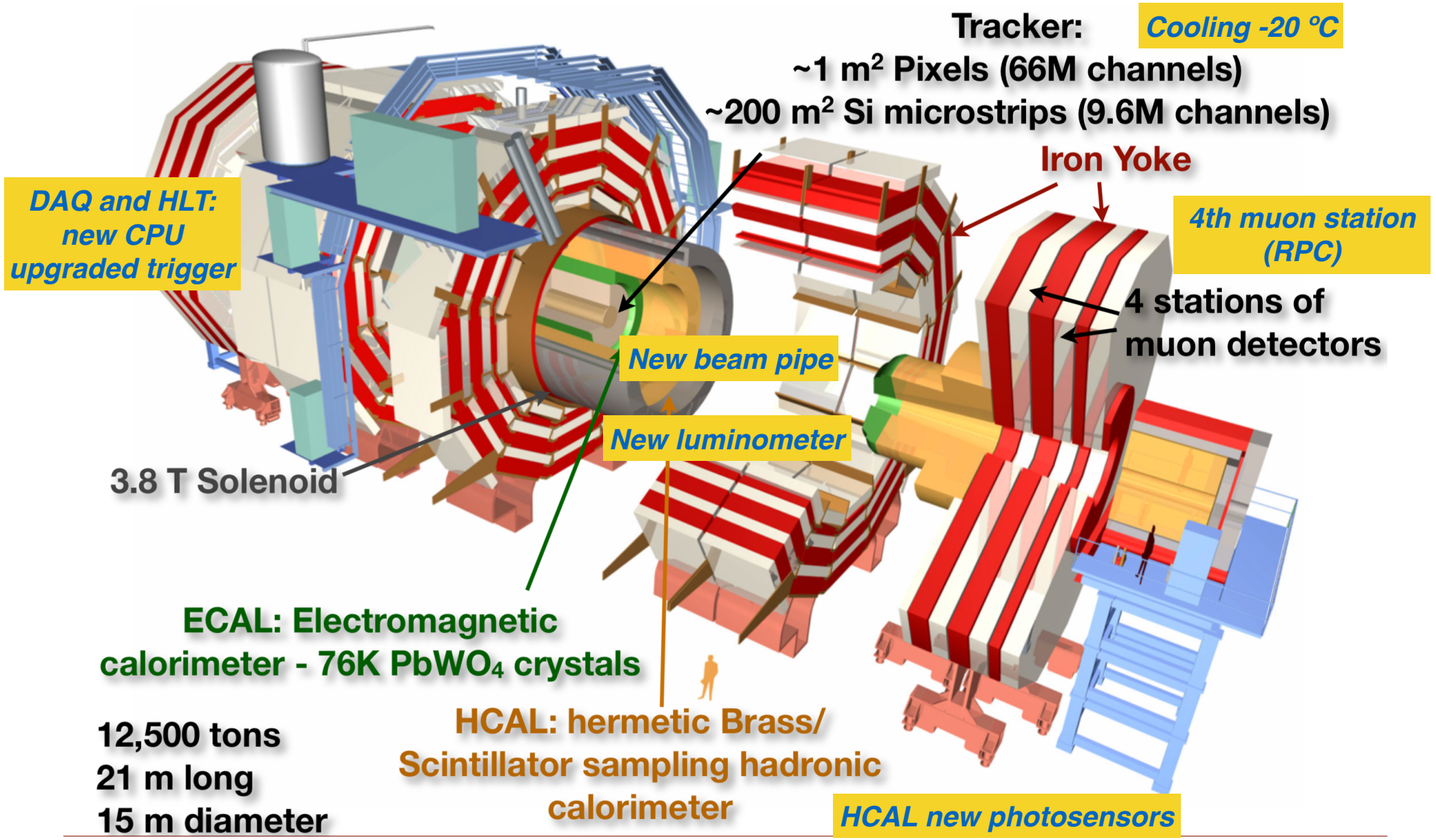
Highlights of CMS 13 TeV results

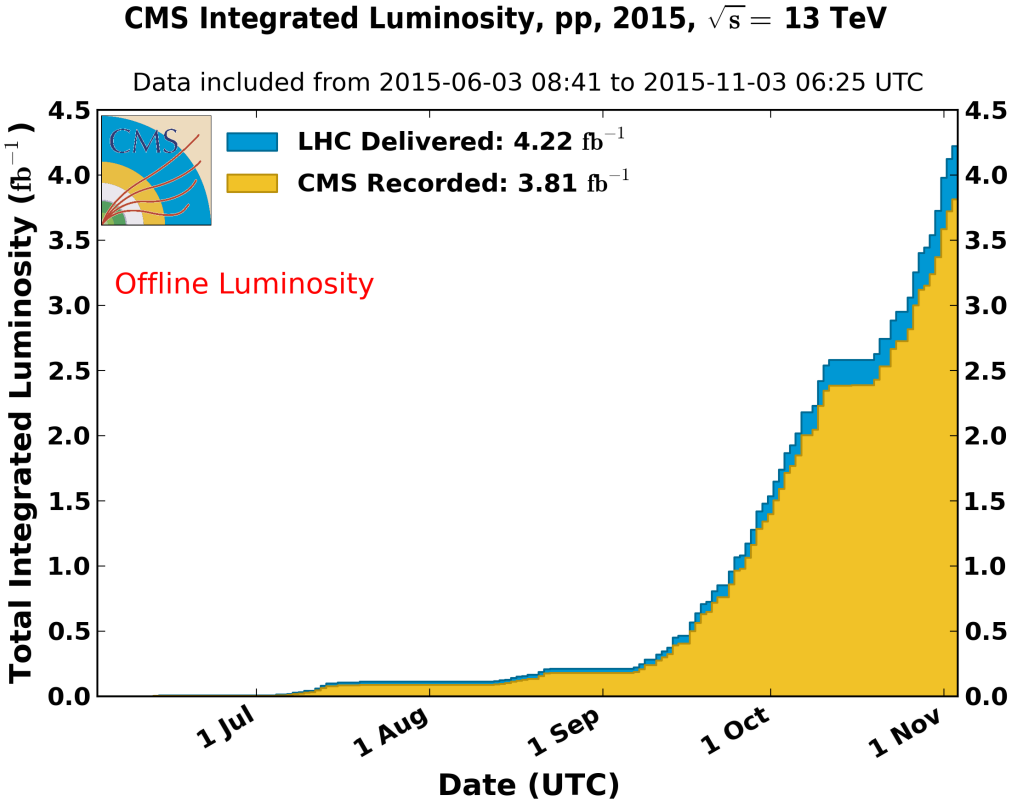
FCPPL workshop - 30/03/2016

Nicolas Chanon for the CMS Collaboration

CMS detector at Run II



Run II dataset



Proton - proton data at 13 TeV

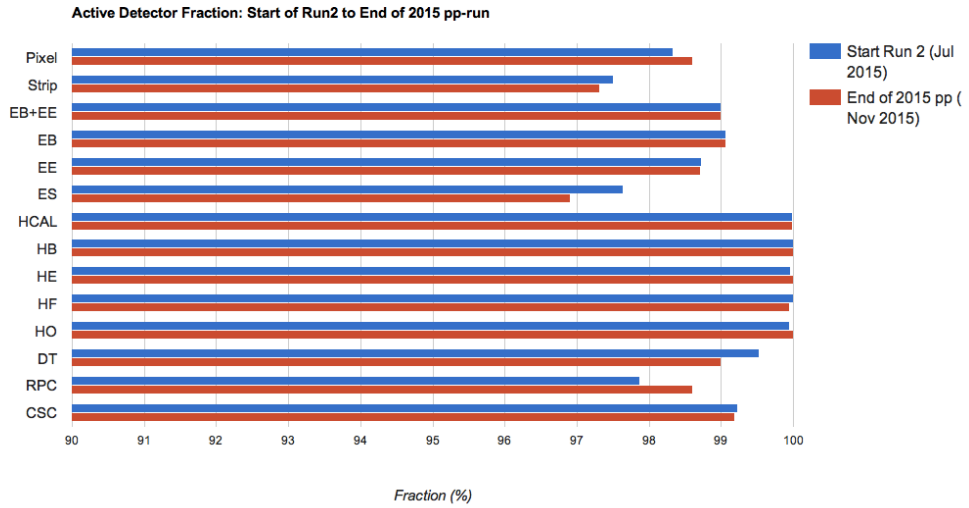
Recorded at 0 T: 1 fb-1

Recorded at 3.8 T : 2.8 fb-1

Data certification, 3.8 T:

- Good for all: 2.2 fb-1
- With |eta|<3 for jets and mET: 2.6 fb-1
- Good for muons: 2.7 fb-1

Fraction of active channels >97%



Pb-pb data

- 5.02 TeV/nucleon (collision energy doubled)
- 0.56nb-1 recorded (4x more than in 2011)
- Analyses ongoing

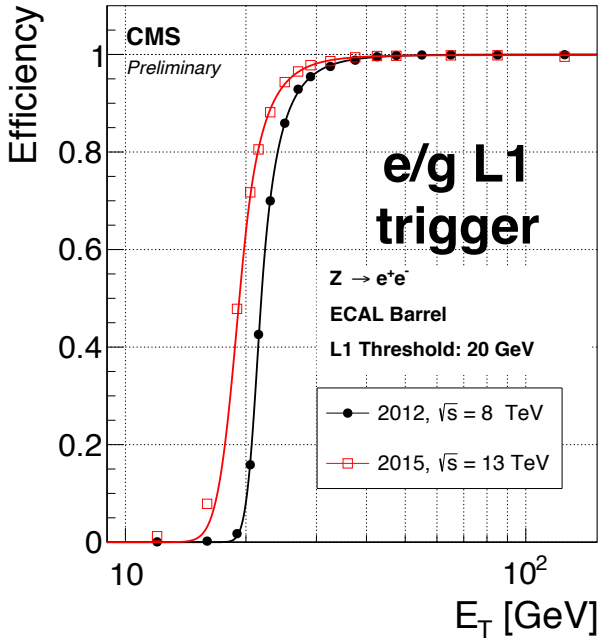
CMS Magnet status

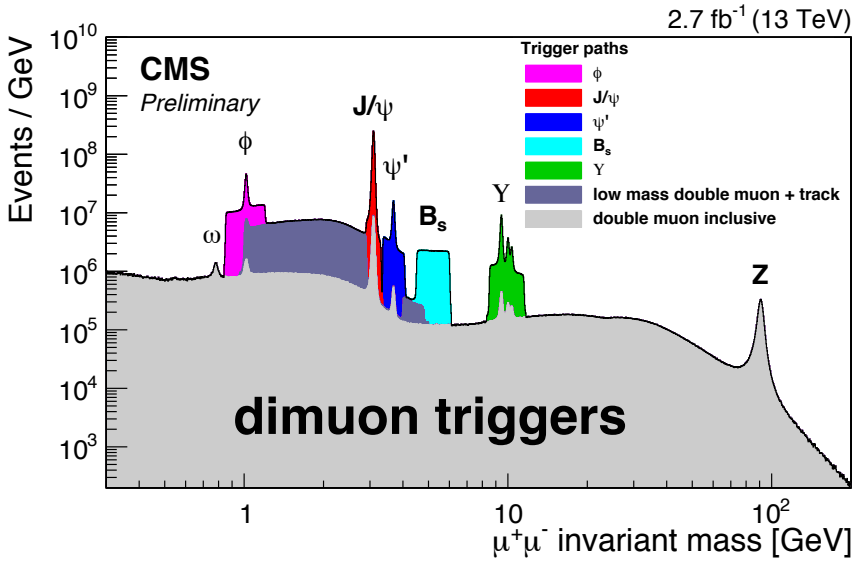
- Before Run II starts it was realised that the performance of the **cryogenic system feeding Liquide He** to the magnet was severely impaired by a **contamination of the Cold box**
- Thanks to efforts from CERN cryogenic and technical departments working with CMS technical coordination, the impact was limited, allowing to **collect ~3/4 of the 2015 delivered luminosity with full magnetic field**

Magnet / cryogenic system revision during YETS 2015-2016:

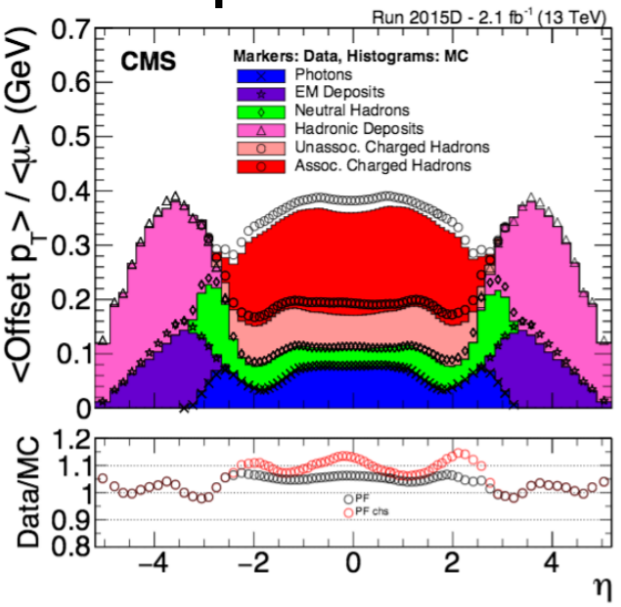
- **Cold box cleaning** with special solvent was successful
- **370g of compressor oil removed**. All evidence consistent with this being the source of instabilities in 2015.
- Oil filters (surface of compressor hall), old oil removal system and coalescers dismounted
  - All **new components delivered**
  - **Reconnection and testing** procedure is lengthy and must be done rigorously before connecting to new He transfer line leading underground the cold box
  - Estimate **“magnet ready” in week of 25 April**

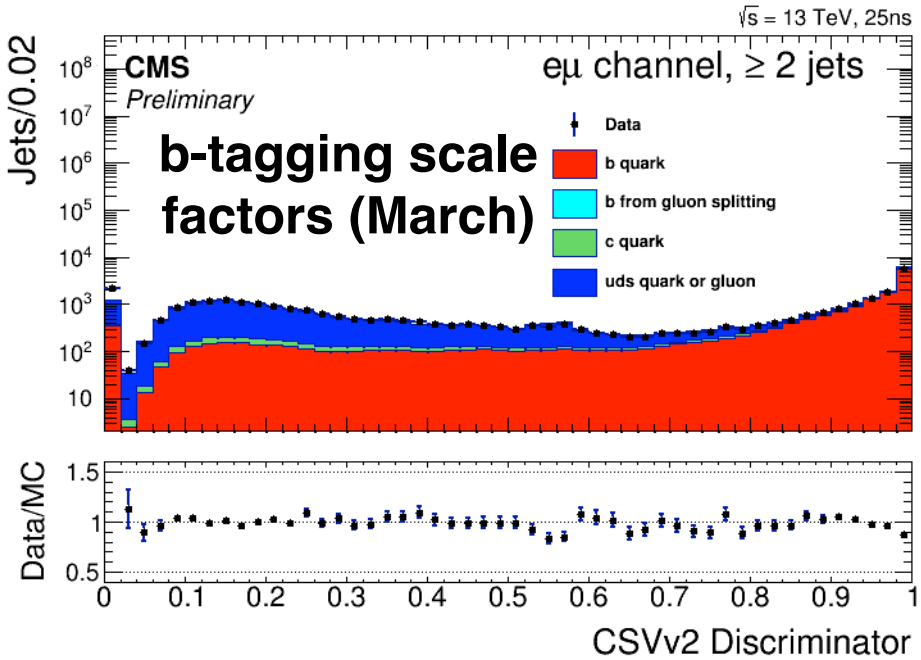
Reconstruction in a nutshell

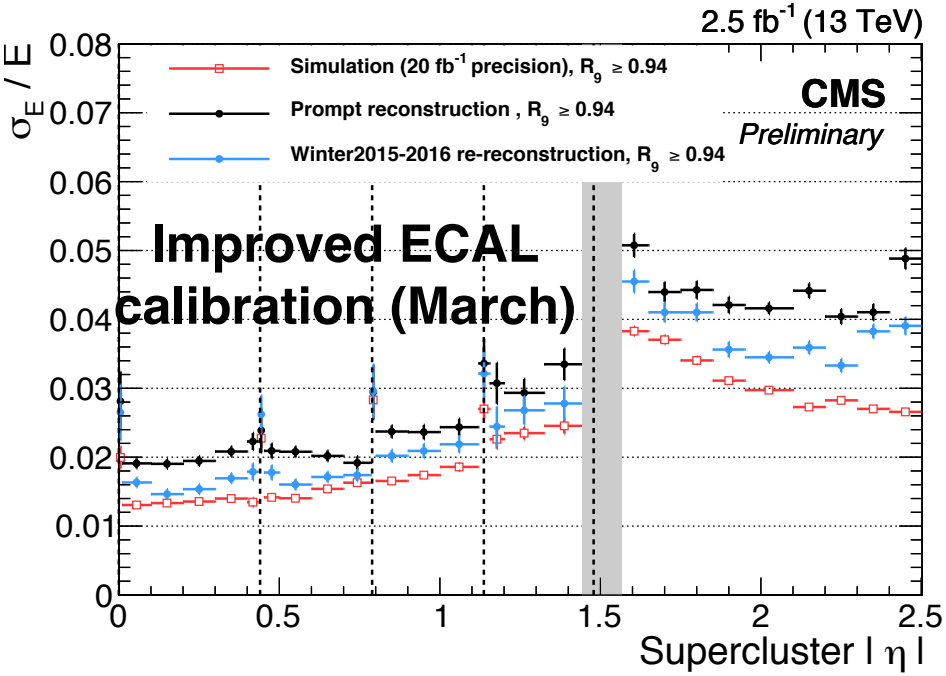




particle flow



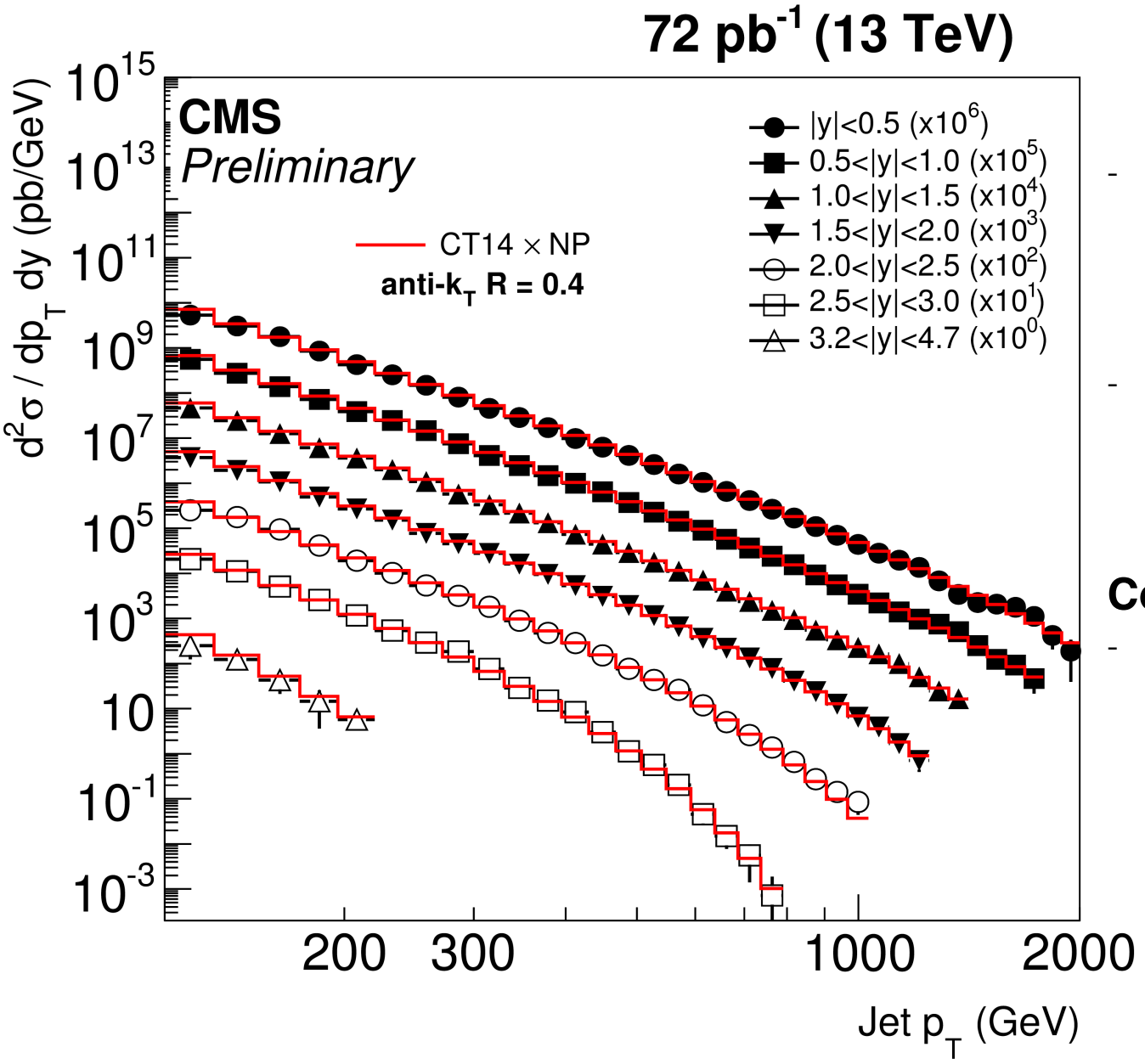




Standard model measurements at 13 TeV

Standard model QCD Jets production

SMP-15-007



- Measurement with prescaled high level triggers as low as pT > 60 GeV
- Jet energy scale uncertainty 1-2% (central region) to 8% (forward region)

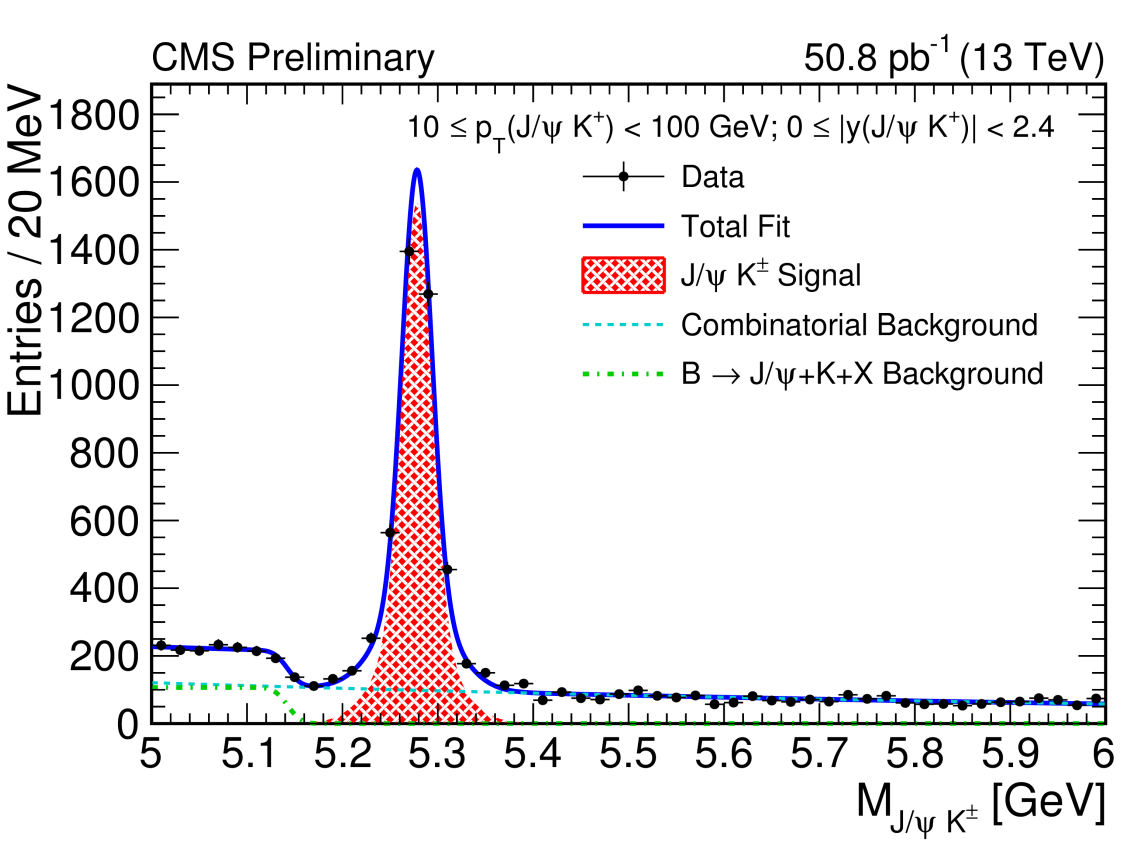
Comparison with theory

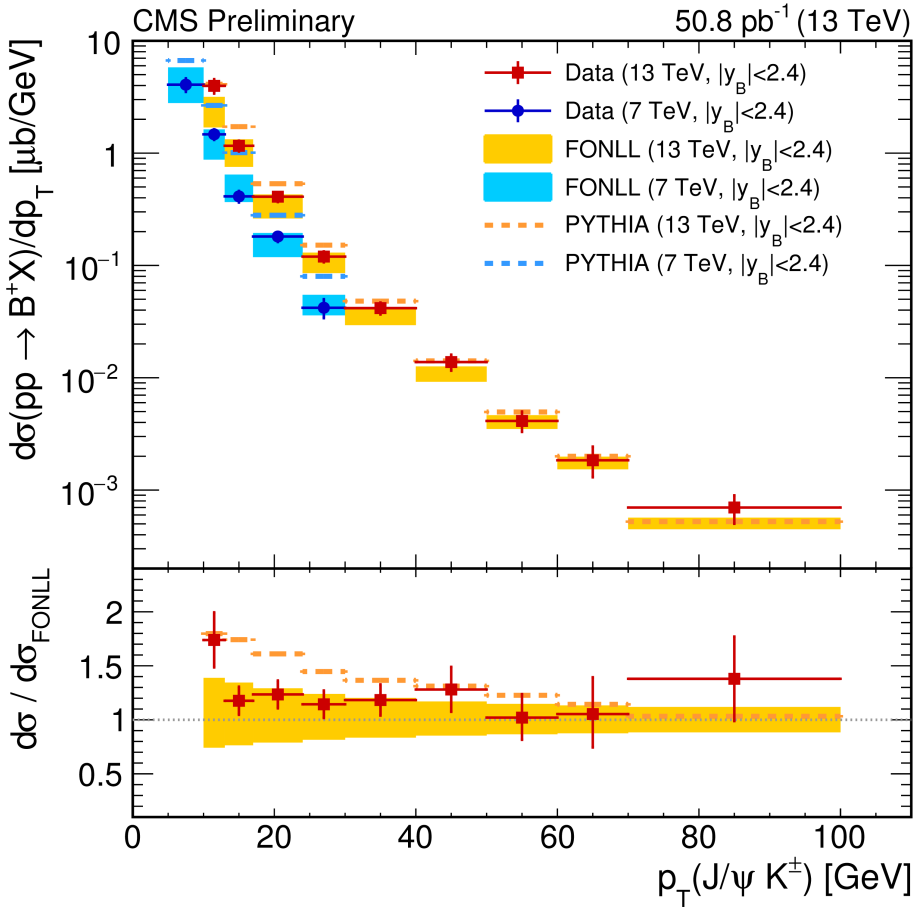
- Good agreement with NLO predictions corrected with non-perturbative correction (some tension at high rapidity)

