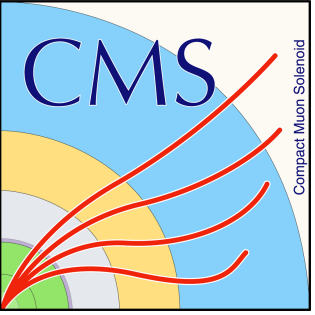
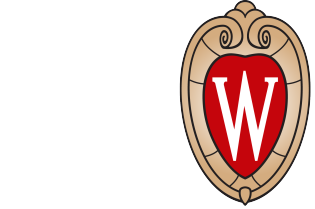




WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

Search for h(125)→aa in CMS data

Cécile Caillol (University of Wisconsin-Madison)

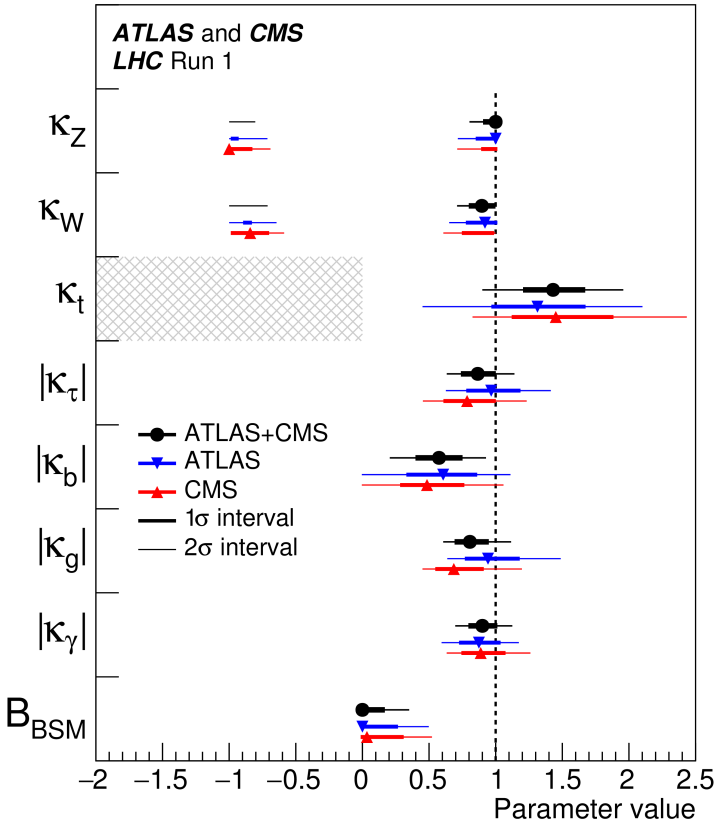
On behalf of the CMS Collaboration

Moriond EWK 2018

Exotic h boson decays

What are the motivations for the existence of exotic h(125) decays?

- The scalar sector is the least known SM sector
- The h boson has a very narrow width: even small couplings to new particles could lead to sizeable B(h→BSM)
- There is no strong reason such decays do not exist
- The scalar sector could be a portal to dark matter
- Easily integrable in various models compatible with all LHC measurements so far (2HDM+S including the NMSSM, dark matter, …)



Which final states?

a→bb

+ **Large BR** if couplings proportional to fermion mass
- Hard to trigger
- Low identification efficiency
- Large jet-backgrounds
- High p_T thresholds

a→μμ

+ Excellent **mass resolution**
+ Easy to trigger
+ Easy identification, with low p_T thresholds (> 5 GeV)
+ Open for any $m_a > 2m_\mu$
- Low BR if couplings proportional to fermion mass

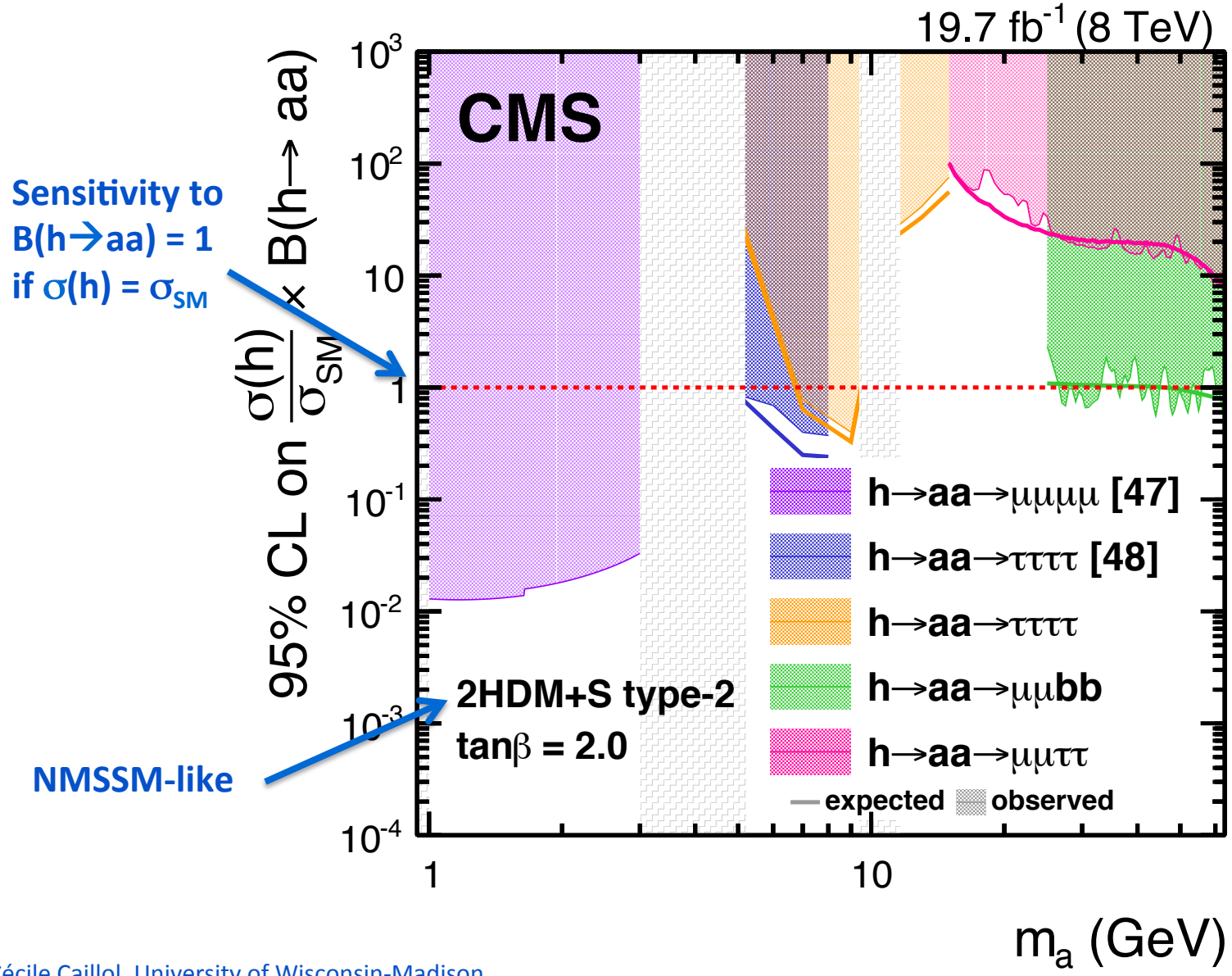
a→ττ

+ **Large BR** if mass-proportional couplings
+ Possible to **trigger** on leptonic τ decays
- Low τ_h identification efficiency, with high p_T thresholds (> 20 GeV)

