Higgs prospects at the LHC

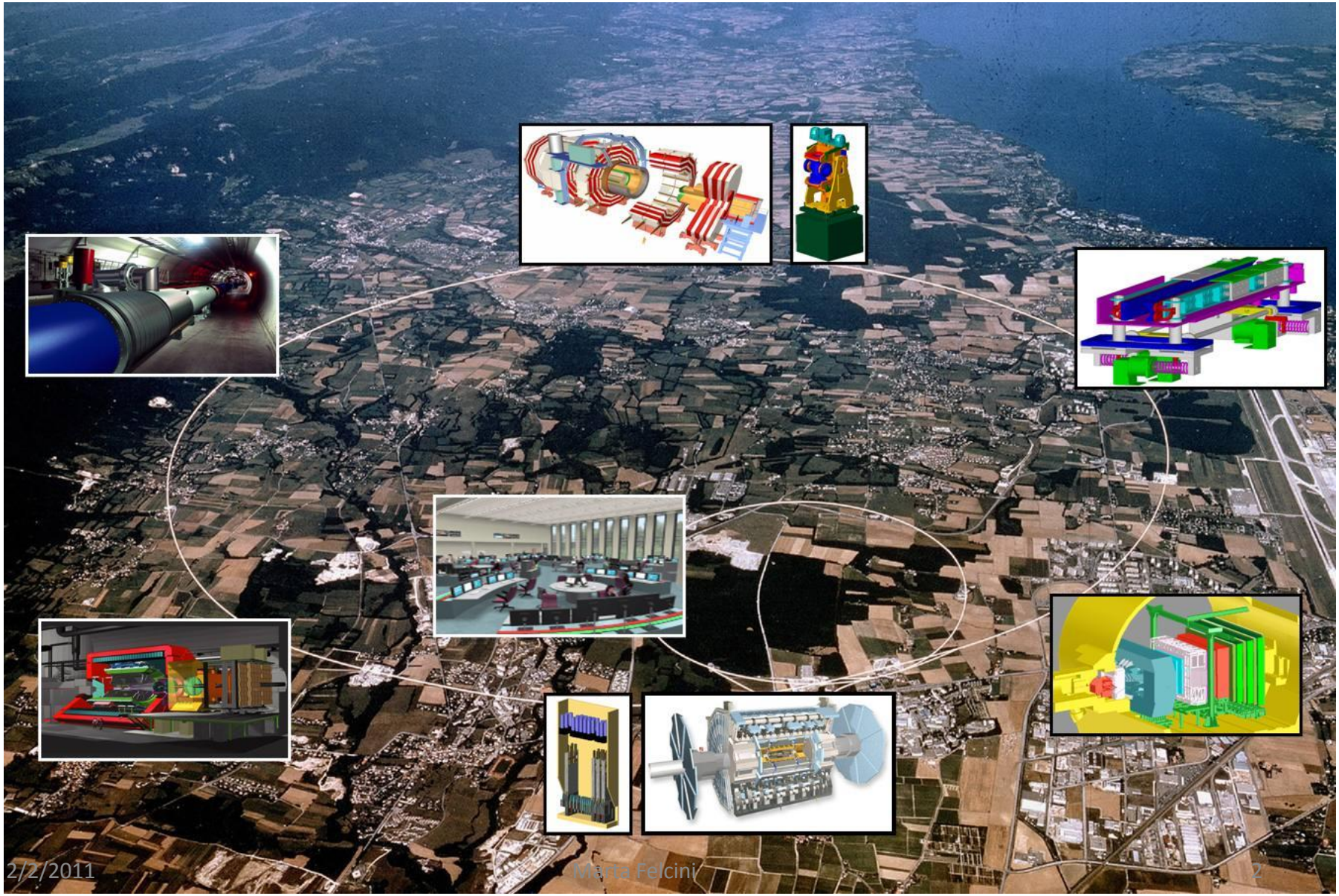
Marta Felcini

IFCA, Santander

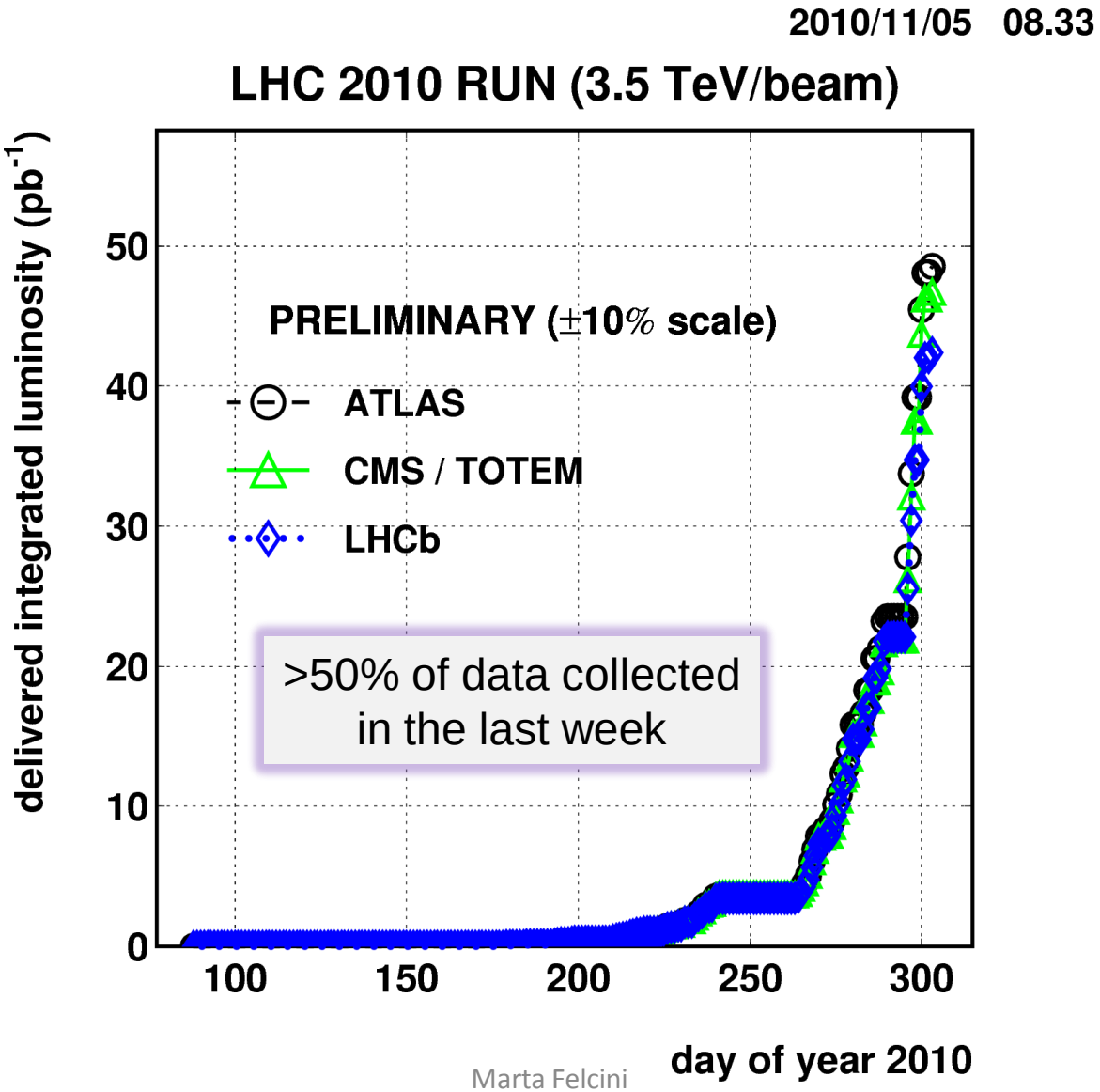
LHCPhenoNet Kick-off meeting

1-4 February 2011, Valencia, Spain

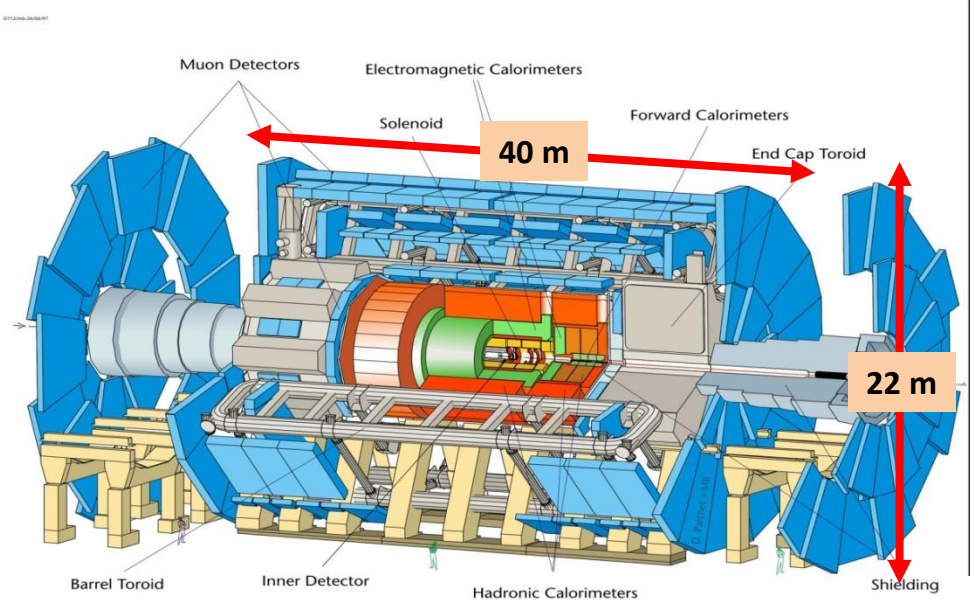
LHC Status and Plans

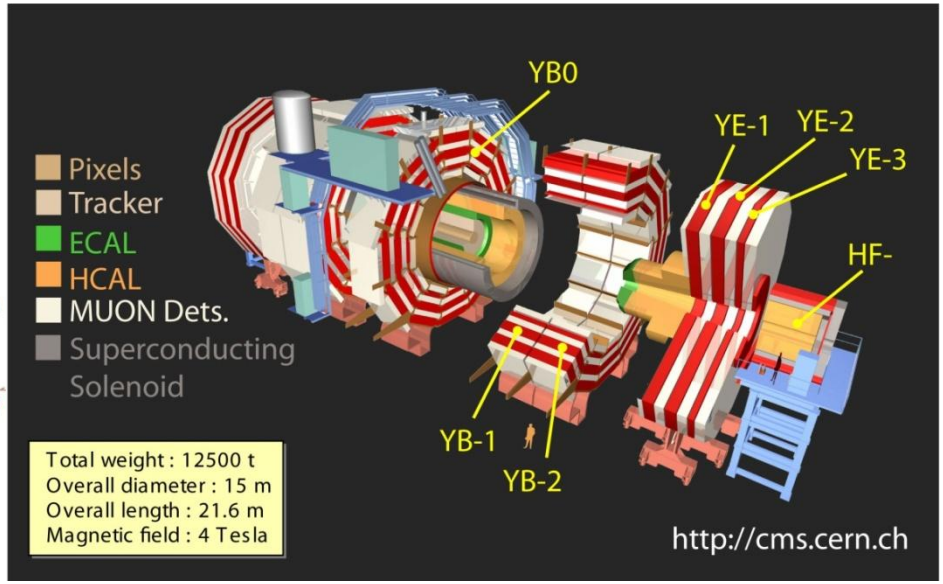


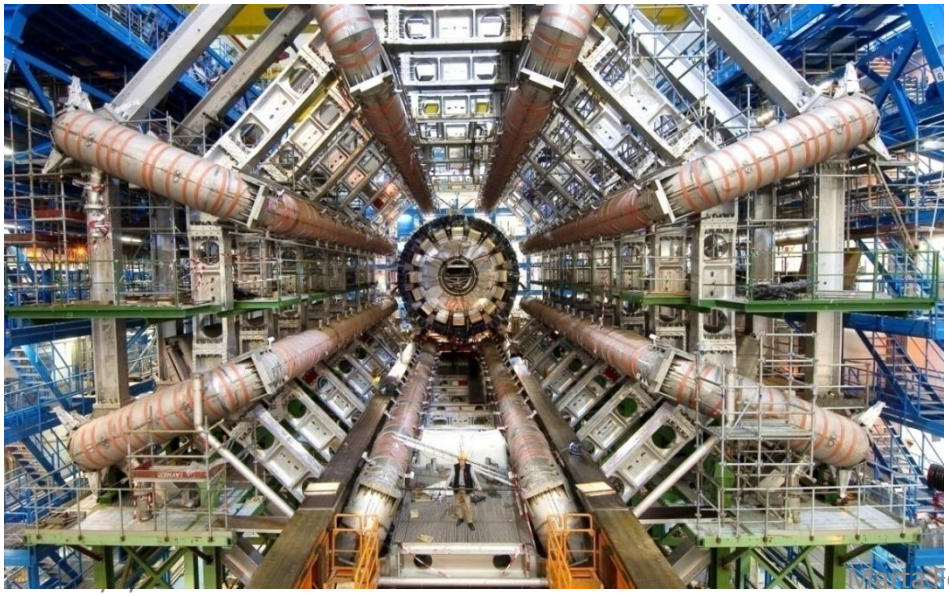
LHC Integrated Luminosity in 2010

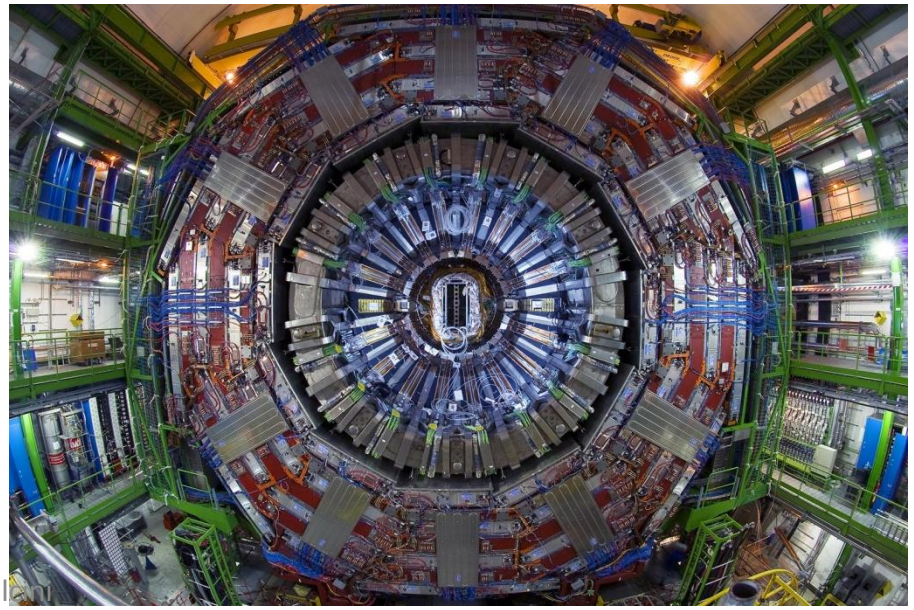


ATLAS and CMS Detectors

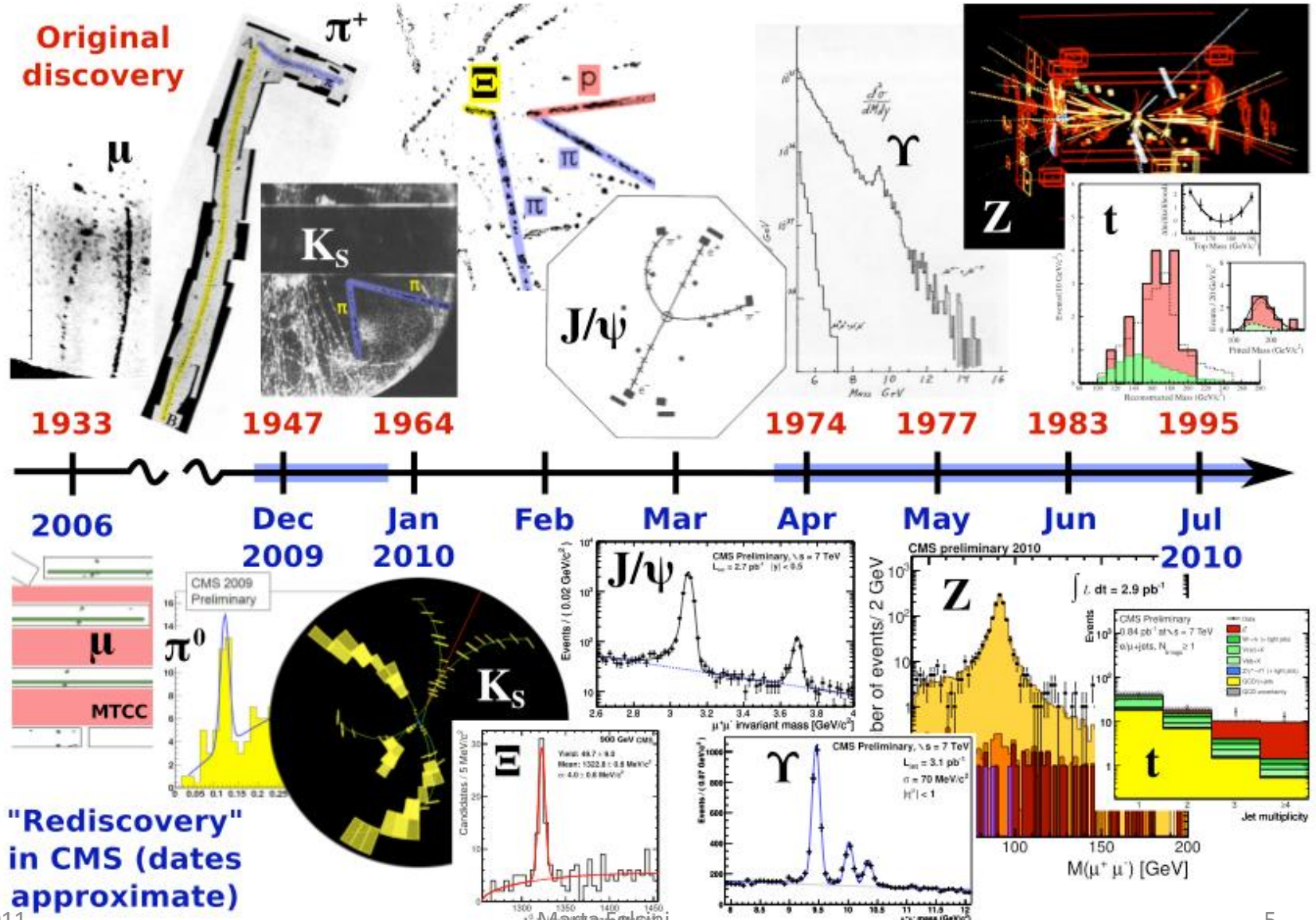




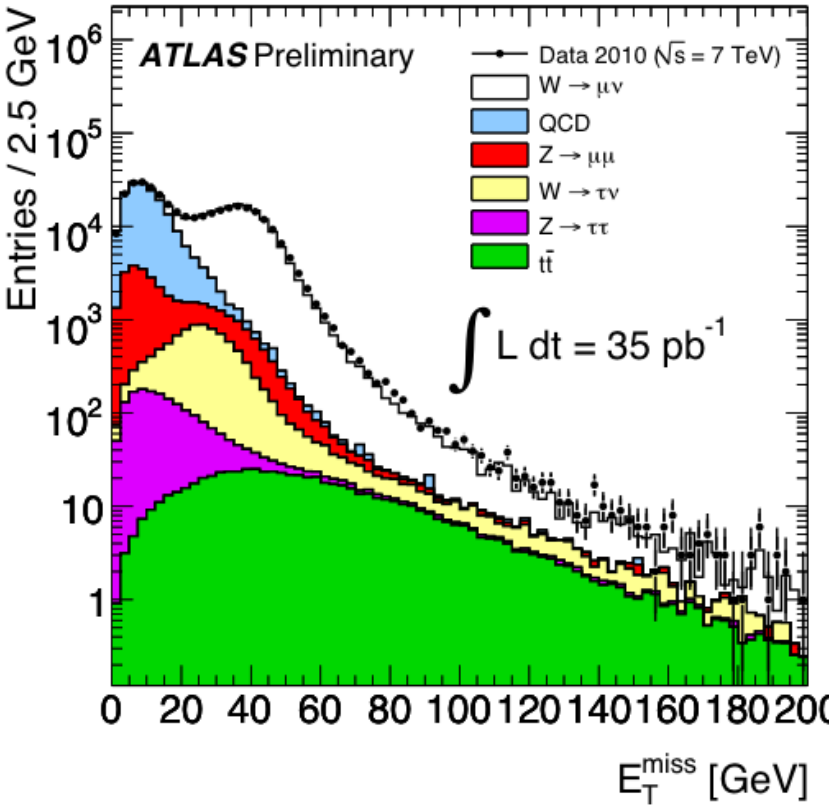


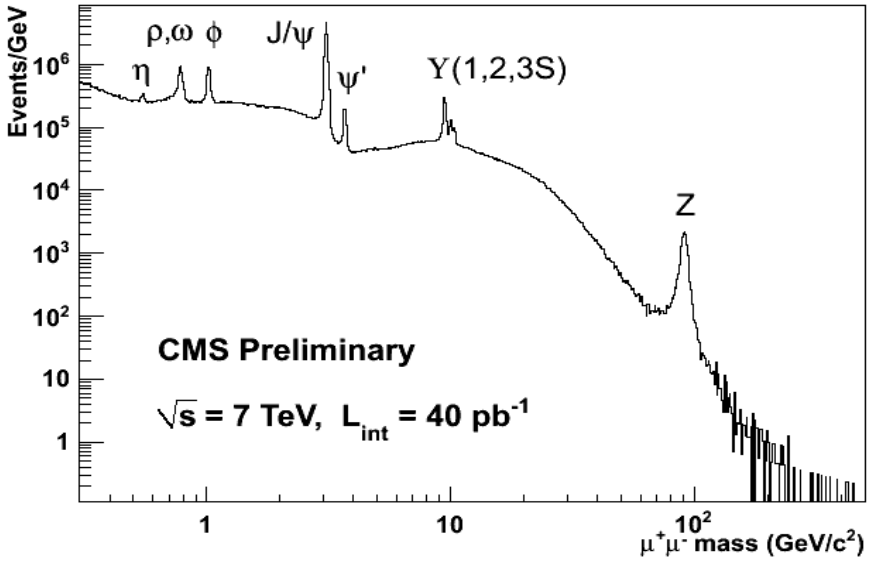


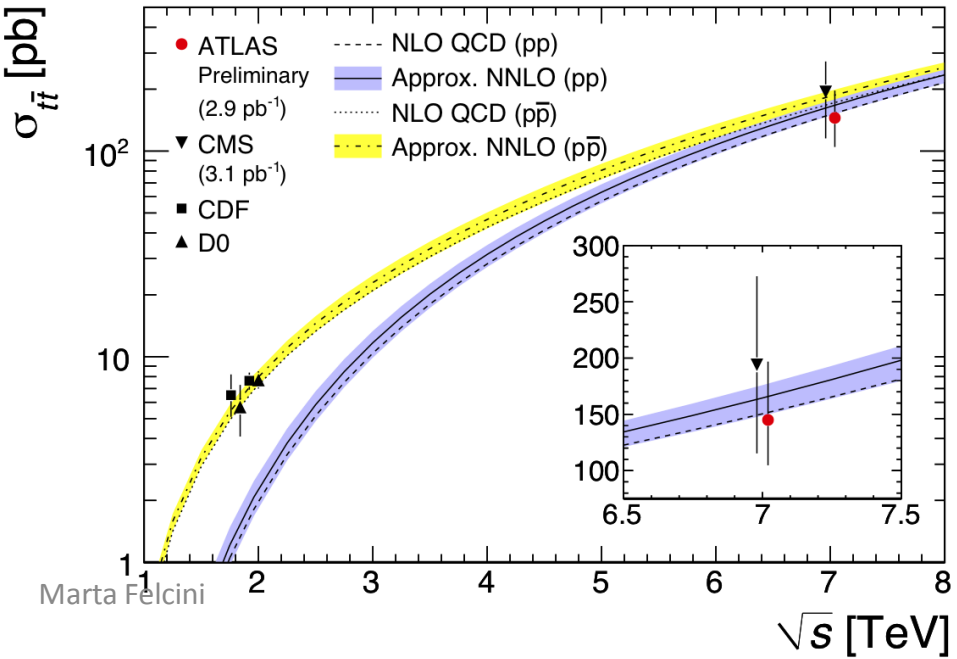
LHC Experiments: SM re-established at 7 TeV



J/Ψ, Υ, W, Z, top quark production







LHC Plan for 2011 and 2012


LHC to run in 2012 – an interview with Rolf Heuer and Steve Myers - CERN Bulletin

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- LHC Report: The shutdown work nearing completion
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- ALICE on the move
- Powering CERN and the LHC
- The new "Jardin de Capucine" crèche brings a

LHC to run in 2012 – an interview with Rolf Heuer and Steve Myers