B-hadron production

BPH-16-003

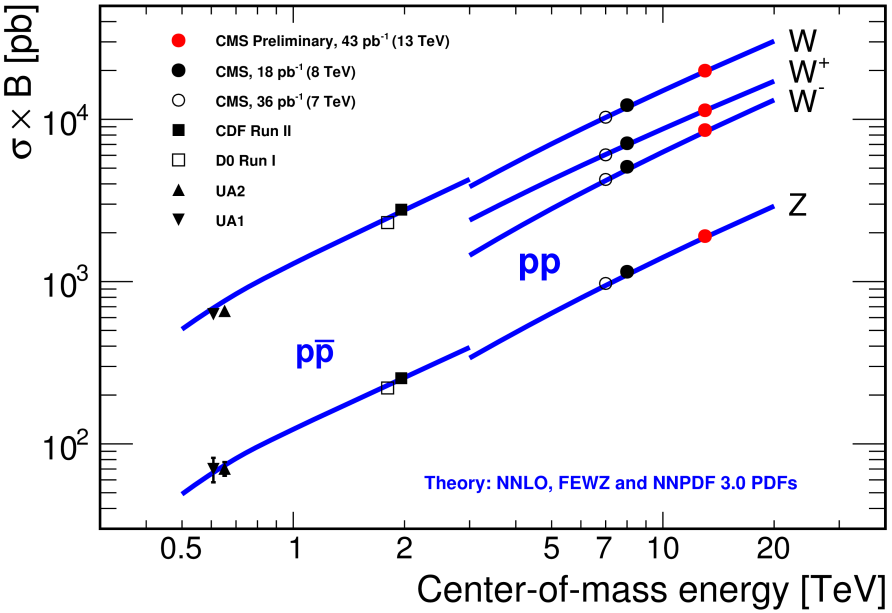
- Cross section of **$B^+ \rightarrow J/\Psi\ K^+$ (with $J/\Psi \rightarrow \mu\mu$)** vs pT and η compared to FONLL predictions and 7 TeV CMS data
- Good agreement with theory up to 100 GeV





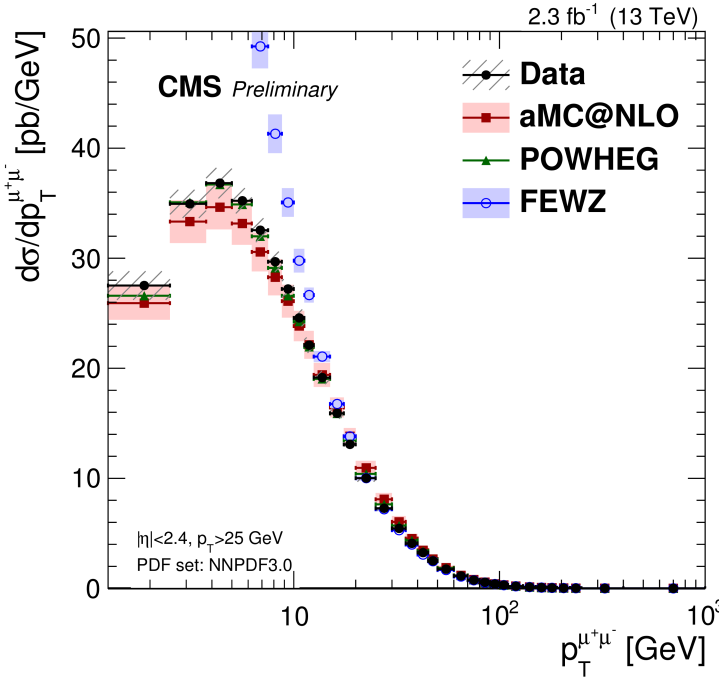
Standard model W and Z bosons

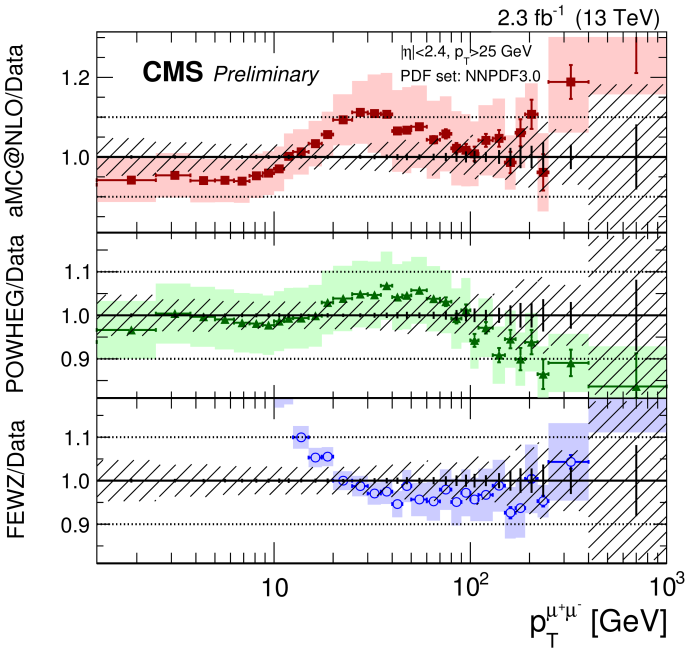
SMP-15-004, SMP-15-010, SMP-15-011

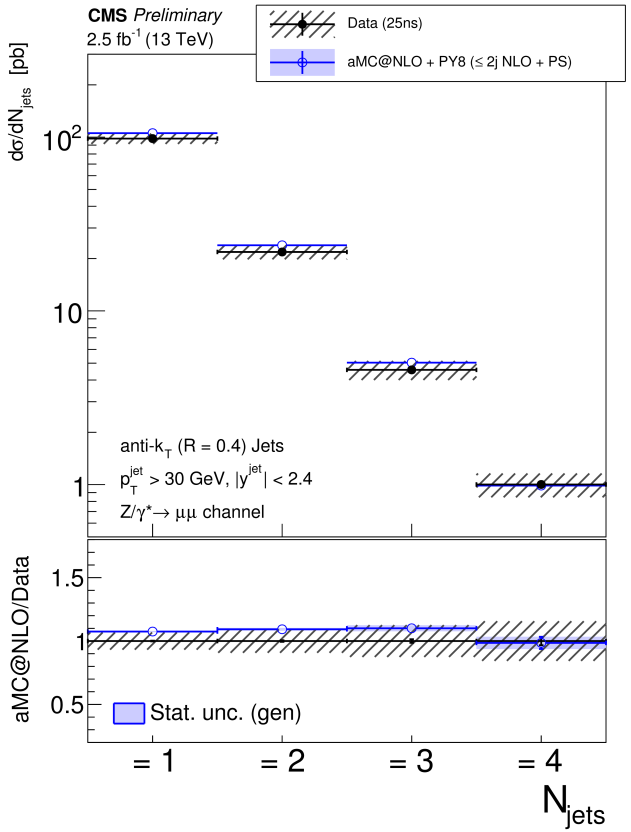


Measure QCD Z and W production

- Inclusively
- Z+jets differential in pT, rapidity and jets
- Overall good agreement with NLO predictions (aMC@NLO, POWHEG)







Standard model WZ and ZZ production

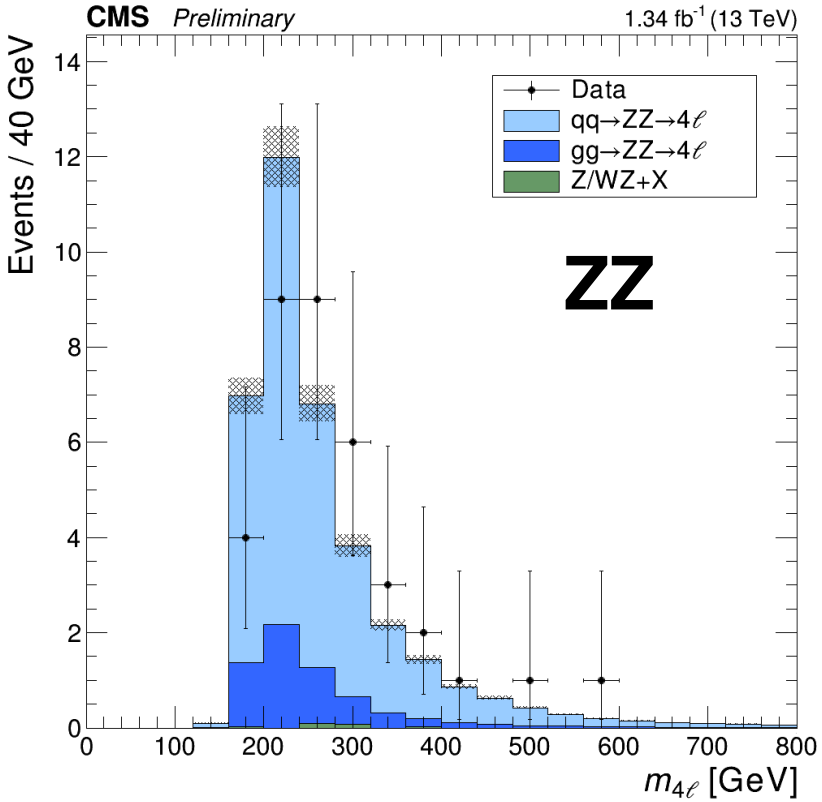
SMP-15-005, SMP-15-006

Re-establish QCD diboson production (background to Higgs boson searches)

ZZ→4l

$\sigma(\mathrm{pp} \to \mathrm{ZZ}) = 16.7^{+2.9}_{-2.6}\,(\mathrm{stat})^{+0.7}_{-0.5}\,(\mathrm{syst}) \pm 0.3\,(\mathrm{theo}) \pm 0.8\,(\mathrm{lum})\,\mathrm{pb}$

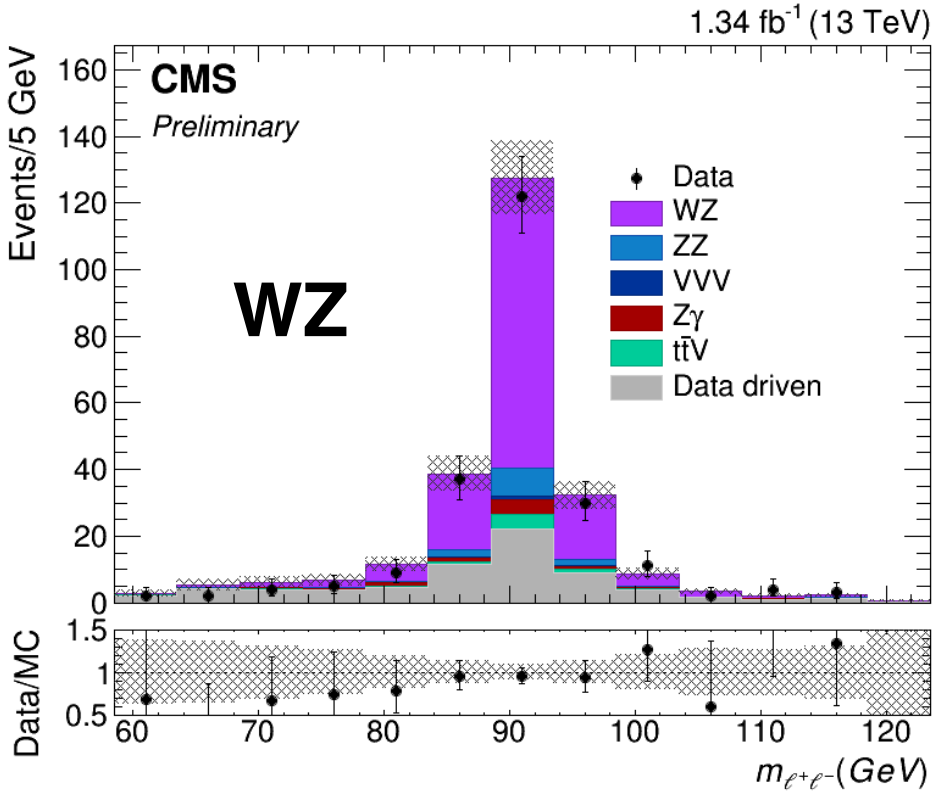
Predictions $16.5^{+0.7}_{-0.5}$ pb



WZ→3lν

$\sigma(\mathrm{pp} \to \mathrm{WZ}) = 36.8 \pm 4.6\,(\mathrm{stat})^{+8.1}_{-6.2}\,(\mathrm{syst}) \pm 0.6\,(\mathrm{theo}) \pm 1.7\,(\mathrm{lum})\,\mathrm{pb}$

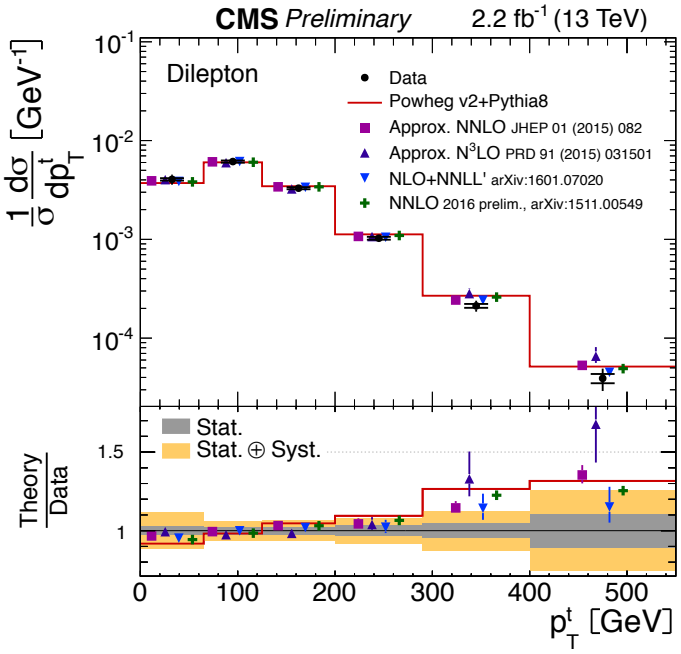
Predictions $42.7^{+1.6}_{-0.8}$ pb

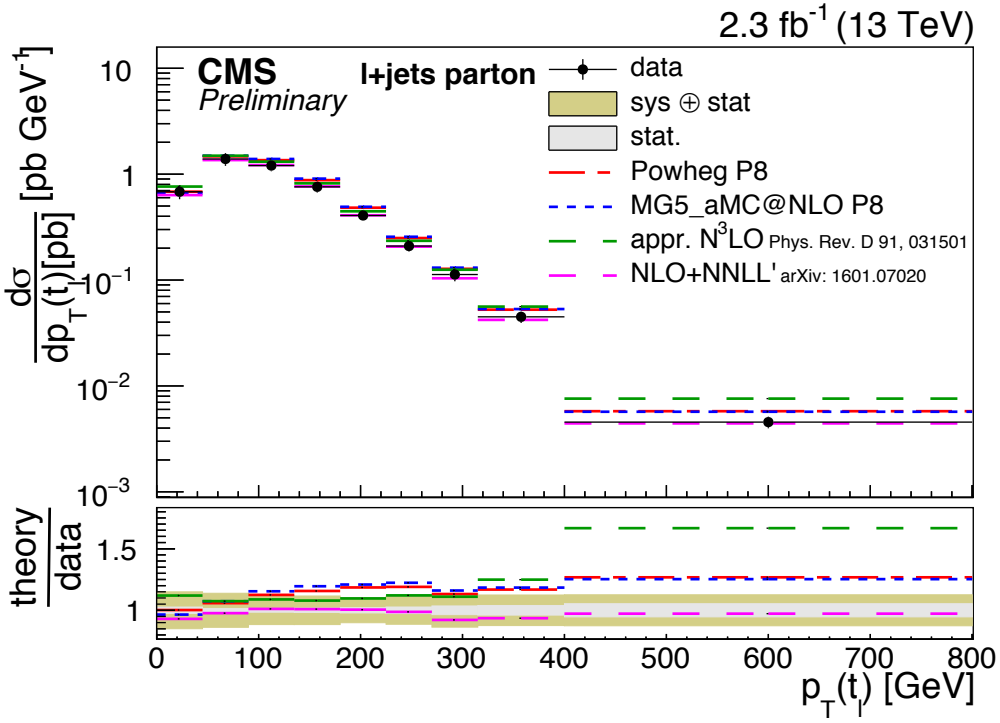


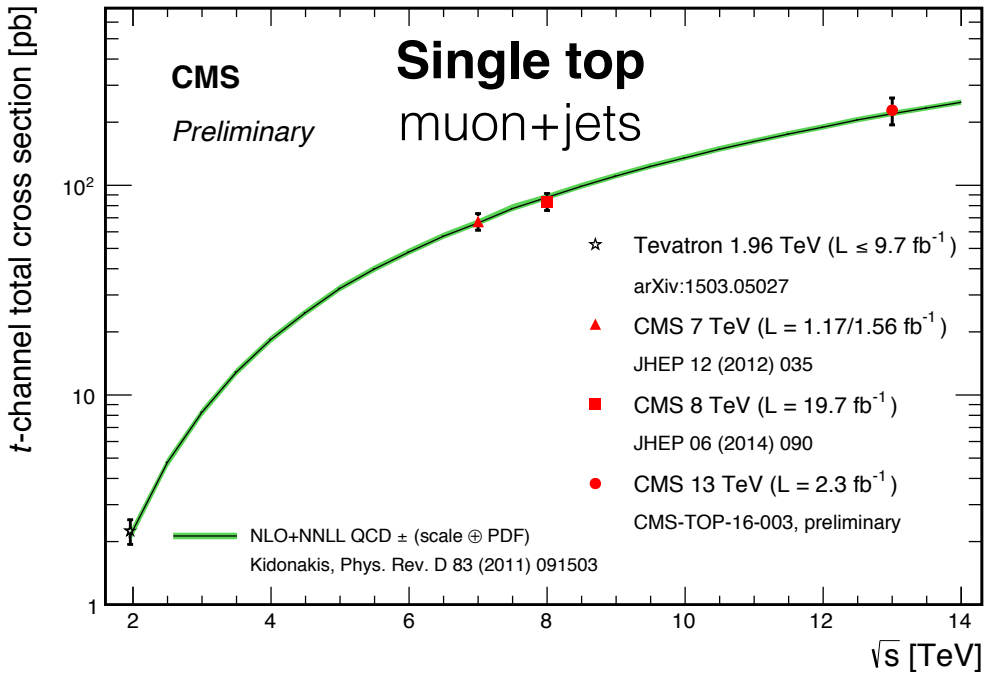
ttbar and single top cross section

TOP-16-008, TOP-16-011, TOP-16-003

- **TTbar Cross section increase** (13 TeV relative to 8TeV) : **x3.3**
- TTbar **differential cross section** measured in lepton+jets and dilepton channels
- **Single top**: t-channel is dominant at the LHC (s-channel and tW amount to 20% of single top)

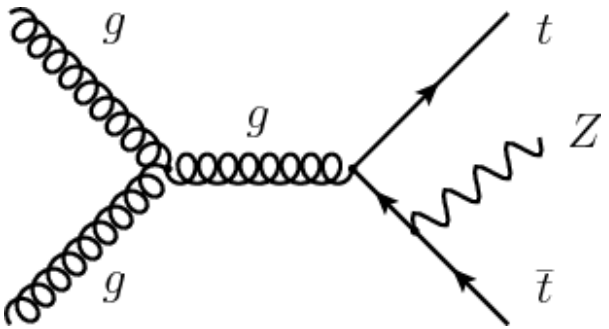






ttbar+Z production

TOP-16-009



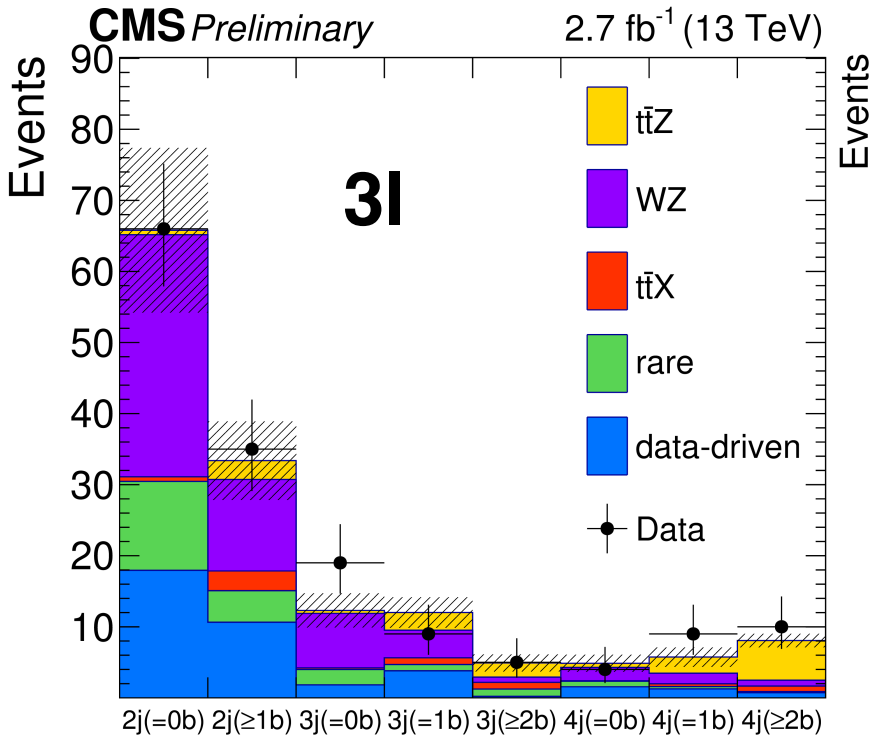
- Background to ttH multi lepton searches
- At 13 TeV, **cross section x4** relative to 8 TeV
- Analysis counting events classified by jets/b-jets multiplicity, in 3l and 4l final state

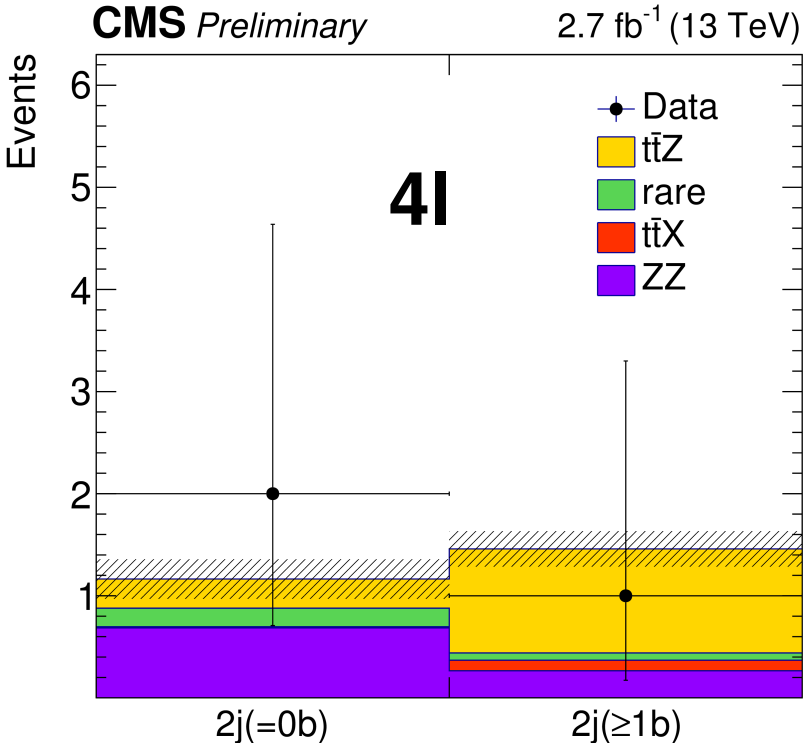
Observation $\sigma(\mathrm{pp} \to \mathrm{t\bar{t}Z}) = 1065\ ^{+352}_{-313}(\mathrm{stat.})\ ^{+168}_{-142}(\mathrm{sys.})$ fb

