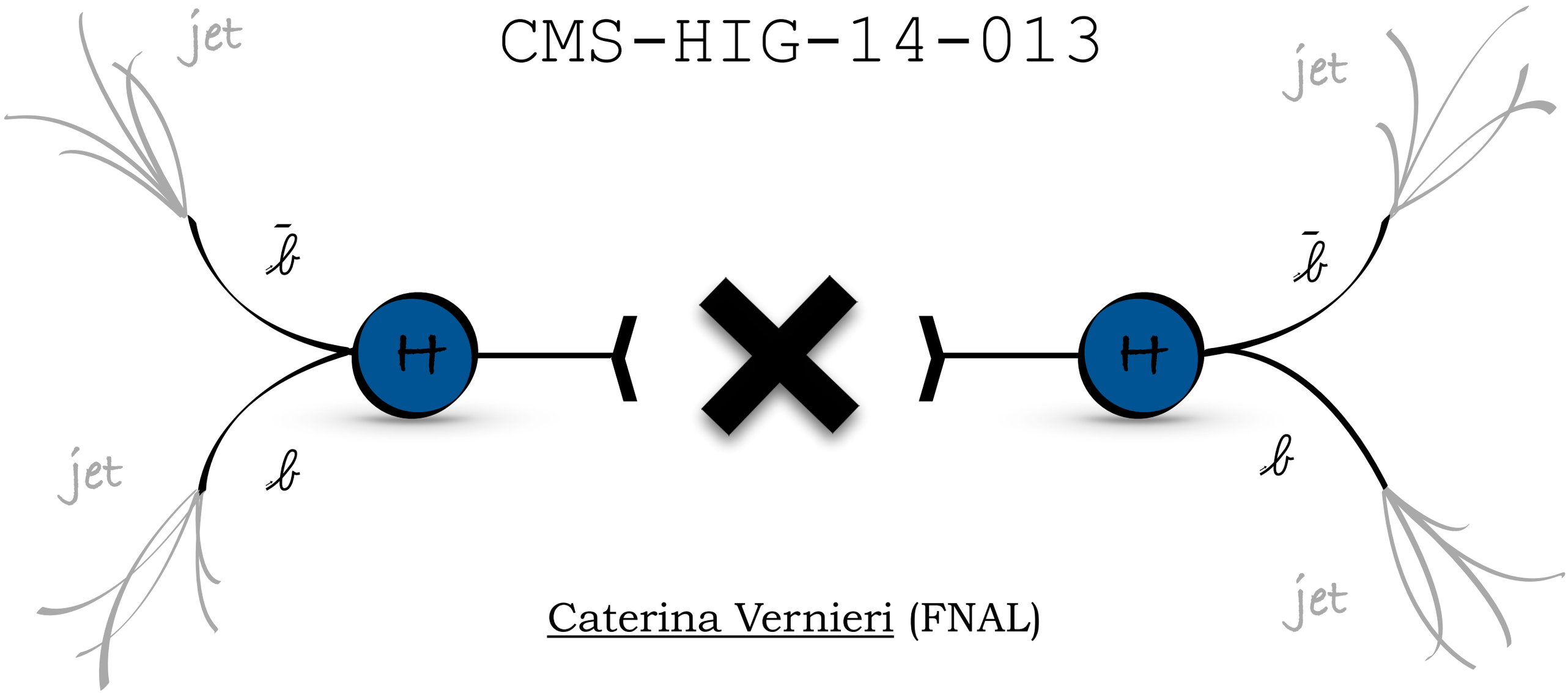
Search for di-Higgs resonances decaying to 4 b-jets in pp collisions at 8 TeV

CMS-HIG-14-013



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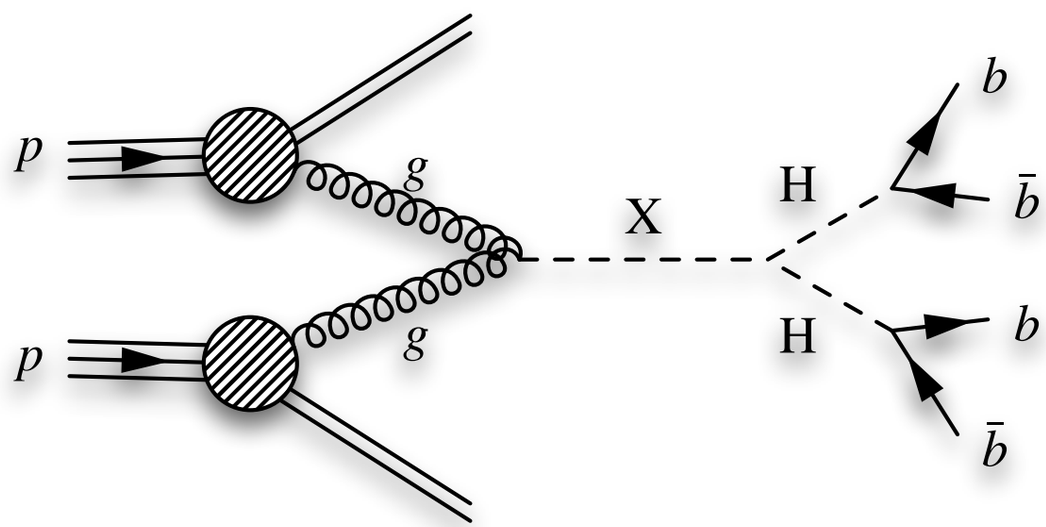
S.Das J.Konigsberg (U Florida)

HH subgroup meeting 08.12.2014

HH(4b), Strategy I

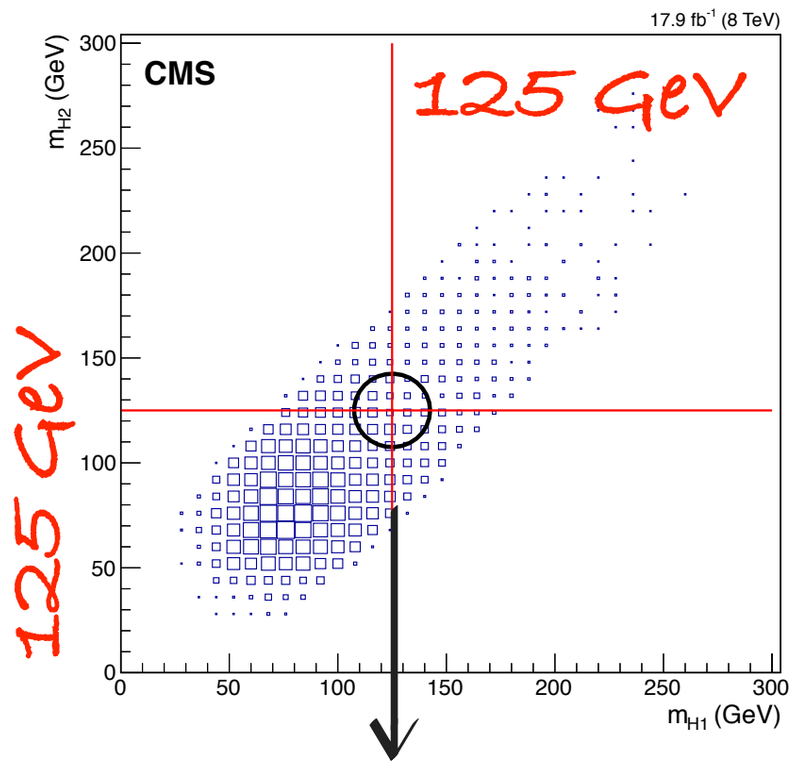
A model independent search for a **narrow width** resonance X→HH(→4b)



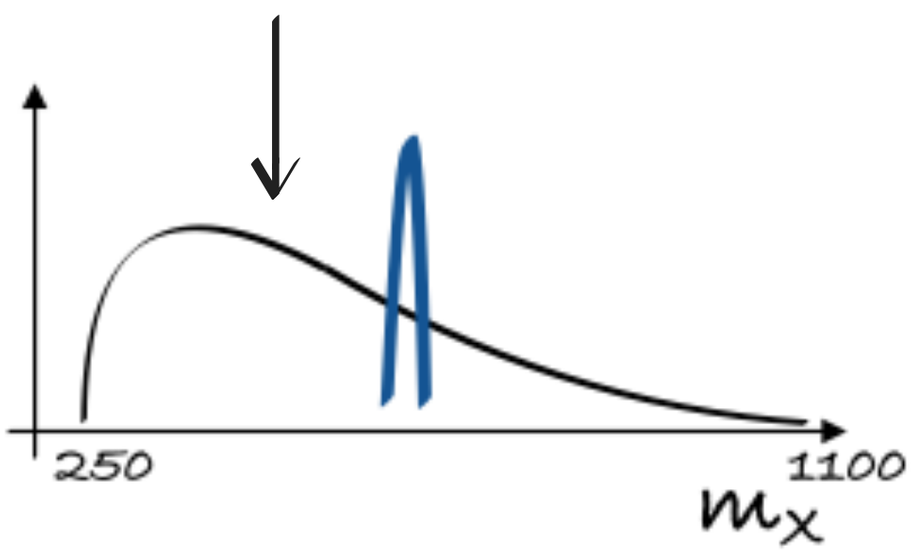
- **high b-tag efficiency**
  - trigger exploits CSV information
  - CMVA tagger offline
    75% b-tag eff and 3.5% mis-tag

- Looking in the **270 GeV - 1.1 TeV mass range**
  - kinematic changes with m_X
  - 3 different mass ranges are analyzed separately

HH(4b), Strategy II



$$m_X^2 = (p^\mu_{H_1} + p^\mu_{H_2})^2$$



- A fit to a resonance and a smooth background
- **Fully hadronic final state**
- Multi-jet QCD is the main background
  - Data-driven modeling
    - The shape is inferred from various control regions
    - The normalization is adjusted in the final fit

