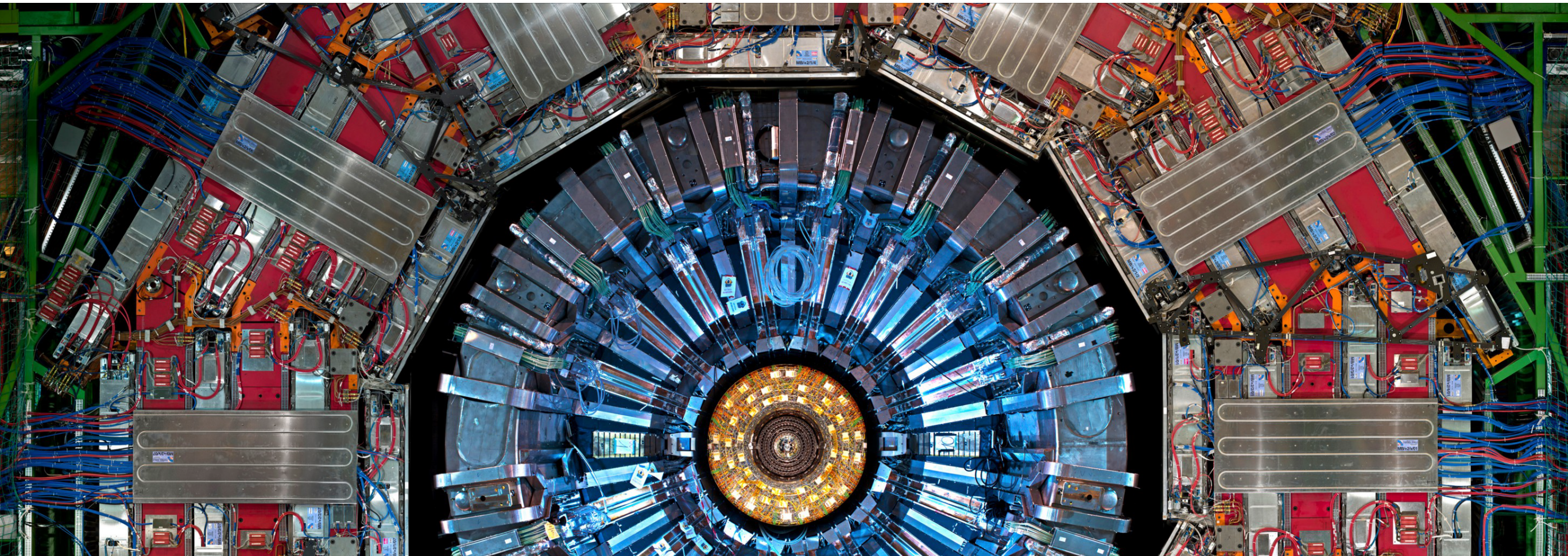
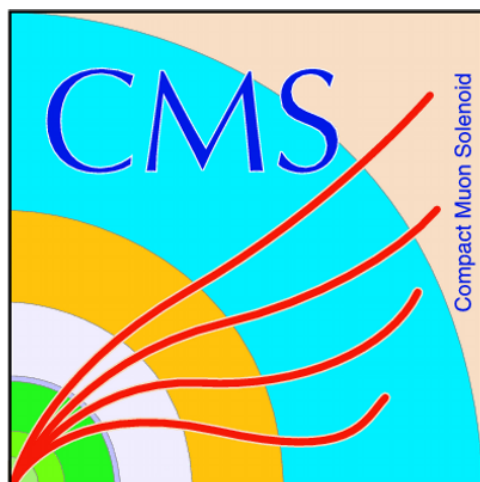




SUSY Higgs searches in fermionic final states with the CMS experiment

LHC Physics Discussion (DESY), May 9th 2016



Francesco Costanza
on behalf of the CMS DESY group

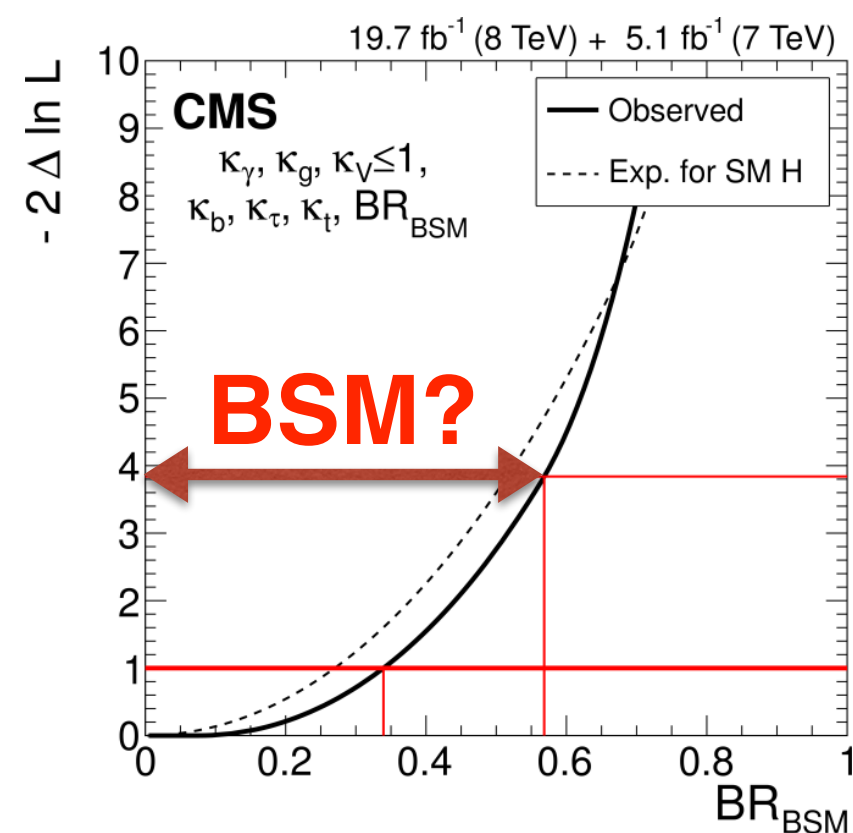
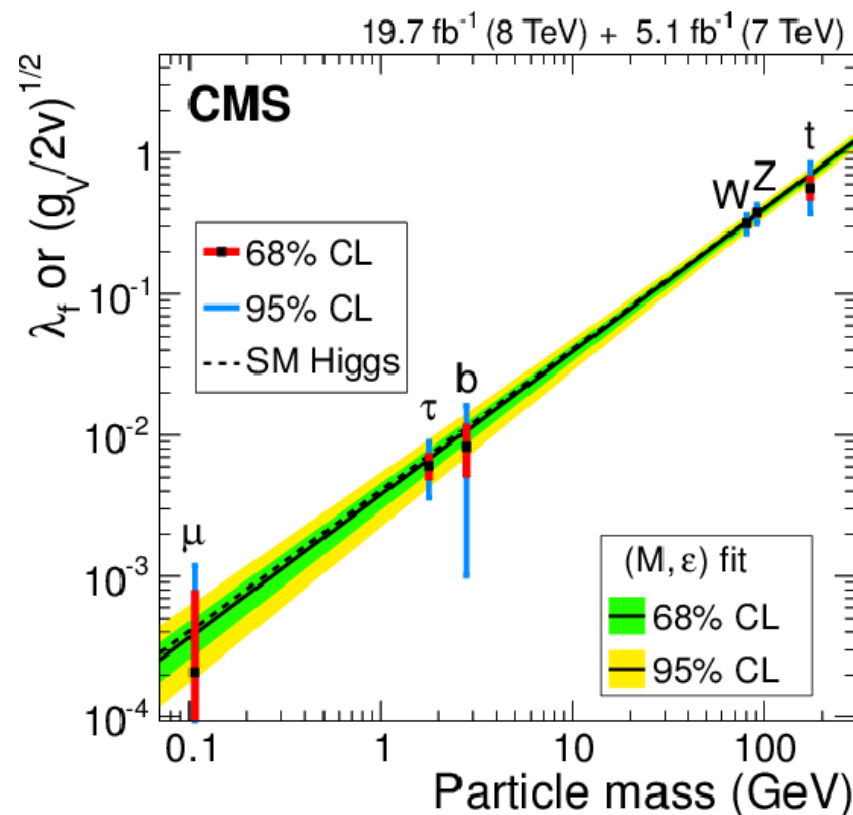
- ▶ The Higgs boson and its possible extended sectors
- ▶ Search for neutral MSSM Higgs bosons decaying into a pair of bottom quarks
J. High Energy Phys. 11 (2015) 071
- ▶ Search for a very light NMSSM Higgs boson produced in decays of the 125GeV scalar boson and decaying into τ leptons in pp collisions at $\sqrt{s} = 8\text{TeV}$
J. High Energy Phys. 01 (2016) 079

The Higgs boson

- ▶ A Higgs boson has been discovered in 2012 by ATLAS and CMS
- ▶ Is it the SM Higgs boson? Or only one SM-like Higgs boson?

Couplings are SM-like, but...

plenty of room for BSM decays!!

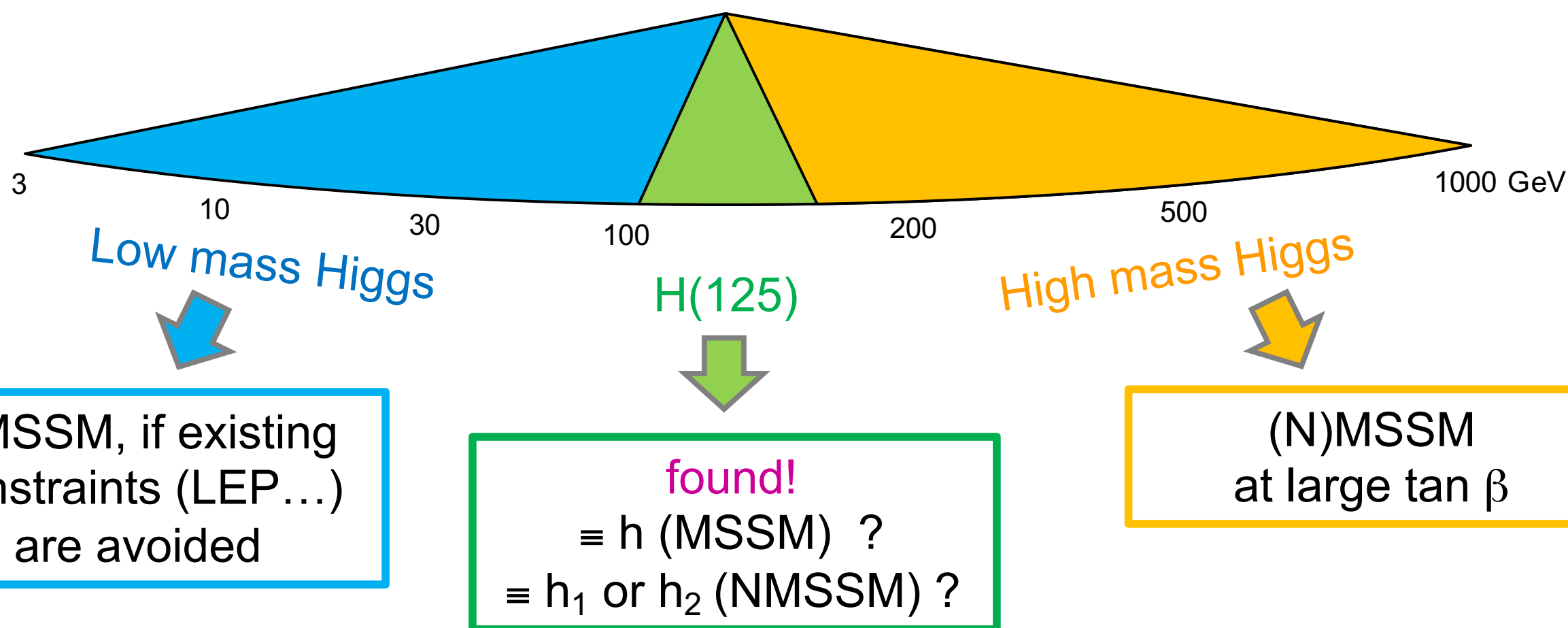


- ▶ Is H(125) the only Higgs boson?
Direct searches are needed to probe a possible extended Higgs sector!
- ▶ SUSY naturally provides an extended Higgs sector → Focus of this talk

