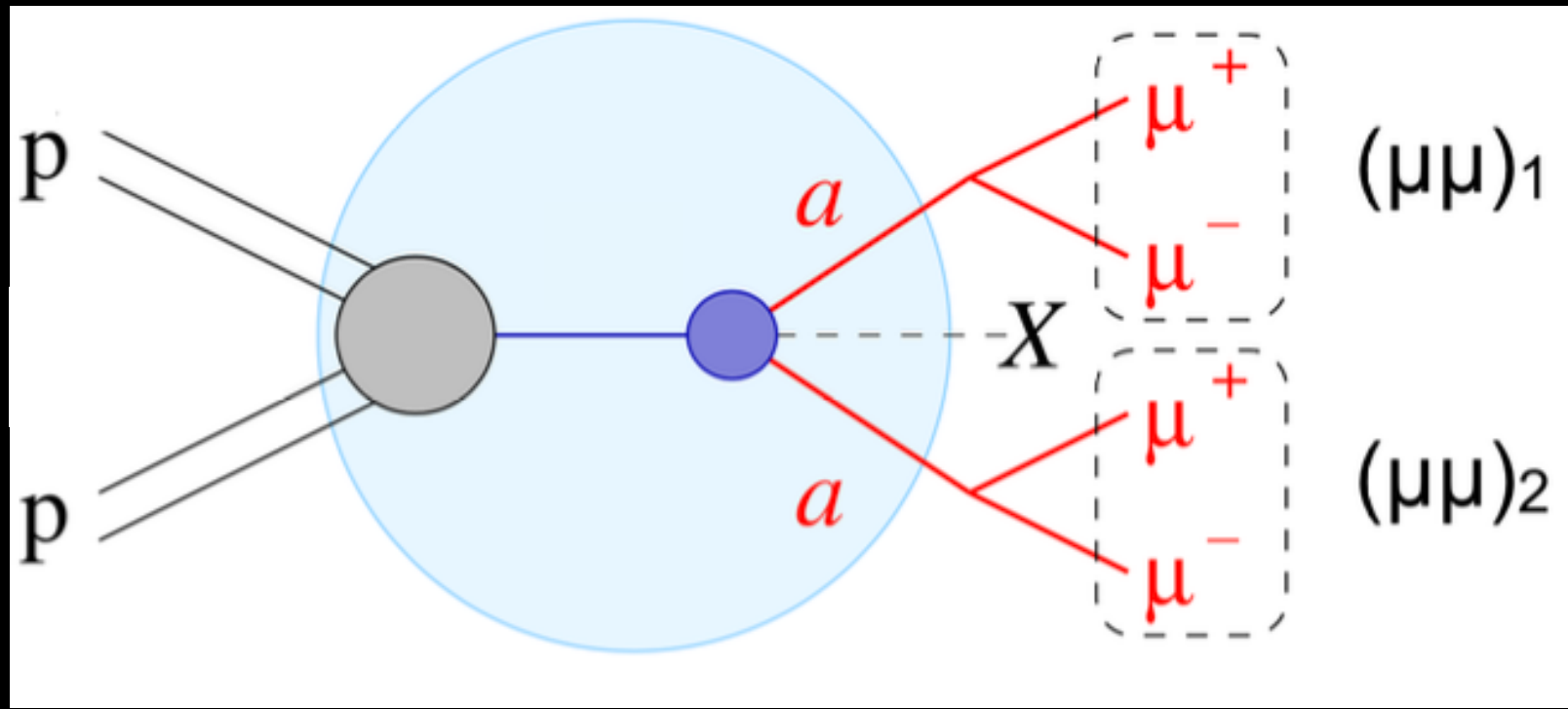
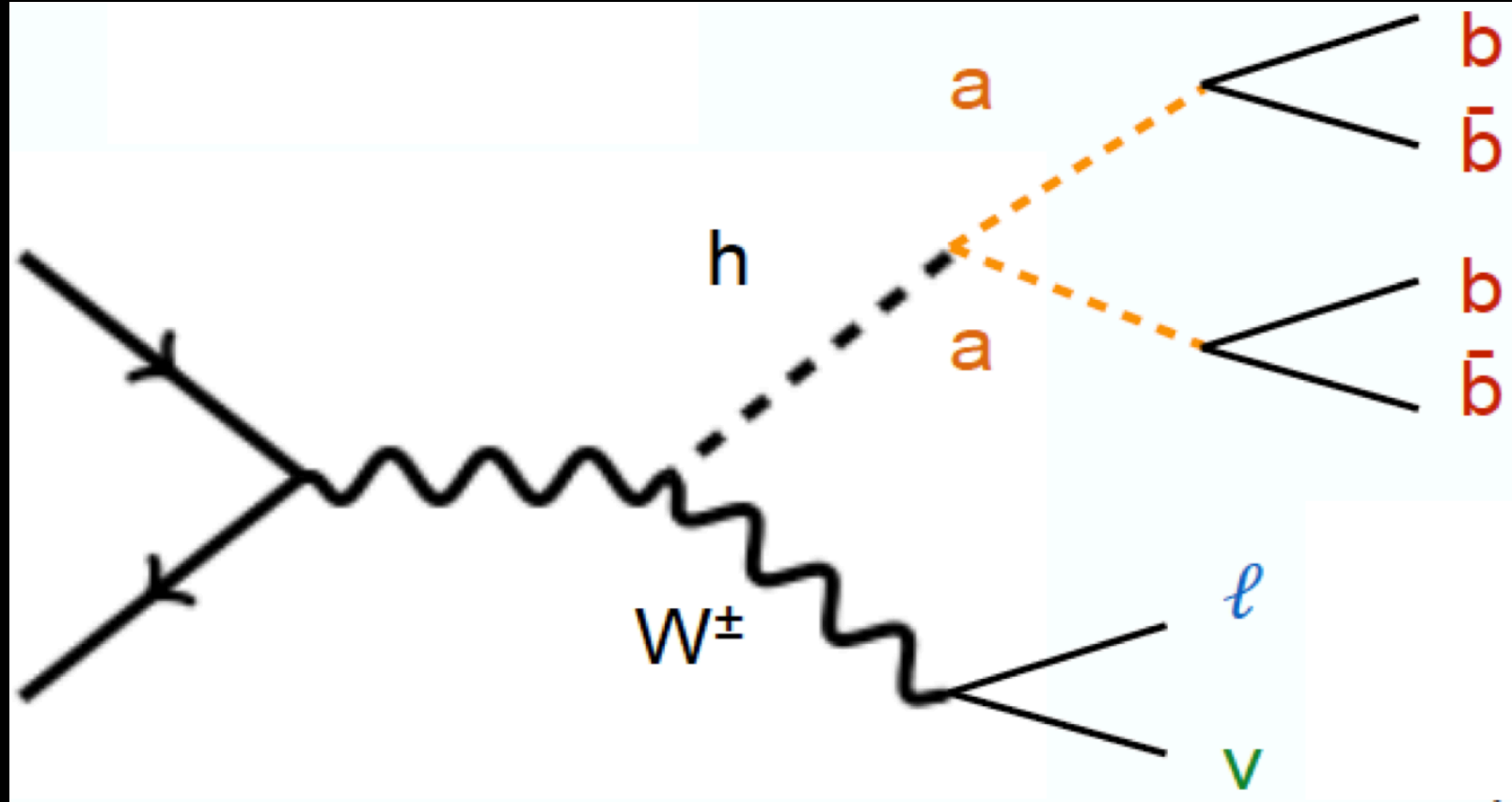
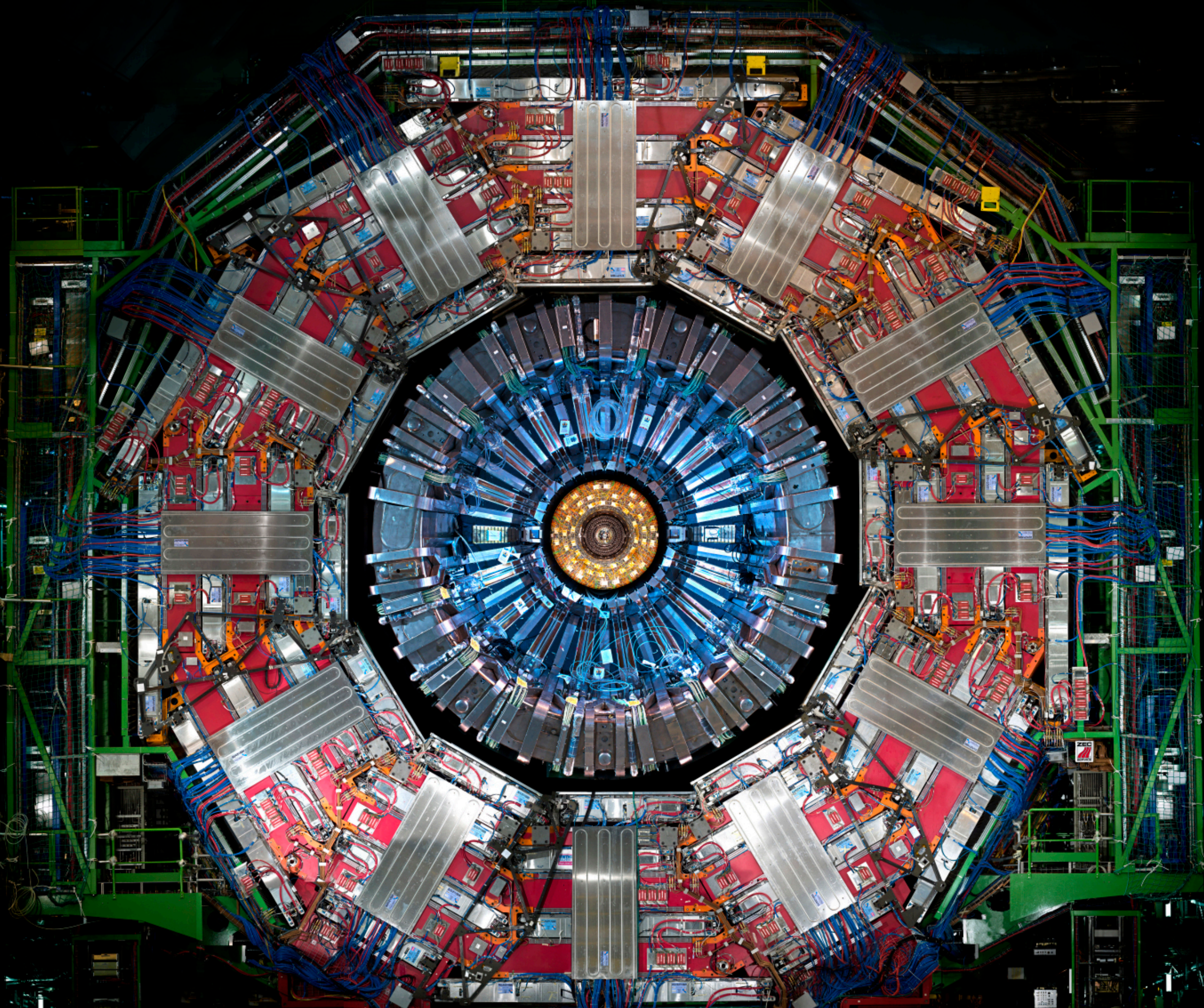


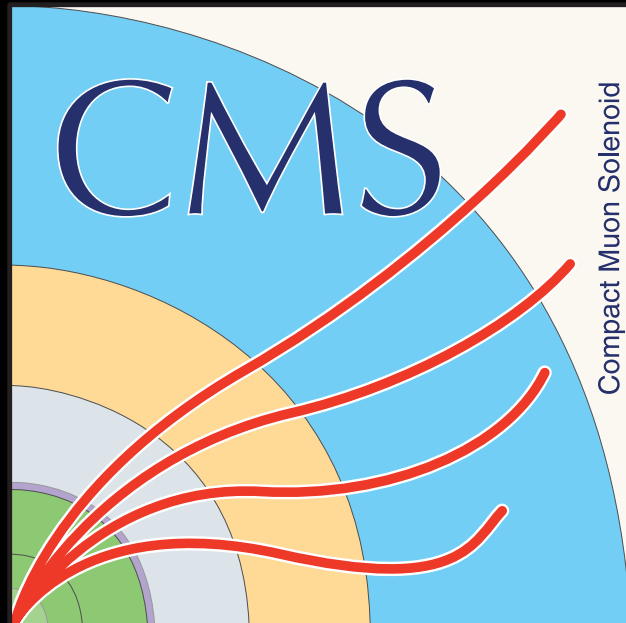
Searches for exotic Higgs decays in CMS



Andrea Malara

On behalf of the CMS collaboration

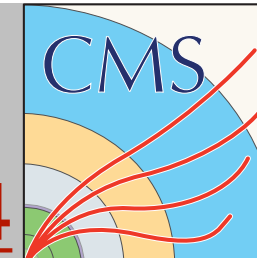
ULB



- ▶ Higgs boson in the Standard Model
 - ▶ good compatibility between observations and predictions
 - ▶ upper bound on Higgs boson decays to new particles is $\mathcal{O}(10\%)$
 - ▶ ... still room for exotic Higgs decays
- ▶ Experimental tools:
 - ▶ Essential to probe new challenging signatures
 - ▶ Important to improve existing techniques
 - ▶ Crucial to develop new strategies (triggers, reconstructions, tagging, ...)
- ▶ This talk:
 - ▶ $H \rightarrow aa \rightarrow 4\mu$: [CMS-PAS-HIG-21-004](#)
 - ▶ $H \rightarrow aa \rightarrow 4b$: [arXiv:2403.10341v1](#)

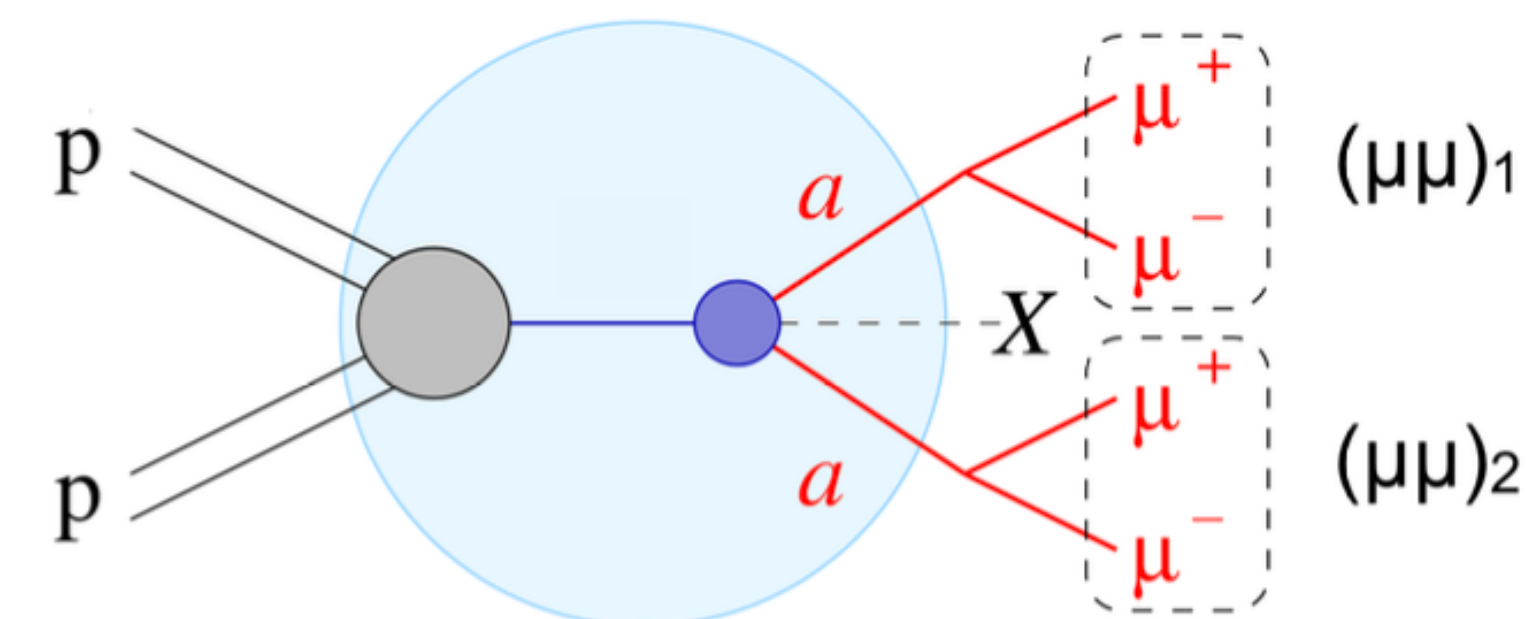
Search for diboson production in 4μ

CMS-PAS-HIG-21-004



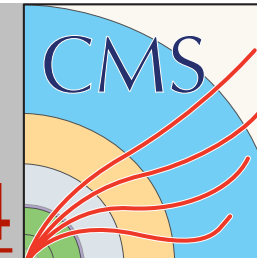
Analysis in a nutshell

- ▶ Model-independent search in 4μ
- ▶ Cover range $0.2 < m_a < 60$ GeV
- ▶ Promptly decaying and long-lived ($c\tau < 10$ cm) bosons
- ▶ Several models probed



