Summary of Higgs and BSM physics at CMS

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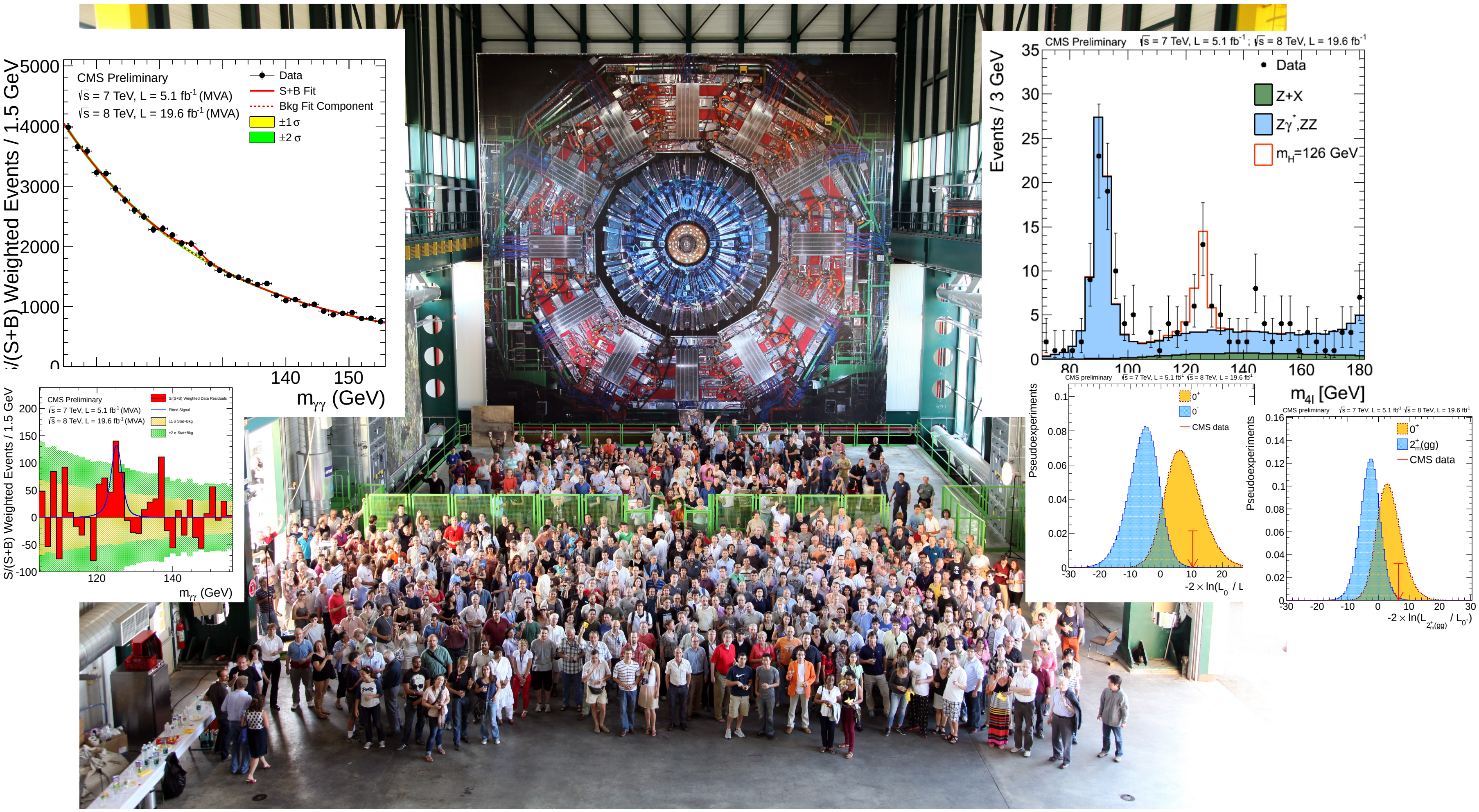


Higgs and Beyond 2013

Tohoku University, Sendai, Japan

June 05, 2013

The July 4th discovery of a new boson opened the new research line at the Energy Frontiers

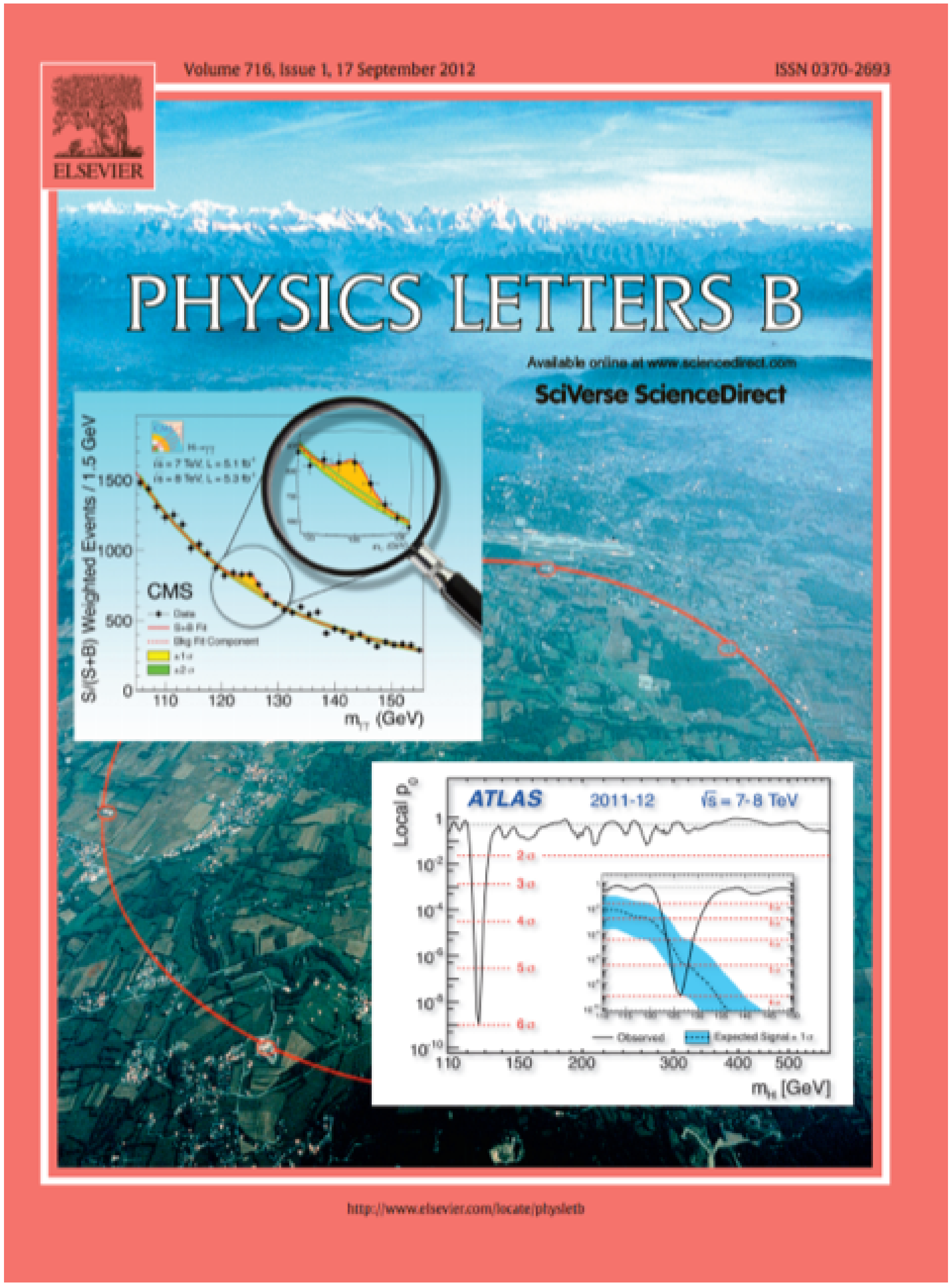
- ☞ Unraveling the Higgs-like boson nature is the major effort at CMS

A Higgs Boson→
The Higgs Boson→
The SM Higgs Boson

- ☞ The SM begins to unravel when probed beyond the range of current accelerators
  - ➠ search for BSM physics

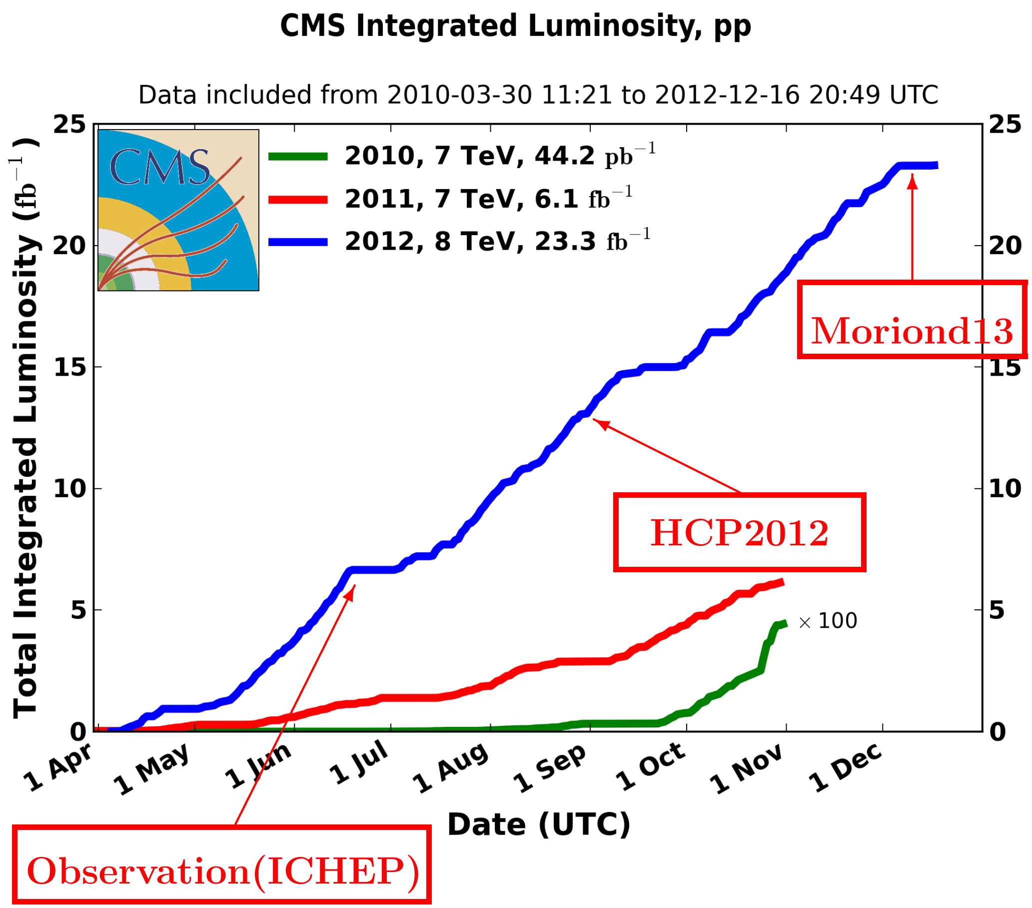
☞ Outline

- ➠ Higgs sector measurements
- ➠ SUSY searches;
- ➠ Dark Matter search in pp-collisions
- ➠ other BSM searches

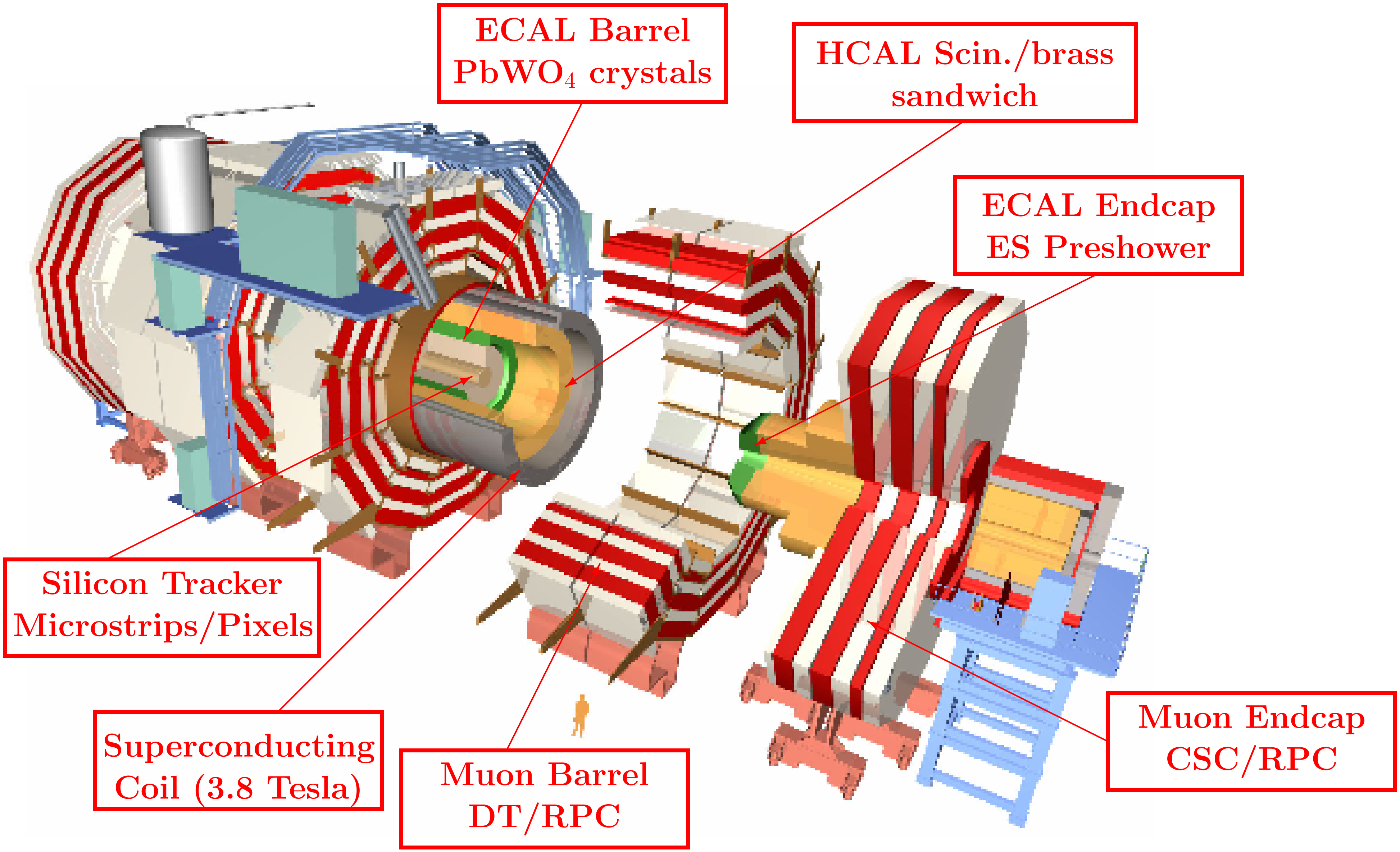


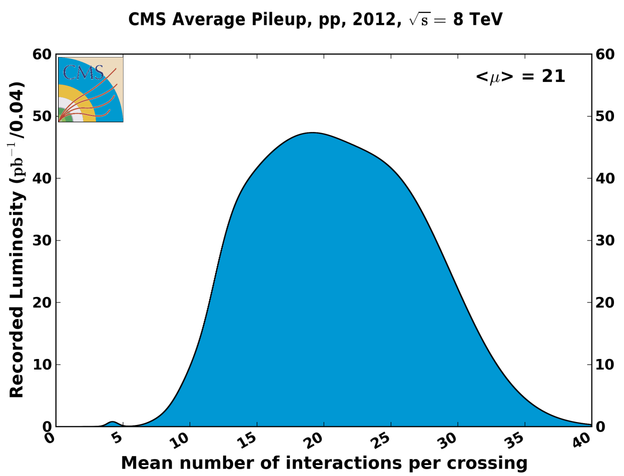
- Stellar performance of the LHC
  - extremely successful operation for these 3 years
  - 7 TeV collisions are started in March 2010
  - upgraded center-of-mass energy to 8 TeV in 2012
- Available dataset for the analyses with all subdetectors on
  - **7 TeV:** $\leq$5.1 fb^{-1}
  - **8 TeV:** $\leq$19.6 fb^{-1}
  - high detector efficiency

LHC restart in 2015 with a collision energy of $\simeq$13 TeV and increased beam intensity



$\sqrt{s}$=8 TeV: 25-30% higher cross section than $\sqrt{s}$=7 TeV at low Higgs boson mass


ECAL Barrel
$PbWO_4$ crystals
HCAL Scin./brass
sandwich
ECAL Endcap
ES Preshower
Silicon Tracker
Microstrips/Pixels
Superconducting
Coil (3.8 Tesla)
Muon Barrel
DT/RPC
Muon Endcap
CSC/RPC



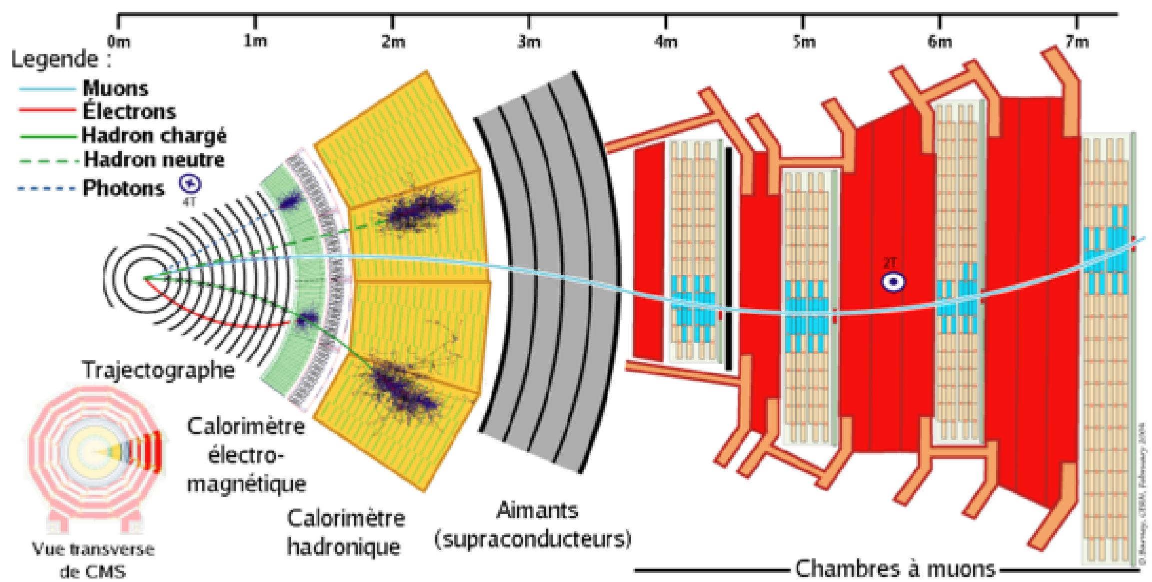
☞ Excellent performance of the CMS experiment in 2012

- 90% of recorded data with all subdetectors on
- peak luminosity $7 \times 10^{33} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ at 8 TeV CM energy
- **mean pile-up (PU) 21 events**

☞ Particle Flow (PF) algorithm:

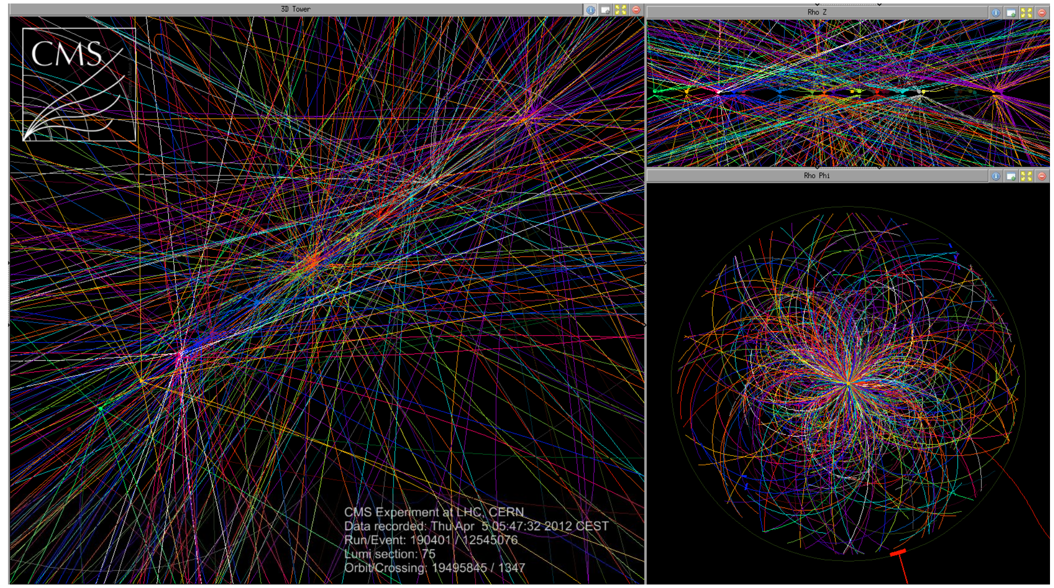
- provides a global event description in form of list of particles
- improvements in jet, tau and E_T^{miss} measurement

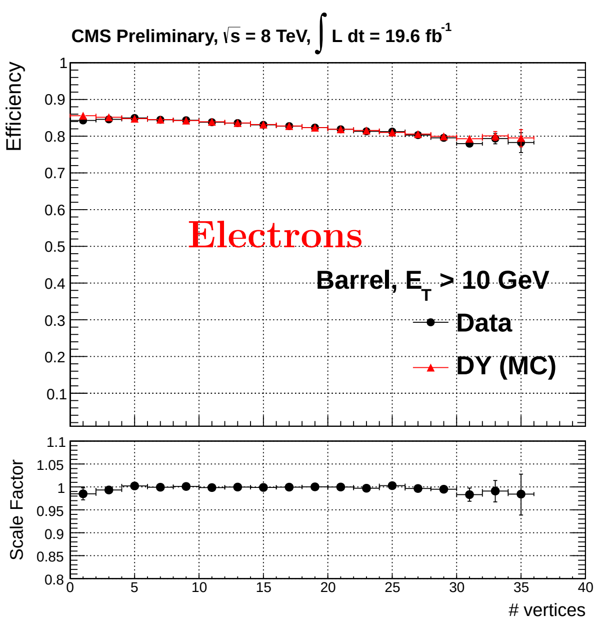
Improves reconstruction performance at high PU

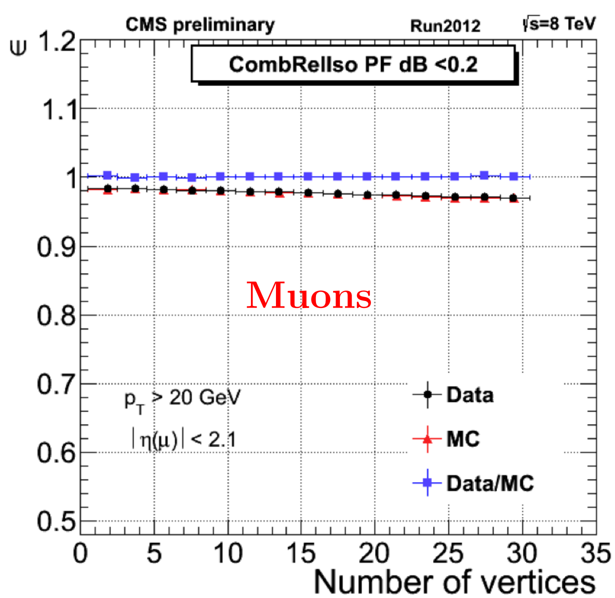


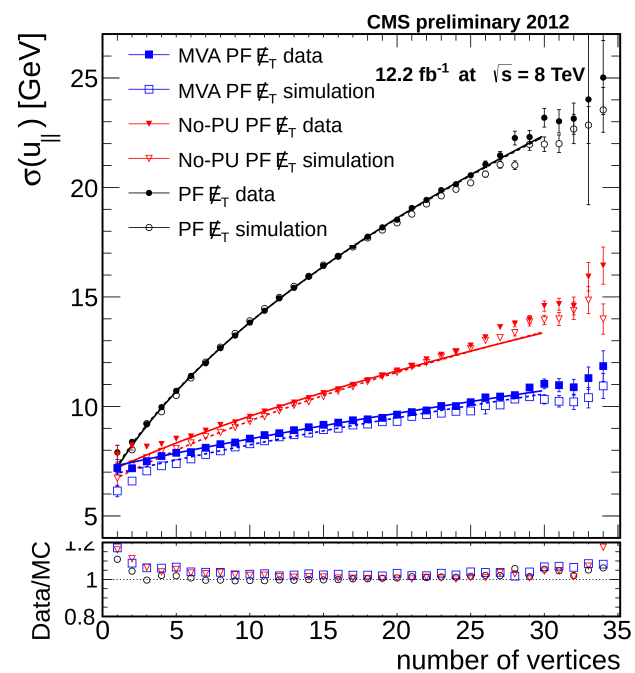
29 distinct vertices have been reconstructed corresponding to 29 distinct collisions within a single crossing of the LHC beam

Leptons and MET are almost insensitive to pileup

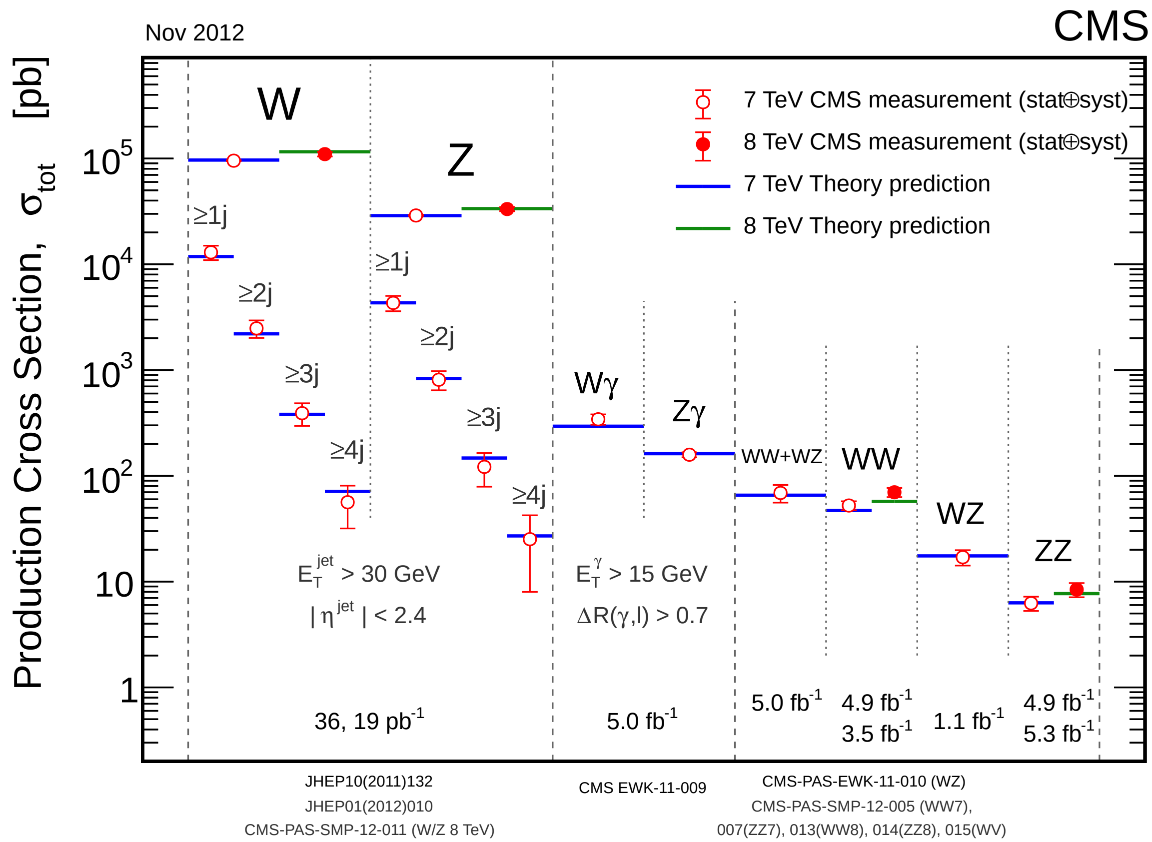


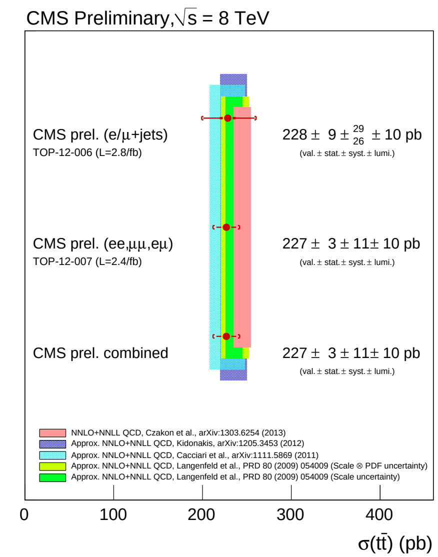


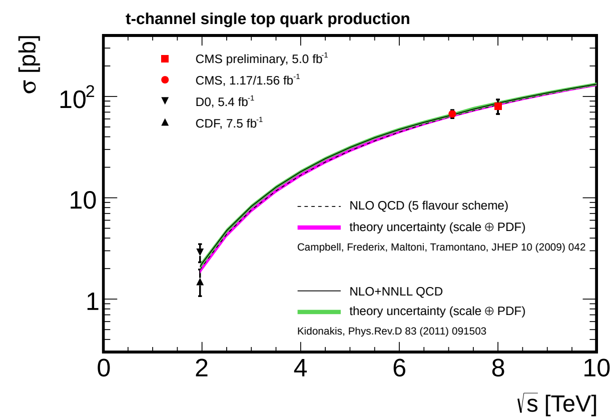




Precise SM Measurements







☞ Good understanding of the detector and accurate theory predictions

- ➠ **precise measurements** of the SM processes over many orders of magnitude
- ➠ good knowledge of **the background to Higgs analyses and BSM searches**

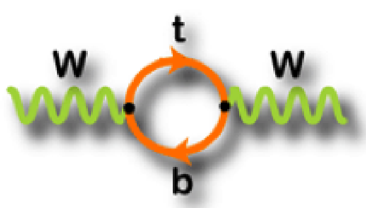
Higgs Boson

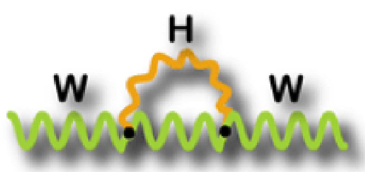
The Standard Model Constrain

- Standard Model (SM) is confirmed to better than 1% uncertainty by 100's of precision measurements
  - **Higgs boson is the only missing piece of the SM**
- Mass of W boson is a fundamental parameter of the SM:

$$\mathrm{m}_W = \sqrt{\frac{\pi\alpha}{G_F\sqrt{2}}}\frac{1}{\sin\theta_W\sqrt{1-\Delta R}}$$

Radiative corrections $\Delta R \sim 4\%$:

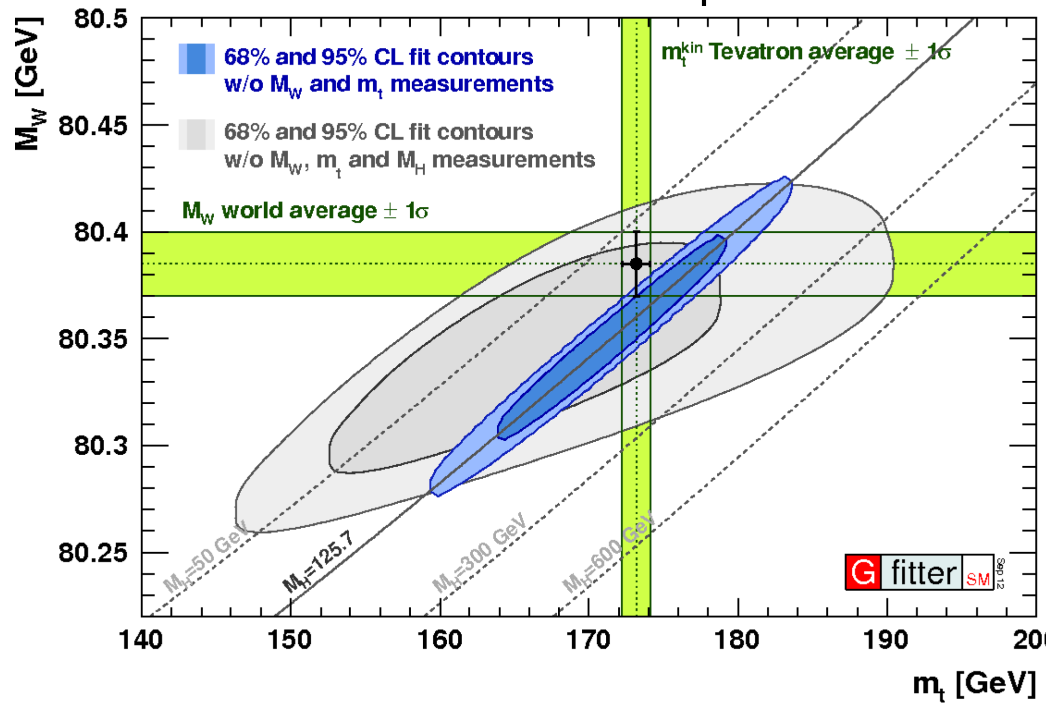




$\Delta R \sim m_t^2$ $\Delta R \sim \log m_H$

m_W = 80385±15 MeV
(World Average - Mar 2012)

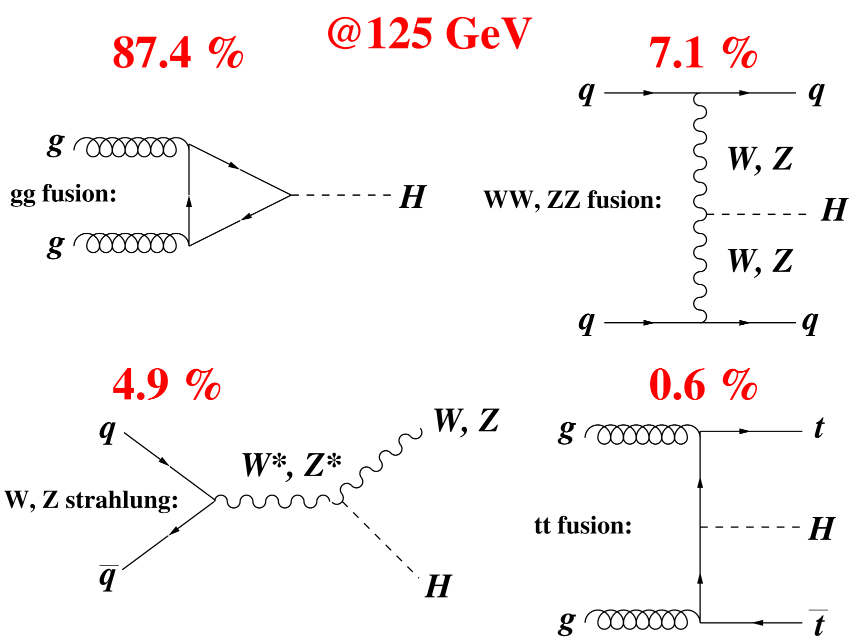
Colliders left little space

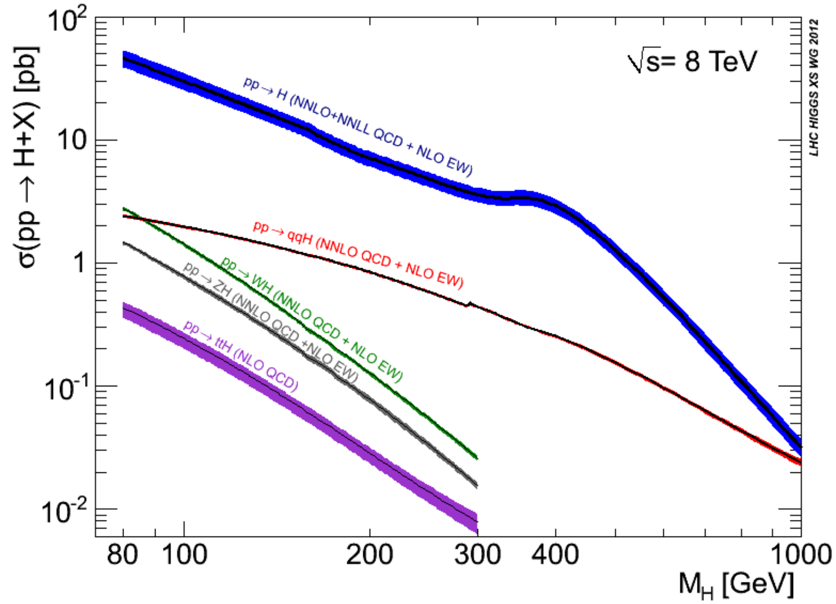


Indirect constrain from precision EW measurements

$\mathrm{m}_H < 169\,\mathrm{GeV}$ at 95% CL

(standard fit)



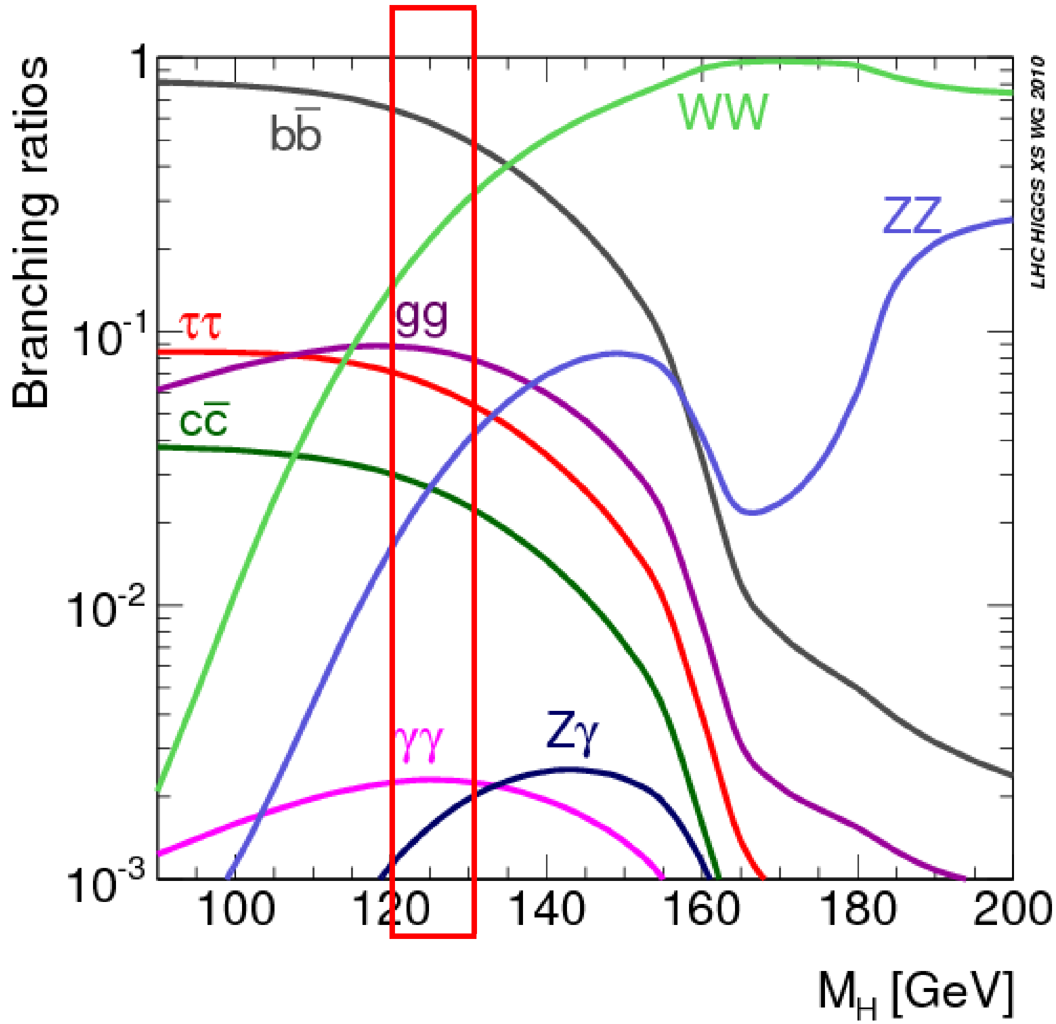


- **ggH production is dominant**
  - large k-factor (∼2)
  - associated jets are emerged due to soft gluon radiation at NLO
  - large theoretical uncertainty
- **VBF has clean signature but low rate**
  - low k-factor (∼1.1)
  - associated with LO jets primarily
  - low theory uncertainty

Very rich mass region but also very challenging...

