SEARCHING THE HIGGS BOSON WITH THE ATLAS EXPERIMENT

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LAL Orsay

UPENN seminar – 10/02/2009

OUTLINE

- ***THE HIGGS BOSON & ATLAS***
- ***SEARCH FOR A STANDARD MODEL HIGGS***
- ***SEARCH FOR A MSSM HIGGS***
- ***CONCLUSIONS***

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THE STANDARD MODEL

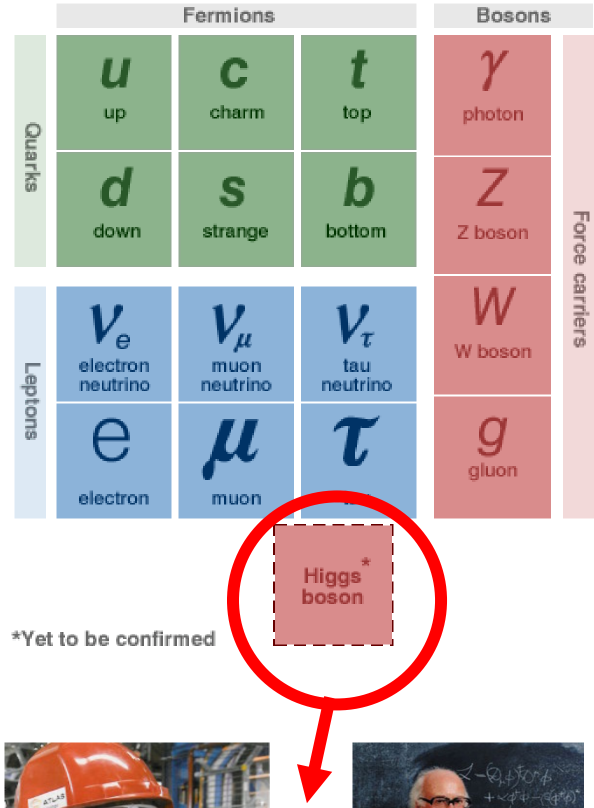
- Standard Model = gauge theory $SU(3)_C \times SU(2)_L \times U(1)_Y$

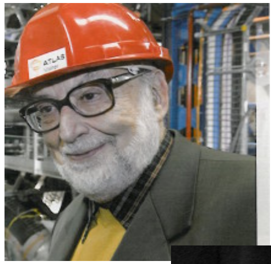
Strong interaction — *Weak interaction* — *Electromagnetic interaction*

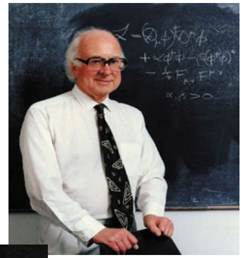
- 3 families of matter
- Massive *W*, *Z* gauge bosons.
- A scalar Higgs field:
  - giving masses to *W*, *Z* through the « Higgs mechanism »
  - giving masses to fermions through Yukawa couplings:

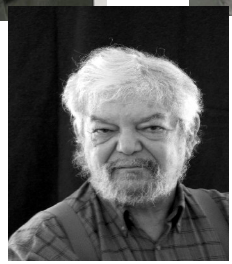
$$-\frac{1}{v} m_f \bar{\psi}_f \phi_h \psi_f$$

- Higgs boson: excitation of the Higgs field
  - it is a scalar boson
  - it has specified couplings
  - it has unknown mass



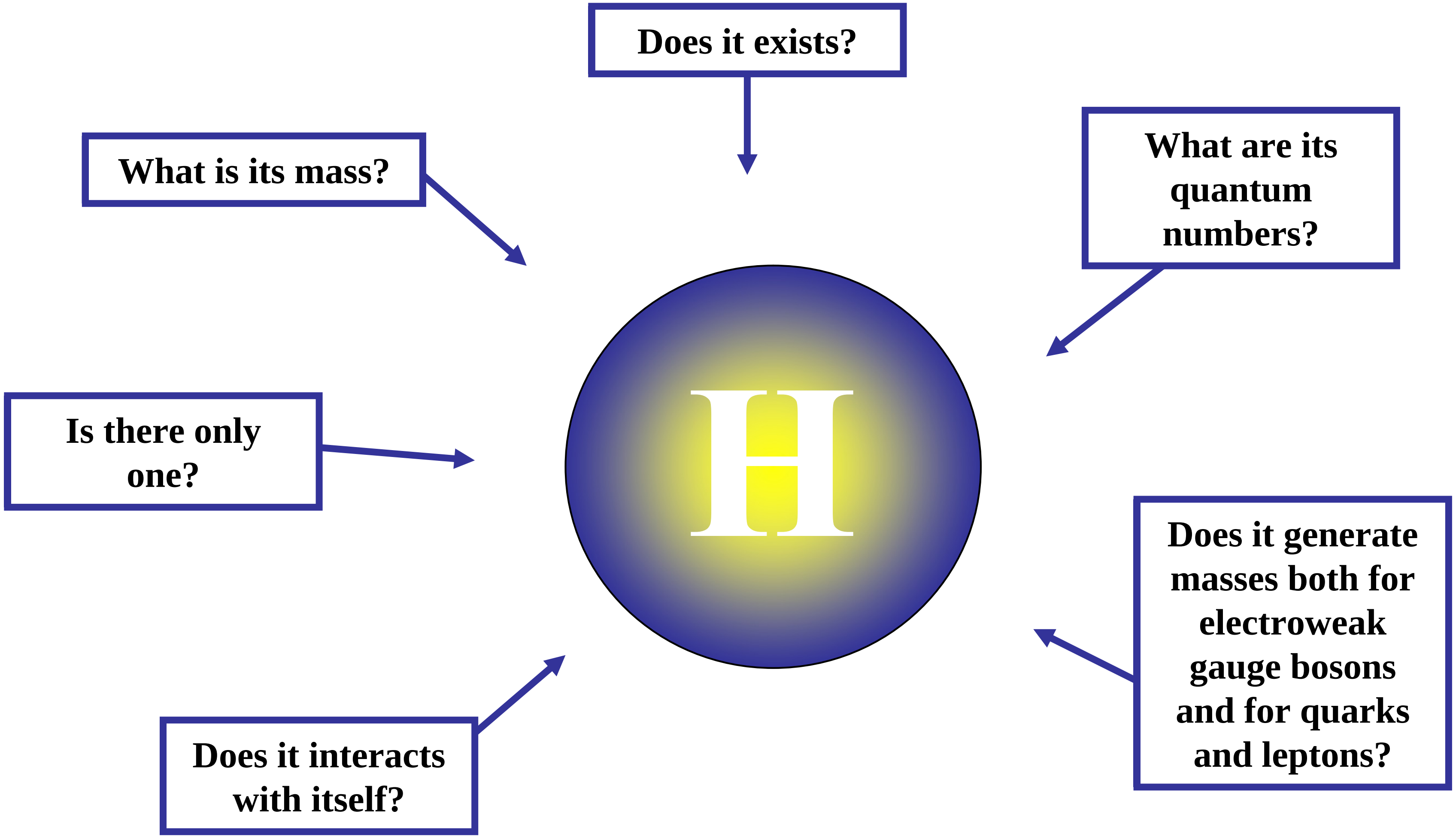






1964
Brout
Englert
Higgs

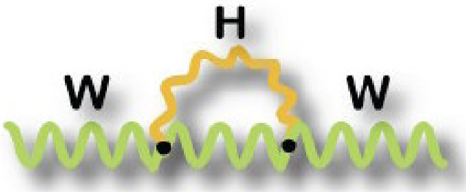
UNSOLVED QUESTIONS



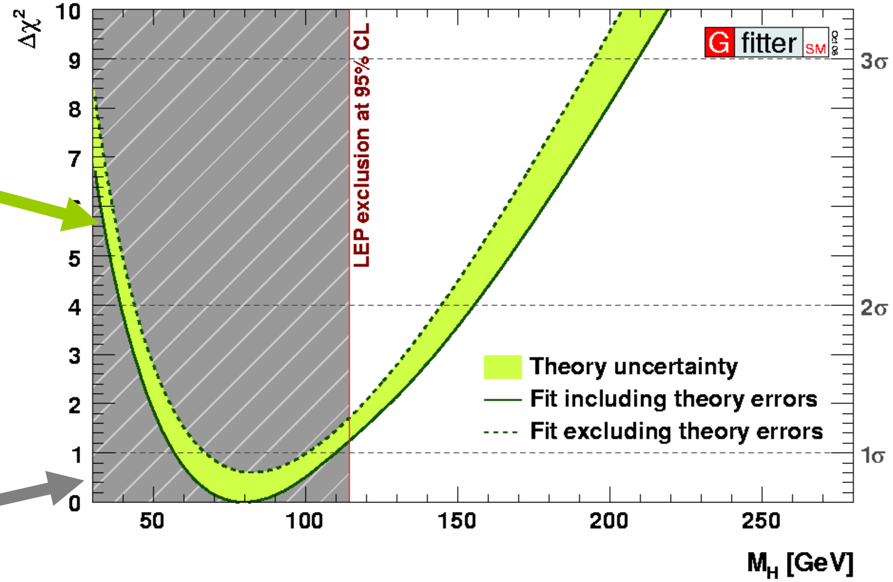
Experiments are trying to answer!

PRESENT LIMITS

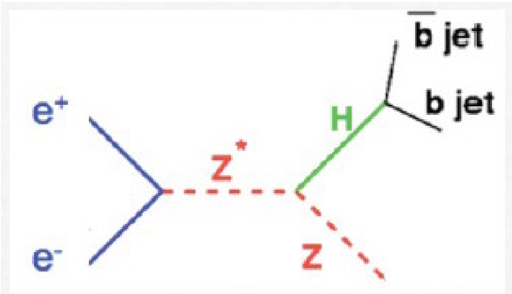
- **The electroweak measurements are sensitive to m_H through radiative corrections:**



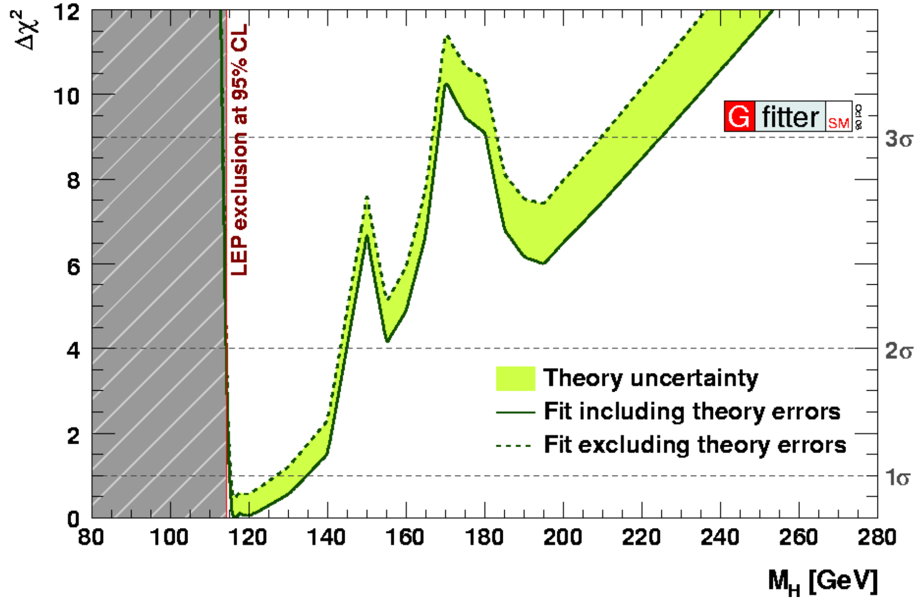
$$\sim \log \frac{m_H}{m_W}$$



- **Direct search at LEP2:**



Including LEP & Tevatron direct searches



LEP limits:

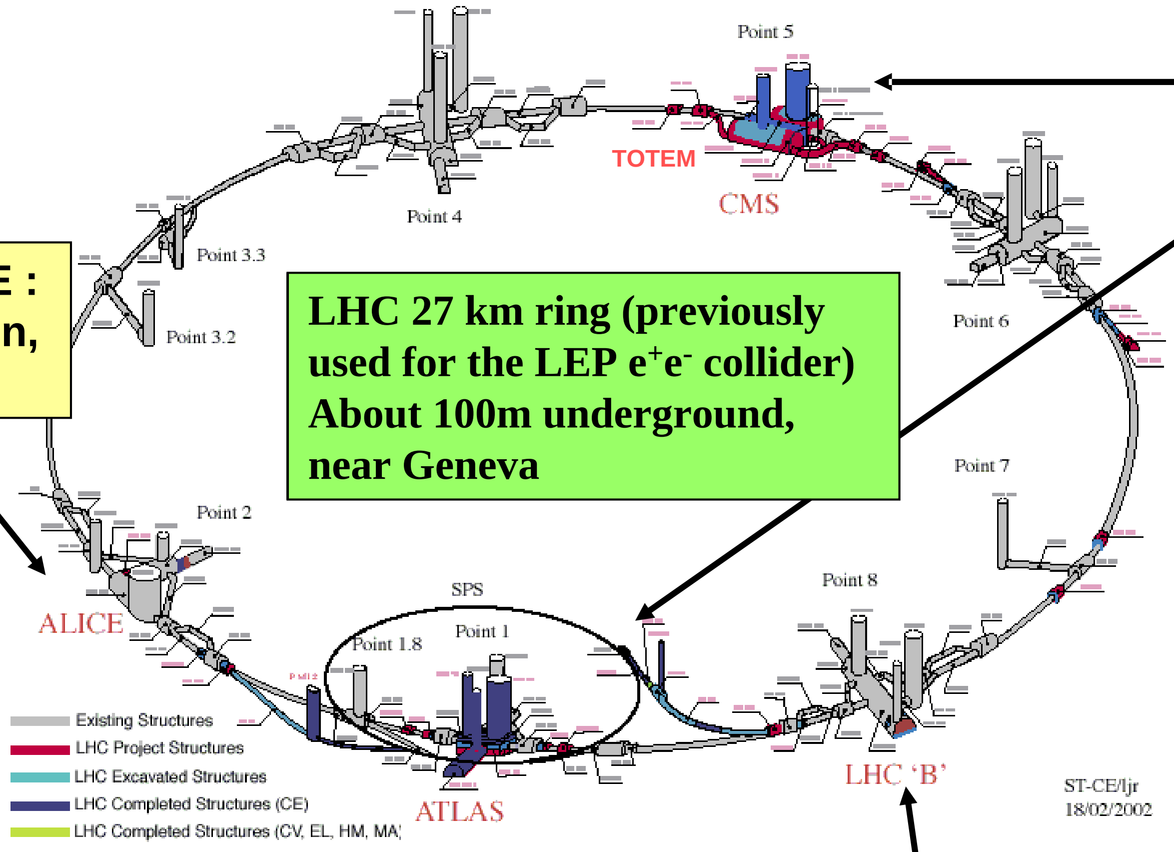
$114.4 < m_H \lesssim 182$ GeV/c²

Directe ***Indirecte***

THE LARGE HADRON COLLIDER

- pp $\sqrt{s} = 14$ TeV $L_{design} = 10^{34}$ cm^{-2} s^{-1} (after 2010)
  $L_{initial}$ < few x 10^{33} cm^{-2} s^{-1} (before)

  Note: $\sqrt{s}$ is x7 Tevatron, L_{design} is x100 Tevatron
- Heavy ions (e.g. Pb-Pb at $\sqrt{s}$ ~ 1000 TeV)



ATLAS and CMS :
pp, general purpose

ALICE :
ion-ion,
p-ion

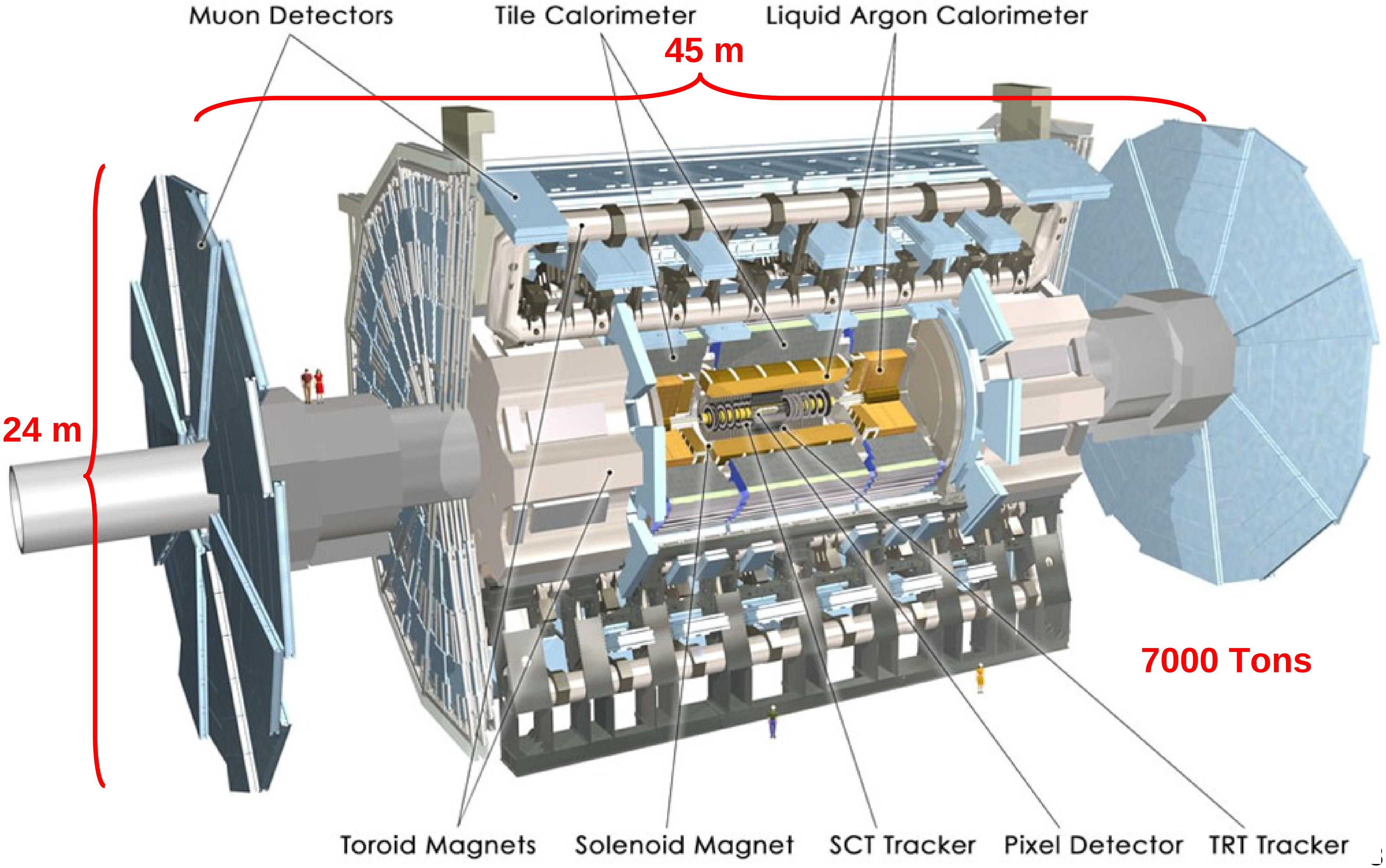
LHC 27 km ring (previously used for the LEP e^+e^- collider)
About 100m underground, near Geneva

The LHC machine is fully installed and was ready to start operation with single beams on 10th September 2008. After the incident happened on 19th September, operations have been postponed…

LHCb :
pp, B-physics, CP-violation

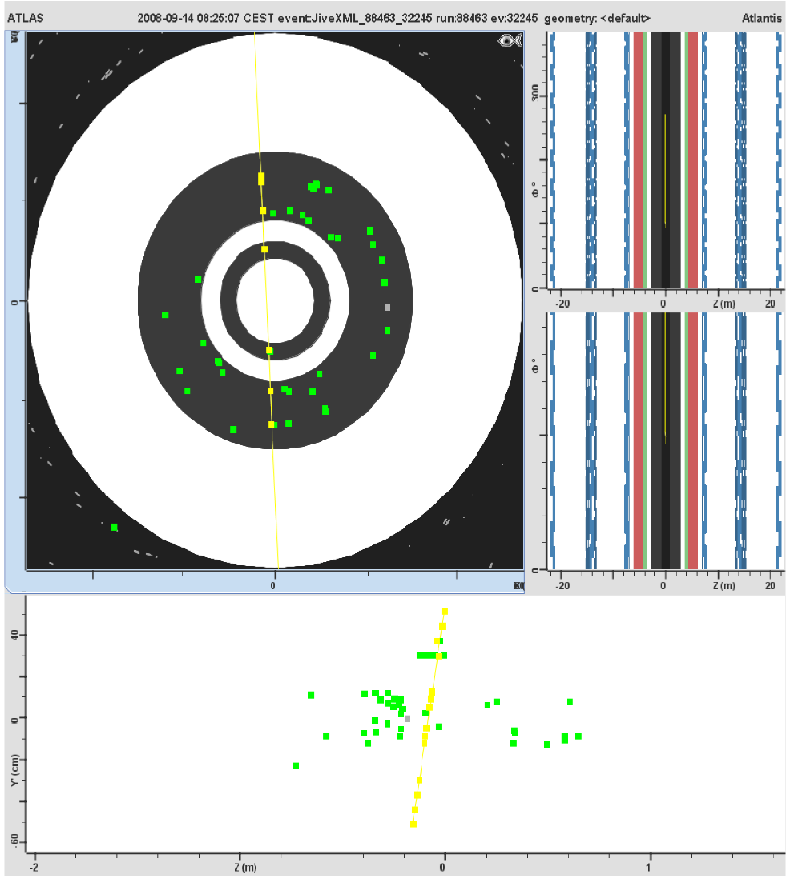
THE ATLAS DETECTOR

The ATLAS experiment: 1900 scientists, 165 institutes, 35 countries!



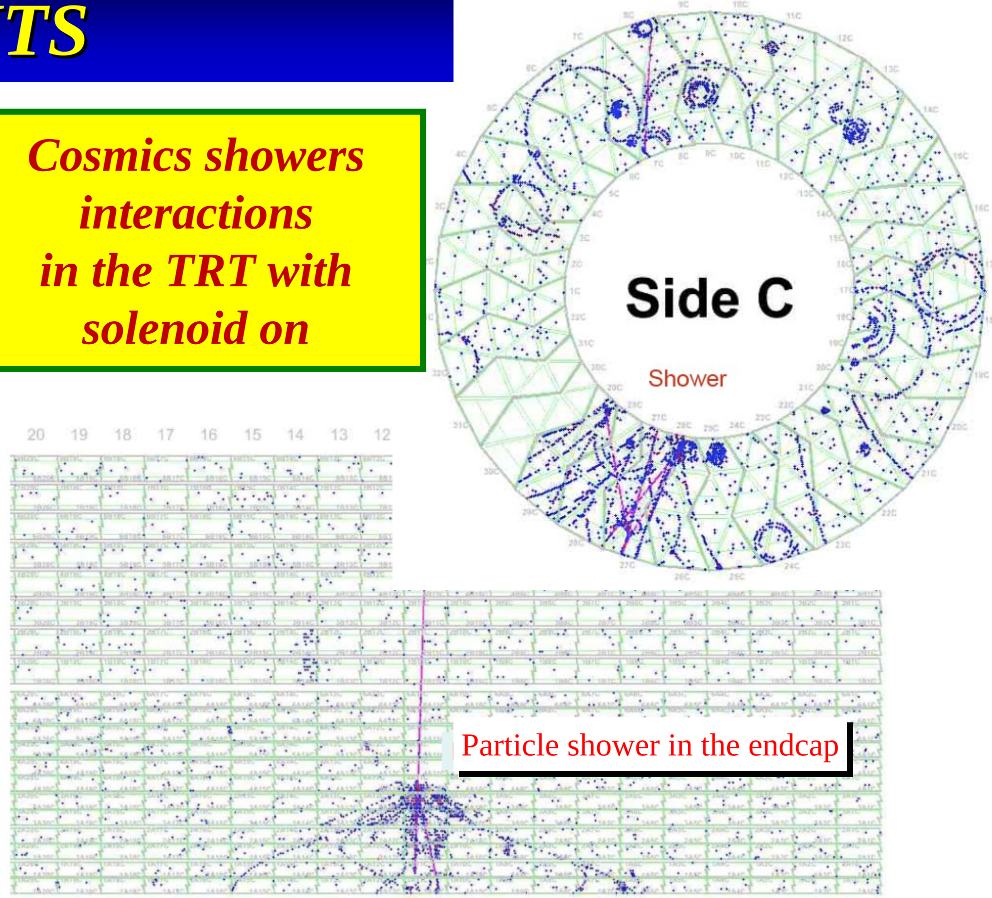
COSMICS EVENTS

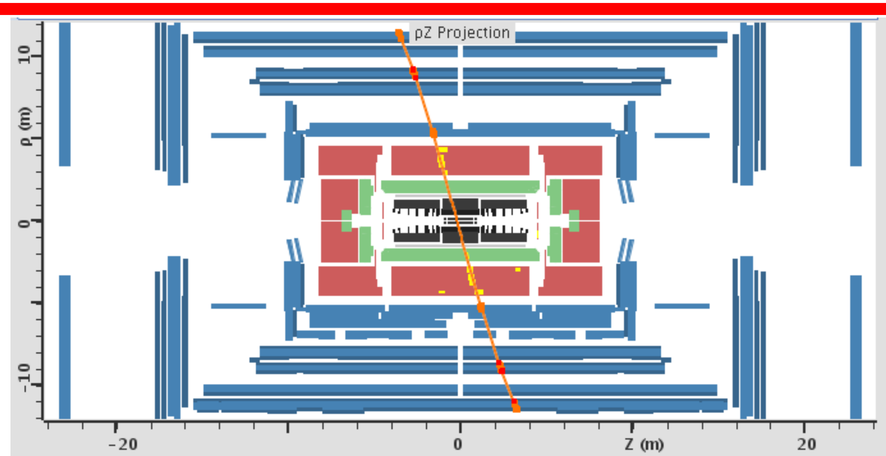
Used for alignment!



