Higgs searches in the H→bb channel

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Course Physics at the LHC
9th July 2012

Outline

- Introduction
  - Why H→bb?
- ATLAS detector
- Reconstruction of leptons, jets, missing ET at ATLAS
- WH
- ZH
- Exclusion limits

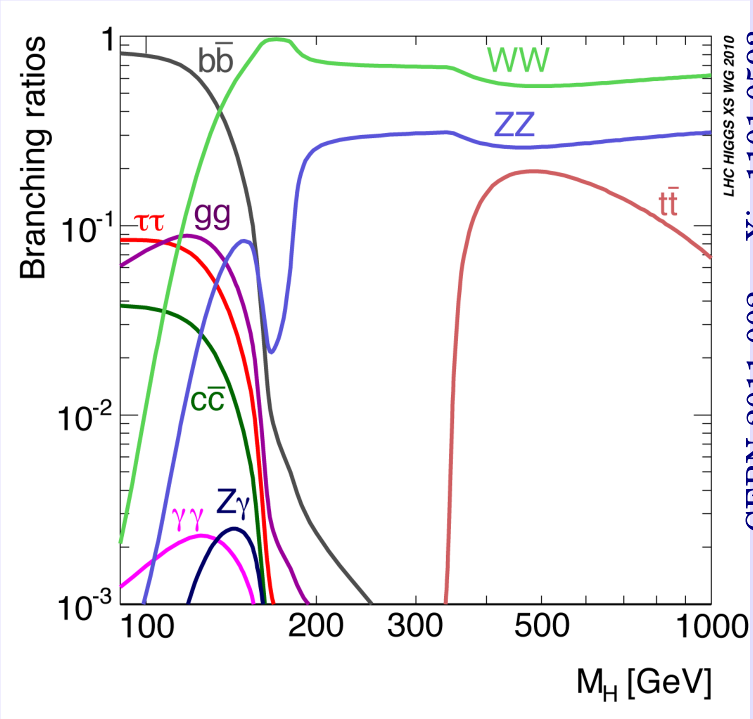
Higgs decays in the SM

Decay branching ratios depend on the Higgs mass

- Low mass range:
  - H→bb dominates
    - Affected by large QCD background
  - H→γγ and H→ZZ have small BR but clear signatures

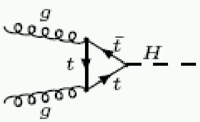
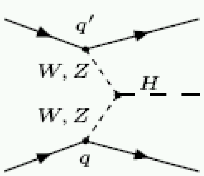
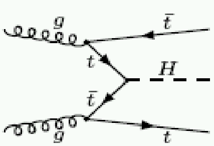
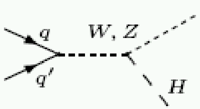
H→bb decay

- It can add new information to searches
- Important to test Higgs boson nature:
  - Might get enhanced in SUSY!
  - Can provide a measurement of the Higgs couplings to quarks

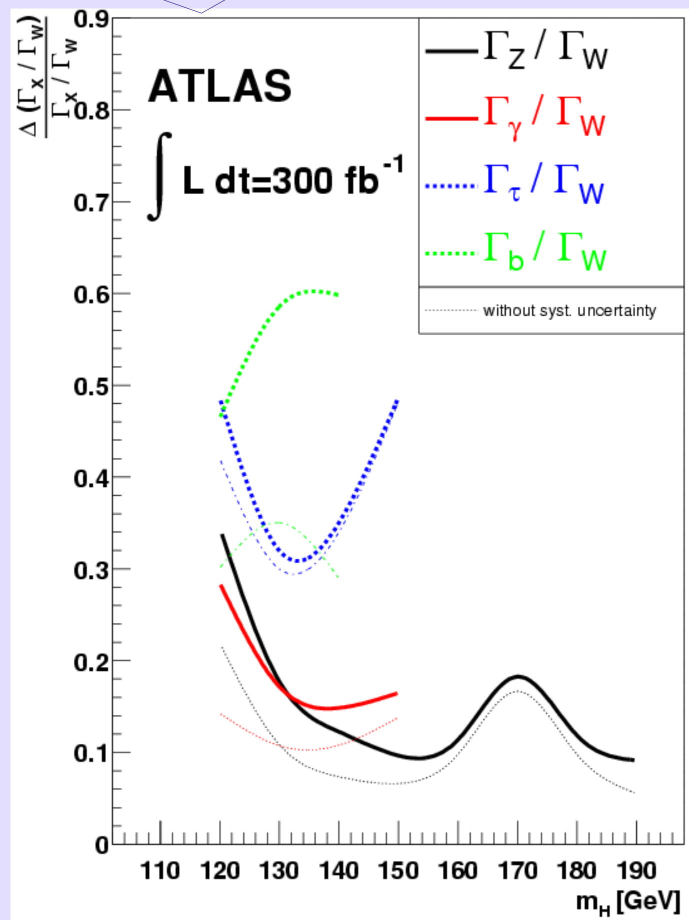


CERN-2011-002; arXiv:1101.0593

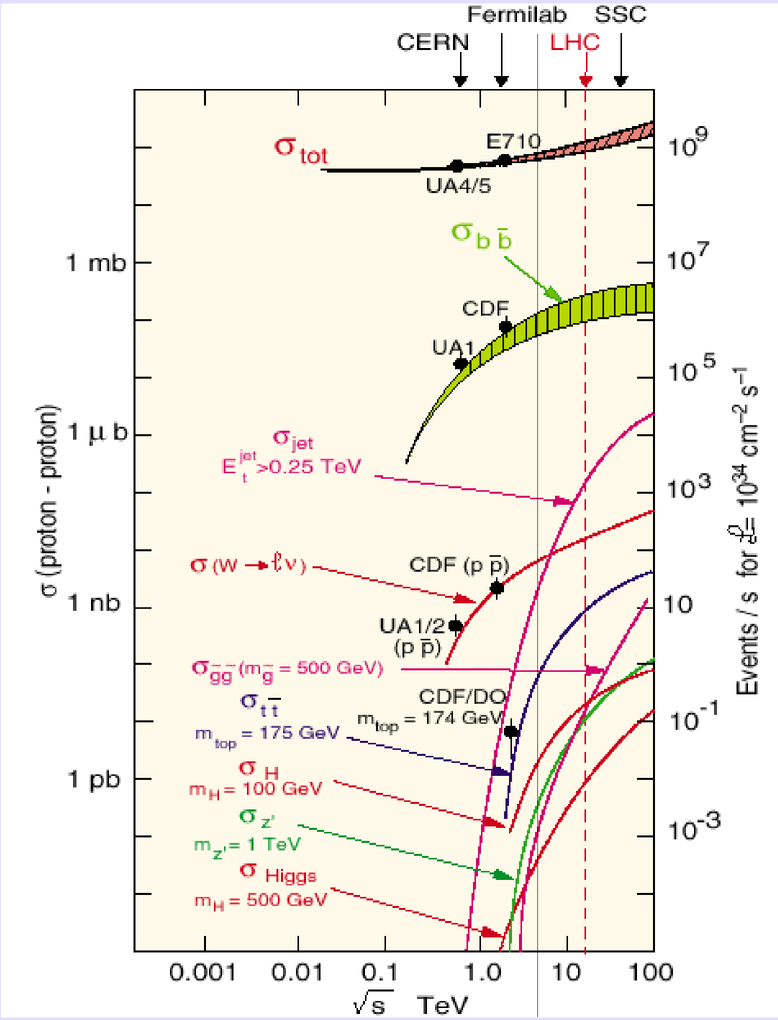
Higgs couplings

	Production	Decay
	GF: Gluon Fusion $(gg \to H)$	$H \to ZZ^{(*)} \to 4l$ $H \to WW^{(*)} \to l\nu\, l\nu$ $H \to \gamma\gamma$
	WBF: Weak Boson Fusion $(qq\,H)$	$H \to ZZ^{(*)} \to 4l$ $H \to WW^{(*)} \to l\nu\, l\nu$ $H \to \tau\tau \to l\nu\nu\, l\nu\nu$ $H \to \tau\tau \to l\nu\nu\,had\nu$ $H \to \gamma\gamma$
	$t\bar{t}H$	$H \to WW^{(*)} \to l\nu\, l\nu\, (l\nu)$ $H \to b\bar{b}$ $H \to \tau\tau$ (not included) $H \to \gamma\gamma$
	WH	$H \to WW^{(*)} \to l\nu\, l\nu\, (l\nu)$ $H \to \gamma\gamma$
	ZH	$H \to \gamma\gamma$

Global fit

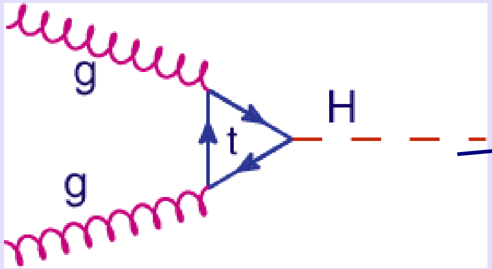


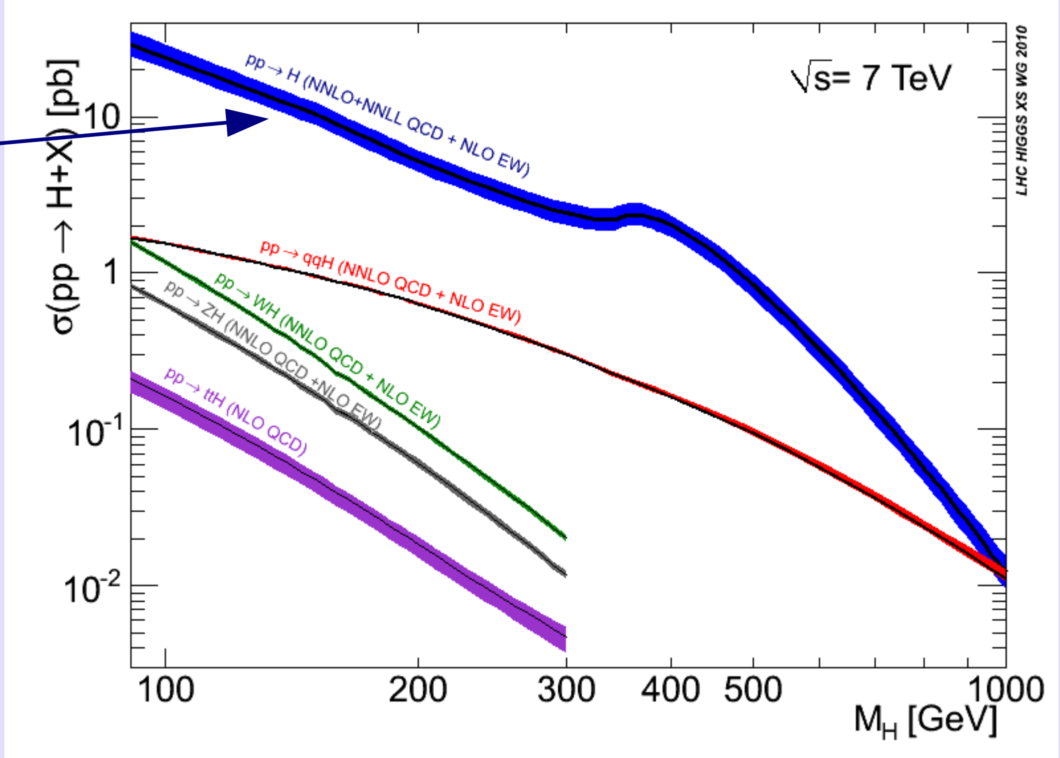
Main backgrounds



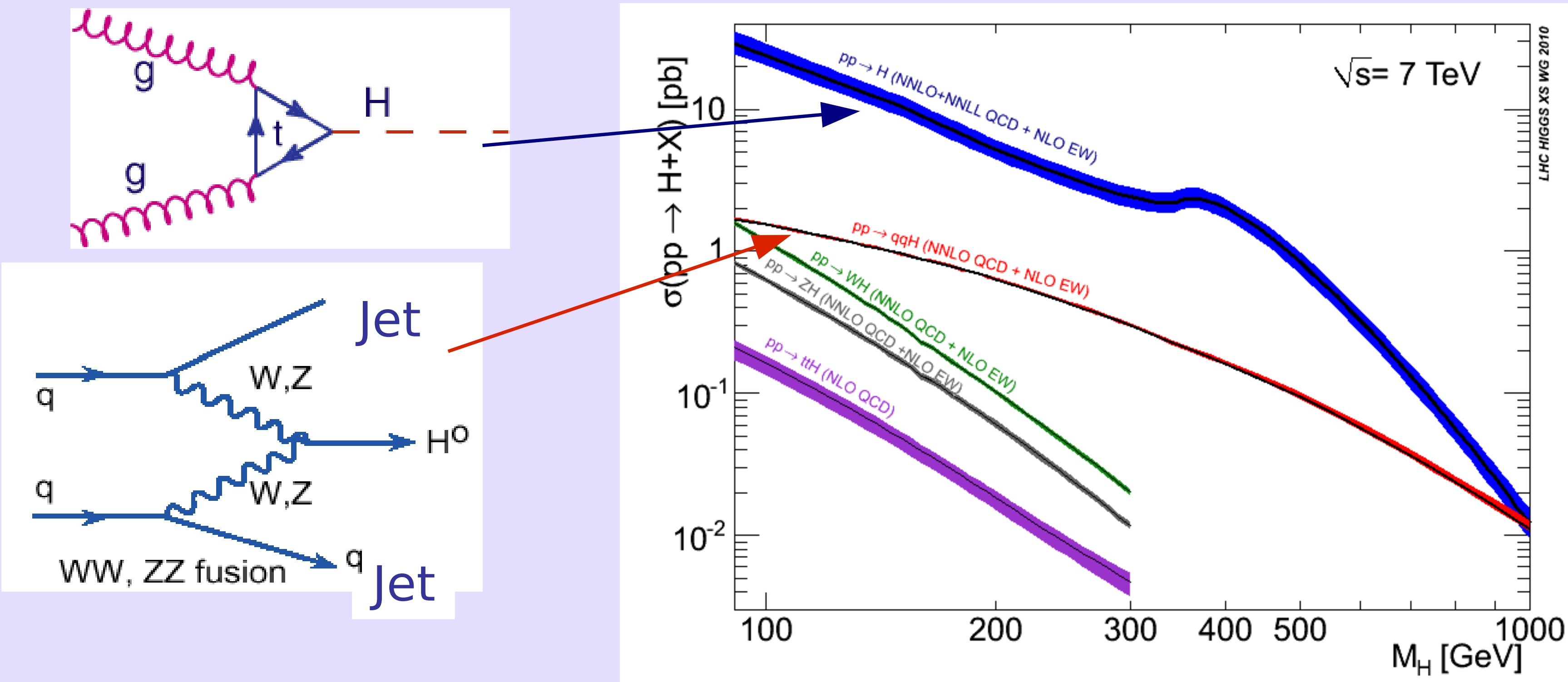
- The di-bjet cross section is about 8 orders of magnitude larger than the Higgs cross section!
- Impossible to isolate a direct pp→H→bb signal
- Will need some handles to lower background
  - Leptons
  - Missing E_T
  - Forward jets

Higgs production



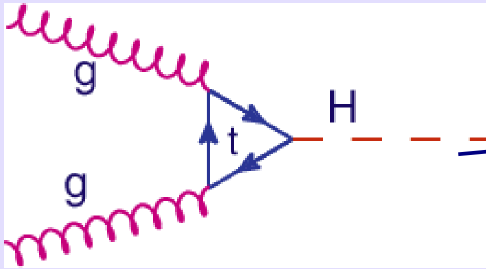


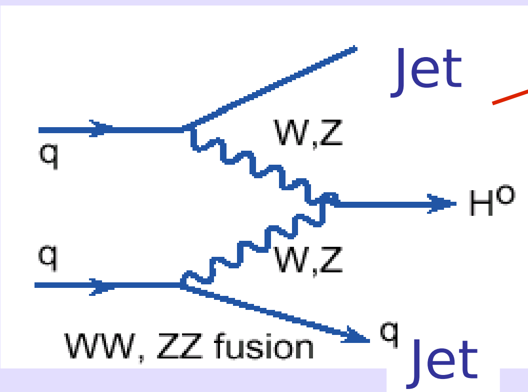
Higgs production

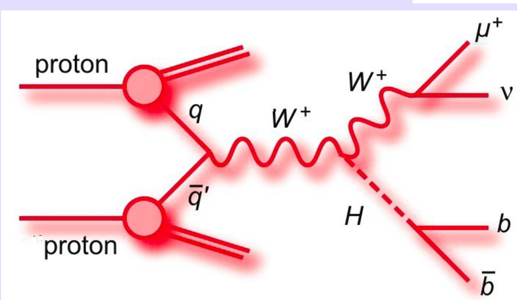


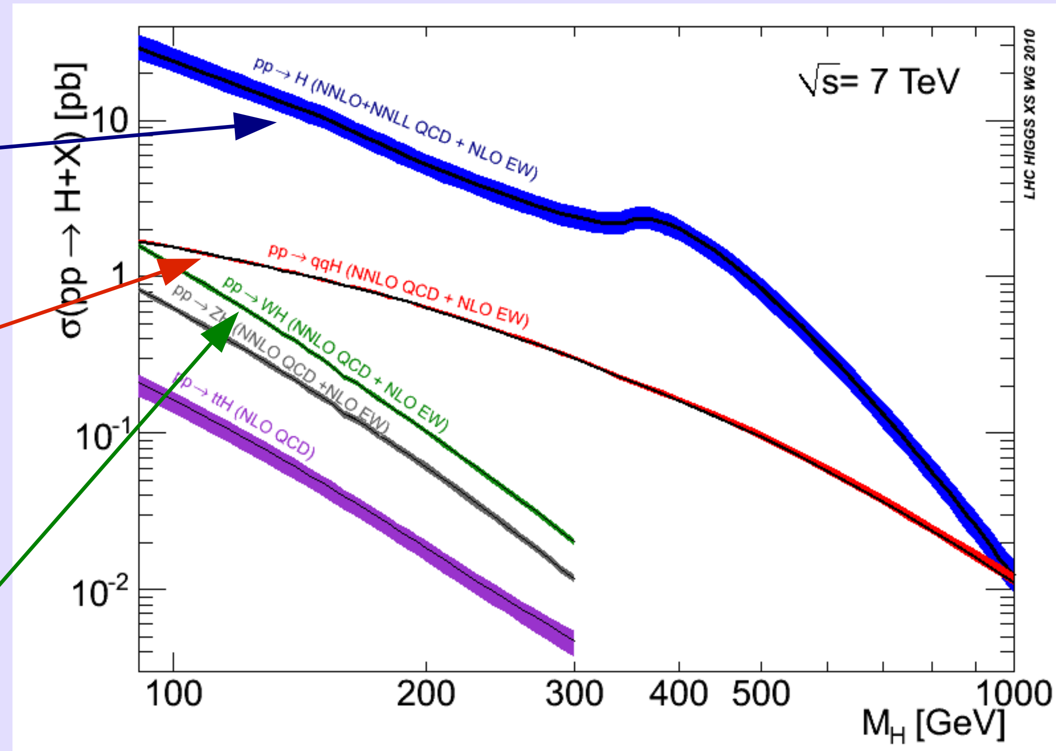
- Two very forward/backward jets produced
- Higgs produced centrally
- Rapidity gap without hadronic activity