NLO predictions $\sigma(\mathrm{t\bar{t}Z}) = 839.3^{+80}_{-92}(\mathrm{scale})\ ^{+25}_{-25}(\mathrm{pdf})\ ^{+25}_{-25}(\alpha_s)$ fb

Channel	Expected significance	Observed significance
3ℓ analysis	2.9	3.5
4ℓ analysis	1.2	0.9
3ℓ and 4ℓ combined	3.1	3.6

Observation at 13 TeV
(was discovered at 8 TeV)

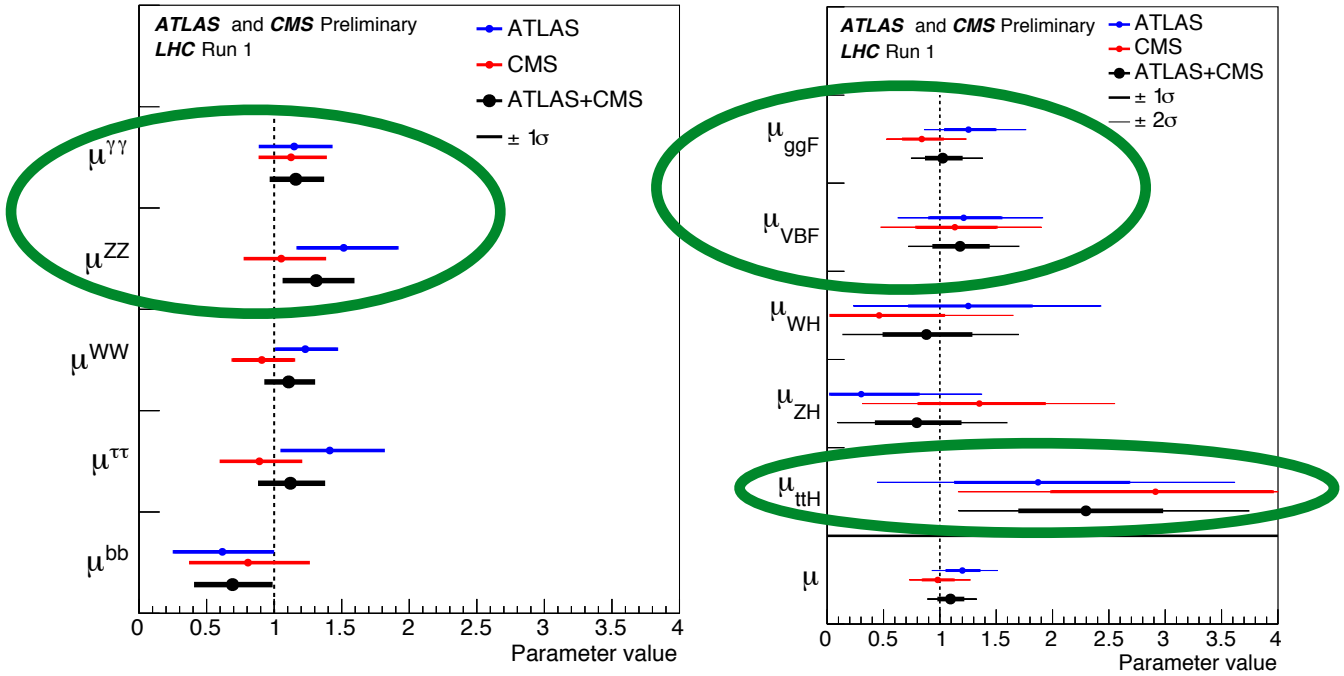




Higgs boson physics at 13 TeV

SM channels investigated with 2015 data

Summary of Run I Higgs couplings



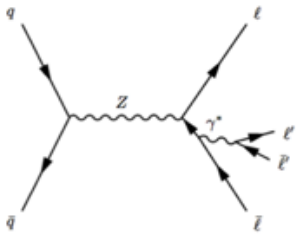
H→ZZ→4l

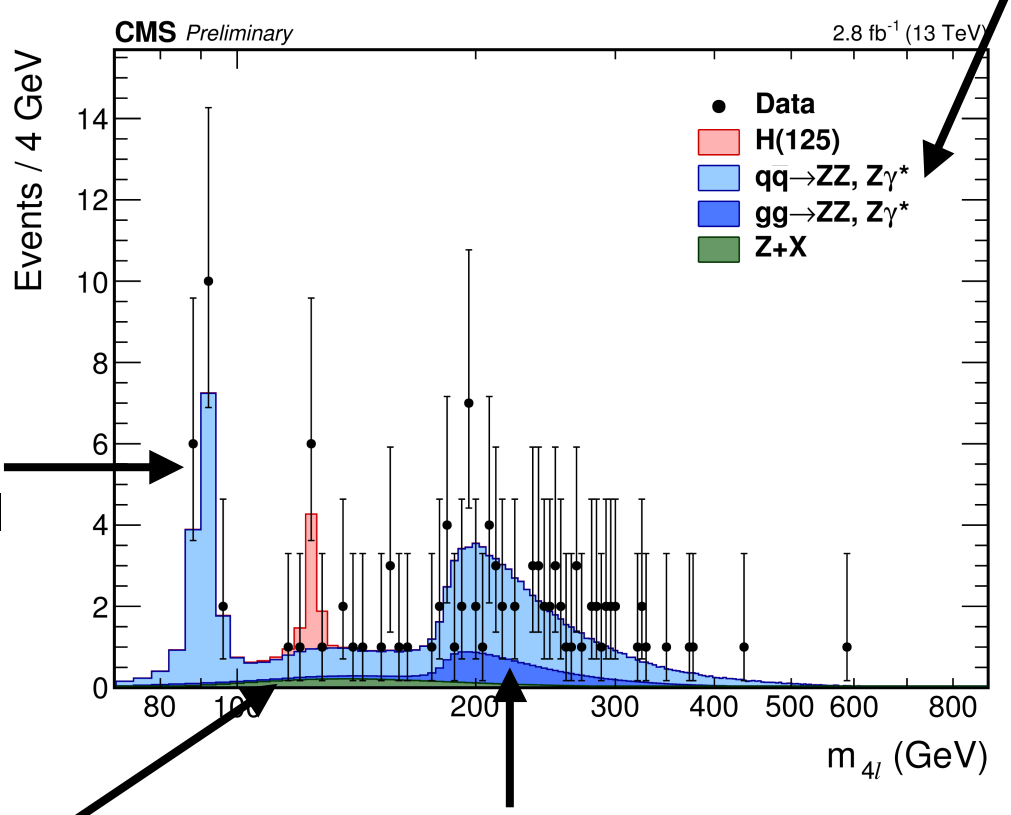
HIG-15-004

Signature: 4e, 2e2μ, 4μ

- Need **momentum** as **low** as pT>7 GeV (electrons) and pT>5 GeV (muons) to not loose too much efficiency missing the 4th lepton

Main backgrounds: ZZ continuum, Z+jets, ttbar





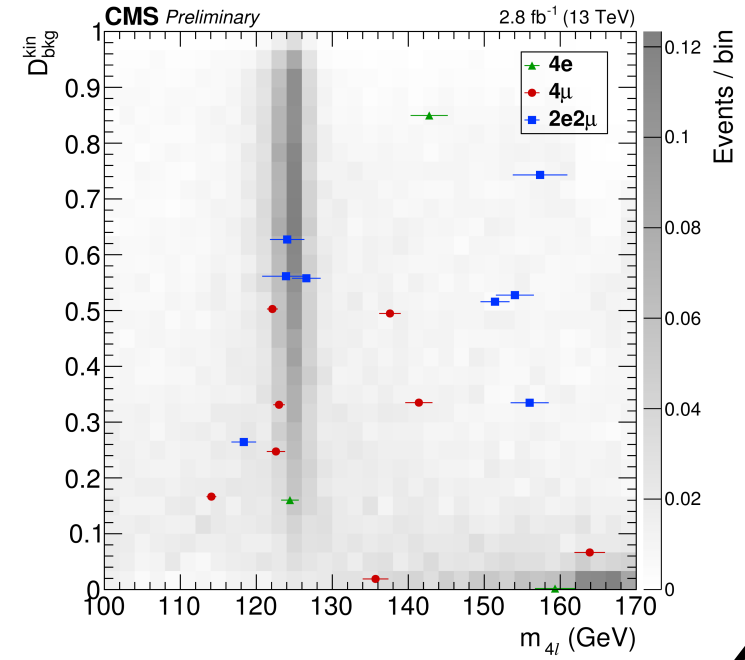
Z→4l: control region

H→ZZ*→4l:
- **Very good s/b~2**
- **2D analysis**

ZZ→4l region: was used to constrain Higgs boson width (Run I)

H→ZZ→4l

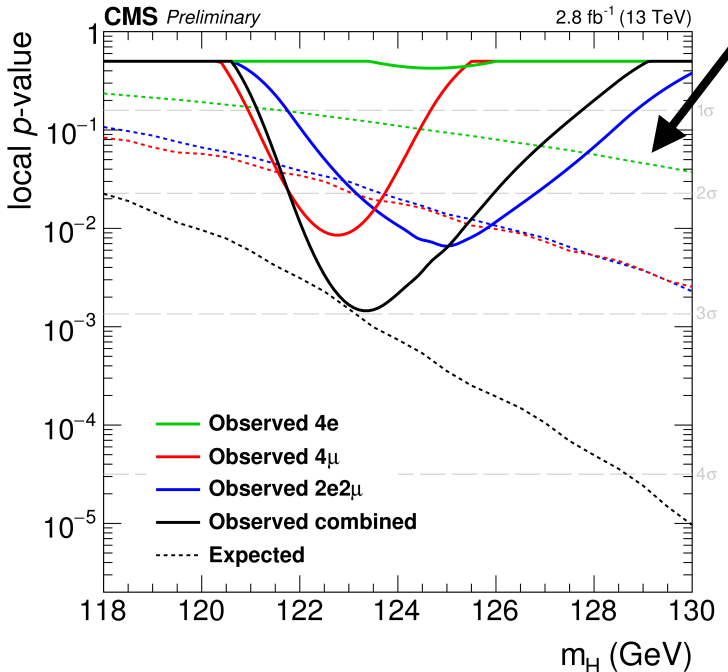
HIG-15-004



Analysis:

- Untagged: Kinematic discriminant, Matrix element based, trained against non-resonant background
- VBF: Fischer discriminant using jet information, trained against gluon fusion signal

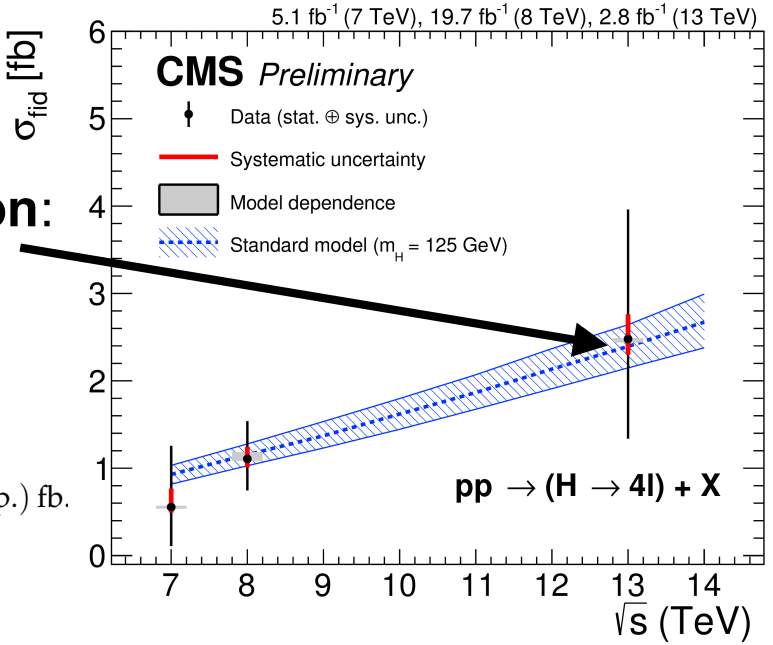
- **$\mu = 0.82^{+0.57}_{-0.43}$ at 125.09 GeV**
- **2.5σ obs** (3.4σ expected)
- Best fit mass $123.4^{+0.8}_{-0.7}$ GeV: agreement within 1.6σ with Run I LHC measurement



Fiducial cross section:

- Correct yield in a fiducial region for detector effects

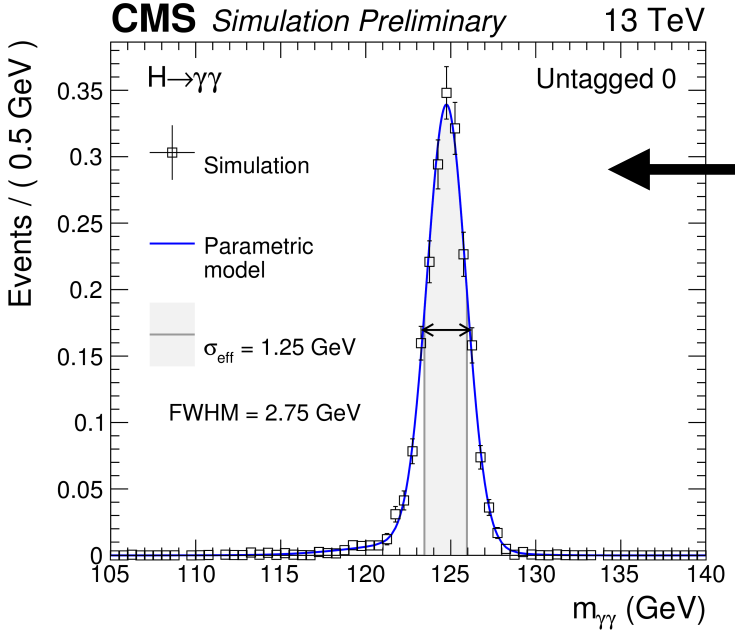
$$\sigma_{\text{fid.}} = 2.48^{+1.48}_{-1.14}(\text{stat.} \oplus \text{sys.})^{+0.01}_{-0.04}(\text{model dep.})\ \text{fb}.$$



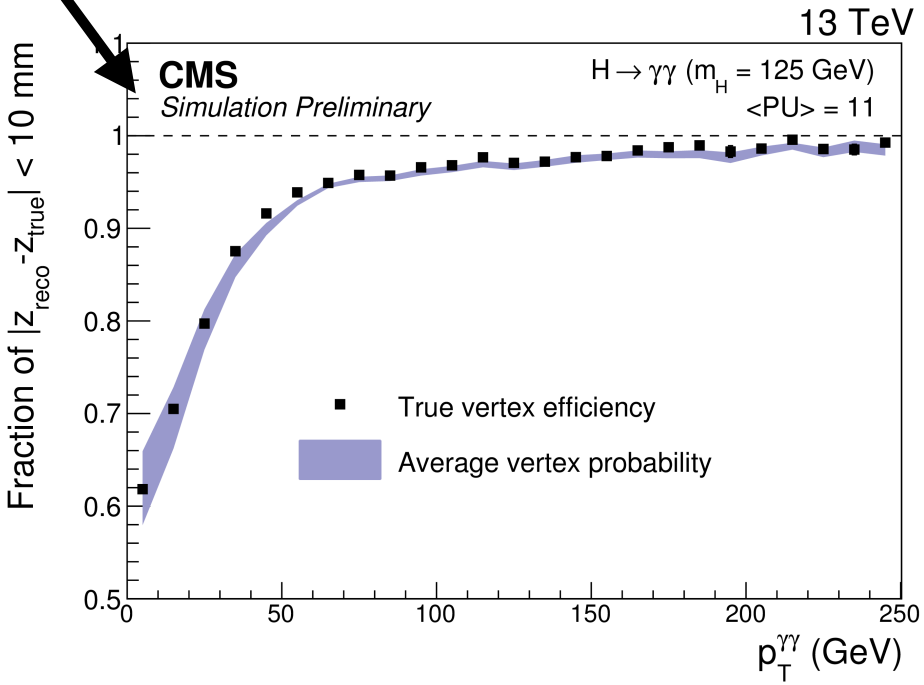
H→γγ analysis

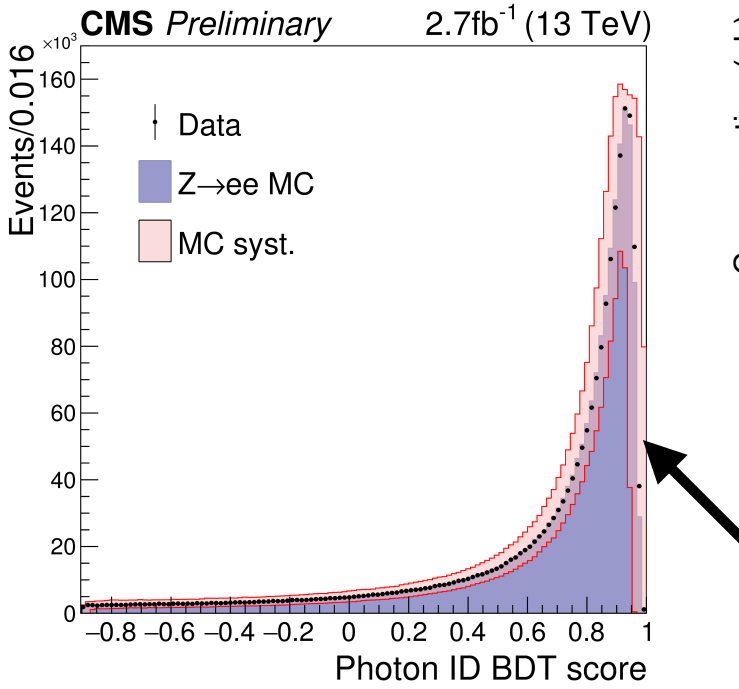
HIG-15-005

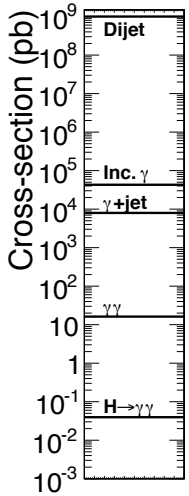
See talk from Camilo Carrillo later this afternoon



- Look for **small signal peak (BR~0.2%) over large background**
- **Photon energy resolution** 1-2 GeV depending on categories: calibration is crucial
- **Vertex finding** among pileup vertices helps improving identification and resolution







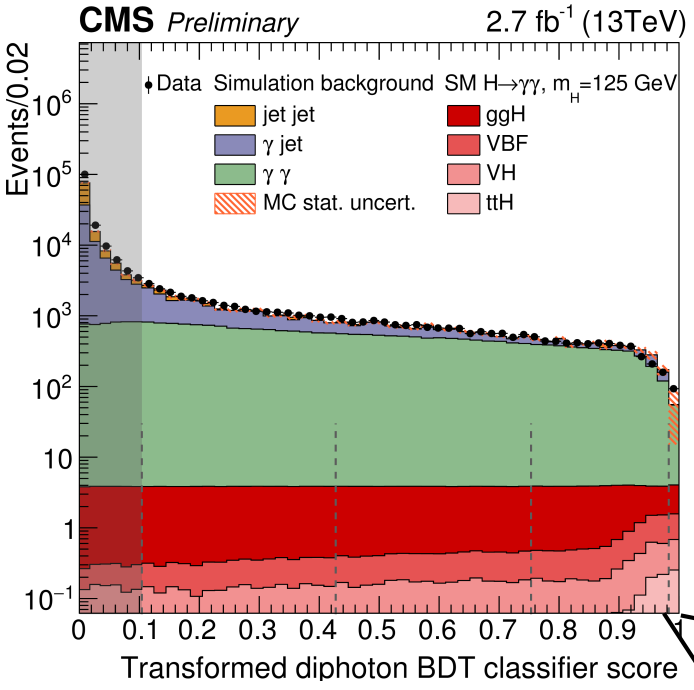
- **Photon identification:** reject jets faking photons with shower shape and isolation using BDT

H→γγ results

HIG-15-005

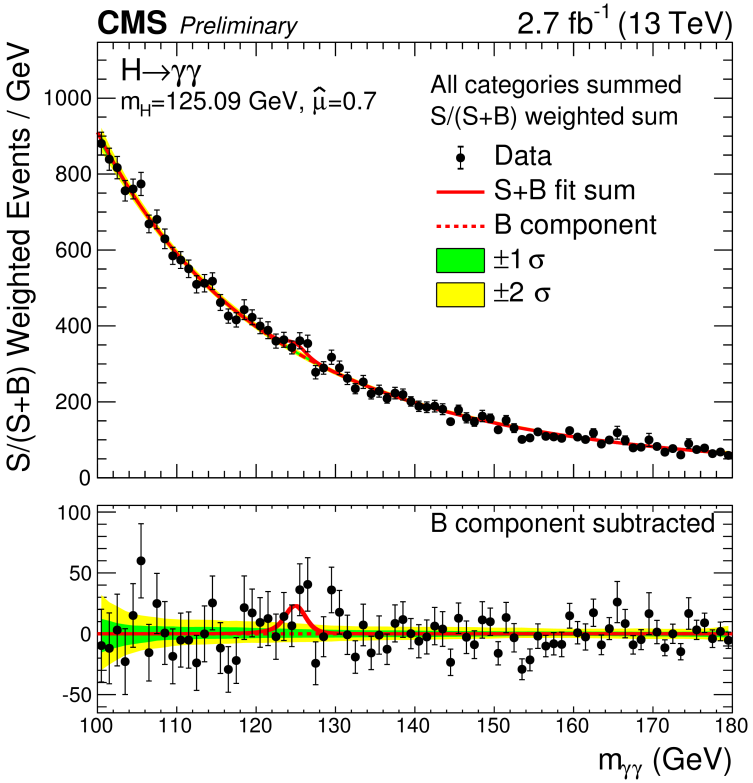
Sensitivity from mass fit

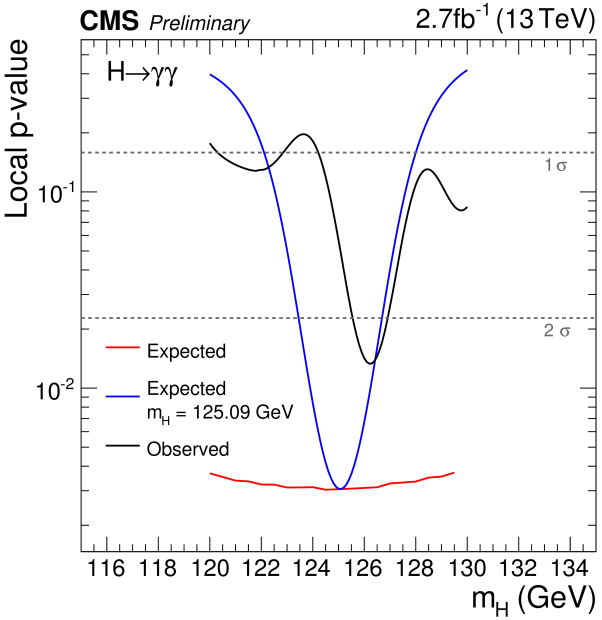
- Untagged, VBF, ttH categories
- **$\mu = 0.7^{+0.47}_{-0.42}$ at 125.09 GeV**
- **1.7σ obs** (2.7σ expected)

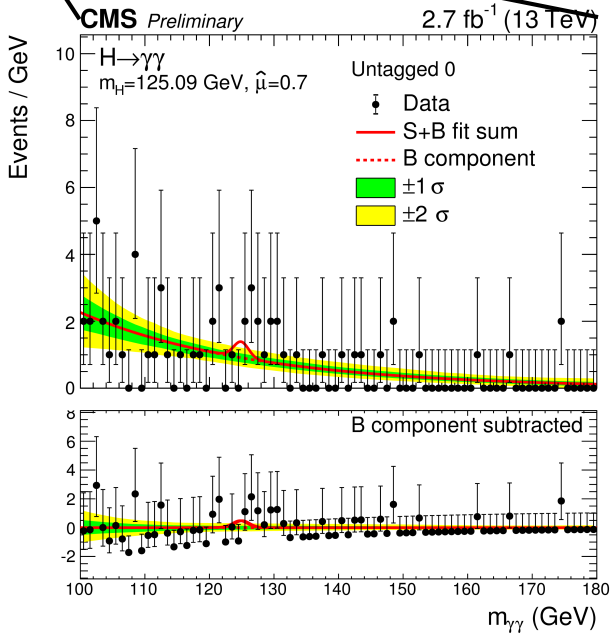


Categories with Diphoton BDT:

- Mass independant
- Kinematics, vertexing, PhotonId output, energy resolution variables

