Study of Higgs → ZZ* → 4 leptons ($e^{\pm}$, $\mu^{\pm}$) channel in ATLAS (contribution to the CSC note)

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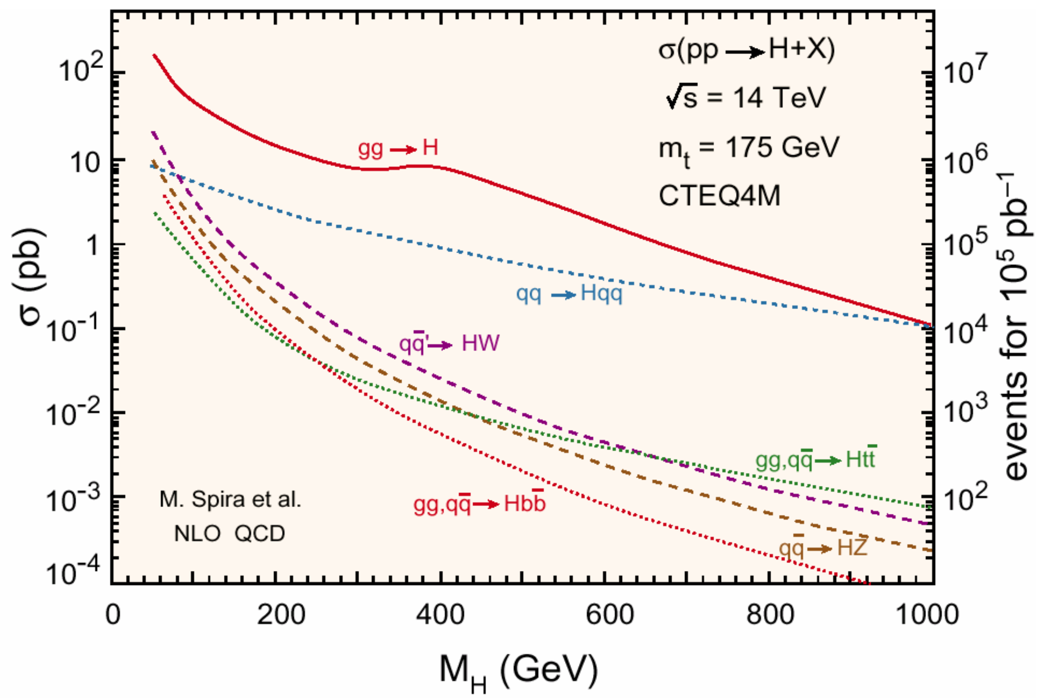
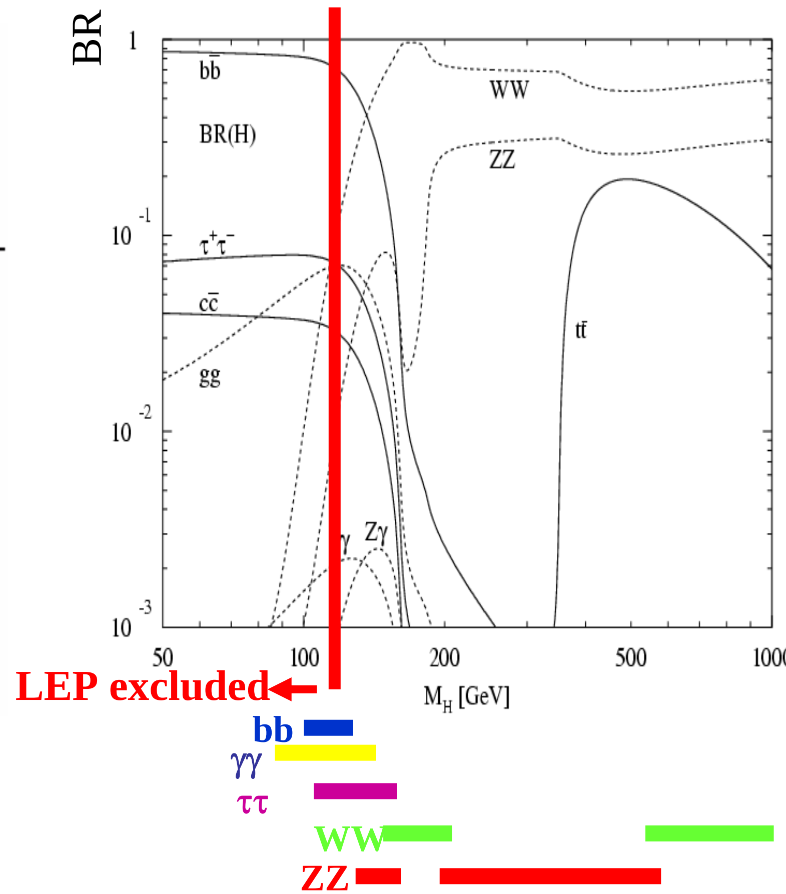
Outline

- Introduction
- Analysis framework
  - Collaboration issues
  - Tools, data samples used
- Current status of analysis
  - Performance studies
  - Analysis strategy and results
- Conclusions, future plans

Introduction: SM Higgs (cross sections and BRs)





$H \rightarrow ZZ^{(*)} \rightarrow 4l$ (e,μ) : clear signature on top of low background

Studies are focused on the mass region: 130 GeV < m_H < $2m_Z$

For m_H < 180 GeV Higgs is narrow → good detector resolution essential

Introduction: Signal and Backgrounds

Signal:

- **H → ZZ(*) → 4l** (l=e,μ)

