Compact
Muon
Solenoid

Alicia Calderón

Instituto de Física de Cantabria (CSIC-UC)

On behalf of the CMS collaboration

XLII International Meeting
on Fundamental Physics
Benasque, 2014, Jan 29

Outline

- LHC and CMS detector
- Precise measurement of standard model processes:
  - **Jets electroweak production**
  - **Top physics**
  - **B Physics**
- Physics of the Higgs boson:
  - **Summary of Higgs boson discovery and properties**
- Searches for physics beyond the standard model:
  - **Supersymmetry, exotica, dark matter**
- Summary and overview of future program

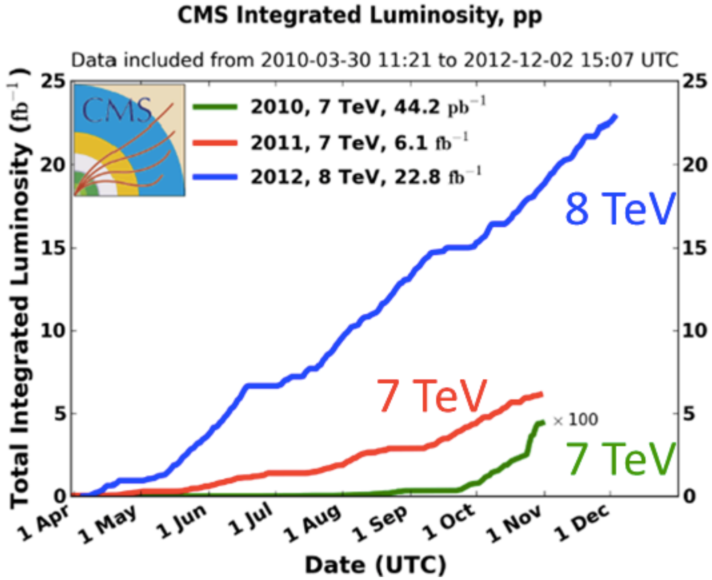
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

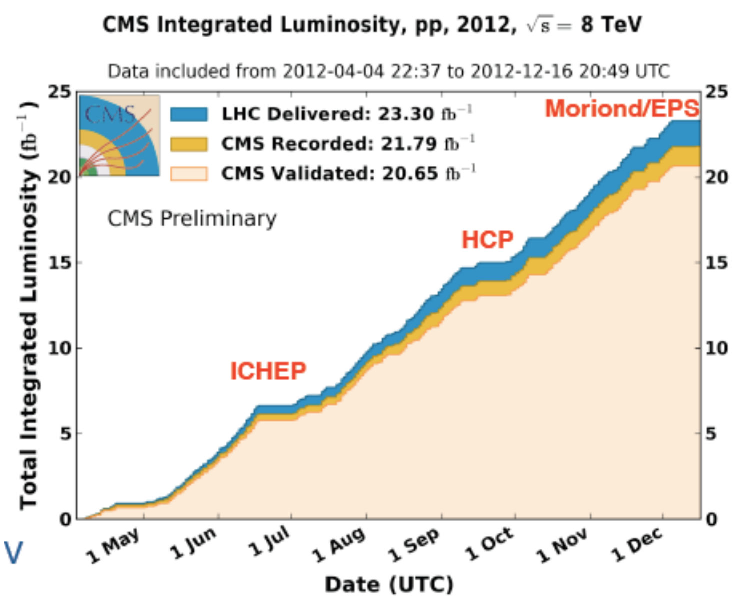
LHC and CMS operations

- The Large Hadron Collider delivered **pp collisions** from 2010 to 2012:
  - **~6 fb-1 of pp collisions at √s = 7 TeV**
  - **~23 fb-1 of pp collisions at √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 √sNN = 2.76 TeV during 2011**
  - **~31 nb-1 of pPb collisions at √spN = 5.02 TeV during 2013**





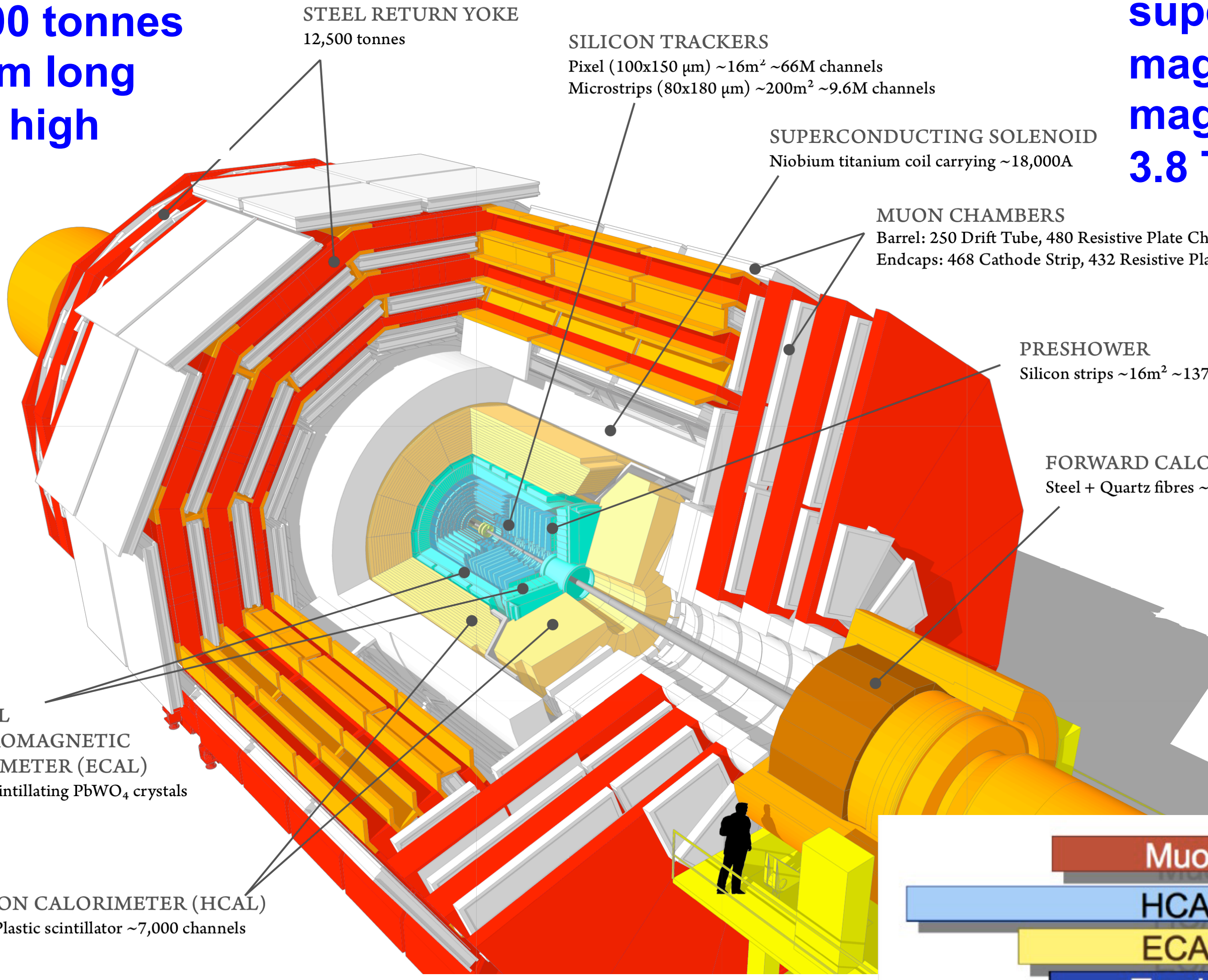
CMS: the collaboration

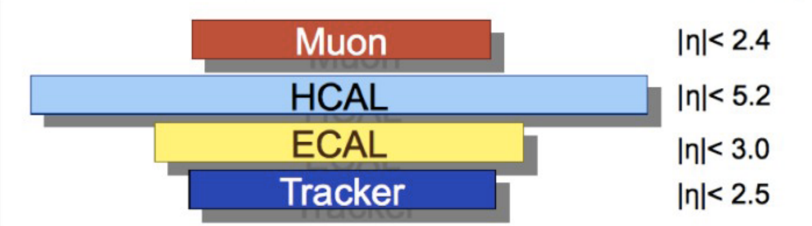
40 countries, 193 institutes
~ 3300 scientist & engineers (including ~ 900 students)

CMS: the detector

14000 tonnes
28.7m long
15m high

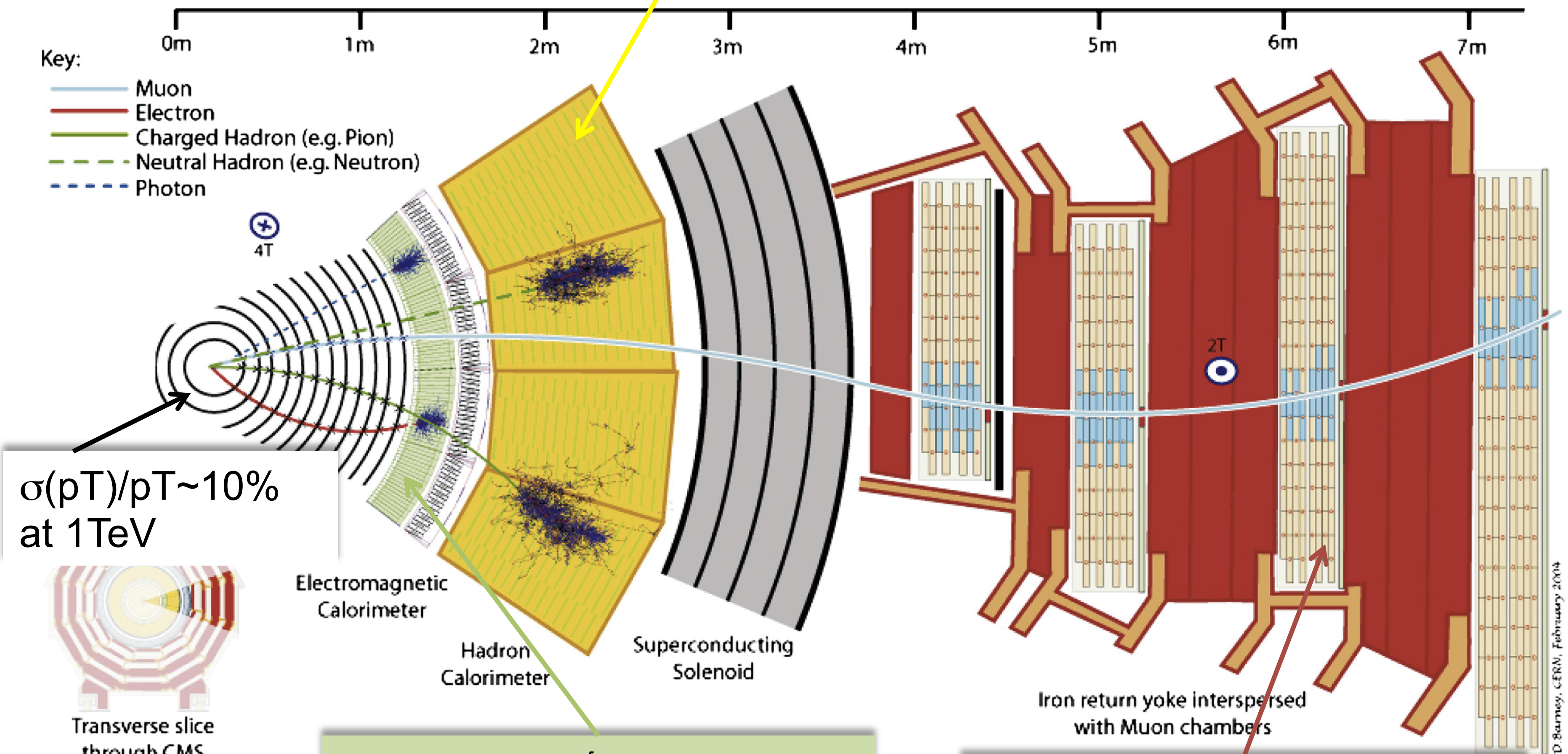
The largest superconducting magnet ever built: magnetic field up to 3.8 T





CMS: the physics objects

$\sigma(E_T)/E_T \sim 100\%/\sqrt{E_T[\mathrm{GeV}]} + 5\%$

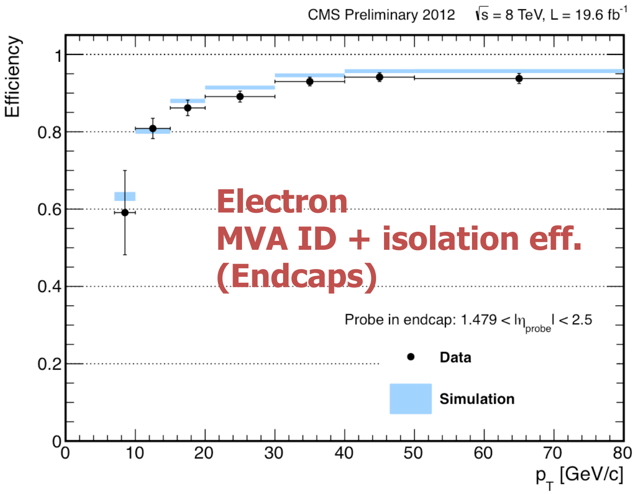


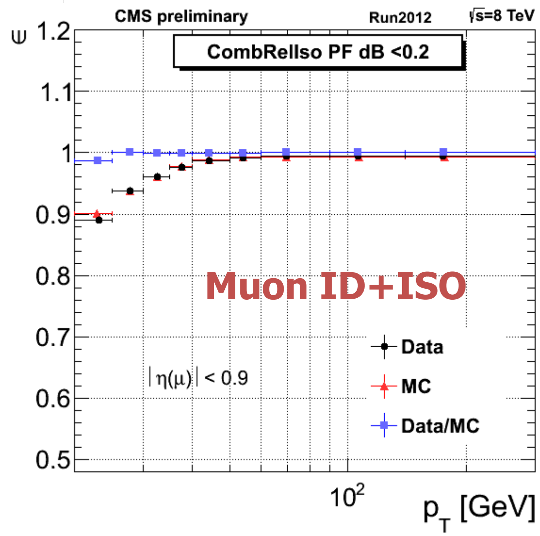
$\sigma(pT)/pT \sim 10\%$ at 1TeV

$\sigma(E)/E \sim 3\%/\sqrt{E[\mathrm{GeV}]} + 0.3\%$

$\sigma(pT)/pT \sim 1\%$ @ 100GeV
$\sigma(pT)/pT \sim 10\%$ @1 TeV

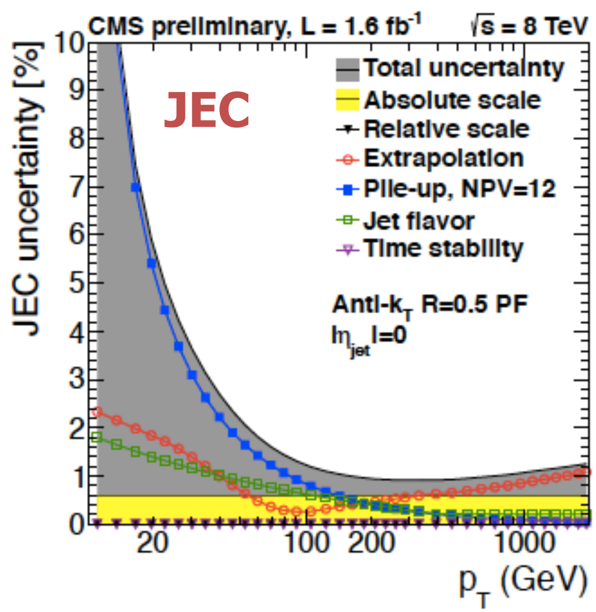
Object reconstruction: performance

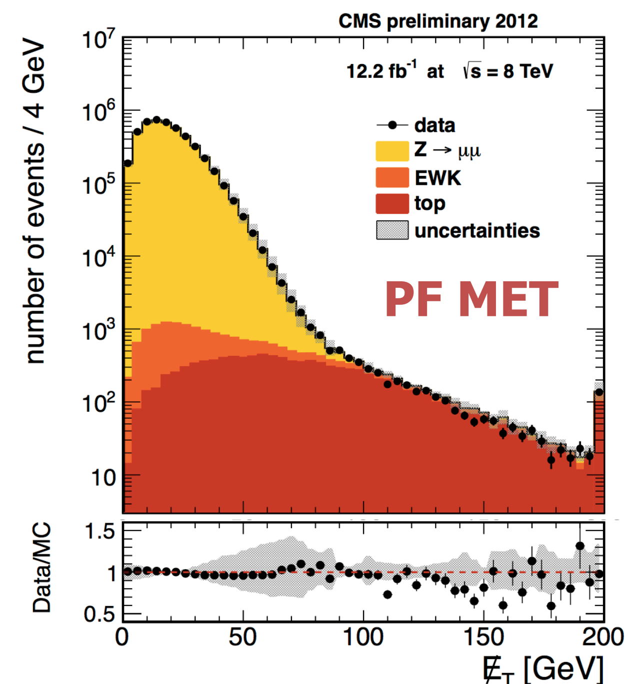




- **High efficiency on lepton ID + Isolation**
  - **> 95% at plateau**
- **Good agreement data/ MC**

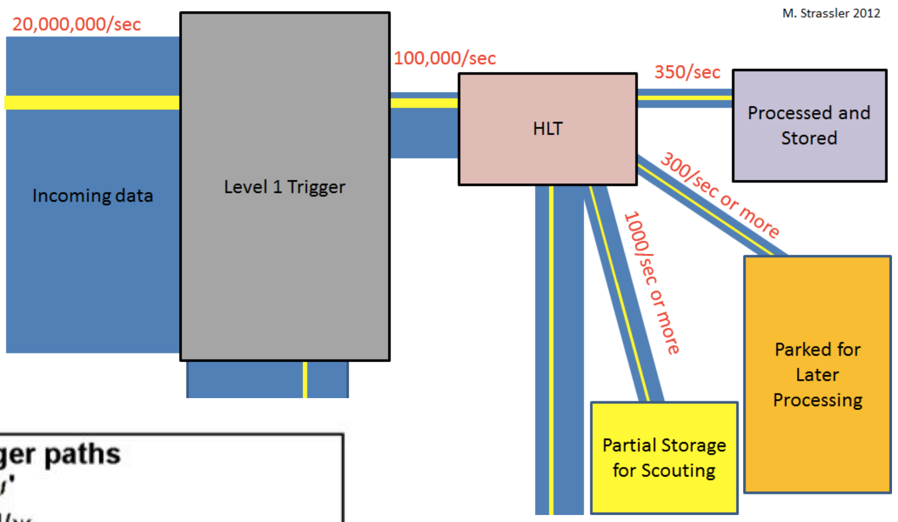
- **Excellent understanding of jet energy calibrations and MET**
  - **4% JEC @ 30 GeV**

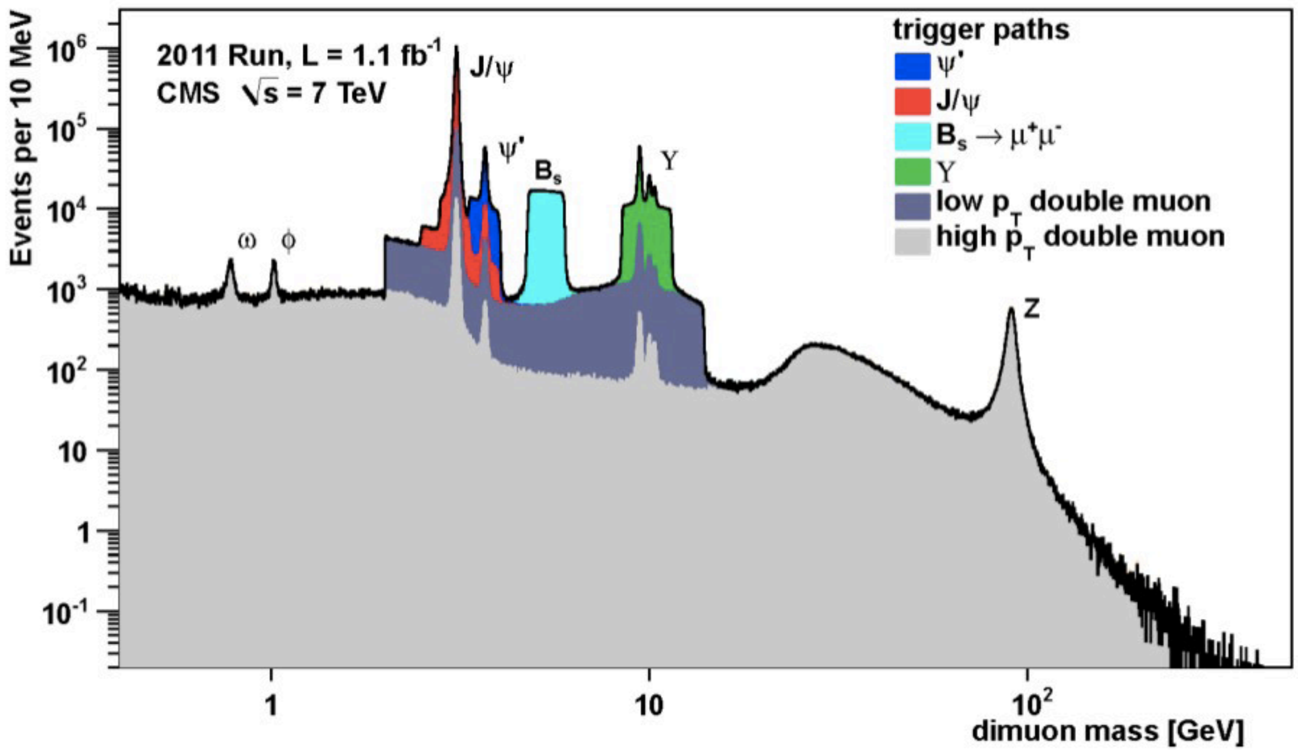




CMS: trigger system

- **Level-1 & HLT menus reduce # of p-p interactions from**: $2x10^7$ Hz (input) down to **~350 Hz (recorded)**,~300 Hz ("parked" for later analysis)

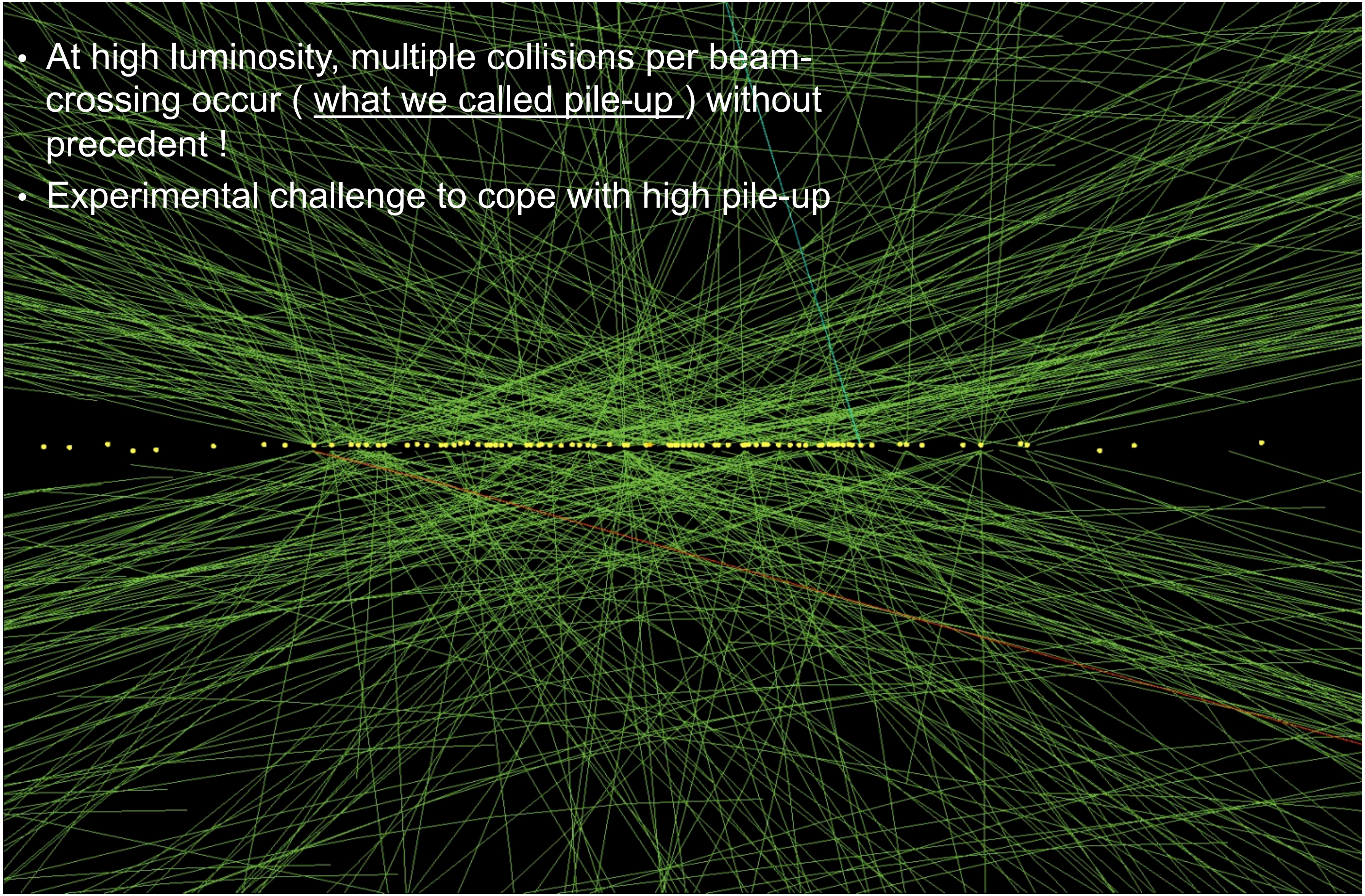




- **Example: dimuon mass distribution from several double-μ trigger paths**: calibration, Bs(μμ), quarkonia, DY+Z

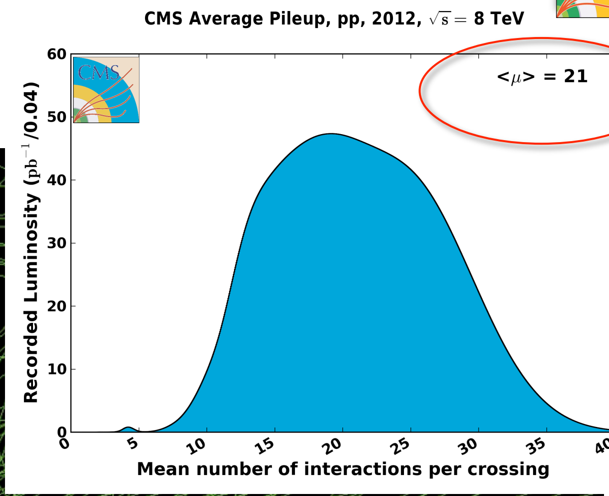
No without challenges

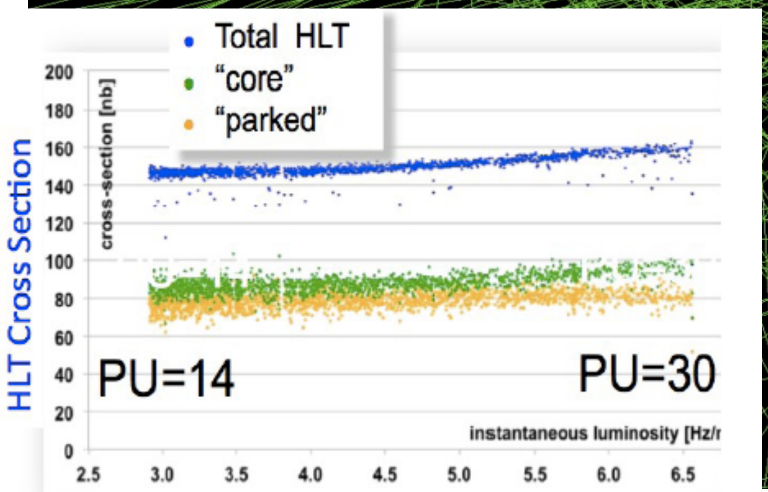
- At high luminosity, multiple collisions per beam-crossing occur (what we called pile-up) without precedent !
- Experimental challenge to cope with high pile-up