SM-like scalar couplings:
B(a→bb) ~ 9 B(a→ττ) ~ 1700 (a→μμ)

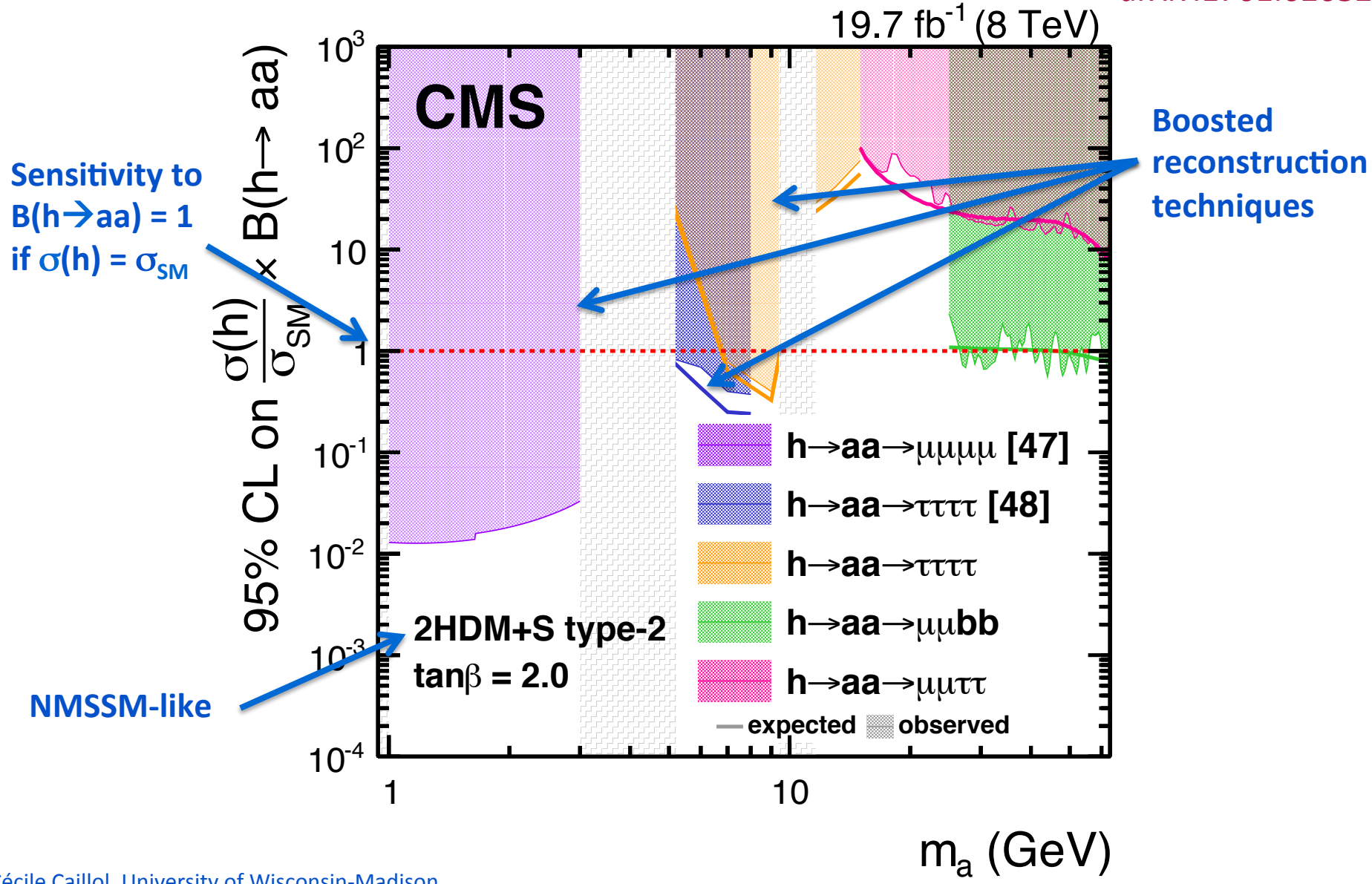
Run-1 CMS results

arXiv:1701.02032



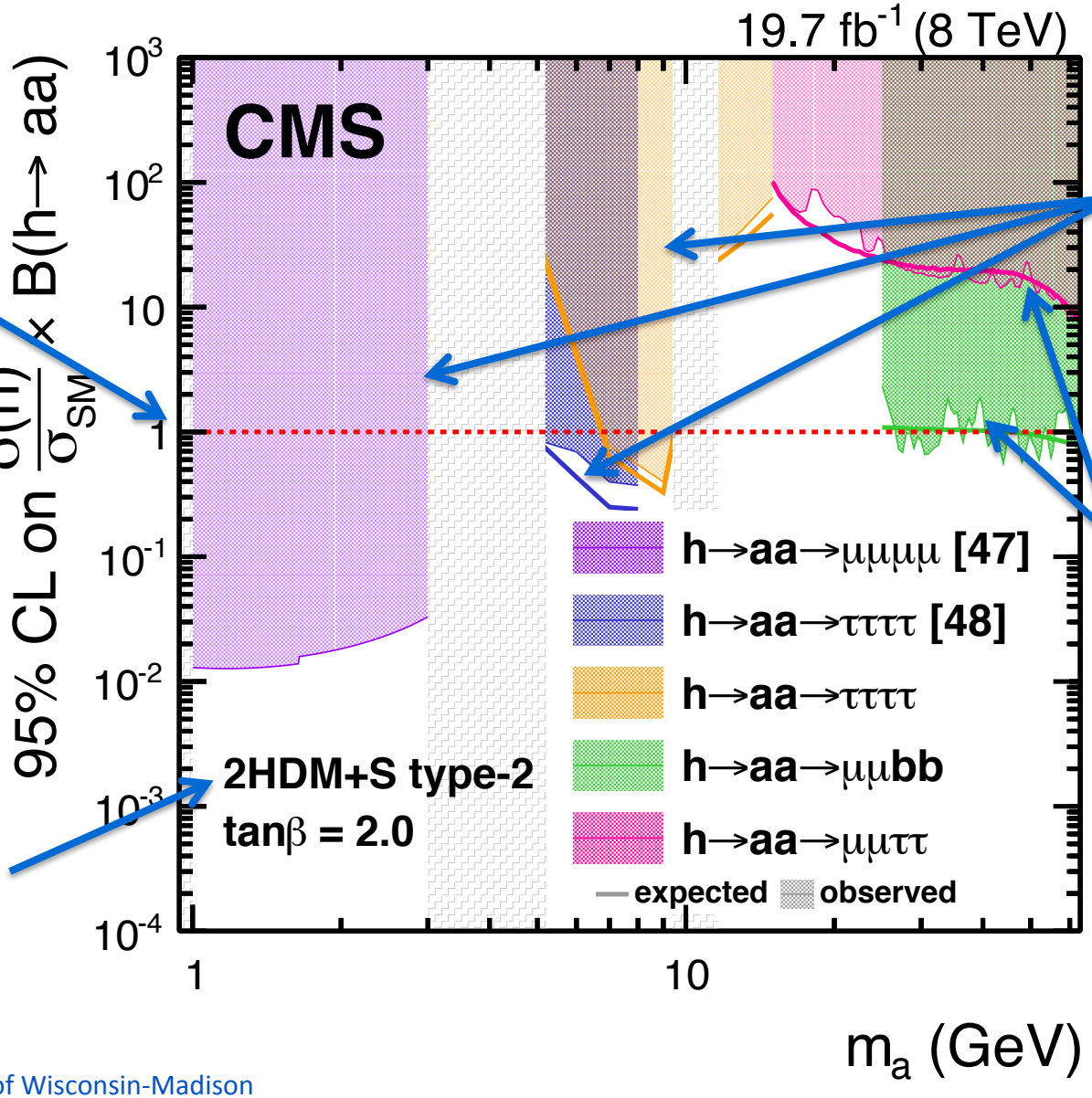
Run-1 CMS results

arXiv:1701.02032



Run-1 CMS results

arXiv:1701.02032



Sensitivity to B(h→aa) = 1 if $\sigma(h) = \sigma_{SM}$

NMSSM-like

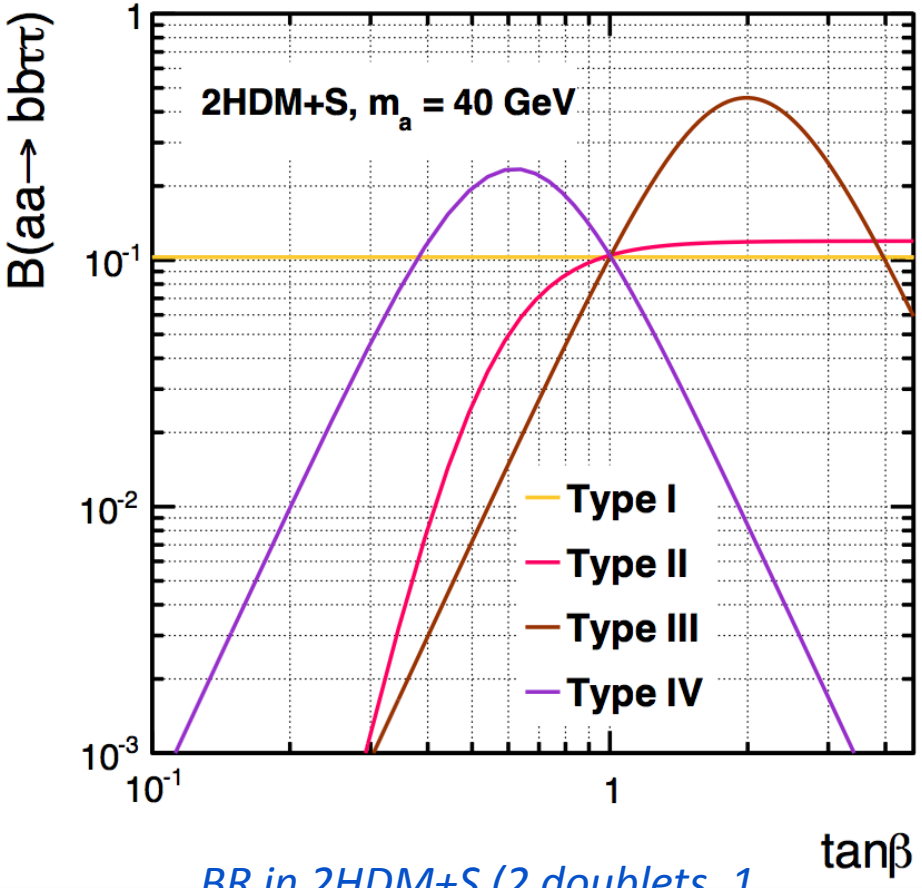
Boosted reconstruction techniques

Well-separated decay products

New run-2 result: h→aa→bbττ

- If B(a→ff) α m_f^2:
  - Dominant decay is a→bb
  - Subleading decay is a→ττ
- h→aa→4b decays are difficult to trigger (4 soft b jets), except in VH production
- h→aa→2b2τ events can be **triggered in ggF** based on the leptonic decay of one of the τ
- In the NMSSM, B(aa→2b2τ) ~ 10-15%

CMS-PAS-HIG-17-024

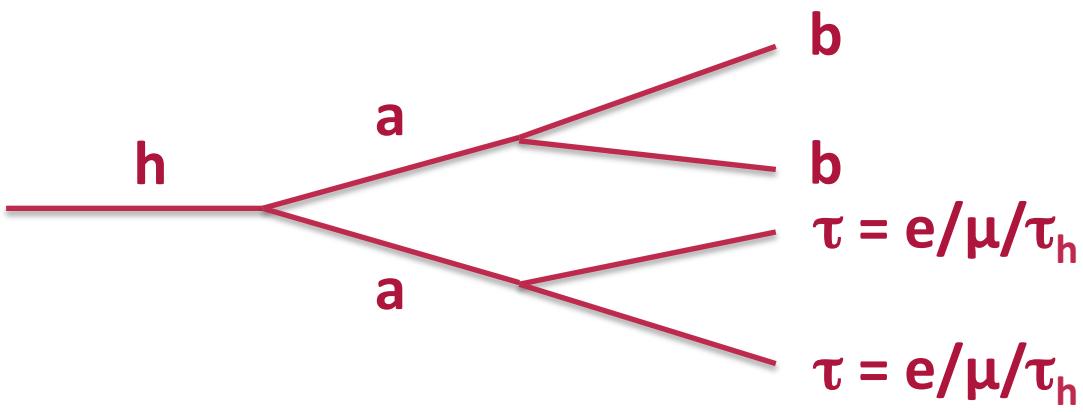


BR in 2HDM+S (2 doublets, 1 singlet, 7 (pseudo)scalars)
The NMSSM is a type II 2HDM+S

Analysis overview

- 3 di-τ final states: **$e\tau_h$, $\mu\tau_h$, $e\mu$**
