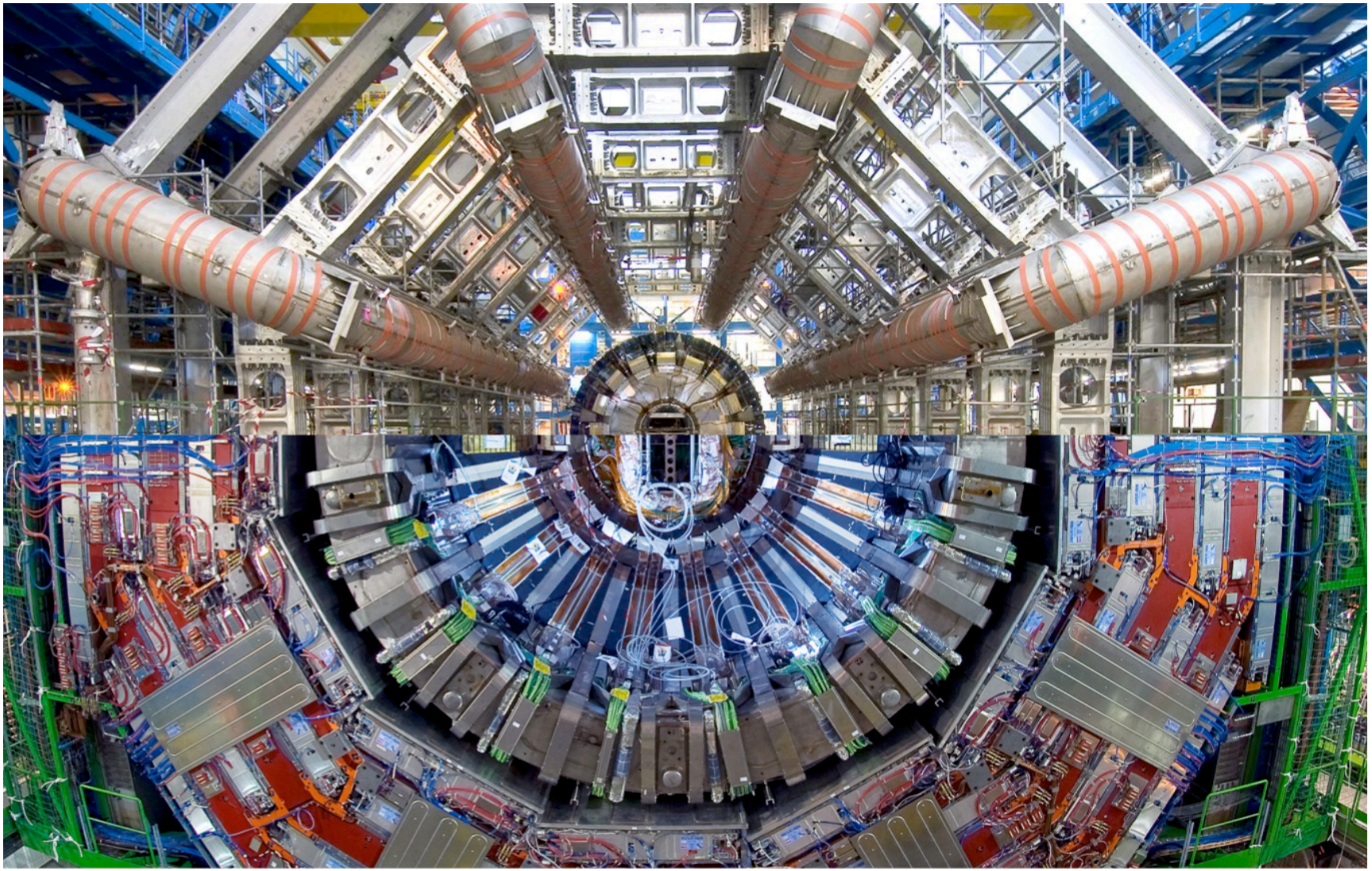
Higgs/SUSY results from Atlas/CMS



Boris Mangano
ETH - Zurich

From Higgs boson discovery to 2015

2012: found a new particle, made some people happy

2012

- Establish excess in as many different channels as possible
- Characterize new particle: production cross-section, mass, spin, couplings ...
- For each experiment, legacy papers with final Run1 results
- Final Run1 combinations of Atlas/CMS and Atlas+CMS results

2015

Recent Higgs publications: 2014-2015

CMS results

H → bb legacy paper
Jan 2014 (**ETHZ**)
PhysRevD.89.012003

H → WW legacy paper
Jan 2014 (**ETHZ**)
JHEP01(2014)096

H → γγ legacy paper, including ttH mode
Jul 2014 (**ETHZ**)
Eur.Phys.J.C(2014) 74:3076

ttH (→bb) with MatrixElement
May 2015 (**ETHZ/UZH**)
Eur.Phys.J.C(2015) 75:251

- For each experiment, legacy papers with final Run1 results
- Final Run1 combinations of Atlas/CMS and Atlas+CMS results

Atlas results

H → ZZ → 4L: fiducial and differential cross-sections
Sep 2014 (**UniGE**)
PhysLettB 738 234-253

H → ZZ → 4L legacy paper on production/couplings
Jan 2015 (**UniGE**)
PhysRevD.91.012006

Recent Higgs publications: 2014-2015

CMS results

Evidence of direct decay to fermions
Jun 2014 (**ETHZ**)
NPHYS3005

Precise determination of mass and tests on couplings (combination)
May 2015 (**ETHZ**)
Eur.Phys.J. C (2015) 75:212

- For each experiment, legacy papers with final Run1 results
- Final Run1 combinations of Atlas/CMS and Atlas+CMS results

Atlas results

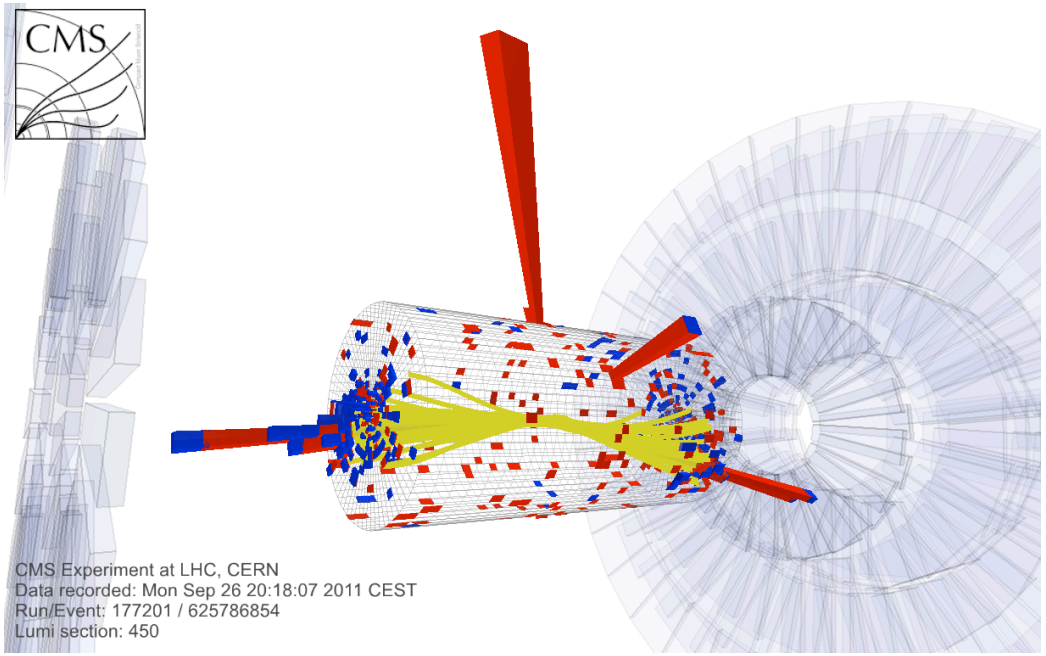
$H \rightarrow 4L + H \rightarrow \gamma\gamma$ legacy paper on mass
Sep 2014 (**UniGE**)
PhysRevD.90.052004

Atlas + CMS results

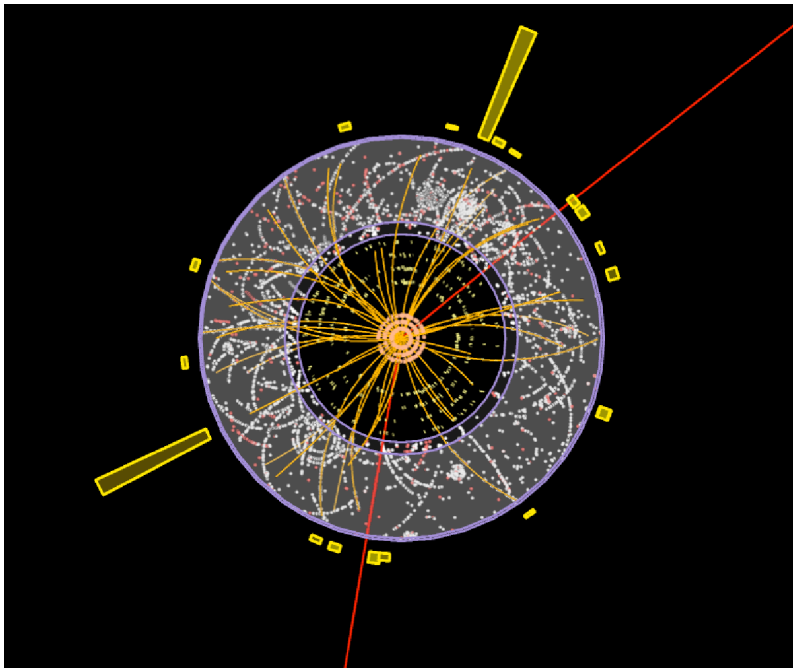
Mass measurement from $H \rightarrow 4L + H \rightarrow \gamma\gamma$ combination
May 2015 (**ETHZ/UniGE**)
PRL 114, 191803 (2015)

