Overview of Physics Results from the CMS Experiment

Somnath Choudhury

(for the CMS collaboration)

4th International Workshop on Hadron Nuclear Physics 2015

7 – 11 July 2015, Krabi (Thailand)

Outline

- Higgs Physics
- EW Measurements
- QCD Physics
- B - physics
- Top physics
- Forward Physics
- BSM Searches
- Heavy Ion Physics

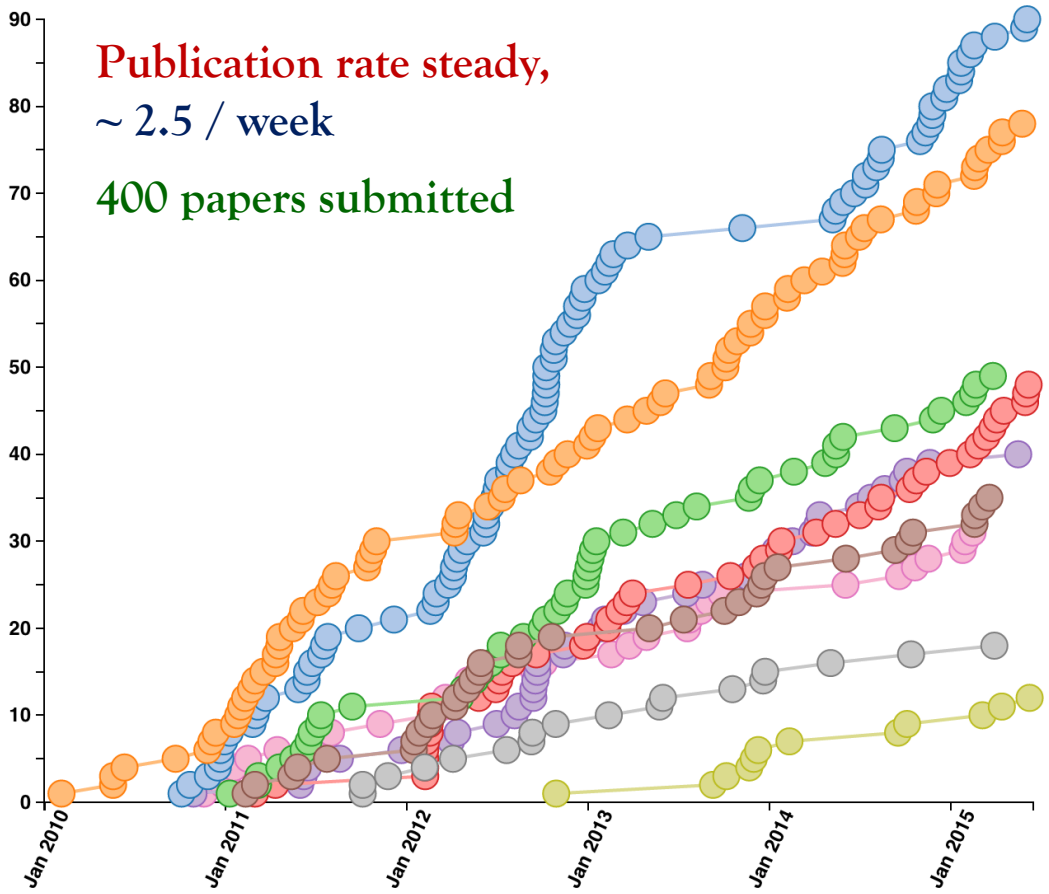
The CMS Collaboration

Publications

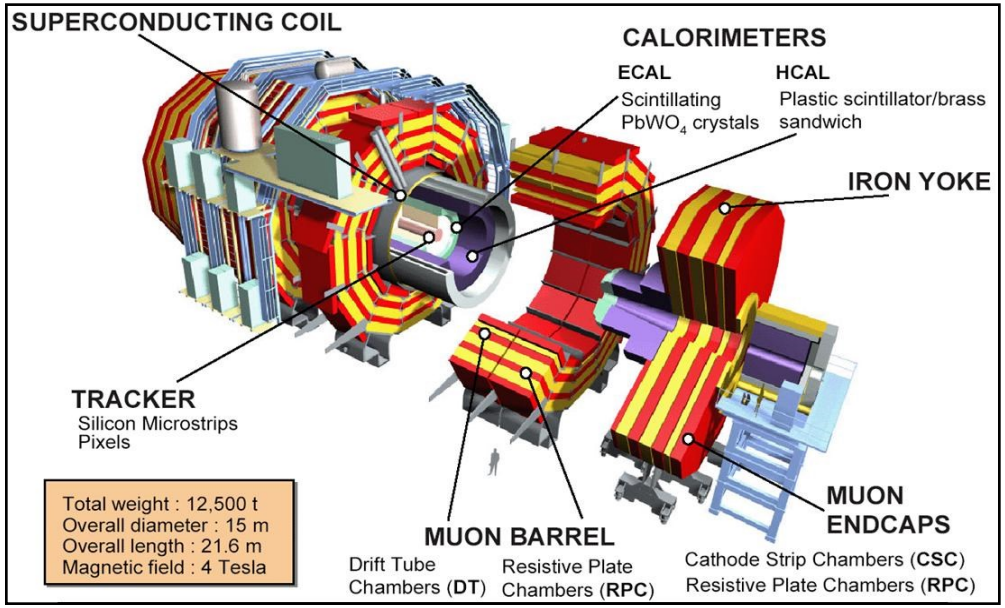
Show all | Total | Exotica | Standard Model | Supersymmetry | Higgs

Top Physics | Heavy Ion | B Physics | Forward Physics | Beyond 2 Generations

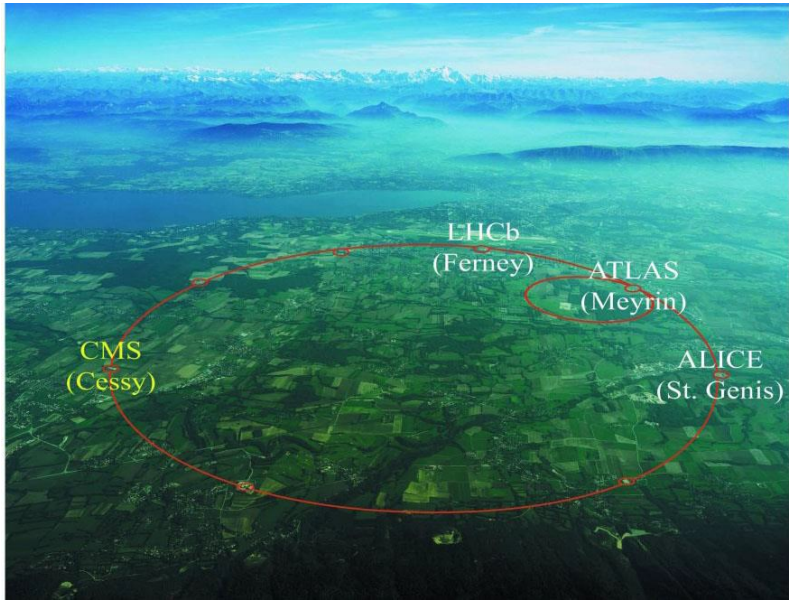
400 papers submitted as of 2015-06-09

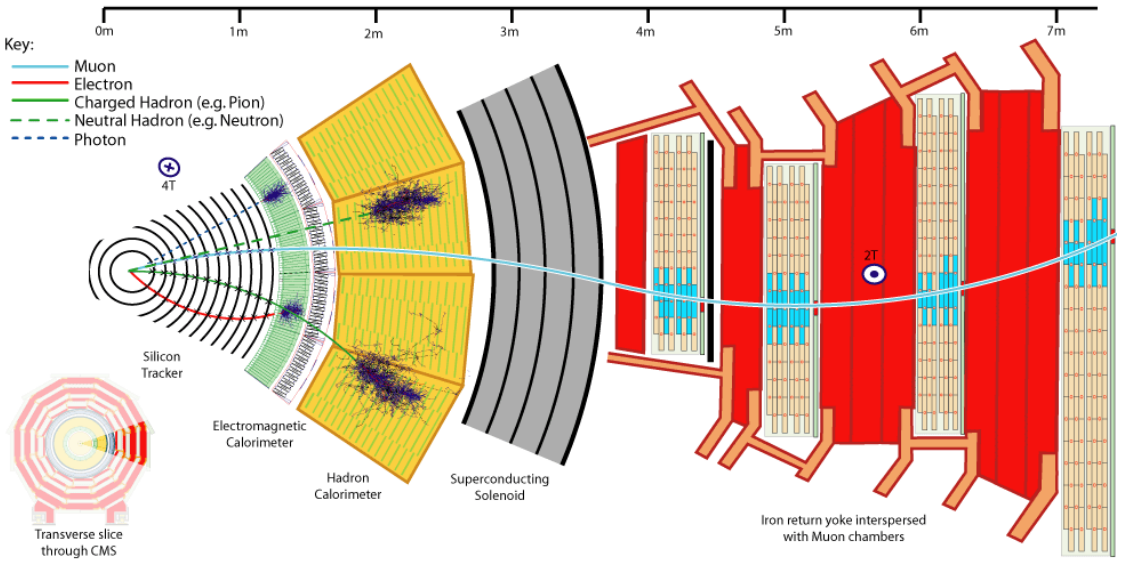


http://cms-results.web.cern.ch/cms-results/public-results/publications/

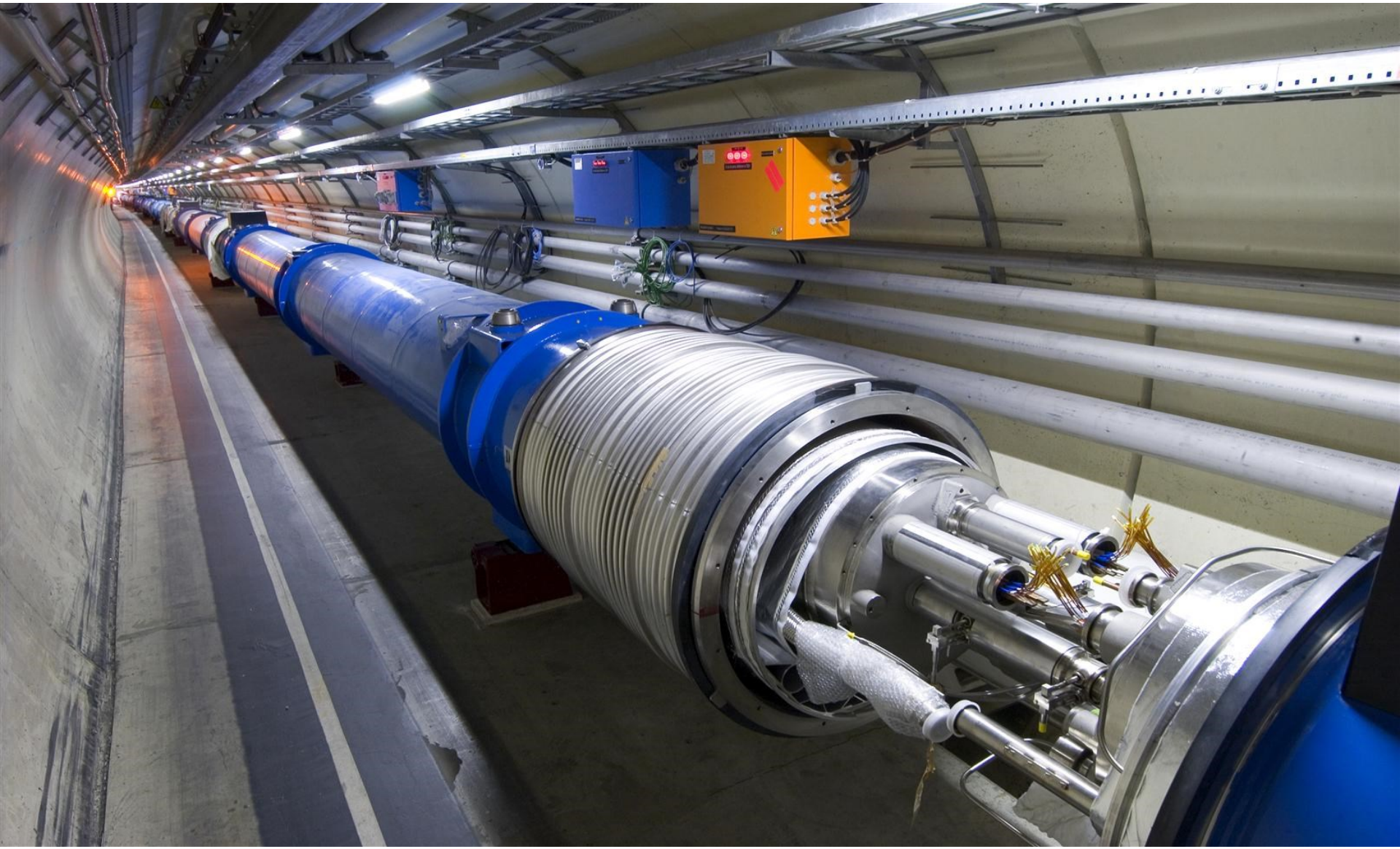


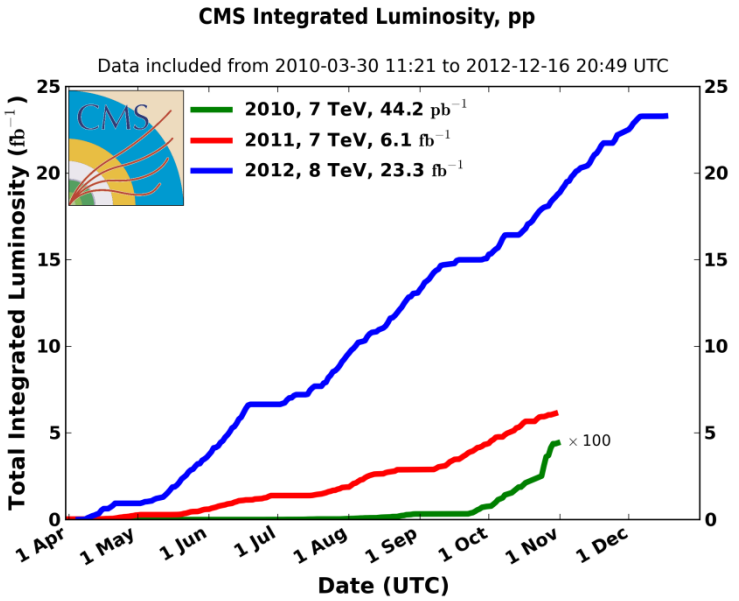
Accelerator, Detector and Physics Objects

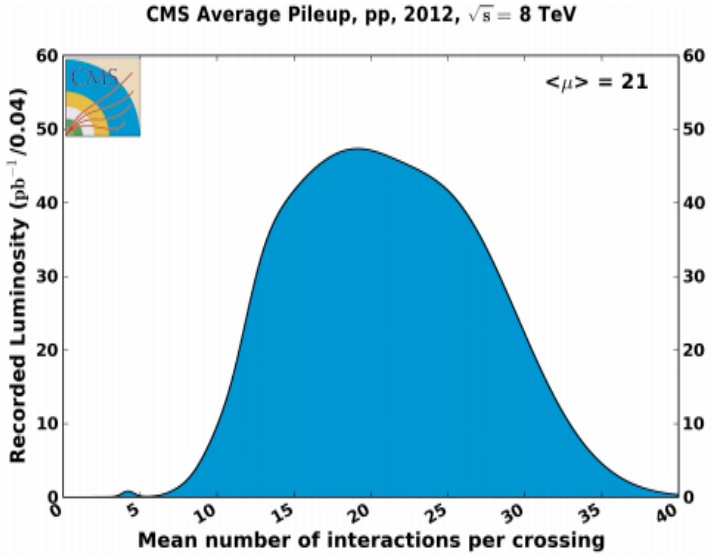


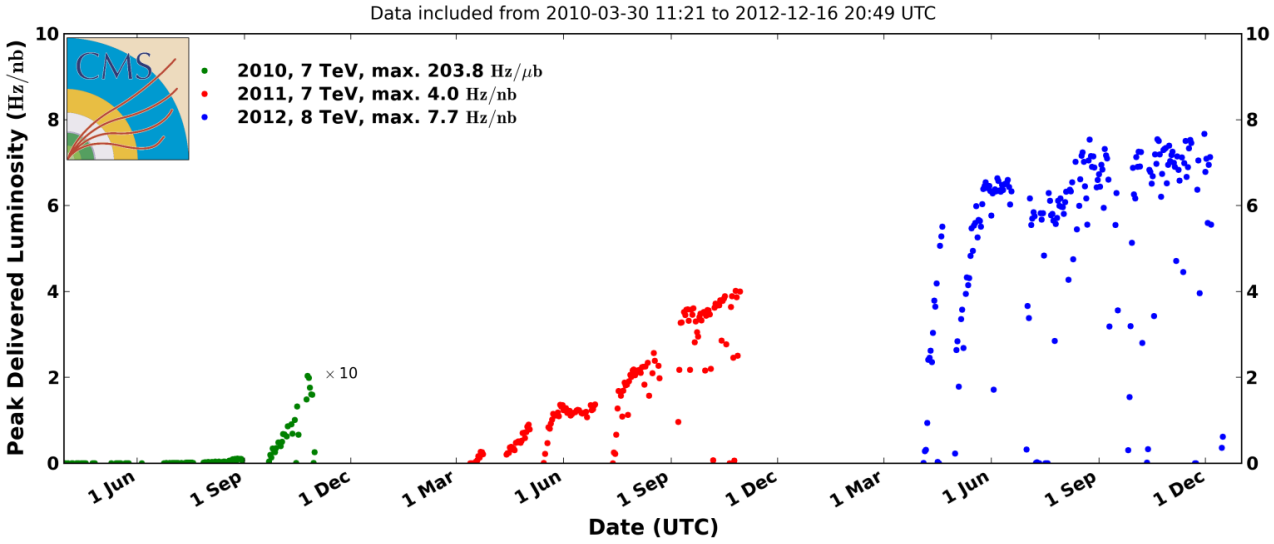


The LHC









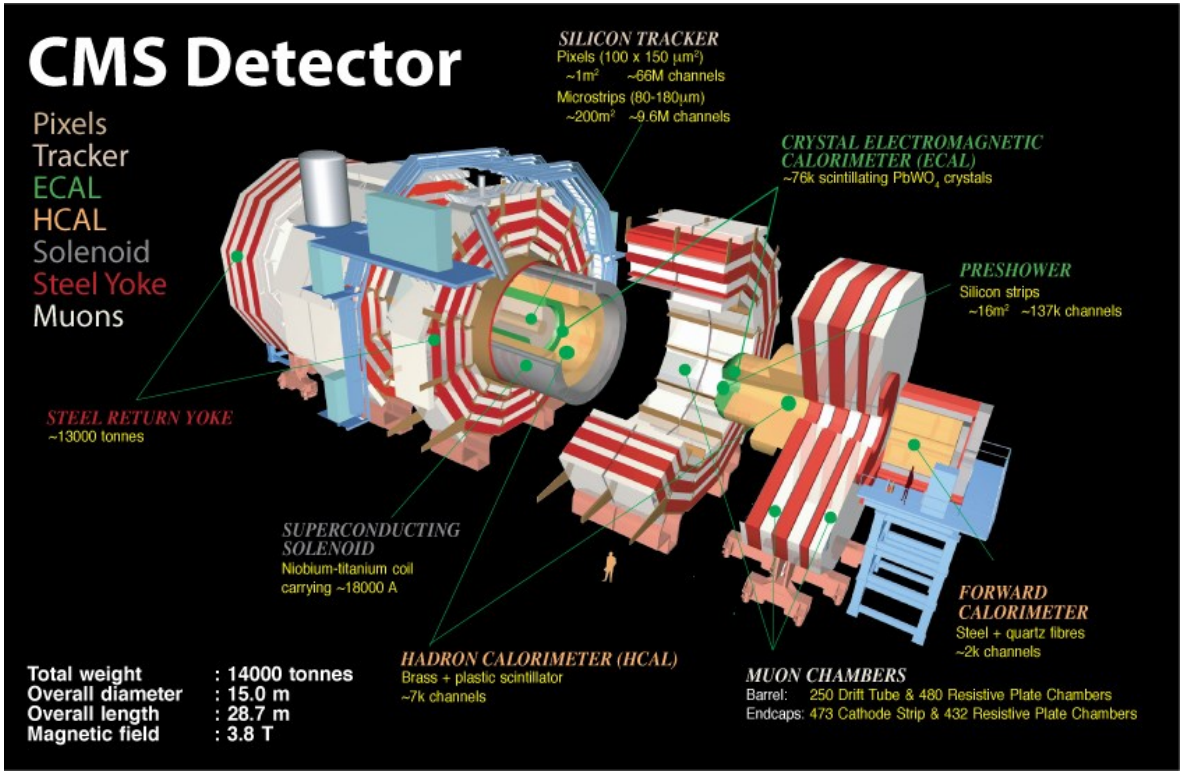
Overall data taking efficiency ~ 91%

3.8 T superconducting solenoid envelop:

- Tracker (silicon pixel and strip detectors) $|\eta| < 2.5$
- ECAL ($PbWO_4$ crystals)
- HCAL (brass/scintillator samplers)