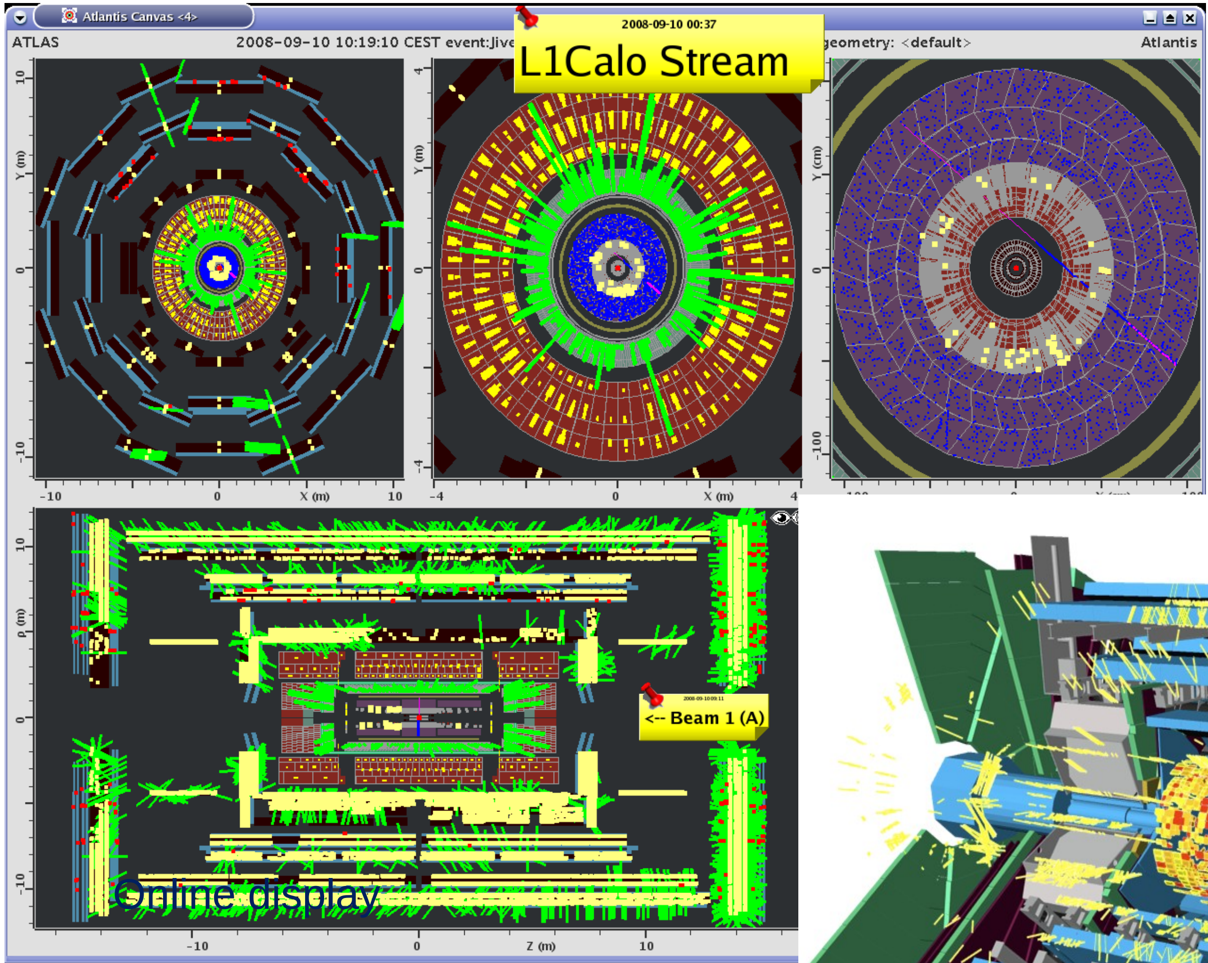
Event with 7 Pixel hits (overlapping L2 modules) and 16 SCT hits

Cosmics showers interactions in the TRT with solenoid on

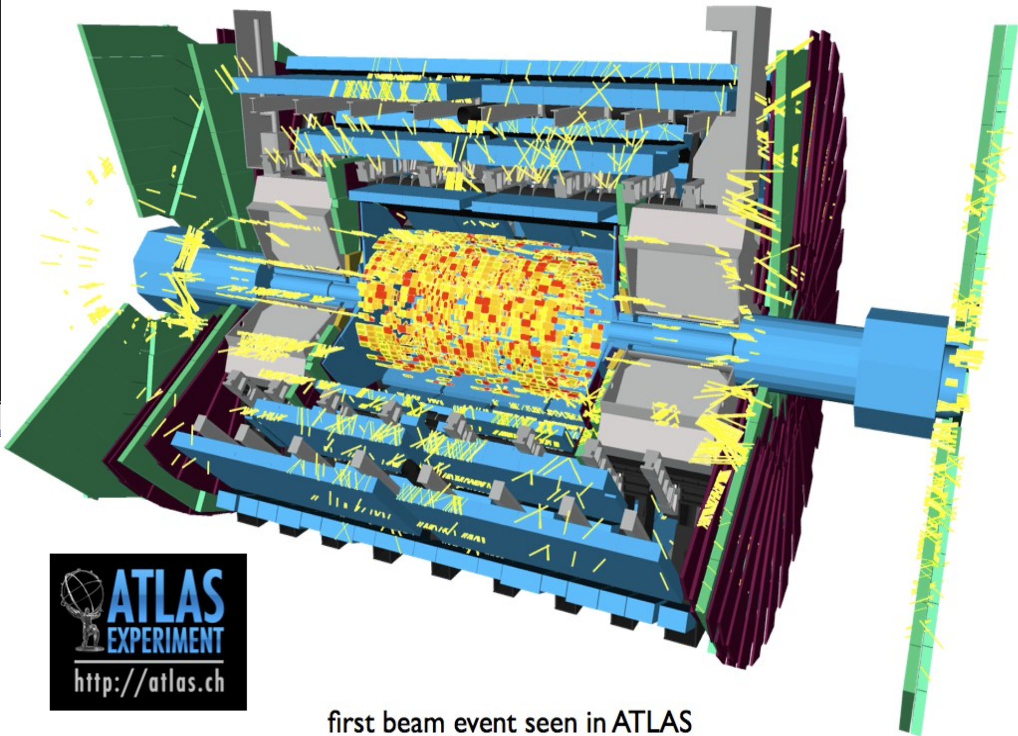




FIRST BEAM-SPLASH EVENT



The very first beam-splash event from the LHC in ATLAS on 10:19, 10th September 2008



first beam event seen in ATLAS

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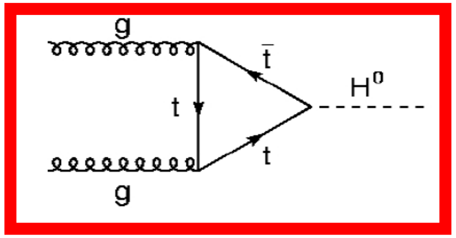
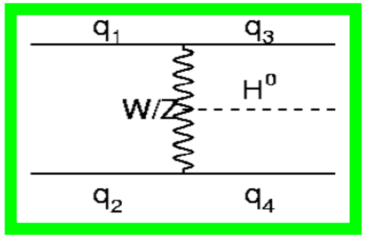
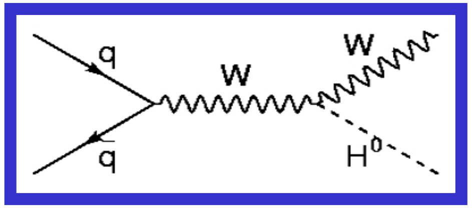
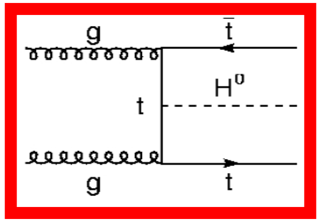
HIGGS PRODUCTION AT THE LHC

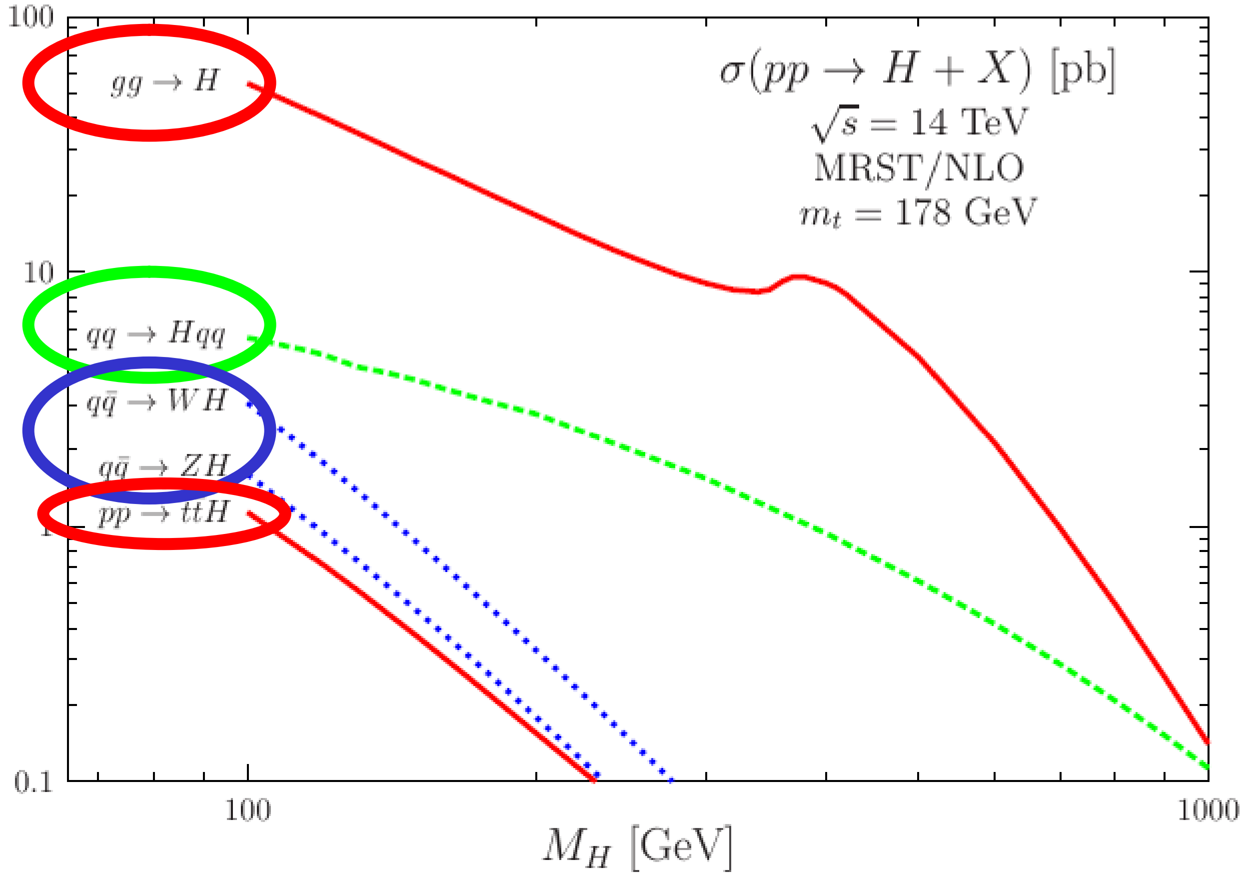








A.Djouadi Phys.Rept.457:1-216

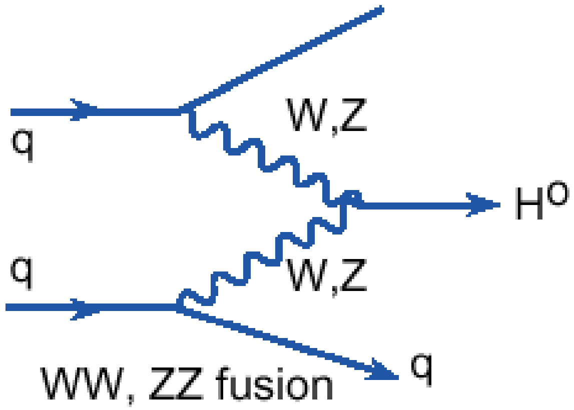


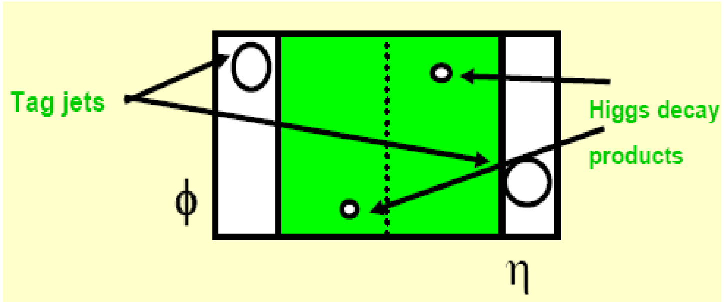
***gg fusion** process is the more abundant, followed by the **Vector Boson Fusion** process.*

Typical uncertainties on cross-section

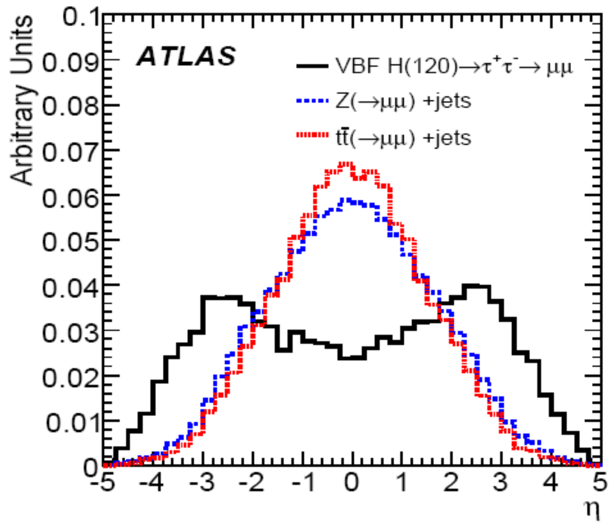
gg	**10 %**	**NNnLO**
VBF	**5%**	**NLO**
WH,ZH	**5%**	**NNLO**
ttH	**15%**	**NLO**

THE VECTOR BOSONS FUSION (VBF)





Rapidity distribution



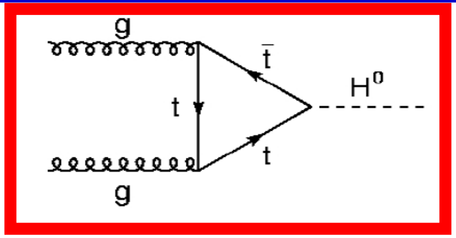
Signature:

- Two forward quark initiated "tag" jets (***large*** ***η separation*** with high-p_T) with large invariant mass M_{jj}
- No jet activity in the central region (between the two tag jets) due to color singlet: rapidity gap →***jet veto***
- Higgs decay products between tag jets in η

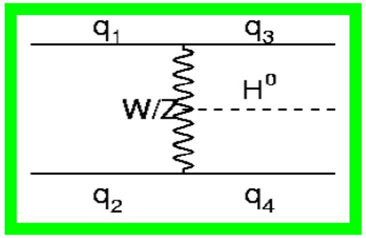
Advantages:

- Provides high signal over background ratios
- Improve and extend measurement of Higgs boson parameters (couplings to bosons, fermions)
- Measure Higgs boson spin and CP properties.

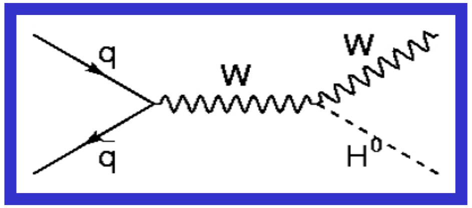
THE SM HIGGS BOSON DECAYS



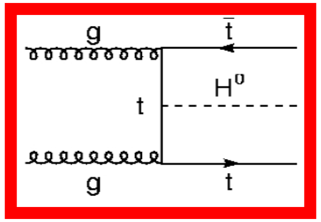
GF **H → WW, ZZ , γγ**



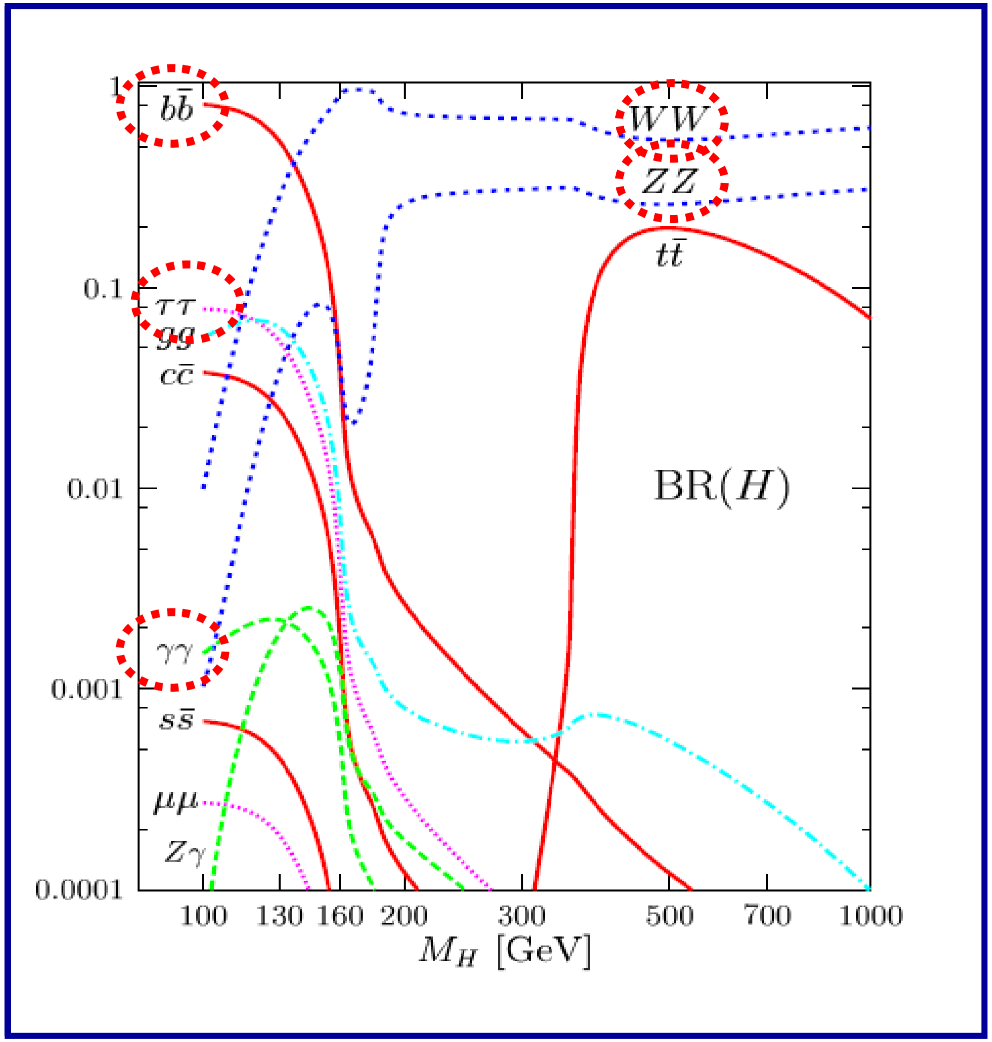
VBF **H → WW , γγ , ττ**



H → WW, γγ



H → WW, γγ, bb



Many channels explored!
All the mass range is covered!

WHICH PARAMETERS CAN WE MEASURE AT LHC?

1. **Mass**

2. **Couplings to bosons and fermions**

3. **Spin and CP**

- Angular distributions in the decay channels:

$H \rightarrow ZZ(*) \rightarrow 4\ \ell$, $H \rightarrow WW(*)$, H->$\tau\tau$ VBF

are sensitive to spin and CP eigenvalue

- $H \rightarrow \gamma\gamma$, if observed, excludes spin 1 (Yang's theorem)

Not for early data … needs to find Higgs first !

4. **Higgs self coupling**

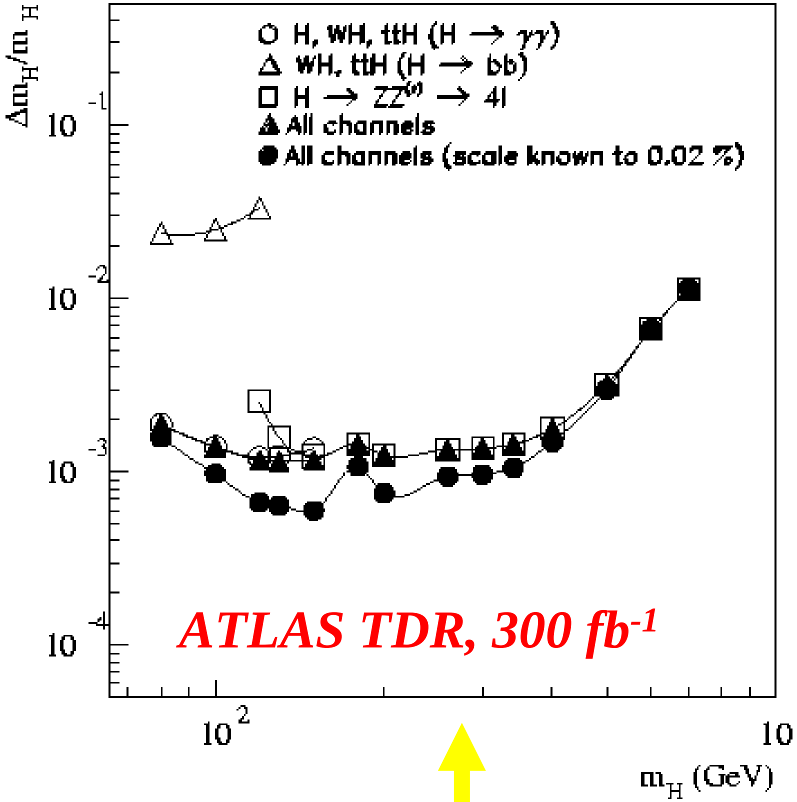
Possible channel: $gg \rightarrow HH \rightarrow WW\ WW \rightarrow \ell\nu\ jj\ \ \ell\nu\ jj$

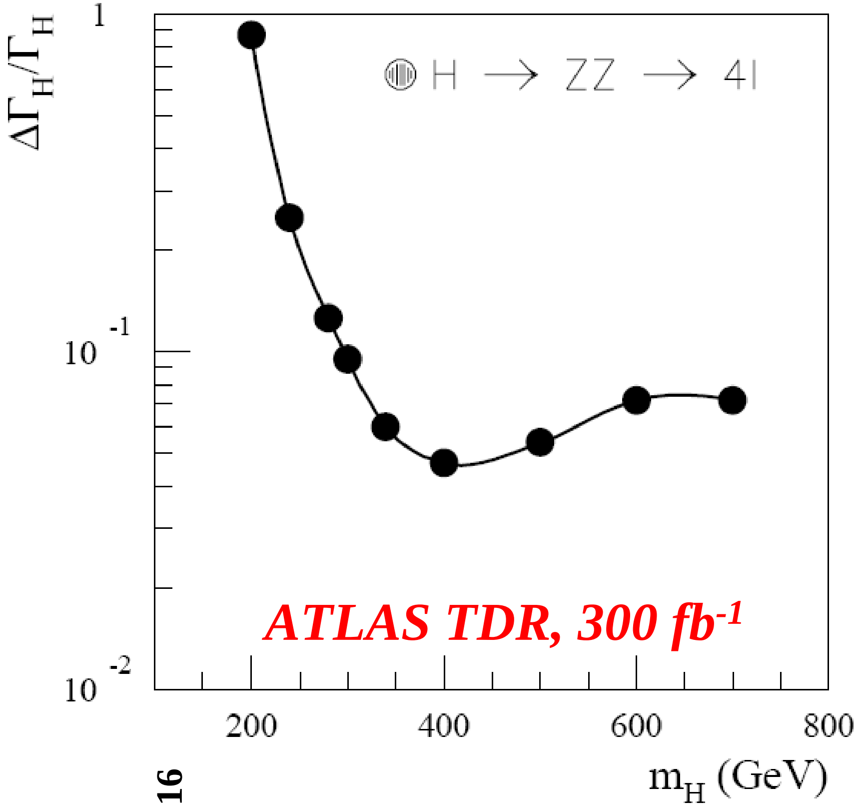
Small signal cross sections, large backgrounds from tt, WW, WZ, WWW, tttt, Wtt,...

No significant measurement possible at LHC!

Very difficult at a possible SLHC (6000 fb^{-1}), limited to mass region around 160 GeV/c^2

DIRECT MASS AND WIDTH MEASUREMENTS

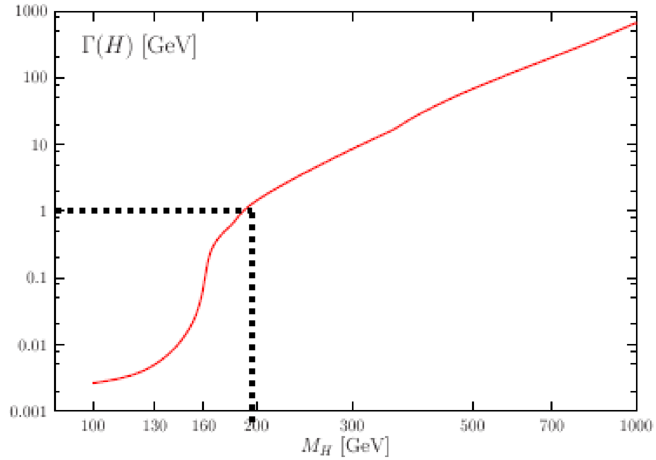




The mass can be directly measured with a precision of 0.1% over a large range (130 - ~450 GeV/c^2)

The width is smaller than the 'leptonic/γ resolution' for low masses

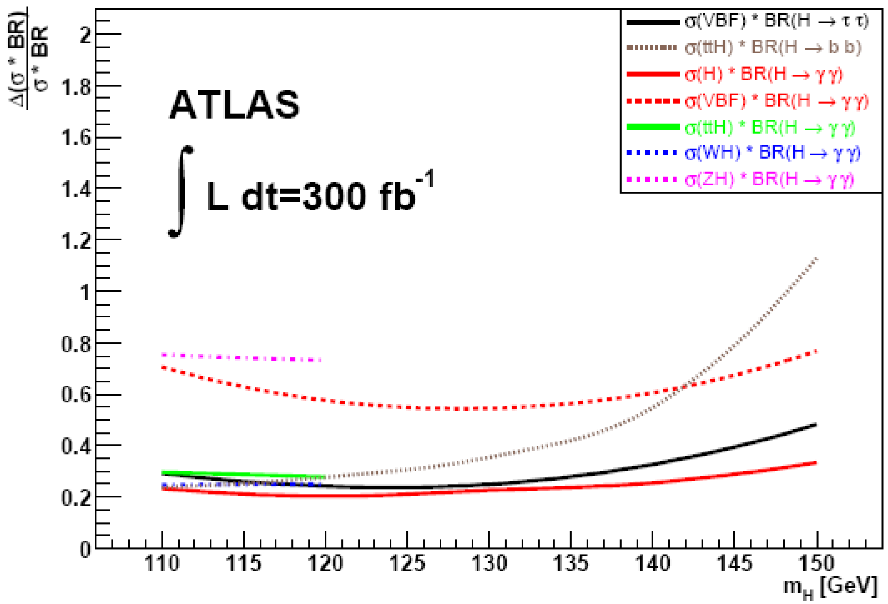
A.Djouadi Phys.Rept.457:1-216

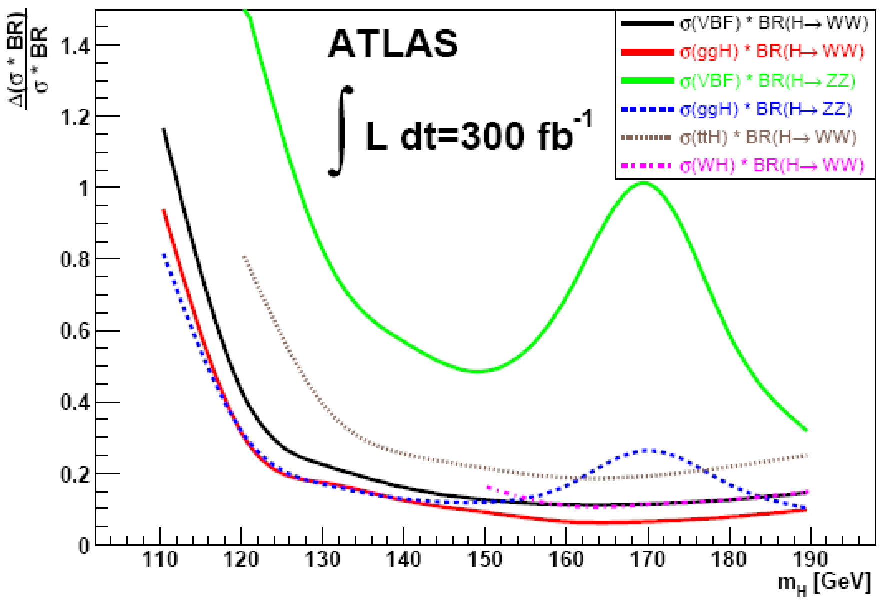


HIGGS COUPLINGS – 1

M.Duhrssen ATL-PHYS-2003-030
M.Duhrssen,S.Heinemeyer,H.Logan,D.Rainwater,G.Weiglein and D.Zeppenfeld Phys Rev D70,113009,2004

Warning: based on 'old' expectations





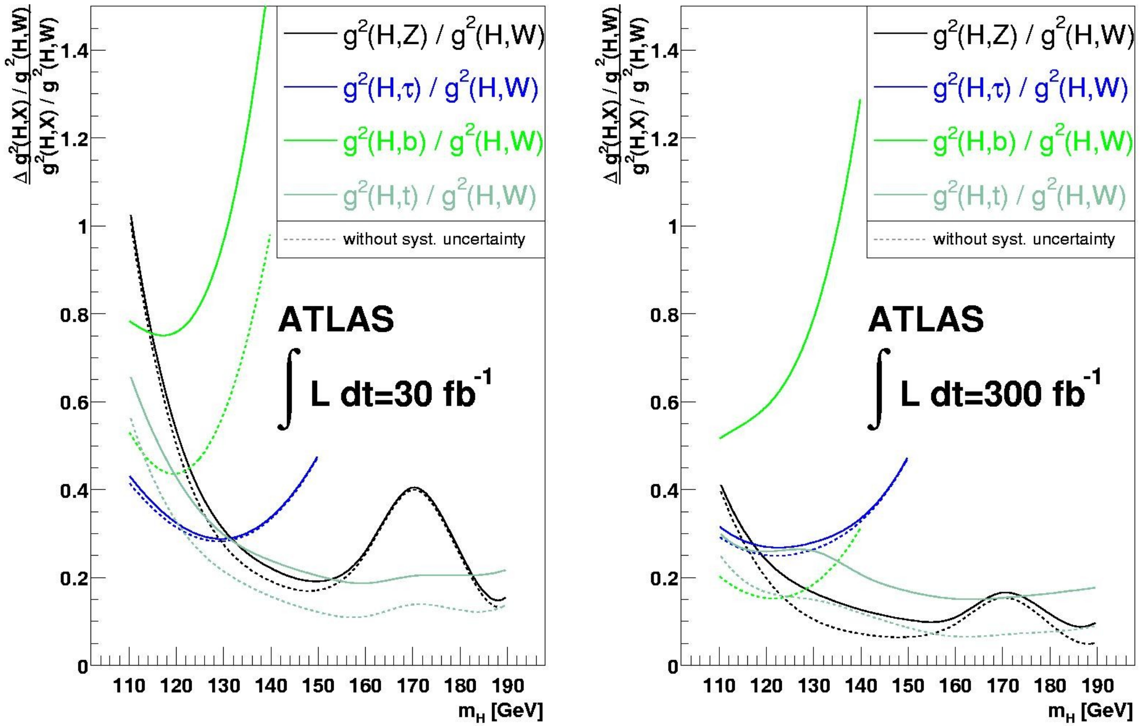
First step: measure *σ*BR* in different channels with *almost* no assumptions (uncertainties comes from selection efficiencies , background evaluation)

HIGGS COUPLINGS – 2

Second step: give the measured *σ*BR* as input in a global likelihood fit

Output: Higgs boson couplings, normalized to the WW-coupling

M.Duhrssen ATL-PHYS-2003-030



Assuming mainly no new particles in loop, express rates and BR as a function of 5 couplings:

g_W g_Z g_t g_b g_τ

Relative couplings can be measured with a precision of ~20% (for 300 fb^{-1})

WHAT'S NEW IN ATLAS HIGGS SEARCHES?

ATLAS: CERN-OPEN 2008-020

Update on the analysis techniques and the discovery potentials!

Warning: ALL ESTIMATIONS ARE BASED ON 14TeV !!!

- Detailed **GEANT simulations** of the detectors.

- New **(N)NLO Monte Carlos** for both signal and backgrounds.
  - MCFM Monte Carlo, J. Campbell and K. Ellis, http://mcfm.fnal.gov
  - MC@NLO Monte Carlo, S.Frixione and B. Webber, wwweb.phy.cam.ar.uk/theory/
  - T. Figy, C. Oleari and D. Zeppenfeld, Phys. Rev. D68, 073005 (2003)
  - E.L.Berger and J. Campbell, Phys. Rev. D70, 073011 (2004)
  - C. Anastasiou, K. Melnikov and F. Petriello, hep-ph/0409088 and hep-ph/0501130
  - Resbos, Diphox, Jetphox
  - …..

- New approaches to match **parton showers and matrix elements**
  - ALPGEN Monte Carlo + MLM matching, M. Mangano et al.
  - SHERPA Monte Carlo, F. Krauss et al.
  - …

  Tevatron data are extremely valuable for validation, work started.

- Better understood **reconstruction methods**

  (partially based on test beam results,…)

- Further studies of **new Higgs boson scenarios**
  - Various MSSM benchmark scenarios
  - CP-violating scenarios
  - Invisible Higgs boson decays
  - …..