Cleanest Higgs boson channels

H → γγ in CMS

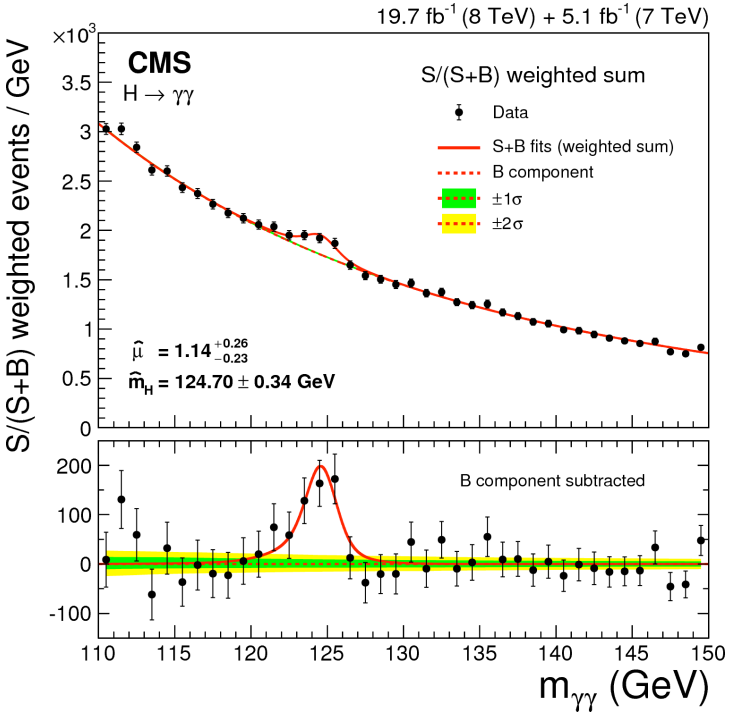


H → ZZ → 4L in Atlas

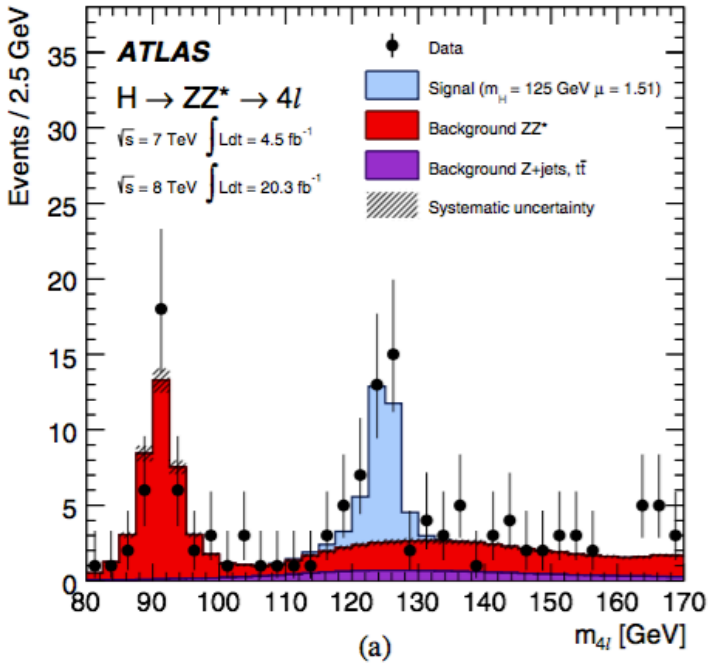


To 1st order, a bump search

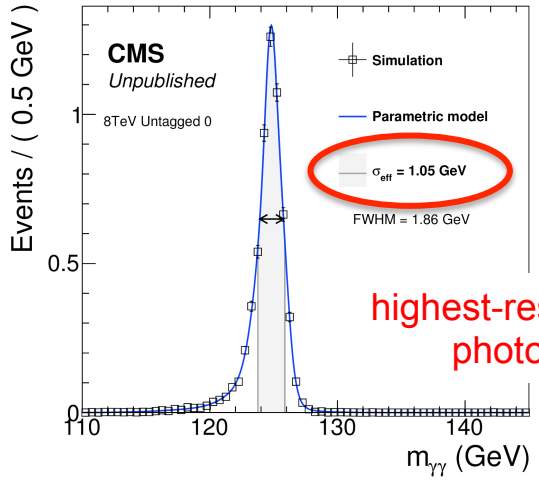
H → γγ in CMS



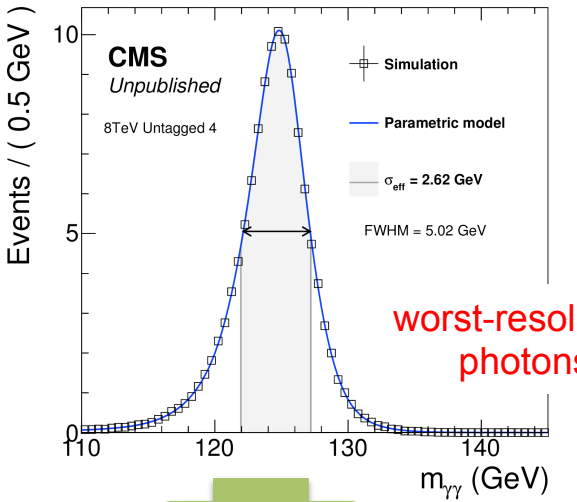
H → ZZ → 4L in Atlas



To 2nd order, a categorization challenge



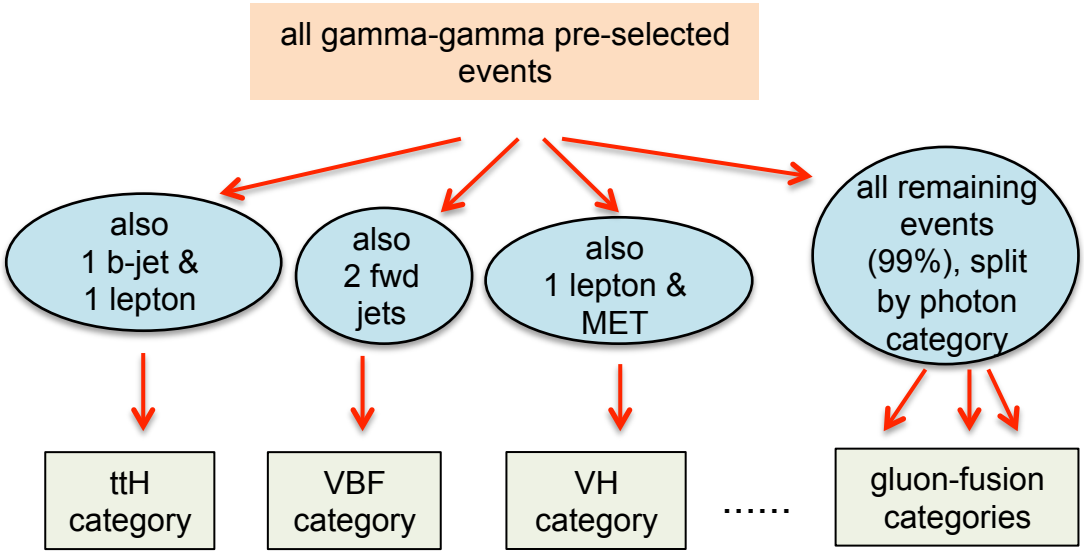
highest-resolution photons



worst-resolution photons

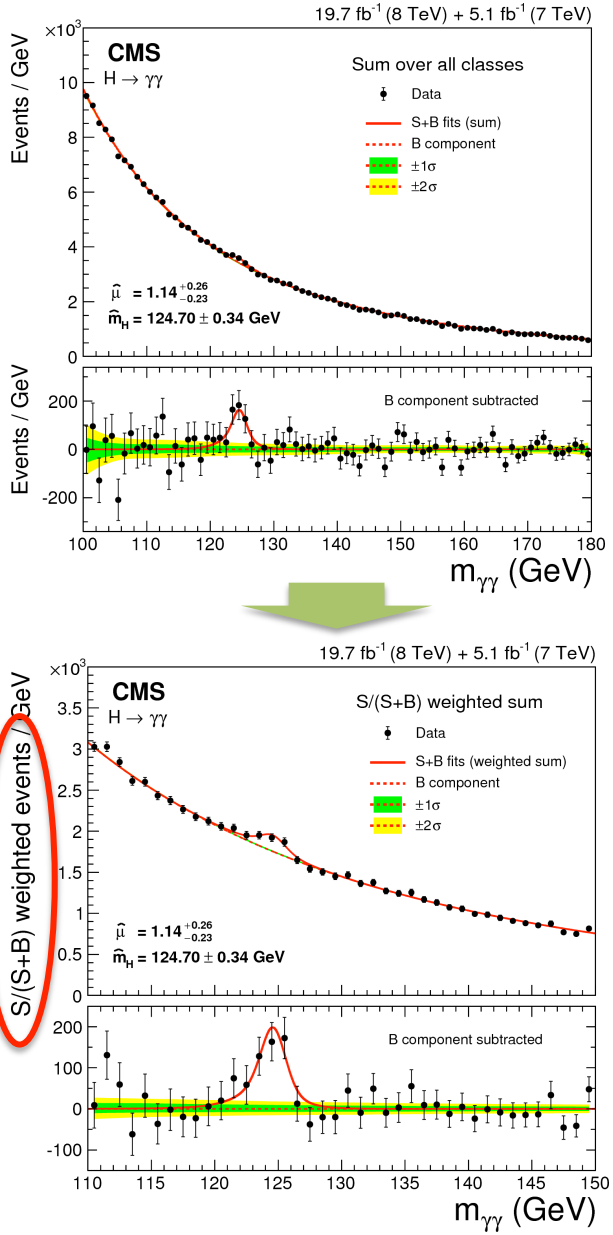
The narrower the signal peak

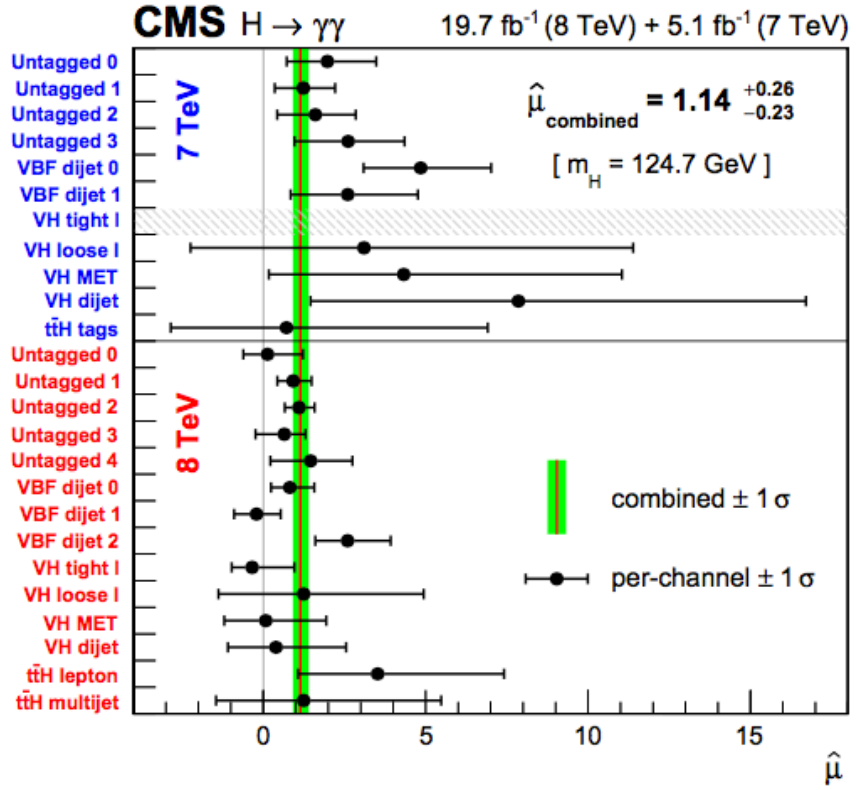
- **the better the S/B ratio**
- **the better the mass determination**



- **Categories with better S/B**
- **Possibility to explore different production mechanisms**

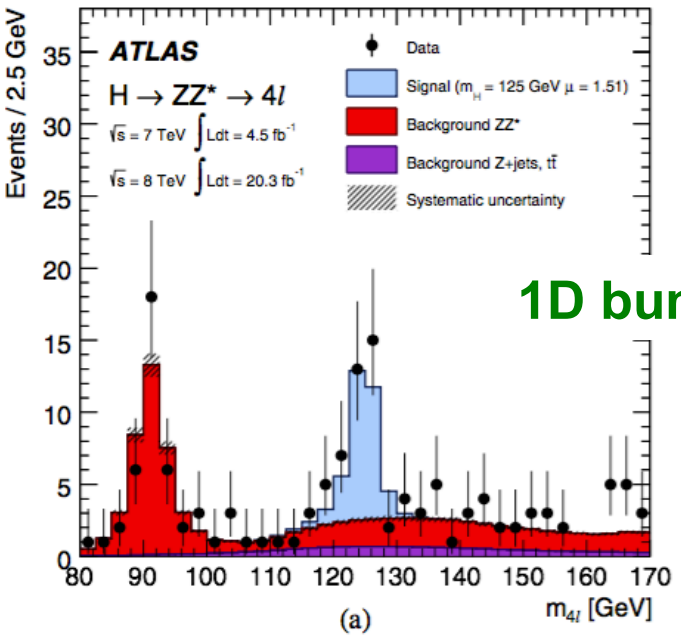
To 2nd order, a categorization challenge



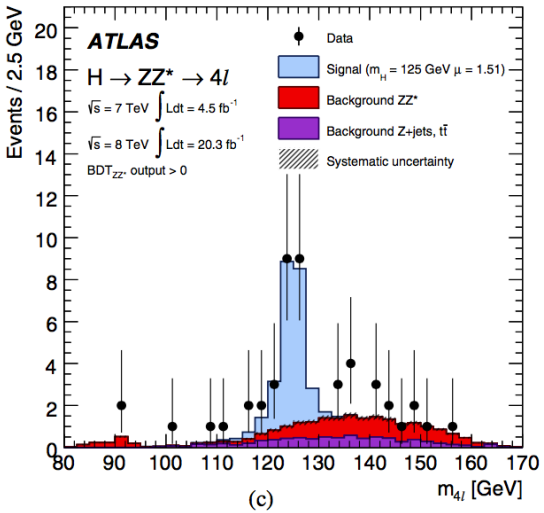


H → γγ legacy paper, including ttH mode
Jul 2014 (**ETHZ**)
Eur.Phys.J.C(2014) 74:3076

