Atlas: Il gruppo e la Fisica

Attivita' Higgs

G. Carlino, F. Cirotto, F. Conventi, L. Merola, L. Paolillo, E. Rossi, A. Sanchez. G. Zurzolo

A. Giannini, C. Calamita e M. D'Errico (tesi triennali fine 2014-inizio 2015)

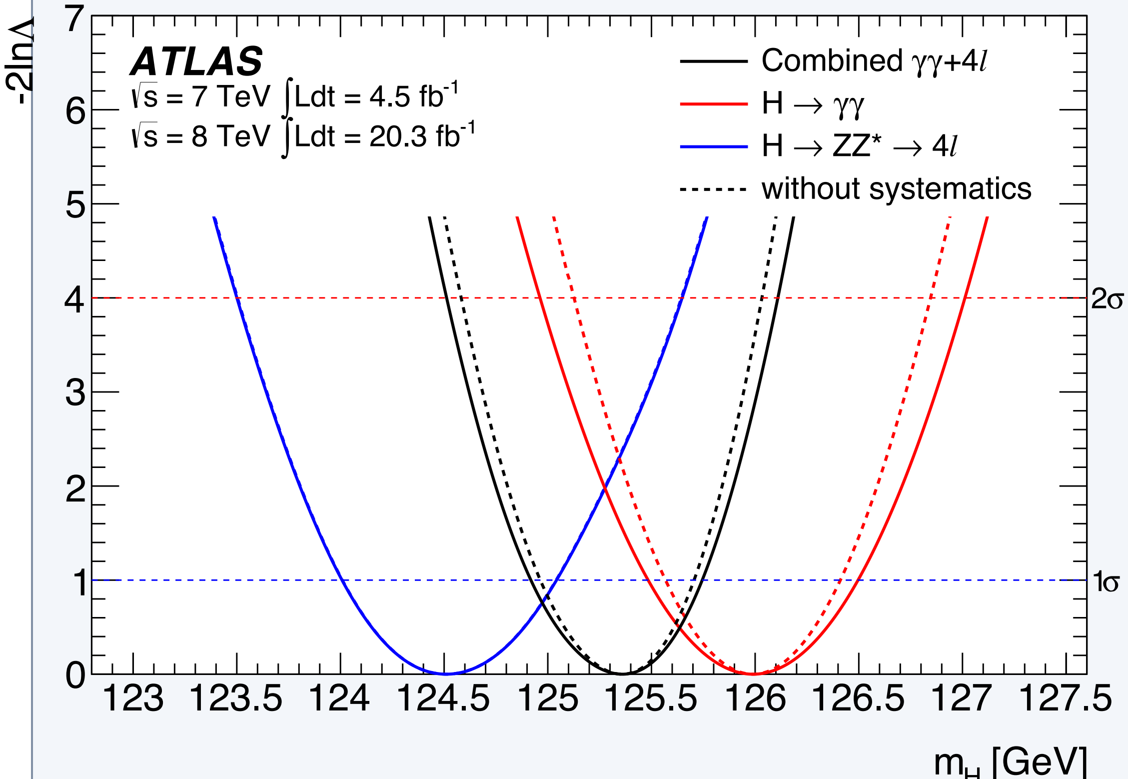
<u>Attivita' Run-I:</u>

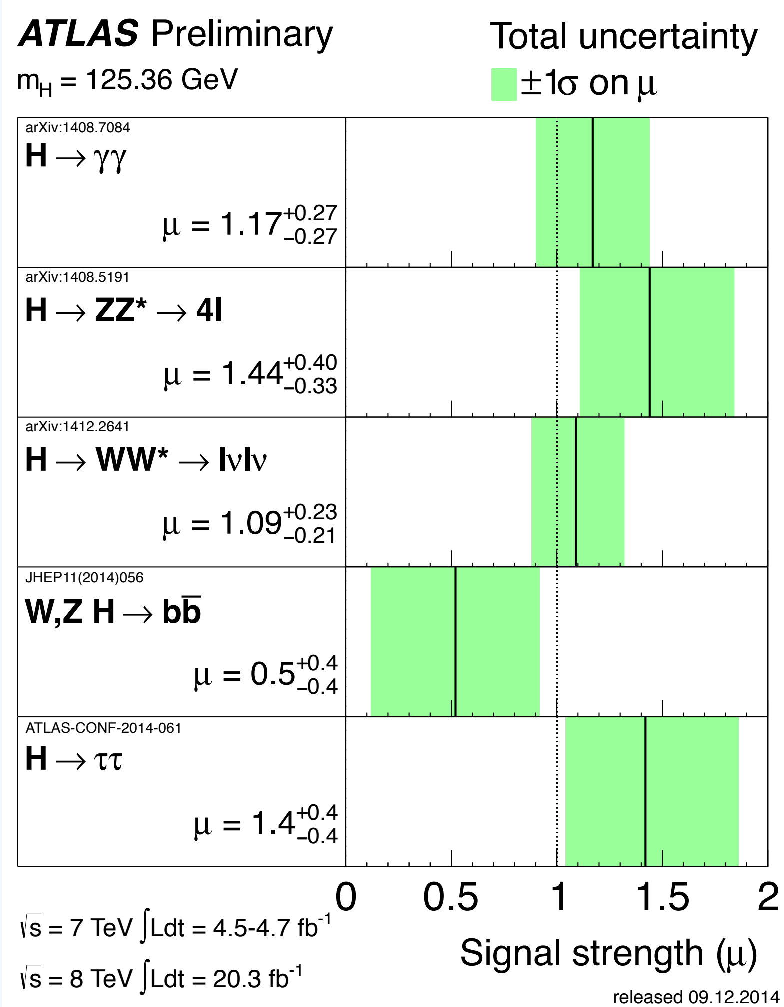
- H→ZZ→4l (analisi spin-CP MELA, fixed hypo, HSG2)
  - Analisi e' stata approvata scorsa settimana, nota pronta (https://cds.cern.ch/record/1648266)
  - Articolo in preparazione (https://cds.cern.ch/record/1974141)
- H→ZZ→qqll (high mass, 2HDM, HSG2)
  - Analisi approvata
  - Nota pronta (https://cds.cern.ch/record/1693159)
- Combinazione dei risultati analisi spin-CP (HSG7)
  - To be ready for Moriond 2015
- Prospettive per il Run-II LHC

Higgs results

Combined mass measurement

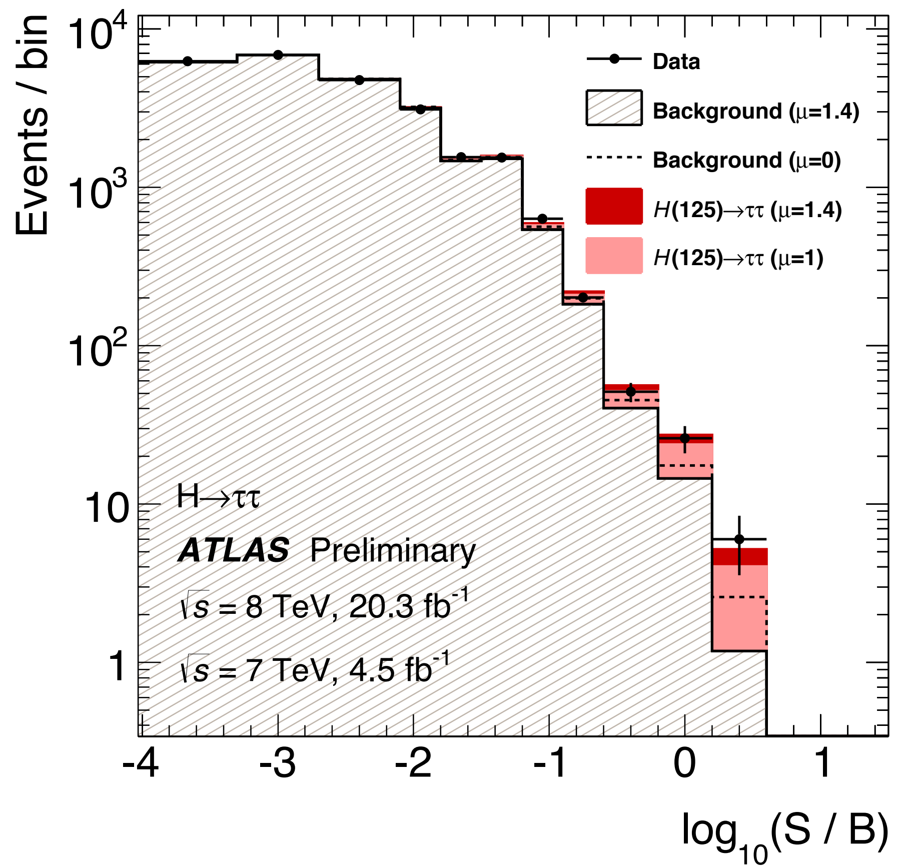
$$m_H = 125.36 \pm 0.37\,(\text{stat}) \pm 0.18\,(\text{syst})\ \text{GeV}$$



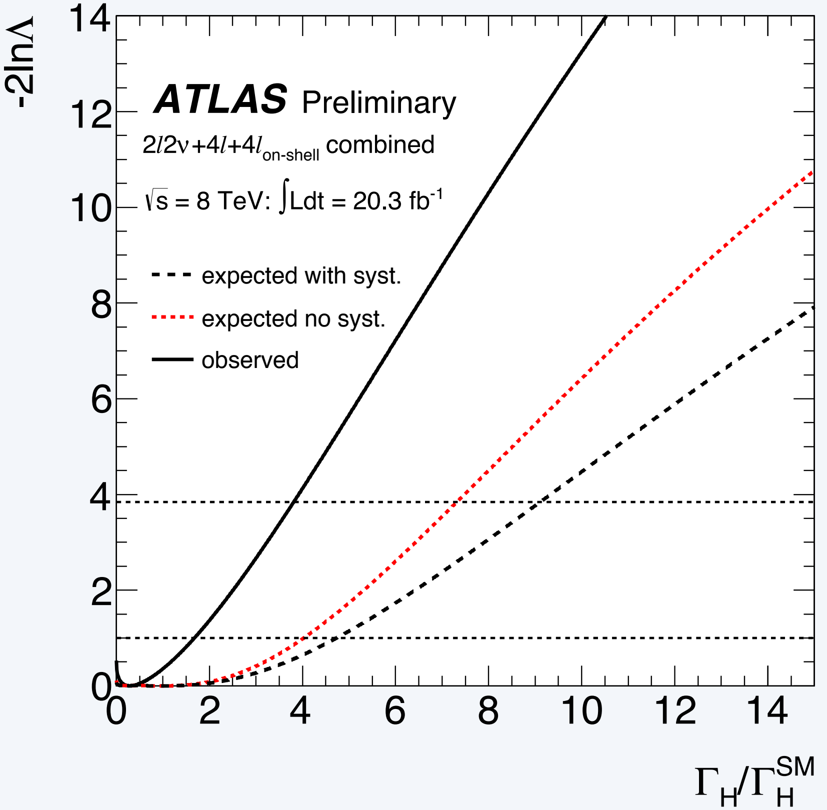


Higgs results

H→ττ ATLAS-CONF-2014-061
(observed significance = 4.5 σ)



