CMS Highlights

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On behalf of the CMS Collaboration

V Jornadas del CPAN
November 25th-27th, 2013
Santiago de Compostela (Spain)

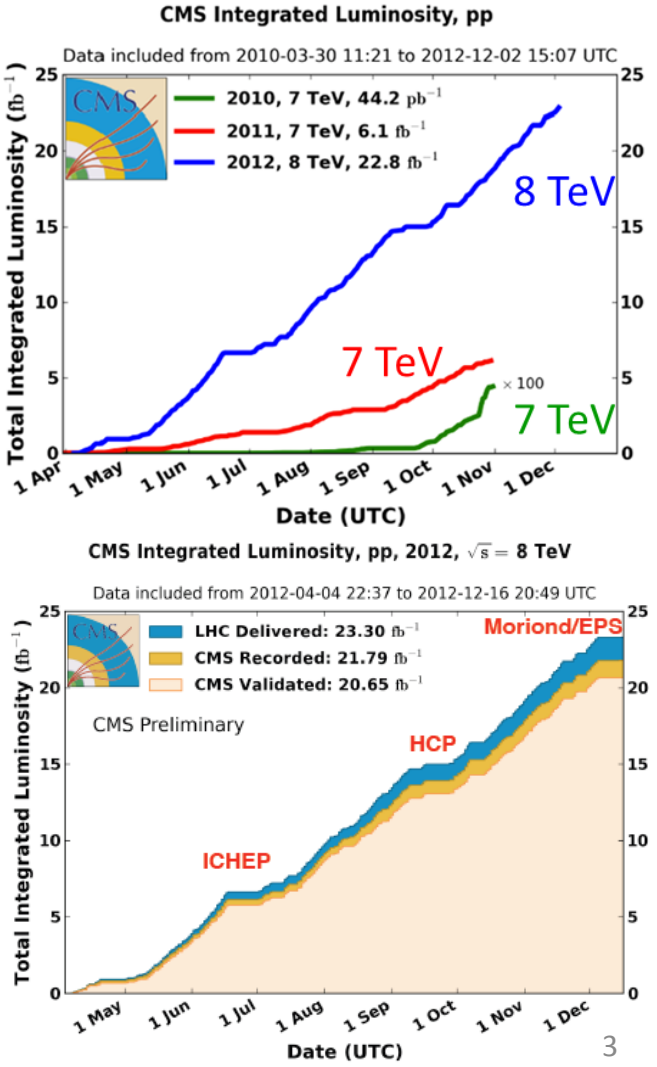
Outline

- LHC and CMS operations
- Precise measurement of standard model processes:
  - ◇ Jet and electroweak production
  - ◇ Top physics
  - ◇ B rare decays
- Physics of the Higgs boson:
  - ◇ Summary of Higgs boson discovery and properties
  - ◇ Highlights of recent results
- Searched for beyond standard model physics:
  - ◇ Supersymmetry, dark matter, exotica
- Recent results in heavy ions physics
- Summary

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

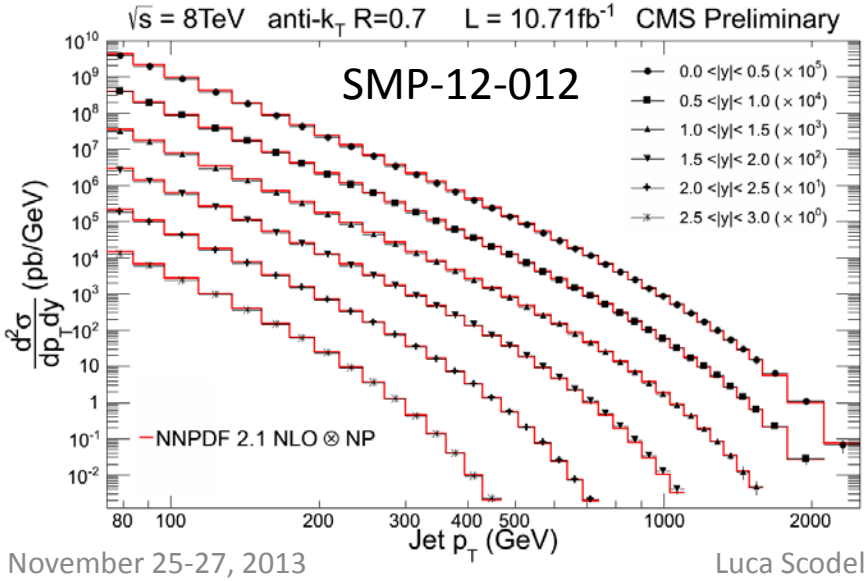
LHC and CMS Operations

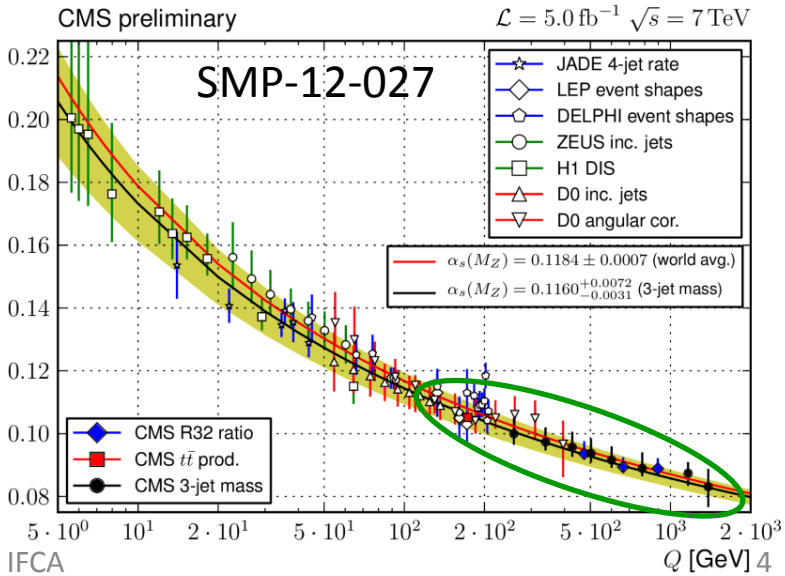
- The Large Hadron Collider delivered pp collisions from 2010 to 2012:
  - ◇ ~6 fb^{-1} of pp collisions at $\sqrt{s}$ = 7 TeV
  - ◇ ~23 fb^{-1} of pp collisions at $\sqrt{s}$= 8 TeV
- The CMS detector proved itself very efficient collection and reconstructing event at high instantaneous luminosity:
  - ◇ ~94% of delivered data were recorded
  - ◇ ~89% of delivered used in analyses
- Also collected heavy ion collision data:
  - ◇ ~150 μb of PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV during 2011
  - ◇ ~31 nb^{-1} of pPb collisions at $\sqrt{s_{pN}}$ = 5.02 TeV during 2013



Jet Production

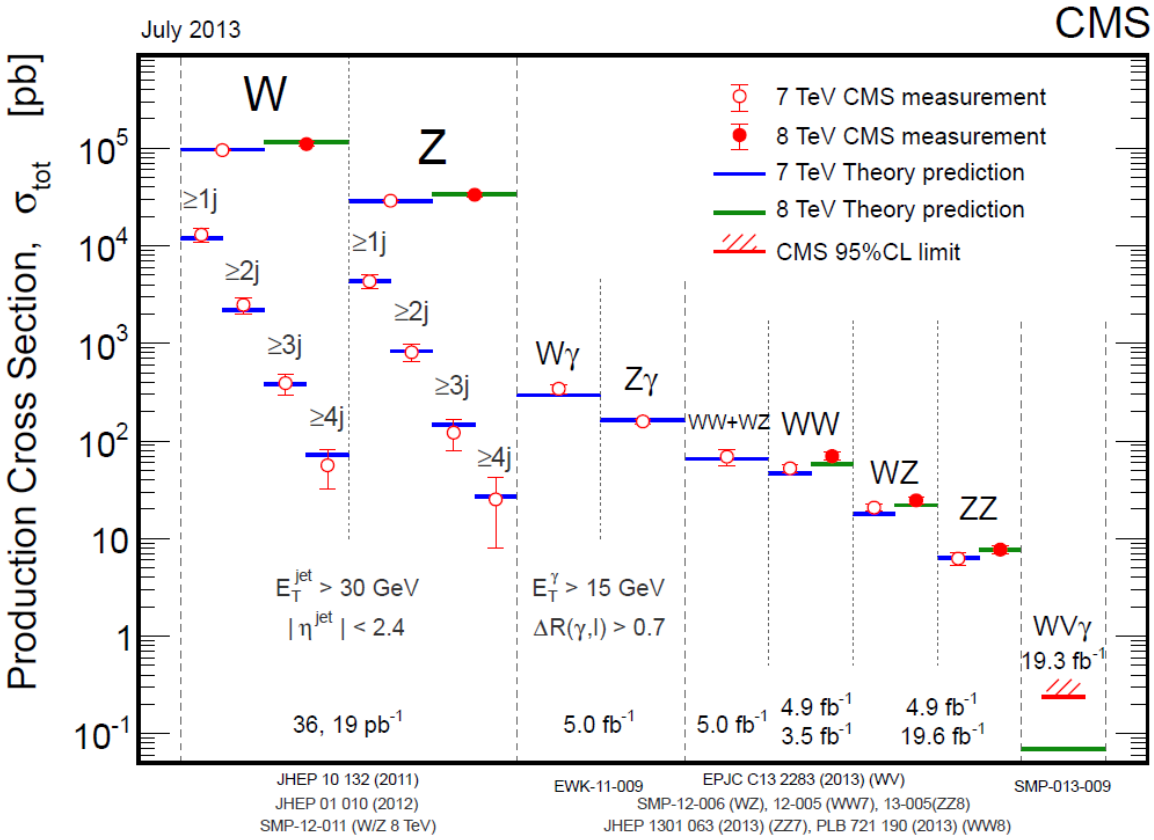
- Differential cross section for inclusive jet production at 8 TeV:
  - ◇ Agreement with NLO⊗NP QCD over ≥7 orders of magnitude
  - ◇ CMS data can be used to constrain the fits of the PDFs
- New measurements of α_s(Q) from 3 jet mass differential cross section and from 3 to 2 jet cross section ratio:
  - ◇ Sensitivity in high Q regime



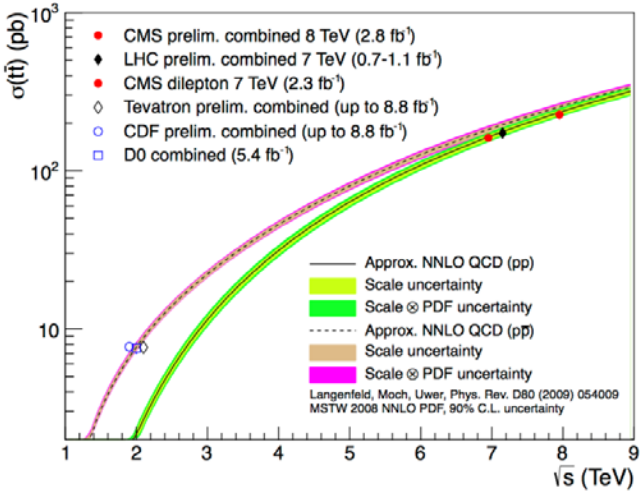


EWK Boson Production

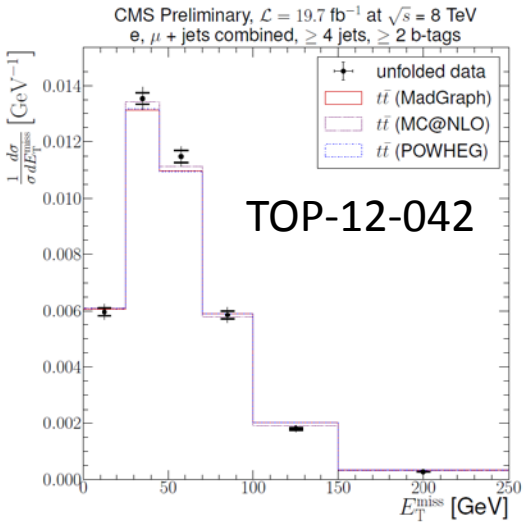
- Cross sections for boson and diboson production:
  - ◇ Good agreement over ~4 order of magnitude