$H \rightarrow \gamma\gamma$

- ***Important channel in the** low mass region.*
- ***It gives the** best mass resolution **thanks to excellent electromagnetic energy resolution***

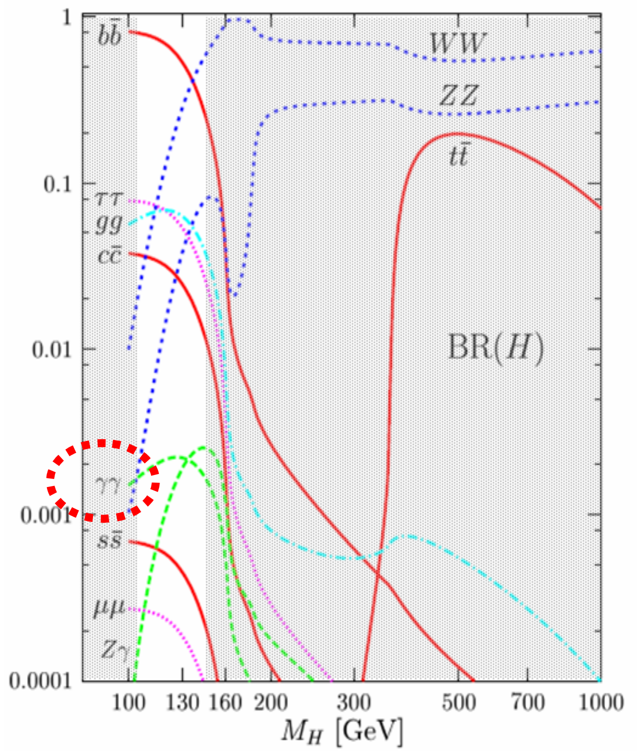
SELECTION

- **Trigger**: at least 2 isolated photons, with $p_T > 20\ GeV/c$ each

  → ε *(respect to offline) = (93.6 ± 0.4)%*
- **Identification cut** exploiting the shower shape.
- **Fiducial cut**: 0< |η| < 1.37 & 1.52 < |η| < 2.37.
- **Isolation cut**: $\Sigma p_T < 4\ GeV/c$, considering all tracks with $p_T > 1 GeV/c$ in a $\Delta R = 0.3$ cone around the electromagnetic cluster.
- **Momentum cut**: $p_T > 25 GeV/c$ and $p_T > 40 GeV/c$ for the two most energetic photons.

Selection efficiency:

ε = 36.0 % (32.2% with pileup $10^{33} cm^{-2} s^{-1}$)



In a mass window ***M_H +/- 1.4σ GeV:***

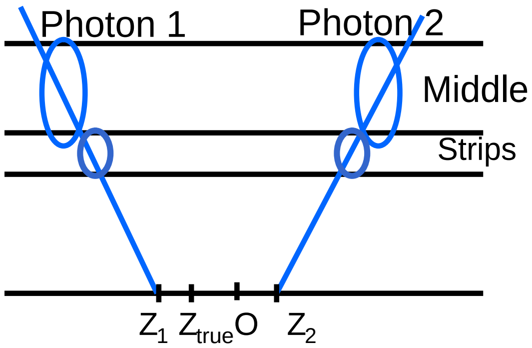
Signal Process	Cross-section (fb)
$gg \rightarrow H$	21
VBF H	2.7
ttH	0.35
VH	1.3

RECONSTRUCTION ISSUES

PRIMARY VERTEX

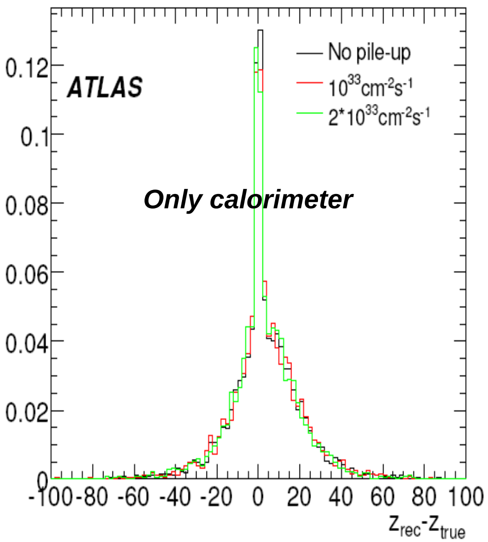
If the vertex is unknown, add 1.4 GeV to the mass resolution.

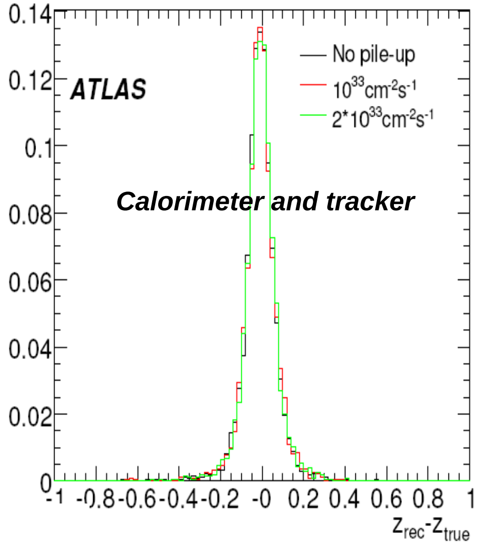
Combine calorimeter and tracker informations!



- Calorimeter → vertex position accuracy of ***19 mm***
- Combining with the tracker information → ***~0.1 mm***

Calorimeter information is useful in case of pile-up or events with low tracks multiplicity.



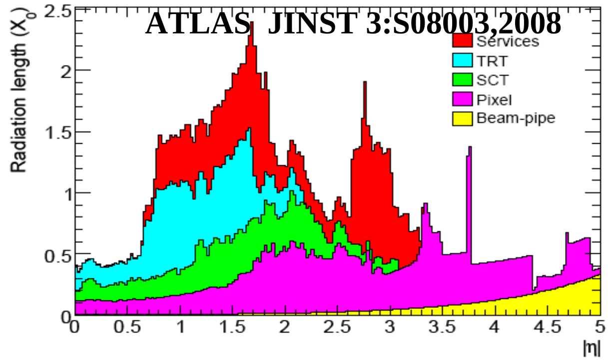


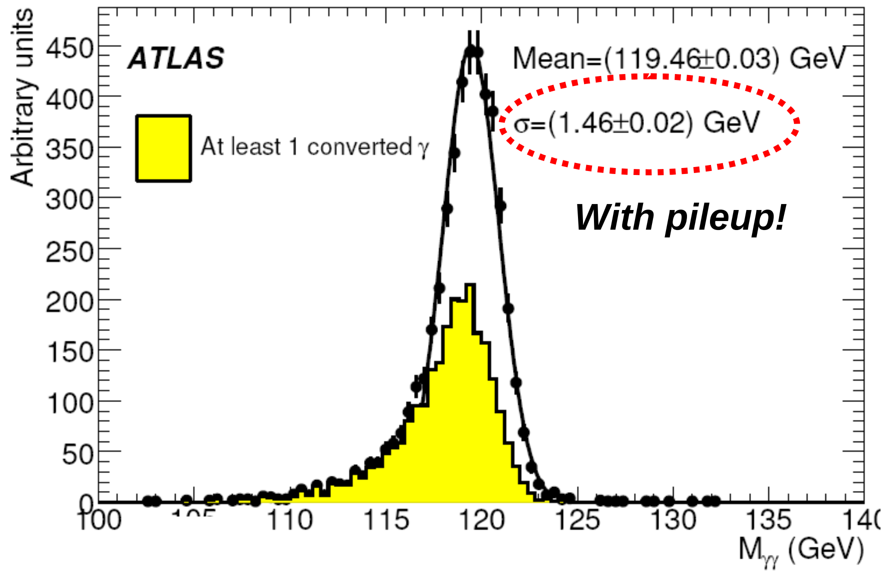
CONVERSIONS

~50% of the events with at least one converted γ !

- ad hoc energy calibration required in late conversions;
- conversion vertex used in computation of the direction;
- used for gamma-jet background estimation.

Also one reconstructed track conversions!





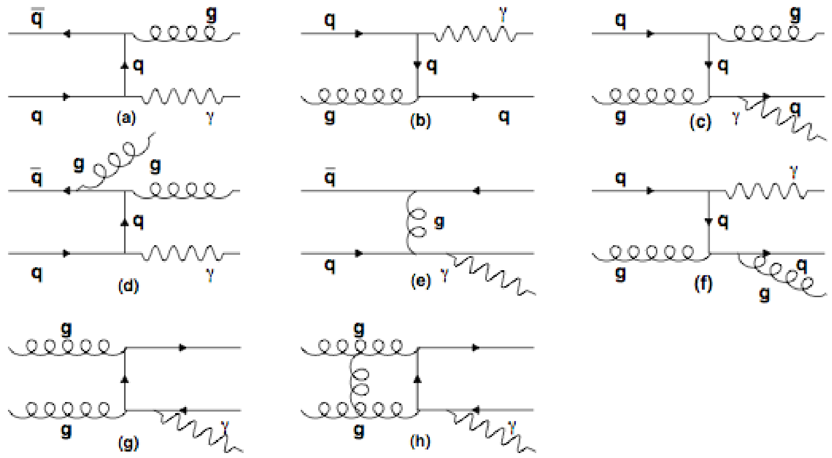
BACKGROUNDS

Background is evaluated with ***NLO*** simulations.
It will be measured from data sidebands.

Within a mass window M_H +/- 1.4σ ***GeV***:

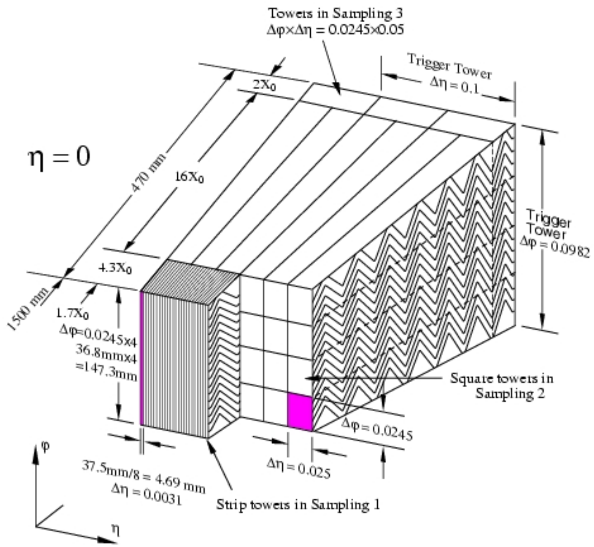
Background Process	Cross-section (fb)
$\gamma\gamma$	562
Reducible γj	318
Reducible jj	49
Drell Yan	18

Example: γ-jet processes



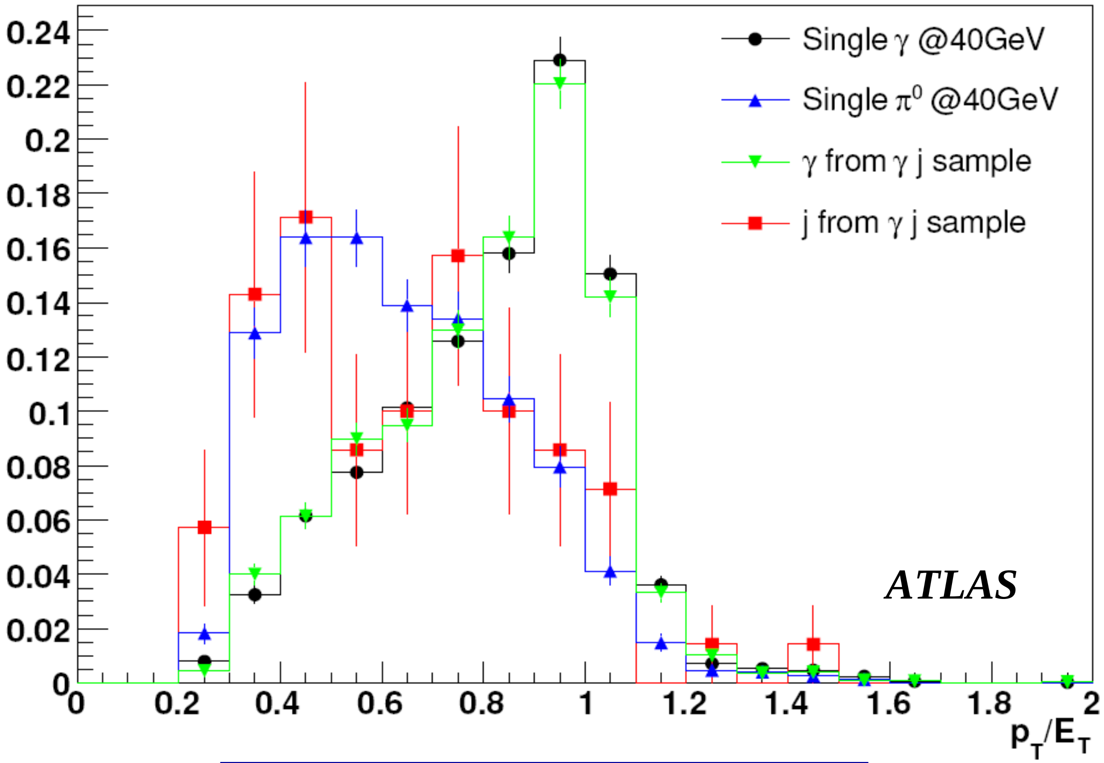
Strategy for jet rejection:

- *Longitudinal segmentation* of the calorimeter.
- Fine segmentation of the first layer (*η-strips*) => good π^0 rejection.
- *Isolation* of the *electromagnetic* cluster.
- *Isolation based on tracks* reconstructed by the inner detector.

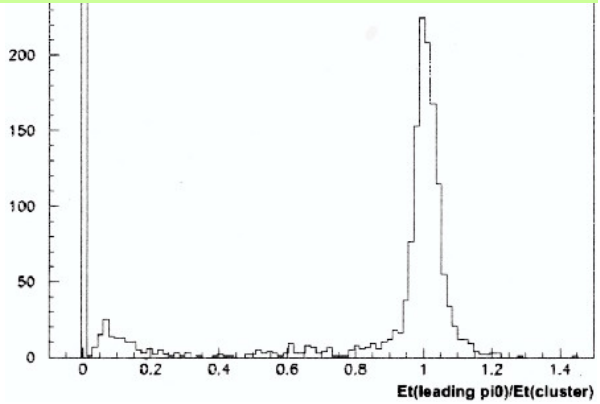


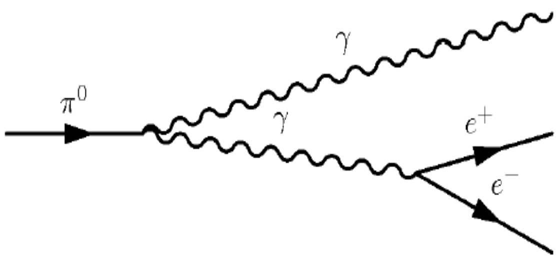
THE REDUCIBLE γjet BACKGROUND

On a selected sample of conversions **we can measure the ratio** p_T / E_T



Most of the energy of selected jets is brought by a leading π^0!

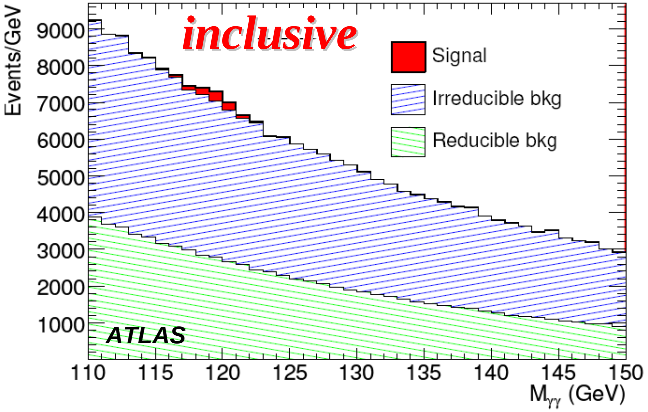


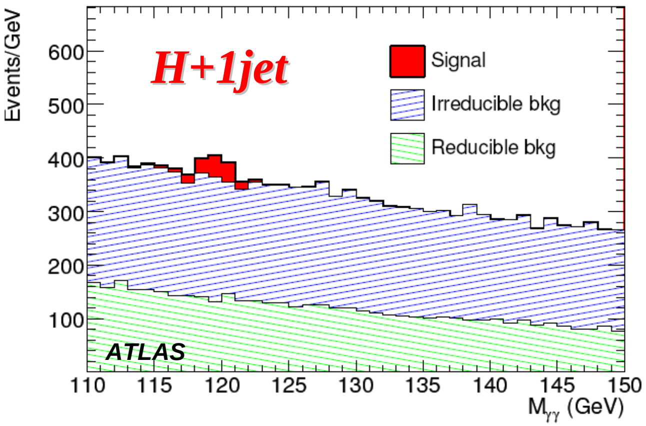


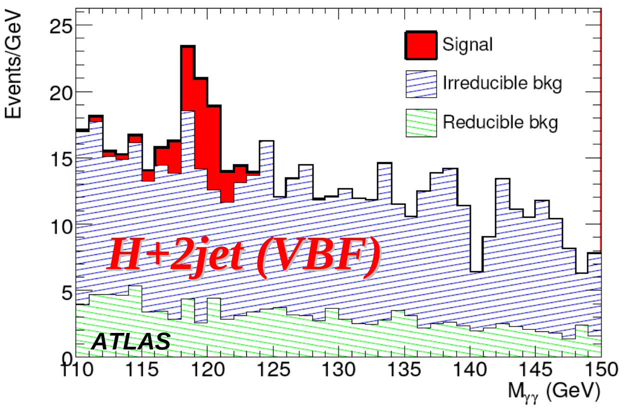
p_T / E_T can be used:

- to **improve γ jet rejection**;
- to **evaluate the γ/jet ratio** on real data.

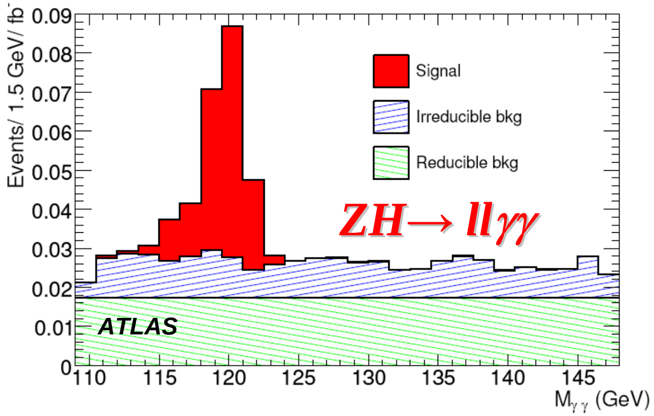
INVARIANT MASSES DISTRIBUTIONS

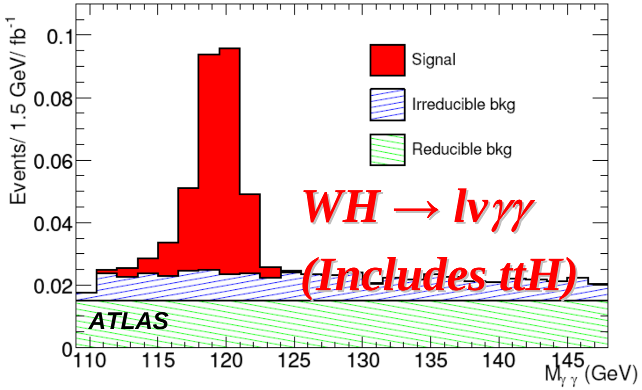






Higher level of purity in associated productions, but less events…



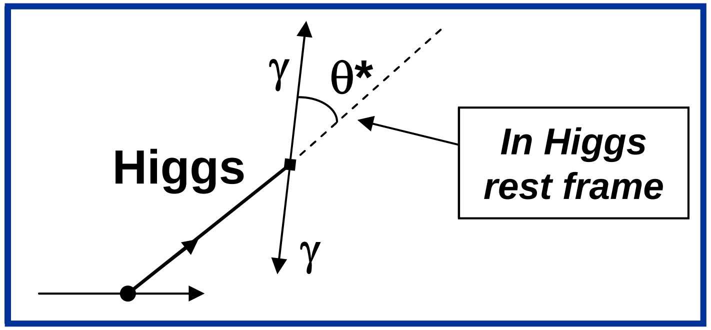


SIGNIFICANCE

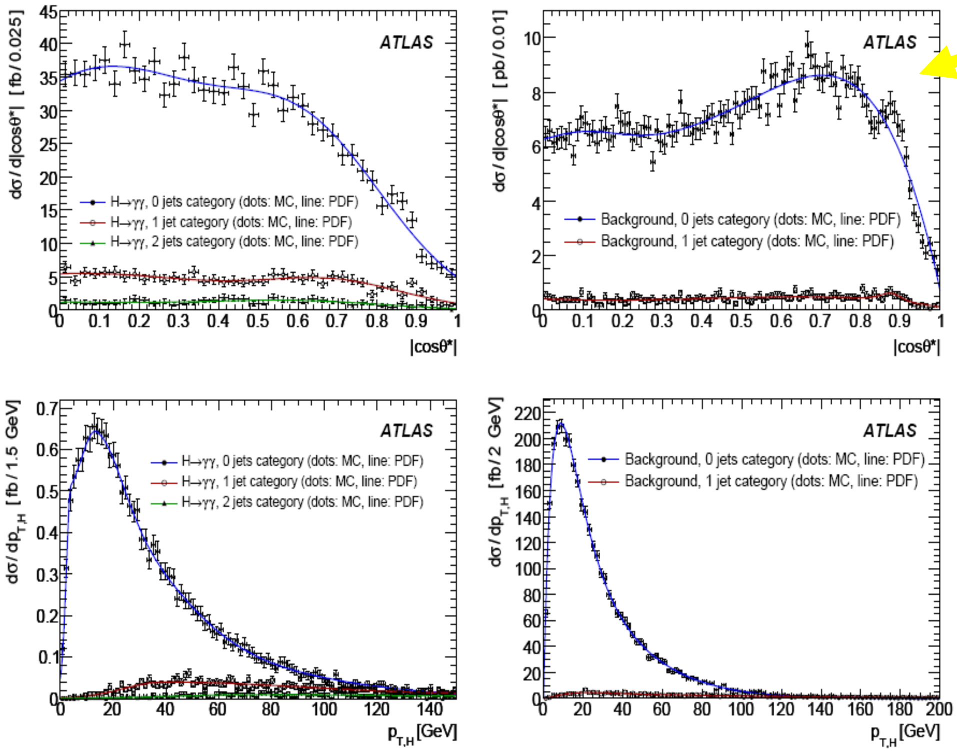
Fit and likelihood ratio are used for setting discovery potential and handle systematics.

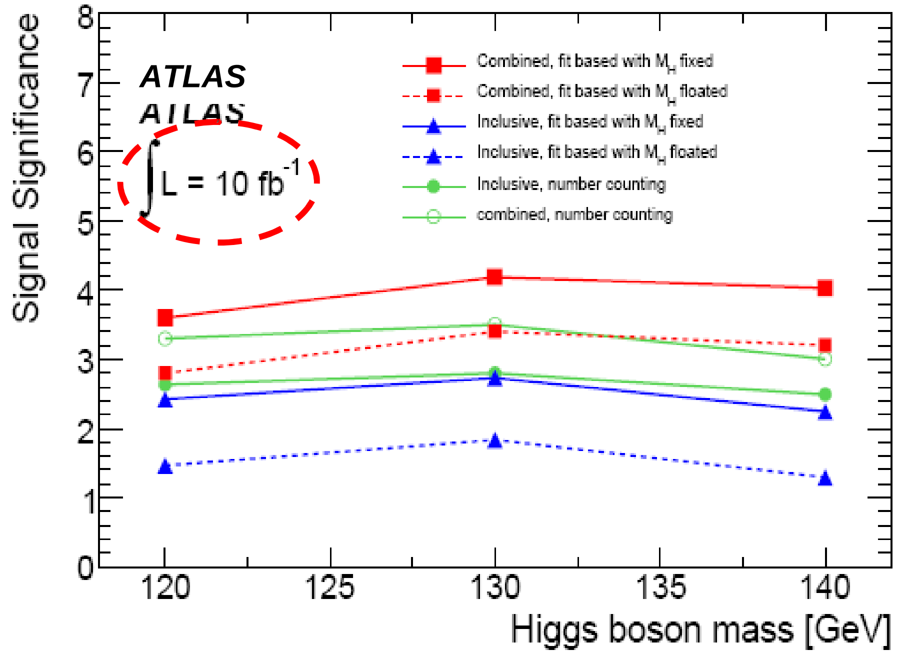
Different fit based approaches:
1- fit only the ***m(γγ)*** distribution;
2- simultaneous fit to ***m(γγ)***, ***P_T(γγ)*** and ***cos θ****

• Fit approaches are also performed with the Higgs ***mass floating***.
• The use of ***categories*** with different resolutions based on *η, jet multiplicity* and *presence of conversions* improves the significance.

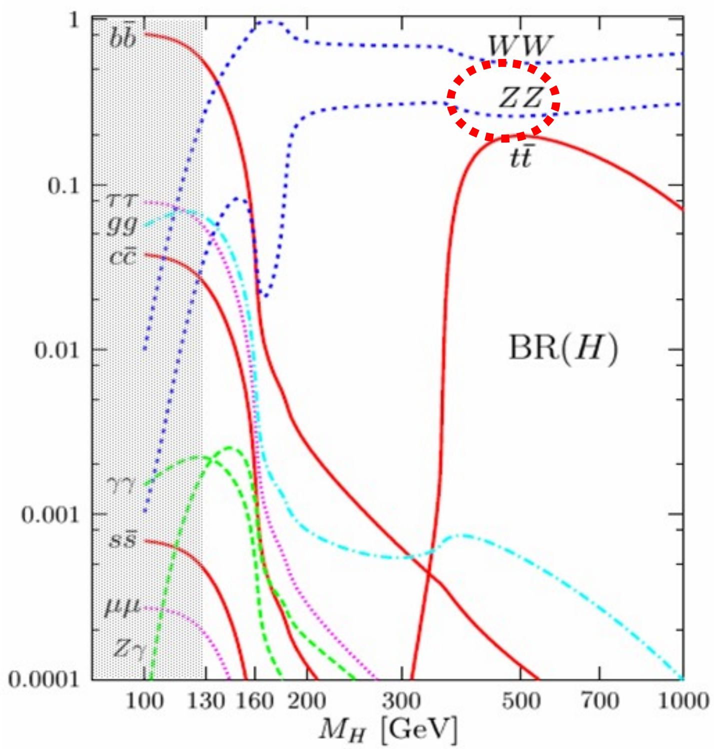


Distributions need to be handled with care: lots of comparisons between different Monte Carlo generators!!!





$H \rightarrow ZZ(*) \rightarrow 4l$



Eff~30-50%

SELECTION

- **Trigger**: - single isolated μ (*e*) with p_T *>20 (25) GeV/c;*
  - two μ (*e*) with p_T *>10 (15) GeV/c.*
- **Kinematic**: - 2 pairs of same flavor opposite charge lept.
  - p_T>7GeV (at least two with p_T>20GeV)
  - calorimeter identification
  - $|M_{(l+l-)\_1} - M_Z| < \Delta M_{12}$ and $M_{(l+l-)\_2} > M_{34}$
- **Fiducial cut**: $|\eta| < 2.5$
- **Isolation cut**: - Calorimeter: $\Sigma E_T/p_T < 0.23$
  - tracker: $\Sigma p_T/p_T < 0.15$
- **Vertexing cut** on maximum lepton ***impact parameter***:

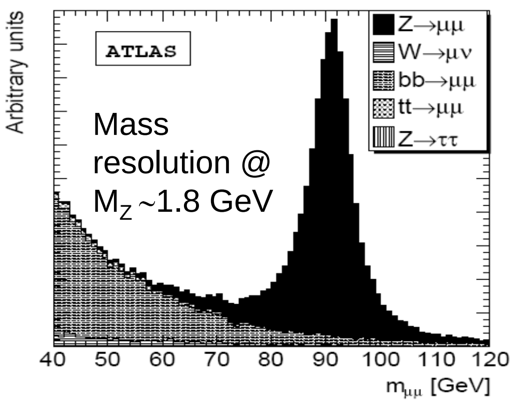
$d_0/\sigma_{d0}<3.5$ *(6.0)* for *μ (e)*

It is the "golden channel"!

- ***Observation of a clear peak on top of a smooth background!***
- ***Wide range of masses explored***

Background will be estimated in sidebands
→ low systematic uncertainties

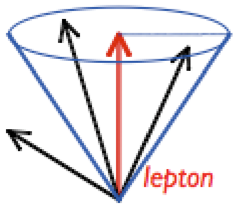
•Look to the *Z* with first data to understand lepton reconstruction and detectors response.
•*Z→ee* mass peak is affected by electron bremsstrahlung.



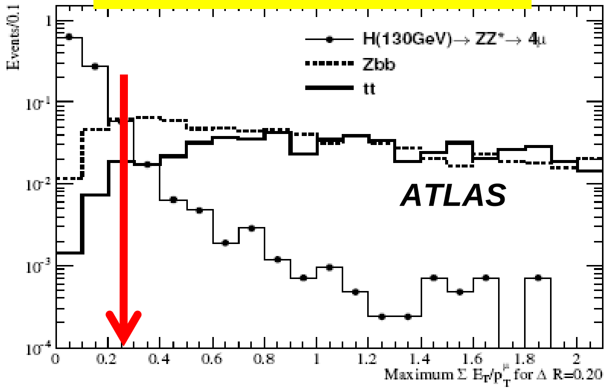
ISOLATION & IMPACT PARAMETER

Reducible backgrounds have activity around leptons from b-decay

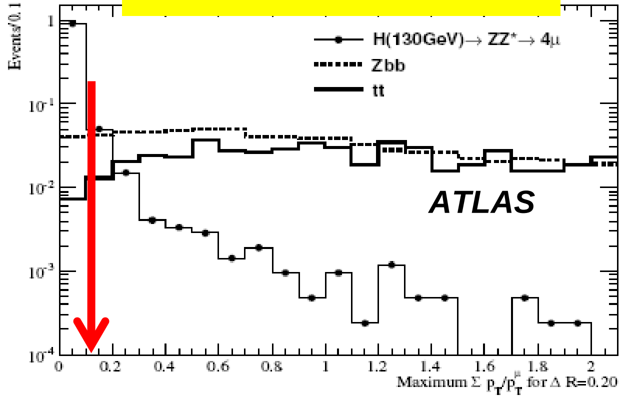
$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$



Calorimetric isolation

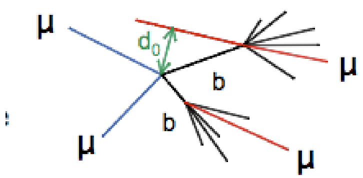


Track isolation

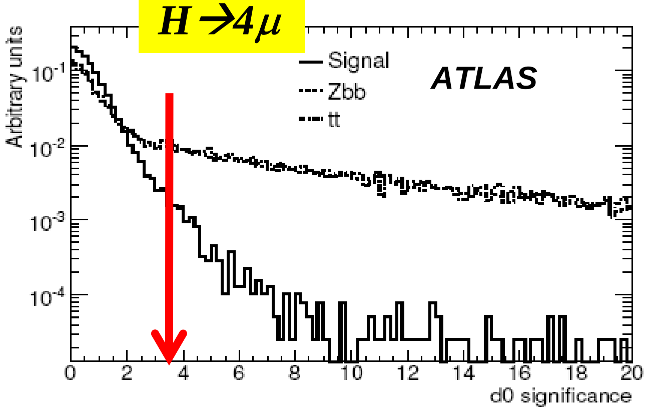


Normalized calorimetric and track isolation (Δ*R=0.2)* for the signal *(m_H = 130)* and the *Zbb* and tt backgrounds in the 4μ channel.