To 3nd order, a multi-dimensional bump search

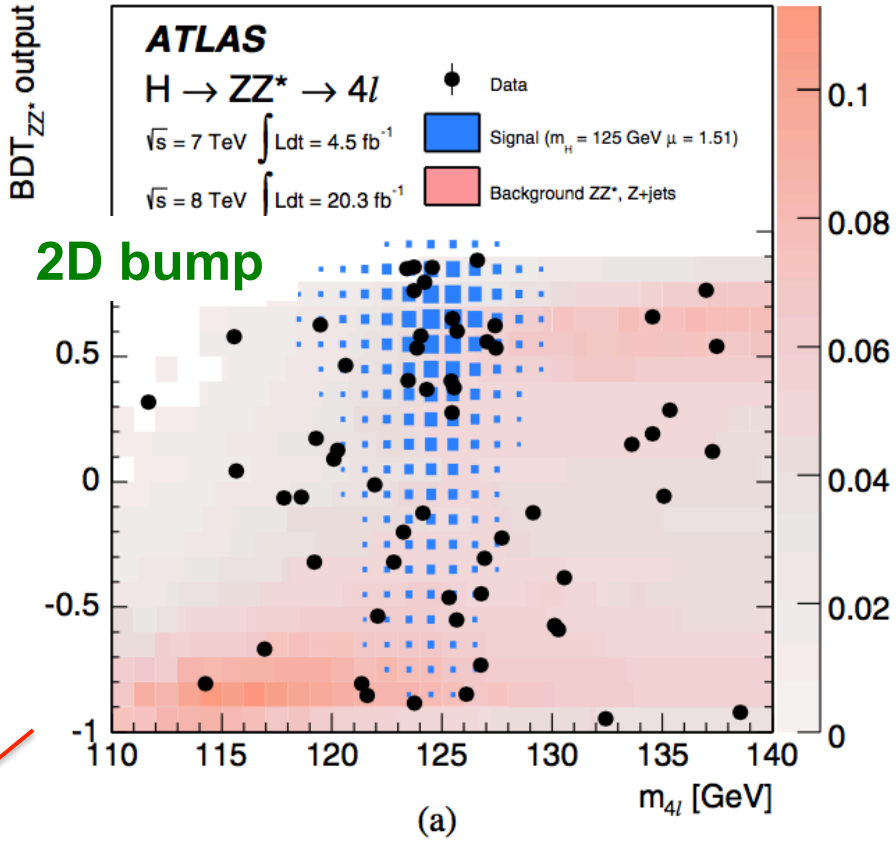


1D bump



BDT > 0

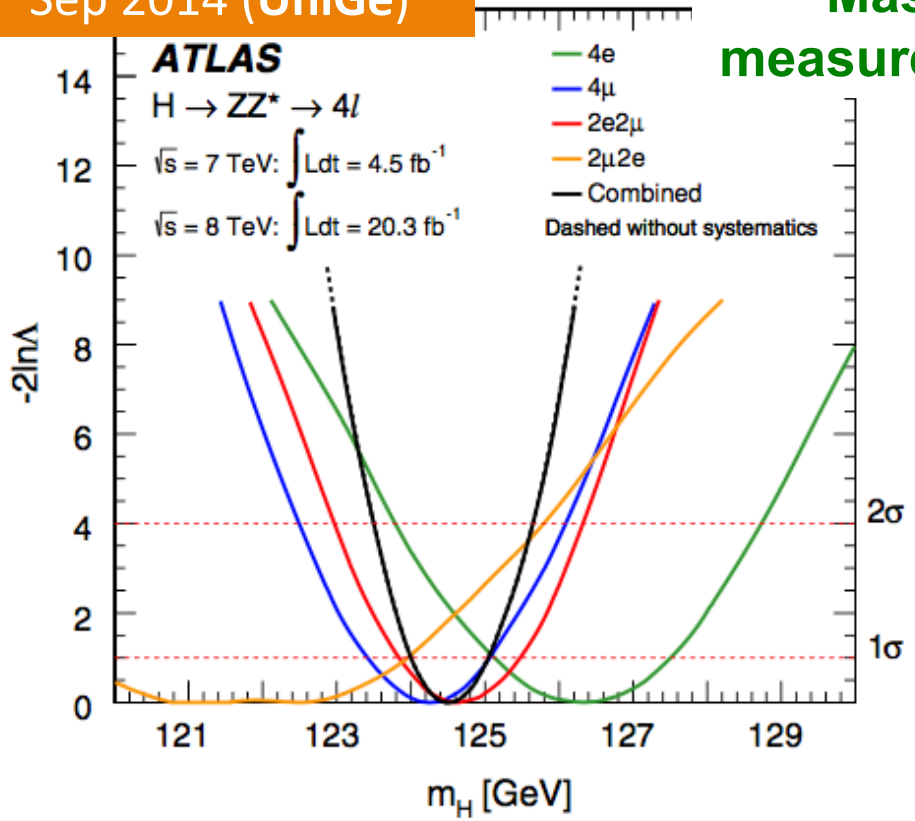
2D bump



ATLAS results from H→ ZZ*→ 4L

PhysRevD.90.052004
Sep 2014 (**UniGe**)

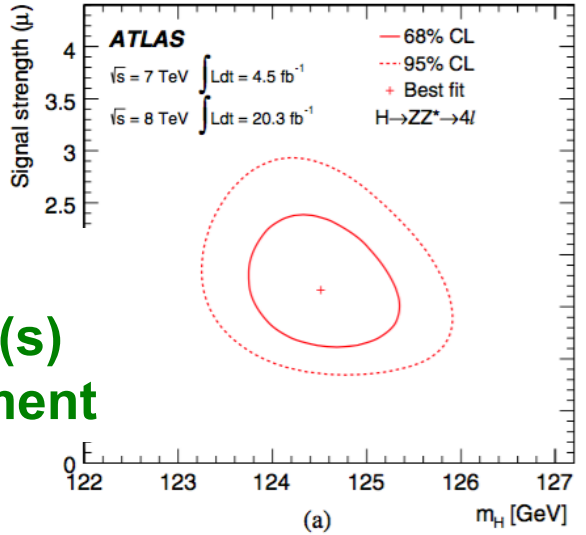
Mass measurement

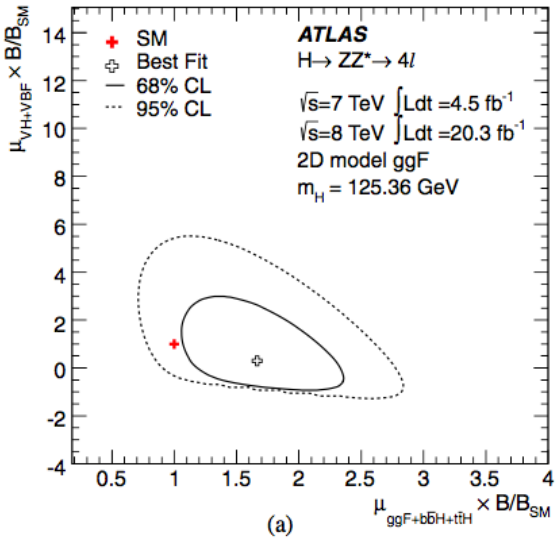


$$m_H = 124.51 \pm 0.52(\text{stat}) \pm 0.06(\text{syst}) \text{ GeV}$$

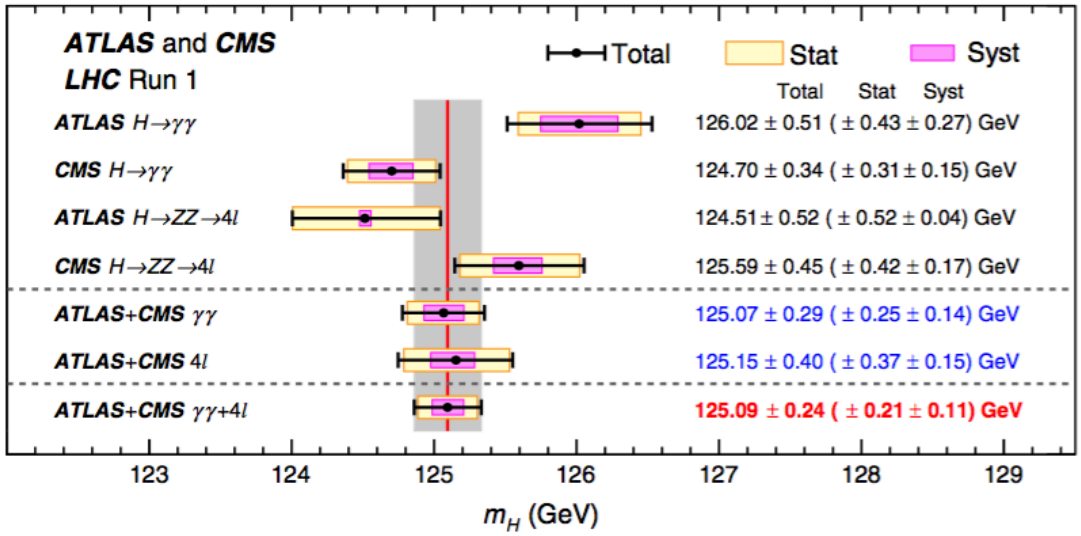
PhysRevD.91.012006
Jan 2015 (**UniGe**)

signal strength(s) measurement

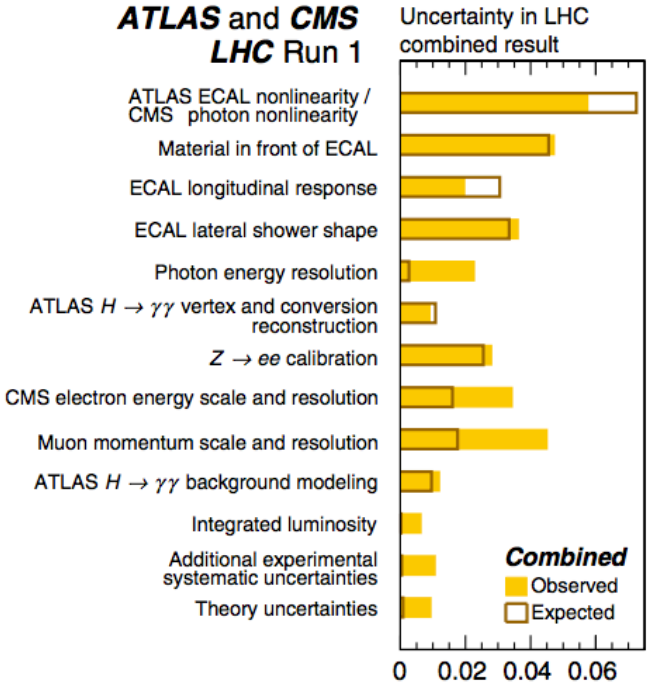




ATLAS-CMS combination: Higgs boson mass



PRL 114, 191803
May 2015



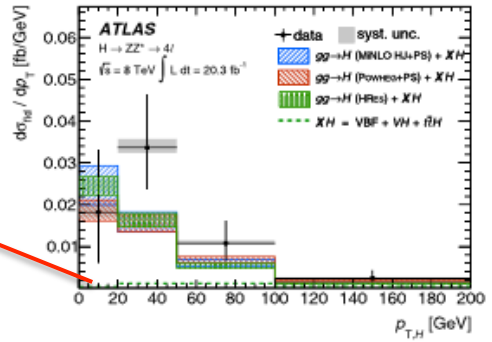
$M_H = 125.09 \pm 0.21(\text{stat}) \pm 0.11\ (\text{syst})$ GeV

- Total uncertainty is still statistically dominated
- Syst.uncert. dominated by uncertainty on photon/electron energy scale and muon momentum scale
- Overall, photon energy scale uncertainty dominates

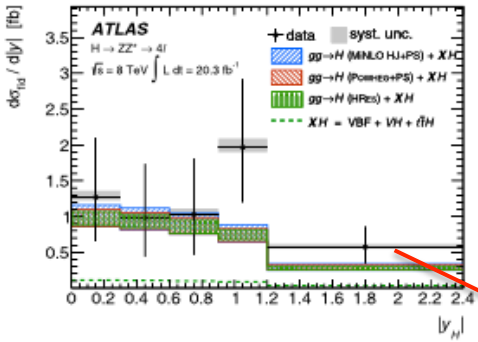
Important progresses both in Atlas and CMS thanks to MVA-regression-based calibration of γ/e energy

Fiducial and differential cross-section with HZZ4L

sensitive to production mechanism



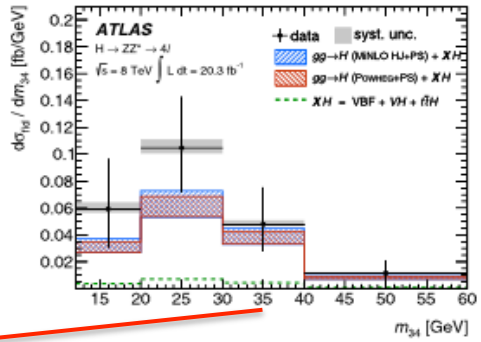
(a)



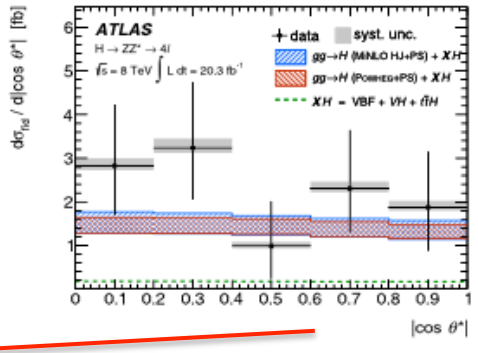
(b)