Extended Higgs sector

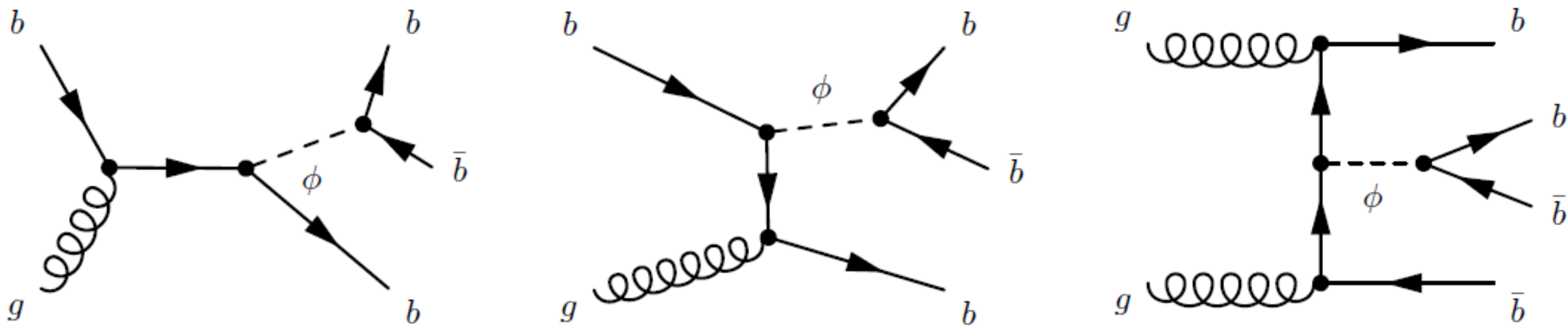
Model	Structure	CP-even	CP-odd	Charged
MSSM	2 doublets	h, H	A	$H^\pm$
NMSSM	2 doublets+1 singlet	h_1, h_2, h_3	a_1, a_2	$h^\pm$

$(h, H, A) \equiv \phi$



- ▶ **b-associated production** enhanced by $\sim 2 \tan^2 \beta$

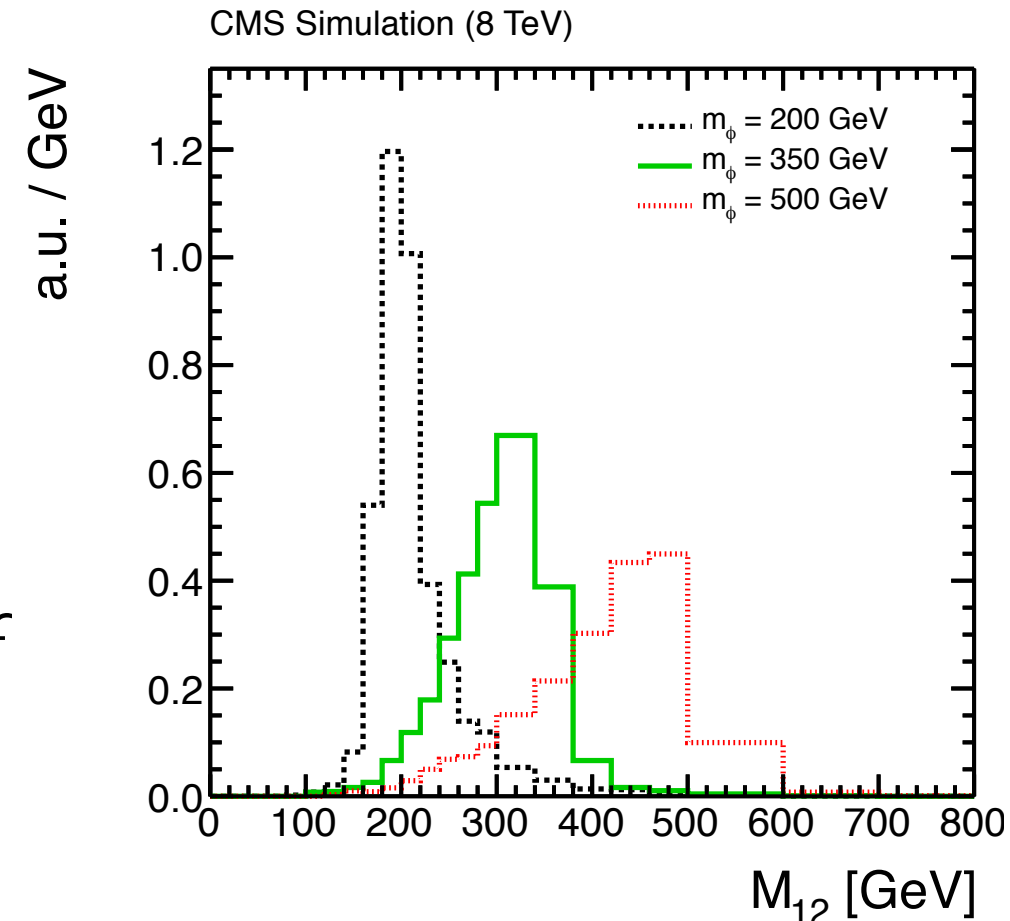
$$\mathcal{B}(\Phi \rightarrow bb) \sim 90\%$$



- ▶ Main challenge: control the huge QCD multijet background
 - ▶ Largely reduced by dedicated **online 2 b-tagged jets trigger**

Analysis strategy

- ▶ Three leading jets tagged as b-jets, $p_T > 80/70/20$ GeV
- ▶ Signal sample of ~ 69 k events
- ▶ Search for peak in the invariant mass distribution of the two leading jets M_{12}
- ▶ Condensed event b-tag estimator X_{123} , based on secondary vertex mass sum of the three leading jets, used for building background templates
- ▶ 2D (M_{12}, X_{123}) background (+signal) fit to data



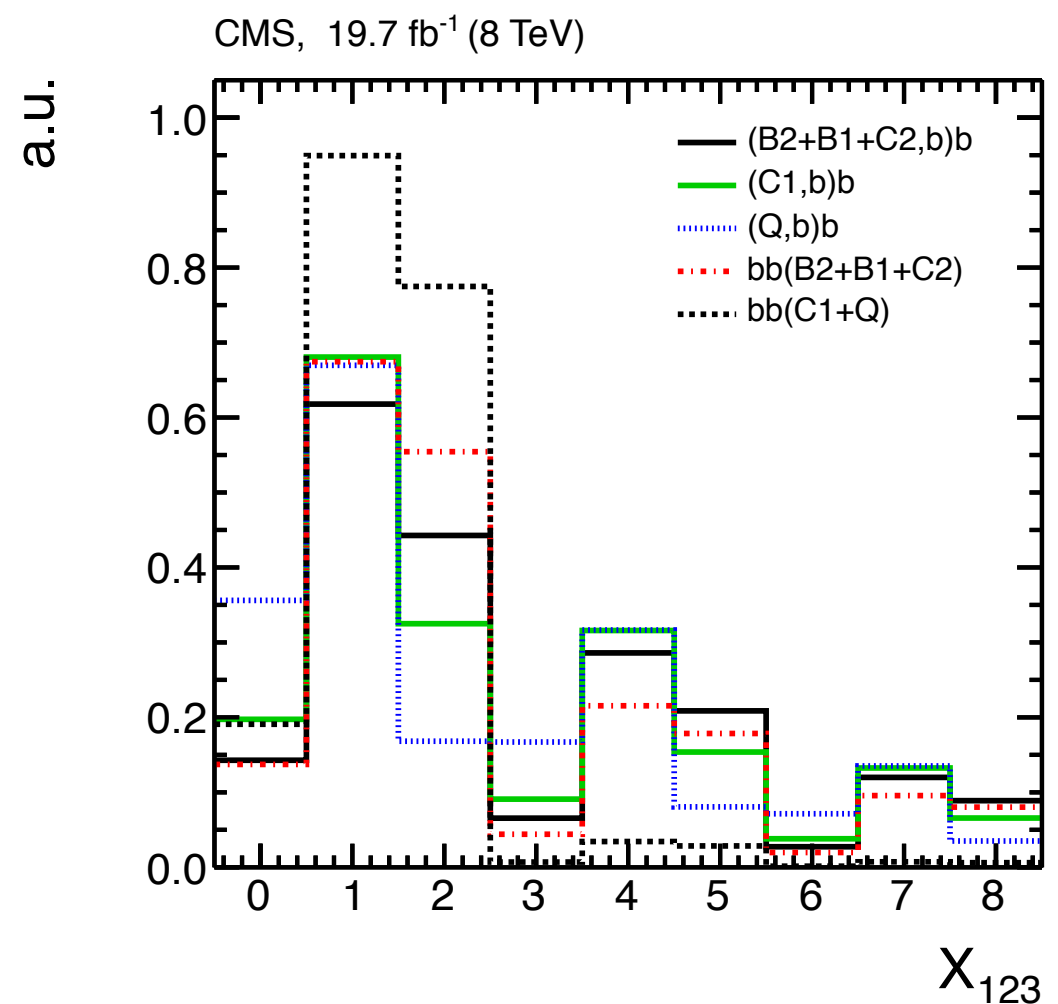
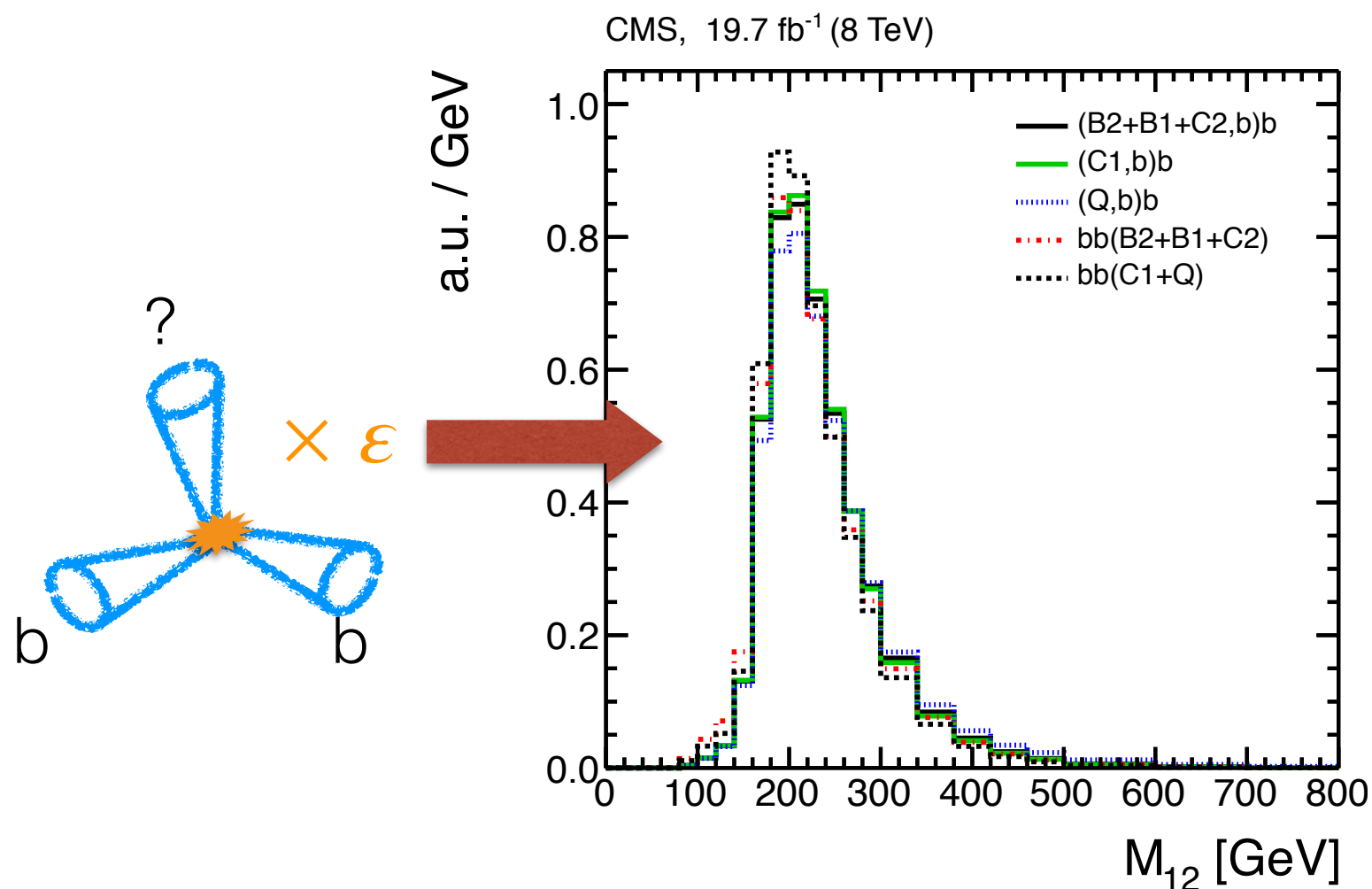
$\Sigma M_{SV,j}$ [GeV]	B_j
0-1	0
1-2	1
2-3	2
>3	3

