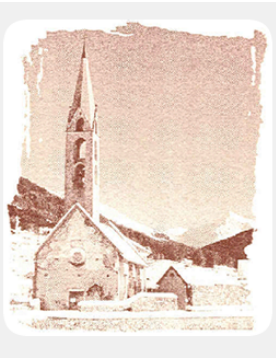
Results from CMS and ATLAS

Electroweak Symmetry, Breaking and Beyond

Paolo Azzurri – INFN Pisa & CERN



54th International Winter Meeting on Nuclear Physics
25-29 January 2016 Bormio (Italy)

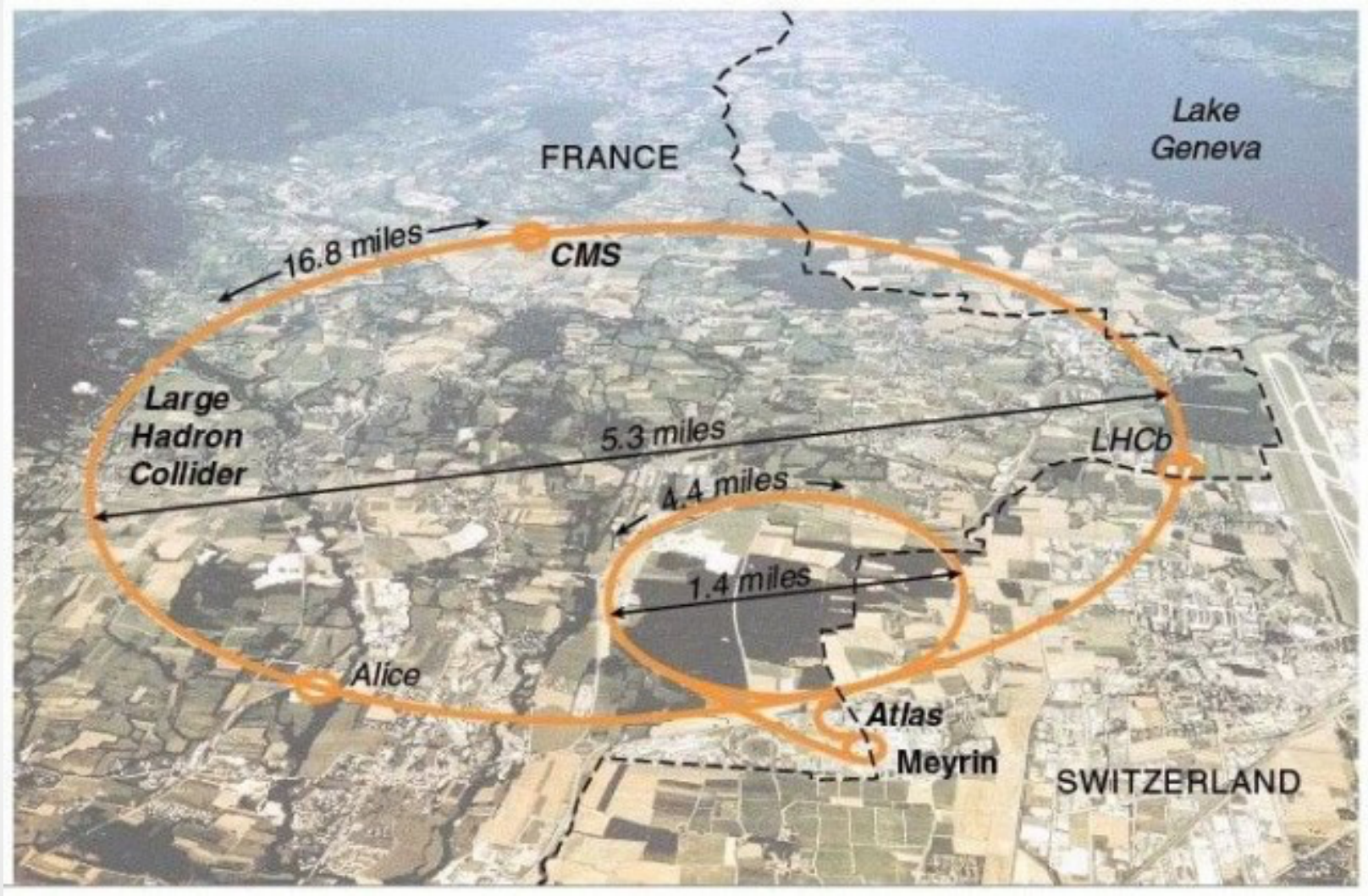
Outline

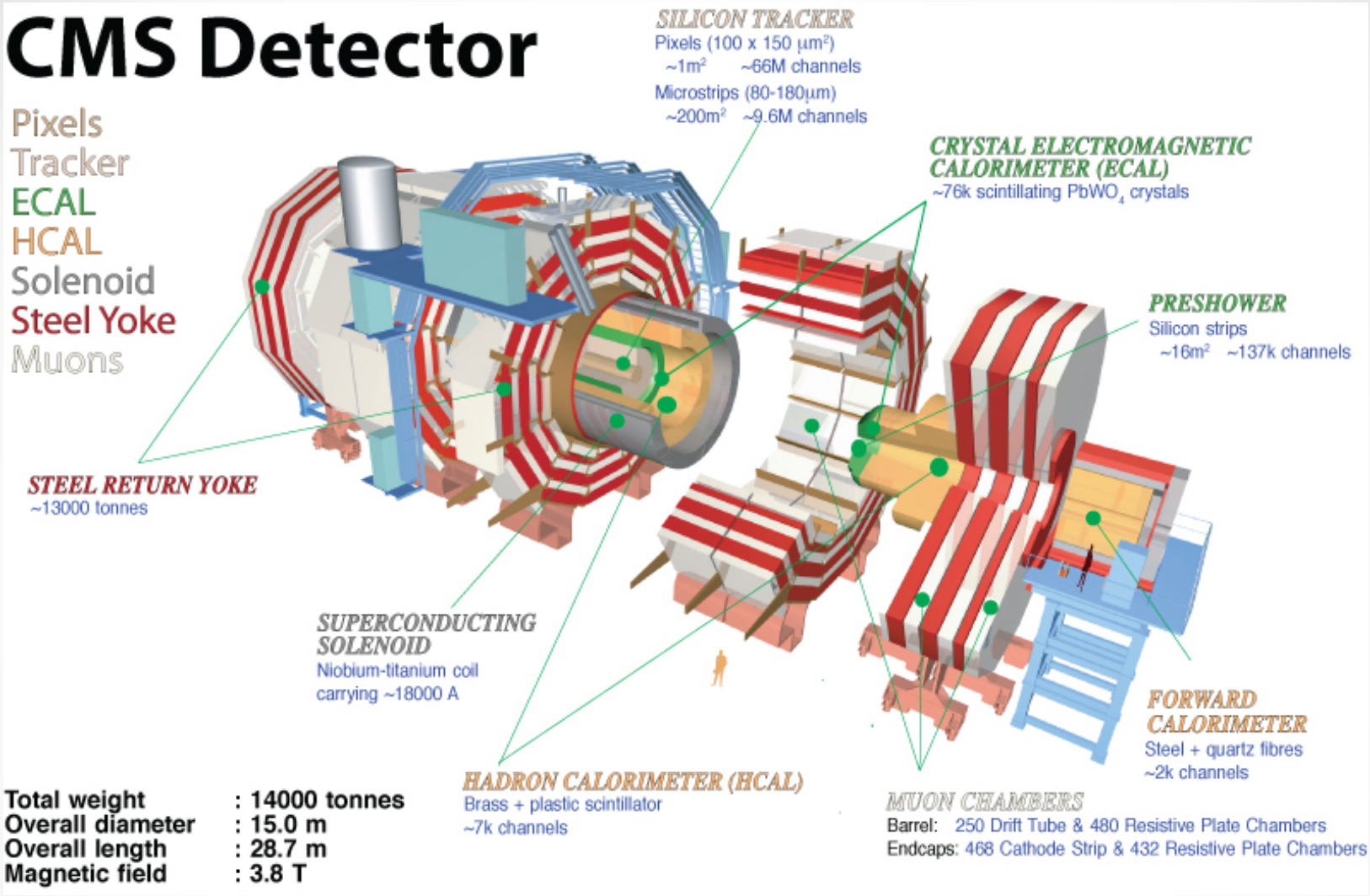
Extending & complementing : S. Bethke
ATLAS & CMS: Strong Interactions and New Physics

- The CMS detector
- Selected Run2 results (ATLAS + CMS)
  - heavy flavor
  - electroweak
  - Higgs
  - Supersymmetry searches

- Summary & Outlook

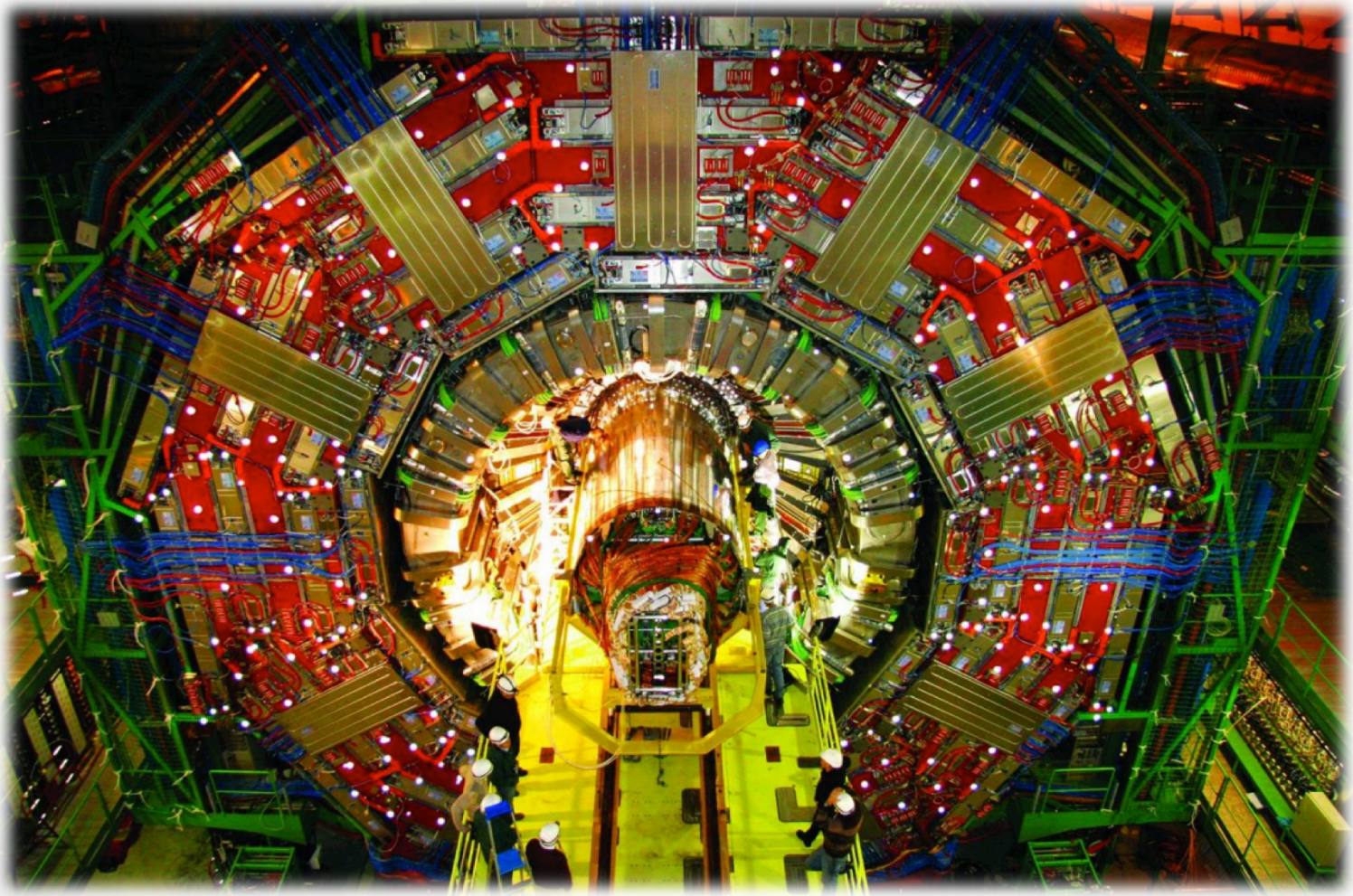
LHC & CMS


FRANCE
Lake
Geneva
16.8 miles
CMS
Large
Hadron
Collider
5.3 miles
LHCb
4.4 miles
1.4 miles
Alice
Atlas
Meyrin
SWITZERLAND

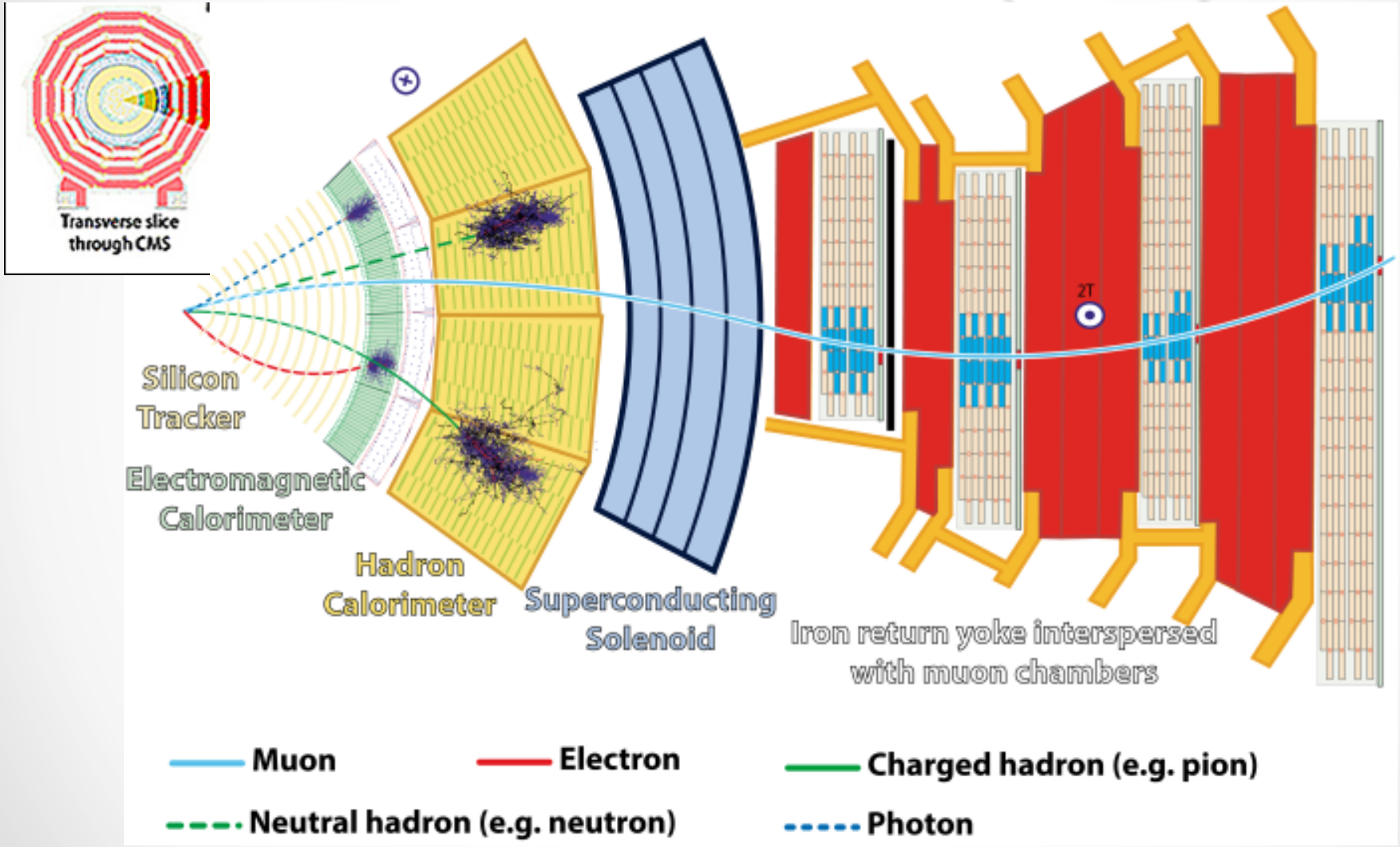


180 institution from 43 countries
1700 physicists, 700 students, 950 engineers/technicians