  - $\tau_h\tau_h$ discarded because of high trigger thresholds, ee and $\mu\mu$ discarded because of low BR and large backgrounds

- At least **1 b tagged jet** ($p_T > 20$ GeV) in addition to the leptons:
  - Most signal events only have one b tagged jet because the generated b jets are too soft



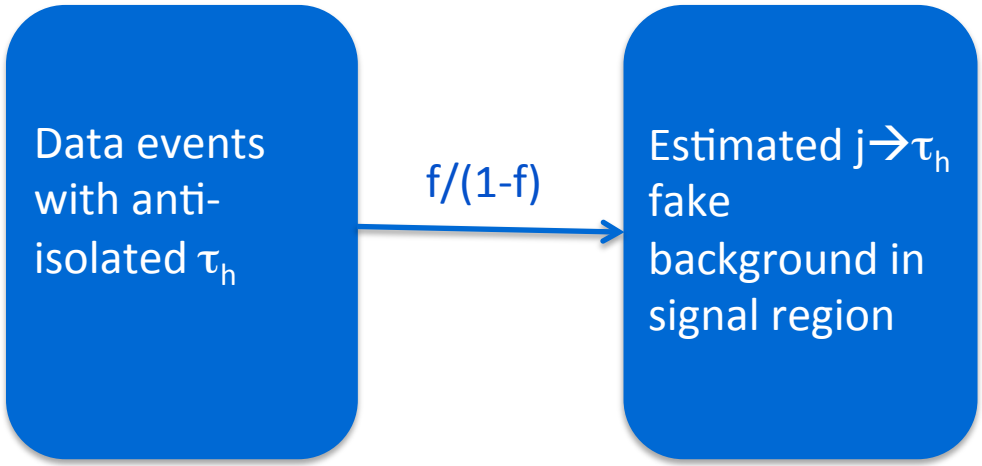
Background estimation

- **ttbar**: NLO Powheg
- **Z→ee/μμ/ττ:** LO Madgraph
  - Corrections for Z p_T spectrum derived from data with Z→μμ + 1 b events
  - Corrections for m_{bll} derived from data with Z→μμ + 1 b events
- **SM Higgs boson** processes considered as backgrounds (H→ττ, ttH, …)
- **Single top** and **diboson**: Powheg/aMC@NLO
- **W+jets**: LO Madgraph
  - In the $e\tau_h$ and $\mu\tau_h$ final state it is estimated from data (see next slide)
- **QCD multijet** estimated from same-sign data (data minus all other processes), rescaled by an OS/SS scale factor
  - In the $e\tau_h$ and $\mu\tau_h$ final state it is estimated from data (see next slide)