Higgs production









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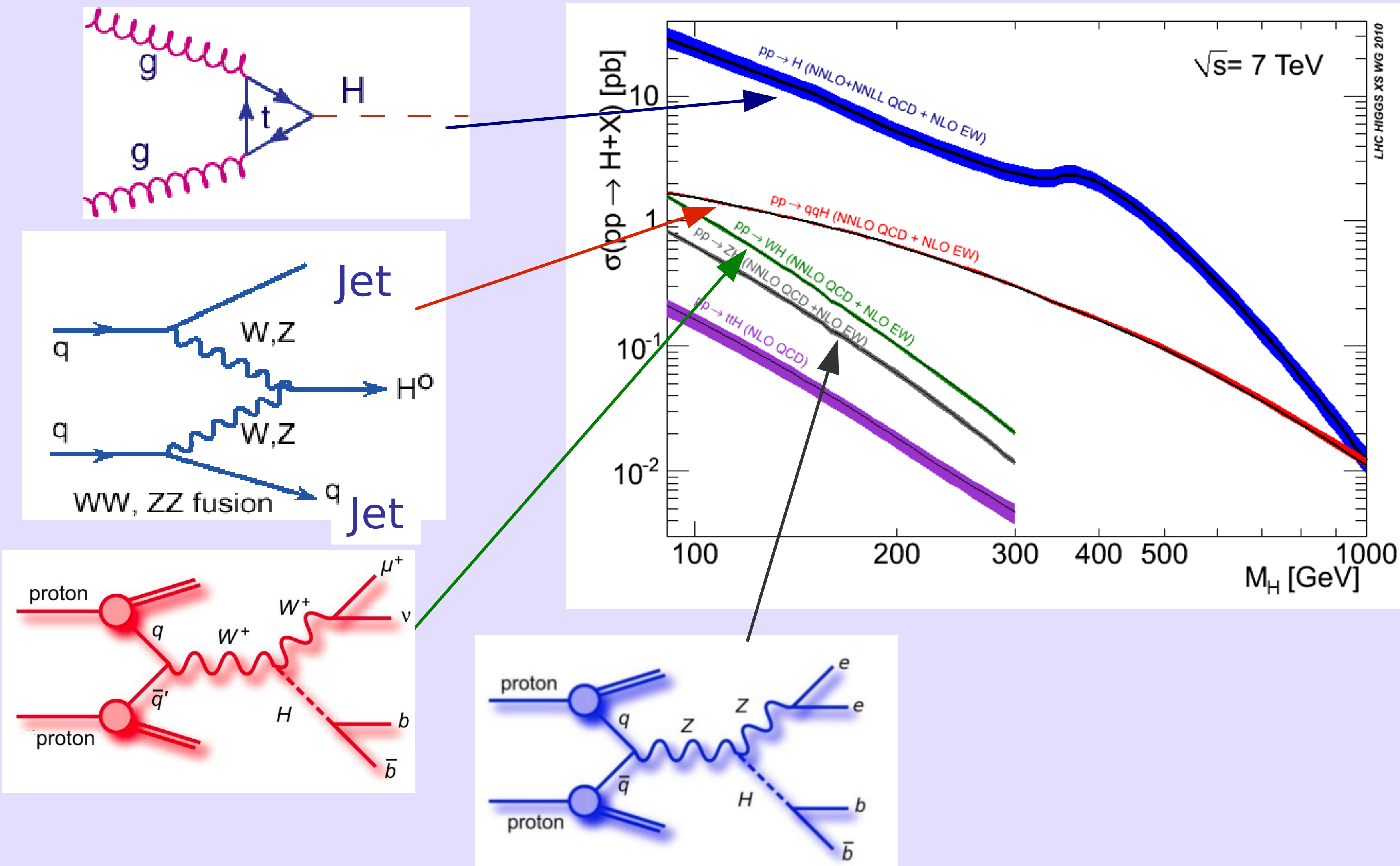
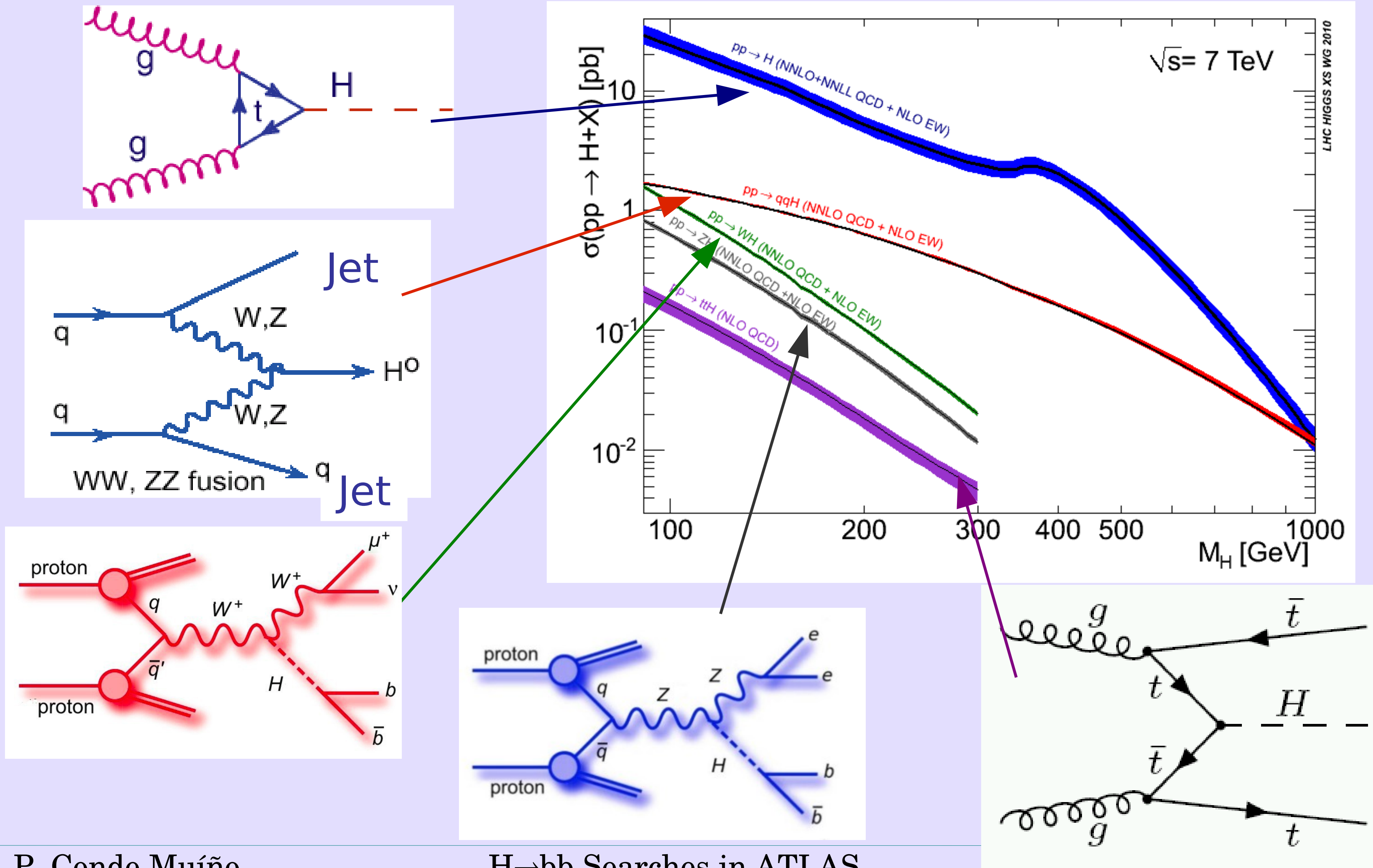


Higgs production



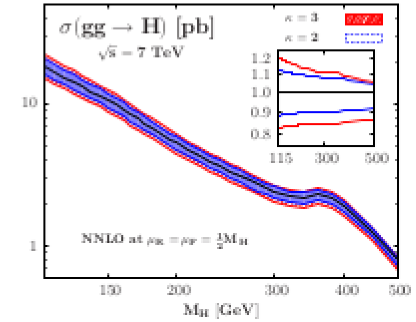
5. SM Higgs production: gg fusion

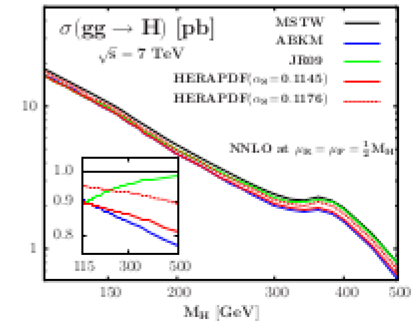
Despite of that, the $gg \to H$ cross section still affected by uncertainties

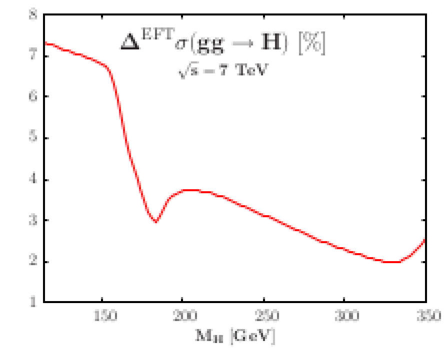
- **Higher-order or scale uncertainties:**
  K-factors large $\Rightarrow$ HO could be important
  HO estimated by varying scales of process
  $$\mu_0/\kappa \le \mu_R, \mu_F \le \kappa\mu_0$$
  at lHC: $\mu_0 = \frac{1}{2}M_H, \kappa = 2 \Rightarrow \Delta_{scale} \approx 10\%$
- **gluon PDF+associated α_s uncertainties:**
  gluon PDF at high–x less constrained by data
  α_s uncertainty (WA, DIS?) affects $\sigma \propto \alpha_s^2$
  $\Rightarrow$ large discrepancy between NNLO PDFs
  PDF4LHC recommend: $\Delta_{pdf} \approx 10\%$@lHC
- **Uncertainty from EFT approach at NNLO**
  $m_{loop} \gg M_H$ good for top if $M_H \lesssim 2m_t$
  but not above and not b ($\approx 10\%$), W/Z loops
  Estimate from (exact) NLO: $\Delta_{EFT} \approx 5\%$
- **Include ΔBR(H$\to$X) of at most few %**

total $\Delta\sigma^{NNLO}_{gg \to H \to X} \approx 20$–25%@lHC

LHC-HxsWG; Baglio+AD $\Rightarrow$



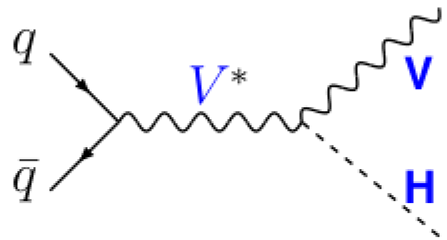




5. SM Higgs production: associated HV

Let us look at all the main Higgs production channels at the LHC:

The associated HV production:



$$\hat{\sigma}_{\rm LO}(q\bar{q} \to VH) = \frac{G_\mu^2 M_V^4}{288\pi\hat{s}} \times (\hat{v}_q^2 + \hat{a}_q^2)\lambda^{1/2} \frac{\lambda + 12M_V^2/\hat{s}}{(1 - M_V^2/\hat{s})^2}$$

Similar to $e^+e^- \to HZ$ process used for Higgs searches at LEP2.

Cross section $\propto \hat{s}^{-1}$ sizable only for low $M_H \lesssim 200$ GeV values.

Cross section for $W^\pm H$ approximately 2 times larger than ZH.

In fact, simply Drell–Yan production of virtual boson with $q^2 \neq M_V^2$

$$\hat{\sigma}(q\bar{q} \to HV) = \hat{\sigma}(q\bar{q} \to V^*) \times \frac{d\Gamma}{dq^2}(V^* \to HV)$$

$\Rightarrow$ radiative corrections are mainly those of the known DY process

(at 2-loop, need to consider also $gg \to HZ$ through box which is $\neq$).

Foz do Arelho, 6–9/09/2011 Higgs Phenomenology – A. Djouadi – p.25/84

5. SM Higgs production: associated HV

Radiative corrections needed:

– for precise determination of σ

– stability against scale variation

HO also needed to fix scales:

– renormalization μ_R for α_s

– factorization μ_F for matching.

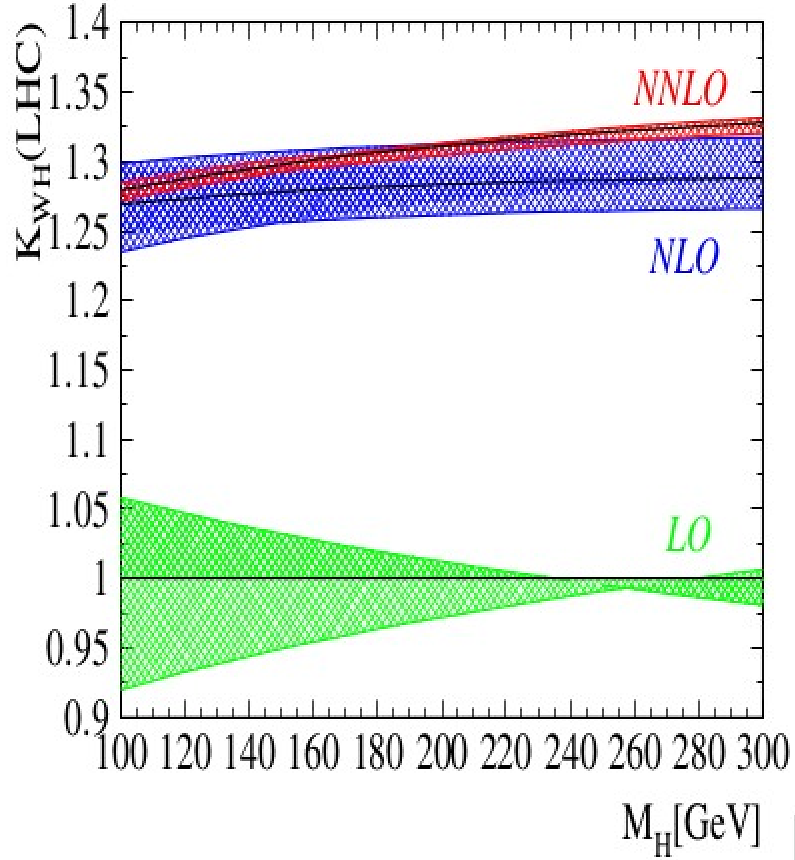
RC parameterized by K–factor:

$$K = \frac{\sigma_{HO}(pp \to H+X)}{\sigma_{LO}(pp \to H+X)}$$

Can also define K-factor at LO.

QCD RC known up to NNLO.

EW RC known at $\mathcal{O}(\alpha)$: small.



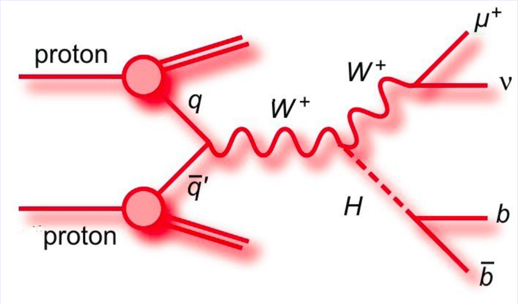
VH search at ATLAS

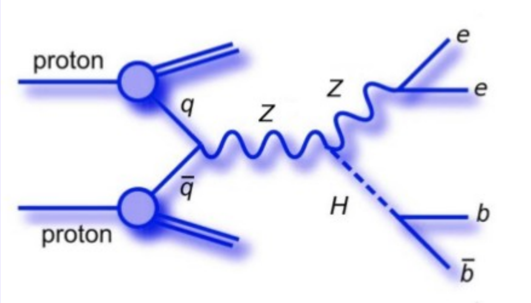
ATLAS has searched for the H➔bb in the associated production channel VH

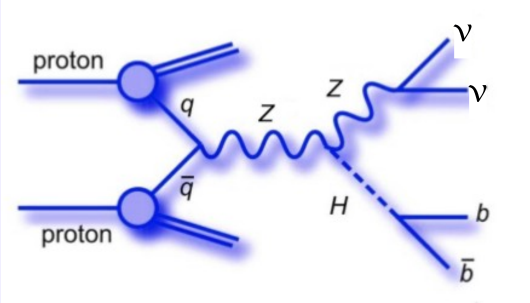
- Search channels:
  - pp→ WH → lν bb
  - pp→ ZH → ll bb
  - pp→ ZH → νν bb

  where l = μ, e (applies to the WH and ZH → ll bb channels)

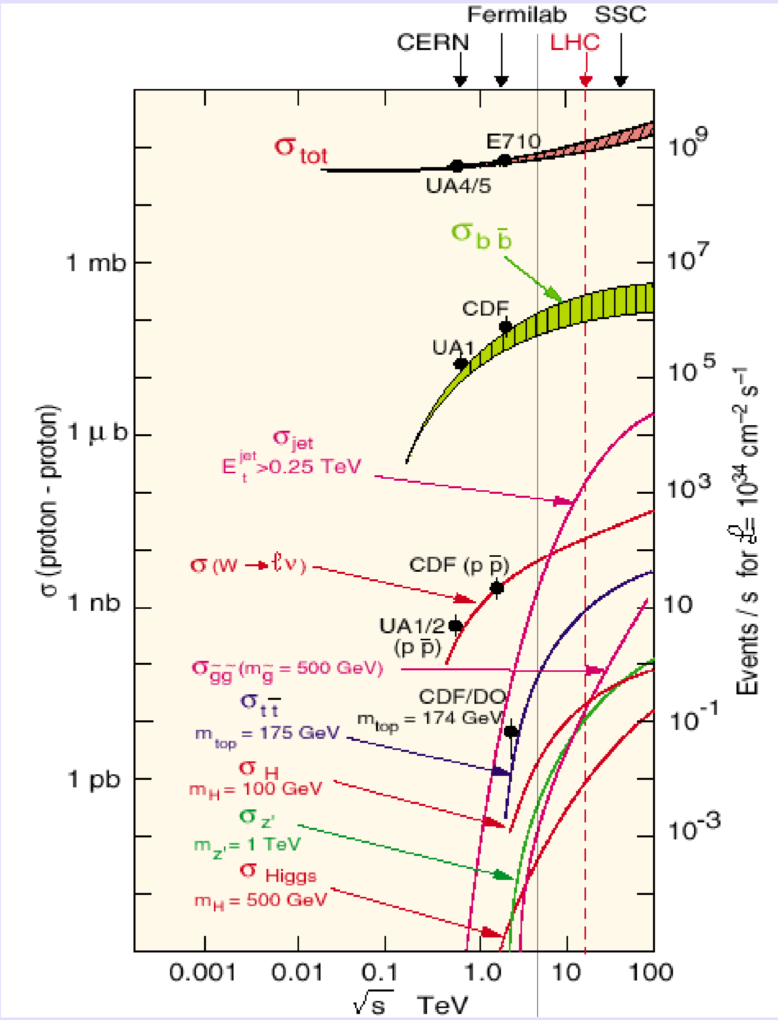
- Clean signatures:
  - High p_T isolated leptons
  - Two b-jets
  - Large E_T^{miss} in the WH channel
  - Very large E_T^{miss} in ZH → νν bb
- **Depend on all sub-detectors!!**