HH(4b), Event Selections

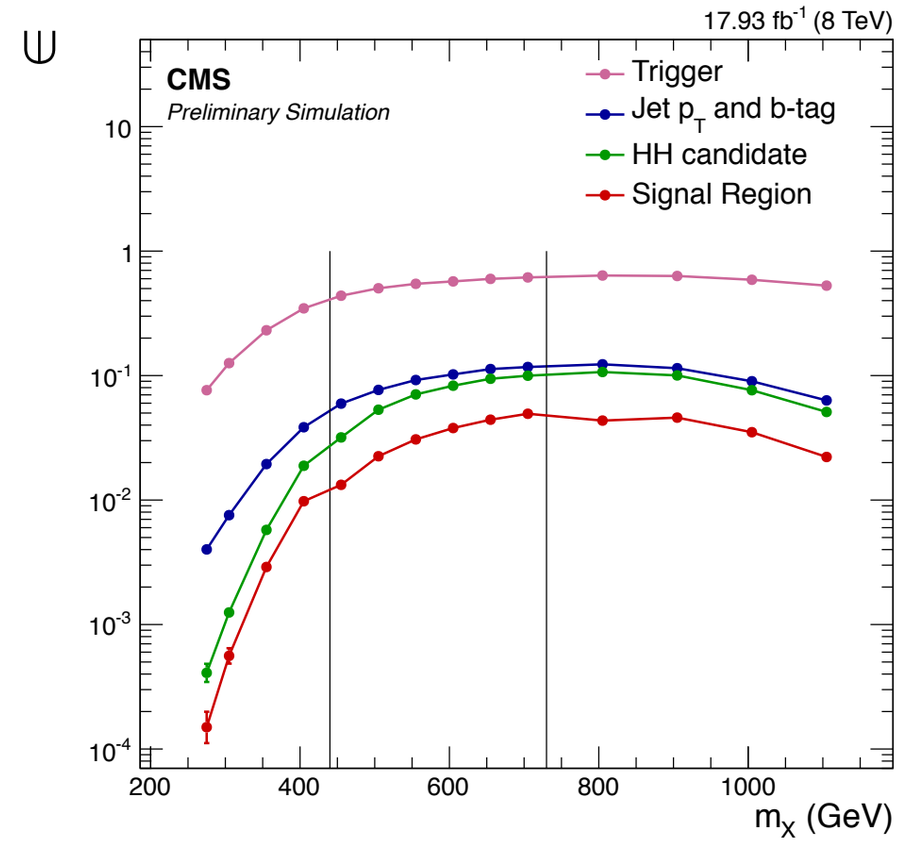
- The trigger requires
  - 4 anti-k_T (0.5) central jets with p_T > 30 GeV
  - 2 with p_T > 80 GeV
  - 2 b-tag

- 4 central jets with p_T > 40 GeV and CMVA>0.71

- Two Higgs candidates
  - $m(b\bar{b}) \sim m_H \pm 35$ GeV
  - at least 2 jets with p_T > 90 GeV
  - $\Delta R(b\bar{b})<1.5$
  - $\Delta R(b\bar{b})<1.5$ and $p_T(b\bar{b})$ > 300 GeV

- Signal Region $\sqrt{\Delta m_{H1}^2 + \Delta m_{H2}^2} < 17.5 \text{ GeV}$

$$\Delta m_{H_{1,2}} = m_{H_{1,2}} - 125 \text{ GeV}.$$



Low Mass Regime

$2m_H < m_X < 450$ GeV

Medium Mass Regime

$450 \text{ GeV} < m_X < 750 \text{ GeV}$

High Mass Regime

$m_X > 700$ GeV

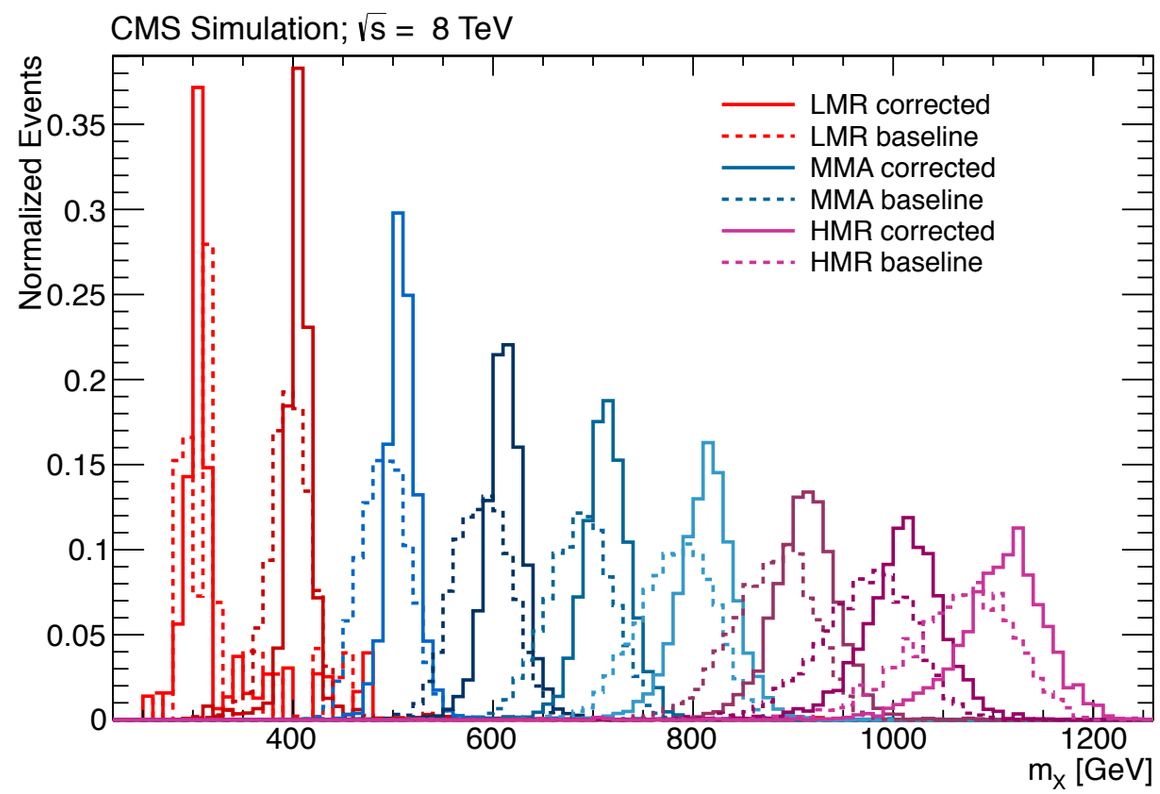
Signal resolution, Kinematic Fit

- each $m(b\bar{b})$ is constrained to m_H within the resolution
  - m_H is well known

$$\left.\begin{array}{l} m(b\bar{b})_1 \\ m(b\bar{b})_2 \end{array}\right\} \sim 125\ \text{GeV}$$

- b-jets 3-momentum corrected through the **kinematic fit technique**
- inputs are: jet η, ϕ and p_T and their related uncertainty
- the corrections mainly affect the jet-p_T

m_X resolution is **4-30 GeV**
m_X improves by **30-60%**



relative improvement larger for the lowest mass points

$$m_X \sim 2m_H + \Delta m_X(E_{H1}, \vec{p}_{H1}, E_{H2}, \vec{p}_{H2})$$

HH(4b), Backgrounds

Several processes can contribute to the signal signature

non-resonant $b\bar{b}b\bar{b}$ **QCD** production is dominant

- plus contribution from $b\bar{b}c\bar{c}$
- thanks to b-tagging jjjj and bbjj are highly reduced
- modeled in data

$t\bar{t}$ mainly from c mis-identified as b-jet ($t \rightarrow bcs$)

- modeled in simulation
- same model as multi-jet

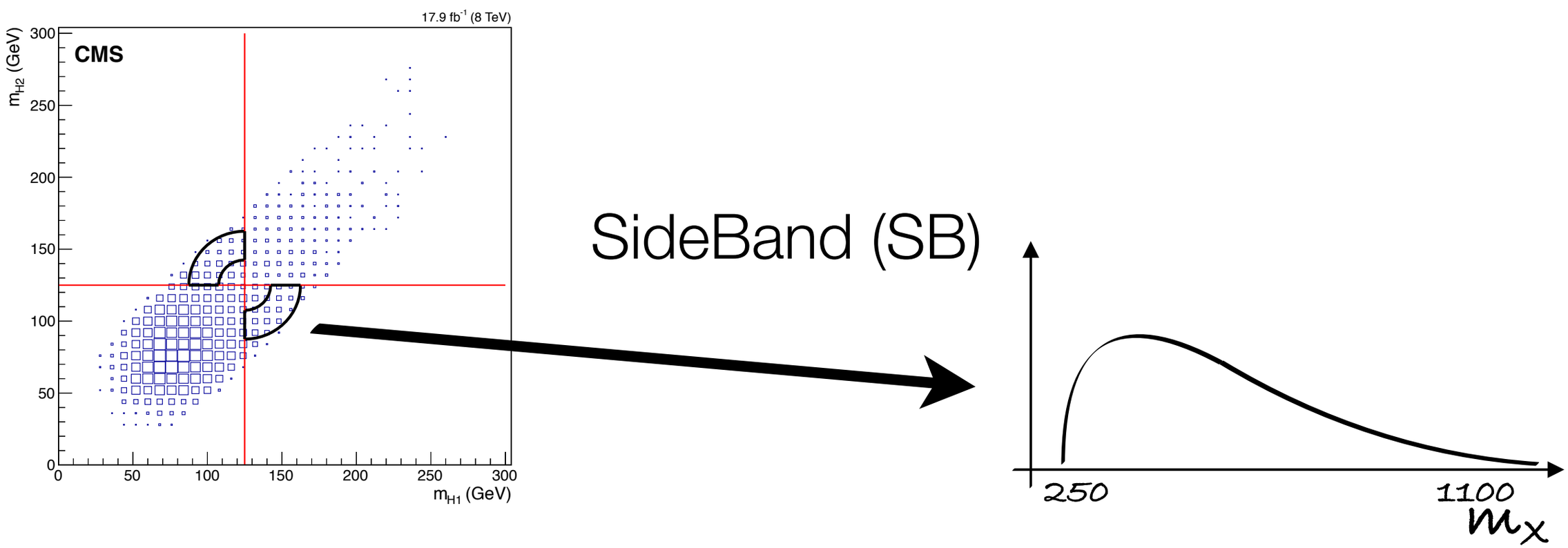
Z boson in association with b-jets, ZH and ZZ associated production

found to be negligible

SB

Multi-jet, modeling

- The QCD multi-jet production appears as a smoothly falling spectrum above the kinematic turn-on driven by the trigger selection.
- A kinematically close phase space (**S**ide**B**and) is used to infer its functional form
  - not signal enriched
- A Gauss-Exp function is found to fit well the SB and various other validation regions
  - we assume this shape for the signal region [assign some systematics to assumption]



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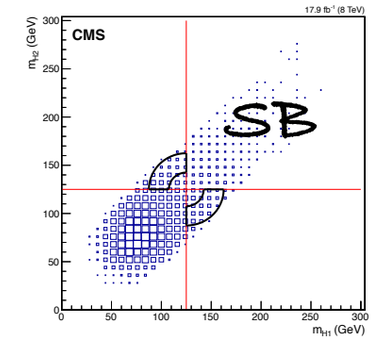

