CMS Overview
Physics Highlights

Compact Muon Solenoid
experiment at the CERN's LHC

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National Centre
for Nuclear Research
NCBJ – Warsaw, Poland

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on New Frontiers in Physics
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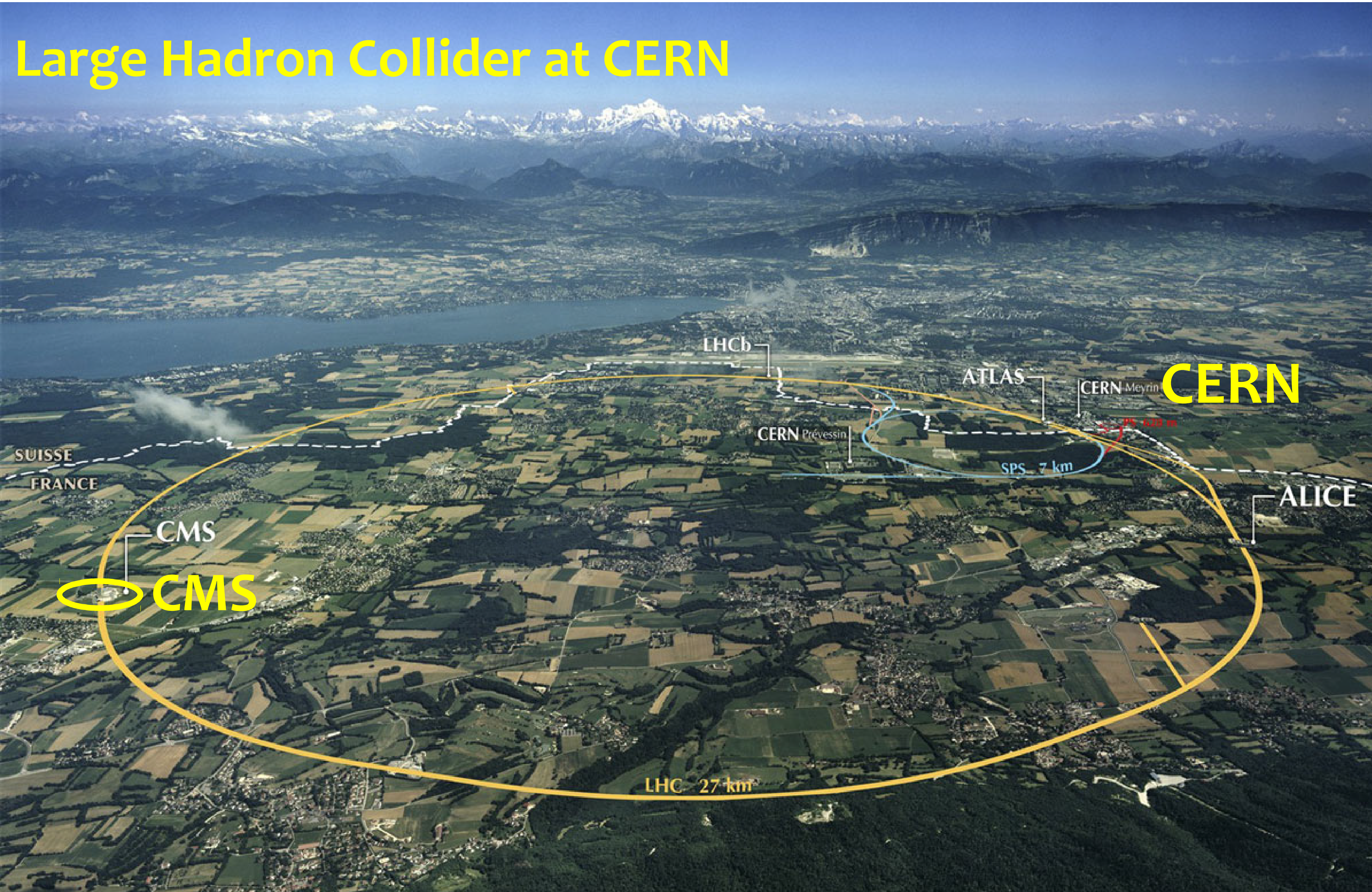
Outline

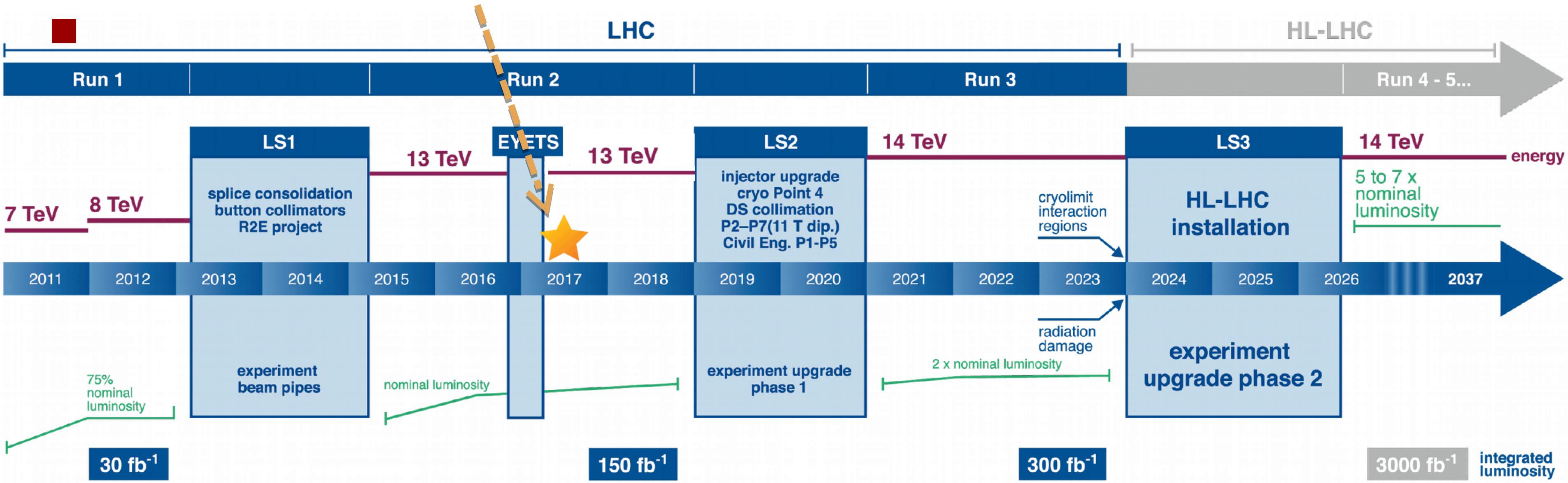
- **LHC** short intro
- **CMS Detector** status
  - Subdetector upgrades for data-taking in 2017
    - New: Pixel detector, L1 Trigger, HF calorimeter readout
    - 2017 Performance
- **CMS Physics highlights** with full 2016 **36/fb 13 TeV** data
  - 79 new results in 2017 realised at:
    - Moriond'17 – 39 publications
    - LHCP'17 – 22
    - EPS-HEP'17 – 20
  - In this talk – only selected *fresh* proton-proton results
    - during this conference – other 22 presentations and 4 posters

Introduction

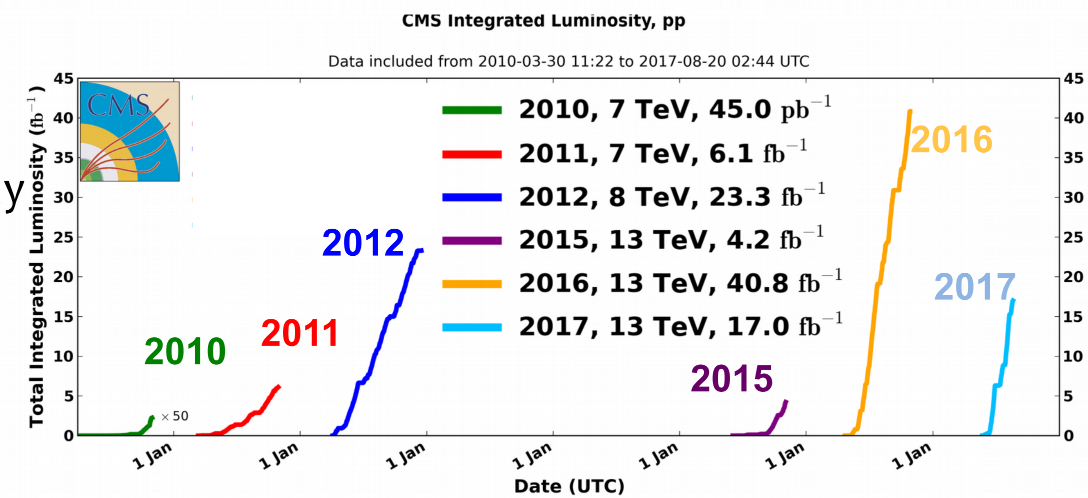


LHC schedule

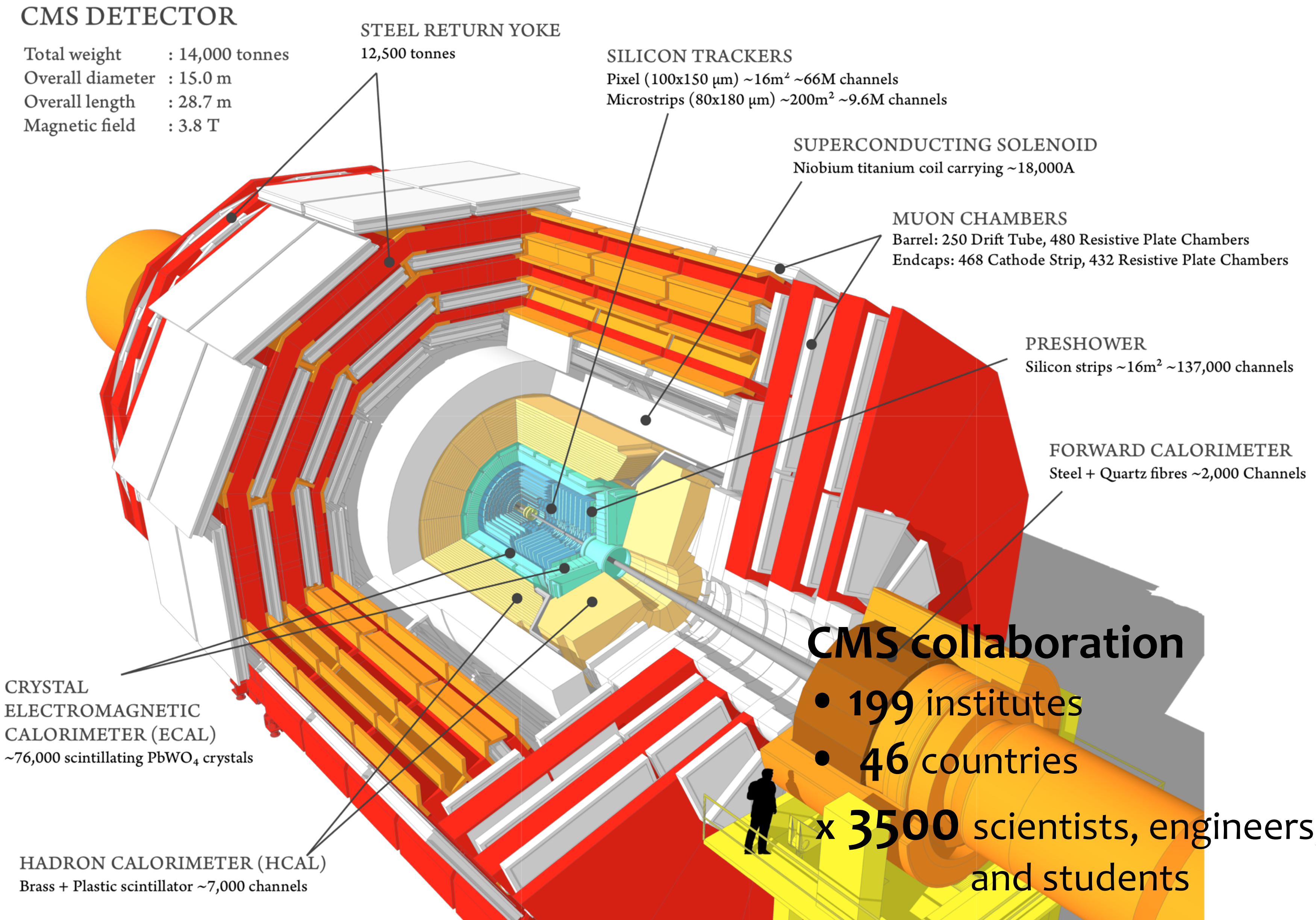
LHC past, present, and future



- LHC proton-proton **data delivered** to CMS till yesterday
- **Run 2: ~60/fb**
  - 2016: **41/fb**
  - 2017: **17/fb**



Compact Muon Solenoid



CMS collaboration

- 199 institutes
- 46 countries

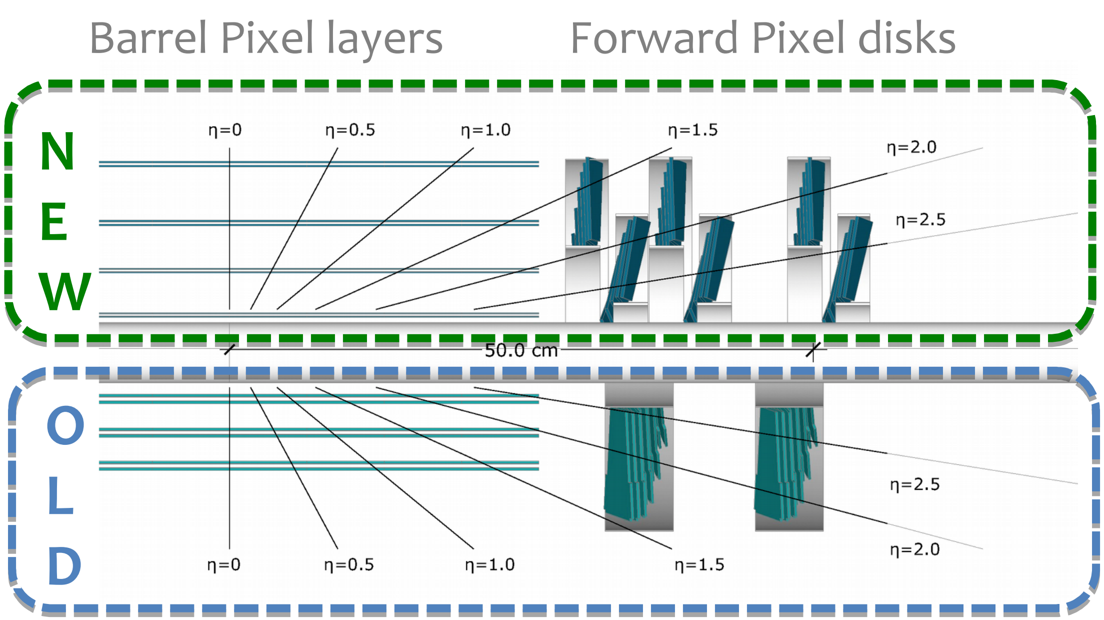
x 3500 scientists, engineers, and students

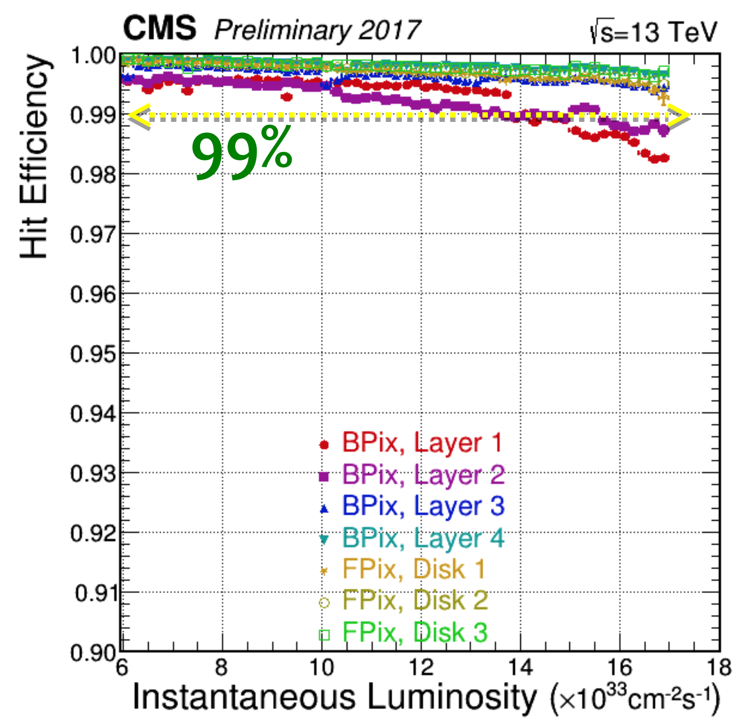
CMS upgrades in 2016/17

Recent upgrades are not yet used for current results

- New **CMS Pixel detector**:
  - 3 layers (barrel) / 2 disks (endcaps) → **4 layers / 3 disks**
    - Improved readout electronics
    - Innermost barrel layer closer to the interaction point
    - Lower material budget
  - Very good efficiency up to **99%** for all pixel detector at $L=1.5e^{34}cm^{-2}s^{-1}$

- Expected improvements in tracking, vertexing and b-tagging



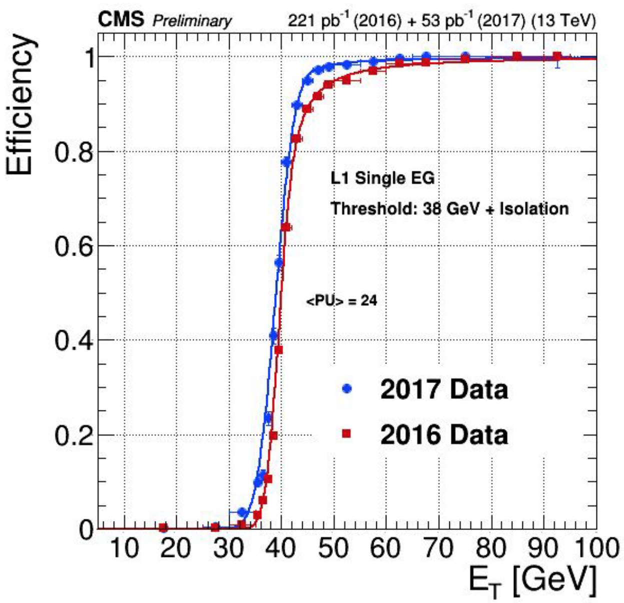


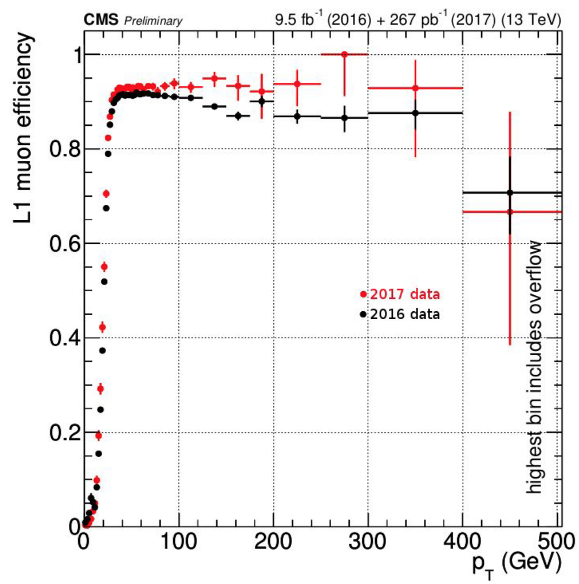
CMS upgrades in 2016/17

CMS-DP-2017-024

- Full upgrade of **L1 trigger** system

  to manage with high inst. luminosity of 1e34 $cm^{-2}s^{-1}$ and high pile-up



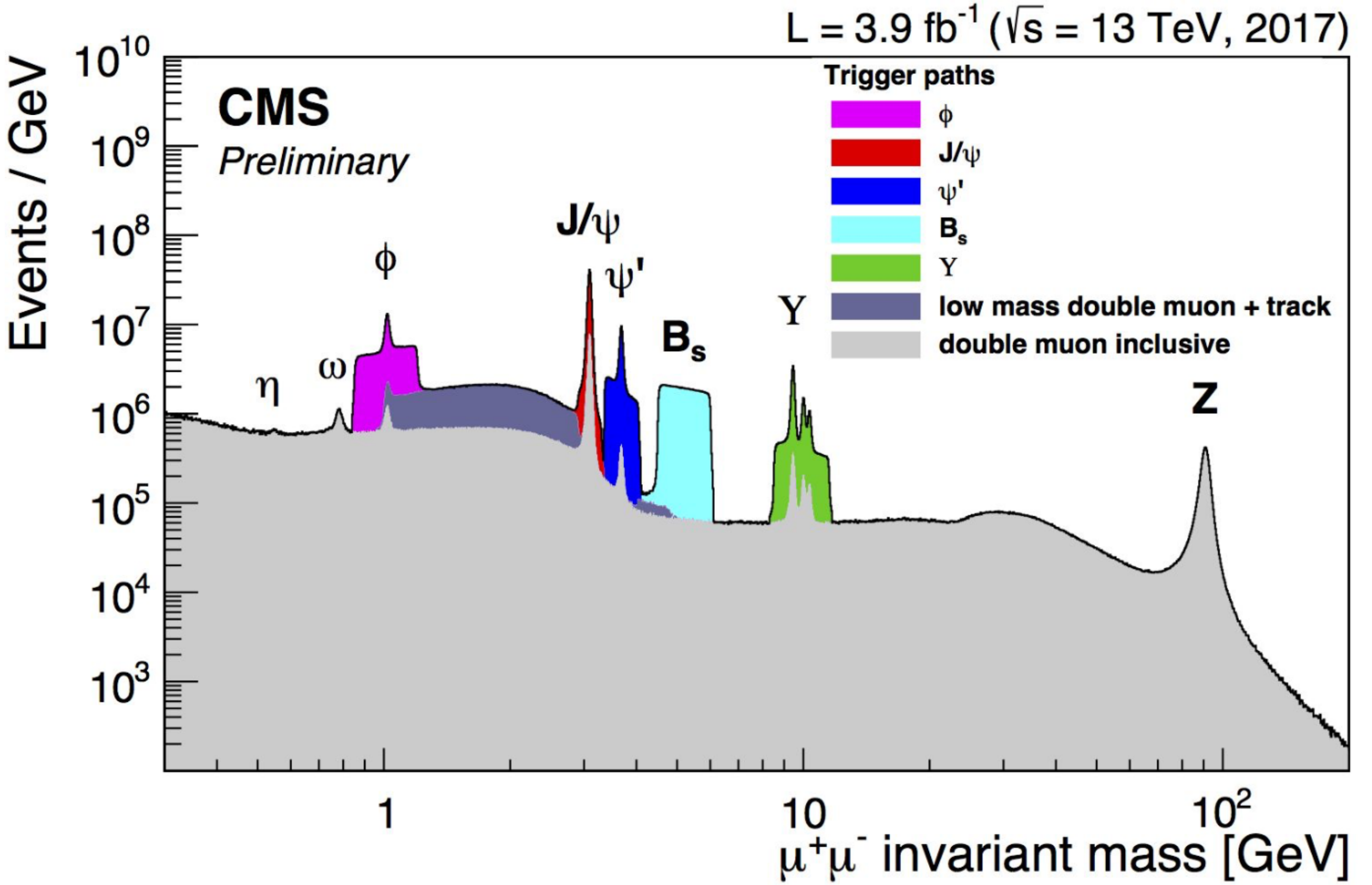


- **L1 electron/photon** trigger **re-optimization**
- better resolution → sharper turnON
- 20% rate reduction
- 15% gain in efficiency (keeping almost no PU dependence)