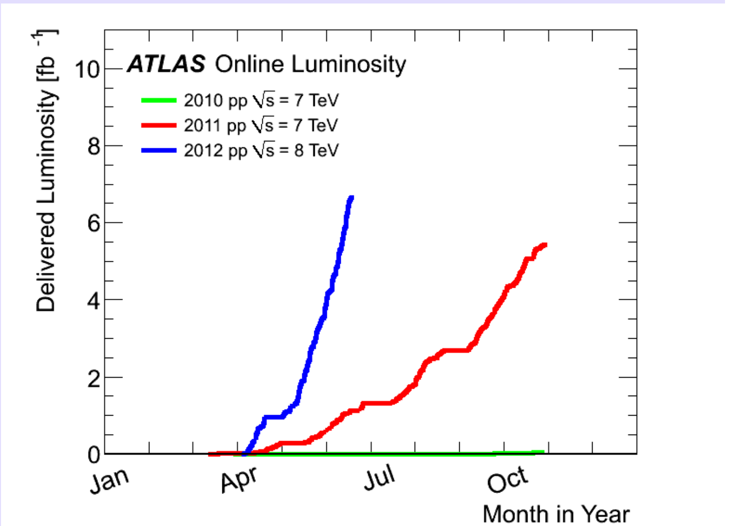


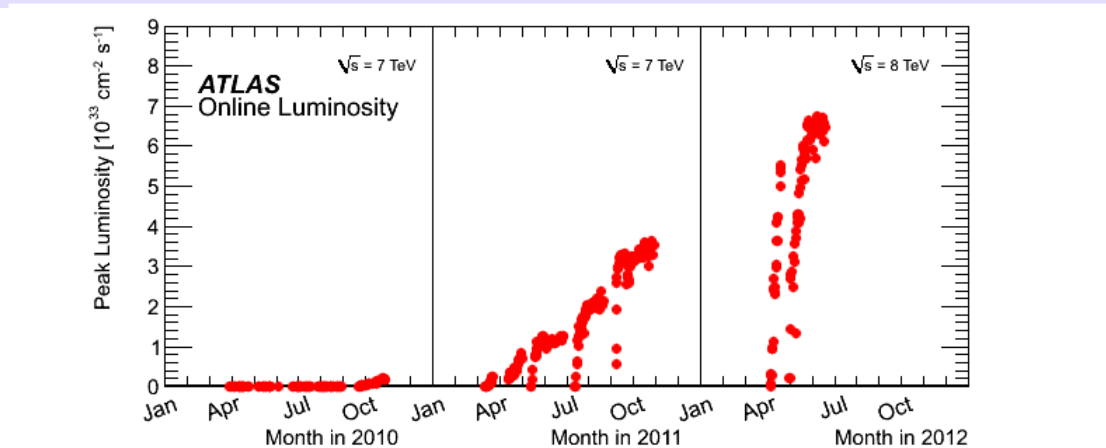
Main backgrounds

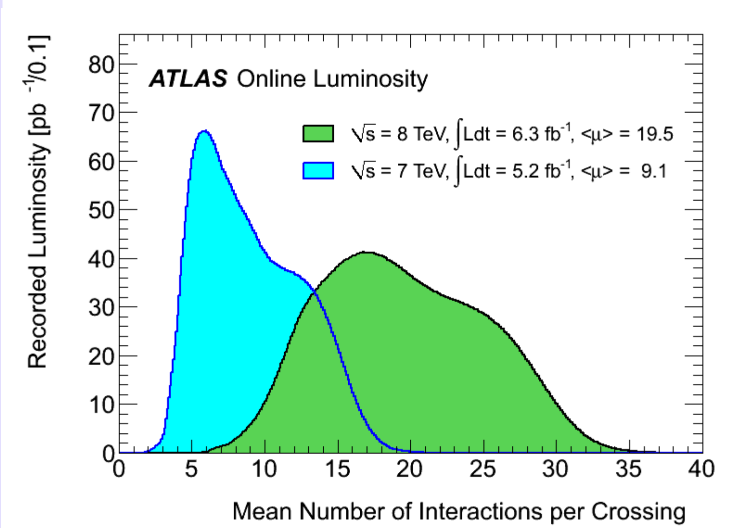


- SM backgrounds:
  - W/Z+jets
  - QCD multijet production
  - Top quark production
  - Di-boson production: WZ, WW, ZZ
- $\sigma_{WH} \approx 2 \cdot \sigma_{ZH}$ but ZH less affected by top background

LHC delivered data







Data sample used for the H→bb results that follow:

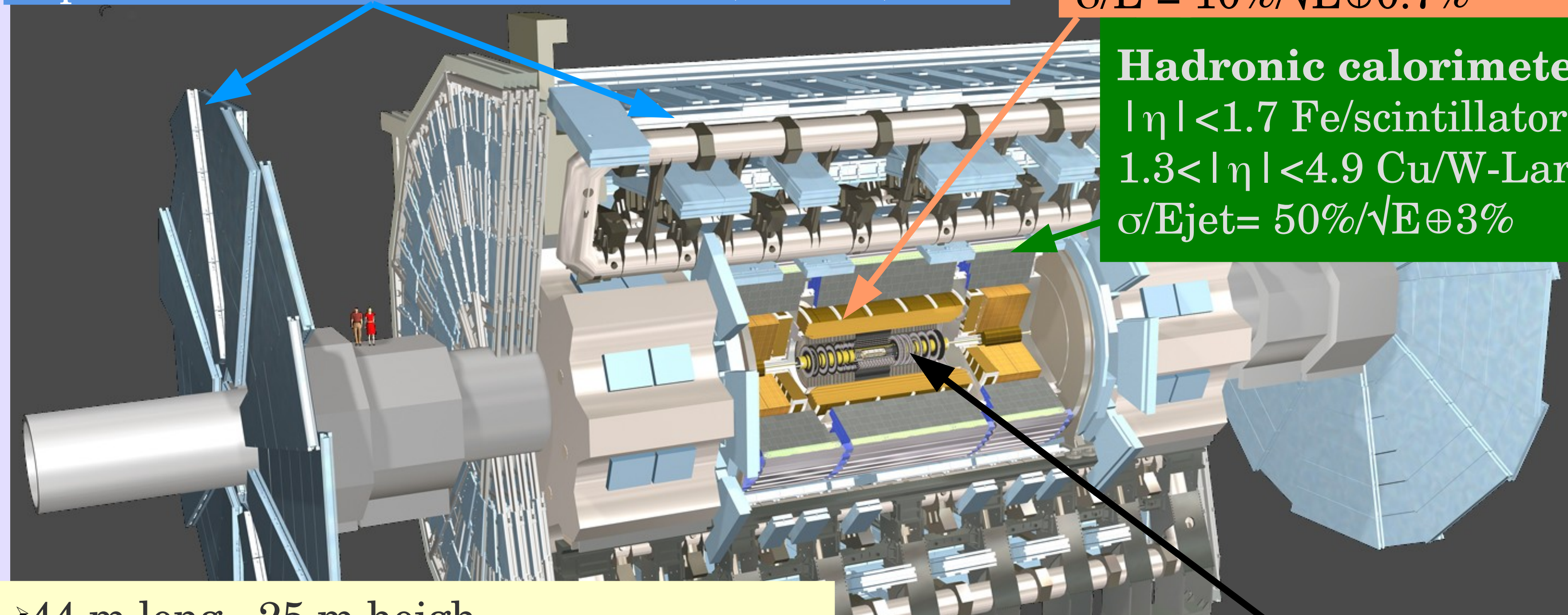
- 5.2 fb^{-1} of 7 TeV pp collisions
- Average pile-up: 6.3/11.6

The ATLAS detector

Muon Spectrometer: |η|<2.7
Air-core toroids and gas-based muon chambers
σ/p_T = 2% @ 50GeV to 10% @ 1TeV (ID+MS)

EM calorimeter: |η|<3.2
Pb-LAr Accordion
$\sigma/E = 10\%/\sqrt{E} \oplus 0.7\%$

Hadronic calorimeter:
|η|<1.7 Fe/scintillator
1.3<|η|<4.9 Cu/W-Lar
$\sigma/E_{jet} = 50\%/\sqrt{E} \oplus 3\%$

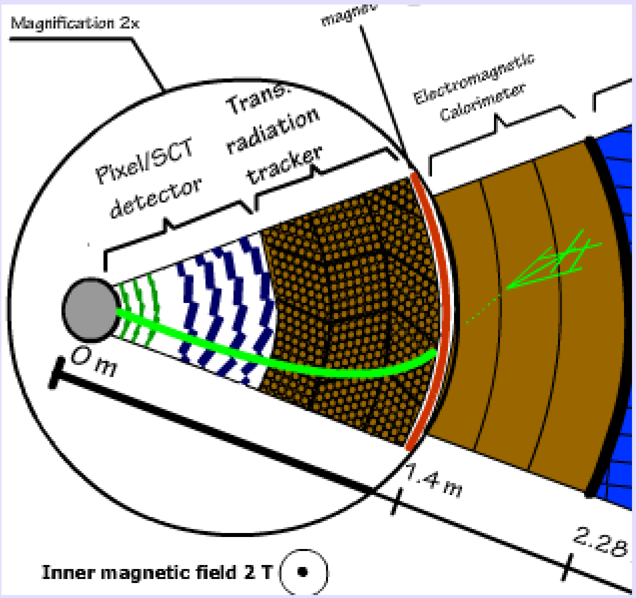


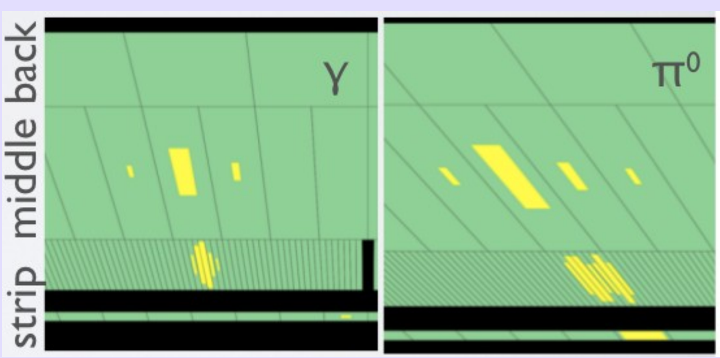
- 44 m long, 25 m heigh
- ≈10^8 electronic channels
- 3-level trigger reducing 40 MHz collision rate to 300 Hz of events to tape

Inner Tracker: |η|<2.5, B=2T
Si pixels/strips and Trans. Rad. Det.
$\sigma/p_T = 0.05\%\ p_T\ (\mathrm{GeV}) \oplus 1\%$

Object reconstruction

Electrons

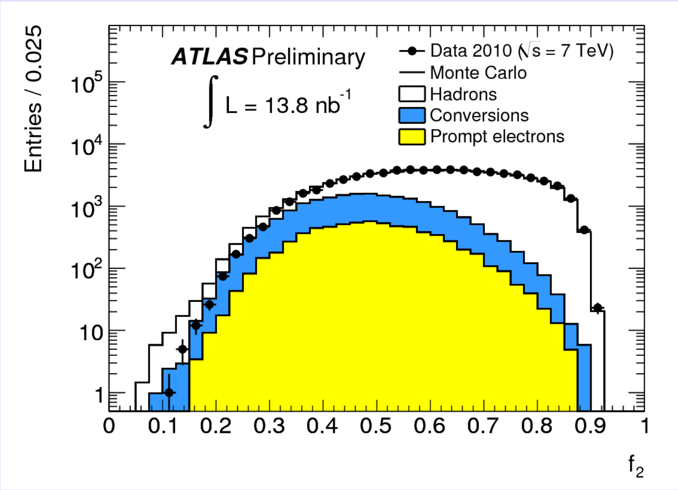


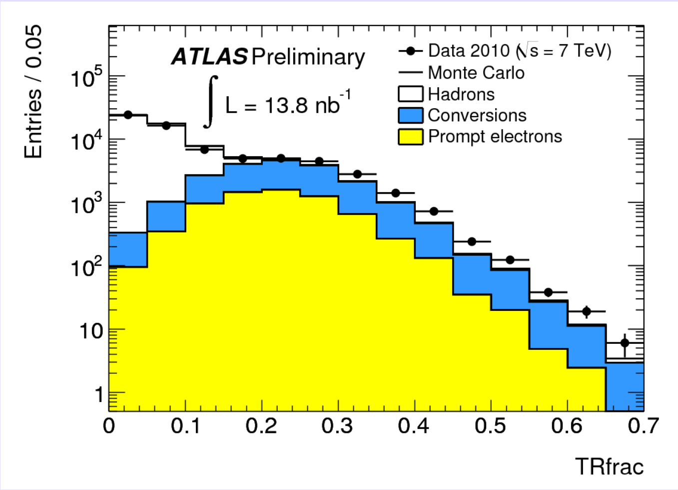


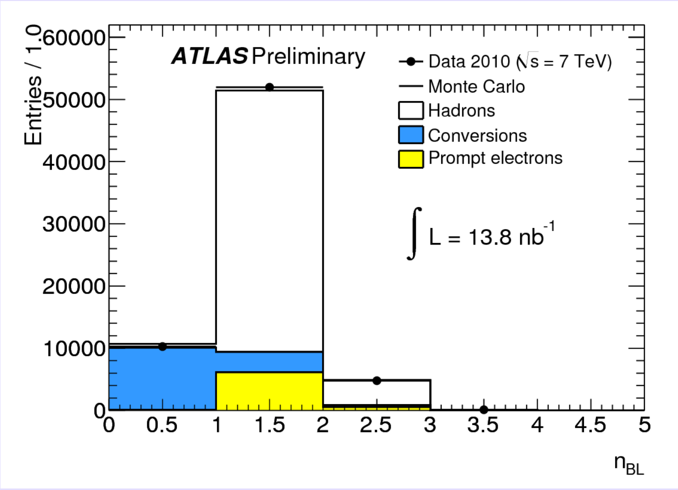
- EM calorimeter clusters:
  - Small leakage in Had. Calorimter
  - Most energy deposited in the second sampling of the EM calorimeter
    - Narrow shower
  - Shower shape in first sampling
- Matching Inner Detector track
  - Good quality
  - Exploit transition radiation
    - Count high thresholds hits in TRT
  - E/p
  - B-Layer hit, track pointing toPV

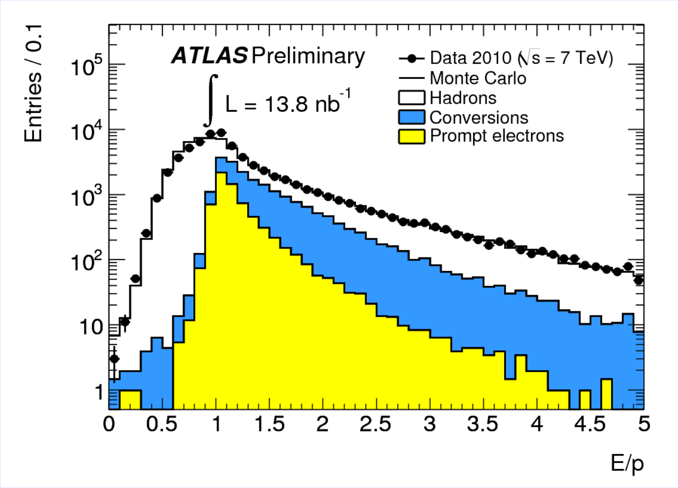
All information combined in a tight id.

Electrons (II)



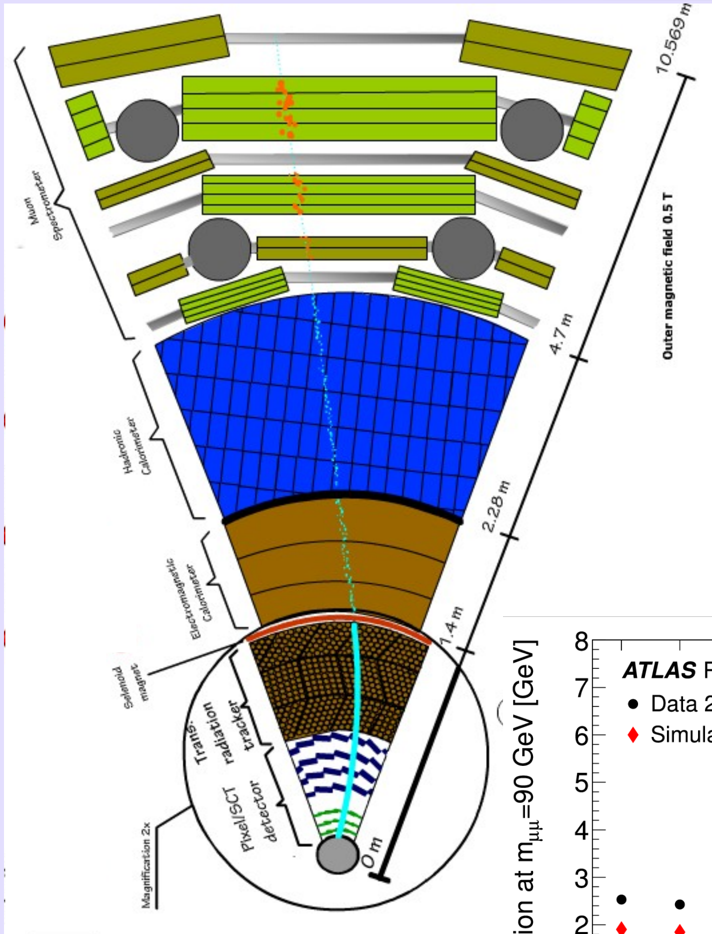


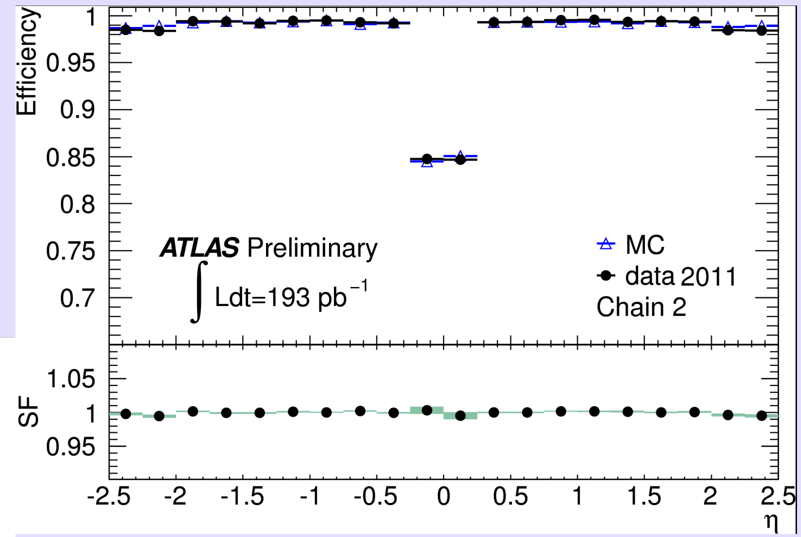


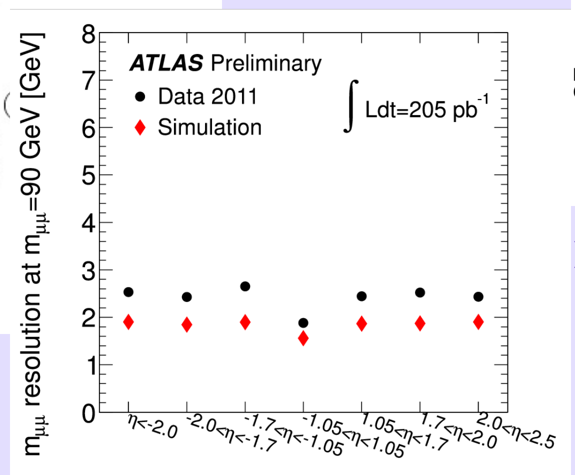


Muons

- Identified by an ID track with
  - Match to muon track
  - Match to a muon segment