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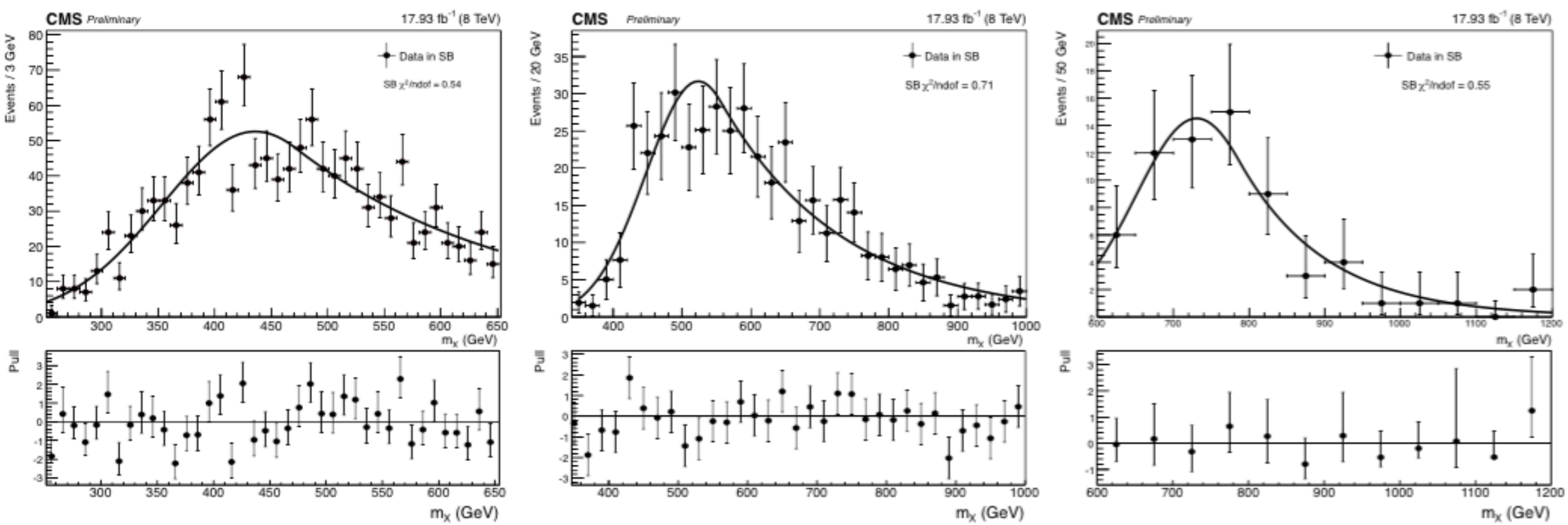
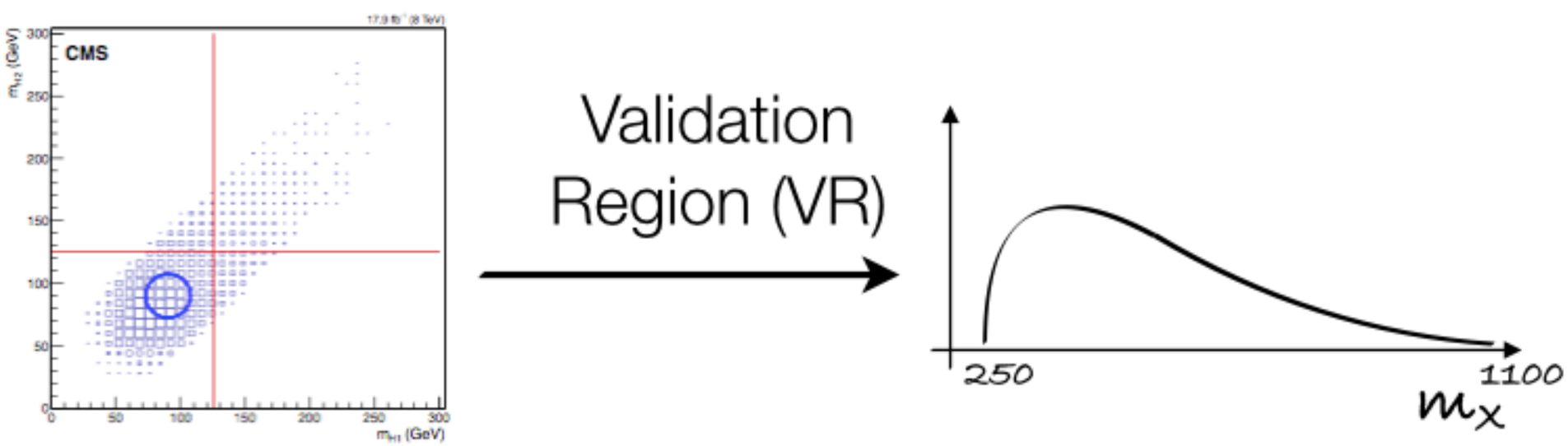


(a) LMR (b) MMR (c) HMR

Multi-jet, Validation

- The validity of the Gauss-Exp to model QCD shapes is tested in several control regions.
  - VR/VB, close to the signal region
    - not signal enriched



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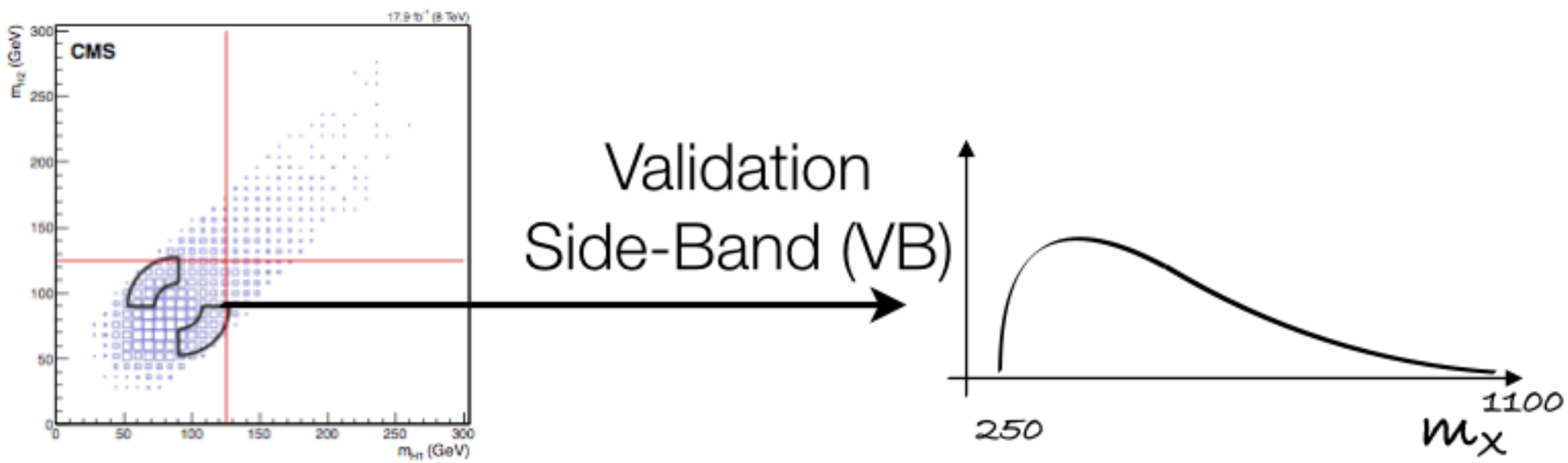

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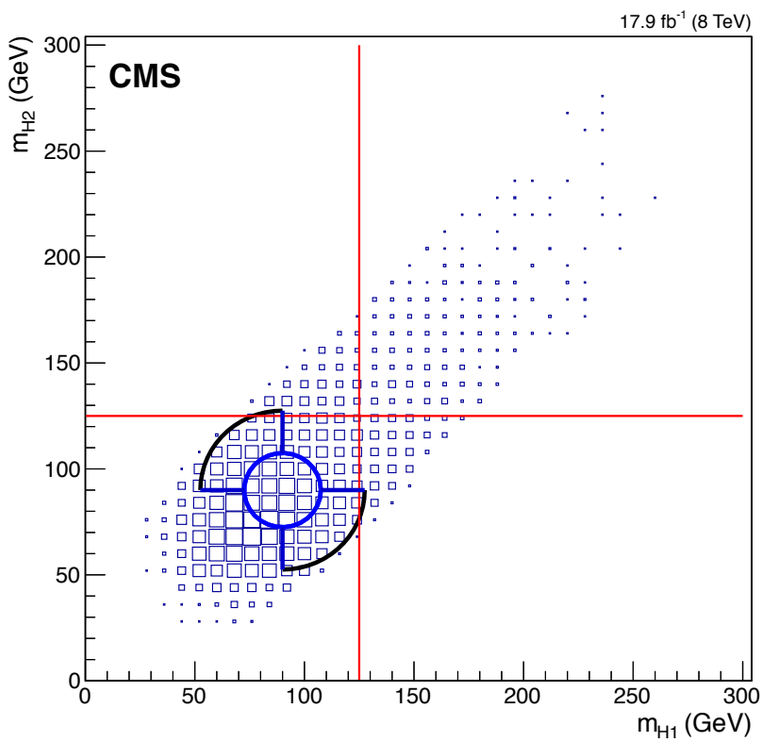
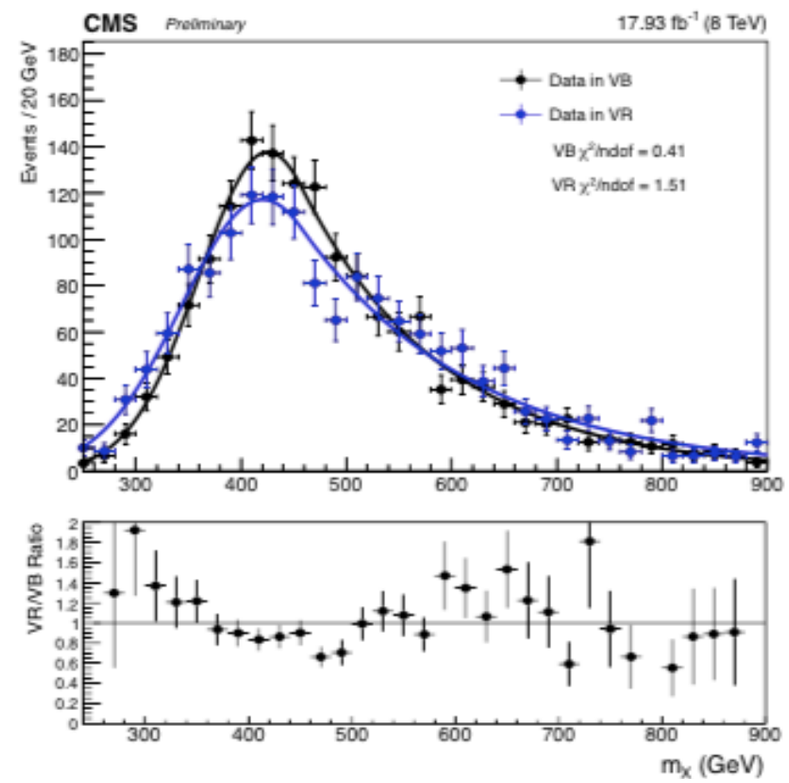
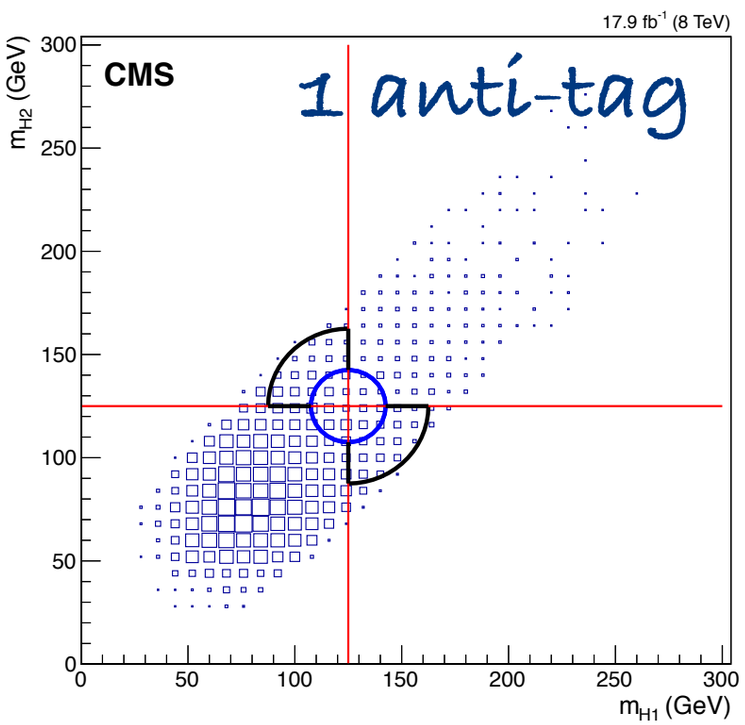