PhysLetters B
738 (234-253)
Sep 2014

sensitive to parton PDFs of the proton

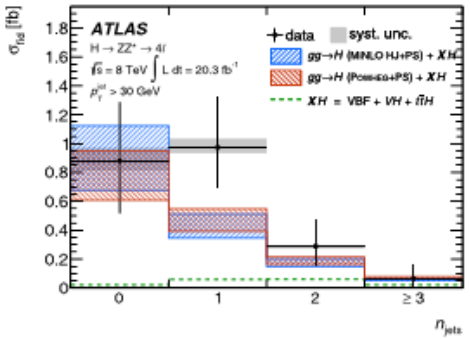


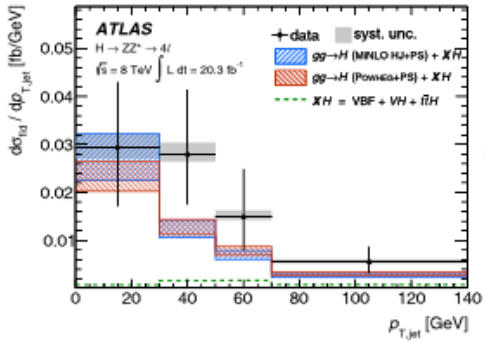
(c)



(d)

sensitive to Lagrangian structure of Higgs boson interactions





Probing QCD radiation effects

Summary on SM Higgs boson

The first big chunk of work is completed.
We learnt a lot and we got a lot of fun

We discovered a new boson and its properties are very close to what we expect from the SM Higgs boson…

Summary on SM Higgs boson

The first big chunk of work is completed.
We learnt a lot and we got a lot of fun

We discovered a new boson and its properties are very close to what we expect from the SM Higgs boson…

…but sometimes things are not what they look like

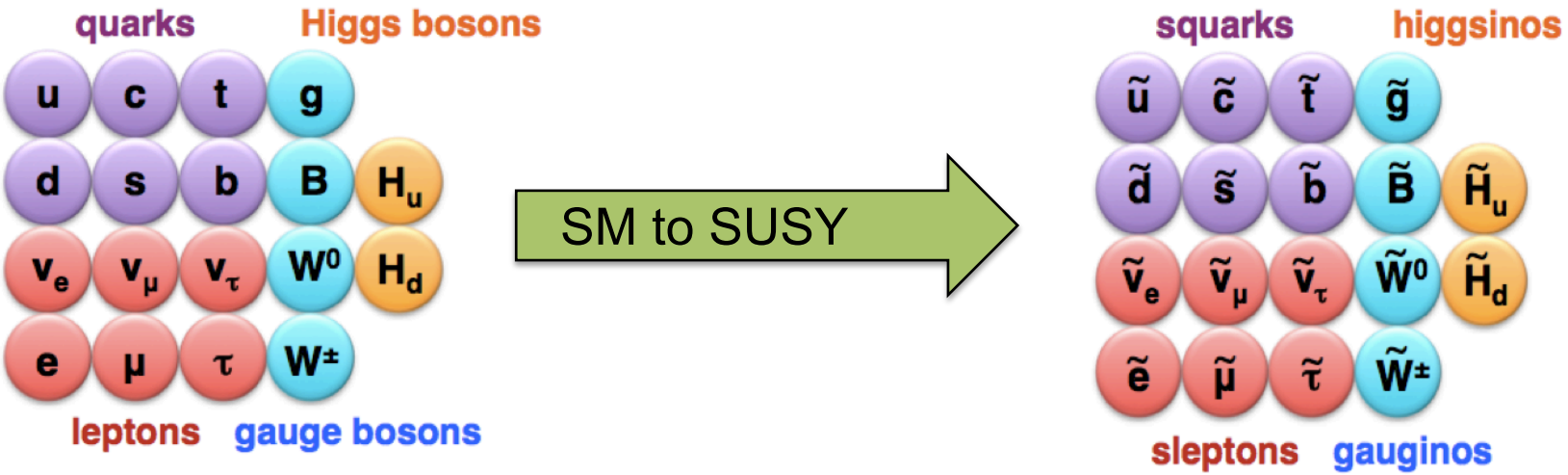
slide stolen from M.Donega'

Going beyond SM: Supersymmetry

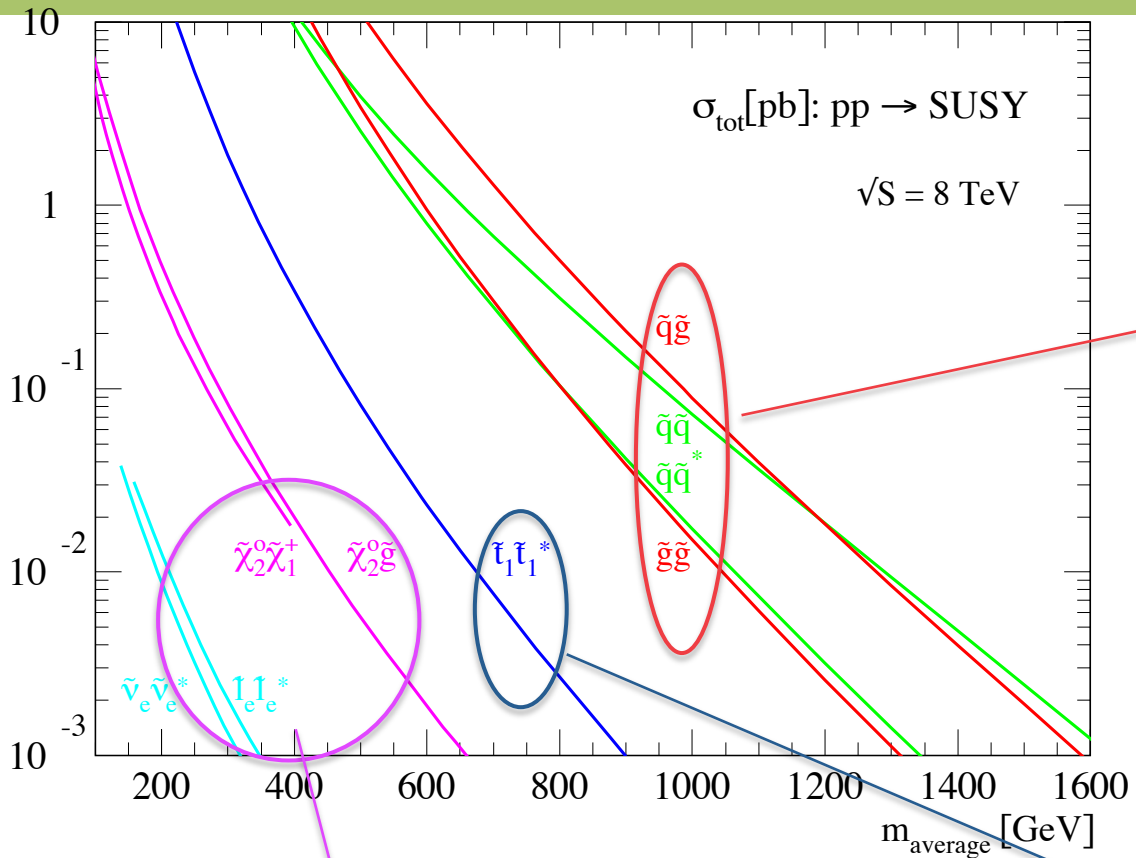
WHY ?

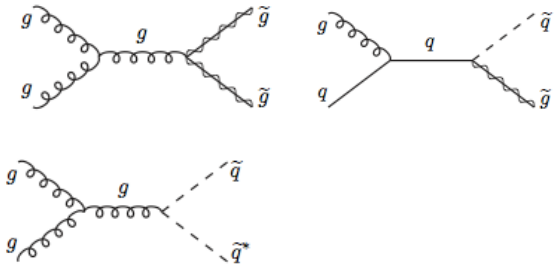
- Dark matter candidate
- Unification of gauge coupling
- Solution to hierarchy problem
- Non-trivial extension to Poincare' group
- .....

HOW ?



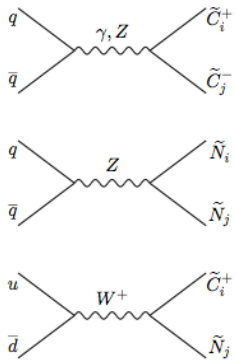
SUSY particle production at the LHC





Gluinos and 1st,2nd generation squarks:

- produced through strong interaction at the LHC



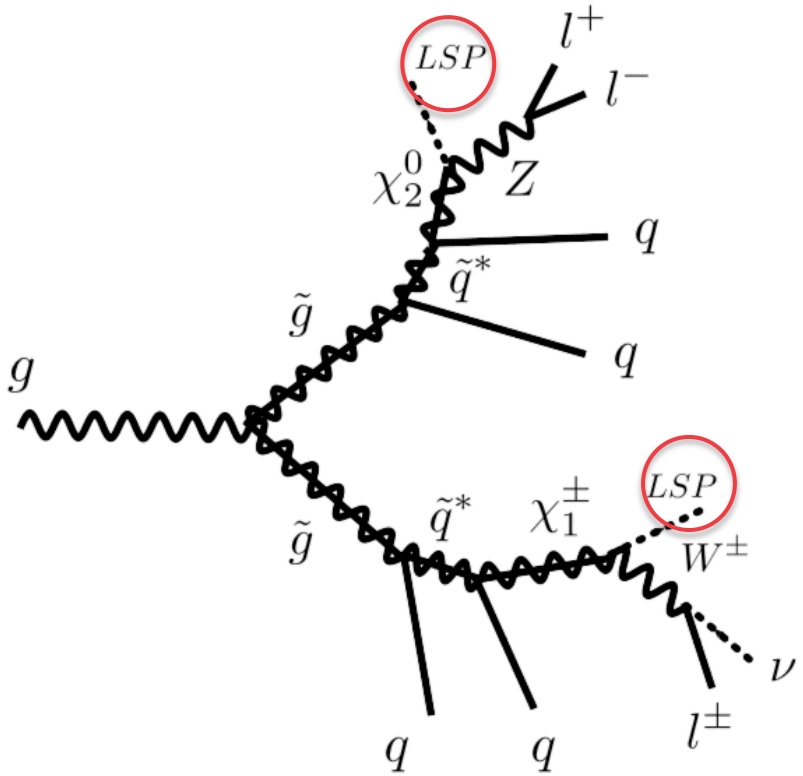
Charginos, neutralinos, sleptons:

- produced through weak interaction.
- "smaller" cross-section

3rd generation squarks:

- "moderate" cross-section for masses up to 500 GeV

Generic SUSY RPC signatures



large undetected transverse momentum (from LSP) + hard hadronic/leptonic activity

Specific SUSY symmetry breaking mechanism and **particle mass spectrum determine SUSY phenomenology**

However, general considerations are possible:

- **If R-parity is conserved, each sparticle decay-chain contains an LSP.**
- If sparticles are as heavy as thought, LSP and all other decay products usually receive a significant boost.