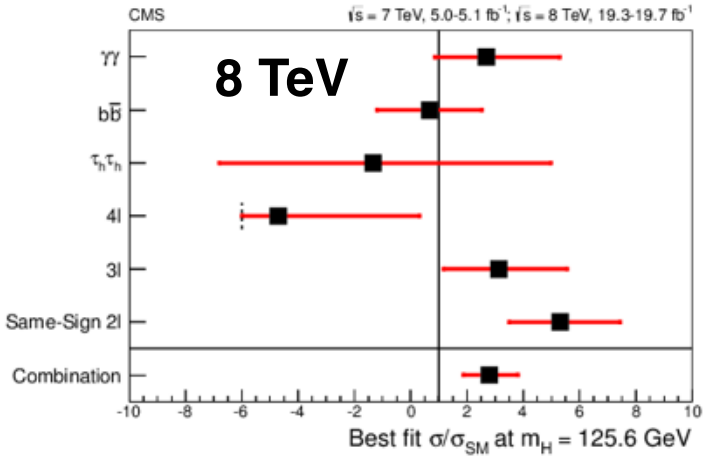






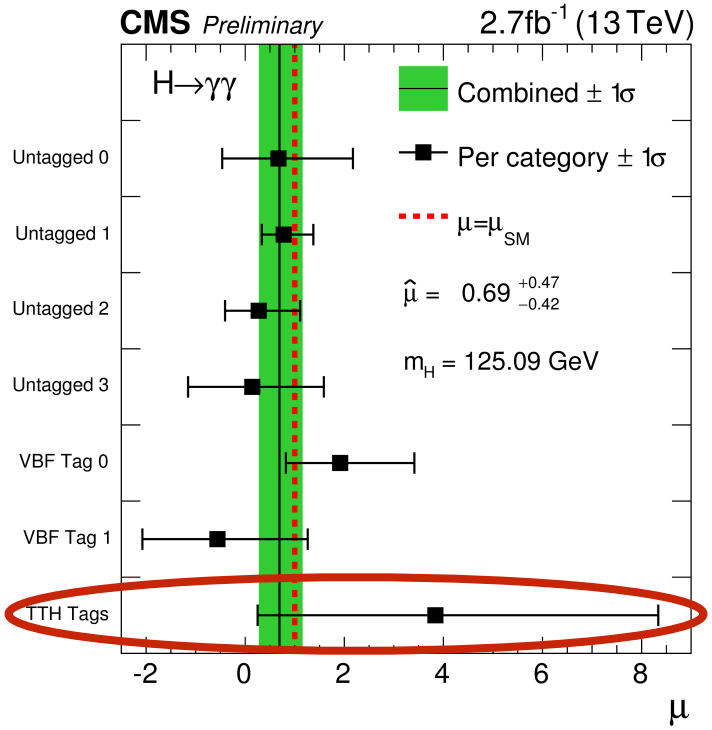
ttH,H→γγ

HIG-15-005



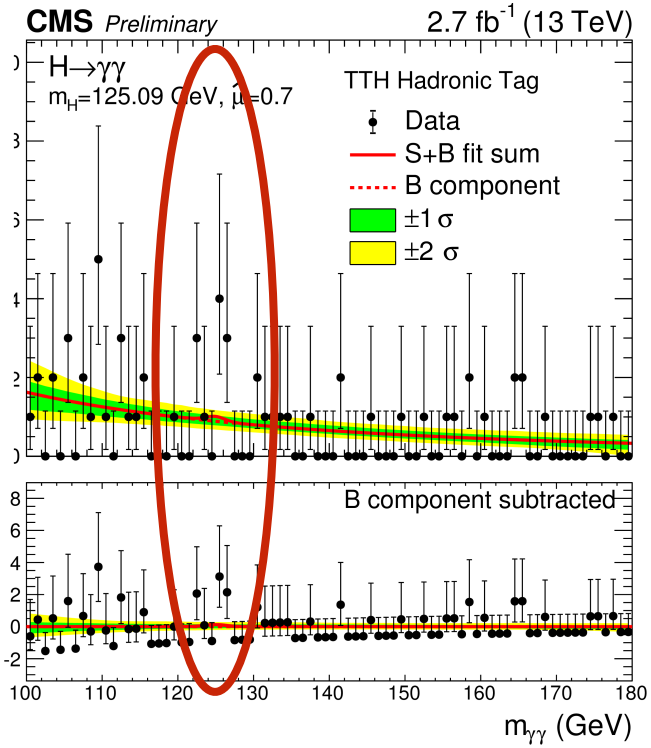
2 ttH categories: hadronic and leptonic

- Tighten photon pT/m requirement (ttH harder than ggh)
- Control region with inverted photonId

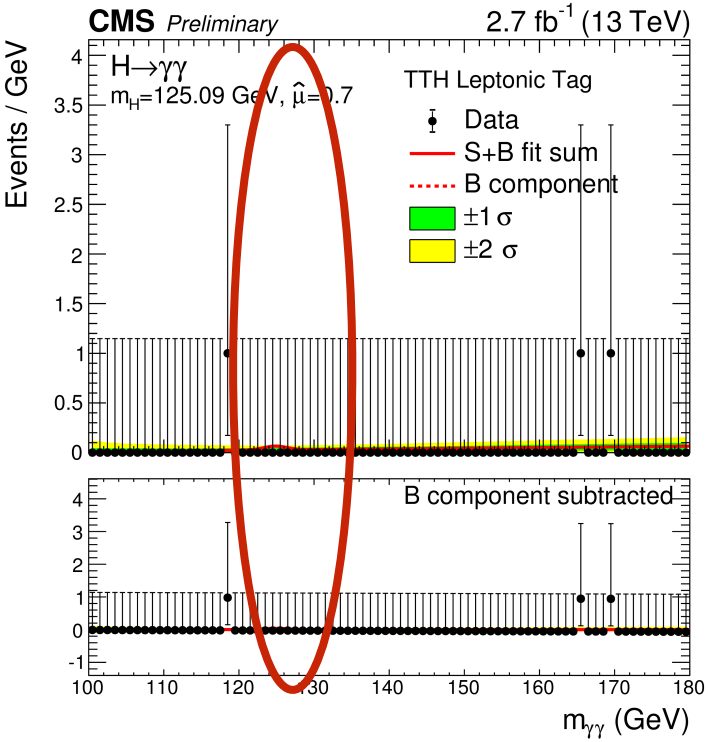


ttH hadronic/leptonic combined: **μ=3.8$^{+4.5}_{-3.6}$**

ttH hadronic tag: 0 lepton, ≥5 jets, ≥1 b-tag



ttH leptonic tag: ≥1 lepton, ≥2 jets, ≥1 b-tag



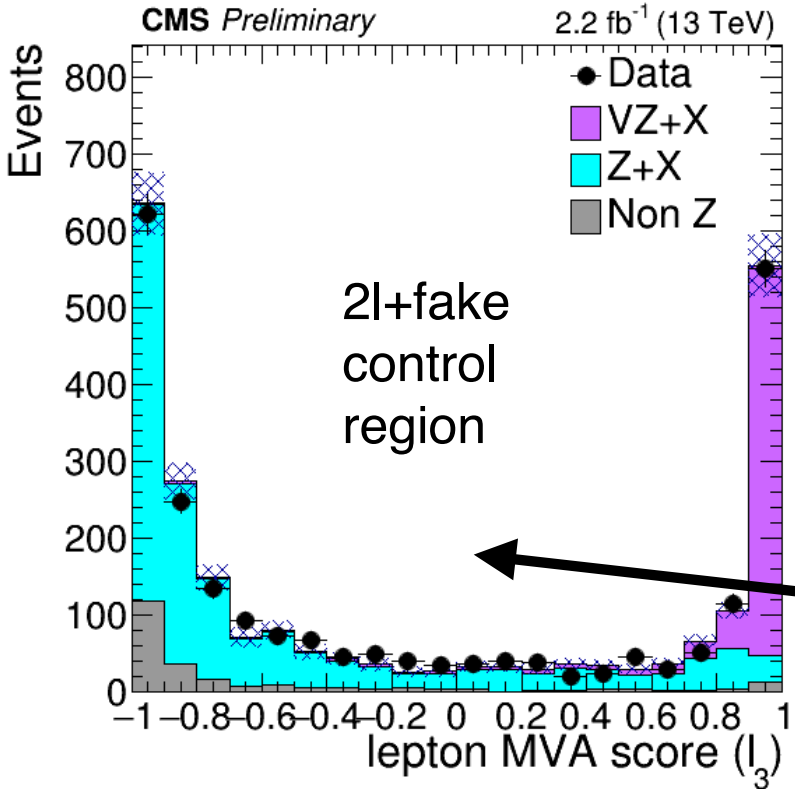
ttH multilepton

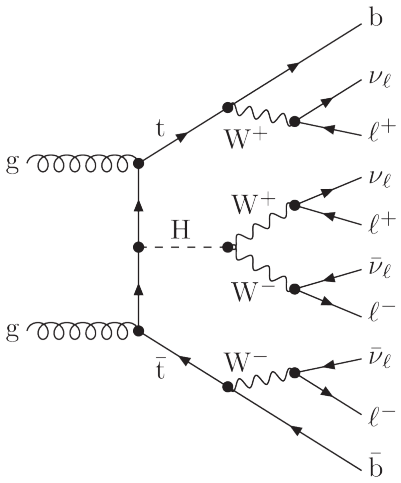
HIG-15-008

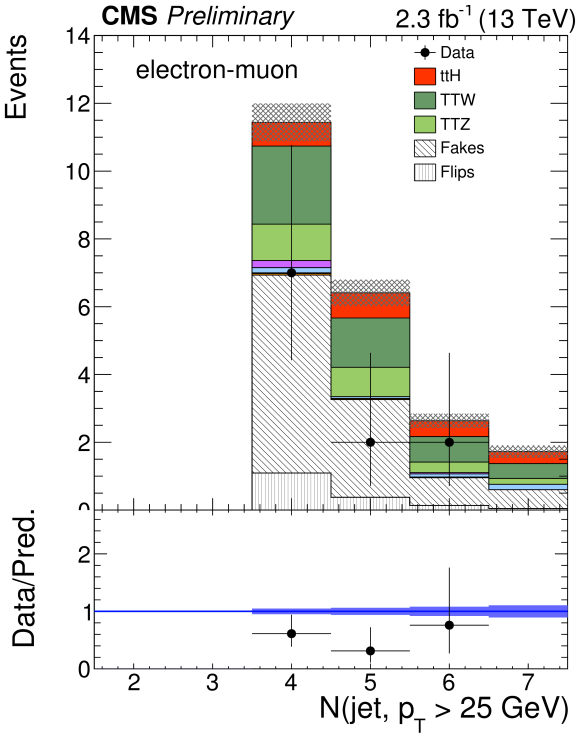
Collaboration IPHC - PKU:
Jing Li (PhD student)

Analysis targeting 2 lepton same-sign (2lss) and ≥3 leptons (3l)

- **Same sign:** ≥4 jets, ≥1 b-tag
- **3 leptons:** ≥2 jets, ≥1 b-tag
- **Backrounds:** tt+W/Z, tt+jets (same-sign required to reduce Drell-Yan and ttZ)
- Background normalisation from control region: loosened identification (fakes), Z to ll (mis-charge)



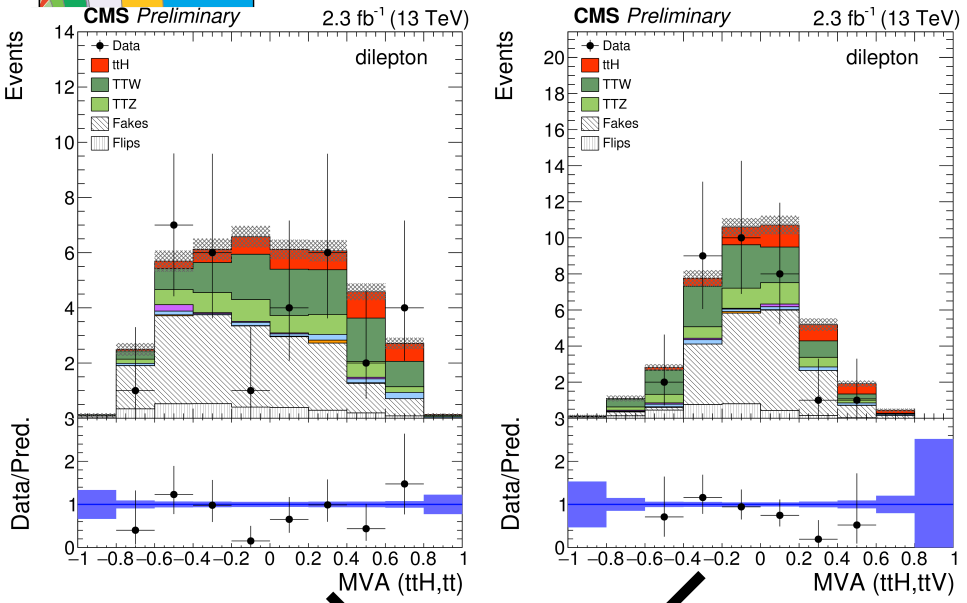




- **Lepton identification** with a BDT using shape, isolation and overlapping jet information

ttH multilepton

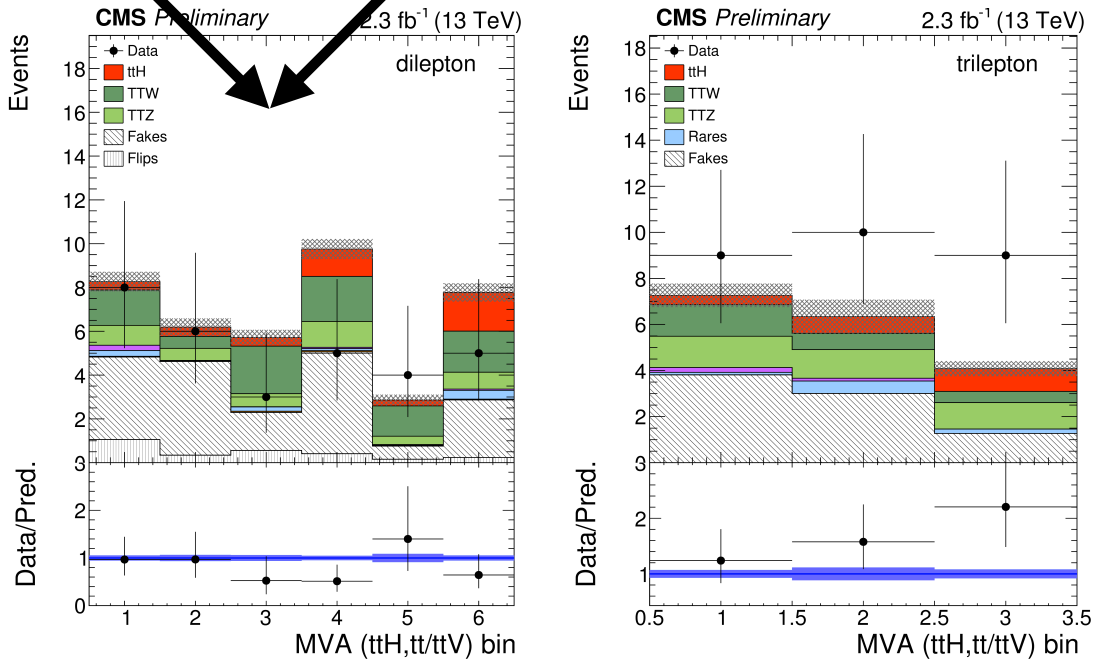
HIG-15-008

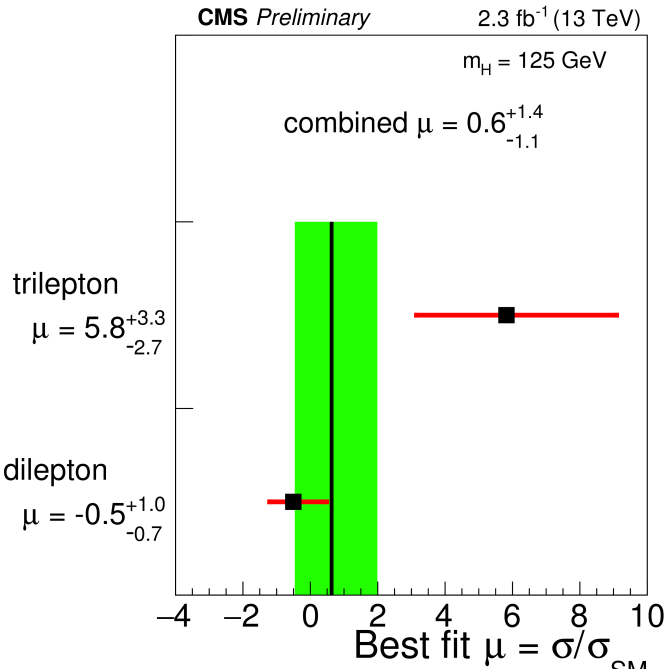


$\mu^{\pm}\mu^{\pm}$	$e^{\pm}\mu^{\pm}$	$e^{\pm}e^{\pm}$	3L
b tight $^{+-}$	b tight $^{+-}$	$^{+-}$	b tight $^{+-}$
b loose $^{+-}$	b loose $^{+-}$		b loose $^{+-}$
SS2L with hadronic tau			

Analysis sensitivity:

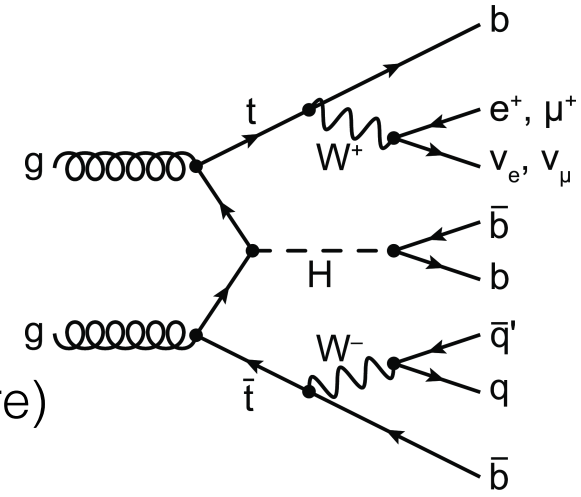
- Train **2 BDTs, against ttbar and ttW/Z**
- **2D BDT analysis : 5 bins (2lss), 3 bins (3l)**
- Measure combined **$\mu=0.6^{+1.4}_{-1.1}$**





ttH,H→bb

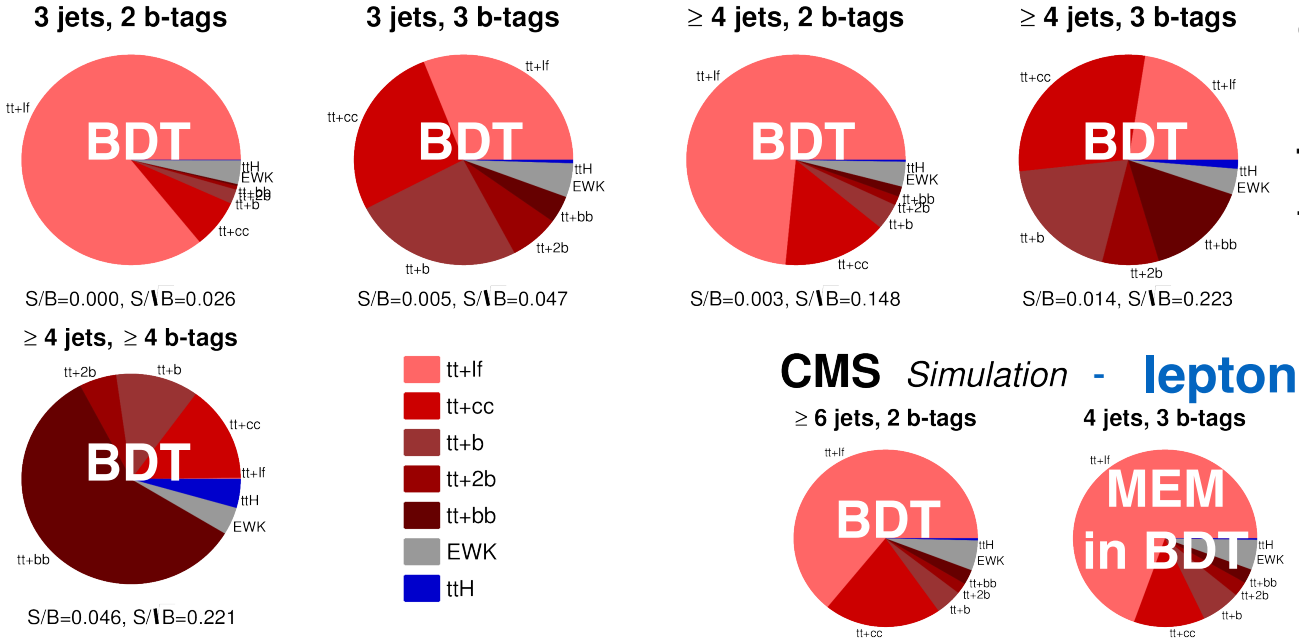
HIG-16-004



Analysis targeting lepton+jets and dileptons

- **l+jets:** =1 lepton, ≥4 jets, ≥2 b-tag
  - Includes **boosted jets** for the first time (fat jet substructure)
- **2l:** 2 opposite sign lepton, ≥3 jets, ≥2 b-tag

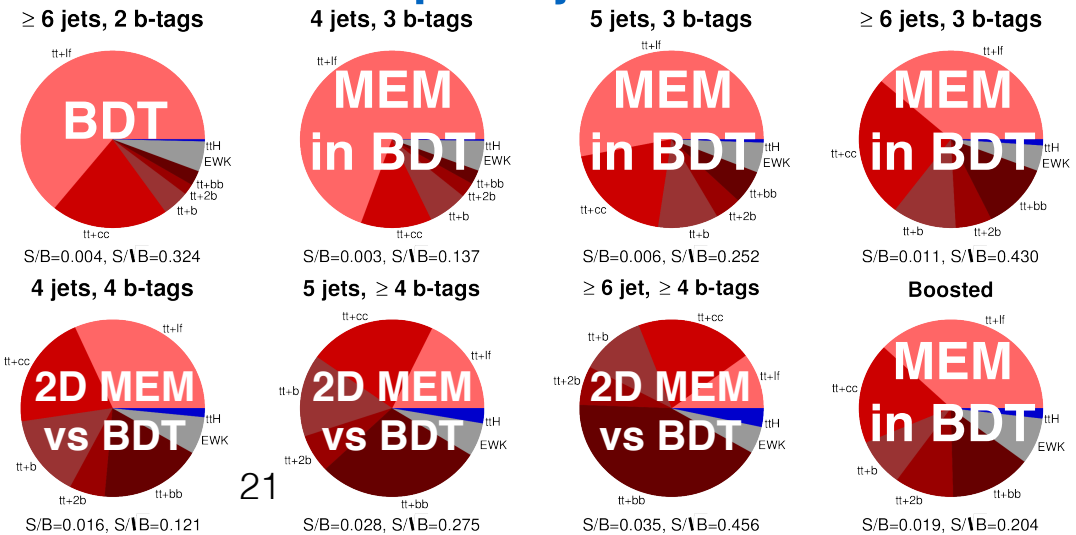
CMS *Simulation* - dilepton



Mass resolution ~10%, jet combinatorics: use **multivariate methods** in jet/b-jet categories

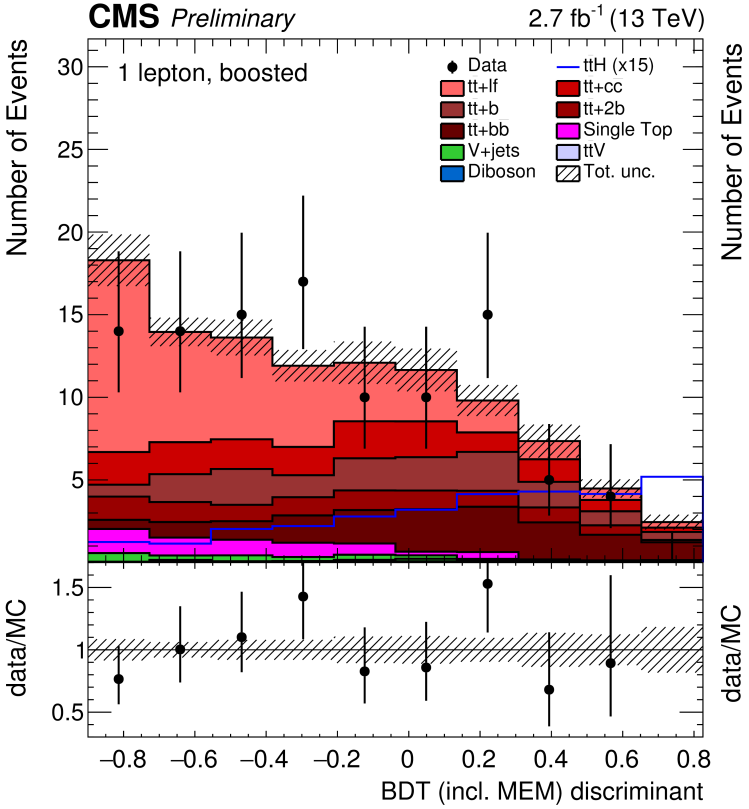
- **BDT**
- **Matrix Element Method** (MEM)

