Recent results of the CMS experiment

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LIP Lisbon

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June 2013 - photo by
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Outline

- Data and pileup
- Higgs
- Jets and vector bosons
- Top physics
- Search for SUSY
- Other searches
- Future perspectives

CMS Detector

CMS DETECTOR

Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

STEEL RETURN YOKE
12,500 tonnes

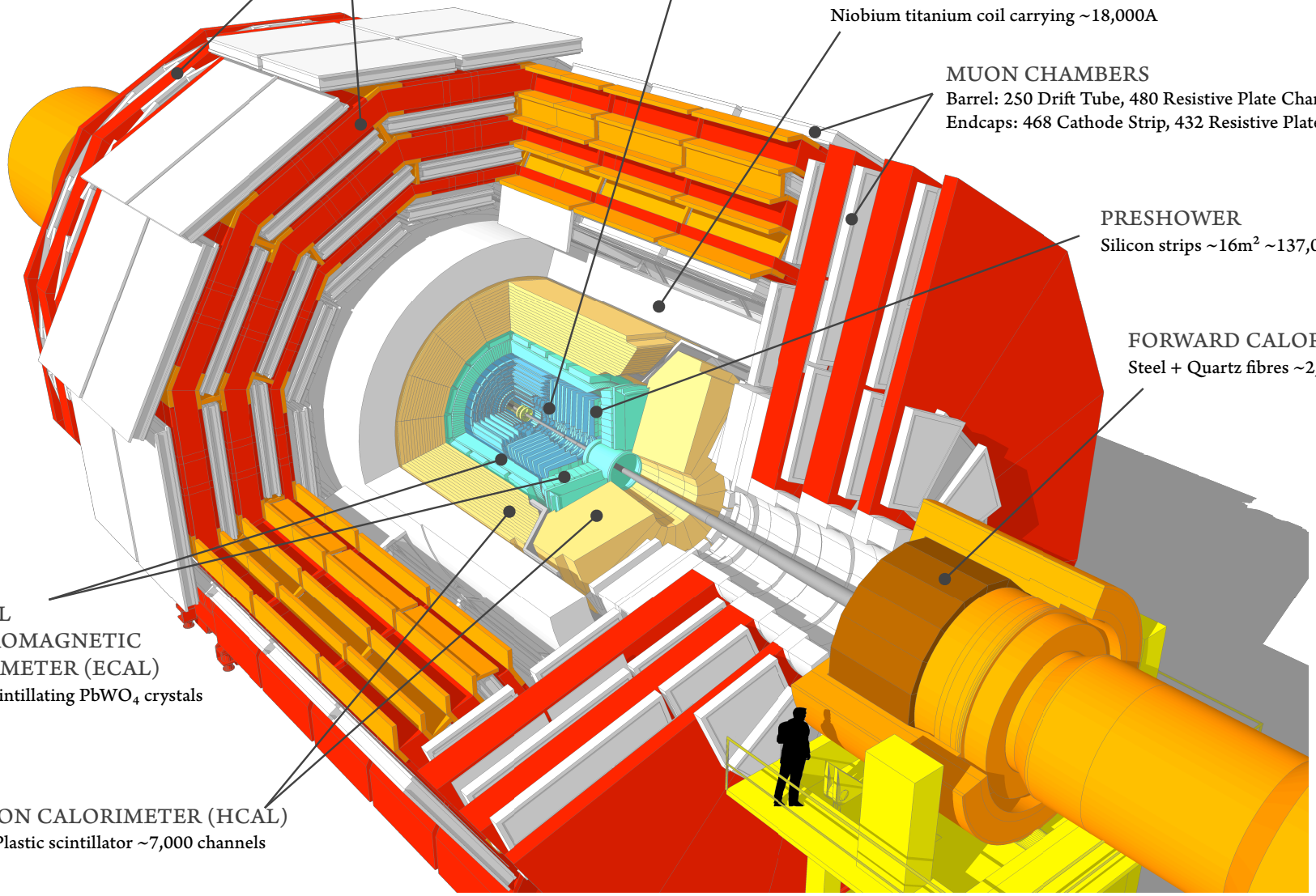
SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A

MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER
Silicon strips ~16m² ~137,000 channels

FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels

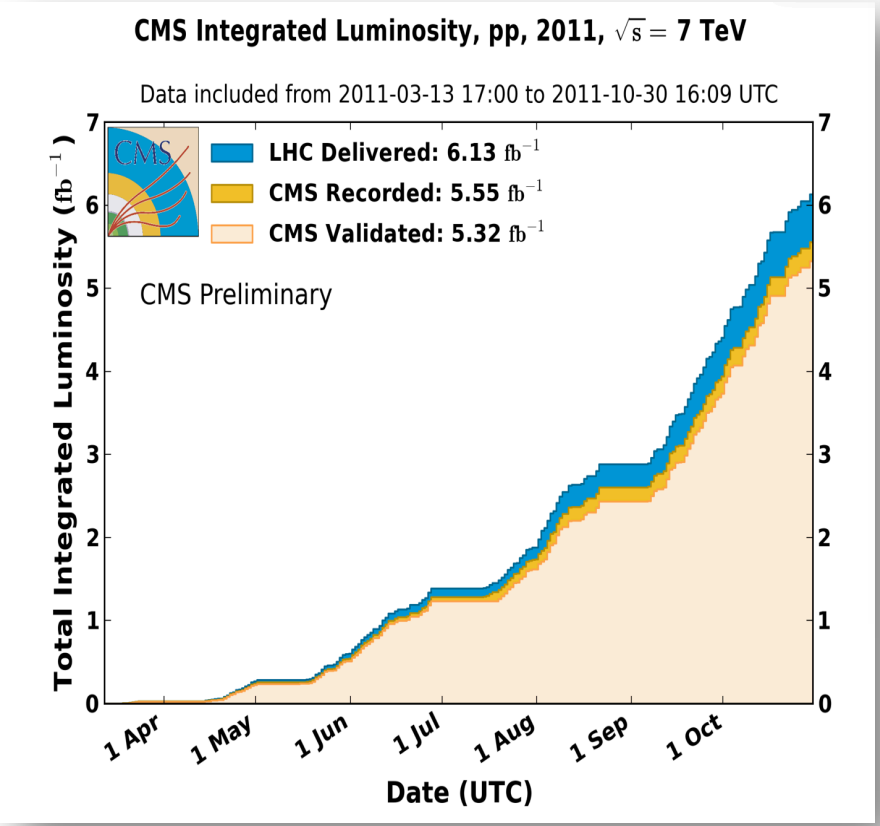


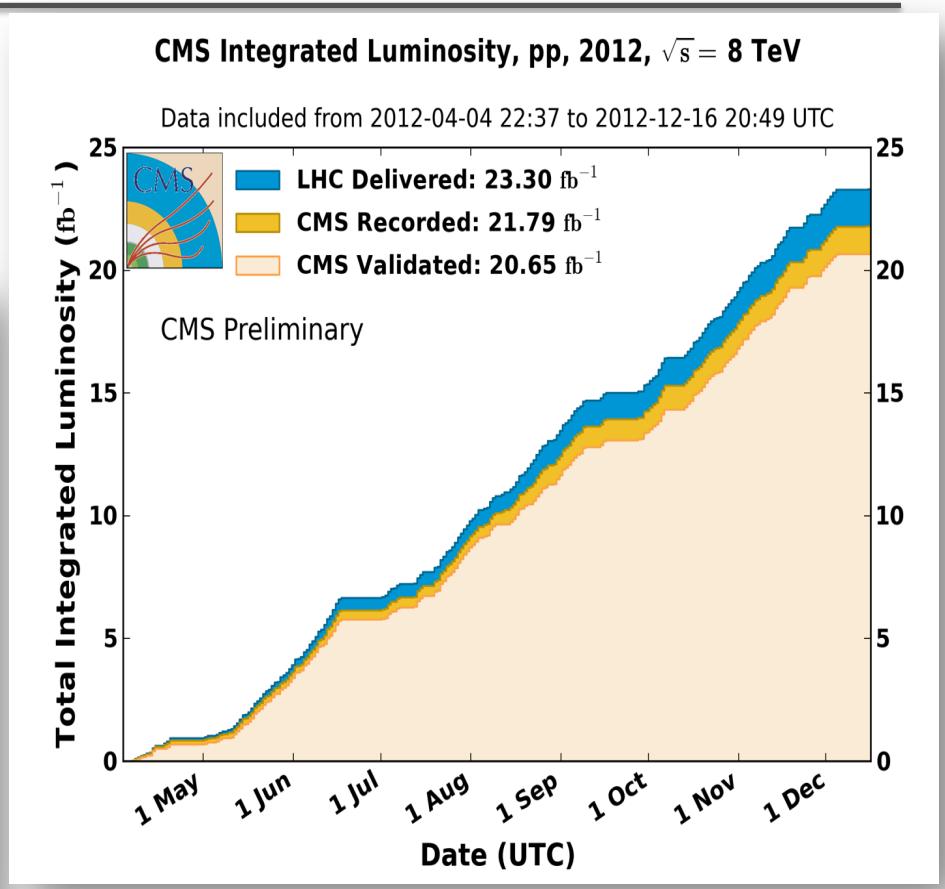
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating $PbWO_4$ crystals

HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

Data taking in 2011-12

L = 5.3 fb^{-1} at 7 TeV
L = 20.7 fb^{-1} at 8 TeV

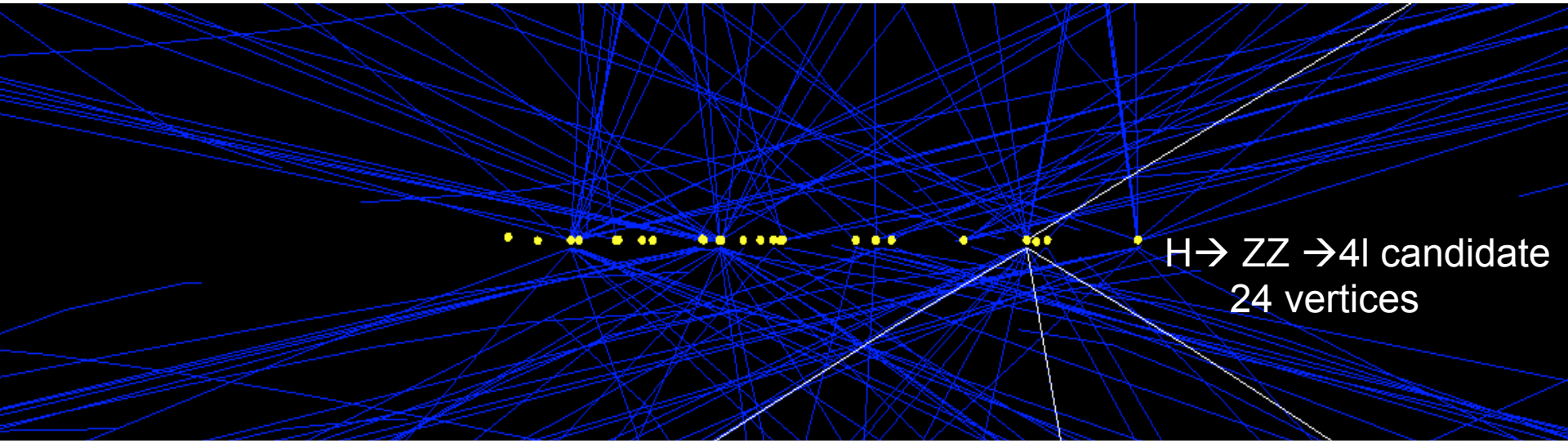


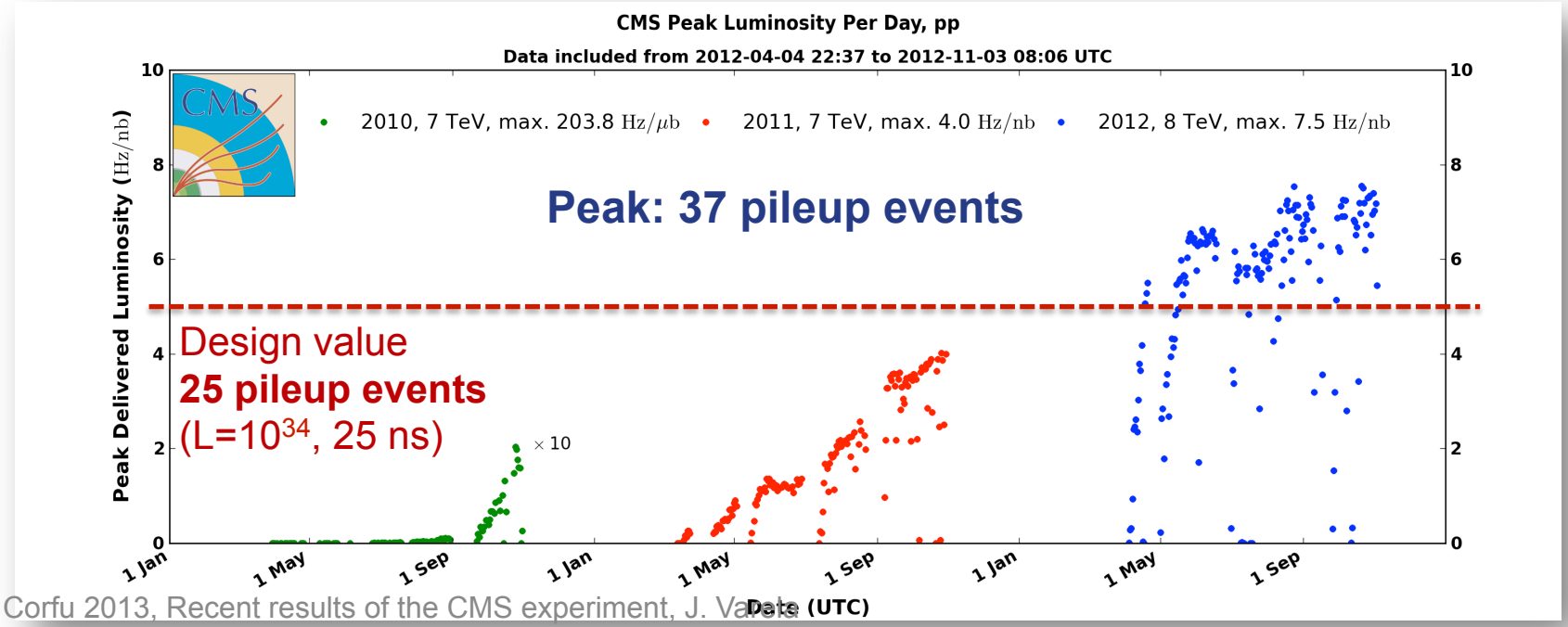


Fraction of delivered data used for physics

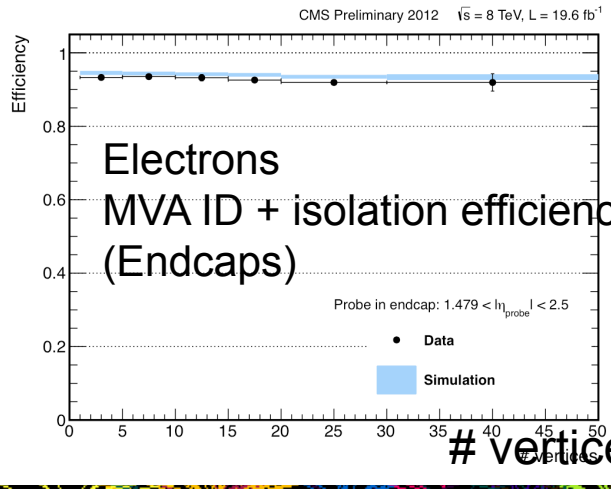
2011: 87%
2012: 89%

Pileup in 2012

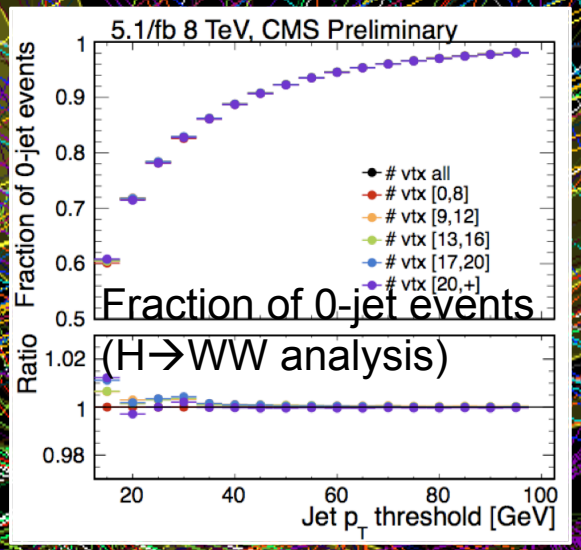




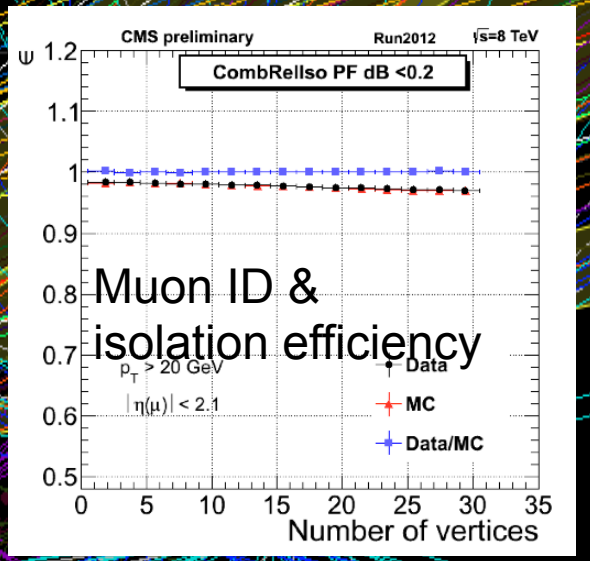
Lepton, jets, MET & pileup



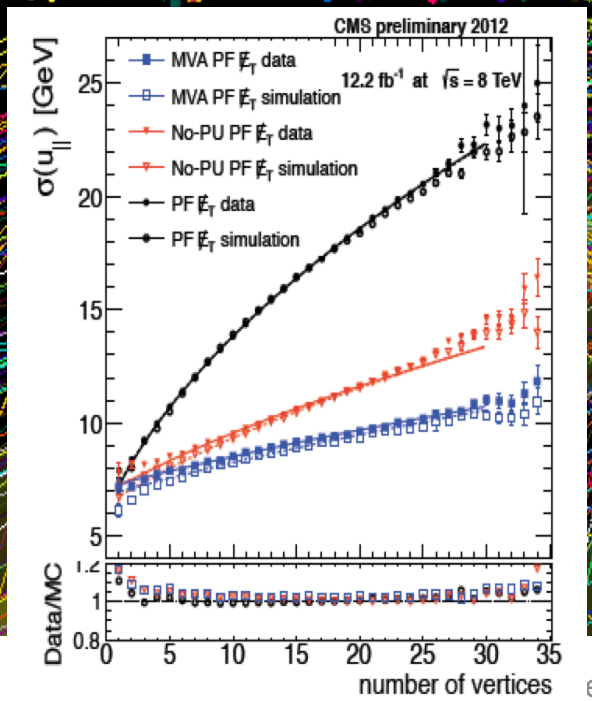
Electrons
MVA ID + isolation efficiency
(Endcaps)



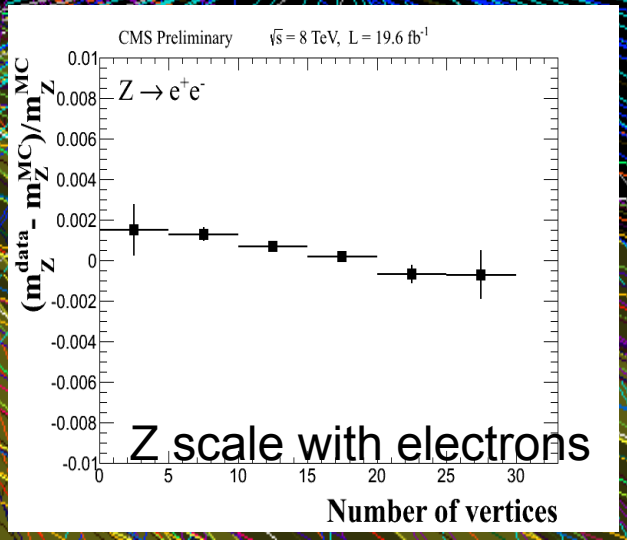
Fraction of 0-jet events
(H→WW analysis)



Muon ID &
isolation efficiency

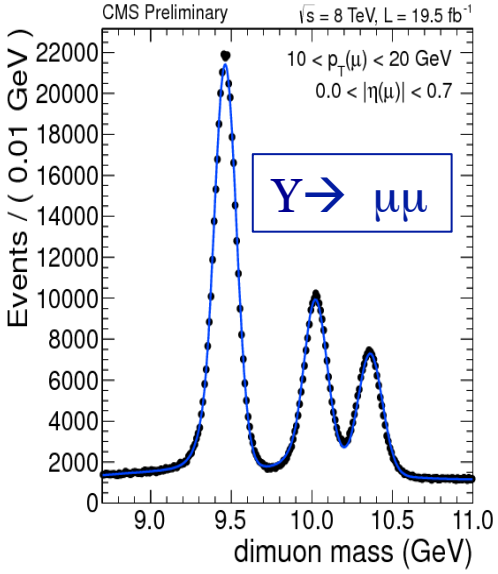


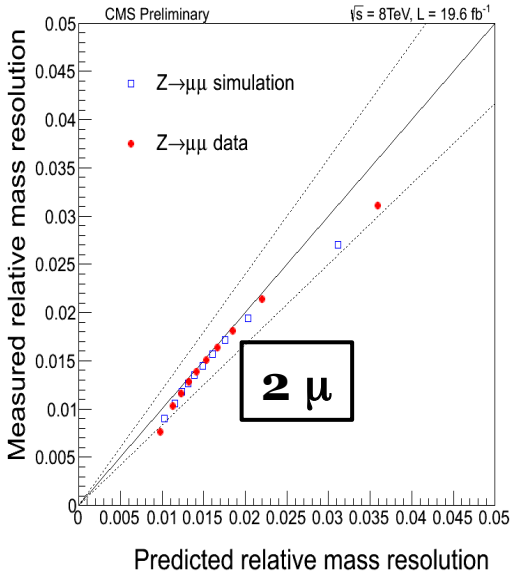
Leptons, jets and MET almost insensitive to pileup

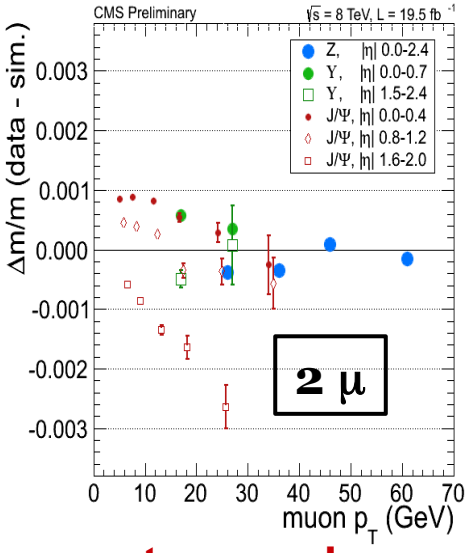


Z scale with electrons

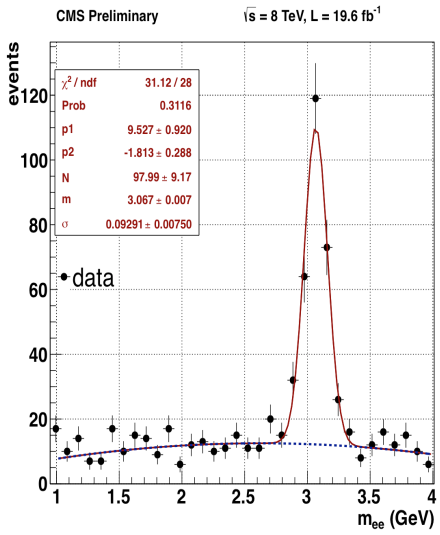
Additional material **Muons & electrons**

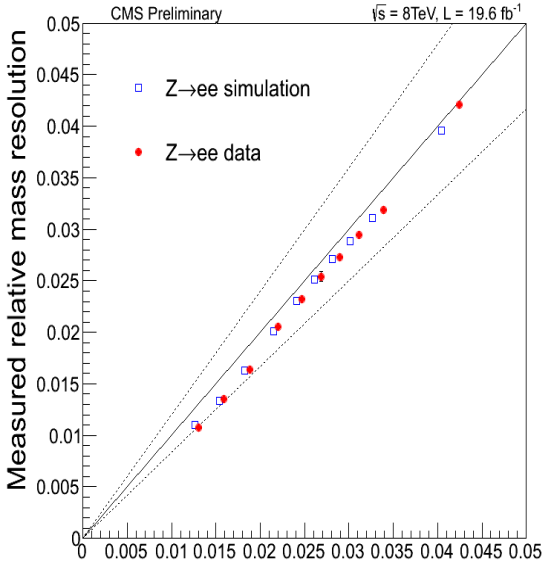


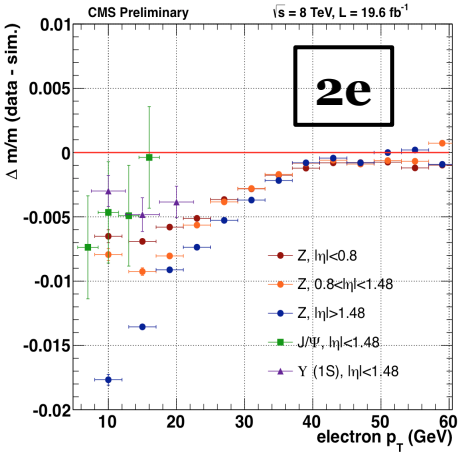




momentum scale:
0.1% for muons;
0.2% for electrons of $35<p_T<50$





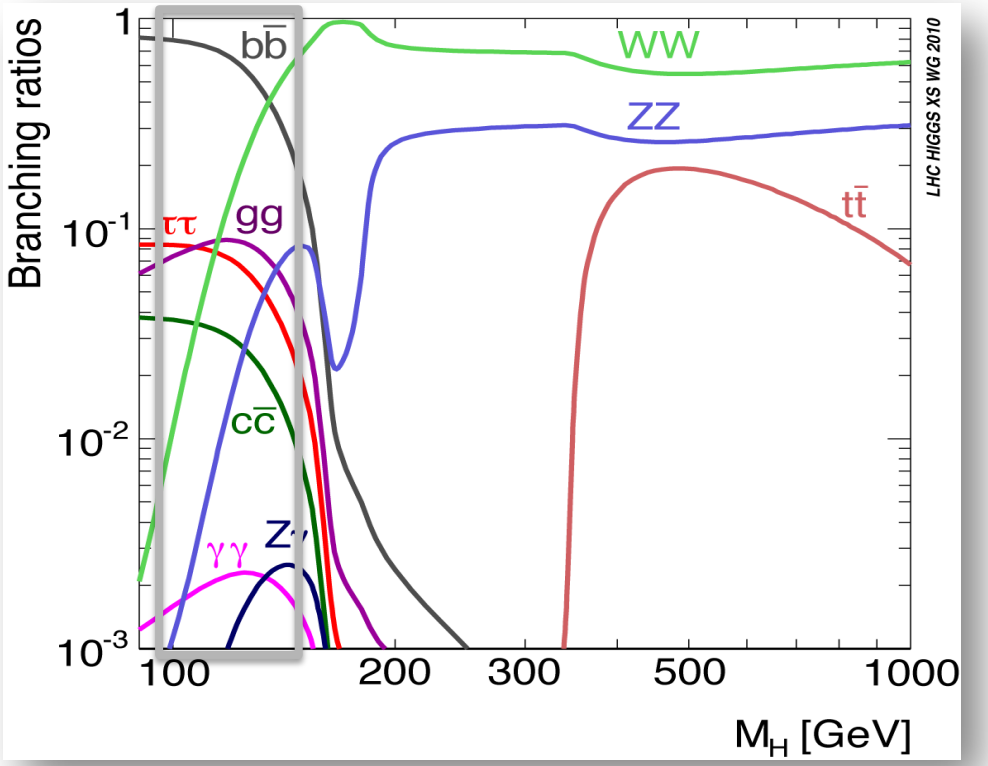


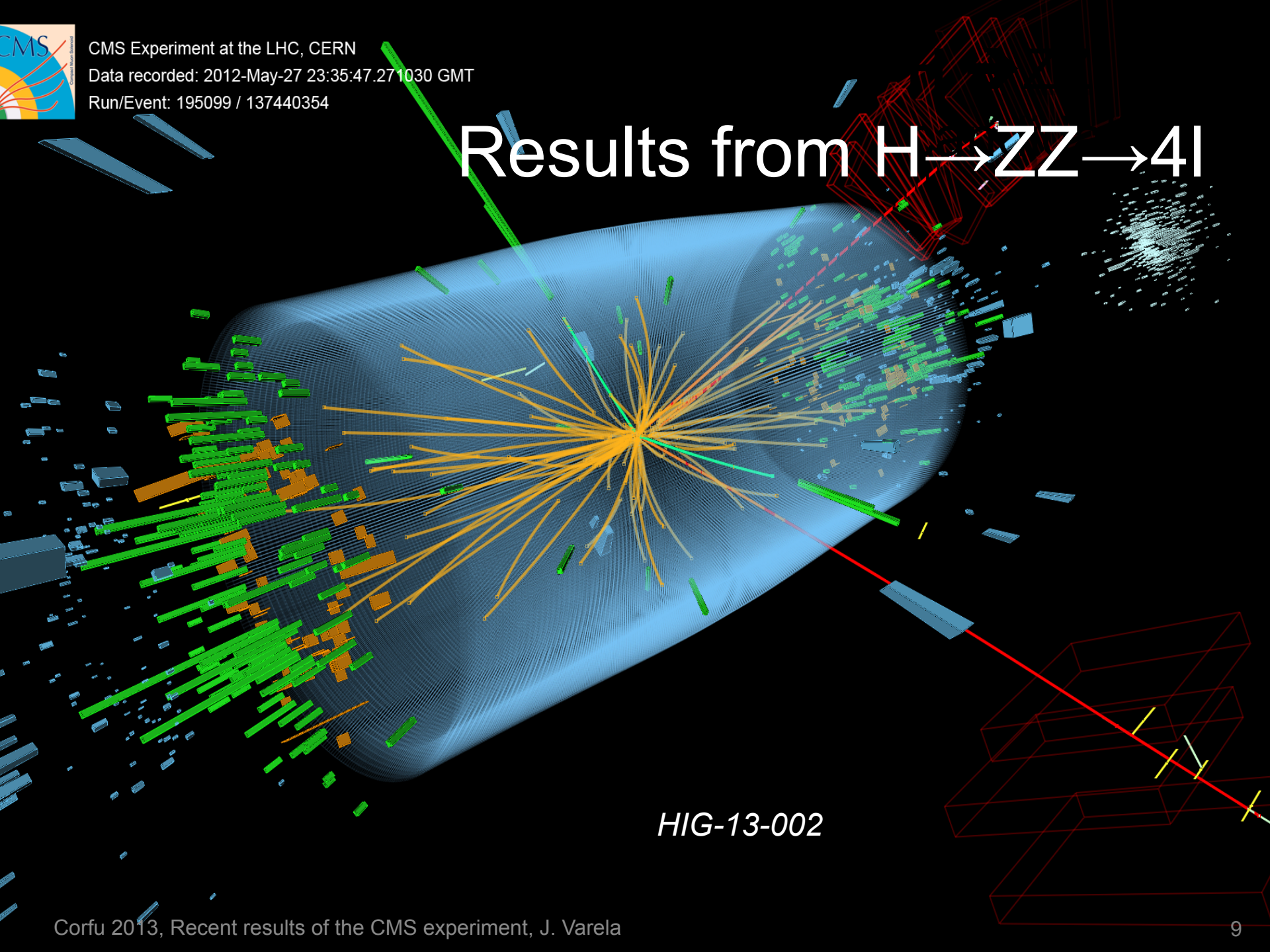
Higgs boson decays

5 decay modes exploited:

	Exp Sig @125.7 GeV	σ_M/M
• bb	2.2σ	10%
• $\tau\tau$	2.6σ	10%
• WW	5.3σ	20%
• ZZ	7.1σ	1-2%
• $\gamma\gamma$	3.9σ	1-2%

- and searches in $Z\gamma$





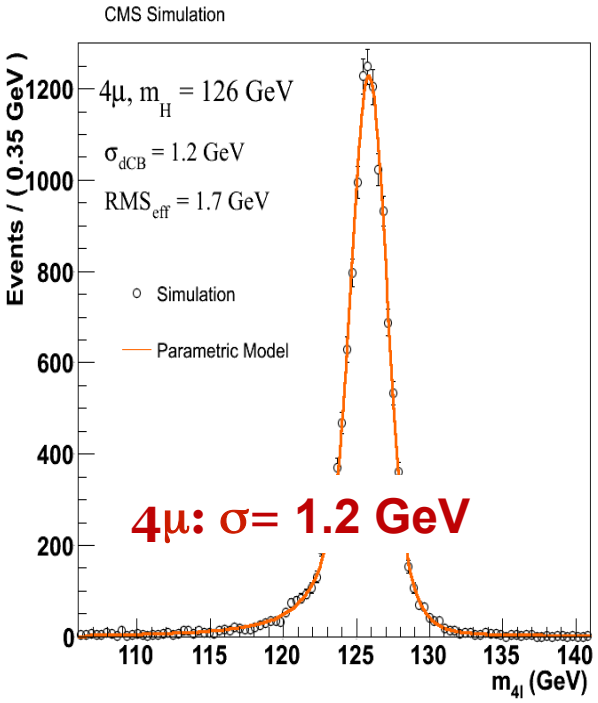
Results from H→ZZ→4l

HIG-13-002

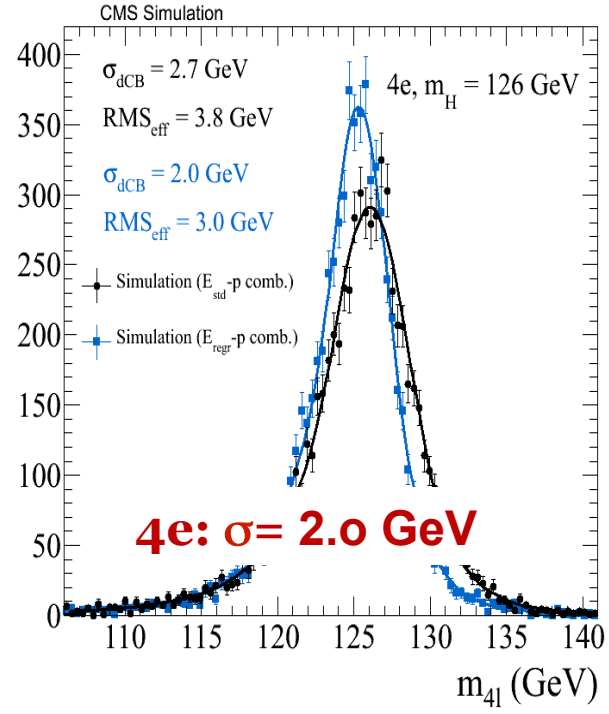
Four lepton mass resolution

Additional material

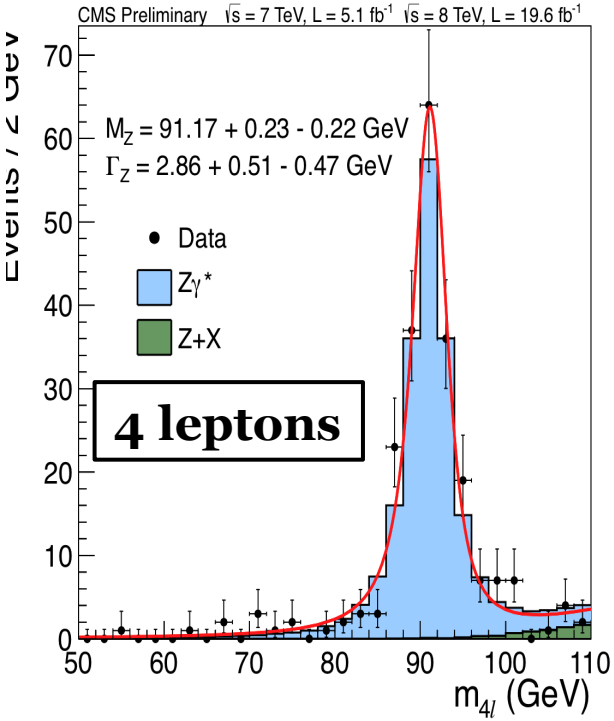
simulation



simulation



data



4 lepton mass resolution = 1 – 2% with uncertainty: 20%

Validated in situ with Z(4l)

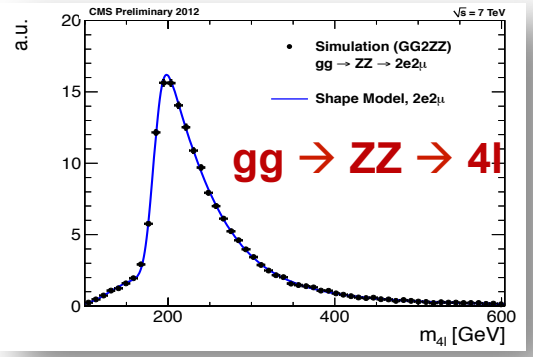
Background modeling and event selection

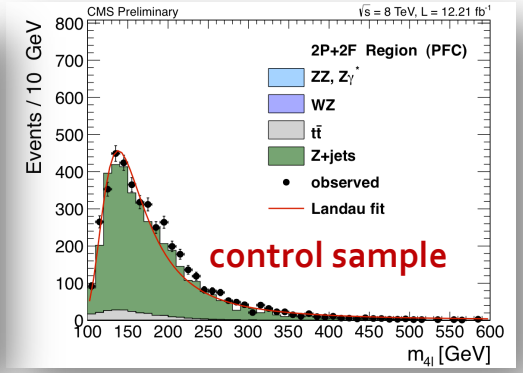
Additional material

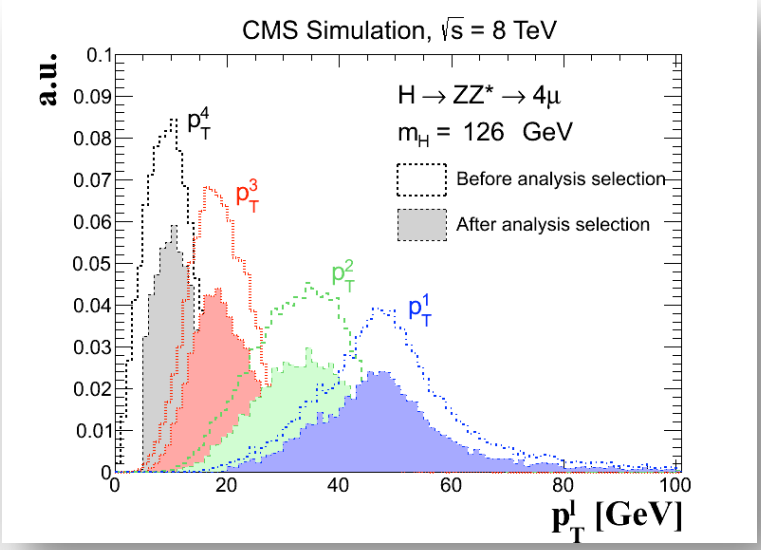
- Background models:
  - irreducible ZZ(*)
    - Estimated using simulation
    - Corrected for data/simulation scale
  - reducible Z+jets, ttbar, WZ
    - Estimated from control samples

Event selection:

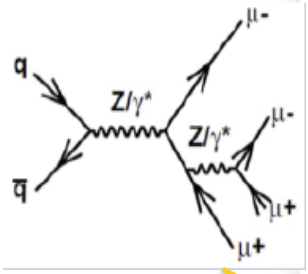
requires the highest possible efficiencies (lepton Reco/ID/ Isolation).

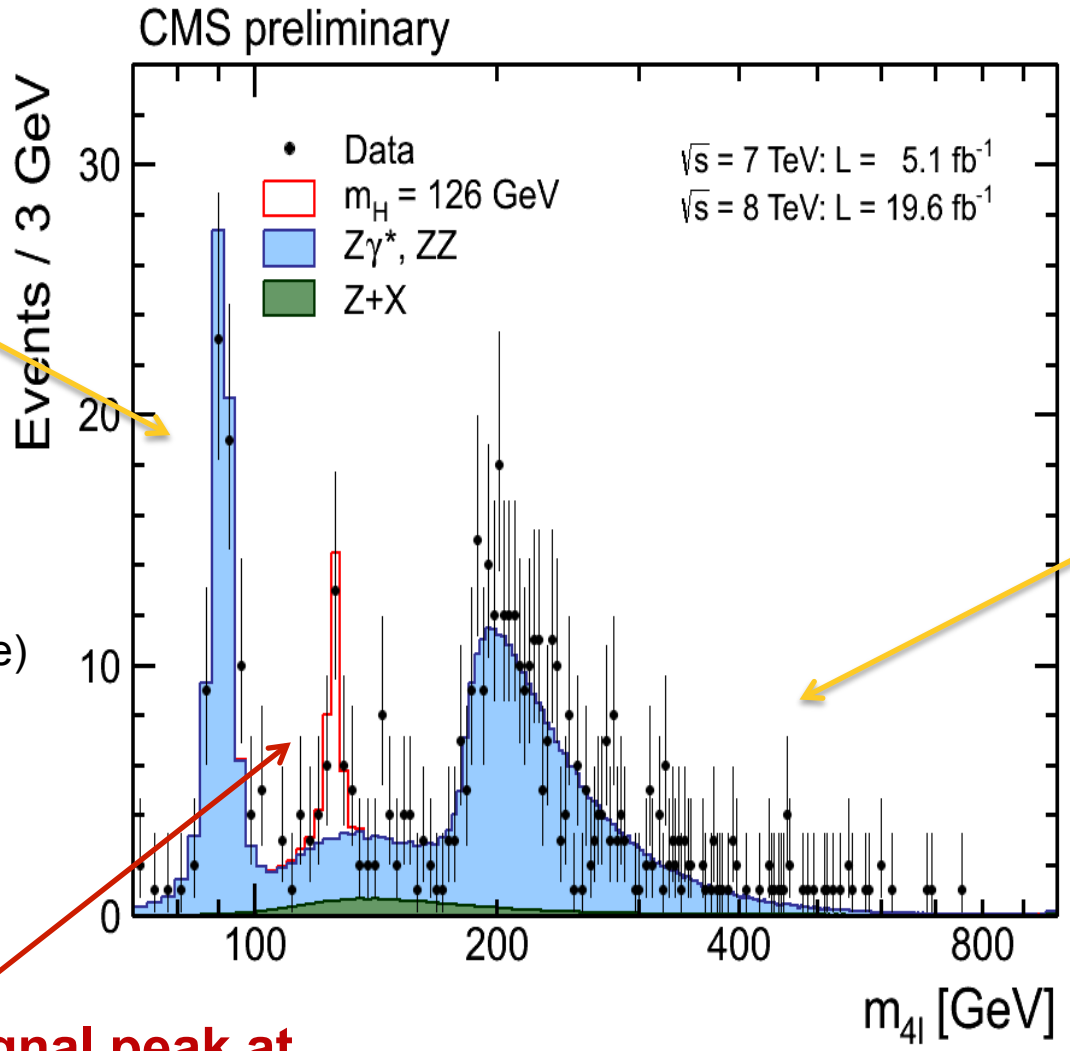






Four lepton mass spectrum





Very good control of the dominant ZZ background

M(4l)>160 GeV
Data 380
MC 364.5

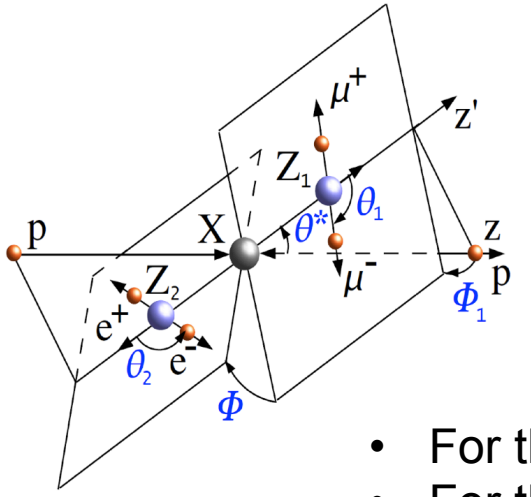
Offline selection cuts:
5 (7) GeV for μ (e) in $|\eta| < 2.4$ (2.5).