Higgs width (via off-shell effects)
Γ_H < 24 MeV ATLAS-CONF-2014-042

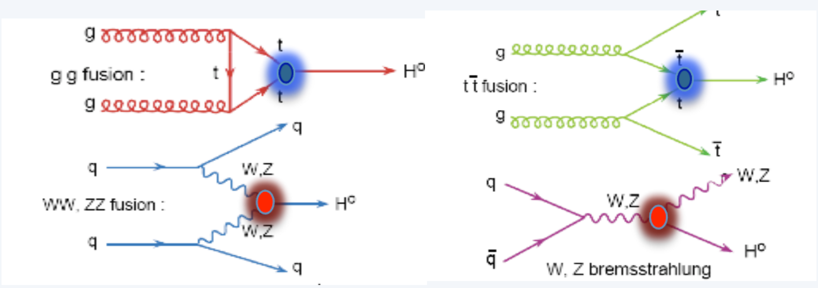


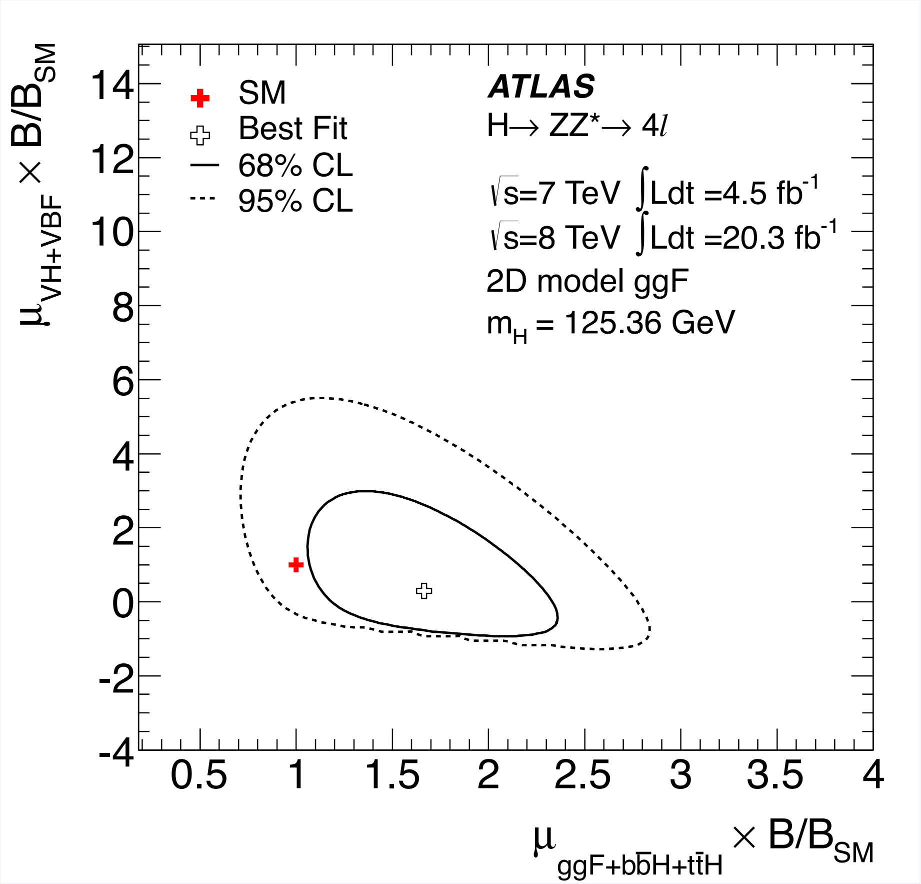
SM Higgs couplings

- I couplings per lo SM Higgs sono di 2 tipi:
  - **"Gauge" couplings (to bosons)**
  - **Yukawa couplings (to fermions)**

E' possibile studiare possibili deviazioni dalle previsioni dello SM utilizzando le diverse modalità di decadimento:

μ(VBF+VH) / μ(ggF+ttH)





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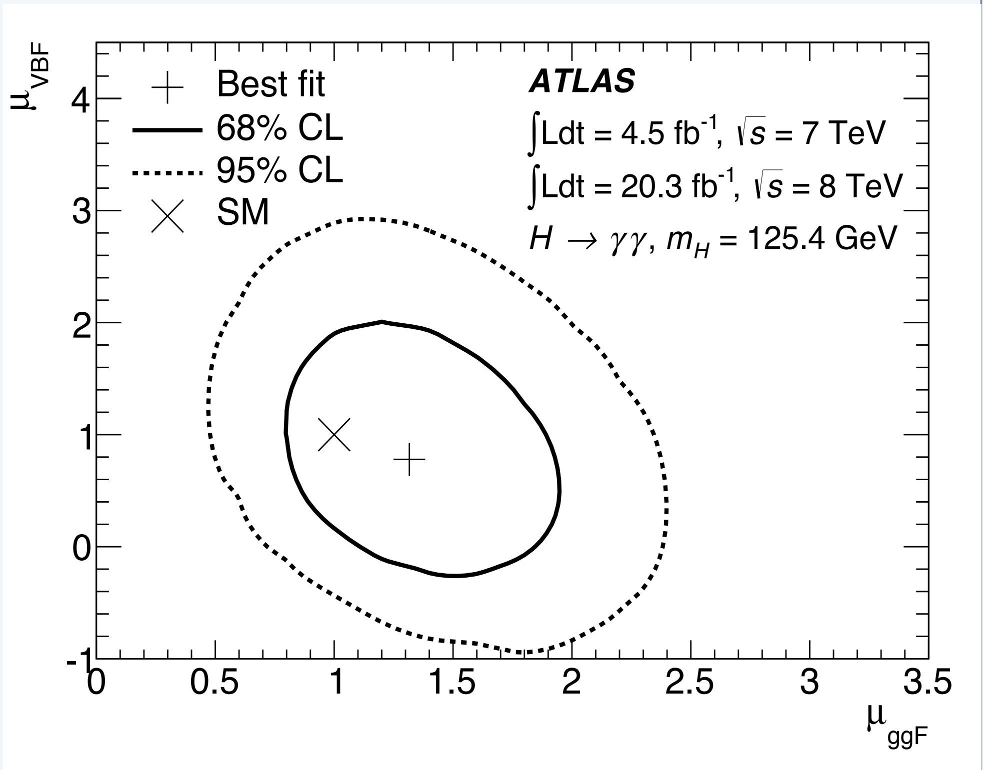
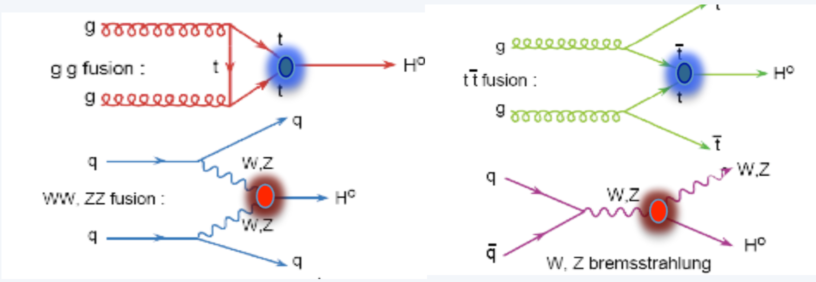
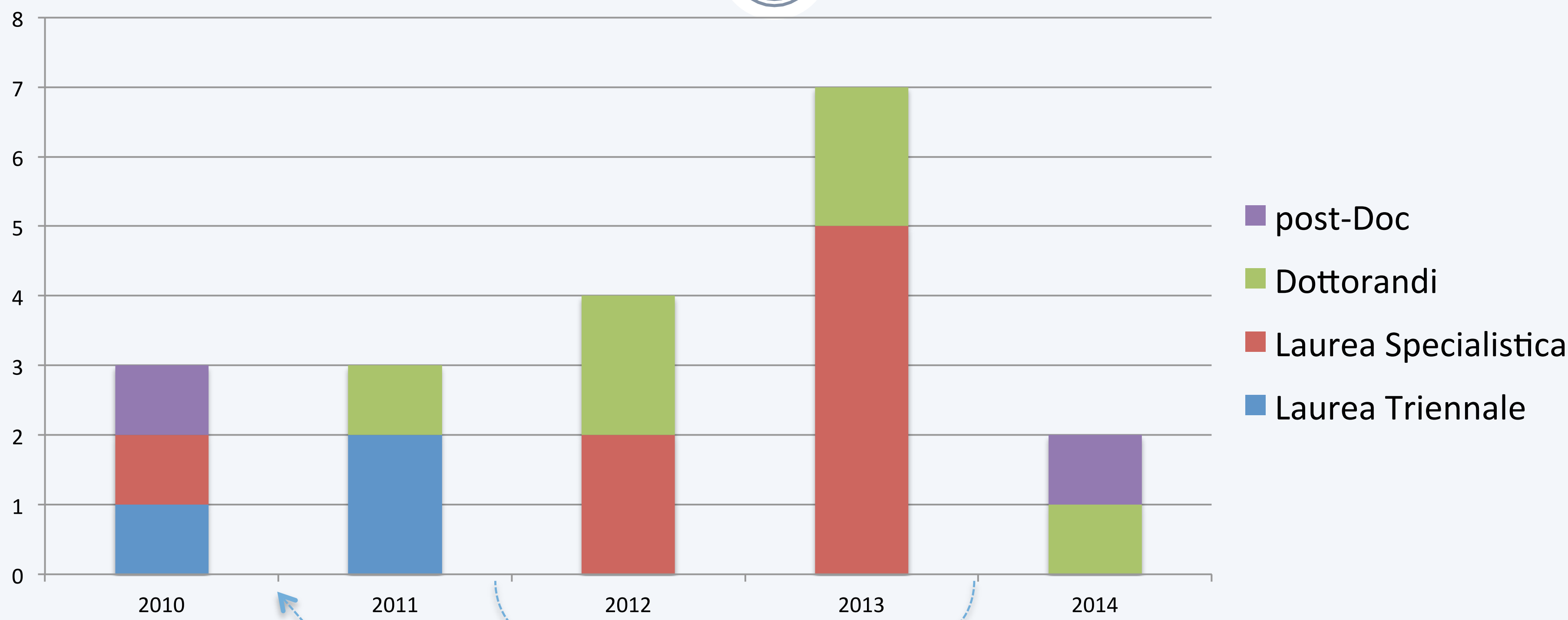




