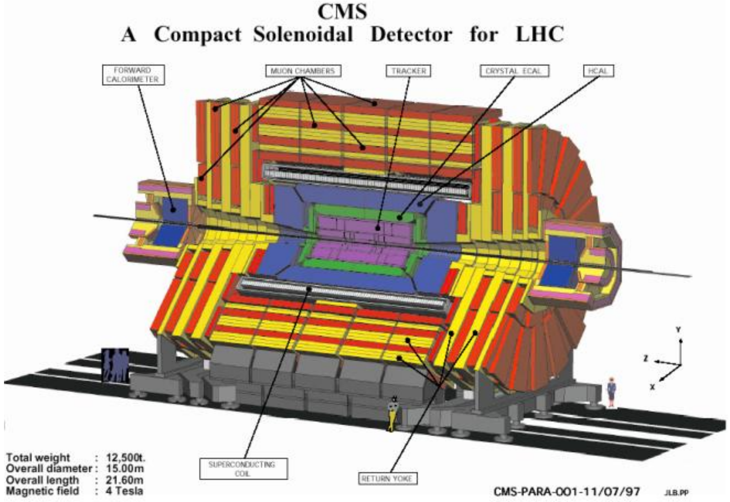
Overview of physics results from CMS

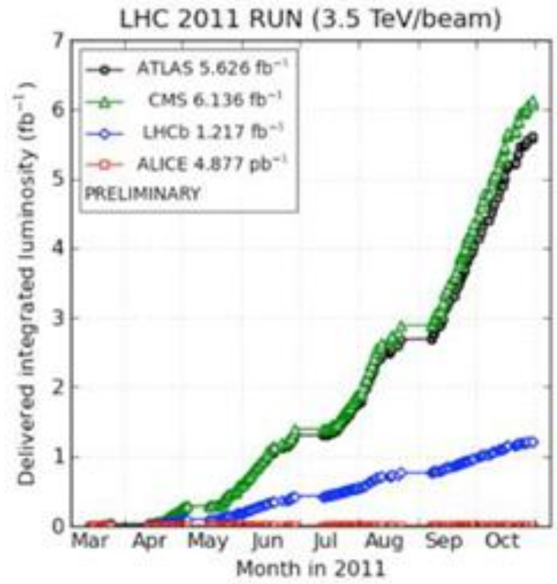
Sergei Shmatov
Joint Institute for Nuclear Research, Dubna
on behalf of CMS Collaboration

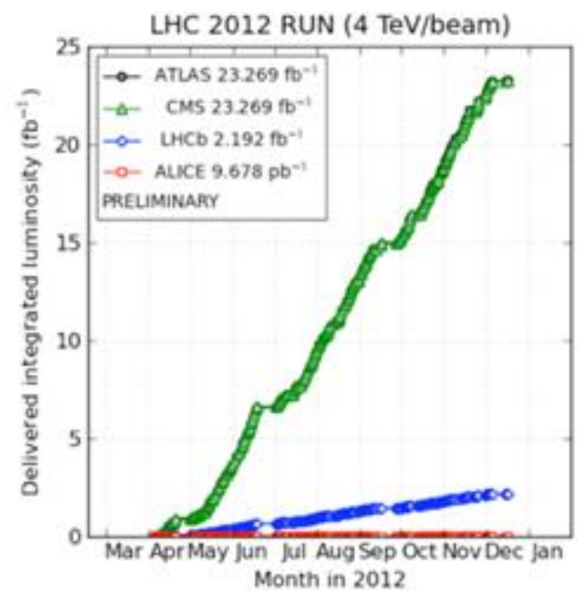


The NPD RAS Conference
"The Physics of Fundamental Interactions"
5-8 Nov 2013, IHEP, Protvino

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



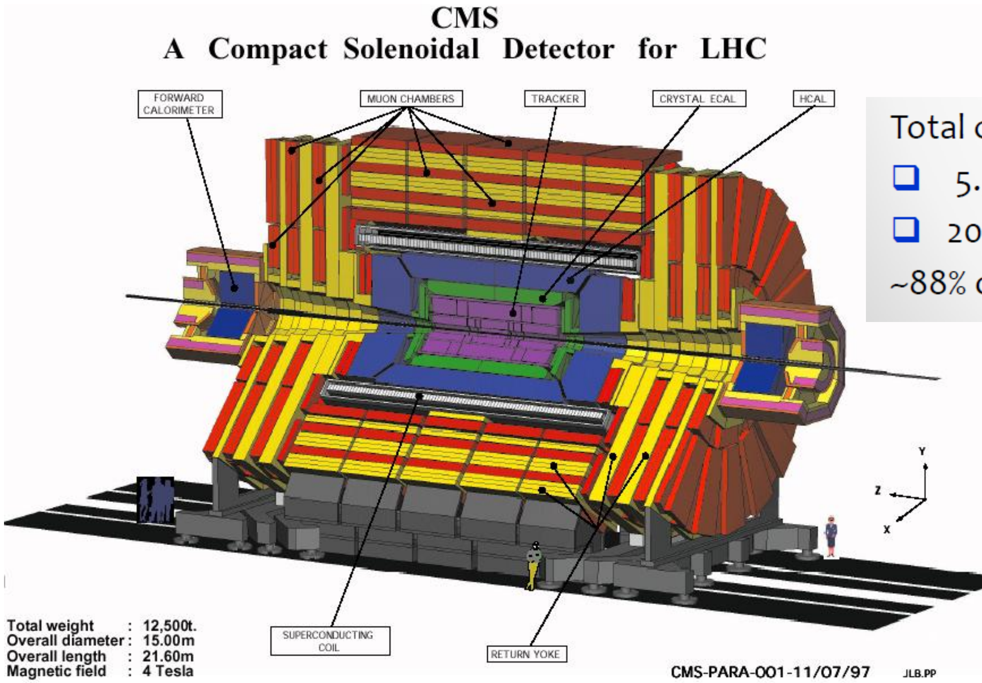


CMS Public Physics Results

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

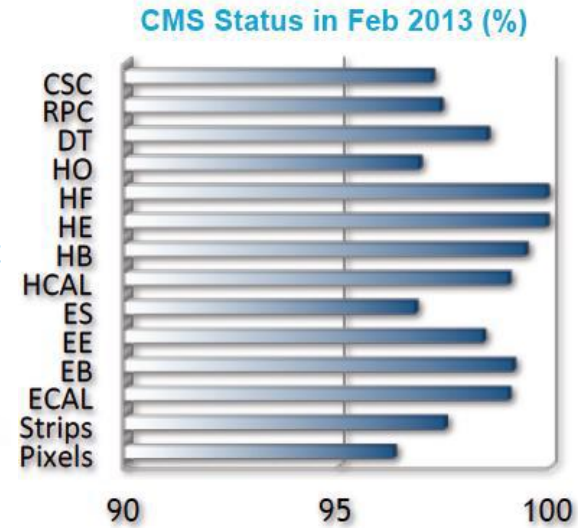
Compact Muon Solenoid

Large general-purpose particle physics detector

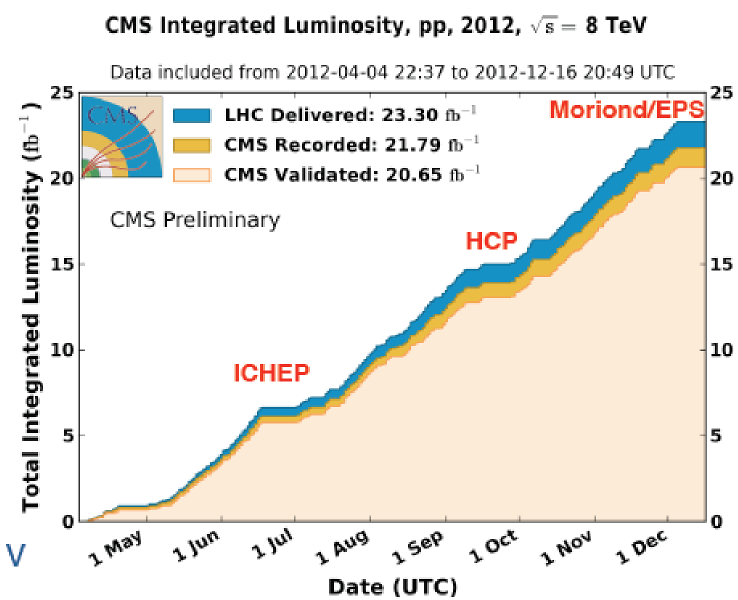


Total certified good data set
- 5.32 fb-1 @ 7 TeV
- 20.65fb-1 @ 8 TeV

~88% of delivered lumi



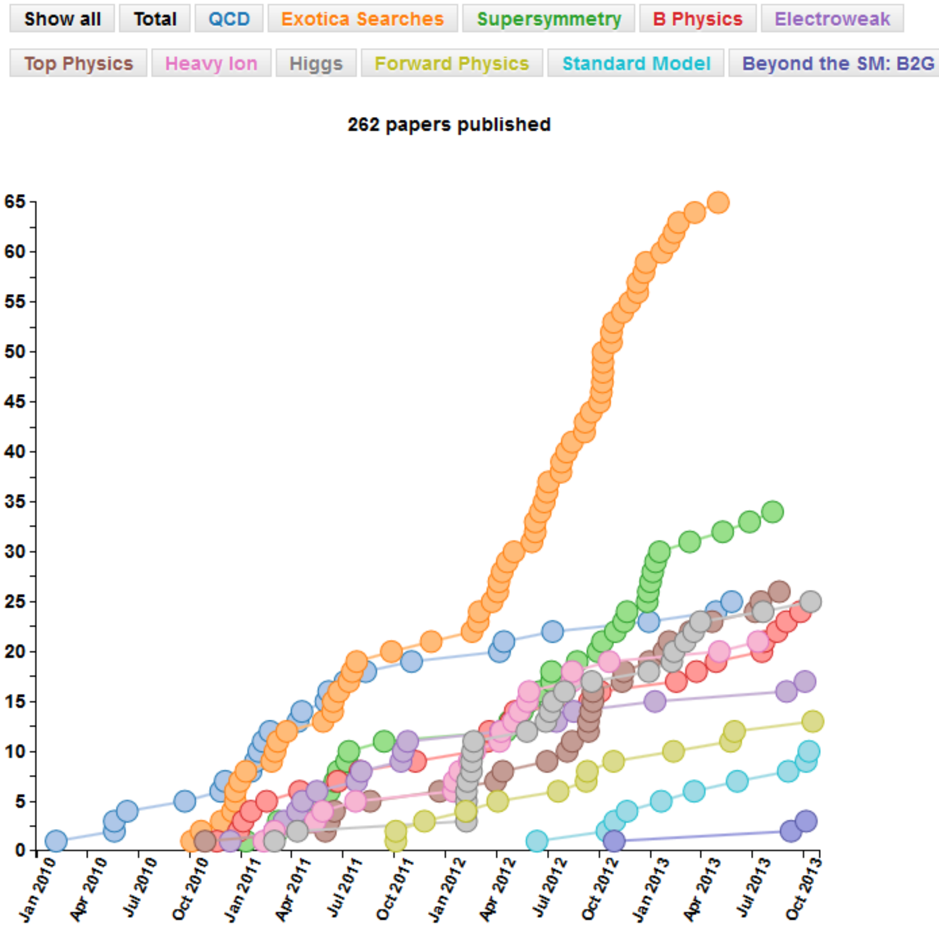
Total weight	*12 500 t*
Overall diameter	*15.00 m*
Overall length	*21.6 m*
Magnetic field	*3.8 Tesla*



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

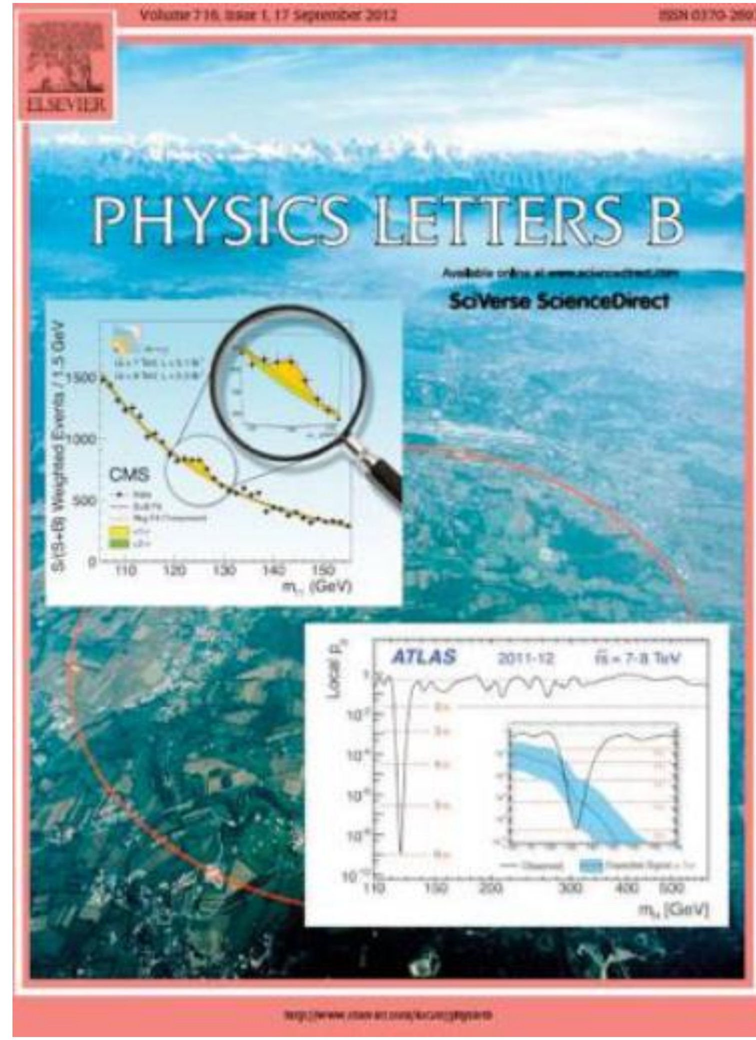
CMS Publications

In 2010-2013 the CMS Collaboration published 262 papers on collision data
(J. High Energy Phys, Phys. Rev. Lett., Phys. Lett. B, Eur. Phys. J. etc)



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

Discovery and Studies of the Higgs Boson

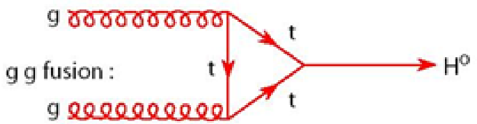


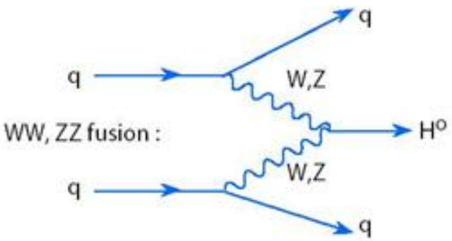
Phys. Lett. B 716 (2012) 30

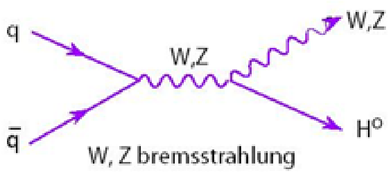
CMS Higgs Public Physics Results

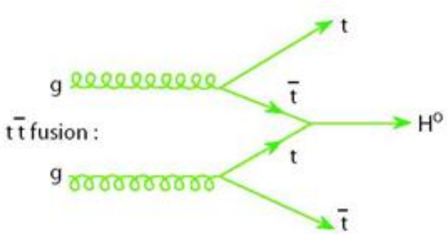
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIG

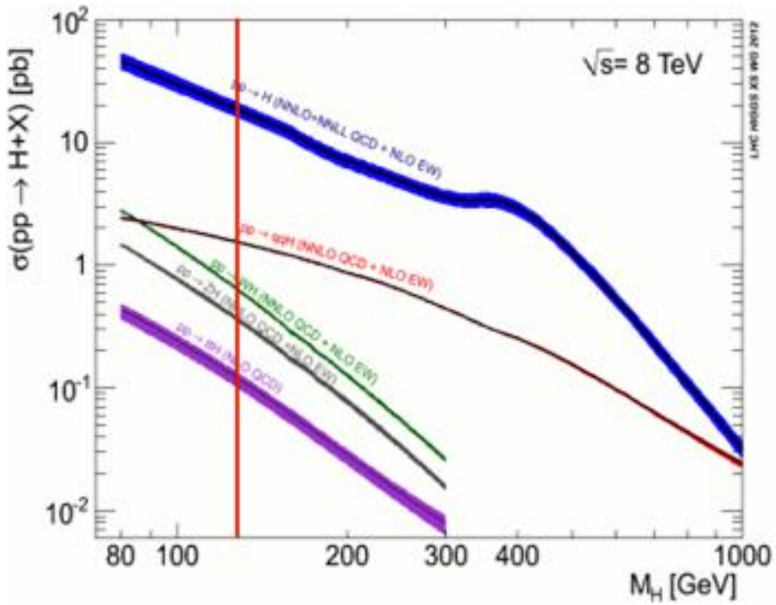
SM Higgs Production











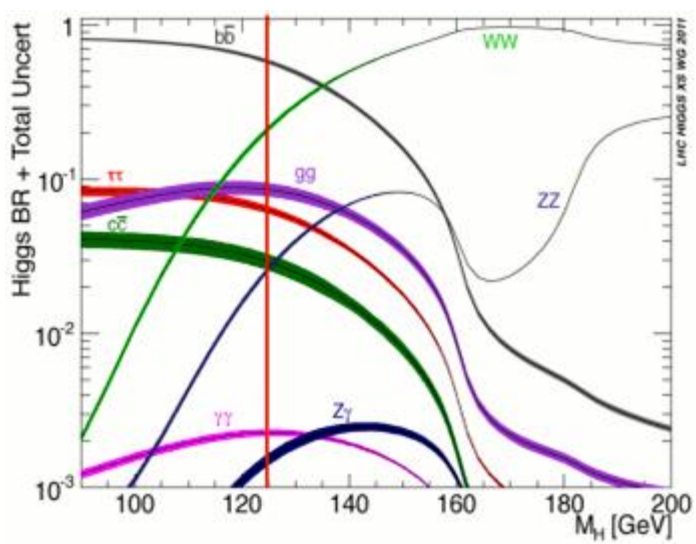
19.5 pb ggF

1.6 pb VBF

1.1 pb VH

0.1 pb $t\bar{t}H$

@ m_H=125 GeV



10%	$H \to bb$
15%	$H \to \tau\tau$
20%	$H \to WW$
1-2%	$H \to ZZ$
1-2%	$H \to \gamma\gamma$

Signature explored at CMS

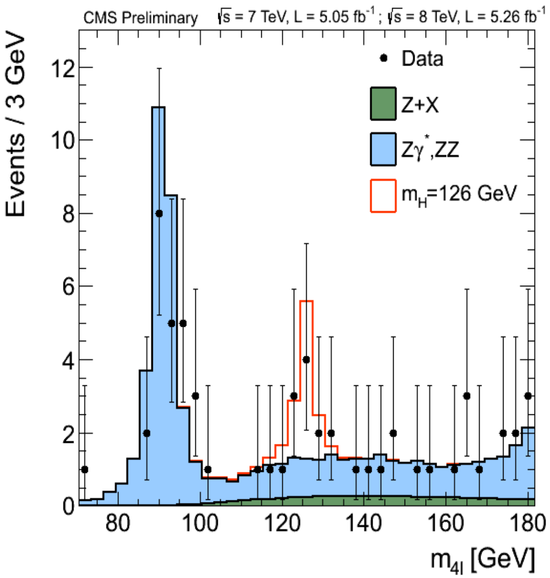
	incl. (ggH)	VBF tag	VH tags	ttH tag
bb		✔	✔	✔
ττ	✔	✔	✔	✔
WW	✔	✔	✔ (3ℓ, Vjj)	✔
ZZ	✔	✔		✔
γγ	✔	✔	✔	✔
Zγ	✔	✔		
μμ	✔	✔		
invis.		✔	✔	

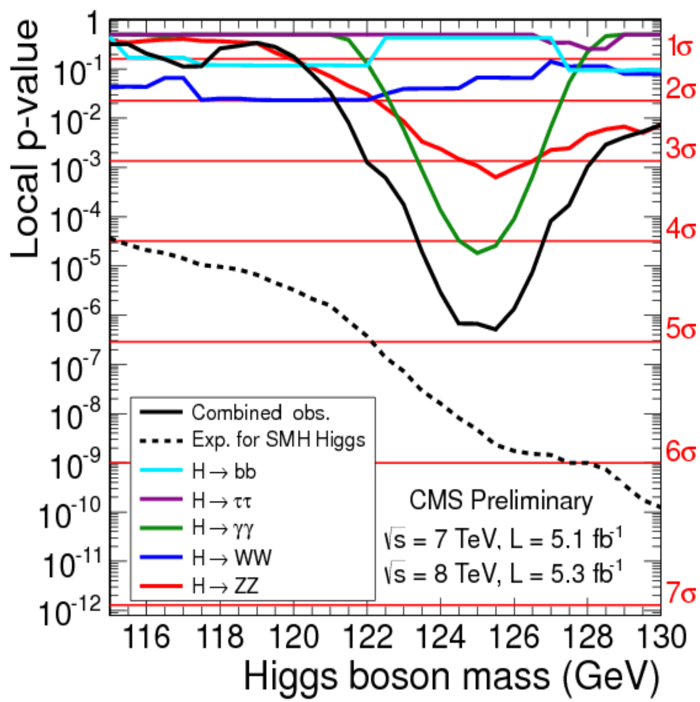
✔= full 8 TeV dataset analyzed, often full 7 TeV too.

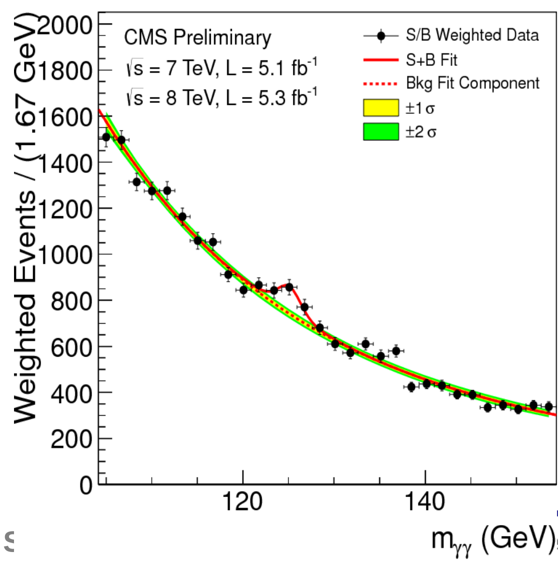
Higgs History: Discovery of New Boson

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 is observed**

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

σ/σ_{SM} = 0.87 ± 0.23

Higgs History: That’s it

Rencontres de Moriond

Navigation

- Homepage
- Purpose
- Accommodations
- Travel
- Registration
- Financial support
  - Application form
- Main dates
- Available equipment
- Tips & Hints

2014 sessions

- Electroweak Session

HEP 2013
Stockholm
18-24 July 2013
(info@eps-hep2013.eu)

Home | News | Preconference webpages | Scientific Program | Social Program | Proceedings | Photos & Participants | Press | Committees | Sponsors

The 2013 European Physical Society Conference on High Energy Physics

EPSHEP 2013 Stockholm, Sweden, 18-24 July, 2013

The 2013 Europhysics conference on High Energy Physics is a biennial conference organized by the I
Particle Physics Division of the European Physical Society since 1971. The conference attracted 70
all over the world.

Nobel Prizes and Laureates

Physics Prizes ▾ ‹ 2013 ›

▾ About the Nobel Prize in Physics 2013

- Summary
- Prize Announcement
- Press Release
- Advanced Information
- Popular Information
- Greetings

▸ François Englert
▸ Peter Higgs

All Nobel Prizes in Physics
All Nobel Prizes in 2013

The Nobel Prize in Physics 2013
François Englert, Peter Higgs

The Nobel Prize in Physics 2013

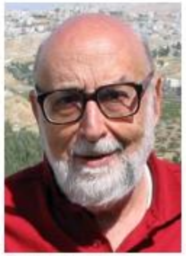


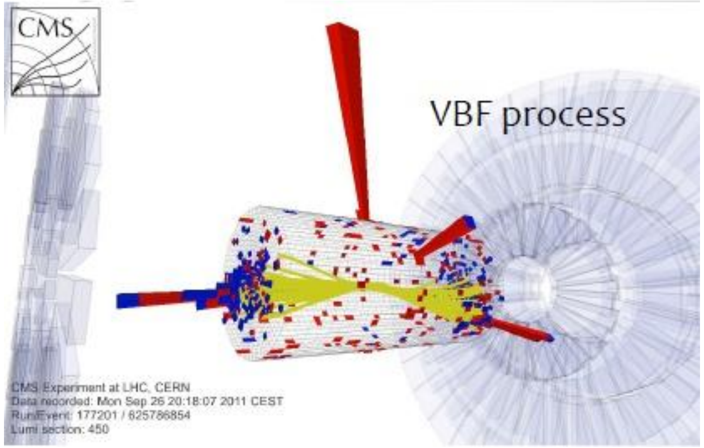
Photo: Pnicolet via Wikimedia Commons
François Englert

Photo: G-M Greuel via Wikimedia Commons
Peter W. Higgs

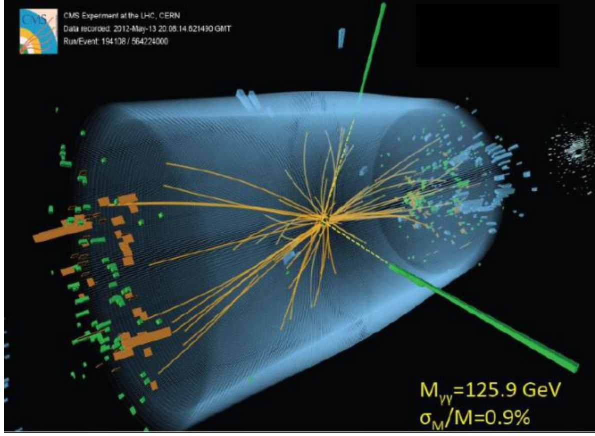
The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*

$H \rightarrow \gamma\gamma$

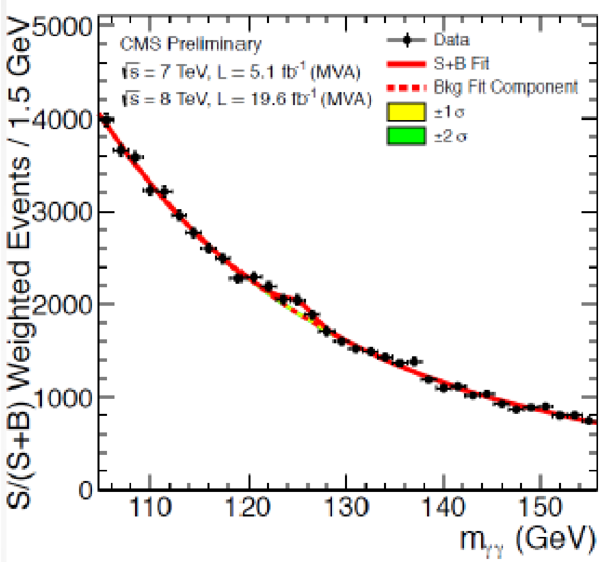
CMS-HIG-13-001

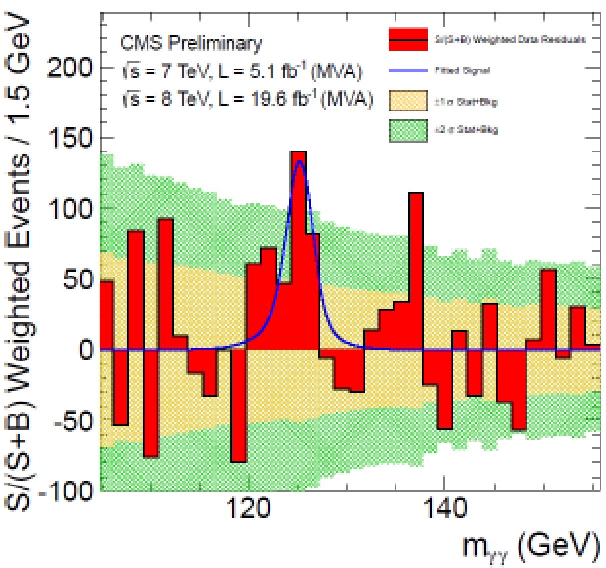


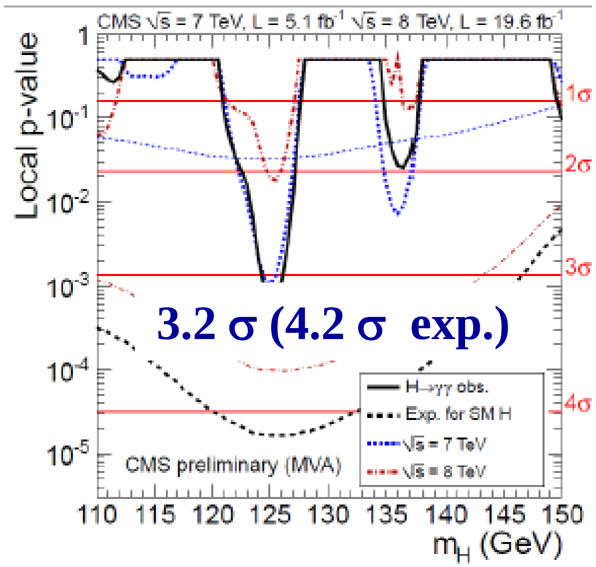
- **Narrow peak from 2 high energy isolated photons**
- **Excellent resolution: 1% in mγγ spectra**