Clean signal peak at ~126 GeV

$\sigma(pp \rightarrow ZZ, 8TeV) = 8.4 \pm 1.0\ (stat.) \pm 0.7\ (syst.) \pm 0.4(lum.)$ pb

$\sigma_{SM}(th) = 7.8 \pm 0.6$ pb

Kinematic discriminant



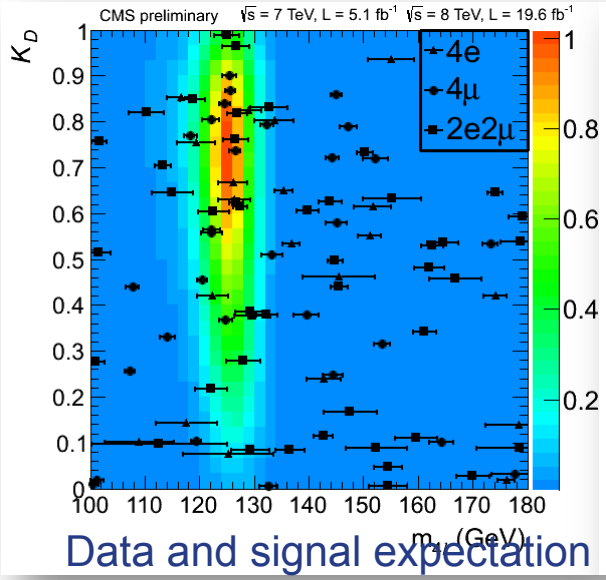
Matrix Element Likelihood Analysis:

uses kinematic inputs for signal to background discrimination

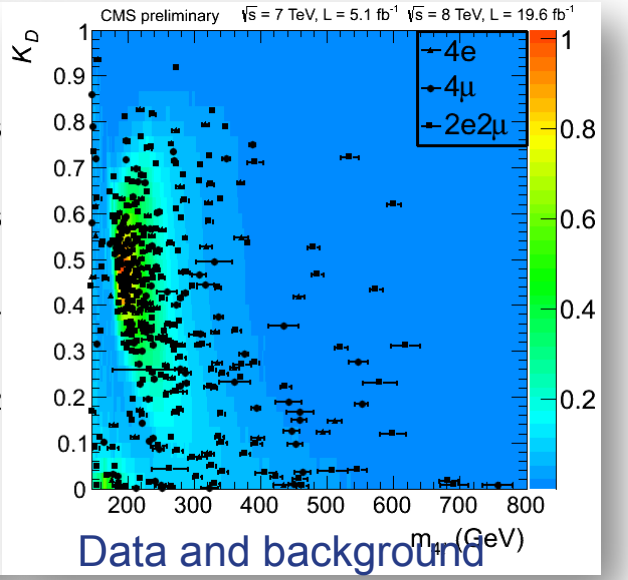
$$\{m_1, m_2, \theta_1, \theta_2, \theta^*, \Phi, \Phi_1\}$$

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

- For the signal use a fully analytic parameterization
- For the background use a simulation of the process $q\bar{q} \to ZZ/Z\gamma$



Data and signal expectation for m_H = 126 GeV



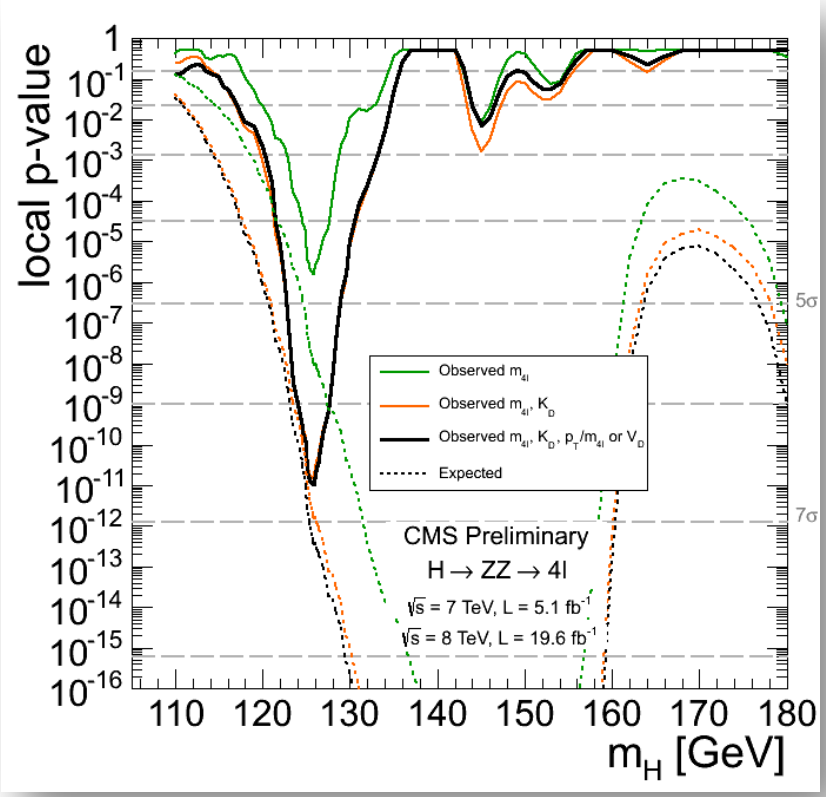
Data and background expectation

K_D distribution is similar for different signal models:

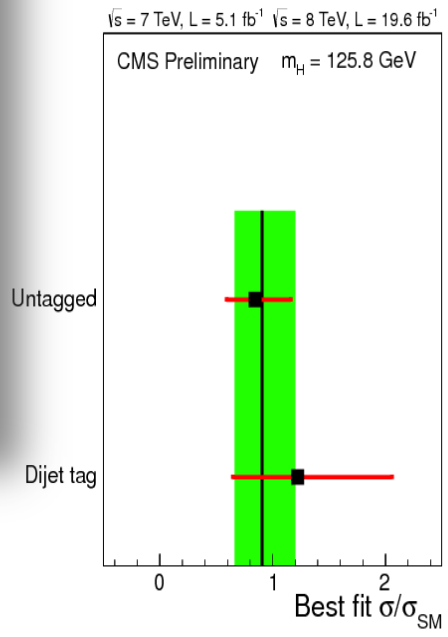
J^P = 0^+, 0^-, 1^-, 1^+,2^+_{mgg} 2^+_{mqq}

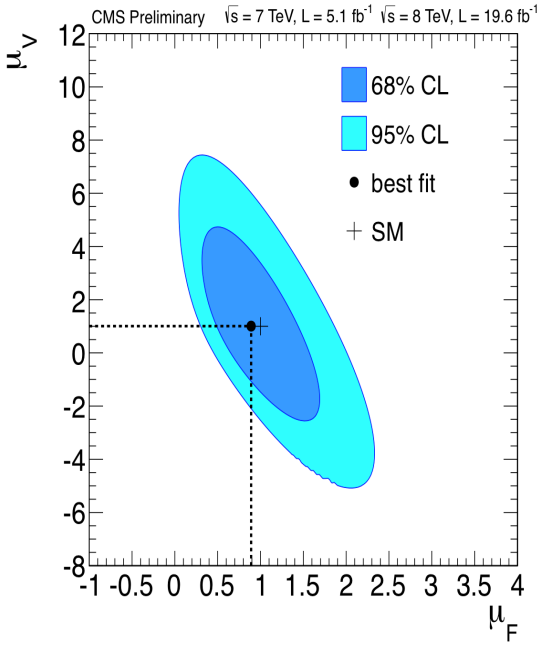
Several parameterizations of matrix elements have been studied with similar results

Results on H→ZZ→4l



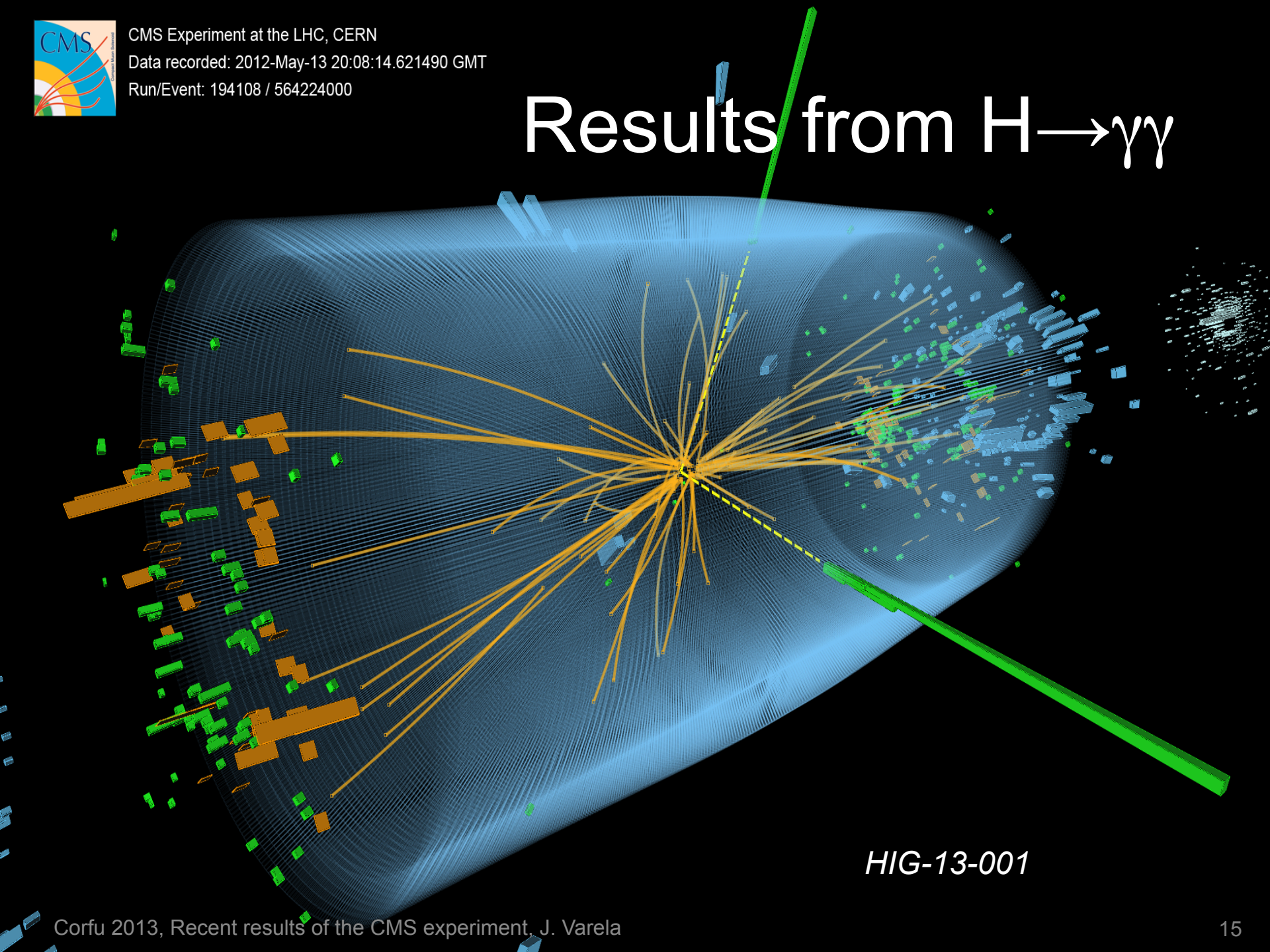
Untagged (0/1 jets) and tagged (2 jet) categories are used to measure the couplings





p-value Expected: 7.1 σ
Observed: 6.7 σ

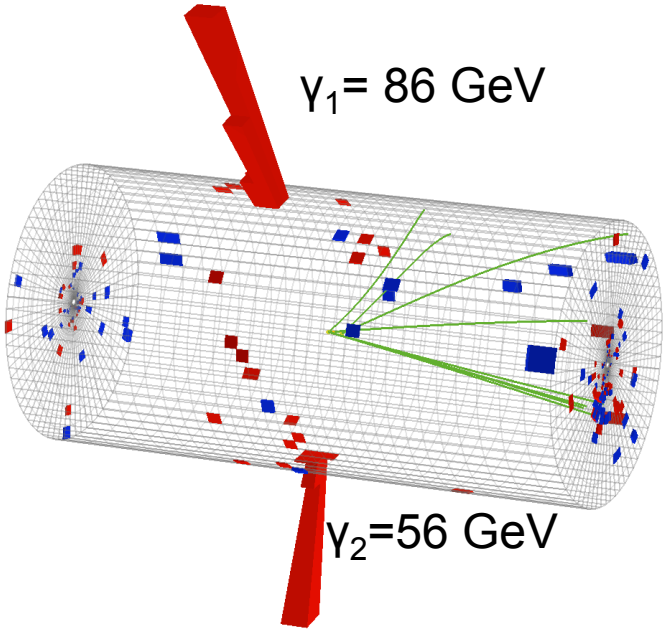
$σ/σSM$ (m_H=125.7 GeV) = 0.92 ± 0.28



Results from H→γγ

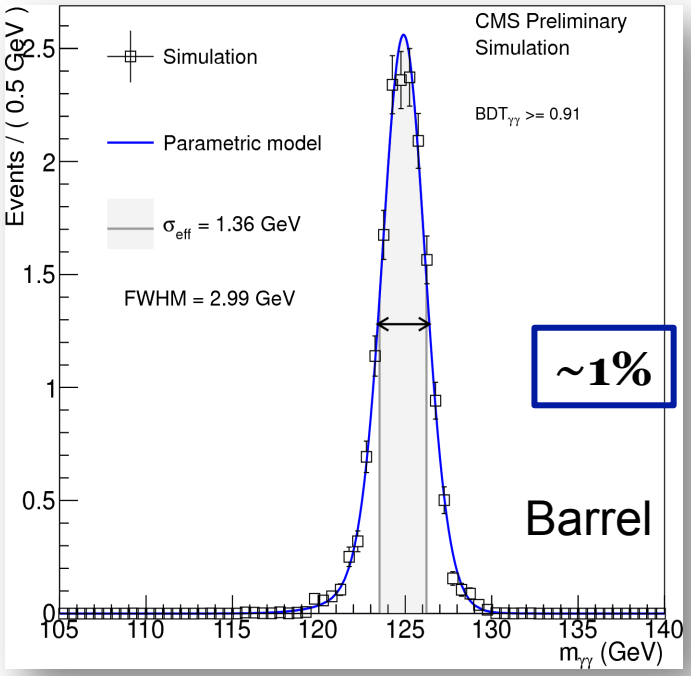
HIG-13-001

$H \rightarrow \gamma\gamma$



Signature:

- Two energetic and isolated photons
- Narrow mass peak on top of a large steeply falling background

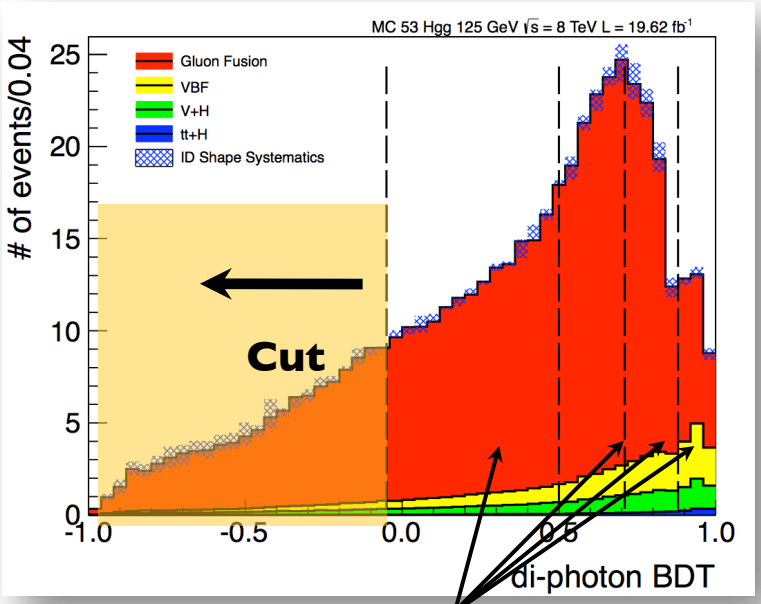


Relevant aspects:

- Photon identification/ background rejection
- Di-photon mass resolution
- Background estimation
- Primary vertex determination (pile-up!)

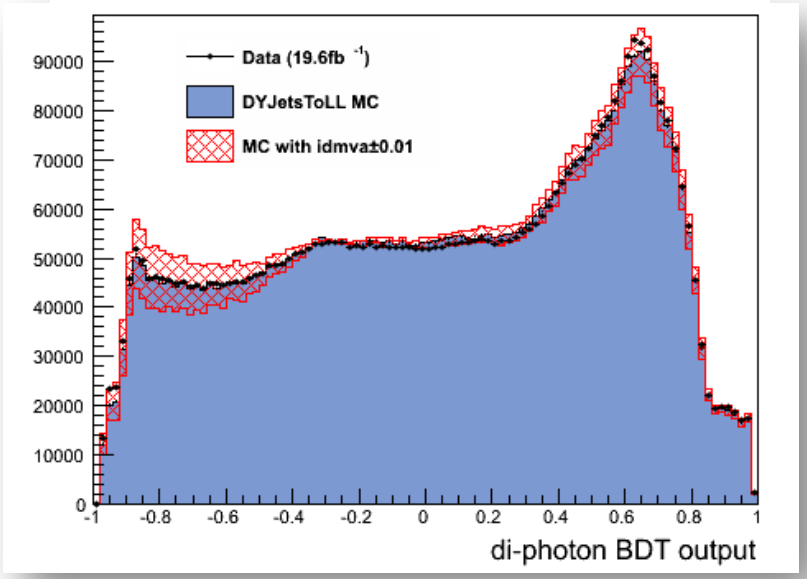
Additional material H→γγ analysis

- Two inclusive analyses:
  - MVA: photons selected with a BDT. Variable in the BDT: photon kinematics, photon ID MVA score (shower shape, isolation), di-photon mass resolution. 4 MVA categories with different S/B
  - Cut-based: photons selected with cuts. 4 categories based on: γ in Barrel/Endcap, (un)converted γ. Each category has different mass resolution and S/B
- 3 VH channels (e, μ and MET tag) + VBF (2 dijet categories)



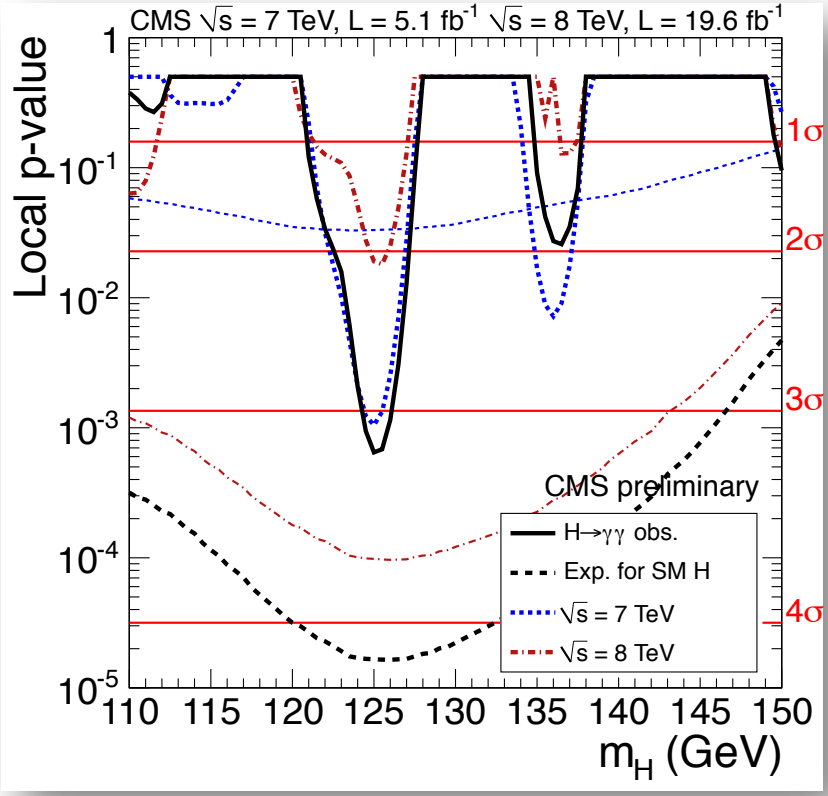
MVA event categories

Output of the MVA validated using Z→ee (where e are reconstructed as γ)



H→γγ: p-values

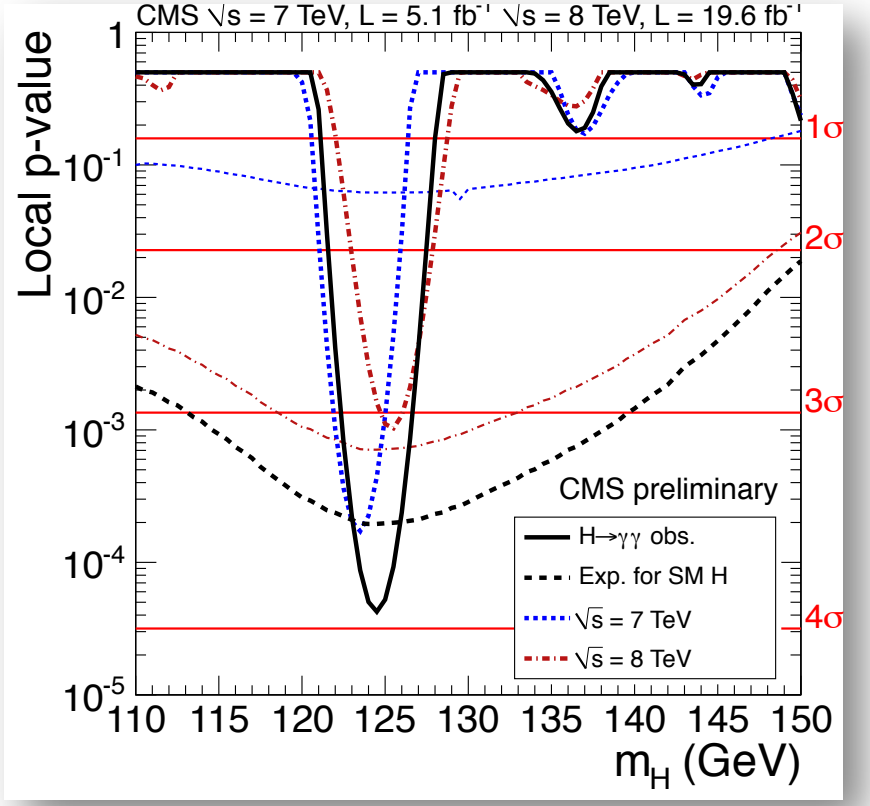
MVA



Significance at 125.0 GeV:

3.2 σ (4.2 exp.)

Cut-based



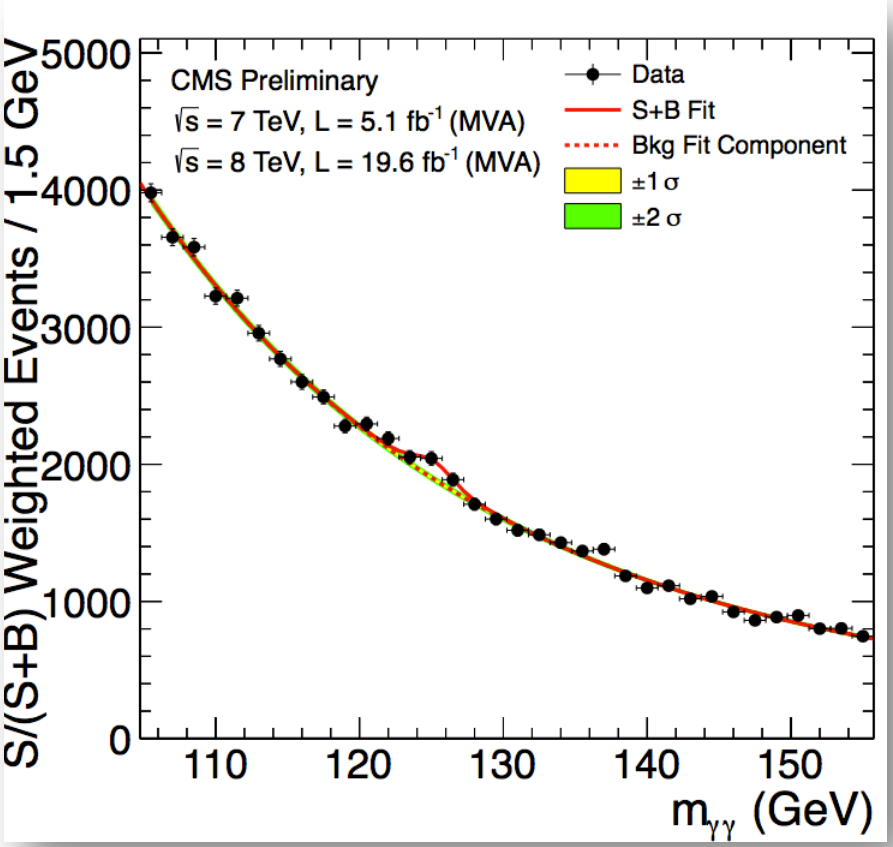
Significance at 124.5 GeV:

3.9 σ (3.5 exp.)

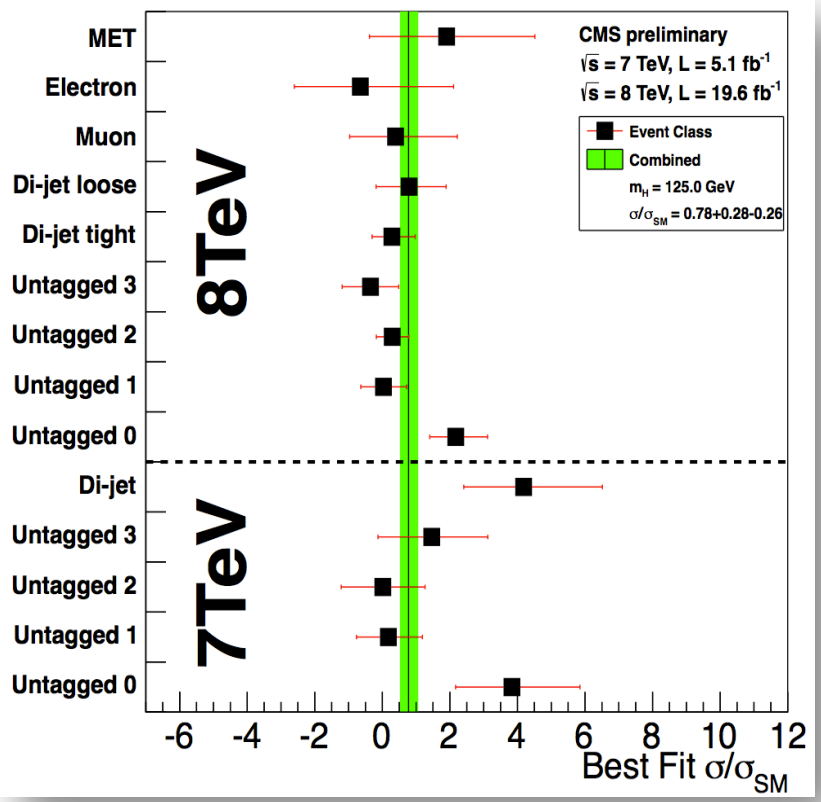
New data, new analysis: Significance decreased compared to previously published results

H→γγ: combined mass plot

MVA



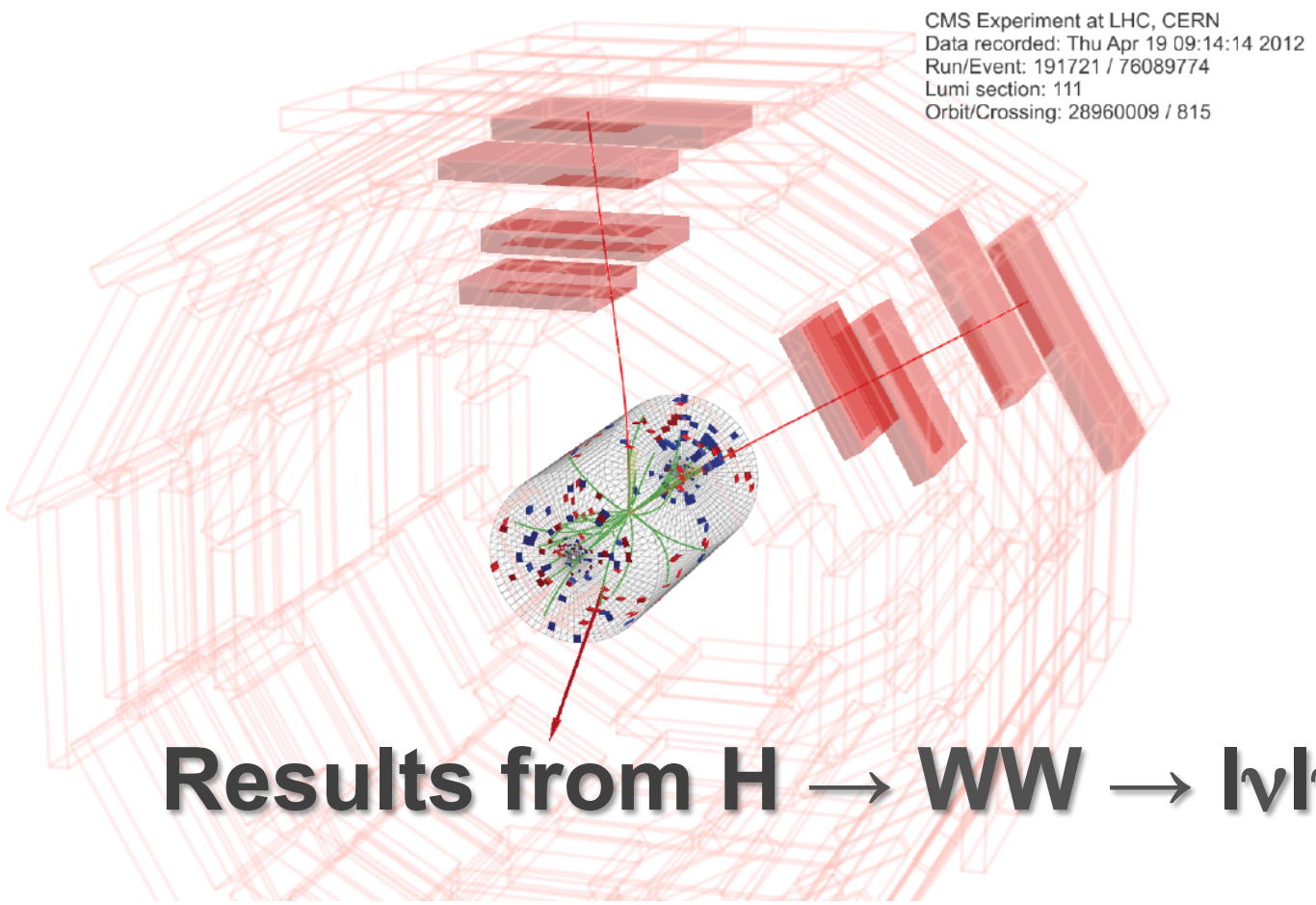
MVA



Each event category is **weighted by S/(S+B)** only for visualization purposes

7+8 TeV:

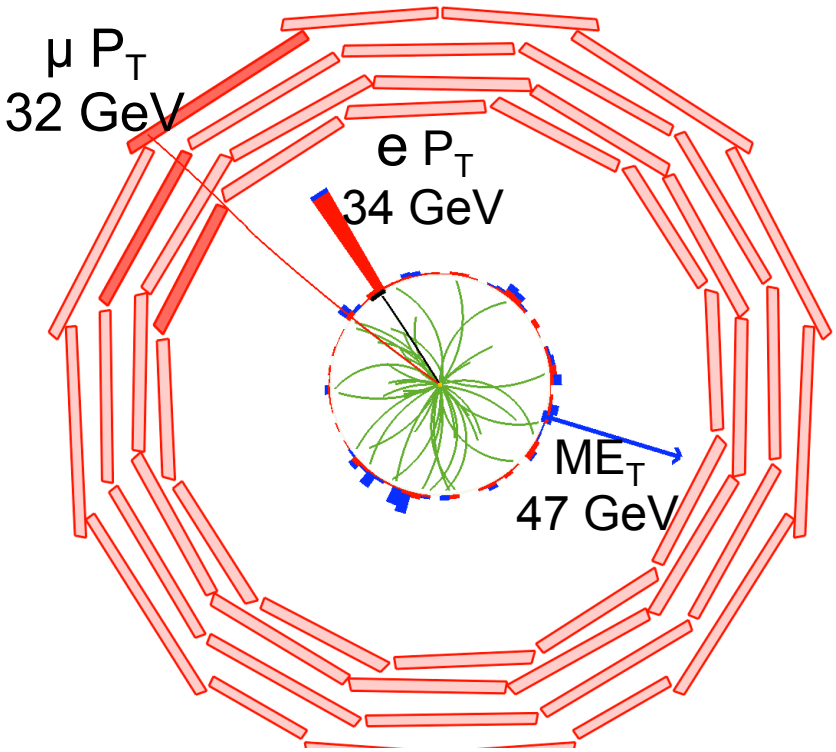
σ/σ_{SM} at 125.0 GeV = $\mathbf{0.78\ ^{+0.28}_{-0.26}}$

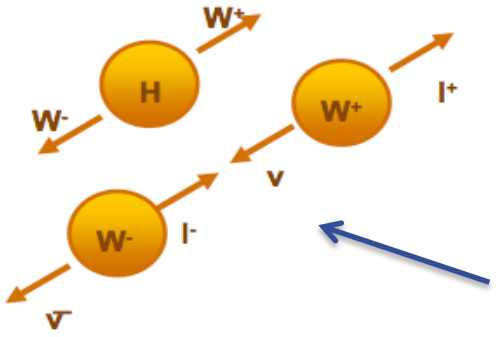


Results from H → WW → lνlν

HIG-13-003

Additional material $H \rightarrow WW \rightarrow l\nu l\nu$





- Channel with very high σ.BR
- Clean signature:
  - 2 isolated, high p_T leptons with small opening angle
  - High Missing E_T
  - Analysis performed on exclusive jet multiplicities (0, 1, 2-jet bins)
  - Different Flavour, Same Flavour leptons
- Discriminant Variables:
  - p_T^l, M_{ll}, M_T, $\Delta\phi$
  - VBF selections for the 2-jets case
- Cut-based and Shape analysis in (M_{ll}-M_T) plane

good sensitivity to spin
small opening angle between leptons

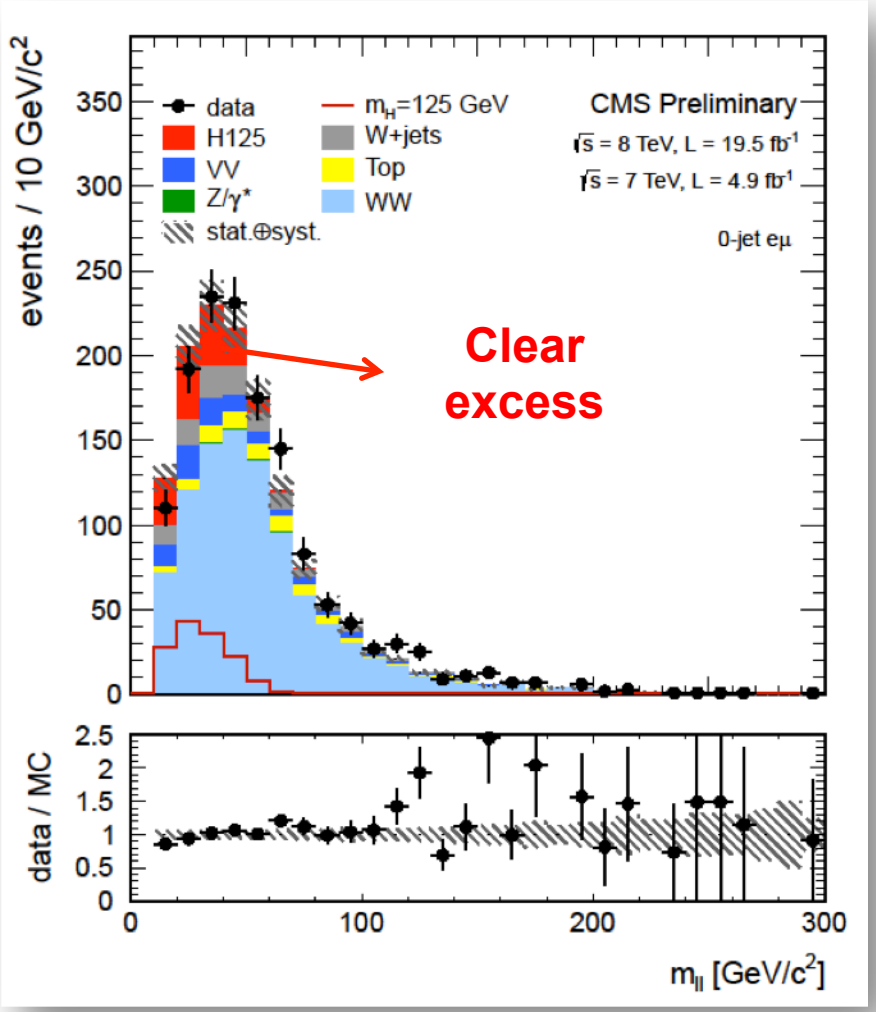
H →WW→lνlν: backgrounds

Additional material

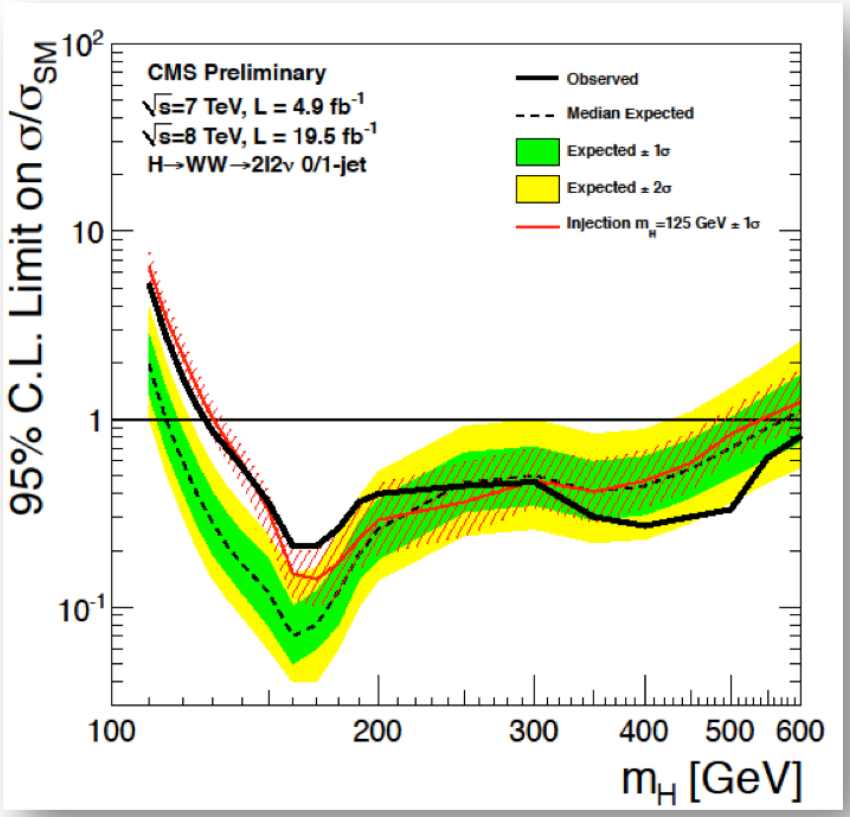
All the backgrounds are estimated from data in "control regions"

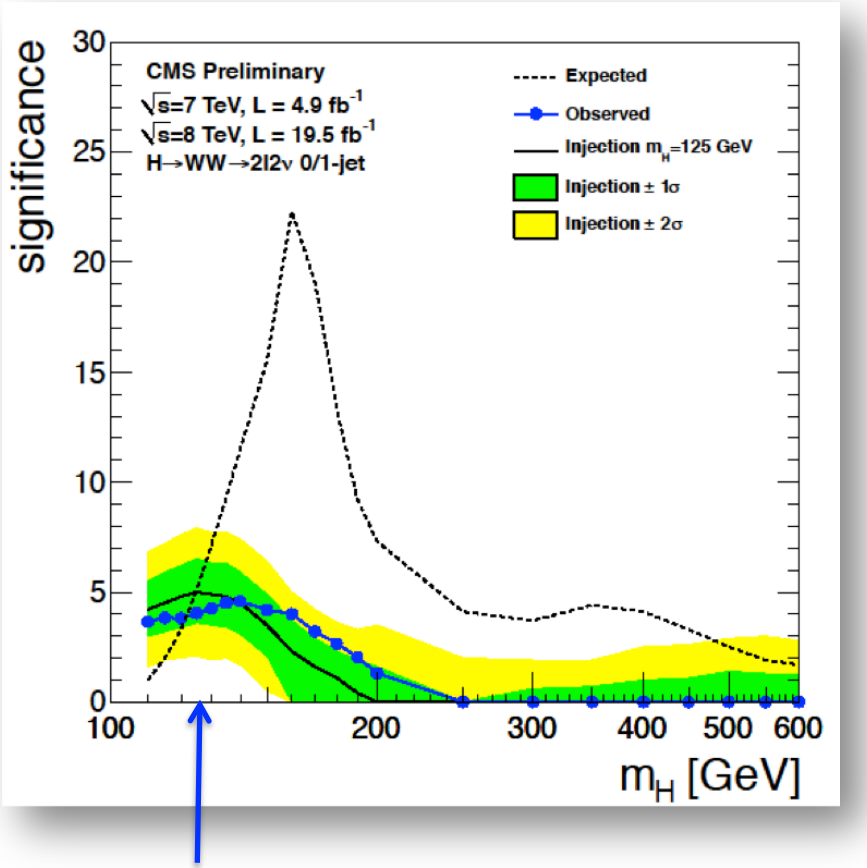
- **Drell –Yan:** Suppressed by M_{ll} and ME_T cuts
- **W+jets (with one jet faking a lepton):** lepton ID is important
- **Top (tt and single top):** b-tag veto (or additional soft muon)
- **WW:** M(ll), M_T and $\Delta\phi$

m_{ll} (0 jet, DF)