Background estimation – $j \rightarrow \tau_h$ fakes

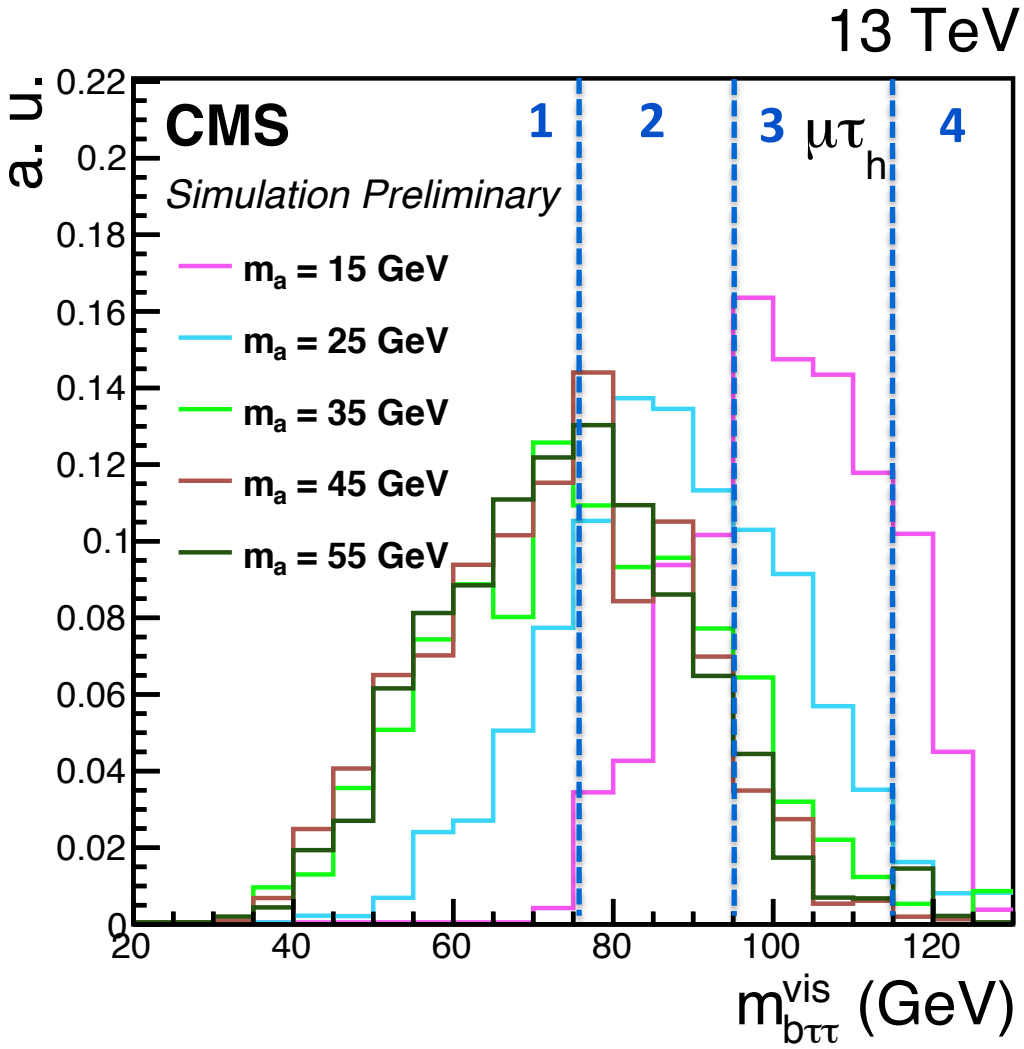
- Events with $j \rightarrow \tau_h$ fakes estimated from data:
  - W+jets, QCD, ttbar semi-hadronic, …
- $j \rightarrow \tau_h$ fake rate measured in data in $Z \rightarrow \mu\mu$ + jets events, and parameterized as a function of the τ_h p_T
- Fake rates applied to events with anti-isolated τ_h

$$f(p_T) = \frac{\text{jets passing } \tau_h \text{ isolation}}{\text{All jets}}$$



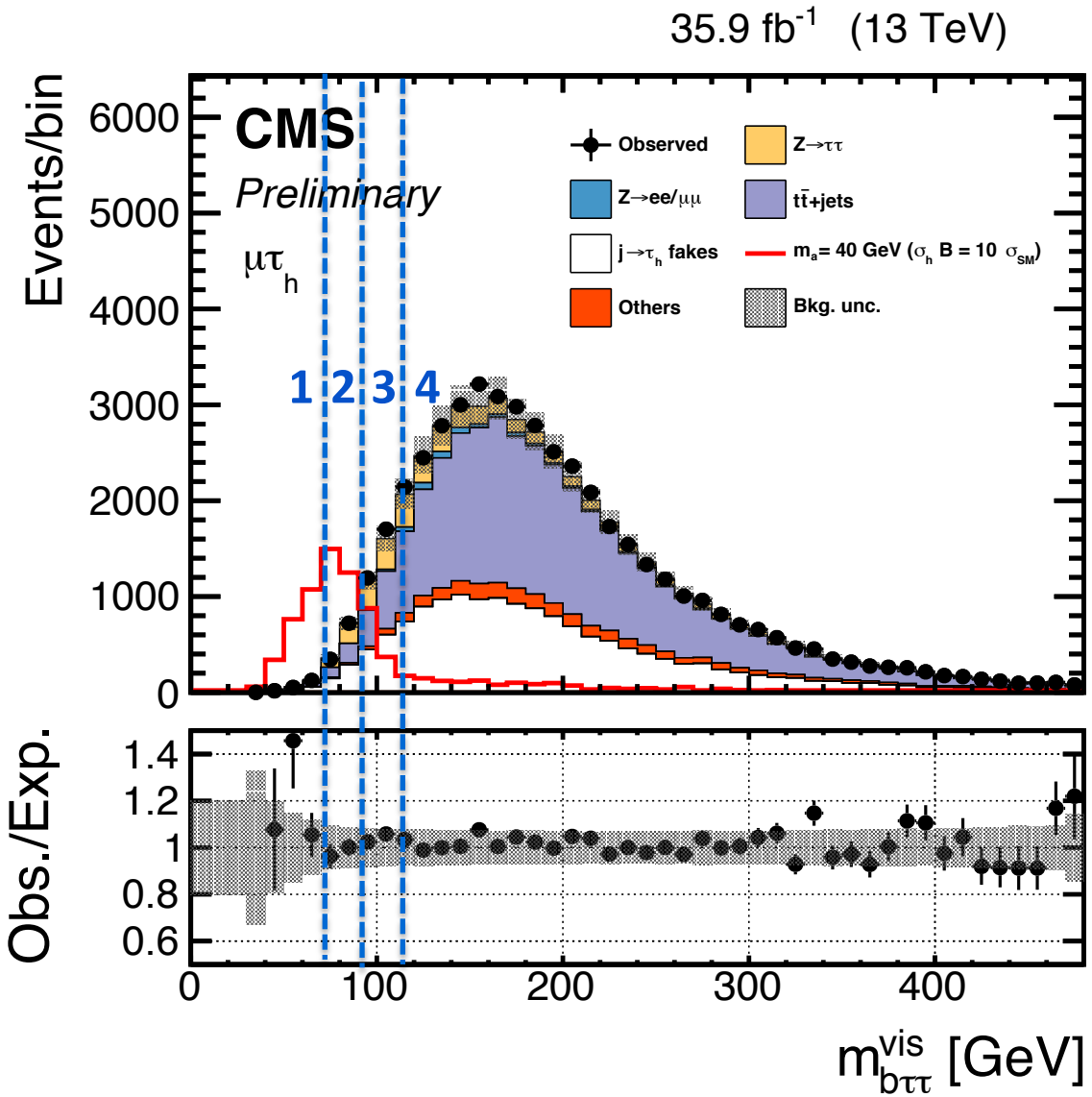
Categorization

- The visible invariant mass of the τ candidates and of the b jet is below 125 GeV for the signal because:
  - Neutrinos in τ decays
  - Softer b-jet not required to be reconstructed
- 4 categories based on $m_{b\tau\tau}$
- The signal proportion in the different categories depends on m_a