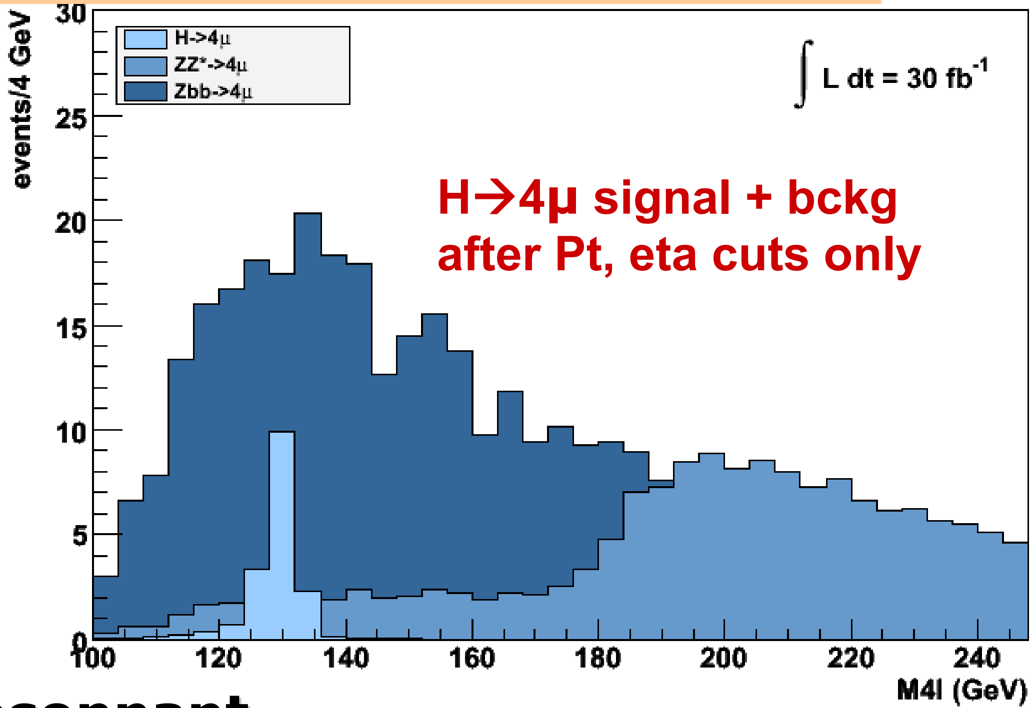
Backgrounds:

Irreducible

- ZZ(*) /γ (*) → 4l
- ZZ(*) /γ (*) → 2l 2τ

Reducible

- Zbb → 4lX **resonnant**
- tt →WbWb →4lX **non resonnant**



X-sections and generators used in ATLAS

type	H→4l mH=150 GeV (NLO calculations)	ZZ→4l LO calculation / Kfactor ~1.3	Zbb→4l LO calculation / no Kfactor	tt→4l NLO calculation
generator	Pythia	Pythia	AcerMC	MC@NLO
x-section	10.5 fb	X 15 Higgs x-section	X 5000 Higgs x-section	X 80000 Higgs x-section

Main contribution with data

Main focus in two areas

Performance

- **Muon identification**
  - Muon Spectrometer / Inner Detector
    - measure resolution, efficiency, fake rate from the data
      - Studies with J/Psi, Z samples
- **Electron identification**
  - Calorimeters / Inner Detector
    - check linearity, uniformity, efficiency
      - e.g minimum bias events for uniformity checks versus phi
      - Zs for uniformity checks versus eta, efficiency checks

Background rejection

Contribution to the Standard Model group

- ZZ
- Zbb (e.g process with cross section calculation with large theoretical uncertainties, direct measurement from the data very useful)

Implication in both areas is essential

Collaboration issues

European Research Training Network "Artemis"

- among 7 institutes (from 2006 to 2010)

  - Higgs→4leptons analysis one of the basic analyses performed within this network
    - Collaboration of people with various expertise; participating Artemis institutes in this analysis (CEA-Saclay, Un. of Sheffield, Un. of Thessaloniki, partially MPI)

First discussions, contacts with colleagues from LAL-Orsay already started in the spirit of exchange of expertise

Analysis Framework and Tools

- Use/test/validation of ATLAS standard tools
  - EV_H4lPreselector: EventView based code
    - Under cvs /offline/PhysicsAnalysis/HiggsPhys/HiggsToFourLeptons
    - Loops on AOD collections of e, μ
      - (no overlap removals for μ)
    - Dump of AOD variables in an Athena Aware Ntuple
  - Final Analysis in root
    - Both Higgs analysis and performance studies

- Development of common tools for the analysis shared among the ARTEMIS group.

- Contribution to the relevant "Csc" note

Analysis Strategy

- Signal selection

  Aim: trigger on the signal

  - **Cuts on Pt distribution of leptons** → **(to trigger the signal)**
  - **Cuts on di-lepton mass m_{ll}** → **(against the reducible bckg tt, Zbb, Zγ* + cascade decays)**

- Background Rejection

  Aim: Reject the reducible background of a factor ~100 after kinematic cuts to keep it at 10% of irreducible background (protection against theoretical uncertainties)

  - **Isolation cuts**
    - **Isolation based on the Inner Detector**
    - **Isolation based on the Calorimeters**
  - **Impact Parameters of leptons**, χ^2 **of common vertex of 4l**

- Higgs mass reconstruction

  Aim: Improve the mass resolution

  - **Combined reconstruction (calo+ID, Muon Spectrometer +ID)**
  - **Mass constraint of Z^0**

Particle Identification / electrons, muons

In this analysis we have used:

electrons:

- *Loose "IsEm" : Cut on* calorimeter observables (e.g energy cuts in 1st , 2nd sampling in various eta bins, cuts on the leakage of the tile)

muons:

- *"STACO" + "MuTag"*
  - STACO: Combined muon reconstruction using Inner Detector (new tracking package) tracks with Muon Spectrometer tracks (Muonboy package)
  - Mutag: Tagging ID tracks with segments (part of tracks in the Inner /Medium stations) from the Muon Spectrometer

Note: We have also compared the performances of the "STACO" to the "MUID" package which provides combined reconstruction of the Muon Spectrometer tracks ("MOORE" package) with the ID tracks ("IpatRec" package)

Data samples and analysis procedure

- Samples used:
  - Signal (~40K events)

Release used for reconstruction

trig1_misal1_csc11.005300.PythiaH130zz4l.recon.AOD.v12000601_tid007180

  - ZZ (~79K events)

trig1_misal1_csc11_V1.005980.Pythiazz4l.recon.AOD.v12000601_tid007884

  - Zbb (~97K events)

