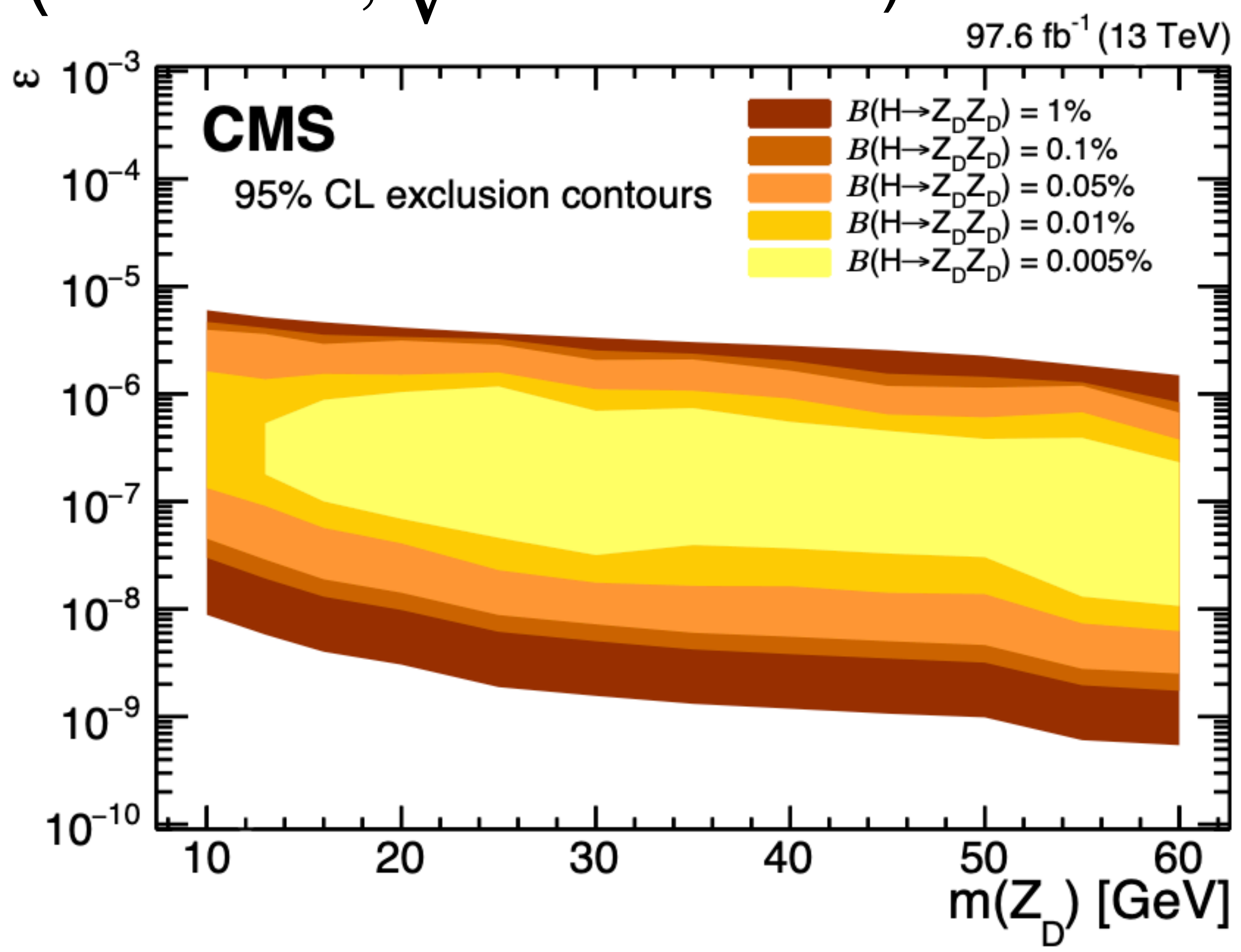

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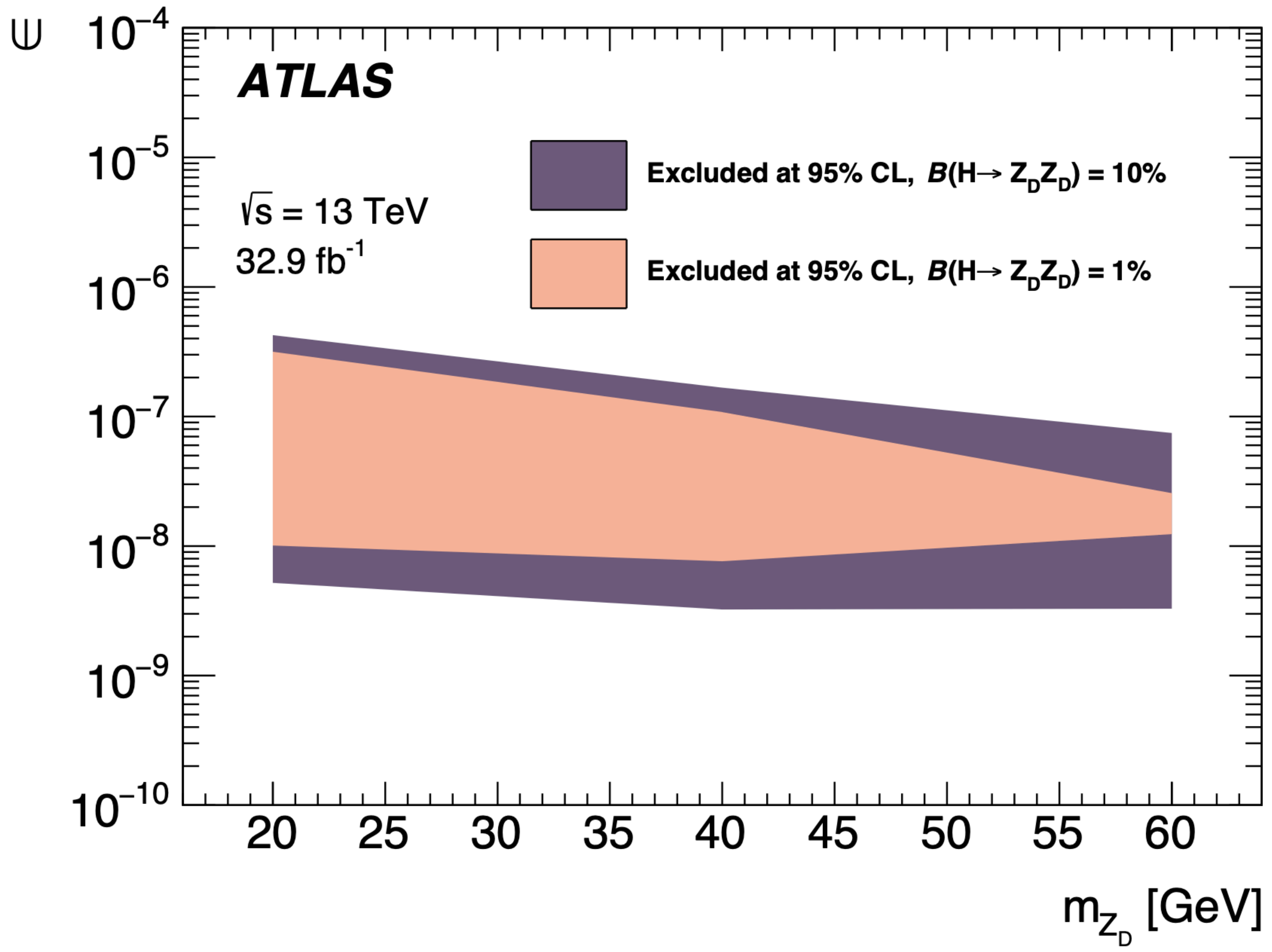
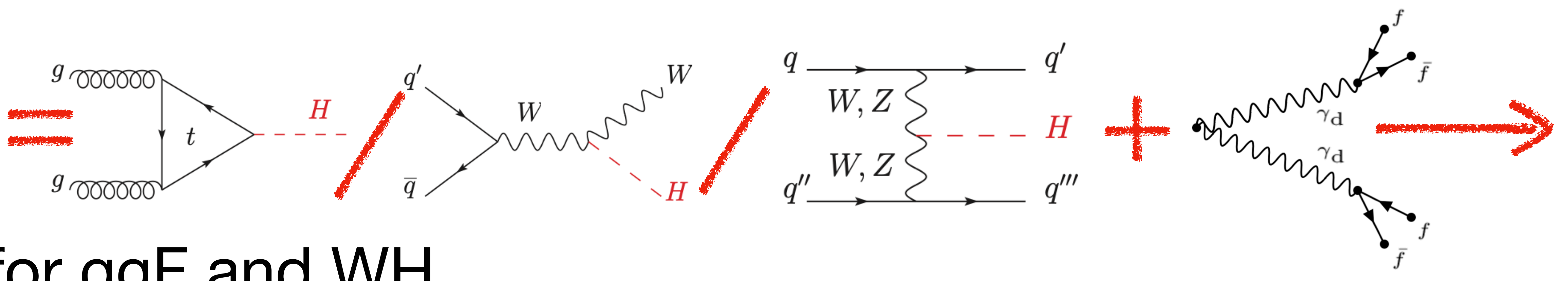


Exclusions up to $BR(H \to 2\gamma_d) = 0.1$ for $m_{\gamma_d} \in [20, 60]$ GeV and $\varepsilon \in [7 \times 10^{-6}, 8 \times 10^{-8}]$

→ CMS in general more sensitive (however ~3 times the data)!

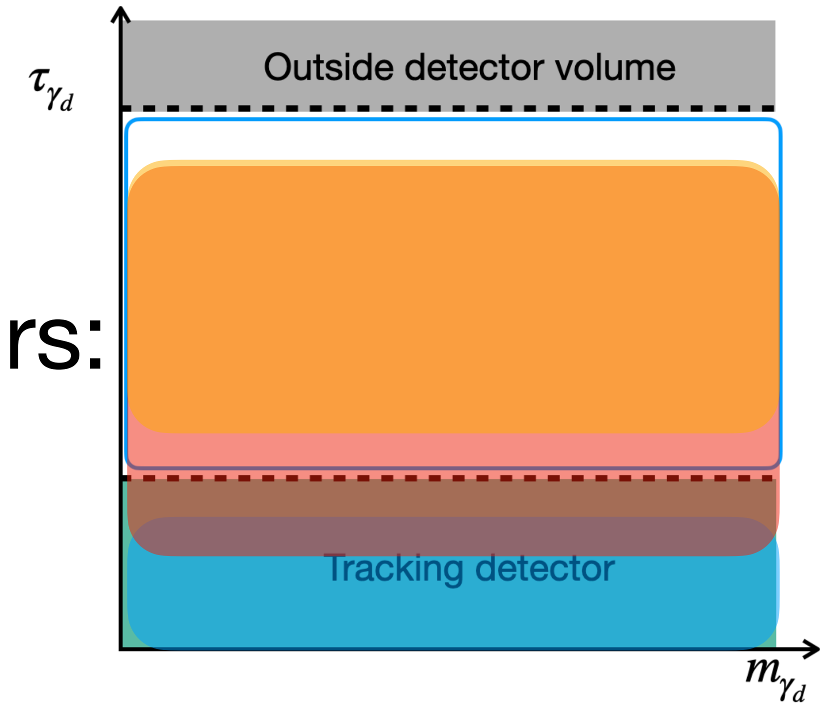
Displaced massive γ_d - displaced fermions

ggF/WH/VBF Higgs boson + HAHM* (Higgs + vector portal) =



Di-fermion pairs:

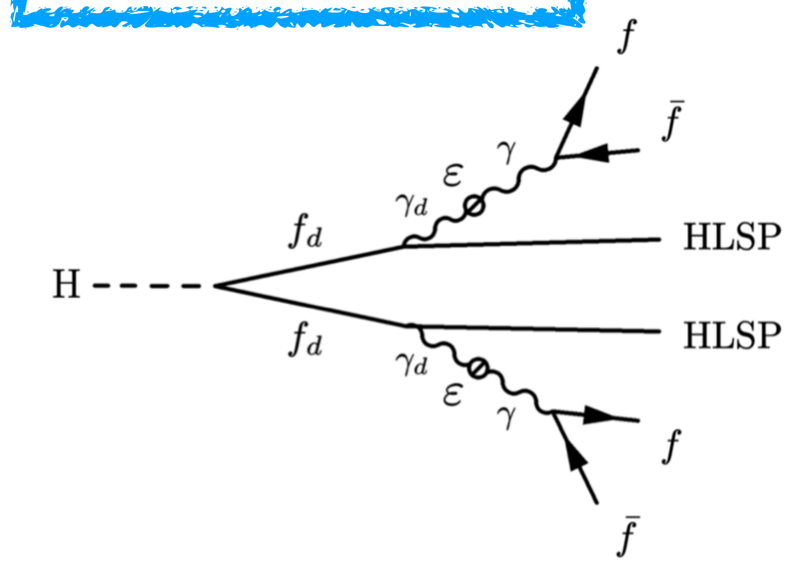
- Displaced
- Soft
- Collimated

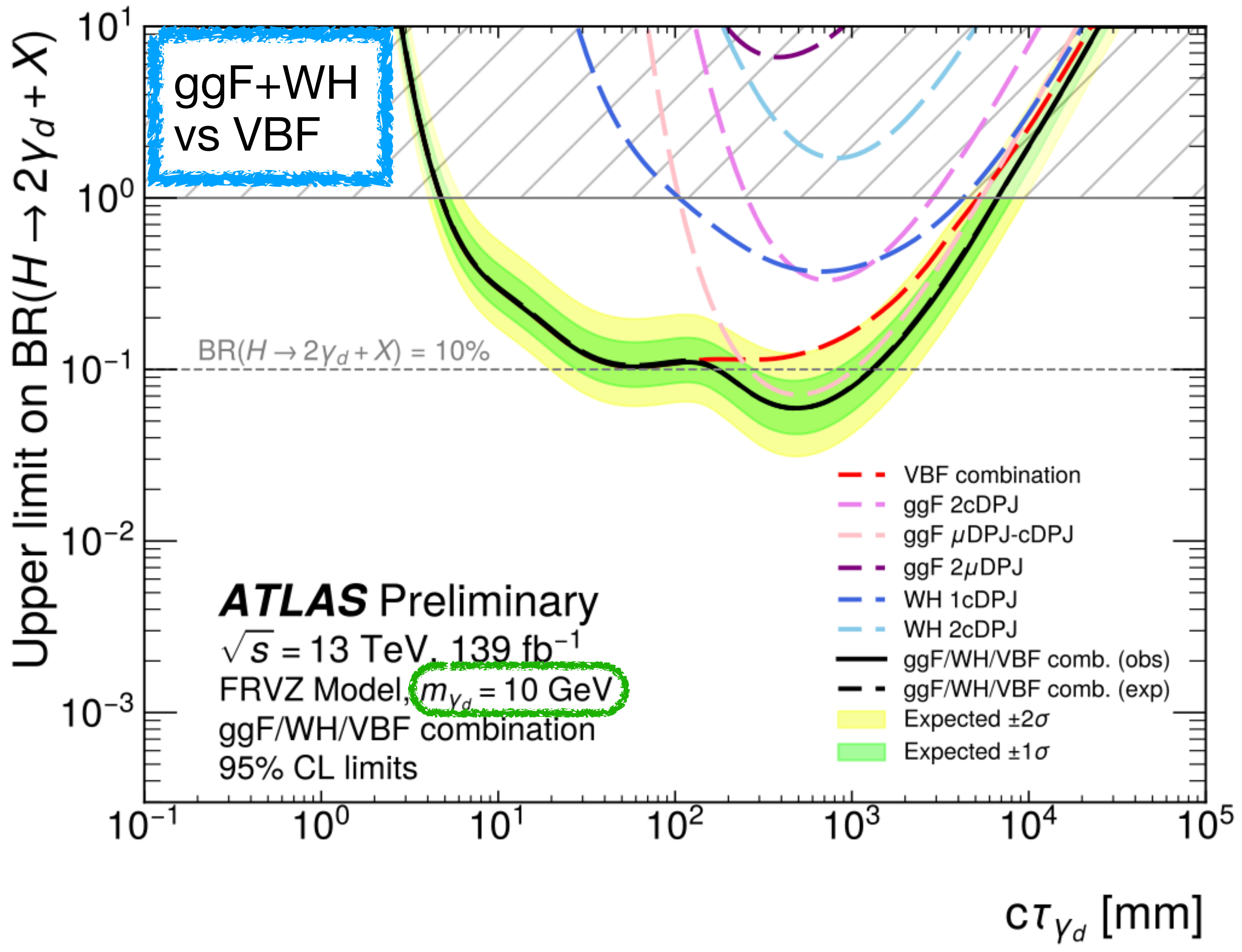


*FRVZ was studied as well for ggF and WH

ATLAS, HAHM and FRVZ, ggF and WH [JHEP06(2023)153] + ATLAS, HAHM and FRVZ, VBF [ATLAS-CONF-2023-051] NEW

Result for FRVZ:





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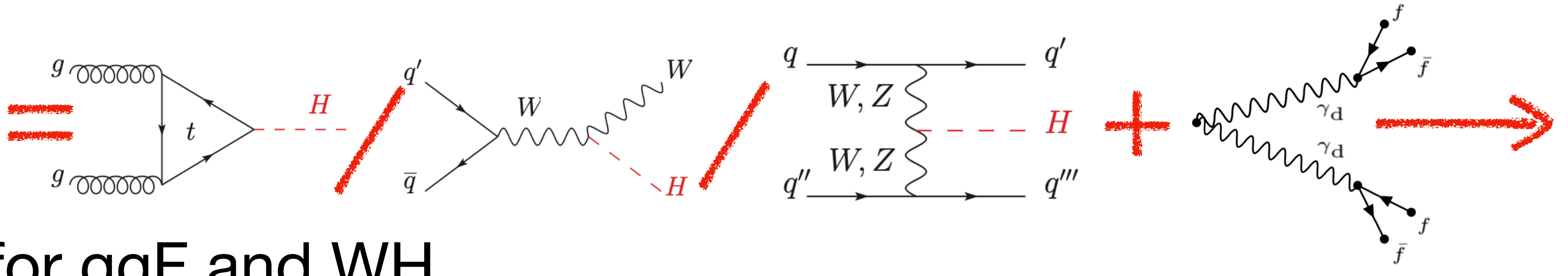

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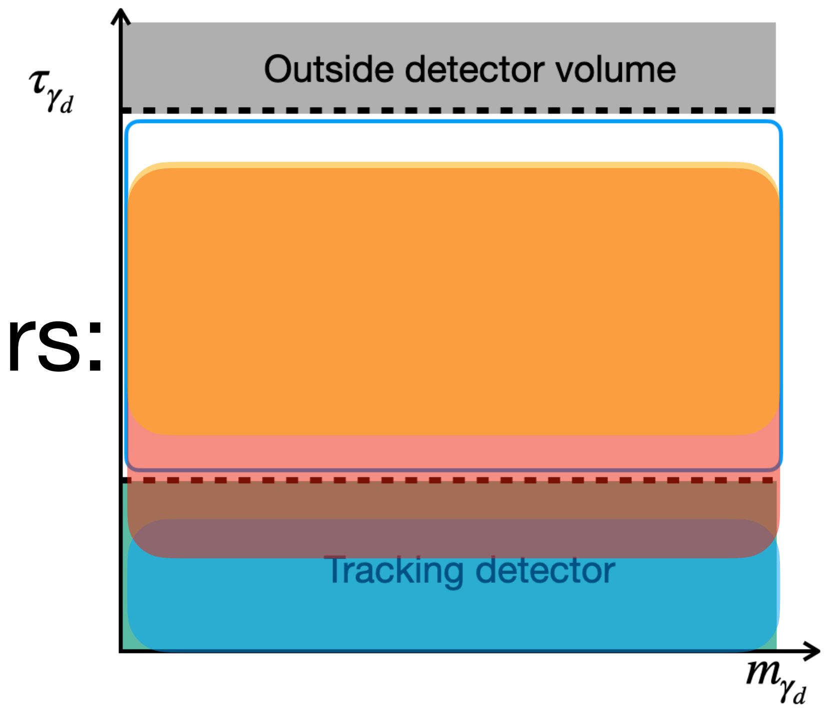

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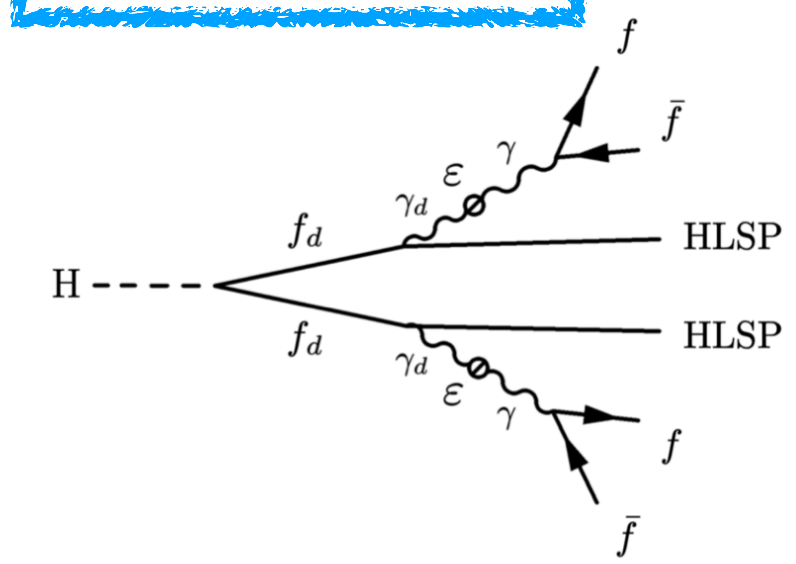
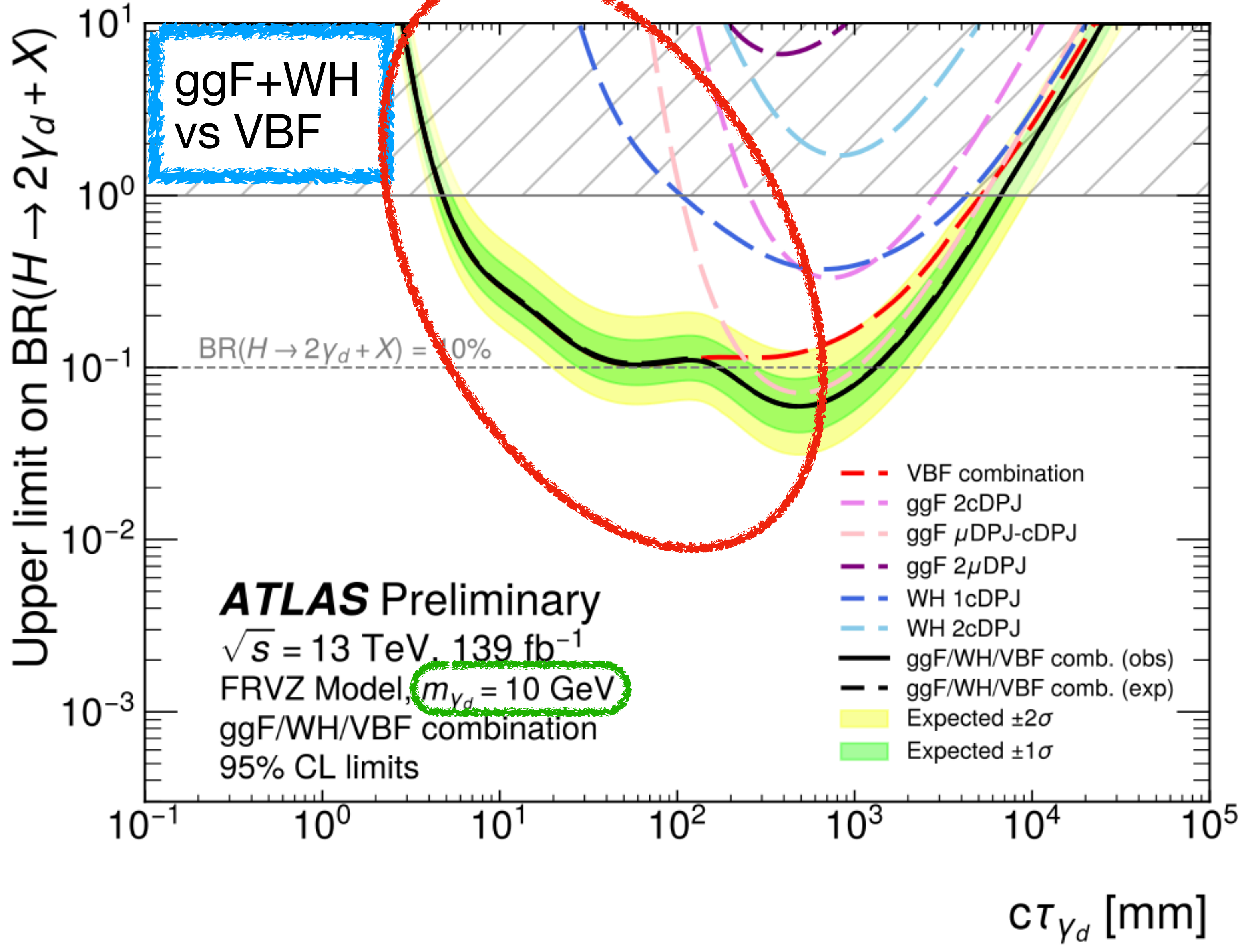
ATLAS, HAHM and FRVZ, ggF and WH [JHEP06(2023)153] + ATLAS, HAHM and FRVZ, VBF [ATLAS-CONF-2023-051] NEW

Result for FRVZ:

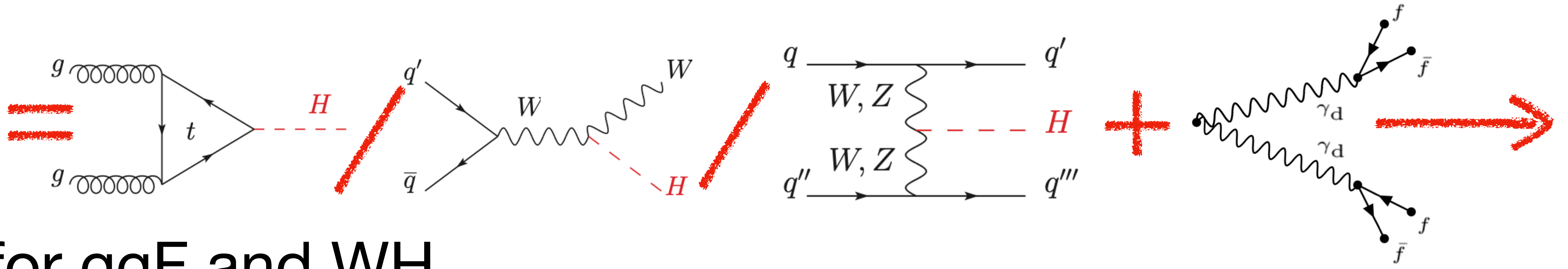




Addition of VBF: sizeable improvement at large γ_d mass

Displaced massive γ_d - displaced fermions

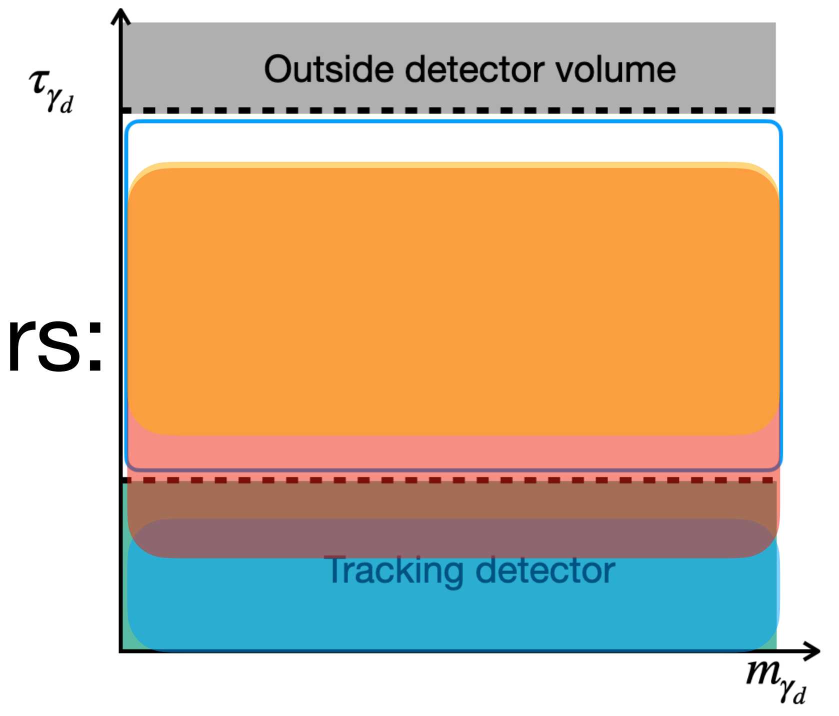
ggF/WH/VBF Higgs boson + HAHM* (Higgs + vector portal) =



*FRVZ was studied as well for ggF and WH

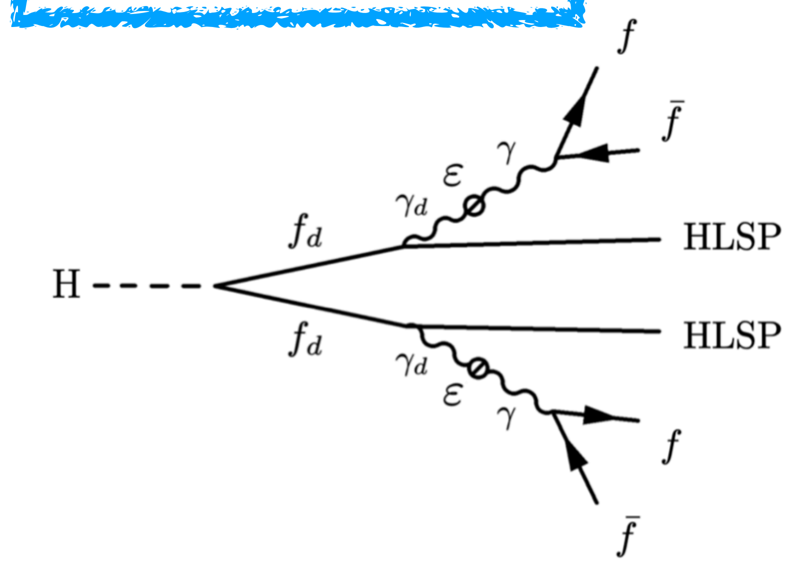
Di-fermion pairs:

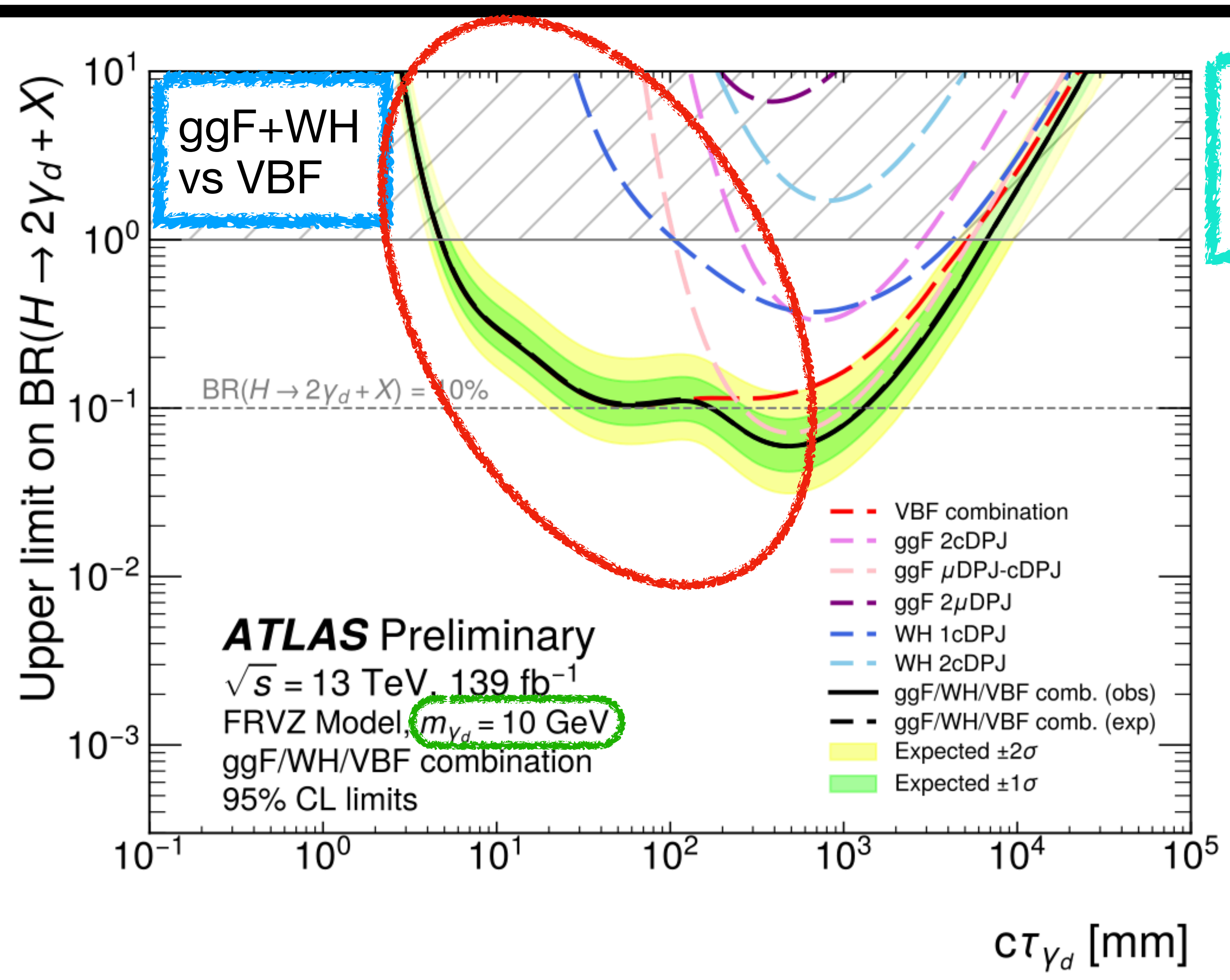
- Displaced
- Soft
- Collimated



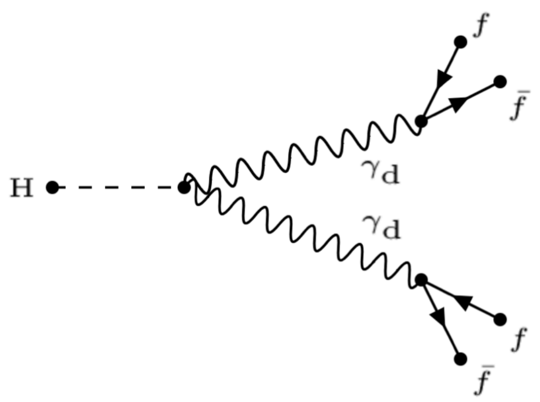
ATLAS, HAHM and FRVZ, ggF and WH [JHEP06(2023)153] + ATLAS, HAHM and FRVZ, VBF [ATLAS-CONF-2023-051] NEW

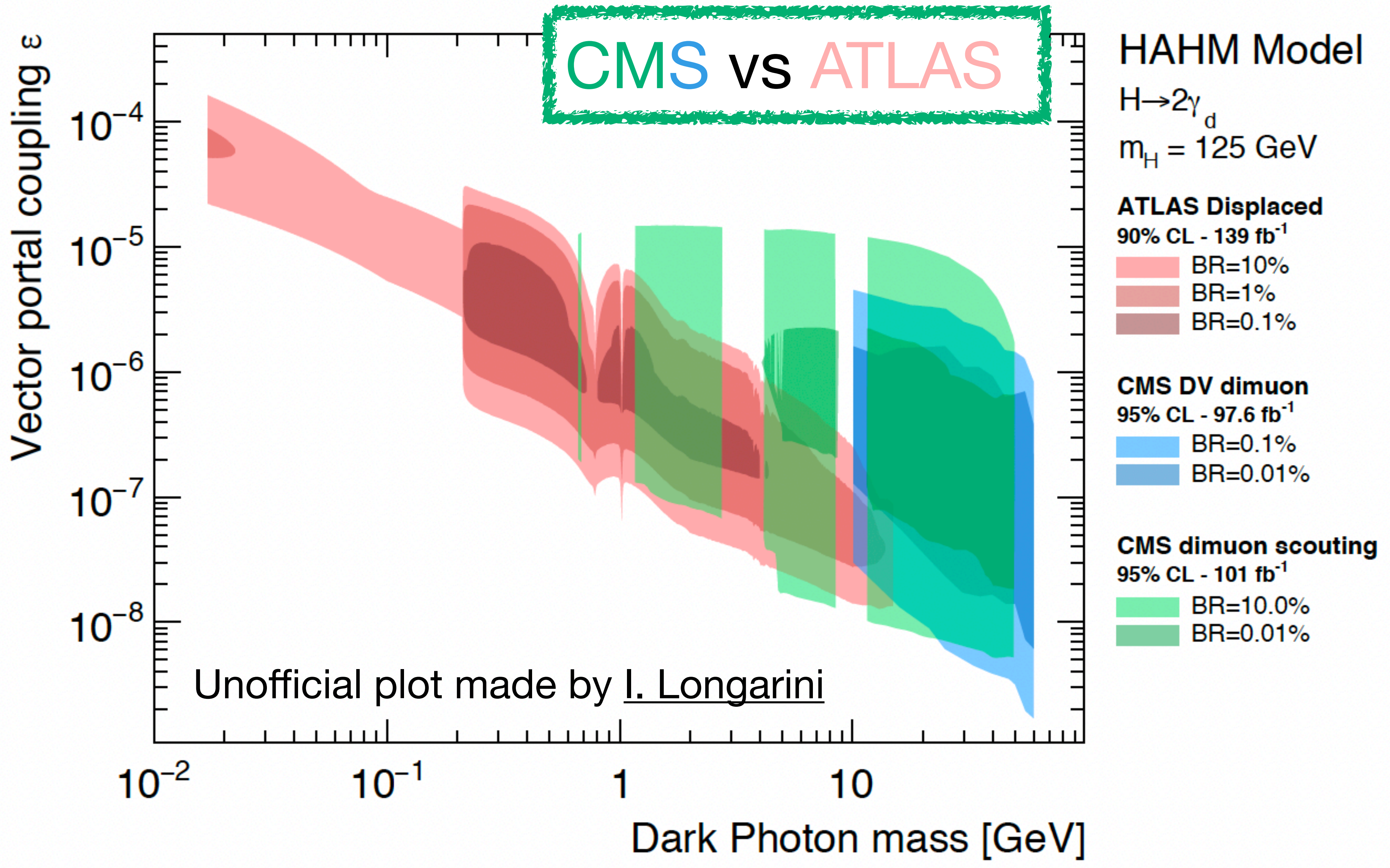
Result for FRVZ:





Result for HAHM:

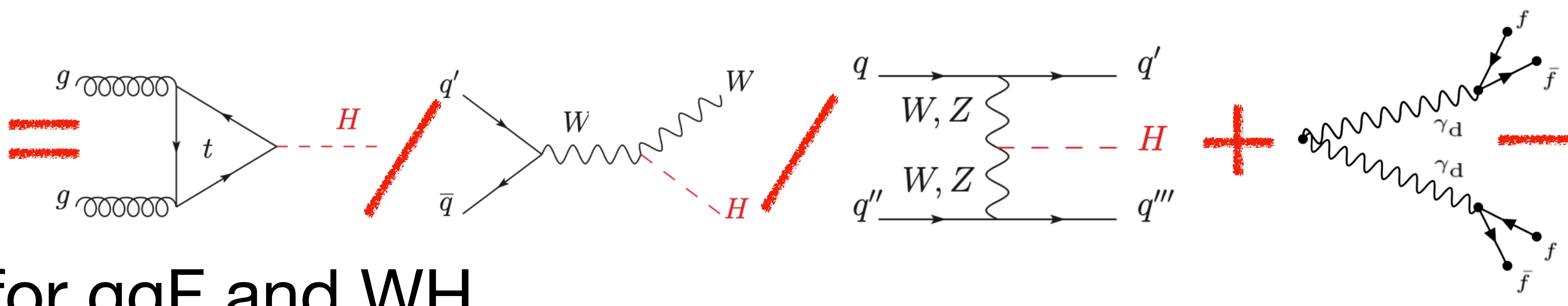




Addition of VBF: sizeable improvement at large γ_d mass

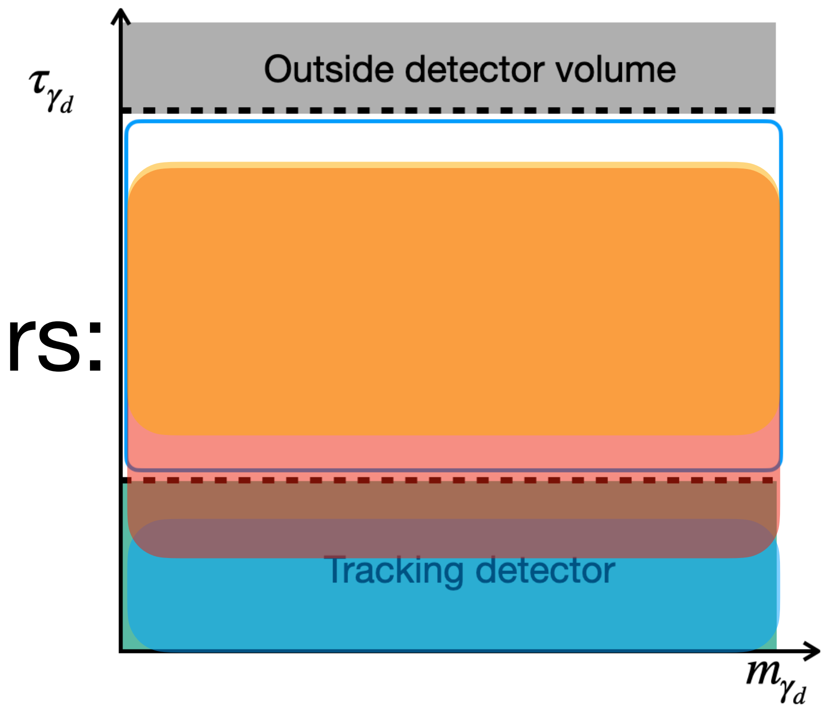
Displaced massive γ_d - displaced fermions

ggF/WH/VBF Higgs boson +
HAHM* (Higgs + vector portal)



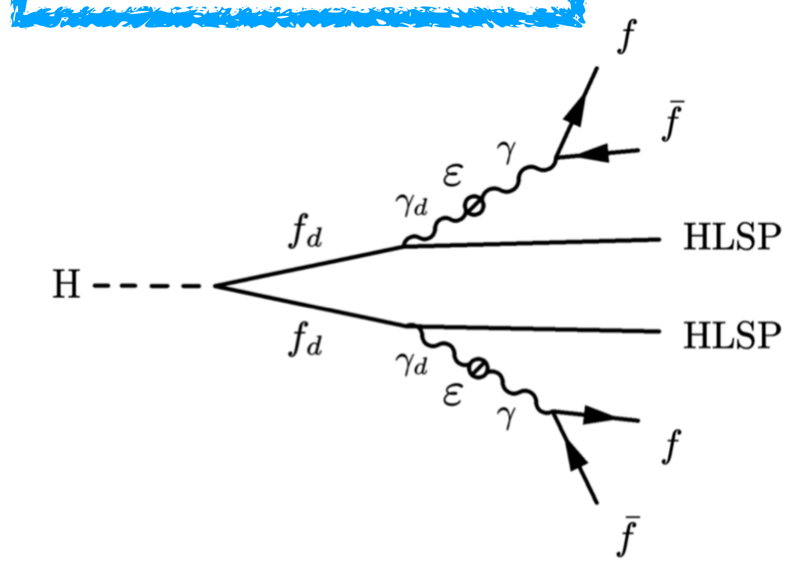
*FRVZ was studied as well for ggF and WH

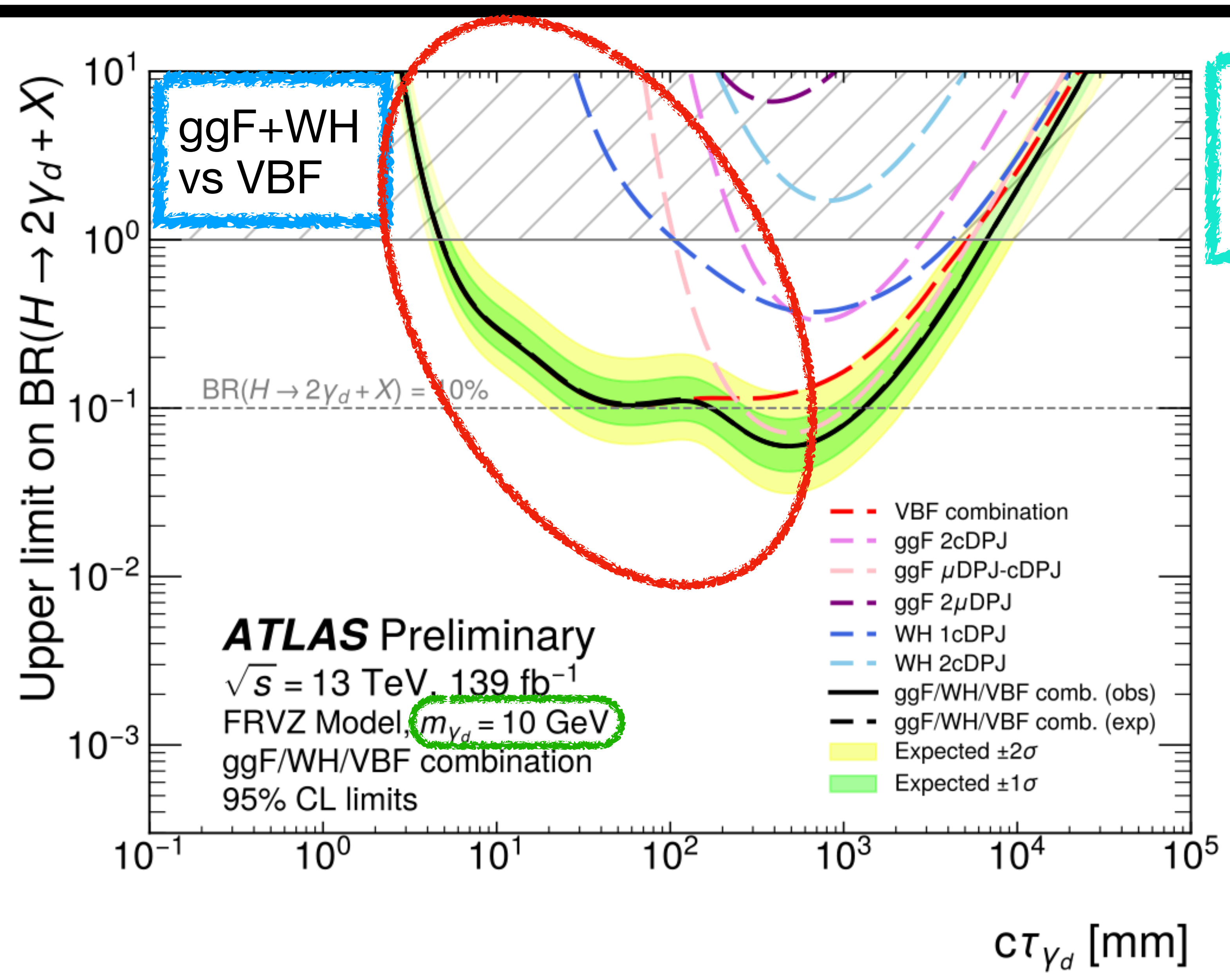
Di-fermion pairs:
- Displaced
- Soft
- Collimated



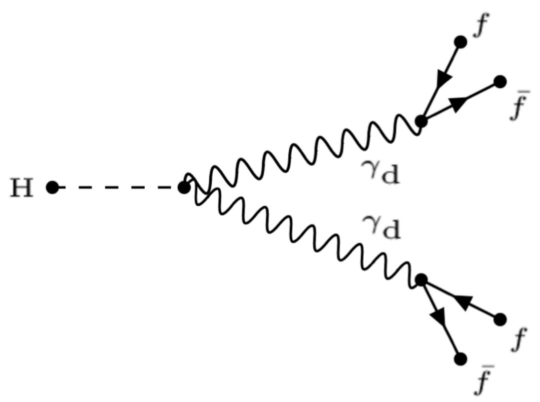
ATLAS, HAHM and FRVZ, ggF and WH [JHEP06(2023)153] + ATLAS, HAHM and FRVZ, VBF [ATLAS-CONF-2023-051] NEW

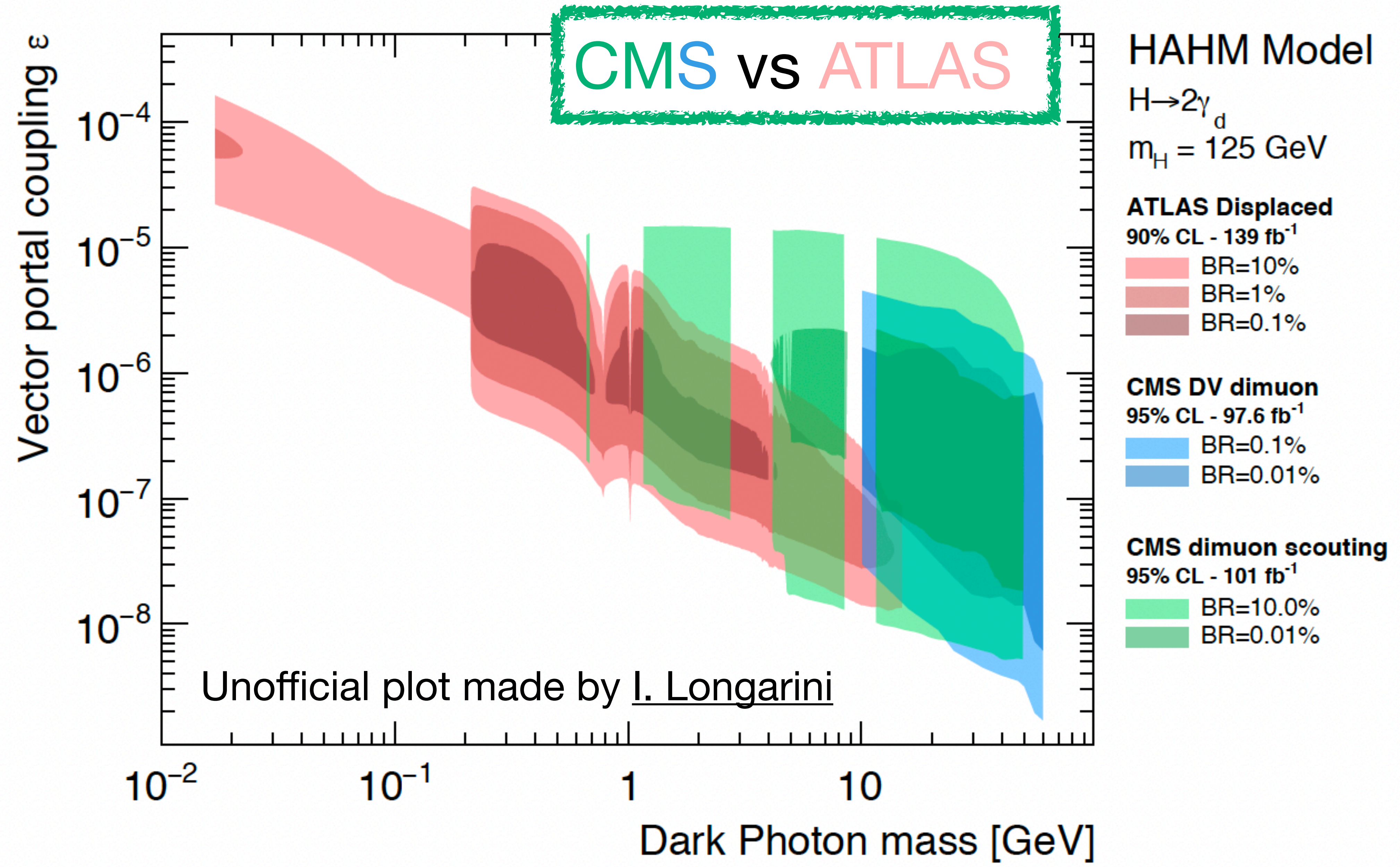
Result for FRVZ:





Result for HAHM:



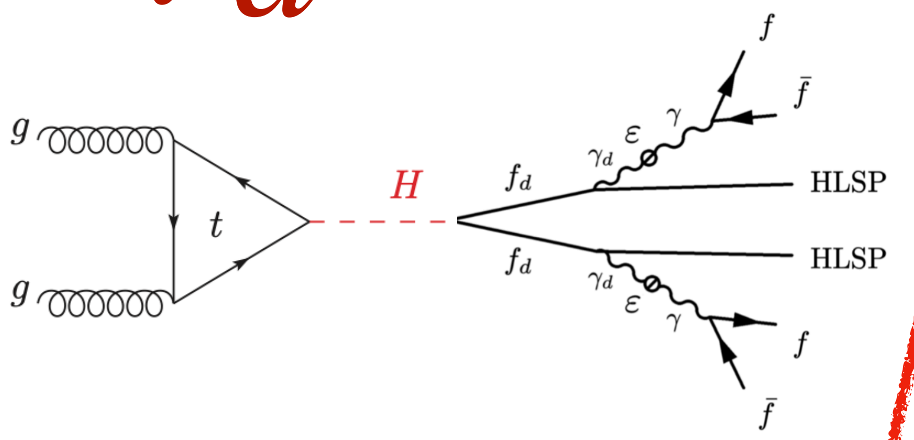


Addition of VBF: sizeable improvement at large γ_d mass

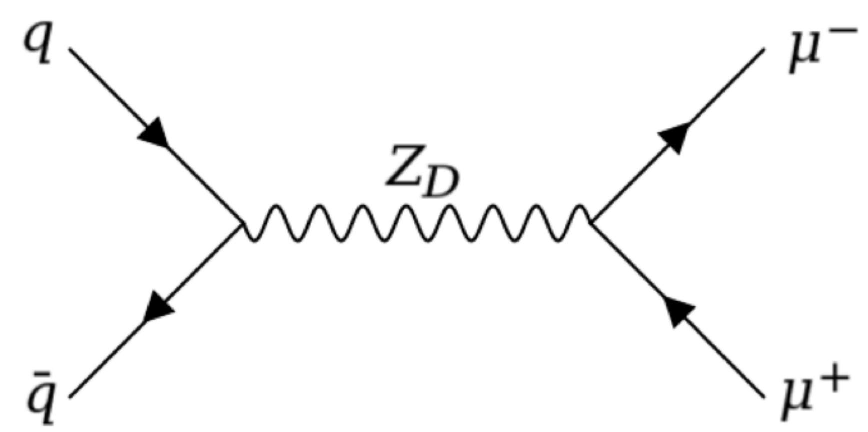
Complementary sensitivities:
- ATLAS where m_{γ_d} decays forbidden or vetoed
- CMS elsewhere

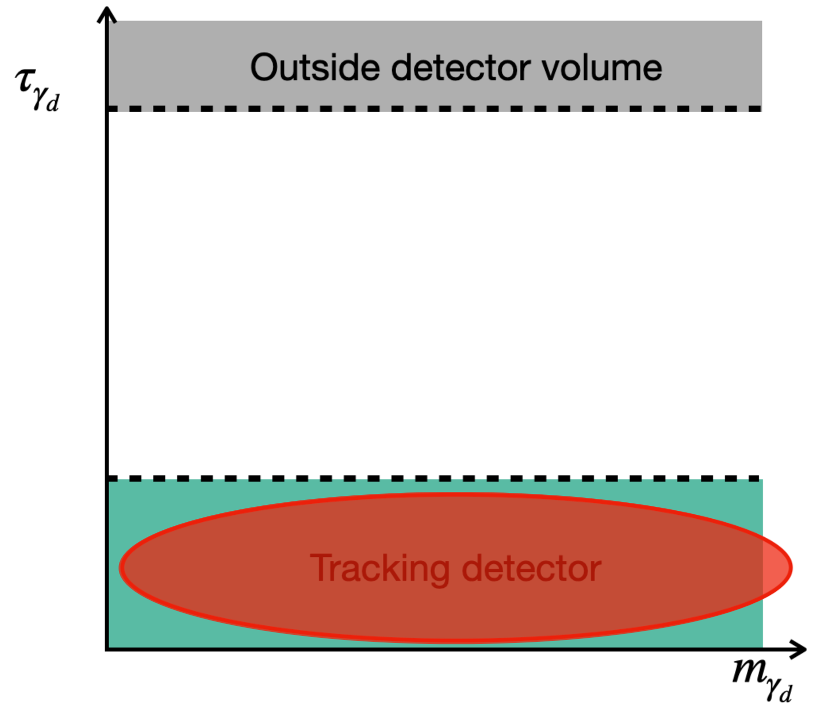
Prompt massive γ_d - prompt lepton pairs

ggF produced Higgs boson + FRVZ (Higgs + vector portal) =



DY (vector portal only) =



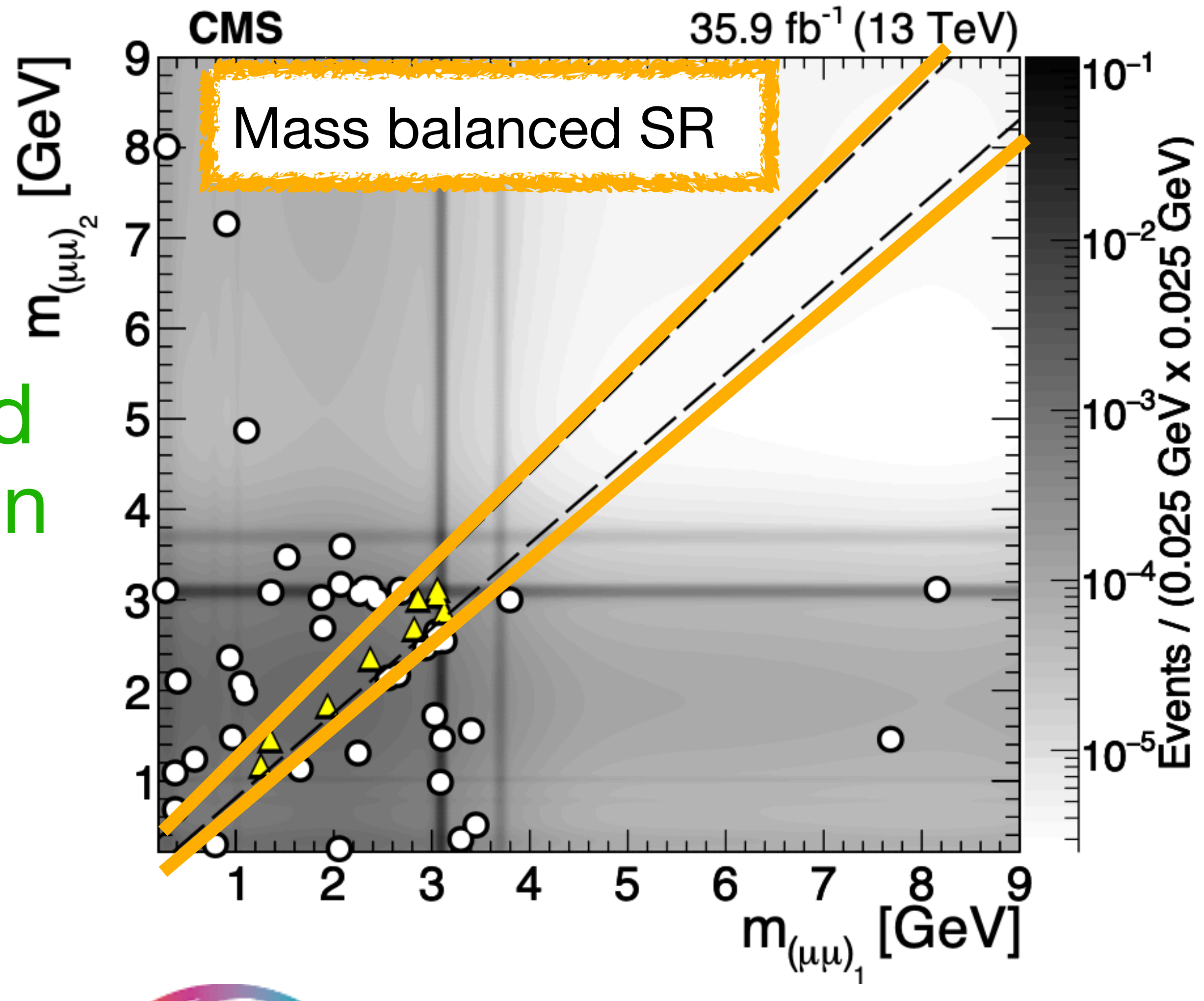


CMS, FRVZ [PLB796(2019)131]