H →WW→lνlν: results

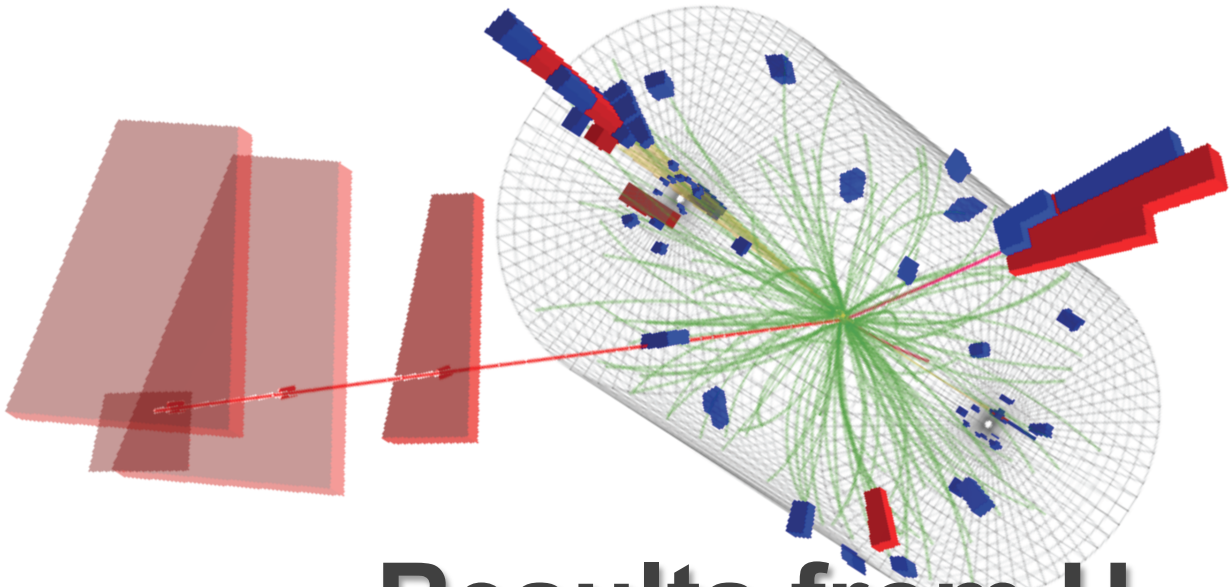




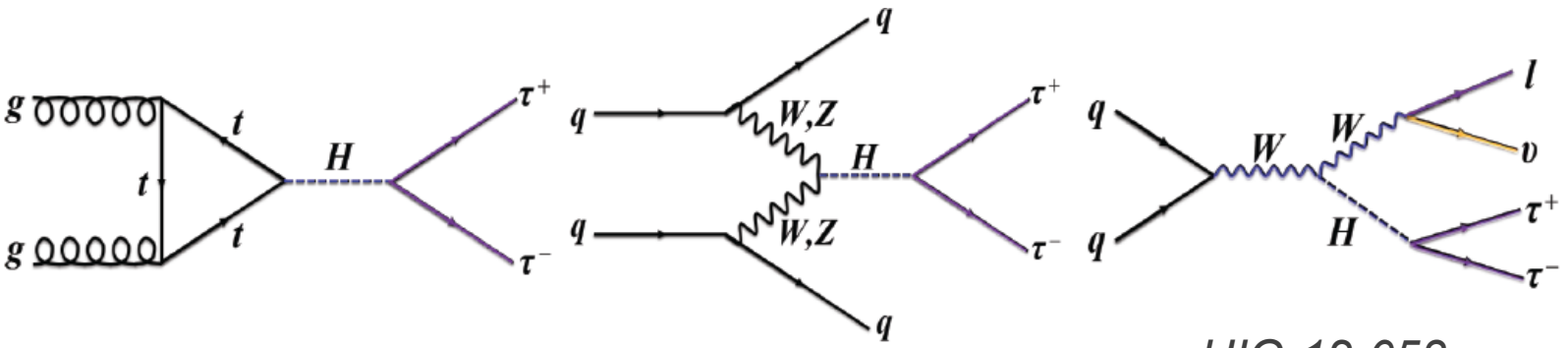
Large excess at low mass compatible with the expected Higgs signal

σ/σ_{SM} at 125 GeV = 0.76 ± 0.21

Significance at 125 GeV: 4.0 σ (5.1 expected)



Results from H → ττ

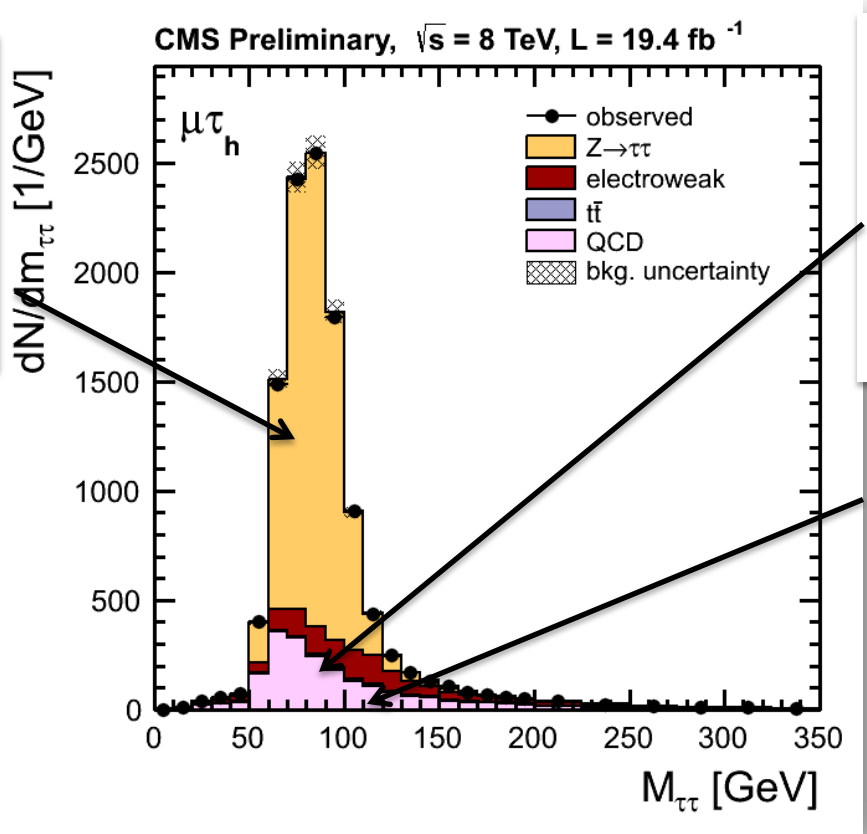


HIG-12-053

Additional material H → ττ analysis

- Reconstructed τ decays: e, μ, τ_{had}
- Categorize events based on number of jets and τ p_T (VH, VBF)
- Template fit to $m_{\tau\tau}$ shape

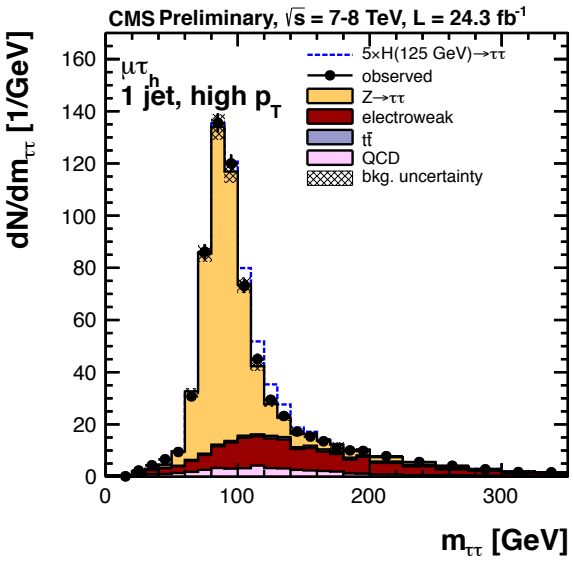
Z→ττ Embedding:
Z→μμ data, replace μ with simulated τ decay
Normalization from Z→μμ data
Syst: 5%

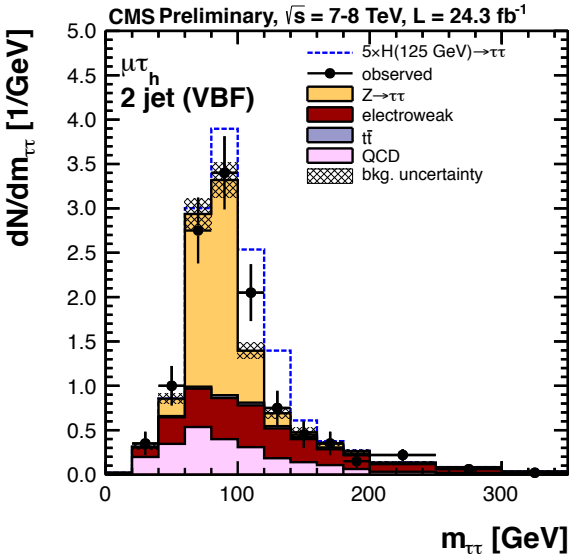


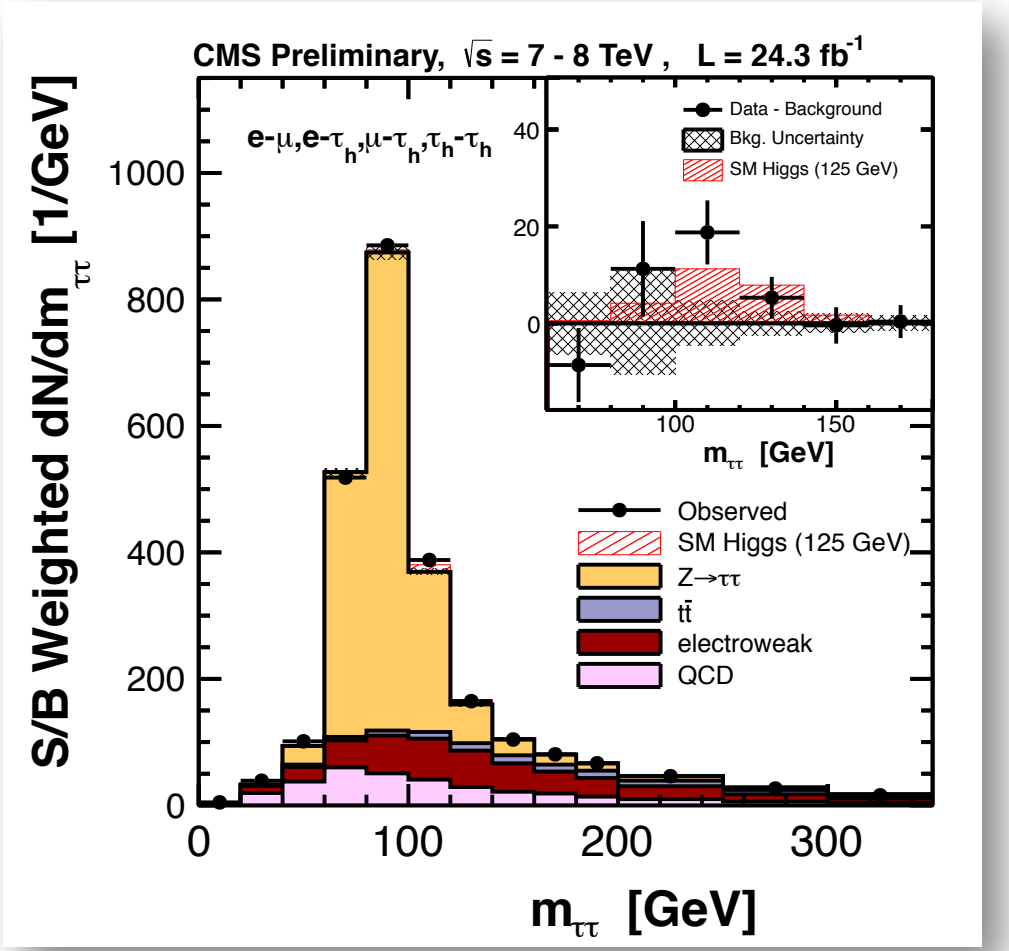
W+jets
Shape from simulation
Normalization from control region
Syst: 10-20%

QCD
SS data, corrected for SS/OS ratio
Syst: 10%

ττ mass spectrum



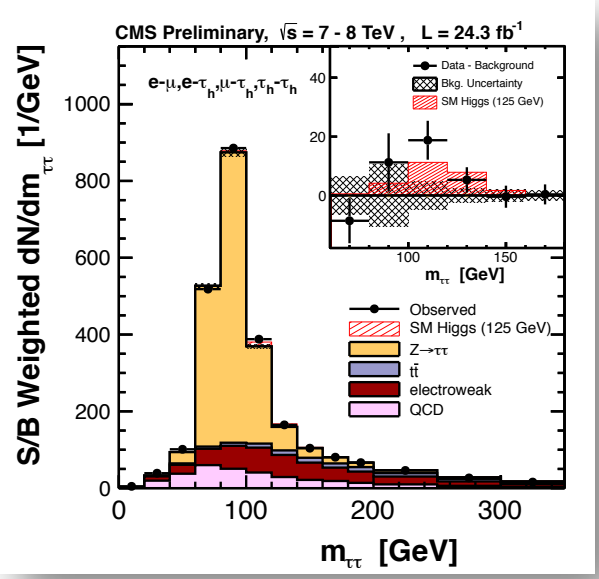


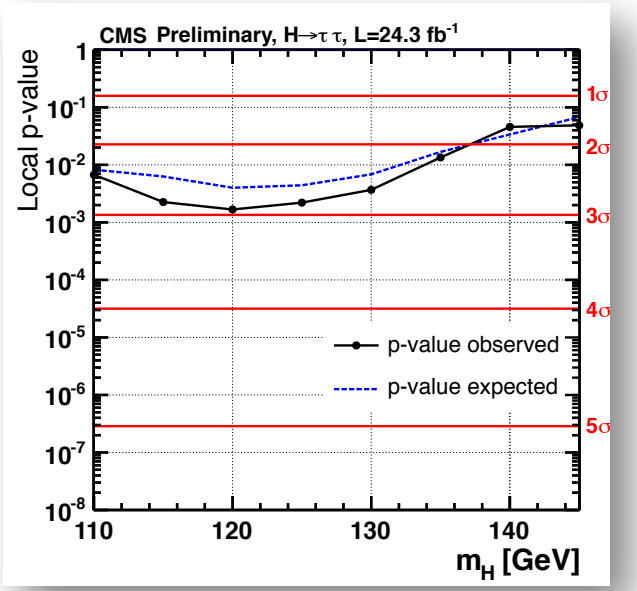


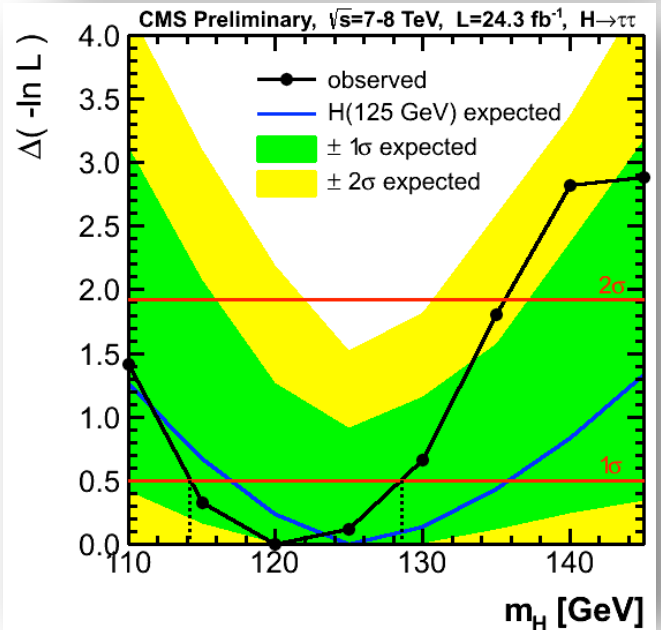
Combine the sensitive categories of all channels with a S/B weight

$H \rightarrow \tau\tau$ results

First strong indication of Higgs decay to fermions







Significance:

2.9 σ @ m_H=125 GeV

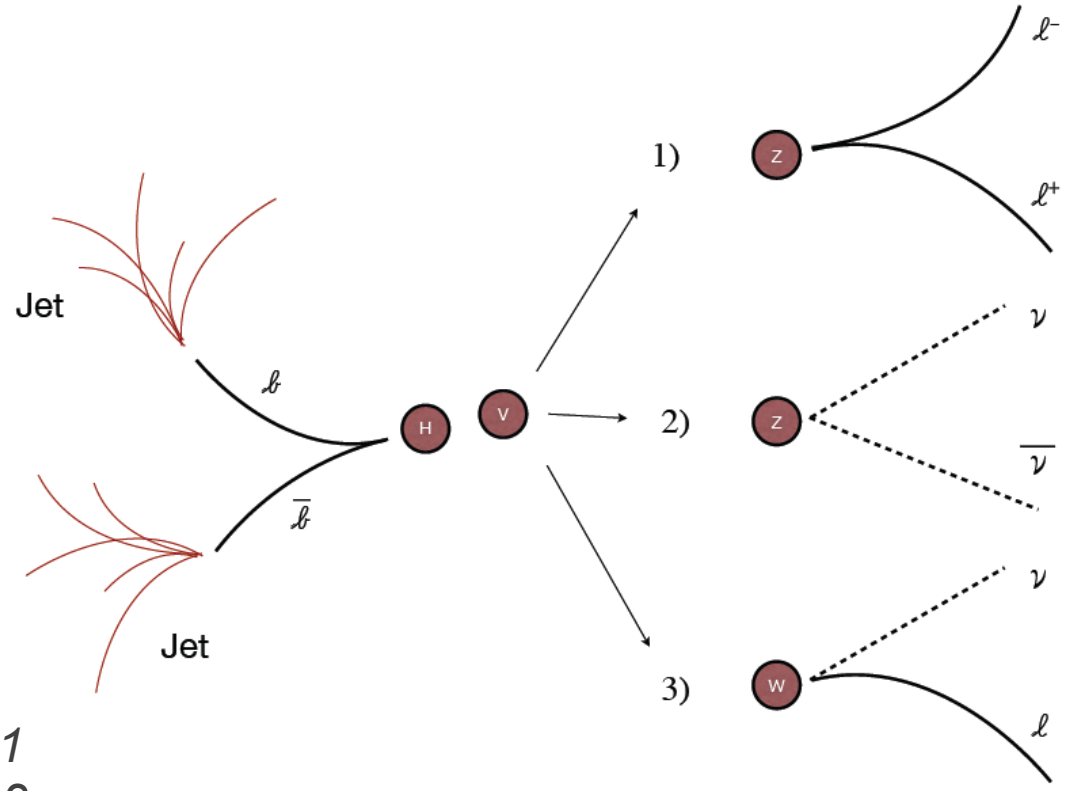
Signal strength:

μ = 1.1 ± 0.4

$m_H = 120^{+9}_{-7}$ (stat+syst) GeV

Results from VH →bb + X

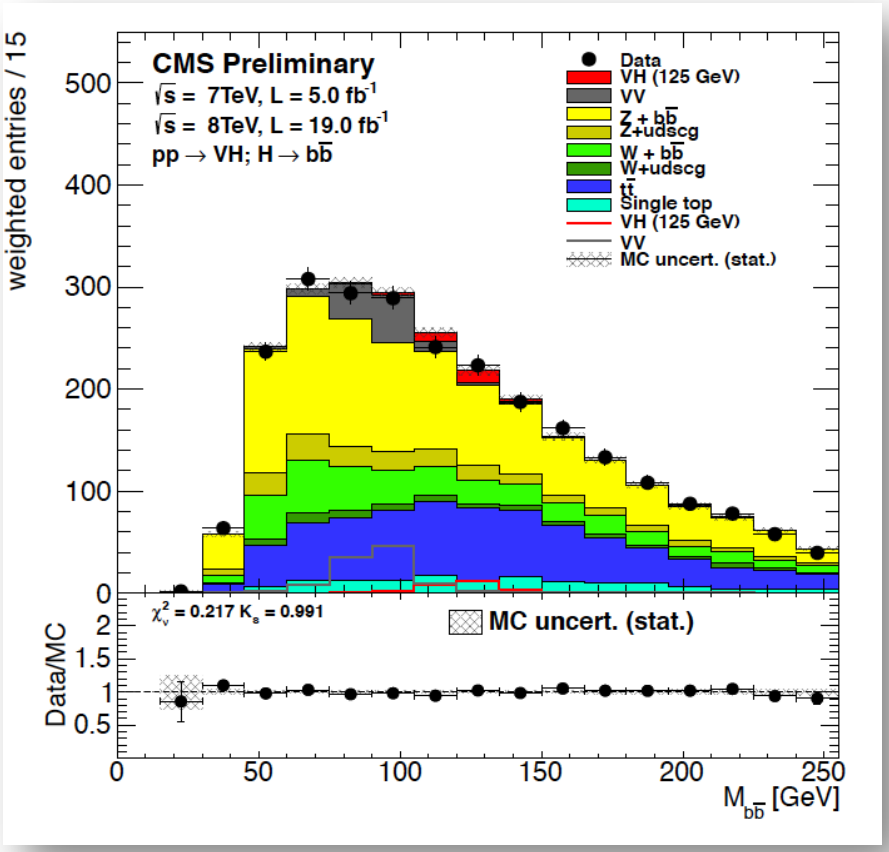
- 2 central b jets plus V (W, Z) decaying into leptons
- Background from V+jets, VV, top+X
- Improved dijet mass resolution
- BDT shape analysis: jets and V kinematics, b tagging



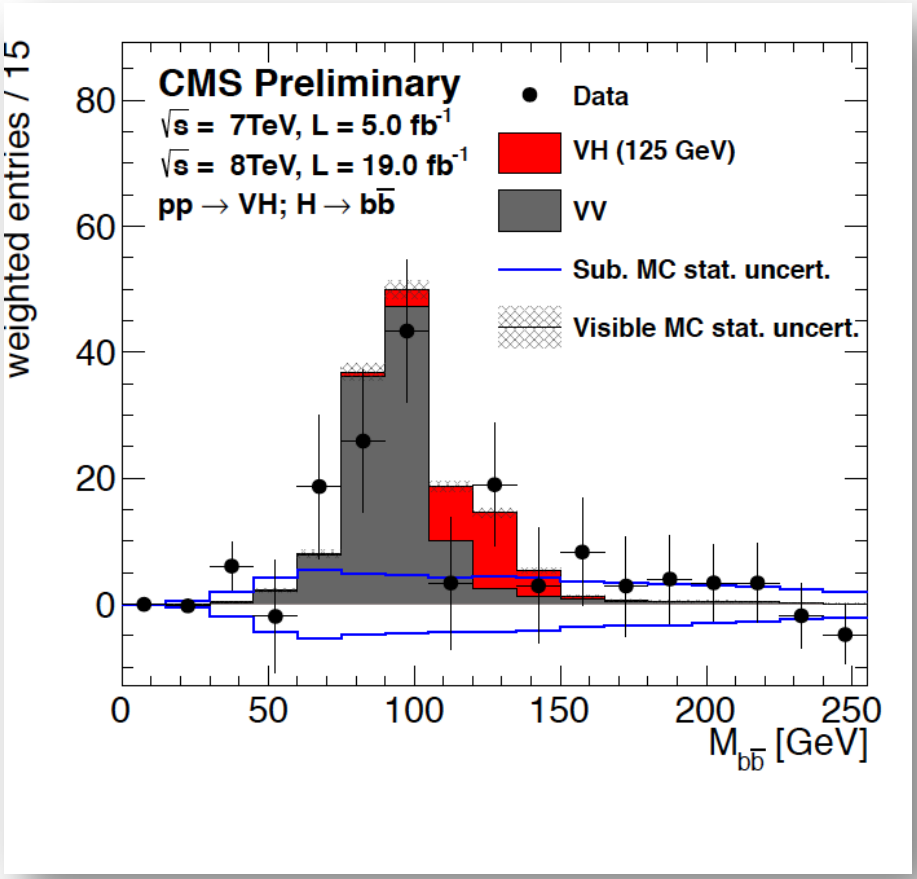
HIG-13-011
HIG-13-012

Dijet mass distributions

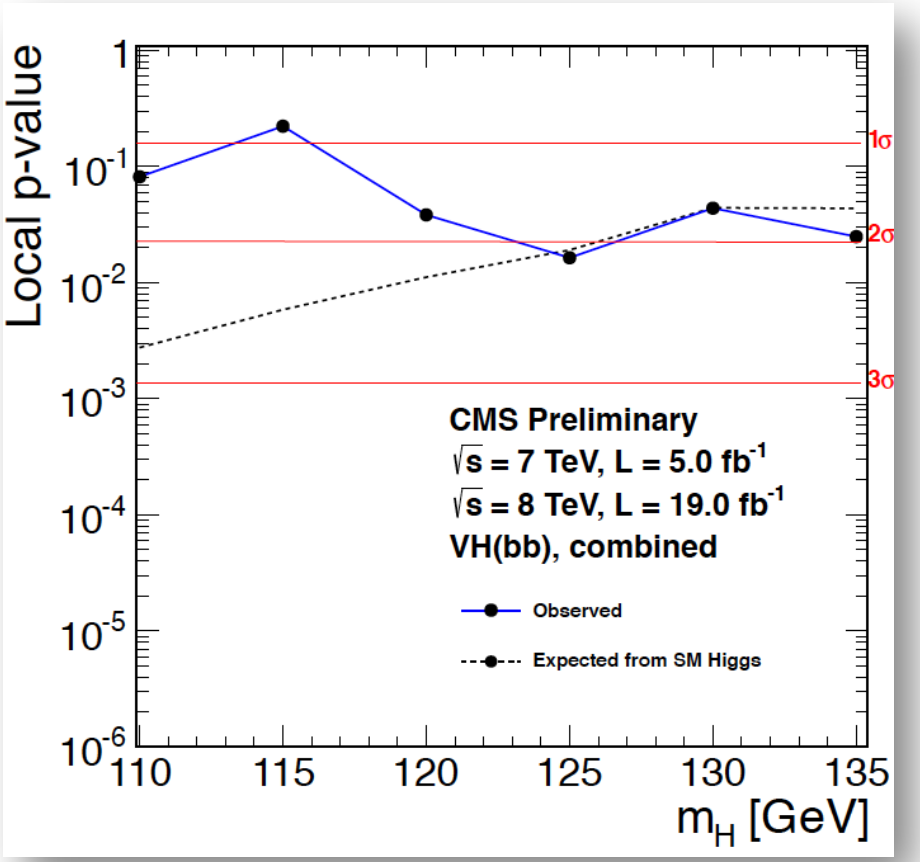
All channels combined

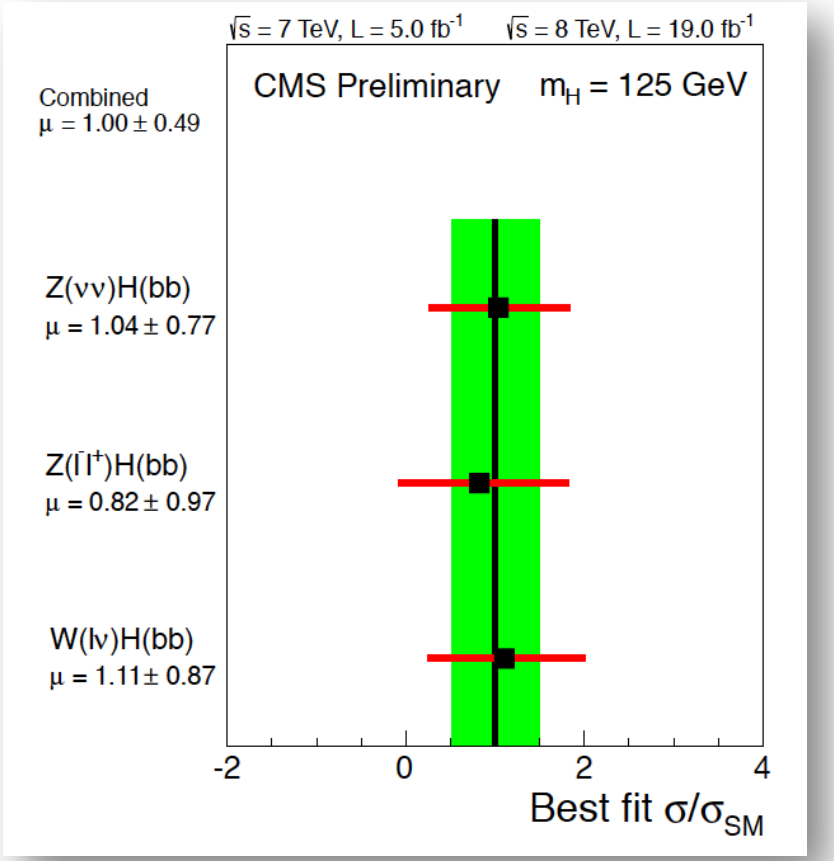


All backgrounds, except VV, subtracted



VH →bb results





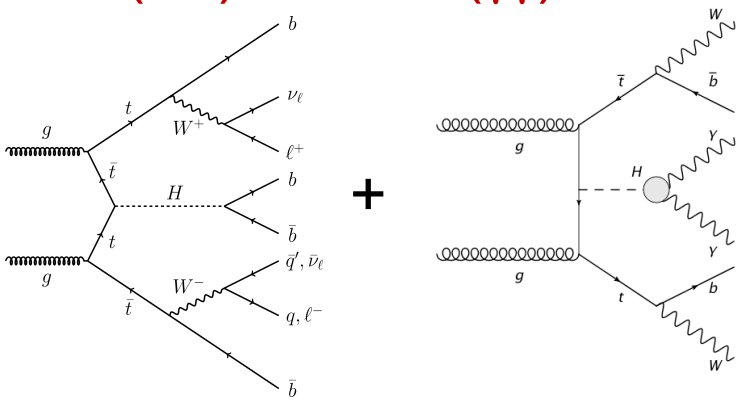
At 125 GeV:

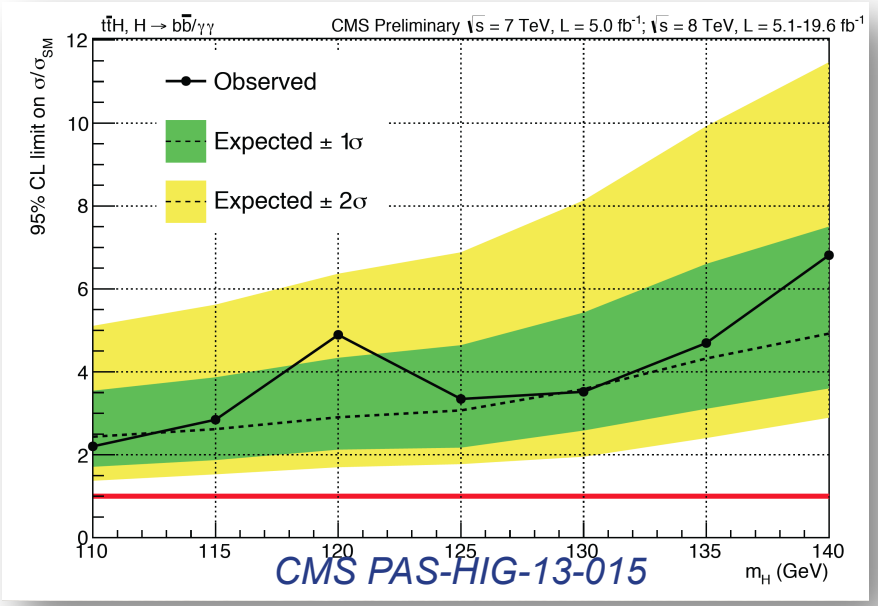
Significance= **2.1σ**

μ = 1.0±0.5

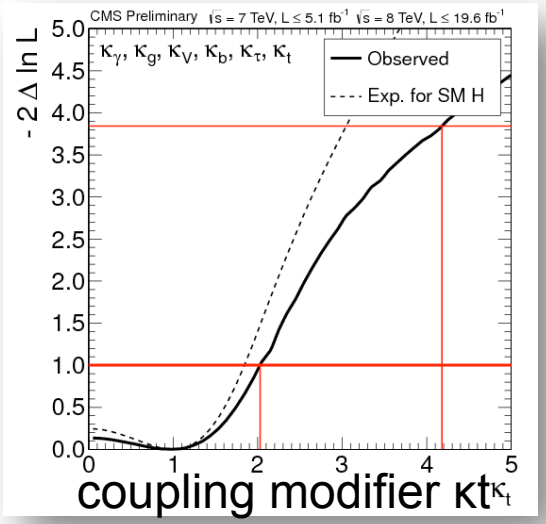
ttH channel and combined fits

Result from combination ttH(bb) and ttH(γγ)

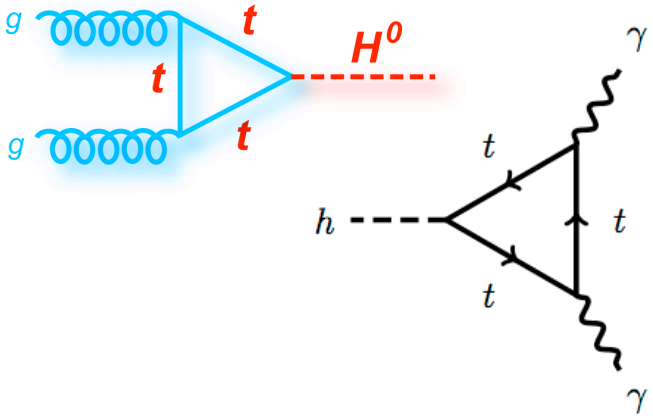




Fit to 5 Higgs channels:



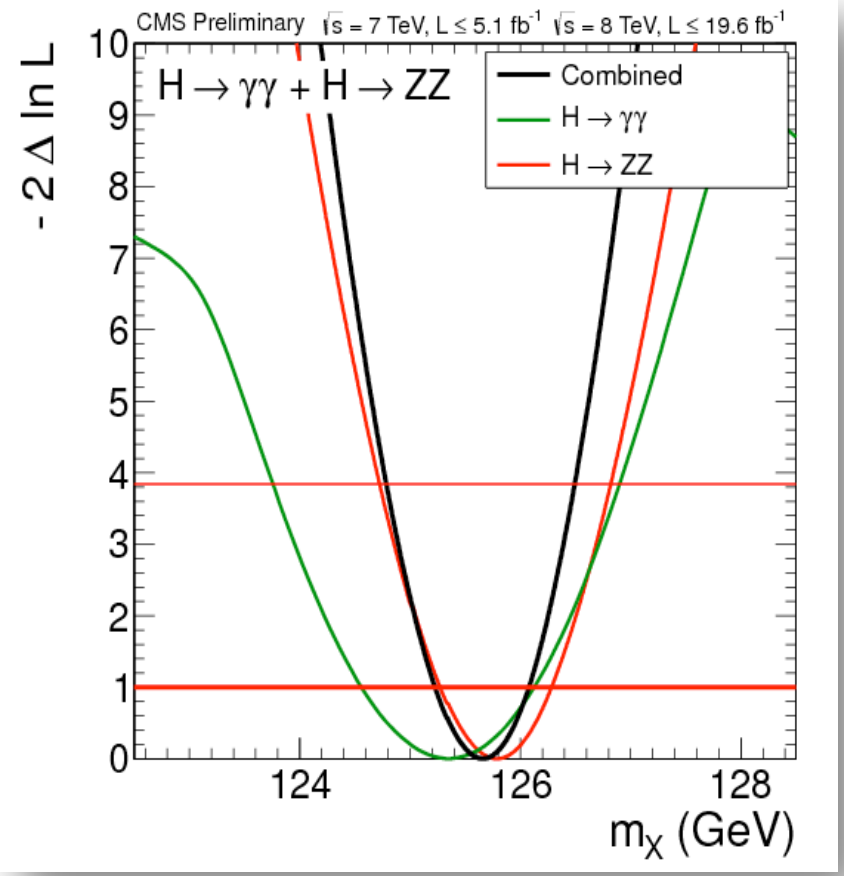
Higgs production via gluon fusion and Higgs decay in two photons depend on Yukawa coupling to top quark



Higgs properties

HIG-13-005

Higgs mass



H →ZZ→4l:

Mass estimation with m_{4l}, KD and $\sigma(m_{4l})$
Very small systematics due the very good control of the leptons scale and resolution:

m_H = 125.8 ± 0.5 (stat.) ±0.2 (syst.) GeV

H →γγ:

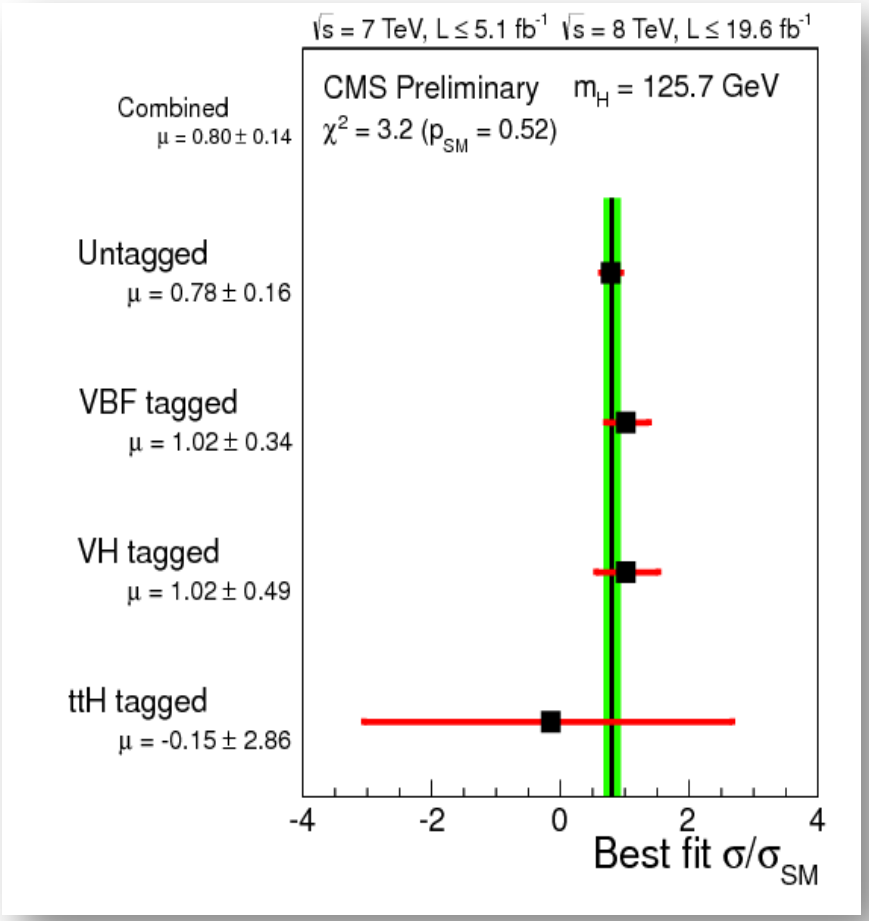
Systematics on the extrapolation from the Z→ee to H→γγ (0.25% from e to γ, 0.4% from Z to H):

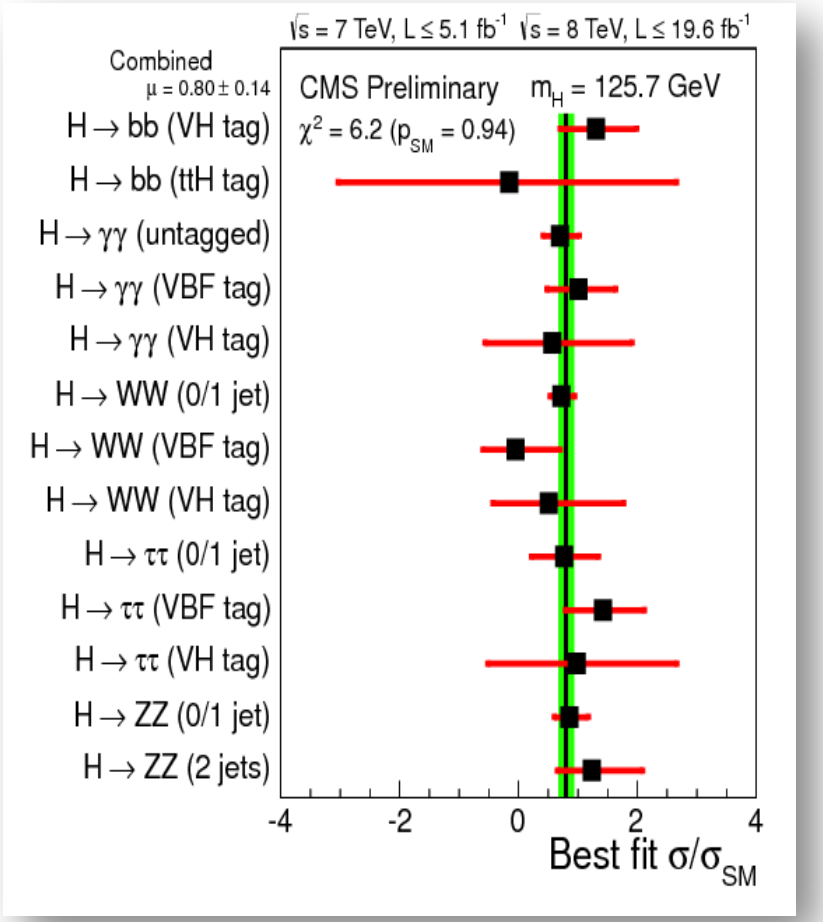
m_H = 125.4 ± 0.5 (stat.) ±0.6 (syst.) GeV

$m_X = 125.7 \pm 0.3^{(stat)} \pm 0.3^{(syst)}$ GeV
$= 125.7 \pm 0.4$ GeV

Consistency of signal with SM

μ signal strength: ratio of σ.BR measurement and SM prediction



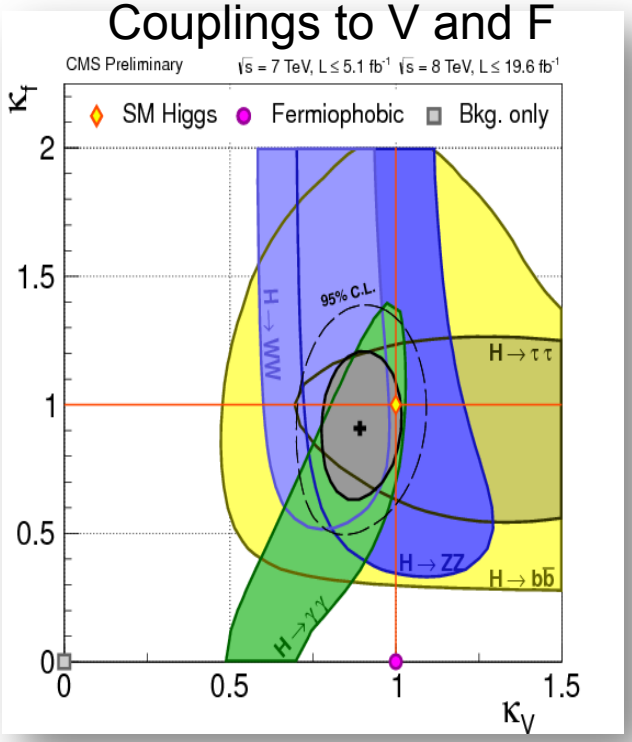


μ=0.80±0.14

Couplings to bosons and fermions

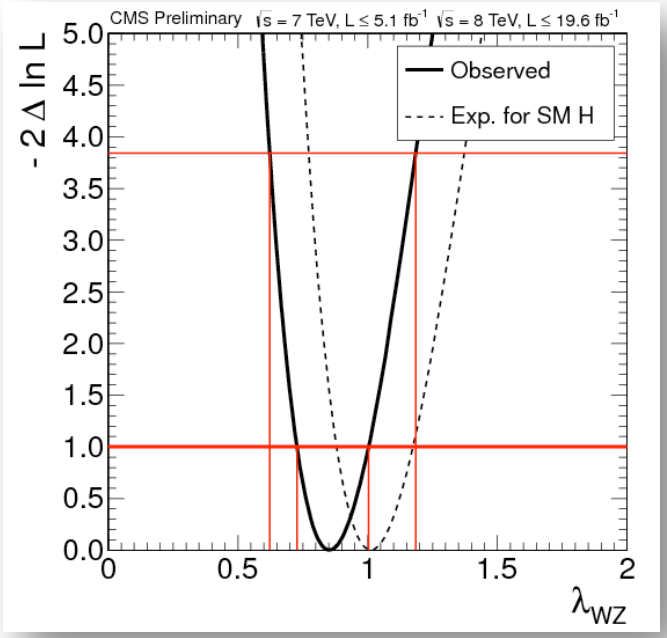
- LHC XS WG benchmark models:
  - Fermionic vs bosonic couplings modifiers: $\kappa_V\ \kappa_f$
  - Search for asymmetries: λ_{WZ}, λ_{du}, λ_{lq}
  - Search for new physics in loops: $\kappa_g\ \kappa_\gamma\ BR_{BSM}$