Search for diboson production in 4μ

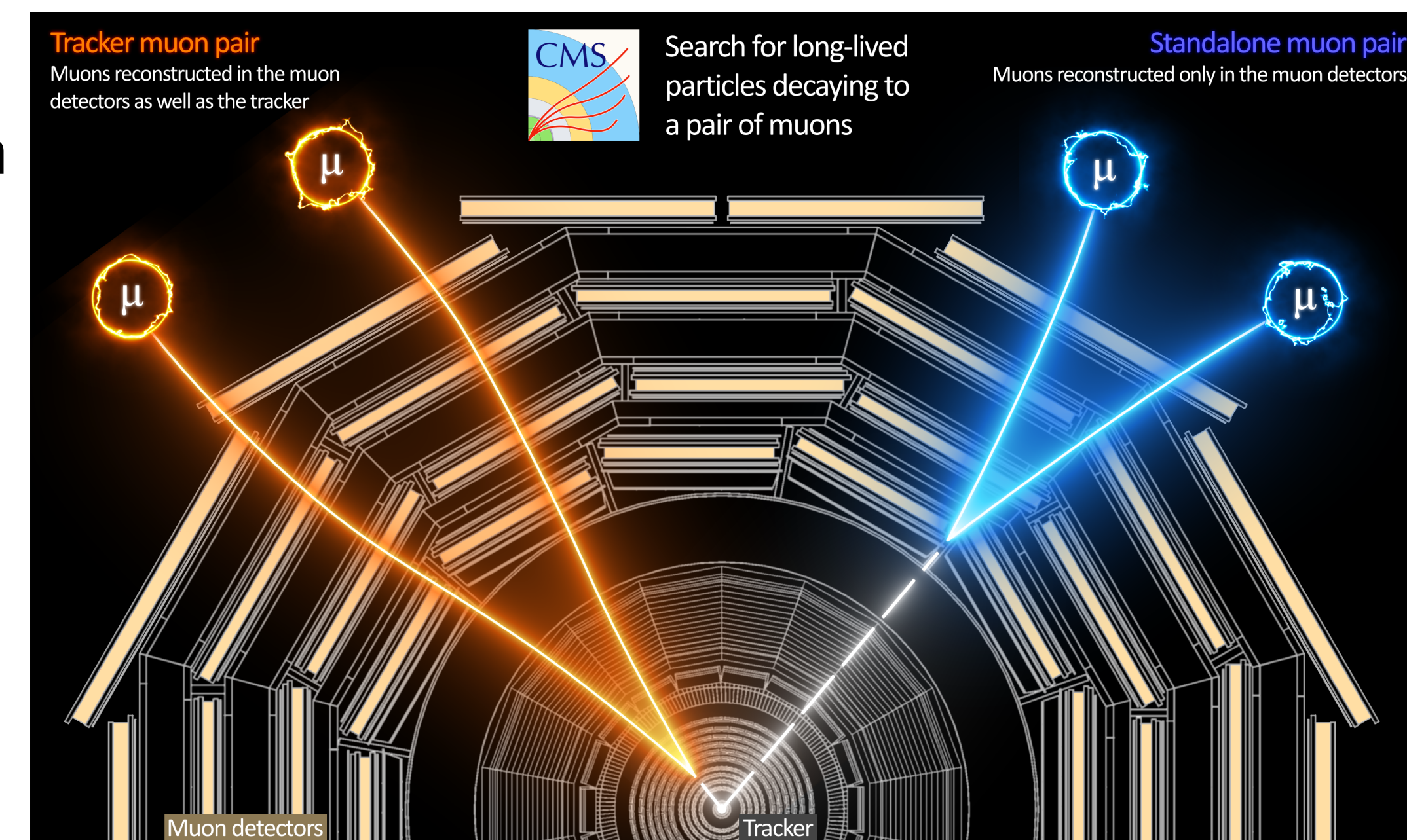
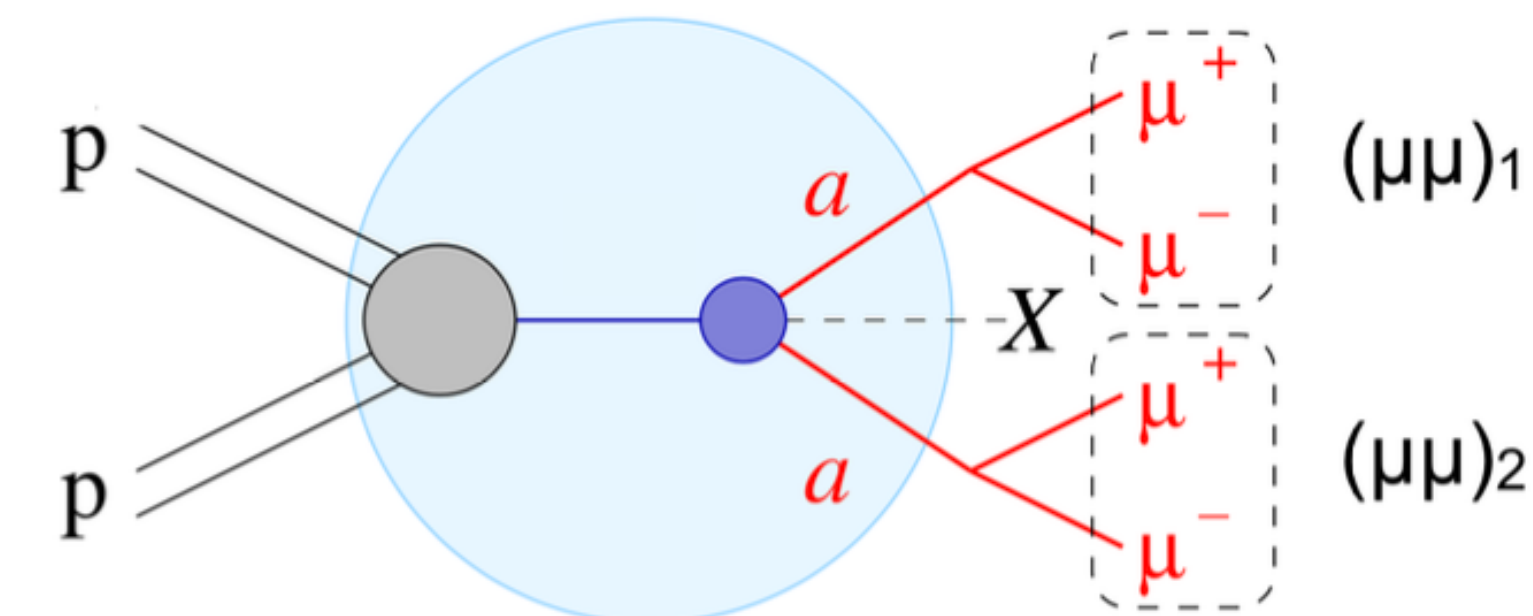
CMS-PAS-HIG-21-004



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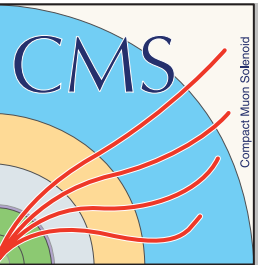
- ▶ New developed trigger with alternative muon reconstruction
 - ▶ Use only muon detector \rightarrow indep. on PV reconstruction
 - ▶ Available in 2018 data only
 - ▶ Sensitive to both prompt and displaced muons



Taken from here

Search for diboson production in 4μ

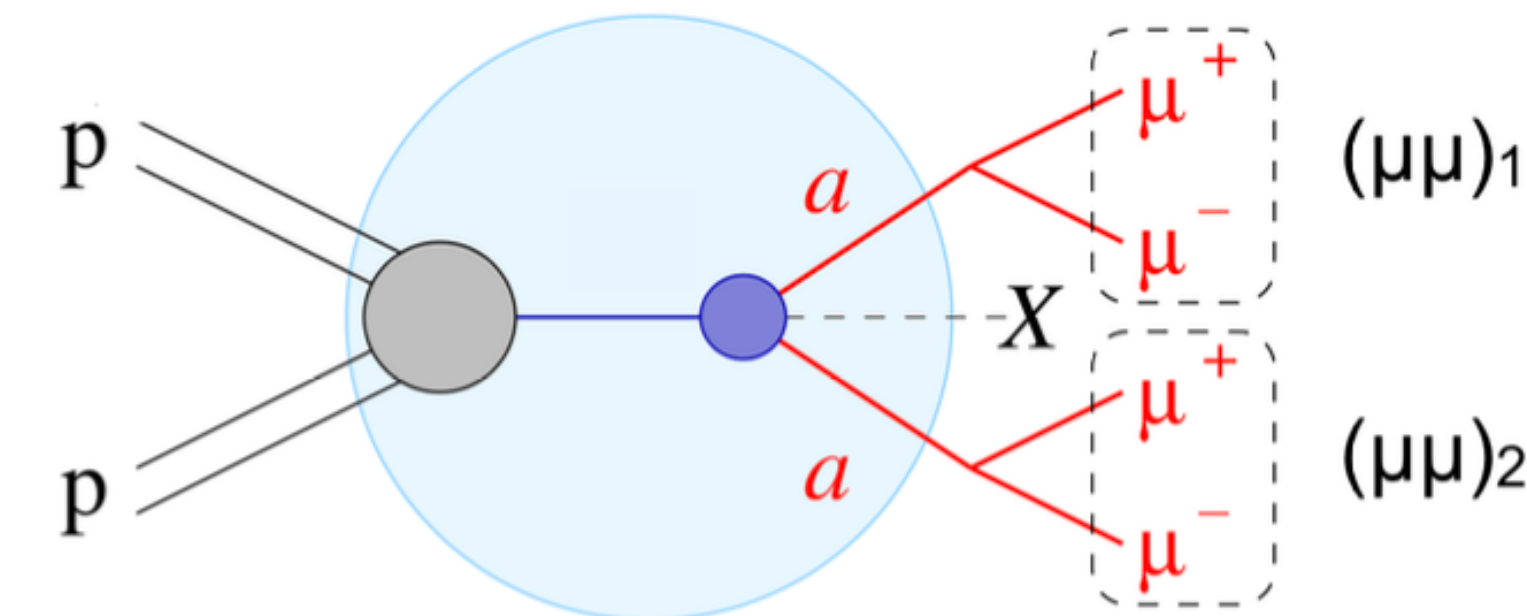
CMS-PAS-HIG-21-004



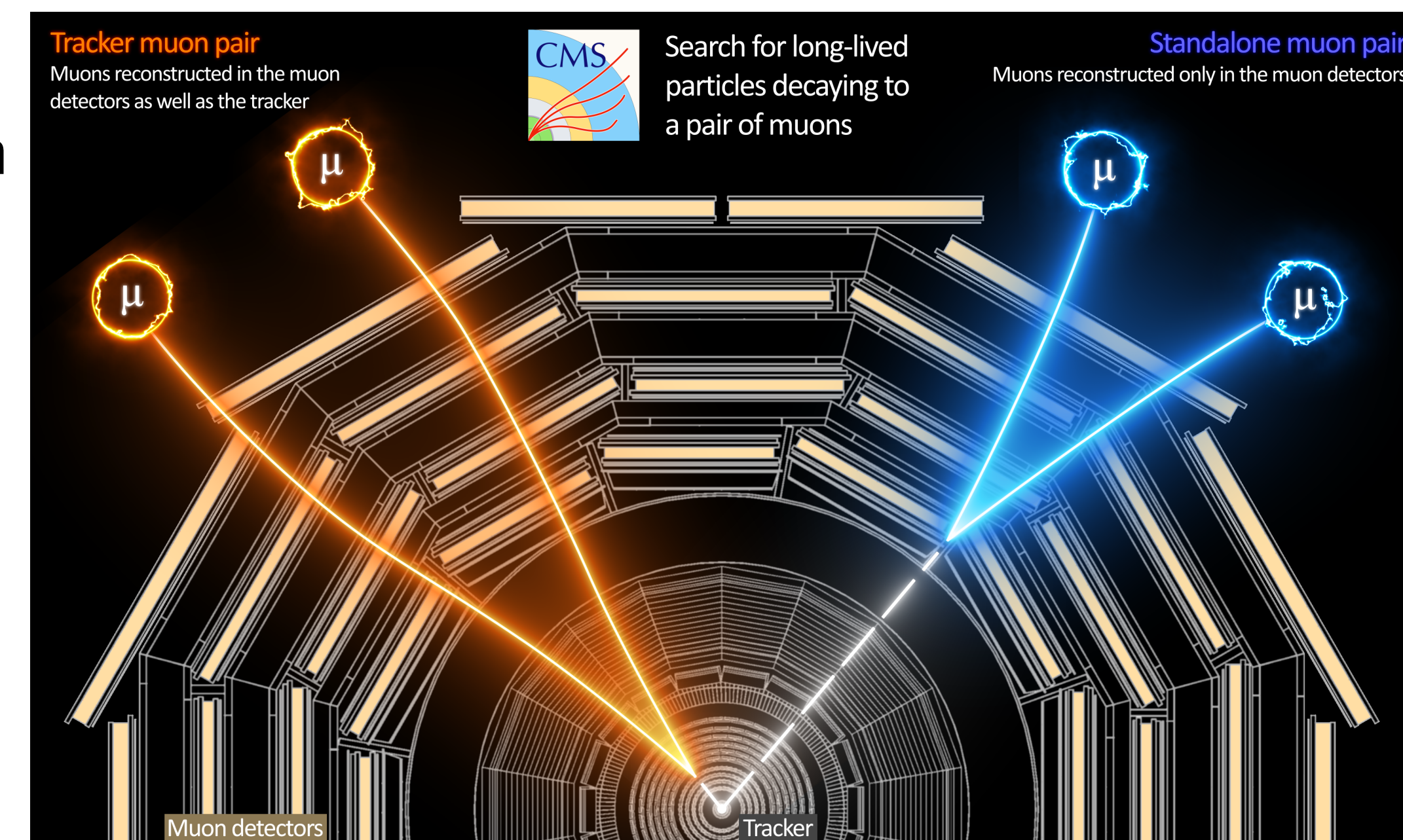
ULB

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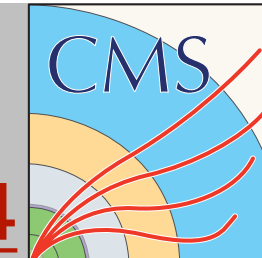
*More details in the poster session:
Poster by Rubén*



Taken from here

Search for diboson production in 4μ

CMS-PAS-HIG-21-004

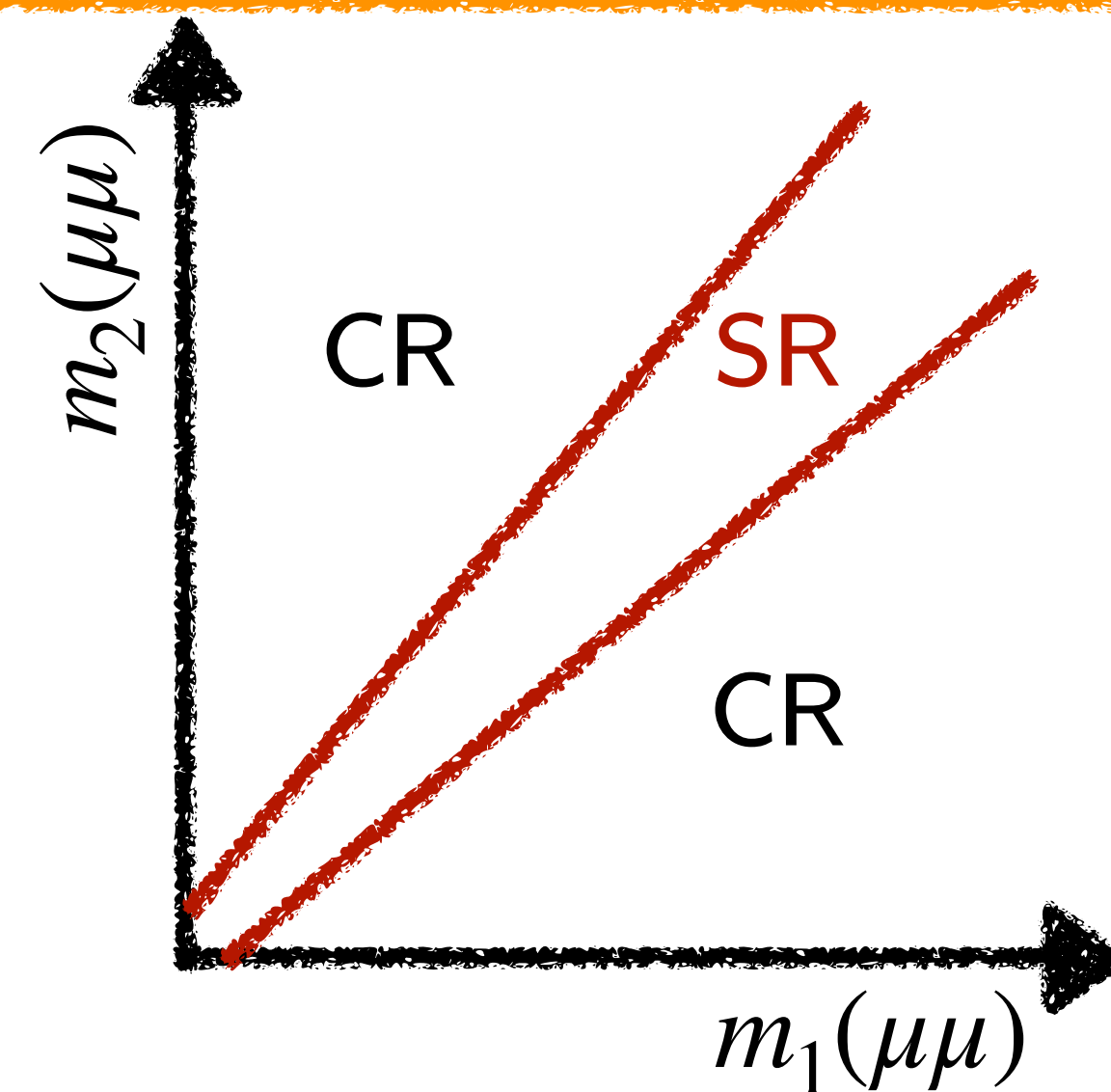
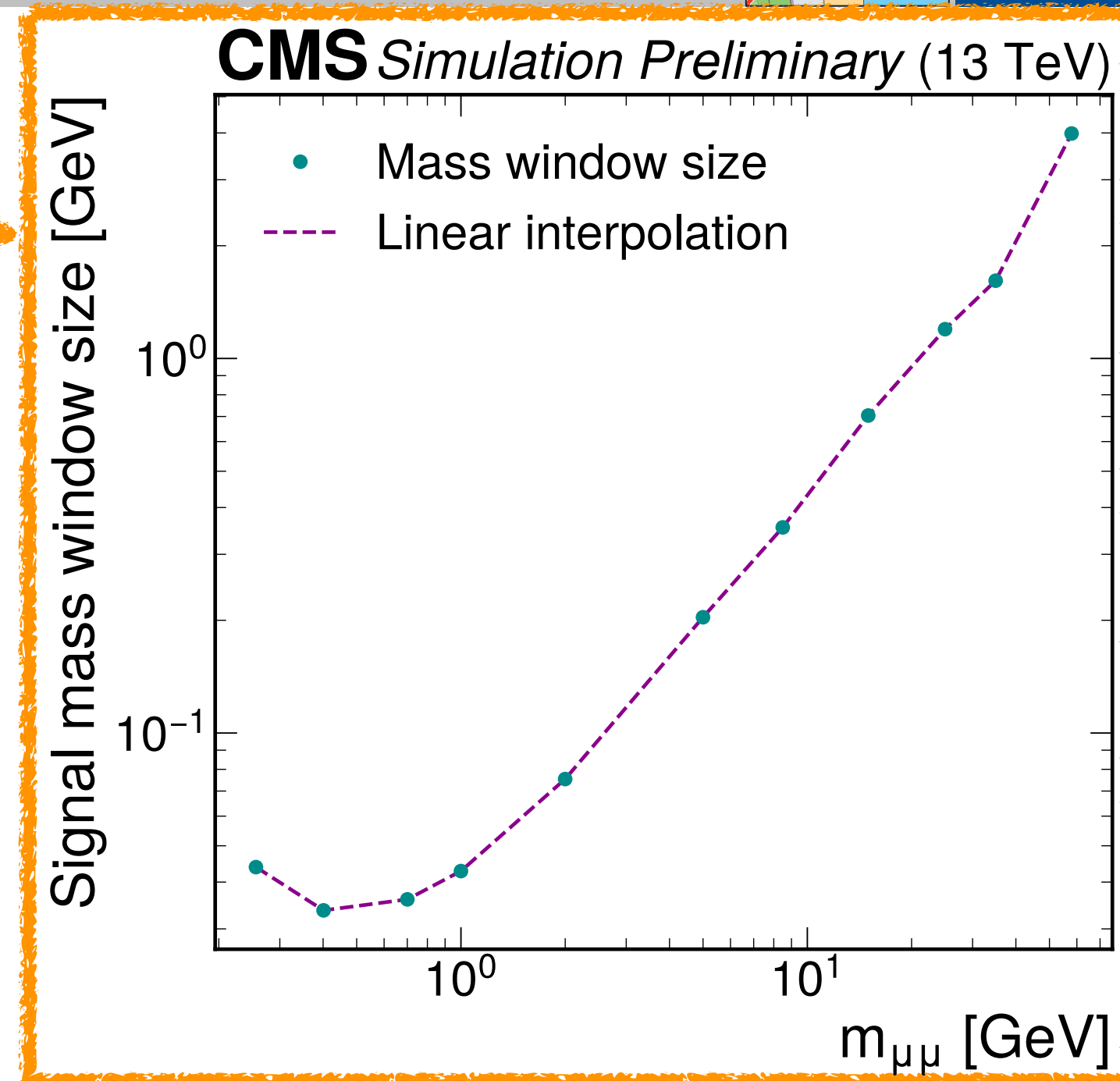