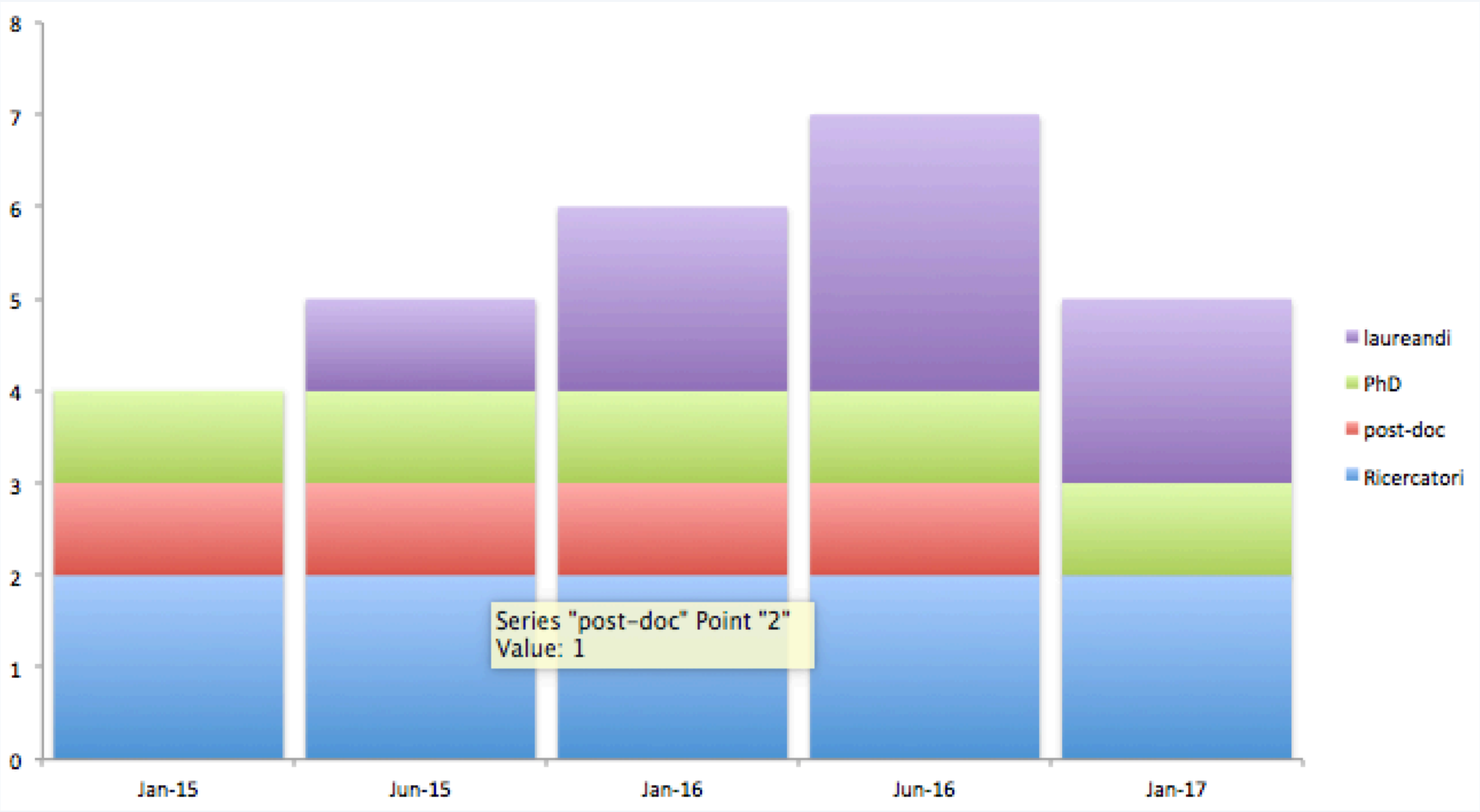
Analisi: In&Out 2013



J/ψ→μμ and B-Physics

Higgs→ZZ→4l: Discovery and Spin-CP
Higgs→ZZ→qqll: High mass resonance
B-Physics

Analisi: In&Out 2014



Analisi Higgs

- **H→ZZ→4l spin-CP**

test d'ipotesi, MEGA fit: Francesco C., Elvira, Francesco Cirotto, Arturo

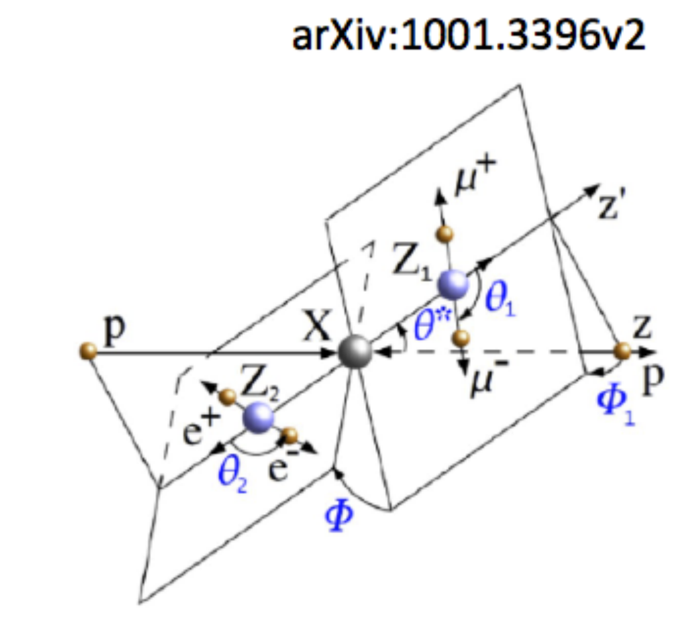
- Elvira co-editor nota 4leptoni spin-CP

- **2HDM (BSM) and SM H→ZZ→qqll**
- Francesco C., Arturo S., Giovanni Z., Lorena P.

H→ZZ→4l

Modifiche rilevanti per spin-CP nella selezione H→ZZ→4l:

- Electron likelihood-ID (reduces by 50% Z+jets background)
- Cluster-track combination to improve electron resolution at low pT
- L'analisi di fixed Hypothesis e' stata approvata
- L'analisi della struttura tensoriale HZZ e' "unblinded"



<u>1 articolo in preparazione</u>

- Spin-CP (Elvira co-editor)

<u>4 articoli pubblicati</u>

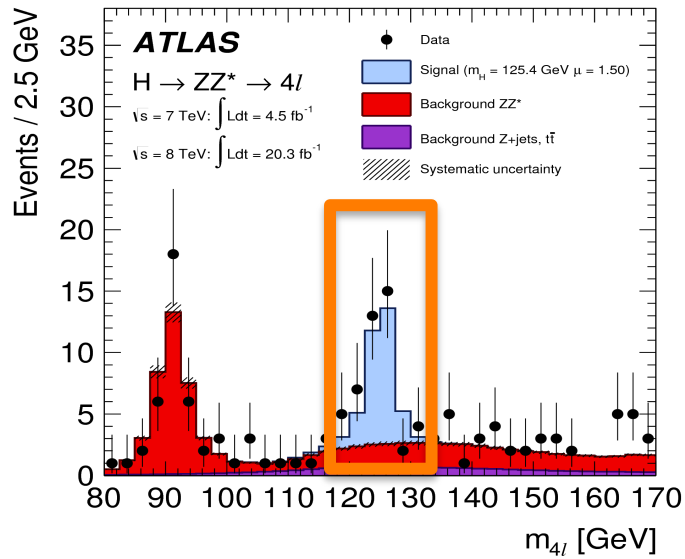
- Massa (combined con gamma-gamma)
- Couplings
- Fiducial and differential x-section
- High mass searches

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults

H→ZZ→4l: Spin-CP analysis introduction

H→ZZ(*)→4l is an ideal channel for spin-CP studies:

- Complete reconstruction of the event topology and high S/B ratio
- Several observables depending on spin-CP available



Event selection:

- Standard cut-based selection of the mass analysis
- Signal produced at 125.5 GeV
- Four categories final states - 4mu, 2e2mu, 2mu2e, 4e
- signal region: 115 GeV < m4l < 130 GeV

For fixed spin-CP hypothesis separation, we studied the following hypotheses:

- Spin-0, generated using Powheg +JHU: Standard Model (0^+), pseudo-scalar (0^-), scalar with higher-dimension operators (0^+_h)
- Spin-2, generated using Madgraph5: graviton-like tensor with minimal couplings (2^+_m) and samples with non universal couplings

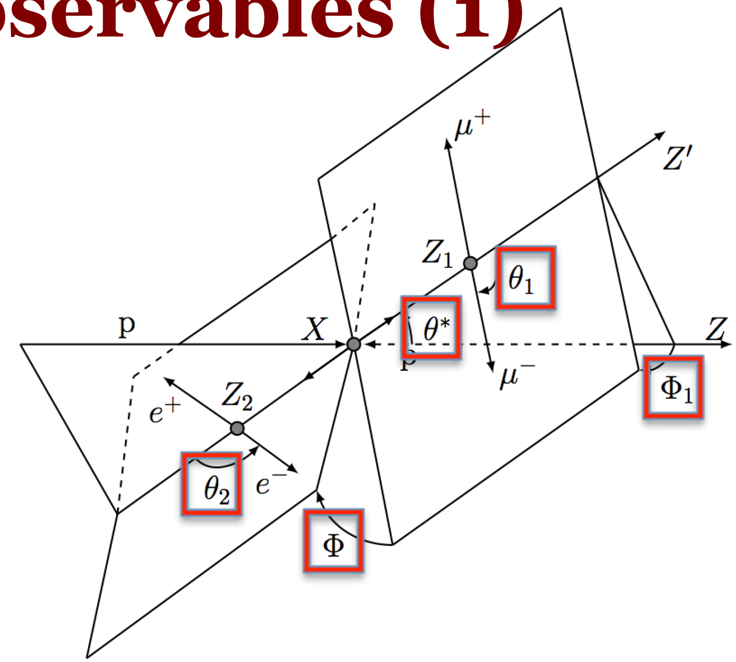
For Measurement of the HZZ tensor structure

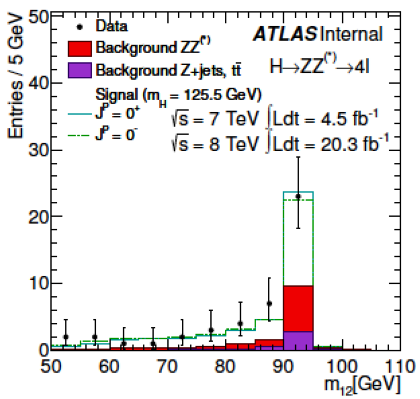
- Analyses allows coupling constants to vary; mixing pure states
- Parametrize fits in coupling ratios:g2/g1 and g4/g1
- Possible to translate to cross section fractions fgi