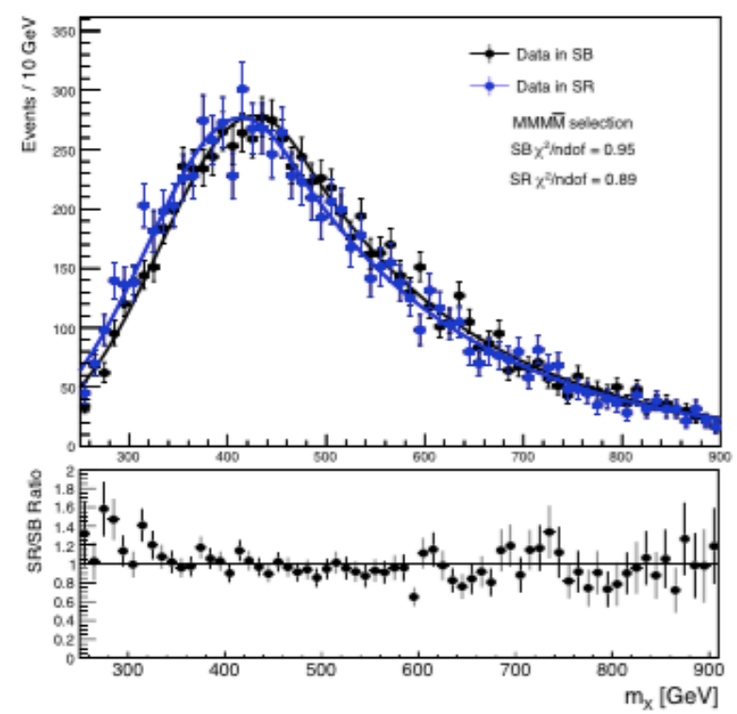


The goodness of fit in the inner region is in agreement with the external sideband result
The ratio shows the goodness of the spectrum compatibility hypothesis

Multi-jet, Validation

- The validity of the Gauss-Exp to model QCD shapes is tested in several control regions.
  - SR/SB by reversing one b-tag requirement
    - similar kinematic





Good compatibility of the spectra in the signal-like with the sideband-like regions

Great flexibility of the chosen fit function in adapting to the different m_X spectra

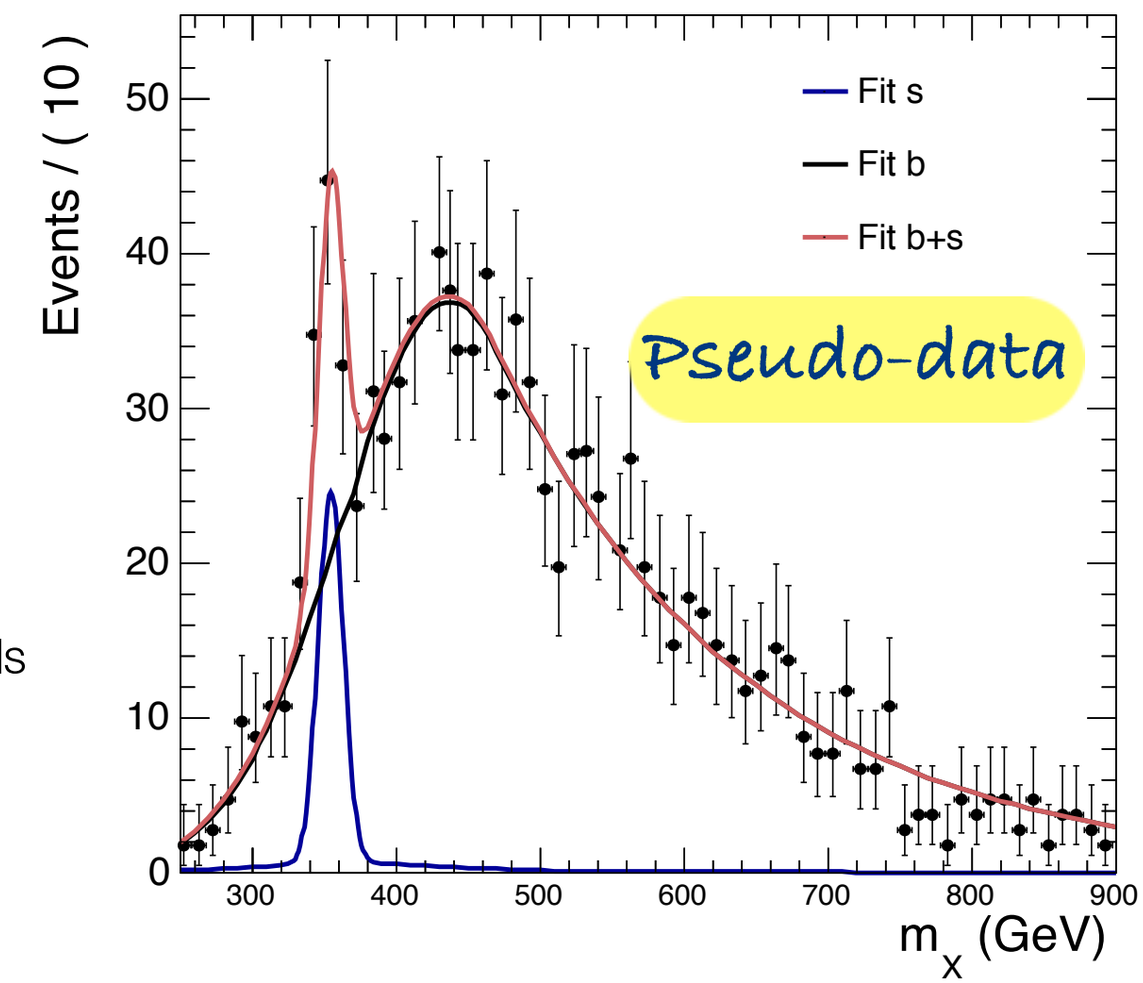
How a signal would look like

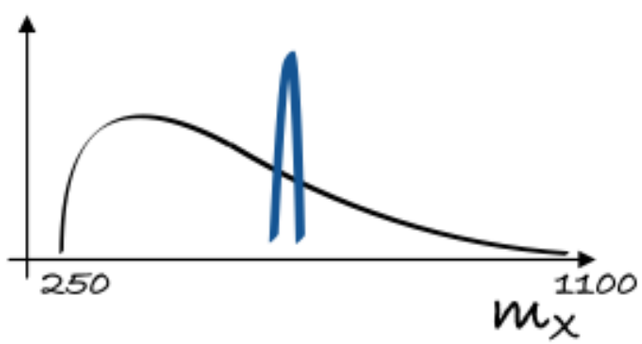
The signal is expected as a **peak** in the m_X distribution on top of **smooth background**

A fit to the m_X distribution in data events is performed in each phase space
LMR, MMR and HMR.

The different components in the final fit are:

- **signal**
  - modeled with a Gaussian + exp/Gaussian for the tails
  - using spin-0 RS1 as benchmark
- **multi-jet**
- **$t\bar{t}$**





- shape from SB
- rate from SR
- σ_{inj} = 1 pb at 350 GeV

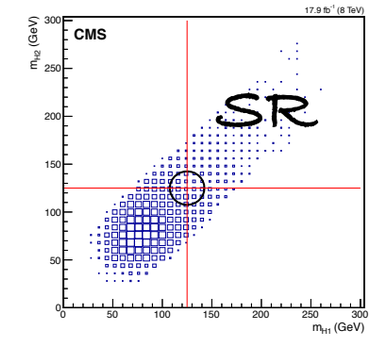
$\mu = 1.25 \pm 0.40$

Systematic Uncertainties

- The multi-jet Gauss-Exp functional shape has been shown
  - to fit well different mass spectra
  - expected to fit well the signal region
  - **NOTE** we checked many shapes, this was the best.
- To assess a systematic uncertainty on this choice we compare with an alternative polynomial functions.
- The derived **uncertainty** degrades the upper limit by 2-30% depending on m_X
- Other systematic uncertainties mostly originate from the limited accuracy of the simulation
  - both the expected acceptance and the shape of the m_X in simulated events
  - their impact on the expected limits is **2% at most**

Source of	Impact in LMR (%)		Impact in MMR (%)		Impact in HMR (%)	
systematic uncertainty	Signal	$t\bar{t}$	Signal	$t\bar{t}$	Signal	$t\bar{t}$
Jet energy scale	0.1 - 1.4	0.02	0.0 - 0.2	0.1	0.1 - 0.3	3.2
Jet energy resolution	0.8 - 2.7	0.8	5.5 - 7	2.1	5.0 - 6.6	7.5
b-tagging scale factor	12.7	12.7	12.7	12.7	12.7	12.7
Trigger b-tag SF	2.8 - 4.1	2.7	2.7 - 3	2.0	2.6 - 2.7	2.5
Trigger p_T SF	5.7- 18.3	9.1	5.4 - 7.4	6.7	6.0 - 8.0	6.9
Normalization	–	15%	–	15%	–	15%