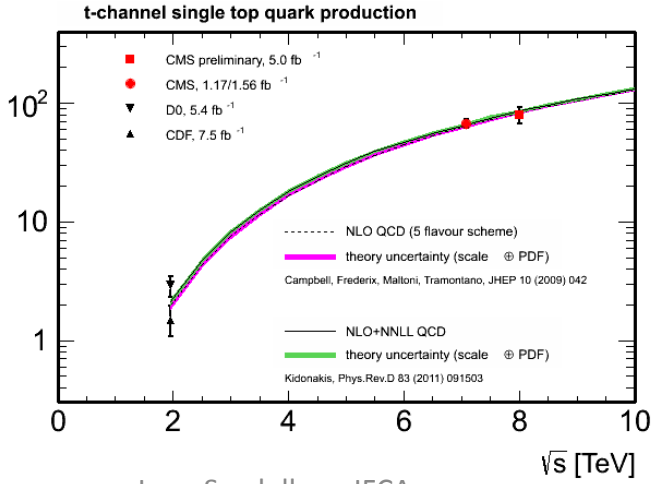


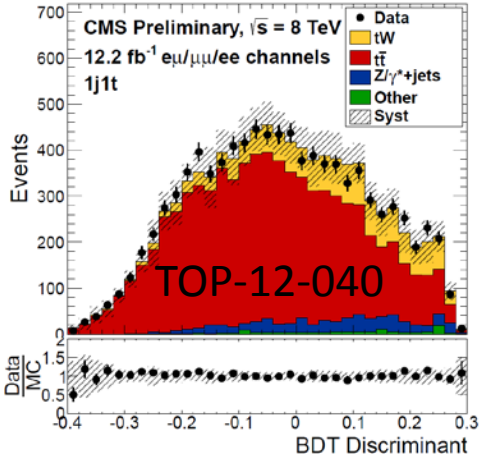
Top Quark Production



- Top pair production cross section precision challenging approx. NNLO QCD calculations
  - ◇ Now testing the theory with precise shape measurements of differential cross sections
- Single top quark production well established also in association to a W boson:
  - ◇ $\sigma(pp \longrightarrow tW+X) = 23.4^{+5.5}_{-5.4}$ pb (6.0σ evidence)

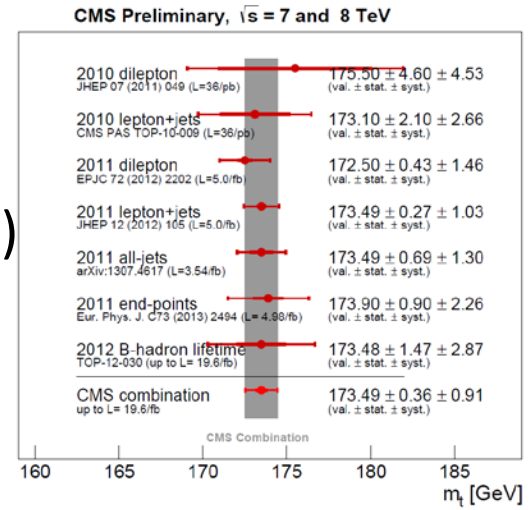


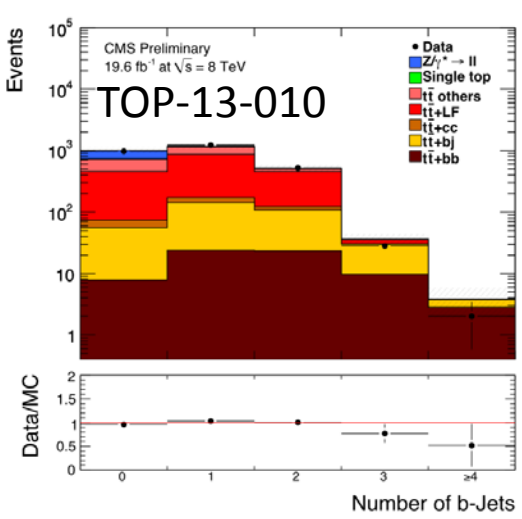


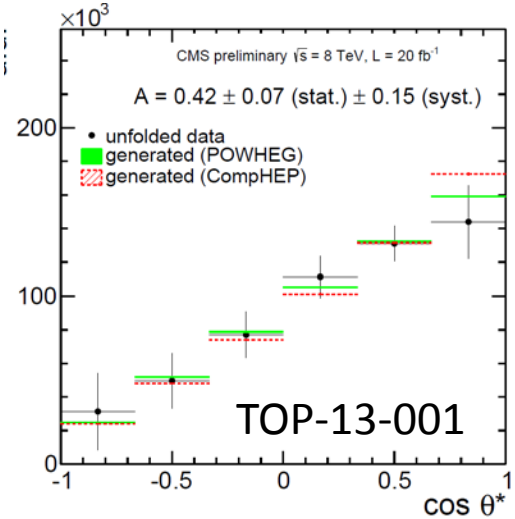


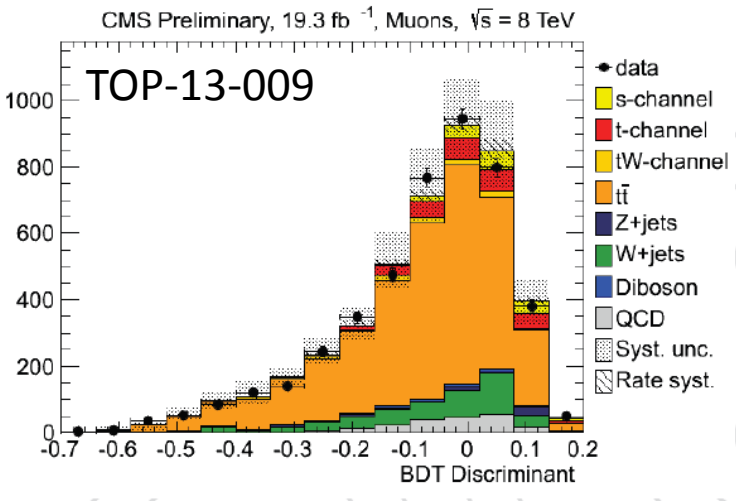
Recent Top Physics Results

- Combined m_t measurement with 0.6% precision
- $t\bar{t}b\bar{b}$ production cross section at 8 TeV:
- $\sigma(t\bar{t}b\bar{b})/\sigma(t\bar{t}jj)$ = 0.022 ± 0.004(stat) ± 0.005(syst)
- Top polarization in single top t-channel:
  - P_t = 0.82 ± 0.12(stat) ± 0.32(syst)
- Upper limit $\sigma^{\text{single top}}_{\text{s-channel}}$ < 11.5 pb @ 95% CL



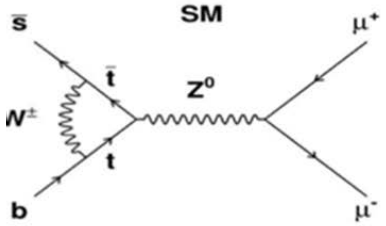






$B^0_{(s)} \to \mu^+\mu^-$

- Rare decays, BR sensitive to new particles



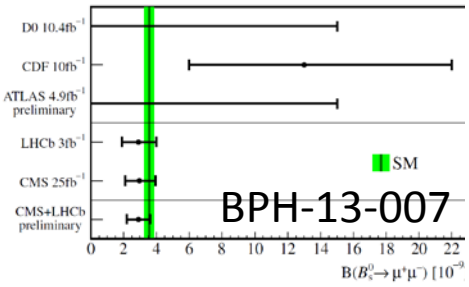
Mode	SM prediction
$B_s \to \mu^+\mu^-$	$(3.54 \pm 0.30) \times 10^{-9}$
$B^0 \to \mu^+\mu^-$	$(0.11 \pm 0.01) \times 10^{-9}$

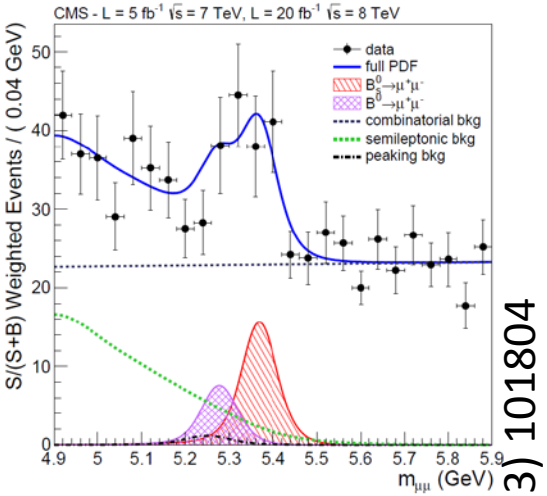
A. Buras et al., arXiv:1208.0934

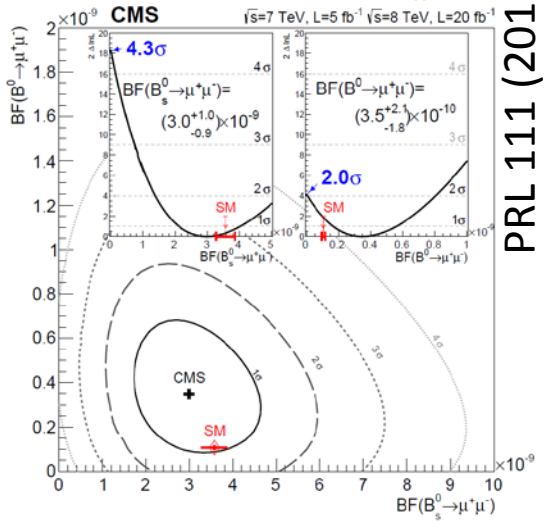
DeBruyn et al., arXiv:1204.1737

C. Davies, arXiv:1203.3862 (and ref. therein)

- CMS results:
  - ◇ $BR(B_s \to \mu^+\mu^-) = (3.0^{+1.0}_{-0.9}) \times 10^{-9}$ (4.3σ evidence)
  - ◇ $BR(B^0 \to \mu^+\mu^-) < 1.1 \times 10^{-9}$ @ 95% C.L.
- Combination with LHCb:
  - ◇ $BR(B_s \to \mu^+\mu^-) = (2.9 \pm 0.7) \times 10^{-9}$
  - ◇ >5σ combined significance
- No sign of new physics yet