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

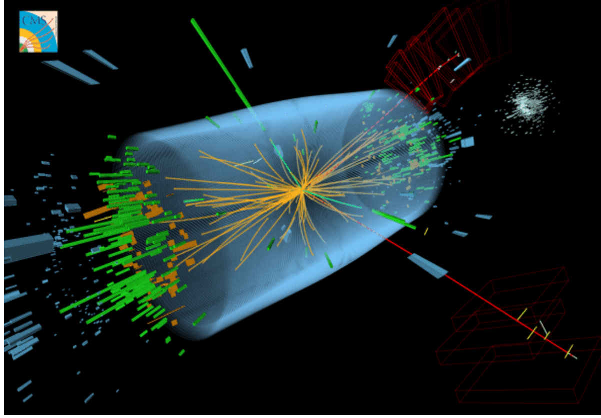


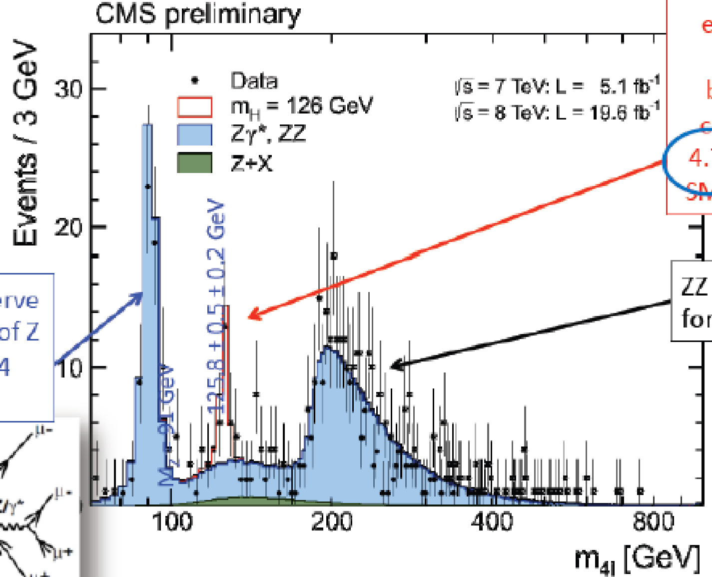




$H \to ZZ^* \to 4l$

CMS-HIG-13-002

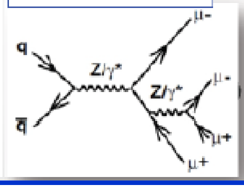




Cluster of events rising above the background consistent at 4.7σ level with SM Higgs signal

ZZ production for $M_{4l} > 2M_Z$

Clearly observe production of Z decay to 4 leptons

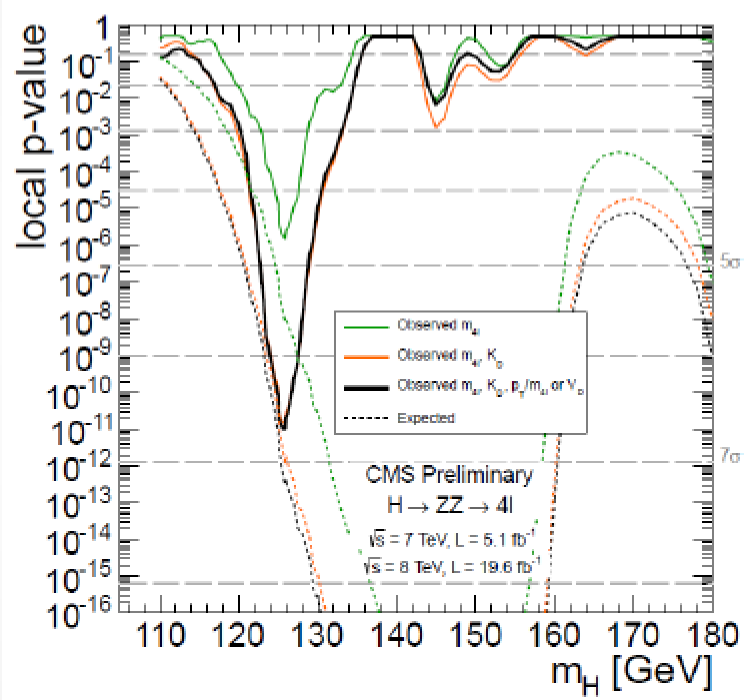


$BR(Z \to 4\ell) = 4.4^{+1.0}_{-0.8}(\text{stat}) \pm 0.2(\text{syst}) \times 10^{-6}$

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

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

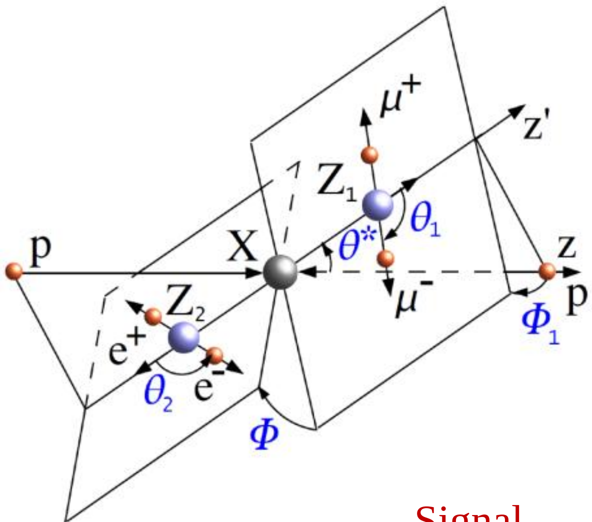
7.1 σ (6.7 σ exp.)



- **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)**

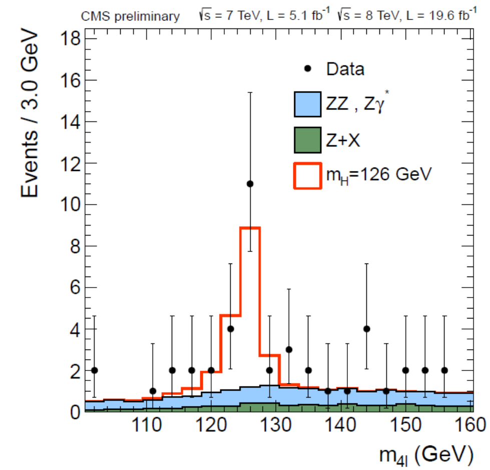
H → ZZ* → 4l (MELA)

CMS-HIG-13-002

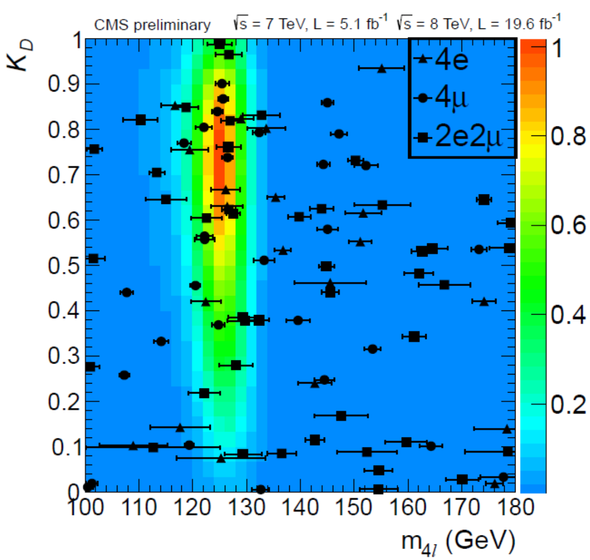


K_D (Kinematic Discriminator) is Matrix Element Likelihood Analysis: uses kinematic inputs for signal to background discrimination (m1, m2, Θ1, Θ2, Φ1, Φ2)

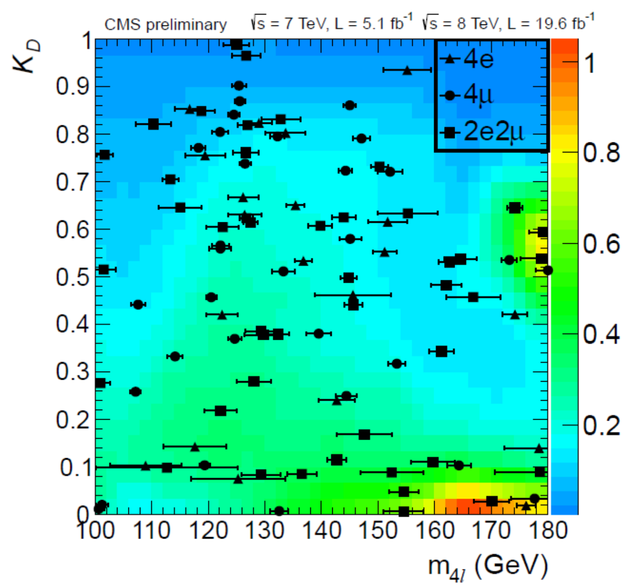
$$\mathrm{MELA} = \frac{P_{Sig}}{P_{Sig}+P_{bkg}}$$

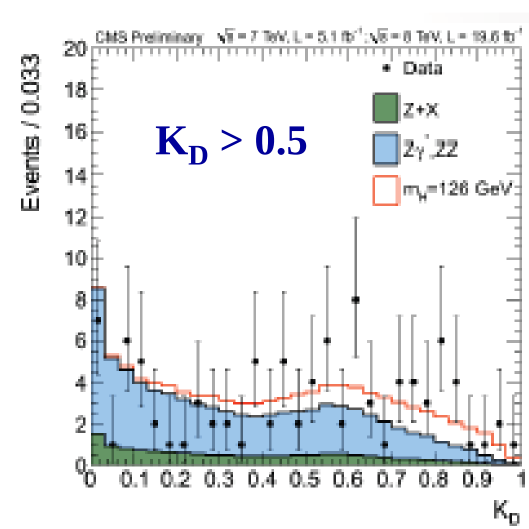


Signal



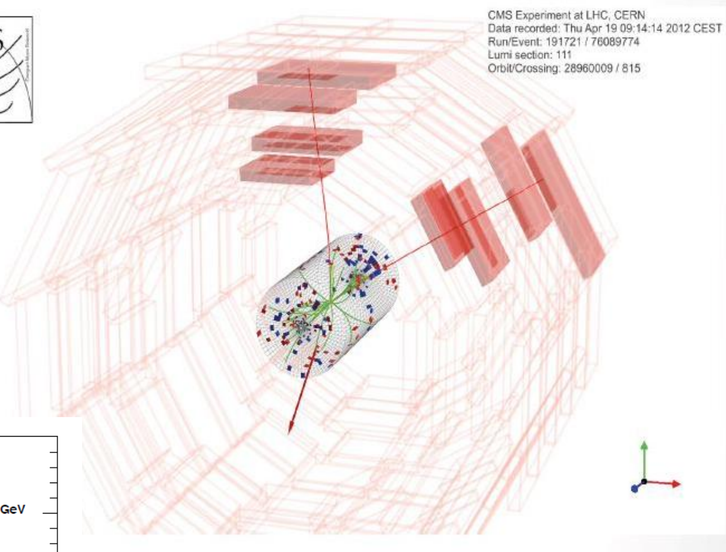
Background





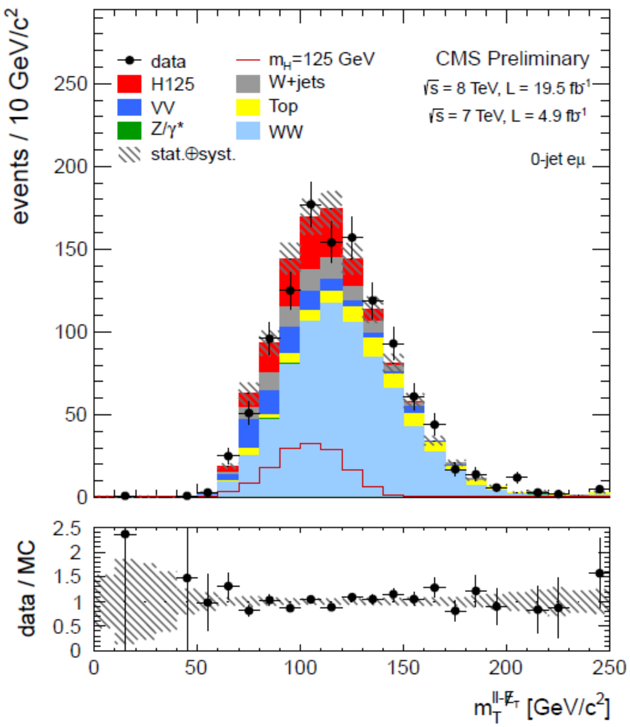
$H \rightarrow WW^*$

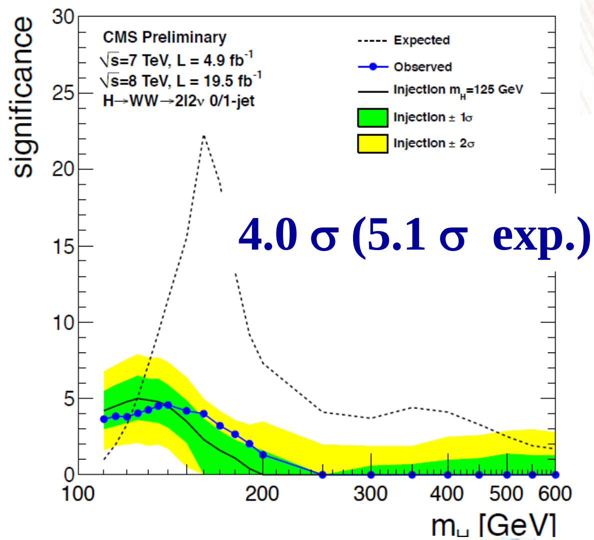
CMS-HIG-13-003



WW* signature

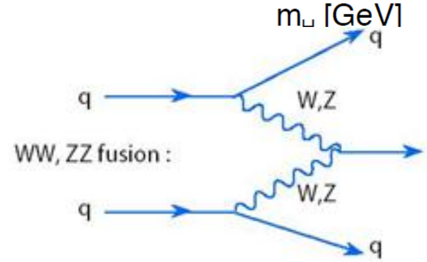
- 2 High pt isolated leptons
- Large momentum imbalance
- no mass peak reconstruction

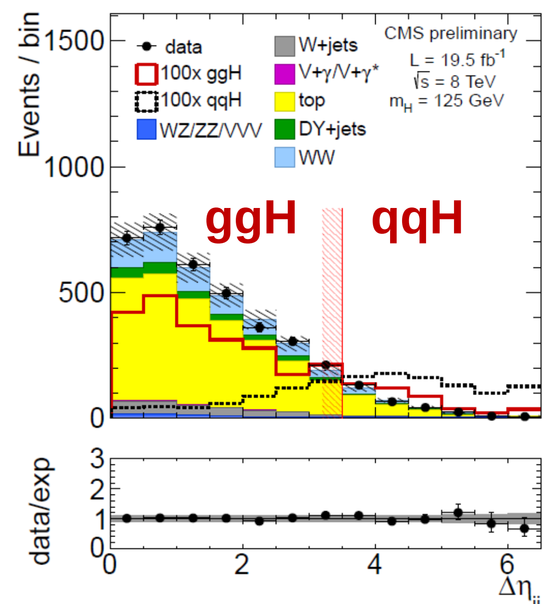




4.0 σ (5.1 σ exp.)

$\sigma/\sigma_{SM} = 0.76 \pm 0.21$





VBF signature

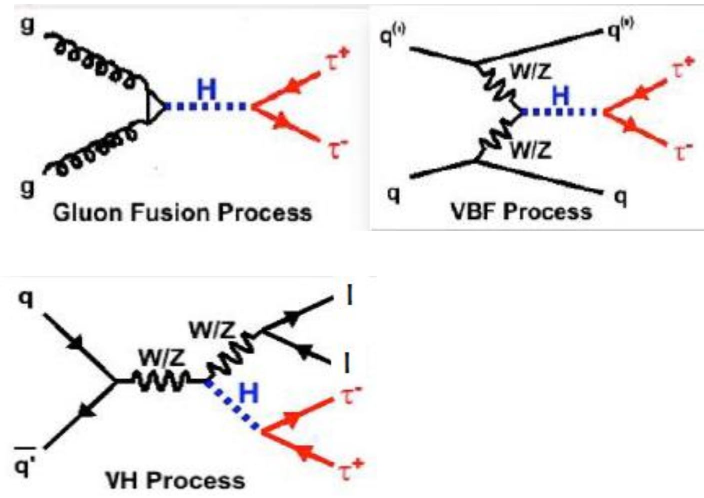
CMS-HIG-13-022

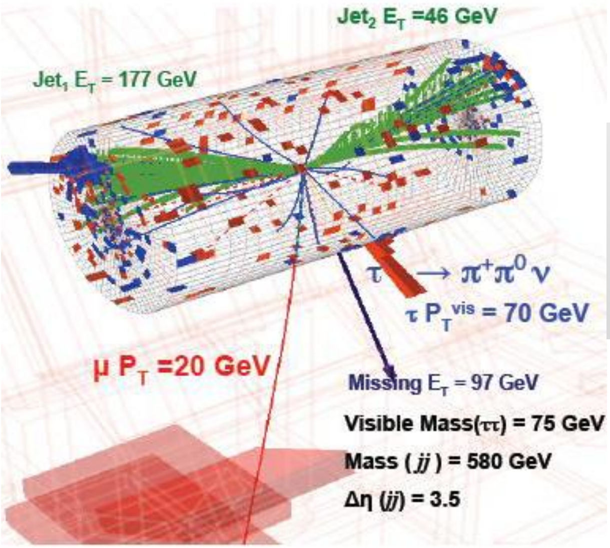
- 2 high-pT jets in forward directions + rapidity gap
- Large momentum imbalance

1.3 σ (2.1 σ exp.)

$H \to \tau\tau$ (coupling to fermions)

CMS-HIG-13-004



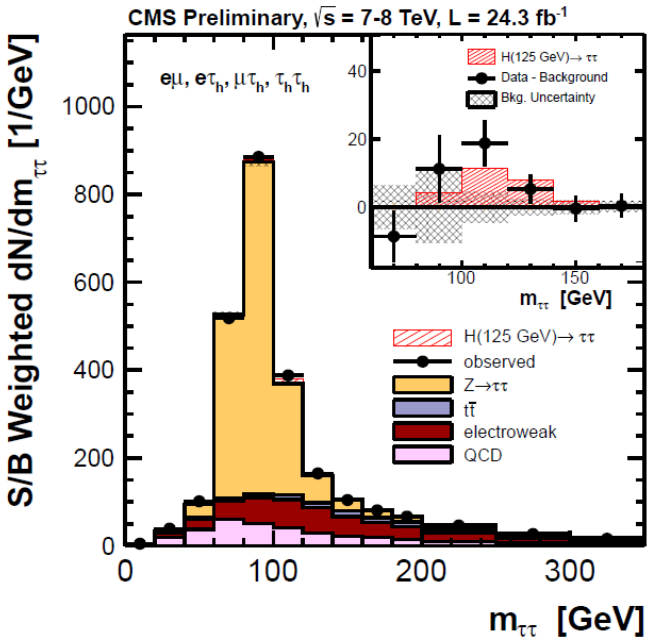


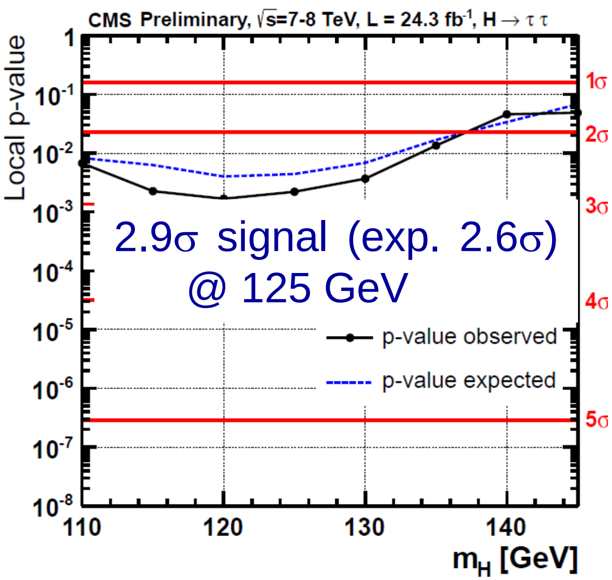
Number of jets categories

0 jets: only to constraint the background

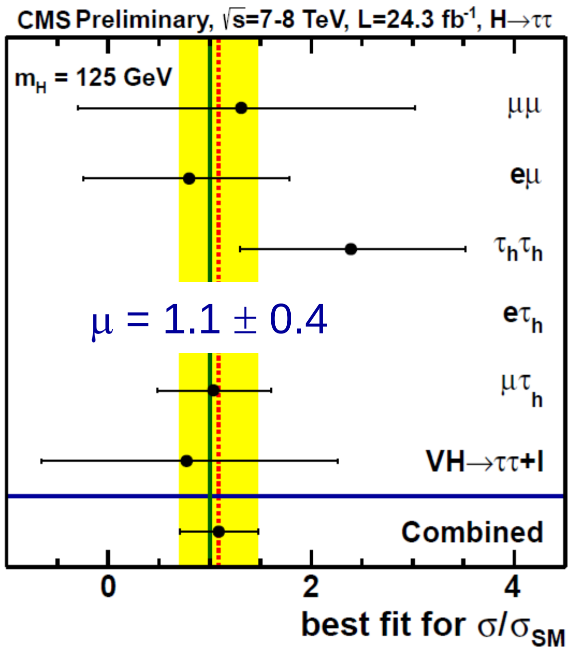
1 jet: low / high pT

2 jets : VBF process





2.9σ signal (exp. 2.6σ) @ 125 GeV



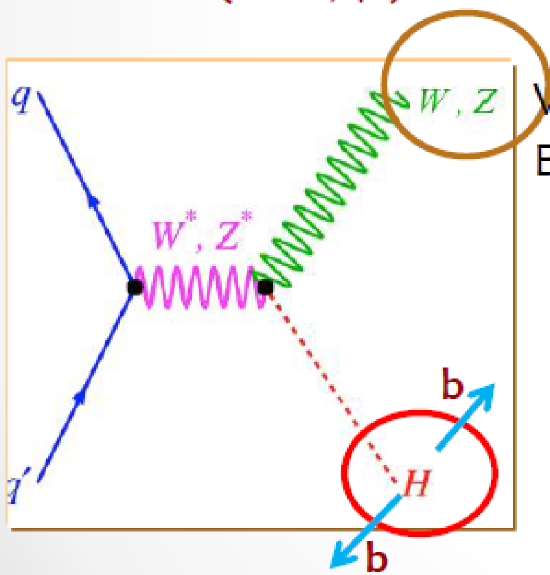
$\mu = 1.1 \pm 0.4$

H → bb (coupling to fermions)

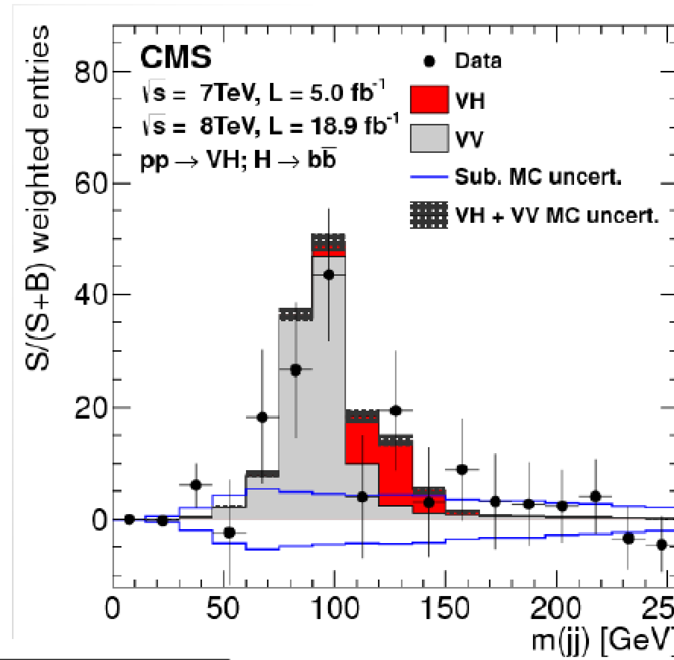
CMS-HIG-13-012

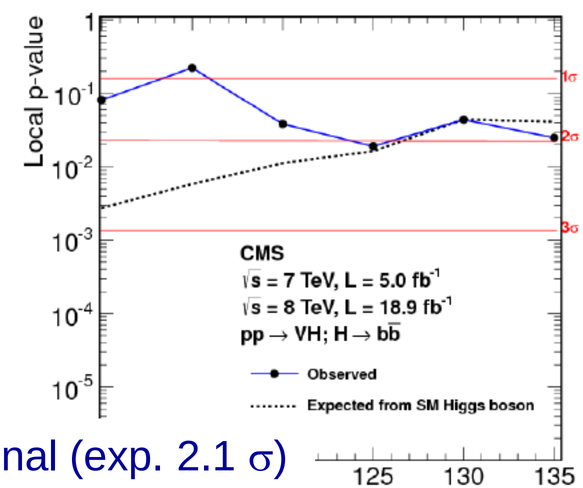
- If SM Higgs → bb has the highest BR
- But very high levels of backgrounds looking for b-pairs alone.
- Look for Associated Production with a Vector Boson (W,Z)

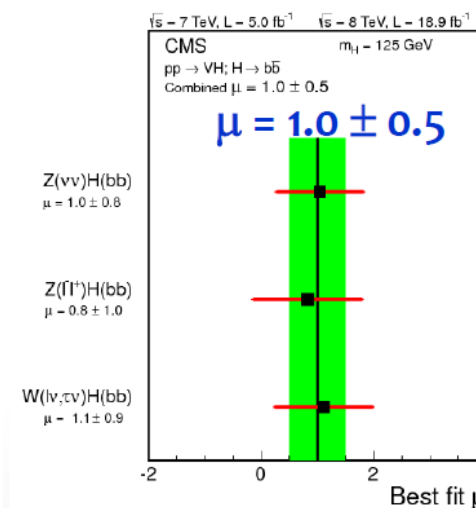
$Z \rightarrow ll\ (l = e, \mu, \nu)$
$W \rightarrow l\nu\ \ (l = e, \mu)$
5 different final states



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	Analyses: 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	$\gamma\gamma + (jj)_{\mathrm{VBF}}$ (two dijet classes for 8 TeV)	1 + 2	<1.5%	5.1	19.6	
	VH-tag	$\gamma\gamma + (\mathrm{e}, \mu, \mathrm{MET})$	3	<1.5%		19.6	
$\mathrm{ZZ} \to 4\ell$	$N_{\mathrm{jet}} < 2$	4e, 4μ, $2e2\mu$	3 + 3	1-2%	5.1	19.6	[64]
	$N_{\mathrm{jet}} \geq 2$		3 + 3				
$\mathrm{WW} \to \ell\nu\ell\nu$	0/1-jets	(DF or SF dileptons) × (0 or 1 jets)	4 + 4	20%	4.9	19.5	[65]
	VBF-tag	$\ell\nu\ell\nu + (jj)_{\mathrm{VBF}}$ (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	$(\mathrm{e}\tau_h, \mu\tau_h, \mathrm{e}\mu, \mu\mu) \times$ (low or high p_{T}^{τ})	16 + 16	15%	4.9	19.6	[68]
	1-jet	$\tau_h\tau_h$	1 + 1				
	VBF-tag	$(\mathrm{e}\tau_h, \mu\tau_h, \mathrm{e}\mu, \mu\mu, \tau_h\tau_h) + (jj)_{\mathrm{VBF}}$	5 + 5				
	ZH-tag	$(\mathrm{ee}, \mu\mu) \times (\tau_h\tau_h, \mathrm{e}\tau_h, \mu\tau_h, \mathrm{e}\mu)$	8 + 8		5.0	19.5	[69]
	WH-tag	$\tau_h\mu\mu, \tau_h\mathrm{e}\mu, \mathrm{e}\tau_h\tau_h, \mu\tau_h\tau_h$	4 + 4				
bb	VH-tag	$(\nu\nu$, ee, $\mu\mu$, eν, $\mu\nu$ with 2 b-jets$)\times$ (low or high $p_{\mathrm{T}}(\mathrm{V})$ 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