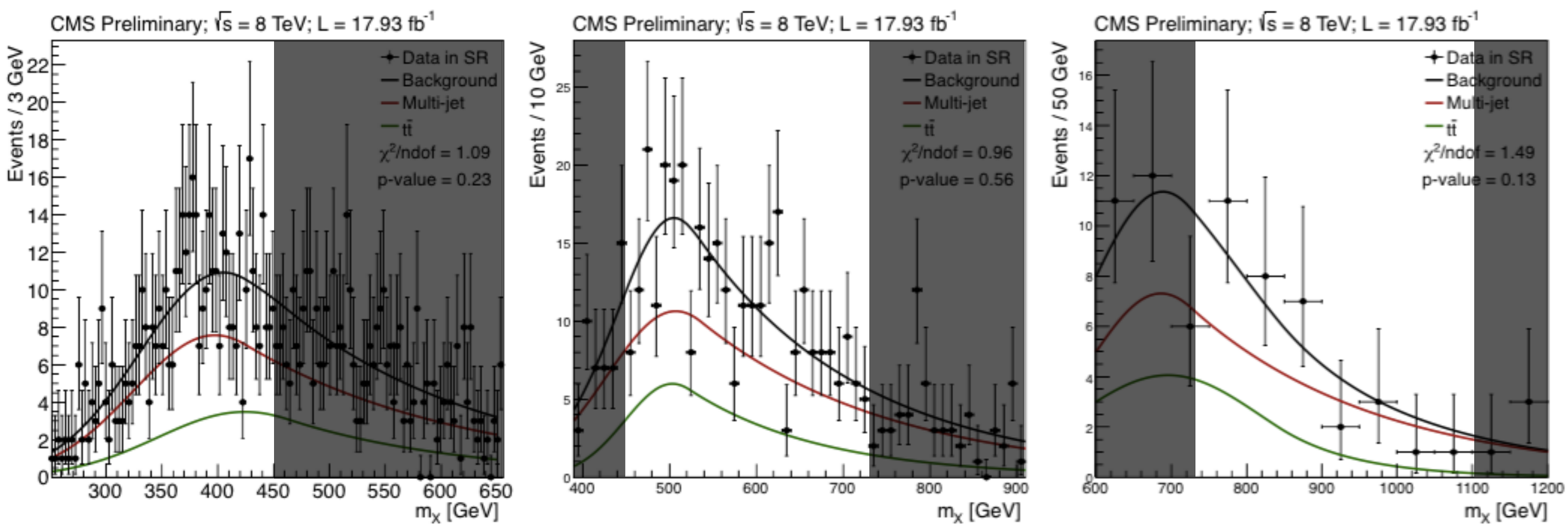
Fit to m_X in the SR



A fit to m_X is performed in each phase space

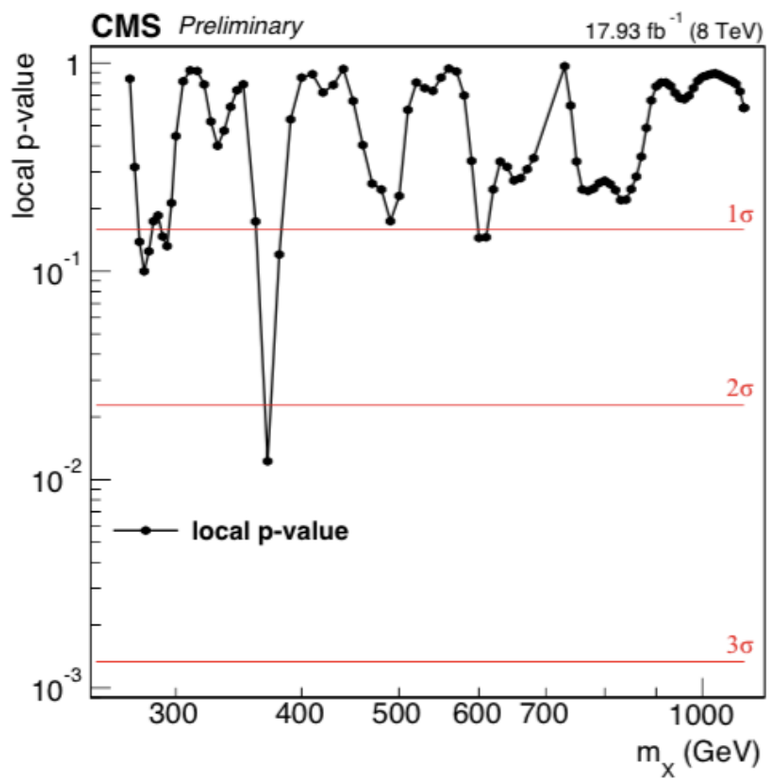
signal extraction performed only in a restricted range of the full spectrum

In the three m_X spectra no visible excess due to the presence of a signal is clearly visible

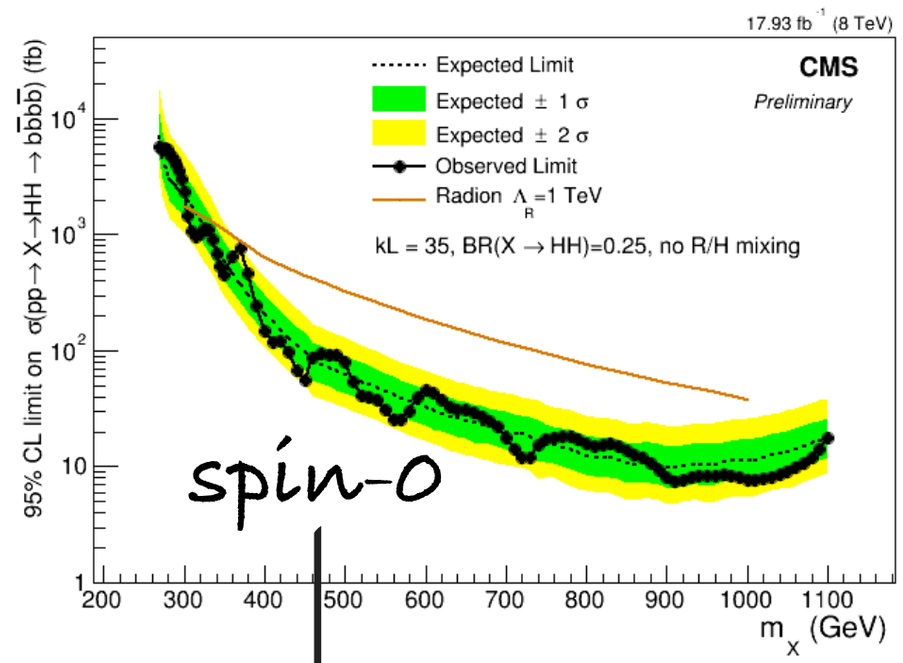


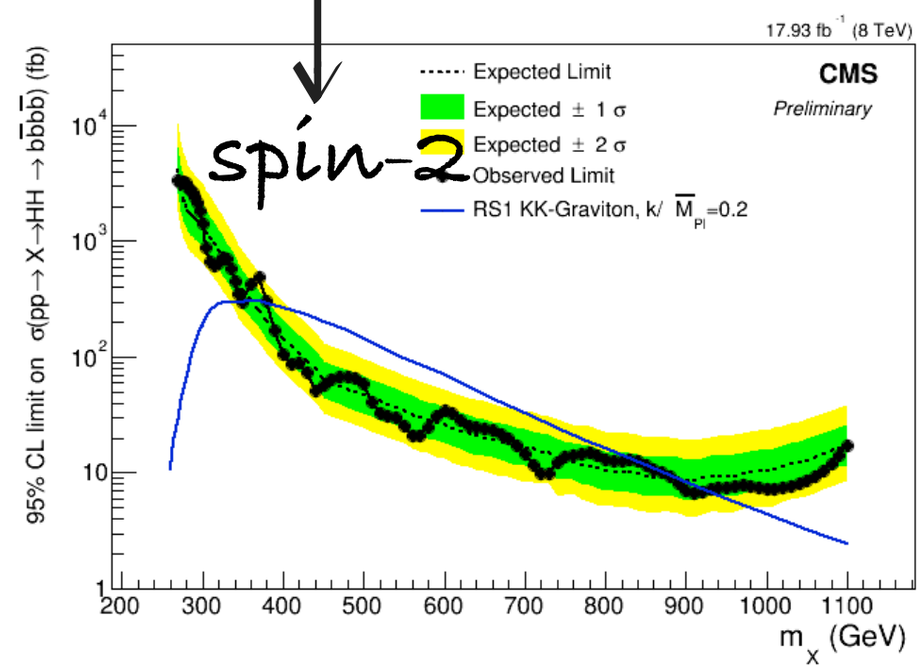
(a) LMR (b) MMR (c) HMR

Observed Limits, Spin-0/2



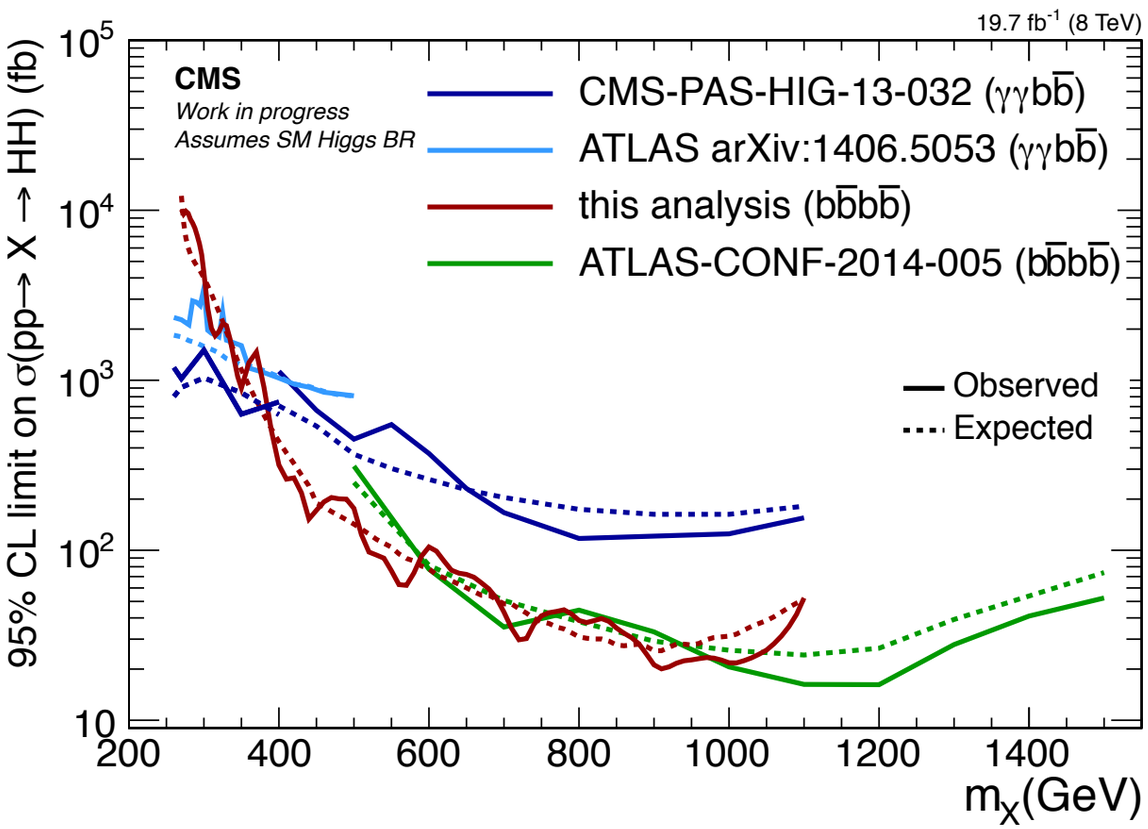
+20-30% signal eff.