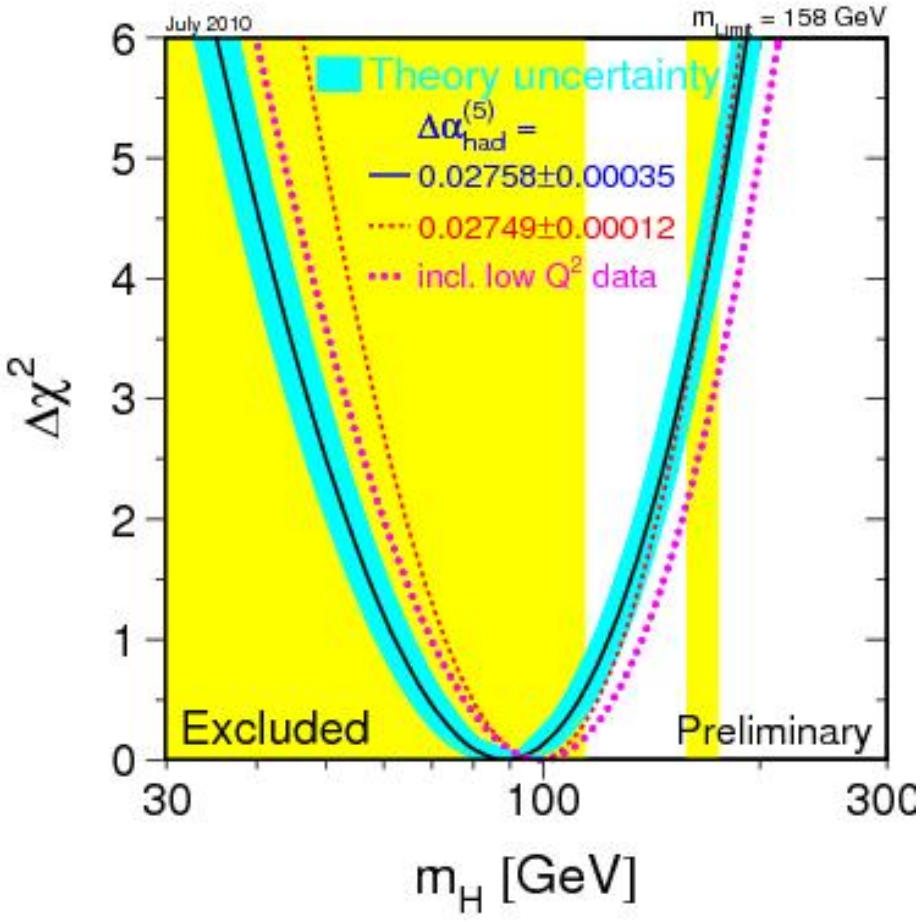
Following the annual LHC Performance Workshop held in Chamonix last week, and a report from the CERN Machine Advisory Committee on Monday, CERN management took some important decisions about the upcoming LHC run. The Bulletin spoke to Director General, Rolf Heuer, and Director for Accelerators and Technology, Steve Myers.

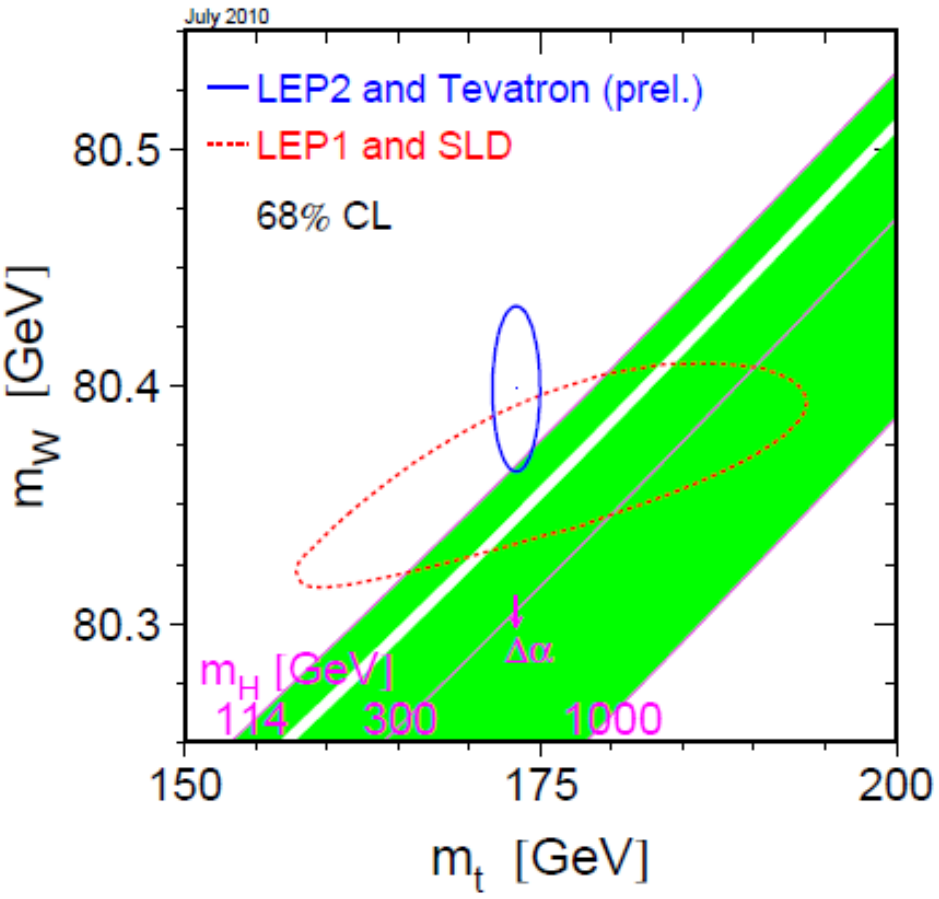
LHC will run at 7 TeV in 2011 and 2012

In a previous plan, LHC would have run in 2011, but shut down in 2012, to consolidate the Accelerator for running, from 2013, at or close to the design collision energy of 14 TeV. The plan has been reviewed, to collect a larger data sample before the long shutdown

Higgs Search Status and Prospects

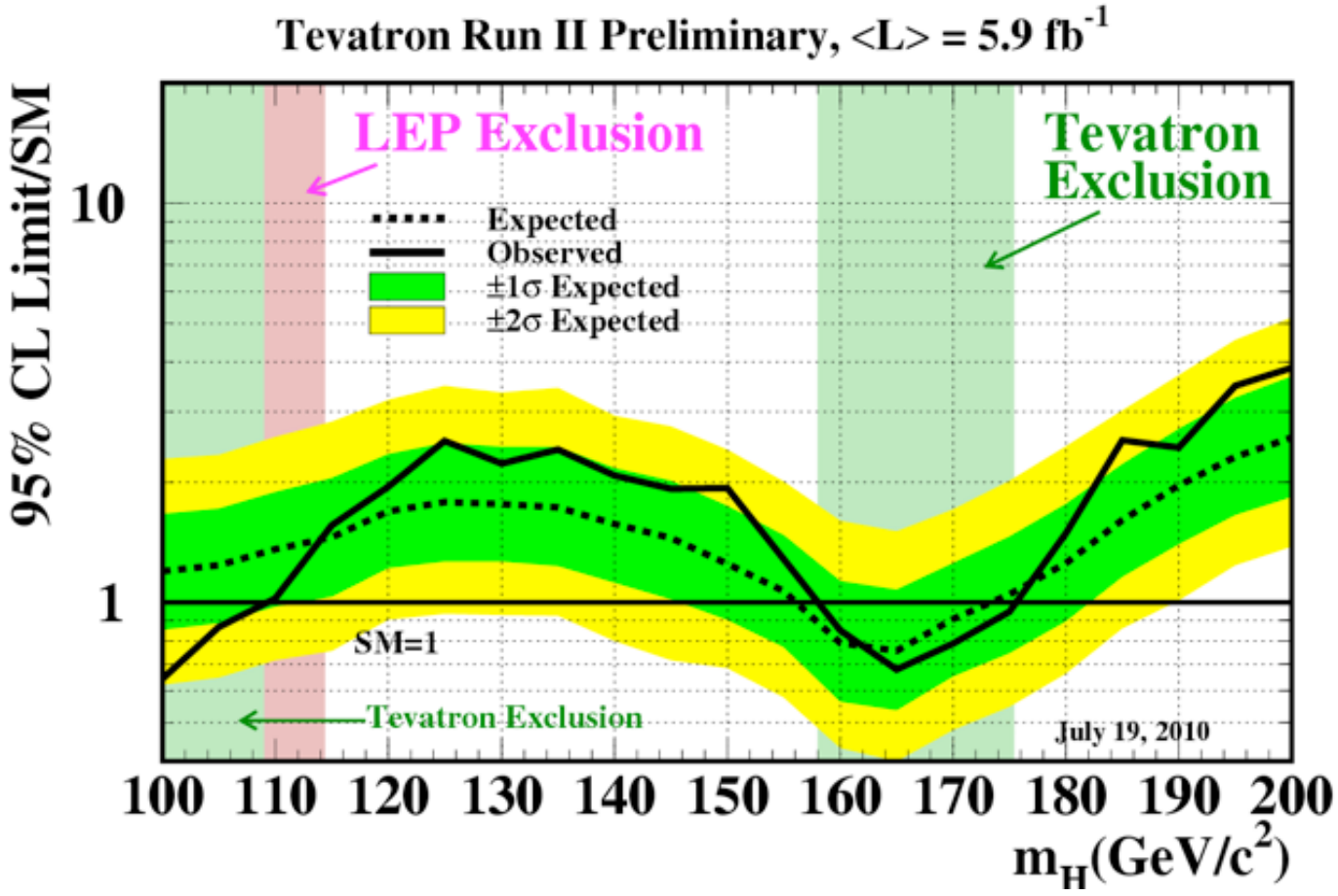
SM Higgs Mass from EW Fits





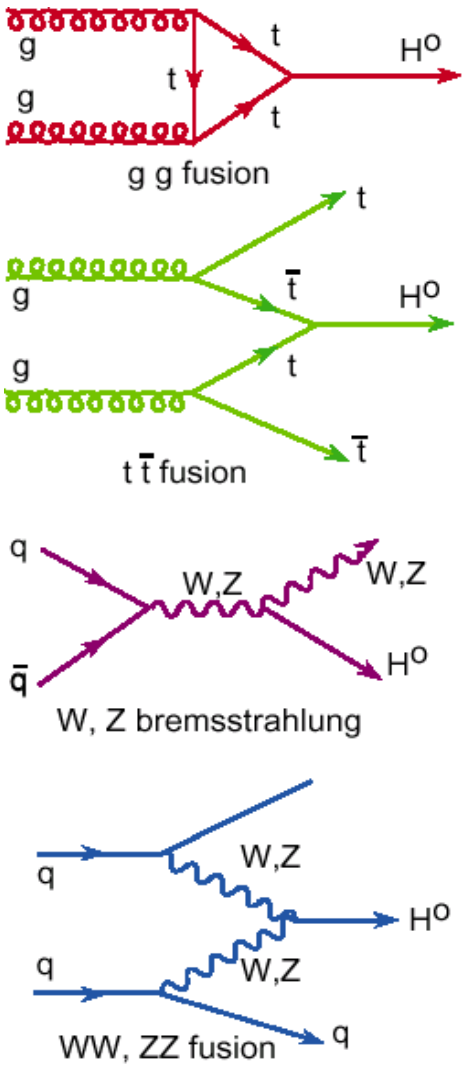
Light Higgs preferred: Higgs mass < 185 GeV @ 95 % CL

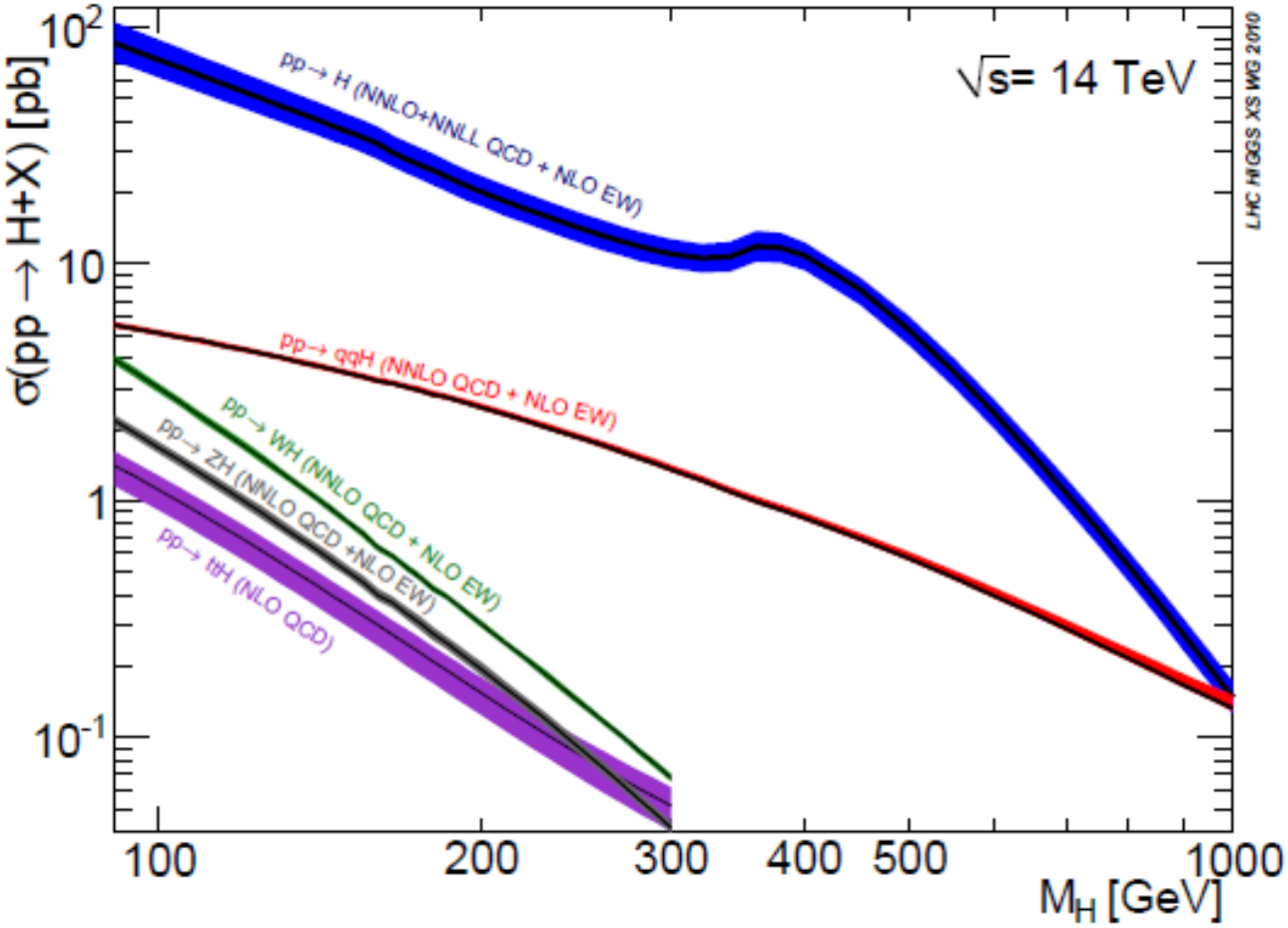
SM Higgs Search at Tevatron (1.96 TeV)



Tevatron experiments CDF and DØ combined SM search results exclude the mass range of 158 GeV to 175 GeV at 95%CL.