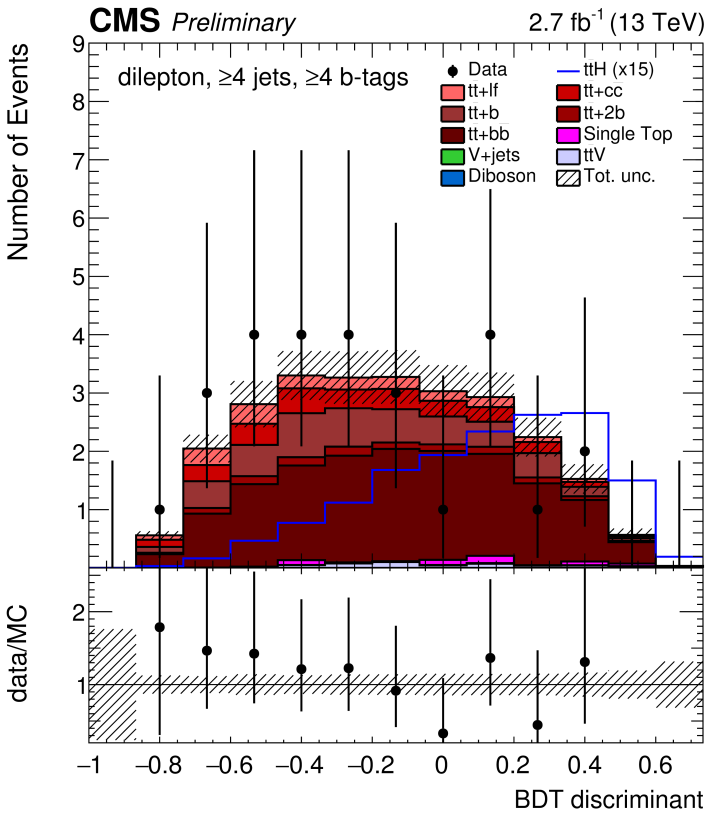
CMS *Simulation* - lepton+jets



ttH,H→bb

HIG-16-004

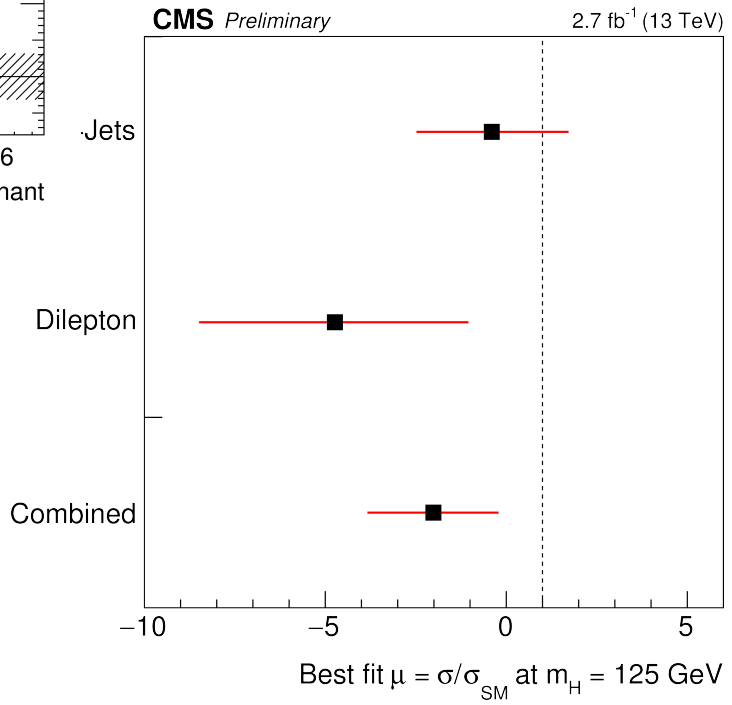




Example of discriminants for two categories

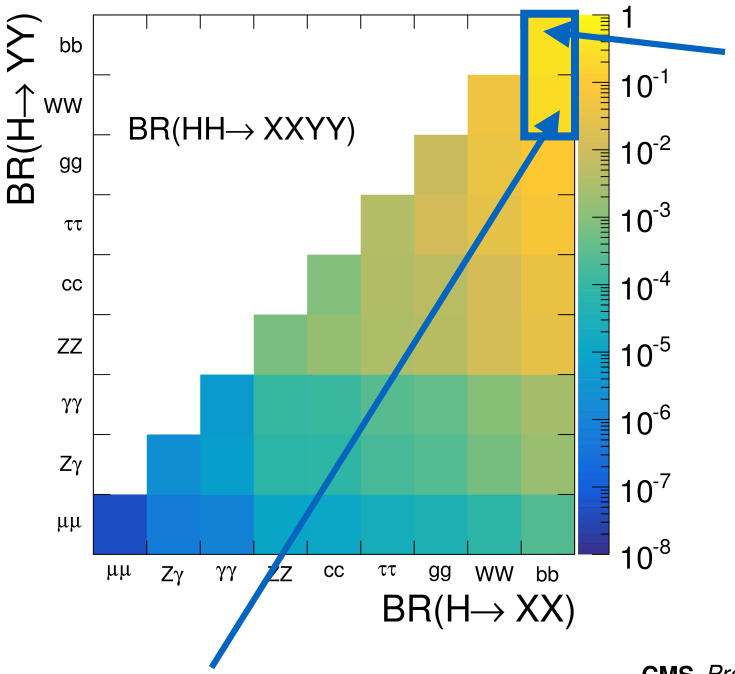
More data is needed for an observation

Channel	Best-fit μ	Observed UL	Expected UL
Lepton+jets	$-0.4^{+2.1}_{-2.1}$	4.0	$4.1^{+1.8}_{-1.2}$
Dilepton	$-4.7^{+3.7}_{-3.8}$	5.2	$7.7^{+3.6}_{-2.3}$
Combined	$-2.0^{+1.8}_{-1.8}$	2.6	$3.6^{+1.6}_{-1.1}$



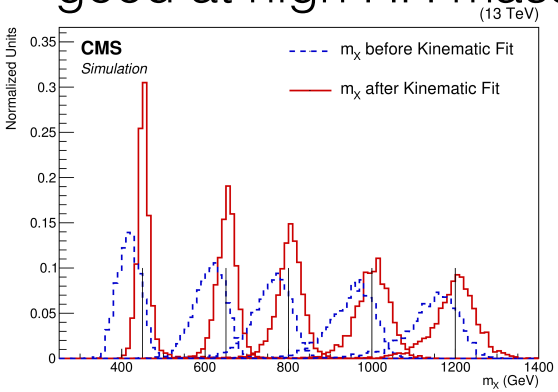
Double Higgs production

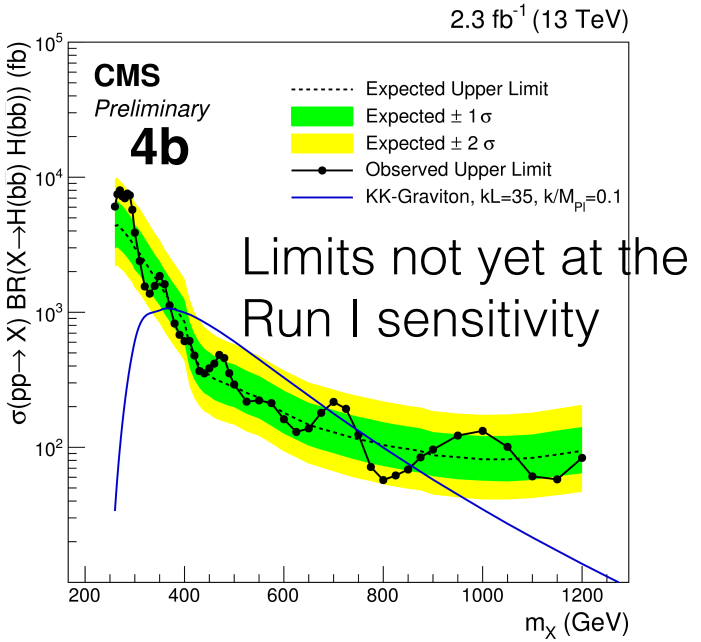
HIG-16-002, HIG-16-011



HH→4b

- Performs especially good at high HH mass

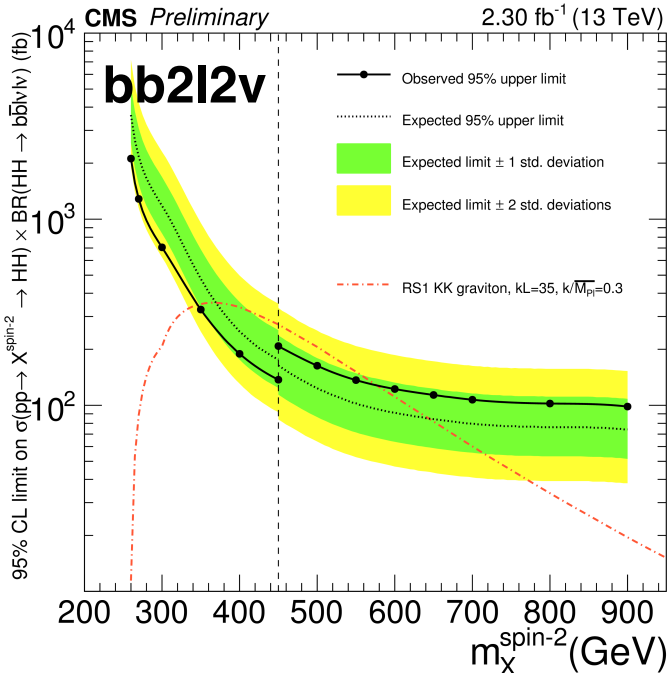


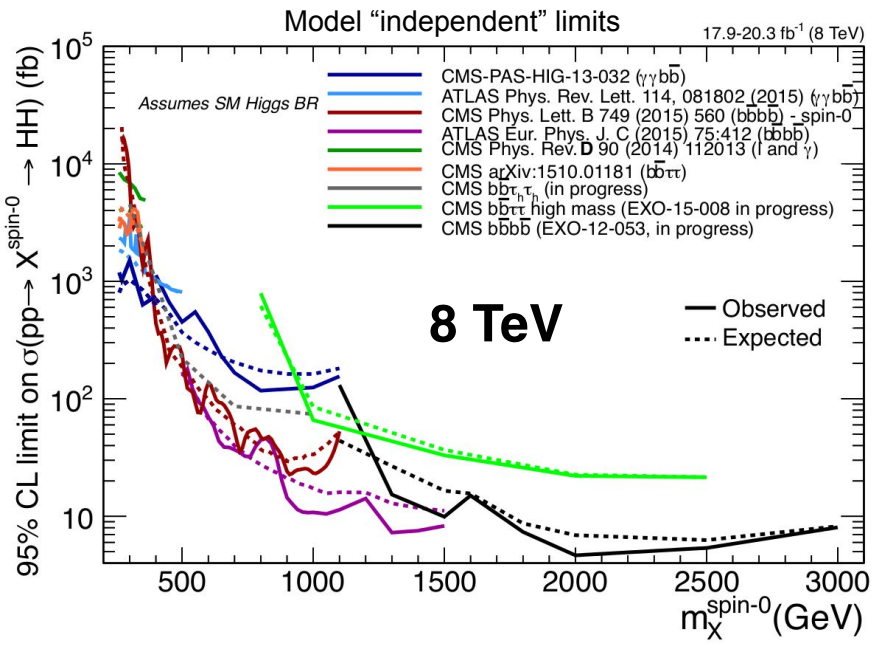


Limits not yet at the Run I sensitivity

HH→bbWW→bb2l2v

- First time this analysis is done at LHC
- Cut and count after selection on a kinematic BDT
- Too early to reach sensitivity to SM triple Higgs coupling: constrain BSM models



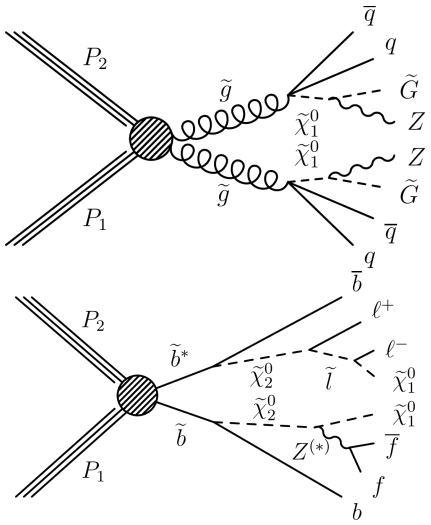


Beyond standard model searches

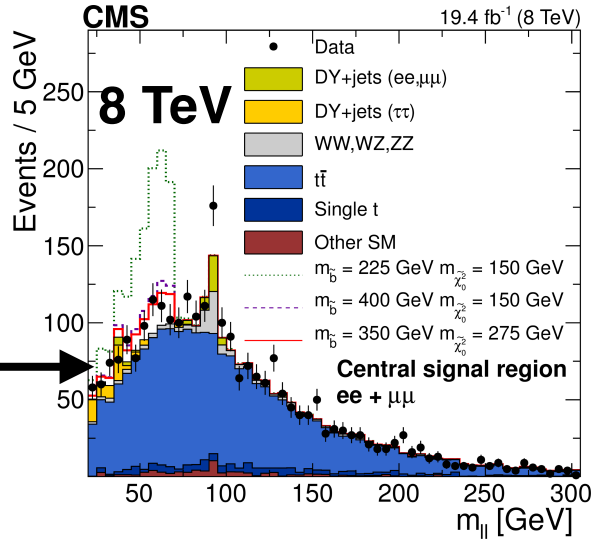
Supersymmetry: 2 opposite sign leptons

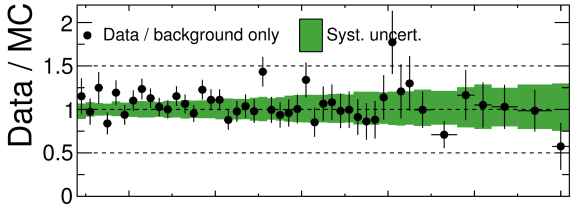
SUS-15-011

2 opposite sign leptons + jets + mET

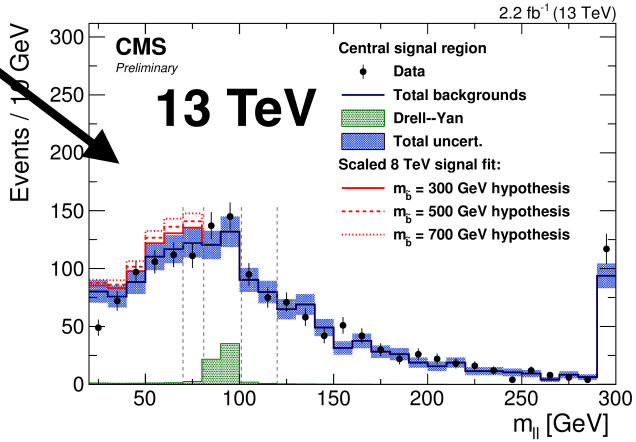


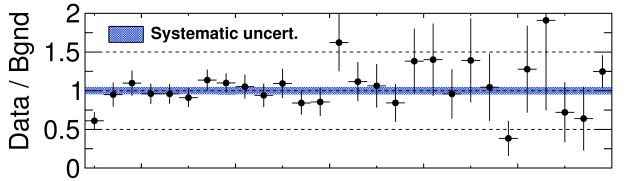
- **"edge" analysis**: CMS excess seen at run I was 2.6σ
- **On-Z** : ATLAS saw 3σ excess at Run I





8 TeV **"edge"** (scaled)



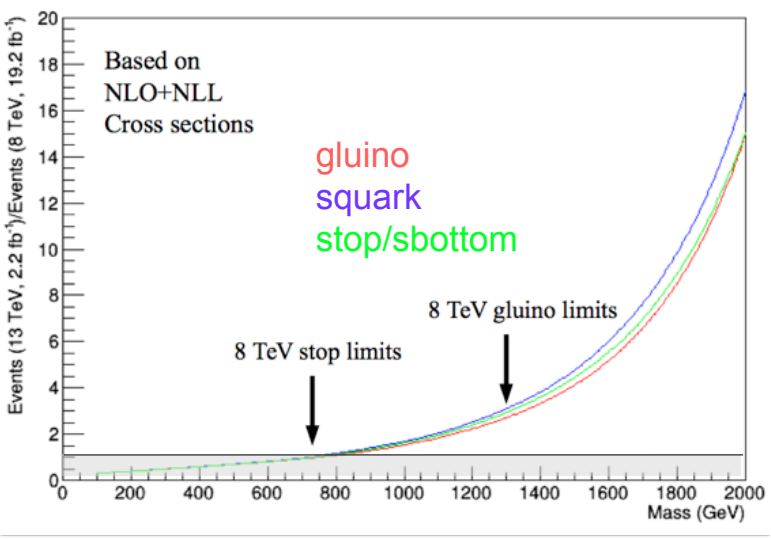


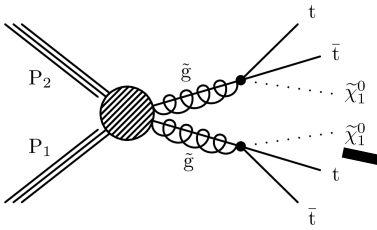
- **Same-flavour background** measured from data in opposite flavour sample (mainly ttbar)
- **Drell-Yan background** estimated from ETmiss template method in γ+jets control sample

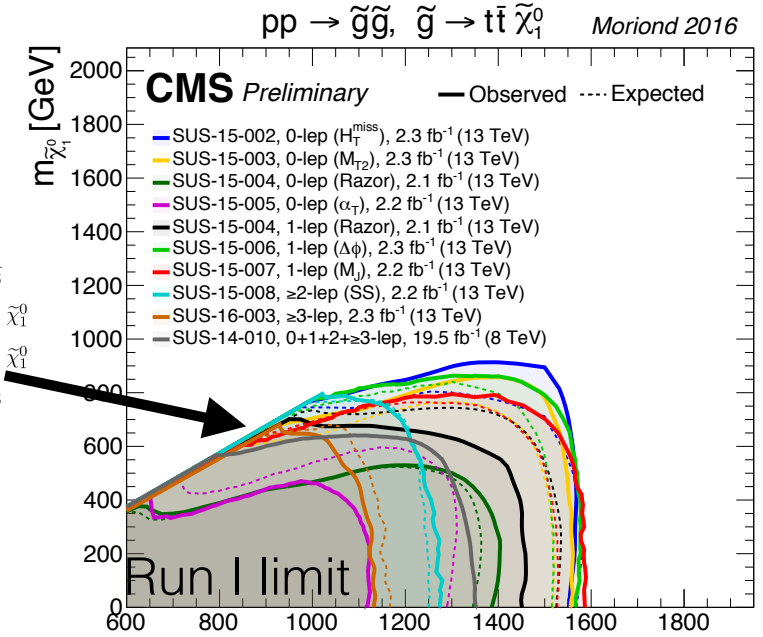
- No significant excess observed in 13 TeV data
- More data needed to exclude CMS Run I excess

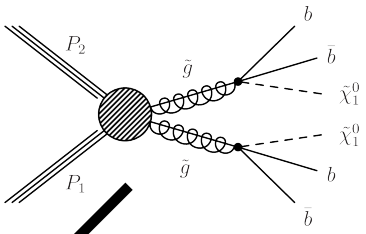
Supersymmetry: gluino/stop searches

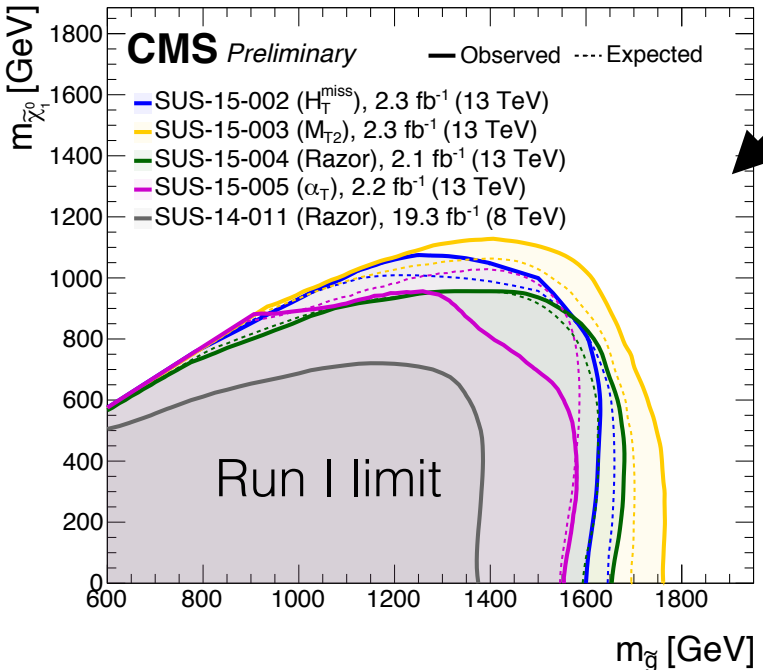
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

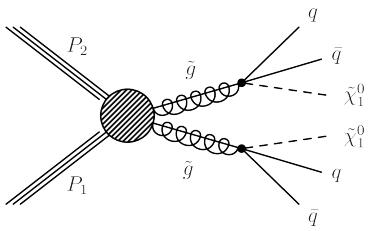


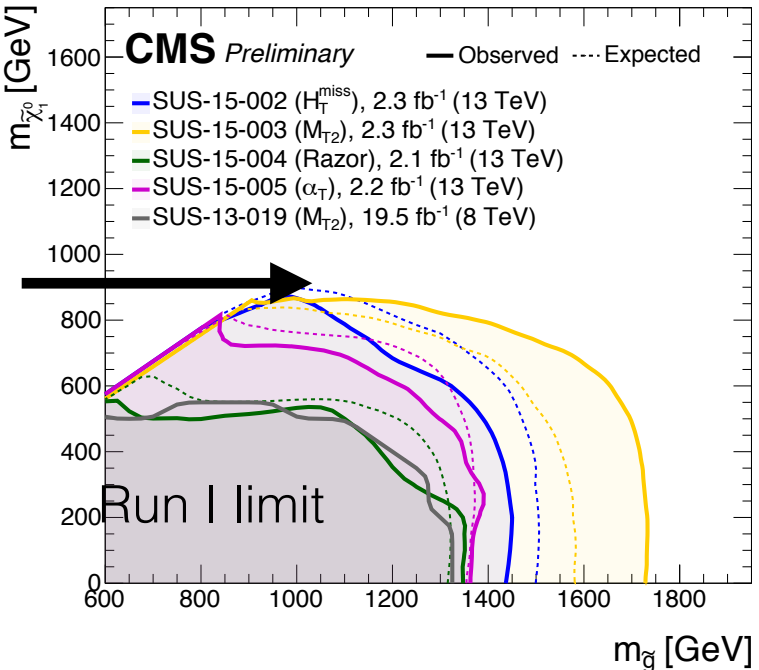












Supersymmetry: gluino/stop searches

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

A large number of SUSY analyses already public

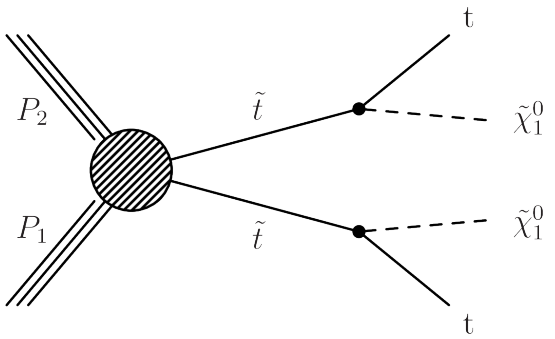
Analyses with best sensitivity to strong production are all-hadronic, for instance:

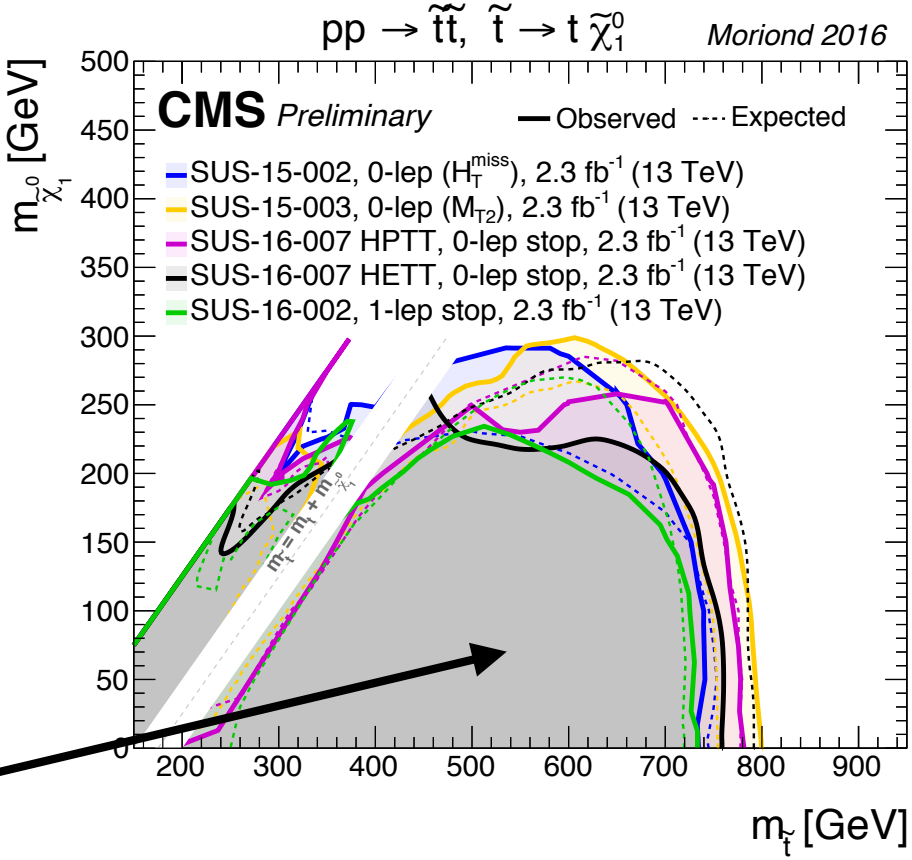
HTmiss analysis (SUS-15-002)