Couplings to V and F



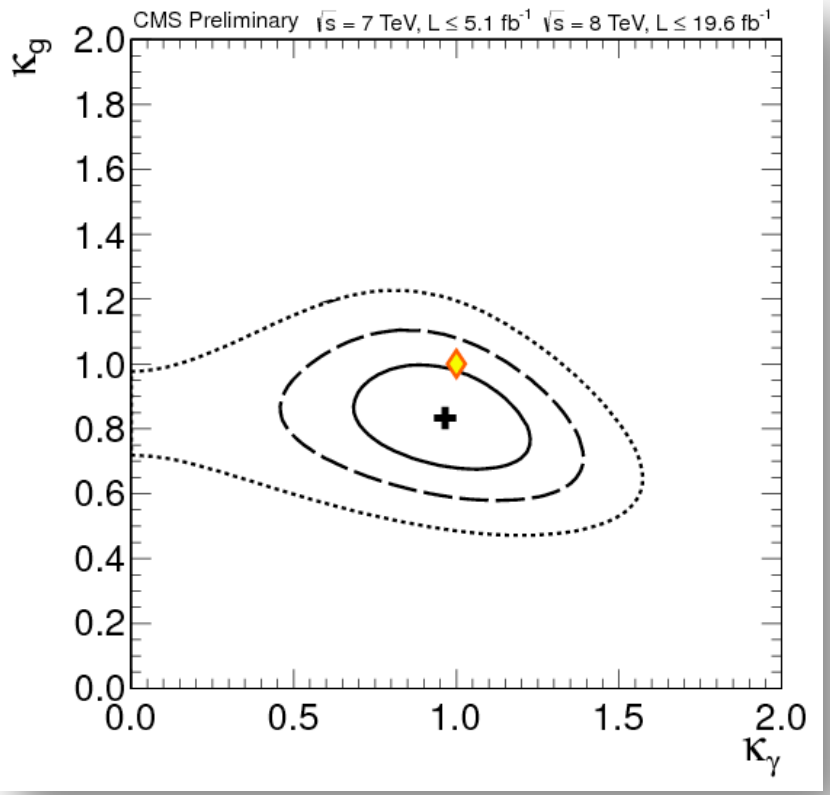
K_V [0.81, 0.97] @ 68% CL
K_F [0.71, 1.11] @ 68% CL

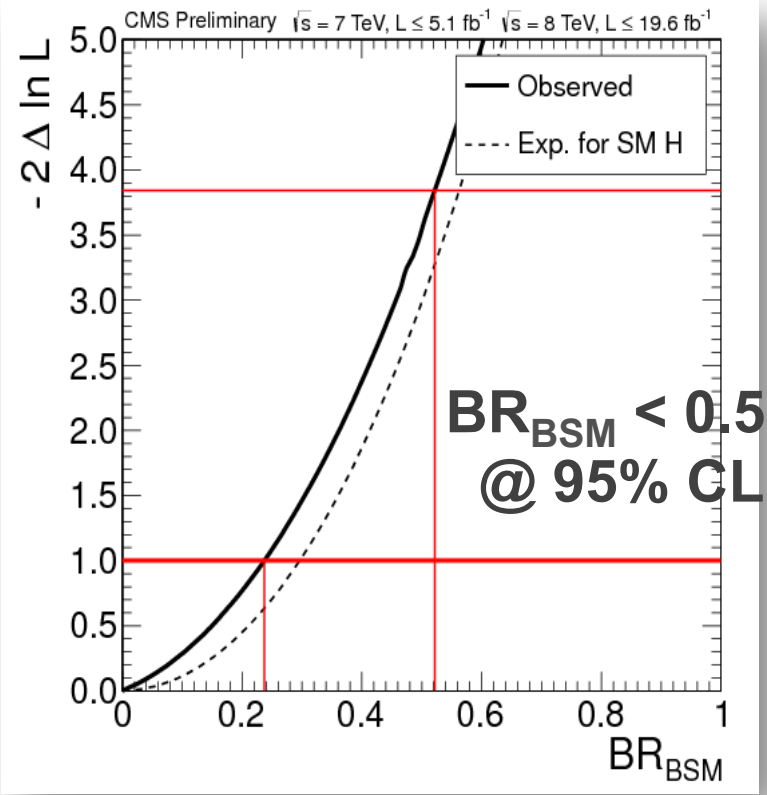
Custodial symmetry



λ_{WZ} [0.73,1.00] @ 68% CL

Couplings to gluons and photons



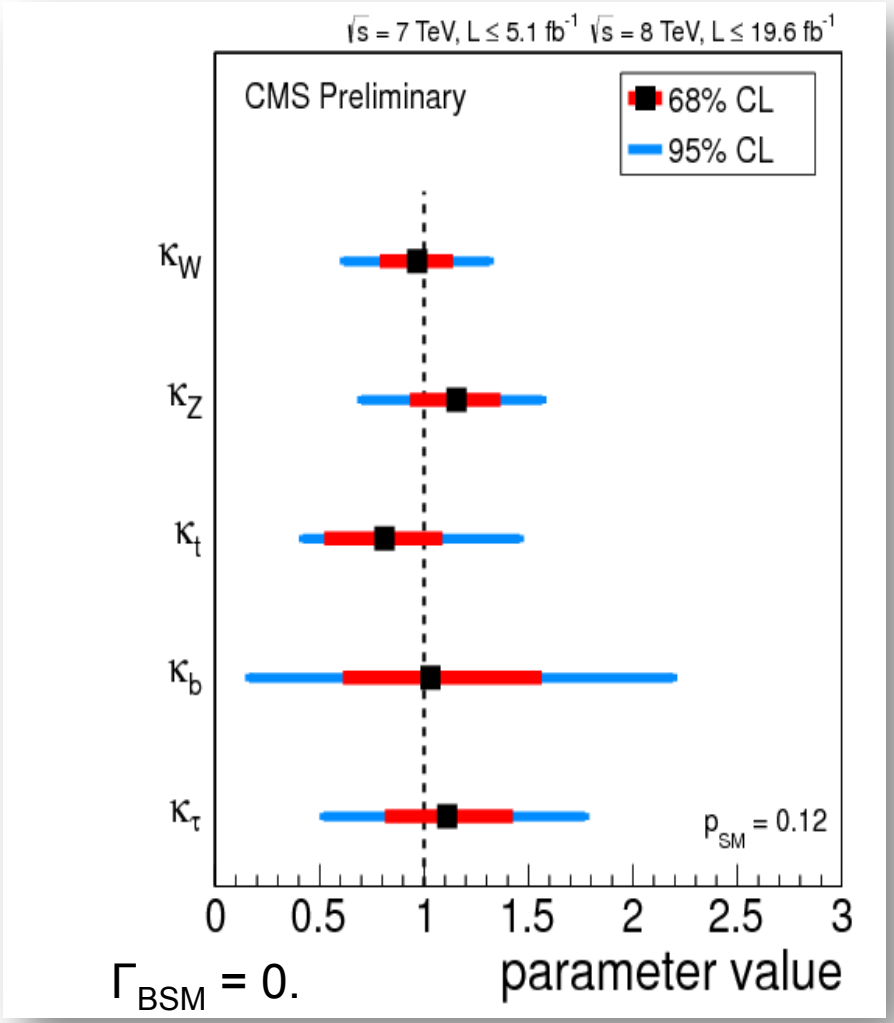


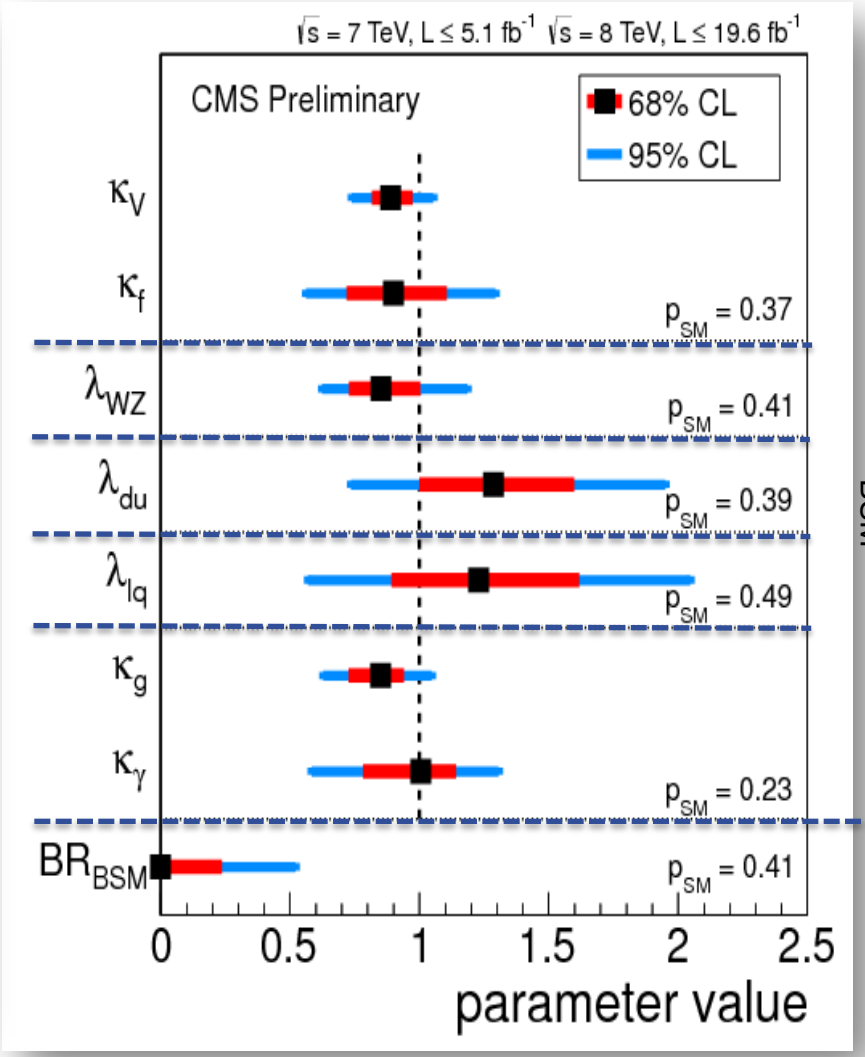
Effective couplings to gluons and photons.

$\Gamma_{BSM} = 0$.

Loop-induced couplings free (κ_γ , κ_g profiled).

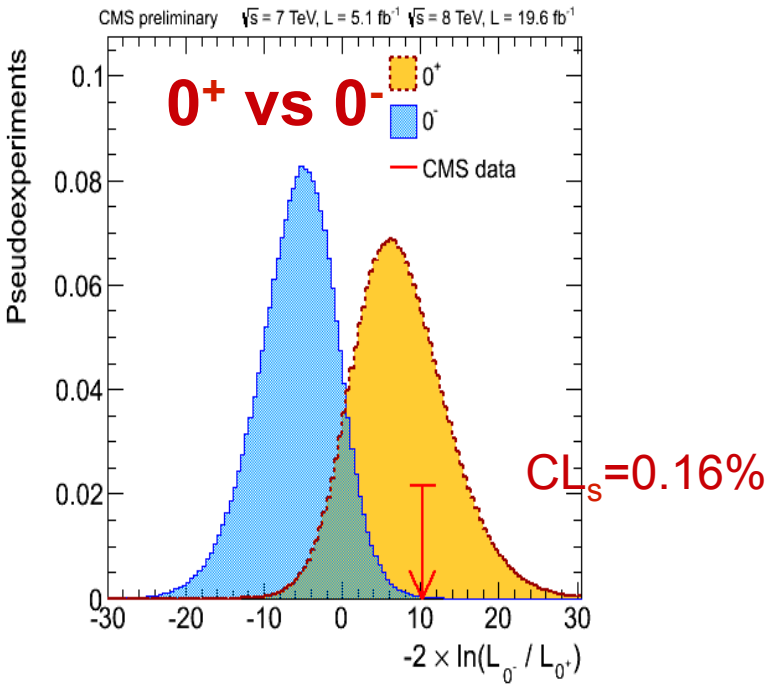
Summary of couplings





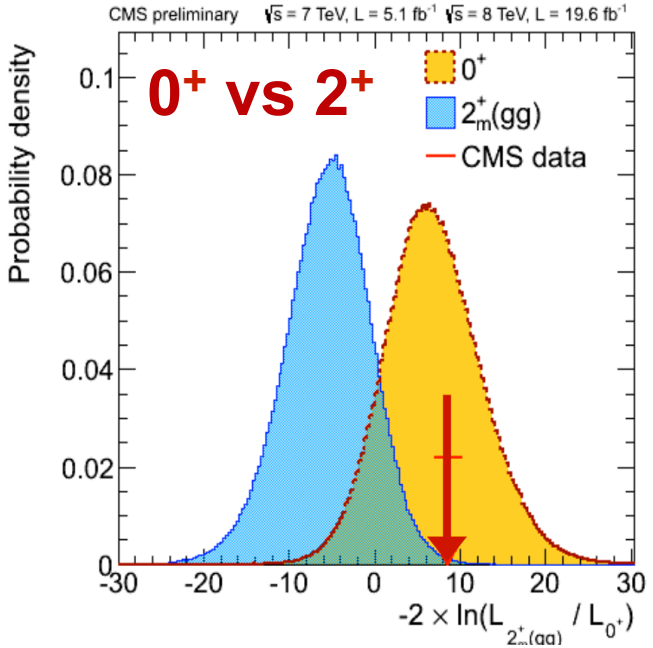
Higgs Spin-Parity

$H \rightarrow ZZ^{(*)} \rightarrow 4l$



CL_s=0.16%

The data disfavours 0^- (pseudoscalar) hypothesis with a CLs value of 0.16%



CLs values for $2^+_m(gg)$:

ZZ	WW	Combined
1.4%	14%	0.6%

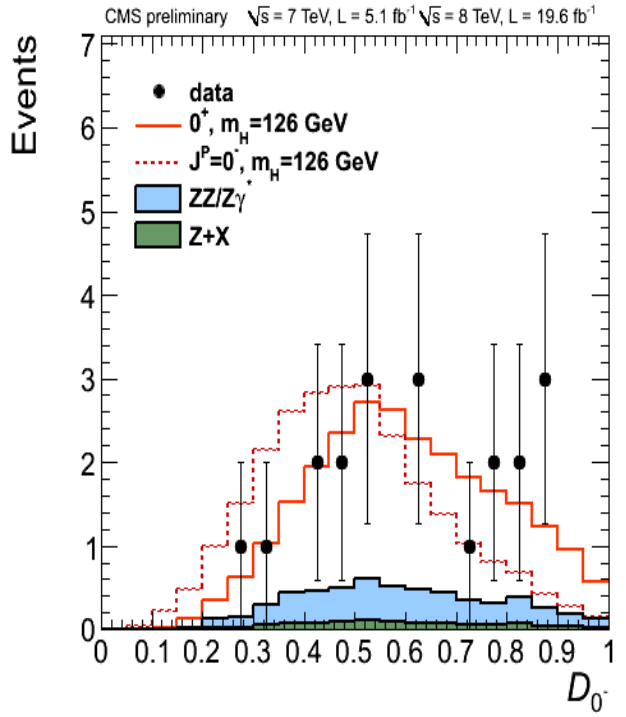
The data disfavours $2^+_m(gg)$ hypothesis with a CLs value of 0.6%

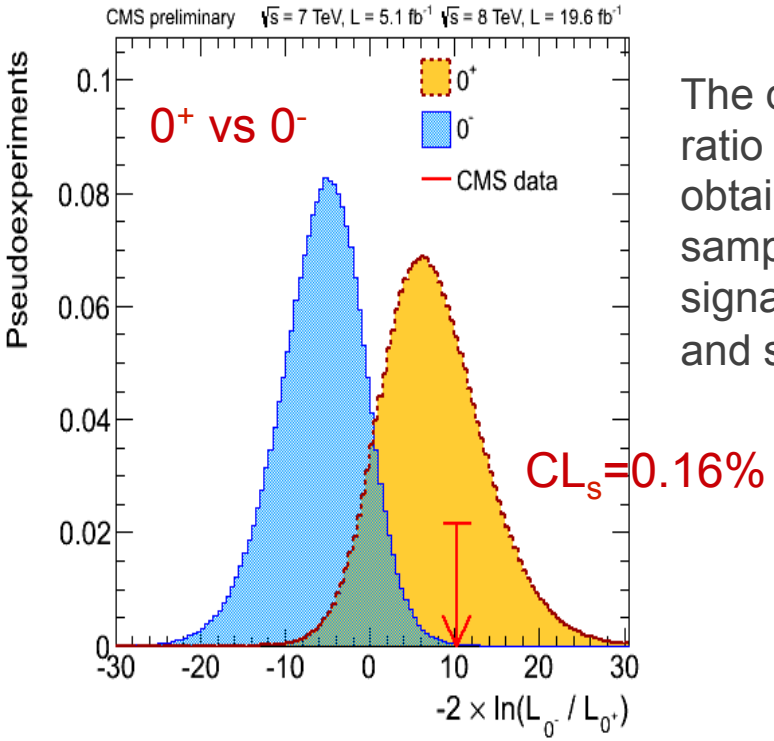
The observations are compatible with the SM Higgs expectation (scalar)

Spin-Parity: 0^+ vs 0^-

- Kinematic Discriminant : $D_{JP}=P_{SM}/(P_{SM}+P_{JP})$
- Second observable: $D_{bkg} = P_{sig}/(P_{sig} + P_{bkg})$
  - P_{bkg} and P_{sig} include the m_{4l} parameterizations
- Likelihood fit of events to 2D distributions (D_{JP}, D_{bkg})

$$H \rightarrow ZZ^{(*)} \rightarrow 4l$$





The distribution of the likelihood ratio $q = -2\ln(L_{JP}/L_{SM})$ is obtained with generated samples of background and signal of seven types (SM 0^+ and six J^P) for m_H=126 GeV.

More J^P hypotheses tested

J^P	CL_s
0^-	0.16%
0_h^+	8.1%
2^+_{mgg}	1.5%
$2^+_{mq\bar{q}}$	<0.1%
1^-	<0.1%
1^+	<0.1%

The data disfavours 0^- (pseudoscalar) hypothesis with a CLs value of 0.16%

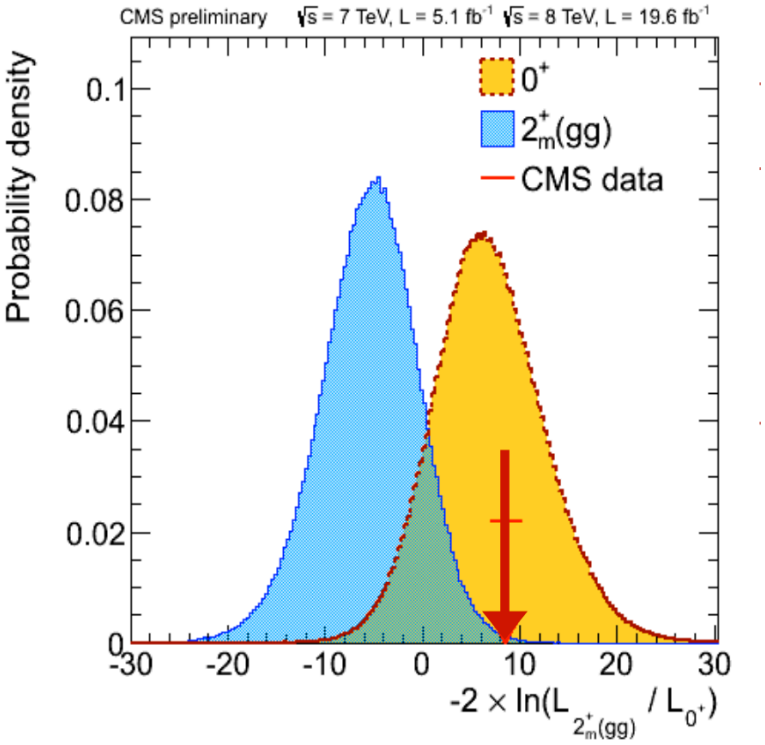
Additional material Spin-Parity: 0^+ vs 2^+

CLs values for $2^+_m(gg)$:

Observed results at measured μ

ZZ	WW	Comb
1.4%	14%	0.6%

- WW: observed results weaker than expected due to best fit $\mu < 1$
- ZZ: observed better than expected due to a fluctuation

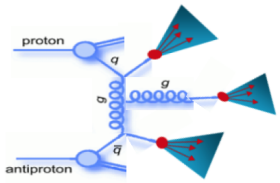


The data disfavours $2^+_m(gg)$ hypothesis with a CLs value of 0.6%

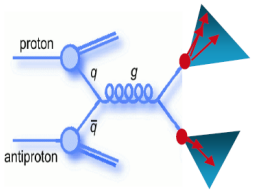
The observations are compatible with SM Higgs expectation (scalar)

Jets and vector bosons

3-jet to 2-jet cross section



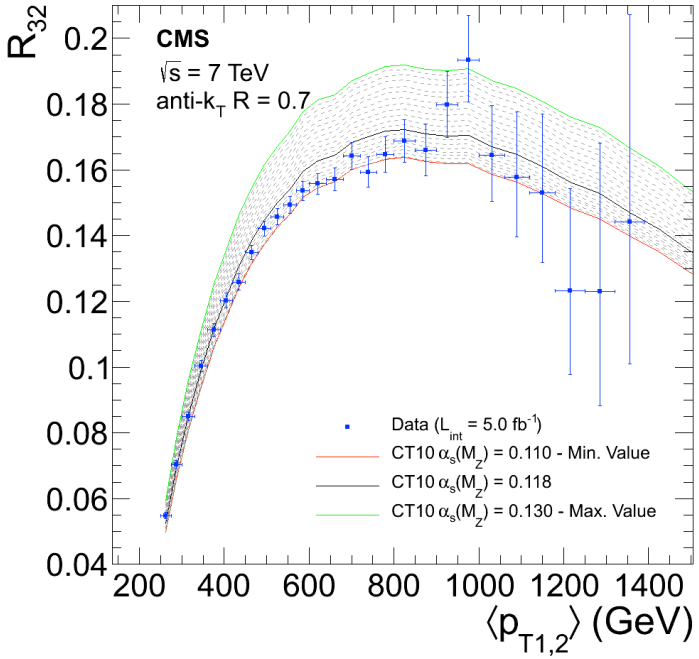
$\Leftrightarrow \alpha_s$

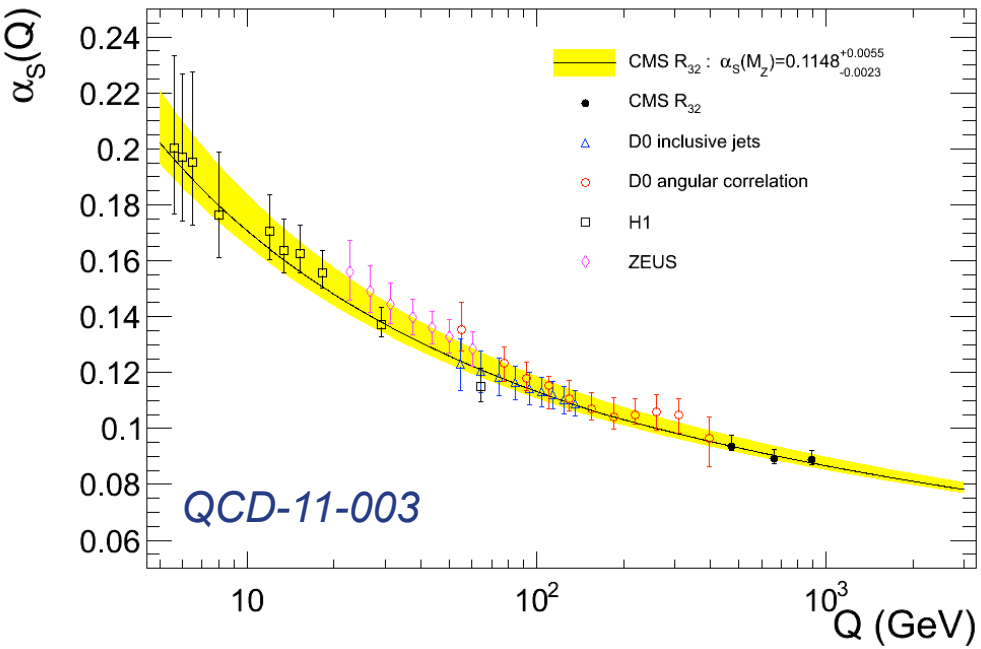


First determination of α_s at momentum scales > 0.4 TeV

- Comparing the ratio in the range 0.42< $\langle p_{T1,2} \rangle$ <1.39 TeV to the predictions of perturbative QCD at next-to-leading order
- Measurement dominated by TH uncertainty: PDF & scale

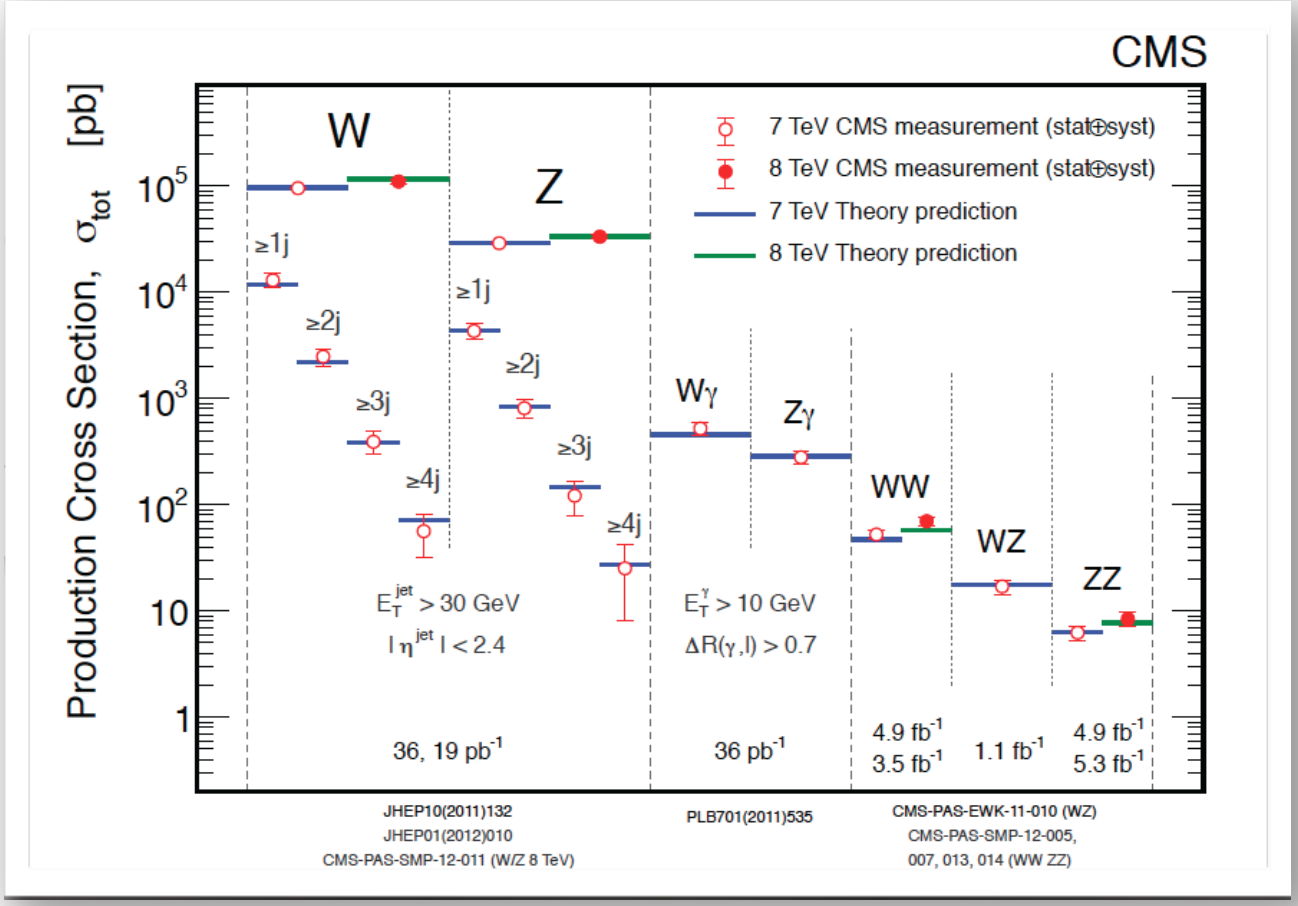
$$\alpha_s(M_Z) = 0.1148 \pm 0.0014(\text{exp.}) \pm 0.0018(\text{PDF})^{+0.0050}_{-0.0000}(\text{scale})$$





Vector bosons

W, Z, WW, and ZZ cross sections at 7 and 8 TeV:



SMP-12-011
SMP-12-013
SMP-12-014

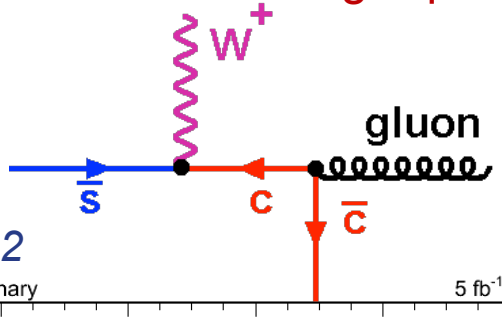
Measured σ (ZZ) = 8.4 ± 1.3 pb
SM (NLO) σ (ZZ) = 7.7 ± 0.4 pb

Measured σ (WW) =69.9 ± 7.0 pb
SM (NLO) σ (WW) = 57.3 ± 2.0 pb

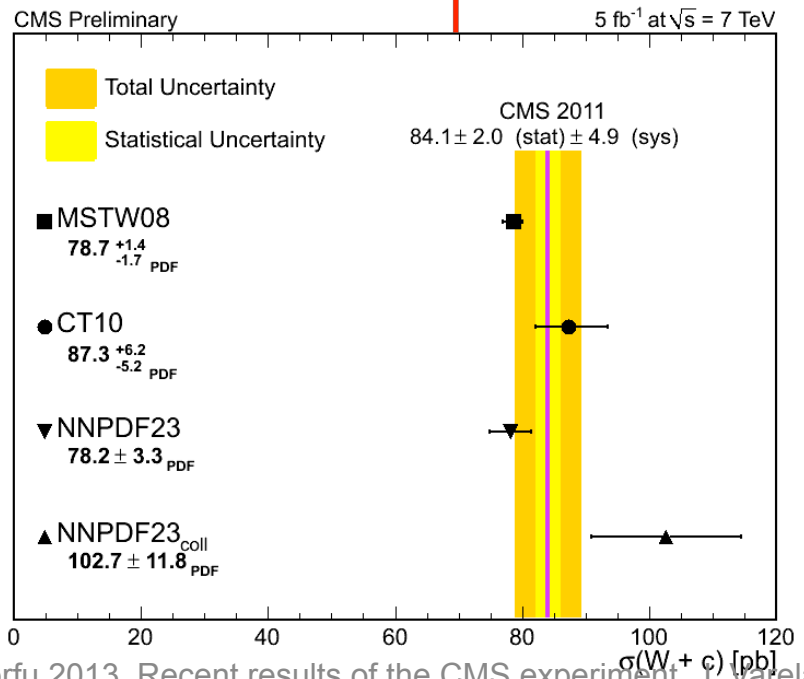
V + heavy quarks

W+c production with exclusive charm tagging via full reconstruction of $D^{\pm}$, D^*, and semileptonic decays

Direct access to the strange-quark PDF



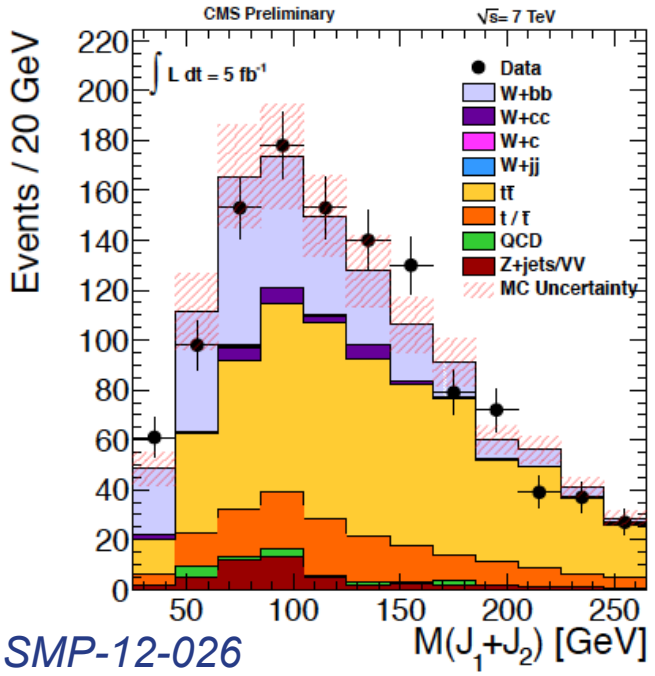
SMP-12-002



W+bb and Z+bb cross section measurements:

- $\sigma \times Br(W \rightarrow \mu\nu) = 0.53 \pm 0.12$ pb @ 7 TeV ($p_T^{b,\mu} > 25$ GeV), in good agreement with NLO prediction of 0.52 ± 0.03 pb
- $\sigma \times Br(Z \rightarrow ll) = 0.36 \pm 0.07$ pb @ 7 TeV ($p_T^{b} > 25$ GeV)

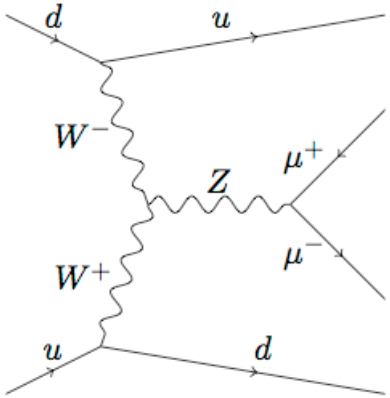
SMP-13-004



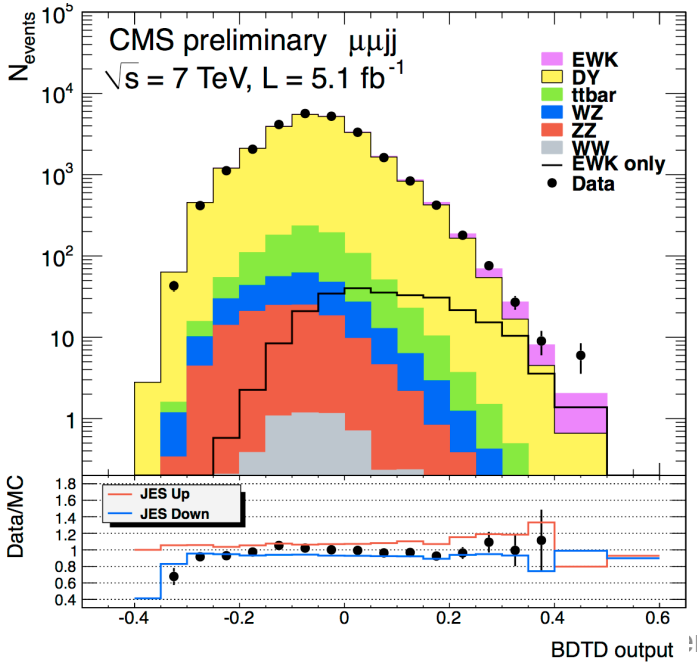
SMP-12-026

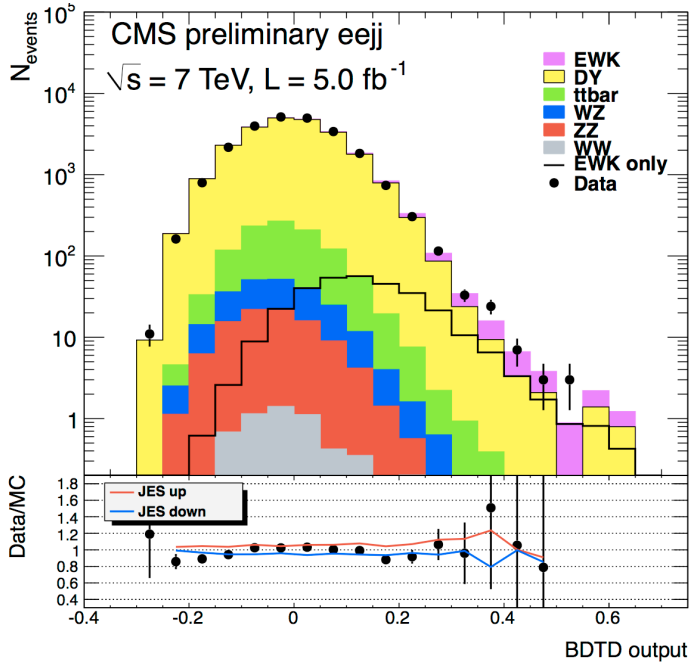
VBF Z production

- First-time ever observed !
- Benchmark for VBF Higgs searches
- Dominant background from standard DY production
  → BDT discriminant used to extract the signal



$$\sigma^{EWK}_{\text{meas},\,\mu\mu+ee} = 154 \pm 24(\text{stat.}) \pm 46(\text{exp.syst.}) \pm 27(\text{th.syst.}) \pm 3(\text{lumi.})\ \text{fb}$$





Agreement with NLO prediction (σ_{NLO}=166 fb, VBFNLO, CT10)

7 TeV

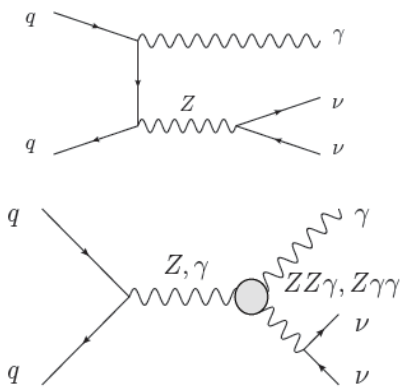
FSQ-12-019

Anomalous TGCs

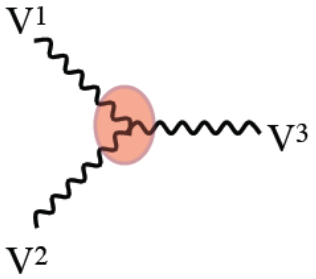
Z(νν)γ cross section:

σ = 21.3 ± 4.2 (stat.) ± 4.3 (syst.) ± 0.5 (lumi.) fb

In good agreement with the theoretical prediction of 21.9 ± 1.1 fb (BAUR).

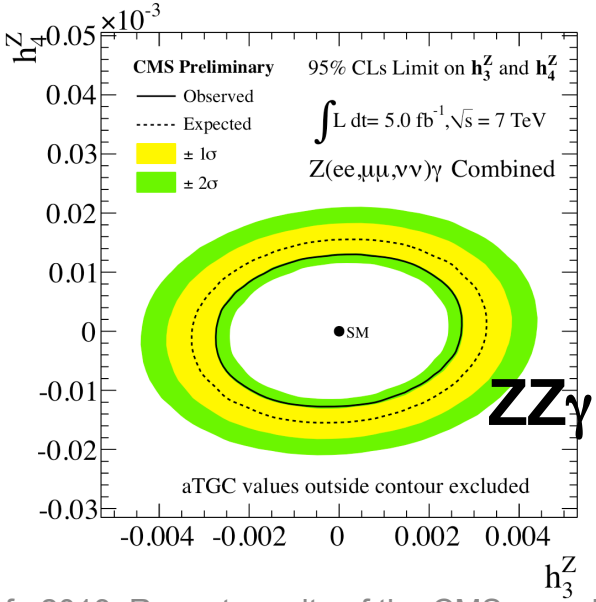


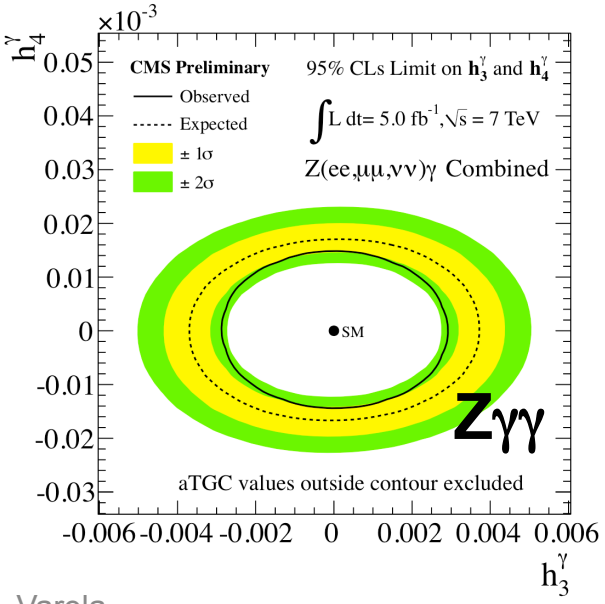
Forbidden in SM



aTGCs in CMS:
EWK-11-009 (Vγ),
SMP-12-015 (WW,WZ)
SMP-12-007 (ZZ),
SMP-12-020 (Zγ)

Z(ee, μμ, νν)γ combined:

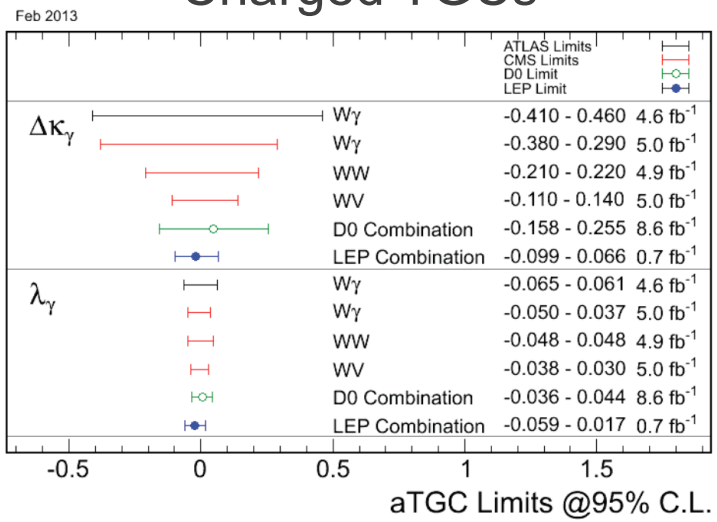




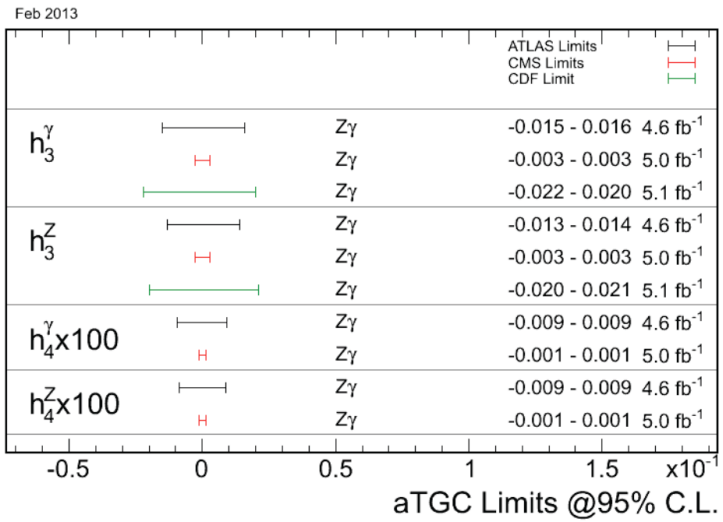
SMP-12-020

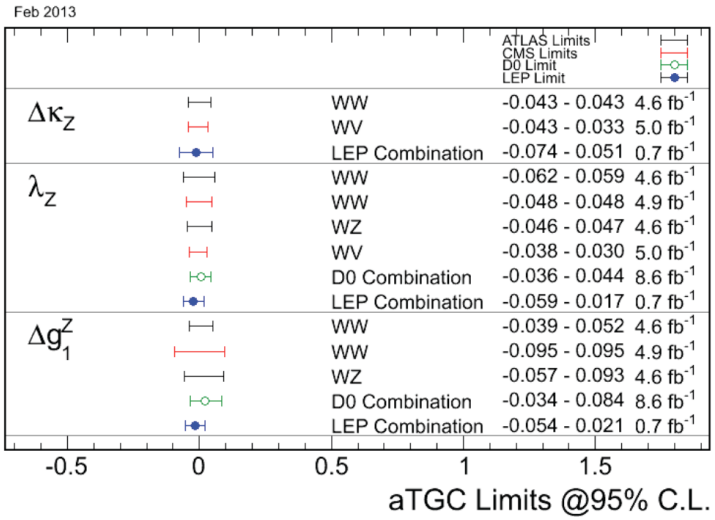
Anomalous TGCs (cont.)

