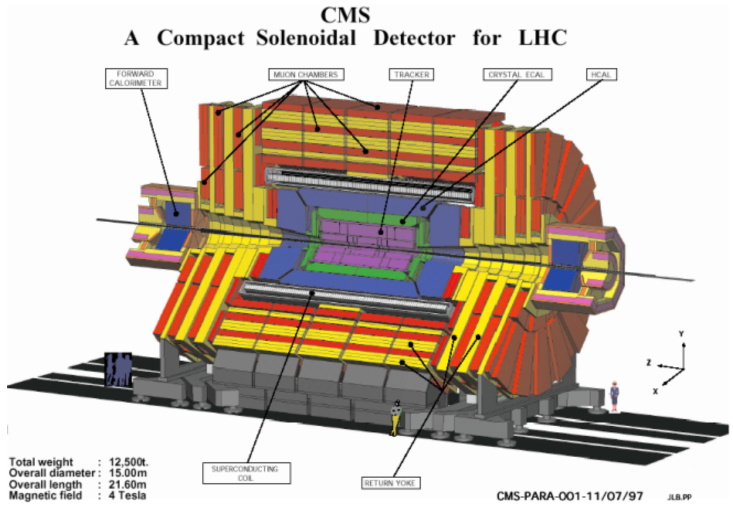
Overview of physics results from CMS

Ilya Gorbunov
Joint Institute for Nuclear Research, Dubna
on behalf of CMS Collaboration

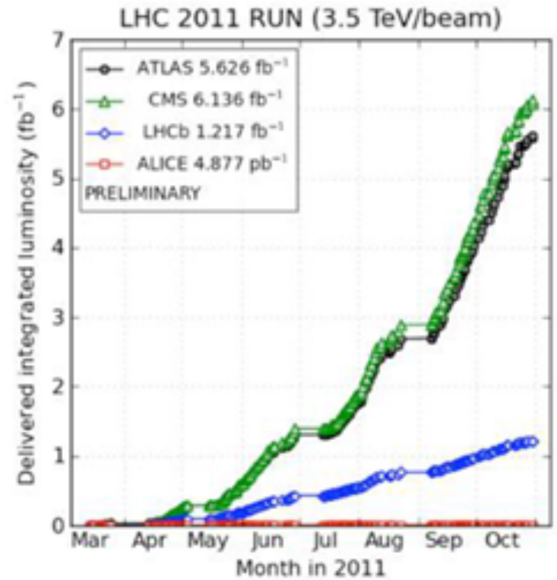


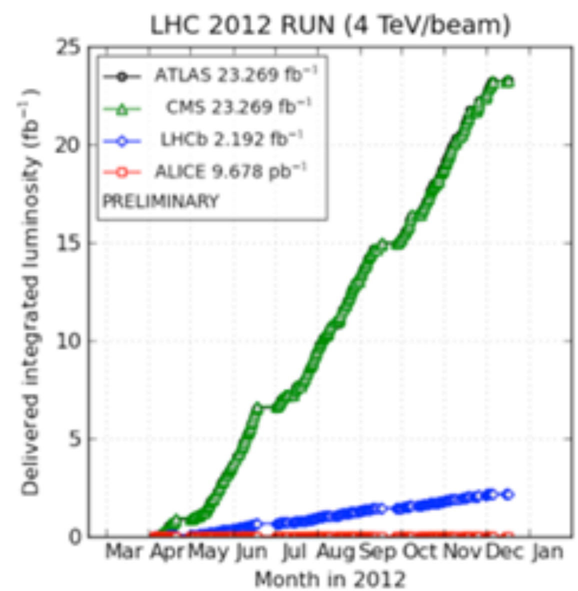
The XXII International Baldin Seminar on High Energy Physics Problems "Relativistic Nuclear Physics and Quantum Chromodynamics“

November 15-20, 2014, JINR, Dubna

OUTLINE

- ❑ Discovery and Studies of the Higgs Boson
- ❑ Standard Model Physics
  - ✓ Vector Bosons & Jets
  - ✓ Forward and Small-x QCD Physics
  - ✓ B Physics and Quarkonia
  - ✓ Top Physics
- ❑ Physics Beyond the Standard Model
  - ✓ Supersymmetry
  - ✓ Exotica, i.e. Physics beyond SM/SUSY/Higgs
- ❑ Heavy Ion



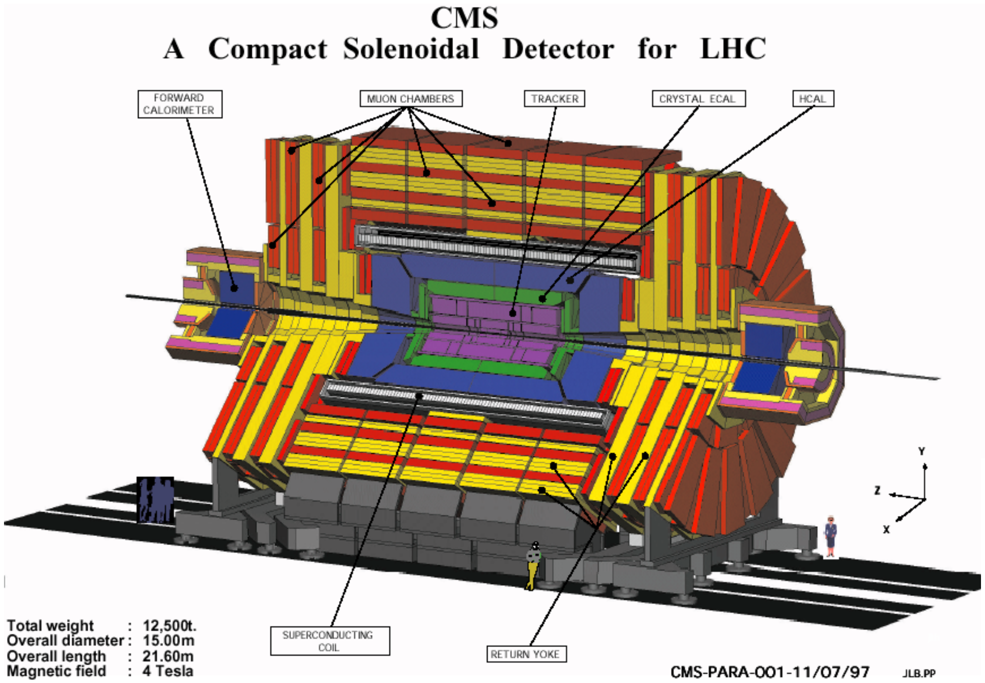


CMS Public Physics Results

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

Compact Muon Solenoid

Large general-purpose particle physics detector

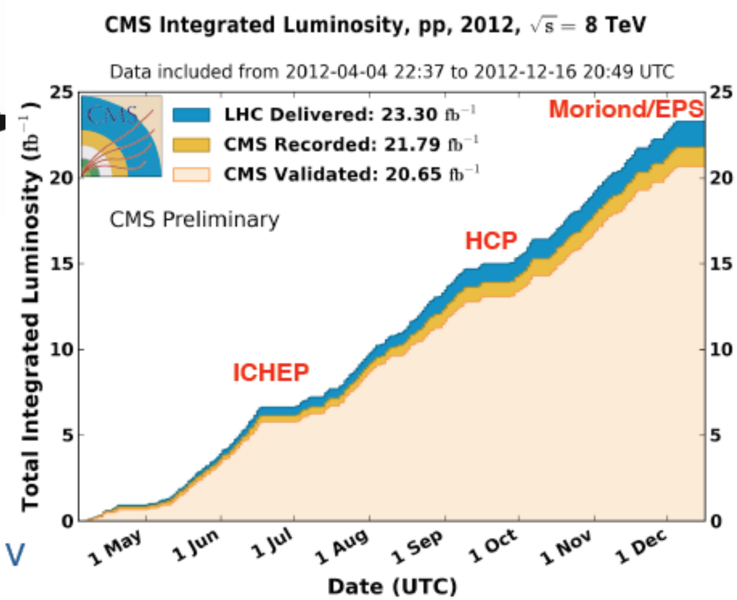


Total certified good data set

- 5.32 fb-1 @ 7 TeV
- 20.65fb-1 @ 8 TeV

~88% of delivered lumi

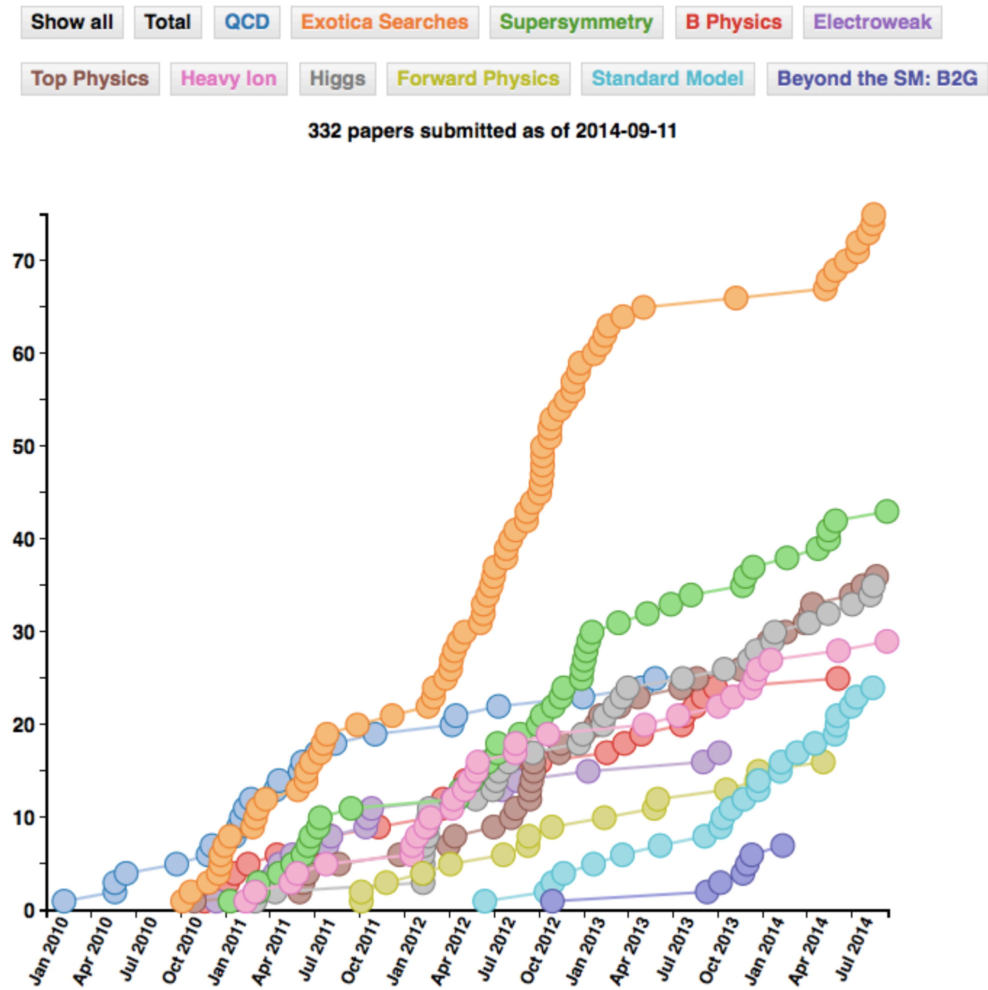
Total weight	*12 500 t*
Overall diameter	*15.00 m*
Overall length	*21.6 m*
Magnetic field	*3.8 Tesla*



Detector subsystems are designed to measure: the energy and momentum of photons, electrons, muons, jets, missing E_T up to a few TeV

CMS Publications

In 2010-2013 the CMS Collaboration published 332 papers on collision data (J. High Energy Phys, Phys. Rev. Lett., Phys. Lett. B, Eur. Phys. J. etc)



332 publications on pp (and pPb/PbPb) physics since January 2010 (03/8/2014)

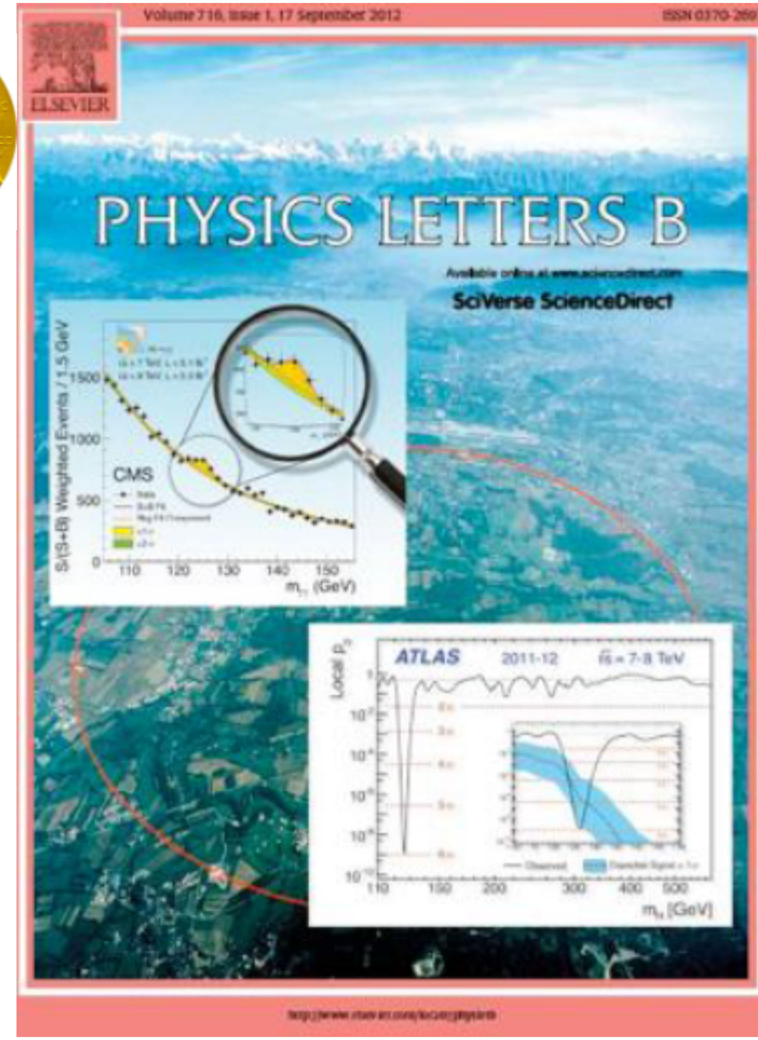
Mostly on exotica searches and supersymmetry (>100 papers together)

Slightly too much for 30 minutes ☹

CERN Document Server

http://cdsweb.cern.ch/collection/CMS%20Papers?ln=en

Discovery and Studies of the Higgs Boson



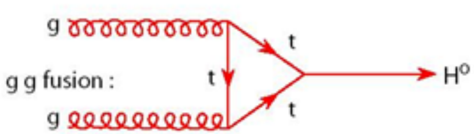
Phys. Lett. B 716 (2012) 30

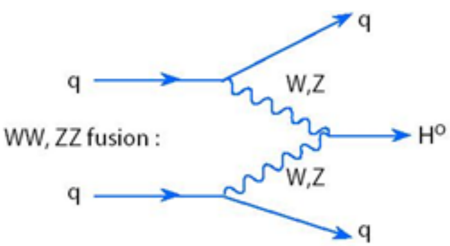
Most cited paper so far (more then 3000 times)

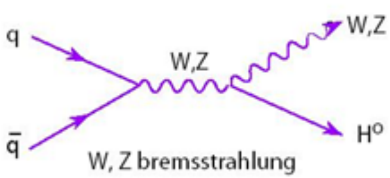
CMS Higgs Public Physics Results

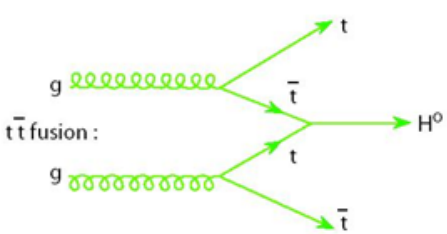
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIG

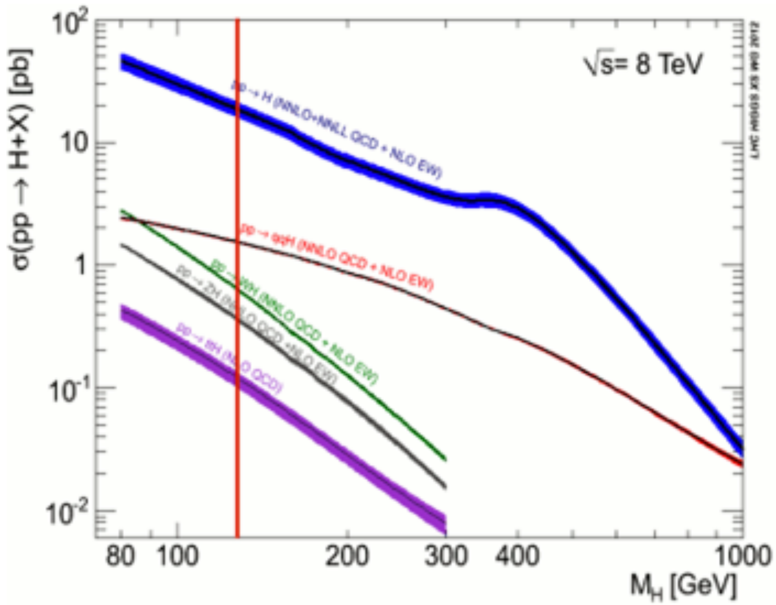
SM Higgs Production











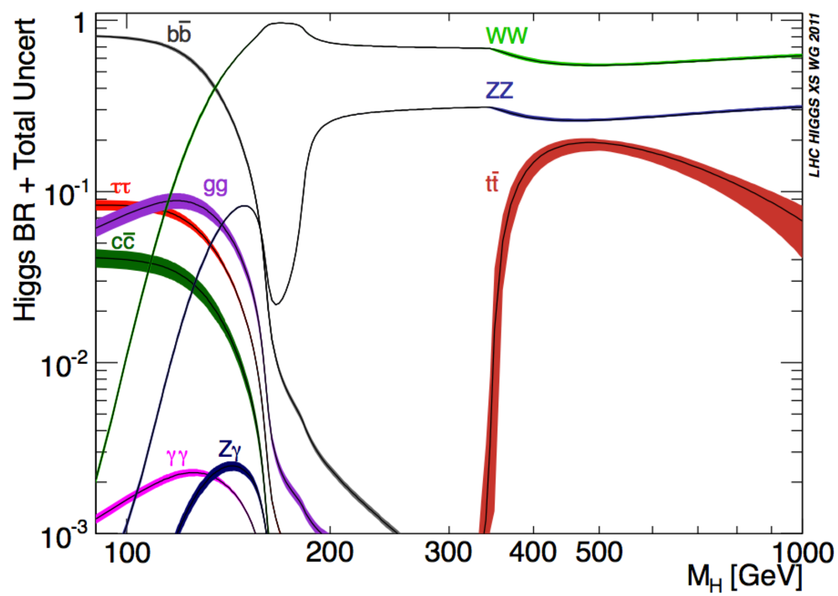
19.5 pb ggF

1.6 pb VBF

1.1 pb VH

0.1 pb $t\bar{t}H$

@ m_H=125 GeV



10%	H → bb
15%	H → ττ
20%	H → WW
1-2%	H → ZZ
1-2%	H → γγ

Signature explored at CMS

Processes/decays studied:

Results released | In progress

	untagged	VBF	VH	ttH
H-> gamgam				
H-> ZZ				
H->WW				
H-> bb				
H-> tau tau				
H-> Zgamma				
H-> mumu				
H-> invisible				

bbH?

+ more exotic channels

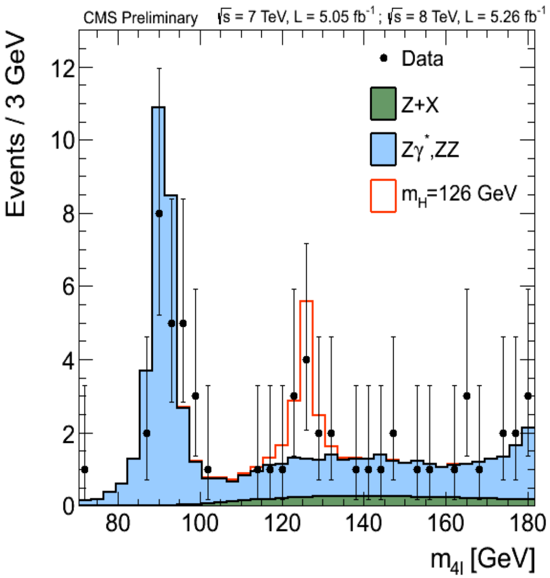
Main decay channel characteristics:

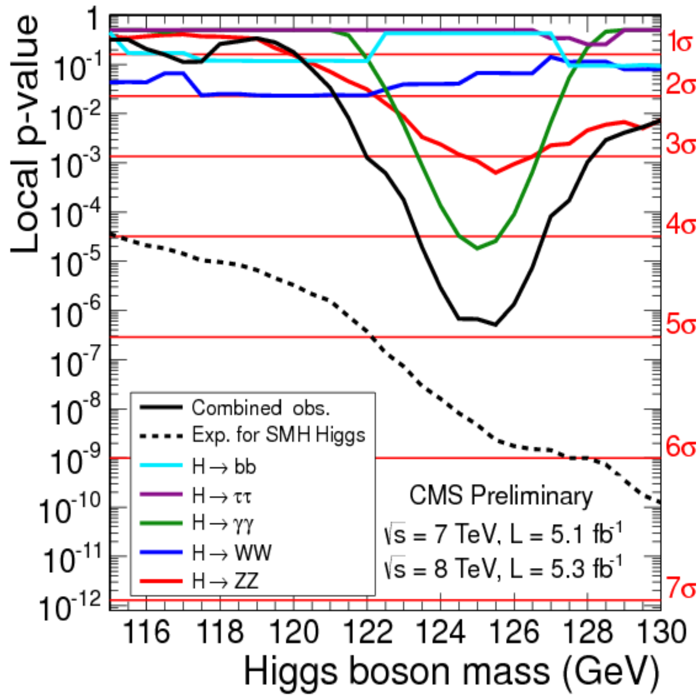
Channel	m_H range (GeV/c^2)	Data used 7+8 TeV (fb^{-1})	m_H resolution
H -> γγ	110-150	5.1+19.6	1-2%
H -> tautau	110-145	4.9+19.6	15%
H -> bb	110-135	5.0+19.0	10%
H -> WW -> lnulnu	110-600	4.9+19.5	20%
H -> ZZ -> 4l	110-1000	5.1+19.6	1-2%

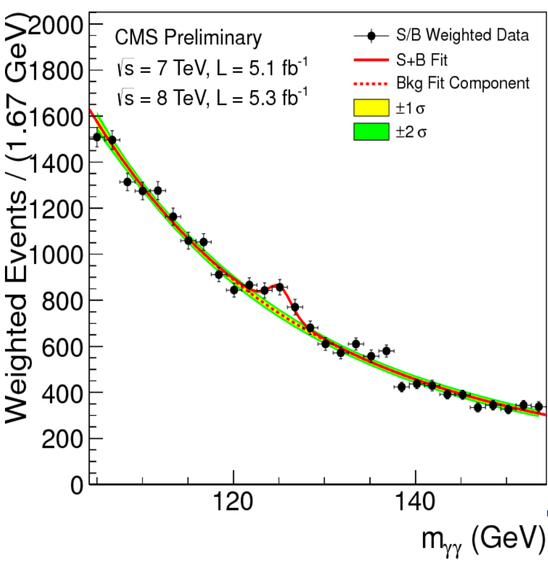
Higgs History: Discovery of New Boson

CMS Higgs searches in 2011-2012 led to new boson discovery with a mass of 125.3 ± 0.4 (stat.) ± 0.5 (syst.) GeV

[Higgs *Seminar* at *CERN - 4 July 2012*]







ICHEP2012 Melbourne

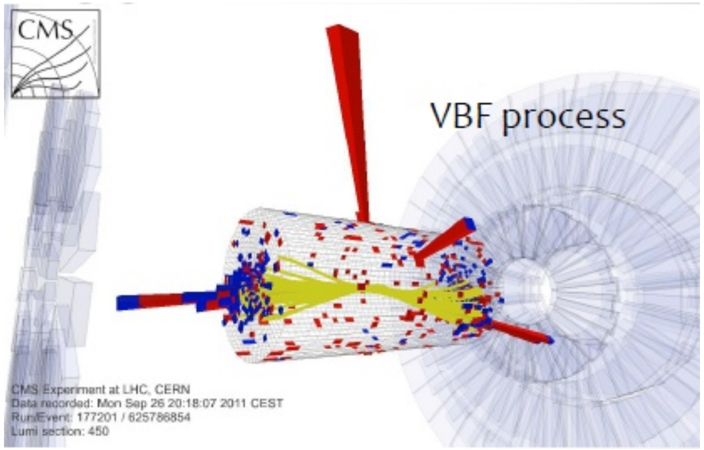
- **γγ: 4,1 σ (spin ≠ 1)**
- **ZZ: 3,2 σ**
- **WW: 1,5 σ**
- **bb and ττ: no excess observed**

Local significance of excess (γγ and ZZ) is 5.0 σ

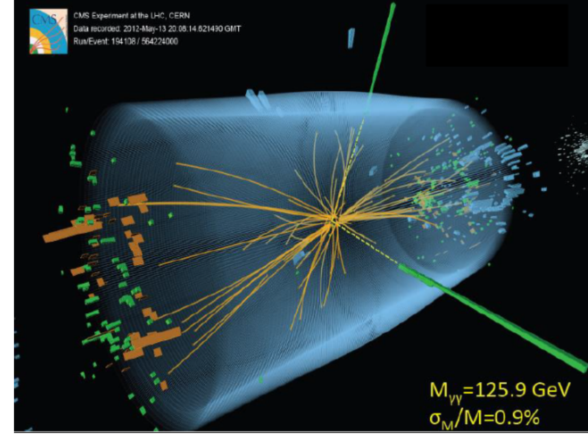
σ/σ_{SM} = 0.87 ± 0.23

H → γγ

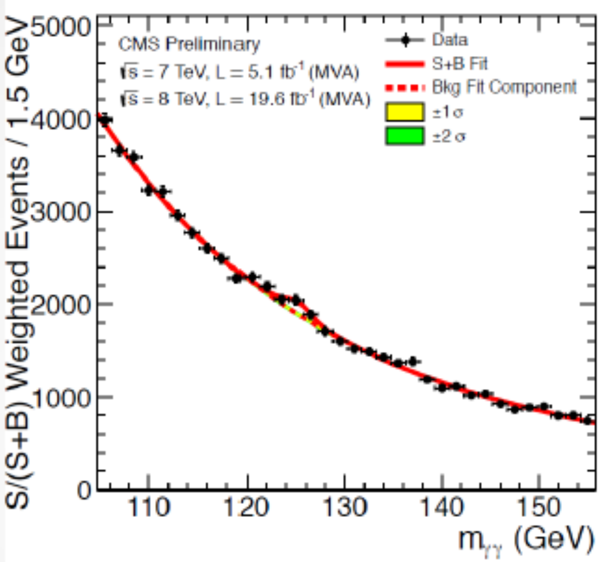
CMS-HIG-13-001

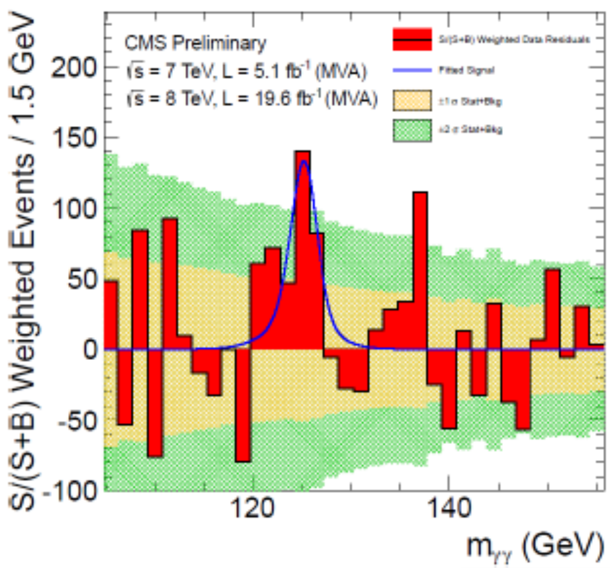


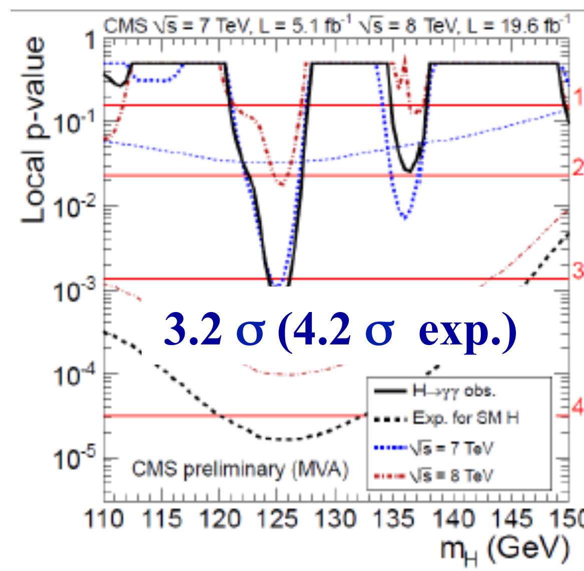
- **Narrow peak from 2 high energy isolated photons**
- **Excellent resolution: 1% in mγγ spectra**



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

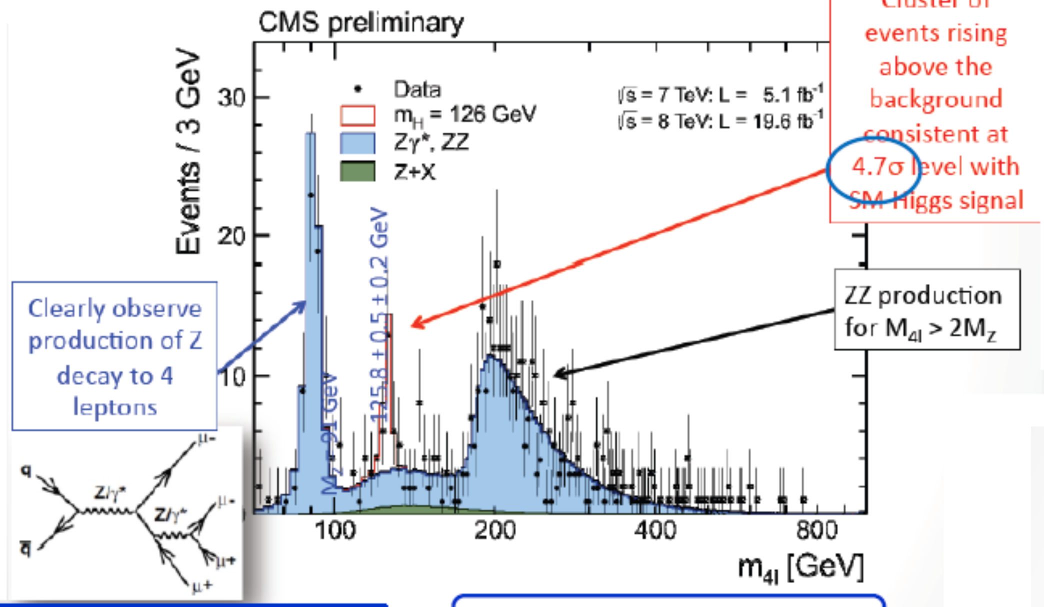






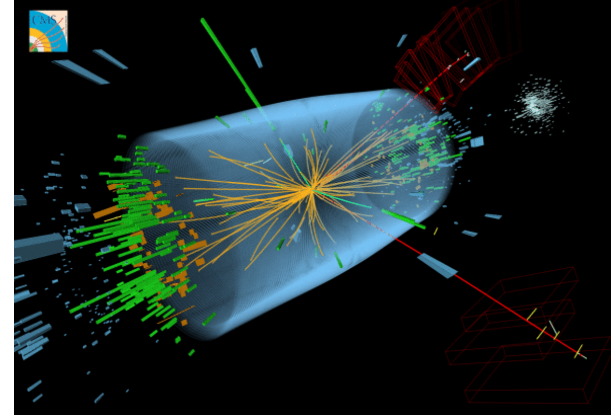
$H \rightarrow ZZ^* \rightarrow 4l$

CMS-HIG-13-002



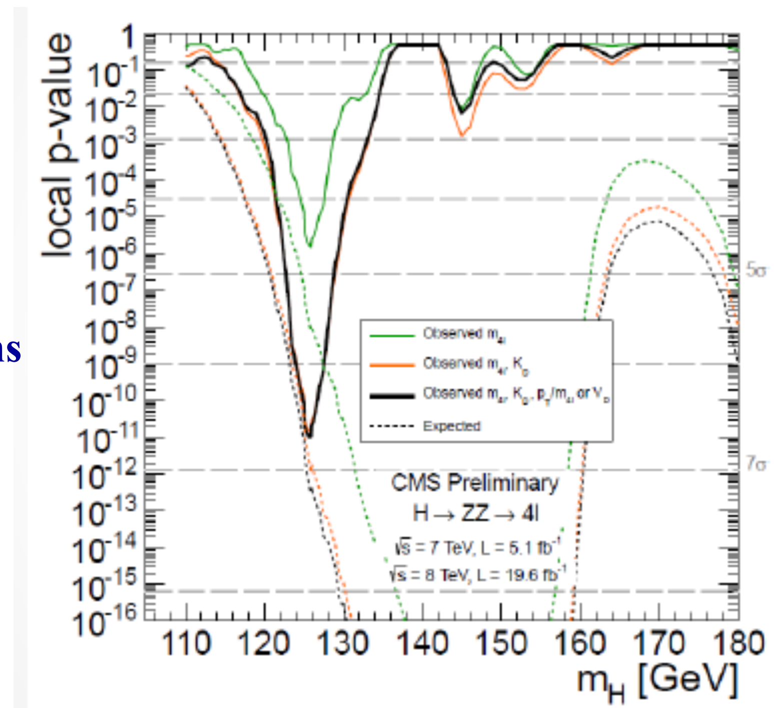
$BR(Z \rightarrow 4\ell) = 4.4^{+1.0}_{-0.8}(\text{stat}) \pm 0.2(\text{syst}) \times 10^{-6}$

$m_H = 125.8 \pm 0.5 \pm 0.2$ GeV



$\sigma/\sigma_{SM} = 0.92 \pm 0.28$

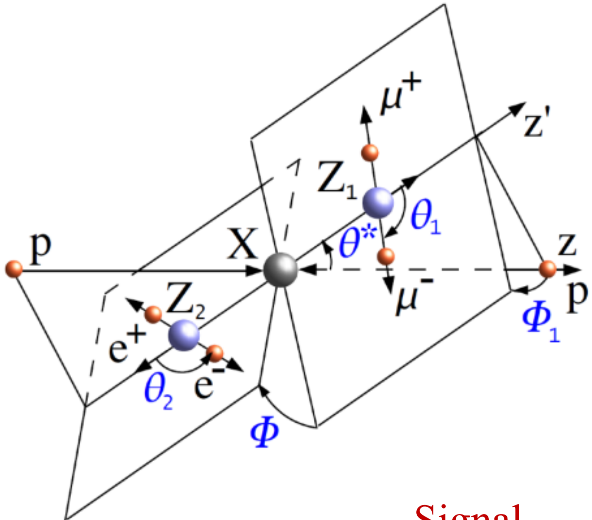
7.1 σ (6.7 σ exp.)