ULB

Analysis strategy

- ▶ Signal region selection
- ▶ Dimuon pairs with any $m(\mu^+\mu^-) < 60$ GeV

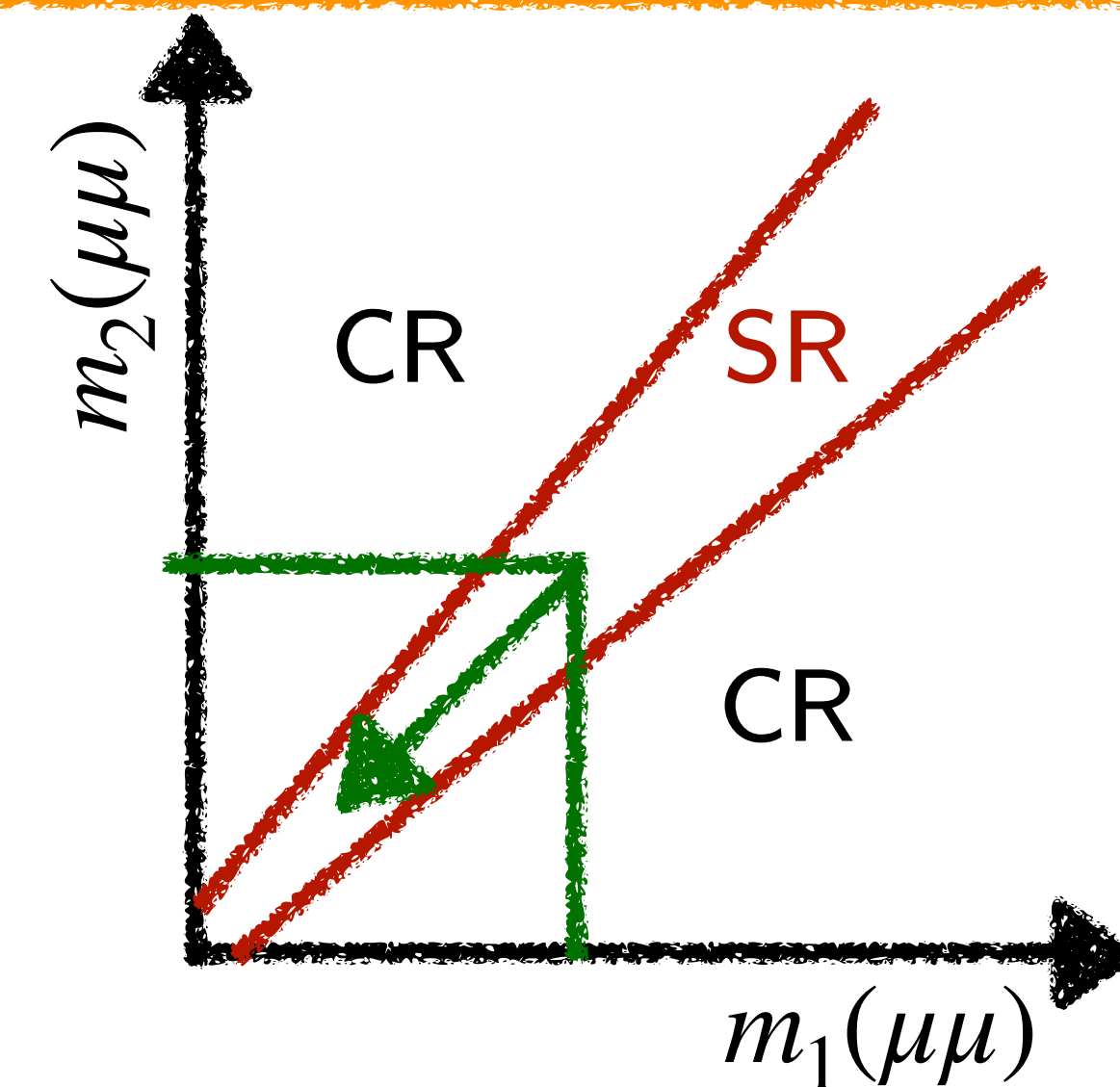
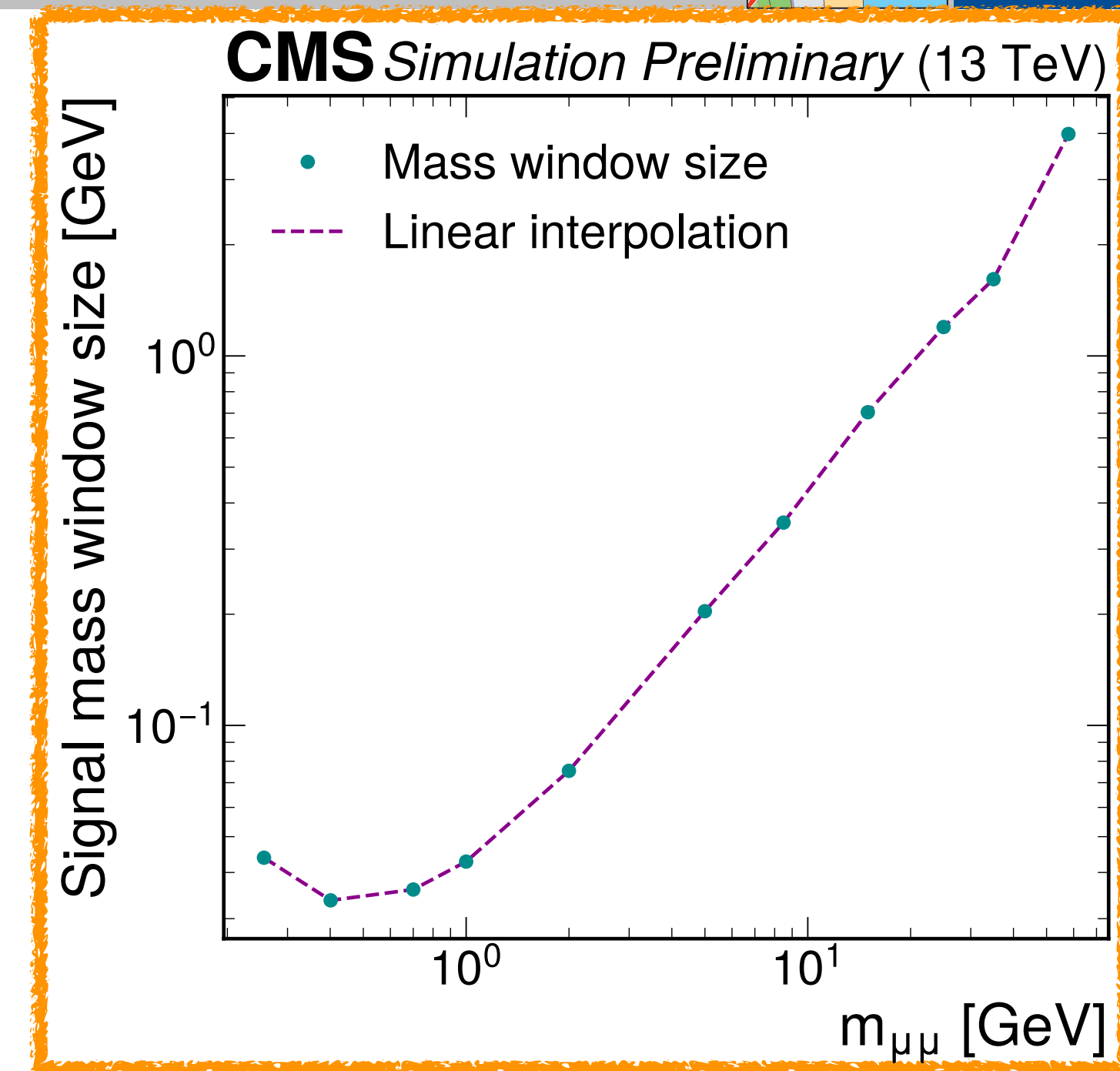
▶ Identical masses $\rightarrow |m_1(\mu\mu) - m_2(\mu\mu)| < F \left(\frac{m_1(\mu\mu) + m_2(\mu\mu)}{2} \right)$



Search for diboson production in 4μ

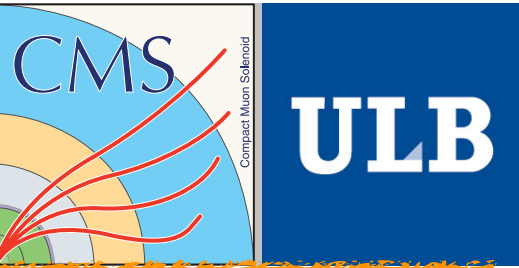
Analysis strategy

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- ▶ Background below Upsilon (Υ) resonance ($m(\mu^+\mu^-) < 9$ GeV):
 - ▶ Dominated by QCD multijet events (e.g. semi-leptonic decay)
 - ▶ Data-driven from control sample from single $\mu\mu$



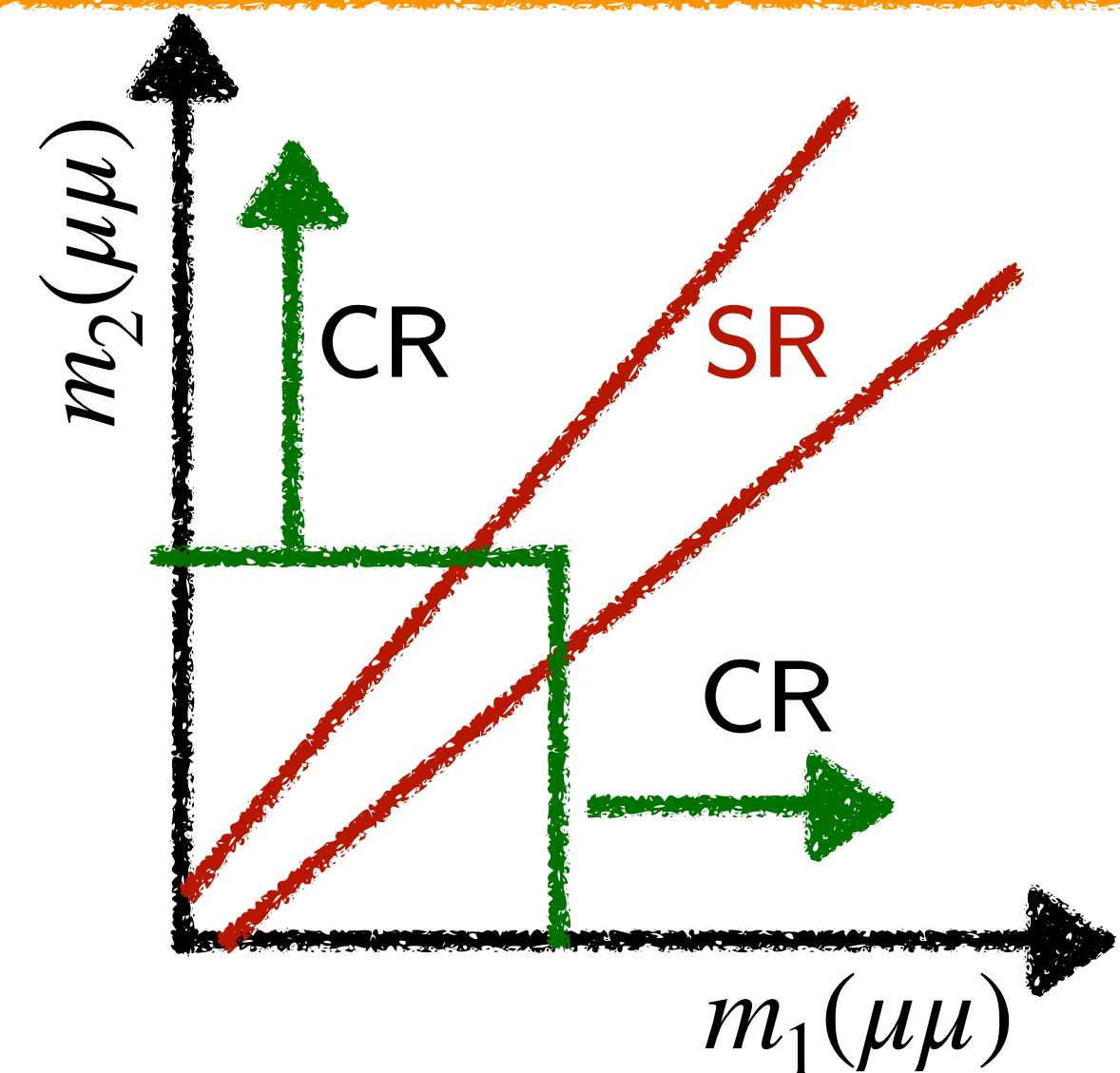
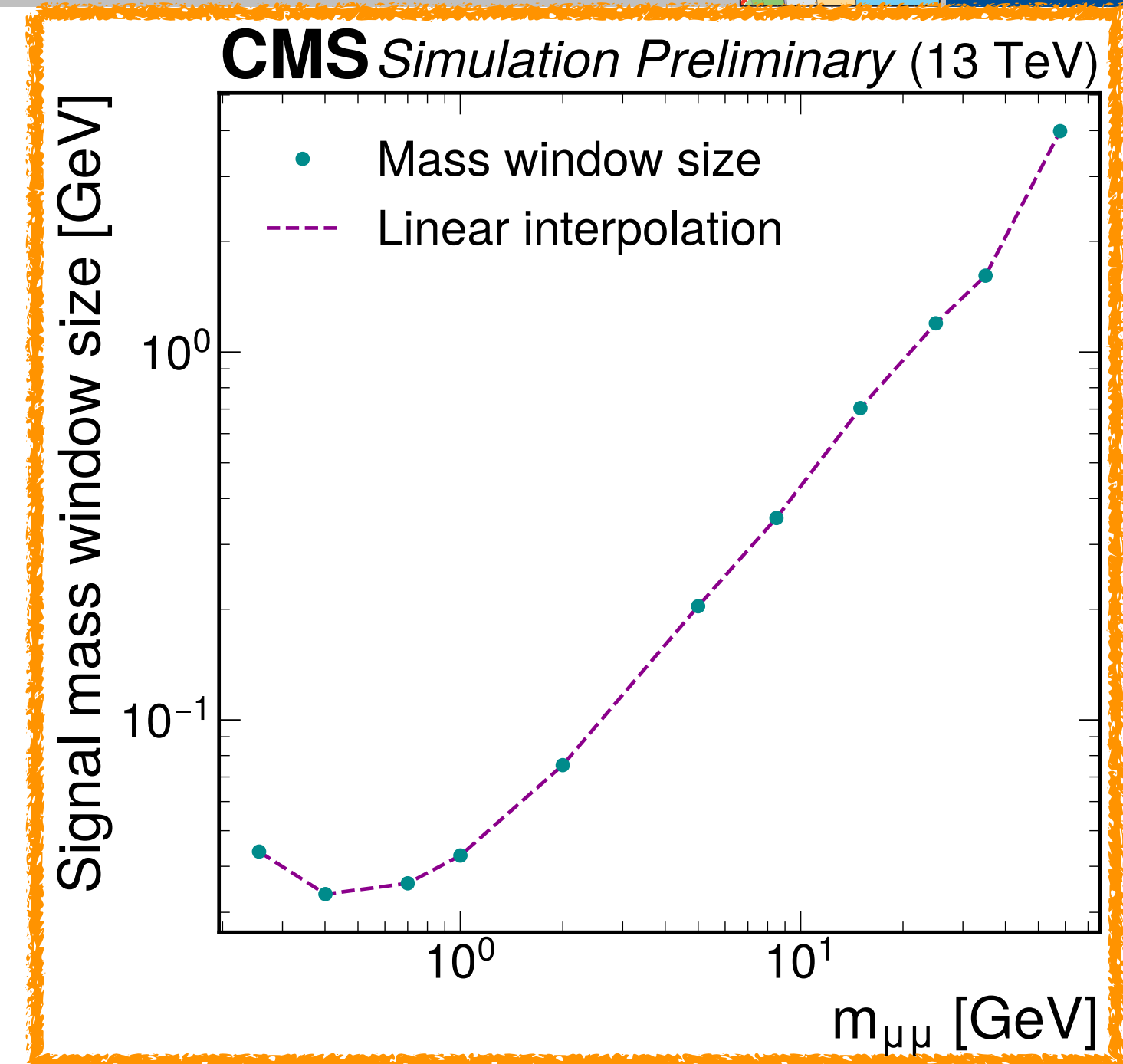
Search for diboson production in 4μ