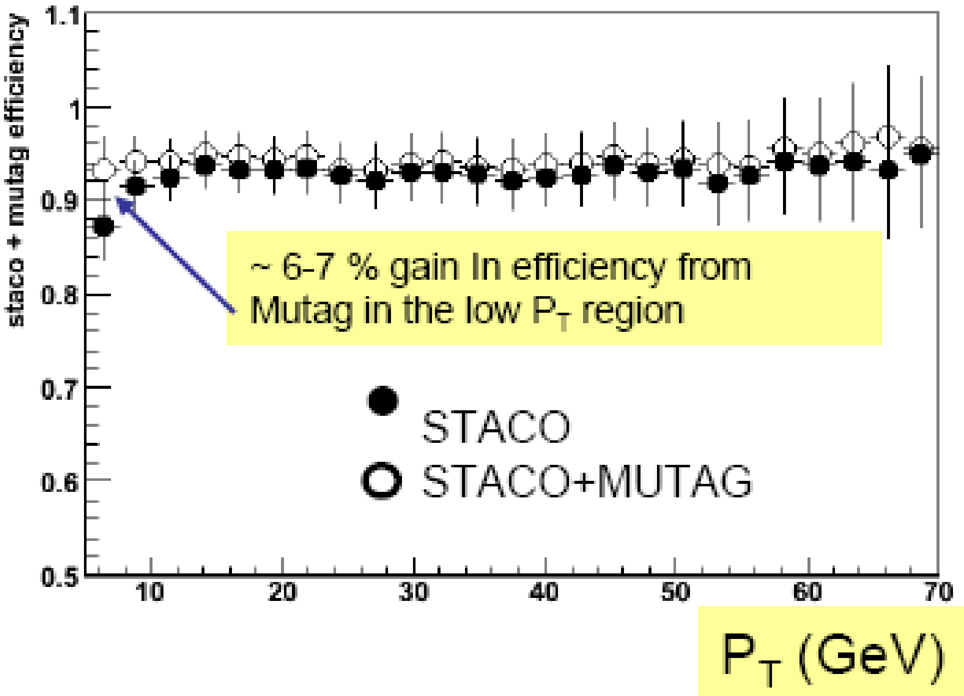
trig1_misal1_mc12.005177.AcerMC_Zbb_4l.recon.AOD.v12000604_tid009504 /8746

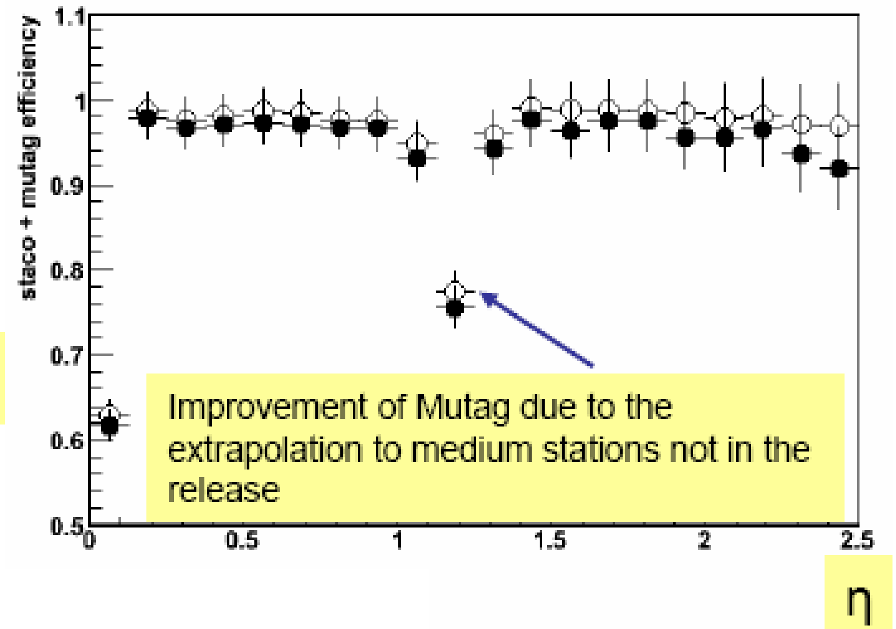
- "misal1" data processed with geometry ATLAS-CSC-01-02-00
  - New magentic field, misaligned geometry with distortions
  - "sf05": cavern background, 5x ATLAS nominal

- Analysis procedure
  - Copy of all AOD files (signal + background) to a local disk using a grid tool
    - Fast, no particular problems encountered.
  - Perform analysis in our local machine.

Performance studies /validation of samples $H \rightarrow 4\mu$

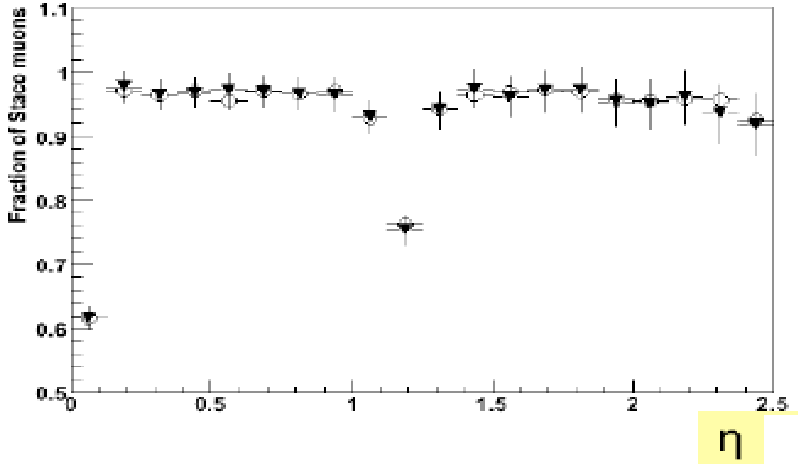
Efficiency of "STACO" and "STACO+MuTag" packages as a function of eta, Pt from $H \rightarrow 4l$ samples with pileup and cavern background