- **2 high-mass pairs of opposite-sign isolated leptons (electrons or muons) coming from primary vertex**
- **Good resolution: 1-2% in mass spectra**
- **Background**
  - ZZ (reducible)
  - WZ, Z+jets, Zbbar, ttbar (reducible)
- **Small Branching (~10^{-3} @125 GeV)**

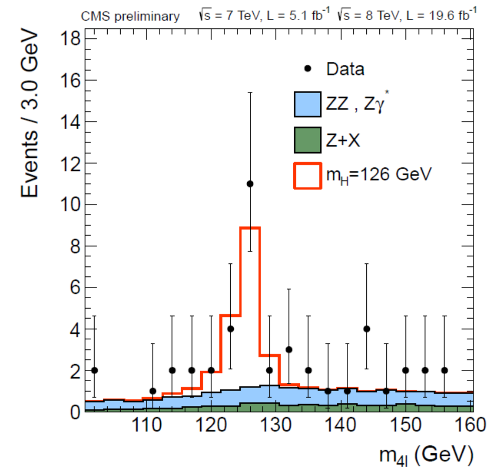
H → ZZ* → 4l (MELA)

CMS-HIG-13-002

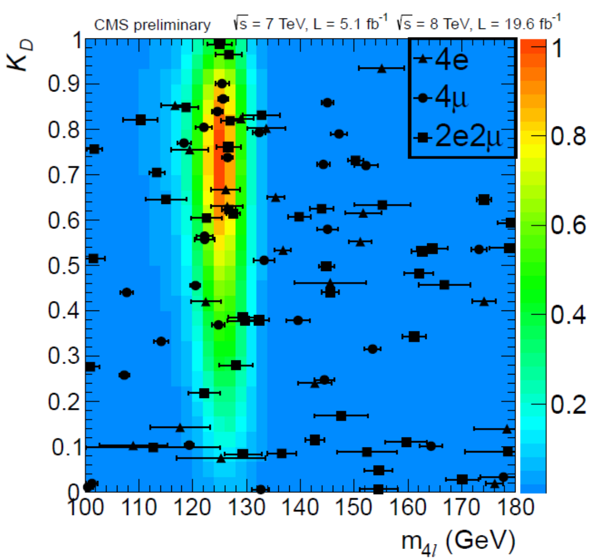


K_D (Kinematic Discriminator) is Matrix Element Likelihood Analysis: uses kinematic inputs for signal to background discrimination (m1, m2, Θ1, Θ2, Φ1, Φ2)

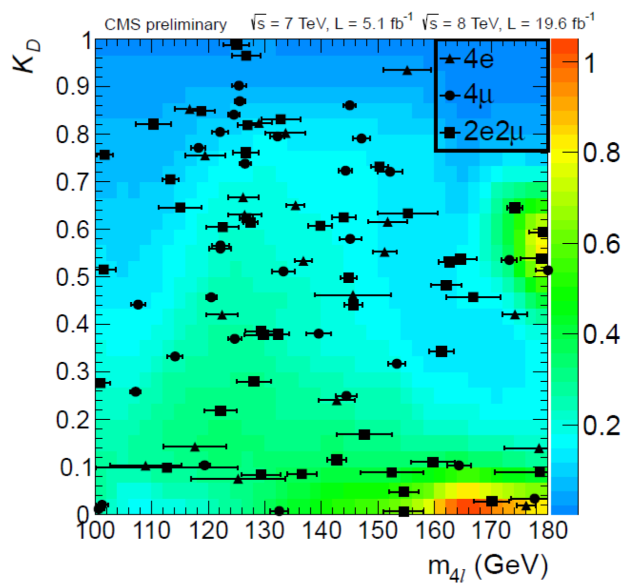
$$\text{MELA} = \frac{P_{Sig}}{P_{Sig}+P_{bkg}}$$

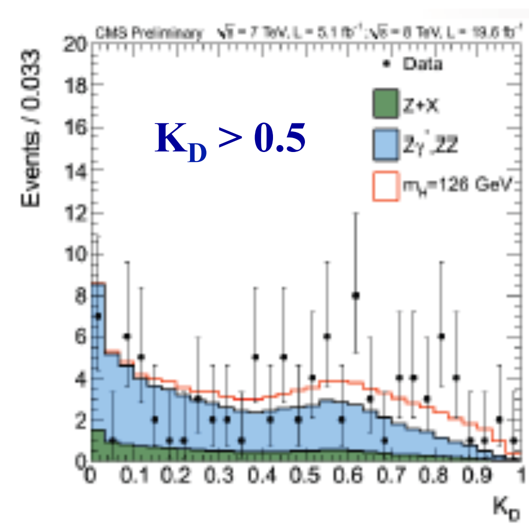


Signal



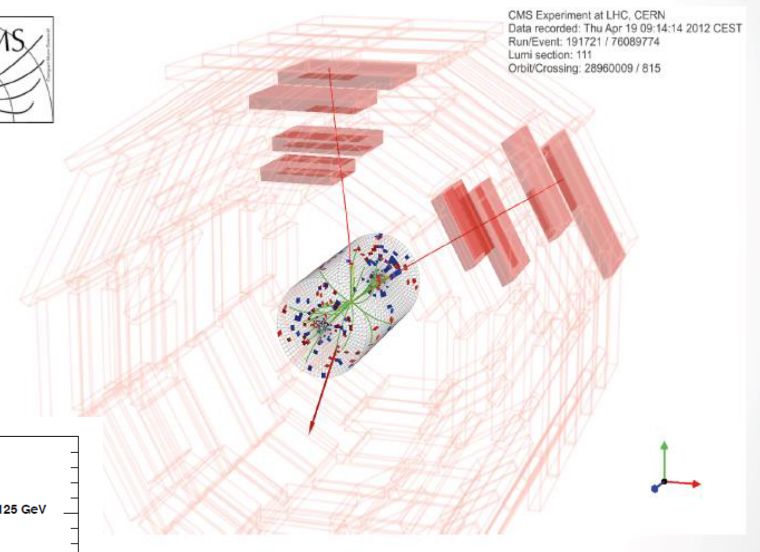
Background





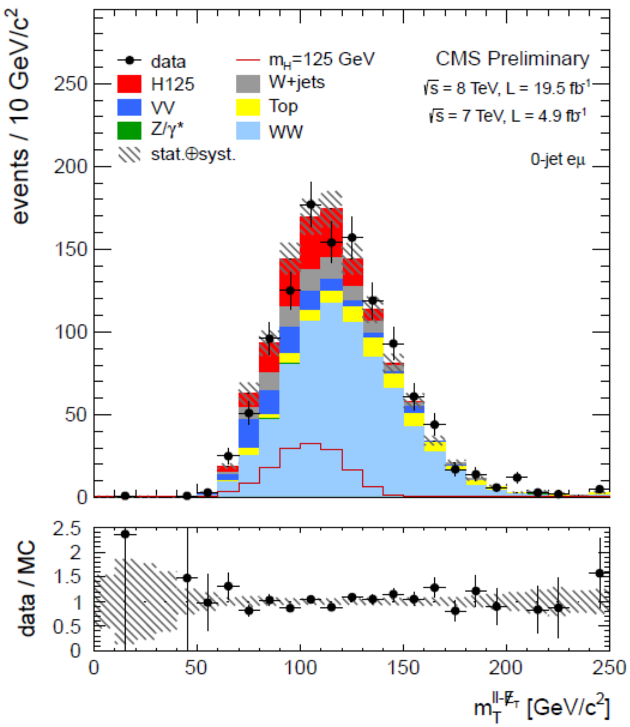
H → WW*

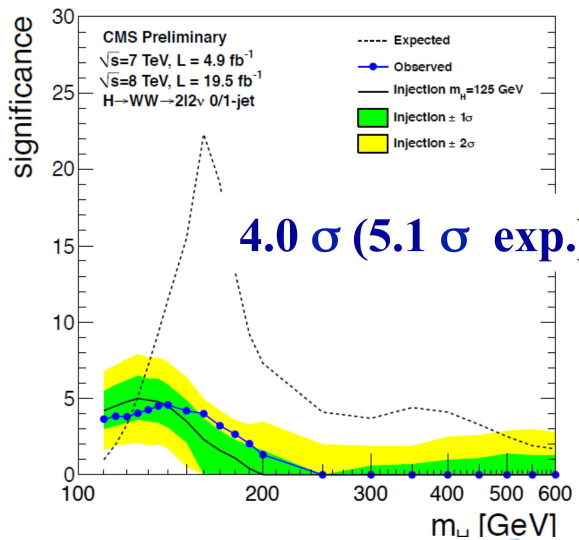
CMS-HIG-13-003



WW* signature

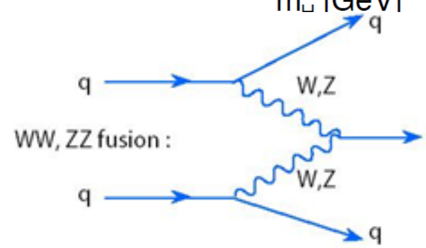
- 2 High pt isolated leptons
- Large momentum imbalance
- no mass peak reconstruction

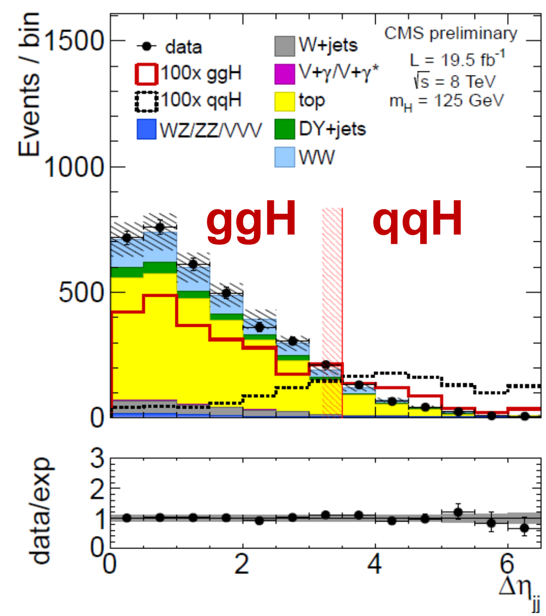




4.0 σ (5.1 σ exp.)

σ/σ_{SM} = 0.76 ± 0.21





VBF signature

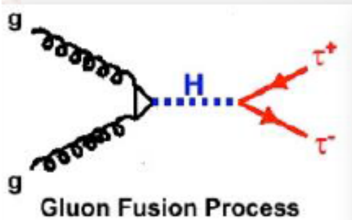
CMS-HIG-13-022

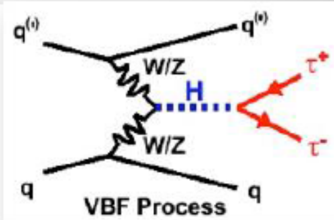
- 2 high-pT jets in forward directions + rapidity gap
- Large momentum imbalance

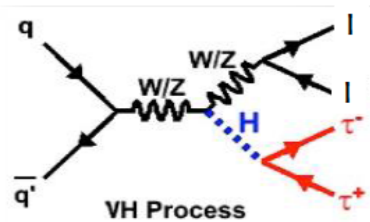
1.3 σ (2.1 σ exp.)

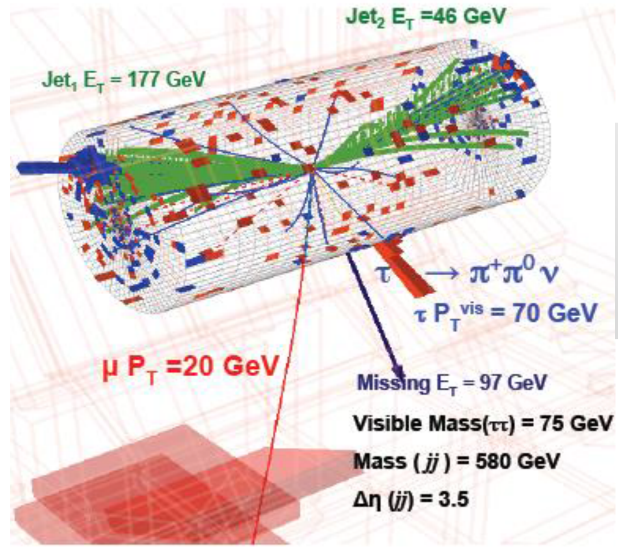
H → ττ (coupling to fermions)

CMS-HIG-13-004

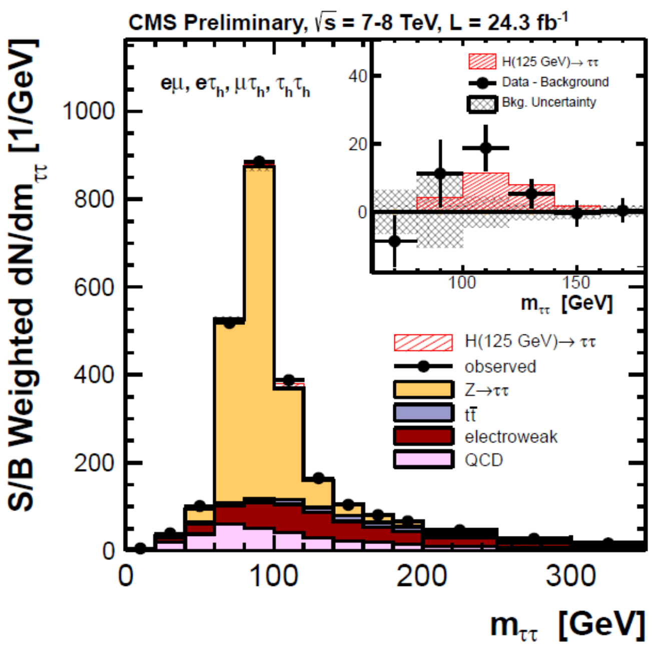


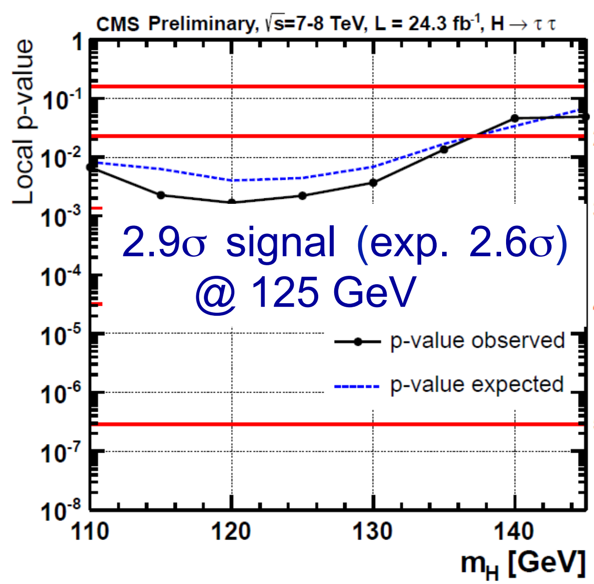


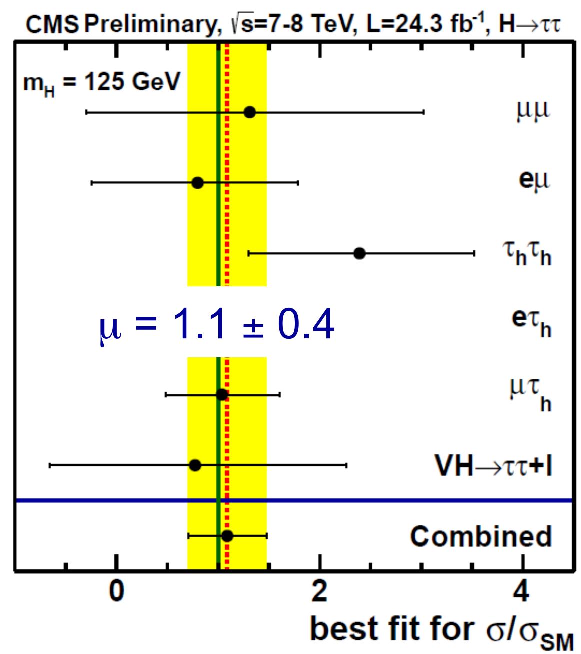




Number of jets categories
0 jets: only to constraint the background
1 jet: low / high pT
2 jets : VBF process





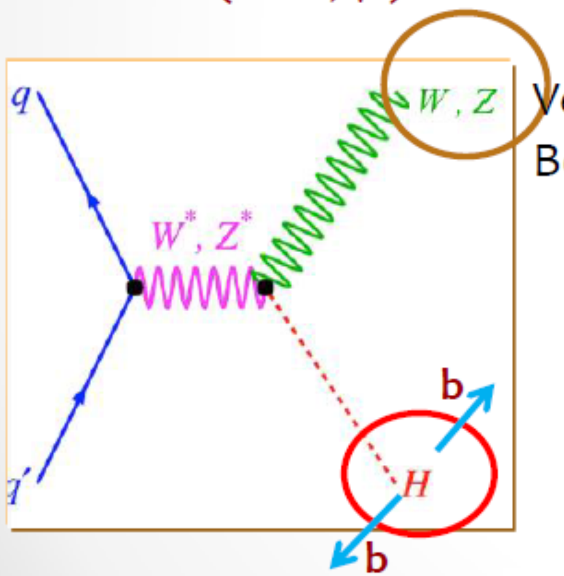


H → bb (coupling to fermions)

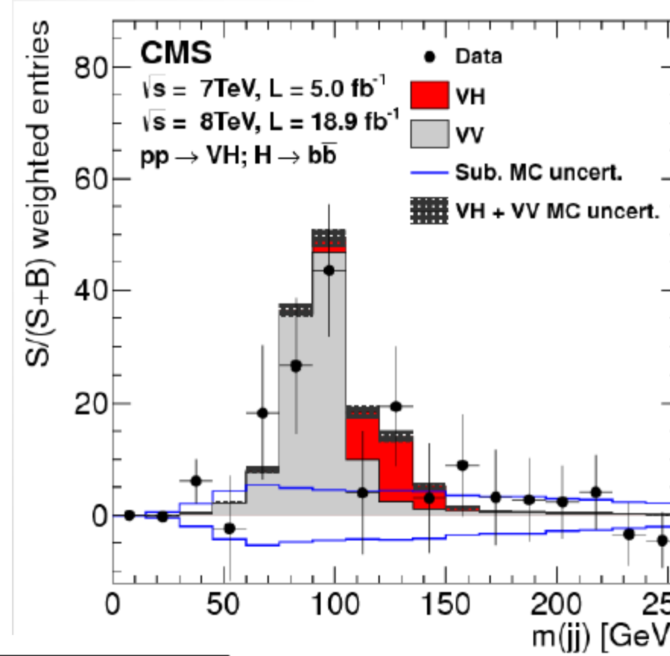
CMS-HIG-13-012

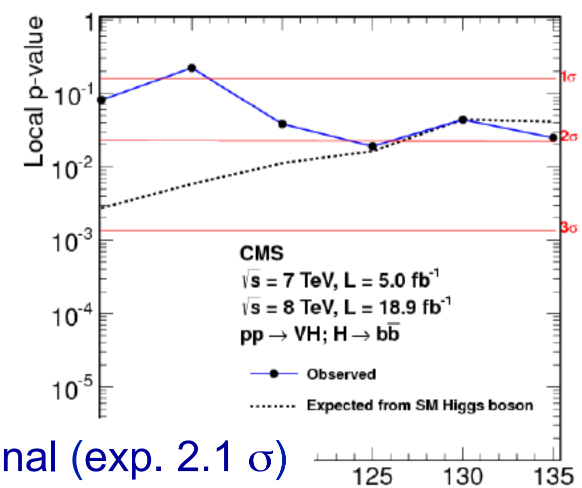
- If SM Higgs → bb has the highest BR
- But very high levels of backgrounds looking for b-pairs alone.
- Look for Associated Production with a Vector Boson (W,Z)

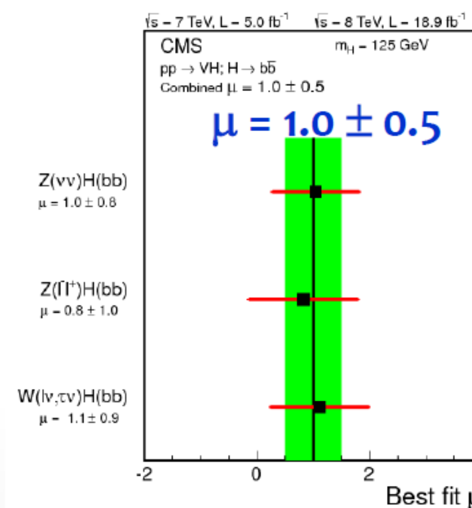
Z→ ll (l = e, μ, ν)
W→ lν (l = e, μ)
} 5 different final states



Vector Boson







2.1σ signal (exp. 2.1 σ) @ 125 GeV

from D. de la Cruz's talk

Higgs Signal Summary

CMS-HIG-13-005

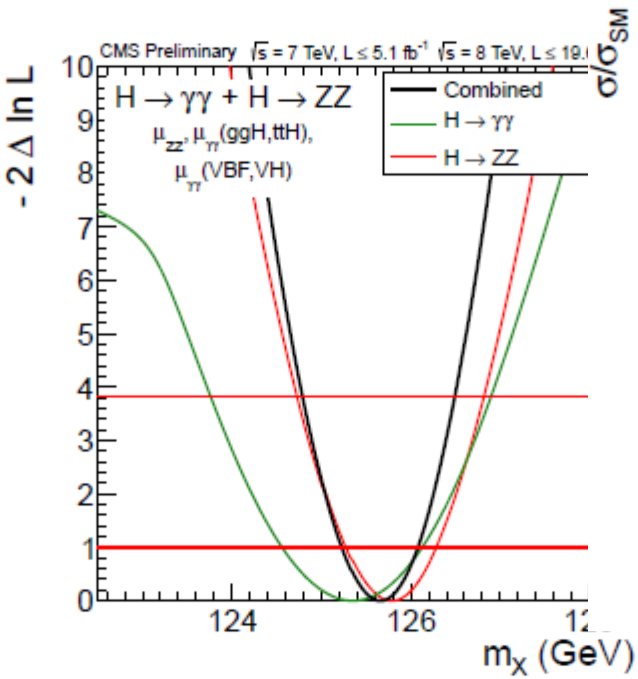
H decay	Prod. tag	Analyses: Exclusive final states	No. of channels	m_H resolution	Lumi (fb^{-1}) 7 TeV	Lumi (fb^{-1}) 8 TeV	Ref.
$\gamma\gamma$	untagged	$\gamma\gamma$ (4 diphoton classes)	4 + 4	1-2%	5.1	19.6	[63]
	VBF-tag	$\gamma\gamma + (jj)_{VBF}$ (two dijet classes for 8 TeV)	1 + 2	<1.5%	5.1	19.6	
	VH-tag	$\gamma\gamma + (e, \mu, MET)$	3	<1.5%		19.6	
$ZZ \to 4\ell$	$N_{jet} < 2$	4e, 4μ, $2e2\mu$	3 + 3	1-2%	5.1	19.6	[64]
	$N_{jet} \geq 2$		3 + 3				
$WW \to \ell\nu\ell\nu$	0/1-jets	(DF or SF dileptons) × (0 or 1 jets)	4 + 4	20%	4.9	19.5	[65]
	VBF-tag	$\ell\nu\ell\nu + (jj)_{VBF}$ (DF or SF dileptons for 8 TeV)	1 + 2	20%	4.9	12.1	[66]
	WH-tag	$3\ell3\nu$ (same-sign SF and otherwise)	2 + 2		4.9	19.5	[67]
$\tau\tau$	0/1-jet	$(e\tau_h, \mu\tau_h, e\mu, \mu\mu) \times$ (low or high p_T^τ)	16 + 16	15%	4.9	19.6	[68]
	1-jet	$\tau_h\tau_h$	1 + 1				
	VBF-tag	$(e\tau_h, \mu\tau_h, e\mu, \mu\mu, \tau_h\tau_h) + (jj)_{VBF}$	5 + 5				
	ZH-tag	$(ee, \mu\mu) \times (\tau_h\tau_h, e\tau_h, \mu\tau_h, e\mu)$	8 + 8		5.0	19.5	[69]
	WH-tag	$\tau_h\mu\mu, \tau_h e\mu, e\tau_h\tau_h, \mu\tau_h\tau_h$	4 + 4				
bb	VH-tag	$(\nu\nu, ee, \mu\mu, e\nu, \mu\nu$ with 2 b-jets$) \times$ (low or high $p_T(V)$ or loose b-tag)	10 + 13	10%	5.0	12.1	[70]
	ttH-tag	(ℓ with 4, 5 or ≥6 jets) × (3 or ≥4 b-tags);	6 + 6		5.0	5.1	[71]
		(ℓ with 6 jets with 2 b-tags); ($\ell\ell$ with 2 or ≥3 b-tagged jets)	3 + 3				

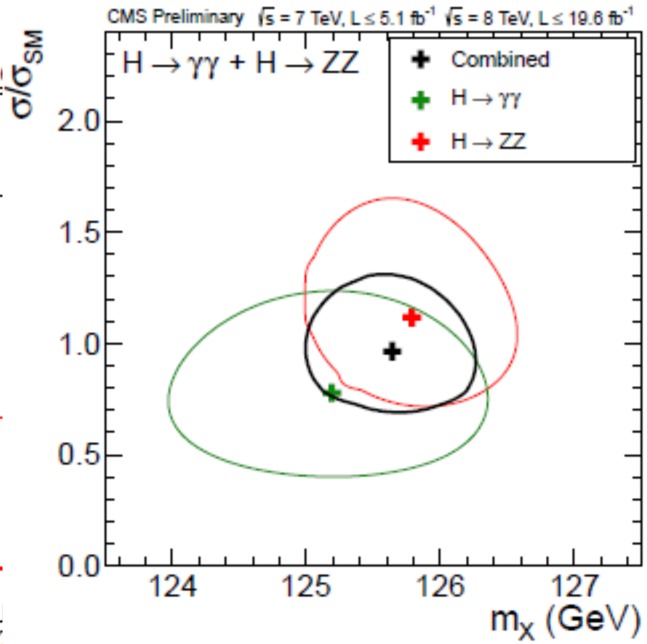
Decay mode	Expected (σ)	Observed (σ)
ZZ	7.1	6.7
$\gamma\gamma$	3.9	3.2
WW	5.3	3.9
bb	2.2	2.0
$\tau\tau$	2.6	2.8

Higgs Properties: Mass and Signal Strength

CMS-HIG-13-005

To measure mass the ZZ → 2l and γγ channels that have excellent mass resolution have been used…

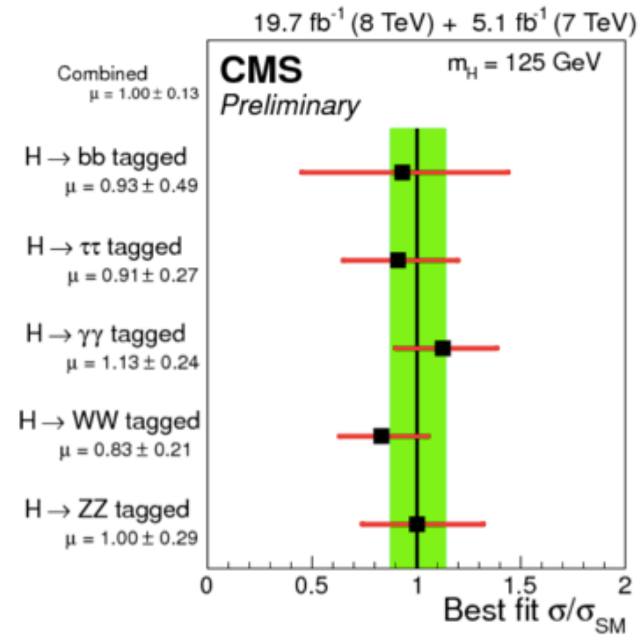




γγ	125.4±0.5±0.6 GeV
ZZ→4l	125.8±0.5±0.2 GeV
comb.	125.7±0.3±0.3 GeV = 127 ±0.4 GeV

…and 5 channels for the signal strength

$$\mu = \frac{\sigma \cdot BR}{(\sigma \cdot BR)_{SM}}$$

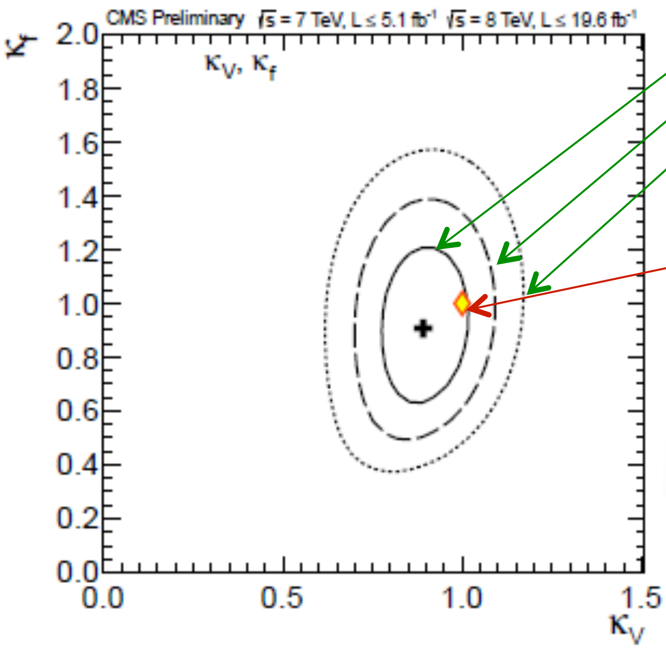


μ = 0.80 ± 0.14 @ m_H=125.7 GeV

Compatible with SM!

Higgs Properties: Couplings

CMS-HIG-13-005



68 % C.L.

95 % C.L.