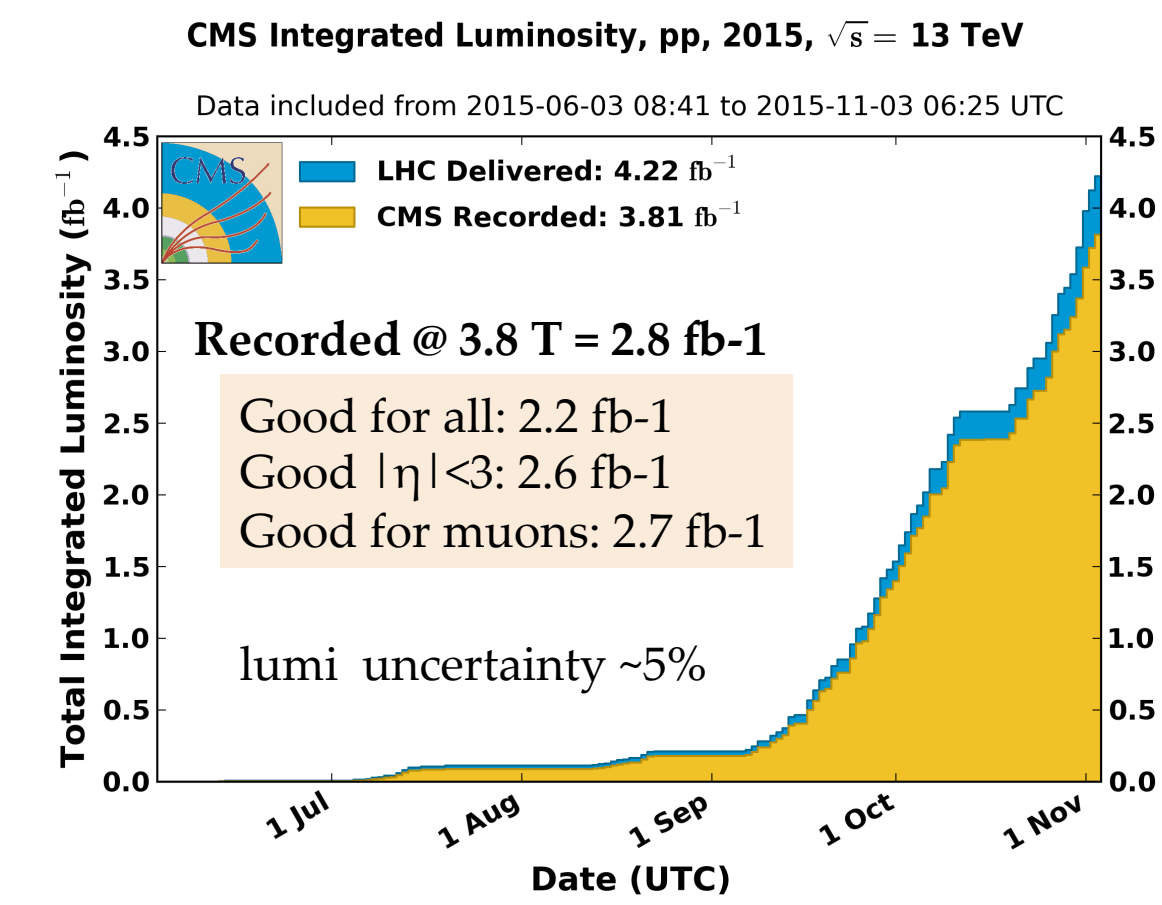
75MPix 3D camera
40M frames/sec



Particles in CMS (slice)



13 TeV pp data (2015)



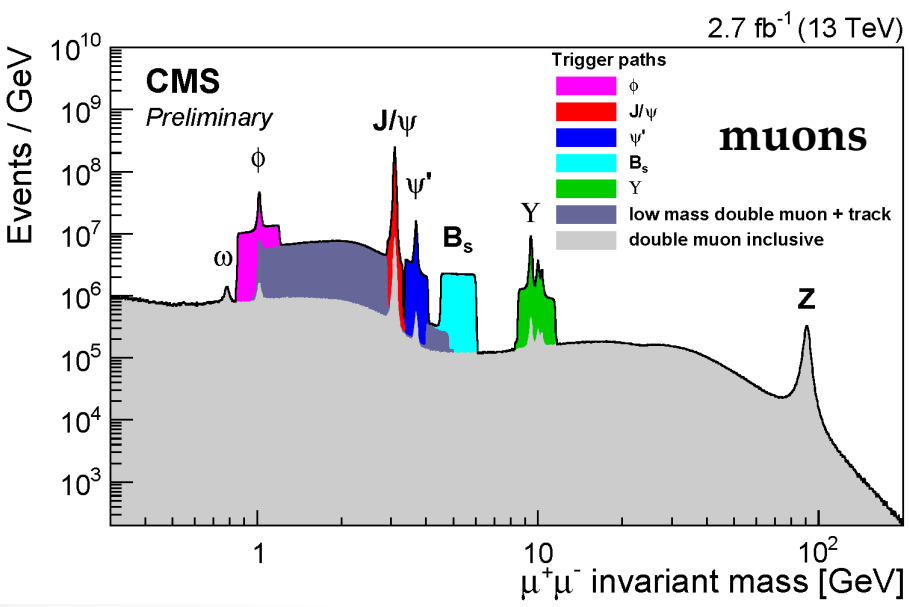
50→25ns min BX
5e33 /cm^2/s max lumi
data taking eff > 90%

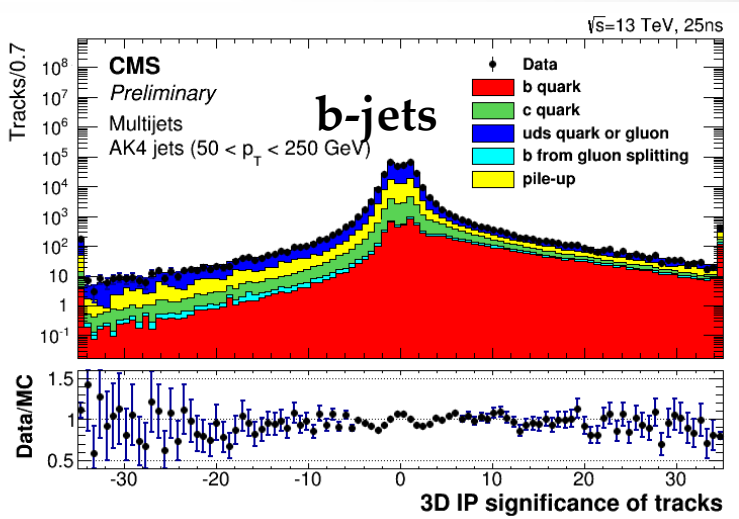
Magnet LHe cryo system harmed by contamination

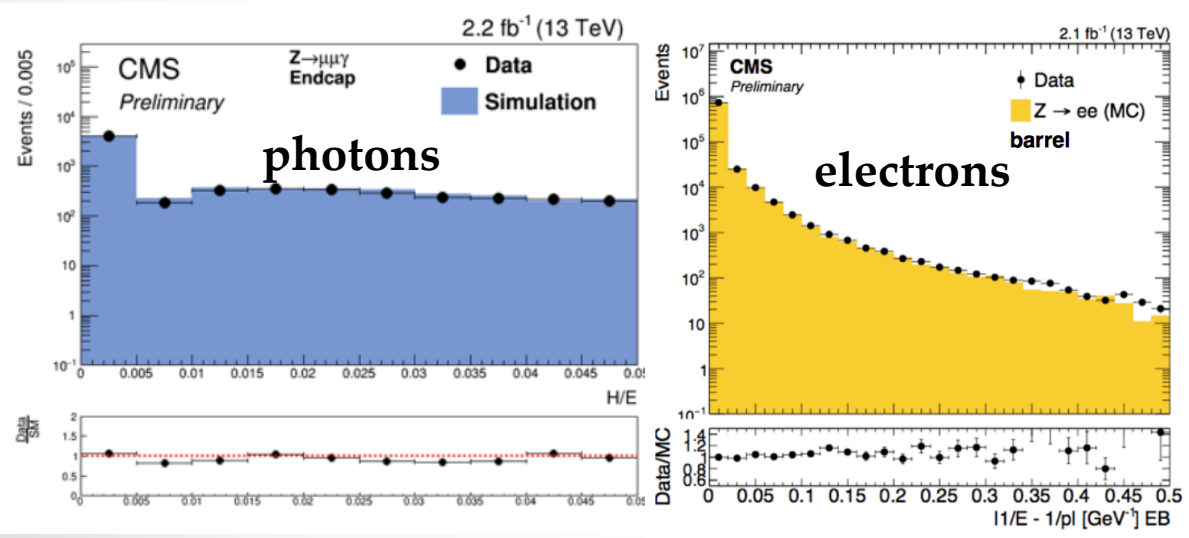
Currently under technical stop repair & cleaning

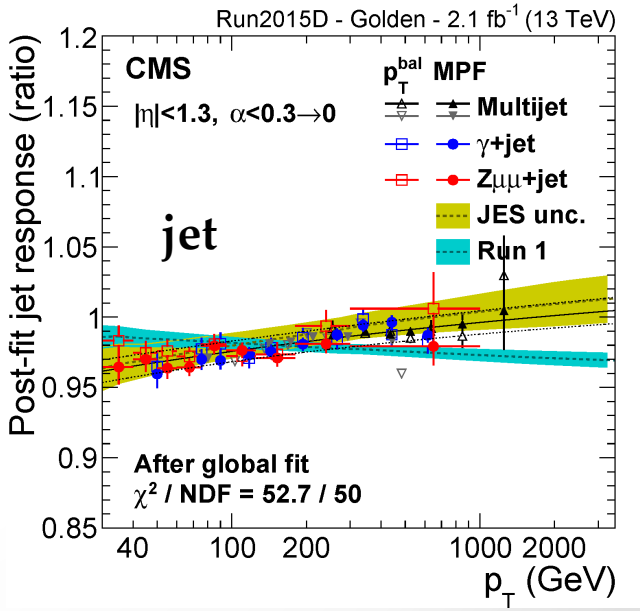
~3⁄4 of the delivered luminosity collected with magnetic field ON

CMS Reconstructed Objects







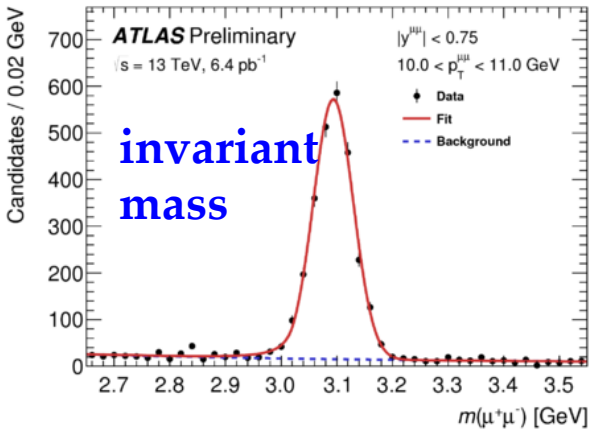


CMS & ATLAS results:

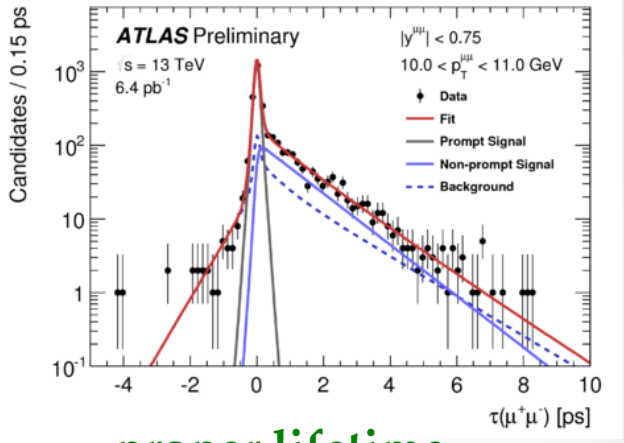
heavy flavor

non-prompt J/ψ

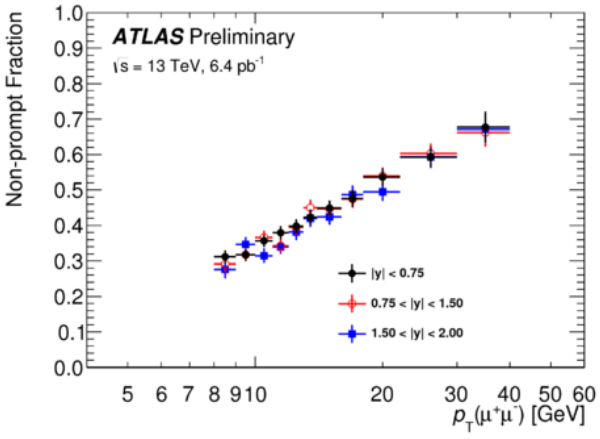
J/ψ dimuons
|y|<0.75
pT=10-11 GeV



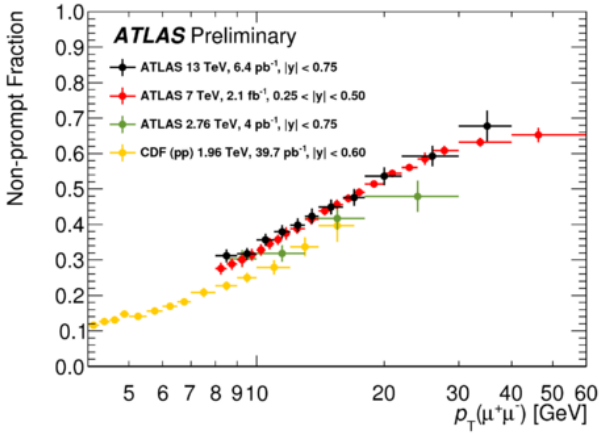
invariant mass



proper lifetime



rapidity invariance



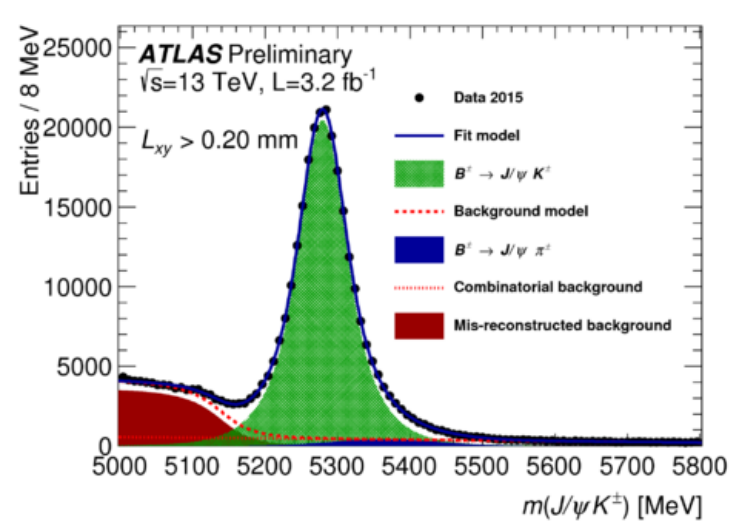
non prompt J/ψ fraction

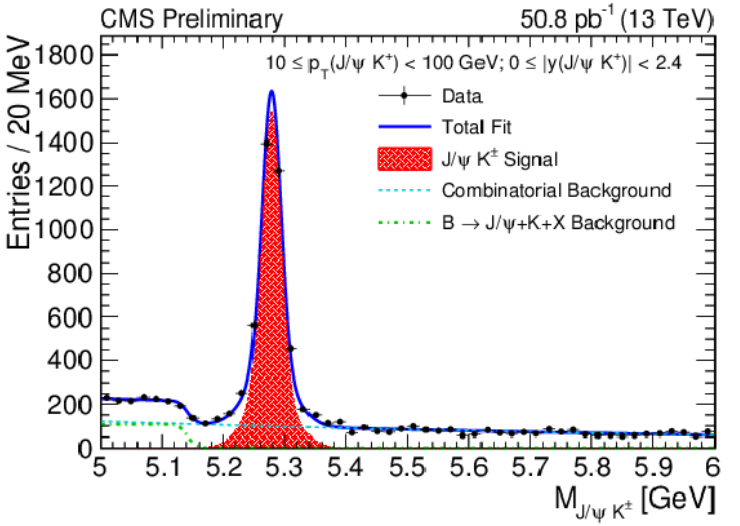
No significant change from $\sqrt{s} = 7$ TeV to $\sqrt{s} = 13$ TeV.

B+ production

CMS BPH-15-004

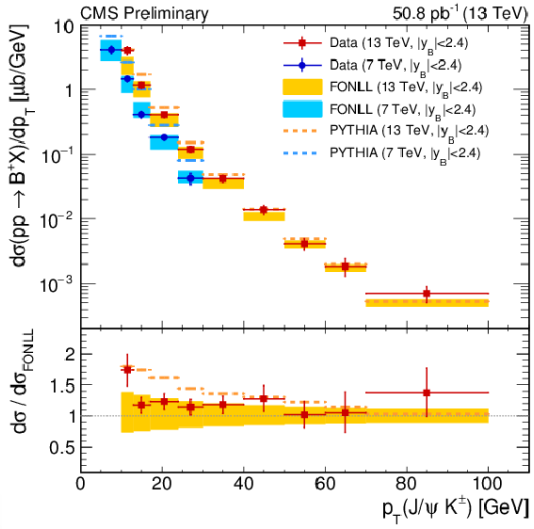
ATLAS-CONF-2015-064

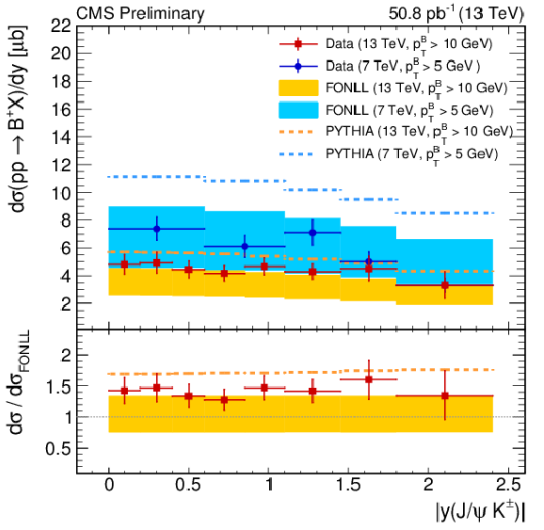




σ(B) vs. p_T and y
compared to predictions,
and data at 7 TeV

Good agreement with
theory up to **p_T ~ 100 GeV**





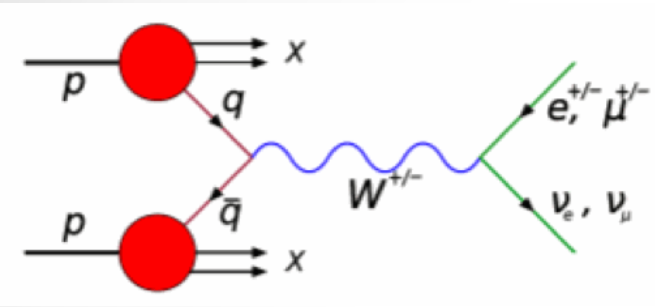
CMS & ATLAS results:

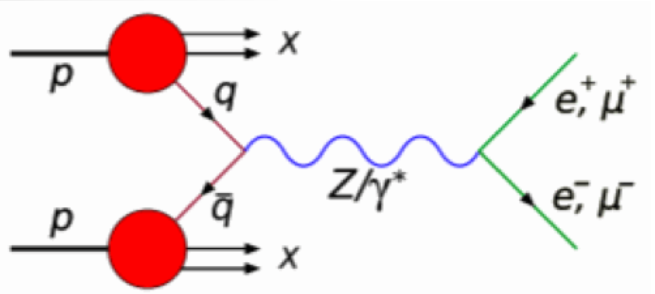
electroweak

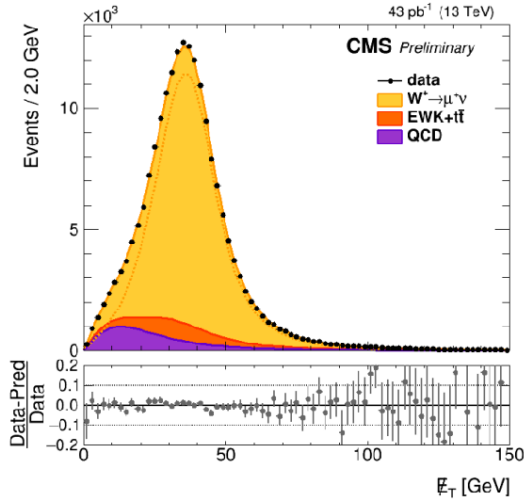
inclusive W/Z

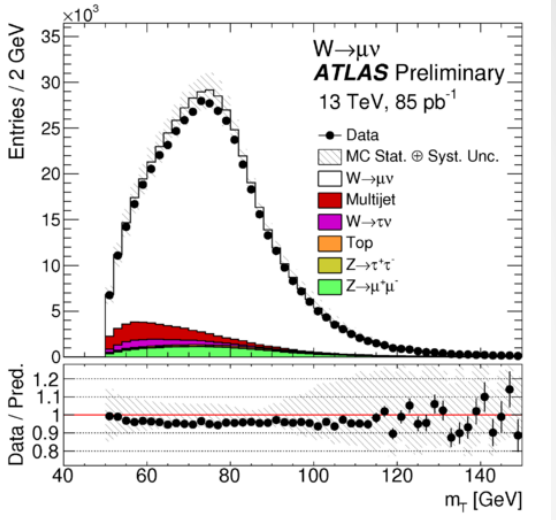
ATLAS-CONF-2015-039

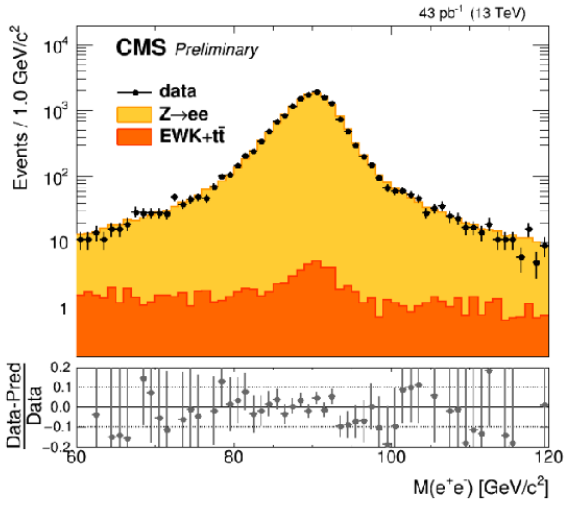
CMS-PAS-SMP-15-004

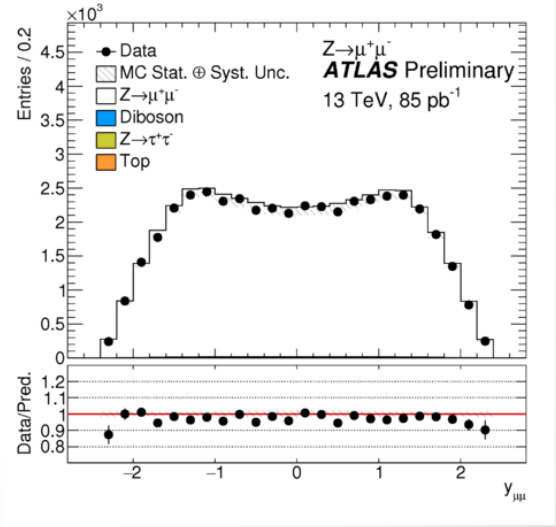












ATLAS-CONF-2015-039

CMS-PAS-SMP-15-004

inclusive W/Z

CMS ($43pb^{-1}$)

σ(W+) B(l+ν)=11370±50(stat)±230(syst)±550 (lumi) pb

σ(W−) B(l−ν)=8580±50(stat)±160(syst)±410 (lumi) pb

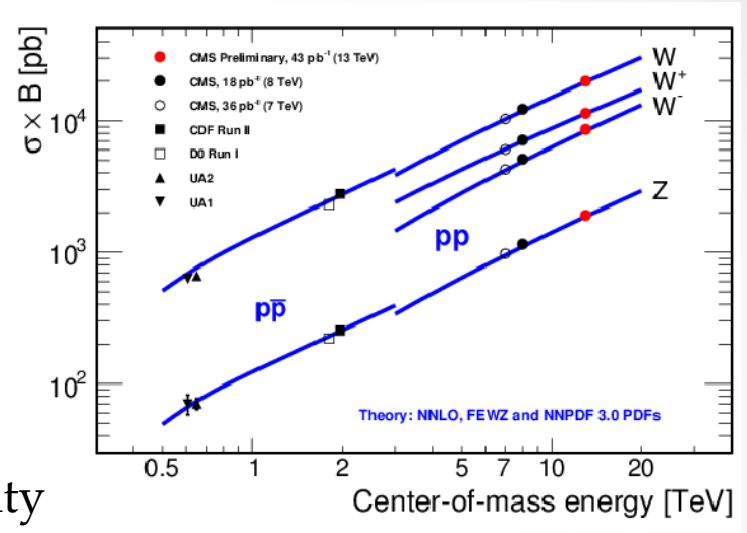
σ(Z) B(l+l−)=1910 ± 10 (stat) ± 40 (syst) ± 90 (lumi) pb

ATLAS ($85pb^{-1}$)

σ(W+) B(l+ν)=10960±20(stat)±440(sys)±990(lumi) pb

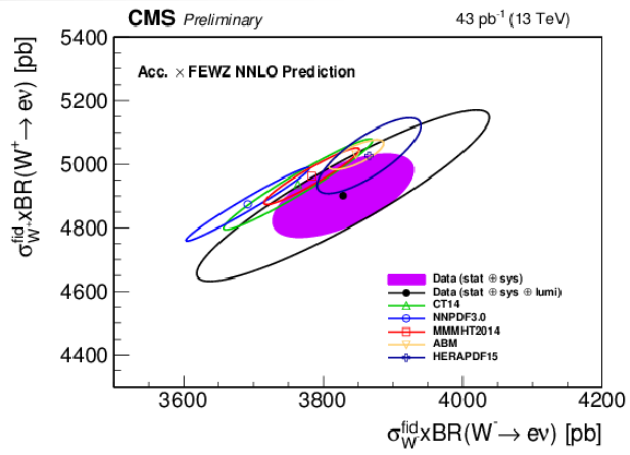
σ(W−) B(l−ν)=8380±20 (stat)±350 (sys)±750(lumi) pb

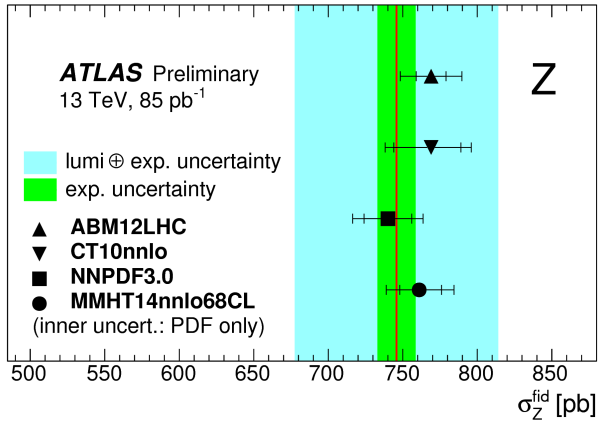
σ(Z) B(l+l−)=1869±7 (stat)±42 (sys)±168 (lumi) pb



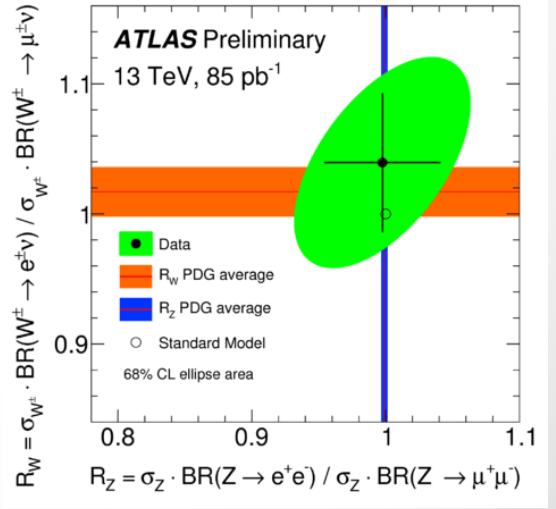
$\Delta\sigma$ limited by **lumi** uncertainty

constraints on proton PDF

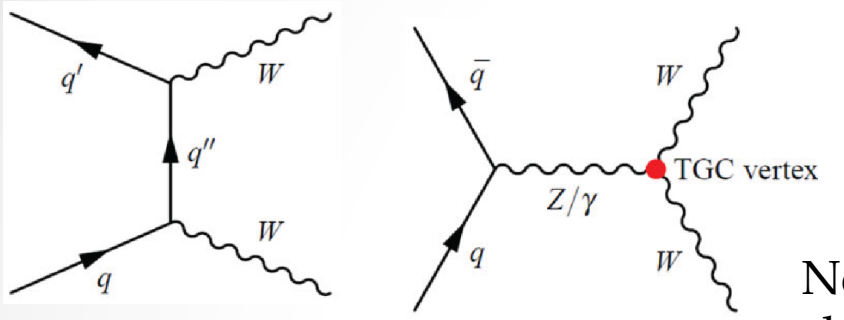




test of e/μ universality



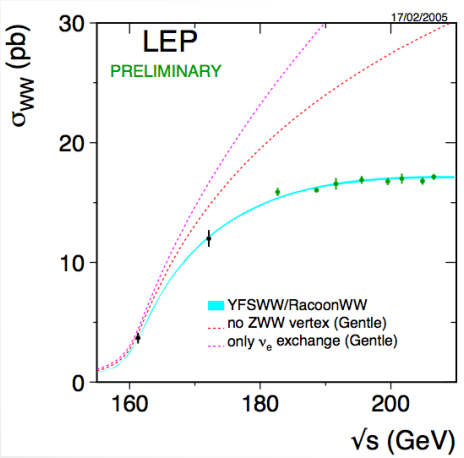
dibosons



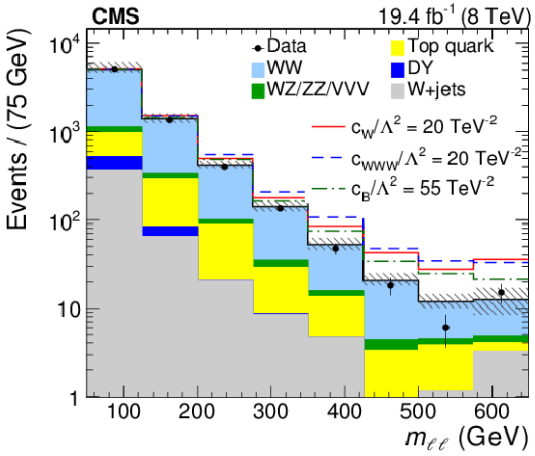
entering the electroweak reign

WW, WZ,ZZ,Wγ,Zγ,WWγ,WZγ,jjWW

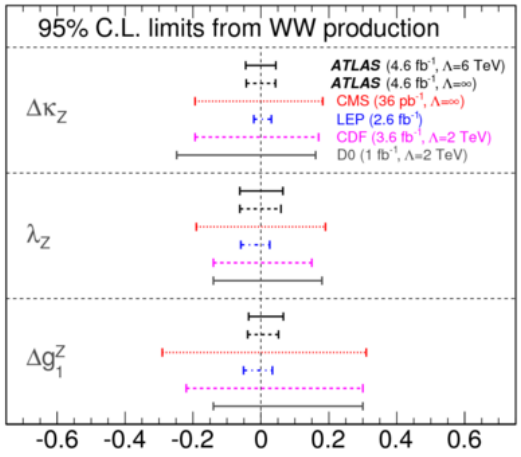
Negative interferences between t-channel and s-channel (TGC) productions [gauge cancellations]



pp→WW arXiv.1507.03268

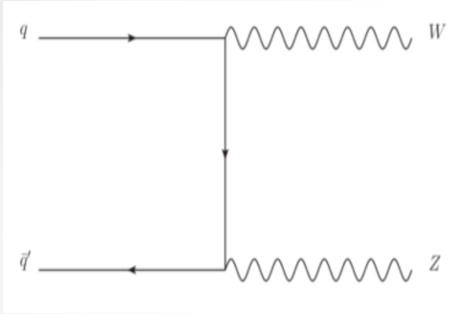


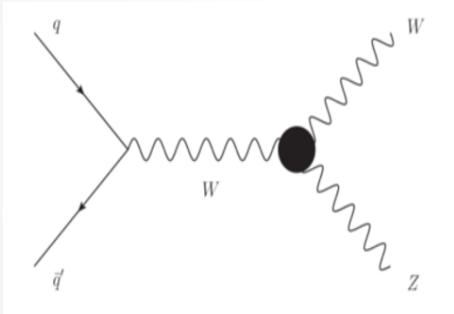
Phys. Rev. D 87, 112001



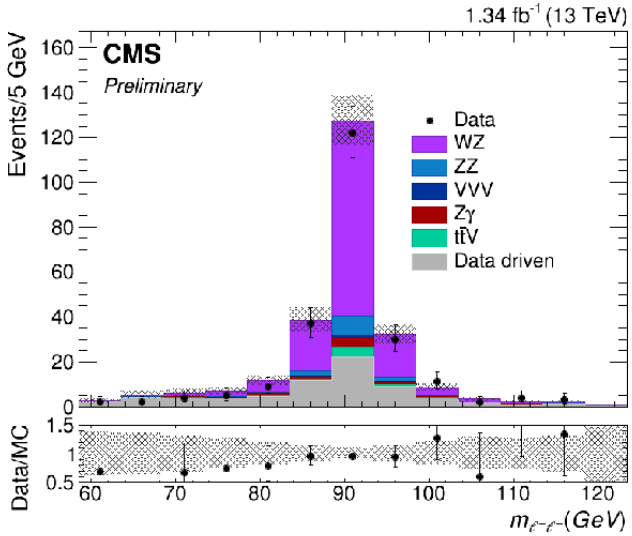
no **WW** ATLAS/CMS update with run2 data yet

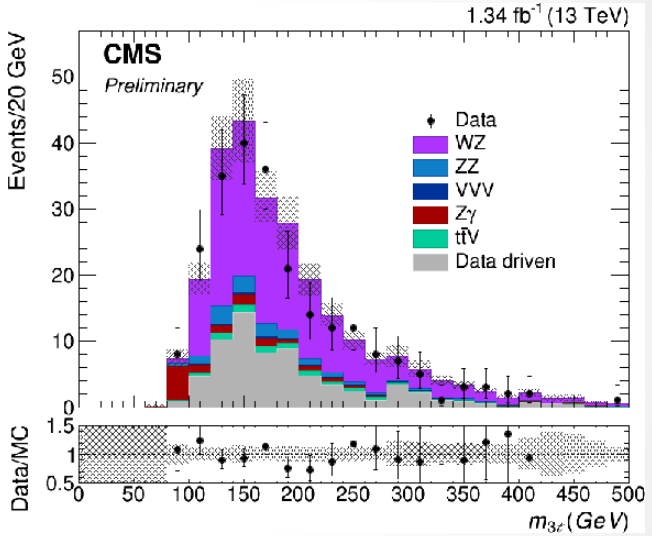
dibosons WZ





$WZ \rightarrow l\nu l'l'$





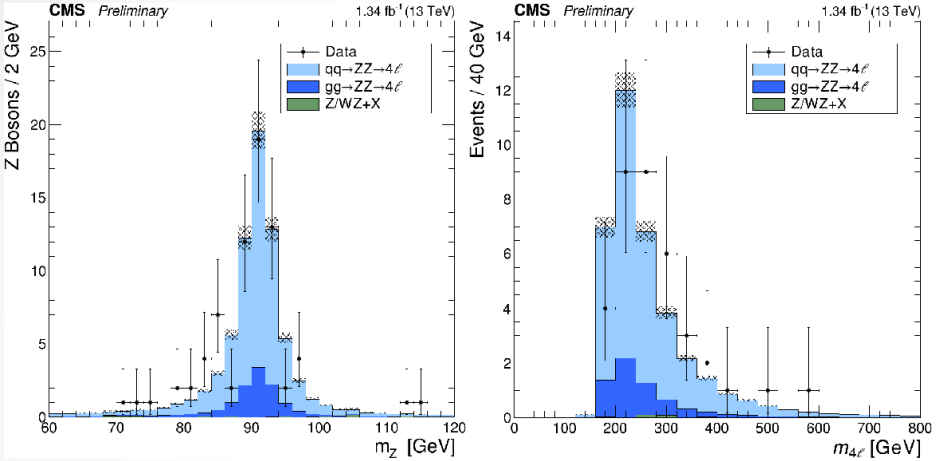
with 1.34 fb^{-1}@13TeV

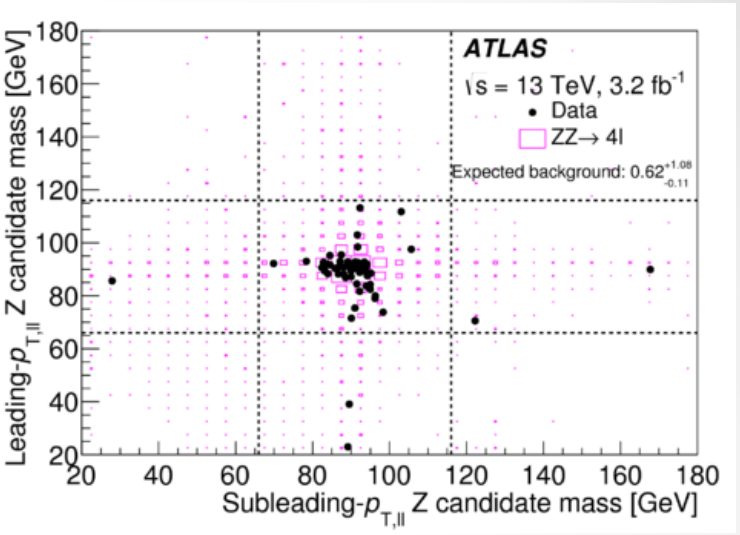
$\sigma(pp \rightarrow WZ) = 36.8 \pm 4.6\ (stat)\ ^{+8.1}_{-6.2}\ (syst) \pm 0.6\ (theo) \pm 1.7\ (lumi)$ pb