  Barrel $|\eta| < 1.48$
  Endcap $1.48 < |\eta| < 3.0$

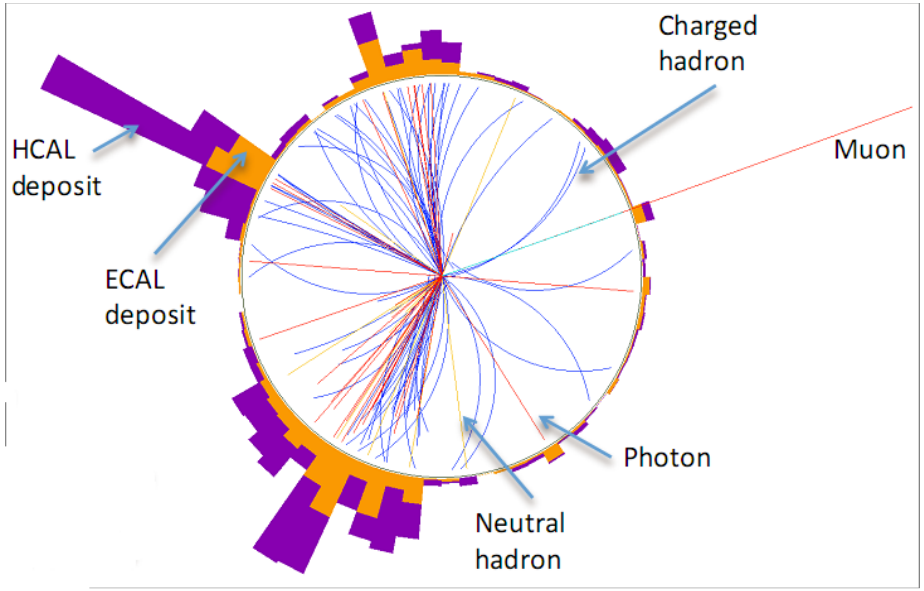
- Muon Chambers – gas ionization detectors embedded in steel return yoke outside the solenoid, $|\eta| < 2.4$
  Drift Tubes, Cathode Strips and Resistive Plate Chambers



⇒ Event description in form of mutually exclusive particles

⇒ identification of all stable particles produced in the event

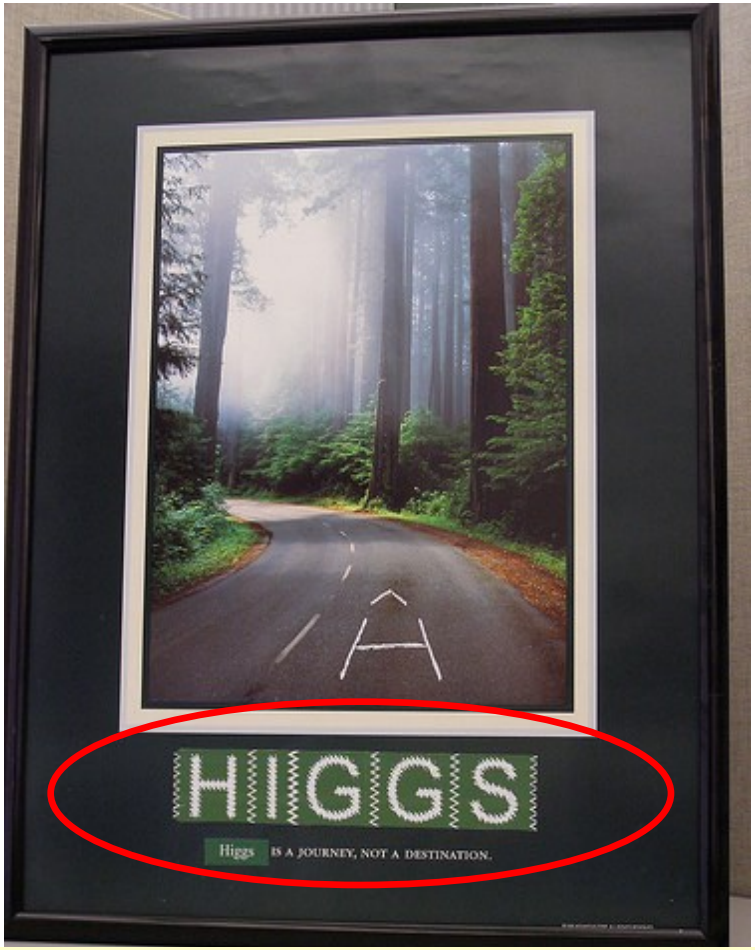
⇒ combining capabilities of each sub-detector most precise measurement of the energy and direction for each particle



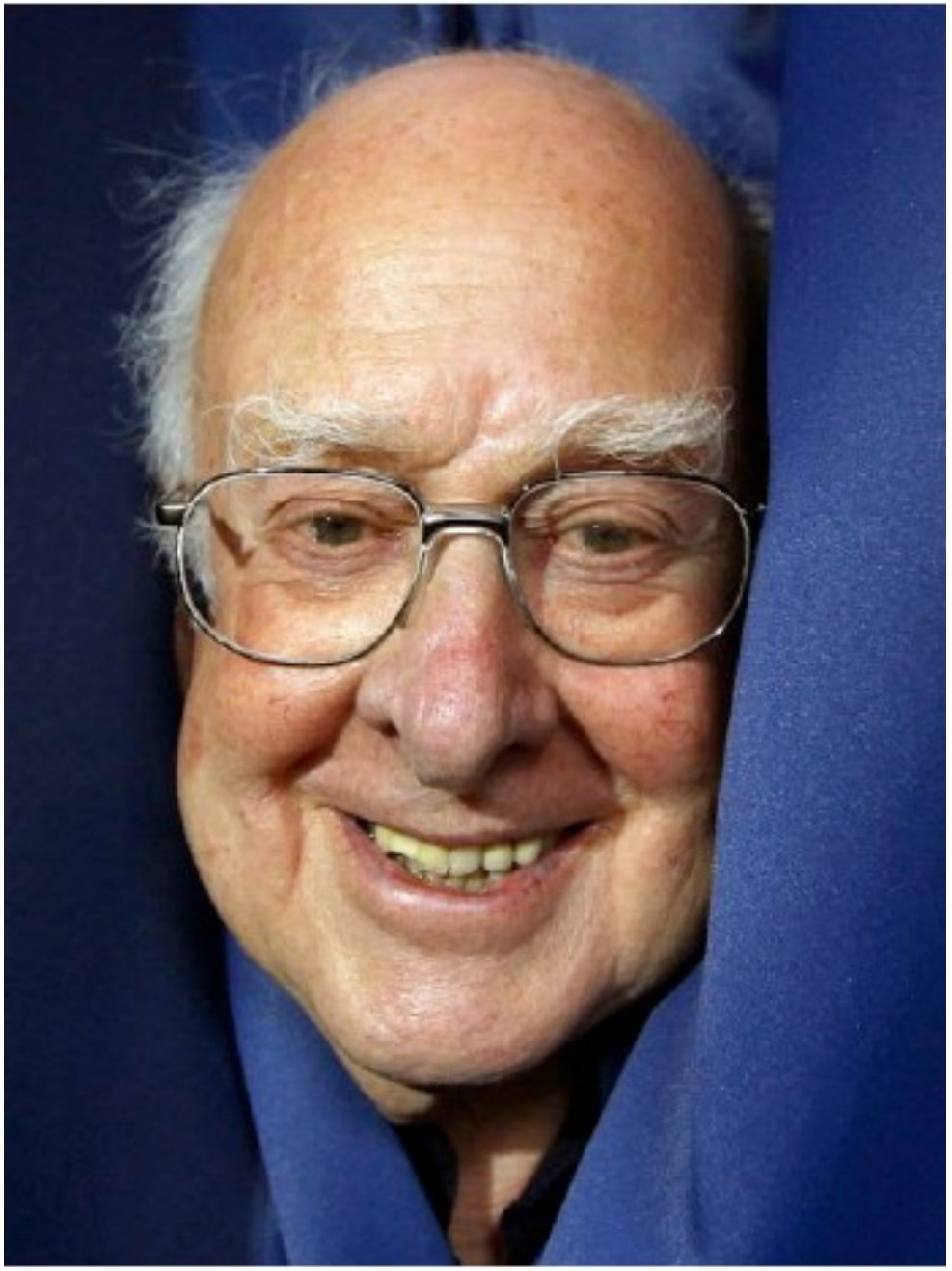
⇒ individual measurements combined by a geometrical linking algorithm, e.g. extrapolating a charged-particle track into ECAL and HCAL particle ID on blocks of linked elements

Physics object reconstruction utilises this technique, excellent performing even at high pileup

Higgs Physics

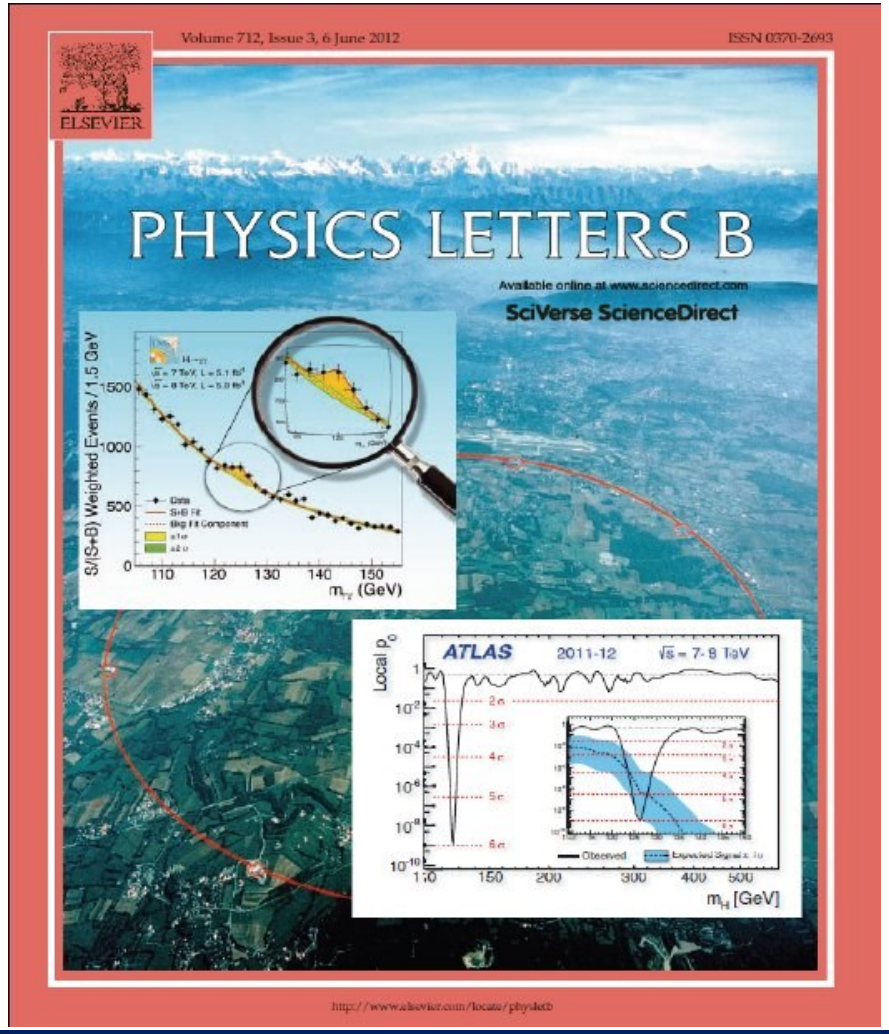


Higgs is a journey,
not a destination



Higgs Boson Discovery

Great achievement to a four decade long quest
A Higgs-like state pinned down at 125 GeV mass

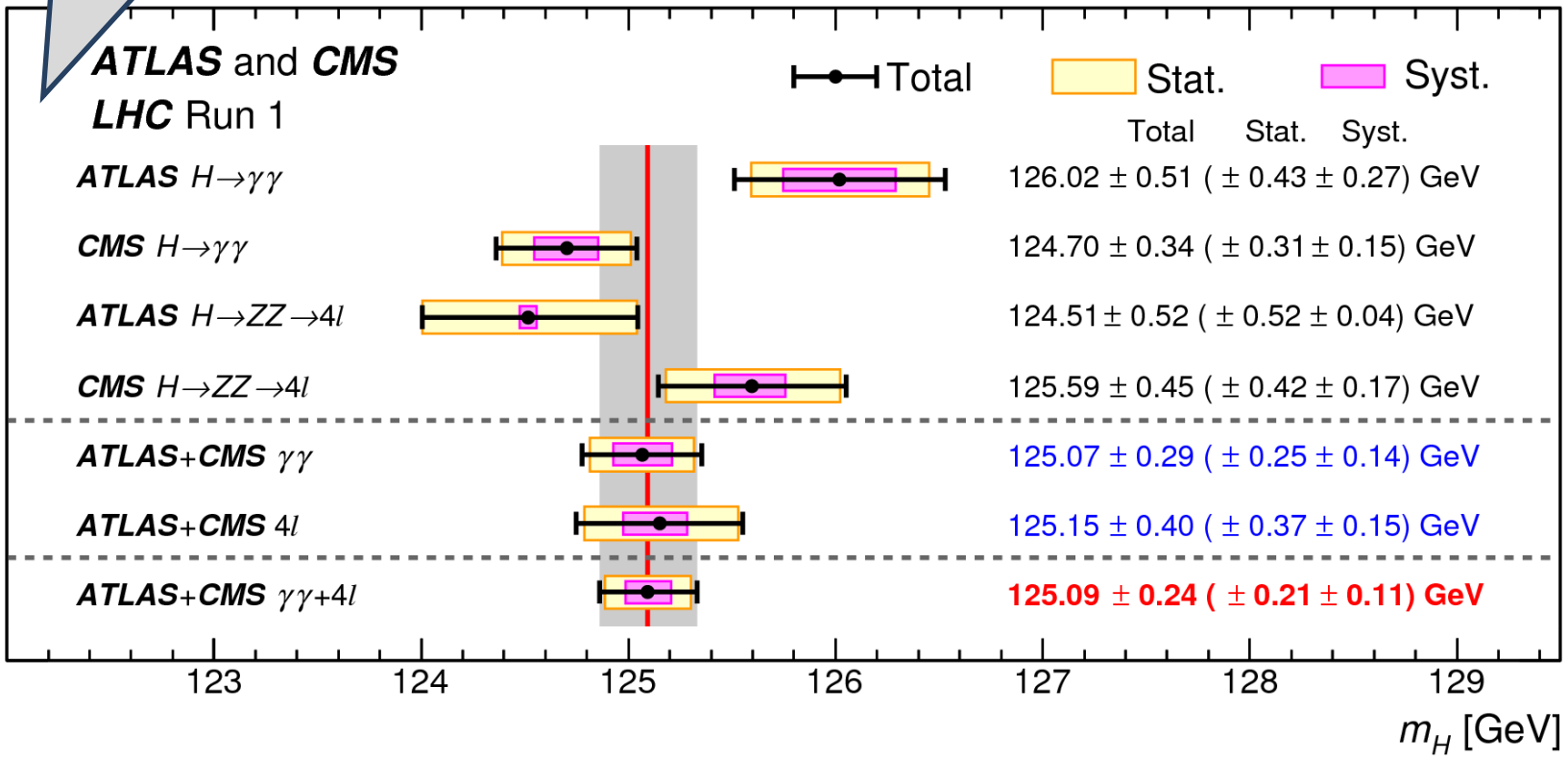


Combined ATLAS + CMS Higgs Mass

Over 5000 authors in a paper

Phys. Rev. Lett. 114 (2015) 191803

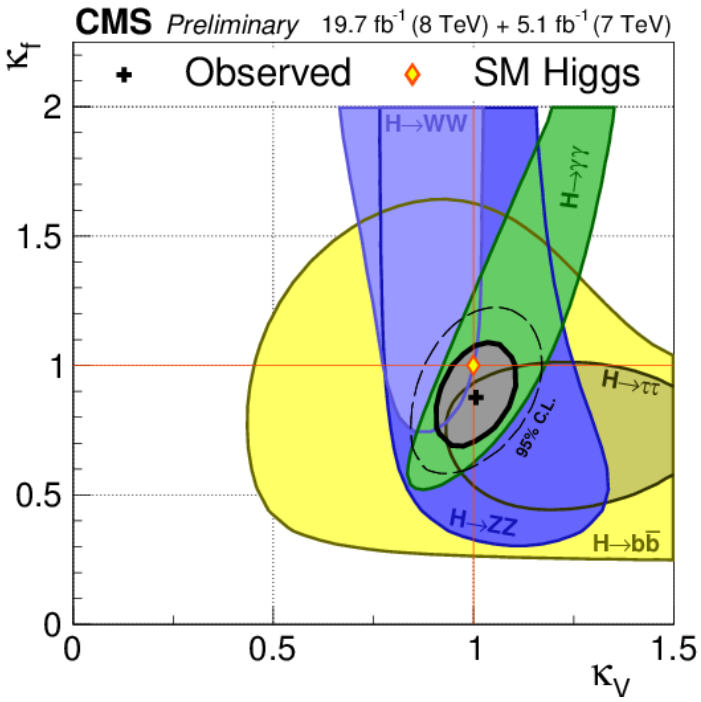
Results from simultaneous fit to the reconstructed invariant mass peaks in $\gamma\gamma$ and $ZZ^* \rightarrow 4l$ channels for ATLAS and CMS