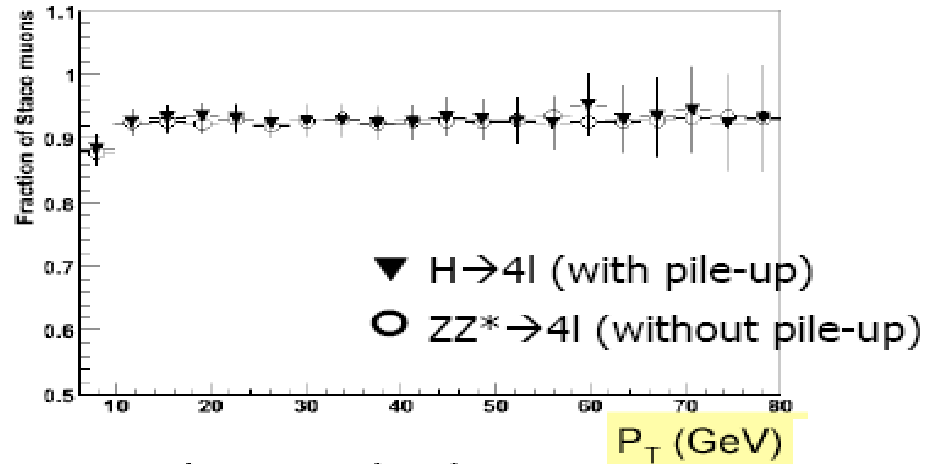




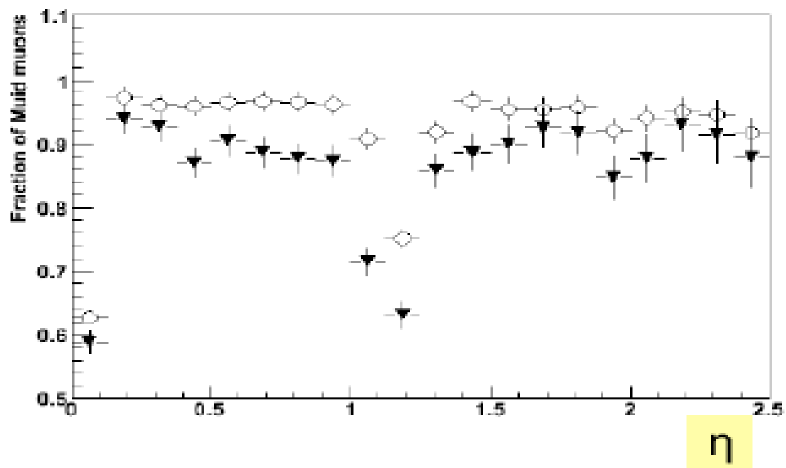
Performance studies with/without pile-up and cavern bckg (H→4μ)

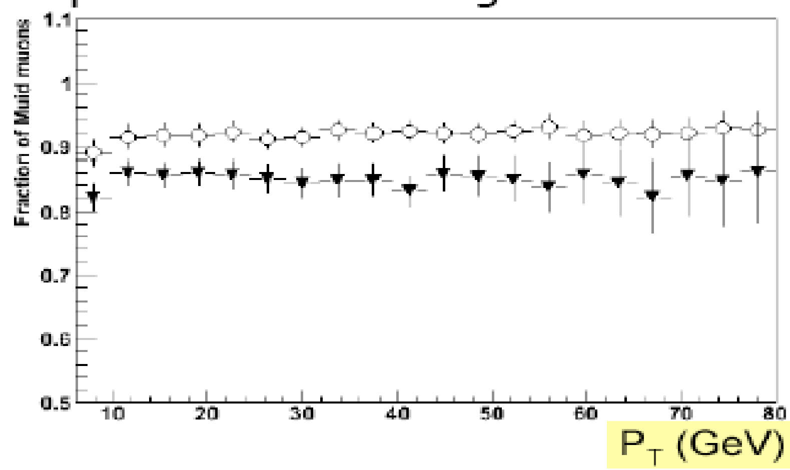
- STACO performance with and without pile-up and cavern background





- Muid performance with and without pile-up and cavern background



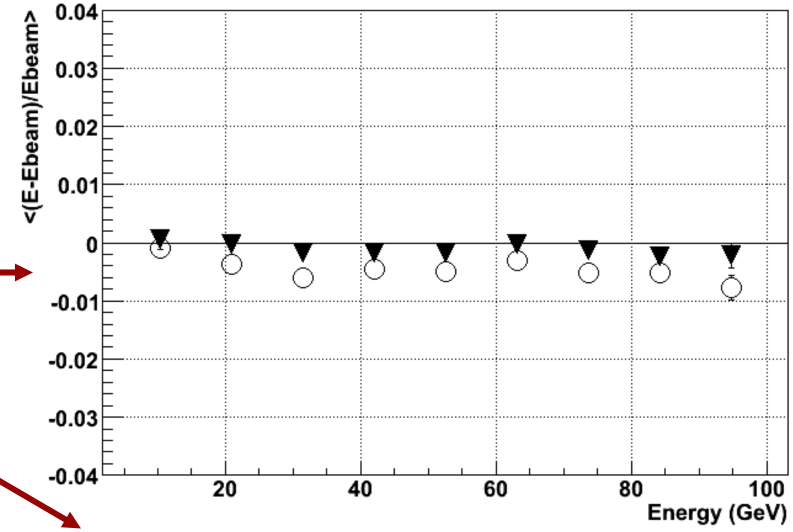


STACO: same performance in samples without/with pile-up, cavern bckg
MUID: sensitive to pileup + cavern bckg samples