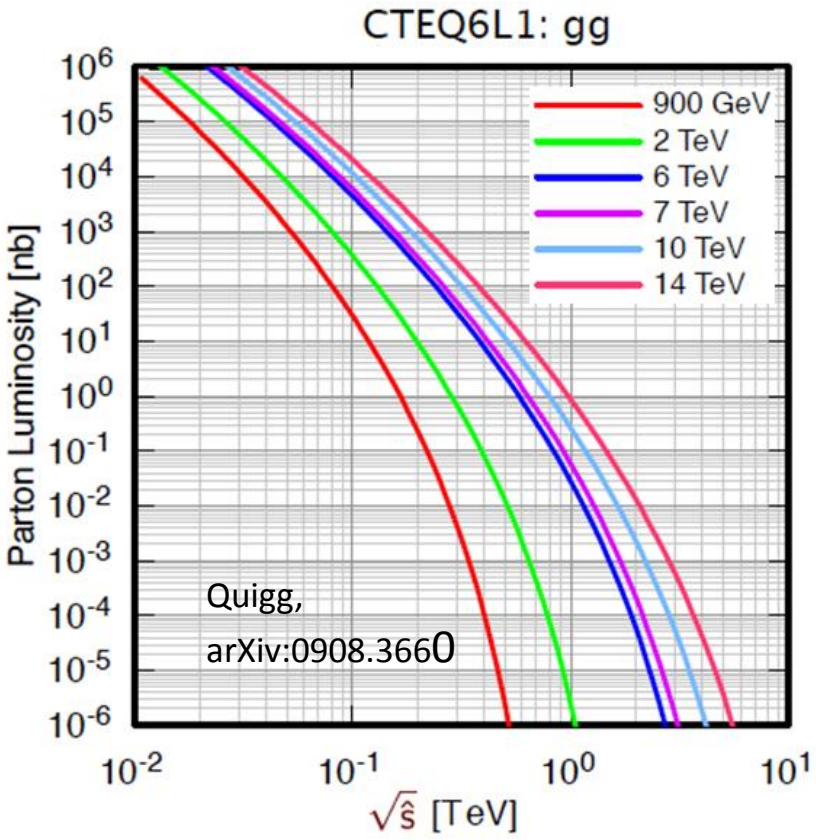
SM Higgs production at LHC (14 TeV)

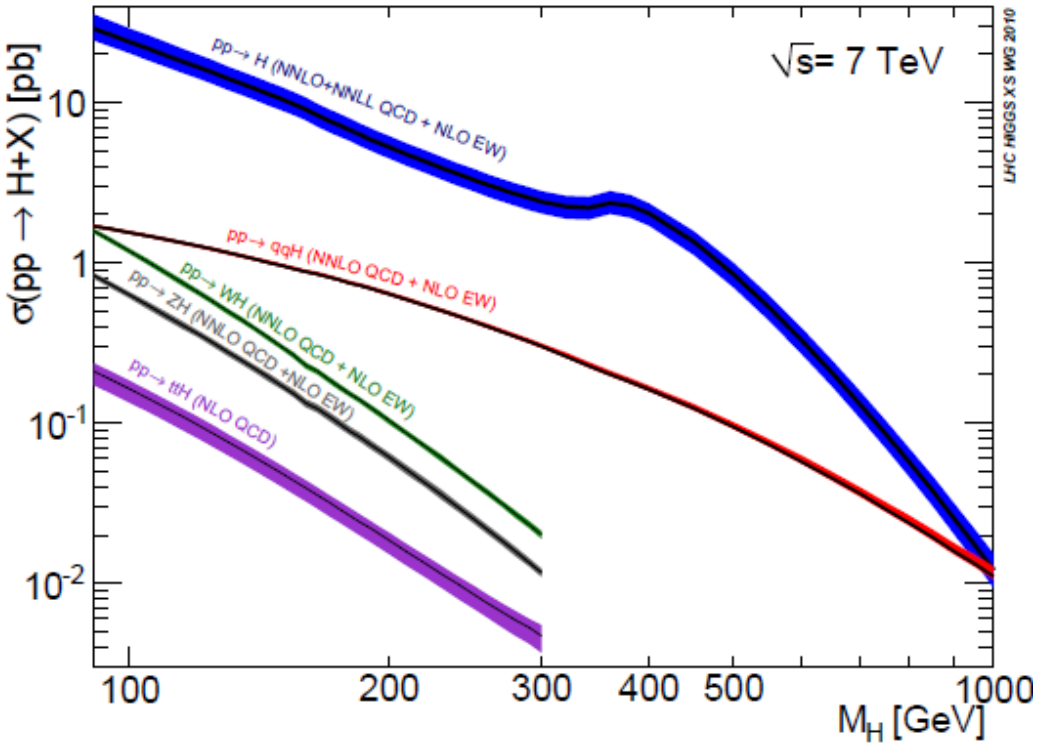




- Higgs production cross-section at N(N)LO
- gluon fusion dominates at LHC for any m_H

SM Higgs Production at 7 TeV vs 14 TeV



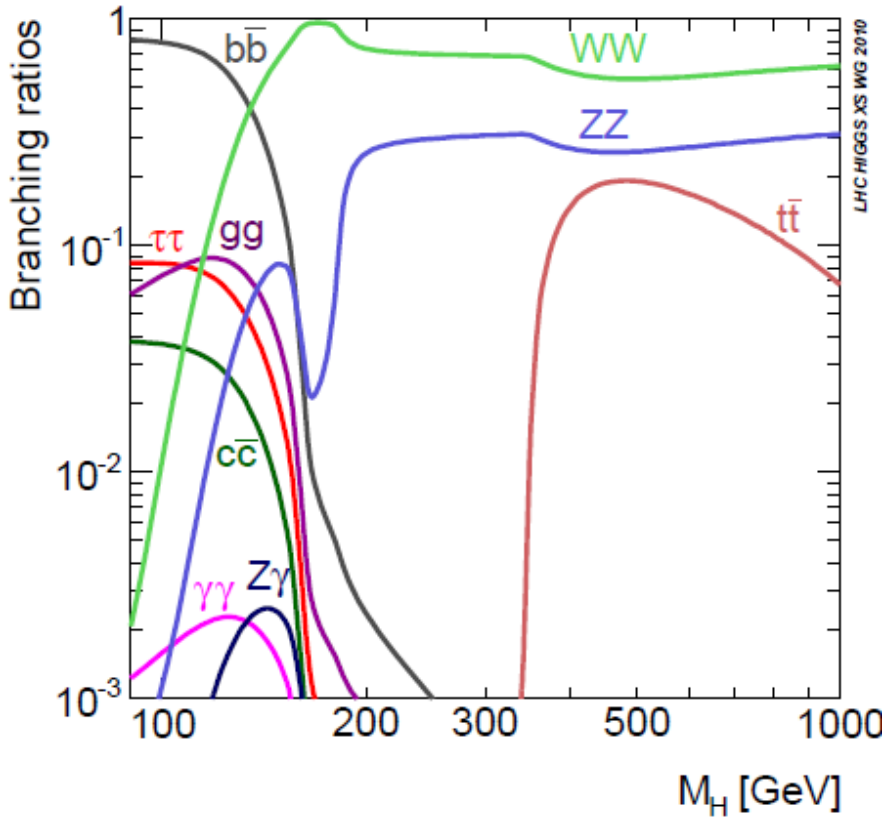


Ratio SM Higgs production LHC(14)/LHC(7)
~4 for MH= 120 GeV
~10 for MH = 600 GeV

14 TeV better for searches (higher cross sections)
… but unsafe for the accelerator

From Chamonix Workshop 2011:
Keep energy at 7 TeV in 2011
compensate with luminosity-> running in 2012

SM Higgs Search Channels



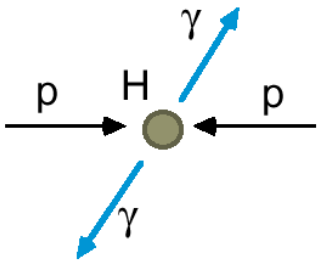
Channels included	Higgs mass range used in analyses (GeV)
H→γγ	115-150
VBF H→ττ	115-145
VH, H→bb (highly boosted)	115-125
VH, H→WW→lνjj	130-200
H→WW→2l2ν + 0/1 jets	120-600
VBF H→WW→2l2ν	130-500
H→ZZ→4l	120-600
H→ZZ→2l2ν	200-600
H→ZZ→2l2b	300-600

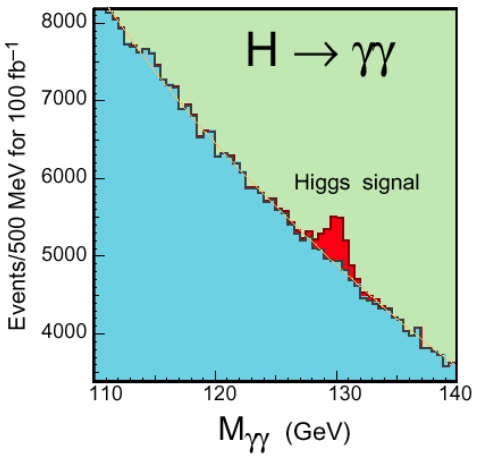
Channels with H → γγ, H → ττ, H → WW*, H → ZZ* are all used for the search

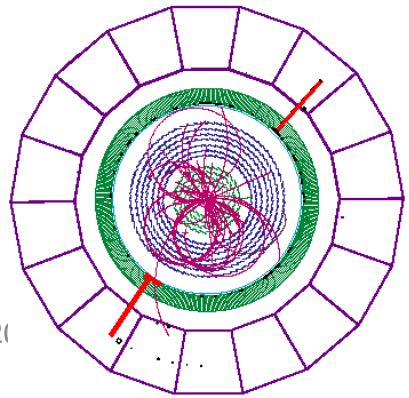
H → γγ and H → ZZ* → 4ℓ are the channels where mass can be measured with ~1% res.