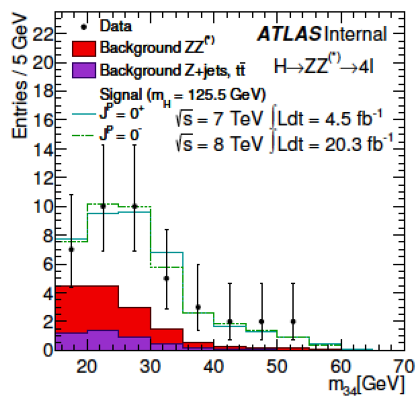
H→ZZ→4l: Spin–Parity Observables (1)

Sensitive variables

- **Intermediate boson masses: m_{12}, m_{34}**
- **production angles: Z_1 production angle θ^* and decay plane angle (Φ_1)**
- **Helicity angles: angle between the Z_1 and Z_2 decay planes (Φ) and decay angles of negative leptons (θ_1,θ_2)**

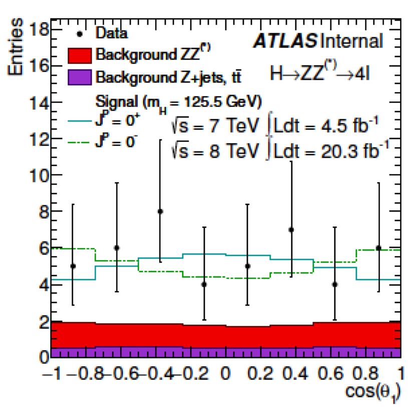


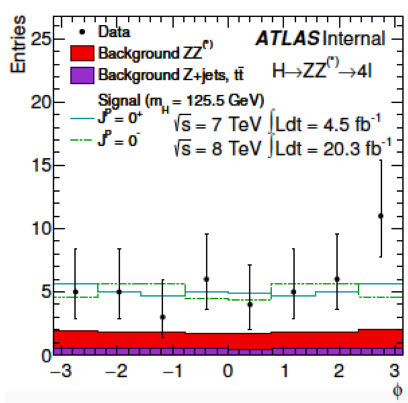


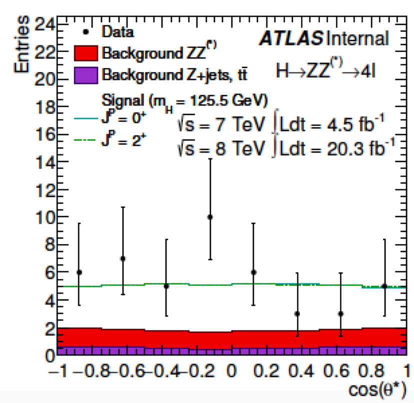


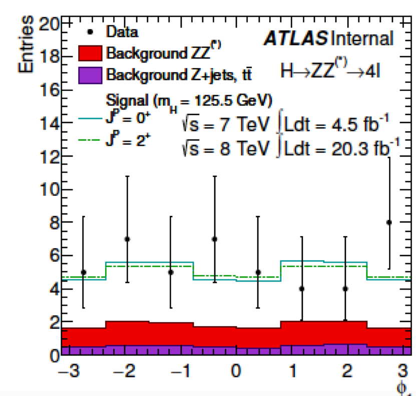
Hypothesis test 7 + 8 TeV: 0^+ / 0^-

Unico canale in grado di studiare il caso di spin 0-





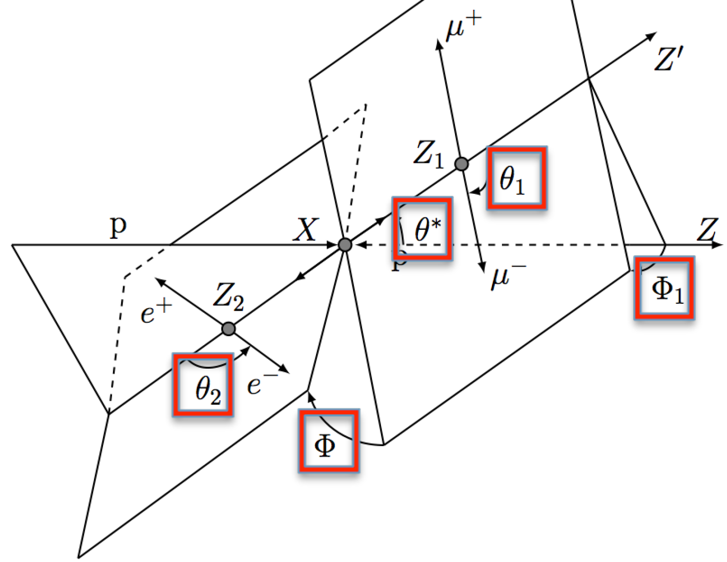


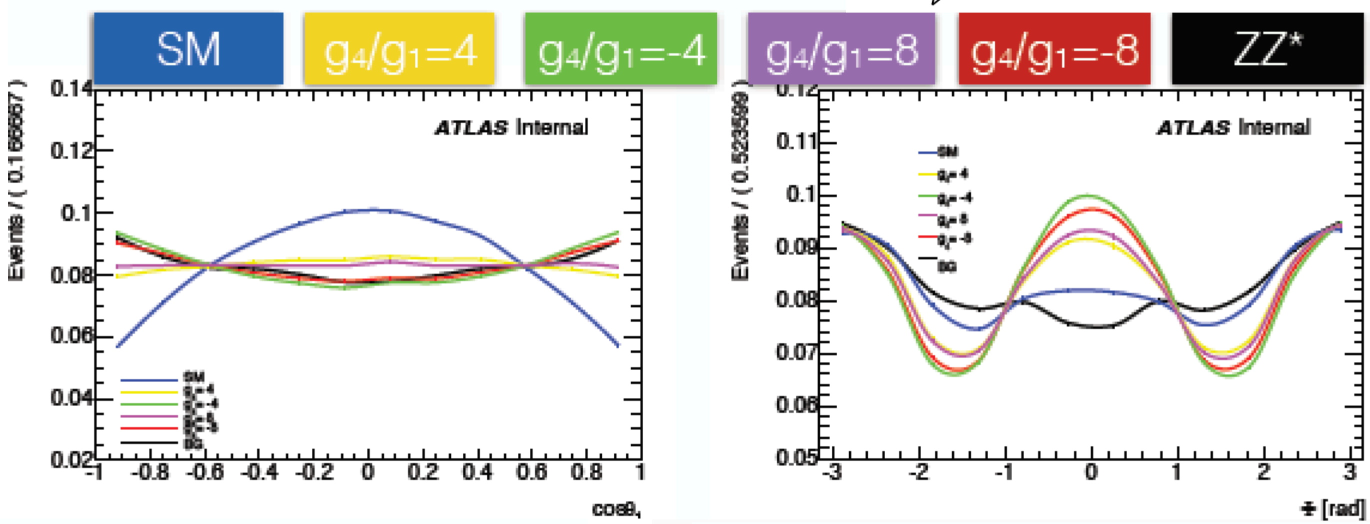


H→ZZ→4l: Spin–Parity Observables (2)

Sensitive variables

- Intermediate boson masses: m_{12}, m_{34}
- production angles: Z_1production angle θ^* and decay plane angle (Φ_1)
- Helicity angles: angle between the Z_1 and Z_2 decay planes (Φ) and decay angles of negative leptons (θ_1,θ_2)



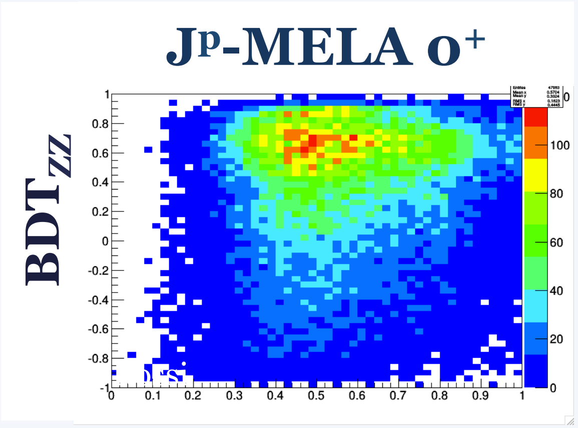


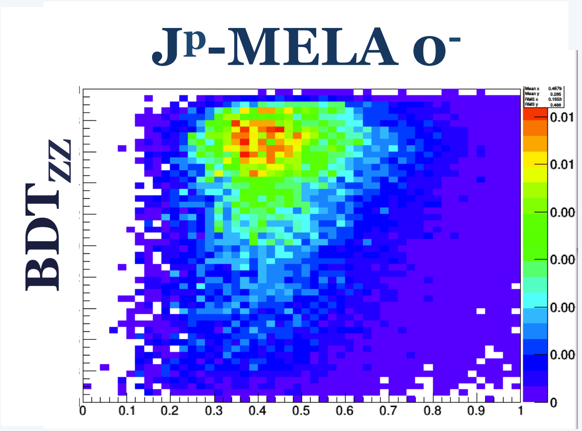
The parameters related to decays are sensitive to the Higgs parity admixture

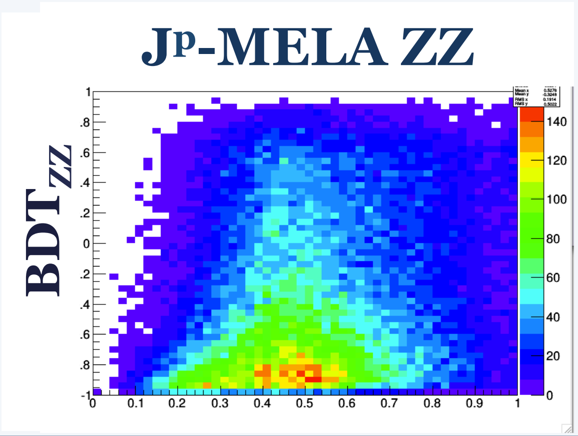
Production angles, (or $p_{T\text{-}4l}$, η_{4l}) and m_{4l} used to reject backgrounds

H→ZZ→4l :Fixed Hypothesis Analyses overview

- ***MELA approach (Napoli and RomeI):***
  - ***Signal to ZZ background discrimination:*** use of a Boosted Decision Tree (BDT_{ZZ}) discriminant has been optimized to separate signal/background (trained on η_{4l}, pt_{4l}, KD → the same used for the Mass analysis) and used to define 8 categories
  - ***J^P-MELA Discriminant*** based on full theoretical calculation of the Matrix Element is used to separate different spin/parity states
- ***BDT approach:***
  - **Signal to ZZ background discrimination:** use of a Boosted Decision Tree discriminant (BDT_{ZZ}) has been optimized to separate signal/background trained on m_{4l}, η_{4l}, pt_{4l}, KD
  - ***A spin-CP BDT (BDT_{JP})*** trained for each spin-parity hypothesis pair using fully simulated signal MC to separate different spin/parity states







H→ZZ→4l spin-CP: List of systematics uncertainties for fixed spin hypothesis analyses