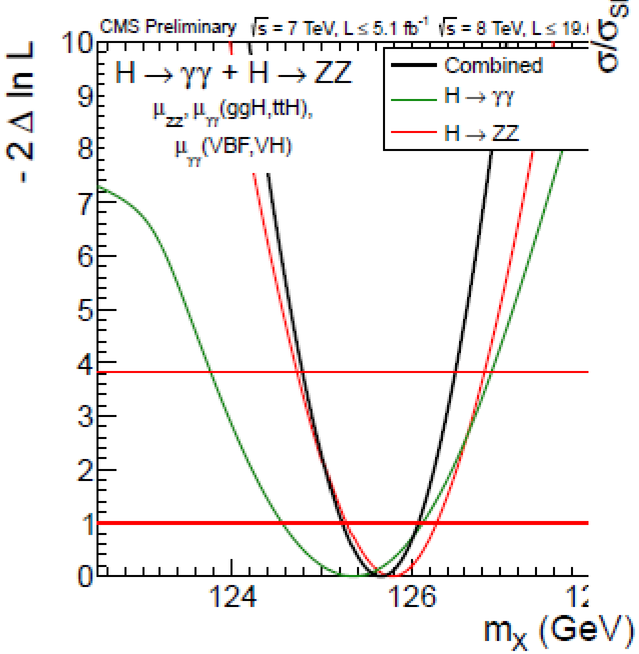
Higgs Properties: Mass and Signal Strength

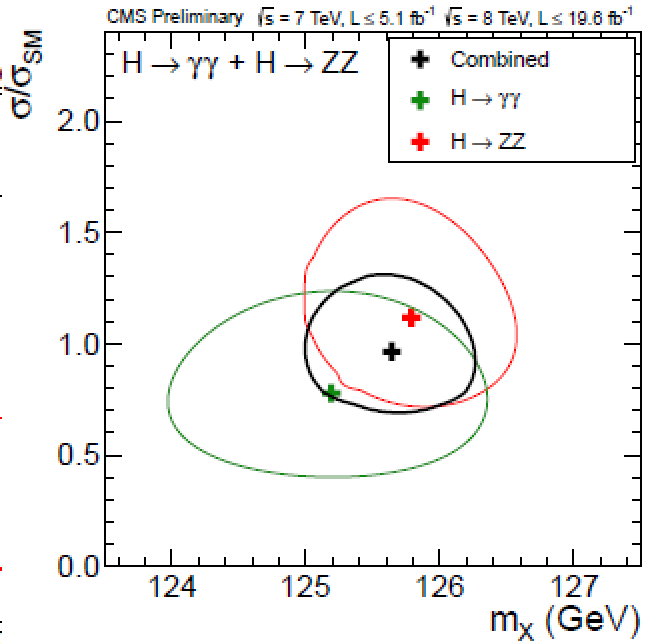
CMS-HIG-13-005

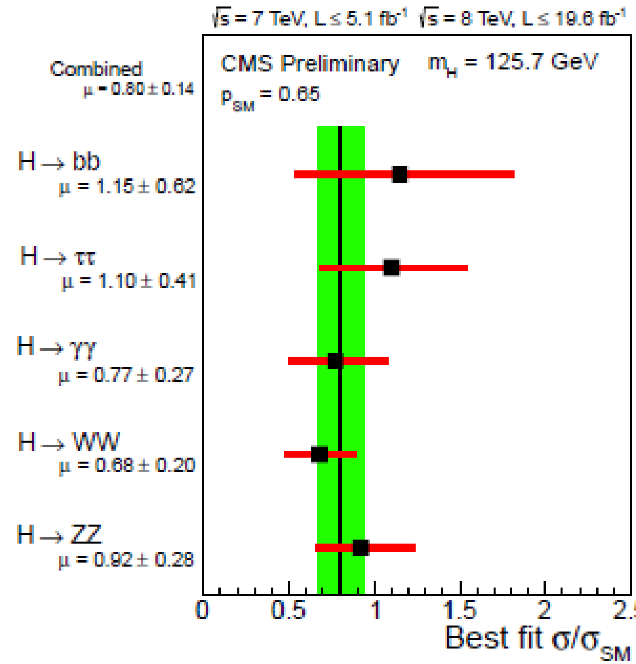
To measure the mass the ZZ → 2l and γγ channels that have excellent mass resolution have been used…

…and 5 channels for the signal strength

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







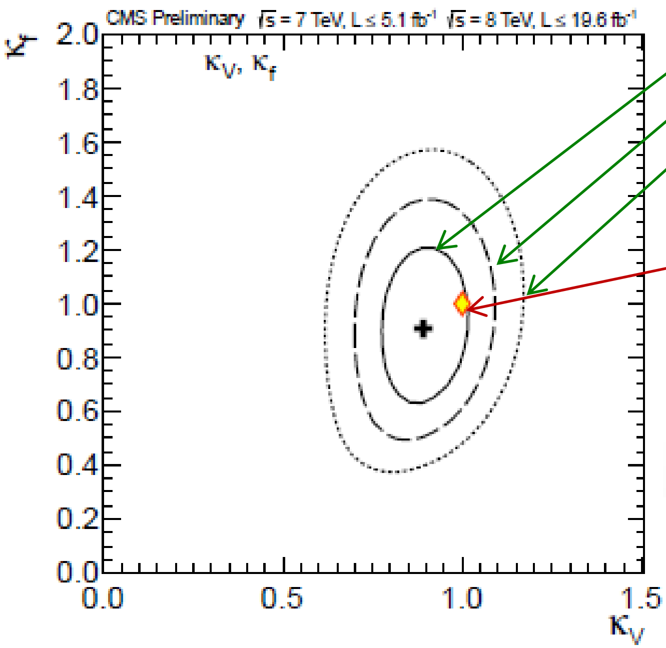
γγ	125.4±0.5±0.6 GeV
ZZ→4l	125.8±0.5±0.2 GeV
comb.	125.7±0.3±0.3 GeV = 127 ±0.4 GeV

μ = 0.80 ± 0.14 @ m_H=125.7 GeV

Compatible with SM!

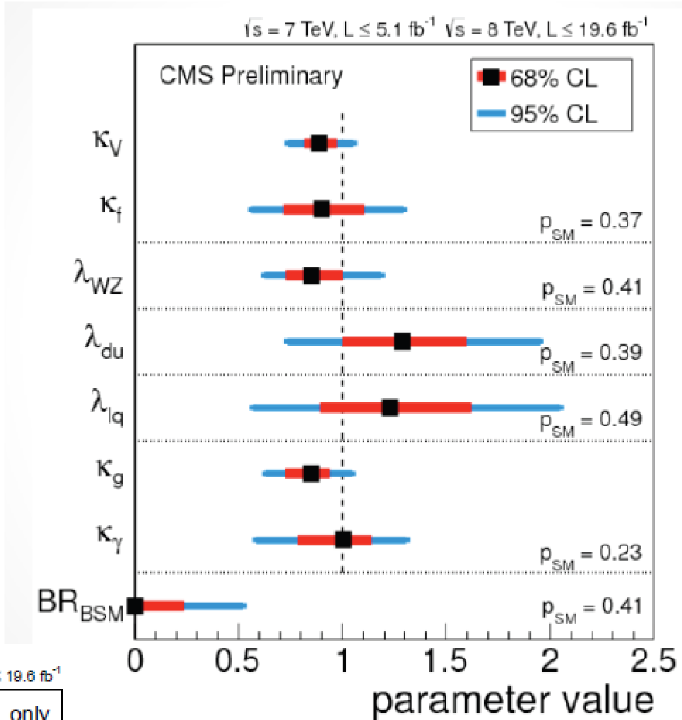
Higgs Properties: Couplings

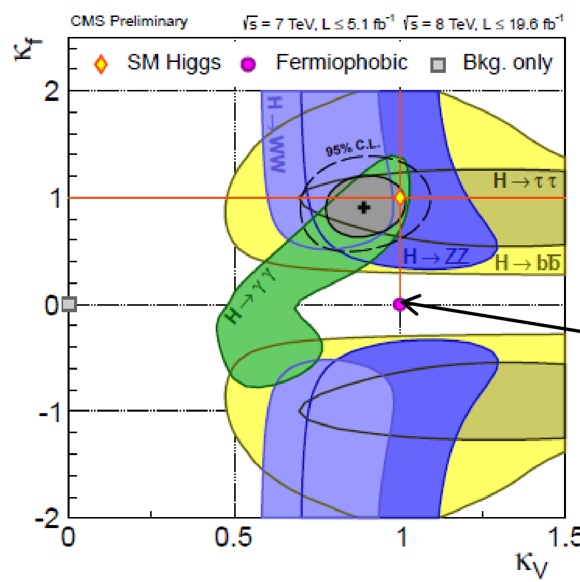
CMS-HIG-13-005



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

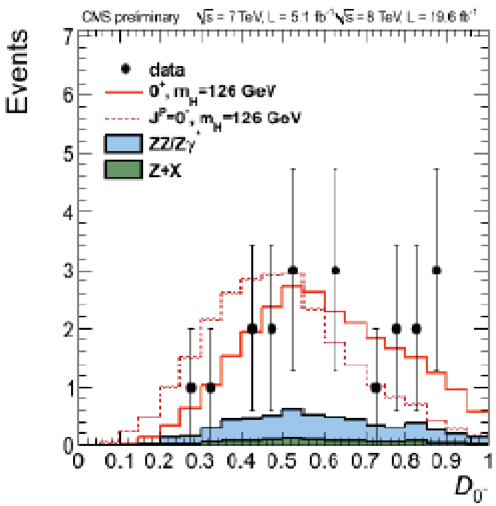
- Spin 0 is required if SM Higgs
- Spin 1 is excluded by $H\to\gamma\gamma$ decay (Landau-Yang theorem)
- Spin 2 induced by KK-graviton couplings

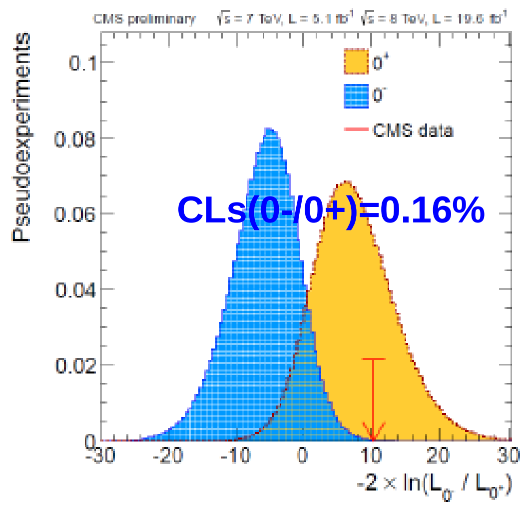
Parity:

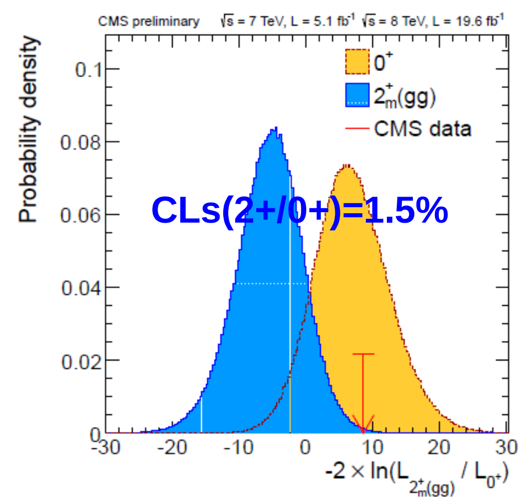
- SM CP-even Higgs
- BSM CP-odd HIggs

$ZZ \to 2l$

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%

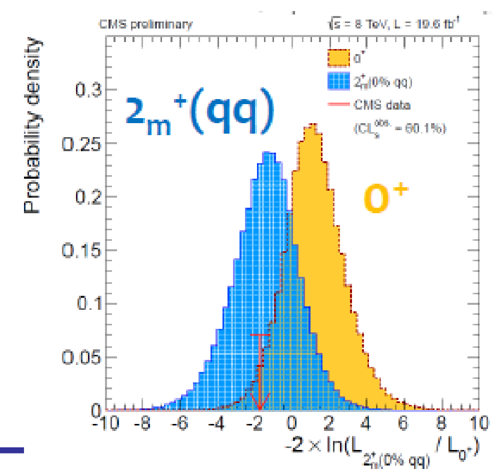
$\gamma\gamma$

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

CMS-HIG-13-016

Compatibility results from Spin-Parity analysis

Source	χ^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



$WW^*\to l\nu l\nu$

CLs(2+/0+)=14%

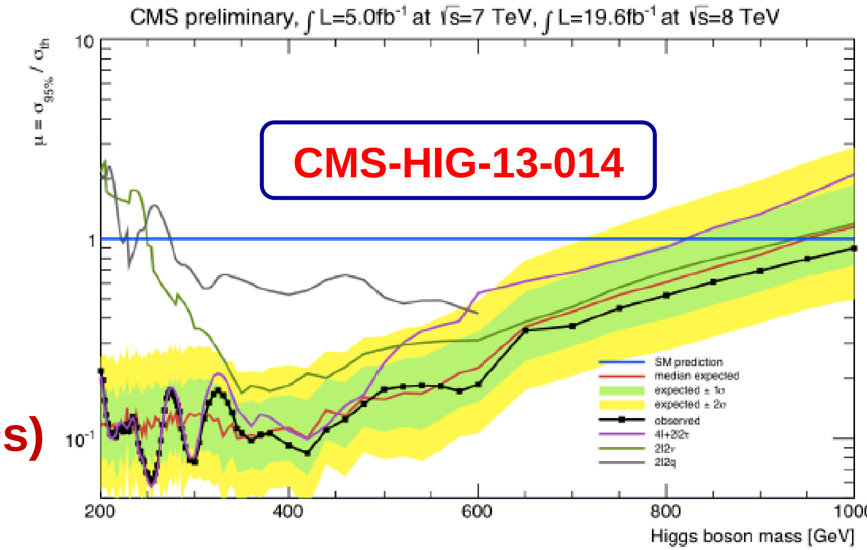
Other Higgs Channels

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

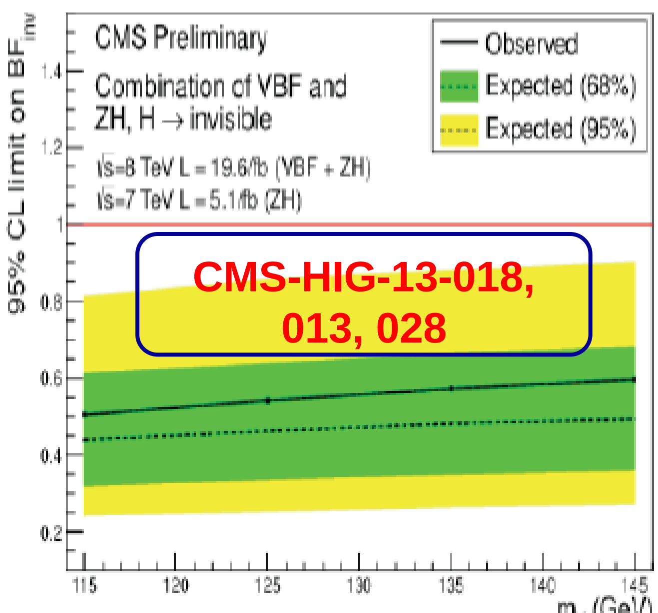
95% CL limits on SM Higgs set

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.)

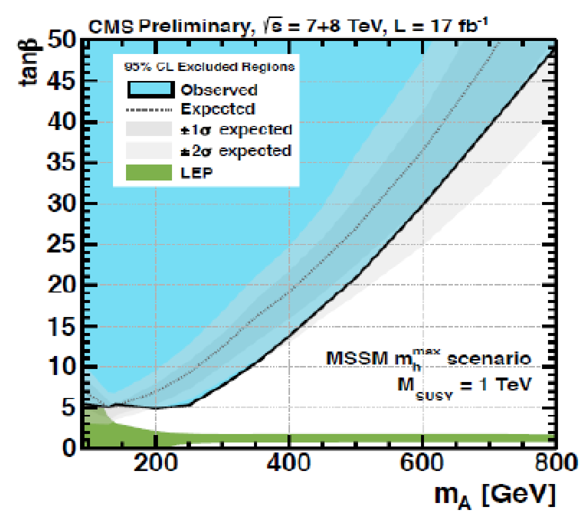
Search for Higgs → μμ (MSSM)

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

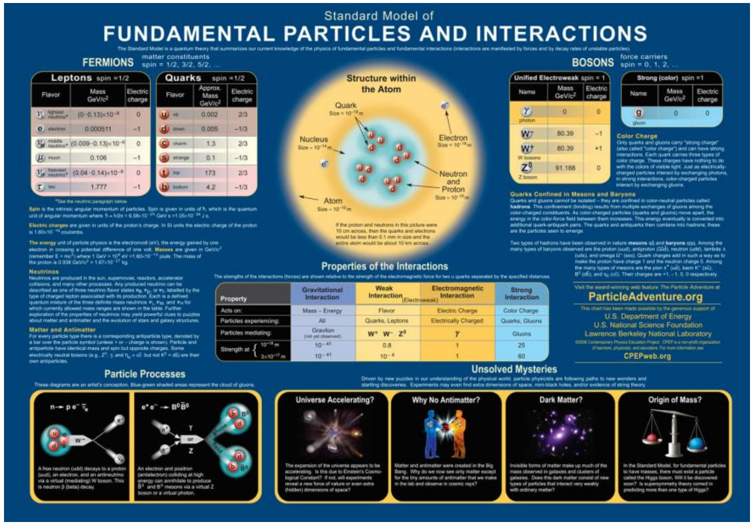
Recent data: ~4xSM sensitivity on strength μ

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

talk by
A. Proskuryakov

CMS B Physics and Quarkonia Physics Public Physics Results

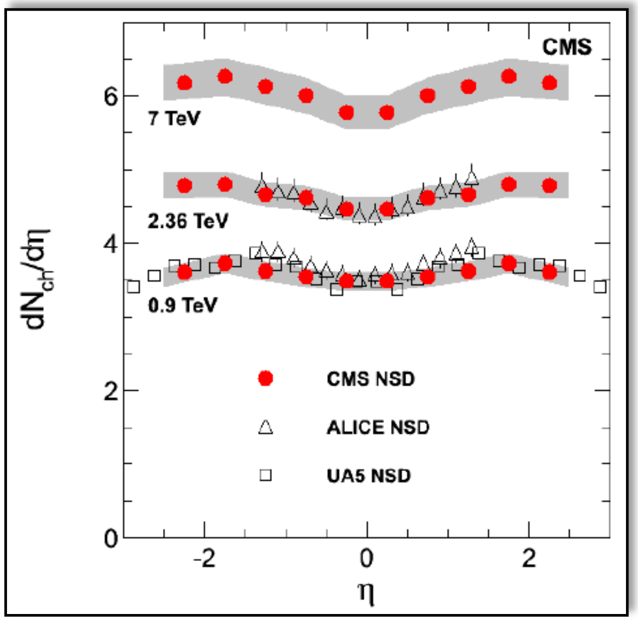
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH

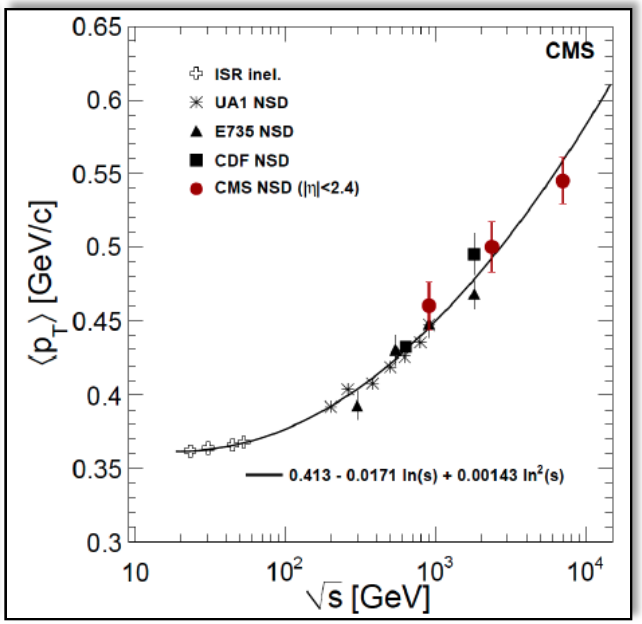
CMS Top Physics Public Physics Results

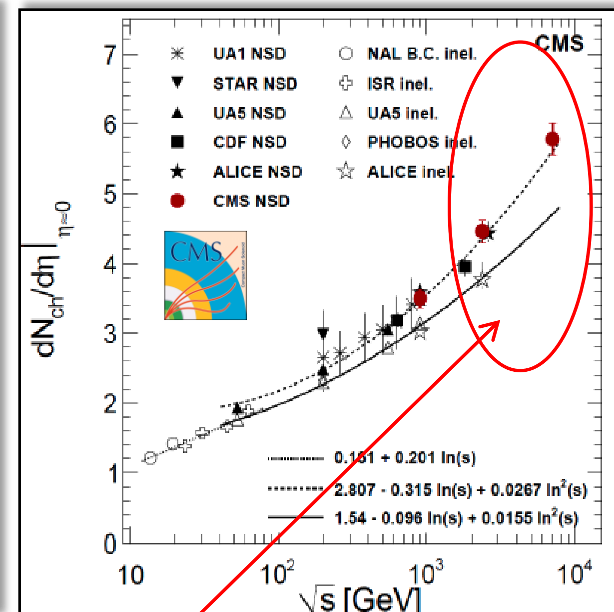
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

Charged Particle

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





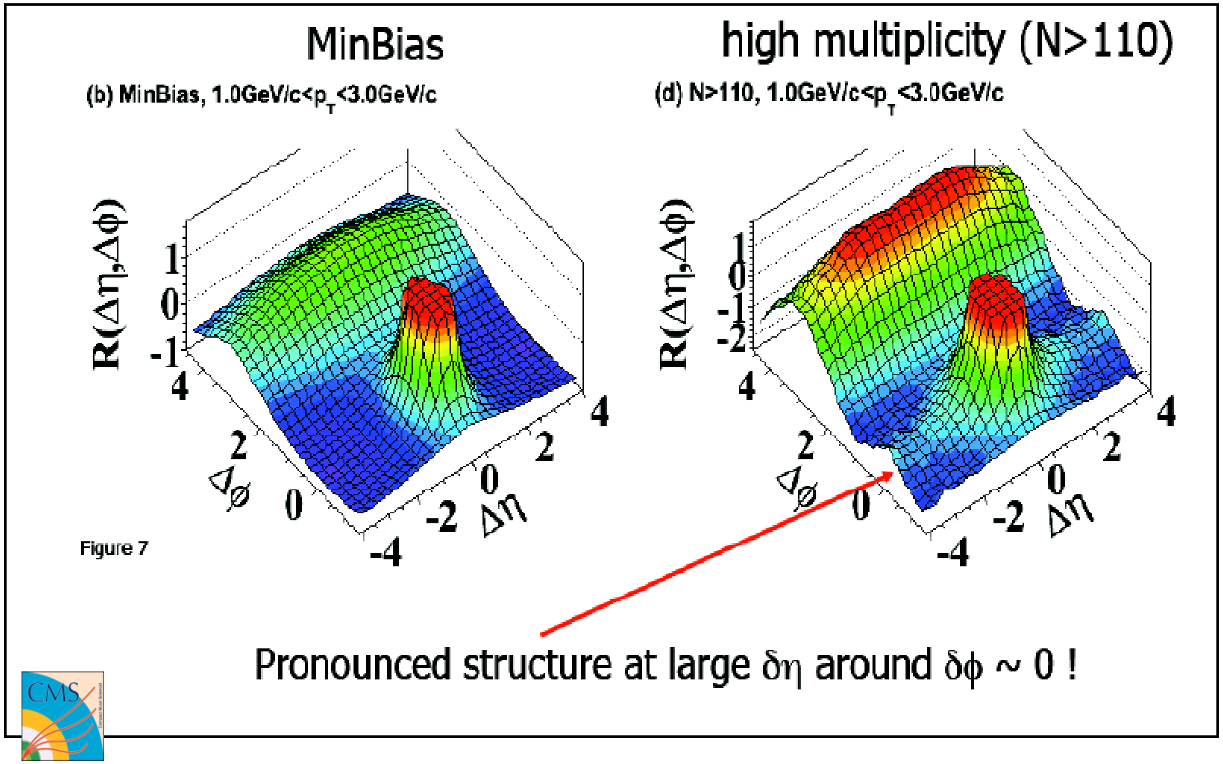


Particle density grows with energy (from 0.9 to 7 TeV) faster than it is expected.

MC fine tunning

Particle Correlations: ridge-effect

JHEP 1009 (2010) 091



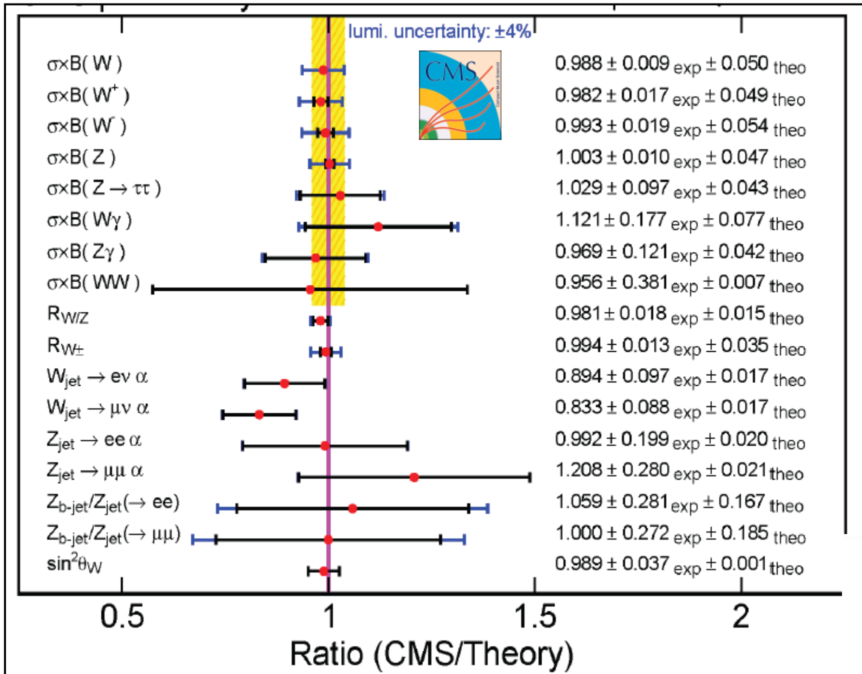
Study the correlation between two charged particles in the angles φ (transverse): Δφ and θ (longitudinal): Δθ

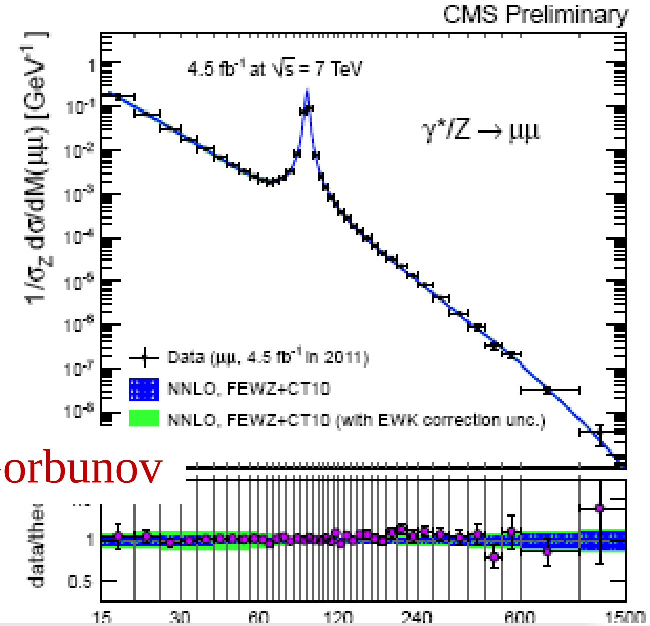
A new phenomenon in the 'stronge force'?