No without challenges

- At high luminosity, multiple collisions per beam-crossing occur (what we called pile-up) without precedent !
- Experimental challenge to cope with high pile-up

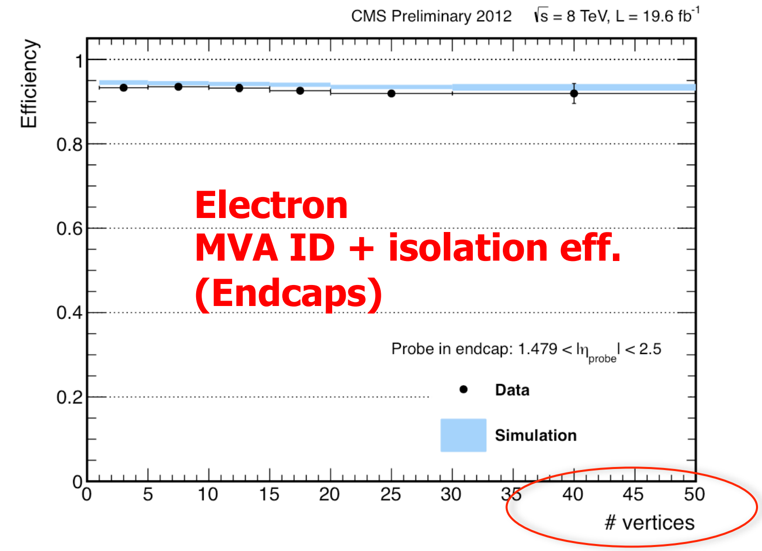




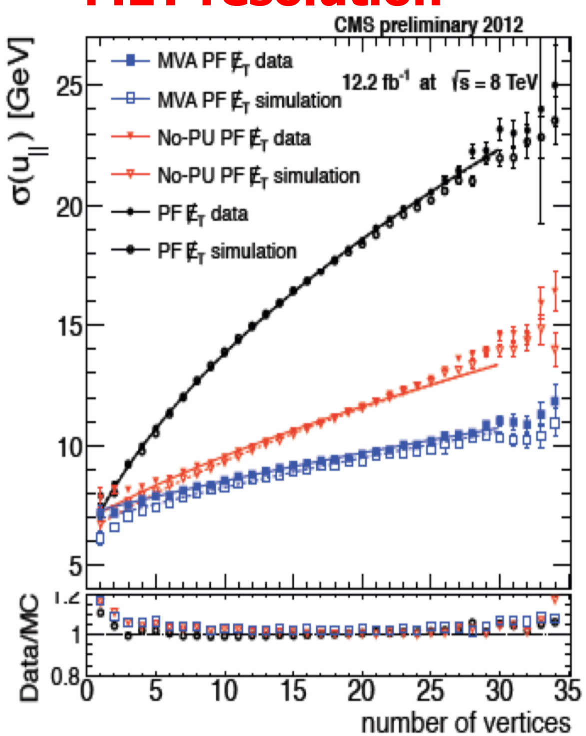
- Highly-flexible HLT system allows CMS to keep a constant-rate cross section with varying pile-up conditions without sacrificing physics

CMS performance under PU

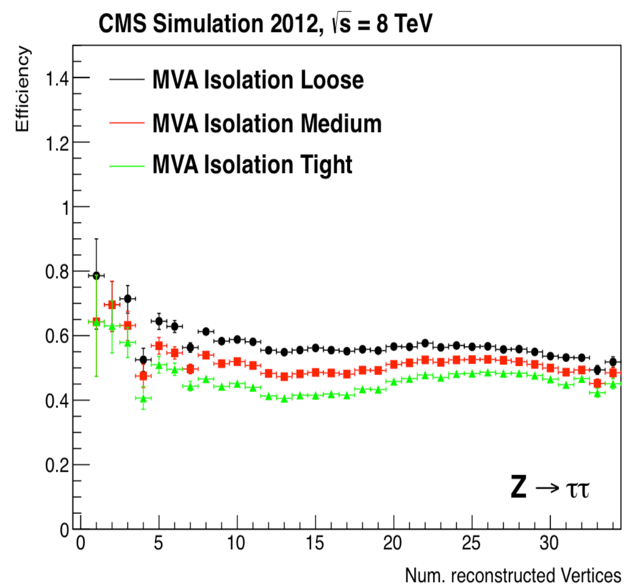
- A lot of effort on correcting PU effects:
  - Object performance as a function of the pile-up: i,.e. the number of reconstructed vertices after PU corrections applied

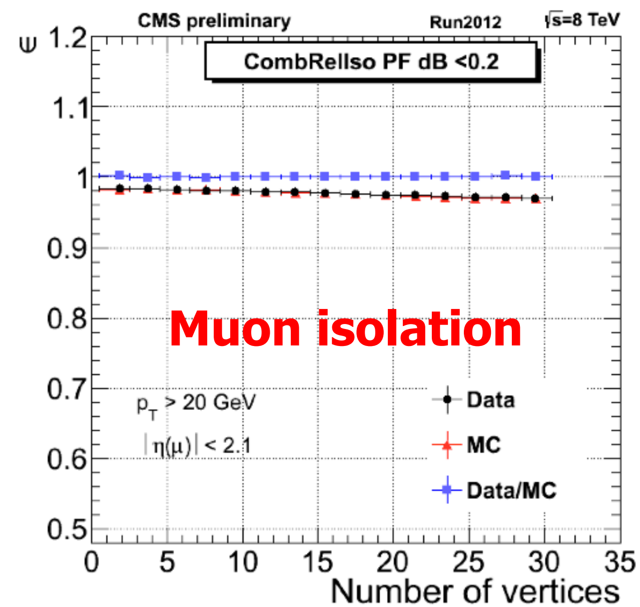


MET resolution



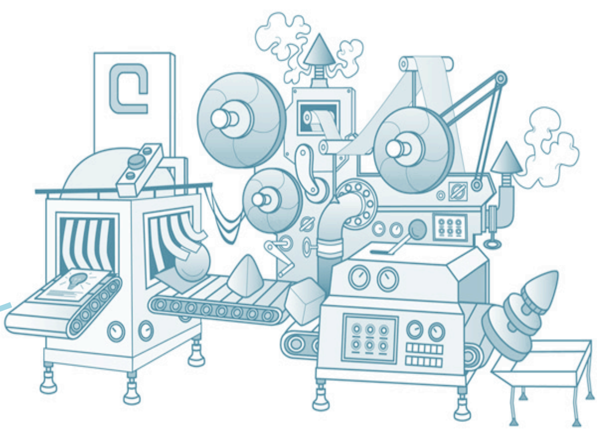
MVA tau reco eff.



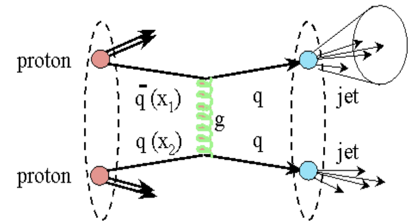


CMS highlight physics results

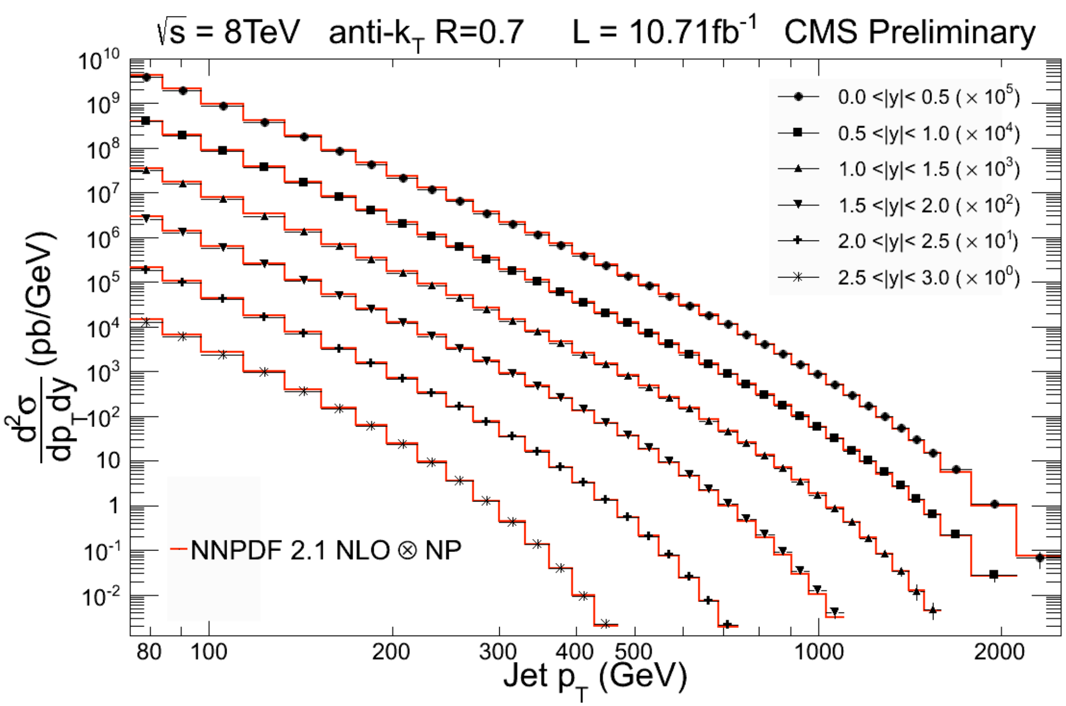
Leptons, Jets, MET .....

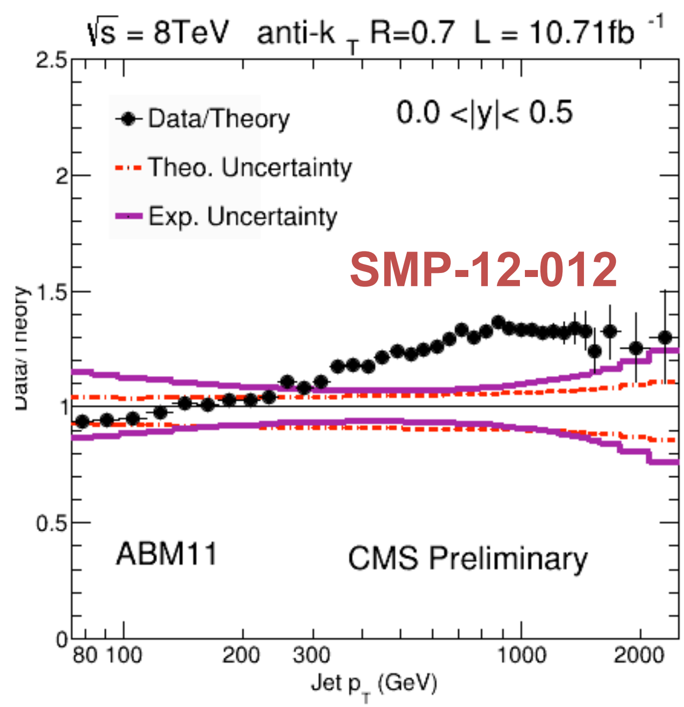


QCD: Jet cross sections



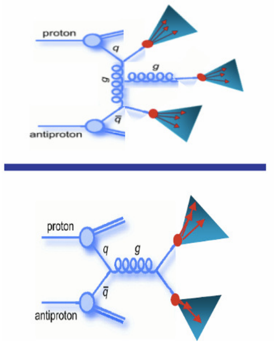
- **Study the strong force using jet production**
- Differential cross section for inclusive jet production at 8 TeV:
  - Agreement with NLO⊗NP QCD over ≥7 orders of magnitude up to 2TeV
- CMS data can be used to constrain the fits of the parton distribution functions (PDFs)
  - Knowing your PDFs is critical for searches and precision tests on x-sections



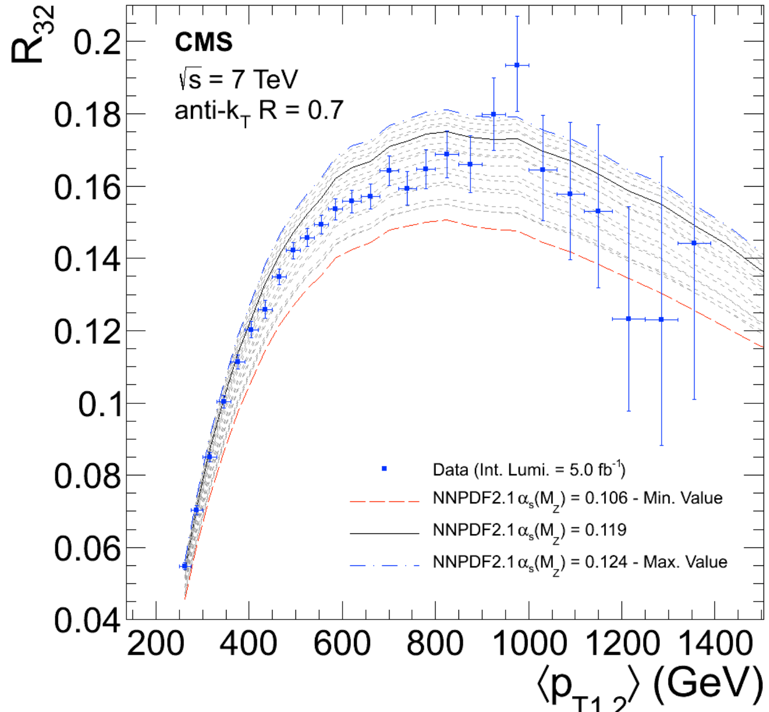


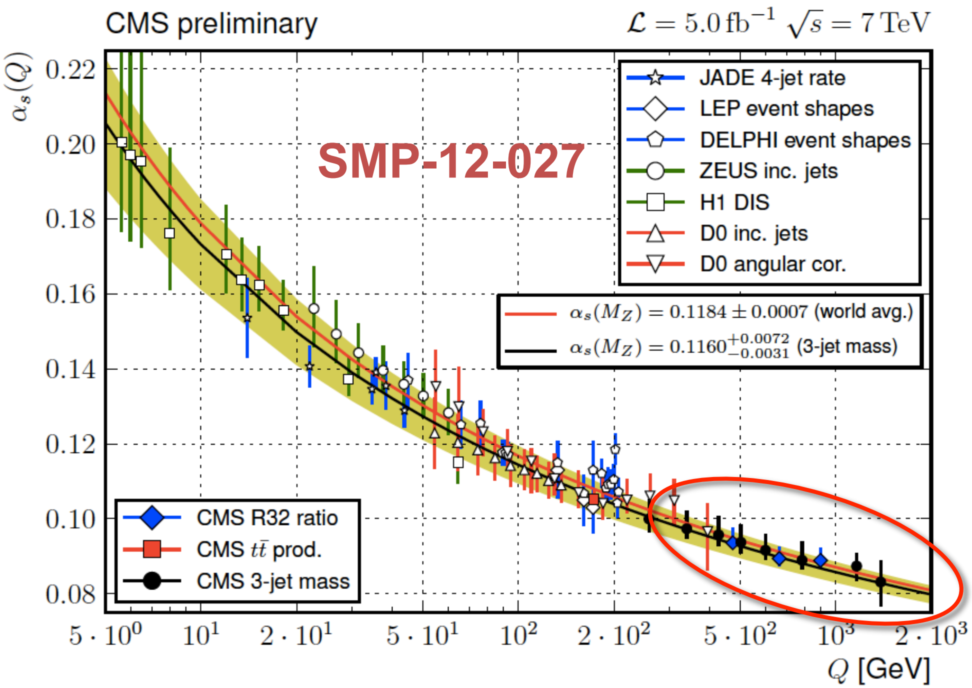
➢ Dominant experimental uncertainty: JES

QCD: Strong coupling from jets x-sections



- New measurements at 7TeV of $\alpha_s(Q)$ from 3 to 2 jet cross section ratio and from 3 jet mass differential cross section
  - Sensitivity in high Q regime



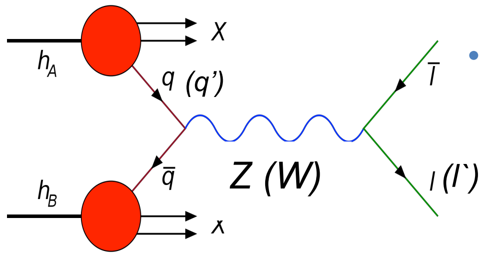


Eur.Phys.J. C73 (2013) 2604

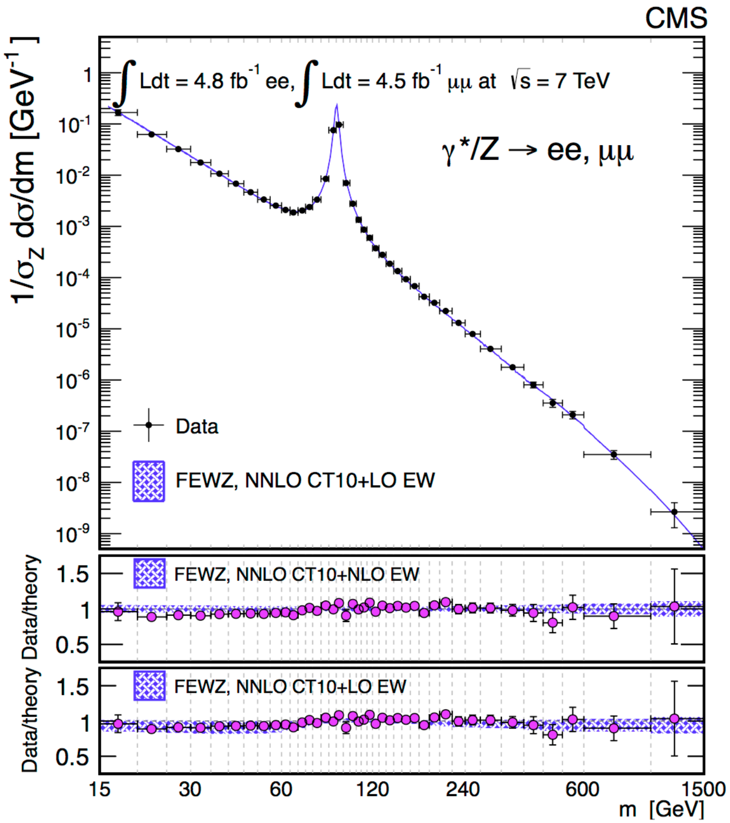
➢ Measurement dominated by TH uncertainty: PDF & (asymmetric) scale uncertainty

Electroweak: W, Z boson production

- **Differential DY+Z x-section** in agreement with NNLO at 7,8 TeV. Quark PDF constraints at low mll

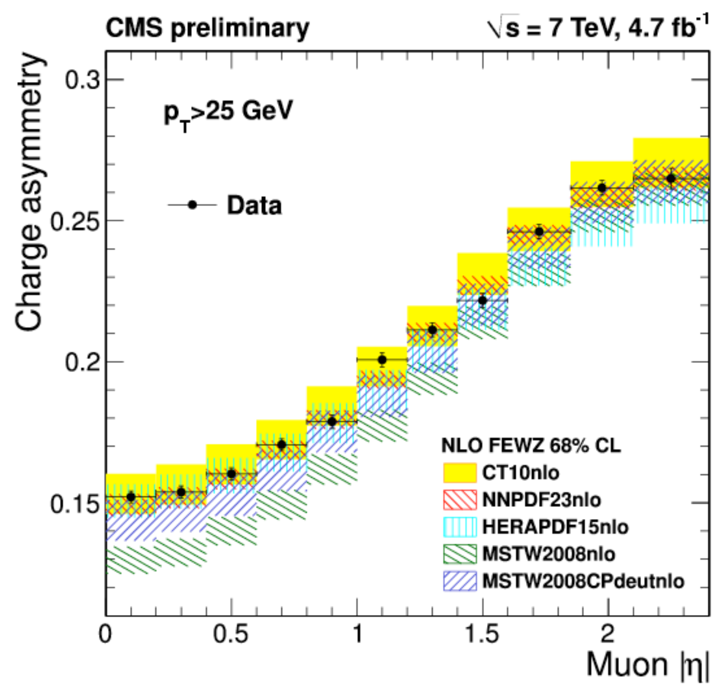


- **W muon charge asymmetry vs |η|** measured to ~1%. Many uncertainties cancel in ratio. Constrains u/d PDF ratio



CMS-PAS-SMP-13-003

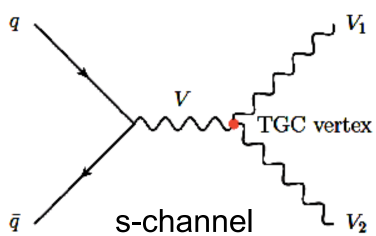
$$\mathcal{A}(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \to \ell^+\nu) - \frac{d\sigma}{d\eta}(W^- \to \ell^-\bar{\nu})}{\frac{d\sigma}{d\eta}(W^+ \to \ell^+\nu) + \frac{d\sigma}{d\eta}(W^- \to \ell^-\bar{\nu})}$$

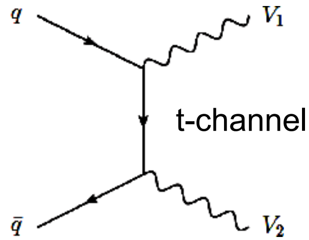


CMS-PAS-SMP-12-021

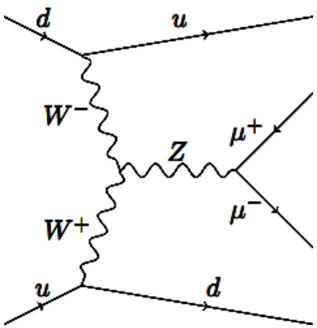
➢ Dominant uncertainty: p scale + unfolding

Electroweak: diboson production

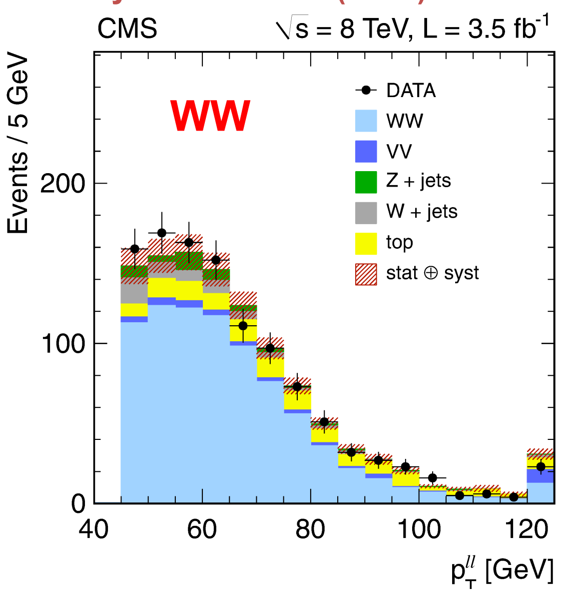


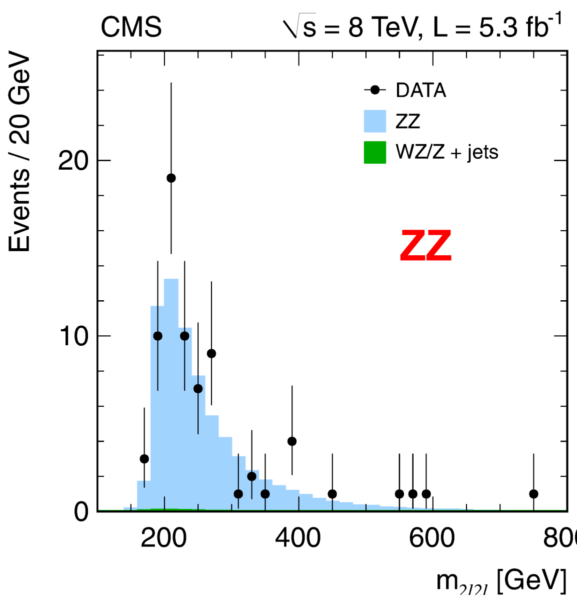


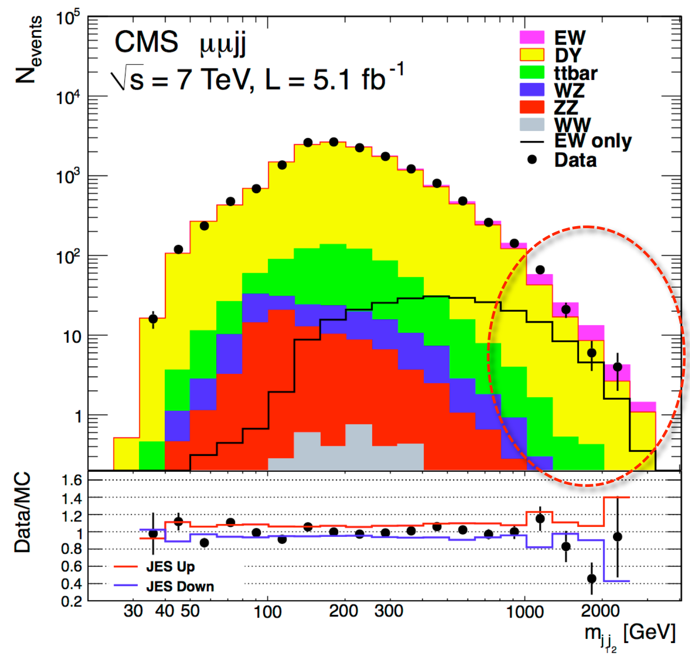
- **1st evidence (~3sigma) for EWK Z production+2 forward jets:**



Phys. Lett. B 721 (2013) 190–211







JHEP 10 (2013) 101

$$\sigma(pp \to W^+W^-) = 69.9 \pm 2.8\,(\text{stat.}) \pm 5.6\,(\text{syst.}) \pm 3.1\,(\text{lum.})\ \text{pb}.$$

WW 10-20% above NLO prediction (7,8TeV)

$$\sigma(pp \to ZZ) = 8.4 \pm 1.0\,(\text{stat.}) \pm 0.7\,(\text{syst.}) \pm 0.4\,(\text{lum.})\ \text{pb}.$$

ZZ in agreement with NLO prediction

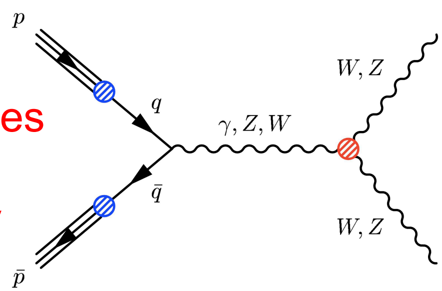
Electroweak: anomalous TGC & QGC

Triple (Quadruple) Gauge Couplings

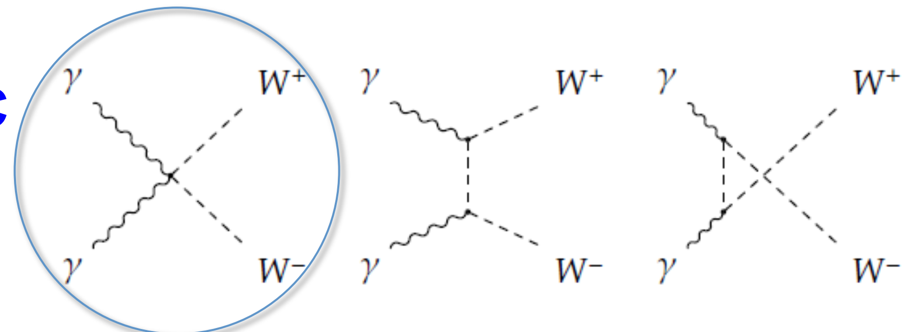
- Diboson final states in scattering topologies and triboson and vector boson scattering final states can be used to set limits on aTGC (aQGC)
  - **Probes Electroweak sector and search deviation from standard model**