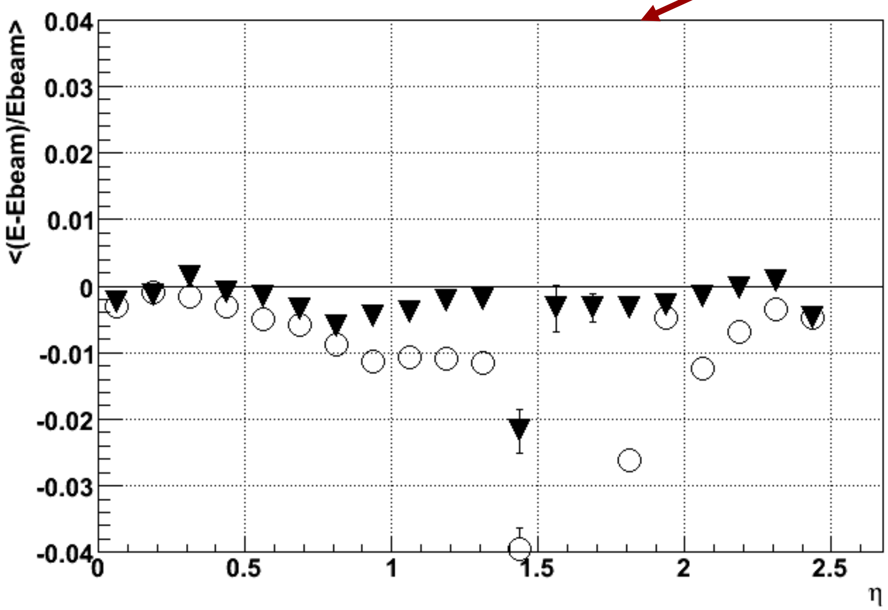
Performance studies /validation of samples H→4e

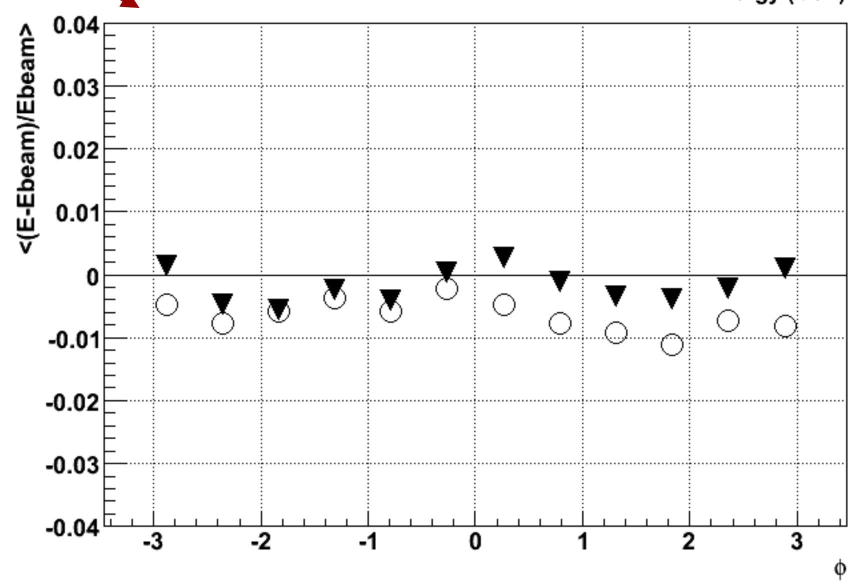
▼ samples with ideal geometry
○ samples of misaligned geometry