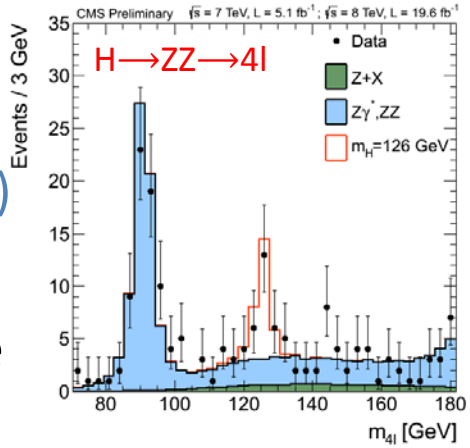
PRL 111 (2013) 101804

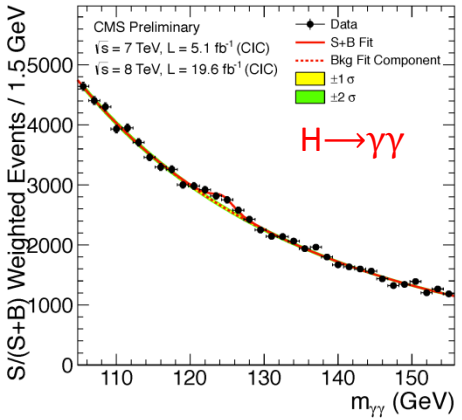
Higgs Boson Signals

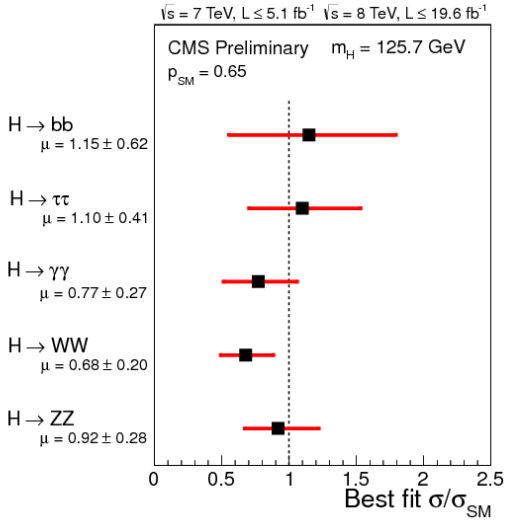
- Signal well established in the discovery channels

  $M_H = 125.7 \pm 0.3(stat) \pm 0.3(syst)$

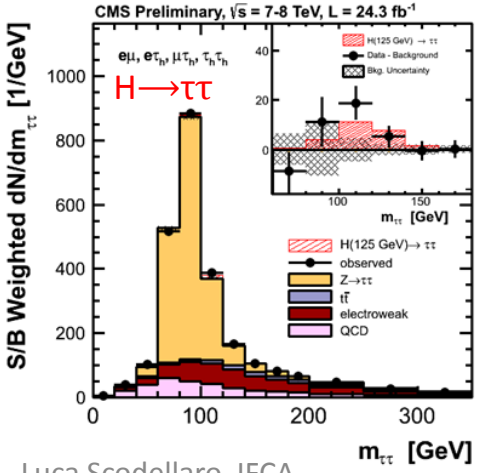
- Signal strengths compatible with SM expectations

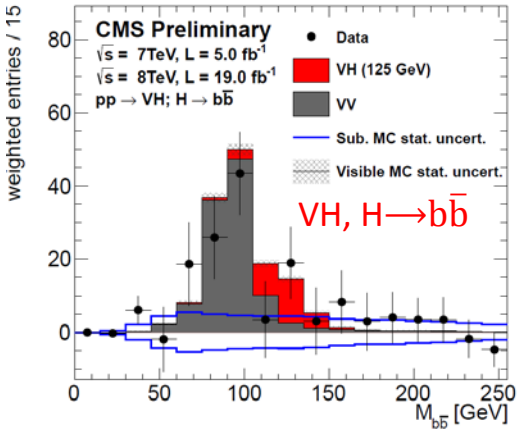






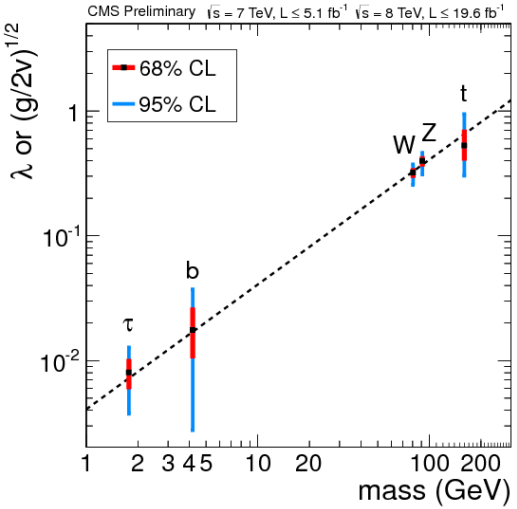
- 3σ combined evidence in fermionic channels

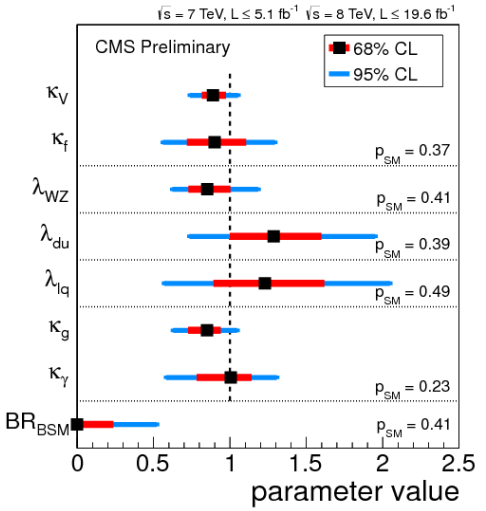




Higgs Properties

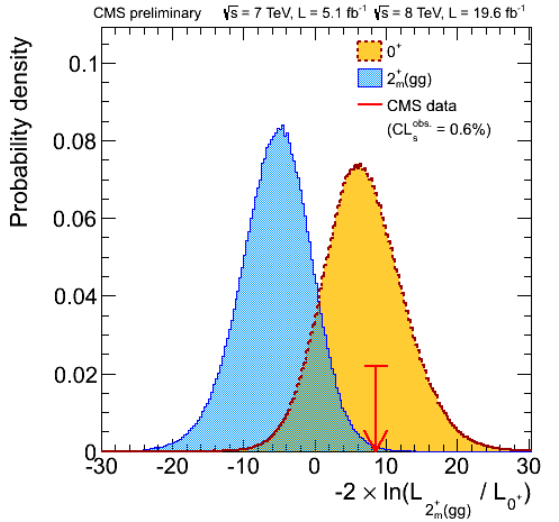
- Couplings from simultaneous fits to observed signals:
  - ◇ Consistent with SM
  - ◇ Test to custodial symmetry, fermion universality and effects from new physics





- Spin and parity from angular distributions in WW, ZZ and γγ:
  - ◇ SM prediction JP = 0+ highly favorite vs. other hypotheses

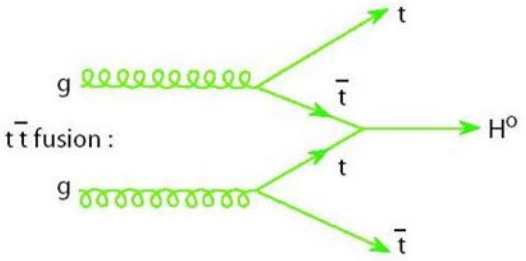
J^P	CL_S
0^-	0.16%
0^+_h	8.1%
2^+_{mgg}	1.5%
2^+_{mqq}	<0.1%
1^-	<0.1%
1^+	<0.1%

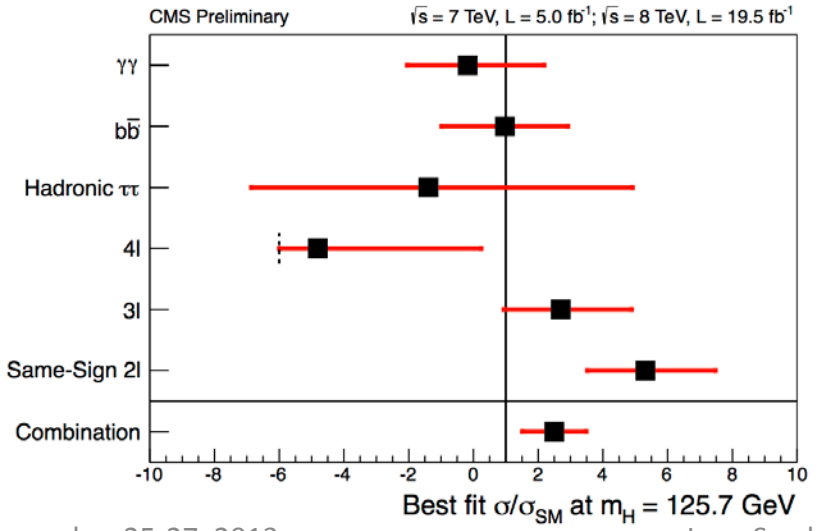


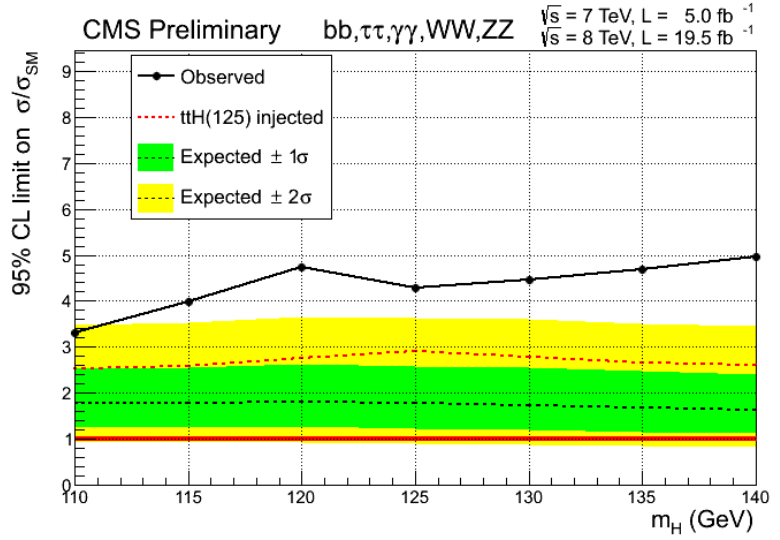
It is an Higgs boson!