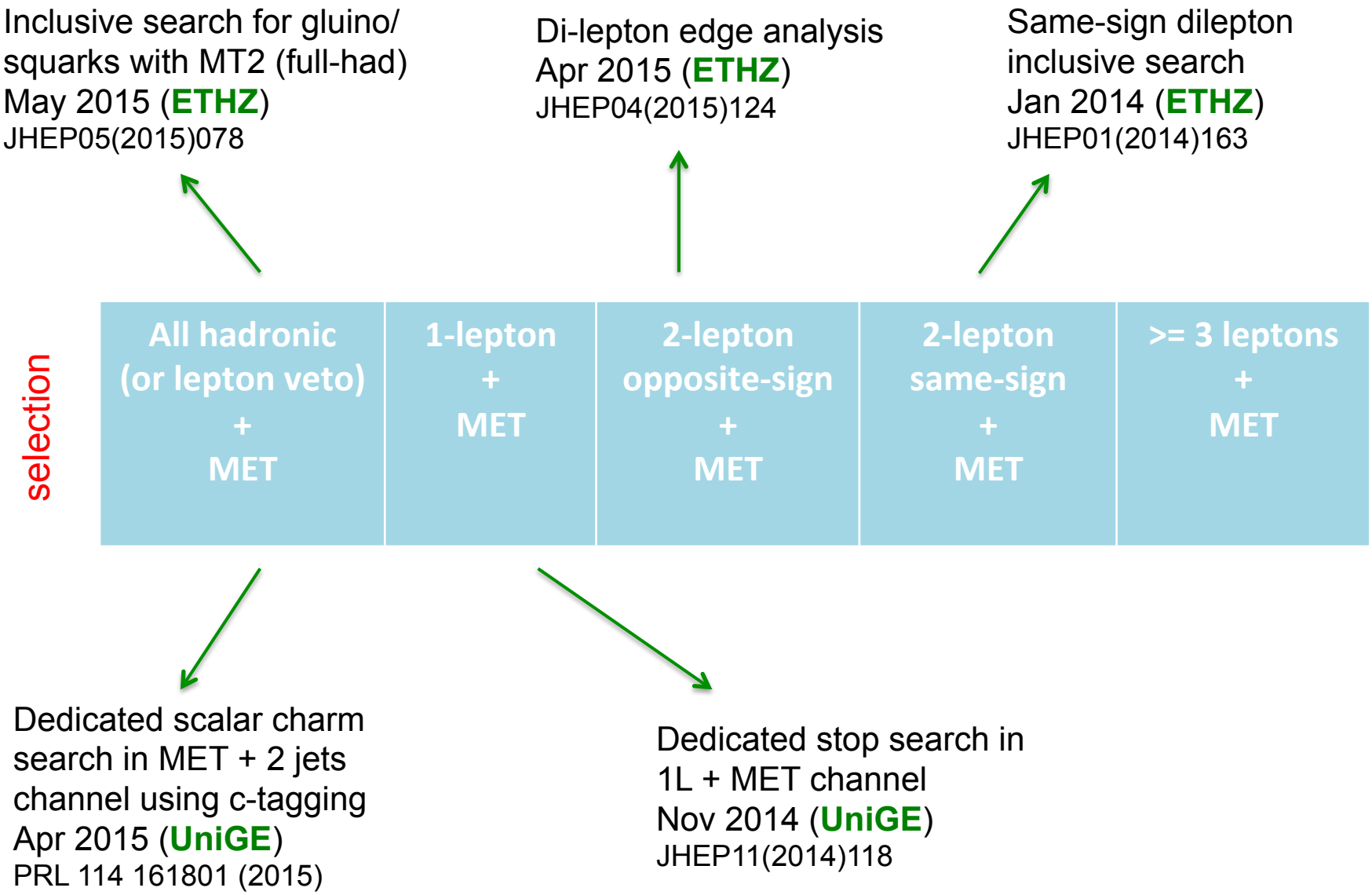
Generic SUSY RPC signatures

selection	All hadronic (or lepton veto) + MET	1-lepton + MET	2-lepton opposite-sign + MET	2-lepton same-sign + MET	>= 3 leptons + MET
main backgrounds	QCD TTbar, W+jets Z→ nunu	TTbar W+jets	TTbar Z→ ll	WZ, ttW, ttZ, ttH 1L process + "fake lepton"	WZ, ZZ ttW, ttZ, ttH 2L process + "fake lepton"

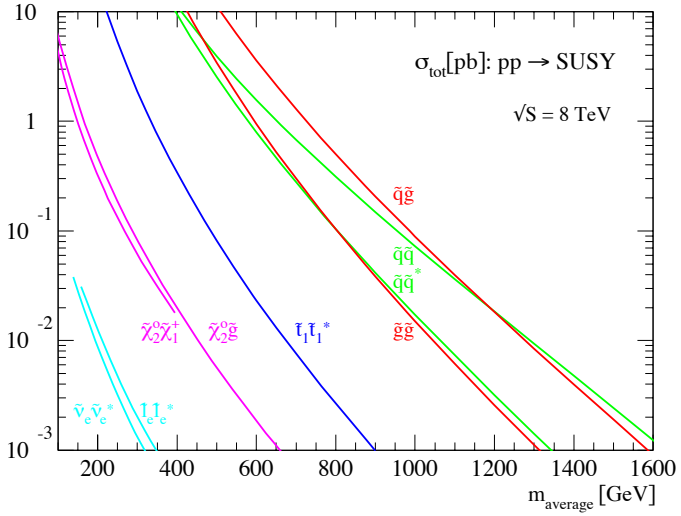
decreasing background

increasing signal acceptance

Publications on 8TeV searches: 2014-2015



Publications on 8TeV searches: 2014-2015



Despite the small EWK cross section, if squarks/gluino are heavy, then **"EWKinos production"** can be the dominant SUSY production at the LHC

selection	All hadronic (or lepton veto) + MET	1-lepton + MET	2-lepton opposite-sign + MET	2-lepton same-sign + MET	>= 3 leptons + MET

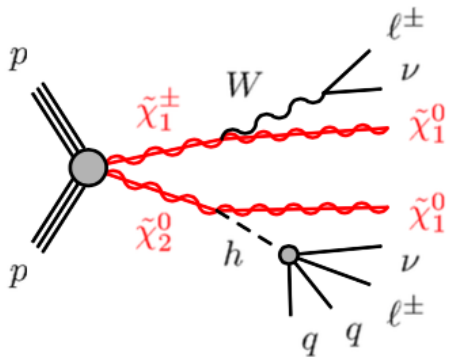
Chargino, Neutralino, and slepton search in 2L and 3L
Sep 2014 (**ETHZ**)
Eur.Phys.J. C (2014) 74:3036

Chargino, Neutralino, and slepton search in 2L + MET
May 2014 (**Bern**)
JHEP05(2014)071

Chargino, Neutralino search in 3L + MET
Apr 2014 (**Bern**)
JHEP04(2014)169

Publications on 8TeV searches: 2014-2015

Depending on mass spectrum, the 2nd neutralino can **decay predominantly to the h^0 Higgs boson**



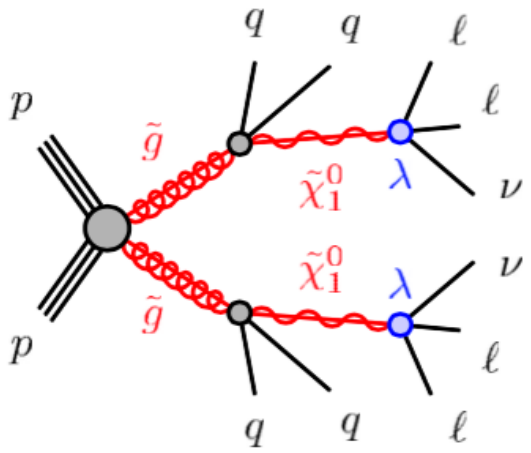
Search Neutralino/Chargino decaying to Higgs boson
May 2015 (**Bern**)
Eur.Phys.J.C(2015)75:208

selection

All hadronic (or lepton veto) + MET	1-lepton + MET	2-lepton opposite-sign + MET	2-lepton same-sign + MET	>= 3 leptons + MET

R-Parity Violation

If R-parity condition is lifted, SUSY final states can be very rich in number of leptons



Search for SUSY in events with 4+ leptons
Sep 2014 (**Bern**)
PhysRevD.90.052001

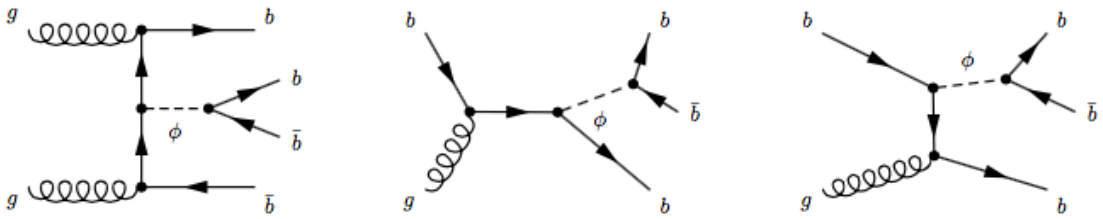
Hot off the press

Between Higgs and SUSY

Search for lepton-flavour-violating decays of the Higgs boson

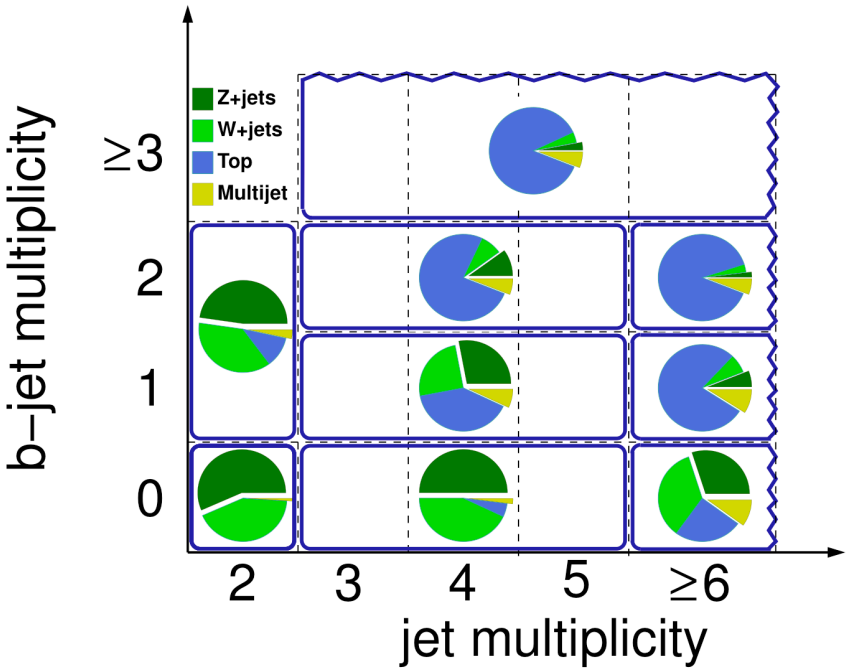
Submitted to PhysLetters B
Feb 2015 (**UZH**)
arXiv:1502:07400

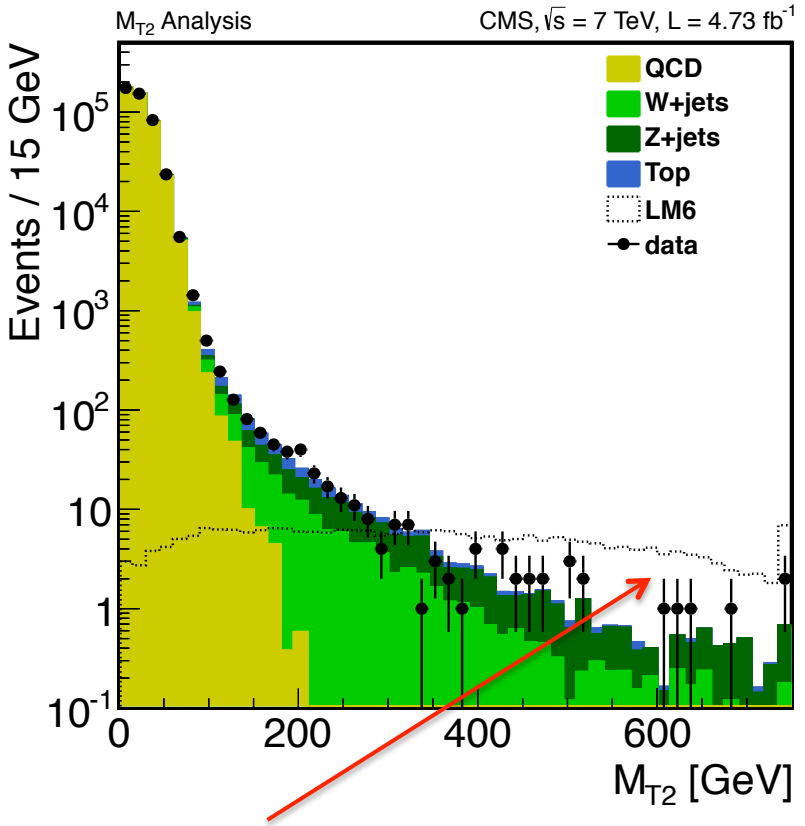
Search for MSSM neutral Higgs boson
H/A → bb in final states with N_b >=3



Submitted to ArXiv over the weekend:
CERN-PH-EP/2015-133
(**UZH**)