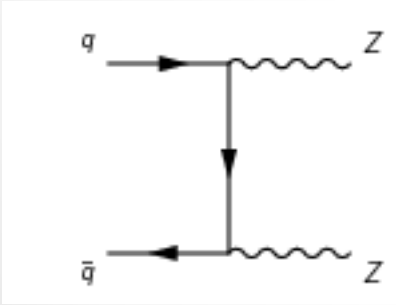
SM : $42.7^{+1.6}_{-0.8}$ pb with MCFM 7.0 / NNPDF3.0

ATLAS CERN-PH-EP-2015-318
CMS SMP-15-005

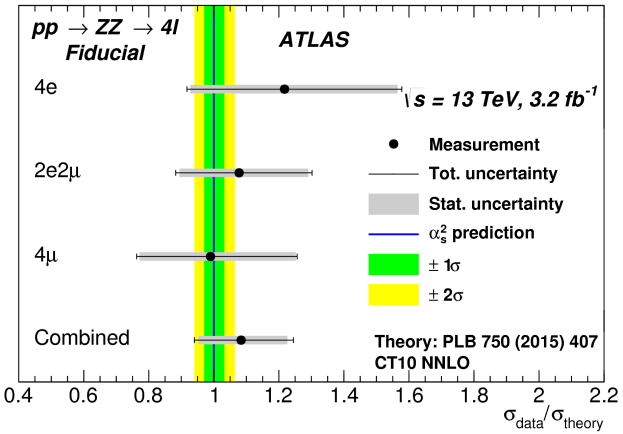
dibosons ZZ

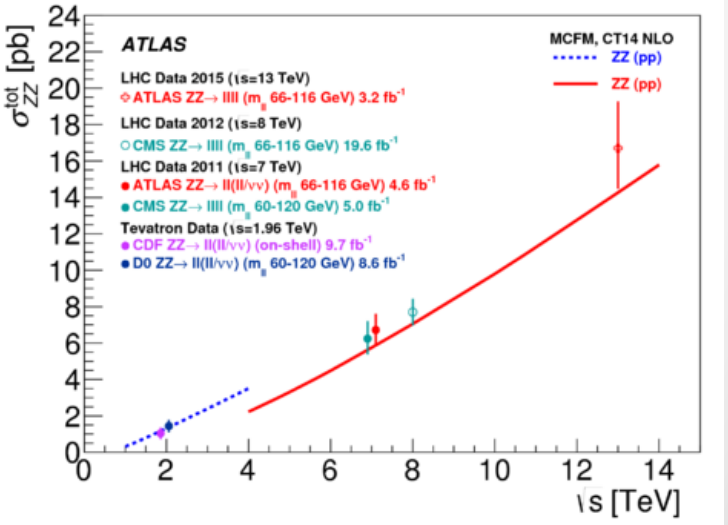






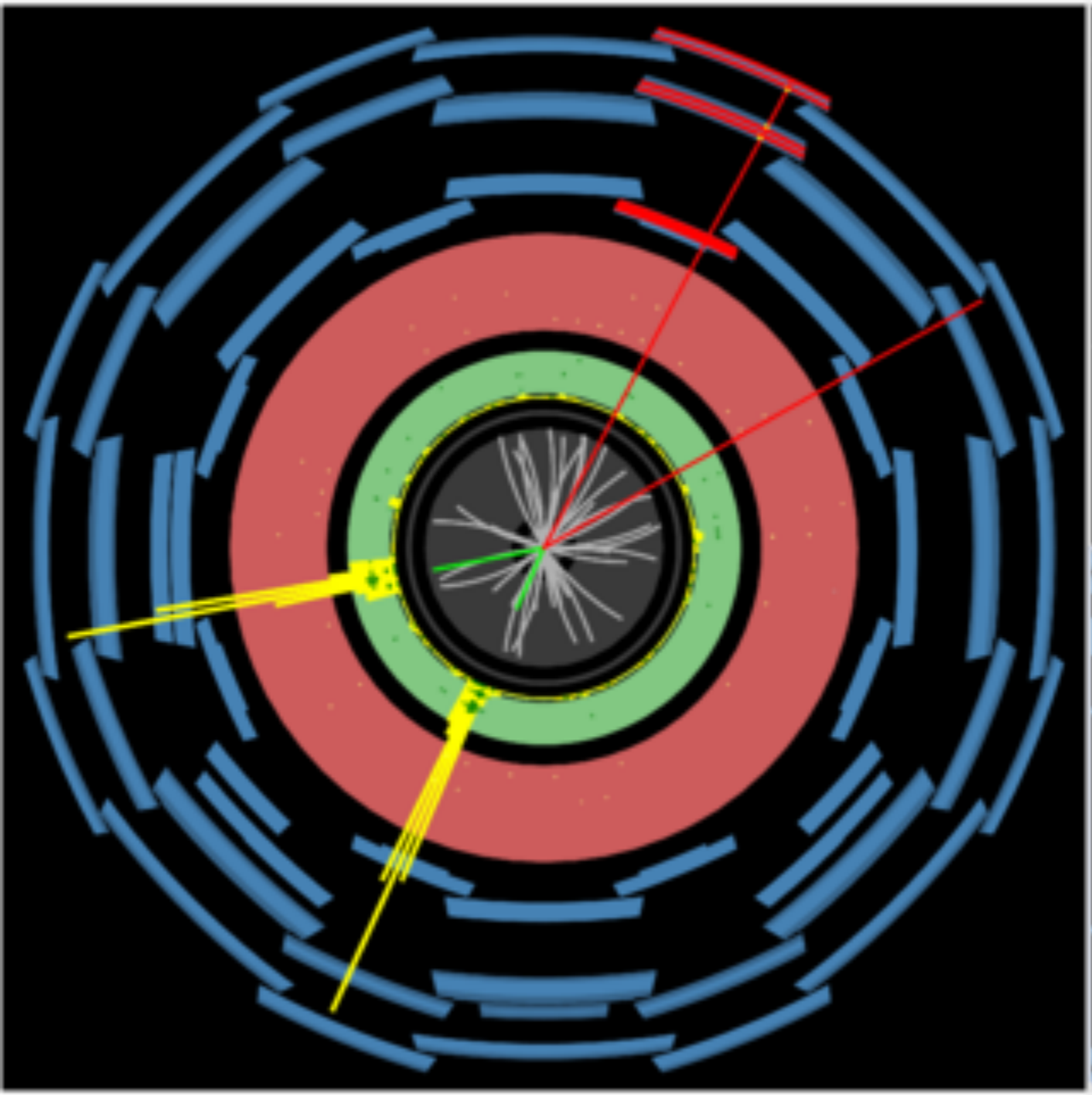
no TGCs





ATLAS 3.2 fb^{-1} : $16.7^{+2.2}_{-2.0}(\text{stat.})^{+0.9}_{-0.7}(\text{syst.})^{+1.0}_{-0.7}(\text{lumi.})$ pb
CMS 1.34 fb^{-1} : $16.7^{+2.9}_{-2.6}(\text{stat})^{+0.7}_{-0.5}(\text{syst}) \pm 0.3(\text{theo}) \pm 0.8(\text{lum})$ pb

SM agreement persists ..

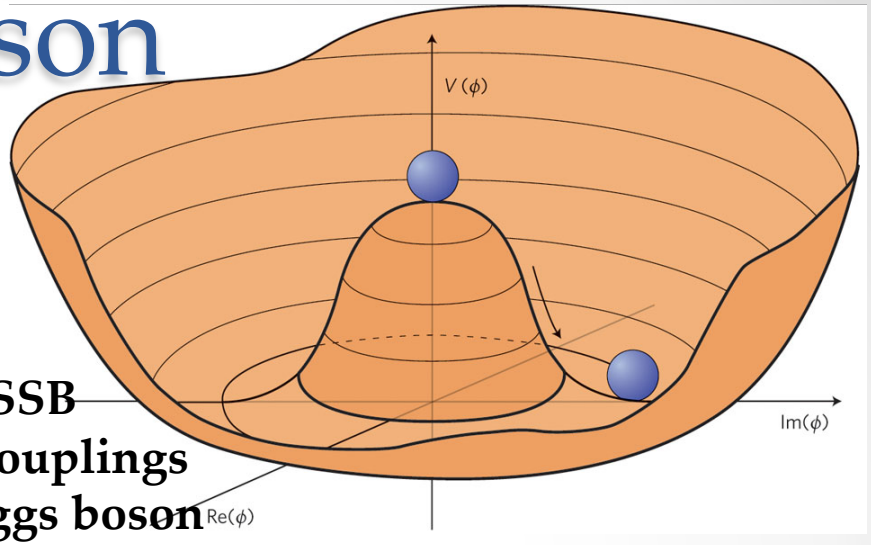



ATLAS
EXPERIMENT
Run Number: 284285, Event Number: 4210157909
Date: 2015-11-01 14:56:38 CET

CMS & ATLAS results:

Higgs

The Higgs boson

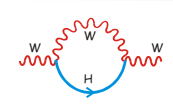


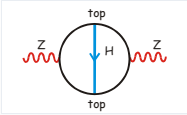
Spontaneously breaks electroweak SU(2)xU(1) (SSB)

→ vector bosons W,Z receive mass terms from SSB
→ fermions receive mass terms from Yukawa couplings
→ SSB leaves a massive scalar particle : the Higgs boson

All SM particles receive mass terms
Cancels divergences and unitarity violation in WW→WW,ZZ

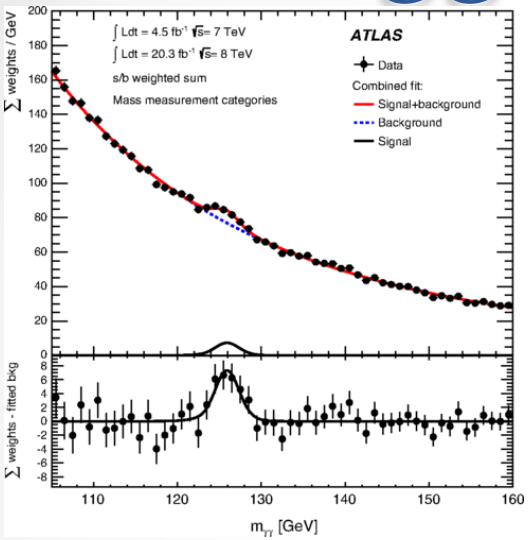
Searched for ~50 years.
Indirect indications from EW precision measurements

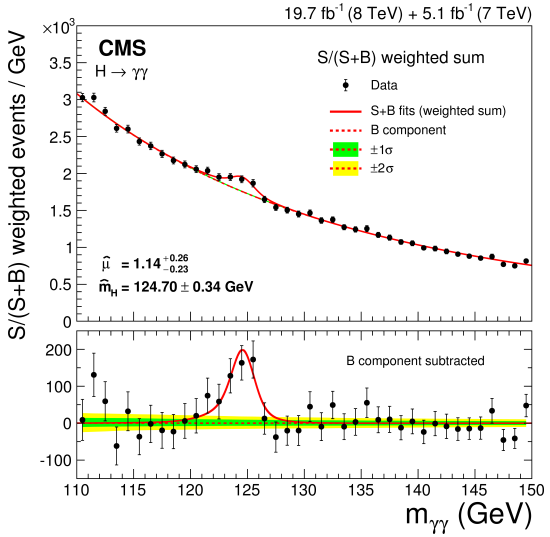


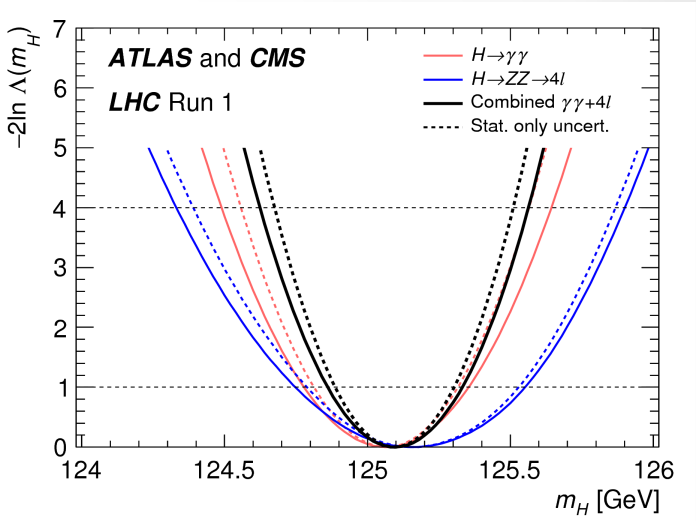


Discovered at the LHC by ATLAS & CMS
5σ/ experiment with 5/fb @7TeV + 5/fb @8TeV (2012)

Higgs mass : Run1 legacy







ATLAS m_H=125.36±0.37(stat)±0.18(syst) GeV

Phys. Rev. D 90 (2014) 052004

CMS $m_H = 125.02^{+0.26}_{-0.27}(\text{stat})^{+0.14}_{-0.15}(\text{syst})$ GeV

Eur.Phys.J.C 75 (2015) 212

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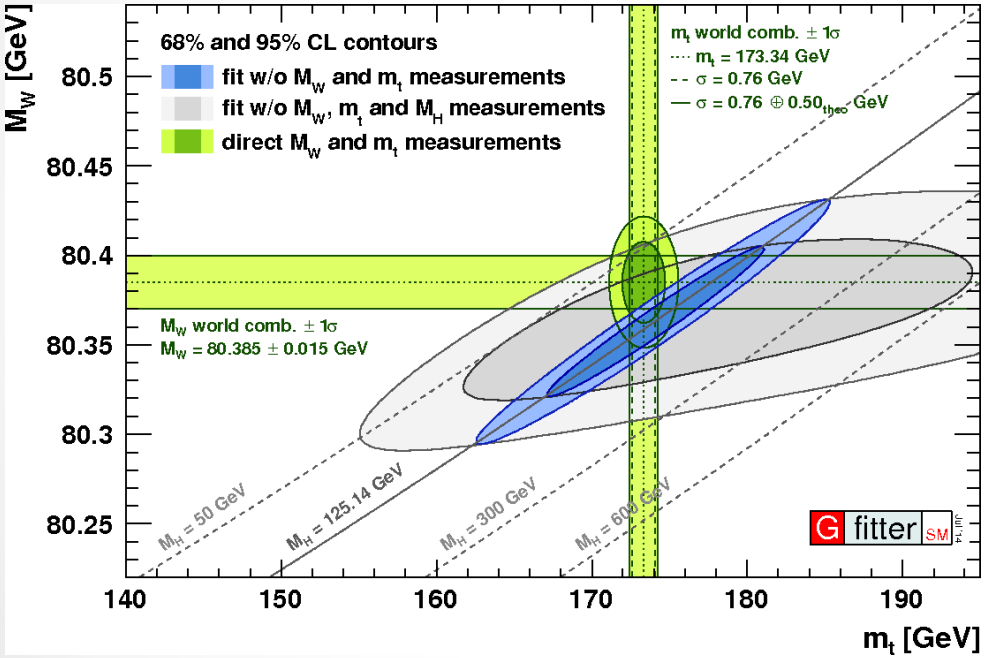
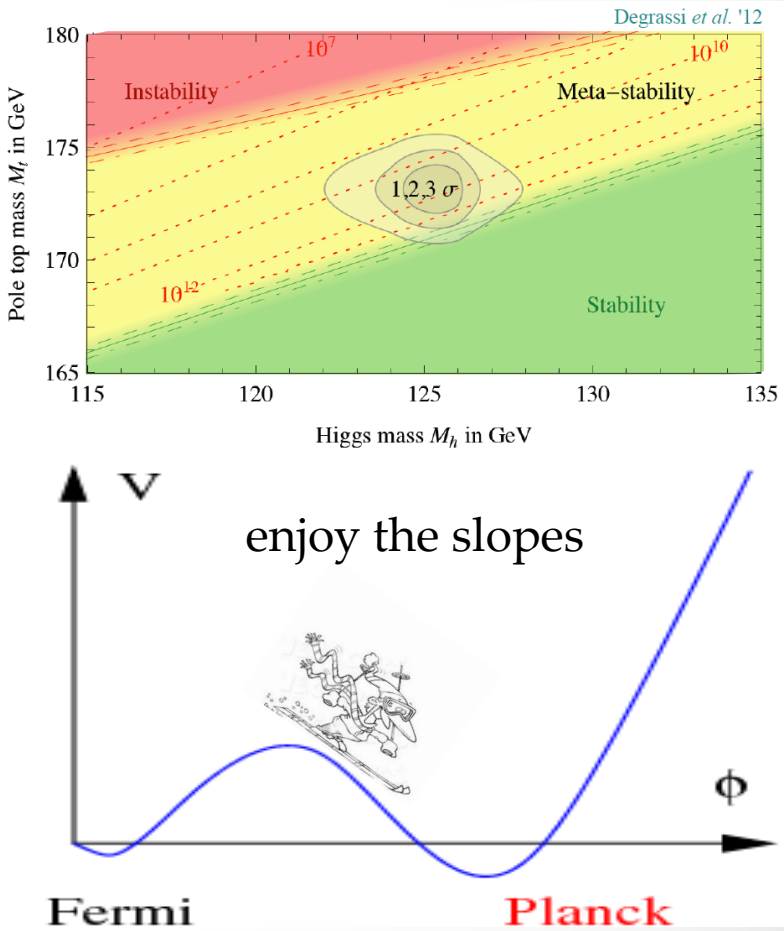
m_H=125.09±0.21(stat.)±0.11(syst.) GeV **0.2% precision**