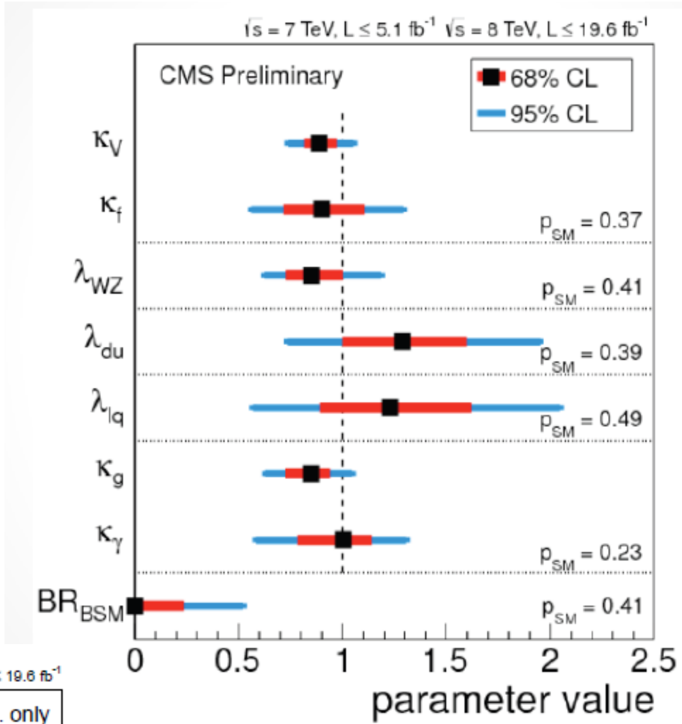
99.7 % C.L.

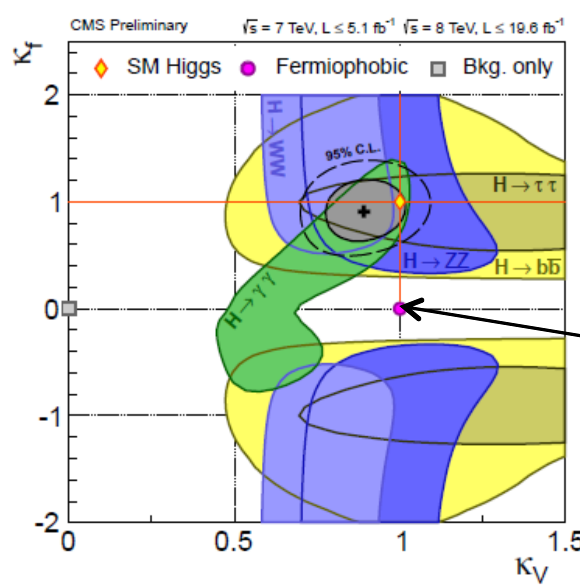
SM

95% CL intervals

k_V :[0.74, 1.06] for k_f =1

k_f :[0.61, 1.33] for k_V =1





The data are compatible with the expectations for the SM Higgs bosons

Fermiofobic Higgs exluded @ 126 GeV

Higgs Properties: Spin and Parity

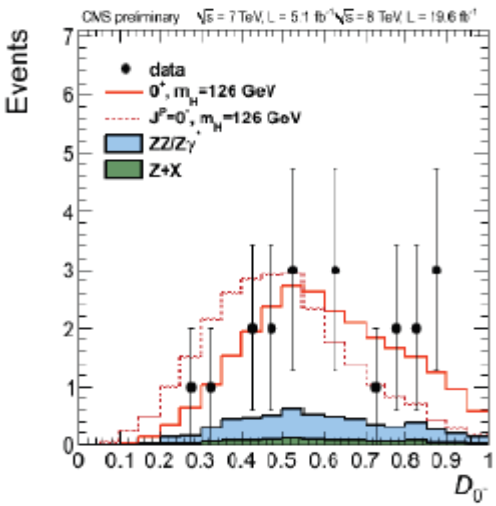
- Spin 0 is required if SM Higgs
- Spin 1 is excluded by $H \to \gamma\gamma$ decay (Landau-Yang theorem)
- Spin 2 induced by KK-graviton couplings

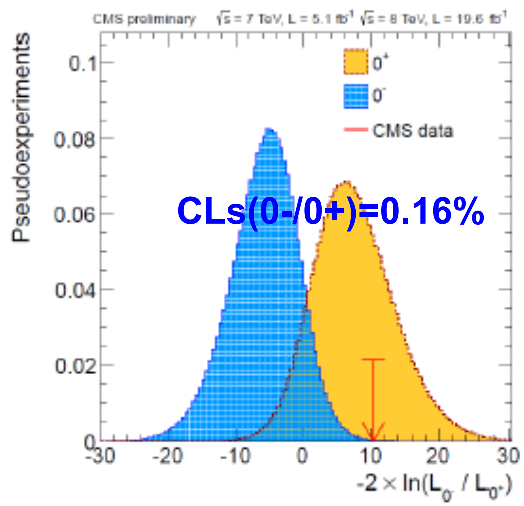
Parity:

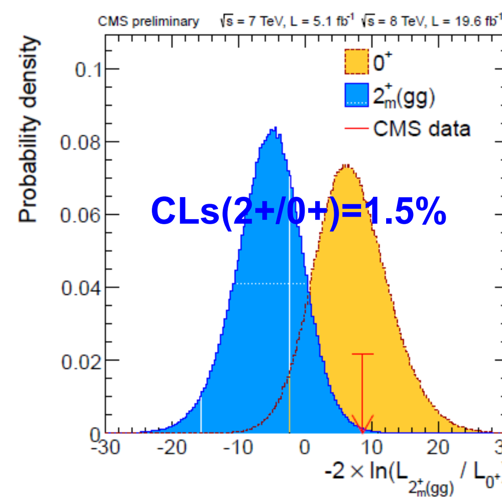
- SM CP-even Higgs
- BSM CP-odd HIggs

ZZ → 2l

Several alternative models tested: 0-, 0^+_h, 1^+, 1^-, 2^+_m(gg), 2^+_m(qq)







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%

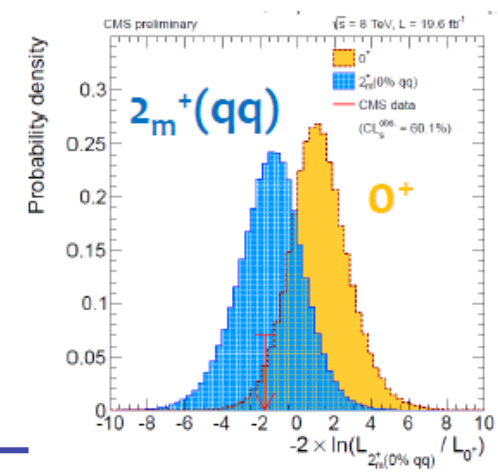
γγ

Spin 0^+ or 2^+_m (graviton-like) (from gg or qq interactions) tested

CMS-HIG-13-016

Compatibility results from Spin-Parity analysis

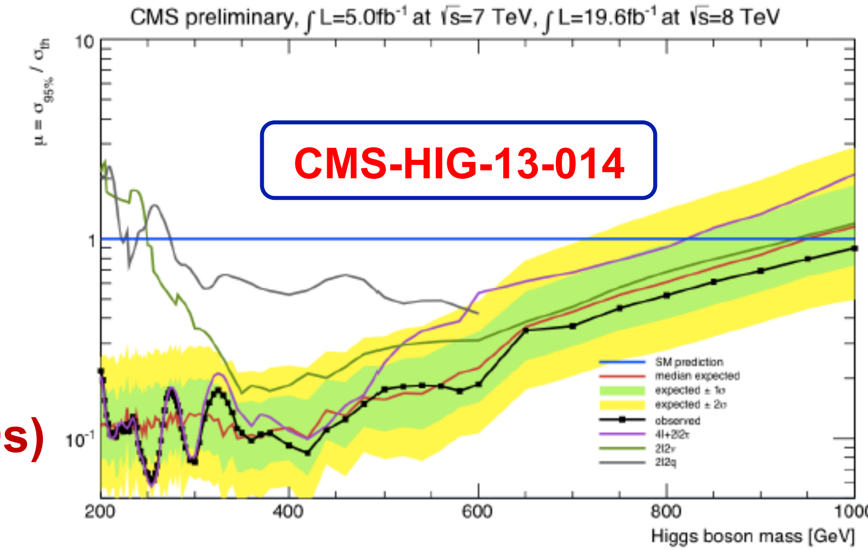
Source	$\chi^2 p$-value
Data vs. 0^+	0.68
Data vs. 2^+_m (100% gg)	0.91
Data vs. 2^+_m (100% $q\bar{q}$)	0.51
Data vs. 2^+_m (50% gg, 50% $q\bar{q}$)	0.81



WW*→lνlν

CLs(2+/0+)=14%

Other Higgs Channels



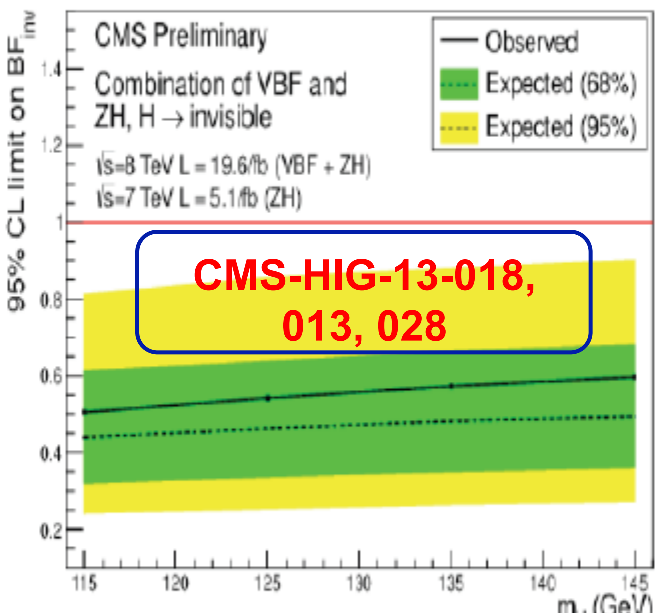
Search for high mass Higgs (Higgs doublets, other Higgs-like resonances etc)

95% CL limits on SM Higgs set

WW: 128 < m < 600 GeV (115-575 exp.)

ZZ: 200 < m < 1000 GeV (200-950 exp.)

Search for invisible Higgs (→ 4ν, in LSP, EDs)



Combining ZH (→ ll) and VBF, 95% CL limit on BR(H→inv) is 54% (46% exp.)

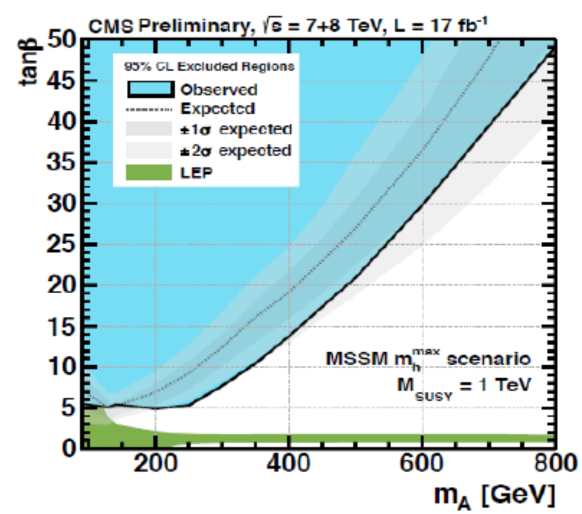
Search for Higgs → μμ (MSSM)

BR is too small (~2.2 x 10^{-4})

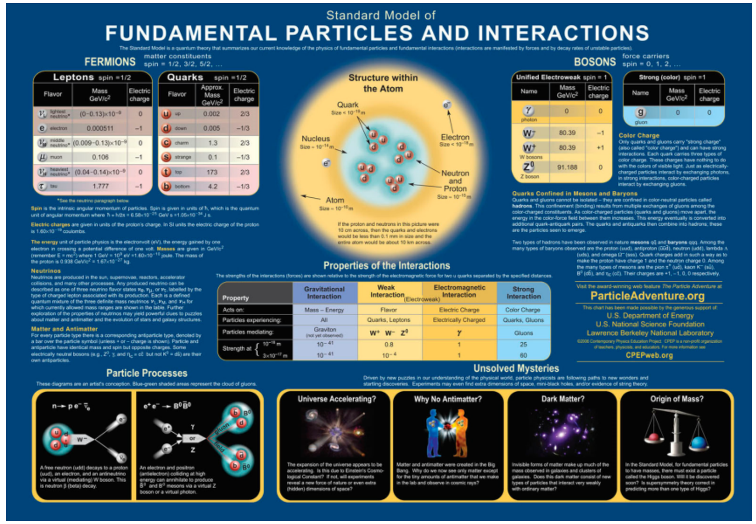
Recent data: ~4xSM sensitivity on strength μ

Search for SUSY Higgs

No evidence of BSM Higgs boson



Standard Model Physics



CMS Standard Model Public Physics Results

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP

CMS Forward and Small-x QCD Physics Public Physics Results

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ

CMS B Physics and Quarkonia Physics Public Physics Results

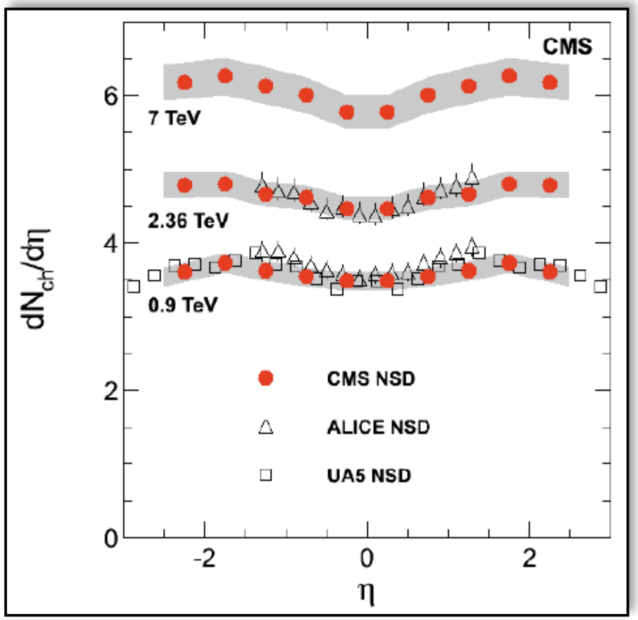
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH

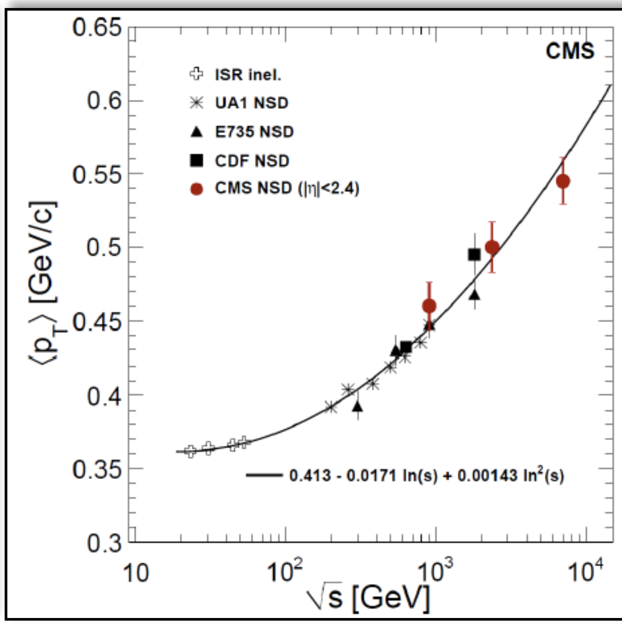
CMS Top Physics Public Physics Results

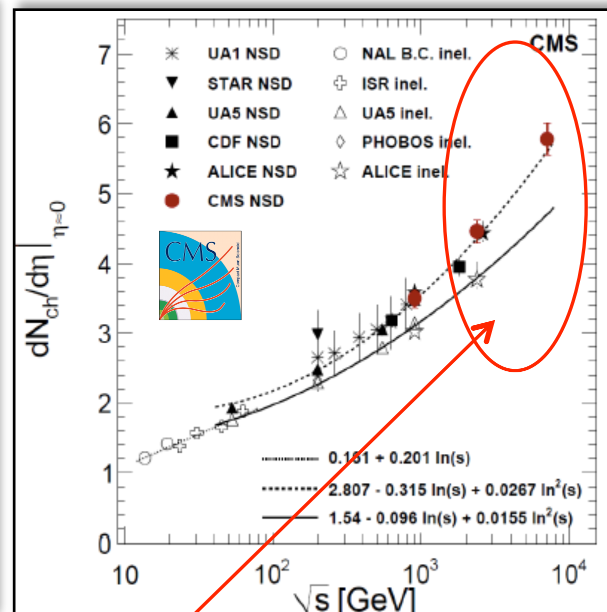
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

Charged Particle

The first CMS results @ 7 TeV were published in June of 2010 (arXiv:1005.3299v1, PRL)





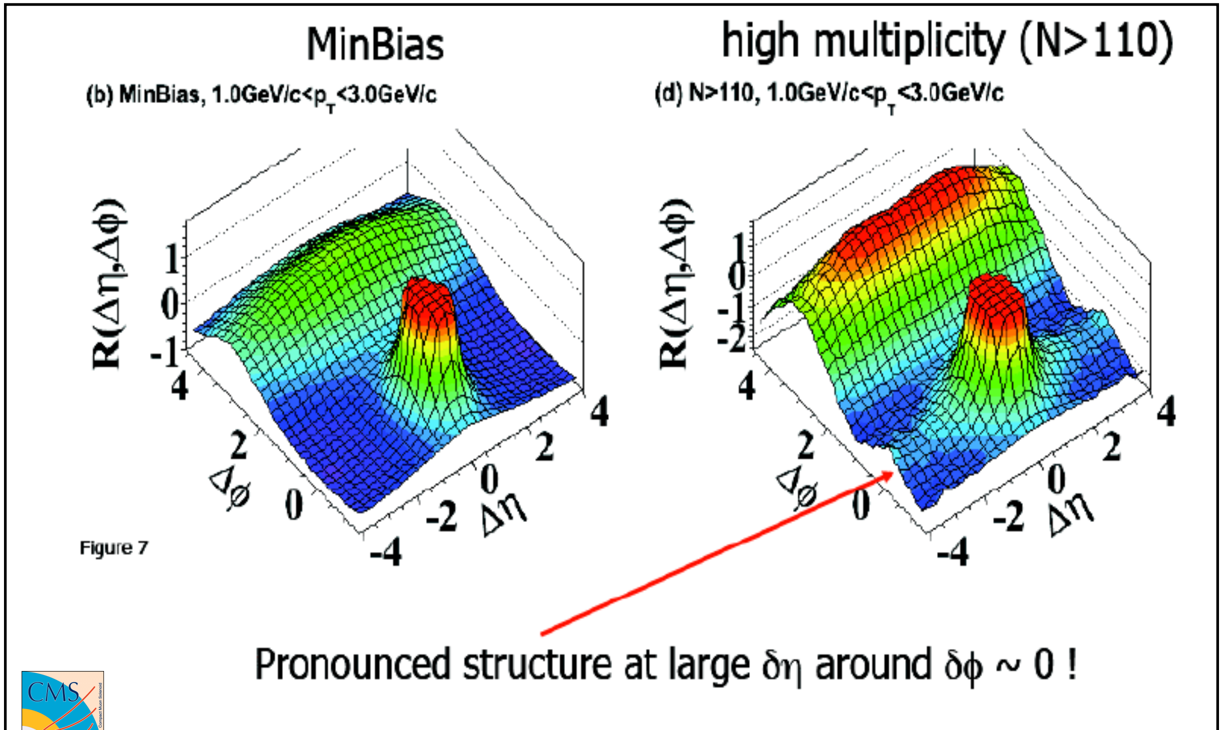


Particle density grows with energy (from 0.9 to 7 TeV) faster than it is expected.

MC fine tunning

Particle Correlations: ridge-effect

JHEP 1009 (2010) 091



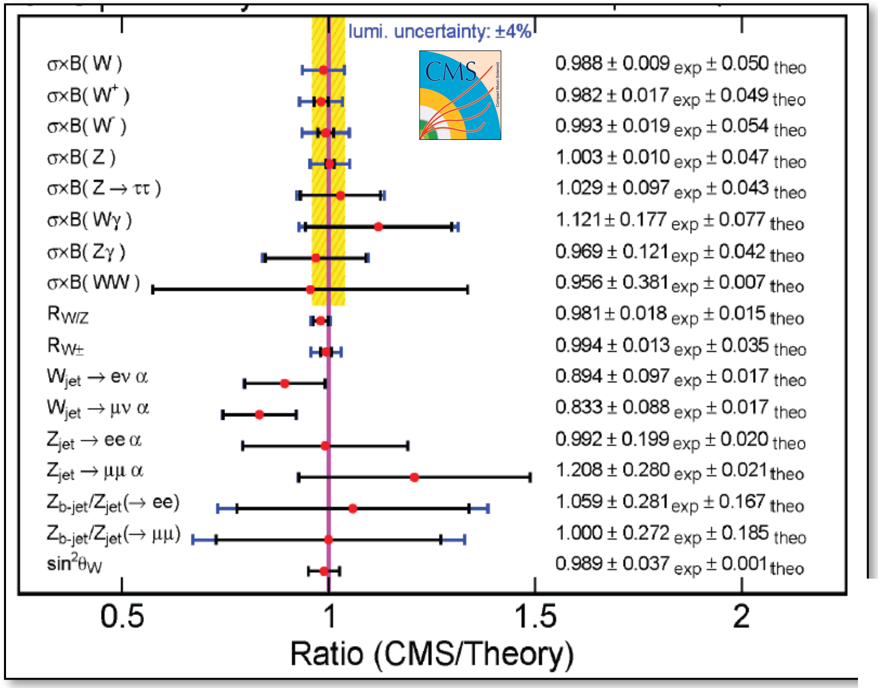
Study the correlation between two charged particles in the angles φ (transverse): Δφ and θ (longitudinal): Δθ

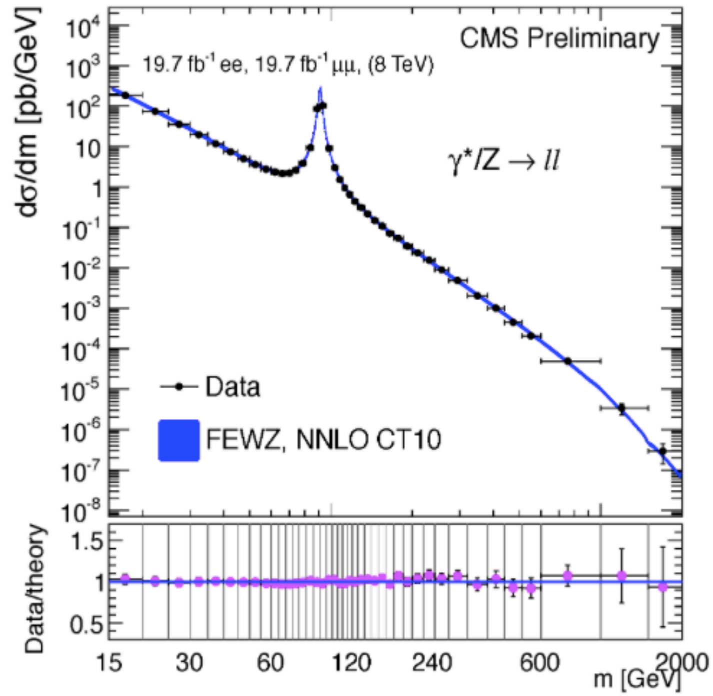
A new phenomenon in the 'stronge force'?

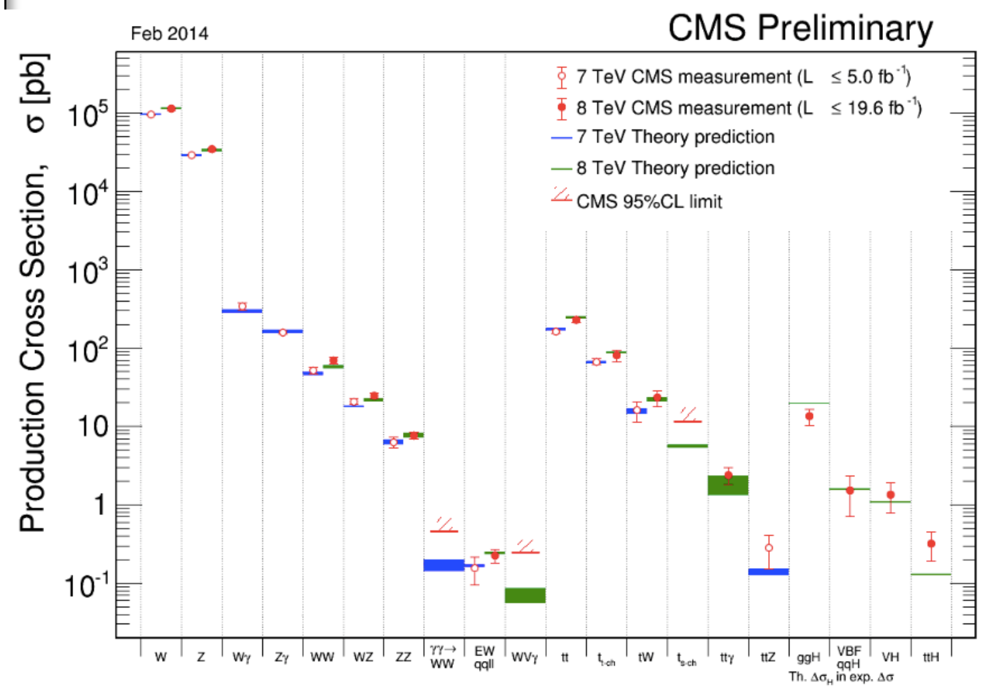
- Multiple interactions?
- C-glass condensates
- Hydrodynamic models?

That particles in some pairs at large Δη are receding from each other at close to the speed of light, but are oriented along the same φ angle – as if the particles were somehow associated together when they were created at the point of collision

EWK Measurements







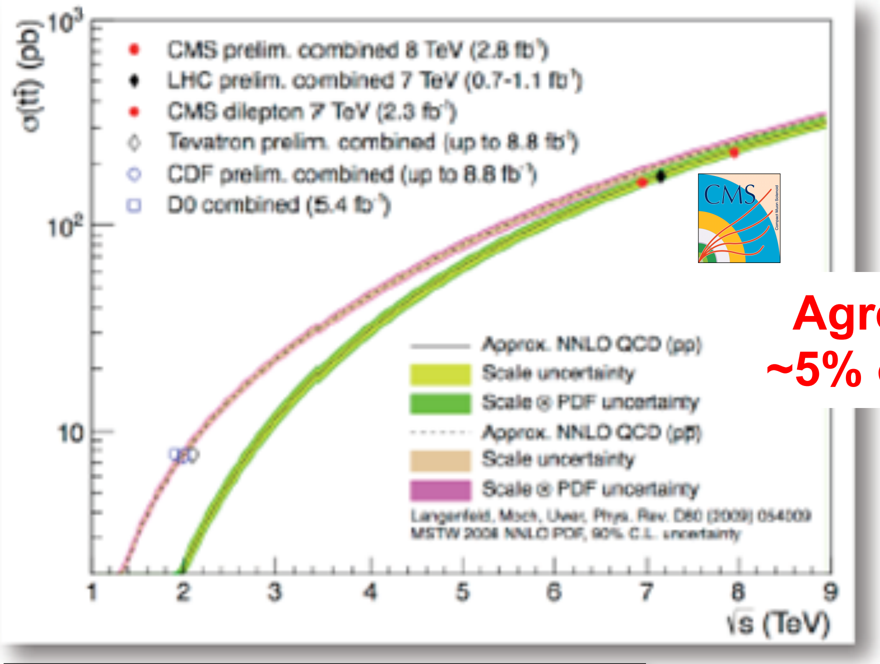
Good understanding of the detectors and accurate theory predictions

- ✓ **precise measurements of SM processes**
- ✓ **background to Higgs and BSM analyses**