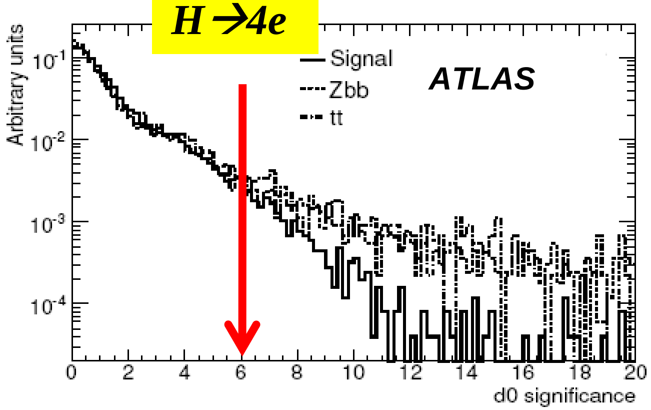
Lepton from b-quark decay do not point towards primary vertex



H→4μ



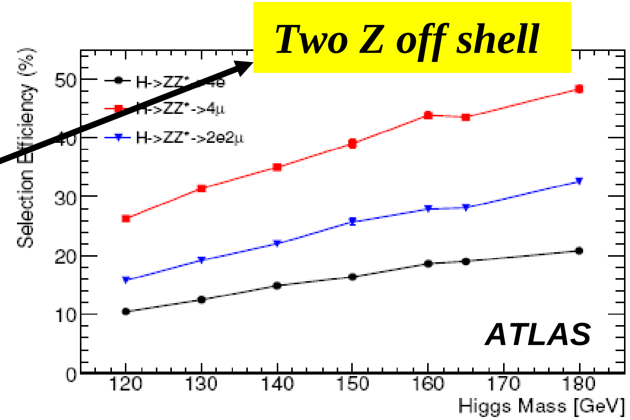
H→4e

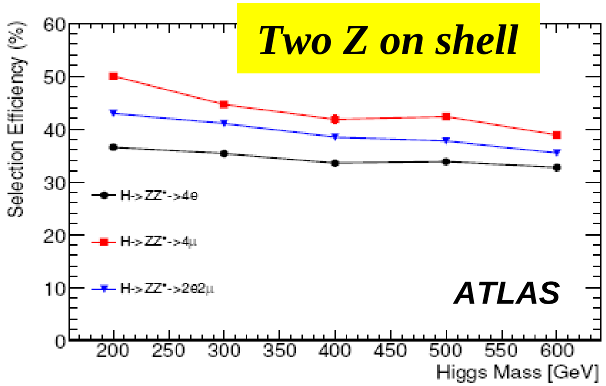


Transverse impact parameter significance in signal and reducible background events.

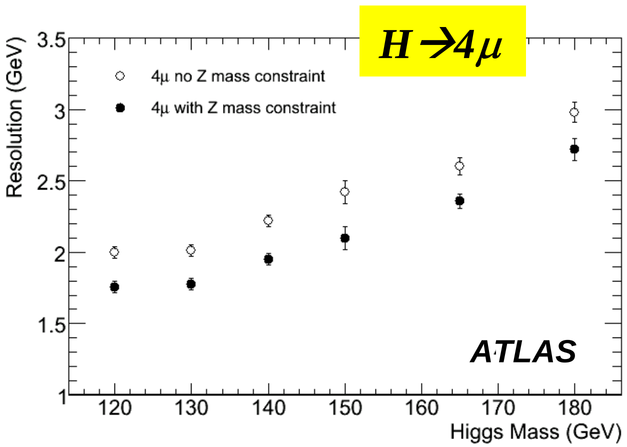
EFFICIENCY & RESOLUTION

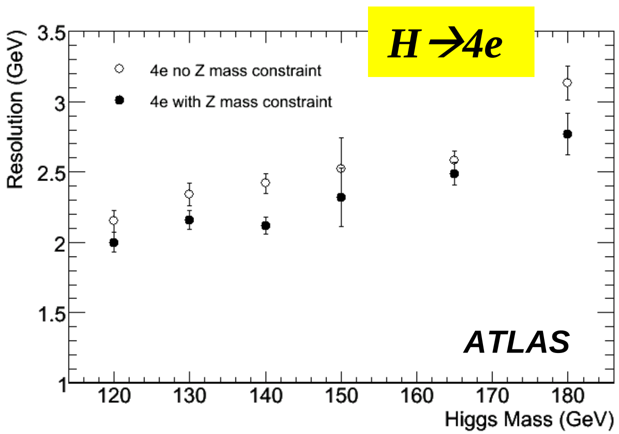
Higher background requires a stronger selection





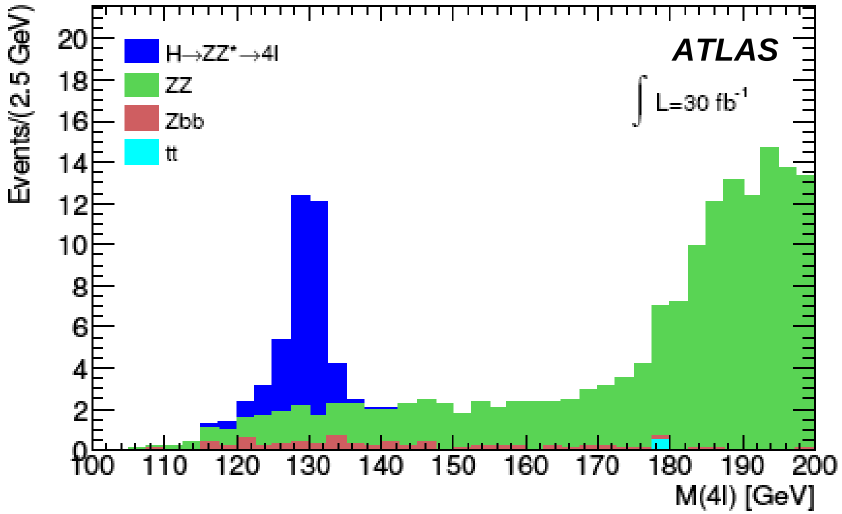
Selection efficiency as a function of the Higgs mass, for each of the three decay channels.

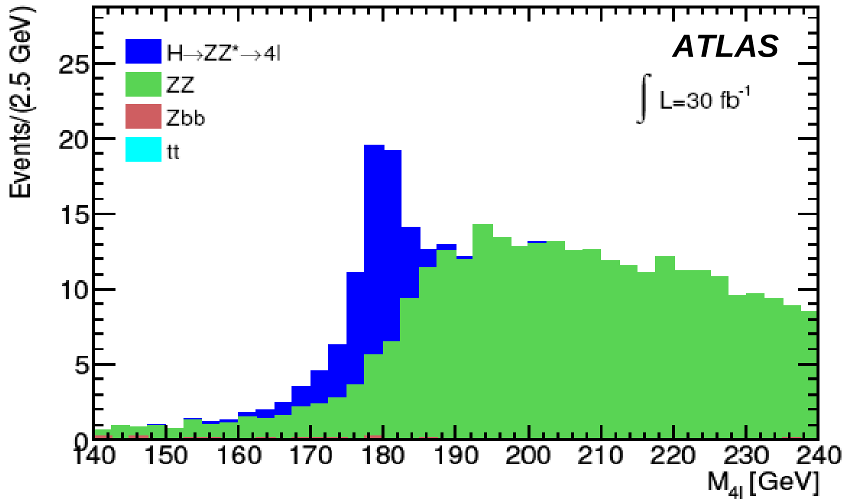




Mass resolution as a function of the Higgs mass. Open circles denote the resolution
Z mass constraint improves resolution.

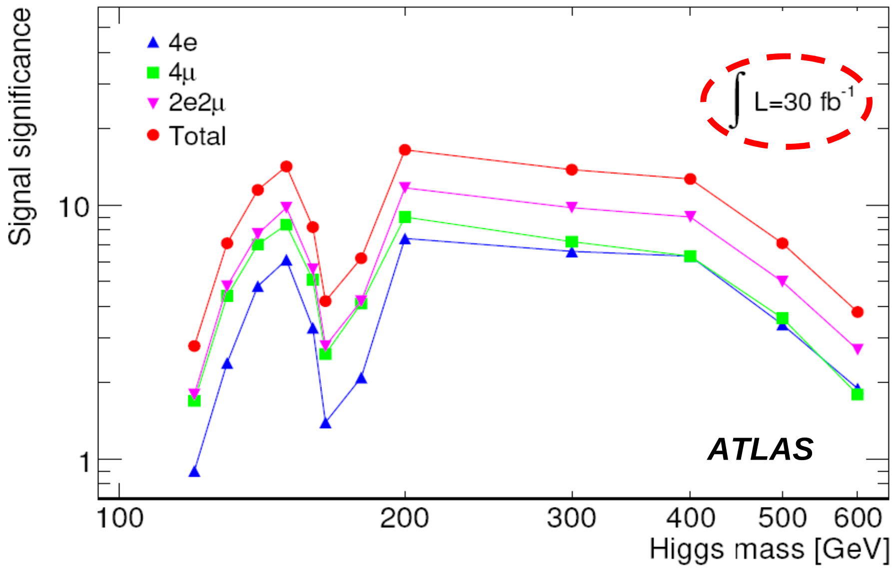
SIGNIFICANCE





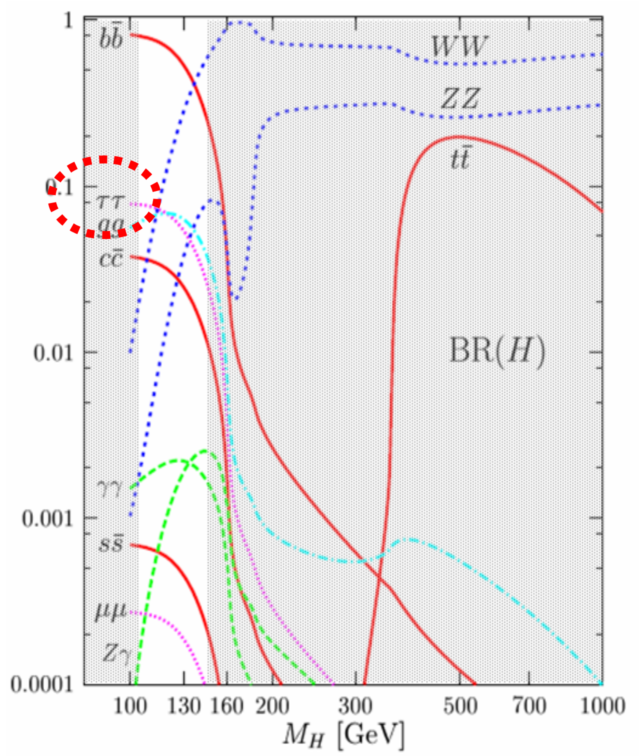
- Significance estimations from number counting and from a ***full range fit*** are consistent.

- **Other approaches** (background only sideband fit, two dimensional fit on M_{ll} and M_{Z^*} with Higgs mass floated) are also explored.



$H \to \tau\tau$ (VBF)

- ***High BR in the low mass region.***
- ***3 channels: ll, lh, hh (65% of τ gives hadrons)***



SELECTION

- **Trigger**: isolated electrons (μ) with $p_T > 22\ (20) GeV/c$ ($\varepsilon \sim 10\%$)

  $\tau + E_T^{miss}$ (ε~3.7%) for the *hh* channel
- **Isolation cut**
- **Likelihood** exploiting the shower shape and the track quality to separate τ and jet.
- **b-jet veto** to kill *tt(+jets)→lvb lvb (+jets)* (background for the *ll* channel)
- select highest E_T jets in opposite hemispheres
- **Central jet veto**

BACKGROUNDS

- $Z \to \tau\tau$ + *jets*
- $W \to \tau\nu$ +*jets*
- *tt+jets*
- *QCD* multi-jets for the *hh* channel

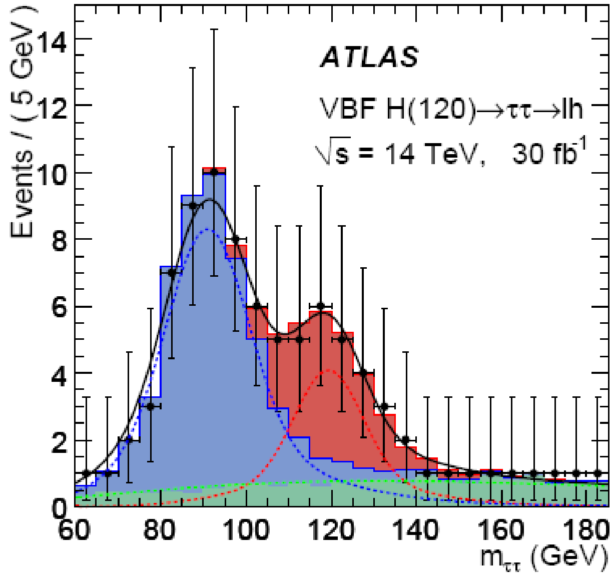
MAIN ISSUES:

- Discrepancies in Monte Carlo generator → impact on veto efficiency
- Estimation of QCD multi-jet → no sensitivity yet on *hh* channel
- Pileup → impact on E_T^{miss} and jet veto

$H \rightarrow \tau\tau$ (VBF)

Experimental challenges:

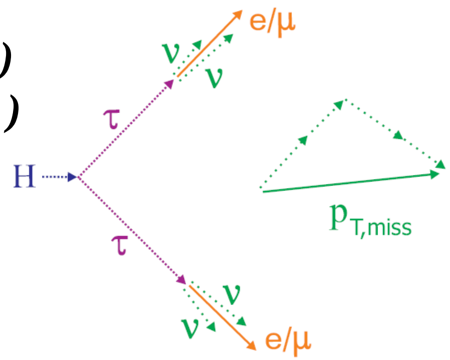
- In-time pileup, out-of-time pileup, underlying event.
  - test simulations & use vertexing for the jet
  - calorimeter timing
  - early data underlying event measurement
- Identification of hadronic τ
- Good E_T^{miss} resolution (since there are neutrinos…)
- Knowledge of the $Z \rightarrow \tau\tau$ background shape in the high mass region: use data $Z \rightarrow \mu\mu$ to emulate it!

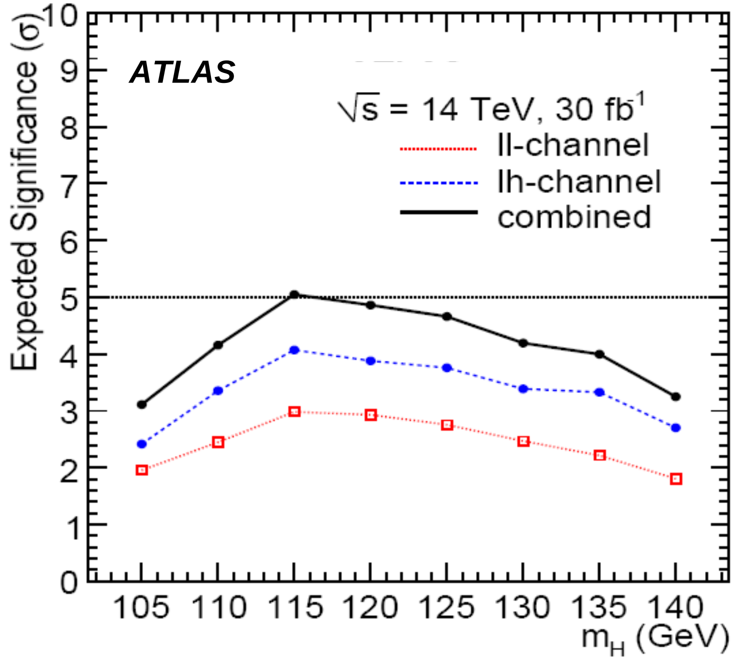


Higgs mass reconstructed using the angle between the two τ and the **collinear approximation:**

$m_{\tau\tau} = m_{ll} / sqrt(X_1 X_2)$

with $X_i = P_T(l_i)/P_T(\tau_i)$





$H \rightarrow WW(*)$

Interesting for $2M_W<M_H<2M_Z$ *where all other decay modes are suppressed.*

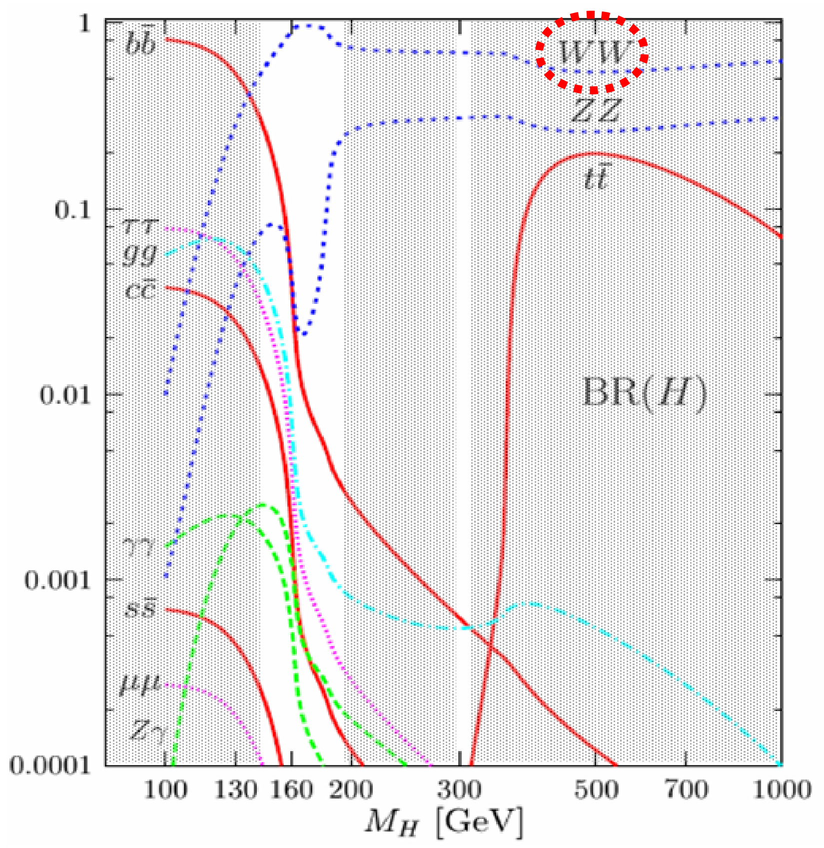
Signature is $e\mu$ *(or lqq)* $+ E_T^{miss}$.

Three channels:

- *- H→WW → e ν μ ν (H+0jet)*
- *- H → WW → e ν μ ν*
- *- H → WW → l ν q q*
- *(only for* M_H*=300 GeV)*

(the last three lines are joined by a brace labelled:) *VBF (H+2jet)*

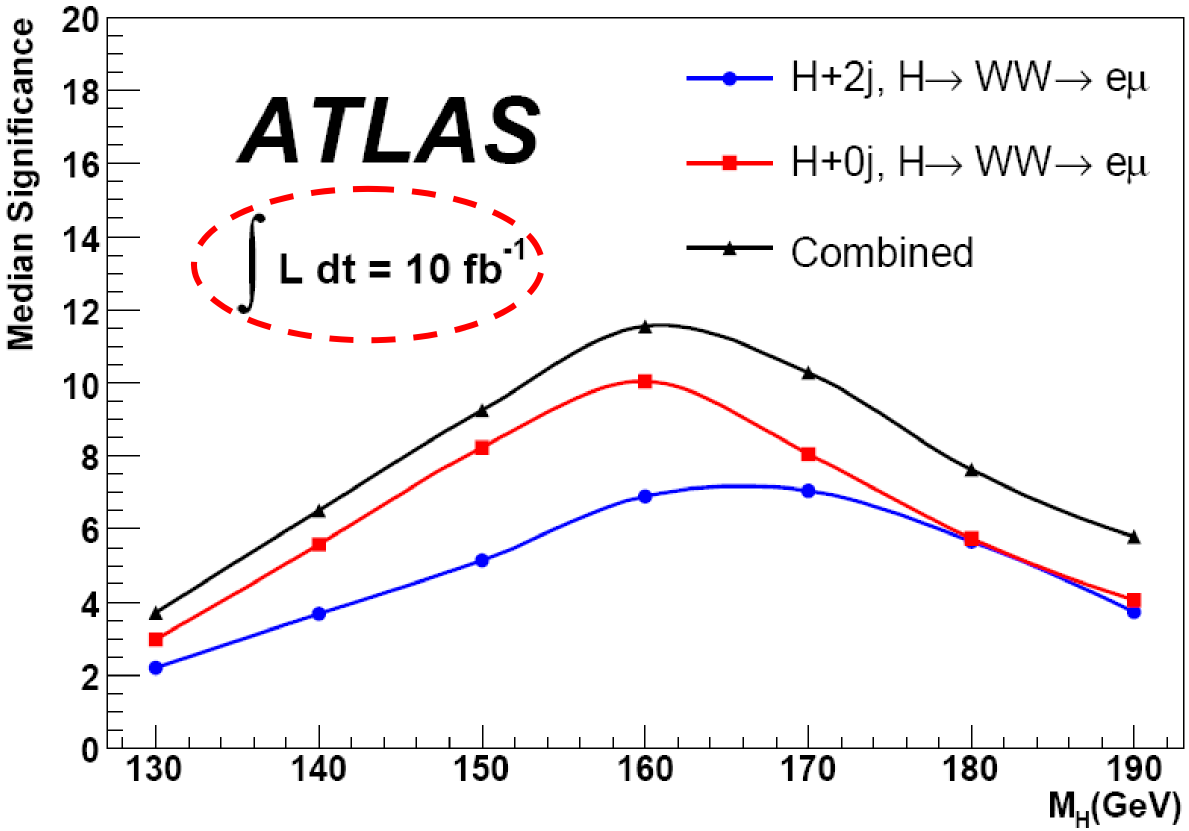
Measure of spin and CP properties possible for heavy H → WW → lvqq



Comments:
- No mass peak ➔ use transverse mass.
- **High backgrounds**: *WW, Wt, ttbar, Z→2l, bb,cc,QCD multijet*

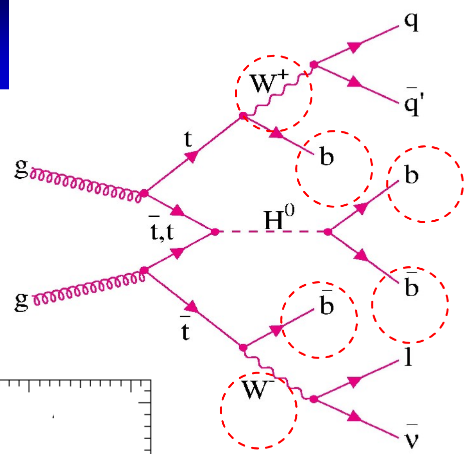
The challenge: precise knowledge of the backgrounds.

SIGNIFICANCE



The estimation of the sensitivity for the H → WW → l ν q q is difficult since a good knowledge of the W+4jet background with first data is needed.

$t\bar{t}H \rightarrow t\bar{t}b\bar{b}$



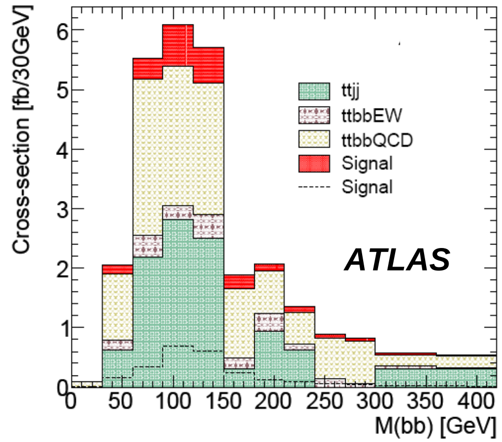
Classified on W decays:

- **W full hadronic has high BR (43%) but large QCD multijet back…**
- **W full leptonic has low BR (5%) and two neutrinos…**
- **W semileptonic is a good compromise with BR=28%(excluding τ)**

Main backgrounds:

- combinatorial from signal (4*b* in the final state)
- *ttjj*, *ttbb*, *ttZ*,…
- *Wjjjjjj*, *WWbbjj*, etc.

Irreducible *ttbb:*
QCD ~10EW



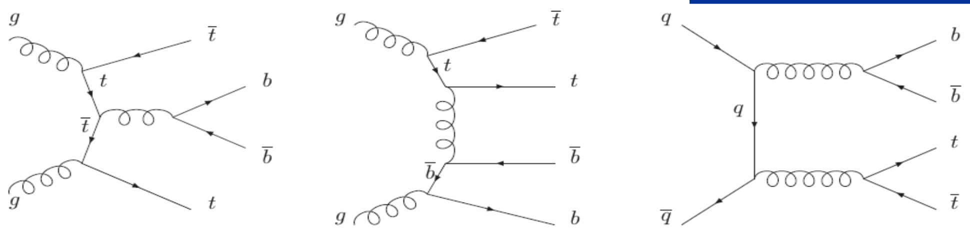


Figure 2: Example of Feynman diagrams for the $t\bar{t}b\bar{b}$ QCD production.

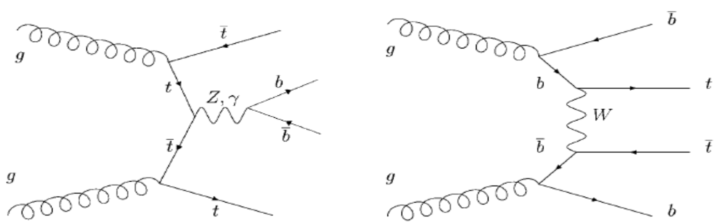
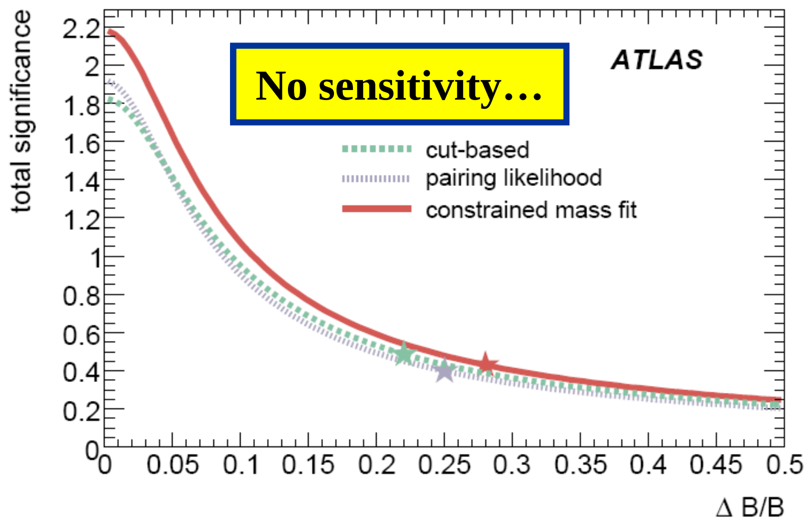
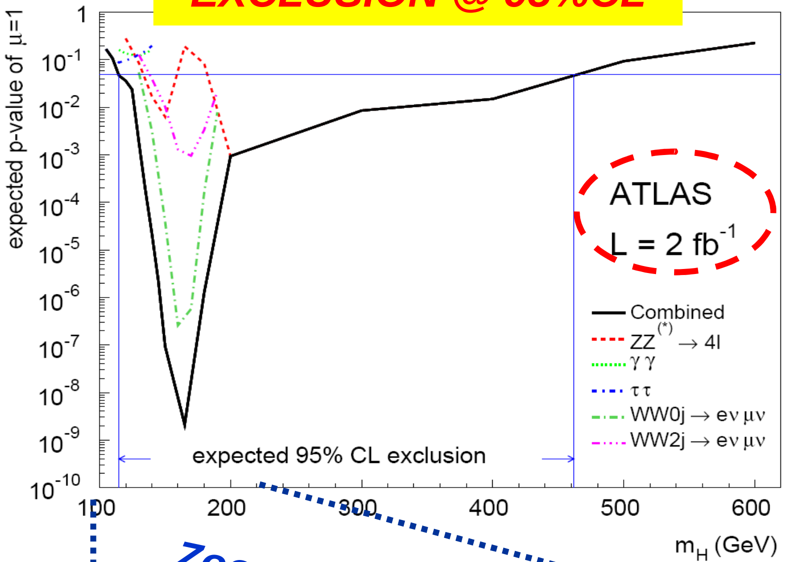


Figure 3: Example of Feynman diagrams for the $t\bar{t}b\bar{b}$ EW production.