B_3	X_{123}		
	$B_1 + B_2$		
	0-1	2-3	4-6
0-1	0	1	2
2	3	4	5
3	6	7	8

Data-driven background estimation

- Background template construction in double b-tagged sample with 2.4M events
- One template for each possible flavor assumption $\times$ 3 jets: 15 templates, only 5 independent
 - weighted by b-tagging probability of the untagged jet according to the assumed flavor
- X_{123} fundamental for template separation

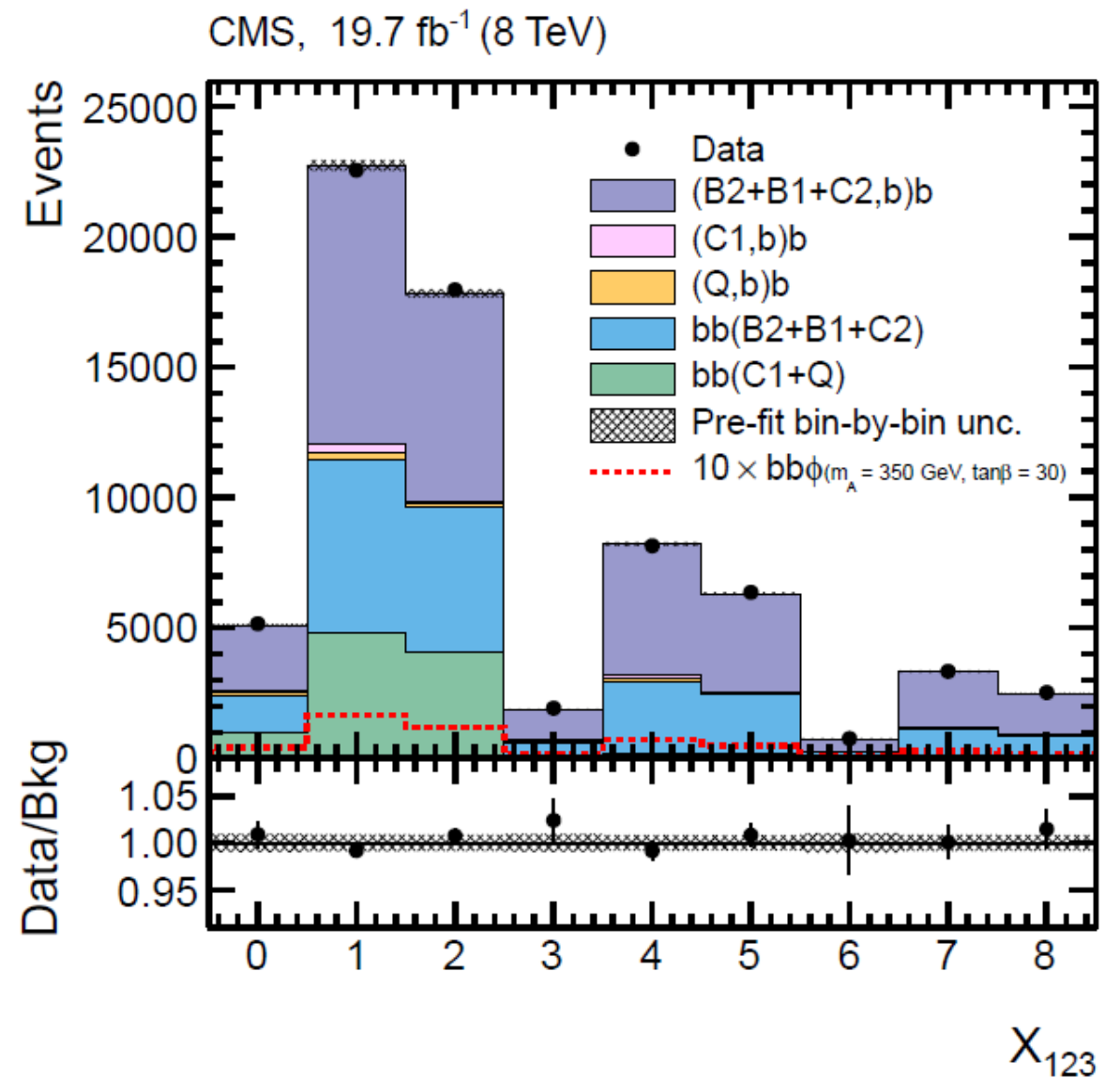
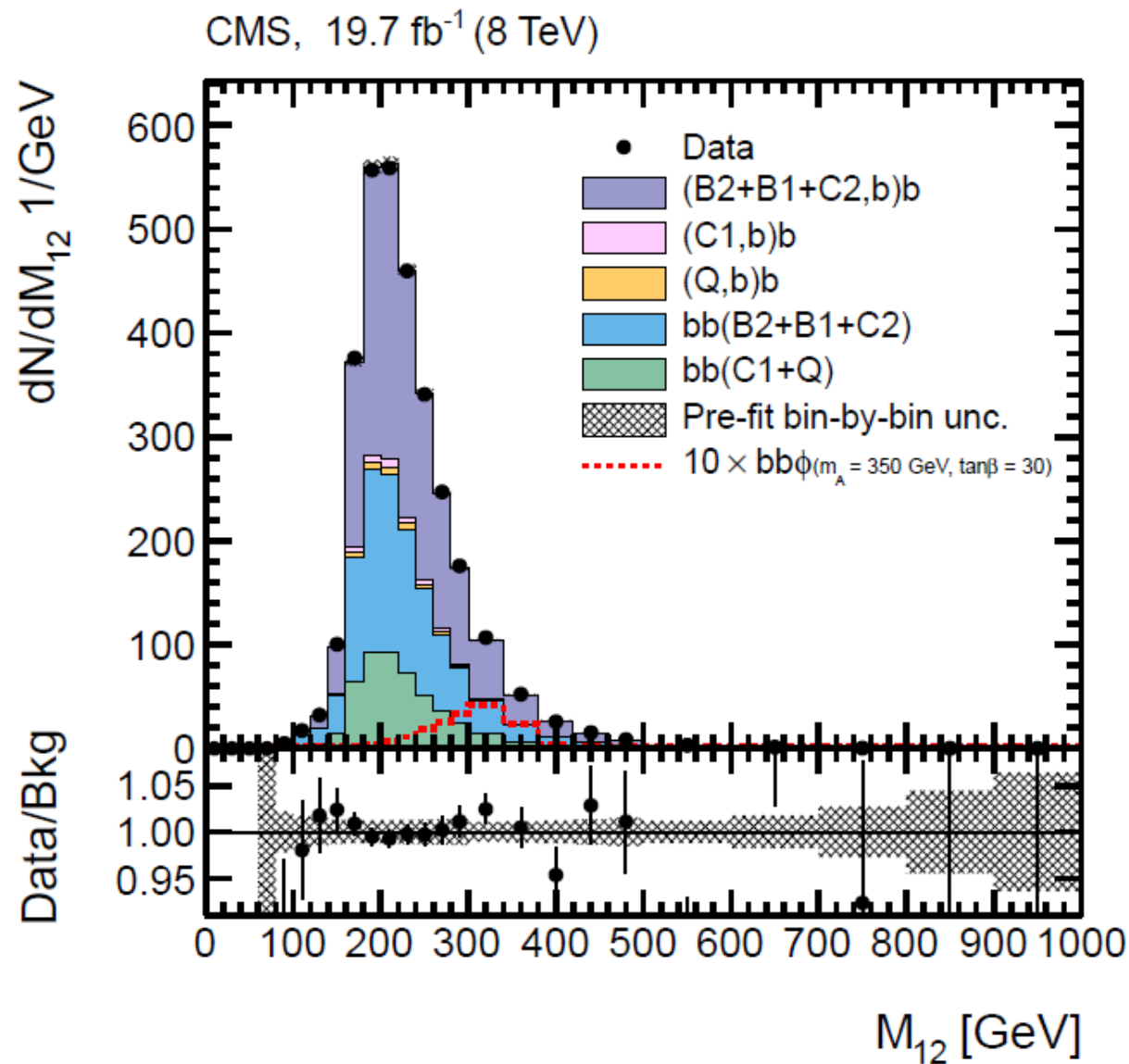
B1	single b-jet
B2	double b-jet
C1	single c-jet
C2	double c-jet
Q	light flavour (udsg) jet