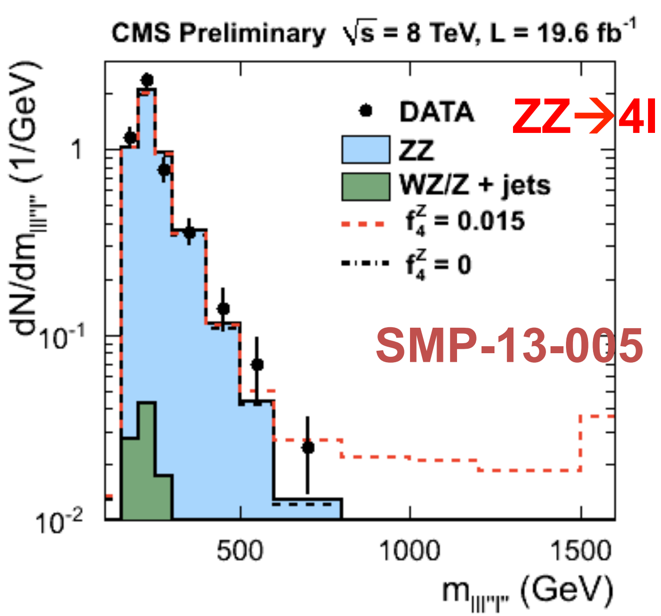
aTGC

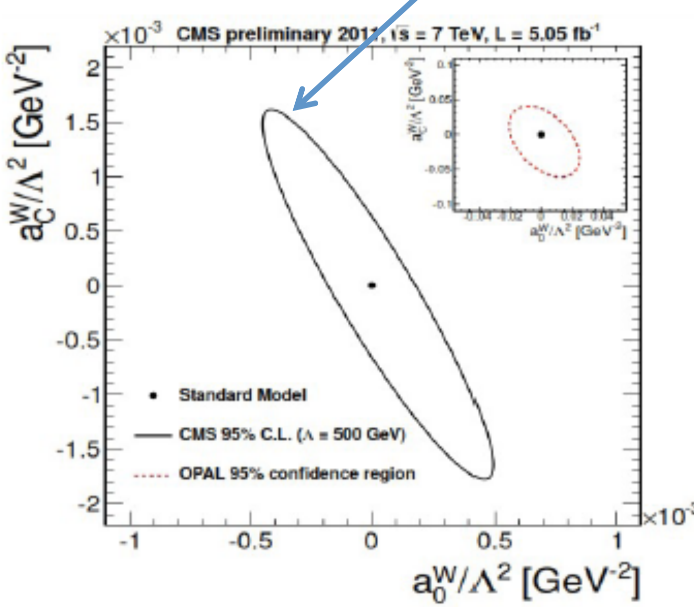
anomalous vertices
ZZγ and ZZZ,
WWγ, WWZ, Zγγ



aQGC





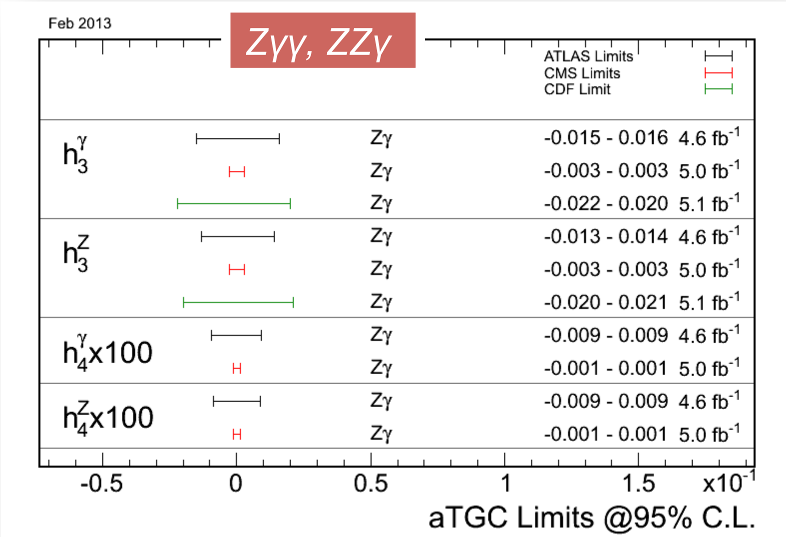


JHEP 1307 (2013) 116

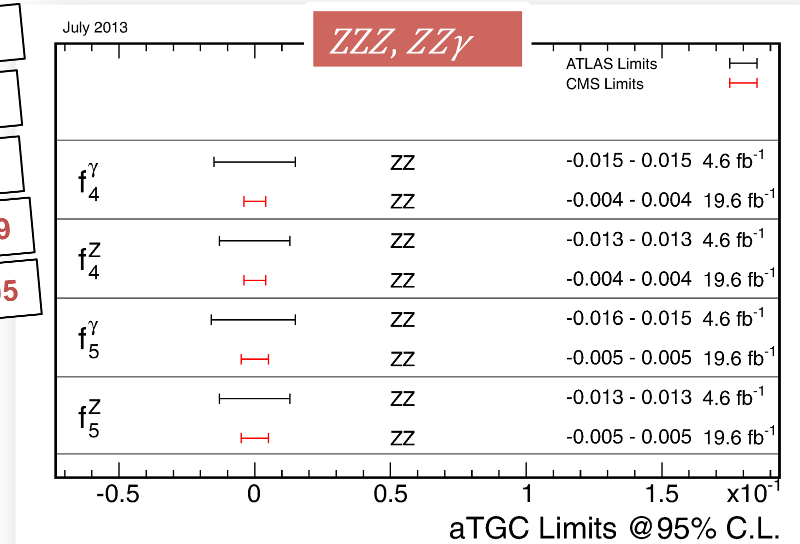
First quartic gauge coupling limits at LHC:
WWγγ limit two orders better than LEP or Tevatron!

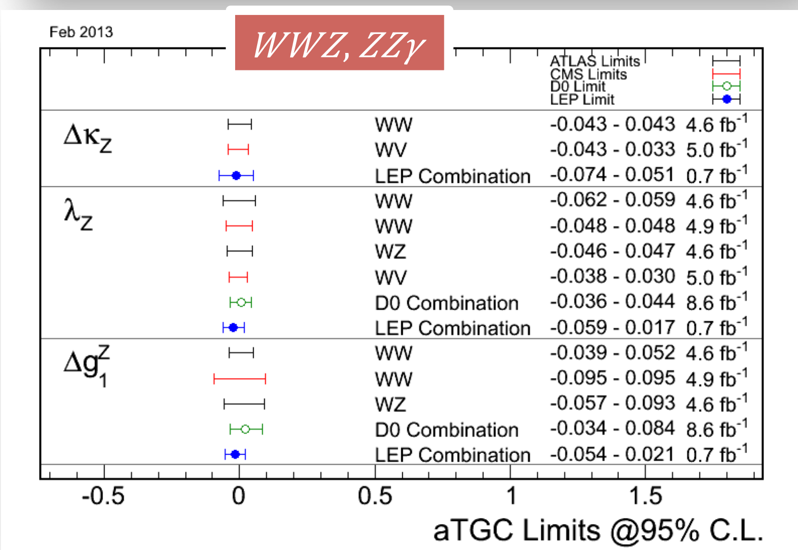
Summary of all aTGC & aQGC Results

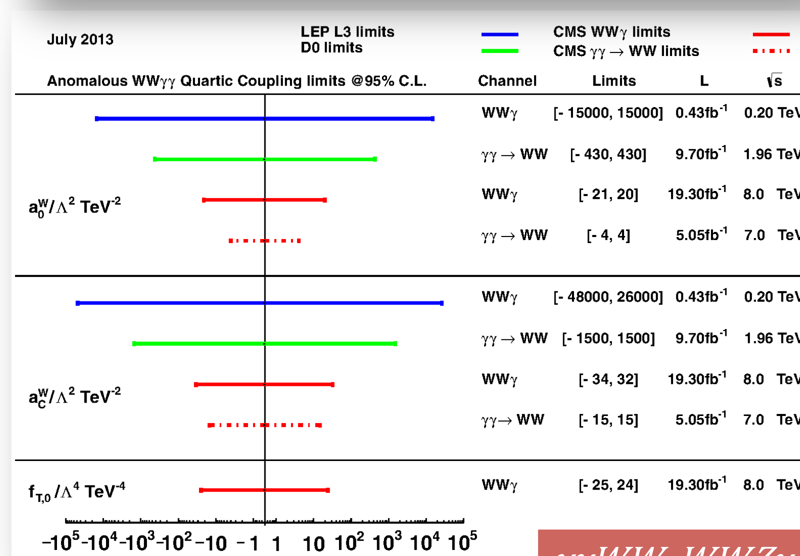
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMPaTGC



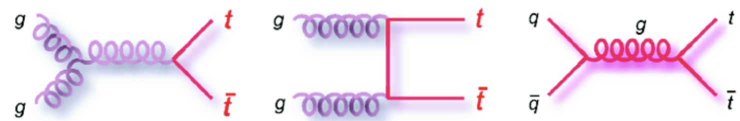
EWK-11-009
SMP-11-005
SMP-12-015
SMP-13-009
SMP-13-005
...

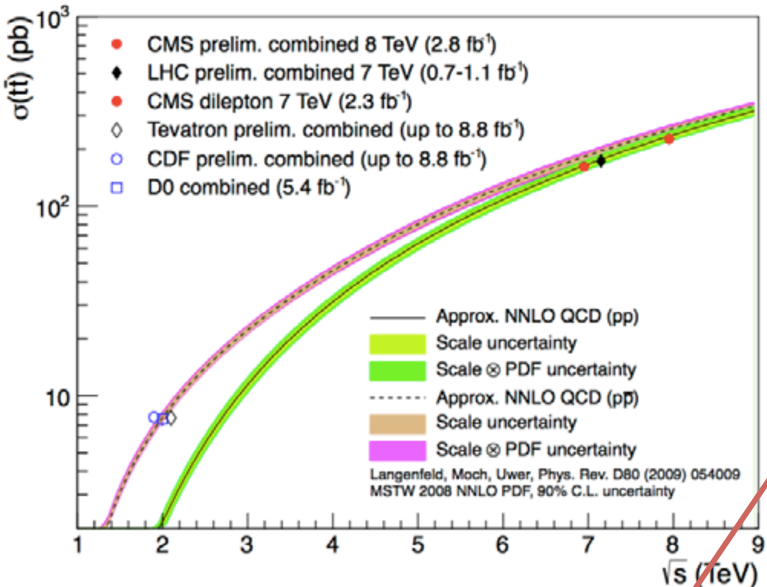




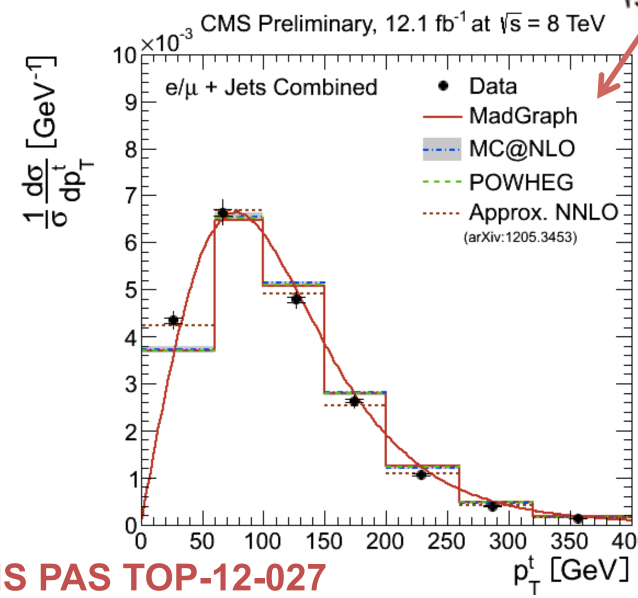


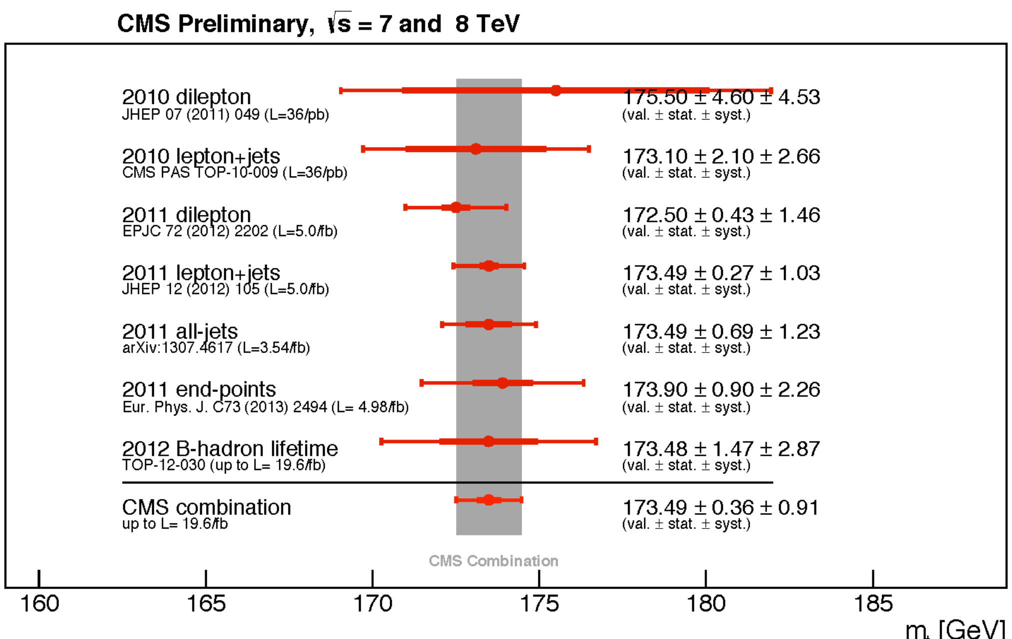
Top quark production





- Top pair produced in strong interaction
- Cross section precision challenging approx. NNLO QCD calculations
- Quality of differential top x-sections can constrain proton gluon (N)NLO PDF

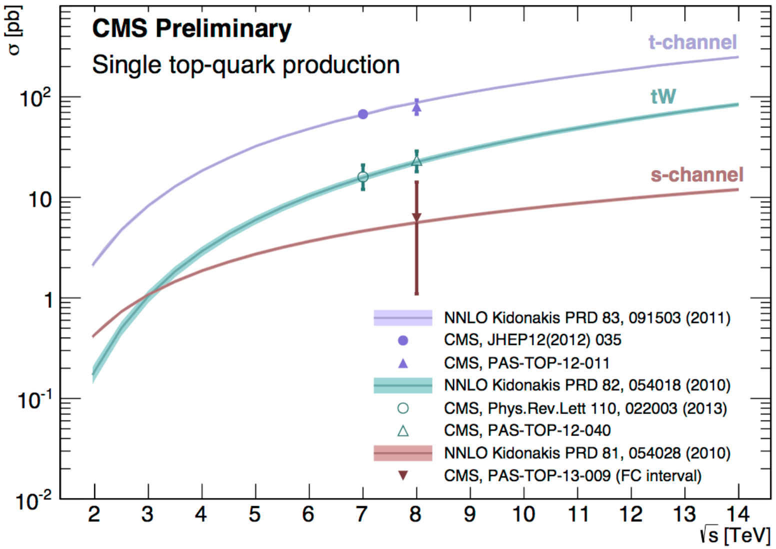


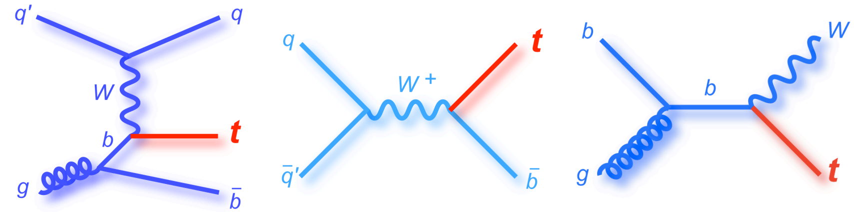


CMS PAS TOP-12-027

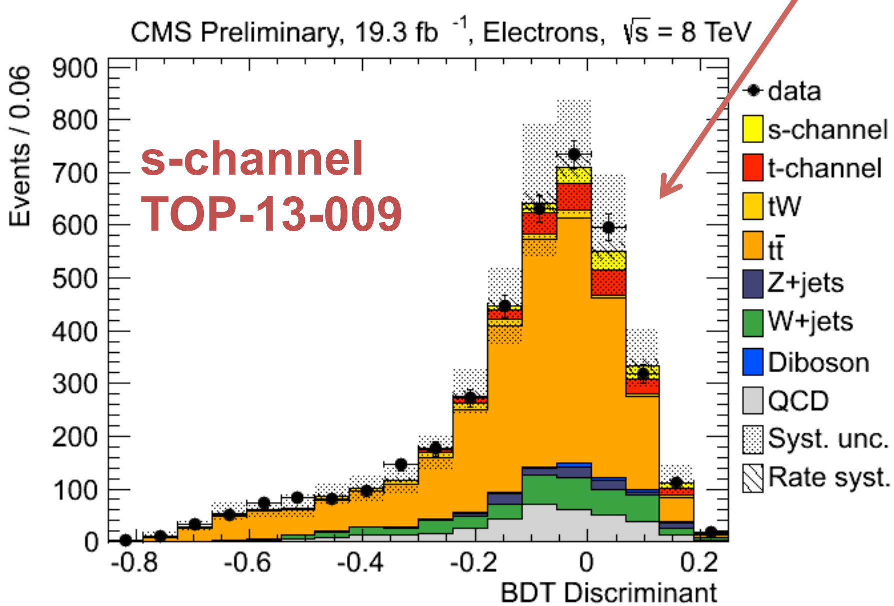
Combined m_{top} measurement with 0.6% precision!

Top quark production

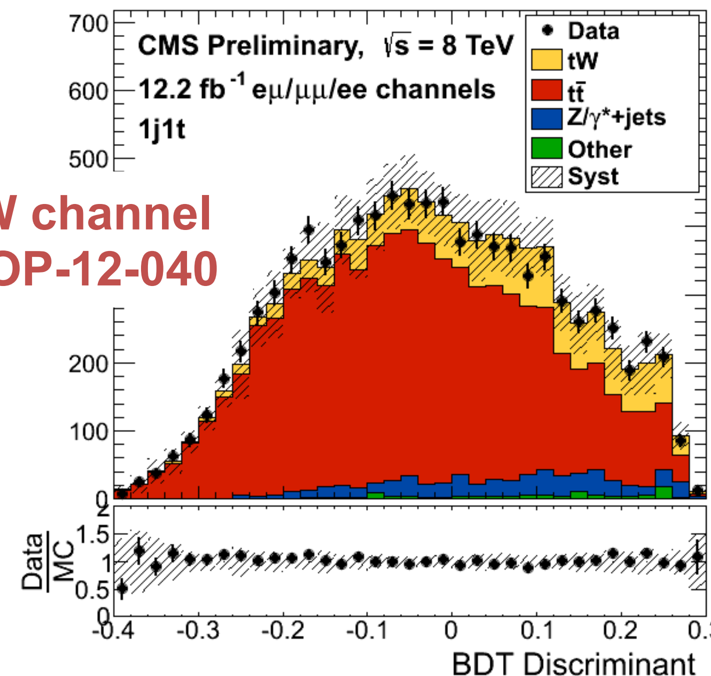




- **Single top production in EWK interaction**
- Well established also in association to a W boson: **tW-channel 6.0σ evidence**
- **2σ excess for s-channel single top production**

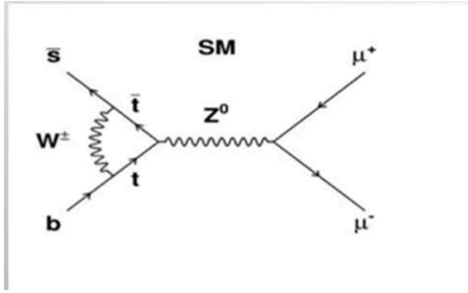


tW channel
TOP-12-040



Rare Decays: $B^0_{(s)}$ to μμ

- **Rare decays, BR sensitive to new particles**

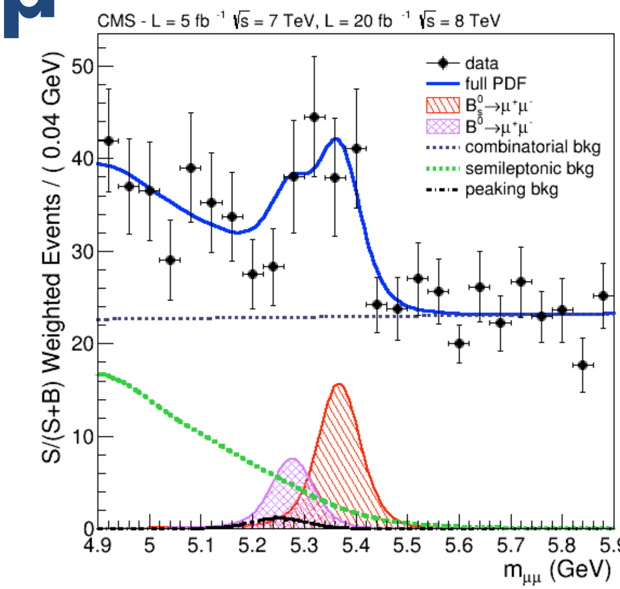


Mode	SM prediction
$B_s \to \mu^+\mu^-$	$(3.54 \pm 0.30) \times 10^{-9}$
$B^0 \to \mu^+\mu^-$	$(0.11 \pm 0.01) \times 10^{-9}$

A. Buras et al., arXiv:1208.0934

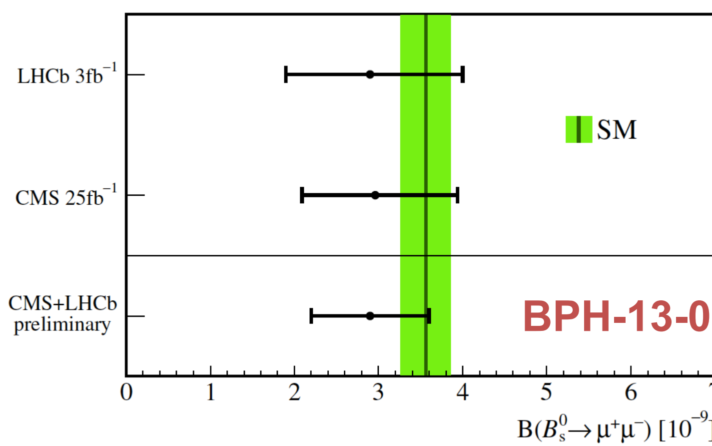
DeBruyn et al., arXiv:1204.1737

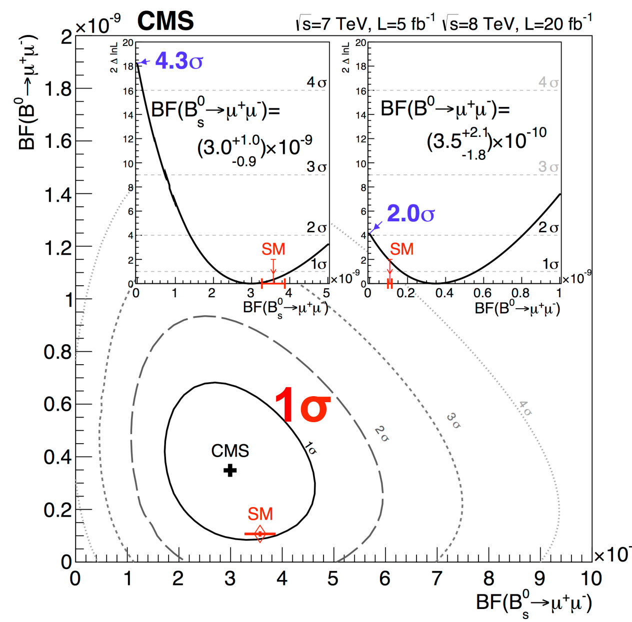
C. Davies, arXiv:1203.3862 (and ref. therein)



- 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:
  - $BR(B_s \to \mu+\mu-) = (2.9 \pm 0.7)$ x 10-9
  - 5σ combined significance

No sign of new physics yet

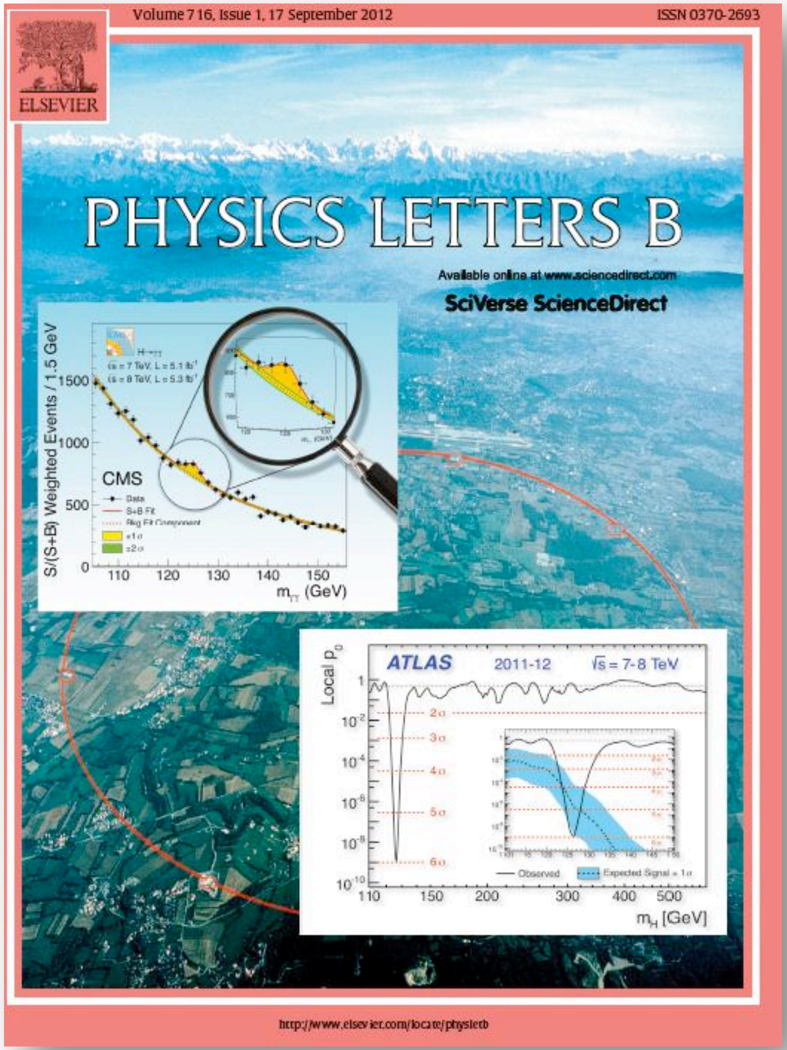




PRL 111 (2013) 101804

Search for the Higgs @ the LHC

Looking back… discovery of new boson Summer 2012


Volume 716, Issue 1, 17 September 2012 ISSN 0370-2693

ELSEVIER

PHYSICS LETTERS B

Available online at www.sciencedirect.com

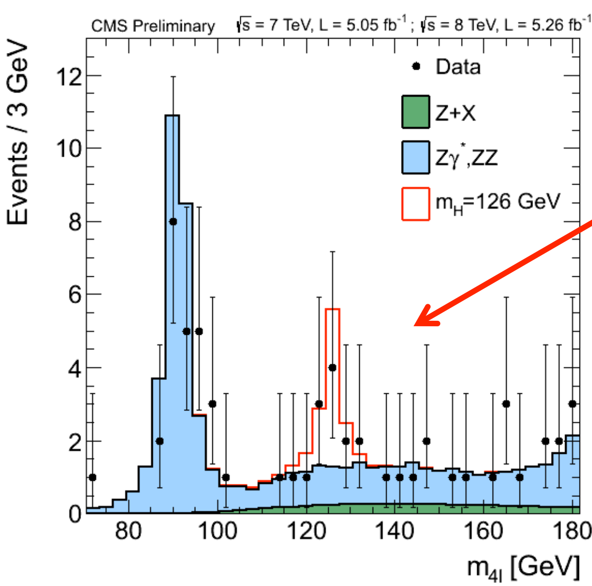
SciVerse ScienceDirect

http://www.elsevier.com/locate/physletb

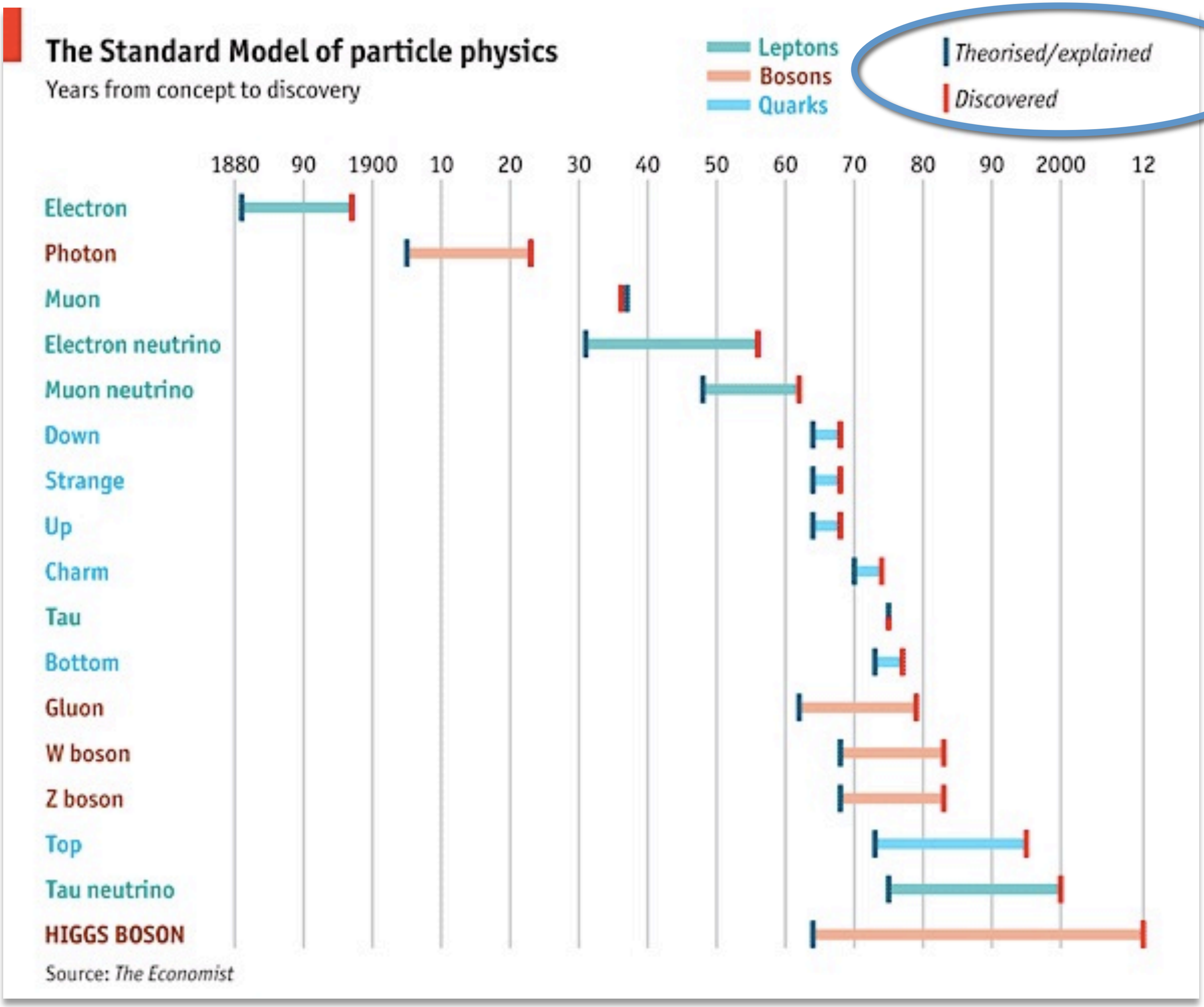
Observation of a new particle with mass of ~125 GeV by ATLAS & CMS

ATLAS: 5.1 σ
CMS: 5.0 σ

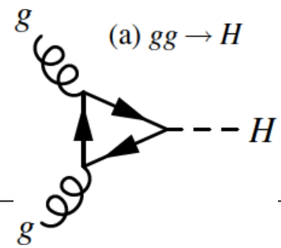
With just:
5 fb-1 @ 7Te V
6 fb-1 @ 8TeV of data!