2015-2016 data
$(35.9\text{fb}^{-1}, \sqrt{s} = 13\,\text{TeV})$

Looking for prompt di-muon pairs

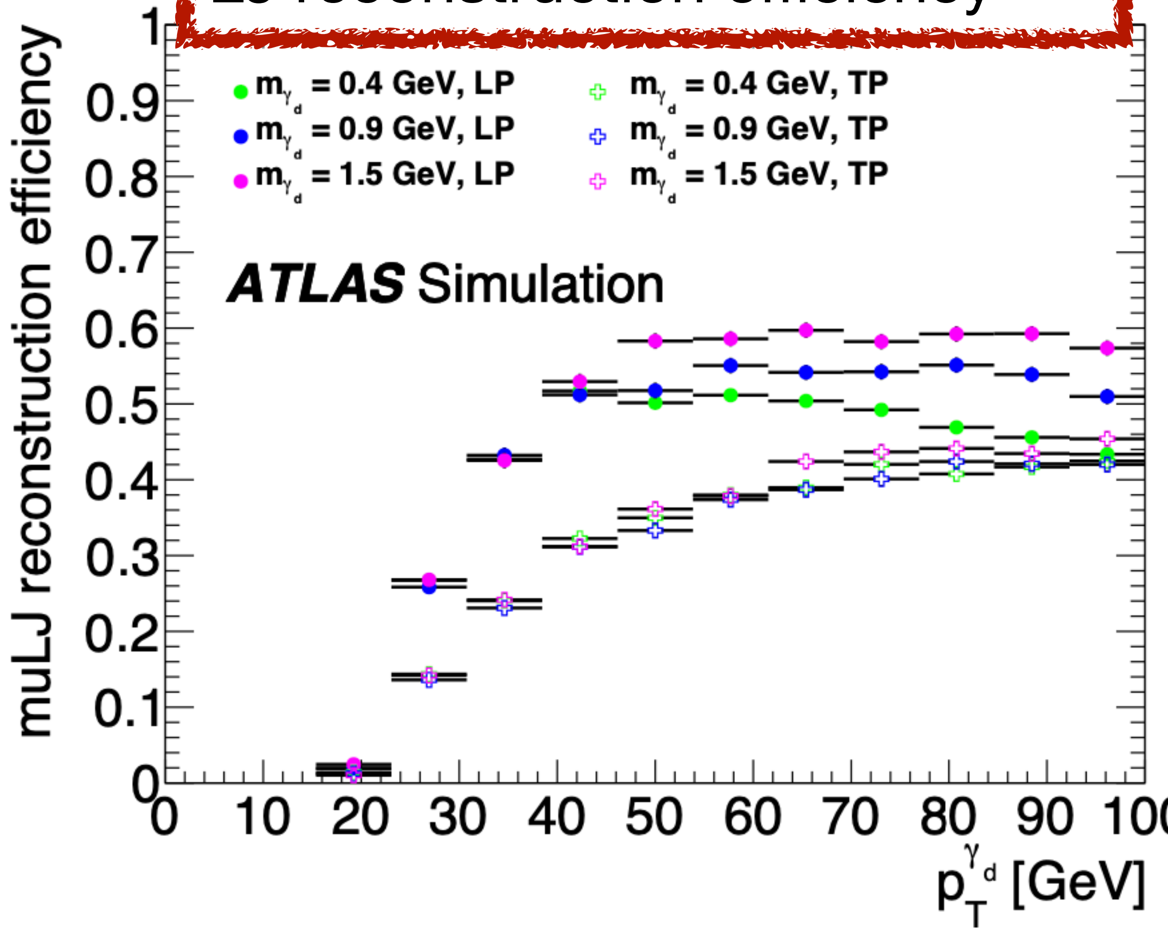
SR defined by di-muon pairs invariant mass balance



ATLAS, FRVZ [JHEP02(2016)062]

Run 1 data $(20.3\text{fb}^{-1}, \sqrt{s} = 8\,\text{TeV})$

Looking for prompt di-lepton pairs



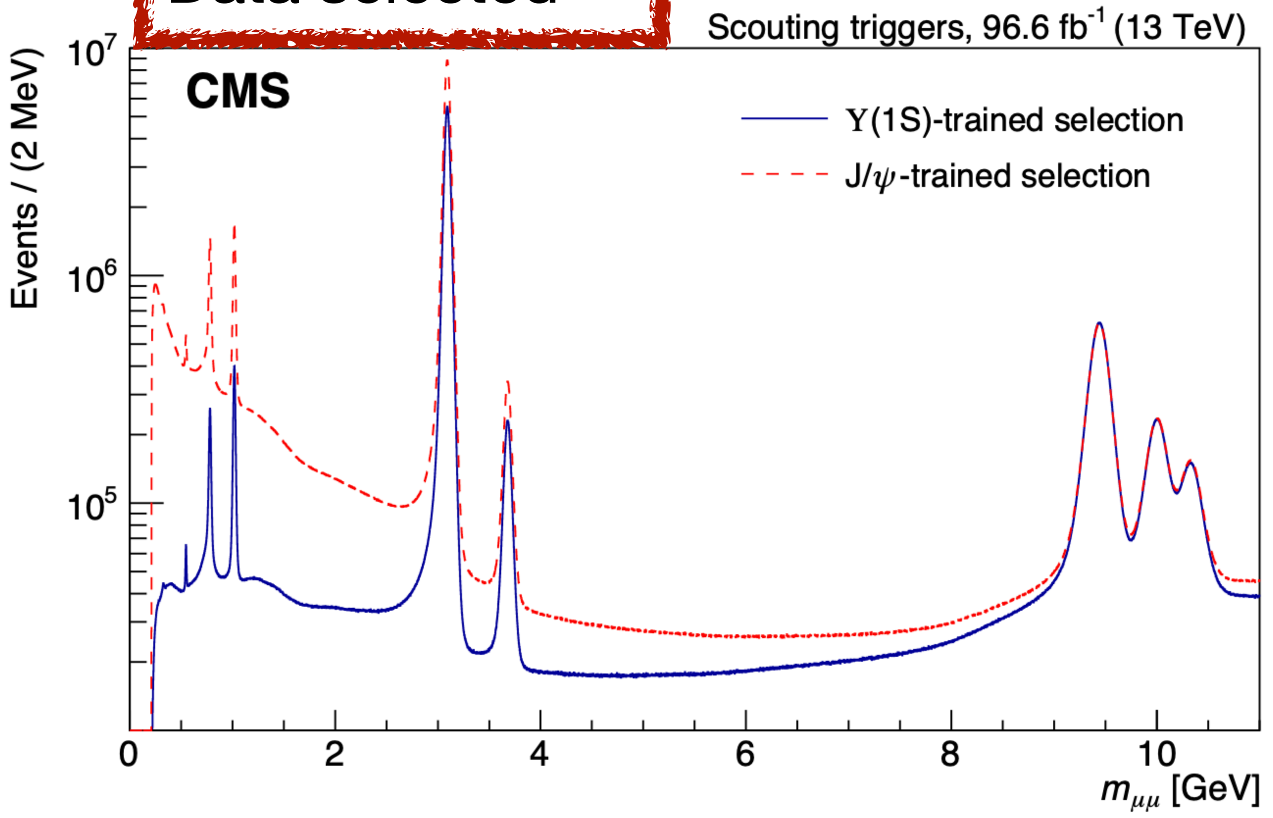
Lepton pairs are collimated → reconstruct them as single object **Lepton Jet (LJ)**

CMS, CERN-EP-2023-165 NEW

2017-2018 data
$(96.6\text{fb}^{-1}, \sqrt{s} = 13\,\text{TeV})$

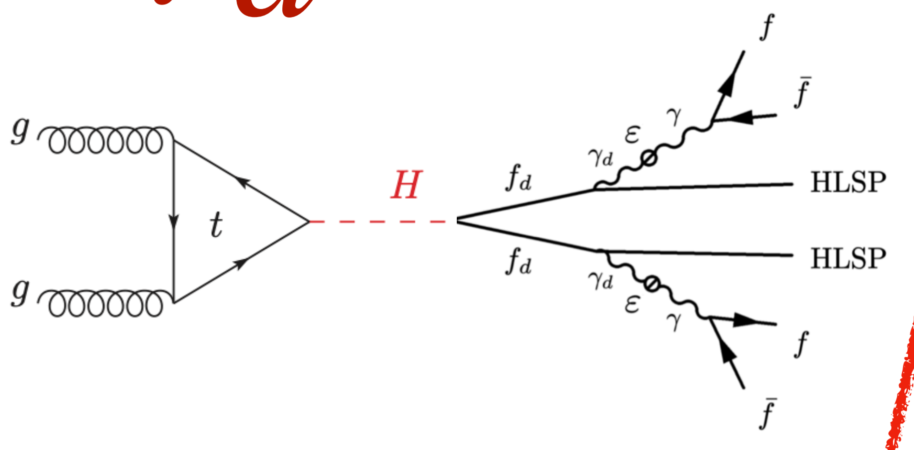
Only vector portal only search in CMS and ATLAS!!

Scouting + BDT

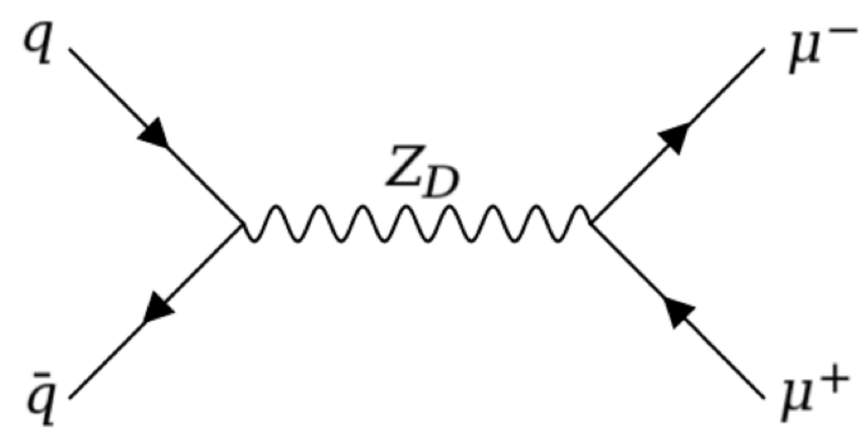


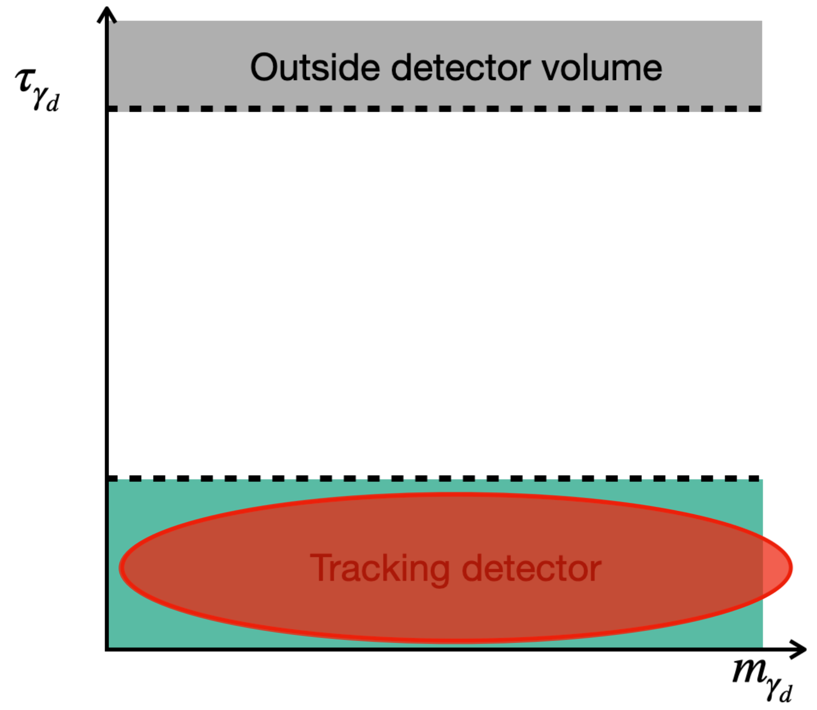
Prompt massive γ_d - prompt lepton pairs

ggF produced Higgs boson + FRVZ (Higgs + vector portal) =

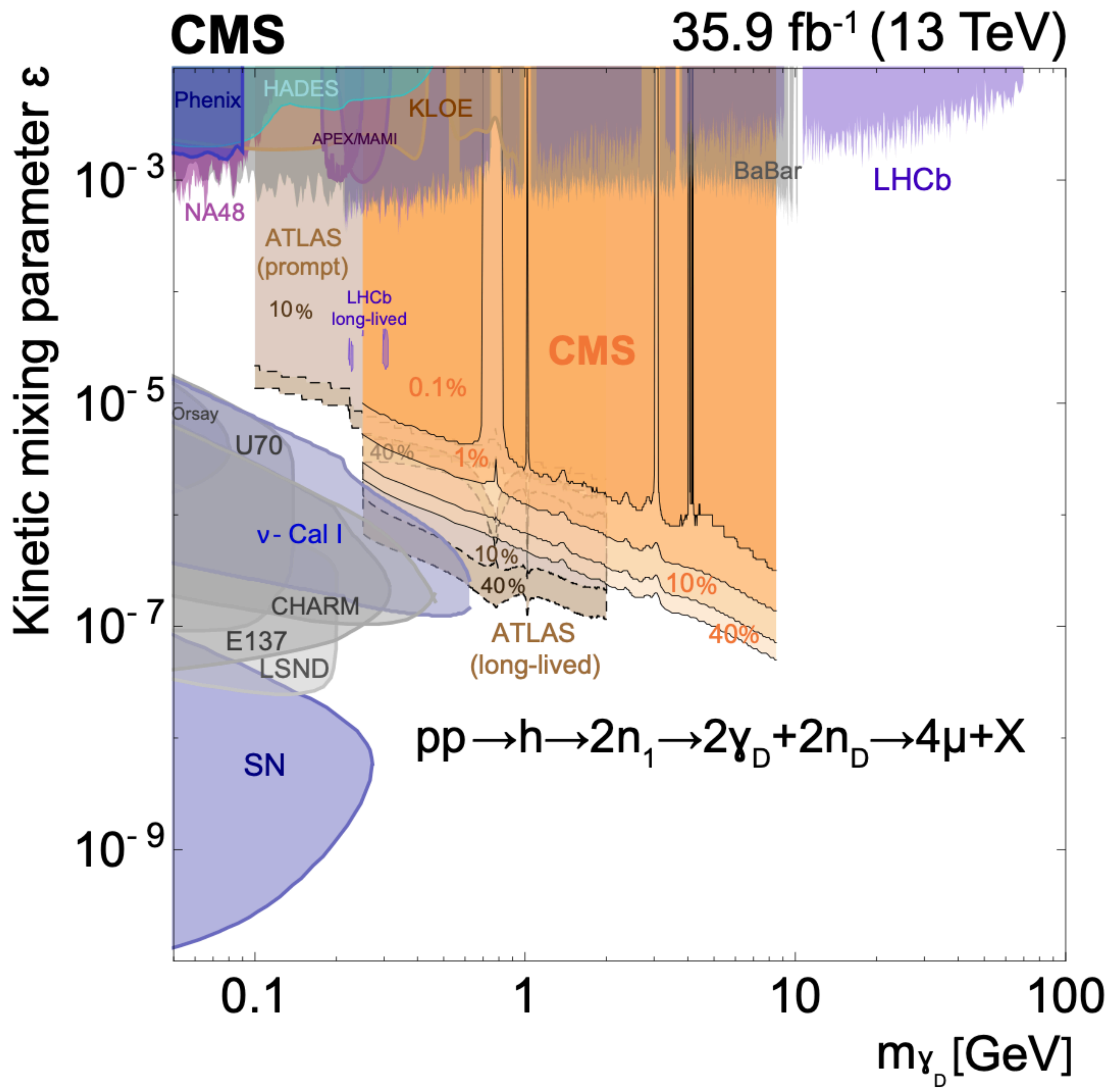


DY (vector portal only) =

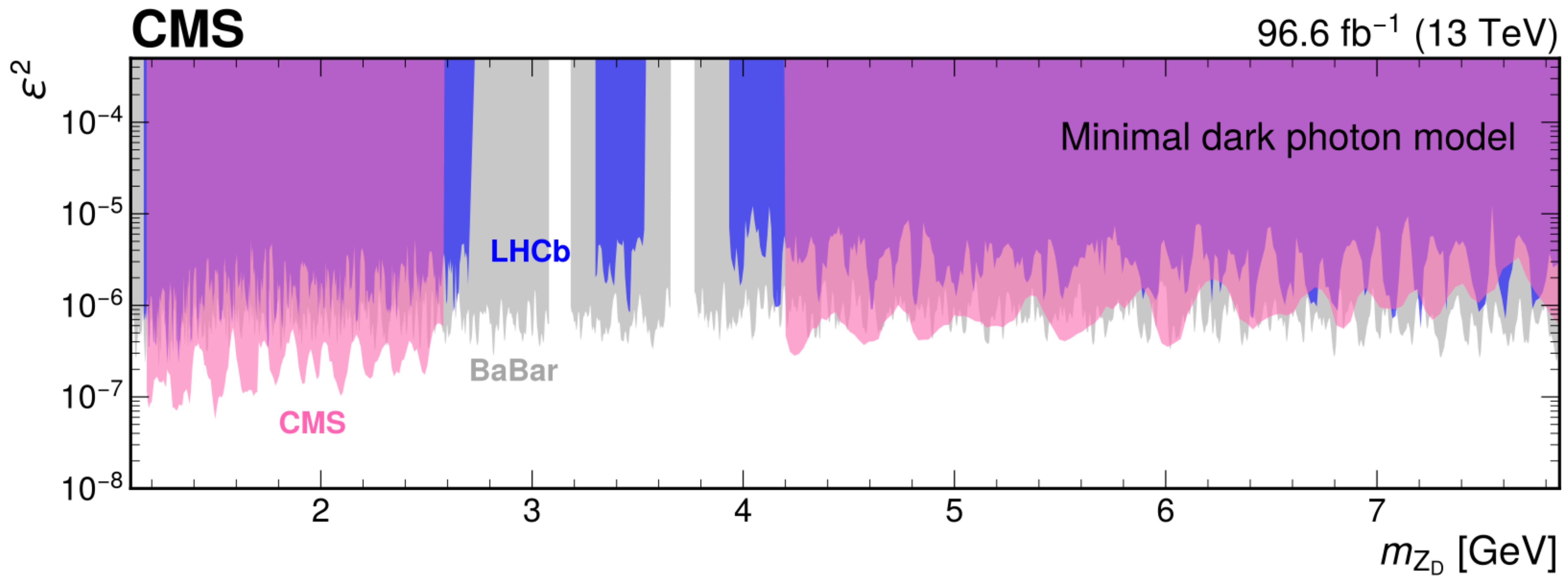




CMS, FRVZ [PLB796(2019)131] & **ATLAS, FRVZ [JHEP02(2016)062]**

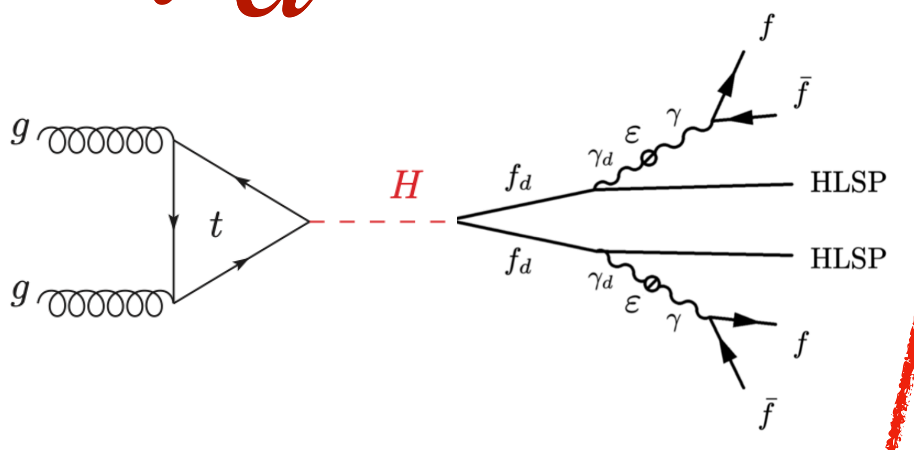


CMS, CERN-EP-2023-165

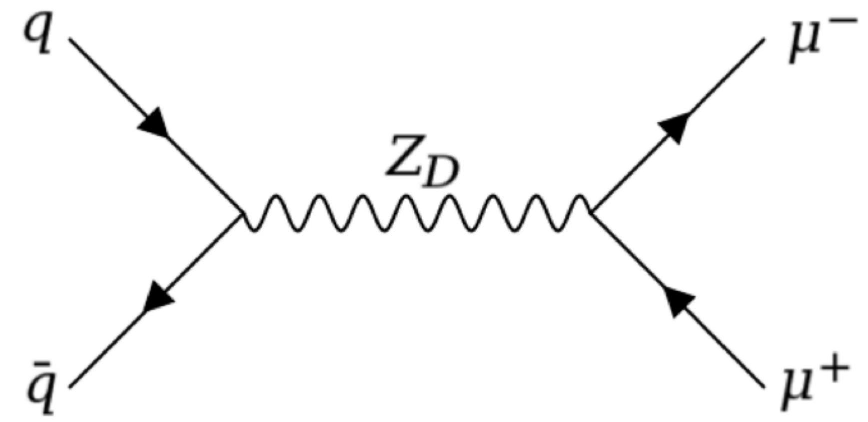


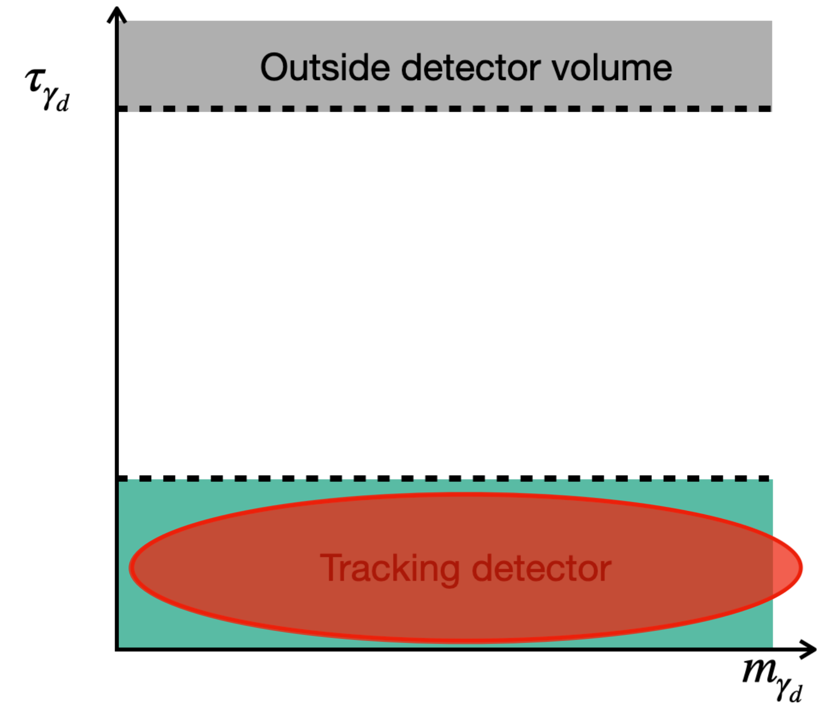
Prompt massive γ_d - prompt lepton pairs

ggF produced Higgs boson + FRVZ (Higgs + vector portal) =



DY (vector portal only) =



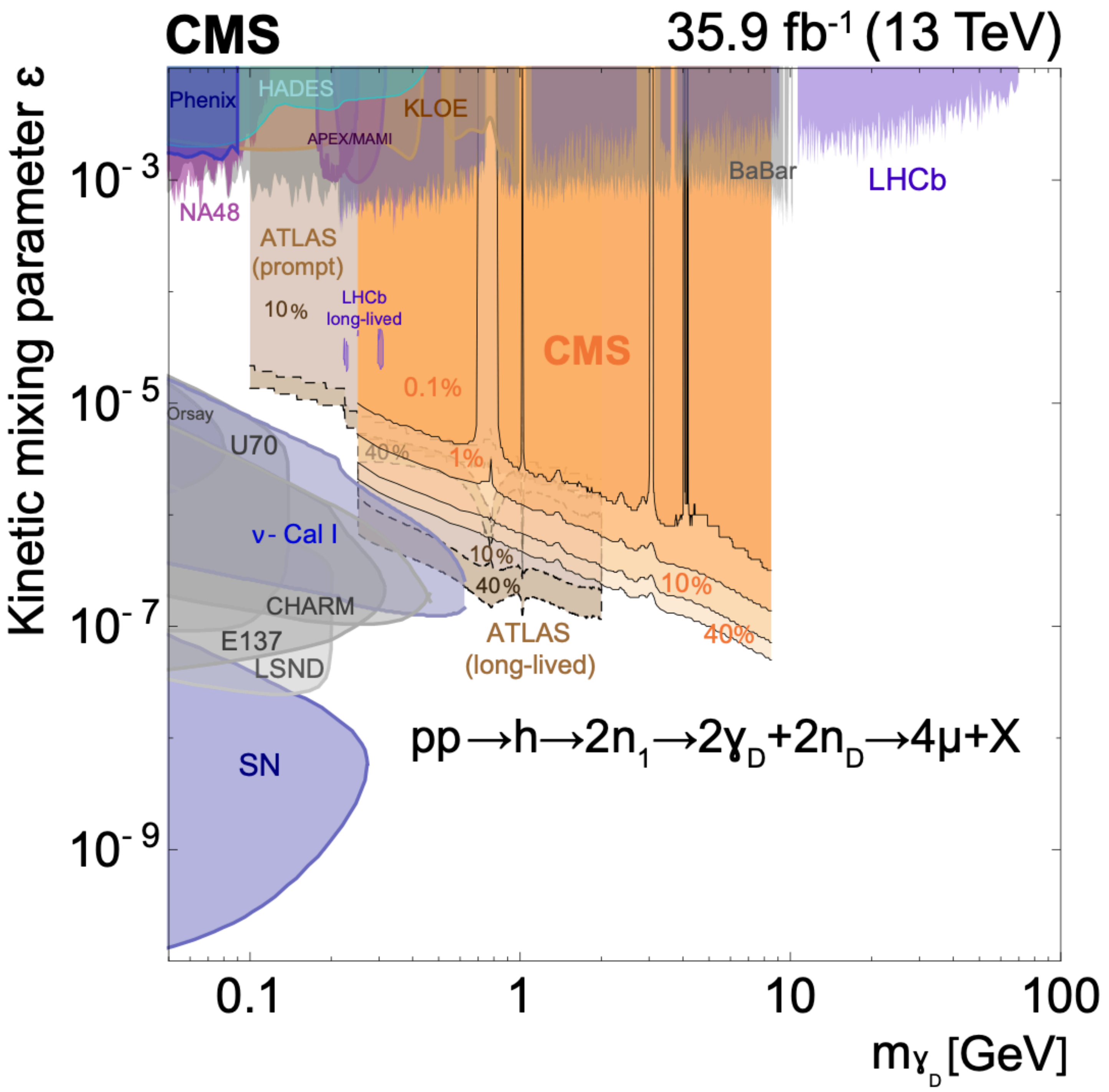


CMS, FRVZ [PLB796(2019)131] & **ATLAS, FRVZ [JHEP02(2016)062]**

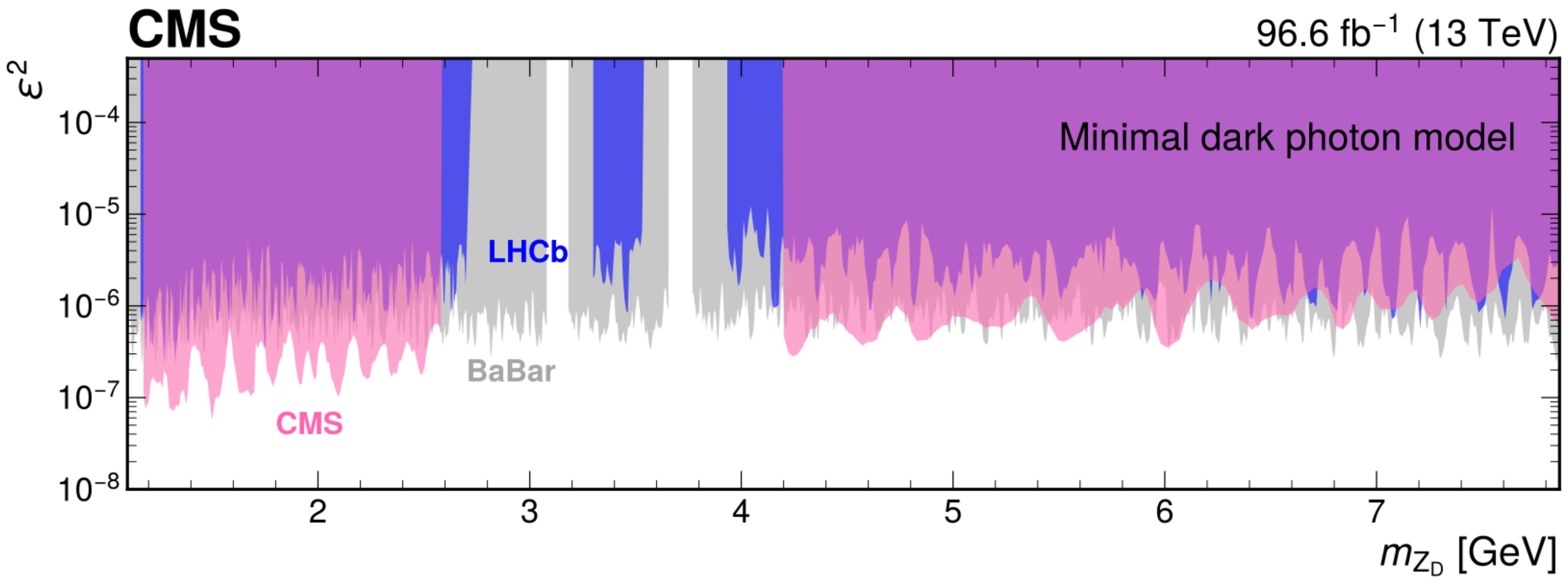
Complementary sensitivities:

- ATLAS where m_{γ_d} decays forbidden or vetoed
- CMS elsewhere

N.B. ATLAS still Run-1 result!