- 5 decay modes exploited: $\gamma\gamma, ZZ, WW, \tau\tau, bb$
- 2 best mass resolution decay modes (~1%): $\gamma\gamma, ZZ$
- Also includes searches in $H \rightarrow Z\gamma$ decays

Decay	Exp. Sign. at 125.7 GeV	σ_M/M
H→ $\gamma\gamma$	3.9	1-2%
H→ZZ→4l	7.1	1-2%
H→WW→2l2ν	5.3	20%
H→bb	2.2	10%
H→$\tau\tau$	2.6	10%

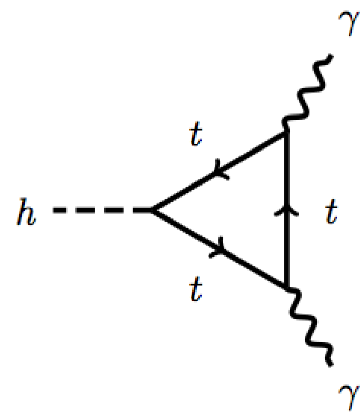


A discovery channel at low masses

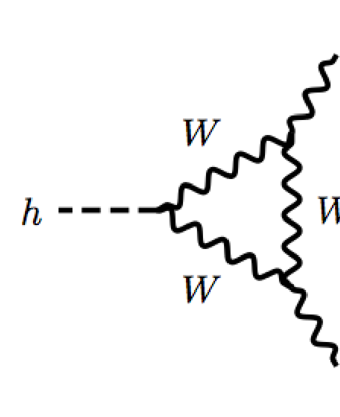
- ☞ **Low signal rate $\mathcal{B} \sim 10^{-3}$**
  - ➠ decay involves virtual loops
  - ➠ has **negative** contribution from the top quark loop
- ☞ **Clean signature in the detector**
  - ➠ identified as a narrow peak on the top of continuous background
- ☞ Interesting for beyond the SM scenario of EWSB (2 HDM) and new physics effects

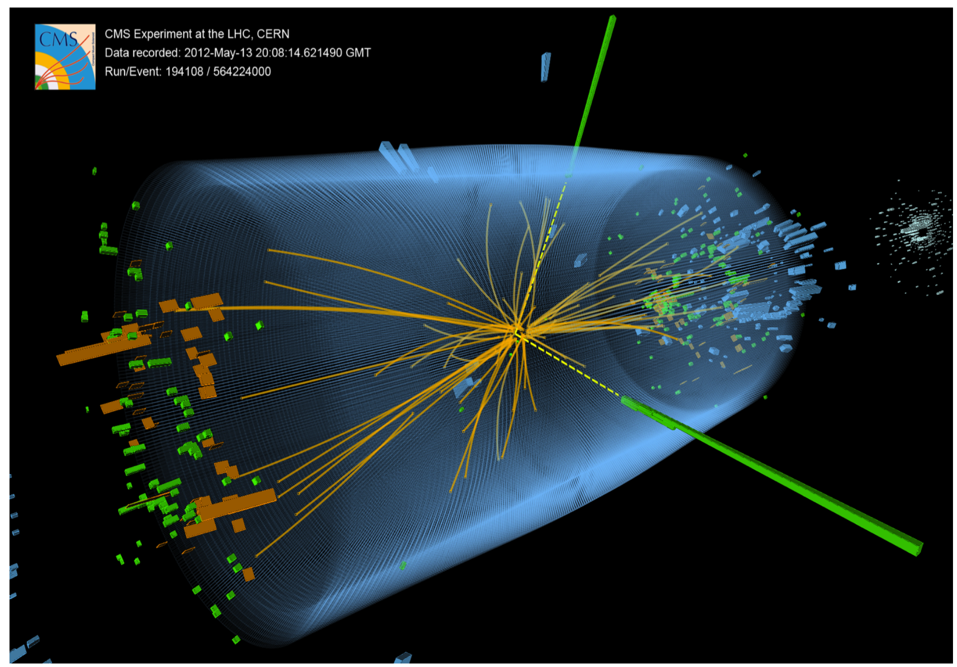
Good performance of ECAL and photon reconstruction are cornerstones of the analysis

$A_t \sim -A_W/5$

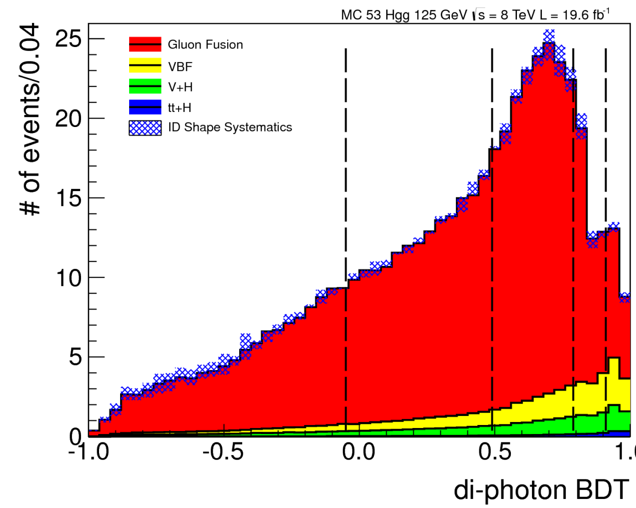


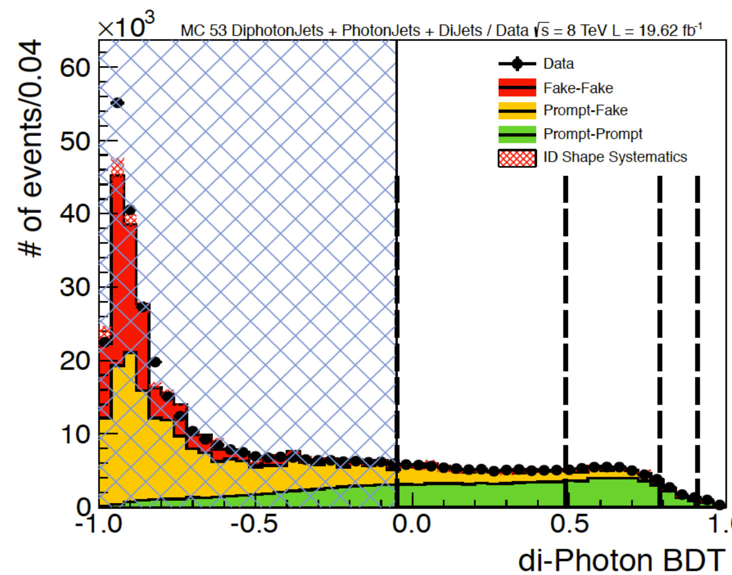
A_W





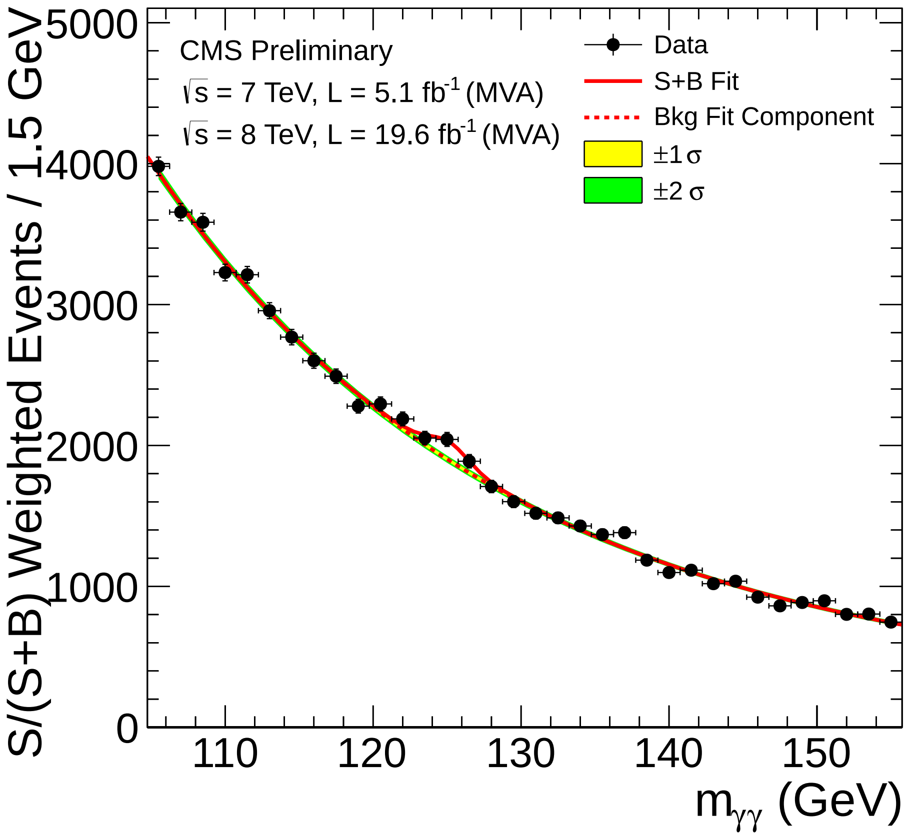
- The MultiVariate Analysis (MVA) classifies with a high score events with:
  - signal-like kinematic characteristics;
    - ➔ predominantly giving high score to high $p_T{}^{\gamma\gamma}$
  - good diphoton mass resolution;
  - photon-like values from the photon identification BDT
- MVA input variables are designed to be mass independent
- Fit $\mathrm{m}(\gamma\gamma)$ in each of 9 categories:
  - **4 diphoton MVA categories**
  - **2 dijet-tagged categories**
  - **2 lepton-tagged categories**
  - **1 MET-tagged categories**

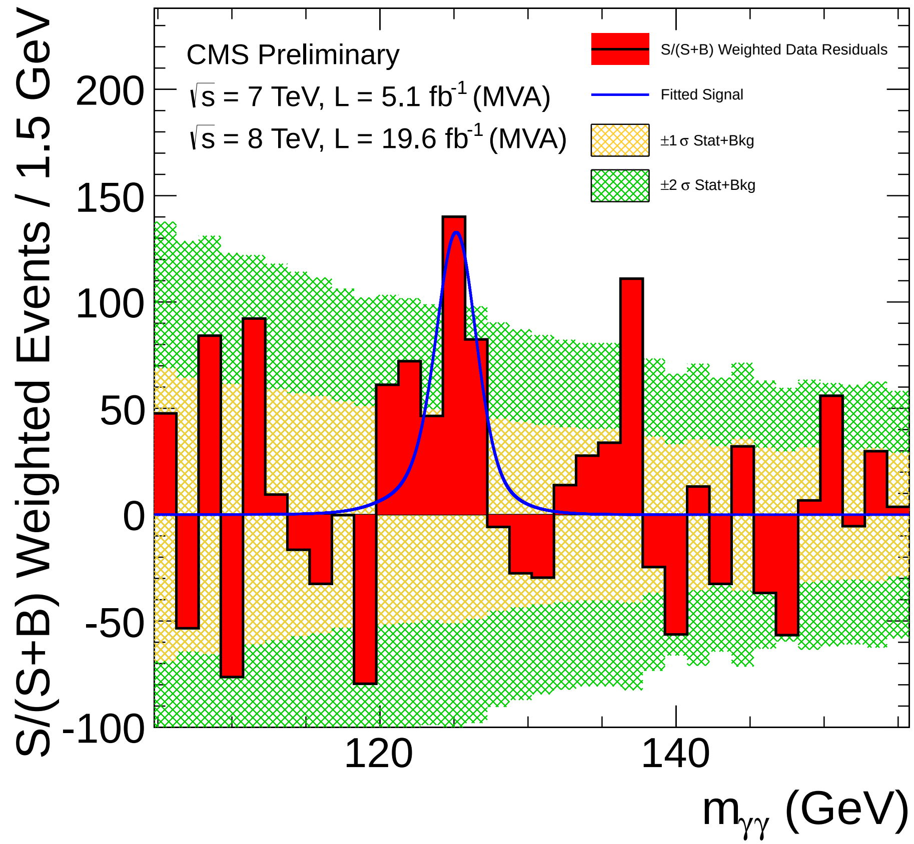




Divide pre-selected event sample into event classes based on MVA output

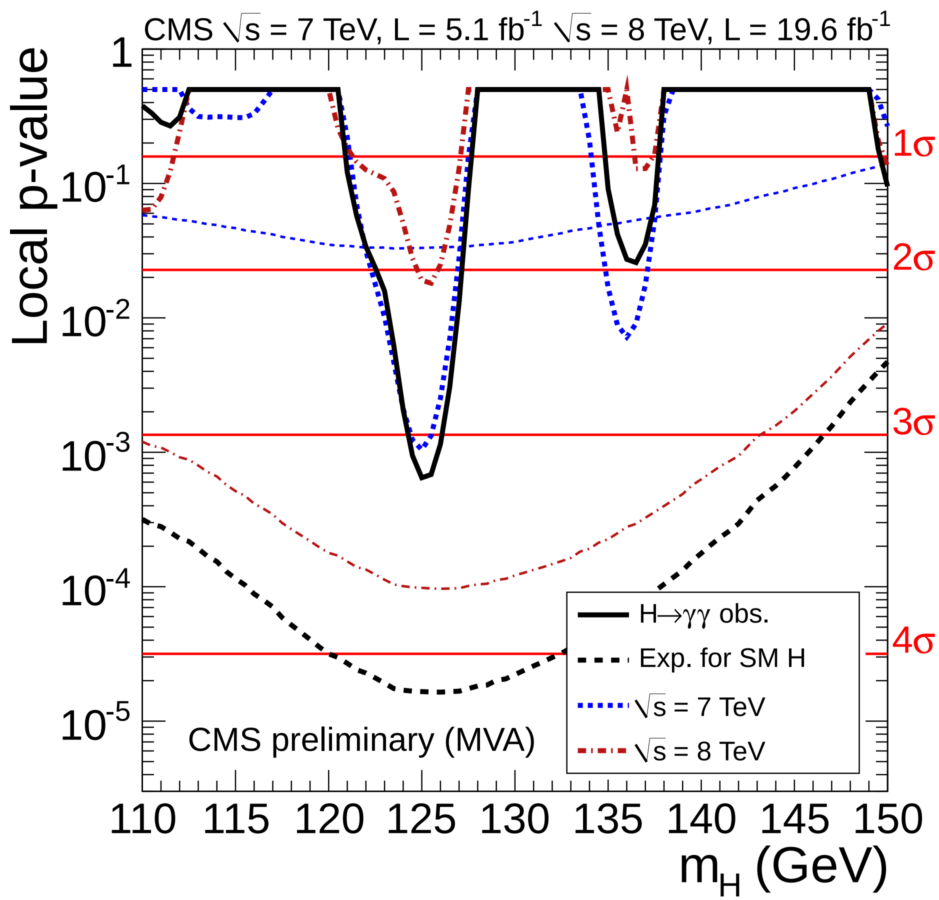
$H \to \gamma\gamma$: S/(S+B) Weighted Mass Spectrum

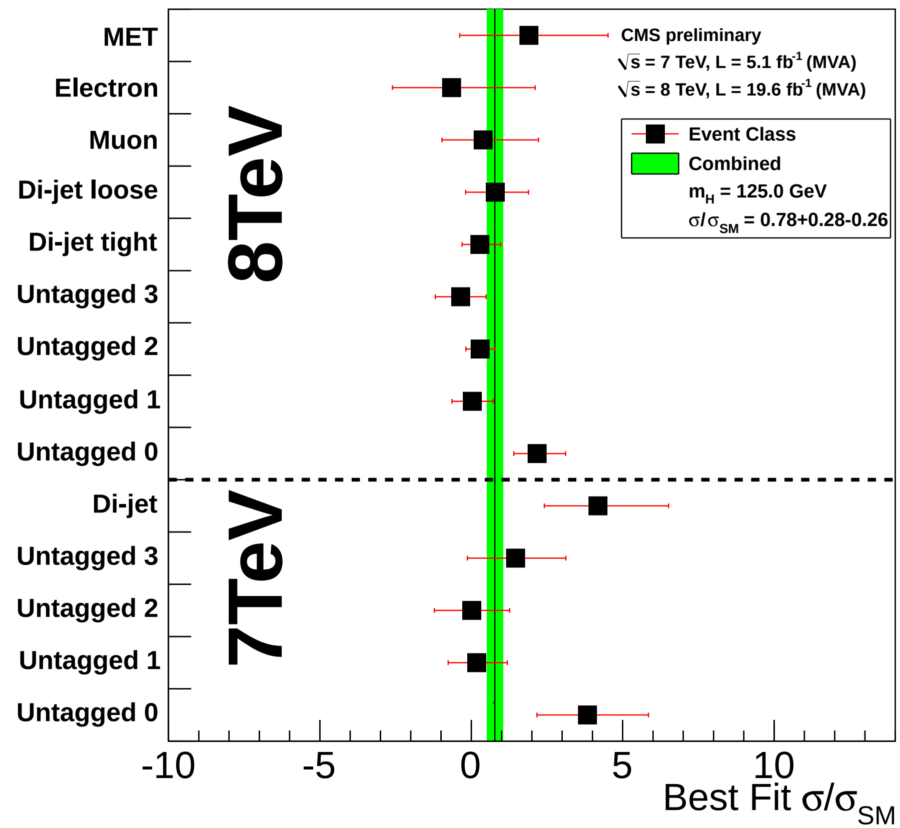




☞ Signal over background ratio in the combined mass spectrum is driven by worse categories (endcap and/or converted γ)

Event weighted mass spectrum w.r.t. expected S/(S+B) assuming the best fitted signal strength makes the peak more pronounced





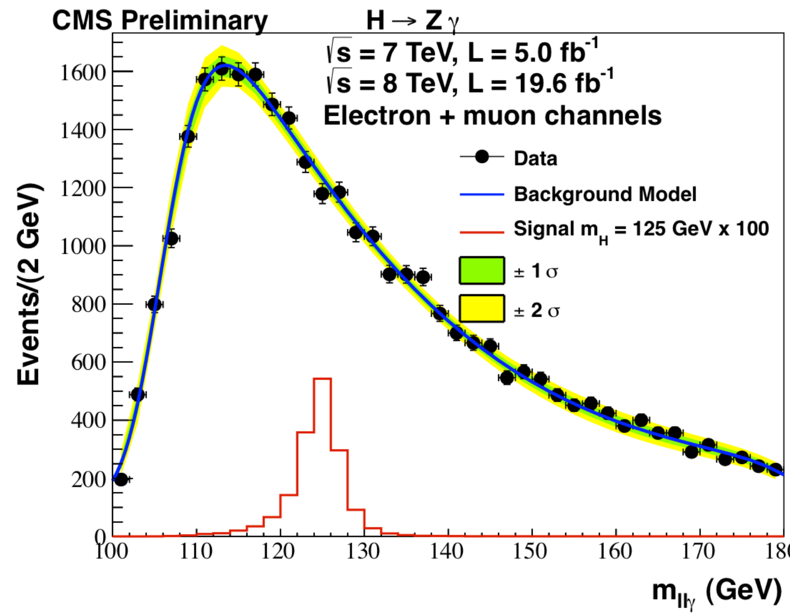
- ☞ Excess around 125 GeV appears consistently in 7 and 8 TeV data
- ☞ Best fitted signal strength at 125 GeV $\sigma/\sigma_{SM} = 0.78 \pm 0.28 \pm 0.26$

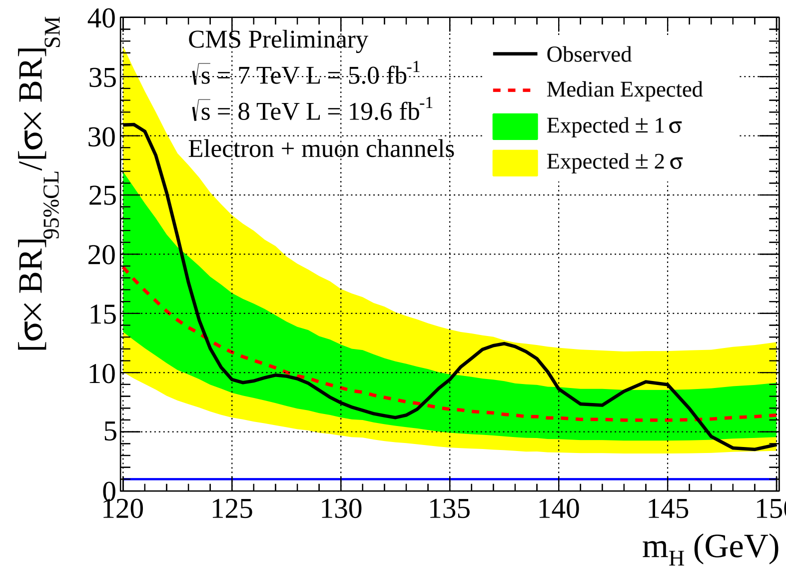
Consistent with the SM expectation within uncertainties

$H \to Z(ll)\gamma,\ l = (e,\mu)$ (HIG-13-006)

- $\mathcal{B}(\mathrm{H} \to \mathrm{Z}\gamma)$ comparable to $\mathcal{B}(\mathrm{H} \to \gamma\gamma)$, but $\mathcal{B}(\mathrm{Z} \to \mathrm{ll})$ suppresses signal by $\sim$20
- Search for a narrow llγ peak on top of a falling background
  - events are classified according to topology of the leptons and the photon, and the photon shower shape
  - main backgrounds are pp$\to$Zγ and DY

Albeit $\mathrm{H} \to \mathrm{Z}\gamma$ has not yet reached the SM sensitivity to distinguish SM from background, cuirrent limit excludes number of models with extended EWSB approaches



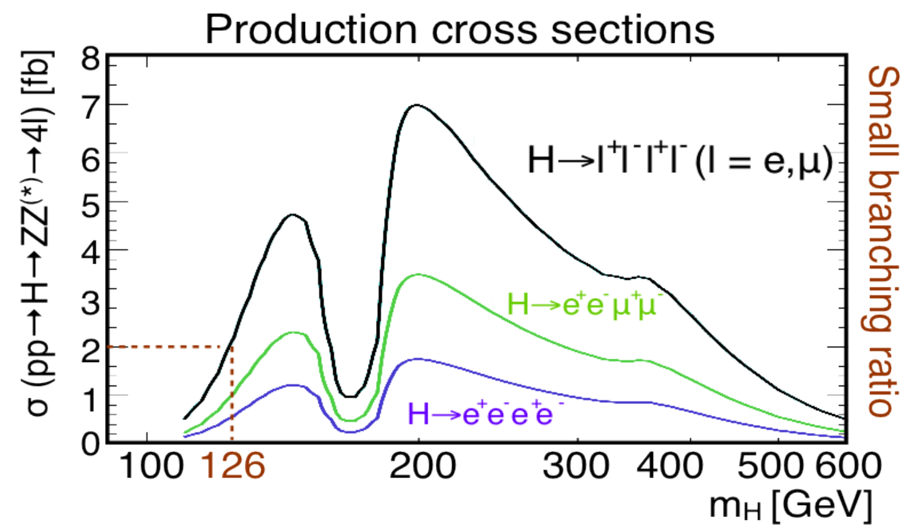


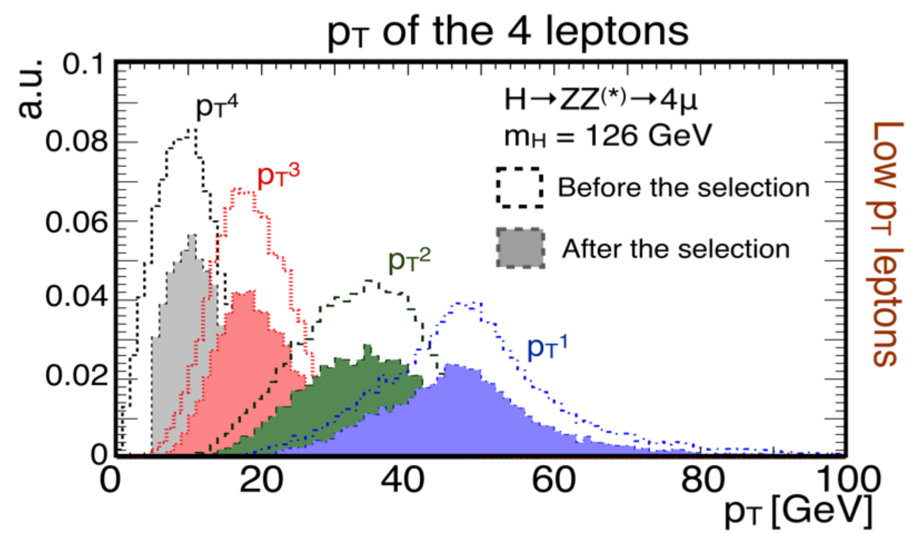
$H \to ZZ^{(*)},\ l = (e, \mu)$ *(HIG-13-002)*

One of the best performing channels in the whole mass range

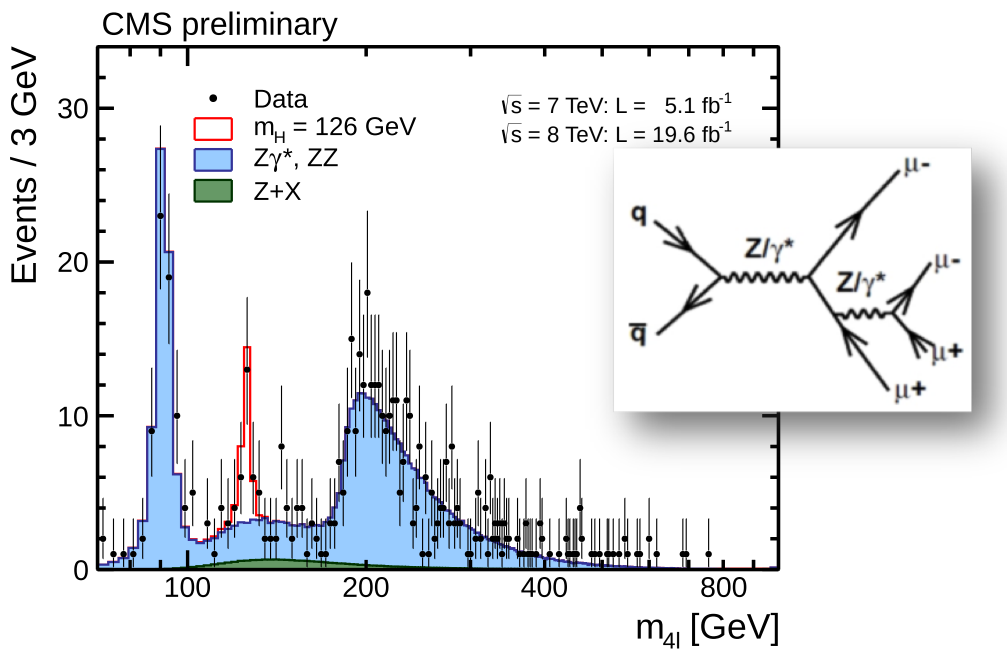
- Clean signature - golden channel
  - low background;
  - narrow mass peak;
  - low branching ratio;
- Extremely demanding channel for selection, requiring the highest possible efficiencies (lepton Reco/ID/Isolation)
- Background:
  - **irreducible:** $ZZ^{(*)}$
  - **reducible:** $Z+b\bar{b}$, $t\bar{t}$, Z+jets, WZ+jets

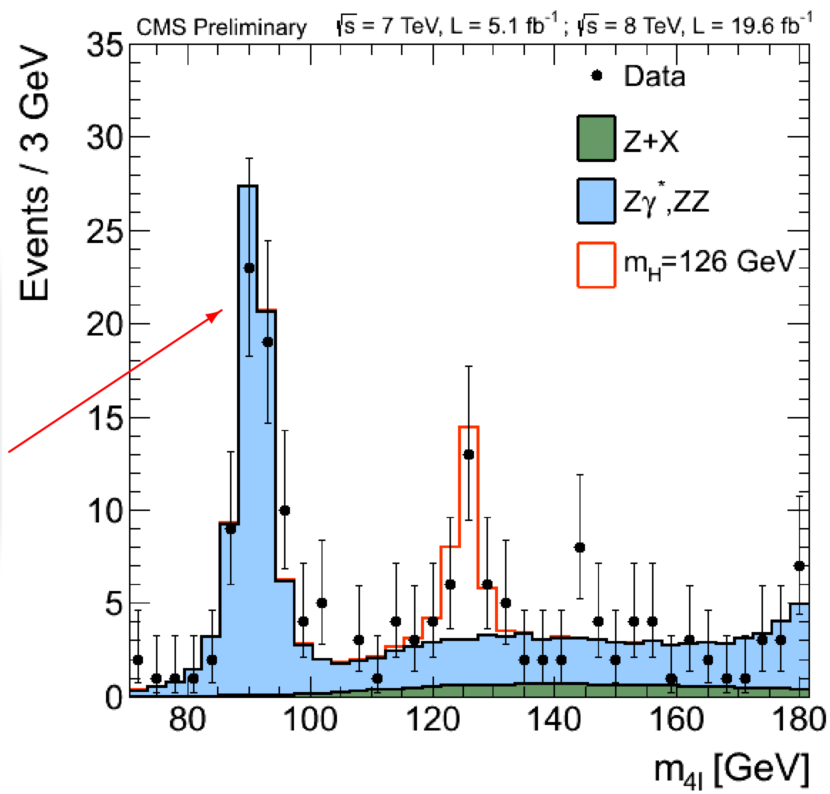
Straightforward for spin/parity measurements and includes VBF channel





$H \to ZZ^{(*)} \to 4l$: Mass Spectrum





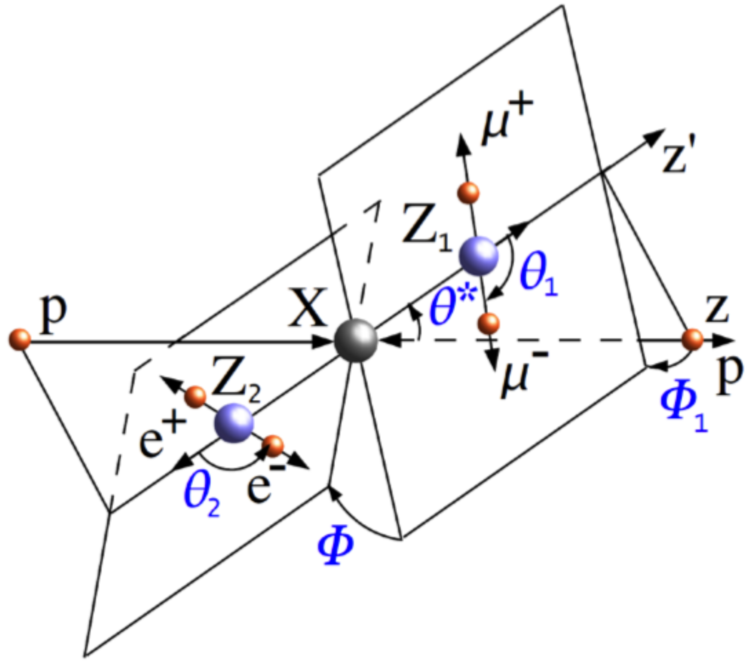
4-lepton mass resolution 1-2%

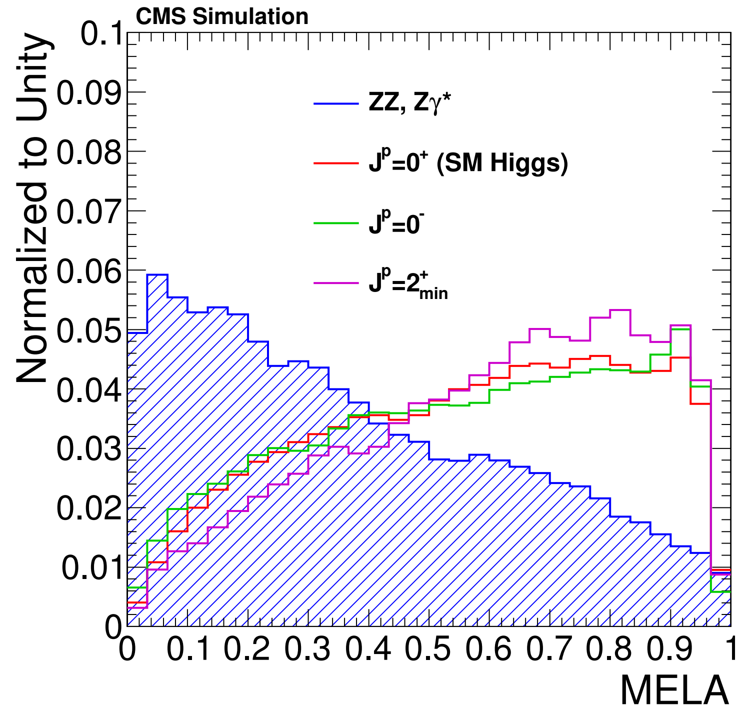
- ☞ 411 expected events in 100-1000 GeV
- ☞ 451 observed events in 100-1000 GeV

event yields in 110-160 GeV →

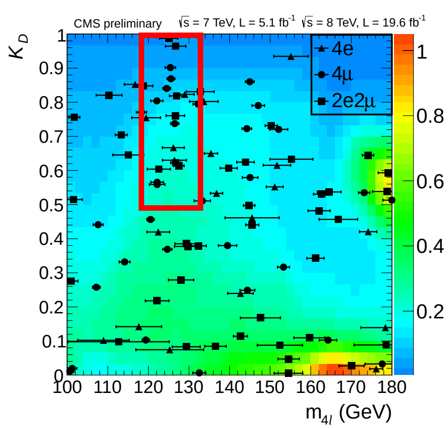
Channel	4e	4μ	$2e2\mu$	4ℓ
ZZ background	6.6 ±0.8	13.8 ±1.0	18.1 ±1.3	38.5 ±1.8
Z+ X	2.5 ± 1.0	1.6 ± 0.6	4.0 ± 1.6	8.1 ±2.0
All background expected	9.1 ± 1.3	15.4 ± 1.2	22.0 ± 2.0	46.5 ±2.7
m_H = 125 GeV	3.5 ±0.5	6.8 ±0.8	8.9 ±1.0	19.2 ±1.4
m_H = 126 GeV	3.9 ±0.6	7.4 ±0.9	9.8 ±1.1	21.1 ±1.5
Observed	16	23	32	71

Decay kinematic fully described by
5 angles and 2 masses

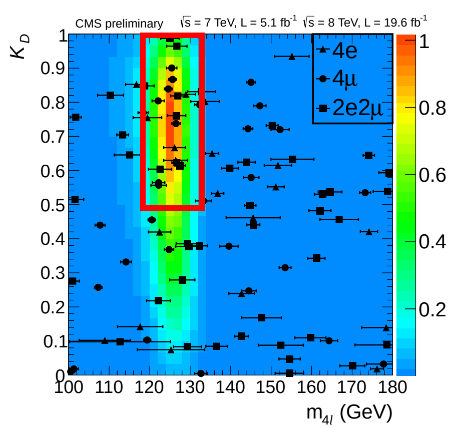




Background



Signal (m_H=126 GeV)

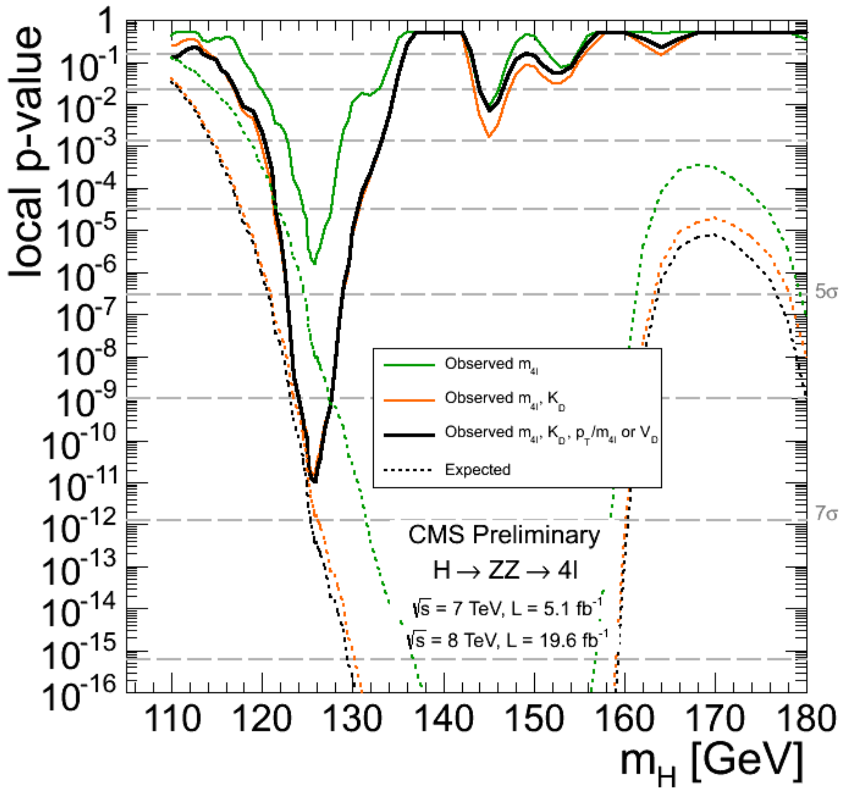


☞ Matrix Element Likelihood Analysis

[arXiv:1001.3396, Phys. Rev. D**81**, 075022(2010)]

$$MELA = \left[1 + \frac{\mathcal{P}_{bkg}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4l})}{\mathcal{P}_{sig}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4l})}\right]^{-1}$$

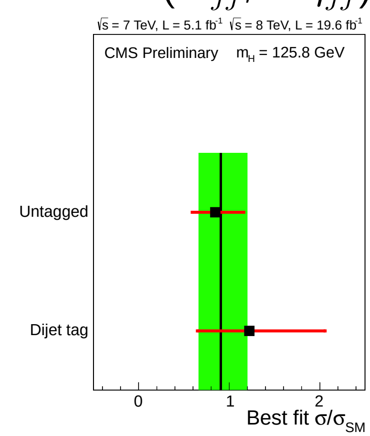
Zoomed mass range

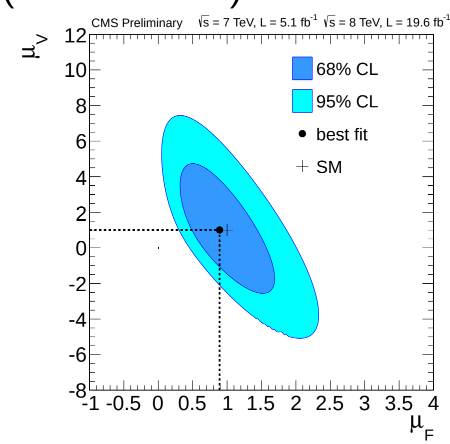


Jet categories to measure couplings

Untagged (0/1 jet): use $p_{T_{4l}}/m_{4l}$ (VBF ∼5%)

Dijet tagged (≥2 jets): use Fisher Discr. (m_{jj}, $\Delta\eta_{jj}$) (VBF ∼20%)

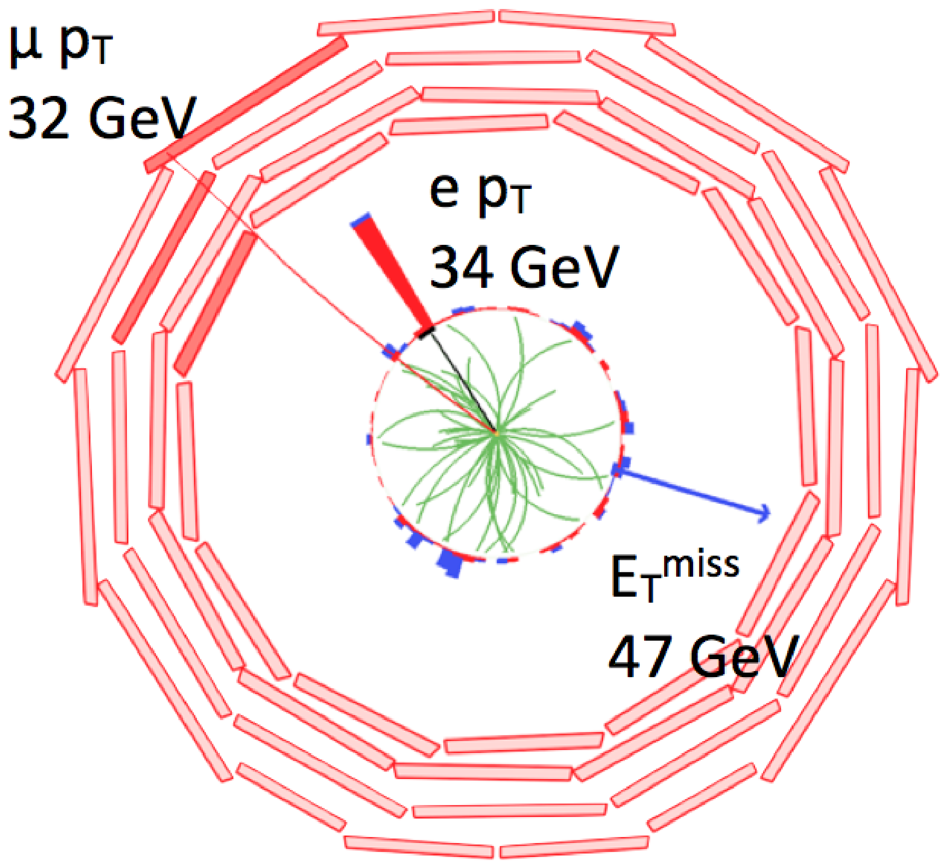




Expected significance at 126 GeV: 7.1σ

Observed significance at 126 GeV: 6.7σ

Measured signal strength at 126 GeV: $\mu = 0.92 \pm 0.28$



Signature with two isolated leptons (electrons or muons) and large missing energy (E_T^{miss})

