SEARCH FOR THE STANDARD MODEL HIGGS BOSON IN THE DECAY CHANNEL H→ZZ→2l2q AT CMS

Matthew Kress

Adviser: Daniela Bortoletto
Preliminary Report
December 4, 2012

Outline

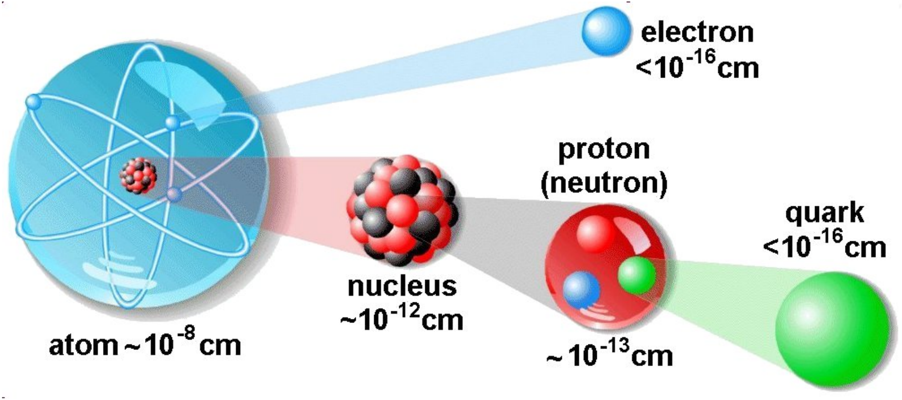
2l2q Team

- *WISCONSIN:* M.U.Mozer
- *CERN:* A.Bonato, P.Lenzi, M.Mannelli
- *CIEMAT:* O.González López, D.Domínguez Vázquez, P.García, J.Hernández, E. Navarro
- *JHU:* A.Gritsan, S.Bolognesi, A.Withbeck, C.Martin, I.Anderson
- *U & INFN-Napoli:* A.Decosa, F.Fabozzi, L.Lista
- *National Central U:* A.P.Singh, S.S.Yu
- *Panjab:* L.K.Saini
- *Purdue:* D.Bortoletto, M.Kress, M.Vidal
- *Rochester:* R.Covarelli, P.Goldenzweig, R.Demina, A.Garcia-Bellido
- *UAM:* G.Codispoti, J.Fernández de Trocóniz
- *METU:* M.Yalvac
- *U & INFN-Firenze:* A.Tropiano, V.Gori, V.Ciulli, E.Gallo

Outline

Sub-atomic World

Particle Physics is the study of the properties of the fundamental building blocks of the universe and the interactions between them.



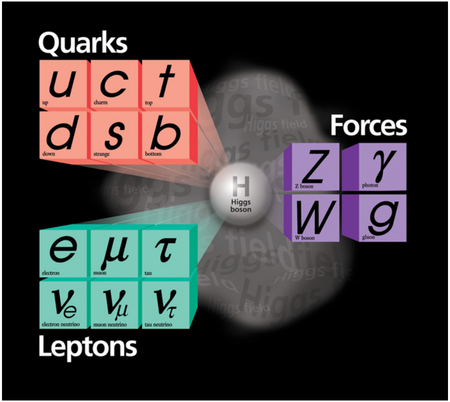
The Four Fundamental Forces

There are four fundamental forces that we know of.

Force	Boson	Charge	Mass
Gravitational	graviton(G)	0	?
Electromagnetic	photon(γ)	0	0
Weak	W boson($W^{\pm}$)	± 1	81 GeV
	Z boson(Z)	0	92GeV
Strong	gluon(g)	0	0

The Standard Model

The Standard Model is the compilation of over 100 years of scientific discoveries and is in excellent agreements with a wide range of experimental observations.

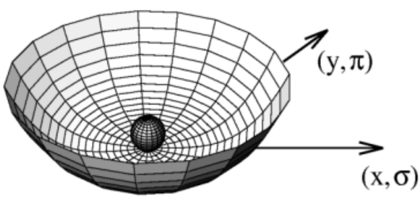


Particle Discoveries

Year	Discovery
1897	e discovery, by J.J. Thompson (cathode ray tube, UK)
1919	proton, Ernest Rutherford (UK)
1930	neutron, James Chadwick (UK)
1936	m, Carl D. Anderson at Caltech
1947	strange quark(K+=usbar, K-=subar)
1956	ν_e discovery (nuclear reactor)
1962	ν_μ discovery at BNL
1968	u and d quark (quark model)
1974	c quark (BNL, SLAC,J/y=ccbar)
1977	tau discovery (SLAC)
1977	b quark (Upsilon, FNAL)
1979	gluon (DESY)
1983	W and Z (CERN)
1995	top quark
2000	ν_t discovery (Fermilab)
2012	??Higgs?? (CERN)

The Higgs Mechanism

- The potential on the left if symmetric as is the potential on the right.
- The ground state symmetry is spontaneously broken in the potential on the right.



- The Higgs field is the simplest of several proposed causes for electroweak symmetry breaking and the means by which elementary particles acquire mass.
- The Higgs boson is the smallest possible excitation of the Higgs field.

Outline

Particle Accelerators

Particle accelerators accelerate particles to high energies.

This allows us to:

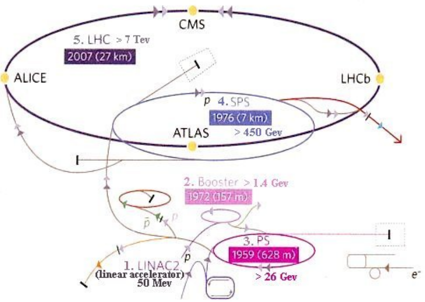
- Look deeper into matter ($E \propto \frac{1}{size}$). "microscope"
- Discover new heavier particles ($E = mc^2$).
- Probe early conditions of the Universe (E = kT).