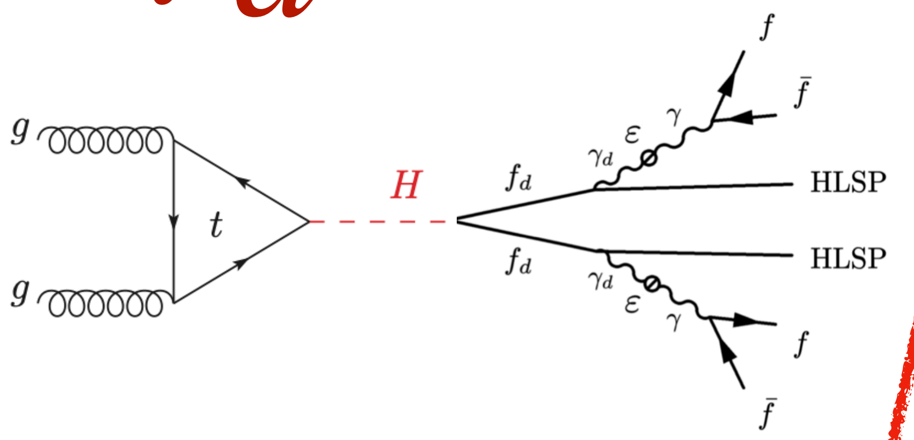


CMS, CERN-EP-2023-165

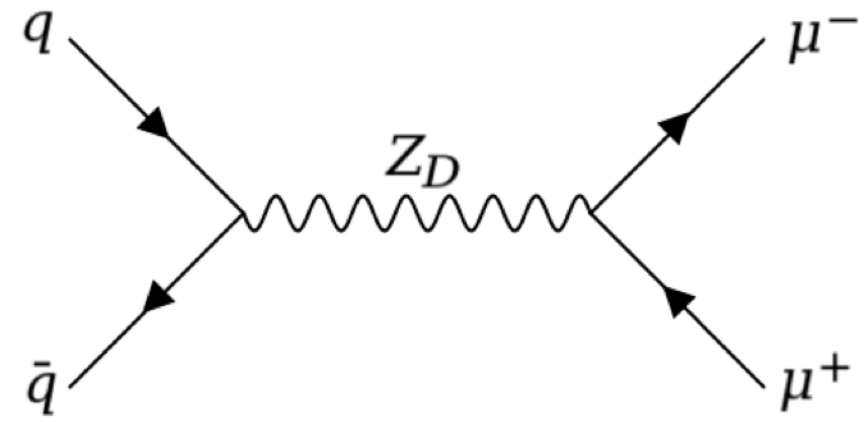


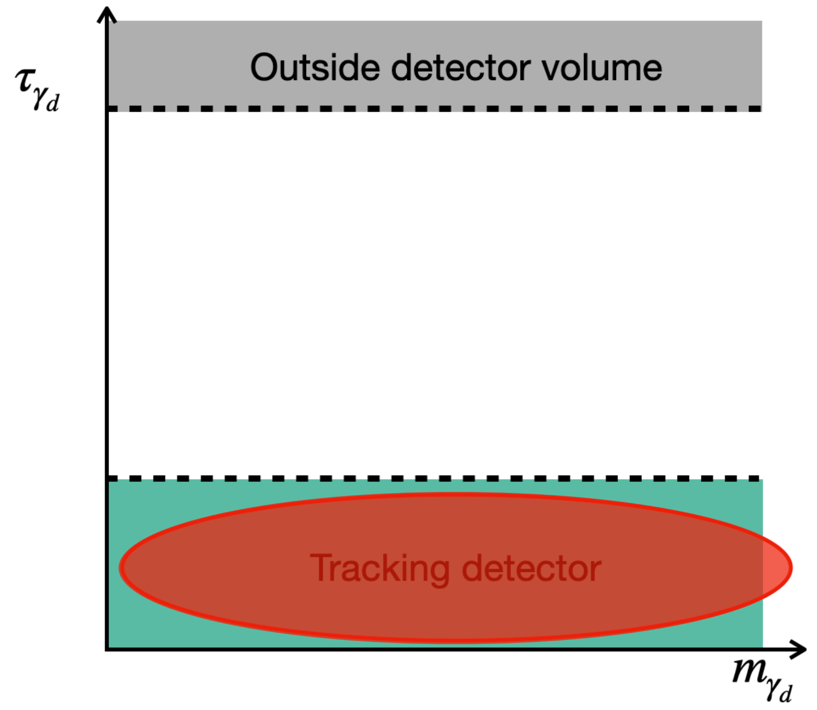
Prompt massive γ_d - prompt lepton pairs

ggF produced Higgs boson + FRVZ (Higgs + vector portal) =



DY (vector portal only) =





CMS, FRVZ [PLB796(2019)131] & **ATLAS, FRVZ [JHEP02(2016)062]**

Complementary sensitivities:

- ATLAS where m_{γ_d} decays forbidden or vetoed
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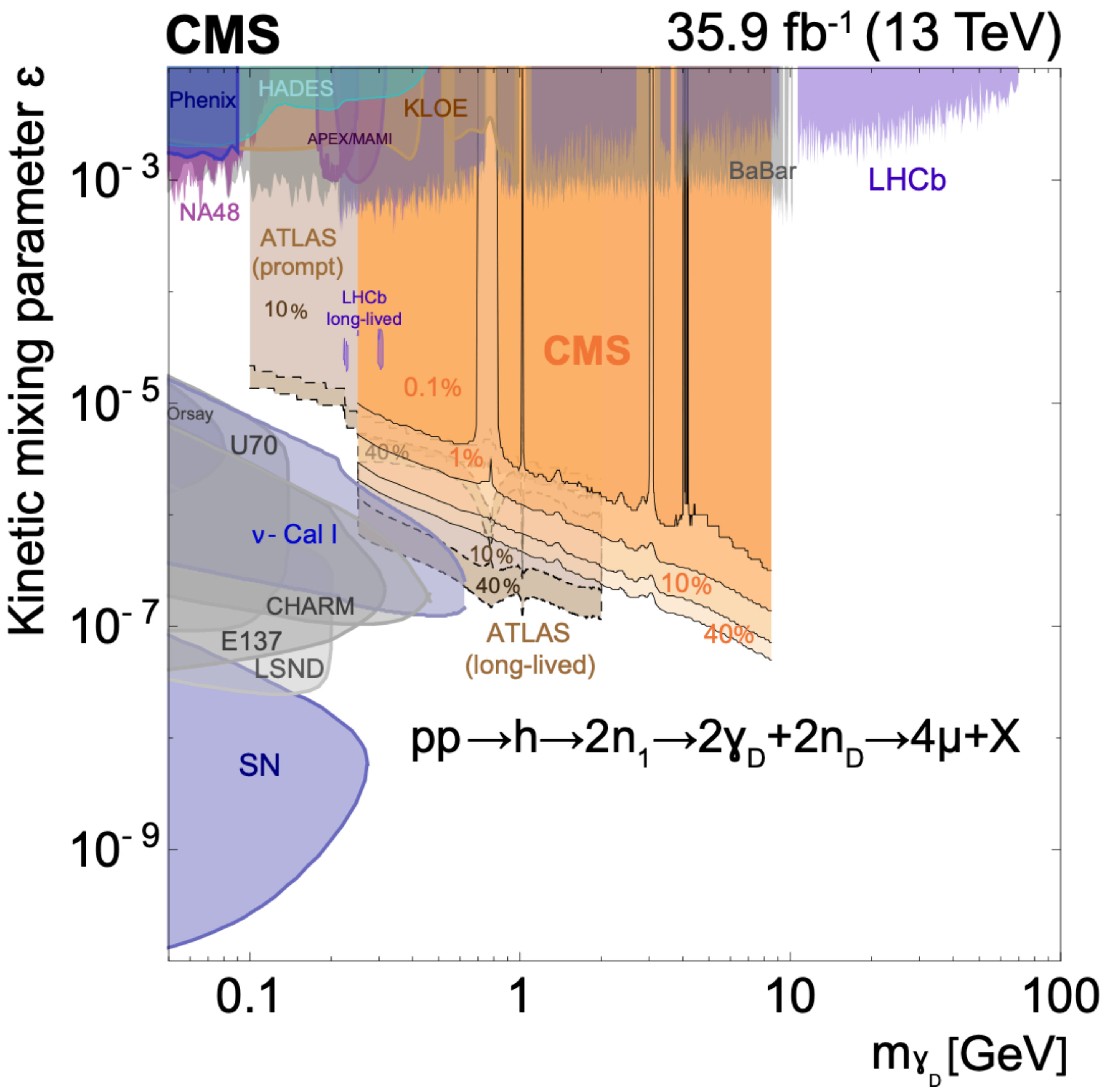
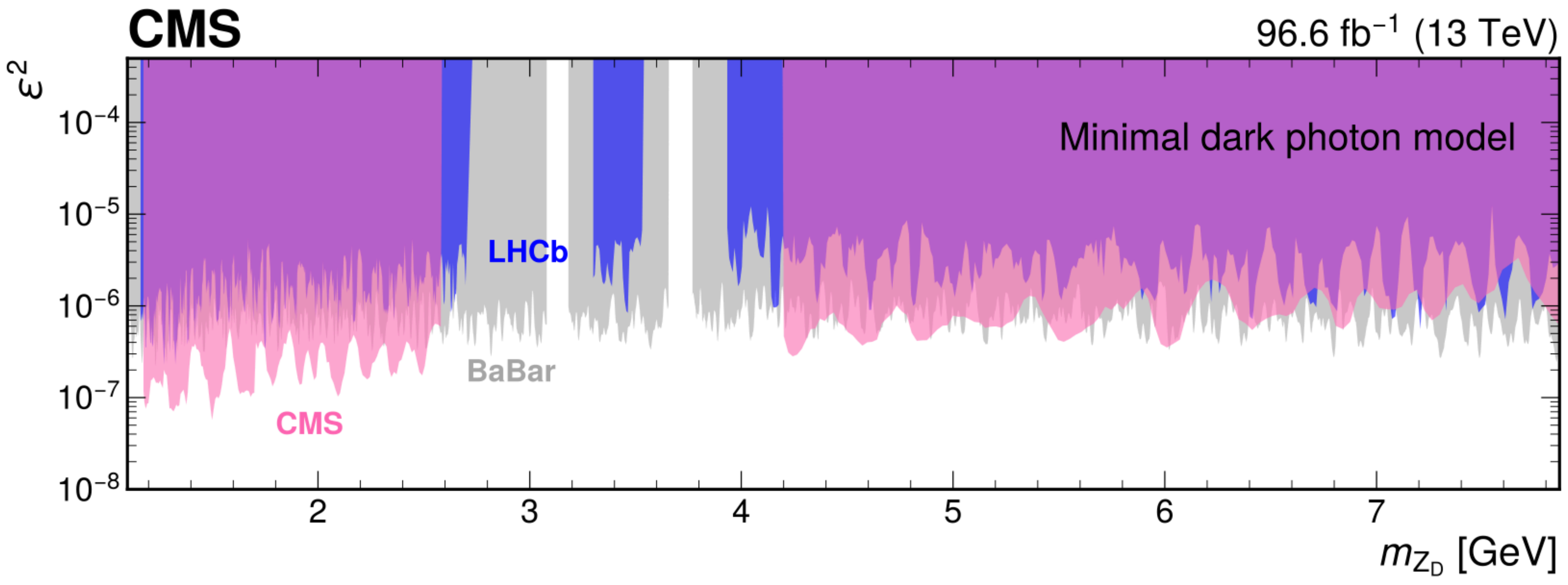
N.B. ATLAS still Run-1 result!



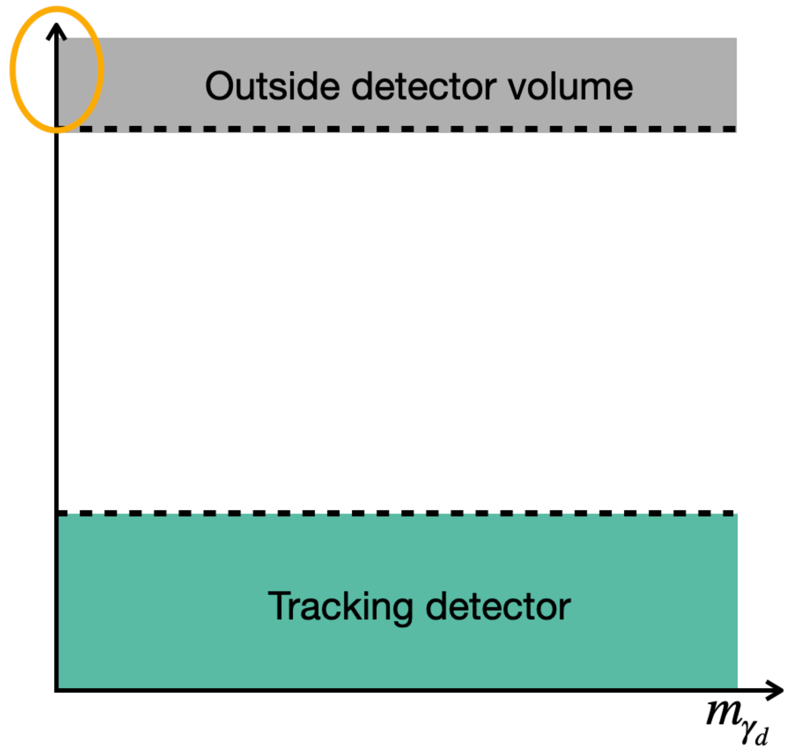
CMS, CERN-EP-2023-165



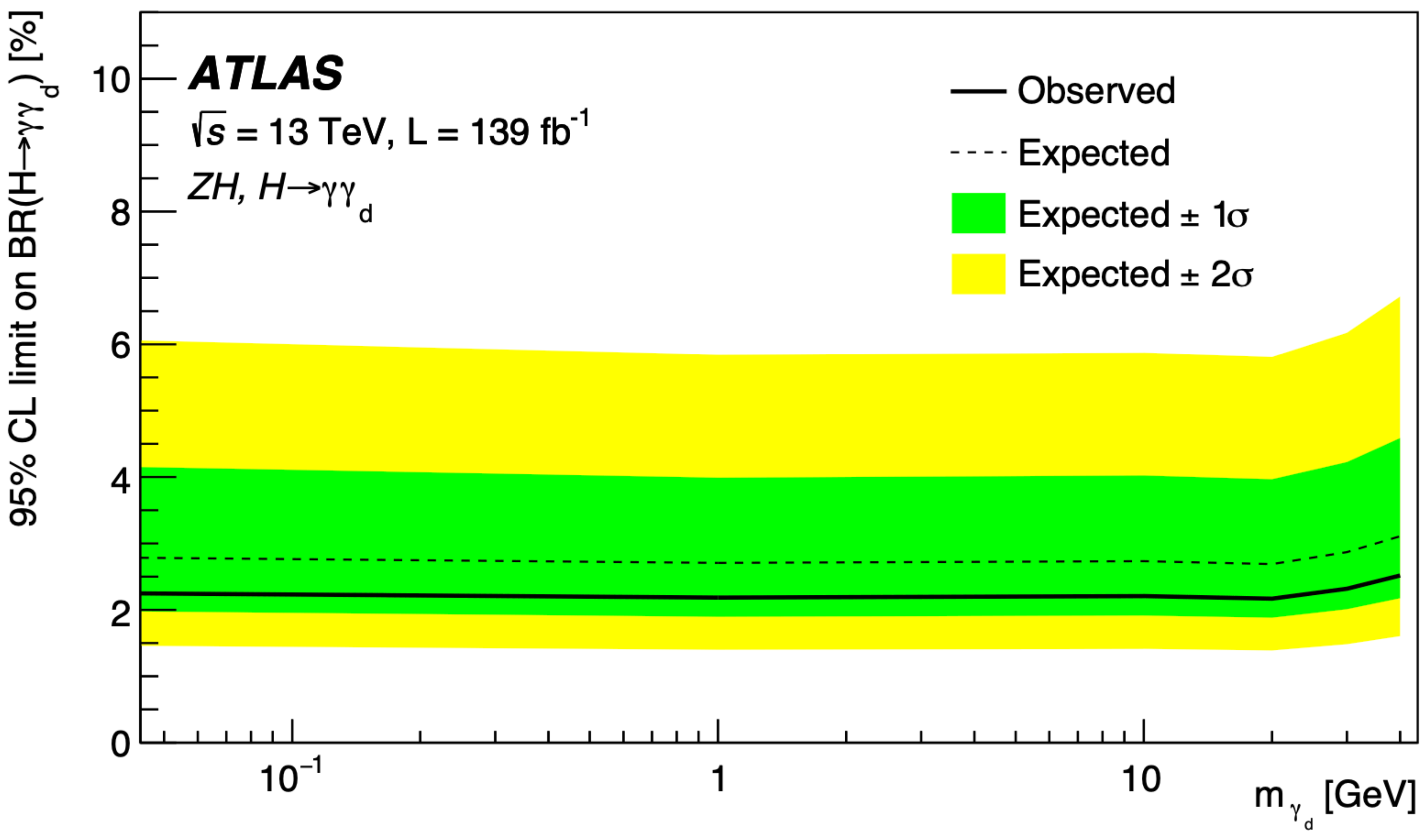
Increase 30% in the limits wrt [PRL124(2020)131802] thanks to BDT!

Invisible γ_d - ZH production mode

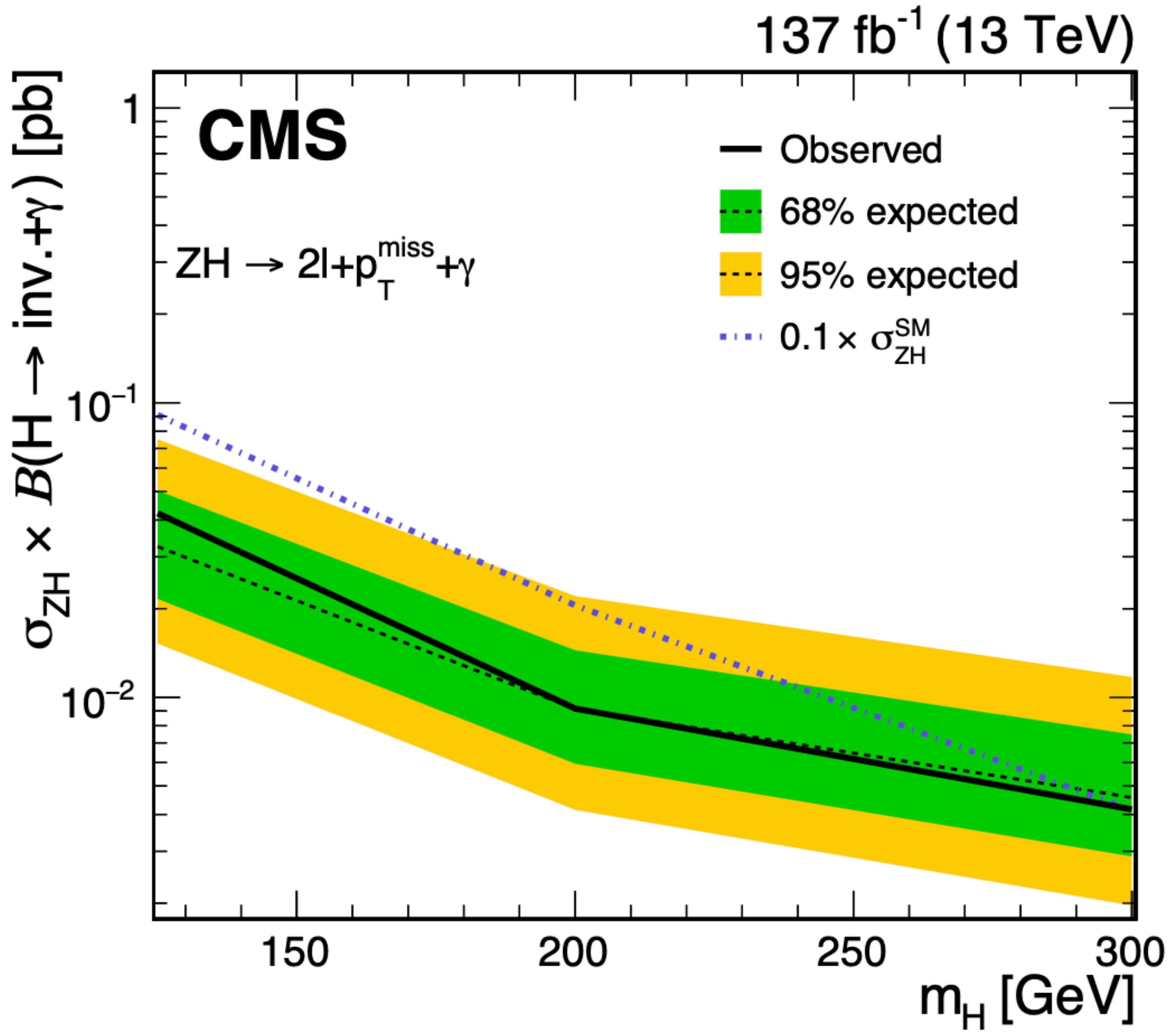
ZH produced Higgs boson + dark photon production = = $\not{E}_T + \gamma$



ATLAS [JHEP07(2023)133]

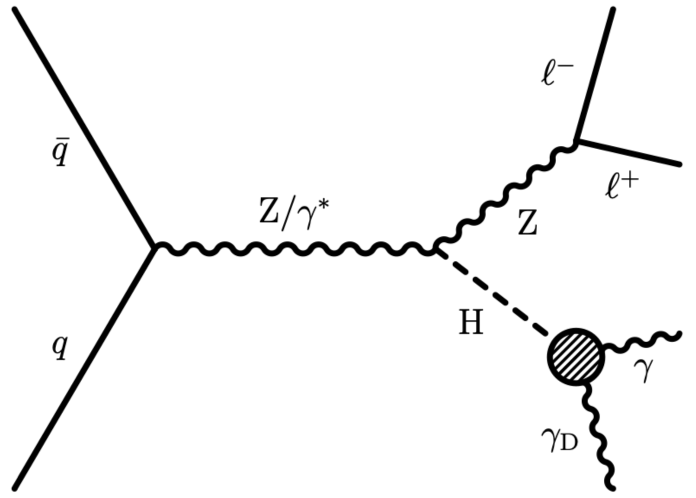


CMS [JHEP10(2019)139]

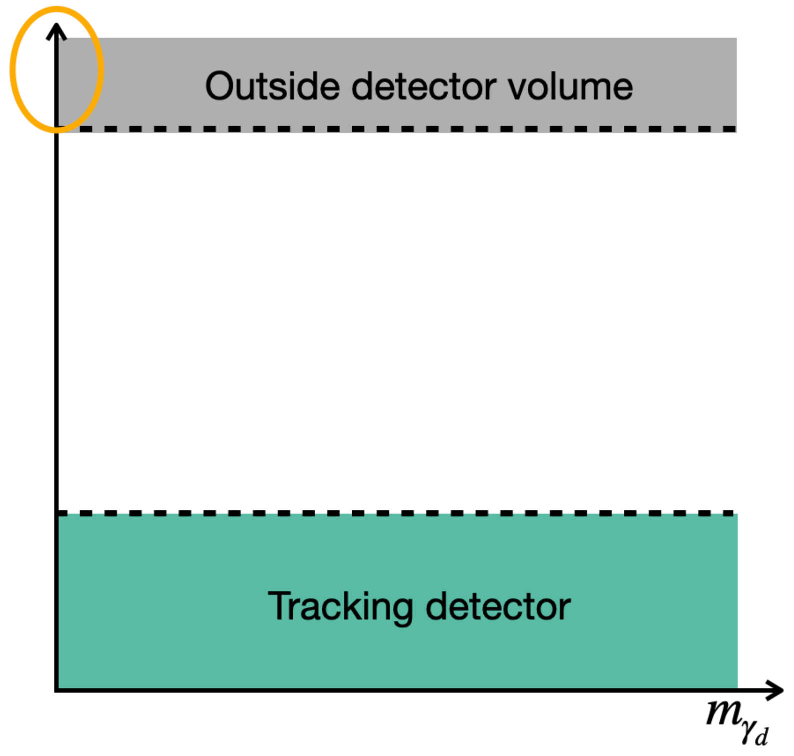


Invisible γ_d - ZH production mode

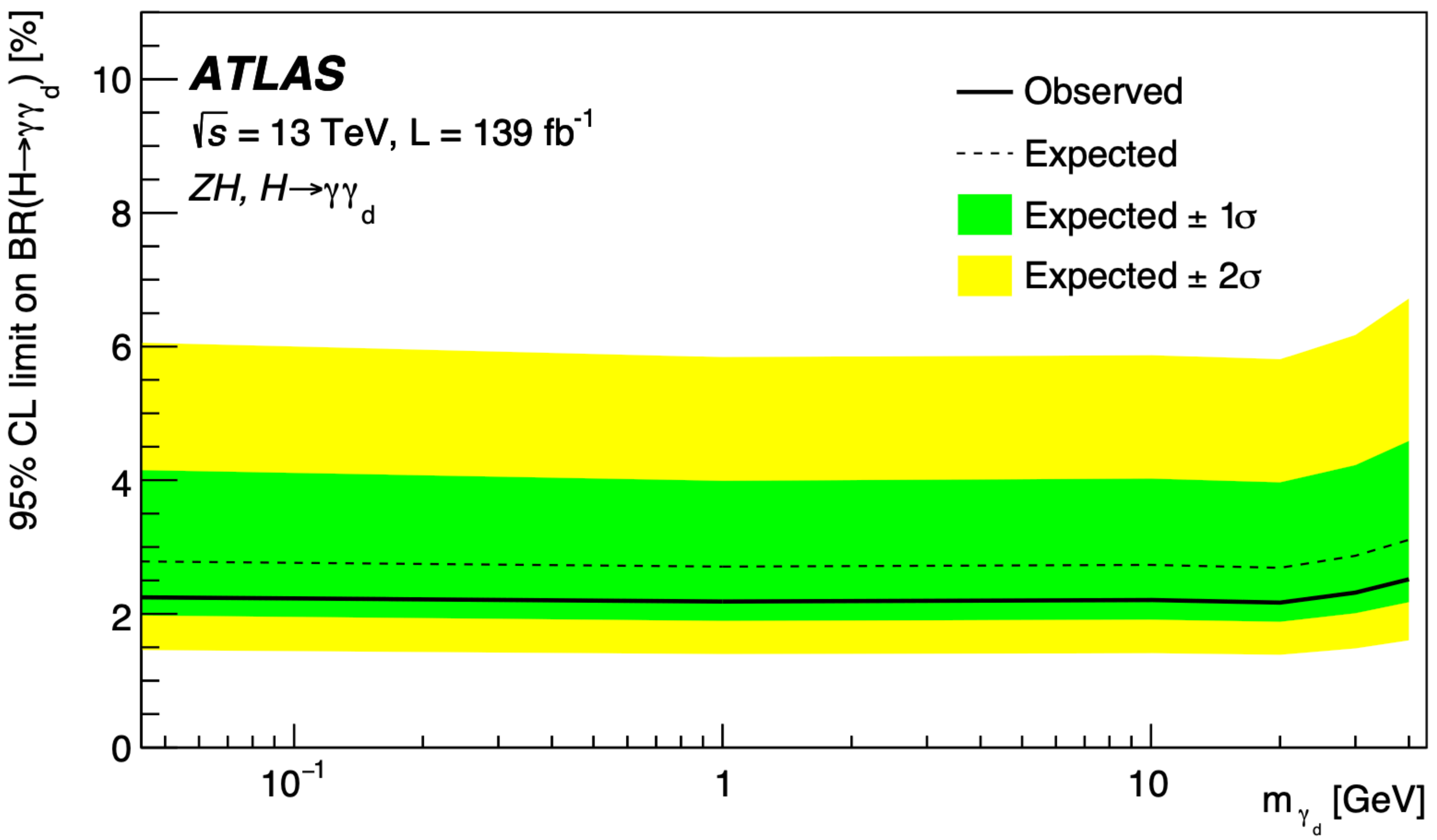
ZH produced Higgs boson + dark photon production =