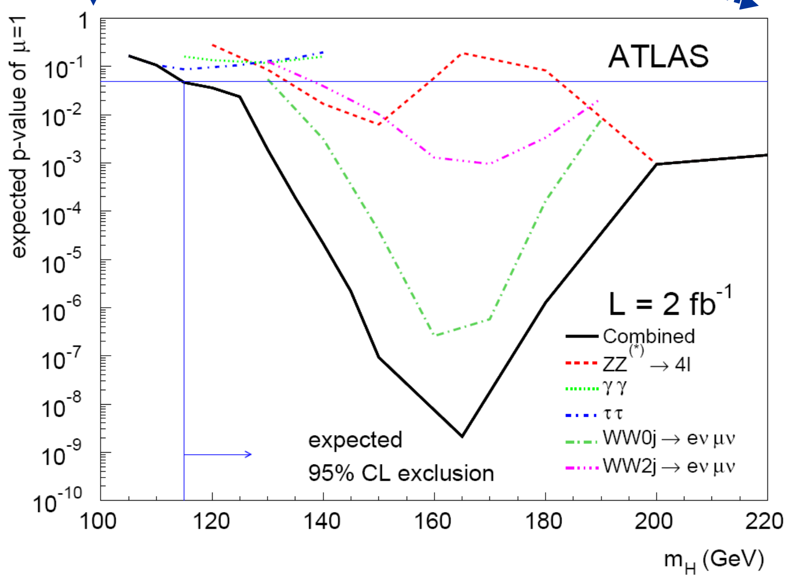


COMBINATION OF THE CHANNELS

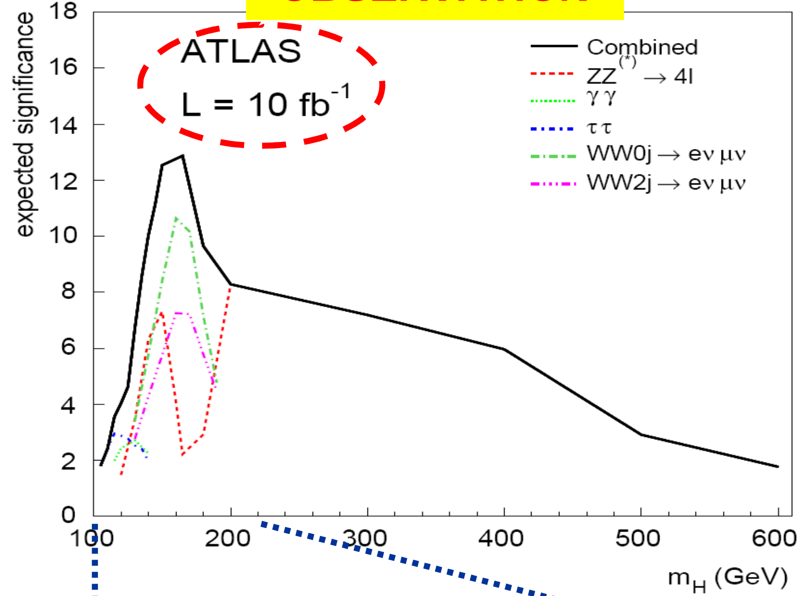
EXCLUSION @ 95%CL

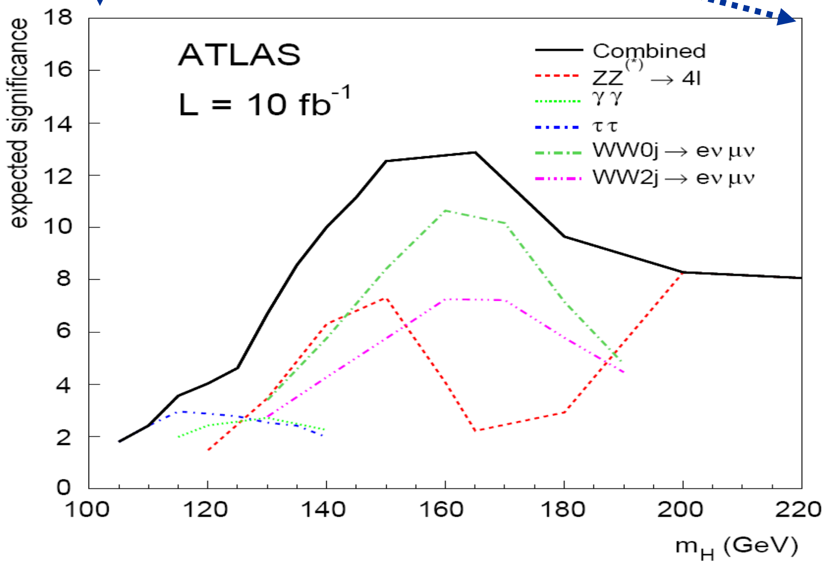


Zooming...



OBSERVATION





ATLAS has very good potentiality to catch the SM Higgs!

OUTLINE

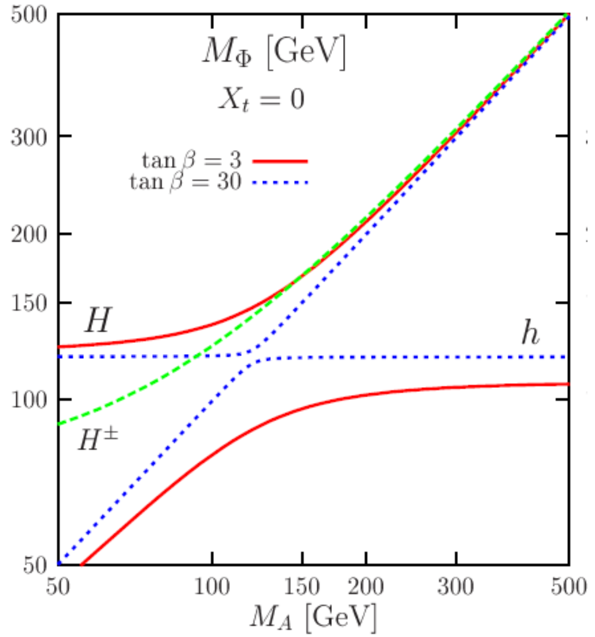
- ***THE HIGGS BOSON & ATLAS***
- ***SEARCH FOR A STANDARD MODEL HIGGS***
- ***SEARCH FOR A MSSM HIGGS***
- ***CONCLUSIONS***

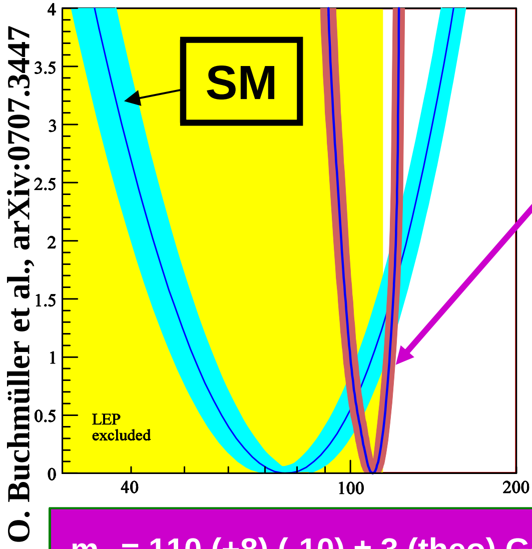
MSSM HIGGS: WHAT WE KNOW FROM THEORY

- **One doublet of Higgs pseudo-scalar fields is replaced with two:**
  - **One couples to up-fermions and has *vev*=v_u**
  - **One couples to down fermions and has *vev*=v_d**

- **2X4-3=5 physical scalar fields/particles: *h, H, A, $H^{\pm}$***

- **Properties at tree level:**
  - **fully defined by 2 free parameters: m_A, $\tan\beta = v_u/v_d$**
  - **CP-odd A:**
    never couples to *Z* or *W*;
    decays to *bb*, $\tau\tau$ (and additionally *tt* for small $\tan\beta$).
  - **CP-even h and H:**
    SM-like near their mass limits vs m_A;
    at large $\tan\beta$ enhanced coupling with down fermions,
    suppressed couplings to *W* and *Z*.
  - **$H^{\pm}$ "strongly" couples to *tb* and $\tau\nu$**
  - **All Higgs bosons are narrow (Γ<10GeV)**





cMSSM

Includes:
- **WMAP**
- **b→ sγ**
- **a_μ**

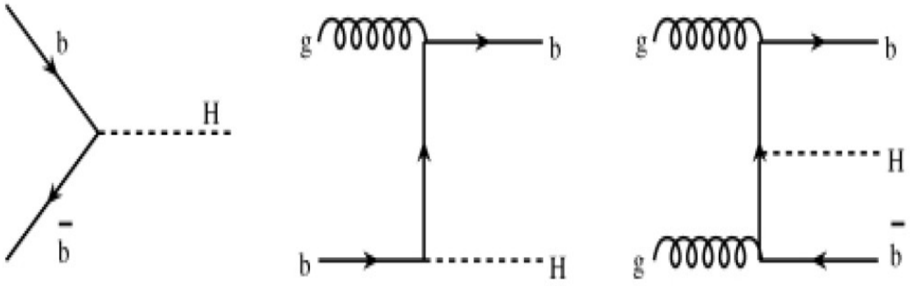
m_h = 110 (+8) (-10) ± 3 (theo) GeV/c^2

….watch the low mass region !

We choose the benchmark scenario m_h^{max} corresponding to maximal theoretically allowed region for m_h.

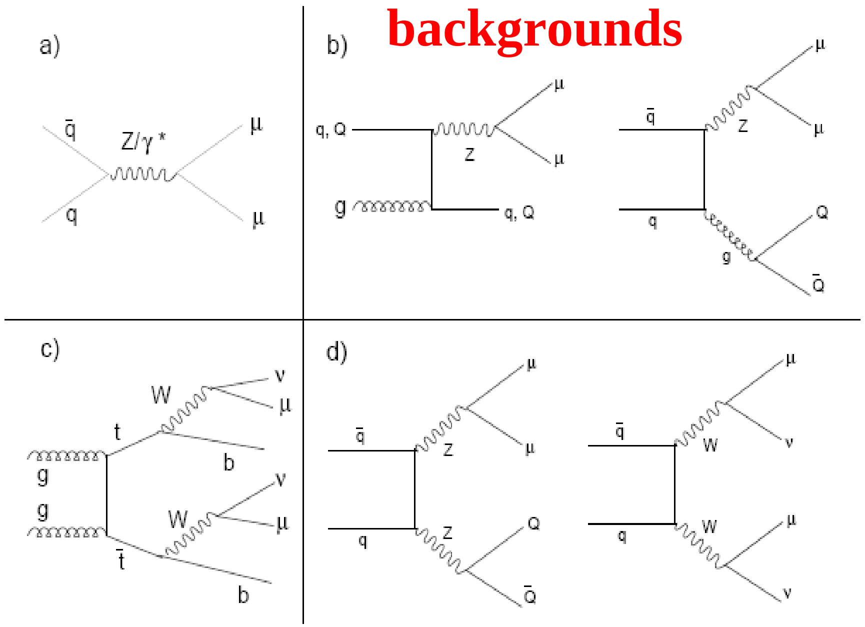
$H \rightarrow \mu\mu$

At high tanβ the associated production with a *b* quark is enhanced respect to gluon gluon fusion



- **Decay prohibited in *SM***
- **Enhanced in *MSSM***
- **Clear signature!**
- **Direct mass measurement (no E_T^{miss})!**

backgrounds

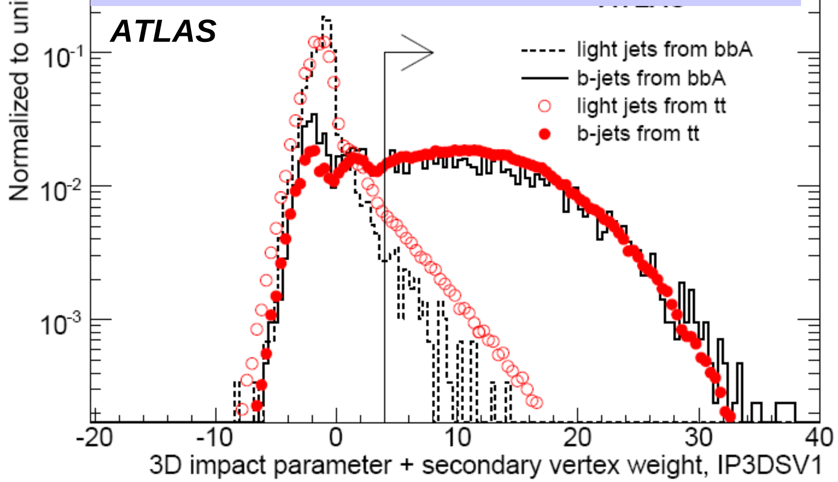


WW and ZZ backgrounds are expected small.

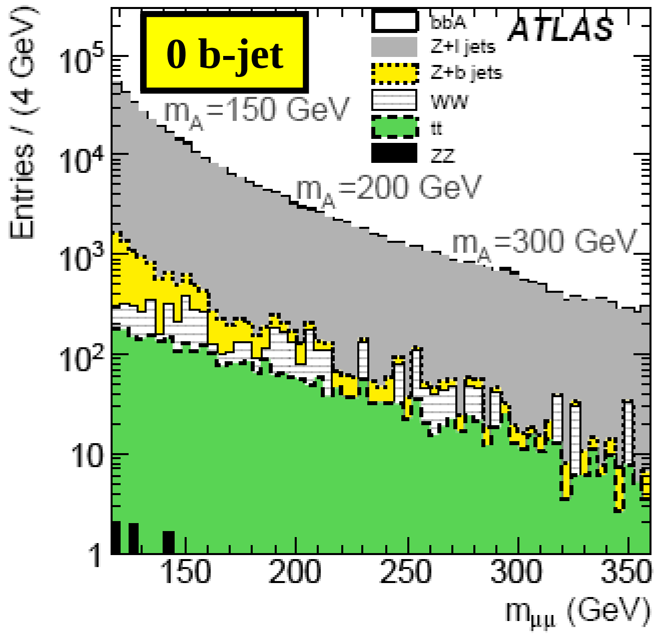
Background rejection:

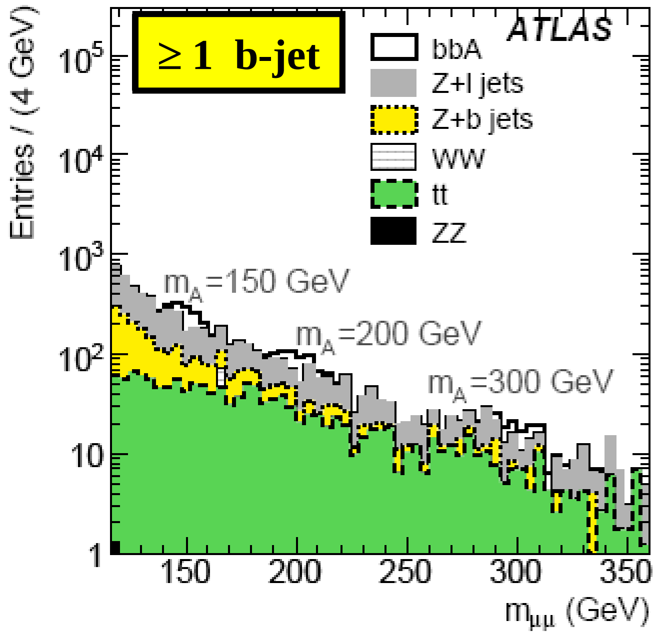
- **Additional jet required => kill Drell-Yan**
- **muon isolation**
- **b tagging (based on longitudinal impact parameter and secondary vertex)**
- **reject large E_T^{miss} (against ttbar)**
- **jet vetos**

64% bTAGGING EFFICIENCY



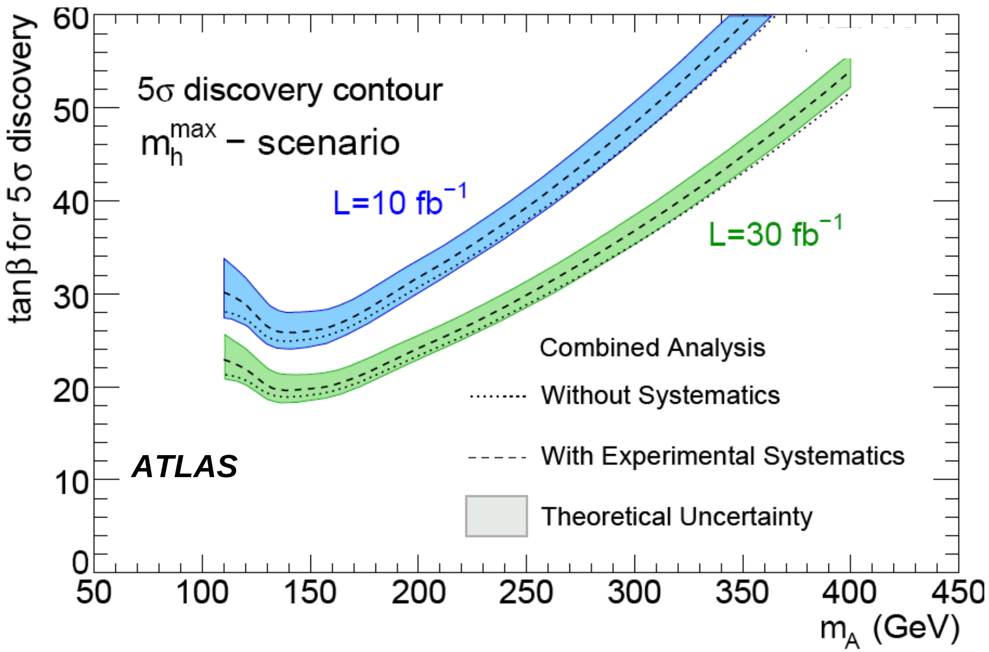
$H \rightarrow \mu\mu$





Excellent dimuon mass resolution of ATLAS is a key point in this analysis

One can measure the width and then « measure » *tanβ* (high width and high signal rate implies high *tanβ*)



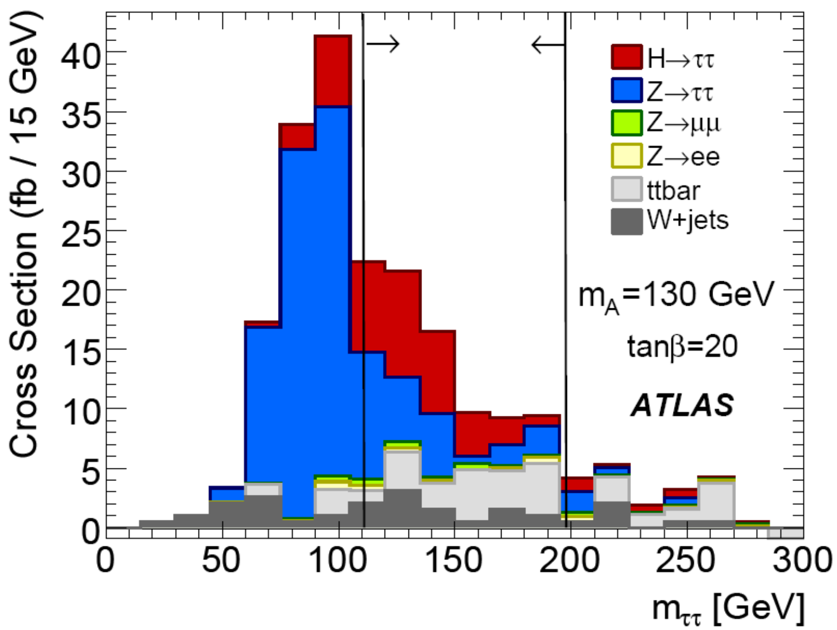
$H \to \tau\tau$ $(\tau \to ll)$

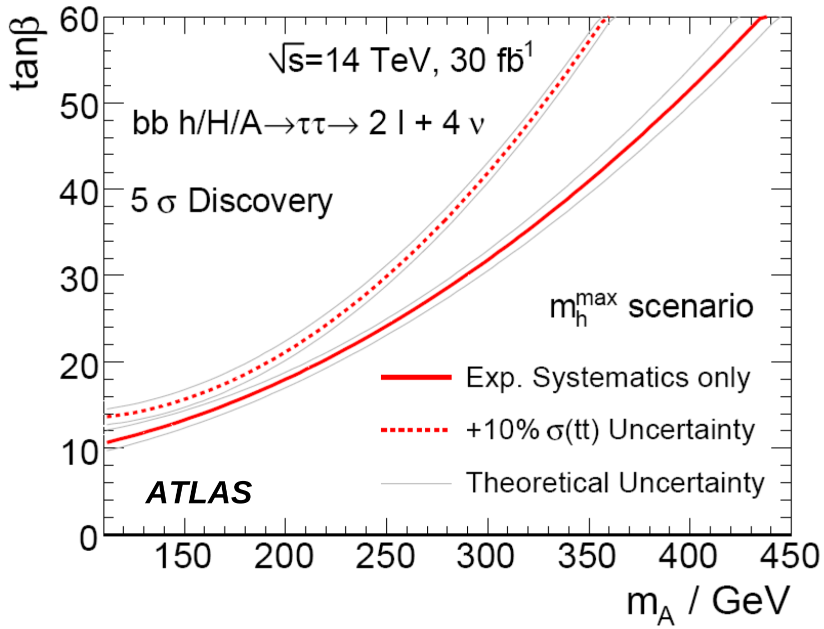
SELECTION.
•**Trigger**: isolated $\mu(e)$ with p_T>20 (25)GeV || two isolated *e* || or one *e* & one μ
• **b-tagging** on at least one jet to suppress light jets
• **Cuts on** ***missing*** E_T ***, b momentum , lepton momentum, number of jets*** **(<3) to reject** ***Z*** **and** ***tt*** **backgrounds**
• **Collinear approximation**

BACKGROUNDS:
•***Drell-Yan***
•$Z \to ee$
•$Z \to \tau\tau$
•***tt***
•***W jets***

Z estimated from data!

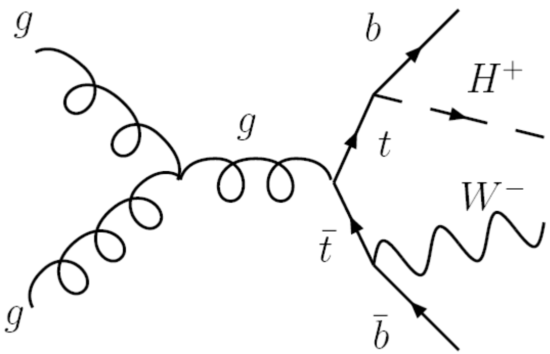
• **Studies ongoing on hadronic** τ **decay mode**
• **Mass reconstruction as for** ***SM VBF*** $H \to \tau\tau$





CHARGED HIGGS SEARCHES

$m(H^+) < m(top)$



$t\bar{t} \to bH^+bW \to b\tau(had)\nu b\ell\nu$

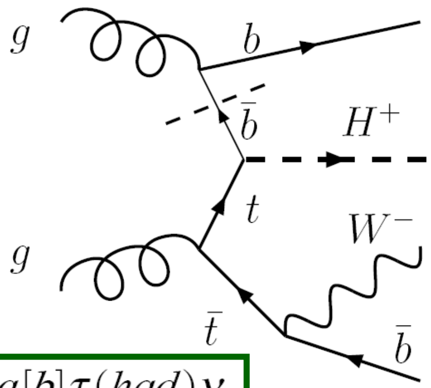
$t\bar{t} \to bH^+bW \to b\tau(lep)\nu bqq$

$t\bar{t} \to bH^+bW \to b\tau(had)\nu bqq$

DECAY MODES:
$H^+ \to \tau\nu$
$H^+ \to tb$

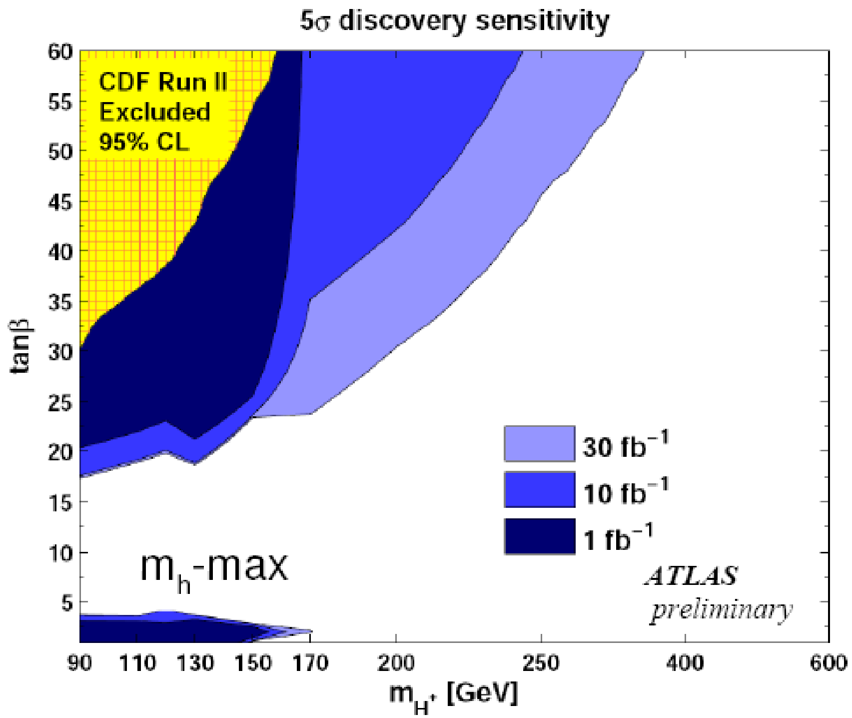
- High $\tan\beta$ well covered already with 10 fb^{-1}
- Intermediate region hard to reach (only exclusion)

$m(H^+) > m(top)$



$gg/gb \to t[b]H^+ \to bqq[b]\tau(had)\nu$

$gg/gb \to t[b]H^+ \to t[b]tb \to bW[b]bWb \to b\ell\nu[b]bqqb$



INVISIBLE HIGGS

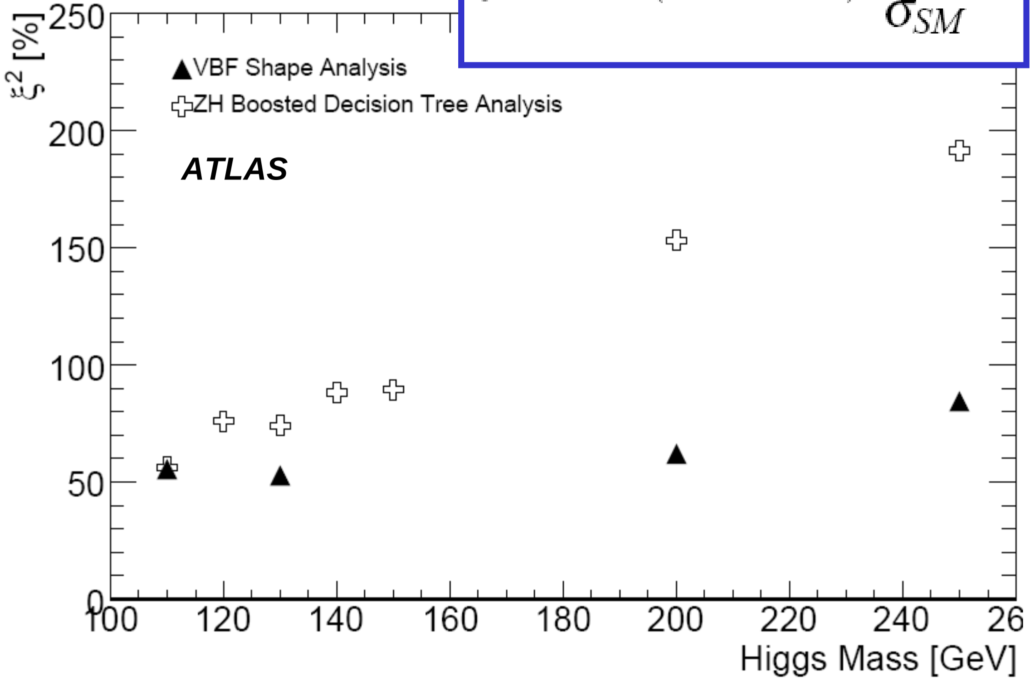
$$\xi^2 = BR(H \to inv.)\frac{\sigma_{BSM}}{\sigma_{SM}}$$

Higgs→Lightest Susy Particle

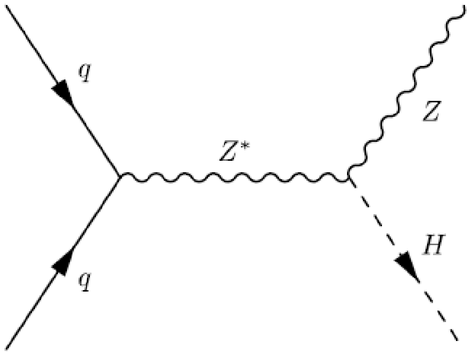
Two production modes analyzed:

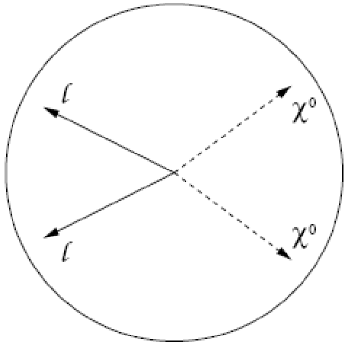
- **Associated production** *ZH*.
  - Background from *ZZ→llνν*.
  - Too much background to analyze *WH*.
- **VBF**.
  - Backgrounds from *QCD-dijets*, *W+jets* and *Z+jets*, when leptons are outside the detector acceptance or *Z → νν*.

Caution: there could be nonSM backgrounds…
Missing energy is crucial



Associated production:
H→ $\chi^0\chi^0$* recoiling against *Z →ll





OUTLINE

- ***THE HIGGS BOSON & ATLAS***
- ***SEARCH FOR A STANDARD MODEL HIGGS***
- ***SEARCH FOR A MSSM HIGGS***
- ***CONCLUSIONS***

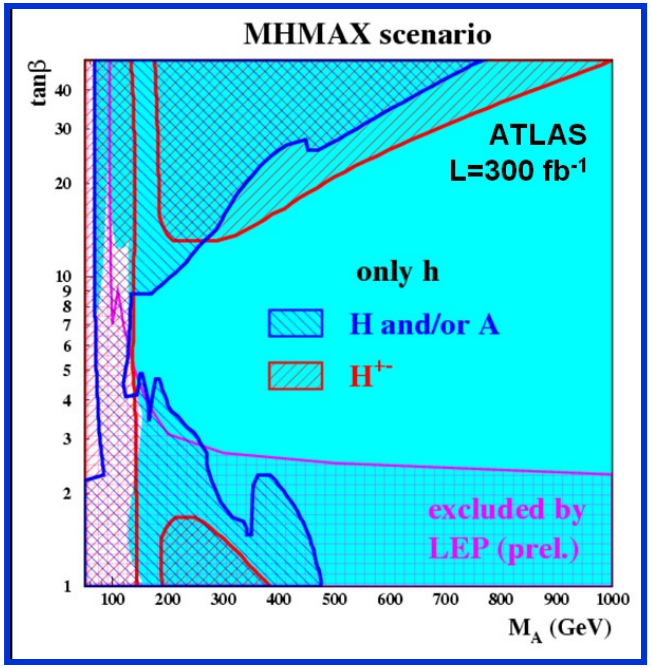
CONCLUSIONS

- Many SM Higgs channels have been studied in detail:
  - already good sensitivity to SM Higgs with few fb^{-1}
  - the full mass range is covered

- MSSM Higgs sector covered in most of the m_A-$\tan\beta$ plane at 30fb^{-1}

- Detailed Higgs properties studies will require a lot of statistics

- Analysis can be still improved!