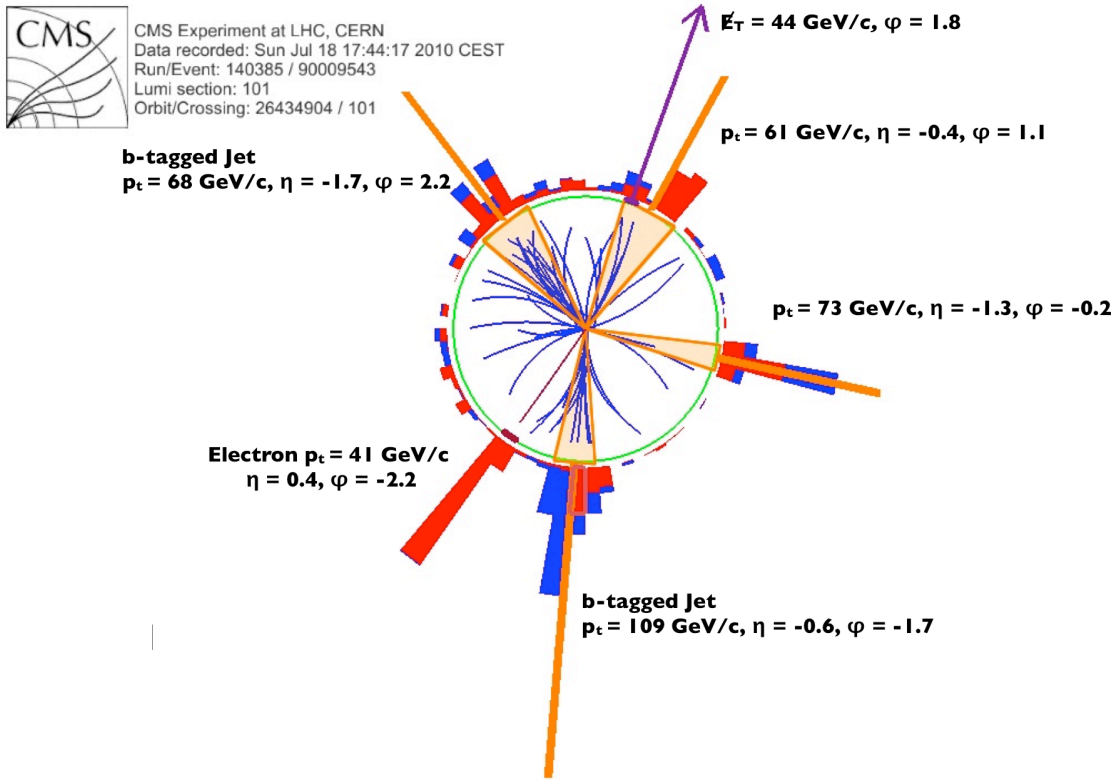
SUSY searches: quite often cut & count exp





Signal events expected in tail of kinematic variables which are usually strongly correlated with MET

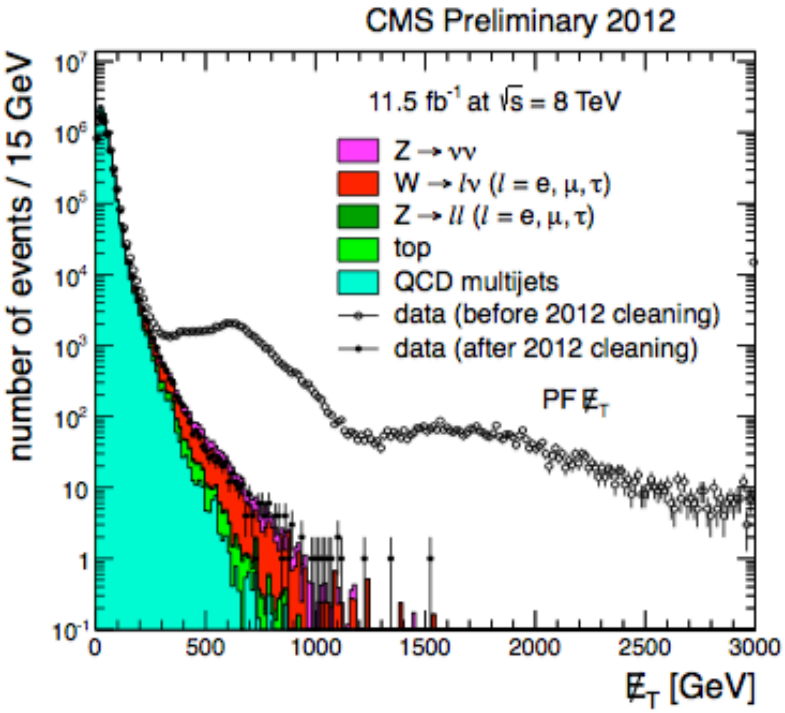
MET reconstruction is challenging



It is enough that just one of these objects (jets, electrons, muons, photons, isolated tracks, etc..) is mis-reconstructed to have MET over-estimation

Always fighting to reduce tails in the MET distribution.

Experience from 2012 and what to expect for Run II



In particular at the beginning of data taking, we will have to monitor “MET noise” in the calorimeters and other sources

~bump searches are possible also in SUSY-land

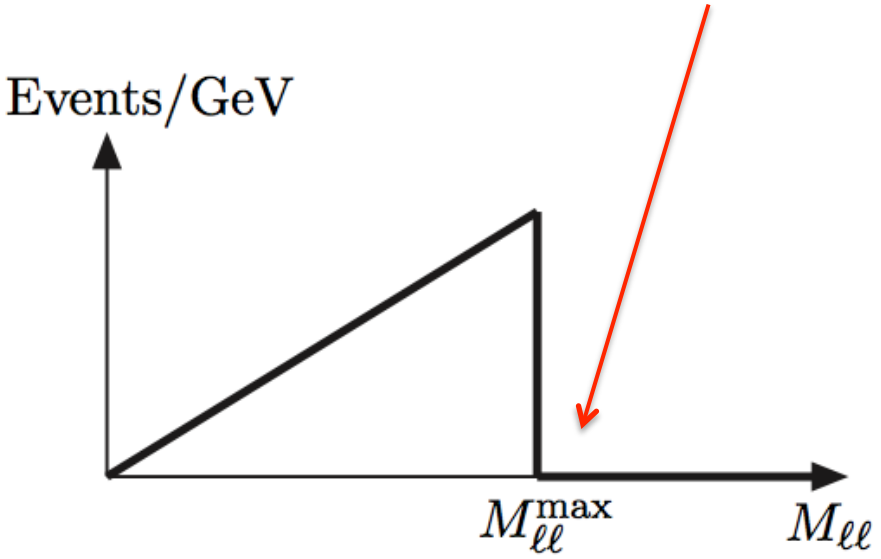
$$\tilde{\chi}_2^0 \rightarrow \ell\tilde{\ell} \rightarrow \tilde{\chi}_1^0 \ell^+ \ell^-$$

$$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \ell^+ \ell^-$$

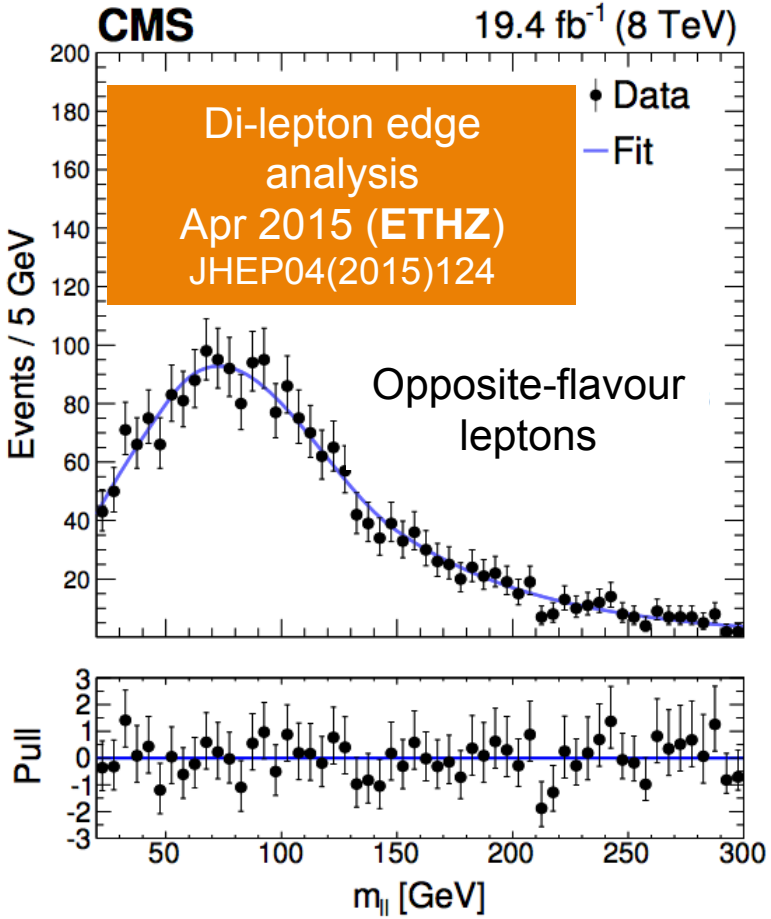
Signature:
opposite-sign same-flavour dilepton pairs + MET

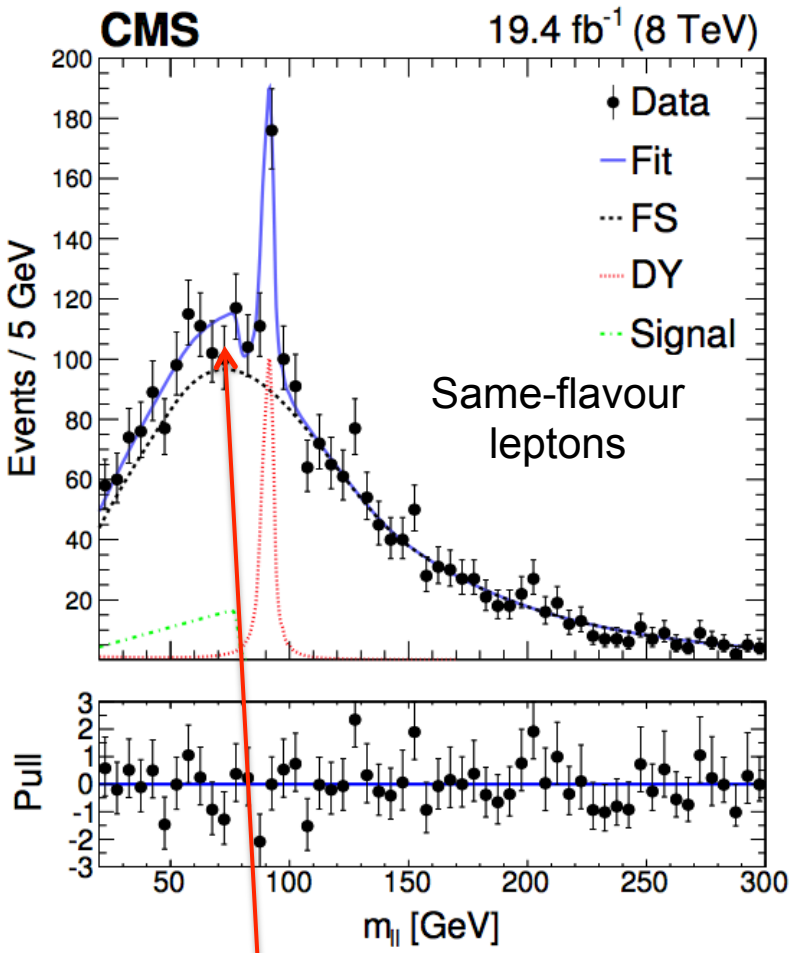
edge position depends on the difference in mass between the two neutralinos