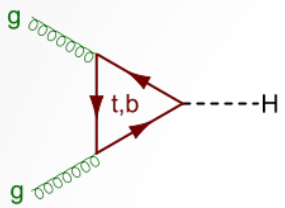
Phys.Rev.Lett.114 (2015) 191803

Higgs mass: Run1 legacy

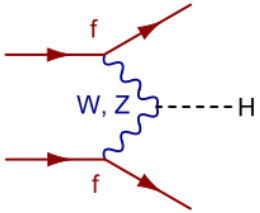




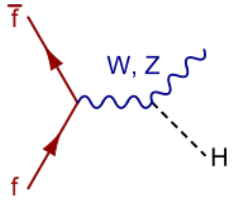
Higgs couplings: Run1 legacy



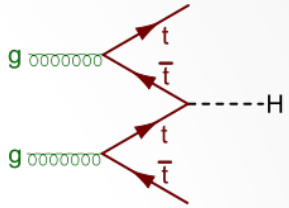
gluon fusion (GF)



vector boson fusion (VBF)



Higgs-strahlung(VH)



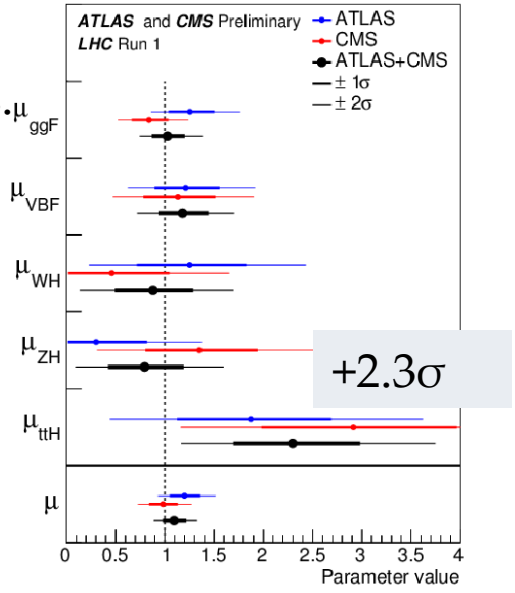
top quark fusion (ttH)

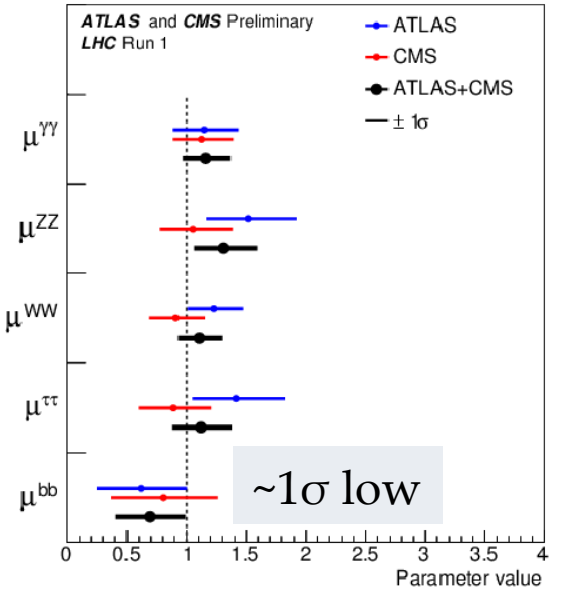
Combined Likelihood of ~580 signal and control distributions.

Care in building acceptance matrix

Care in treating correlations among (~4200) systematic effects

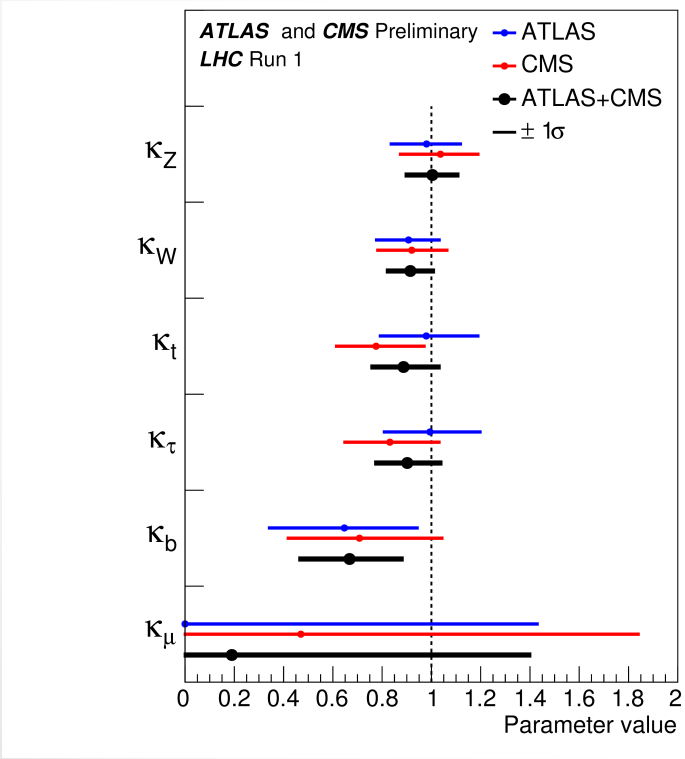
$\mu=\sigma/\sigma_{SM}= 1.09^{+0.11}_{-0.10}$

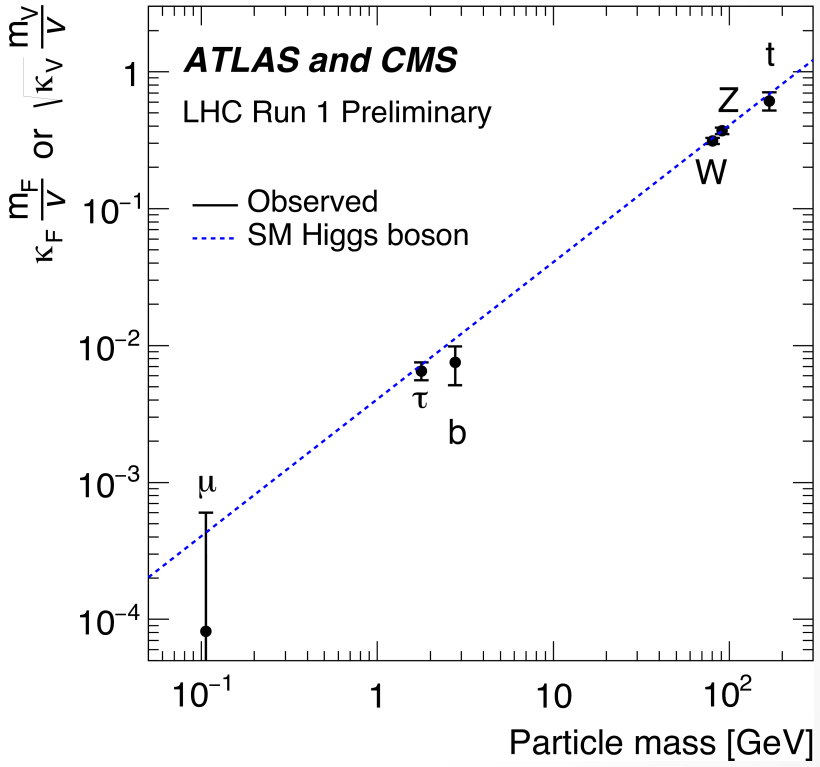




Higgs couplings: Run1 legacy

coupling modifiers κ
also in SM loops

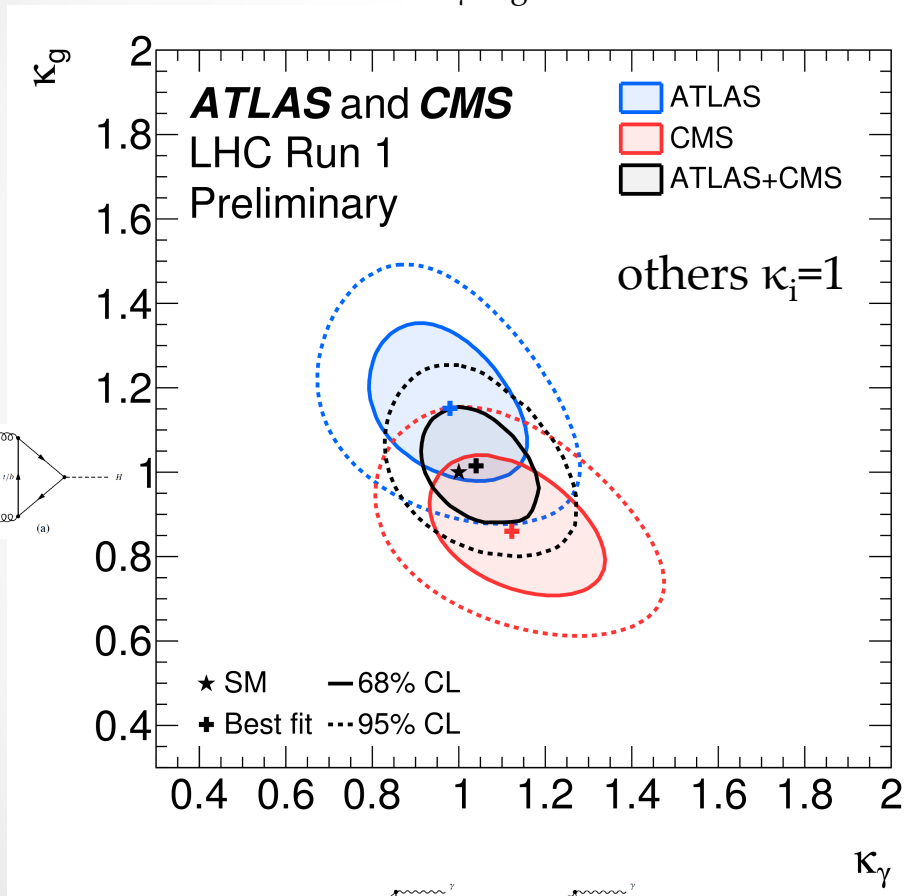


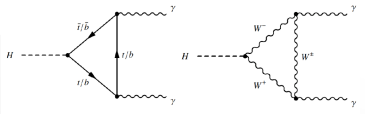


e.g. κ_t constrained by GF($\gamma\gamma$)

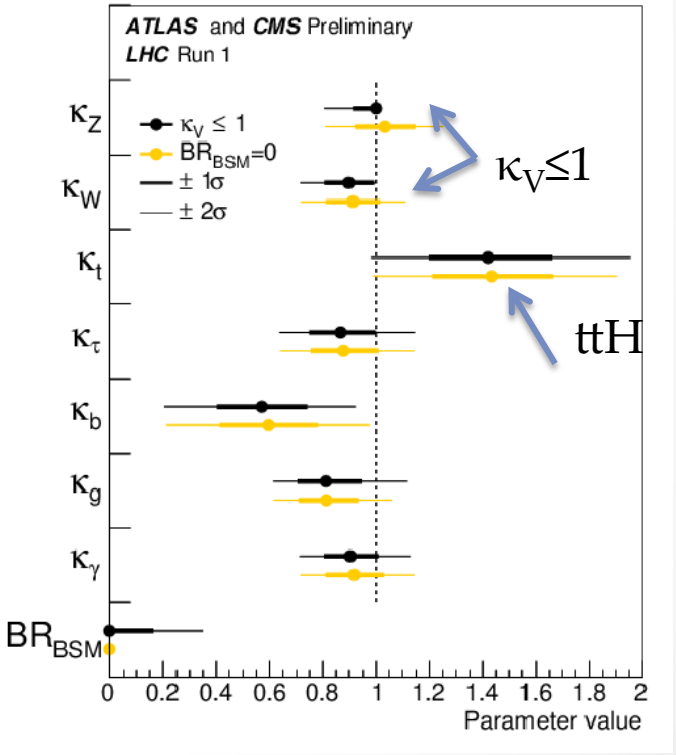
Higgs couplings: Run1 legacy

additional κ_γ, κ_g BR(BSM)=0



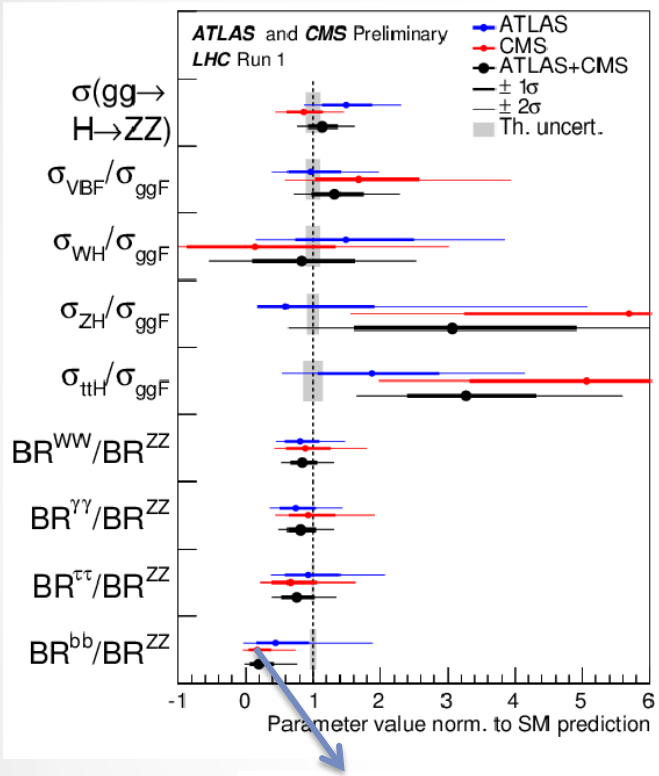


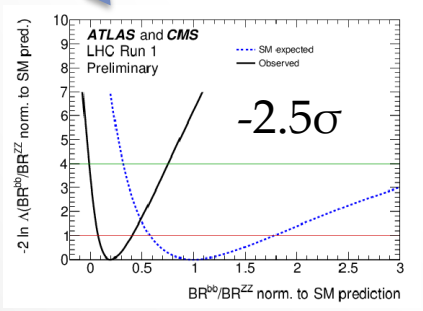
BR(BSM)>0 $\Gamma_H = \dfrac{\kappa_H^2 \cdot \Gamma_H^{SM}}{1 - BR_{BSM}}$



BR(BSM)<0.34 at 95% CL

Higgs coupling ratios





bb/ZZ

cross section and BR ratios
more generic exploration with
reduced systematic uncertainties

H→bb deficit enhanced by VH & ttH excesses in other decay modes

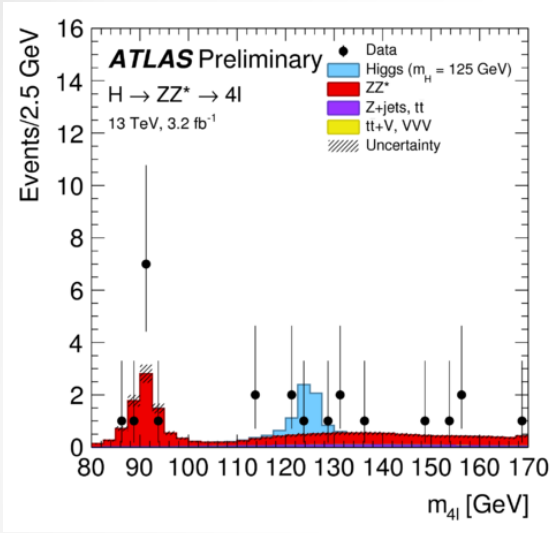
ATLAS Hbb
VH: μ=0.52±0.40
ttH : μ=1.5±1.1

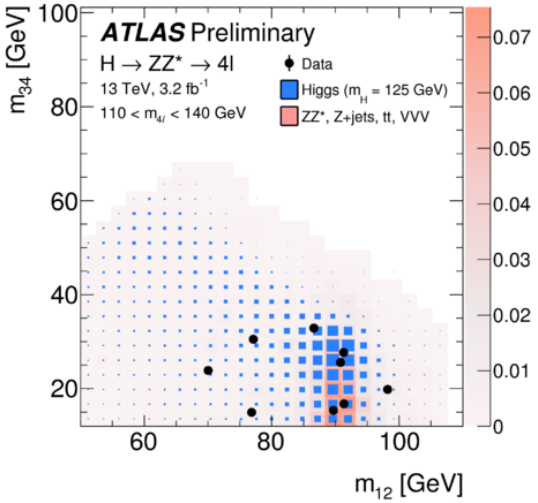
CMS Hbb
VH: μ=0.89±0.43
ttH : μ=0.7±1.8
VBF: μ=2.8±1.5