$t\bar{t}H$

- Important test of the Yukawa coupling of the top quark
- Several final states from top and Higgs decays:
  - ◇ Higgs to Multi-leptons, $b\bar{b}$, $\tau\tau$, or $\gamma\gamma$
- Combined sensitivity on signal strength $\mu<2$:
  - ◇ Excess driven by same sign dimuon channel
  - ◇ Expected factor ~5 in production at 13 TeV

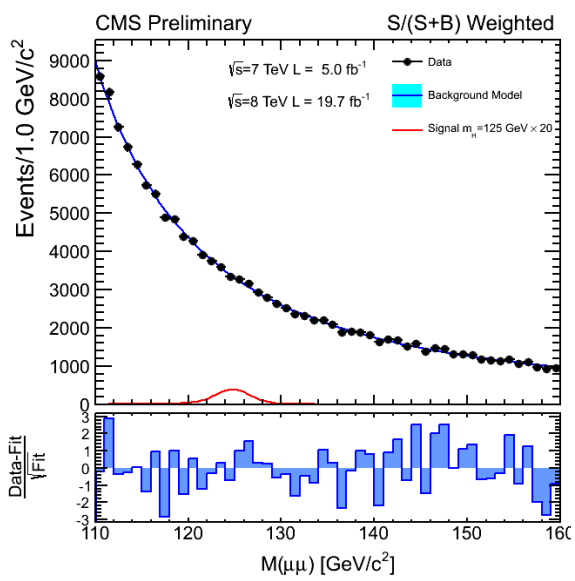


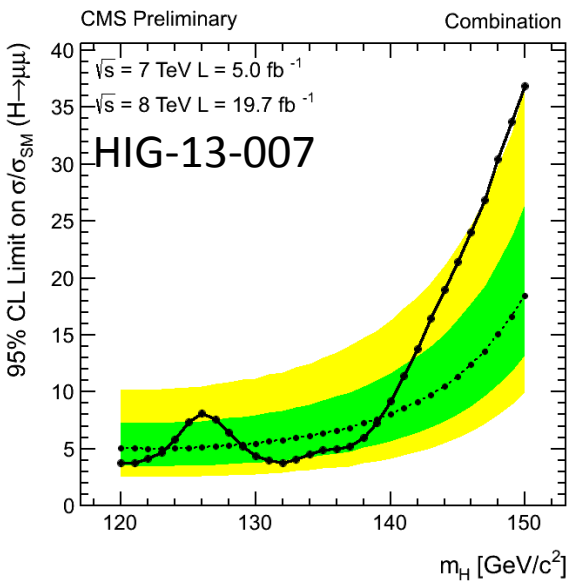


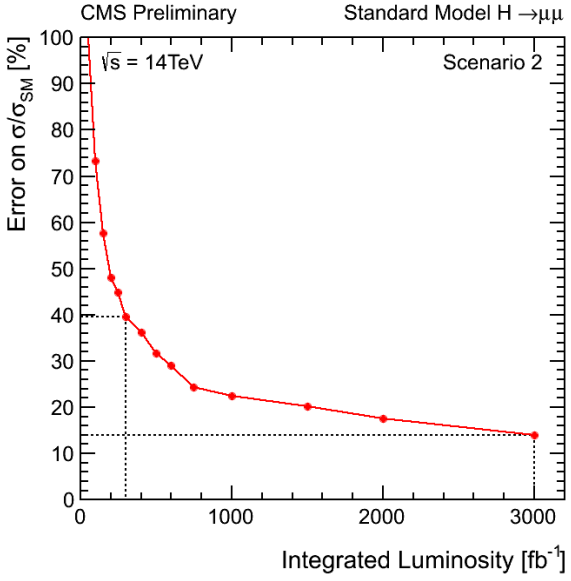


$H \rightarrow \mu^+\mu^-$

- Interesting test of the Yukawa coupling for 2nd generation fermions
  - ◇ Expected branching ratio in the SM is BR($H \rightarrow \mu^+\mu^-$) = 2.2 x 10^{-4}
- Inclusive search for gluon fusion and vector boson fusion production:
  - ◇ Observed (expected) upper limit for m_H=125 GeV is $\mu = \sigma/\sigma_{SM}$<7.4 (5.2)
- RunII can reach a precision of 40% (14%) on μ with 300 (3000) fb^{-1}

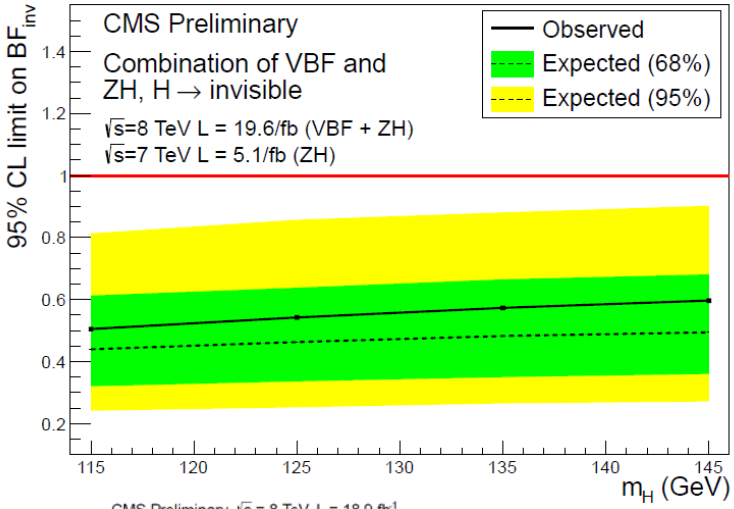


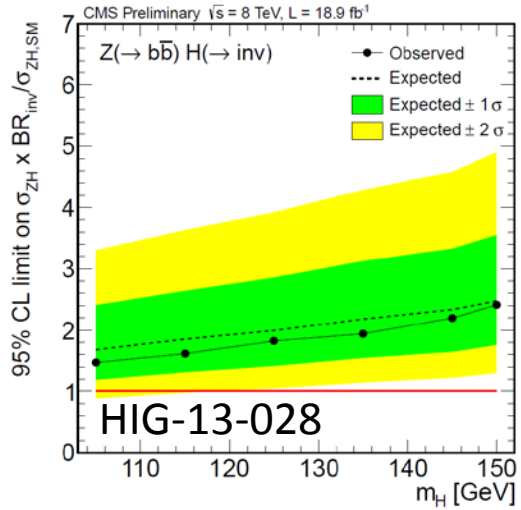




Higgs to Invisible

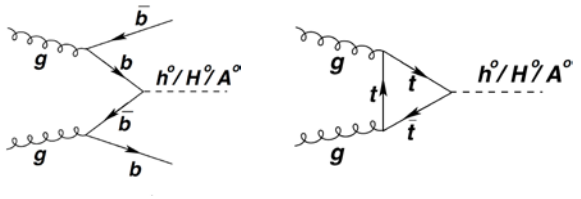
- Sensitive to new physics:
  - ◇ Higgs into LSP or dark matter
  - ◇ Decay particles into extra-dimensions
- Combination of two analyses:
  - ◇ ZH production, with Z→ll and H→χχ
  - ◇ VBF: MET + 2 jets with large Δη
- Assuming SM cross sections:
  - ◇ BR(H→ νν)<0.54 for m_H=125 GeV
- New search for ZH → $b\bar{b}\chi\chi$:
  - ◇ Sensitivity at ≲2 times the standard model production

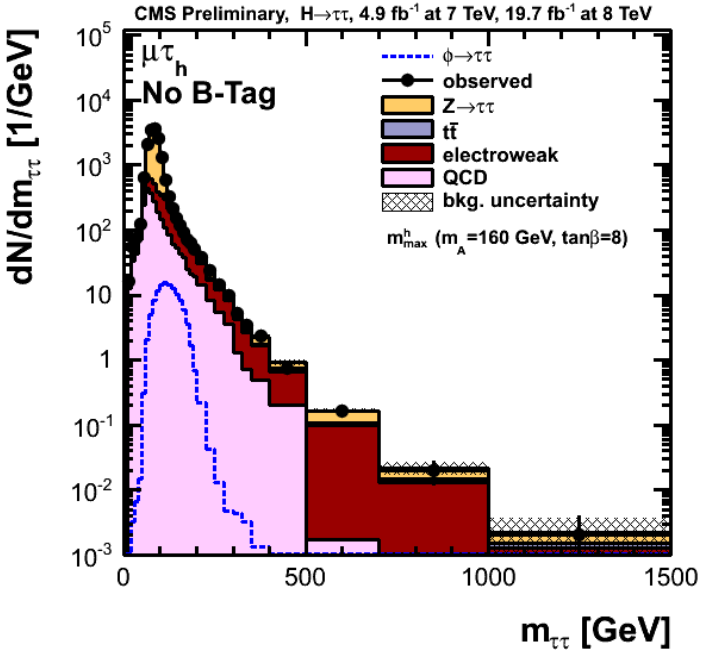


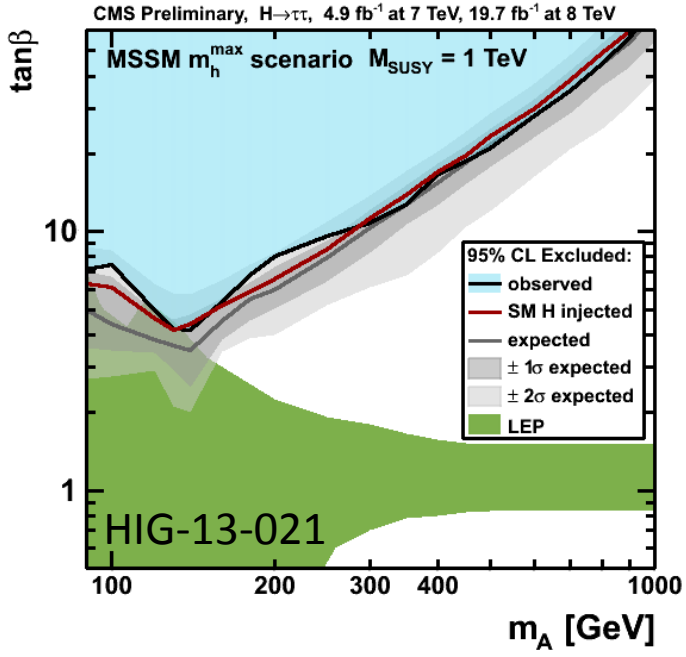


MSSM Higgs Bosons

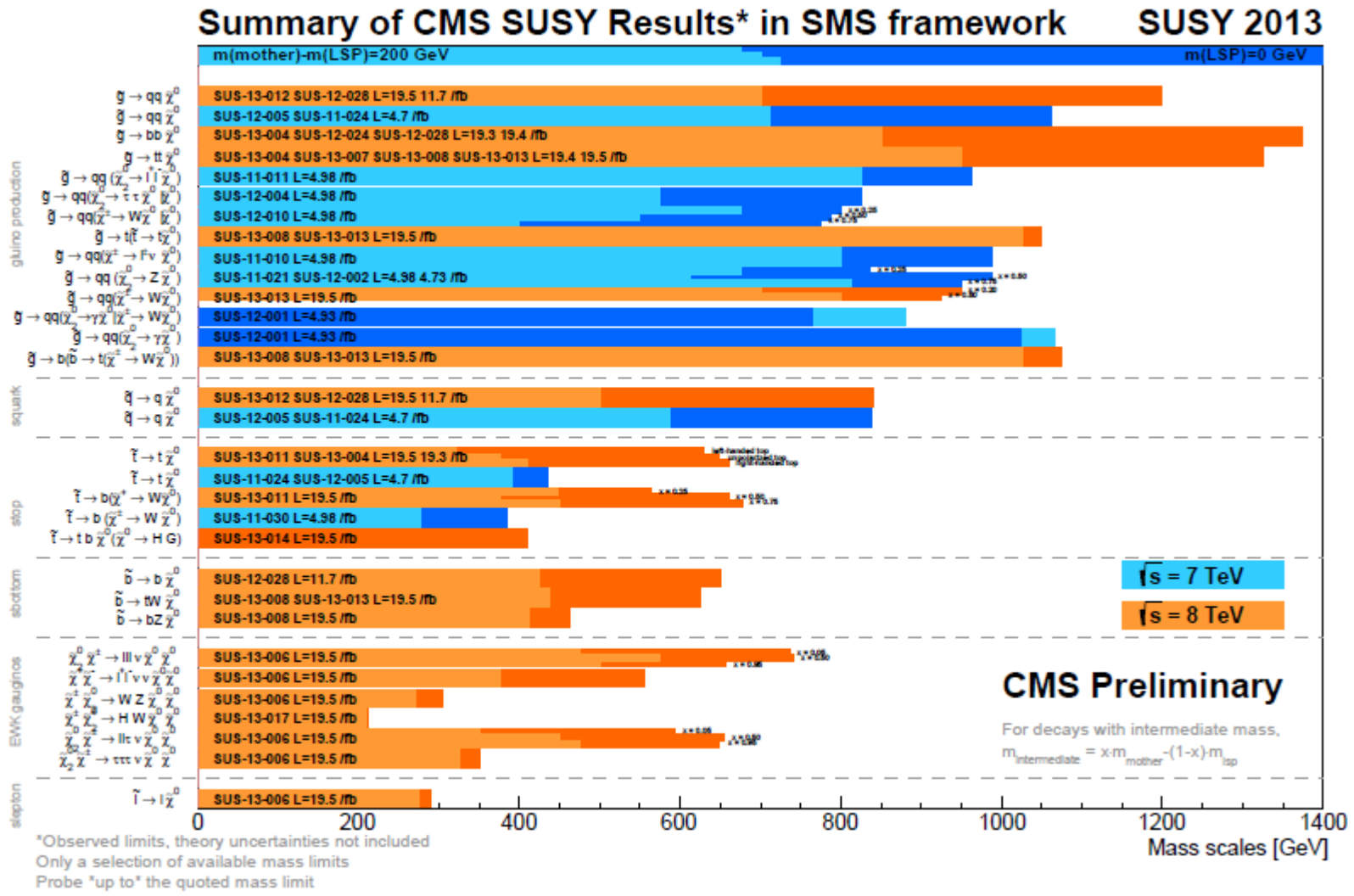
- CMS searched for $\phi^0 \to b\bar{b}$, $\tau\tau$, $\mu\mu$ and for $H^{\pm}$ signals
- Recent result for $\phi^0 \to \tau\tau$:
  - ◇ Including production associated to $b\bar{b}$
  - ◇ No evidence for a MSSM Higgs boson