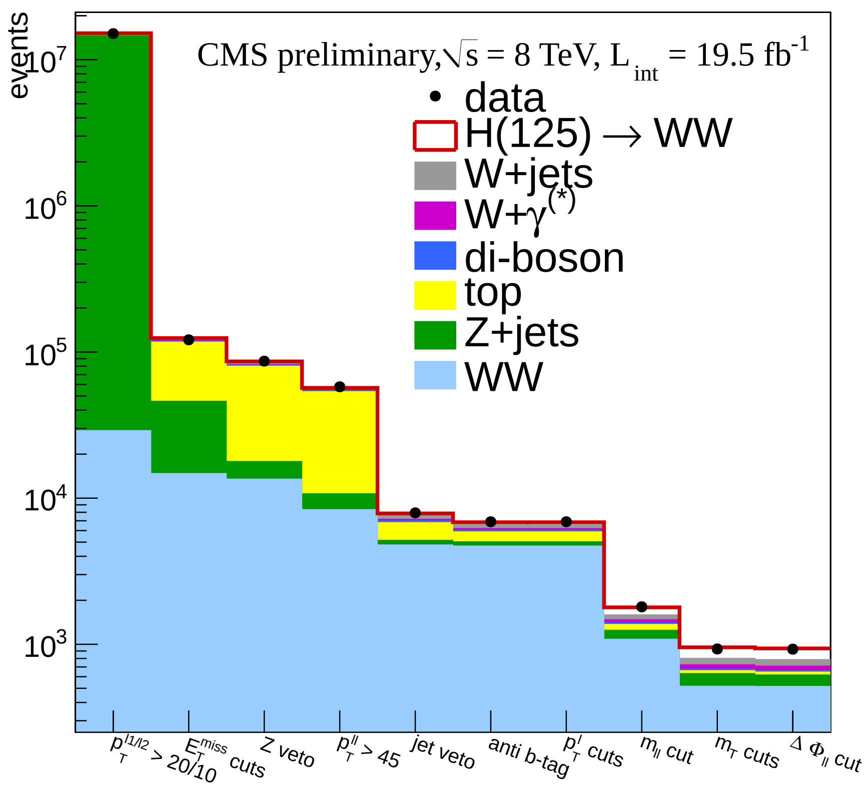
High sensitivity, but low mass resolution channel

- Characteristics
  - highest rate
  - manageable background
  - **there is no mass peak**
  - basically counting experiment
- Highly sensitive to a SM Higgs boson around 160 GeV
- With the development of tools optimized for LHC pileup conditions it is possible to extend sensitivity **down to 120 GeV**

Updated result deploys 2D shape technique for most sensitive categories

☞ **Background estimation is the most important part of analysis**

➠ underestimation of backgrounds leads to a signal-like excess



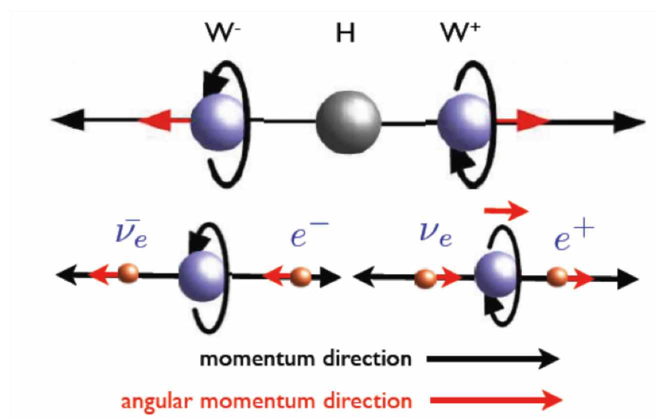
☞ Key selection requirements:

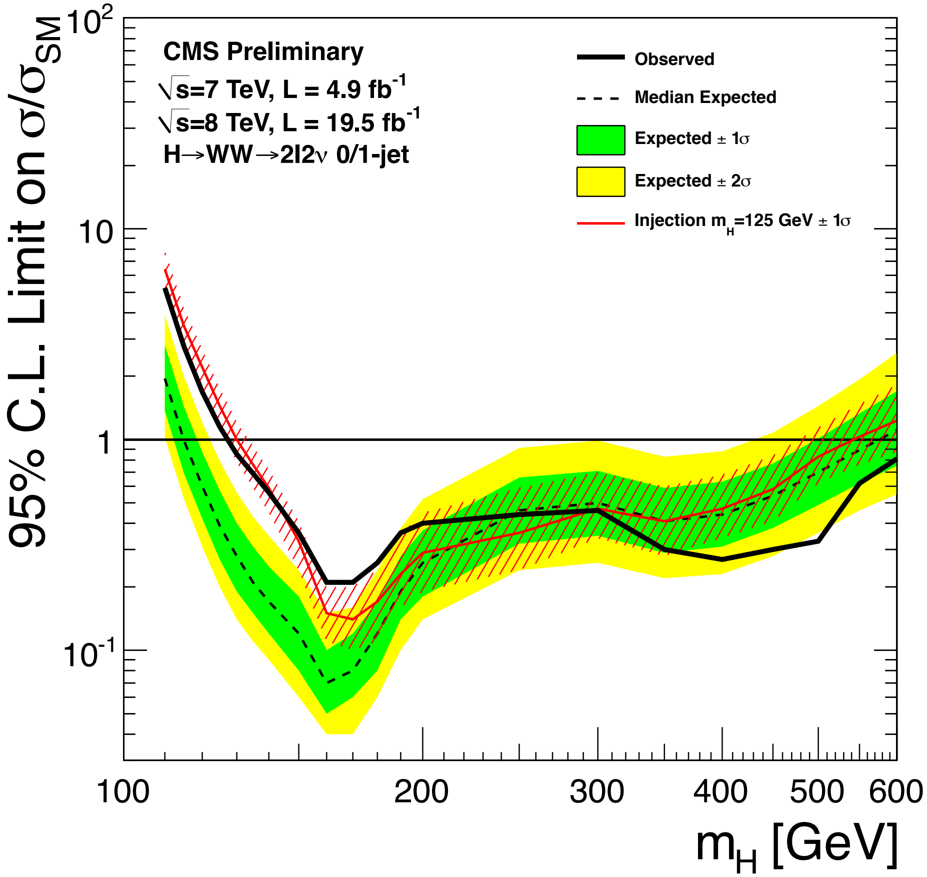
➠ QCD, Wjets: $p_T >$10 GeV, tight identification and isolation

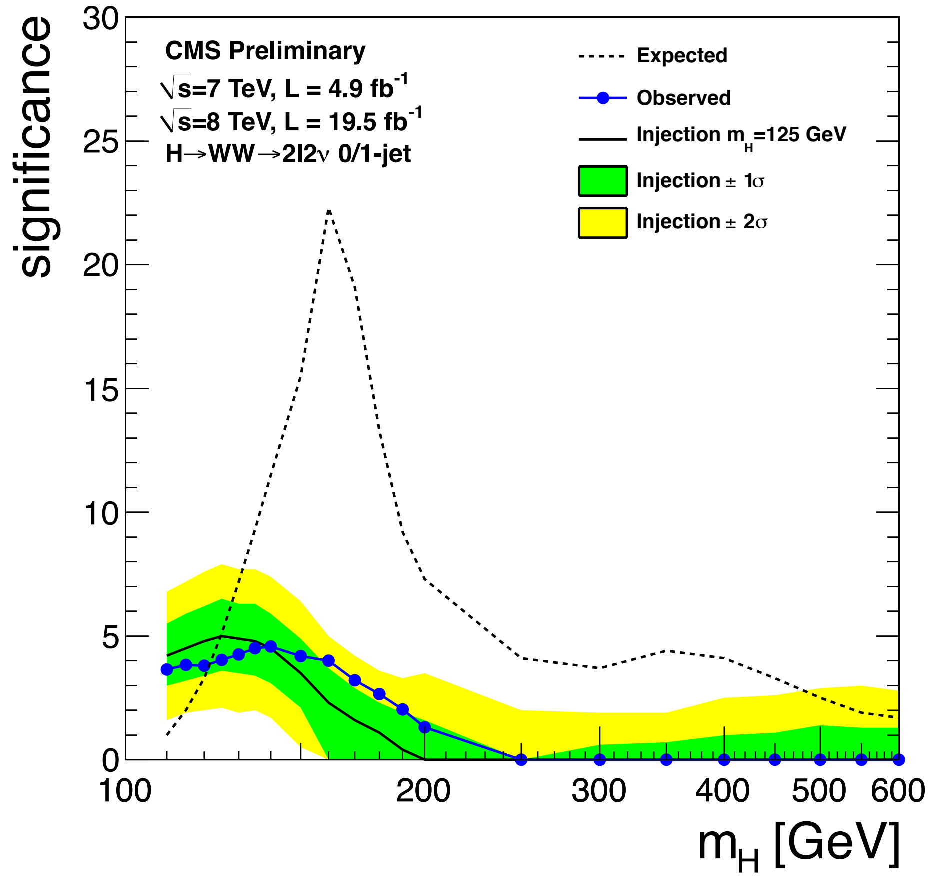
➠ Drell-Yan: large $E_T^{\rm miss}$, Z veto

➠ Top: number of jets, b-jet veto

➠ WW: m_{ll}, $\Delta\phi_{ll}$: small $\Delta\phi_{ll}$ – Higgs scalarity



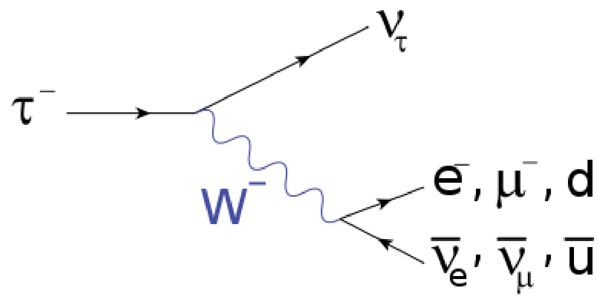


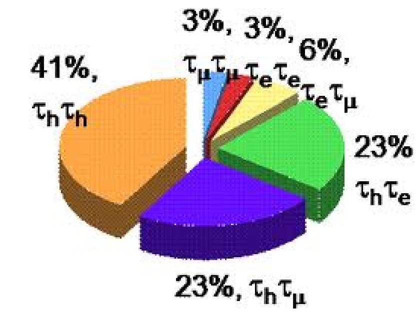


Measured signal strength at 125 GeV: $\mu = 0.76 \pm 0.21$

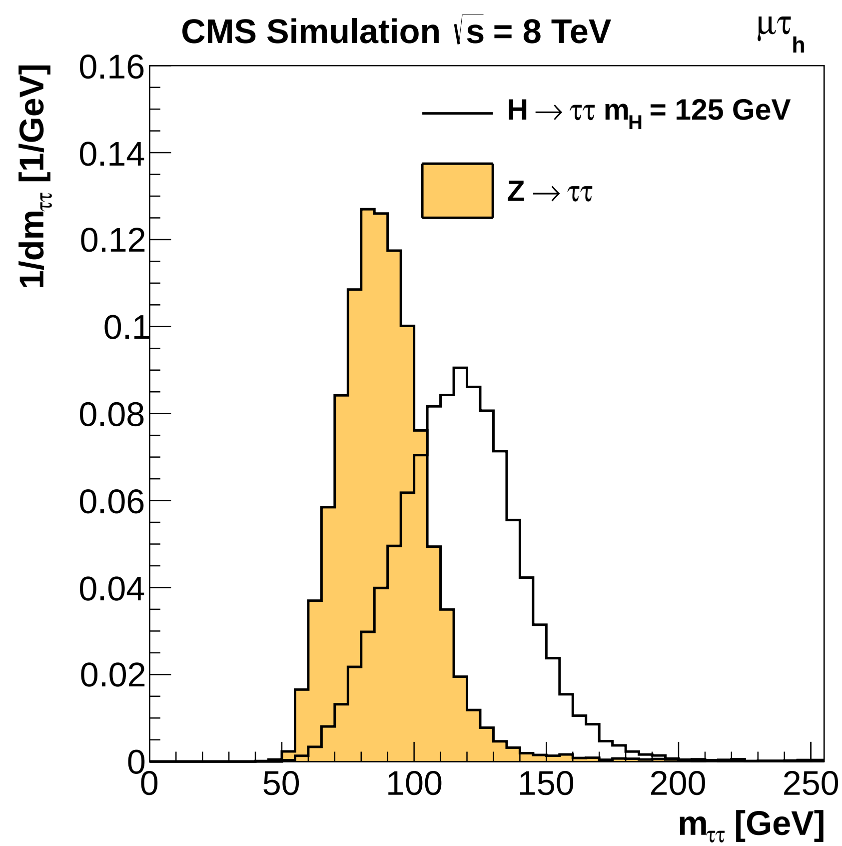
Expected significance at 125 GeV: **5.1σ**
Observed significance at 125 GeV: **4.0σ**

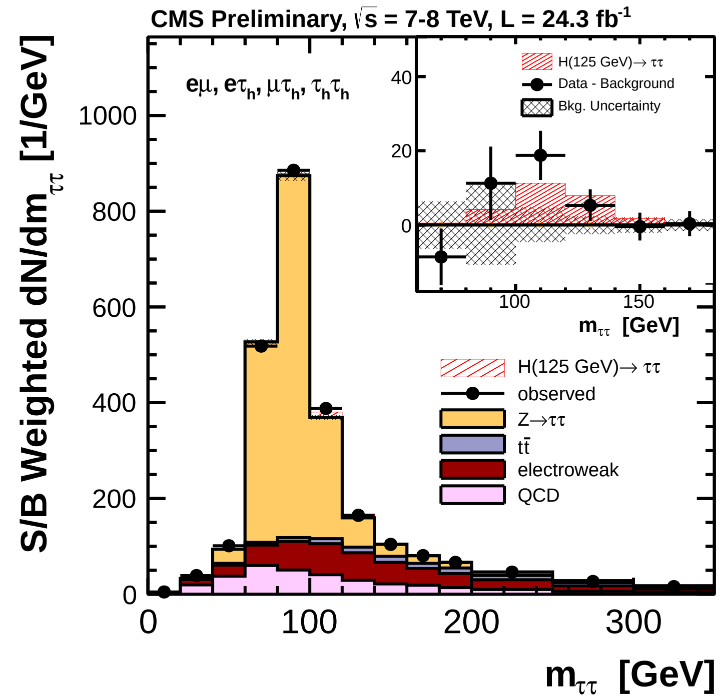
Excess is consistent with a SM Higgs boson with a mass around 125 GeV





- ☞ Characteristics and importance
  - probes coupling to leptons
  - sensitive to all production modes
  - high $\sigma \times \mathcal{B}$ at low mass
  - enhanced $\sigma \times \mathcal{B}$ in MSSM
  - challenging large backgrounds: DY$\to \tau\tau$, W+jets, QCD
- ☞ Analyze decays of tau pairs: $\mathbf{e}\boldsymbol{\mu}$, $\boldsymbol{\mu\mu}$, $\mathbf{e}\boldsymbol{\tau_h}$, $\boldsymbol{\mu\tau_h}$, $\boldsymbol{\tau_h\tau_h}$
- ☞ **Full $m(\tau\tau)$ reconstruction**
  - event-by-event estimator of true $m(\tau\tau)$ likelihood
  - mass peaks at true value
    - ➔ 20% improved resolution with respect to visible mass

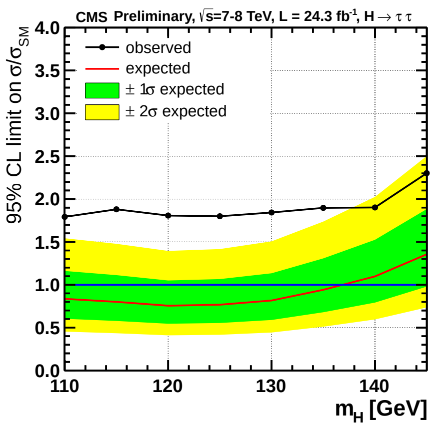


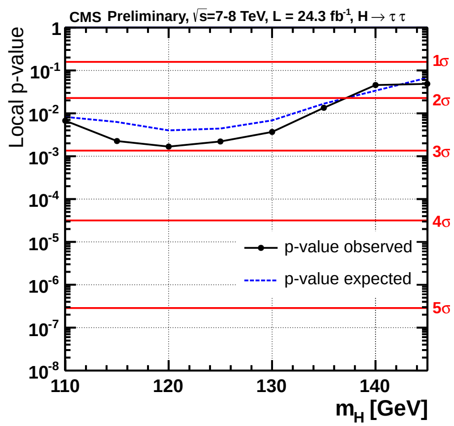


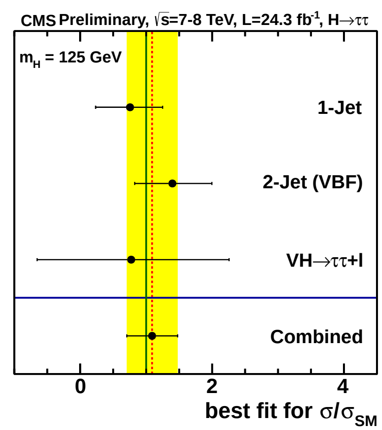
Events are classified according to jet multiplicity

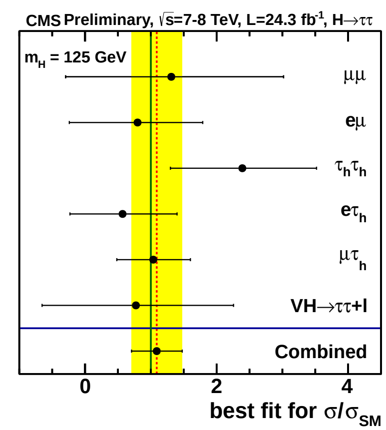
(all categories are fit simultaneously)

☞ No attempt to extract signal from 0-jet category: constrain energy scales and efficiencies





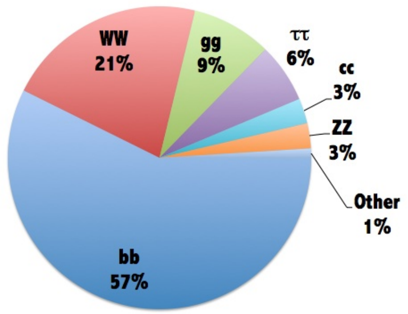


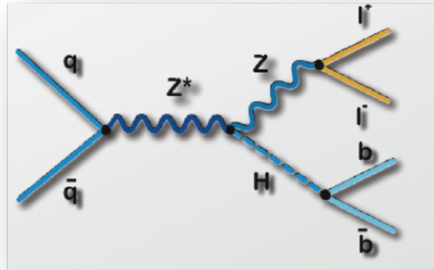


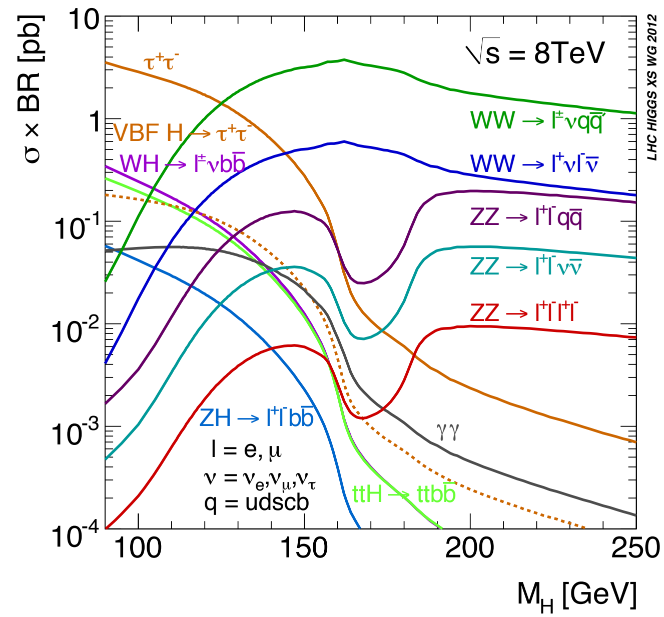
Reached **1xSM** sensitivity:
clear excess 2.9σ at 125 GeV

Measured signal strength at 125 GeV: $\mu = 1.1 \pm 0.4$

Higgs decays at m_H=125GeV







☞ Characteristics and importance

➠ largest $\mathcal{B}$ for $m_H < 130$ GeV

➠ **key piece of the observation puzzle**

➠ tests specific production and decay couplings

☞ Challenge: $\sigma(b\bar{b}) \sim 10^7 \times \sigma \times \mathcal{B}(H \to b\bar{b})$

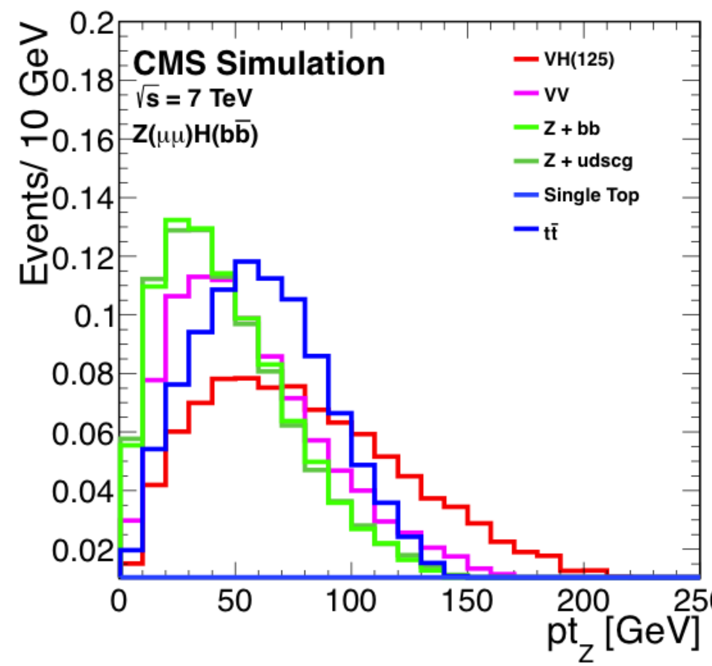
☞ Search in associated production with W or Z

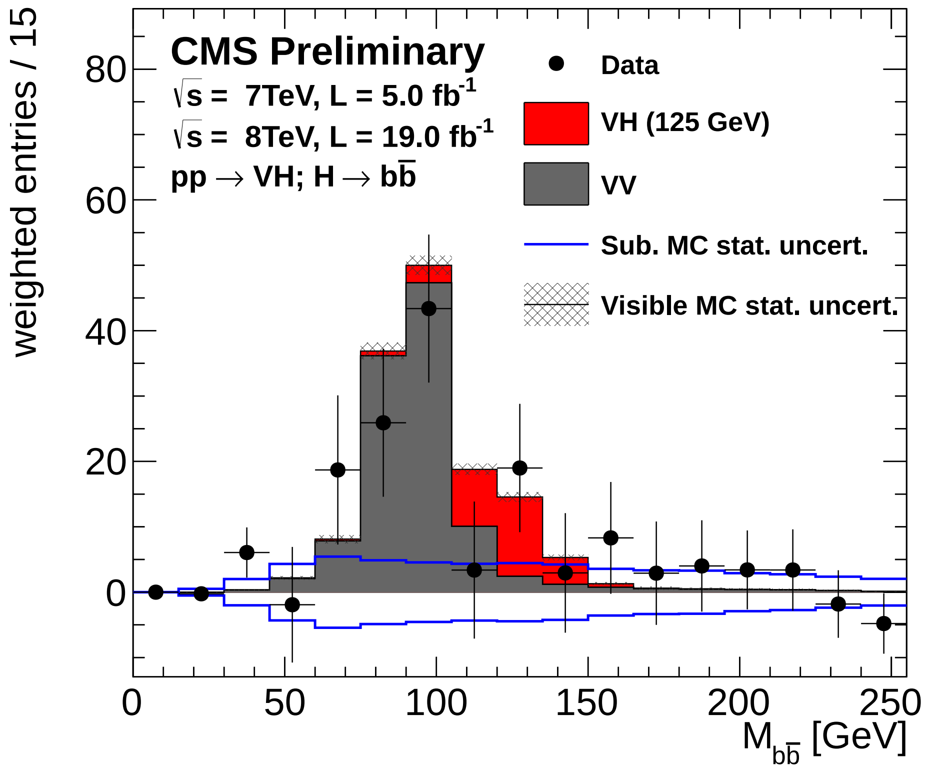
➠ 5 channels: $Z(ll)H(bb)$, $Z(\nu\nu)H(bb)$, $W(l\nu)H(bb)$

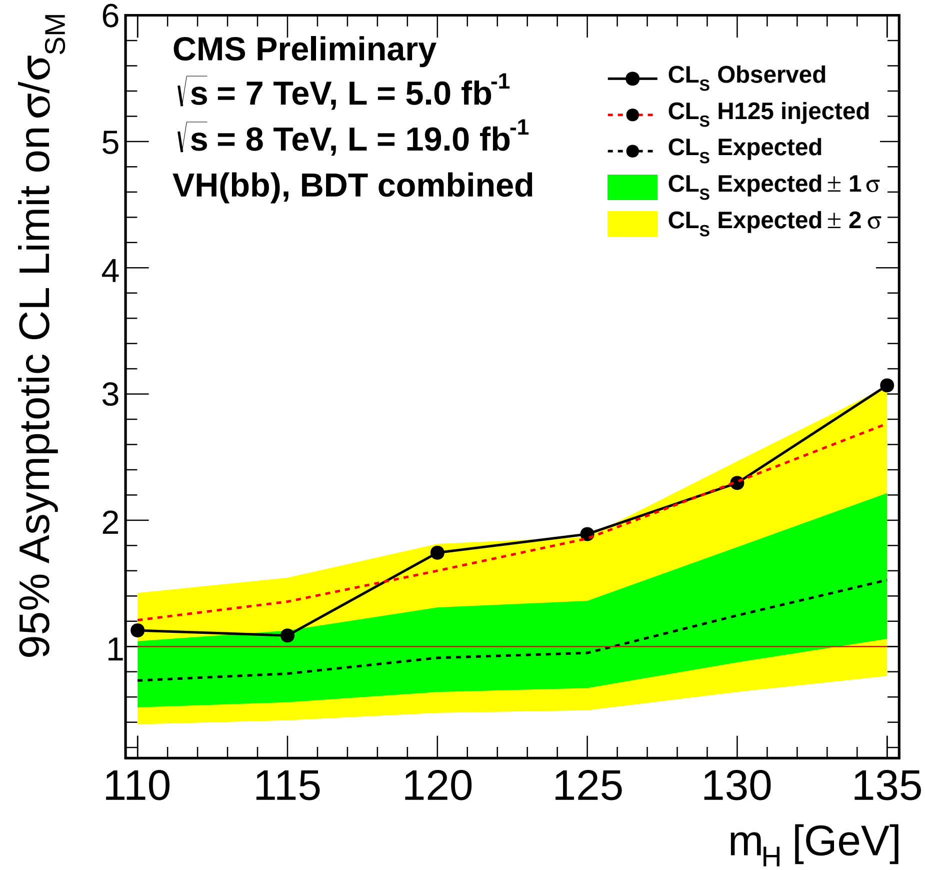
➠ final states with leptons, $E_T^{\rm miss}$, b-jets

➠ boosted vector bosons

➠ **2 b-jet mass resolution 9%**







Diboson excess shows up in the data and reasonably described by simulation

☞ Estimated backgrounds from data in control regions: **QCD, Vbb, Vjets**

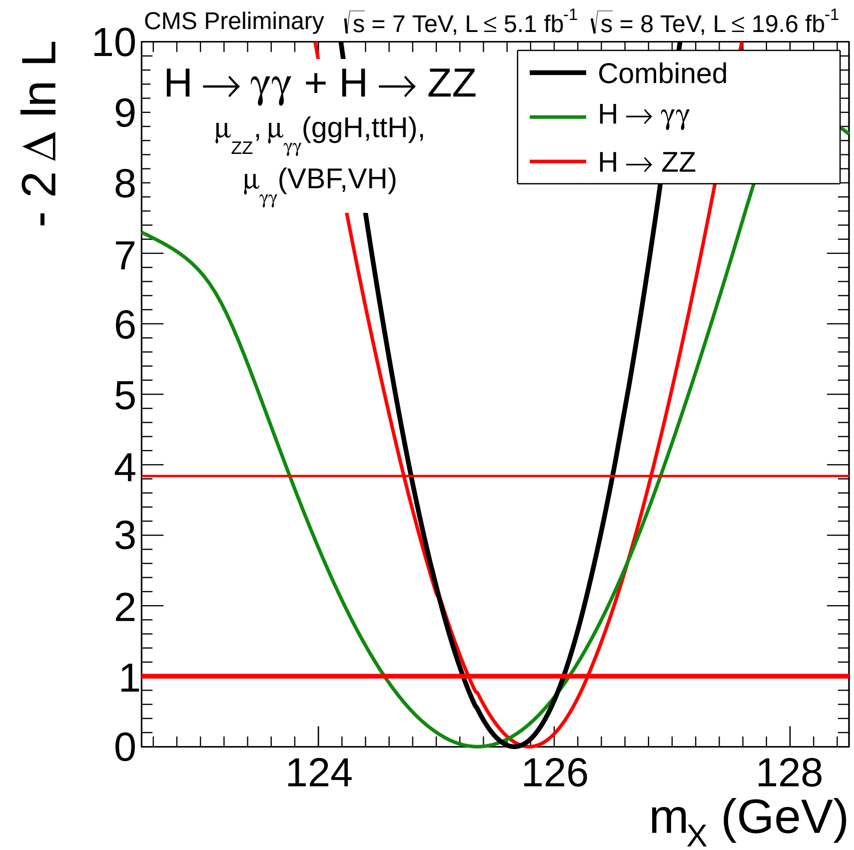
☞ Reached SM sensitivity below 125 GeV

Observed excess about 2.1σ is compatible with a SM Higgs boson with a mass around 125 GeV

- Allow for free cross sections in three channels and fit for the common mass

[HIG-13-005]

Combine two best mass resolution decays $\gamma\gamma$ and ZZ



H→ZZ→4l:

- limited by statistics
- exploit m(4l) and k_D
- very good control of lepton energy scale and resolution

$m_X = 125.8 \pm 0.5(\text{stat}) \pm 0.2(\text{syst})$ GeV

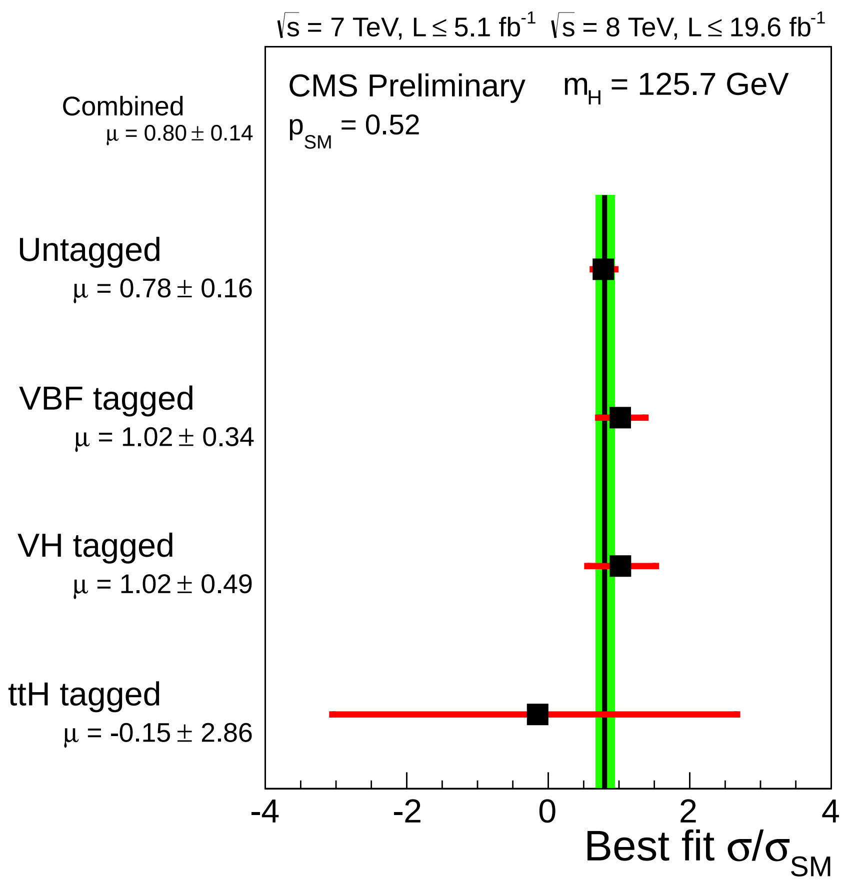
H→ $\gamma\gamma$:

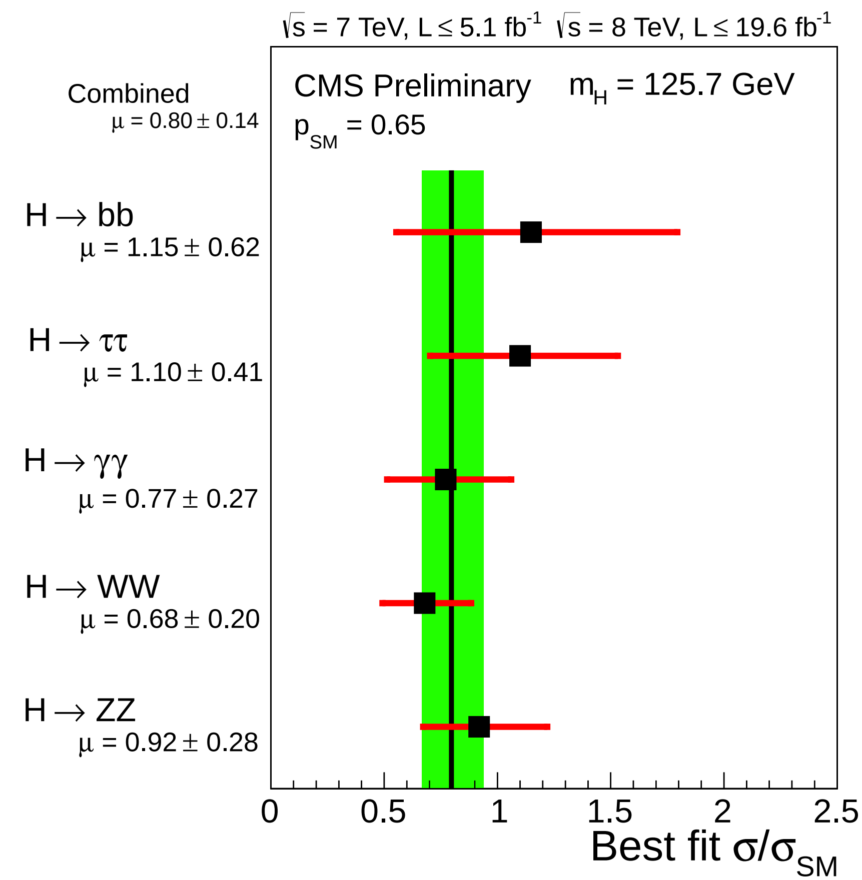
- limited by systematics
- 0.2% due to $e \to \gamma$ uncertainty
- 0.4% extrapolation Z→ee to H→ $\gamma\gamma$

$m_X = 125.4 \pm 0.5(\text{stat}) \pm 0.6(\text{syst})$ GeV

$m_X = 125.7 \pm 0.3(\text{stat}) \pm 0.3(\text{syst})$ GeV

[HIG-13-005]





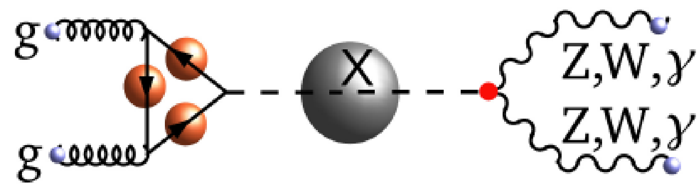
☞ Overall best-fit signal strength in the combination: $\boldsymbol{\sigma/\sigma_{SM} = 0.80 \pm 0.14}$

Event yields in different production and decay modes are self-consistent

☞ Same amplitude for production A($VV \to X$) and decay A($X \to VV$):

$$\textbf{Spin 0:}\ A(X \to VV) = v^{-1}\epsilon_1^{*\mu}\epsilon_2^{*\nu}(\mathbf{a_1} g_{\mu\nu} M_X^2 + \mathbf{a_2} q_{1\mu} q_{2\nu} + \mathbf{a_3} \epsilon_{\mu\nu\alpha\beta} q_1^\alpha q_2^\beta)$$

☞ Parity



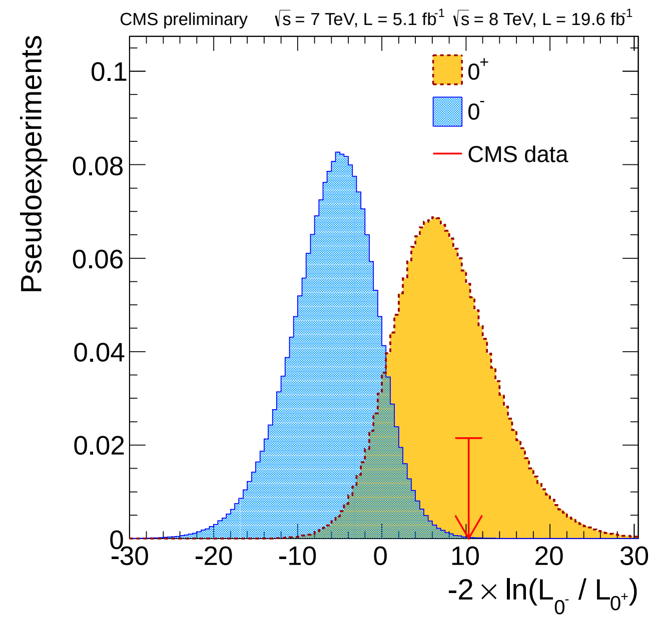
- SM CP-even Higgs $\to$ ZZ,WW:
  ➔ $\mathbf{a_1} \neq 0$, $\mathbf{a_2} \sim O(10^{-2})$, $\mathbf{a_3} \sim O(10^{-11})$
- BSM CP-odd Higgs: $\mathbf{a_3} \neq 0$

☞ Spin

- spin 0 is required if it is a Higgs
- spin-1 excluded by H$\to \gamma\gamma$ decays (Landau-Yang theorem)
- spin-2 induced by KK-graviton couplings

H→ZZ→4l is most straightforward

J^P	production	comment	expect (μ=1)	obs. 0^+	obs. J^P	CL_s
0^-	$gg \to X$	pseudoscalar	2.6σ (2.8σ)	0.5σ	3.3σ	0.16%
0_h^+	$gg \to X$	higher dim operators	1.7σ (1.8σ)	0.0σ	1.7σ	8.1%
2_{mgg}^+	$gg \to X$	minimal couplings	1.8σ (1.9σ)	0.8σ	2.7σ	1.5%
$2_{mq\bar{q}}^+$	$q\bar{q} \to X$	minimal couplings	1.7σ (1.9σ)	1.8σ	4.0σ	<0.1%
1^-	$q\bar{q} \to X$	exotic vector	2.8σ (3.1σ)	1.4σ	$>4.0\sigma$	<0.1%
1^+	$q\bar{q} \to X$	exotic pseudovector	2.3σ (2.6σ)	1.7σ	$>4.0\sigma$	<0.1%



The data disfavours the 0^- hypothesis with 99.8% CL

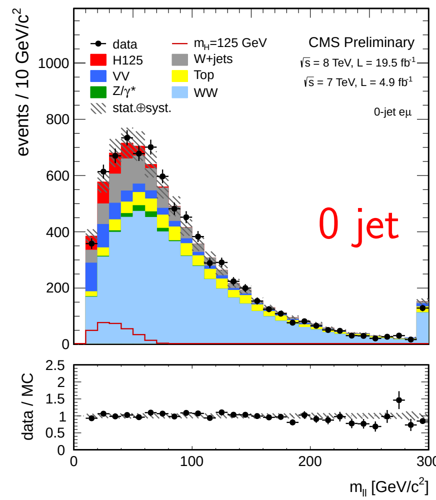
Spin-0 and 2 are only allowed by H→ $\gamma\gamma$ channel