CMS-PAS-HIG-21-004



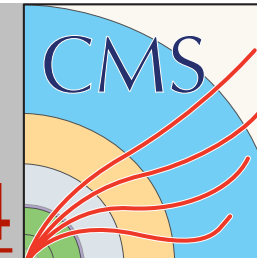
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 - ▶ Dominated by QCD multijet events (e.g. semi-leptonic decay)
 - ▶ Data-driven from control sample from single $\mu\mu$
- ▶ Background above Upsilon (Υ) resonance ($m(\mu^+\mu^-) > 11$ GeV):
 - ▶ Primary sources are: EWK ZZ, $t\bar{t}$, DY events
 - ▶ Smooth template with Gaussian kernel density estimate (KDE)
 - ▶ Normalisation derived from data



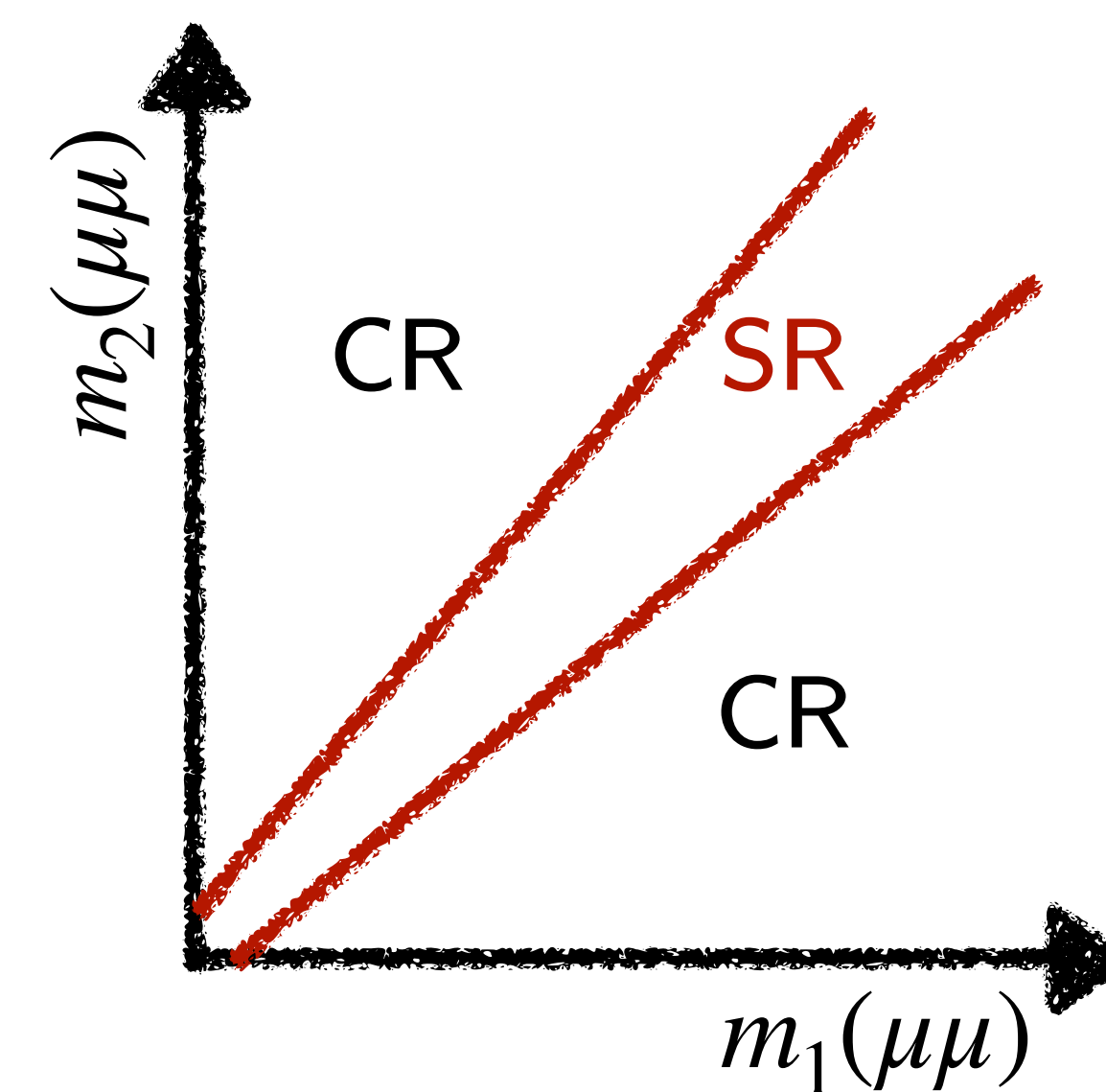
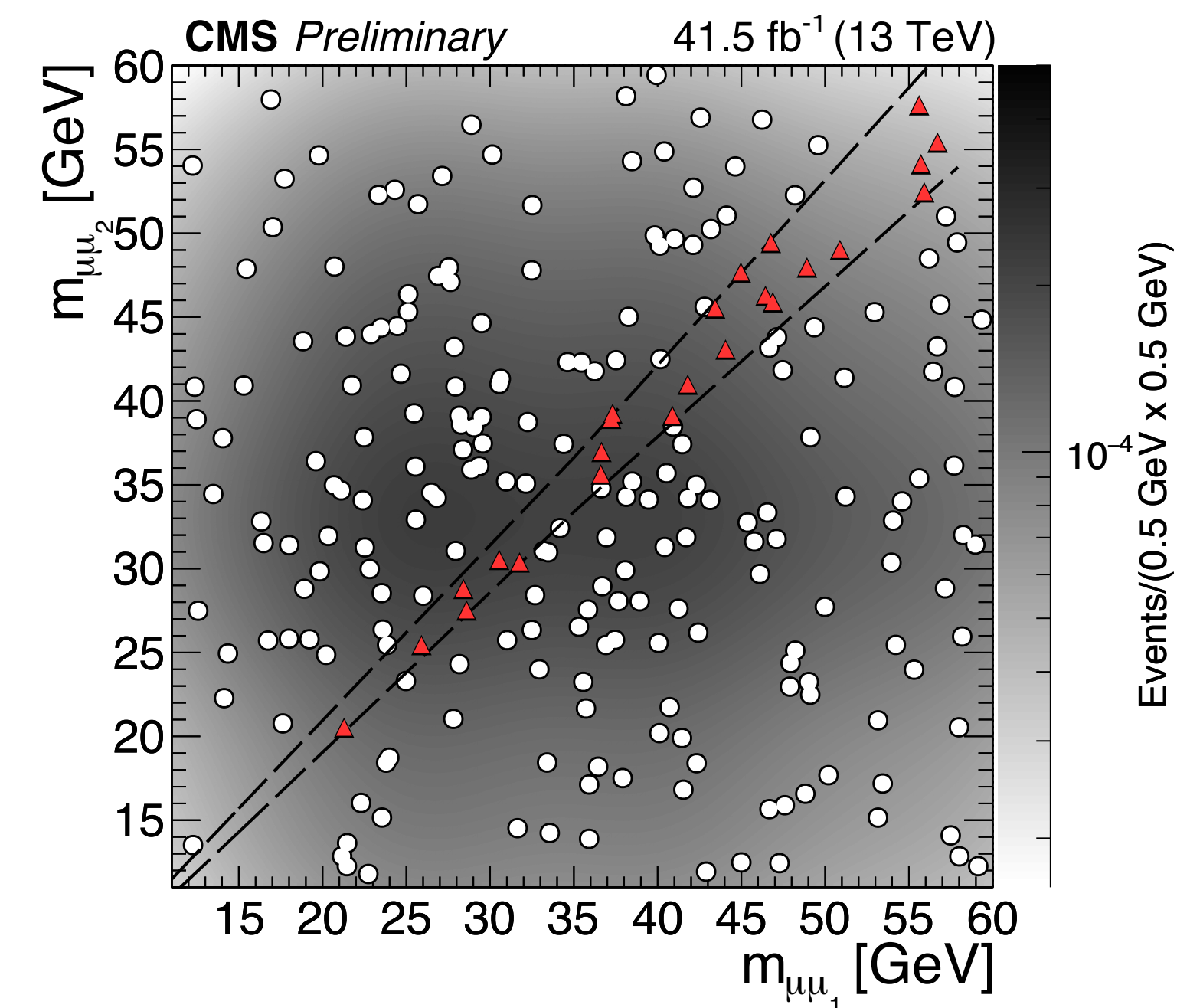
Search for diboson production in 4μ

CMS-PAS-HIG-21-004



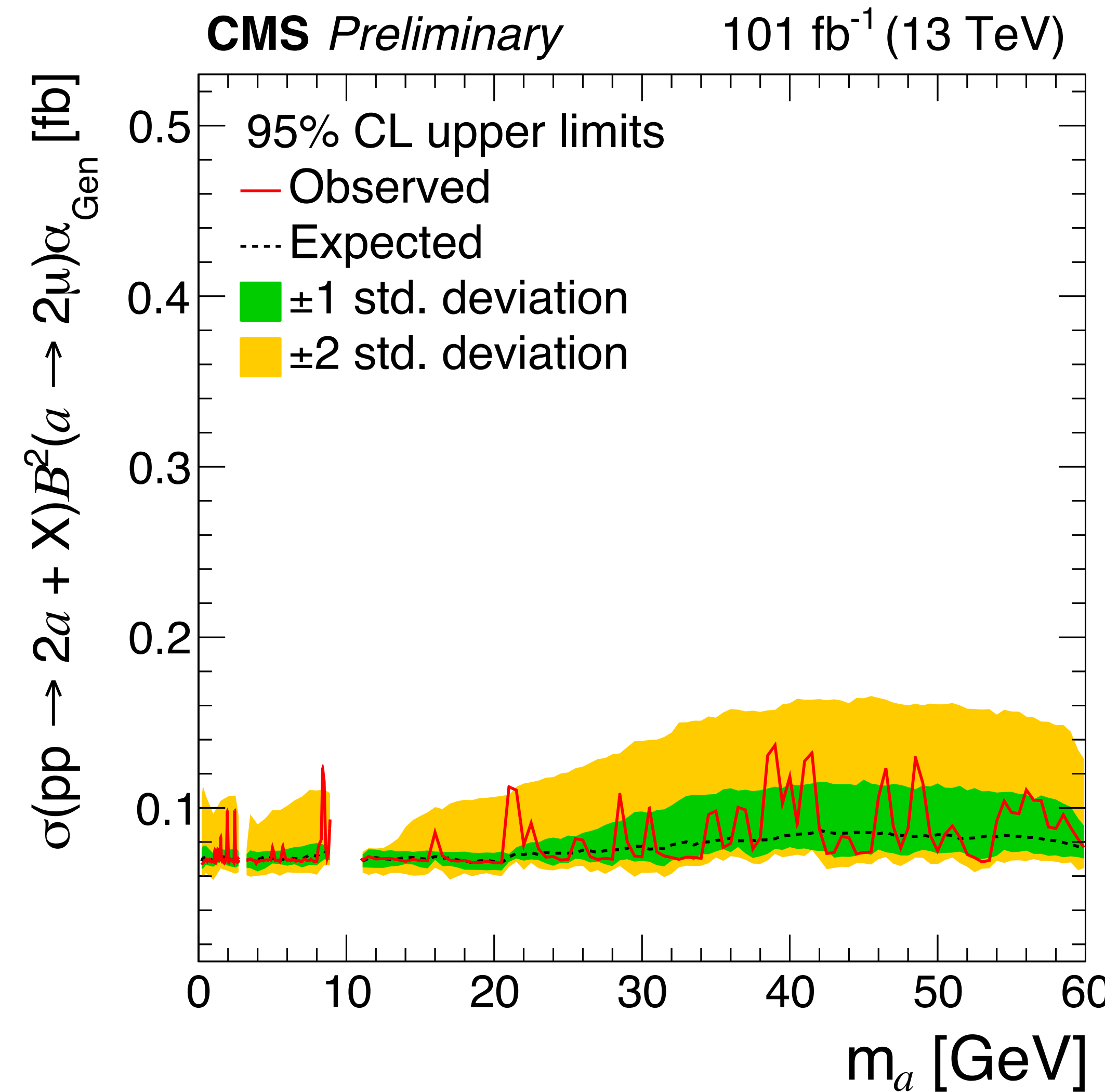
Results

- ▶ Events in SR are consistent with the expectation
- ▶ **Red triangles** are data events in the SR
- ▶ White circles are data events in the CR
- ▶ Background prediction shown in grayscale



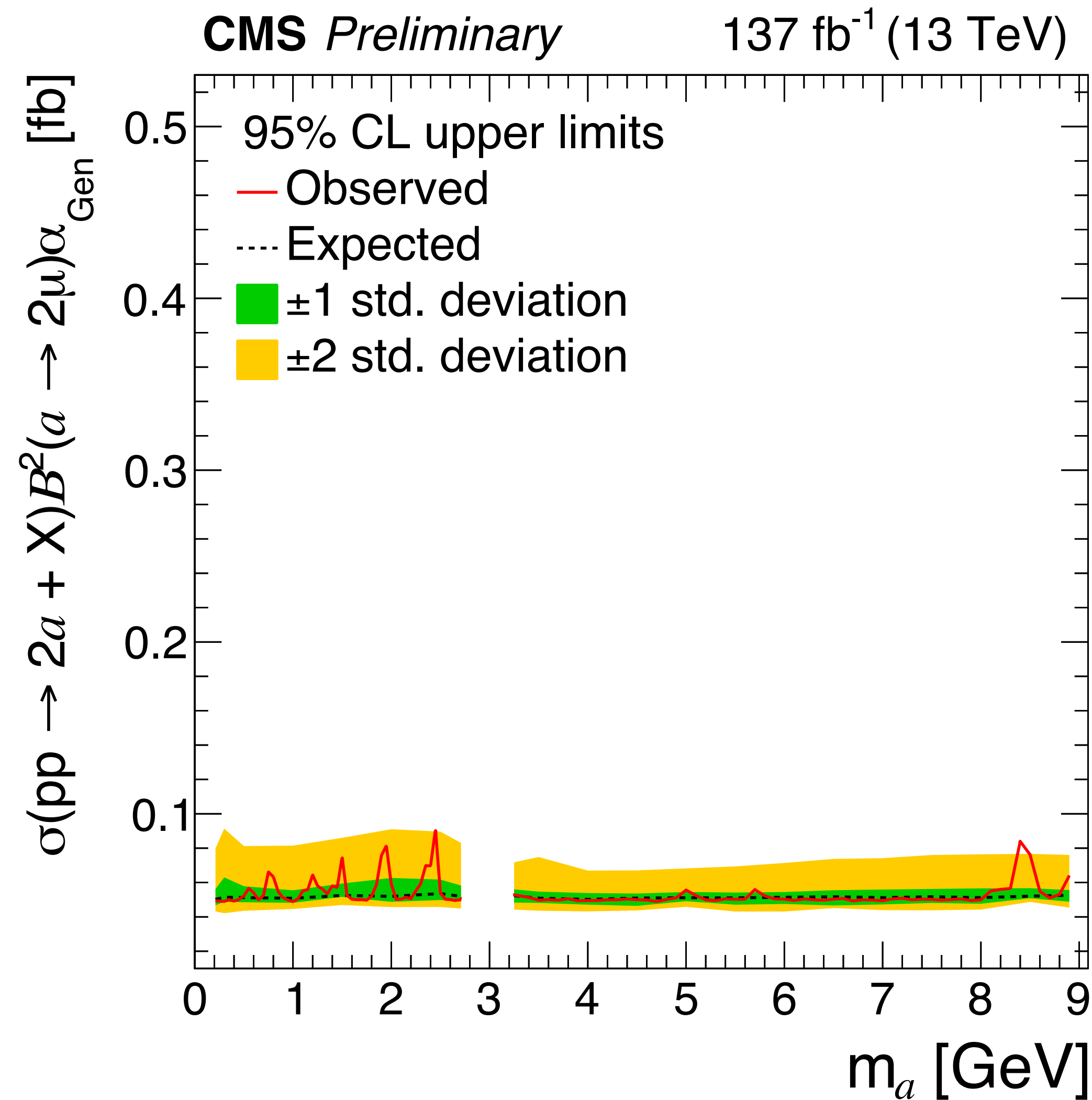
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- ▶ Model-independent limits:
 - ▶ In the range $0.2 < m_a < 60$ GeV for 2017+2018