Common systematic uncertaities (same as in the Mass analysis):

- Normalization systematics
  - Luminosity uncertainty
  - ZZ and Higgs Signal QCD scale PDF+α_S uncertainties
  - Branching ratio H → ZZ uncertainties
- Shape systematics (Normalization uncertainties negligible)
  - Electron & photon energy scale and resolution uncertainties
  - Muon momentum scale and resolution uncertainties

- Normalization and Shape systematics
  - **Uncertainty of Higgs mass in MC modeling:** we shift the 4 leptons mass (m4l_constrained) by +/-0.5 GeV to estimate the shape variations and we use a ~5% to take into account the yields normalization changes
  - Trigger efficiency
  - Muon/electron reco & ID efficiencies
  - Electron reco & ID, and cut efficiencies
  - Uncertainty on Reducible background

MELA specific systematics:

- Shape systematic: uncertainty on the wrong-pair fraction (fWP): we estimate the error on the wrong-pair fraction comparing PowHeg and JHU samples and to be conservative we took the highest difference as variation (10%)

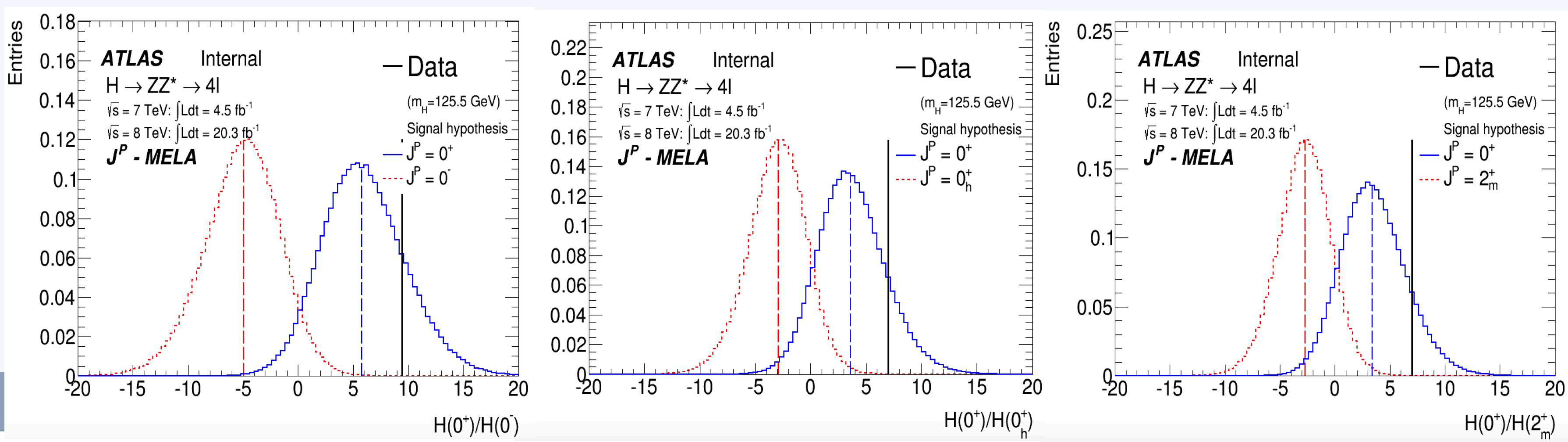
BDT specific systematics:

- smoothing uncertainty to signal, ZZ bkg and reducible bkg shape (parameter variations nominal value =0.35, variation(0.3,0.4), using 3 nuisance parameters)

Expected results at 7+8 TeV

7 + 8 TeV		0^-	0^+_h	2^+_m
expected significance: Asimov generated with μ=1	MELA approach	2.57 ± 0.02	2.06 ± 0.01	1.99 ± 0.01
expected significance: profiling to the data	MELA approach	3.38 ± 0.02	2.63 ± 0.01	2.59 ± 0.01

Signal strength (μ) from fitting the data	0^+ (0^-)	0^+ (0^+_h)	0^+ (2^+_m)
MELA approach	1.58 ± 0.39 (1.47 ± 0.36)	1.61 ± 0.37 (1.46 ± 0.33)	1.64 ± 0.37 (1.43 ± 0.35)



H→ZZ→4l spin-CP: Test d'ipotesi

- **Primi risultati su Run-I (Phys. Lett. B 726 (2013), pp. 120-144)**
- **Risultati finali su Run-I → Analisi approvata ma risultati non ancora pubblici**
- **Articolo in stato avanzato di preparazione**

Studio della struttura tensoriale del vertice H→ZZ

The goal of the analysis is to probe BSM contributions to HZZ tensor structure:

- **Hypothesis tests indicate that pure CP-odd state is excluded**
- **Similarly the Standard Model is favoured over the pure 0^{+}_{h} state**
- **The observed resonance may however not be an eigenstate but rather a mix of pure states**

Analysis Methods

Nine-dimensional Matrix Element Method* *(Napoli, RomeI and ANL & Chicago):

- Use analytical matrix element at parton level to describe all final state observables as function of coupling ratios
- Correct description for detector effects using morphed MC templates
- Angular distributions and masses are used directly as observables

Matrix Element Observable fit

- Use Optimal Observables to study tensor structure
- Matrix element re-weighting gives observable distributions with full detector simulation for points of g2/g1 and g4/g1
- Use pdf morphing to arrive at a continuous description

Studio della struttura tensoriale del vertice H→ZZ

- Model-independent approach to extract the resonance spin, parity and couplings
- Explore Higgs properties using decay Kinematics angular analysis of decay products

Scattering amplitude describing the interaction of generic Higgs-like resonance of spin zero with the two Z bosons:

$$A(X \to V_1 V_2) = v^{-1}\left[\underbrace{g_1 M_V^2 \varepsilon_1^* \varepsilon_2^* + g_2 f_{\nu\mu}^{*(1)} f^{*(2)\nu\mu}}_{\text{CP-EVEN}} + \underbrace{g_4 f_{\nu\mu}^{*(1)} \tilde{f}^{*(2)\nu\mu}}_{\text{CP-ODD}}\right]$$

J^P	Production	Decay configuration	
0^+	gg→X	$g_1=1$ $g_2=g_4=0$	Standard Model Higgs
0^+_h	gg→X	$g_1=0$ $g_2=1$ $g_4=0$	Scalar with higher-dimension operators
0^-	gg→X	$g_1=g_2=0$ $g_4=1$	Pseudo-scalar

- **g_i's are effective coupling constants**
- Related to spin-0 models tested in the fixed hypothesis tests
- Analyses allows coupling constants to vary; mixing pure states
- **Parametrize fits in coupling ratios: g2/g1 and g4/g1**
- Possible to translate to cross section fractions fgi
- Note: It was previously demonstrated that "g3"could be absorbed in g2

Nine-dimensional Matrix Element Method
(Napoli, RomeI and ANL & Chicago)

- Shape model is directly based on nine observables:

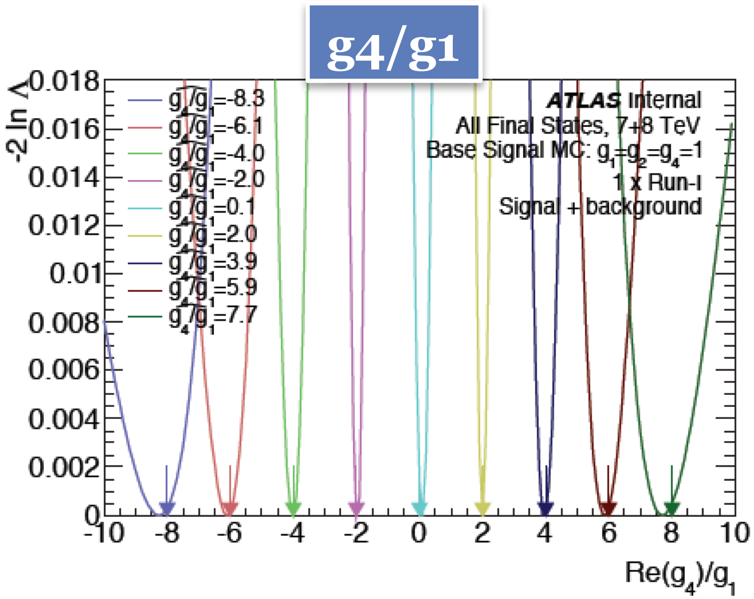
$$\bar{x} = (m_{4l},\ p_{T,4l},\ \eta_{4l},\ \cos\theta*,\ \cos\theta_1,\ \cos\theta_2,\ \phi,\ m_{12},\ m_{34})$$

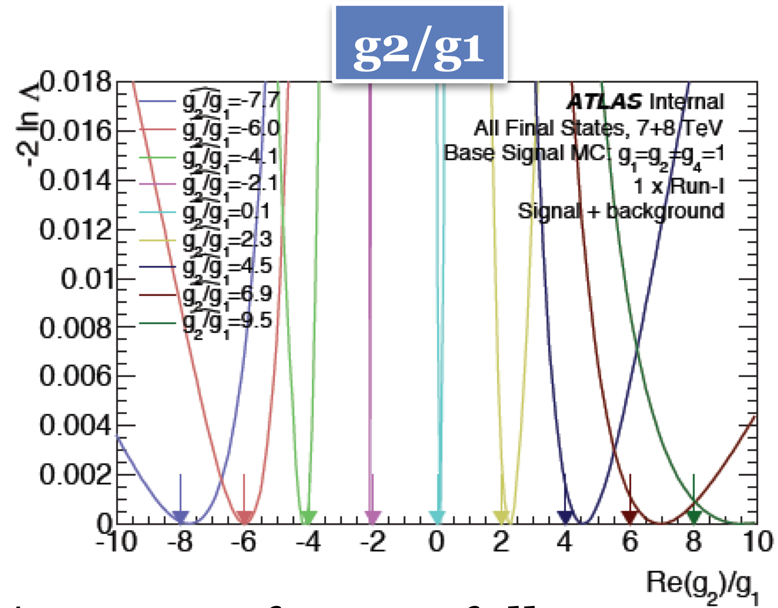
- **Signal: has four components that altogether describe the 9 observables**
  - m4l, cos(**θ***) → binned 1D templates from MC, smoothed by linearly interpolation between bin centres
  - (pT,4l , **η**4l) → binned 2D template from MC
  - (cos(**θ**1), cos(**θ**2), **Φ**, m12, m34) → Analytical prediction from ME, corrected for detector acceptance, efficiency, resolution using 2- or 3-D templates from MC
  - Detector corrections for the 5D piece are re-derived for different values of g2/g1, g4/g1 before a probability model is build by linear morphing

- **ZZ* and reducible backgrounds: each have 6 components to cover the 9 observables**
  - m4l → smooth Kernel Density Estimator
  - (m12, m34), (pT,4l , **η**4l), cos(**θ***), (cos(**θ**1), cos(**θ**2)), **Φ** → Binned MC templates