All this while being controlled in the laboratory.

The LHC Accelerator

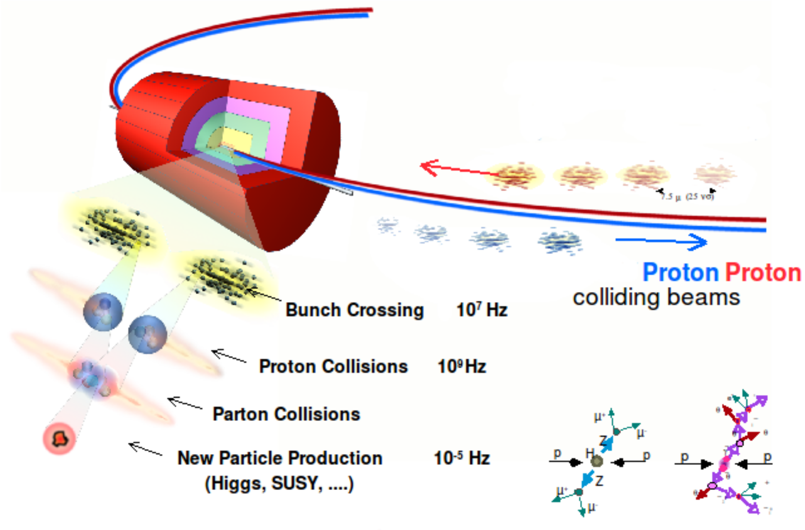
- Proton-proton collider
- Circumference: 26.7 km
- Tunnel: 100 meters underground
- dipoles operate at 8.3 T
- 1232 superconducting Niobium-Titanium magnets
- better vacuum and colder than inter-planetary space

Injection Scheme

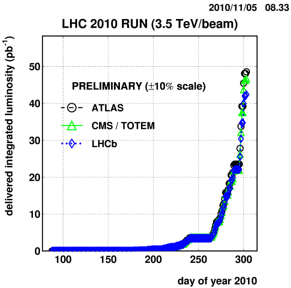


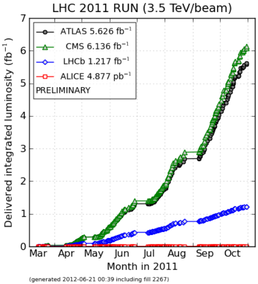
- Linac2 → 50 MeV
- Proton Synchrotron → 1.4 GeV
- Super Protron Synchrotron → 450 GeV
- LHC → 4.0 TeV