- Sensitivity to WED predictions in the intermediate/high mass region
- The low mass region sensitivity not enough to probe (N)MSSM predictions

Observed Limits, Comparison



No significant deviation from expectation

$h(\gamma\gamma)h(b\bar{b})$ $h(b\bar{b})h(b\bar{b})$ complementary

- $hh(b\bar{b}b\bar{b})$ results are sensitive to spin hypothesis
- best channel for $m_X > 400$ GeV

Constraints on WED (Radion and Graviton), 2HDM

- Overall hh is competitive with VV searches to test WED

This result extends in the $b\bar{b}b\bar{b}$ final state the search for $m_X < 500$ GeV

the best limits on the cross section $X \to HH$ in the mass range

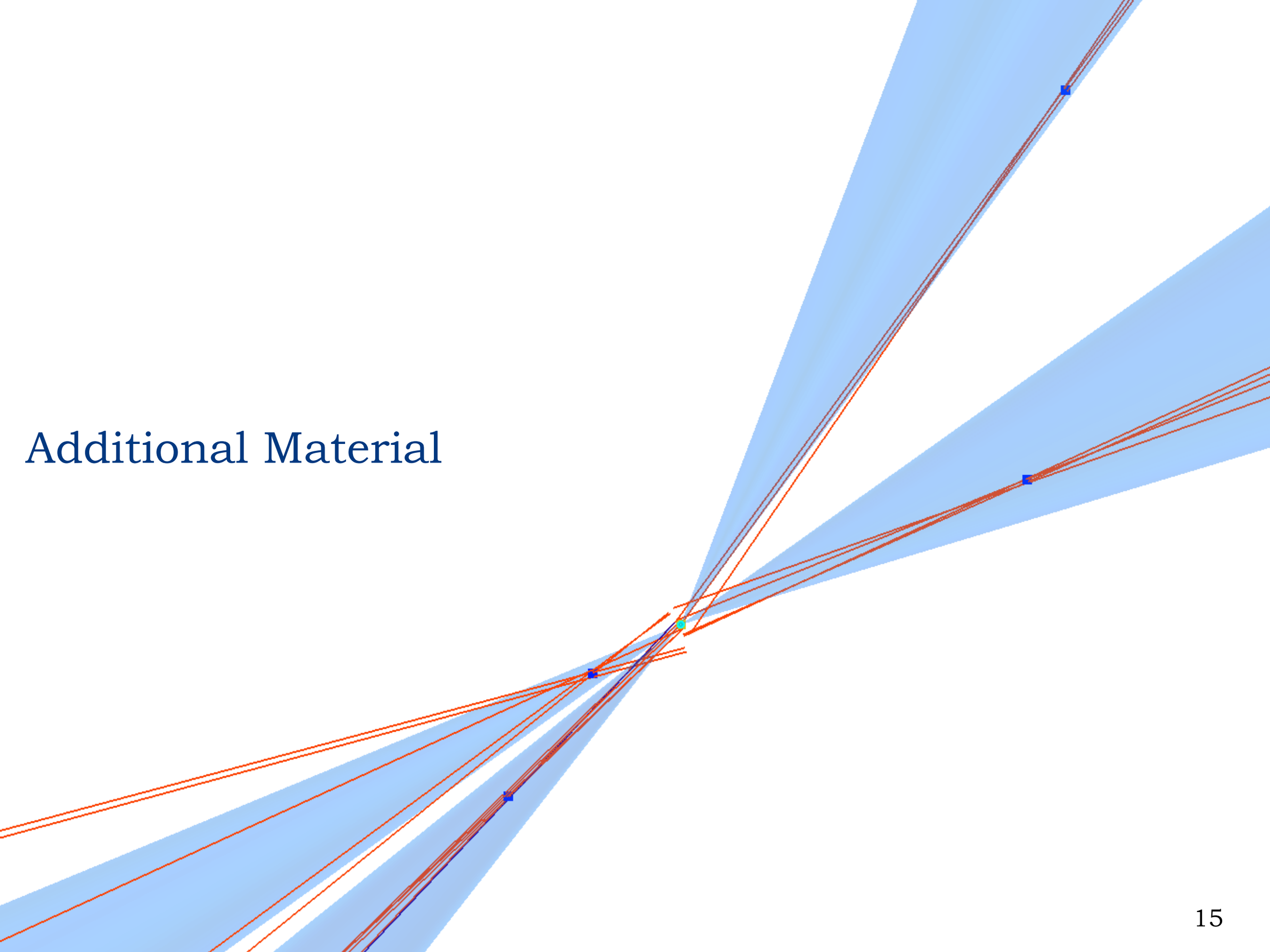
- from 380 to 600 GeV (921 - 93 fb)
- from 700 to 970 GeV (136 - 23 fb)

13

Conclusions & Outlook for Run II

- **No** statistically significant signal **excess** is observed.
- Upper limits at 95% CL_S on the production cross section times BR in HH
  - best **sensitive channel** (result) in the **medium mass scenario**
  - Signal efficiency is derived using specific narrow resonance models
    - for spin-dependency we provide two sets of results for both the spin-0 and spin-2 hypotheses
    - (apart from this **how model independent are these limits?**)
- At 13 TeV an unexplored phase space for New Physics searches
  - Enhanced sensitivity to resonant double Higgs production
  - Biggest challenge is to maintain high trigger efficiency keeping the rate within the budget
    - similar trigger strategy : multi-jet +b-tag trigger
  - Investigate a bit more the narrow width approximation and provide an interpretation of results for **different width hypotheses**

Additional Material



HH(4b), Backgrounds

Several processes can contribute to the signal signature

multi-jet production σ(jjjj) : σ($b\bar{b}$jj) : σ($b\bar{b}b\bar{b}$)=6500:200:1

top-pairs, dibosons production

Z boson in association with b-jets

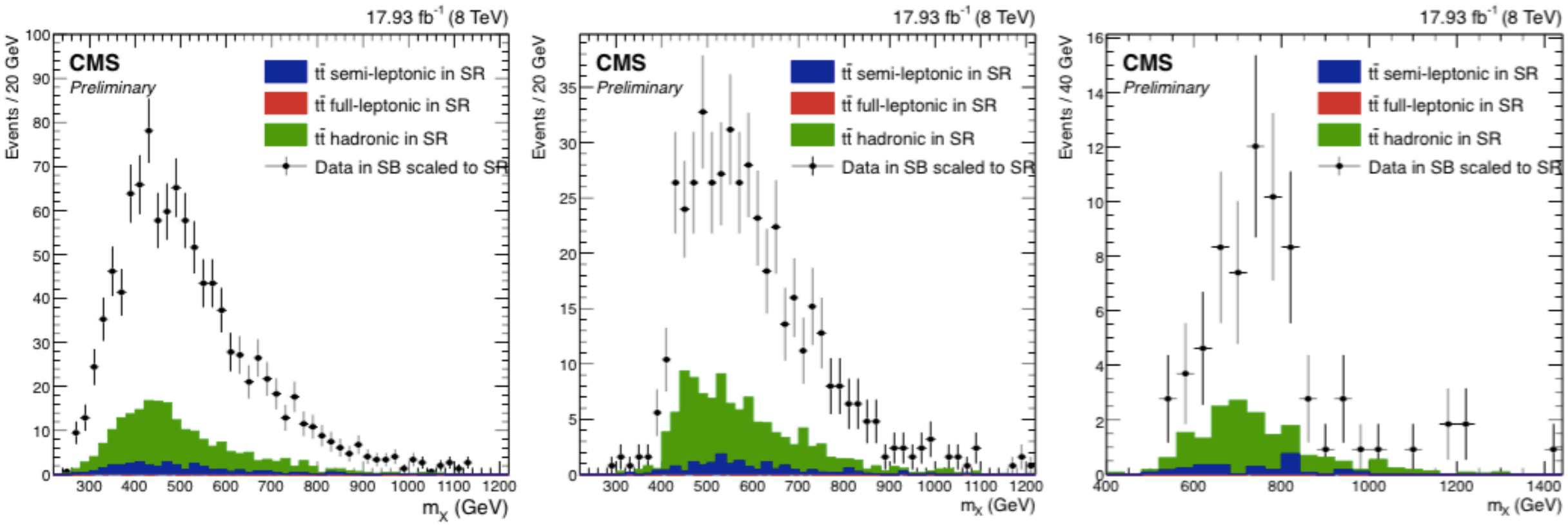
process	$\sigma_{\text{theo.}}$	ϵ			$\sigma \times \text{BR}(4b)_{\text{eff}}$
	[pb]	$\epsilon^{4j}_{\text{sel}}$	$\epsilon^{4b}_{\text{tag}}$	$\epsilon^{4b}_{\text{sel}}$	[pb]
$b\bar{b}b\bar{b}$	~ 30	1	$(0.75)^4$	$\sim$0.3	9
$b\bar{b}c\bar{c}$	~ 60	1	$(0.75)^2 \cdot (0.23)^2$	$\sim$0.03	1.8
$b\bar{b}$jj	$\sim 6 \cdot 10^3$	1	$(0.75)^2 \cdot (0.03)^2$	$\sim 5 \cdot 10^{-4}$	3
jjjj	$2 \cdot 10^5$	1	$(0.03)^4$	$\sim 8 \cdot 10^{-7}$	0.16
$t\bar{t}$	252.8	$(0.67)^2$	$(0.75)^2 \cdot (0.23)^2$	0.01	2.5
Z+jj	$3.5 \cdot 10^3$	(0.04)	$(0.75)^2 \cdot (0.03)^2$	$\sim 2 \cdot 10^{-5}$	0.07
ZH	0.4	$(0.15) \cdot (0.57)$	$(0.75)^4$	$\sim$0.02	0.008
ZZ	8.3	$(0.15)^2$	$(0.75)^4$	$\sim$0.007	0.05

non-resonant $b\bar{b}b\bar{b}$ QCD production is dominant

thanks to b-tagging jjjj and $b\bar{b}$jj are highly reduced

$t\bar{t}$, modeling

Evaluated in the SR from simulated events.