SM Higgs Search Strategies - Examples

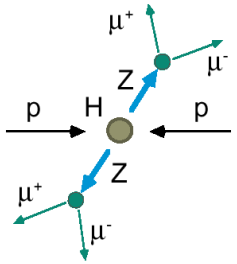
Low M_H < 140 GeV

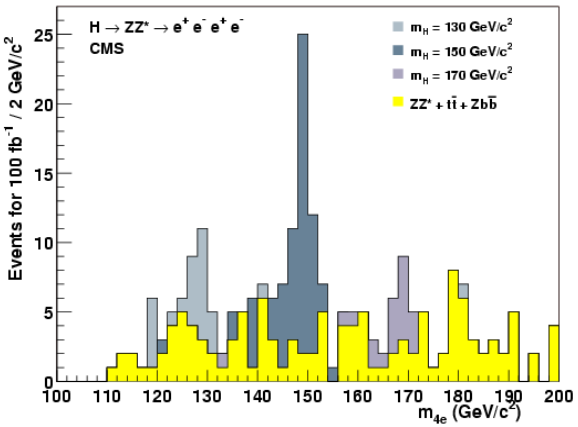




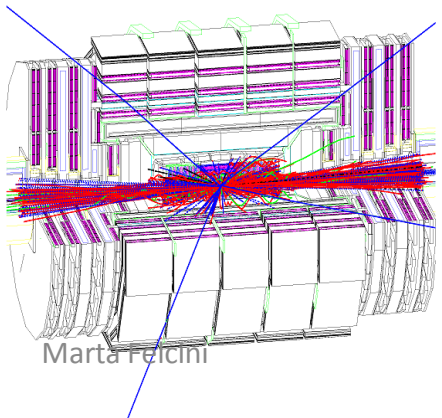


Medium 130<M_H<500 GeV/

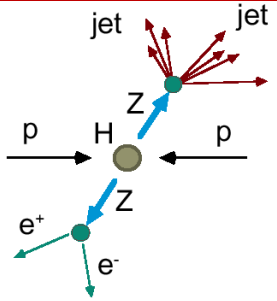


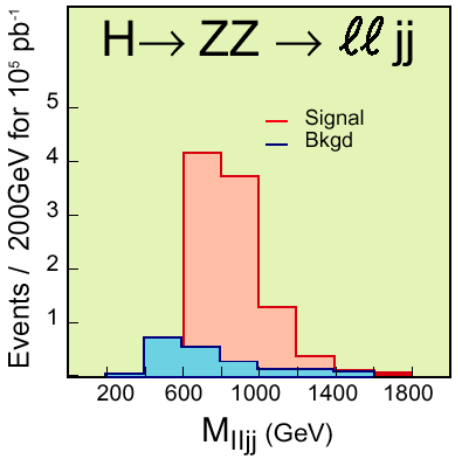


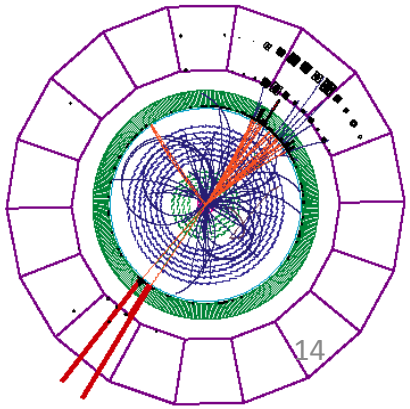
H (150 GeV) → Z^0Z^{0*} → 4μ



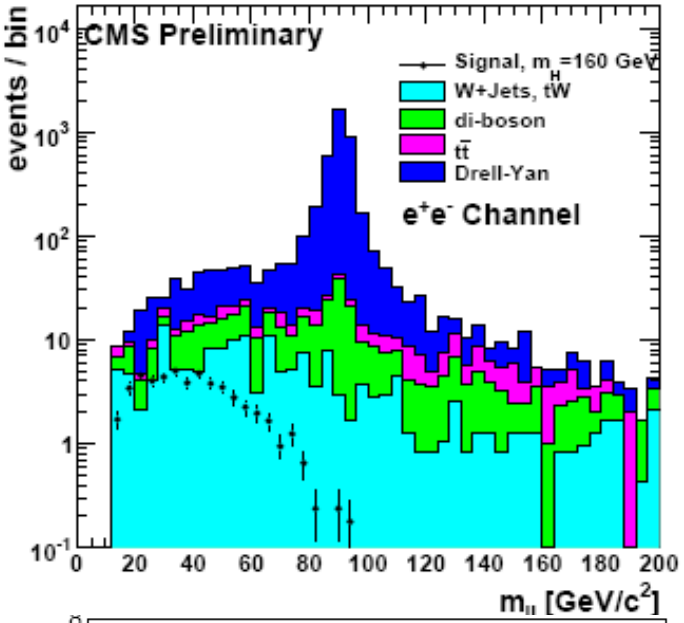
High M_H > ~500 GeV/c^2

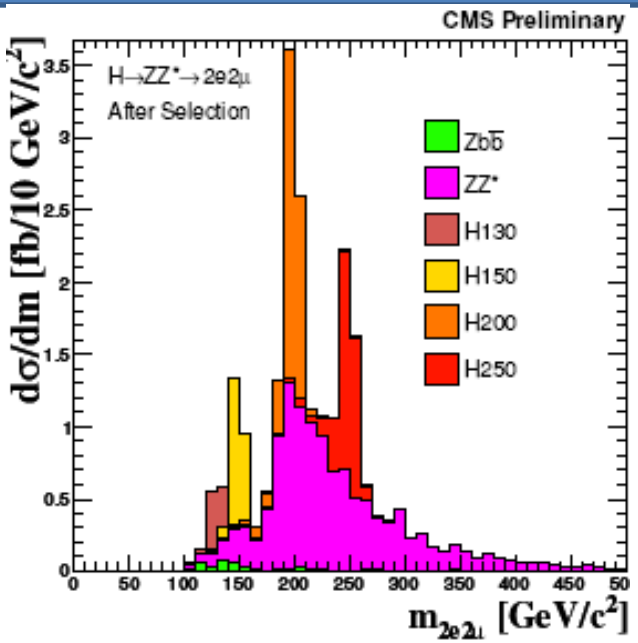


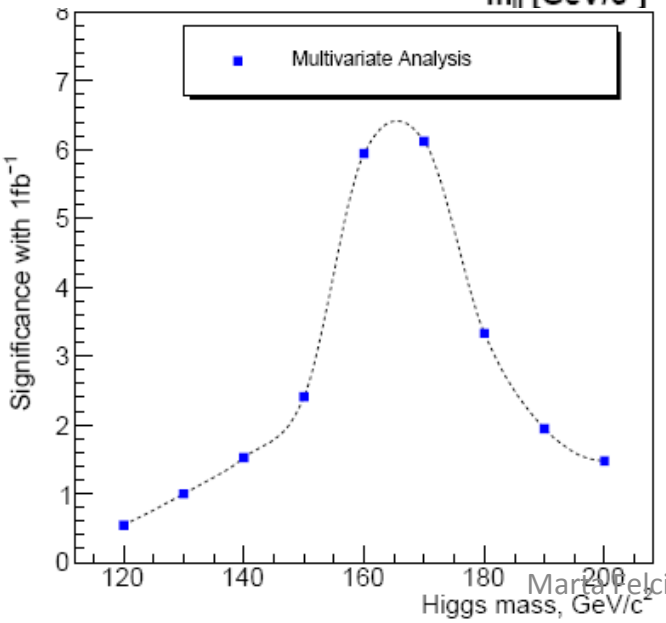


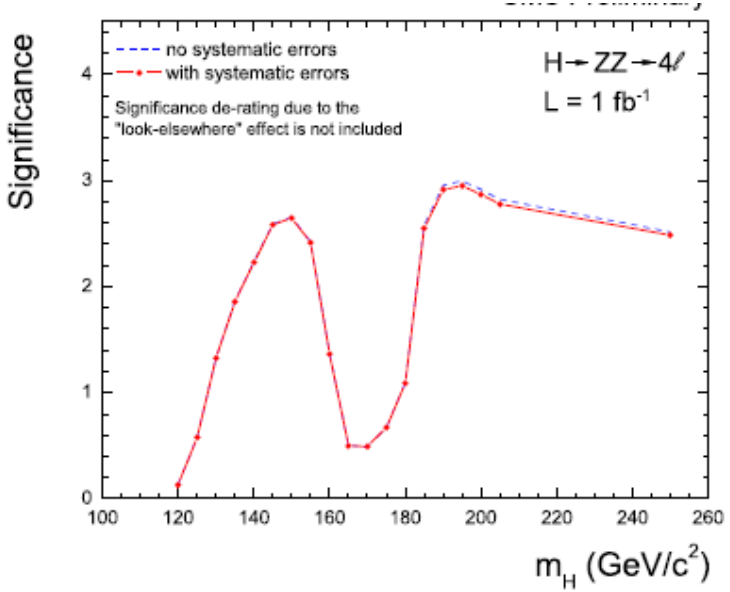


H → WW → llνν , H → ZZ → 4l

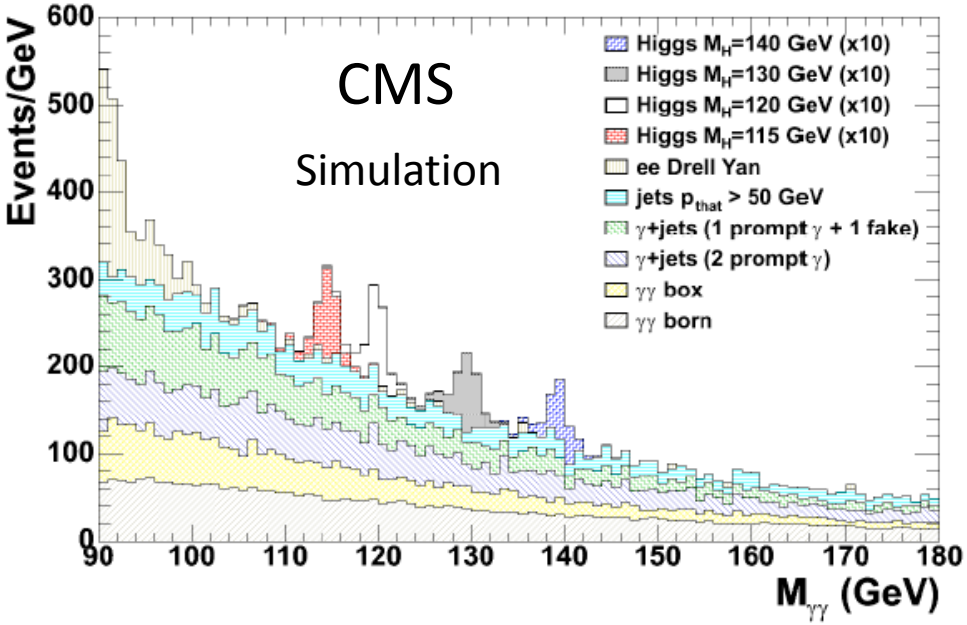


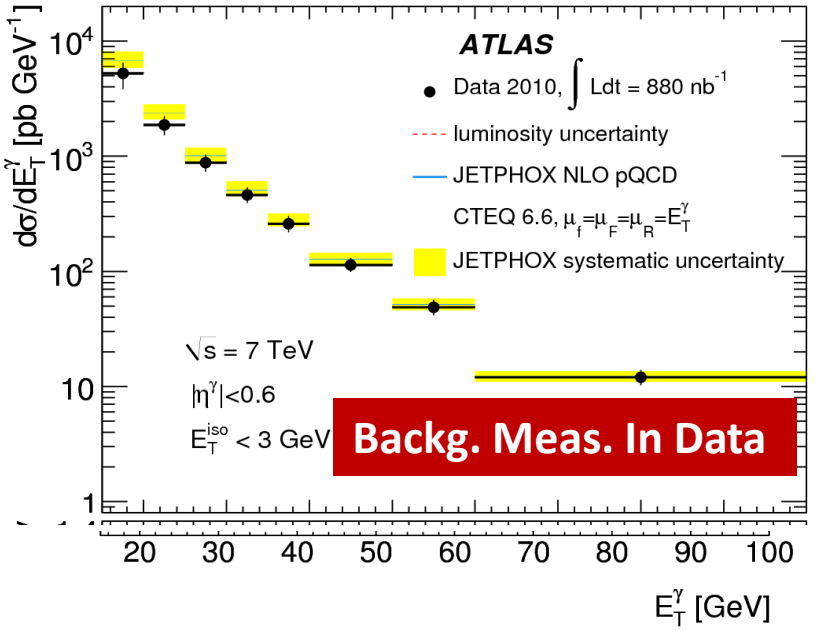


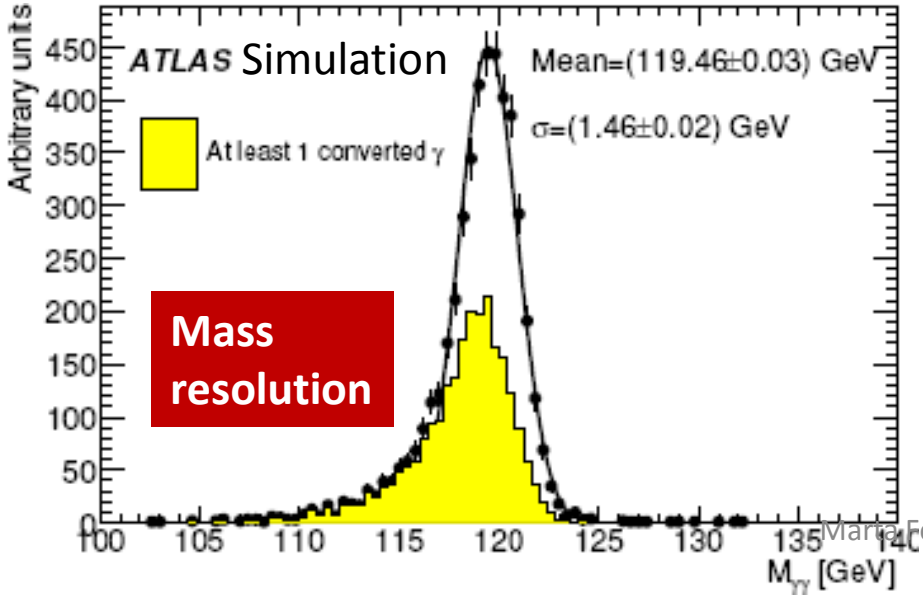


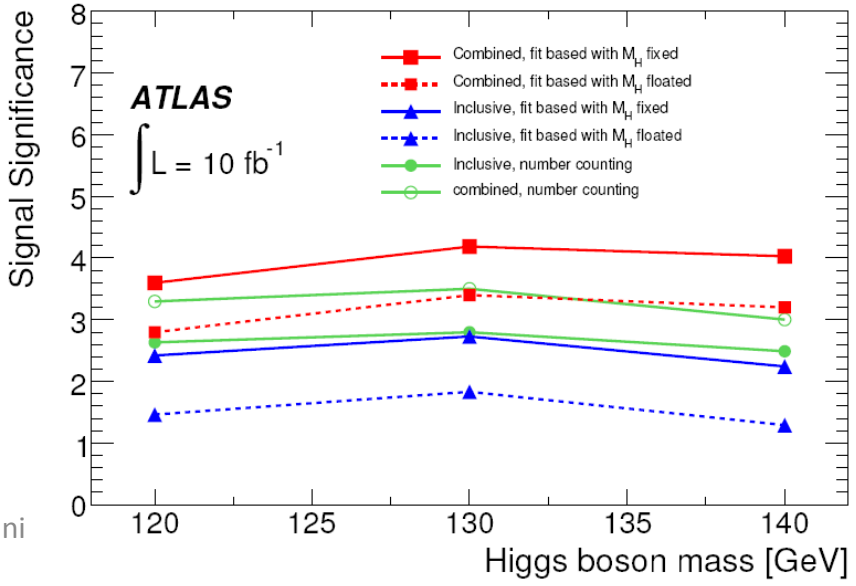


$H \rightarrow \gamma\gamma$







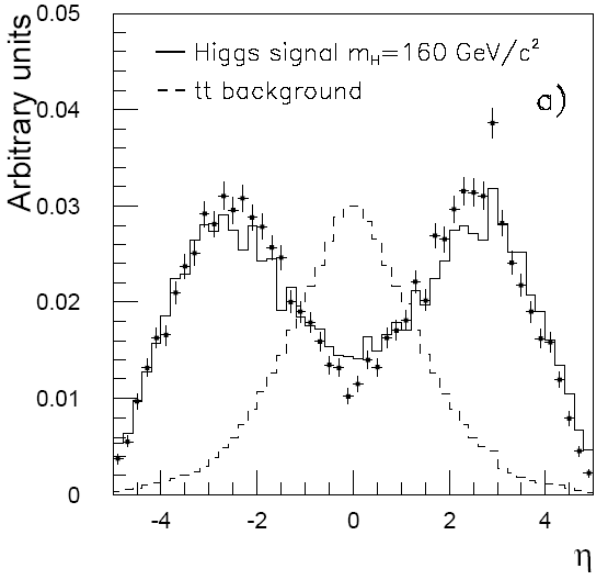


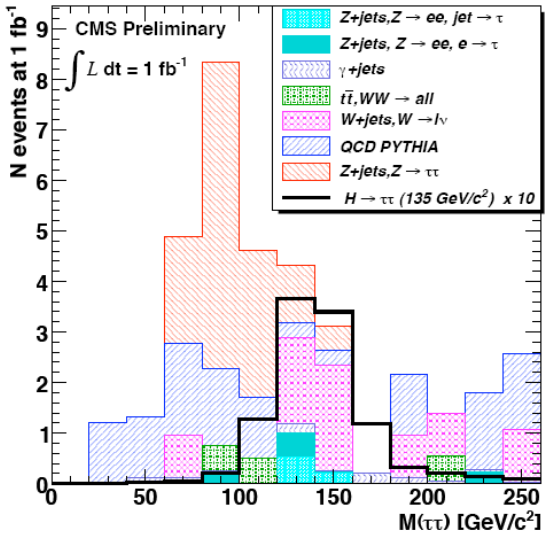
VBF qqH, H → ττ or H → WW

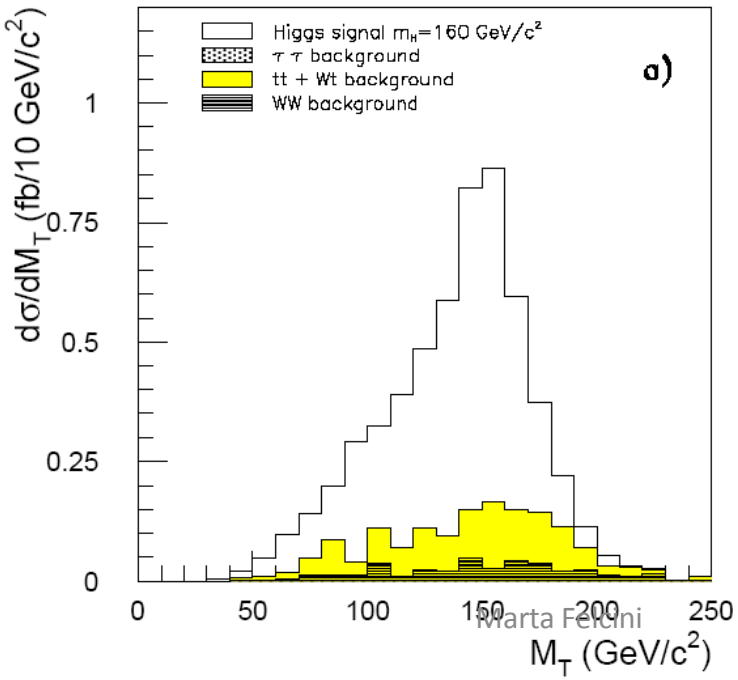
Improve S/B requiring

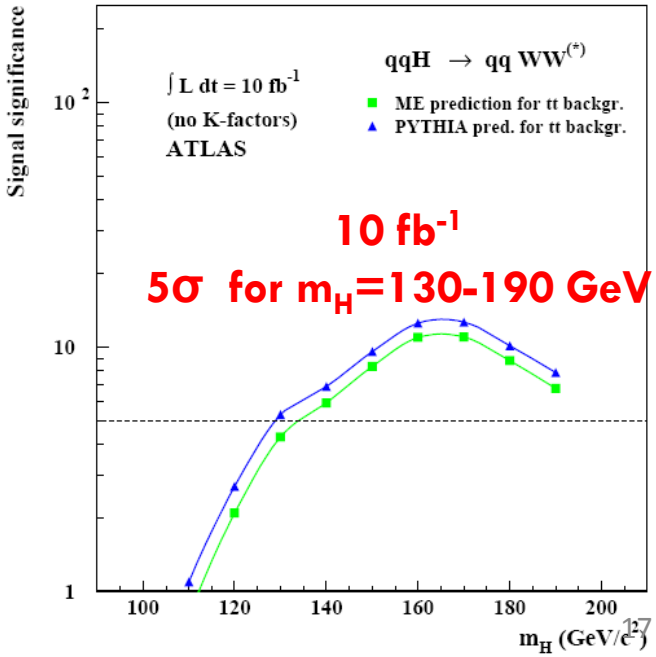
- **Forward jets**
- **Central jet veto**

Simulation Studies



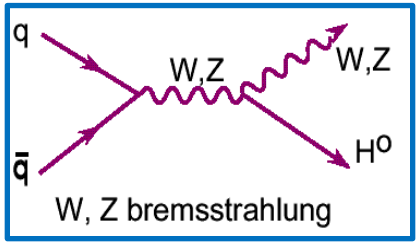


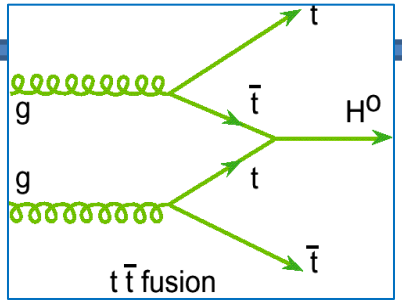




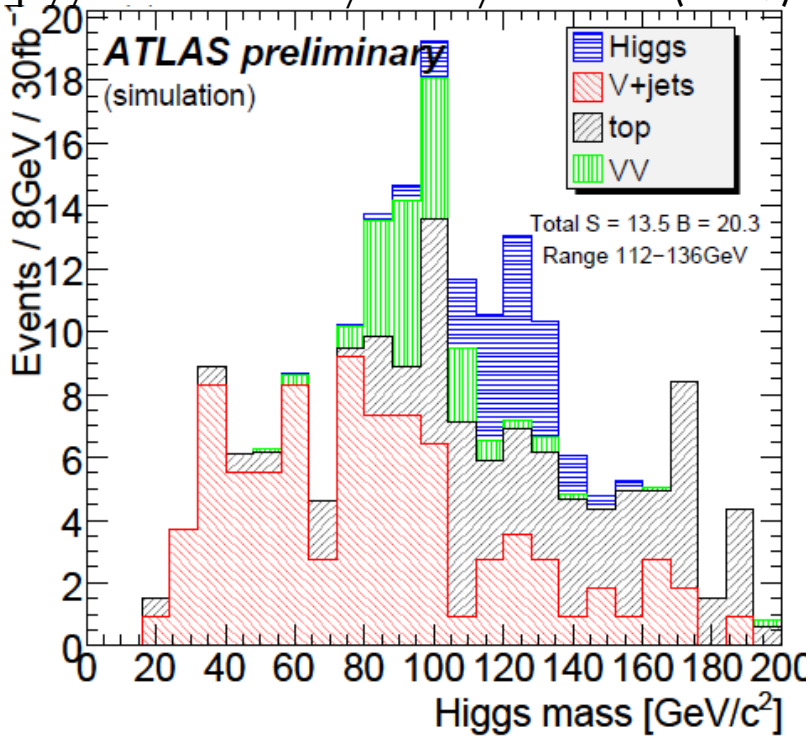
VH and ttH, H→bb

ATLAS new study

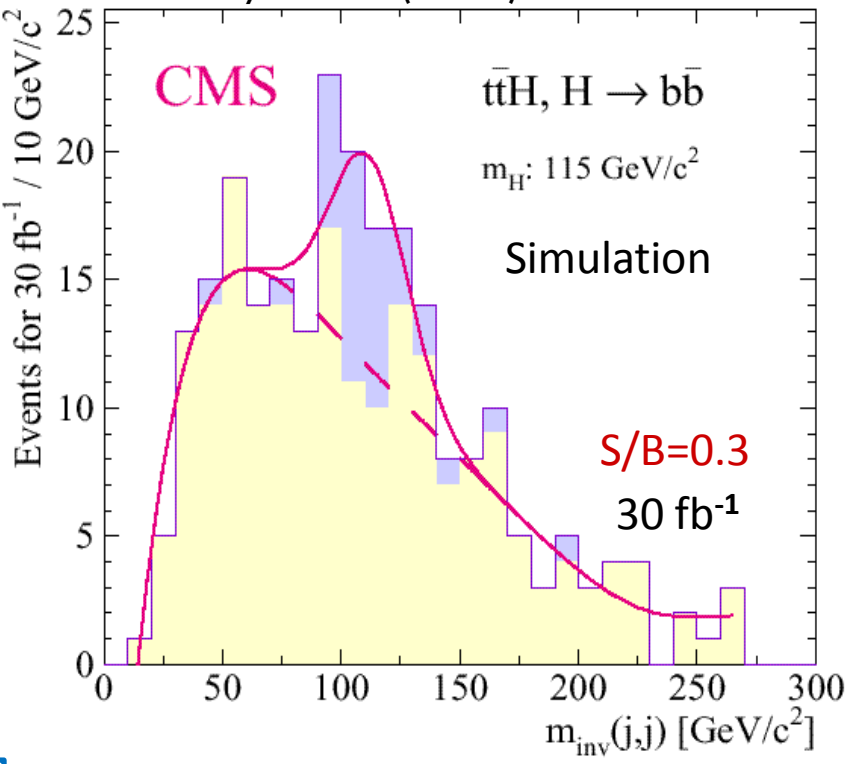




http://cdsweb.cern.ch/record/1201444 (2009)



J. Phys. G 34 (2007) 995-1579

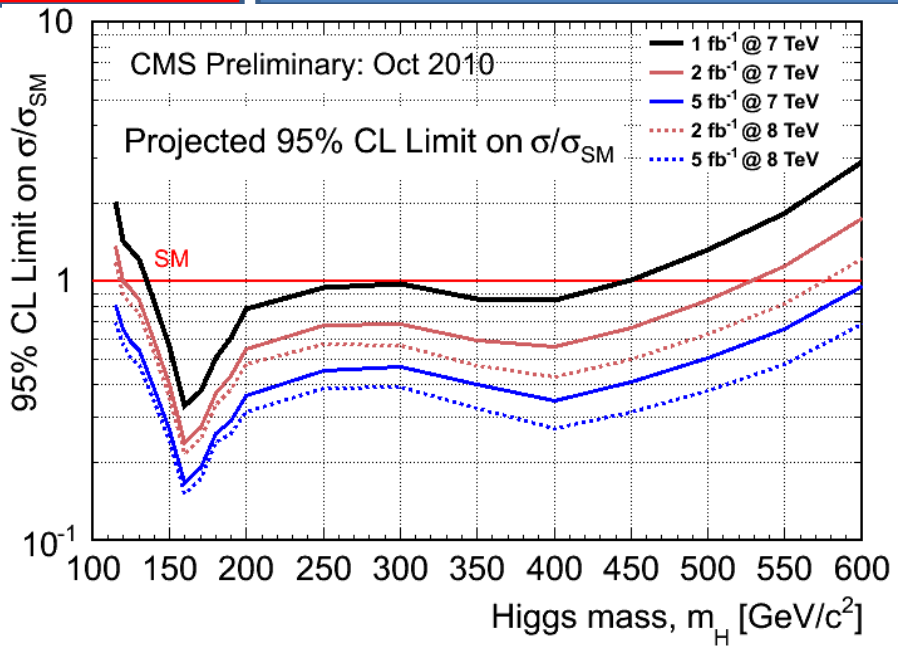


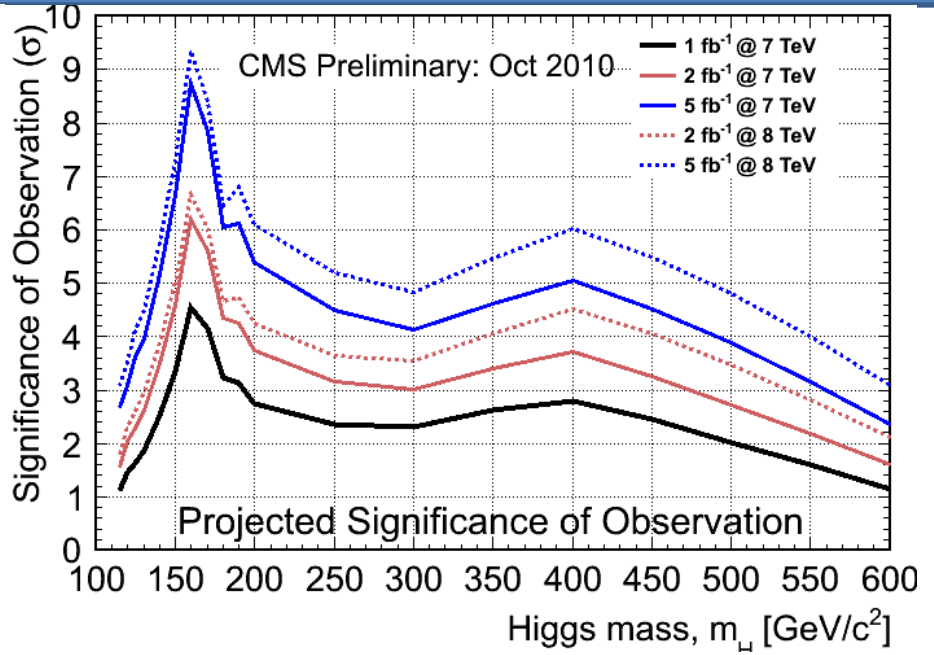
Recent ATLAS re-analysis of the VH channel, employing improved jet reconstruction techniques to identify high pT Higgs events