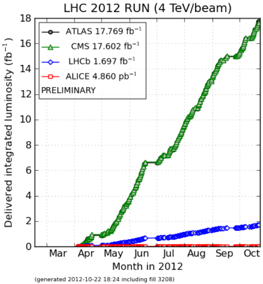
LHC Environment



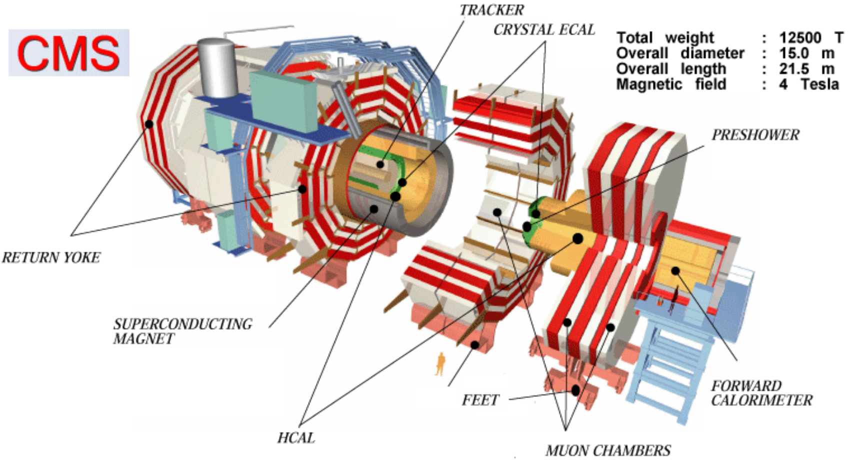
LHC Delivered Data



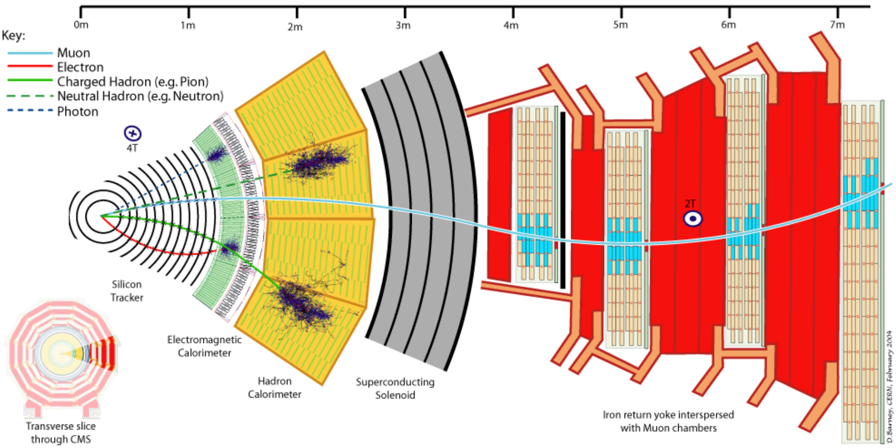




Compact Muon Solenoid

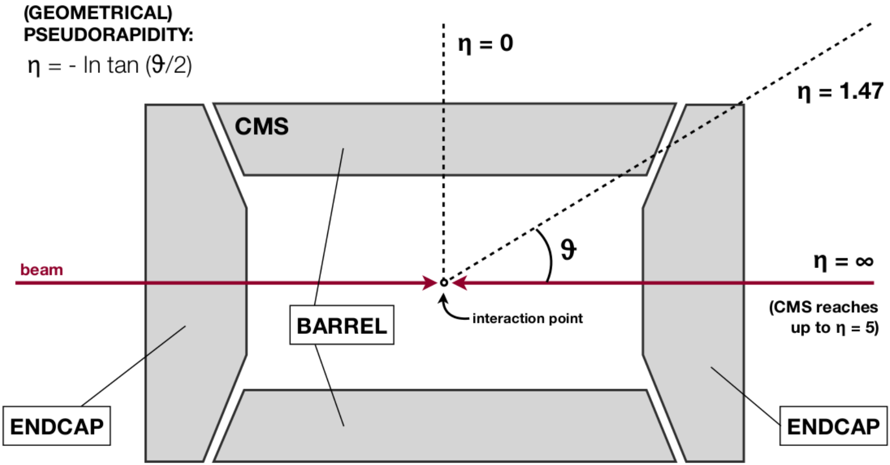


CMS Slice



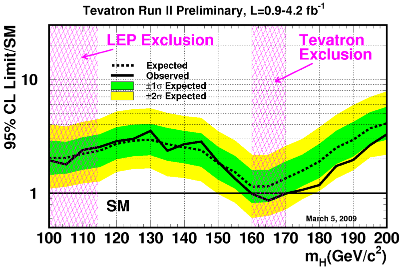
0m
1m
2m
3m
4m
5m
6m
7m
Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS
D.Barney, CERN, February 2004

CMS Detector Glossary



The Missing Piece

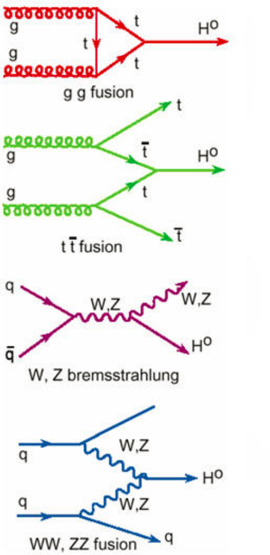
Before LHC



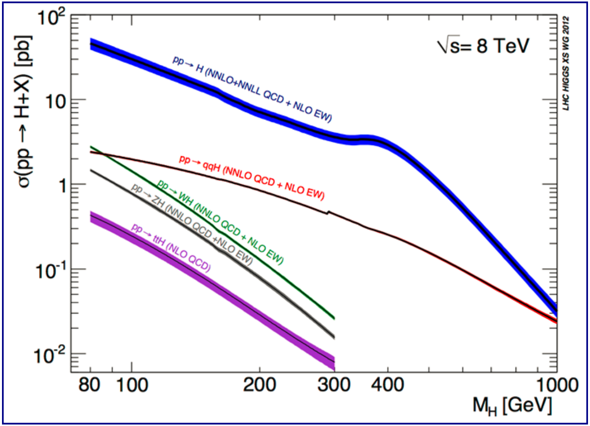
Experimental constraints:

- From direct searches at LEP and Tevatron.
- Indirect ones from LEP precision EWK measurements.

Higgs Production

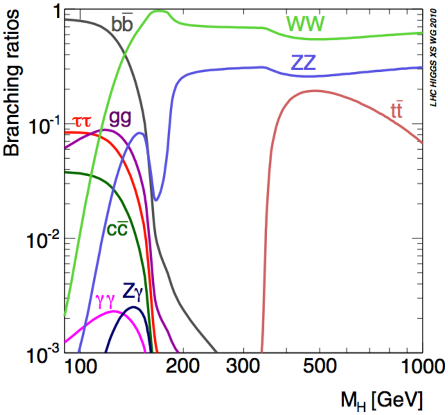


Gluon-gluon fusion ($gg \rightarrow H$) and vector-boson fusion ($qq \rightarrow qqH$) are dominant



Higgs Decay

- Discovery strategy depends on the available decay channels.
- Decays with leptons provide clean signatures.

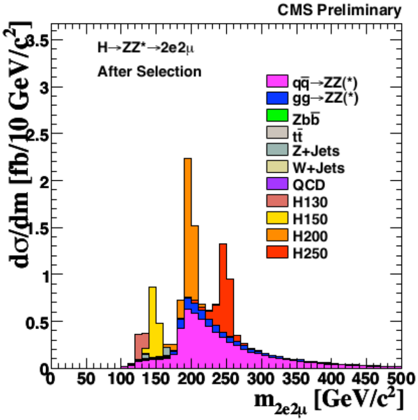


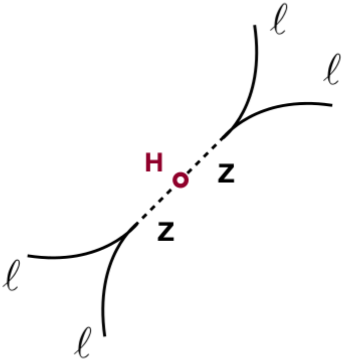
Main Discovery Channels

- $H \to \gamma\gamma$
- $H \to W^+W^-$
- $H \to ZZ$

The $H \to ZZ$ Decay

- Decay to two Z bosons is the most promising discovery channel for $m_H > 180 GeV$.
- If both Z bosons decay to electrons or muons you get a very clean signature.