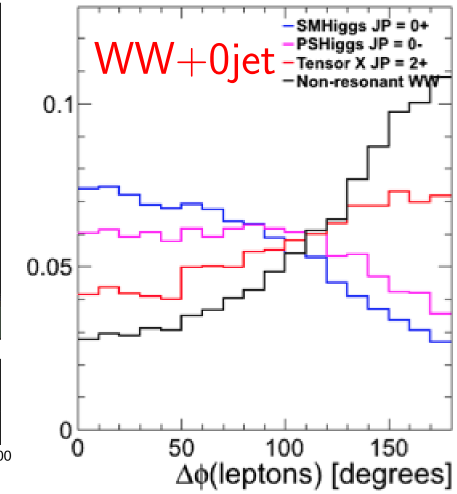
- Discrimination between spin-0 and spin-2 is straightforward with WW and ZZ:
  - WW is most significant (0-jet only)
  - modify selections to extend spin-2 enriched phase space

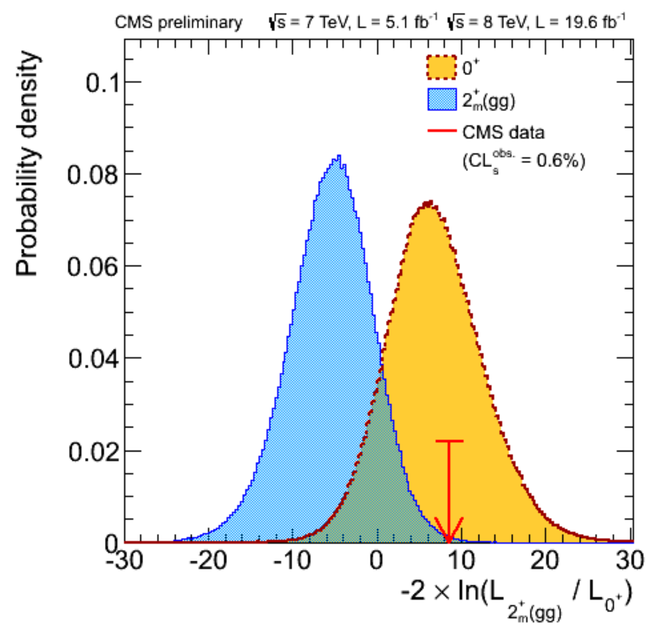
	ZZ	WW	Comb
exp.	6.8%	1.4%	0.2%
obs.	1.4%	14.0%	0.6%

- Observed results weaker than expected especially for WW due to best fit μ <1 (like having less luminosity)
- Observed better than expected for ZZ due to a fluctuation

The data disfavours the 2^+_m hypothesis with 99.4% CL







The observation is well compatible with SM Higgs expectations (0^+)

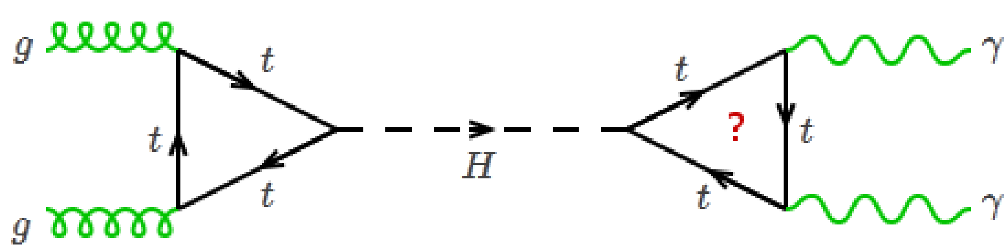
- Attach a modifier to the SM prediction

$$\sigma\mathcal{B}(ii \to H \to ff) \sim \frac{\Gamma_{ii}\Gamma_{ff}}{\Gamma_{tot}} = \sigma_{SM} \cdot \mathcal{B}_{SM} \frac{k_i^2 \cdot k_f^2}{k_H^2}$$

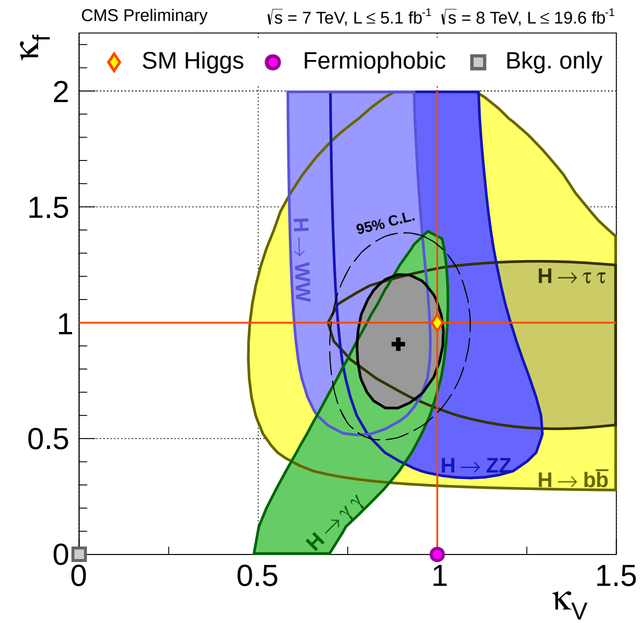
- **Estimate Higgs boson couplings into “Vectorial” and “Fermionic” sets:**
  - resolve H$\to \gamma\gamma$ loop at NLO predictions
  - interference between W and top contributions lead to linear dependency on k_V or k_F
  - H$\to \gamma\gamma$ is the only channel that is sensitive to their relative sign

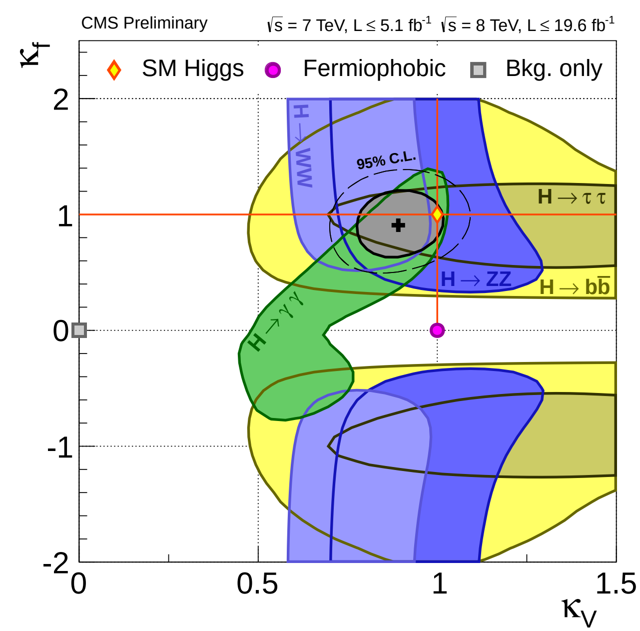
    ➔ possible to sort out degeneracy

$\boldsymbol{\Gamma_{gg} \sim k_F^2}$ $\boldsymbol{\Gamma_{\gamma\gamma} \sim |\alpha k_V + \beta k_F|^2}$

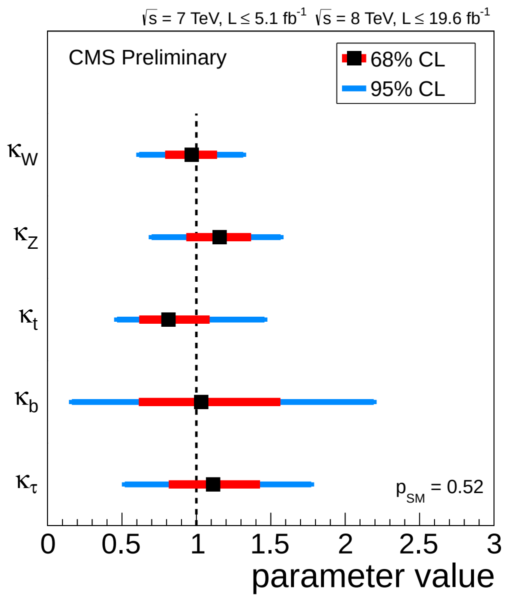


In agreement with the SM within uncertainties

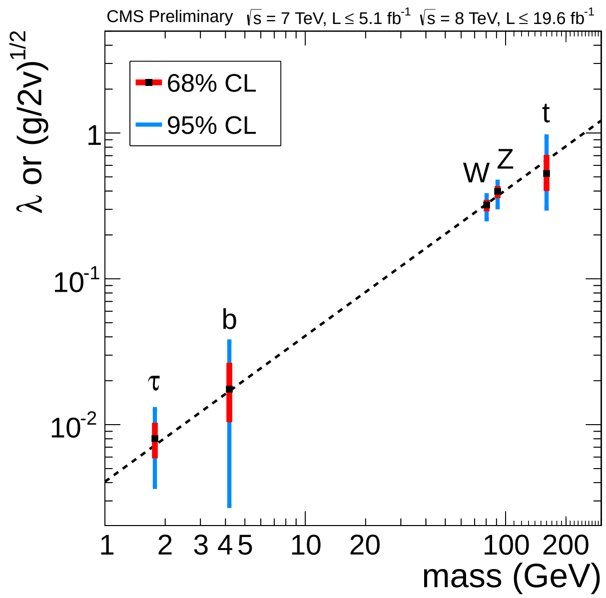




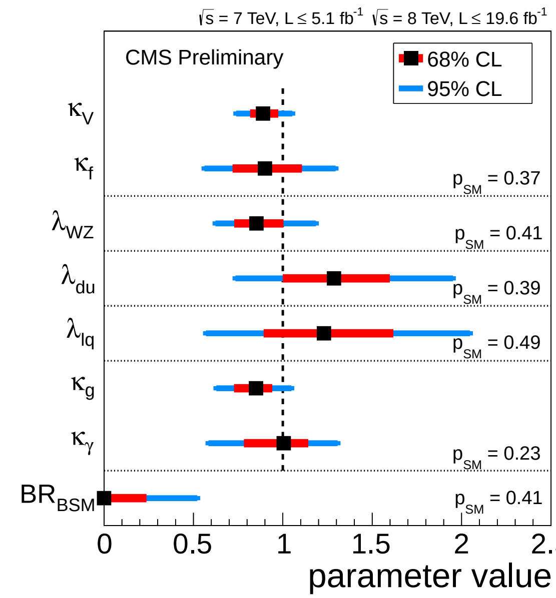
Compatibility with the SM Higgs Boson Couplings



The generic five-parameter model not effective loop couplings (the SM structure is assumed for loop-induced couplings)



Not effective loop couplings as function of the mass



New particles can modify the loop-mediated couplings and contribute to the total width

$$\Gamma_{tot} = \sum \Gamma_{i(SM)} + \Gamma_{BSM}$$

No significant deviations from the SM Higgs boson are found so far

The boson that we found looks rather "standard" scalar at first sight:
check the vacuum stability up to the Plank scale $M_{Pl} \sim 10^{19}$ GeV

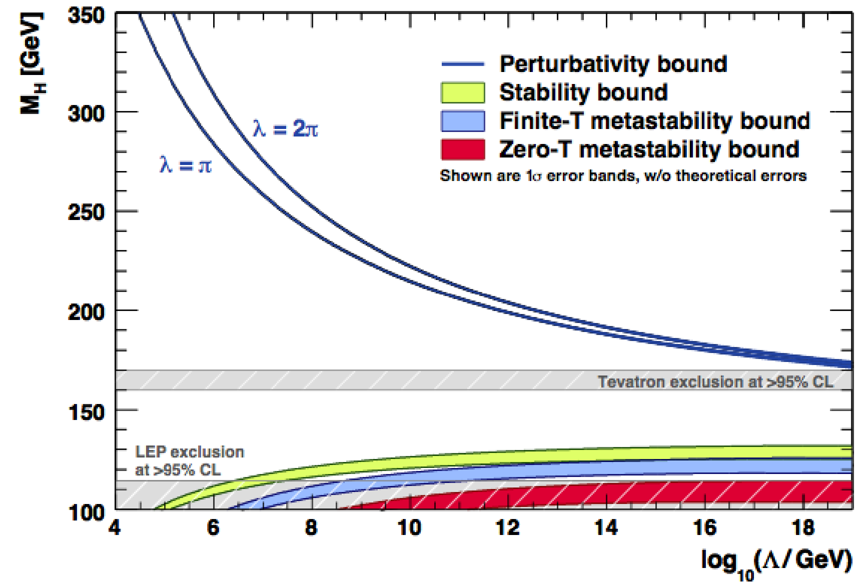
- ☞ Experimental clues of the BSM physics
  - ➠ Dark Matter (DM) points to WIMPs
  - ➠ Baryon Asymmetry of the Universe requires $\not{B}$ processes
  - ➠ neutrino mass
- ☞ **Indirect Searches**
  - ➠ precision coupling measurement

$$\Delta k/k \propto 1/M_\Lambda^2$$

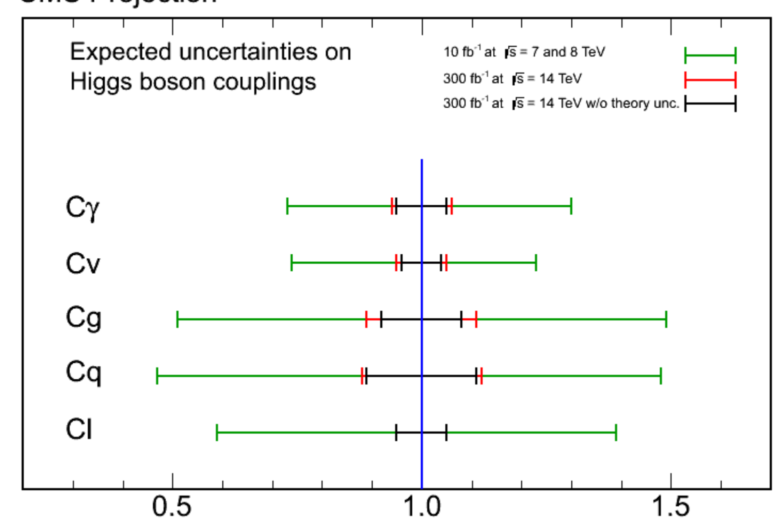
additional Higgs Singlet models, compositness, 2HDM (MSSM and NMSSM)

- ☞ **Direct Searches of BSM**
  - ➠ SUSY, DM, heavy resonances

[J.Ellis, et al., Phys. Lett. **B679**:369-375 (2009)]



CMS Projection



$\Delta k/k \sim$10(1)%$\Rightarrow M_\Lambda \sim$1-1.5(3-4) TeV

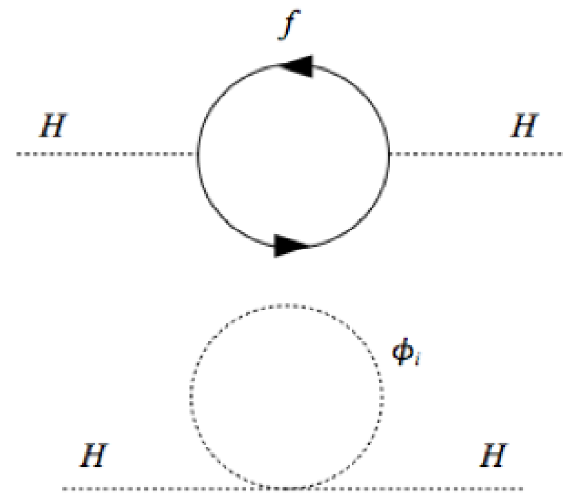
SUSY Searches

☞ Hierarchy Problem

➠ in the SM the quantum corrections for the mass of the Higgs boson require a miraculous cancellation as

$$\mathcal{O}(10^{30}) - \mathcal{O}(10^{30}) \sim \mathcal{O}(10^{4})$$

Fine-tuning in MSSM→ Natural SUSY



$$\Delta M_H^2 \sim \frac{\lambda_f^2}{4\pi^2}\left[(m_f^2 - m_S^2)\log\left(\frac{\Lambda}{m_S}\right)\right]$$

Little hierarchy problem:

large mass of squarks re-introduce fine-tuning

☞ Dark Matter

$$\mathbf{P_R} = (-\mathbf{1})^{\mathbf{2S+3B+L}} \begin{cases} S- & \text{spin} \\ B- & \text{barion number} \\ L- & \text{lepton number} \end{cases}$$

$$\mathrm{P_R} = -1 \quad \text{for spart.}$$
$$\mathrm{P_R} = +1 \quad \text{for SM part.}$$

R-Parity Conservation (RPC):

1. lightest sparticle (LSP) stable
2. sparticles are produced in pairs
3. cascade decay down to the LSP (DM candidate)

☞ Gauge Unification

[arXiv:1110.6926]

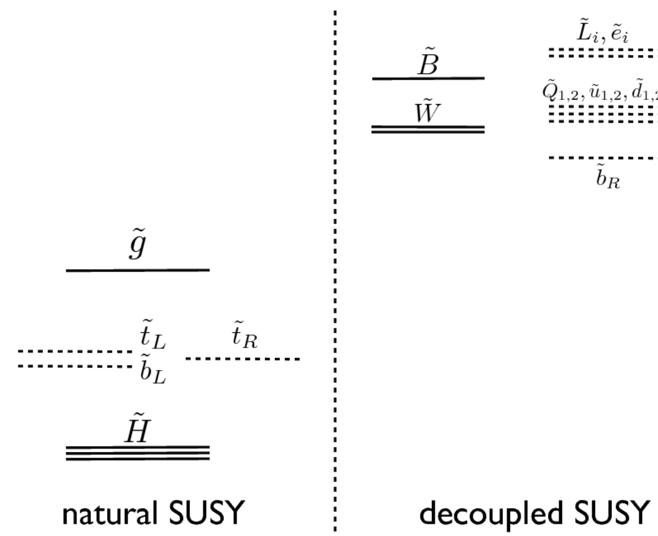
☞ Disclaimers:

- ➠ SUSY is broken by unknown mechanism
- ➠ introduces many free parameters in theory
- ➠ results are presented in a given model using assumptions
- ➠ most current results are given in Simplified Models: single decay chain, 100% BR, etc

$$m_{\tilde{g}} \leq 1500 \text{ GeV}$$
$$m_{\tilde{t},\tilde{b}_L} \leq 700 \text{ GeV}$$
$$m_{\tilde{\chi}^0_{1,2},\tilde{\chi}^+_1} \leq 350 \text{ GeV}$$

☞ Strategy is based on phenomenology oriented approach:

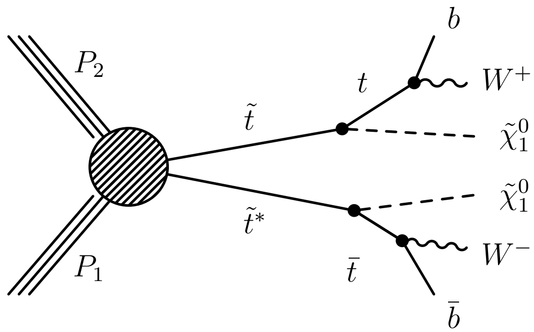
- ➠ **natural spectrum** in RPC scenario
- ➠ strong production in RPC scenario
- ➠ R-Parity Violation (RPV) scenario
- ➠ extended Higgs sector in SUSY: h,H,A,H$^{\pm}$



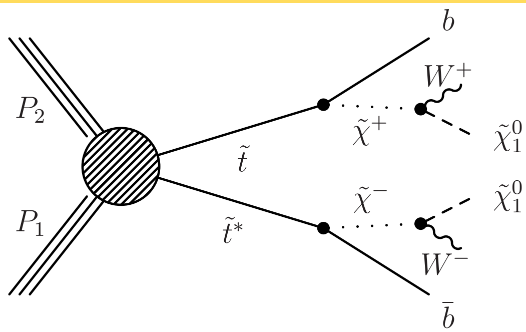
Large 1st and 2nd generation squarks, bino/wino, sleptons can be heavy without compromising **naturalness**

[SUS-13-011]

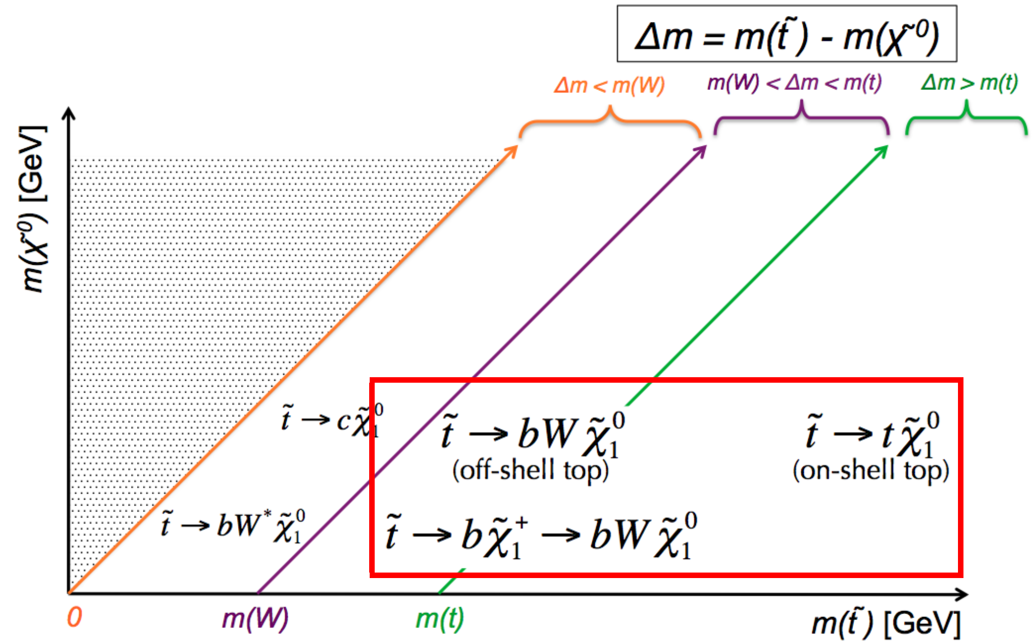
$\tilde{t}\tilde{t} \to t\bar{t}\tilde{\chi}_1^0\tilde{\chi}_1^0$



$\tilde{t}\tilde{t} \to b\bar{b}\tilde{\chi}_1^+\tilde{\chi}_1^- \to b\bar{b}W^+W^-\tilde{\chi}_1^0\tilde{\chi}_1^0$



Model Parameter Space

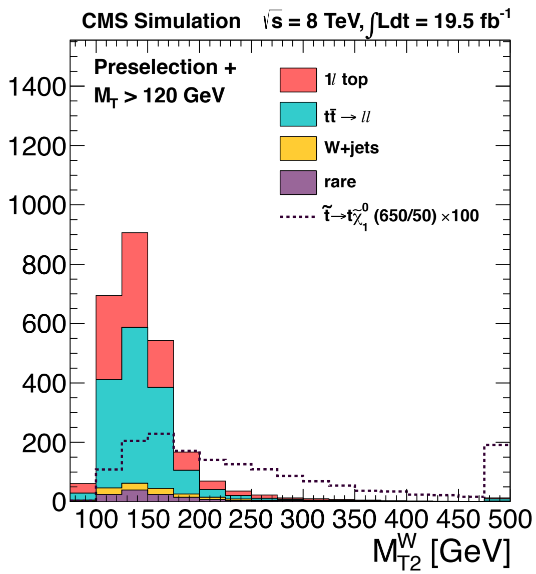


- Similar to $t\bar{t}$ signature with MET from undetected $\tilde{\chi}_1^0$ LSP
  - focus on 1e/μ channel $\to$ large $\mathcal{B}$ and clean

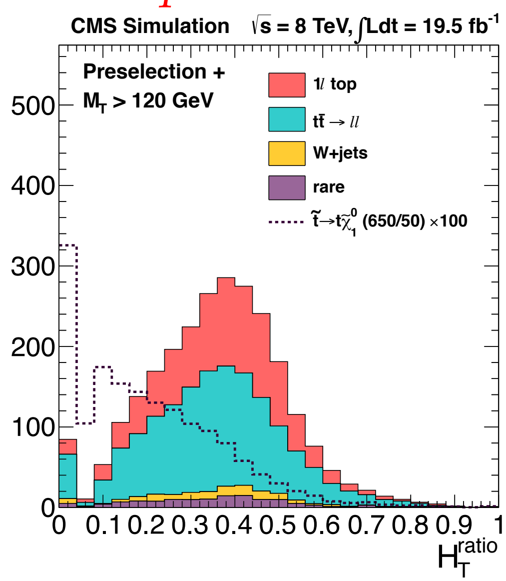
- **Analysis challenge**
  - **small mass** ($\sim$ **m$_t$**): sizable XS, large $t\bar{t}$
  - **high mass** ($>>$ **m$_t$**): different kin., low XS

Discriminate against background using BDT optimizatior for kinematical variables

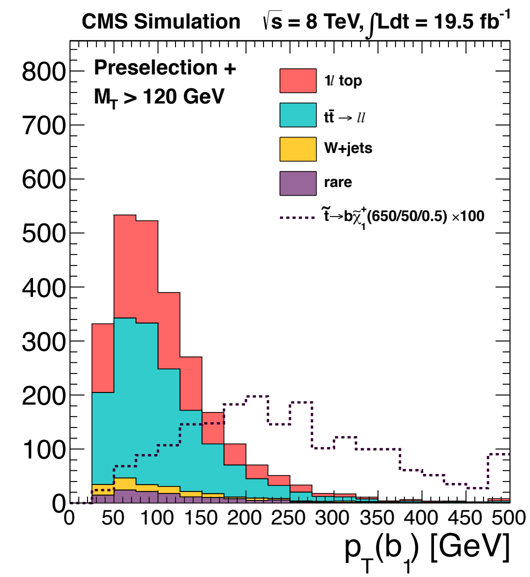
M_{T2}^{W} [JHEP07 (2012) 110]

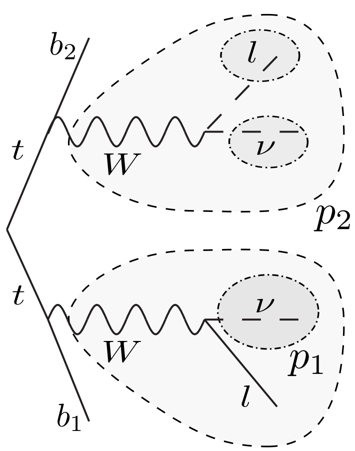


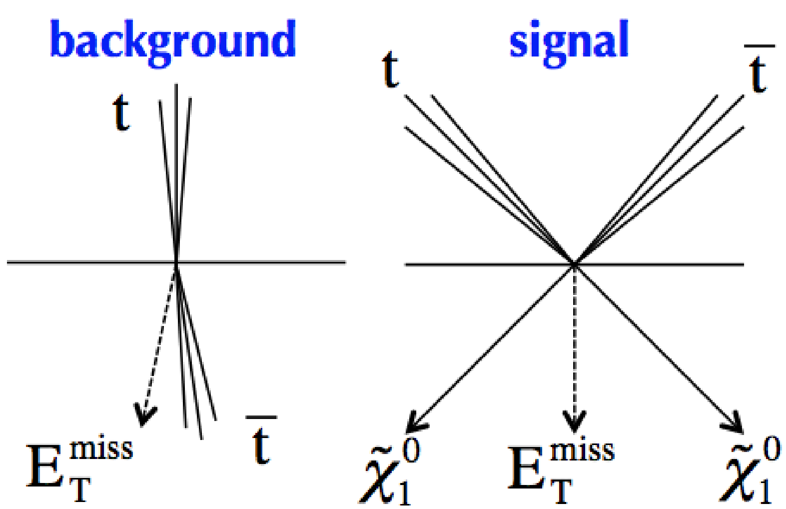
Fraction of H_T in same hemisphere as MET

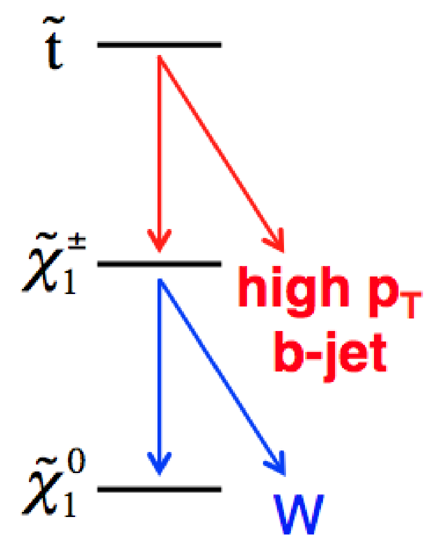


Leading b-jet p_T

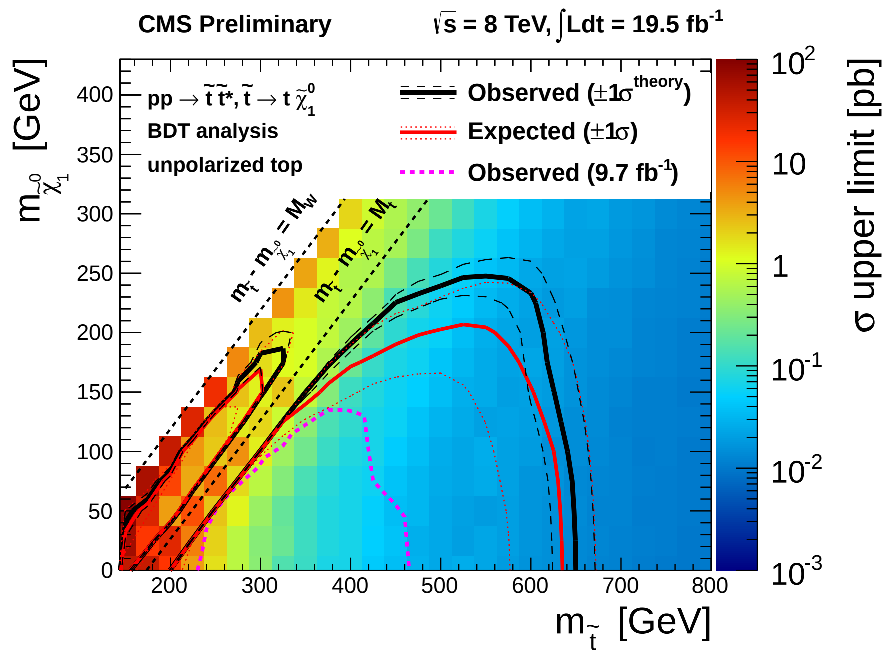




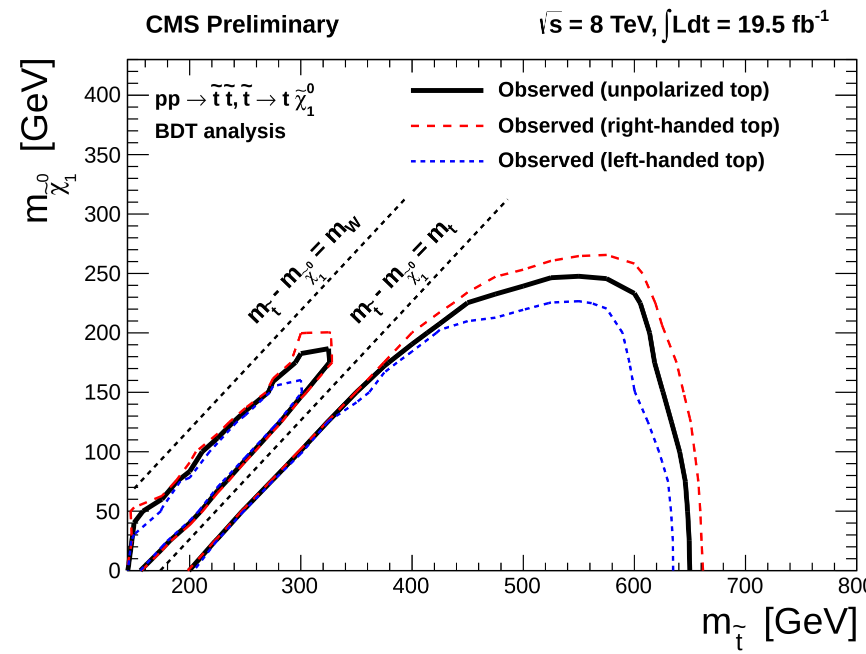




Limits from BDT signal regions



Polarization Dependence



☞ Analysis sensitive to $\Delta M > m_t$ and $\Delta M < m_t$ **but not $\Delta M \sim m_t$**

- ➠ search for stops in gluino-mediated cascade processes
- ➠ precise subtraction of $t\bar{t}$ background

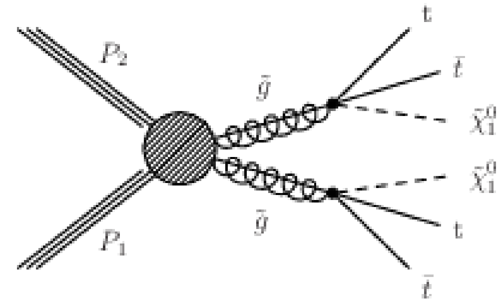
Exclude stops $m_{\tilde{t}} \leq 625$ GeV for neutralinos $m_{\tilde{\chi}^0_1} \leq 225$ GeV

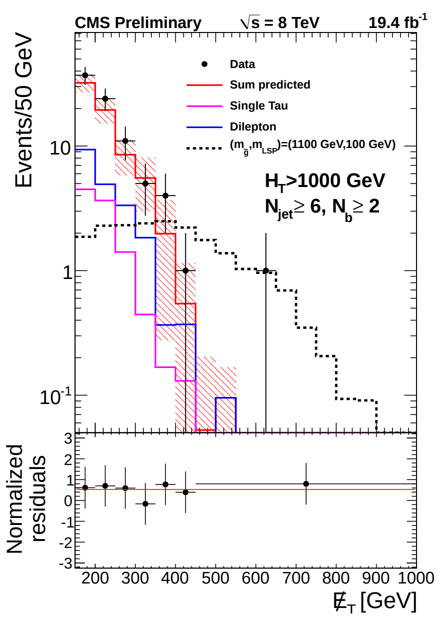
☞ Signal acceptance depends on top polarization from $\tilde{t} \to t\tilde{\chi}^0_1$

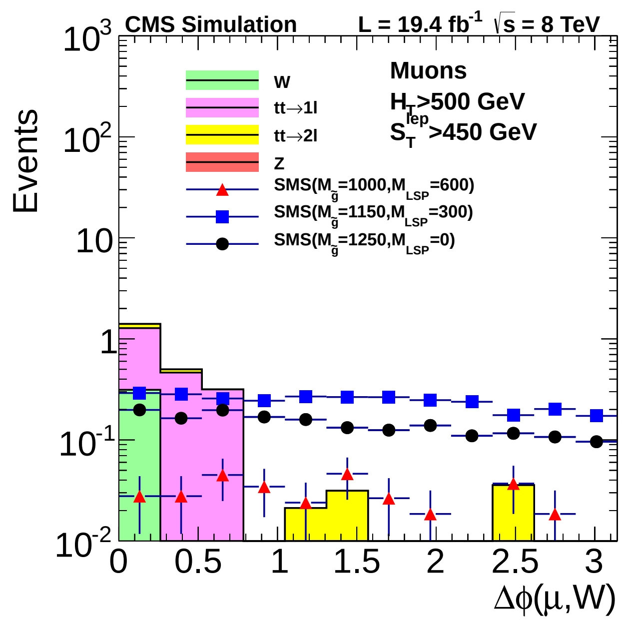
- ➠ depends on left/right stop mixing and $\tilde{\chi}^0$ composition
- ➠ compare mass limits for unpolarized (nominal) vs. left/left-handed tops
- ➠ impact on mass limits about 20 GeV

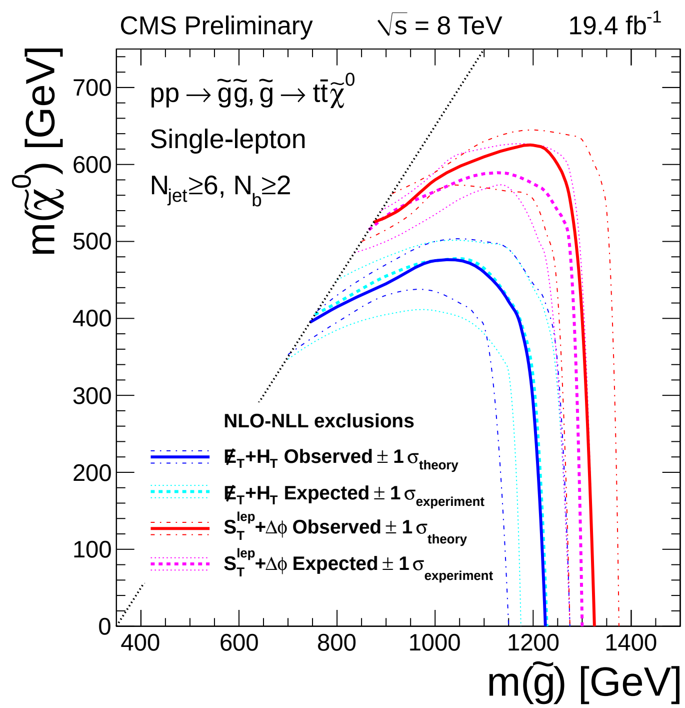
[SUS-13-007]

- Involve strong production processes and cascade decays to the LSP and a single lepton ($\tilde{g} \to \tilde{t}t, \tilde{b}b$)
  - hadronic objects $\geq$6jets, $\geq$2 b-jets plus MET
  - event categorization by $\mathrm{H_T}$, MET and $\mathrm{N_{b-jets}}$
  - Two complementary approaches:
    Lepton Spectrum: MET>250 GeV
    Delta Phi: $\mathrm{S_T} = p_T{}^{\mathrm{lep}}$+MET for $\Delta\phi$(W,l)>1









Background uncertainty from the MET scale and MC statistics on the single lepton scale factor

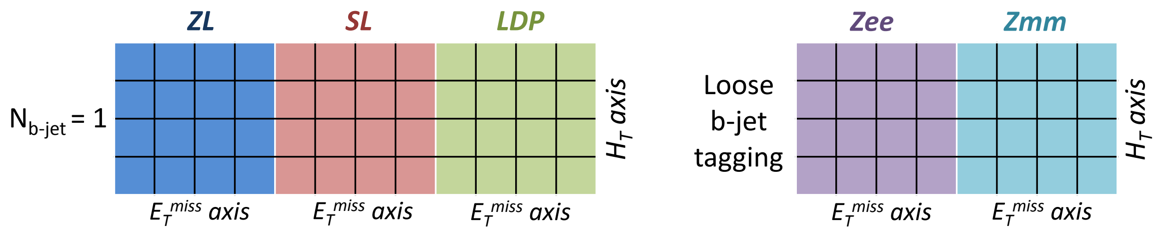
$\mathbf{m_{gluino}} < 1.3$ TeV are excluded for neutralino masses below 0.5 TeV

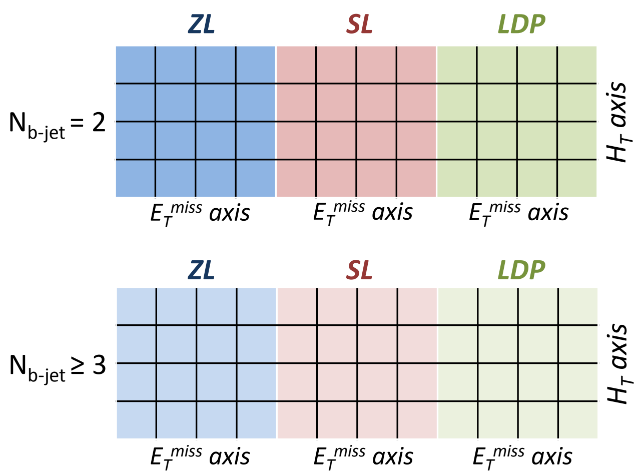
☞ **Gluino mediated** pair production of $\tilde{b}$ and $\tilde{t}$ squarks [arXiv:1305.2390] subm. to PLB

- hadronic final state: $\geq$3jets, $\geq$1 b-jets plus MET
- event categorization by $\mathrm{H_T} = \Sigma_{jet}\, p_T$, MET and $\mathrm{N_{b-jets}}$