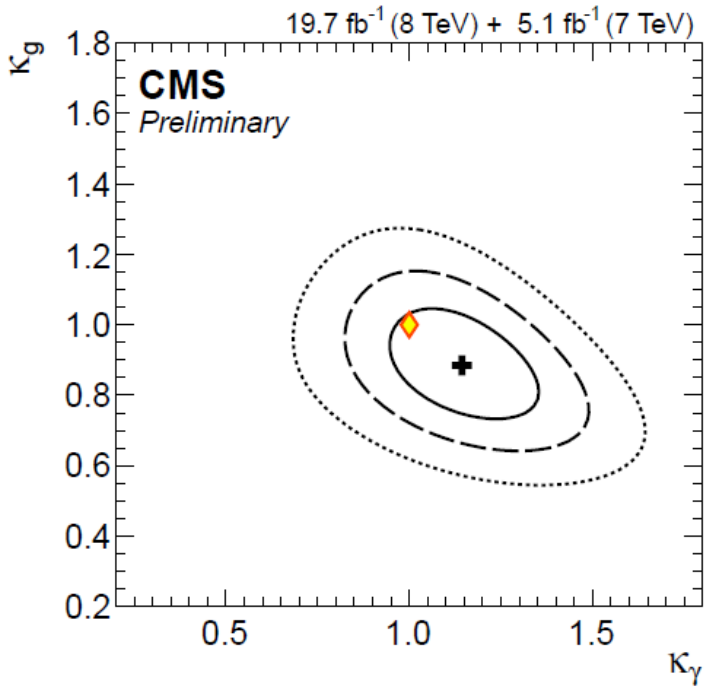


Higgs Coupling

CMS-PAS-HIG-14-009

2D likelihood scan for κ_g and κ_γ parameters assuming that $\Gamma_{BSM}=0$



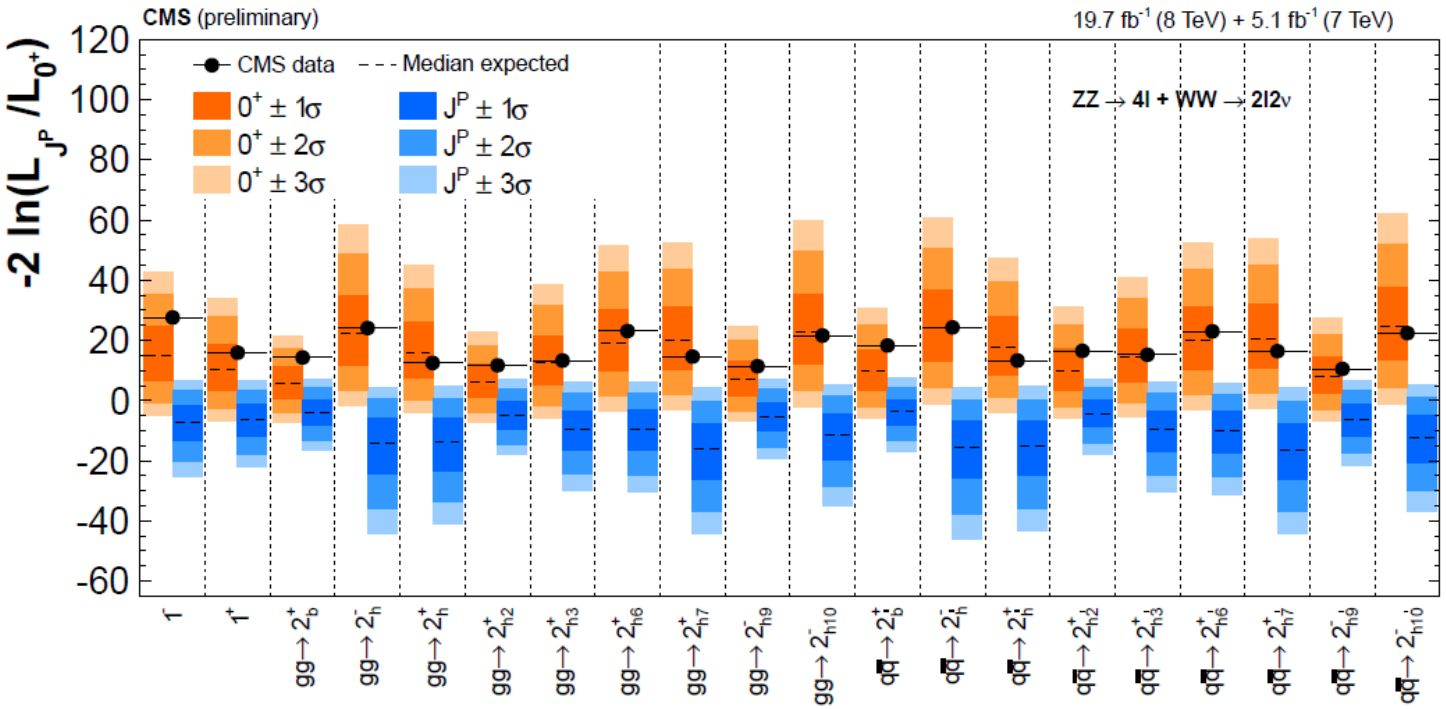


Results within 1σ of Standard Model prediction

CMS-PAS-HIG-14-014

Using full angular information defining 4 lepton system

- For each hypothesis create kinematic discriminant for SM vs alternative hypothesis
- Perform 2D fit of hypothesis discriminant versus background discriminant and perform hypothesis test



Several J^P hypotheses have been tested
Consistency with the SM scalar boson

Higgs Width

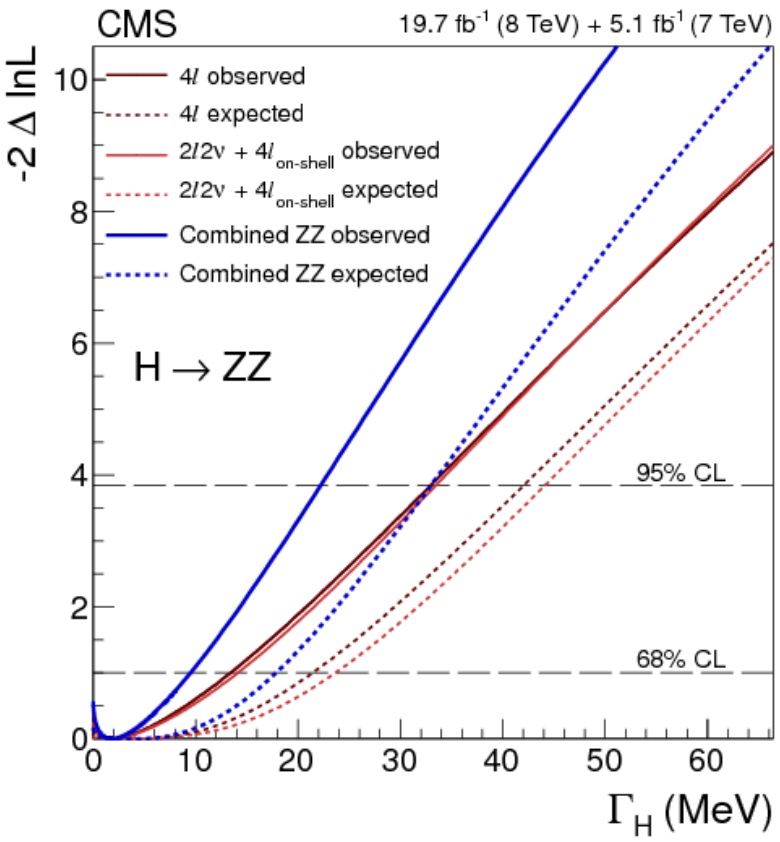
Proposed by
F. Caola, K. Melnikov, PRD 88 (2013) 054024
N. Kauer, G. Passarino, JHEP 08 (2012) 116
J. Campbell et al. (arXiv:1311.3589)

Physics Letters B 736, 64 (2014)

On shell and off shell production in ZZ:

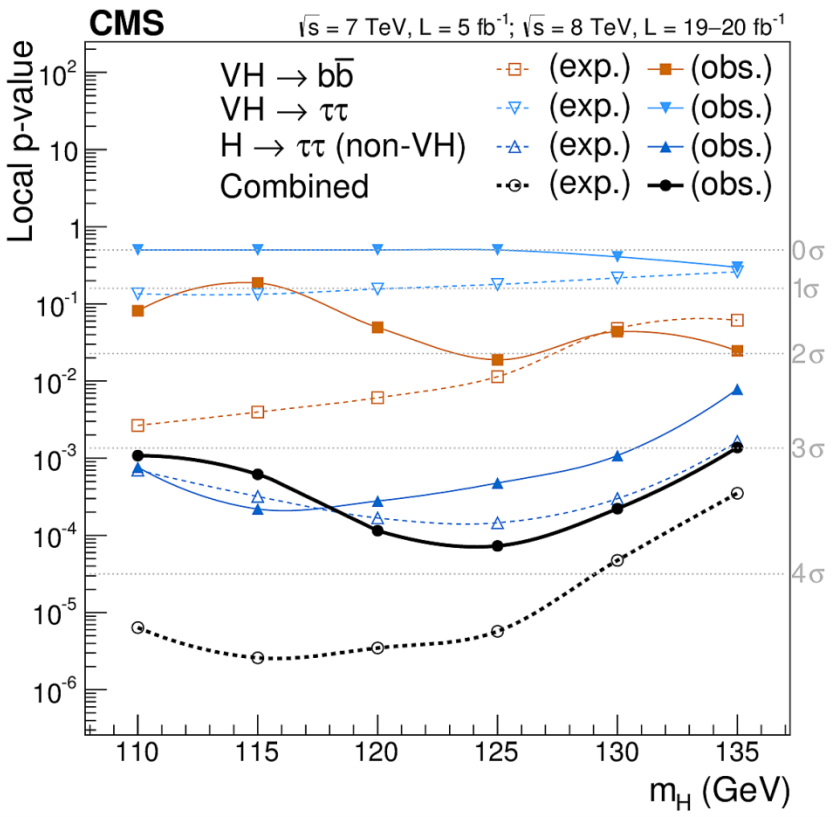
$$\sigma^{\text{on-shell}}_{gg\to H\to ZZ} \sim \frac{g^2_{ggH} g^2_{HZZ}}{m_H \Gamma_H}$$

$$\sigma^{\text{off-shell}}_{gg\to H\to ZZ} \sim \frac{g^2_{ggH} g^2_{HZZ}}{(2m_Z)^2}$$

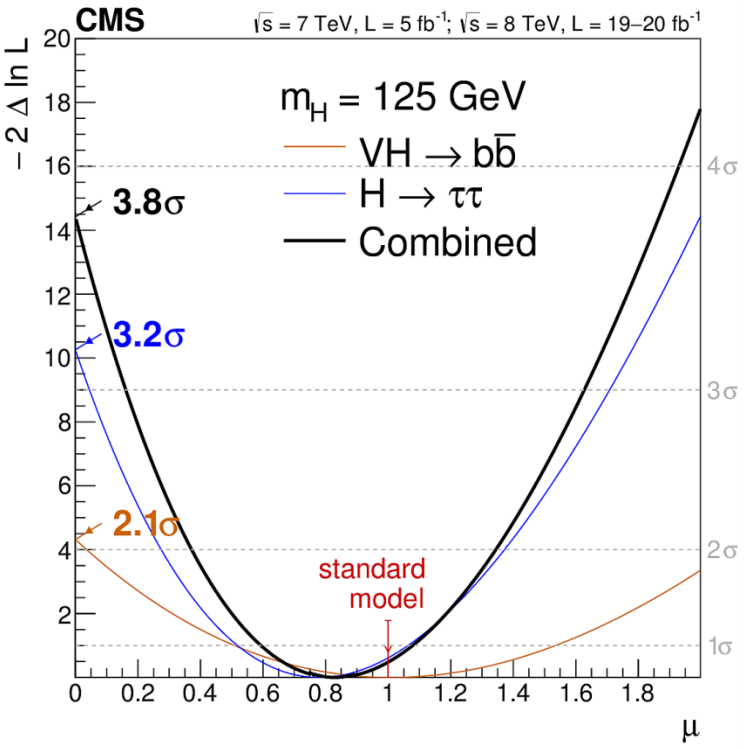


- Observed limit of 5.4 x SM corresponding to ~ 22 MeV @ 95% CL

Nature Physics 10, 557 (2014)



Channel ($m_H = 125\,GeV$)	Significance (σ)		Best-fit
	Expected	Observed	μ
$VH \to b\bar{b}$	2.3	2.1	1.0 ± 0.5
$H \to \tau\tau$	3.7	3.2	0.78 ± 0.27
Combined	4.4	3.8	0.83 ± 0.24



Strong evidence for the direct coupling of the 125 GeV Higgs boson to fermions, with an observed (expected) significance of 3.8σ (4.4σ)

Higgs Story So Far

- We know it exists! Phys. Lett. B 716 (2012) 30
- We know its a **boson**.

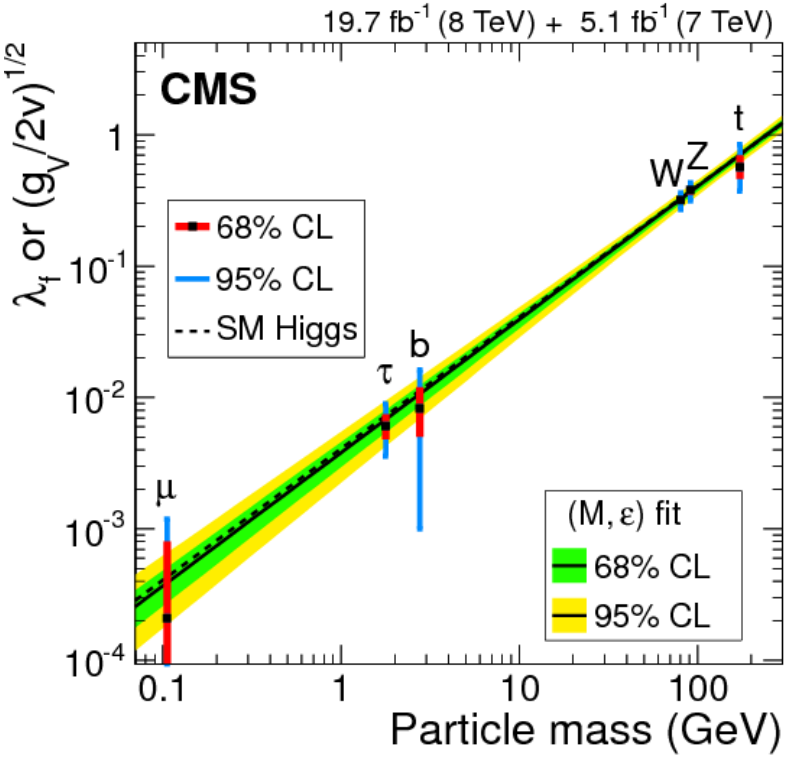
- We know its **mass** : CMS PAS HIG-14-009

$$m_H(\text{CMS}) = 125.03\ ^{+0.26}_{-0.27}\ (\text{stat})\ ^{+0.13}_{-0.15}(\text{syst})$$

- We have strong evidence that it **couples to fermions** Nat. Phys. 10 (2014) 557
  Couplings are determined within 15 to 20% accuracy, leaving room for **BSM physics**

- We have reasons to believe that it is a **spin 0 CP even** object
  Phys. Rev. D 89 (2014) 092007

- We know it's a **Higgs boson**!



Is this **THE Higgs** boson (of the SM) or is it just **A Higgs** boson?

BSM Higgs

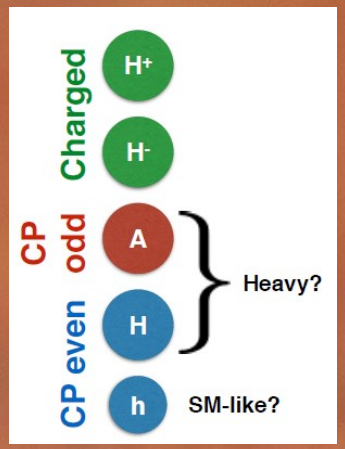
- Run I searches covered a large range of BSM Higgs boson signatures

- LHC is the discovery machine
  → the adventure in the TeV energy regime has just begun

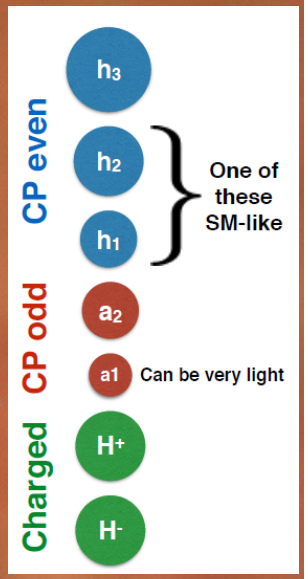
Lepton Flavour Violating Higgs Decays

Invisible Higgs Decays

MSSM / 2 HDM

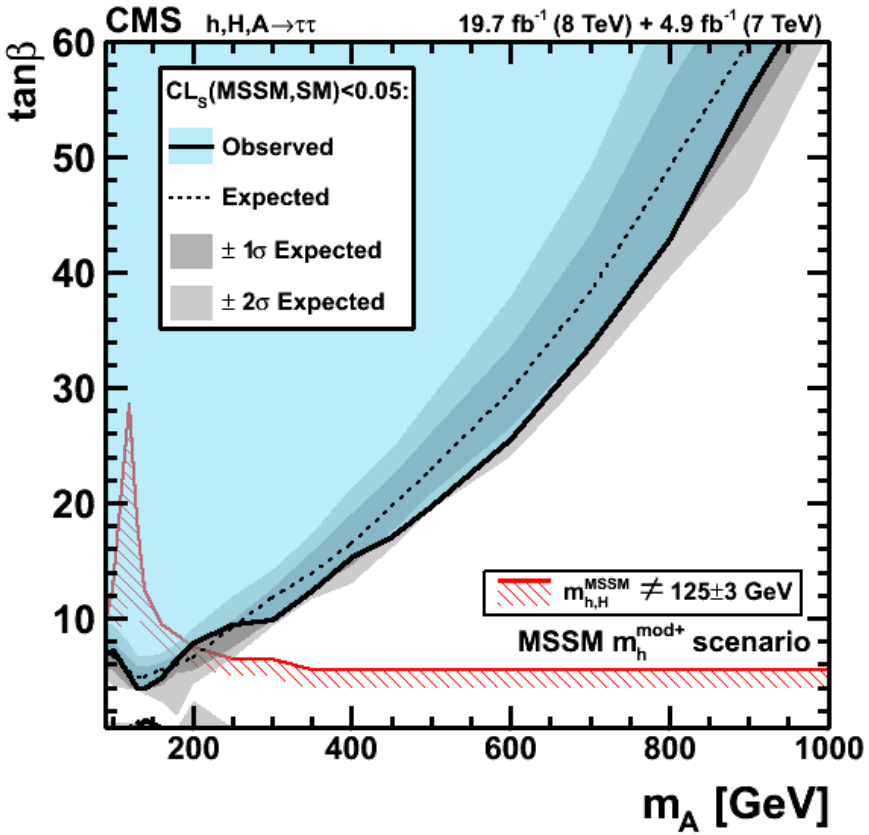


Next-to-MSSM (NMSSM)



Neutral MSSM Higgs

https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13021PaperTwiki



95% CL upper bound on cross-section x $\mathcal{Br}$ ($\Phi \rightarrow \tau\tau$) – based on the mass shape of $m_{\tau\tau}$ distribution mapped to m_A – tanβ plane (4FS + 5FS)