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

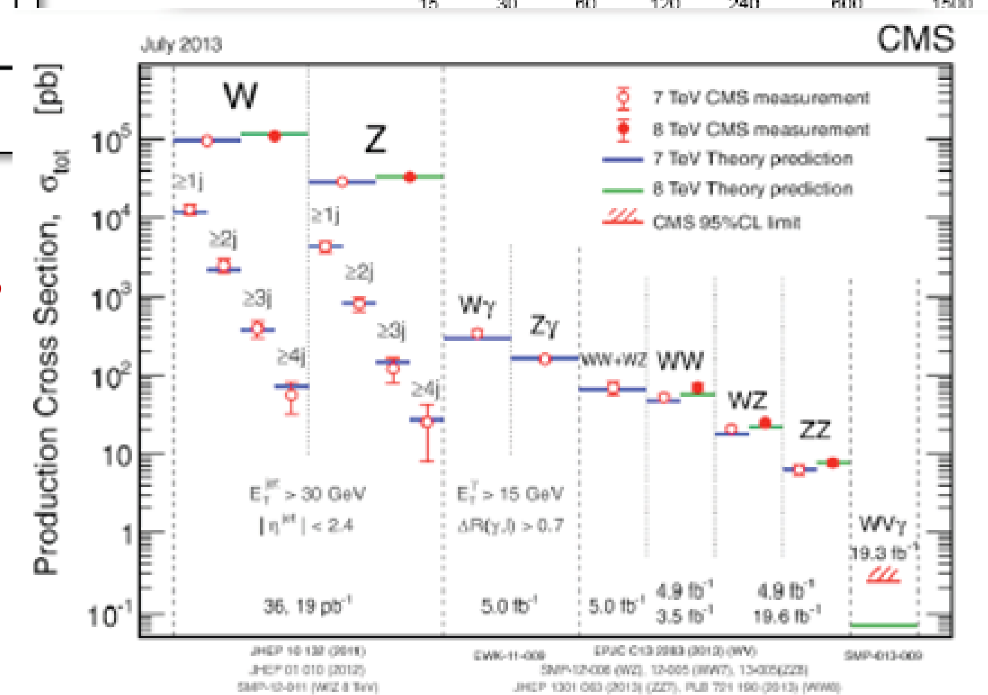
That particles in some pairs at large Δη are receding from each other at close to the speed of light, but are oriented along the same φ angle – as if the particles were somehow associated together when they were created at the point of collision

EWK Measurements





talk by I.Gorbunov



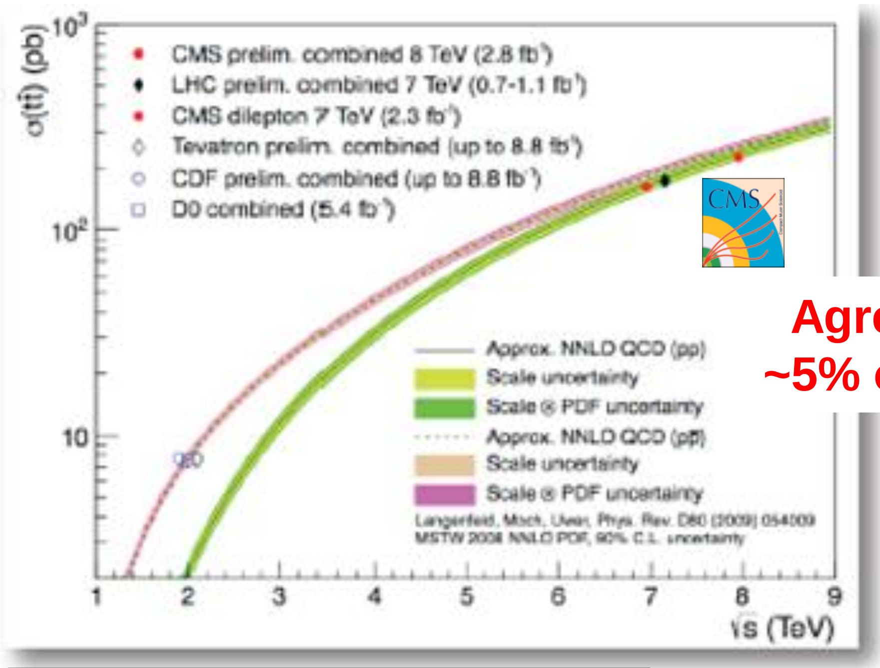
Good understanding of the detectors and accurate theory predictions

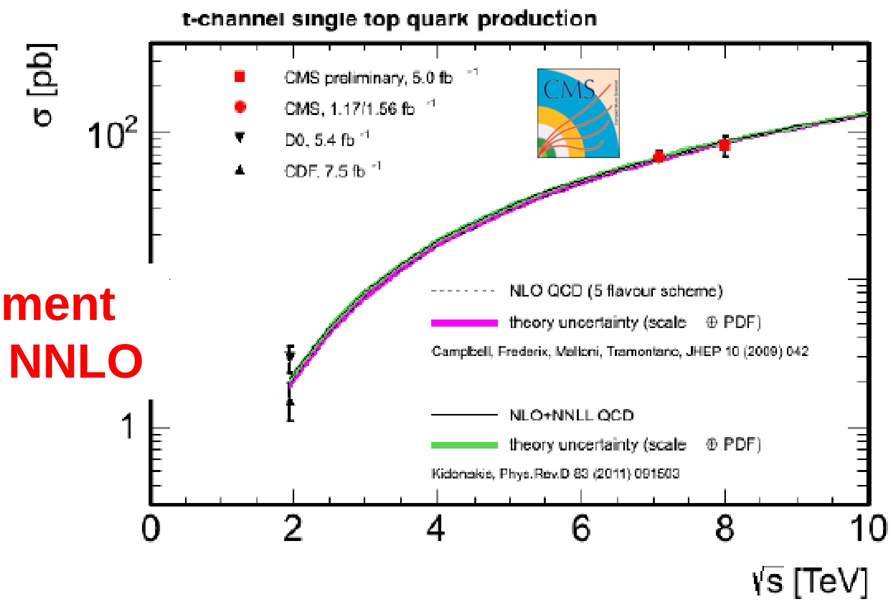
- ✓ **precise measurements of SM processes**
- ✓ **background to Higgs and BSM analyses**

LHC is t-Factory

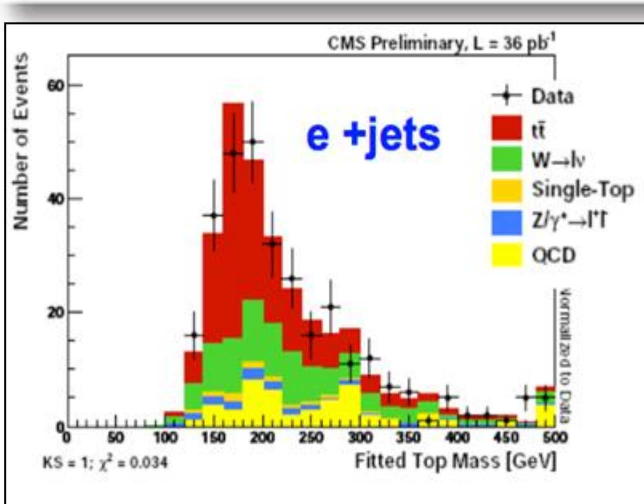
for details see talk by N. Tsirova

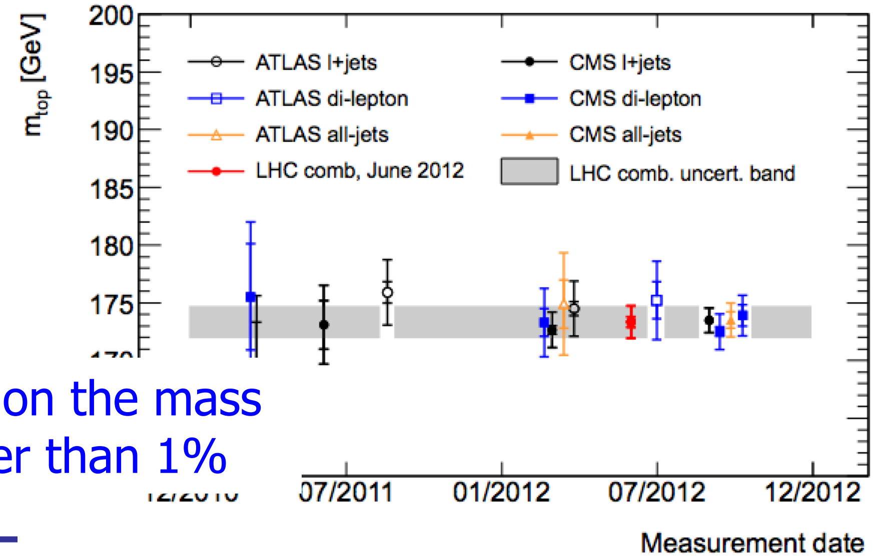
Single production





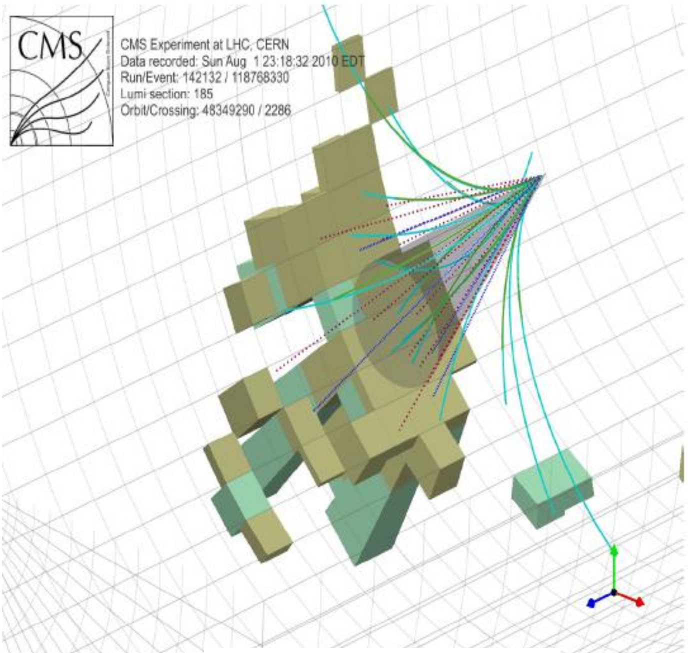
Agreement ~5% of NNLO

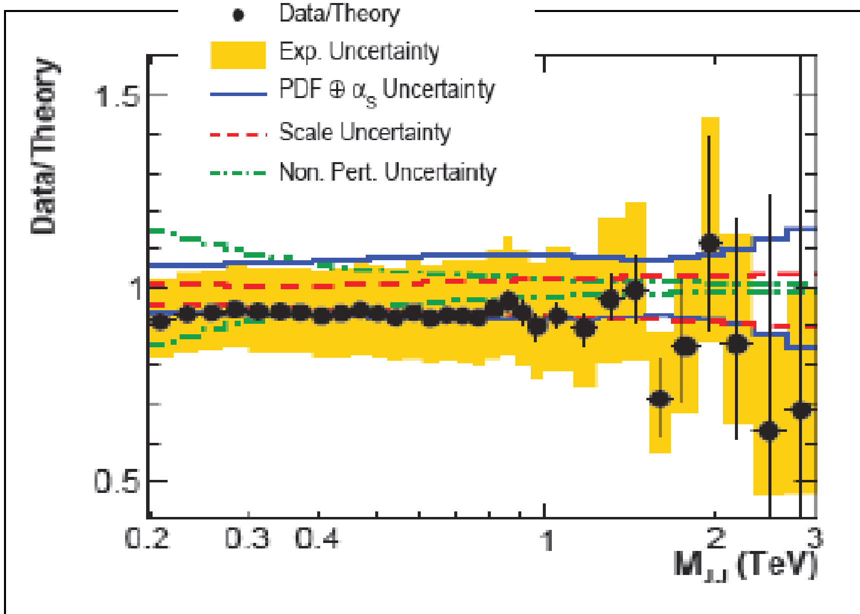




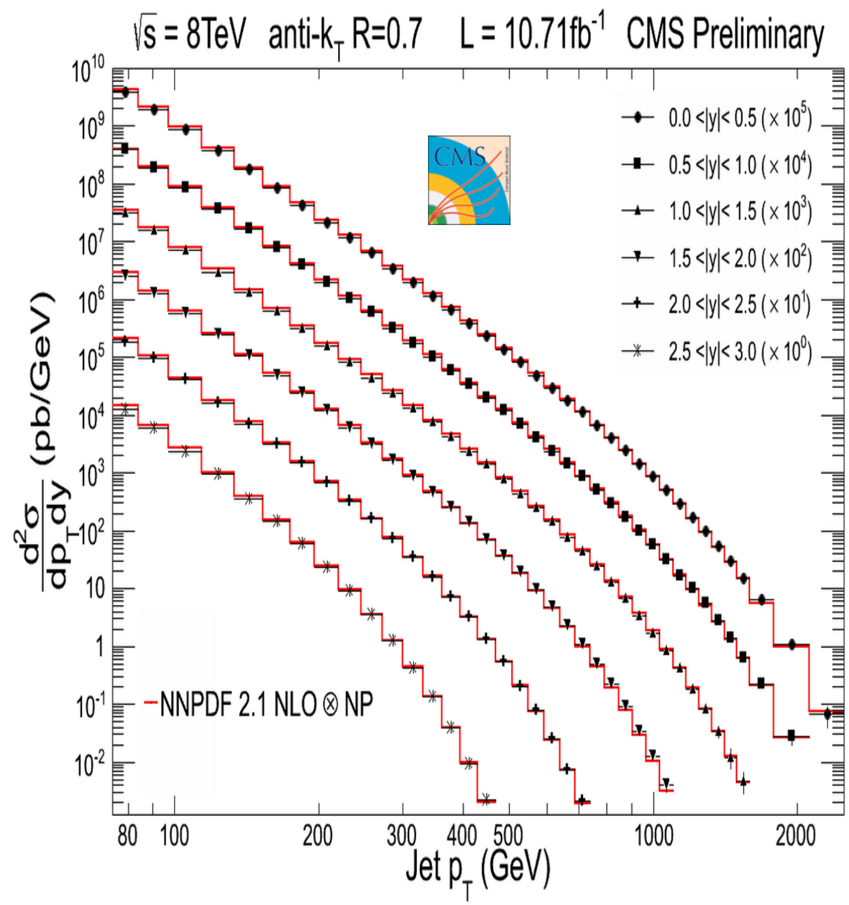
Precision on the mass now better than 1%

Jet Physics



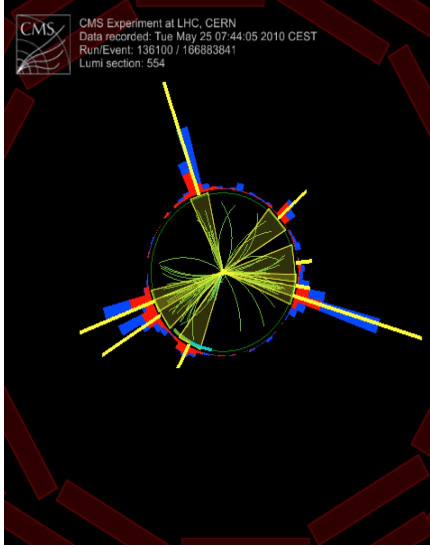


CMS-PAS-SMP-12-012



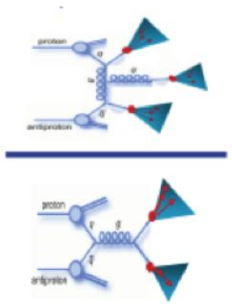
The results are in a good agreement with NLO calculations up to 2 TeV jets

Multijet Events



3-jet to 2-jet Cross Section Ratios

Mjj = 420 - 1390 GeV,
p_T > 150 GeV

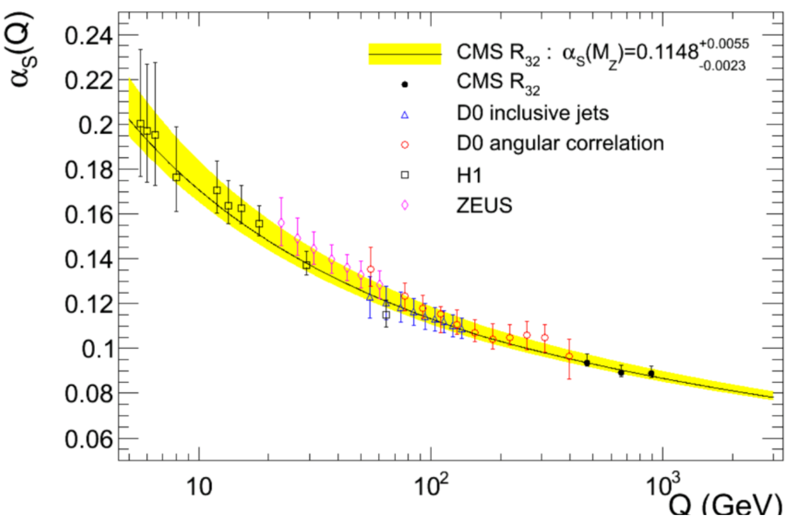


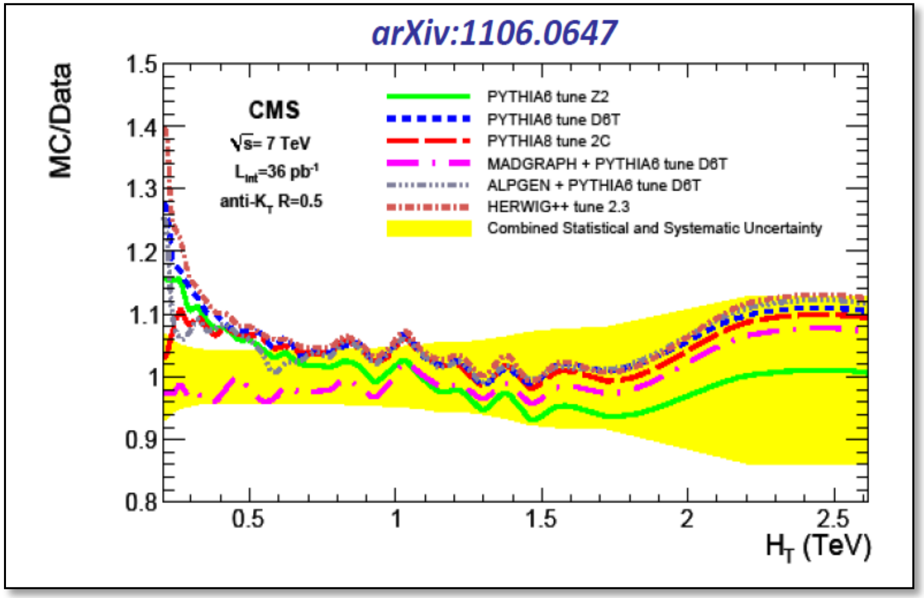
$\Leftrightarrow \alpha_s$

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

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

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





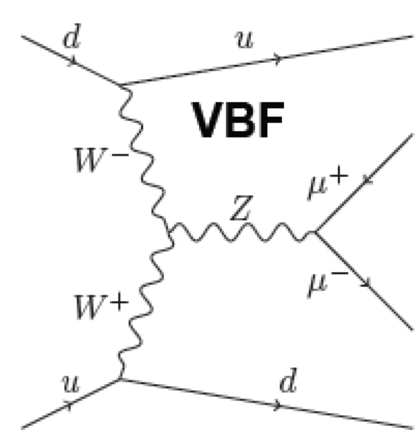
Good agreement with SM for H_T of 0.5 up to 3 TeV

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

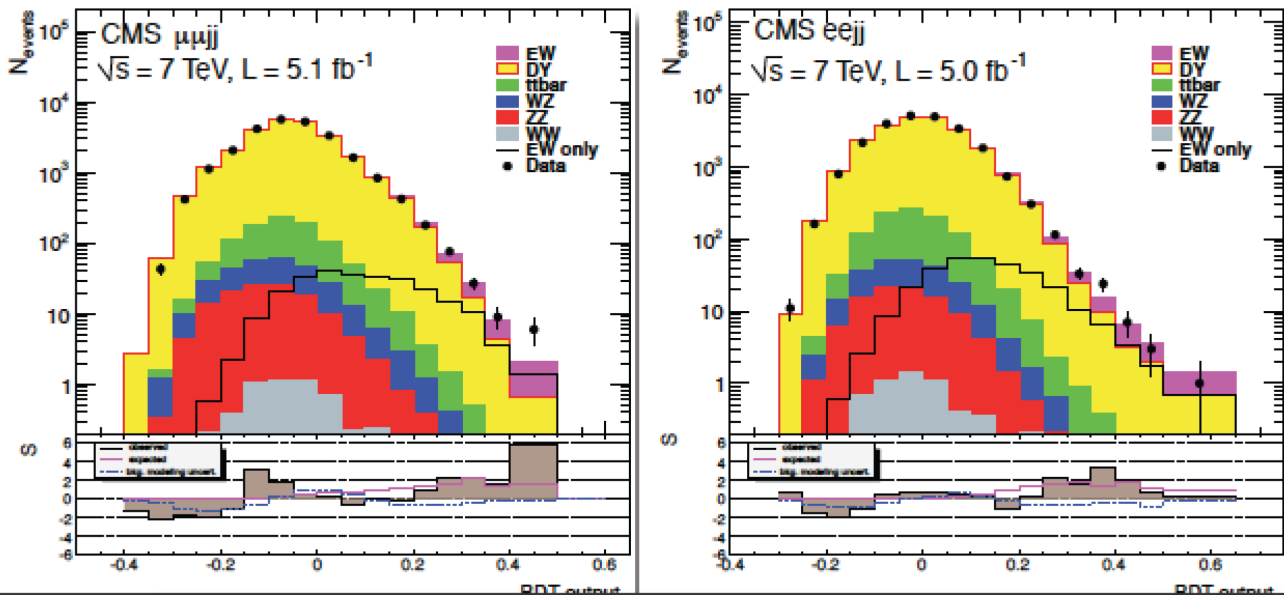
arXiv:1304.7498

Evidence for EWK VBF Process

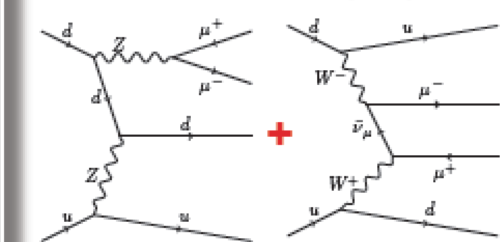
- Evidence for a VBF Z boson production – a crucial measurement for the Higgs VBF studies (paper to be submitted)
  - Thought to be very hard due to dominant channel background
- Require large rapidity gap between the tag jets and use advanced multivariate techniques (BDT) to extract signal
- See ~3σ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



Negative interference with:



Multiperipheral



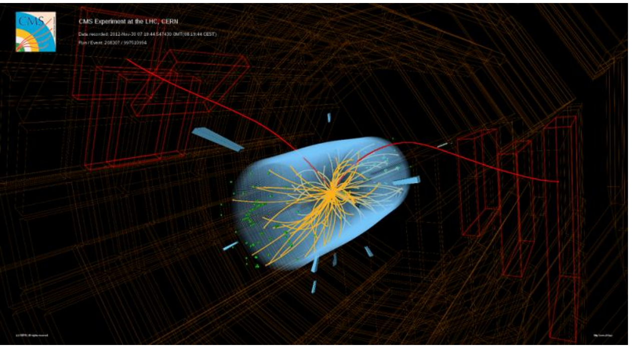
Bremsstrahlung

CMS Collaboration arXiv:1305.7389

from A. De Roeck's talk

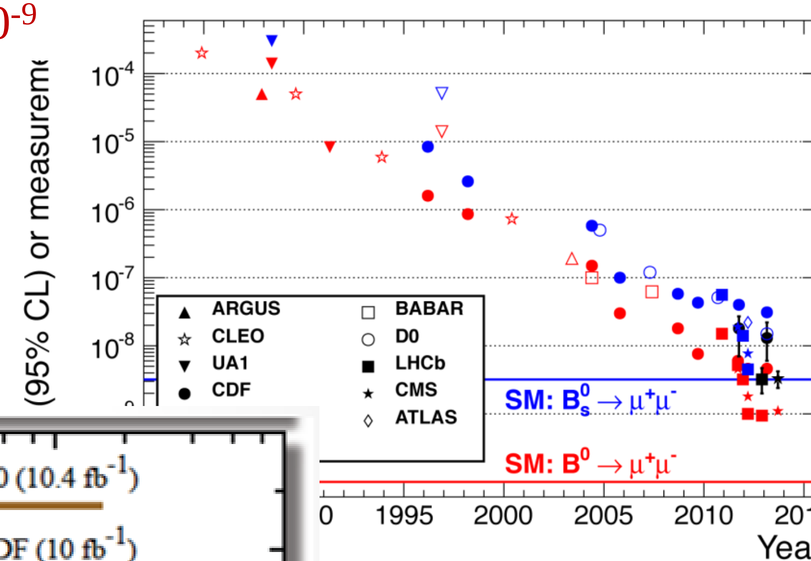
$B_s \to \mu\mu$

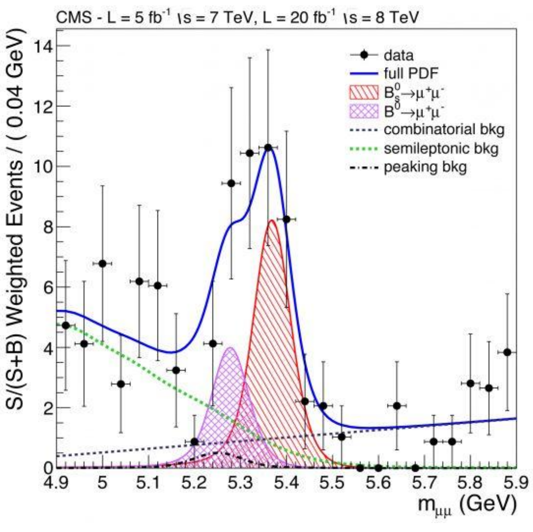
PRL 111 (2013) 101804

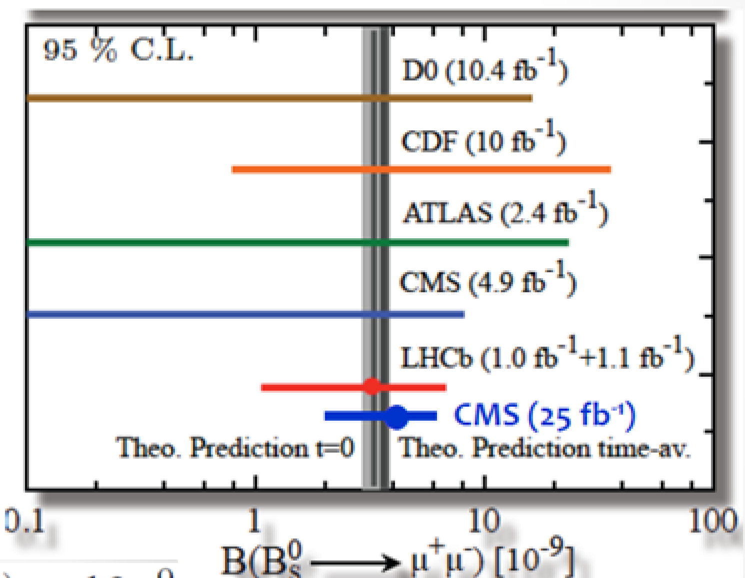


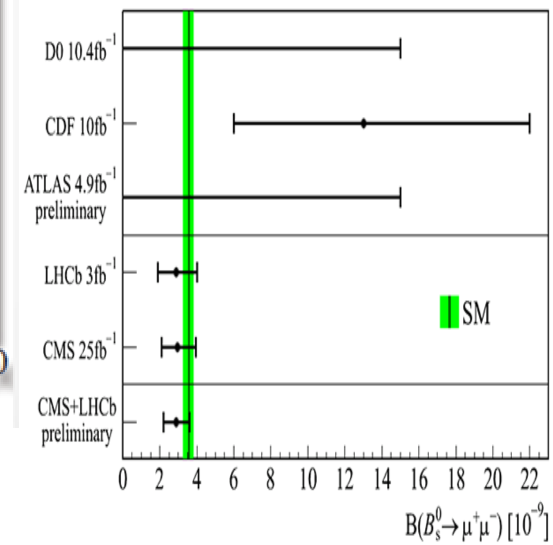
Quest for many year to find a signal BSM

SM: 3.56±0.30)×10^{-9}









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

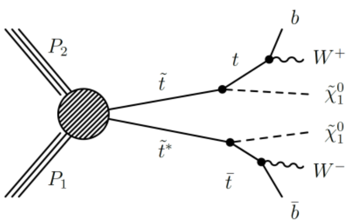
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.1 \times 10^{-9}$$

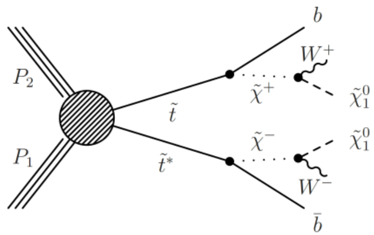
Highlights of Supersymmetry

CMS Supersymmetry Public Physics Results

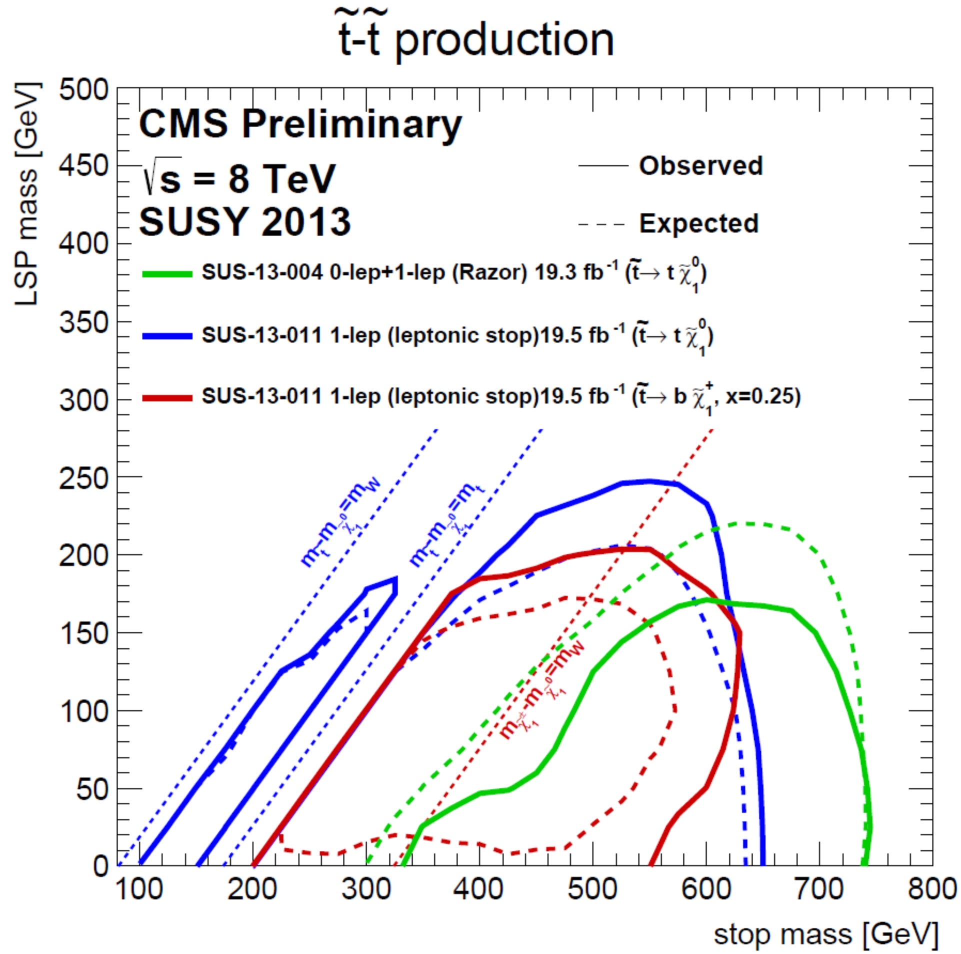
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

Stop Searches





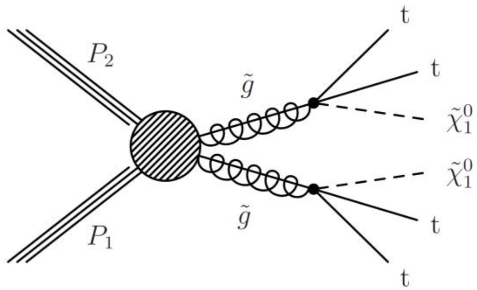
SUS-13-011, SUS-13-004

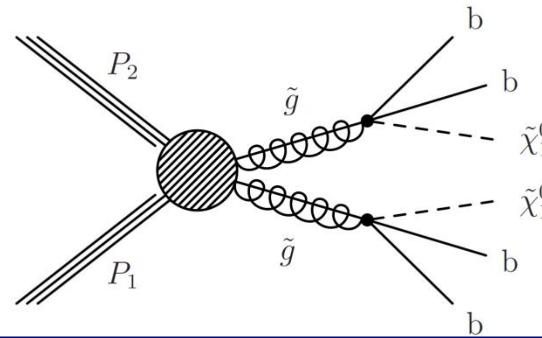


The combinations of stop and neutralino masses inside the contours are excluded by the experimental results.