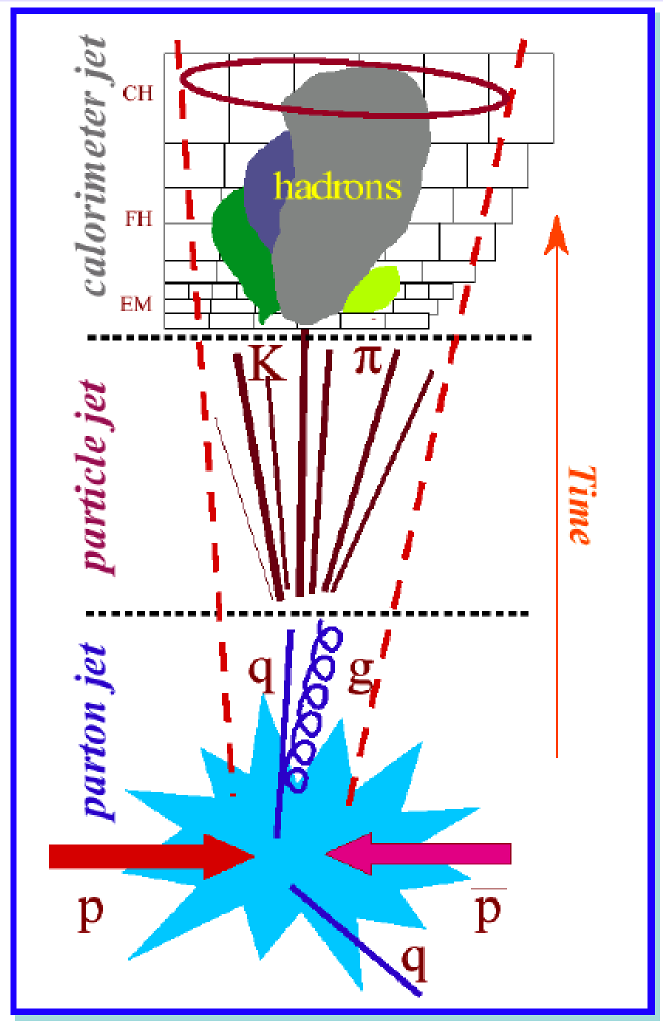






- Monte Carlo simulation corrected to reproduce muon resolution

Jet reconstruction



- B-quarks cannot be reconstructed
  - Recombination into hadrons
  - Subsequent hadron decays
- Can only see *jets* of particles
  - Parton level: outgoing partons
  - Hadron level: spray of long lived observable particles
  - Calorimeter level: energy depositions
- Jet algorithms:
  - Relate the measurements to the original partons
  - Should have the same behaviour at parton, particle and detector level

Anti-kT algorithm

1. Start with a list of preclusters.

2. For each precluster i, define

$$d_i = p_{T,i}^{-2}$$

For each pair of preclusters,

$$d_{ij} = \min(p_{T,i}^{-2}, p_{T,j}^{-2}) \frac{\Delta R_{ij}^2}{D^2}$$

3. Find the minimum of all d_i and d_{ij}.

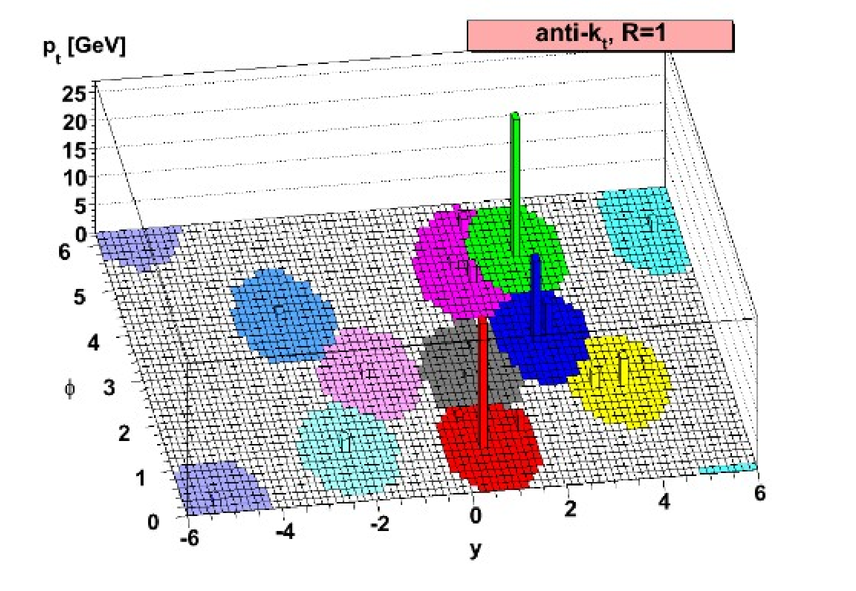
4. If d_{min} is a d_{ij}, merge preclusters i and j into a new precluster.

5. If d_{min} is a d_i, precluster i is a jet.

6. Repeat until no preclusters remain.

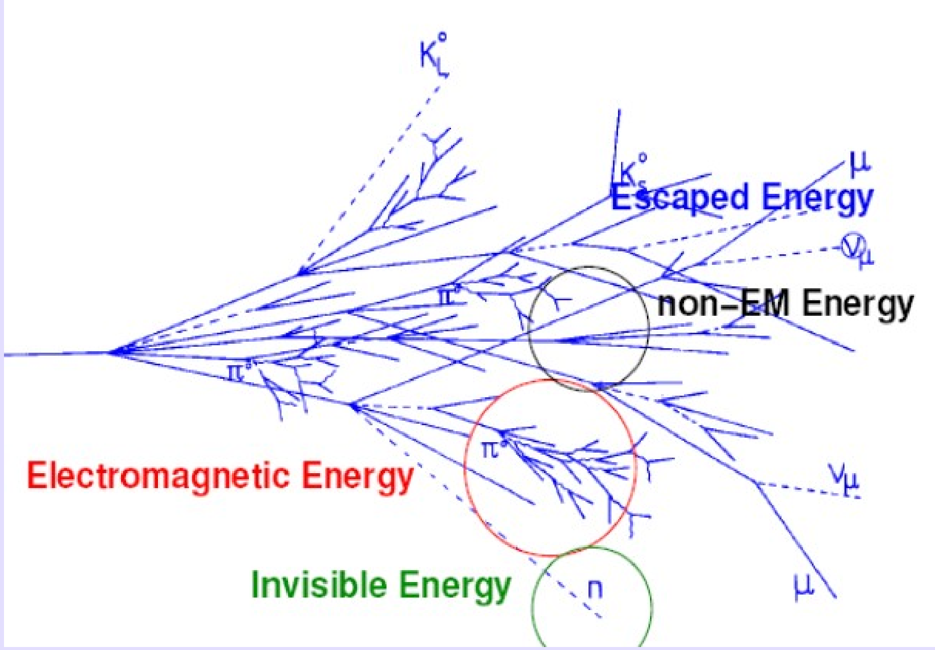
/5/09 Kerstin Perez, ISSI

- Merge objects with high relative k_T
- Soft stuff within R of a high k_T object will be merged with it.
- If two hard jets are close the energy will be shared based on ΔR_{ij}



Jet energy calibration

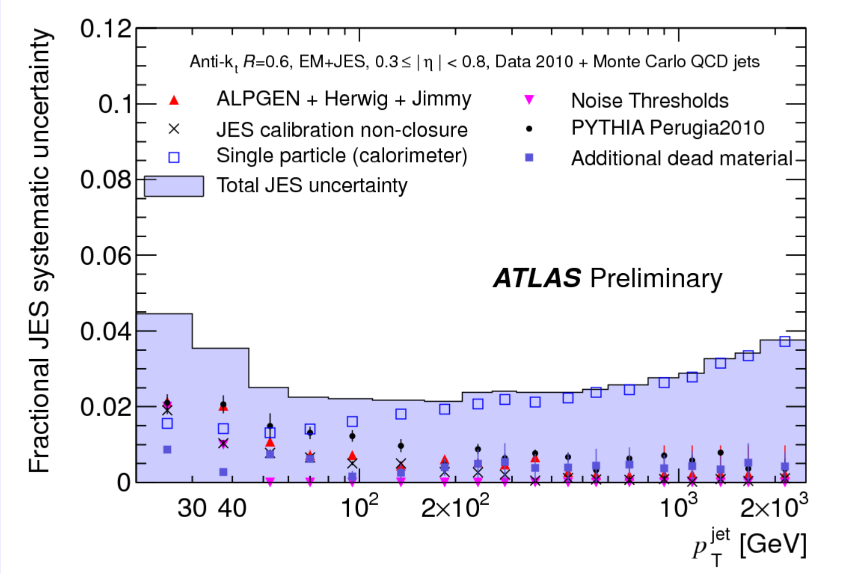
- Hadronic showers consist of:
  - Visible EM energy: ~50%
  - Visible non-EM energy: ~25%
  - Invisible energy: ~25%
    - Nuclear excitation and break-up
  - Escaped energy: ~2%
- Each component is dependent on energy and subject to large fluctuations
- In addition:
  - Energy loses due to algorithmic effects
  - Energy deposition from other particles in the same event

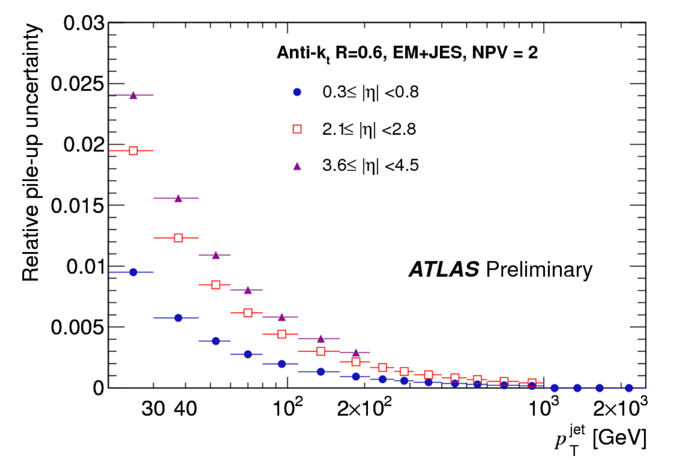


Need to correct the jet energy with dedicated calibration tools

Jet energy scale uncertainty

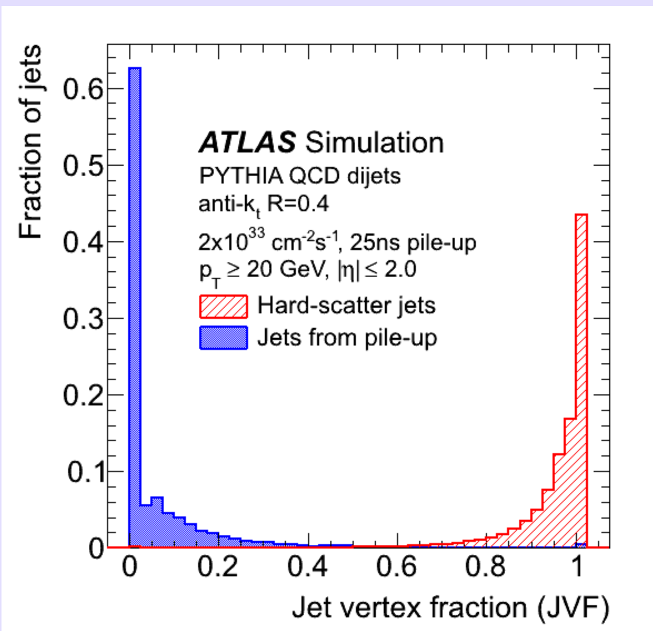
- JES for light jets uncertainty dominated by
  - Underlying event and hadronization models
  - Single particle response
  - Closure tests of calibration algorithm
- Pile-up uncertainty
  - Energy from extra pp collisions in the same event
- b-jet energy scale uncertainty
  - 2.5% in addition
  - Coming from b-jet fragmentation models

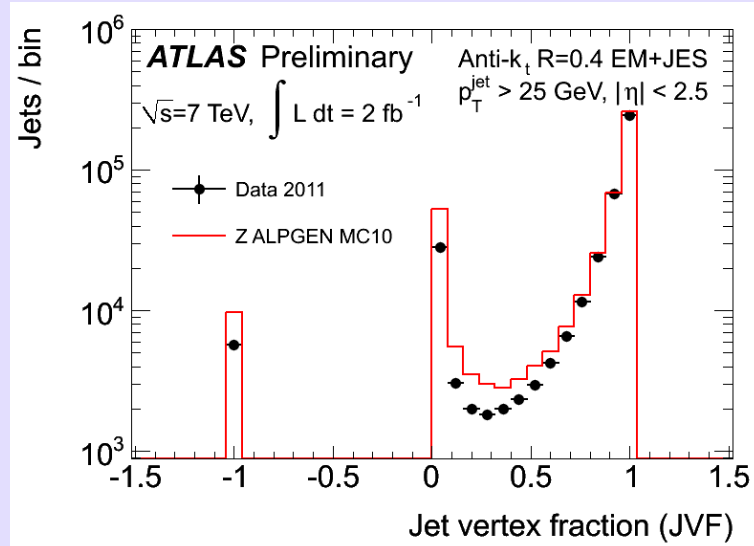


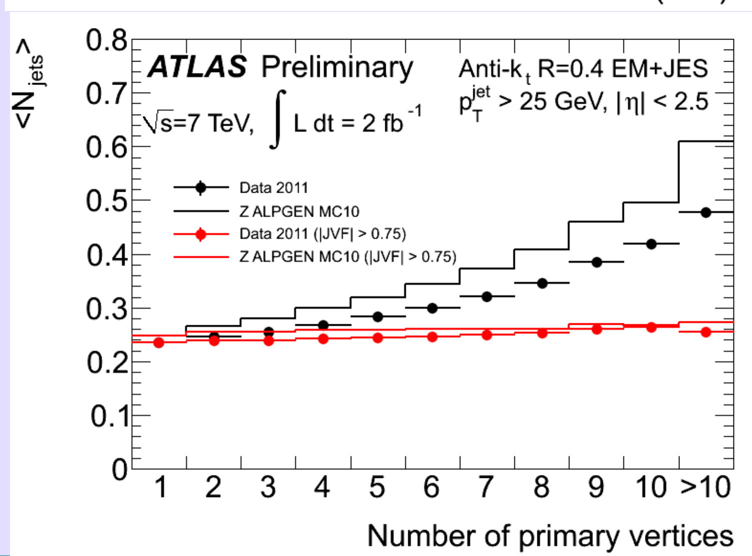


Jet selection

- Jet vertex fraction: fraction of tracks belonging to the main primary vertex should be larger than 0.75

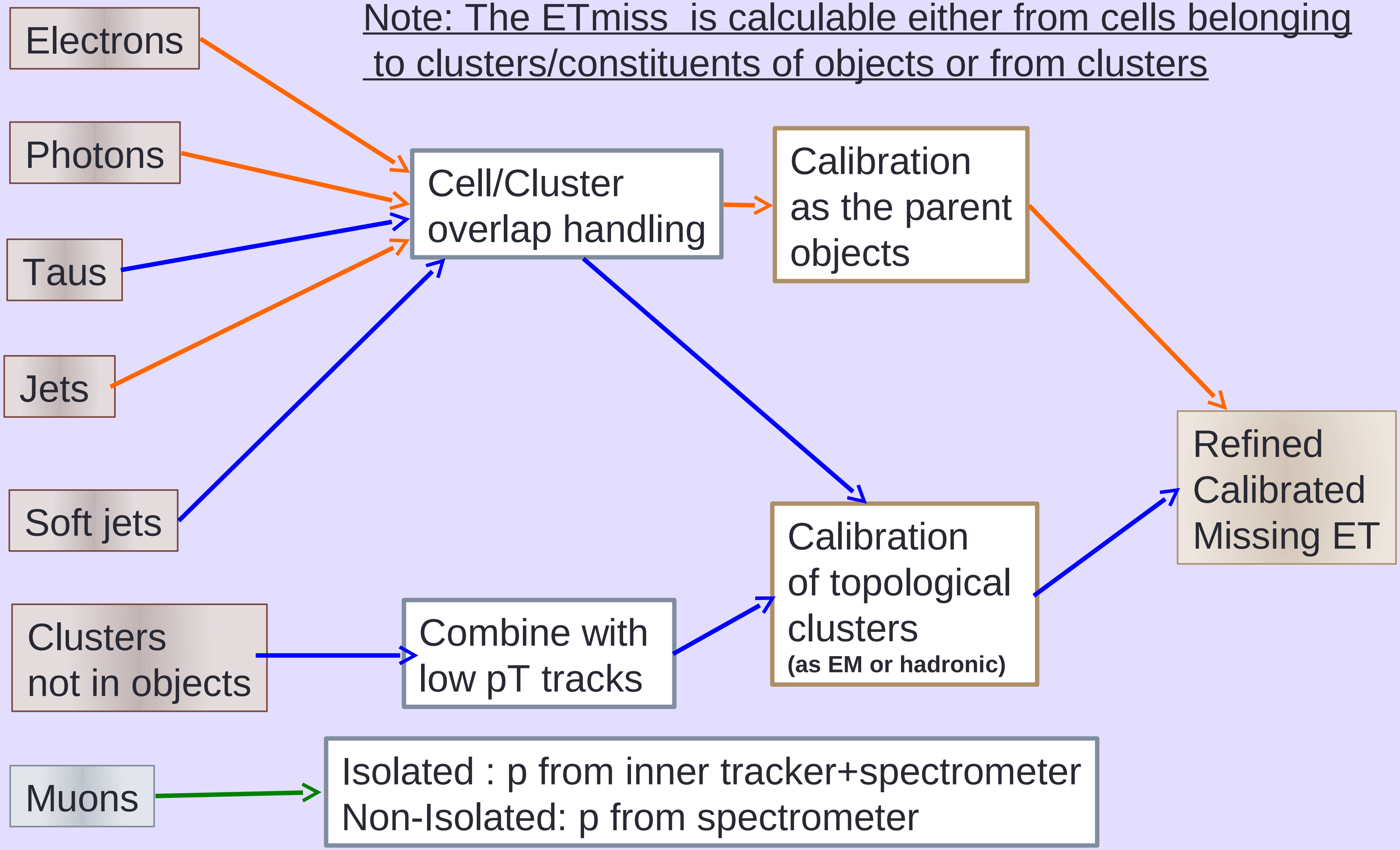




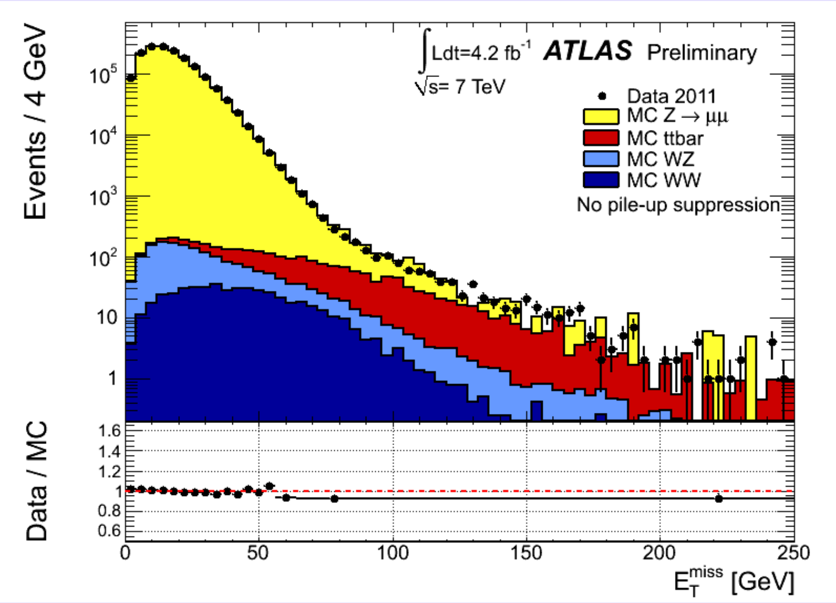


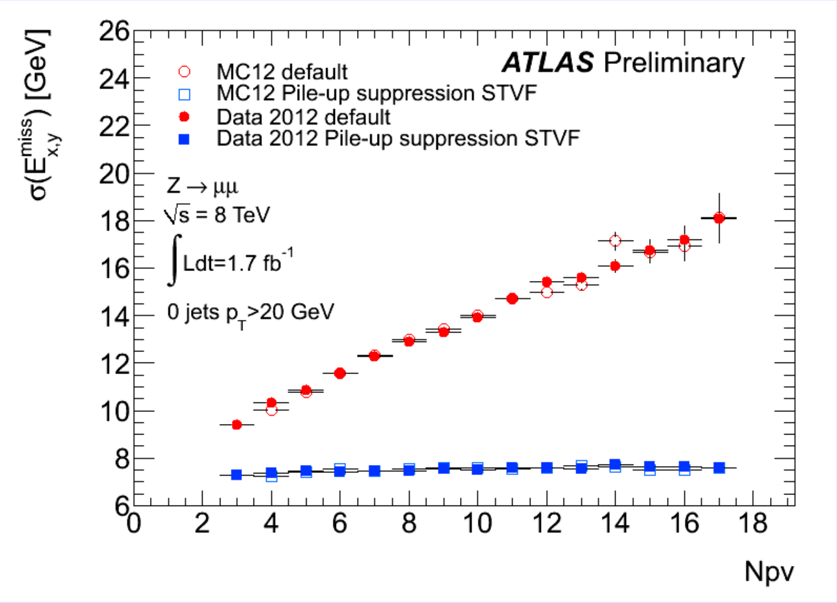
Missing transverse energy

Note: The ETmiss is calculable either from cells belonging to clusters/constituents of objects or from clusters