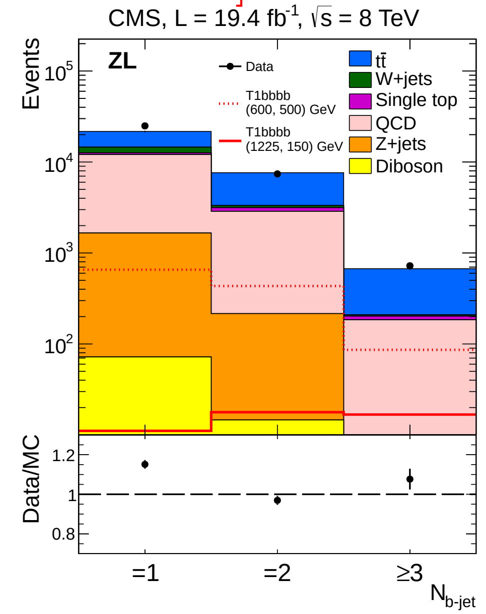
Event sample legend

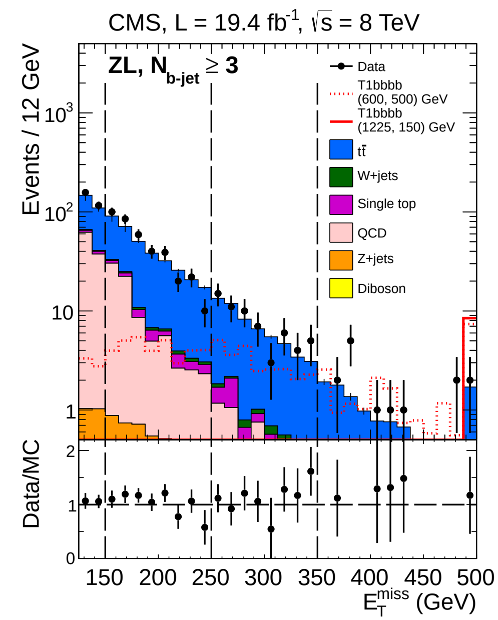
ZL = Zero Lepton; signal sample	***SL*** = Single Lepton; top & W+jets control sample	***LDP*** = low $\Delta\hat{\phi}_{min}$; QCD control sample	***Zee*** = Z → e⁺e⁻; Z to $\nu\bar{\nu}$ control sample	***Zmm*** = Z → μ⁺μ⁻; Z to $\nu\bar{\nu}$ control sample





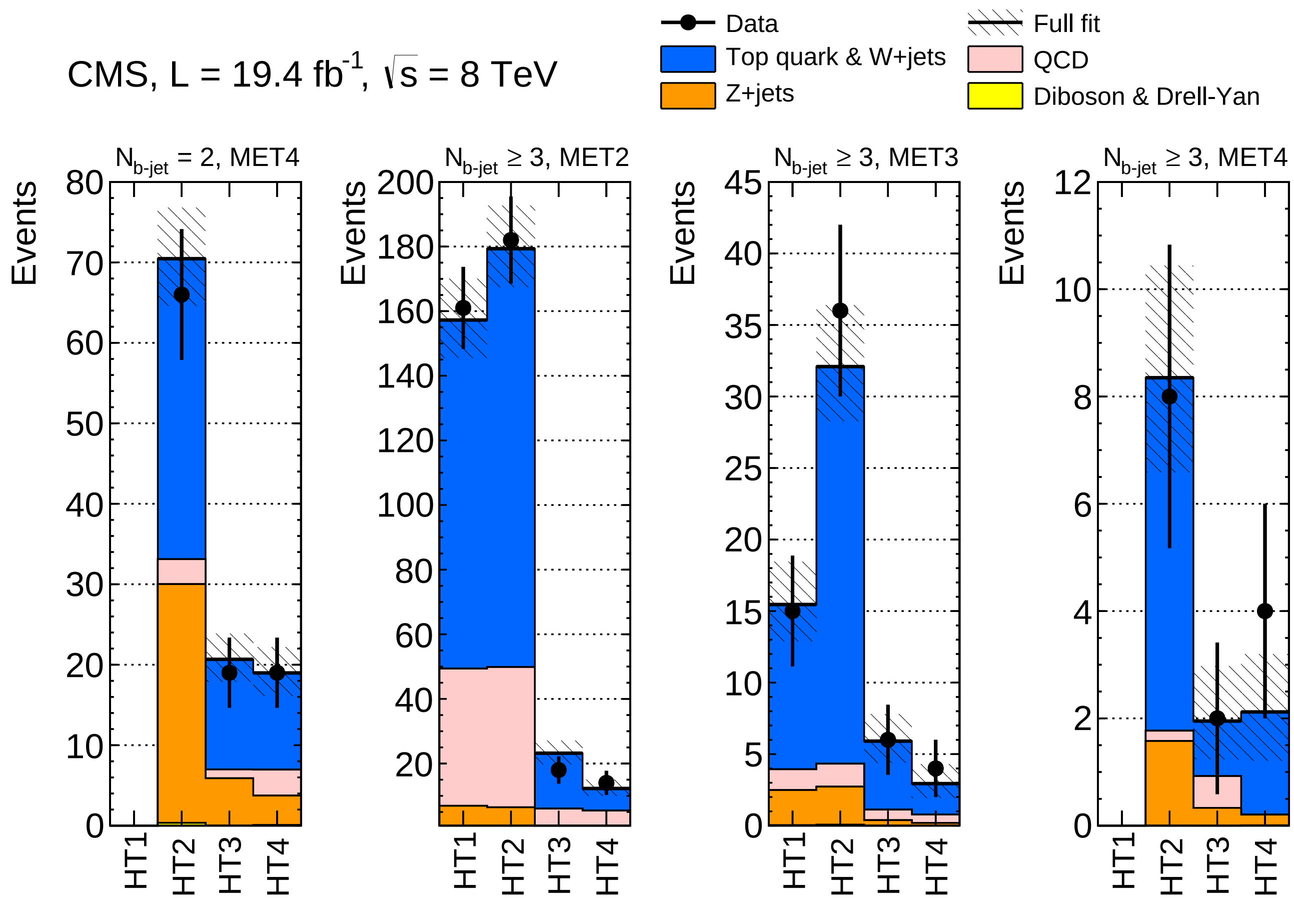
Bin	H_T (GeV)	E_T^{miss} (GeV)
1	400 – 500 (HT1)	125 – 150 (MET1)
2	500 – 800 (HT2)	150 – 250 (MET2)
3	800 – 1000 (HT3)	250 – 350 (MET3)
4	> 1000 (HT4)	> 350 (MET4)





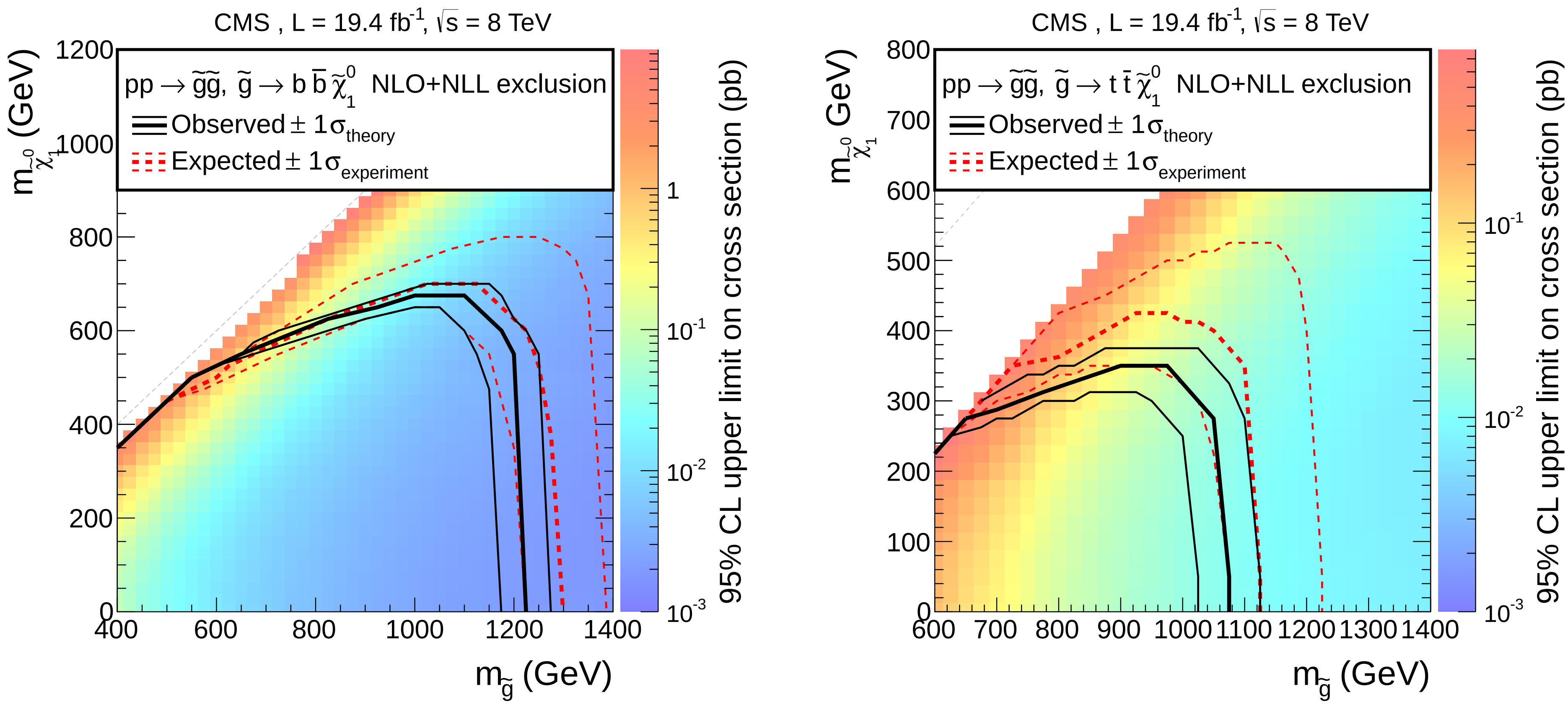
Background estimated from data control samples:
e/μ+jets (SL), invert $\Delta\phi^{\rm min}$ (LDP), Z→ll (Zee, Zmm)

Binned likelihood fit performed simultaneously over all $\mathrm{H_T}$, MET and $\mathrm{N_{b-jets}}$ bins in signal and control regions



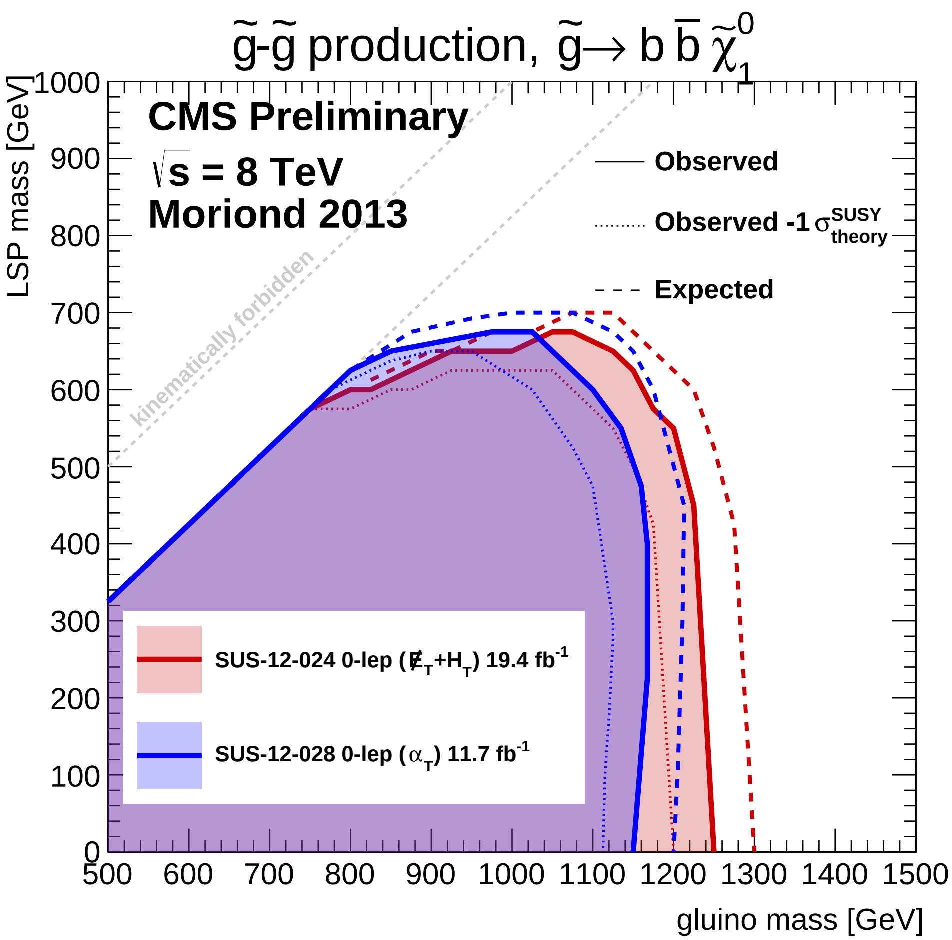
Events with $\mathrm{N_{b-jets}} \geq 3$: most sensitive to the signal

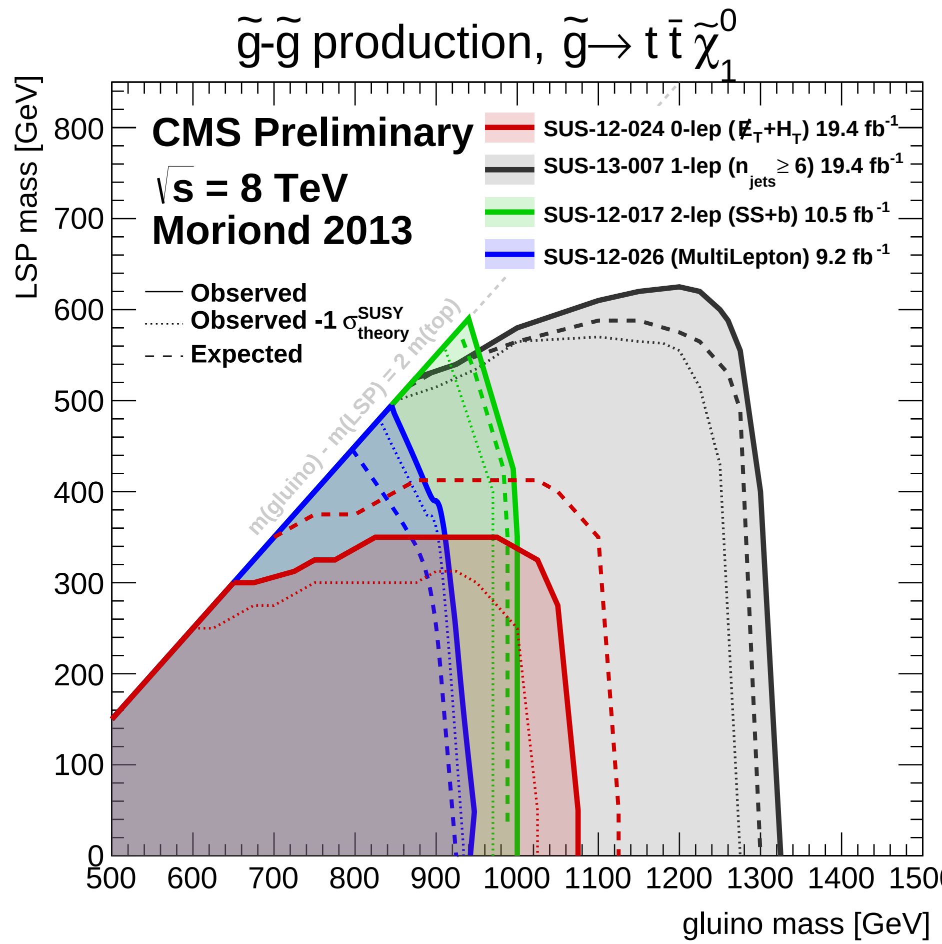
No significant excess in data observed



$m_{gluino} > 1200(1025)$ GeV at low mass LSP for 4b (4t) final state

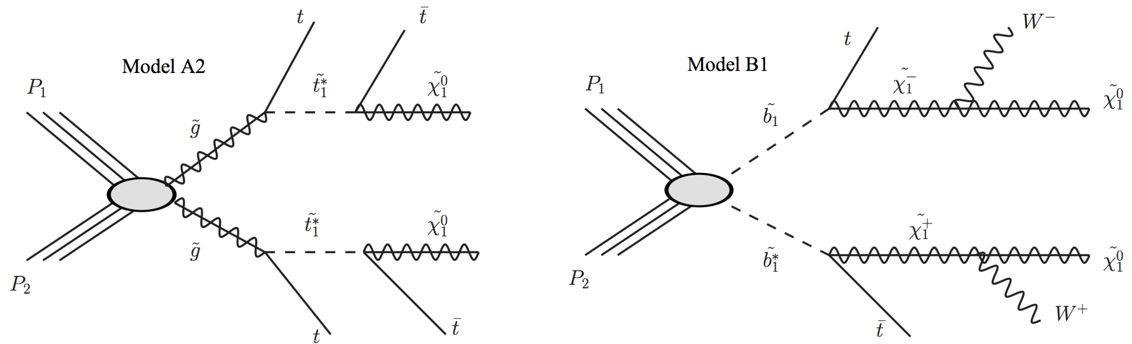
SUSY: Summary for $\tilde{b}$ and $\tilde{t}$ Production



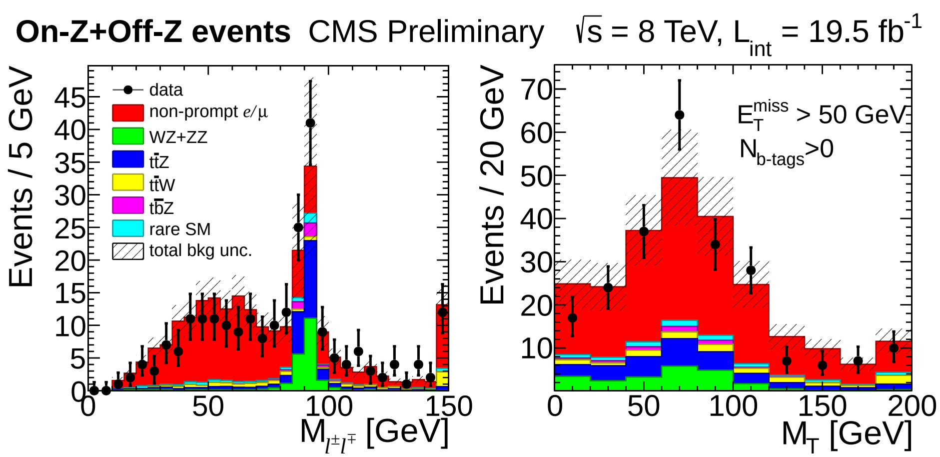


$m_{gluino} \geq 1.3$ TeV at low mass LSP (single lepton $\tilde{g} \to tt\tilde{\chi}_1^0$ cascade decay)

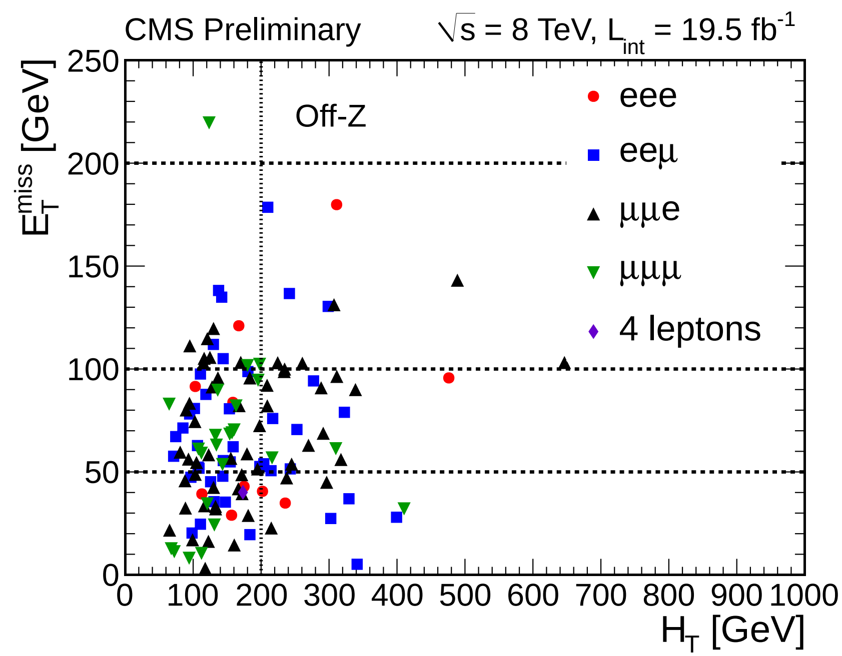
- Gluinos and sbottoms may lead to 4W+multi-b final states
- Sensitive to stop produced in cascade decays



- 3l+b: clean signature, low background
  - $\geq$3 isolated high-p_T leptons
  - $\geq$2 jets, $\geq$1 b-jet
  - MET>50 GeV

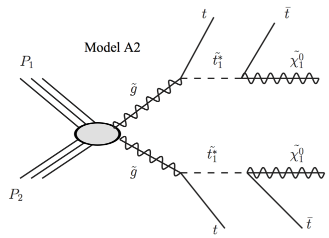


Event categorization according to Z→ll presence

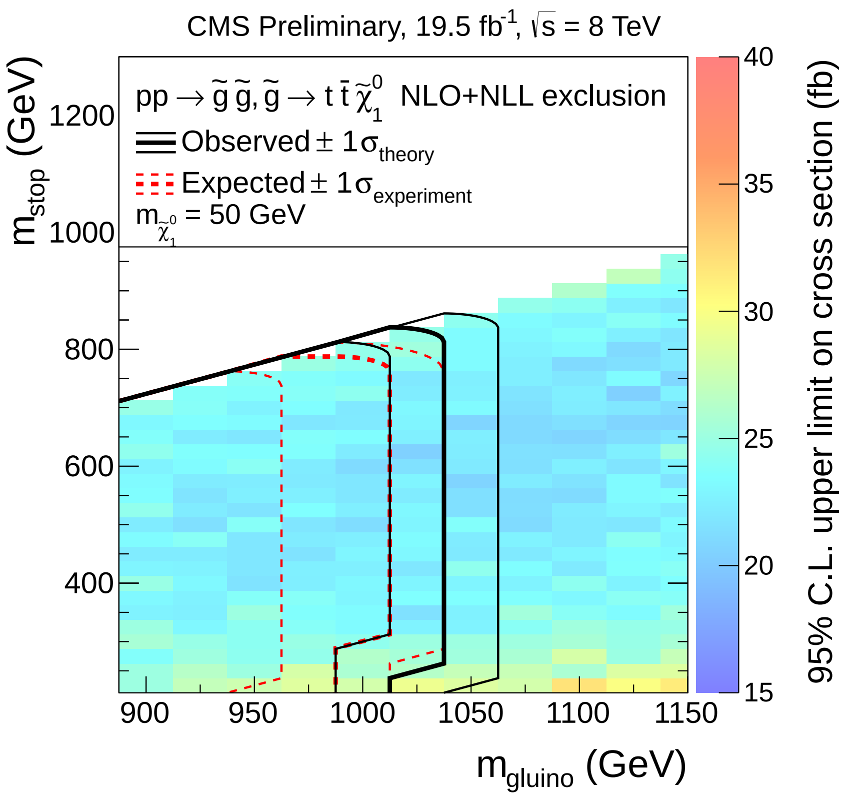


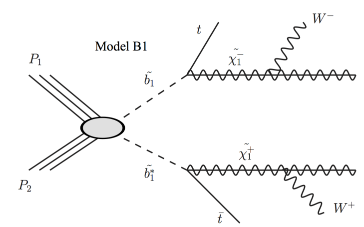
Perform simultaneous event counting in search regions

[SUS-13-008]

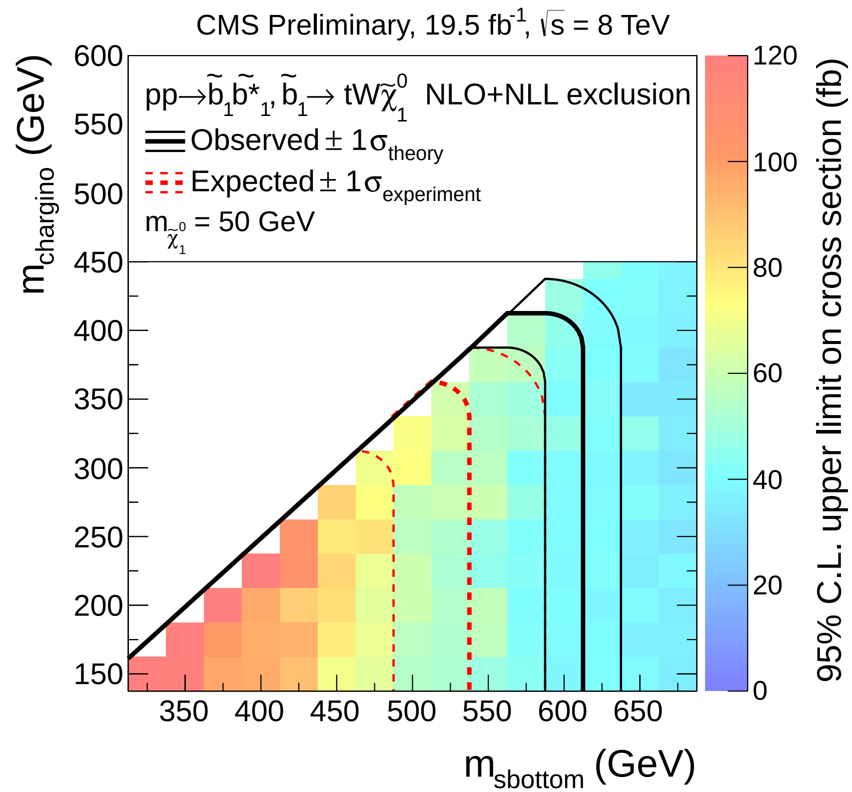


Gluino-mediated stop production





Sbottom pair production wtih $\tilde{b} \to t\tilde{\chi}_1^-$



Signal region: $\geq$4jets, $\geq$2b-jet, large H_T and MET

Probe gluino up to ~1 TeV

Signal region: $\geq$2jets, $\geq$1b-jet, large H_T and MET

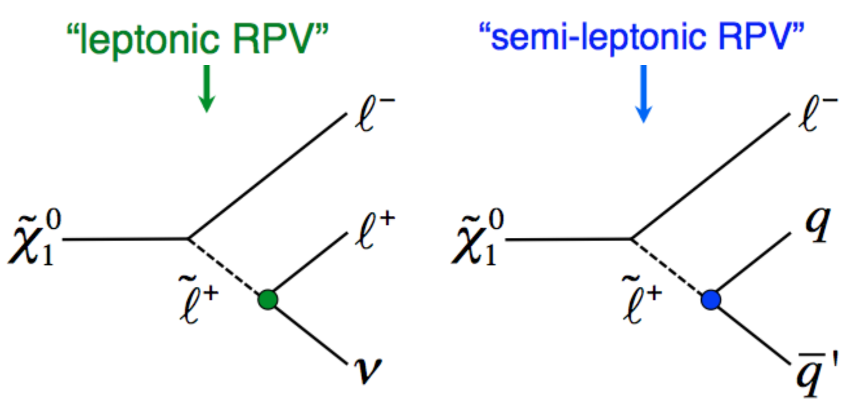
Probe sbottoms up to 600 GeV

☞ **Proton stability** forbids simultaneous $\not{L}$ and $\not{B}$

- ➠ impose R-parity in MSSM
- ➠ two other possibilities $\not{L}$ or $\not{B}$
- ➠ LSP is not stable (DM candidate?)

☞ $\not{L}$: LSP will decay to two leptons

$$\Delta L_{RPV} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \ldots$$

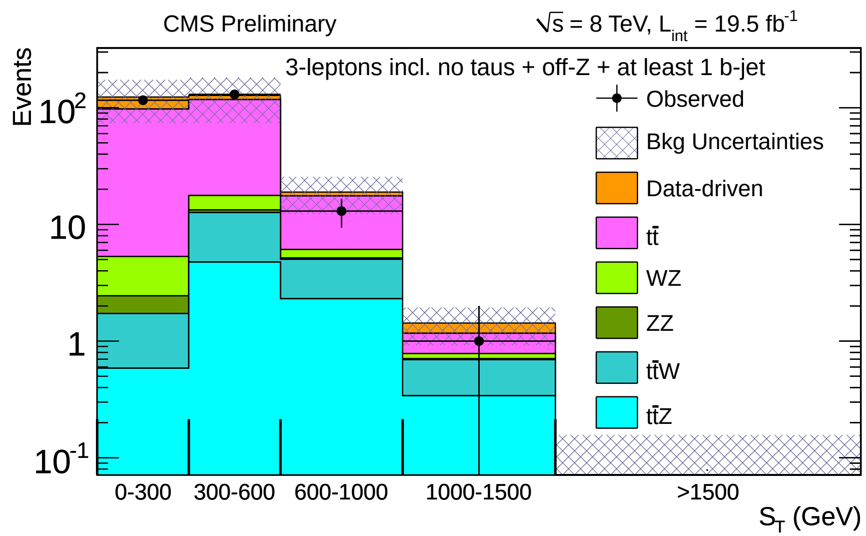


Unstable LSP significantly reduces MET, additional objects

☞ Search for anomalous production with **≥3-leptons and at least 1 b-jet**

☞ Use event energy scale as sensitive observable

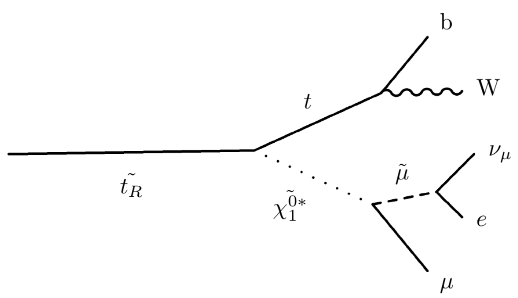
$$S_T = \Sigma_{jet}\, p_T + \Sigma_{lep}\, p_T + MET$$

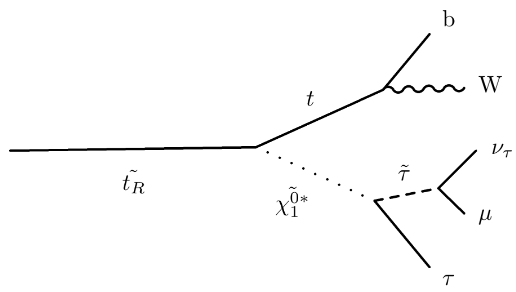


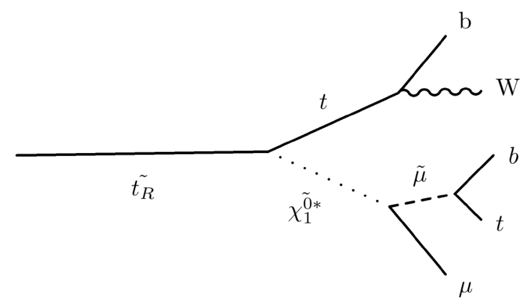
No excesses above the SM background expectation, no evidence for RPV stops

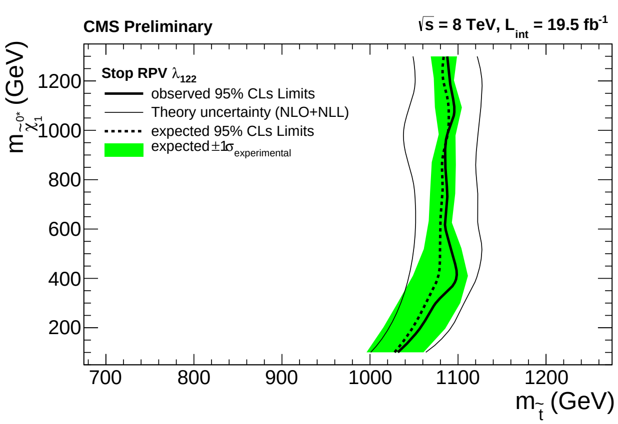
[SUS-13-003]

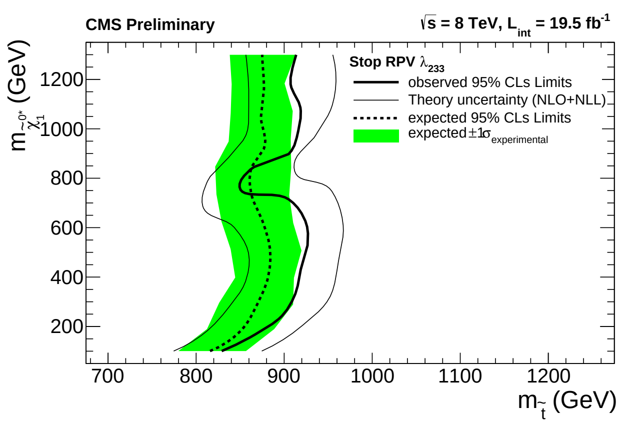
Leptonic RPV	Leptonic RPV	Semi-leptonic RPV
λ_{122}: e, $\mu-$ enriched	λ_{233}: μ, $\tau-$ enriched	λ'_{233}: μ, b, $\tau-$ enriched

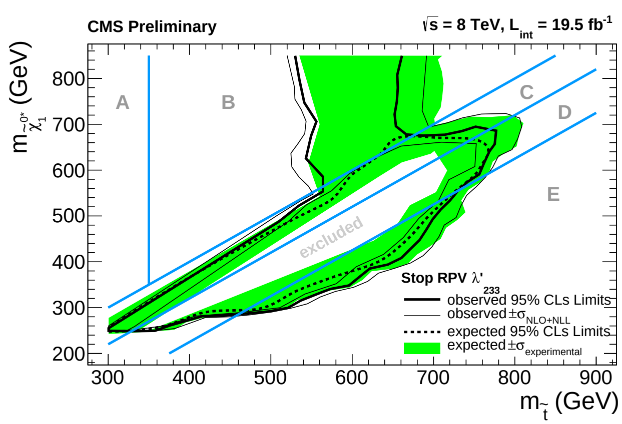












Probe stop up to kinematic limit about 1.1 TeV

[SUS-13-010]

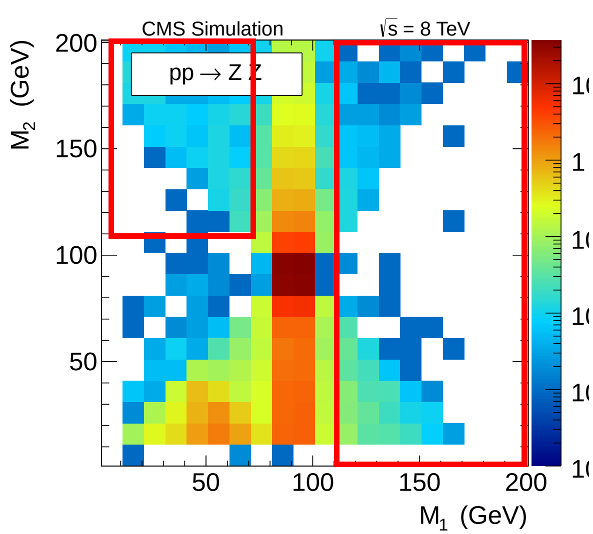
LRPV naturally gives multilepton signatures

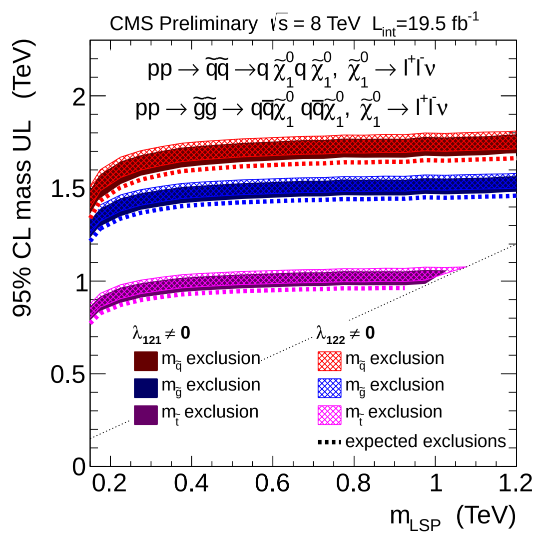
$\tilde{\chi}_1^0 \tilde{\chi}_1^0 \to 4l$

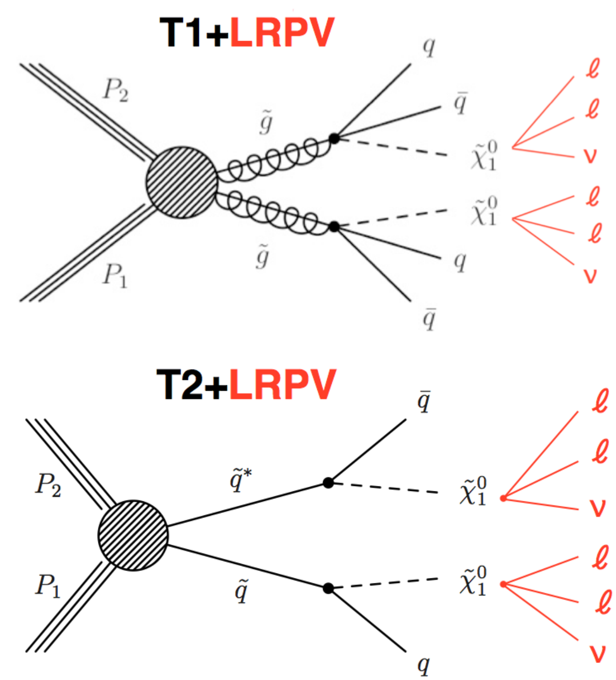
$\lambda_{121} > 0$: electron-enriched

$\lambda_{122} > 0$: muon-enriched

- Search for anomalous production with 4 leptons
  - M_1 - mass of opposite-sign, same-flavor dilepton around M_Z
  - M_2 - mass of the other lepton pair
- Define signal regions in M_2 versus M_1 plane
  - suppress ZZ background

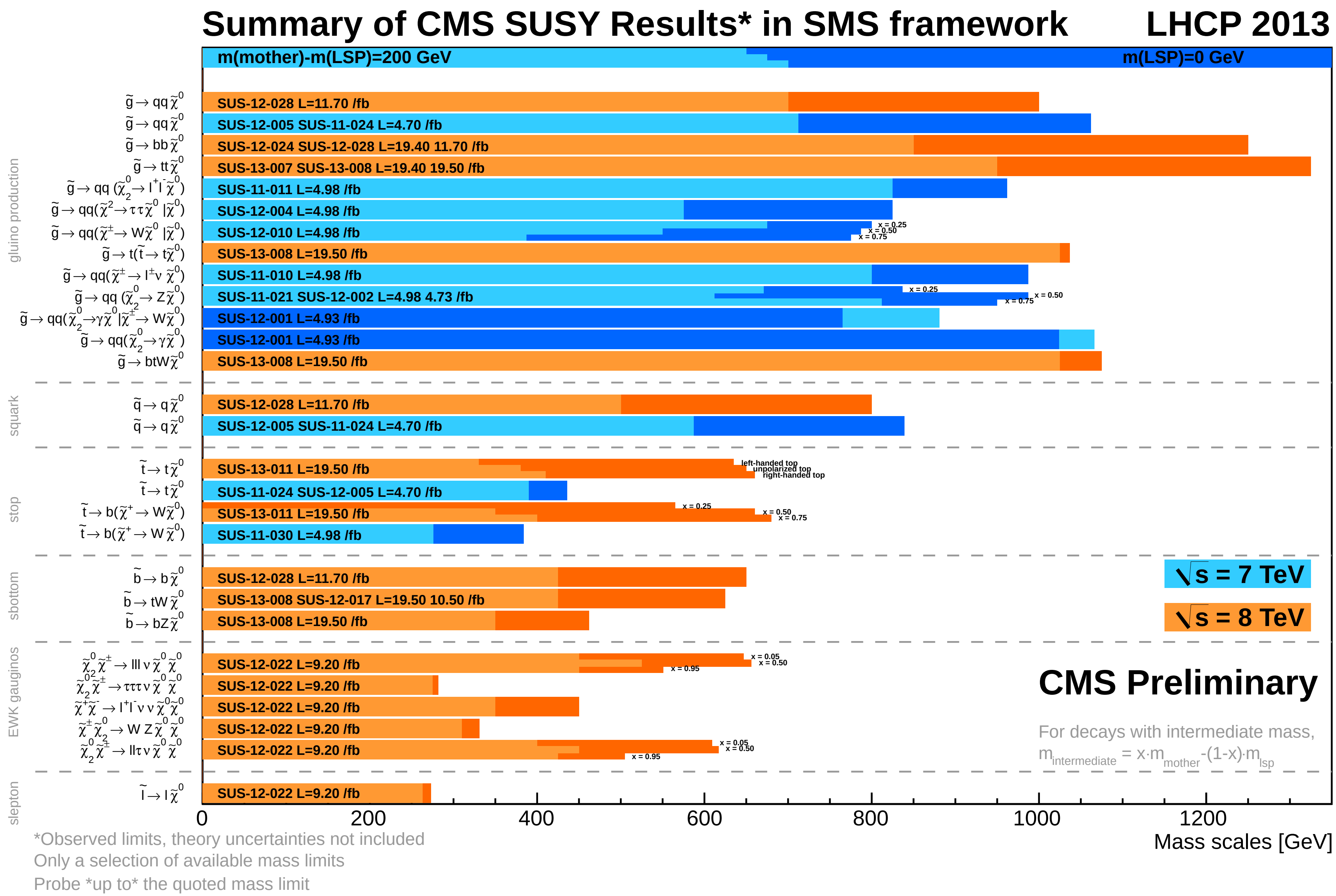






$N_{bkg} = 3.0 \pm 0.6$ev., $N_{data} = 1$ev. $\to$ **upper limit 3.4 events**

Probe $m_{\tilde{g}} \sim 1.5$ TeV, $m_{\tilde{t}} \sim 1.0$ TeV, $m_{\tilde{q}} \sim 1.7$ TeV