Linearity



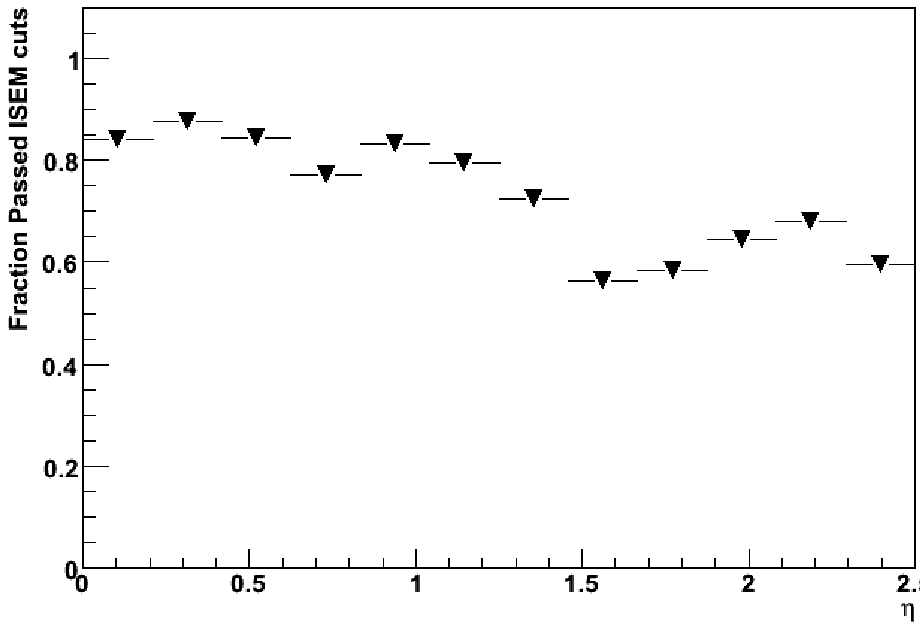
Uniformity versus η , φ

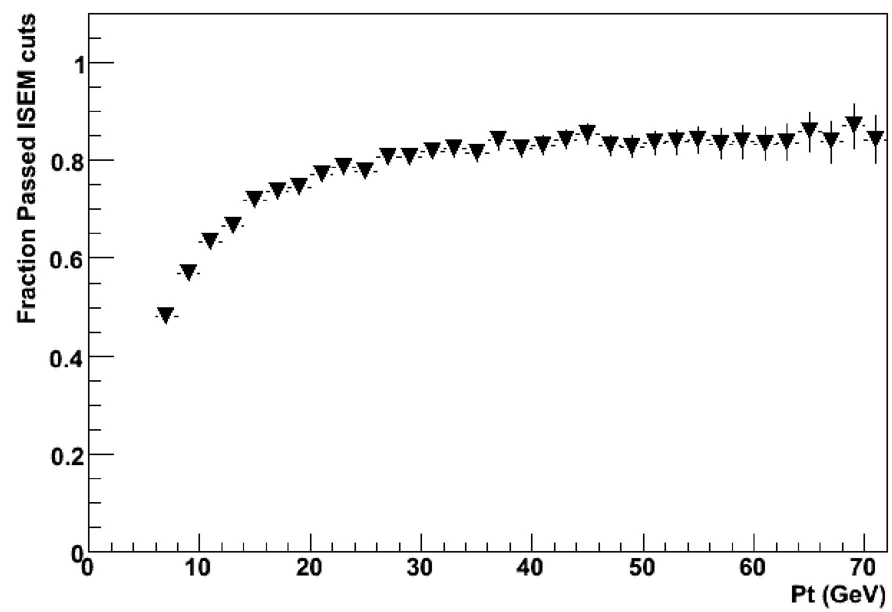




Performance studies /validation of samples H→4e

"IsEm" efficiency versus **η** ,P_t

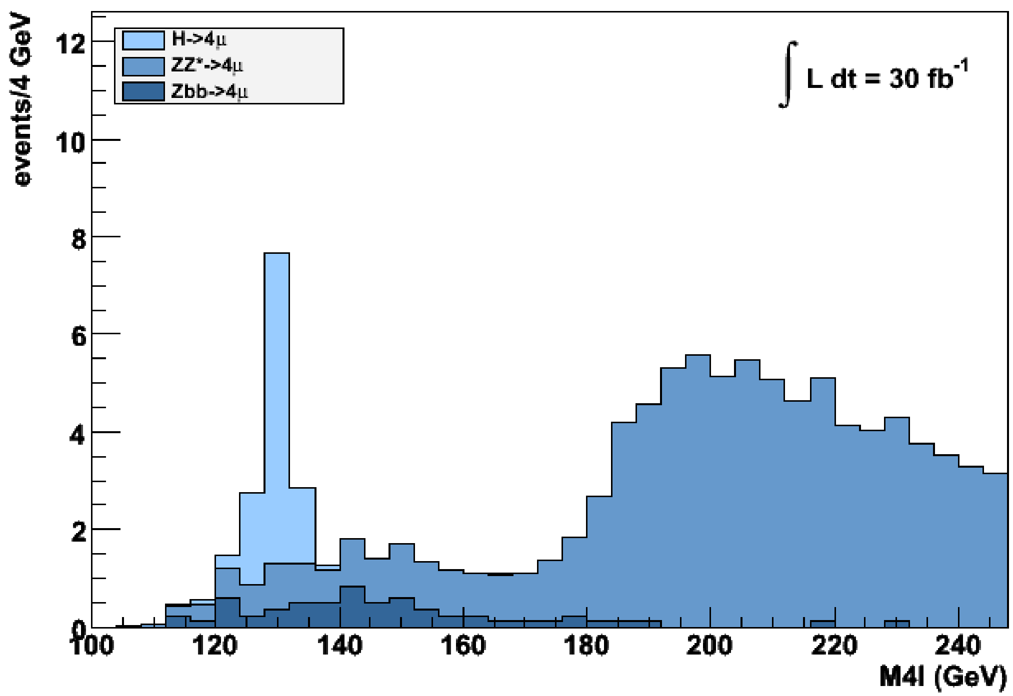




Cut flow in H→4μ channel, mass plot (30 fb $^{-1}$)

Relative efficiencies (%) for signal + bckg starting from a 4l (l=e,μ) sample

Cuts	H→4μ	ZZ*→4μ	Zbb→4μ
4μ combined in η range	18%	16%	8%
4μ combined Pt>7 GeV	88%	92%	51%
2μ combined Pt>20 GeV	94%	98%	86%
Calo isolation	89%	85%	14%
Track isolation	95%	97%	49%
Impact Parameter cuts	96%	94%	56%
Z mass reconstruction	72%	92%	33%
Higgs mass window	92%	1%	11%
Total events per fb^{-1}	**0.31**	**0.08**	**0.02**

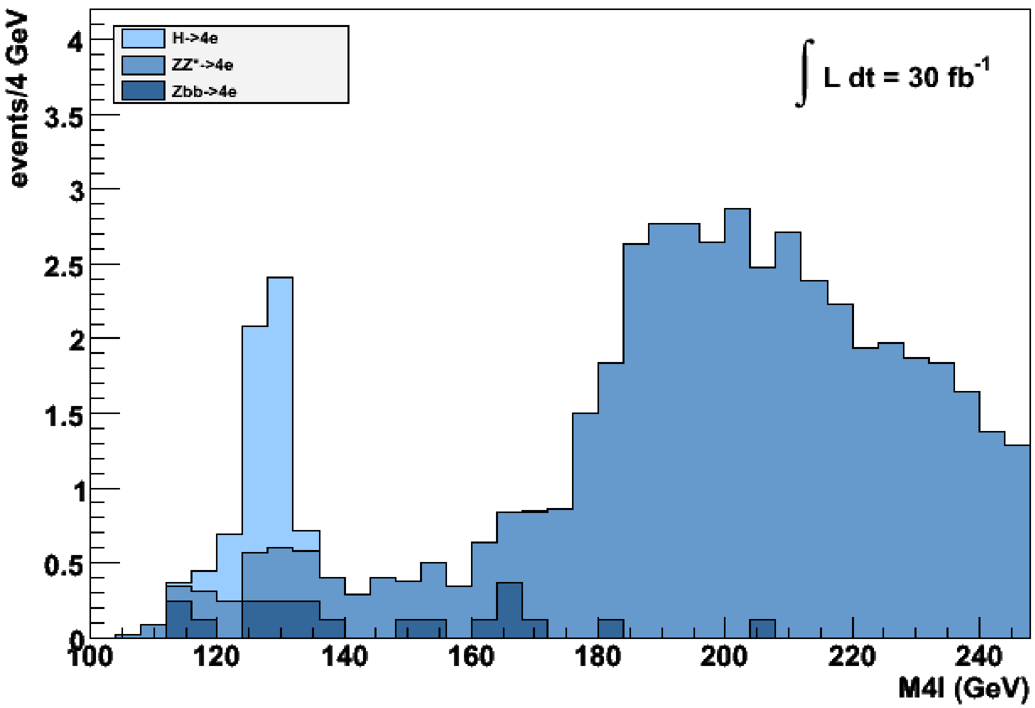


expect ~10 signal events in the mass window ±5 GeV from the Higgs mass of 130 GeV

Cut flow in H→4e channel, mass plot (30 fb $^{-1}$)