H→ZZ tensorial structure: Closure tests

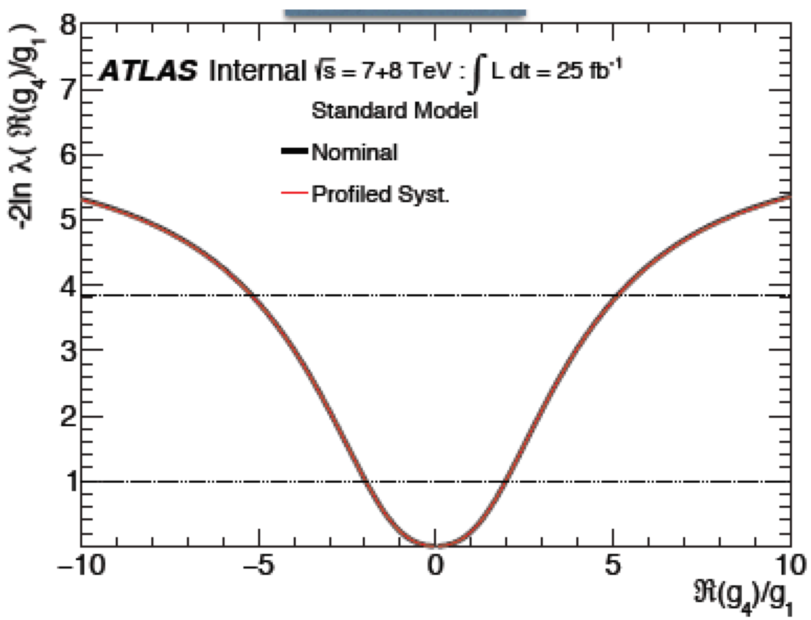
Likelihood scans for different hypothesised data models

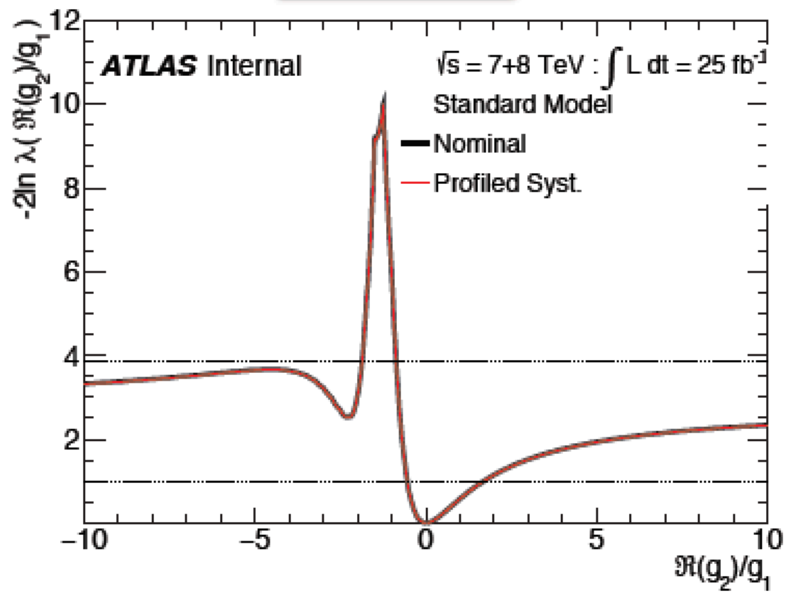




- Asimov data created in g2/g1 and g4/g1 steps of 2 over full range (-10, 10)
- Demonstrate that fits locate minima precisely
- Asimov samples are created from statistically Independent MC

Expected sensitivity with influential systematics: g4/g1 and g2/g1 scan





g4/g1 – Excluded @ 95CL

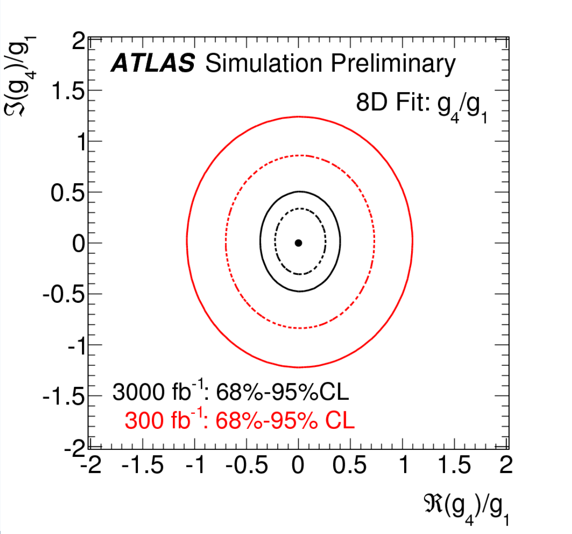
ME-Obs - No Syst	(-∞, -5.21] ∪ [5.16, ∞)
ME-Obs - Prof. Syst	(-∞, -5.21] ∪ [5.19, ∞)

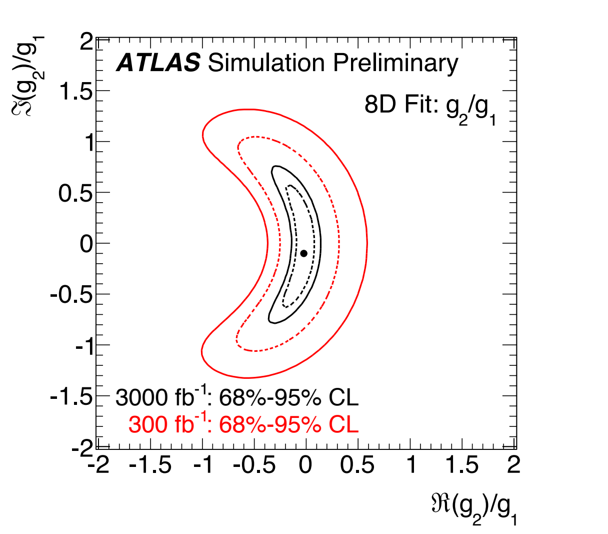
g2/g1 – Excluded @ 95CL

ME-Obs - No Syst	[-1.86, -0.86]
ME-Obs - Prof. Syst	[-1.86, -0.86]

Studio della struttura tensoriale del vertice H→ZZ

- Primi risultati su g_2 e g_4 con i dati di Run-I (sensitivita’ limitata) → Analisi in fase di approvazione
- Prospettive per Run-II e oltre (gia’ inlcuse nelle note ECFA di Ottobre 2013)





ATL-PHYS-PUB-2013-013

8D fit		
Luminosity	f_{g4}	f_{g2}
300 fb^{-1}	0.2	0.29
3000fb^{-1}	0.06	0.12

H→ZZ→qqll

- Ricerca ad alta massa (200-1000 GeV)
- Risultati e limiti per SM Higgs, EWS Higgs-like resonance, BSM Higgs (2HDM)
- Analisi suddivisa per categorie:
  - ggF and VBF
  - 0,1,2 btag jets
- Merged jets category (for M_H>700 GeV)

H→ZZ→qqll

The H → ZZ→ llqq channel is one of the most important search channels for heavy resonances

fully reconstructable final state
high cross section (~20 times higher than the 4l - but much more background)
similar sensitivities for mH ≳ 300 GeV

Main backgrounds

- Z + jets: very similar signature, cross section ~10000 times higher (wrt/ SM Higgs)
- Top
- QCD: can be strongly reduced thanks to leptons
- diboson: is actually the only irreducible background but turns out to be less important than other backgrounds

H→ZZ→qqll Boosted regime

- For $m_H \gtrsim 700$ GeV the two Z's have a relevant boost, giving rise to more and more collimated final state objects
- Since jets have a finite size, they can overlap thus reducing the efficiency of the standard (resolved) selection
- We look for massive anti-kt R=0.4 jets in events failing the standard selection
  - 2 leptons + 1 jet
  - 2 leptons + ≥2 jets, $m_{jj} < 50$ GeV or $m_{jj} > 150$ GeV

Exp. limit on σ/σ_{SM} - no systs.

m	resolved only	resolved +merged	improvement (%)
700	0.390	0.389	0.3
800	0.520	0.508	2.3
900	0.837	0.736	12.1
1000	1.891	1.103	41.7

SM Higgs Results Run-I

Mass, spin, CP, and flavor

- mH ~125.5 ± 0.5 GeV
- looks like 0^+ as in SM, though only marginally favored over some alternatives
- fraction of CP odd coupling in ZZ is < ~50%
- no FCNC seen, BR($t \to Hc$) ≲ 1%

Production:

- discovery established ggF production & now VBF production also firmly established
- evidence for VH ~2σ
- ttH: not yet, look out for Run-II

Decays:

- γγ, WW, ZZ >> 5σ
- ττ at ~4σ (lack of μμ as expected ⇒ not a flavor-universal coupling)
- bb ~2σ
- BR(H→invisible/undetected) < ~60%
- total width < ~4.2x SM

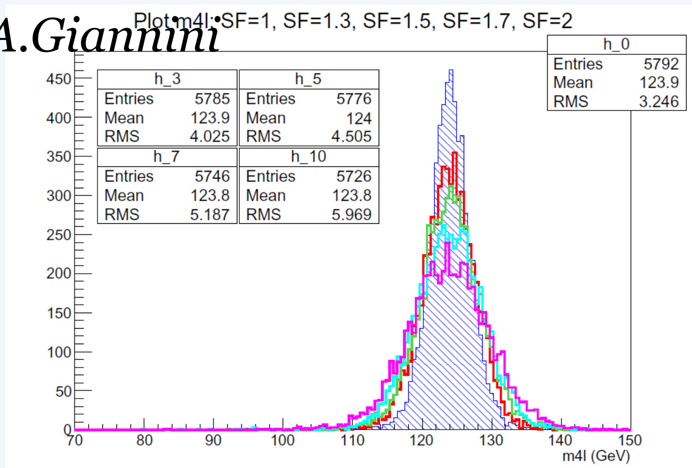
Overall coupling pattern:

- consistent with the SM, though ~2σ tension seen

Attivita tesi triennali

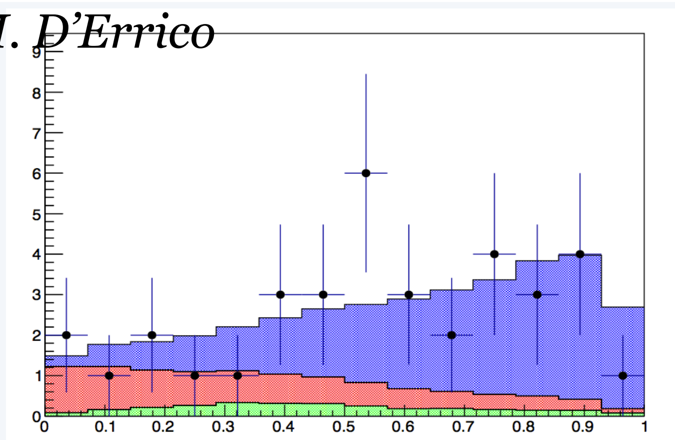
- Atlas "Toy analysis" using Run-I data sample