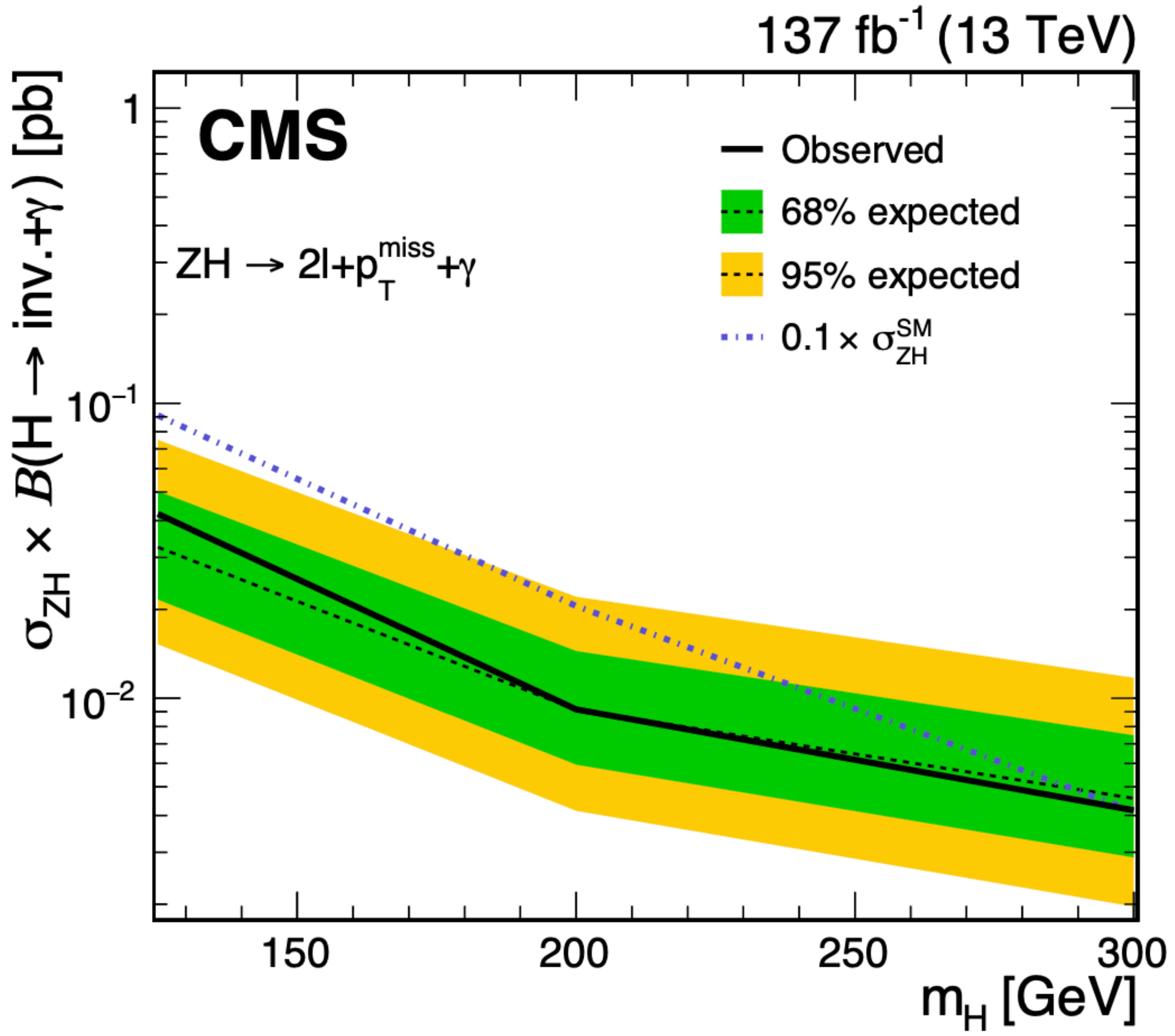
= $E_T\!\!\!\!/ + \gamma$



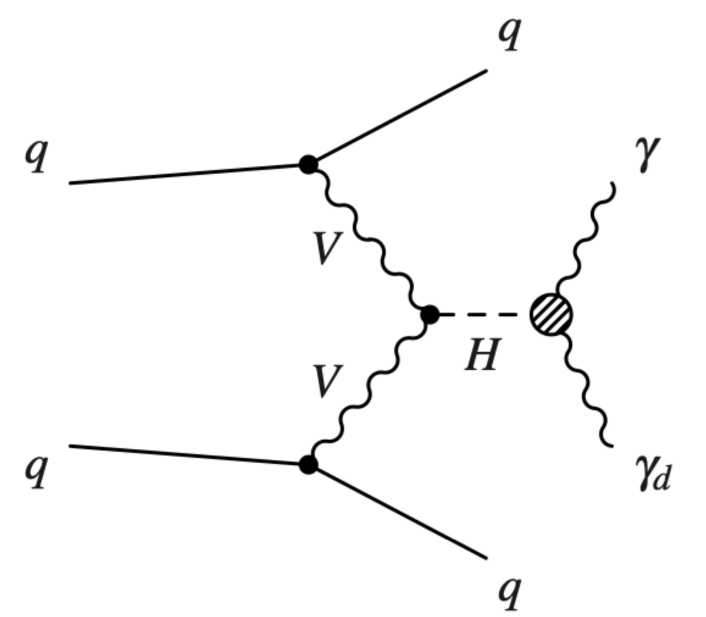
ATLAS [JHEP07(2023)133]

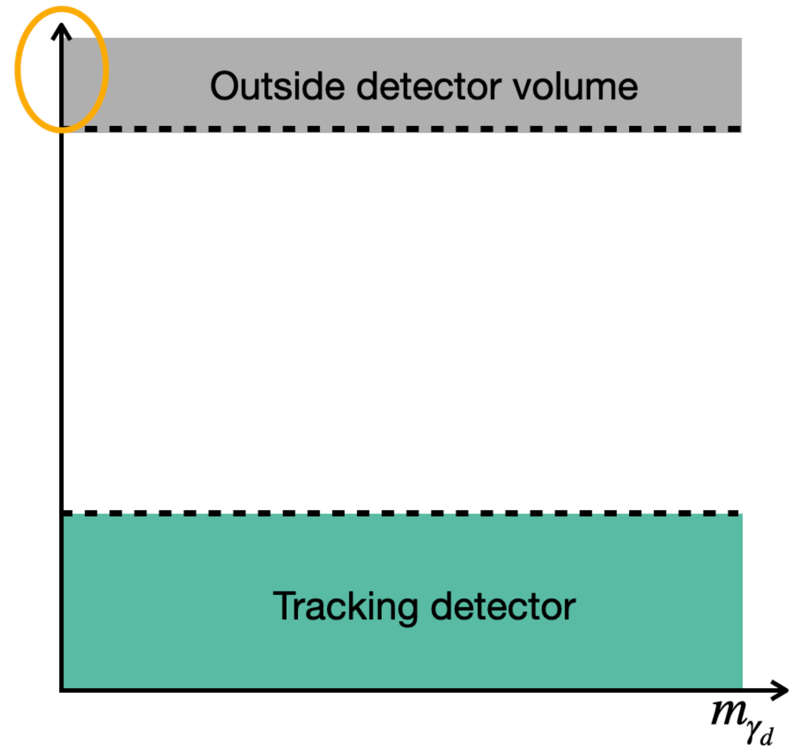


CMS [JHEP10(2019)139]

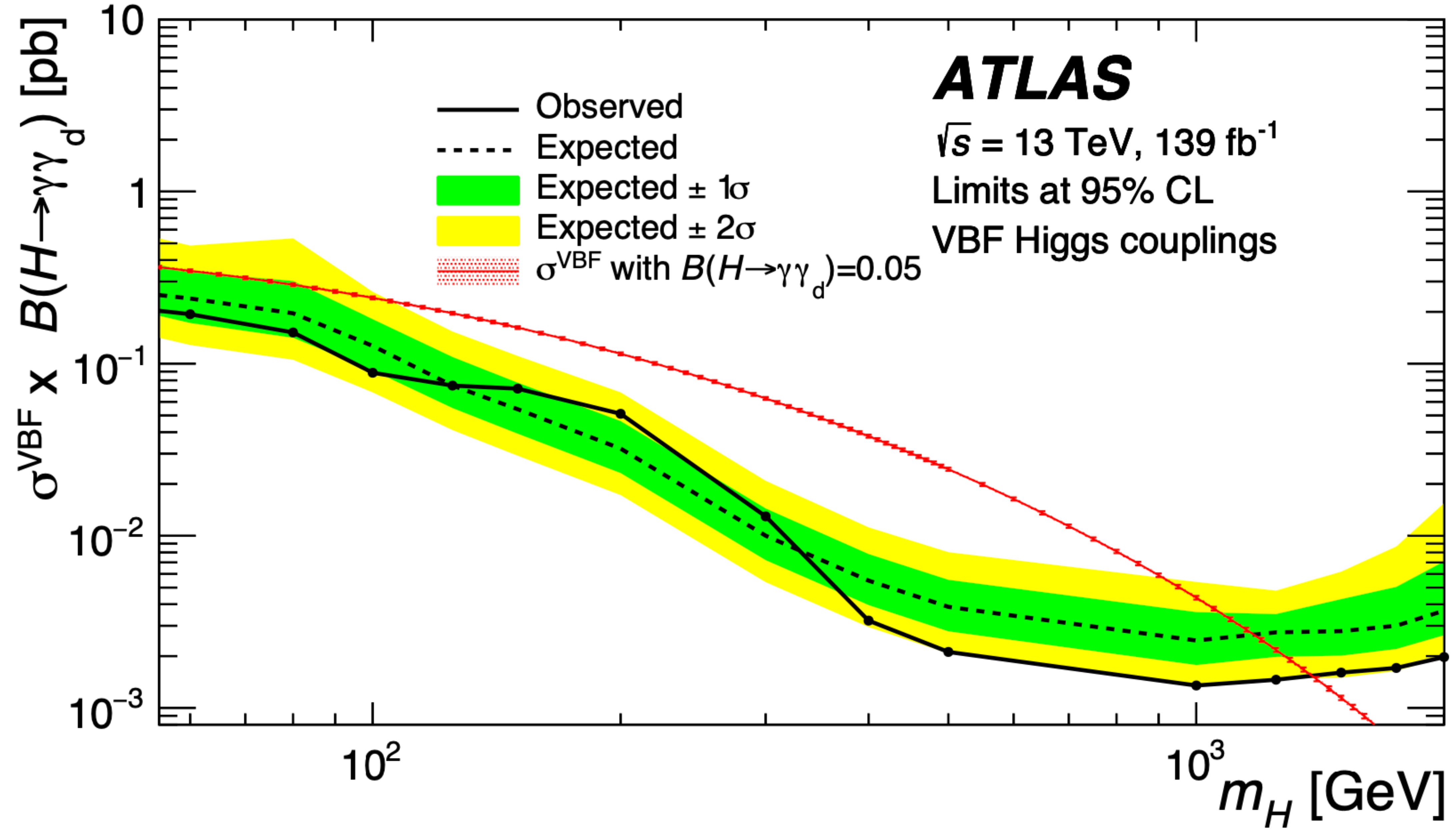


Invisible γ_d - VBF production mode

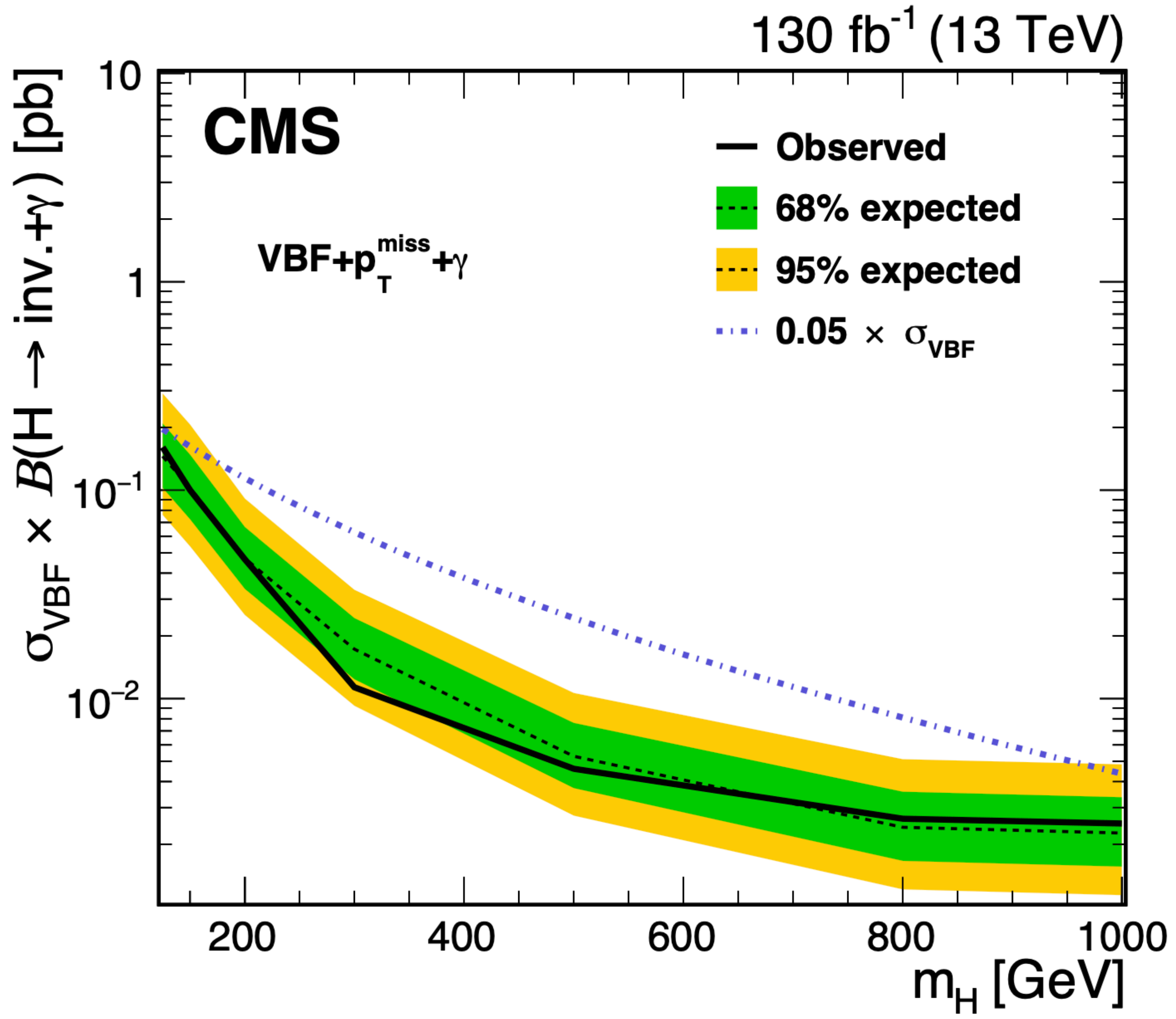
VBF produced Higgs boson + dark photon production =  = $\not{E}_T + \gamma$



ATLAS [EPJC82(2022)105]

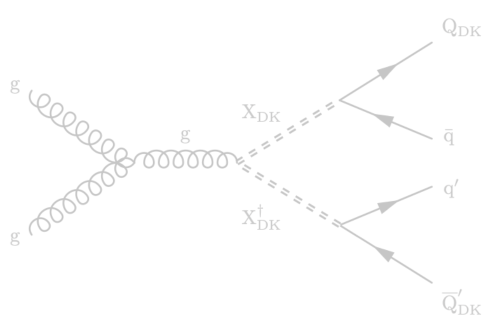


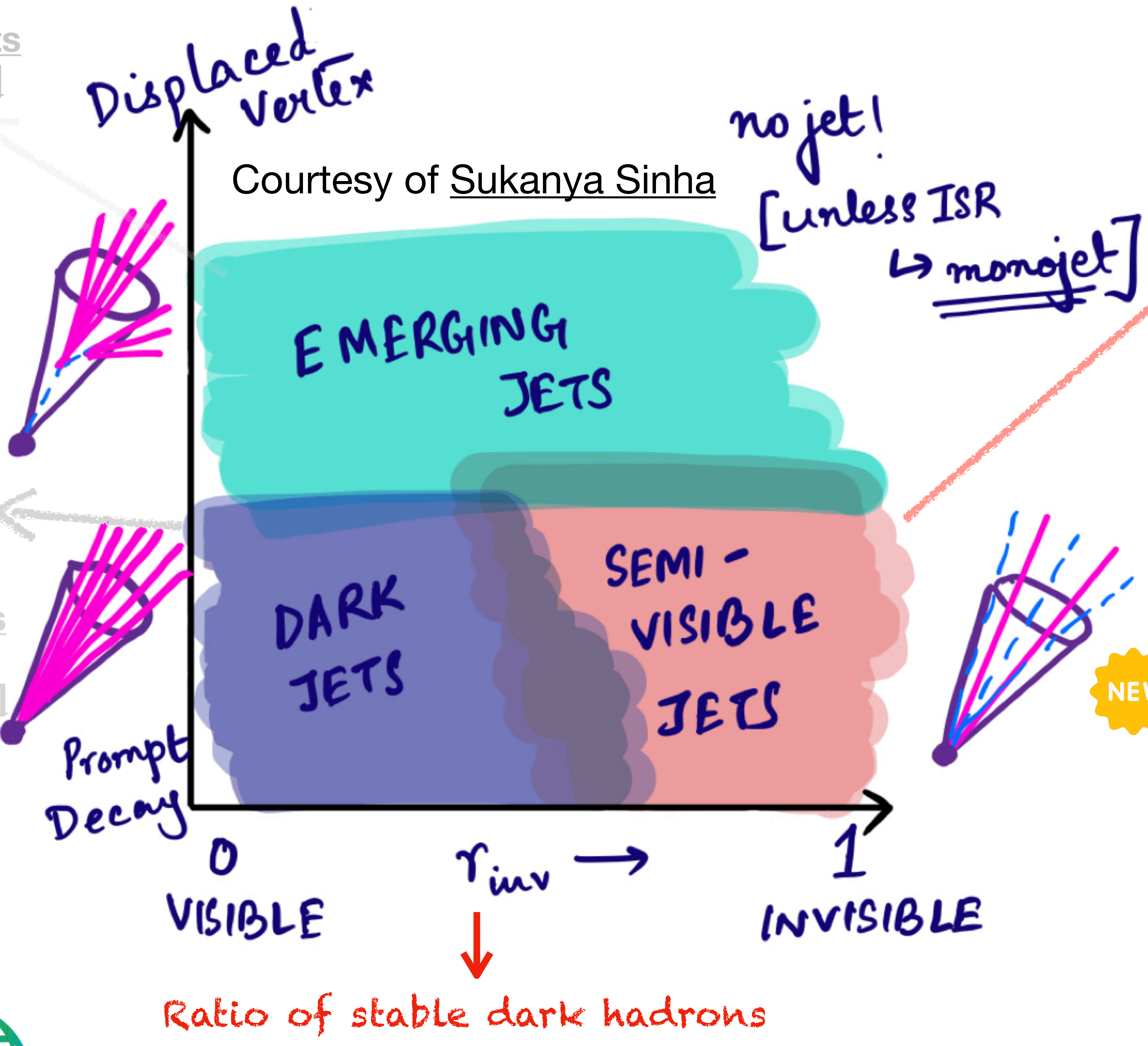
CMS [JHEP03(2021)011] + combination



Dark QCD searches covered here

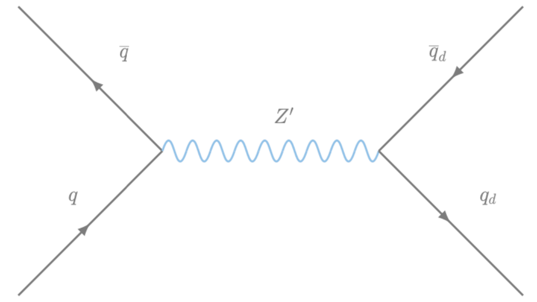
CMS, emerging jets
[JHEP02(2019)179]



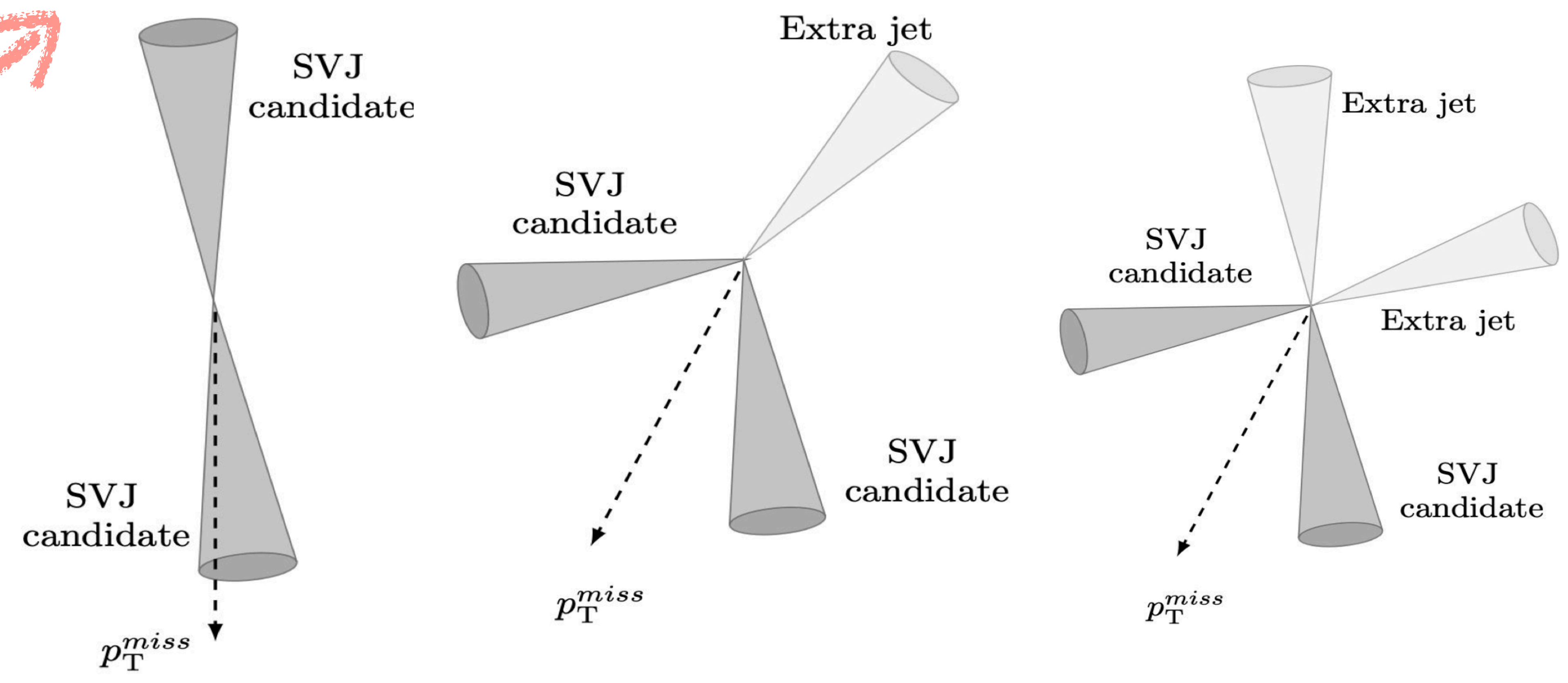


Di-jet (wide jets) signature:

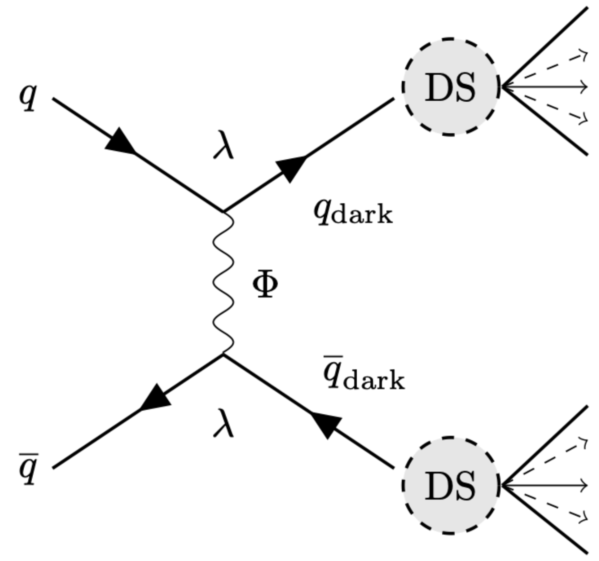
NEW ATLAS, dark jets
[ATLAS-CONF-2023-047]



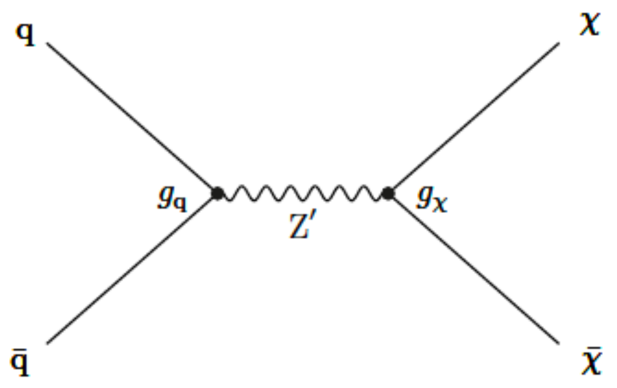
Jets and p_T^{miss}:



NEW ATLAS, t-channel
[CERN-EP-2023-084]

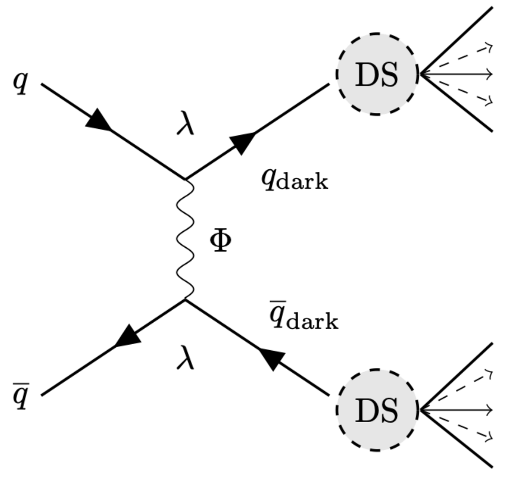


CMS, s-channel
[JHEP06(2022)156]

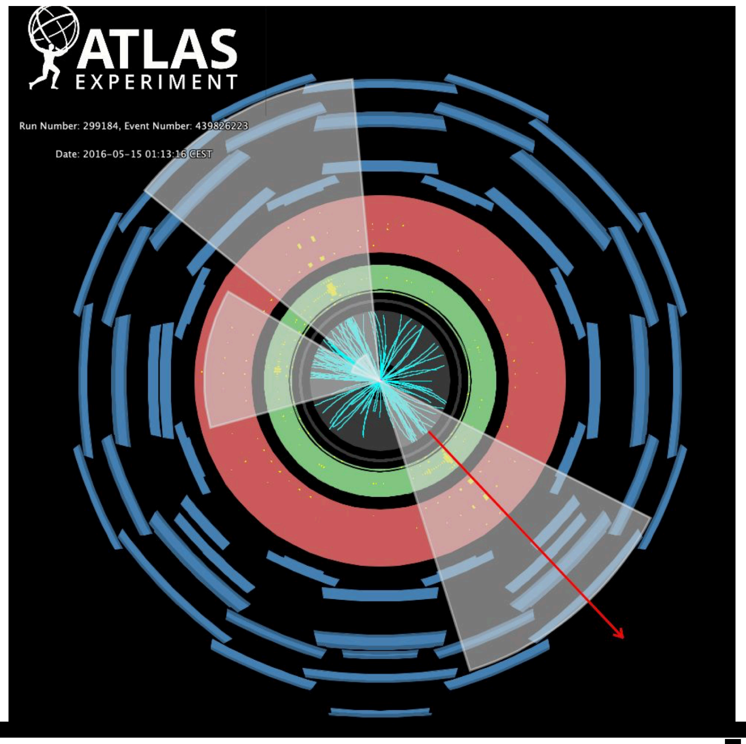


Semi-visible jets

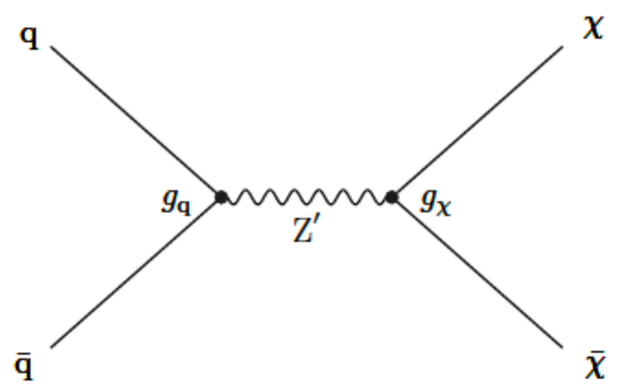
Sensitive to:
- m_Φ
- r_{inv}
- m_D
- λ (coupling strength)



NEW **ATLAS, t-channel [CERN-EP-2023-084]**



Sensitive to:
- $m_{Z'}$
- r_{inv}
- m_D
- α_D (running coupling of dark QCD)



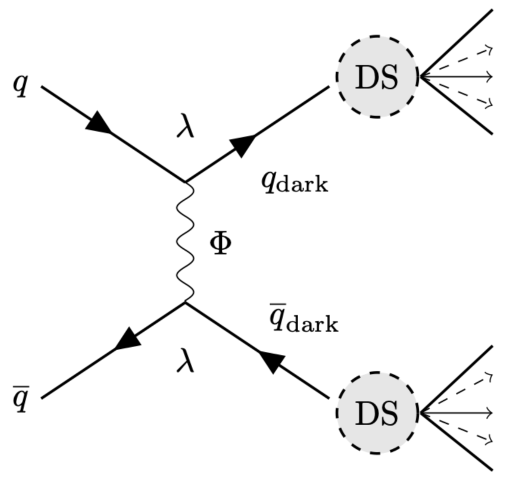
→ Both di-jet events with high E_T^{miss} close-by to jets