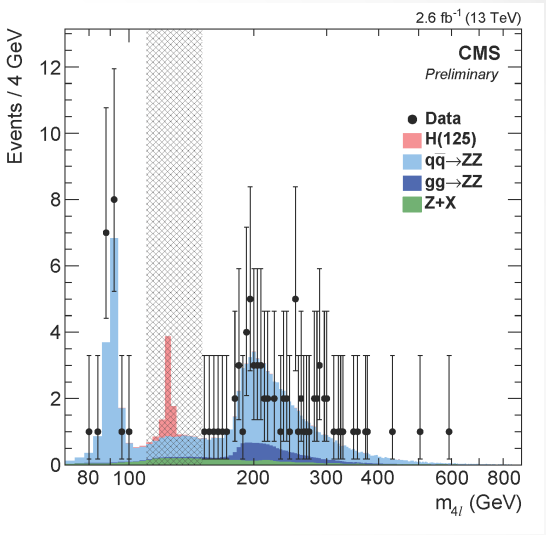
+ Tevatron: VH(bb) : μ=1.6±0.7

… still need to establish H coupling to down quarks

Higgs @13 TeV : ZZ*→4l



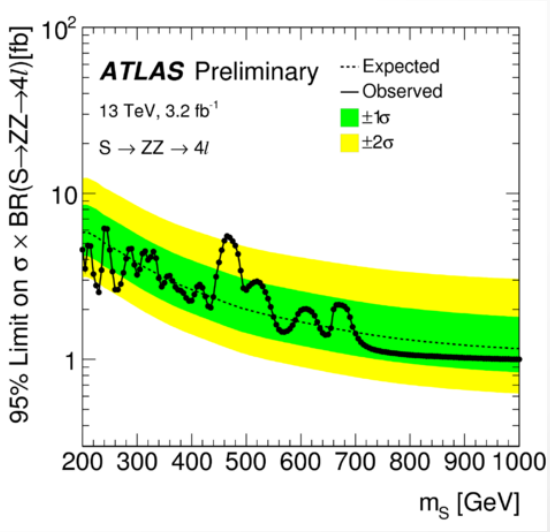


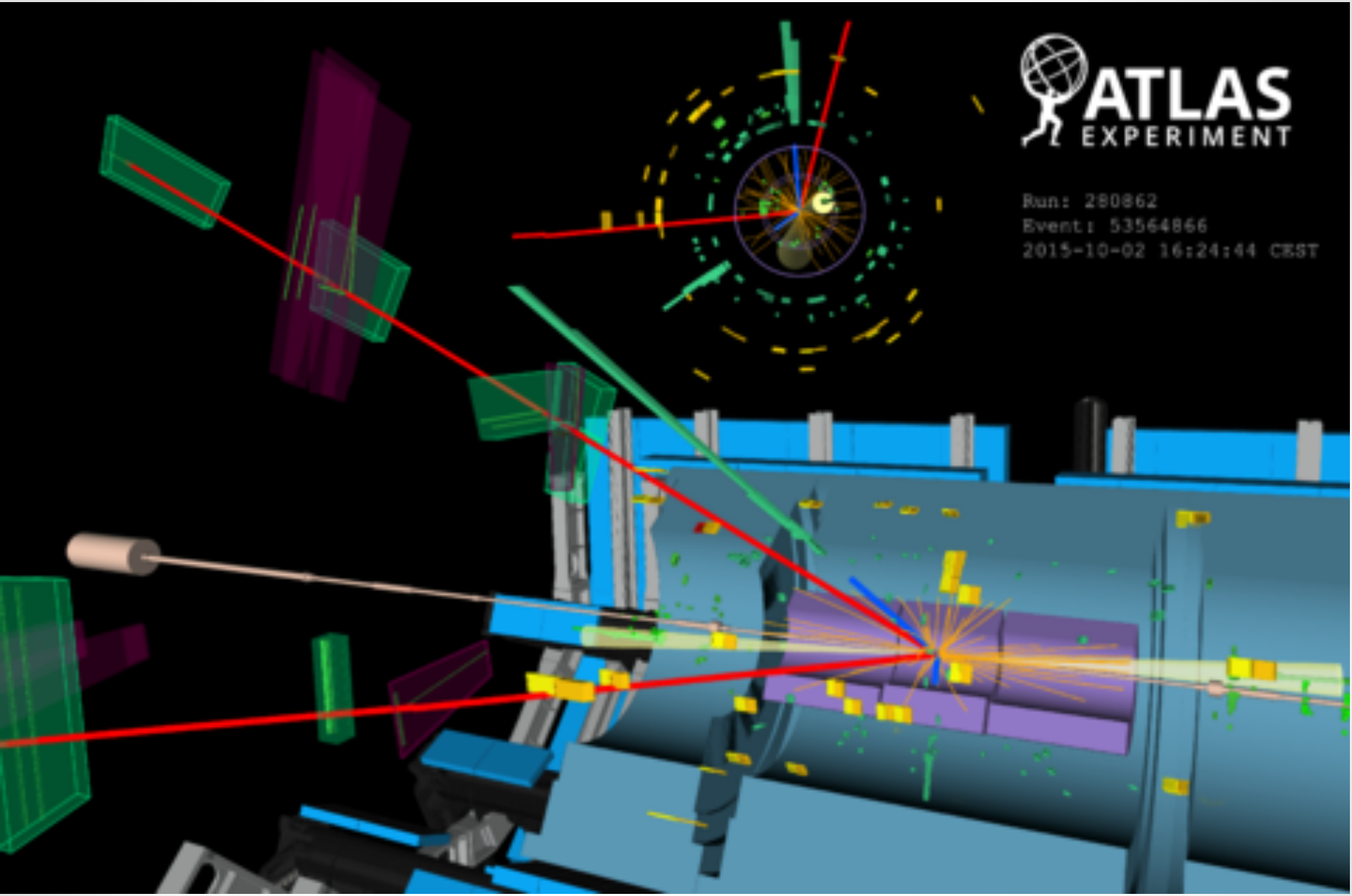


expect 4 signal candidates: fitted 1.0+2.3-1.5

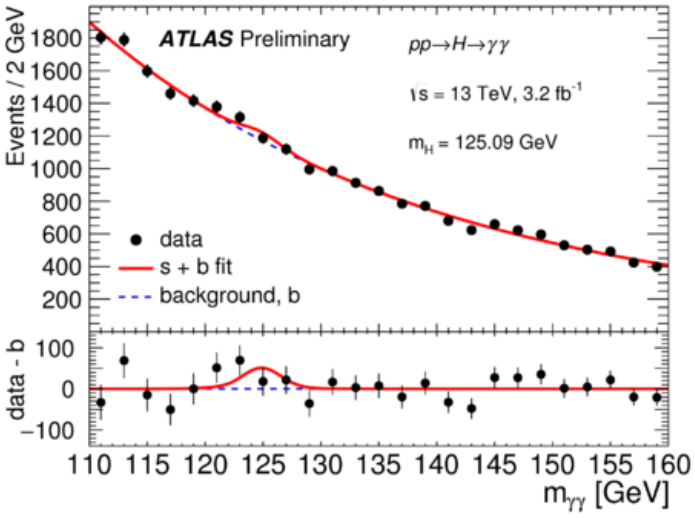
Expected sensitivity to SM Higgs: 2.8 σ
Observed : 0.7σ

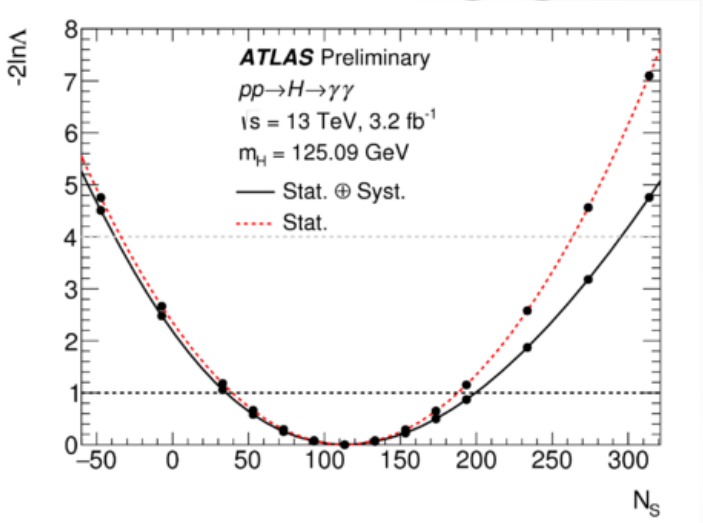
cross section $\sigma = 12^{+25}_{-16}$ pb

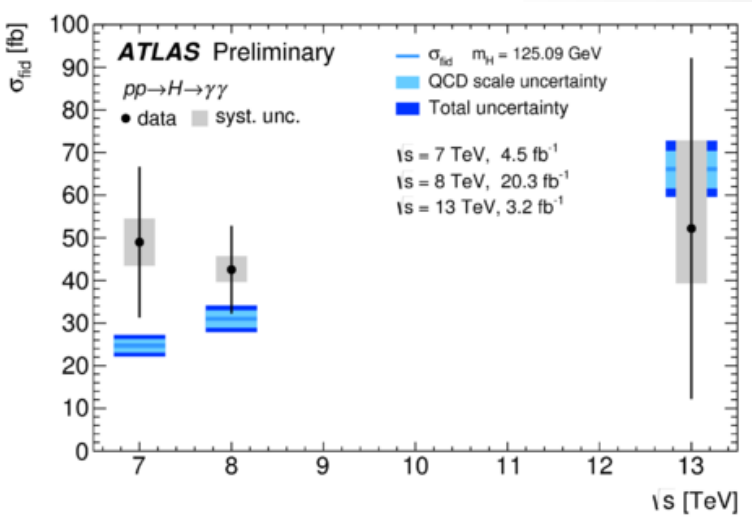



ATLAS
EXPERIMENT
Run: 280862
Event: 53564866
2015-10-02 16:24:44 CEST

Higgs @13 TeV : →γγ





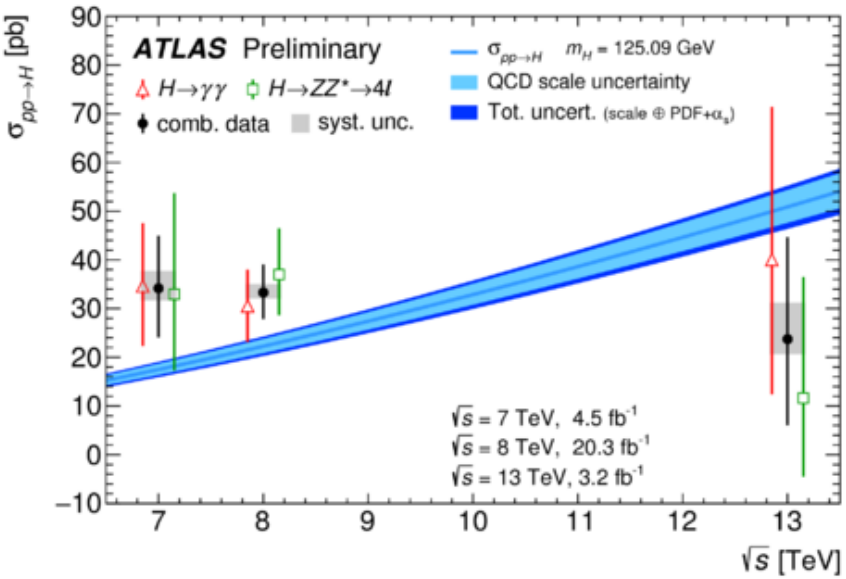


inclusive analysis
- Photon ET thresholds: 0.25 mγγ and 0.35 mγγ
- Track and Calorimeter based isolation criteria
- Simple fit function for background estimate
- **Number of candidate events fitted**:

113 ± 74 (stat) $^{+43}/_{-25}$ (syst)

Sensitivity to SM Higgs: **1.9**σ (Observed **1.5**σ)

Higgs @13 TeV : →γγ + 4l



Combined observation significance:
- Expected: **3.4**σ
- Observed: **1.4**σ

Compatibility with SM: **1.3**σ

	7 TeV	8 TeV	13 TeV
Acceptance factor			
$H \to \gamma\gamma$	0.620 ± 0.007	0.611 ± 0.012	0.570 ± 0.006
$H \to ZZ^* \to 4\ell$	0.467 ± 0.010	0.460 ± 0.010	0.427 ± 0.006
Fiducial cross section [fb]			
$H \to \gamma\gamma$	49 ± 18	43 ± 10	52^{+40}_{-37}
$H \to ZZ^* \to 4\ell$	$1.9^{+1.2}_{-0.9}$	2.1 ± 0.5	$0.6^{+1.3}_{-0.9}$
Total cross section [pb]			
$H \to \gamma\gamma$	35^{+13}_{-12}	$30.5^{+7.5}_{-7.4}$	40^{+31}_{-28}
$H \to ZZ^* \to 4\ell$	33^{+21}_{-16}	37^{+9}_{-8}	12^{+25}_{-16}
Combination	34 ± 10 (stat.) $^{+4}_{-2}$ (syst.)	$33.3^{+5.5}_{-5.3}$ (stat.) $^{+1.7}_{-1.3}$ (syst.)	24^{+20}_{-17} (stat.) $^{+7}_{-3}$ (syst.)
LHC-XS	17.5 ± 1.6	22.3 ± 2.0	$50.9^{+4.6}_{-4.4}$

CMS & ATLAS results:

SUSY searches

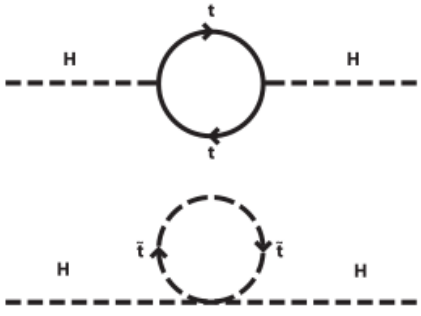
Supersymmetry (SUSY)

symmetry between fermions and bosons
→ super partners (double particle content)
→ broken symmetry

Provides Gauge coupling unification

Ameliorates hierarchy problem (fine tuning)
(protects Higgs mass from quantum corrections)

Provides Dark matter candidate
Stable Lightest SUSY Particle (RPC)

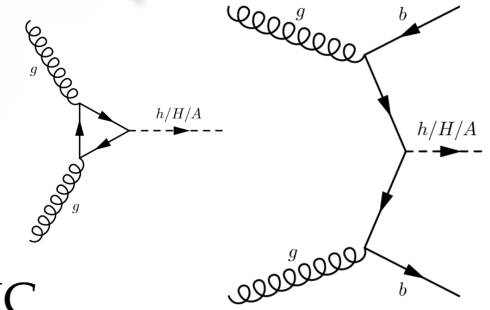


Searched for ~40 years.

2015 Run2 eyes open for high mass, strongly produced SUSY gluino / squark pairs: $\sigma(13TeV)/\sigma(8TeV)$ = **15-35** for M=**1-1.5 TeV**

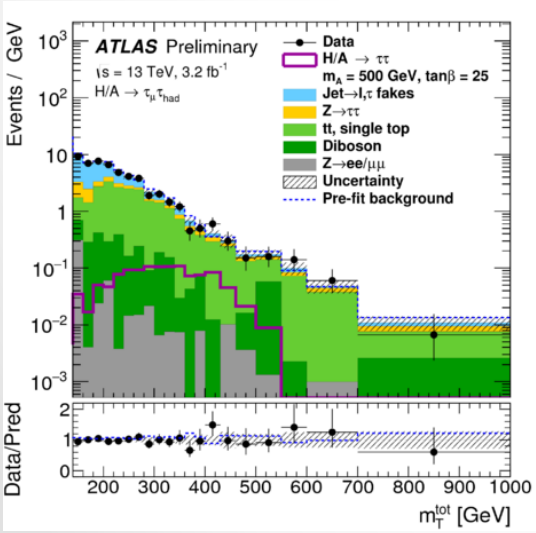
SUSY(2HDM): H/A → ττ

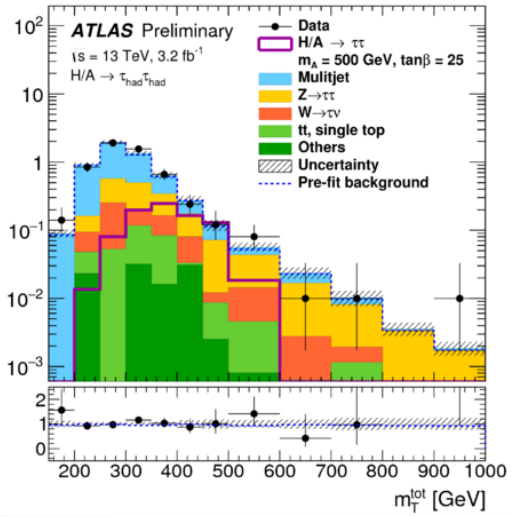
signal enhanced
at large tanβ



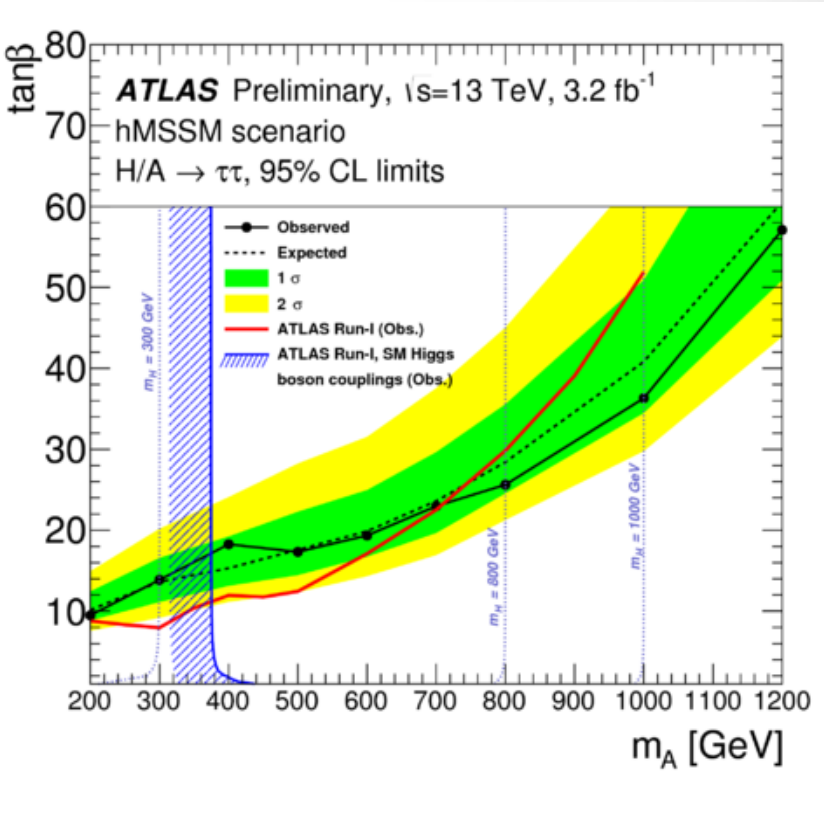
$\tau_{lep}\tau_{had}$
- Z and top from MC
- W+jets and QCD from fakes (tau ID)

$\tau_{had}\tau_{had}$
QCD background from fakes method
(checks in Same Sign Validation region)