- At least 4 jets, large HT (scale sum pT of jets), large HTmiss (vector sum of jets momenta)
- Many search regions in number of jets, b-jets, HT and HTmiss

MT2 analysis (SUS-15-003)

- Similar strategy, using an transverse mass-like variable

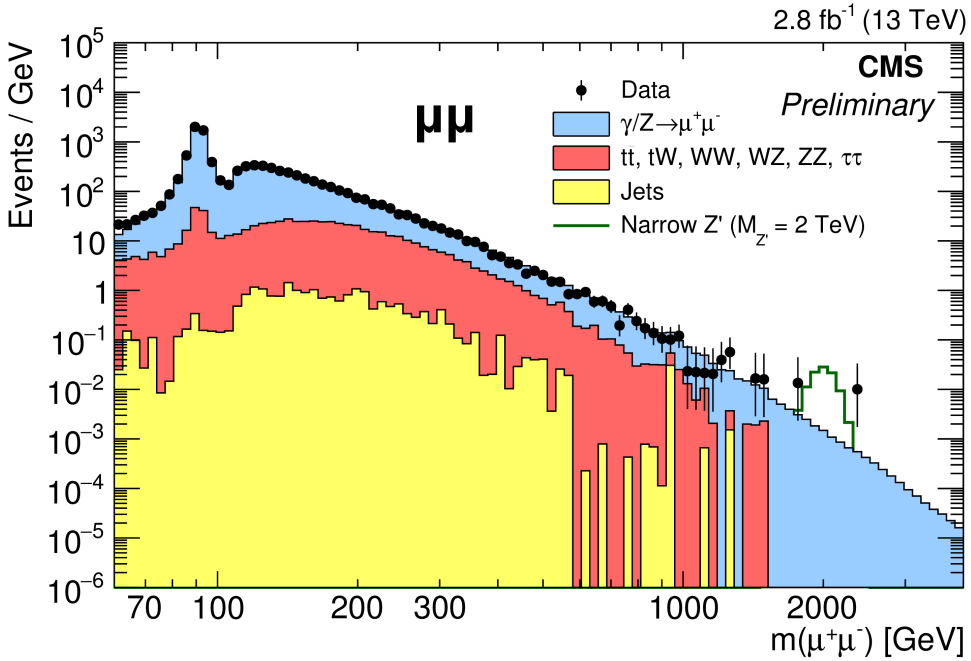


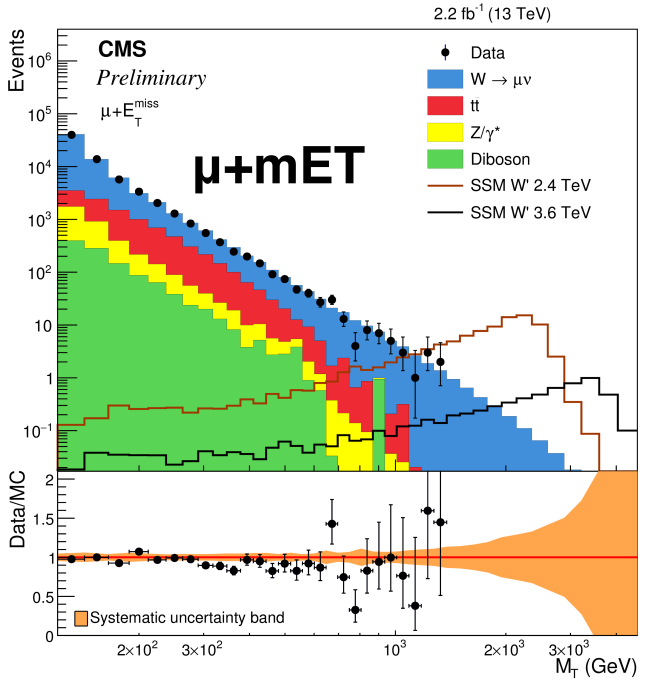


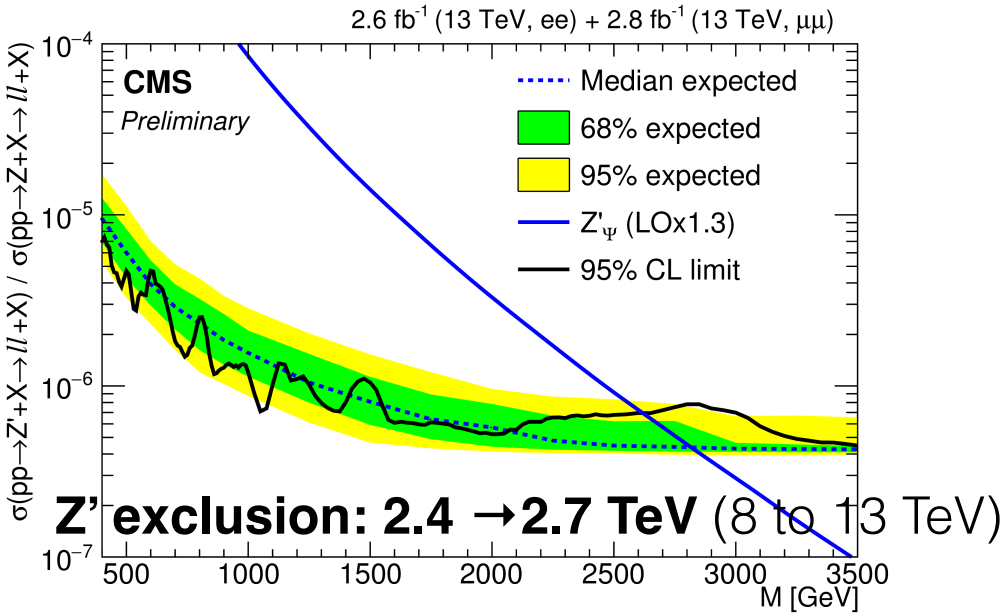
- **Exclusion limits on gluino up to < 1.7 TeV**, for simplified models and low LSP mass: significantly **exceeds Run I limits**
- **Stops limits** are similar to 8 TeV (~same number of events expected)

Search for W' or Z' resonances

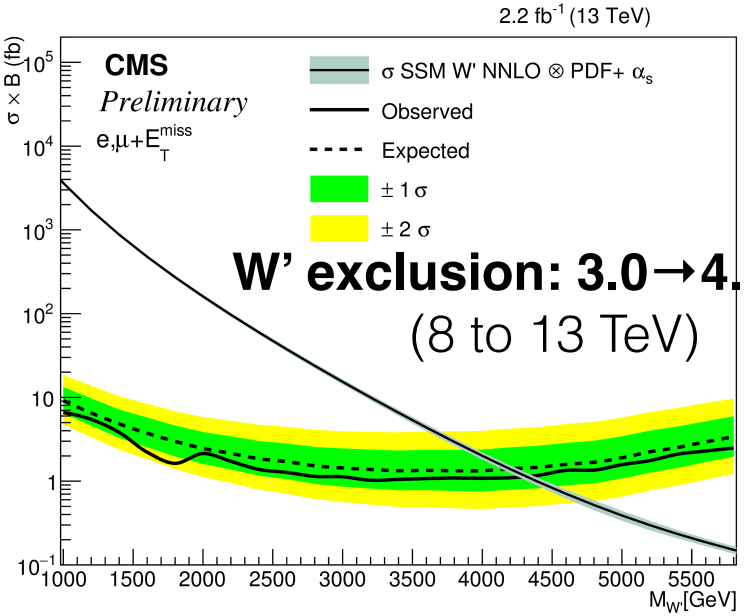
EXO-15-005, EXO-15-006







Z' exclusion: 2.4 →2.7 TeV (8 to 13 TeV)



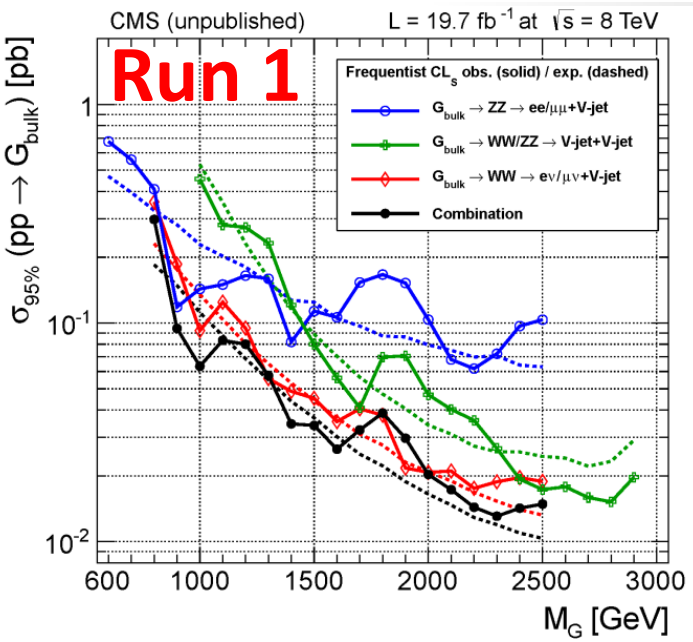
W' exclusion: 3.0→4.3 TeV
(8 to 13 TeV)

Diboson high mass searches

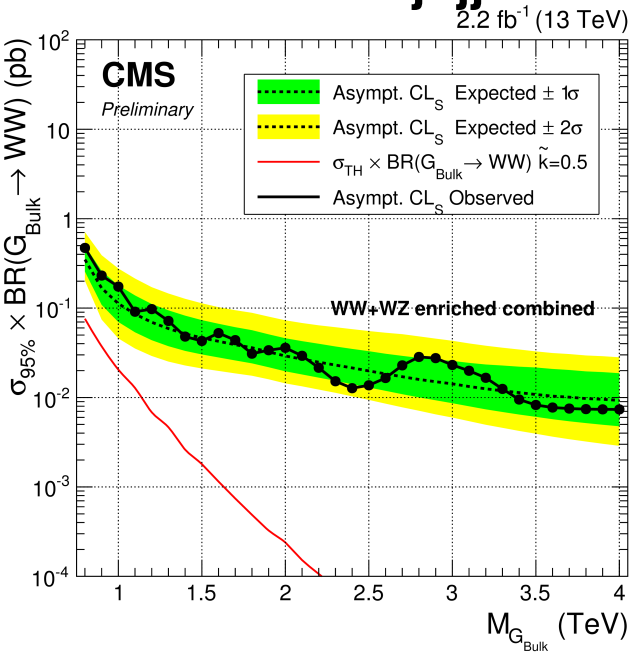
EXO-15-002

Run I: 2σ excess near 1.8-2.0 TeV

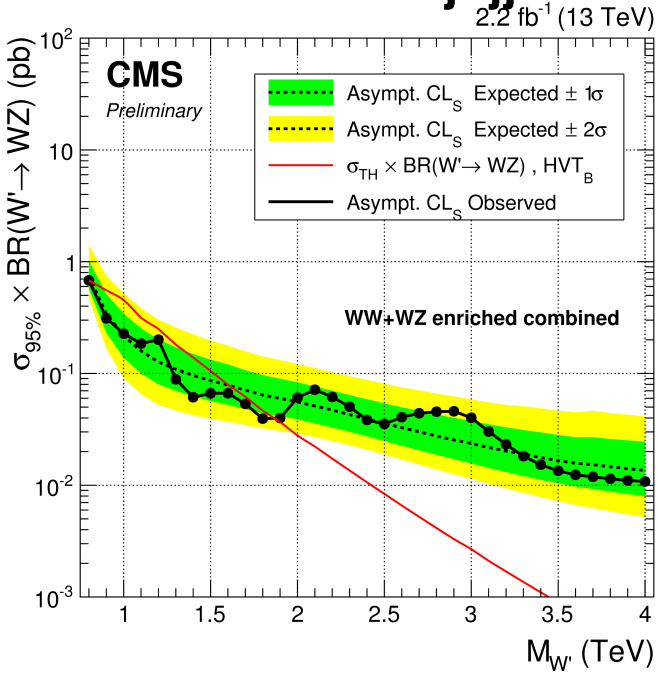
- Repeat searches using most sensitive categories: **hadronic and semi-leptonic**
- **Boosted W/Z-jets** reconstructed with anti-kt 0.8 algorithm, further identified with jet substructure
- Categorization in dijet mass for optimal sensitivity to WW,WZ,ZZ signals
- 13 TeV: no excess found around 2 TeV, more data needed to exclude run I excess



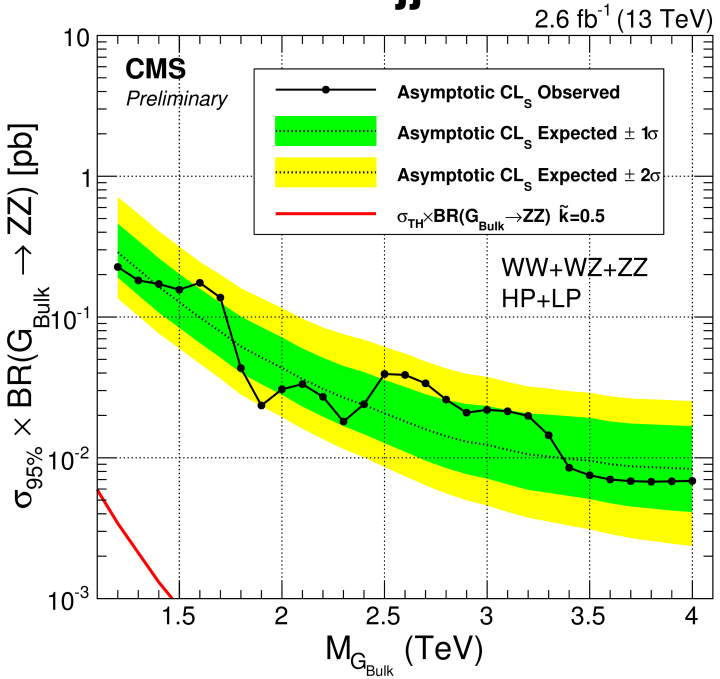
WW→lνj+jj



WZ→lνj+jj



ZZ→jj

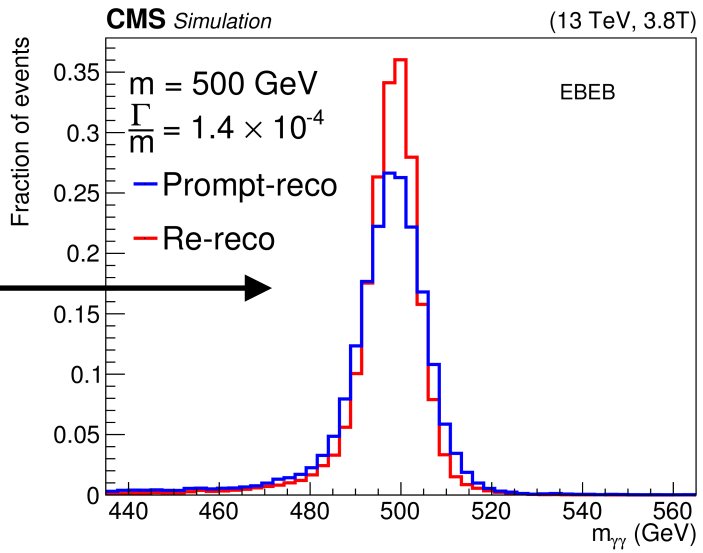


High mass searches with diphotons

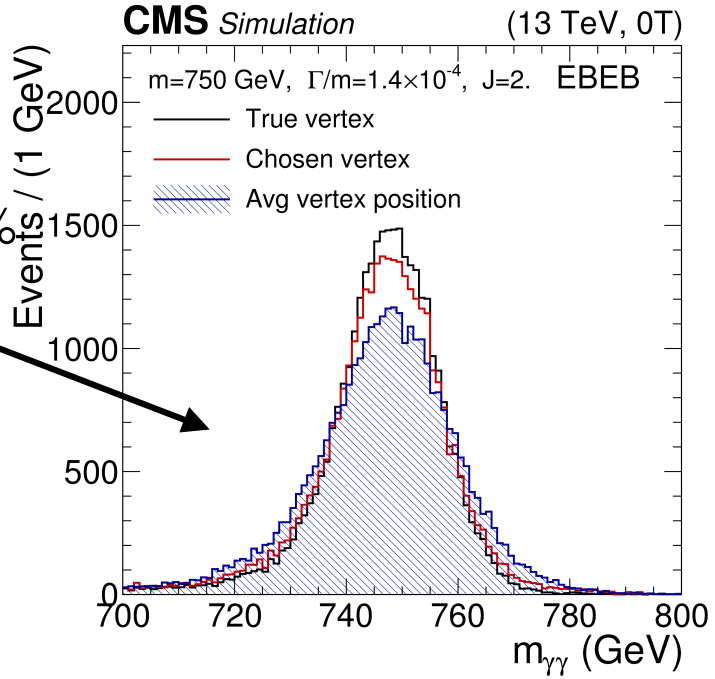
EXO-16-018

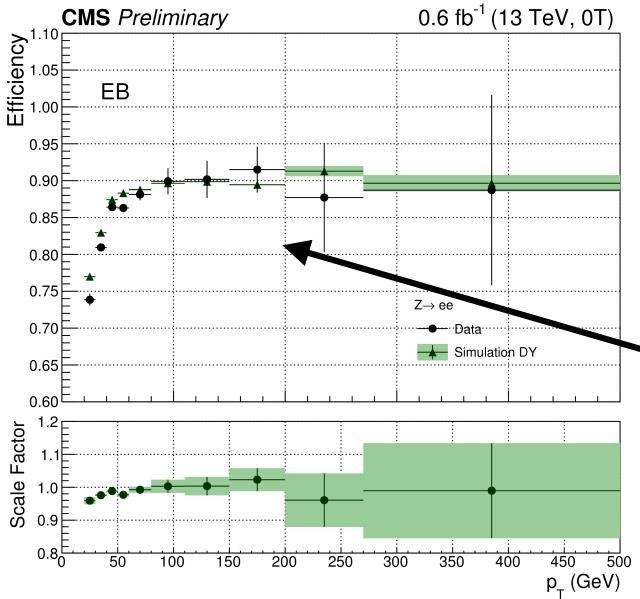
Analysis updated since December Jamboree

- **New ECAL calibration**:
  - **resolution improved by ~30%** (10% better analysis sensitivity)
- Includes **data with no magnetic field: 0.6 fb-1**
  => 0T improves also sensitivity by 10%
  - **Updated calibration:** 1% difference in energy scale correction relative to 3.8T



- **0T Vertexing:** simple track counting, 60% efficient (90% efficient at 3.8T)





- **0T photon identification**: efficiency similar at high photon pT

High mass searches with diphotons

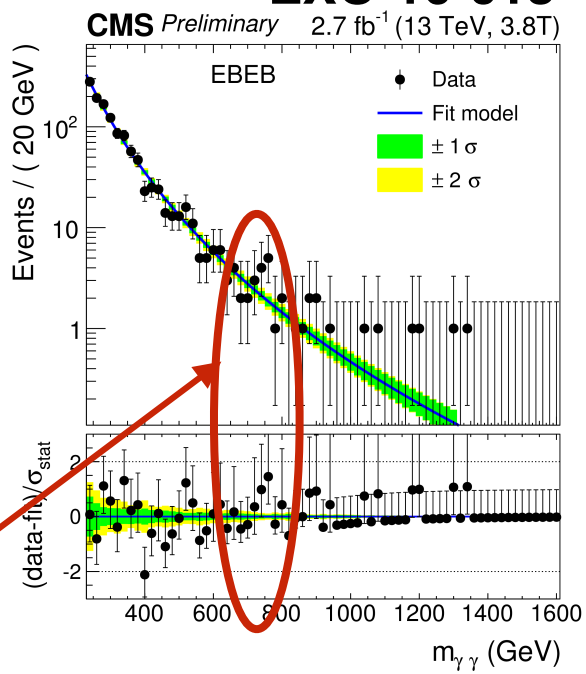
Mass fit with

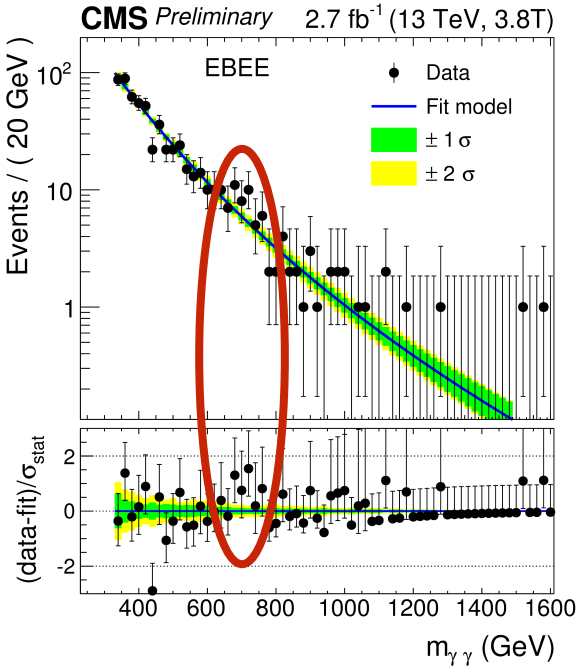
$$f(m_{\gamma\gamma}) = m_{\gamma\gamma}^{a+b\cdot\log(m_{\gamma\gamma})}$$

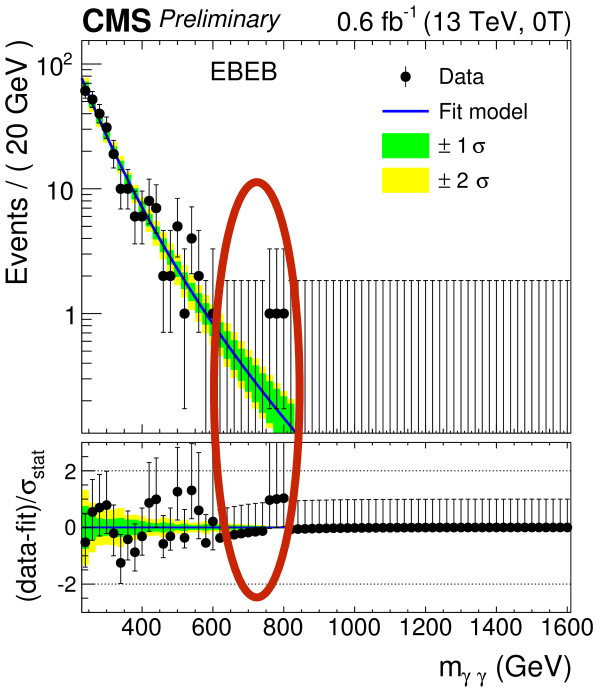
- parameters as nuisance parameters
- Possible mismodeling accounted in the systematic uncertainties

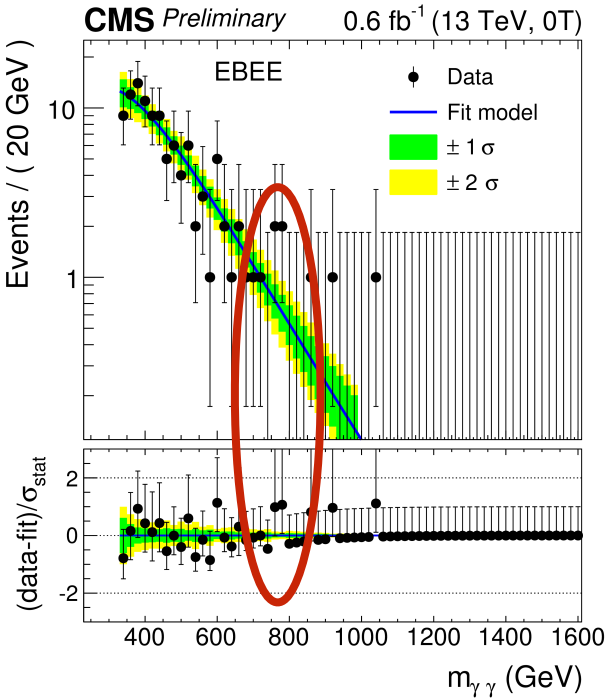
Excess driven by category with **two photons in the barrel, at 3.8 T**