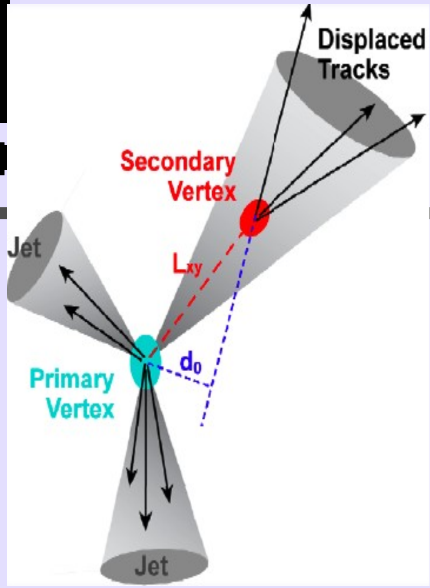
Missing ET performance

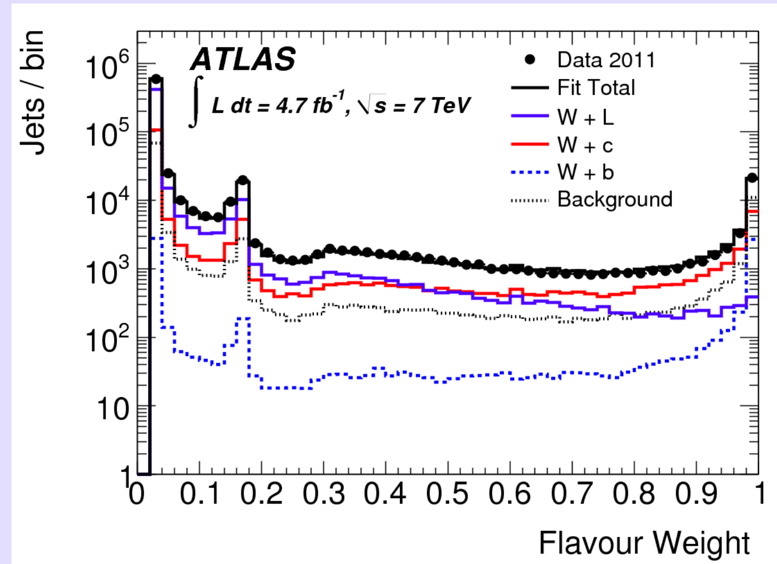




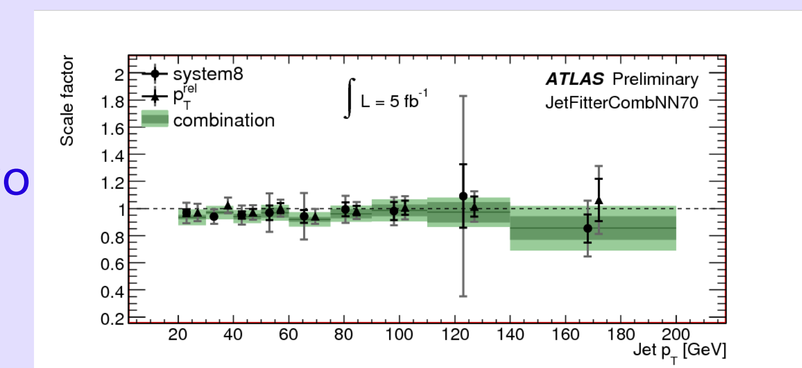
- Good data-MC agreement in 2011
- ETmiss resolution worsens significantly with increasing pile-up
- Corrections:
  - CellOut and SoftJets terms scaled by the ratio of: sum p_T of tracks associated to the main primary vertex over all tracks.
- Result: flat dependence in the number of primary vertices

b-jet selection

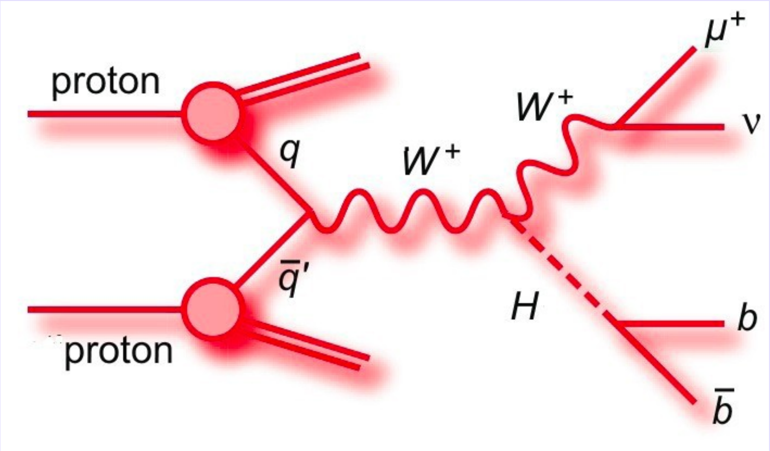




- Combine the 3D impact parameter and secondary vertex information using a Neural Network
  - ε(light)~0.6%, ε(c-jets)~20%, ε(b-jets)~70%
- Compared efficiency in data-MC with two different methods
  - Scale factors very close to 1

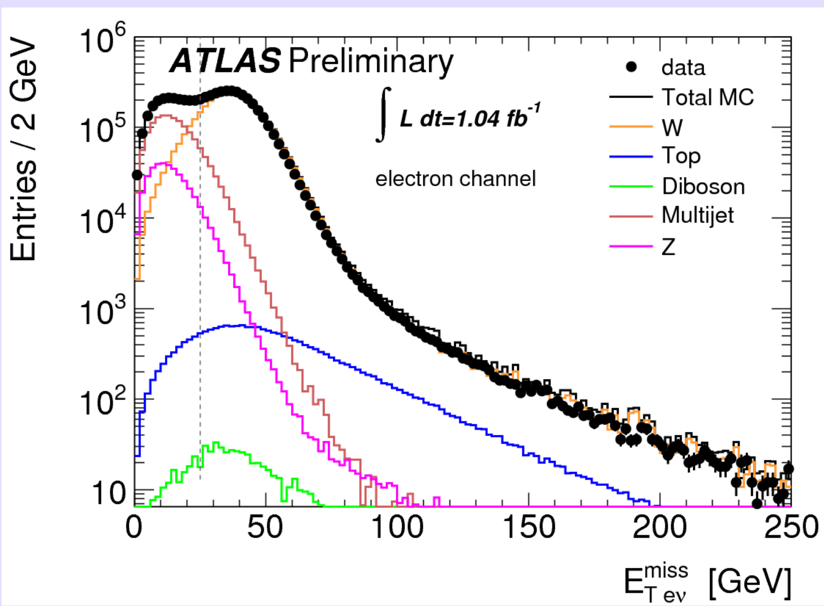


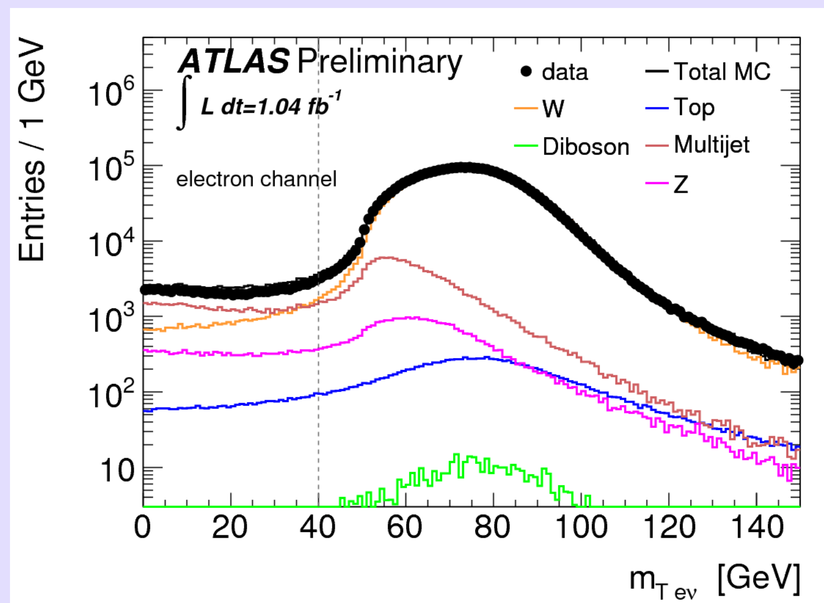
WH → lν bb selection



WH → lν bb selection

- Trigger: e (p_T^e>20 GeV or 22 GeV for latest periods) or μ (p_T^μ>18 GeV)
- Exactly 1 isolated lepton with p_T >25 GeV
- E_T^{miss} > 25 GeV
- $M_T=[2p_T^l p_T^\nu(1-\cos\Delta\varphi_{l\nu})]^{1/2}$ > 40 GeV

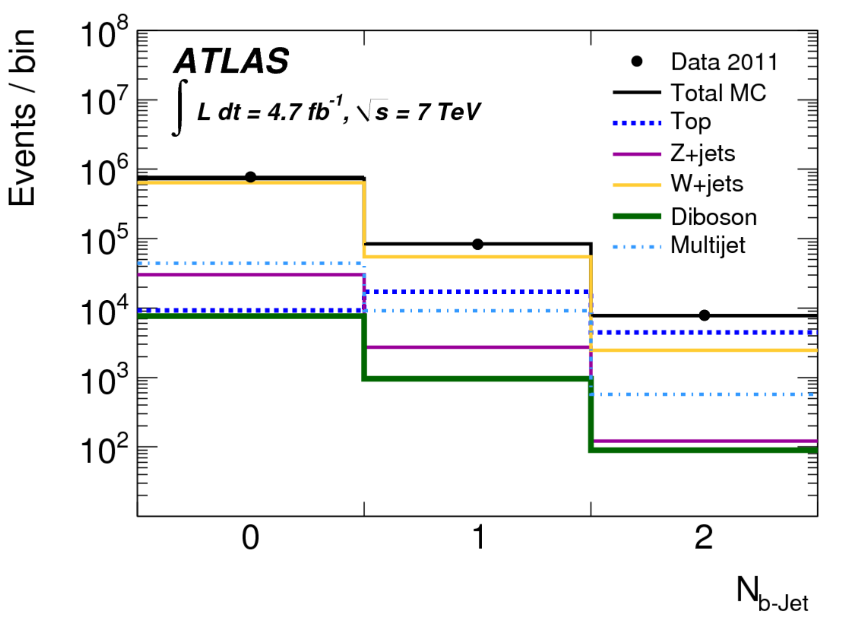




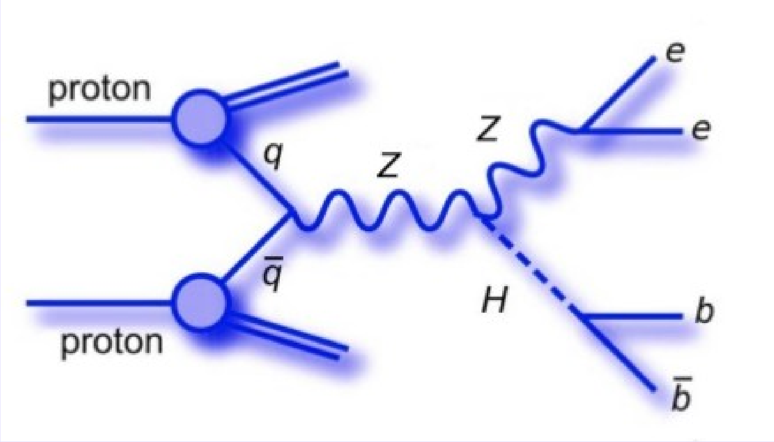
WH → lν bb selection (II)

- Exactly 2 jets with E_T^{lead} > 45 GeV and $E_T^{sublead}$>25 GeV
  - For Higgs mass reconstruction: $|\eta_{jet}|$<2.5
  - No other jets with: $|\eta_{jet}|$<4, p_T>20 GeV
  - ΔR>0.7 if p_T^Z< 200 GeV
- Both jets b-tagged

After the selection, the dominant background is W+jets, followed by top and QCD multijet production

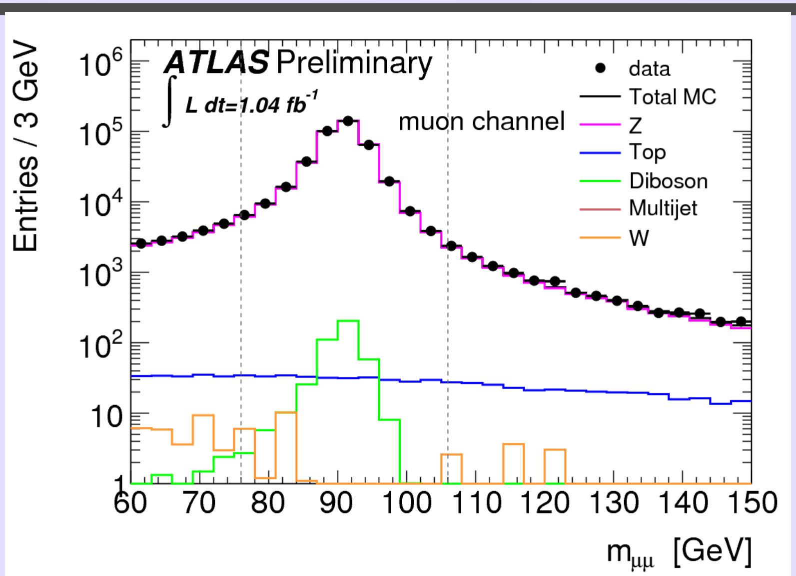


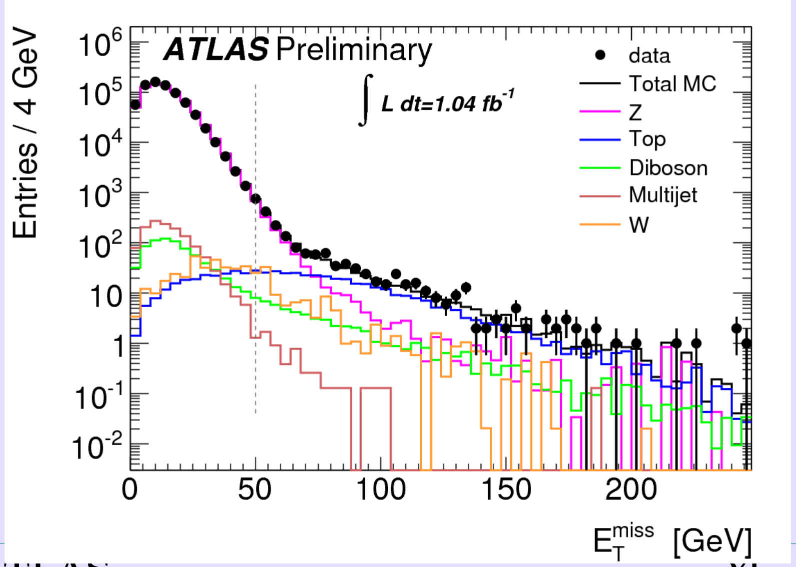
ZH → ll bb selection



ZH → ll bb selection

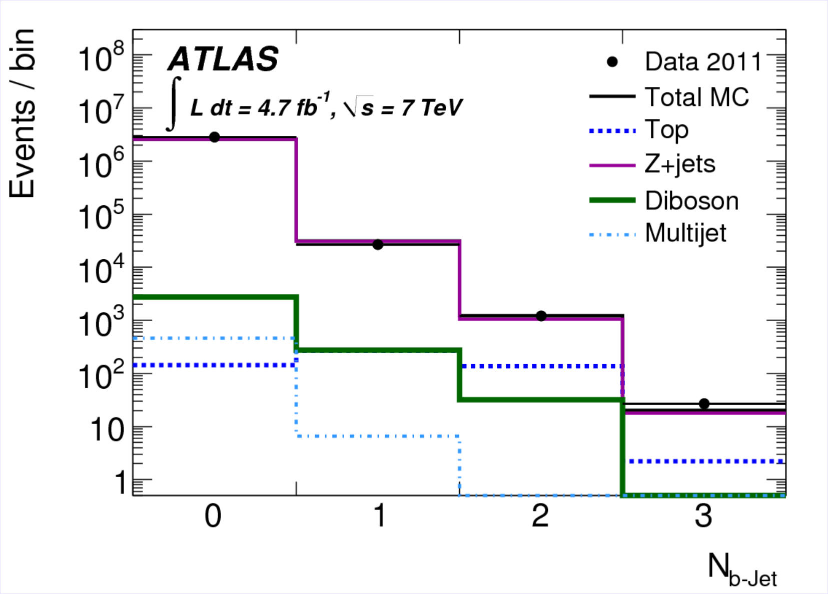
- Trigger:
  - e (p_T^e>20 GeV or 22 GeV)
  - μ (p_T^μ>18 GeV)
  - 2e/2μ trigger (p_T^l>12 GeV)
- Exactly 2 leptons p_T > 20 GeV
- Z mass cut: 83 < m_{ll} < 99 GeV
- E_T^{miss} < 50 GeV
- Exactly two b-tagged jets
  - E_T^{lead} > 45 GeV
  - $E_T^{sublead}$>25 GeV
  - ΔR>0.7 if p_T^Z< 200 GeV