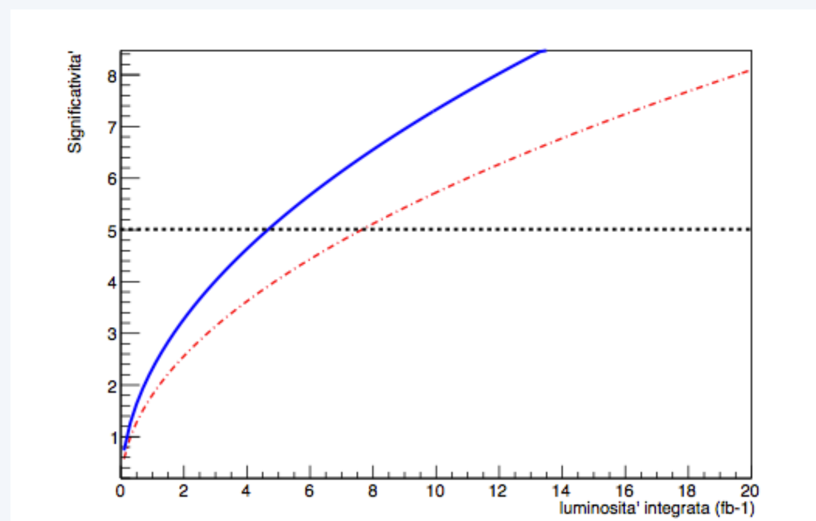
A.Giannini



	Risoluzione nominale (≈5%)	Risoluzione 2 · nominale (≈10%)
Eventi Higgs	8.9	7.2
Separazione $0^+/0^-$	1.908	1.66

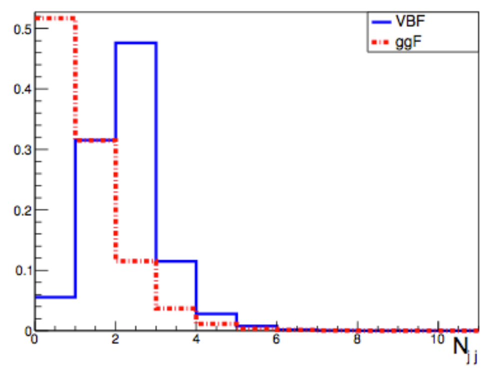
M. D'Errico

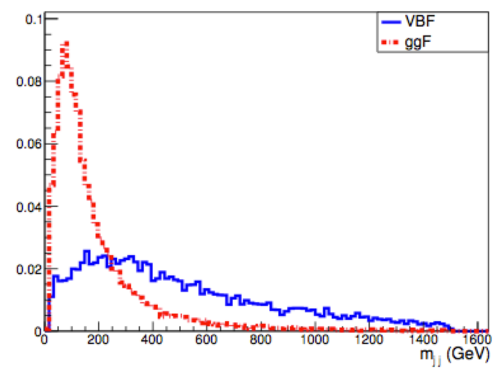


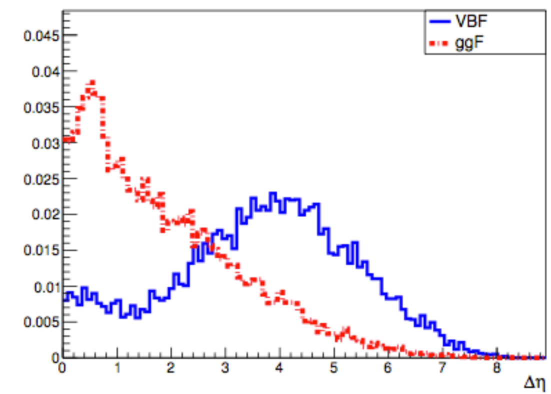


Attivita tesi triennali

C. Calamita



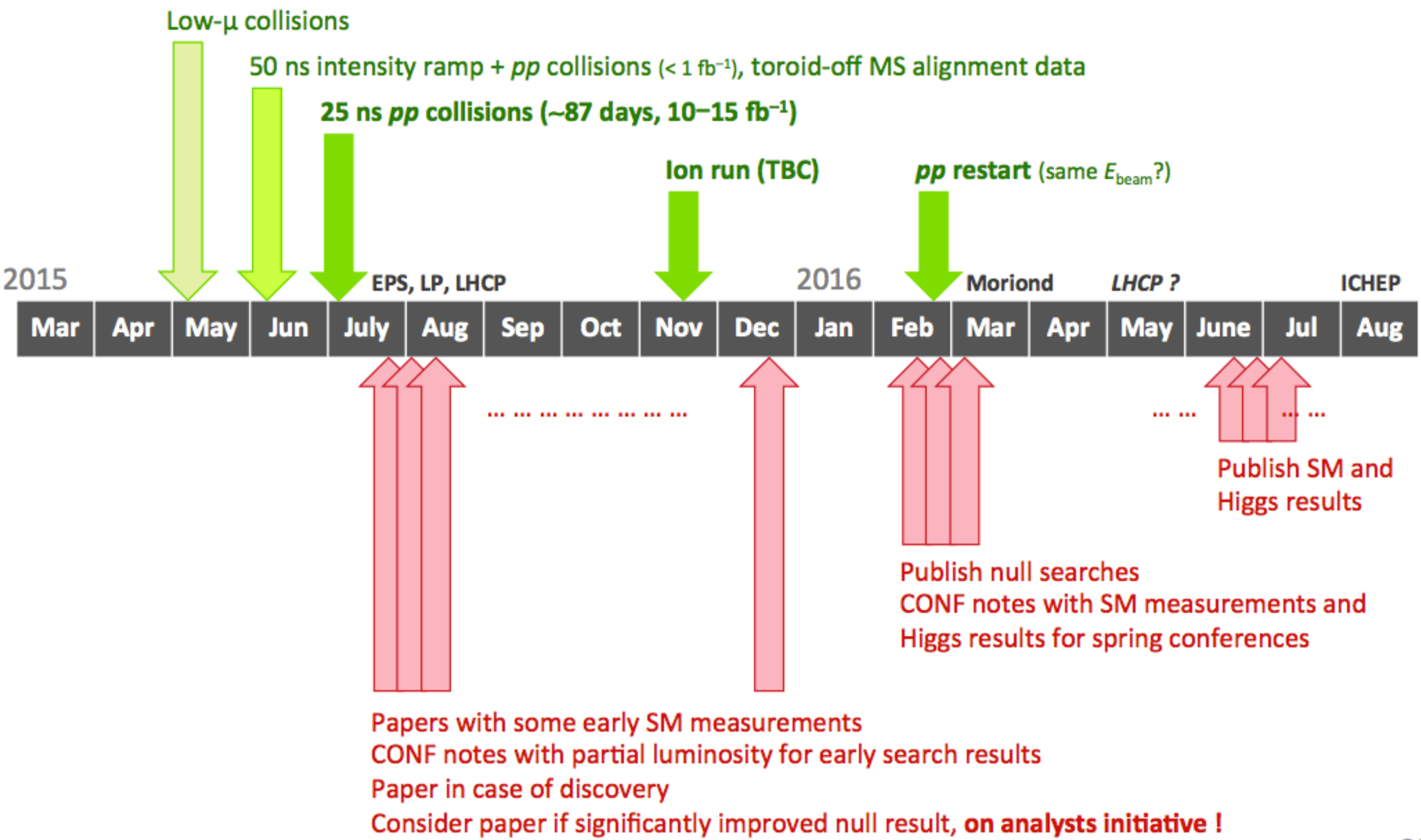




		"Truth Monte Carlo"		
	Category	ggF: gg→ H	VBF: qq→ qqH	VH: $q\bar{q}$ → VH
Ricostruiti	ggF: gg→ H	0.73	0.14	0.34
	VBF: qq→ qqH	0.13	0.58	0.28
	VH: $q\bar{q}$ → VH	0.14	0.28	0.39

Planning for 2015 and beyond — publications

Evolving slides



BSM Higgs searches

Neutral Heavy Higgs to Fermions	
	H/A->(b)$\tau\tau$ (LL,LH,HH)
	H/A->(b)μμ
	H/A->(b)bb
	H/A->tt

Neutral Heavy Higgs to Bosons	
	H->$\gamma\gamma$
	H->ZZ->4l
	H->ZZ->ll$\nu\nu$
	H->ZZ->llqq
	H->ZZ->$\nu\nu$qq
	H->WW->lνlν
	H->WW->lνqq

Neutral Heavy Higgs to Bosons, including light Higgs	
	(H->)hh->$\gamma\gamma$bb
	(H->)hh->4b
	(H->)hh->bb$\tau\tau$
	(H->)hh->VV$\gamma\gamma$->4j$\gamma\gamma$,
	(H->)hh->WW$\gamma\gamma$->lνqq$\gamma\gamma$
	A->Zh->ll$\tau\tau$ (LL,LH,HH)
	A->Zh->(ll/$\nu\nu$)bb

Heavy and light Charged Higgs	
	H+->$\tau\nu$+jets
	H+->tb (resolved)
	H+->tb s-chan (had, L+j)
	H+->$\tau\nu$+lep(s)
	H+->μν
	H+->cs
	H+->cb
	- AW
	H+->Wh (WH, WA)
	H+->Wγ
	H+->tb (boosted)
	H+->WZ->tb (lνqq, qqll)
	H++

LFV / FCNC / rare decays	
	H->τμ, τe
	H->eμ
	H->J/$\psi\gamma$, Υγ
	H->ZJ/ψ, ZΥ
	H->ϕγ
	t->cH (various

Exotics decays with MET, Dark-sector Inspired	
	mono H (->$\gamma\gamma$+MET)
	mono H (->bb+MET)
	mono H (->4l+MET)
	H->$\gamma\gamma$dark
	ZH->(ll)INV
	VBF H->INV
	VH->(jj)INV
	ttH->INV (various
	ggF H->INV (monojet).

Exotics decays with no MET, Dark-sector / NMSSM Inspired	
	H->ZdarkZ(dark)->4l
	h->2a->μμμμ
	h->Za->llμμ
	a->μμ
	h->2a->4γ(multiphoton)
	h->2a->bbμμ
	h->2a->bb$\tau\tau$
	(bb)a->(bb)$\tau\tau$->(bb)eμ
	h->2a->4τ
	H+->aW

BSM Higgs searches

Simplified models

All the topologies that we have identified can be achieved within "simplified models". Motivation: capture all the relevant phenomenology while keeping only minimal necessary ingredients.

Common is: additional scalars or pseudoscalars which can couple to SM Higgs or can be produced at the LHC pp collisions.