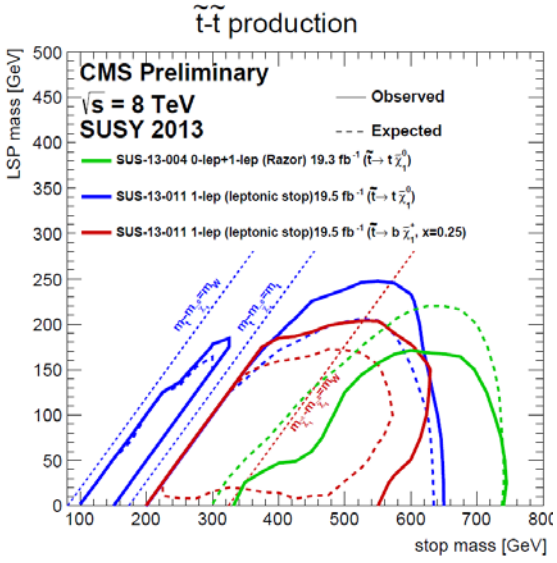


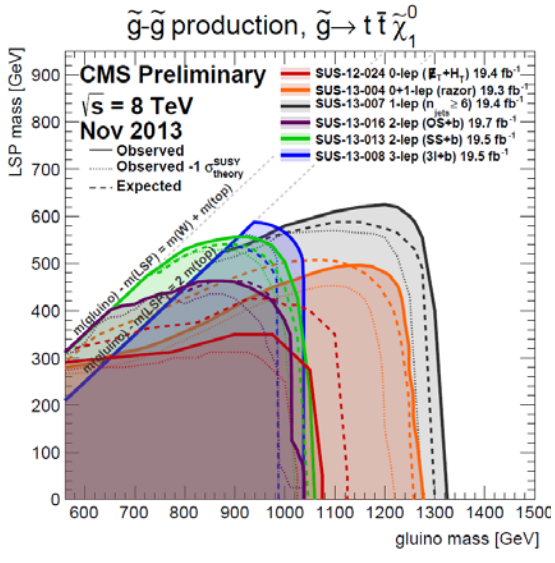
Supersymmetry

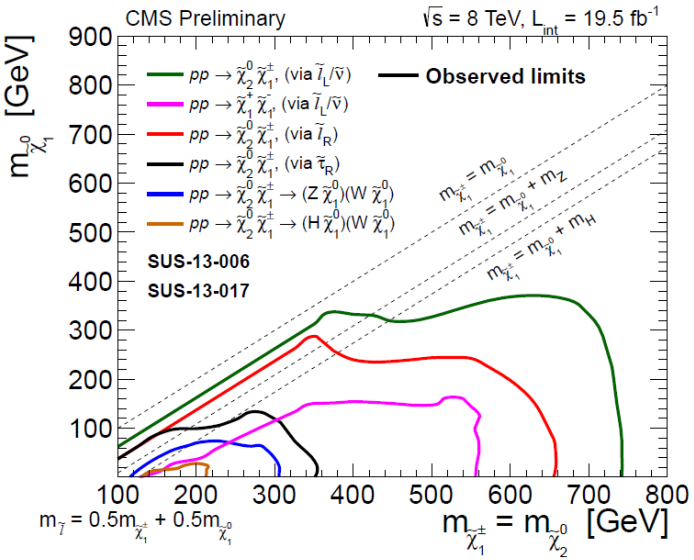


Supersymmetry

- Focus on natural SUSY and light third generation:
  - ◇ Searches for direct and gluino mediated stop production
  - ◇ Limits at ~700 GeV for stop mass and ~1.3 TeV for gluino mass
- Searches for electroweakino ($\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm$) pair production
  - ◇ Mass limits between 200-700 GeV depending on the decay model

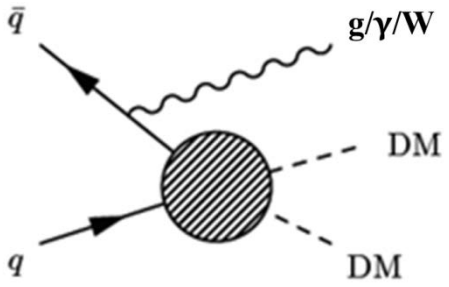


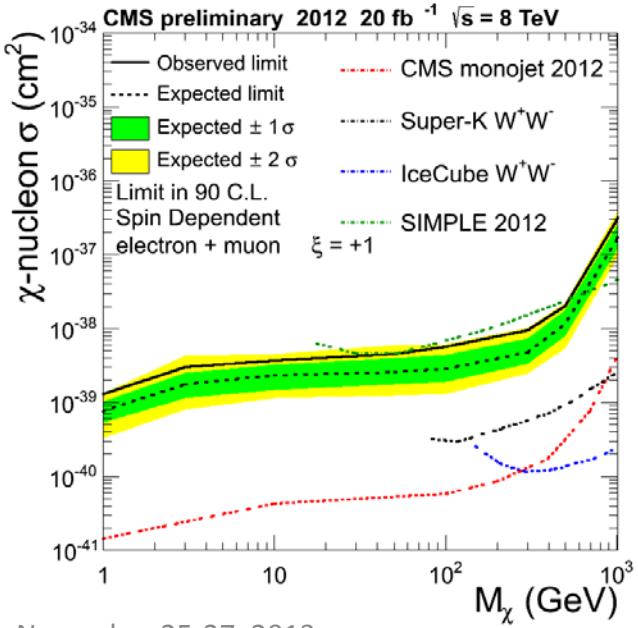


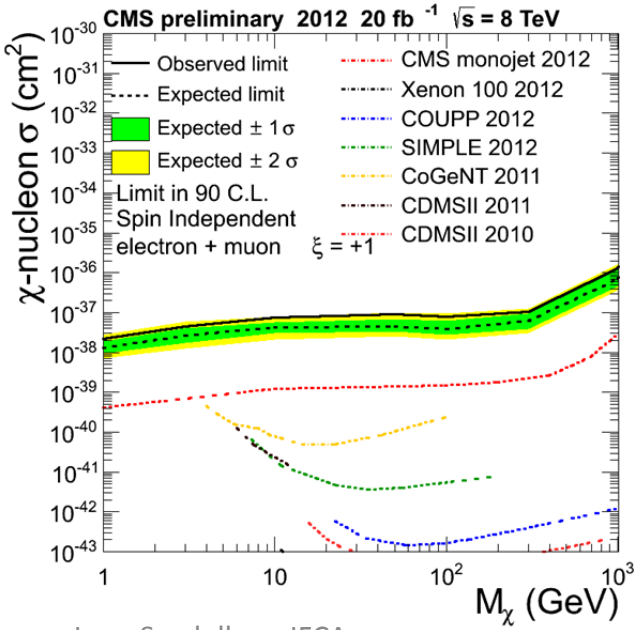


Dark Matter

- Searches for DM production in association to g, γ or W(⟶lν):
  - ◇ Monojet, monophoton or monolepton final states
- Limits dependent on mediator nature:
  - ◇ Vector mediator ⟶ spin independent
  - ◇ Axial-vector mediator ⟶ spin dependent





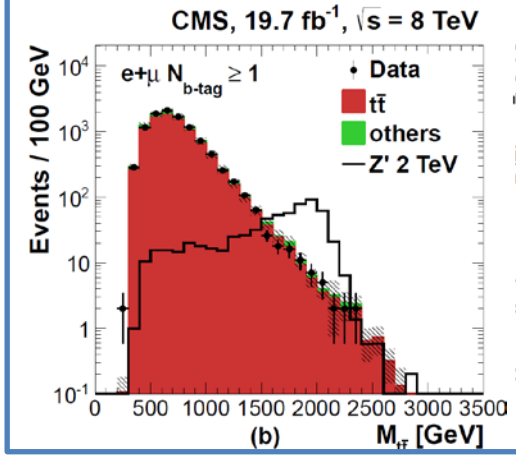


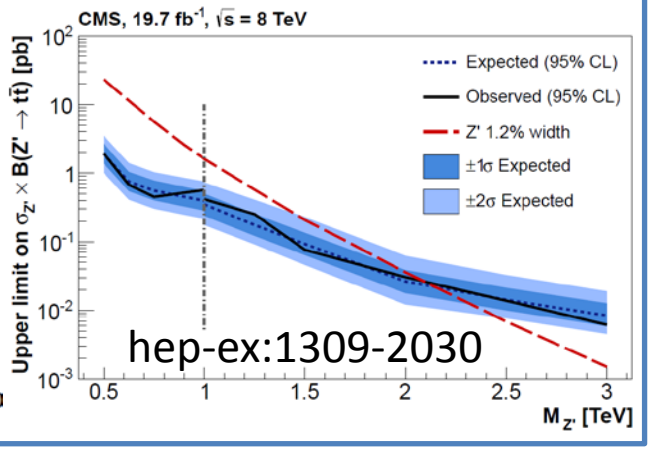
Latest results from monolepton channel EXO-13-004

Also shown results from monojet channel EXO-12-048

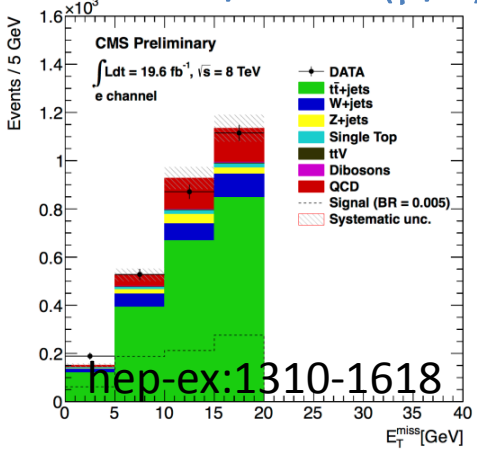
Beyond 2 Generations

- Resonances in $t\bar{t}$ pair production:
  - ◇ M>2 TeV for Z' resonances with $\Gamma_{Z'}/M_{Z'}$=1.2%