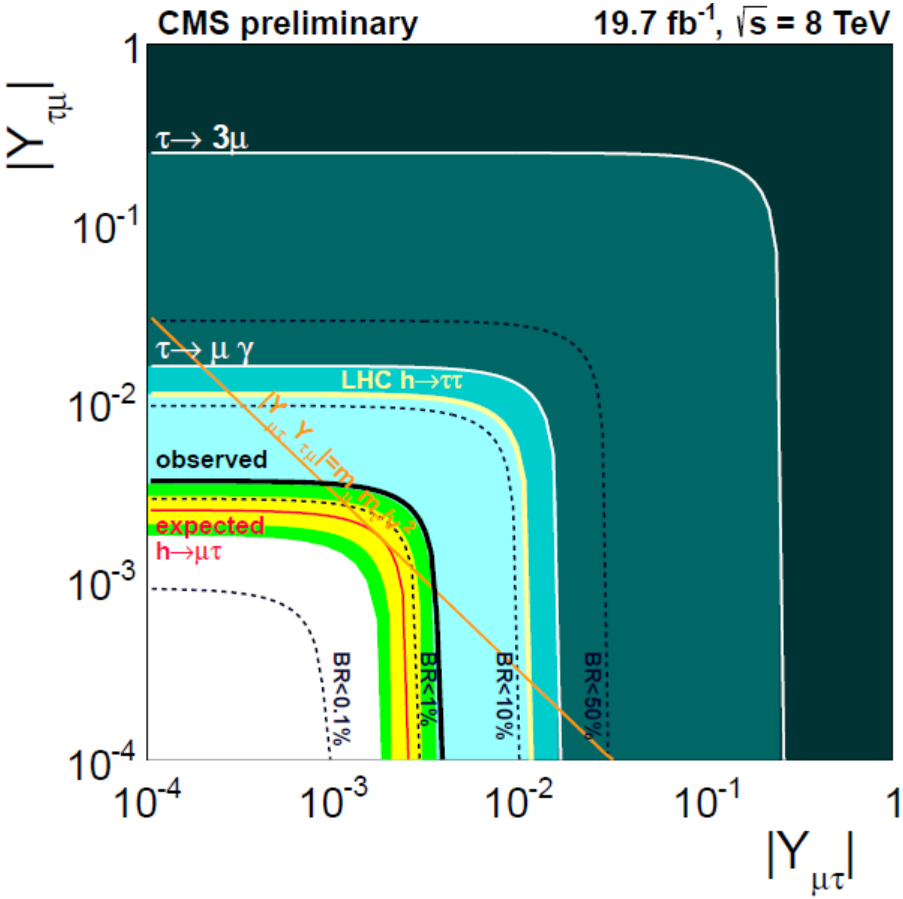
Excludes previously unexplored region: reaching tan $\beta \sim 3.9$ at $m_A = 140$ GeV

CMS PAS HIG-14-005

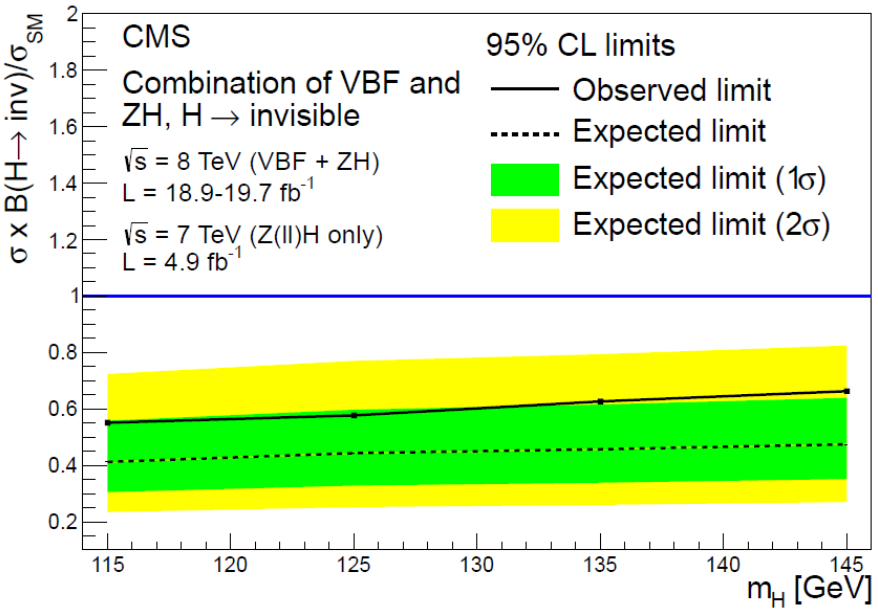
$$B(H \to l^{\alpha} l^{\beta}) = \frac{\Gamma(H \to l^{\alpha} l^{\beta})}{\Gamma(H \to l^{\alpha} l^{\beta}) + \Gamma_{SM}}$$

$$\Gamma(H \to l^{\alpha} l^{\beta}) = \frac{m_h}{8\pi}(|Y_{l^{\beta} l^{\alpha}}|^2 + |Y_{l^{\alpha} l^{\beta}}|^2)$$

- Constraint placed on B(H →μτ) < 1.57% at 95% CL
- The best fit branching fraction is B(H →μτ) = $(0.89^{+0.40}_{-0.37})$%
- The limit is subsequently used to constrain the $Y_{\mu\tau}$ Yukawa coupling



Eur. Phys. J. C 74 (2014) 2980

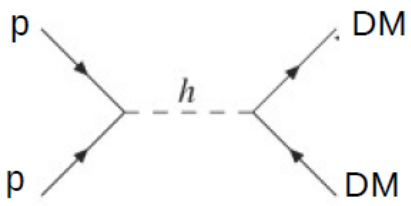


Excluded on 95% CL:

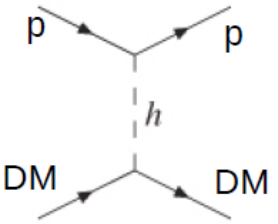
BR(H → inv.) < 0.58 at 125 GeV

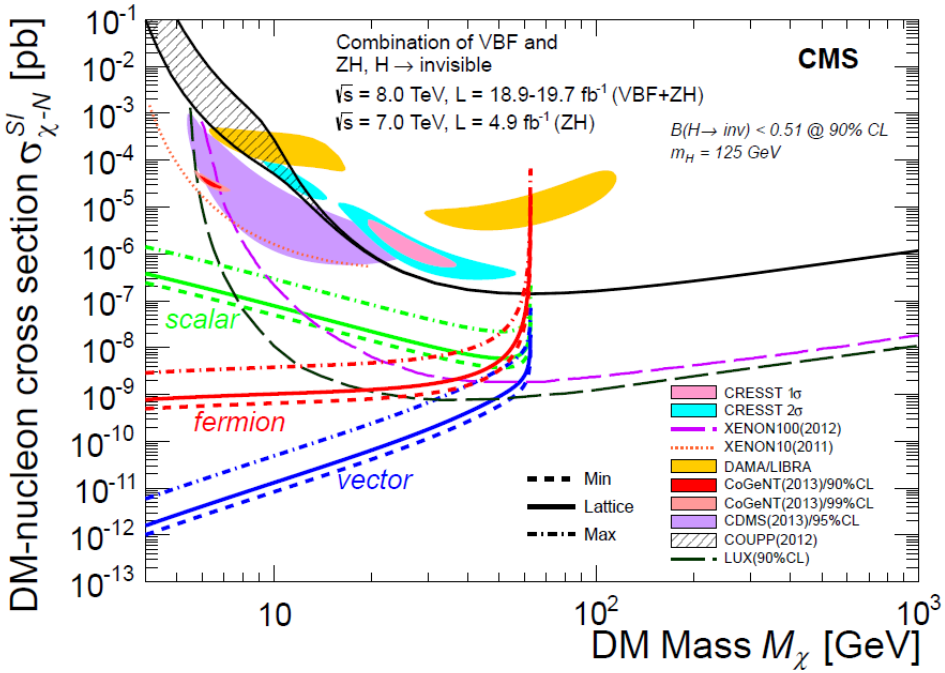
(expected < 0.44)

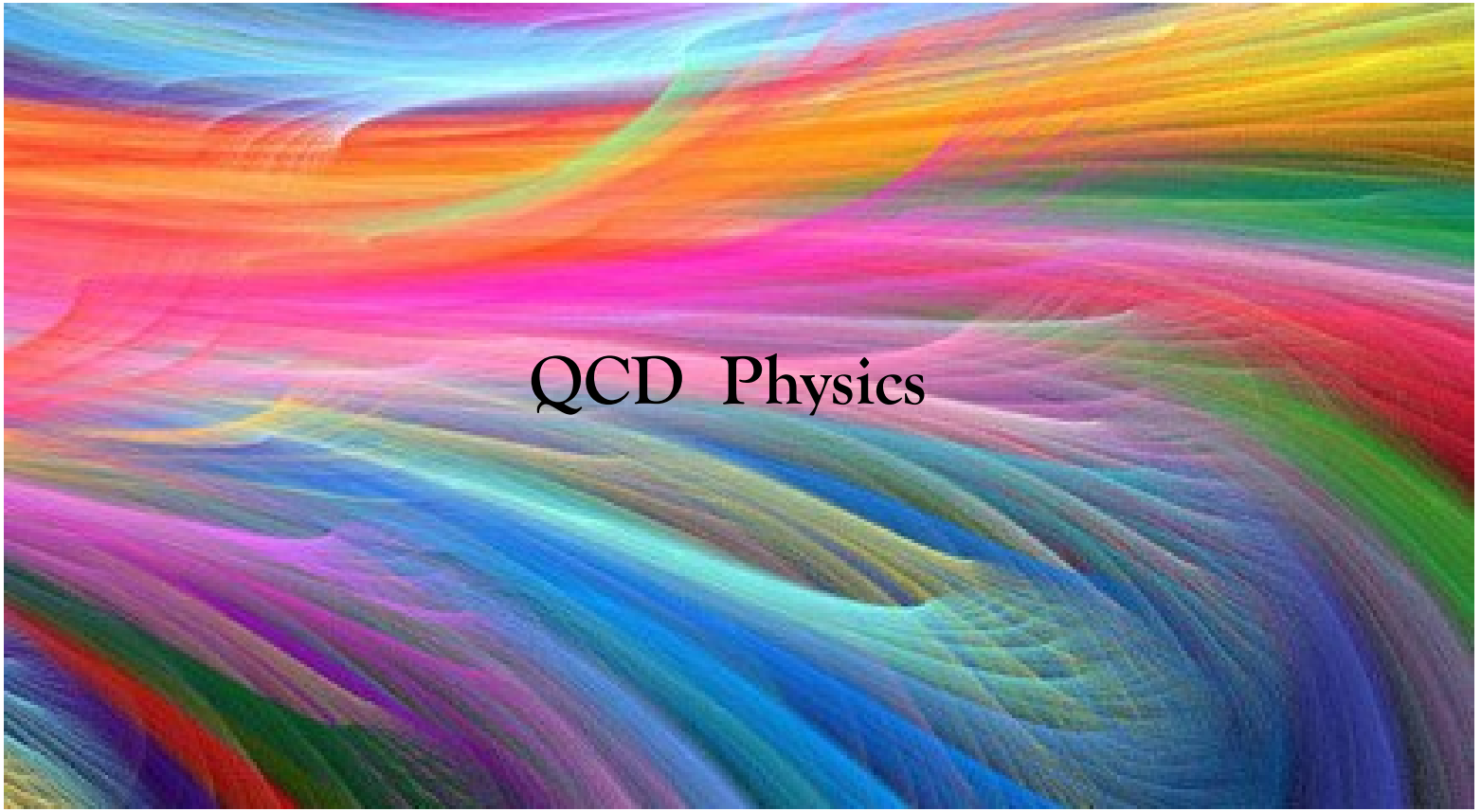
Measured:



Translate into:

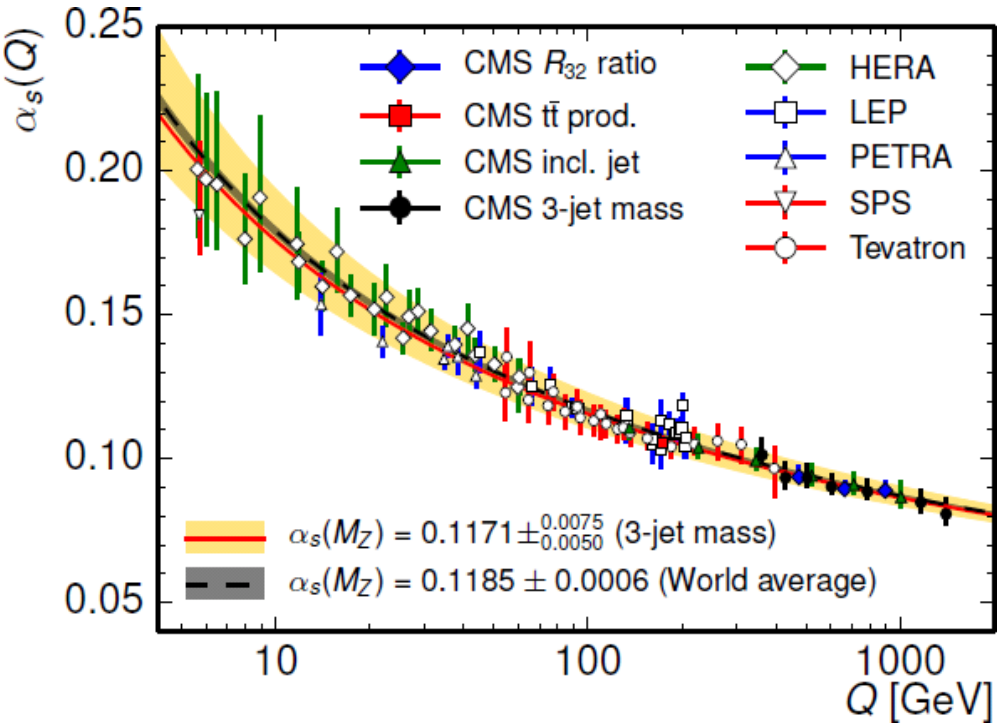





QCD Physics

α_s measurement

Ratio of 3-jets of 2-jets, 3-jet mass, and incl. jet x-sections constrain α_S up to so far unprobed scales $Q \sim 1.4$ TeV



arXiv:1410.6765, arXiv:1412.1633

Measurements dominated by theoretical uncertainty.
PDF & scale uncertainty, e.g. incl. jets:

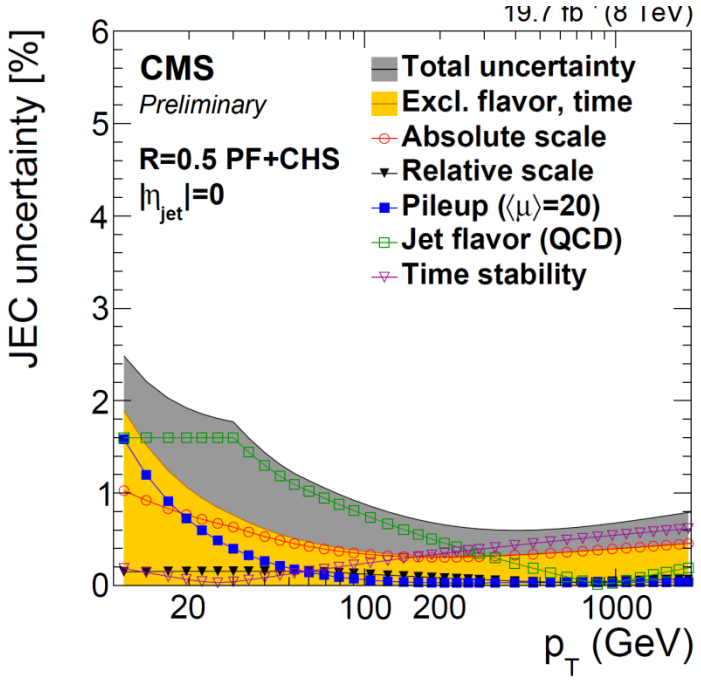
$$\alpha_S(M_Z) = 0.1185 \pm 0.0019\,(\text{exp})\,^{+0.0060}_{-0.0037}\,(\text{theo})$$

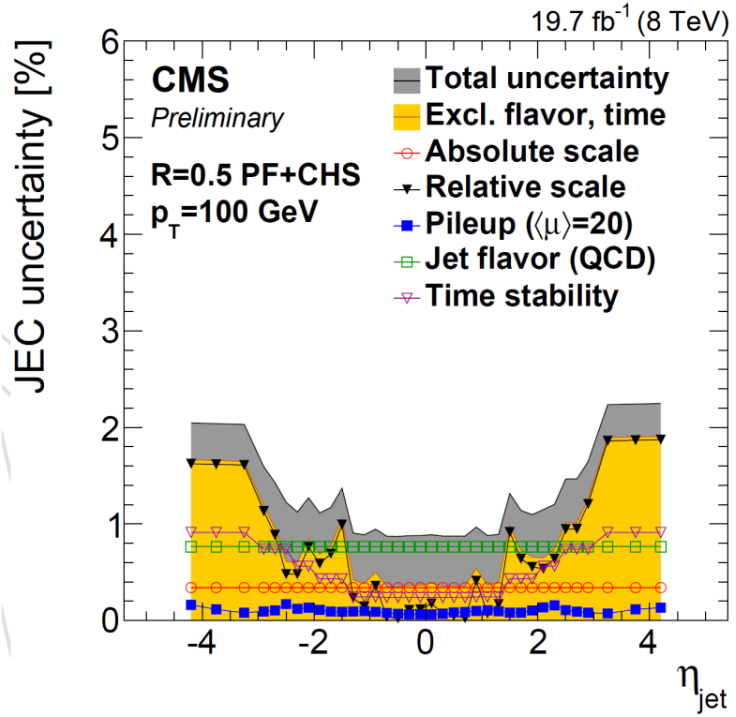
Jet Energy Scale

CMS-JME-13-004

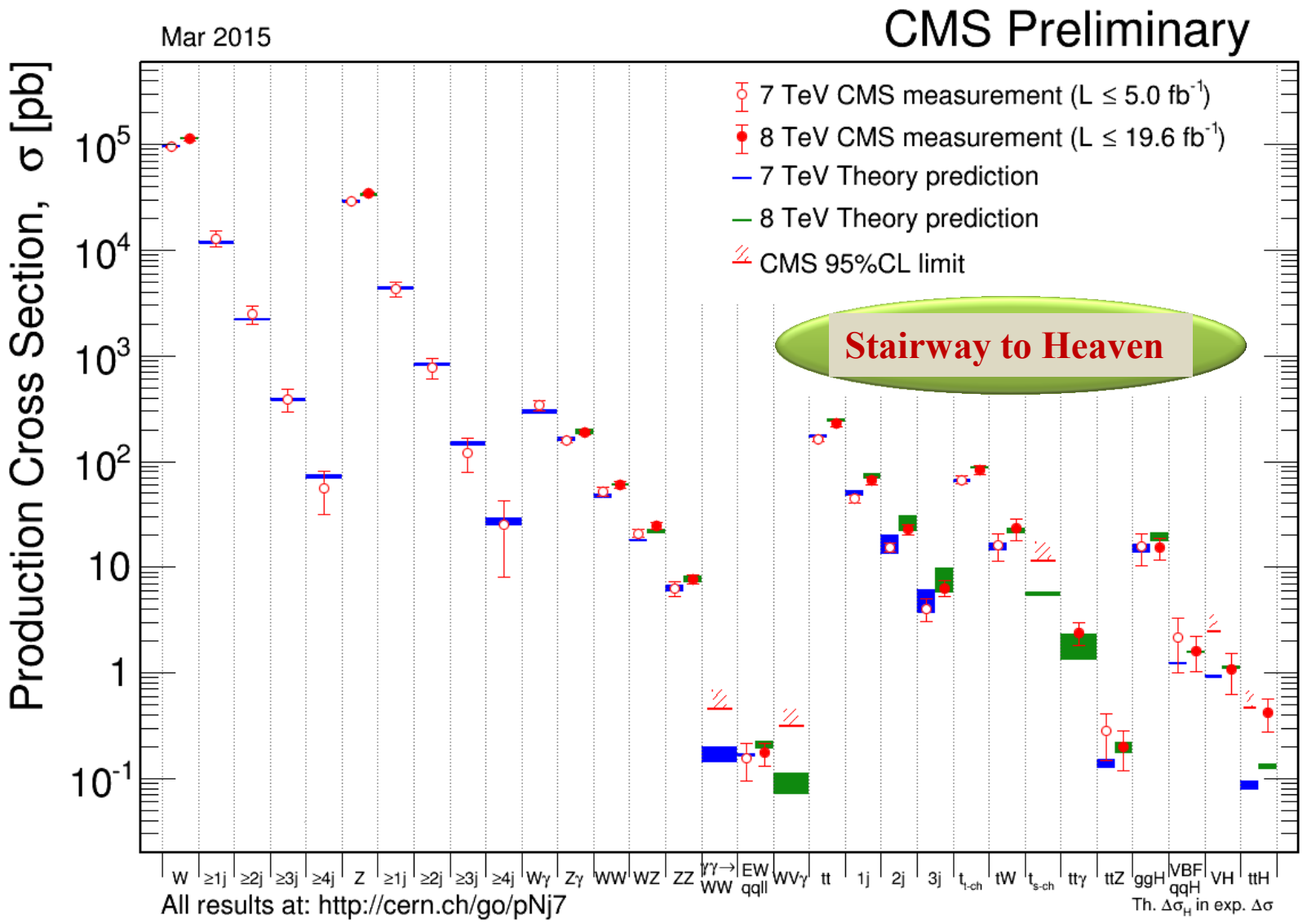
Legacy performance for jet energy scale and resolution for 8 TeV data