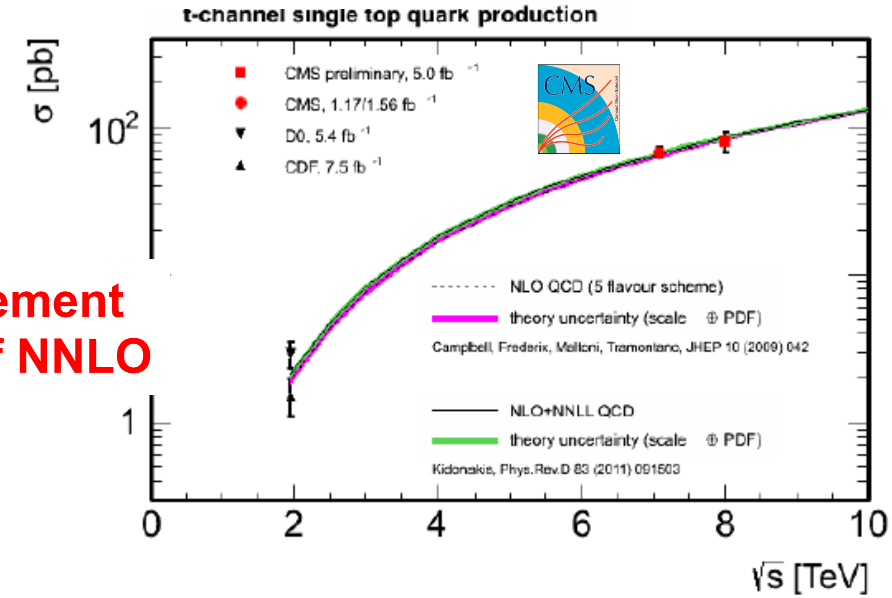
LHC is t-Factory

CMS PAS TOP-10-008
Preprint arXiv:1106.3052

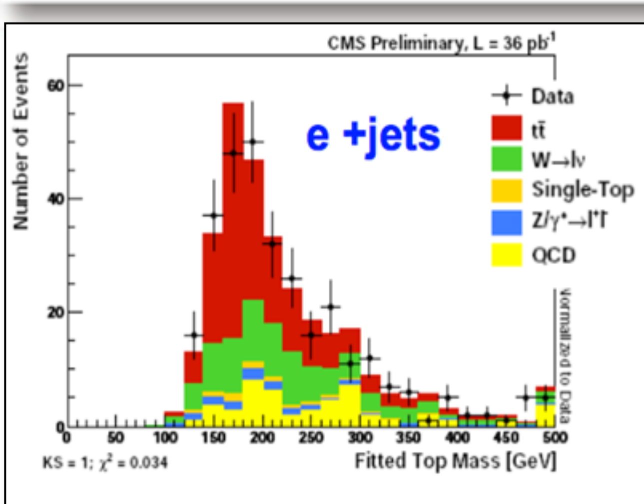
Pair production

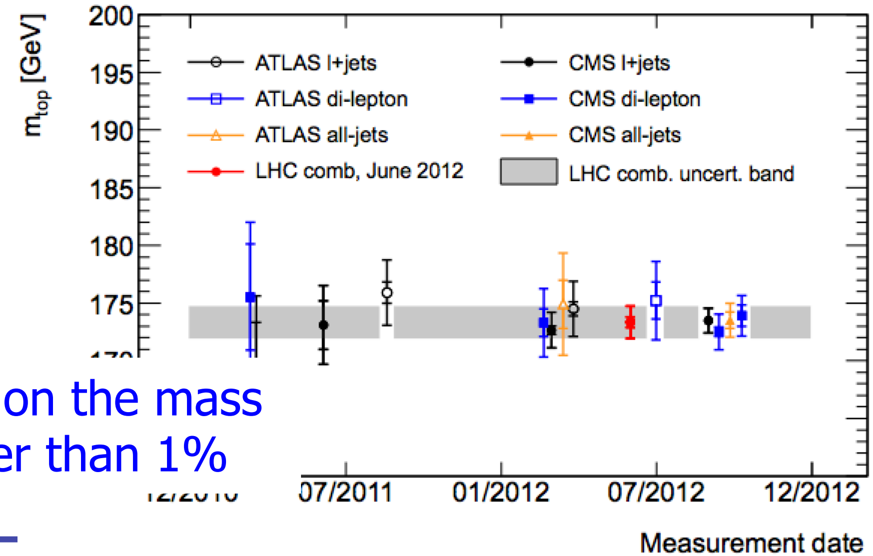


Single production



Agreement ~5% of NNLO

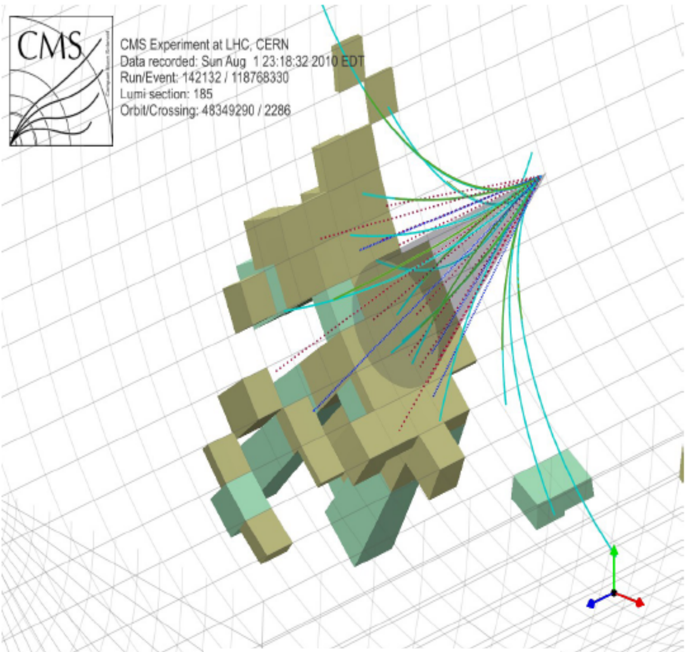


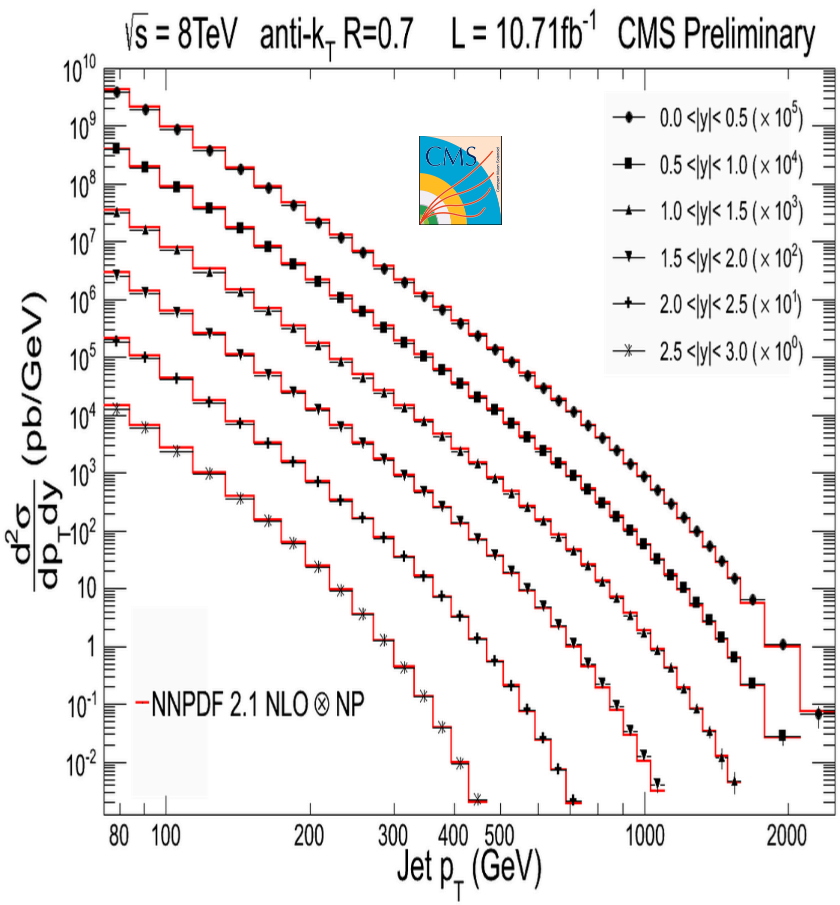


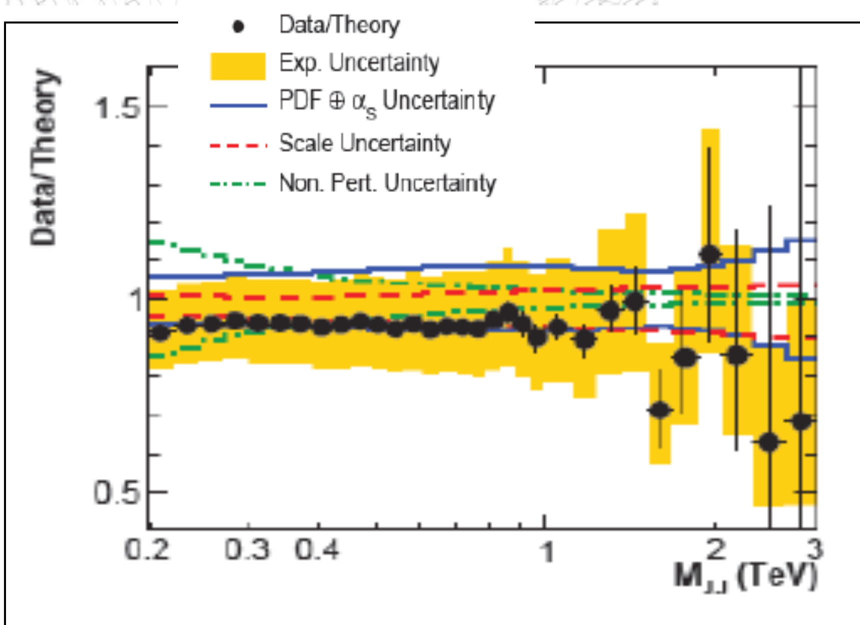
Precision on the mass now better than 1%

Jet Physics

CMS-PAS-SMP-12-012



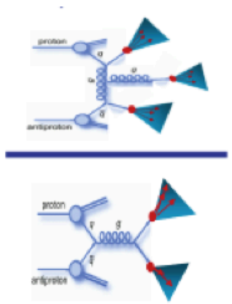




The results are in a good agreement with NLO calculations up to 2 TeV jets

Multijet Events

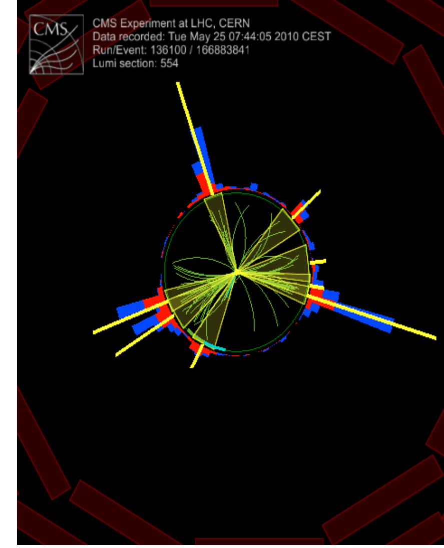
3-jet to 2-jet Cross Section Ratios



Mjj = 420 - 1390 GeV,
p_T > 150 GeV

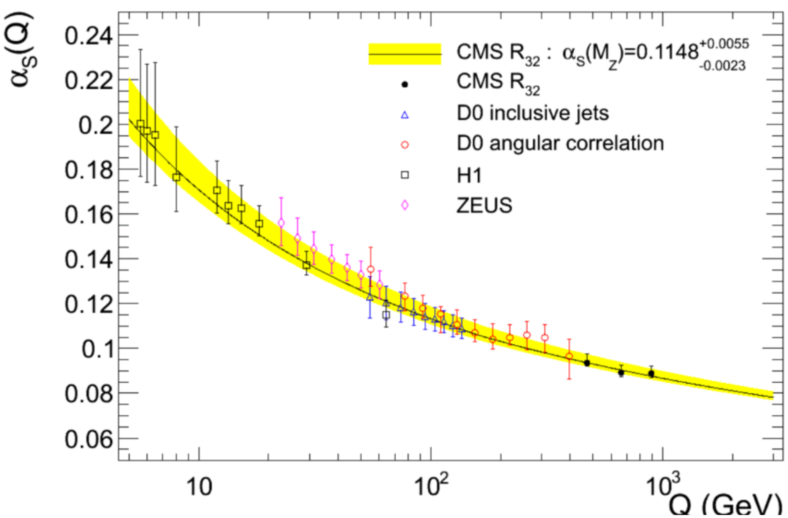
$\Leftrightarrow \alpha_S$

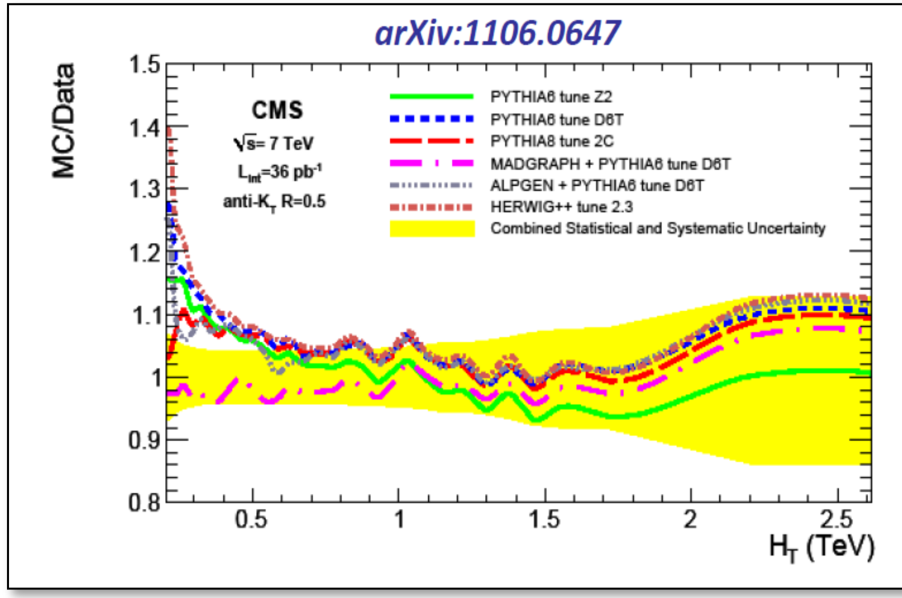
$$H_T = \sum p_T^{jet}$$



$$R_{32} = \frac{d\sigma_{3+}/dp_T}{d\sigma_{2+}/dp_T} \propto \alpha_s(Q)$$

$$Q = \langle p_{T1,2} \rangle = \frac{p_{T1} + p_{T2}}{2}$$





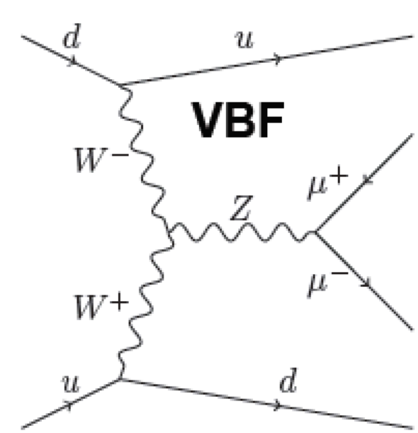
Good agreement with SM for H_T of 0.5 up to 3 TeV

$$\alpha_S(M_Z) = 0.1148 \pm 0.0014\,(\text{exp.}) \pm 0.0018\,(\text{PDF})^{+0.0050}_{-0.0000}\,(\text{scale}) = 0.1148\,^{+0.0055}_{-0.0023},$$

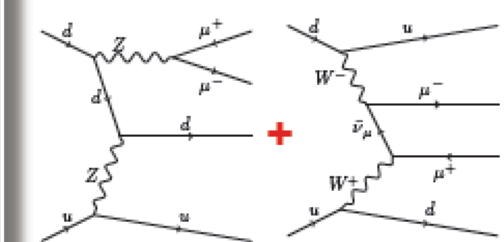
arXiv:1304.7498

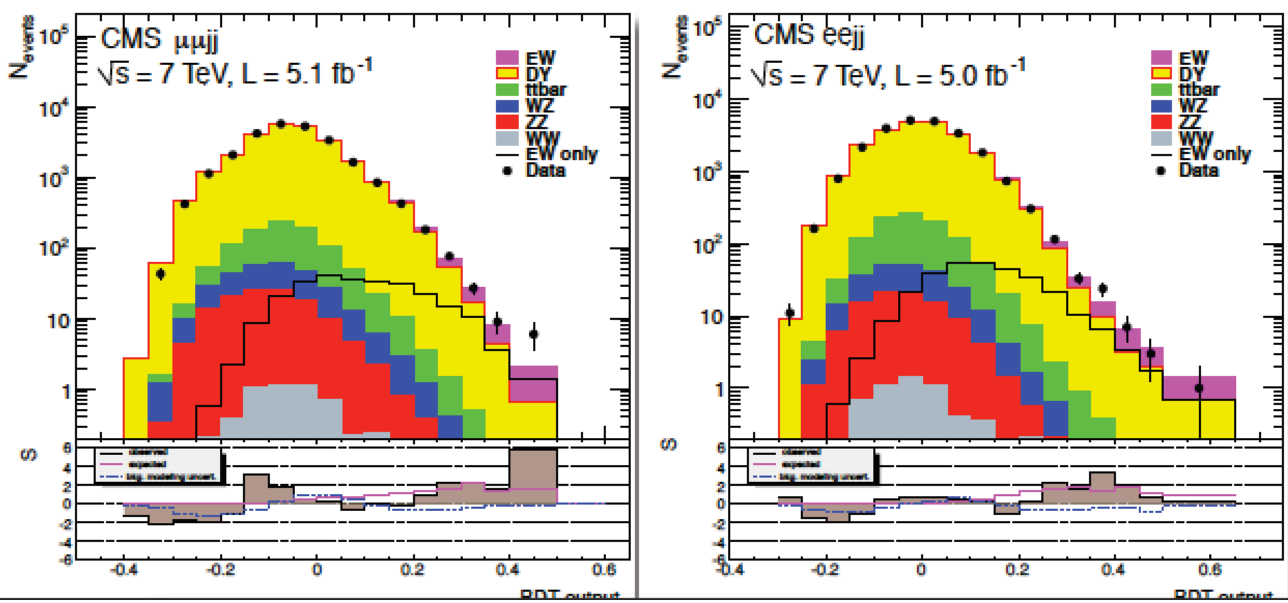
Evidence for EWK VBF Process

- Evidence for a VBF Z boson production – a crucial measurement for the Higgs VBF studies (paper to be submitted)
  - Thought to be very hard due to dominant channel background
- Require large rapidity gap between the tag jets and use advanced multivariate techniques (BDT) to extract signal
- See ~3σ evidence for EW production of the Z
- Measured cross section:
  - $\sigma(\mu\mu+ee) = 154 \pm 24$ (stat.) ± 46 (syst.) ± 27 (th.) ± 3 (lum.) fb
  - Theoretical NLO cross section: 166 fb



Negative interference with:





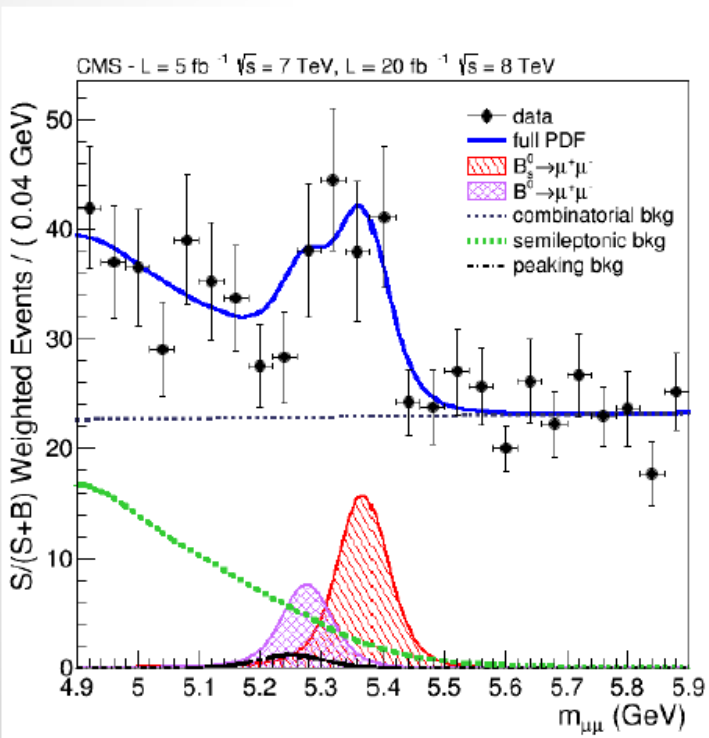
CMS Collaboration arXiv:1305.7389

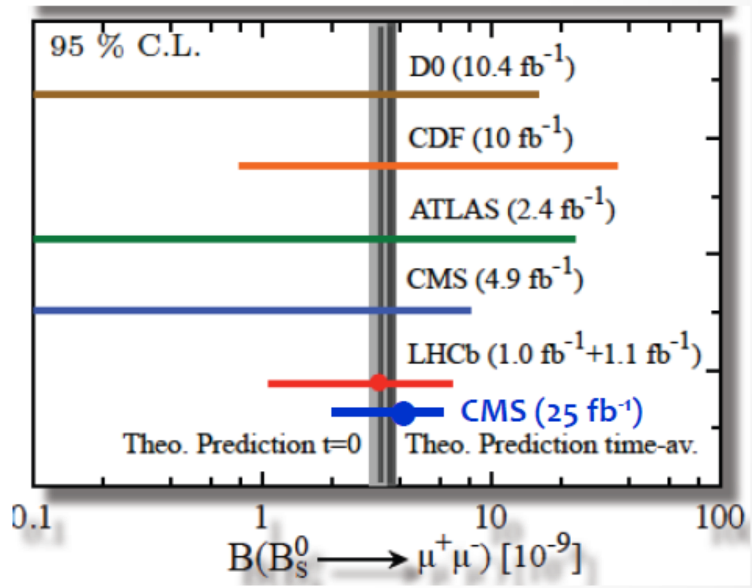
from A. De Roeck's talk

$B_s \to \mu\mu$

PRL 111 (2013) 101804

- Quest for many years to find a deviation of the SM prediction is coming to an end
- Evidence (and measurement) of decay, consistent with SM
- No sign of new physics on this front





$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.0^{+1.0}_{-0.9}) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.1 \times 10^{-9}$$

from D. de la Cruz's talk

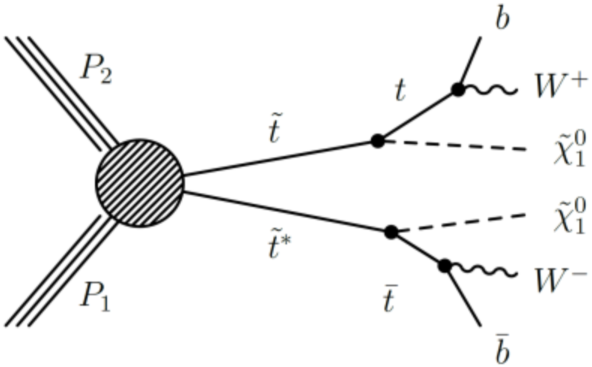
Highlights of Supersymmetry

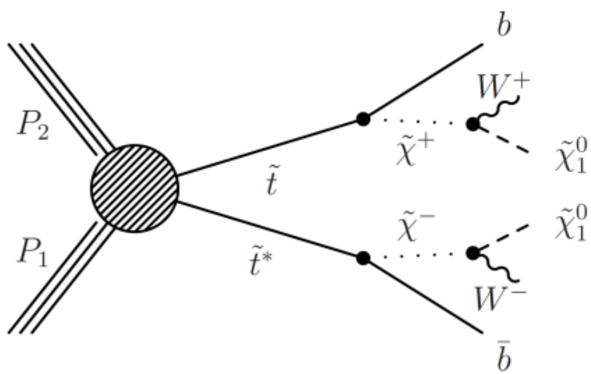
CMS Supersymmetry Public Physics Results

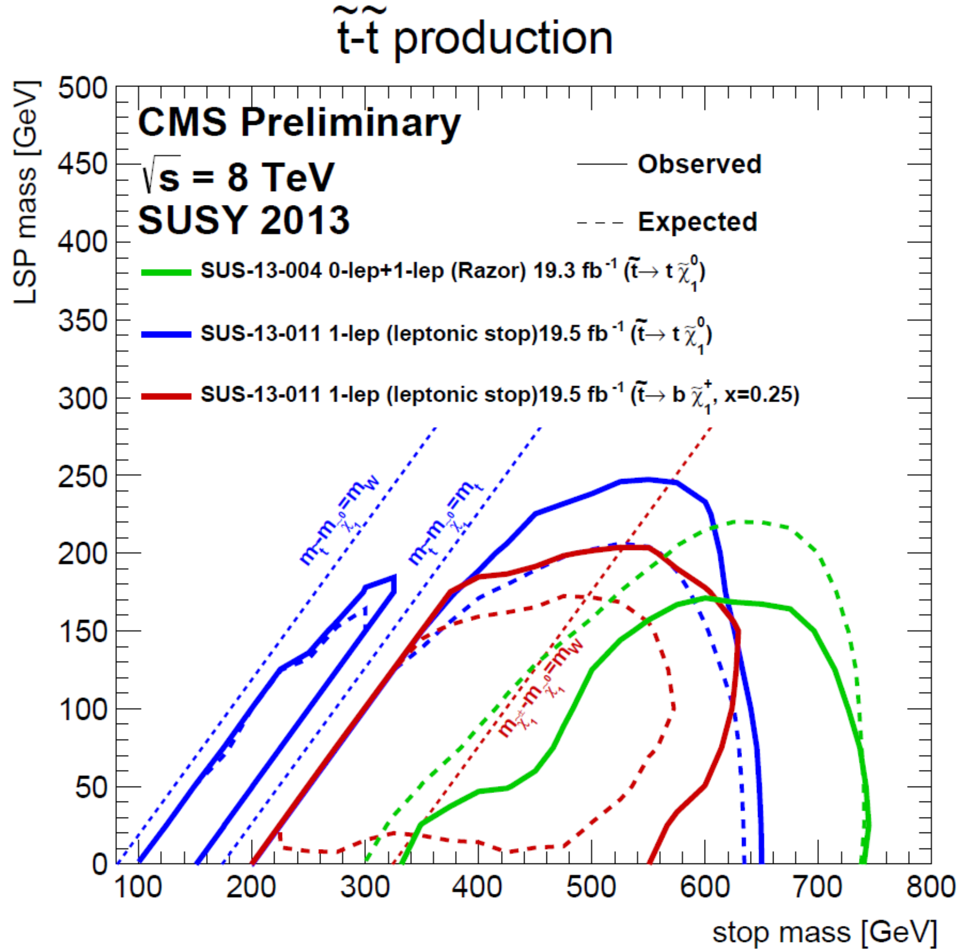
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

Stop Searches

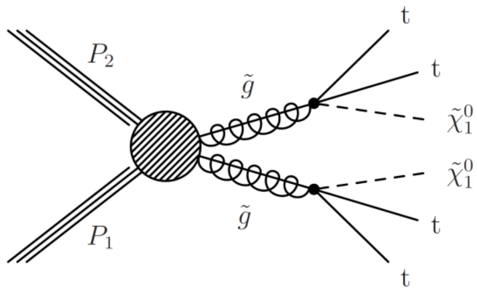
SUS-13-011, SUS-13-004



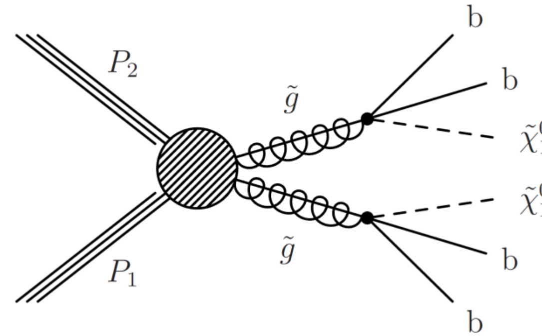




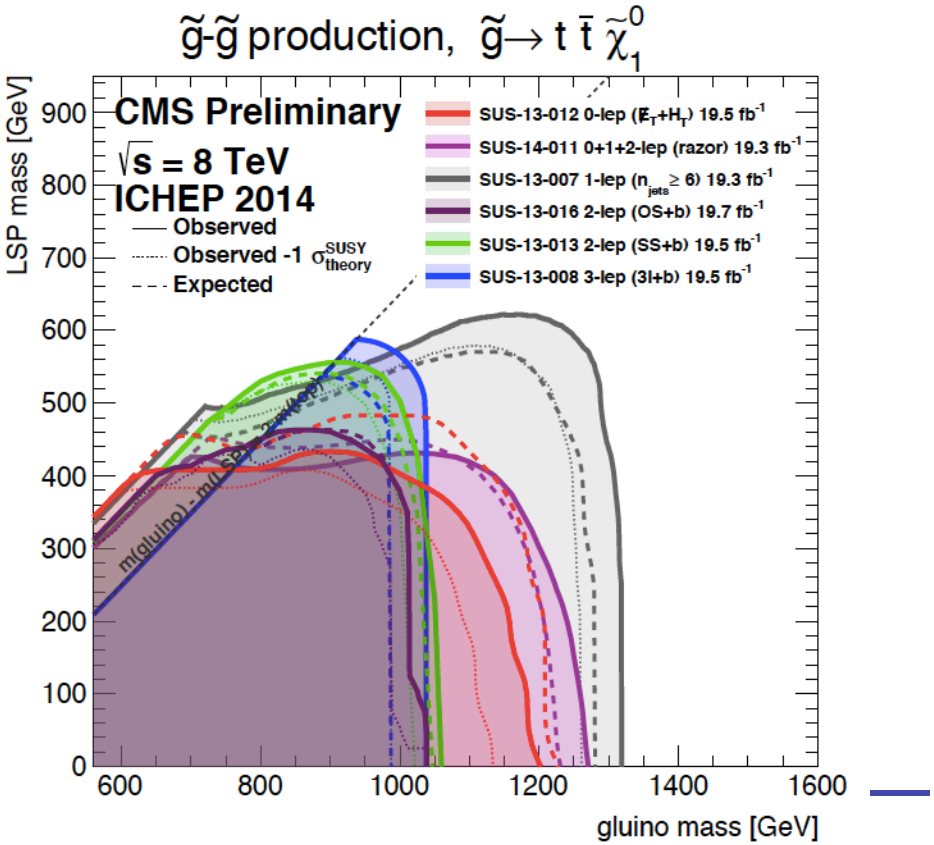
Gluino Searches

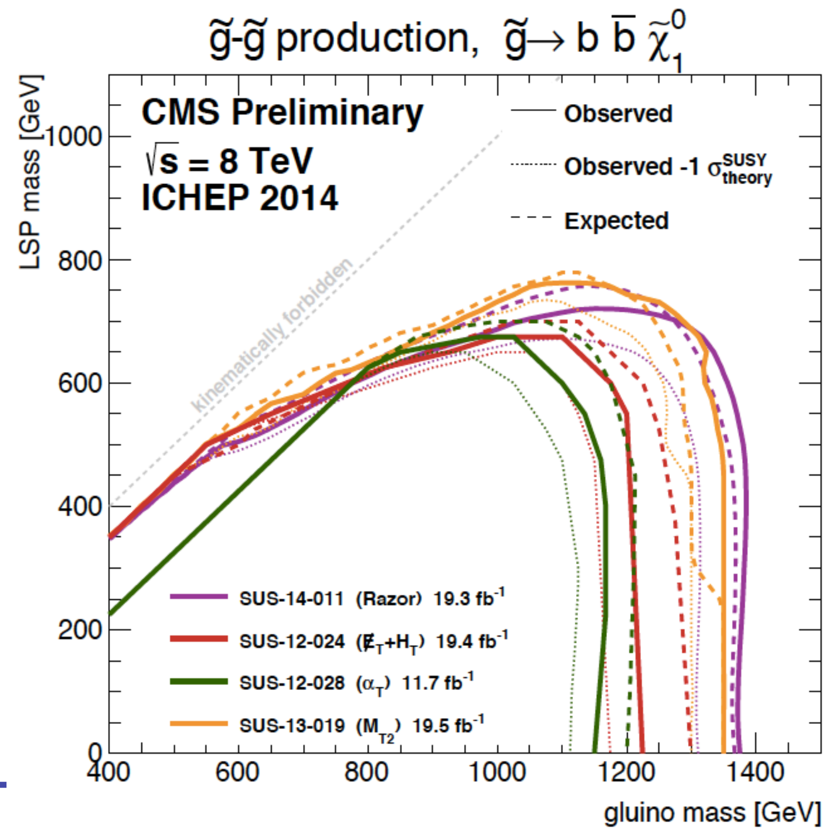


SUS-12-024, SUS-12-028, SUS-13-004, SUS-13-007, SUS-12-026, SUS-13-008, SUS-13-013, SUS-14-011

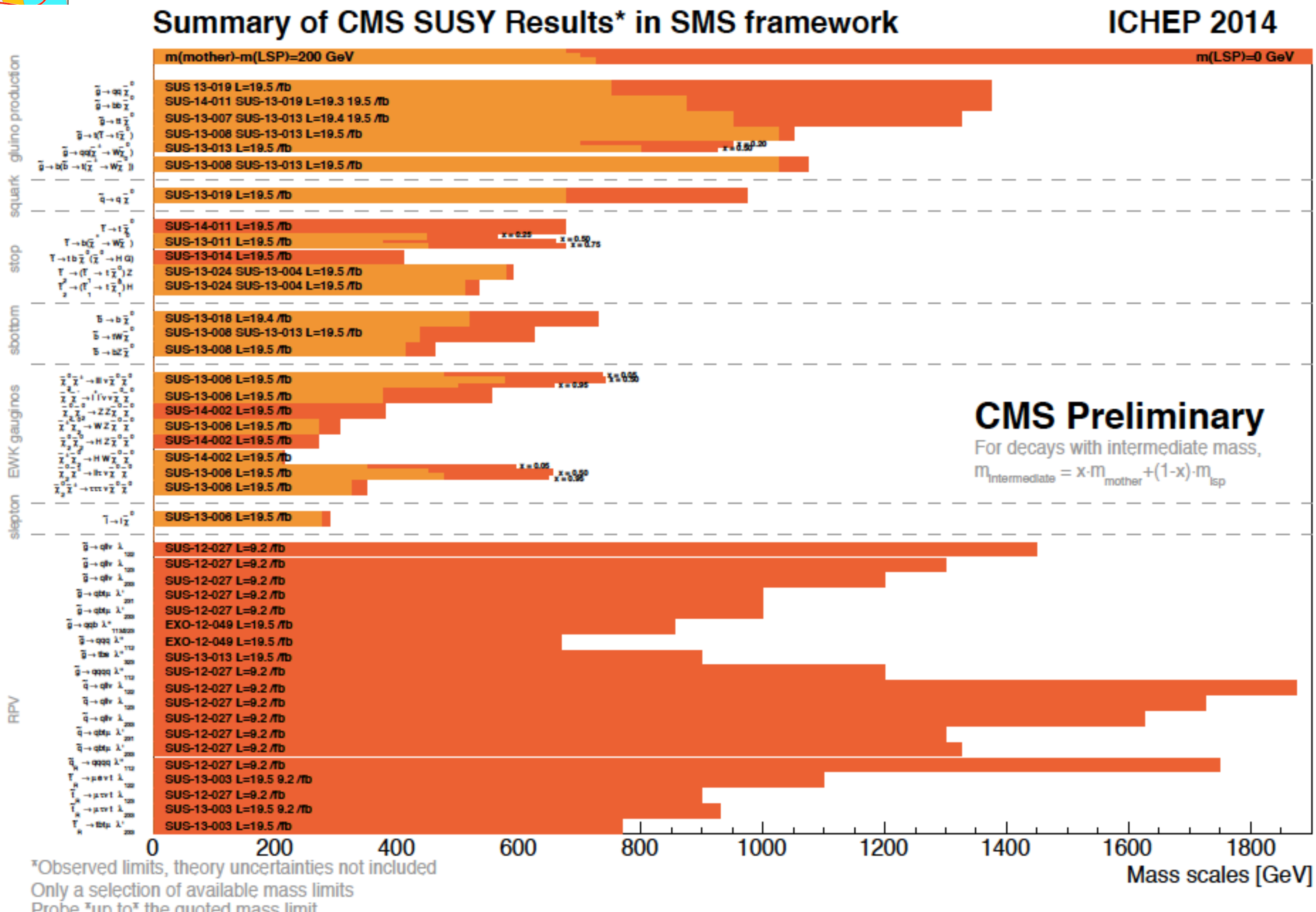


SUS-12-024, SUS-12-028, SUS-13-004, SUS-14-011





Supersymmetry Summary (95% C.L.)