- **L1 muon** trigger **new track finders**
- Improved L1 muon track finding and p_T resolution, and efficiency
- Lowest unprescaled threshold 25 GeV in 2017

CMS Performance in 2017

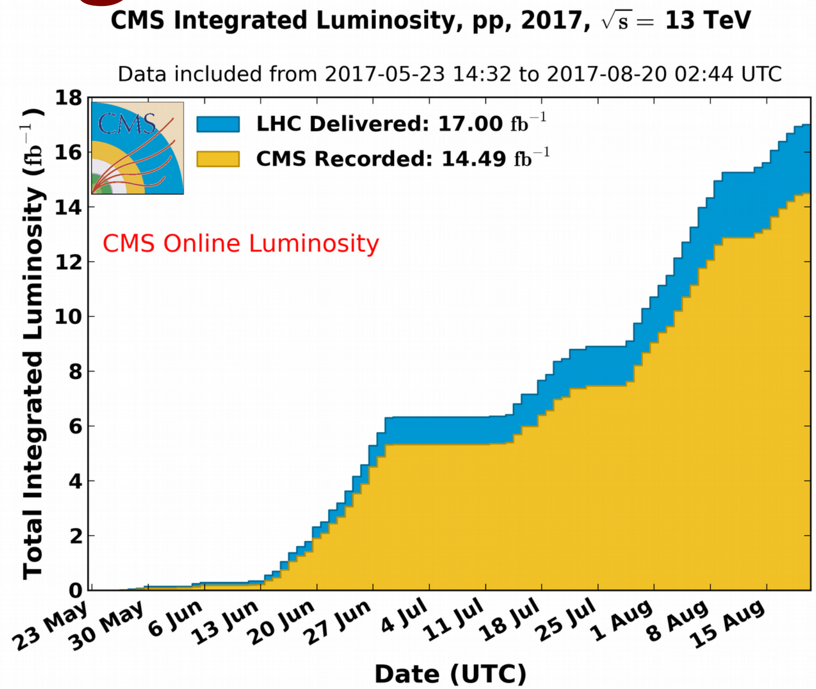
- First illustration of di-muon spectrum taken with inclusive and dedicated muon trigger paths

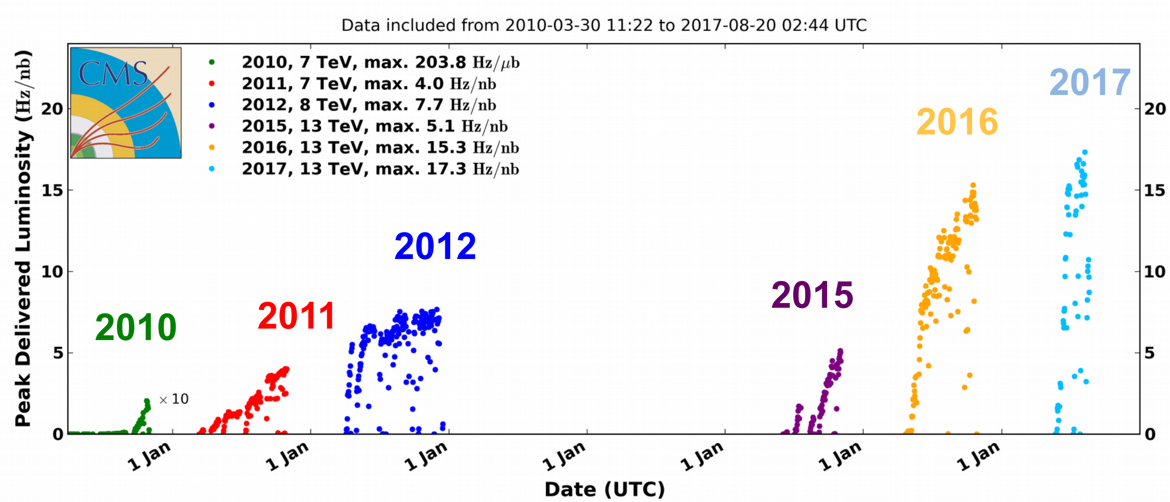


Data taking in 2017

CMSLumi2017

- CMS data-taking efficiency **> 85 %**
- Some time was dedicated for testing the new Pixel detector
- Successful restart of the LHC
- Reaching inst. luminosity of $1.7e^{34}$ $cm^{-2}s^{-1}$

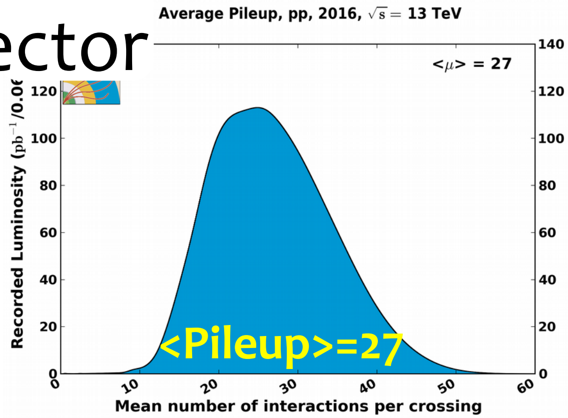


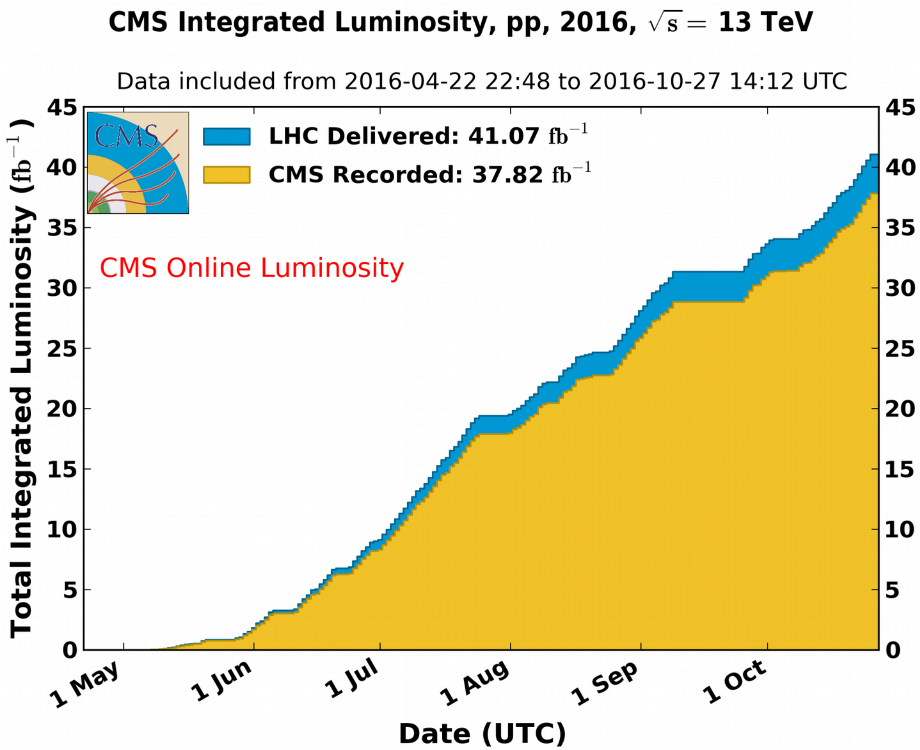


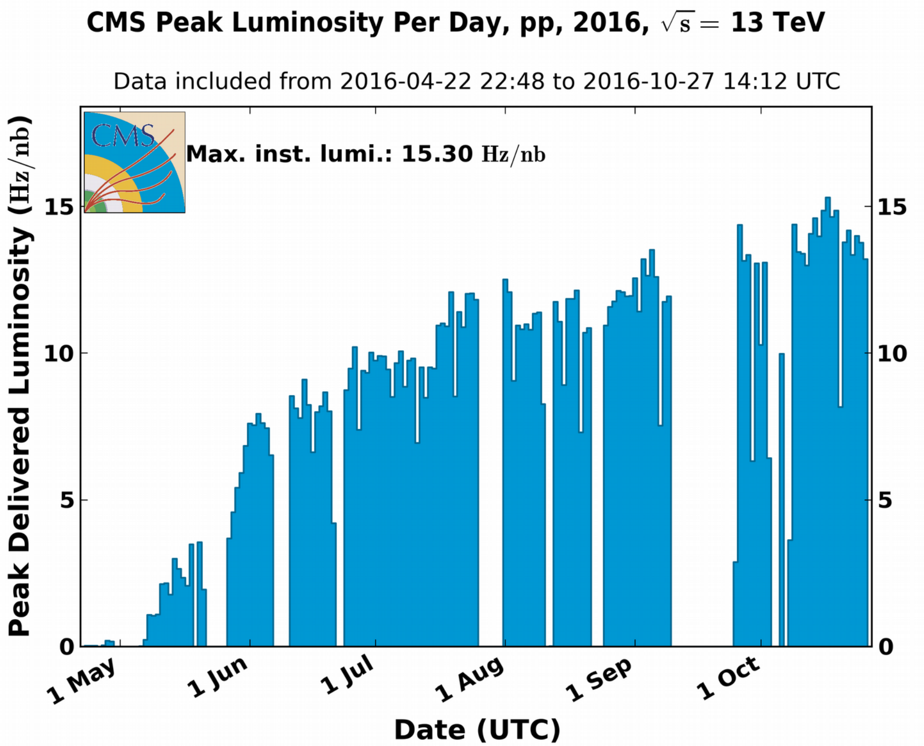
Data in 2016 → new results

CMSLumi2016

- Excellent performance of the CMS detector
  - Efficiency of data-taking (**41/fb**) for:
    - **38/fb**, recording **> 92%**
    - **35.9/fb, good for physics > 87%**

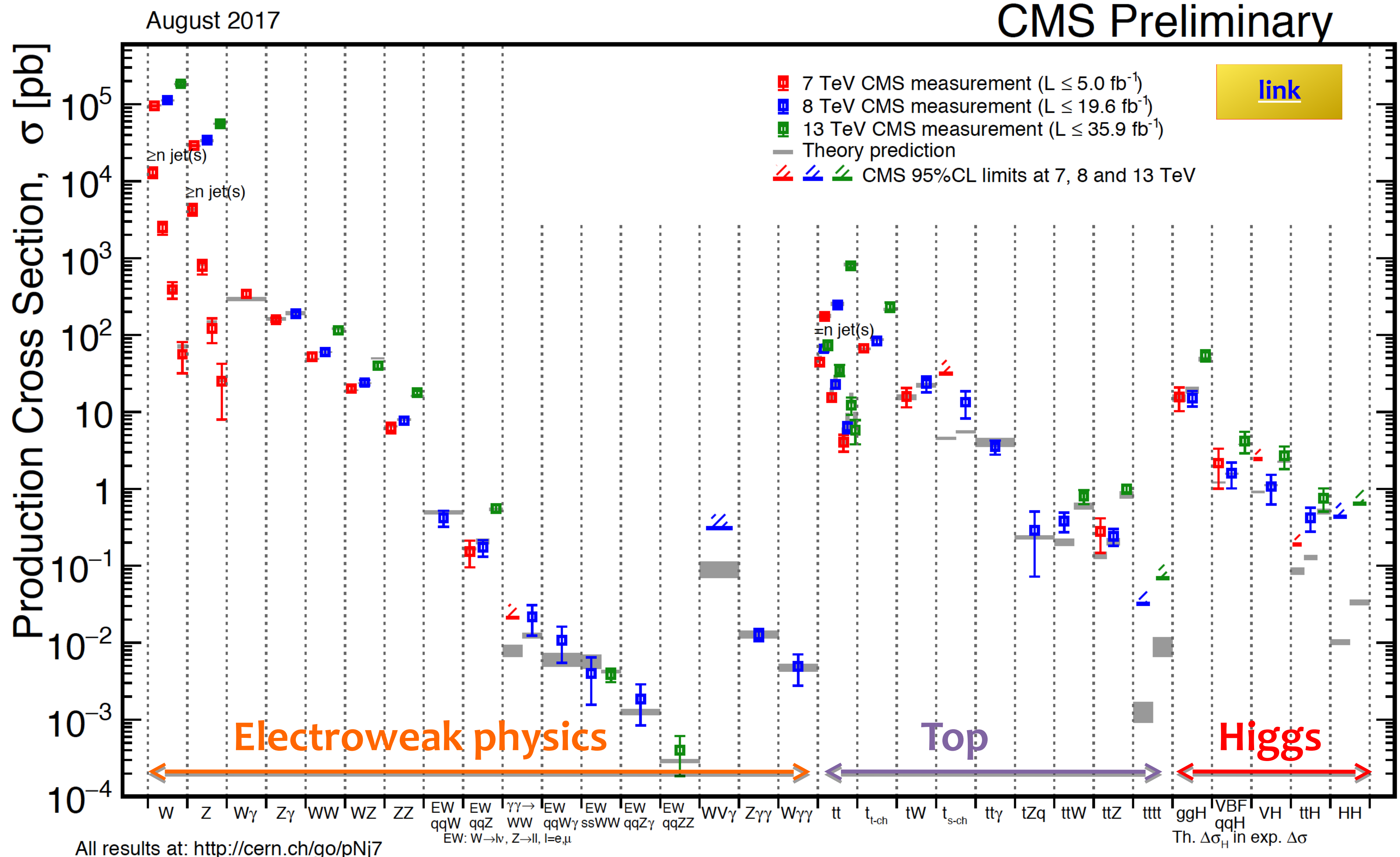






Run 1&2 legacy – Nature is SM-like

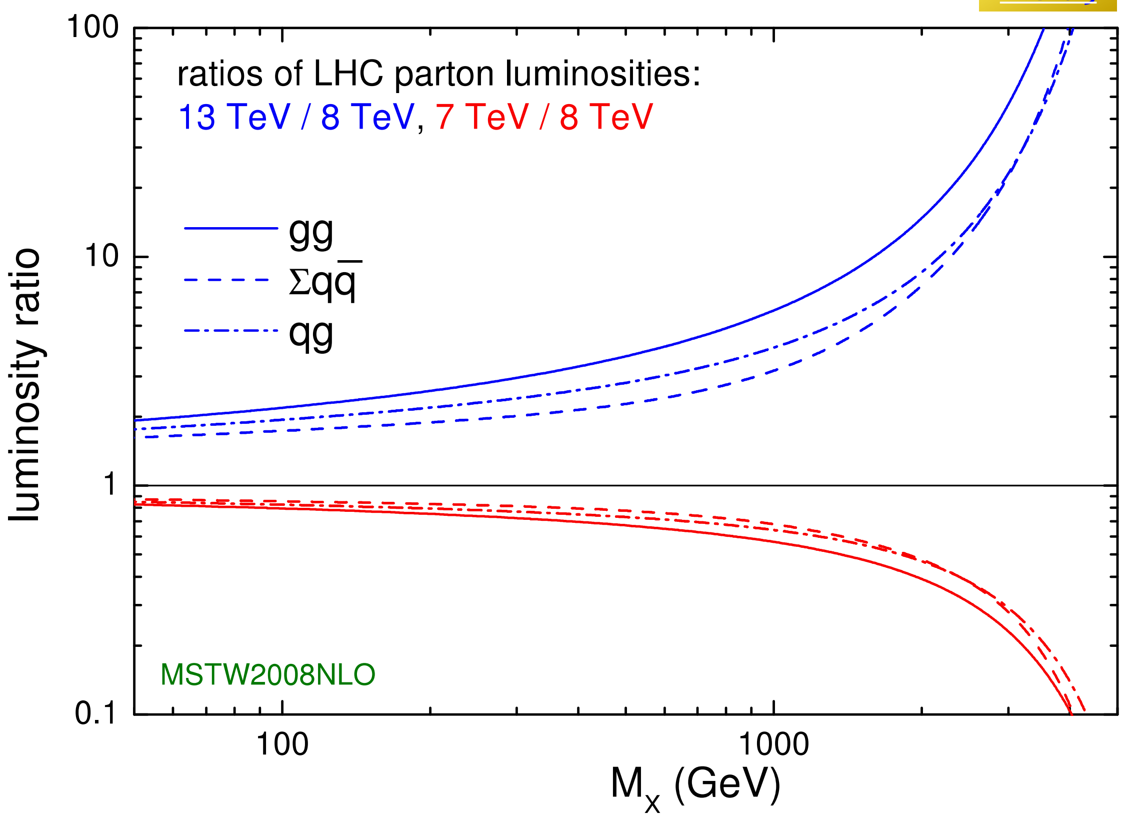
- Theoretical description of high-Q^2 processes is with high agreement with LHC data



Run 2 continues – opened perspective

- **Higgs boson** and **precise SM measurements**
  new possibilities for deciphering the properties opened up

WJS2013



New Physics
– no sign, but….

- Large increase in signal xsecs for heavy particles

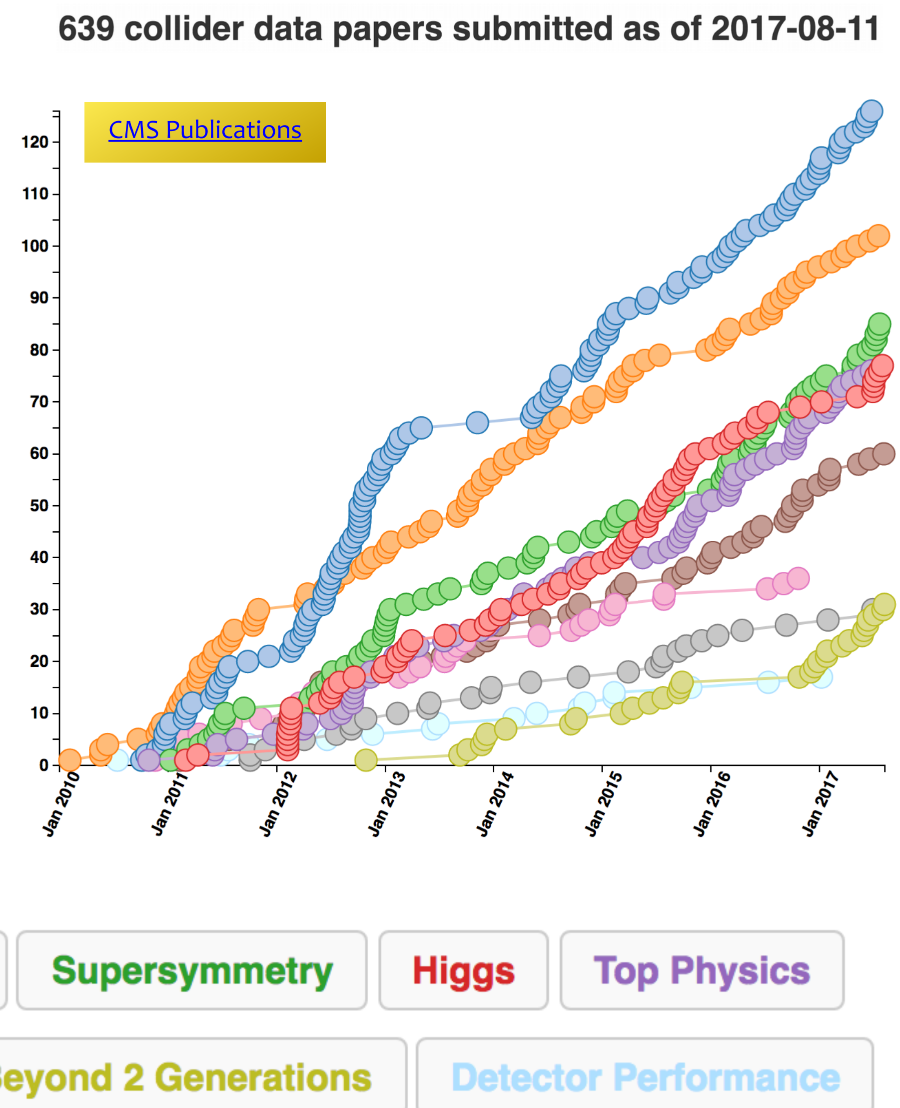
  from 8→13 TeV

- Strong gluino pair production privileged

CMS Physics Highlights

CMS pp Physics (in this talk):

- **Standard Model**
  - Electroweak Physics
- **Higgs**
- **Top Physics**
- Searches:
  - **SUSY**
  - **Exotica**
    - Dark Matter



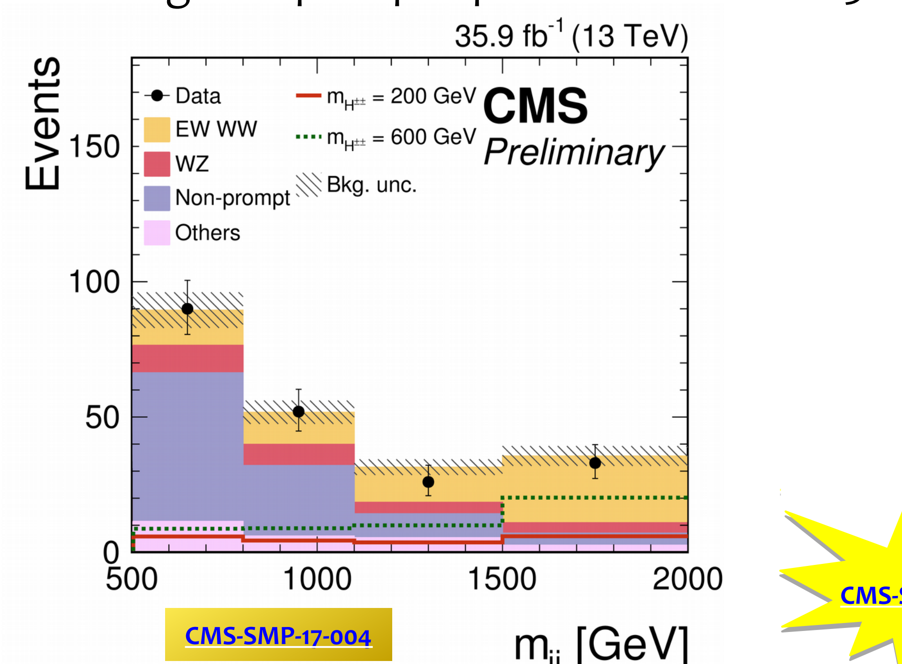
Electroweak precise measurements

- Challenging Standard Model predictions

EWK Gauge Couplings

- **Diboson** and **W/Zjj processes** extensively studied
- Vector-boson scattering is the ideal testbench to study of the EWK sector

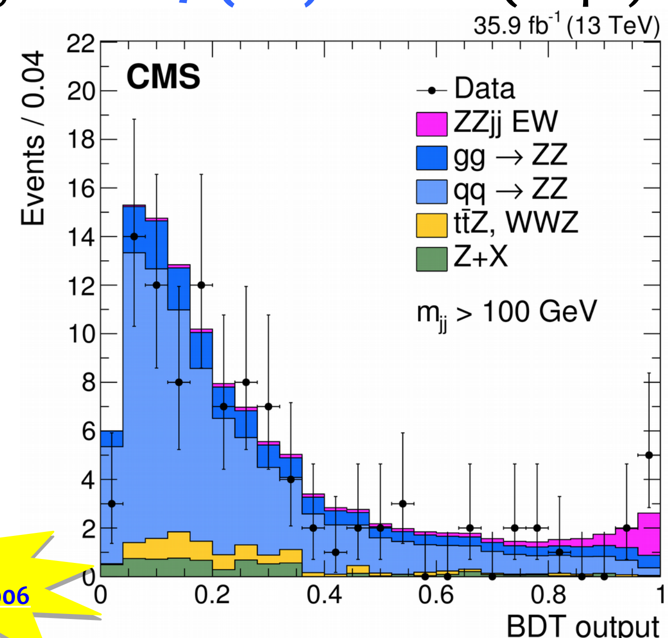
- First **5.5 σ observation** of **EWK same-sign WWjj** production
  - Evts: two leptons of the same charge, moderate MET, 2 jets with large rapidity separation and large dijet mass
  - Bkg: non-prompt leptons and the WZ $\rightarrow 3\ell\nu$



CMS-SMP-17-004

- **First measurement of VBS** in the **ZZjj** channel at the LHC
  - Evts: fully leptonic (*4l*) final state

EWK ZZjj is measured with sign. of **2.7 (1.6) σ** obs.(exp.)