Categorization

- Low $m_{b\tau\tau}$ categories have little background
- Highest $m_{b\tau\tau}$ category (4) contains most backgrounds → used to control backgrounds in low $m_{b\tau\tau}$ categories

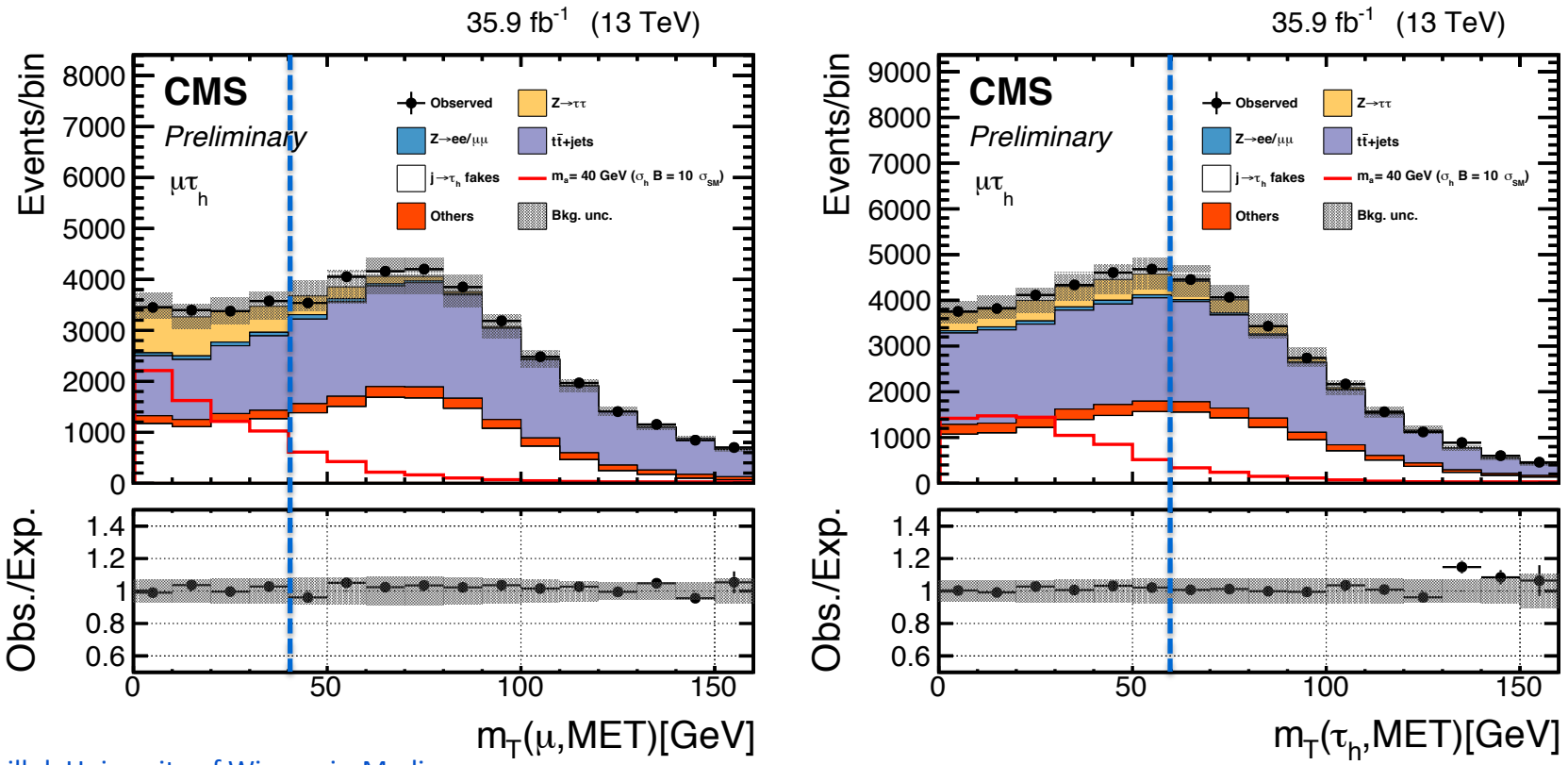


Further selection criteria

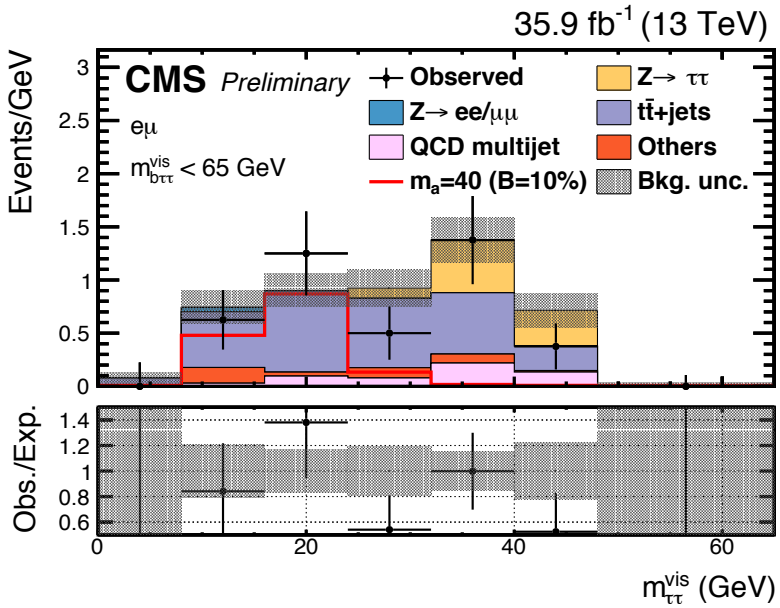
- Selection based on the transverse mass between each τ candidate and the MET