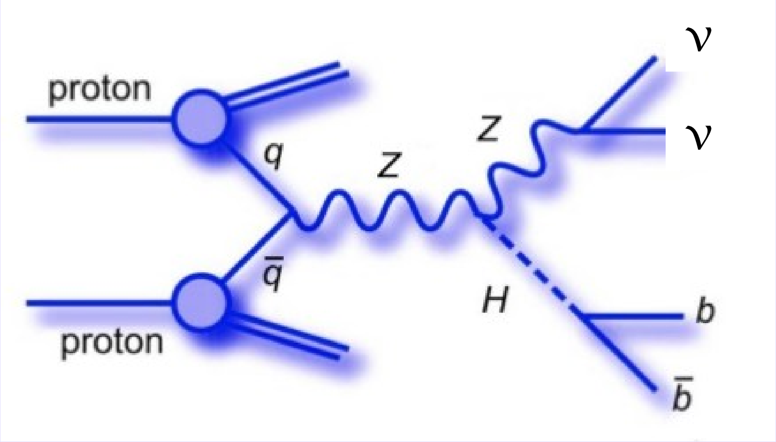


ZH ➔ ll bb selection

- Background dominated by Z+jets, top and dibosons
  - Multijets negligible



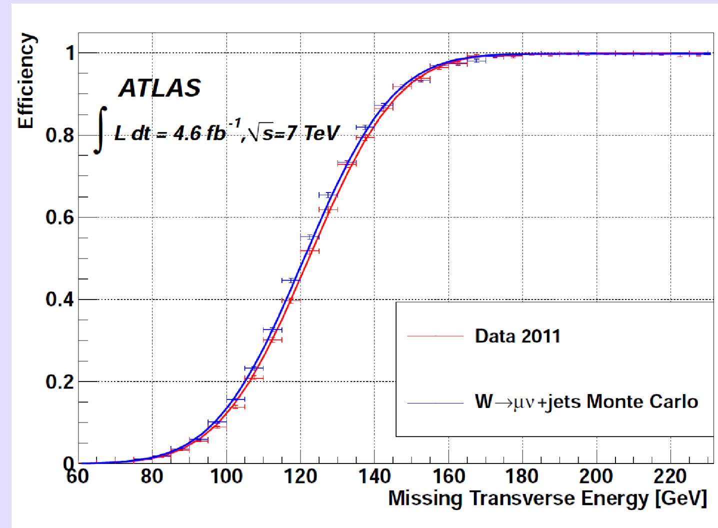
ZH → νν bb selection

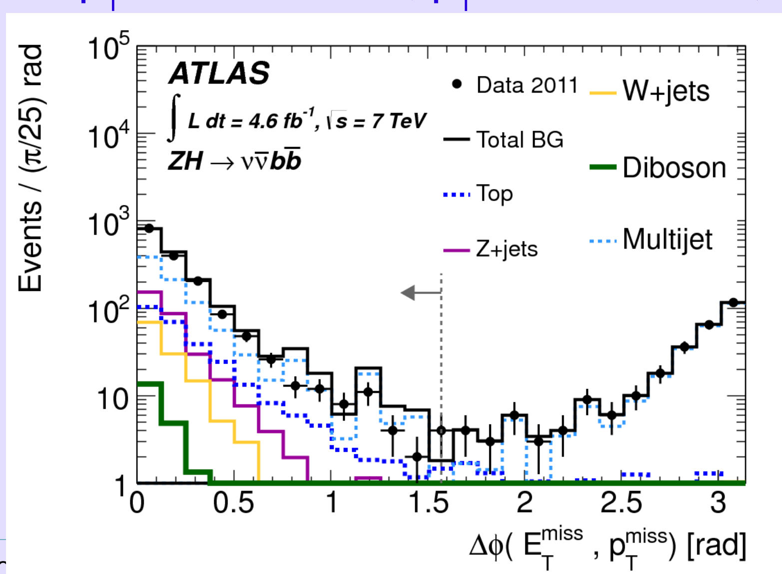


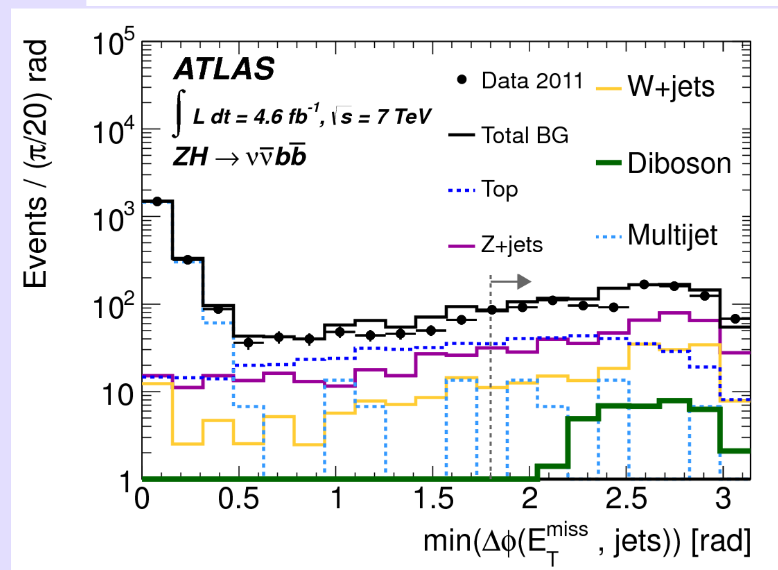
ZH → νν bb selection

- Trigger: E_T^{miss} > 70 GeV
- E_T^{miss} > 70 GeV, p_T^{miss} >30 GeV
- $\Delta\phi(E_T^{miss}, p_T^{miss}) < \pi/2$
- $\Delta\phi(E_T^{miss}$,nearest jet$) > 1.8$
- $\Delta\phi(E_T^{miss}$, bb$) > 2.7$ (2.9) for

  $p_T^V < 160$ GeV ($p_T^V \geq 160$ GeV)



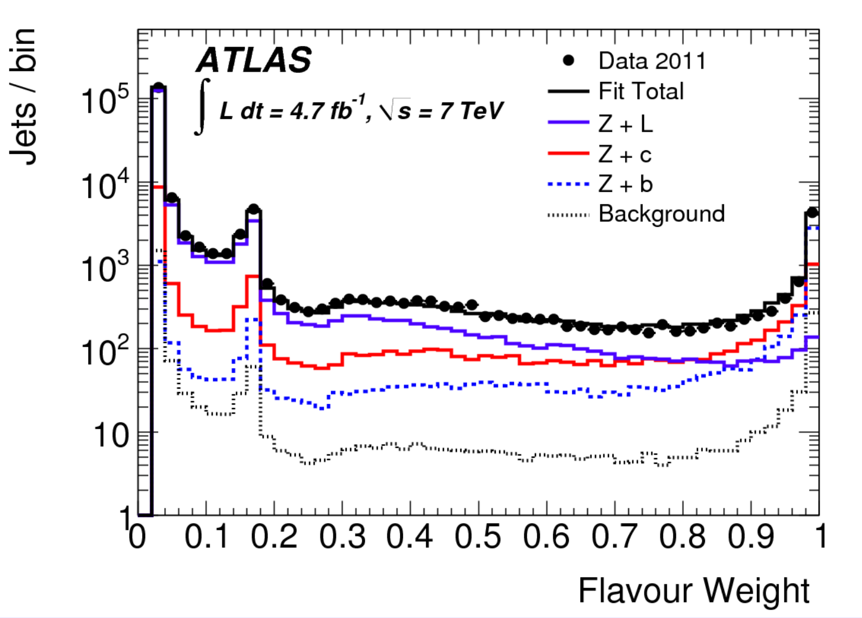




Background estimation

W/Z+jets flavour composition

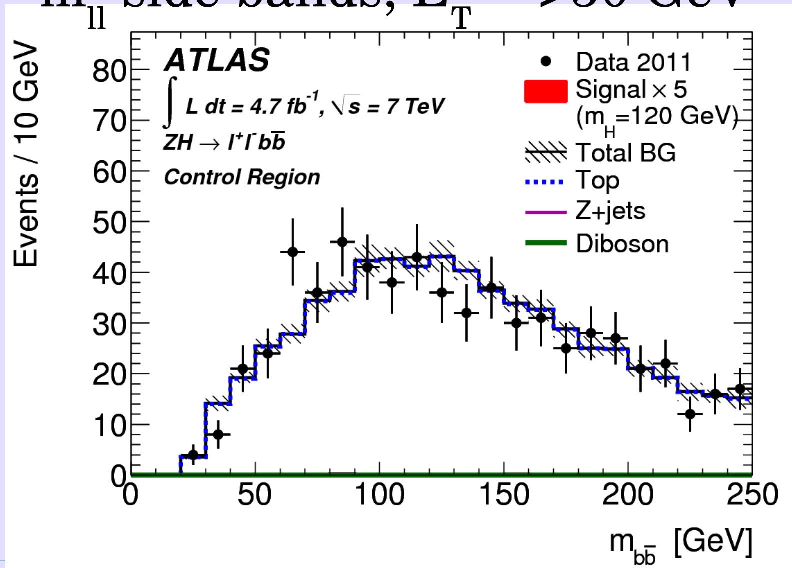
- Determine separate W/Z+b, W/Z+c and W/Z+light-jet fractions from data in 2-jet events requiring m(jet-jet) < 80 GeV:
  - in events with one b-tagged jet, based on the b weight of the second jet.
  - in events with no b-tagged jets, based on the b weight of the first two jets.
- Shapes from exclusive MC samples
- Absolute normalization from m_{bb} distribution in sidebands



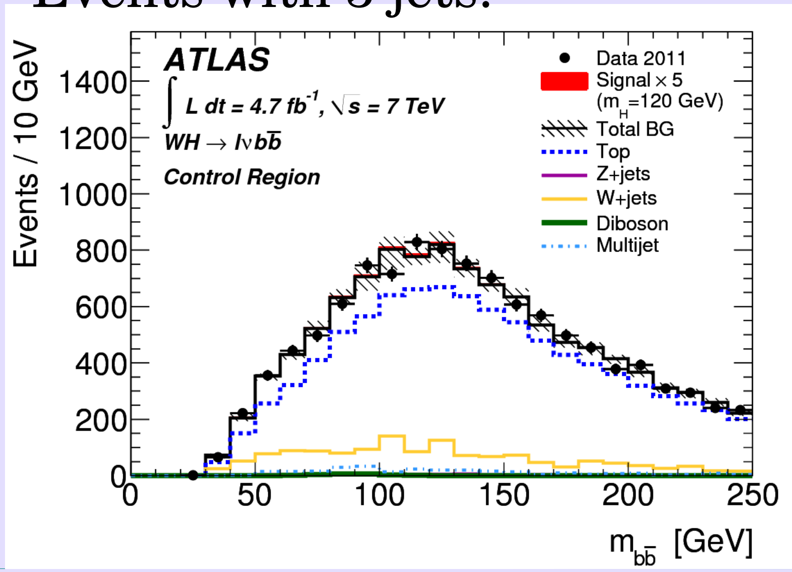
W+jets/Z+jets and top backgrounds

- Simultaneous fit to m_{bb} side bands and top control regions:
  - m_{bb} < 80 GeV, 150 < m_{bb} < 250 GeV
  - Ratio sigle-top/top pair production from NLO QCD calculation
- Extrapolation of these backgrounds to signal region done with MC
- Good agreement data-MC after the corrections

m_{ll} side bands, E_T^{miss}>50 GeV

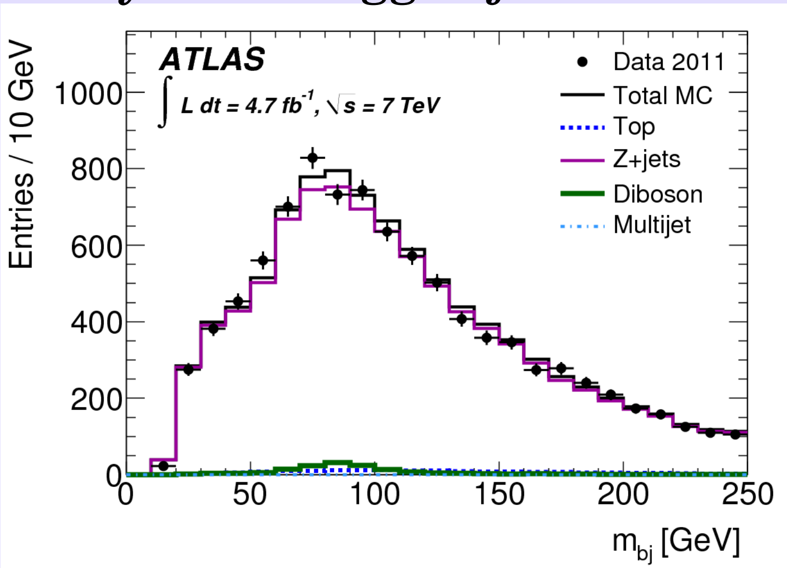


Events with 3 jets:



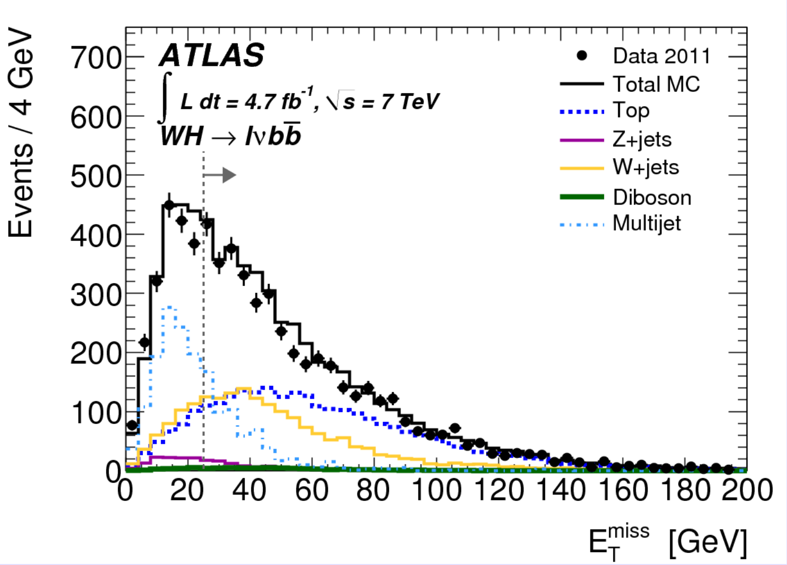
Z+jets control regions

Only one b-tagged jet:



Multi-jet background

- Templates from multi-jet enriched sample obtained by reversing isolation criteria
- Fit:
  - E_T^{miss} for WH
  - m_{ll} for ZH
    - Negligible background!
- Tested results in a multi-jet control region
- For ZH→νν bb:
  - Ratio of events with $\Delta\phi(E_T^{miss}$,nearest jet)>1.8 and <1.8, for $\Delta\phi(E_T^{miss}, p_T^{miss})>\pi/2$
  - Apply the ratio to the region with $\Delta\phi(E_T^{miss}, p_T^{miss})<\pi/2$



Sources of systematic uncertainties

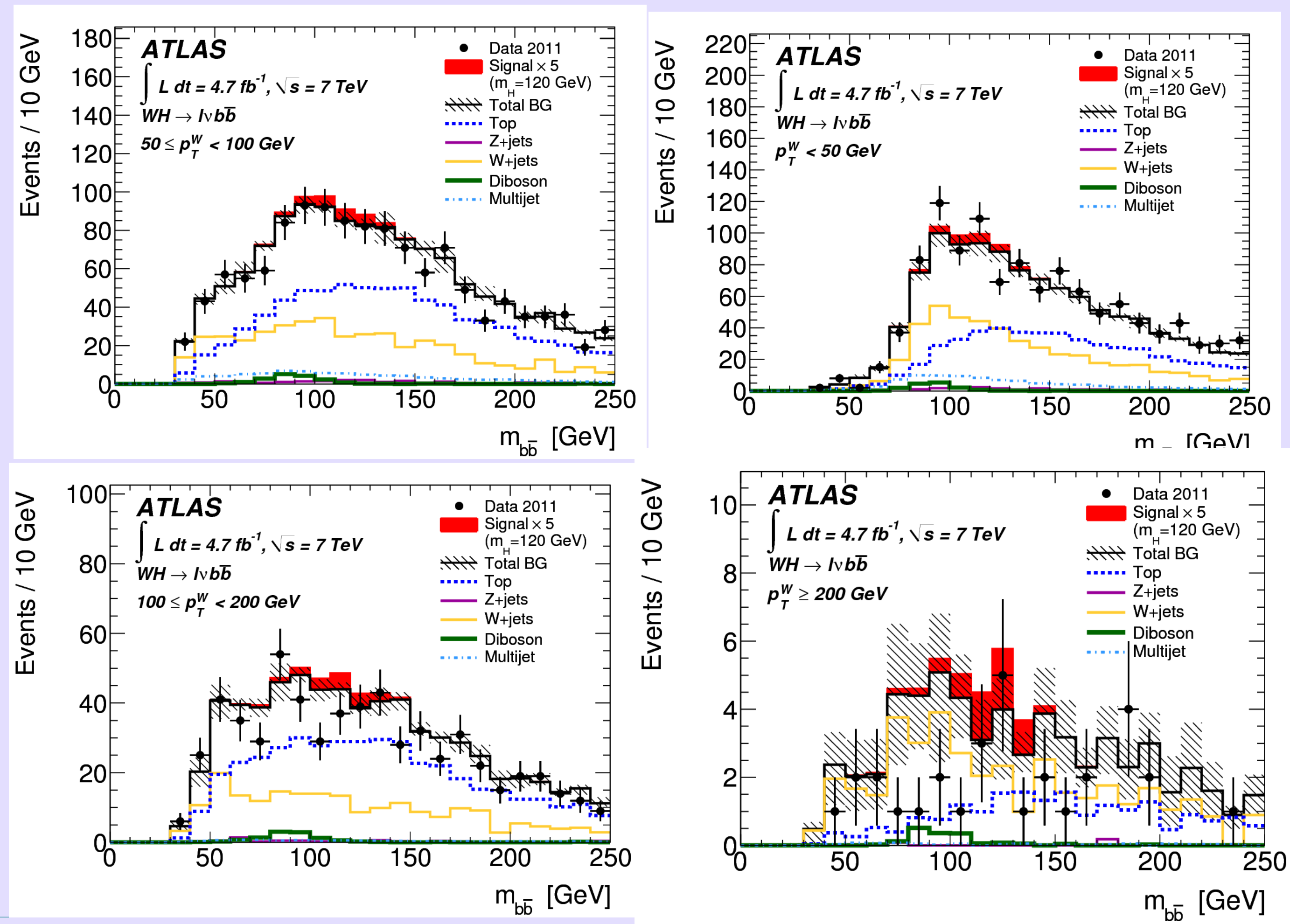
- Leading instrumental effects:
  - b-tagging efficiency: 5-19% depending on $p_T^{b\text{-jet}}$
  - b-jet energy scale: 3-14% depending on η, p_T
- Backgrounds:
  - W+jet, Z+jets flavour composition: varied by 30% (from fit)
  - W+jet, Z+jet, top uncertainties from the fits and comparisons done in the control regions
- Theoretical uncertainties: 4% for both WH, ZH.
- PT of the W and Z bosons: 4-8% depending on the channel
  - Differences in acceptance between PYTHIA and POWHEG due to jet veto
- Luminosity: 3.9%

bin	$ZH \to \ell^+\ell^- b\bar{b}$ p_T^V [GeV] 0-50	50-100	100-200	>200	$WH \to \ell\nu b\bar{b}$ p_T^V [GeV] 0-50	50-100	100-200	>200	$ZH \to \nu\bar{\nu} b\bar{b}$ p_T^V [GeV] 120-160	160-200	>200
Number of events for $80 < m_{b\bar{b}} < 150$ GeV											
signal	1.3 ± 0.1	1.8 ± 0.2	1.6 ± 0.2	0.4 ± 0.1	5.0 ± 0.6	5.1 ± 0.6	3.7 ± 0.4	1.2 ± 0.2	2.0 ± 0.2	1.2 ± 0.1	1.5 ± 0.2
top	17.4	24.1	7.3	0.2	229.9	342.7	201.3	8.2	35.2	8.3	4.1
W+jets	–	–	–	–	285.9	193.6	85.8	17.5	13.2	7.8	4.8
Z+jets	123.2	119.9	55.9	6.1	11.1	10.5	2.8	0.0	31.5	11.9	7.1
diboson	7.2	5.6	3.6	0.7	12.6	11.9	7.8	1.4	4.6	4.3	3.6
multijet	–	–	–	–	55.5	38.2	3.6	0.2	–	–	–
total BG	148 ± 10	150 ± 6	67 ± 4	6.9 ± 1.2	596 ± 23	598 ± 16	302 ± 10	27 ± 5	85 ± 8	32 ± 3	20 ± 3
data	141	163	61	13	614	588	271	15	105	22	25
Components of the relative systematic uncertainties of the background [%]											
b-tag eff	1.4	1.0	0.3	4.8	0.9	1.3	0.9	7.2	4.1	4.2	5.5
BG norm	3.6	3.4	3.6	3.8	2.7	1.8	1.8	4.5	2.7	2.2	3.2
jets/E_T^{miss}	2.1	1.2	2.7	5.1	1.5	1.4	2.1	9.5	7.7	8.2	12.1
leptons	0.2	0.3	1.1	3.4	0.1	0.2	0.2	1.7	0.0	0.0	0.0
luminosity	0.2	0.1	0.2	0.4	0.1	0.1	0.1	0.2	0.2	0.5	0.7
pileup	0.9	1.6	0.5	1.3	0.1	0.2	0.8	0.5	1.6	2.5	3.0
theory	5.2	1.3	4.7	14.9	2.2	0.3	1.6	14.8	2.9	4.0	7.7
total BG	6.9	4.3	6.6	17.3	3.9	2.7	3.4	19.6	9.7	10.6	16.0
Components of the relative systematic uncertainties of the signal [%]											
b-tag eff	6.4	6.4	7.0	13.7	6.4	6.4	7.0	12.1	7.1	8.2	9.2
jets/E_T^{miss}	4.9	3.2	3.5	5.5	5.8	4.6	3.7	3.3	7.3	5.1	6.3
leptons	0.9	1.2	1.7	2.6	3.0	3.0	3.0	3.2	0.0	0.0	0.0
luminosity	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
pileup	0.5	1.1	1.8	2.2	1.2	0.3	0.3	1.6	0.2	0.2	0.0
theory	4.6	3.6	3.3	5.3	4.4	4.7	5.0	8.0	3.3	3.3	5.6
total signal	10.1	9.1	9.6	16.5	11.4	10.8	11.0	16.0	11.8	11.4	13.4