Exotica

- Heavy Resonances and Non-Resonant Signals (extended gauge models, extra dimensions, technicolor) ⇒ dileptons, dijets, diphotons, ttbar, WZ
- Mono-particle + Missing ET (extended gauge models, extra dimensions, technicolor) ⇒ mono-jet + MET, mono-photon + MET, mono-lepton + MET
- Black Holes (extra dimensions) ⇒ high-multiplicity events
- Leptoquarks
- 4^{th} Generation ⇒ lepton + jet, dilepton

CMS Exotica Public Physics Results

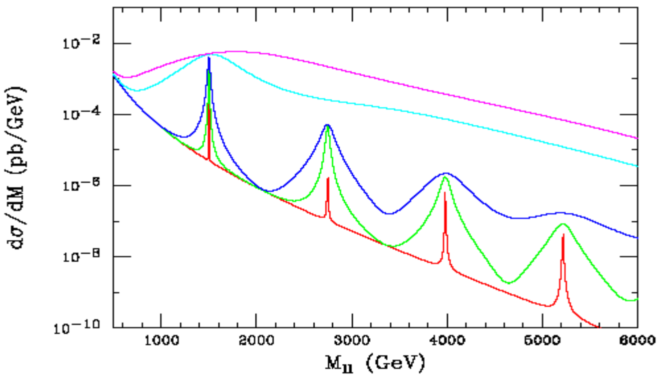
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

CMS Beyond-two-generations (B2G) Public Physics Results

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G

Heavy Resonances

- ❑ Extra gauge bosons predicted by extended gauge models (left-right symmetric models and GUT-inspired models)
- ❑ Kaluza-Klein graviton excitations arising in extra dimensions models with curved bulk space (Randall-Sundrum model)
  - ➢ Small extra spatial dimensions, Curved bulk space (AdS_5 - slice)
  - ➢ Well separated graviton mass spectrum

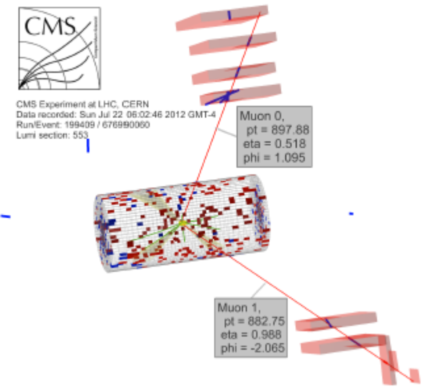


- ❑ Kaluza-Klein excitations of SM gauge bosons in large flat extra-dimensions (TeV-1 Models)
  - ➢ Bosons could also propagate in the bulk
  - ➢ Fermions are localized at the same (opposite) orbifold point: destructive (constructive) interference between SM gauge bosons and KK excitations
- ❑ Technicolor

Signals: di-leptons/di-jets/di-photons resonance states in high (~TeV) invariant mass range ⇒ new particles would be observed as a bump, excess in the mass spectrum

Excellent momentum and energy resolutions are required !!

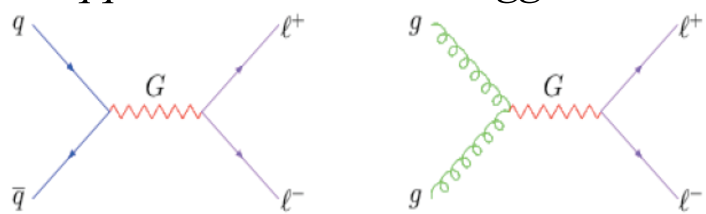
Dileptons: Spectra



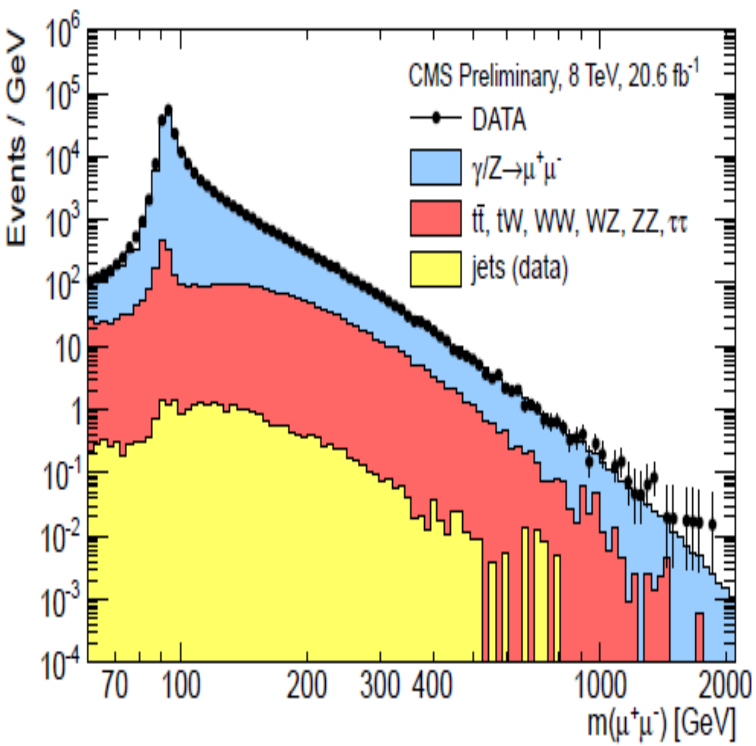
M = 1.824 TeV

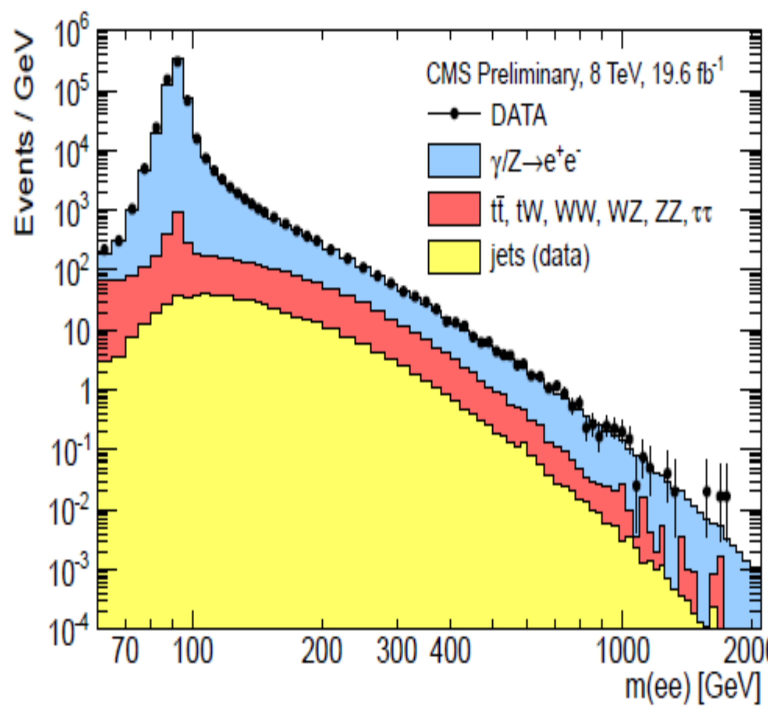
New Physics ($Z'/Z_{KK}/G_{KK}$) contributions to SM processes:

$q\bar{q} \to l^+l^-$ $\qquad$ $gg \to l^+l^-$



CMS PAS EXO-12-061



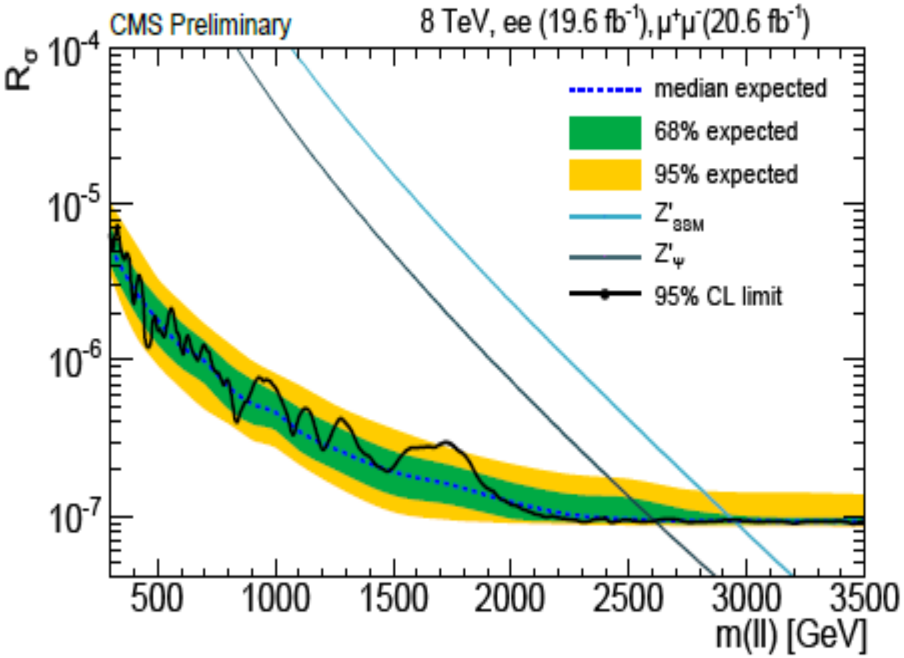


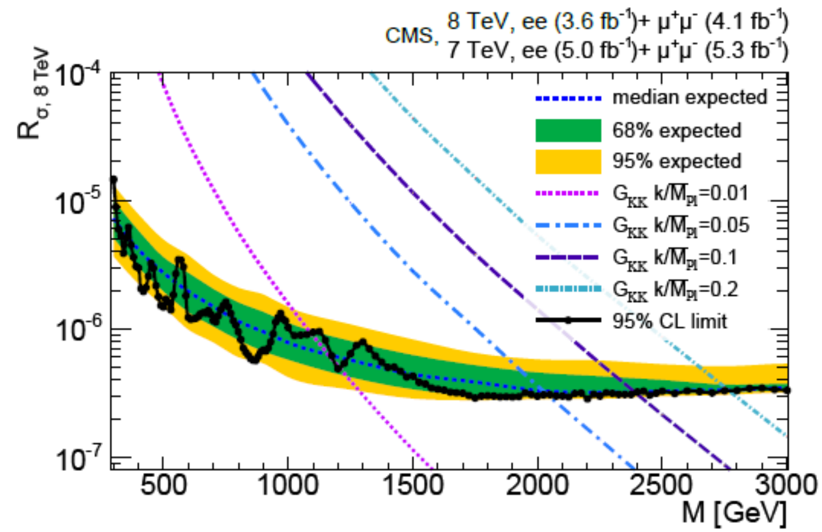
Dileptons: Limits

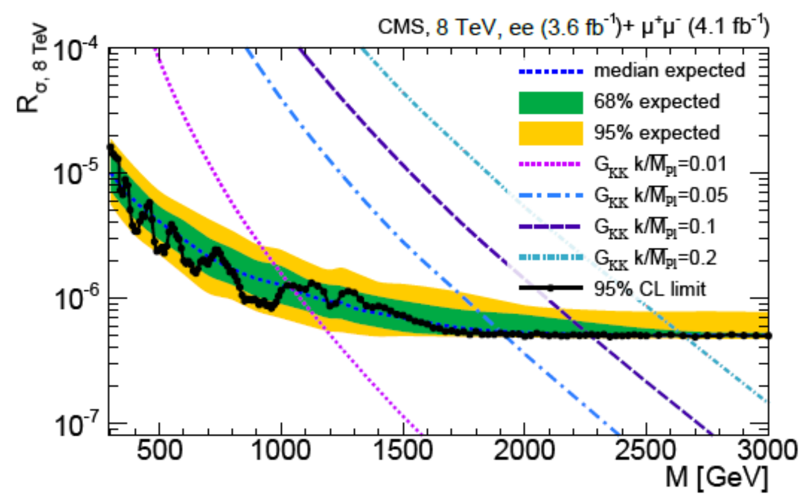
Phys.Lett. B720 (2013) 63

$$R_\sigma \equiv \frac{\sigma(pp \to Z' + X \to \ell\ell + X)}{\sigma(pp \to Z + X \to \ell\ell + X)}$$

CMS PAS EXO-12-061



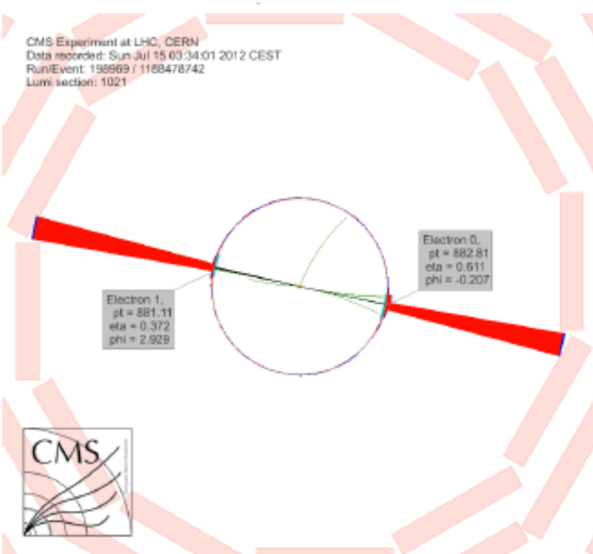


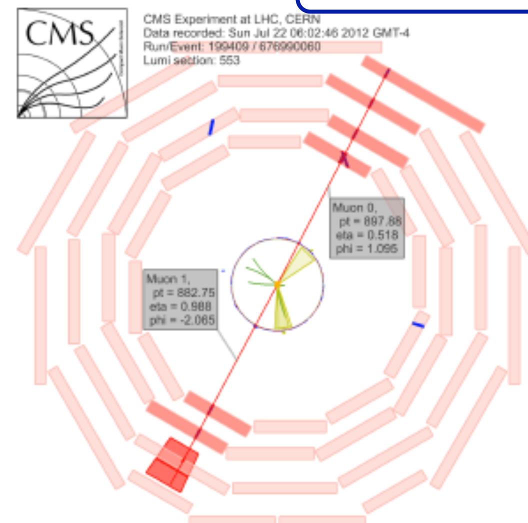


A Z' with standard-model-like couplings can be excluded below 2950 GeV, the superstring-inspired Z' below 2600 GeV, and RS Kaluza–Klein gravitons below 2030 (2390) GeV for couplings of 0.05 (0.10)

Highest Dilepton Mass at CMS

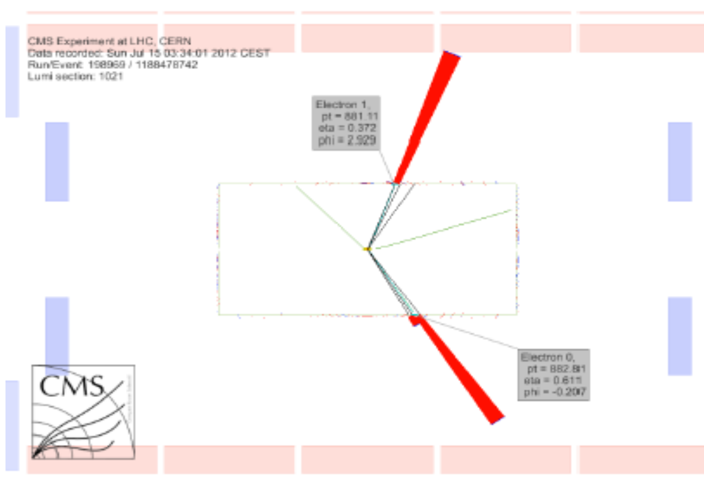
CMS PAS EXO-12-061

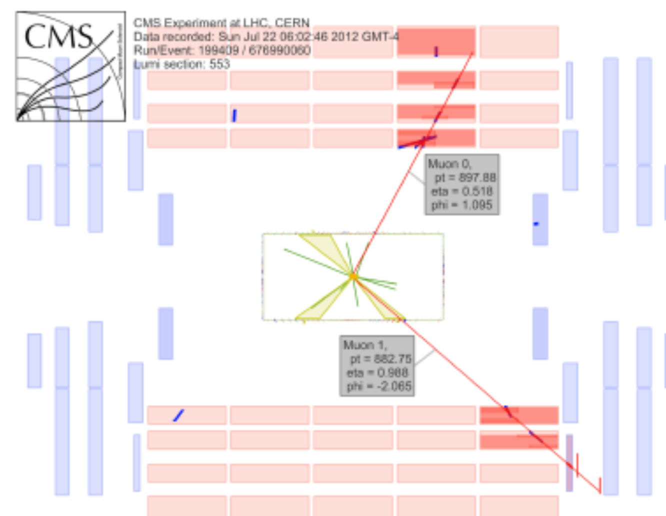




Dielectron, M = 1.776 TeV

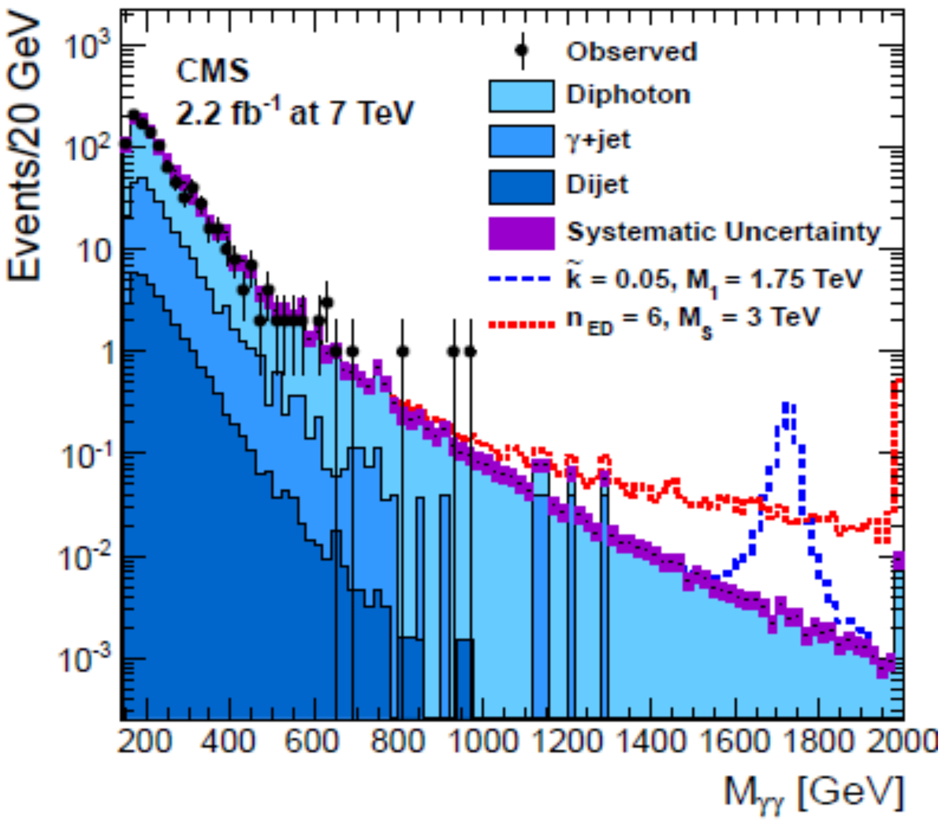
Dimuon, M = 1.824 TeV

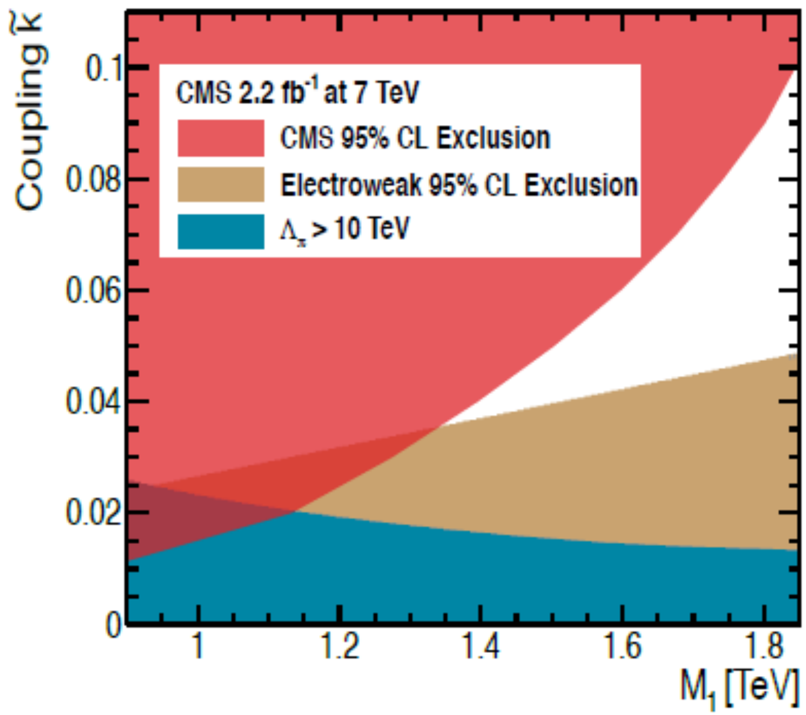




Diphotons

Phys.Rev.Lett. 108 (2013) 111801



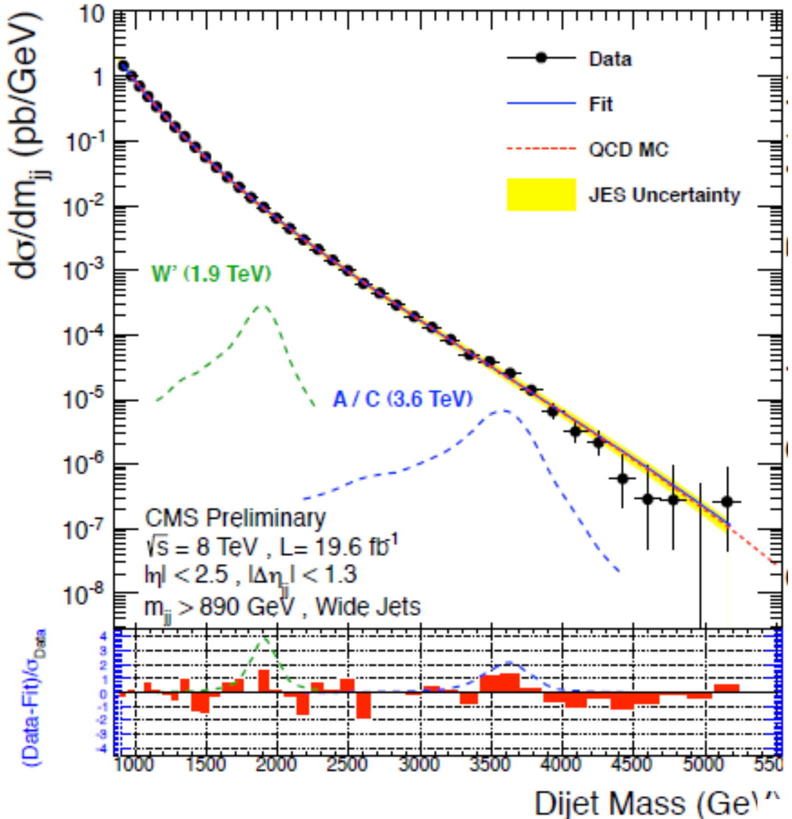


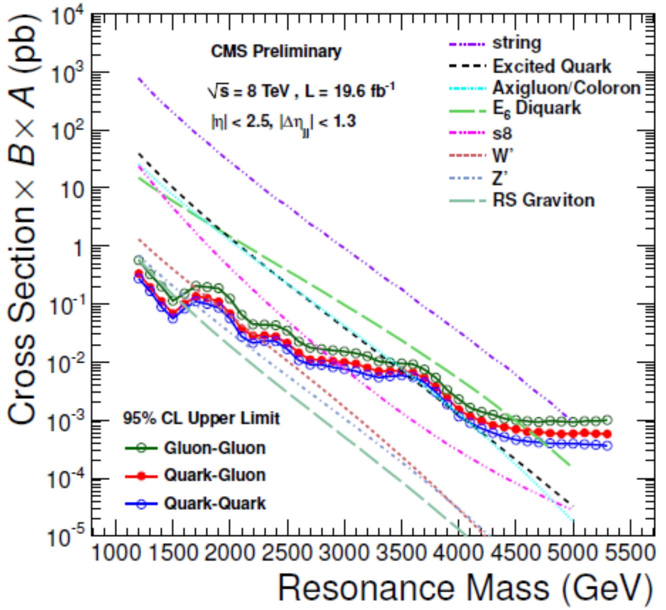
RS Kaluza–Klein gravitons below

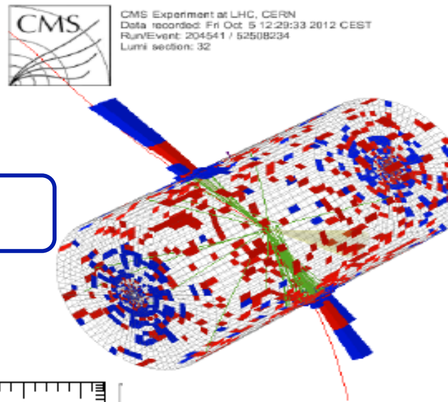
$\tilde{k}$	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
M_1 [TeV]	0.86	1.13	1.27	1.39	1.50	1.59	1.67	1.74	1.80	1.84

Dijets

CMS PAS EXO-13-059





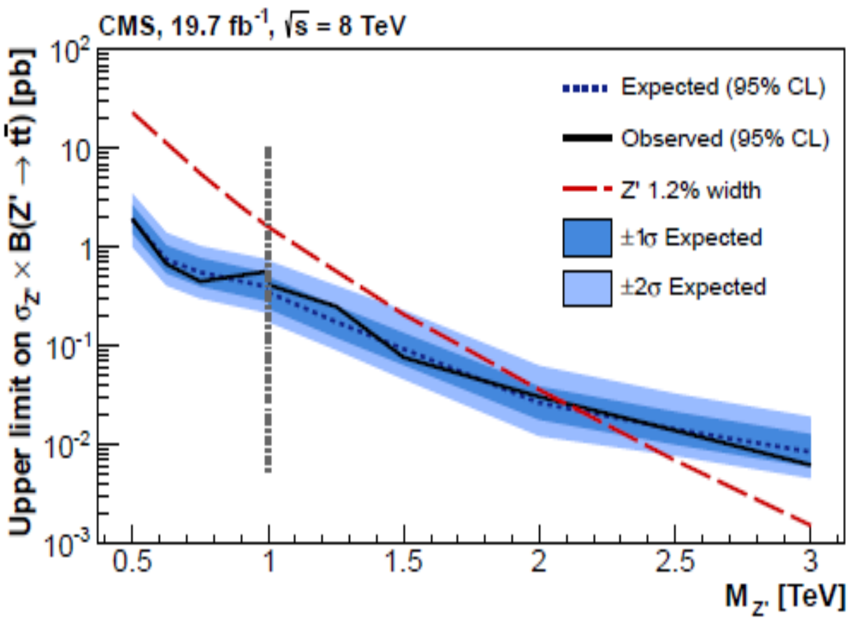


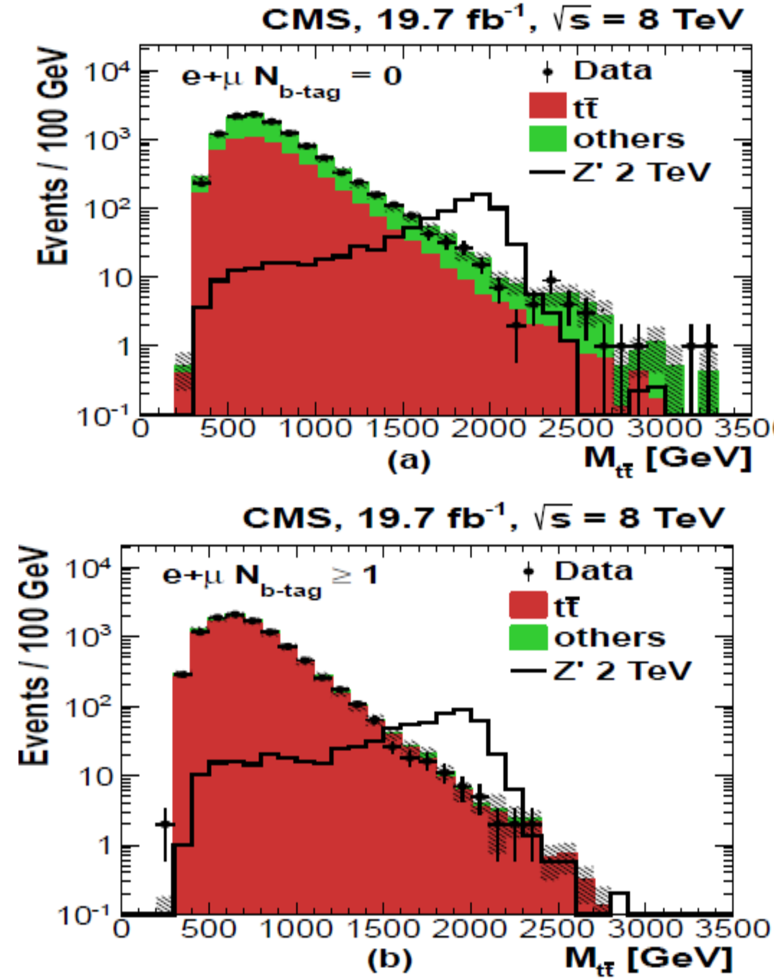
Model	Final State	Obs. Mass Excl. [TeV]	Exp. Mass Excl. [TeV]
String Resonance (S)	qg	[1.20,5.08]	[1.20,5.00]
Excited Quark (q^*)	qg	[1.20,3.50]	[1.20,3.75]
E_6 Diquark (D)	qq	[1.20,4.75]	[1.20,4.50]
Axigluon (A)/Coloron (C)	$q\bar{q}$	[1.20,3.60] + [3.90,4.08]	[1.20,3.87]
Color Octet Scalar (s8)	gg	[1.20,2.79]	[1.20,2.74]
W′ Boson (W′)	$q\bar{q}$	[1.20,2.29]	[1.20,2.28]
Z′ Boson (Z′)	$q\bar{q}$	[1.20,1.68]	[1.20,1.87]
RS Graviton (G)	$q\bar{q}$+gg	[1.20,1.58]	[1.20,1.43]

ttbar

arXiv: 1309.2030

0.2 x SM limits on σ(Z′→ ttbar in the all-hadronic channel) for Z′ heavier than 1 TeV

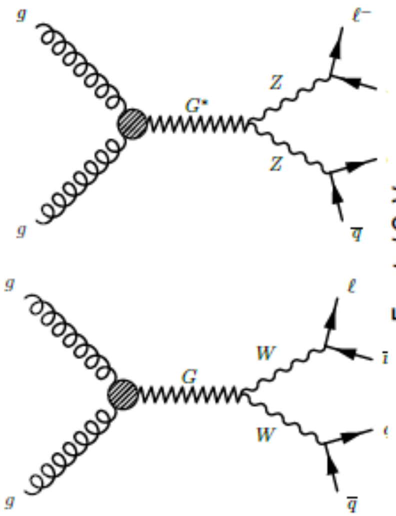


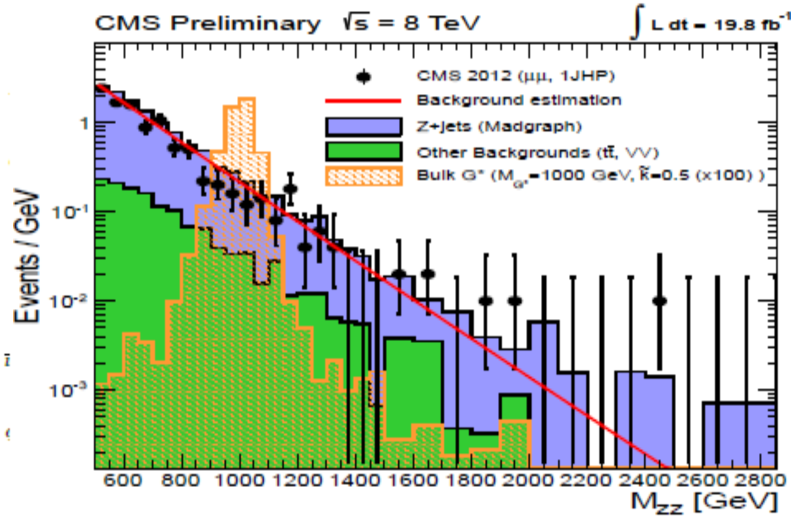


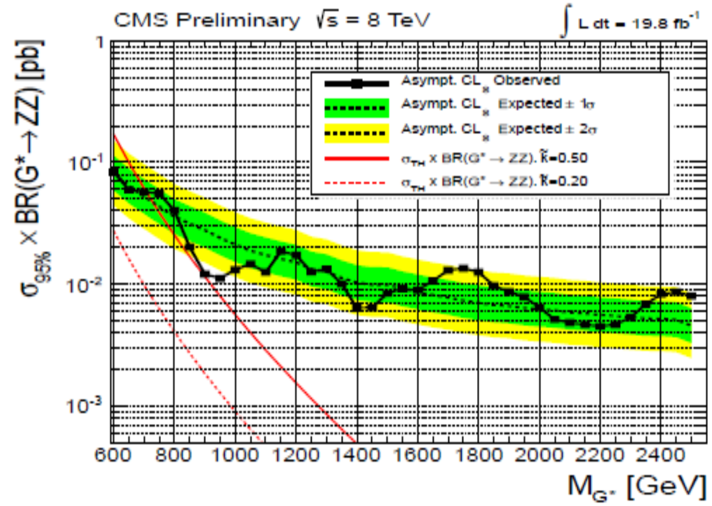
Model	Observed Limit	Expected Limit
Z' $(\Gamma_{Z'}/M_{Z'} = 1.2\%)$	2.1 TeV	2.1 TeV
Z' $(\Gamma_{Z'}/M_{Z'} = 10\%)$	2.7 TeV	2.6 TeV
RS KK gluon	2.5 TeV	2.4 TeV