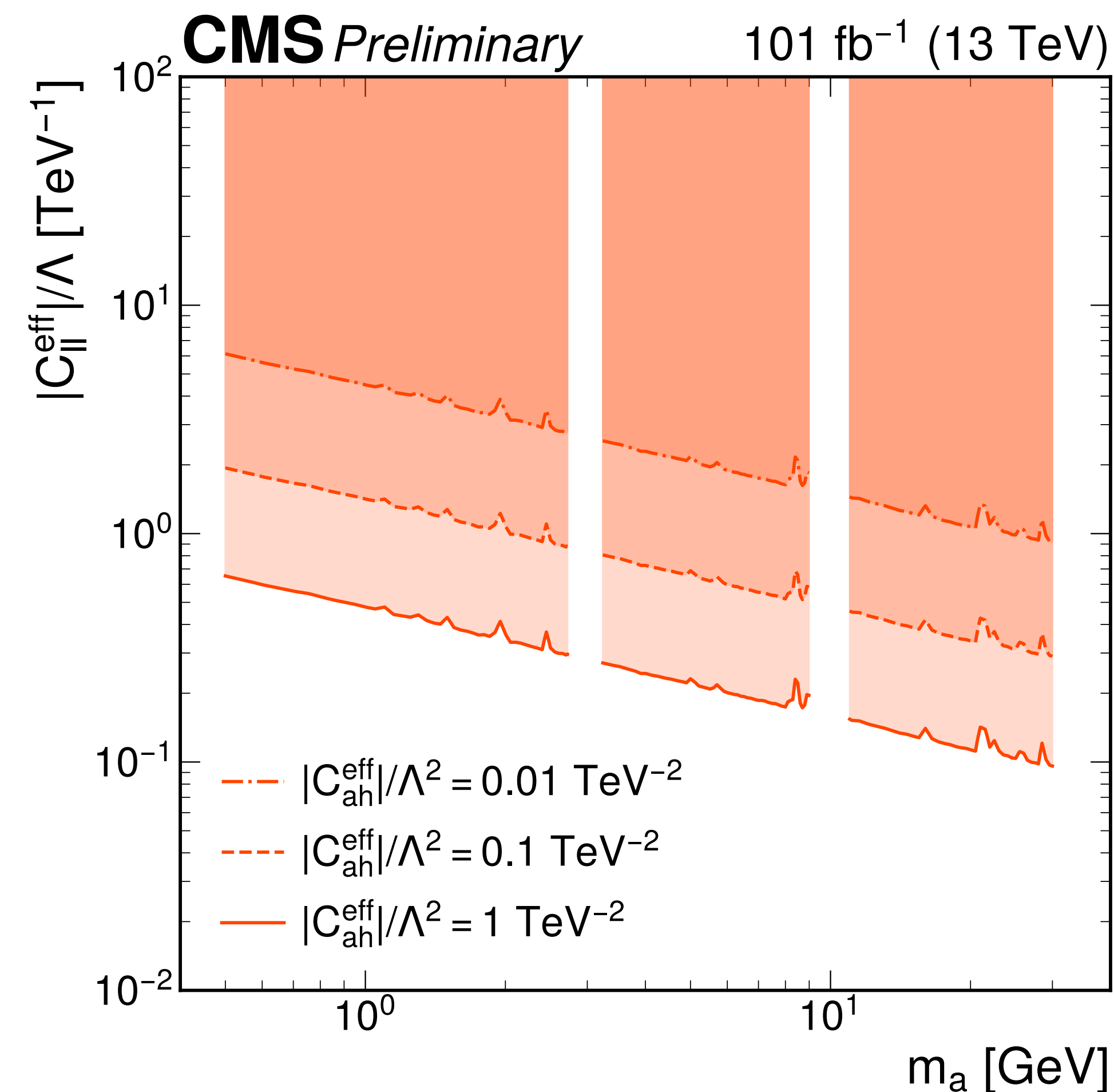
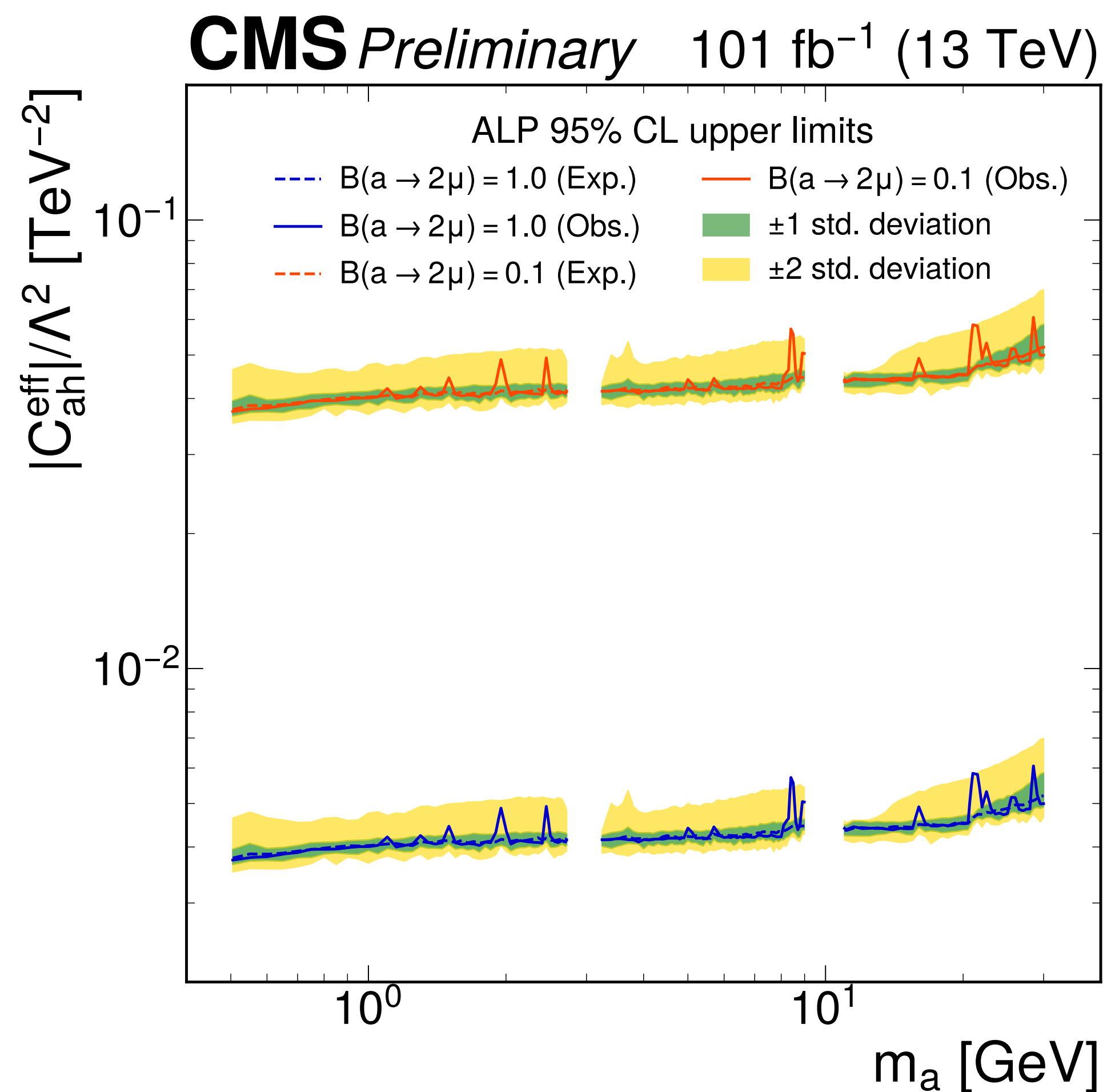
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- ▶ Model-independent limits:
 - ▶ In the range $0.2 < m_a < 60$ GeV for 2017+2018
 - ▶ In the range $0.2 < m_a < 9$ GeV, with 2016 previous results



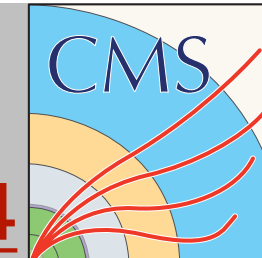
Interpretations

- ▶ Model-dependent limits:
- ▶ ALPs: limits on effective couplings



Search for diboson production in 4μ

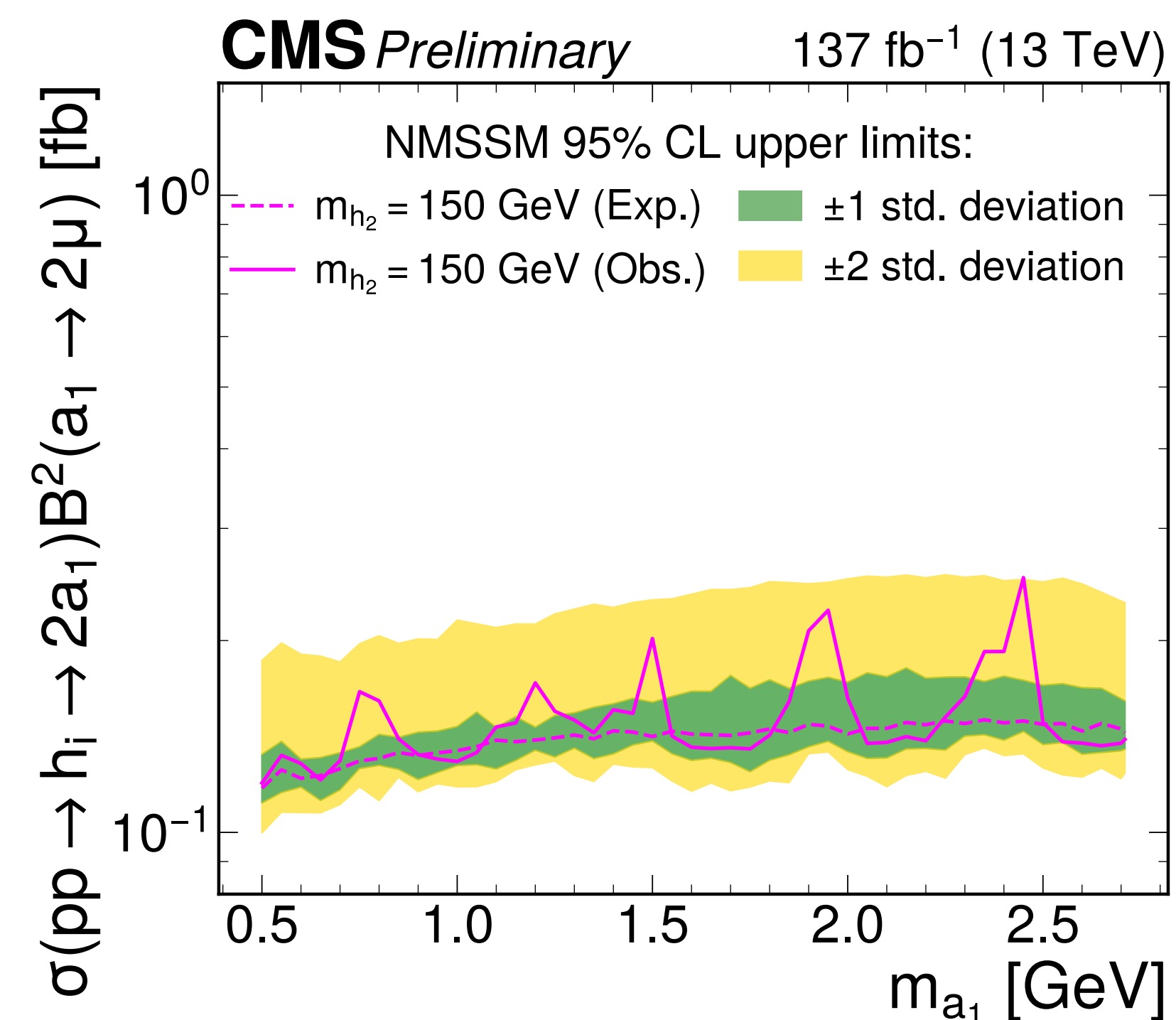
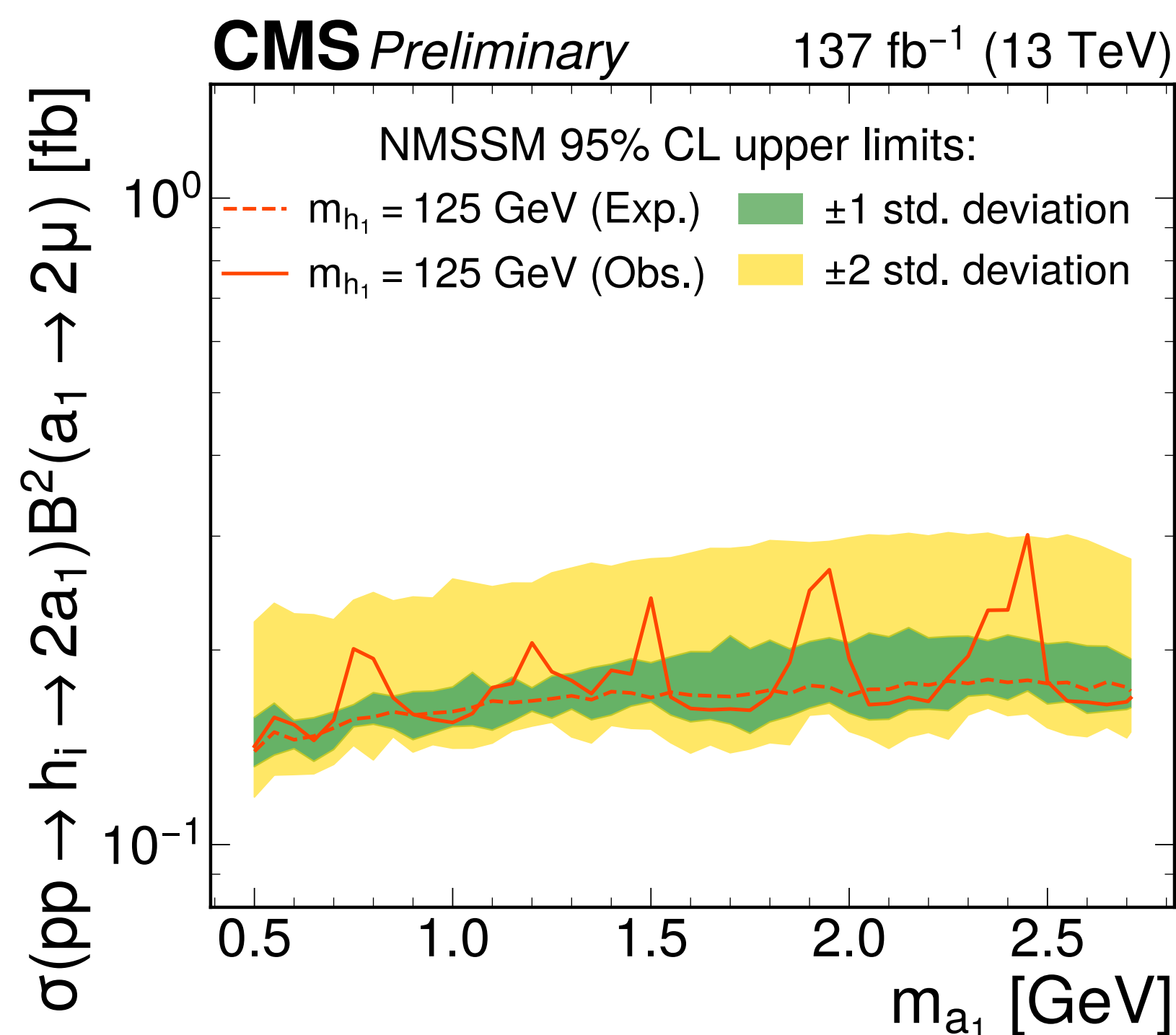
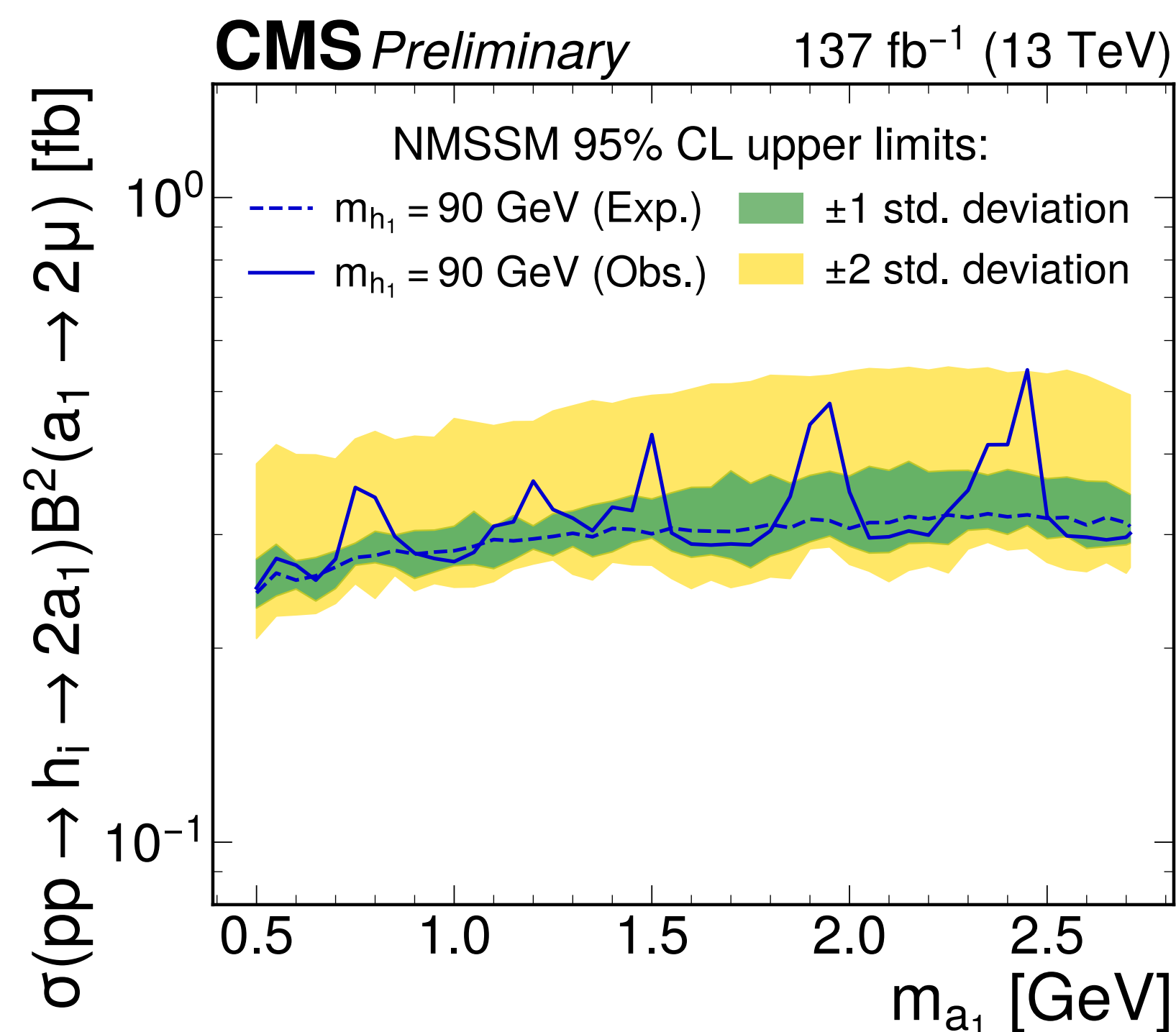
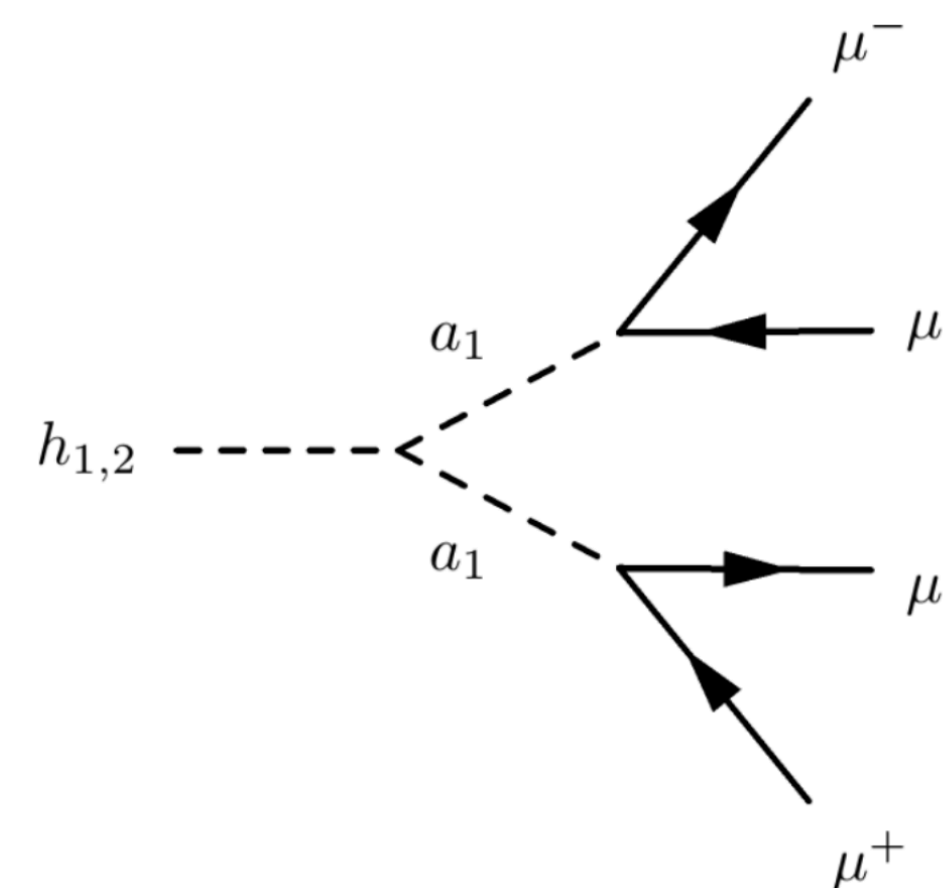
CMS-PAS-HIG-21-004