Peculiarity of this channel:
"edge" in the M_{LL} distribution



CMS Edge analysis



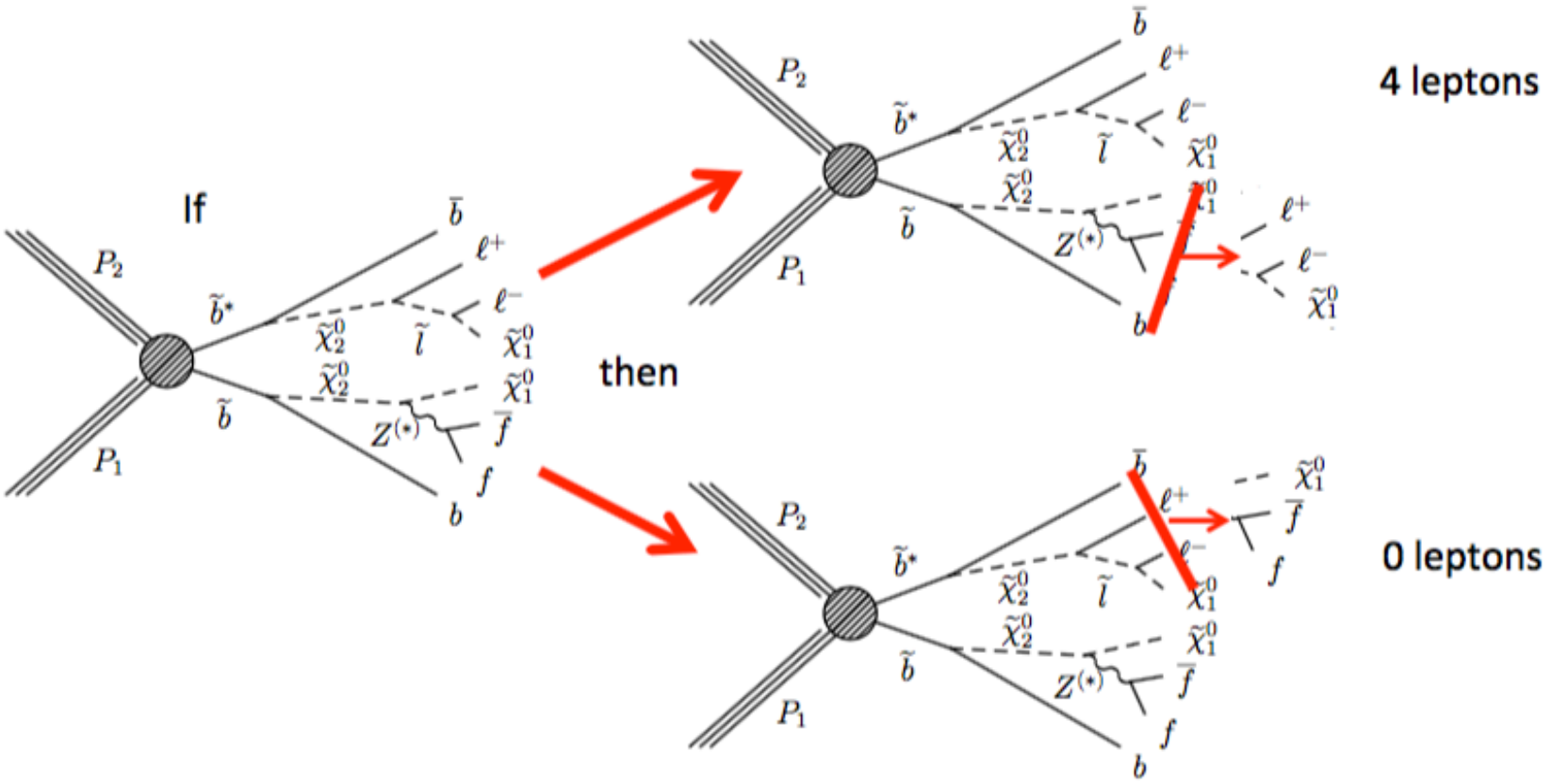


Example of ~straight-forward data-driven background estimation

local significance of 2.4 σ

Lesson learned for Run II

A possible discovery in one channel has implications for other channels

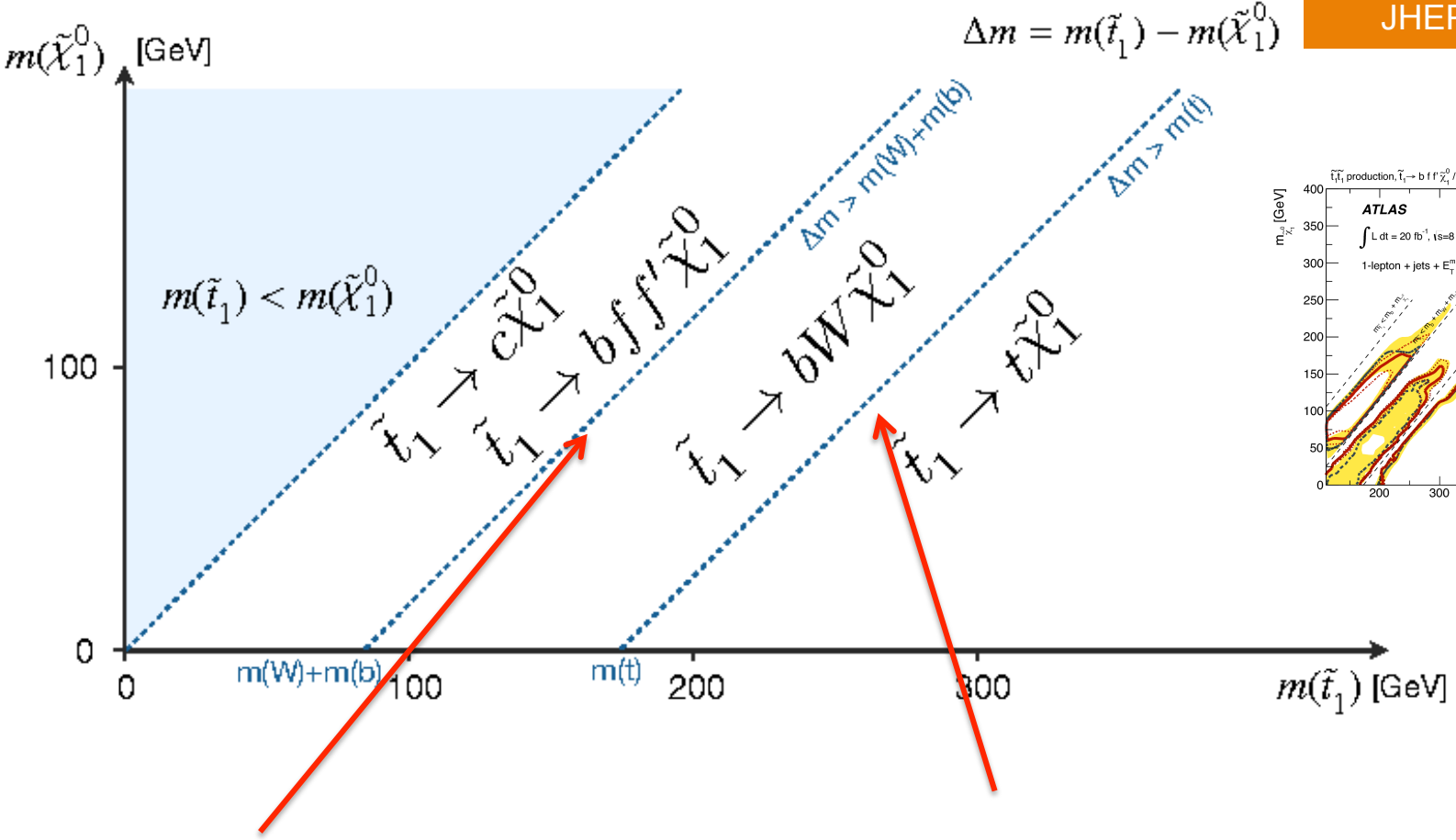


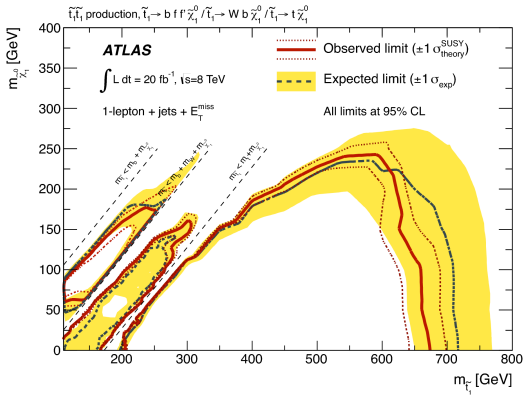
Need to have a broad search program with well distinguished final states to corroborate any possible excess seen in data

Lesson learned for Run II

Need to cover every corner of SUSY parameter space

Dedicated stop search in 1L + MET channel Nov 2014 (**UniGe**) JHEP11(2014)118

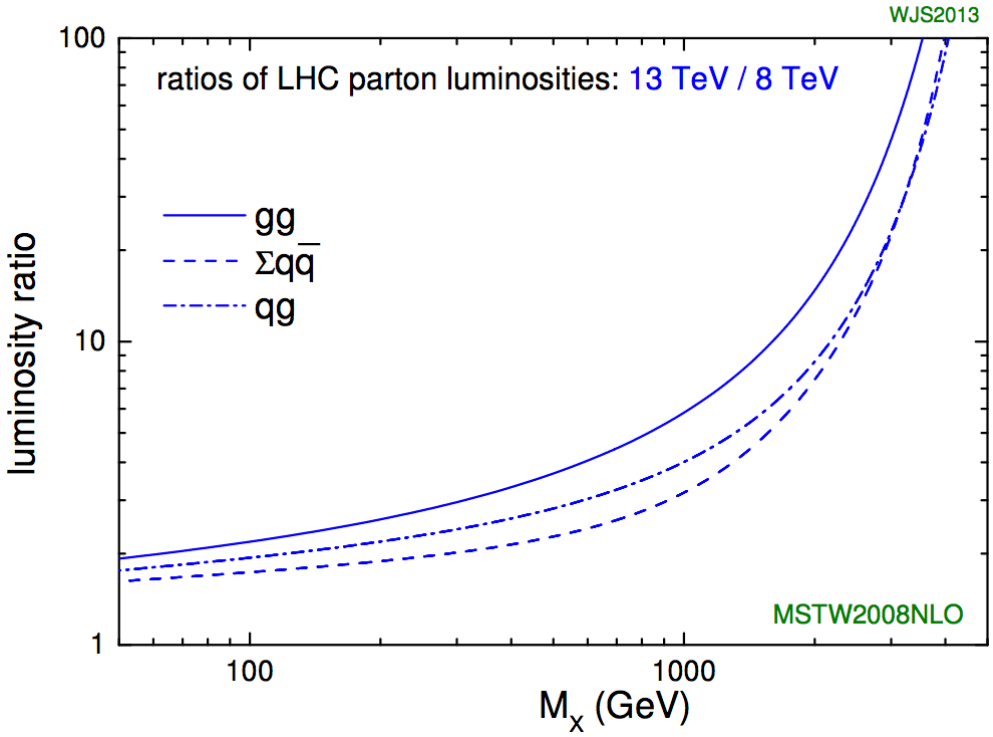




b-quark produced at rest

LSP produced at rest. Signal looks like SM TTbar production: “stealth stop” region

In few days from now



For gluino searches, better sensitivity with just 3 /fb @ 13TeV than with full Run I data

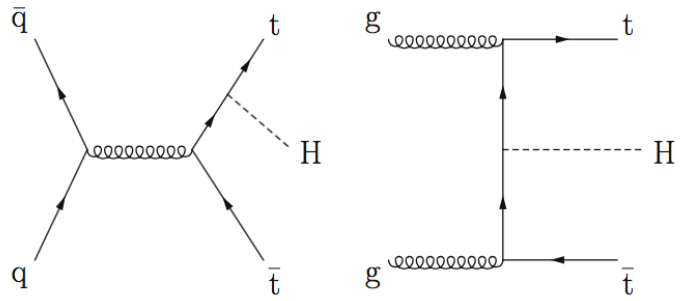
Exciting days ahead ...

Backup slides

Atlas/CMS combination for Higgs mass

	Uncertainty in ATLAS results [GeV]: observed (expected)		Uncertainty in CMS results [GeV]: observed (expected)		Uncertainty in combined result [GeV]: observed (expected)	
	$H \to \gamma\gamma$	$H \to ZZ$llll	$H \to \gamma\gamma$	$H \to ZZ$llll	ATLAS	CMS
Scale uncertainties:						
ATLAS ECAL non-linearity / CMS photon non-linearity	0.14 (0.16)	–	0.10 (0.13)	–	0.02 (0.04)	0.05 (0.06)
Material in front of ECAL	0.15 (0.13)	–	0.07 (0.07)	–	0.03 (0.03)	0.04 (0.03)
ECAL longitudinal response	0.12 (0.13)	–	0.02 (0.01)	–	0.02 (0.03)	0.01 (0.01)
ECAL lateral shower shape	0.09 (0.08)	–	0.06 (0.06)	–	0.02 (0.02)	0.03 (0.03)
Photon energy resolution	0.03 (0.01)	–	0.01 (<0.01)	–	0.02 (<0.01)	<0.01 (<0.01)
ATLAS $H \to \gamma\gamma$ vertex & conversion reconstruction	0.05 (0.05)	–	–	–	0.01 (0.01)	–
$Z \to ee$ calibration	0.05 (0.04)	0.03 (0.02)	0.05 (0.05)	–	0.02 (0.01)	0.02 (0.02)
CMS electron energy scale & resolution	–	–	–	0.12 (0.09)	–	0.03 (0.02)
Muon momentum scale & resolution	–	0.03 (0.04)	–	0.11 (0.10)	<0.01 (0.01)	0.05 (0.02)
Other uncertainties:						
ATLAS $H \to \gamma\gamma$ background modeling	0.04 (0.03)	–	–	–	0.01 (0.01)	–
Integrated luminosity	0.01 (<0.01)	<0.01 (<0.01)	0.01 (<0.01)	<0.01 (<0.01)	0.01 (<0.01)	
Additional experimental systematic uncertainties	0.03 (<0.01)	<0.01 (<0.01)	0.02 (<0.01)	0.01 (<0.01)	0.01 (<0.01)	0.01 (<0.01)
Theory uncertainties	<0.01 (<0.01)	<0.01 (<0.01)	0.02 (<0.01)	<0.01 (<0.01)	0.01 (<0.01)	
Systematic uncertainty (sum in quadrature)	0.27 (0.27)	0.04 (0.04)	0.15 (0.17)	0.16 (0.13)	0.11 (0.10)	
Systematic uncertainty (nominal)	0.27 (0.27)	0.04 (0.05)	0.15 (0.17)	0.17 (0.14)	0.11 (0.10)	
Statistical uncertainty	0.43 (0.45)	0.52 (0.66)	0.31 (0.32)	0.42 (0.57)	0.21 (0.22)	
Total uncertainty	0.51 (0.52)	0.52 (0.66)	0.34 (0.36)	0.45 (0.59)	0.24 (0.24)	
Analysis weights	19% (22%)	18% (14%)	40% (46%)	23% (17%)	–	