Systematic uncertainties

Source	Type	Target	Impact
Online b tagging	Rate	Signal	11%
Integrated luminosity	Rate	Signal	0.1%
Jet trigger	Rate + Shape	Signal	0.1%
Jet energy scale	Rate + Shape	Signal	0.5%
Jet energy resolution	Rate + Shape	Signal	0.1%
Offline b tagging (bc)	Rate + Shape	Signal + Background	2–16%
Offline b tagging (udsg)	Shape	Background	0.2%
Template stat. uncertainty	Shape	Background	1–21%
Secondary vertex mass sum	Shape	Signal + Background	0.9%
bb purity correction	Shape	Background	3.4%
Online b tagging correction	Shape	Background	0.5%

MSSM $\Phi \rightarrow bb$ Search: Fit results

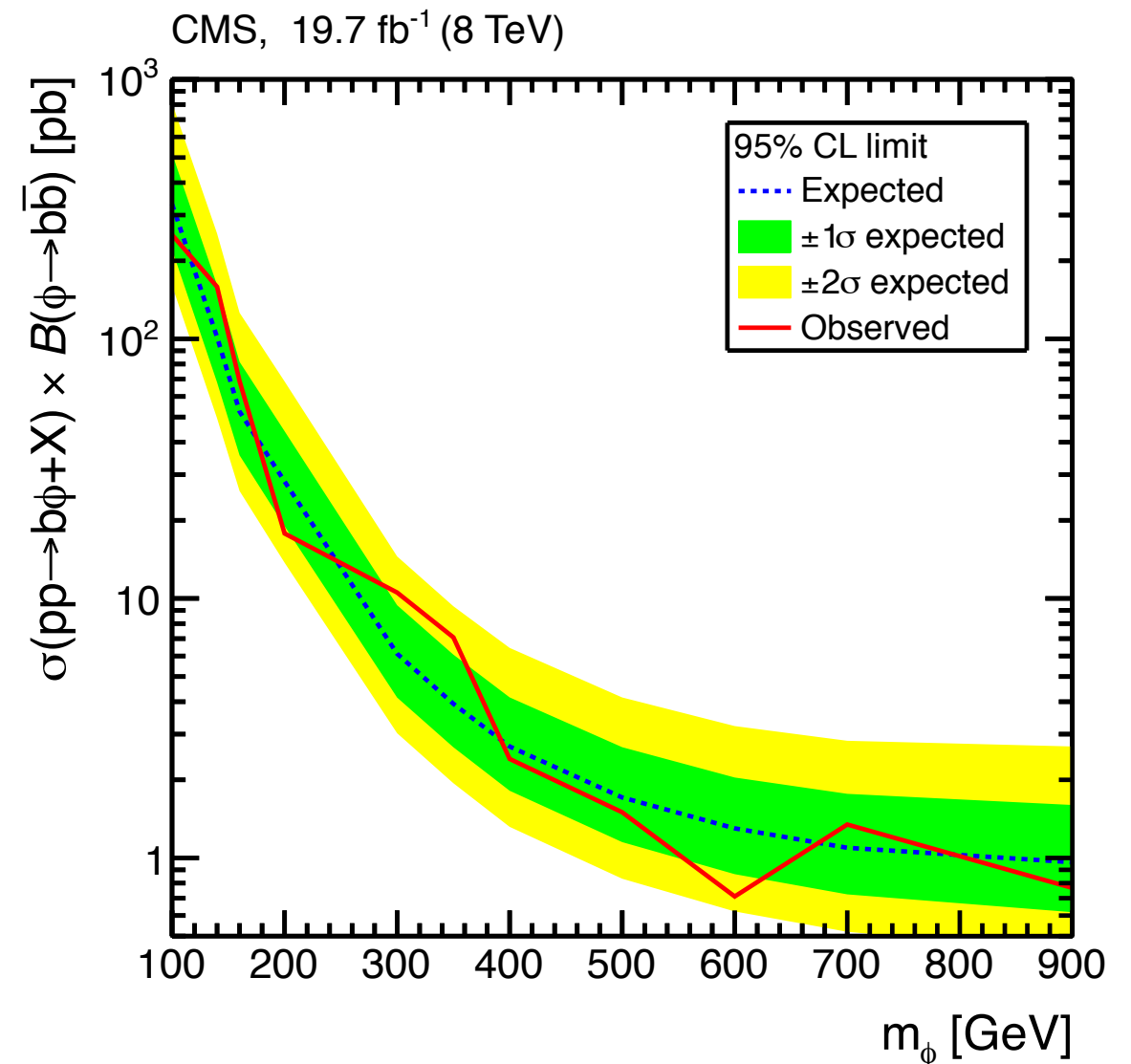
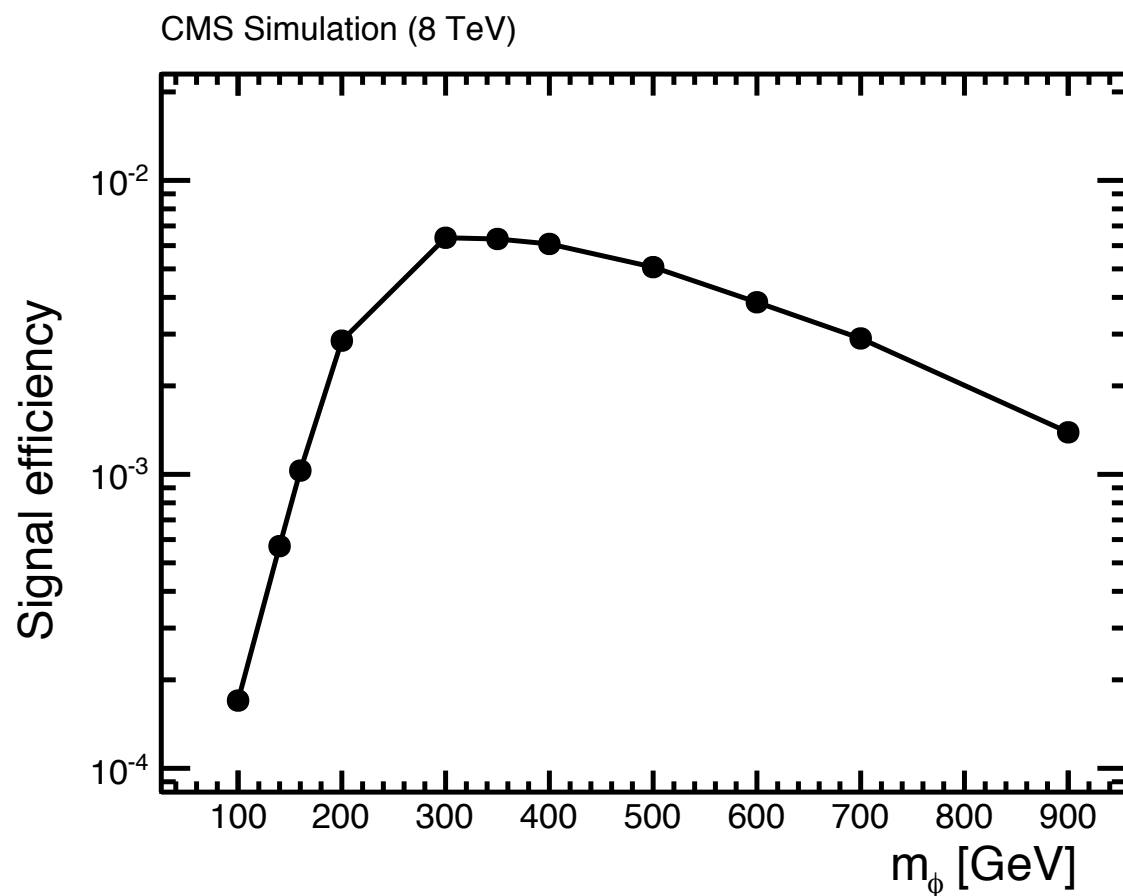


- Background only hypothesis describes the data well within the uncertainty of template fits with $\chi^2/N_{\text{dof}} = 207.9/209$