NEW
CMS-SMP-17-006

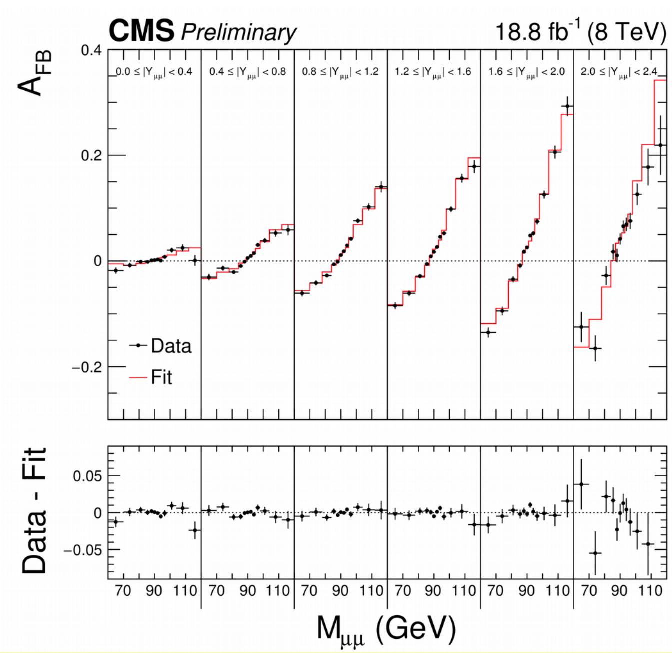
$$\sigma_{th} = 0.29^{+0.02}_{-0.03}\ \text{fb}$$

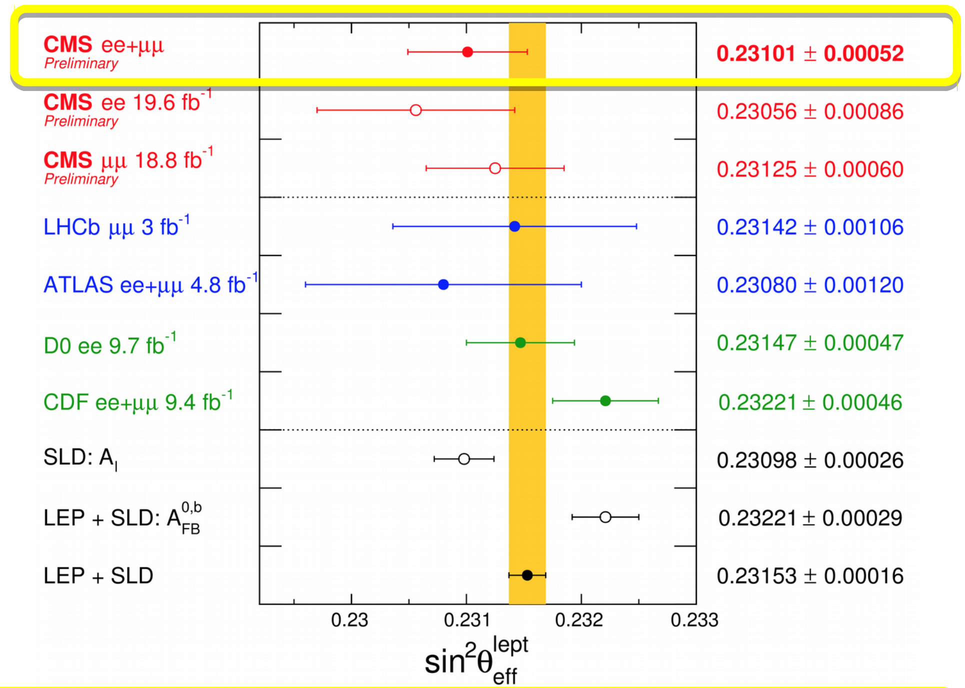
$$\sigma_{EW}(pp \rightarrow ZZjj \rightarrow \ell\ell\ell'\ell'jj) = 0.40^{+0.21}_{-0.16}\ (\text{stat})\ ^{+0.13}_{-0.09}\ (\text{syst})\ \text{fb}$$

Electroweak mixing angle at 8 TeV

CMS-SMP-16-007

- Precise measurement with the forward-backward asymmetry A^{FB} of Drell-Yan (ee and μμ) events at 8 TeV
  - Improved lepton momentum calibration, angular event weighting, and additional PDF constraints
- $Sin^2\theta$ extraction by fitting A^{FB} inv. mass and rapidity bins
- **Most precise measurement of $sin^2\theta$ at the LHC**
- Allows to constrain PDFs

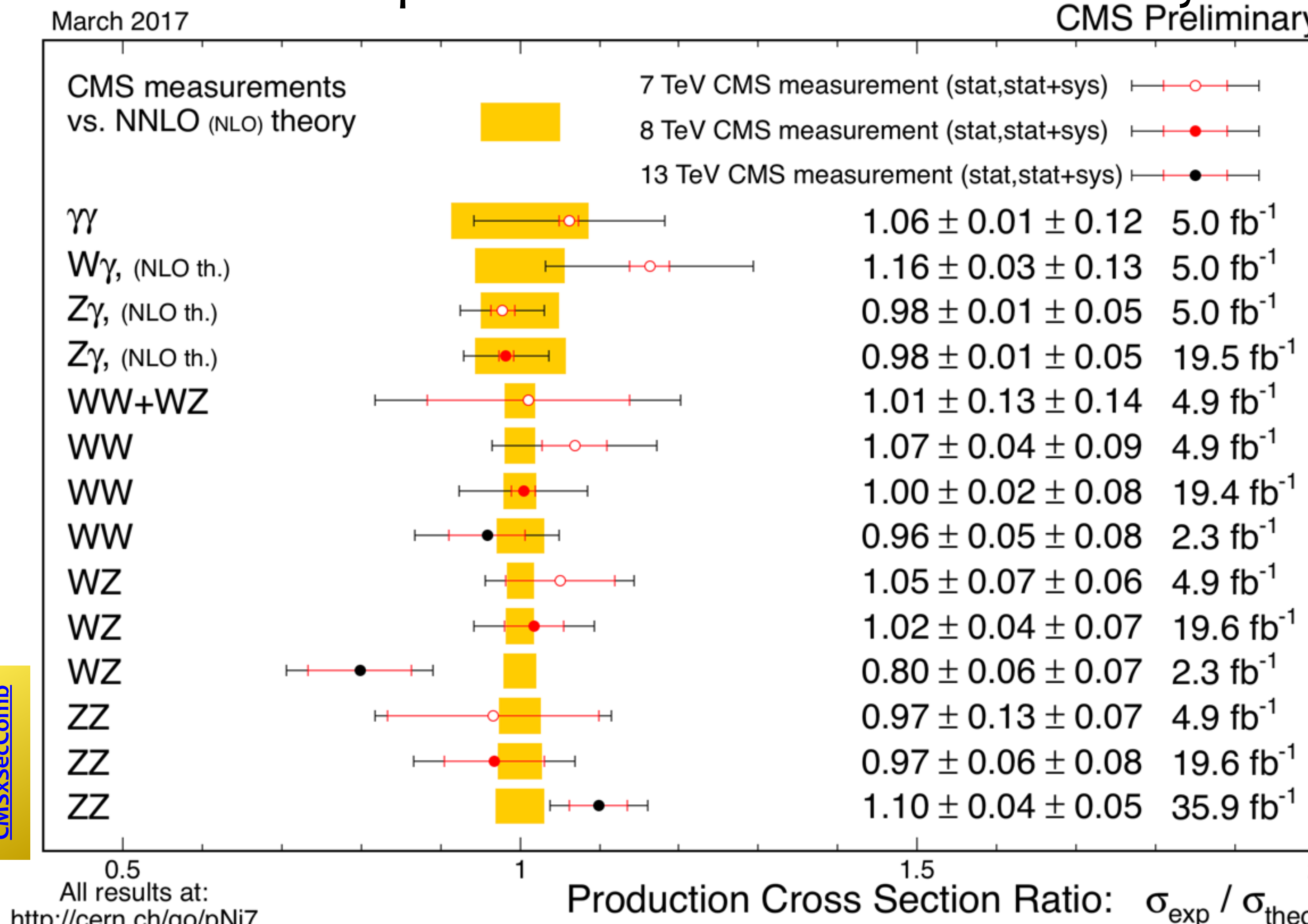




$$\sin^2\theta_{\rm eff}^{\rm lept} = 0.23101 \pm 0.00036({\rm stat}) \pm 0.00018({\rm syst}) \pm 0.00016({\rm theory}) \pm 0.00030({\rm pdf})$$

EWK boson measurements

- **Good agreement with SM to date**
- Precision will be improved with increased luminosity



CMSxSecComb

Production Xsec Ratio:exp/theo

EWK boson measurements

- **Good agreement with SM to date**
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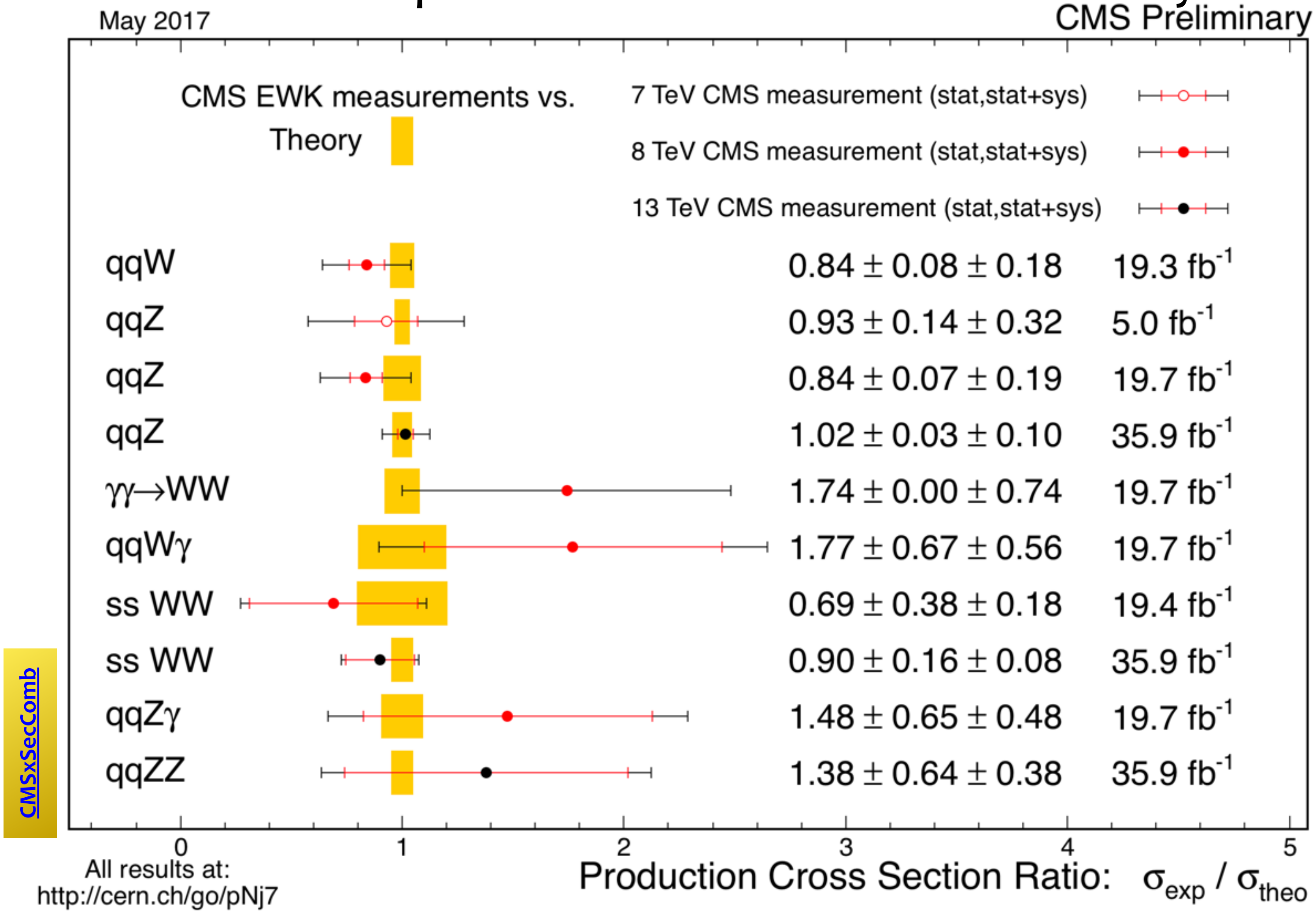
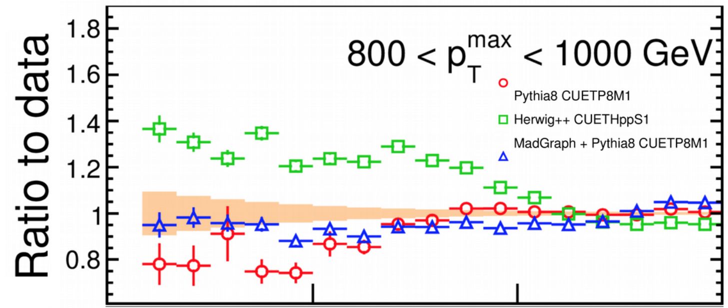


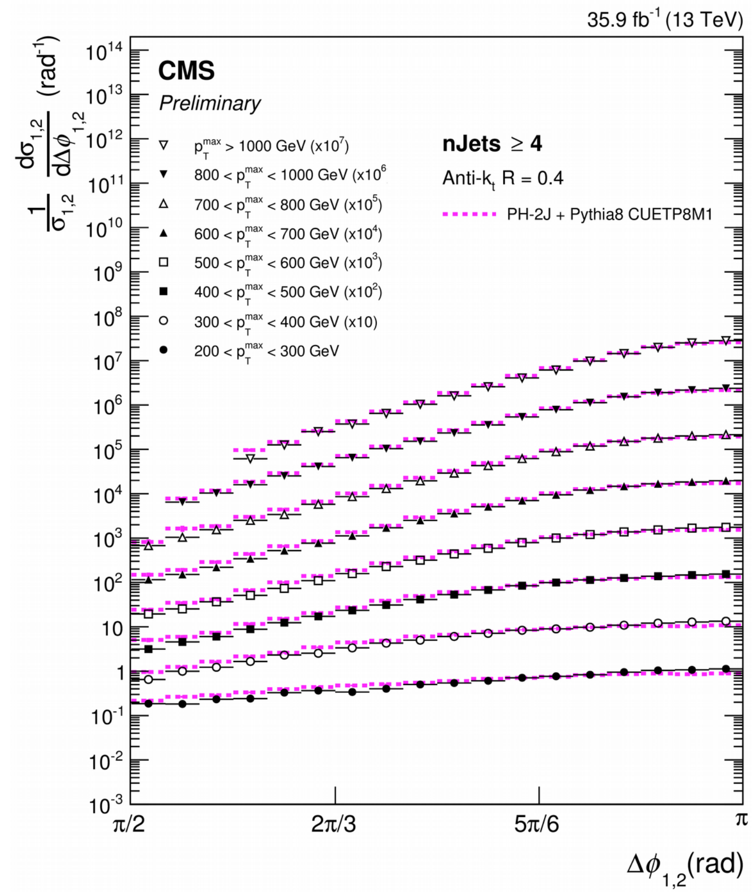
Production Xsec Ratio:exp/theo

QCD stress tests

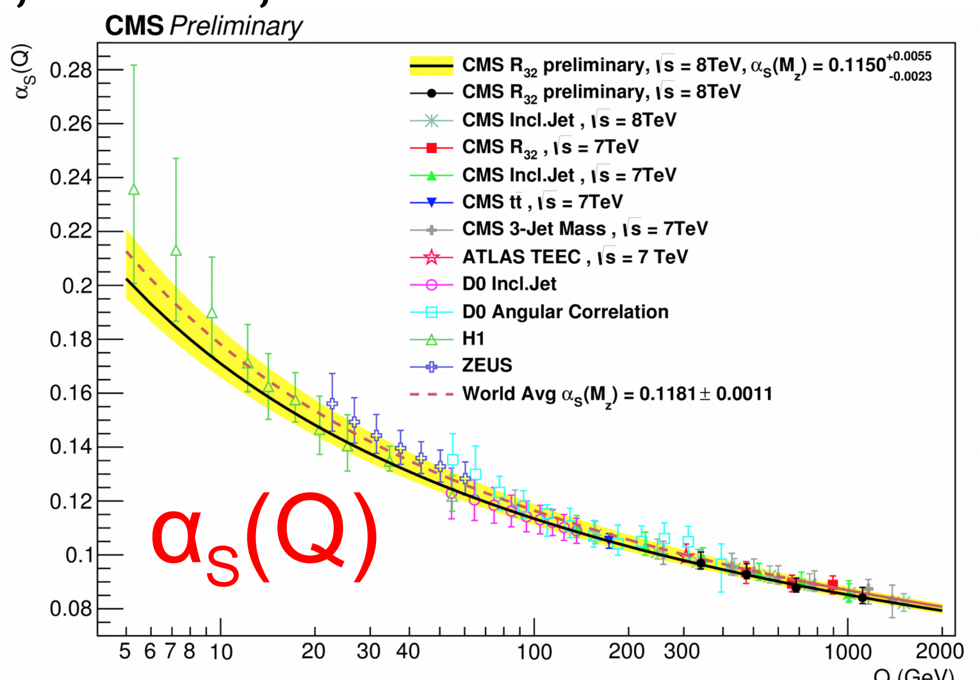
CMS-SMP-16-014

- Jet production at 13 TeV with full 2016
- Measurements of the normalized inclusive 2-jet, 3-jet, and 4-jet xSec. differential in $\Delta\phi_{1,2}$
  - Observations emphasize the need to improve predictions for multijet production
- $\alpha_s(M_Z)$ inferred from a fit of the ratio of the 3-jet over 2-jet event xSec





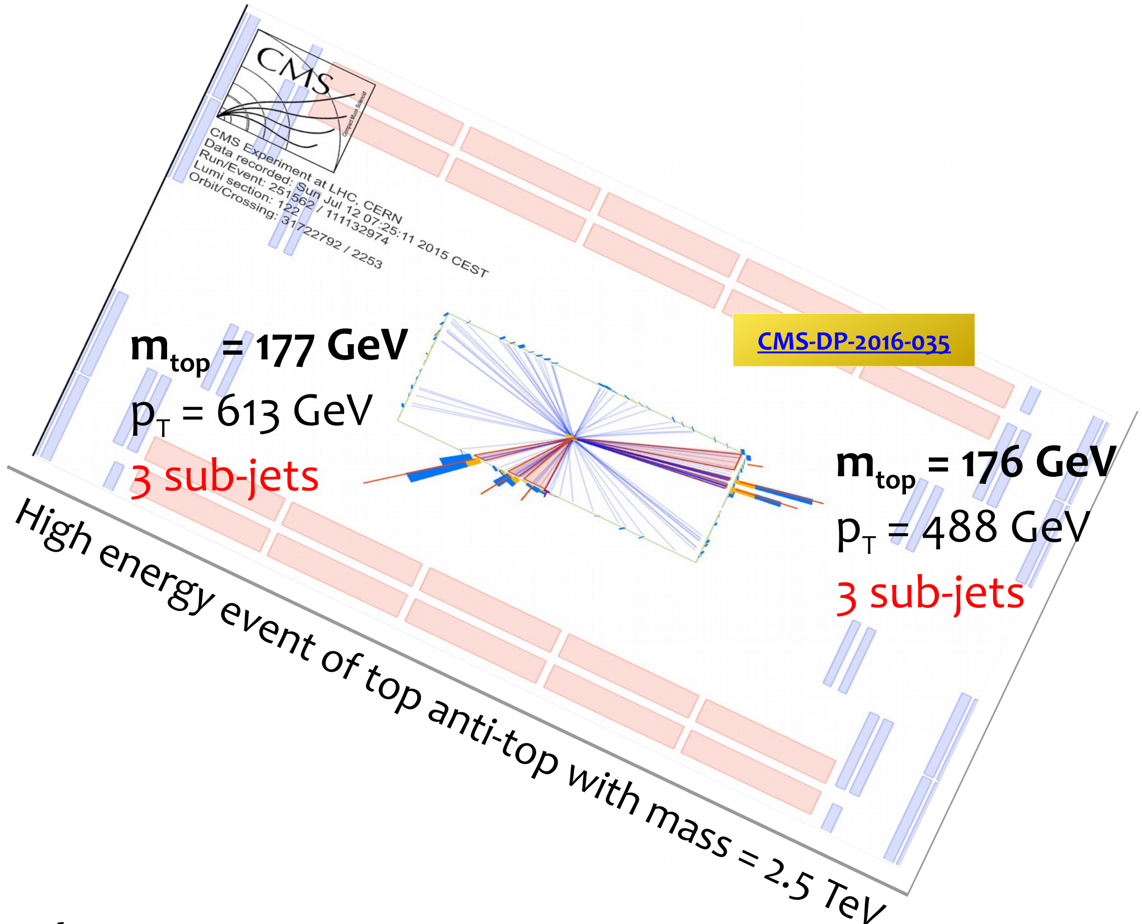
4-jet xSec. in $\Delta\phi_{1,2}$ for 8 p^T_{max} regions