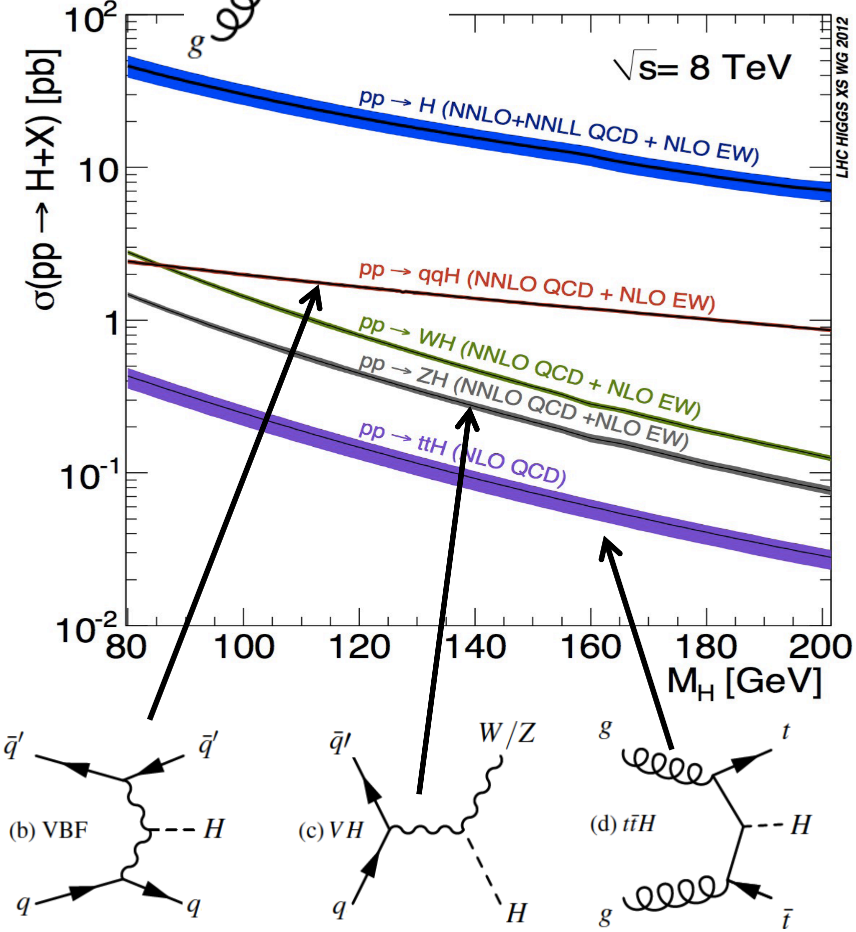
H->ZZ


The Standard Model of particle physics
Years from concept to discovery
Leptons
Bosons
Quarks
Theorised/explained
Discovered
1880
90
1900
10
20
30
40
50
60
70
80
90
2000
12
Electron
Photon
Muon
Electron neutrino
Muon neutrino
Down
Strange
Up
Charm
Tau
Bottom
Gluon
W boson
Z boson
Top
Tau neutrino
HIGGS BOSON
Source: The Economist

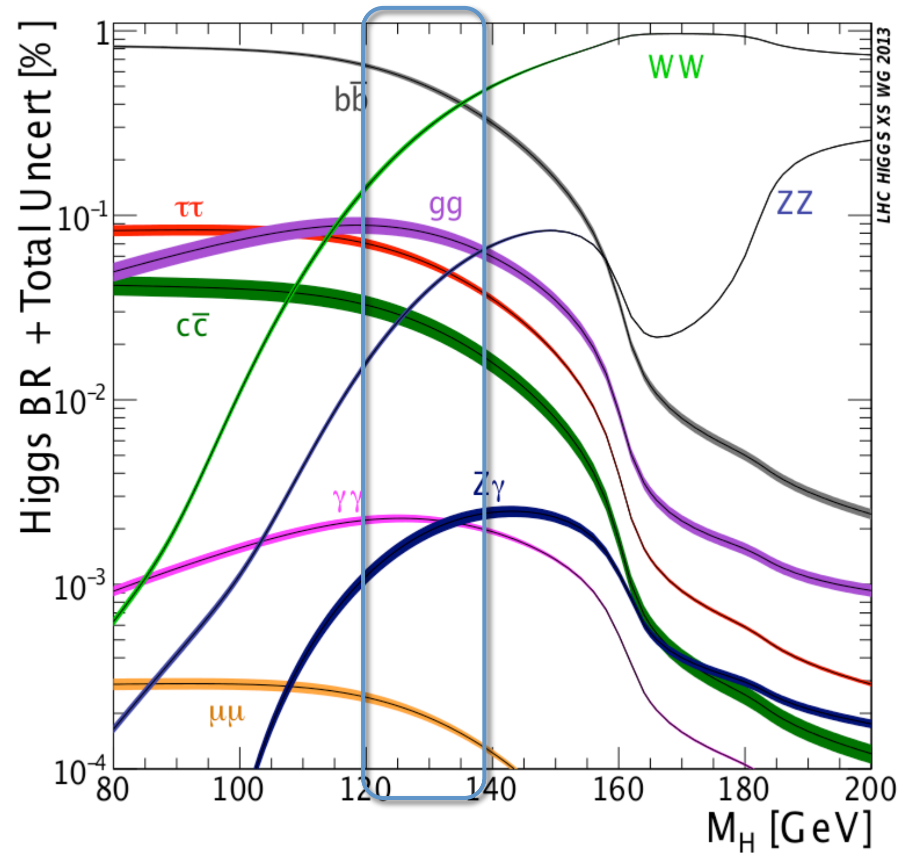
SM Higgs boson: LHC production & decays



Gluon-fusion: dominant



VBF & associated prod

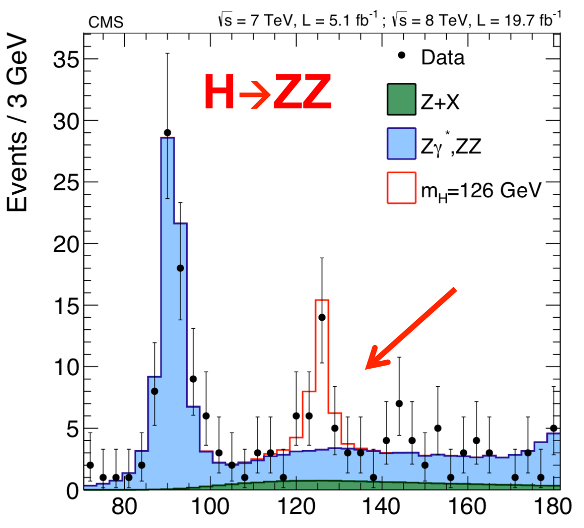


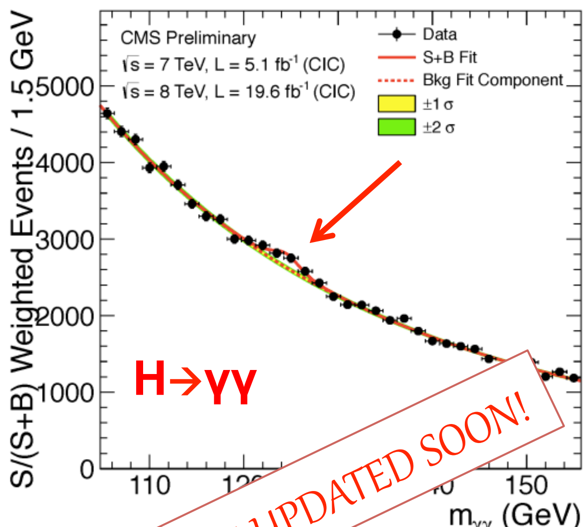
«Cleanest» channels, good masss resolution (1-2%): H → γ's, leptons

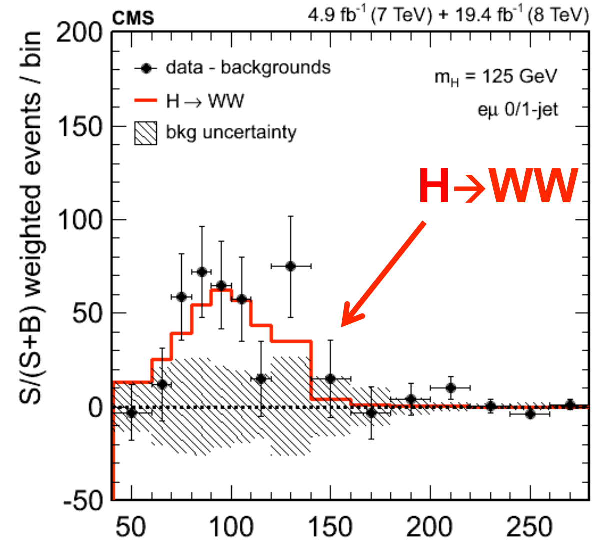
Large x-section channels, lower mass resolution (20%) : H → WW, ττ, bb

Higgs Boson Signals: couplings to bosons

- CMS Higgs searches in 2011-2012 led to new boson discovery with a mass of **M_H = 125.7±0.3(stat)±0.3(syst)**

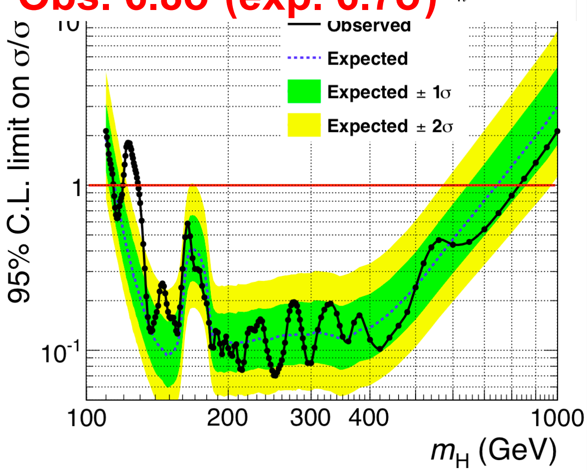




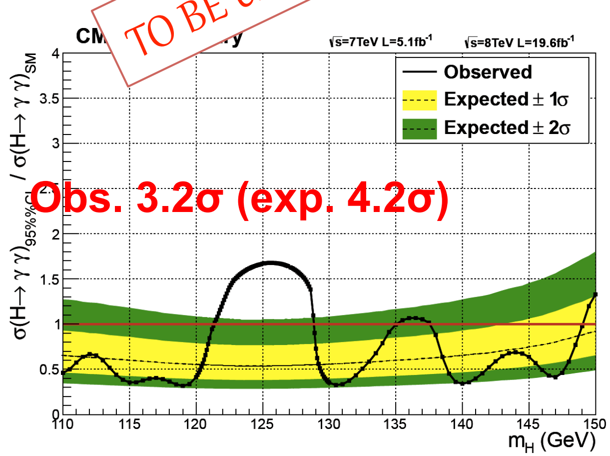


TO BE UPDATED SOON!

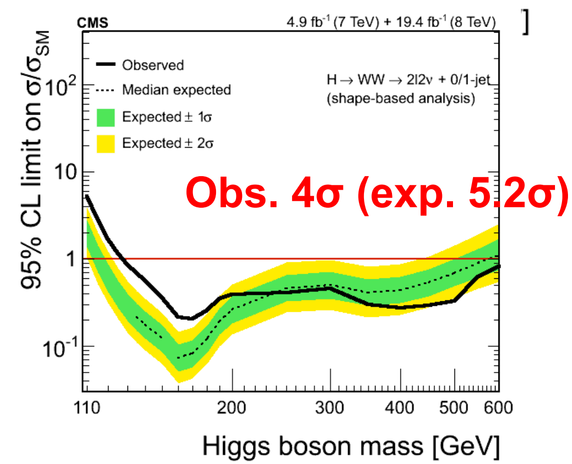
Obs. 6.8σ (exp. 6.7σ)



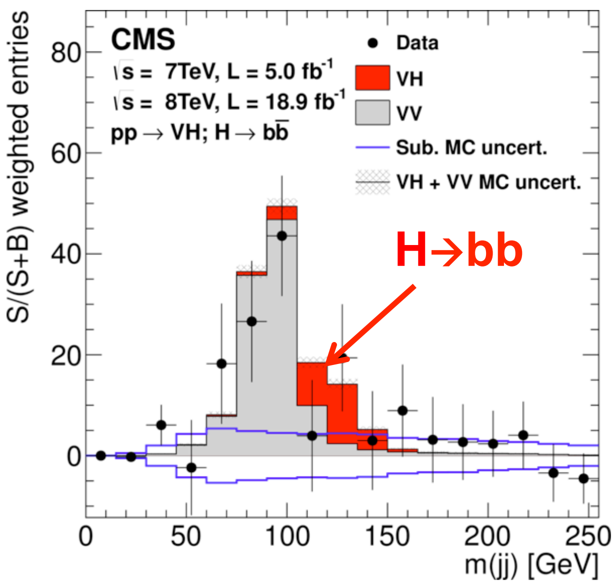
Obs. 3.2σ (exp. 4.2σ)

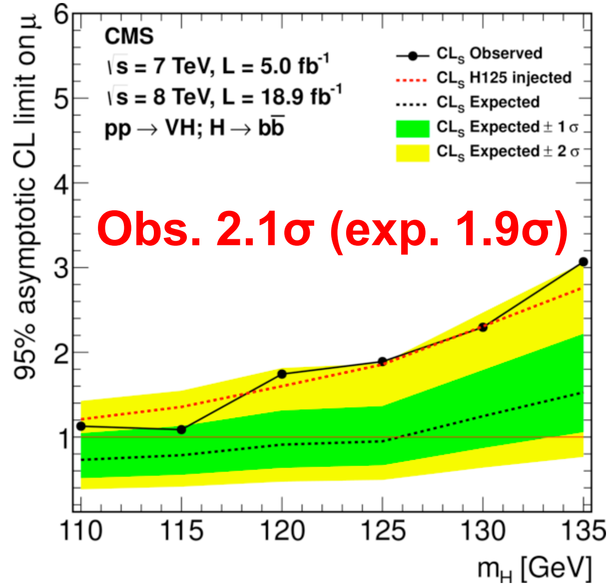


Obs. 4σ (exp. 5.2σ)

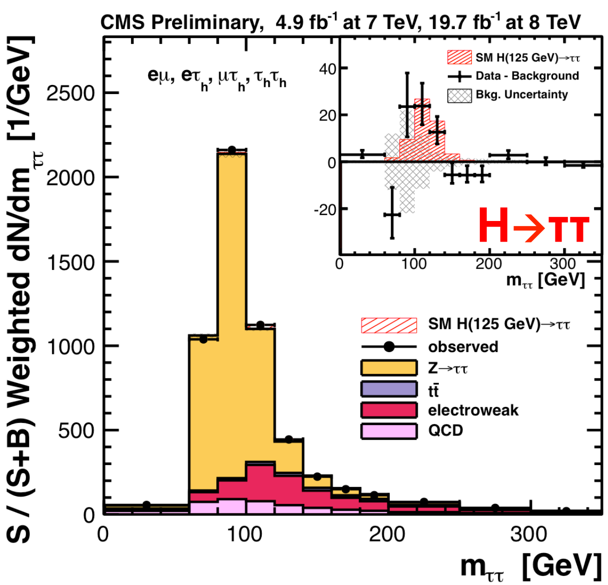


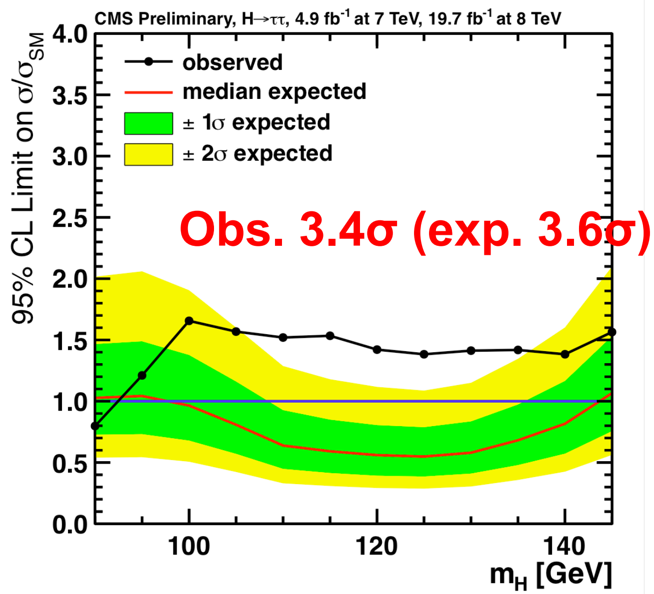
Higgs Boson Signals: couplings to fermions





New result, Dec. 2013!



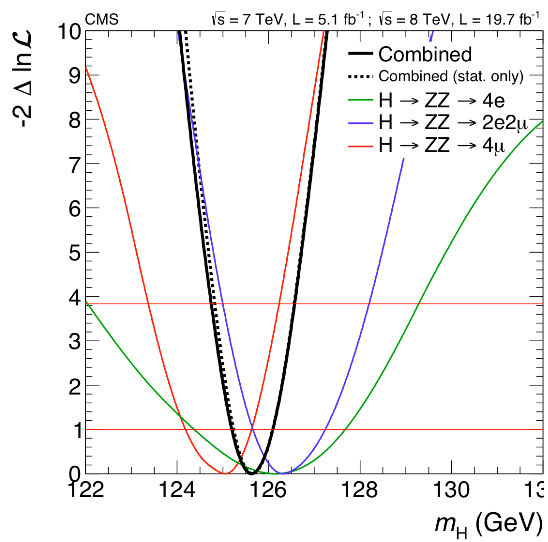


- **4σ combined (bb+ττ) evidence in fermionic channels**
- **Strong evidence of fermionic Higgs decays !**

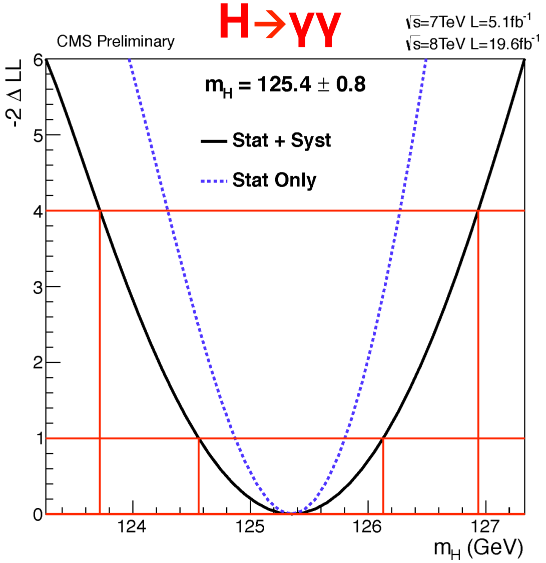
Higgs properties

- **Mass peak position**

H→ZZ



H→γγ

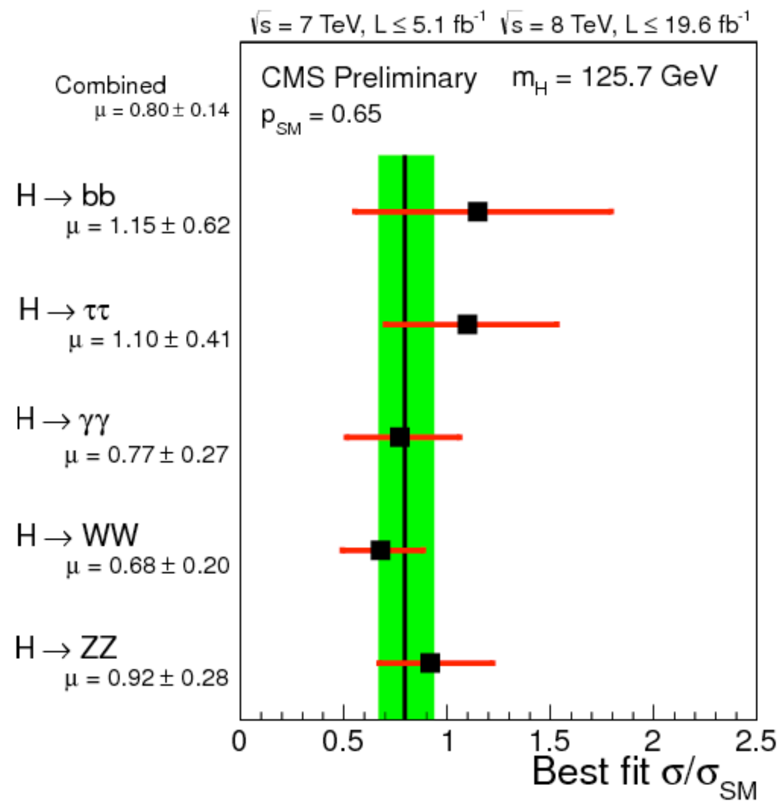


H→ZZ
125.6 ± 0.4 (stat.) ± 0.2 (syst.) GeV

H→γγ
125.4 ± 0.5(stat.) ± 0.6(syst.) GeV

Precision to 0.3-0.5 %

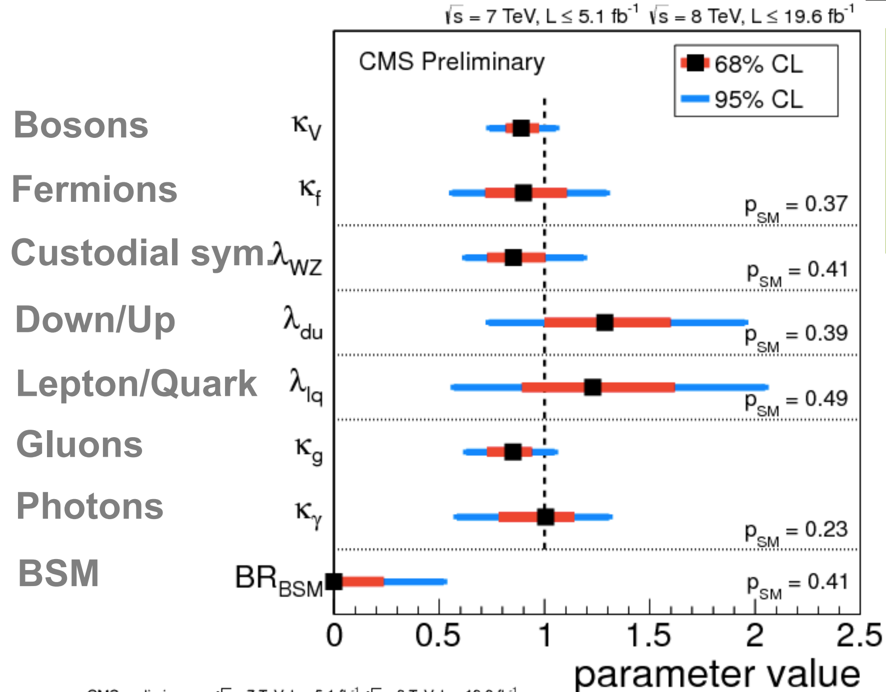
- **Best fit of signal strength $\mu = \sigma/\sigma_{SM}$** compared to expectation from SM Higgs boson among observed channels.



Consistency across decay modes, and agree with SM within 2 σ.