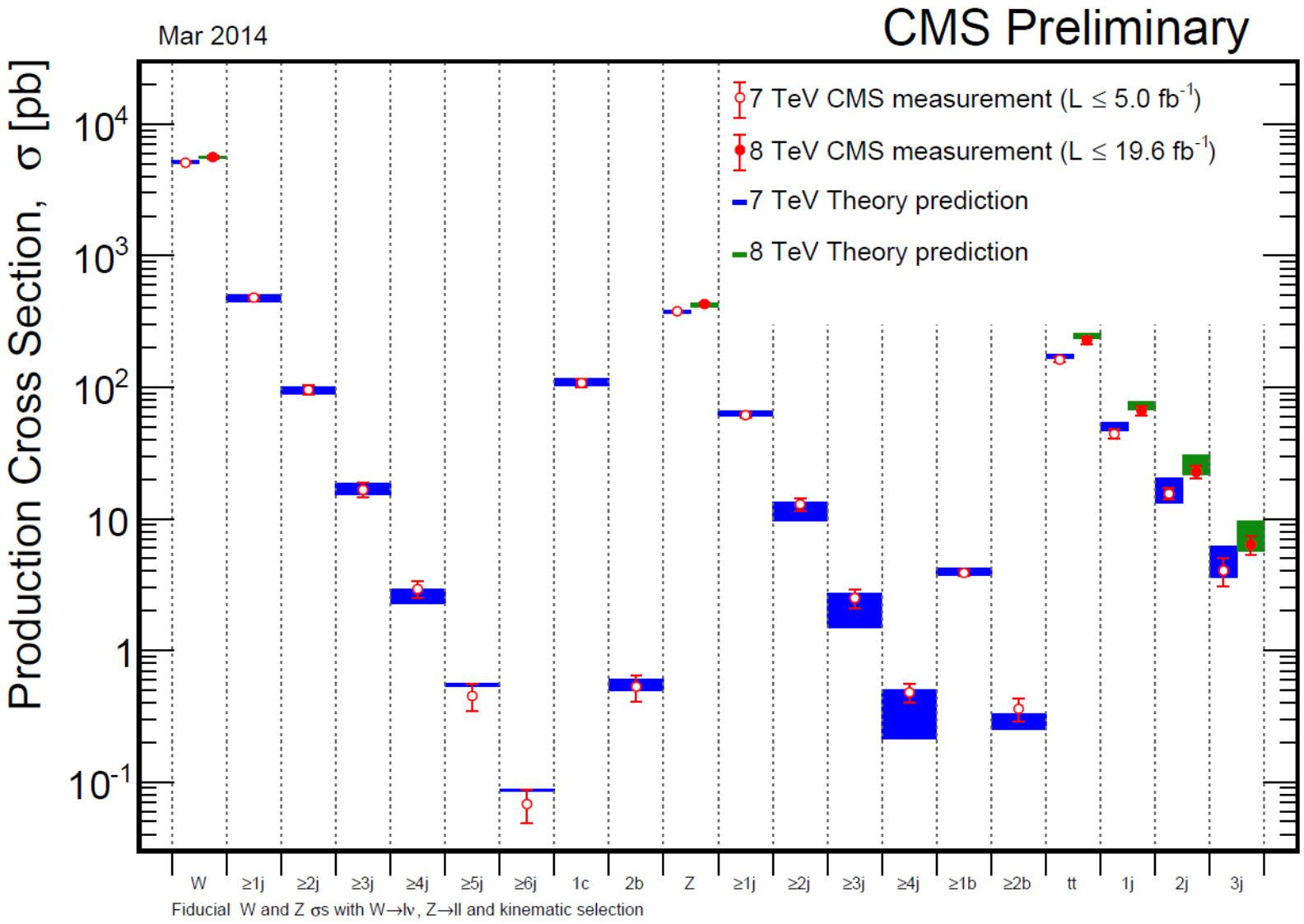
- Corrections derived accounting for pile-up, detector response, residual η and p_T dependence, and (optionally) flavour
- Corrections derived using a mix of dijet, Z+jet, and γ+jet data
- Uncertainties < 3% across the phase space considered by most analyses





Electroweak Physics


CMS Preliminary
Mar 2015
Production Cross Section, σ [pb]
7 TeV CMS measurement (L ≤ 5.0 fb-1)
8 TeV CMS measurement (L ≤ 19.6 fb-1)
7 TeV Theory prediction
8 TeV Theory prediction
CMS 95%CL limit
Stairway to Heaven
W ≥1j ≥2j ≥3j ≥4j Z ≥1j ≥2j ≥3j ≥4j Wγ Zγ WW WZ ZZ γγ→WW EW qqll WVγ tt 1j 2j 3j t-ch tW s-ch ttγ ttZ ggH VBF qqH VH ttH
All results at: http://cern.ch/go/pNj7
Th. Δσ_H in exp. Δσ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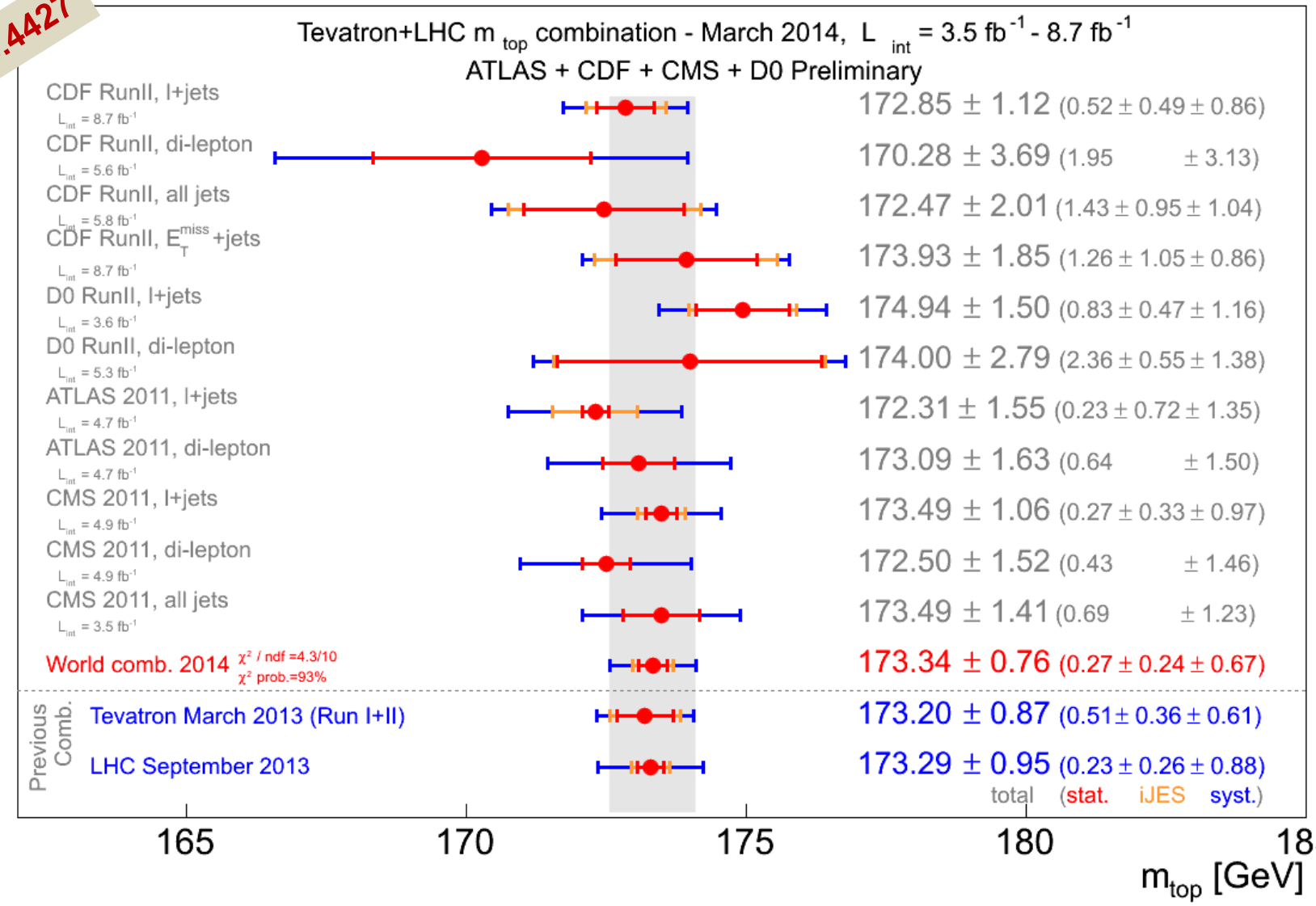
8 TeV Theory prediction
W
≥1j
≥2j
≥3j
≥4j
≥5j
≥6j
1c
2b
Z
≥1j
≥2j
≥3j
≥4j
≥1b
≥2b
tt
1j
2j
3j
Fiducial W and Z σs with W→lν, Z→ll and kinematic selection

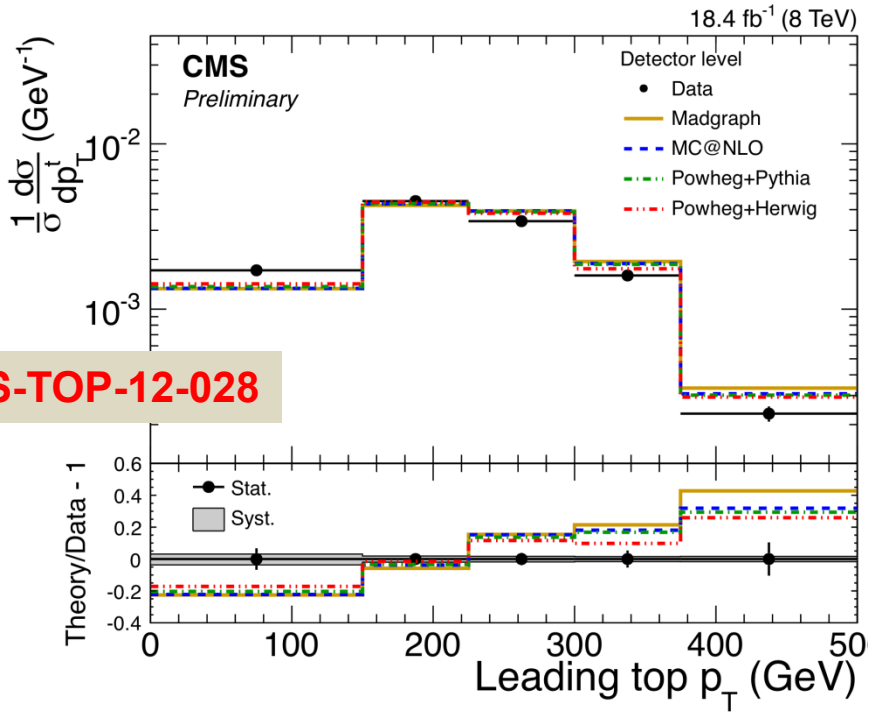
Top Physics

Combined LHC + Tevatron Top Mass

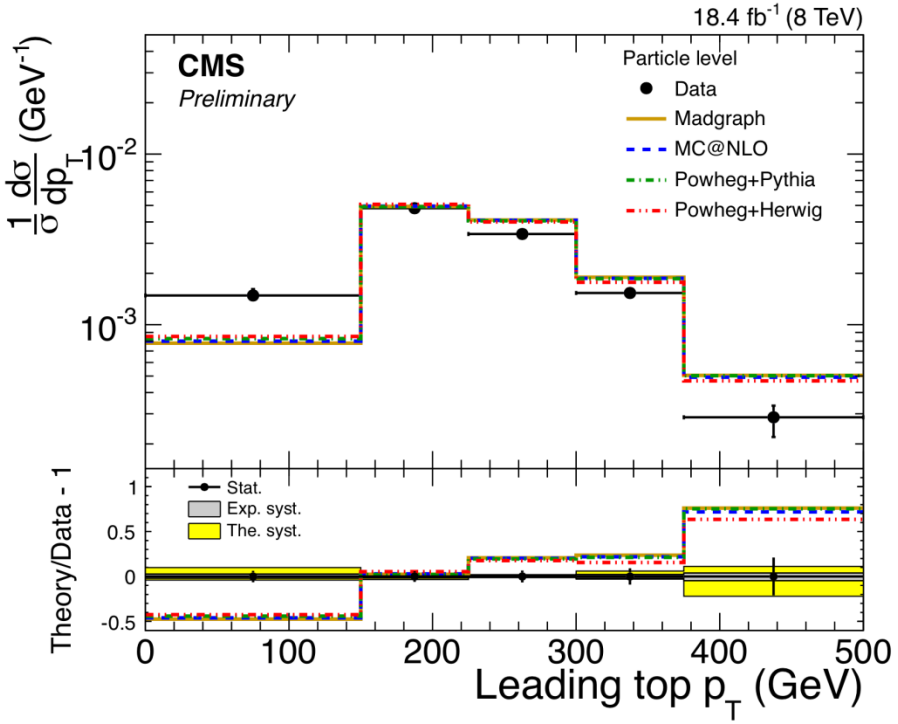
arXiv: 1403.4427



Top Pair Differential Cross-section



CMS-TOP-12-028



Inclusive cross sections
275.6 ± 39.0 pb (14% precision)

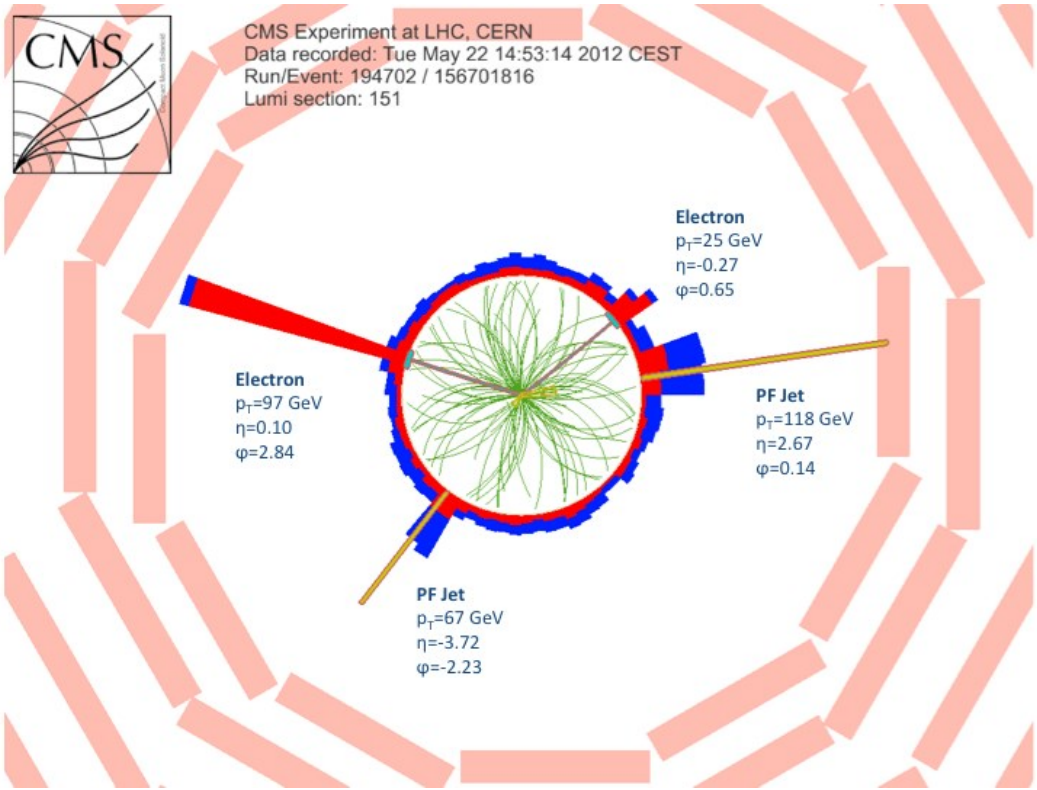
dominated by JES and BTag uncertainties performed differential measurements as a function of top p_T

- results presented at detector, parton, and particle level
- theory predicts systematically harder spectrum
- in agreement with measurements in lepton+jets and dilepton channels at parton level