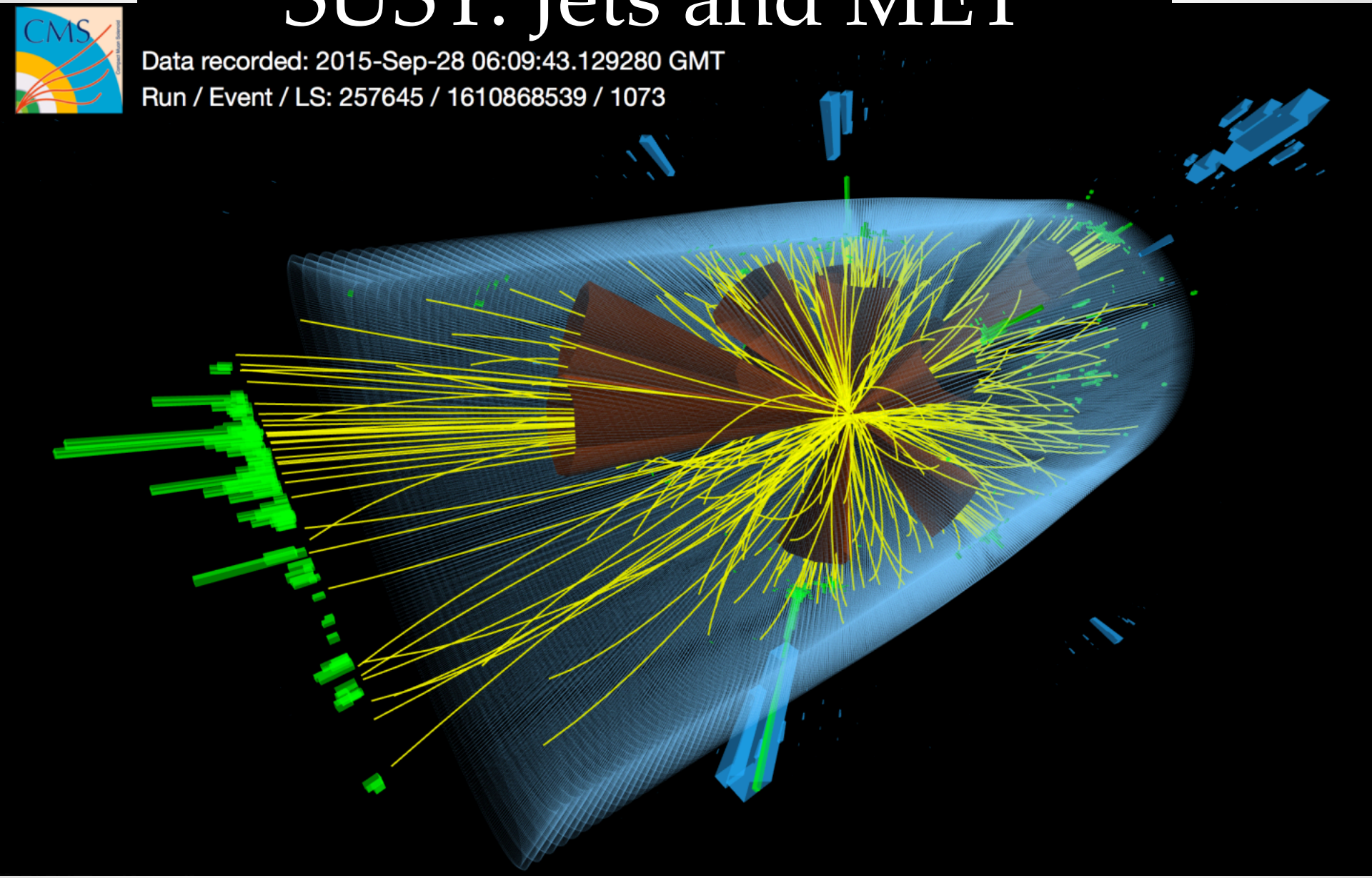


Aiming at all production modes inclusively



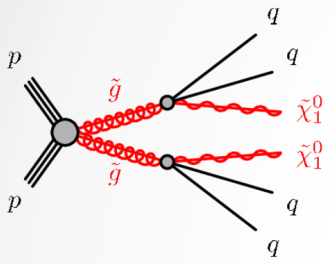
new Run2 excluded area for
m_A>700 and tanβ>20

SUSY: Jets and MET

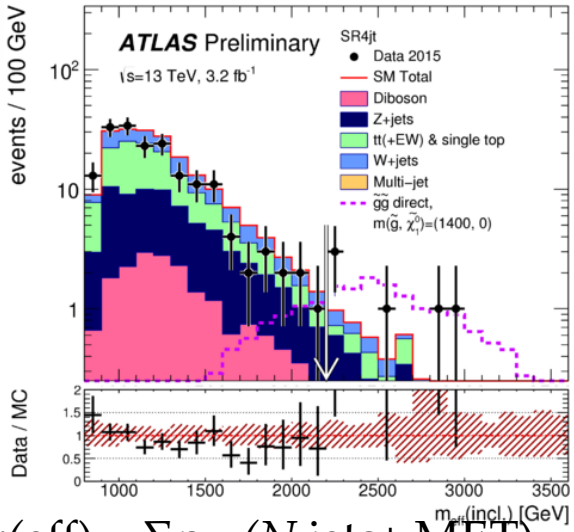


ATLAS-CONF-2015-062
ATLAS-CONF-2015-077

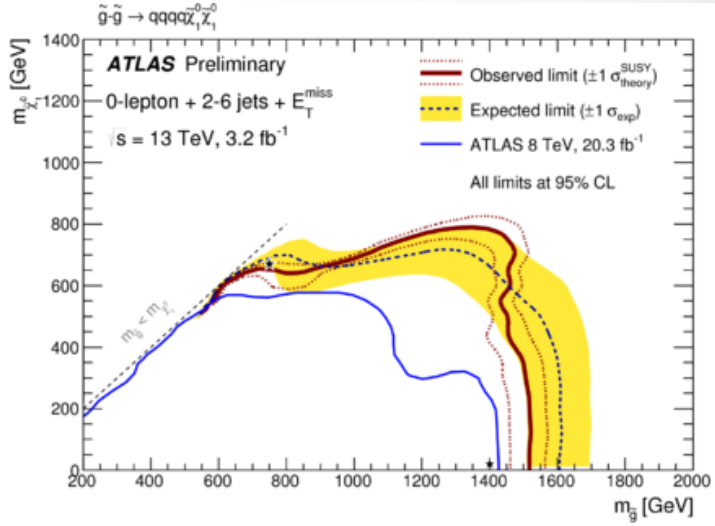
SUSY: Jets and MET

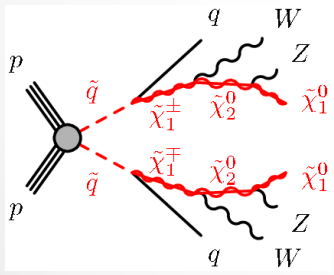


0L+(2-6)J+MET

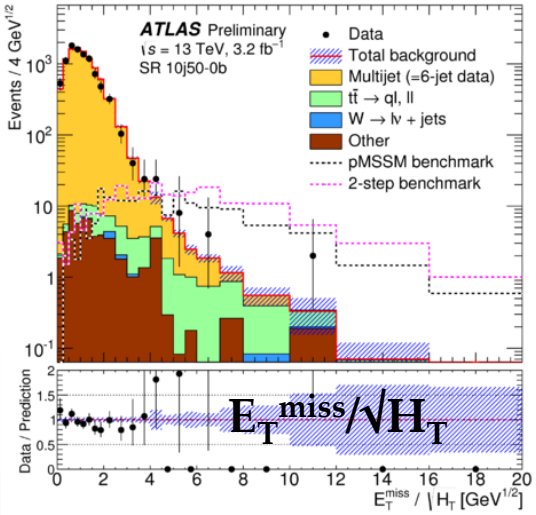


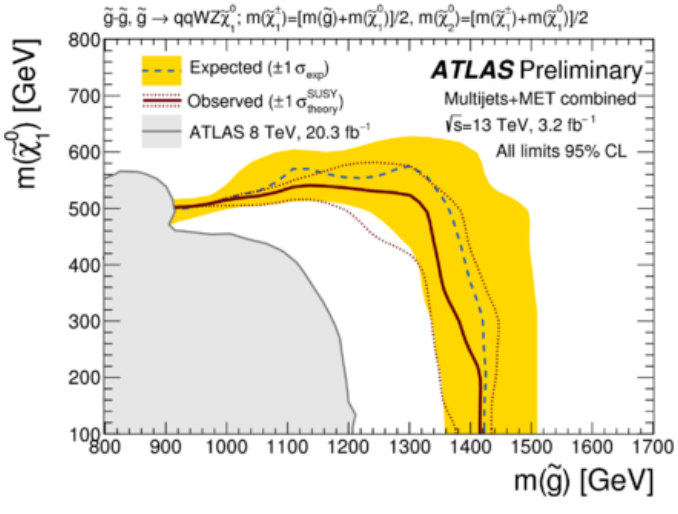
$m(\text{eff}) = \Sigma p_T$ (N jets+ MET)





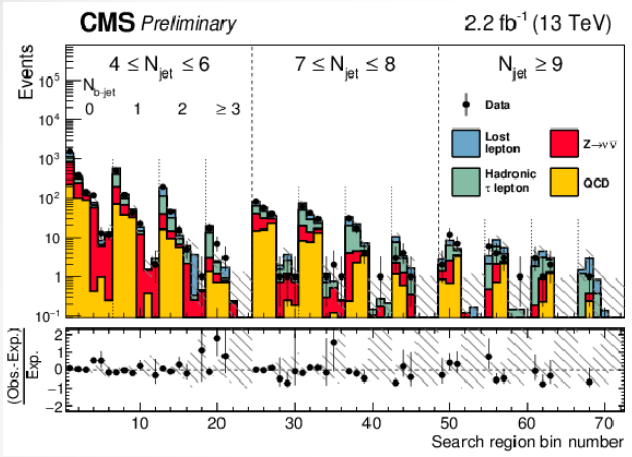
0L+(7-10)J+MET



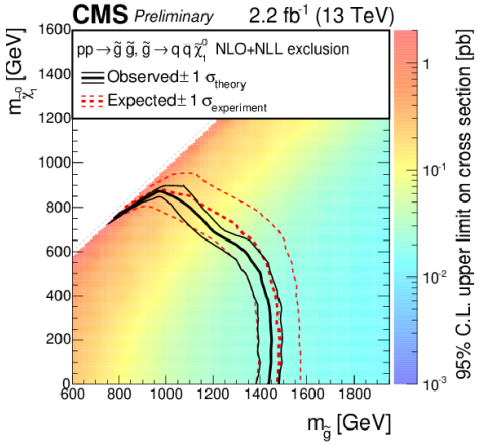


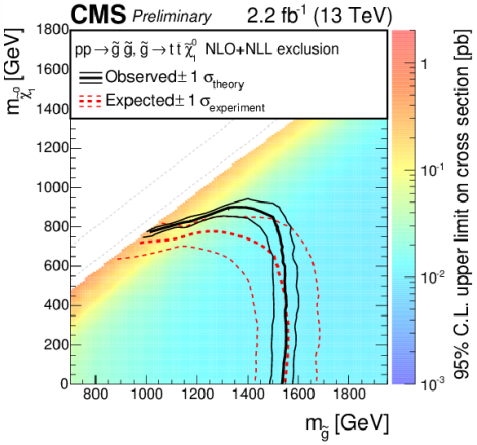
CMS-PAS-SUS-15-002
CMS-PAS-SUS-15-003

SUSY: Jets and MET



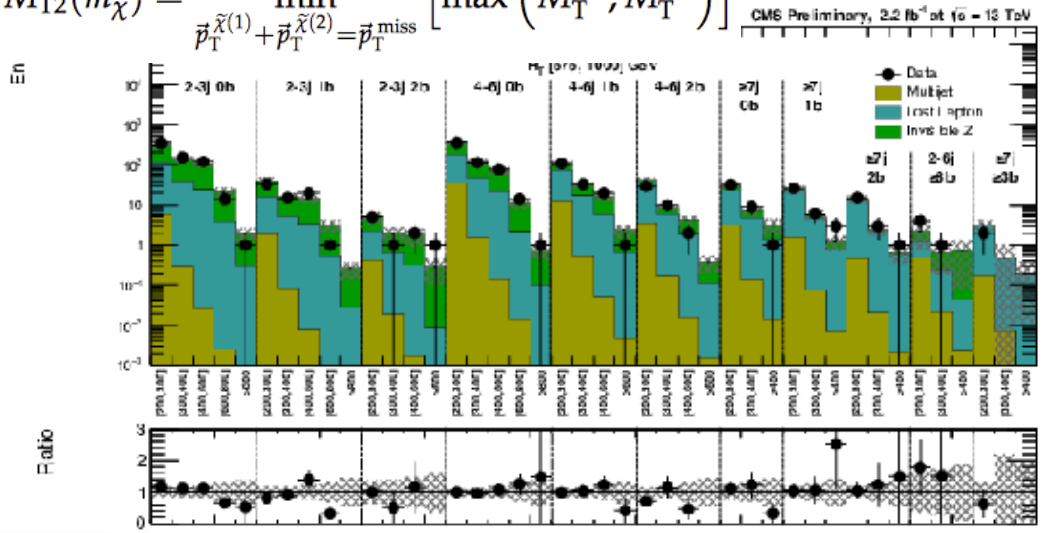
72 search regions of Nj, Nb, MET, HT

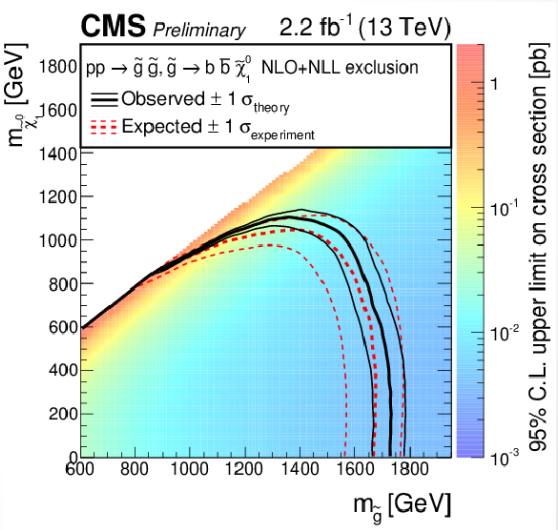




"stranverse" mass

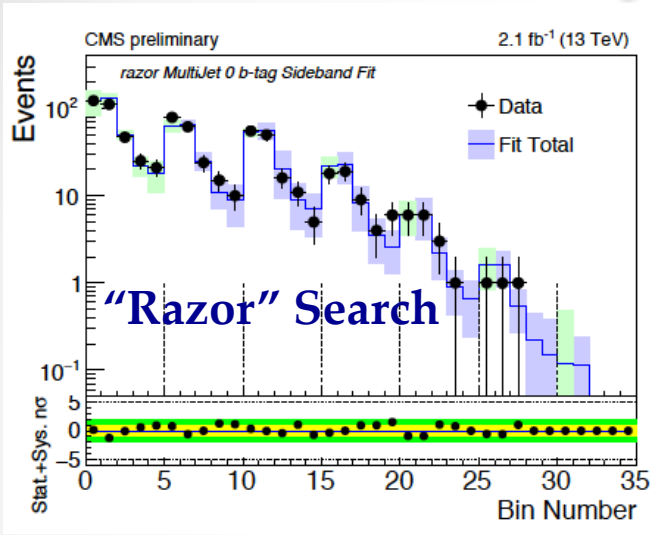
$$M_{T2}(m_{\tilde{\chi}}) = \min_{\vec{p}_T^{\,\tilde{\chi}(1)} + \vec{p}_T^{\,\tilde{\chi}(2)} = \vec{p}_T^{\,\text{miss}}} \left[\max\left(M_T^{(1)}, M_T^{(2)} \right) \right]$$