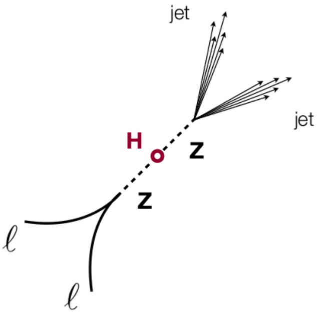




The $H \to ZZ \to llqq$ channel

Large Yields:

- BR($Z \to qq$) = 70%
- BR($ZZ \to 2l2q$) = 20 $\times$ $BR(ZZ \to 4l)$
- BR($ZZ \to 2l2q$) = 3.5 $\times$ $BR(ZZ \to 2l2\nu)$



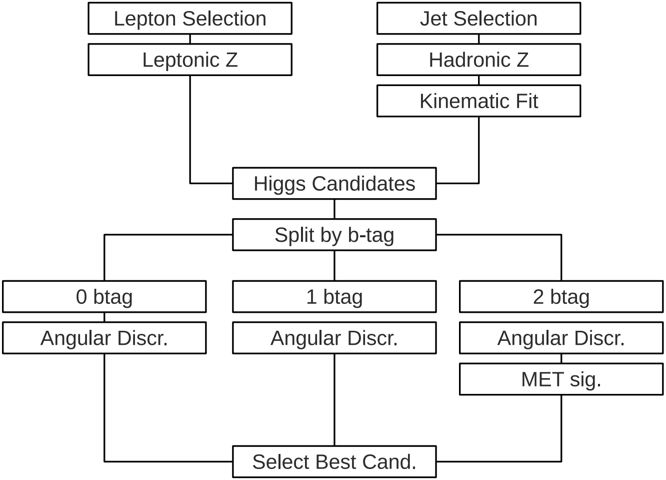
Drawbacks

- Bad resolutions coming from jets.
- Large backgrounds coming from Z+jets

Full decay is reconstructed (closed kinematics)

Outline

Analysis workflow



Samples

Data is Double Electron and Double Muon datasets.

Background

MC Sample	Generator	Percent of Final Region
Z+Jets	MADGRAPH	80%
tt	PYTHIA	7%
ZZ	PYTHIA	11%
WZ	PYTHIA	2%
WW	PYTHIA	<1%

The signal Monte Carlo samples are POWHEG.
$m_H =$200,210,220,230,250,275,300,325,
350,375,400,425,450,475,500,525,550,575,600 GeV

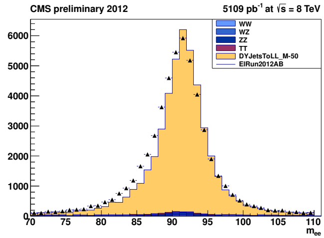
We are using the official prescriptions from the POGs for both Lepton ID and Isolation.

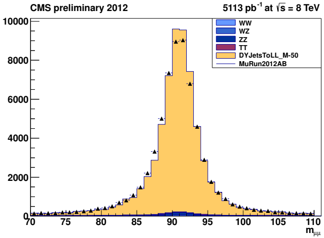
Electrons

- GSF Elecrons
- $p_T > 40/20$ GeV, $|\eta| < 2.5$
- Working Point Loose
- + Tight trigger cuts
- PU corrected ISO < 0.15

Muons

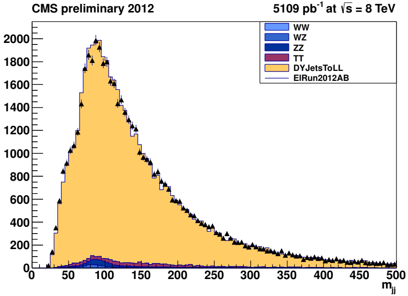
- reco::Muons
- $p_T > 40/20$ GeV, $|\eta| < 2.4$
- Tight Muon
- PU corrected ISO < 0.12

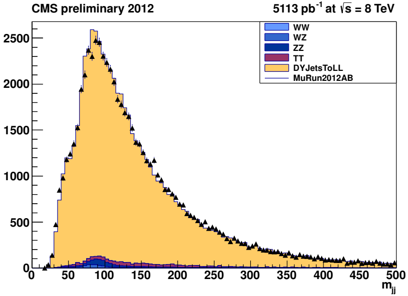




Jets

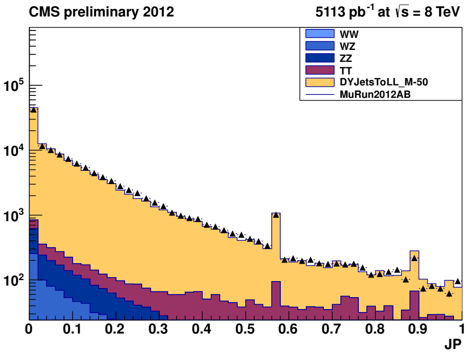
- AK5PF, L1FastJet+L2+L3
- $p_T > 30$ GeV , $|\eta| < 2.4$





b-tagging

- Using **JP algorithm**, "loose" and "medium" WPs, allowing migrations among the tagging categories when applying the SF to MC
- Up to date using the latest calibrations available for the JP algorithm