Relative efficiencies (%) for signal + bckg starting from a 4l (l=e,μ) sample

Cuts	H→4e	ZZ*→4e	Zbb→4e
4e combined in η range	8%	8%	0.6%
4e combined Pt>7 GeV	90%	96%	50%
2e combined Pt>20 GeV	95%	99%	84%
Calo isolation	96%	98%	74%
Track isolation	91%	88%	46%
Impact Parameter cuts	86%	83%	60%
Z mass cuts	66%	92%	36%
Higgs mass window	79%	1%	21%
Total events per fb^{-1}	**0.1**	**0.04**	**0.02**

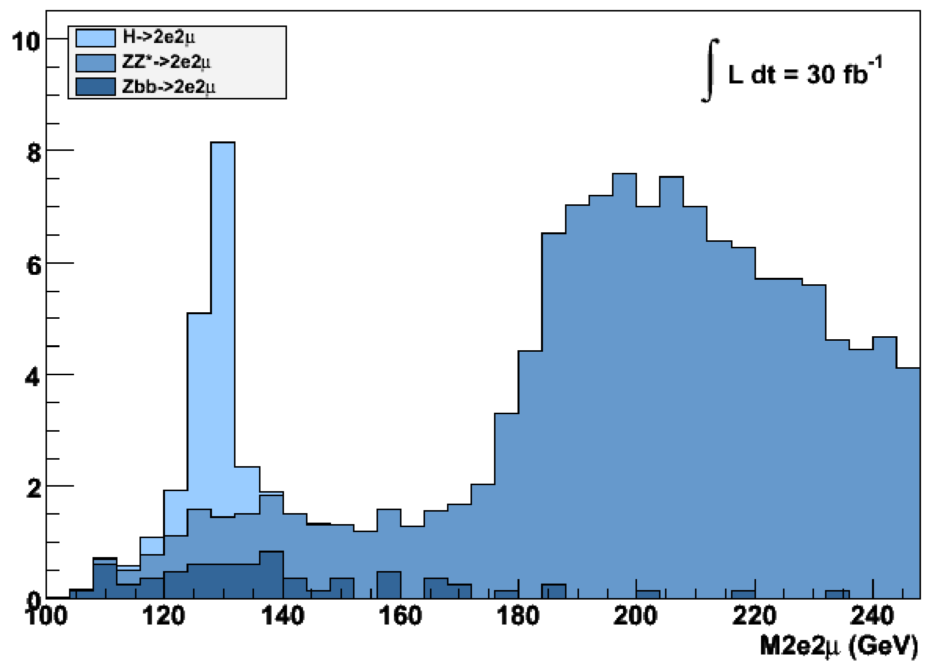


expect ~3 signal events in the mass window ±5 GeV from the Higgs mass of 130 GeV

Cut flow in H→2μ2e channel, mass plot (30 fb $^{-1}$)

Relative efficiencies (%) for signal + bckg starting from a 4l (l=e,μ) sample

Cuts	H→ 2μ2e	ZZ*→ 2μ2e	Zbb→ 2μ2e
2μ2e combined in η range	26%	26%	17%
4l combined Pt>7 GeV	83%	84%	26%
2l combined Pt>20 GeV	95%	98%	87%
Calo isolation	88%	89%	18%
Track isolation	94%	93%	47%
IPcuts	90%	88%	55%
Zmass cuts	68%	92%	42%
Higgs mass window	86%	1%	18%
Total events per fb $^{-1}$	**0.35**	**0.09**	**0.04**



expect ~10 signal events in the mass window ±5 GeV from the Higgs mass of 130 GeV

Conclusions Future plans

Current status of the H→4l analysis was presented.

- ***Software issues***: Test of the full ATLAS software chain and the grid tool without any particular problems.
  - Common tools within “ARTEMIS” were developed to perform this analysis

- ***CSC note***: Many groups working together cross checking their results; a good strategy for the start of data taking period.
  - Group ARTEMIS very active in this analysis, contributing to the preparation of the note

H→4l csc note

https://twiki.cern.ch/twiki/bin/view/Atlas/HiggsToFourLeptonsCSCnote

- ~14 institutes, ~40 people participating to the analysis
- Technical analysis: To ensure the consistency all analyses that (independent and based (in general) on different data formats,) a "test" of the analysis software implementing a "technical" set of selection cuts complemented by a set of reference plots.
  - **Cross checks of results proved to be very useful; Very good strategy to apply during real data taking period.**

e.g of results, tables produced out of this technical analysis

H-->2e2mu (Staco)

Cut	Artemis	Athens	Cosenza	Madrid	Orsay	Roma	SMU	Wisc AOD	Wisc AAN
none	39250	39250		39250		39250	39250	39250	39250
1.1	8133	7781				7781	7781	7782	7782
1.2	6413	6427				6427	6427	6444	6444
2.1-2.4	4353	4358				4357	4358	4358	4358
3.1		2306		2138		2306	2306	2306	2306
3.2	3653	3654		3357		3654	3654	3654	3654
3.3		4158		3834		4157	4158	4158	4158
4.1		3404		3319					
4.2		3265		3595					
5.x		2803		2696					

Conclusions Future plans

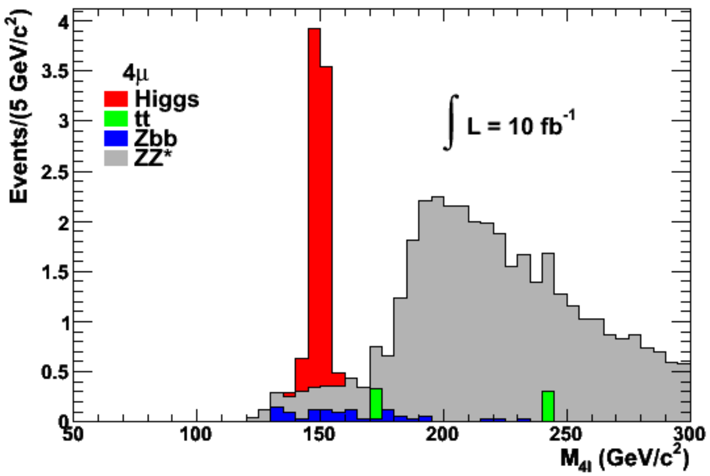
Within this analysis we are focusing our interest on the following areas /open issues:

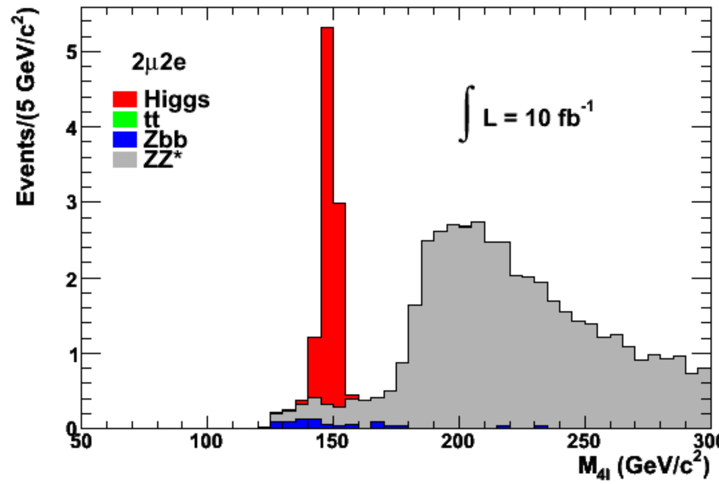
- Concerning the backgrounds:
  - We dispose of small statistics on the reducible backgrounds (tt, Zbb) ; need of more drastic filter cuts at generation level
  - Zbb background need to check carefully the various generators and the theoretical uncertainties on the calculation of cross sections
- Concerning the performance:
  - Studies, checks, validation of e,μ samples
- Concerning the software tools:
  - Try to have an analysis program flexible enough to adapt to the official ATLAS output scheme (DPD, root access e.t.c)

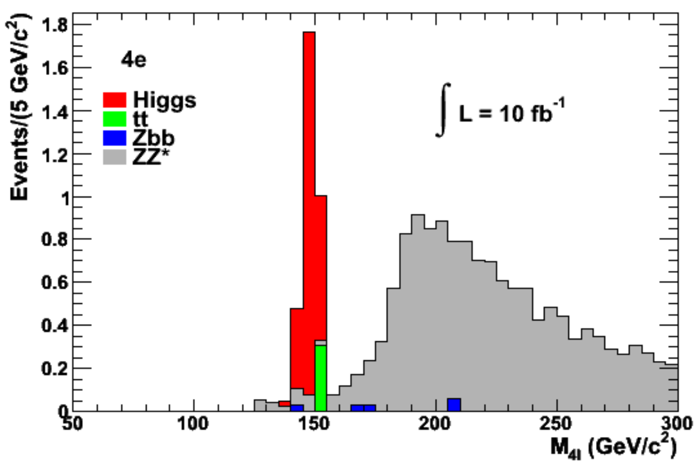
BACKUP SLIDES

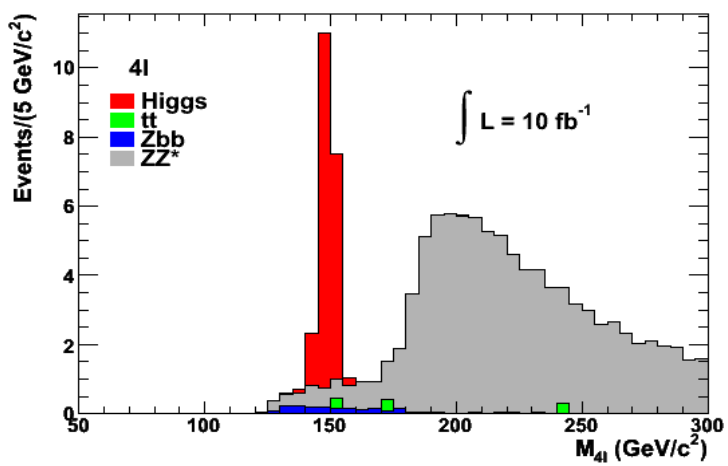
Signal + Background with 10 fb^{-1}

Plots from H→4lepton working group to be shown
From F. Gianotti on the 12th of September at the SPC meeting









Particle Identification /electrons

- cut on fraction of energy deposited in 1st sampling

PhysicsElectronTester.CutF1 = [0.005]

- cut on hadronic energy

PhysicsElectronTester.CutHadLeakage = [0.018, 0.018, 0.020, 0.045, 0.030, 0.025, 0.015]

- cut on ratio e237/e277

PhysicsElectronTester.CutReta37 = [0.800, 0.800, 0.600, 0.850, 0.910, 0.910, 0.910]

- cut on shower width in 2nd sampling

PhysicsElectronTester.CutWeta2c = [0.0140, 0.0140, 0.020, 0.0150, 0.0140, 0.0140,0.0125]

- cut on Delta Emax2 in 1st sampling

PhysicsElectronTester.CutDeltaEmax2 = [0.25, 0.45, 0.45, 0.53, 0.40, 0.40, 0.30]

- cut on Emax2 - Emin in 1st sampling

PhysicsElectronTester.CutDeltaE = [150., 150., 100., 300., 200., 150., 150.]

- cut on total width in 1st sampling

PhysicsElectronTester.CutWtot = [4.00, 4.00, 3.00, 3.10, 2.10, 1.55, 1.40]

- cut on width in 1st sampling

PhysicsElectronTester.CutWeta1c = [0.80, 0.80, 0.75, 0.75, 0.68, 0.65, 0.60]

- cut on Fside in 1st sampling

PhysicsElectronTester.CutFracm = [0.35, 0.48, 0.47, 0.48, 0.27, 0.25, 0.20]

Conclusions Future plans

- What can do in this channel with different $\mathscr{L}$?
  - 1fb^{-1} : Concentrate on performance studies
  - 10 fb^{-1} : H→4l channel already feasible…
  - 30 fb^{-1} : H→4l channel clearly feasible

Number of expected events in the Higgs mass window ± 5 GeV from the Higgs mass of 130 GeV.

Integrated Luminosity	H→4l (m_H=130 GeV)	ZZ→4l	Zbb→4l
1 fb^{-1}	0.8	0.2	0.08
10 fb^{-1}	8	2.1	0.8
30 fb^{-1}	24	6.3	2.4