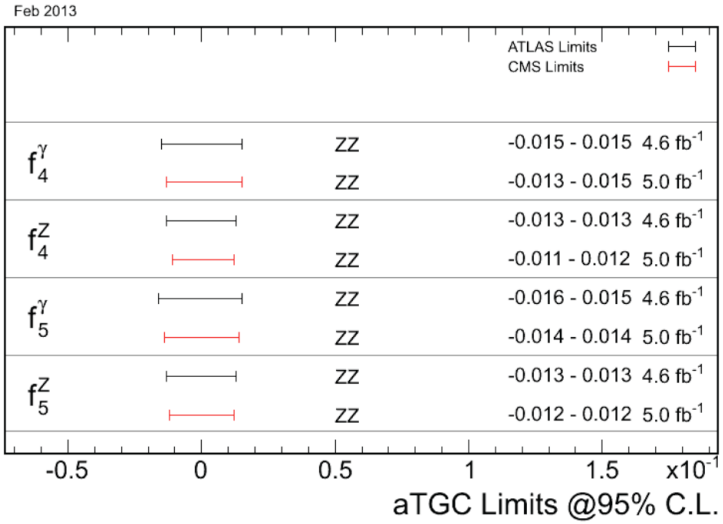
Charged TGCs



Neutral TGCs







LHC measurements approaching LEP sensitivities

LHC measurements already exceeded LEP sensitivities

Top quark

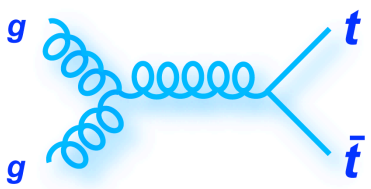
Top quark physics

The top quark is an interesting object:

- The heaviest elementary particle *(mass ~ 173 GeV , similar to tungsten atom)*
- The largest Yukawa coupling to Higgs boson ($y_t \approx 1$)
- The only quark that doesn't hadronize *($\tau(had) \sim h/\Lambda_{QCD} \sim 2\ 10^{-24}$ s; $\tau(top) \sim h/\Gamma_{top} \sim 5\ 10^{-25}$ s)*

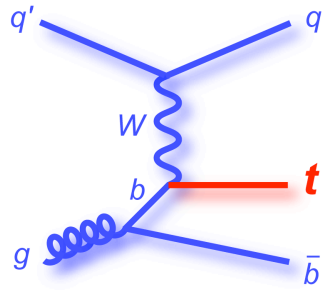
Top pair production:

Consistent with SM predictions?
Polarizations and spin correlations?
Charge asymmetries?
Resonant production?



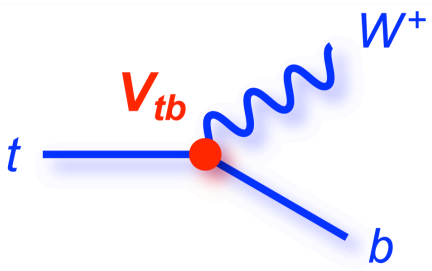
Single top production:

V_{tb} from cross-section
t-channel, s-channel,
associated production



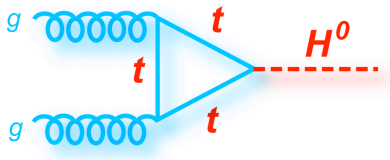
Top decay:

Is $V_{tb} = 1$?
Anomalous couplings in Wtb vertex?
Rare decays by FCNC to γq, Zq, qg ?
$t \rightarrow H^+ b$?



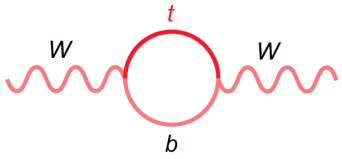
Top-Higgs coupling:

Coupling to Higgs boson
as predicted in SM?

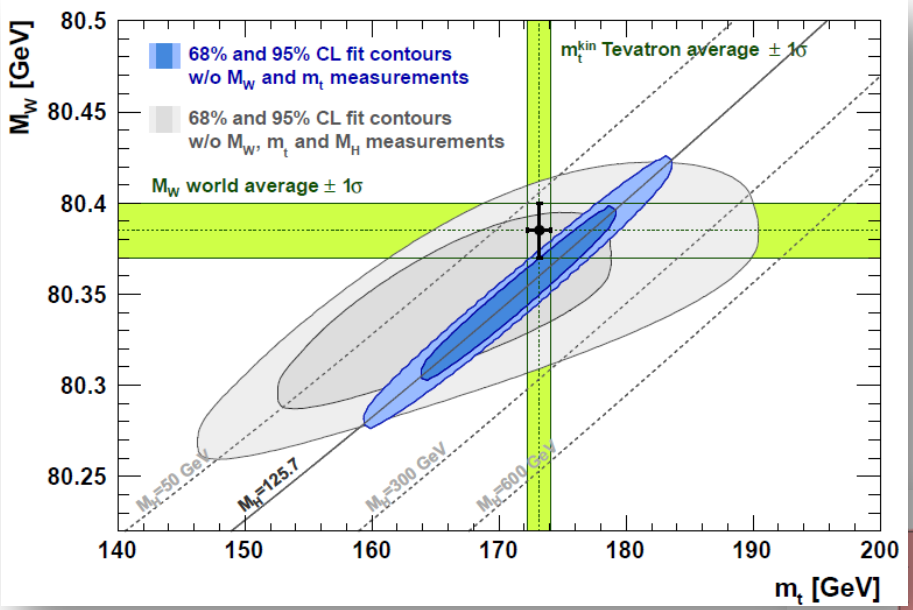


Mass measurement:

Compatible with SM relation to m_W and m_H?
CPT invariance in top sector $m_{top} = m_{anti\text{-}top}$?

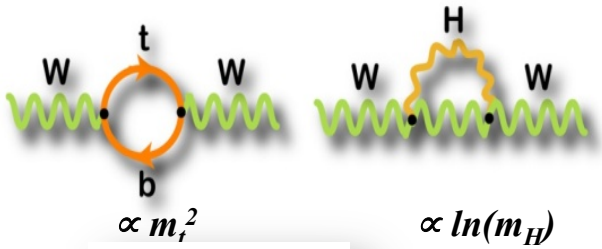


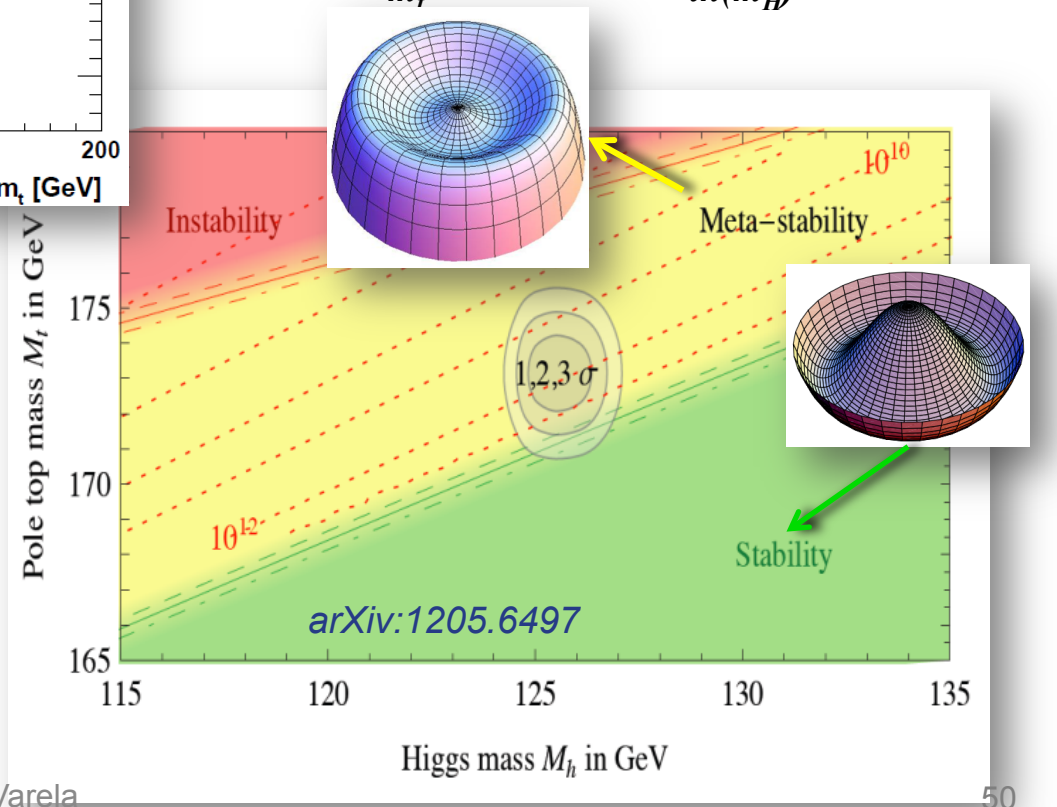
Top mass in the standard model



Correlation between m_t and m_W measurements is not shown

m_t, m_W, m_H are related at loop level



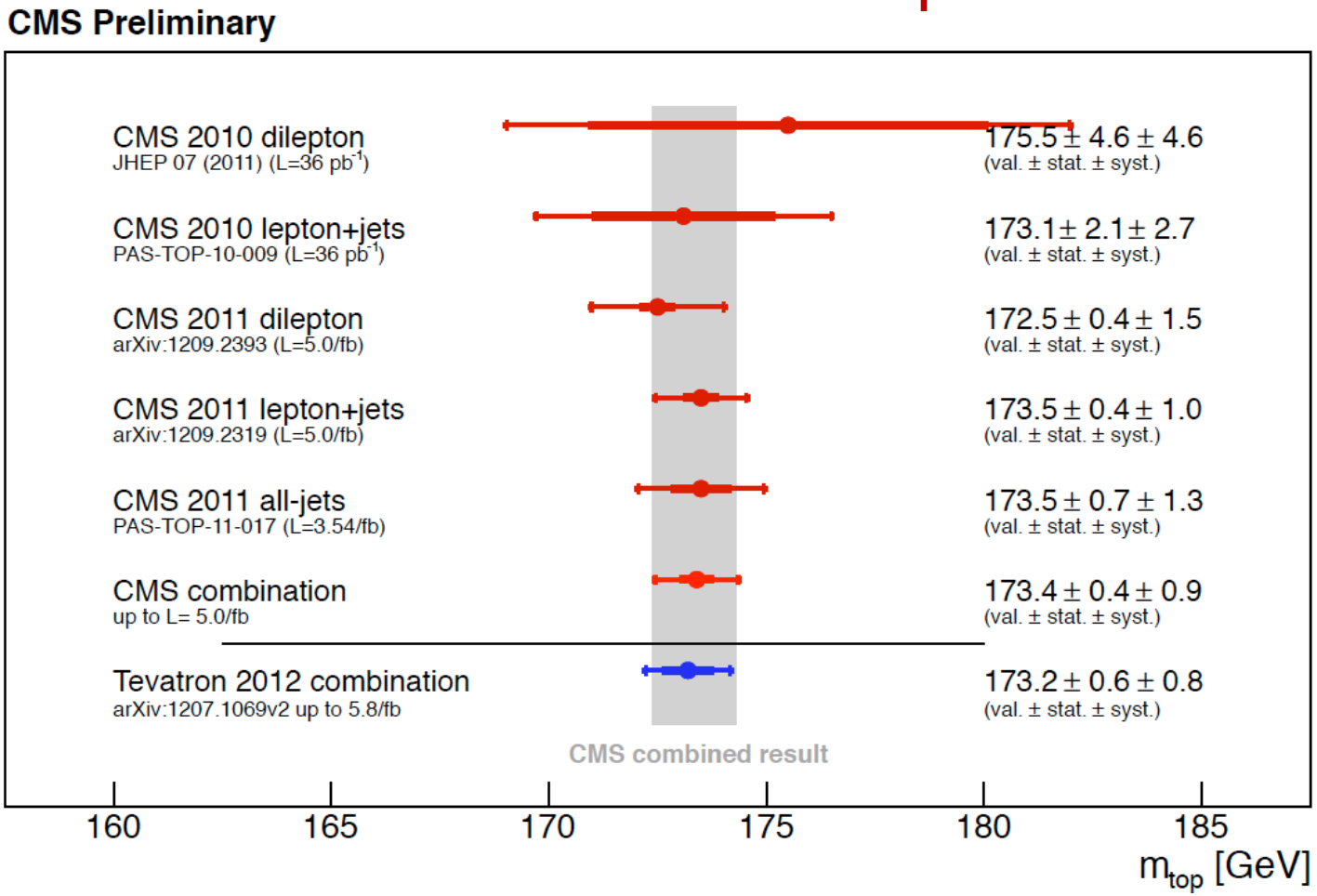


Vacuum stability is dependent of m_{top}

Top mass measurement

The CMS measurement has reached the same precision of the Tevatron.

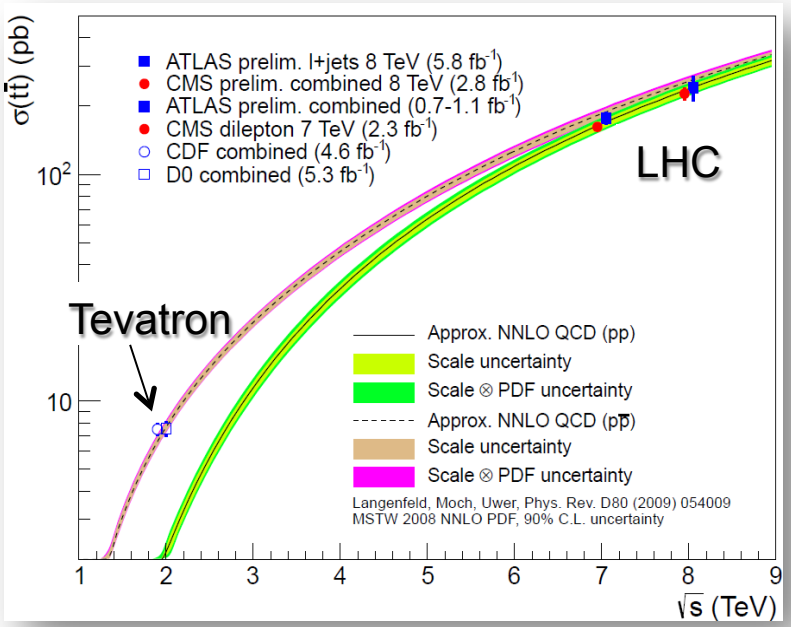
0.5% precision



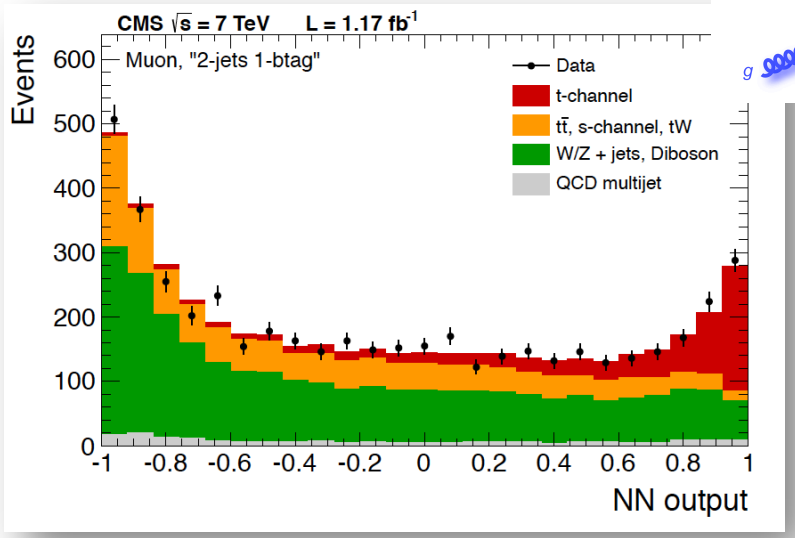
Top quark production

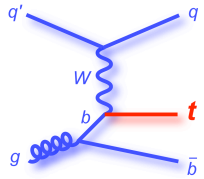
- Excellent agreement of Tevatron and LHC measurements with QCD
- Comparable experimental and theoretical uncertainties ~ ±5%

top-antitop cross section



Single top production





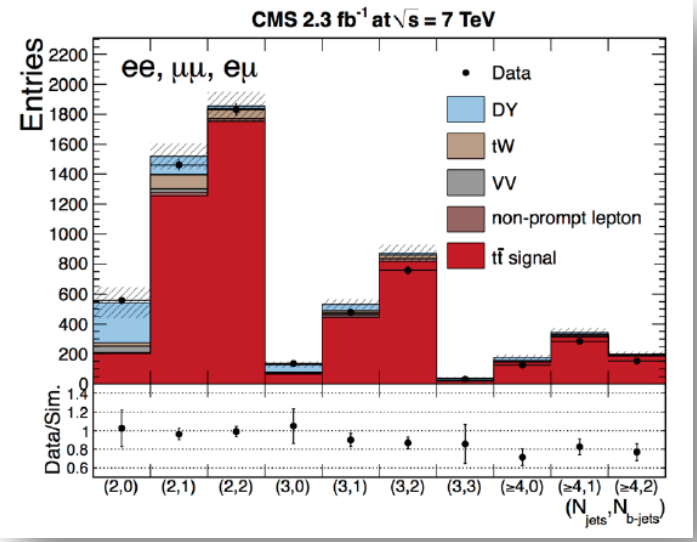
t-channel 7 TeV :
σ_t = 67.2 ± 6.1 pb (CMS)
|Vtb| = 1.020 ± 0.046 (exp.) ± 0.017 (th.)

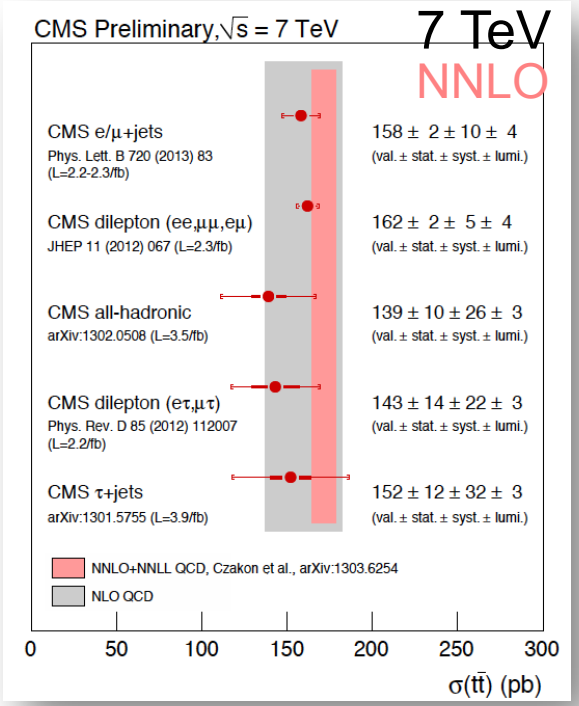
t-channel 8 TeV:
σ_t = 80.1 ± 13 pb *(CMS-PAS-TOP-12-011)*
|Vtb| = 0.96 ± 0.08 (exp.) ± 0.02 (th.) pb

Top pair cross section at 7 TeV

Additional material

Dileptons:





Most precise measurement at 7 TeV (CMS dilepton)

σ_{tt}=162 ± 2 (stat.) ± 5 (syst.) ± 4 (lumi.) pb ±4 %

Main systematics:

- Jet energy scale
- W branching fractions
- Lepton efficiencies

NNLO+NNLL predictions (mt=173.3 GeV)

Collider	σ_{tot} [pb]	scales [pb]	pdf [pb]
LHC 7 TeV	172.0	$^{+4.4(2.6\%)}_{-5.8(3.4\%)}$	$^{+4.7(2.7\%)}_{-4.8(2.8\%)}$

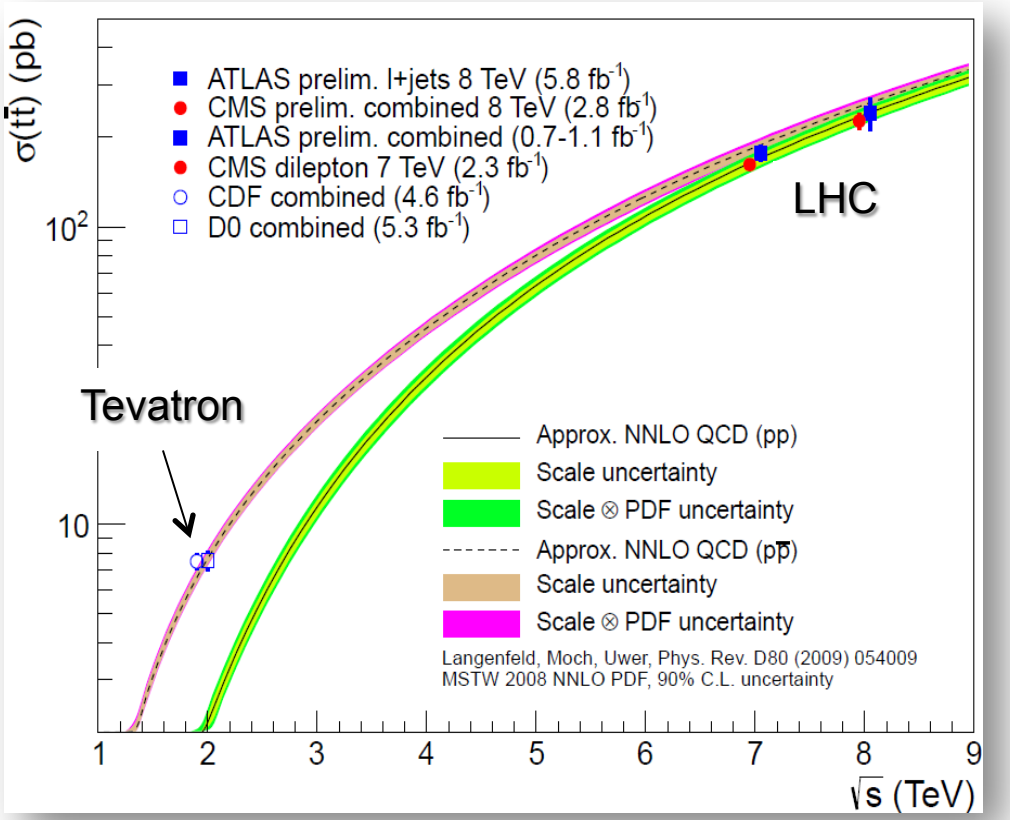
±4 %

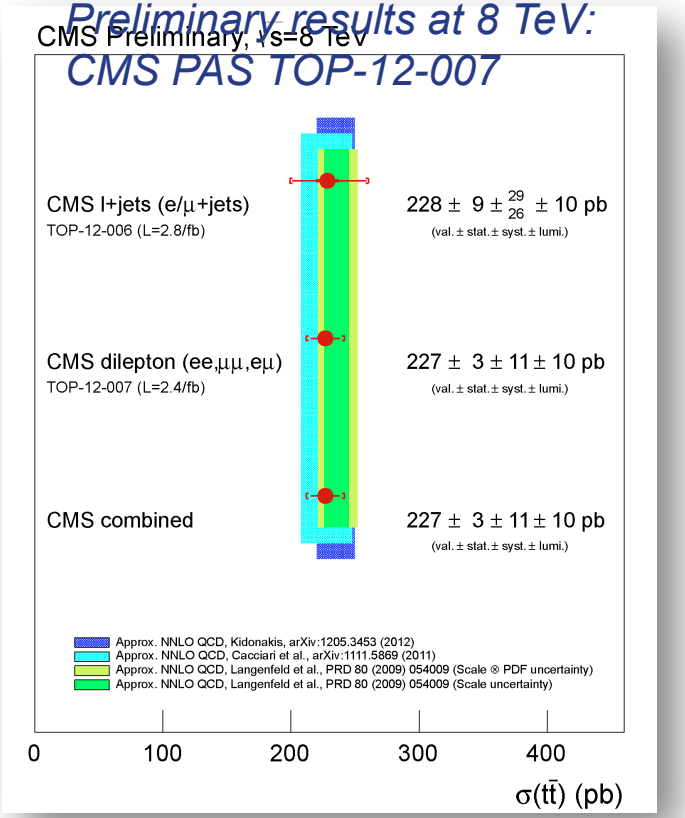
Czakon, Fiedler, Mitov, arXiv:1303.6254

Top pair cross section at 8 TeV

Additional material

- CMS preliminary measurements at 8 TeV are available
- Excellent agreement of Tevatron and LHC measurements with QCD
- Comparable experimental and theoretical uncertainties ~ ±5%





Top pair differential cross sections

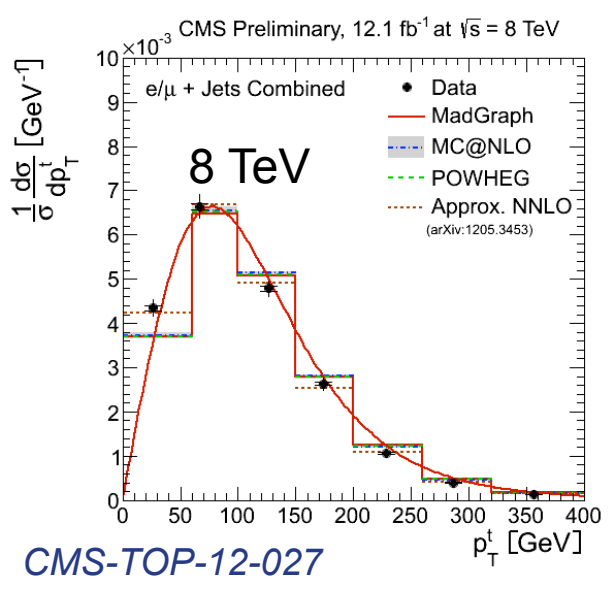
Measurement of top pairs in different regions of the phase space at LHC

- Constrain MC predictions
- Contribute to PDF determination
- Sensitivity to new physics

Experimental aspects:

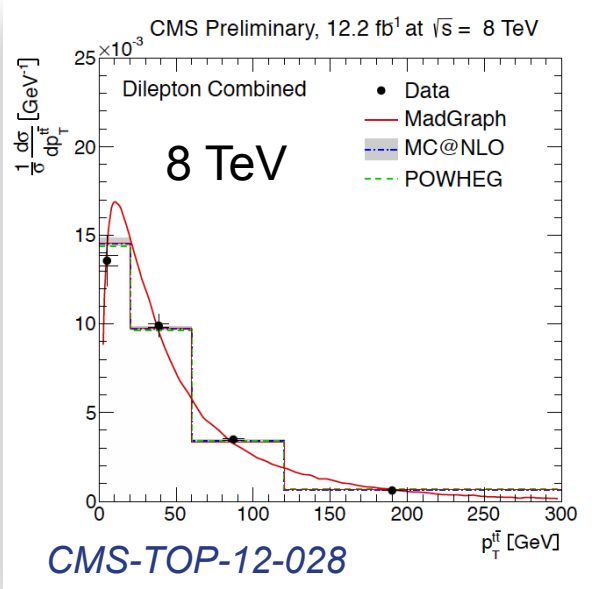
- detector effects unfolded allow direct comparison to predictions
- full reconstruction of top quark kinematics
- measurements are systematics dominated; full covariance matrix is provided

$p_T(t)$, l+jets



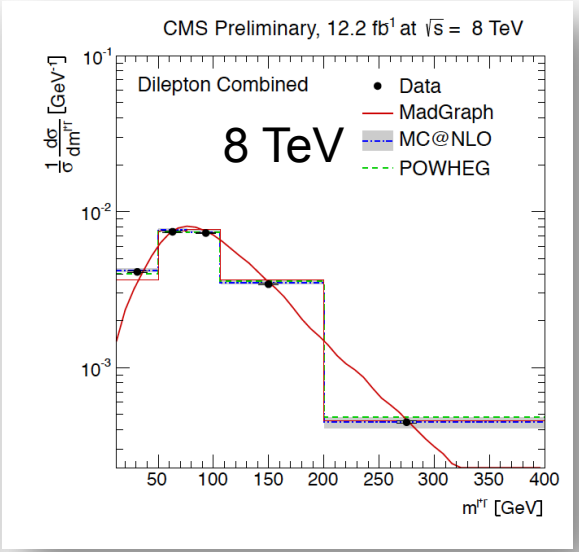
CMS-TOP-12-027

$p_T(tt)$, dilepton



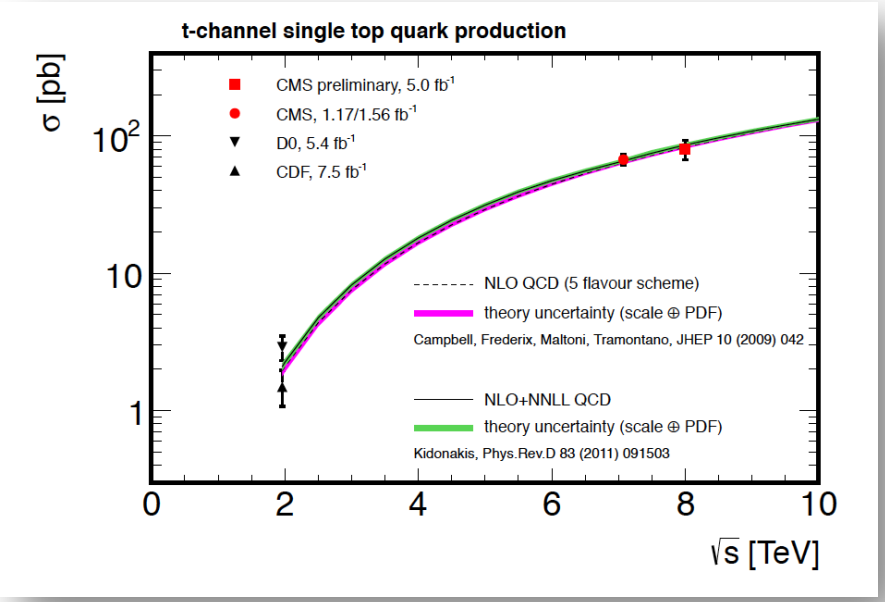
CMS-TOP-12-028

m(tt), dilepton



Single top production

Main systematics:
- generator, ISR/FSR
- b-tagging

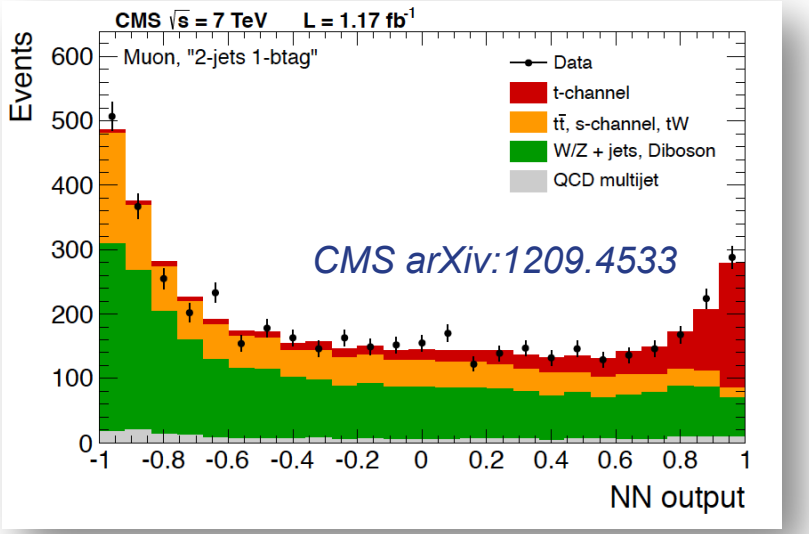


SM calculation at 8TeV:

$$\sigma_t^{\text{th}} = 87.2^{+2.1}_{-0.7}\,(\text{scale})^{+1.5}_{-1.7}\,(\text{PDF})\ \text{pb}$$

N. Kidonakis, arXiv:1205.3453

Multivariate techniques using full event properties to optimize sensitivity



t-channel 7 TeV : *(CMS arXiv:1209.4533)* Vtb uncert.

σ_t = 67.2 ± 6.1 pb (CMS)

|Vtb| = 1.020 ± 0.046 (exp.) ± 0.017 (th.) ±5%

t-channel 8 TeV:

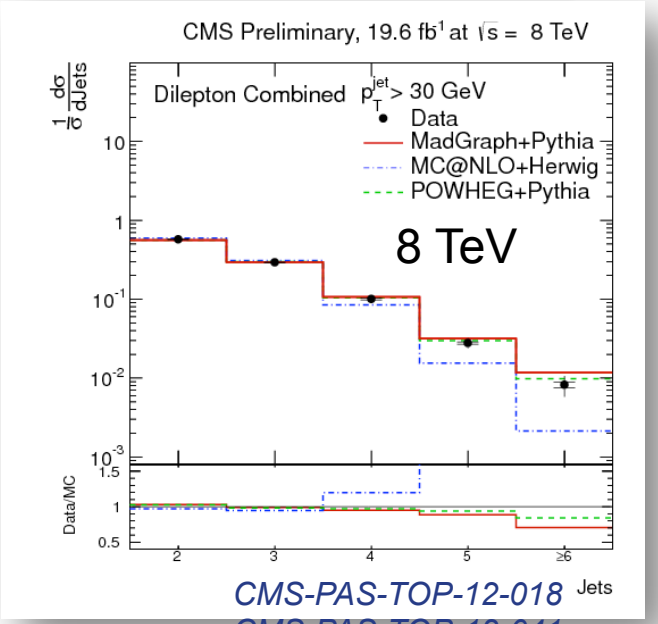
σ_t = 80.1 ± 13 pb *(CMS-PAS-TOP-12-011)*

|Vtb| = 0.96 ± 0.08 (exp.) ± 0.02 (th.) pb ±8%

Top pair associated production

Additional jets from QCD radiation

- top mass measurement systematics
- background in searches for new physics



CMS-PAS-TOP-12-018
CMS-PAS-TOP-12-041

Additional heavy flavor jets in di-lepton events

- additional bbar jets

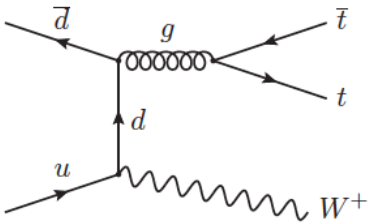
(CMS-PAS-TOP-12-024)

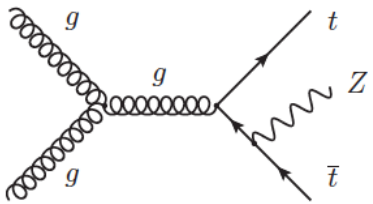
$$\sigma(t\bar{t}b\bar{b})/\sigma(t\bar{t}jj) = 3.6 \pm 1.1(\text{stat.}) \pm 0.9(\text{syst.})\%$$

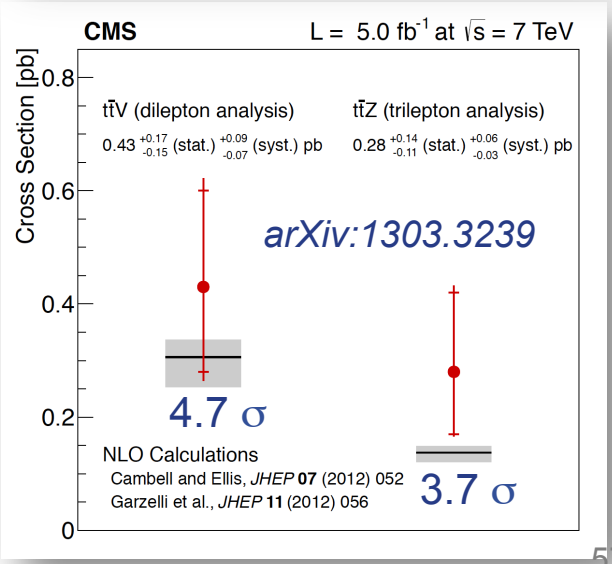
- larger than the predictions using MADGRAPH (1.2%) and POWHEG (1.3 %)

Top pair associated to V and to Z

measures coupling between t and Z







Ratio B(t→Wb) / B(t→Wq)

- Top events in dilepton channel
- Requires good understanding of b-tagging efficiency and ISR/FSR background jets
- Background estimated from data

R → $|V_{tb}|$ with the assumption of CKM unitarity and 3 generations:

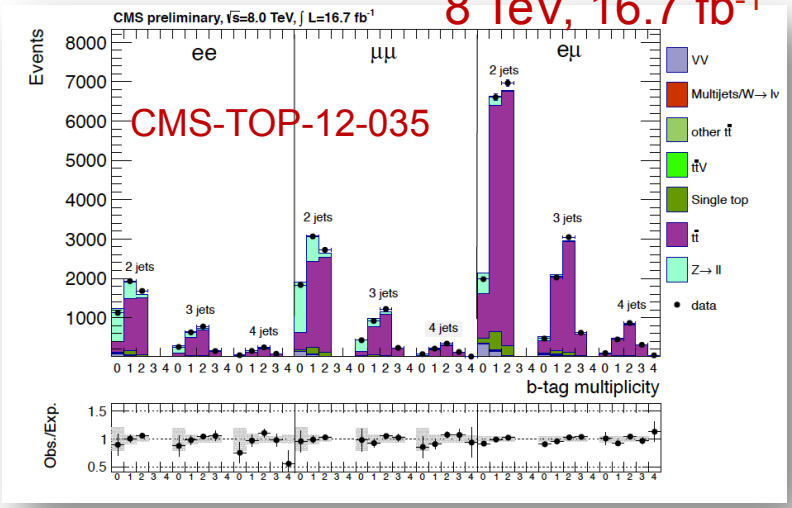
$$R = \frac{B(t \to Wb)}{\sum_{q=d,s,b} B(t \to Wq)} = |V_{tb}|^2$$

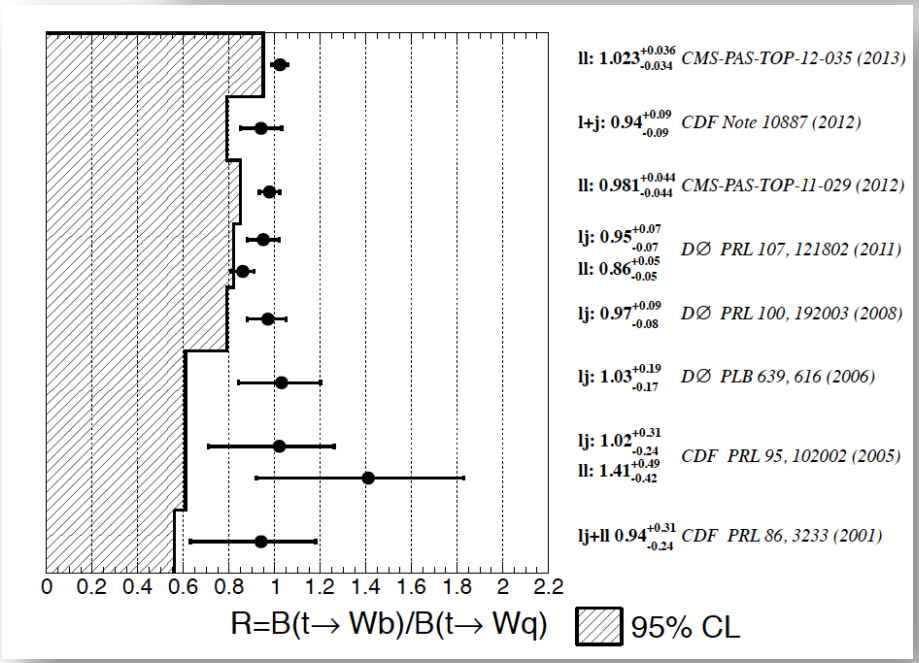
$$R = 1.023^{+0.036}_{-0.034}\,(stat. + syst.)$$

$$R > 0.945 \;@\; 95\%\ \mathrm{CL}$$

$$|V_{tb}| = 1.011^{+0.018}_{-0.017}\,(stat. + syst.)$$

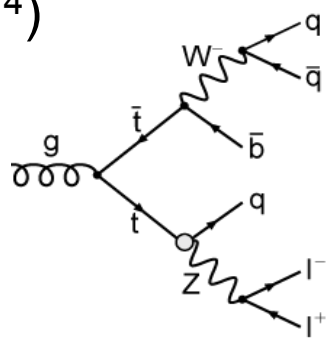
$$|V_{tb}| > 0.972 \;@\; 95\%\ CL$$





Search for FCNC in top decays

- In the SM, decay t → Zq (q=u,c) is highly suppressed O(10^{-14})
- In some model (e.g. RPV SUSY) branching fraction O(10^{-4})
- Search for FCNC in top quark decays t → Zq
  - Event topology: tt → Wb+Zq → lνb + llq



Previous results in 2012 (7 TeV)

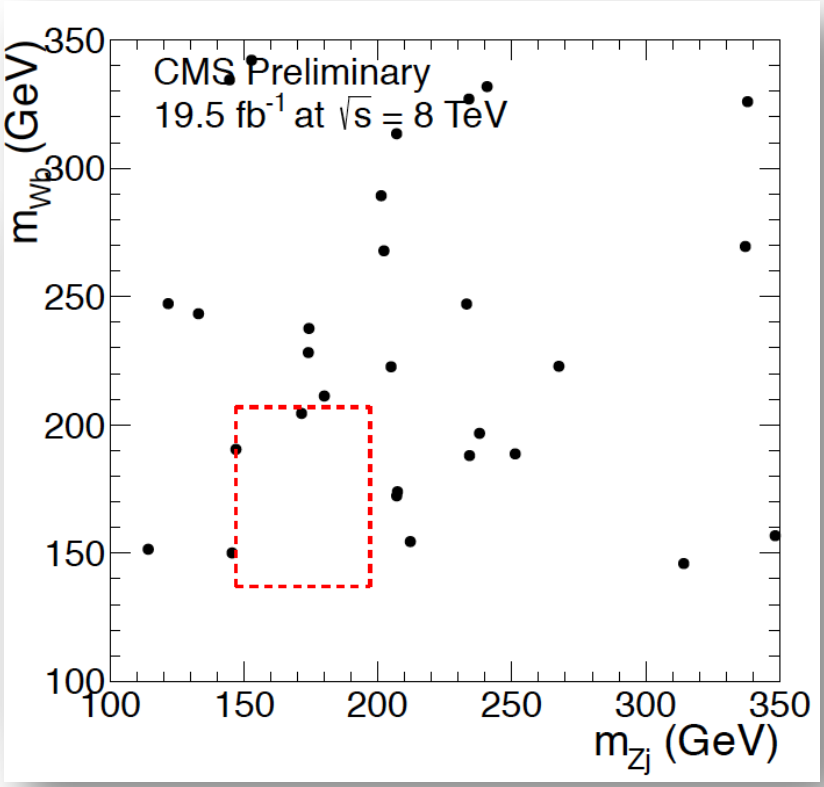
- CMS: BR($t \to Zq$) < 2.1x10^{-3} 5.0 fb^{-1}