$\alpha_s(M_Z)$= 0.1150 ± 0.0010 (all except scale) +0.0050−0.0000 (scale)

CMS-SMP-16-008

Top quark

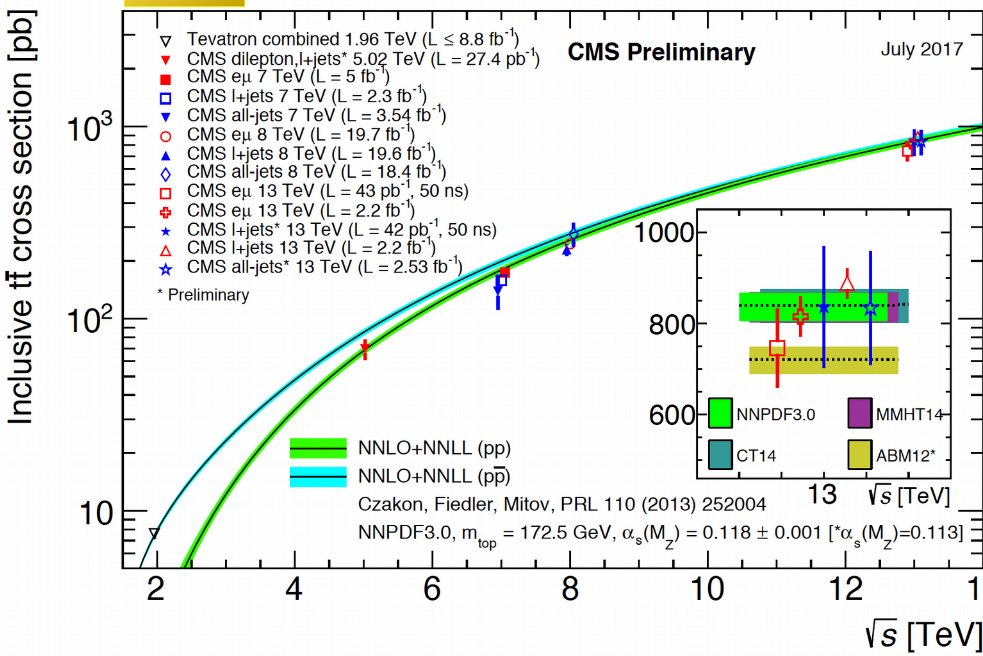


LHC is a top quark factory

- ~10 top pairs every second @ 10^{34} $cm^{-2}s^{-1}$ inst. luminosity
- Wide and detailed studies under top quark
- Testing SM and BMS physics

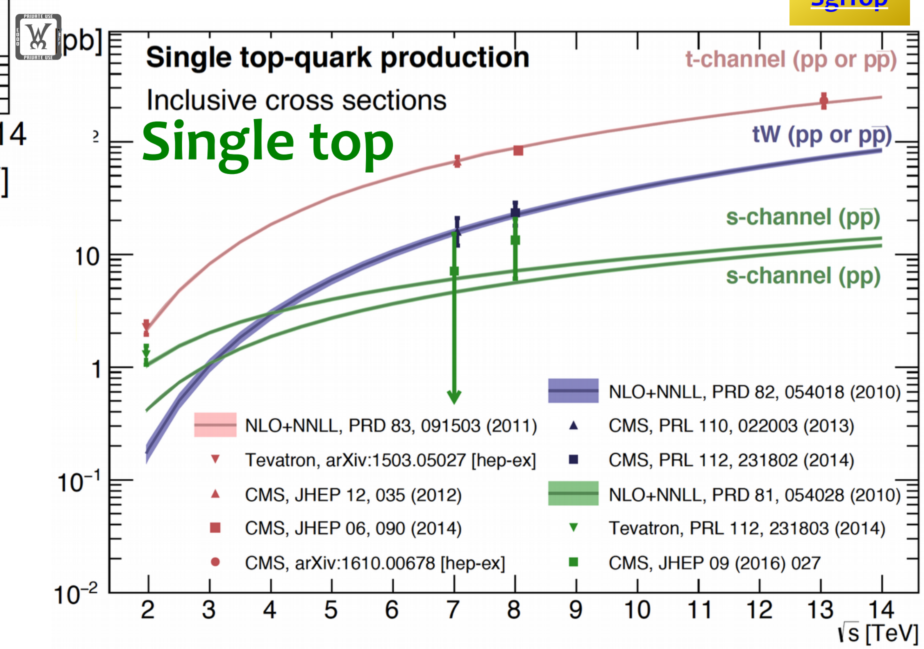
Top quark production

TtSig



√s	σ(tt) [pb]	L[fb⁻¹]
5 TeV	~70	0.03
7 TeV	~170	5
8 TeV	~250	19.7
13 TeV	~800	2.3

SglTop

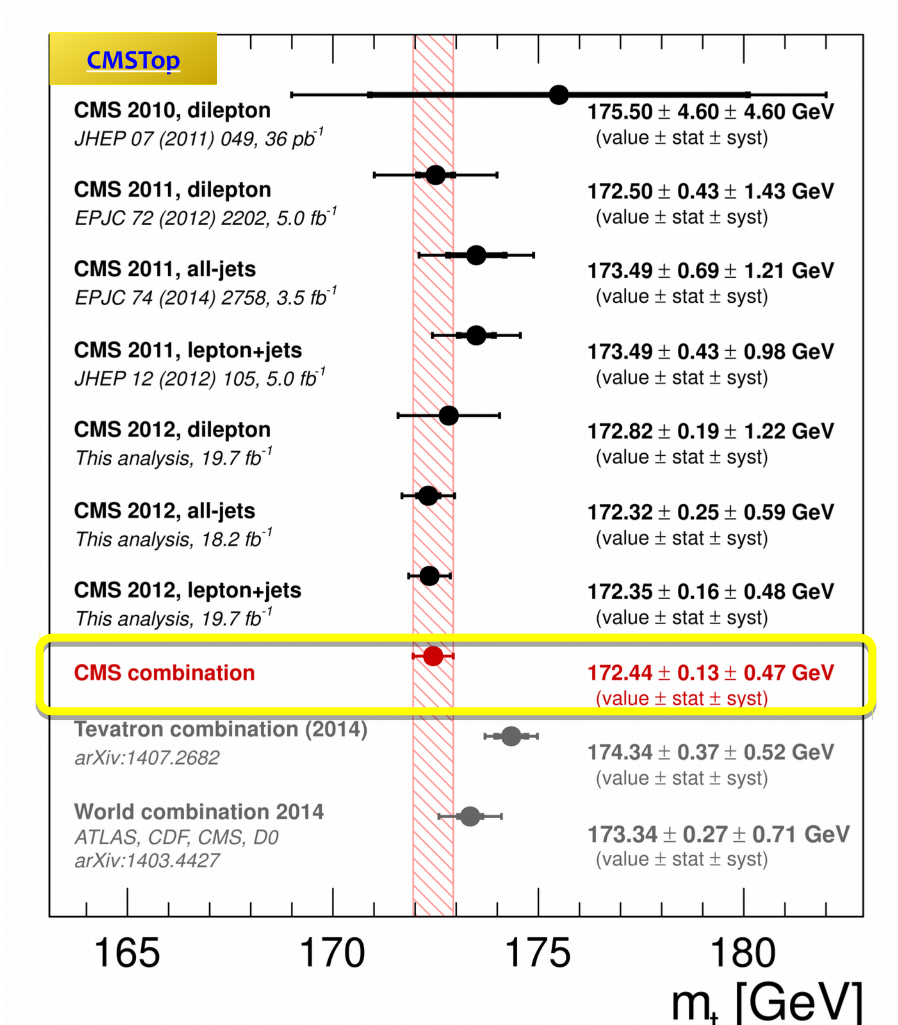


CMS-TOP-16-023

- New **xsec** (69.5 ± 8.4 pb) **for tt pair** prod. @ 5 TeV
  (special short run in 2016, L=27.4/pb)
- Evts: 1 muon and at least 4jets, 2b-tag

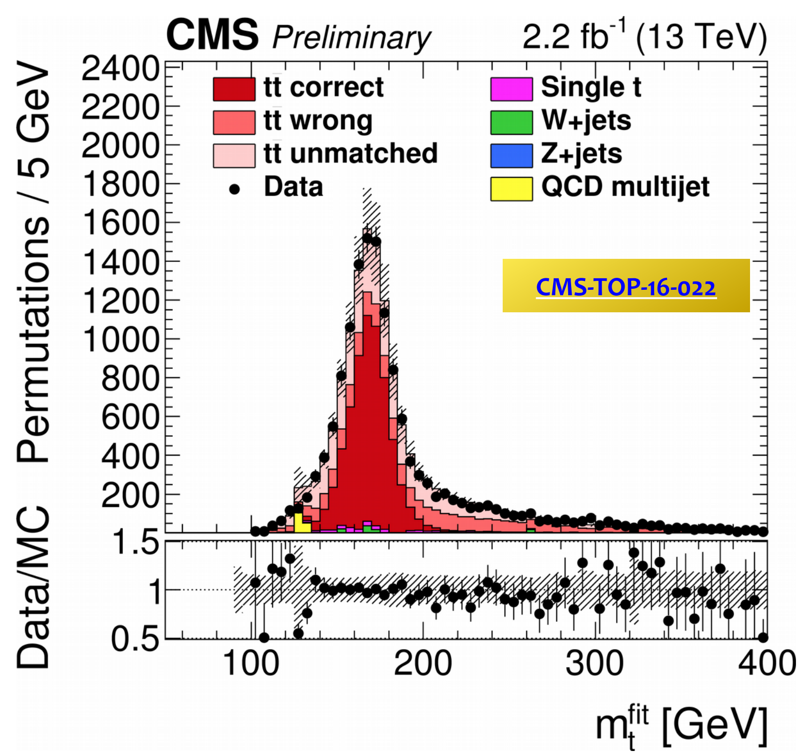
Top quark mass

- Great accuracy (~0.3%) in the CMS **top mass** measurement from Run 1



- First **top mass** measurement from **μ +jets** with 13TeV with only 2.2/fb

M_{top} = 172.62 ± 0.38± 0.70 GeV



Rare top processes

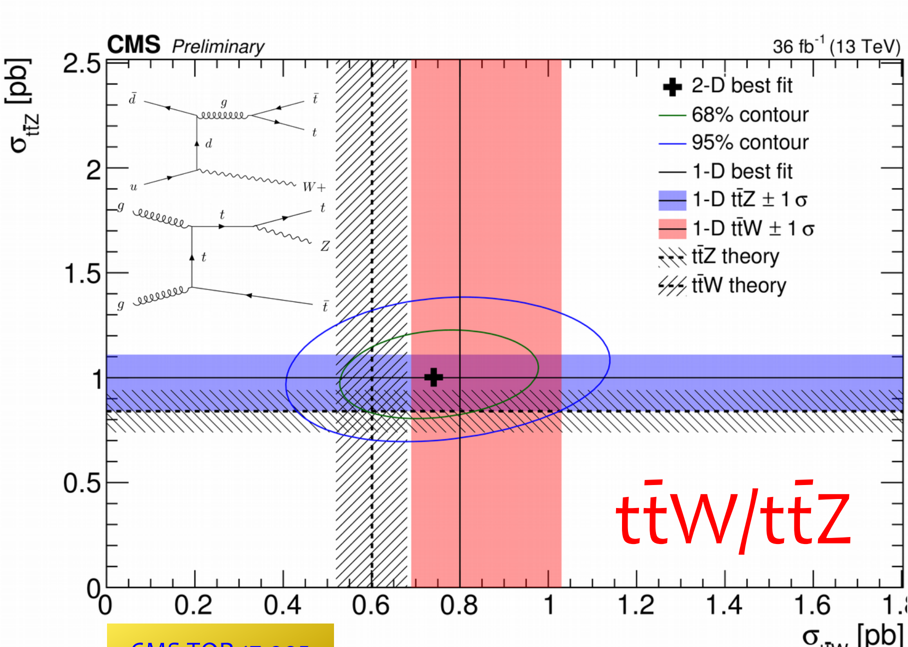
- **Top pair prod. with W/Z**
  Same-charge dilepton, 3- and 4-lepton final states where the jet and b-jet multiplicities are exploited to enhance the signal-to-bkg ratio
- Measured xSec. are in agreement with SM predictions

$\sigma(ttZ) = \mathbf{1.00}^{+0.09}_{-0.08}\,(\text{stat.})\,^{+0.12}_{-0.10}\,(\text{sys.})$ **pb**

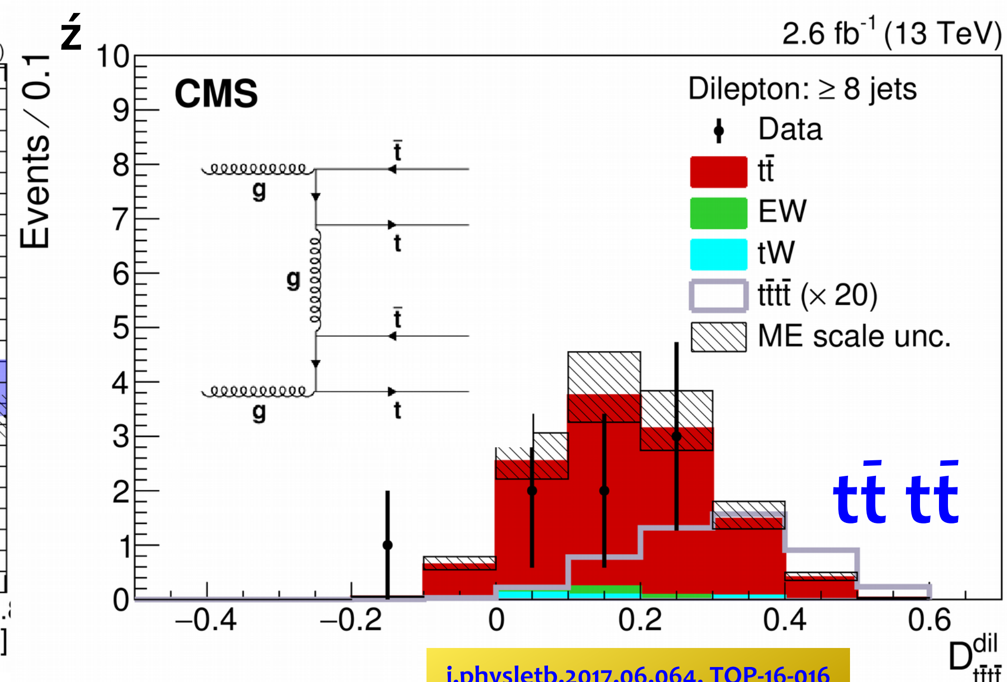
$\sigma(ttW) = \mathbf{0.80}^{+0.12}_{-0.11}\,(\text{stat.})\,^{+0.13}_{-0.12}\,(\text{sys.})$ **pb**

- **Four top production**
  Single-lepton +jets and the opposite-sign +jets channels
  Boosted decision trees to combine information on the global event and jet properties to distinguish between $t\bar{t}t\bar{t}$ and $t\bar{t}$ production
- Upper limit on xSec.
  combined with same-sign dilepton search

σ(tttt) < 69 fb @ 95% C.L. (7.4xSM)

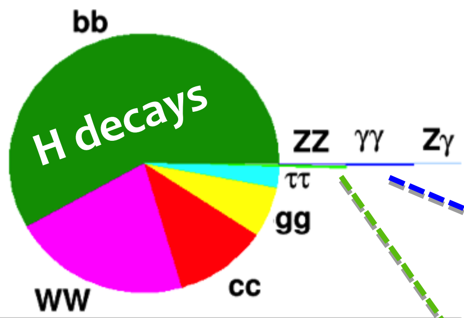


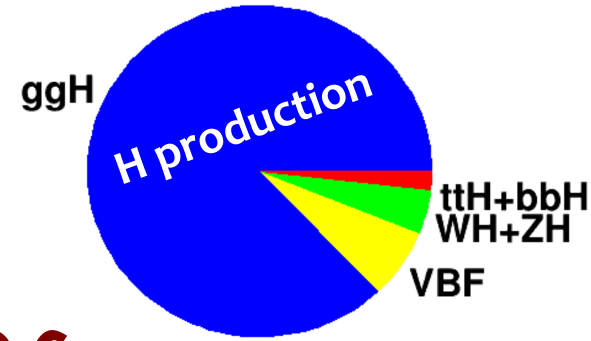
CMS-TOP-17-005



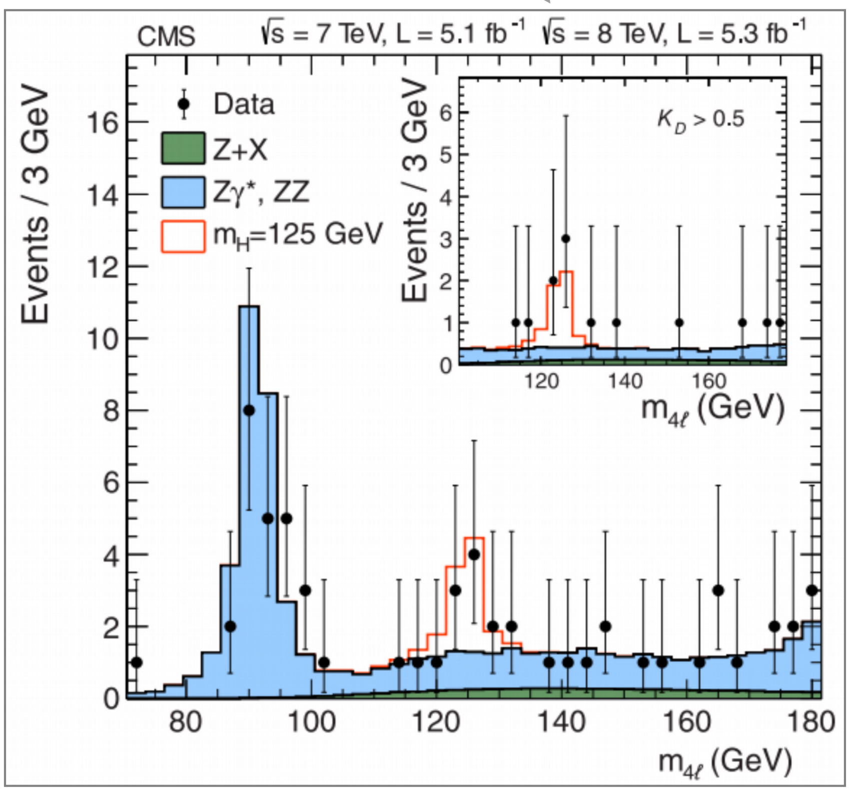
j.physletb.2017.06.064, TOP-16-016

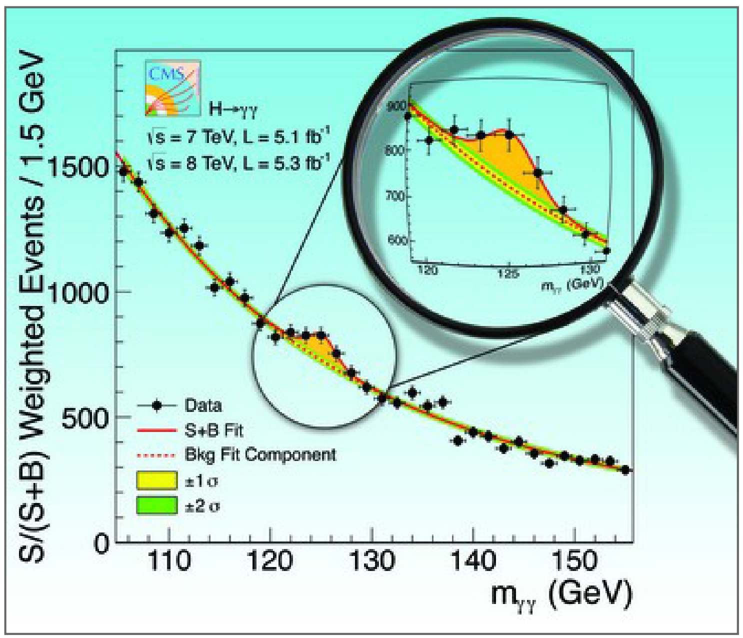
5^{th} anniversary of the Higgs boson





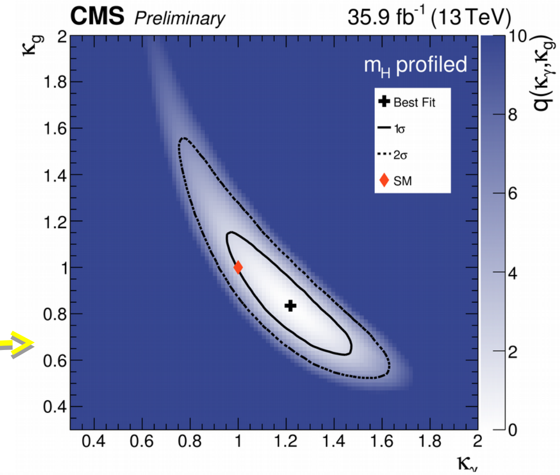
4^{th} July 2012

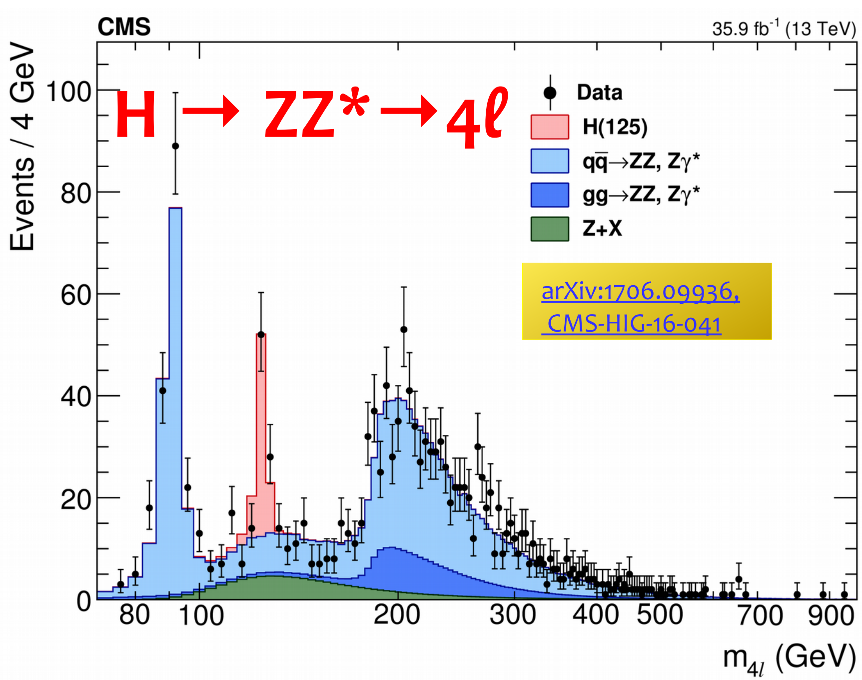


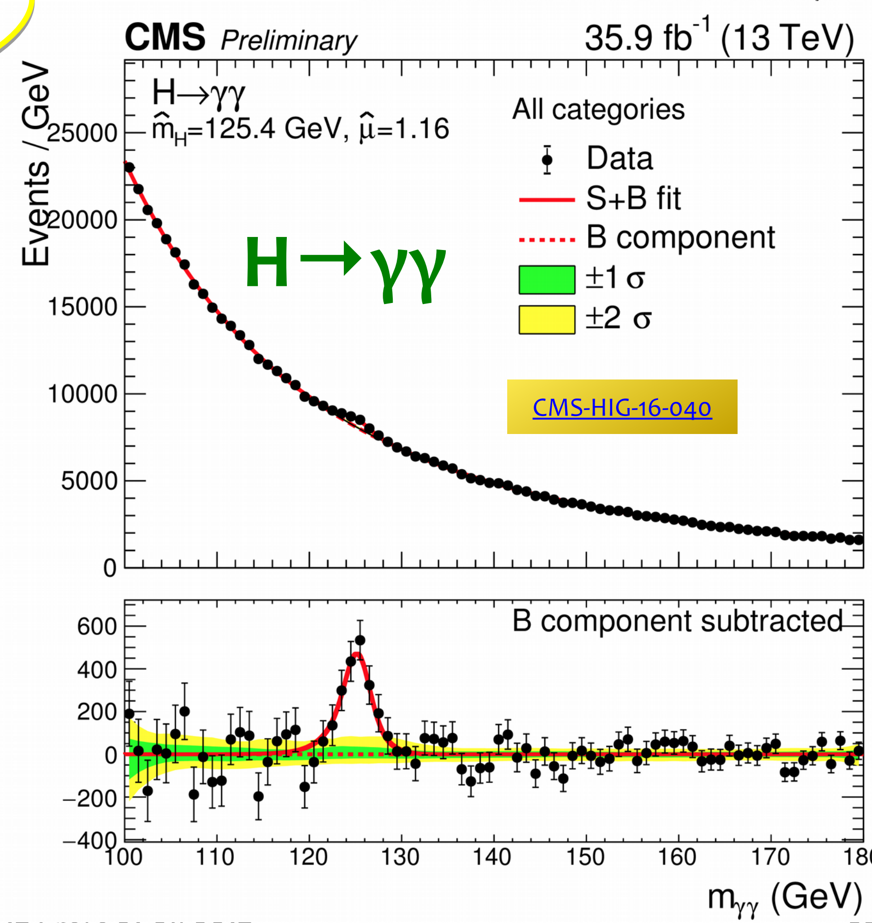


Higgs boson production

- New measurement at 13 TeV in $H \rightarrow ZZ^* \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$
- Discovery channels despite small BF of ~0.013% (4ℓ), ~0.23%($\gamma\gamma$)
- Consistent with SM