The red contour assumes that the stop decays to a top quark and a neutralino, the blue contour assumes that the stop decays to a bottom quark and a chargino.

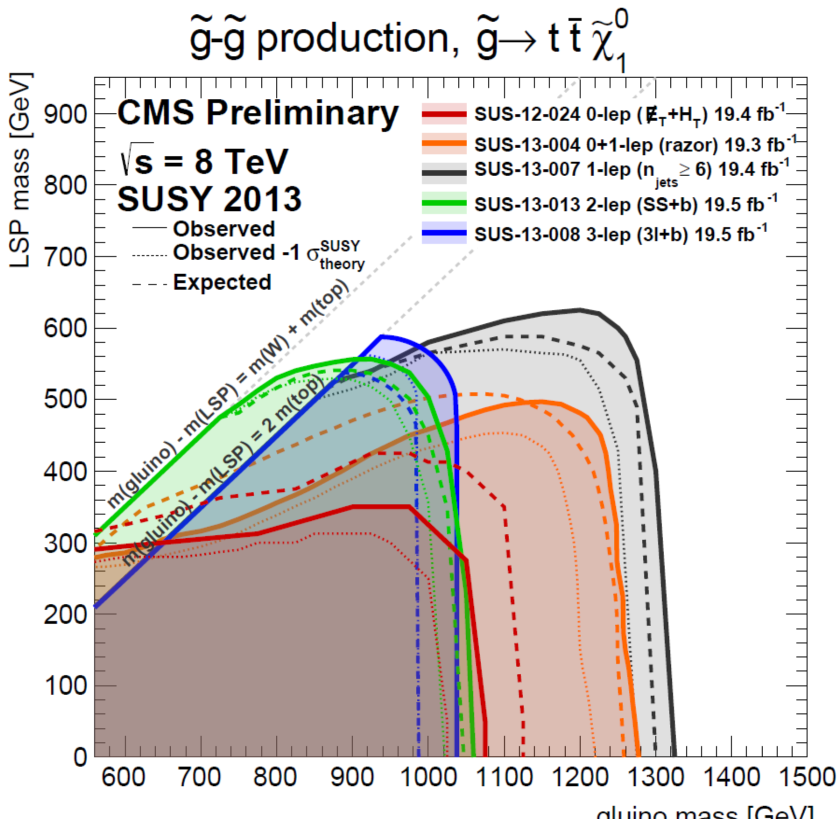
Gluino Searches

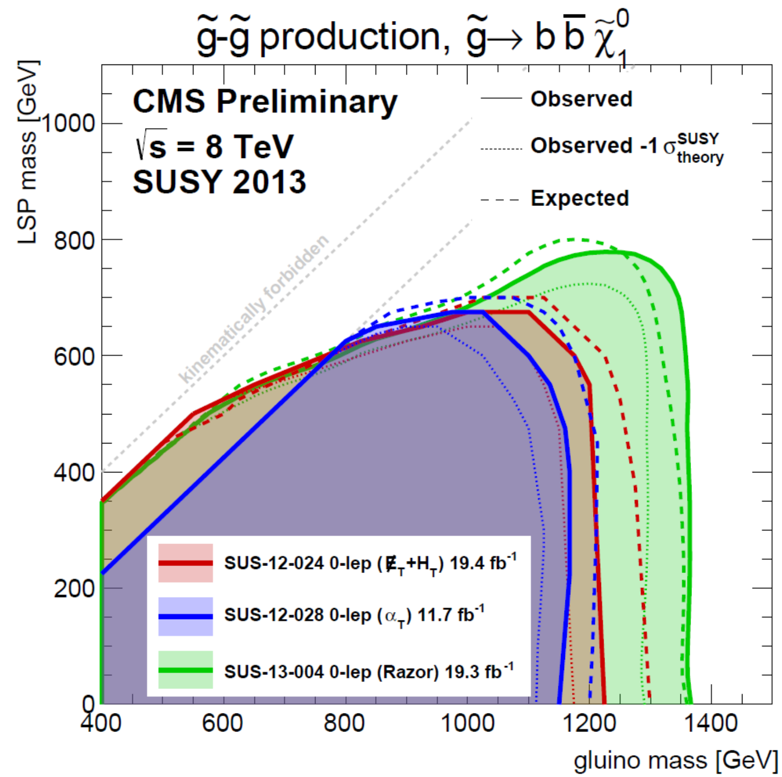




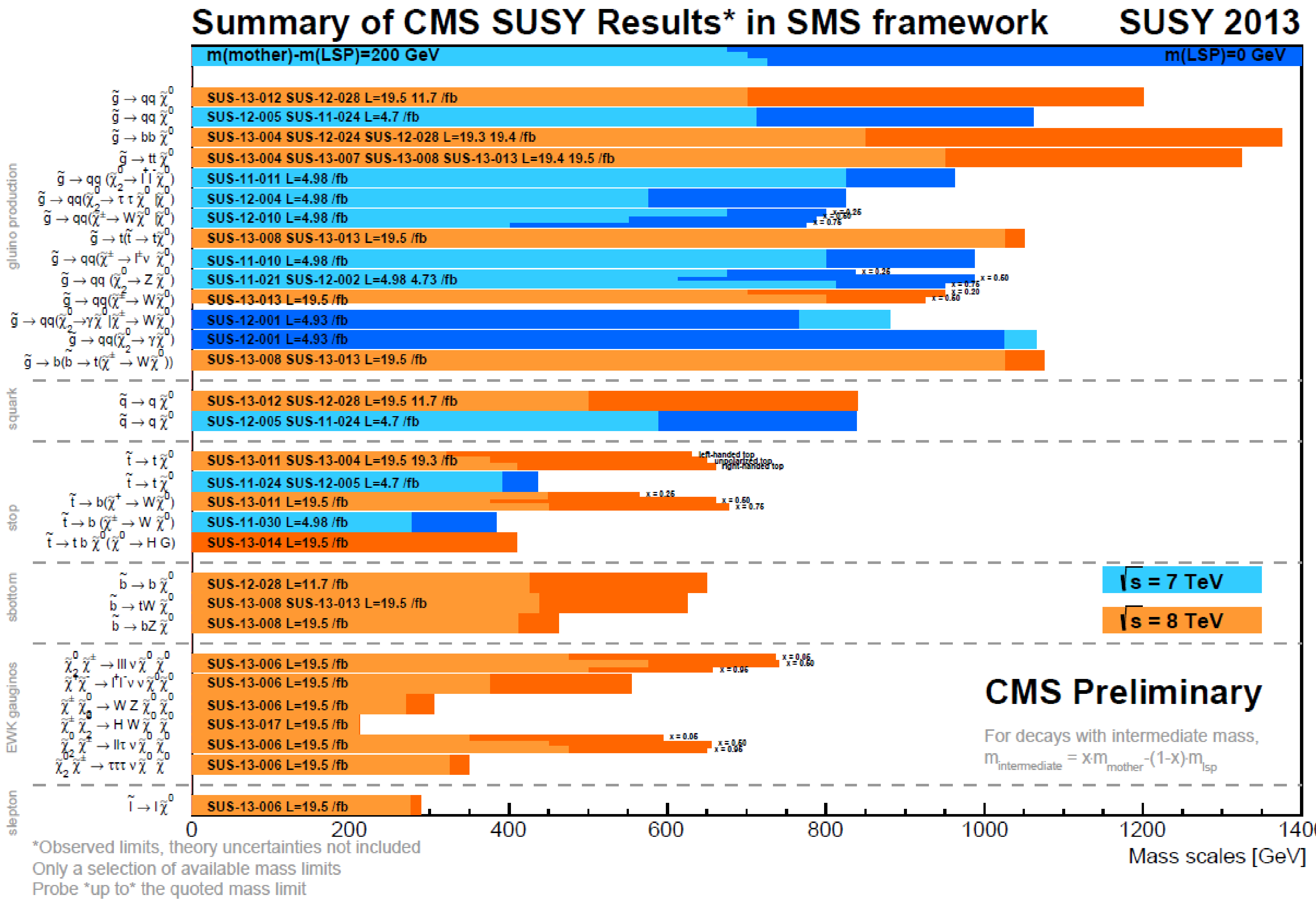
SUS-12-024, SUS-12-028, SUS-13-004, SUS-13-007, SUS-12-026, SUS-13-008, SUS-13-013

SUS-12-024, SUS-12-028, US-13-004





Supersymmetry Summary (95% C.L.)



for other details see talk by Alexander Lanyov

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
- 4th Generation ⇒ lepton + jet, dilepton

CMS Exotica Public Physics Results

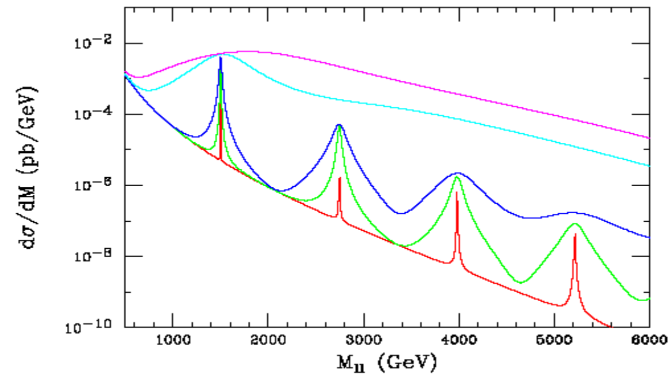
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

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



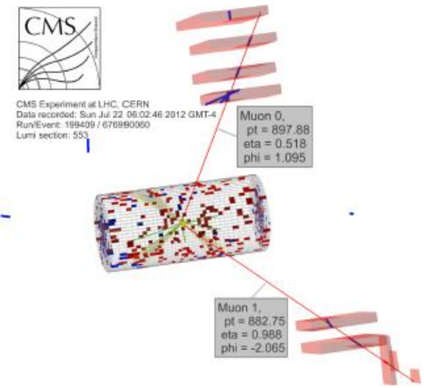
- Kaluza-Klein excitations of SM gauge bosons in large flat extra-dimensions (TeV-1 Models)
  - Bosons could also propagate in the bulk
  - Fermions are localized at the same (opposite) orbifold point: destructive (constructive) interference between SM gauge bosons and KK excitations
- Technicolor

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

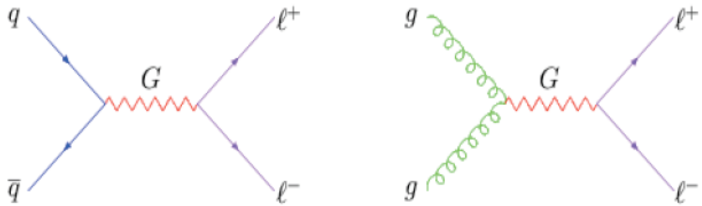
Excellent momentum and energy resolutions are required !!

Dileptons: Spectra

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

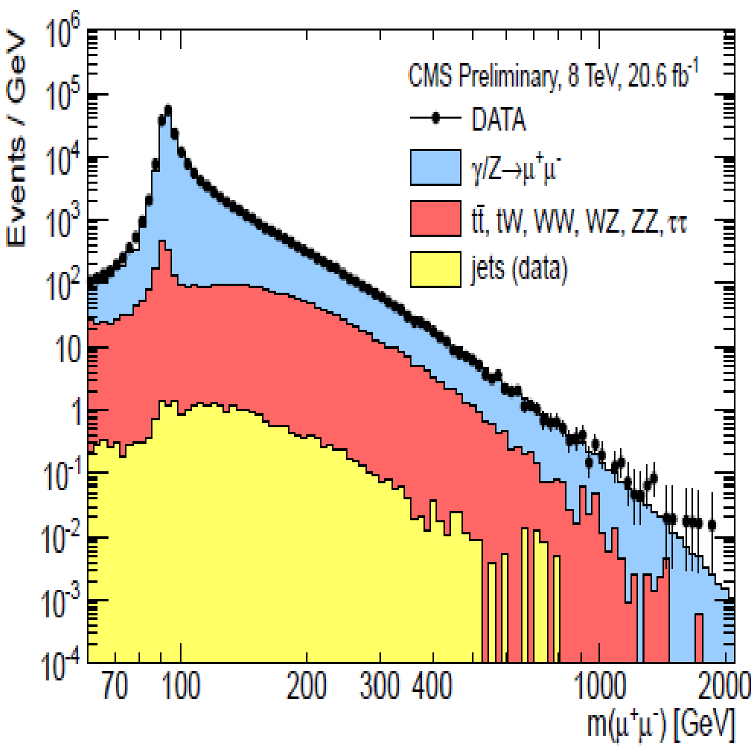


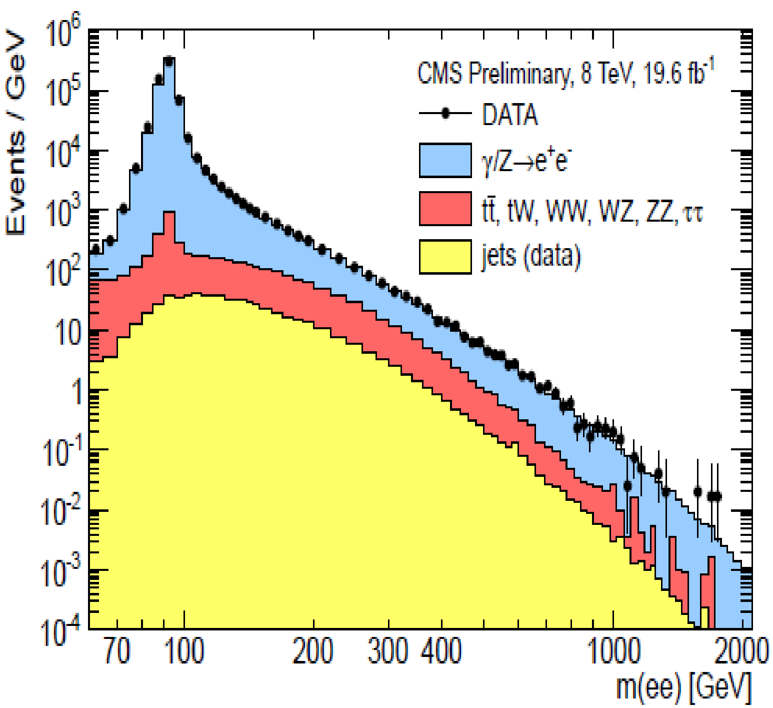
$q\bar{q} \to l^+l^-$ $\qquad$ $gg \to l^+l^-$



CMS PAS EXO-12-061

M = 1.824 TeV



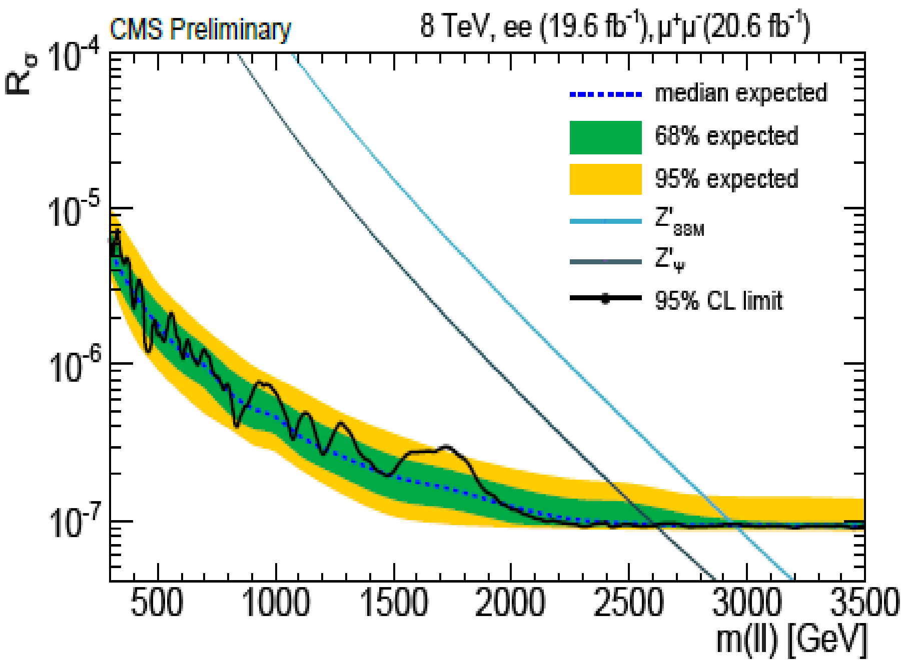


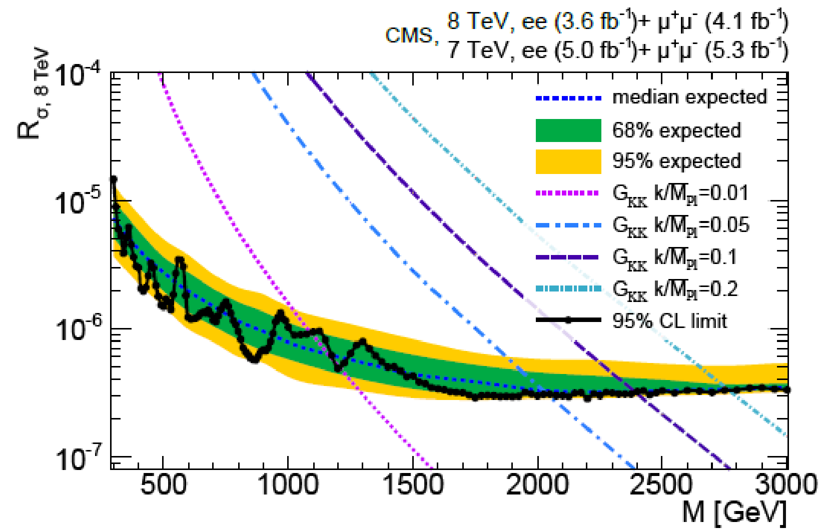
Dileptons: Limits

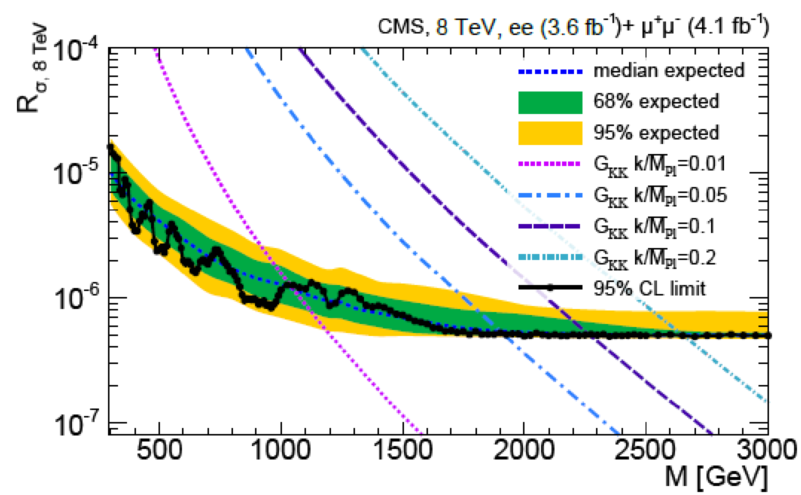
Phys.Lett. B720 (2013) 63

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

CMS PAS EXO-12-061



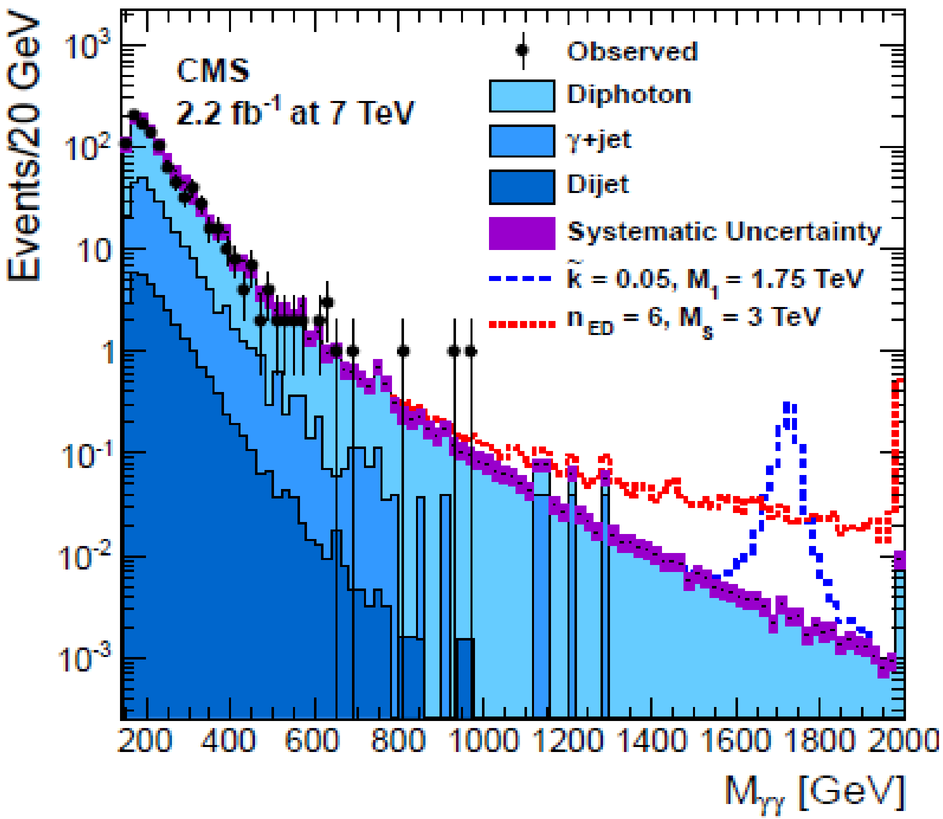


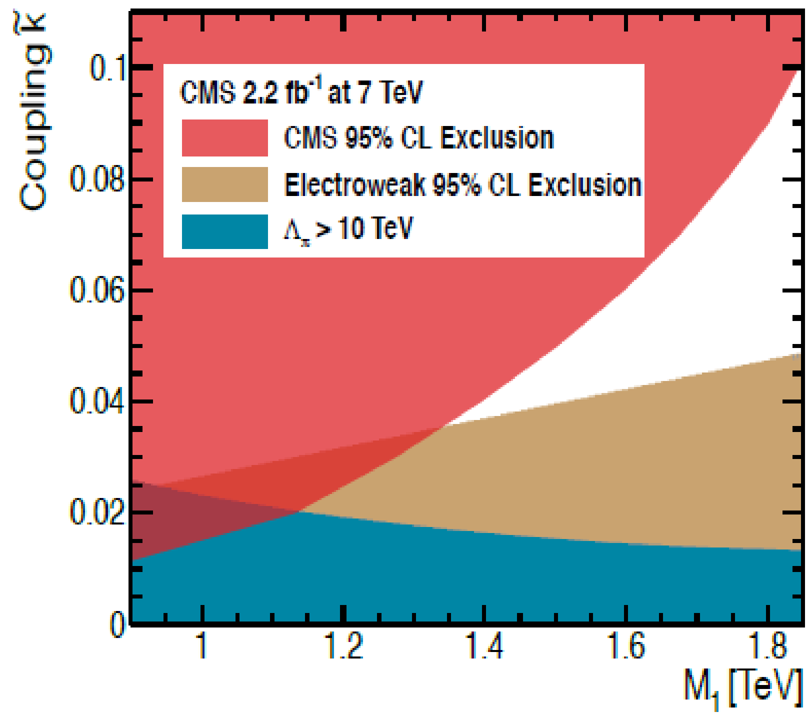


A Z' with standard-model-like couplings can be excluded below 2950 GeV, the superstring-inspired Z' below 2600 GeV, and RS Kaluza–Klein gravitons below 2030 (2390) GeV for couplings of 0.05 (0.10)

Diphotons

Phys.Rev.Lett. 108 (2013) 111801



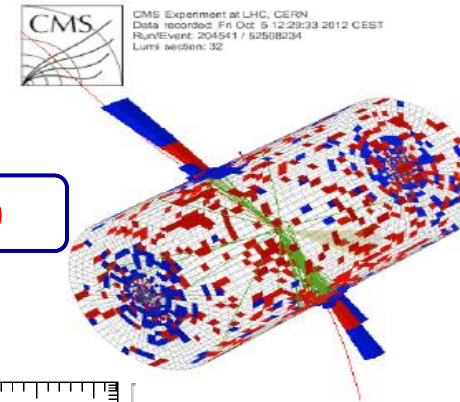


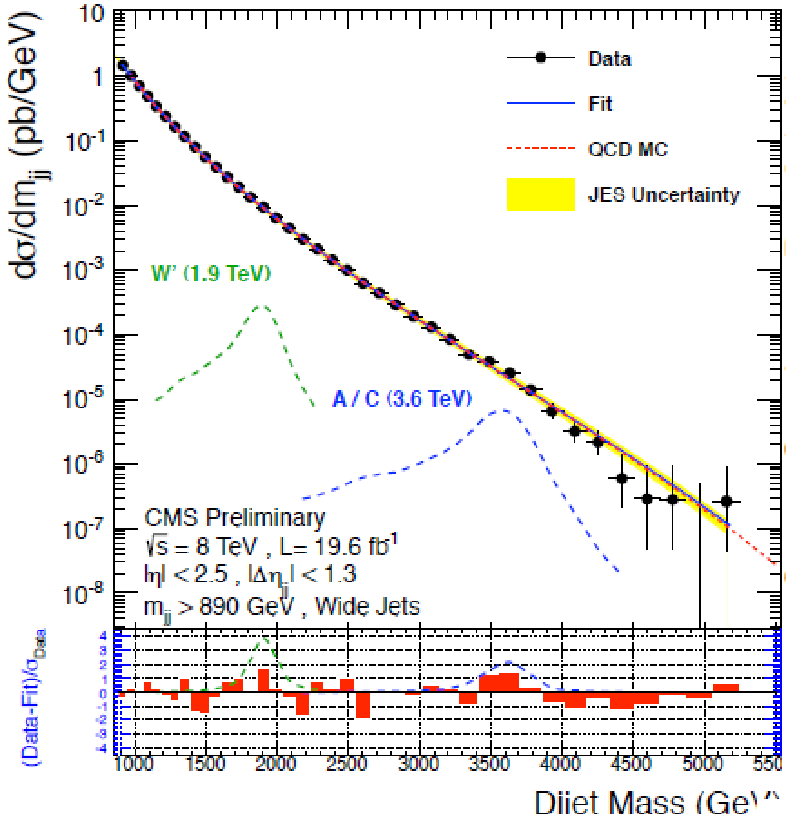
RS Kaluza–Klein gravitons below

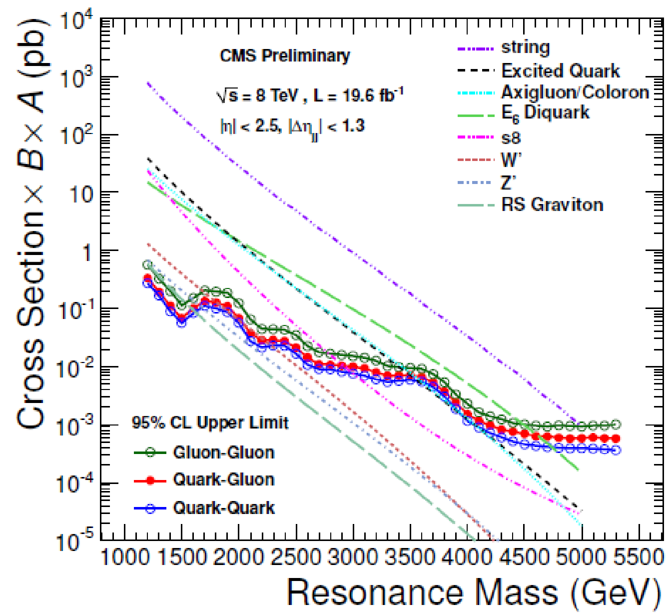
$\tilde{k}$	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
M_1 [TeV]	0.86	1.13	1.27	1.39	1.50	1.59	1.67	1.74	1.80	1.84