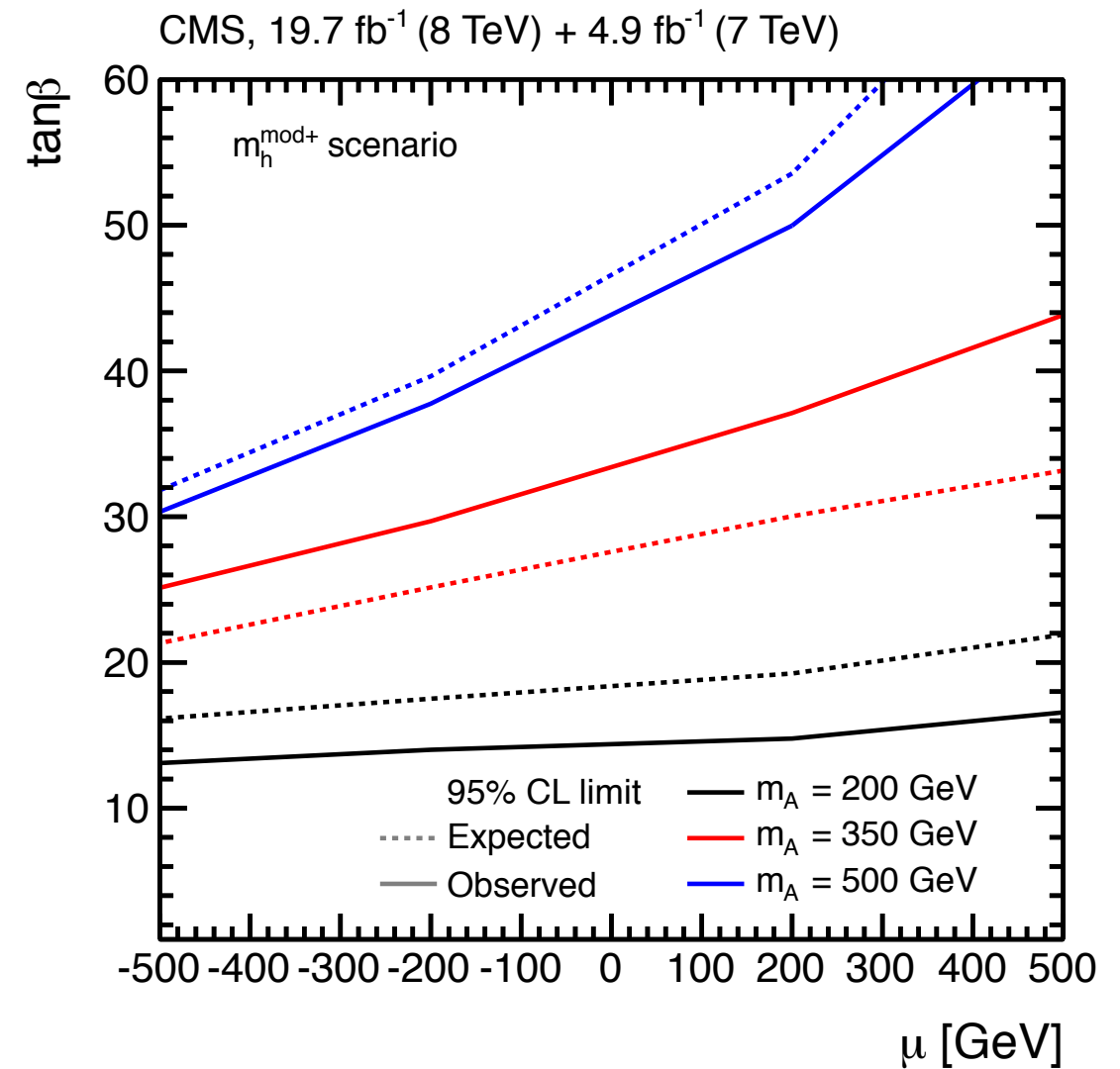
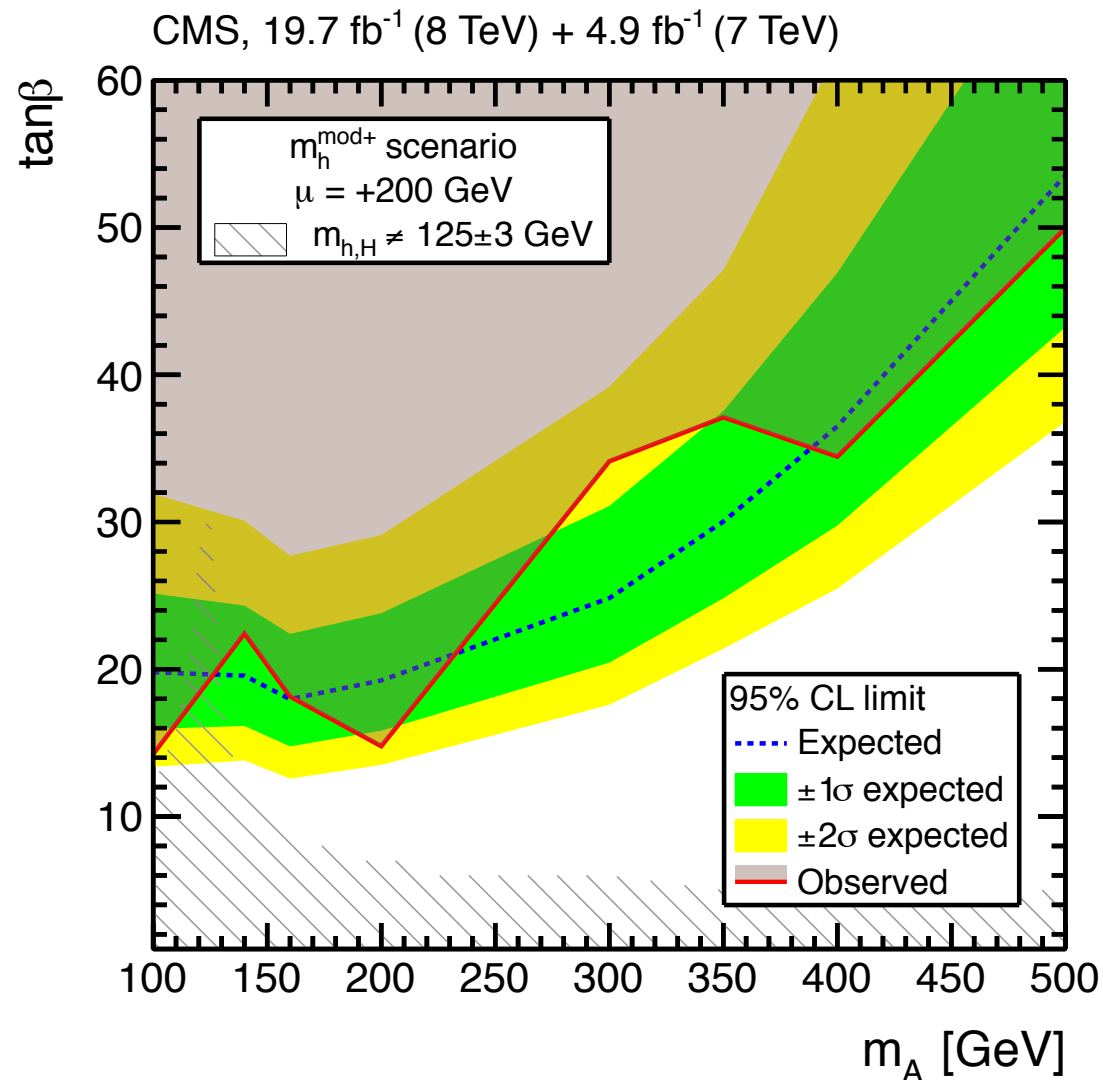
No evidence for MSSM Φ ... yet!



J. High Energy Phys. 11 (2015) 071



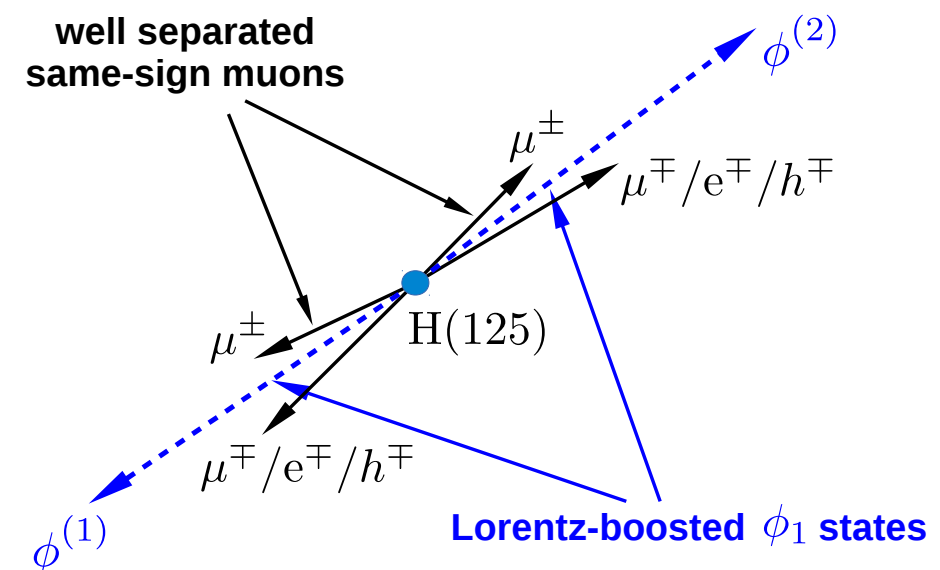
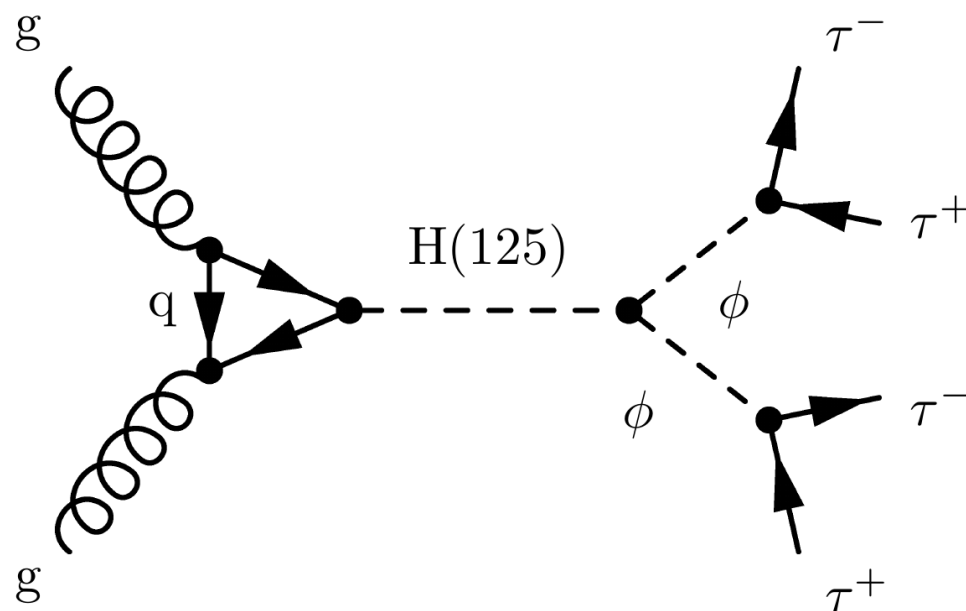
- ▶ The signal efficiency measured in simulation is used to convert the upper limits on the fraction of signal events to upper limits on $\sigma\mathcal{B}$.
- ▶ The upper limits set by this analysis range between 300 and 1pb for $m_\phi = 100 - 900\text{GeV}$



- ▶ Significant improvement wrt 7TeV analysis
- ▶ Combined limits on $\tan \beta$ in the $m_h^{\text{mod}+}$ benchmark scenario* range from 14 to 50: best limits at LHC in this channel
 * *M. Carena et al, Eur.Phys.J. C 73 (2013) 2552*
- ▶ Detailed study of upper limits dependence on higgsino mass parameter