arXiv:1706.09936, CMS-HIG-16-041

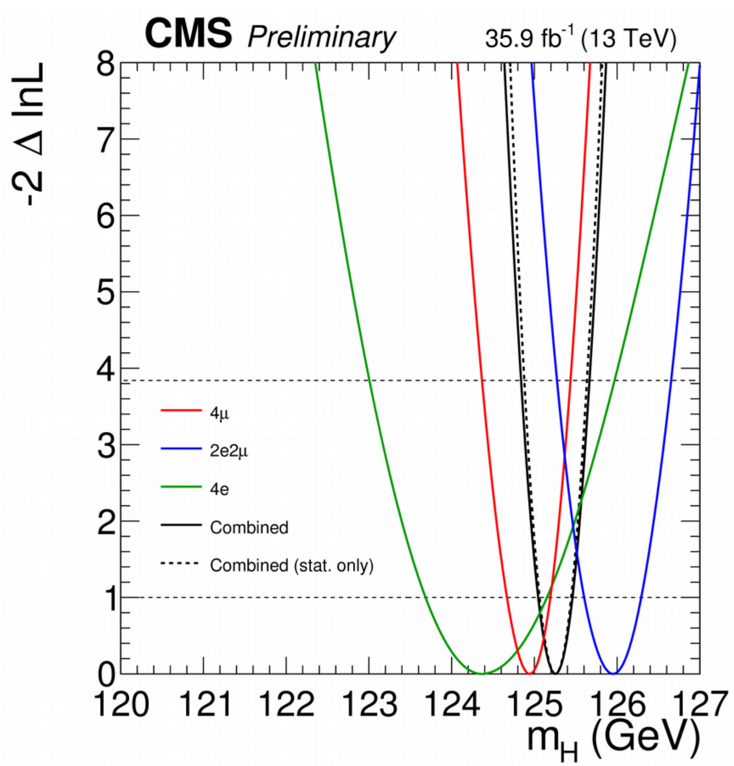
Higgs mass and xSec

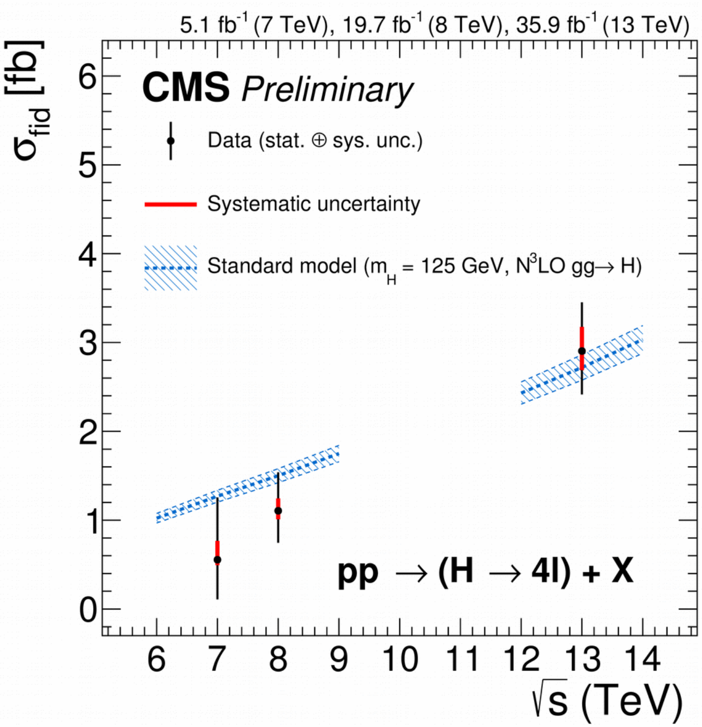
- Mass measurement in golden channel: **H → ZZ*→4ℓ** via ggH, VH, VBF

$$m_{\mathrm{H}} = 125.26 \pm 0.20(\mathrm{stat.}) \pm 0.08(\mathrm{sys.})\ \mathrm{GeV}$$

- As good as the world average of the ATLAS+CMS combination from Run 1

$$m_H = 125.09 \pm 0.21\ (\mathrm{stat.}) \pm 0.11\ (\mathrm{syst.})\ \mathrm{GeV}$$



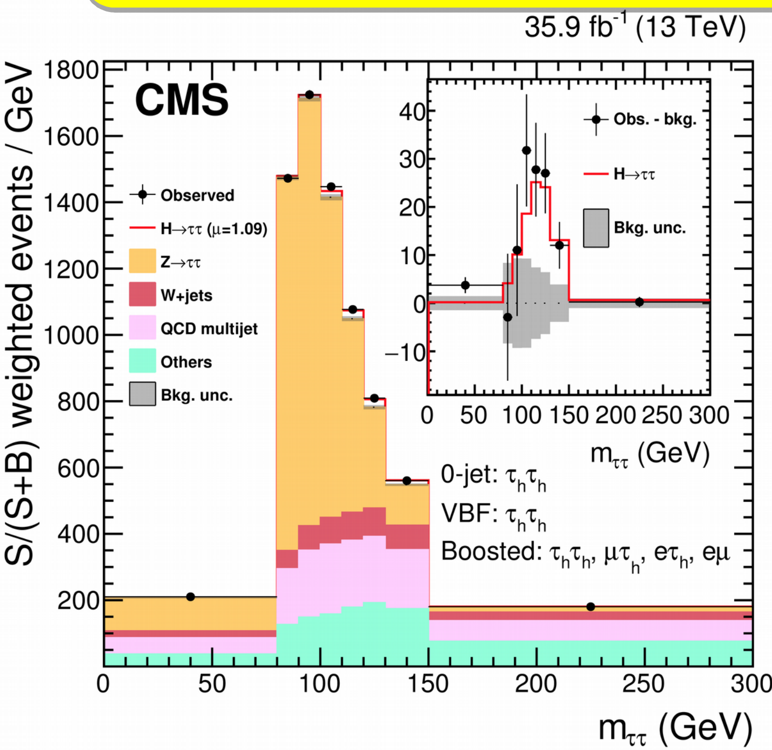


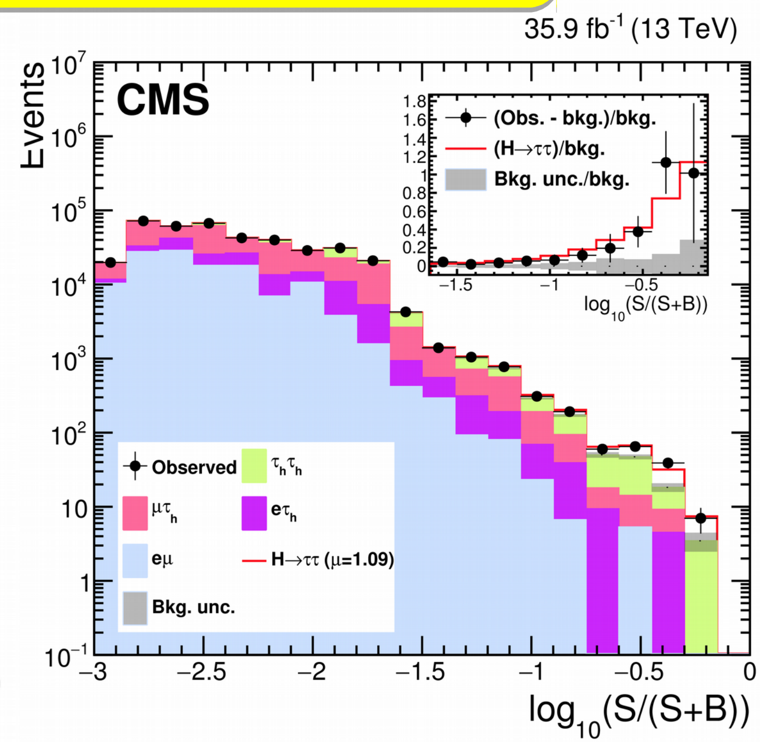
Fiducial cross sections as a function of √s

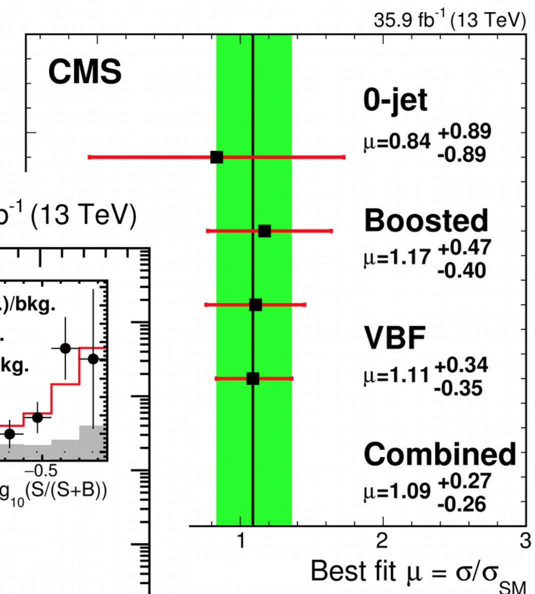
Higgs couples to τ lepton

arXiv:1708.00373, CMS-HIG-16-043

- **First observation** of **H→ττ** at CMS with the full 2016 dataset using **excellent CMS tau tagging**
  - Tau semi-hadronic & leptonic decay channels
    - 4 final states (**ττ, μτ, eτ,** eμ)
    - 3 categories (0-jet, VBF, Boosted)
- CMS observed **H→ττ** at **4.9 σ** wrt **4.7 σ** expected
- Run 1 + Run 2'16 result: **5.9 σ**







Best fit

$\mu = \sigma/\sigma_{SM}$

$$\mu = 1.09^{+0.27}_{-0.26}$$

Higgs Physics: H→bb

NEW
CMS-HIG-16-044

- Dominant H decay channel (58.1%), but with huge QCD bb background
- Presence of the vector boson (leptons, MET) **supresses highly QCD**

- **Sig:** 2b-tag jets + 2 lep (+1 leptMET), (+MET) extracted via a simultaneous fit of all control regions and signal regions
- **Bkg:** fitted in simultaneous fit for V+jets and ttbar

- Analysis **validated for Z→bb**
  - **5.0 σ observation**

- **For m_H = 125 GeV,**

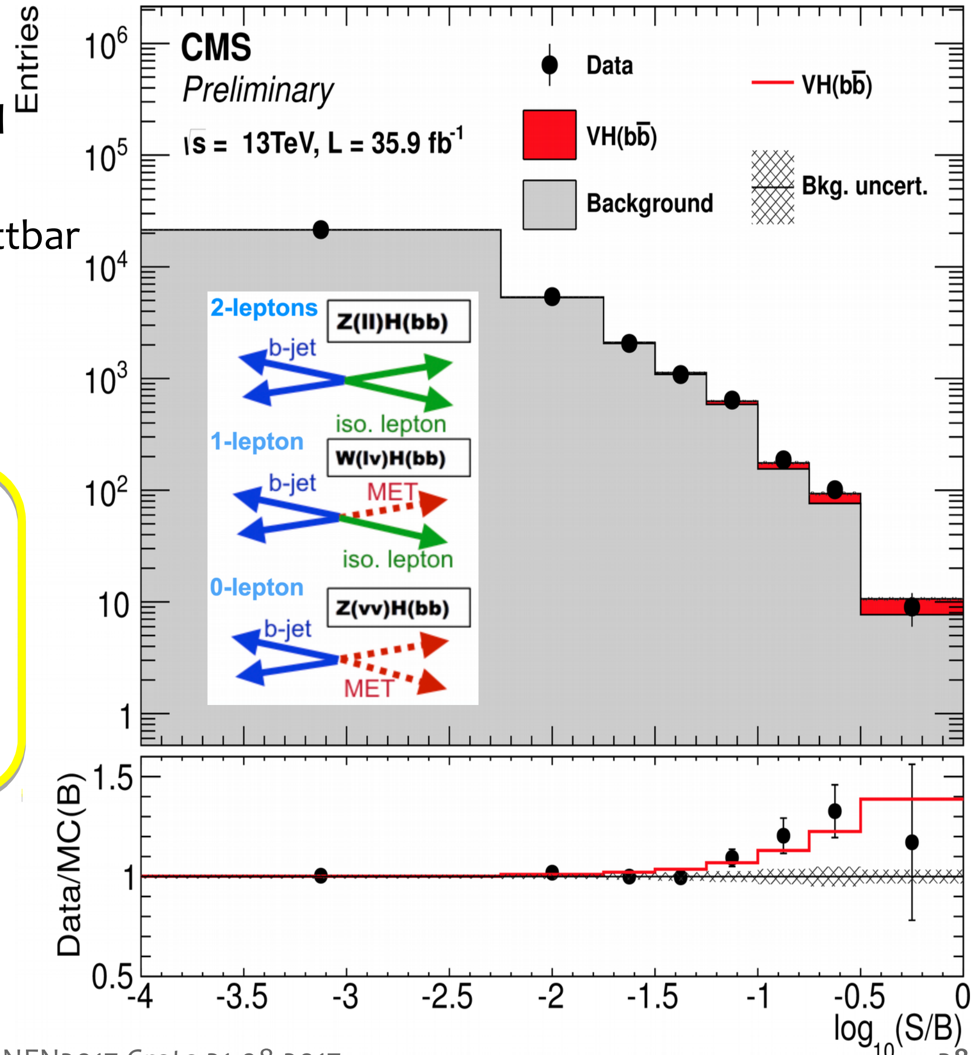
  Run 1&2 excess of **events observed** with local sig. of

  3.8 σ (**3.8 σ** SM exp.)

Strong evidence

- Signal strength

$$\mu = \sigma/\sigma_{SM} = 1.06^{+0.31}_{-0.29}$$



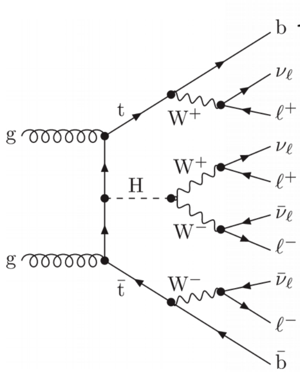
Higgs – top production

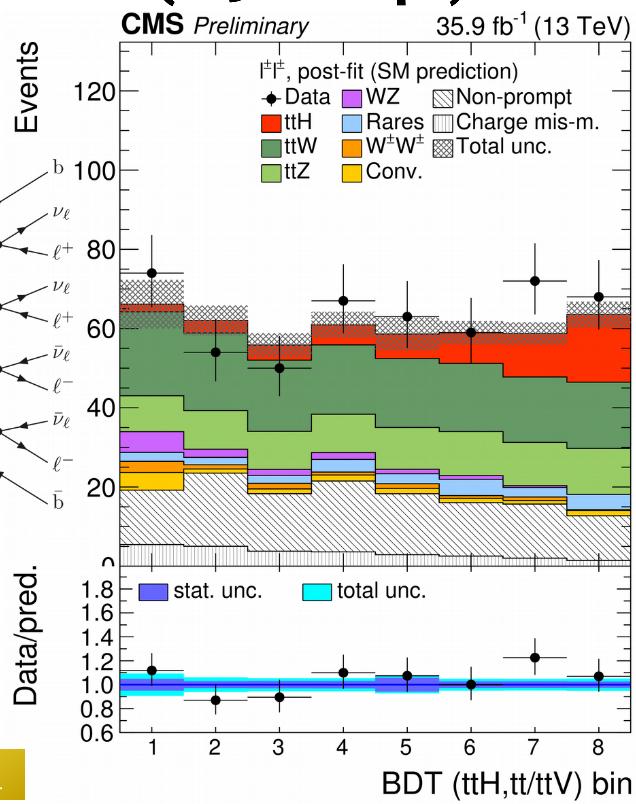
- Direct test of **H-t coupling** using ttH and tHq channels
  - H decaying to WW*, ZZ* or ττ
    - 2 same-sign leptons or at least 3 leptons , and b-tag jets
- **Evidence for ttH signal**

  3.3 σ obs. (2.5 σ exp.) comb.2015 & 2016

Upper limit on σ $^{tH+ttH}$ x BR

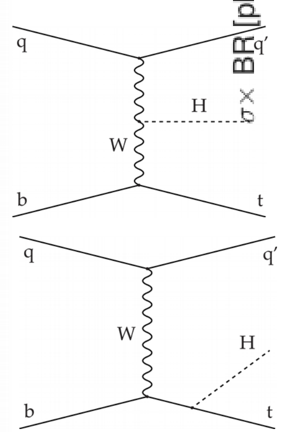
0.64 pb obs. (0.32 exp.)

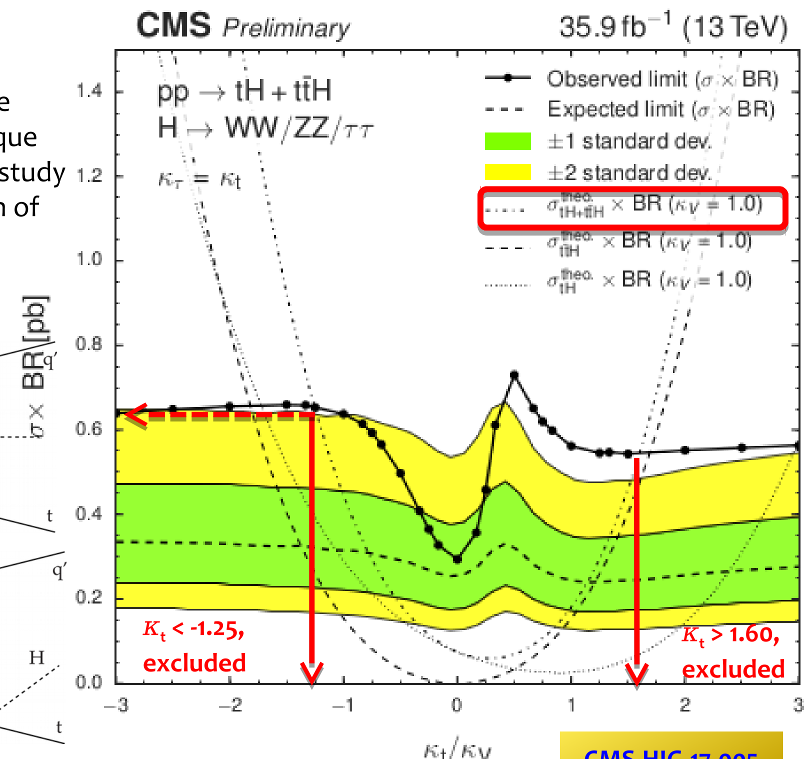




CMS-HIG-17-004

Single top in the t-channel – unique opportunity to study the relative sign of the coupling