Higgs properties

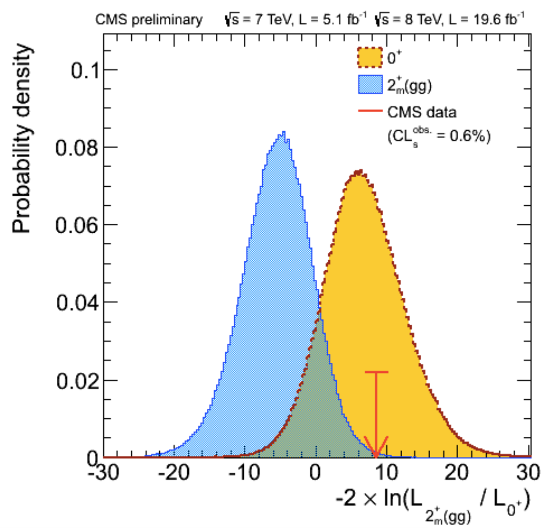
- **Couplings from simultaneous fits to observed signals**
- Define scale factors K as the ratio with respect to SM couplings (arXiv:1209.0040)
  - Test to custodial symmetry, fermion universality and effects from new physics



$\Gamma_{BSM} = 0$

$m_H = 125.7$ GeV

- **Spin and parity** from angular distributions in WW, ZZ and γγ
  - Studied pseudo-scalar, spin-1 and spin-2 models excluded at 95% CL or higher

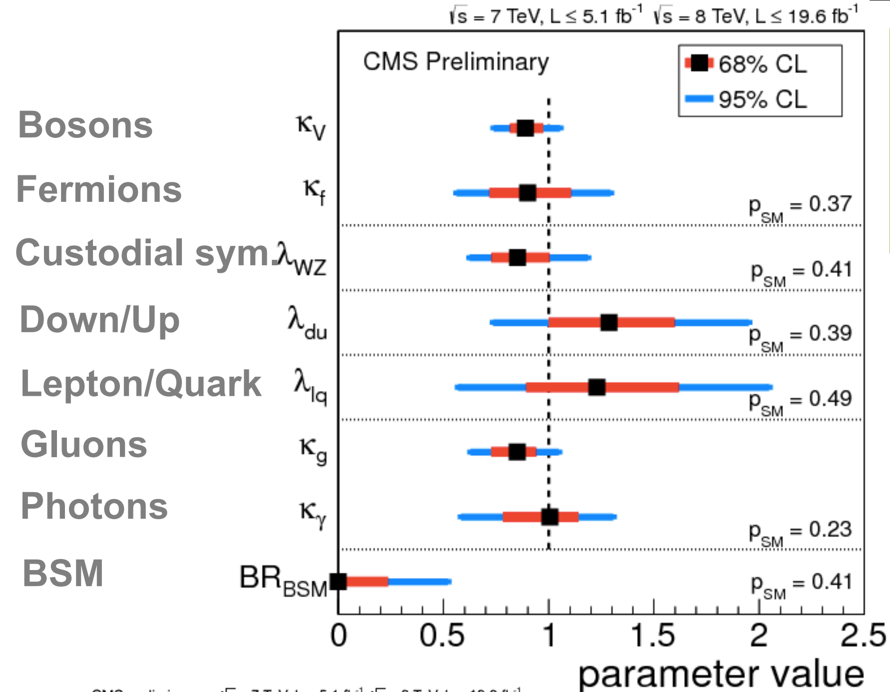


J^P	CL_s
0^-	0.16%
0^+_h	8.1%
2^+_{mgg}	1.5%
2^+_{mqq}	<0.1%
1^-	<0.1%
1^+	<0.1%

➢ **Properties indicate no deviation from H(SM) so far**

Higgs properties

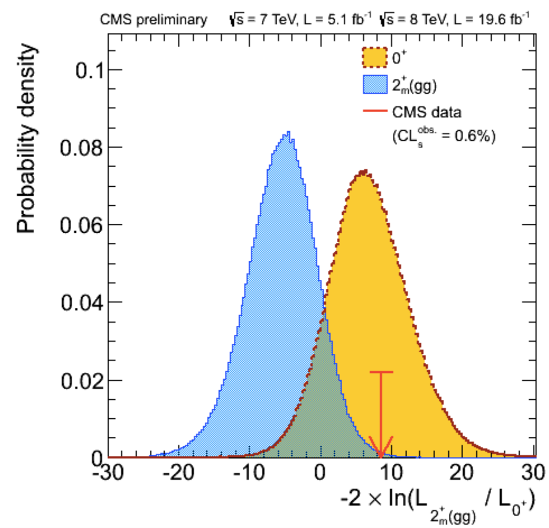
- **Couplings from simultaneous fits to observed signals**
- Define scale factors K as the ratio with respect to SM couplings (arXiv:1209.0040)
  - Test to custodial symmetry, fermion universality and effects from new physics



$\Gamma_{BSM} = 0$

m_H = 125.7 GeV

- **Spin and parity** from angular distributions in WW, ZZ and γγ
  - Studied pseudo-scalar, spin-1 and spin-2 models excluded at 95% CL or higher

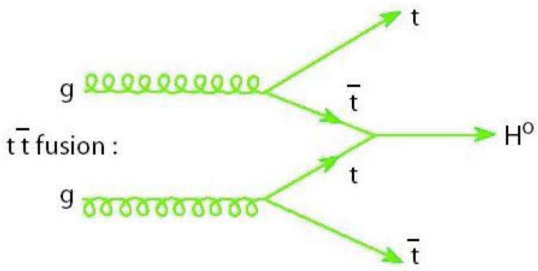


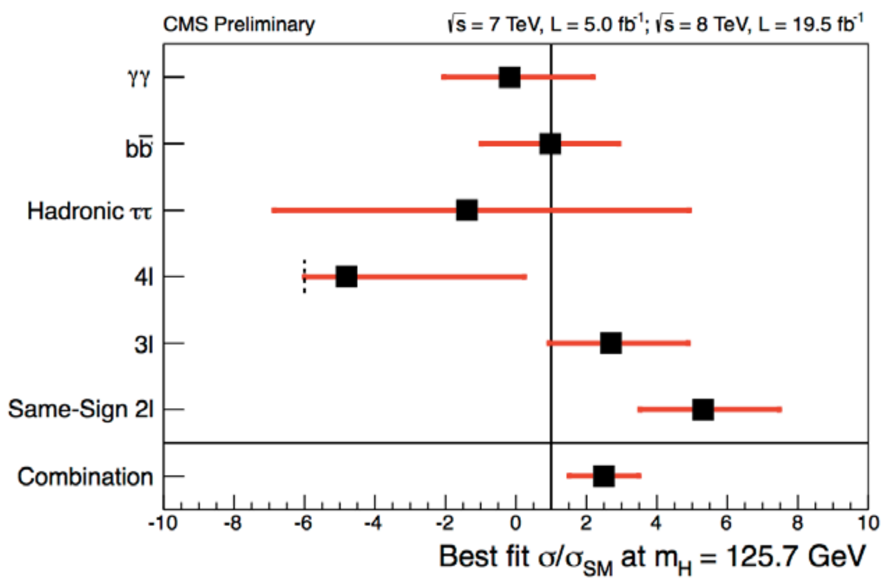
J^P	CL_s
0^-	0.16%
0^+_h	8.1%
2^+_{mgg}	1.5%
2^+_{mqq}	<0.1%
1^-	<0.1%
1^+	<0.1%

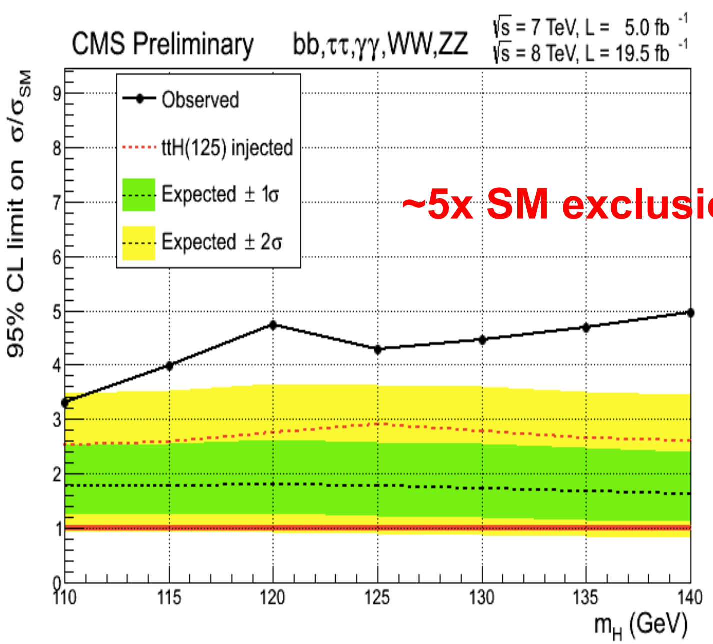
➢ **Properties indicate no deviation from H(SM) so far**

Other Higgs channels: $t\bar{t}H$

- Important test of the Yukawa coupling of the top quark
  - **Several final states from top and Higgs decays: Higgs Multi-leptons, bb, ττ, or γγ**
- Combined sensitivity on signal strength μ < 2:
  - **excess driven by same sign dimuon channel**
- Expected factor ~5 in production at 13 TeV

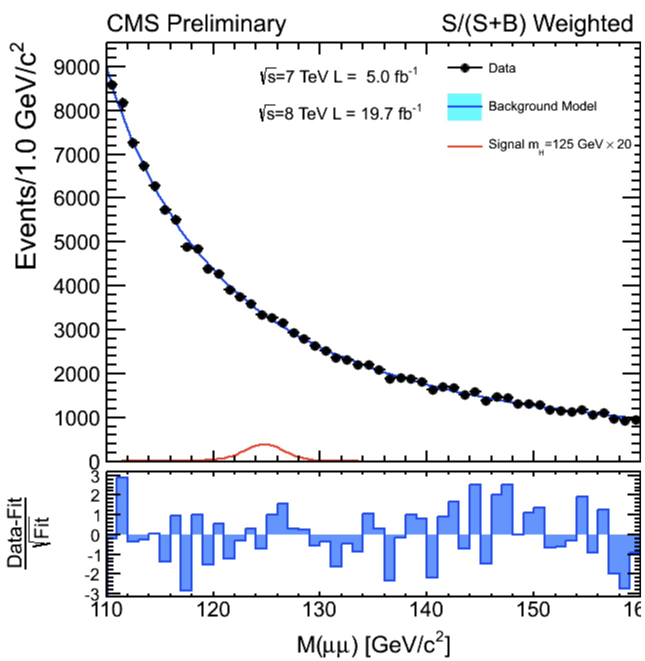


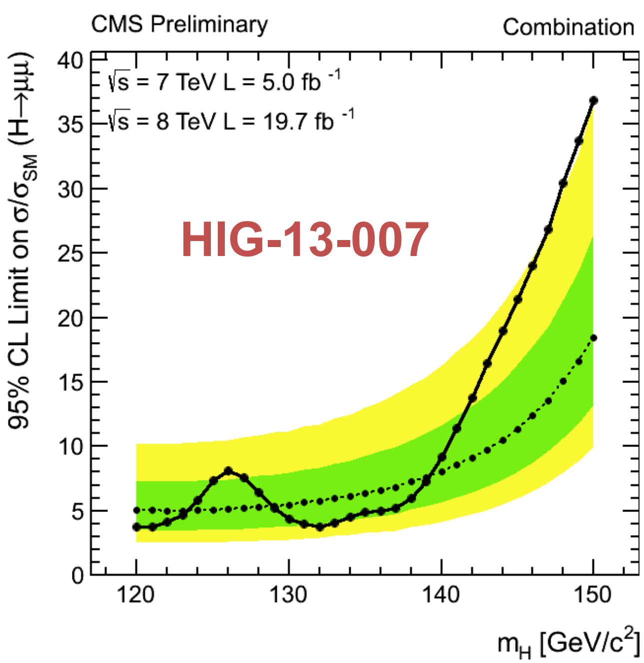


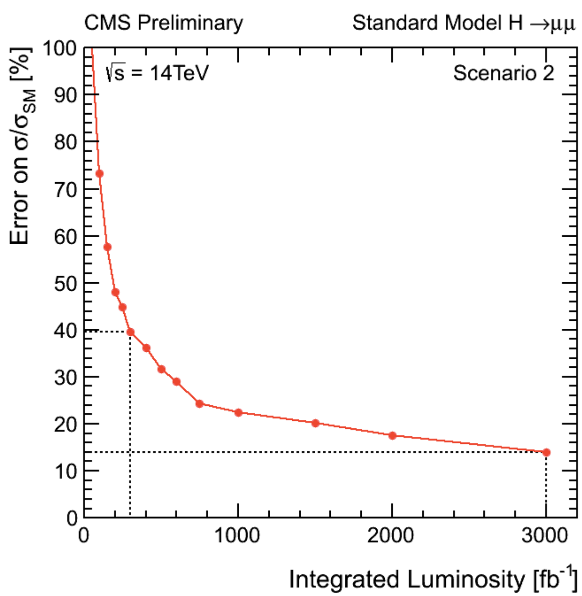


Other Higgs channels: $H \to \mu^+\mu^-$

- Interesting test of the Yukawa coupling for 2nd generation fermions
  - **Expected branching ratio in the SM is BR($H\to\mu+\mu-$) = 2.2 x 10^{-4}** (MSSM and other BSM can predict higher BR)
- 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}

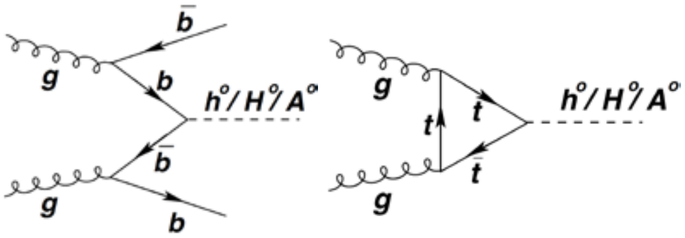


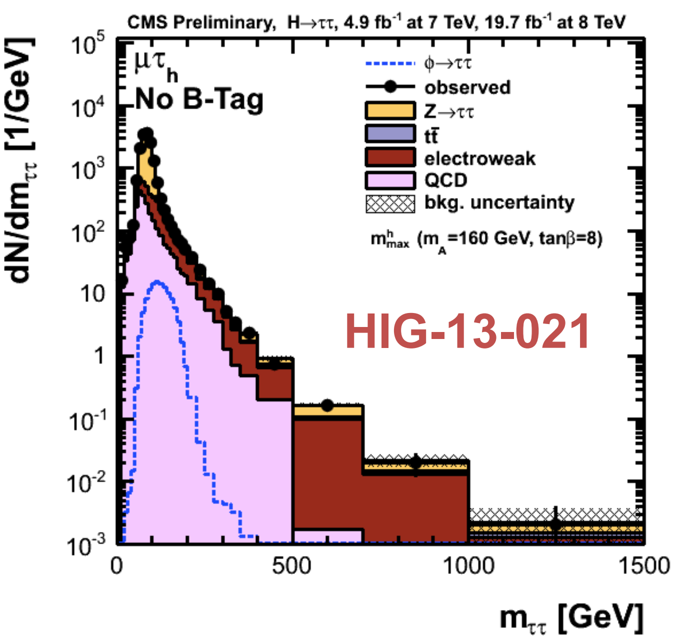


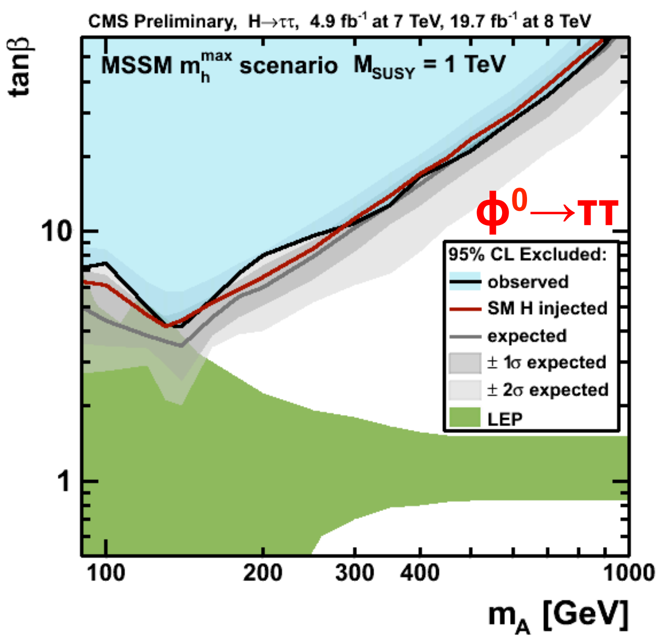


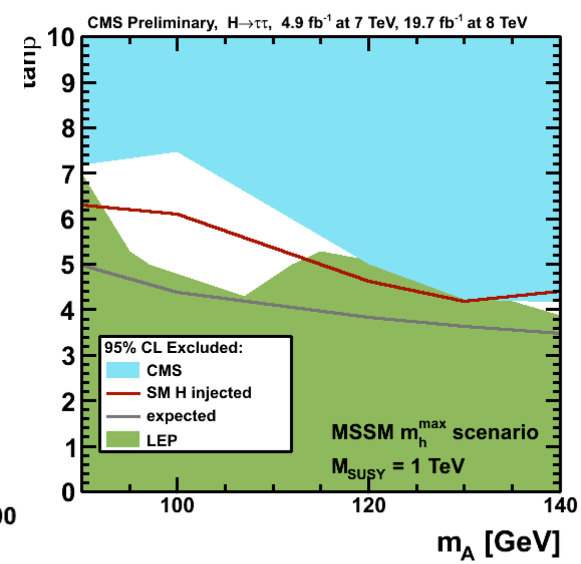
MSSM Higgs Bosons

- CMS searched for $\phi^0 \to bb$, ττ, μμ and for $H^{\pm}$ signals
- Recent result for neutral higgs: $\phi^0 \to \tau\tau$:
  - **Including production associated to bb**
- No evidence for a MSSM Higgs boson

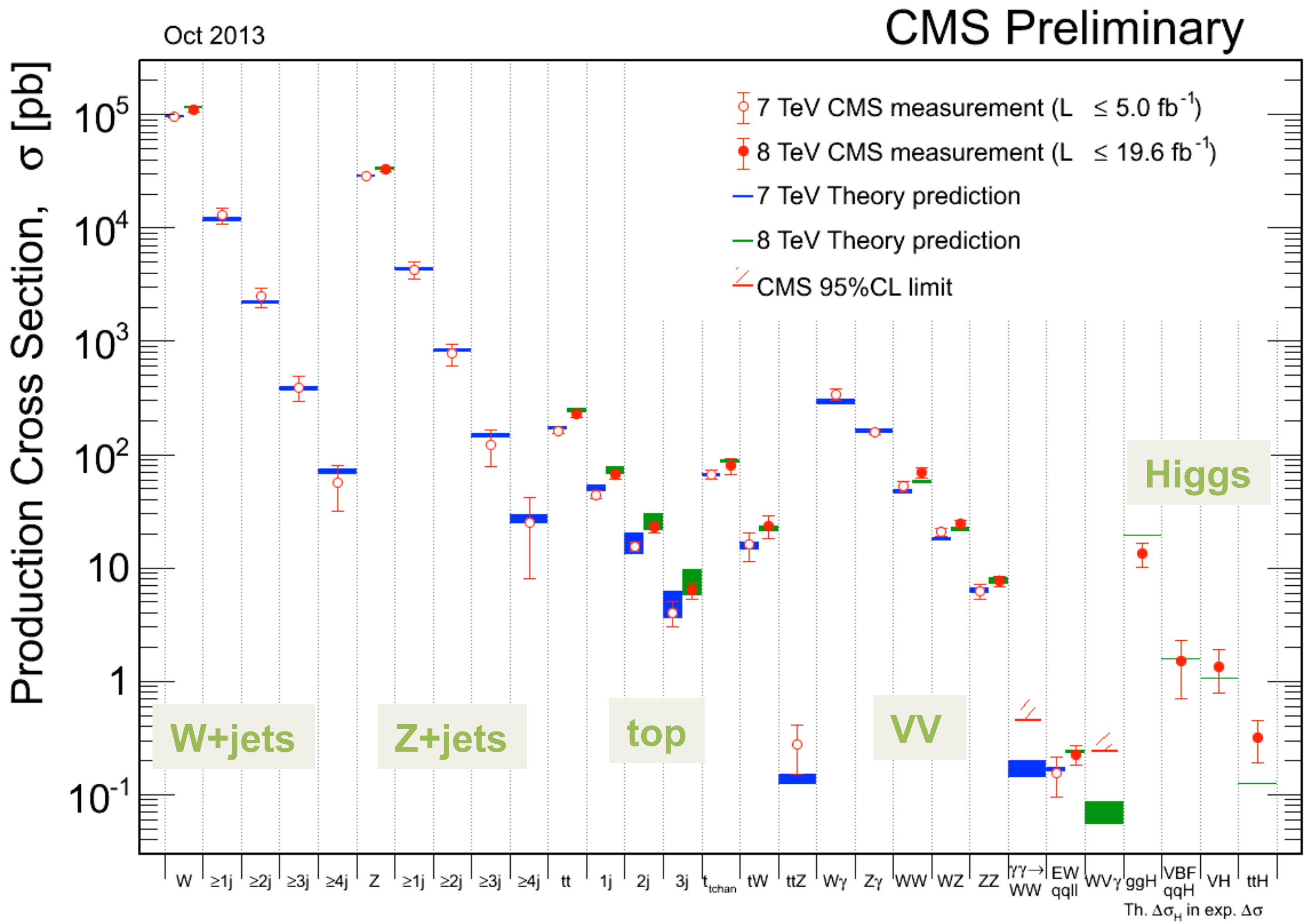








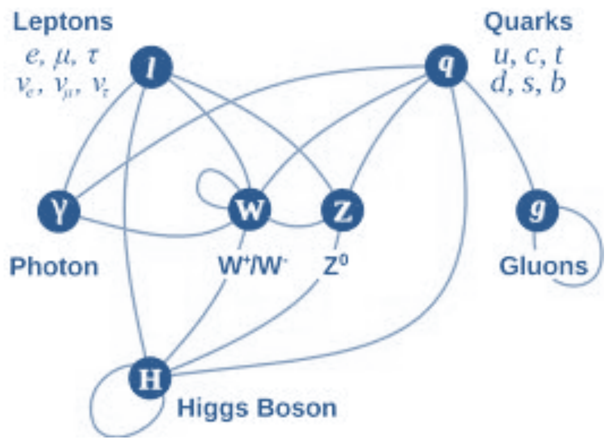
Precise SM measurements: the key to discovery



- Very good agreement with **NLO (or approx. NNLO)** predictions at 7, 8 TeV

All predicted elements of the SM have now been verified!

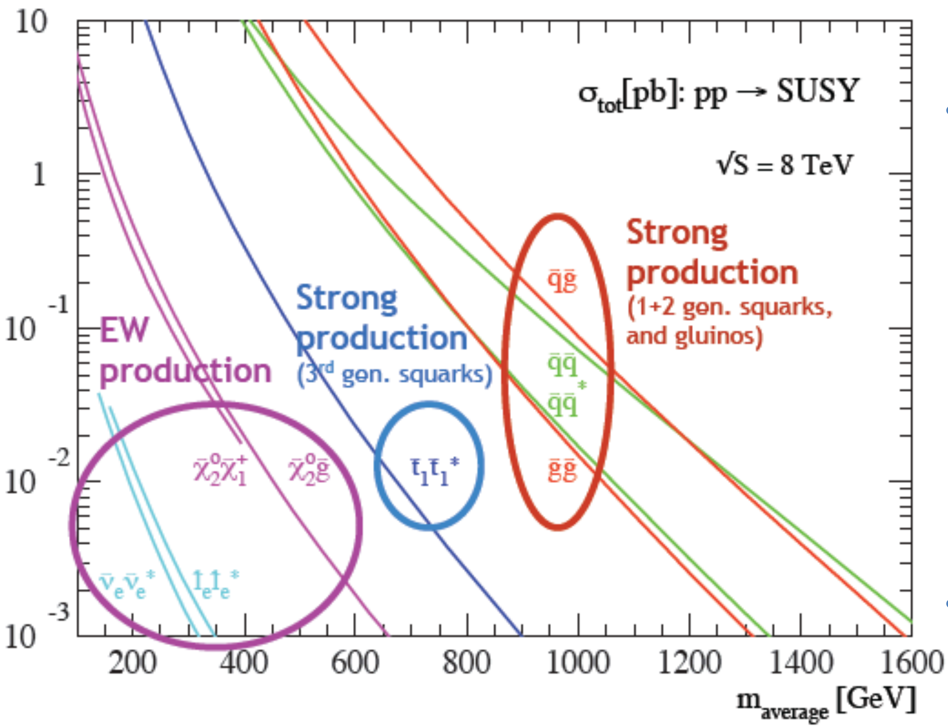
- *Higgs was last missing piece.*
- *Yet SM remains an incomplete description of Nature!*



BSM: SUSY searches

- **Searches driven by the production xsec and thus luminosity**

NLO(-NLL) s(pp® SUSY) [pb]



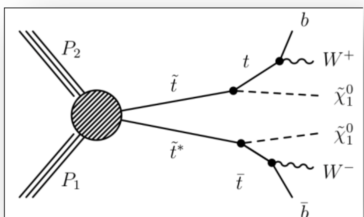
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections

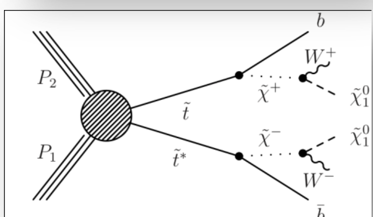
- Early analyses dominated by broad and inclusive searches for strong gluino and squark production
- Increasing luminosity gave access to rarer production channels:
  - **Additional motivation from the discovery of the Higgs boson move experimental strategy and interpretation to "Natural SUSY" scenarios**
    - light 3th generation squarks (specially stops)
    - EWK production (also with Higgs in final state)
- The goal of experiments is to develop strategies to cover the rich decay spectrum:
  - Focus on X→ LSP + SM production (RPC): large MET signatures
  - Also RPV and long-live particles.