- Analysis motivated by NMSSM scenarios* with $2m_\tau < m_\Phi < 2m_b$

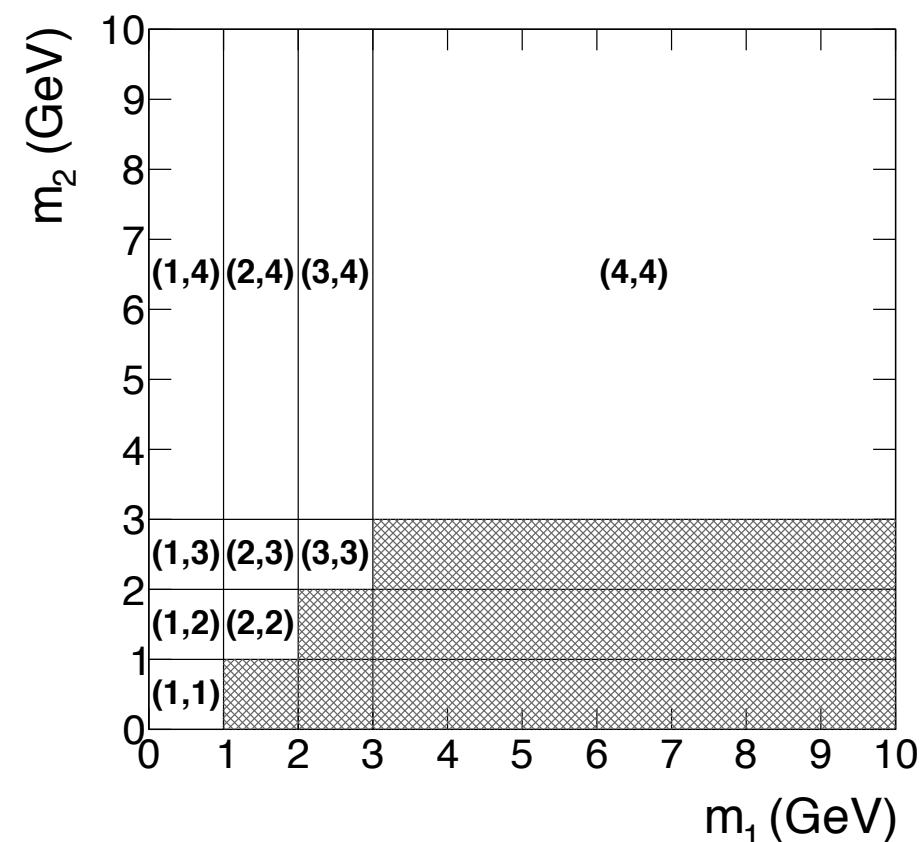
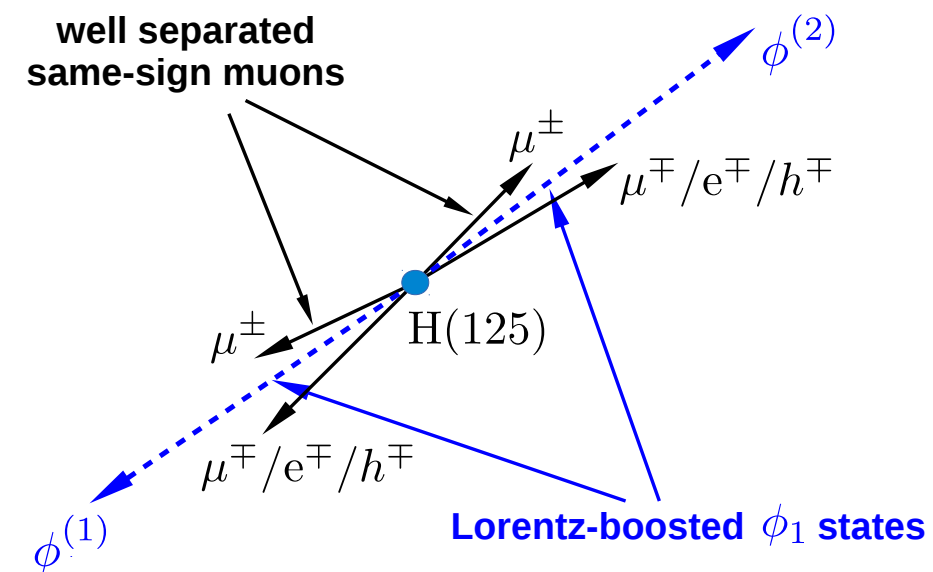
$$(\sigma\mathcal{B})_{\text{sig}} \equiv \sigma(gg \rightarrow H(125)) \mathcal{B}(H(125) \rightarrow \Phi\Phi) \mathcal{B}^2(\Phi \rightarrow \tau\tau) \sim 5\text{pb}$$



- Each Φ is identified from one τ decaying to μ and the other τ decaying to $\mu/e/h$ ($\tau^{\text{one-prong}}$)
 - Additional acceptance factor to account for the selected 4τ decays: 3.5%
- Main challenge: control the huge QCD multijet background, with μ from B-hadron decay

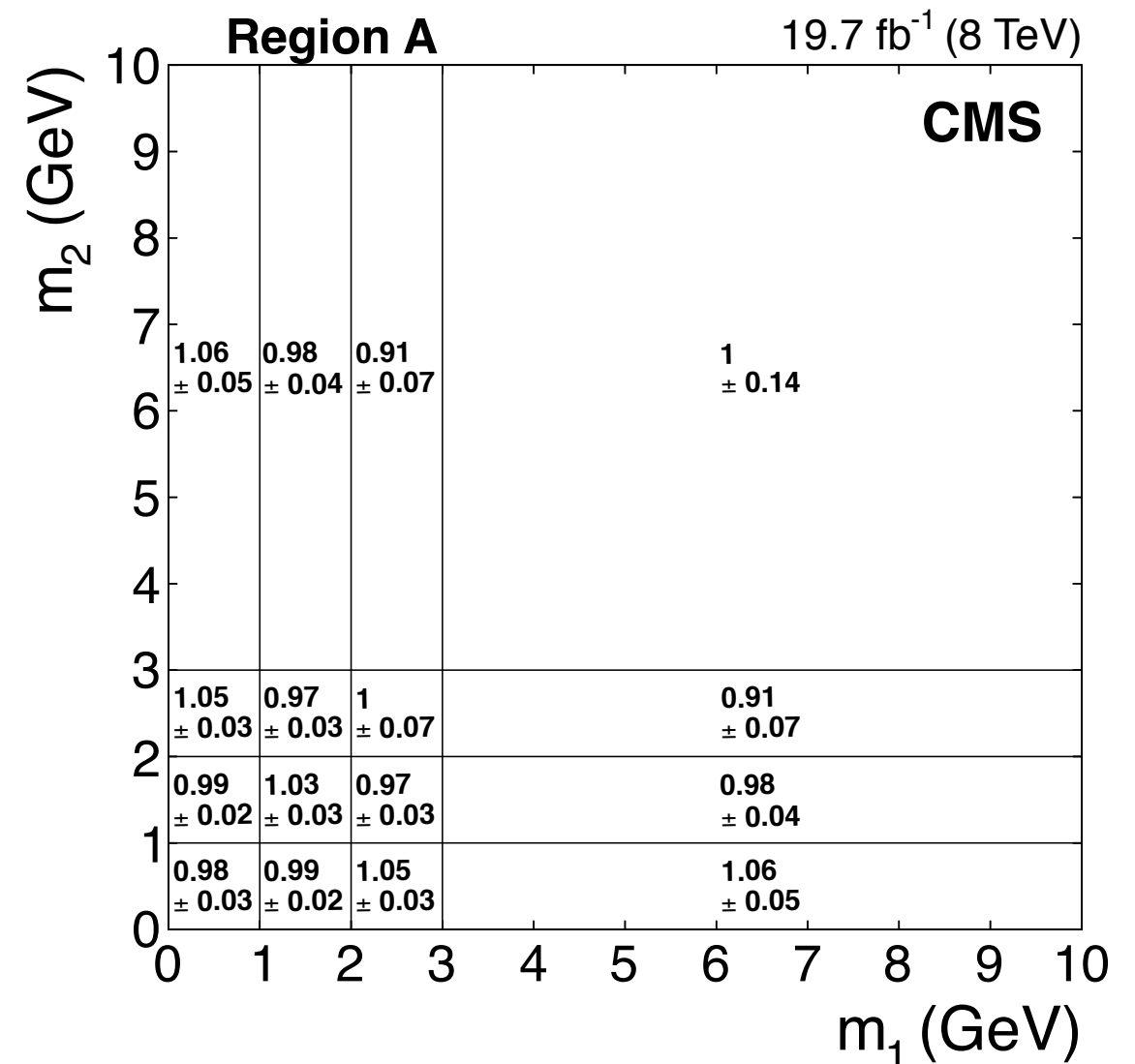
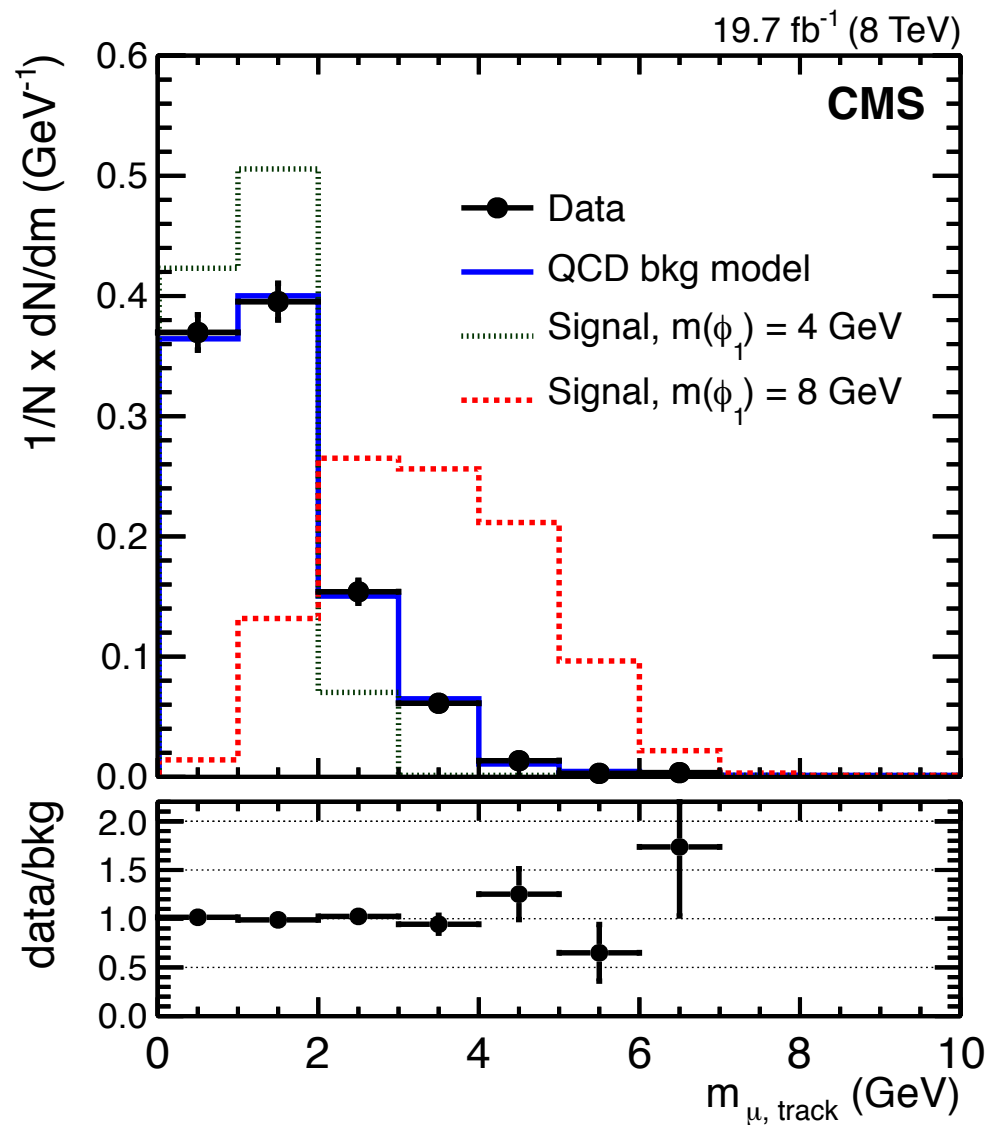
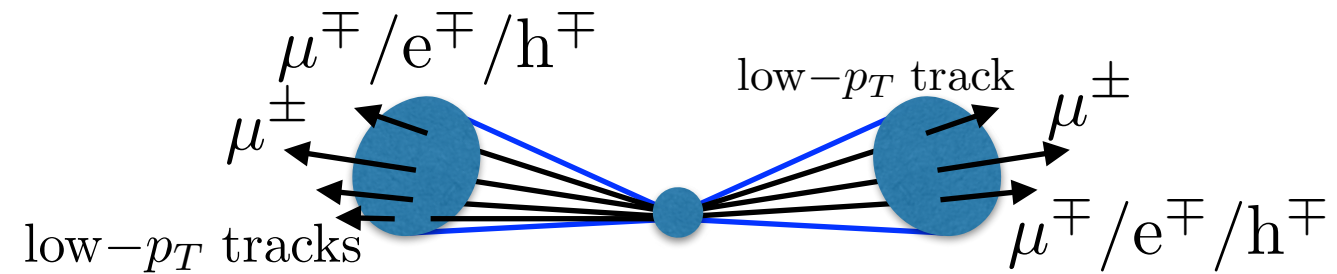
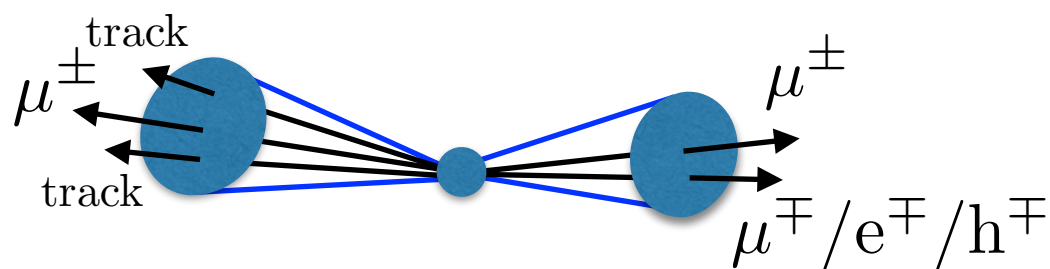
* N.-E. Bomark et al. *PoS(Charged2014)029*, S.F. King et al. *Phys. Rev. D* 90 (2014) 095014