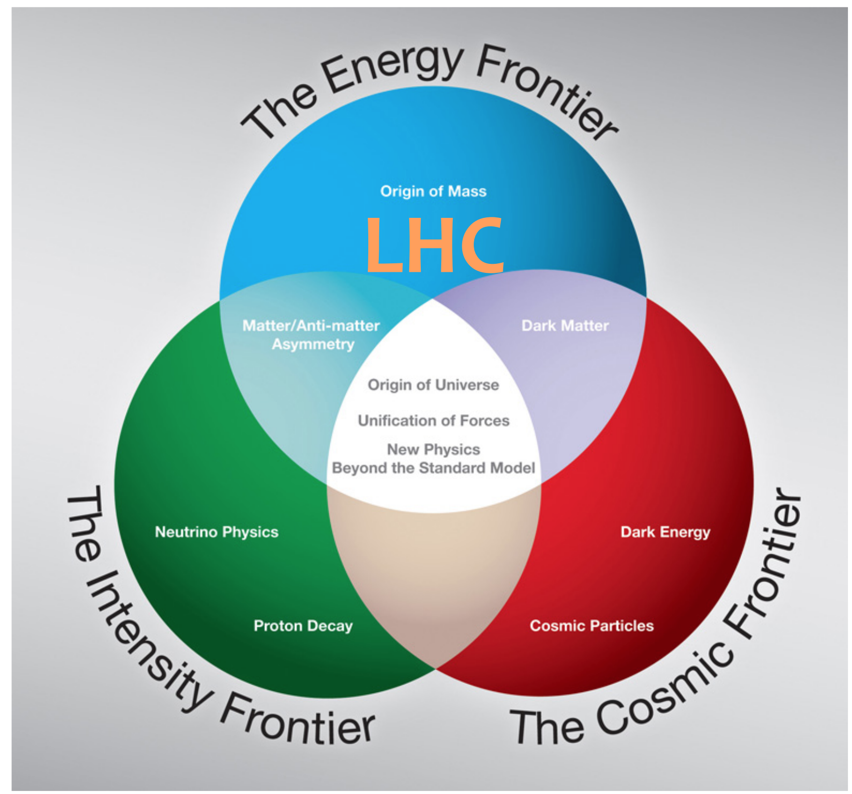


CMS-HIG-17-005

Searches

LHC is a unique place to search for **new particles**

- **directly** and
- **indirectly**
  – precise SM measurements

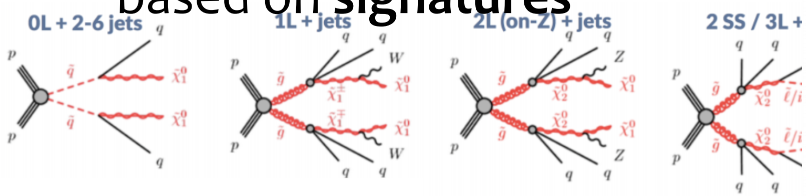


Strong SUSY

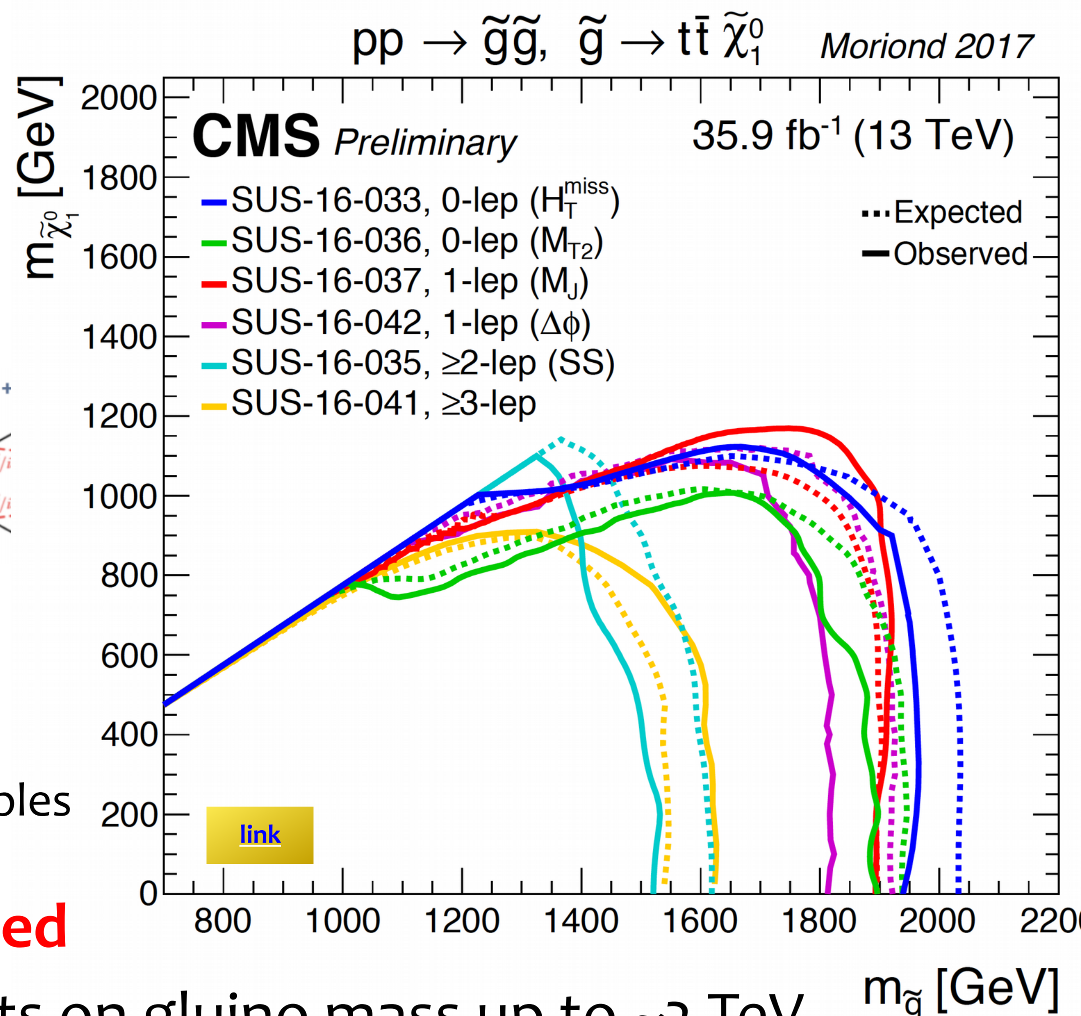
- Gluino or squark (gg,qq,gq) production
- **Sig.:** Jets+MET

  $+N_{jet} + N_{b\text{-}tag\ jet}$

- Experimental search based on **signatures**



- and **kinematical variable** sensitive to SUSY
- Multiple signal regions and searches in bins of different variables

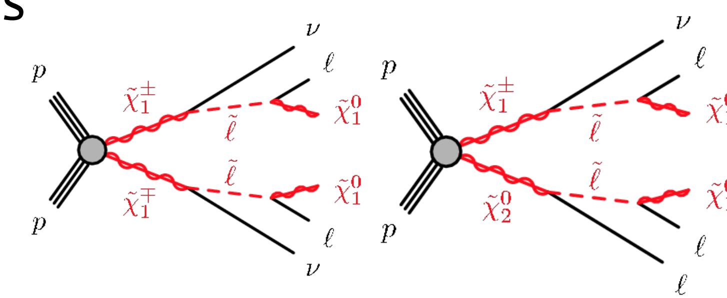


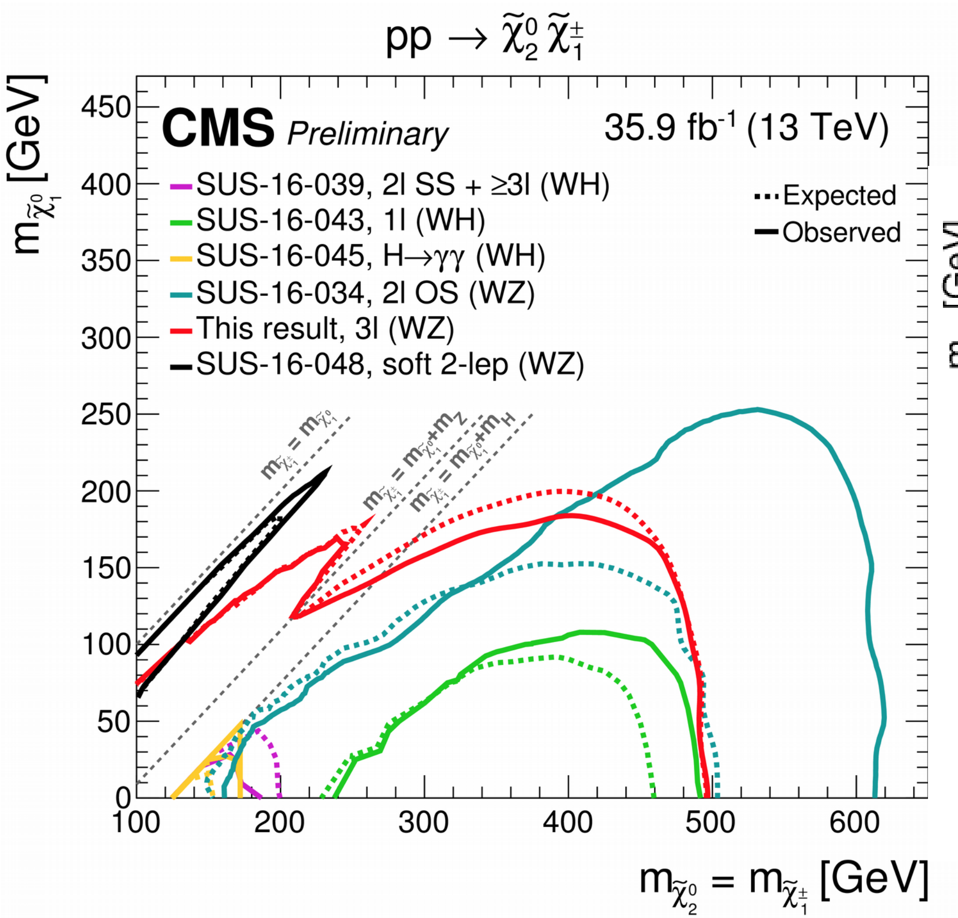
- **No SUSY particles detected**

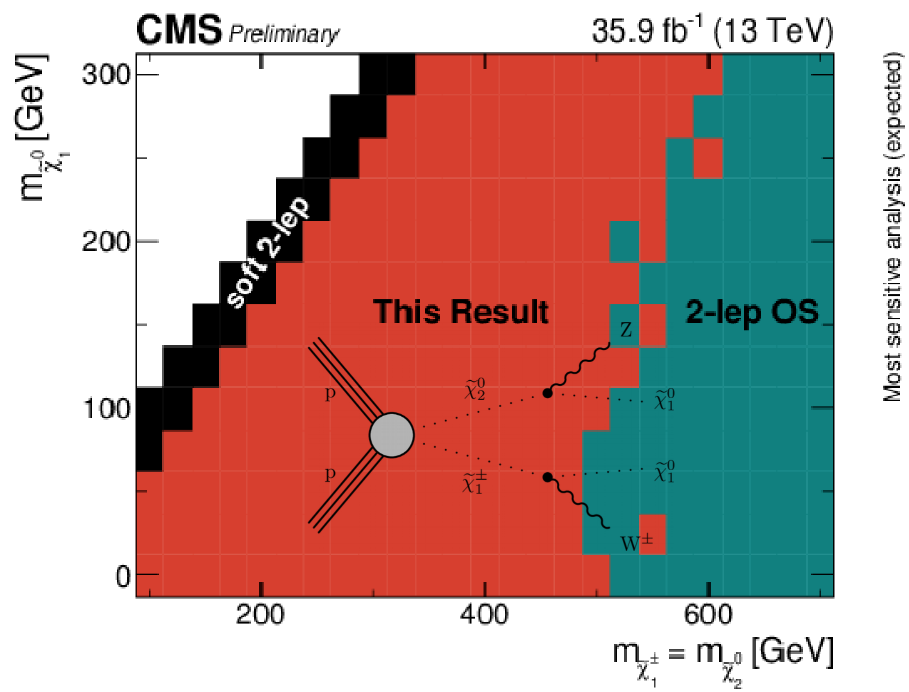
Run 2'16 at 13 TeV: Limits on gluino mass up to ~2 TeV

Electroweak SUSY

- Electroweak SUSY production and decays of **chargino** and **neutralino**
- Statistical combination of several searches
  - Improvement of 40 GeV on the limit mass
- Optimized **analysis with 2- and 3-leptons**



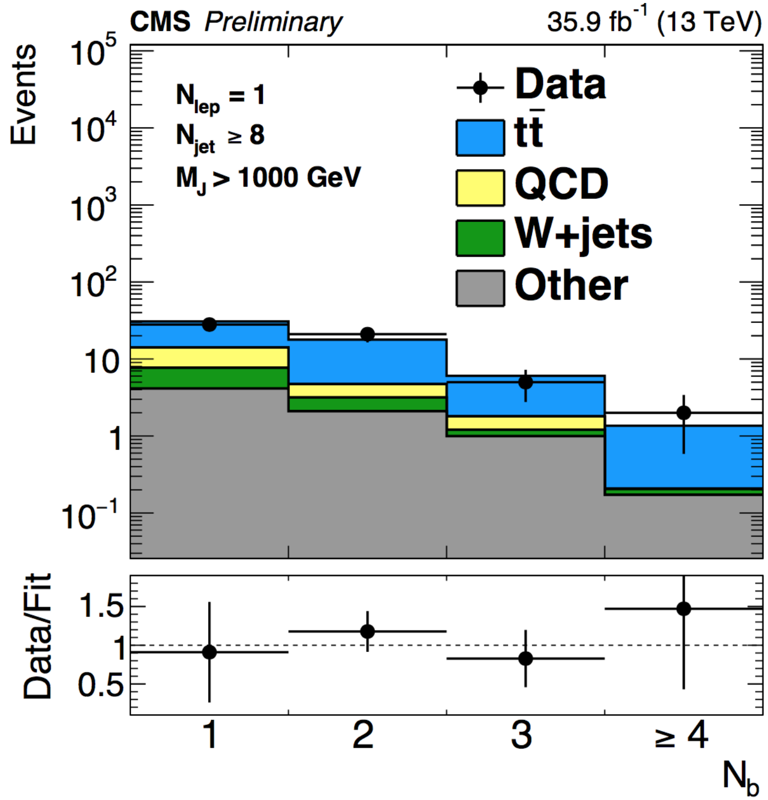


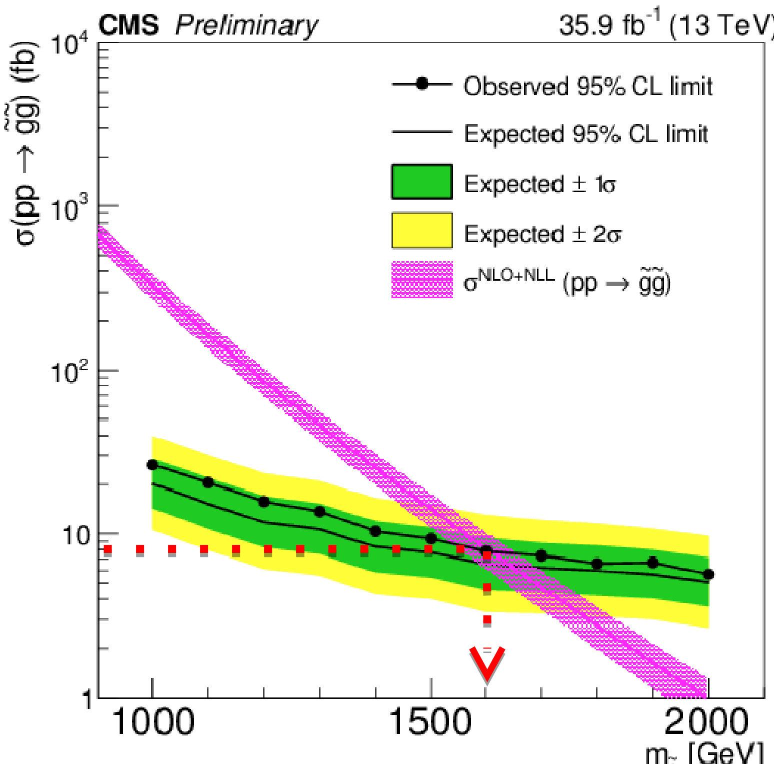


SUSY R-parity violation

NEW CMS-SUS-16-040

- R-parity can be not conserved!
- Minimal flavour violation, λ_{tbs}, $\tilde{g} \rightarrow \tilde{t}\, t \rightarrow t\, b\, s$
- **Signature:** single lepton, large jet multiplicity, and large q-quark jet multiplicity, NO requirement on MET
- Signal extraction through shape fit to N_b in bins of N_{jet} and M_J



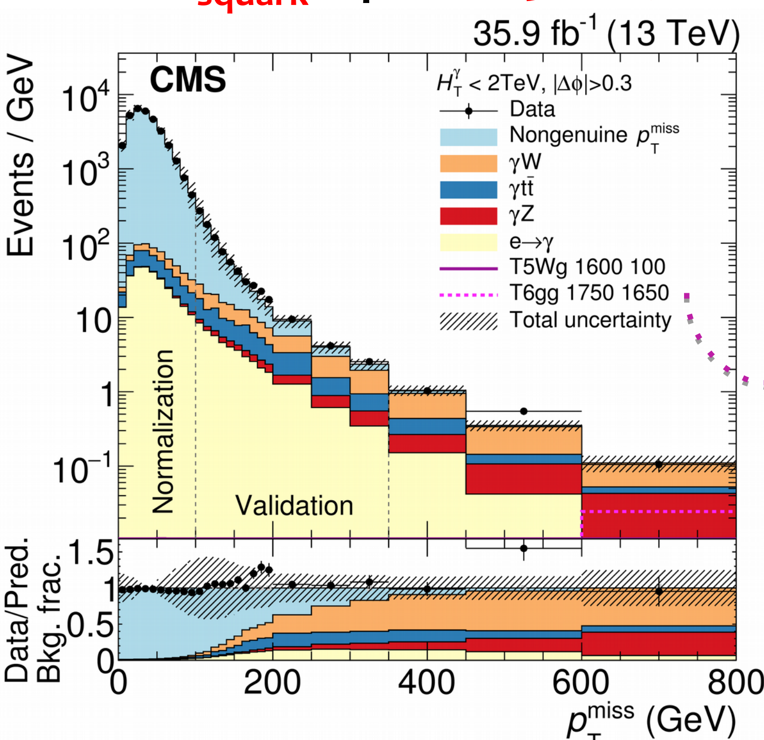


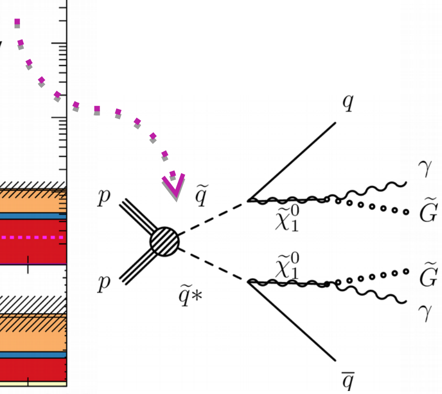
Gluino mass > 1610 GeV (95% C.L.)

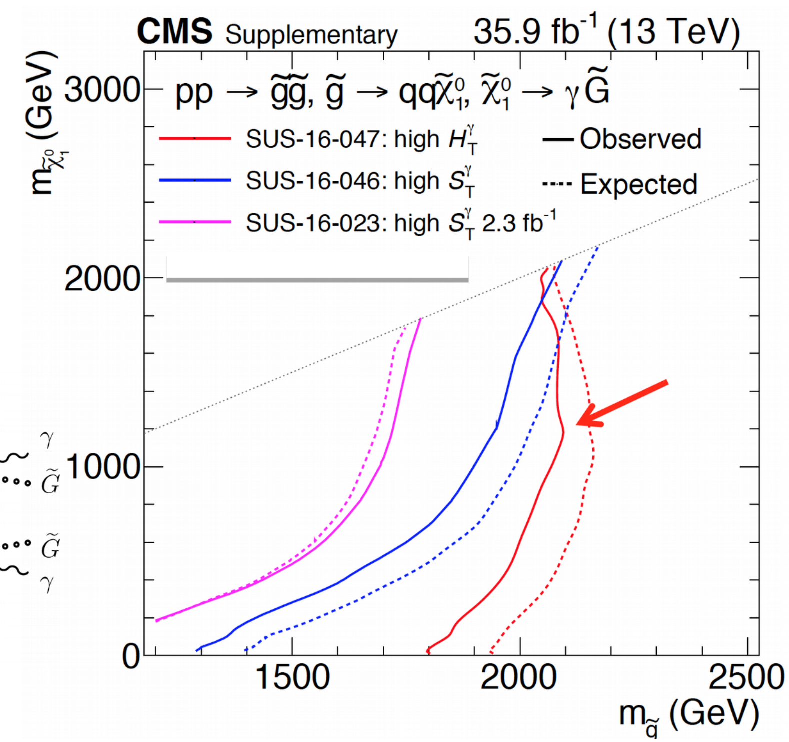
Gauge Mediated SUSY

arXiv:1707.06193, CMS-SUS-16-047

- Search for BSM with at least 1 photon, large MET, and large H_T
- **Sig:** strongly produced GMSB with N1→ γ G
- **New limits** depending $m_{neutralino}$ & BR:
  - m_{gluino} up to **1.5-2.0 TeV**
  - m_{squark} up to **1.3-1.65 TeV**
- **Complementary searches:**
  - γ V, γγ, γ+lepton, multi-lepton
  - Provide weaker limits



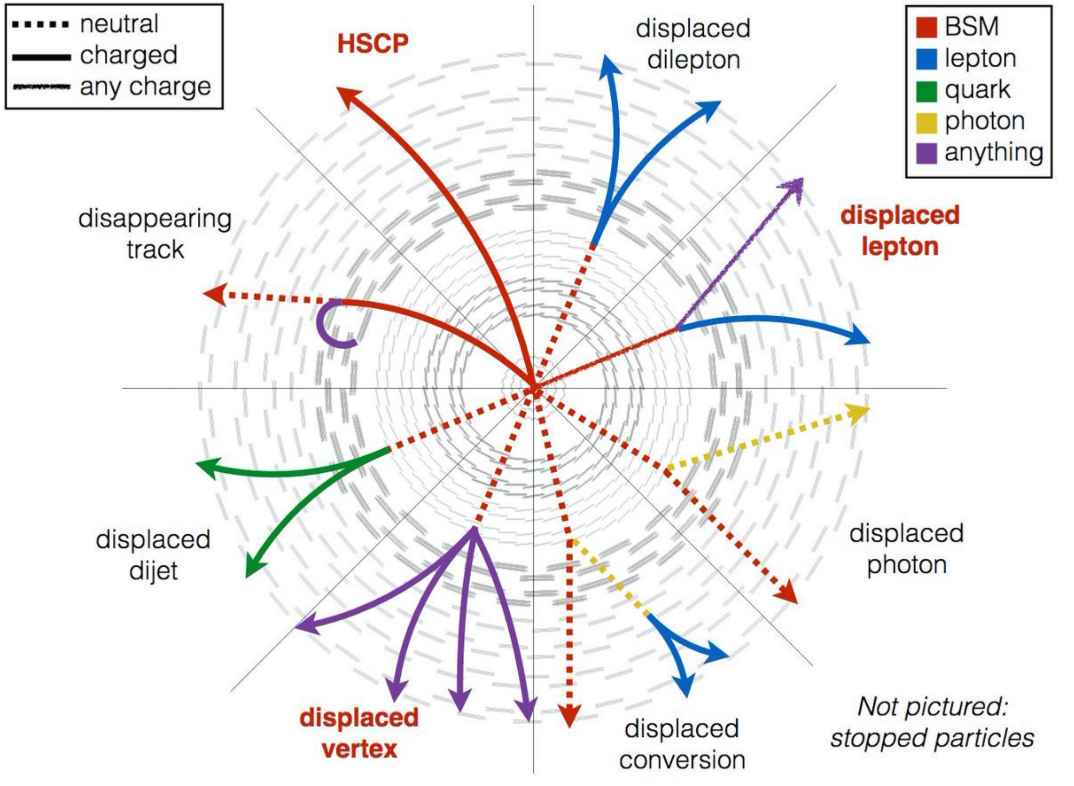




Long-lived particles

LLPs are foreseen by many BSM models

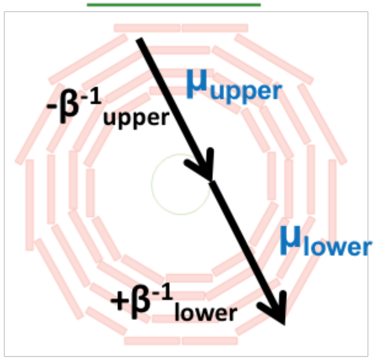
- Small coupling, small mass splitting, hidden sector
- **Signature depends on lifetime**