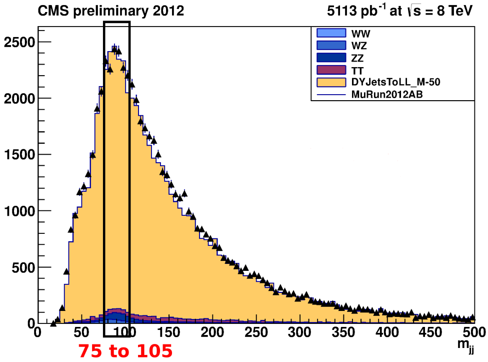


0 - tag	Both Jets < Loose
1 - tag	> Loose and < Medium
2 - tag	> Loose and > Medium

Signal and Sideband Regions

Study Regions

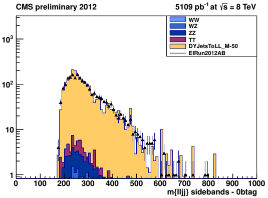
- Signal Region is 70 < m_{ll} < 110 GeV and 75 < m_{jj} < 105 GeV
- Also we are looking at the sidebands region, defined as 60< m_{jj} <75 GeV || 105< m_{jj} <130 GeV (i.e. outside signal window 75< mjj < 105 GeV).



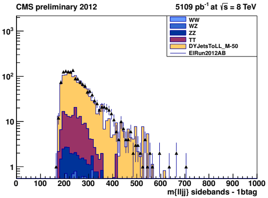
Data-MC m_{lljj} plots - Side Band Region

Electrons

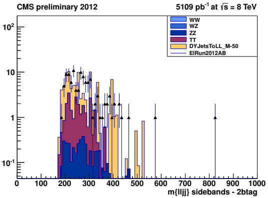
0-tag



1-tag

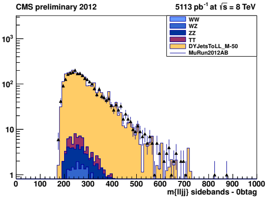


2-tag

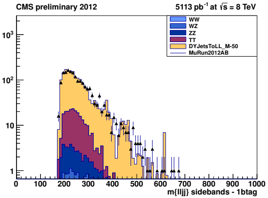


Muons

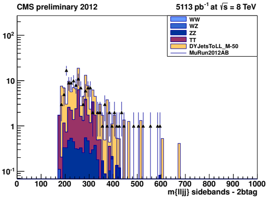
0-tag



1-tag

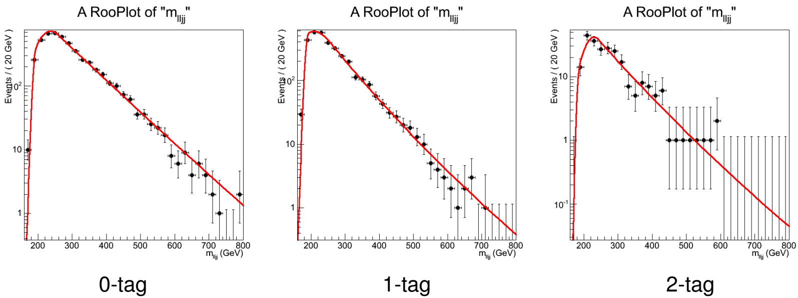


2-tag



Background Estimation

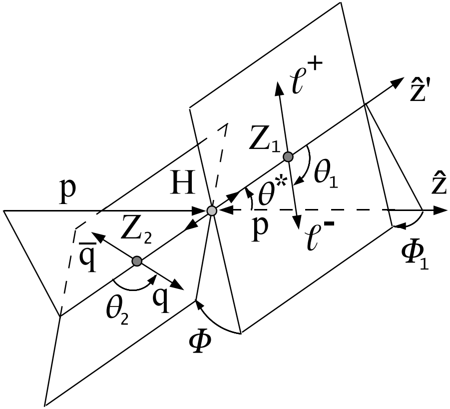
- We use the mjj sideband in data to get the normalization and a MC shape correction.
- The fit is to a Fermi*CrystallBall function



Outline

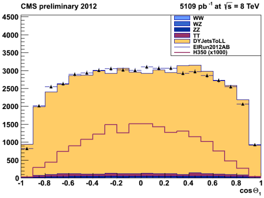
Helicity and Production Angles

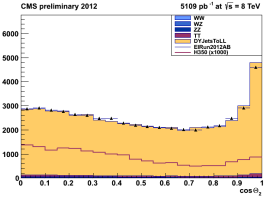
Final state kinematics completely determined by 5 angles.

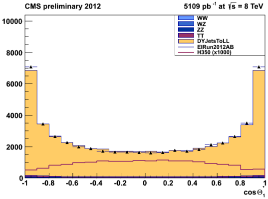


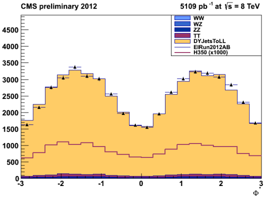
$cos(\theta^*), cos(\theta_1), cos(\theta_2), \Phi, \Phi_1$