ULB

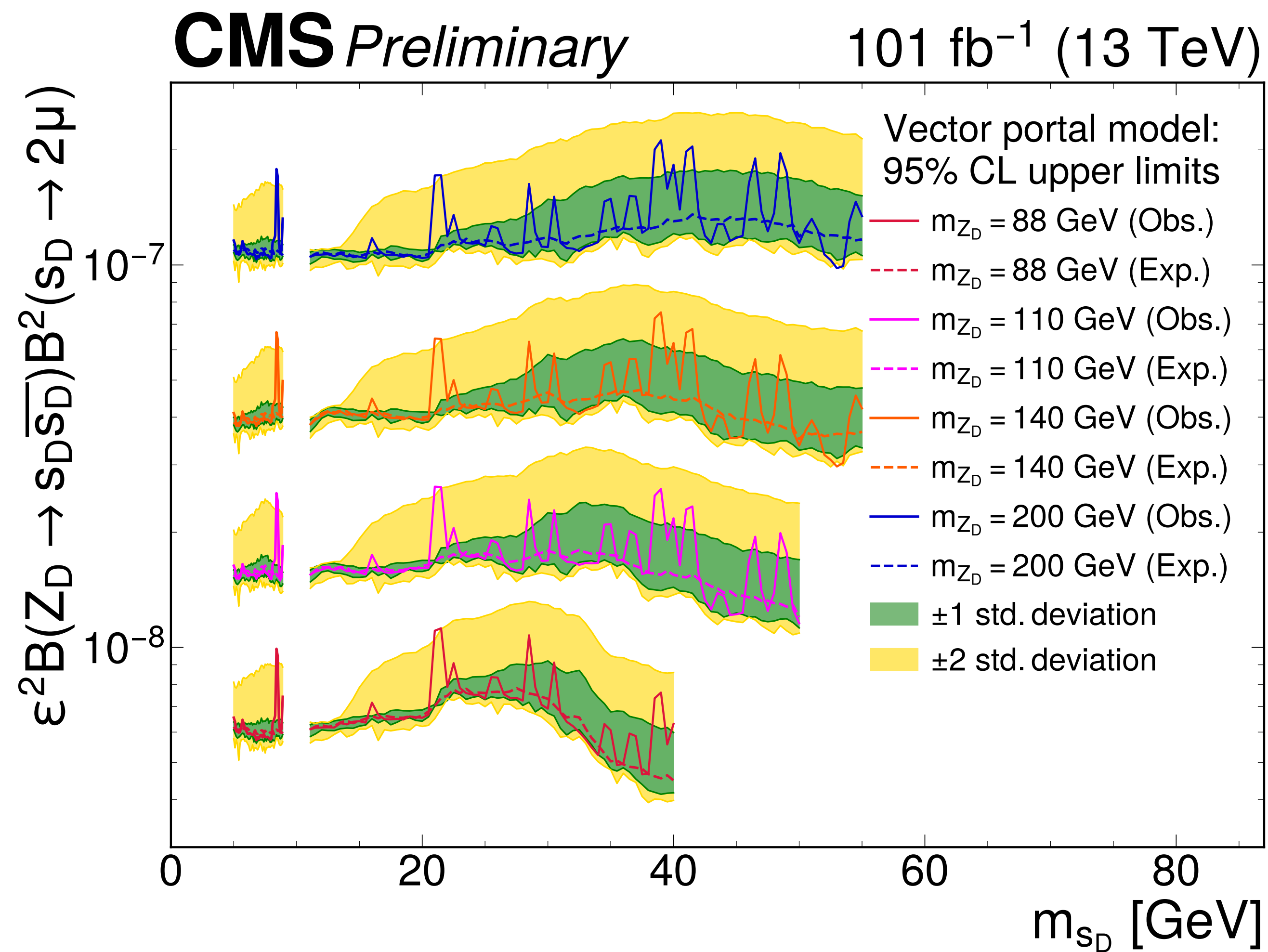
Interpretations

- ▶ Model-dependent limits:
- ▶ ALPs: limits on effective couplings
- ▶ NMSSM and vector portal models



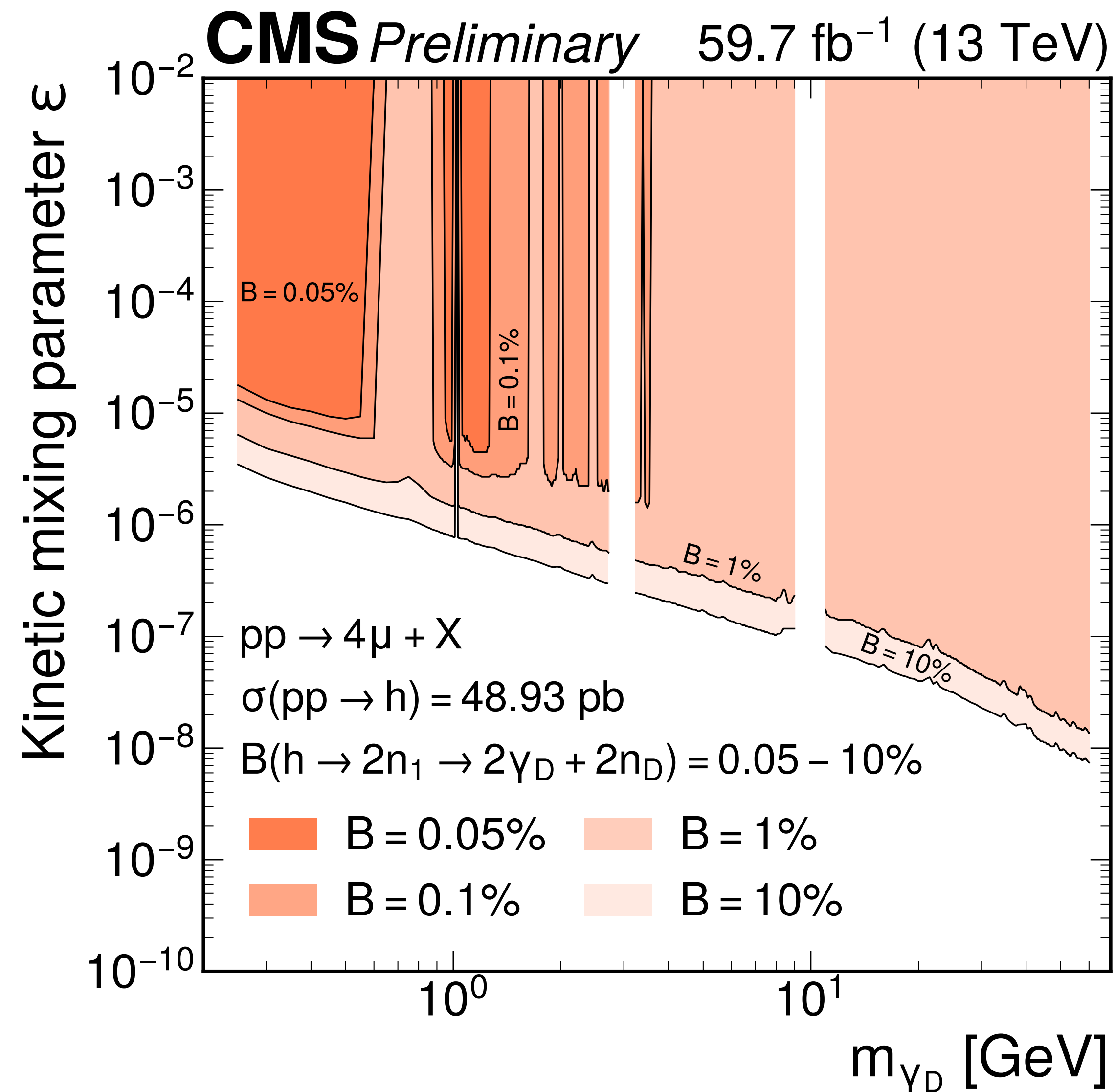
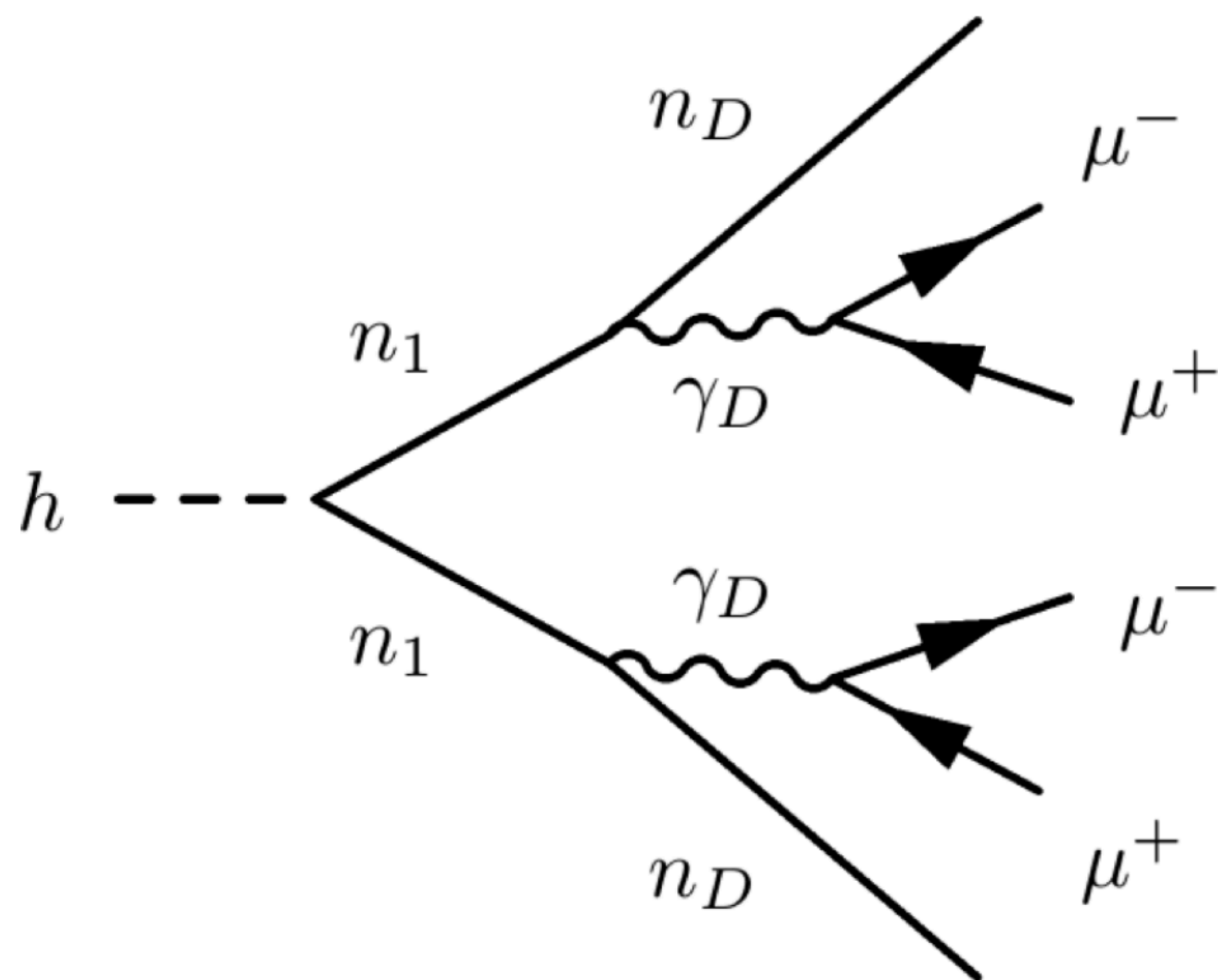
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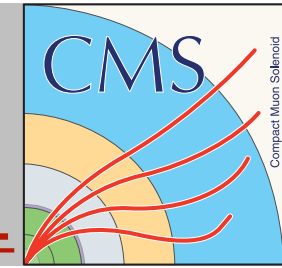
Interpretations

- ▶ Model-dependent limits:
 - ▶ ALPs: limits on effective couplings
 - ▶ NMSSM and vector portal models
 - ▶ Dark SUSY and massive dark photon ($c\tau < 10$ cm)



Search for $H \rightarrow aa \rightarrow b\bar{b}b\bar{b}$

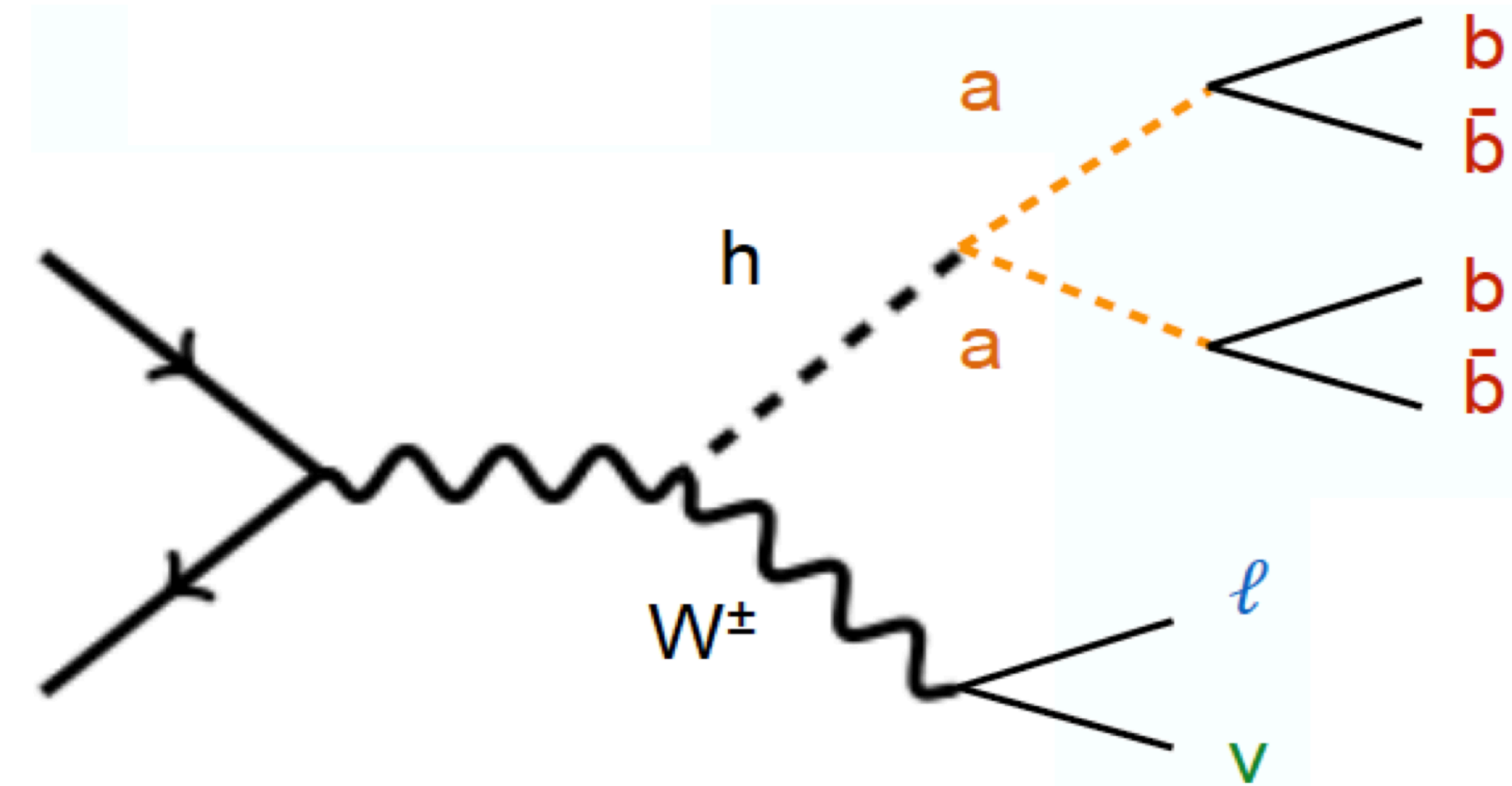
arXiv:2403.10341v1



ULB

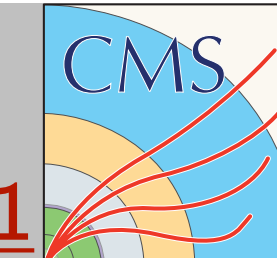
Strategy

- ▶ Final state with 4b
- ▶ Cover range $0.2 < m_a < 60$ GeV
- ▶ Associated production (VH) into 1ℓ and 2ℓ final states
- ▶ Single and dilepton triggers
- ▶ Single lepton + MET $\rightarrow W \rightarrow m_T > 50$ GeV \rightarrow suppress QCD
- ▶ Dilepton system consistent with Z boson mass \rightarrow suppress $t\bar{t}$