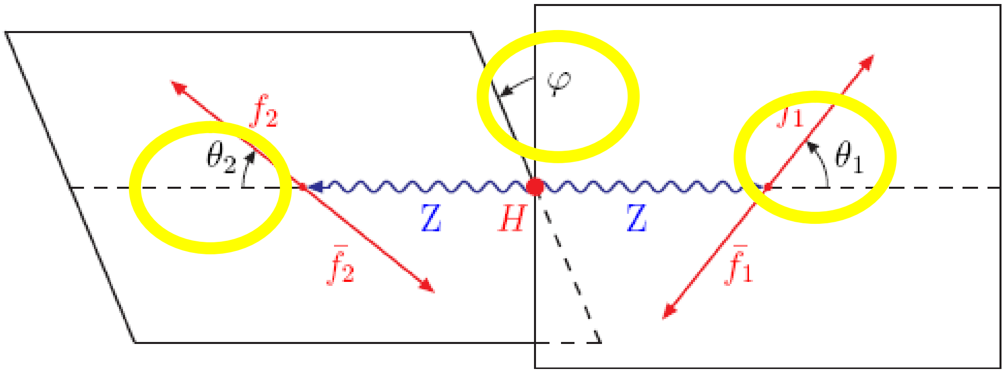


FIND MORE DETAILS IN:

ATLAS: CERN-OPEN 2008-020

BACKUP

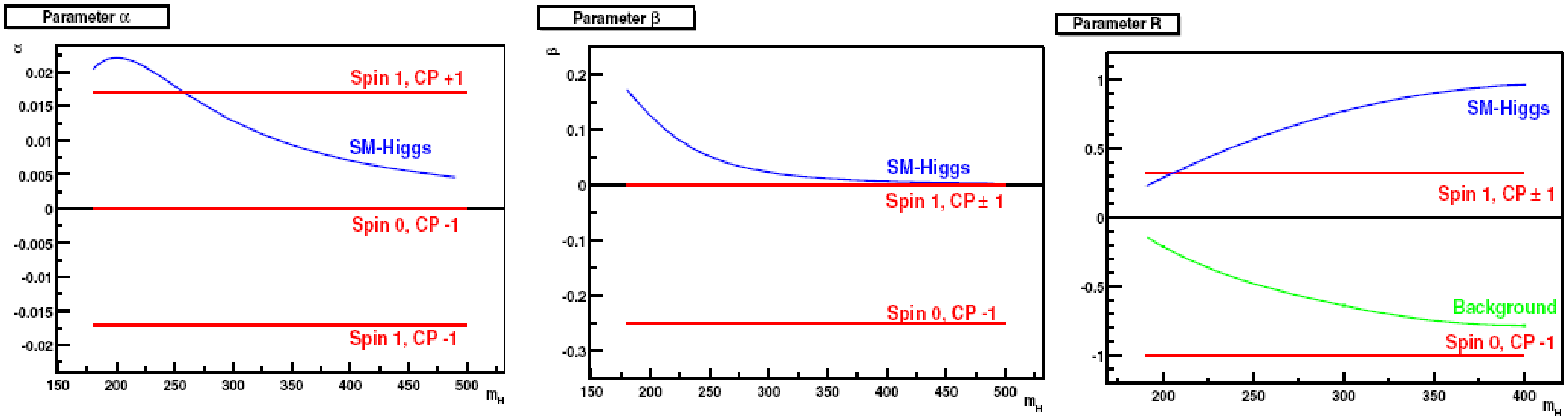
ANGULAR DISTRIBUTIONS IN H→ZZ → 4l



$$F(\phi) = 1 + \alpha \cdot \cos(\phi) + \beta \cdot \cos(2\phi)\ .$$

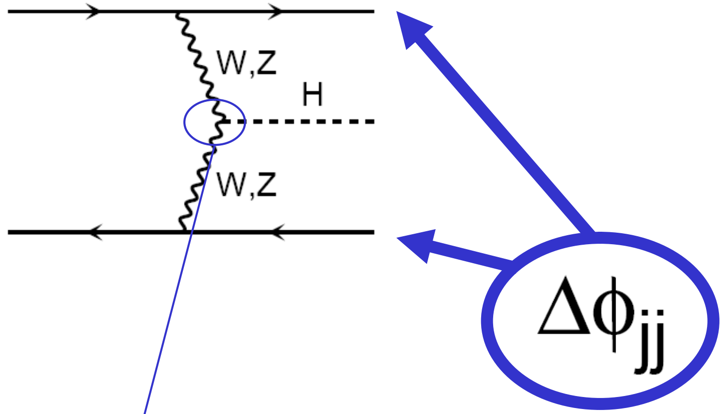
$$G(\theta) = T \cdot (1 + \cos^2(\theta)) + L \cdot \sin^2(\theta)$$

$$R := \frac{L - T}{L + T}$$



C.P.Buszello,I.Fleck,P.Marquard and J.J. van der Bij Eur Phys J C32,209,2004

ANOMALOUS HIGGS COUPLINGS IN VBF



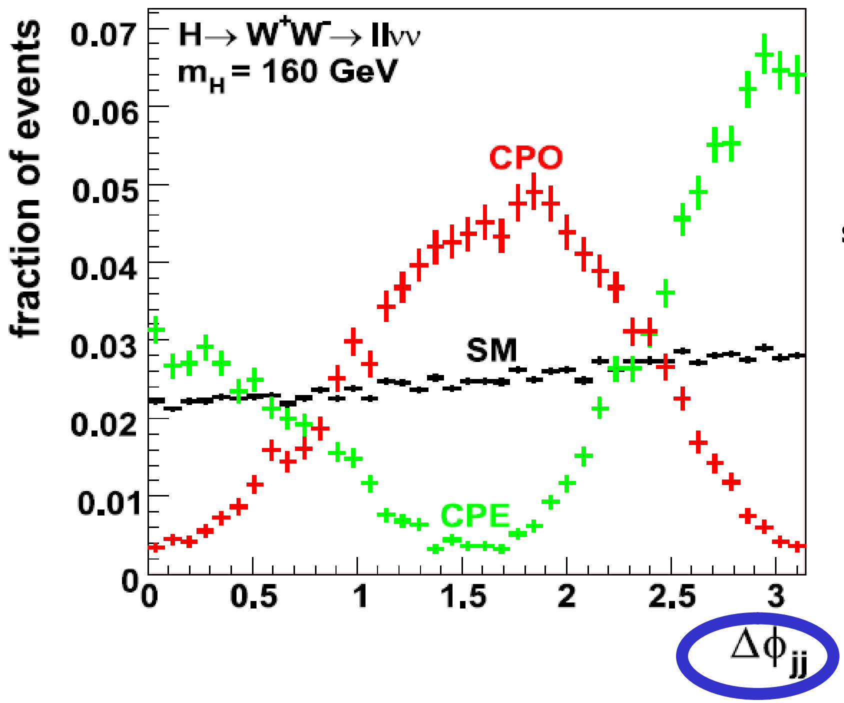
T.Plehn,D.Rainwater and D.Zeppenfeld Phys Rev Lett 88,051801,2002
T.Figy and D.Zeppenfeld Physics Letters B 591 (2004) 297-303
V.Hankele,G.Klamke,D.Zeppenfeld and T.Figy Phys.Rev.D74:095001,2006
C.Ruwiedel,M.Schumacher and N.Wermes Eur.Phys.J.C51:385-414,2007

SM

$$T^{\mu\nu}(q_1,q_2) = a_1(q_1,q_2)g^{\mu\nu} + a_2(q_1,q_2)[q_1\cdot q_2 g^{\mu\nu} - q_2^{\mu}q_1^{\nu}] + a_3(q_1,q_2)\varepsilon^{\mu\nu\rho\sigma}q_{1\rho}q_{2\sigma}.$$

CPE

CPO

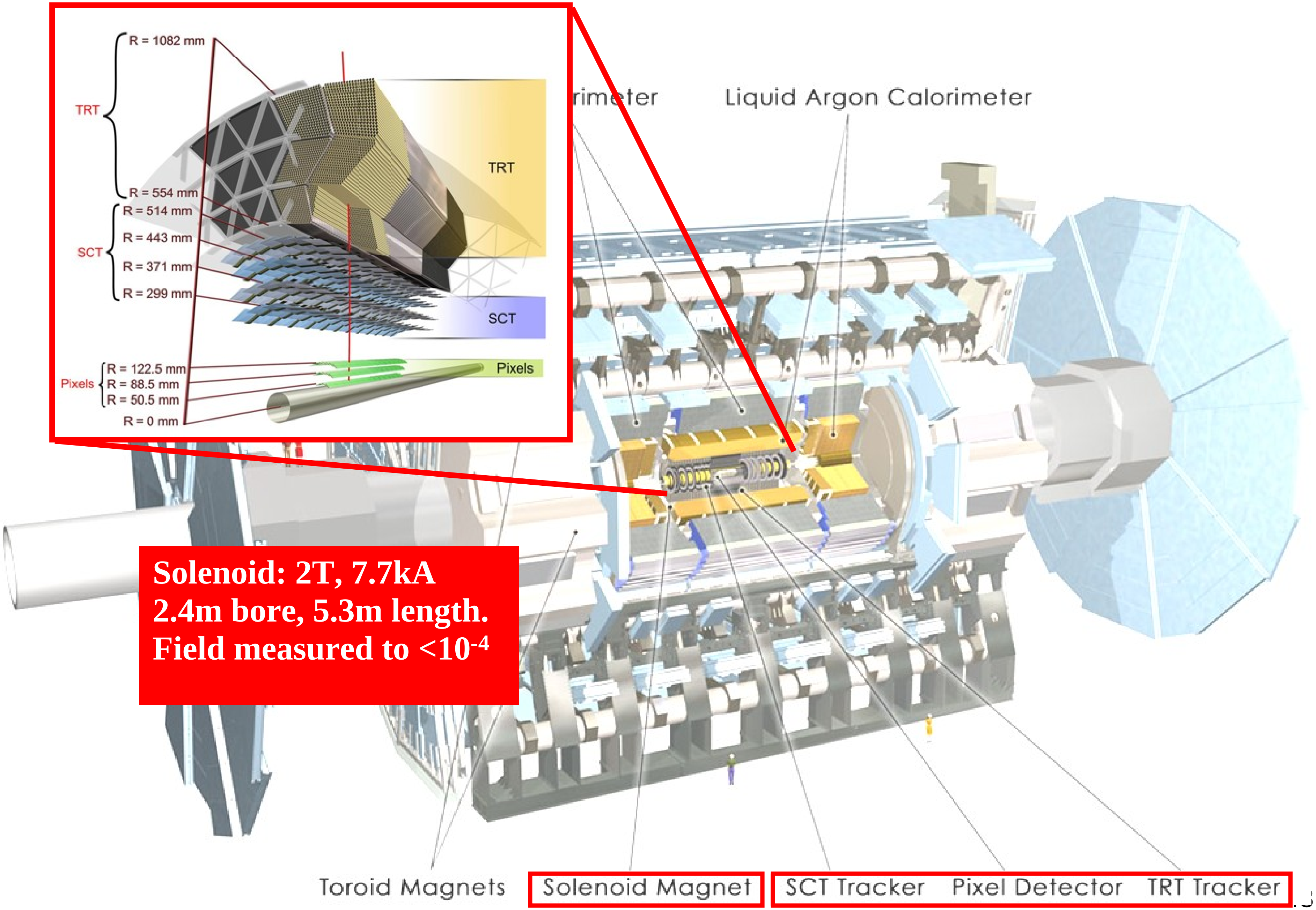


statistics in this plot is infinite!

CPE and CPO anomalous couplings:

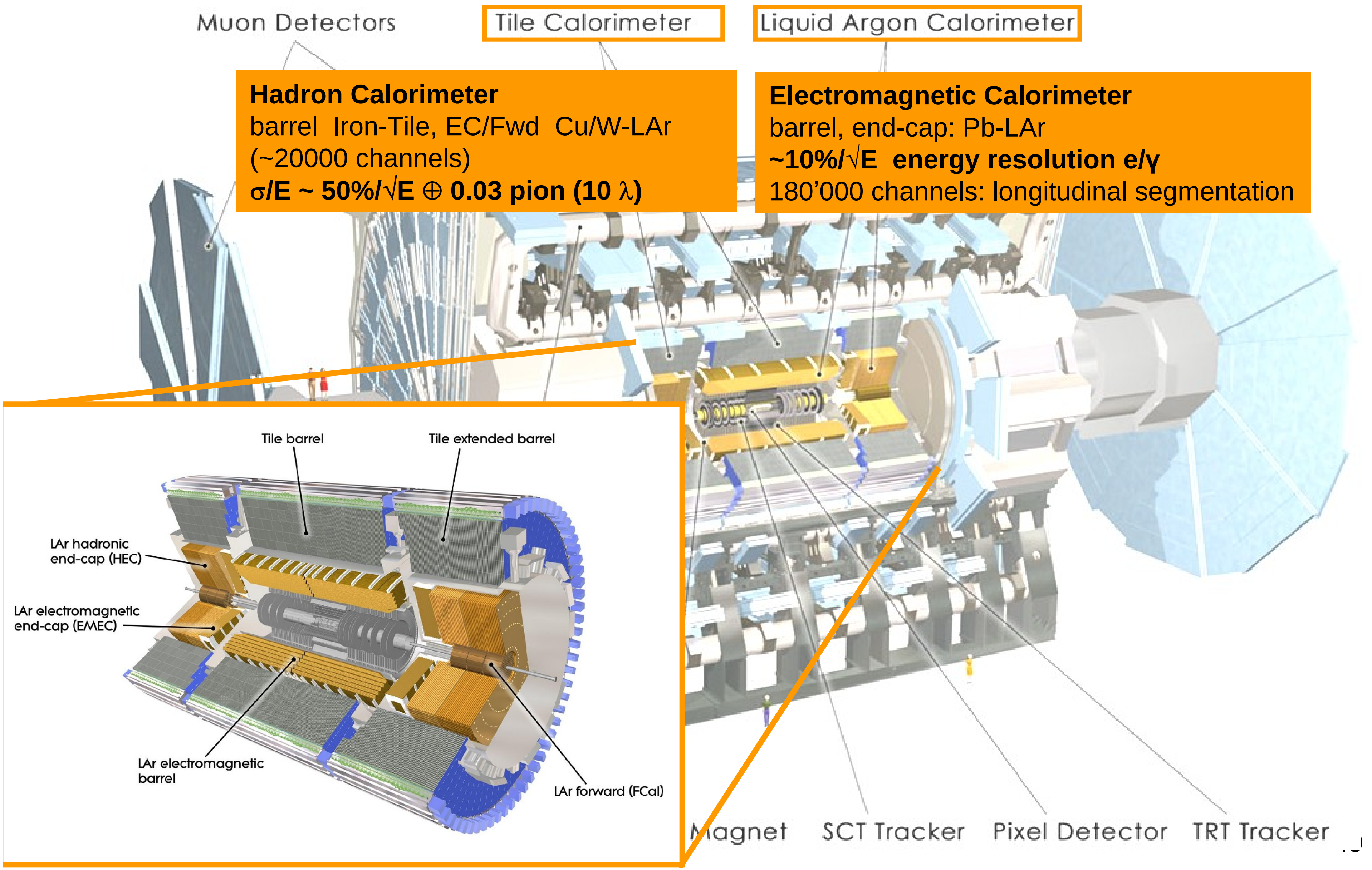
- **with *10 fb⁻¹* can be excluded at 5σ in *H→WW→ llνν* for *m_H=160 GeV* .**
- **with *30 fb⁻¹* can be excluded at *2σ* in *H→ττ* for *m_H=120 GeV.***

THE ATLAS DETECTOR

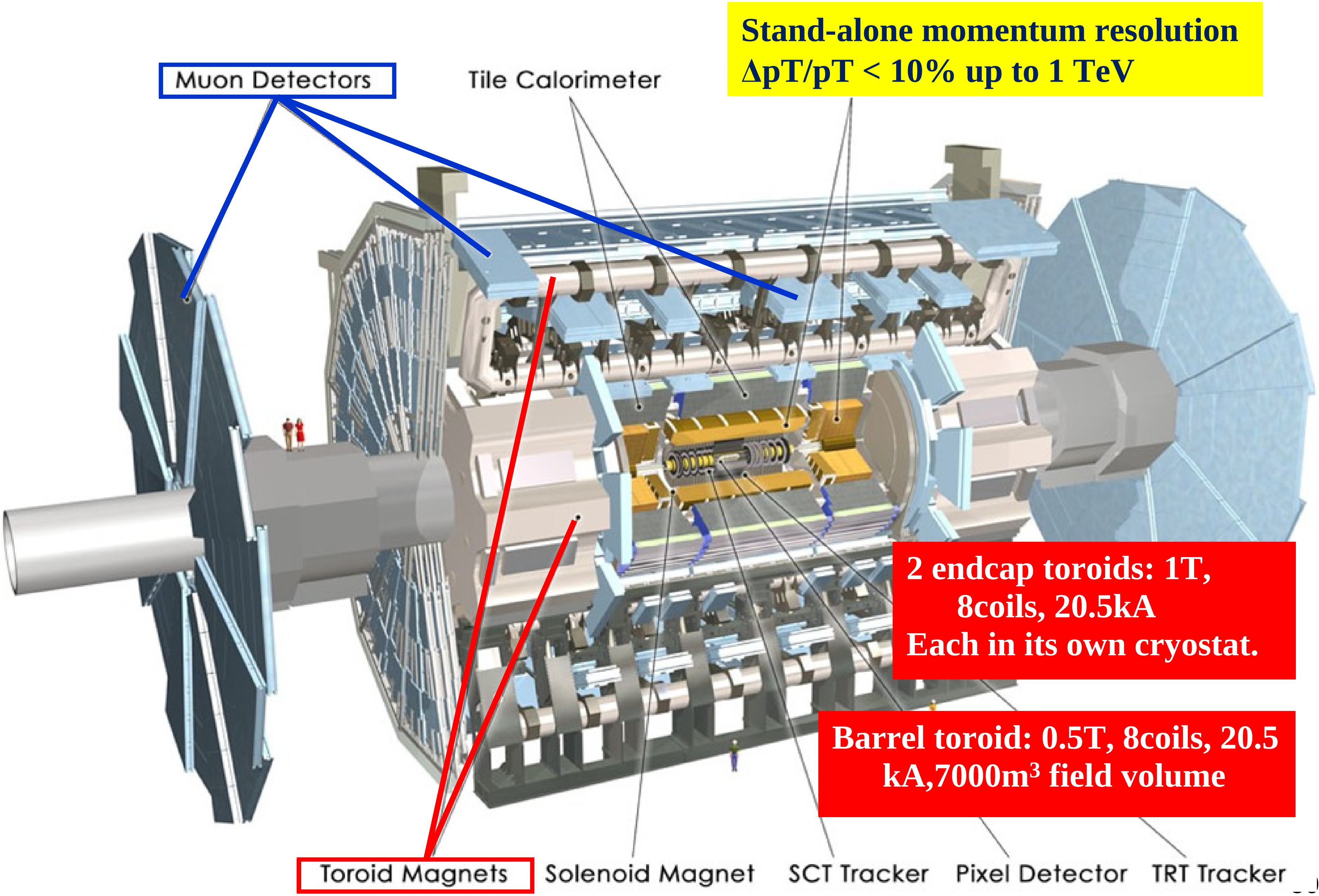


Solenoid: 2T, 7.7kA
2.4m bore, 5.3m length.
Field measured to <10^{-4}

THE ATLAS DETECTOR



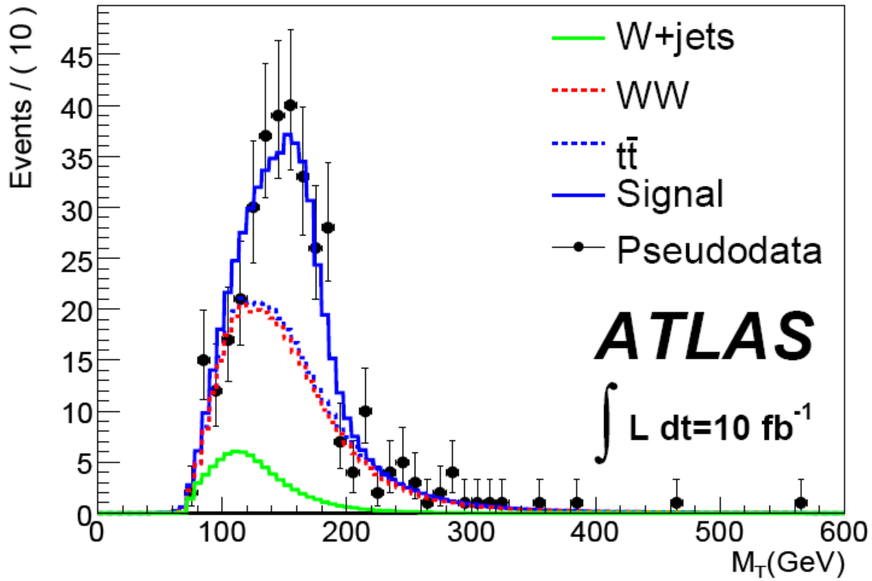
THE ATLAS DETECTOR

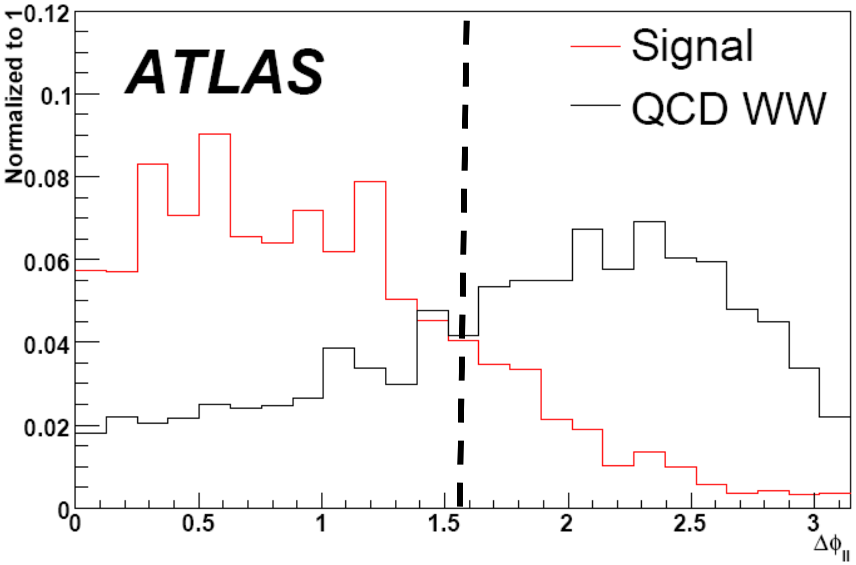


EVENTS SELECTION: H+ 0jets

• Fit the *transverse mass* and the *transverse momentum* of the candidates in *two bins of the dilepton opening angle $\Delta\phi$* in the transverse plane;
• Account for the ratio of the background in the two regions
• Extract the signal and background mixture in the signal region.

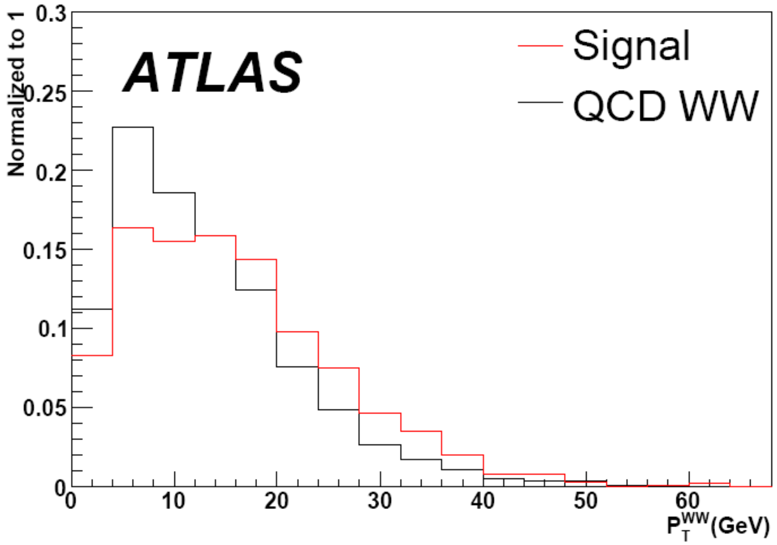
The transverse mass distribution in the region $\Delta\phi$<1.575 and p_T^{WW}>20 GeV.





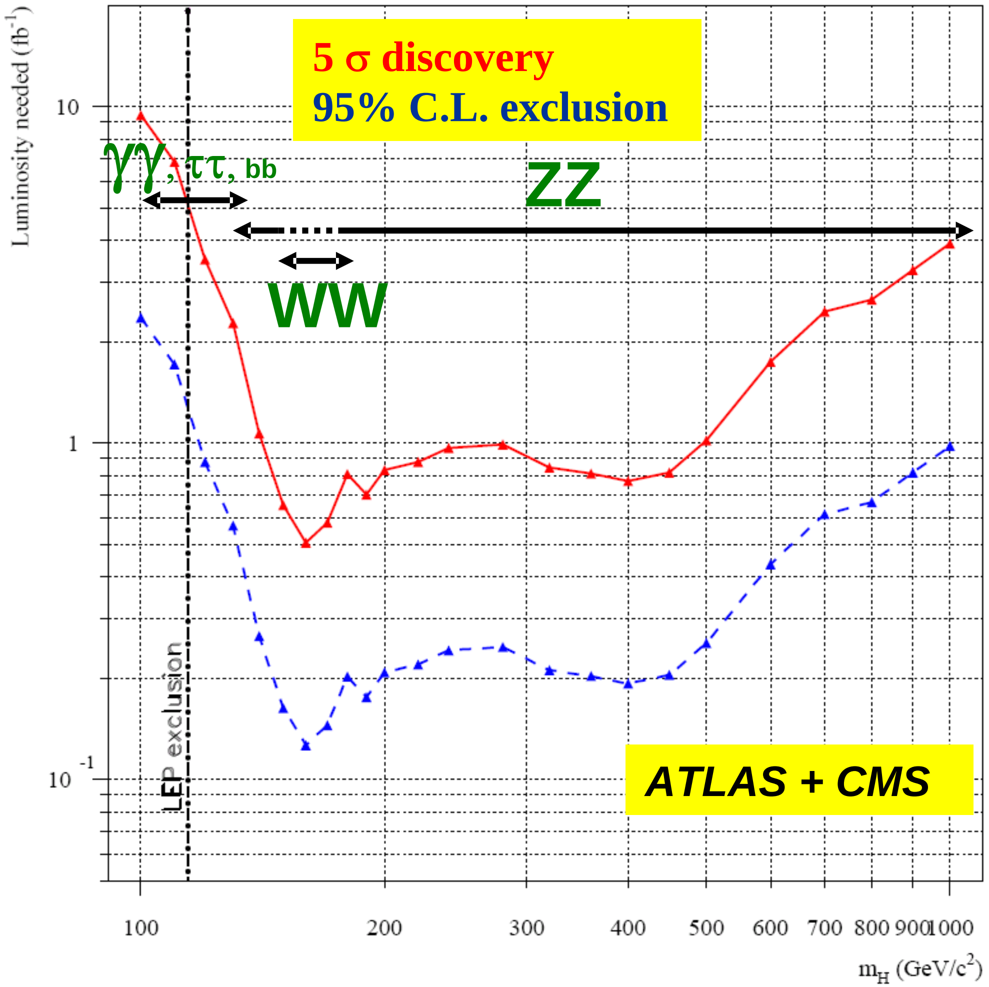
Signal region

Control region



PROSPECTS FOR A DISCOVERY AT LHC (<2006)

rough estimate of discovery potential



J.J. Blaising, A. De Roeck, J. Ellis, F. Gianotti, P. Janot, G. Rolandi and D. Schlatter, **Eur. Strategy workshop (2006)**

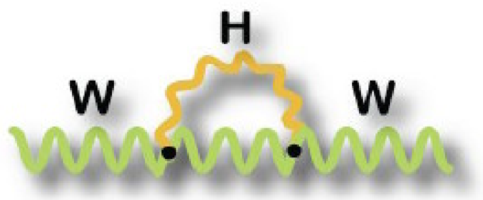
- With 1 fb-1, a 95% CL limit can be set in most of the mass range
- Hardest for low masses

Warnings:

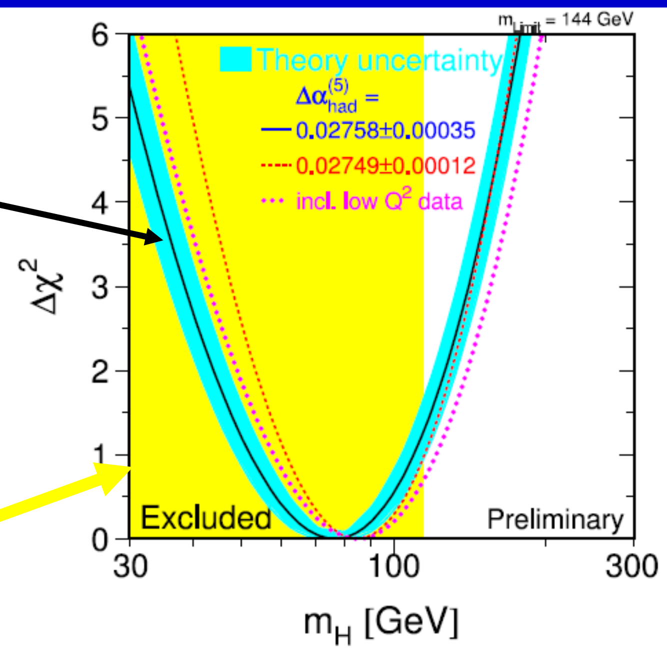
- these curves are optimistic on the *ttH, H→ bb* performance
- systematic uncertainties assumed to be luminosity dependent