CMS, s-channel [JHEP06(2022)156]

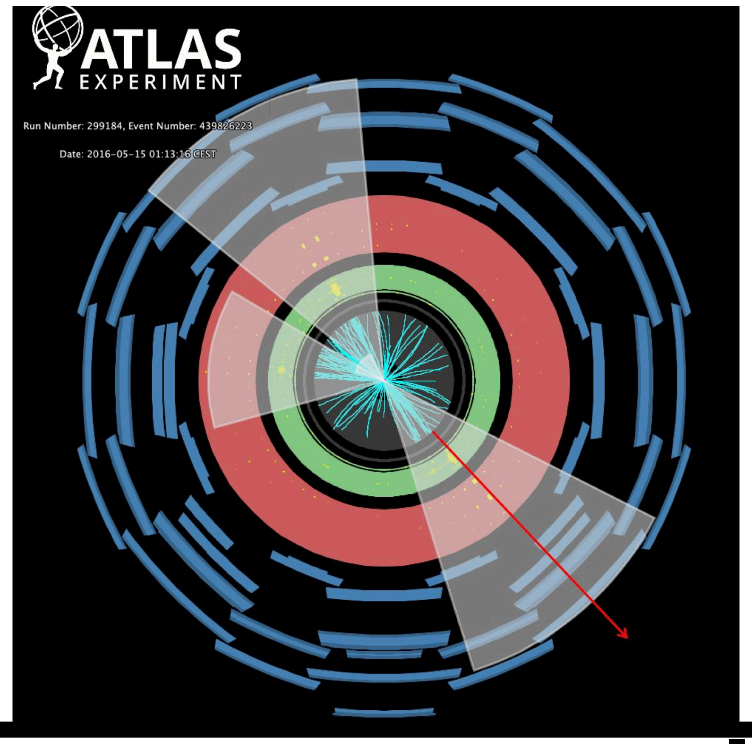
Semi-visible jets

Sensitive to:

- m_{Φ}
- r_{inv}
- m_D
- λ (coupling strength)

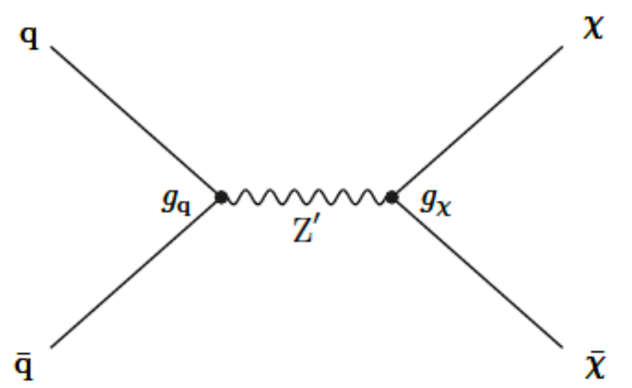


NEW **ATLAS, t-channel [CERN-EP-2023-084]**



Sensitive to:

- $m_{Z'}$
- r_{inv}
- m_D
- α_D (running coupling of dark QCD)

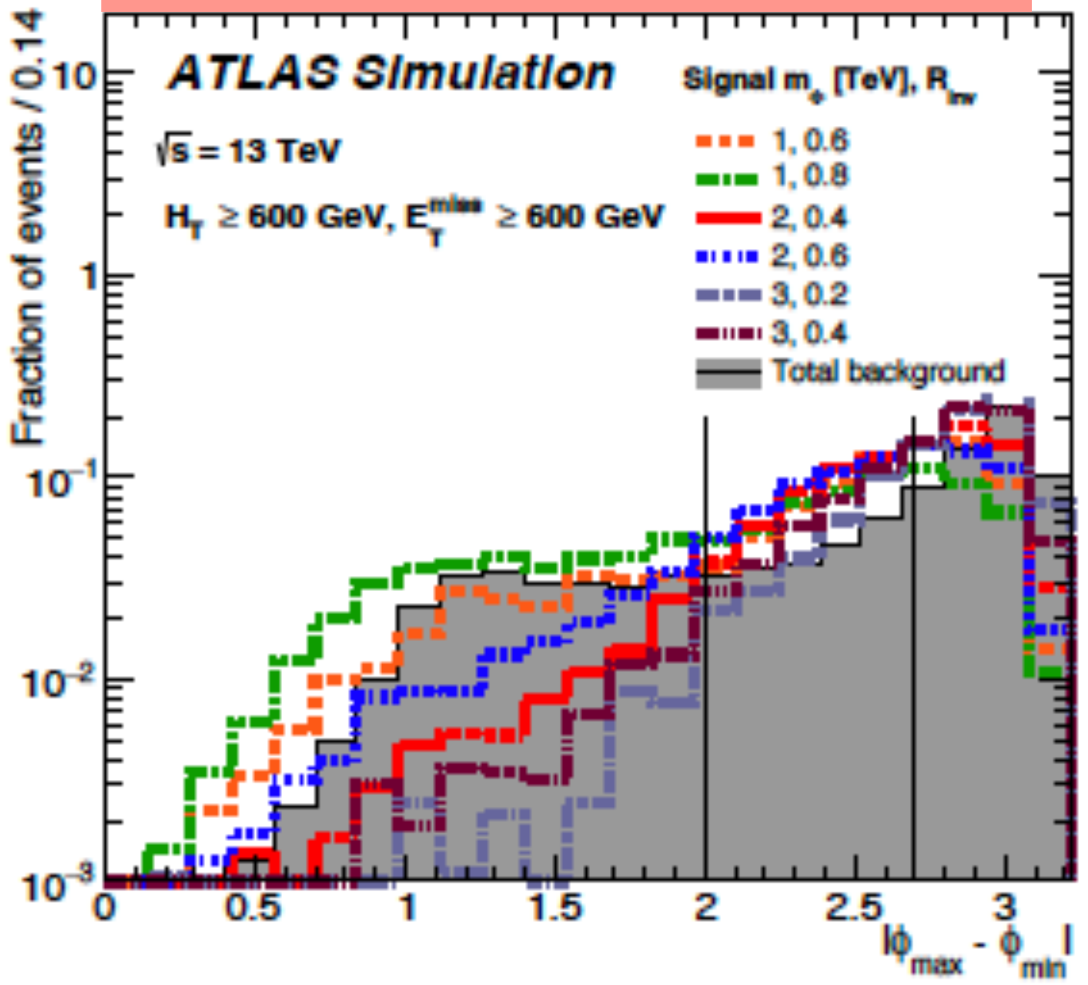


→ Both di-jet events with high E_T^{miss} close-by to jets

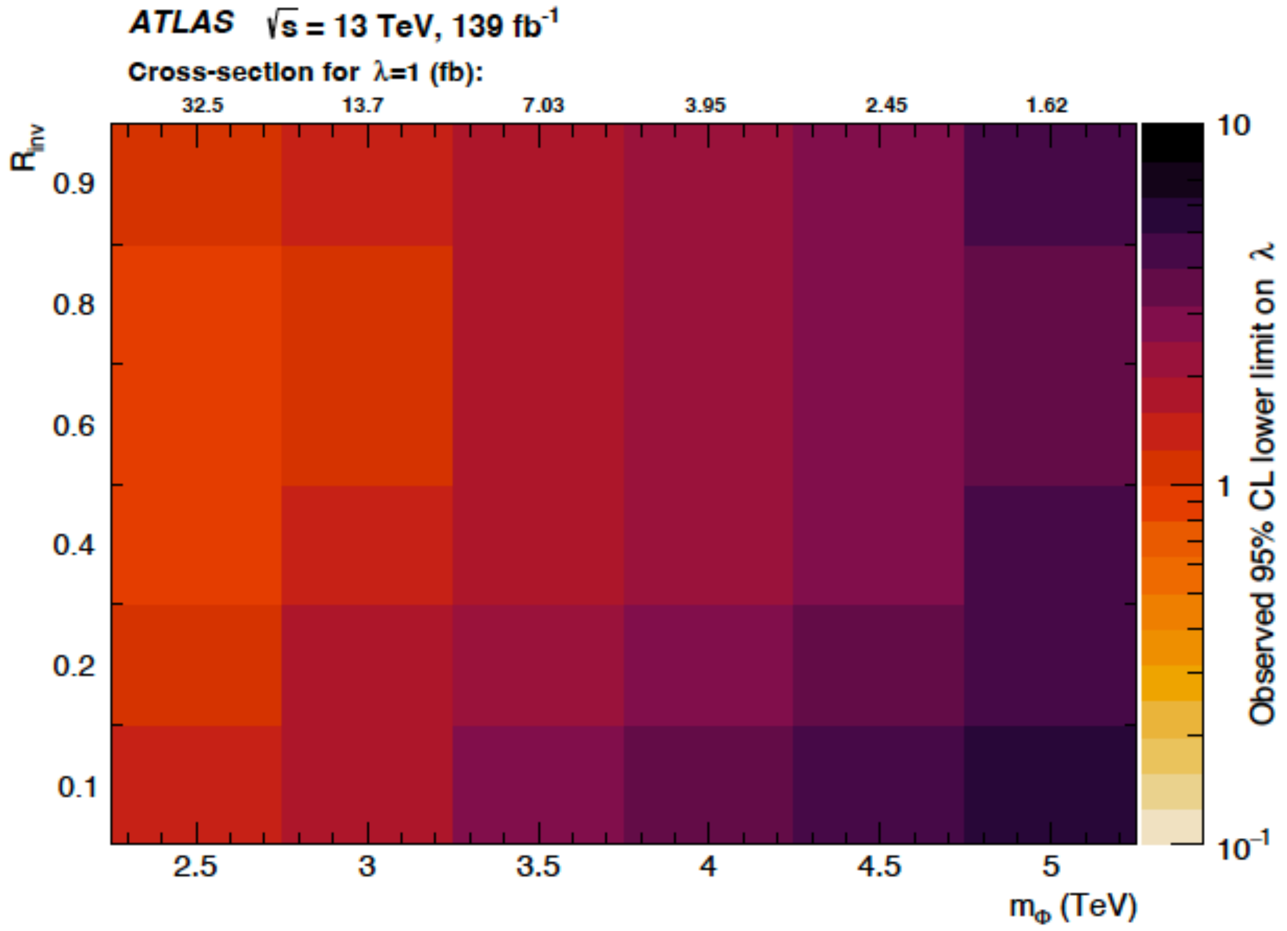
CMS, s-channel [JHEP06(2022)156]

E_T^{miss} trigger, background estimated via CRs enriched in different type of bkgs

Jets angular separation



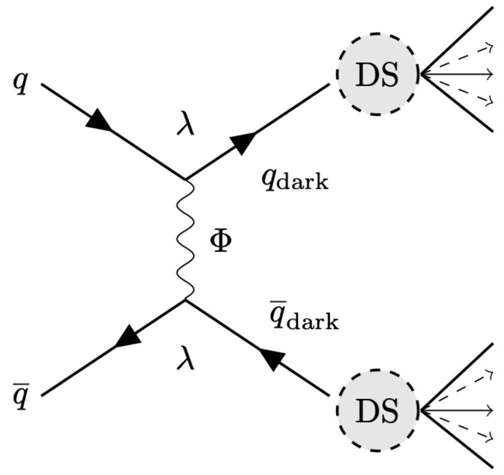
Limits on xSec



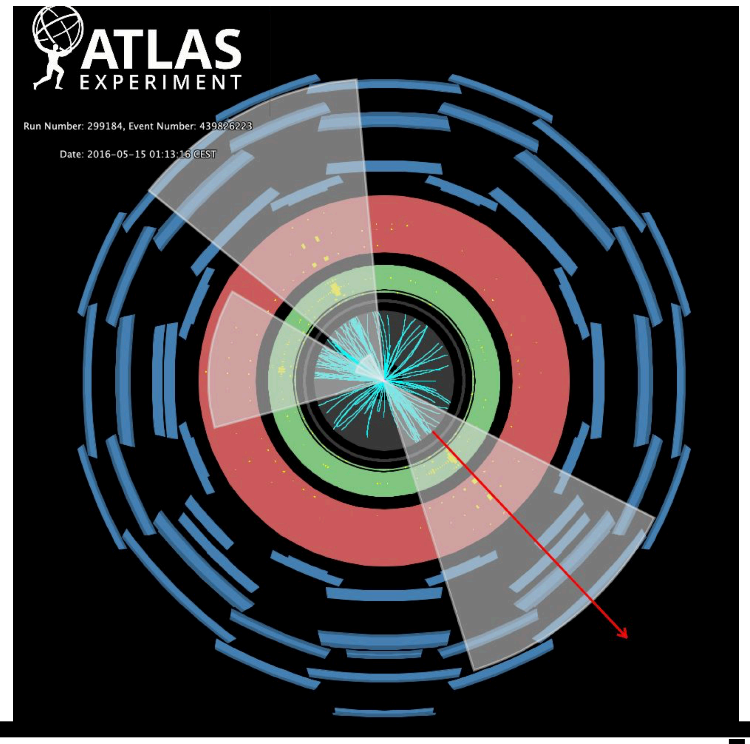
Semi-visible jets

Sensitive to:

- m_Φ
- r_{inv}
- m_D
- λ (coupling strength)

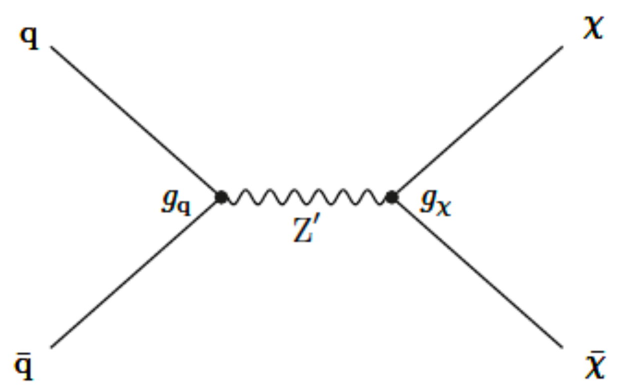


NEW **ATLAS, t-channel [CERN-EP-2023-084]**



Sensitive to:

- $m_{Z'}$
- r_{inv}
- m_D
- α_D (running coupling of dark QCD)

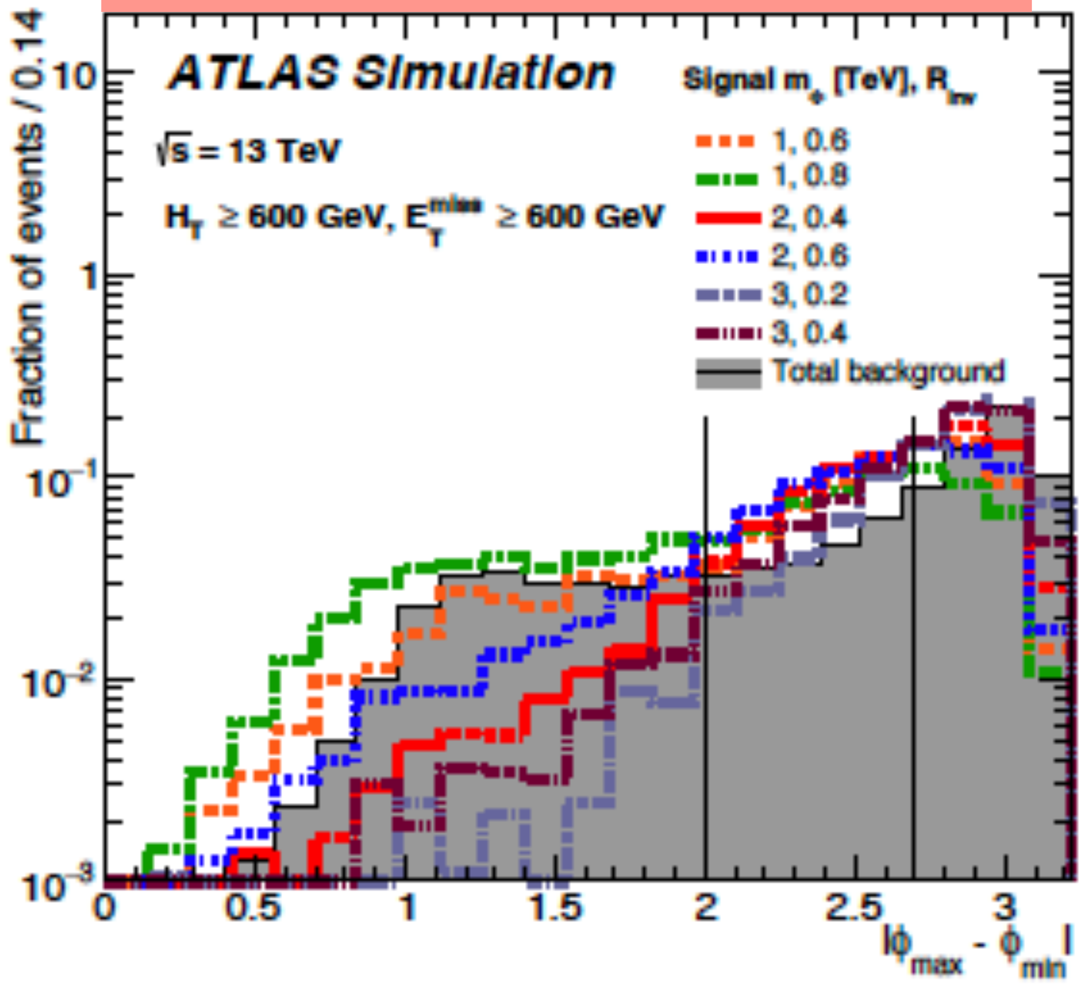


→ Both di-jet events with high E_T^{miss} close-by to jets

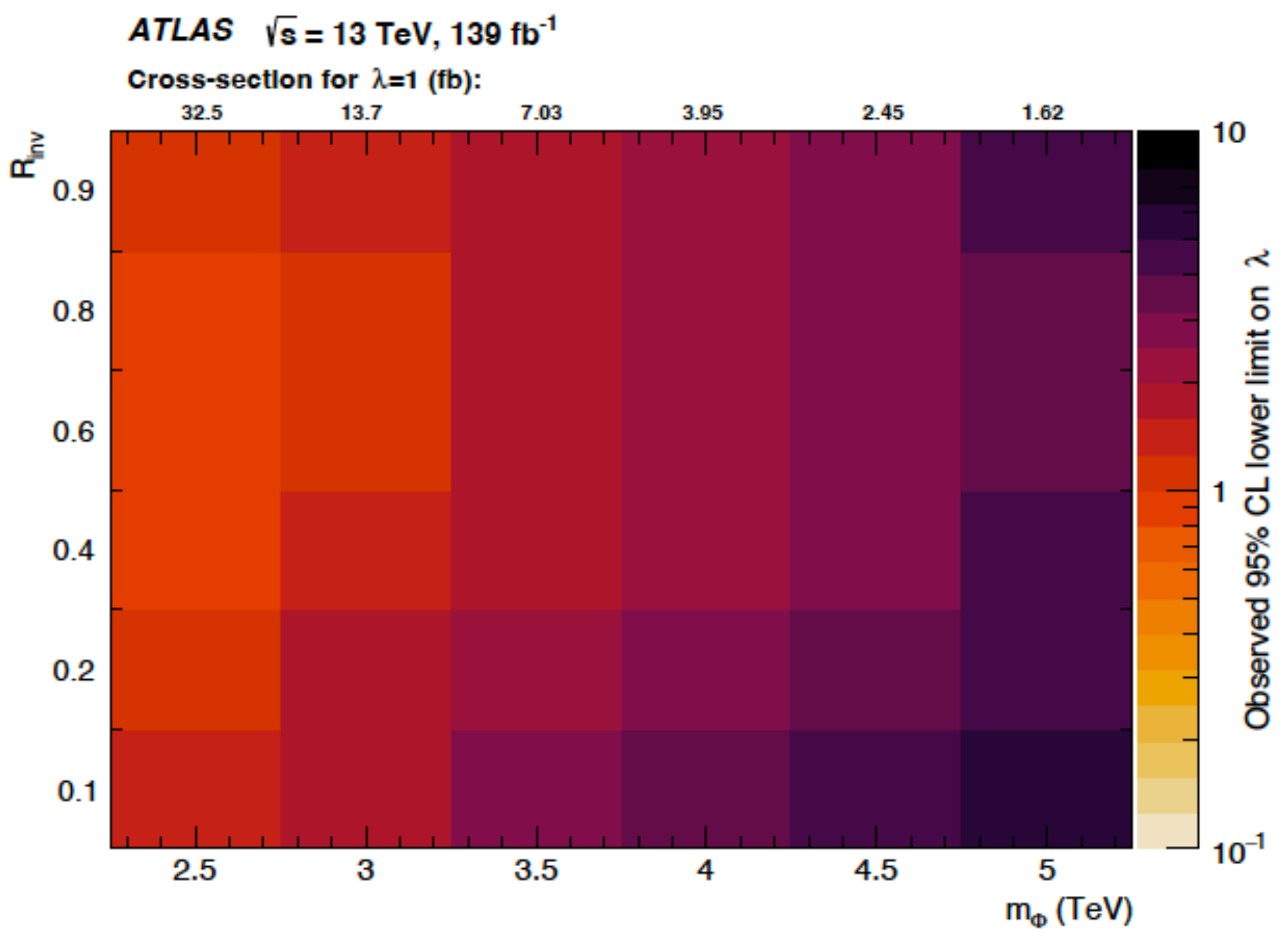
CMS, s-channel [JHEP06(2022)156]

E_T^{miss} trigger, background estimated via CRs enriched in different type of bkgs

Jets angular separation

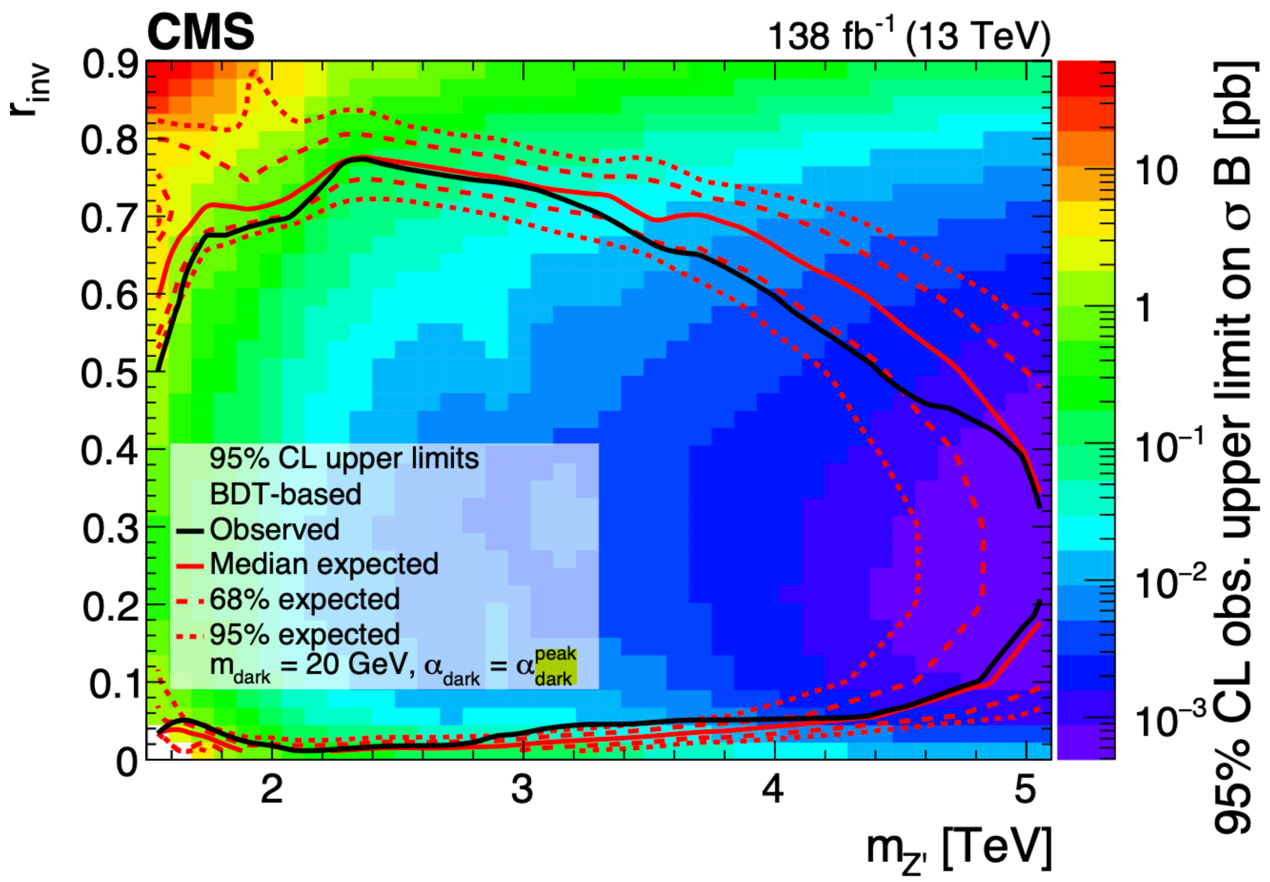


Limits on xSec

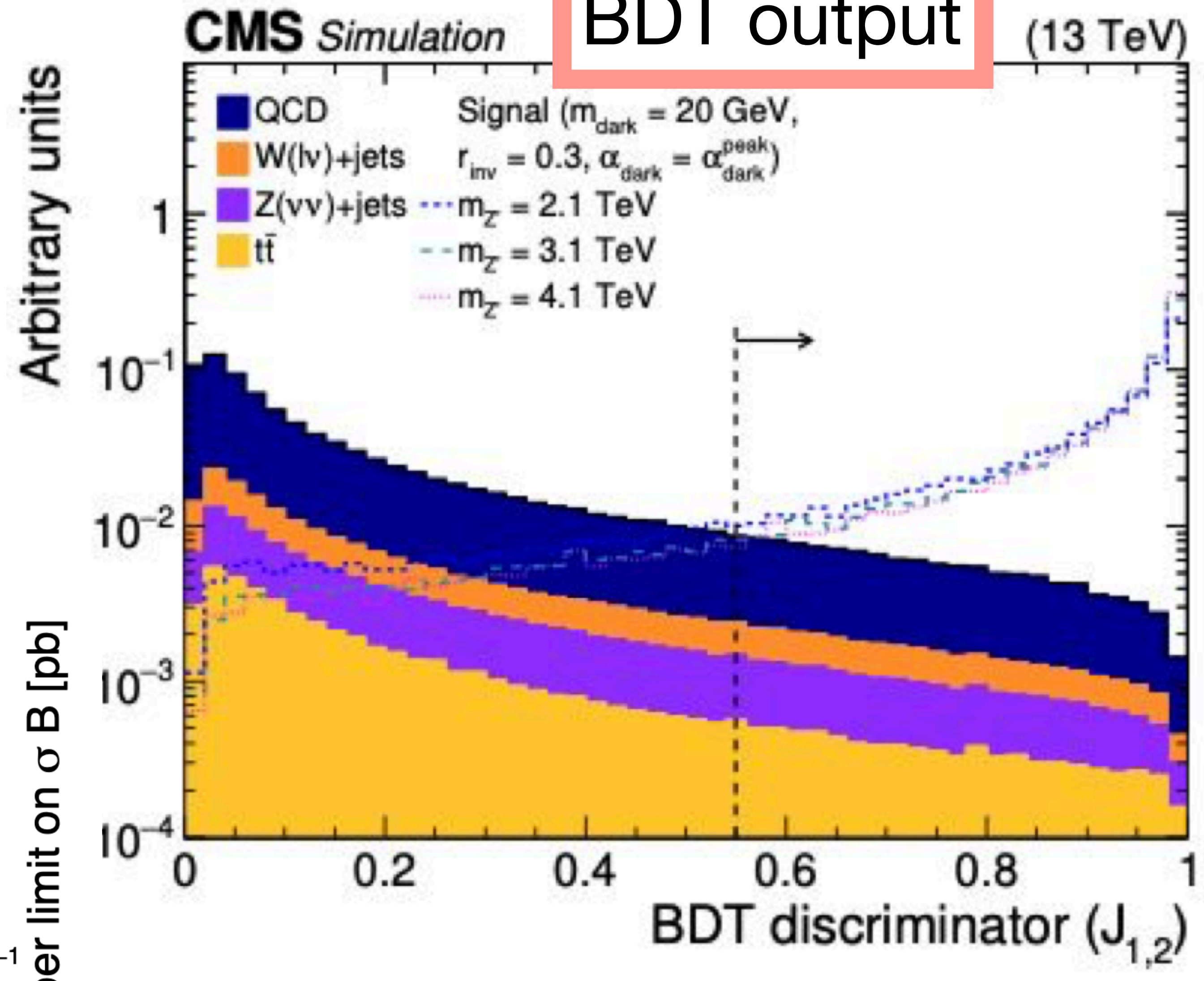


Use BDT discriminant (based on jets substructure)