CMS-PAS-TOP-12-037

New result (CMS 8 TeV, 19.5 fb^{-1})

BR($t \to Zq$) < 7x10^{-4} at 95% CL

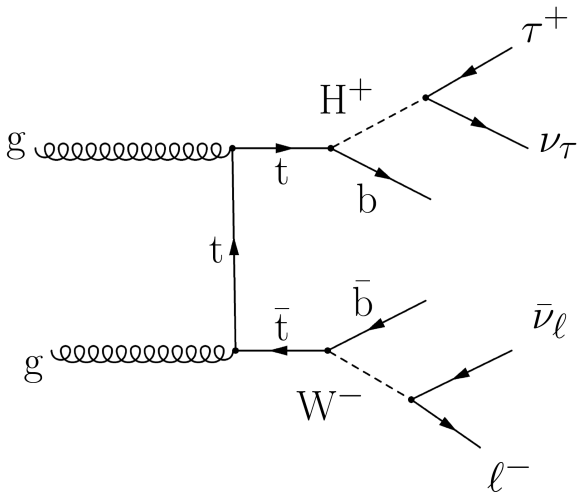
Selection	data-driven estimation	SM MC prediction
t → Zq ($B = 0.1\%$)	—	$6.36 \pm 0.08 \pm 1.27$
WZ	$1.54 \pm 0.12 \pm 0.74$	$0.87 \pm 0.10 \pm 0.62$
ZZ		$0.07 \pm 0.01 \pm 0.05$
Drell-Yan		$0.00 \pm 0.03 \pm 0.02$
$t\bar{t}$	$1.60 \pm 4.96 \pm 0.44$	$0.74 \pm 0.70 \pm 0.52$
$Zt\bar{t}$		$1.09 \pm 0.13 \pm 0.77$
$Wt\bar{t}$		$0.09 \pm 0.05 \pm 0.06$
tbZ		$0.33 \pm 0.02 \pm 0.23$
Total background	$3.14 \pm 4.97 \pm 1.17$	$3.19 \pm 0.72 \pm 2.26$
Observed events	1	—
Expected limit	$\mathcal{B}(t \to Zq) < 0.10\%$	—
Observed limit	$\mathcal{B}(t \to Zq) < 0.07\%$	

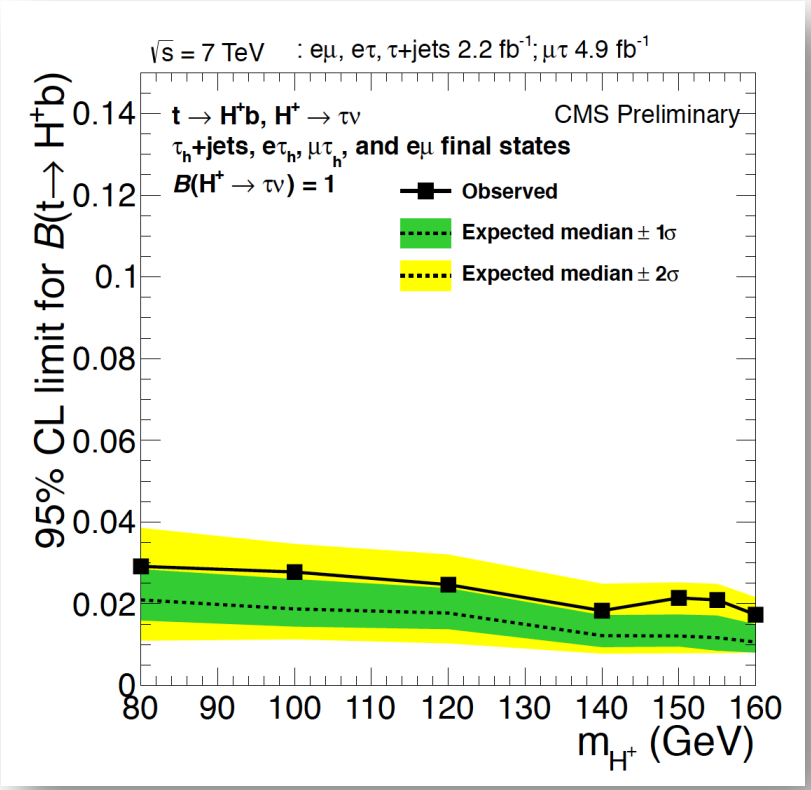


Search for top decaying in H^+

- Search for decays of the top quark in light charged Higgs
- Assumes BR($H^+ \rightarrow \tau\,\nu$) = 100%
- Upper limits on the branching fraction B($t \rightarrow H^+ b$) in the range of 1-3 %

CMS-PAS-HIG-12-052





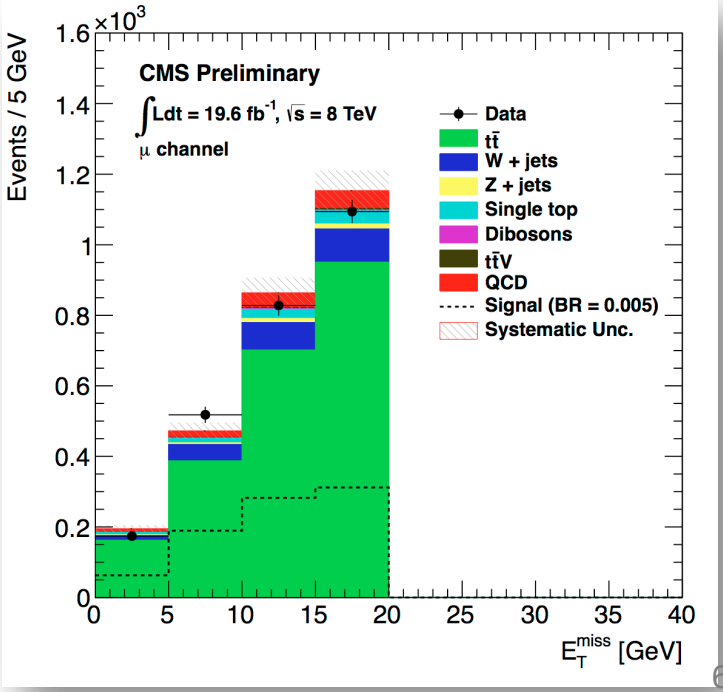
Search for BNV in top quark decays

Additional material

- Search for **baryon number violating** top-quark decays
  - BNV occurs in several models of physics beyond the SM
  - Search for $t \to \bar{b}\bar{c}\mu^+$ $t \to \bar{b}\bar{u}e^+$
- CMS study of events with low $E_{T_{miss}}$, one isolated lepton and five jets, one of which is b-tagged.
  - No significant excess is observed over SM expectations

Combined (electron+muon) limit of 0.0015 at 95% C.L. on the branching fraction of BNV top decay into a lepton and 2 jets

CMS PAS B2G-12-023

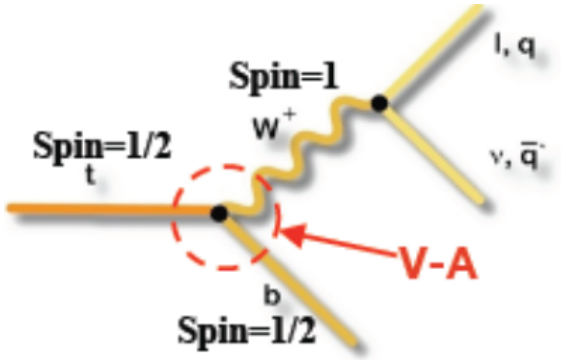


Angular distributions in top decays

Probing Wtb vertex:

- W helicity is sensitive to the V-A coupling
- Measure $d\sigma/d\cos\theta^*$, the angle between the lepton and the b directions (in the W rest frame)

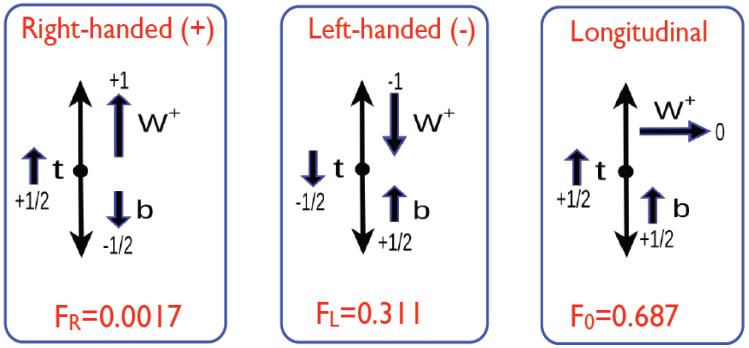
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\ell^*} = \frac{3}{8}(1+\cos\theta_\ell^*)^2 F_R + \frac{3}{8}(1-\cos\theta_\ell^*)^2 F_L + \frac{3}{4}\sin^2\theta_\ell^* F_0$$

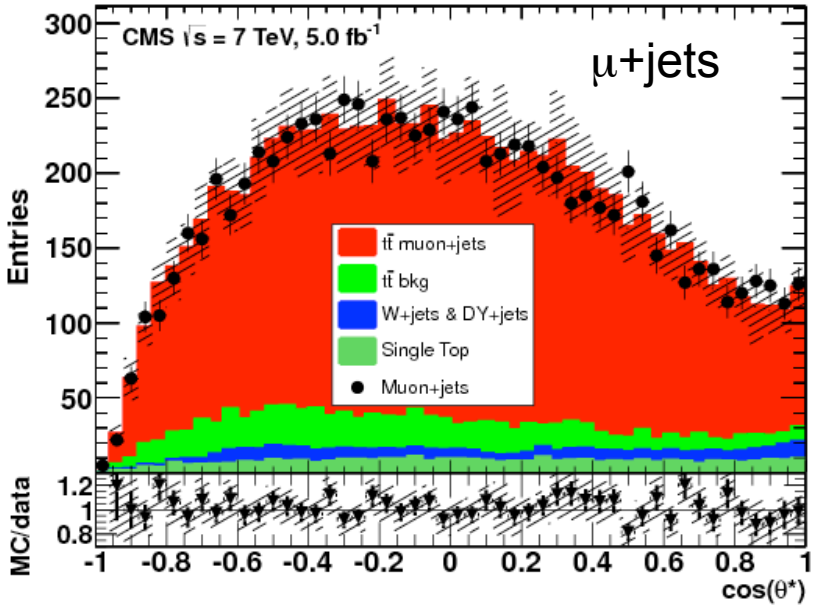


W polarization fractions calculated at NNLO QCD:

$F_0 = 0.687 \pm 0.005$
$F_L = 0.311 \pm 0.005$
$F_R = 0.0017 \pm 0.0001$

Czarnecki et al., PR D 81 (2010) 111503



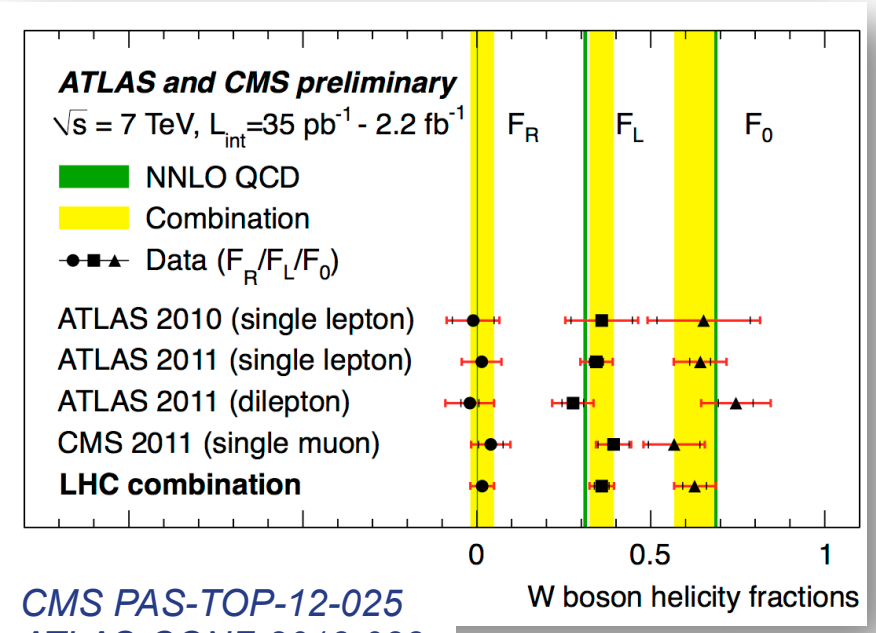


W polarization in top pair events

- First LHC combination:
  F_0=0.626 ± 0.034 (stat.) ± 0.048 (syst.)
  F_L=0.359 ± 0.021 (stat.) ± 0.028 (syst.)
- CMS dilepton *PAS-TOP-12-015*

$$F_L = 0.288 \pm 0.035(stat.) \pm 0.050(syst.)$$
$$F_0 = 0.698 \pm 0.057(stat.) \pm 0.063(syst.)$$
$$F_R = -0.014 \pm 0.027(stat.) \pm 0.055(syst.)$$

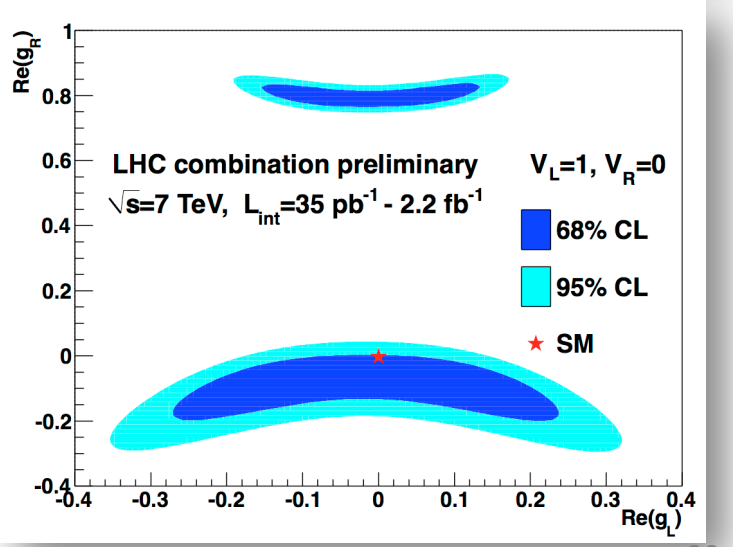
- **Results are in agreement with predictions from NNLO QCD**



CMS PAS-TOP-12-025
ATLAS-CONF-2013-033

Exclusion limits on anomalous Wtb couplings:

$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\,\gamma^{\mu}\,(V_L P_L + V_R P_R)\,t\,W_{\mu}^{-}$$
$$-\frac{g}{\sqrt{2}}\bar{b}\,\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\,(g_L P_L + g_R P_R)\,t\,W_{\mu}^{-} + \text{h.c.}$$

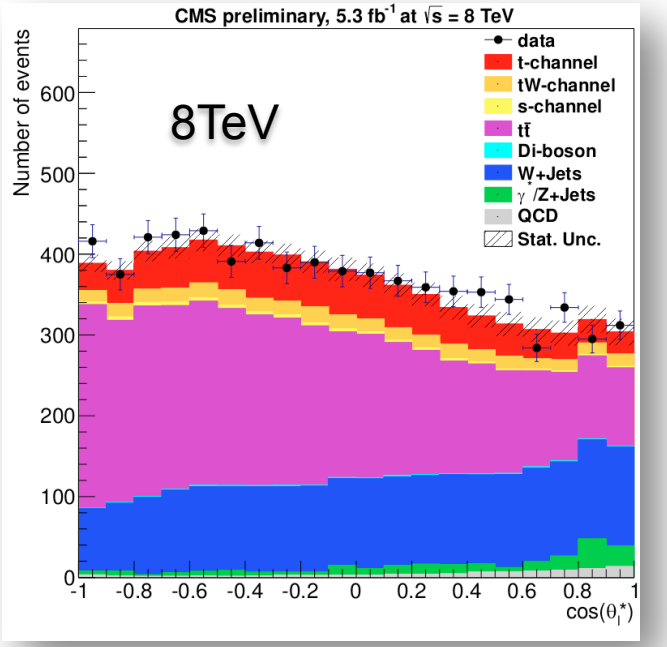


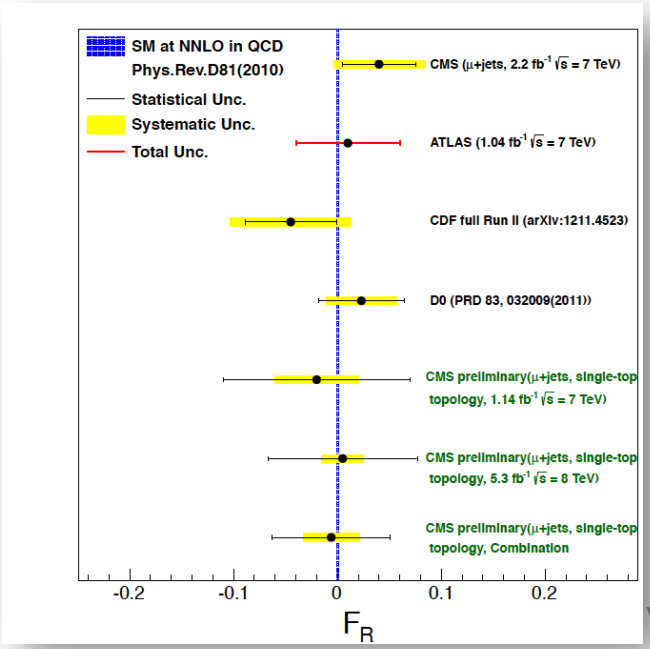
W polarization in single top events

Additional material

First measurement in single-top events

- 7 and 8 TeV, μ+jets events
- Helicity fractions and W+jets contribution simultaneously extracted.
- Consistent with the SM and with the measurement in ttbar channels





$$F_L = 0.293 \pm 0.069(stat.) \pm 0.030(syst.)$$
$$F_0 = 0.713 \pm 0.114(stat.) \pm 0.023(syst.)$$
$$F_R = -0.006 \pm 0.057(stat.) \pm 0.027(syst.)$$

CMS PAS-TOP-12-020

Top polarization in top pair events

In the SM, **in top pair events**, the top quark is produce unpolarized

Some models that predict large top quark forward-backward asymmetry have different predictions of the top quark polarization.

Distribution of polar angle of the charged lepton in the top quark's rest frame:

$$W(\cos\theta_i) \propto 1 + \alpha_i p \cos\theta_i$$

α_i spin analyzing power (α_{lepton}=1)

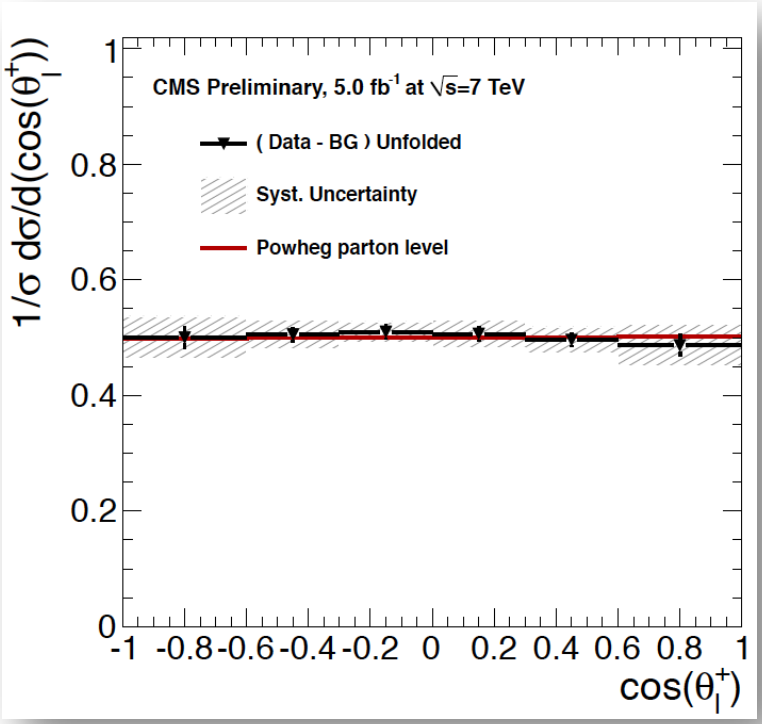
Measurements of top polarization in the helicity basis:

(dilepton channel)

p = -0.009 ± 0.029 (stat.) ± 0.041 (syst.)

CMS PAS-TOP-12-016

Background-subtracted and unfolded distribution



Top spin correlations

Additional material

SM predicts correlation of spin of the top and antitop

- Measured from angular distributions of the top decay products (in dilepton events)
- Use $\Delta\phi$ between leptons which don't require top reconstruction
- Sensitive to New Physics

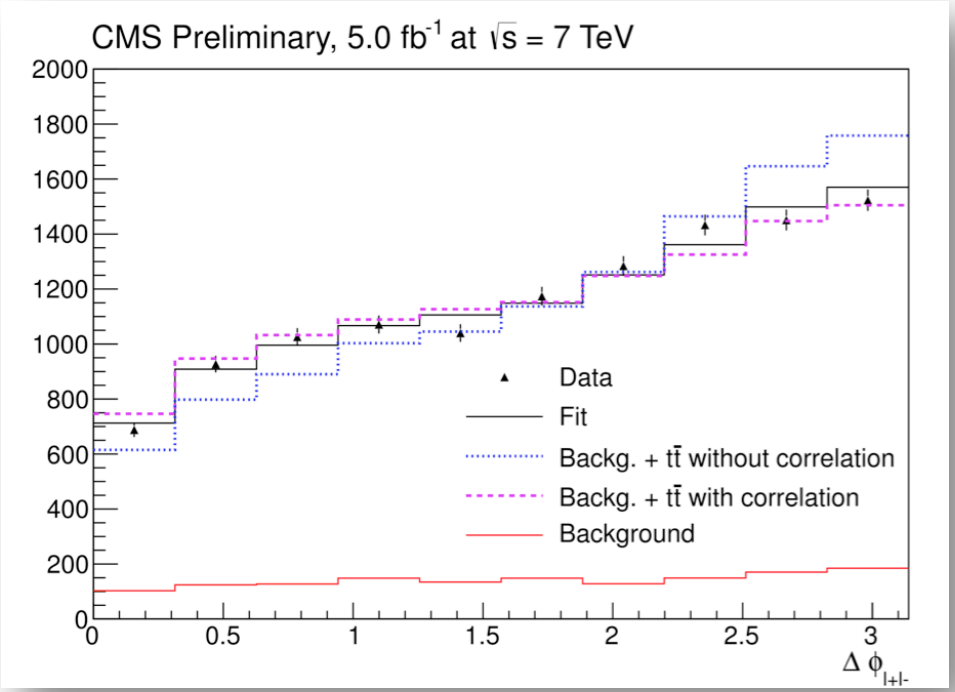
Spin correlation coefficient:

$$A = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\uparrow\downarrow) - N(\downarrow\uparrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\uparrow\downarrow) + N(\downarrow\uparrow)}$$

Measurement (helicity basis):

A= 0.24±0.02(stat.)±0.08(syst.)

Standard model prediction: A=0.31



CMS PAS TOP-12-004

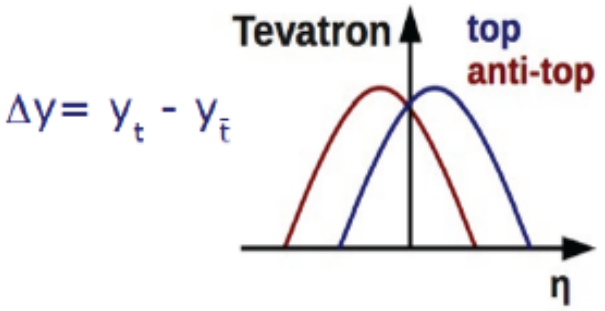
FB and charge asymmetries

ppbar collisions at Tevatron

- Pair production dominated by qqbar annihilation
- **Forward-backward asymmetry** of top-antitop production

Tevatron

$$A_{FB}^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

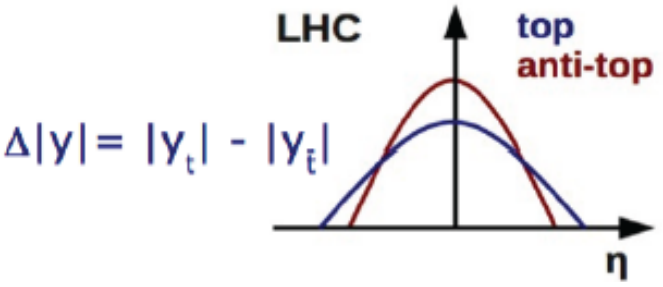


pp collisions at LHC

- Despite symmetric collisions it is possible to define a **charge asymmetry**
- top quarks are preferably emitted at larger rapidities than antitop quarks in qq annihilation
- charge asymmetry at the LHC can be enhanced by selecting events with large rapidities, large Mtt, and/or small P_T^{tt}

LHC

$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

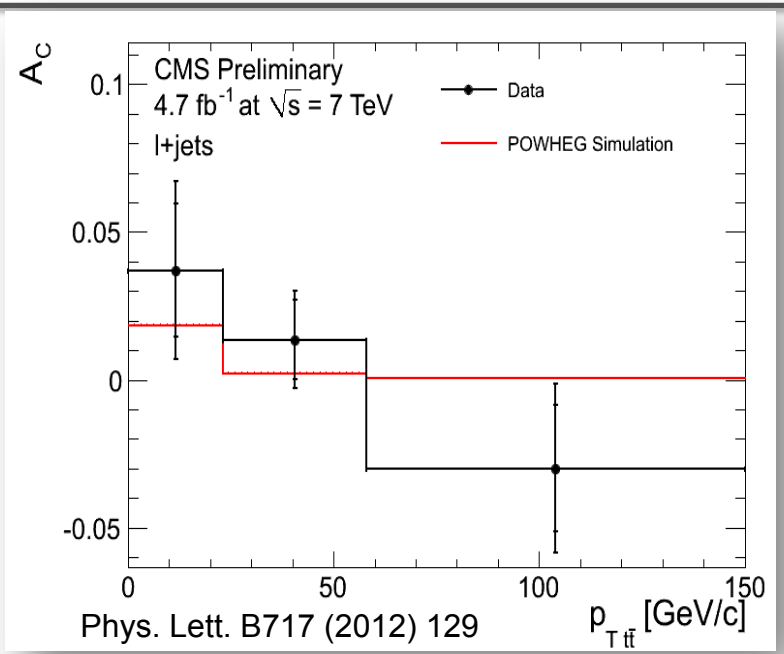


Charge asymmetries

Charge asymmetries with detector effects unfolded

Good agreement with data within uncertainties

To be followed in 2015 with more statistics.



CMS (7 TeV, 5 fb^{-1})		
Di-leptons	$0.050 \pm 0.043\ ^{+0.010}_{-0.039}$	CMS PAS-TOP-12-010
Lepton+jets	$0.004 \pm 0.010 \pm 0.012$	Phys. Lett. B717 (2012) 129
SM	0.0115 ± 0.0006	Kühn et al., JHEP 1201 (2012) 063

B physics

A portal to physics beyond the SM

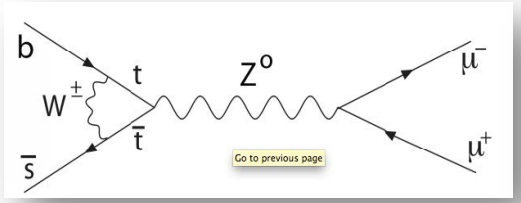
Almost 30 years of searching for $B_{d/s} \rightarrow \mu\mu$

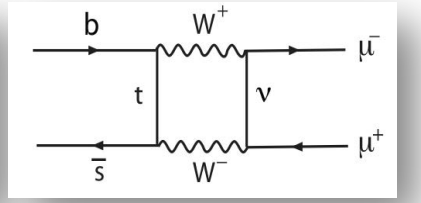
Forbidden at tree level

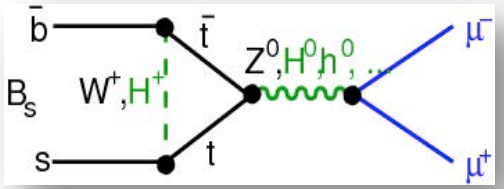
SM prediction

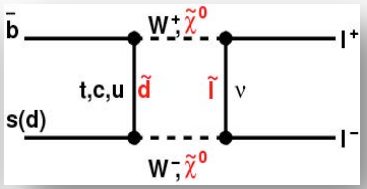
$BR(B_s \rightarrow \mu\mu) = (3.56 \pm 0.18) \times 10^{-9}$

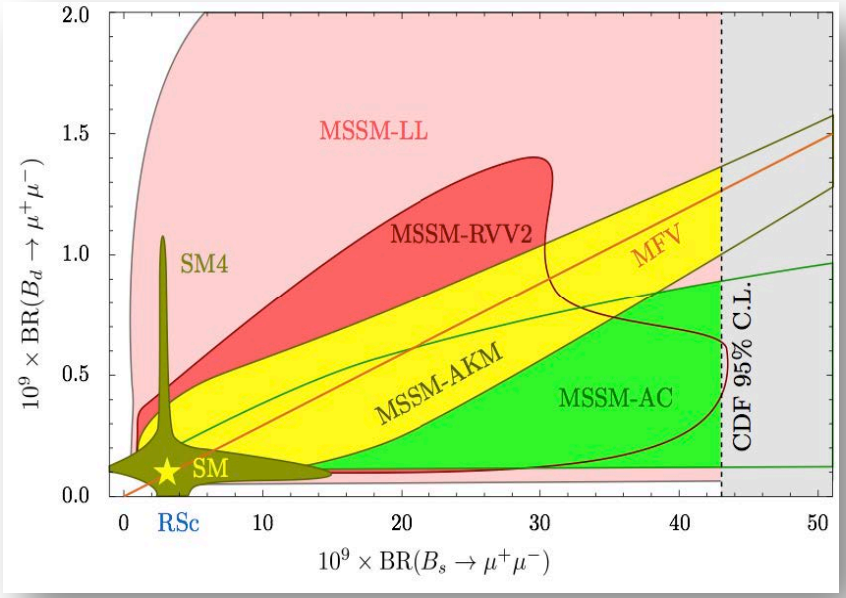
Possible enhancements from new physics via loop/box contributions.











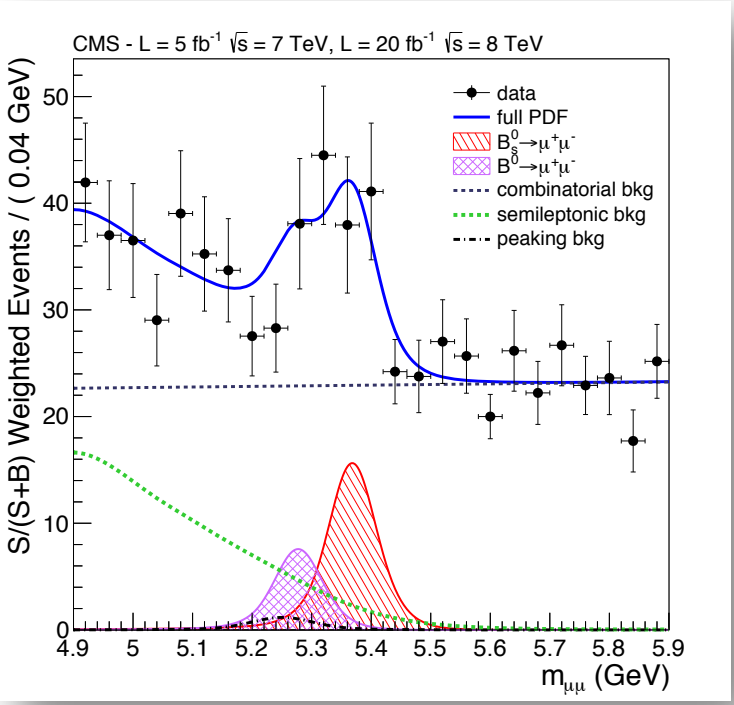
- 2HDM: BR(Bs/d→μμ) ∝ tan⁴β and m(H+)
  - *J. R. Ellis et al, JHEP 05 (2006) 063*
- MSSM: BR(Bs/d→μμ) ∝ tan⁶β
  - *J.Parry, Nucl. Phys. B 760 (2007) 38*
- Leptoquarks
  - *S. Davidson and S. Descotes-Genon*
  - *JHEP 11 (2010) 073*
- 4th generation top
  - *Wei-Shu Hou, Masaya Kohda, Fanrong Xu,*
  - *Phys. Rev. D87, 094005 (2013).*

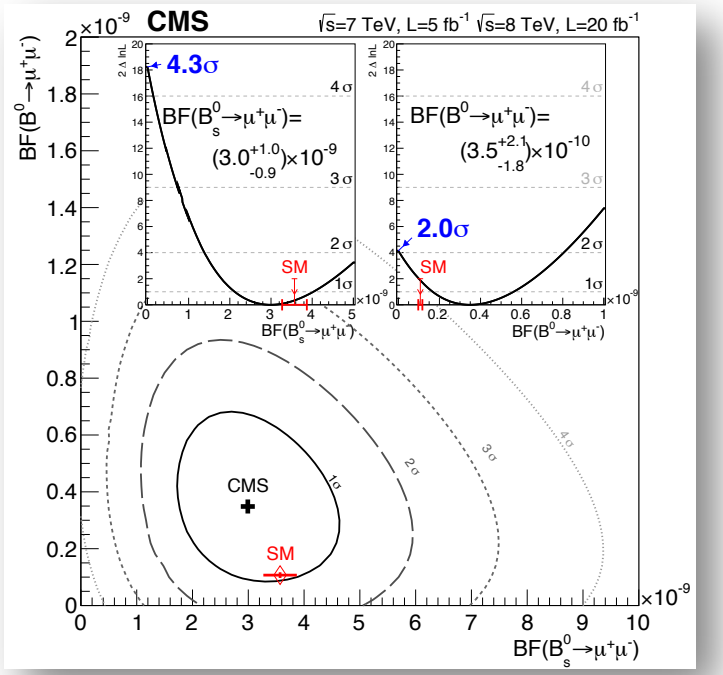
$B_s(\mu\mu)$ results

- The results:
  - $B(B_s \rightarrow \mu\mu) = (3.0^{+1.0}_{-0.9}) \times 10^{-9}$
  - $B(B_d \rightarrow \mu\mu) < 1.1 \times 10^{-9}$
- Preliminary combination with LHCb:
  - $B(B_s \rightarrow \mu\mu) = (2.9 \pm 0.7) \times 10^{-9}$

Significance:

4.3σ (4.8σ exp.)



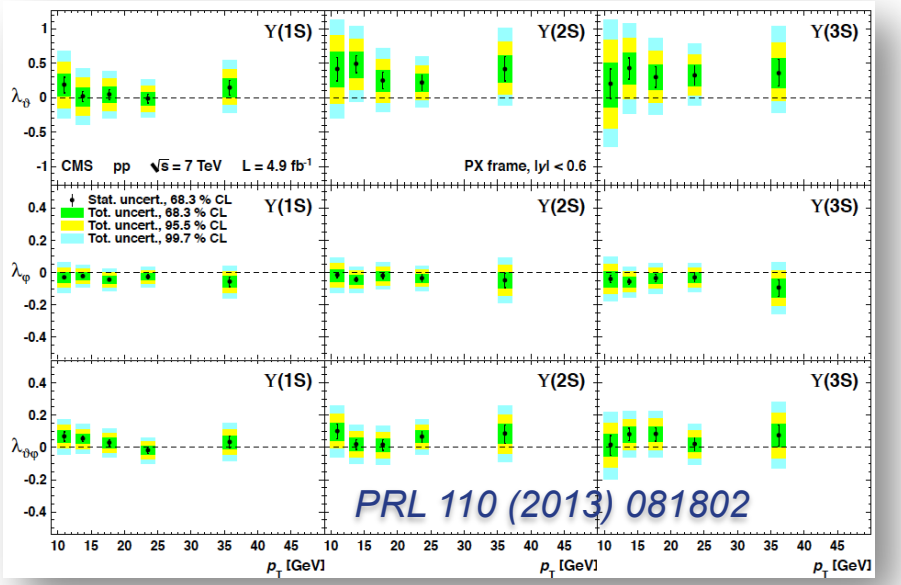


arXiv:1307.5025, PRL

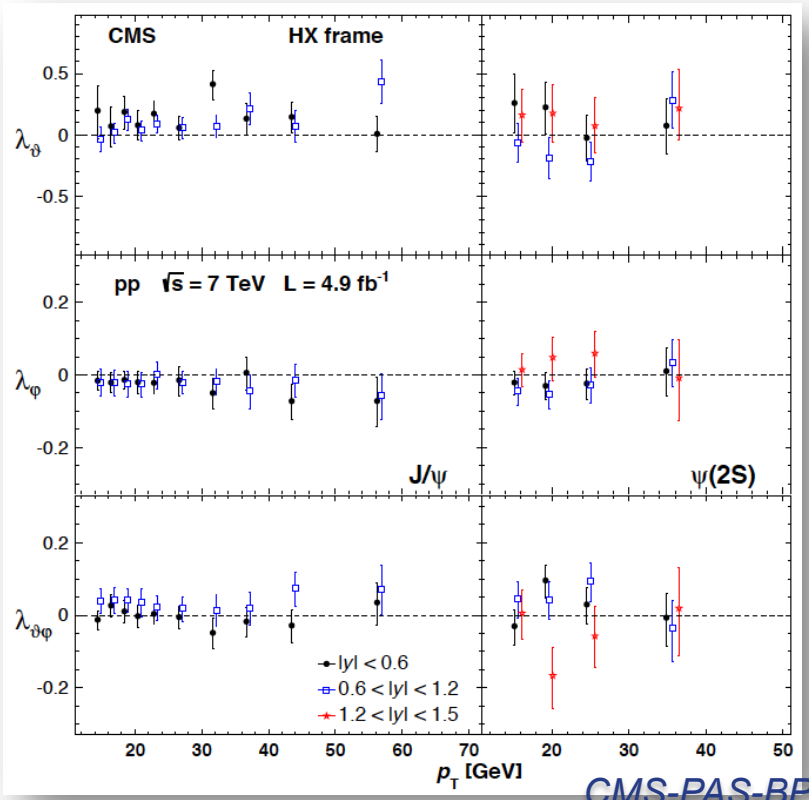
Prompt J/Ψ and ϒ Polarization

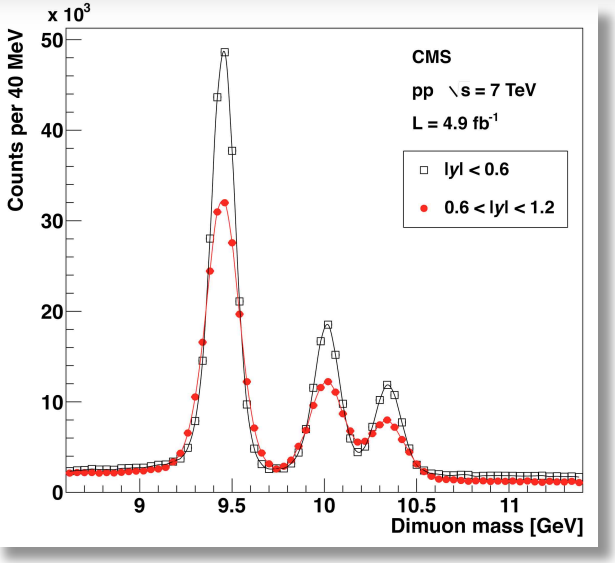
1st meas. of prompt J/Ψ and ϒ(nS) polarization at the LHC
- Now extended to Ψ(2S) polarization measurement

No evidence for large polarizations
- An issue for NRQCD that needs to be resolved!