Di-boson Resonances

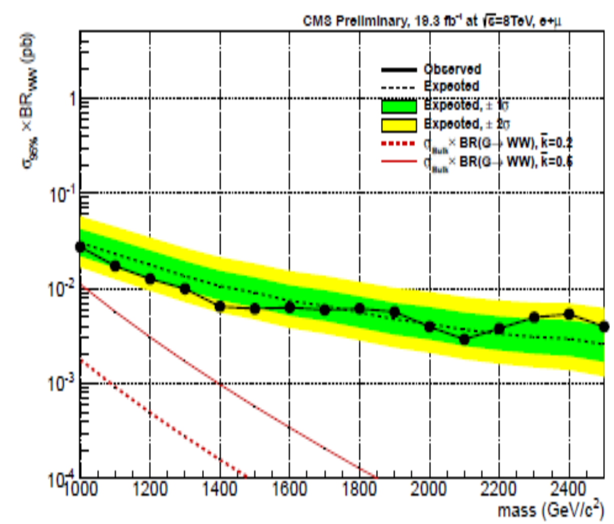
EXO-12-021, EXO-12-022







ZZ: mass limit for RS graviton is 710 GeV
for c = 0.5



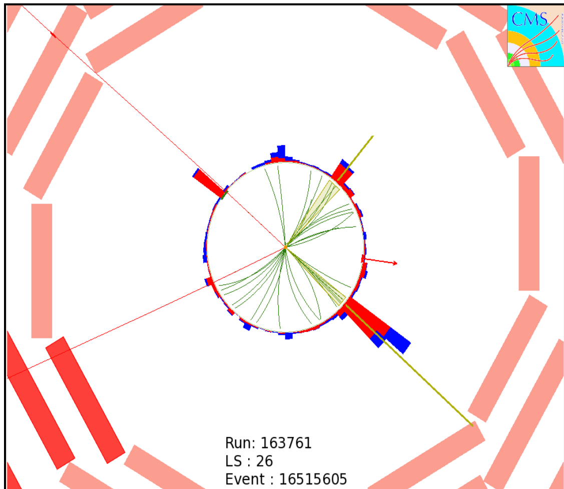
WW: graviton production x-section upper limit is 70 fb for mass from 0.8 TeV up to 2.5 TeV

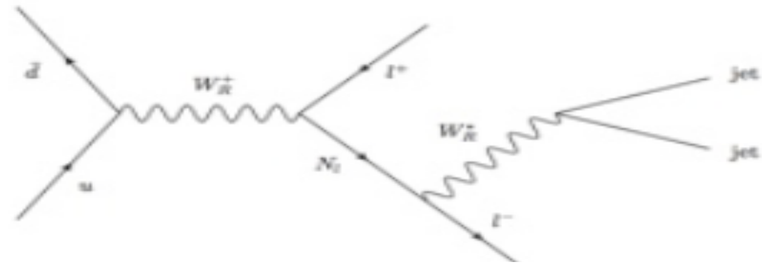
WZ: SSM W' mass limit is 1.143 TeV @ 7 TeV (PRL 109 (2012) 141801)

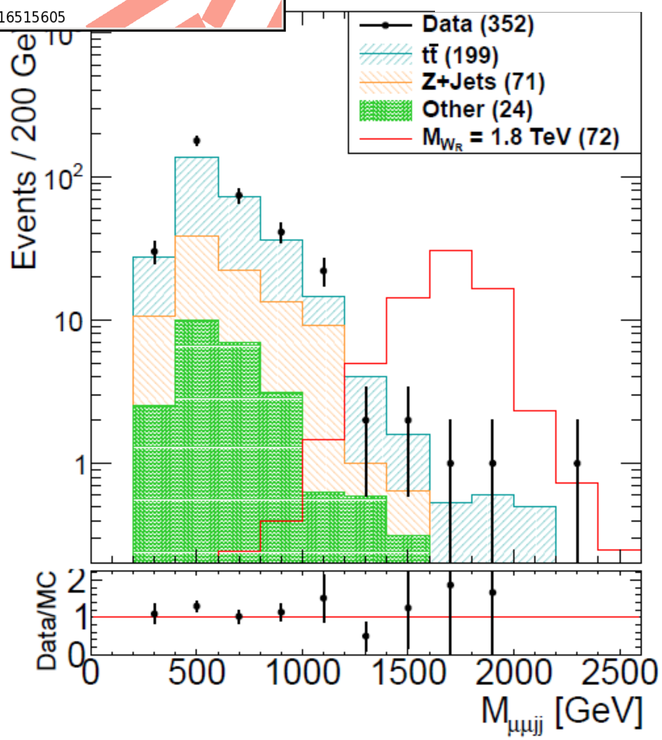
(Lepton-Lepton) + (Jet-Jet) Resonance

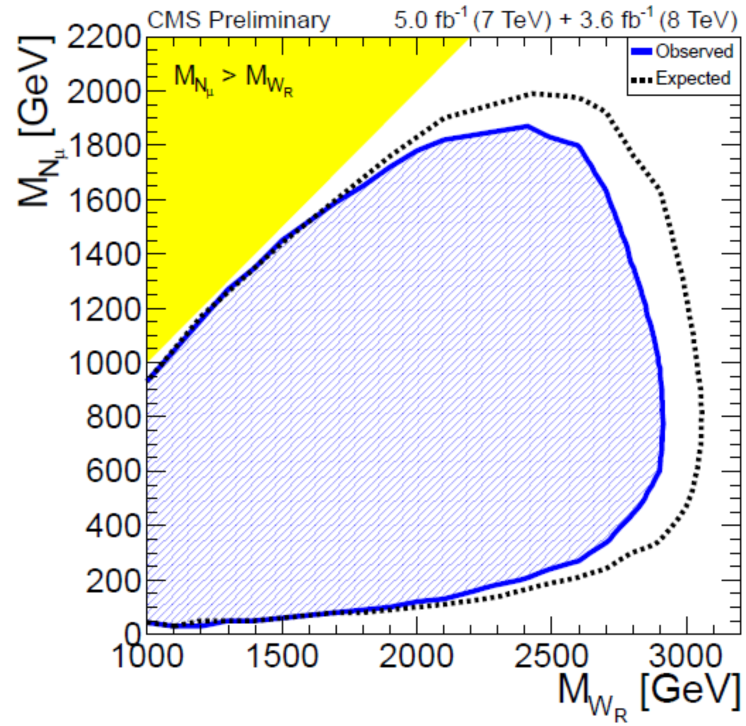
CMS PAS EXO-12-017

W_R and heavy neutrino from LR models





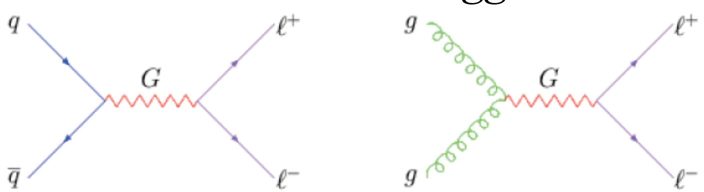


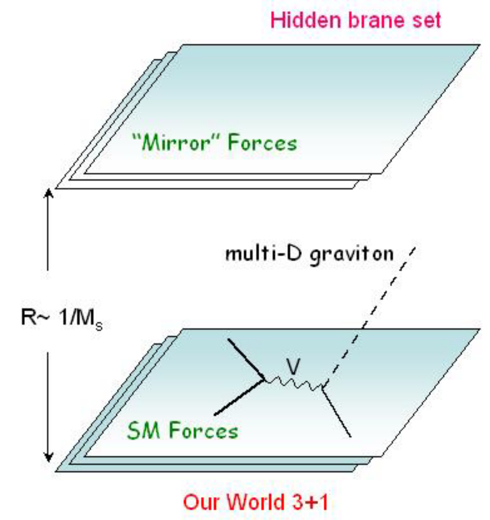


Non-Resonant Signals

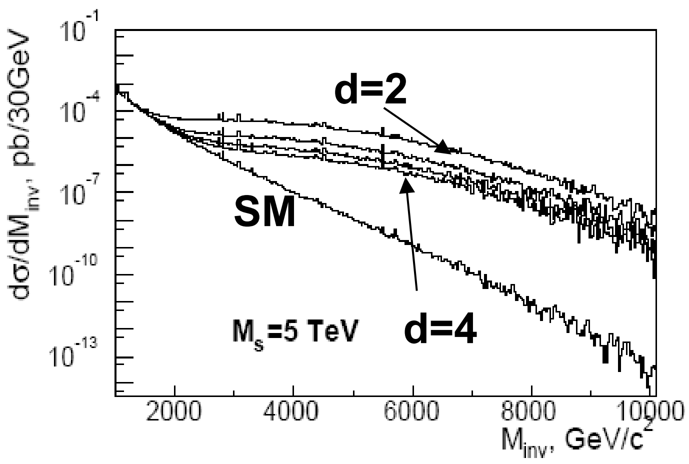
- ADD-graviton contribution in the SM processes (Drell-Yan, diphotons productions)

$q\bar{q} \to l^+l^-$ $gg \to l^+l^-$





- Compositeness



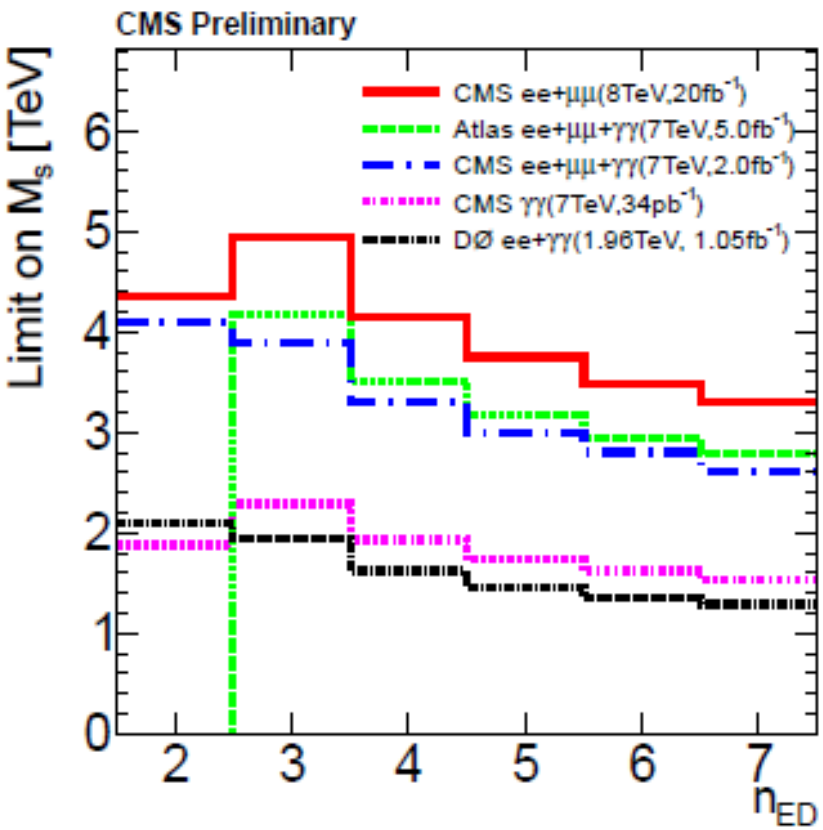
Signals: excess in di-particle spectrum

Exclusion Limits for ADD

for details see talk by Maria Savina

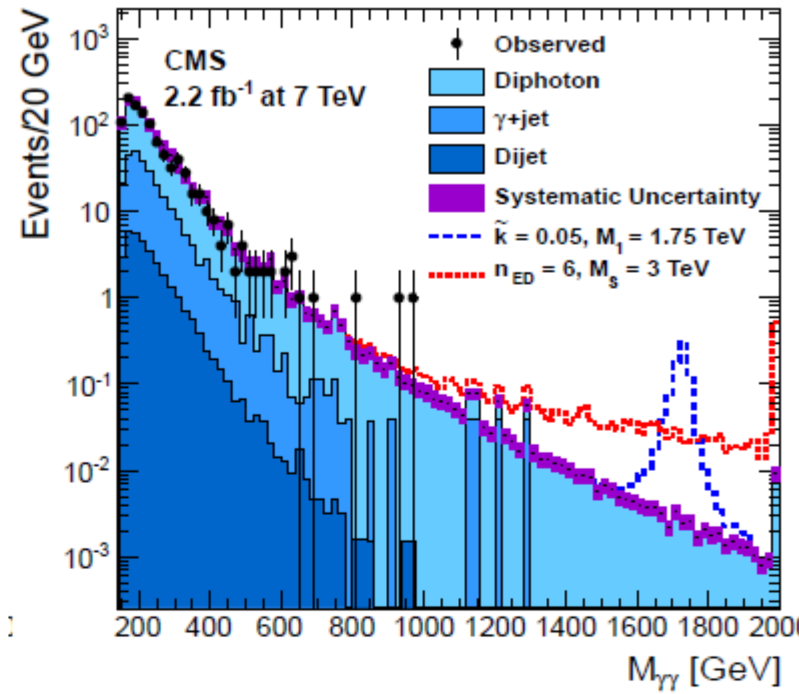
CMS PAS EXO-12-027, 12-031

Dimuons



Diphotons

PRL 108 (2012) 111801



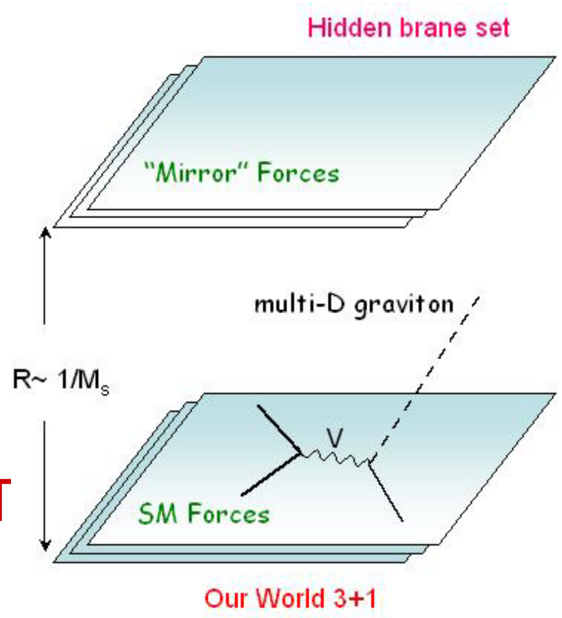
The effective Planck scale less than 2.3-2.8 TeV is excluded

Mono-Particle + MET

- Extra gauge bosons (W′) predicted by extended gauge models (left-right symmetric models and GUT-inspired models)

- Kaluza-Klein graviton emission in large flat extra-dimensions (ADD model)

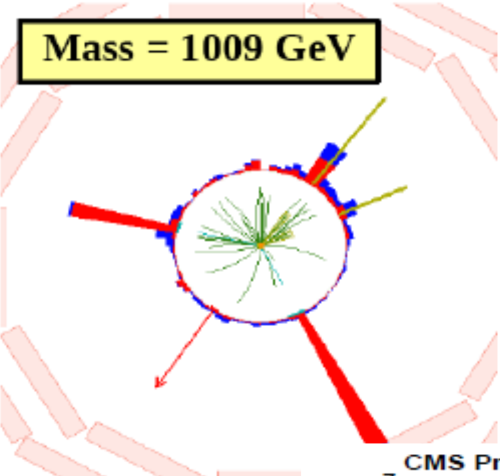
- Technicolor



Signals: lepton + MET, photon +MET, jet +MET

Lepton + MET

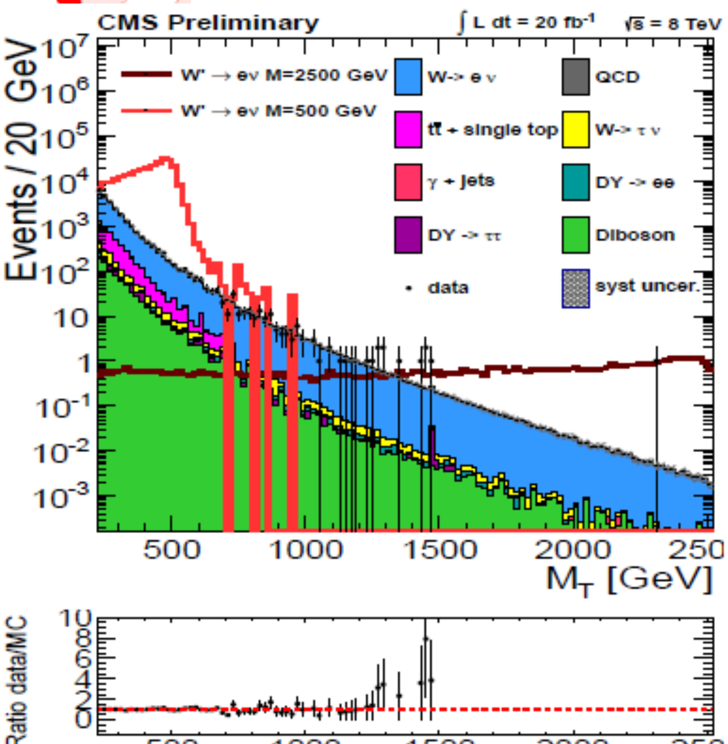
CMS PAS EXO-12-060

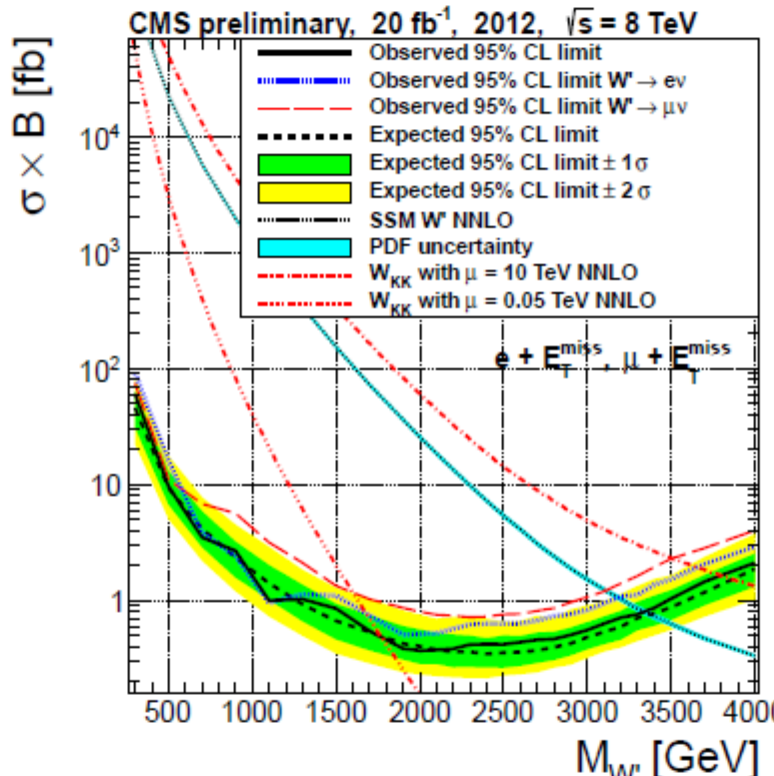


Signature is W-like at high mas
Background is SM W production!

W' with SM-like coupling is exluded with $M_{W'}$ = 3.35 TeV

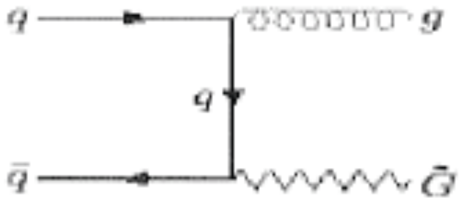
$$M_T = \sqrt{2 \cdot p_T^{\ell} \cdot E_T^{\text{miss}} \cdot (1 - \cos\Delta\phi_{\ell,\nu})}$$

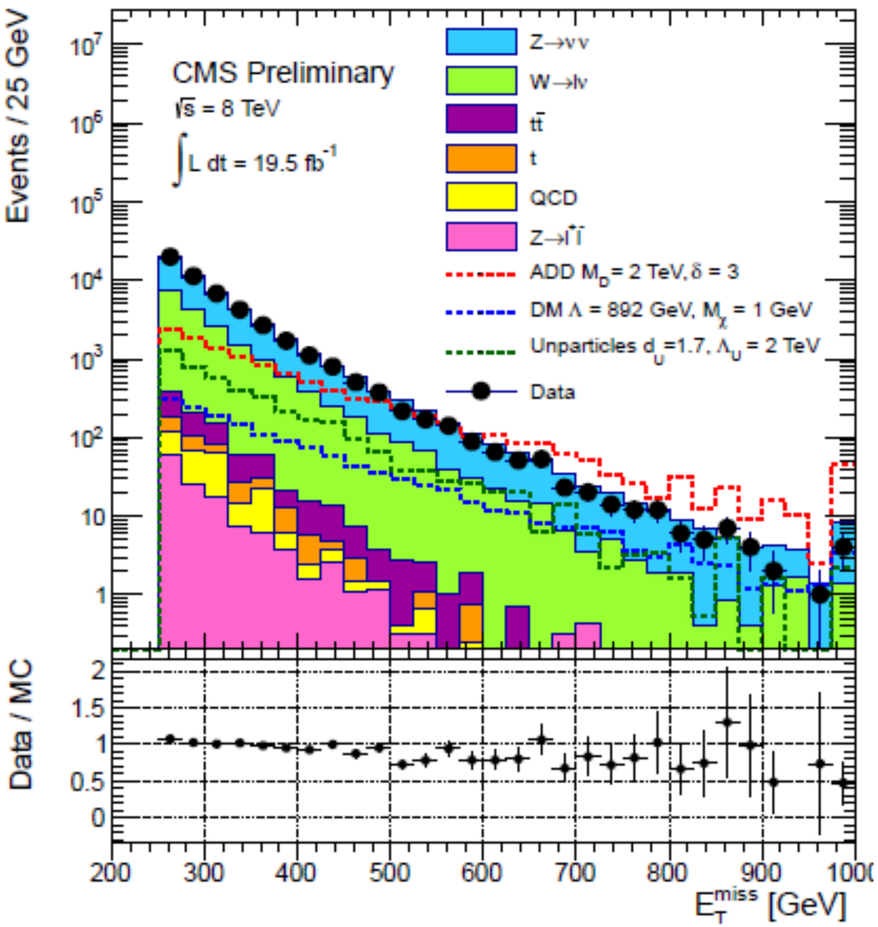


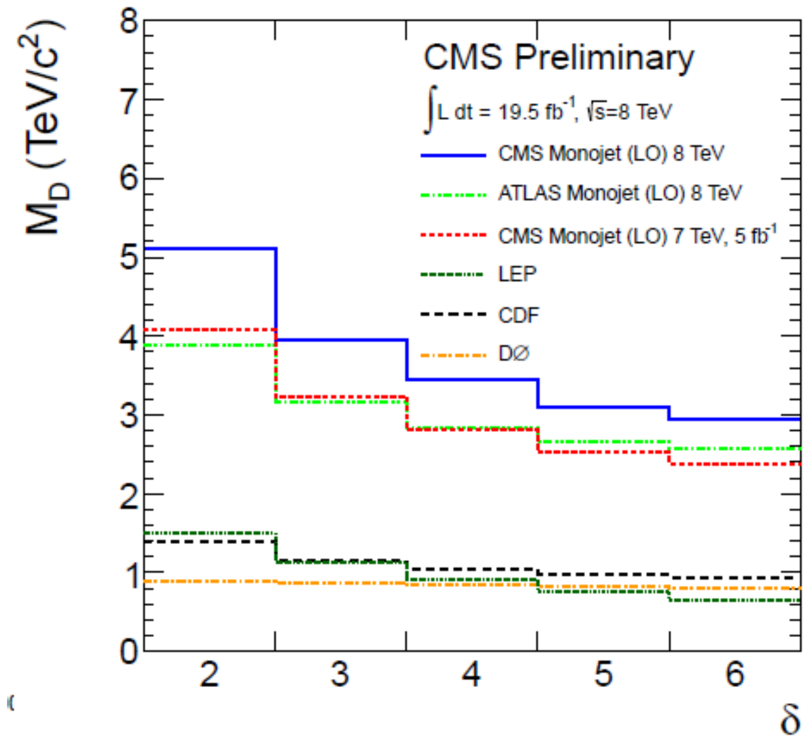


Jet + MET

CMS PAS EXO-12-048



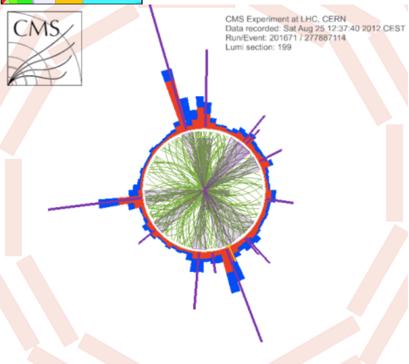




MET (GeV) →	> 250	> 300	> 350	> 400	> 450	> 500	> 550
ADD LO $M_D = 3$ TeV, $\delta = 3$	4496	2888	1885	1265	881	603	422
ADD LO $M_D = 4$ TeV, $\delta = 3$	1071	685	454	310	210	150	108
DM $\Lambda = 850$ GeV, $M_\chi = 1$ GeV	1774	1103	693	454	297	202	137
DM $\Lambda = 950$ GeV, $M_\chi = 1$ GeV	1137	707	444	291	190	129	88
Unparticles $d_U = 1.7$, $\Lambda_U = 2$ TeV	4328	2220	1237	700	378	218	141
Unparticles $d_U = 1.7$, $\Lambda_U = 3$ TeV	1859	905	478	247	158	103	60

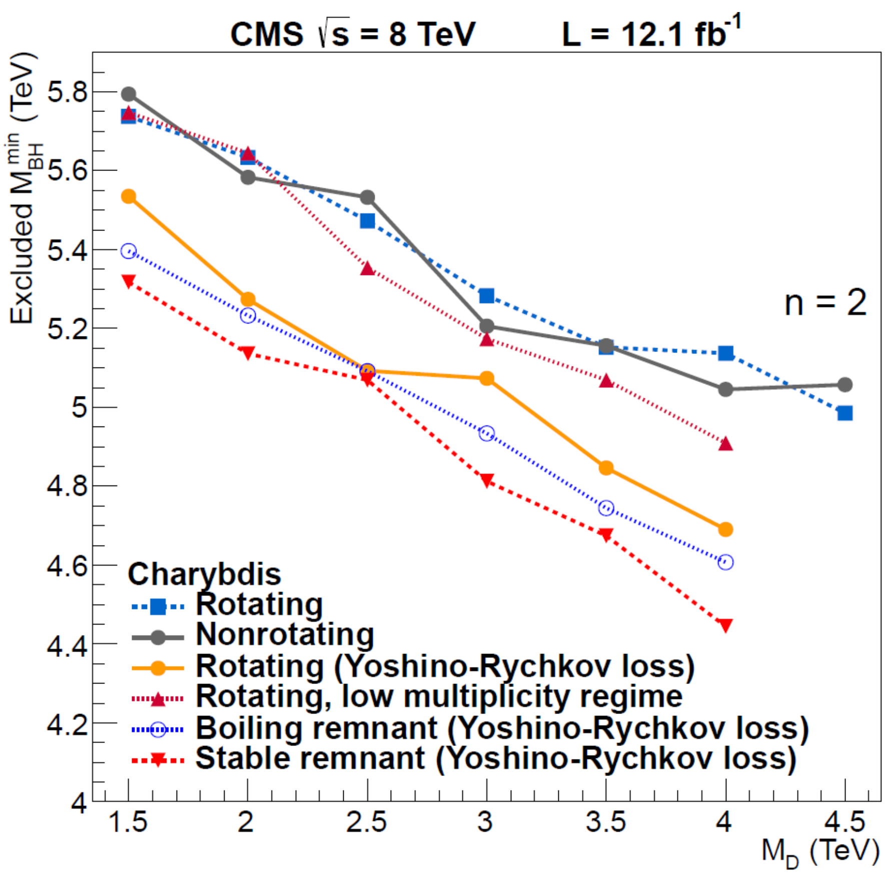
Black Holes

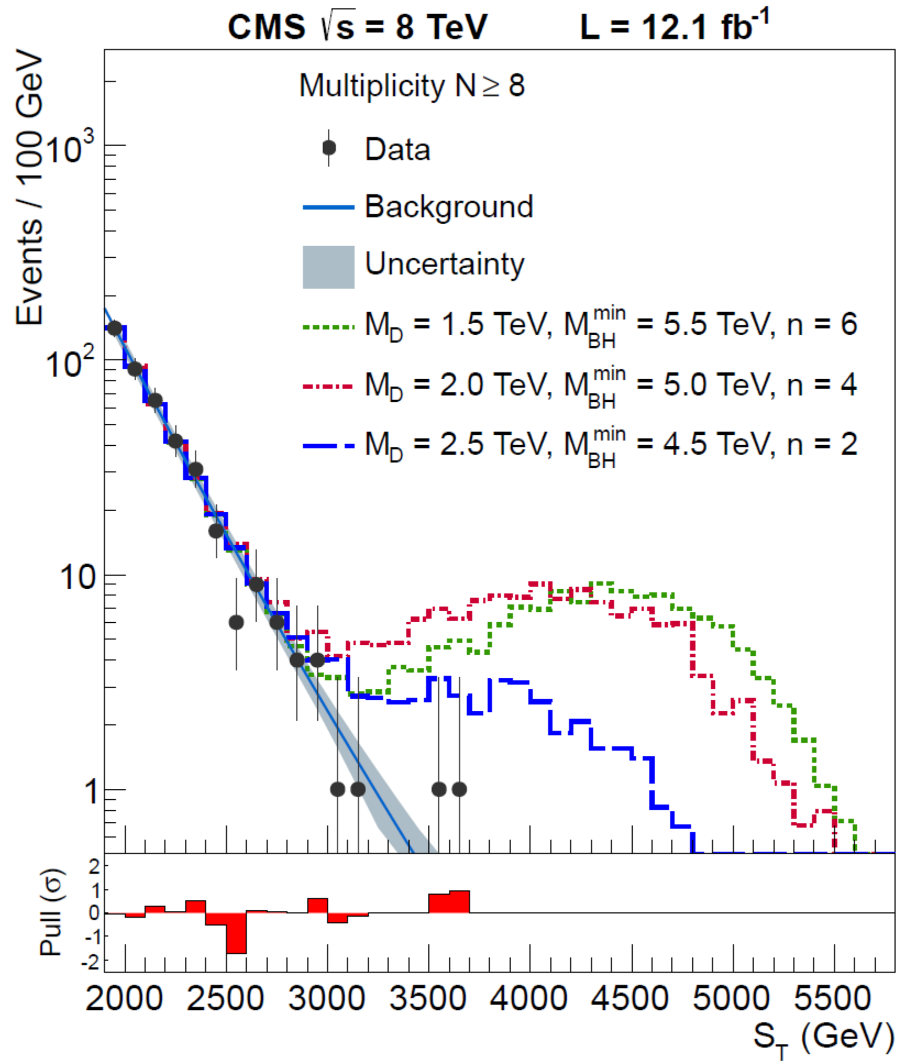
for details see talk by M.V. Savina



JHEP07(2013)178

$$S_T = \sum E_T$$



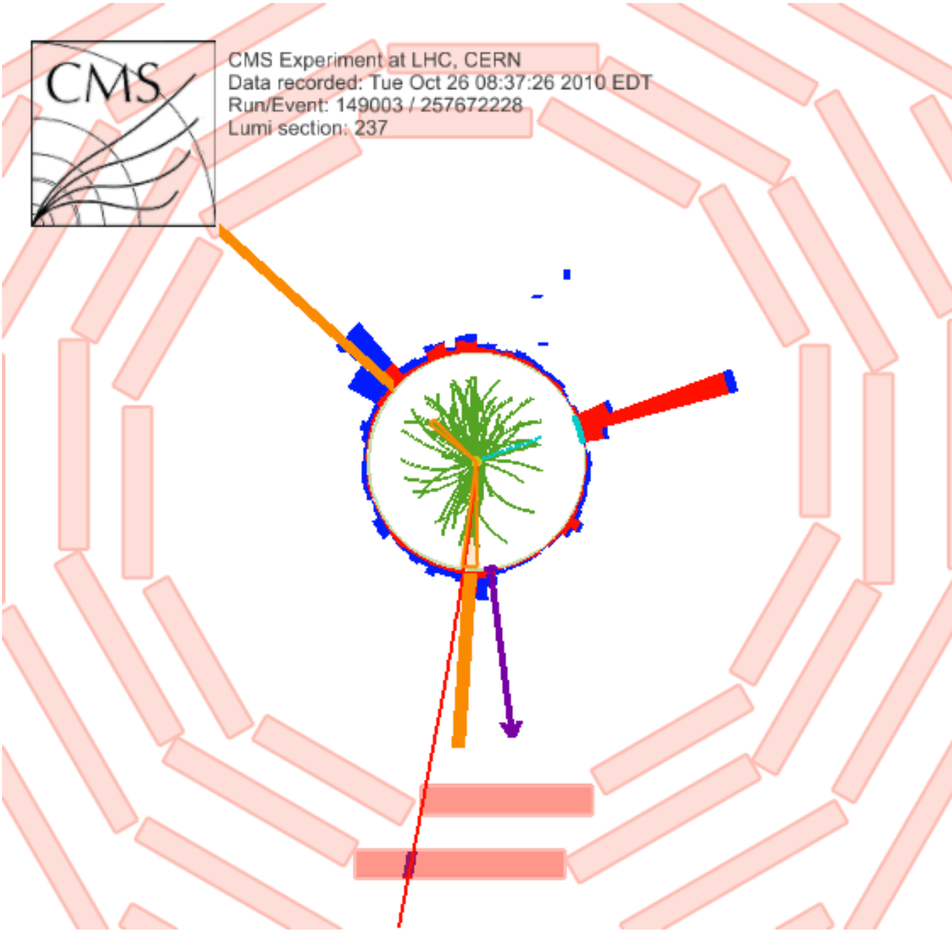


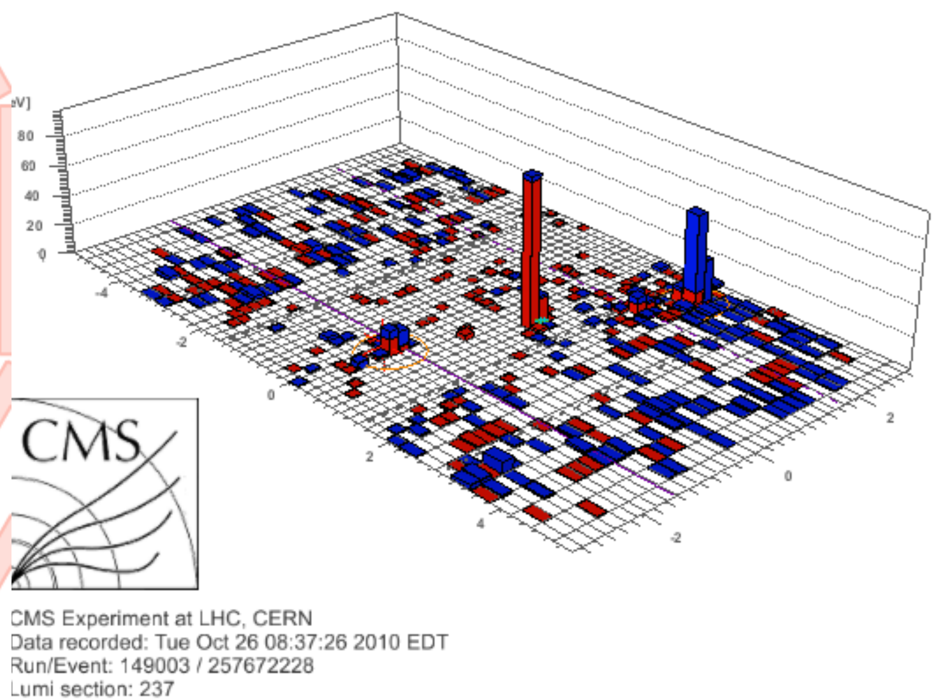
CMS set limits on the inimum BH mass of 4.4-5.8 TeV

Leptoquarks

An LQ carries color, has fractional electric charge, can have spin 0 or spin 1, and couples to a lepton and a quark with coupling strength β!