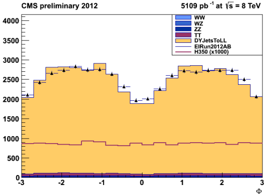
Electron Helicity and Production Angles



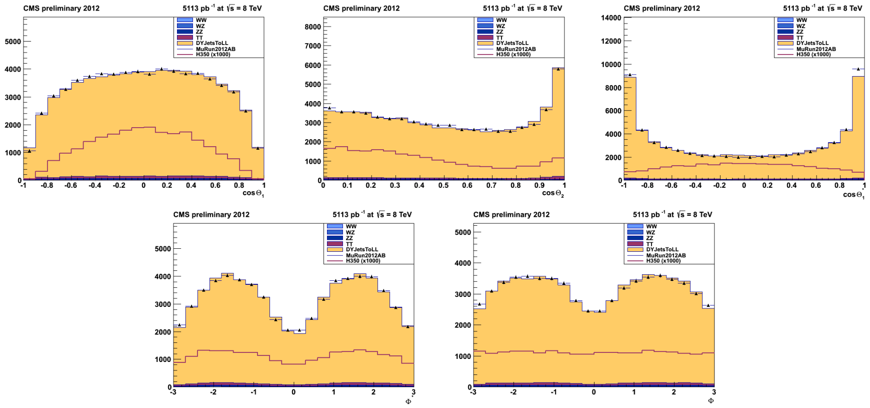






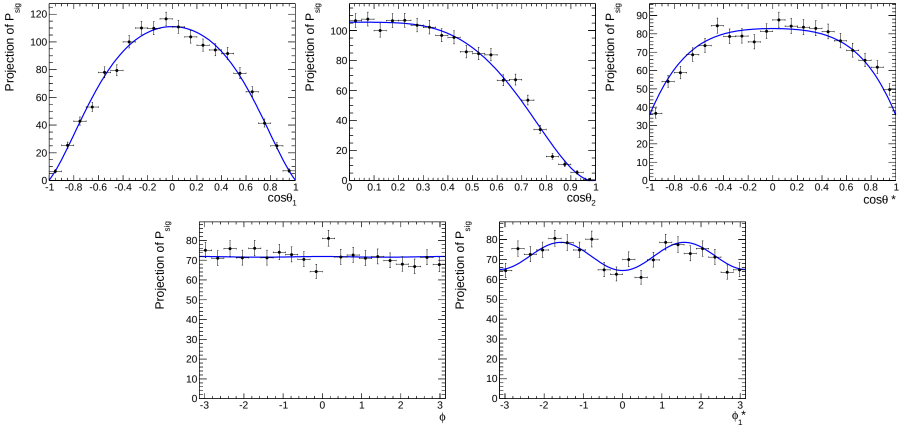


Muon Helicity and Production Angles



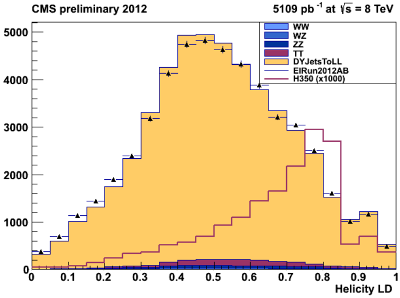
Angular Distribution Fits

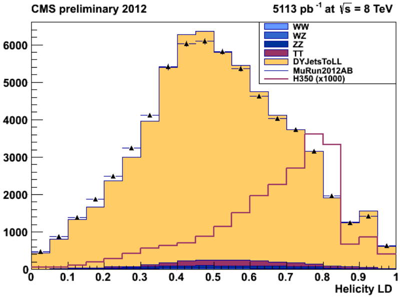
Example fits at for 500 GeV (475 - 550 GeV).



Helicity LD

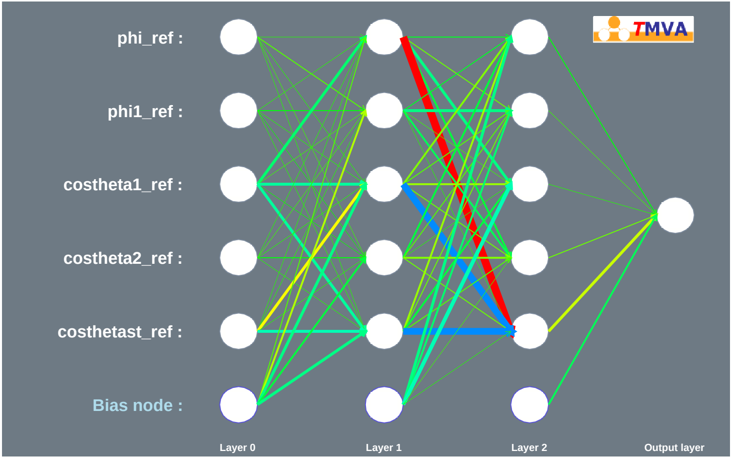
$$LD = \frac{P_{sig}}{P_{sig} + P_{bkg}}$$





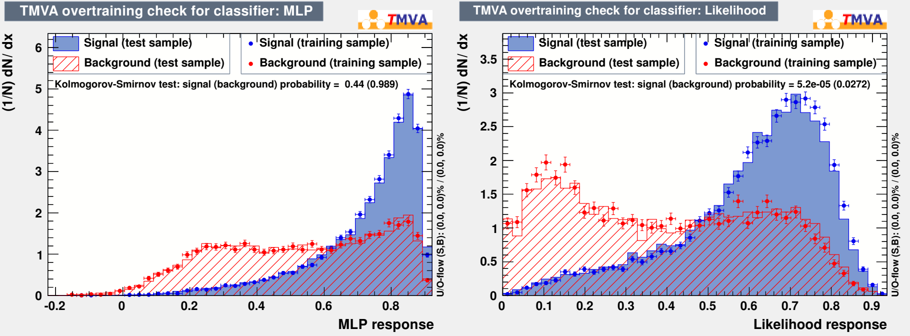
	0 *b*-tag	1 *b*-tag	2 *b*-tag
Helicity LD	$> (0.55 + 0.00025 \times m_{ZZ})$	$> (0.302 + 0.000656 \times m_{ZZ})$	> 0.5