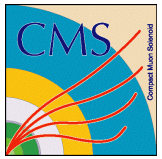


PRL 110 (2013) 081802





CMS-PAS-BPH-13-003

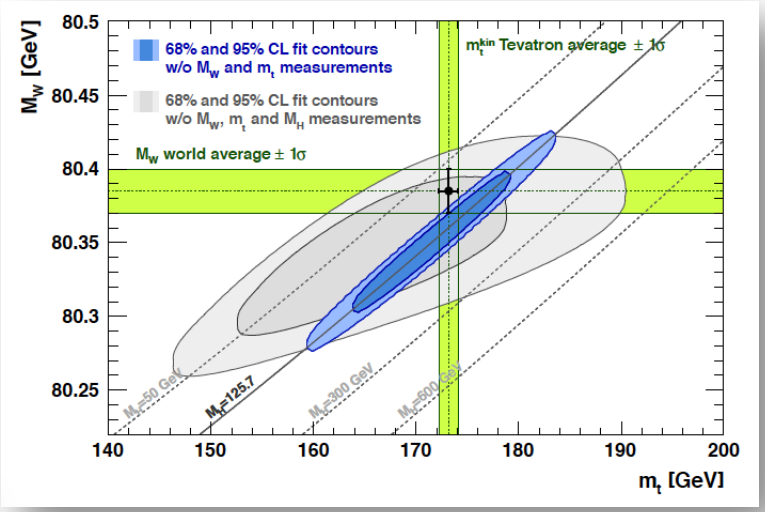


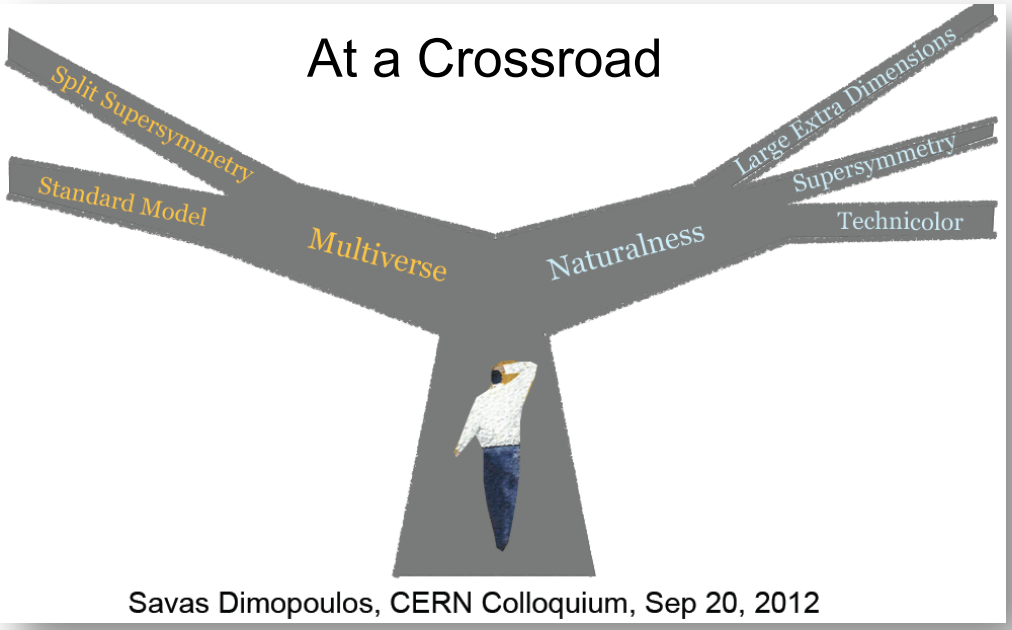
Searches Beyond the Standard Model

The standard model and beyond

Standard Model:

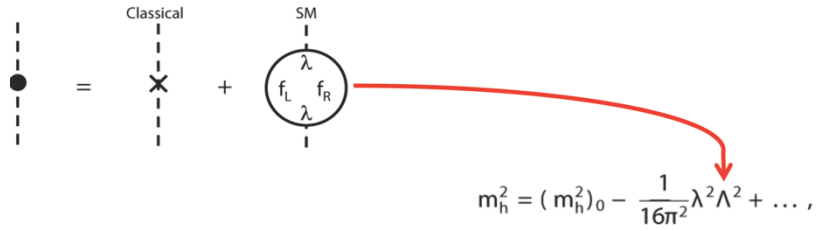
the astonishing brain power of a certain ape species



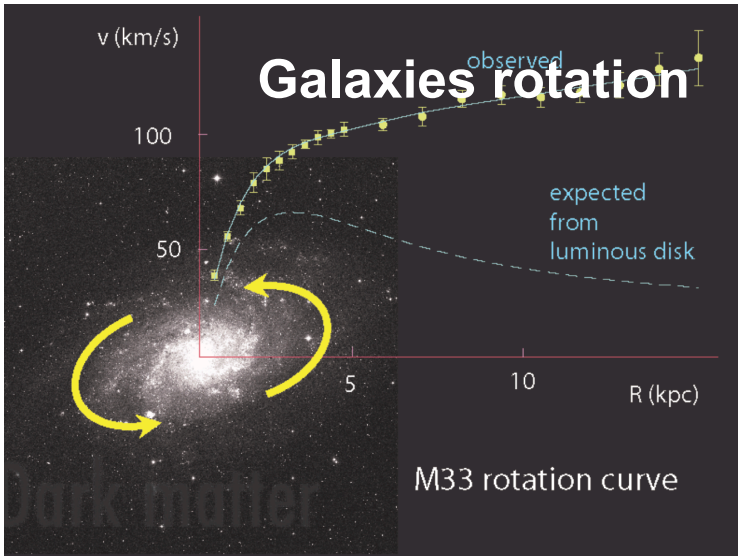


Higgs mass is a huge problem:

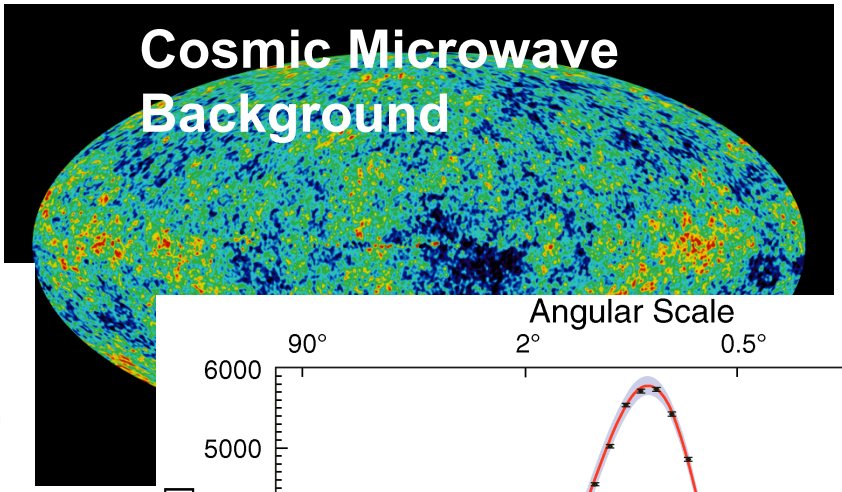
Miraculous cancelations are needed to keep the Higgs mass < 1 TeV

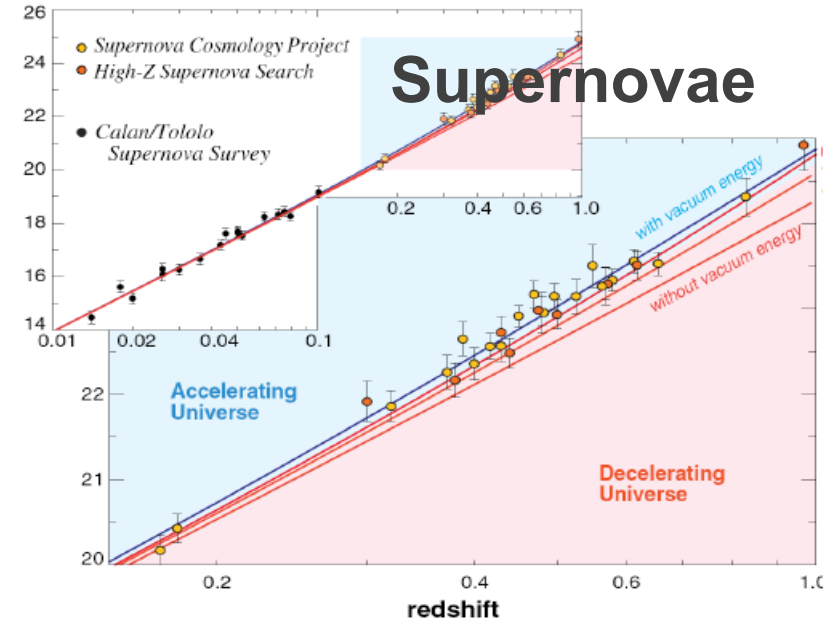


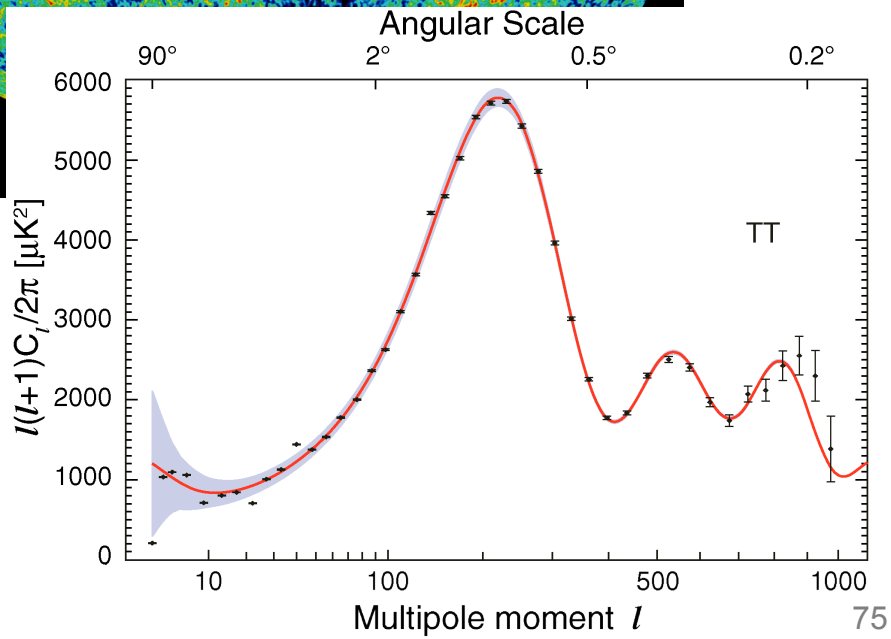
The connection to cosmology



Precision cosmology measurements give strong motifications for new physics:
Galaxies rotations, accelerating expansion, CMB uniformity, space flatness



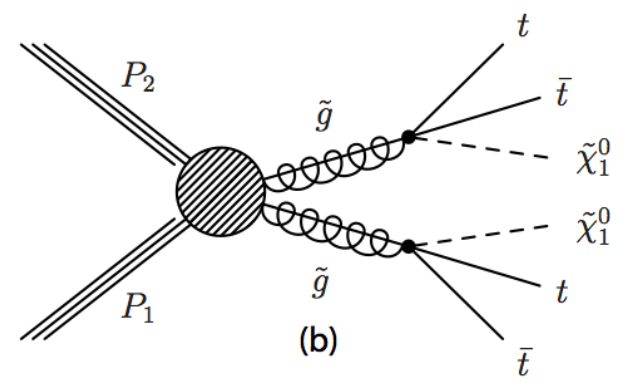




Search for SUSY

gluino → stop searches

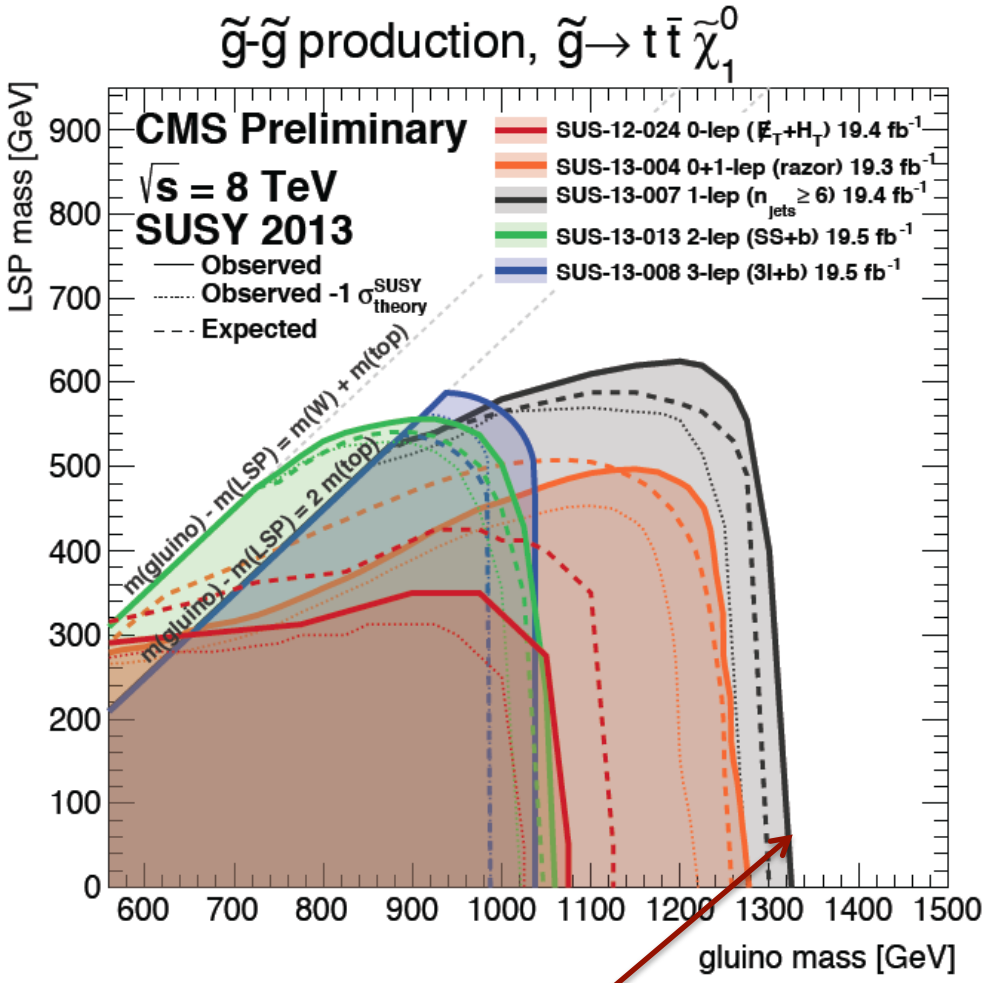
General SUSY searches:
Simplified Model Spectra (SMS)



Assumption:

$$\mathrm{BR}(\tilde{g} \to t\bar{t}\tilde{\chi}_1^0) = 100\%$$

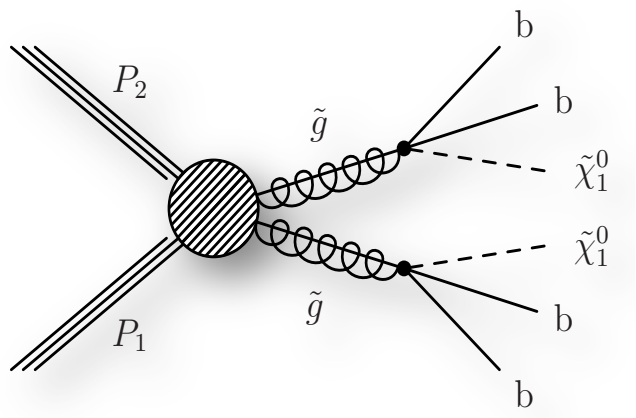
CMS PAS SUS-12-024, SUS-13-007
SUS-13-008, SUS-13-013



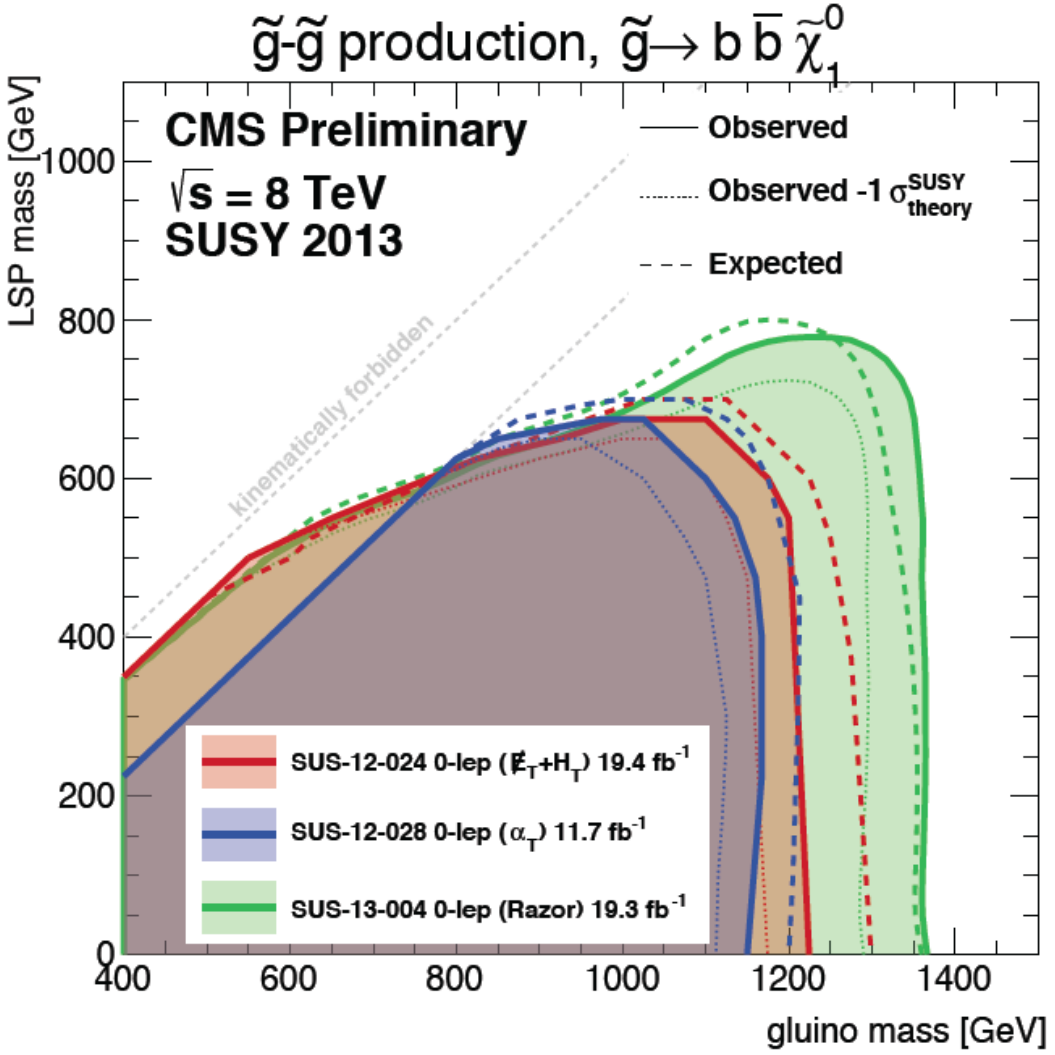
1 lepton + ≥6 jets + ≥2 b jets

gluino → sbottom searches

Search for gluino decaying to sbottom then bottom quarks and neutralinos

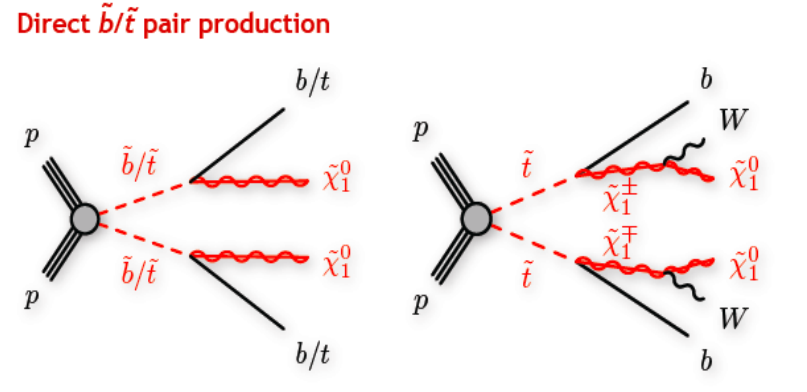


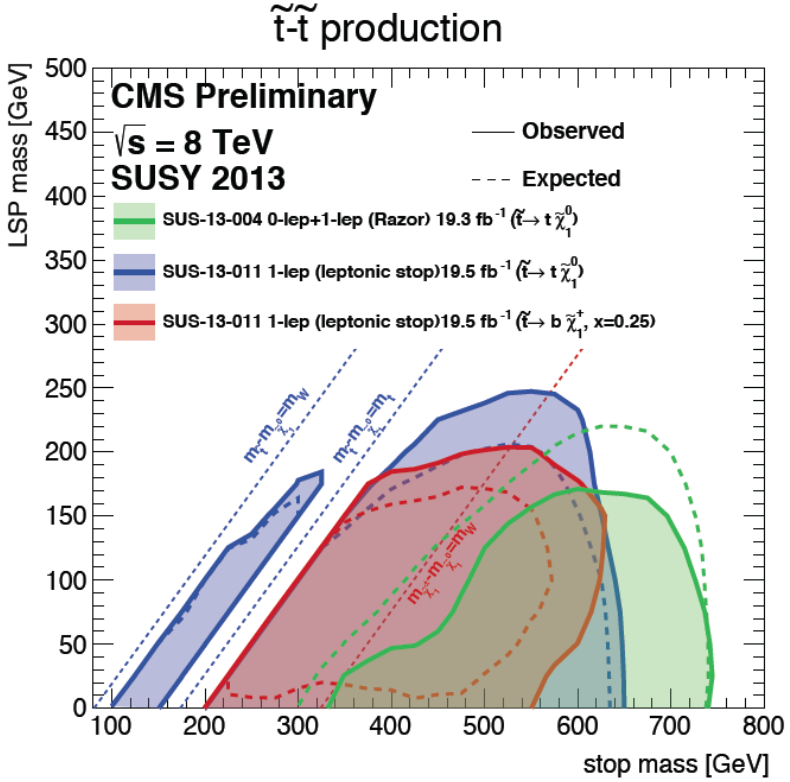
CMS PAS SUS-12-024, SUS-12-028



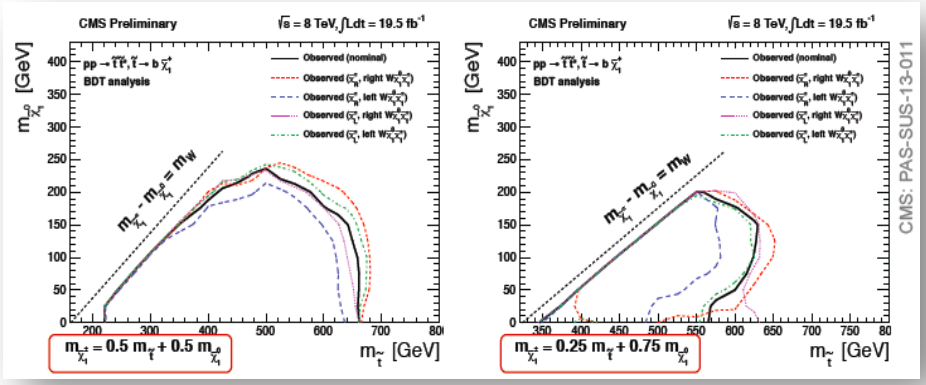
Search for direct stop production

- Single isolated, high pT electron or muon, > 4 jets, > 1 b-tagged jet, large missing ET and transverse mass (MT);
- Search using razor variables in events with b-jets





Limits depend on mass hierarchy:



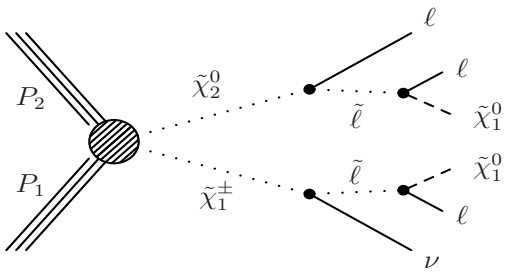
Limits on the top-squark and neutralino masses vary 10–20 GeV depending on the top-quark polarization.

$\chi^+\chi^0$ searches

SUS-12-022

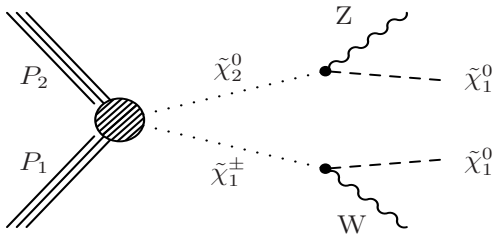
Models with decays into sleptons

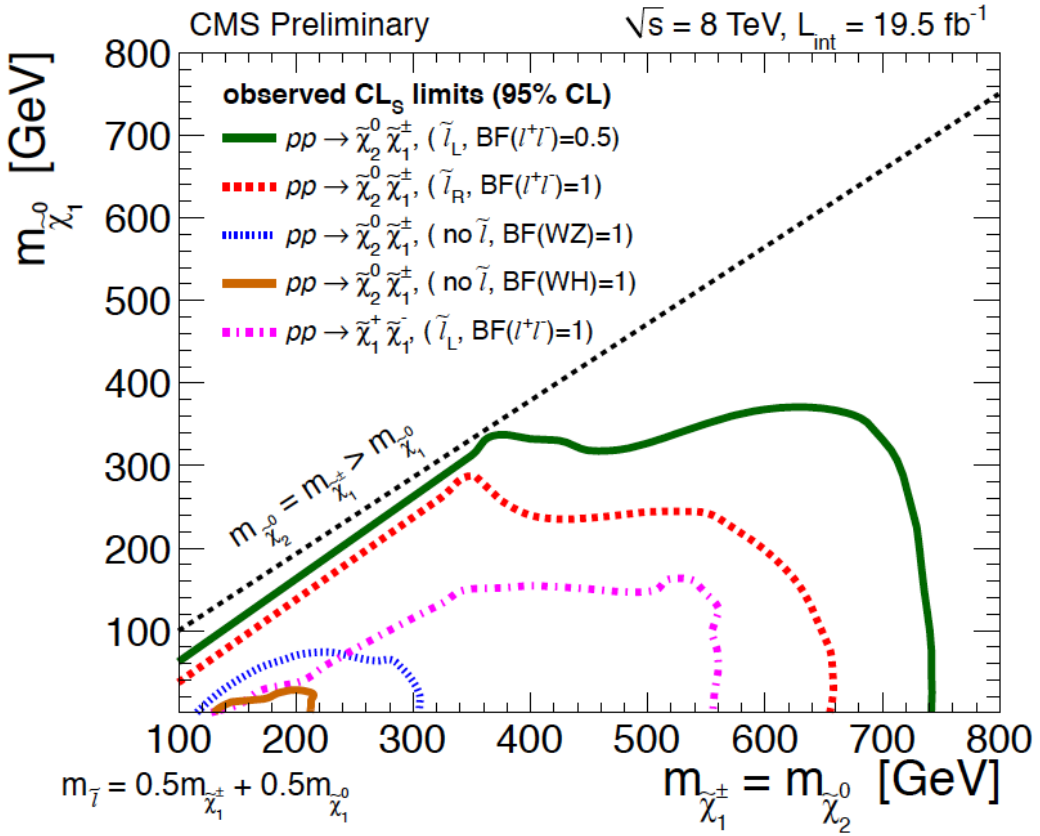
- Trilepton + MET
- Same-sign dileptons



Models with decays into W and Z

- Z→ℓℓ + ℓ + MET
- Z→ℓℓ + W/Z→jet-jet + MET
- Four leptons

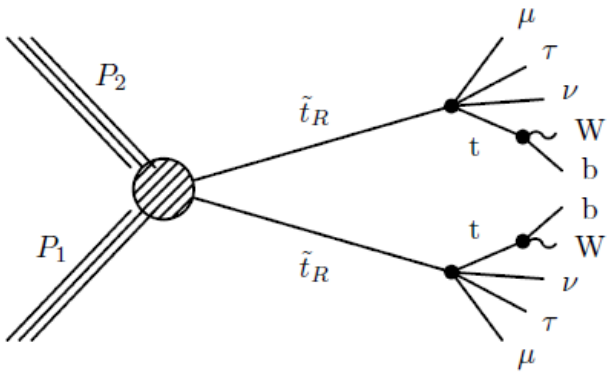




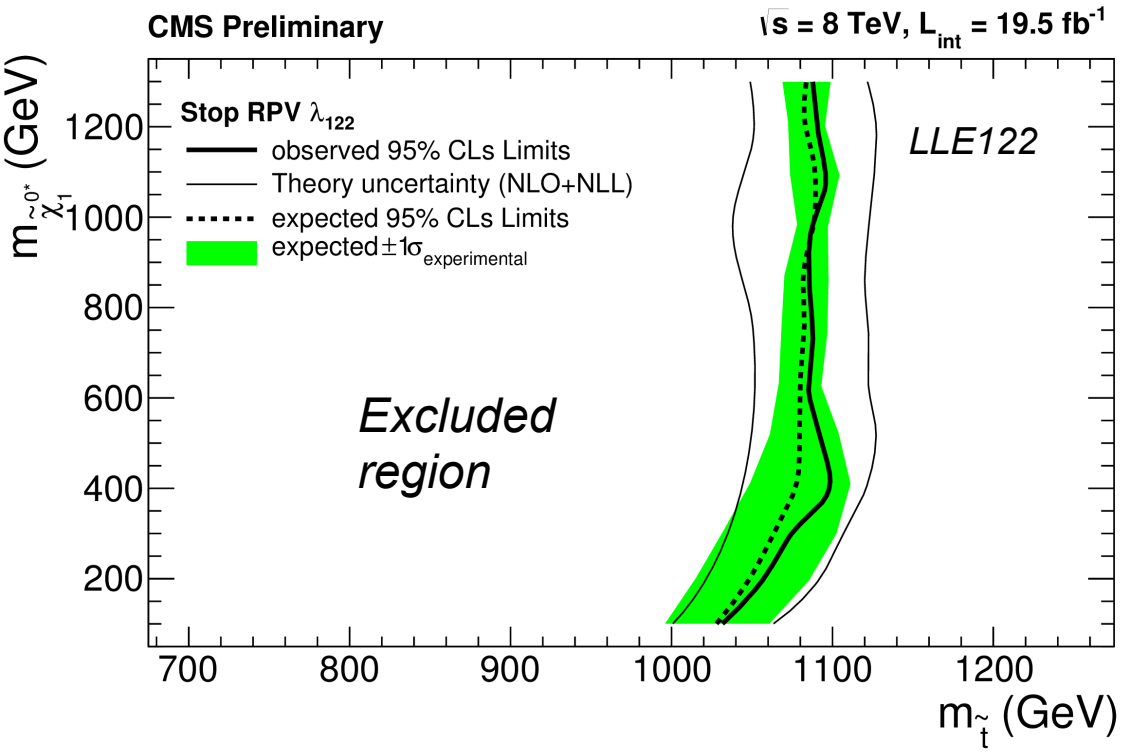
Search for RPV stop

Additional material

- R-parity violation
  - No stable SUSY particle → less MET than conventional SUSY
- ≥3 leptons+b
  - Including up to 1 τ→had



SUS-13-003

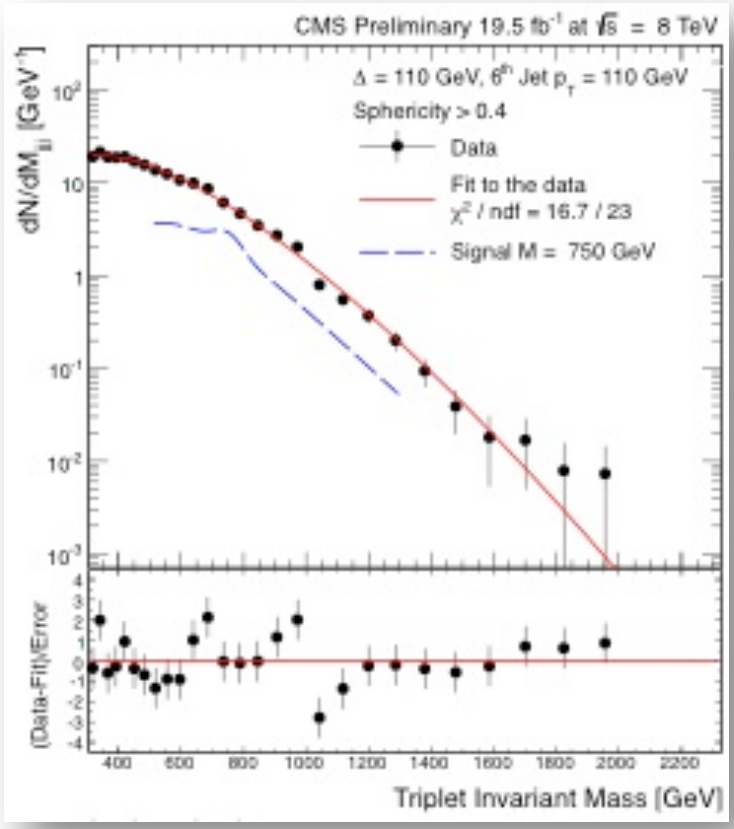


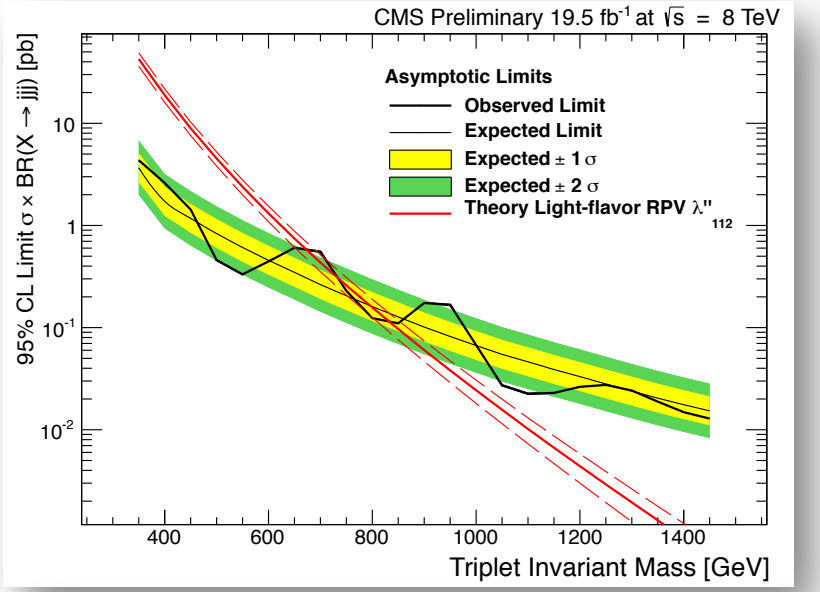
RPV Gluinos in 3 jets

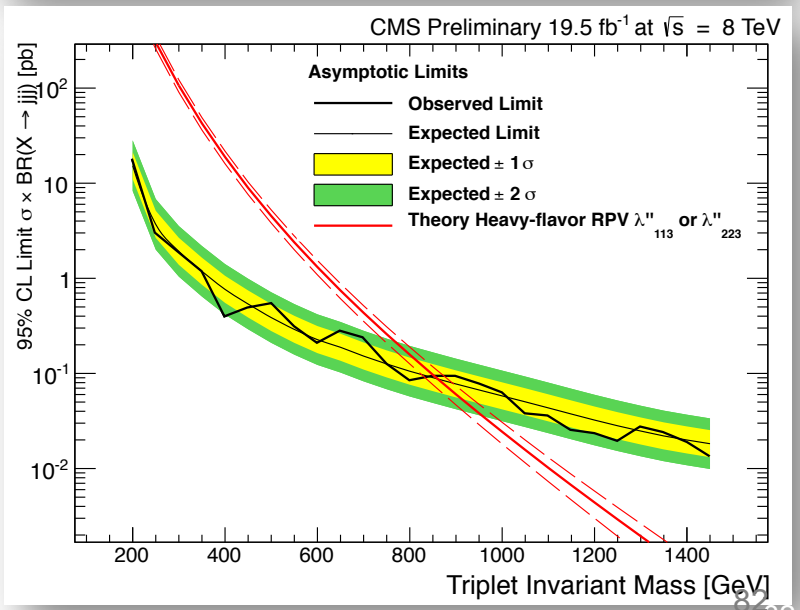
Additional material

Search for RPV decays of a gluino in 3 jets (either qq′q″ or bqq′)

EXO-12-049





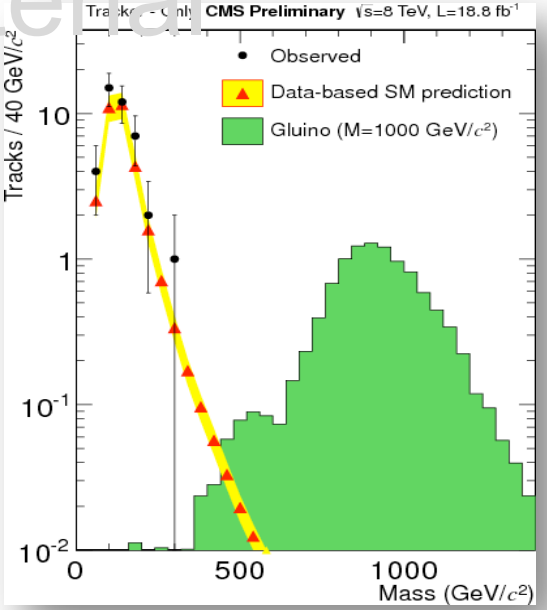


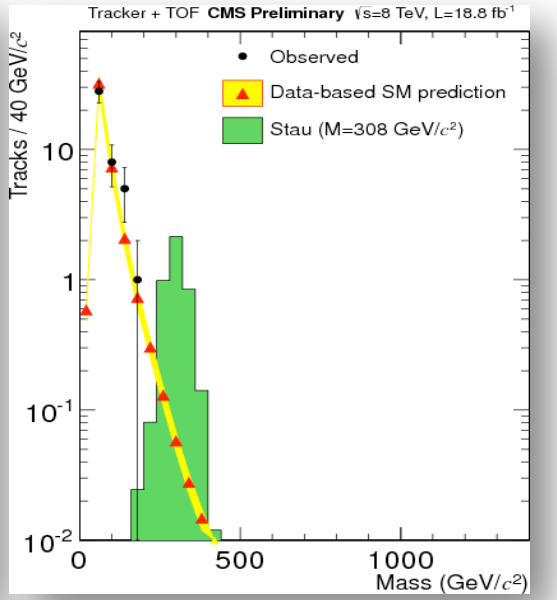
Searches for long-lived SUSY

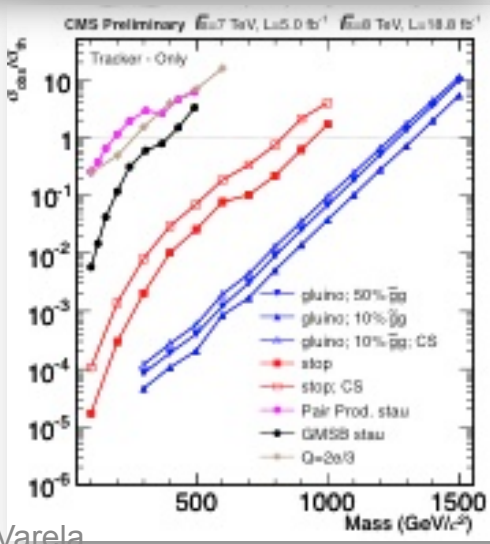
Additional material

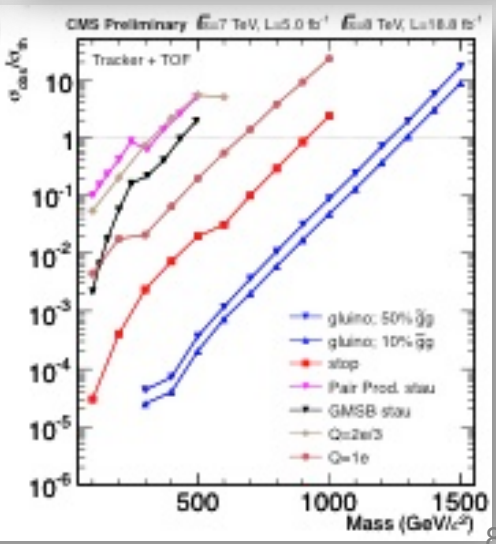
- Extends HSCP search to full 8 TeV statistics
  + 7 TeV reanalysis
- Background prediction
  - Use absence of correlation between p_T spectrum and the mass as determined from ionization
- Strong limits
  - Gluinos, stops, and staus
    - Use combination of tracker+TOF and tracker-only analyses