EXO-16-018







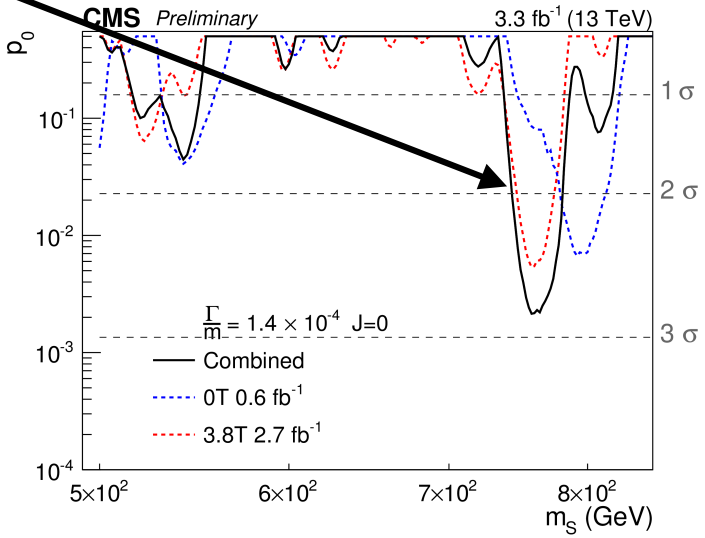


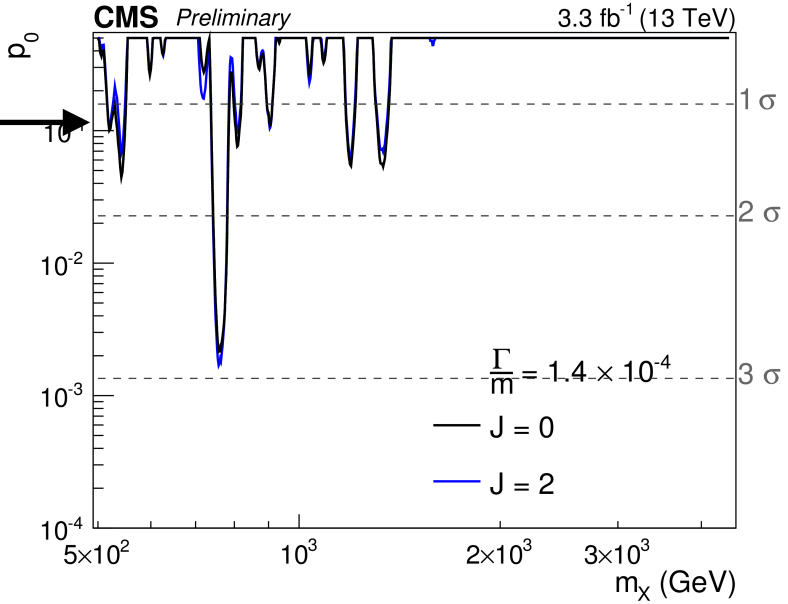
High mass searches with diphotons

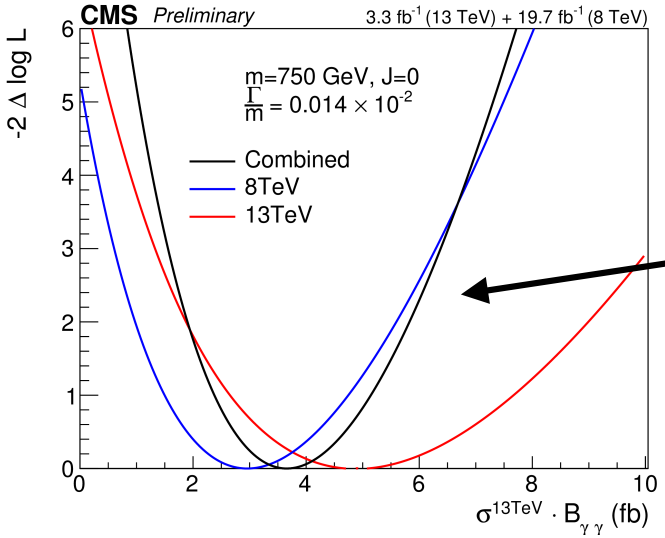
EXO-16-018

Largest excess: m_X=760 GeV and Γ/m=1.4x10^{-4}

- Interpretation: **spin 0** and spin 2 resonance
- **Compatibility between 0T and 3.8T** datasets

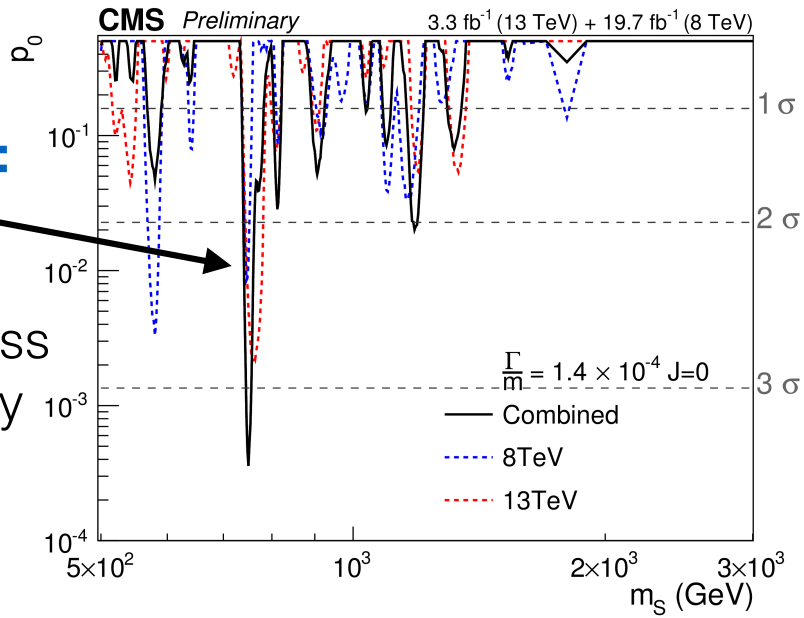






Combination with 8 TeV:

- **Local p-value: 3.4σ**
- **Global p-value: 1.6σ**
- Compatibility with excess seen at 8 TeV, scaled by J=0 cross-section ratio (x4.2)



Conclusions

Standard model measurements

- Standard model program at 13 TeV well started : first (differential) cross sections, vector bosons and top quark production

Higgs boson physics

- First measurements available (diphoton, ZZ), more data needed for a rediscovery at 13 TeV
- ttH analyses in main channels are ready, more data is also needed here

Beyond standard model searches

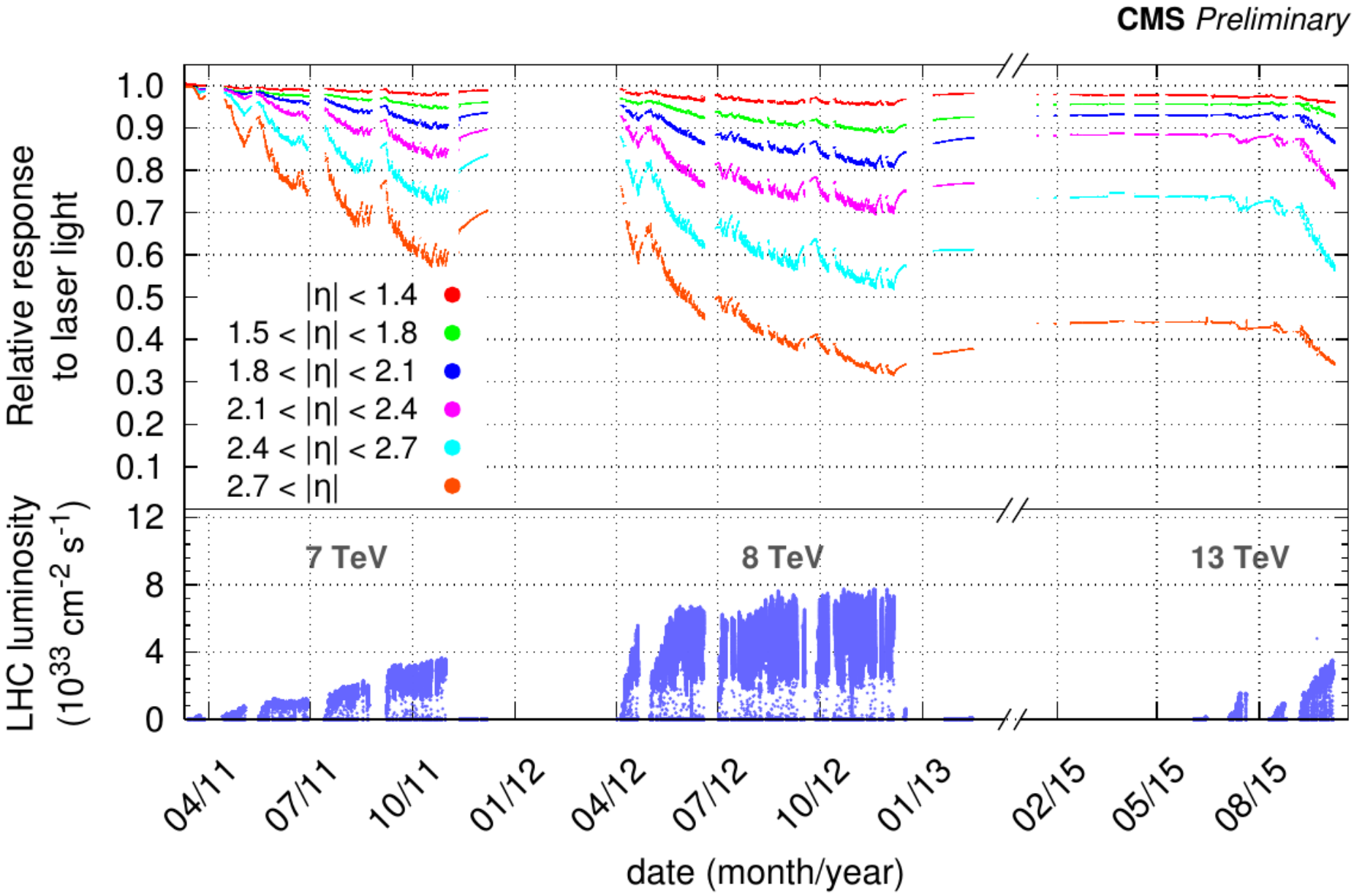
- A large number of SUSY analyses pushing limits in strong production are available
- Some Run I excesses did not show up (yet?) at 13 TeV
- Further analysis of diphoton shows a modest excess at 760 GeV

Many more CMS analyses are public and were not presented in this talk !

2016 data taking period will start soon: hopefully it will tell us more about the Higgs coupling to fermions, a possible new resonance and maybe some other surprises !

Back-up slides

ECAL laser monitoring

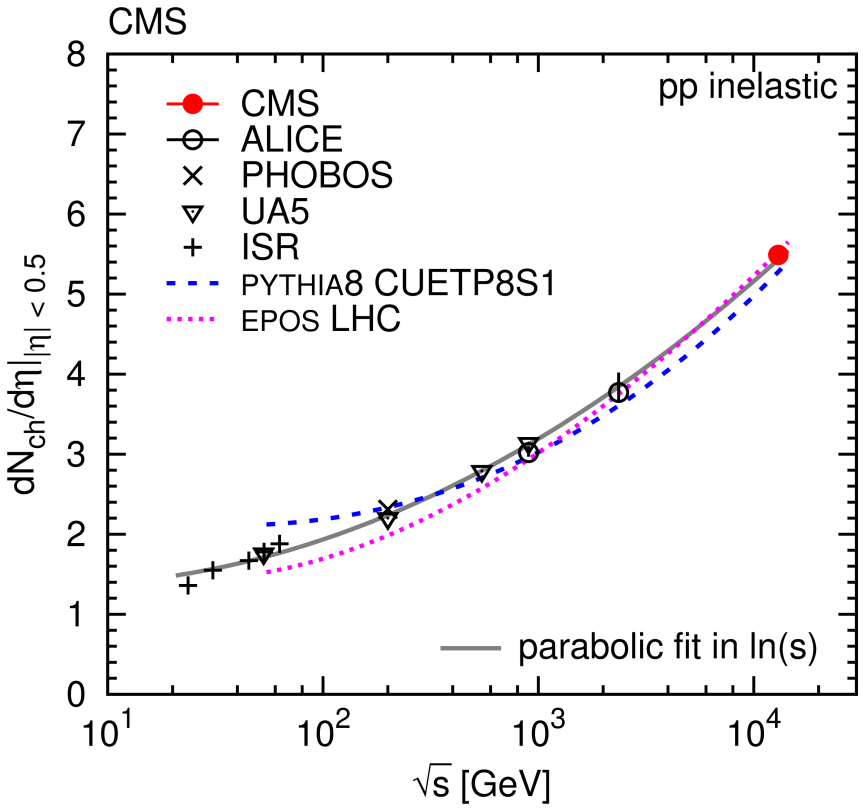


Charged particles and the “ridge”

FSQ-15-001, FSQ-15-002

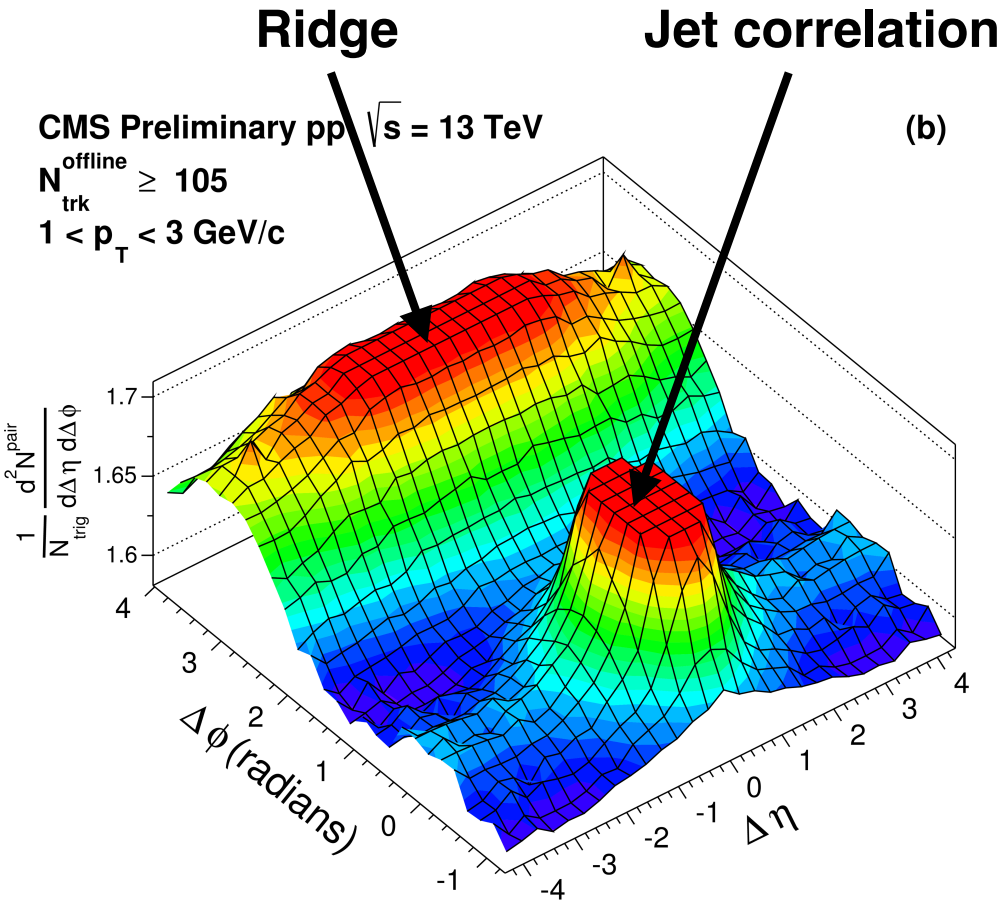
Measurement of pseudo-rapidity of charged hadrons (dN/dη)

- Data consistent with expected center of mass energy dependence



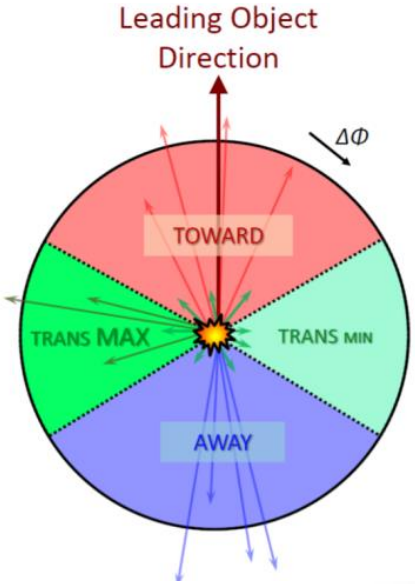
Two-particle correlation

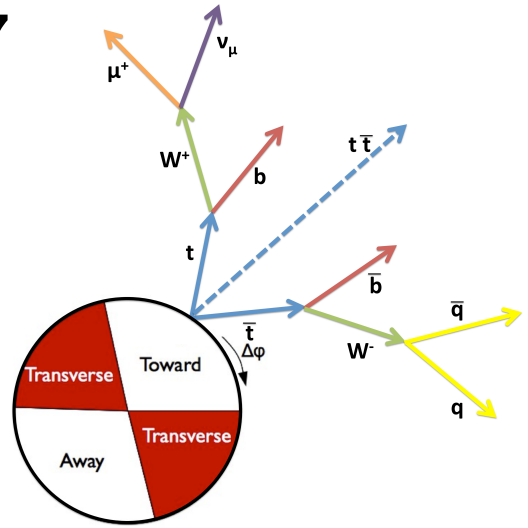
- In events with high track multiplicity Ntk>105
- Confirms presence of a ridge-like structure, similar to Pb-Pb

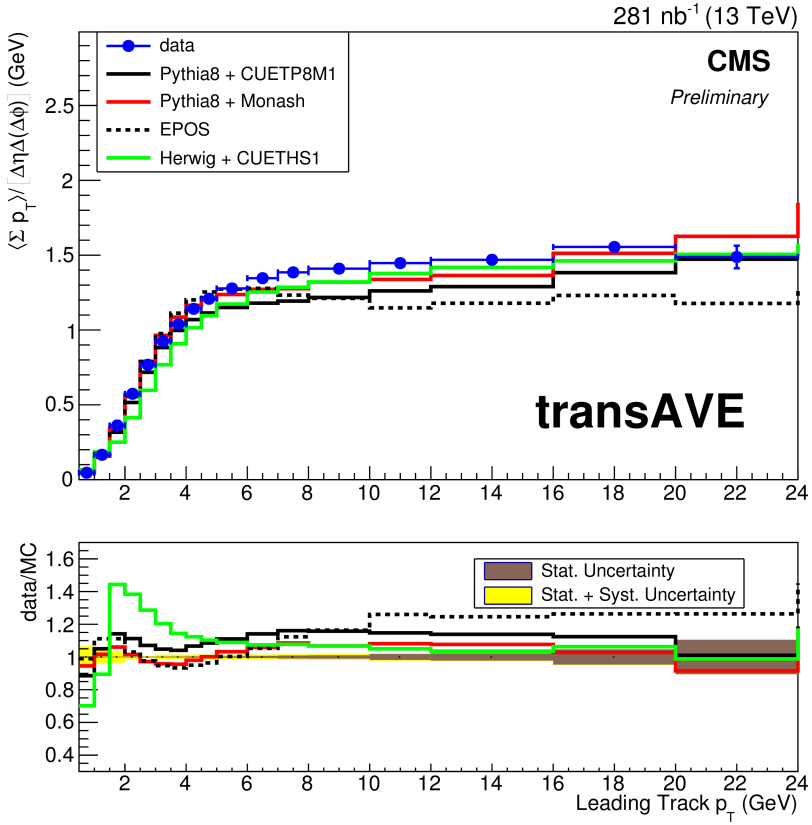


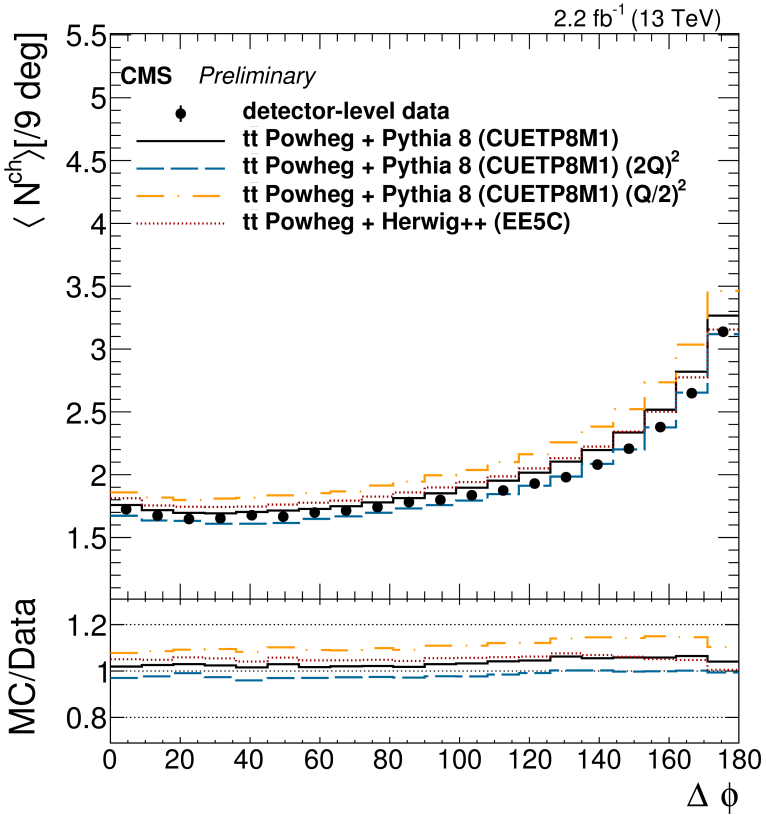
Underlying event

FSQ-15-007, TOP-15-017



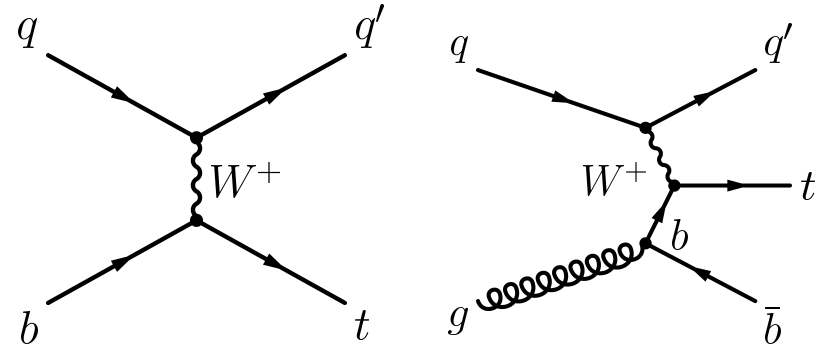




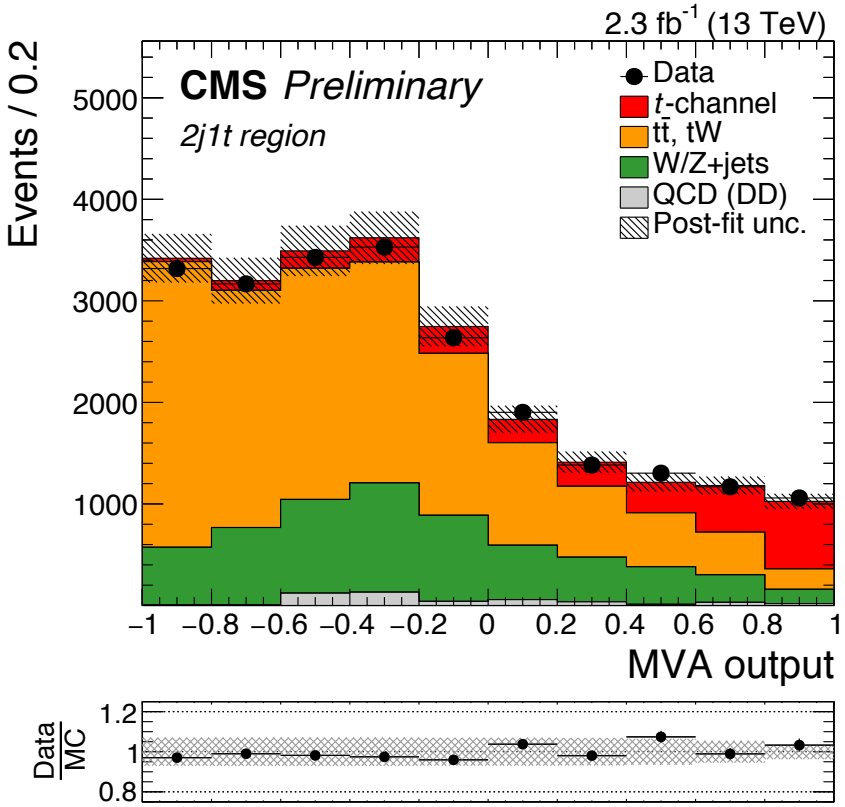


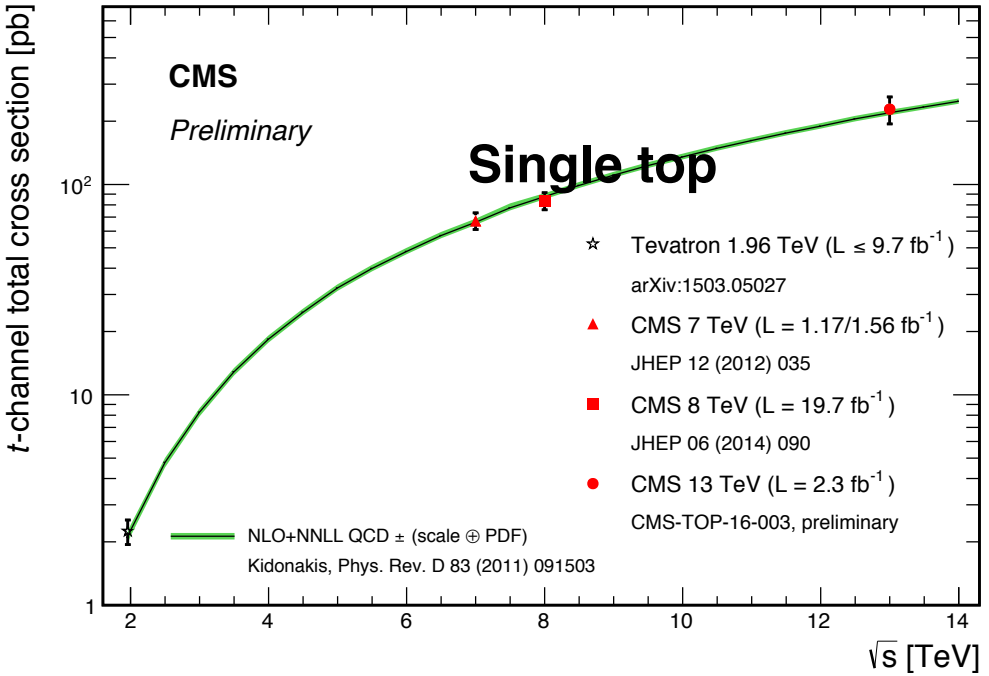
t-channel single top

TOP-16-003



- t-channel is dominant at the LHC (s-channel and tW amount to 20% of single top)
- Analysis with muon+jets final state
- Statistical treatment : fit of neural network output in each jet/b-jet category
- Most important variable: |η| of light jet (forward in t-channel)