Limits on xSec

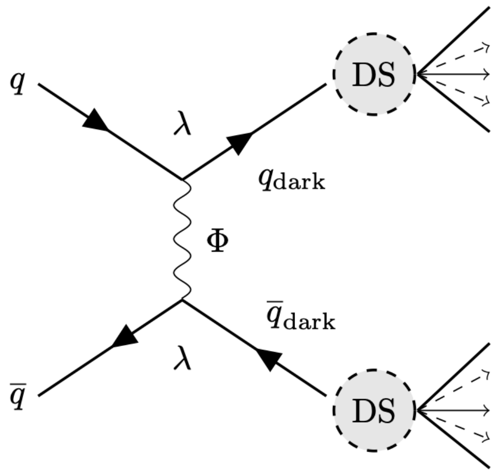


BDT output

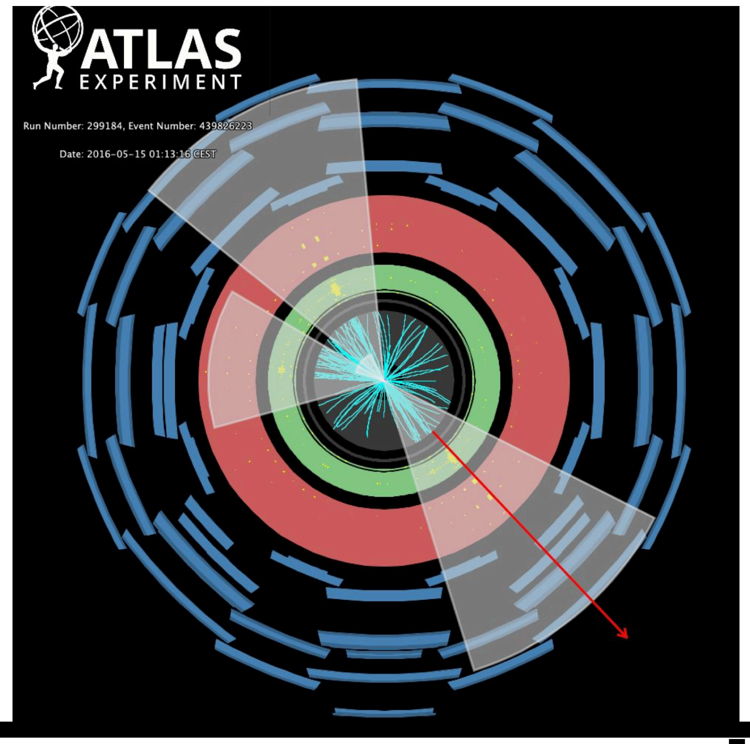


Semi-visible jets

Sensitive to:
- m_Φ
- r_{inv}
- m_D
- λ (coupling strength)



NEW **ATLAS, t-channel [CERN-EP-2023-084]**



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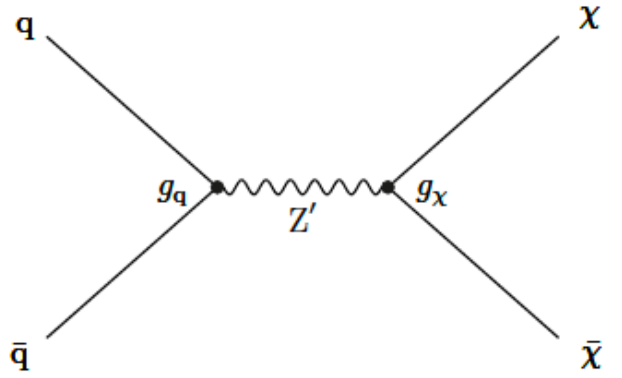

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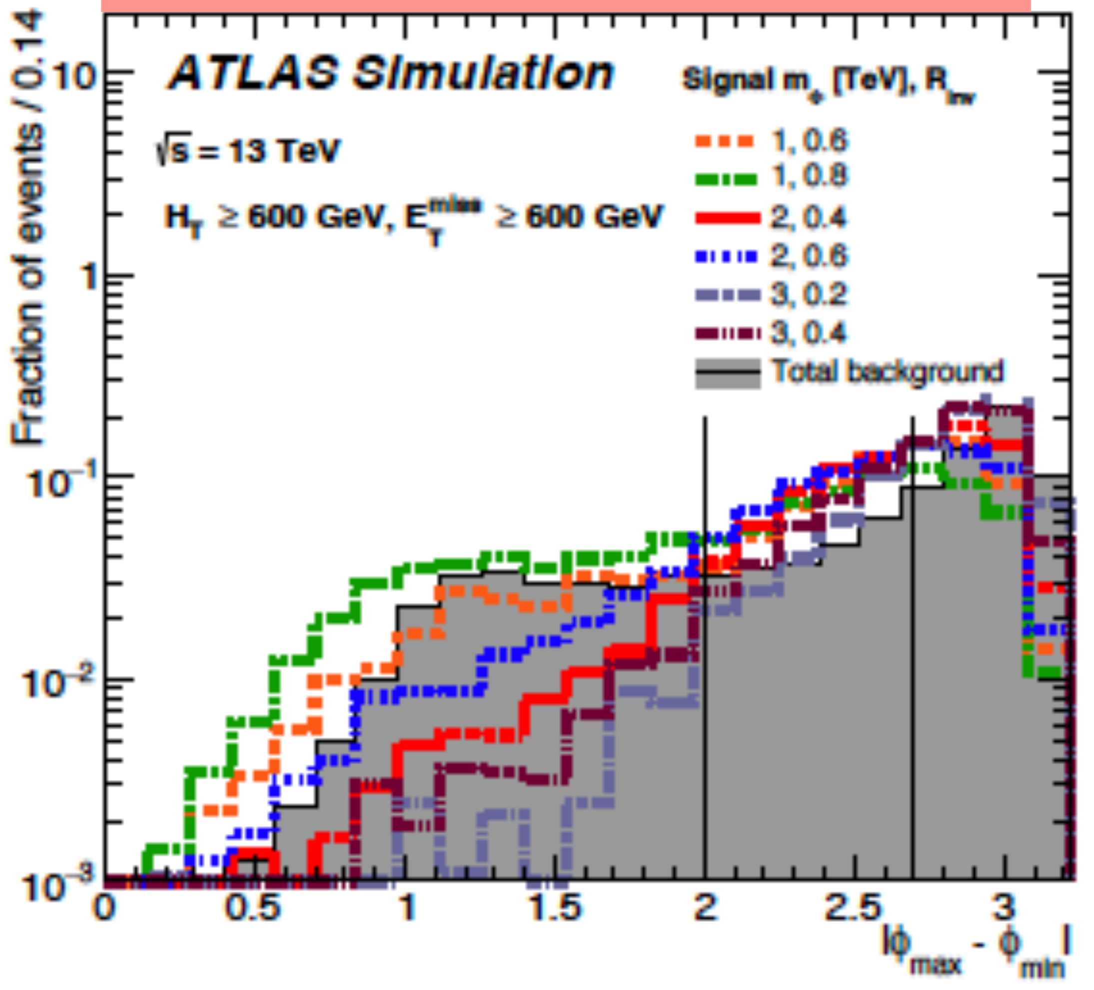
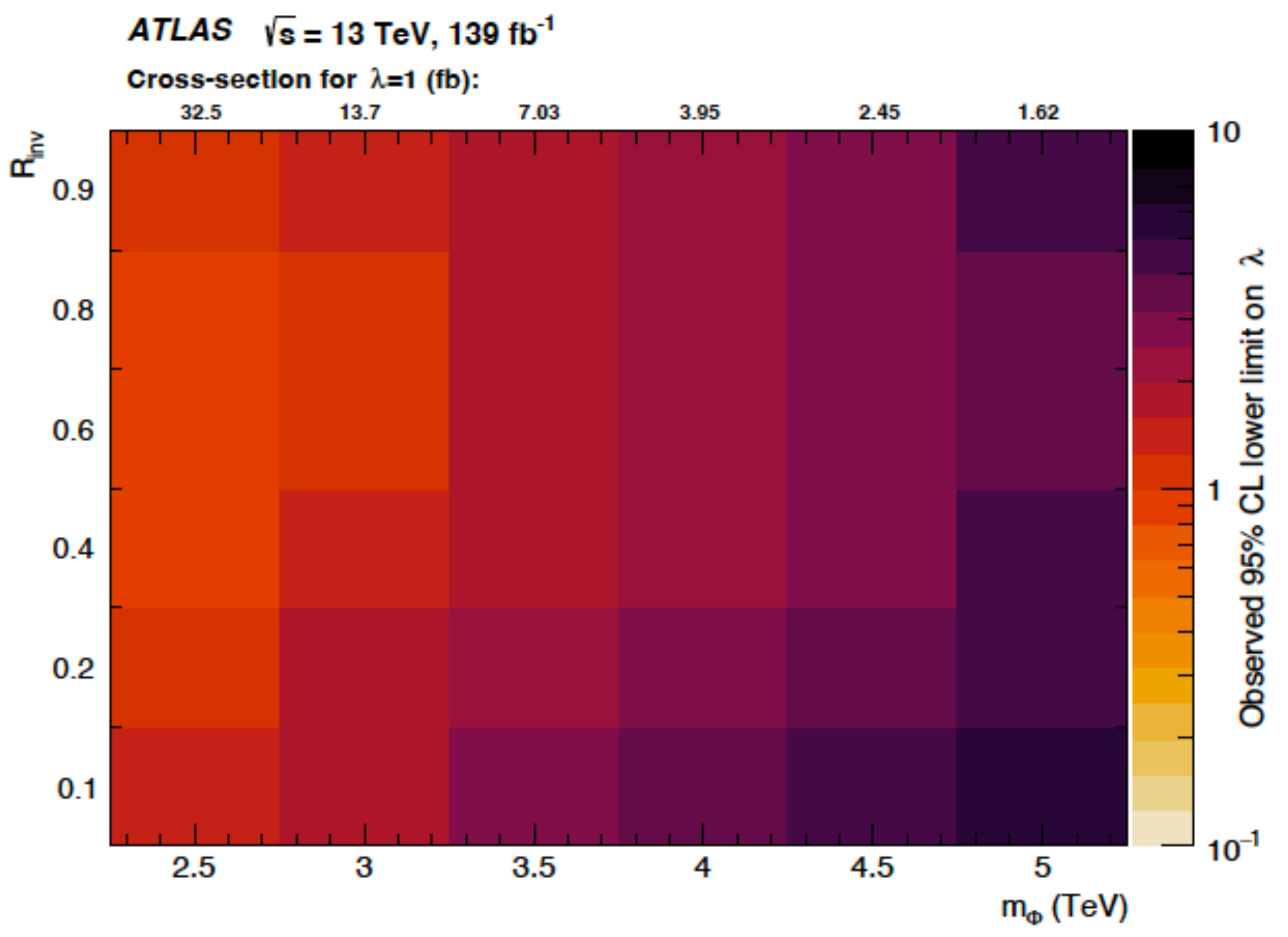


Limits on xSec



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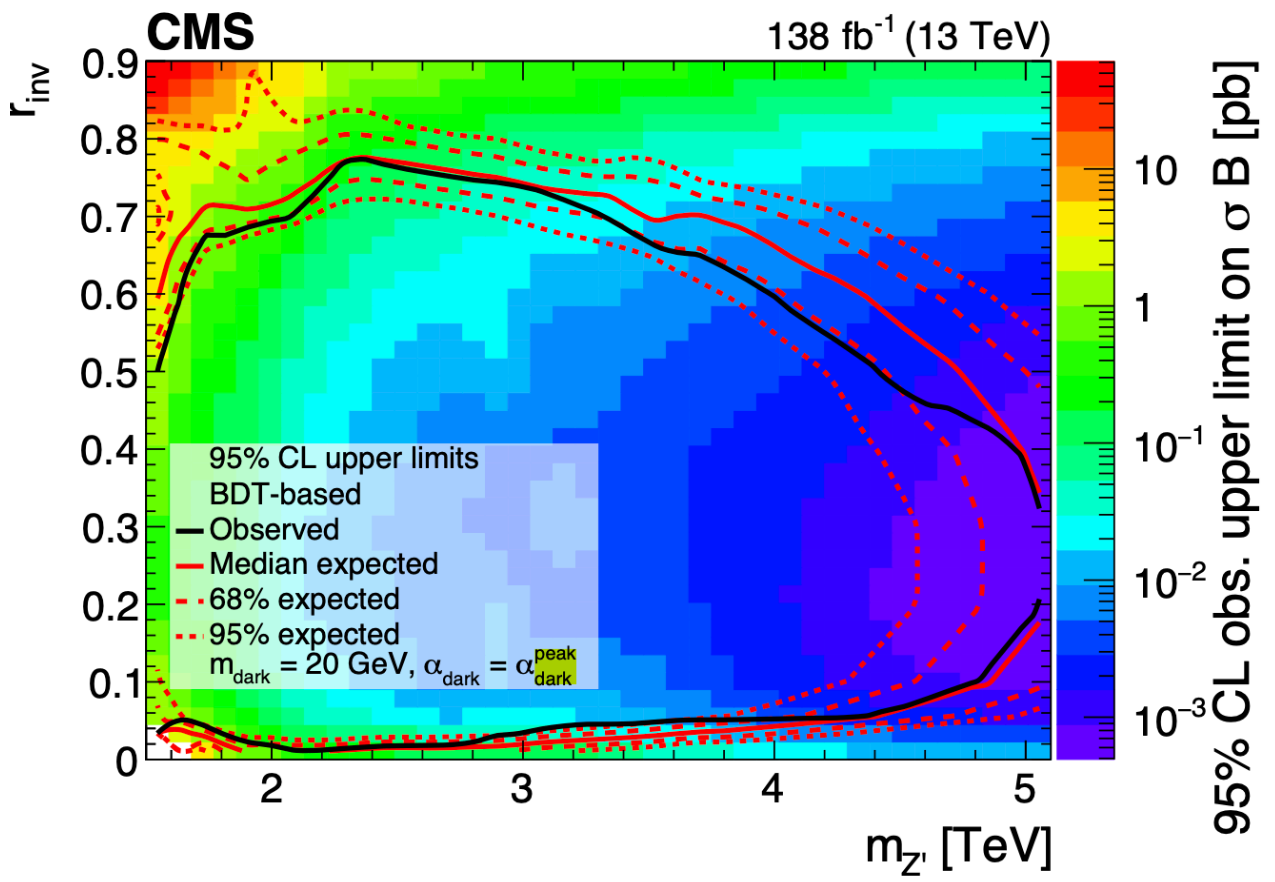

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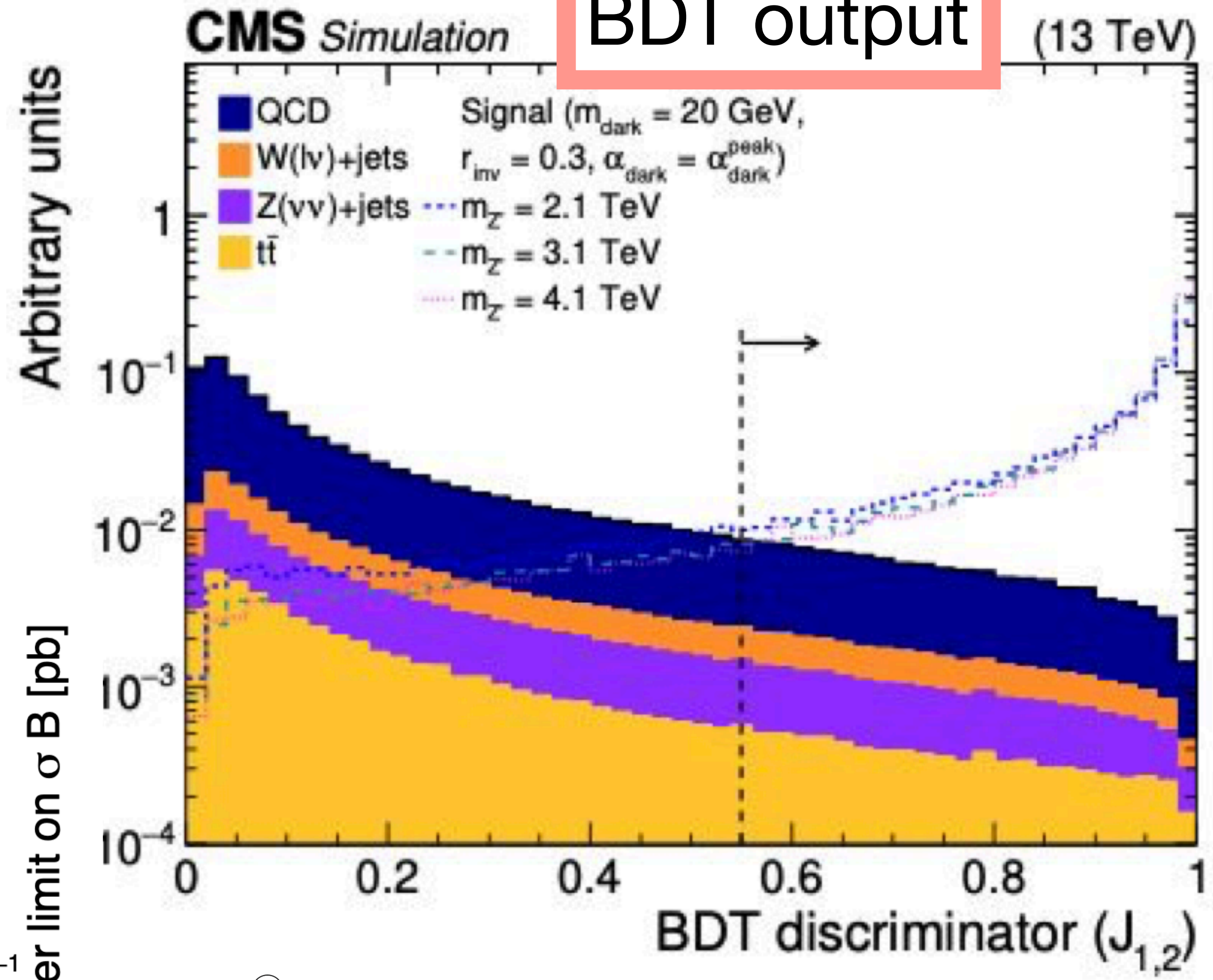

Dark shower modelling [(YOUNGST@R workshop)]

Triggering displaced, non-pointing, soft muons

Muons searches limited by:

- Soft muons → high L1 p_{T} thresholds
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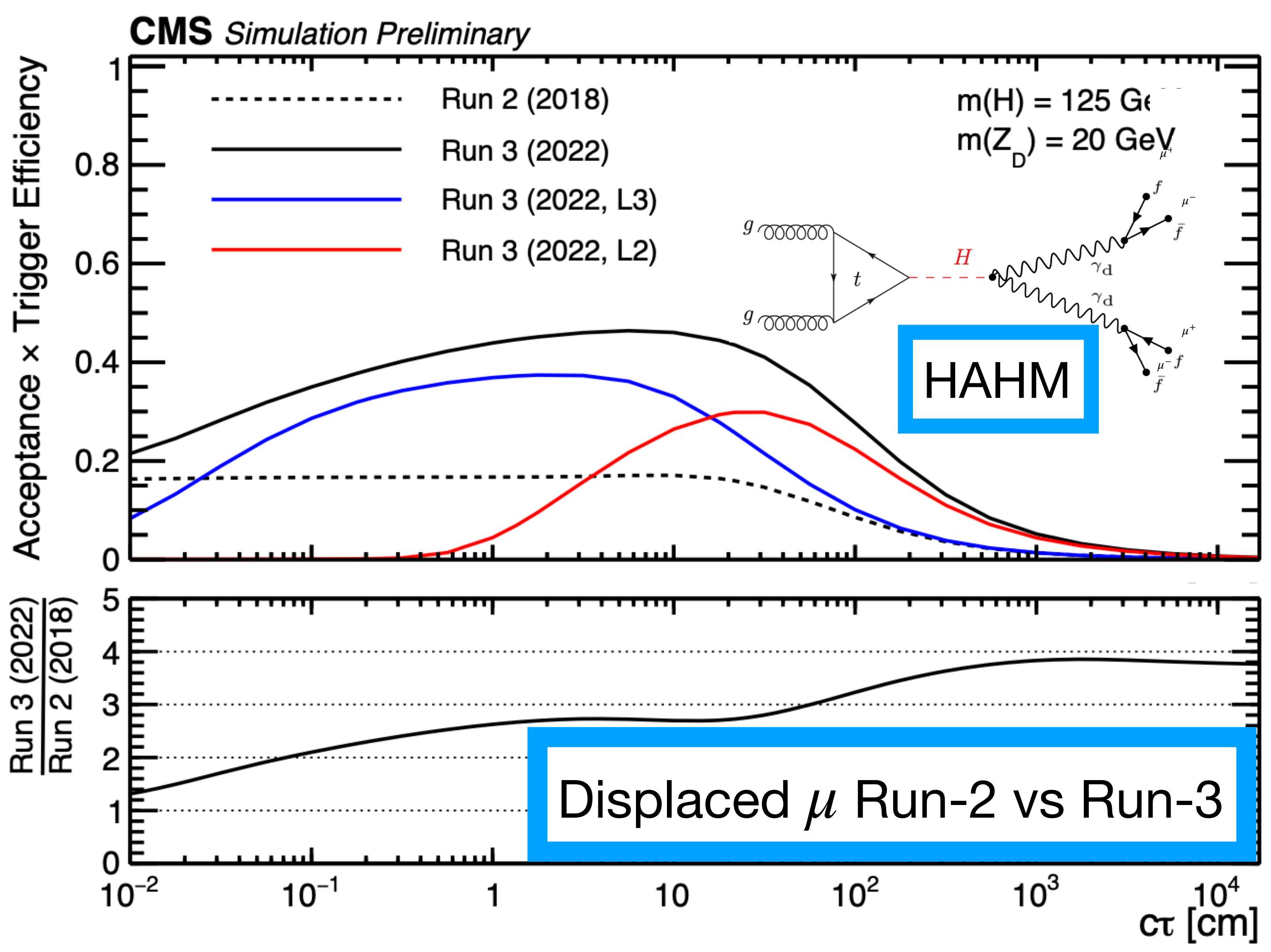
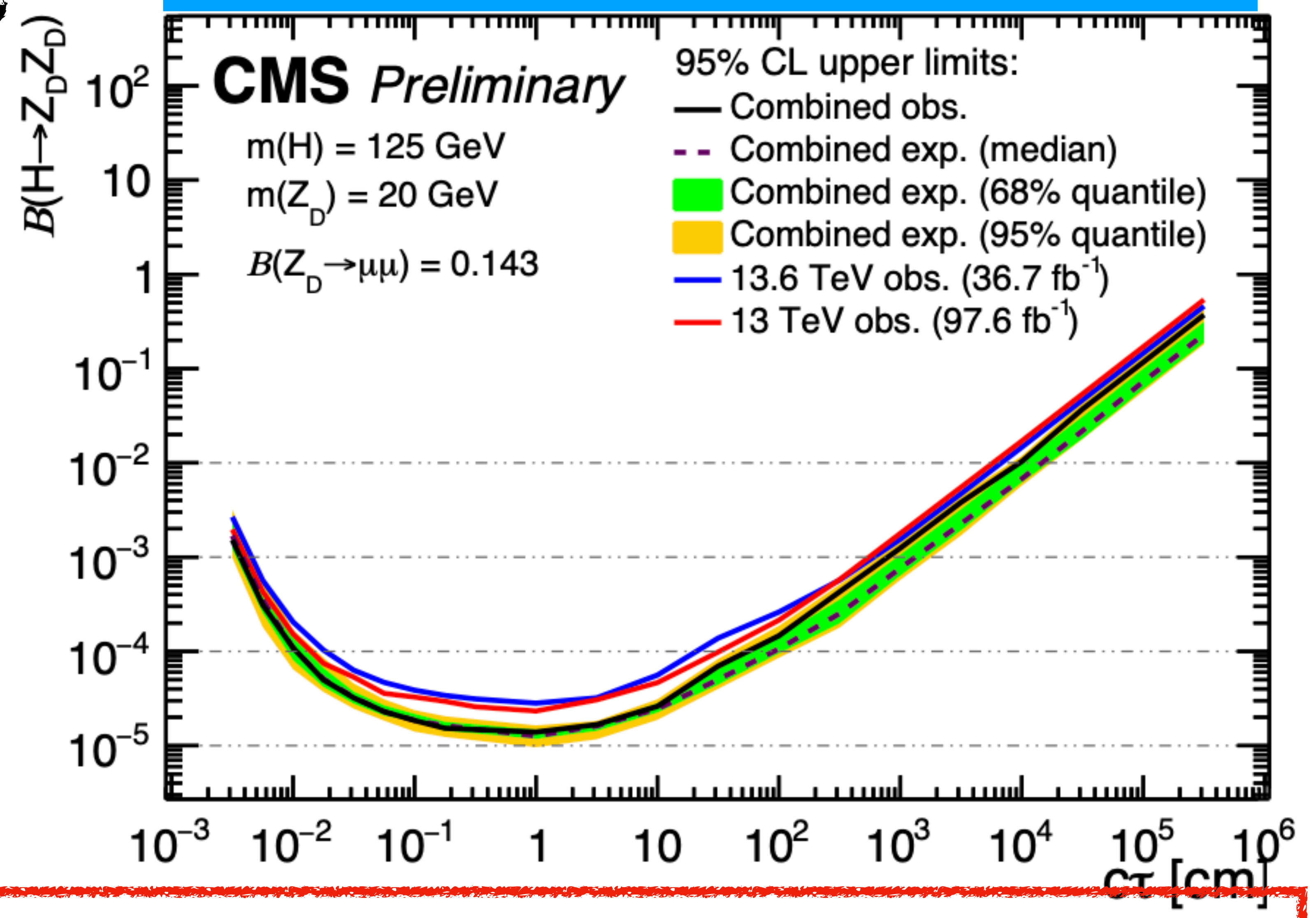
NEW CMS loosened first two → New result for displaced muons: [**CMS PAS EXO-23-014**]



Run-3 CMS displaced μ exclusion



2022 Run-3 competitive sensitivity wrt Run-2 (but 1/3 of data!!)

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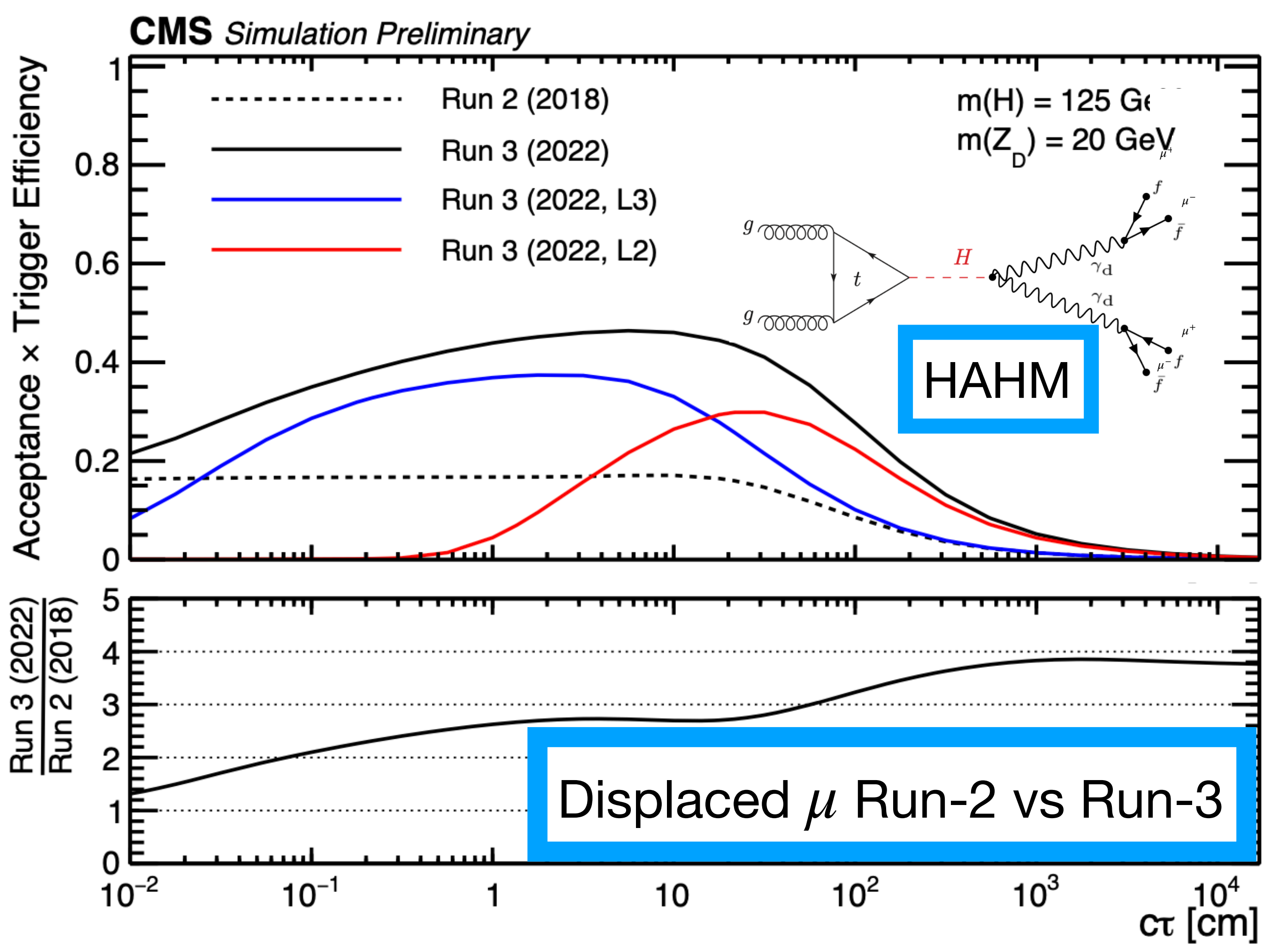