EXO-12-026

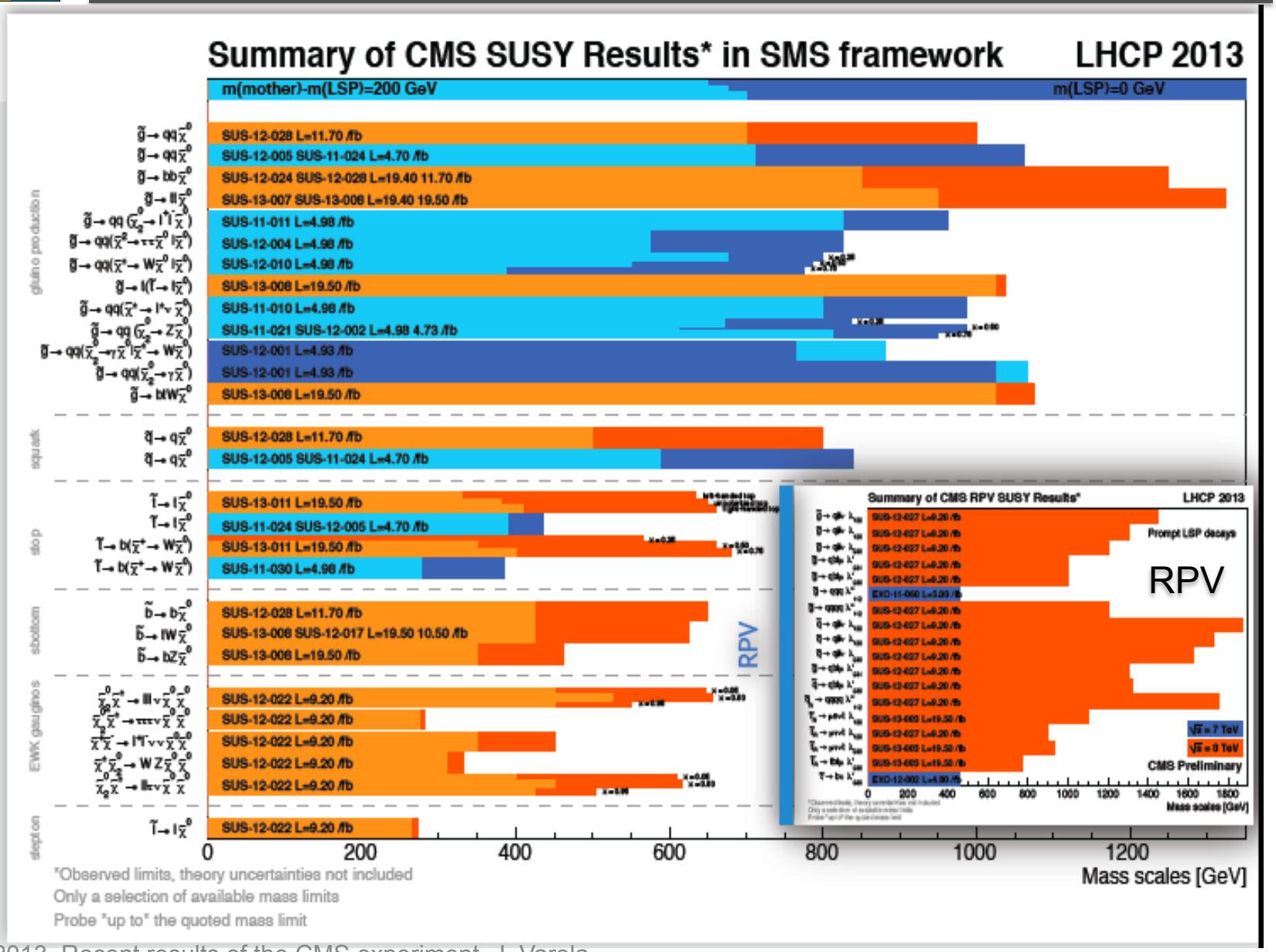






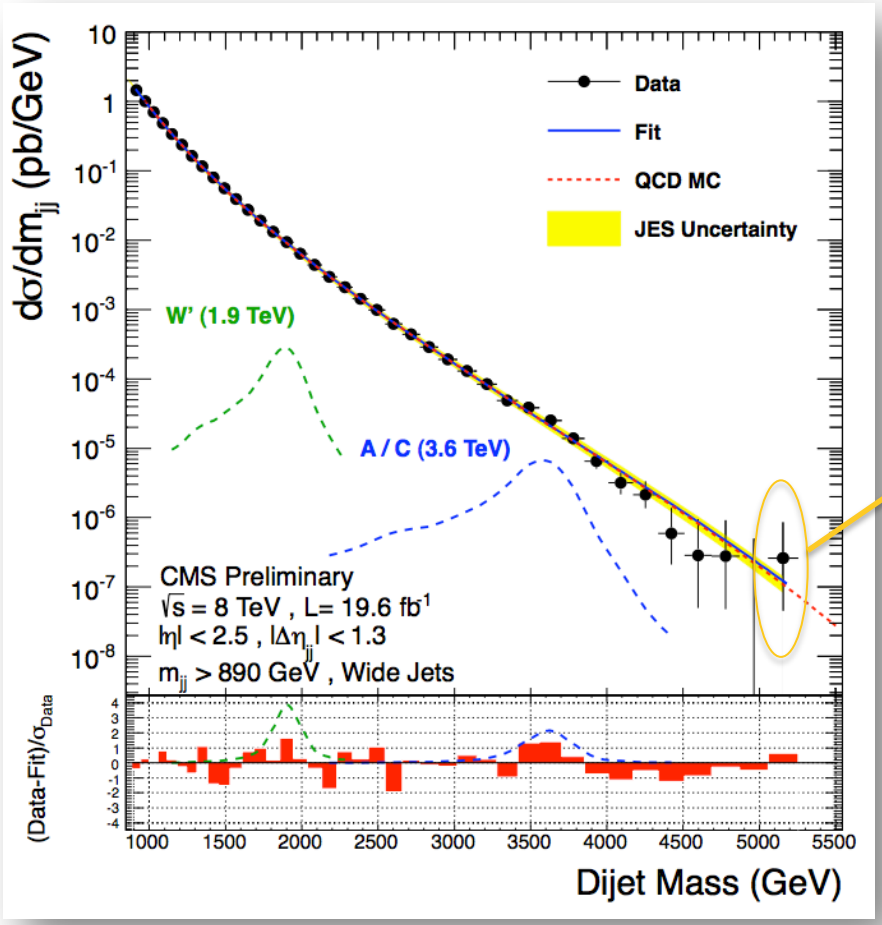


SUSY (no show) tables

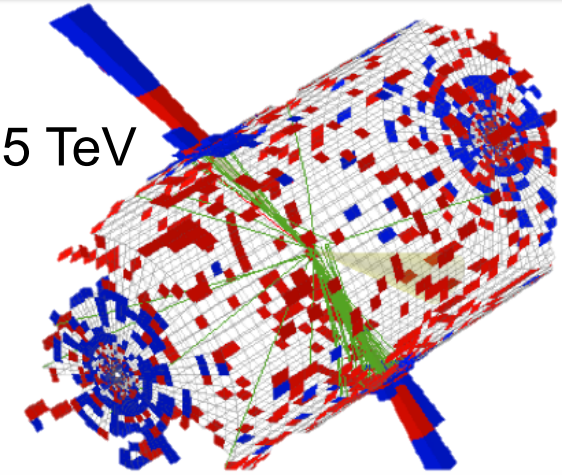


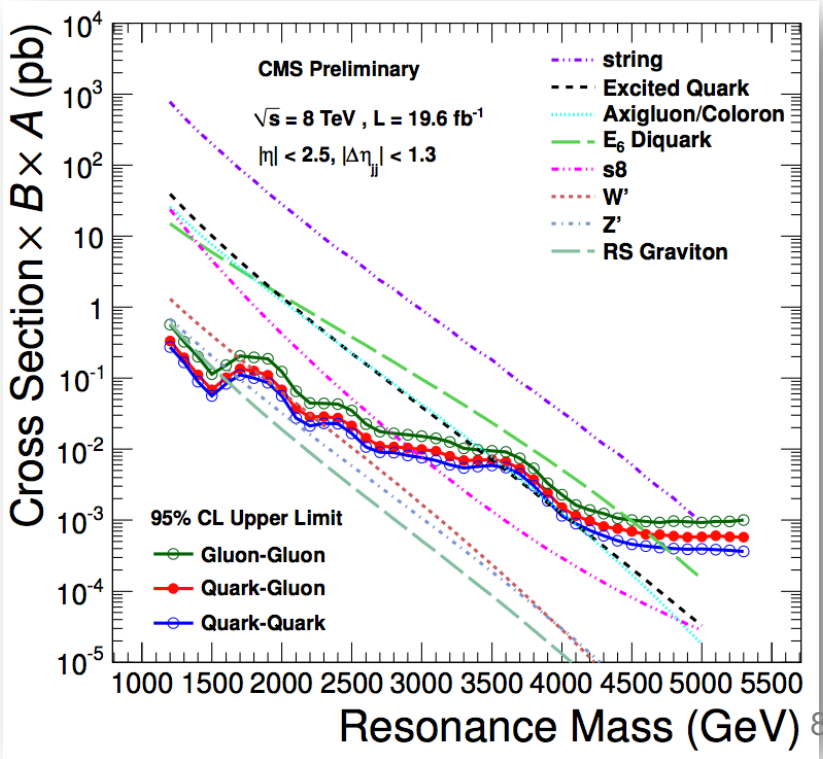
Other searches

Dijet resonance search



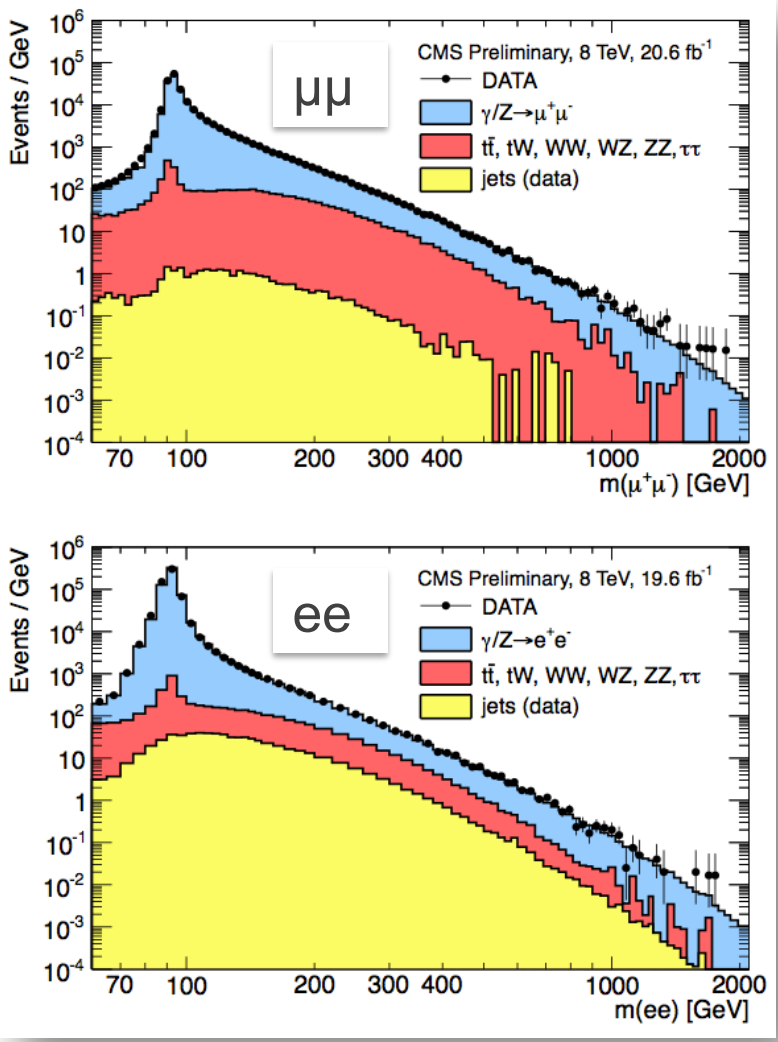
M_{jj} = 5.15 TeV



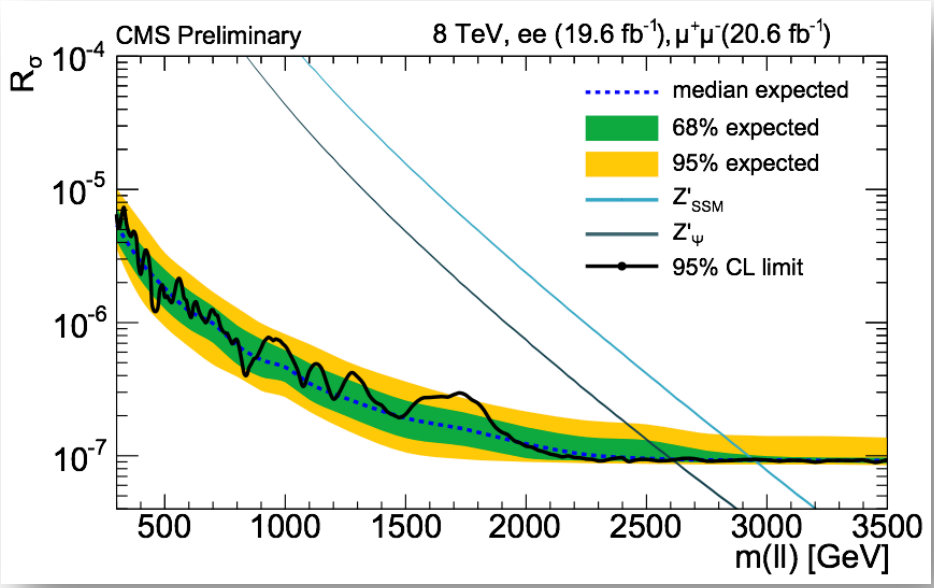


EXO-12-059

Dilepton resonance search



- Z' → e+e-/μ+μ-
- Data to almost 2 TeV, limits to almost 3 TeV

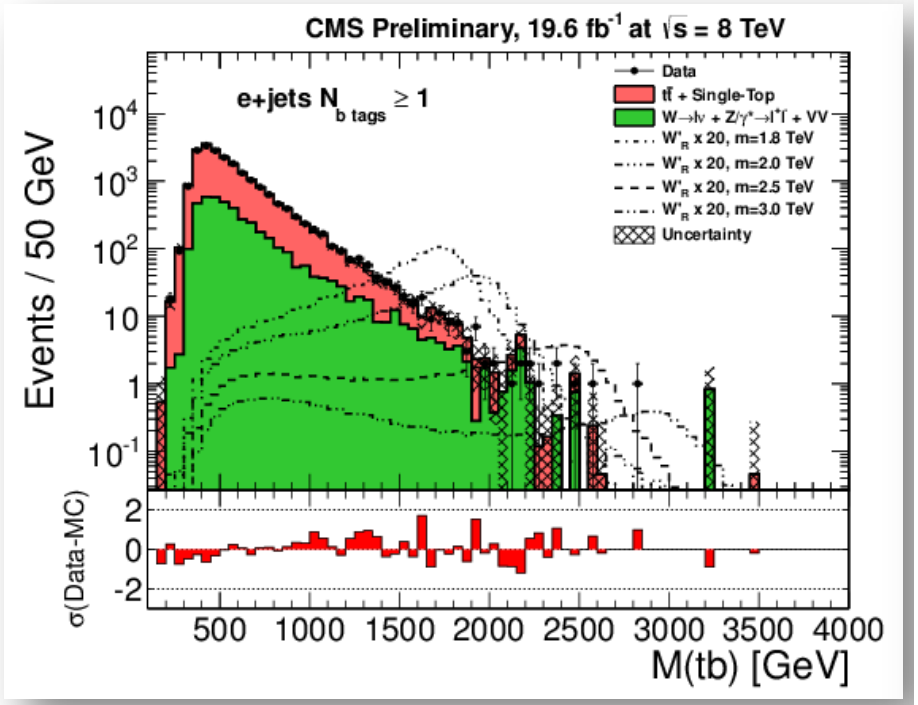


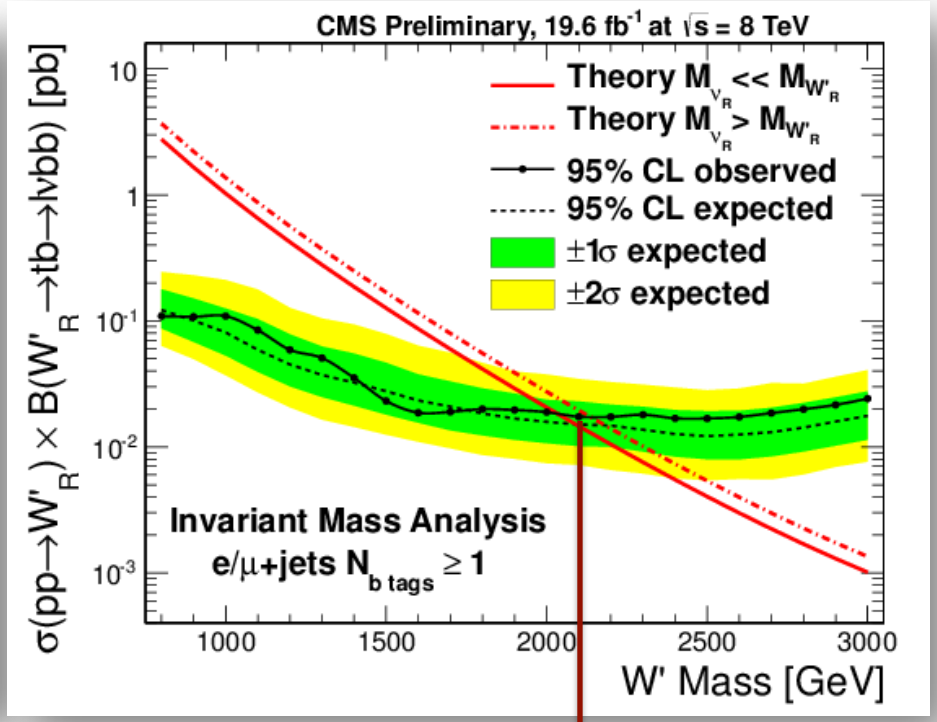
EXO-12-061

W'→tb search

- Heavy W'
  - Predicted by little Higgs, extra dimensions, technicolor, etc
- Lepton+jets+MET signature
  - Use W,t mass constraints to solve for neutrino momentum and reconstruct W' mass

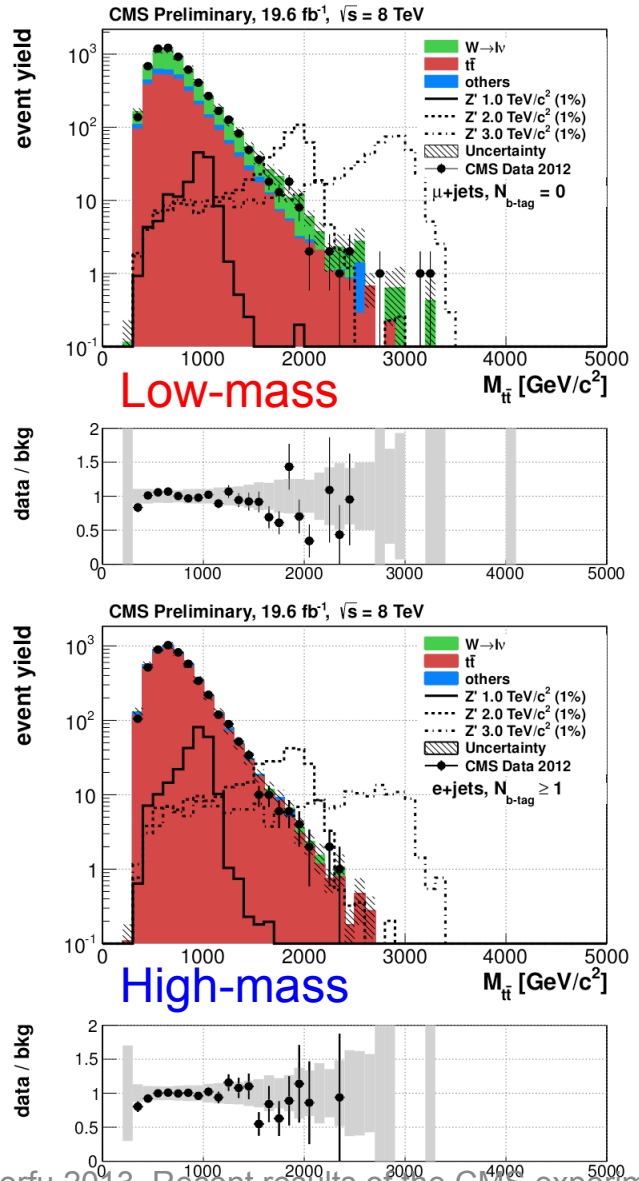
B2G-12-010





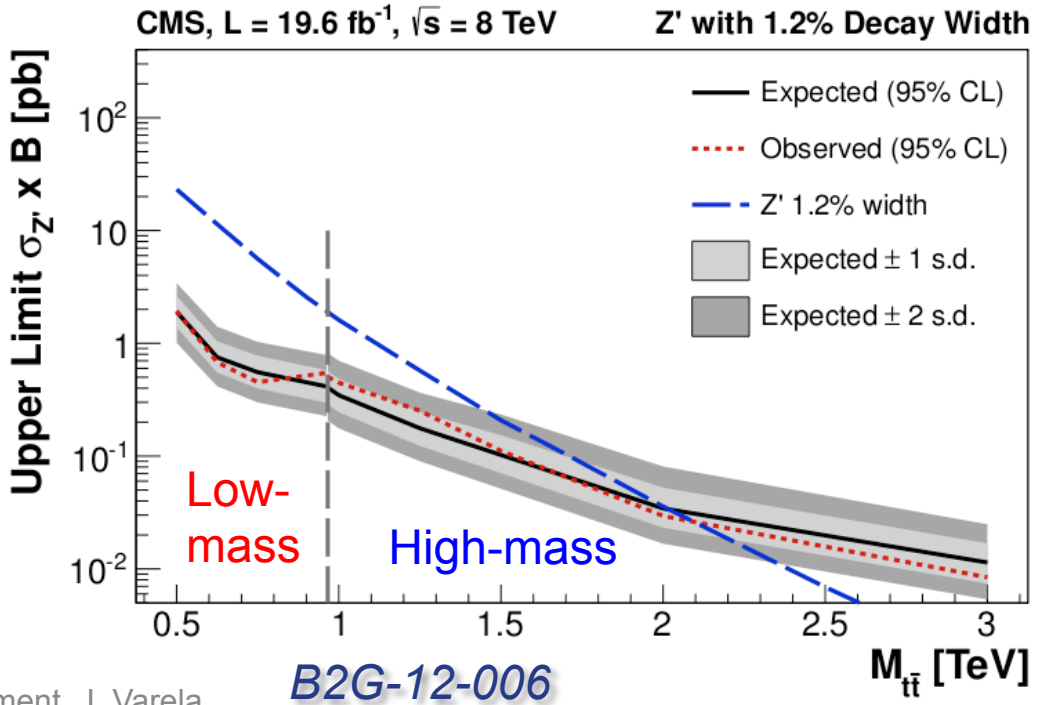
Exclude < 2.1 TeV

Search for tt resonances



New search for tt-resonances in the l+jets +MET channel with full Run 1 data

- Optimized separately for low-mass (non-boosted, M_{tt} < 1 TeV) and high-mass (boosted) regimes
- Sets most stringent limits today



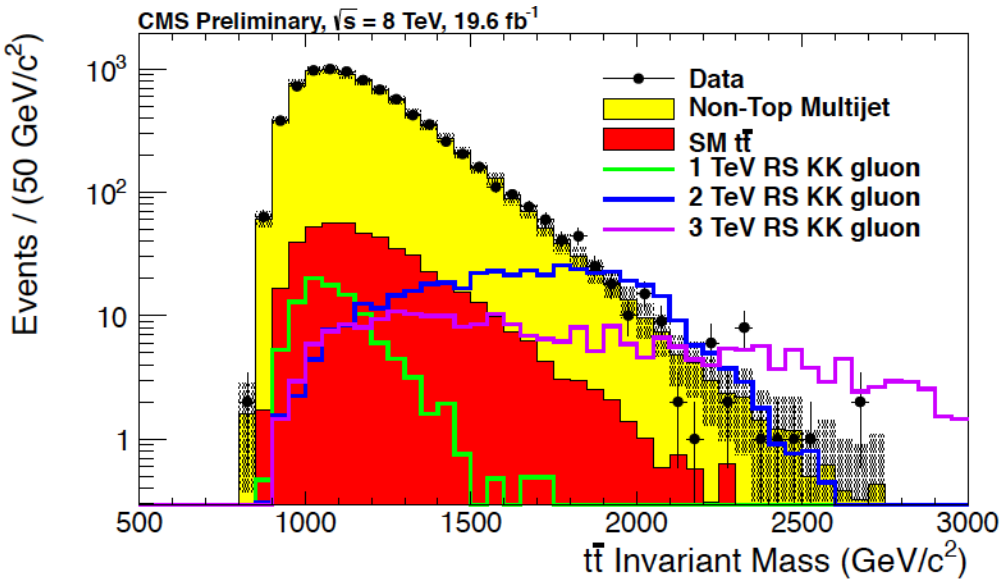
Search for resonant top-pair production

Additional material

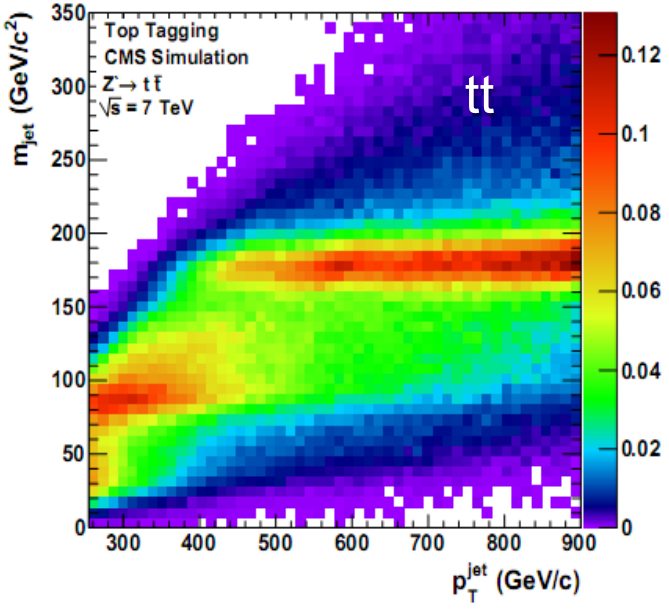
Event kinematics strongly depend on the mass of the intermediate state

- **Low mass analyses:** standard tt reconstruction
- **High mass analyses:** top tagging from jet substructure

8 TeV single lepton, all hadronic



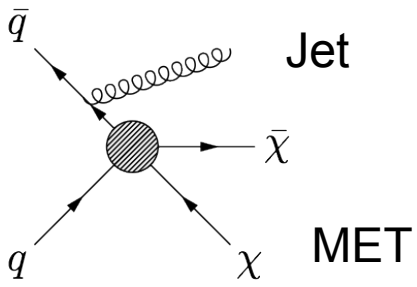
KK gluon (R-S) > 2.7 TeV

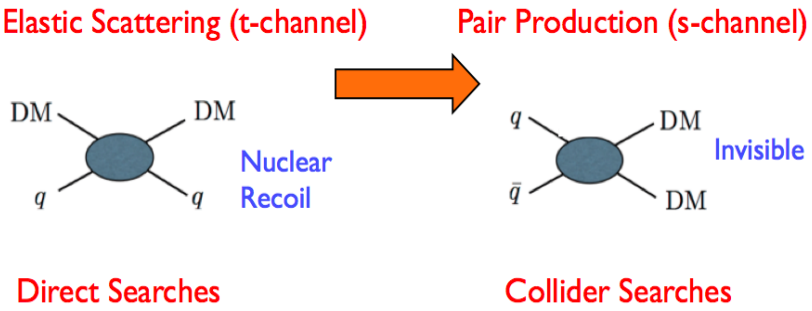


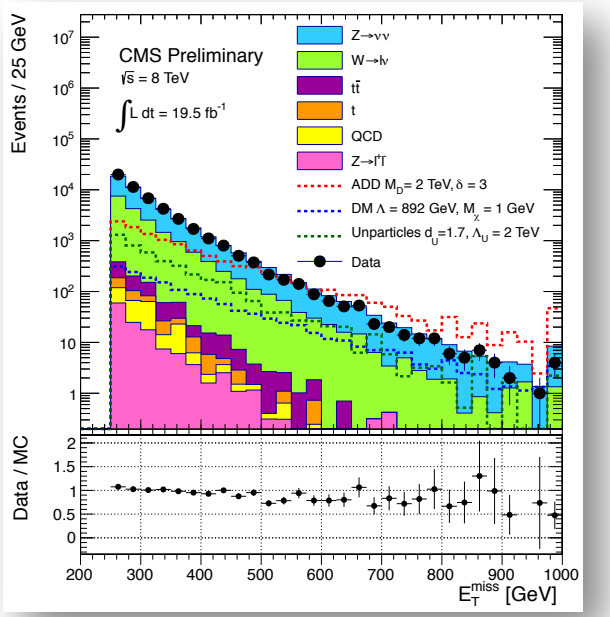
CMS PAS-B2G-12-005
CMS PAS-B2G-12-006

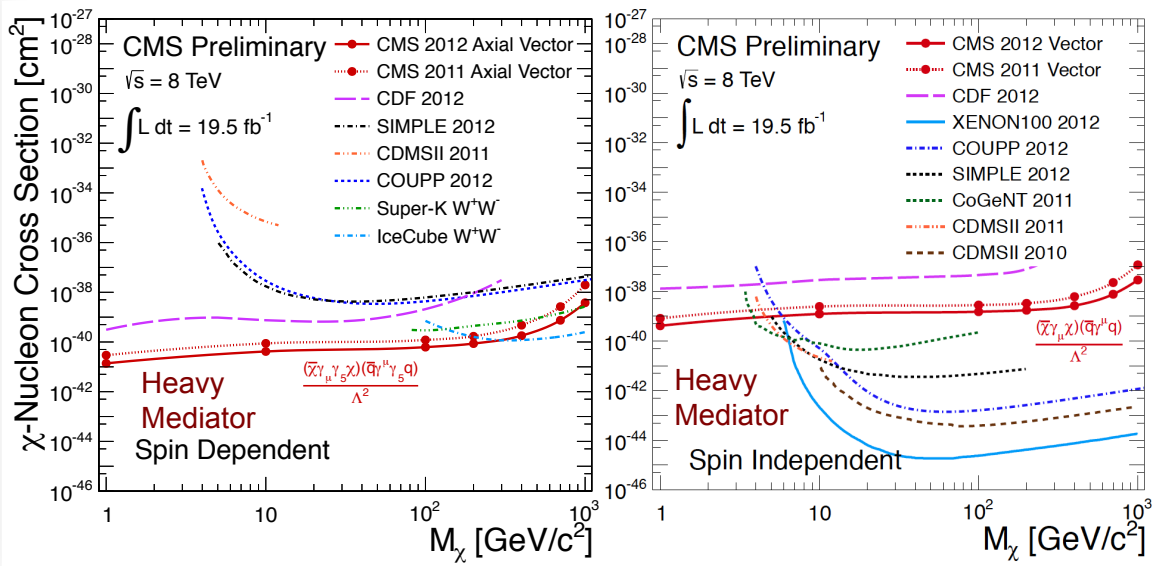
Monojets for Dark Matter

Stringent limits on extra dimensions and dark matter in the monojet channel







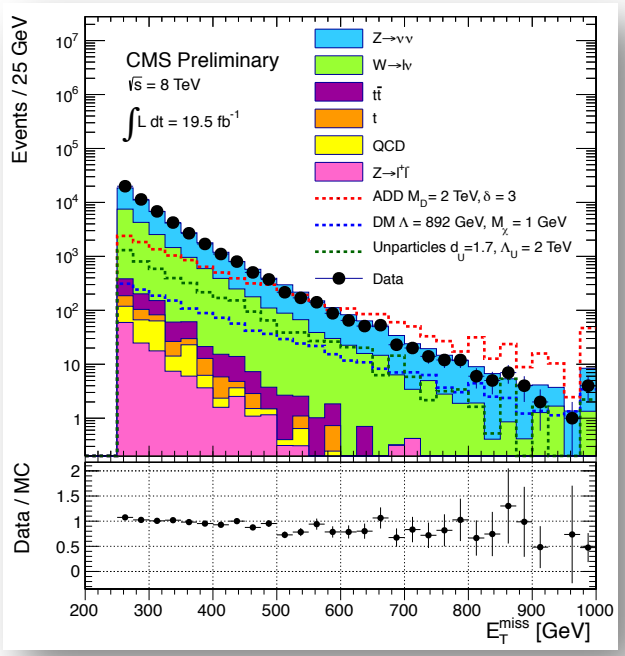


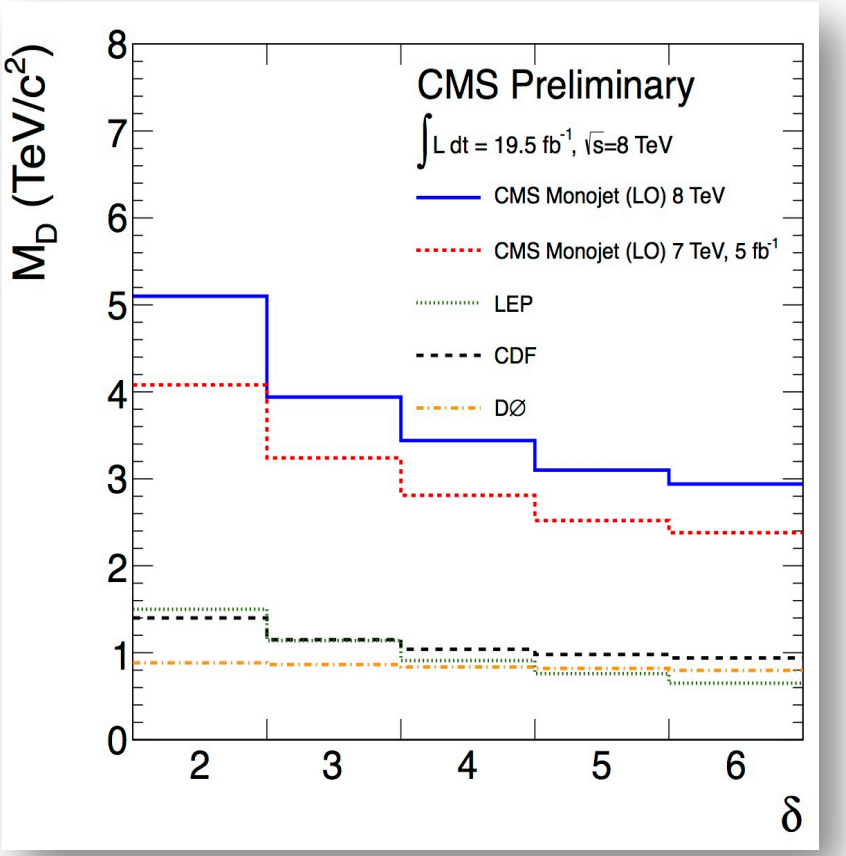
EXO-12-048

Search for Extra Dimensions

- Can also look for evidence of KK Gravitons
  - ADD Extra Dimensions

Additional material



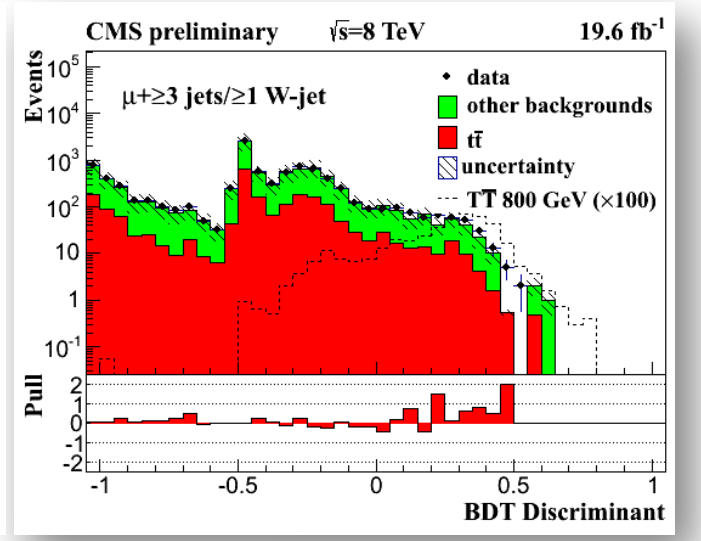


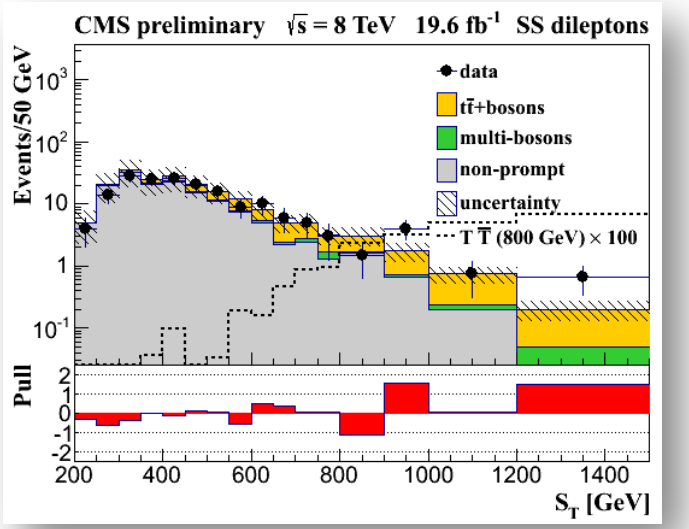
CMS-PAS-EXO-12-048

Search for Top partners

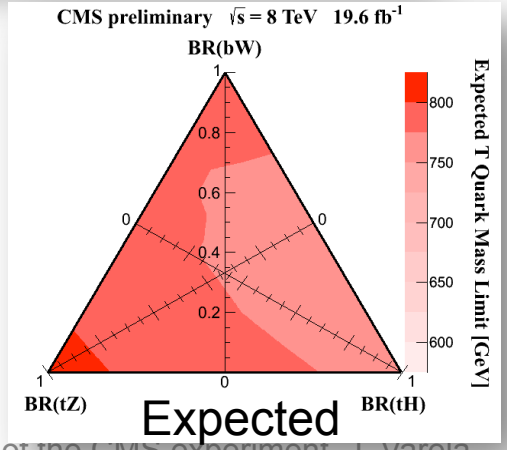
Search for vector-like T quark in various possible decay modes in the combinations of l+jets and dileptons

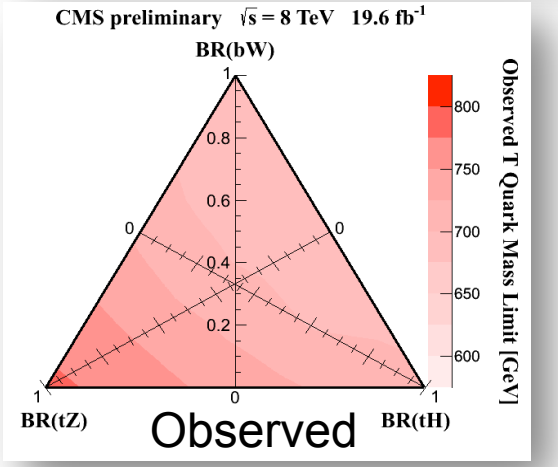
Additional material



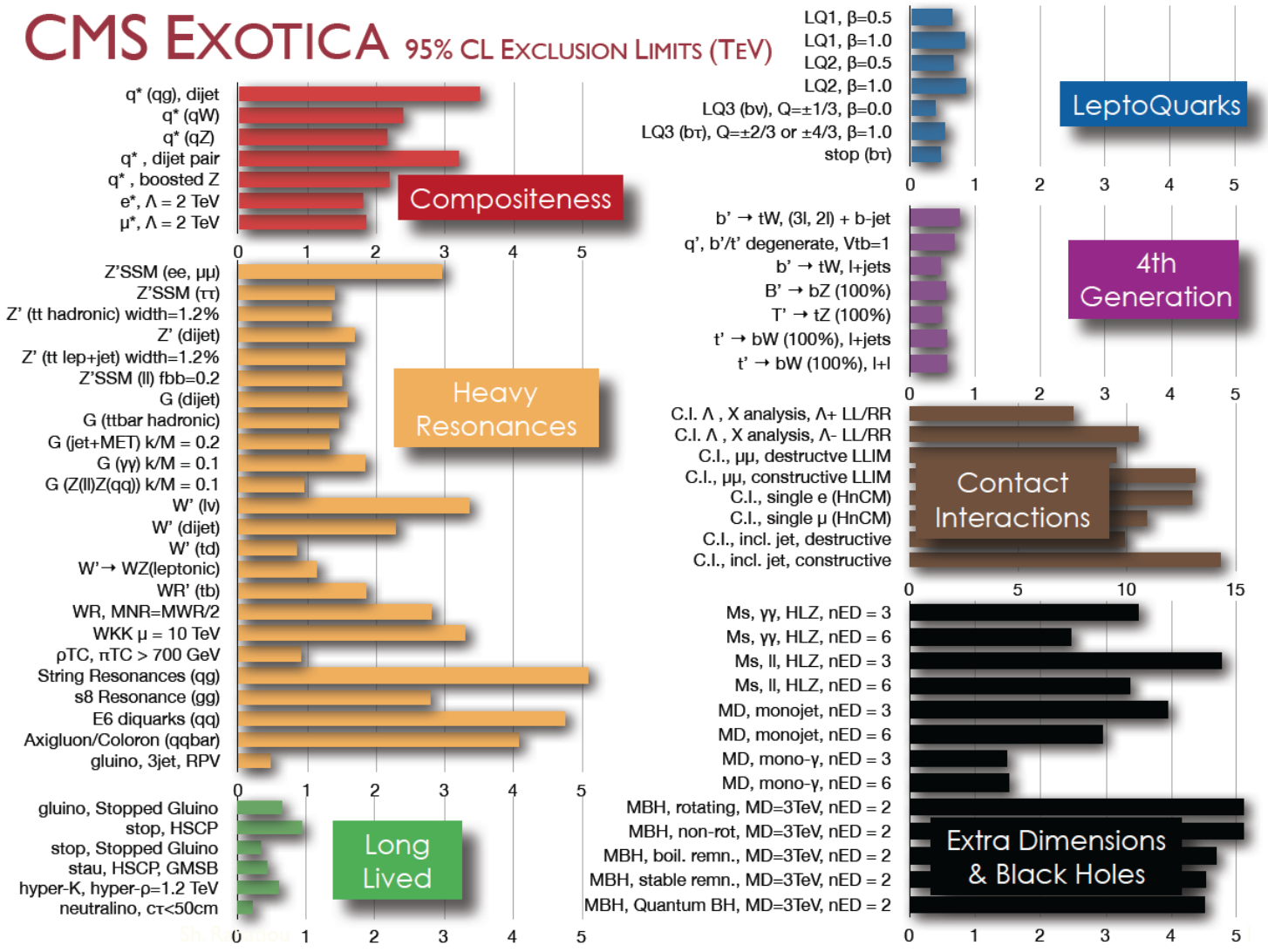


B2G-12-015



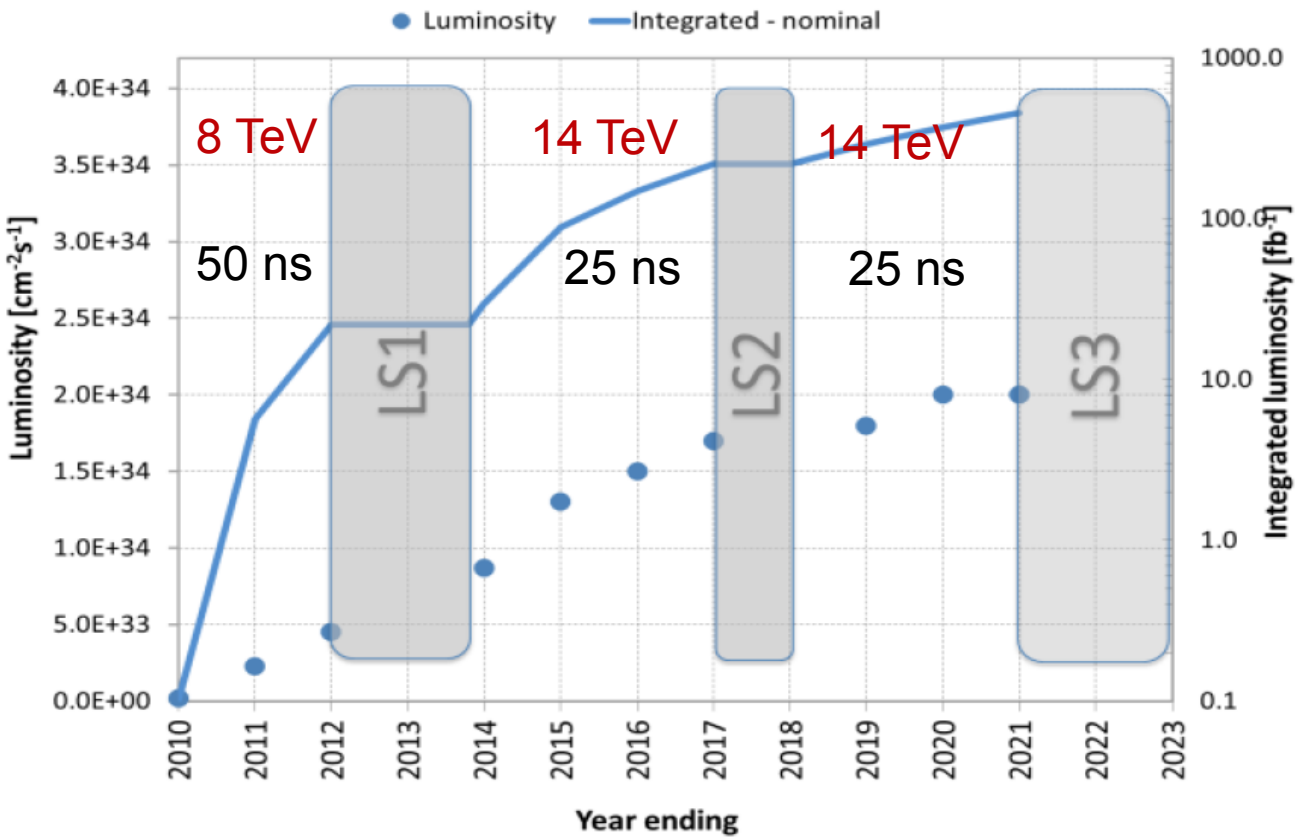


Exotica (no show) tables



Future perspectives

LHC projections



14 TeV

HL-LHC

Luminosity-leveled at 5×10^{34} Hz/cm^2

7×10^{33} Hz/cm^2
30 fb^{-1}

LS1

2×10^{34} Hz/cm^2
300 fb^{-1}

LS3

10^{35} Hz/cm^2
3000 fb^{-1}

CMS Upgrades: Phase 1 Upgrade — Phase 2 Upgrade

Physics motivations

What's beyond the Standard Model?

Nominal LHC beam energy (14 TeV) will allow the full exploitation of the Terascale:

- search for SUSY, Extra Dimensions, etc.
- search for the unknown

High luminosity will allow very precise measurements of the Higgs sector:

- look for deviations to the Standard Model at the level of a few percent.

CMS Upgrade phases

LS1 Projects:

- Completes muon coverage (ME4)
- Improve muon trigger (ME1), DT electronics
- Replace HCAL photo-detectors in Forward (new PMTs) and Outer (HPD → SiPM)

2014

Expected conclusion dates are indicated

Phase 1 Upgrades:

- New Pixels, HCAL SiPMs and electronics, and L1-Trigger
- Preparatory work during LS1:
  - new beam pipe
  - test slices of new systems

2018

Phase 2 Upgrades: scope to be defined in Technical Proposal (2014)

- Tracker Replacement
- Forward Calorimetry and Muons
- Further Trigger upgrade: Track Trigger

2023

Outlook I

- LHC achieved an astonishing performance in Run 1.
- CMS succeeded to meet all challenges, and to produce an unprecedented wave of physics results.
- Many new measurements with full proton-proton dataset collected in 2011-12 (~25 fb^{-1}).
- The agreement of data with the Standard Model is impressive.
- In the $H \rightarrow ZZ(4l)$ channel, a signal significance of 6.7σ is now observed. In $H \rightarrow \gamma\gamma$ updated results on the signal strength, $\mu = \sigma/\sigma_{SM} \sim 0.8 \pm 0.3$.
- Two independent determinations of the Higgs mass: 125.8 ± 0.6 GeV, in $H \rightarrow ZZ(4l)$; and 125.4 ± 0.8 GeV, in $H \rightarrow \gamma\gamma$.

Outlook II

- The pure pseudoscalar hypothesis is excluded at 99.8% C.L. and simple spin 2 models are excluded with greater than 99.4% C.L.
- Strong evidence is seen in $H \rightarrow \tau\tau$ channel (significance ~3σ).
- These measurements strongly indicates that the new particle is a Higgs boson, responsible for the Electroweak Symmetry Breaking.
- However they are still fall from the precision required to rule out all BSM scenarios.
- No evidence of new physics in the 7-8 TeV data creates a big expectation on the LHC restart at 14 TeV in 2015.