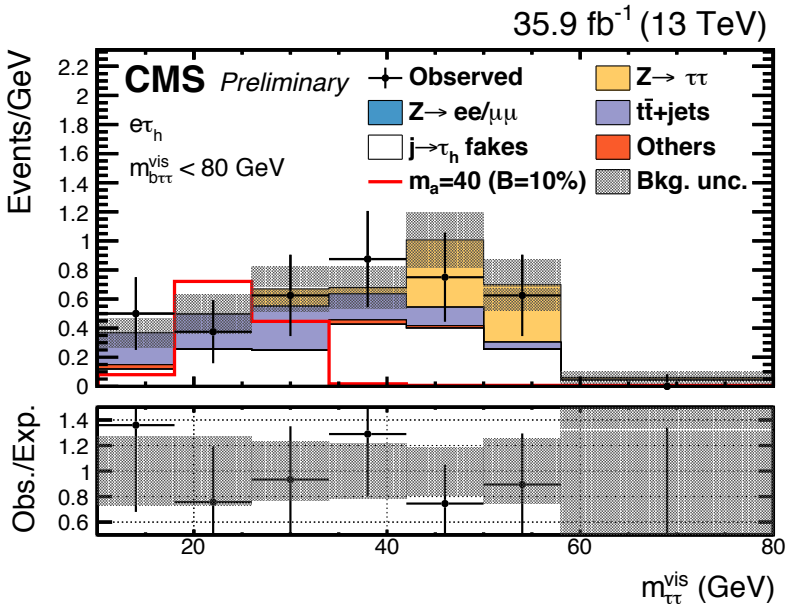
$$m_{\mathrm{T}}(\ell, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}) \equiv \sqrt{2 p_{\mathrm{T}}^{\ell} p_{\mathrm{T}}^{\mathrm{miss}} [1 - \cos(\Delta\phi)]}$$

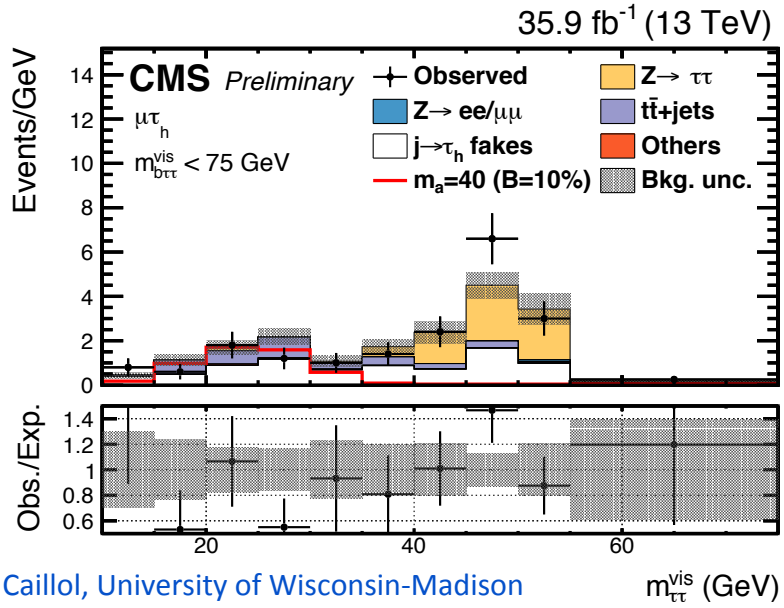
- Thresholds depend on final state and category



Results – Category 1





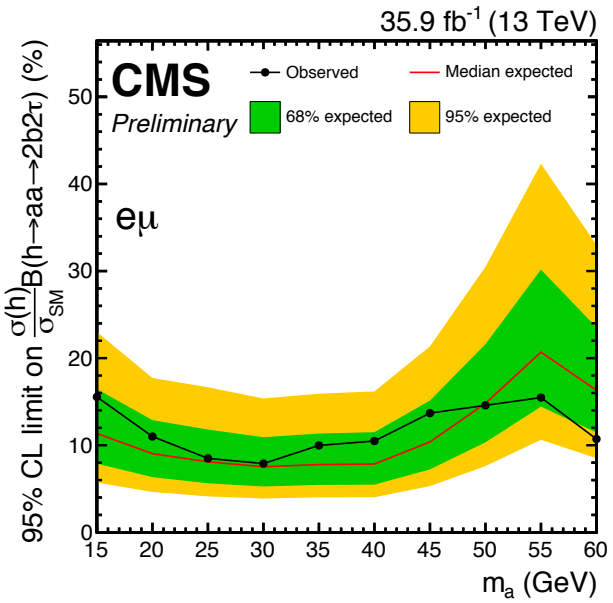


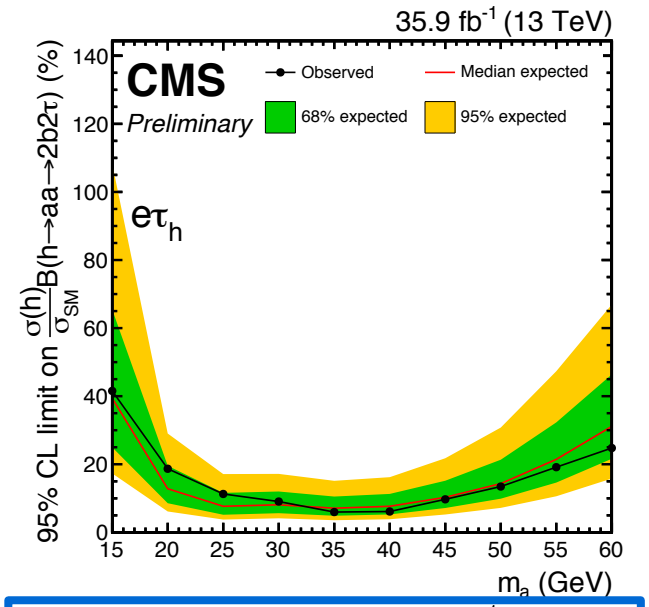
- Lowest $m_{b\tau\tau}$ category, which is the most sensitive
- Results extracted by fit to visible di-τ mass distributions (expected to peak below m_a)

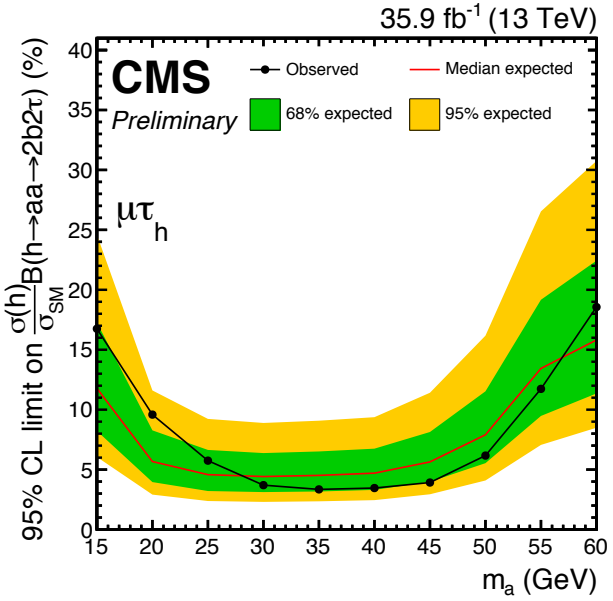
Main systematic uncertainties

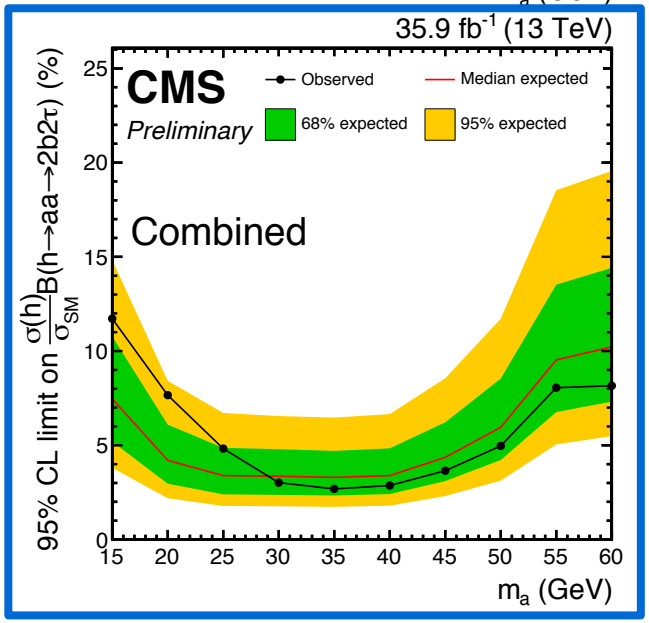
Uncertainty	Description
τ_h identification	5%
e/μ identification	2%
τ_h energy scale	1.2% per decay mode, with effect on $m_{b\tau\tau}$ and $m_{\tau\tau}$ distributions
b jet identification	5—10% depending on p_T, with effect on $m_{b\tau\tau}$ distribution
Norm Z→ll bkg	7%
Norm. j→τ_h fakes bkg	20%, constrained to 7% after fit
Norm ttbar bkg	6%
Shape Z→ττ	Uncertainties on Z p_T and $m_{b\tau\tau}$ corrections, with effect on $m_{\tau\tau}$ distribution
Bin-by-bin	Each bin or each distribution can be varied within its statistical uncertainty (coming from limited MC statistics, or limited observed events in control regions)