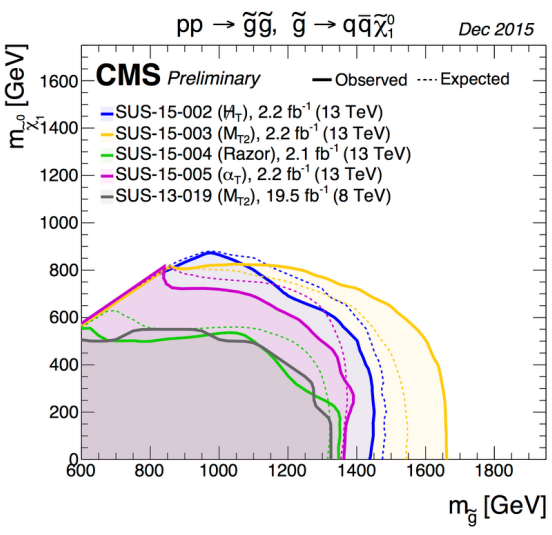


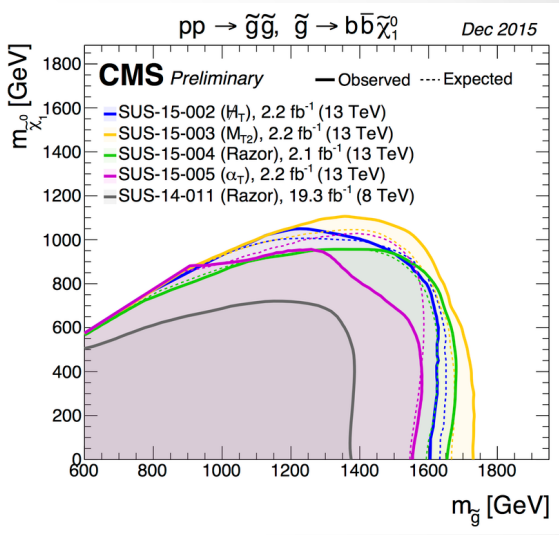


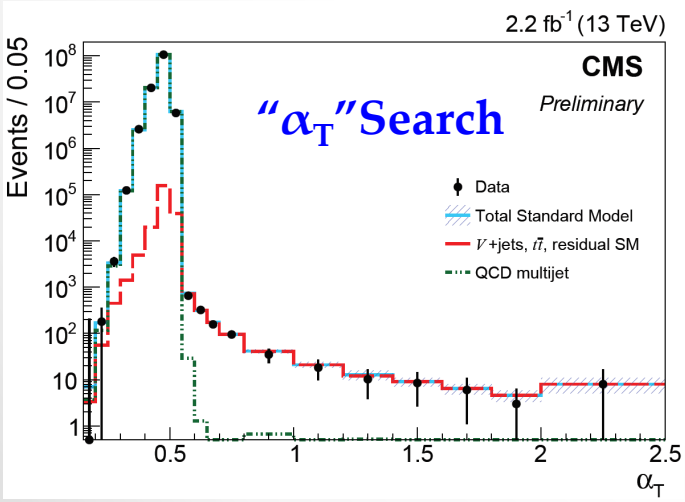
CMS-PAS-SUS-15-004
CMS-PAS-SUS-15-005

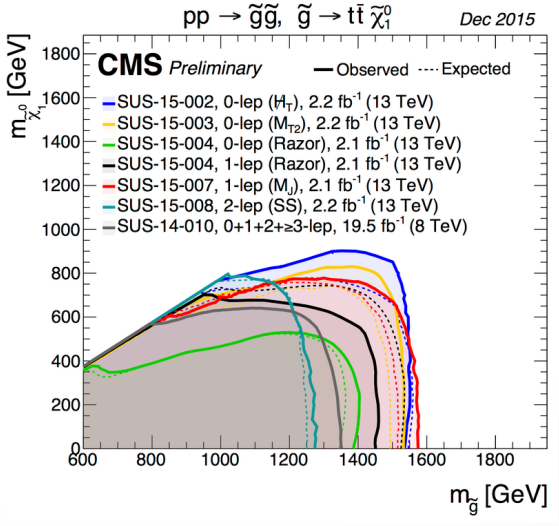
SUSY: Jets and MET









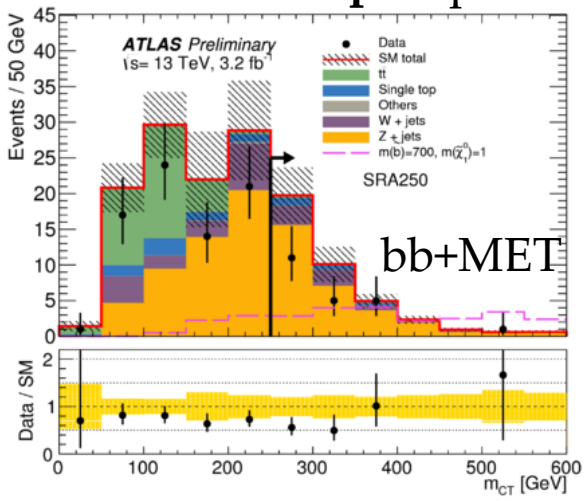


Gluino mass Exclusions > 1.7 TeV*
Run 1 > 1.4 TeV

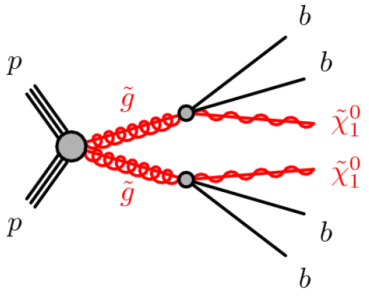
ATLAS-CONF-2015-066
ATLAS-CONF-2015-067
ATLAS-CONF-2015-082

SUSY: Jets and MET

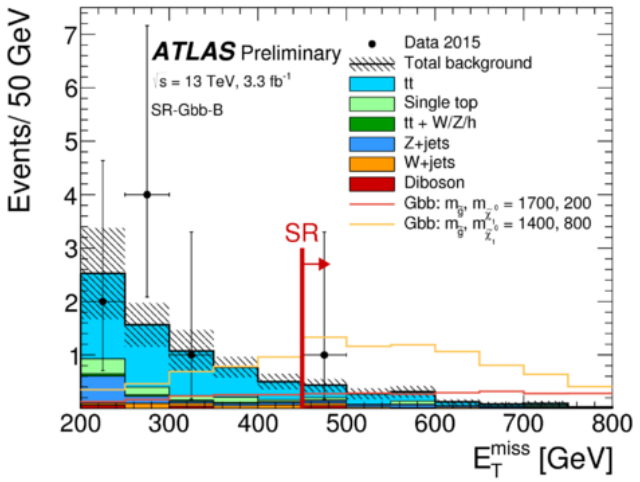
direct Sbottom pair production



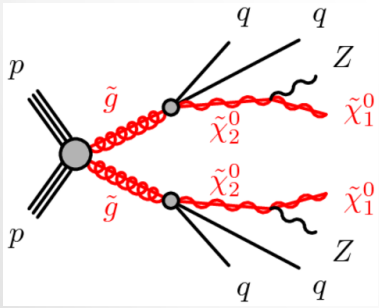
bb+MET



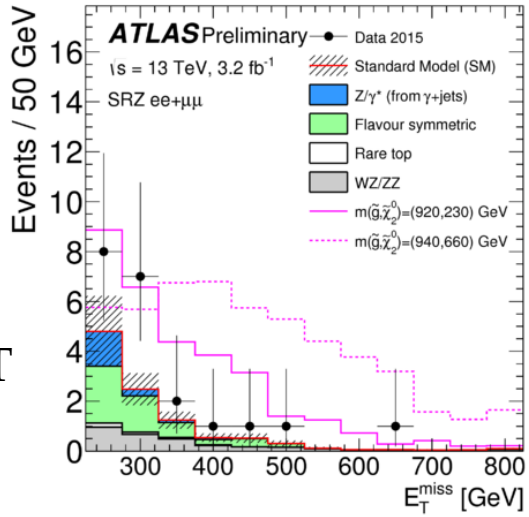
gluino-mediated stop and sbottom

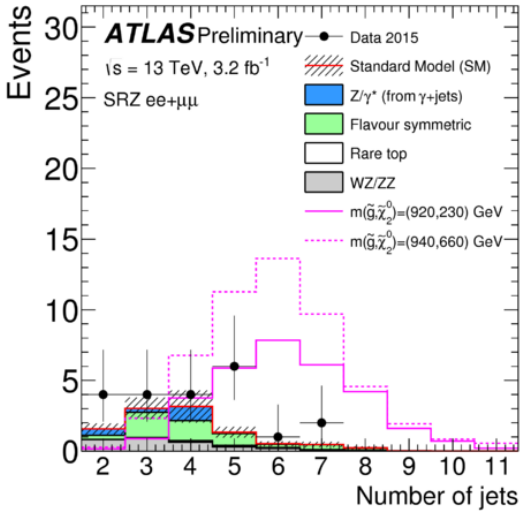


Z+MET: Run1 : 29 events
10.8±2.2 *exp* (3σ excess)



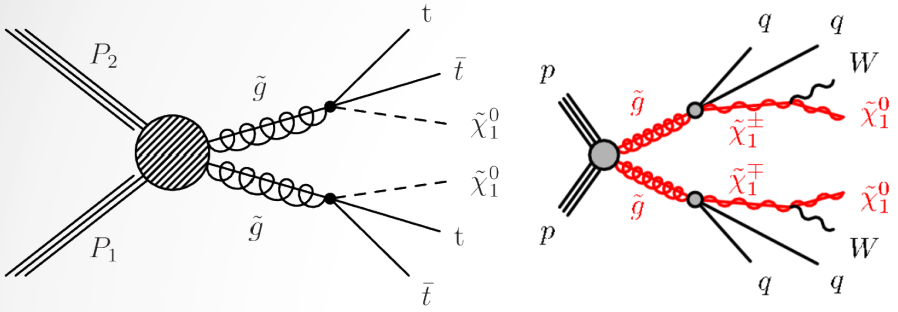
21 events (ee+μμ) with **10.4±2.4** *exp* **(2.2σ excess)** intermediate MET

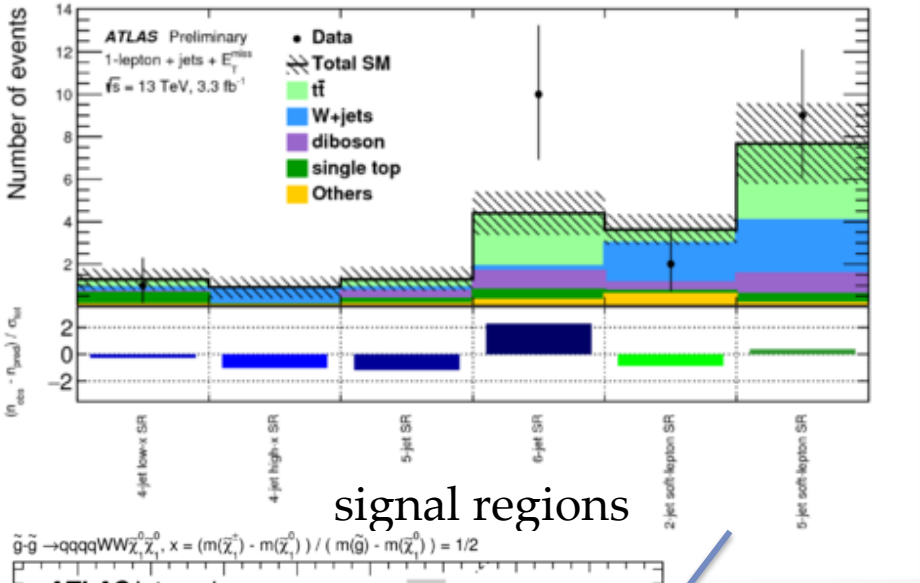




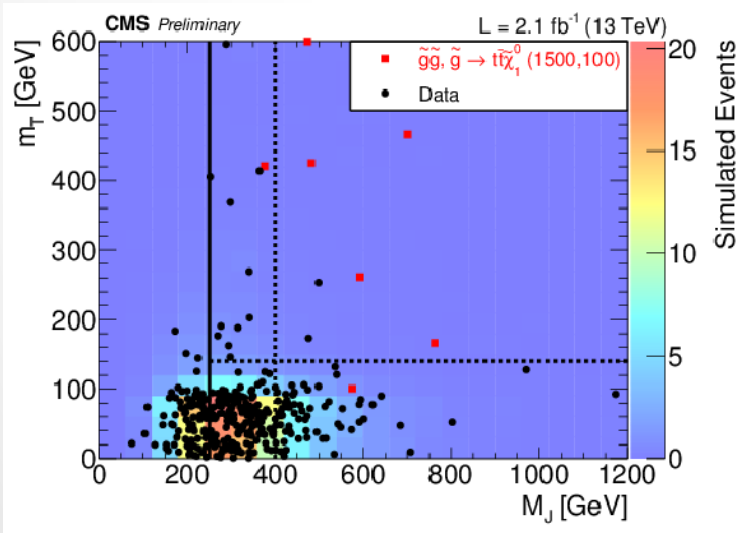
SUSY : lepton + jets

CMS-PAS-SUS-15-007
ATLAS-CONF-2015-076

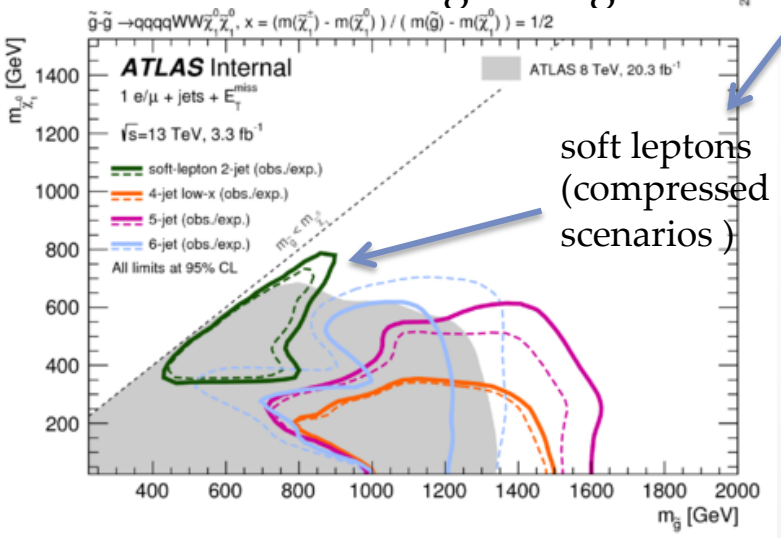




signal regions



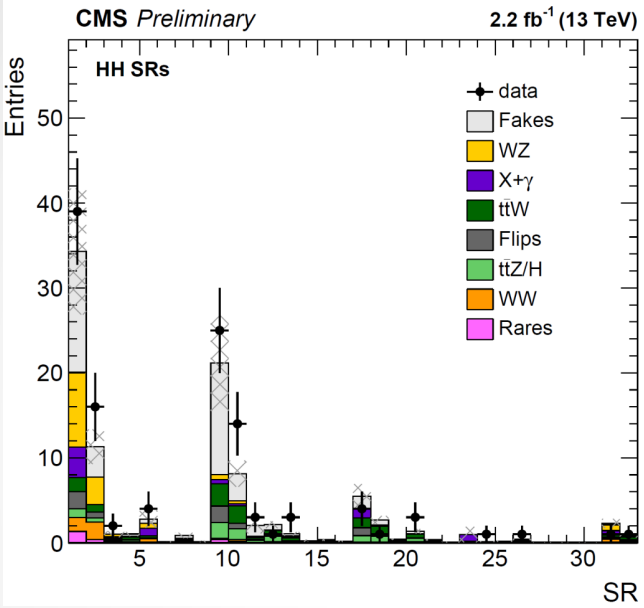
sum of masses of large radius jets

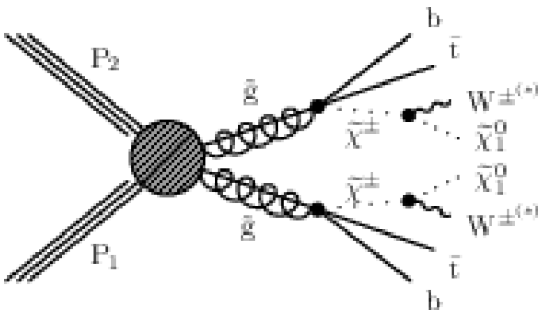


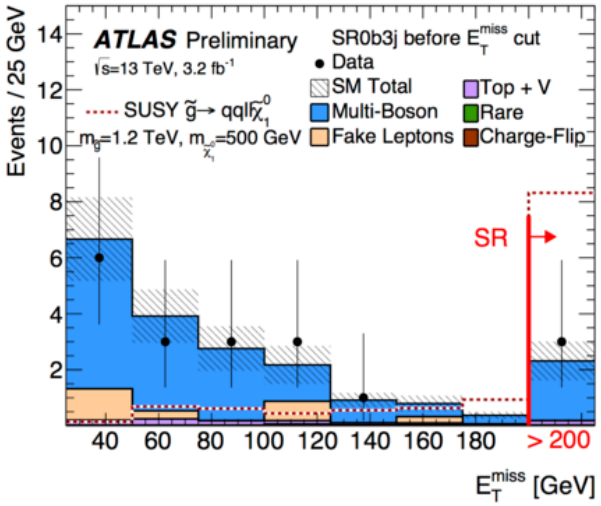
soft leptons (compressed scenarios)

SUSY same sign leptons

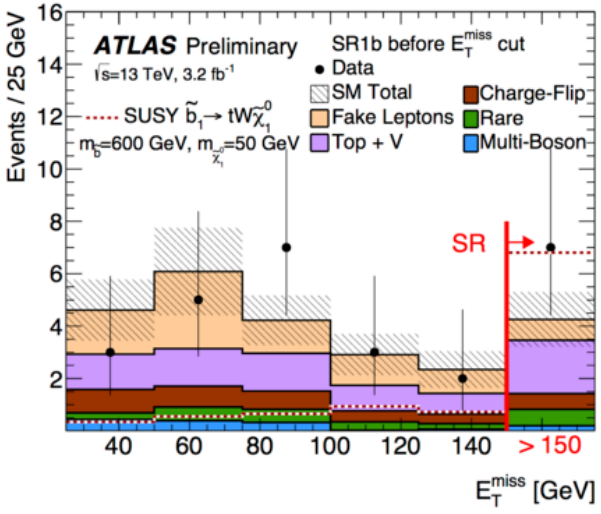
CMS-PAS-SUS-15-008
ATLAS-CONF-2015-078

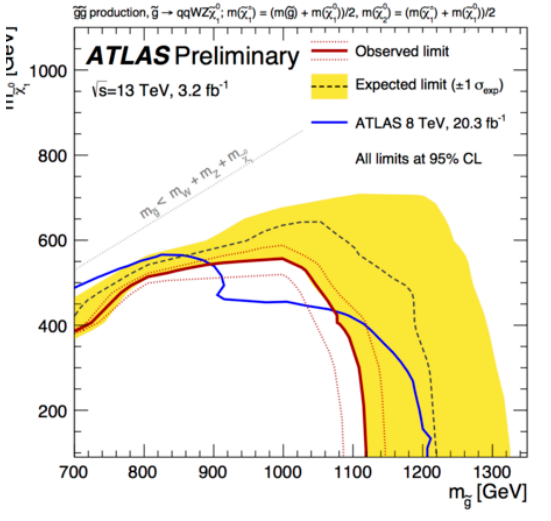






Binned in
Njet, nB, MET, HT, MT
background from non-prompt leptons (measured in data)





Summary & Outlook

- Nice start of Run2 in 2015 with ~3/fb pp@13TeV
- Selected Run2 results (ATLAS + CMS)
  - electroweak measurements σ x2 and $\delta\sigma/\sigma$ x2
  - first glimpse of Higgs boson (~σ x 2-4)
  - nothing yet from (many!) SUSY searches
- Just the first small step in the max LHC energy era
  - Run2 →20/fb→100/fb in 2016→2018
  - Run3 (phase1) →300/fb in →2022
  - Run4-5-6 (phase2 up)3000/fb in →2035

the frontier energy and intensity exploration of the electroweak symmetry, its breaking and beyond has just begun