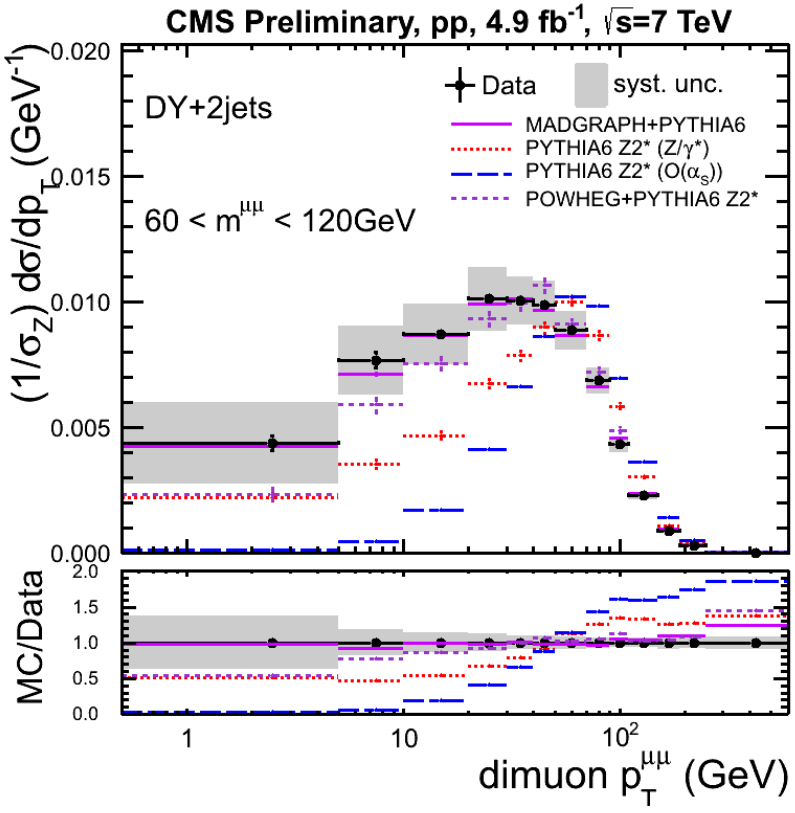
Forward & Small-x QCD Physics

DY / Z + jets

CMS-PAS-FSQ-12-035



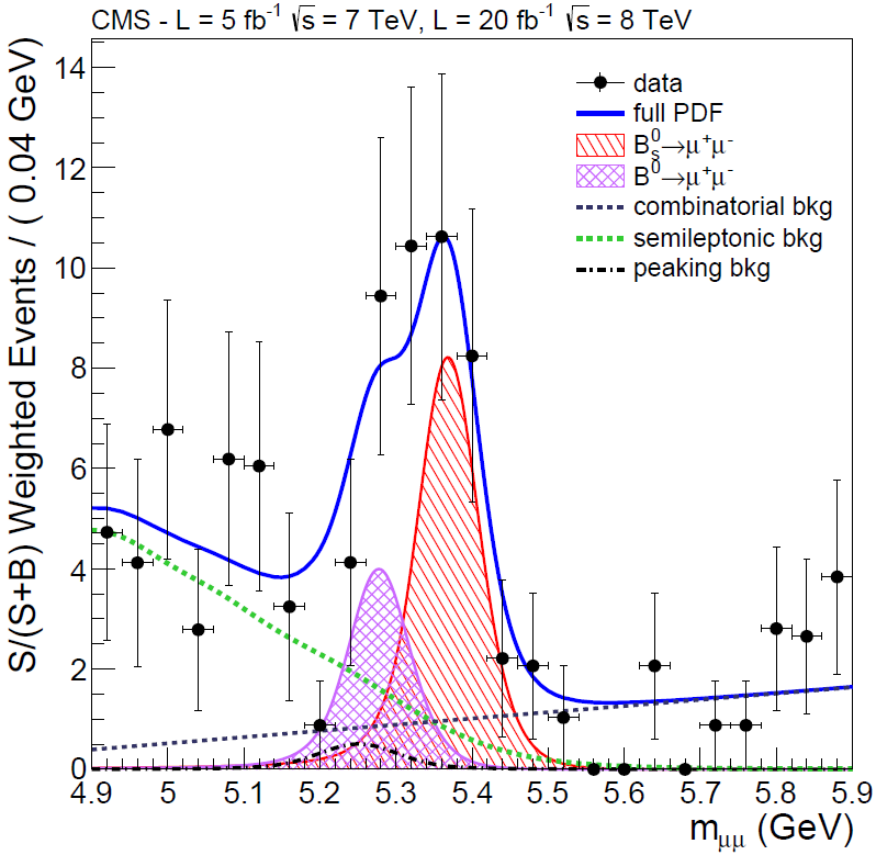
CMS-PAS-FSQ-13-003

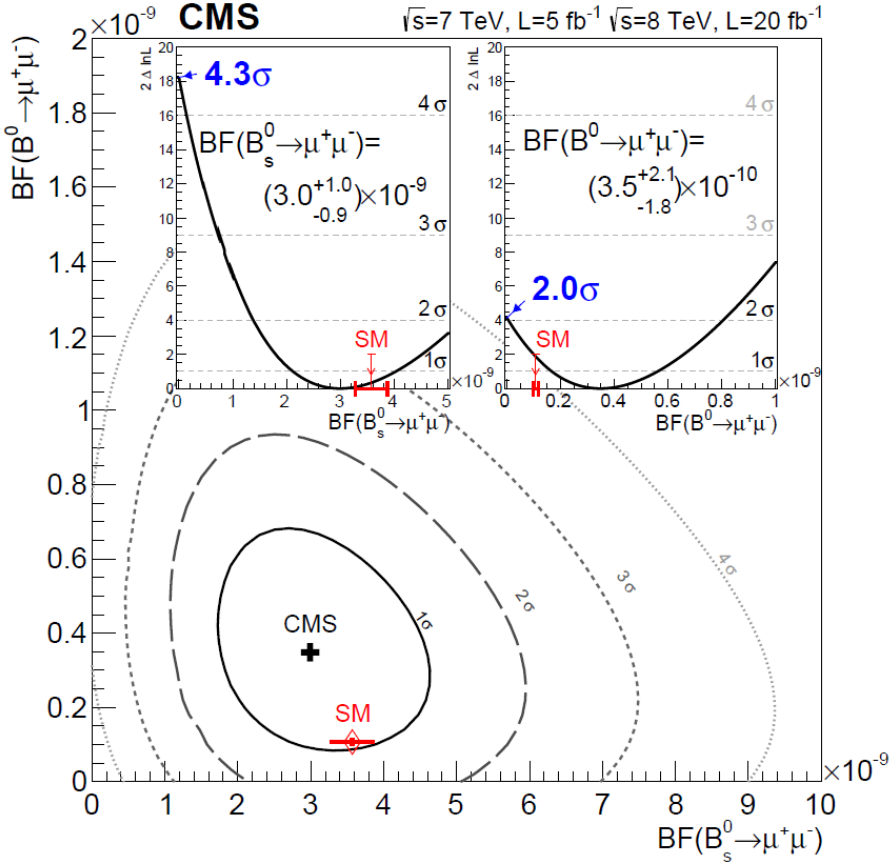


B - physics

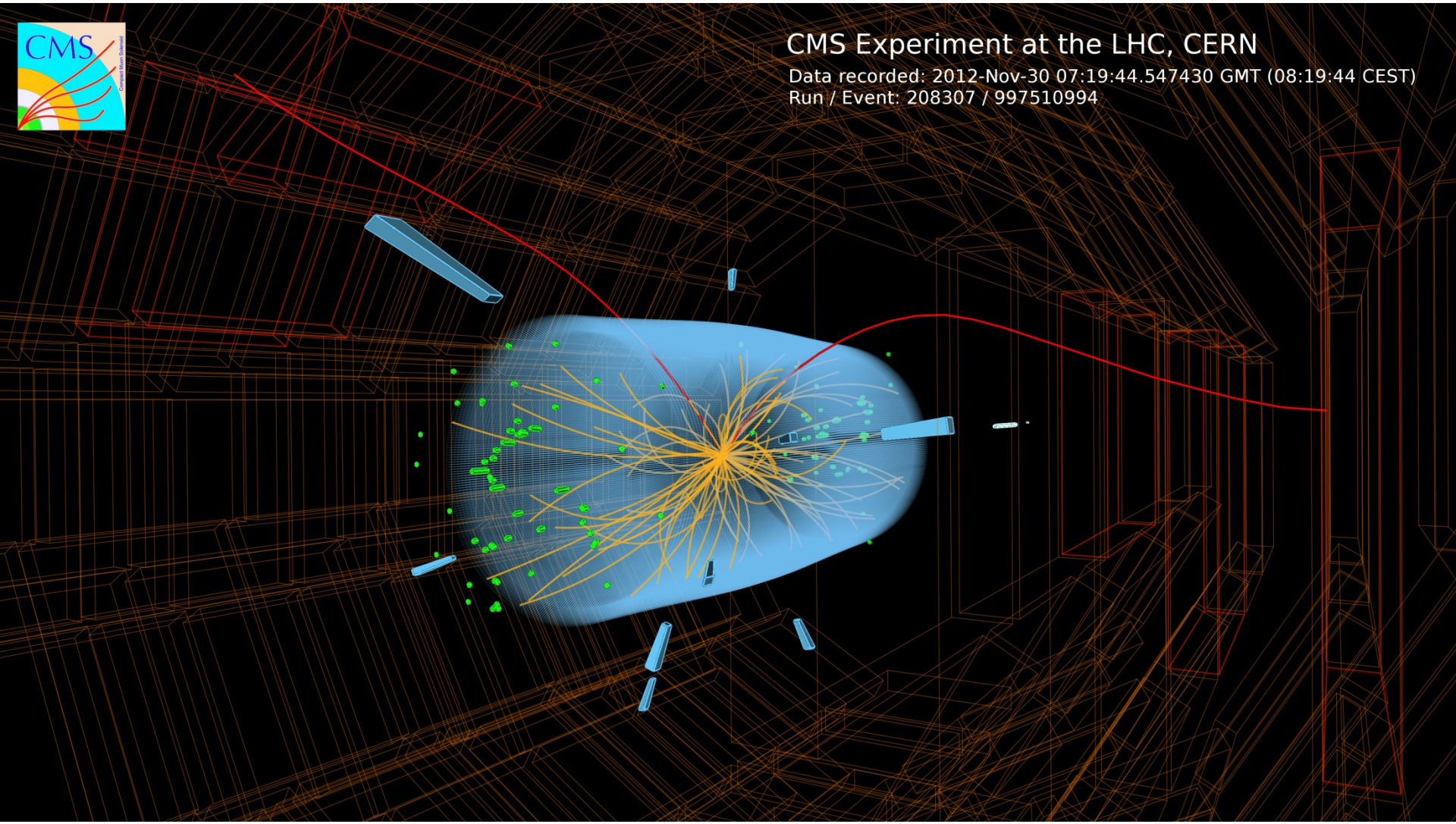
Phys. Rev. Lett. 111 (2013) 101804

maximum-likelihood fit to dimuon invariant mass distribution for BF ($B_S \to \mu^+\mu^-$), significance 4.3σ



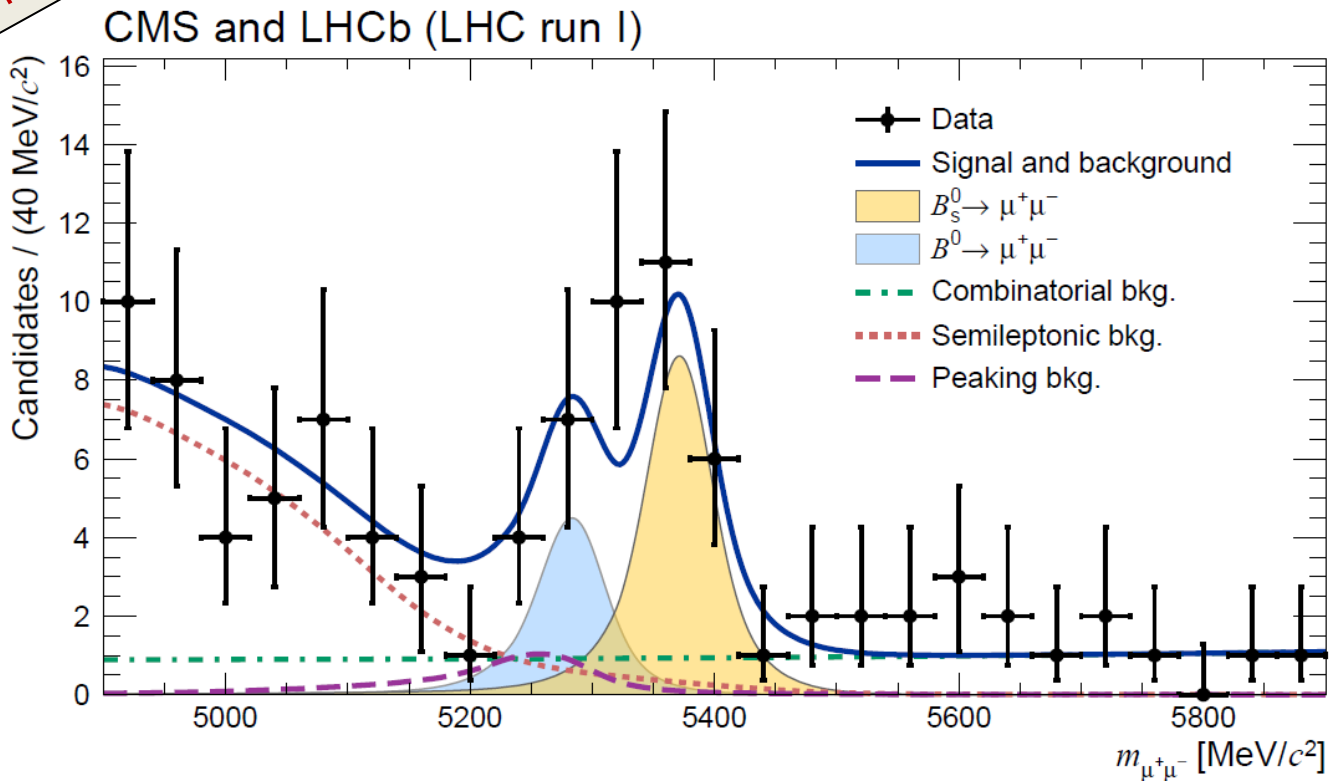


Event Display $B_s \rightarrow \mu\mu$



Combined CMS + LHCb
$B_s \rightarrow \mu\mu$ Results

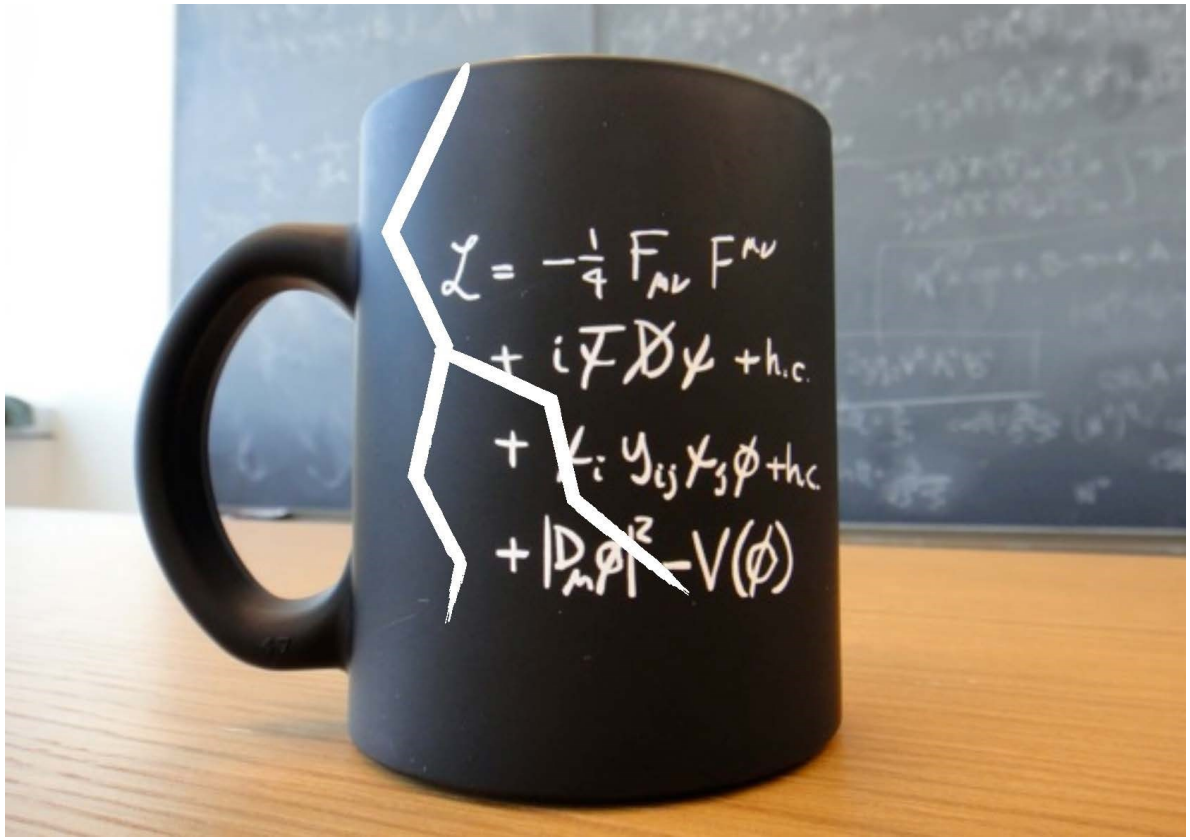
Nature 522 (2015) 68



First observation of the $B^0_S \rightarrow \mu^+\mu^-$ decay, with **6σ** significance, and the best measurement of its branching fraction so far, and **3σ evidence** for the $B^0 \rightarrow \mu^+\mu^-$ decay

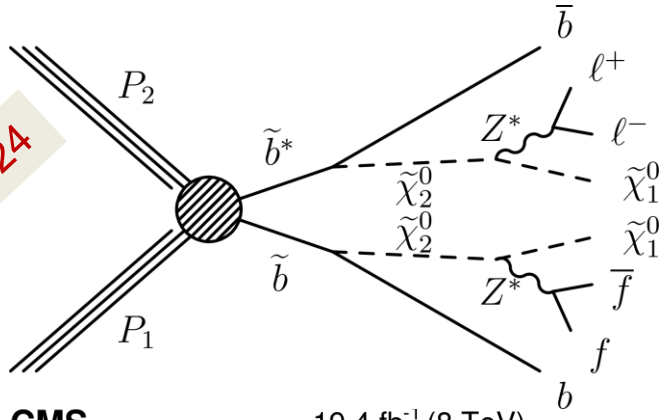
"They have been stuck in that model, like birds in a gilded cage, ever since."