Limits







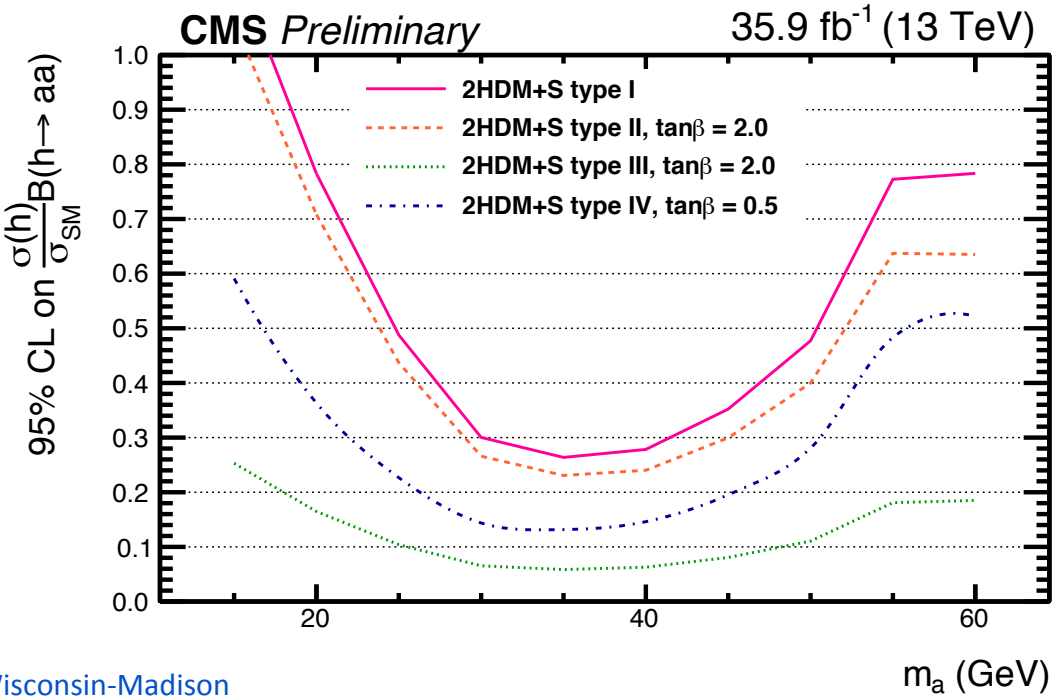


- No significant excess in any channel
- $\mu\tau_h$ is the most sensitive channel:
  - Large BR wrt $e\mu$
  - Low trigger thresholds wrt $e\tau_h$

Result interpretation in 2HDM+S

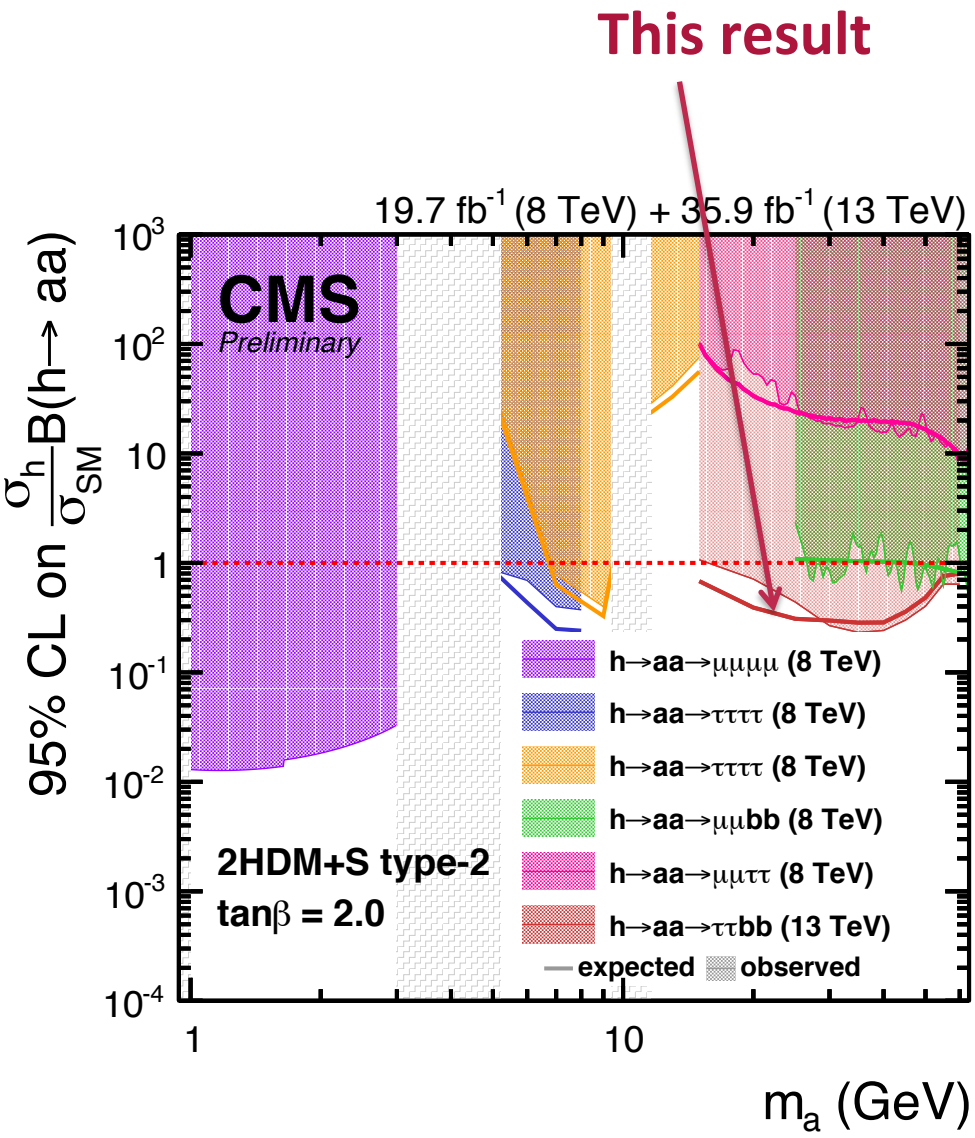
- Limits on σ_h/σ_{SM} X B(h→aa) can be set using the a→XX branching fractions predicted in 2HDM+S
- Results depend on tan β = vev(ϕ_2)/vev(ϕ_1) (except in type I, and moderately in type II)