- ▶ 2 high- p_T muons (17/10 GeV)
- ▶ H(125) boost from ISR and boosted Φ : large angular separation of Φ s each with collimated decay products
- ▶ Same-sign μ pair with $\Delta R > 2$ eliminates Drell-Yan process, gauge boson pair and $t\bar{t}$ production
- ▶ Each μ accompanied by one opposite-sign track with $p_T > 2.5\text{GeV}$ at $\Delta R < 0.5$
- ▶ No other tracks with $p_T > 1\text{GeV}$
- ▶ IP constraints to reject B-hadron decay products
- ▶ Bkg: μ -decay of b-hadrons, and a) cascade decay of $b \rightarrow c \rightarrow \mu$ or b) muon pairs from quarkonium states
- ▶ 2D-fit in $(m(\mu_1, \text{track}_1), m(\mu_2, \text{track}_2))$



Data-driven background estimation

$$f_{2D}(m_1, m_2) = C(m_1, m_2) f_{1D}(m_1) f_{1D}(m_2)$$



Systematic uncertainties

Source	Value	Affected sample	Type	Effect on the total yield
Statistical uncertainties in $C(i, j)$	2–14%	bkg.	bin-by-bin	—
Extrapolation uncertainties in $C(i, j)$	2–22%	bkg.	bin-by-bin	—
Integrated luminosity	2.6%	signal	norm.	2.6%
Muon ID and trigger efficiency	2% per muon	signal	norm.	4%
Track selection and isolation efficiency	5% per track	signal	norm.	10%
MC statistical uncertainties	7–100%	signal	bin-by-bin	4–6%
Theory uncertainties in the signal acceptance				
μ_r and μ_f variations	1%	signal	norm.	1%
PDF	1%	signal	norm.	1%
Effect of b quark loop contribution to $gg \rightarrow H(125)$	3%	signal	norm.	3%