LMR ~ 22%

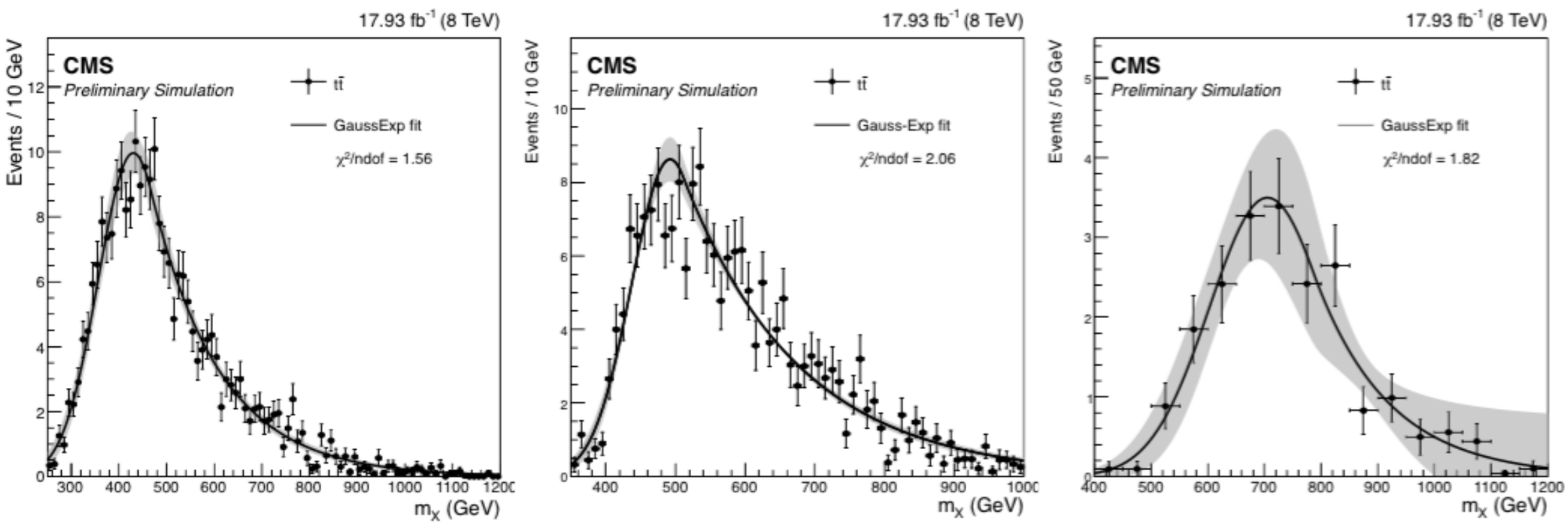
MMR ~ 27%

HMR ~ 28%

$t\bar{t}$ modeled in simulation
Same function used for the multi-jet background.

$t\bar{t}$, Template

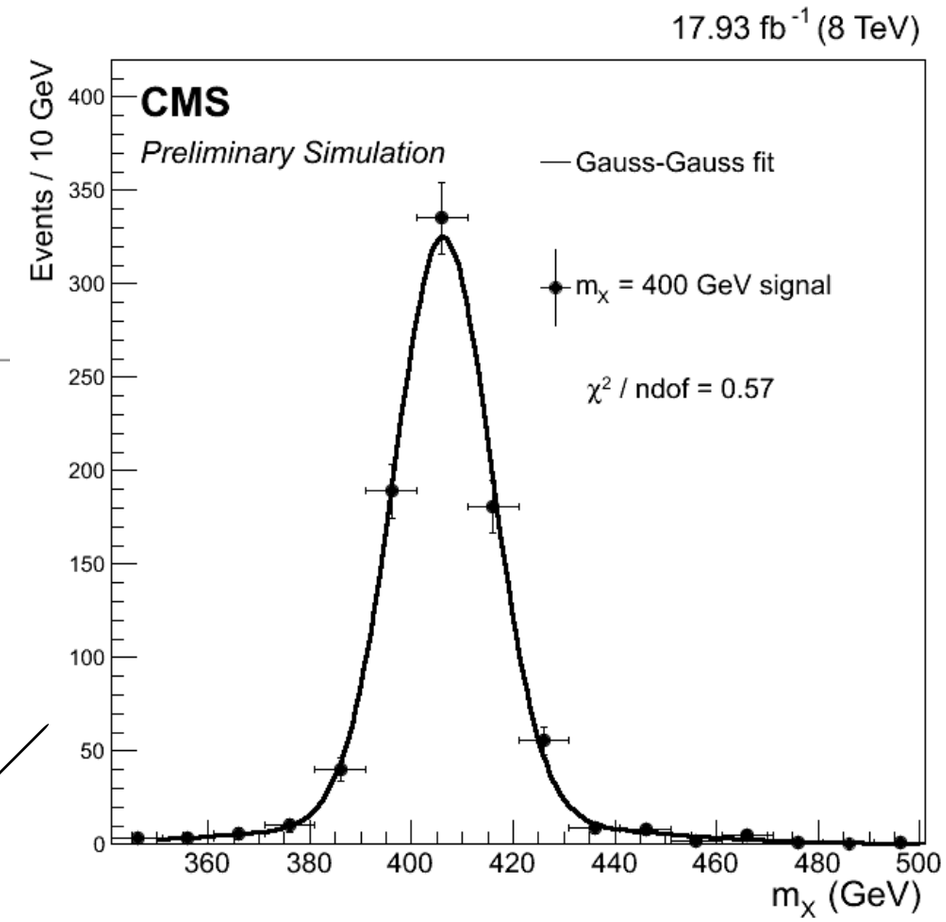
The impact of the $t\bar{t}$ contribution to the shape of the m_x distribution is studied in the SB
Subtracting the $t\bar{t}$ contribution does not affect the multi-jet shape
the peaks of the two components have slightly different mean values and widths.
The $t\bar{t}$ contribution is treated as a separate component
modeled in simulation by means of the same function used for the multi-jet background.

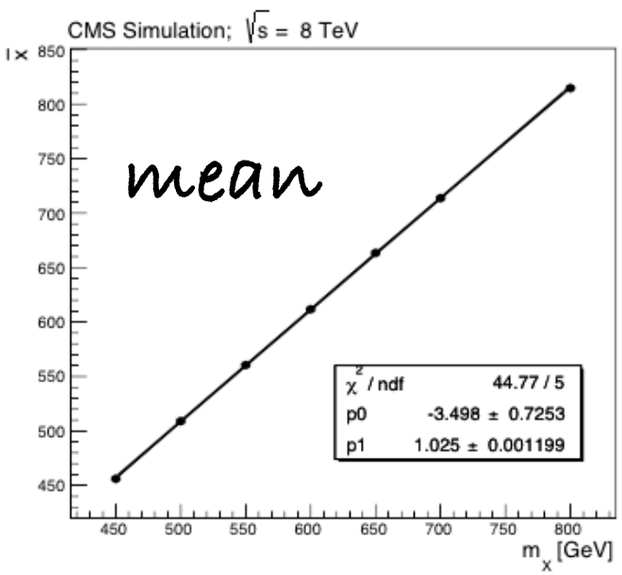


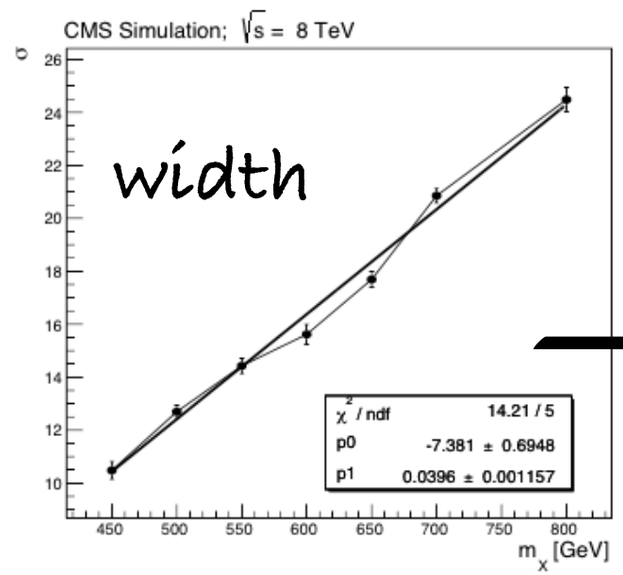
(a) LMR (b) MMR (c) HMR

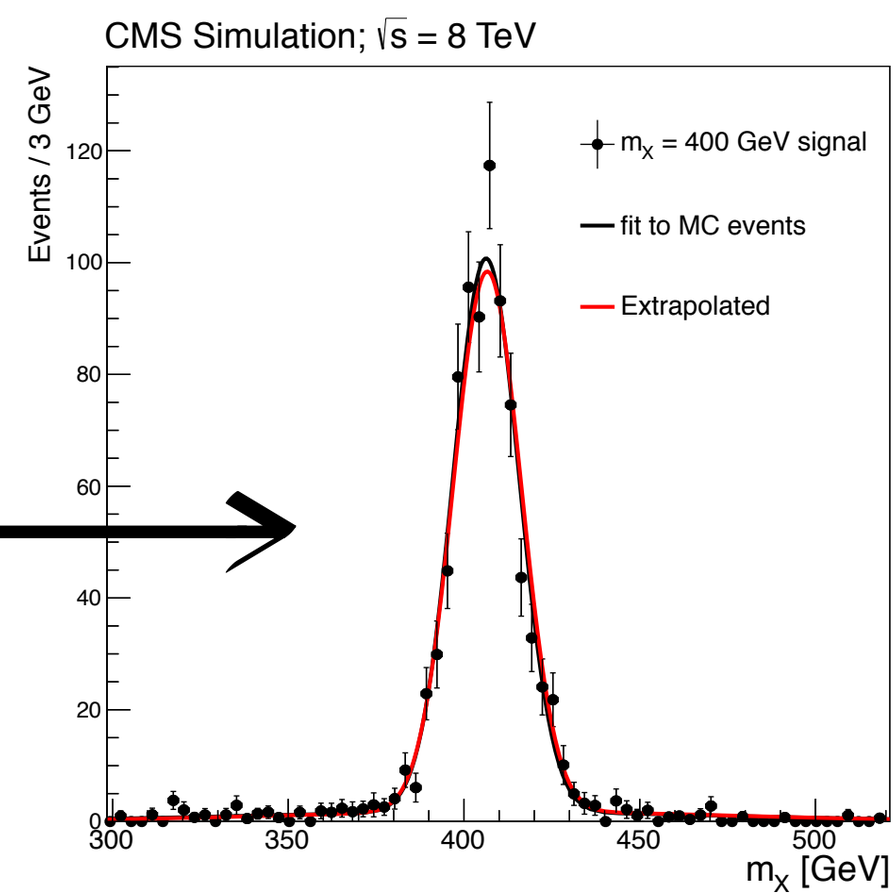
Signal Model

- Gaussian to model the core resonance
- Simulated samples are available for (few) fixed mass points
- Shapes for intermediate values are obtained with parameters interpolation