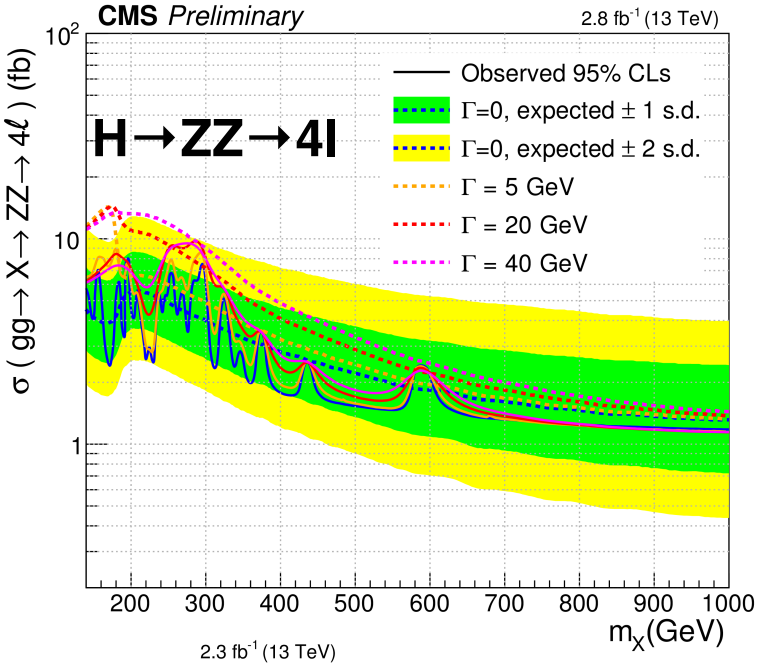


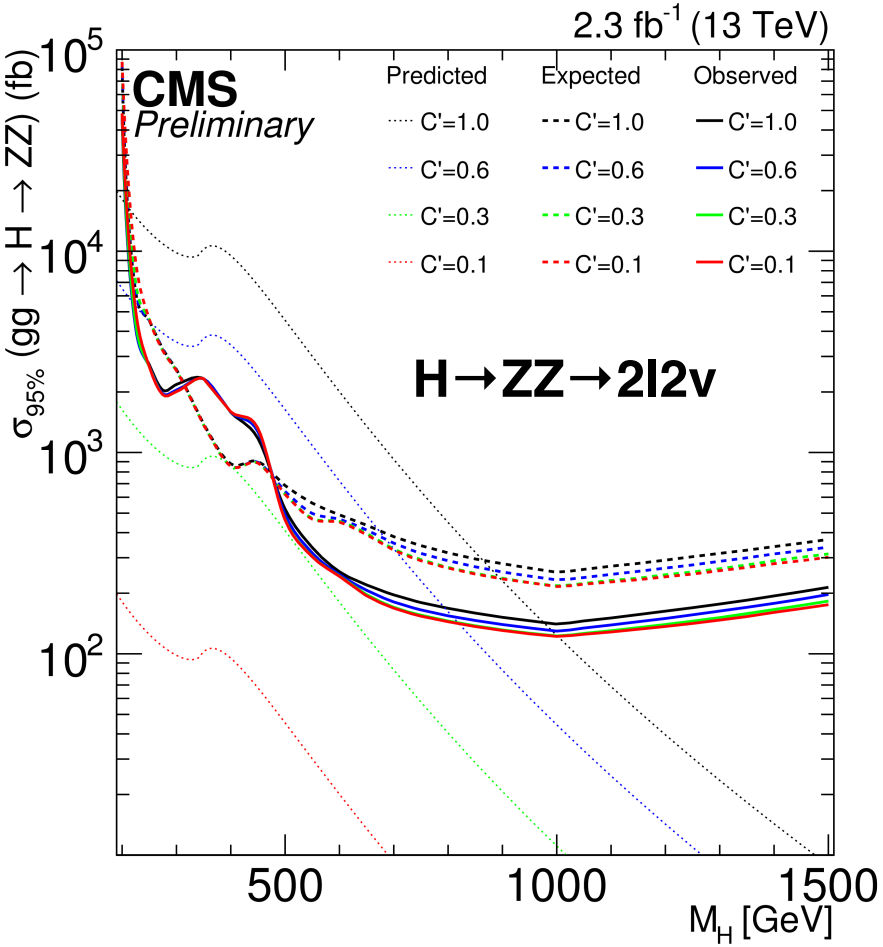
High mass Higgs boson searches

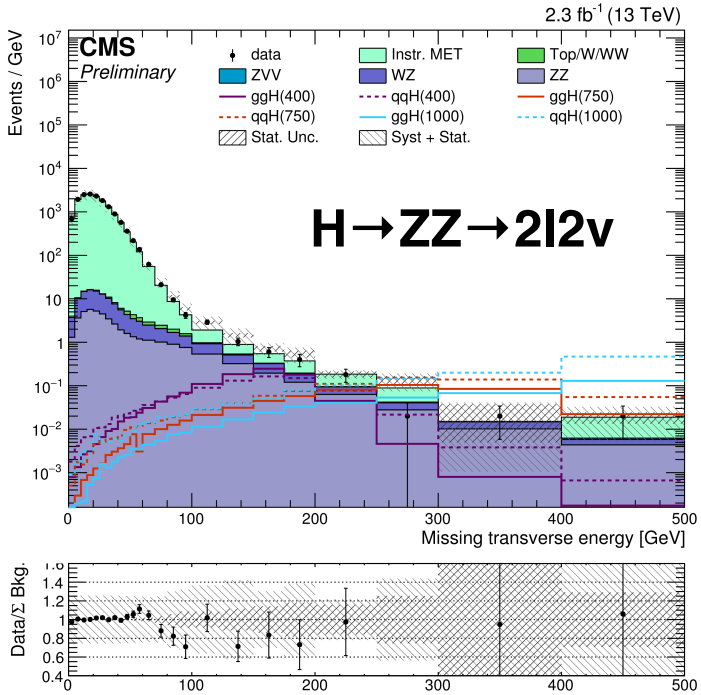
HIG-15-004, HIG-16-001

Various searches performed at high Higgs mass

- **H→ZZ→4l** with various width, and in 2HDM
  - No event beyond 600 GeV
- **H→ZZ→2l2v** in 2HDM models
  - No excess found up to 1500 GeV



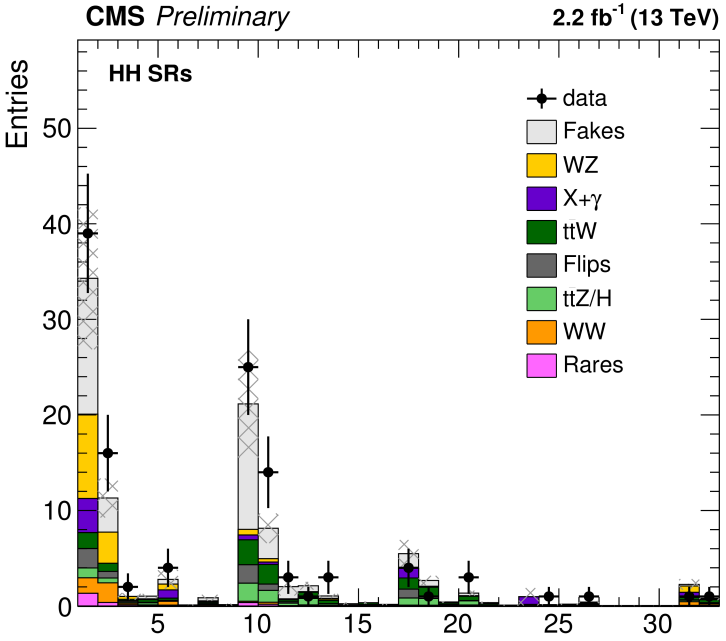




Supersymmetry: 2 same sign leptons

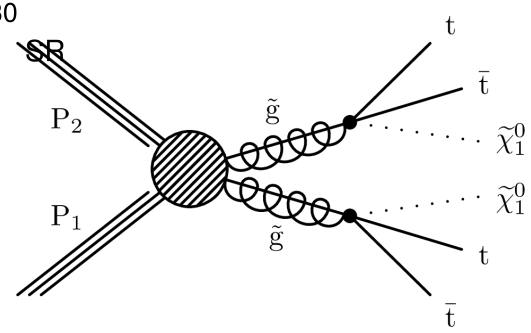
SUS-15-008

2 same sign leptons + mET

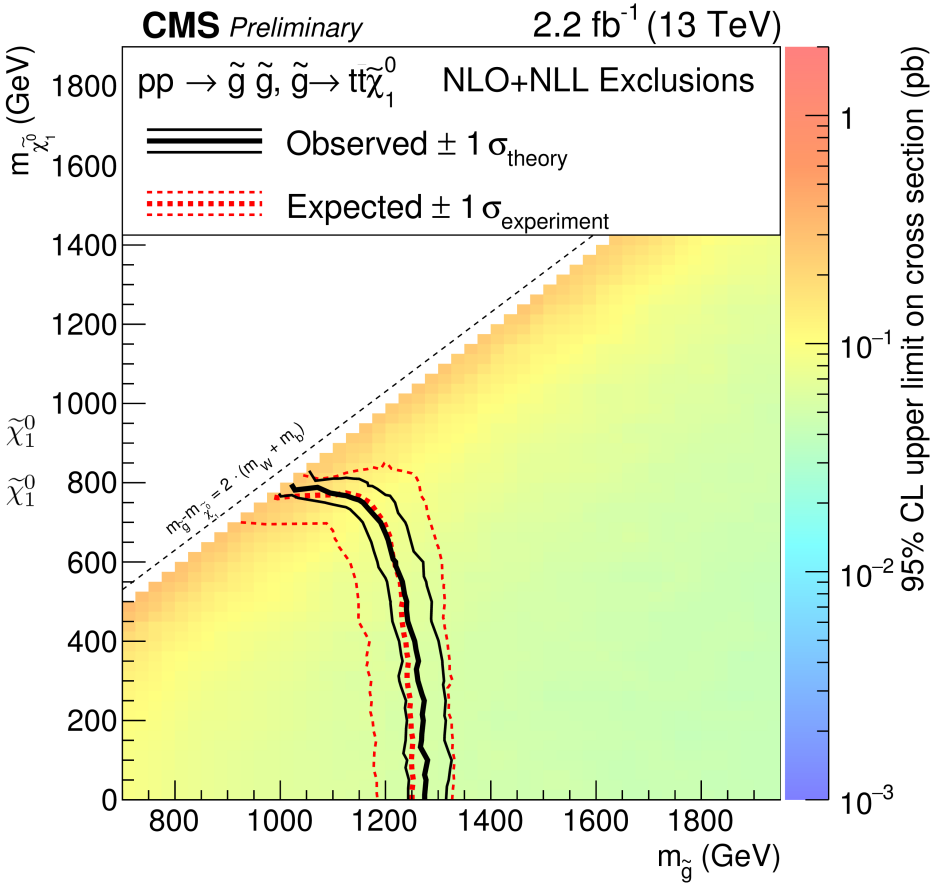


- **Searching for excesses** in high and low pT signal regions, low/high mET, low/high HT

Limits within simplified model: (high lepton pT)



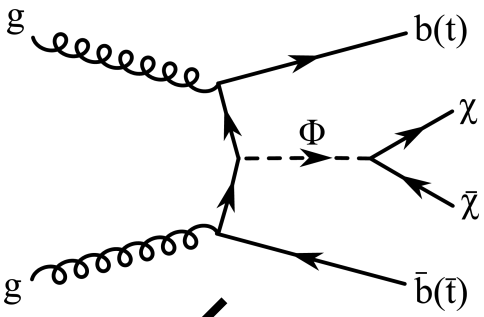
Model independent: XS > 1.5 fb-1

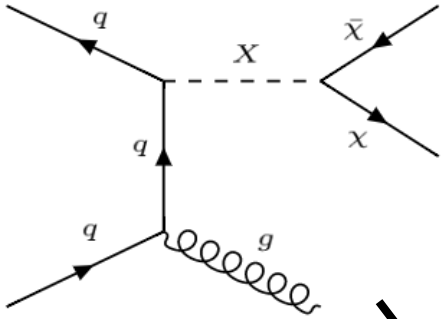


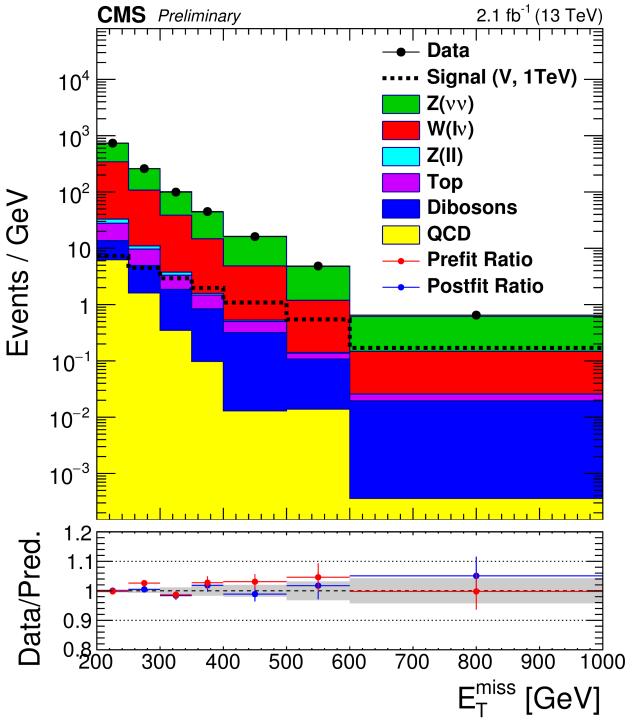
Generic dark matter searches

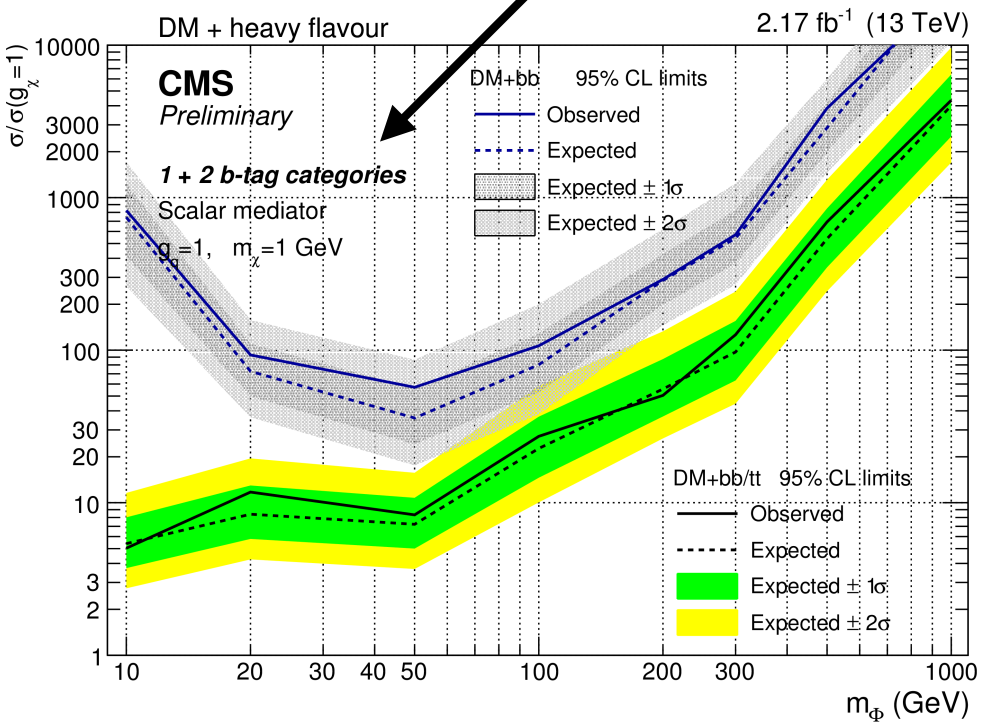
EXO-15-003, B2G-15-007

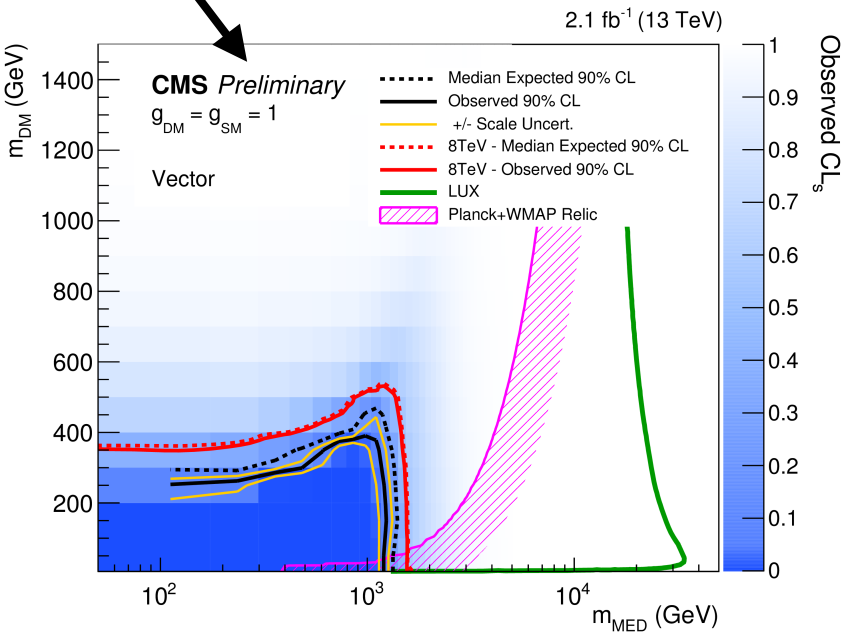
Final states: jet+mET, b+mET



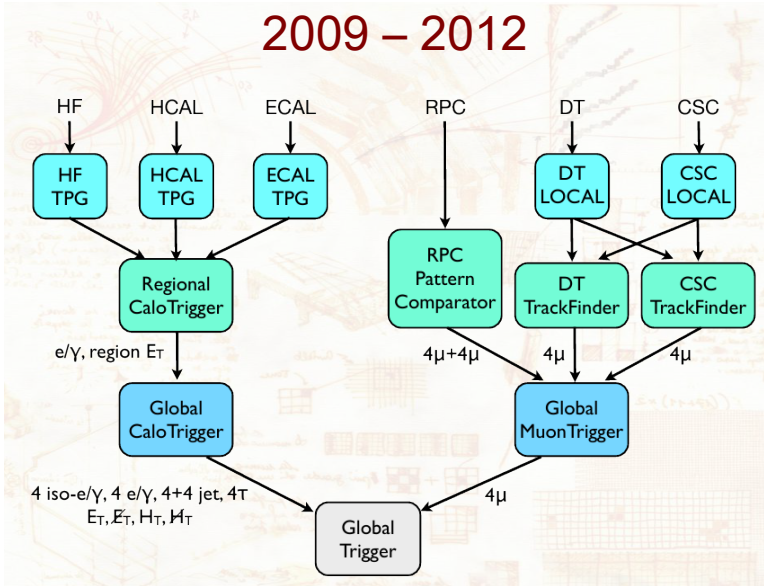


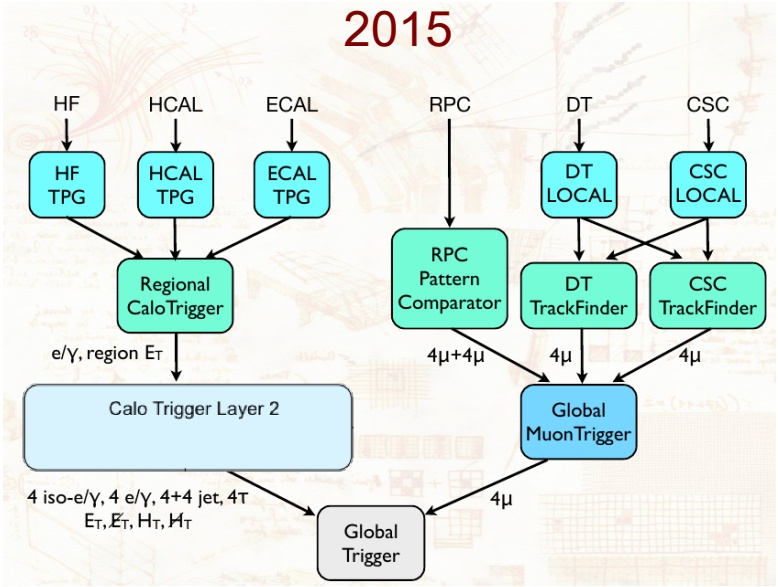


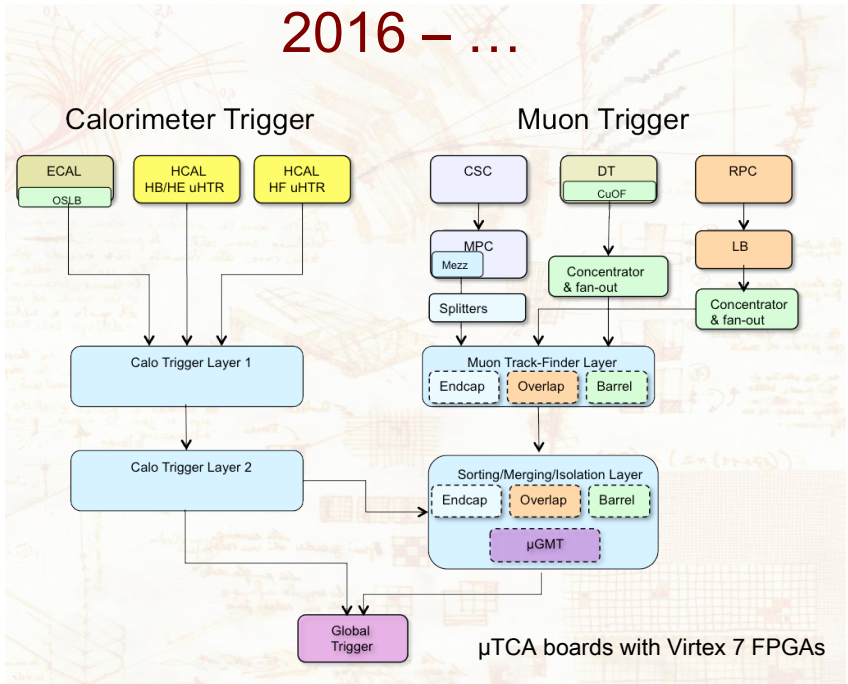




Trigger upgrade







CMS news from YETS 2015-2016

Level 1 Trigger "stage 2" upgrade:

- Faster readout with coarse granularity : new hardware for improved performance
- **uTCA global muon trigger:**
  - select 8 leading muon candidates
  - Muon fake rate reduction x2-3 with similar efficiency
- **L1 Calo trigger:**
  - Layer 1: build trigger towers from ECAL and HCAL inputs, applied position and energy dependent calibrations
  - Layer 2 : implements pattern recognition (jets,e,gamma,tau) and computes global quantities (mET, HT…)

Tracker: No major intervention, new calibration started.
ECAL: refurbishment of low voltage power supplies. Units installed and operated.
HCAL: several maintenance tasks. Commissioning of uTCA trigger.
Muon system: testing ongoing of the new crates

All detectors participating in mid-week global runs