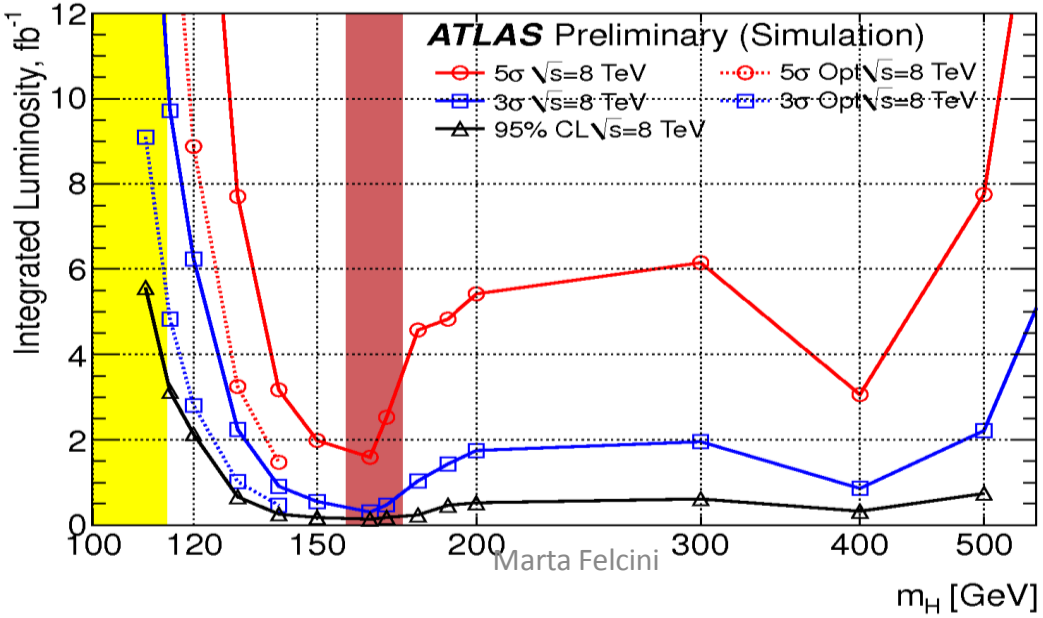
Key Issue: Background Estimate and Uncertainty

Channel	Main background	S/B (luminosity)	Background Syst. for 5σ	Proposed technique/comments
H->γγ	Irreducible γγ Reducible γ+jets	3-5% (10/fb)	0.8%	Side-bands (bkg shape not known a priori)
VH, H->bb	Vbb, tt, Wt	60% (30/fb)	30%	Control region and extrapolation
ttH, H->bb	ttbb	30% (30/fb)	6%	Mass side-bands Anti b-tagged ttjj ev.
H->ZZ*-> 4l	ZZ->4l Reducible tt, Zbb	300-600% (1-10/fb)	60%	Mass side-bands Stat Err <30% 30fb^{-1}
H->WW*->llνν	tt , Drell-Yan, VV, tW, W+jets	30-150% (1-10/fb)	6-30%	No mass peak - Control region and extrapolation
VBF channels	Tails QCD/EW	Study forward jet tag and central jet veto		Use EW ZZ and WW QCD Z/W + jets
VBF H->WW	tt, WW, Wt	50-200% (1-10/fb)	10%	Study Z,W,WW and tt plus jets
VBF H->ττ	Zjj, tt	50-200% (1-10/fb)	10-40%	Mass side-bands Beware of resolution tails

SM Higgs Search Performance at 7 TeV







Summary 1 – Status and prospects

In 2010 the LHC has delivered pp collisions at 7 TeV,
the highest energy ever attained in the lab

The LHC experiments have efficiently collected and analyzed the collision data and, in few months of data taking, measured a large number of SM processes and compared to higher order theoretical SM predictions.
Within the experimental uncertainties good agreement with the SM.

This successful year and the resulting understanding of collision physics at the highest energy Is **the baseline for an effective searches in the next years**

The LHC will deliver pp collisions at 7 TeV in 2011 and 2012 w/ an expected integrated luminosity **of few (5?) fb^{-1} by the end of 2012**, before a shutdown of 1 year for consolidation work, and **resuming collisions in 2014 at ~14 TeV.**

Based on updated Higgs simulation studies and detector performance in 2010 at 7 TeV, it is inferred that **the data sample expected in 2011-2012, will give access to a large fraction of the SM Higgs mass range for exclusion and for discovery in the 130-200 GeV range, w/ order 5^{-pb} of collision data.**

Summary 2 - Key issues for an effective search

Precise (higher order) event generators for SM processes

Whenever possible, SM cross-sections will be measured inclusively and differentially. Higgs (and other rare) signals are looked for in extreme kinematic regions (tails of the SM processes) where a precise measurement of the SM contribution is limited by low data statistics. Thus we must extrapolate from high stat regions to low stat region. In this process, it is highly beneficial to use precise MC generators to reduce the uncertainty of the extrapolation.

-> Ongoing activity in the LHC Higgs Cross Section WG – welcome to join or collaborate

Precise (higher order) event generators for SM and BSM Higgs processes

To reduce the uncertainty on the signal efficiency prediction.

-> Ongoing activity in the LHC Higgs Cross Section WG – welcome to join / collaborate

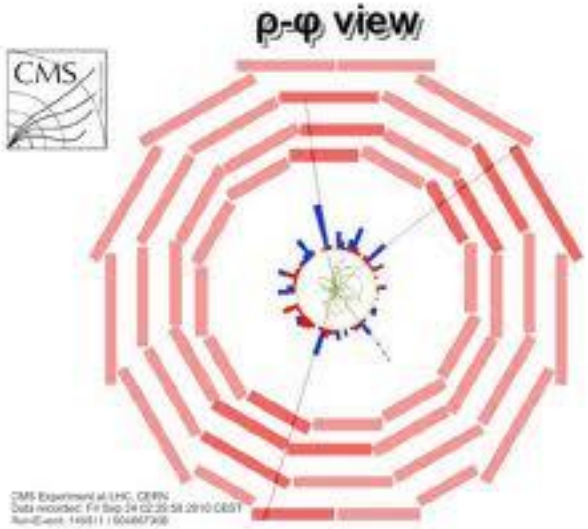
Interpretation of the search results beyond the context of the SM Higgs

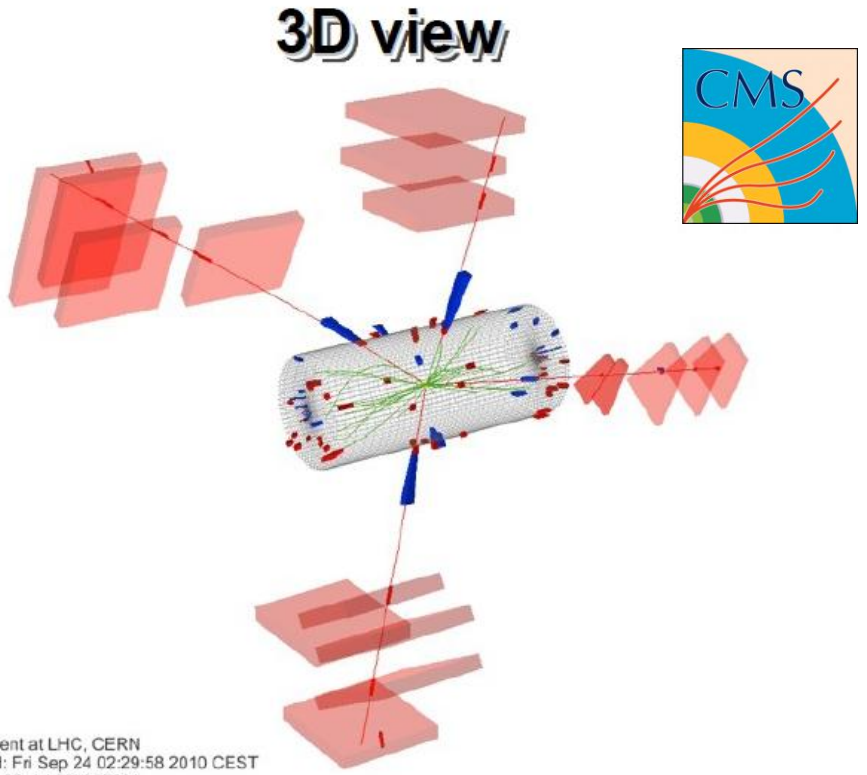
-> Ongoing activity eg by "Global BSM fits and LHC data" WG and the Les Houches workshop

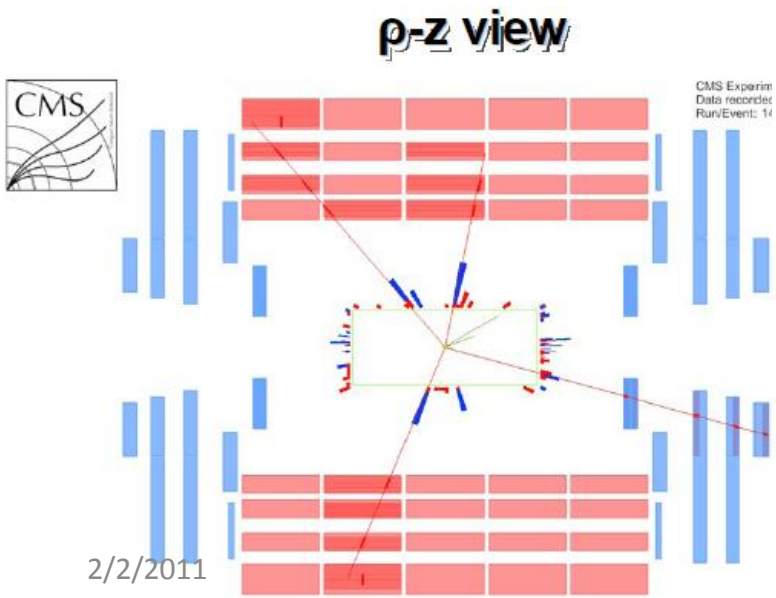
Design of efficient triggers for signals from SM Higgs and other popular BSM models , but also consider more general and "model-independent" searches

-> collaboration with theorists highly welcome

First ZZ → 4μ event observed in CMS



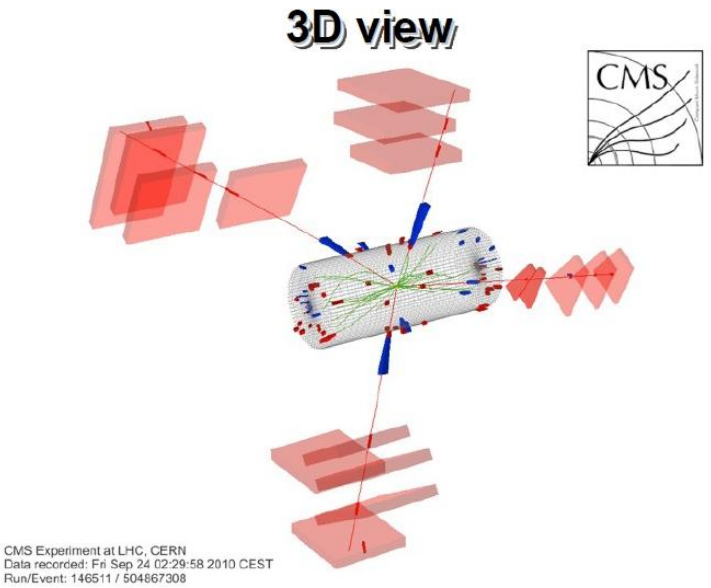




CERN-CMS-DP-2010-038
http://cdsweb.cern.ch/record/1305134

Epilogue

http://robertgraham.wordpress.com/anarchists-in-the-spanish-revolution-1936-1939



A Revolution is Coming

…

Thank You

To the Organizers for their kind invitation.

To the colleagues of the LHC Collaborations, for all the brilliant results.

And special thanks to the colleagues from whom I "borrowed" material for this talk:
C. Biino, De Filippis, A. De Roeck, M. Ferro-Luzzi, A. Koriotov, C. Mariotti, B. Murray, A. Nikitenko, N. Pastrone, G. Rolandi, V. Sharma

Bibliography

ATLAS Higgs Public Results
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults

ATLAS Sensitivity Prospects for 1 Higgs Boson Production at the LHC Running at 7, 8 or 9 TeV
ATL-PHYS-PUB-2010-015

ATLAS Sensitivity Prospects for Higgs Boson Production at the LHC Running at 7 TeV
ATL-PHYS-PUB-2010-009

CMS Physics Results
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

CMS Higgs Physics Results
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIG

Projected sensitivity for Standard Model Higgs boson searches at 7 and 8 TeV, and 1-10 fb^{-1}
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIGStandardModelProjections

Bibliography

Handbook of LHC Higgs Cross Sections: 1. Inclusive Observables

http://arxiv.org/PS_cache/arxiv/pdf/1101/1101.0593v2.pdf

LHC Higgs Cross Section Working Group

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

Backup

BSM Higgs Studies for LHC

The main goal of the Monte Carlo based BSM Higgs experimental studies is to set-up the search - trigger, background estimation methods, analysis tools - into final states and topologies different from those studied for the SM Higgs , but potentially relevant and even dominant in BSM scenarios.

In BSM scenarios like
- ❑ **SUSY: MSSM, NMSSM, THD,…**
- ❑ **Extra Dimensions**
- ❑ **Little Higgs**
- ❑ **Models with extra bosons and fermions**
- ❑ **Others…**

Final states with:
- ❑ **multiple b's and/or taus**
- ❑ **lepton resonances**
- ❑ **cascade decays**
- ❑ **invisible decays**

…can be dominant Higgs signatures

ATLAS & CMS MC studies result into predictions of the experimental discovery reach
First observation (mass, charge,…) and detailed measurements (couplings, spin, CP,…)
to determine the role of the newly detected Higgs-like particles, in view of possible

Early discovery and measurement	Observation	Open question
Neutral Higgs low mass<185 GeV	Consistent w/ SM or MSSM	SM, MSSM , other BSM?
Neutral Higgs high mass>185 GeV	Inconsistent with SM	MSSM, other BSM ?
More than one neutral Higgs	inconsistent with SM	MSSM, other BSM ?
Charged Higgs	inconsistent with SM	MSSM, other BSM ?
Other BSM particles /interactions	inconsistent with SM	BSM Model? Higgs sector?

Setting-up the Search for Discovery

Determine trigger conditions to be highly efficient on "BSM look-alike" SM physics (loosely defined signal region, model ind.)

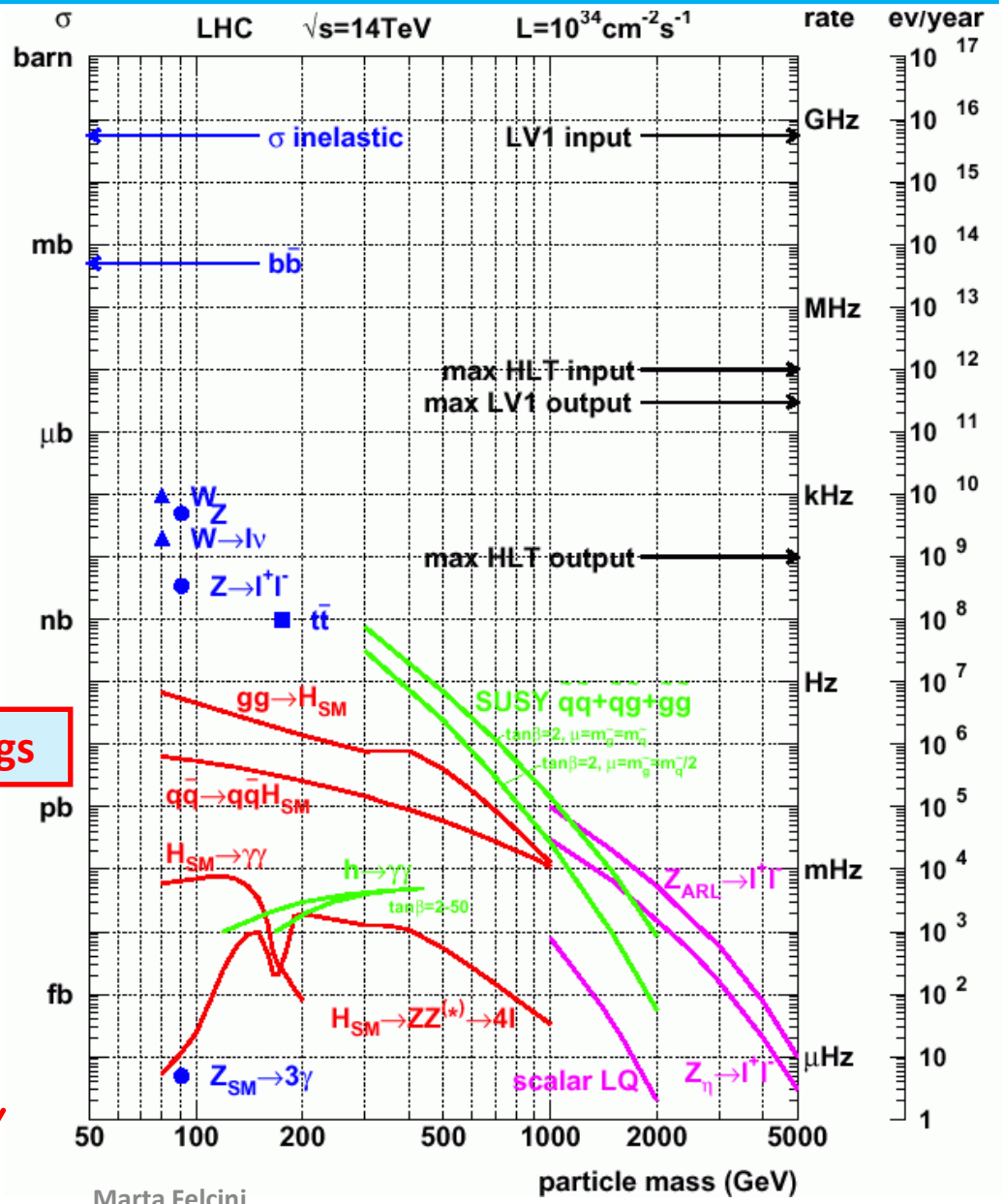
Determine SM background contributions define reliable methods to measure the SM background from data itself (measure SM tails, rare SM processes, W/Z+njets, tt+njets, WW, WZ, ZZ,etc)