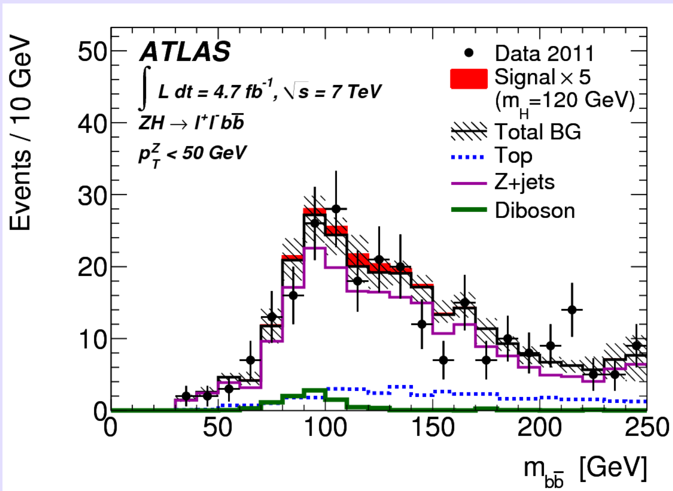
Results

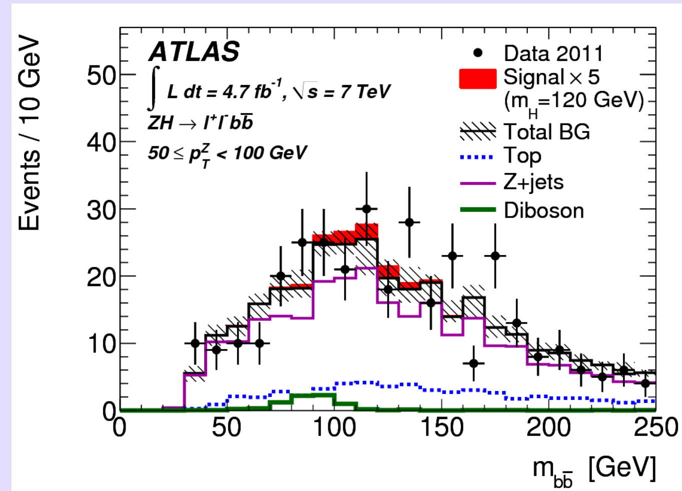
WH → lν bb results

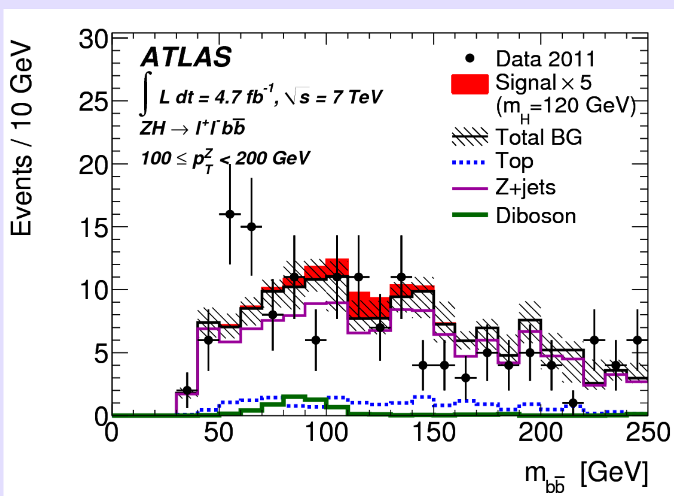
- No excess of events observed

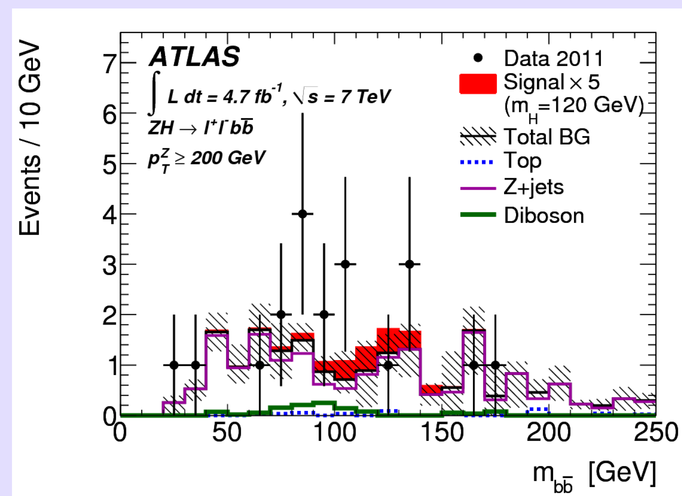


ZH → ll bb results

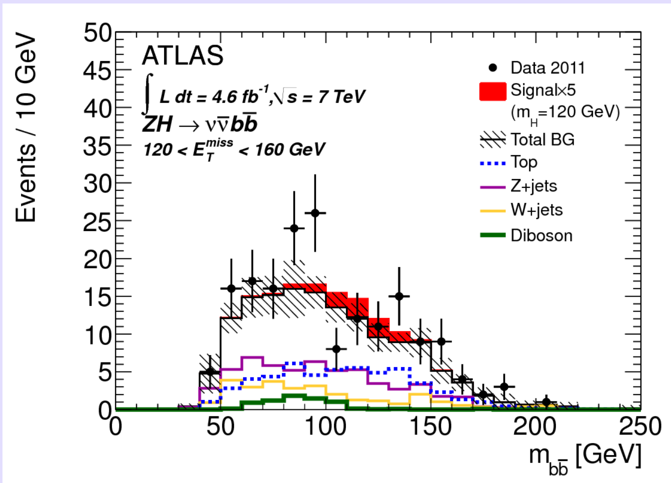


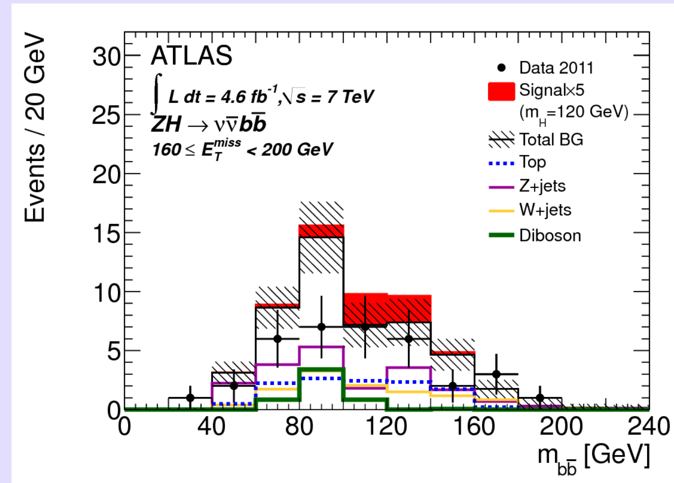


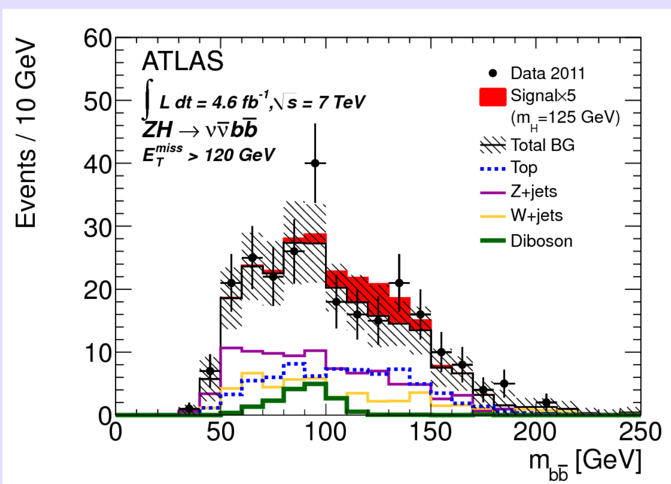


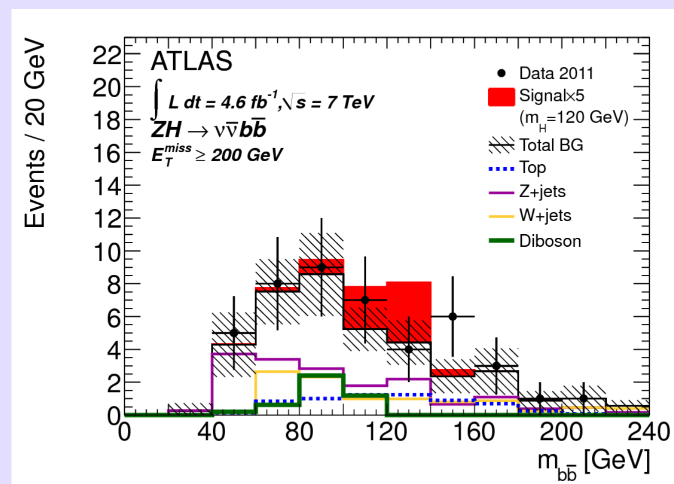


ZH →νν bb results



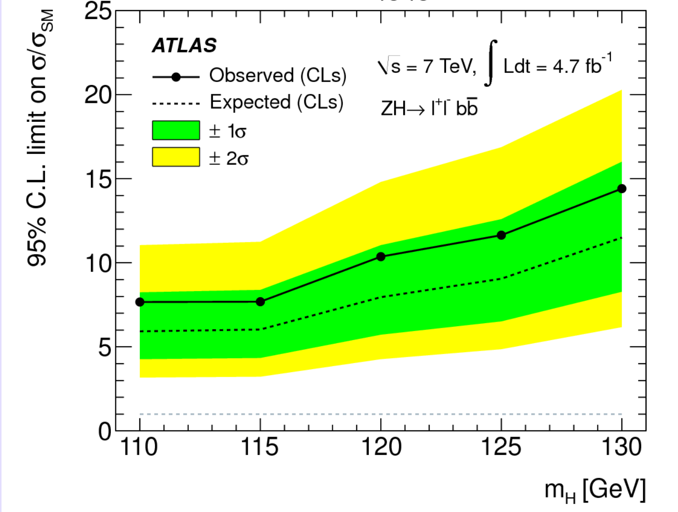




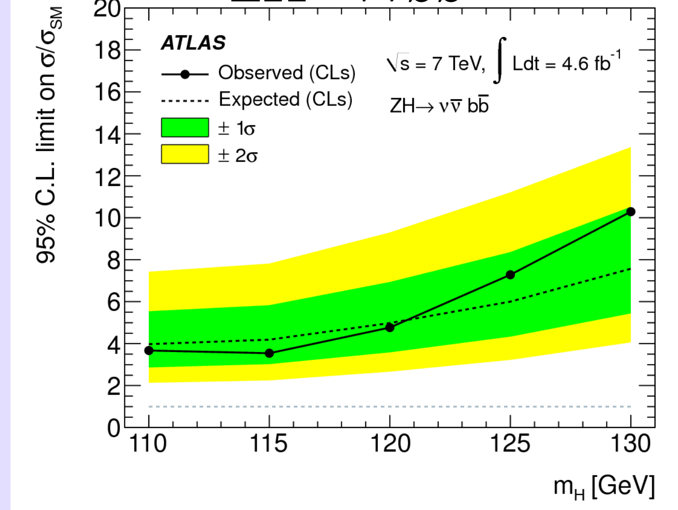


Exclusion limits

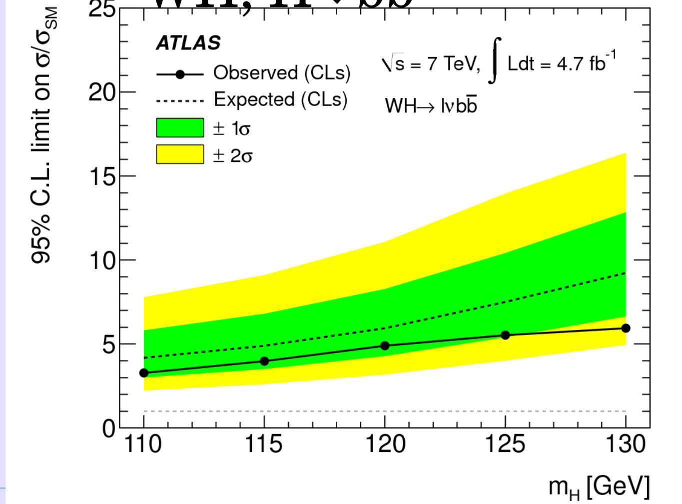
ZH→ll bb



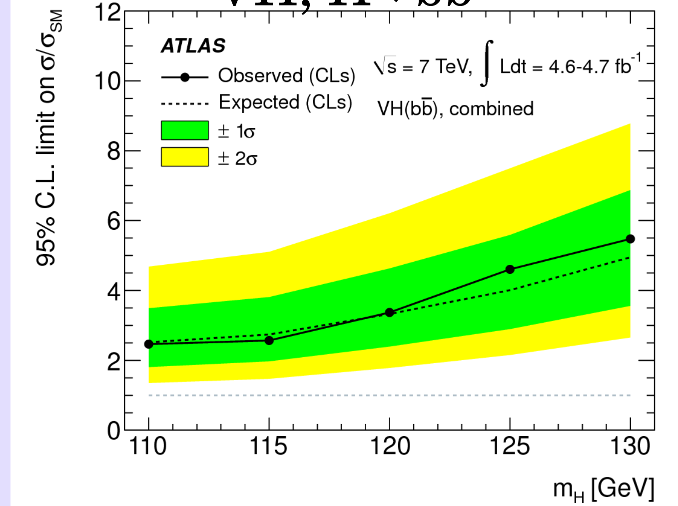
ZH→ννbb



WH, H→bb

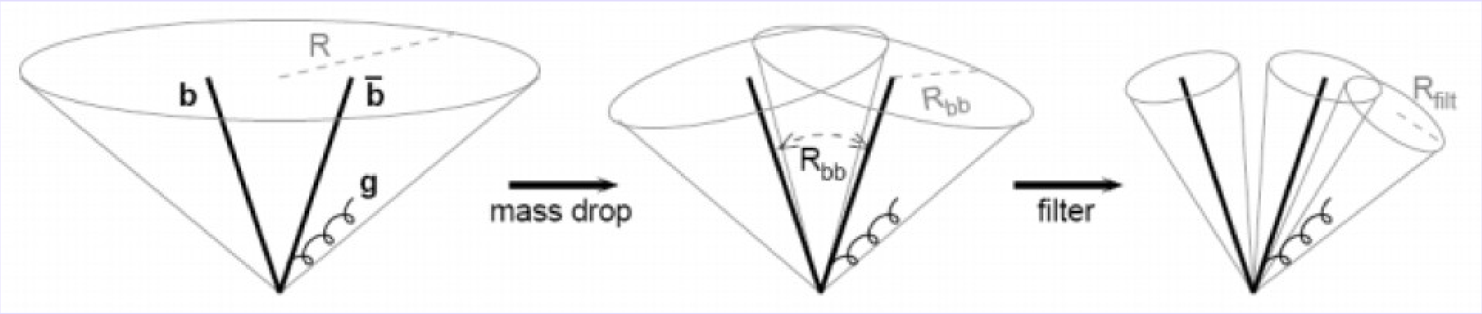


VH, H→bb



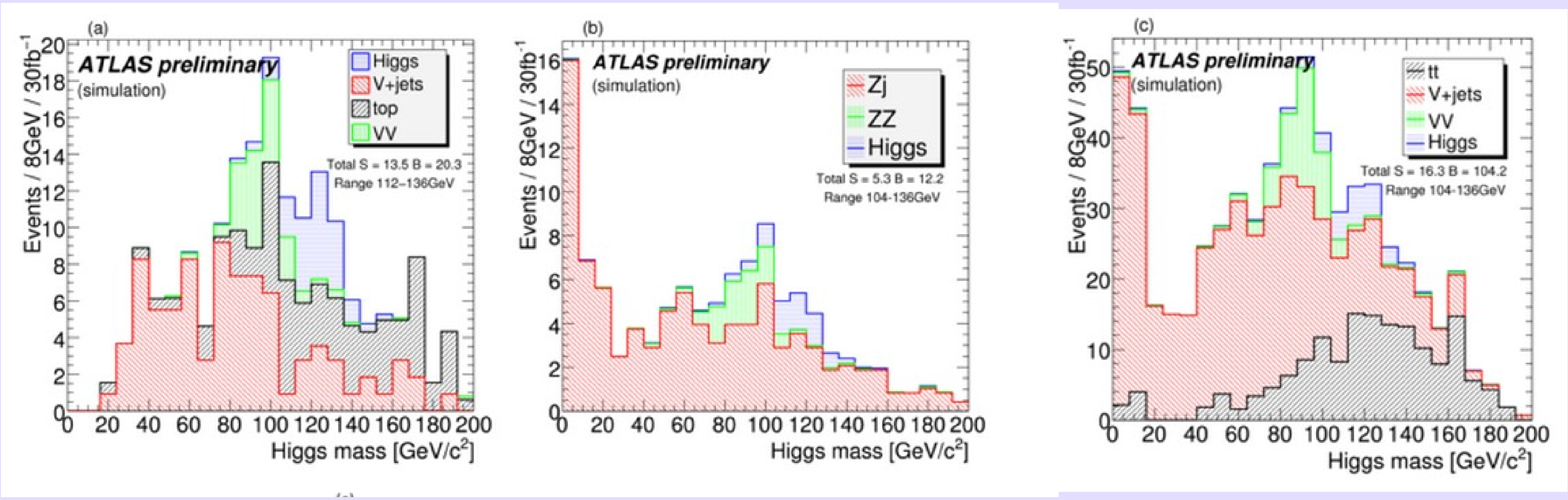
For the future: boosted H→bb

- Alternative procedure: search for high p_T Higgs to a b-quark pair
- Higgs p_T > 200 GeV
  - 5% signal acceptance but larger decrease in backgrounds
- Select V events (V=W,Z decaying leptonically) and search for a single H→bb jet:
  - Search for a high p_T jet (Cambridge-Aachen algorithm, R=1.2)
  - Search jet clustering in reverse order to look for a large mass drop



(Phys.Rev. Lett. 100(2008) 242001)