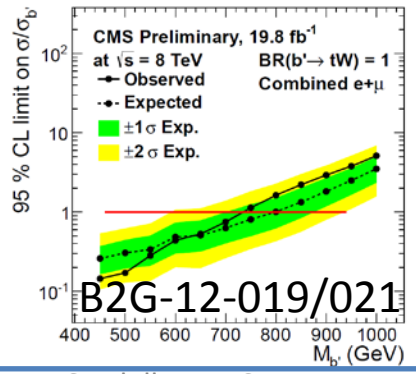


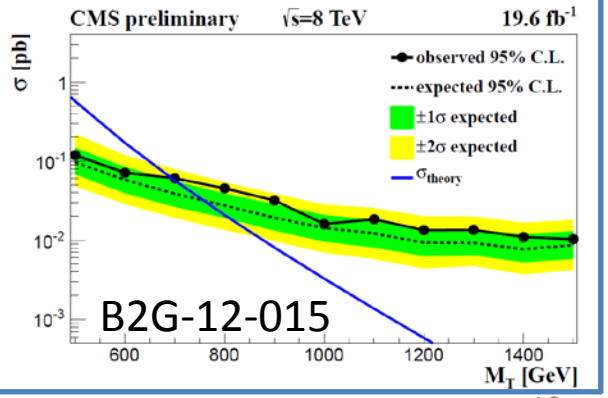


- BNV $t \to bql$ decay:
  - ◇ B<0.16/0.17%(μ/e)

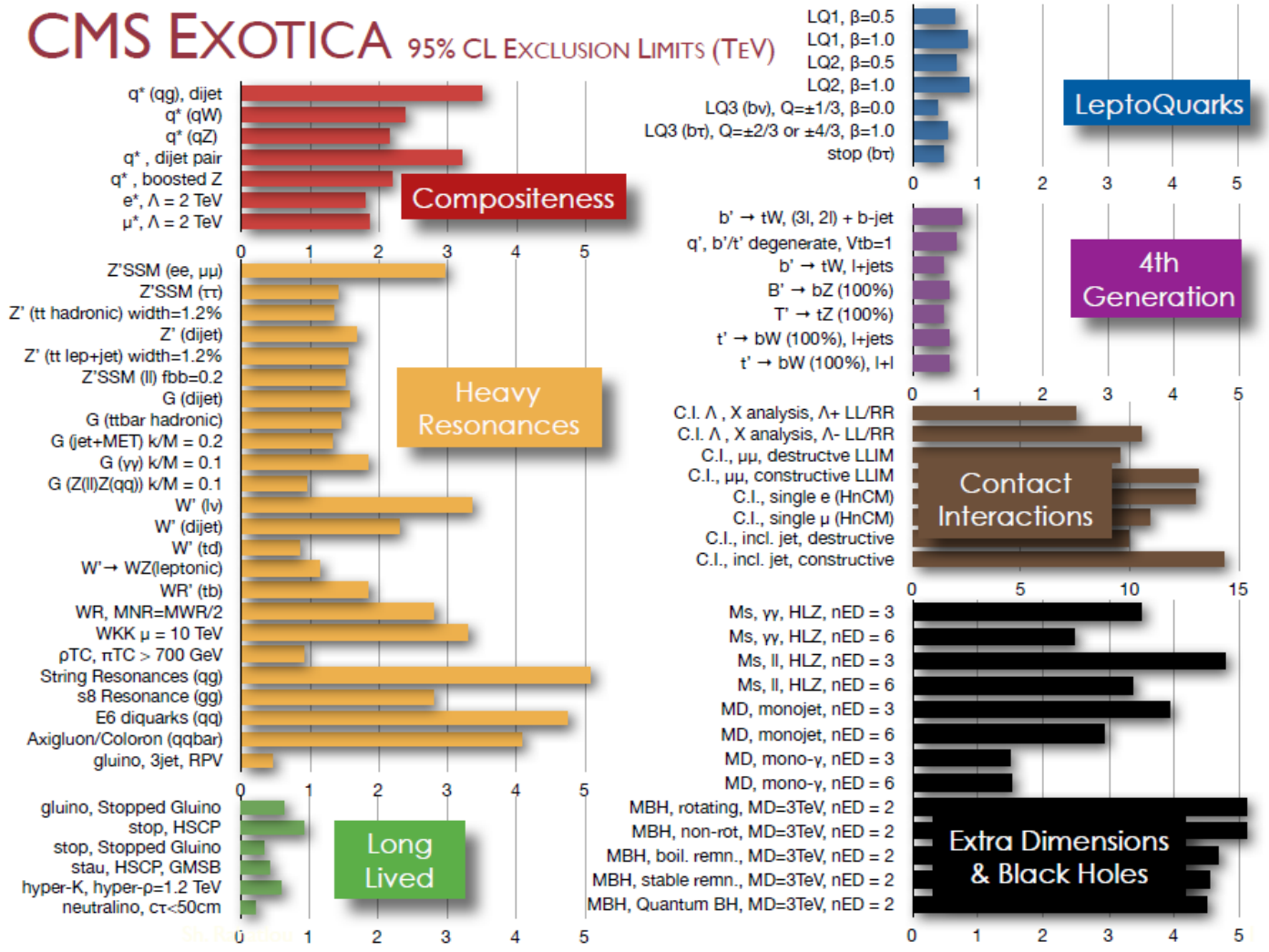


- Vector-like partners of b and t quarks:
  - ◇ $m_{b'} > 582\text{-}732$ GeV
  - ◇ $m_T > 690 \div 782$ GeV



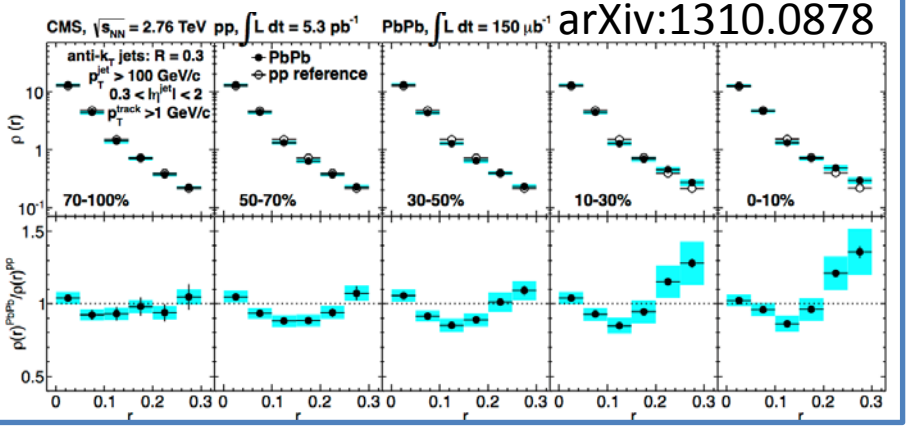


Summary of Exotica Searches



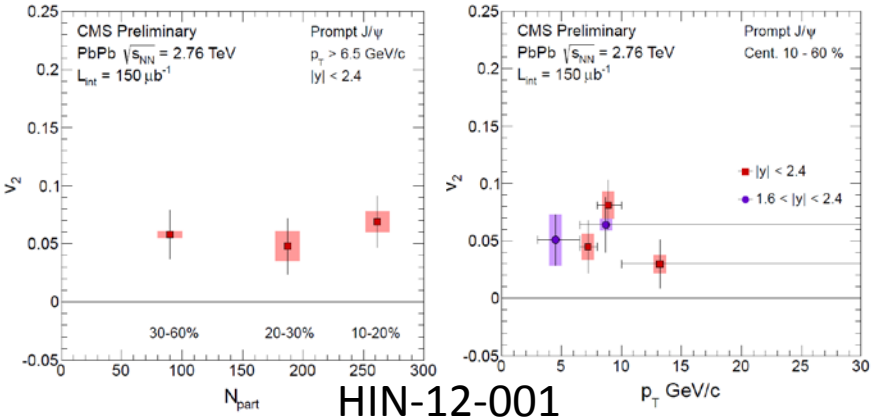
Recent Results in Heavy Ions Physics

- First measurement of jet shapes:
  - Radial distribution of p_T in the jet
  - pp collisions used as a reference
  - Broadening of jets in the medium for most central PbPb collisions