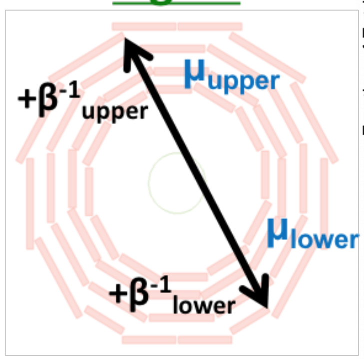
LLP: stopped particles

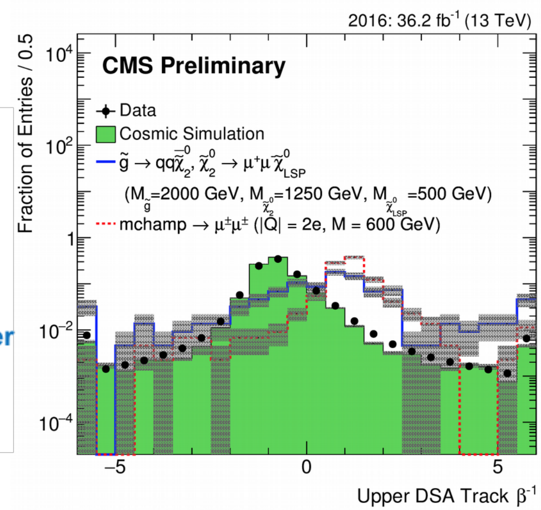
- **LLP** (gluino or |Q|=2e) is **stopped inside the detector** and **decay to muons** from rest after unknown time (sensitivity to lifetimes between 0.1 μs and 10^6 s)
- Events recorded **out-of-time with collisions** with the custom trigger

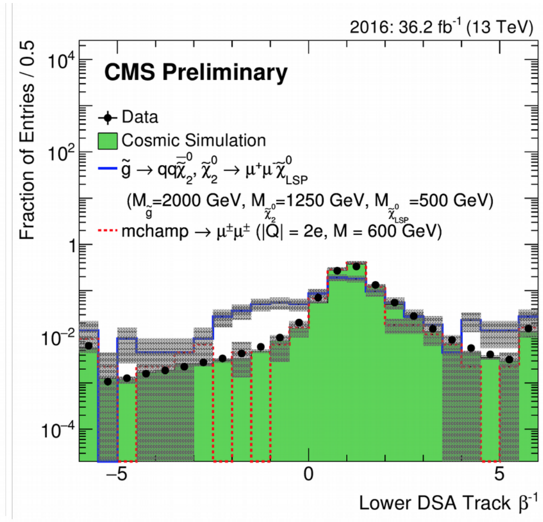
Cosmics



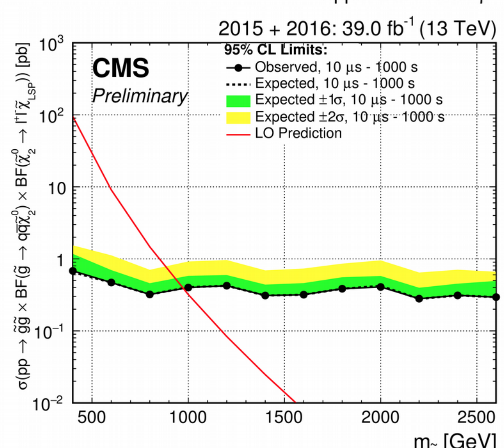
Signal

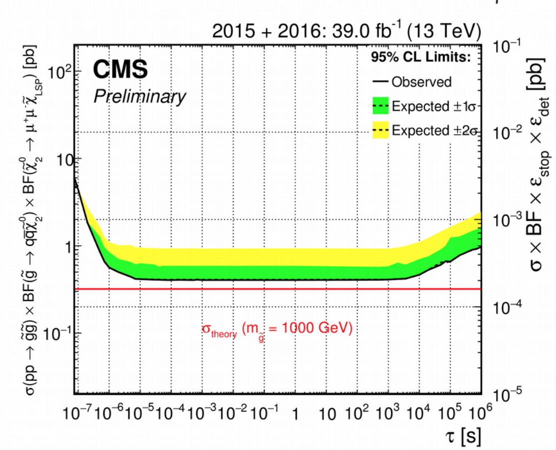






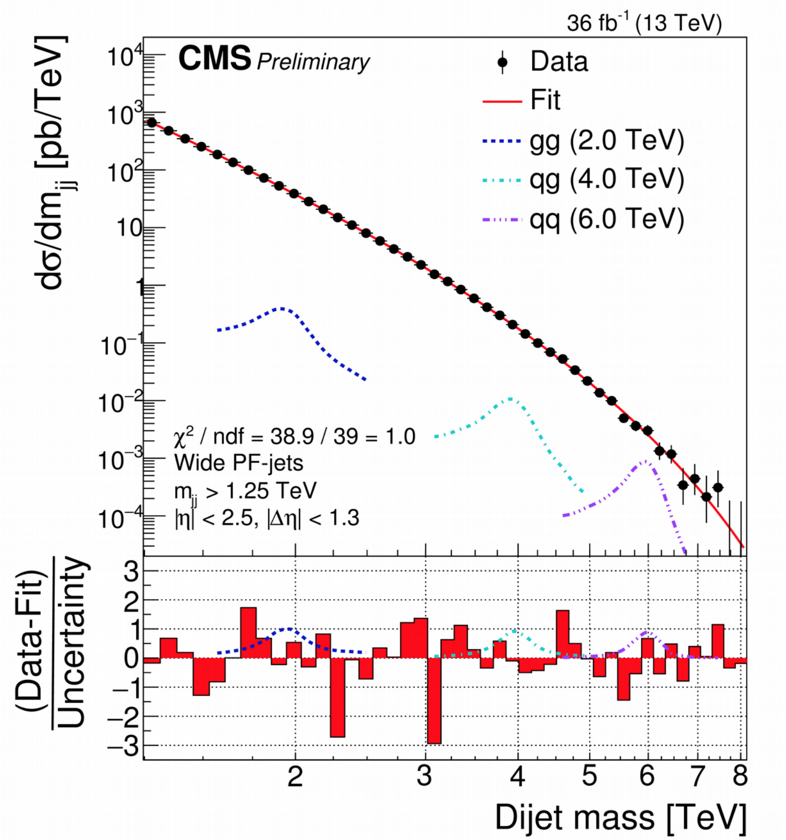
- **No events** observed
- 13 orders of magnitude of the lifetime tested
- Excluded gluinos with mass between 400 and 970 GeV, assuming 100% BF to muons



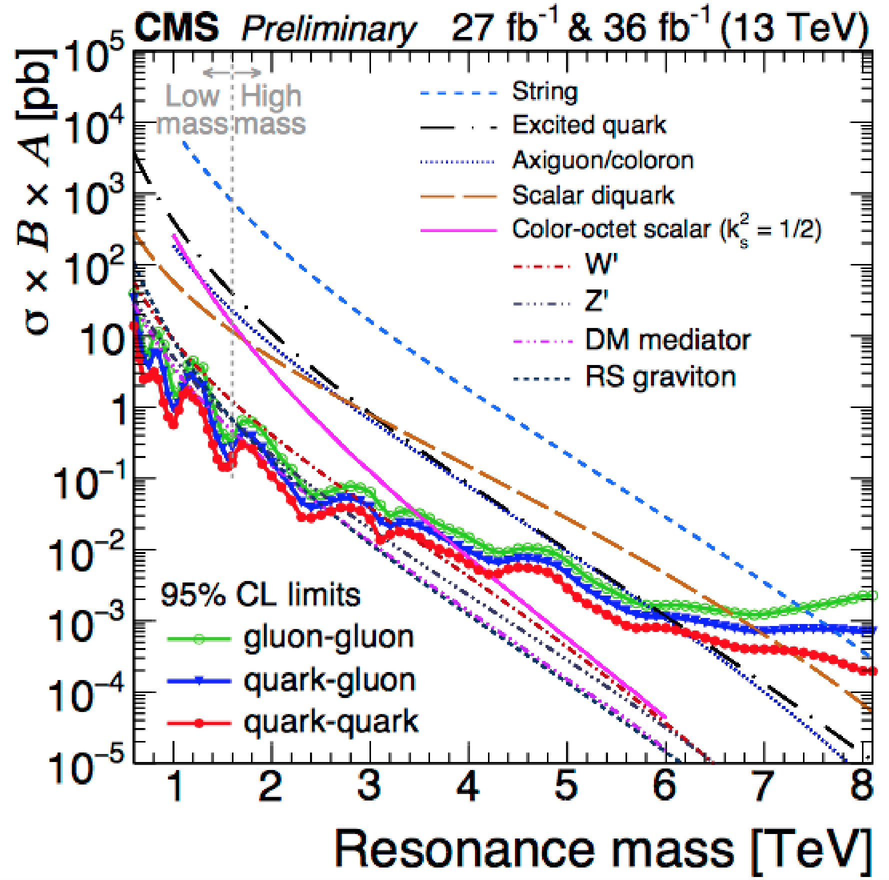


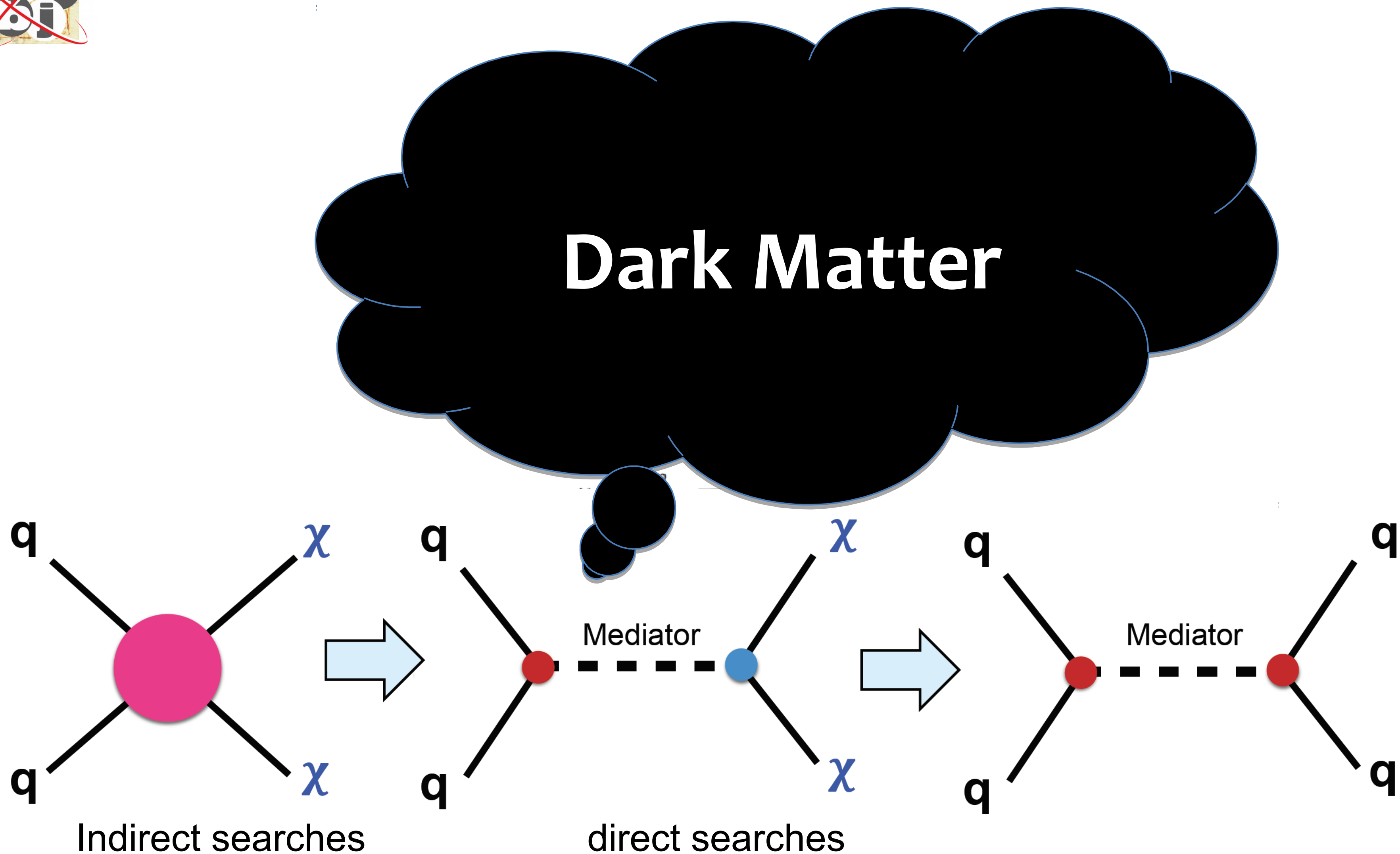
Heavy resonance searches

- Many BSM models predict narrow **di-X resonances**
  - X – many object in the final state analysed
- Di-jets (from Axigluons, colorons, W'/Z' bosons, color octet scalars, string resonances, RS, etc)



Generic limit on di-jet resonances, up to 7.7 TeV



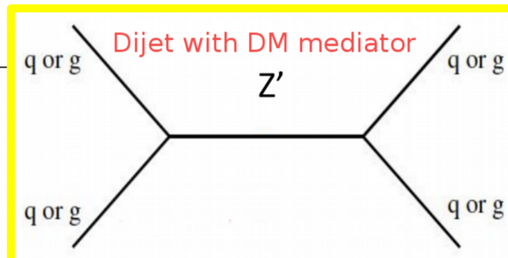


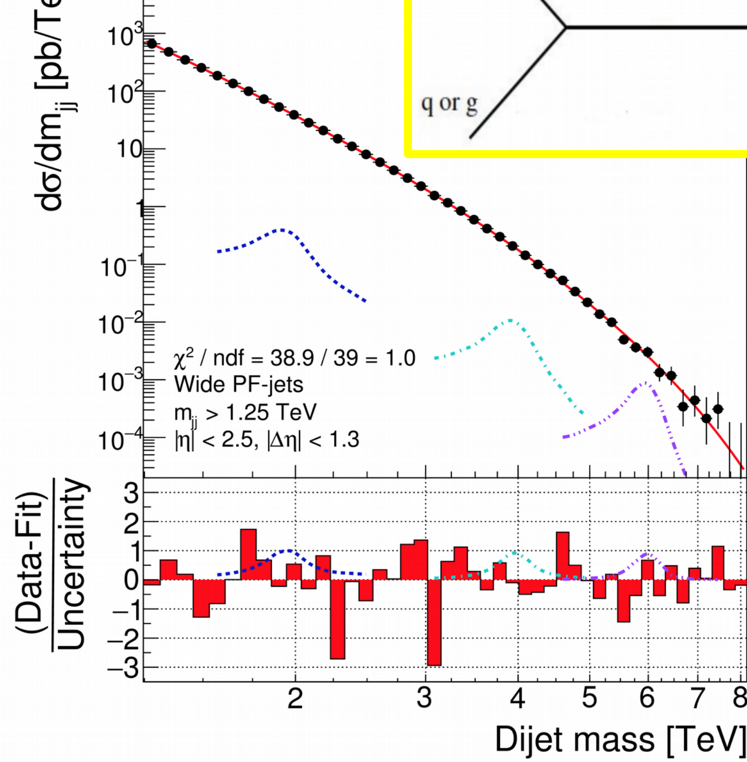
Vector and **scalar** interactions → **spin-independent (SI)** DM-nucleon interactions
Axial-vector interactions → **spin-dependent (SD)** DM-nucleon interactions

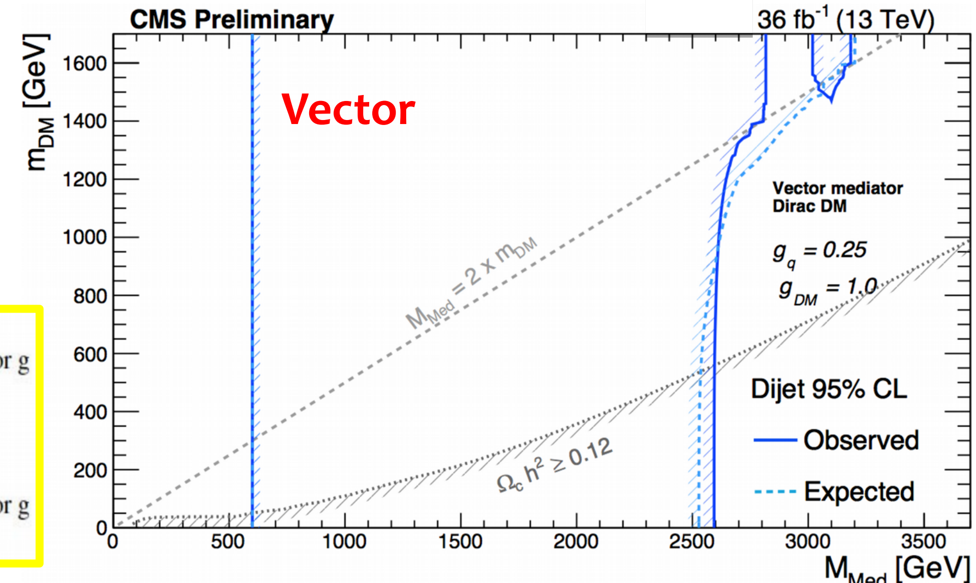
Dijet searches

CMS-EXO-16-056

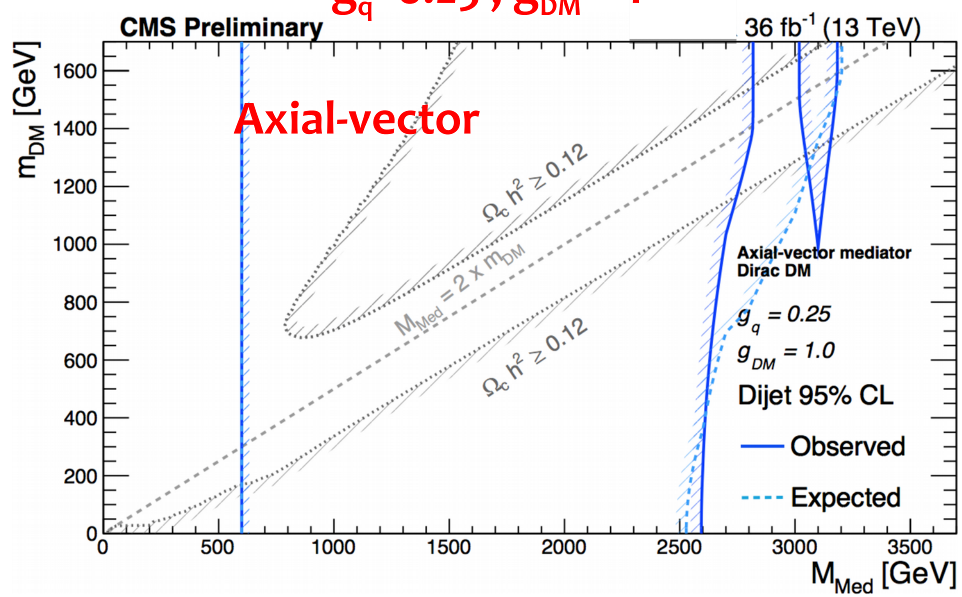
- **Used for the DM interpretation**
- New 36/fb **upper limit on mass of mediator 2.6 TeV** extends previously reported limits in the dijet channel (2.0TeV @13/fb)



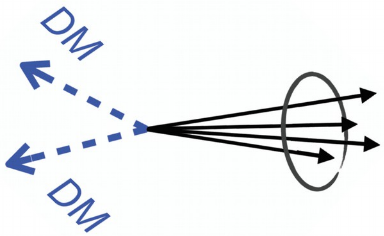




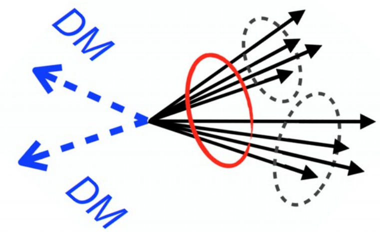
g_q=0.25 , g_{DM} = 1

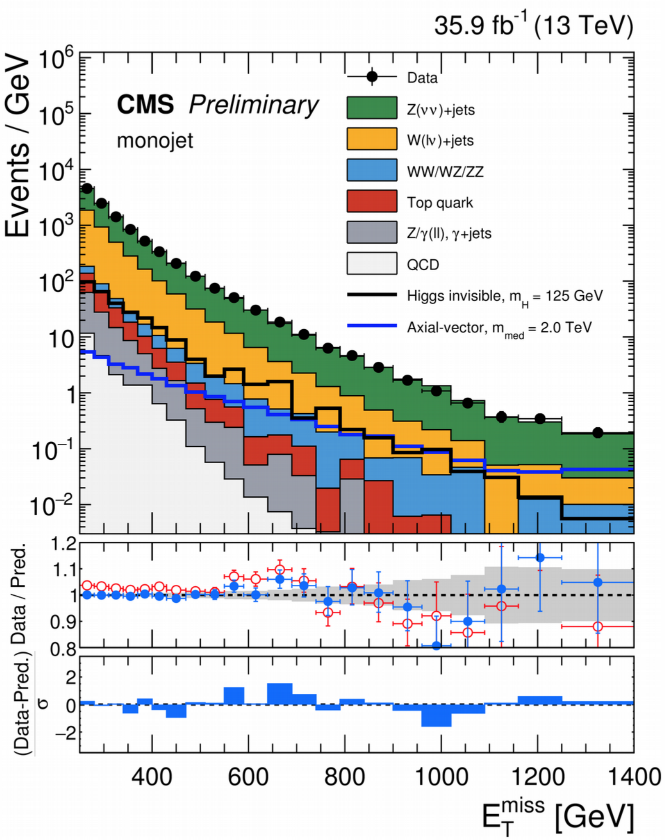


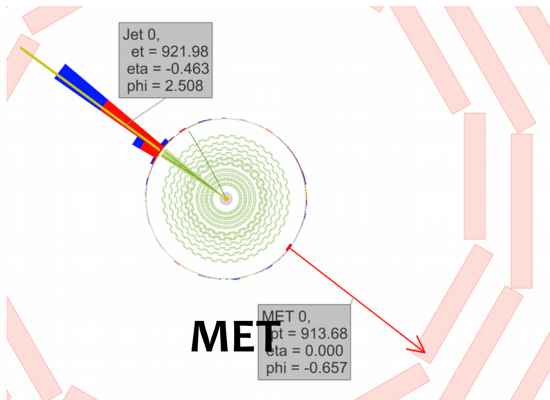
Mono-object searches for DM

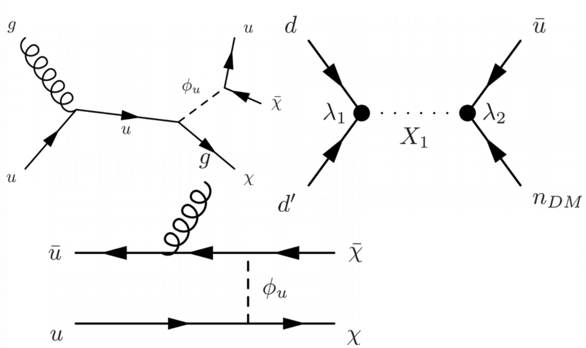


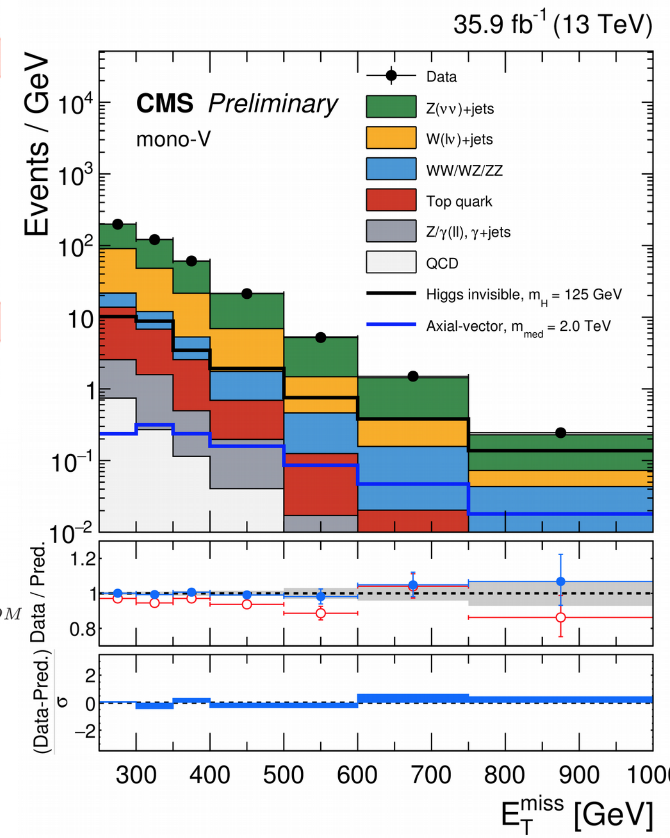
- Searching for **excess on MET** with **mono-jet** or **mono-V**