Boosted MC study

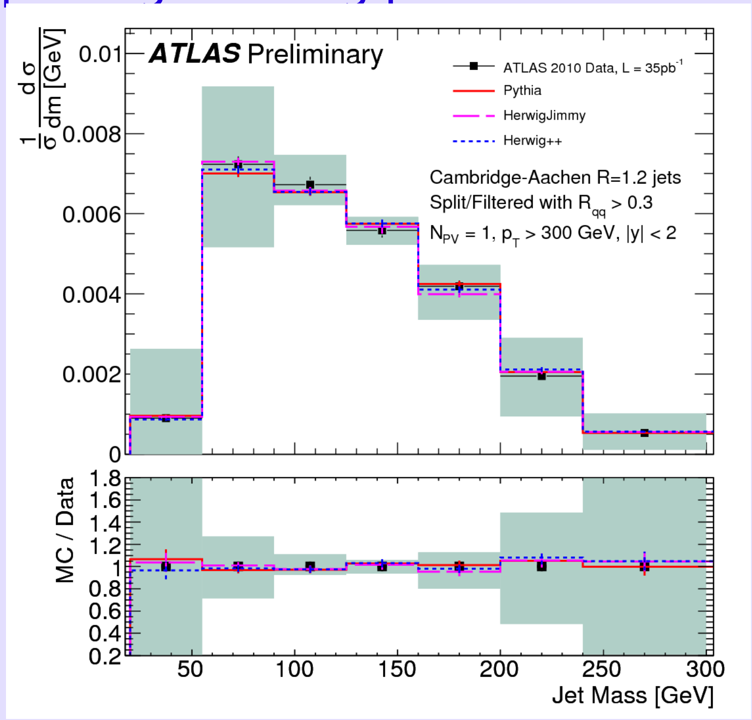


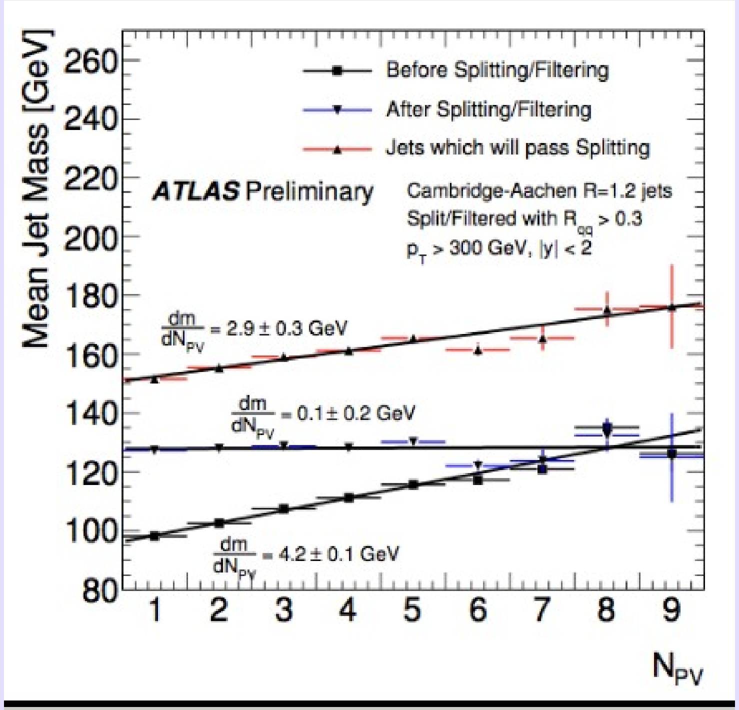
Monte Carlo (full simulation) ATLAS study:

- Cut based analysis
- The three channels together could reach 3.7σ with 30 fb^{-1}
- But the sensitivity drops fast when the background uncertainty increases

Boosted split/filtered jets

- Detailed study of QCD jets substructure
- After splitting/filtering, the jet mass is well modelled by the LO parton shower generators
- Splitting/filtering procedure reduces jet mass sensitivity to pile-up

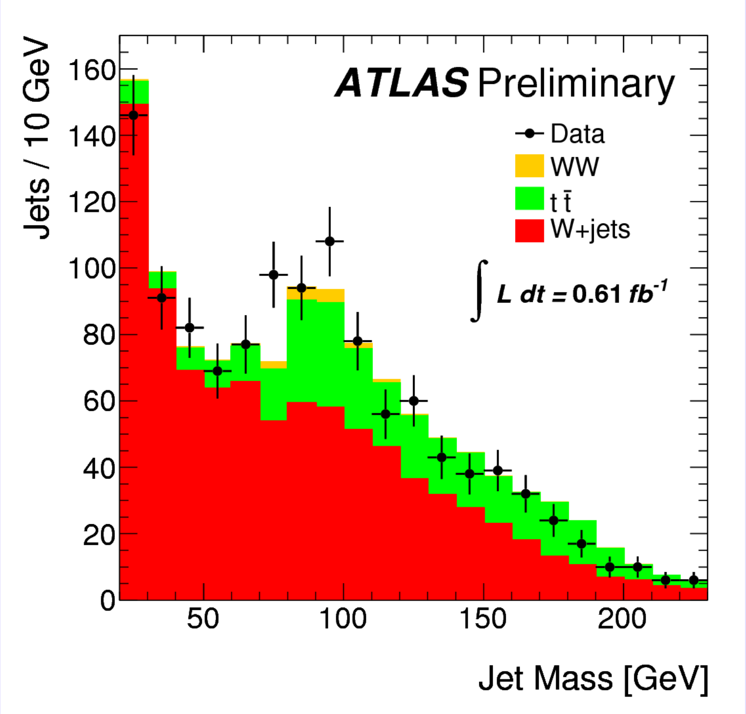




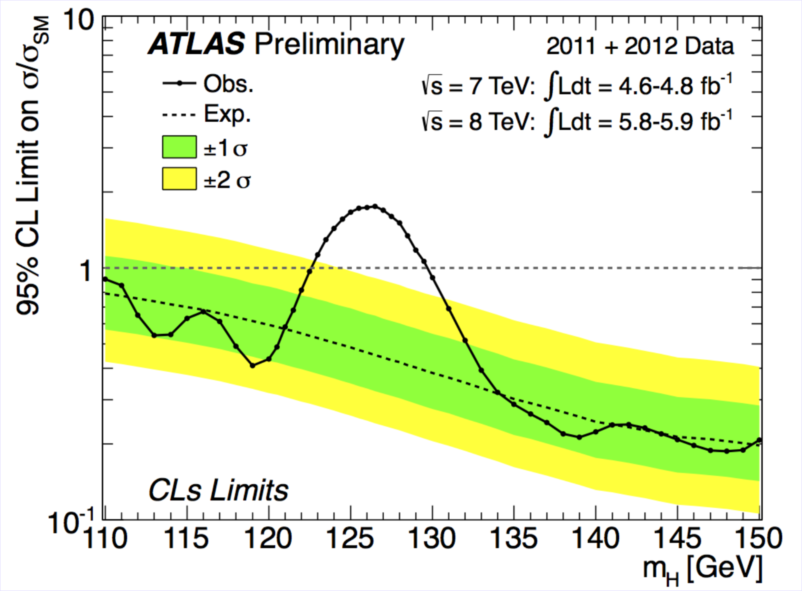
First Higgs boosted studies

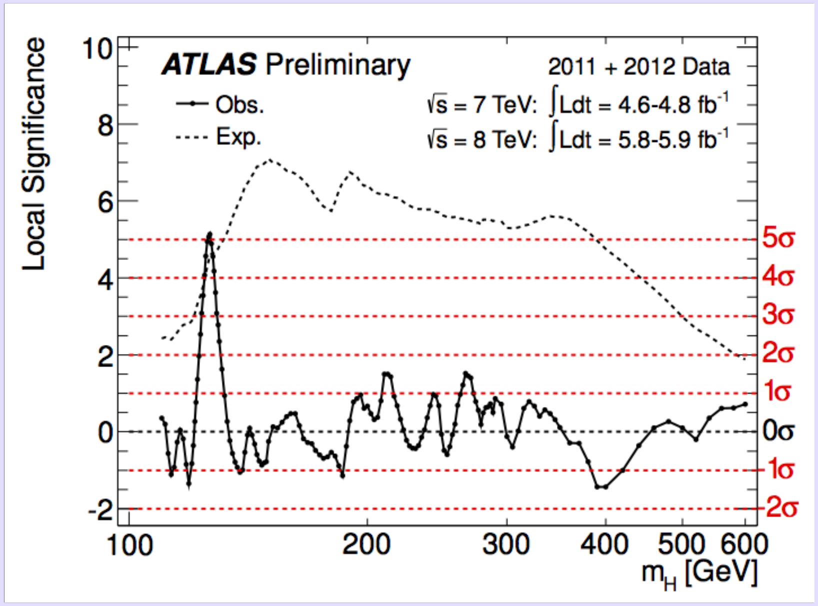
- Select events consistent with $W \rightarrow l\nu + 1$ jet, with $p_T^{jet} > 180$ GeV and $\Delta\varphi^{W,jet} > 1.2$
  - Apply jet filtering (C/A, R = 1.2)
  - No b-tagging is applied
- tt, W+jets, and SM WW processes included
- Peak consistent with W→jj in tt events

These first results are encouraging, promising new results with boosted jet substructure techniques in the near future



Observation of a signal

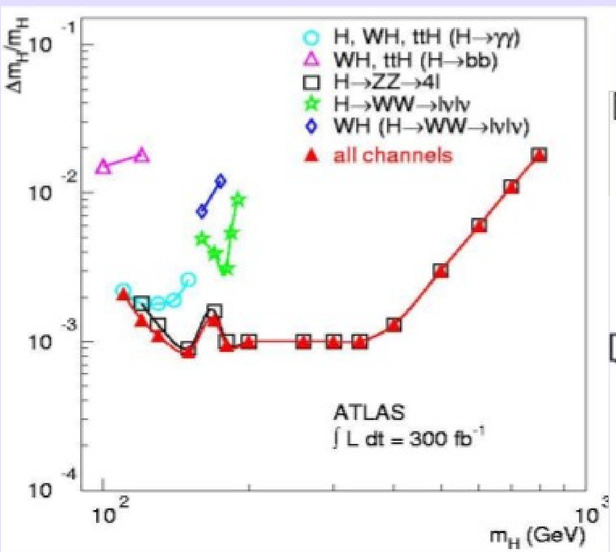


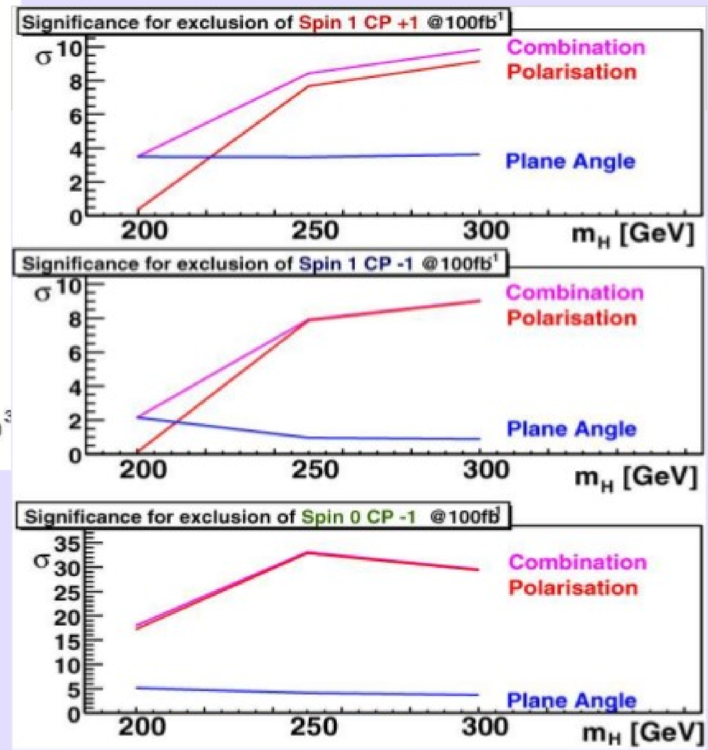


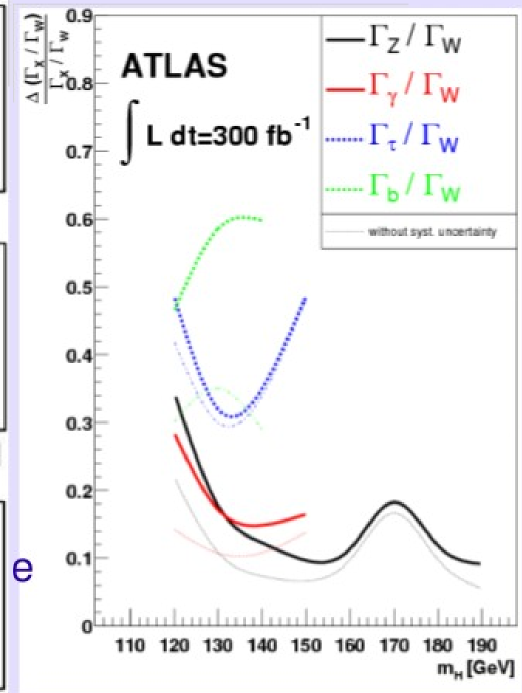
- Máximo observado a 126.5 GeV
  - Significância local: 5σ
  - Probabilidade de flutuação do fundo: 3×10^{-7}
- Significância global:
  - 4.1-4.3σ (para LEE em 110-600 o 110-150 GeV)

But…

- It will take several years at 14 TeV center of mass energy to demonstrate if any signal is the SM Higgs!







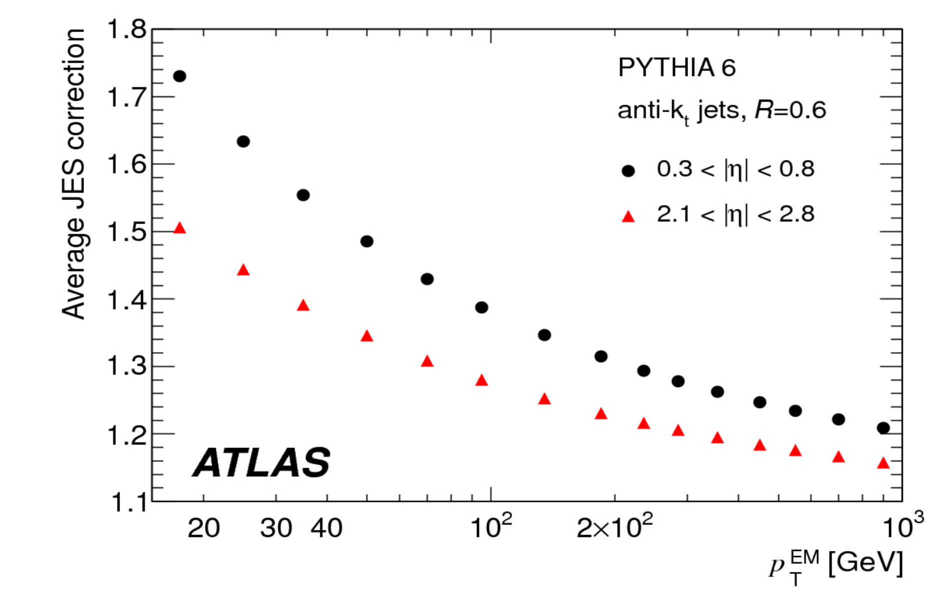
Acknowledgements

QUADRO DE REFERÊNCIA ESTRATÉGICO NACIONAL
PORTUGAL 2007.2013
COMPETE
PROGRAMA OPERACIONAL FACTORES DE COMPETITIVIDADE
FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

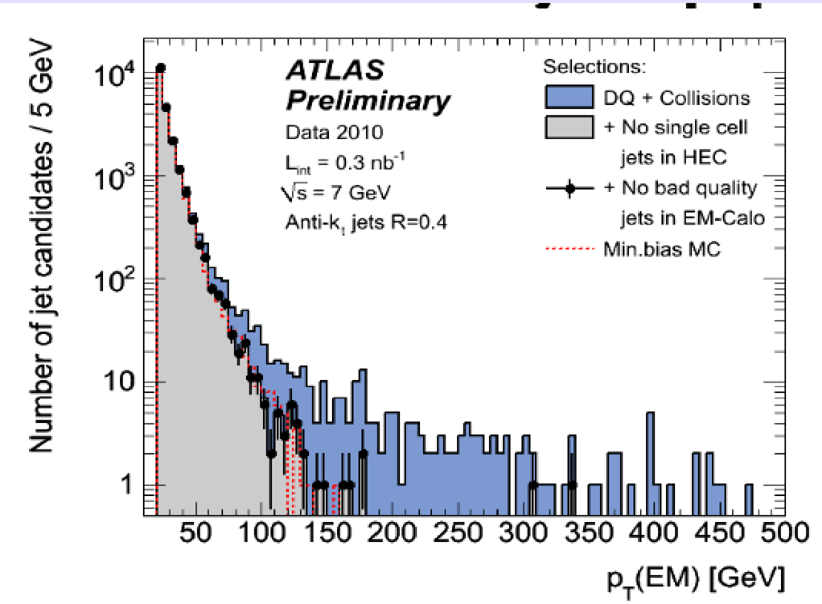
Backup

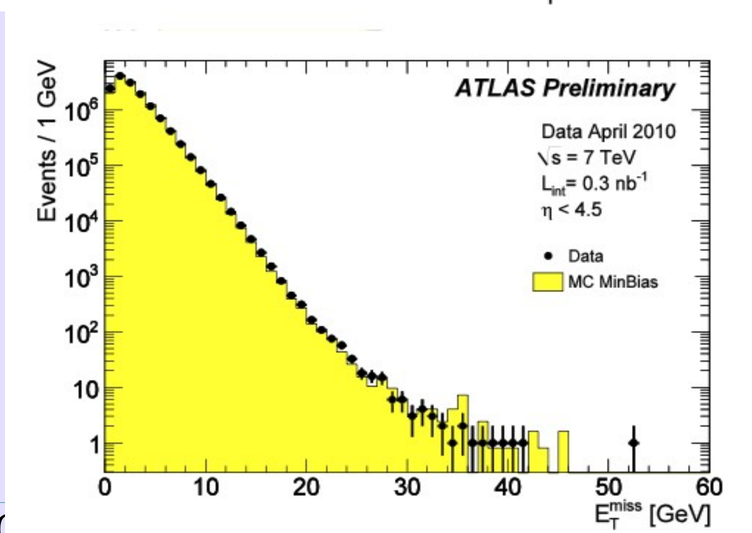
Jet Energy Calibration

- EM energy scale set with test-beam measurements for e/μ
- Needs corrections for
  - Calorimeter non-compensation
  - Dead material corrections
  - Particles whose shower is not contained in the calorimeter
  - Algorithmic effects
- Jet level corrections derived from MC



Jet cleaning





- Jet and E_T performance studied in minimum bias events
- Apply jet cleaning cuts to remove noise jets
  - Non-collisions background (cosmic muons, beam-gas collisions)
  - Noise cells
- After cleaning cuts
  - Jet p_T spectrum consistent with MC
  - E_T resolution in agreement with MC

Higgs in SUSY

- SUSY solves the hierarchy problem, provides a candidate for dark matter, a mechanism for unification of EW and strong forces, ...
- In the Higgs sector

Requires two Higgs doubles of opposite Hypercharge (one for up-sector, one for down-sector)

$$\Phi_{(Y=-1)} = \begin{pmatrix} \phi_1^{0*} \\ -\phi_1^{-} \end{pmatrix} \qquad \Phi_{(Y=+1)} = \begin{pmatrix} \phi_2^{+} \\ \phi_2^{0} \end{pmatrix}$$

5 physical Higgs bosons

2 charged : H^+ and H^-
2 CP even neutral : H and h
1 CP odd neutral : A

Higgs masses derivable from MSSM parameters

H^+, H^-: $M^2 = M_W^2 + M_A^2$ (at tree-level)
h : $M < M_Z$ (at tree-level) → 130 GeV (rad. corr.)

In SUSY, the couplings of the Higgs to fermions, boson may change

- H→bb might dominate in the entire mass range!