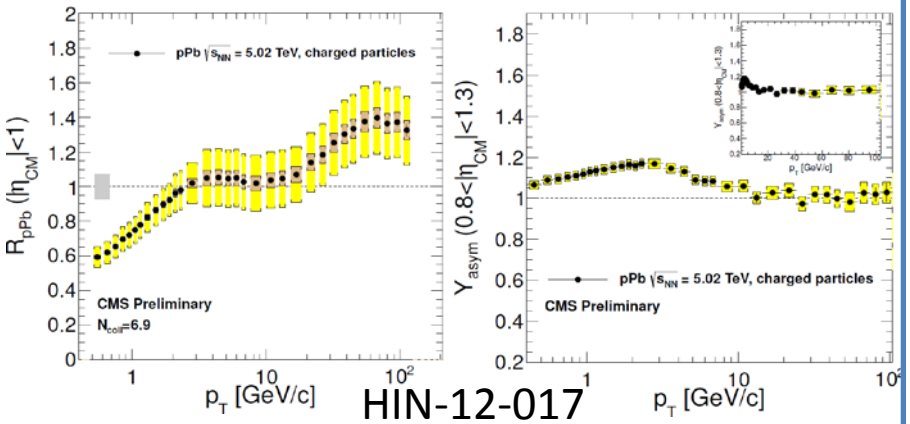
arXiv:1310.0878

- Prompt J/ψ azimuthal anisotropy:
  - No strong kinematic dependence



HIN-12-001

- Charged particle p_T spectra in pPb
  - R_{pPb} and charge asymmetry



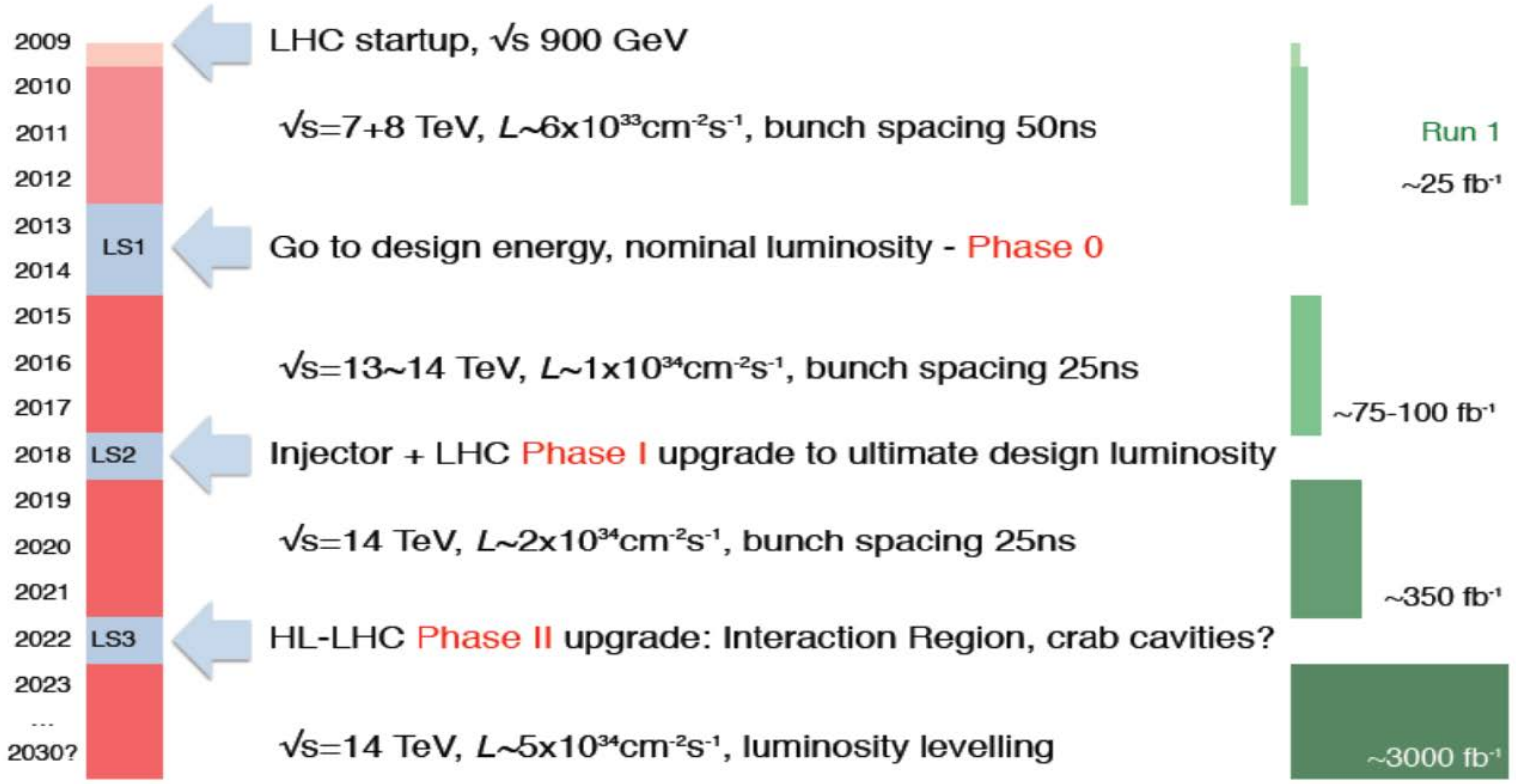
HIN-12-017

Summary

- Very successful two years of data taking at the LHC
- Precise measurements of SM processes:
  - ◇ Top physics reaching Tevatron precision and exploring new channels
- Discovery of an Higgs boson and measurement of its properties:
  - ◇ Now testing new production mechanisms and rare decay modes
- Searches for beyond the standard model phenomena:
  - ◇ Supersymmetry, dark matter, exotica
- Results for B and heavy ion physics competitive with those from dedicated experiments

Now focusing on CMS detector upgrade to meet the challenges of RunII data taking at high energy and high luminosity

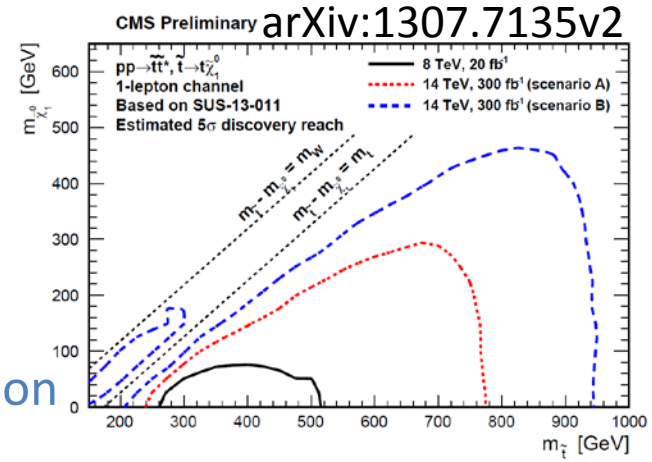
LHC Schedule and CMS Upgrade

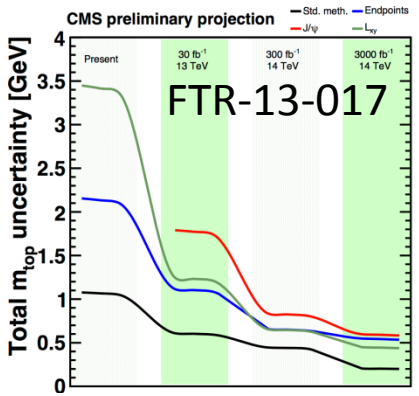


- LS1: complete muon coverage (ME4), improve muon trigger, DT electronics, replace HCAL photo-detectors in Forward (new PMTs) and Outer (HPD→SiPM)
- LS2: new pixel detector, HCAL SiPM and electronics, L1 trigger upgrade
- LS3: new tracker and forward detectors, further trigger upgrade

CMS Physics Program Priorities

- Data taking up to ~2022 (300 fb^{-1}):
  - ◇ Measure Higgs boson properties
  - ◇ Search for new physics at higher mass scale
- Data taking with HL-LHC (3000 fb^{-1}):
  - ◇ Measure Higgs couplings with ultimate precision
  - ◇ Study vector boson scattering
  - ◇ Search for new physics in rare processes





arXiv:1307.7135v2

L (fb^{-1})	$\gamma\gamma$	WW	ZZ	bb	$\tau\tau$	$Z\gamma$	$\mu\mu$	inv.
300	[6, 12]	[6, 11]	[7, 11]	[11, 14]	[8, 14]	[62, 62]	[40,42]	[17, 28]
3000	[4, 8]	[4, 7]	[4, 7]	[5, 7]	[5, 8]	[20, 24]	[20,24]	[6, 17]

FTR-13-016

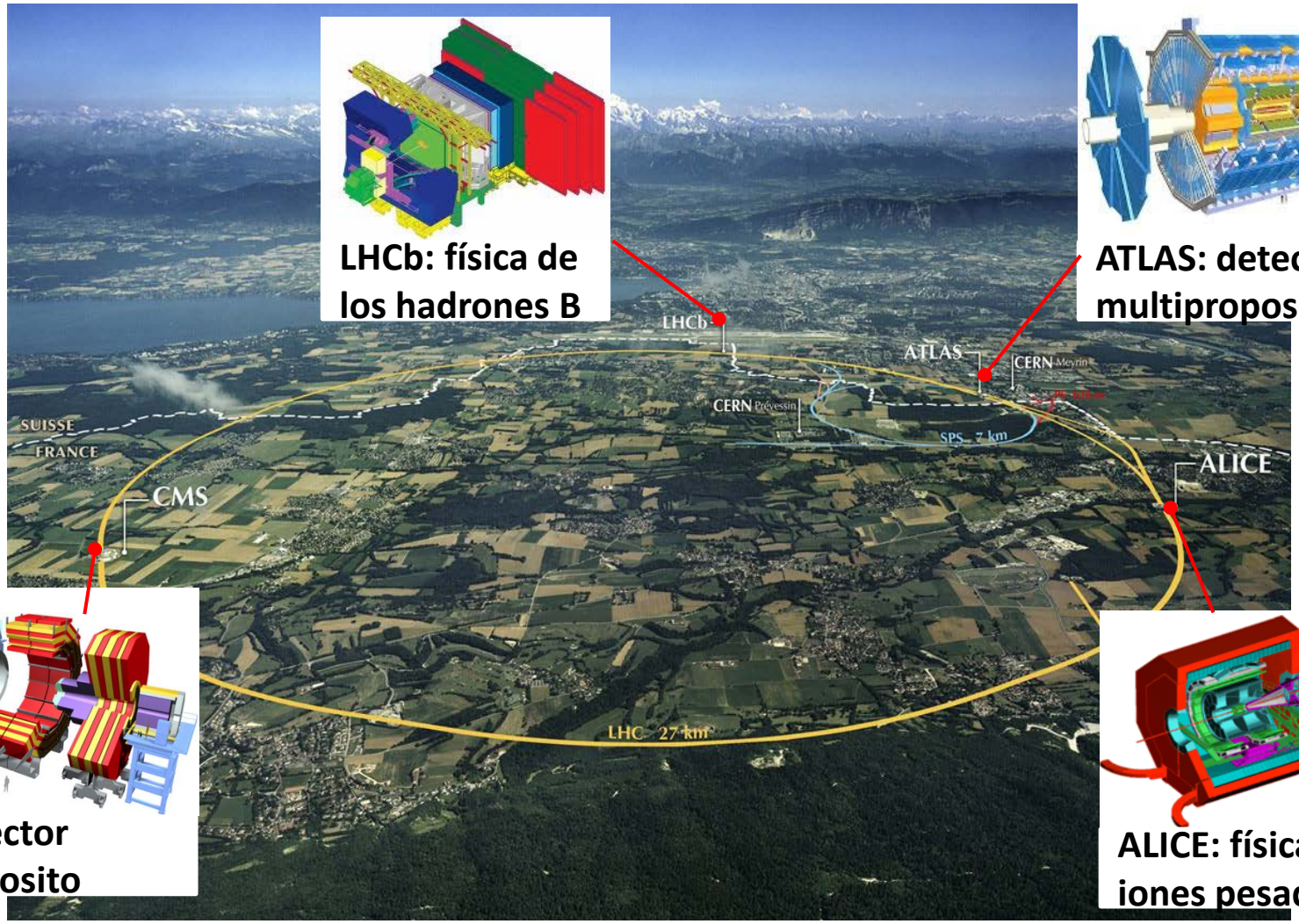
$\mathcal{B}(t \to Zq)$	19.5 fb^{-1} @ 8 TeV	300 fb^{-1} @ 14 TeV	3000 fb^{-1} @ 14 TeV
Exp. bkg. yield	3.2	26.8	268
Expected limit	$< 0.10\%$	$< 0.027\%$	$< 0.010\%$
1 σ range	$0.06 - 0.13\%$	$0.018 - 0.038\%$	$0.007 - 0.014\%$
2 σ range	$0.05 - 0.20\%$	$0.013 - 0.051\%$	$0.005 - 0.020\%$

FTR-13-006

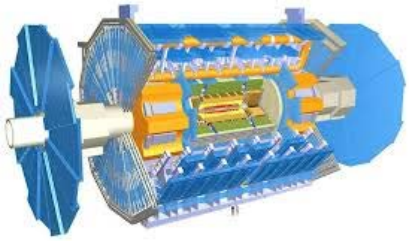
Significance	3σ	5σ
SM EWK scattering discovery	75 fb^{-1}	185 fb^{-1}
f_{T1}/Λ^4 at 300 fb^{-1}	0.8 TeV^{-4}	1.0 TeV^{-4}
f_{T1}/Λ^4 at 3000 fb^{-1}	0.45 TeV^{-4}	0.55 TeV^{-4}