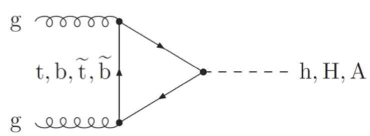
Summary of CMS SUSY Results* in SMS framework
LHCP 2013
m(mother)-m(LSP)=200 GeV
m(LSP)=0 GeV
gluino production
SUS-12-028 L=11.70 /fb
SUS-12-005 SUS-11-024 L=4.70 /fb
SUS-12-024 SUS-12-028 L=19.40 11.70 /fb
SUS-13-007 SUS-13-008 L=19.40 19.50 /fb
SUS-11-011 L=4.98 /fb
SUS-12-004 L=4.98 /fb
SUS-12-010 L=4.98 /fb
SUS-13-008 L=19.50 /fb
SUS-11-010 L=4.98 /fb
SUS-11-021 SUS-12-002 L=4.98 4.73 /fb
SUS-12-001 L=4.93 /fb
SUS-12-001 L=4.93 /fb
SUS-13-008 L=19.50 /fb
squark
SUS-12-028 L=11.70 /fb
SUS-12-005 SUS-11-024 L=4.70 /fb
stop
SUS-13-011 L=19.50 /fb
left-handed top
unpolarized top
right-handed top
SUS-11-024 SUS-12-005 L=4.70 /fb
SUS-13-011 L=19.50 /fb
SUS-11-030 L=4.98 /fb
sbottom
SUS-12-028 L=11.70 /fb
SUS-13-008 SUS-12-017 L=19.50 10.50 /fb
SUS-13-008 L=19.50 /fb
EWK gauginos
SUS-12-022 L=9.20 /fb
SUS-12-022 L=9.20 /fb
SUS-12-022 L=9.20 /fb
SUS-12-022 L=9.20 /fb
SUS-12-022 L=9.20 /fb
slepton
SUS-12-022 L=9.20 /fb
√s = 7 TeV
√s = 8 TeV
CMS Preliminary
For decays with intermediate mass,
m_intermediate = x·m_mother-(1-x)·m_lsp
0
200
400
600
800
1000
1200
Mass scales [GeV]
*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

☞ EWSB through 2 isospin Higgs doublets in MSSM $\phi \to \tau\tau (\phi = \mathrm{h, H, A})$:

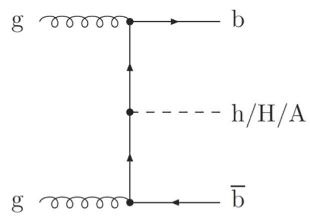
$$\sigma \times \mathcal{B} \sim \tan^2 \beta$$

➠ event categorization by number of b-jets and tau lepton final states

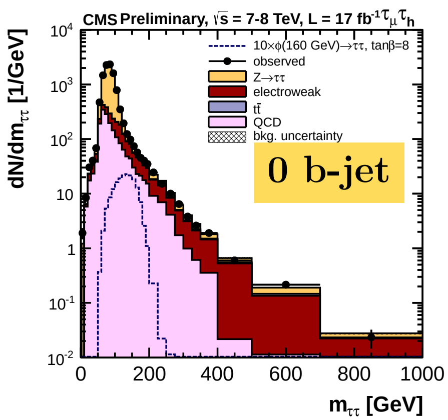
- 2 main Production Processes:

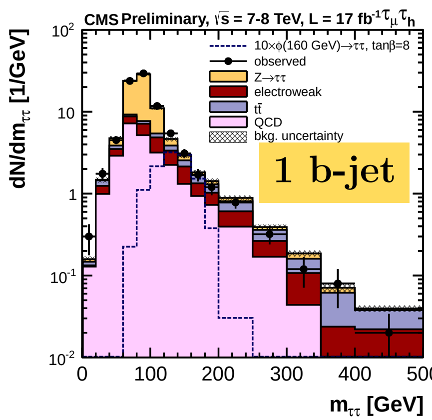


\+



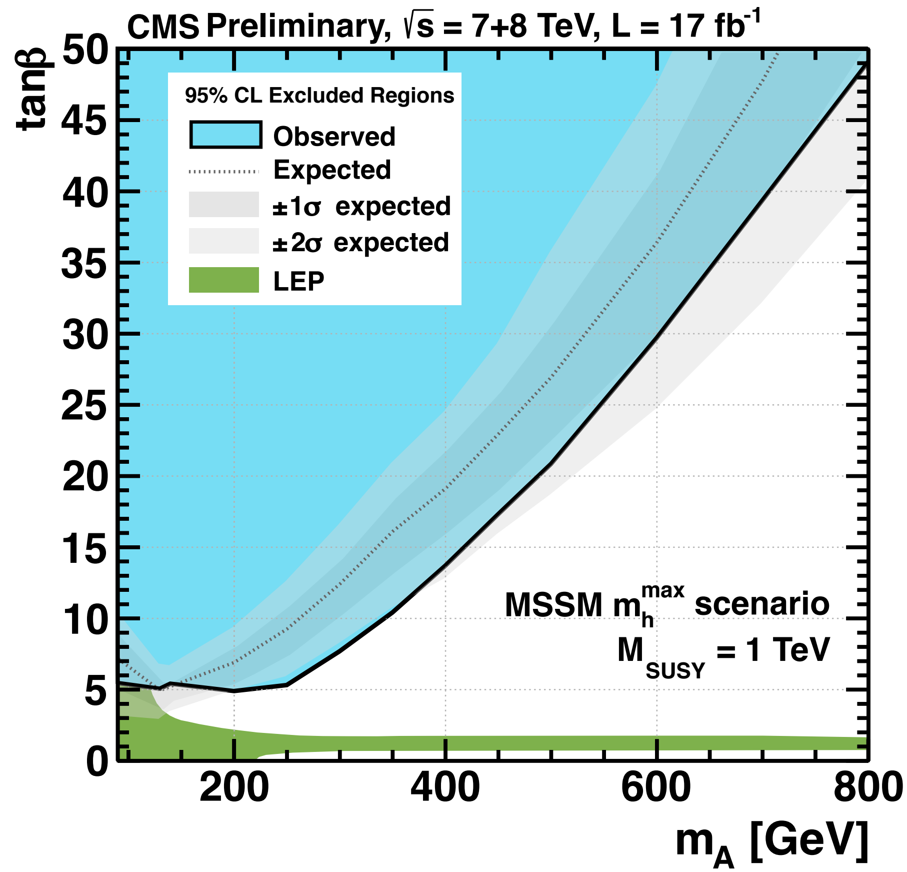
- Cross-section increases ~tan β²





No excess is observed in the tau-pair invariant mass spectrum

Exclusion limits in the MSSM parameter space of $\mathrm{m_A}$ *and* $\tan\beta$ *in the* $\mathrm{m_{h_{max}}}$ *scenario*



SUSY modifies tree-level couplings

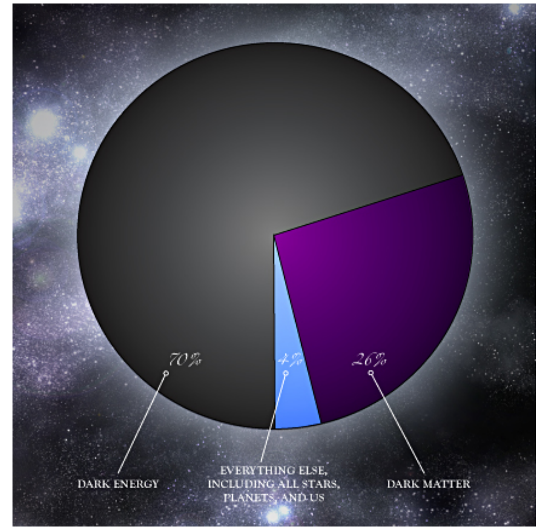
A is difficult to find at moderate $\tan\beta \sim 5$

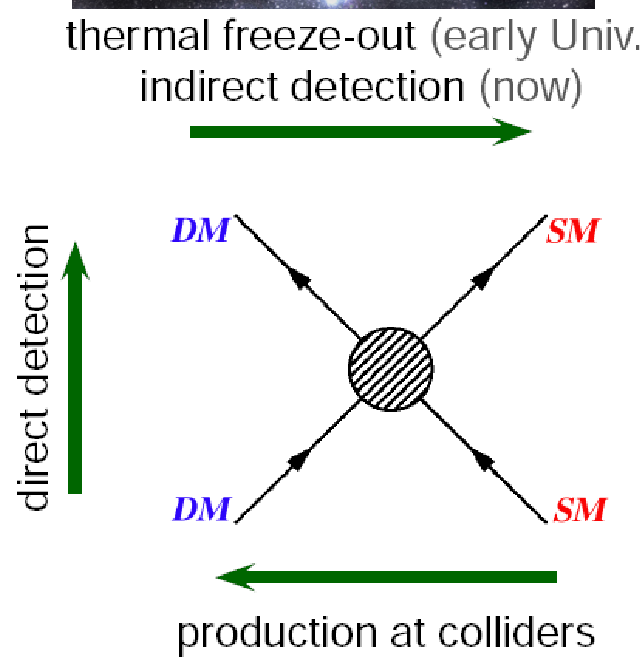
Largest effect $\Delta k_{\tau,b}/k_{\tau,b} \sim 100\%/\mathrm{m_A^2}$

Dark Matter

Dark matter (DM) existence is well established based on gravitational effects

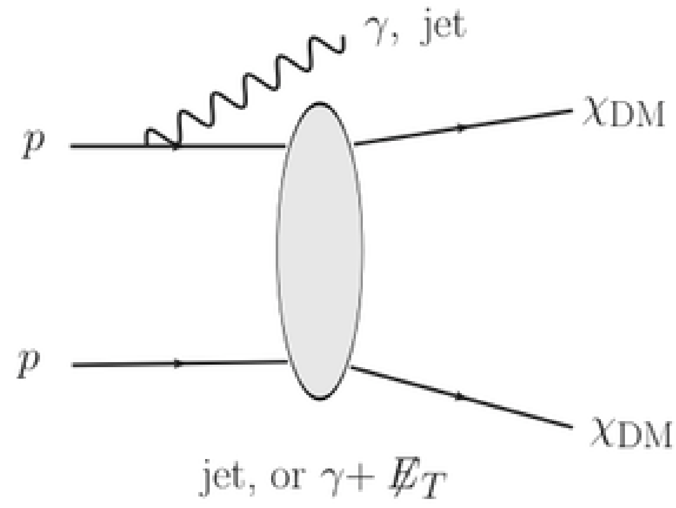
- **Experimental constrains**
  - it is neutral and stable massive particle
  - ruled out several SM candidates $\Rightarrow$ no remaining SM candidate
  - can interact with SM particles
  - in the best case it's cold DM
    Weakly Interacting Massive Particle (WIMP)
- LHC can produce DM through the same process that is used in **direct** (DM-nucleon scattering) and **indirect** (DM annihilation) searches
  - in the detector it's undetectable (as neutrinos)
  - LHC can potentially establish its origin through property measurements

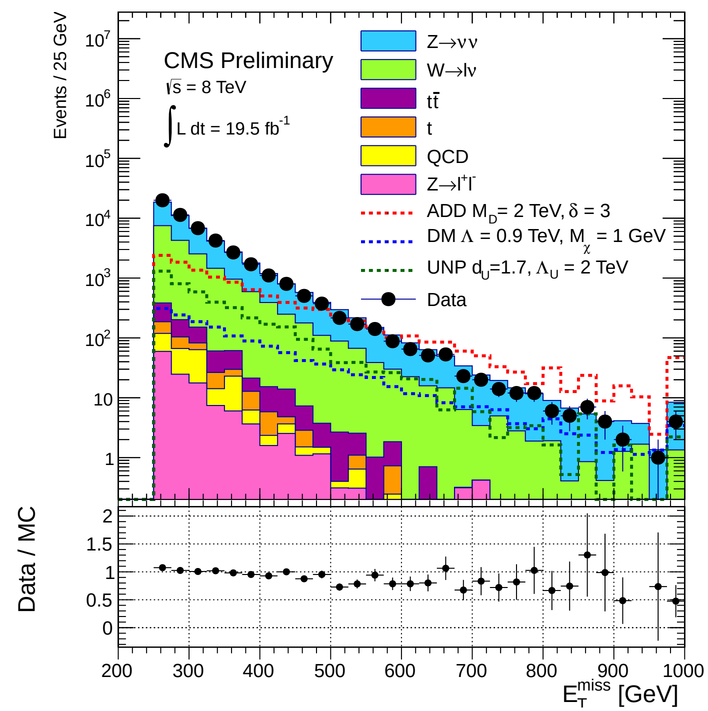




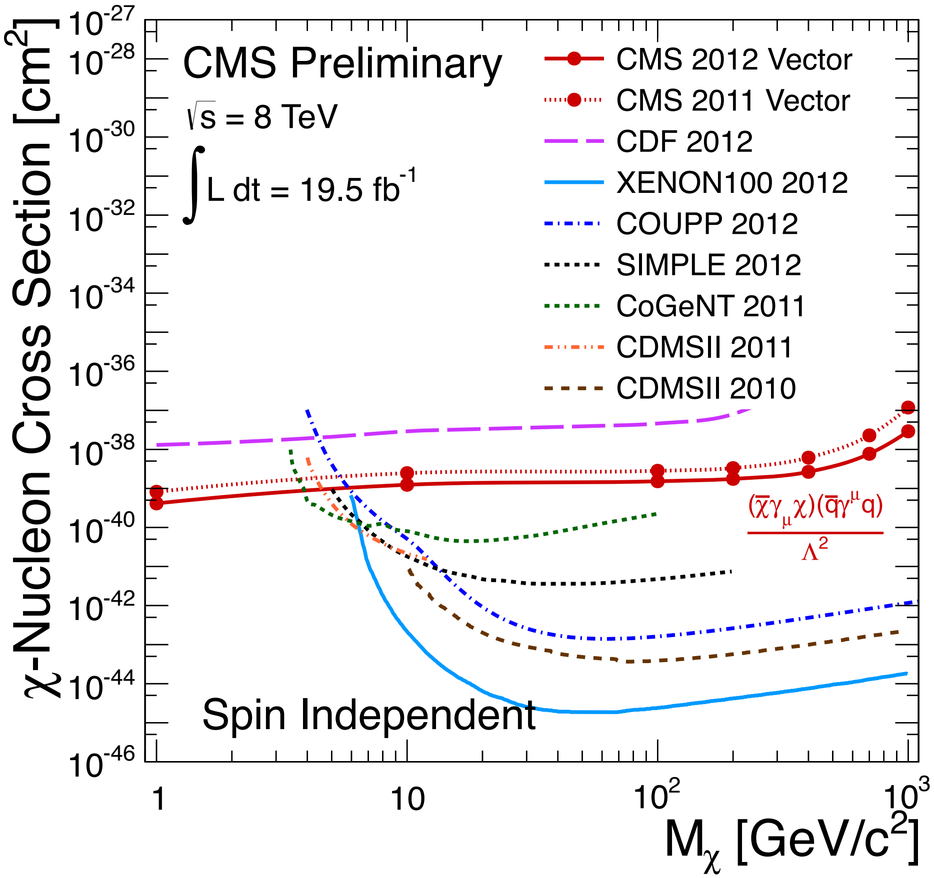
- DM particles are produced in pairs after ISR
  - signature with MET and mono-jet/photon
  - dominant background is Z$\rightarrow \nu\nu$+X
  - couplings between SM and DM can be probed and compared with direct detection results
- For heavy mediator (M$\geq$100 GeV), mono-jet production is about x1000 of direct-detection one
- Universal Extra Dimensions (UED) provides natural DM candidate through KK-partner of U(1) hypercharge boson
  - signature similar to SUSY (l+jets+MET)
  - KK-partners have same spin as SM particles

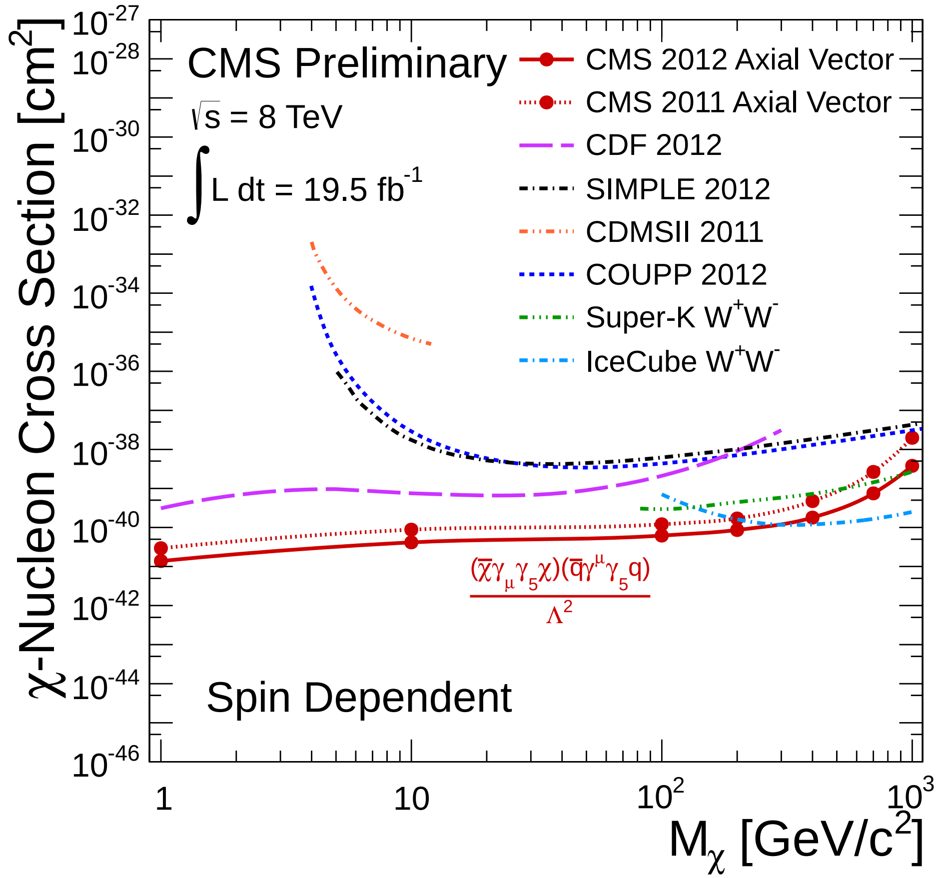
Data are consistent with Standard Model background expectation





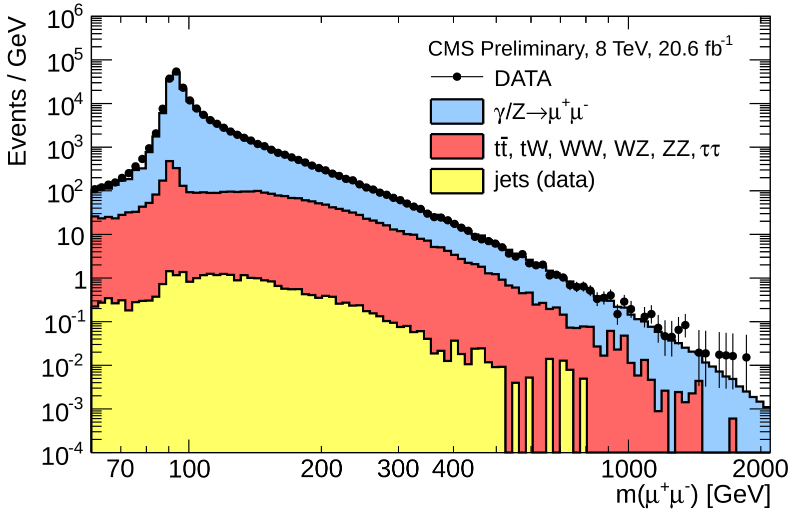
[EXO-12-048]

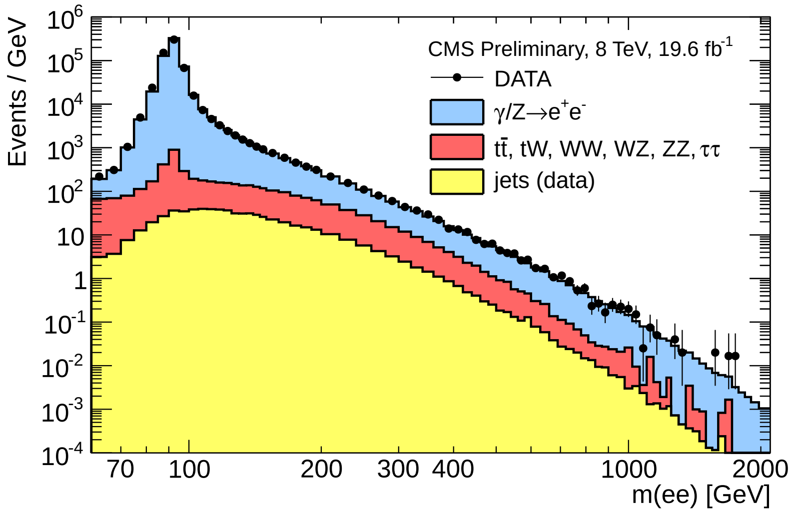




- It is assumed that the DM particles are Dirac fermions
- Collider results **dominate in spin dependent searches**
- **Cover low mass range** for spin independent searches

Exotica Searches



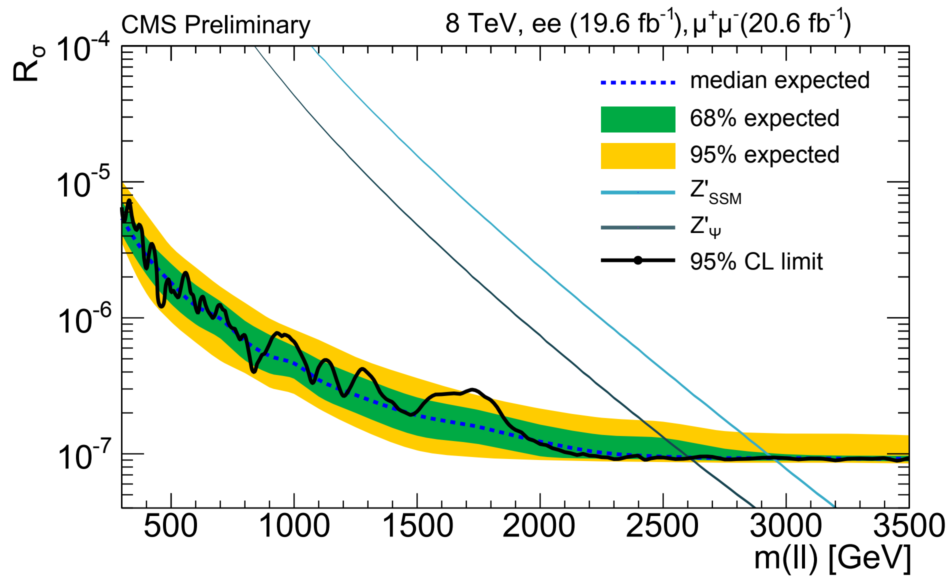


Data/MC agreement over many orders of magnitude: **no deviations from background estimate**

[EXO-12-061]

Many systematic uncertainties cancel out in ratio

$$R_\sigma = \frac{\sigma(pp \to Z' + X \to ll + X)}{\sigma(pp \to Z + X \to ll + X)}$$



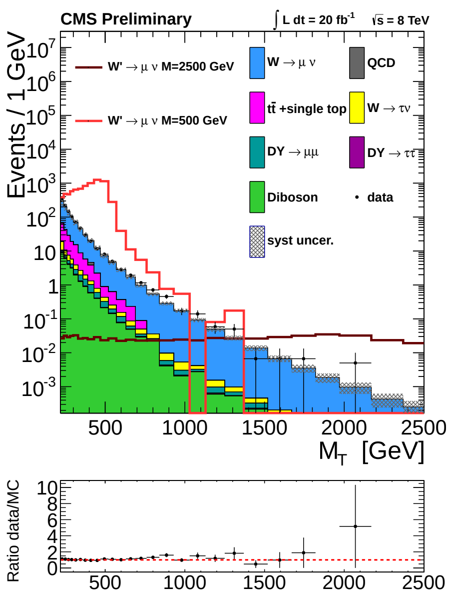
SM-like couplings: $m_{Z',SSM} > 2.96$ TeV

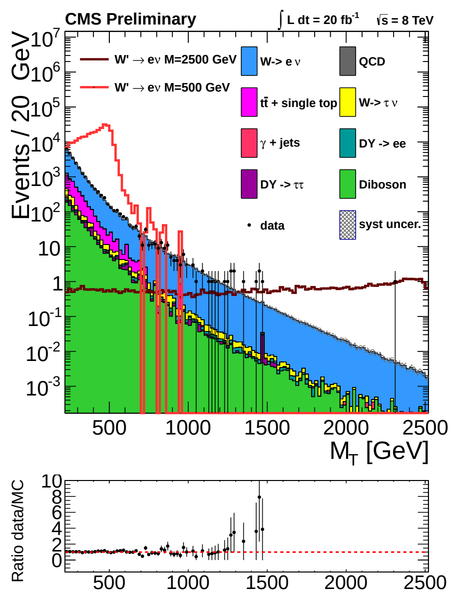
Superstring-inspired: $m_{Z',\psi} > 2.6$ TeV

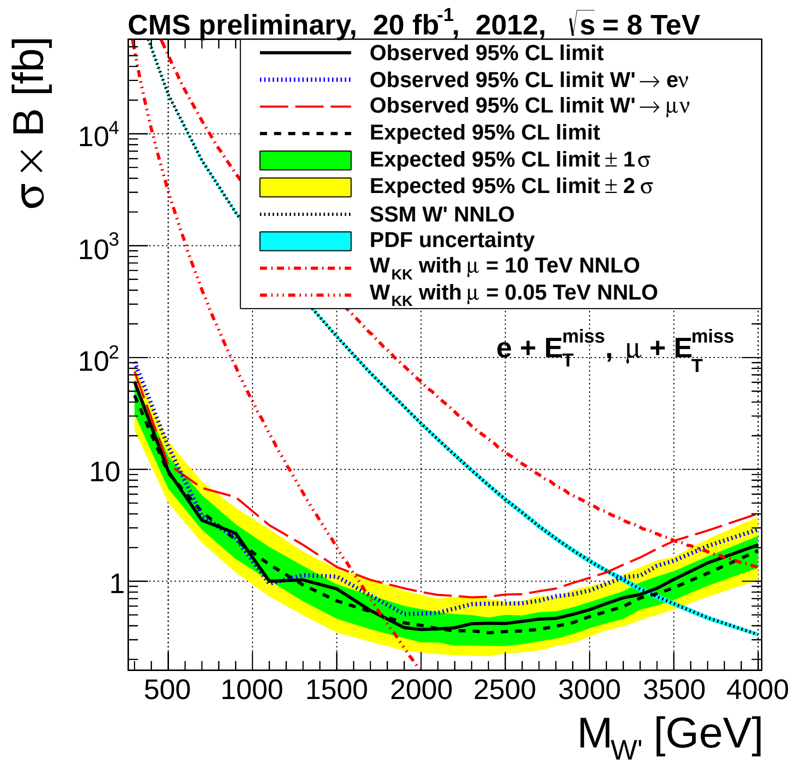
Look for Jacobian peak on falling M_T *distribution:*

$$M_T = \sqrt{2 \cdot p_T{}^l \cdot E_T^{miss} \cdot (1 - \cos \Delta\phi_{l,\nu})}$$

[EXO-12-060]







☞ Background prediction given by MC

➠ fit to background with empirical function: $f_{M_T} = \frac{a}{(M_T^3 + bM_T + c)^d}$

SM-like couplings: $m_{W',SSM} > 3.35$ TeV

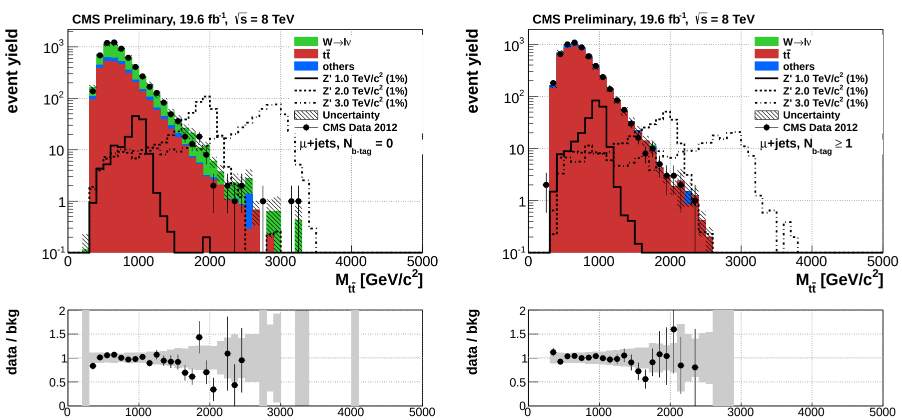
UED second KK excitation (W^2_{KK}): $m > 1.7(3.7)$ TeV for μ=0.05(10) TeV

No significant deviations from background expectation

[B2G-12-006]

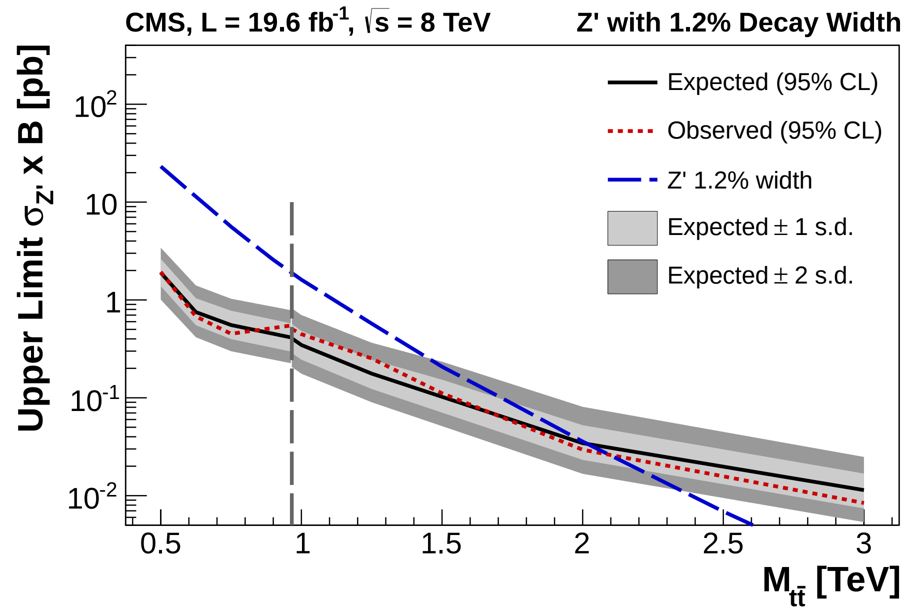
☞ Two dedicated searches:

- ➠ optimized for $t\bar{t}$ production at the kinematic production threshold
- ➠ optimized for $t\bar{t}$ production produced with high Lorentz boosts

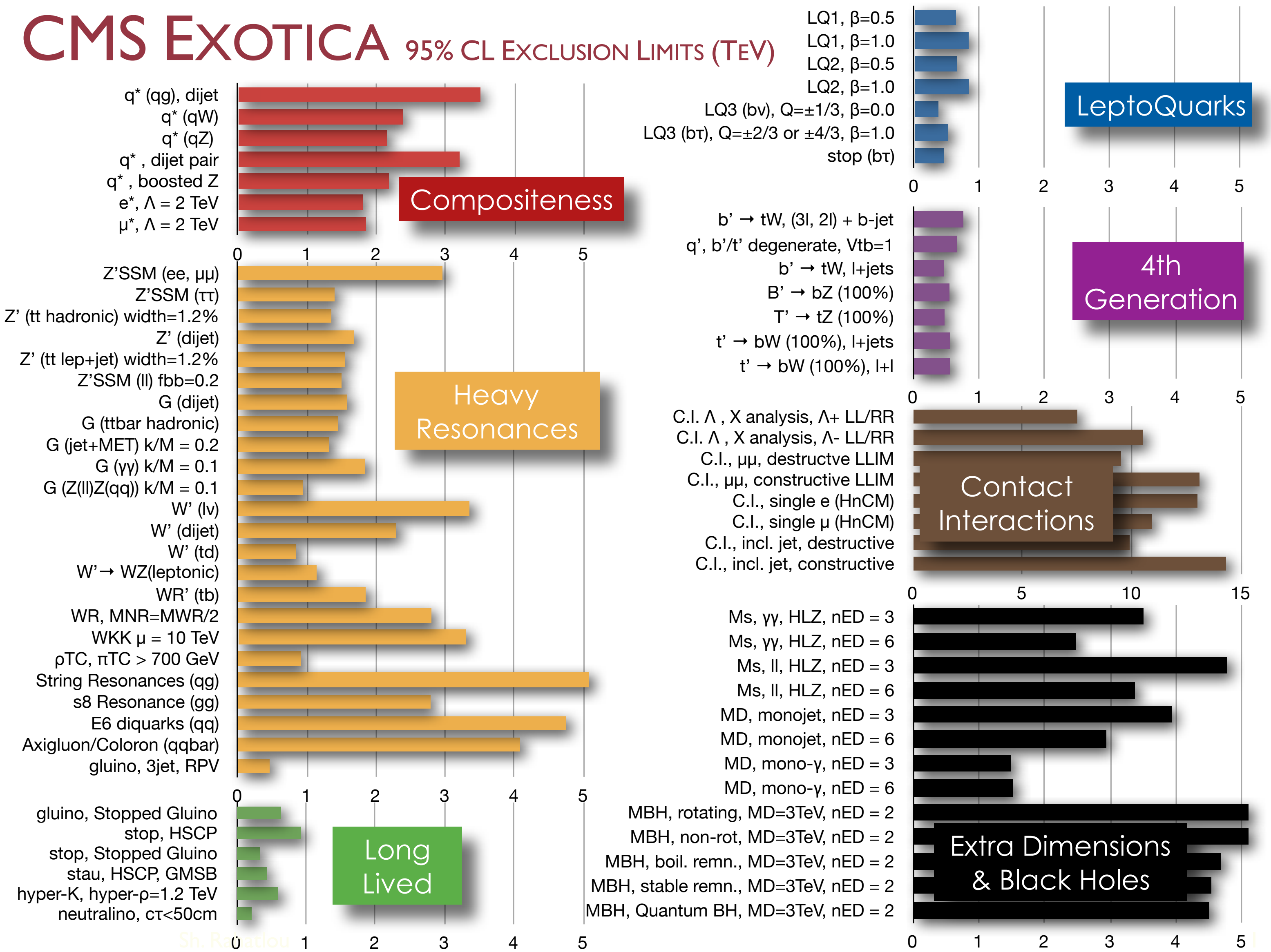


Data/MC agreement over many orders of magnitude: **no deviations from background estimate**

The 95% CL upper limits on production cross-section



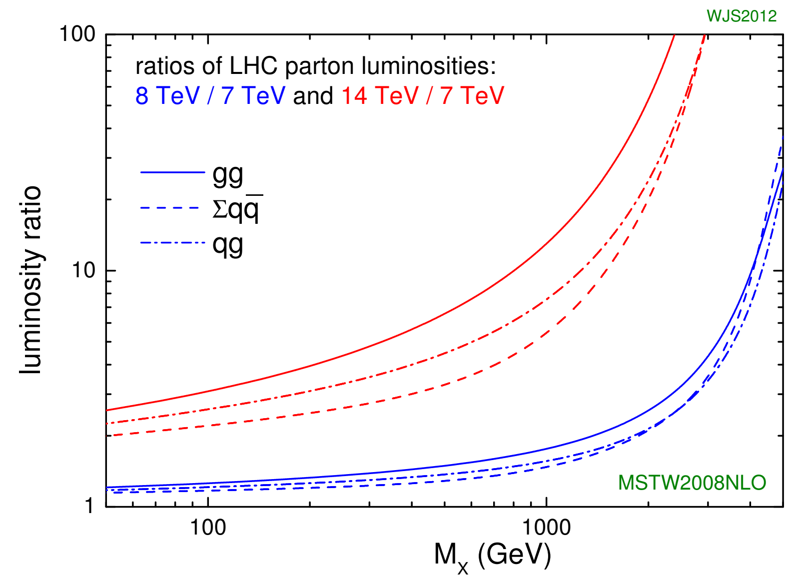
Topcolor Z', width 1.2%: $m_{Z'} > 2.10$ TeV
Topcolor Z', width 10%: $m_{Z'} > 2.68$ TeV
KK excitation of the gluon: $m_{g_{KK}} > 2.69$ TeV

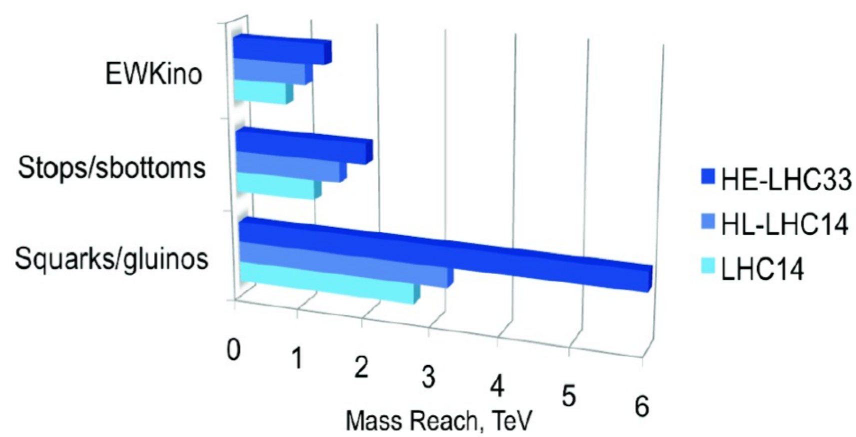

CMS EXOTICA 95% CL EXCLUSION LIMITS (TEV)
Compositeness
q* (qg), dijet
q* (qW)
q* (qZ)
q* , dijet pair
q* , boosted Z
e*, Λ = 2 TeV
μ*, Λ = 2 TeV
Heavy Resonances
Z'SSM (ee, μμ)
Z'SSM (ττ)
Z' (tt hadronic) width=1.2%
Z' (dijet)
Z' (tt lep+jet) width=1.2%
Z'SSM (ll) fbb=0.2
G (dijet)
G (ttbar hadronic)
G (jet+MET) k/M = 0.2
G (γγ) k/M = 0.1
G (Z(ll)Z(qq)) k/M = 0.1
W' (lv)
W' (dijet)
W' (td)
W'→ WZ(leptonic)
WR' (tb)
WR, MNR=MWR/2
WKK μ = 10 TeV
ρTC, πTC > 700 GeV
String Resonances (qg)
s8 Resonance (gg)
E6 diquarks (qq)
Axigluon/Coloron (qqbar)
gluino, 3jet, RPV
Long Lived
gluino, Stopped Gluino
stop, HSCP
stop, Stopped Gluino
stau, HSCP, GMSB
hyper-K, hyper-ρ=1.2 TeV
neutralino, cτ<50cm
LeptoQuarks
LQ1, β=0.5
LQ1, β=1.0
LQ2, β=0.5
LQ2, β=1.0
LQ3 (bv), Q=±1/3, β=0.0
LQ3 (bτ), Q=±2/3 or ±4/3, β=1.0
stop (bτ)
4th Generation
b' → tW, (3l, 2l) + b-jet
q', b'/t' degenerate, Vtb=1
b' → tW, l+jets
B' → bZ (100%)
T' → tZ (100%)
t' → bW (100%), l+jets
t' → bW (100%), l+l
Contact Interactions
C.I. Λ , X analysis, Λ+ LL/RR
C.I. Λ , X analysis, Λ- LL/RR
C.I., μμ, destructve LLIM
C.I., μμ, constructive LLIM
C.I., single e (HnCM)
C.I., single μ (HnCM)
C.I., incl. jet, destructive
C.I., incl. jet, constructive
Extra Dimensions & Black Holes
Ms, γγ, HLZ, nED = 3
Ms, γγ, HLZ, nED = 6
Ms, ll, HLZ, nED = 3
Ms, ll, HLZ, nED = 6
MD, monojet, nED = 3
MD, monojet, nED = 6
MD, mono-γ, nED = 3
MD, mono-γ, nED = 6
MBH, rotating, MD=3TeV, nED = 2
MBH, non-rot, MD=3TeV, nED = 2
MBH, boil. remn., MD=3TeV, nED = 2
MBH, stable remn., MD=3TeV, nED = 2
MBH, Quantum BH, MD=3TeV, nED = 2
0 1 2 3 4 5
0 5 10 15