	Type-1	Type-2	Type-3 (lepton specific)	Type-4 (flipped)
ℓ	ϕ_2	ϕ_1	ϕ_1	ϕ_2
u	ϕ_2	ϕ_2	ϕ_2	ϕ_2
d	ϕ_2	ϕ_1	ϕ_2	ϕ_1



Conclusion

- First time h→aa→bbττ decays are probed: large branching fraction (heavy b and τ), and possible to trigger in ggF production
- No significant excess of events observed
- In the NMSSM, B(h→aa) > 23% excluded at 95% CL for m_a ~ 35 GeV → **most sensitive results so far at the LHC**
- **Limits improved by several factors in 25 < m_a < 62.5 GeV, and by more than 1 order of magnitude in 15 < m_a < 25 GeV**



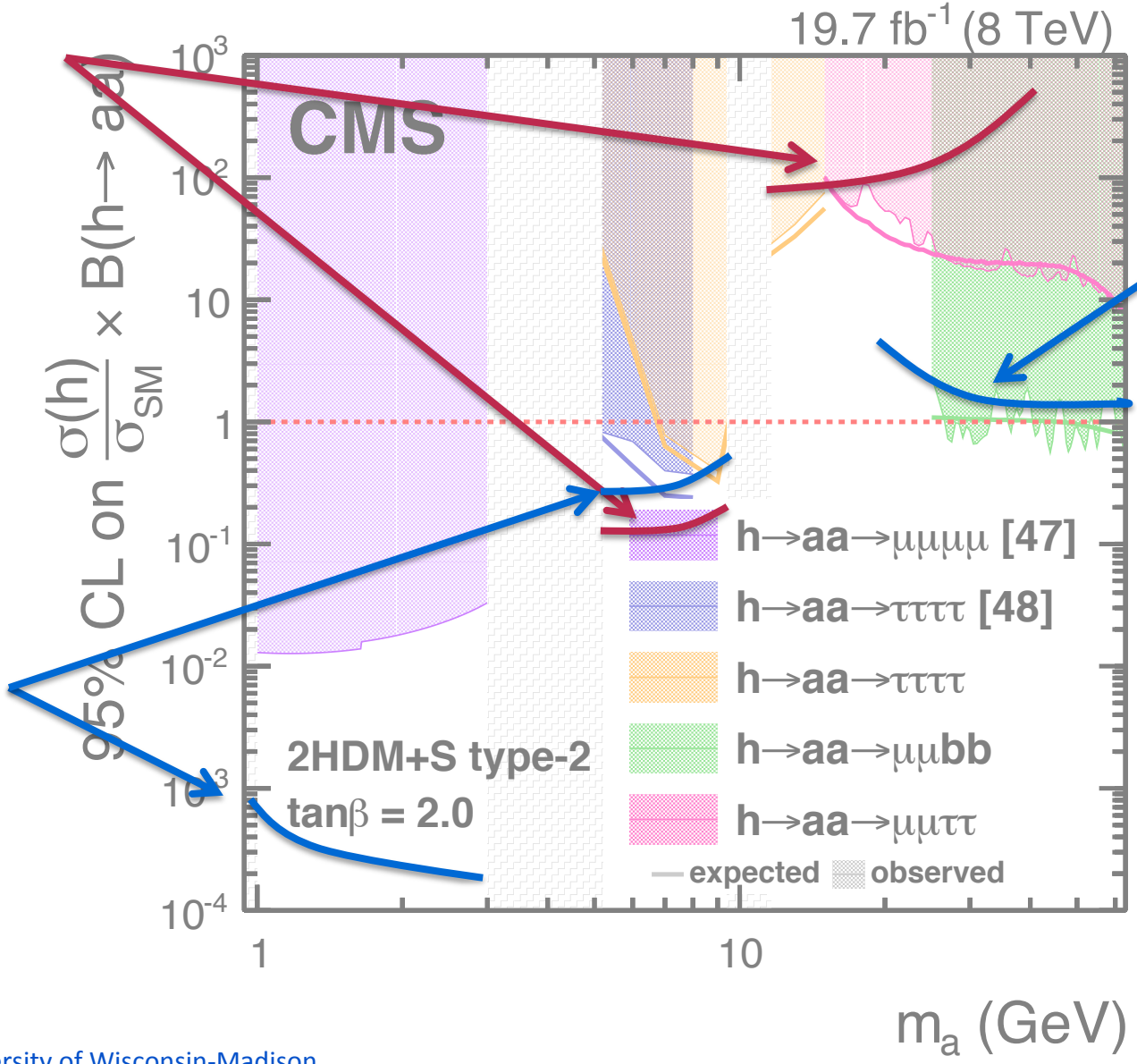
BACKUP

Preselection

	$\mu\tau_h$	$e\tau_h$	$e\mu$
$p_T(\tau_h)$	> 25 GeV	> 25 GeV	-
$p_T(\mu)$	> 20 GeV	-	$> 24/10$ GeV
$p_T(e)$	-	> 26 GeV	$> 13/24$ GeV
$p_T(b)$	> 20 GeV	> 20 GeV	> 20 GeV
$\lvert\eta(\tau_h)\rvert$	< 2.3	< 2.3	-
$\lvert\eta(\mu)\rvert$	< 2.1	-	< 2.4
$\lvert\eta(e)\rvert$	-	< 2.1	< 2.4
$\lvert\eta(b)\rvert$	< 2.4	< 2.4	< 2.4
Isolation (τ_h)	MVA	MVA	-
Isolation (μ)	< 0.15	-	< 0.15
Isolation (e)	-	< 0.10	< 0.10

What about ATLAS?

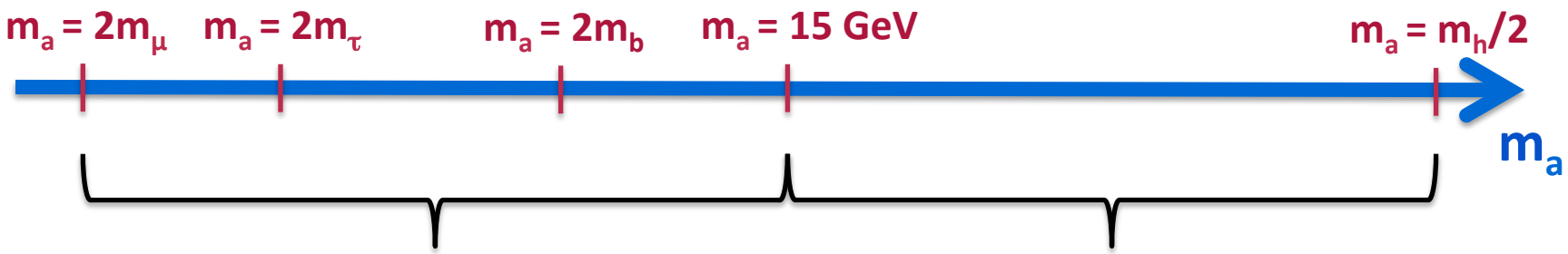
h→aa→2μ2τ
2012 data
arXiv:
1606.08391



Wh, h→aa→4b
2015 data
arXiv:
1606.08391

h→aa→4μ
2016 data
arXiv:
1802.03388

Role of m_a in analysis strategy



- Boosted pseudoscalars
- Special reconstruction techniques to reconstructed collinear decay products (isolation cones overlap

- Decay products of pseudoscalars well separated → normal reconstruction

4μ final state before a→ττ opens

a→ ττ channel is open and dominates if fermion mass proportionality

a→ bb channel is open and dominates if fermion mass proportionality

Result interpretation – Scan with tan β

- Limits in type III and type IV 2HDM+S strongly depend on tan β