Typical Natural-SUSY searches (8 TeV)

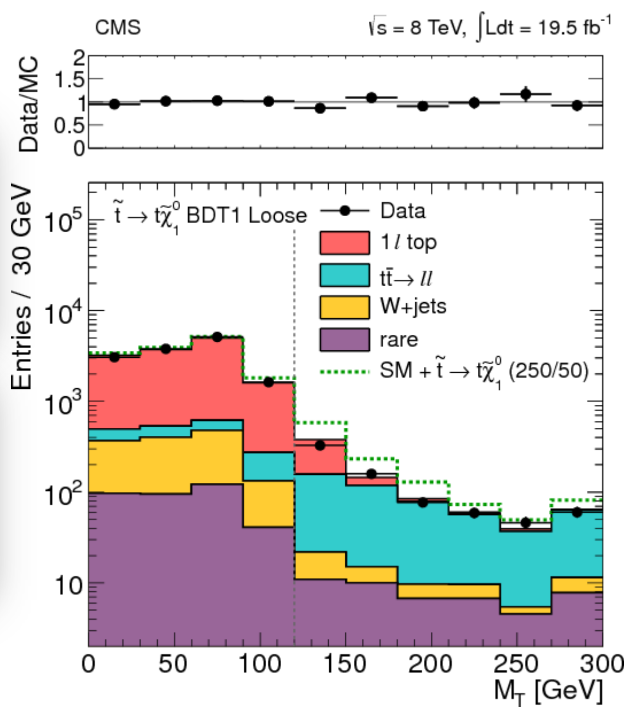
- **After 2 years of dedicated efforts…**
- **Searches for direct stop production**
  - **SUSY simplified model limits at ~700 GeV for stop mass depending on mass of LSP**

SUS-13-011

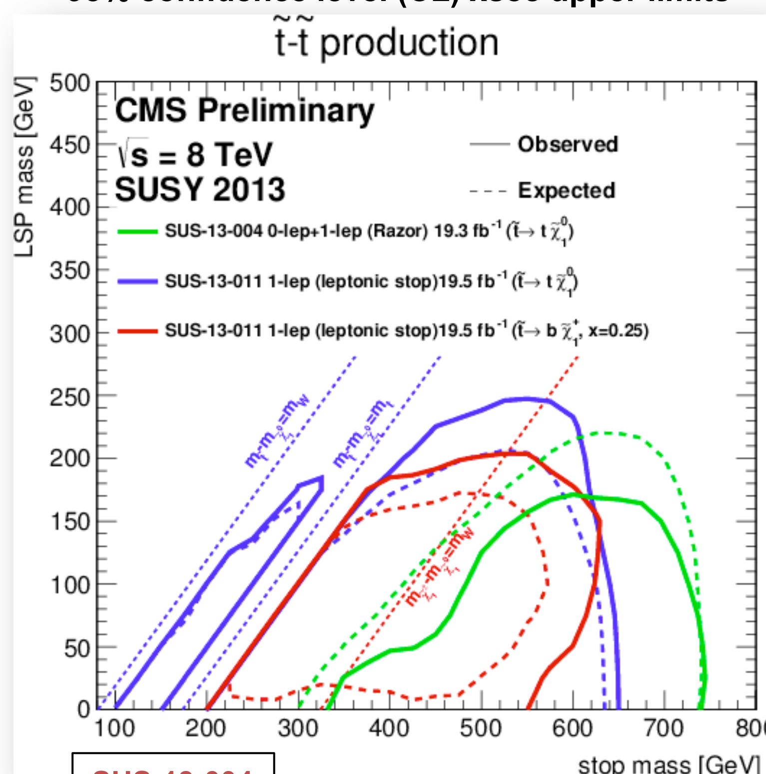




Signature: 1 lepton+ jets (b-tagged) + MET



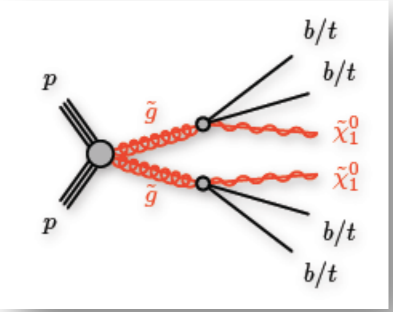
95% confidence level (CL) xsec upper limits

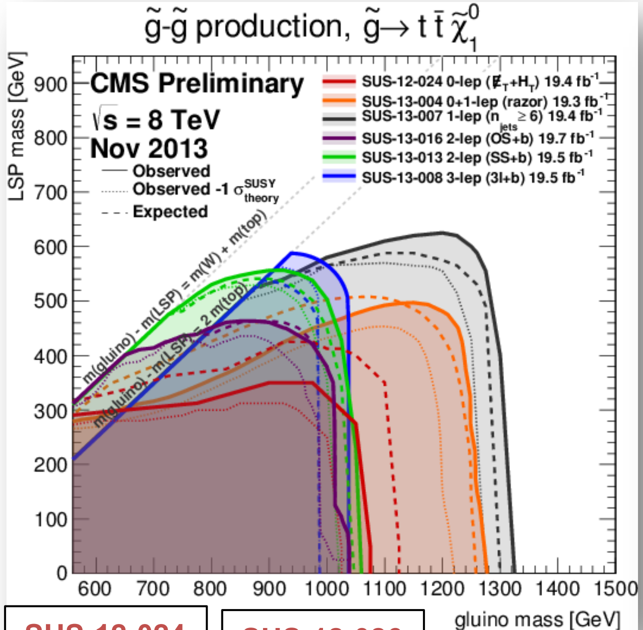


SUS-13-004
SUS-13-011

Typical Natural-SUSY searches (8 TeV)

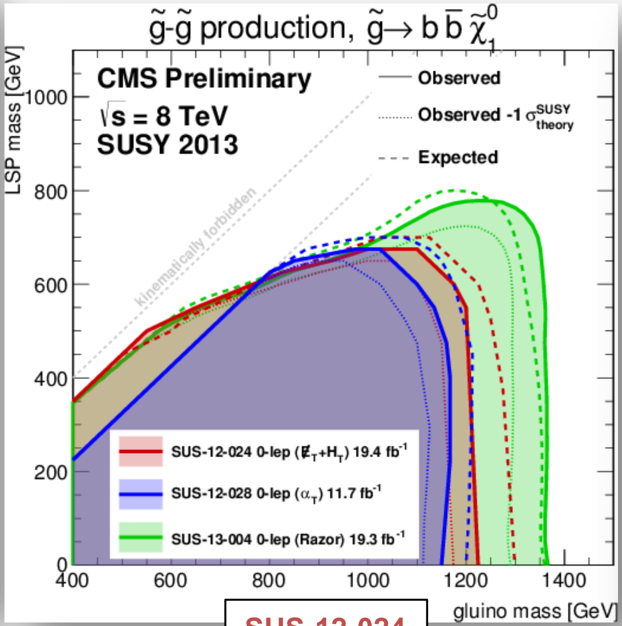
- **Searches for gluino decays to stop or sbottom quarks**
  - **SUSY simplified model limits at ~1.3 GeV for gluino mass depending on mass of LSP and decay mode**



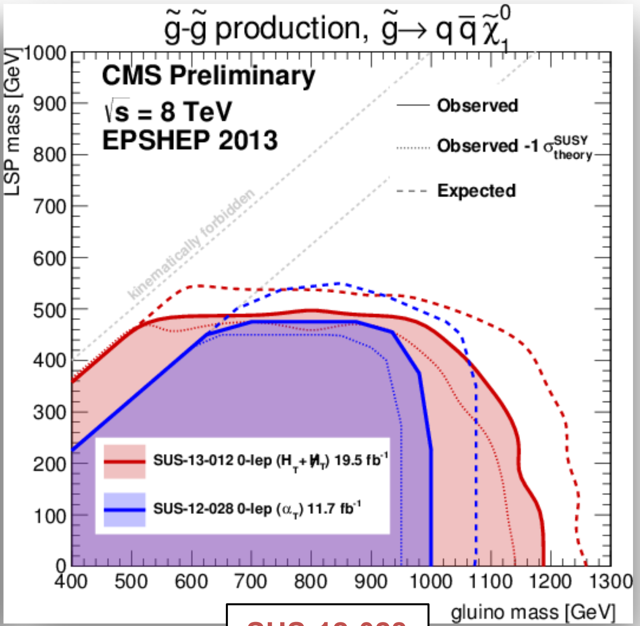


SUS-12-024
SUS-12-028
SUS-13-004
SUS-13-007

SUS-12-026
SUS-13-008
SUS-13-013
SUS-13-016



SUS-12-024
SUS-12-028
SUS-13-004

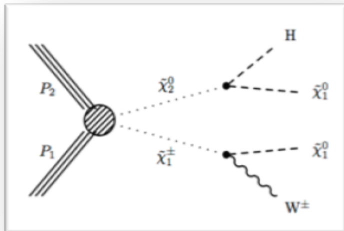


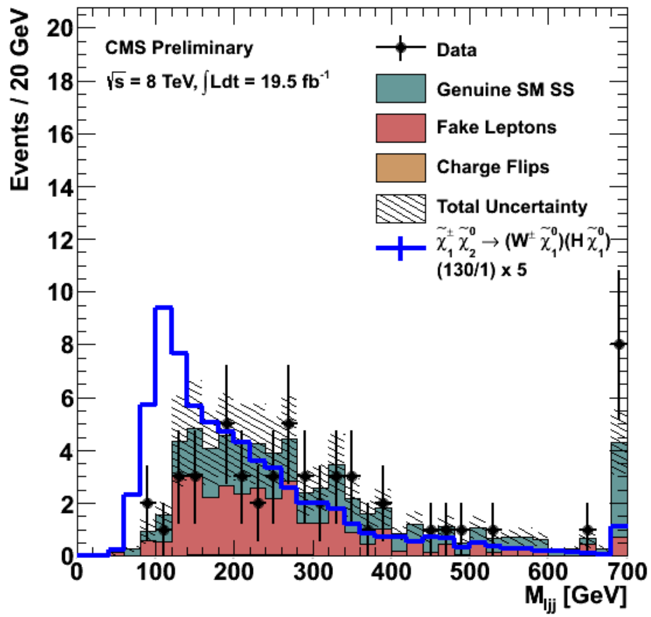
SUS-12-028
SUS-13-012

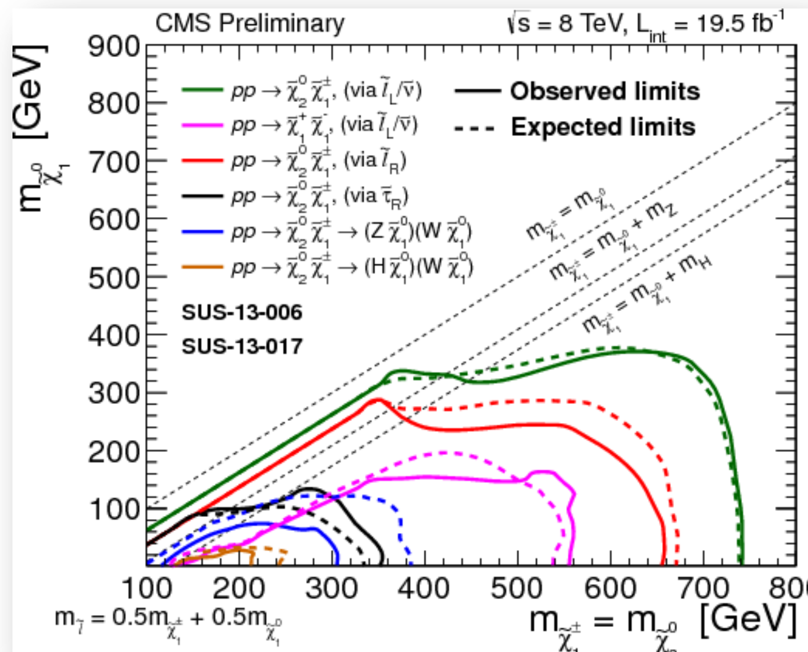
SUSY EWK production (8 TeV)

- **Searches for electroweakino $(\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm)$ pair production and sleptons**
  - **SUSY simplified model mass limits between 200-700 GeV depending on mass of LSP the decay mode**

SUS-13-017





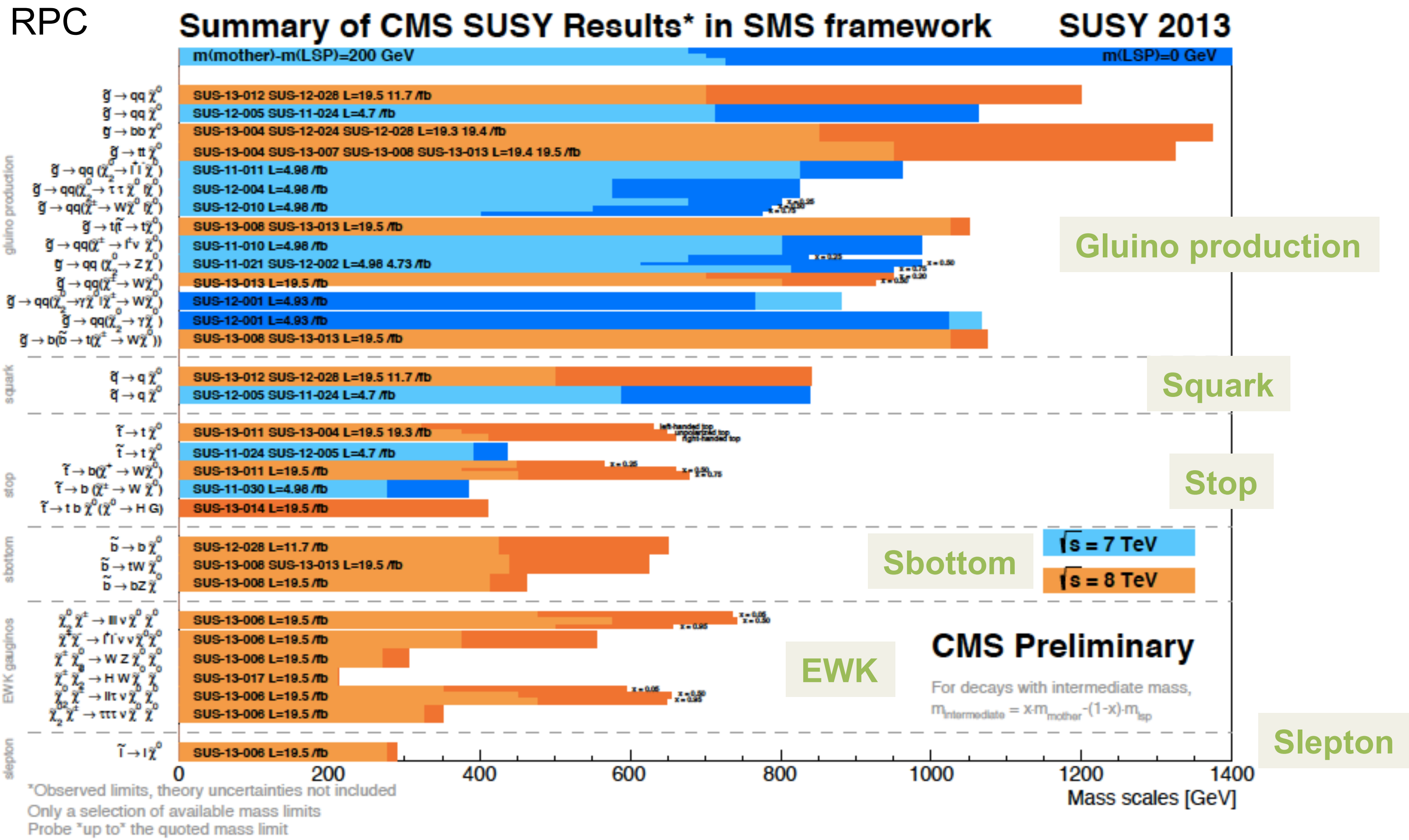


Signature:
- Exactly 1 lepton+ 2 jets (b-tagged) + MET
- SS dileptons + jets + MET
- Multileptons + MET

SUS-13-006
SUS-13-017

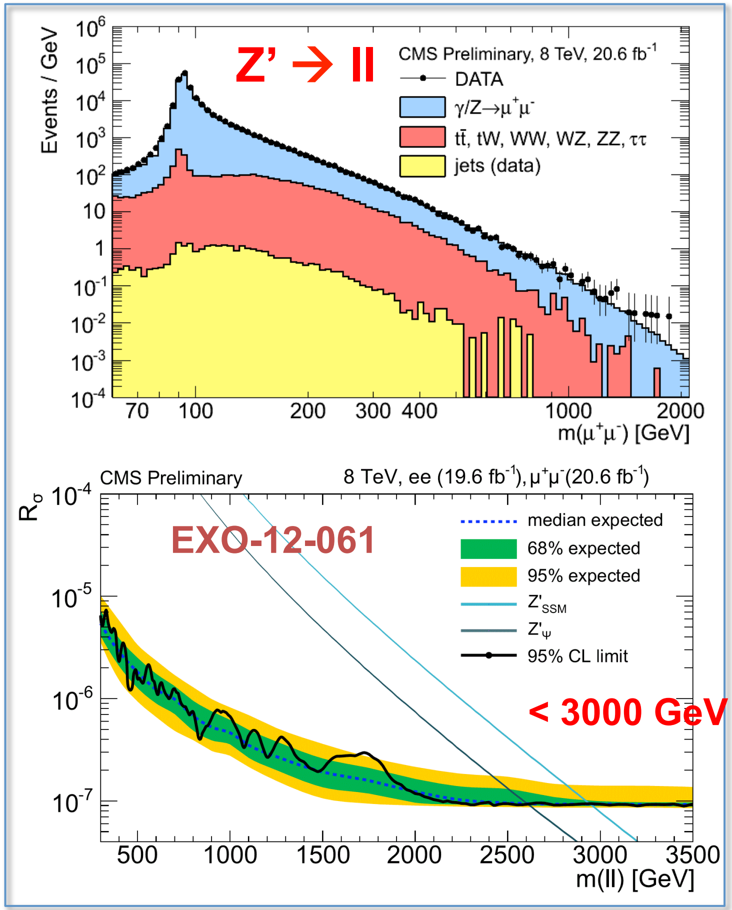
Overview SUSY searches

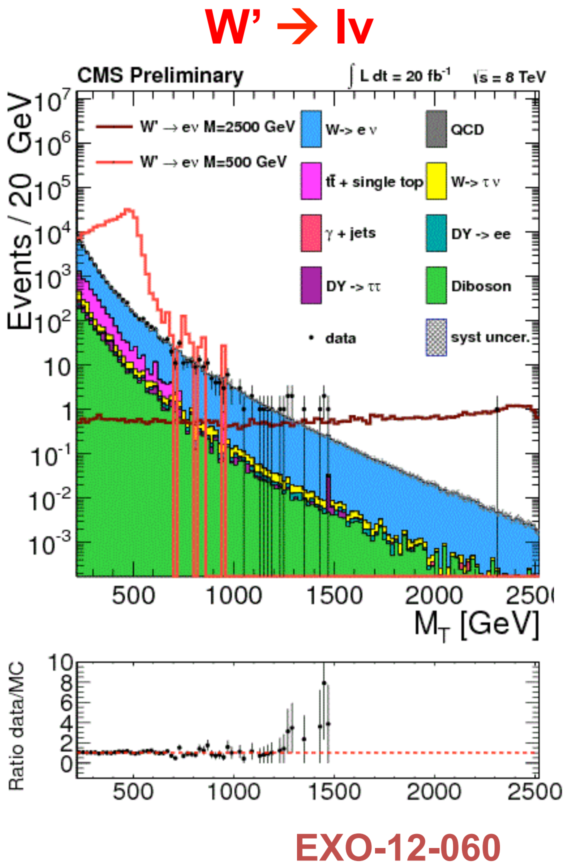
RPC

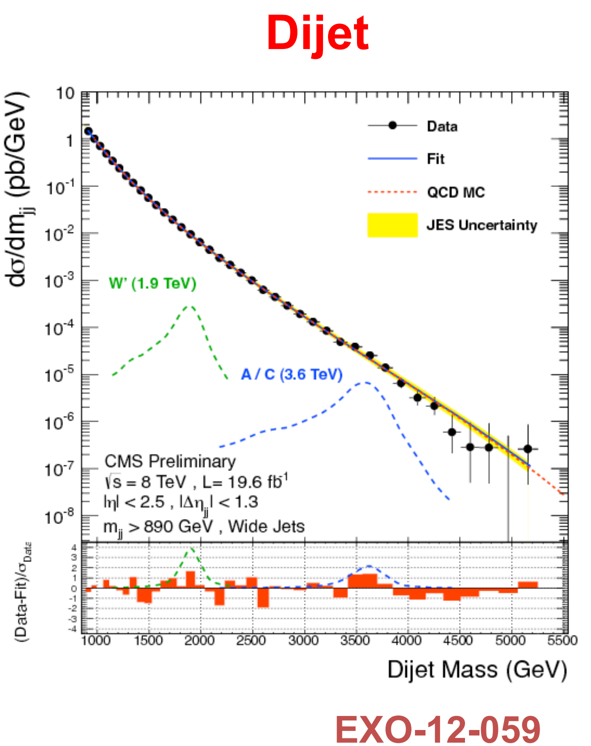


BSM searches: High-mass resonances

- **«Simple» procedure:**
  - Reconstruct pairs of high-pT objects: jets, leptons, bosons, …
  - Look at inv. mass, M_T tails for deviations from smooth SM backgrounds.
  - Interpret (lack of) excess within (simplified) BSM models: Set limits for NP

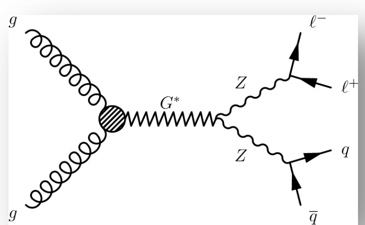


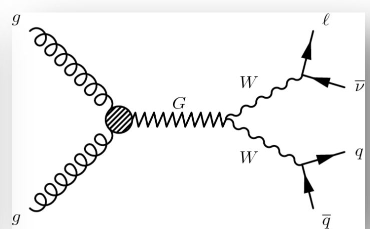


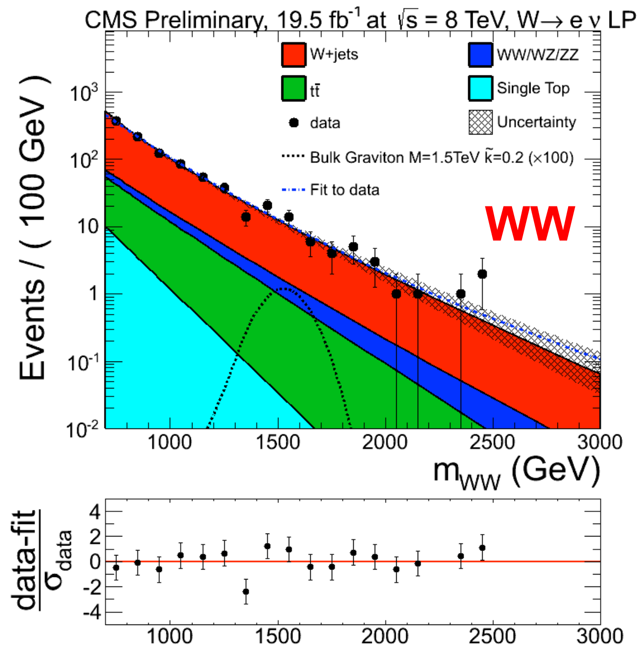


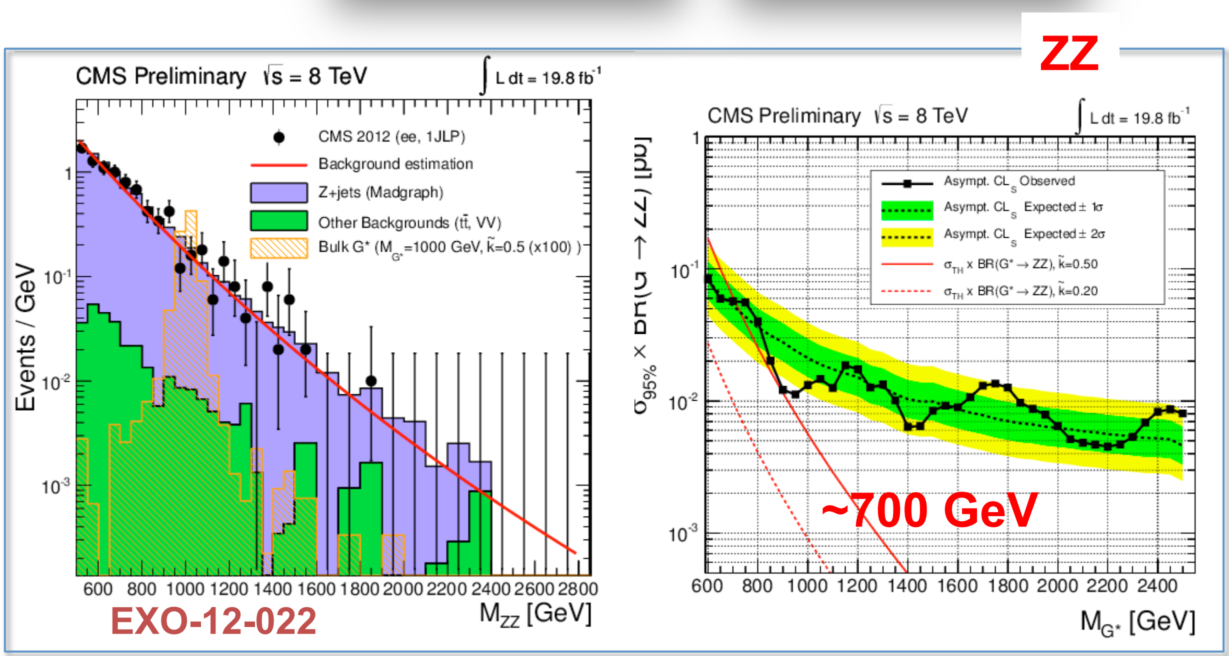
BSM searches: High-mass resonances

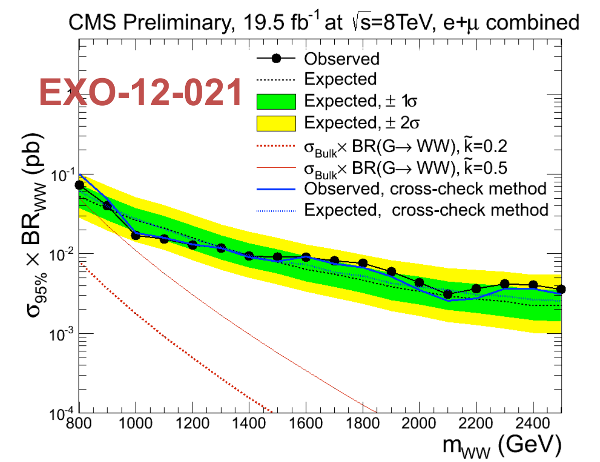
- **Di-boson resonances**
  - Search for deviations in final WW, ZZ, WZ states
  - Excellent momentum and energy resolutions are required







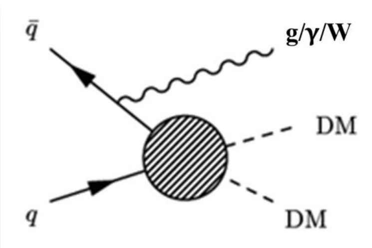


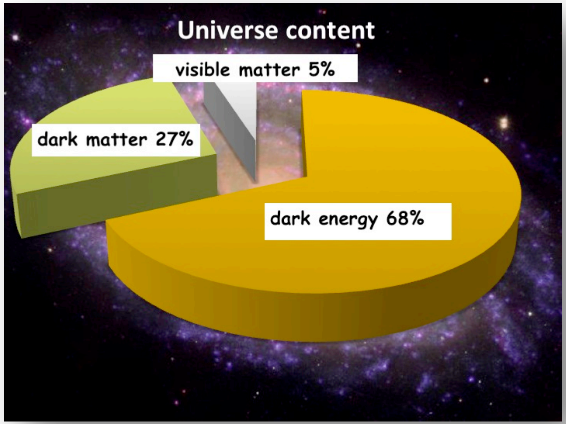


BSM: Dark matter = new heavy particle?