Dijets

CMS PAS EXO-13-059





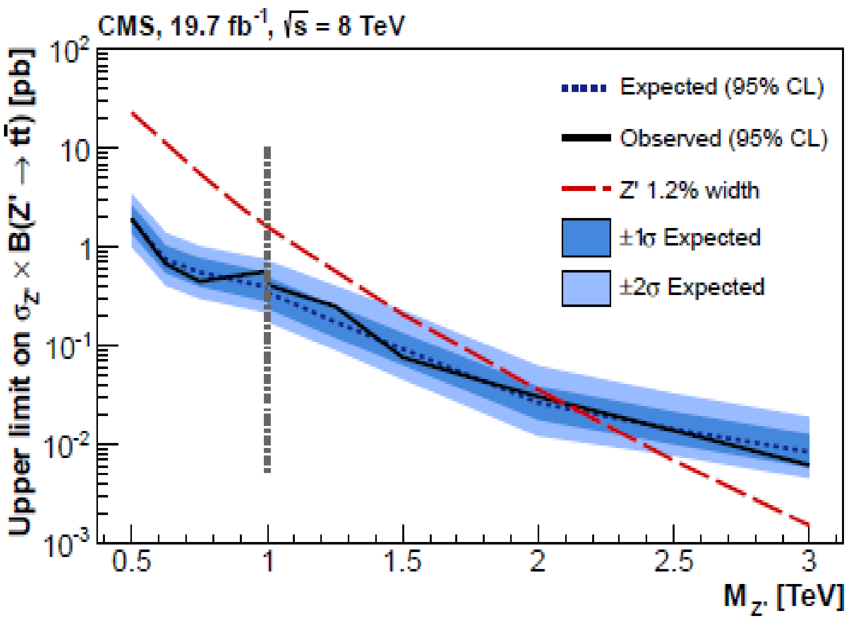


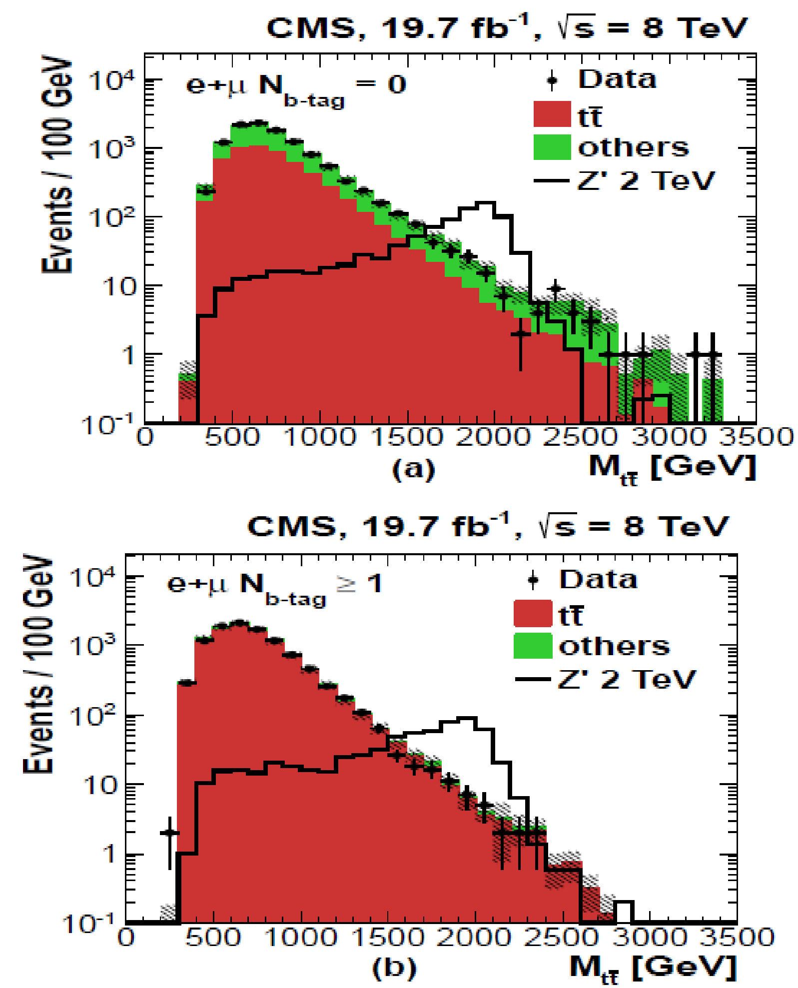
Model	Final State	Obs. Mass Excl. [TeV]	Exp. Mass Excl. [TeV]
String Resonance (S)	qg	[1.20,5.08]	[1.20,5.00]
Excited Quark (q^*)	qg	[1.20,3.50]	[1.20,3.75]
E_6 Diquark (D)	qq	[1.20,4.75]	[1.20,4.50]
Axigluon (A)/Coloron (C)	$q\bar{q}$	[1.20,3.60] + [3.90,4.08]	[1.20,3.87]
Color Octet Scalar (s8)	gg	[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

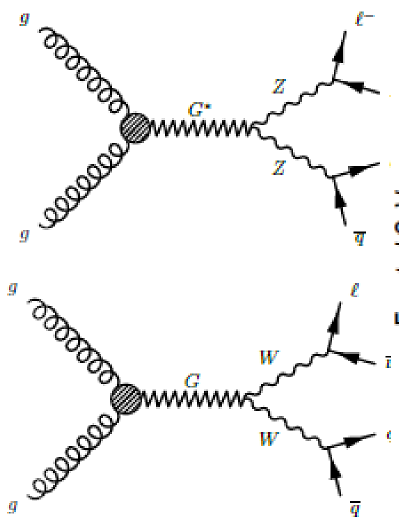


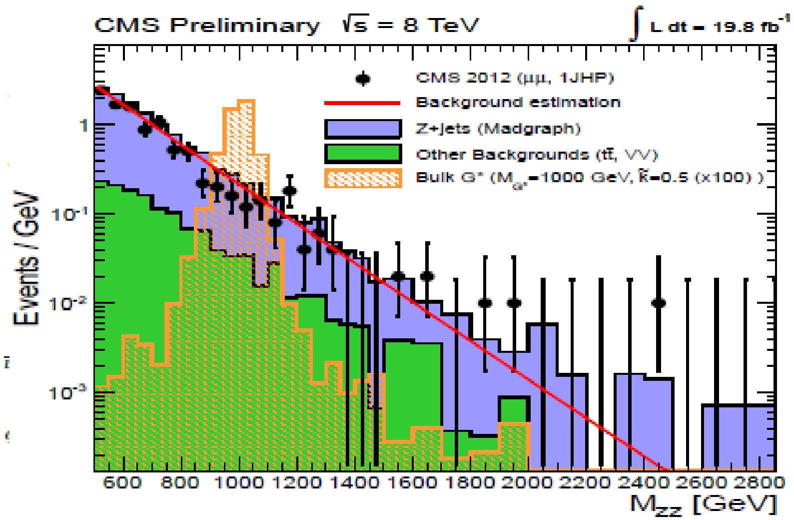


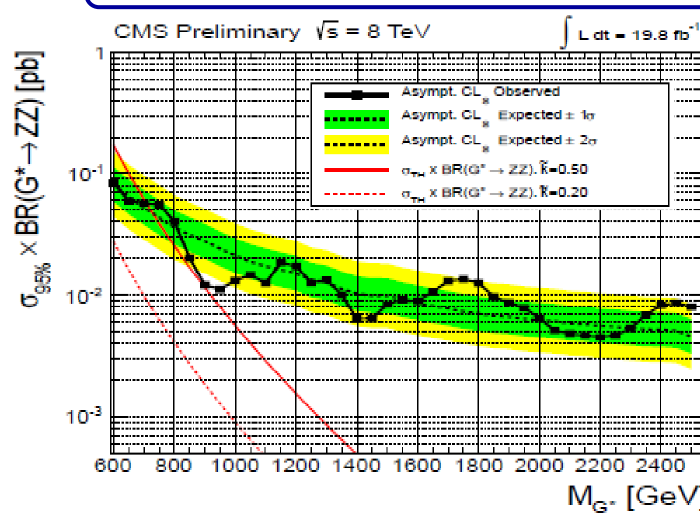
Model	Observed Limit	Expected Limit
Z' $(\Gamma_{Z'}/M_{Z'} = 1.2\%)$	2.1 TeV	2.1 TeV
Z' $(\Gamma_{Z'}/M_{Z'} = 10\%)$	2.7 TeV	2.6 TeV
RS KK gluon	2.5 TeV	2.4 TeV

Di-boson Resonances

EXO-12-021, EXO-12-022



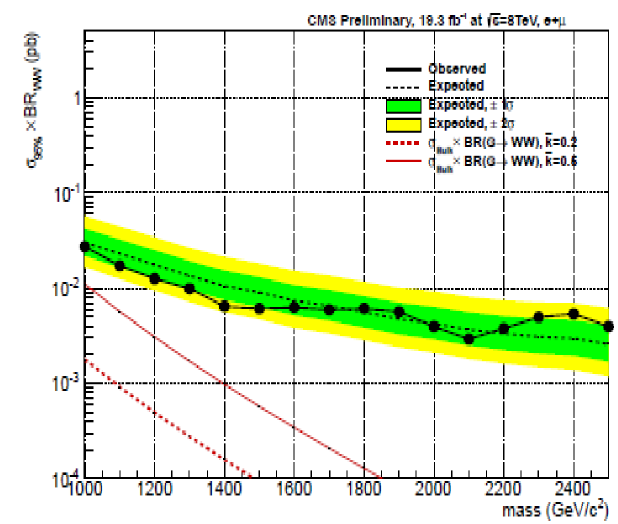




ZZ: mass limit for RS graviton is 710 GeV
for c = 0.5

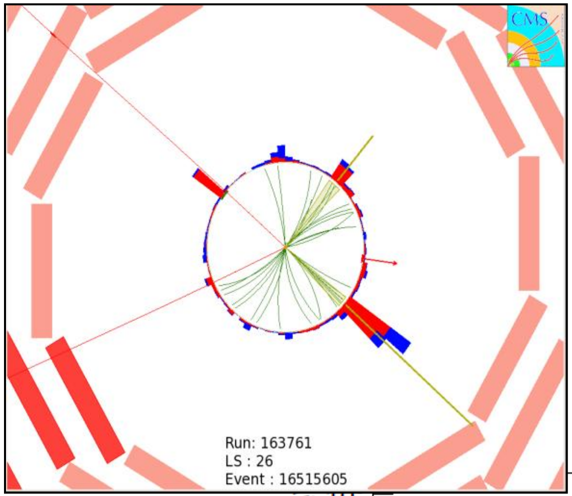
WW: graviton production x-section upper limit is 70 fb for mass from 0.8 TeV up to 2.5 TeV

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

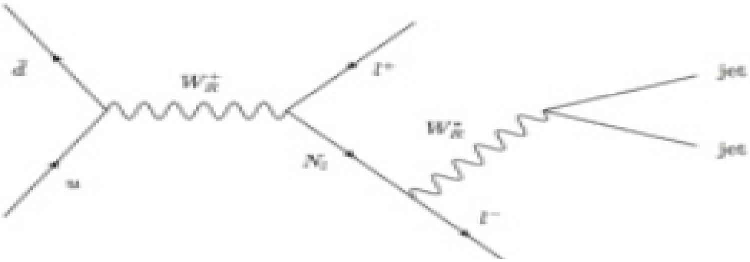


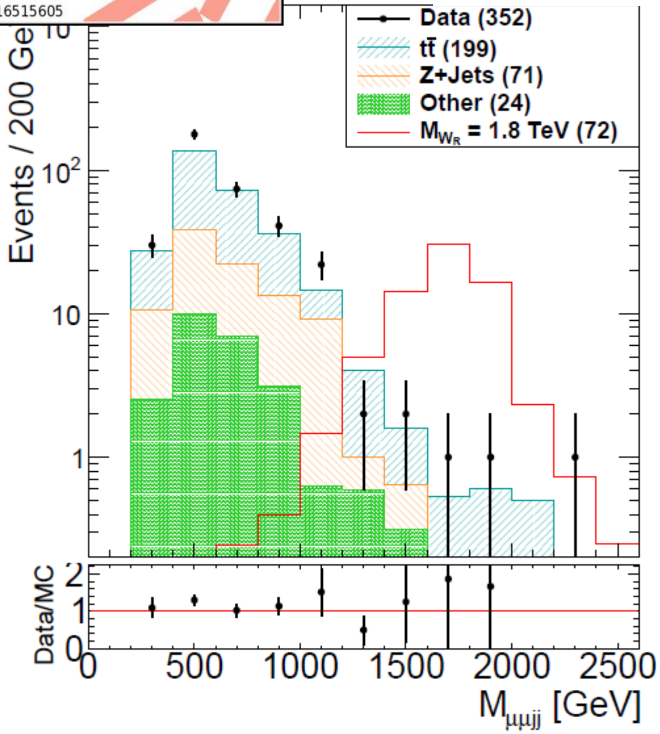
(Lepton-Lepton) + (Jet-Jet) Resonance

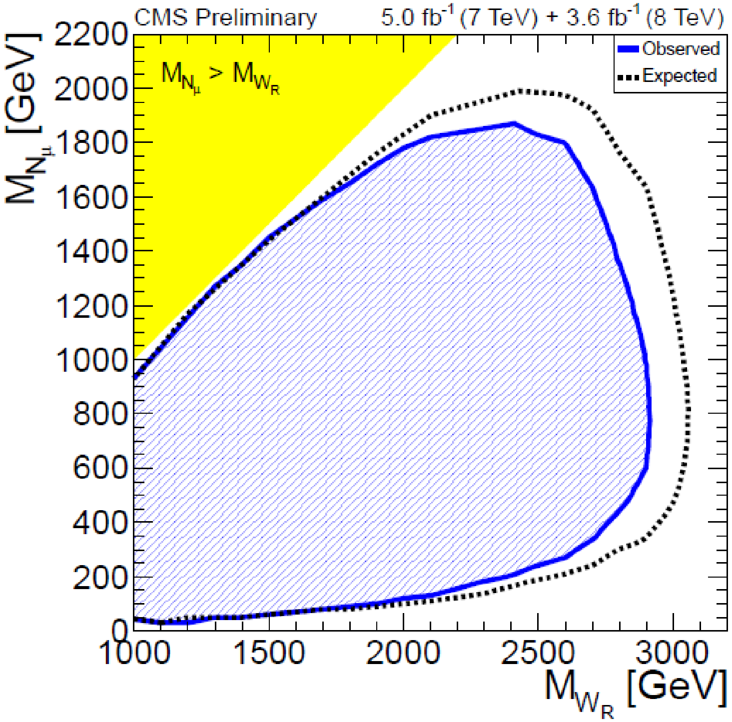
CMS PAS EXO-12-017



W_R and heavy neutrino from LR models

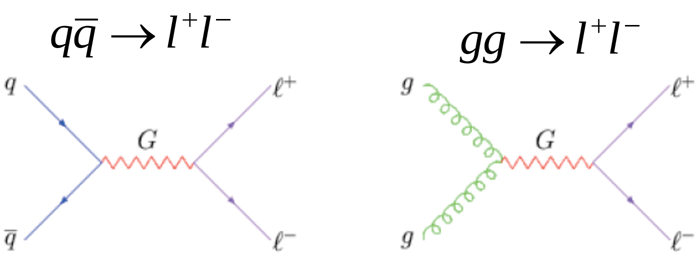


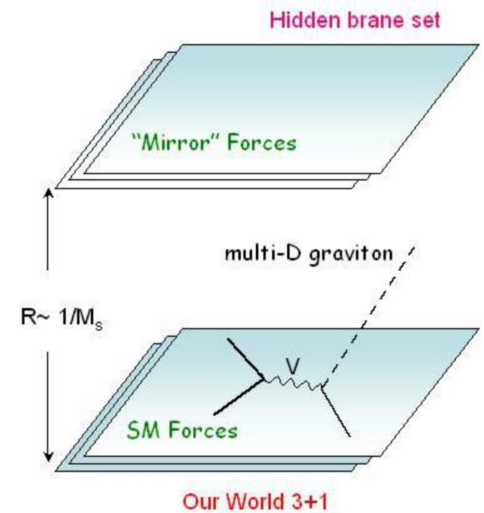




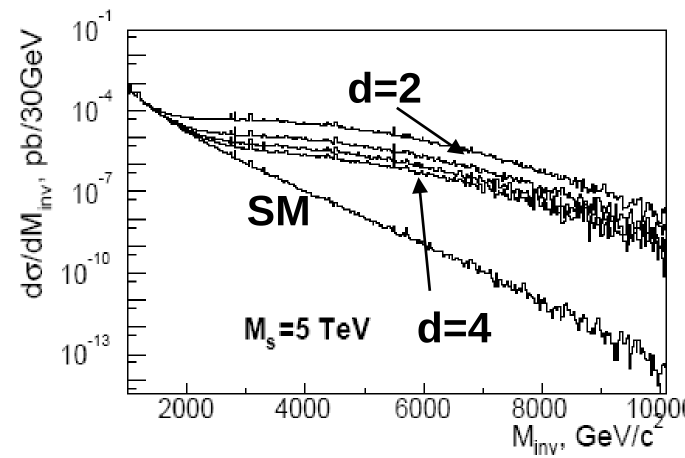
Non-Resonant Signals

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





- Compositeness



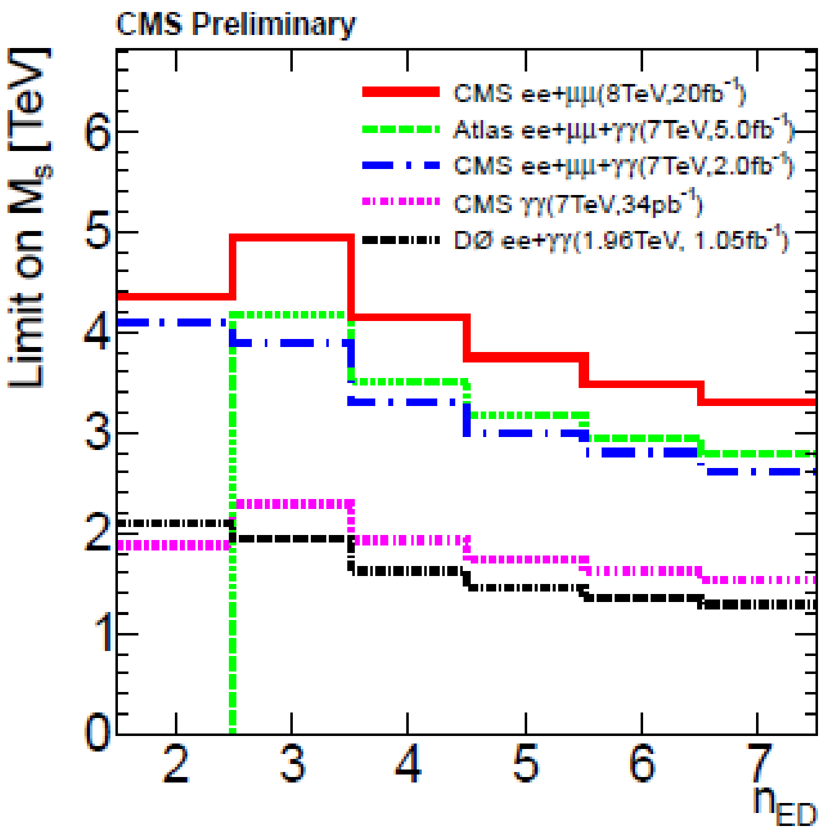
<u>Signals:</u> excess in di-particle spectrum

Exclusion Limits for ADD

for details see talk by Maria Savina

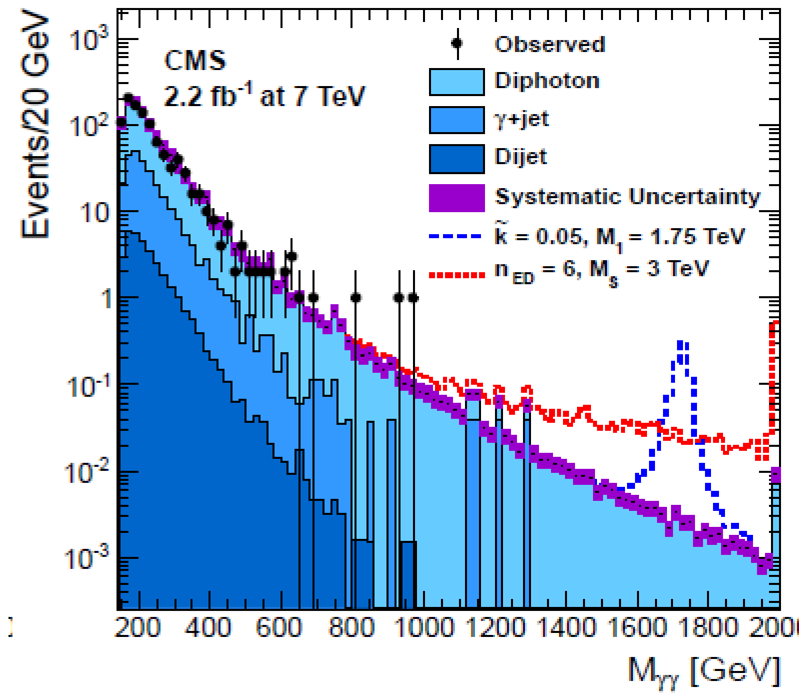
CMS PAS EXO-12-027, 12-031

Dimuons



Diphotons

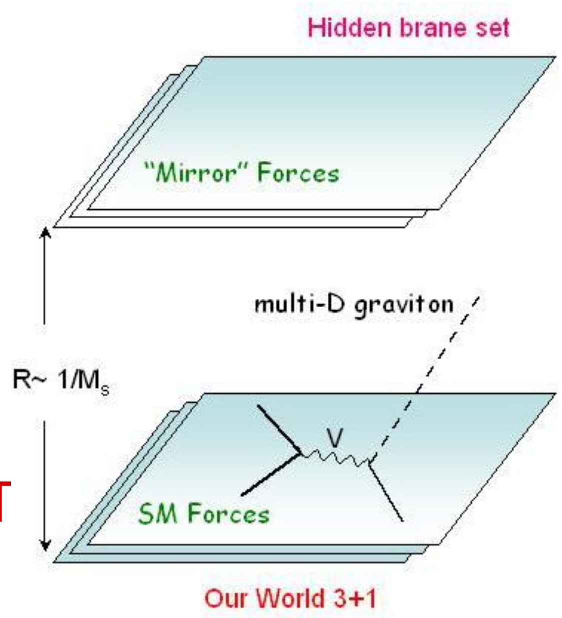
PRL 108 (2012) 111801



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

Mono-Particle + MET

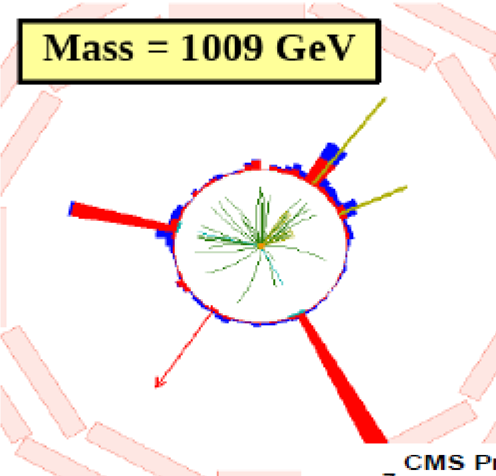
- Extra gauge bosons (W′) predicted by extended gauge models (left-right symmetric models and GUT-inspired models)
- Kaluza-Klein graviton emission in large flat extra-dimensions (ADD model)
- Technicolor



<u>Signals:</u> lepton + MET, photon +MET, jet +MET

Lepton + MET

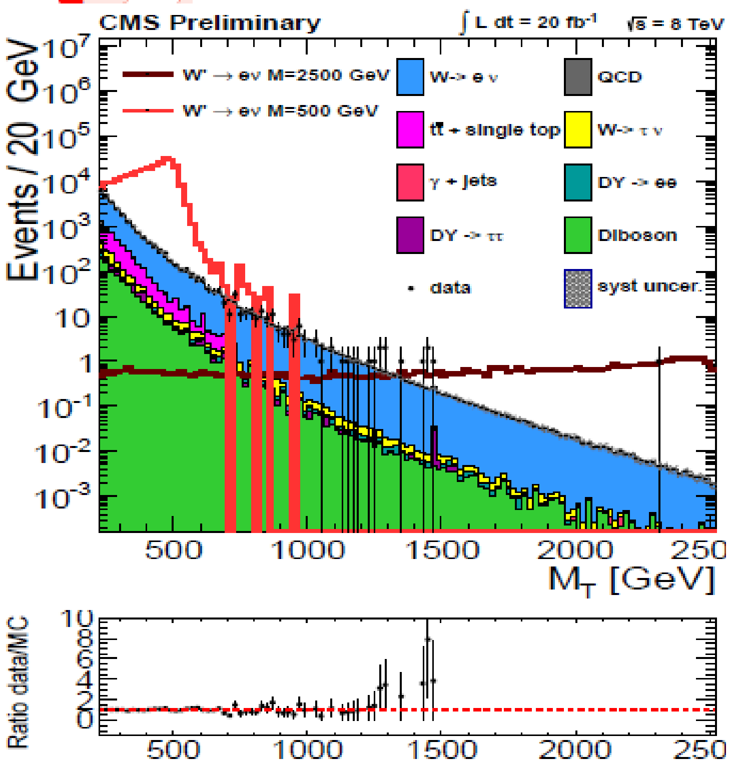
CMS PAS EXO-12-060

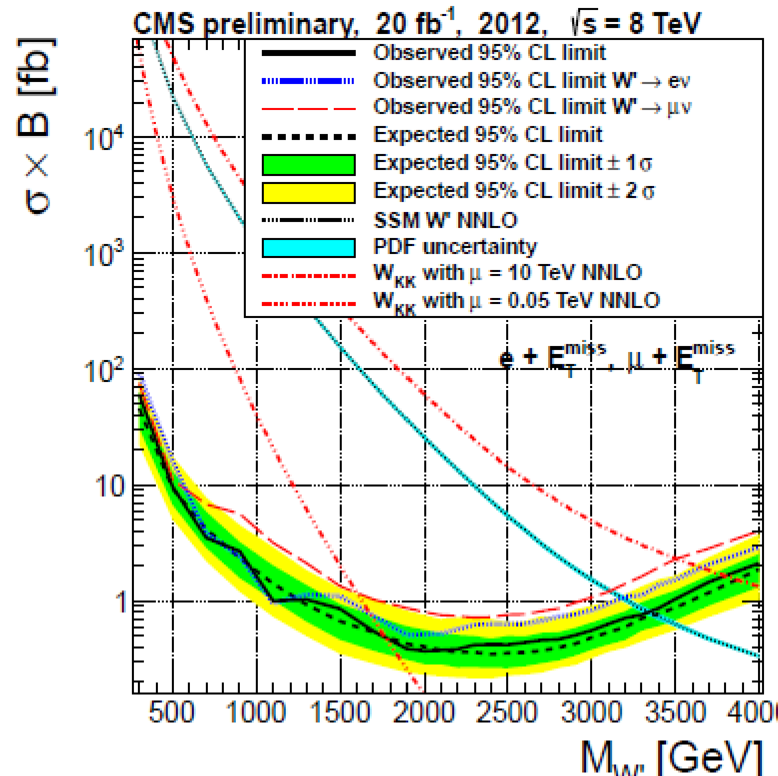


Signature is W-like at high mas
Background is SM W production!