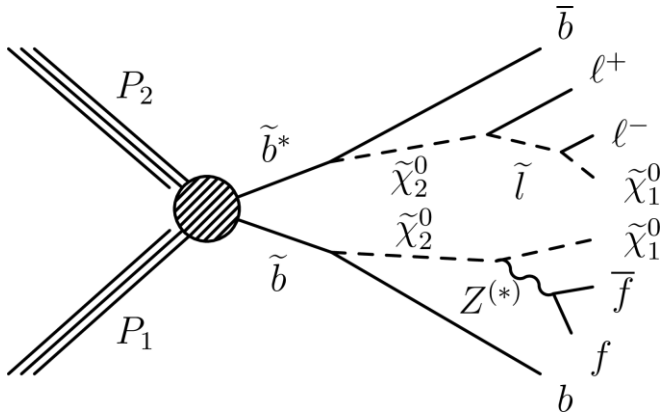
BSM Physics

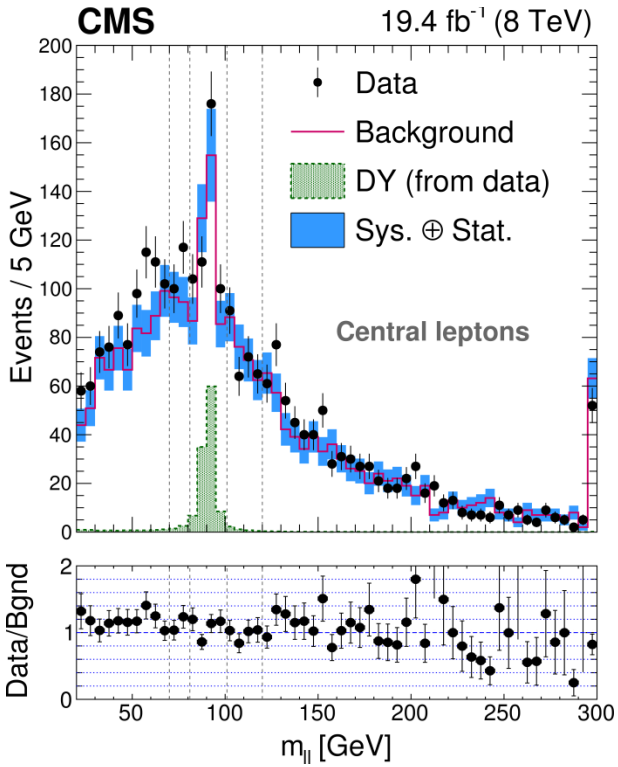


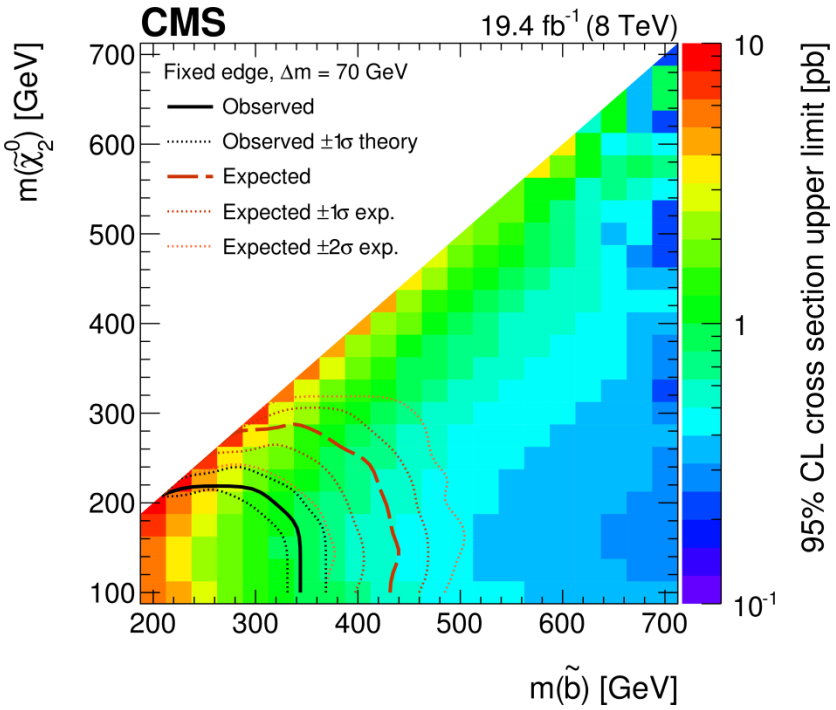
SUSY - OS dileptons

JHEP 04 (2015) 124

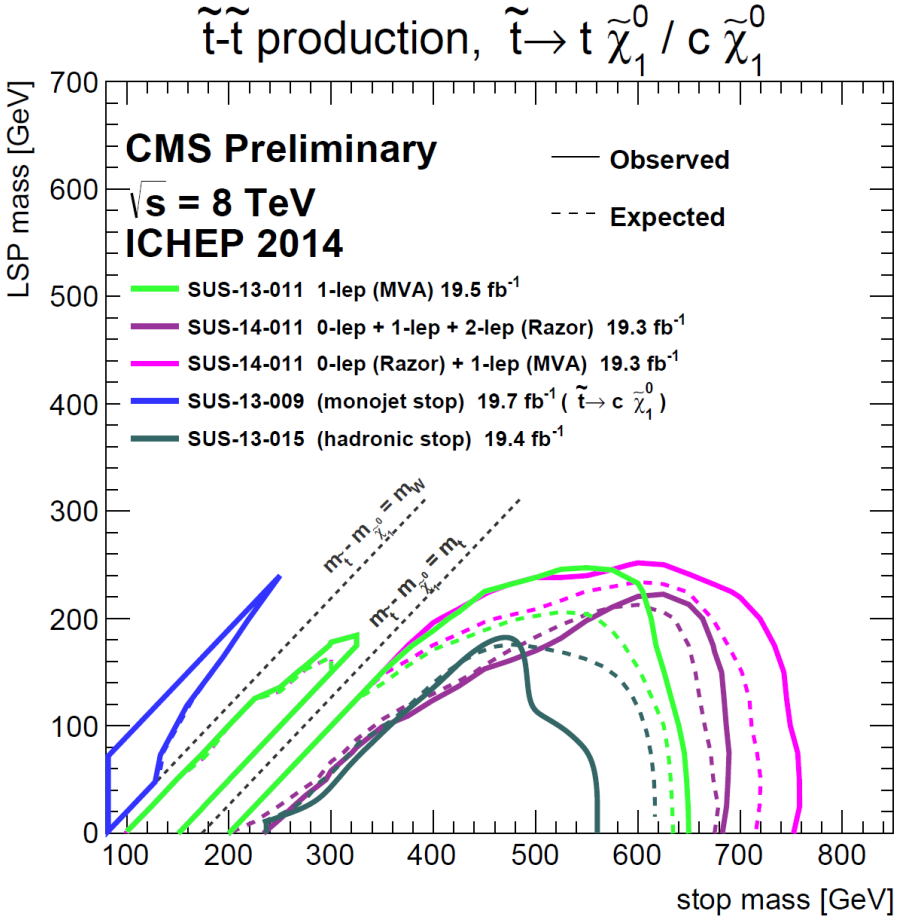


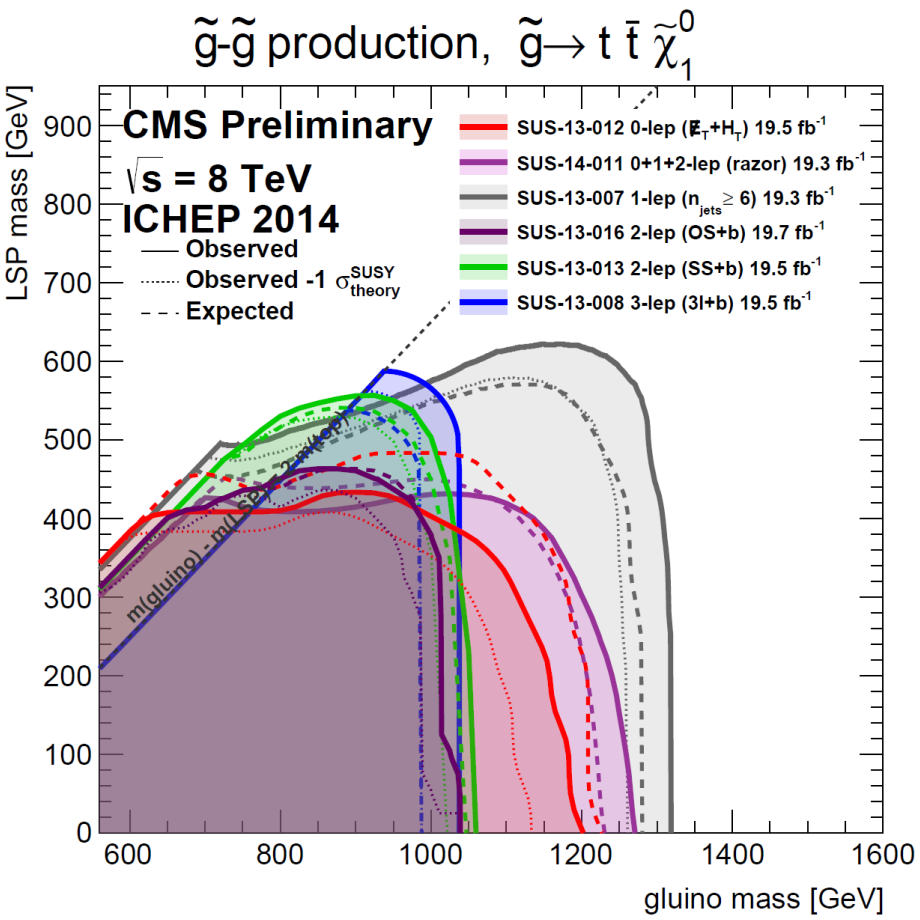






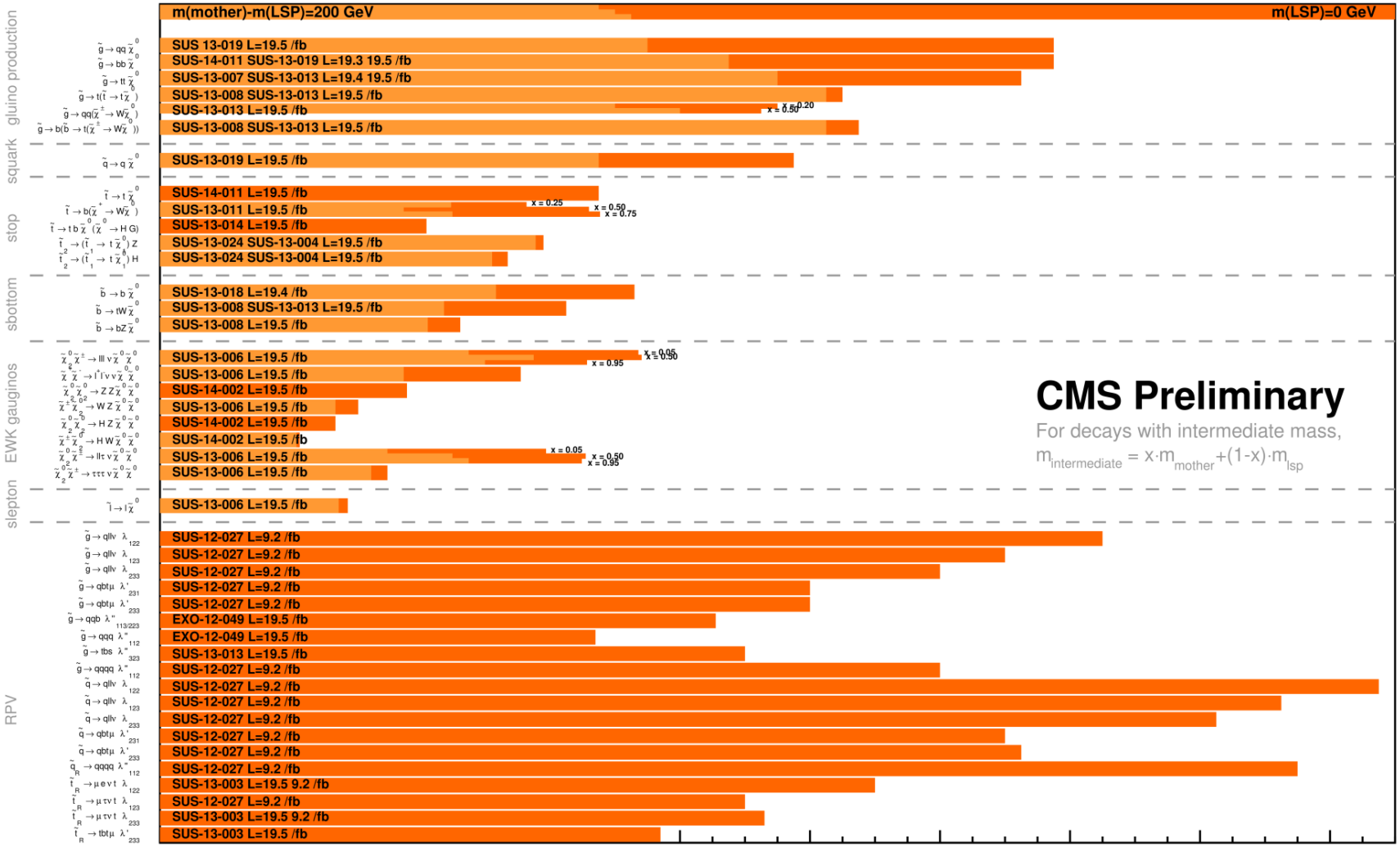
SUSY limits





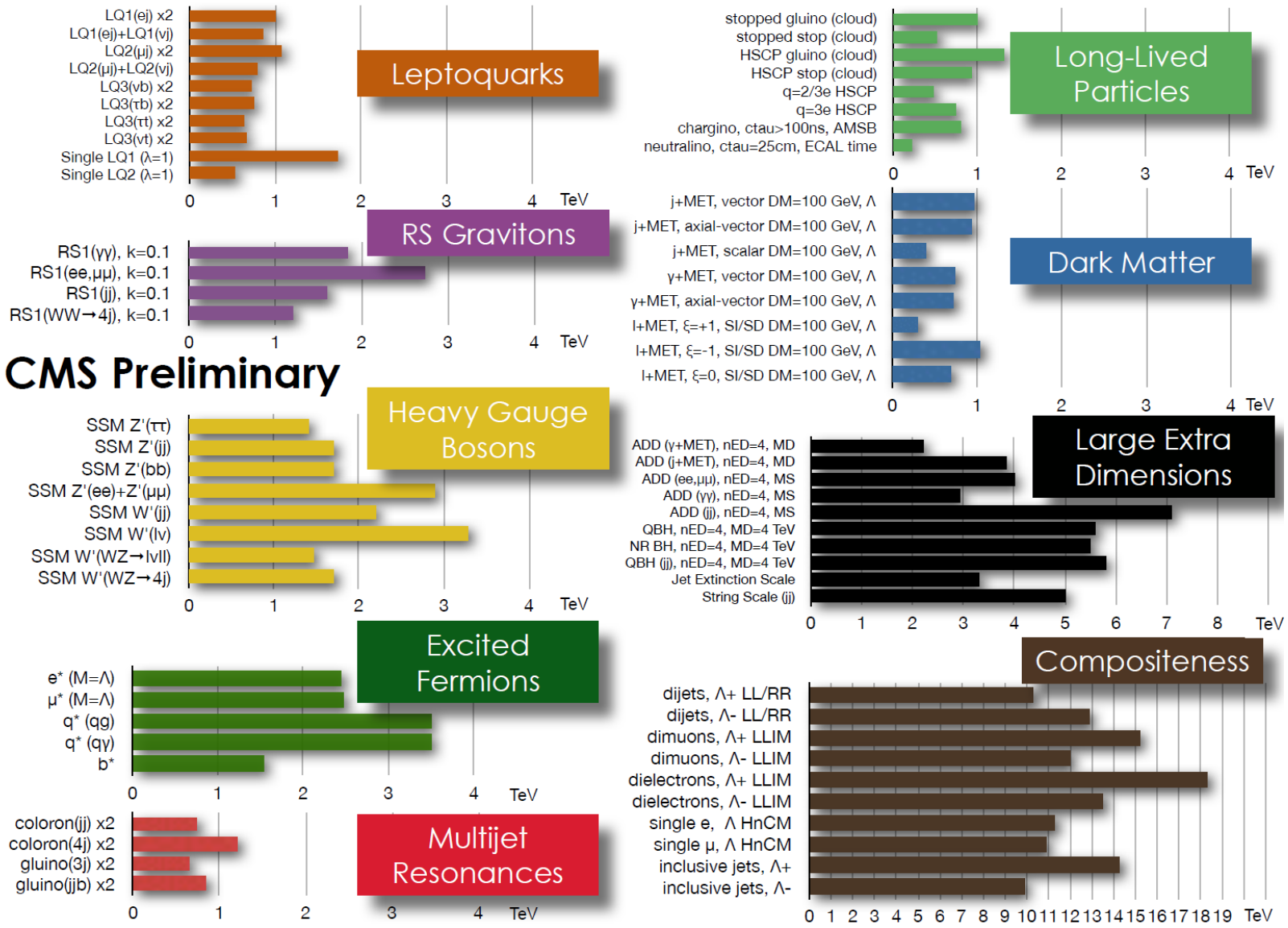
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

SUSY searches summary

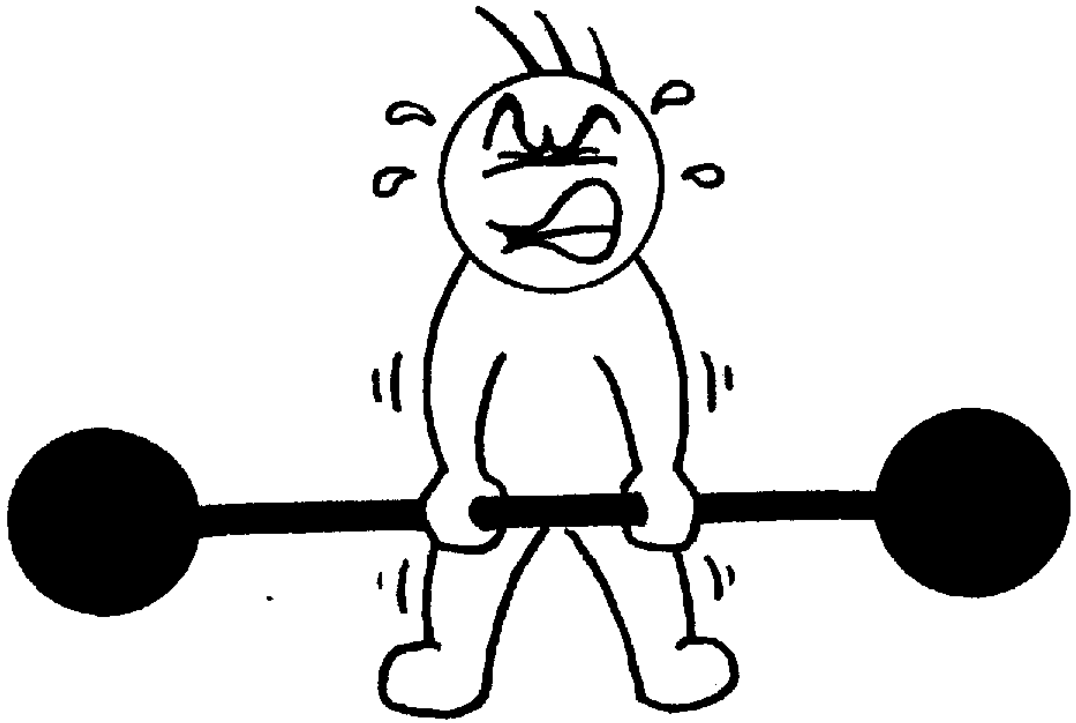


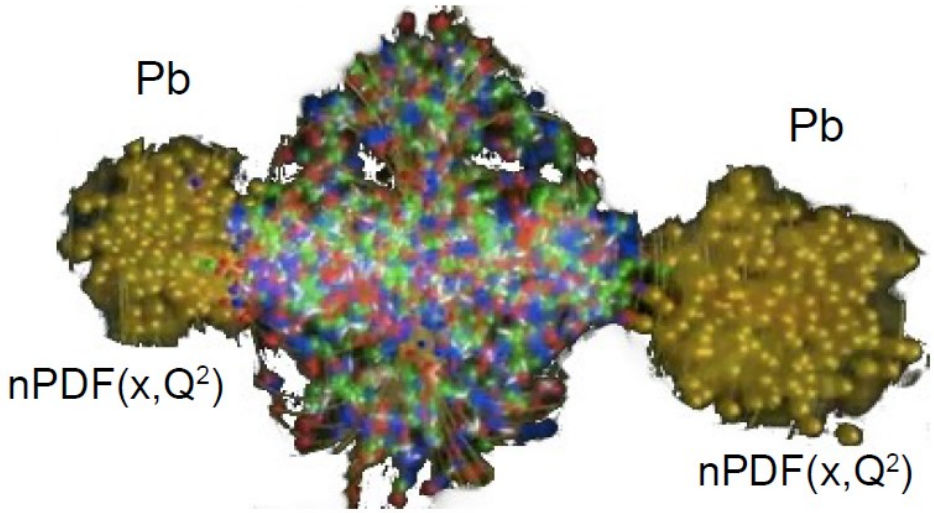
*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