PRESENT LIMITS

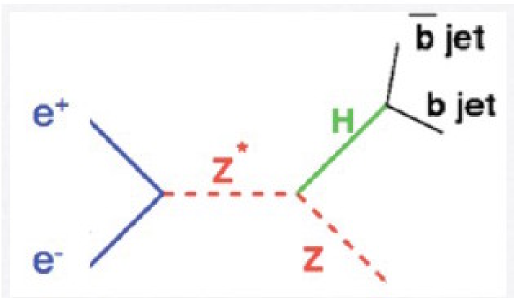
- **The electroweak measurements are sensitive to m_H through radiative corrections:**



$$\sim \log \frac{m_H}{m_W}$$



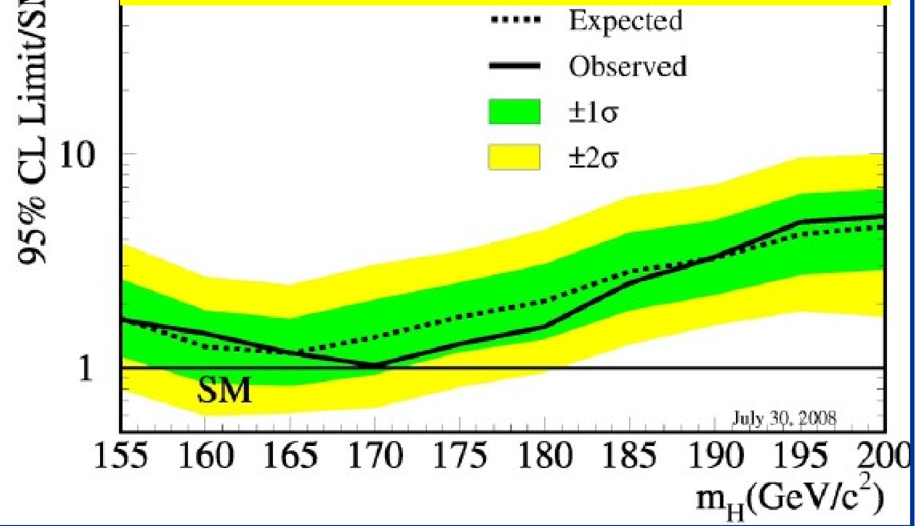
- **Direct search at LEP2:**



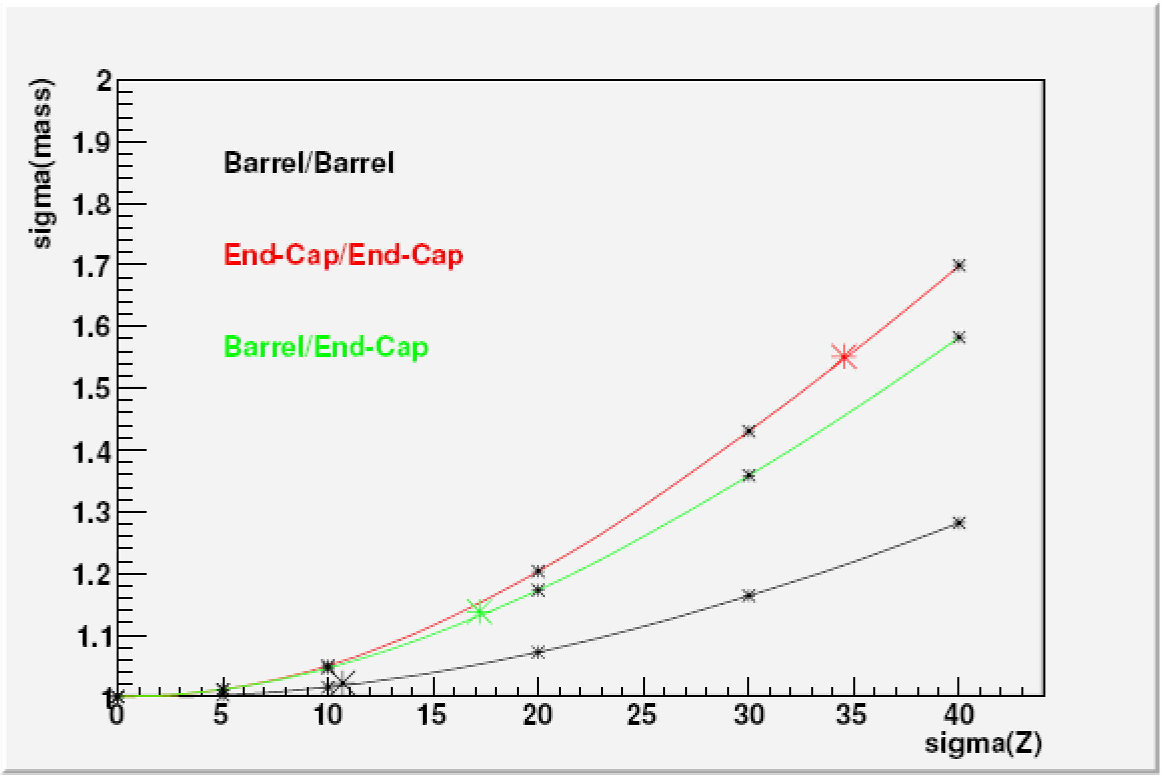
LEP limits:
$114.4 < m_H \lesssim 182$ GeV/c²

Directe ***Indirecte***

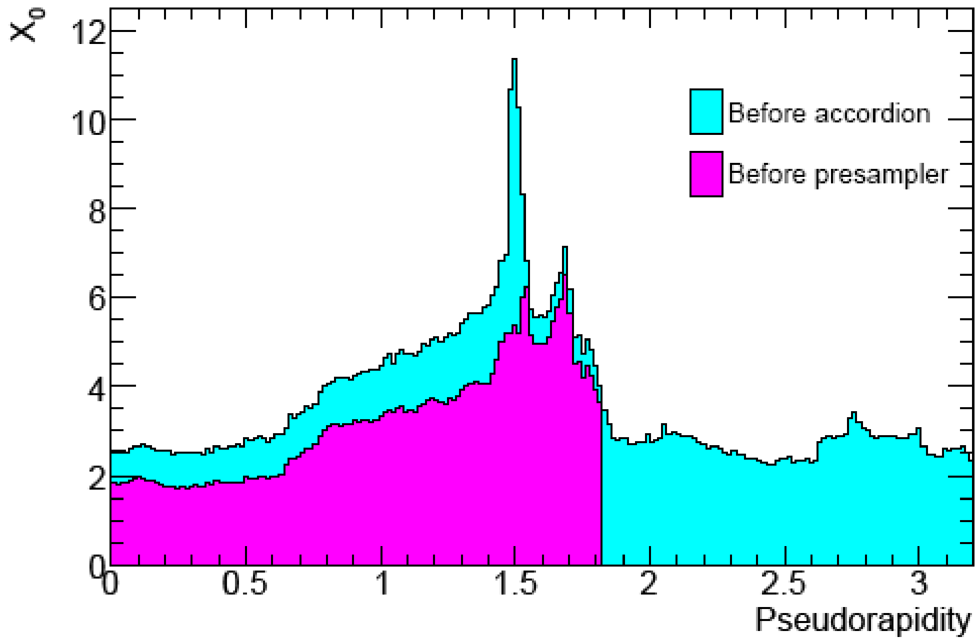
ICHEP08: Tevatron excludes m_H=170 GeV with 3fb^{-1}



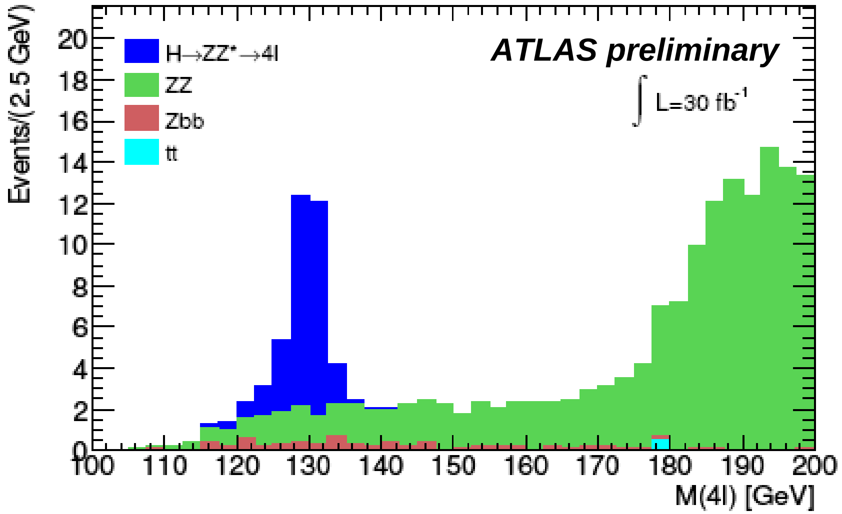
I.Koletsou CERN-THESIS-2008-047, LAL-08-38

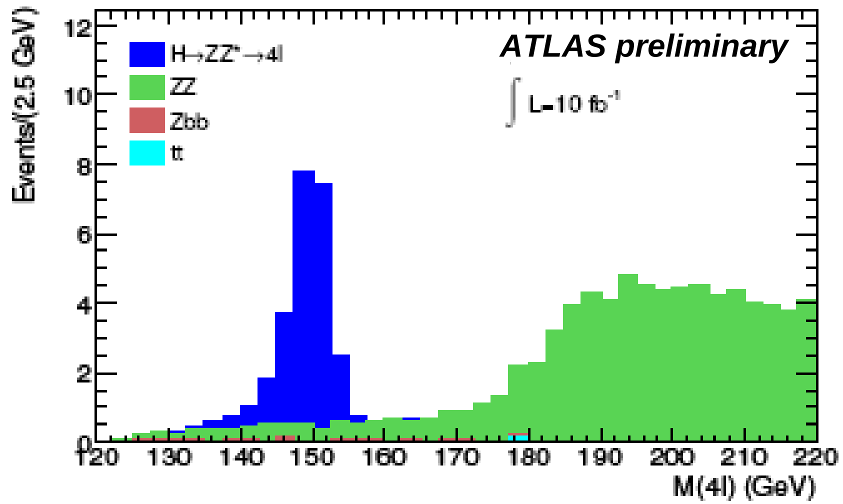


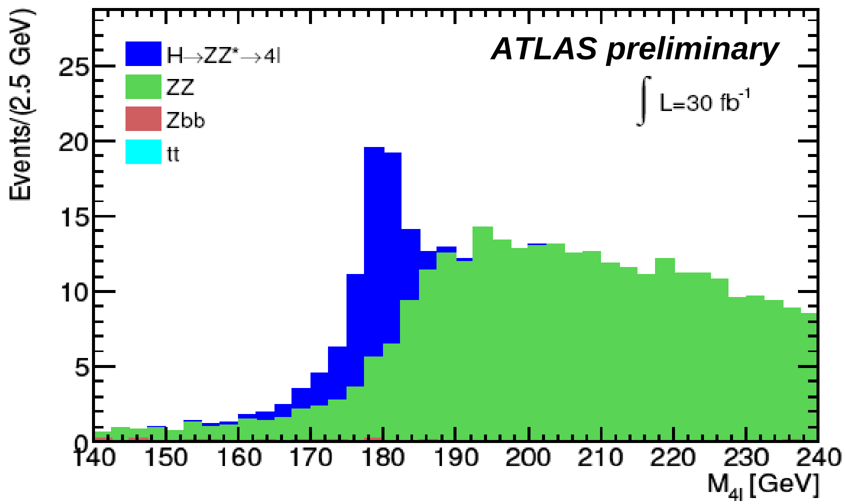
MATERIAL BEFORE CALORIMETER

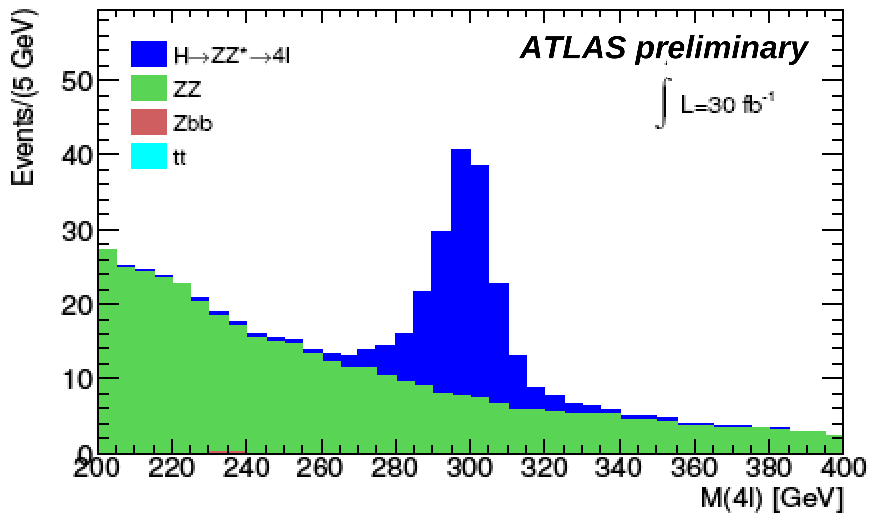


INVARIANT MASS DISTRIBUTIONS









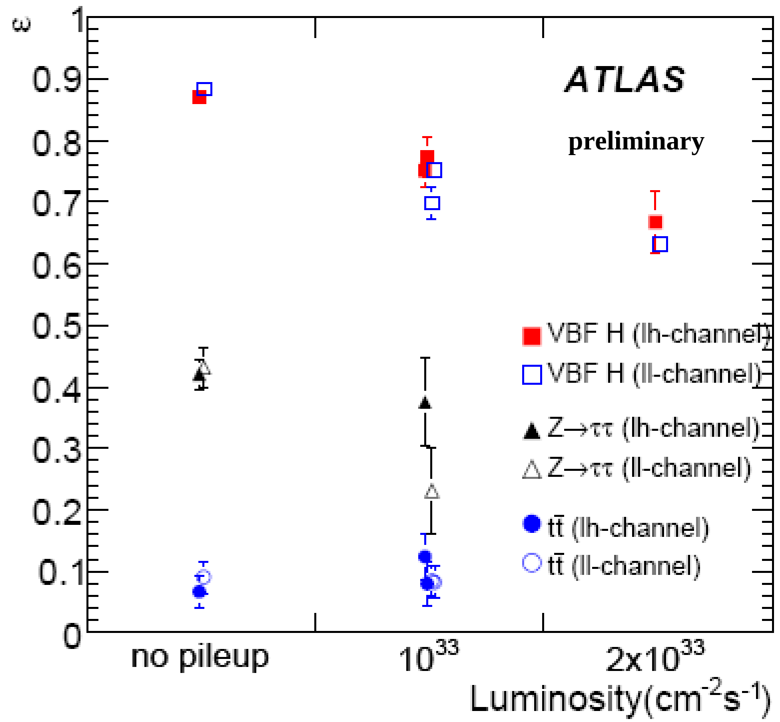


Figure 7: Central jet veto performance in the presence of varying levels of pileup for signal and background samples.

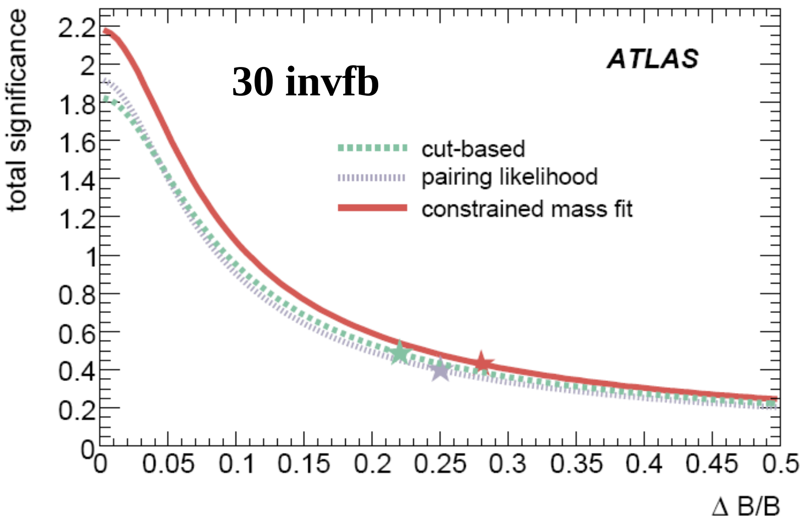
$t\bar{t}H \rightarrow t\bar{t}b\bar{b}$

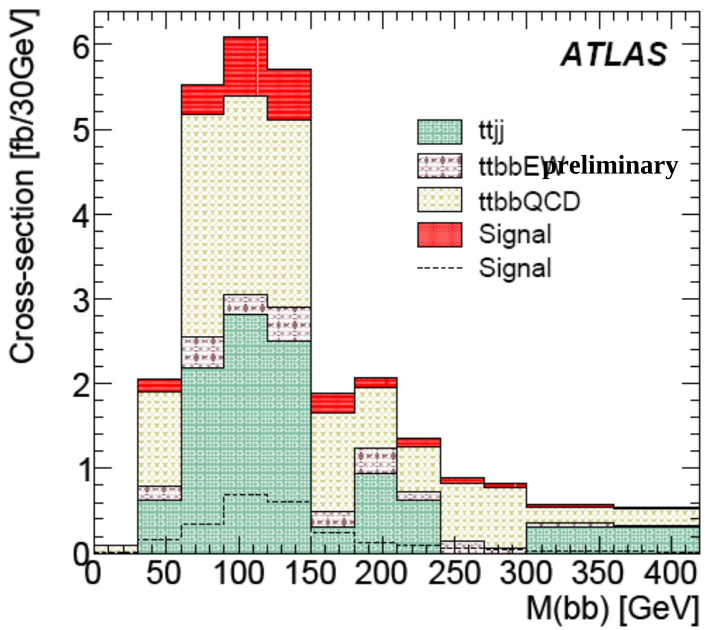
- Trigger requires: high p_T isolated lepton & E_T^{miss} to identify the *W*
- b-tagging is crucial

Three approaches:

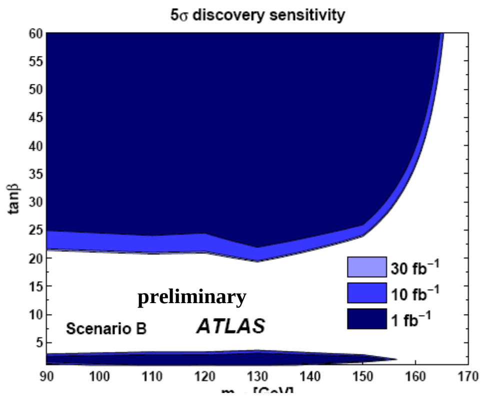
- Cut based analysis
- Likelihood analysis using invariant masses, angles and distances between jets
- Analysis with mass-constrained fit to the measured missing energy, jet and lepton four momenta (to reduce combinatorics).

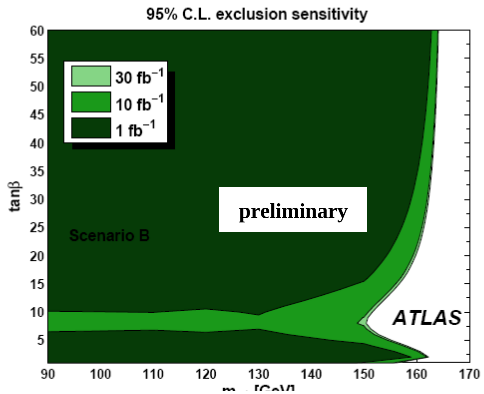
No sensitivity…



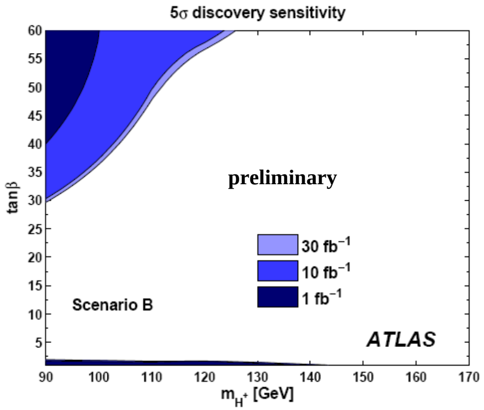


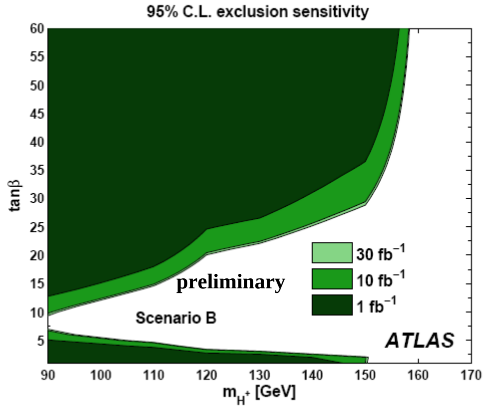
new ATLAS



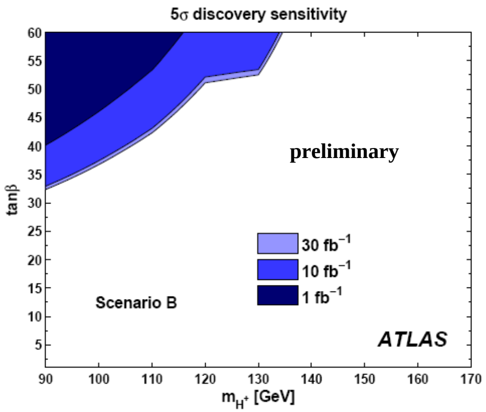


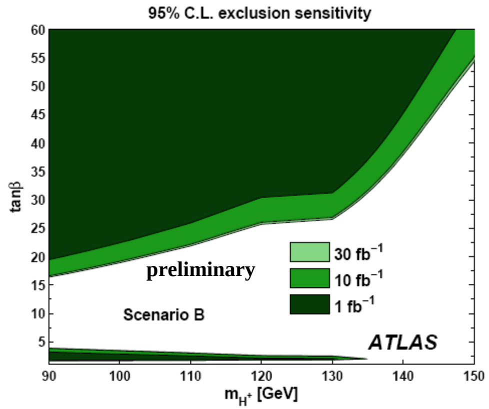
$$t\bar{t} \to bH^{+}bW \to b\tau(had)\nu bqq$$





$$t\bar{t} \to bH^{+}bW \to b\tau(lep)\nu bqq$$





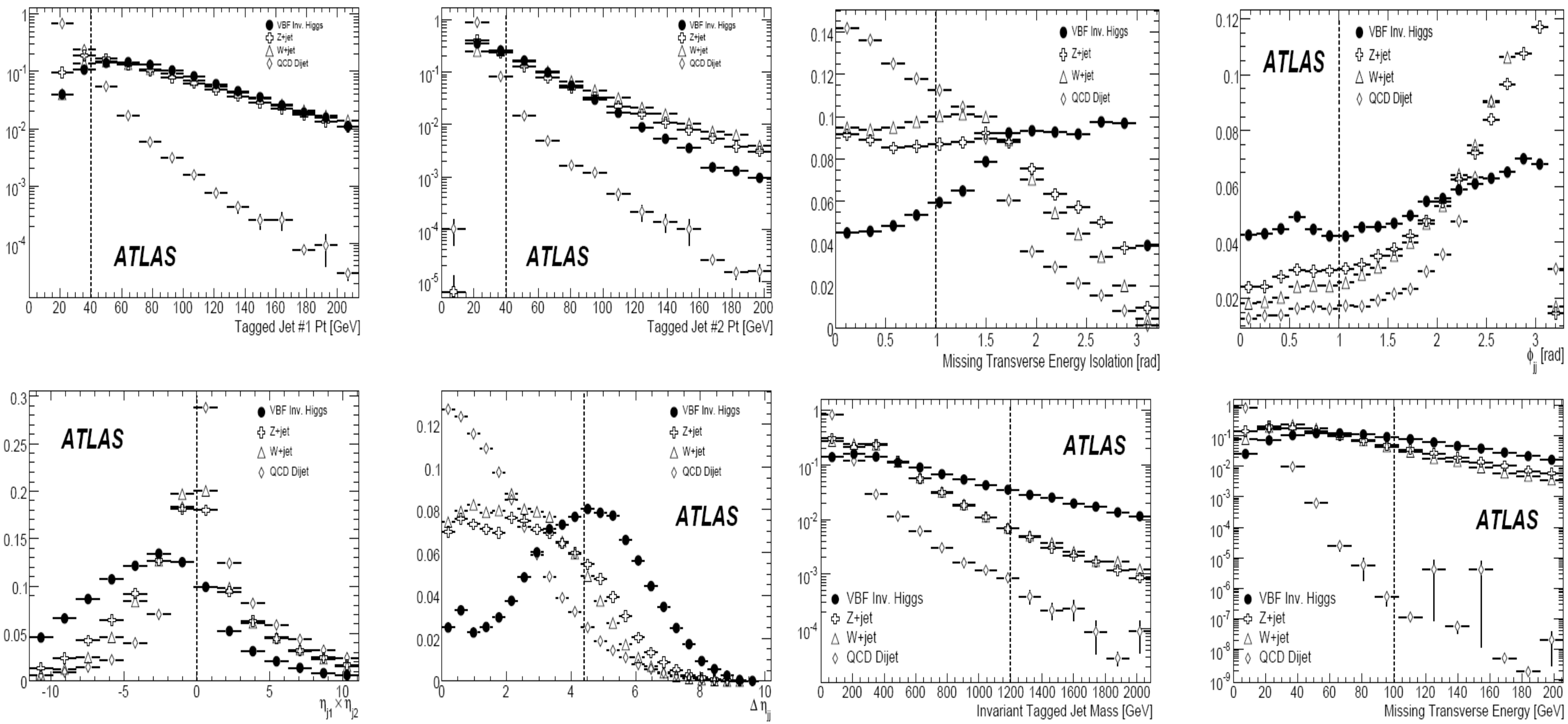
$$t\bar{t} \to bH^{+}bW \to b\tau(had)\nu b\ell\nu$$

Light H+

INVISIBLE HIGGS: VBF TOPOLOGY

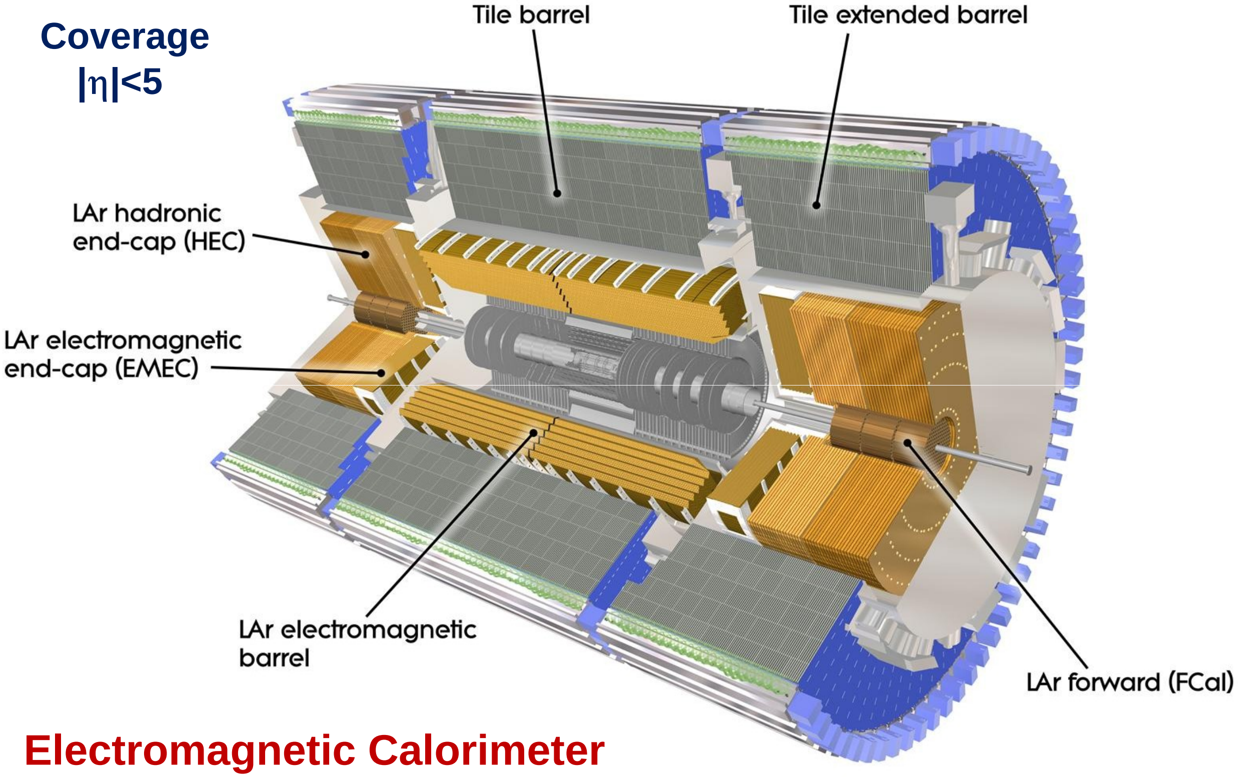
SELECTION:

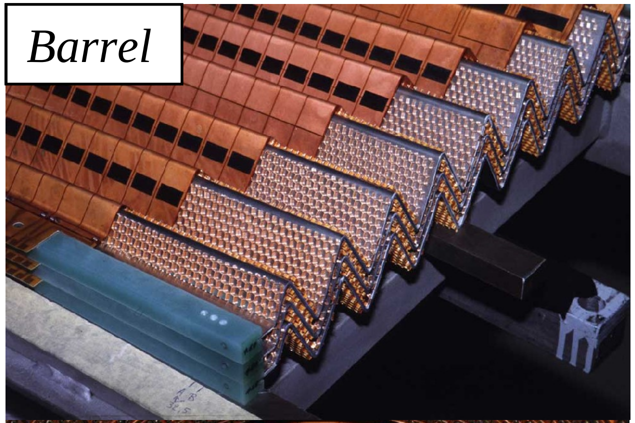
- **Tag jets p_T>40, |η|<5, $\eta_1 * \eta_2$<0, Δη>4.4**
- **Require $E_T$miss →not expected in QCD jets**
- **cut on jet invariant mass 1200GeV →reject QCD dijets which are softer**
- **Missing transverse energy isolation variable →reduce effect of cracks**
- **Reject W+jets and Z+jets cutting on hard p_T leptons**
- **Central jet veto**
- **ϕ_{jj} (in background also jet from radiative processes are present: $q\bar{q} \rightarrow gV$ and $qg \rightarrow qV$)**