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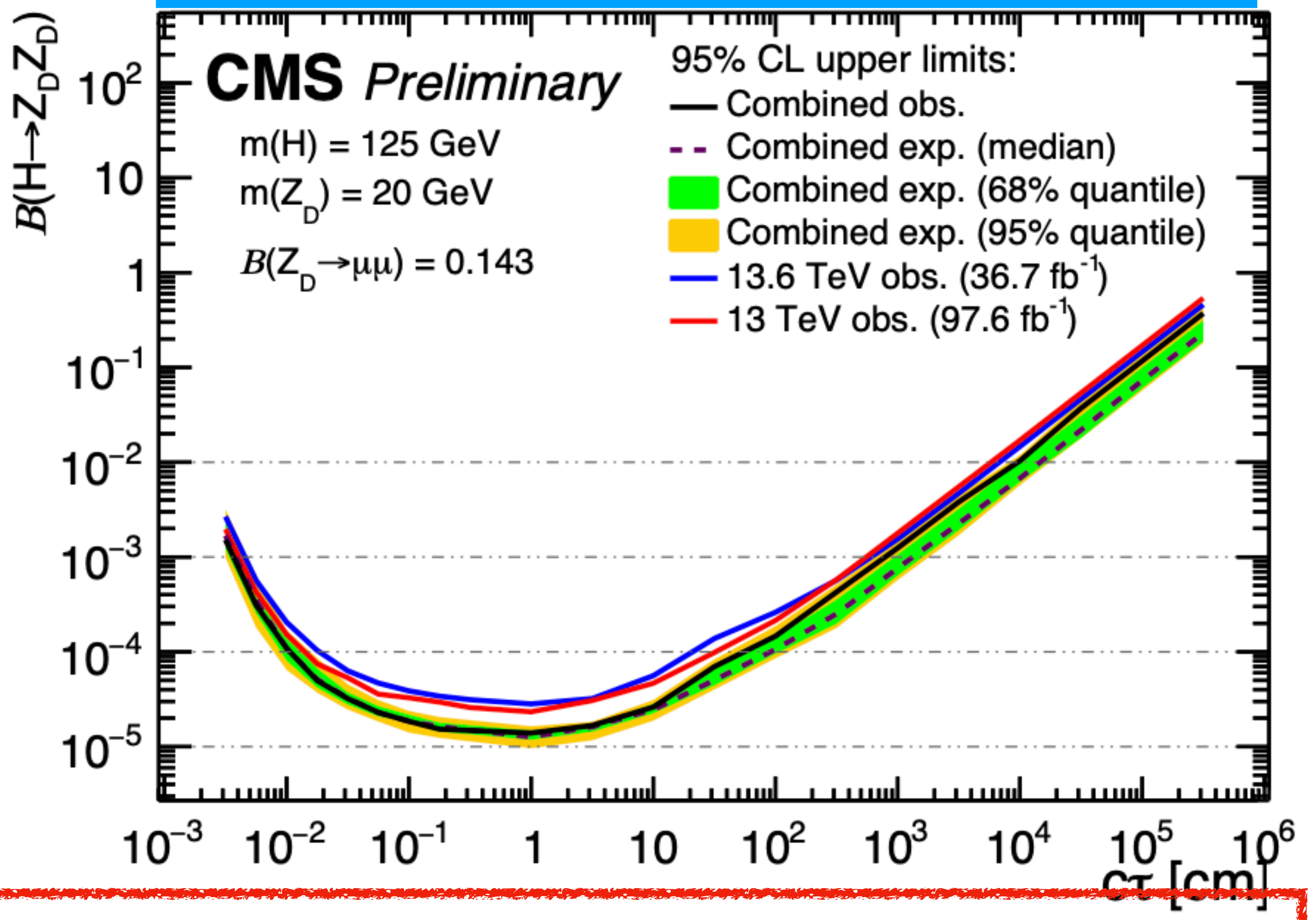

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CMS Scouting triggers:

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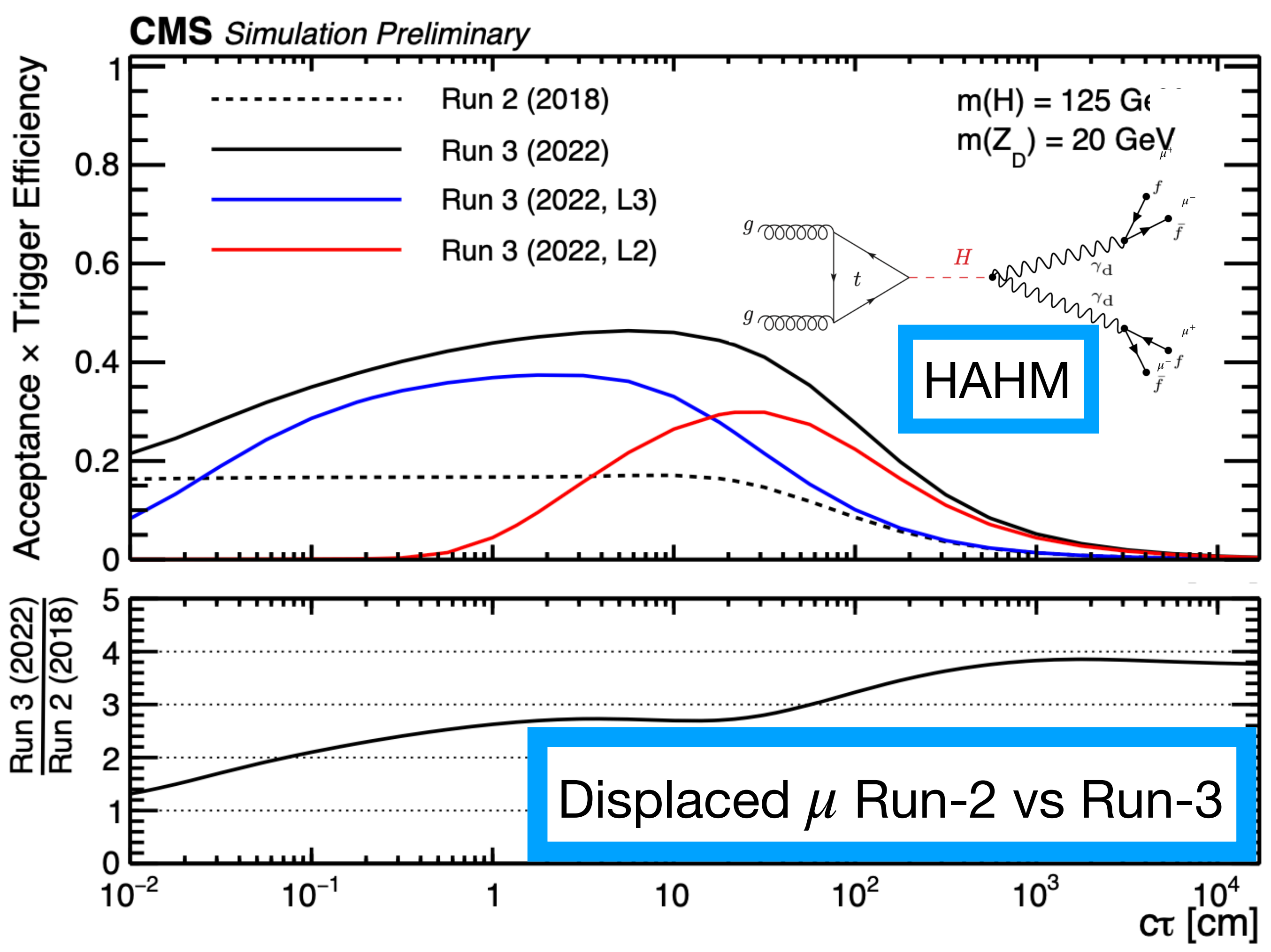

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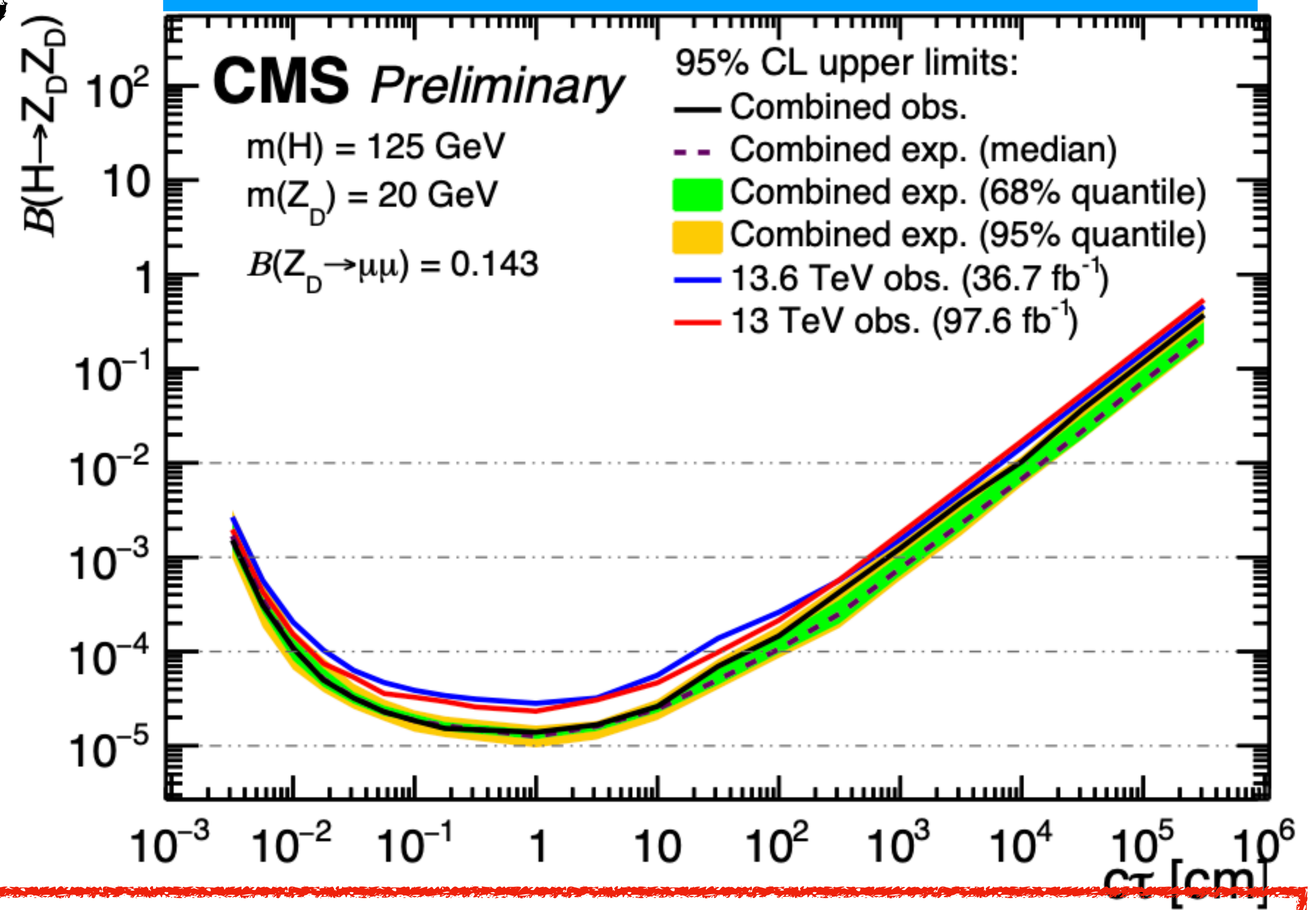

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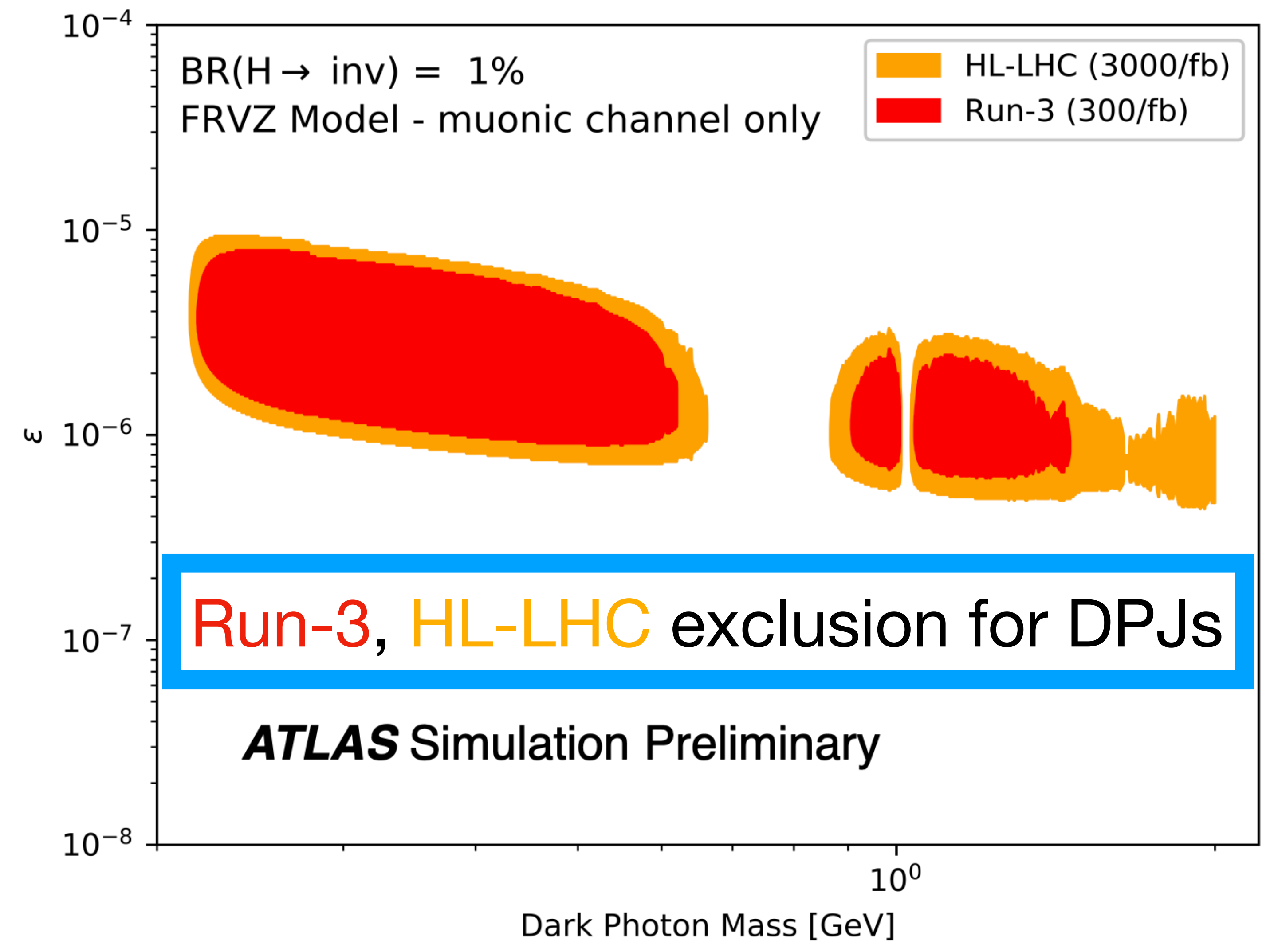
Run-3 and HL projection of the ATLAS analysis for displaced Dark Photon Jets (DPJs) [**ATL-PHYS-PUB-2019-002**]



Sizable improvements due to trigger requirements loosened (beamspot+collimation) on top of luminosity

Large Radius Tracking for displaced tracks

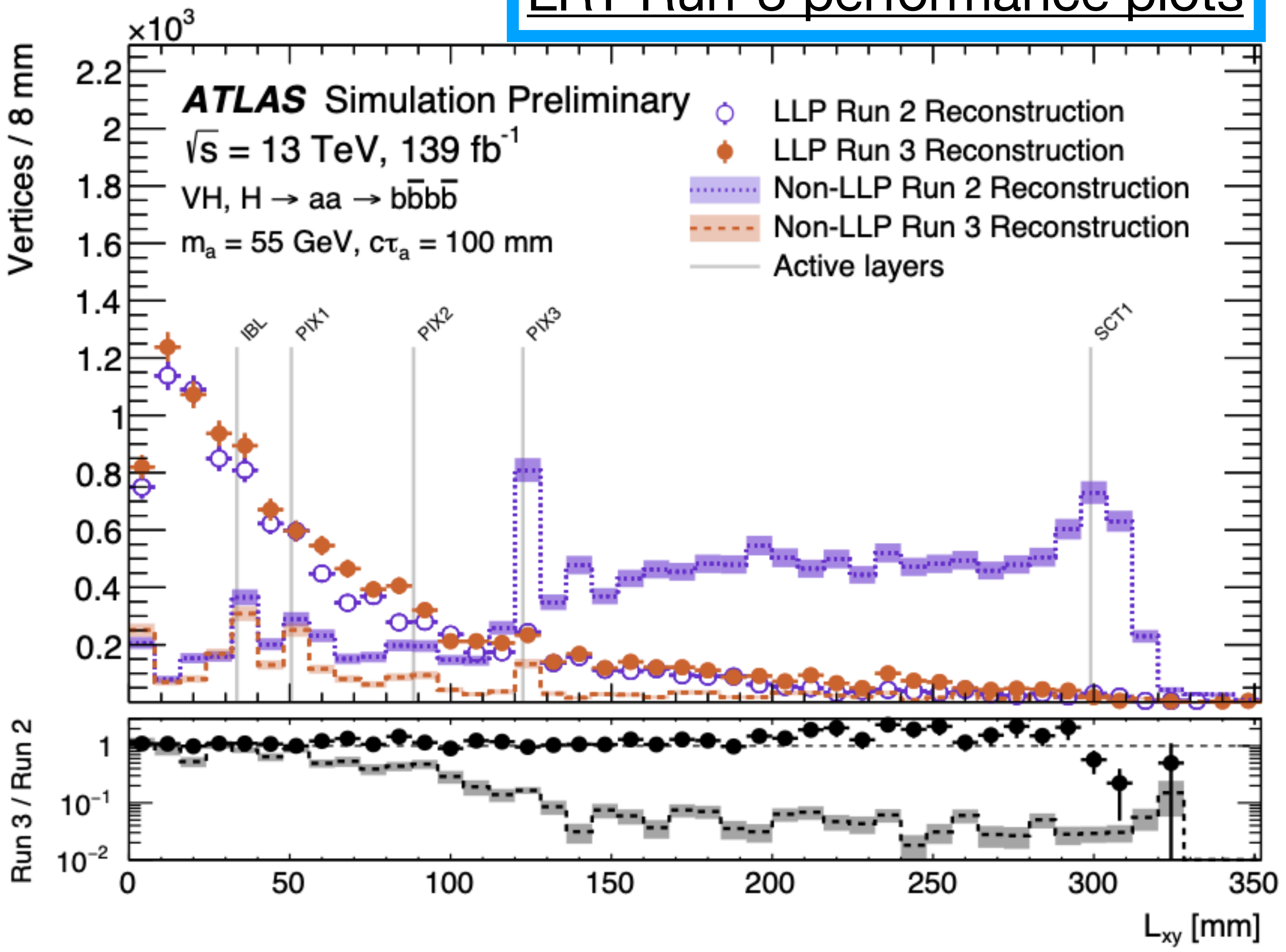
Standard tracking requires $|d_0| < 10\,\mathrm{mm}$ → displaced tracks are suppressed!

Large Radius Tracking (LRT) relaxes requirements to $|d_0| < 300\,\mathrm{mm}$ and $|z_0| < 500\,\mathrm{mm}$

In Run-2 standard and LRT too computationally expensive →in Run-2 LRT could be run only on 10% of data

Standard tracking optimised and new LRT→ lower computational time, negligible performance loss!

LRT Run-3 performance plots

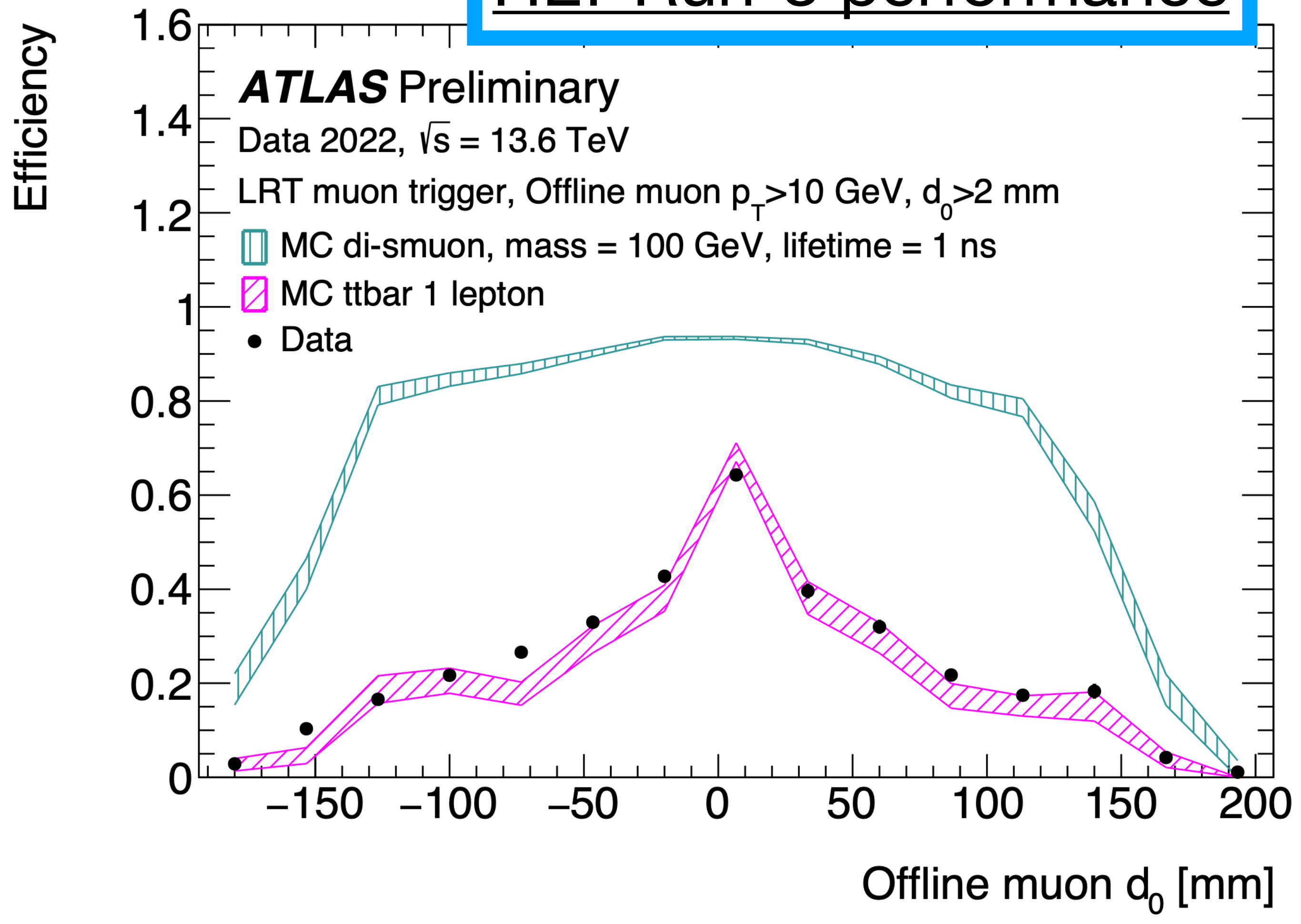


Run-3 LRT efficiency small increase, but very large decrease of fake rate ($\sim 90\,\%$) wrt **Run-2**

→ In Run-3 LRT can be run at the online level for all the events!

In Run-3 already **running at the HLT level**, expected **sizeable sensitivity** for displaced scenarios!

HLT Run-3 performance

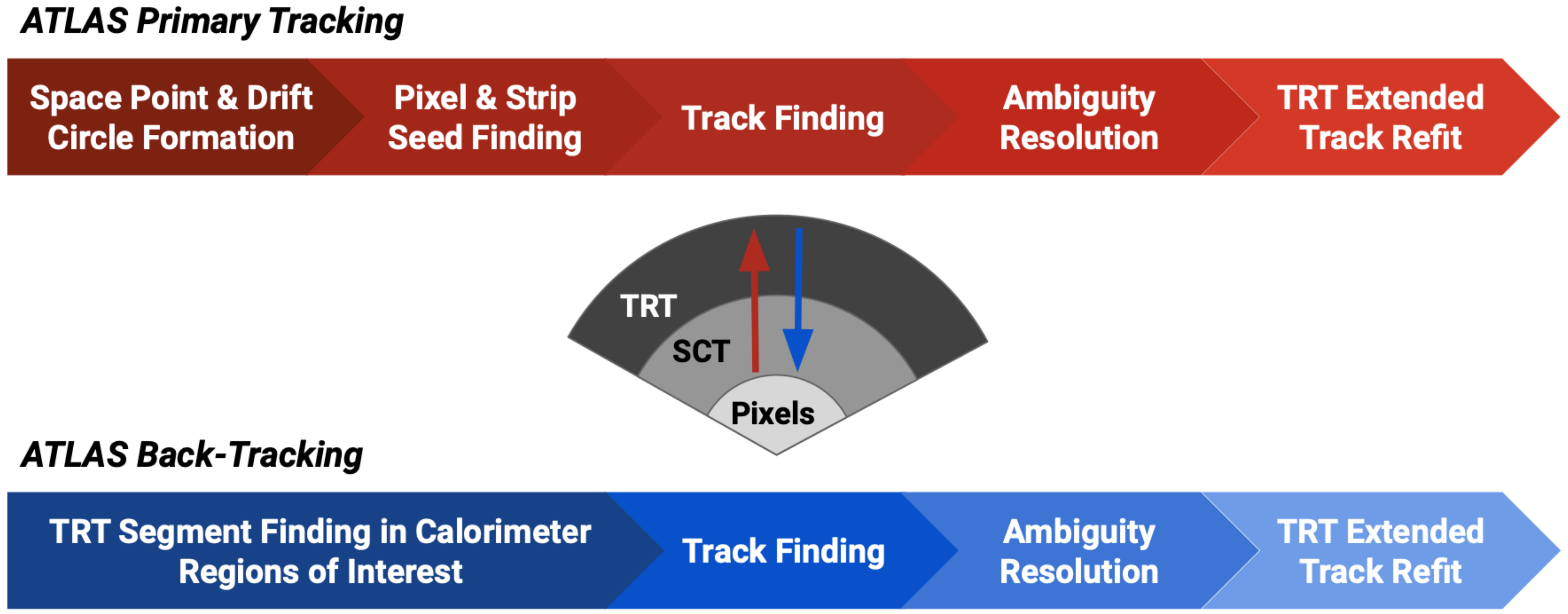


Standard tracking optimisation

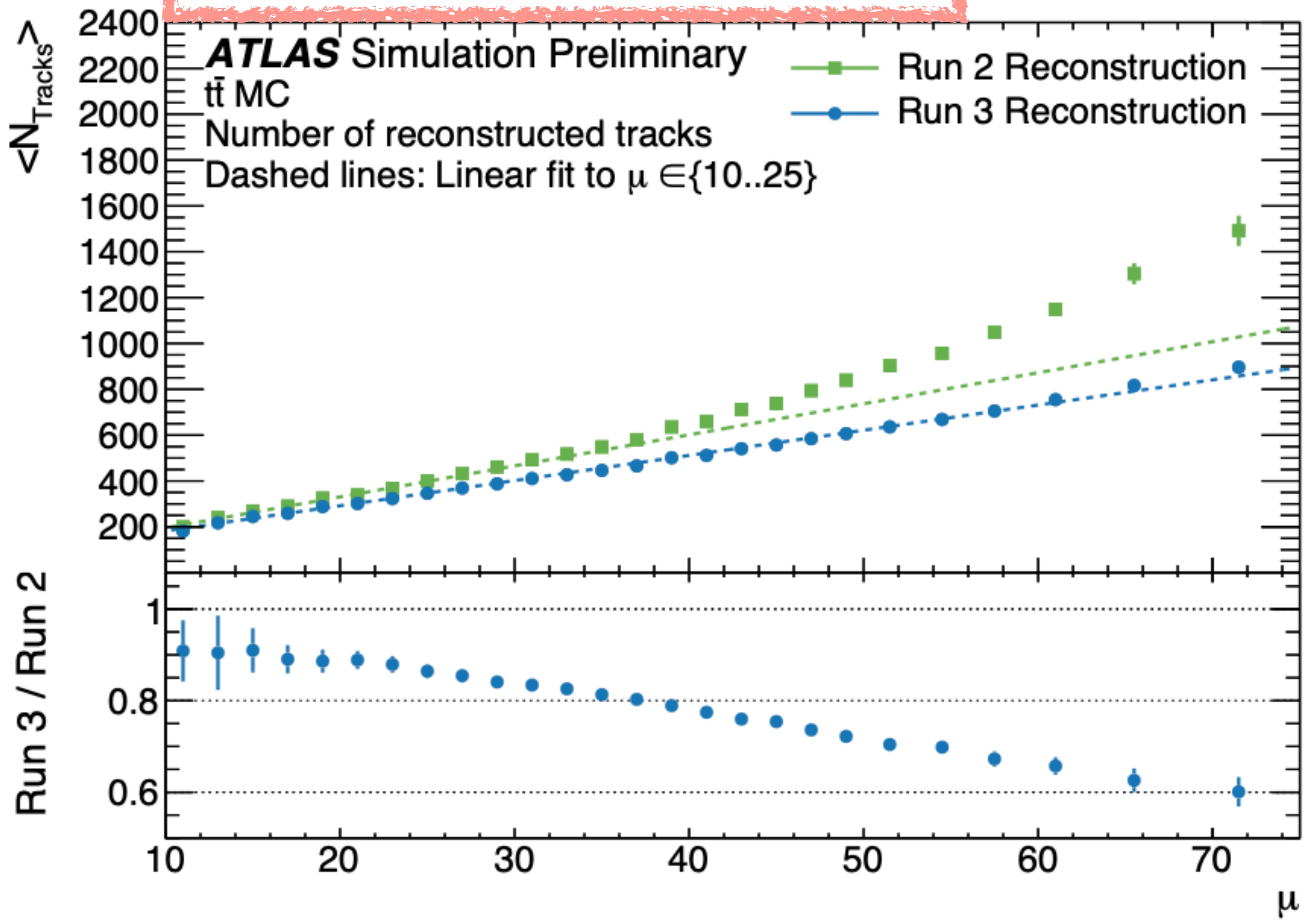
Run-3: more interaction per bunch-crossing (pile-up, μ) wrt Run-2 → tracking optimisation is needed

Run-3 new tracking algorithm:

- Requirements tightened
- Vertex finding algorithm changed
- Ambiguity resolution to suppress fakes changed



Linear with pile-up



Reduced CPU time