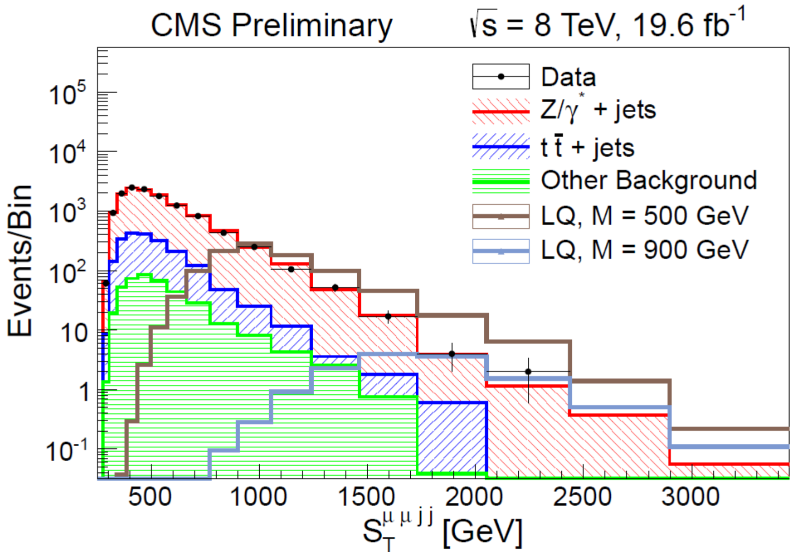
An LQ would decay to a charged lepton and a quark, with an unknown branching fraction λ, or a neutrino and a quark, with branching fraction 1- β

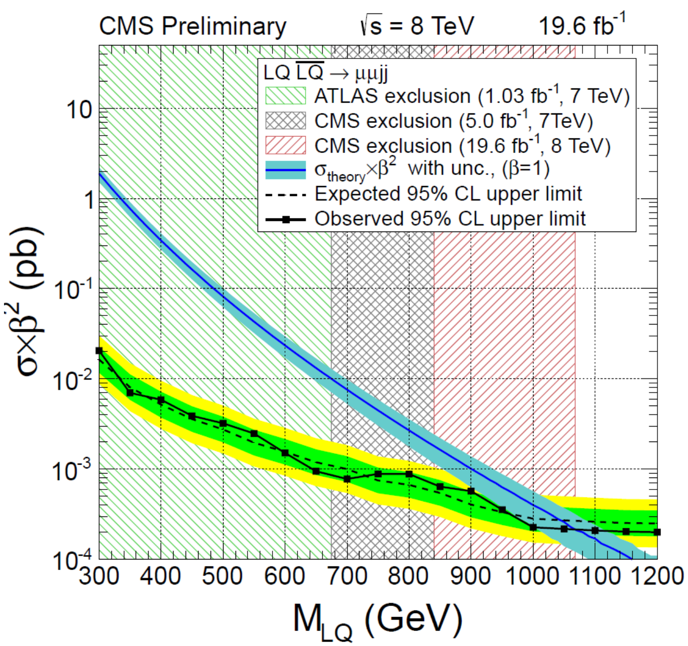


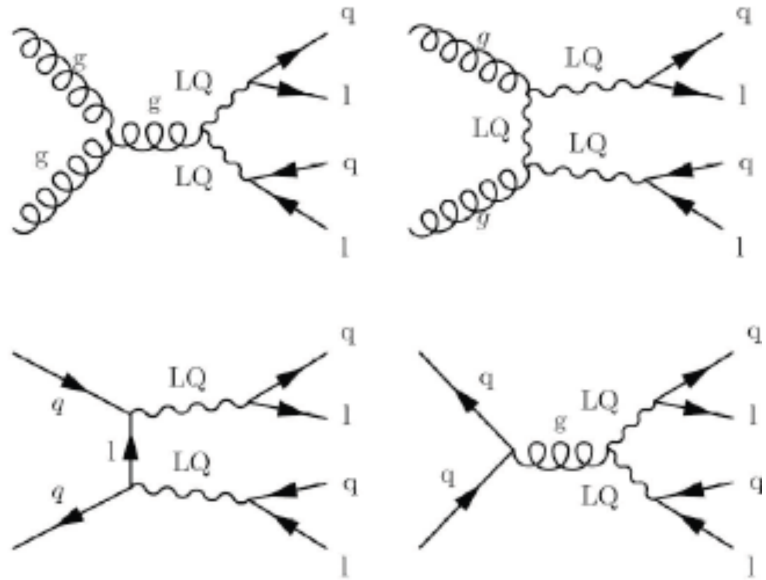


Leptoquarks

EXO-12-042



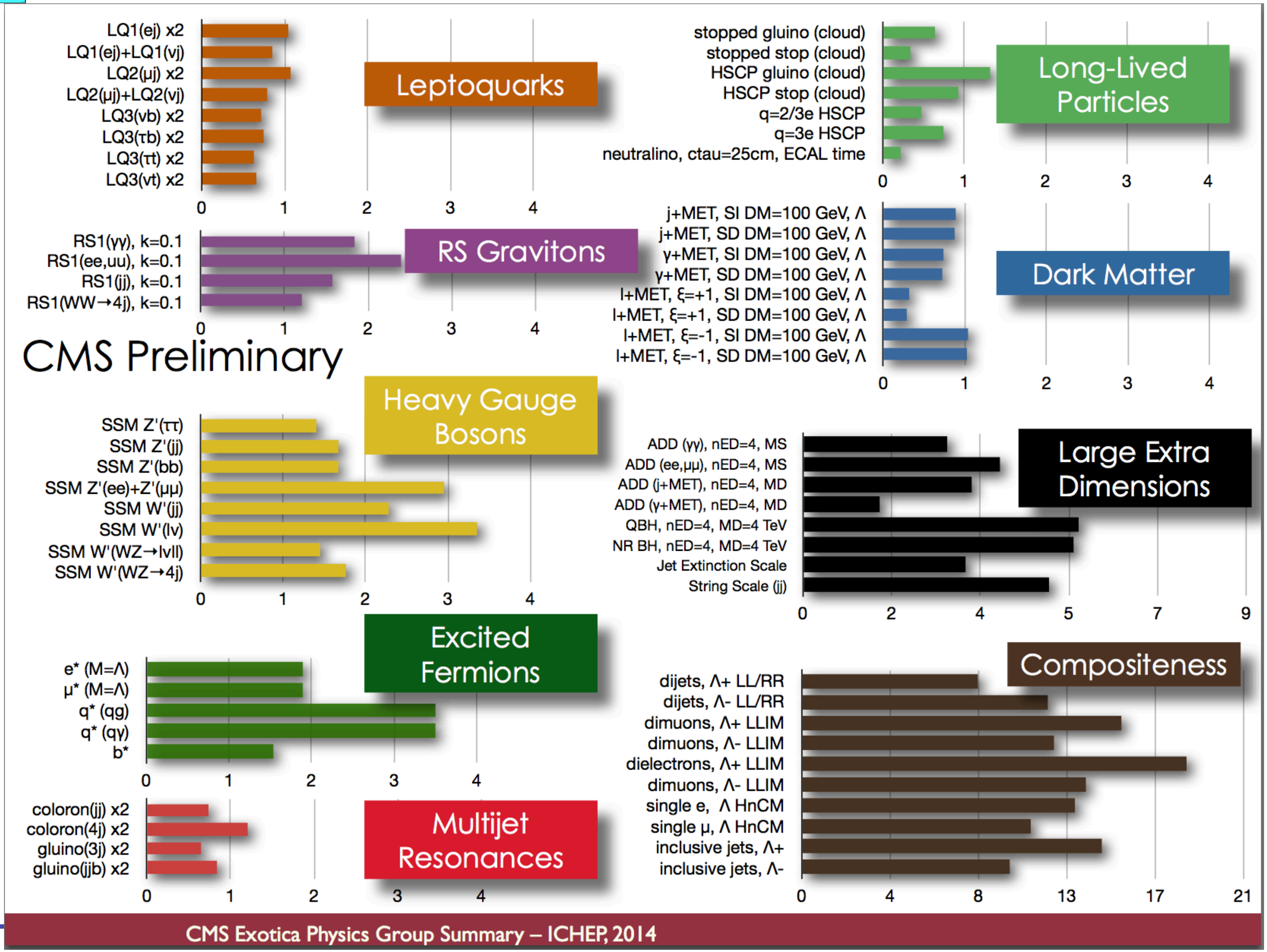




S_T is the sum of the magnitudes of the p_T of the two leading electrons and two leading jets.

A 95% C.L. lower limit is set on the mass of a first-generation scalar leptoquark at 1070 (785) GeV for β = 1 (0.5)

CMS Exotica Summary (95% C.L.)



Heavy Ion (PbPb) @ 2.76 TeV/nuclon

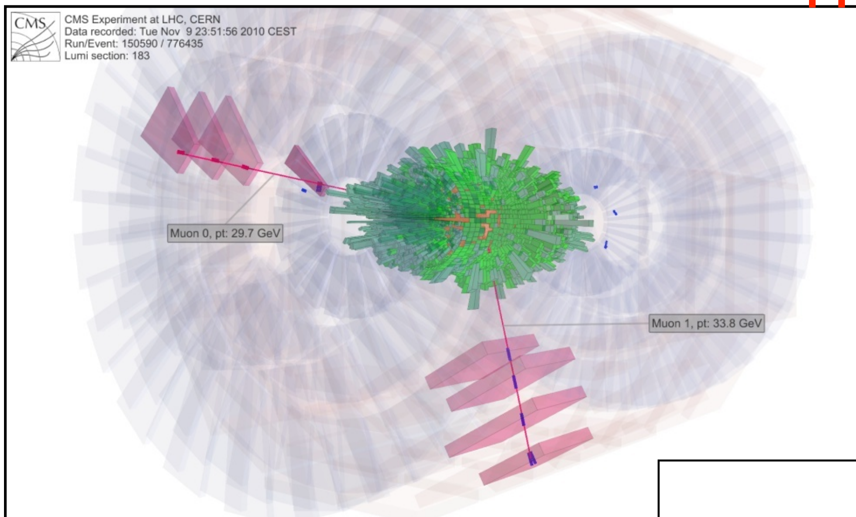
CMS Heavy Iona Public Physics Results

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN

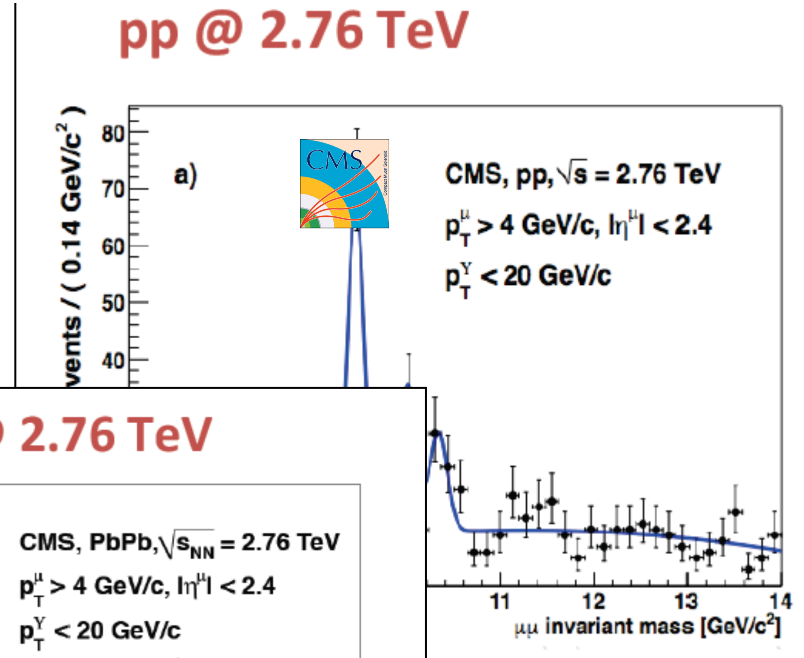
Resonances in HI

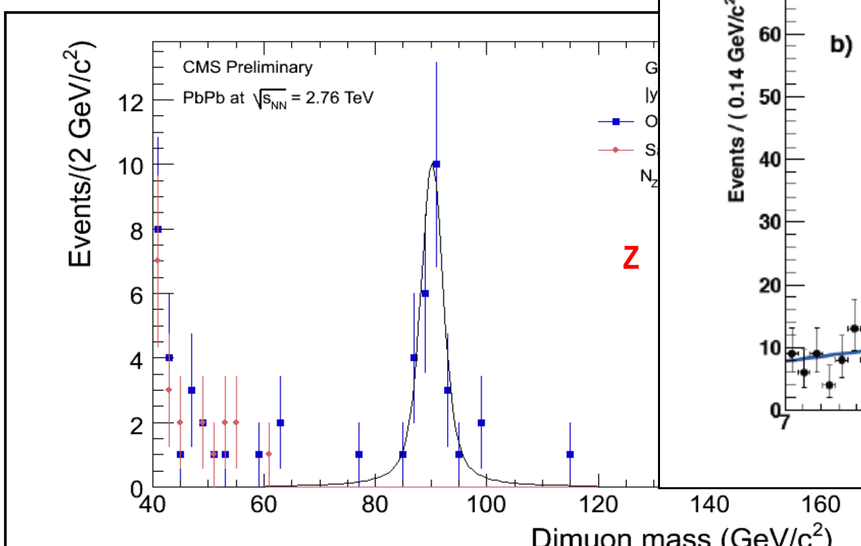
arXiv:1208.2826

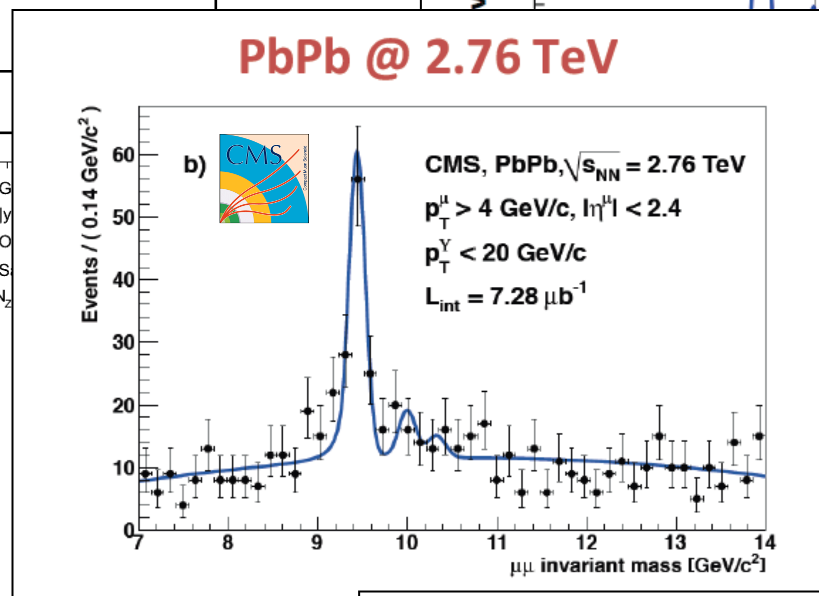
Υ suppression



arXiv:1105.4894 ; CMS-HIN-11-007 ; CERN-PH-EP-2011-074



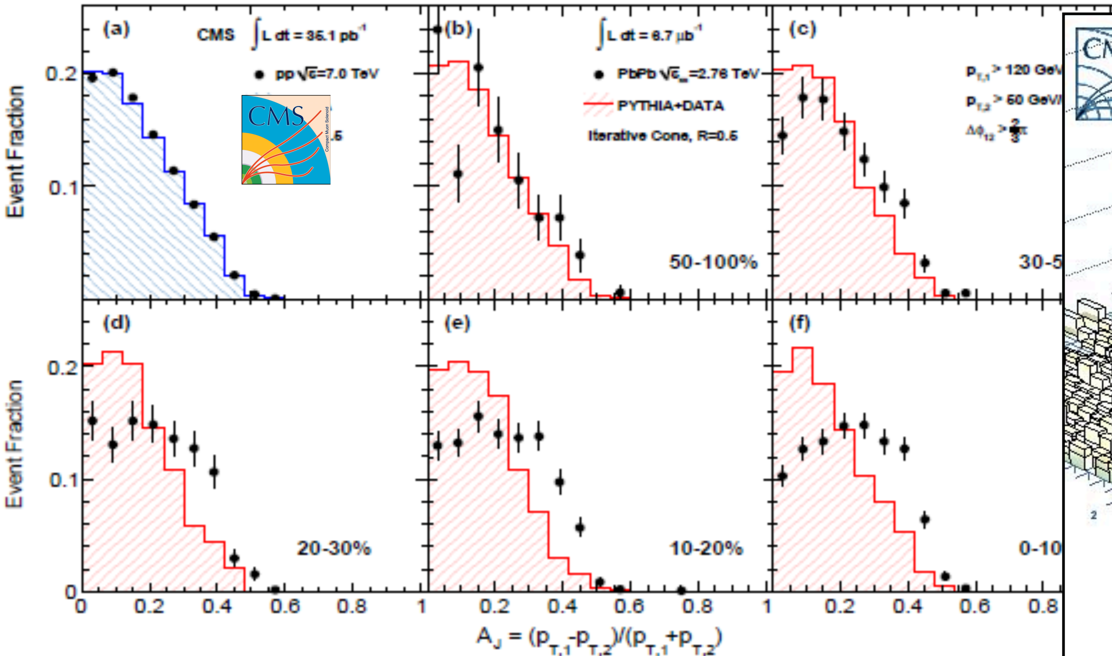


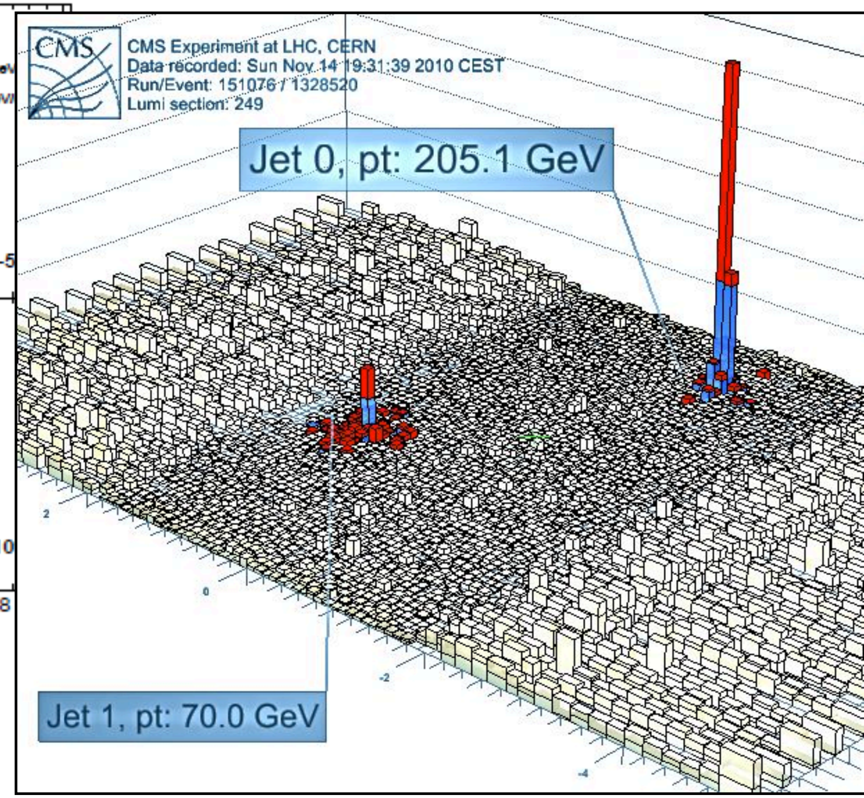


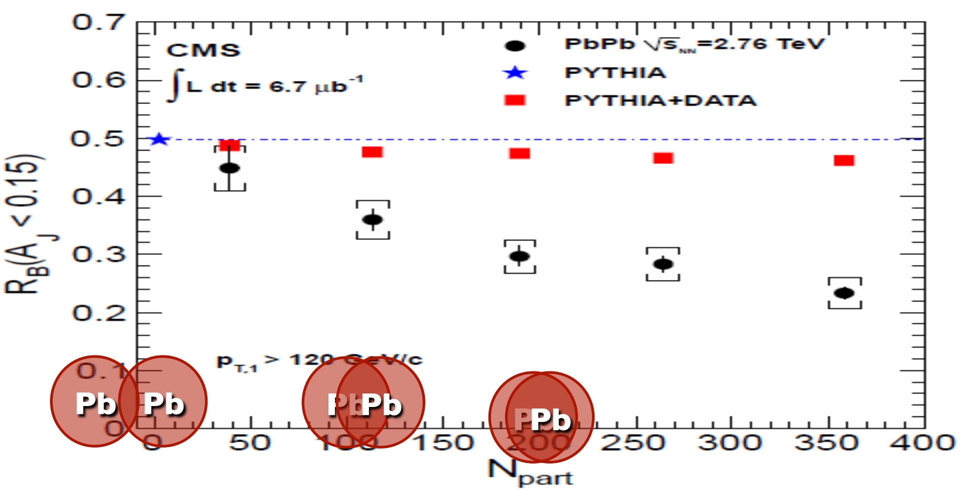
$$\frac{\Upsilon(2S+3S)/\Upsilon(1S)|_{\mathrm{PbPb}}}{\Upsilon(2S+3S)/\Upsilon(1S)|_{\mathrm{pp}}} = 0.31 \pm 0.17 \pm 0.03,$$

Jet Quenching

Phys. Rev. C84 (2011) 024906







Conclusions and Outlook

- ❑ Being based on excellent detector performance
  - ✓ TeV leptons, photons, jets
  - ✓ Mono-particle + associated missing energy
  - ✓ Complex signatures

CMS discovered a new boson

- ❑ CMS has performed studies of the discovered boson in many different channels $\Rightarrow$ SM Higgs Boson

- ❑ CMS explored the Standard Model in many channels with high precision and set new limits on New Physics (SUSY, Exotica)

- ❑ The collaboration is preparing for RUN2 @ 13 TeV, starting in 2015 (~100 fb-1 for ~2016)

OUTLINE

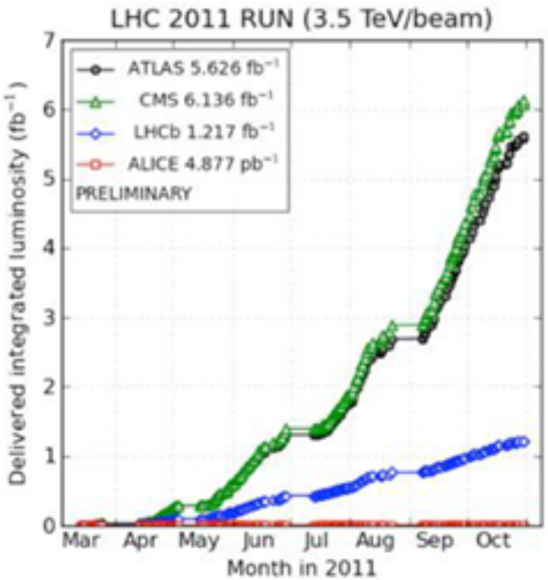
Exotica at LHC is Physics beyond SM/SUSY/Higgs

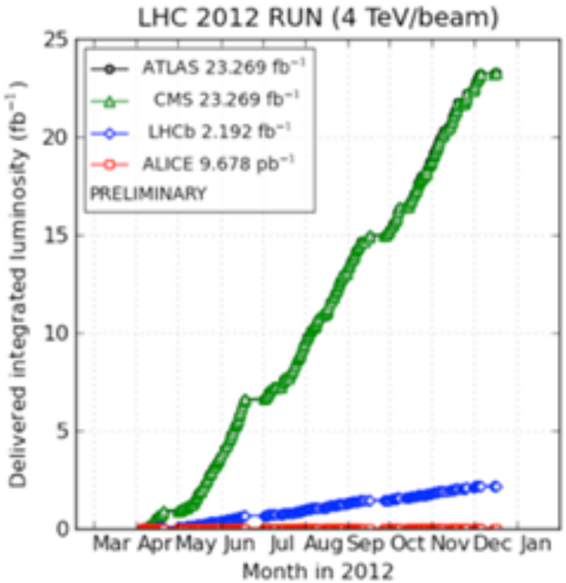
- ❑ Heavy Resonances (extended gauge models, extra dimensions, technicolor) ⇒ dileptons, dijets, diphotons, ttbar, WZ
- ❑ Non-Resonant Signals
- ❑ Mono-particle + Missing ET (extended gauge models, extra dimensions, technicolor) ⇒ mono-jet + MET, mono-photon + MET, mono-lepton + MET
- ❑ Black Holes (extra dimensions) ⇒ high-multiplicity events
- ❑ Leptoquarks
- ❑ 4^{th} Generation ⇒ lepton + jet, dilepton