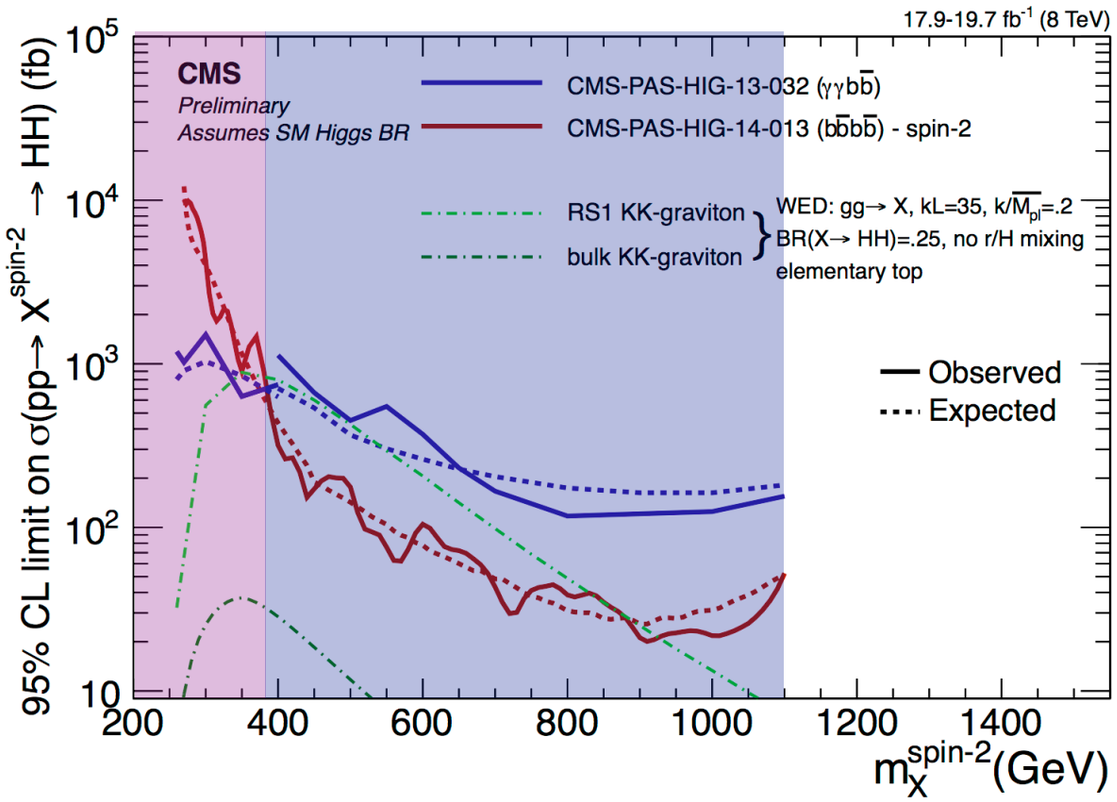


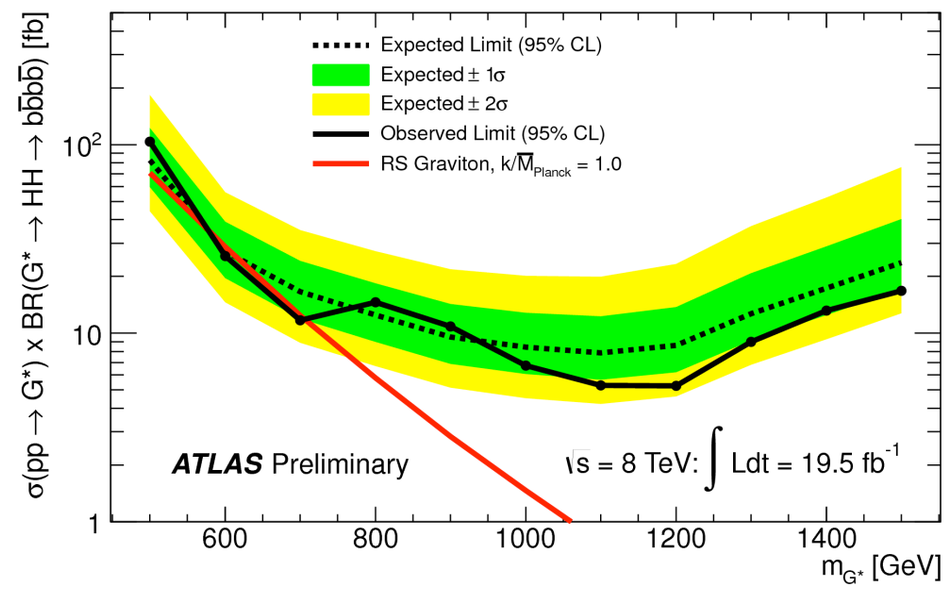


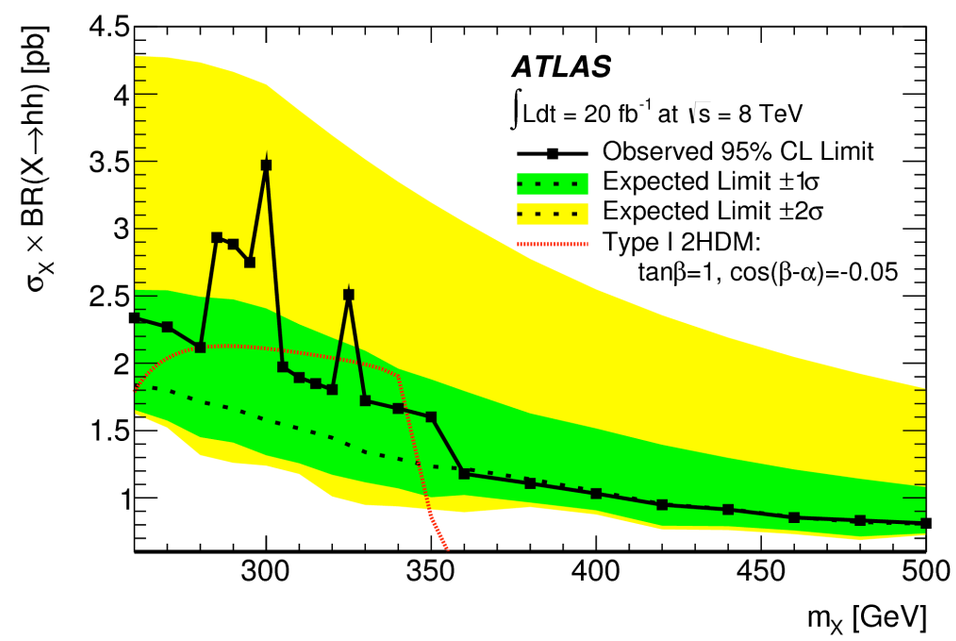




X→hh, Results







No significant deviation from expectation

h(γγ)h($b\bar{b}$) h($b\bar{b}$)h($b\bar{b}$) complementary

hh(4b) results are sensitive to spin hypothesis

best channel for m_X > 400 GeV

Constraints on WED (Radion and Graviton), 2HDM

Overall hh is competitive with VV searches to test WED

Spin-0, m vs excluded Λ

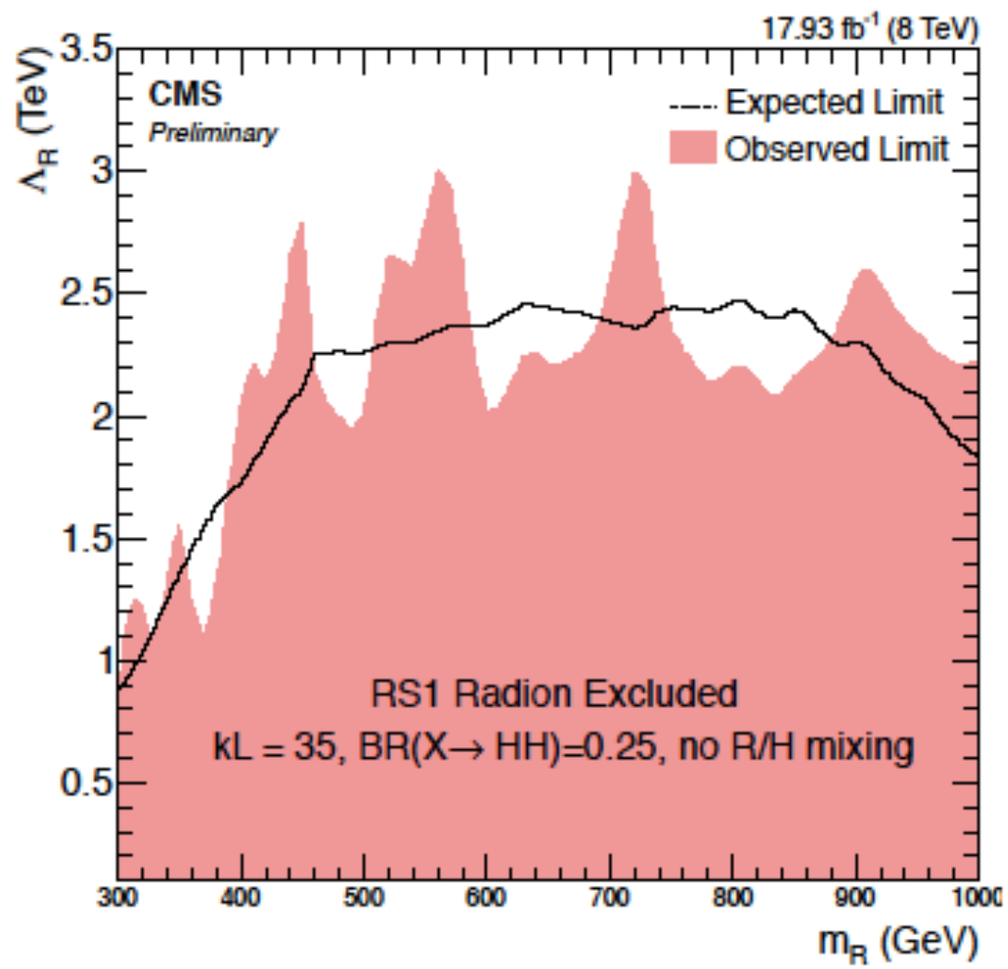


Figure 8.12: The observed and expected lower limit of Λ_R at 95% CL_S as function of m_X, assuming kL=35, no radion-Higgs mixing and BR(X→HH) equal to 0.25.