Backup Material

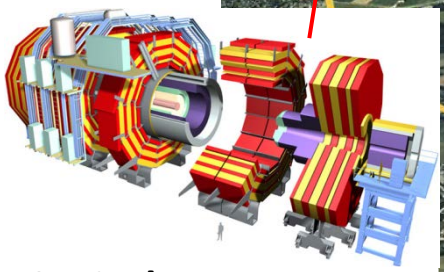
The Large Hadron Collider



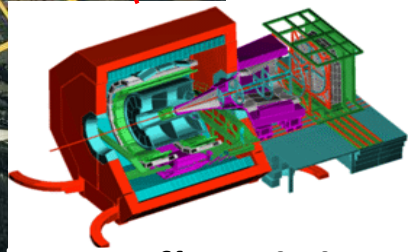
LHCb: física de los hadrones B



ATLAS: detector multiproposito

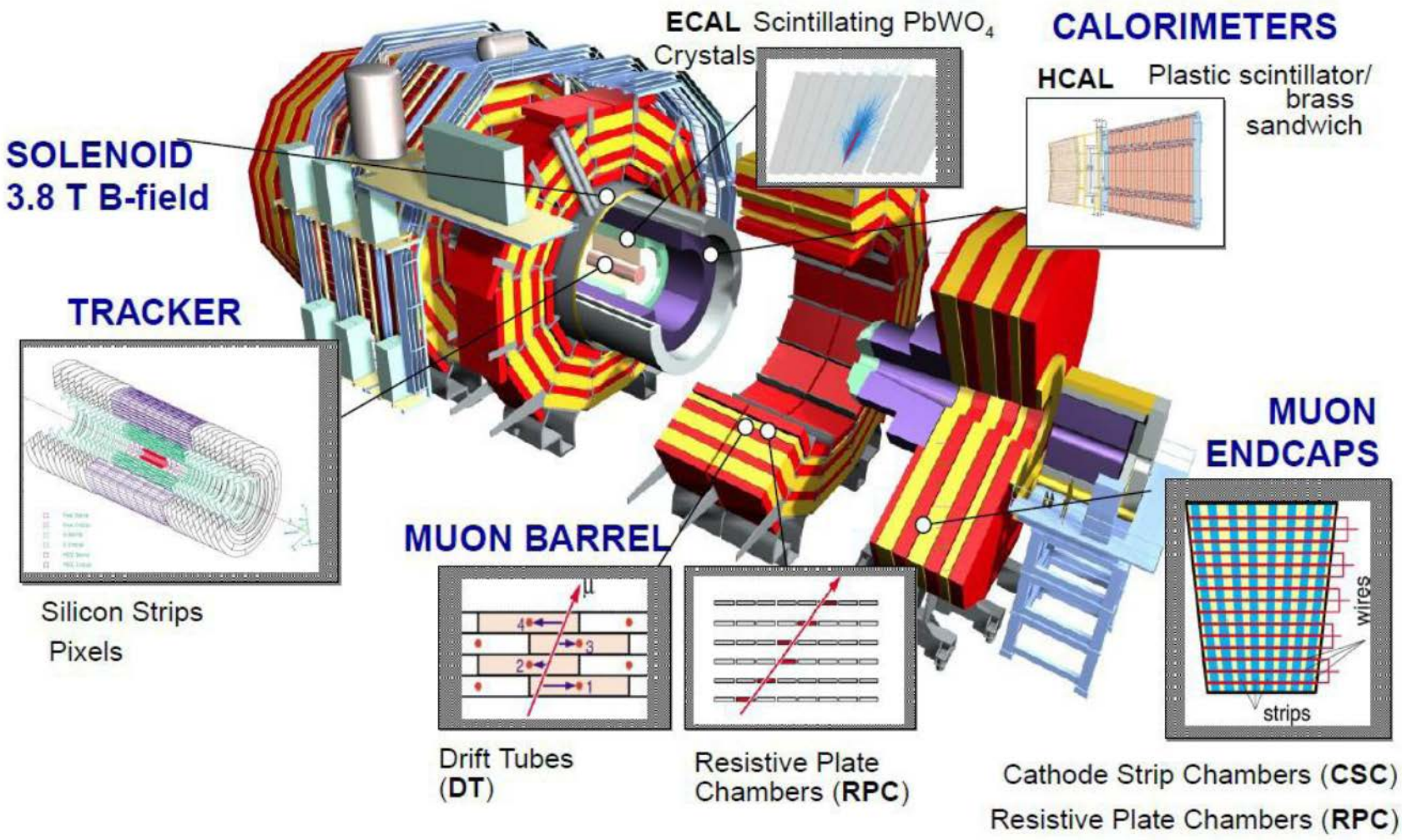


CMS: detector multiproposito



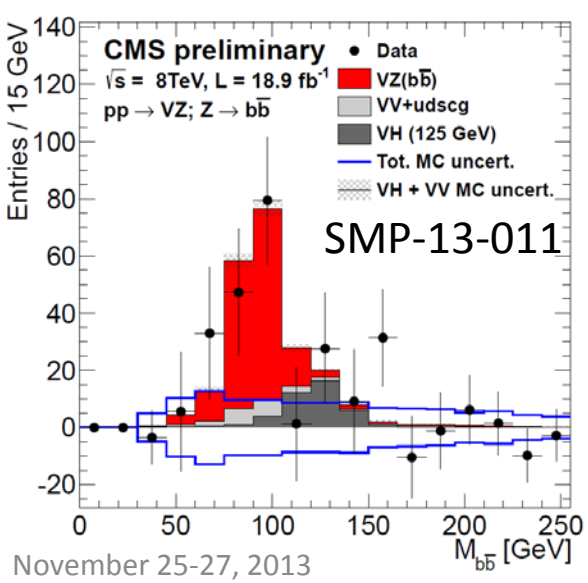
ALICE: física de los iones pesados

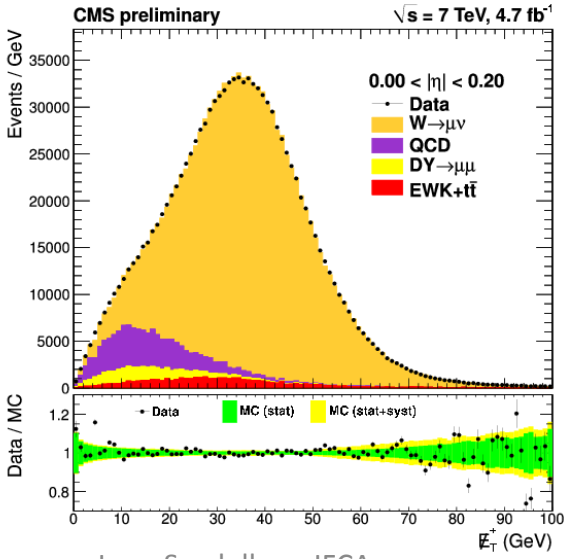
The CMS Detector

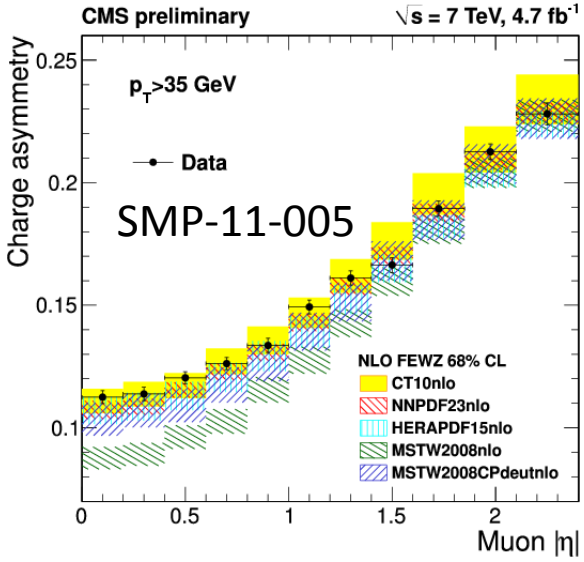


Recent EWK Physics Results

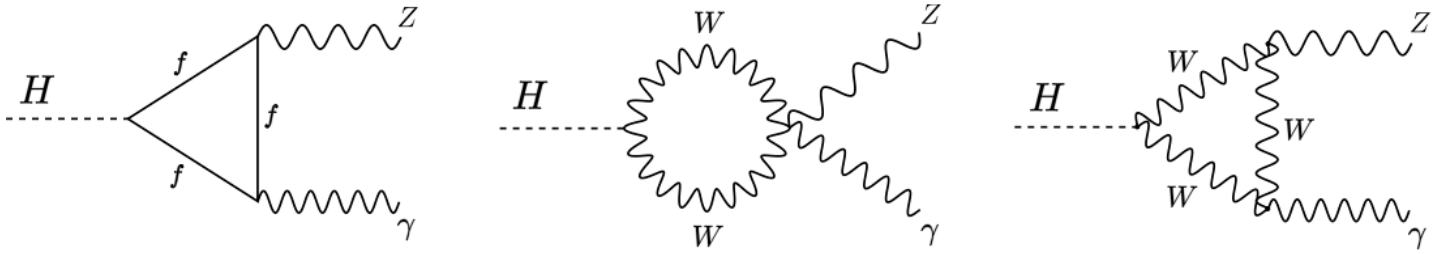
- VZ cross section in the Z → $b\bar{b}$ channel at 8 TeV
  - ◇ $\sigma(pp \to WZ)$ = 30.7 ± 9.3(stat.) ± 7.1(syst.) ± 4.1(theo.) ± 1.0(lumi.) pb
  - ◇ $\sigma(pp \to ZZ)$ = 6.5 ± 1.7(stat.) ± 1.0(syst.) ± 0.9(theo.) ± 0.2(lumi.) pb
- New measurement of W charge asymmetry in the muon channel
  - ◇ W signal extracted by missing E_T distribution
  - ◇ Important constraints to the PDFs







$H \to Z\gamma$


H
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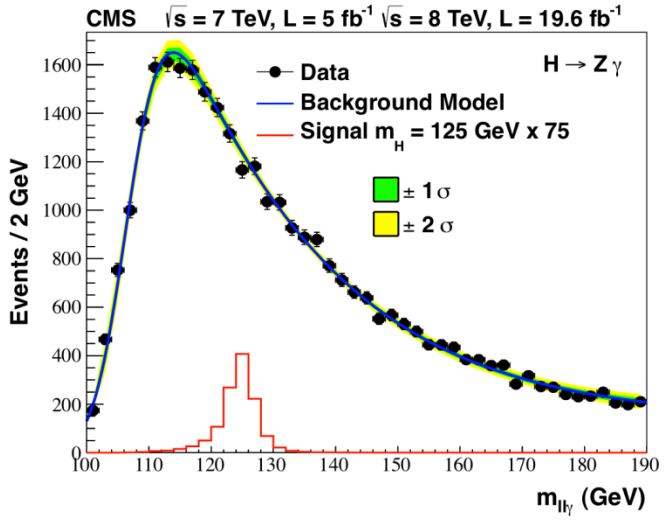
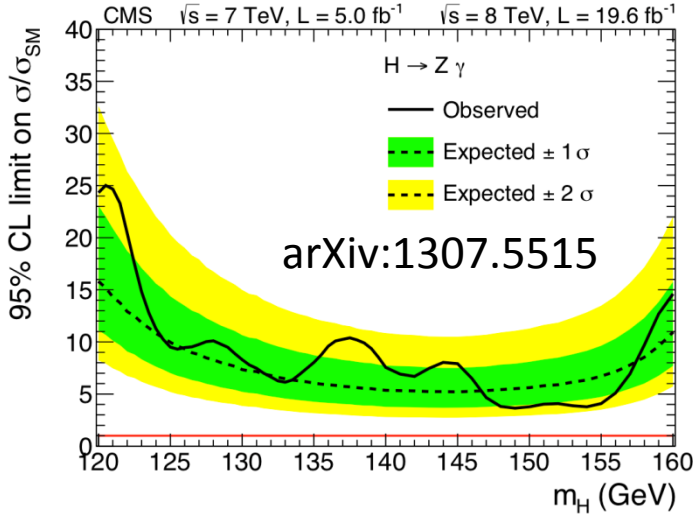

CMS √s = 7 TeV, L = 5 fb-1 √s = 8 TeV, L = 19.6 fb-1
H → Z γ
Data
Background Model
Signal m_H = 125 GeV x 75
± 1 σ
± 2 σ
Events / 2 GeV
m_llγ (GeV)


CMS √s = 7 TeV, L = 5.0 fb-1 √s = 8 TeV, L = 19.6 fb-1
H → Z γ
Observed
Expected ± 1 σ
Expected ± 2 σ
arXiv:1307.5515
95% CL limit on σ/σ_SM
m_H (GeV)

High Mass Higgs