Define signal region (model dependent), determine discriminating quantities to maximize signal-to-background ratio and minimize (stat. and syst.) uncertainties

Maximize discovery reach for early observation (event yield, mass, charge,…), as a function of model parameters, depending on integrated luminosity

Define methods for detailed Higgs measurements (couplings, spin, CP,…) to determine the role of the newly detected Higgs-like particles,

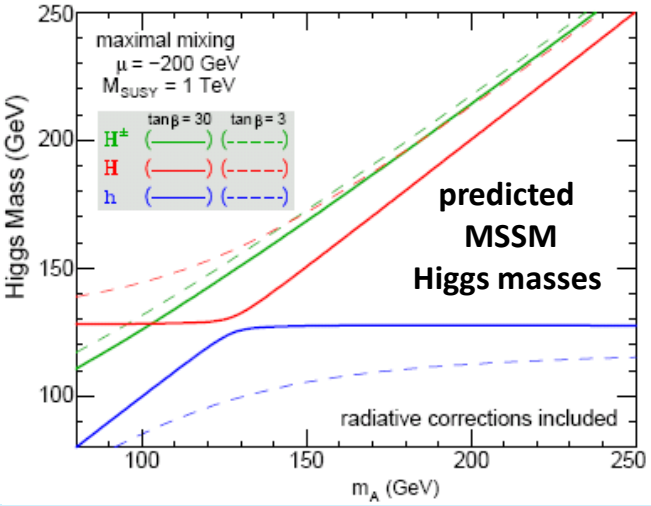
Higgs



Higgs in MSSM and extensions

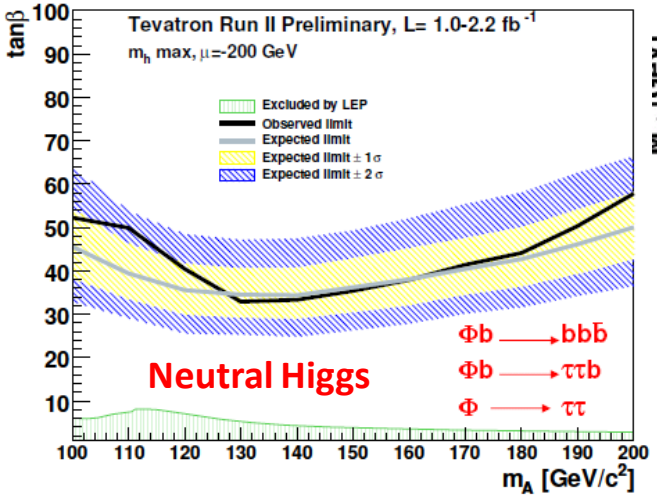
Model predictions:

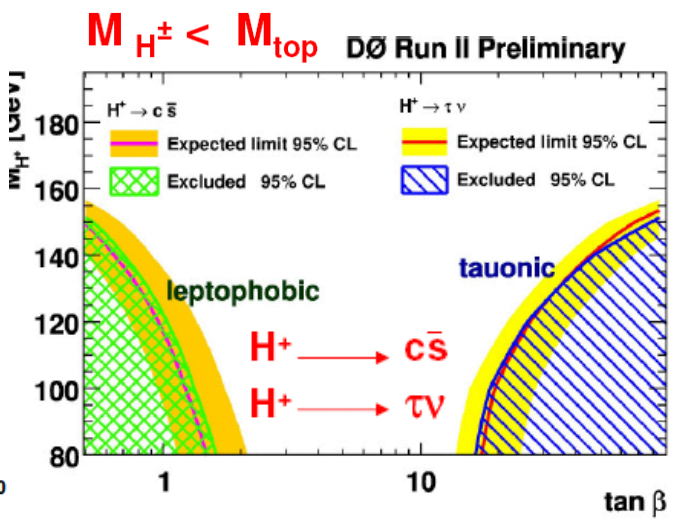
- light (<~130 Gev), neutral CP-even Higgs, h
- heavier neutral CP-even Higgs, H
- neutral CP-odd Higgs A
- charged Higgs bosons (C= +/-1)
- decays to known gauge bosons and fermions
- may decays to SUSY particles, if light enough
  -> visible cascade and invisible decays

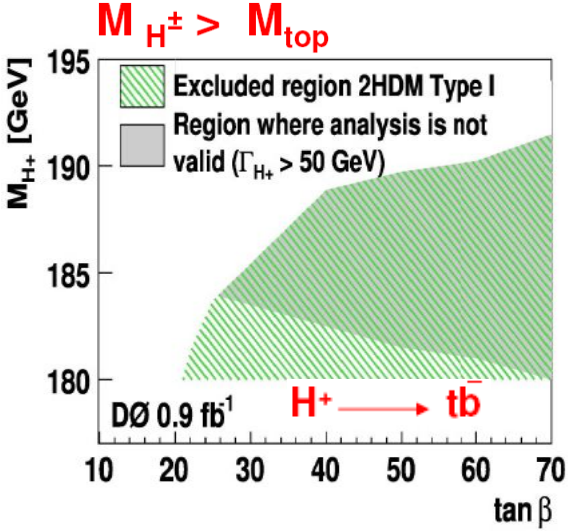


Present experimental status 2009 : MSSM parameter space bounded by LEP and Tevatron negative searches for neutral and charged Higgs bosons

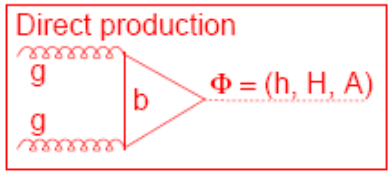
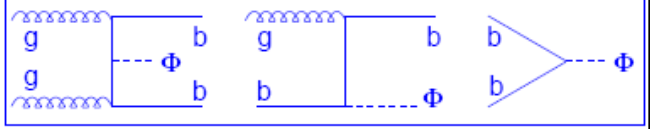
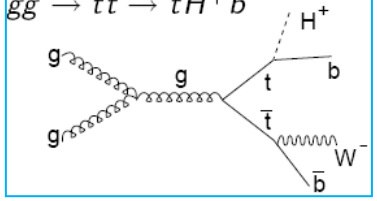
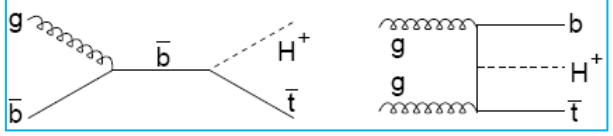
FERMILAB-PUB-09-394-E







MSSM Higgs LHC Searches at a glance

Particle	Dominant production processes	Decay	Final states investigated
Neutral Higgs Bosons h, H, A	Direct production  Associated production with b–quarks dominating production at large tan β  	$h/H/A \to b\bar{b}$ at large tan β , dominant decay, large background $h/H/A \to \tau^+\tau^-$ L arge BR, clean final state $h/H/A \to \mu^+\mu^-$ Very low BR but very good mass resolution	SM Higgs-like final states, from VBF $qqh/H - \tau\tau$d direct production with $h \to \gamma\gamma$ $h/H/A \to \tau^+\tau^- \to \ell\ell + 4\nu$ $\to \ell\tau_{jet} + 3\nu$ $\to \tau_{jet}\tau_{jet} + 2\nu$ $h/H/A \to \mu^+\mu^-$
Charged Higgs Bosons H+, H-	Light $H^\pm$ ($m_{H^\pm} < m_{top}$): $gg \to t\bar{t} \to \bar{t}H^+b$  Heavy $H^\pm$ ($m_{H^\pm} > m_{top}$): $g\bar{b} \to \bar{t}H^+$ and $gg \to \bar{t}bH^+$  	For $m_{H^\pm} < m_{top}$: $H^\pm \to \tau^\pm\nu$ For $m_{H^\pm} > m_{top}$: $H^\pm \to tb$ and $H^\pm \to \tau^\pm\nu$	$tt \to (H^\pm b)(W^\mp b) \to$ $\to (\tau_{jet}\nu\nu b)(\ell^\mp\nu b)$ $\to (\tau_{jet}\nu\nu b)(qqb)$ $\to (\ell\nu\nu\nu b)(qqb)$ $gg, gb \to t[b]H^\pm \to$ $\to (Wb)[b](\tau\nu) \to (bqq)[b](\tau_{jet}\nu\nu)$ $\to (Wb)[b](tb) \to (b\ell\nu)[b](bqqb)$

MSSM Higgs Reach

$b\bar{b}\,(h/H/A \to \tau^+\tau^-$

$\to \tau_{jet}\tau_{jet} + 2\nu$

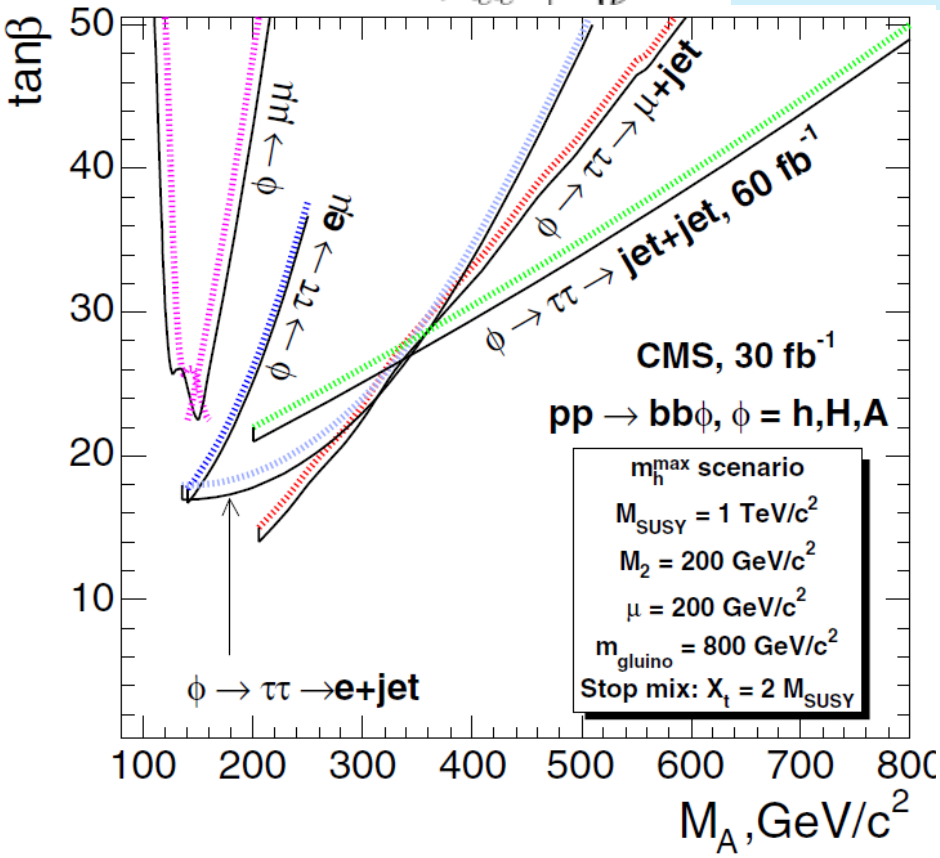
$\to \ell\tau_{jet} + 3\nu$

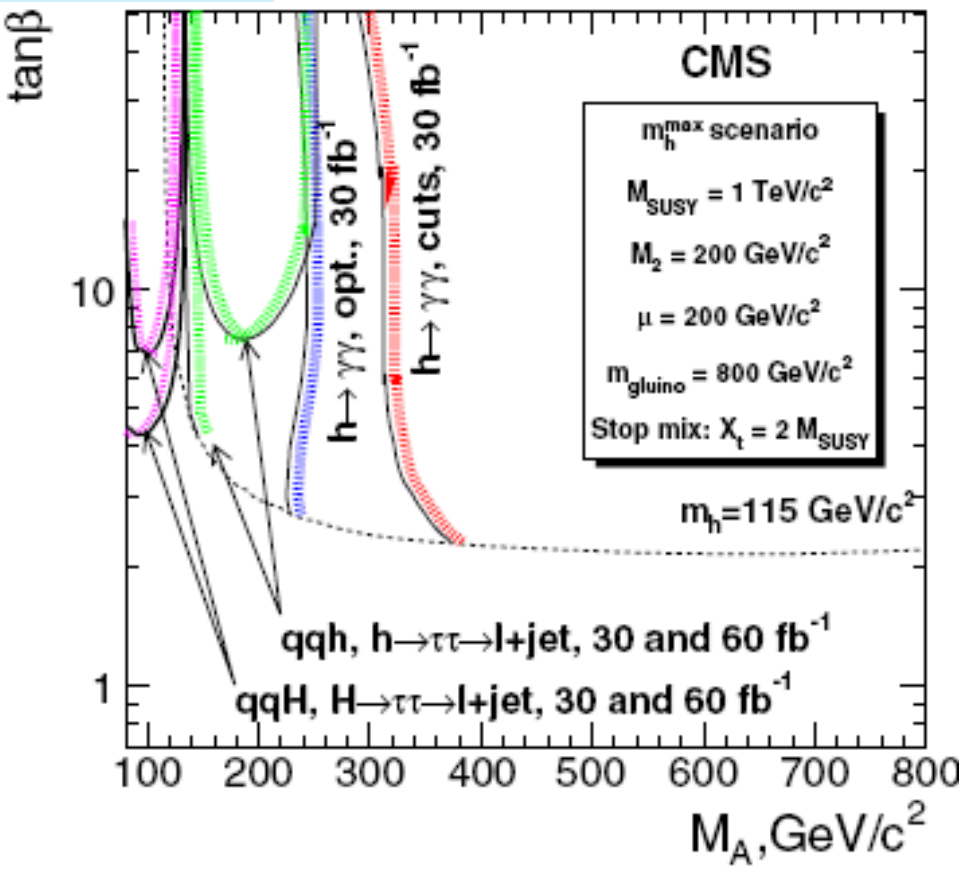
$\to \ell\ell + 4\nu$

VBF $qqh/H \to \tau\tau$ and $h \to \gamma\gamma$

SM Higgs searches interpreted in MSSM

5 σ discovery contours





(*)**m_h^{max} scenario** designed to provide the most conservative MSSM exclusion limits from LEP

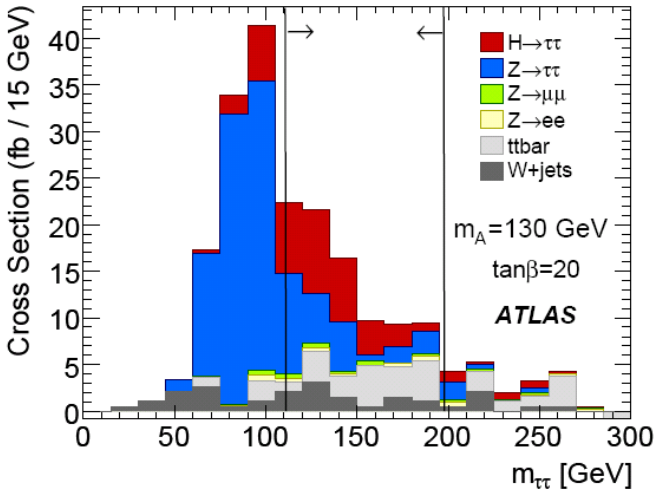
MSSM Higgs Reach with Dilepton Final States

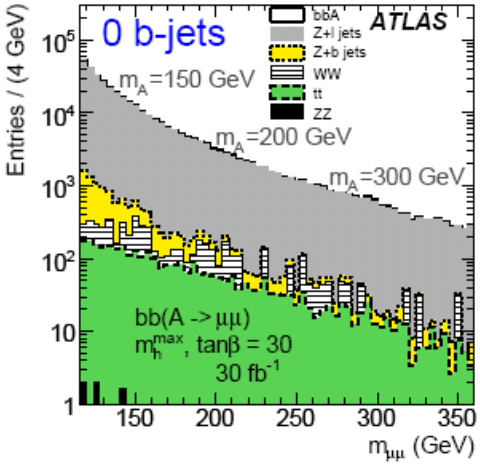
$b\bar{b}\,(h/H/A \to \tau^+\tau^-$

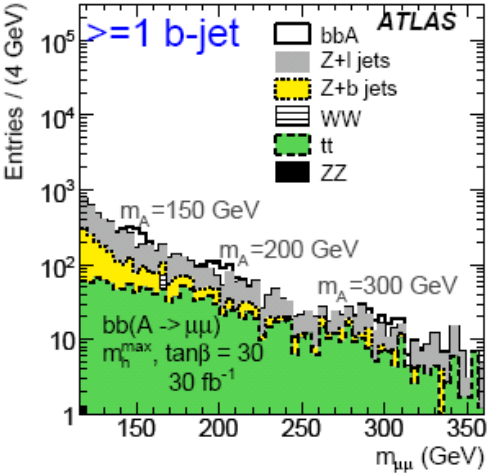
ττ→2l +4ν

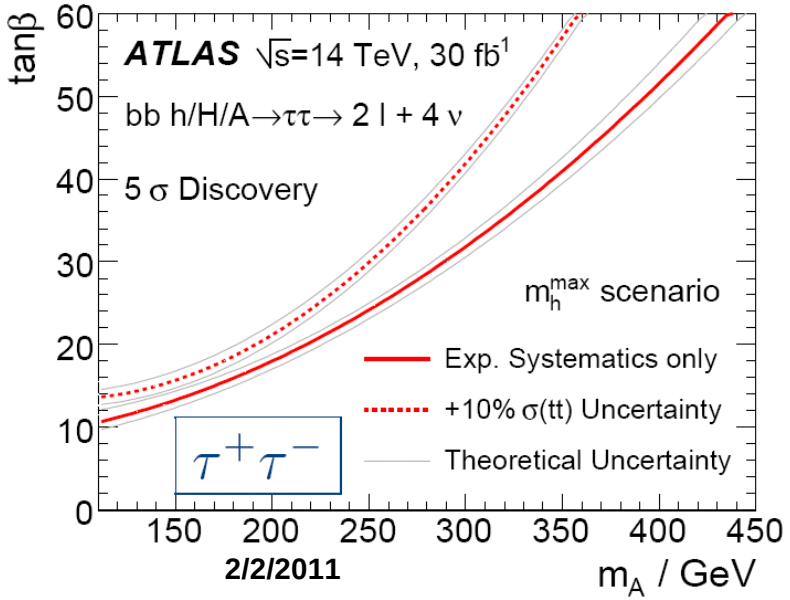
$b\bar{b}\,(h/H/A \to \mu^+\mu^-$

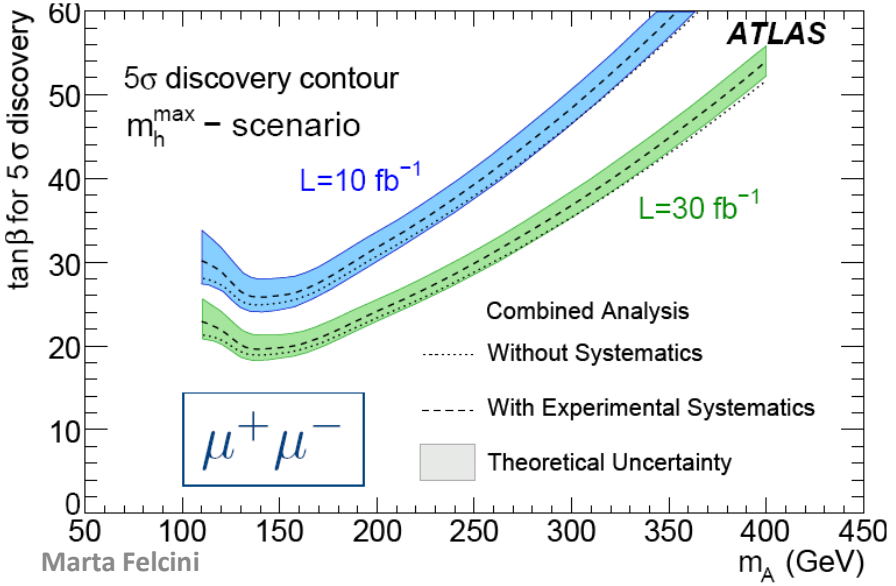
low BR, but good mass resolution







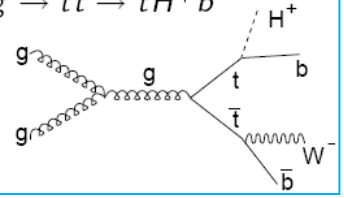




Charged Higgs Discovery Reach

Light $H^{\pm}$ ($m_{H^{\pm}} < m_{top}$):