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

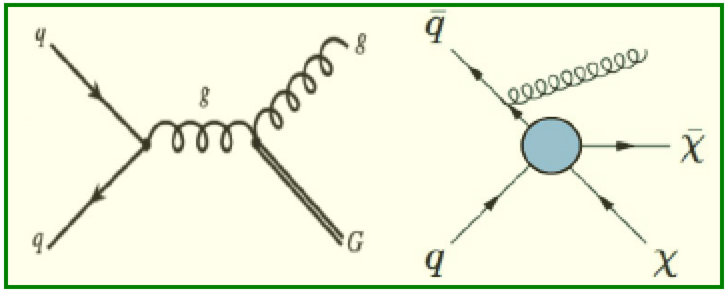
$$M_T = \sqrt{2 \cdot p_T^{\ell} \cdot E_T^{\text{miss}} \cdot (1 - \cos \Delta\phi_{\ell,\nu})}$$

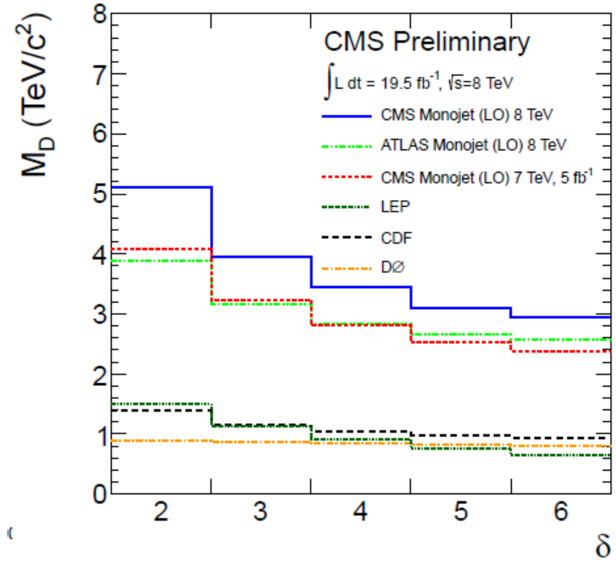


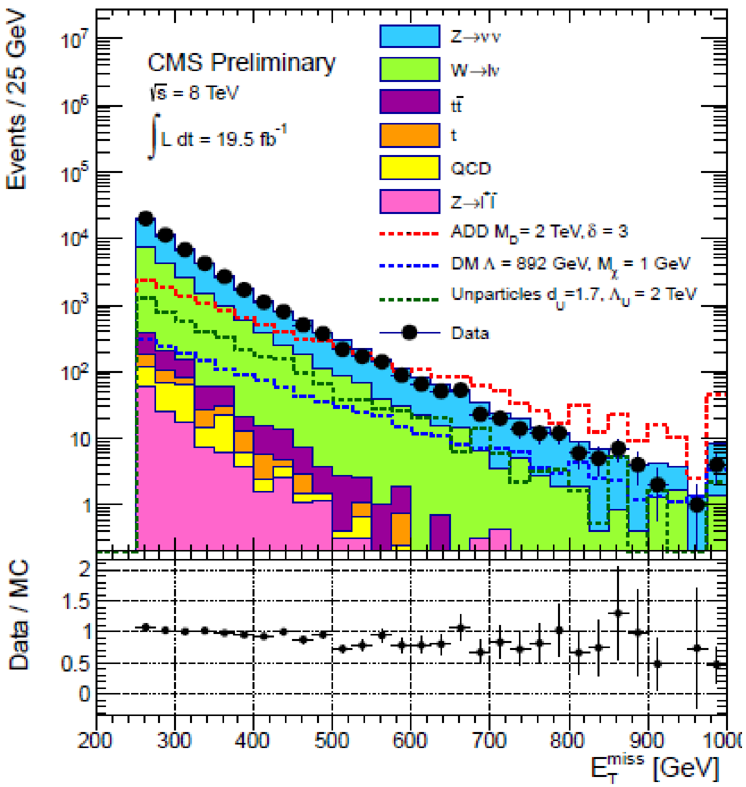


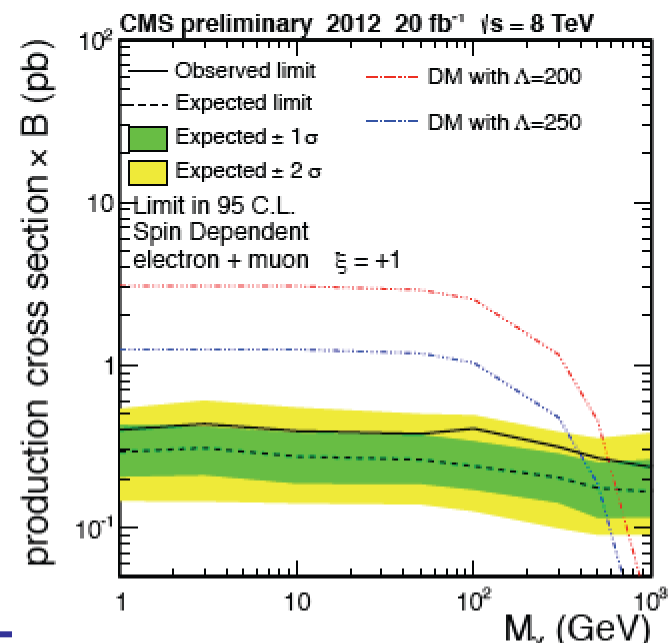
Jet + MET

CMS PAS EXO-12-048





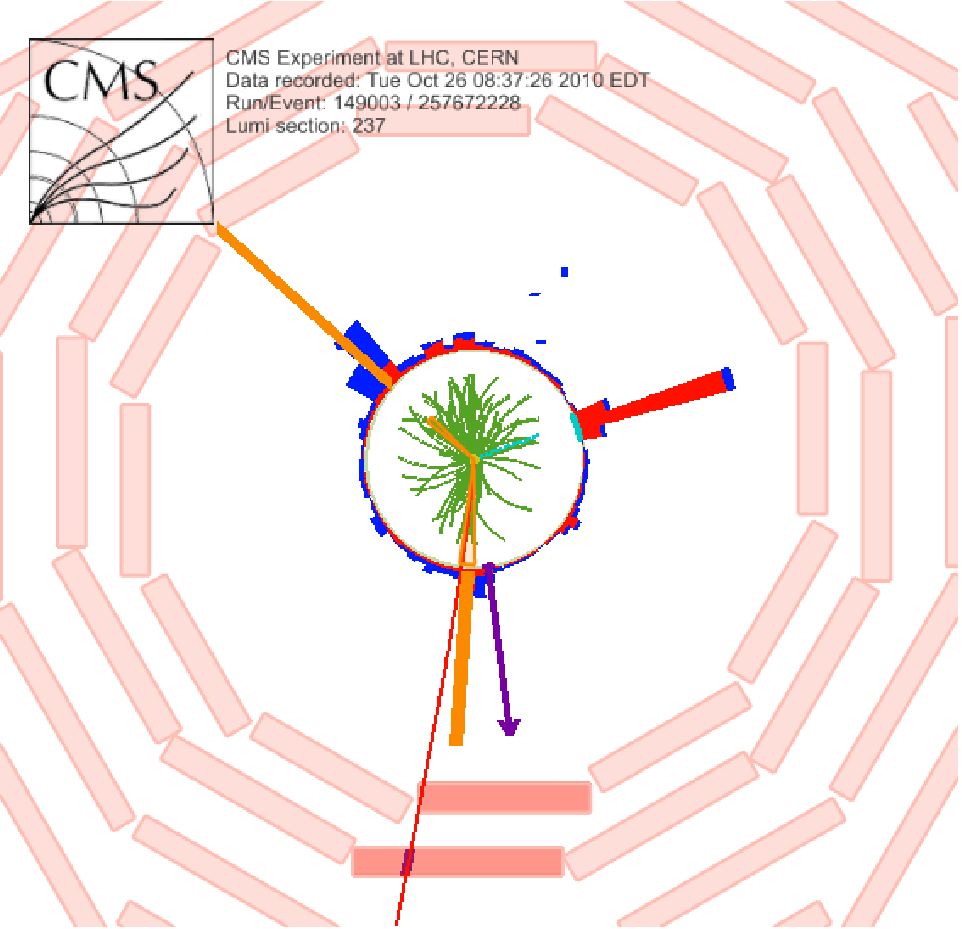




Multiparticle Events

- Black Holes
- Leptoquarks
- etc

Signals: jets + leptons + photons + MET

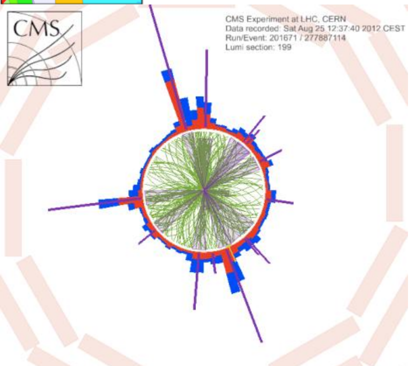


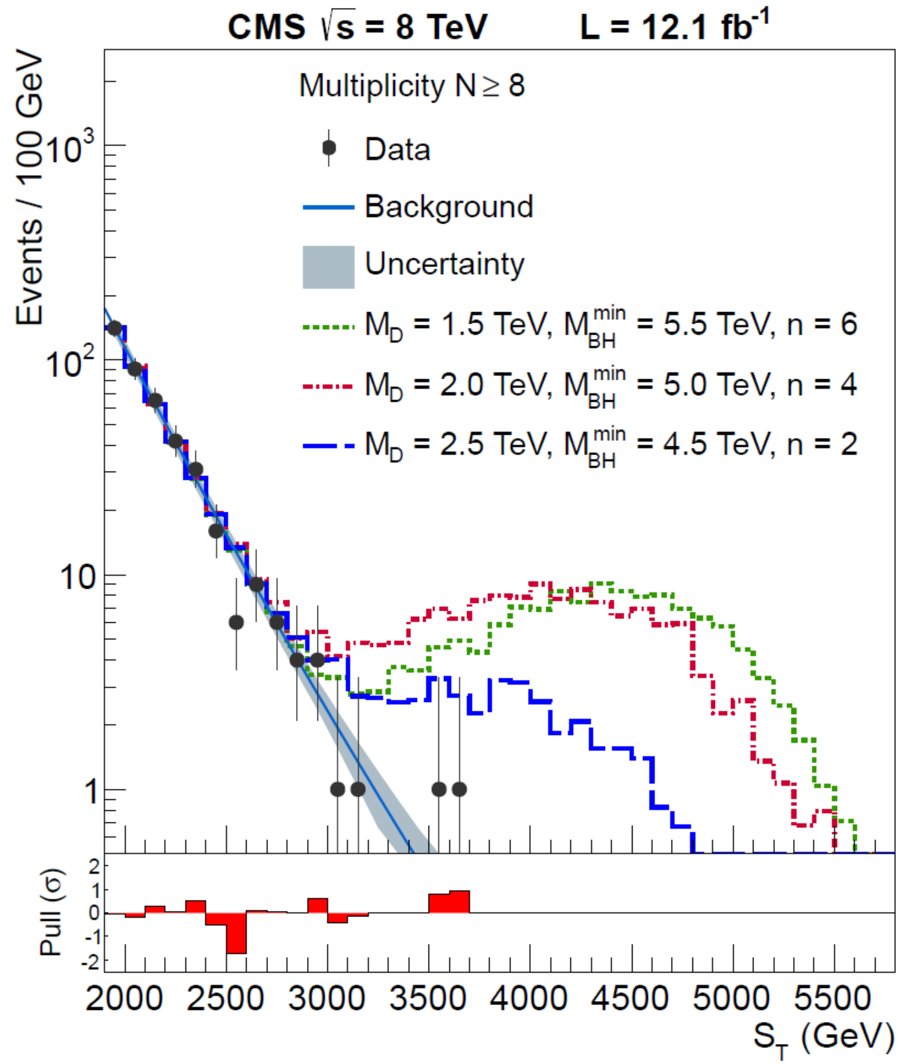
Black Holes

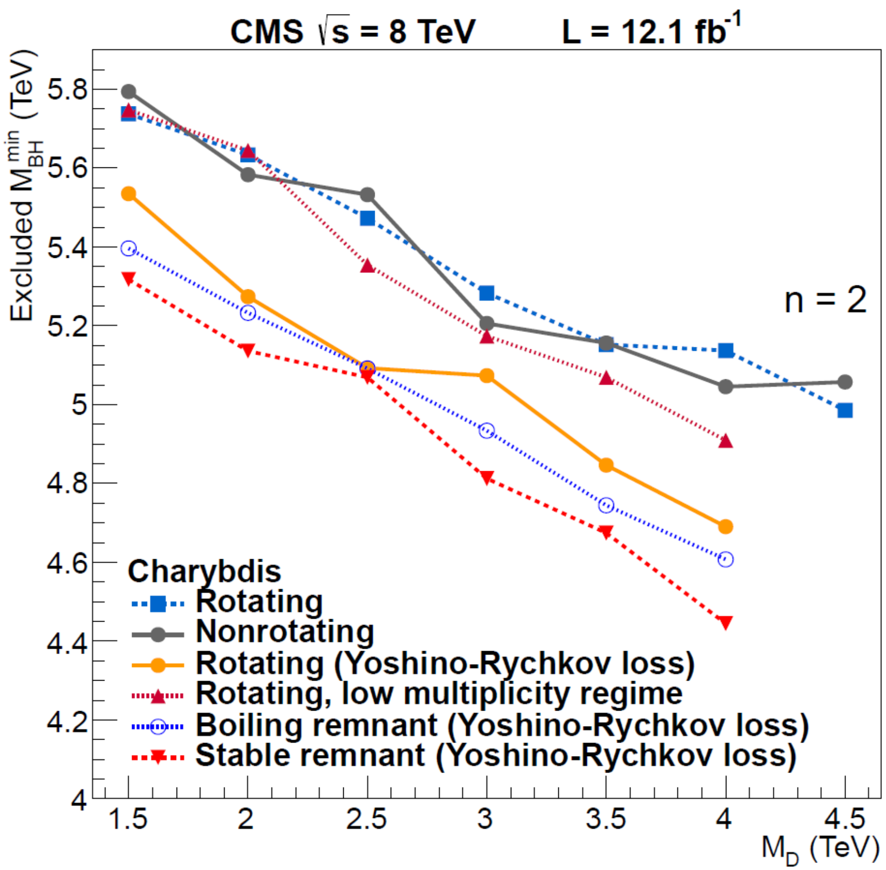
for details see talk by M. Savina

JHEP07(2013)178

$$S_T = \sum E_T$$



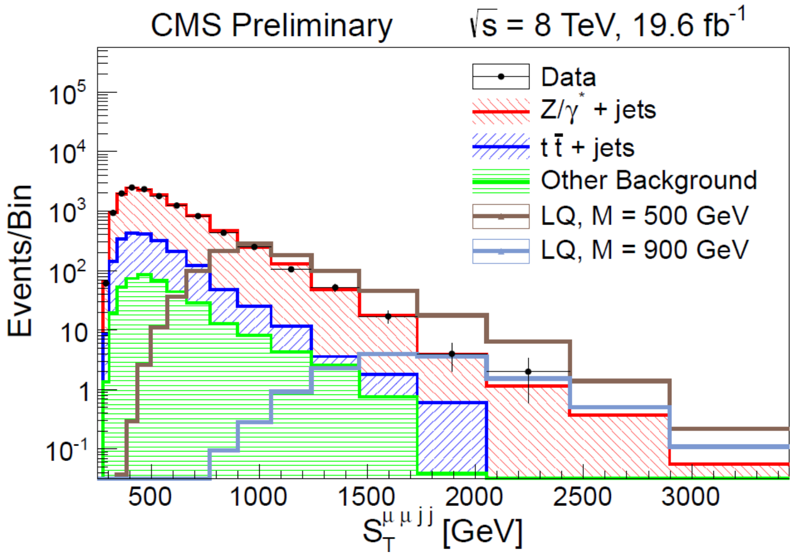


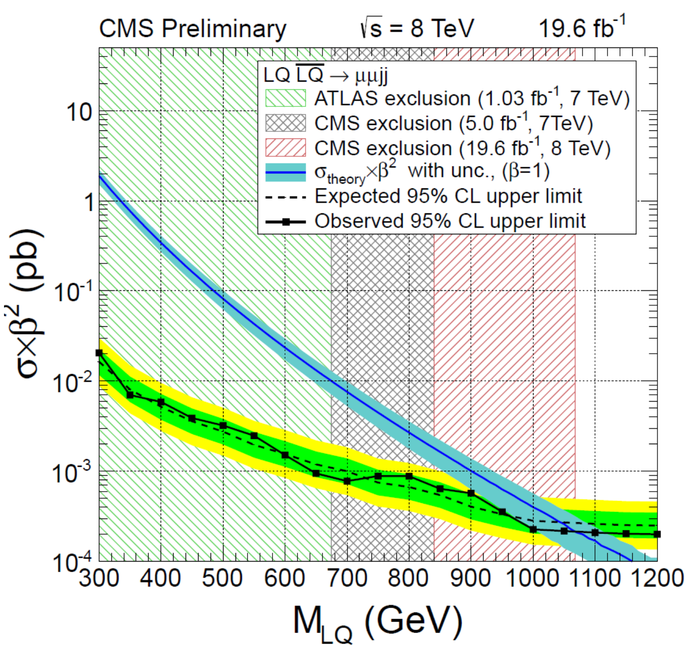


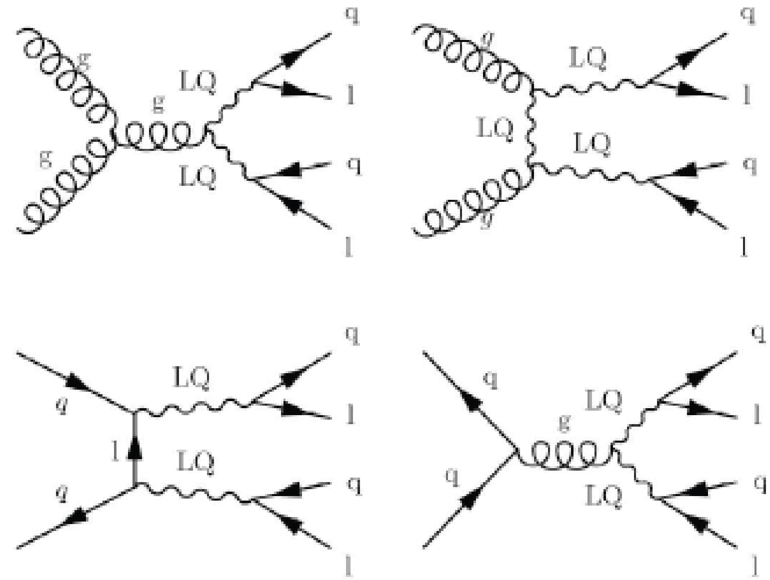
CMS set limits on the
inimum BH mass of 4.4-5.8 TeV

Leptoquarks

EXO-12-042



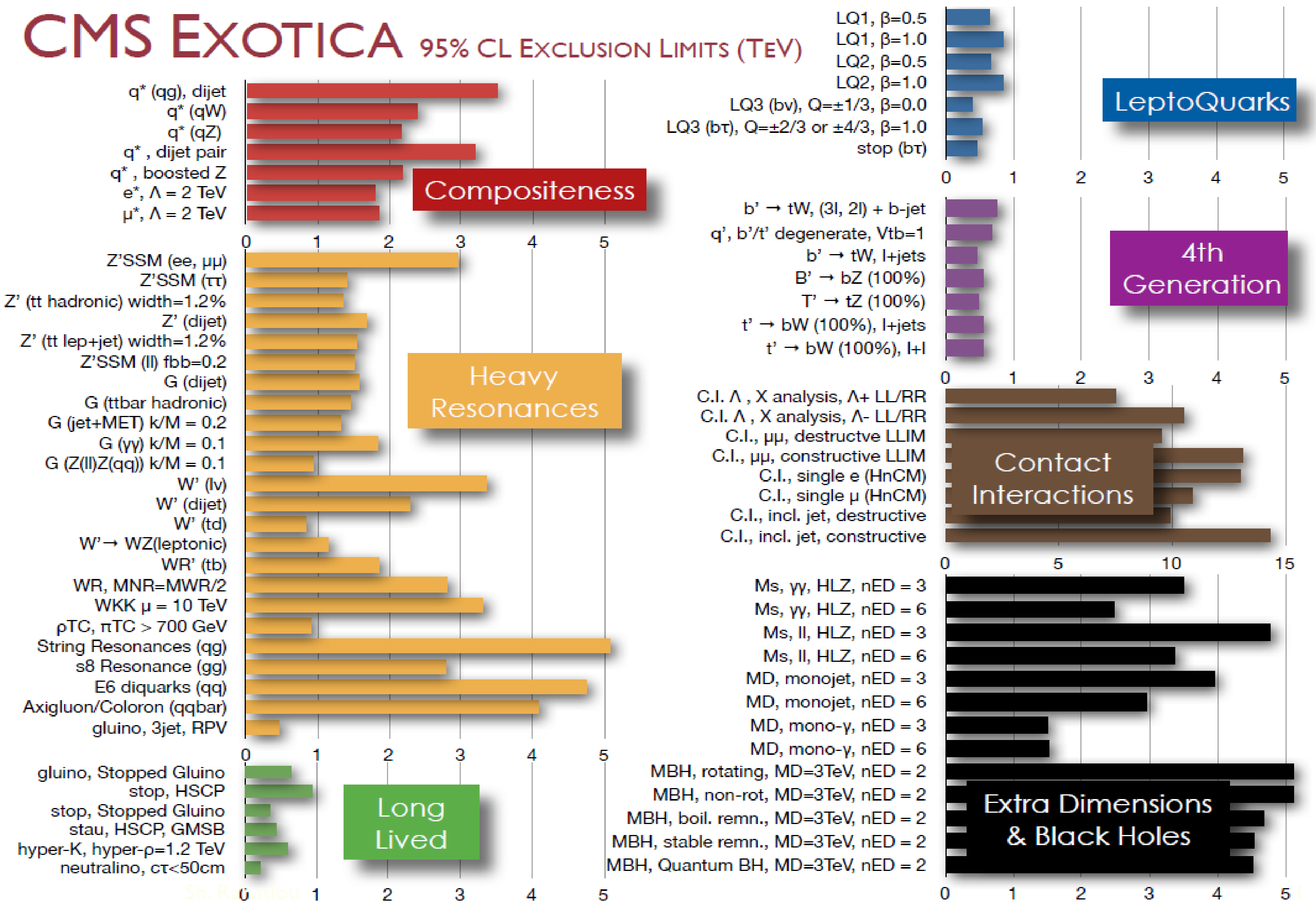




S_T is the sum of the magnitudes of the p_T of the two leading electrons and two leading jets.

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.)

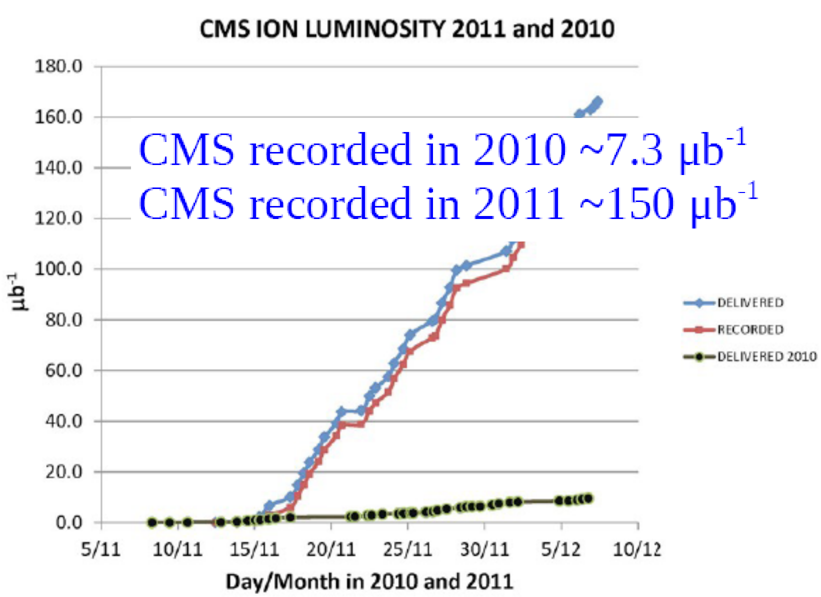


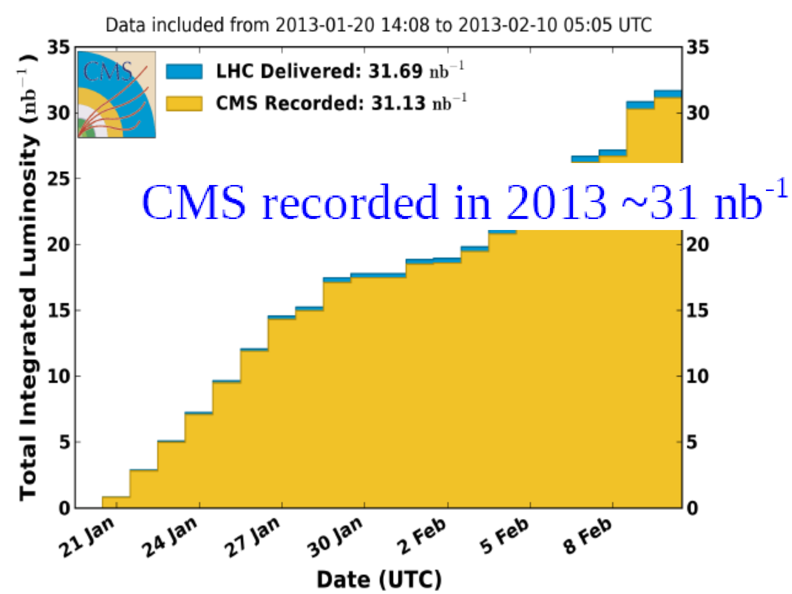
for details see talk by I. Lokhtin

Heavy Ion (PbPb) @ 2.76 TeV/nuclon and pPb @ 5.02 TeV/nuclon

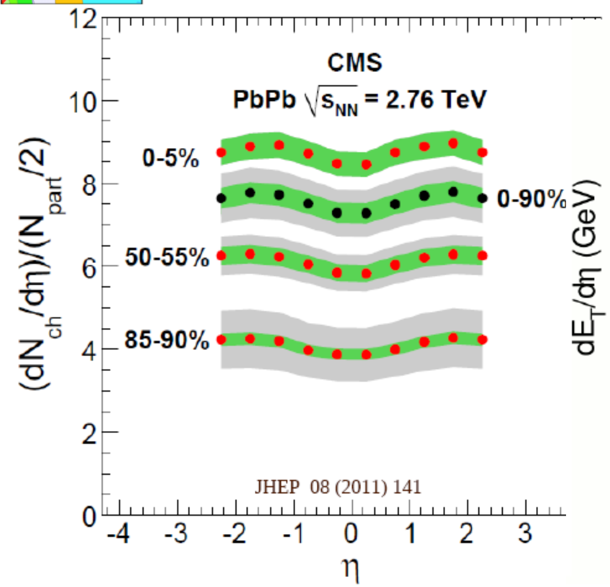
CMS Heavy Iona Public Physics Results

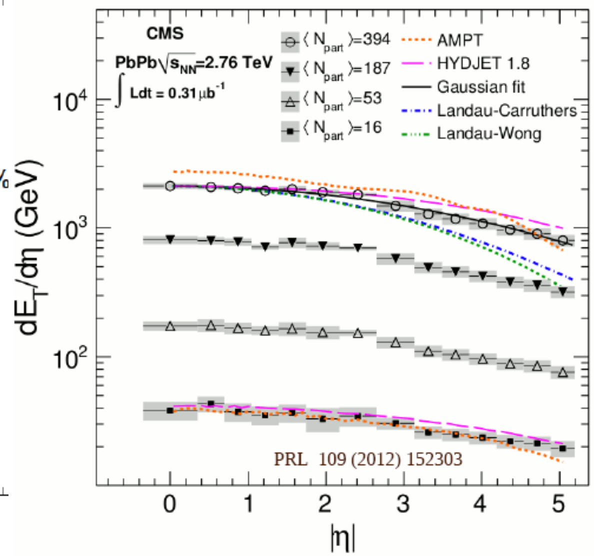
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN