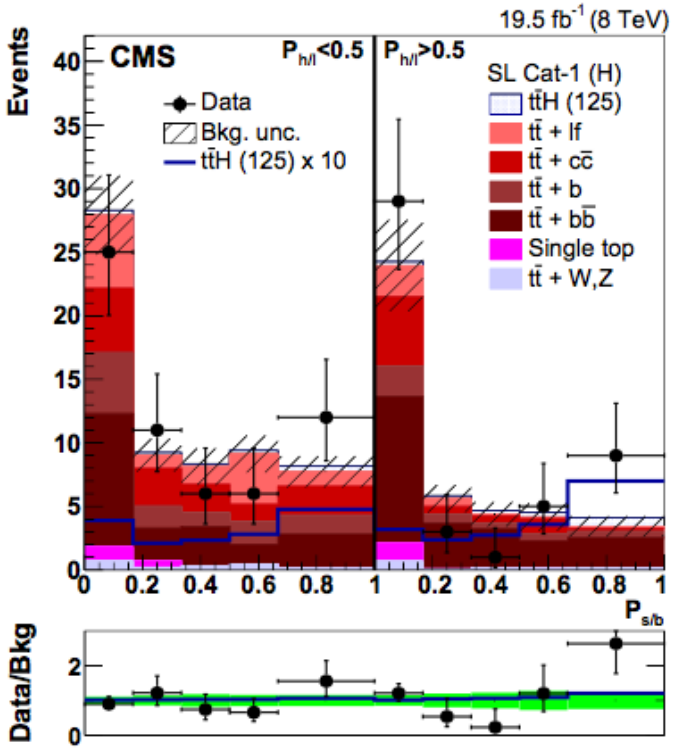
ttH with matrix-element

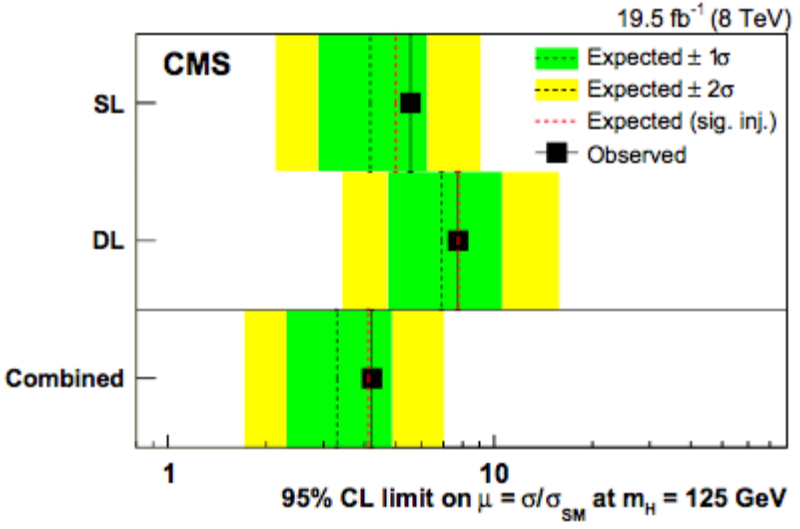


Eur. Phys. J. C
75-251
May 2015

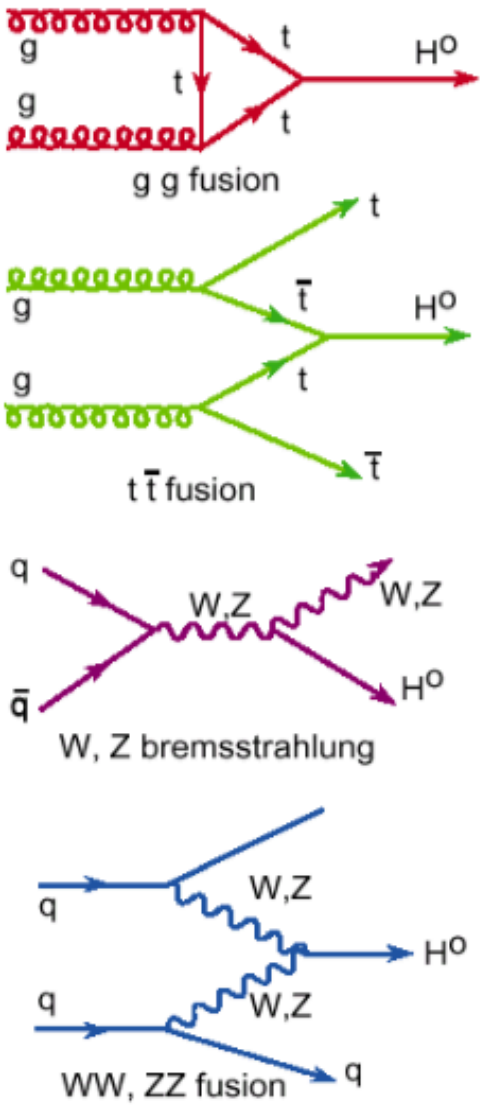
$$P_{s/b} = \frac{w(\mathbf{y}|t\bar{t}H)}{w(\mathbf{y}|t\bar{t}H) + k_{s/b}\, w(\mathbf{y}|t\bar{t} + b\bar{b})}$$

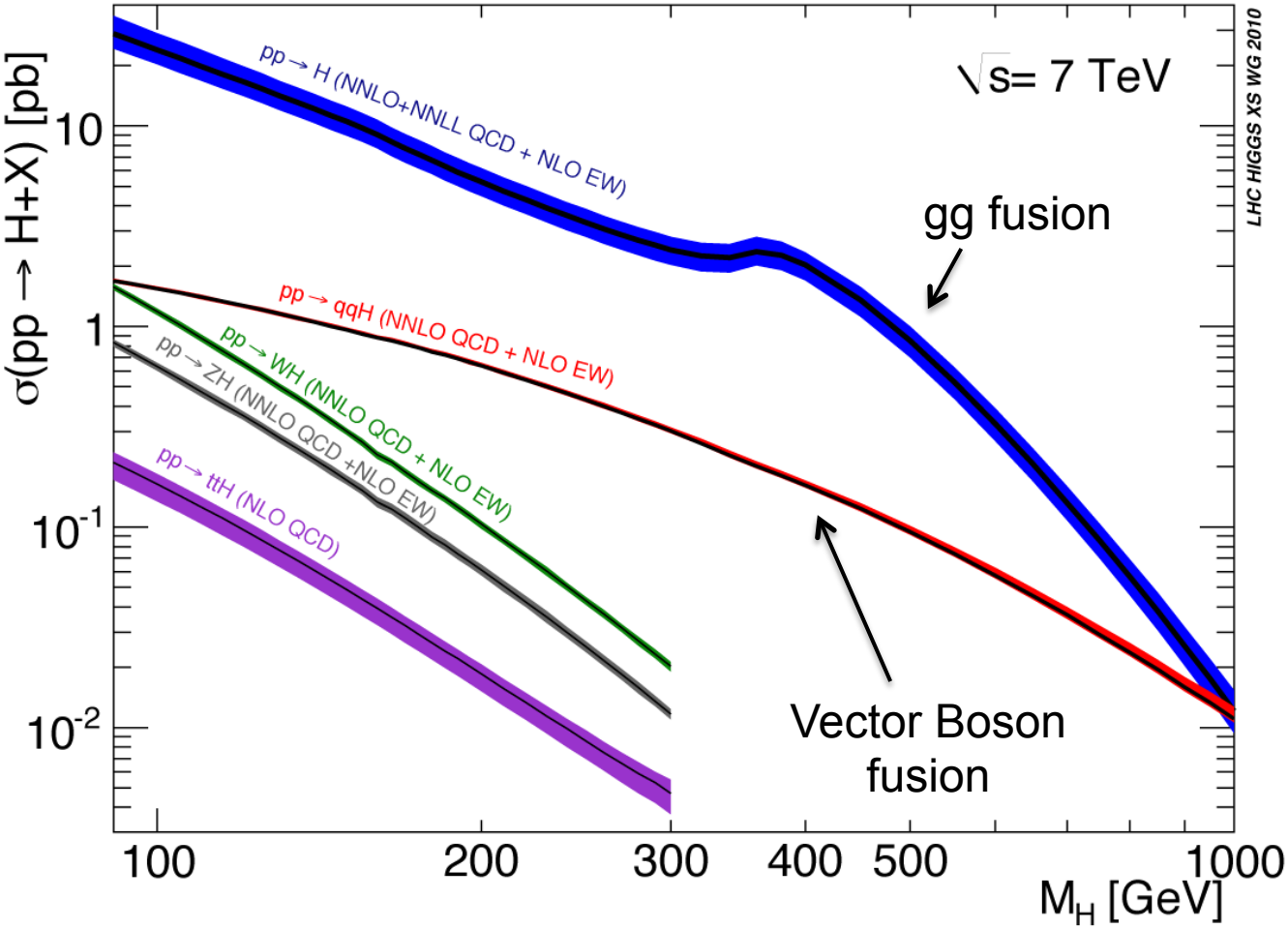
$$P_{h/l} = \frac{f(\boldsymbol{\xi}|t\bar{t} + hf)}{f(\boldsymbol{\xi}|t\bar{t} + hf) + k_{h/l}\, f(\boldsymbol{\xi}|t\bar{t} + lf)}$$



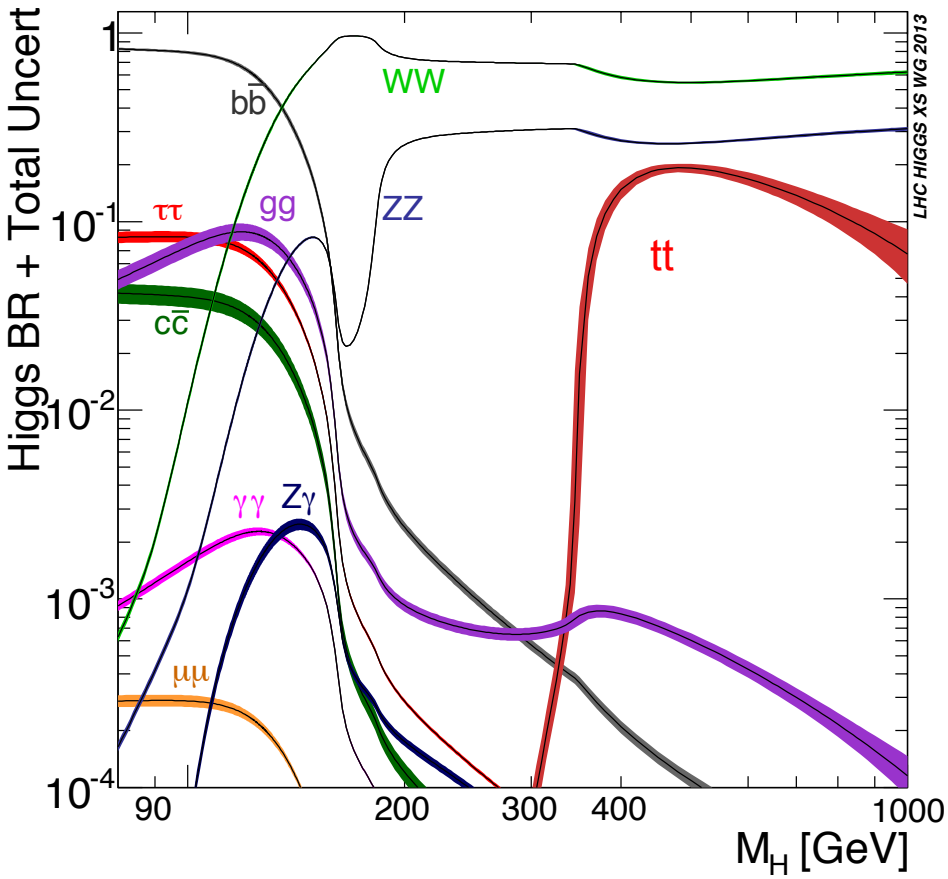


SM Higgs boson production @ LHC





SM Higgs decay modes



1-lepton searches: direct stop production