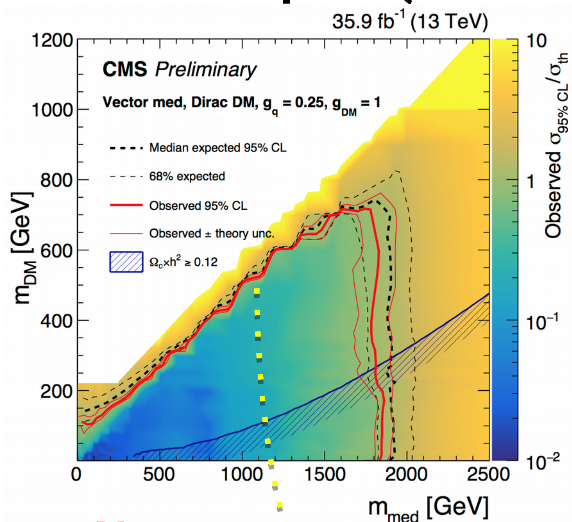
Bkg. evaluated with combined fit to the data in control samples

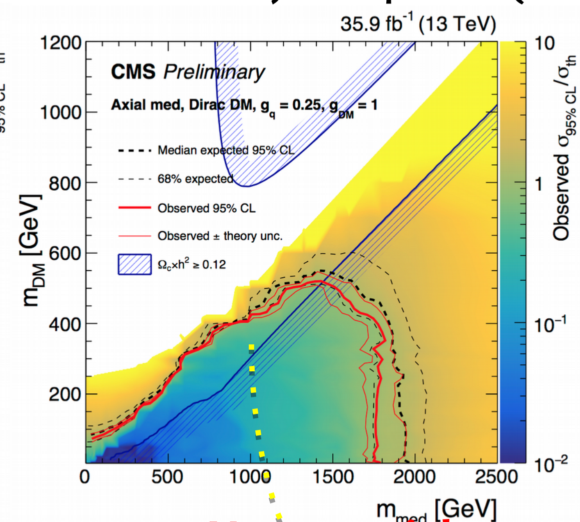
No significant excess of events is observed with respect to the SM backgrounds

CMS-EXO-16-048

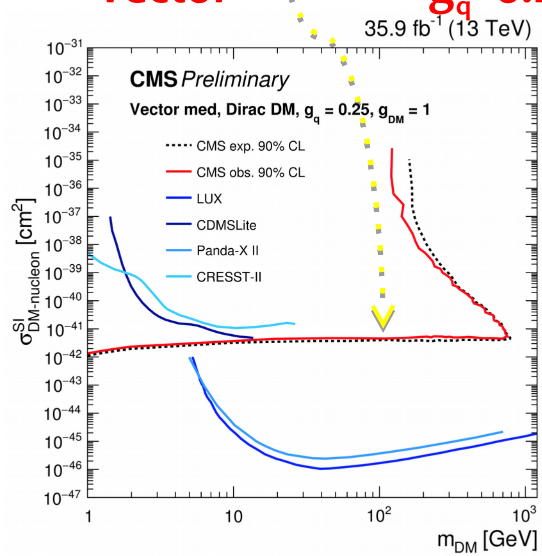
Mono-object search results

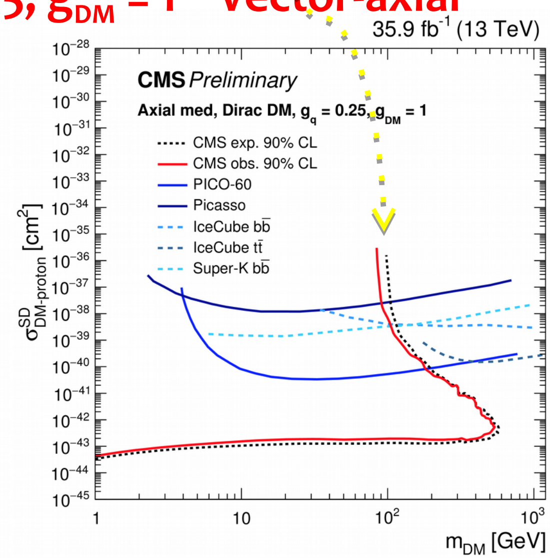
- **Limits* for simplified models** in which **DM** production is mediated by **spin-1 (vector or vec-axial)** or spin-0 (scalar, pseudo-scalar) particles





Vector g_q=0.25, g_{DM} = 1 **Vector-axial**

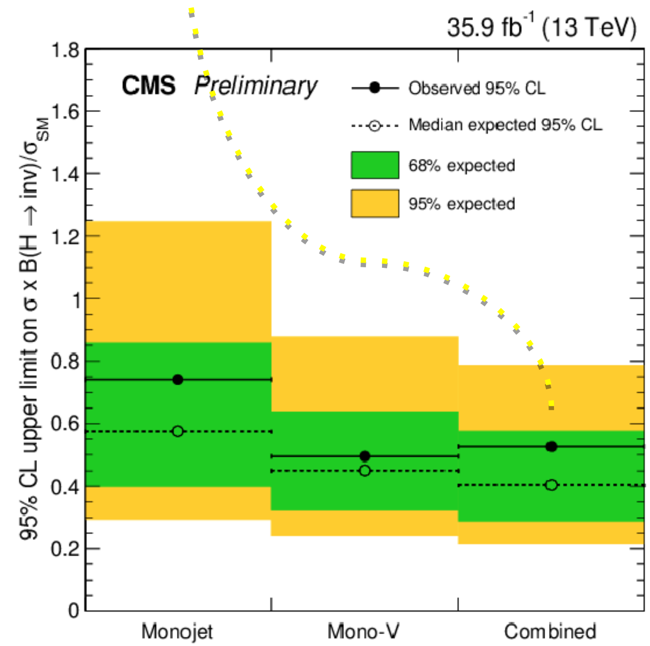




* **strongly depend on** the chosen couplings and model scenario

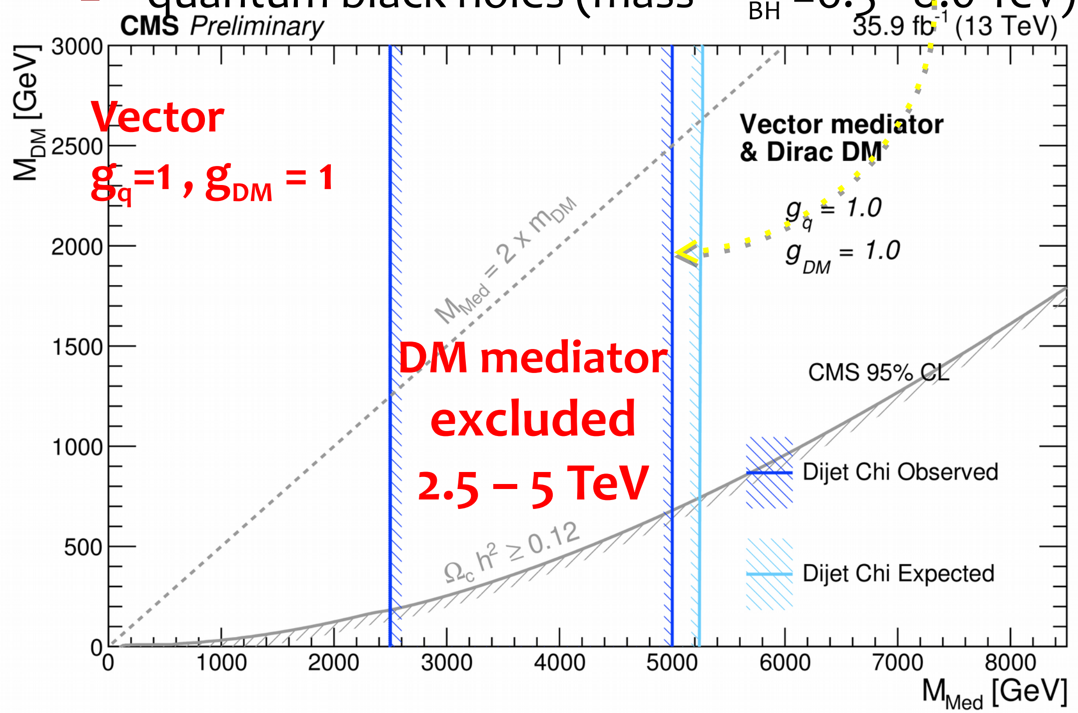
Boson as a mediator

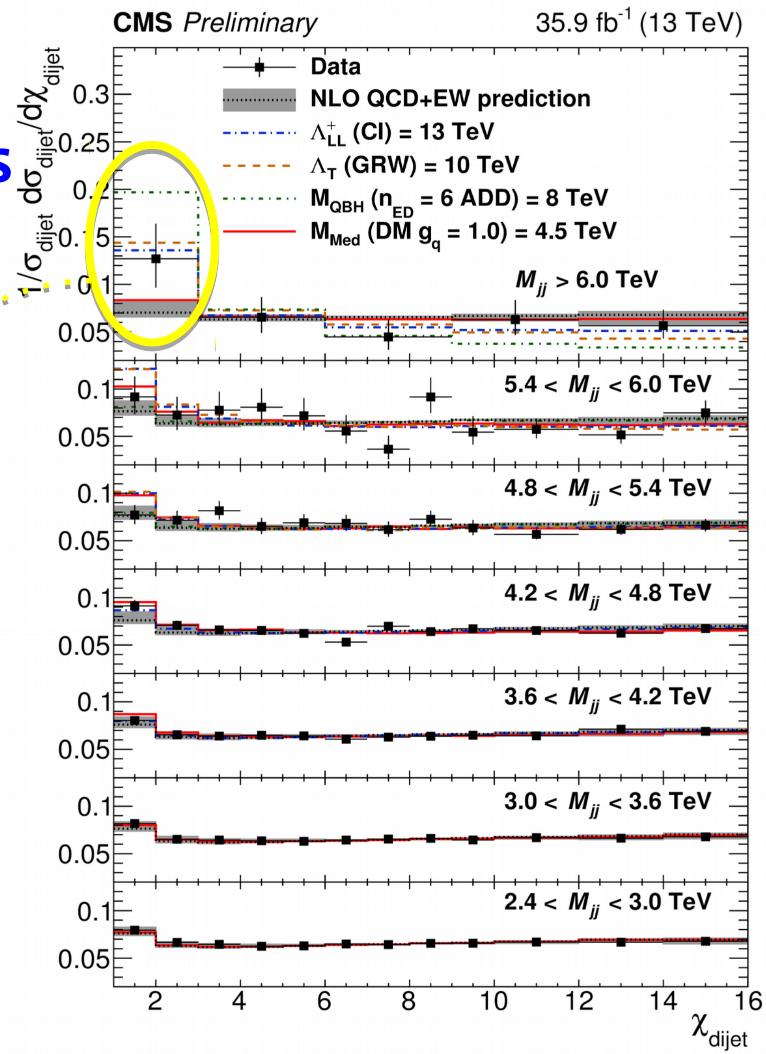
Obs. (exp.) 95% C.L. upper limit of 0.53 (0.40) on the invisible BR of **SM-like 125 GeV Higgs**



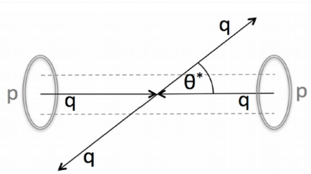
Dark Matter searches

- **Dijet angular correlation** search probes **interactions** between **quarks** and **DM particles**
- Also constrains models of
  - quark contact inter. (scale$^{limit}_{CI}$ = 13.1 – 17.4 TeV)
  - ExDim (mass$^{limit}_{graviton}$ = 10.6 TeV)
  - quantum black holes (mass$^{limit}_{BH}$ =6.3 –8.0 TeV)





$$\chi_{dijet} = e^{|y_1 - y_2|} \sim \frac{1+|\cos\theta^*|}{1-|\cos\theta^*|}$$



CMS Highlights summary

- **Excellent performance** of LHC and the CMS detector
  resulting in **publications with the 13 TeV data of Run 2'16**

- **Precise measurement of Higgs and Standard Model**
  starting with the increase of luminosity
  - **Higgs is very SM-like**
    the observation of decays to taus and **an evidence for decays to b-quarks**

- **New Physics can be discovered** if it exists at the TeV scale
  - ~3 times more data (**150/fb**) till end of 2018 than now (>**50/fb**)
  - and ~3 orders of magnitude (**3000/fb**) more for HL-LHC

References:

- **Next CMS presentations during the conference**
  Details and much more about the CMS physics , its performance, and the future

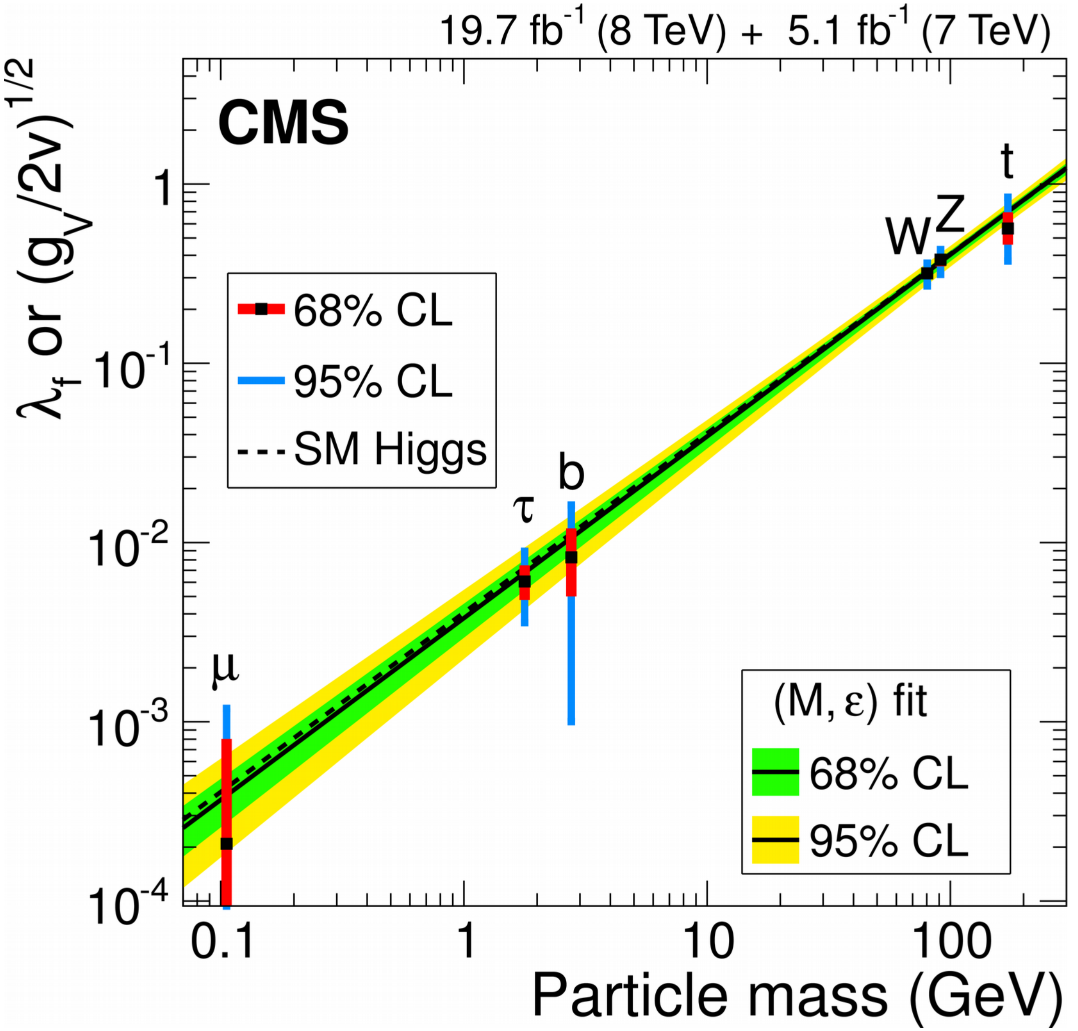
- All CMS public results: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

Thank you!

Supported in part by the NCN grant:
2014/039982014/15/B/ST2/03998

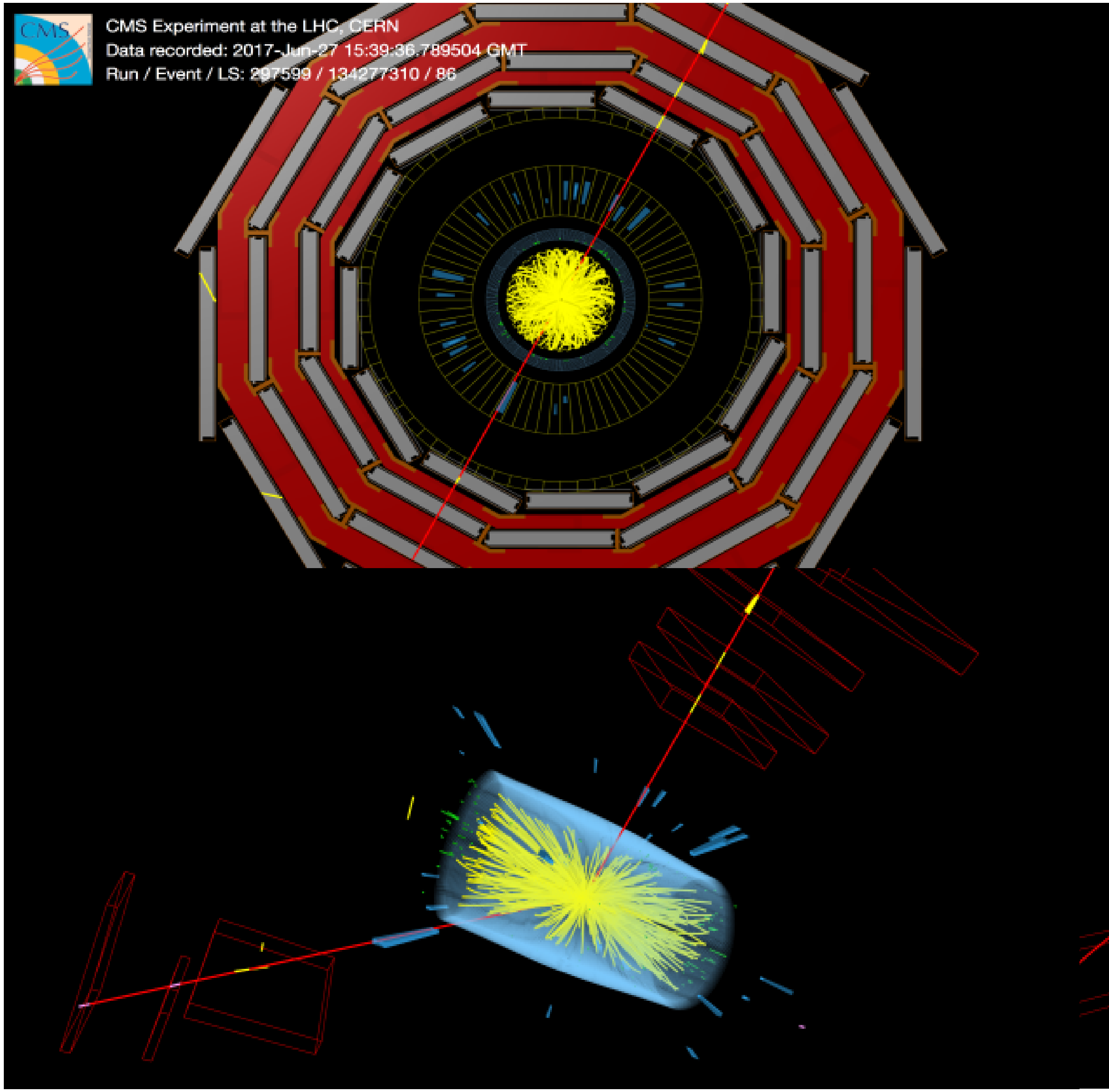
BACKUP

Higgs



19.7 fb-1 (8 TeV) + 5.1 fb-1 (7 TeV)
CMS
λ_f or $(g_V/2v)^{1/2}$
68% CL
95% CL
SM Higgs
μ
τ
b
W
Z
t
(M, ε) fit
68% CL
95% CL
0.1
1
10
100
Particle mass (GeV)

High Pt event in 2017



2017 highest **di-muon** mass candidate with mass = **2.4 TeV**