Search for $H \rightarrow aa \rightarrow b\bar{b}b\bar{b}$

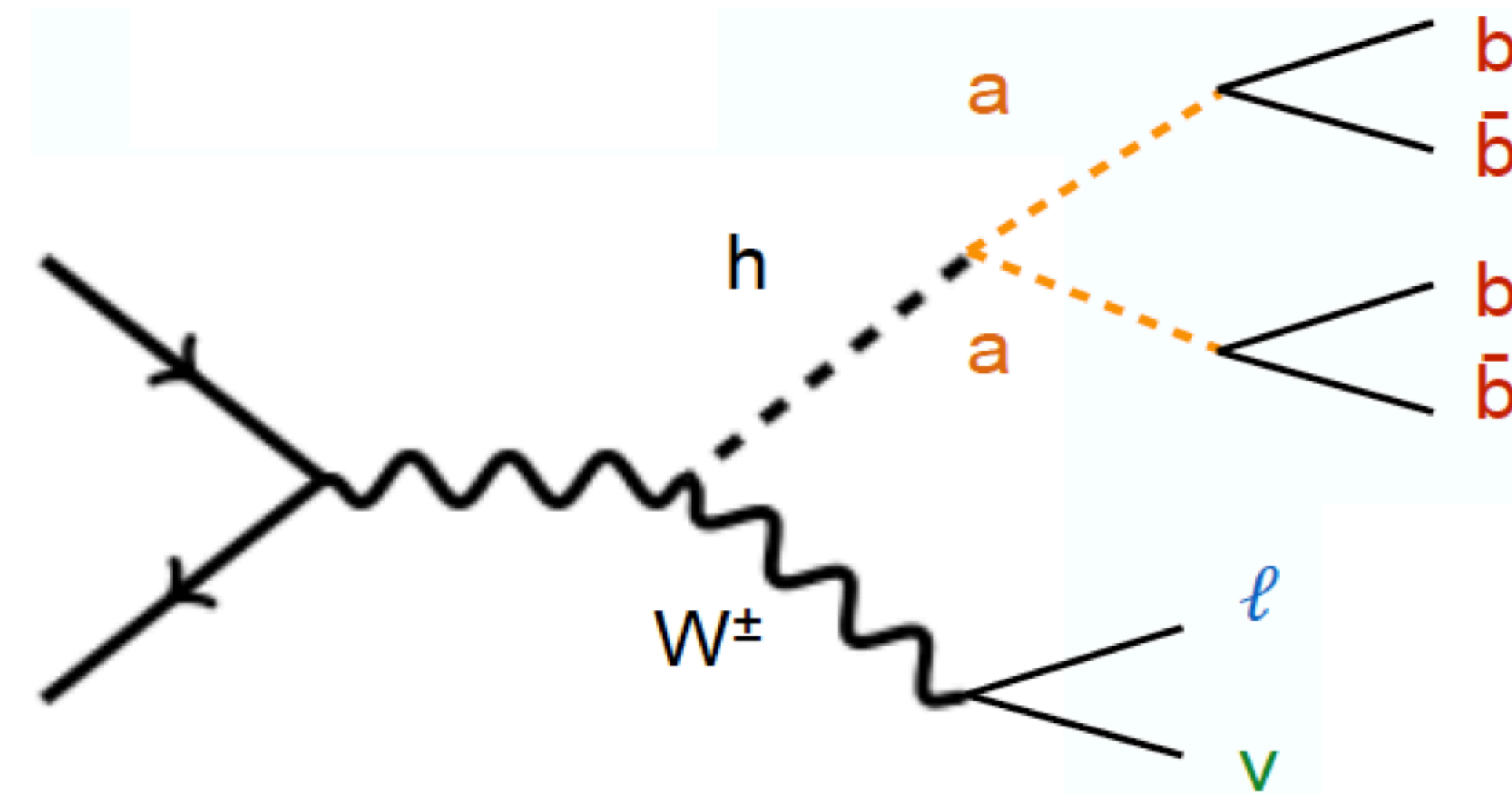
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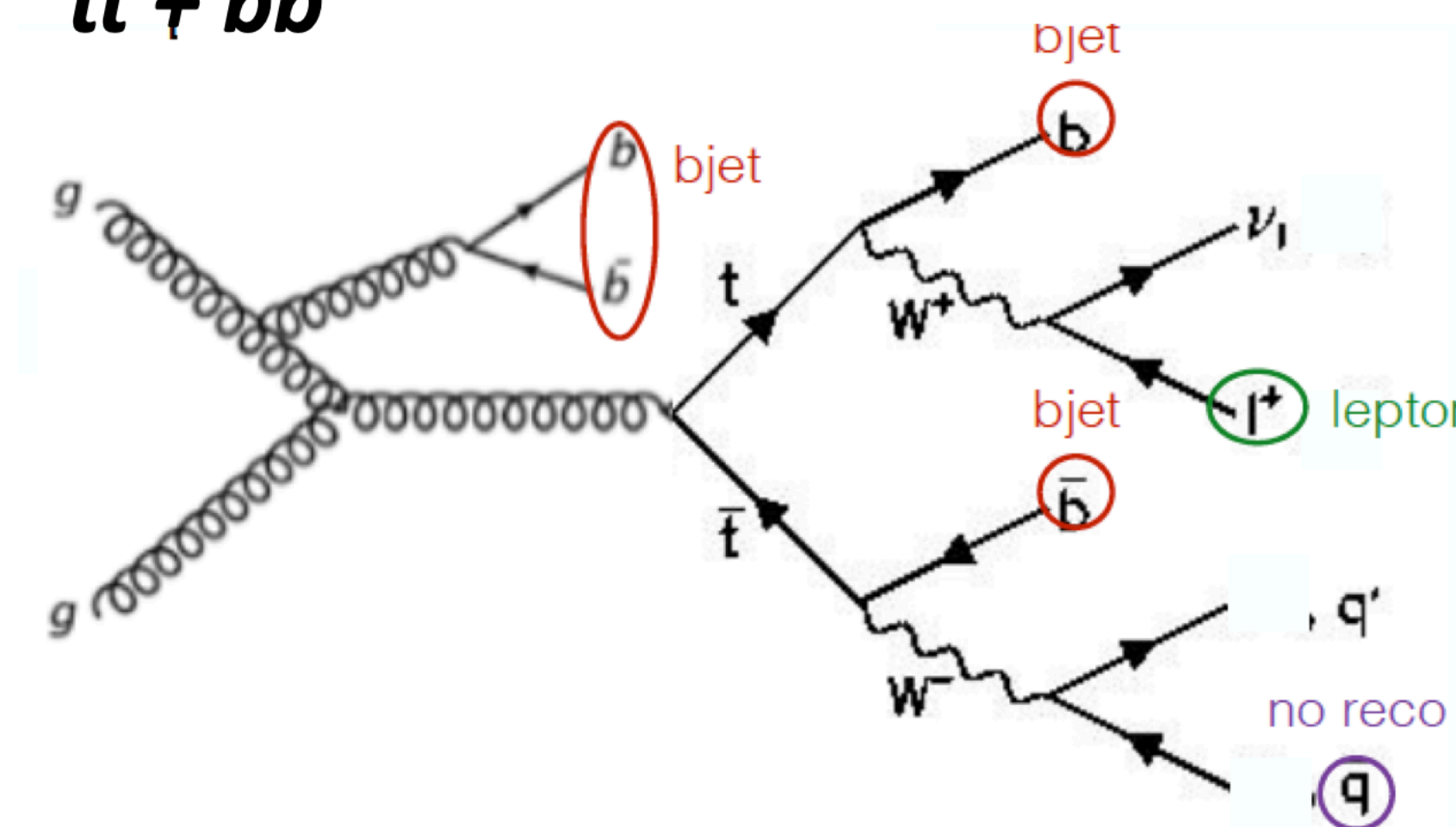
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 - ▶ Dilepton system consistent with Z boson mass \rightarrow suppress $t\bar{t}$
- ▶ Signal regions based on b-tagging and jet multiplicity
 - ▶ 4b \rightarrow resolved case
 - ▶ 3b \rightarrow boosted case and failed reconstruction
- ▶ Control regions to estimate background:
 - ▶ 1ℓ : $t\bar{t} + b\bar{b}$ and $t\bar{t} + c\bar{c}$
 - ▶ 2ℓ : $Z + jet$

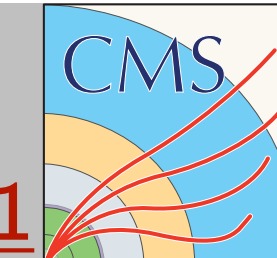


$t\bar{t} + b\bar{b}$



Search for $H \rightarrow aa \rightarrow b\bar{b}b\bar{b}$

arXiv:2403.10341v1



ULB

Control regions

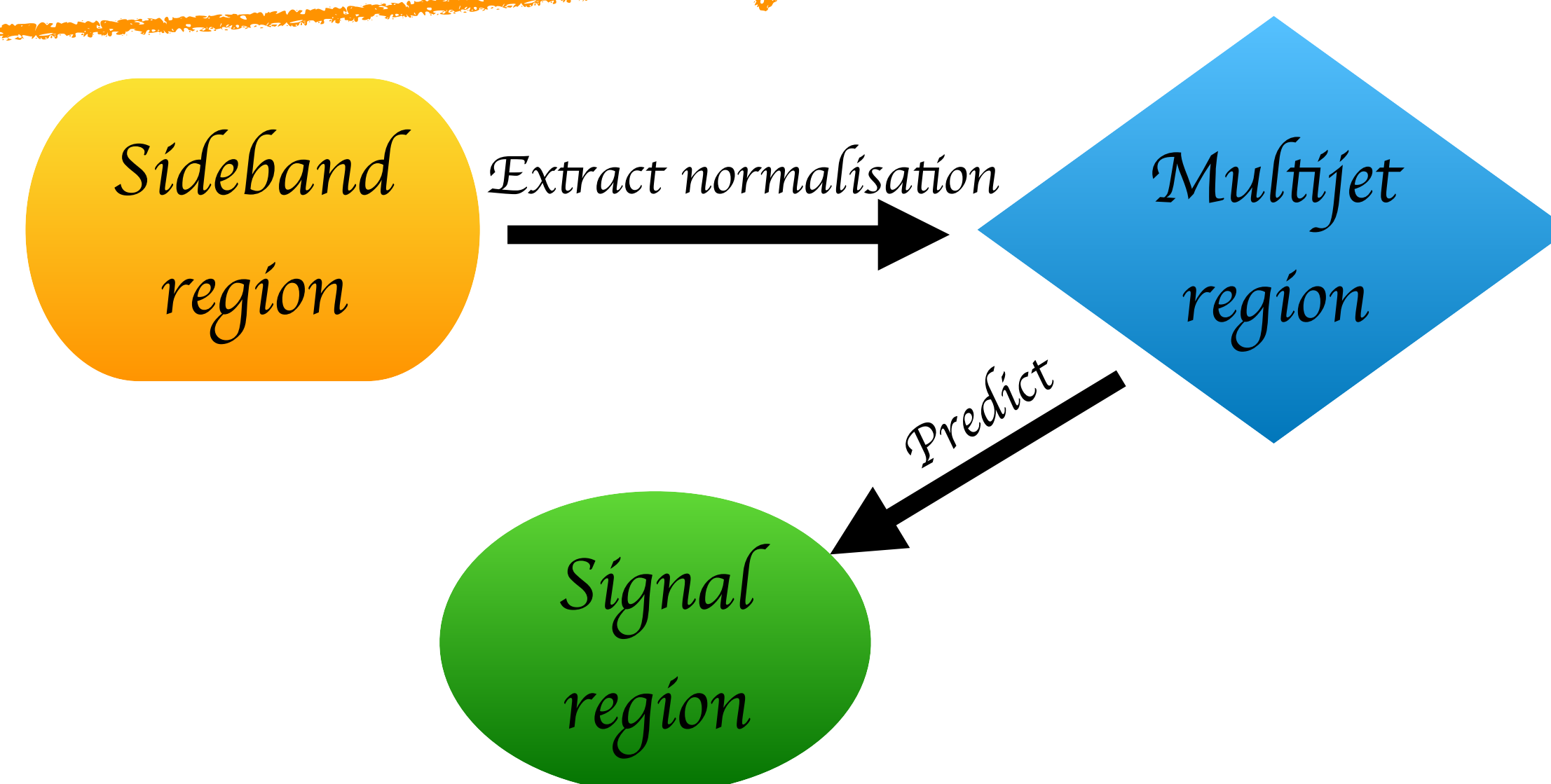
- ▶ One control region for each signal region
- ▶ Lower number of b-tagged jets
- ▶ $t\bar{t}$ + jets background
- ▶ Categorised in jet flavour (at particle level)
- ▶ Shape estimated from simulation
- ▶ Normalisation constrained by data in CR
- ▶ V + jets background
- ▶ Similar procedure as for $t\bar{t}$ + jets

Label	(N_b, N_j)	Description
WH channel		
SR (3b)	(3b, 3–4j)	3b signal region
SR (4b)	(4b, 4j)	4b signal region
CR (3b)	(2b, 3j)	W / $t\bar{t}$ + jets control region
CR (4b)	(2b, 4j)	$t\bar{t}$ + jets control region
ZH channel		
SR (3b)	(3b, $\geq 3j$)	3b signal region
SR (4b)	(4b, $\geq 4j$)	4b signal region
CR (3b)	(2b, 3j)	DY control region
CR (4b)	(2b, 4j)	DY control region

Control regions

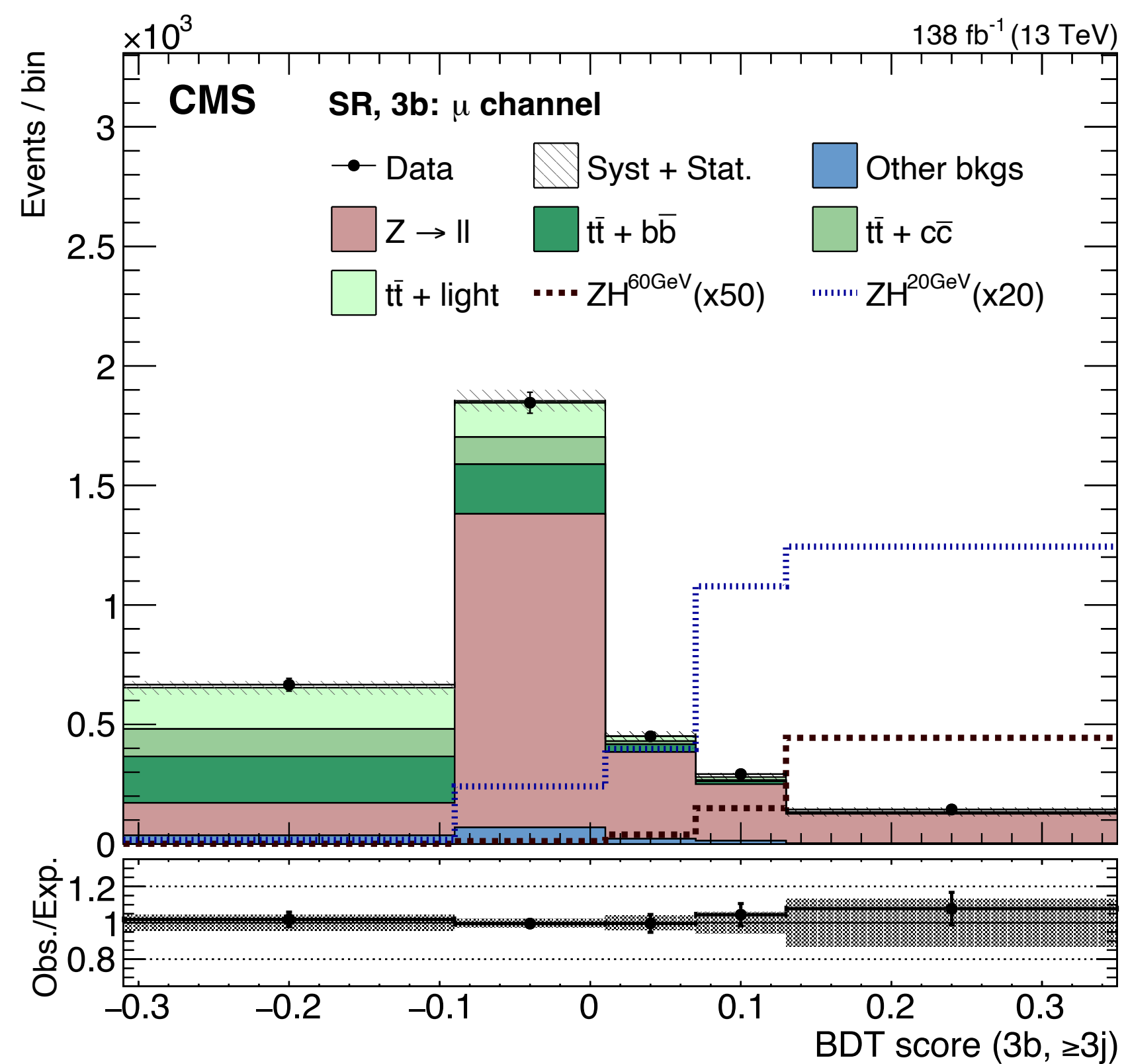
- ▶ One control region for each signal region
- ▶ Lower number of b-tagged jets
- ▶ $t\bar{t}$ + jets background
 - ▶ Categorised in jet flavour (at particle level)
 - ▶ Shape estimated from simulation
 - ▶ Normalisation constrained by data in CR
- ▶ V + jets background
 - ▶ Similar procedure as for $t\bar{t}$ + jets
- ▶ Multijet background
 - ▶ Inverted lepton isolation requirement
 - ▶ Sideband to extract normalisation

Label	(N_b, N_j)	Description
WH channel		
SR (3b)	(3b, 3–4j)	3b signal region
SR (4b)	(4b, 4j)	4b signal region
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ZH channel		
SR (3b)	(3b, $\geq 3j$)	3b signal region
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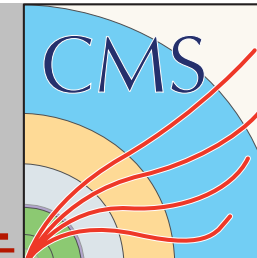
Results

- ▶ Usage of boosted decision tree (BDT)
- ▶ Enhanced sensitivity
- ▶ Trained on kinematic variables
- ▶ Separate training for each category