Neural Network with TMVA Package



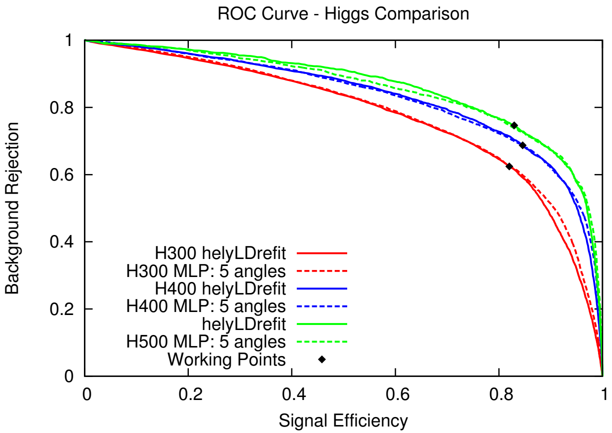
Neural Network Training and Testing

The trainings are done after preselection and additionally require at least one B-tagged Medium jet Left: Training 400 GeV Higgs boson with a MLP neural network. Right: Training 400 GeV Higgs boson with a Likelihood.



MLP vs Helicity LD

The working point is the background rejection point that we currently achieve in the two tag region in our analysis.

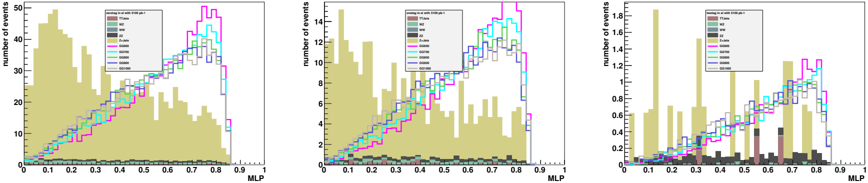


High Mass MVA Introduction

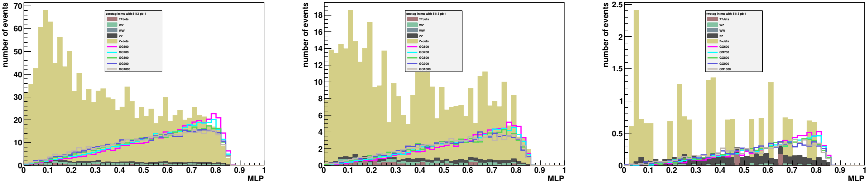
- Since the current helyLD optimization does not work at high mass I am looking at the performance of the straight forward MLP neural network performance in the High Mass region.
- This looks at a training on the Higgs 400GeV signal sample (a trianing that works well for 300-600 as shown in previous talks) as well as the same training but on a Higgs 800 GeV signal sample.
- These signal samples are the Gluon-Gluon samples

MLP

Electrons (zero,one,two)



Muons (zero,one,two)



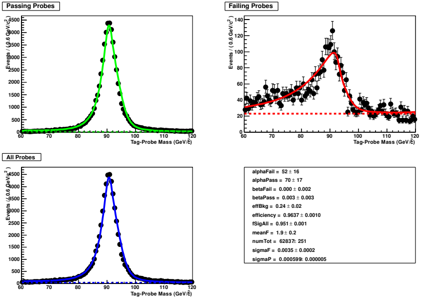
Outline

1. Standard Model
2. Experiment
3. Event Selection
4. Signal Region Optimization
5. Statistical Analysis and Results
6. Next Steps

Tag and Probe

- Method to use Z boson to calculate efficincy of Data and Monte Carlo.
- One lepton is “good” (tag) and the other is used for the calculations(probe).
- Compairing Monte Carlo to data gives us Scale Factors.

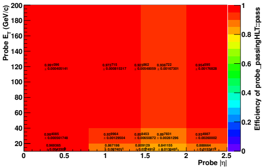
SuperCluster to GSF Electron



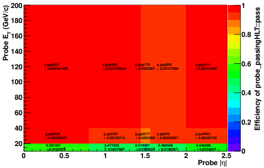
Triggers

- Muons
  - HLT_Mu17_Mu8
  - HLT_Mu17_TkMu8

Electron Leg 8 GeV WPLoose to HLT



Electron Leg 17 GeV WPLoose to HLT

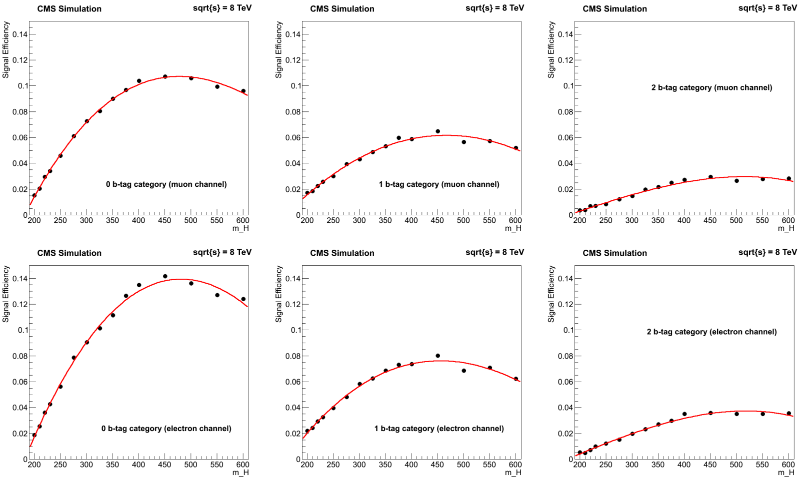


- Electrons
  - HLT_Ele17_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL _Ele8_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL
- EMu (for backround estimation and analysis checks)
  - Mu8_Ele17_CaloIdT_CaloIsoVL
  - Mu17_Ele8_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL

We are using the POG provided scale factors for electrons and computing the WP to HLT ourselves.