Explored a very vast range of masses, parameters, signatures
... but let us leave no stone unturned

- **It is to early put away a new physics at the TeV-scale**
  - always assumptions involved to derive "absolute" SUSY limits (Simplified Model)
  - limits decrease if assumptions are given up
  - a lot of room to look for more signatures and models
- **LHC reuse with ≃13-14 TeV will be a new game**
  - significant step toward both **small couplings** and **large masses**
  - improve sensitivity on **mass scale about x2** with respect to 8 TeV searches

Parton Luminosities:
rise due to steep fall-off of the lower energy PDF at large x





Summary

- **Vigorous update of the main results with the full statistics is available**
- **The boson that we found looks rather "standard" scalar at first sight**
  - fermionic final states starting to build up excess
  - **data disfavor the pseudo-scalar 0^- and spin-2 hypotheses**
  - couplings are in agreement within uncertainties with the SM predictions
- **Focusing on the 3rd Generation SUSY $\rightarrow$ no evidence for SUSY**
  - searches for **"light"** sbottom/stop target **"natural" SUSY** scenarios
    - ➔ probe stops **m(stop) $\geq$ 650 GeV**
    - ➔ probe gluinos **m(gluino) $\geq$ 1300 GeV**
    - ➔ probe sbottoms **m(sbottom)$\geq$ 600 GeV**
  - RPV searches target multileptons and low MET signature
- **Broad array of Dark Matter and heavy resonance searches**
  $\rightarrow$ no evidence for BSM signal

Overall we see so far is very well compatible with the Standard Model

The "14" TeV revamp of LHC will enable us to probe heavier particles, and potentially open up a new realm of Particle Physics

Backup

☞ **Exclusion:**

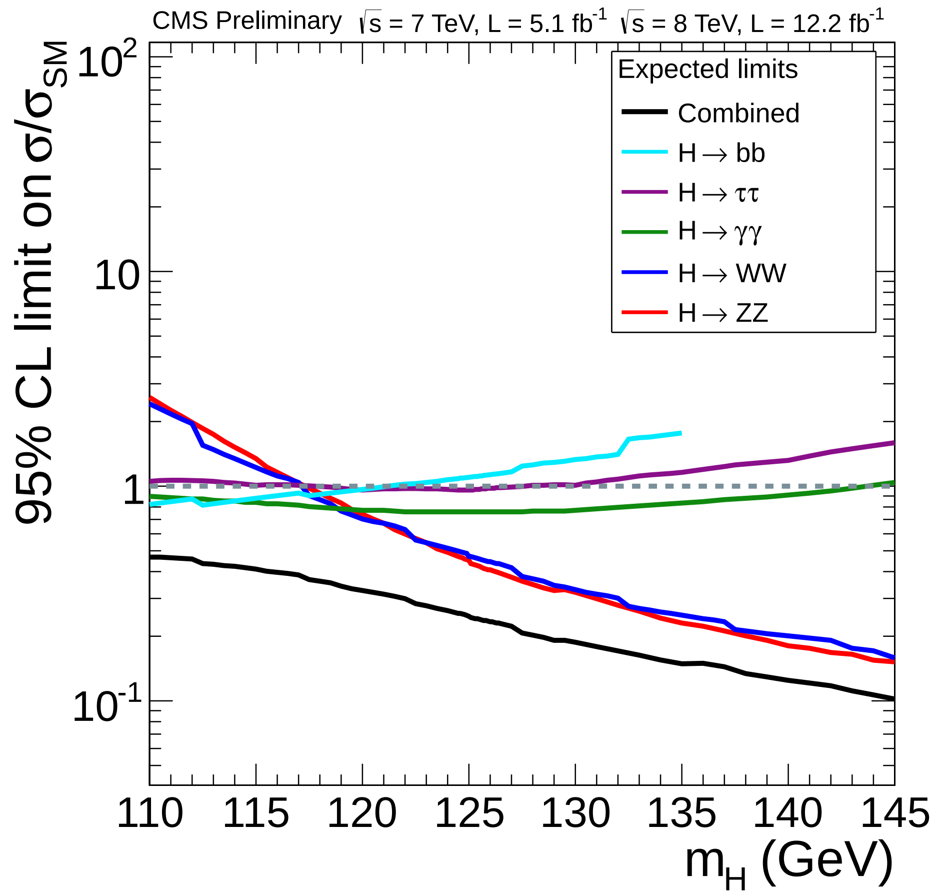
$$q_\mu = -2\log\frac{\mathcal{L}(data|\mu s(m_H)+b)}{\mathcal{L}(data|\hat{\mu} s(m_H)+b)}$$

$$\mu = \frac{\sigma(m_H)}{\sigma_{SM}(m_H)}$$

- CLs measures compatibility of the data with HIGGS hypothesis
- if CLs=0.05 the signal hypothesis is excluded at the 95% CL

☞ **Blind analysis in 2012**

- all selection criteria in the analyses were fixed before looking at the result in the signal region



The five decay modes have comparable sensitivities for exclusion in low mass region

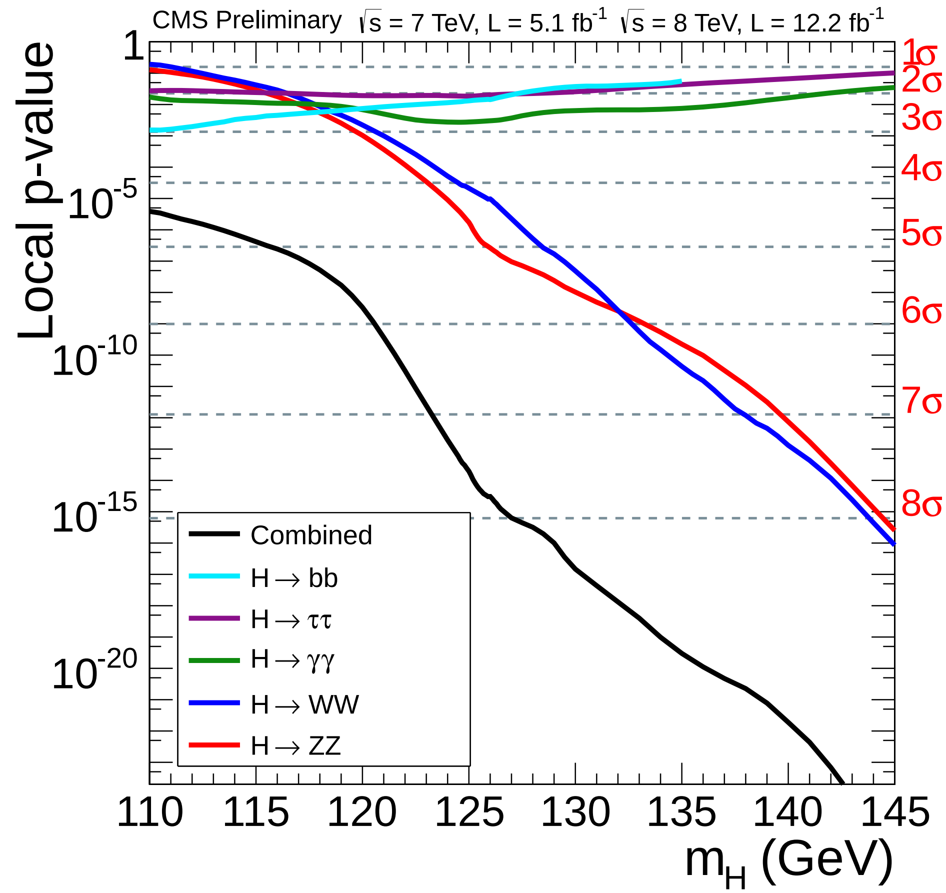
- **P-values:**

$$q_0 = -2 \log \frac{\mathcal{L}(data|b)}{\mathcal{L}(data|\hat{\mu}s(m_H)+b)}$$

  - p_0 measures the compatibility of the data with NO-HIGGS hypothesis

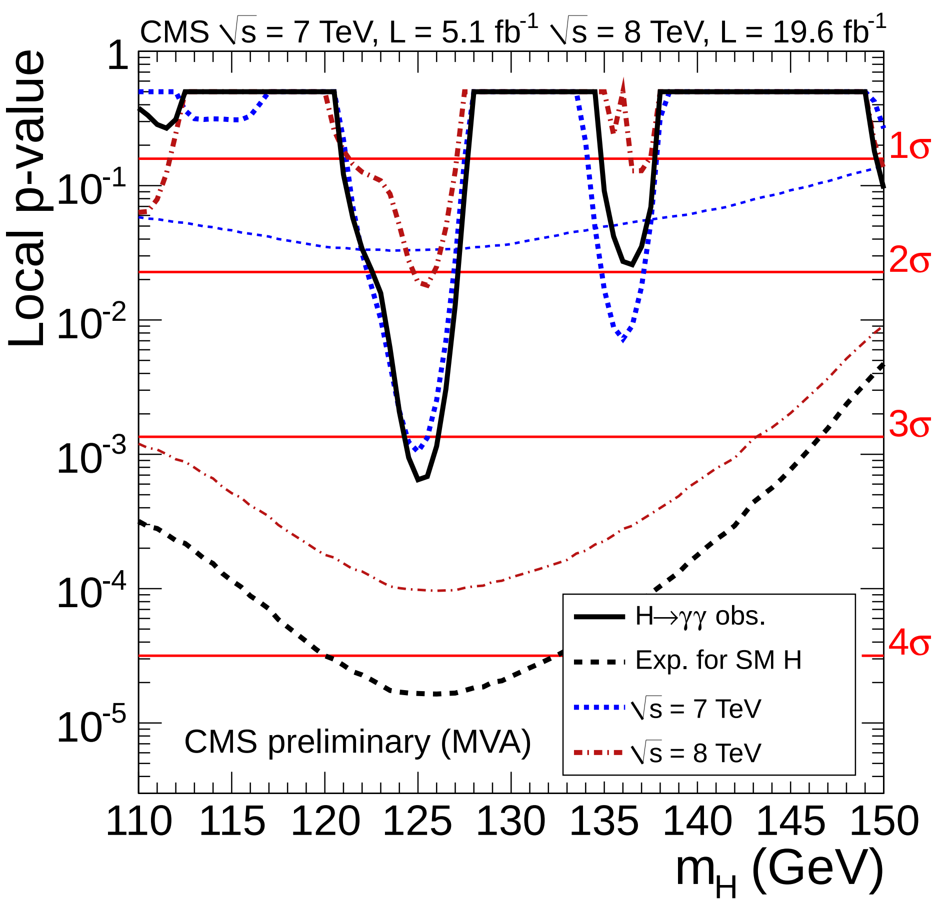
$$Prob(q_0 > q_0^{obs}|m_H)$$

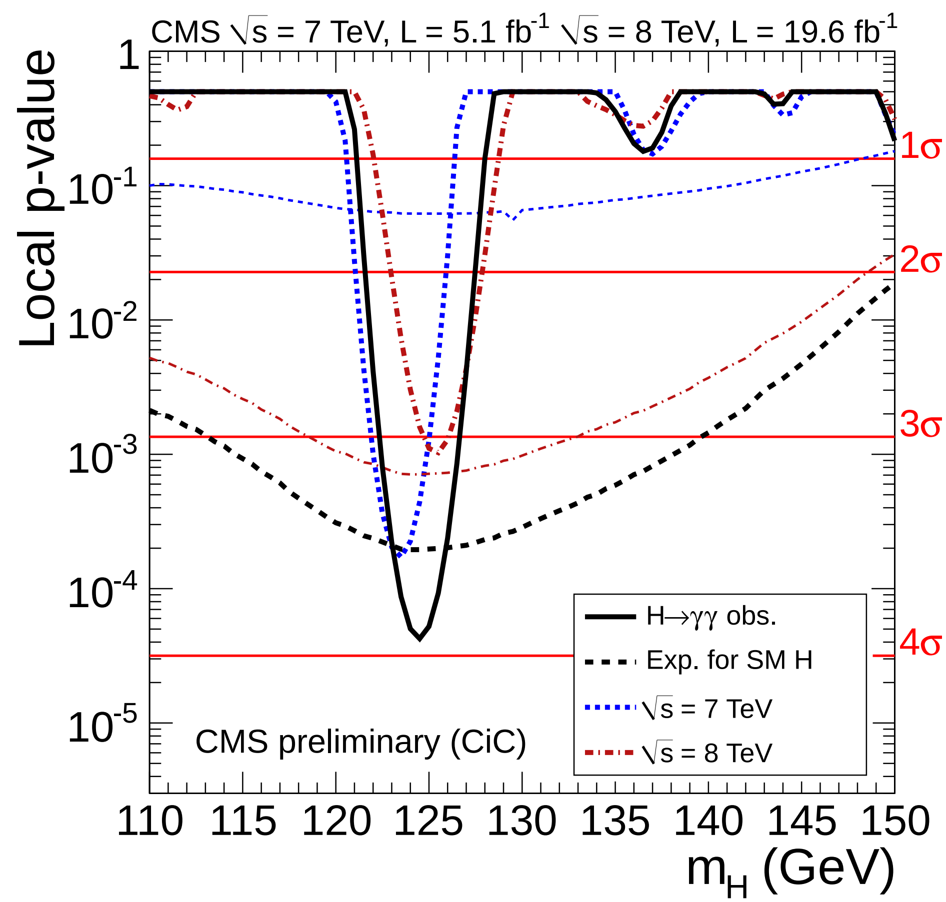
- **Very rich mass region but also very challenging...**
  - 5 decay modes exploited: $\gamma\gamma, ZZ, WW, \tau\tau, bb$
  - 2 best mass resolution decay modes: $\gamma\gamma, ZZ$



$H \to \gamma\gamma$ dominates in sensitivity for discovery below 120 GeV while $H \to ZZ$ above 120 GeV

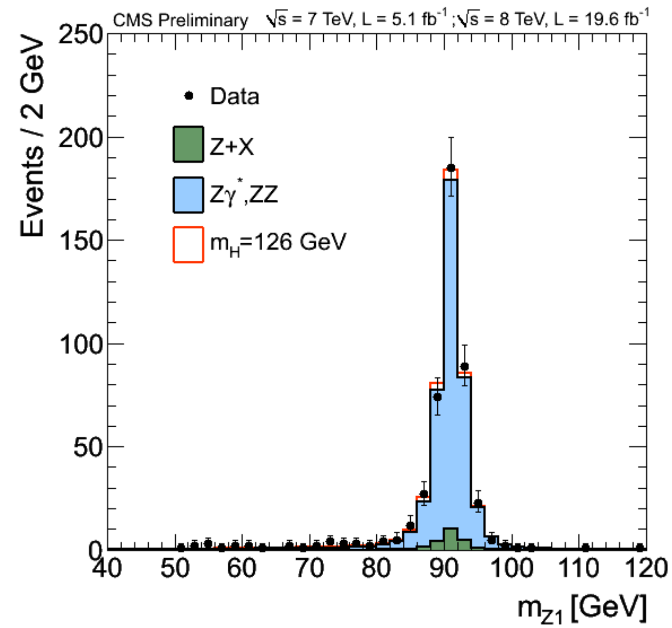
$H \to \gamma\gamma$: P-Value and Significance

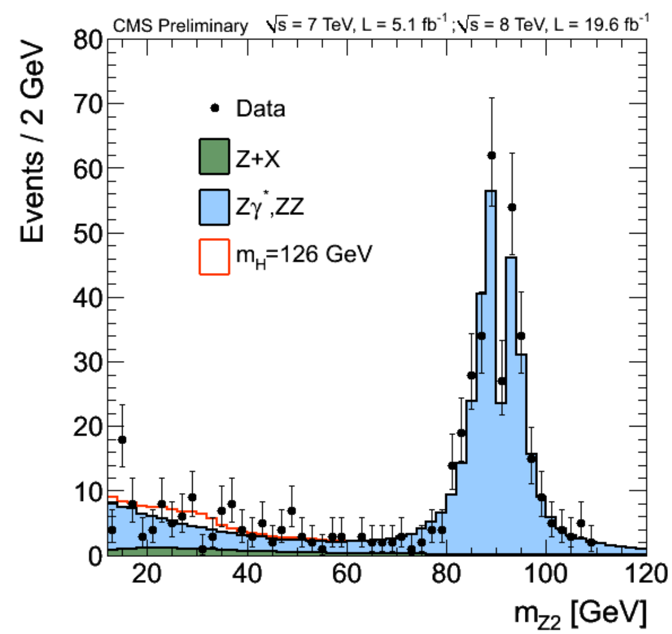


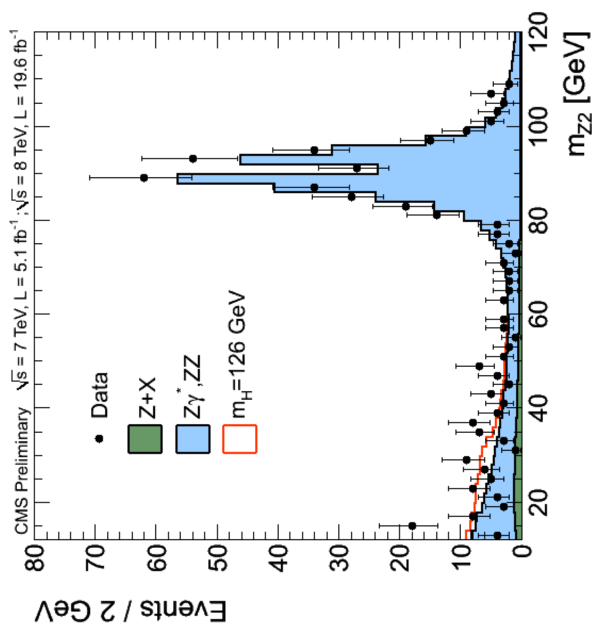


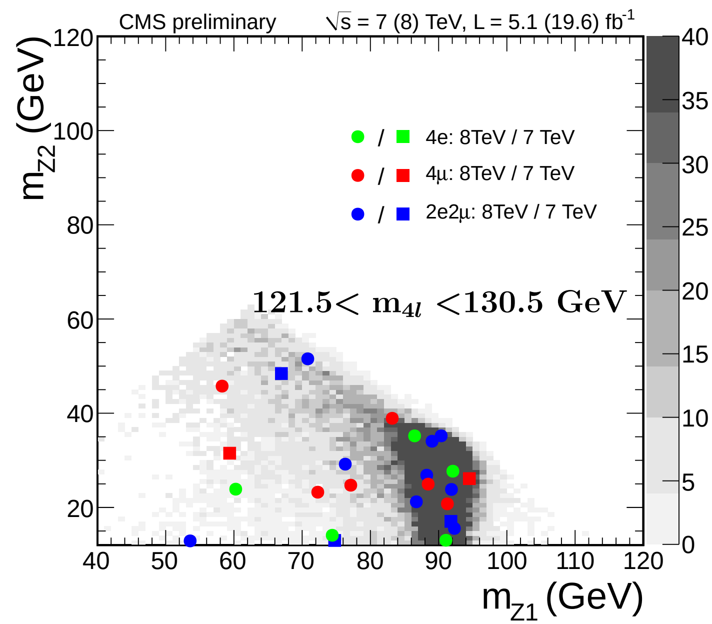
Excess around 125 GeV appears consistently in 7 and 8 TeV data

- **Trigger:** di-lepton signatures (ee, $e\mu$ or $\mu\mu$)
- Lepton selection
  - muons: $p_T > 5\,\text{GeV}$, $|\eta| < 2.4$
  - electrons: $p_T > 7\,\text{GeV}$, $\eta < 2.5$
  - isolated, compatible with PV
- Final State Radiation (FSR) recovery algorithm
  - applied on each Z for photons near the leptons
  - 6% events affected, 2% added in analysis
- Form Z from opposite-sign and same flavor pairs:
  - **first Z candidate (Z1)**
    - ➔ chosen as pair with $m(ll)$ closest to m_Z
    - ➔ apply: $40 < m(ll) < 120\,\text{GeV}$
  - **second Z candidate (Z2)**
    - ➔ build from remaining highest p_T leptons
    - ➔ apply: $12 < m(ll) < 120\,\text{GeV}$

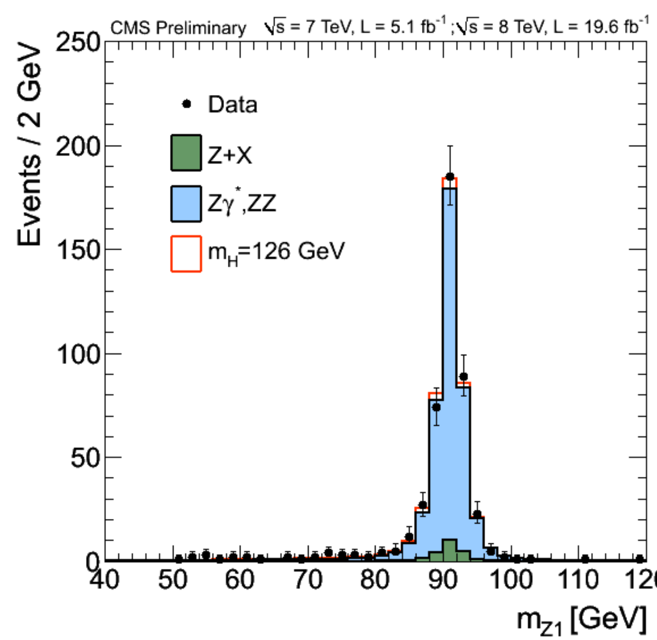






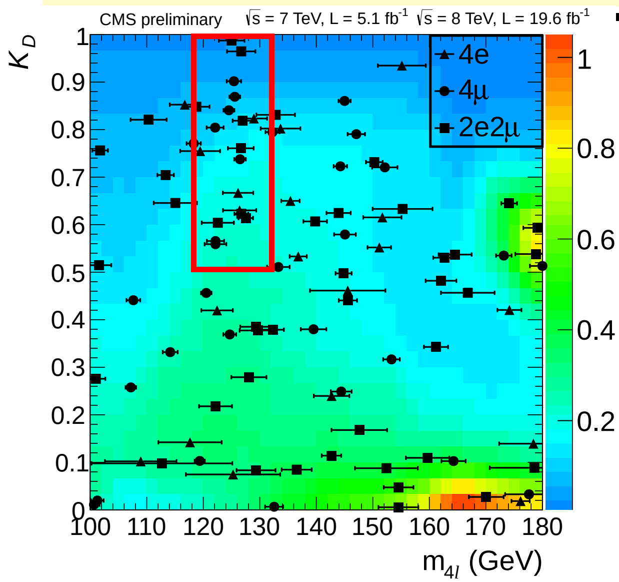


☞ Peak around 125 GeV got more significant with extra 7 fb^{-1} of data

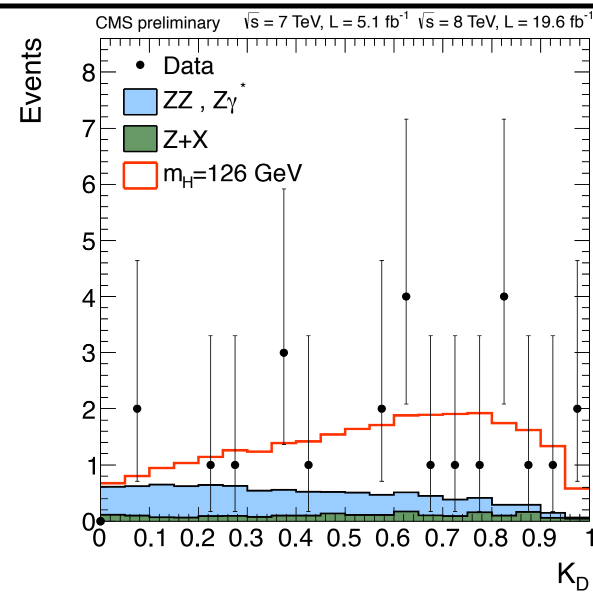


m_{Z1} versus m_{Z2} scatter plot looks as expected: Z2 is off-shell

$H \to ZZ^{(*)} \to 4l$: *Statistical Analysis*

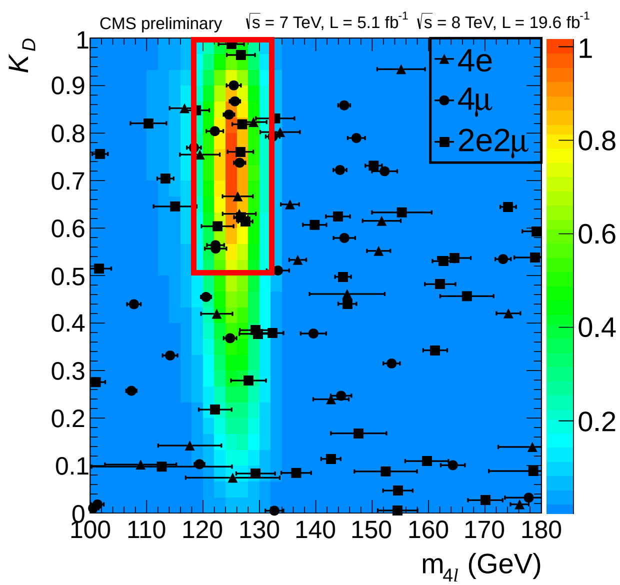


data wrt background expectation

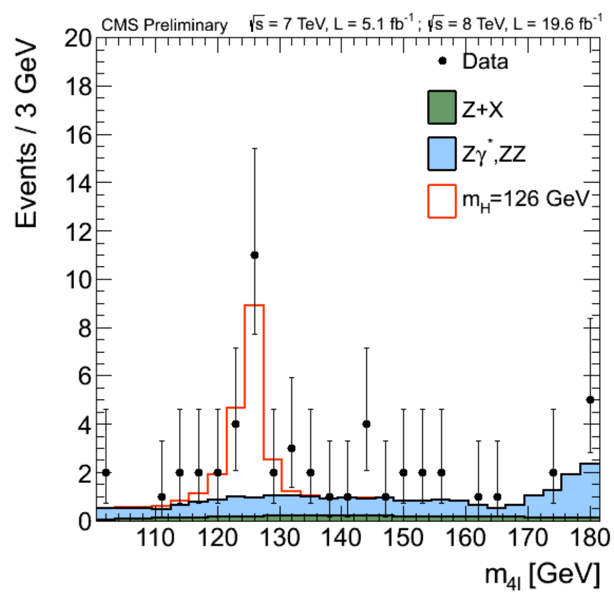


Analysis performed using a 2D fit of likelihood discriminant and m(4l)

for illustration:
MELA projection in m(4l) 121.5-130.5 GeV

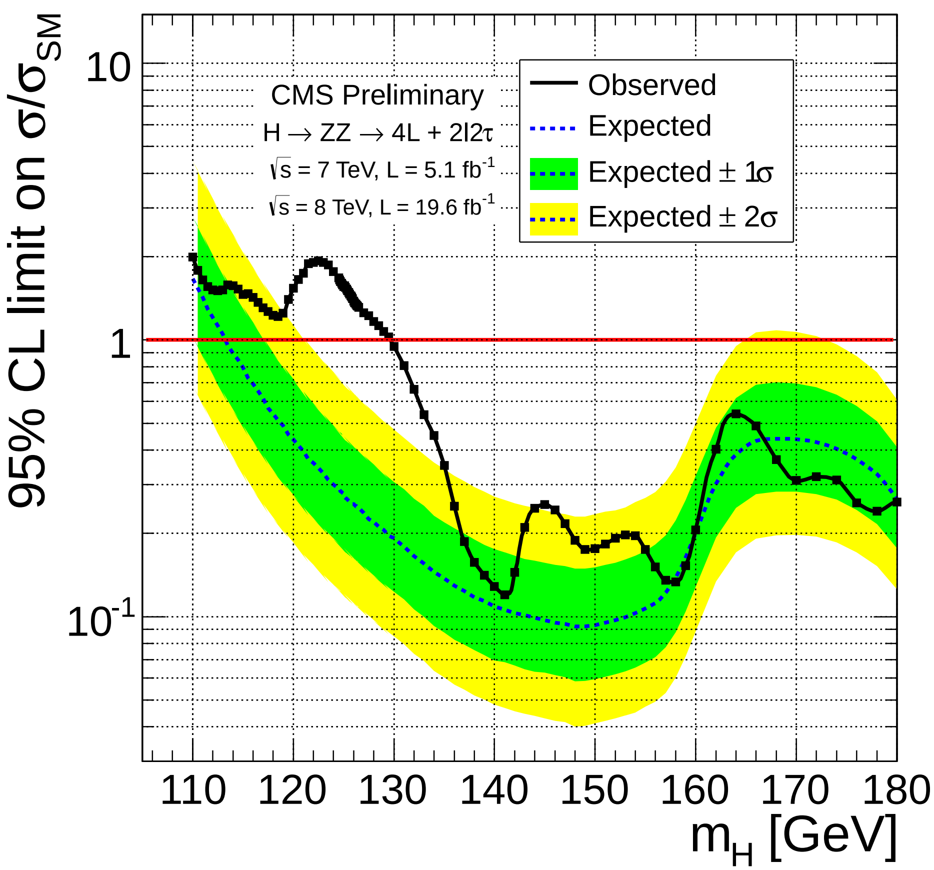


data wrt signal (m_H=126 GeV) exp.

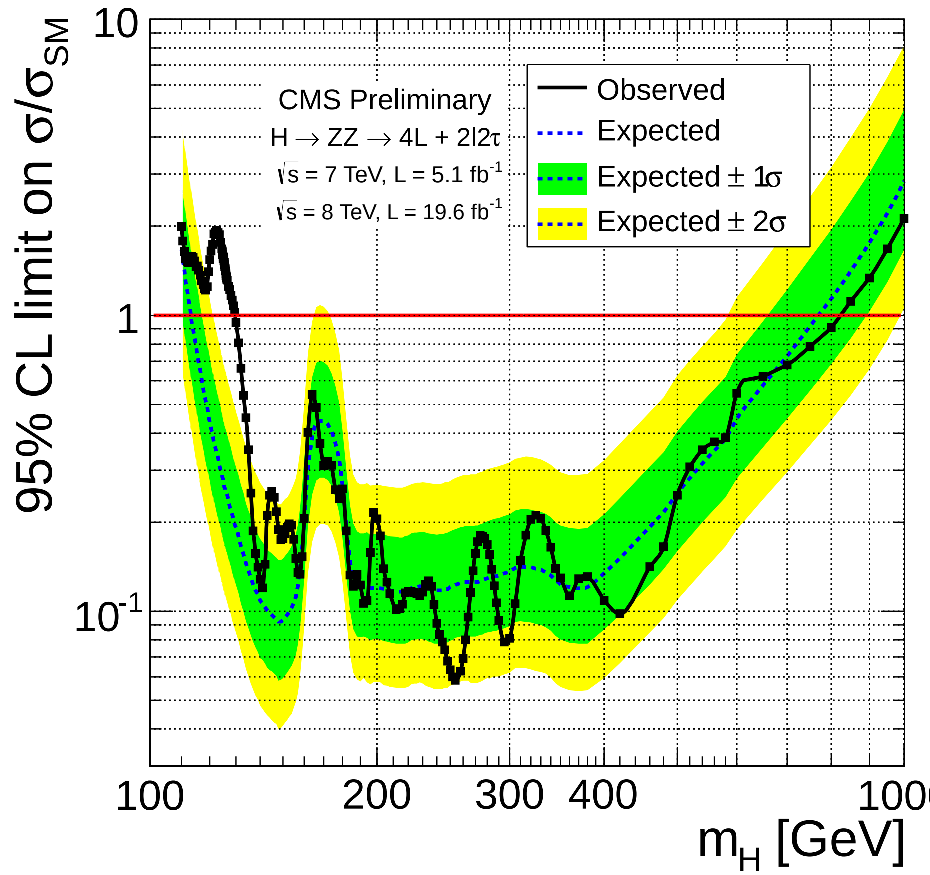


for illustration:
m(4l) with cut MELA>0.5

Zoomed mass range



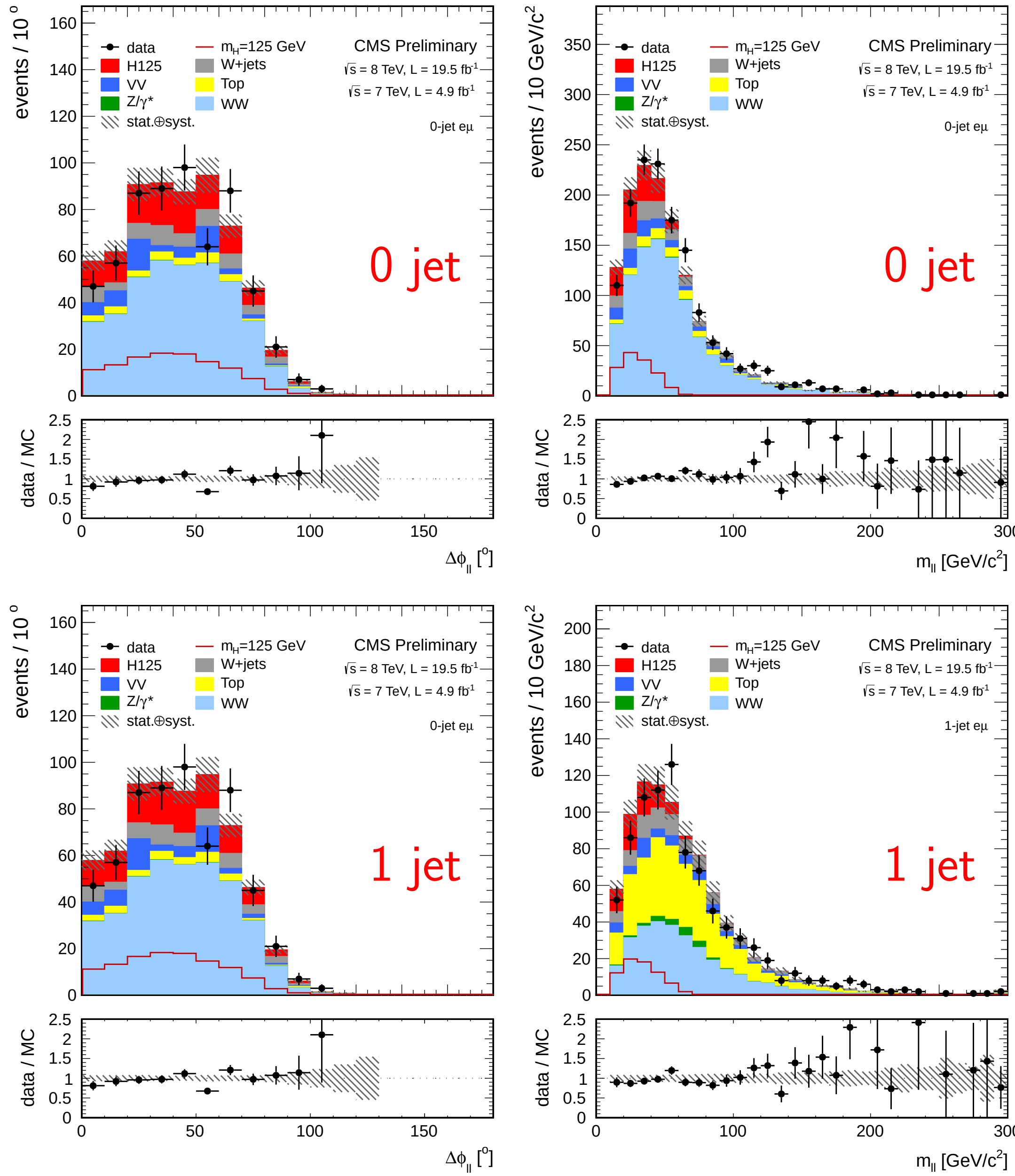
Full mass range



Expected exclusion at 95% CL: 117-760 GeV

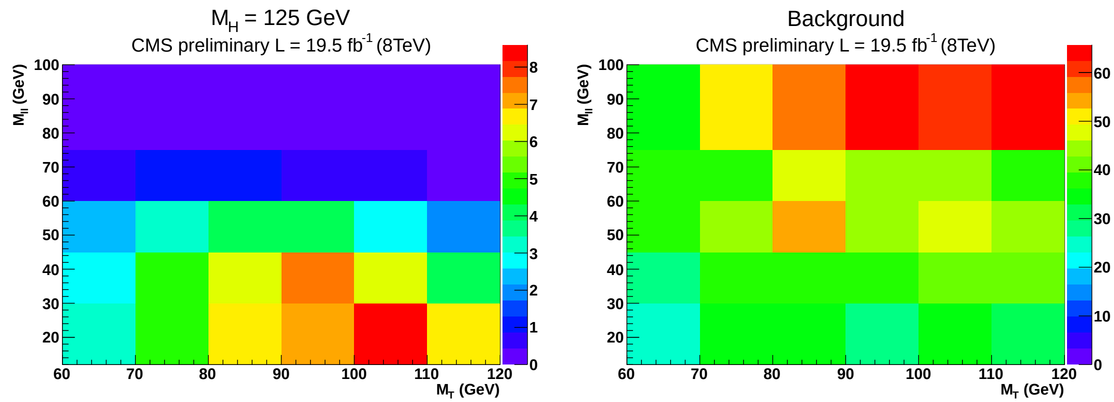
Observed exclusion at 95% CL: 129-810 GeV

Two main kinematic variables: $\mathbf{\Delta\phi_{ll}}$ and $\mathbf{m(ll)}$

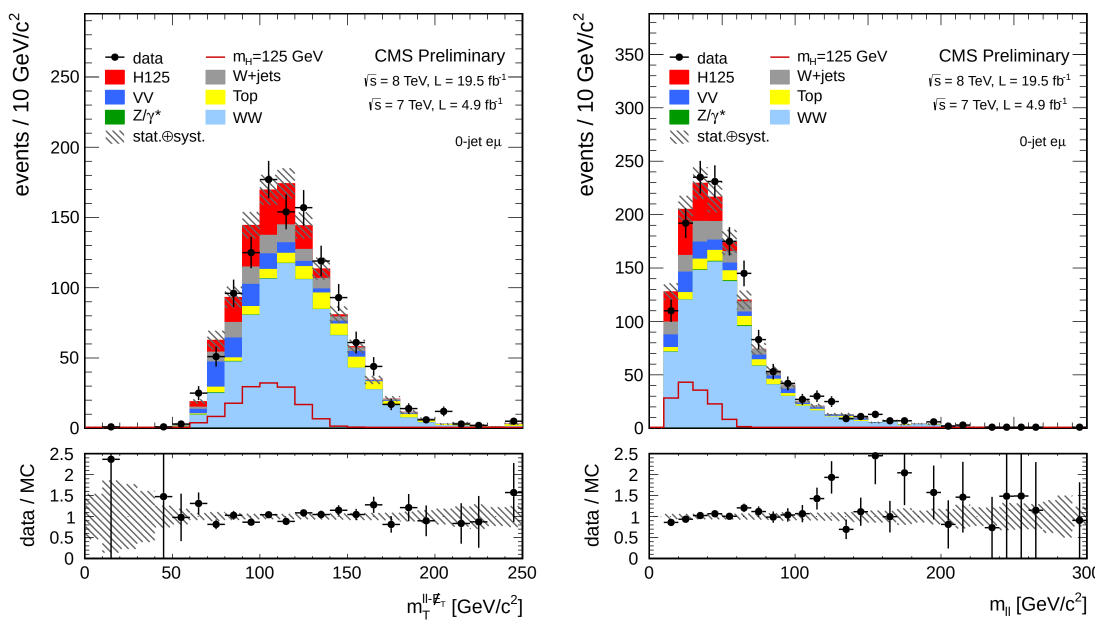


- Event classification
  - **0/1 jet and VBF**
  - final state lepton flavors
- Data driven bkg. estimation:
  - **W+jets**: fake rate measured in QCD enriched data sample
  - **DY**: normalized in Z mass
  - **Top**: b-tagging efficiency measured in top control region in data
  - **WW**: extrapolate from background enriched region of the phase space

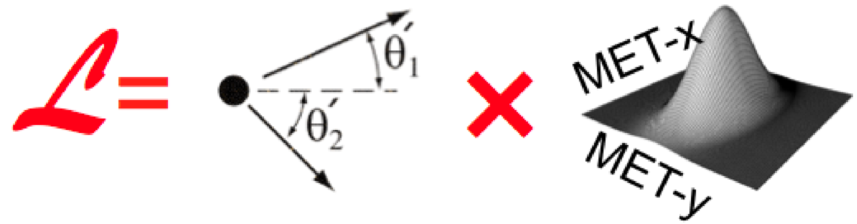
2D kinematic variables: $m_T^{ll-E_T^{\text{miss}}}$ and m(ll)