Search for $H \rightarrow aa \rightarrow b\bar{b}b\bar{b}$

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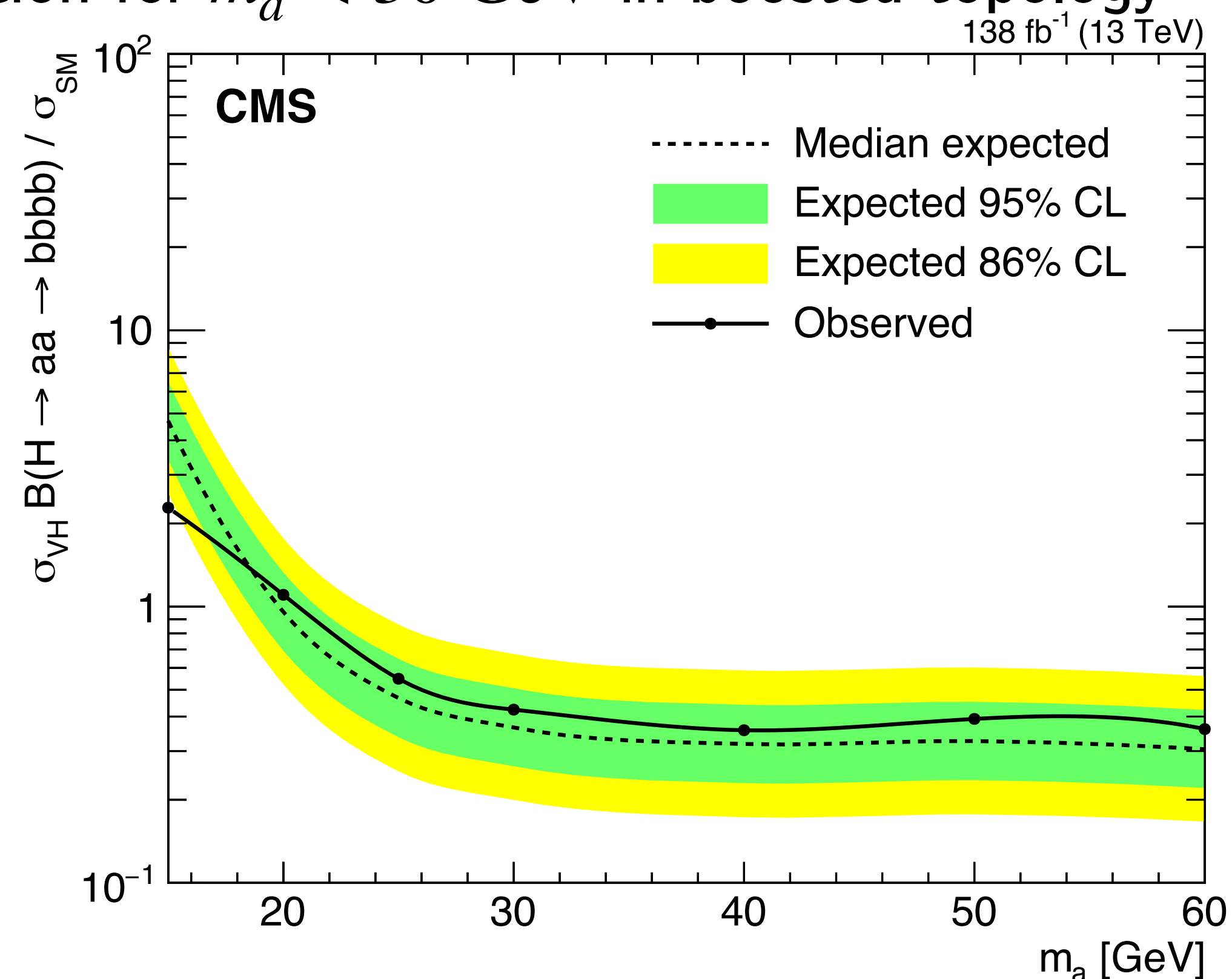
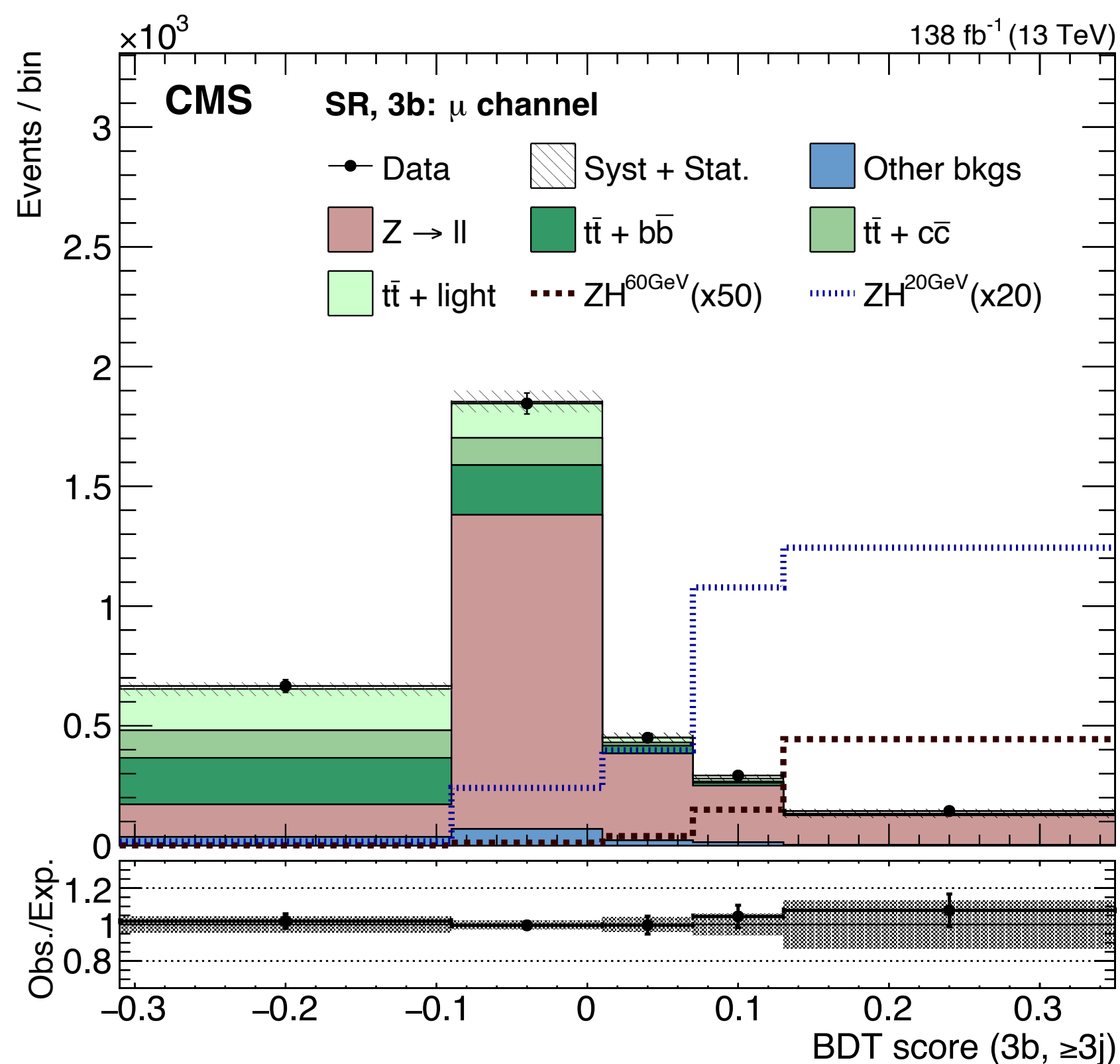


ULB

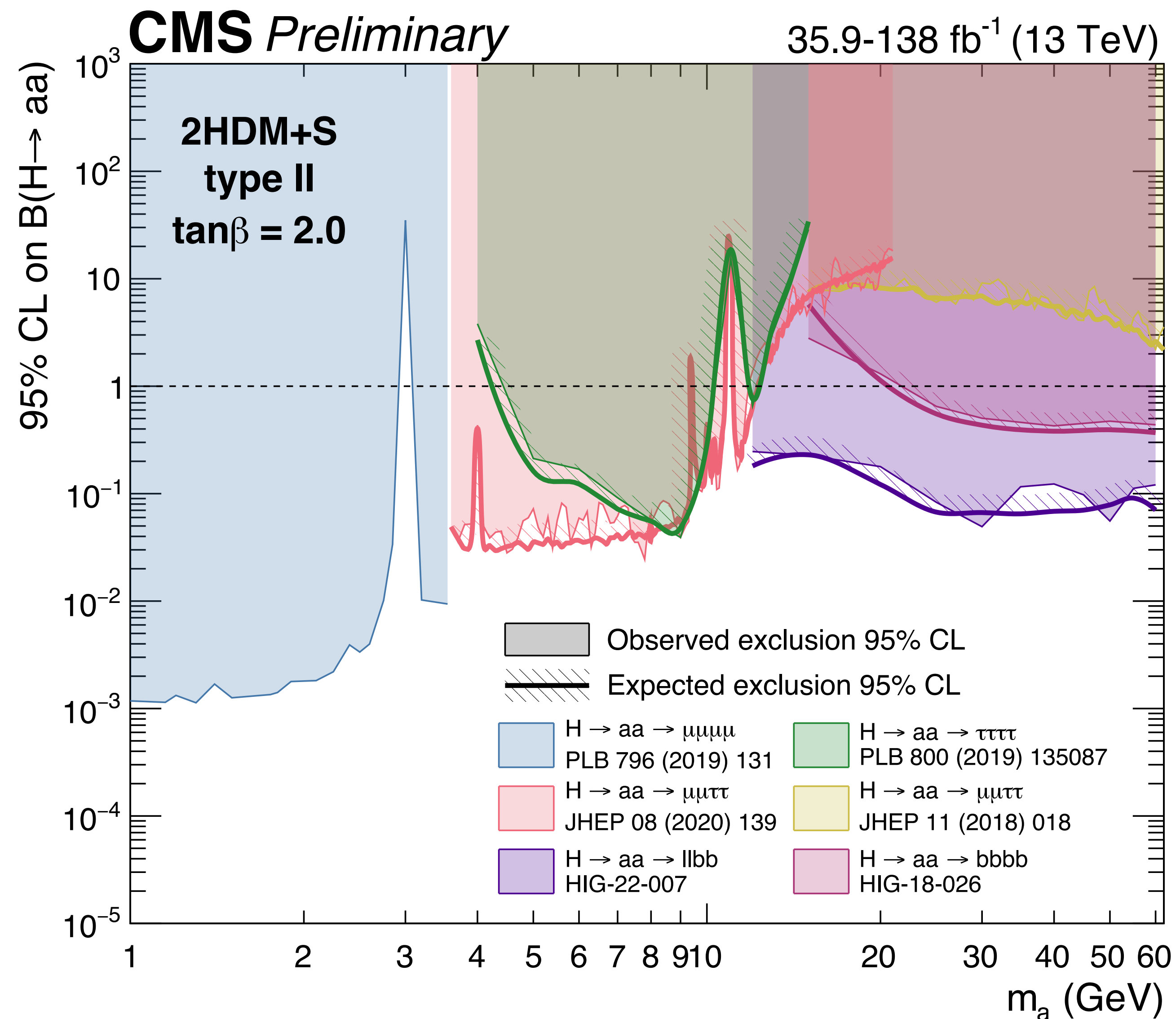
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- ▶ Enhanced sensitivity
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- ▶ Separate training for each category

- ▶ Simultaneous fit of CRs and SRs
- ▶ Statistical uncertainty dominate
- ▶ Model-independent limits
- ▶ Assume unitary branching fraction
- ▶ Degradation for $m_a < 30$ GeV in boosted topology

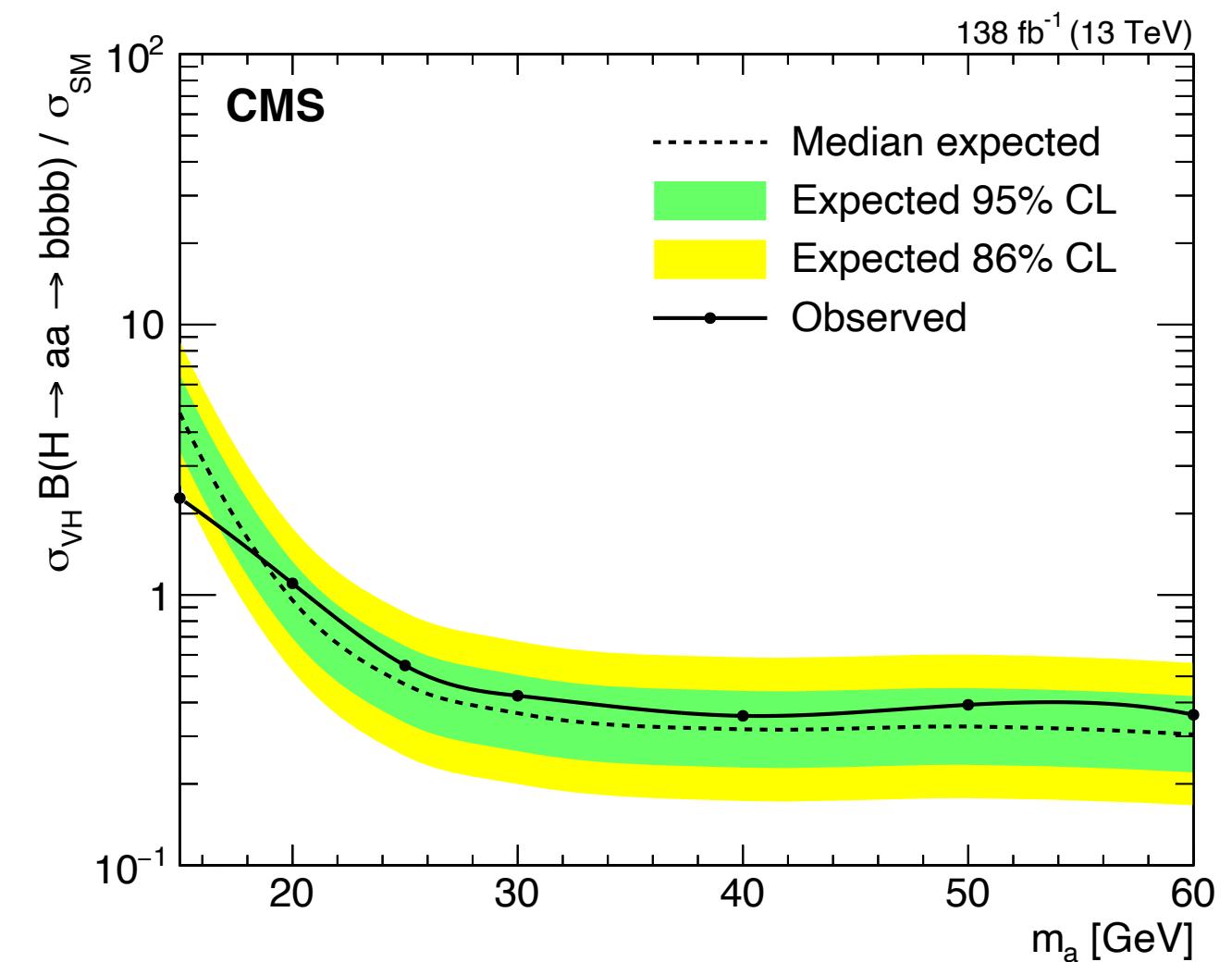
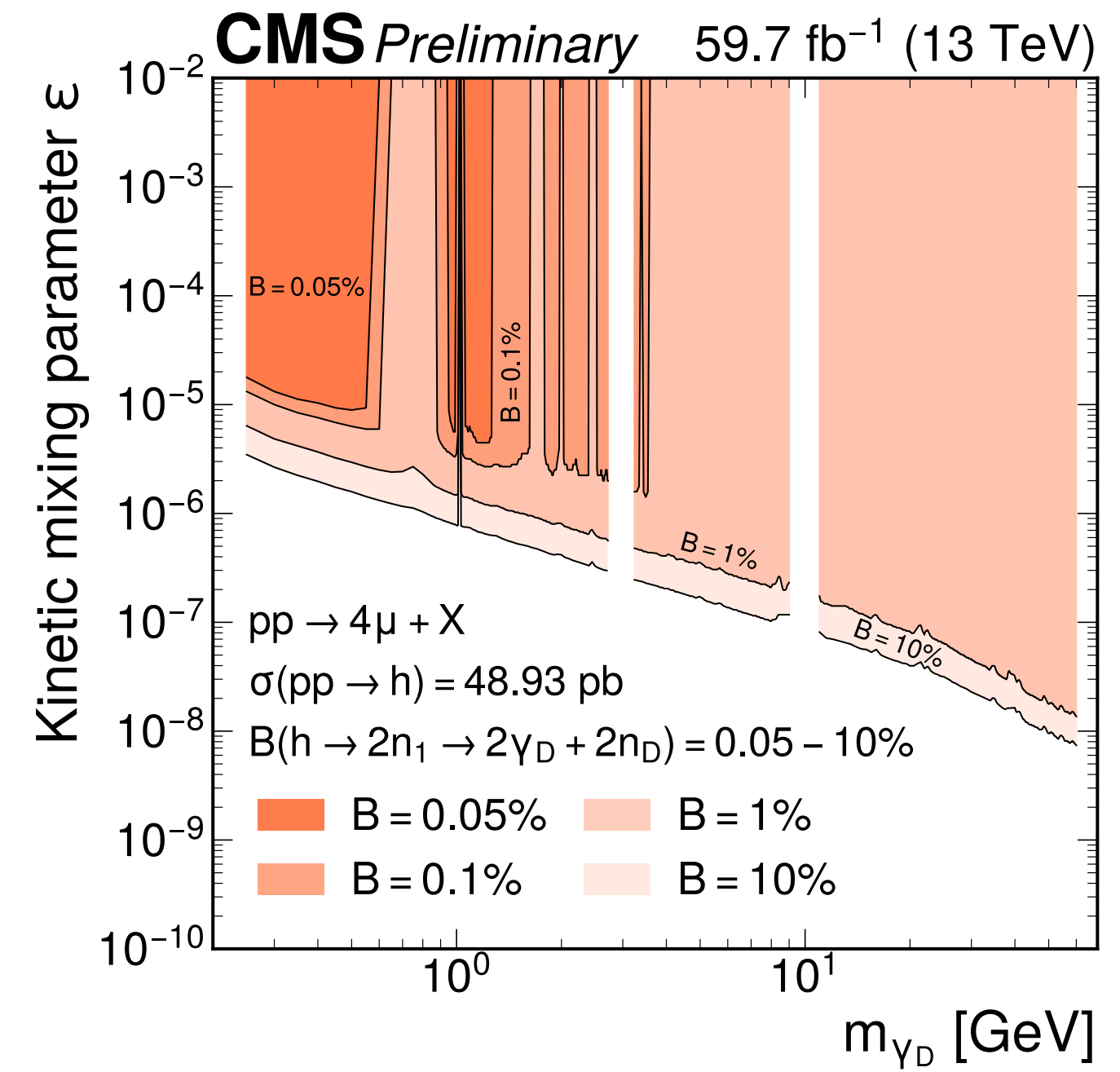


- ▶ More searches performed in CMS
- ▶ Different final states covered
- ▶ Provide complementary sensitivity
- ▶ Allow coverage of parameter space



- ▶ Presented the latest searches for exotic Higgs decays within CMS
 - ▶ Focus on $0.2 < m_a < 60$ GeV
 - ▶ Model independent results
 - ▶ Model specific interpretations

- ▶ Stay tune for more results:
 - ▶ new Run3 data to provide further insight
 - ▶ Improvements from the Run2 experience
 - ▶ unexplored final states



Thank you for your attention!