CMS Exotica Public Physics Results

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

LHC/CMS Operation

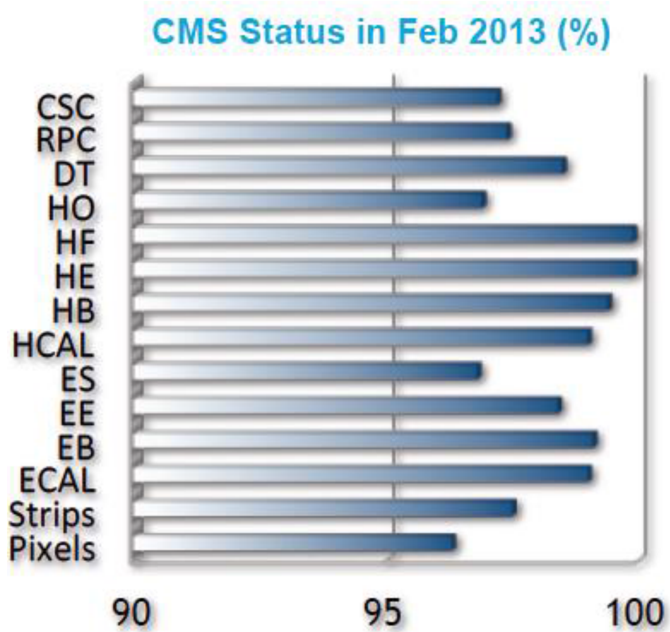


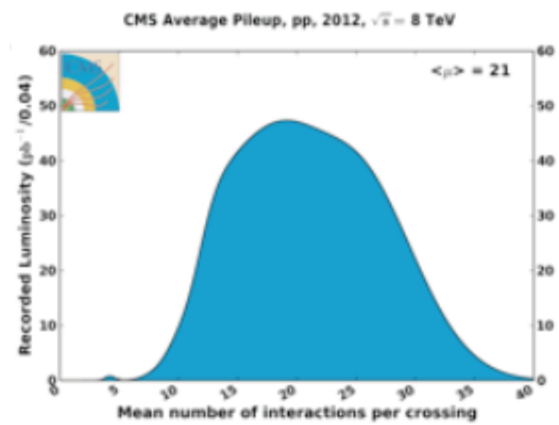


LHC provided

6.1 fb^{-1} at a 7 TeV center-of-mass energy for 2011

23.4 fb^{-1} at a 8 TeV center-of-mass energy for 2012



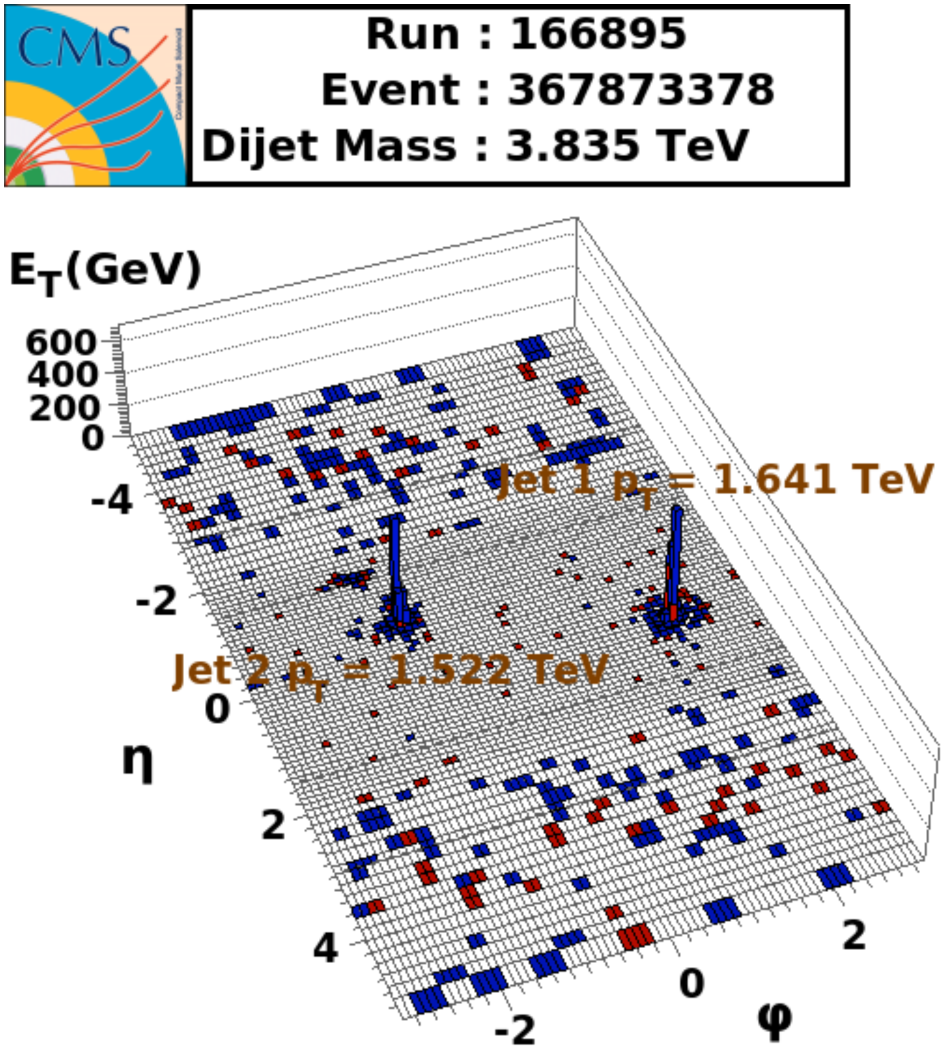


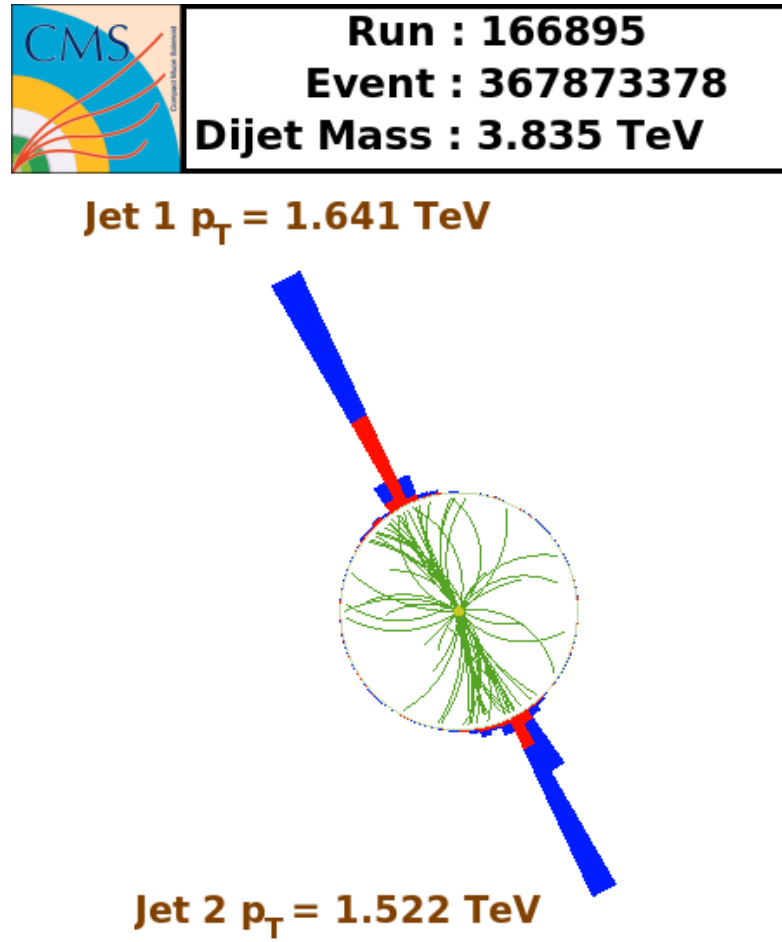
Excellent performance of subdetectors during the 3 years

Higgs History: This is Higgs

Highest Dijets Mass at CMS

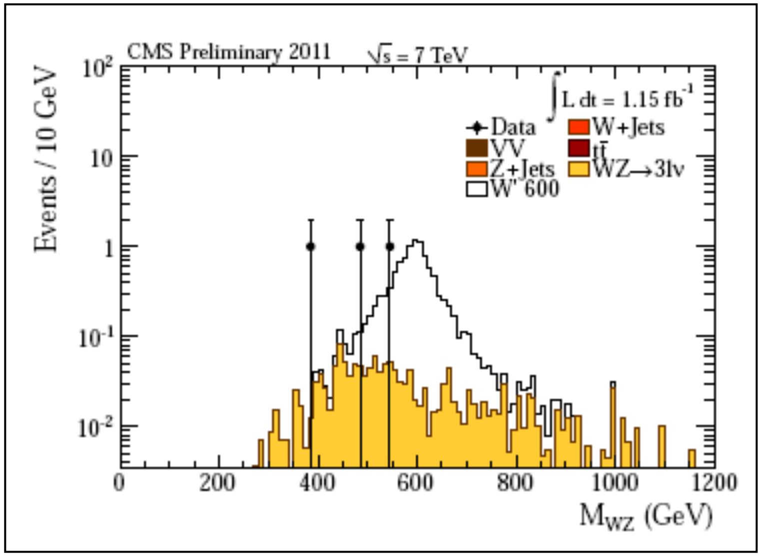
CMS PAS EXO-11-015

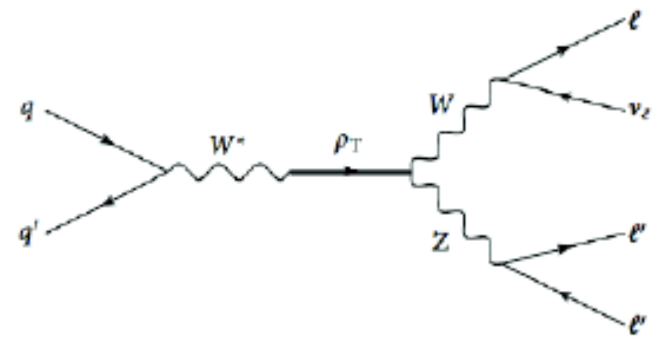


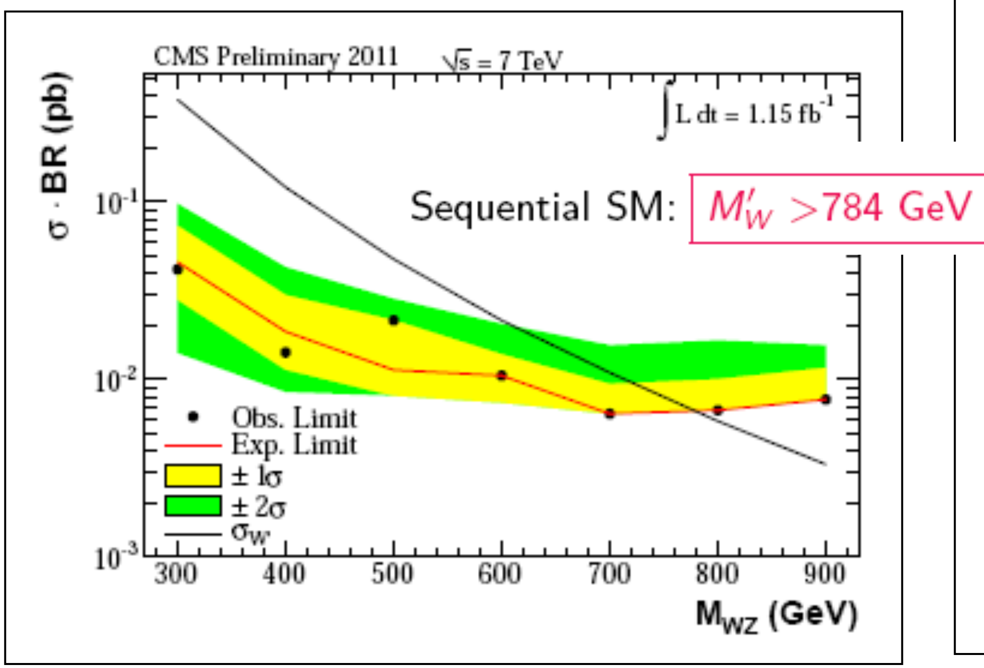


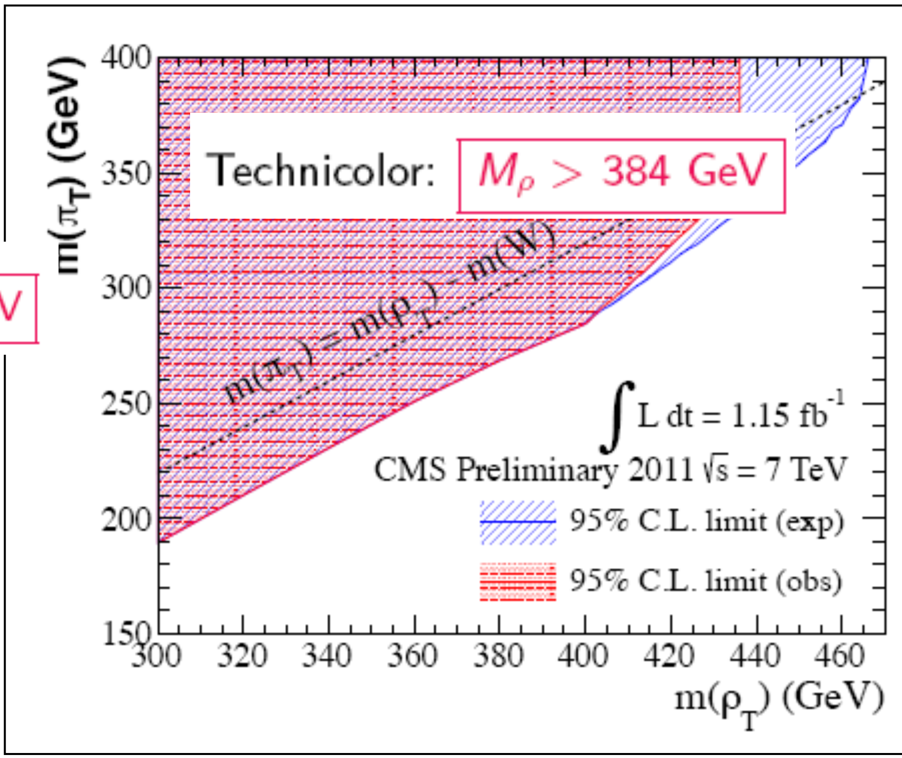
WZ Resonances

CMS PAS EXO-11-041



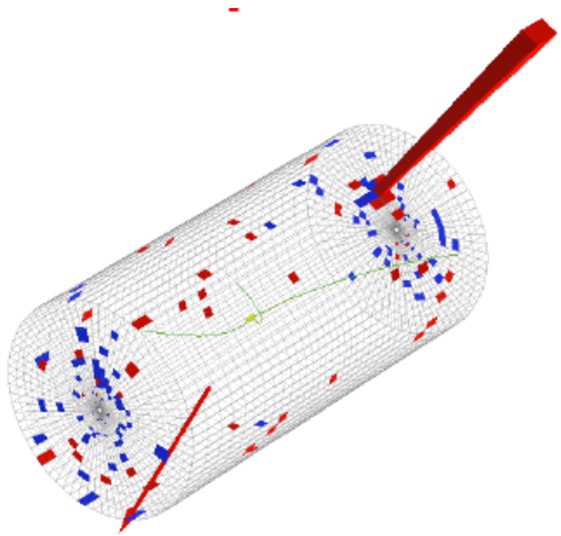


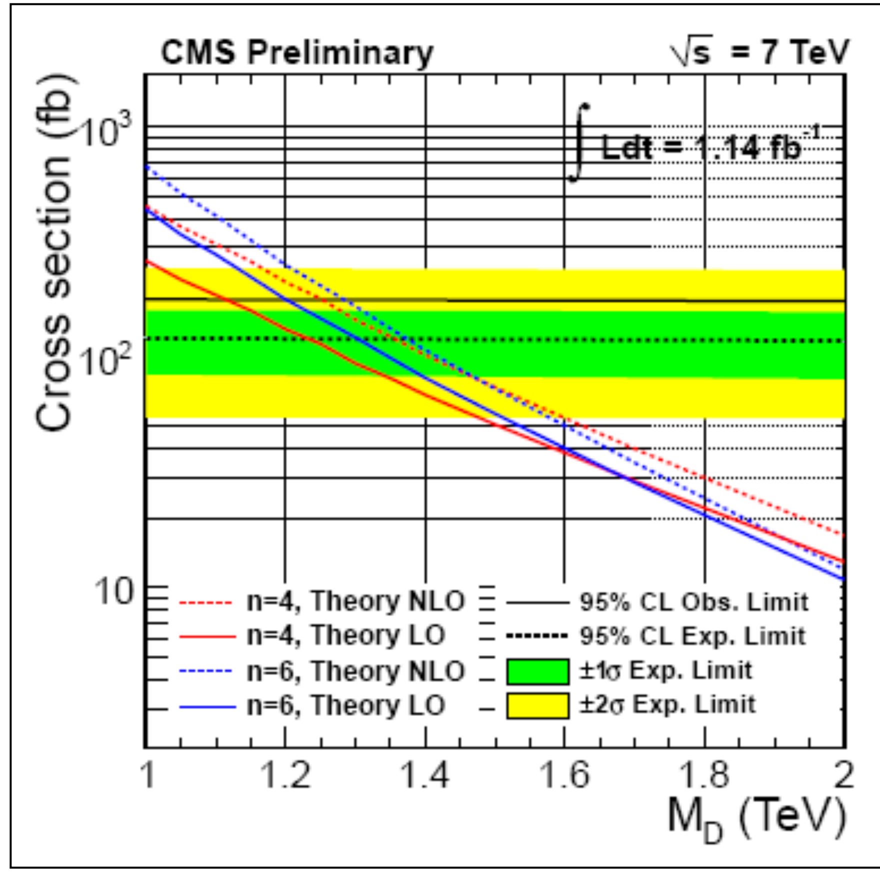


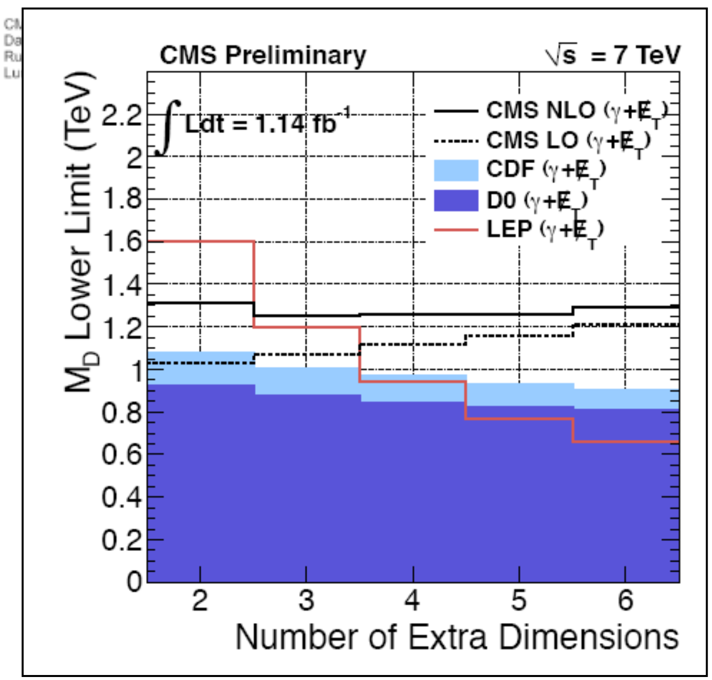


Photon + MET

CMS PAS EXO-11-058





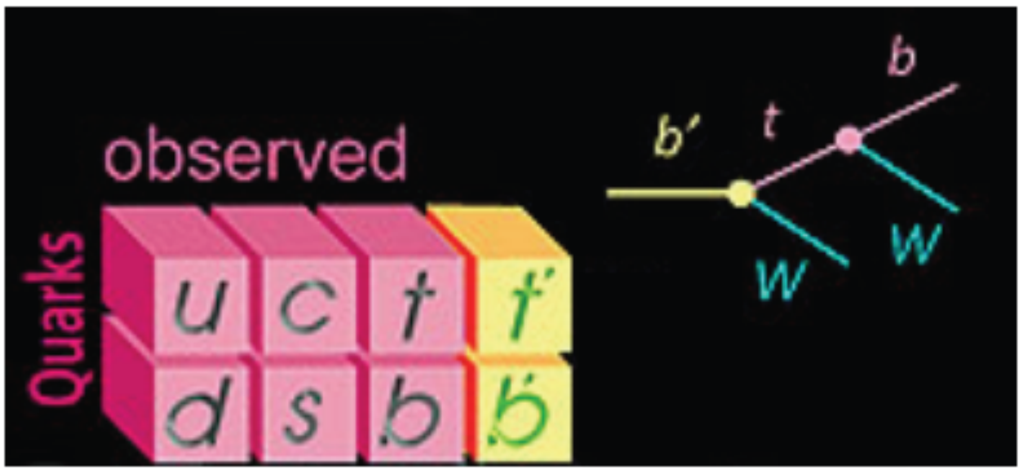


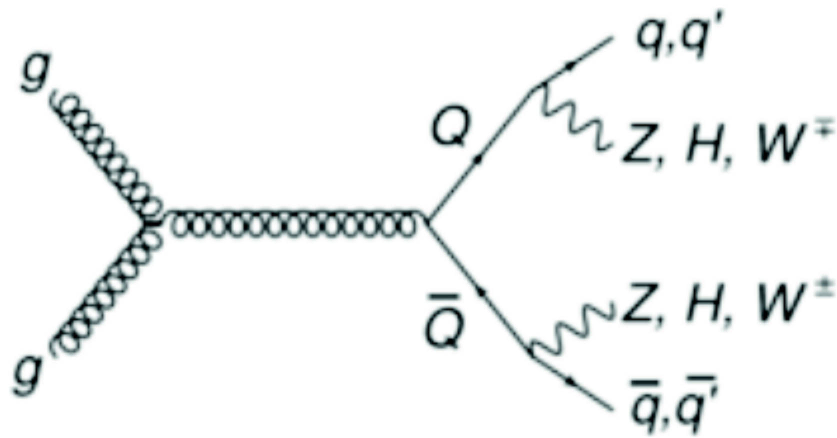
CMS extends the current limits to be $M_D >$ 1.25-1.31 TeV for n = 2 - 6

4^{th} Generation

Recently renewed interest, since it has been shown that the EWK bounds are less constraining for a non-degenerate fourth generation!

With a fourth generation, indirect bounds on the Higgs boson mass can be relaxed, and an additional generation of quarks may possess enough intrinsic matter and anti-matter asymmetry to be relevant for the baryon asymmetry of the Universe!



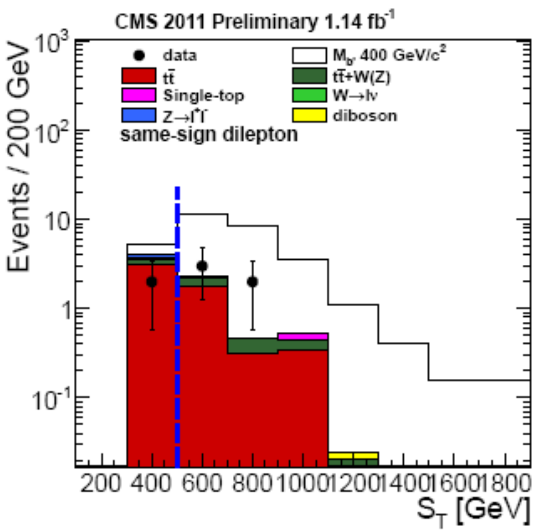


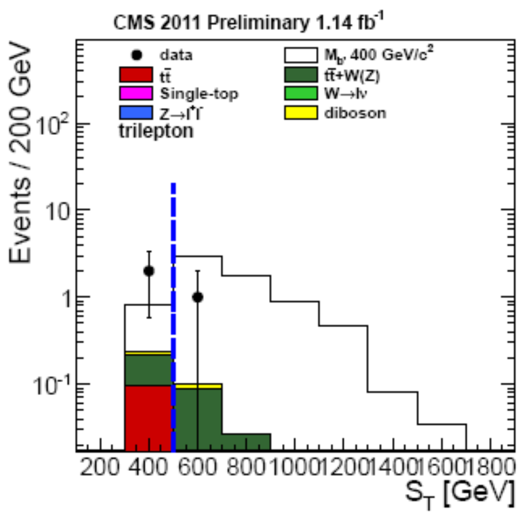
$b' \to t + W$

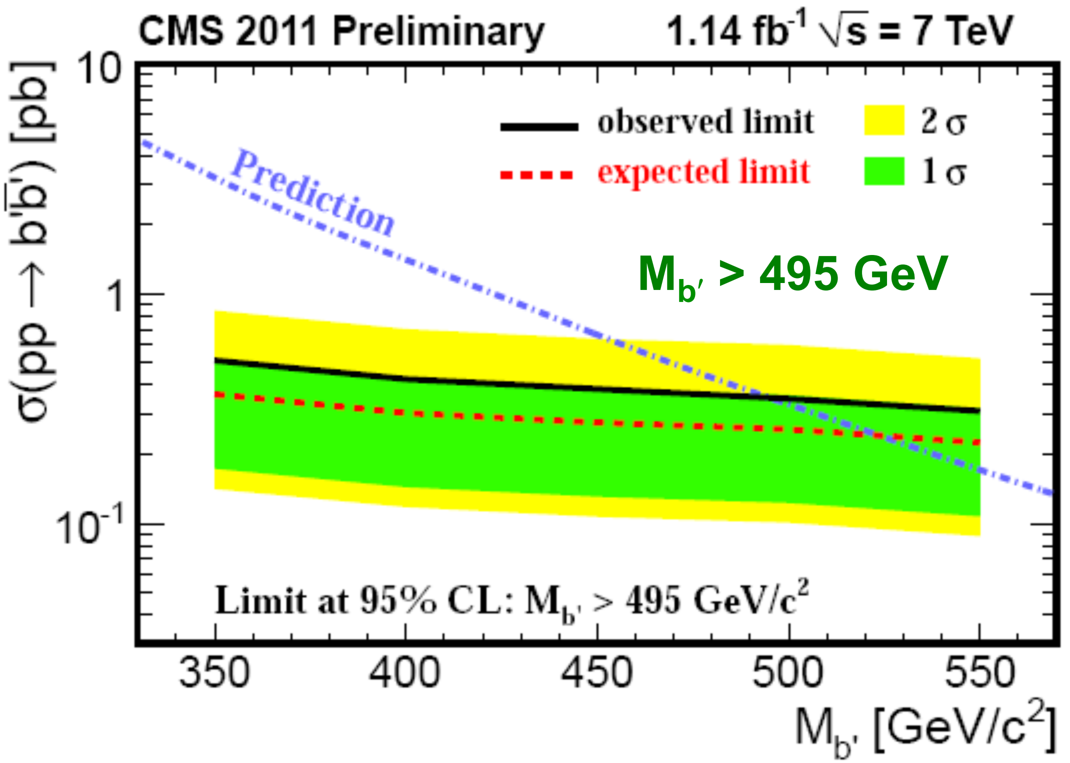
$$b'\bar{b}' \to tW^-\bar{t}W^+ \to bW^+W^-\bar{b}W^-W^+$$

CMS PAS EXO-11-036

$$S_T \equiv \sum p_T(jets) + \sum p_T(leptons) + \not{E}_T$$







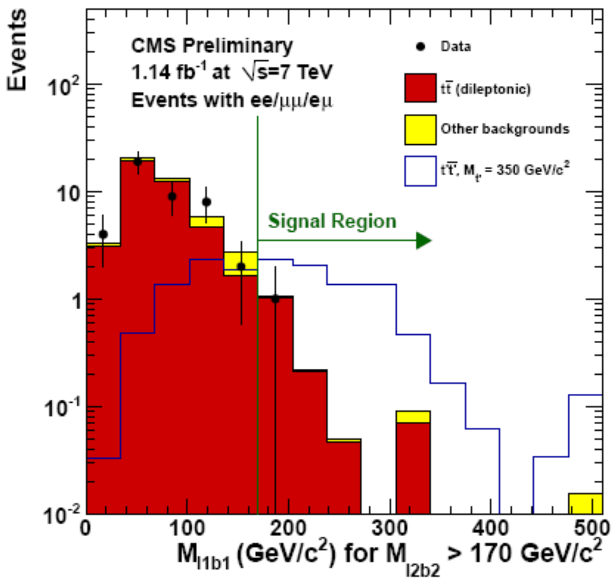
Searching of t′(1)

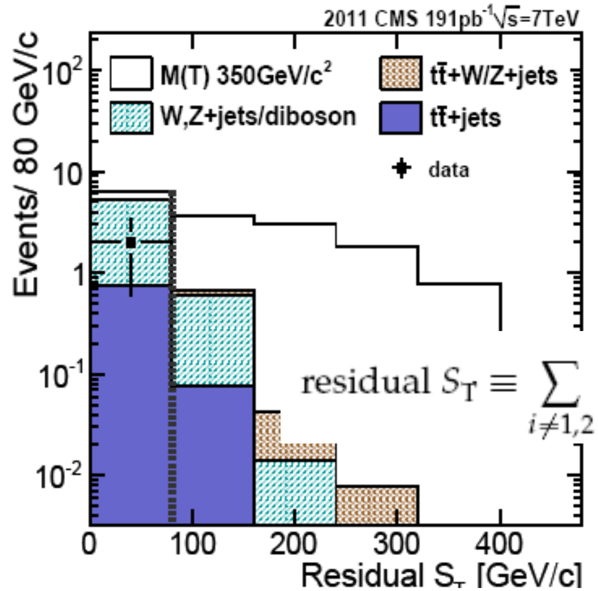
CMS PAS EXO-11-050

CMS PAS EXO-11-005

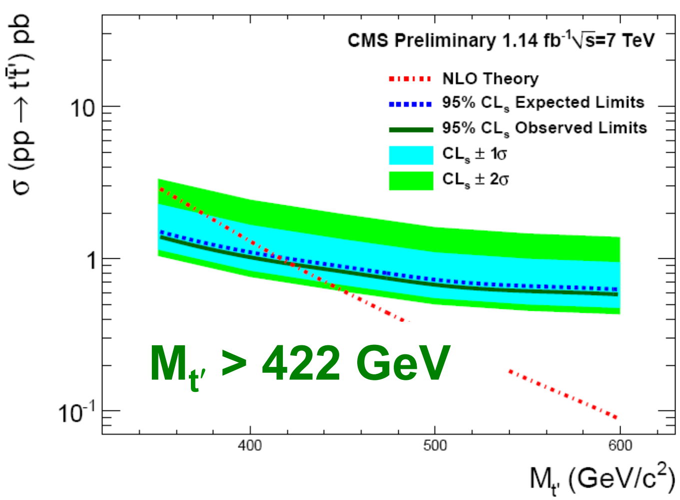
$$t'\bar{t}' \to bW^+\bar{b}W^- \to b\ell^+\nu\bar{b}\ell^-\bar{\nu}$$

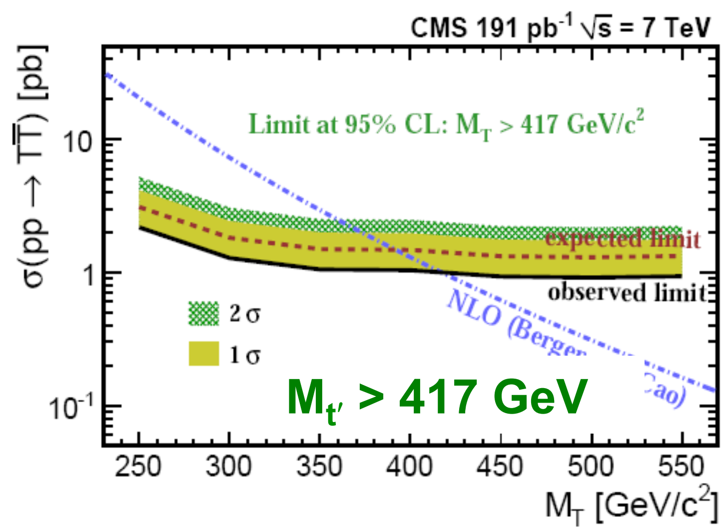
$$t'\bar{t}' \to tZ\ \bar{t}Z \to bW^+W^-bZZ$$





$$\text{residual } S_T \equiv \sum_{i\neq 1,2} p_T(\text{jet}_i) + \sum_{i\neq 1,2} p_T(\text{lepton}_i)$$

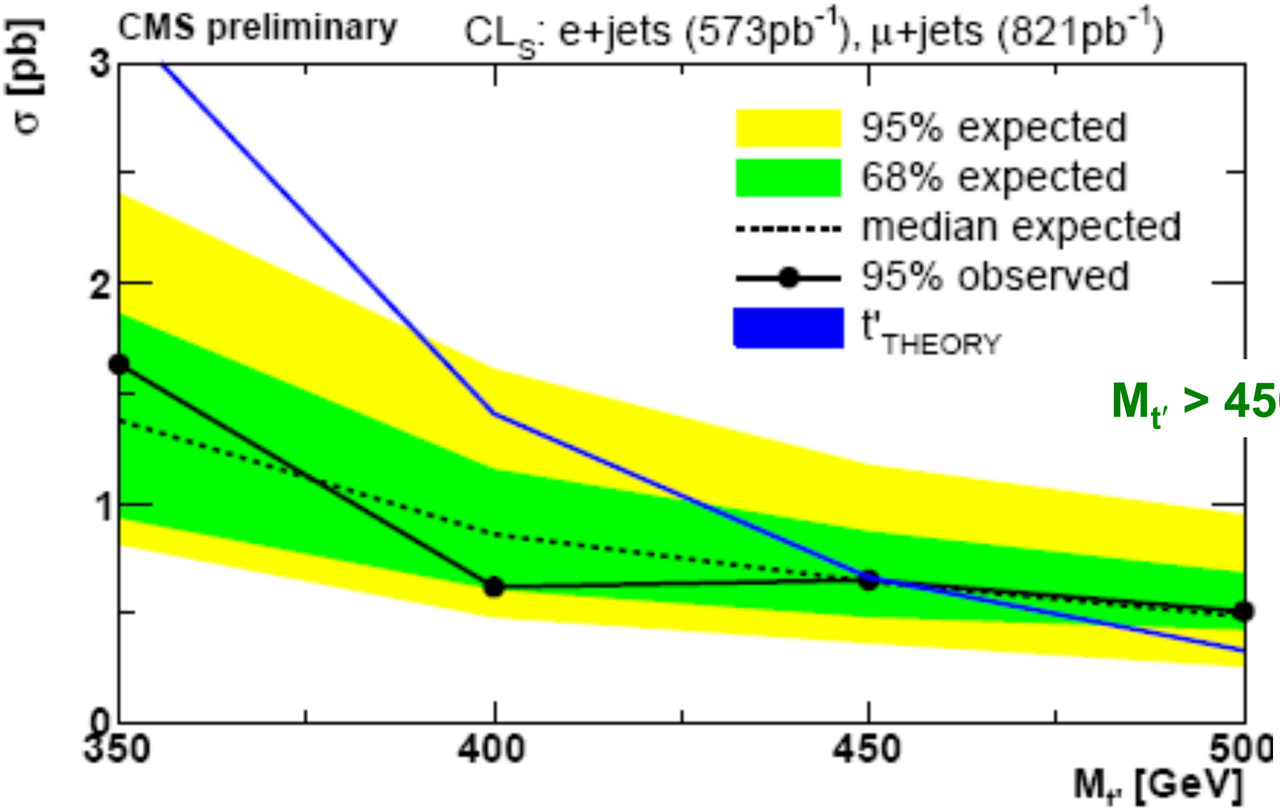




Searching of t′(2)

CMS PAS EXO-11-051

$$t'\bar{t}' \rightarrow WbW\bar{b} \rightarrow \ell\nu bq\bar{q}\bar{b}$$



$M_{t'}$ > 450 GeV

Signature explored at CMS

	incl. (ggH)	VBF tag	VH tags	ttH tag
bb		✔	✔	✔
ττ	✔	✔	✔	✔
WW	✔	✔	✔ (3ℓ, Vjj)	✔
ZZ	✔	✔		✔
γγ	✔	✔	✔	✔
Zγ	✔	✔		
μμ	✔	✔		
invis.		✔	✔	

✔ = full 8 TeV dataset analyzed, often full 7 TeV too.