Efficiency Fit

The signal efficiency as a function of the Higgs mass is fitted to a polinomial in order to be estimatated for those Higgs mass hypothesis where no Monte-Carlo sample is available

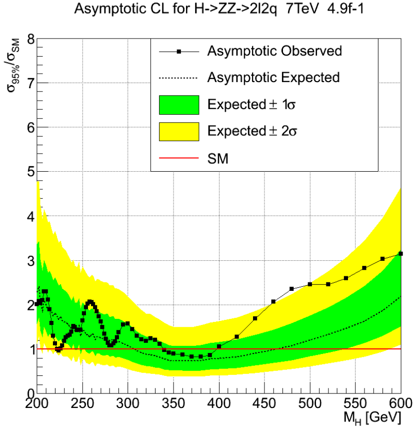


Systematics

source	0 *b*-tag	1 *b*-tag	2 *b*-tag	comment
muons reco	2.7%			tag-and-probe study
electrons reco	4.5%			tag-and-probe study
jet reco	1%–8%			JES-uncert., JER uncert. negligible; correlated between categ
pileup	1-2%			correlated between categ
b-tagging	2-7%	3-5%	10-11%	anti-correlated between categ.
MET	–	–	3-4%	loose requirement
production mechanism (PDF)	2-4%			PDF4LHC, acceptance only
production mechanism (WBF)	1%			
production mechanism (lineshape)	0-3%			only for $M_H > 400$
luminosity	4.4%			same for all analyses
Higgs cross-section (for R)	13–18%			detailed table from YR available

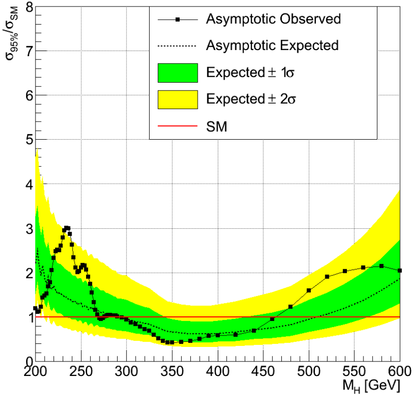
2011 Results

Limit on the expected 95% CL upper limit on the product of the Higgs boson production cross section and the branching fraction of H→ZZ (black dots.), for the recorded luminosity in 2011 of 4.9 fb^{-1} at 7TeV. Yellow and Green bands represent the 68% and 95% ranges of expectation.



Limit on the expected 95% CL upper limit on the product of the Higgs boson production cross section and the branching fraction of H→ZZ (dash line(and observed upper limit (black dots.) Yellow and Green bands represent the 68% and 95% ranges of expectation.

CMS Preliminary 2012, 5.1fb-1 $\sqrt{s}$=8TeV



Outline

Next Step

- Train analysis for high mass range (from 600 GeV to 1000 GeV).
- Run limit calculations on the MVA analysis.
- Run tag and probe efficiency calculations for muons.
- Optimize Z_{ll} and Z_{jj} cuts for preselection.
- Improve reconstruction of high mass jets.
- Run analysis over full 2012 data sample at the end of the run.

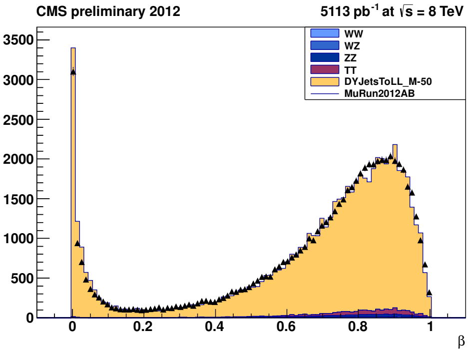
Thank You

BACKUP

Pile-up Rejection

β is the sum of transverse momenta of all charged particles in the jet coming from the primary vertex, normalized to the total sum of transverse momenta of all charged particles in the jet.

- Using β variable to remove candidates with PU-like jets
- Cutting on $\beta \geq 0.2$



$\frac{Signal}{\sqrt{Signal + Background}}$

400GeV Training

	Electron			Muon		
Sample	zero	one	two	zero	one	two
GG600	0.215	0.224	0.309	0.232	0.210	0.345
GG700	0.086	0.089	0.121	0.088	0.083	0.134
GG800	0.035	0.036	0.052	0.036	0.033	0.057
GG900	0.016	0.016	0.023	0.016	0.015	0.025
GG1000	0.009	0.009	0.012	0.009	0.008	0.013

800GeV Training

	Electron			Muon		
Sample	zero	one	two	zero	one	two
GG600	0.204	0.223	0.297	0.225	0.198	0.344
GG700	0.084	0.091	0.118	0.088	0.082	0.140
GG800	0.035	0.039	0.053	0.038	0.034	0.061
GG900	0.017	0.018	0.023	0.017	0.016	0.027

Difference in $\frac{Signal}{\sqrt{Signal + Background}}$ 400 vs 800

	Electron			Muon		
Sample	zero	one	two	zero	one	two
GG600	4.93%	0.18%	4.17%	2.98%	5.49%	0.33%
GG700	1.72%	-2.75%	2.58%	0.36%	1.57%	-3.91%
GG800	-1.71%	-7.89%	-2.51%	-4.42%	-2.47%	-7.02%
GG900	-2.87%	-8.16%	0.30%	-5.16%	-4.40%	-8.41%
GG1000	-2.62%	-8.38%	-1.75%	-4.26%	-2.13%	-10.91%