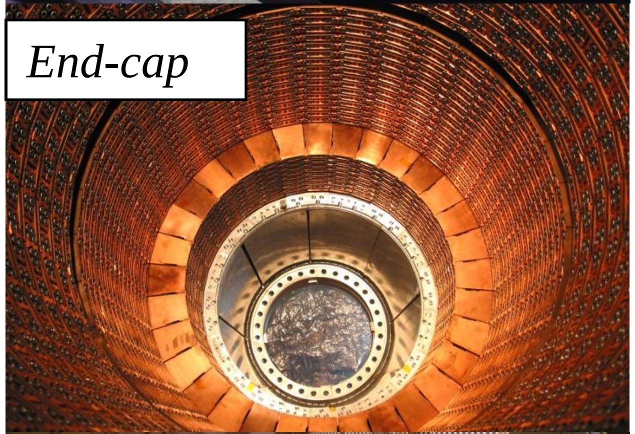


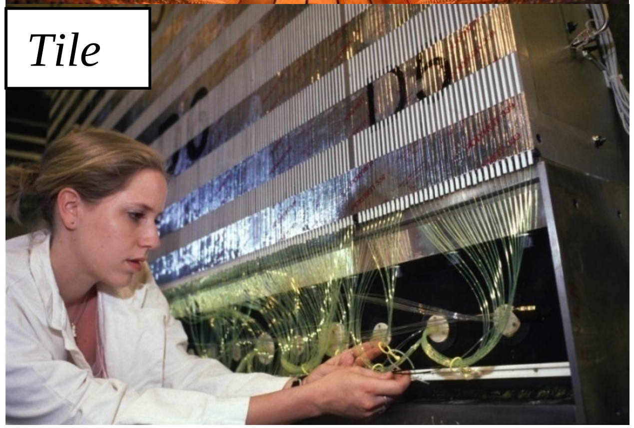
CALORIMETER

Coverage
|η|<5









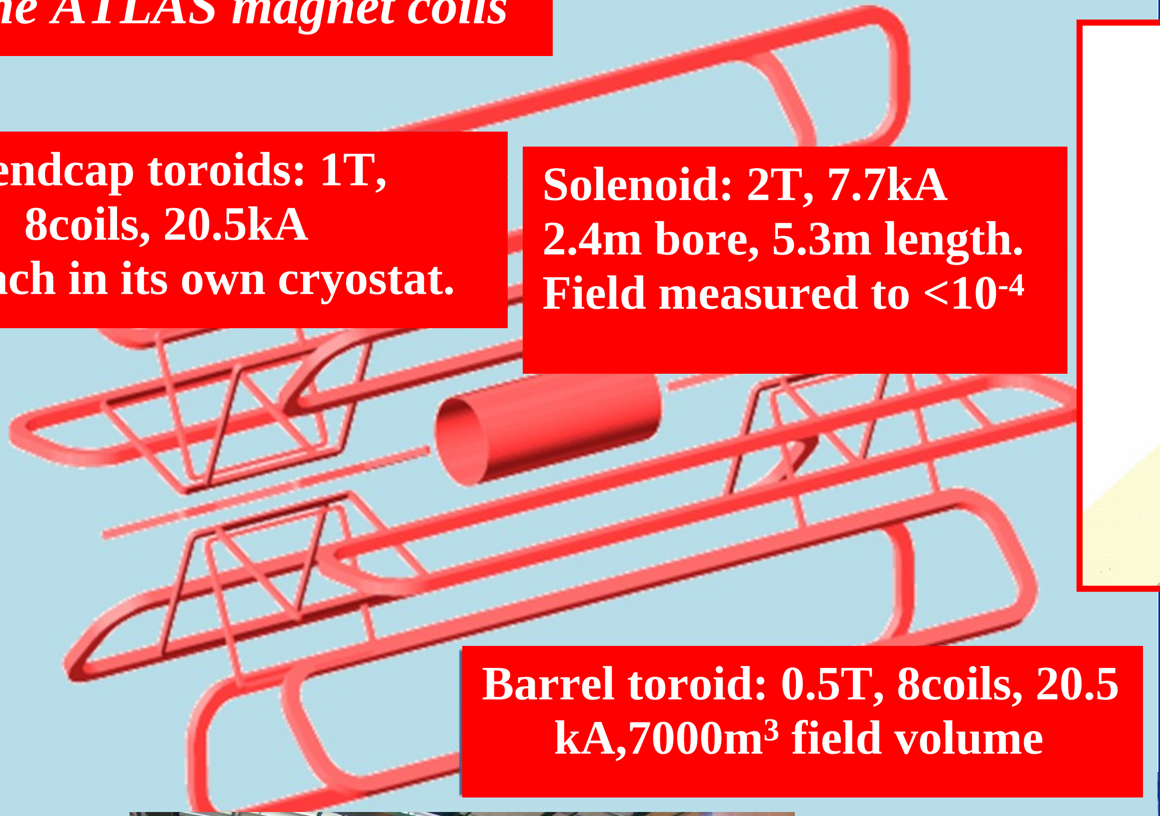
Electromagnetic Calorimeter
barrel, end-cap: Pb-LAr
~10%/√E energy resolution e/γ
180’000 channels: longitudinal segmentation

Hadron Calorimeter
barrel Iron-Tile, EC/Fwd Cu/W-LAr (~20000 channels)
σ/E ~ 50%/√E ⊕ 0.03 pion (10 λ)

Trigger for e/γ , jets, missing E_T

MAGNETS

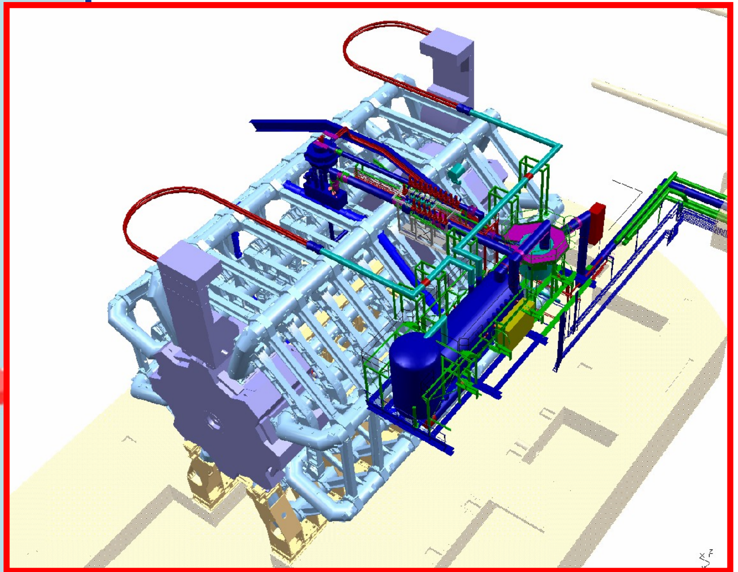
The ATLAS magnet coils

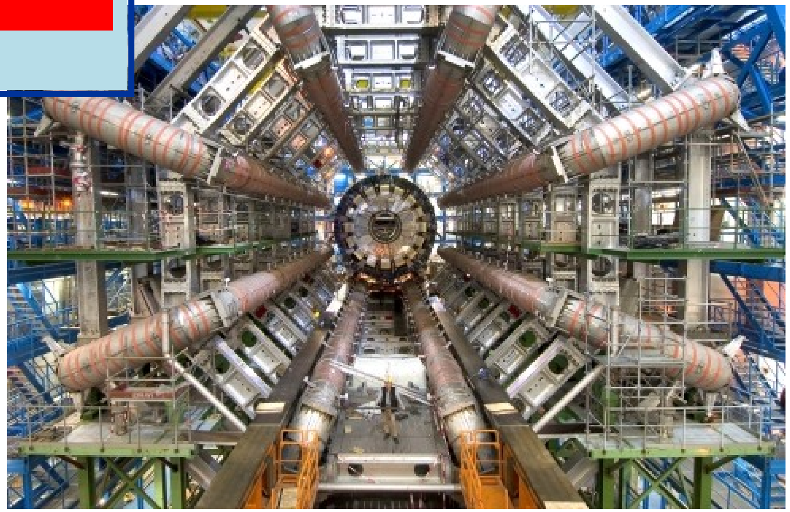


2 endcap toroids: 1T, 8coils, 20.5kA Each in its own cryostat.

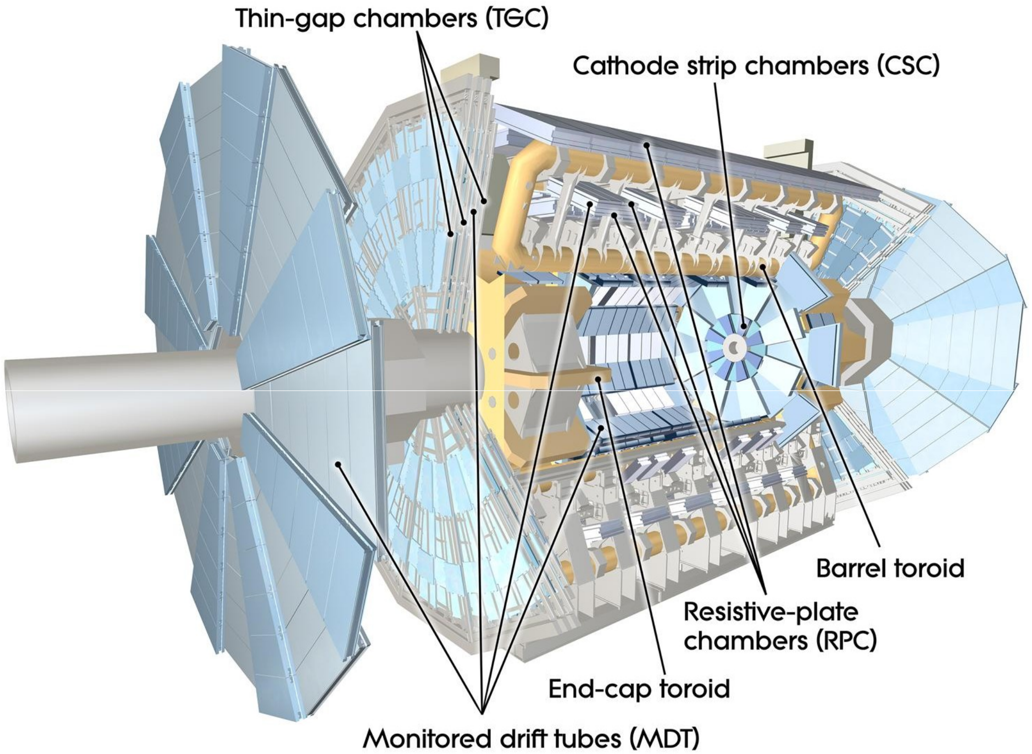
Solenoid: 2T, 7.7kA 2.4m bore, 5.3m length. Field measured to <10^{-4}

Barrel toroid: 0.5T, 8coils, 20.5 kA,7000m^3 field volume



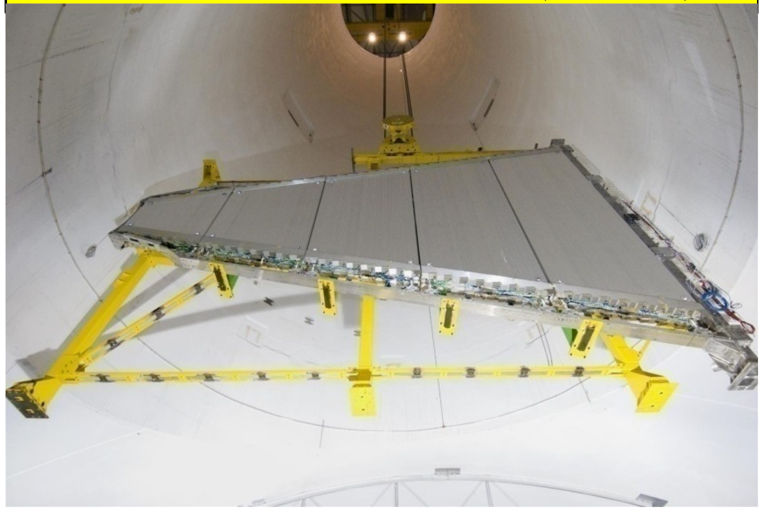


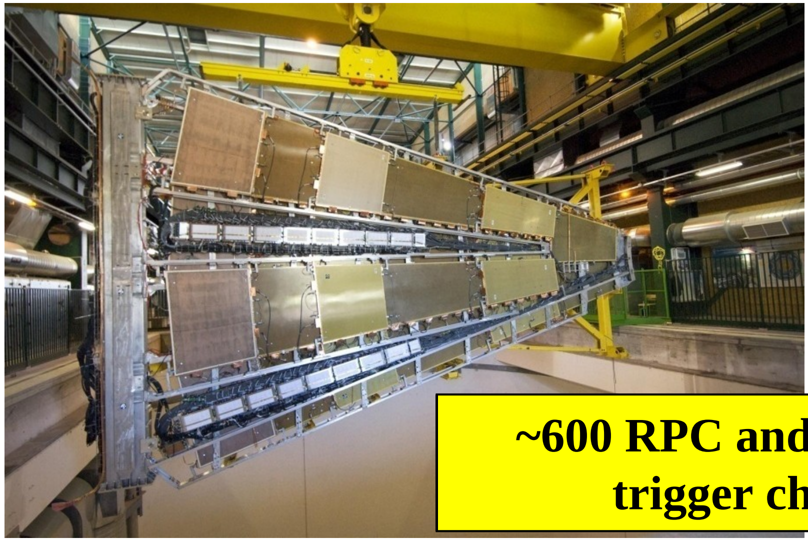
MUONS DETECTOR



Stand-alone momentum resolution $\Delta pT/pT < 10\%$ up to 1 TeV

~1200 MDT precision chambers for track reconstruction (+ CSC)



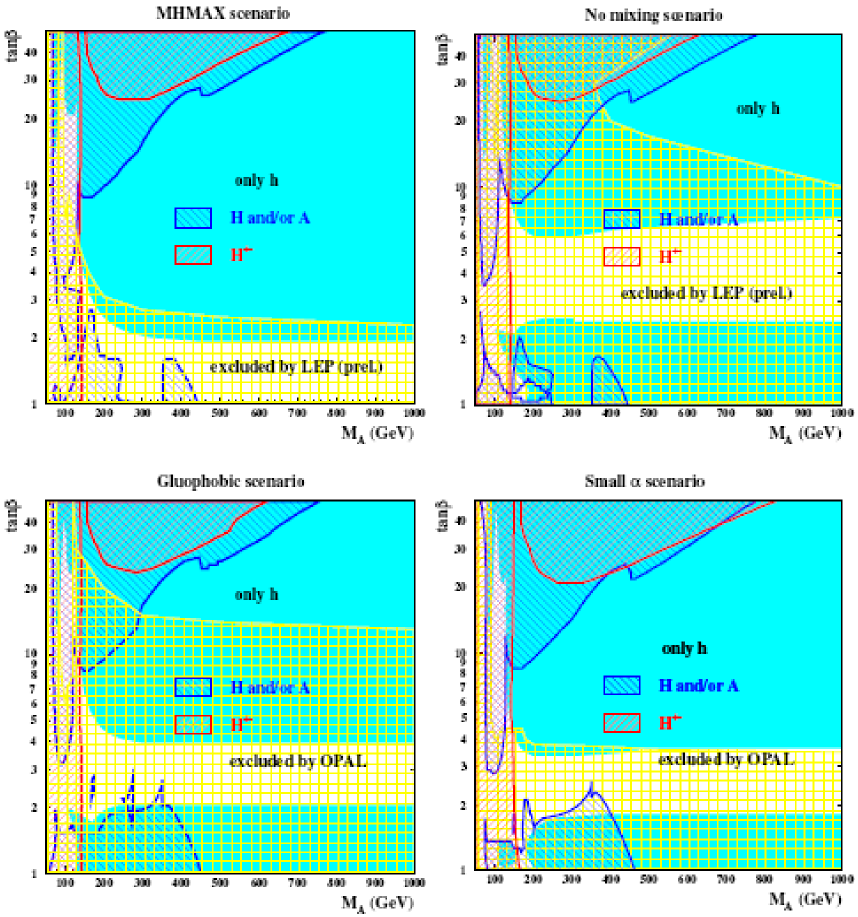


~600 RPC and ~3600 TGC trigger chambers

Updated MSSM scan for different benchmark scenarios

Benchmark scenarios as defined by M.Carena et al. (h mainly affected)

ATLAS preliminary,   30 fb^{-1},   5σ discovery

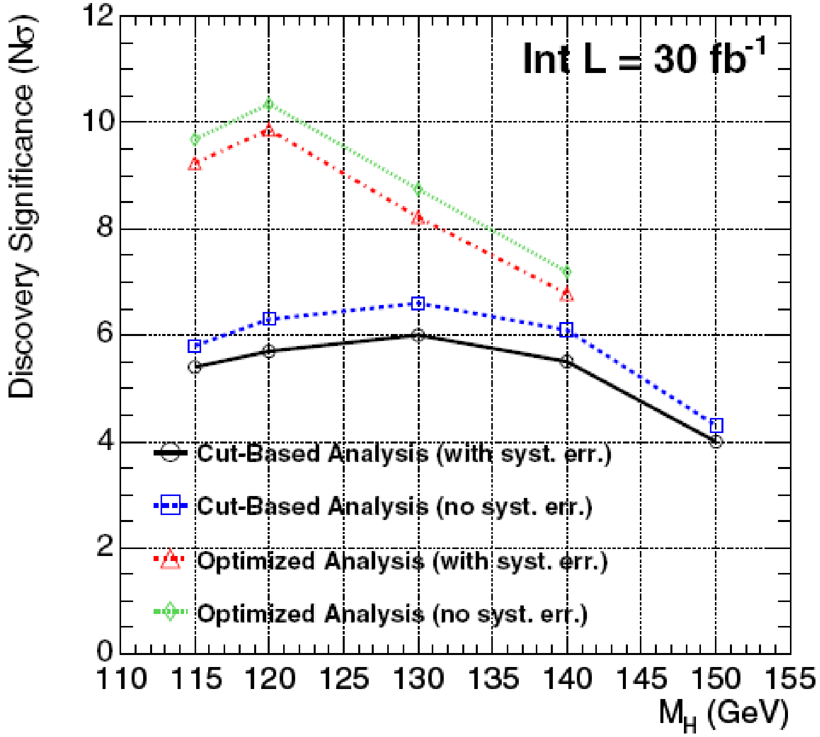


MHMAX scenario (M_{SUSY} = 1 TeV/c^2)
maximal theoretically allowed region for m_h

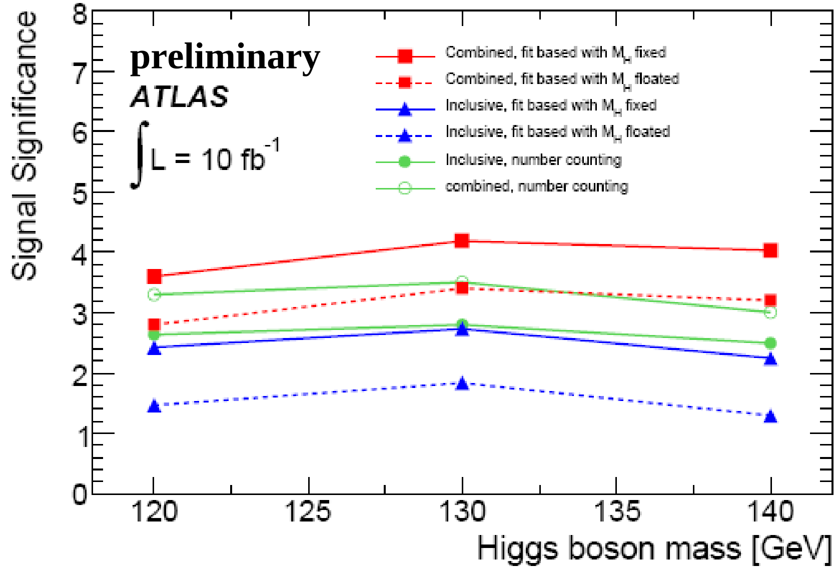
Nomixing scenario (M_{SUSY} = 2 TeV/c^2)
(1TeV almost excl. by LEP)
small m_h → difficult for LHC

Gluophobic scenario (M_{SUSY} = 350 GeV/c^2)
coupling to gluons suppressed
(cancellation of top + stop loops)
small rate for g g → H, H→ $\gamma\gamma$ and Z→4 ℓ

Small α scenario (M_{SUSY} = 800 GeV/c^2)
coupling to b (and **t**) suppressed
(cancellation of sbottom, gluino loops) for large tan β and M_A 100 to 500 GeV/c^2



CMS optimized : NN with kinematics as input , using categories (η , cluster size ≡ conversion info)



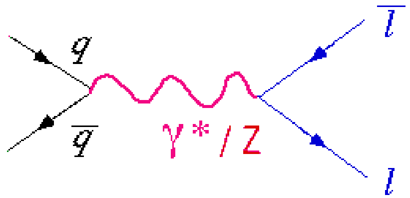
ATLAS : combined fit using variables (p_T ,# jets , cosθ*) and categories (η , conversions)

small differences ~ understood

NOTE: differences in K factors and use of categories might explain the different significance in number counting?

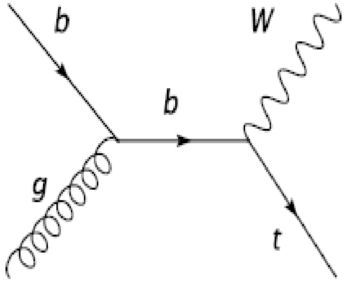
SELECTION AND BACKGROUNDS

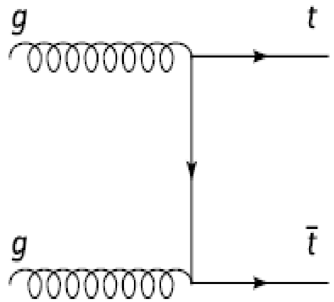
- No mass peak ➔ use transverse mass.
- **Reconstruction:**
  - Trigger : single or double lepton selection *1μ20i or 1e25i*;
  - Offline: select events with exactly two isolated (tracking and calorimeter) opposite sign primary leptons and E_T^{miss}.
  - Specific reconstructions for different channels

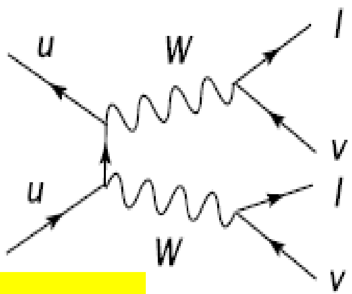


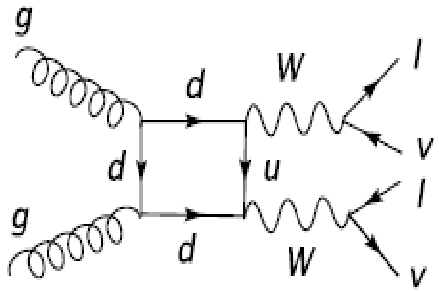
- **High backgrounds: *WW, Wt, ttbar, Z→2l, bb,cc,QCD multijet***

Process	Cross-section(pb)
$gg \to H \to WW$ ($M_H = 170$ GeV)	19.418
VBF $H \to WW$ ($M_H = 170$ GeV)	2.853
VBF $H \to WW$ ($M_H = 300$ GeV)	0.936
$qq/qg \to WW$	111.6
$gg \to WW$	5.26
$pp \to t\bar{t}$	833
$Z \to \tau\tau$+jets	2015
W+jets	20510









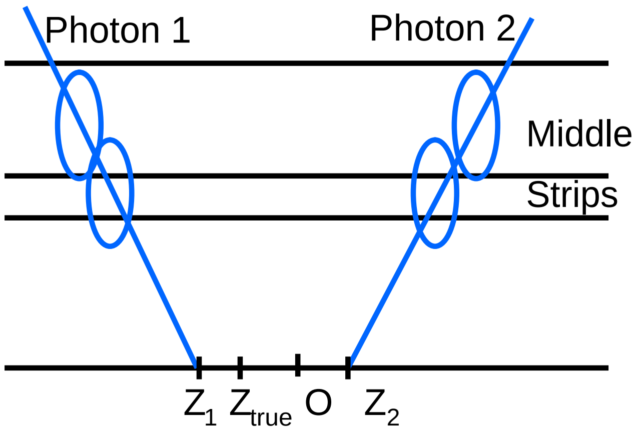
The challenge: precise knowledge of the backgrounds.

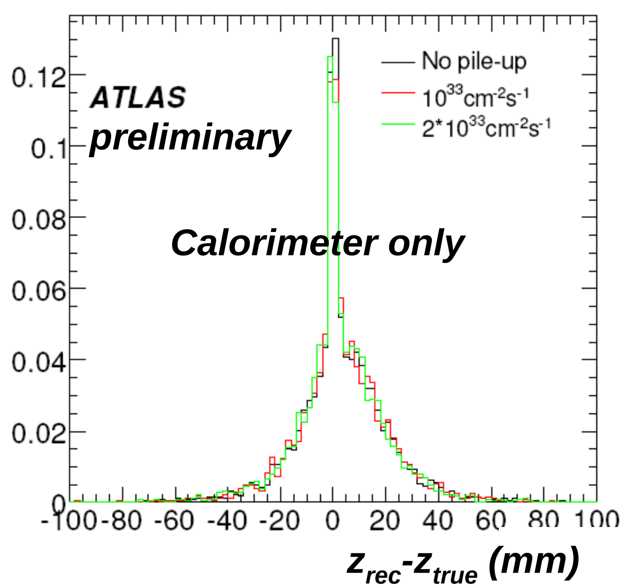
PRIMARY VERTEX RECONSTRUCTION

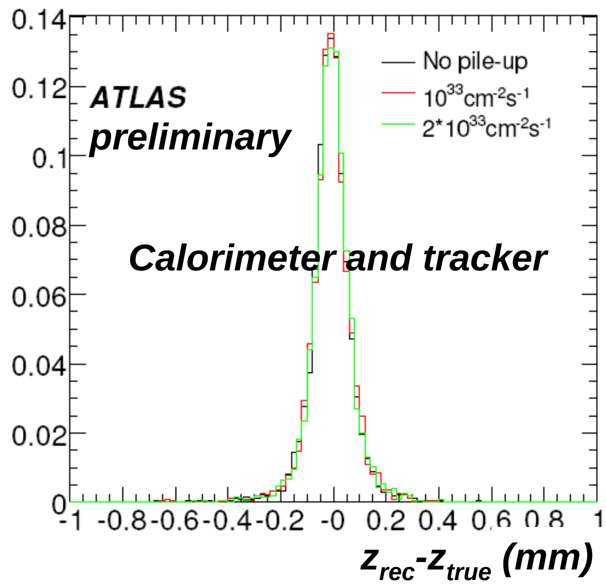
If the vertex is unknown, add 1.4 GeV to the mass resolution.

Tracker and calorimeter informations are combined:

- Using calorimeter longitudinal segmentation and pre-shower strips → vertex position accuracy is ***19mm*** (17mm when using conversions).
- Combining with the tracker information → ***~0.1 mm***
- ***Calorimeter information is useful in case of pile-up or events with low tracks multiplicity.***







BACKGROUNDS

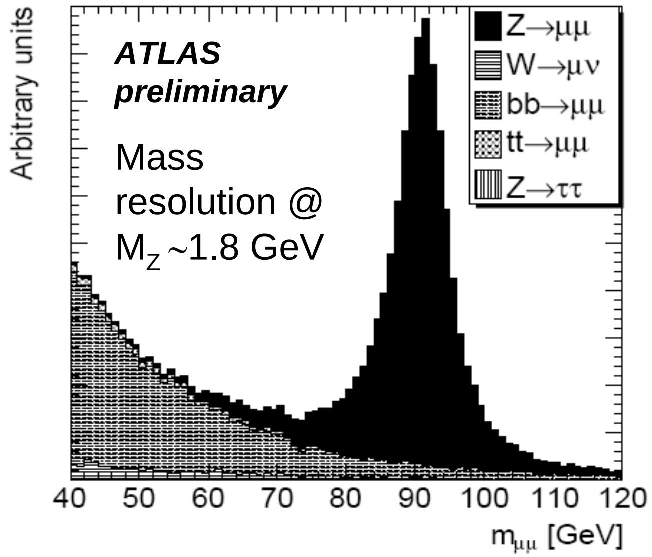
Backgrounds:

- *qq,gg → ZZ(*) →4l (l=e,m,t)*
- *qq → Zbb →4l*
- *qq → Zbb →3l*
- *qq,gg →tt*
- *qq,gg →WZ →3l*
- *Z →2l+X*

Background will be estimated in sidebands
→ low systematic uncertainties

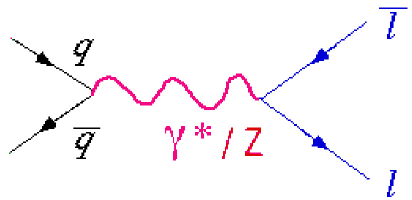
•Look to the *Z* with first data to understand lepton reconstruction and detectors response.

•*Z →ee* mass peak is affected by electron bremsstrahlung.



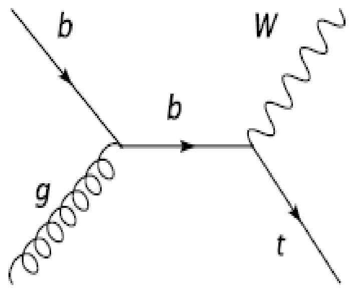
SELECTION AND BACKGROUNDS

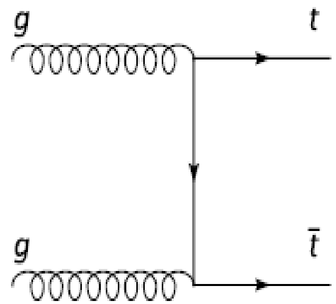
- No mass peak ➔ use transverse mass.
- **Reconstruction:**
  - Trigger : single or double lepton selection *1μ20i or 1e25i*;
  - Offline: select events with exactly two isolated (tracking and calorimeter) opposite sign primary leptons and E_T^{miss}.
  - Specific reconstructions for different channels

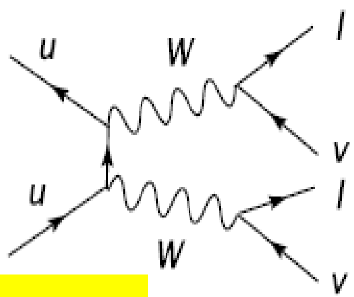


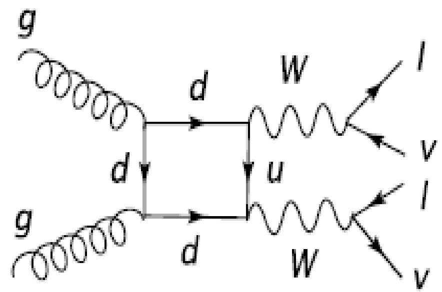
- **High backgrounds**: ***WW, Wt, ttbar, Z→2l, bb,cc,QCD multijet***

Process	Cross-section(pb)
$gg \to H \to WW$ $(M_H = 170$ GeV$)$	19.418
VBF $H \to WW$ $(M_H = 170$ GeV$)$	2.853
VBF $H \to WW$ $(M_H = 300$ GeV$)$	0.936
$qq/qg \to WW$	111.6
$gg \to WW$	5.26
$pp \to t\bar{t}$	833
$Z \to \tau\tau$+jets	2015
W+jets	20510









The challenge: precise knowledge of the backgrounds.