- ☞ Event classification
  - 0/1 jet and VBF
  - final state lepton flavors
- ☞ **Different flavor (DF) are most sensitive categories**
- ☞ 8 TeV data with new 2D shape analysis
  - **DF with 0/1 jet**
  - shape analysis (m_{ll}, m_T)

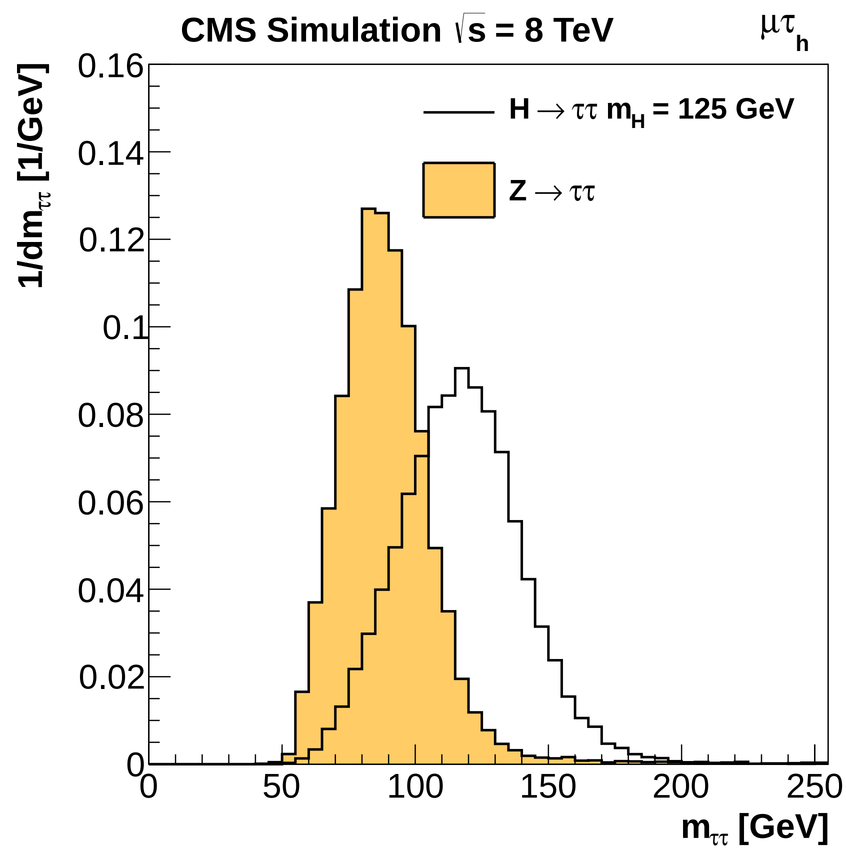


	0-jet	1-jet	2-jet
DF	2D shape	2D shape	cut&count
SF	cut&count	cut&count	cut&count



☞ **Full $m(\tau\tau)$ reconstruction**

- event-by-event estimator of true $m(\tau\tau)$ likelihood
  - ➔ Inputs: 4-vectors of visible products and x- and y-components of E_T^{miss}
  - ➔ Matrix Element used for $\tau \to l\nu\nu$
  - ➔ Phase-Space is used for $\tau_h \to \pi$



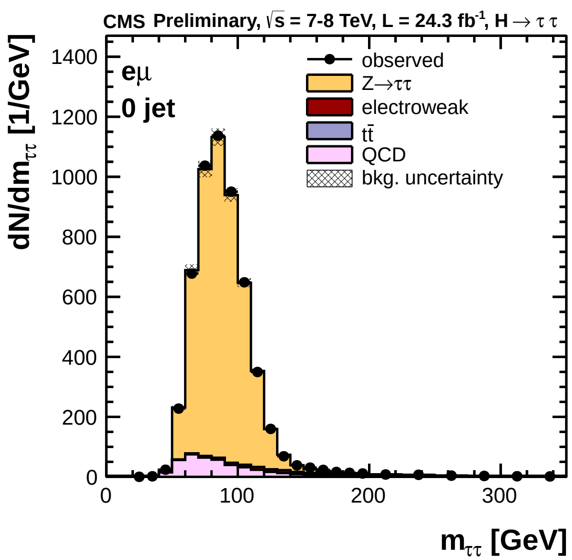
☞ Mass peaks at true value

- **20% improved resolution** with respect to visible mass
- better separation of H from Z

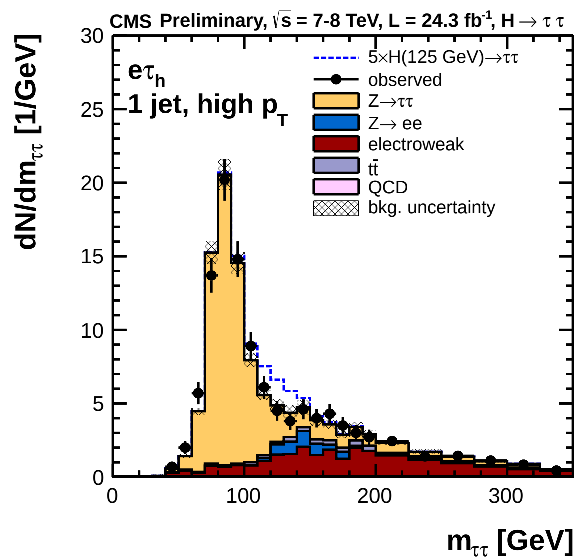
Di-tau mass resolution 15-20%

Events are classified according to jet multiplicity

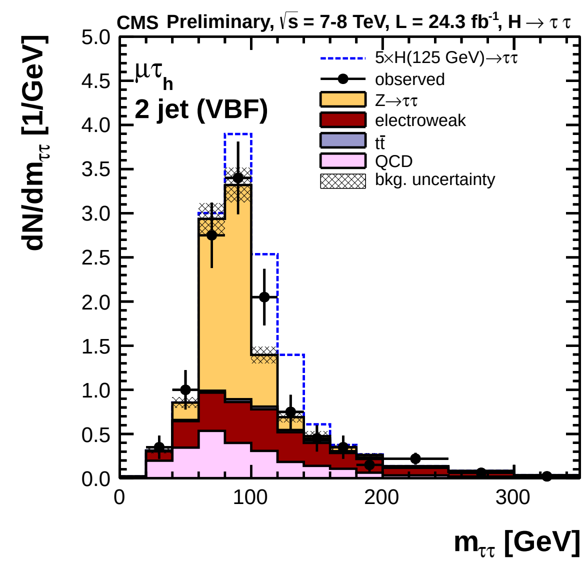
(all categories are fit simultaneously)



0 jet



1 jet



VBF

- No attempt to extract signal from this category
  - constrains fit energy scales and efficiencies
- Enhanced sensitivity to ggH production
  - improved resolution
  - splitting into low and high p_T categories
- Enhanced sensitivity to VBF production
  - 2jets, rapidity gap
  - highest sensitivity for $m_H < 130\,\mathrm{GeV}$

☞ Event yields in different production times decay modes are self-consistent

☞ **Break down top-quark couplings from vector boson**

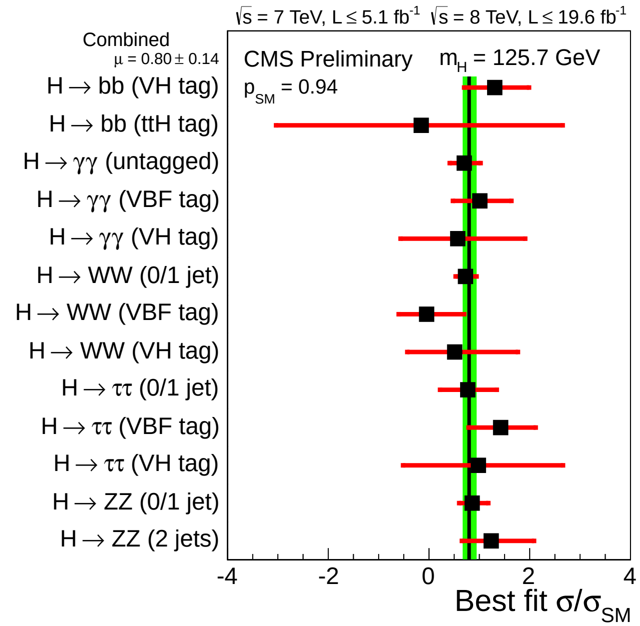
➠ assume the SM branching fractions

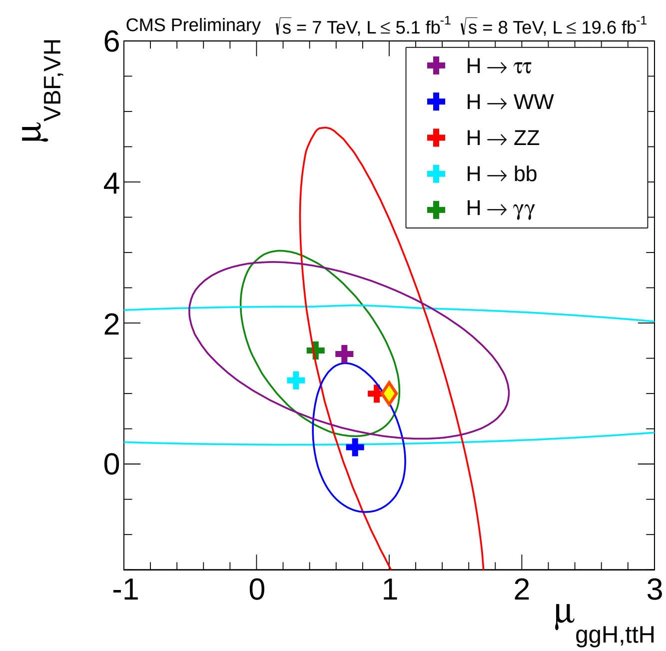
Current combination of channels

∨ updated analysis ∨ HCP analysis

	untagged	VBF-tag	VH-tag	ttH-tag
$H \to \gamma\gamma$	∨	∨	∨	
$H \to bb$			∨	∨
$H \to \tau\tau$	∨	∨	∨	
$H \to WW$	∨	∨	∨	
$H \to ZZ$	∨	∨		

Compatible with SM within 1σ for each decay channel: looks Higgs-like





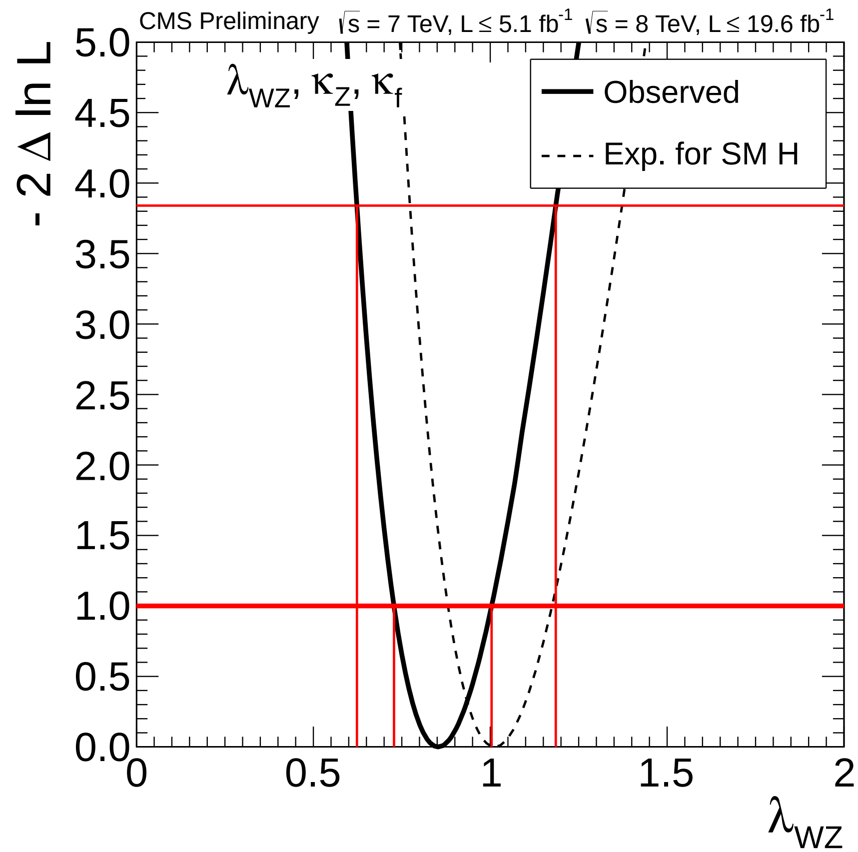
- Combination of "inclusive" WW (0/1jet) and ZZ yields gives the ratio of the Higgs couplings to WW and ZZ, g_W/g_Z, which is protected by **custodial symmetry**

$$\rho = \frac{M_W}{M_Z \cos\theta_W} = \frac{g_W}{g_Z \cos\theta_W} = 1$$

  - $\rho \neq 1$ **is possible in new physics models**

- Perform combination of all channels to assess $\lambda_{WZ} = k_W/k_Z$
  - likelihood scan versus 3 n.d.f.: λ_{WZ}, k_Z, and k_F gives

$\lambda_{WZ} = [0.62 - 1.19]$ at 95% CL



Consistent with the SM expectation

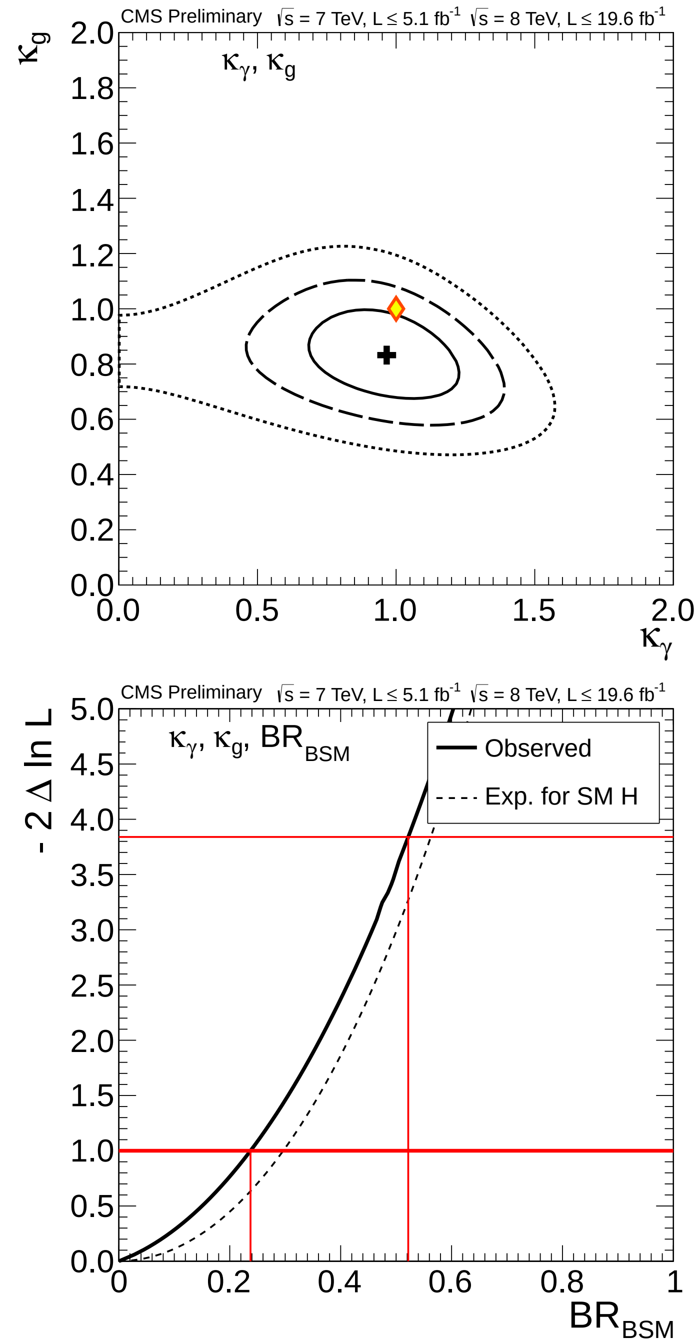
☞ New particles can modify the loop-mediated couplings and contribute to the total width

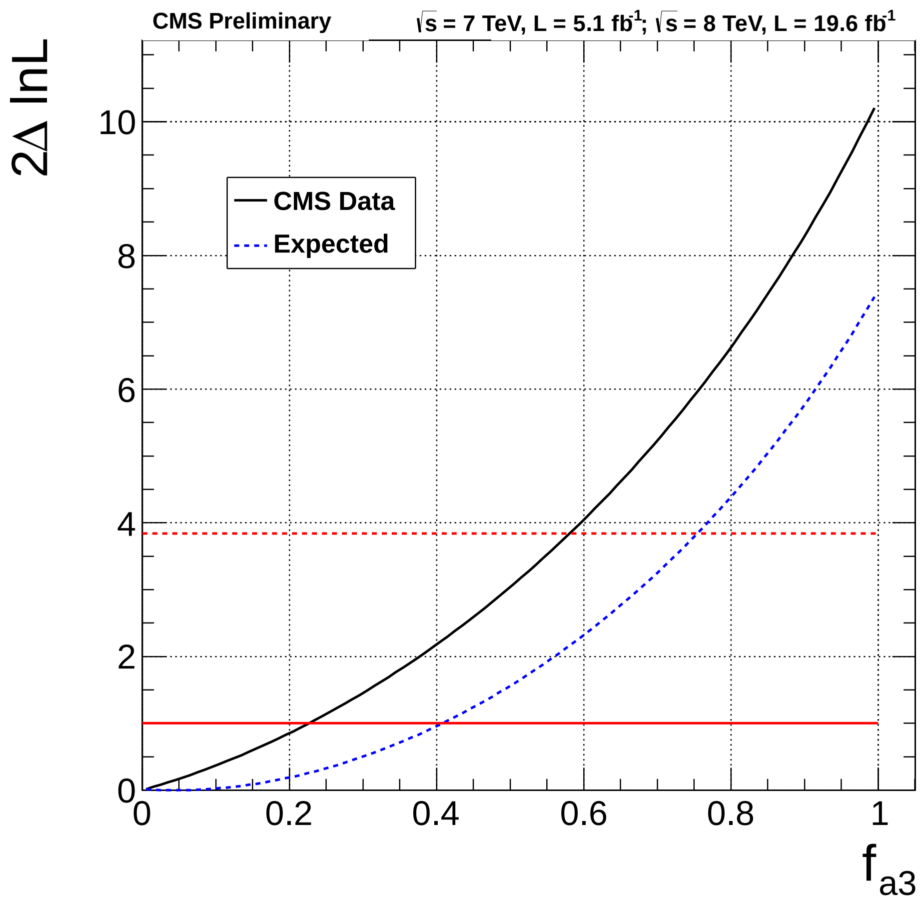
$$\Gamma_{tot} = \sum \Gamma_{i(SM)} + \Gamma_{BSM}$$

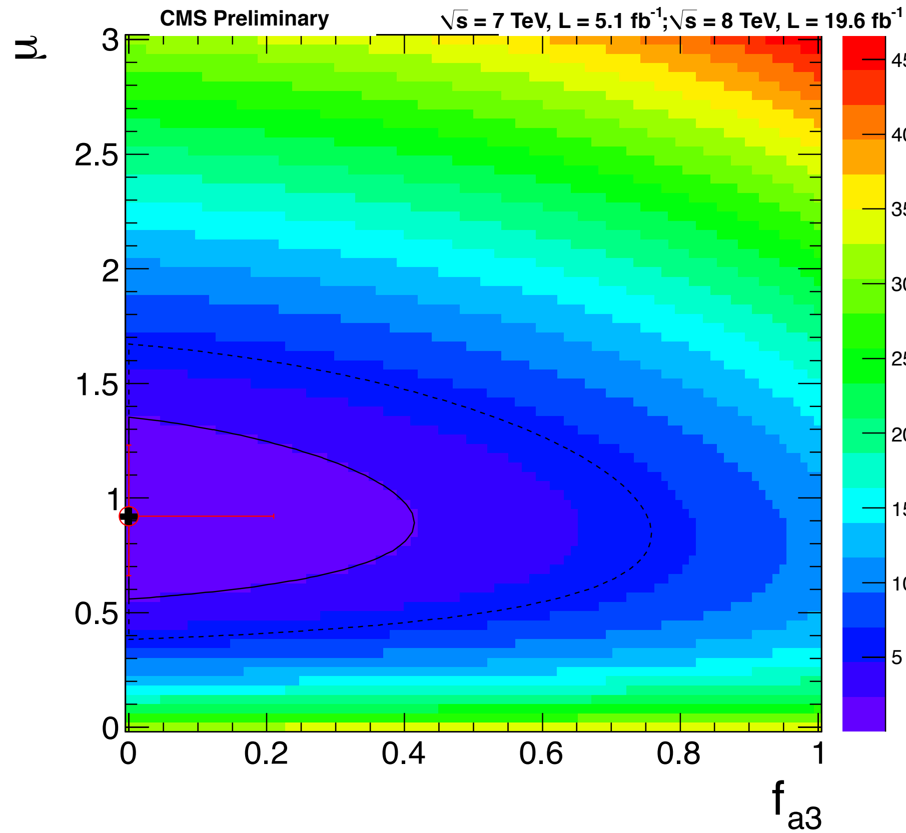
☞ Parametrize the photon and the gluon loops with effective scale factors (k_g,k_γ)

☞ Allow total width to scale as $1/(1\text{-}\mathcal{B}_{\text{inv}})$

No large invisible branching fraction







Expected separation between SM 0^+ and 0^- is 2σ

Fraction of CP-violating combination to the decay amplitude: $f_{a3} = 0^{+0.2}_{-0.0}$

Data disfavor $J^P = 0^-$ at 2.5σ ($< 3\%$ CL)

$J^P = 0^+$ is consistent with observation (0.6σ)

Spin-0 and 2 are only allowed by H→ $\gamma\gamma$ channel

☞ Discrimination between spin-0 and spin-2 is straightforward with WW and ZZ:

- currently WW heavily relies on spin-0 assumption
- WW is most significant (0-jet only)
- preliminary result with ZZ nonsensitive enough

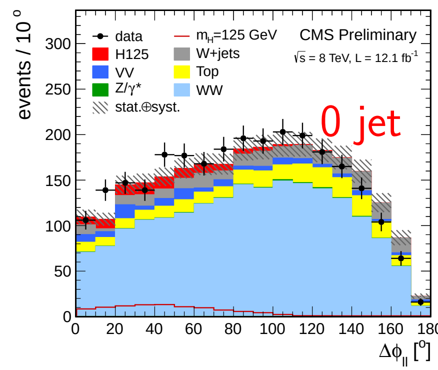
☞ H→ $\gamma\gamma$ is highly performing channel, but extremely damaging for acceptance

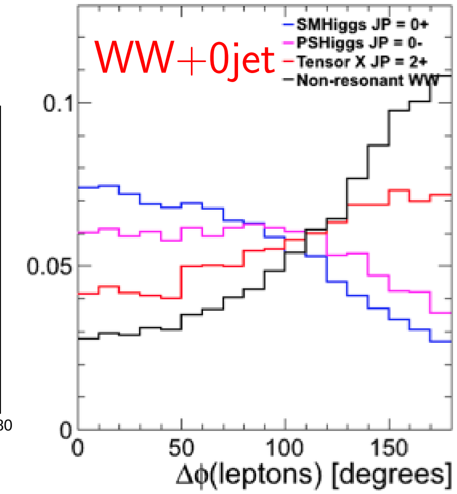
$$\frac{16}{5}\frac{d\sigma(X_{J=2}\to\gamma\gamma)}{\sigma d\Omega} \propto 1+\mathbf{A}\times\cos^2\theta^*+\mathbf{B}\times\cos^4\theta^*$$

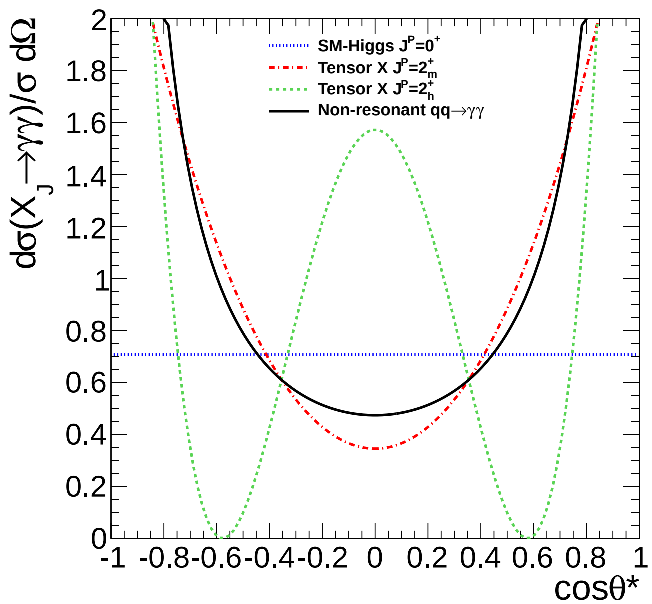
à la KK-graviton couplings $\mathbf{2^+_m}$: A=6, B=1

About 4σ separation before LHC shutdown combining 3 channels

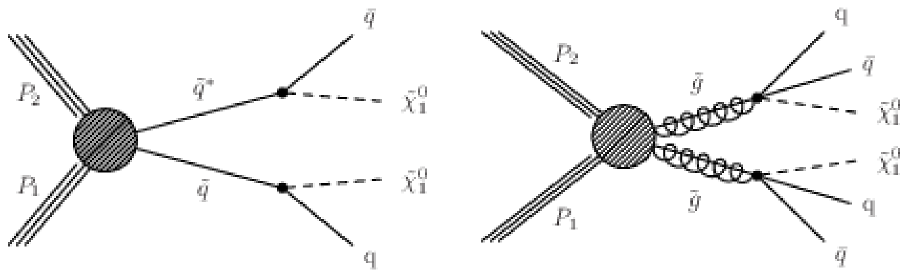
[arXiv:1208.4018]







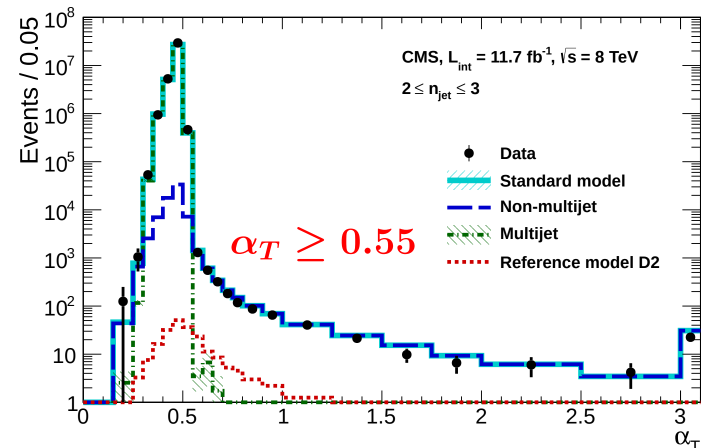
Discrimination gets diluted after application of analysis cuts and background inclusion

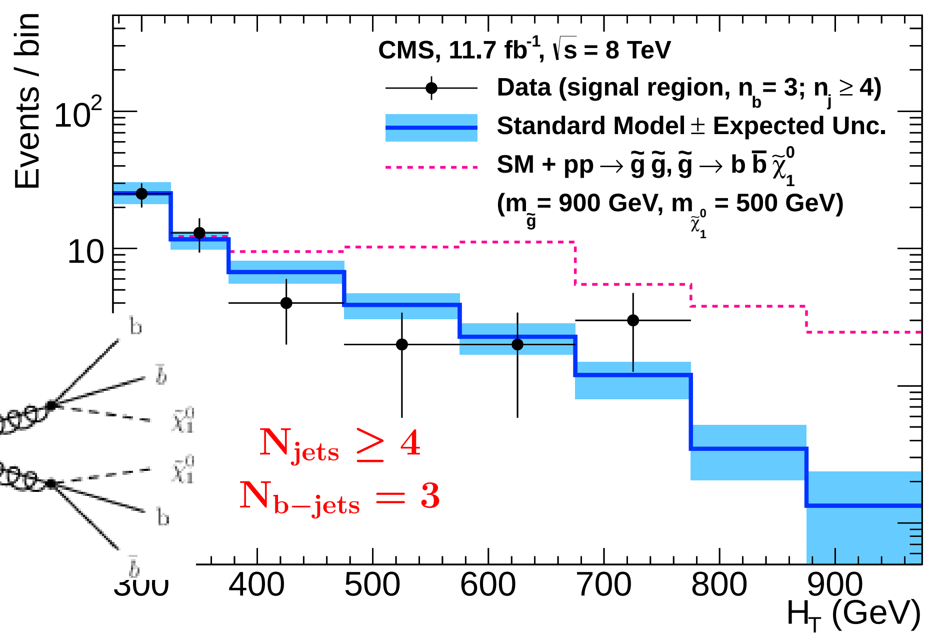


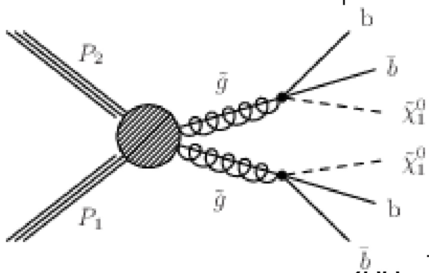
Dijet *Multijet*

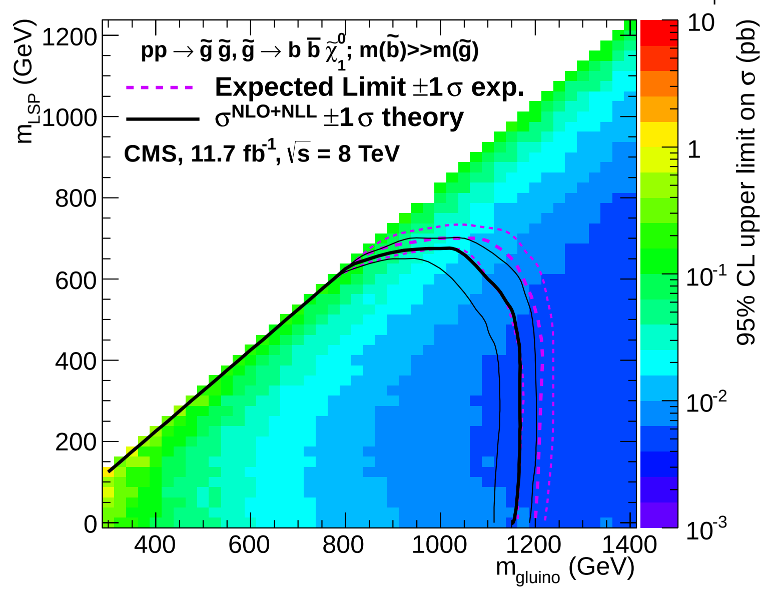
$$\boldsymbol{\alpha_T = \frac{E_T^{j2}}{M_T} = \frac{1}{2} \times \frac{1-(\Delta H_T/H_T)}{\sqrt{1-(\not{H}_T/H_T)^2}}}$$

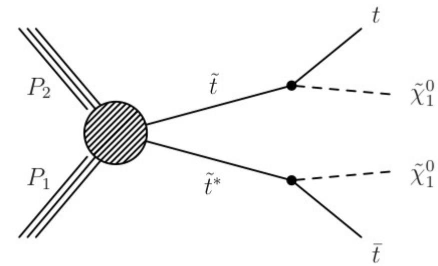
- ☞ Direct and gluino-mediated production of squarks
- ☞ **Hadronic final state:** $\geq$2 jets plus MET
  - ➠ event categorization by $\mathrm{H_T}$(>275 GeV), $\mathrm{N_{jets}}$ (2,3, $\geq$4) and $\mathrm{N_{b-jets}}$ (0,1,2,3, $\geq$4)





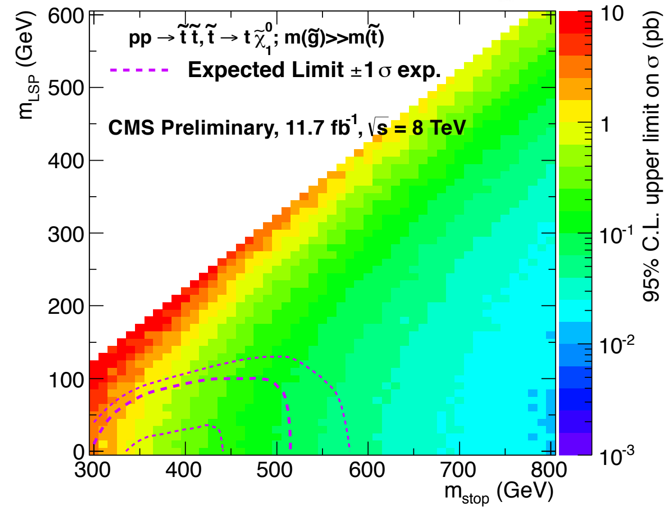






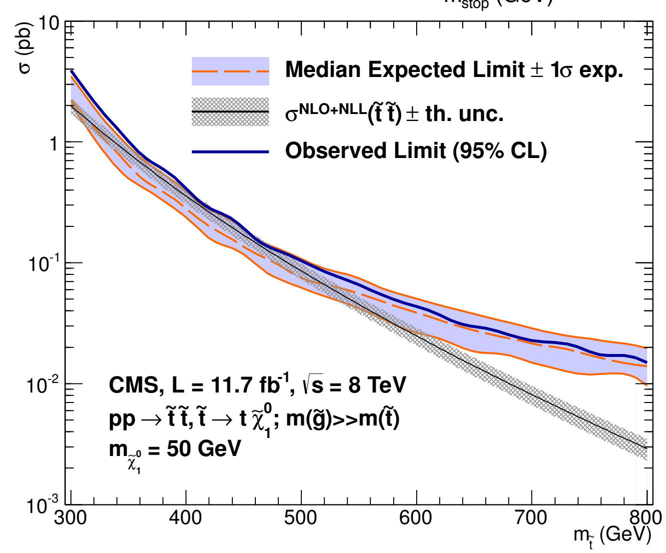
☞ Interpretations in 6 simplified models

- direct/gluino-mediated pair-production of $\tilde{q}$, $\tilde{b}$, $\tilde{t}$
- improve expected limits by ~200 GeV w.r.t. 7 TeV



Observed (expected) mass limits on parent sparticle and LSP

Model	m_{parent}	m_{LSP}
$pp \to \tilde{q}\tilde{q}^* \to qq\chi_1^0\chi_1^0$	775(850)	325 (350)
$pp \to \tilde{b}\tilde{b}^* \to bb\chi_1^0\chi_1^0$	600(675)	200 (250)
$pp \to \tilde{t}\tilde{t}^* \to tt\chi_1^0\chi_1^0$	-(520)	- (100)
$pp \to \tilde{g}\tilde{g} \to qqqq\chi_1^0\chi_1^0$	950(1050)	450 (550)
$pp \to \tilde{g}\tilde{g} \to bbbb\chi_1^0\chi_1^0$	1125(1200)	650 (700)
$pp \to \tilde{g}\tilde{g} \to tttt\chi_1^0\chi_1^0$	950(1075)	325 (325)



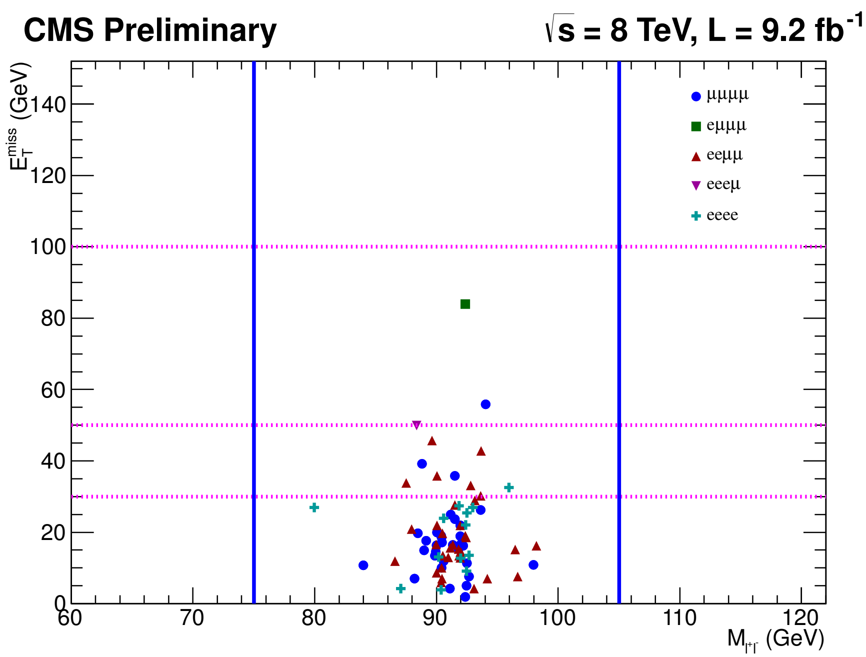
No observed exclusion for direct $\tilde{t}$ production:

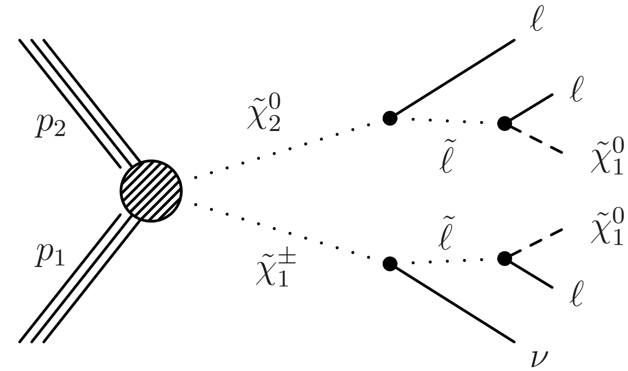
expect to exclude [320-500] GeV for $m_{\text{LSP}} = 50$ GeV

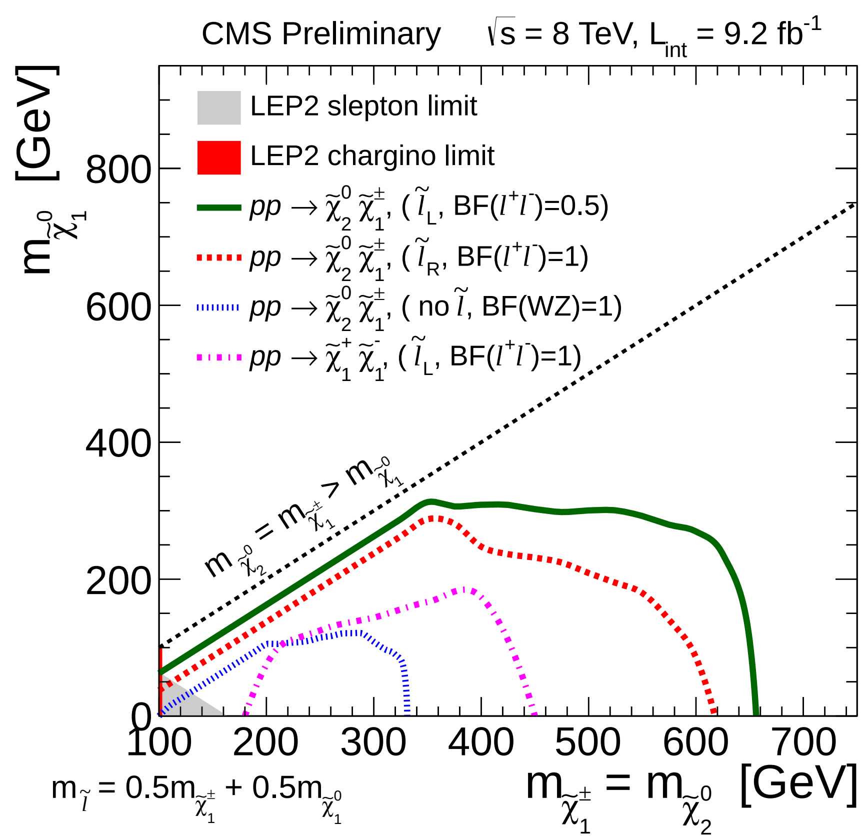
☞ 3 leptons plus MET: OSSF lepton pair, where the 3rd lepton is either e or μ

☞ 4 leptons plus MET: on-Z OSSF

Set limits on the direct production of *charginos, neutralinos, and sleptons*







Interpretation of the Z+dijet and 4-lepton analyses in gauge-mediated symmetry breaking (GMSB)

exclusion in terms of $\mu \simeq m_{\tilde{\chi}_1^\pm} \simeq m_{\tilde{\chi}_1^0}$

exclude $\mu < 370$ GeV at 95% CL