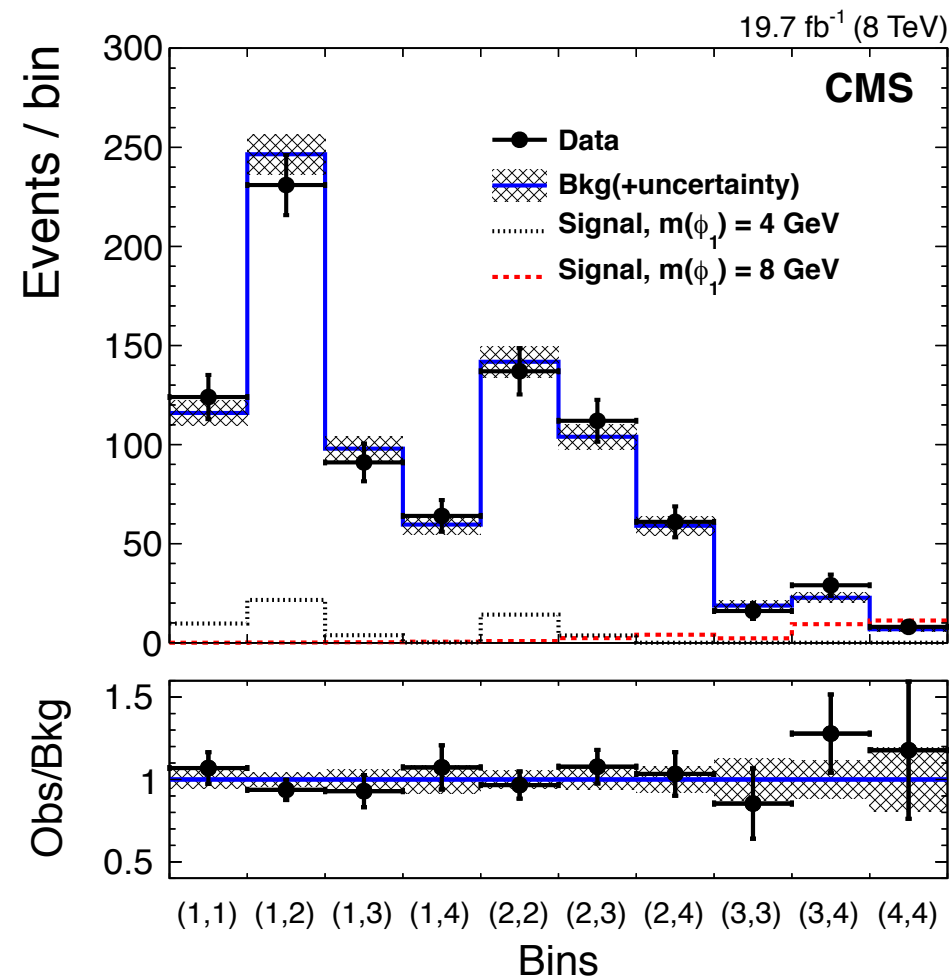
$$Z \rightarrow \mu\mu$$

$$Z \rightarrow \tau\tau$$

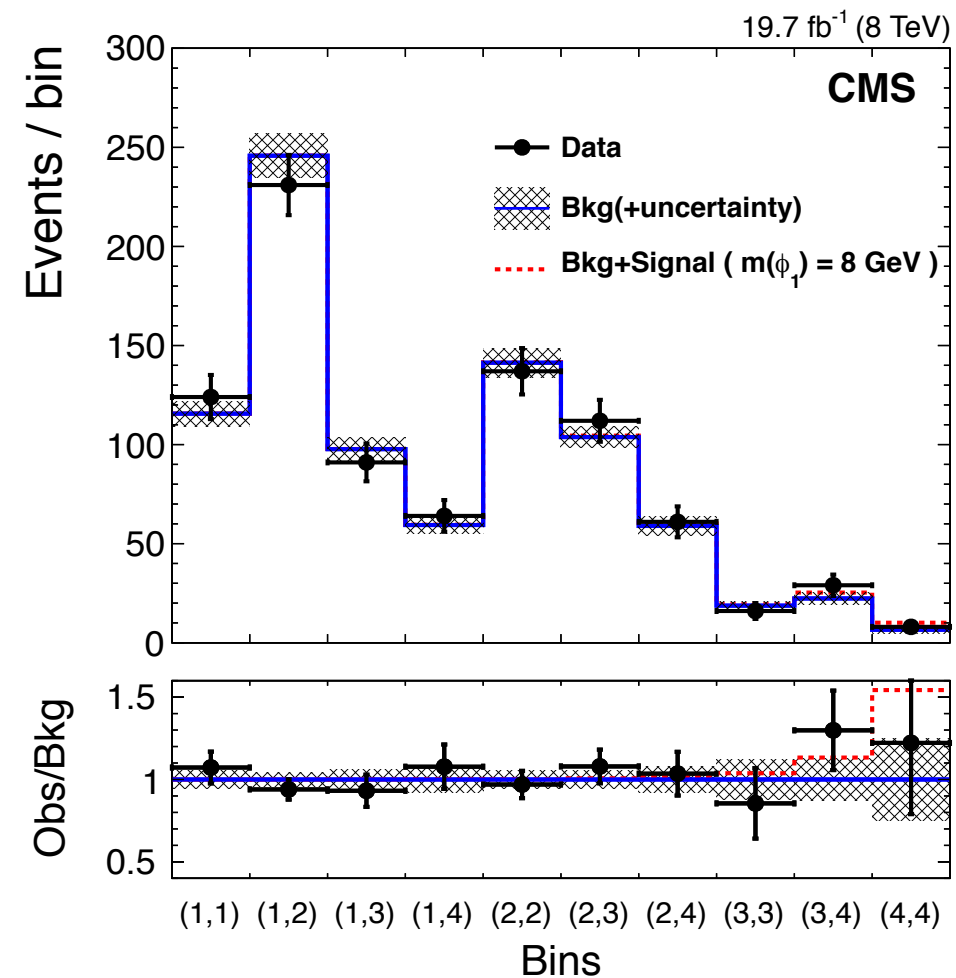
dependence on NMSSM parameters

Implemented as nuisance parameters in the fit

Bkg-only hp



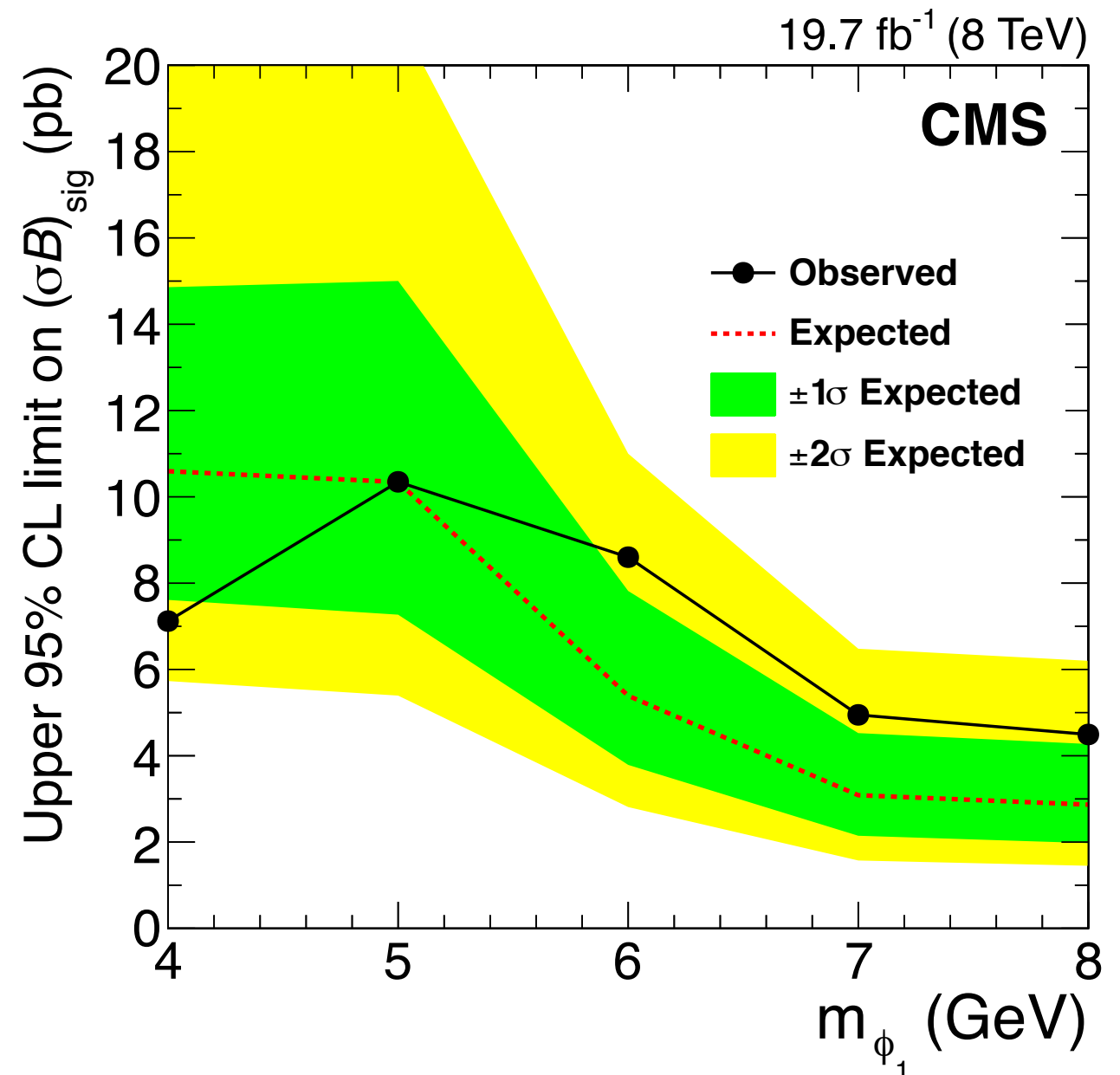
Bkg+Signal hp



- ▶ Bkg-only hypothesis fits data very well
- ▶ Small excess found for $6 \leq m_\Phi \leq 8 \text{ GeV}$ with local significance $1.2 - 1.4\sigma$

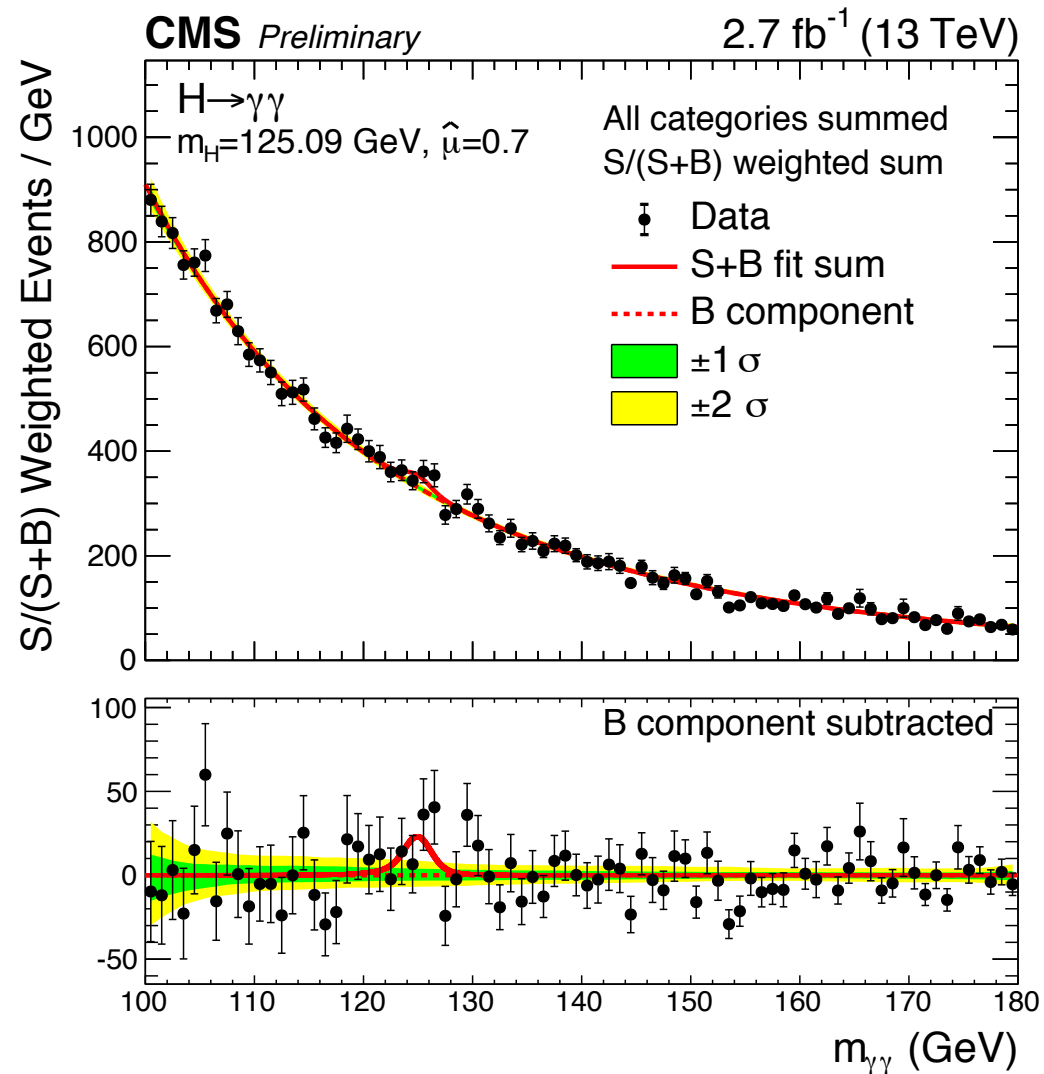
No evidence for NMSSM Φ ... yet! 😊

- ▶ The observed limit is compatible with the expected limit within 2σ in the entire tested range $4 \leq m_{\Phi} \leq 8\text{GeV}$
- ▶ The observed limit ranges from 4.5pb at $m_{\Phi} = 8\text{GeV}$ to 10.3pb at $m_{\Phi} = 5\text{GeV}$

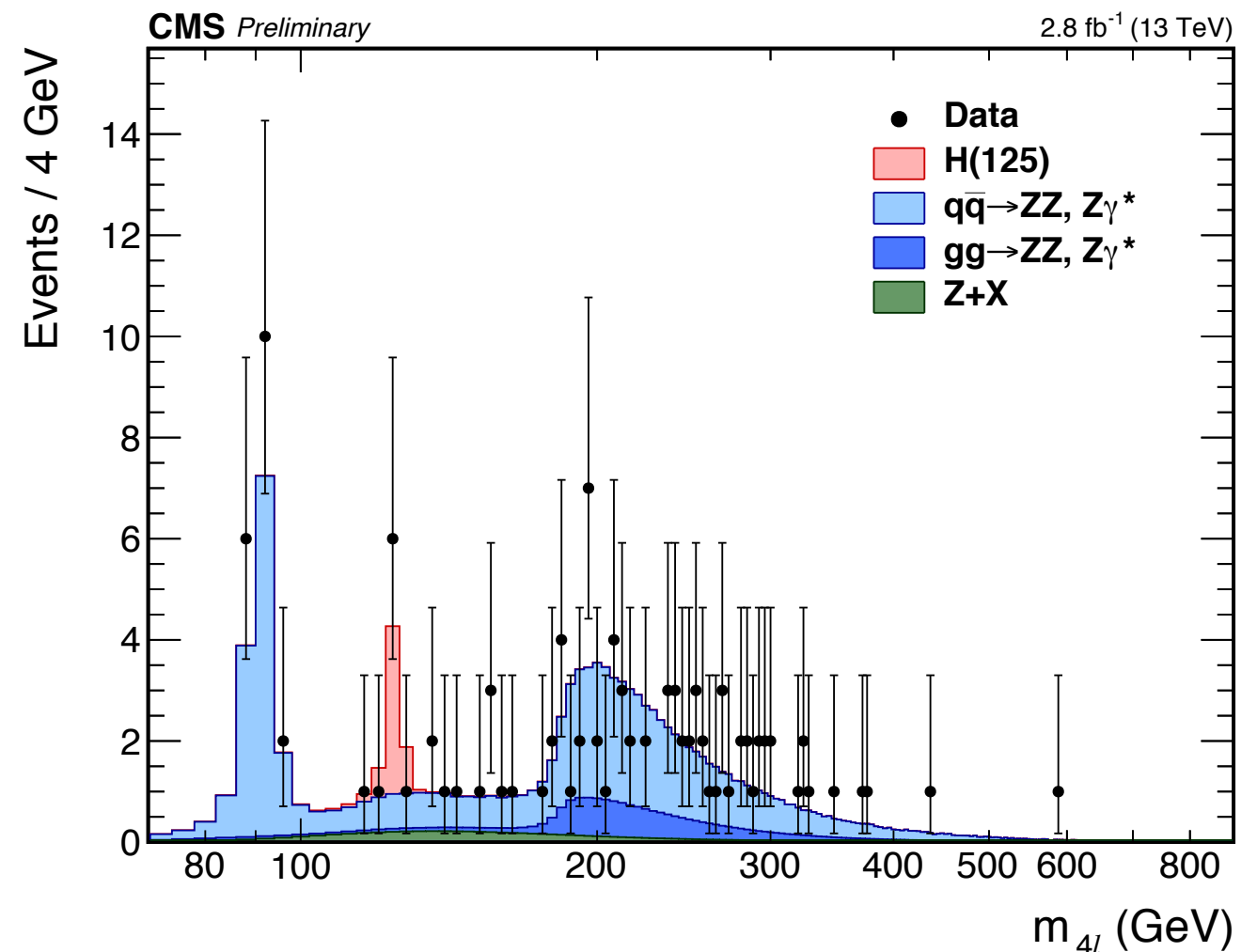


A look at $\sqrt{s} = 13\text{TeV}$

CMS-PAS-HIG-15-005



CMS-PAS-HIG-15-004



- ▶ More interesting results targeting Summer conferences, with a strong DESY contribution.
- ▶ New refined trigger dedicated for MSSM $\Phi \rightarrow b\bar{b}$

Conclusions

- ▶ Results on high and low mass Higgs boson searches with the CMS experiment have been presented
- ▶ No evidence for an (N)MSSM Higgs boson was found
- ▶ Upper limits on $\sigma(pp \rightarrow b\Phi + X) \mathcal{B}(\Phi \rightarrow b\bar{b})$ are set in the range **300-1pb** for $m_\Phi = 100-900$ GeV
 - ▶ Results are interpreted in the context of $m_h^{\text{mod}+}$ and others benchmark scenarios
- ▶ Upper limits on $\sigma(gg \rightarrow H(125)) \mathcal{B}(H(125) \rightarrow \Phi\Phi) \mathcal{B}^2(\Phi_1 \rightarrow \tau\tau)$ are set in the range **4.5-10.3pb** for $m_\Phi = 4-8$ GeV
- ▶ CMS Higgs analyses are at the end of a **successful commissioning** stage at $\sqrt{s} = 13\text{TeV}$ and **first results are already public**
- ▶ More interesting results are expected for Summer conferences!

Backup

MSSM $\Phi \rightarrow b\bar{b}$ search: Interpretation