- SM + scalar (Higgs portal)
- 2HDM (with and without an extra neutral scalar)

SUSY (MSSM, nMSSM), Hidden Valley, little Higgs, etc..

BSM Higgs searches

Two Higgs Doublets Model (2HDM)

Four types of 2HDM:

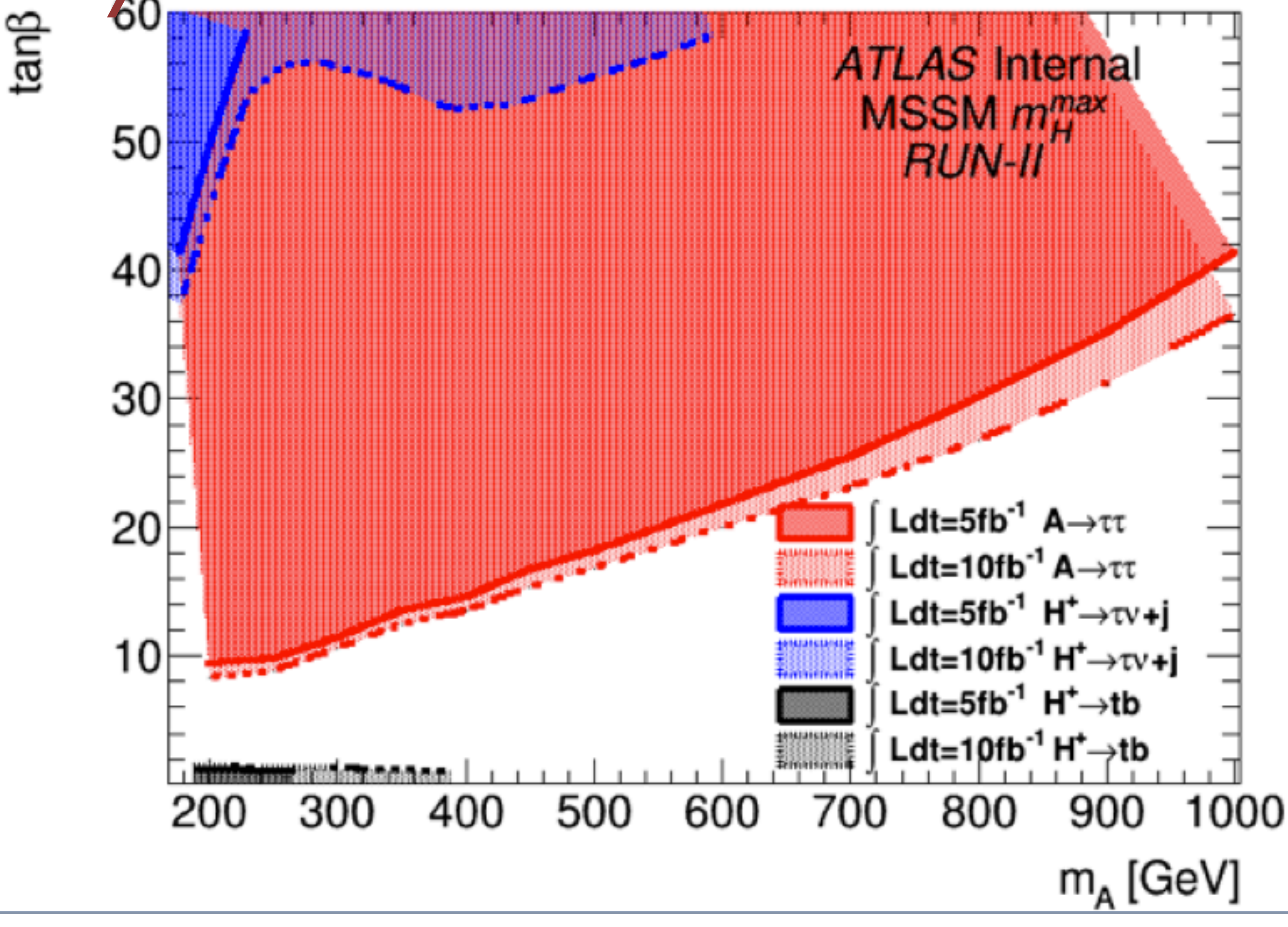
- ∗ type I (all fermions couple to a single Higgs doublet)
- ∗ type II (MSSM-like, down-type fermions couple to H_2 and up-type to H_1)
- ∗ type III (leptonic-specific, $H_1/H_2 \longleftrightarrow$ leptons/quarks)
- ∗ type IV (anti-holomorphic coupling to up/down)

- > **Five physical particles: h, H, A, H^+, H^-**
- **Sector input:** $\tan\beta = \frac{v_u}{v_d}, m_A^2 \to m_{h,H}$, α: **H-h mixing**

- **h**: Similar to the H_{SM}
- **A**: bb, $\tau\tau$, tt decays (no VV decays, hZ suppressed)
- **H**: Same as A since WW, ZZ & hh are suppressed

- For tanβ>>1 only decays to b or τ
  - Br $\phi \to$ bb ~90%, Br $\phi \to \tau\tau$ ~10%
- For tanβ~1 can get H→WW,ZZ,hh; A→hZ;

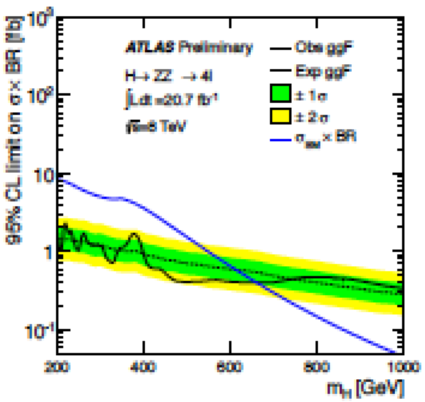
H/A→ττ

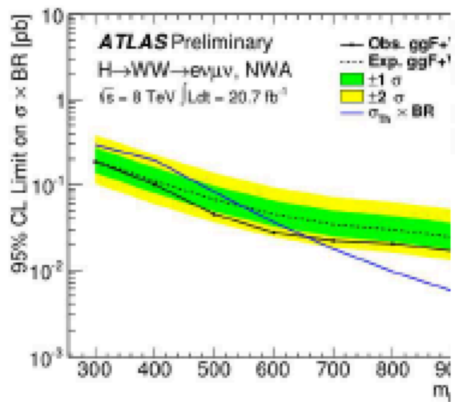


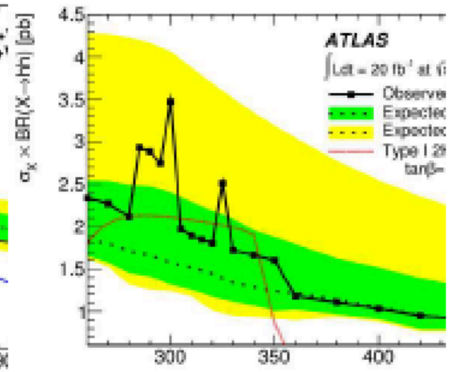
tanβ
ATLAS Internal
MSSM m_H^{max}
RUN-II
∫ Ldt=5fb⁻¹ A→ττ
∫ Ldt=10fb⁻¹ A→ττ
∫ Ldt=5fb⁻¹ H⁺→τν+j
∫ Ldt=10fb⁻¹ H⁺→τν+j
∫ Ldt=5fb⁻¹ H⁺→tb
∫ Ldt=10fb⁻¹ H⁺→tb
m_A [GeV]

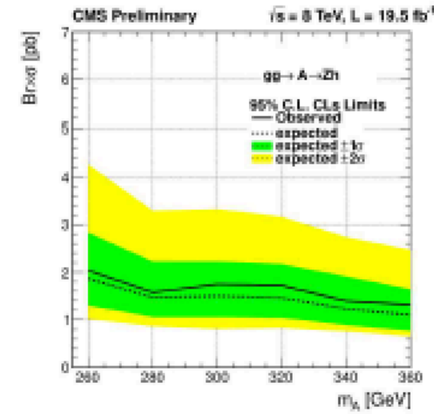
Extend search for heavy SM Higgs for MSSM

$pp \to H \to ZZ$ $\quad pp \to H \to WW$ $\quad pp \to H \to hh$ $\quad pp \to A \to hZ$





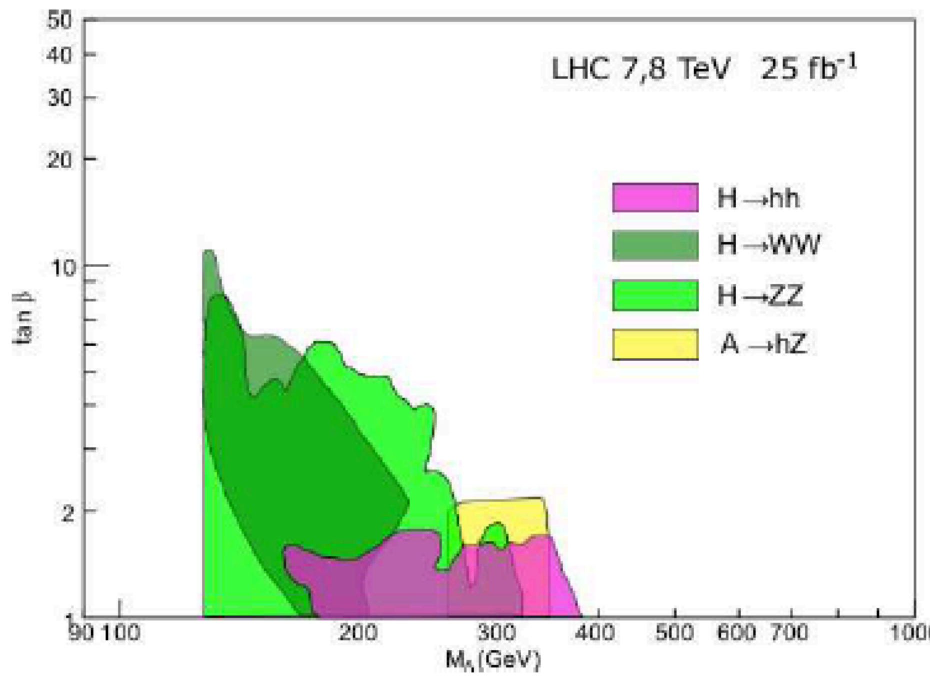




[New model independent approach proposed by] ***Djouadi, Maiani, Polosa, Quevillon, Riquer***

A preliminary analysis of ATLAS+CMS constraints at 7+8 TeV with 25 fb−1 data

Can be vastly improved!



Strategie di Analisi Run-II

Analisi "veloce" con 2-5 fb^{-1} (Moriond 2016)

- A/H→ tau tau
- Dijet resonances (model independent)

Analisi 20 -100 fb^{-1} (2015-2018)

- High mass BSM Higgs (ZZ o hh)
- A/H→ tau tau + analisi spin/CP
- Mono-Jet (Exotica and DarkMatter)