→ **Weakly Interacting Massive Particle (WIMP)**

- **CMS searches for DM production in association to g, γ or W(⟶lν):**
  - Monojet, monophoton or monolepton final states + MET



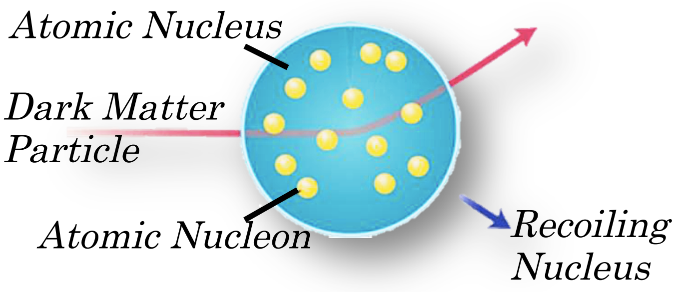


(*) After Planck results

- **Derived limits using LHC data and compared to direct-detection experiments:**
  - Non-collider experiments: dark matter nucleon cross section limits.
  - Effective field theory: limits dependent on mediator nature

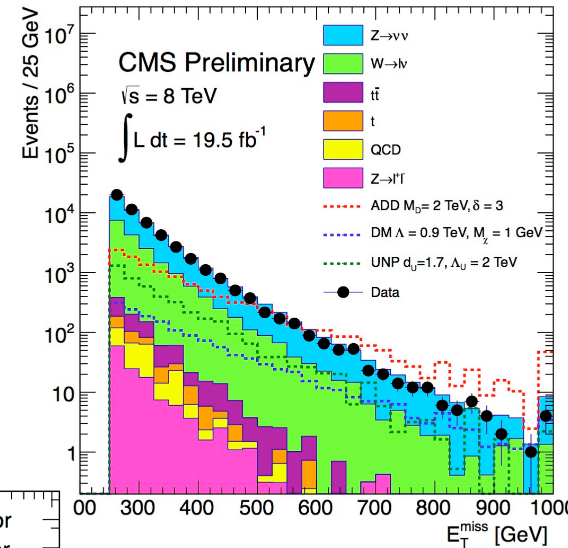
    Vector mediator ⟶ spin independent

    Axial-vector mediator ⟶ spin dependent

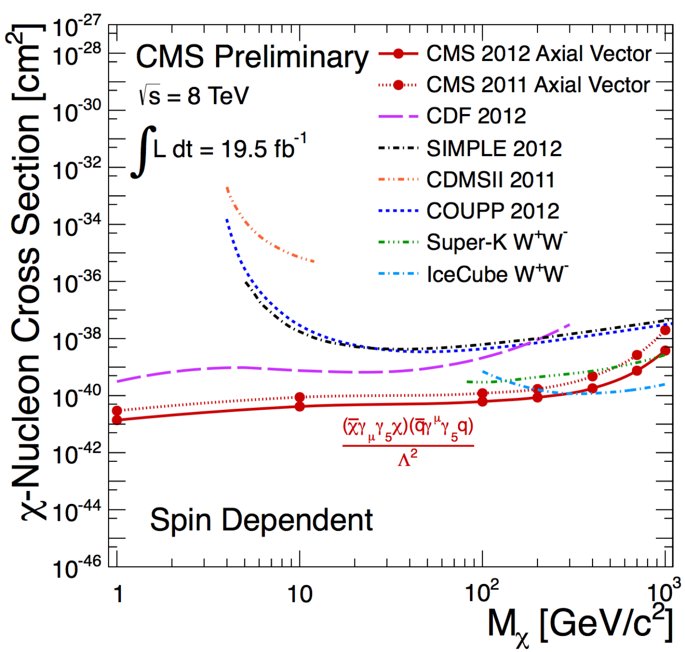


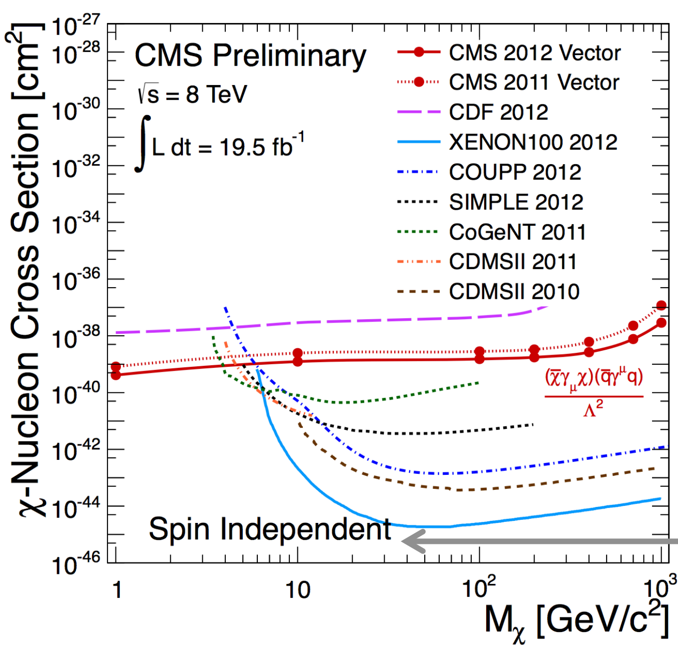
BSM searches: generic dark-matter

- **Search for new physics in monojet events**
- Complementary to direct underground/space searches.
  - MonoJet 90% CL upper limits on Cross-section of Dark Matter with ordinary matter for mχ
  - **Collider experiments particularly sensitive to low mχ**



EXO-12-048

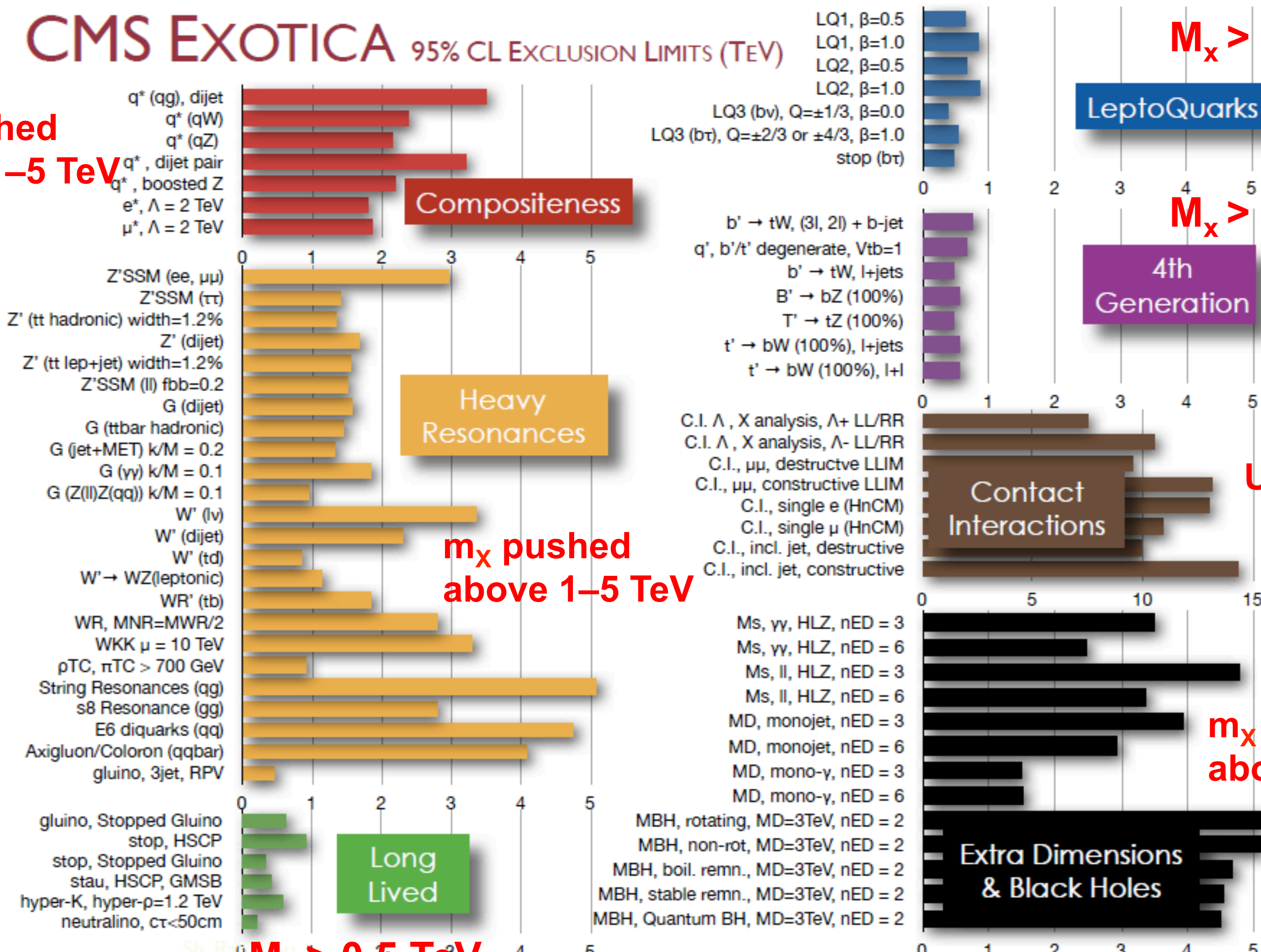




LUX result somewhere here

No strong indication for dark matter at CMS found.

Overview BSM (non-SUSY) searches



m_X pushed above 1–5 TeV

m_X pushed above 1–5 TeV

M_X > 0.5 TeV

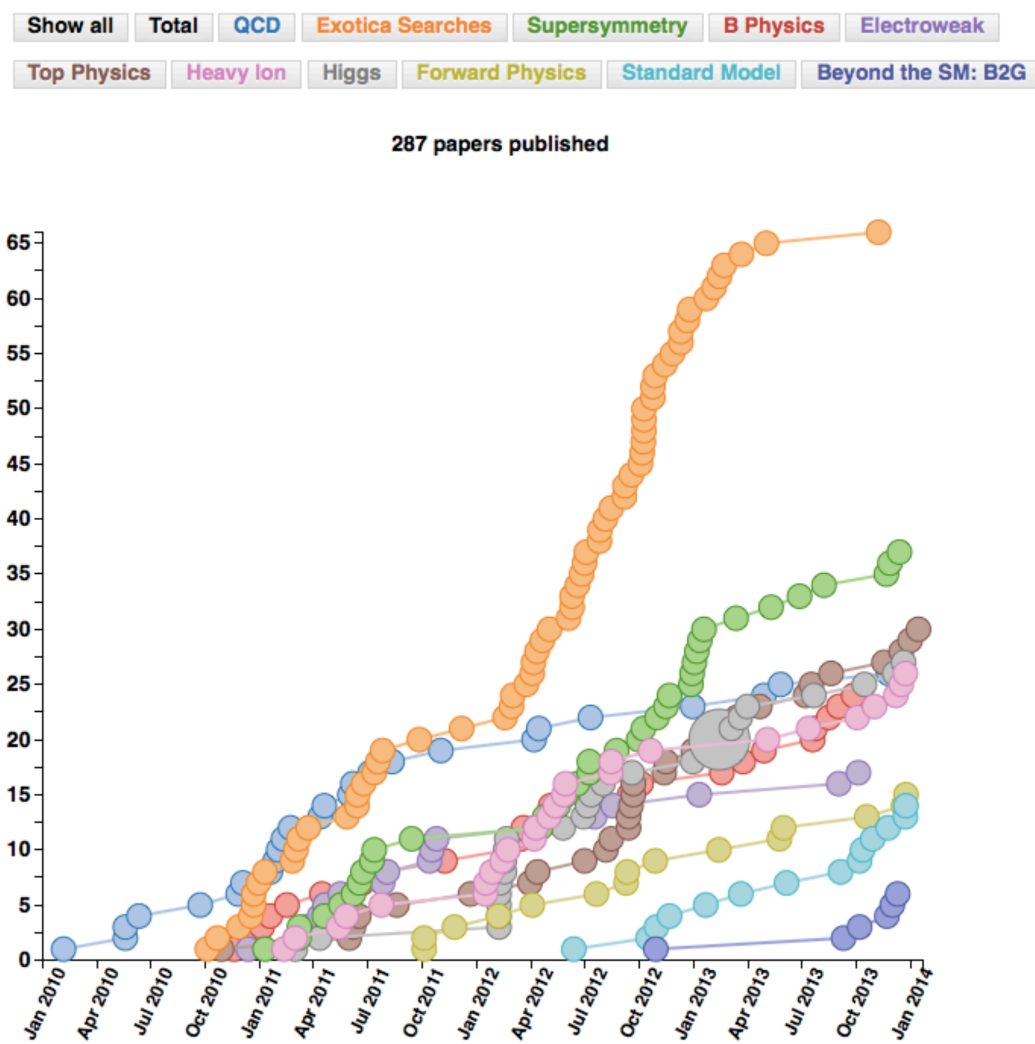
M_X > 0.5 TeV

M_X > 0.5 TeV

Up to 10 TeV

m_X pushed above 1–5 TeV

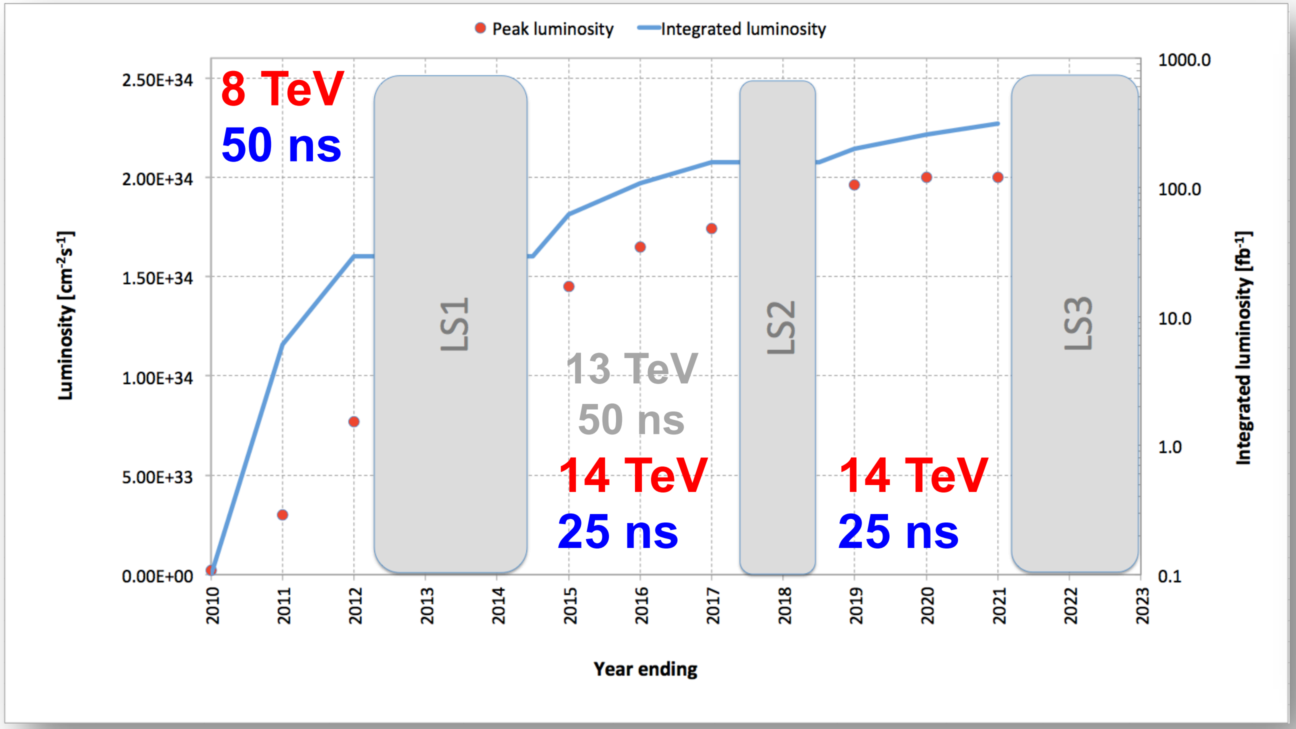
The consequence: a lot of reading material



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

The future …

The Future of the LHC



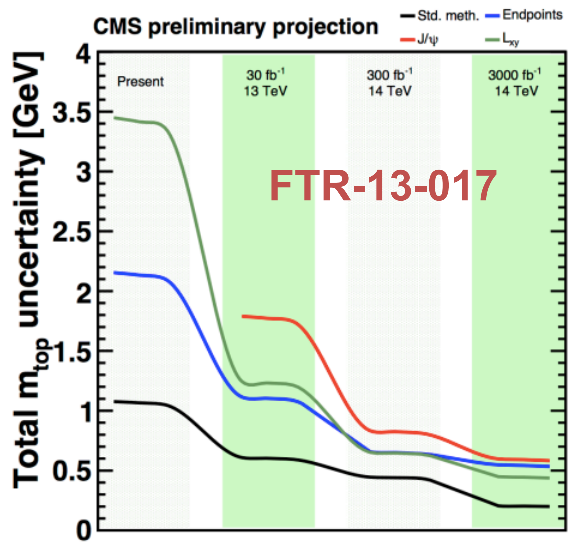
14 TeV

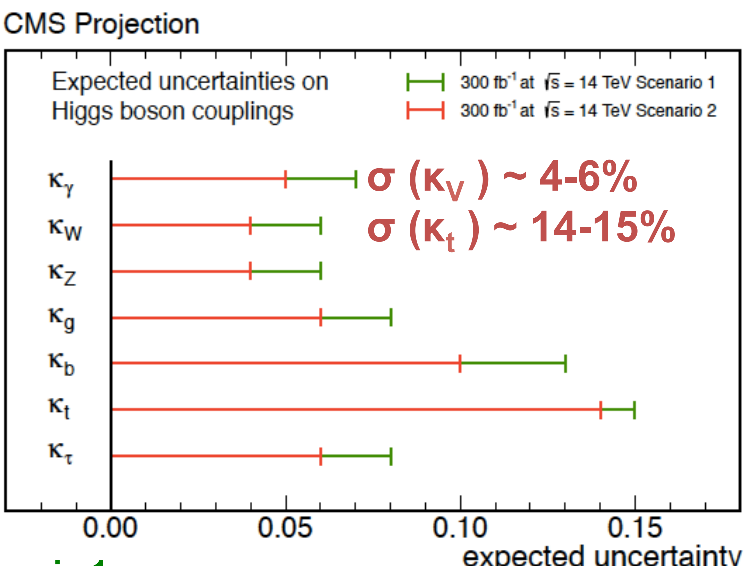
HL-LHC

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

CMS Physics Program Priorities

- **With data collected until ~2022 (~300 fb^{-1})**
  - Measure Higgs-like boson properties
    - individual couplings with 5-10% precision
  - Search for new physics at higher mass scale

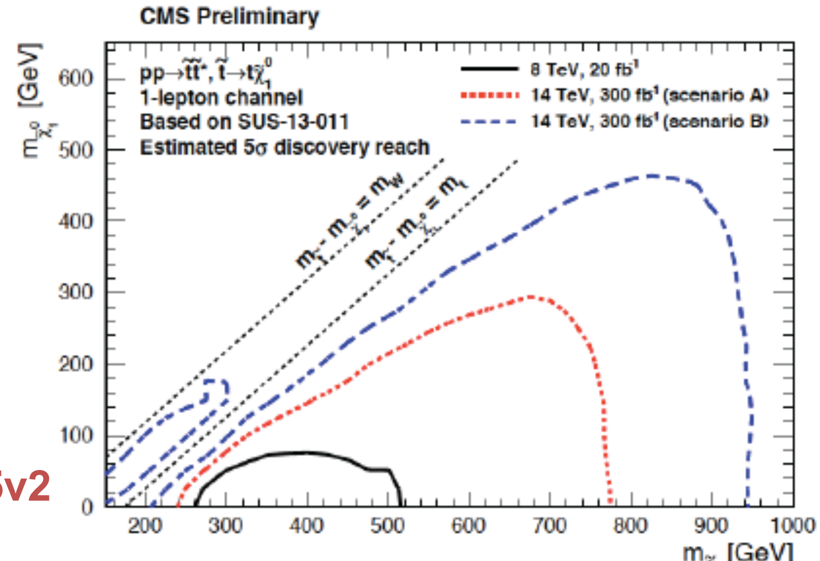




Scenario 1:
- 2012 systematics

Scenario 2:
- theory syst: scaled by a factor 1/2
- other systematics scaled by 1/√L

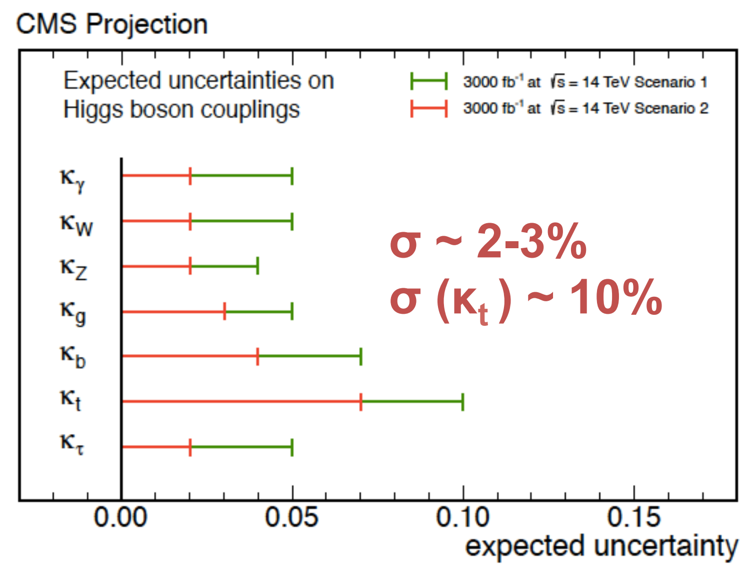
arXiv:1307.7135v2



CMS Physics Program Priorities

arXiv:1307.7135v2

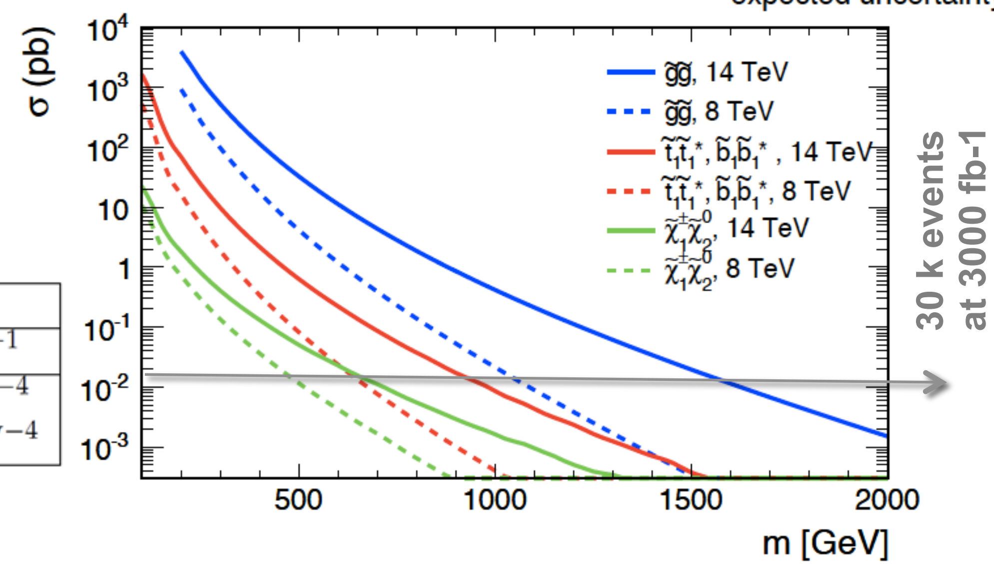
- **With data collected until ~2032 (~3000 fb^{-1})**
  - Measure Higgs-like couplings with ultimate precision
    - The decay H→μμ can be observed with a significance of 5 sigma
  - Probe SUSY up to m(gluino) ~ 2 TeV
  - Study vector boson scattering
  - Search for new physics in rare processes



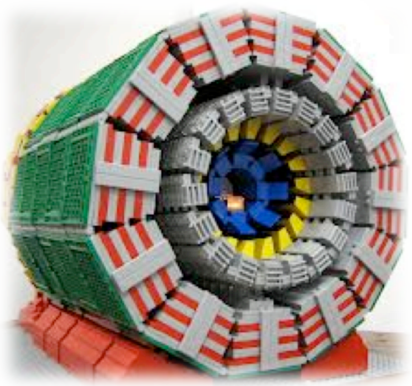
FTR-13-006

Sensitivities for SM EWK scattering discovery and aQGC.

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}



Concluding remarks



- **The 2011-2012 LHC run has fostered great successes by CMS:**
  - **Higgs boson: final discovery** and consequent detailed studies
  - **Observation of $B_s \rightarrow \mu\mu$ decays** and new resonances
  - **World's best top mass measurement**, large number of other precise measurements and searches in top sector
  - Exclusion of SUSY in wide range of parameter space, long list of searches for new phenomena
  - Wide program of precision measurements in EW parameters and QCD
- **After shutdown the new energy regime will bring sensitivity to higher energy scales, measurements of Higgs couplings, and more…**

Thank you ;)

Is there anything beyond the Standard Model?

Backup material

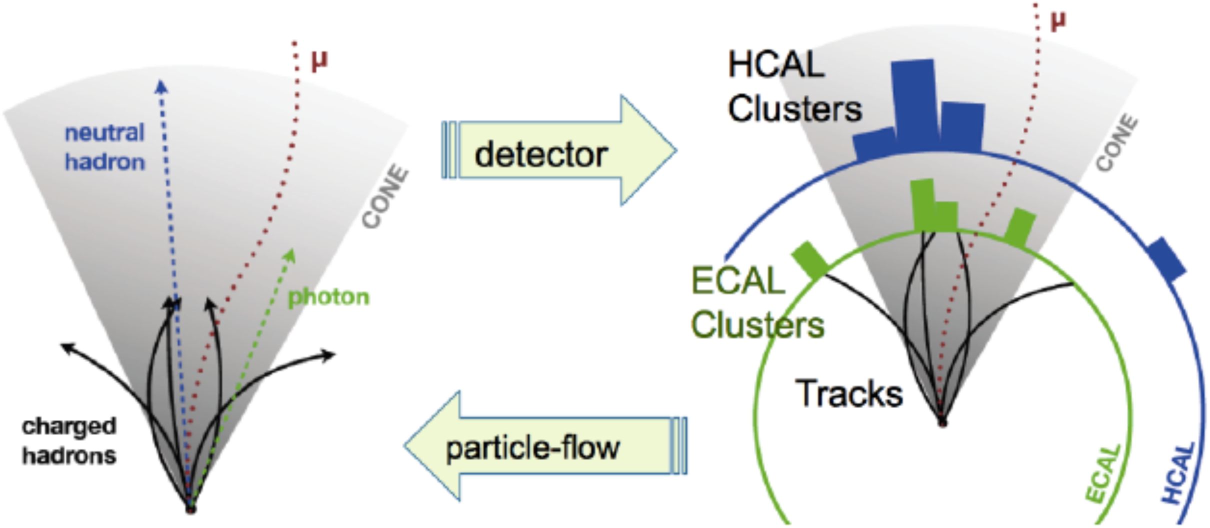
Some goals of the Large Hadron Collider

- Solve some **open questions** in HEP:

1. **Mass generation problem**: What is the origin of the SM elementary particle masses ? Higgs boson ? other mechanism ?
2. **Hierarchy / fine-tuning problem:** Higgs mass runs up «uncontrolled» up to Planck scale… what stabilizes m_{Higgs} up to m_{Planck} (10^{16} orders-of-magnitude!?) ? SUSY ? extra-D ? ... ?
3. **Dark matter problem:** SM describes only 5% of Universe (visible fermions-bosons). ~1/4 universe = invisible matter. SUSY ? Other particles ?
4. **Flavour problem:** Origin of matter-antimatter asymmetry in the Universe ? Why so many types of matter particles ?
5. **QCD in non-perturbative regime:** Why quark confinement ? Total hadronic x-sections ?