$gg \to t\bar{t} \to \bar{t}H^{+}b$



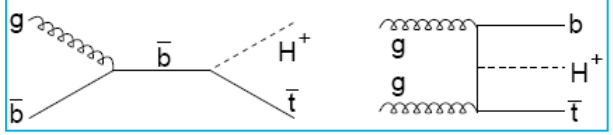
$\to b\tau(had)\nu bqq$

$\to b\tau(lep)\nu bqq$

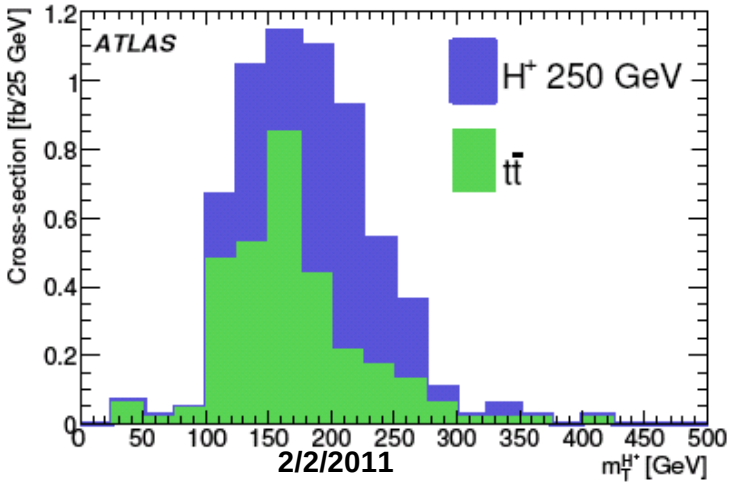
$\to b\tau(had)\nu b\ell\nu$

Heavy $H^{\pm}$ ($m_{H^{\pm}} > m_{top}$):

$g\bar{b} \to \bar{t}H^{+}$ and $gg \to \bar{t}bH^{+}$

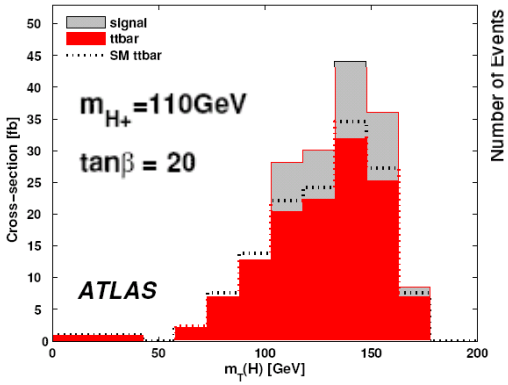


$t[b]H^{+} \to bqq[b]\tau(had)\nu$

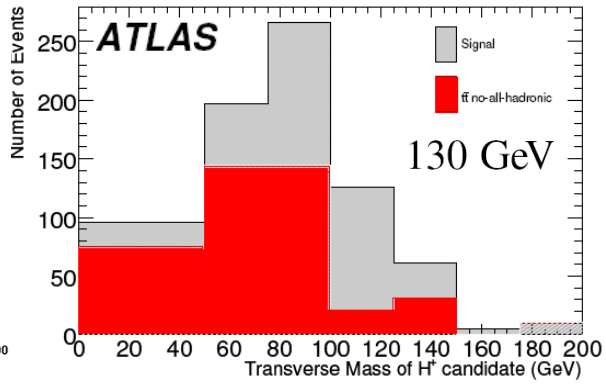


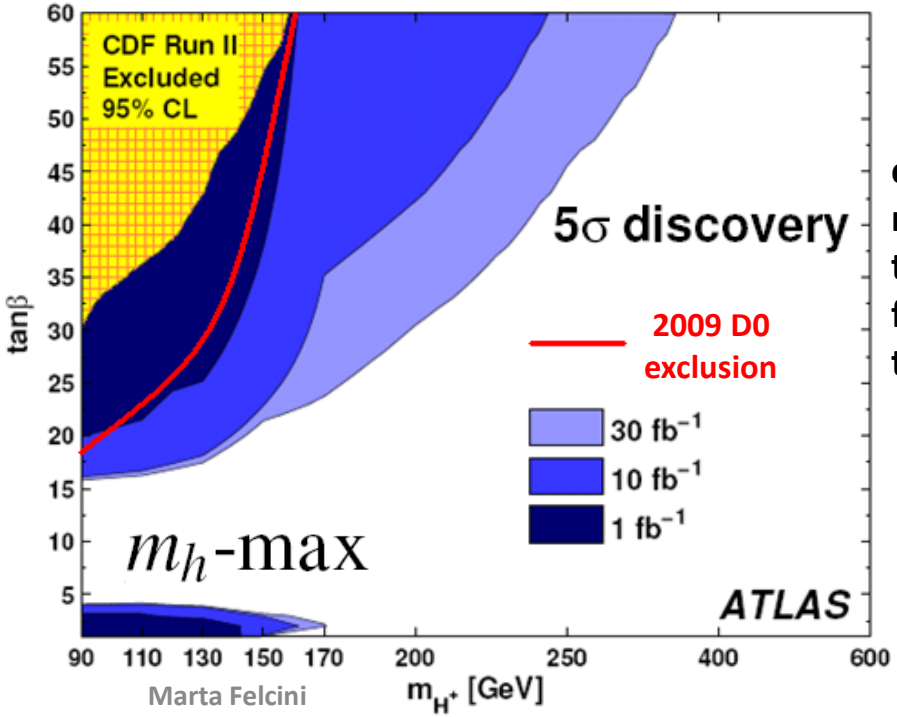
2/2/2011

$b\tau(lep)\nu bqq$



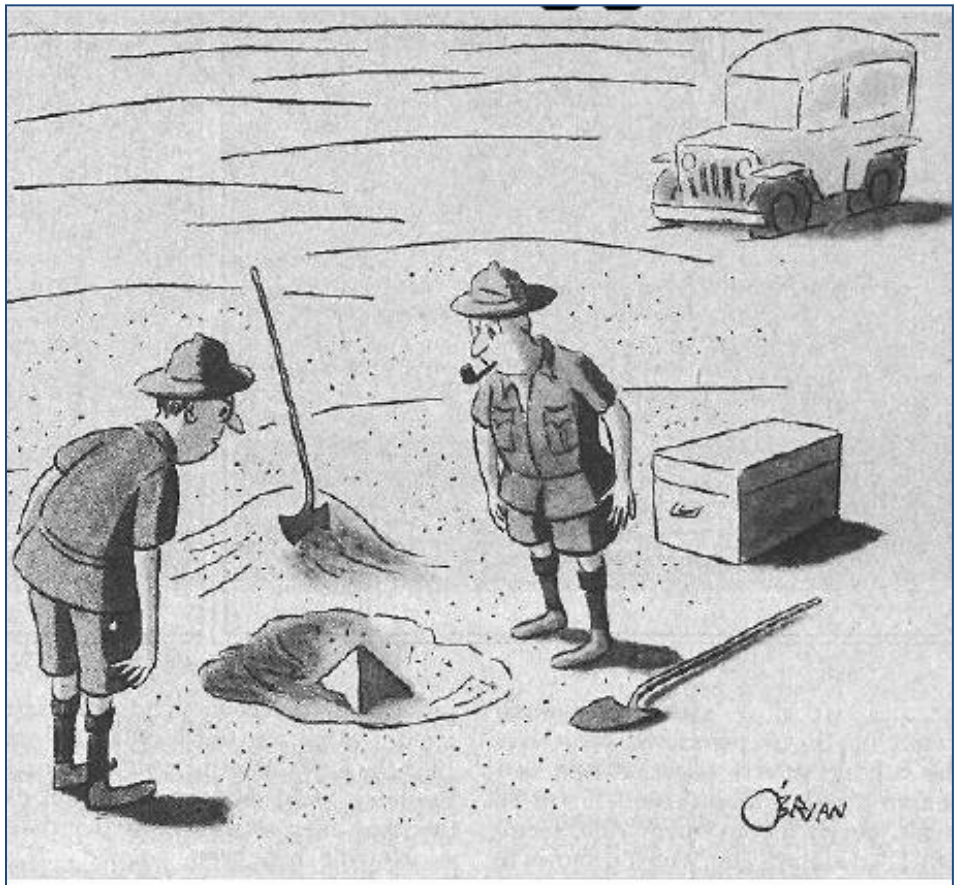
$b\tau(had)\nu bqq$





exclusion region up to ~600 GeV for large tan β

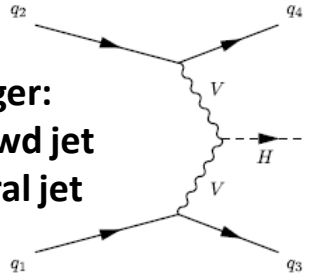
Beyond MSSM



"This could be the discovery of the century. Depending, of course, on how far down it goes."

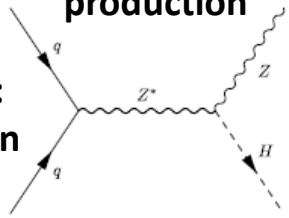
Invisible Higgs

H production via VBF



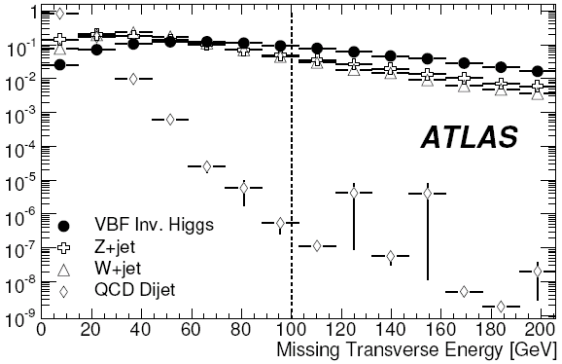
Trigger: MET+fwd jet +central jet

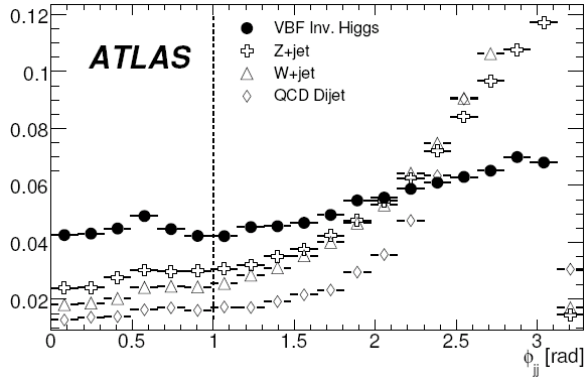
HZ associated production



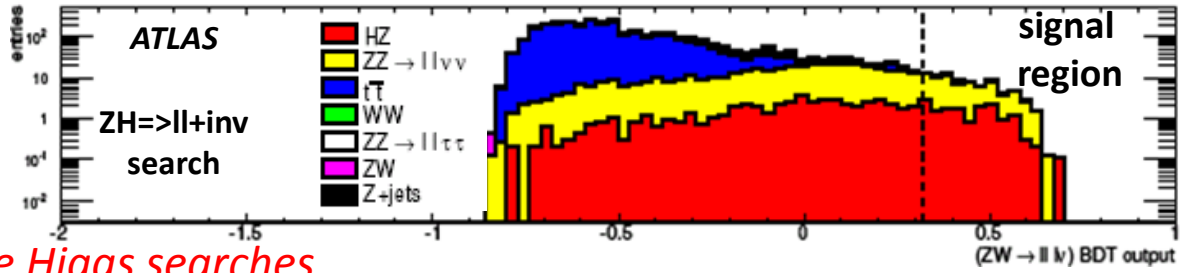
Trigger: (di)lepton

Cut-based and tagging jet azimuthal angle shape analysis





Boosted Decision Tree (BDT) analysis



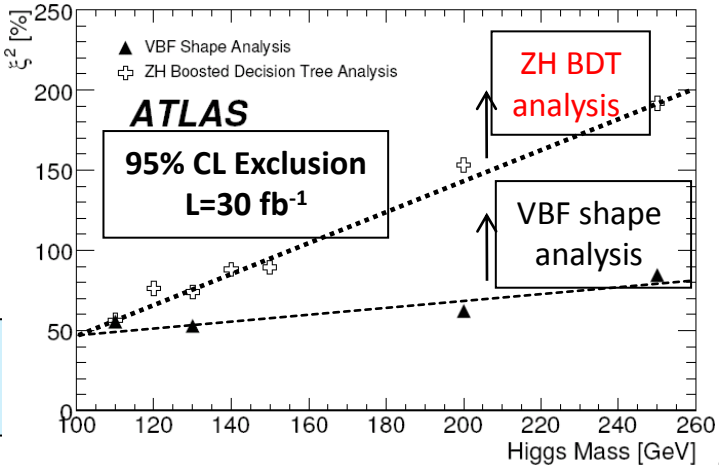
see also CMS poster on invisible Higgs searches

Reach of VBF shape analysis and ZH BDT analysis

$$\xi^2 = BR(H \to inv.)\frac{\sigma_{BSM}}{\sigma_{SM}}$$

VBF shape analysis more performant at high H mass
combine both channels (VBF and ZH) to establish signal.

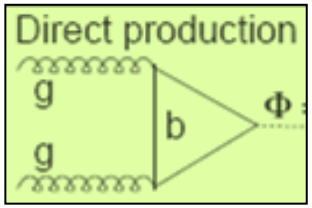
Signal excluded (observable) with 30 (~100) fb-1 for $\xi^2 > 0.5$, as e.g. for $\sigma_{BSM} = 0.5\ \sigma_{SM}$ and 100% BR_{inv}



Extra Dimensions

5D Randall–Sundrum model:

Scalar sector: Radion ϕ and Higgs h

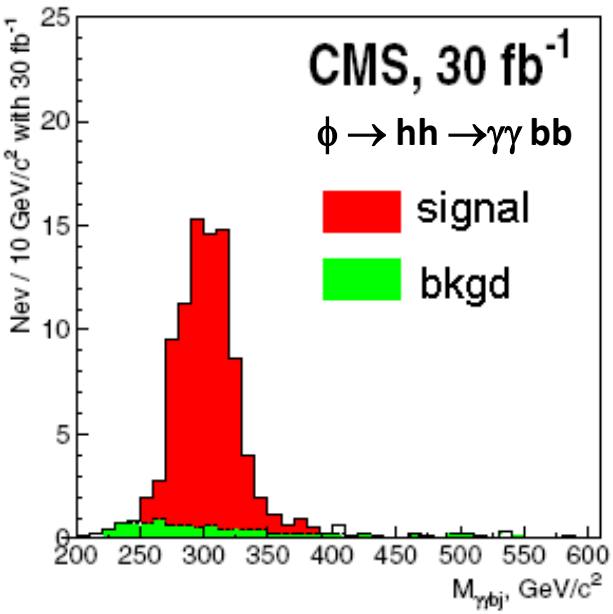


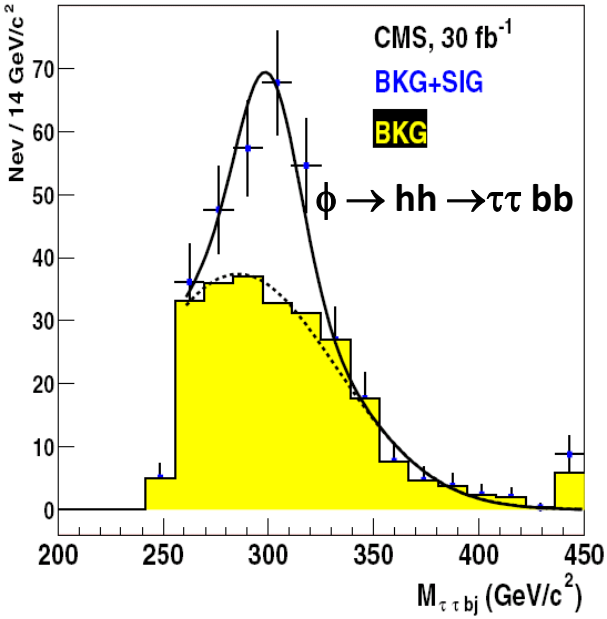
$\phi \rightarrow hh \rightarrow \gamma\gamma\ bb$

$\phi \rightarrow hh \rightarrow \tau\tau\ bb$

$m_\phi = 300$ GeV

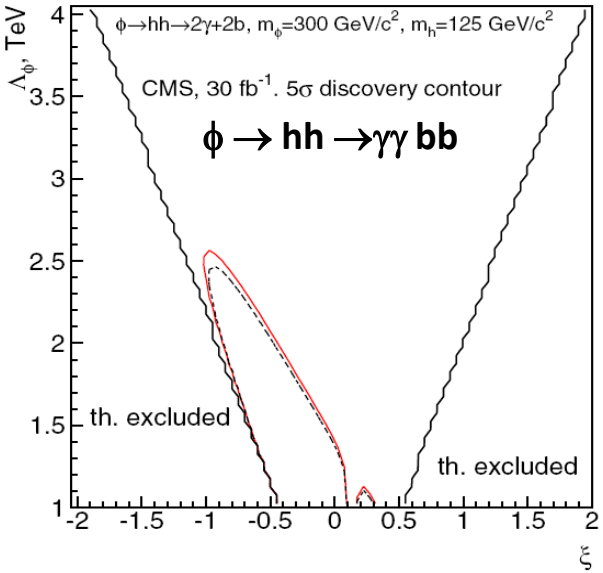
$m_h = 125$ GeV

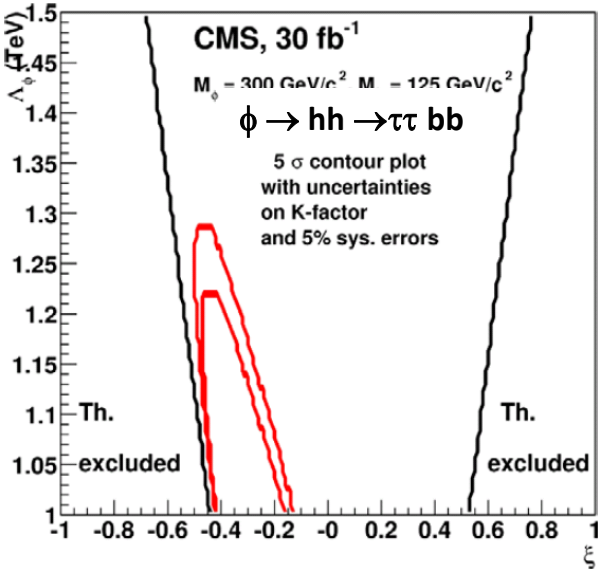




RS scalar sector parameters:

- **Higgs - radion mix. parameter ξ**
- **radion mass m_ϕ**
- **Higgs mass m_h**
- **v.e.v of the radion field Λ_ϕ.**





Littlest Higgs Model - Doubly Charged Higgs

Littlest Higgs or ***Minimal "Little Higgs" model***
N. Arkani-Hamed et al, JHEP07(2002)034

Predicts **a light SM-like Higgs-like particle**
a new set of **heavy gauge bosons *W', Z'***
a vector-like **heavy quark T pair** and
a pair of doubly charged Higgs bosons

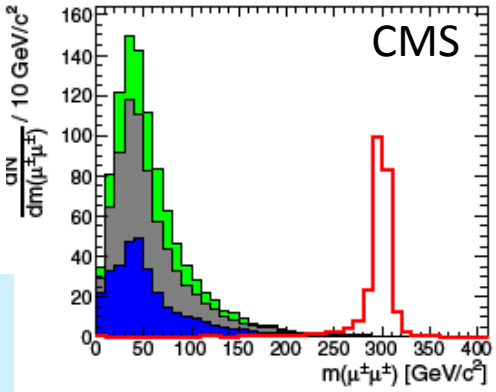
Search in four lepton final states

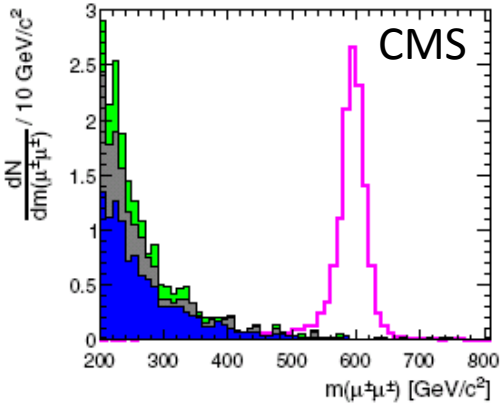
Consider pair production and leptonic decay

Pair production (Drell-Yan): $pp \rightarrow \Delta^{++}\Delta^{--}$

Decay (LV): $\Delta^{\pm\pm} \rightarrow \ell^{\pm}\ell^{\pm}$

Reconstruct invariant mass of same charge leptons -> very small SM background

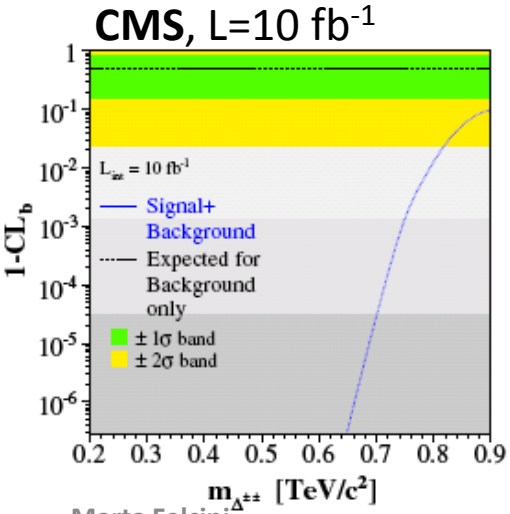


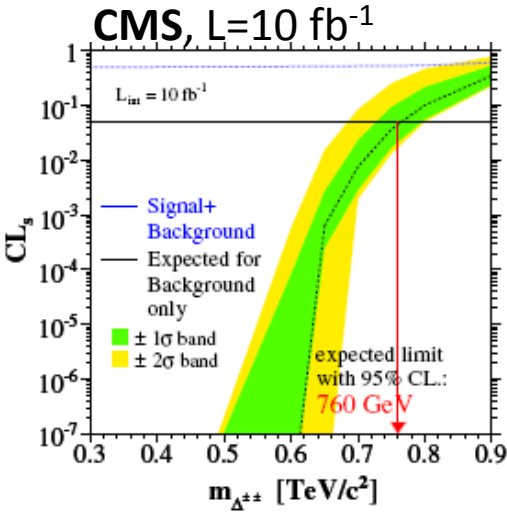


Four muon channel, L=10 fb^{-1}

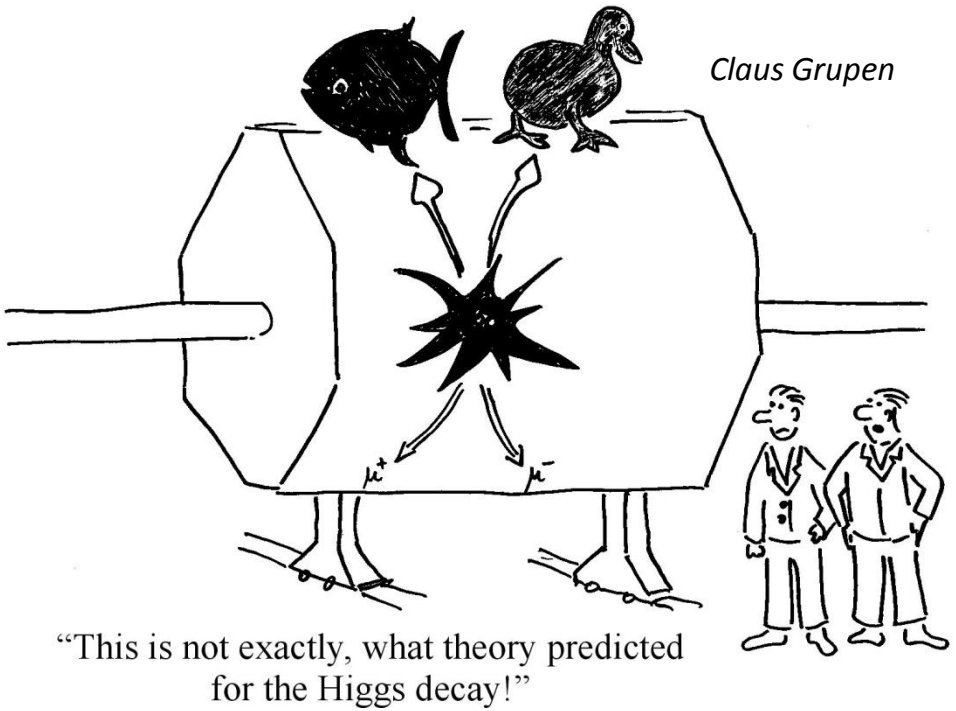
Exclude (95%CL) signal masses up to **760 GeV**

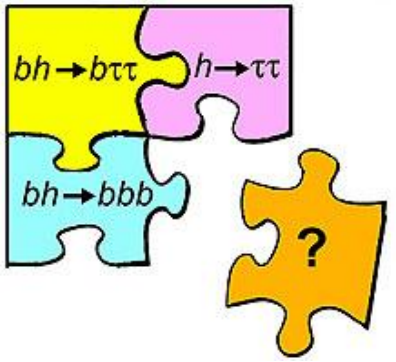
Detect => 5 σ signal for masses up to **650 GeV**





Higgs Measurements



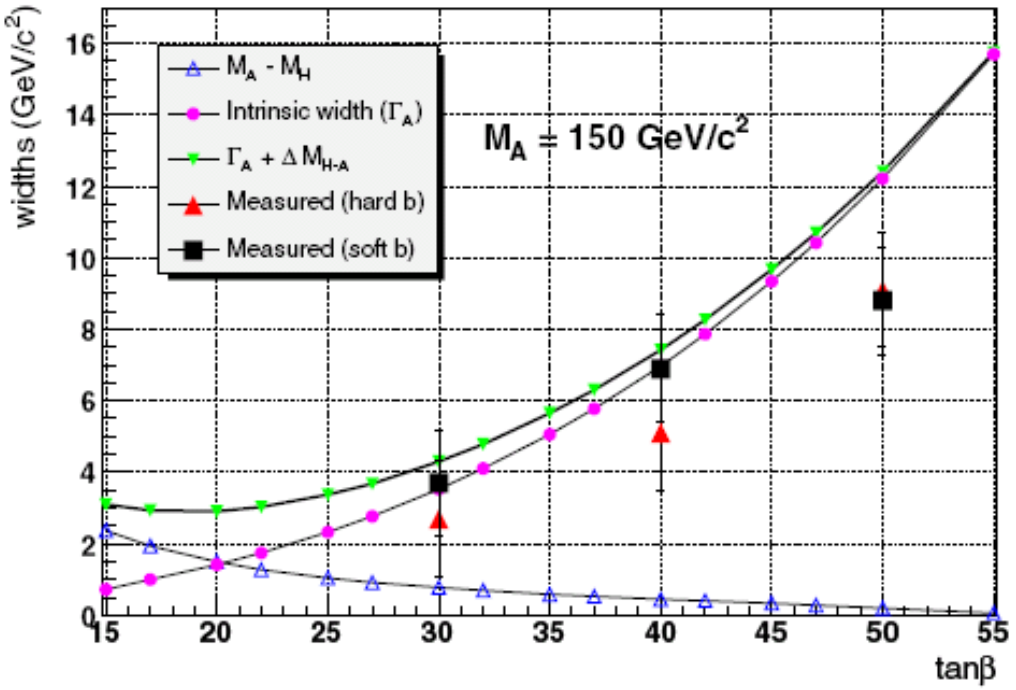


Ex: Measurement of tan β

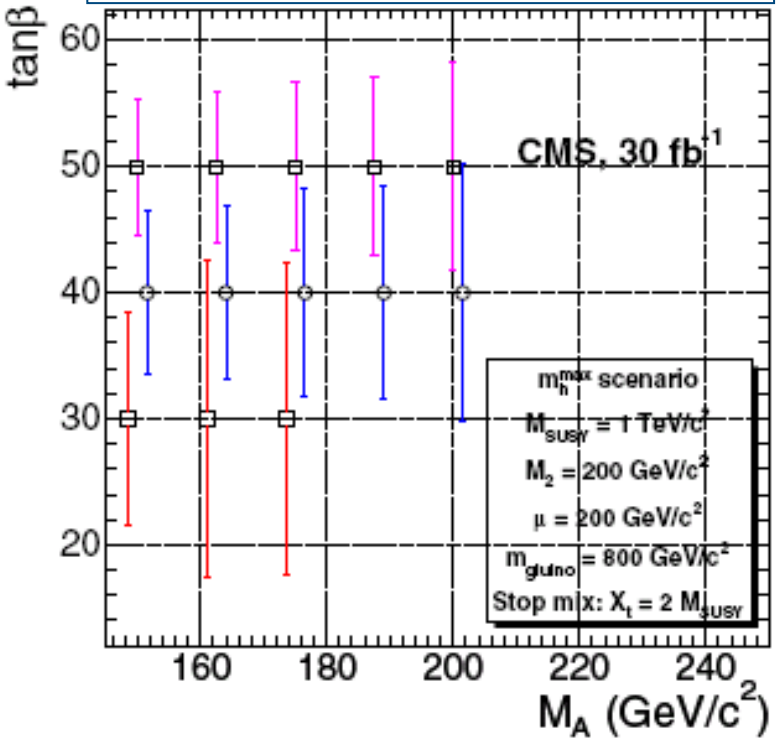
Associated $b\bar{b}H$ production with $H \to \mu^+\mu^-$

Direct measurement of the Higgs boson width, Γ(H/A), sensitive to tan β value

MSSM relation between the Higgs boson width and tan β is exploited in the m_h-max scenario



Uncertainty on tan β measurement from the Higgs width measurement



For **large tan β** values, the A and H mass tends to overlap: $\Delta_{A\text{-}H} = M_A - M_H \Rightarrow 0$ (blue points)
Measured values (black and red) to be compared to $\Gamma_A + \Delta_{A\text{-}H}$ values (green points)

Three set of points for three tan β values as a function of the A mass

Ex: Measurement of Higgs Spin and CP

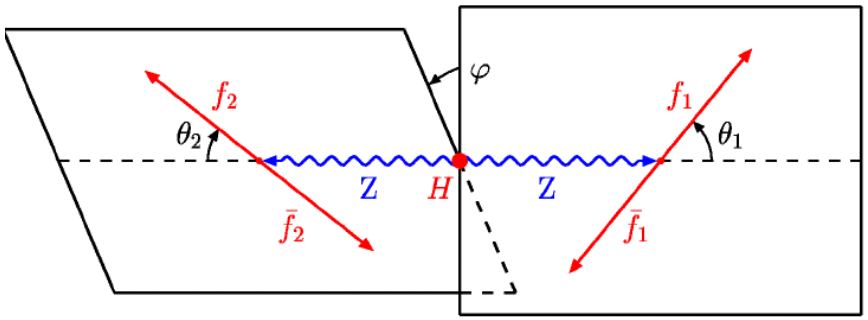
Spin:

- Spin 1 rouled out if H→γγ or gg→H is observed
- **Angular correlation of decay products in H→ZZ**
- Testing for spin 0 in WBF H→WW→lνlν

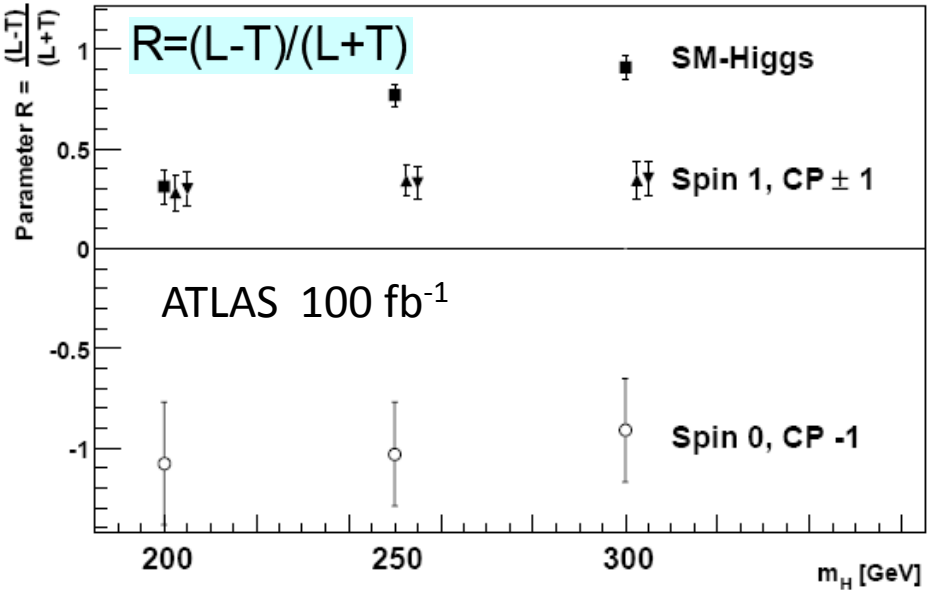
CP :

- Angular correlations of decay products in gg→H→ZZ→4l
- Angular correlations of tagging jets in WBF H→WW and H→ττ
- Possible : angular correlations in ttH
- Possible : angular/momentum correlations of τ decay products in H→ττ

Ex.: Determine Spin/CP from angular correlation of decay products in H→ZZ



polar angle θ of leptons in Z rest frame



Polar angle distribution: $G(\theta)=T^*(1+\cos^2\theta)+L^*\sin^2\theta$

$R=(L-T)/(L+T)$

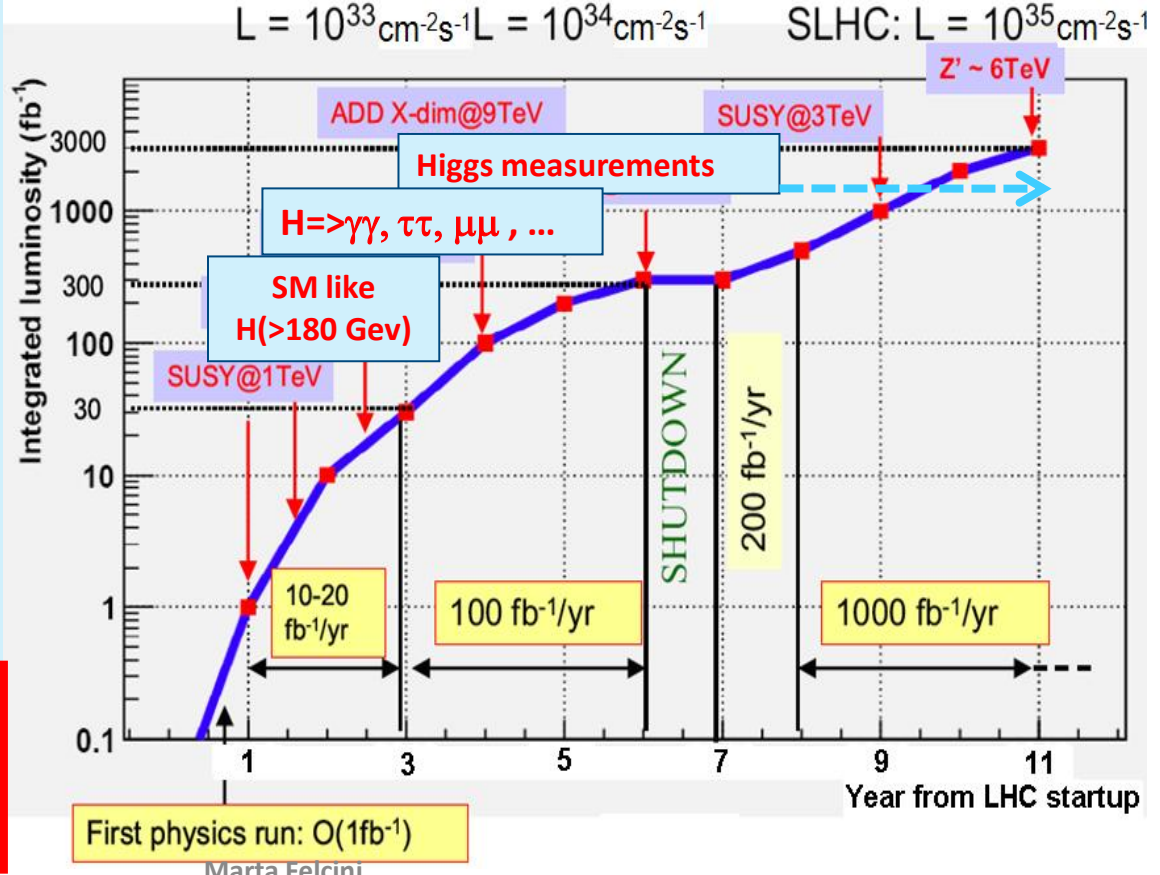
Conclusions

Many BSM models and Higgs signatures have been studied by the LHC collaborations
=> models particularly helpful in setting up search strategies (trigger, data driven background estimation methods, analysis tools,…)

Determined experimental discovery reach, in SUSY (MSSM and extensions) and non SUSY models => BSM Higgs-like signals observed and early measured with less then 1 fb^{-1} to few ten fb^{-1}

Detailed properties will be scrutinized to fully establish the nature of the newly discovered particles
⇒Measurement strategies developed
⇒good precision may need high stat.s (ultimate LHC and SLHC) …

More information (e.g. from other discoveries and measurements) may be available - we will combine all (Higgs and non Higgs) measurements to sharpen our understanding…



We are ready for… discoveries…

References

ATLAS and CMS "Expected Performance" Books

ATLAS:
Expected Performance **of the** ATLAS **Experiment - Detector, Trigger and Physics.**
By The ATLAS Collaboration (G. Aad *et al.*). Jan 2009. 1852pp.
e-Print: **arXiv:0901.0512** [hep-ex]; CERN-OPEN-2008-020
http://cdsweb.cern.ch/record/1125884?ln=en
and References therein

CMS:
CMS technical design report, volume II: Physics performance.
By The CMS Collaboration (G.L. Bayatian *et al.*). CERN-LHCC-2006-021, CMS-TDR-008-2, 2007.
Published in **J.Phys.G34:995-1579,2007**
and References therein