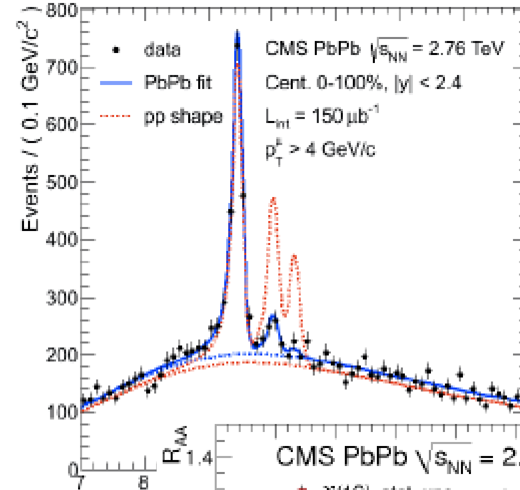


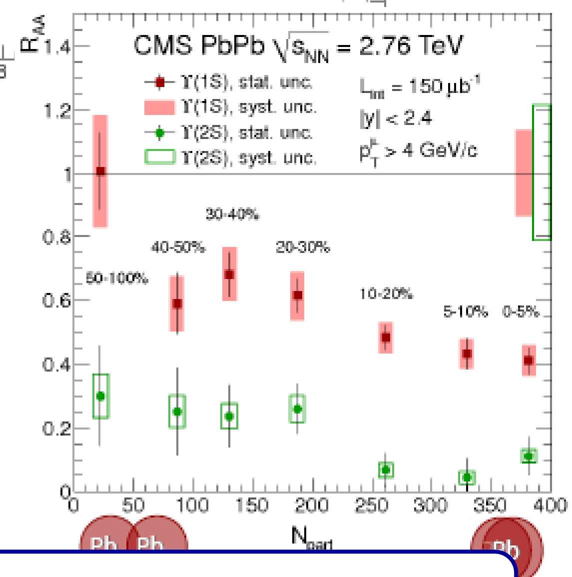
PbPb Highlights





Υ suppression

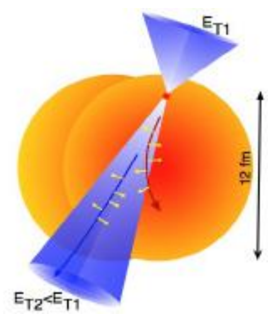


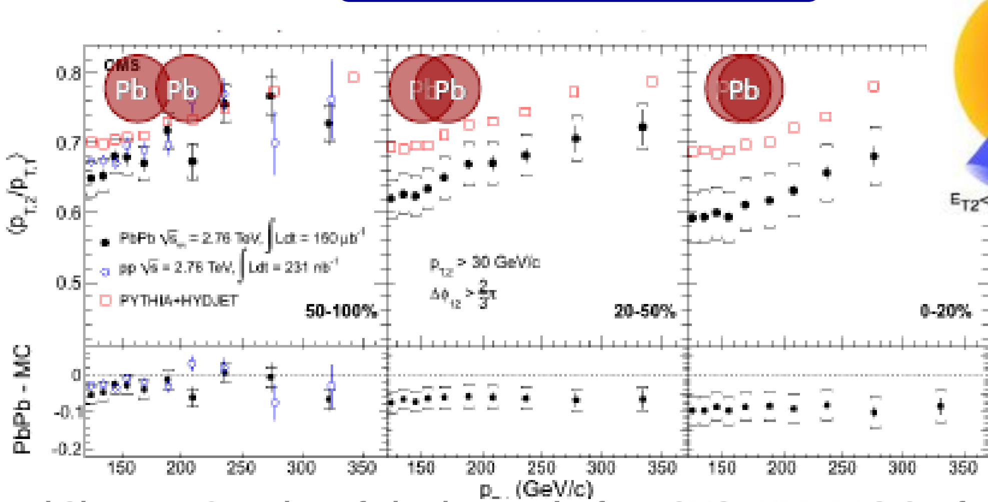


for central case dNch/dη ≈ 1600 (2.2 higher than @ RHIC)

Jet Quenching

PLB 712 (2012) 176v



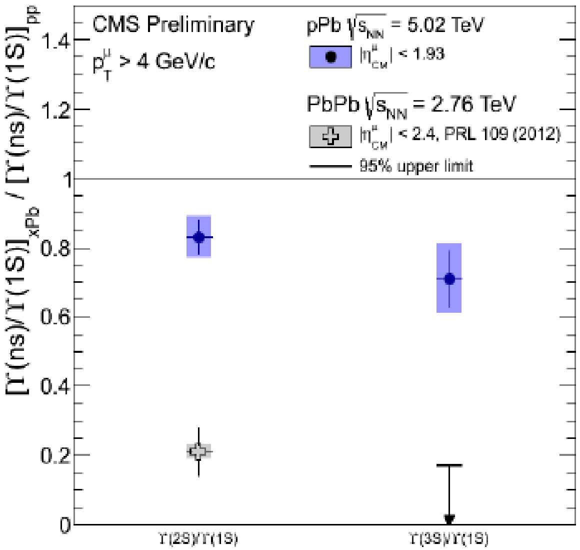


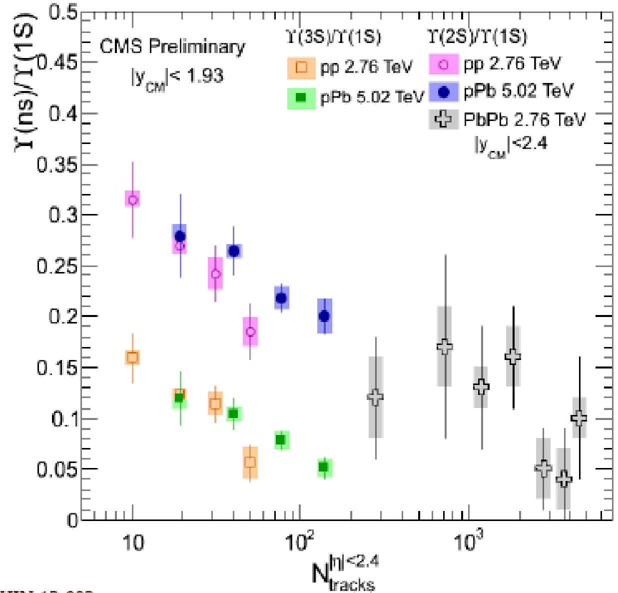
PLB 109 (2012) 222301

$$\Upsilon(2S)/\Upsilon(1S)_{PbPb} / \Upsilon(2S)/\Upsilon(1S)_{pp} = 0.21 \pm 0.07 \pm 0.02$$

pPb Highlights

Quarkonia suppression





CMS-PAS-HIN-13-003

JHEP 07 (2011) 076

Ridge-effect

p+p 7 TeV

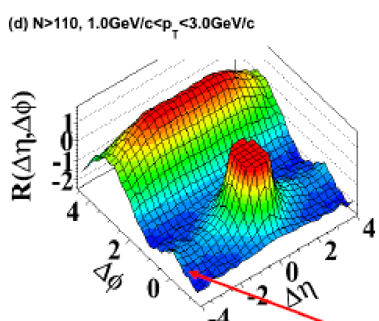
JHEP 09 (2010) 091

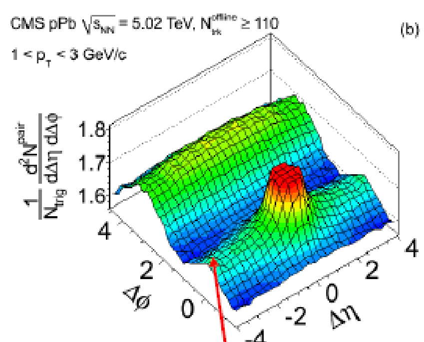
p+Pb 5.02 TeV

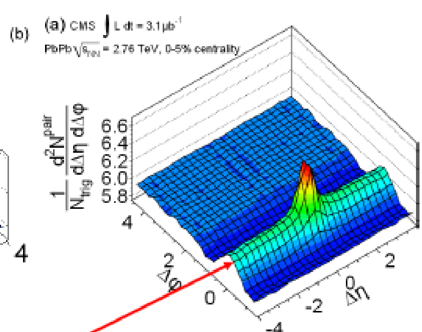
PLB 718 (2013) 795

Pb+Pb 2.76 A TeV, 0-5%

JHEP 07 (2011) 076







JHEP 09 (2010) 091

PLB 718 (2013) 795

”Ridge” *(long-range azimuthal correlations)* is observed by CMS in high multiplicity pp and pPb as well as in central PbPb collisions

Conclusions

- 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 (2013)

- 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)

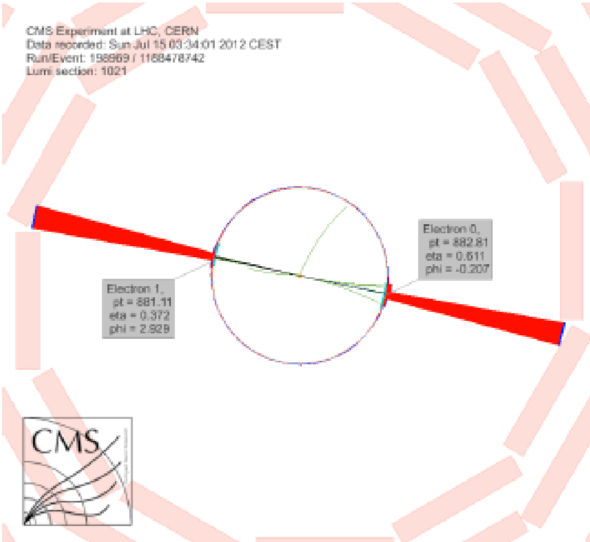
CMS Talks @ This Conference

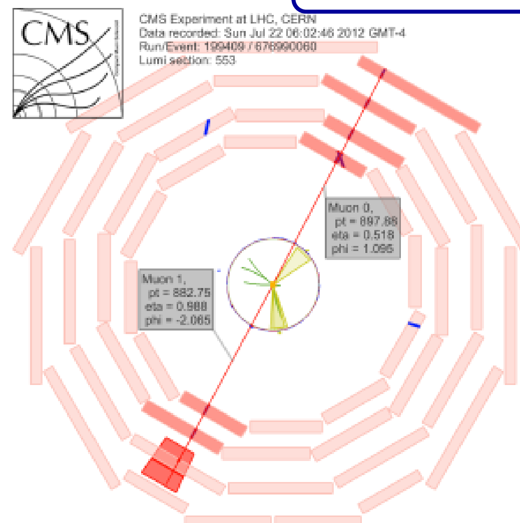
1. Alexander Proskuryakov “Difraction at CMS”
2. Alexander Lanyov “Recent CMS Results of Searches for Physics Beyond Standard Model”
3. Maria Savina “Search for KK-states of graviton and microscopic black holes with the CMS detector at the LHC”
4. Ilya Gorbunov “Study of Drell-Yan processes with CMS”
5. Natalia Tsirova “Single top quark studies with CMS”
6. Sergei Shulga “Particle multiplicity in jets at CMS”
7. Igor Lokhtin “Heavy Ion Physics at the LHC with CMS ”

Thank you for your attention

Highest Dilepton Mass at CMS

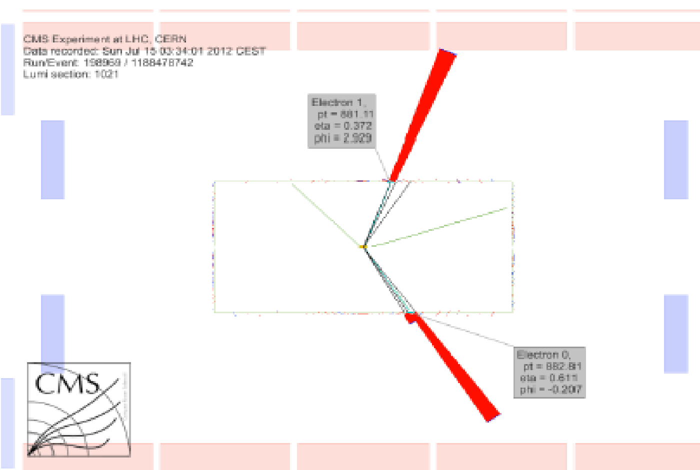
CMS PAS EXO-12-061

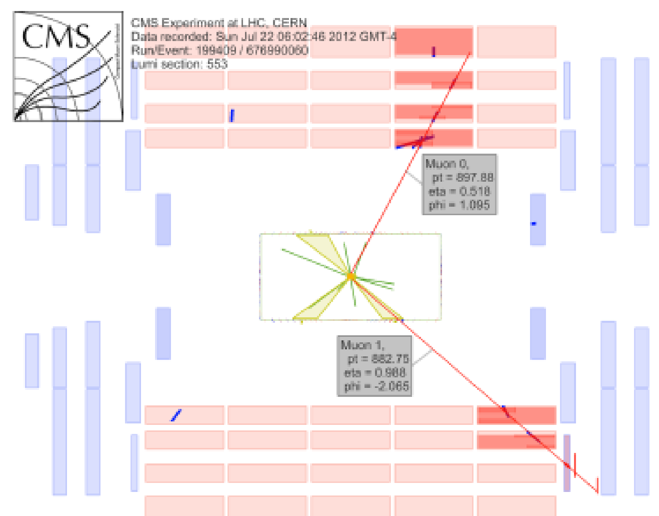


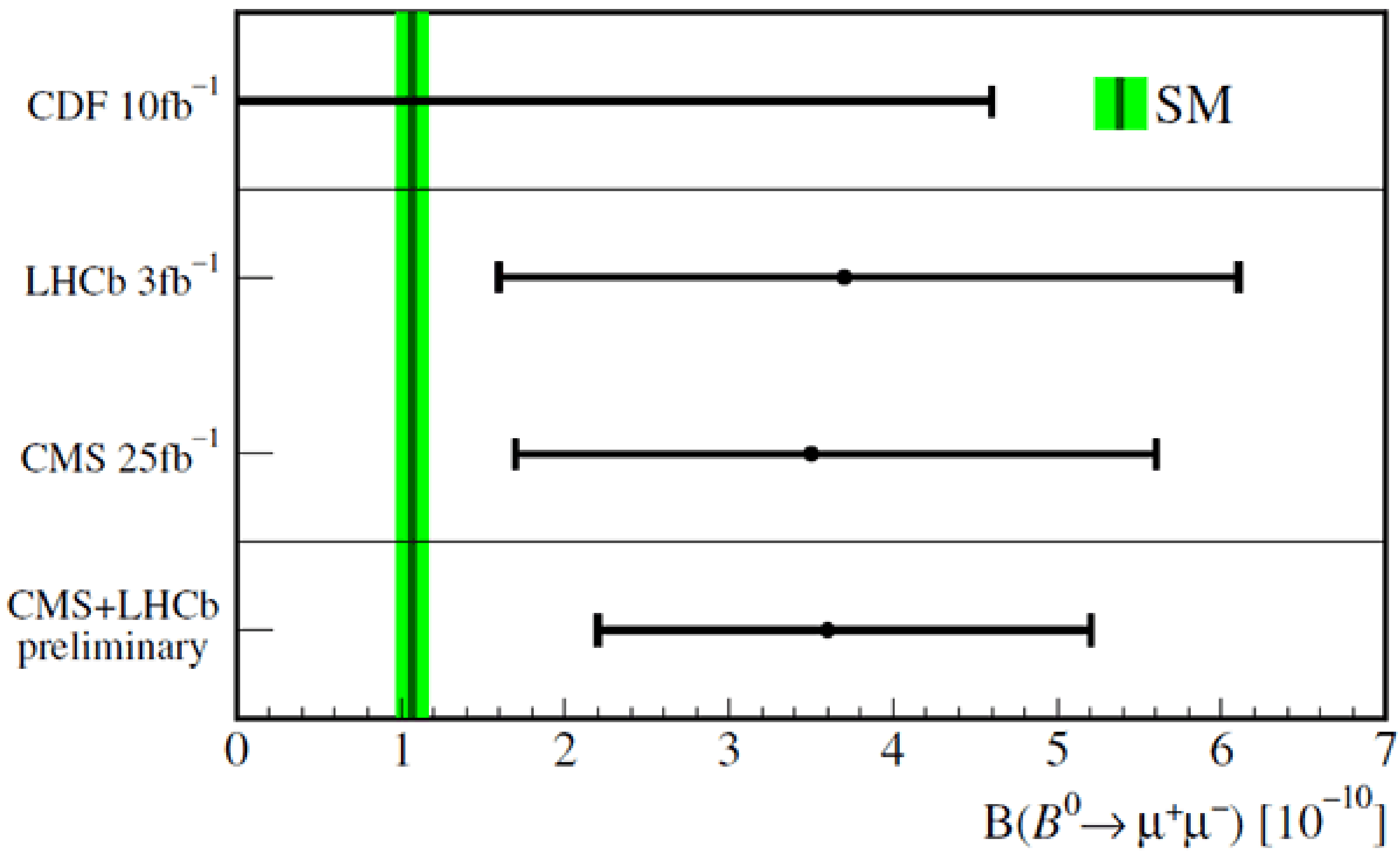


Dielectron, M = 1.776 TeV

Dimuon, M = 1.824 TeV



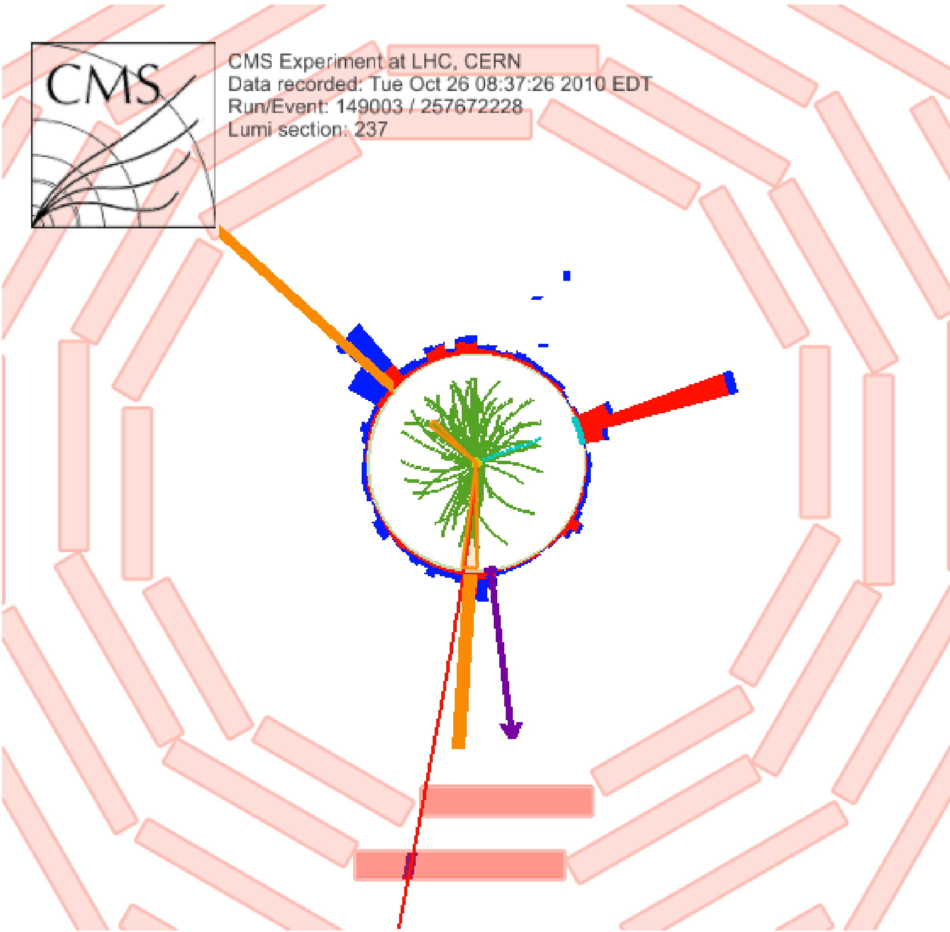


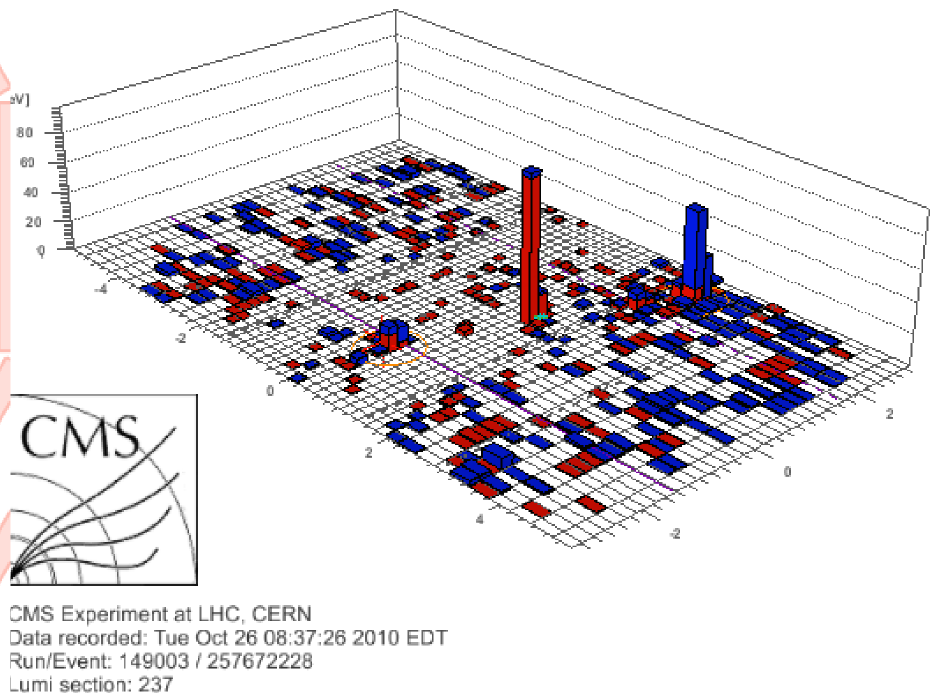

CDF 10fb^{-1}
SM
LHCb 3fb^{-1}
CMS 25fb^{-1}
CMS+LHCb preliminary
0
1
2
3
4
5
6
7
$B(B^0 \to \mu^+\mu^-)$ [10^{-10}]

Leptoquarks

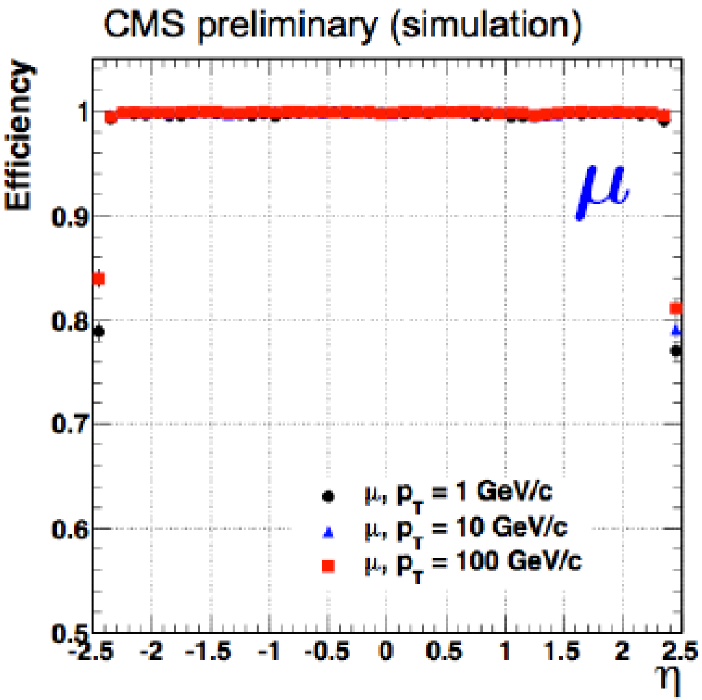
An LQ carries color, has fractional electric charge, can have spin 0 or spin 1, and couples to a lepton and a quark with coupling strength β!

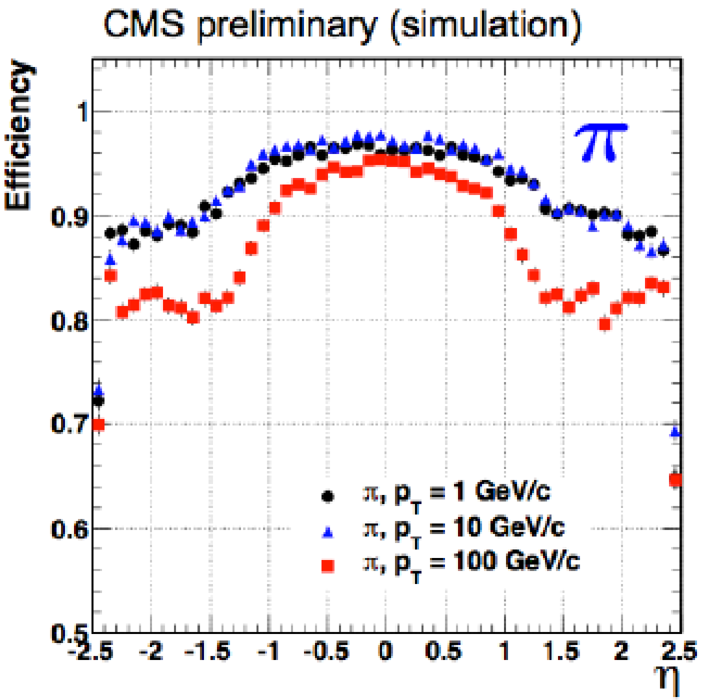
An LQ would decay to a charged lepton and a quark, with an unknown branching fraction λ, or a neutrino and a quark, with branching fraction 1- β





Tracker Performance

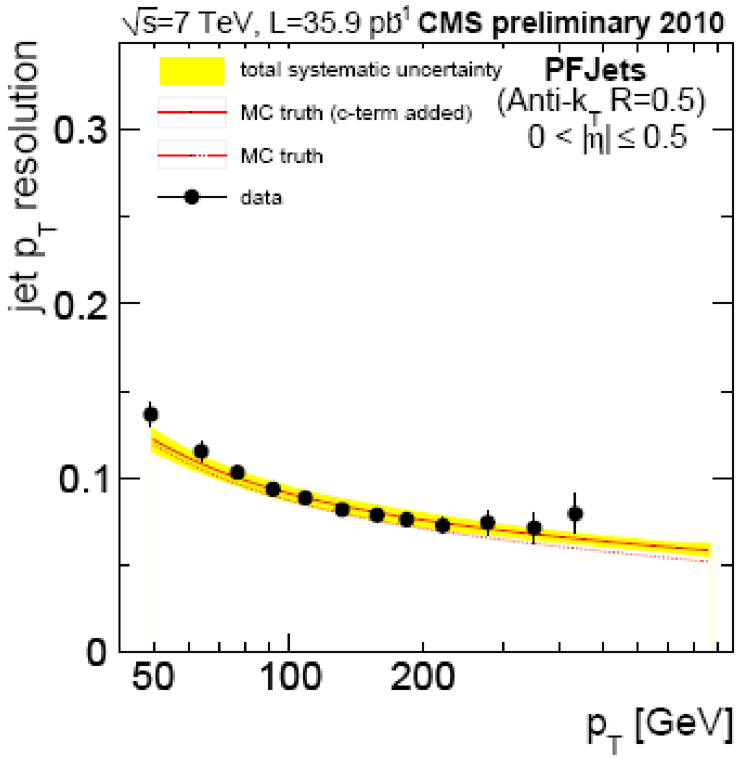




$$\frac{\sigma(p_T)}{p_T} \approx 10^{-4} \cdot p_T \oplus 0.005$$

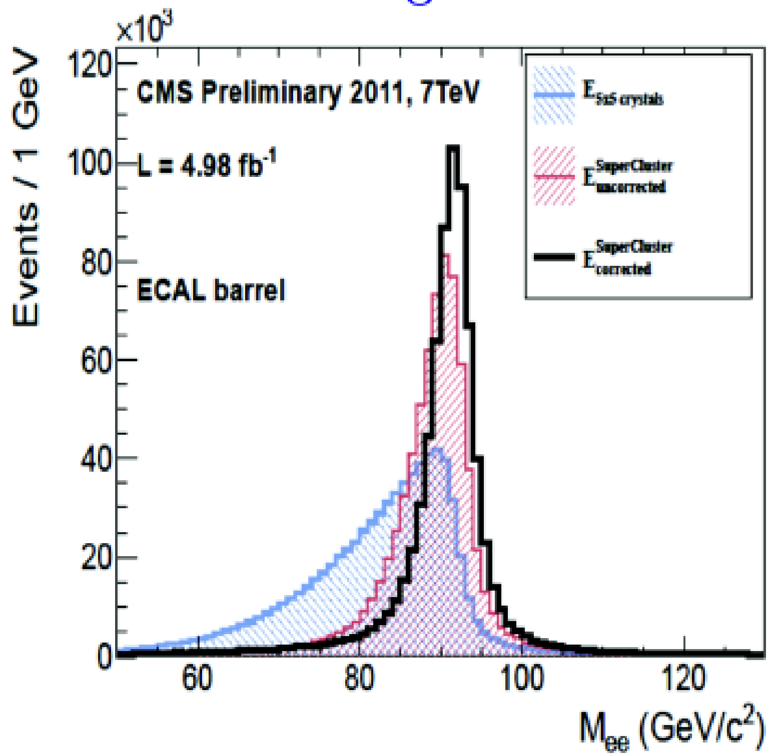
Calorimeter Performance

PF Jet p_T resolution



$$\frac{\sigma(E)}{E} \approx \frac{1.0}{\sqrt{E}} \oplus 0.05$$

ECAL Clustering and Bremsstrahlung Corrections



$$\frac{\sigma(E)}{E} \approx \frac{0.03}{\sqrt{E}} \oplus 0.003$$