Object reconstruction: Particle Flow

- CMS exploits fine granularity and 3.8T magnetic field in the inner tracker region to define a **Gloval Event Description**

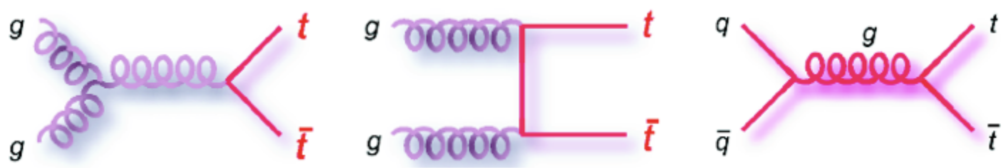


- Optimal combination of information from all CMS sub-detectors produces a list of reconstructed particles: energy and direction
- **e, γ, μ, charged and neutral hadrons** used in analysis (as if they came from a list of generated particles) used as building blocks for **jets, b-jets, taus, MET, isolation**

Top quark production

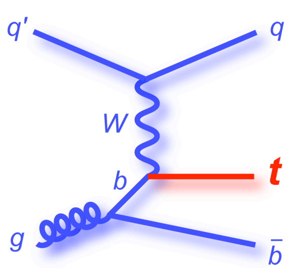
- **Top quark pairs produced in strong interaction via:**
  - gluon-gluon fusion: dominant mode at LHC
  - quark- antiquark annihilation

	LHC	Tevatron
gg	~ 85%	~ 10%
qq	~ 15%	~ 90%

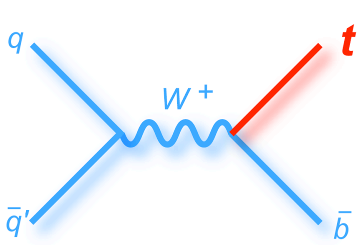


σ (7TeV) ≈ 163 pb (@ approx. NNL0)
σ (8TeV) ≈ 246 pb (@ NNL0+NNLL)

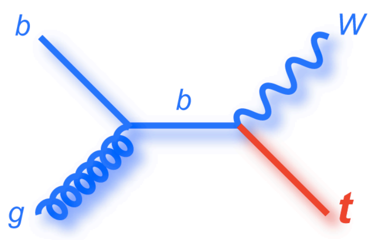
- **Single top quark produced in EWK interaction via:**



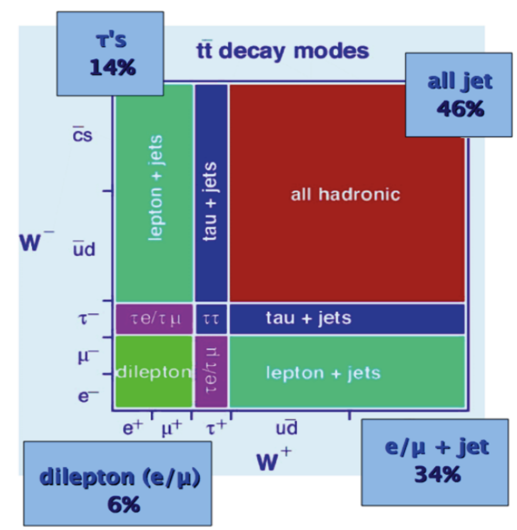
t-channel
σ (7TeV) ≈ 64 pb
σ (7TeV) ≈ 87 pb



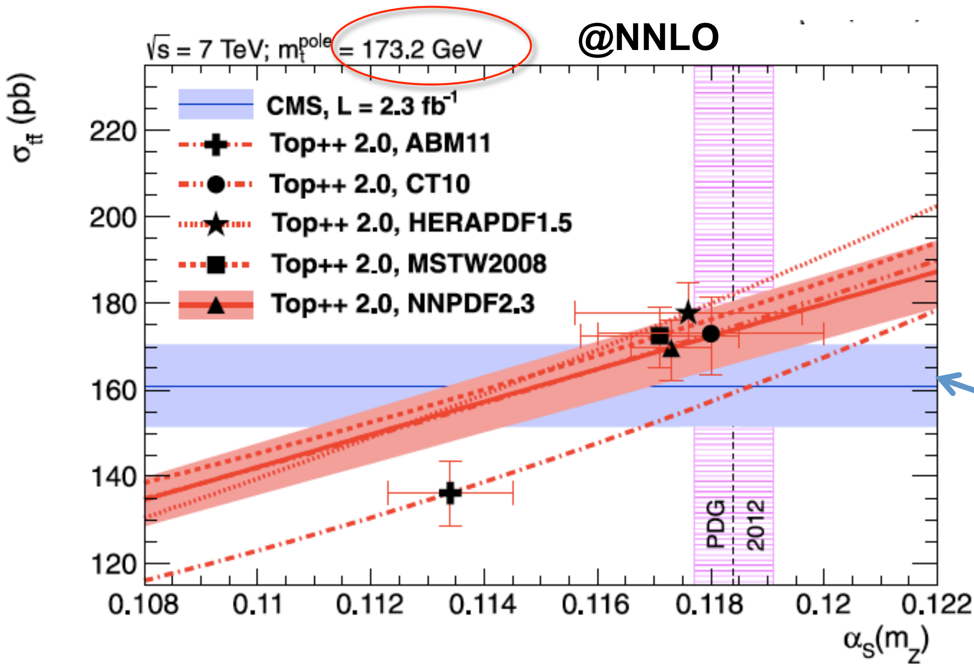
s-channel
σ (7TeV) ≈ 4.6 pb
σ (7TeV) ≈ 5.6 pb



tW-channel
σ (7TeV) ≈ 15.7 pb
σ (7TeV) ≈ 22.4 pb



QCD: α_s from the tt cross section

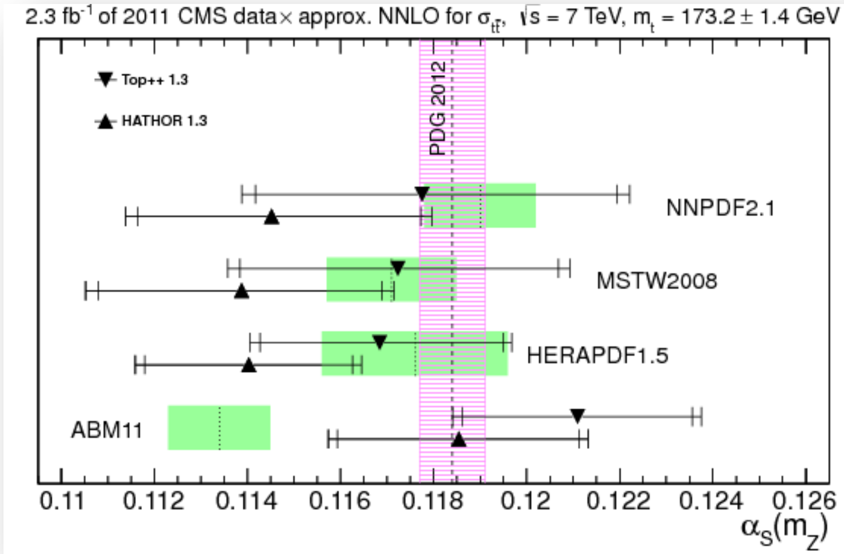


- Cross section for top quark pairs production is function of the top mass or α_s :
  - **Constraining mass pole we can determine α_s value**

σ_{tt} (173.2 GeV) = 161.0 pb (err. 4%)

Top++ and NNPDF2.3
(less assumptions of PDF parametrization)

$$\alpha_S(m_Z) = 0.1178^{+0.0046}_{-0.0040}$$



Higgs couplings

- Several production and decay mechanisms contribute to signal rate → interpretation is difficult
- **A better option: measure deviations of couplings from the SM prediction (*LHCXSWG YR3: arxiv:11307.1347*)**
  - series of benchmark parametrizations
- **Basic assumptions:**
  - there is only one underlying state at mH=125.5 GeV
  - width of the Higgs boson is neglected (narrow-width approximation) for decoupling production and decay

$$(\sigma \cdot \mathrm{BR})(ii \to \mathrm{H} \to ff) = \frac{\sigma_{ii} \cdot \Gamma_{ff}}{\Gamma_{\mathrm{H}}}$$

  - same tensor structure of the SM Higgs boson : JCP = 0++ (tested independently by ATLAS/CMS/Tevatron)
    - only allow for modification of coupling strengths
- Under these assumptions all production cross sections and branching ratios can be expressed in terms of a few common multiplicative factors to the SM Higgs couplings

$$\Gamma_H = \kappa_H^2 \cdot \Gamma_H^{SM}; \quad \Gamma_f = \kappa_f^2 \cdot \Gamma_f^{SM}; \quad \sigma_i = \kappa_i^2 \cdot \sigma_i^{SM}$$

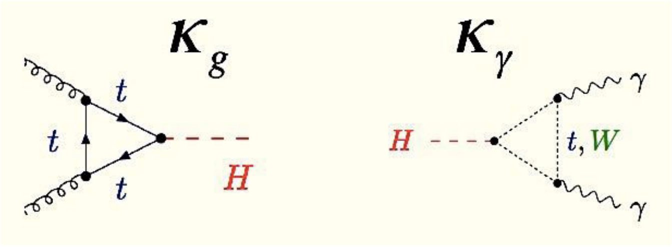
- Example:

$$\sigma \cdot \mathrm{BR}(gg \to \mathrm{H} \to \gamma\gamma) = \sigma_{\mathrm{SM}}(gg \to \mathrm{H}) \cdot \mathrm{BR}_{\mathrm{SM}}(\mathrm{H} \to \gamma\gamma) \cdot \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_\mathrm{H}^2}$$

Coupling Modifiers

- Universality of k's for fermions and gauge bosons $\mathbf{k_F = k_b = k_t = k_T}$, $\mathbf{k_V = k_W = k_Z}$ can be assumed

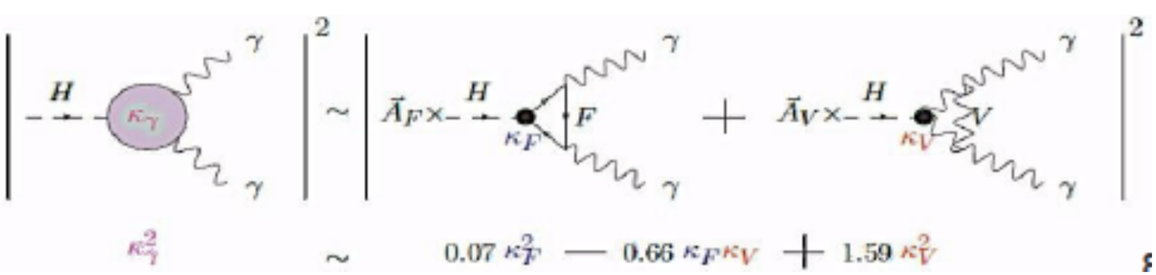
- Scale factors of loop induced couplings ($\mathbf{k_g}$, $\mathbf{k_\gamma}$) and the total width $\mathbf{k_H}$ can be treated effectively (allowing for possible additional particles)



$\kappa_H(\kappa_W, \kappa_Z, \kappa_b, \ldots)$ $\kappa_g(\kappa_t, \kappa_b)$ $\kappa_\gamma(\kappa_t, \kappa_W, \ldots)$

  - … or can be expressed in terms of fundamental factors $\mathbf{k_W}$, $\mathbf{K_z}$, **K t**… (assuming the SM contents)
  - total width: $\kappa_H^2 \approx 0.75\kappa_F^2 + 0.25\kappa_V^2$

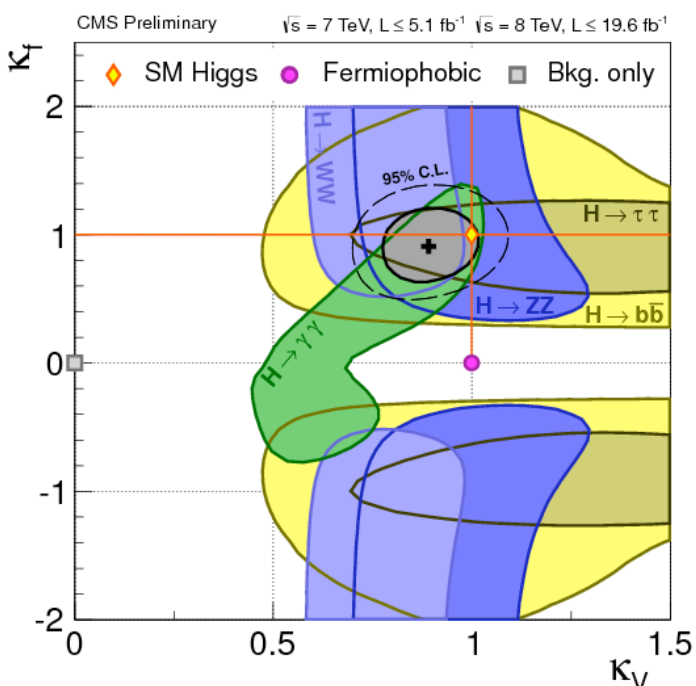
- Photon vertex loop H→γγ mediated by W and fermions (mainly top) → sensitivity to relative sign between $\mathbf{k_V}$ and $\mathbf{k_F}$ from the interference $\mathbf{k_V k_F}$ term
  - → **kV** assumed positive
  - → two minima



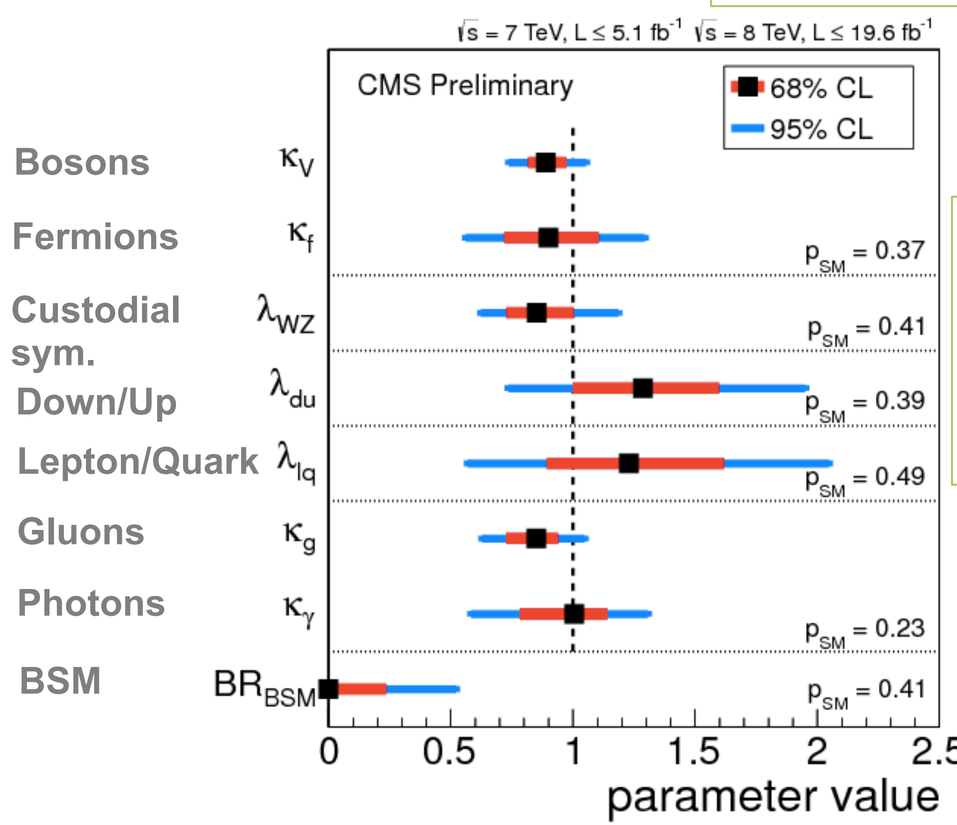
Higgs properties

- **Couplings from simultaneous fits to observed signals**
  - Measure deviations of couplings from the SM prediction: define scale factors K as the ratio with respect to SM couplings (arXiv:1209.0040)
- Test to custodial symmetry, fermion universality and effects from new physics
- **Within uncertainties, quite a SM Higgs-like statement...**

m_H = 125.7 GeV



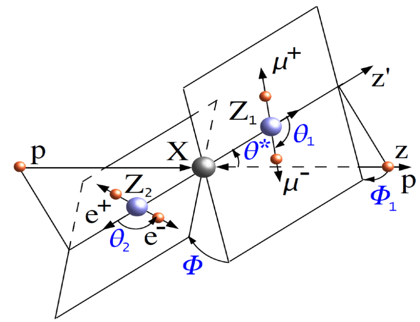
SM prediction $K_f = K_V = 1$

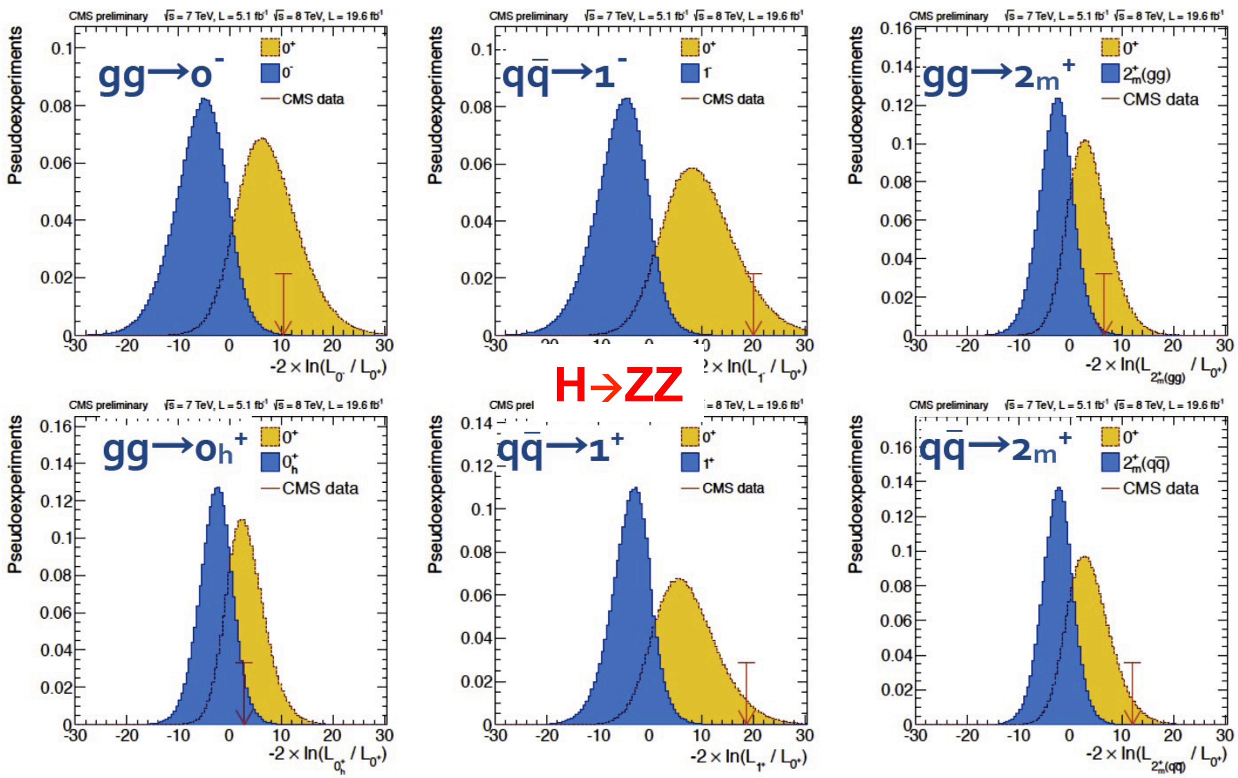


$\Gamma_{BSM} = 0$

Higgs properties

- **Spin and parity** from angular distributions in WW, ZZ and γγ
  - Studied pseudo-scalar, spin-1 and spin-2 models excluded at 95% CL or higher



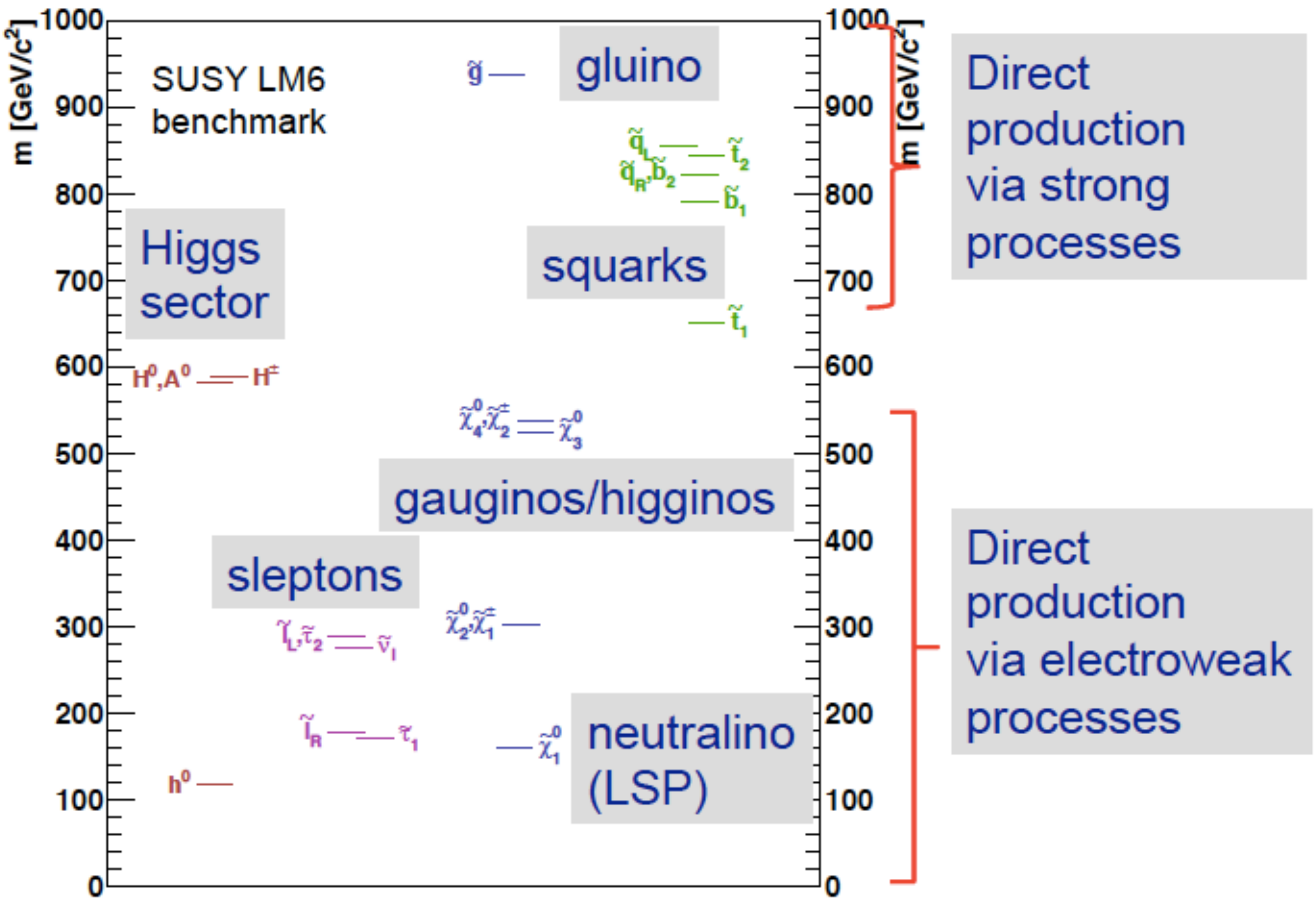


J^P	CL_s
0^-	0.16%
0^+_h	8.1%
2^+_{mgg}	1.5%
2^+_{mqq}	<0.1%
1^-	<0.1%
1^+	<0.1%

SM prediction JP = 0+ highly favorite vs. other hypotheses

➢ **Properties indicate no deviation from H(SM) so far**

Big themes: many (& complex) signatures

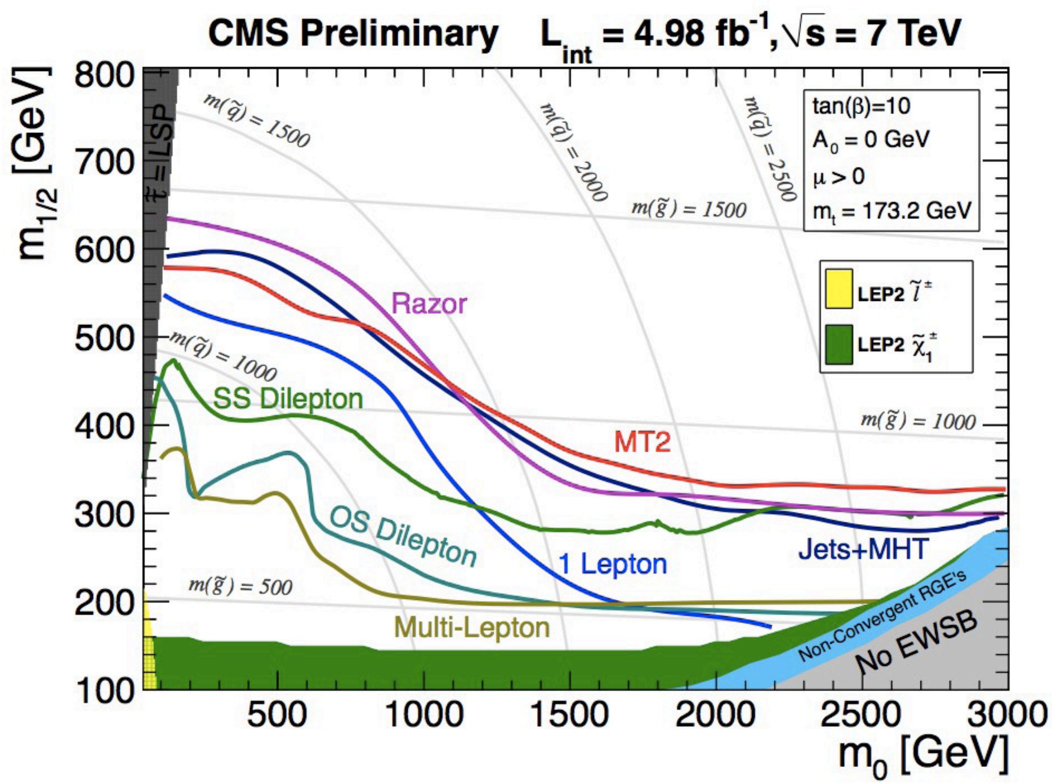


Constrained SUSY searches (7 TeV)

- Many searches with multiple observables: Spartner masses pushed to increasingly heavier (TeV) masses. No «simple» SUSY so far …
  - cMSSM or mSUGRA = minimal SUSY SM extension with least # of params (m0,m1/2,tanβ,A,signμ)

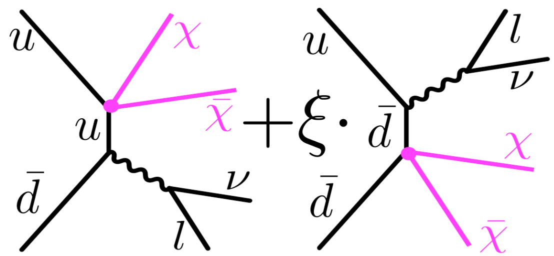
➢ **2011 was a very rich year for limits on SUSY**

➢ **Most limits from inclusive search program: i.e. MET + jets**

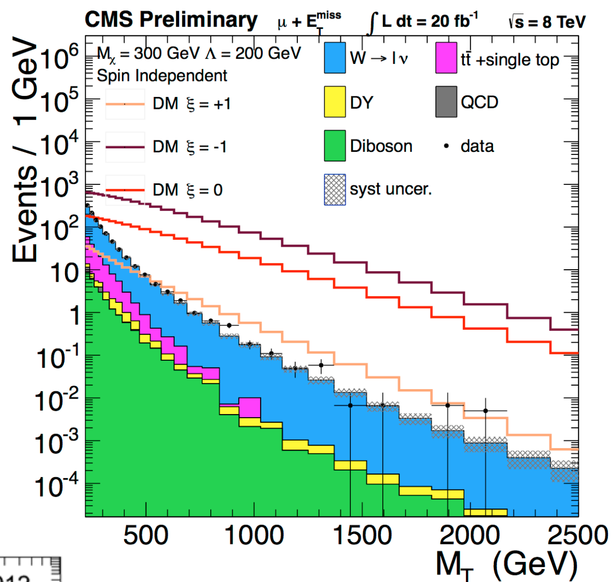


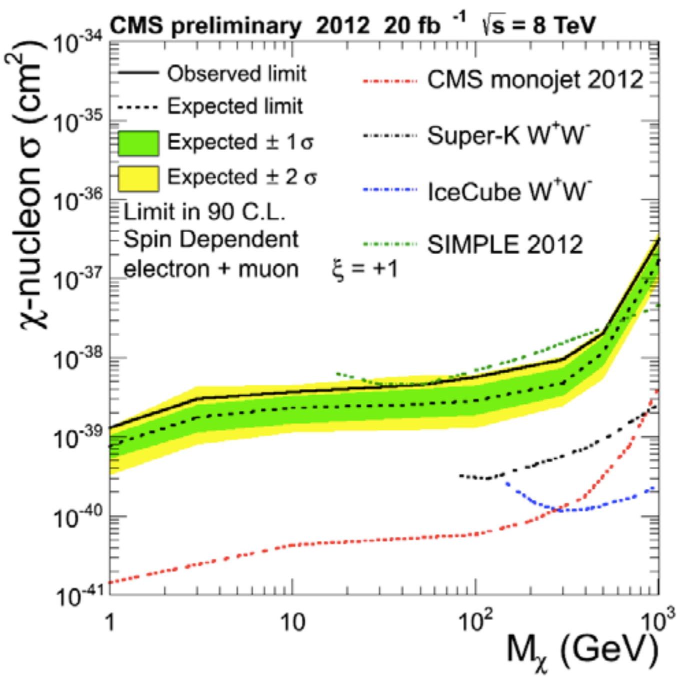
BSM searches: generic dark-matter

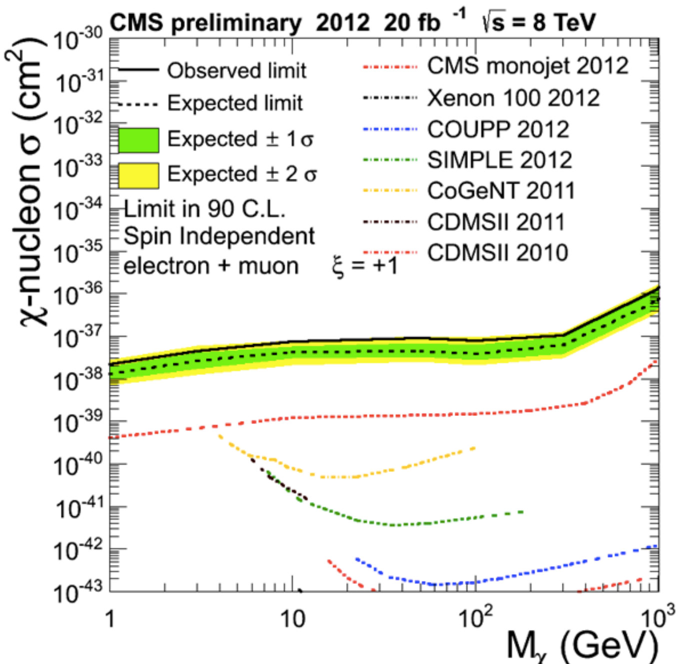
- Search for dark matter in the mono-lepton channel (W/Z + MET searches)



EXO13-004







No strong indication for dark matter at CMS found.