Exotic Physics Searches

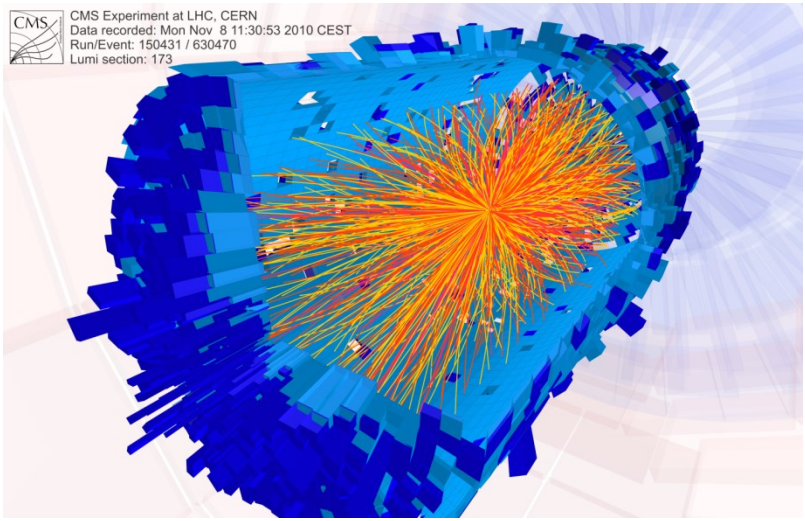


Heavy Ion Physics



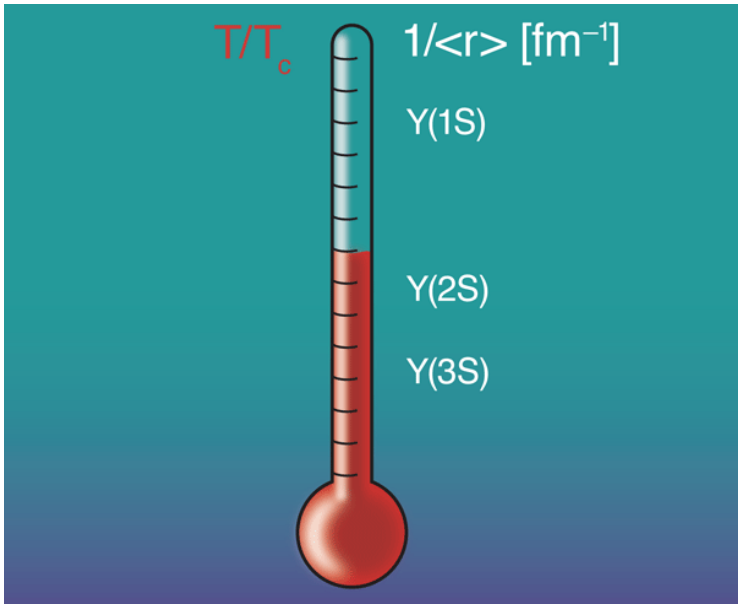


Quark-gluon plasma



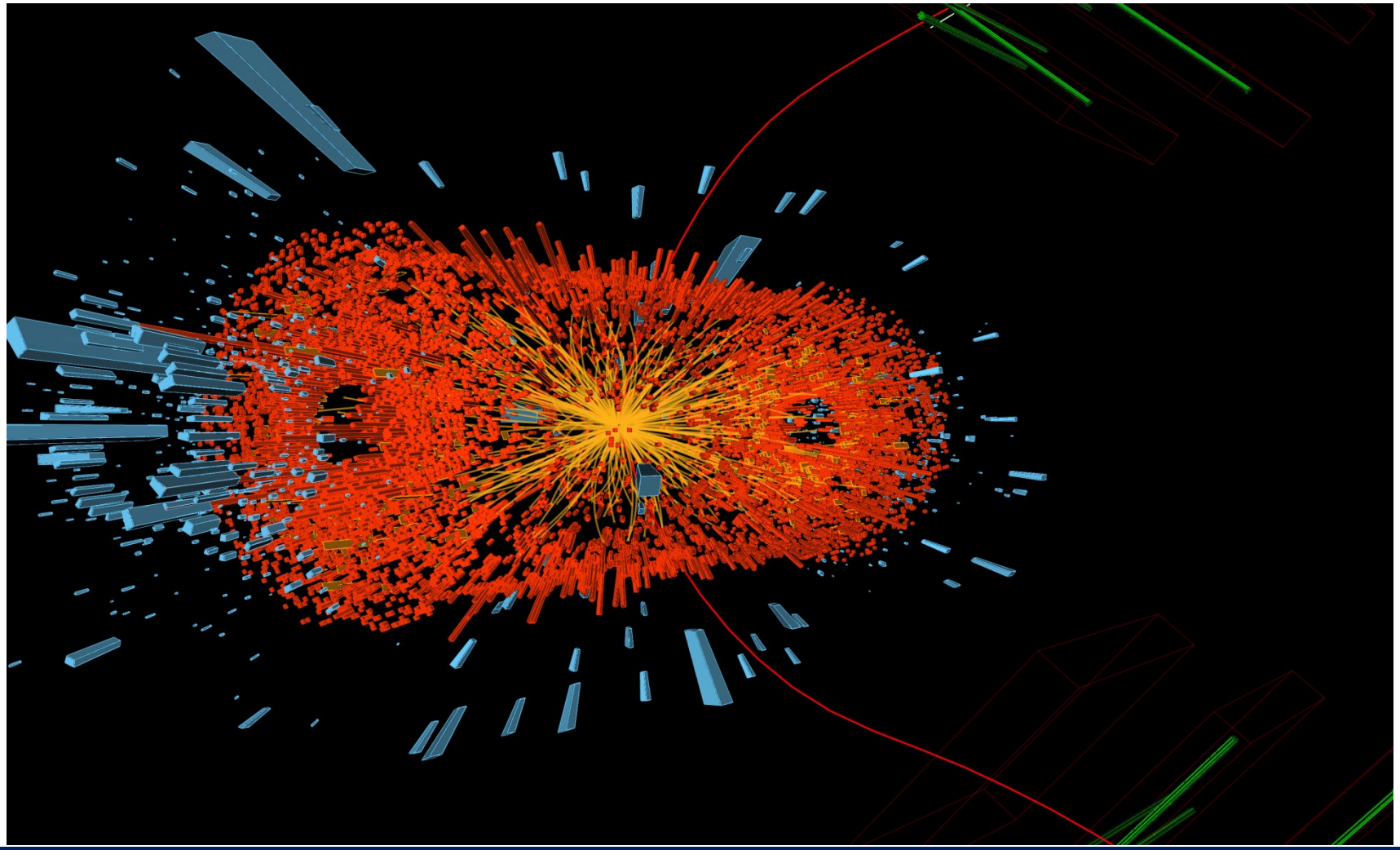
Smashing heavy nuclei inside particle colliders creates a hot nuclear matter thought similar to the primordial QGP

To explore properties of the medium, CMS compares the properties of the particles produced in heavy ion collisions (PbPb) with those produced in proton collisions



ϒ Production

CMS first experiment to successfully separate signals of the **three ϒ states** in heavy ion collisions



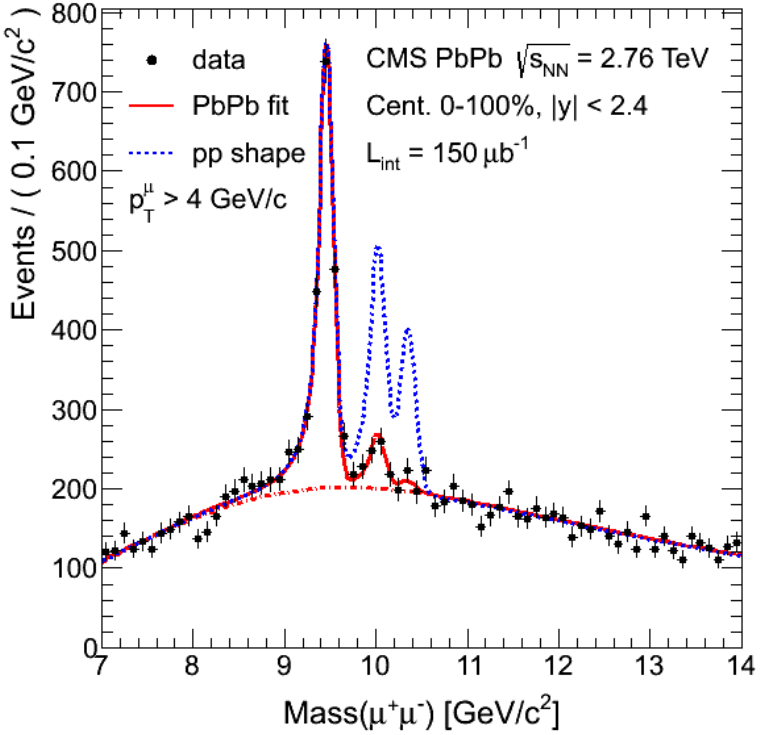
ϒ Suppression

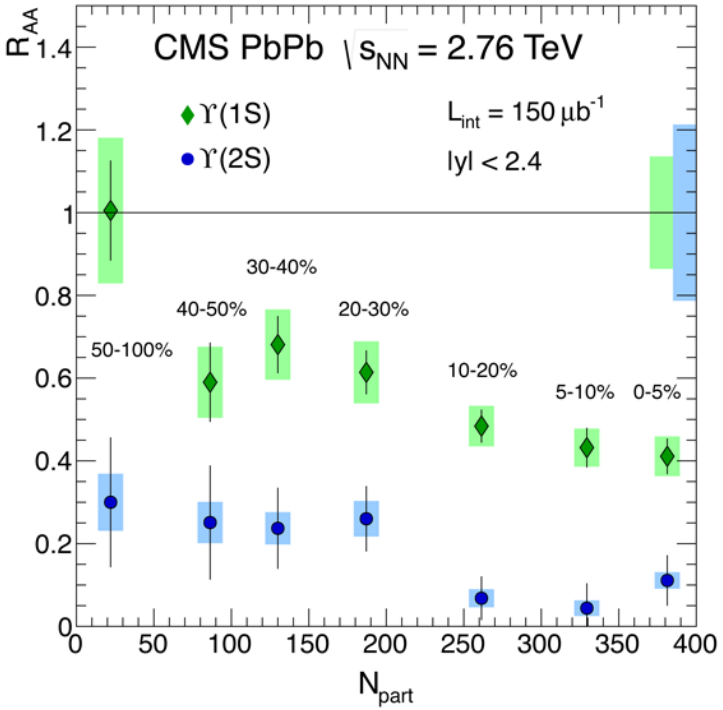
PRL 109 (2012) 222301

Having to traverse the hot medium will cause particles such as ϒ, produced in these interactions, to "**melt**" or be suppressed in it

Bound states possibly destroyed as a result of interacting with the medium before they could decay into muons

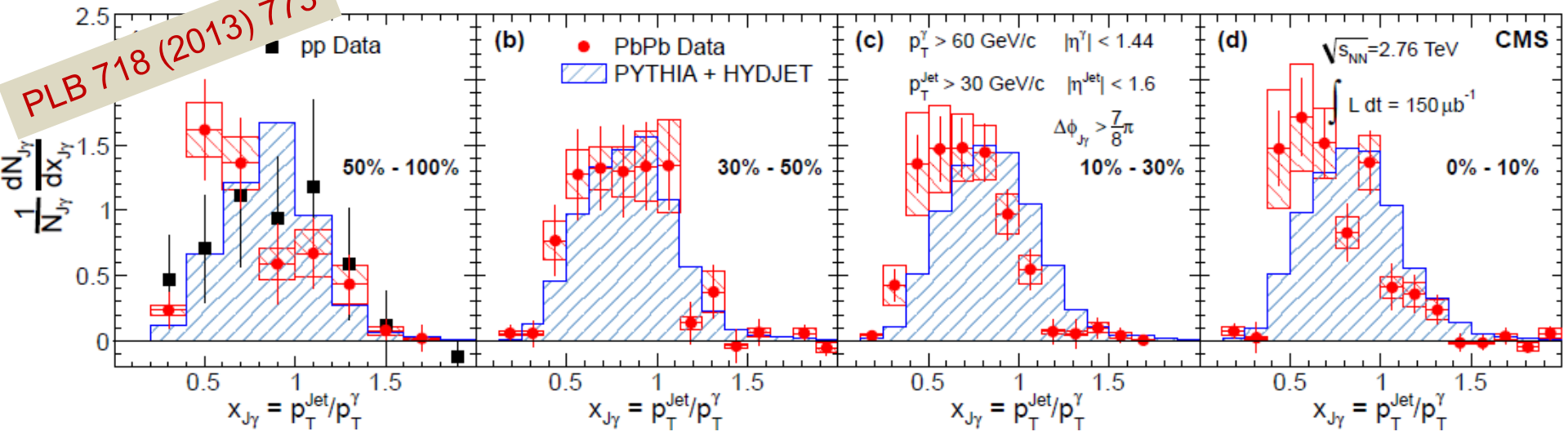
Ratio of **ϒ(2S) to ϒ(1S) ~ 21%** and ratio of **ϒ(3S) to ϒ(1S) ~ 6%** in PbPb collisions relative to those with pp collisions - results with **5σ significance**

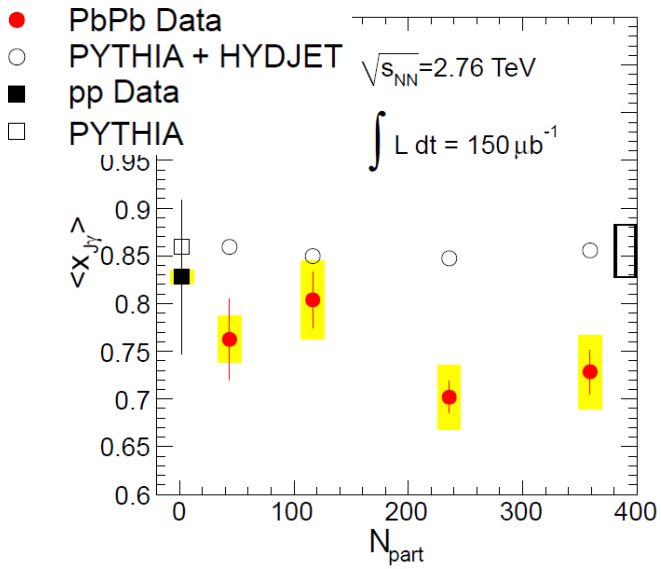




γ + jet

PLB 718 (2013) 773



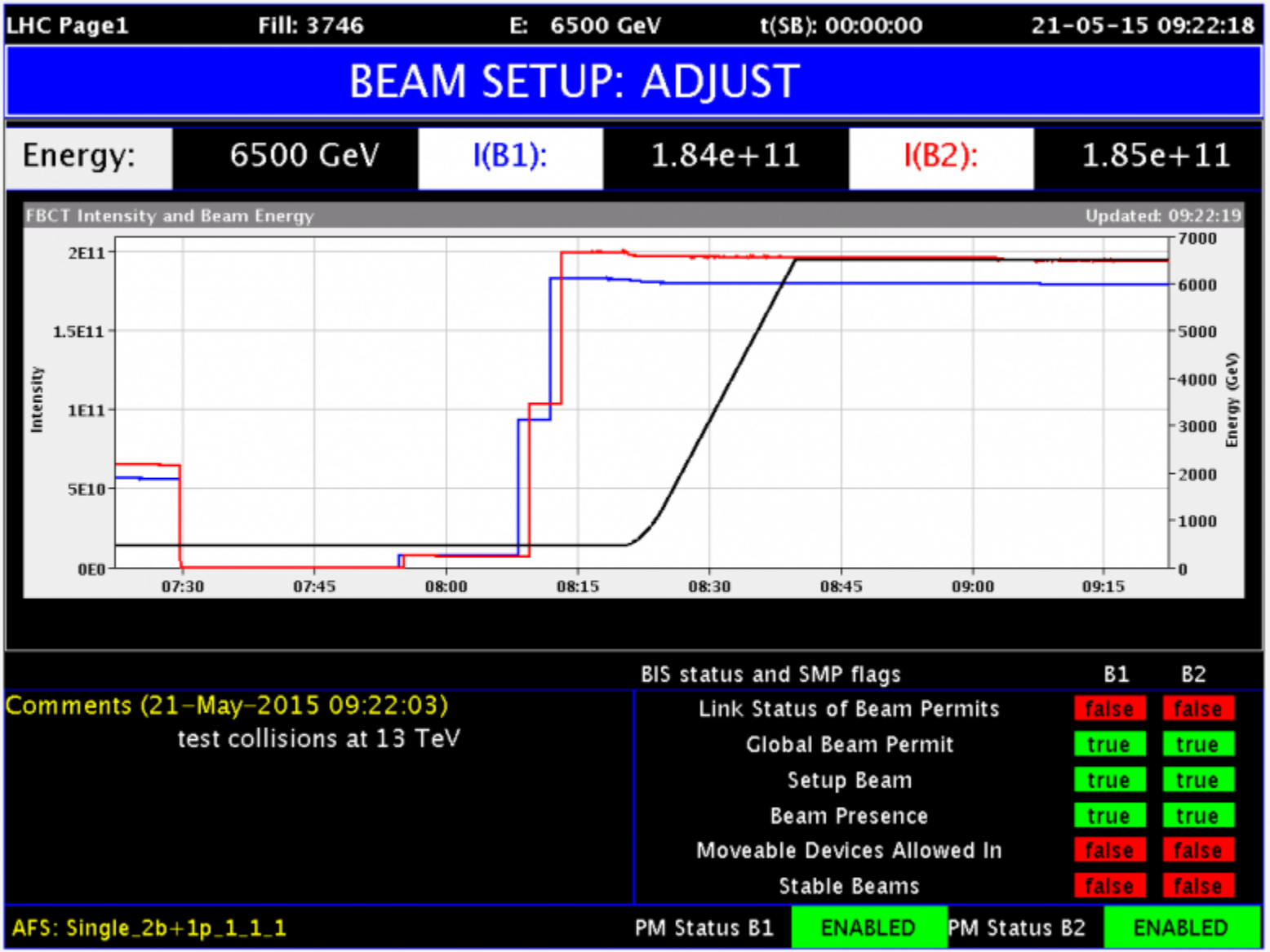


γ–jet momentum balance as function of collision centrality and compared to pp data and PYTHIA calculations

Isolated photon as an estimate of the partonic energy at production allows unbiased characterization of in-medium parton energy loss

With increasing collision centrality, a significant decrease in the ratio p_T^{Jet}/p_T^γ relative to pp observed

Summary & Prospects



Summary

After the 125 GeV **Higgs boson discovery**, the measurement of its properties cross-section have been performed at LHC run-1
A first Higgs combination measurement of ATLAS and CMS on **Higgs mass**
In the BSM Higgs searches, **no additional Higgs bosons** have been detected

Cross-section measurement in **electroweak, top and QCD physics** very well compared to theoretical predictions
Top mass measurement combining LHC and Tevatron data

$B_S \rightarrow \mu^+\mu^-$ observed for the first time and the results combined with LHCb

The heavy ion physics program yielded excellent results on the state of nuclear matter characterization

No new physics detected so far in Higgs or SUSY sector or other exotic scenarios / dark matter searches

But

we only collected < 1% of the LHC Luminosity @ half the center-of-mass energy

Prospects

13 TeV run has started and the hunt for new physics has begun