Physics at hadron collider with Atlas

3rd lecture

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Outline

UNIVERSITÀ DEGLI STUDI DI ROMA LA SAPIENZA

- Introduction to Hadron Collider Physics
- 1st { LHC and ATLAS detector
- Test of Standard Model at LHC
  - Parton distribution function
  - QCD + jet physics
- 2nd { Electroweak physics (Z/W –bosons)
  - **Top physics**
- 3rd { **Search for Higgs boson**
- 4th { Supersymmetry
- Conclusions

Cross Section of Various SM Processes

The LHC <u>uniquely</u> combines the two most important virtues of HEP experiments:

1. High energy 14 TeV
2. and high luminosity
   $10^{33} - 10^{34}/cm^2/s$

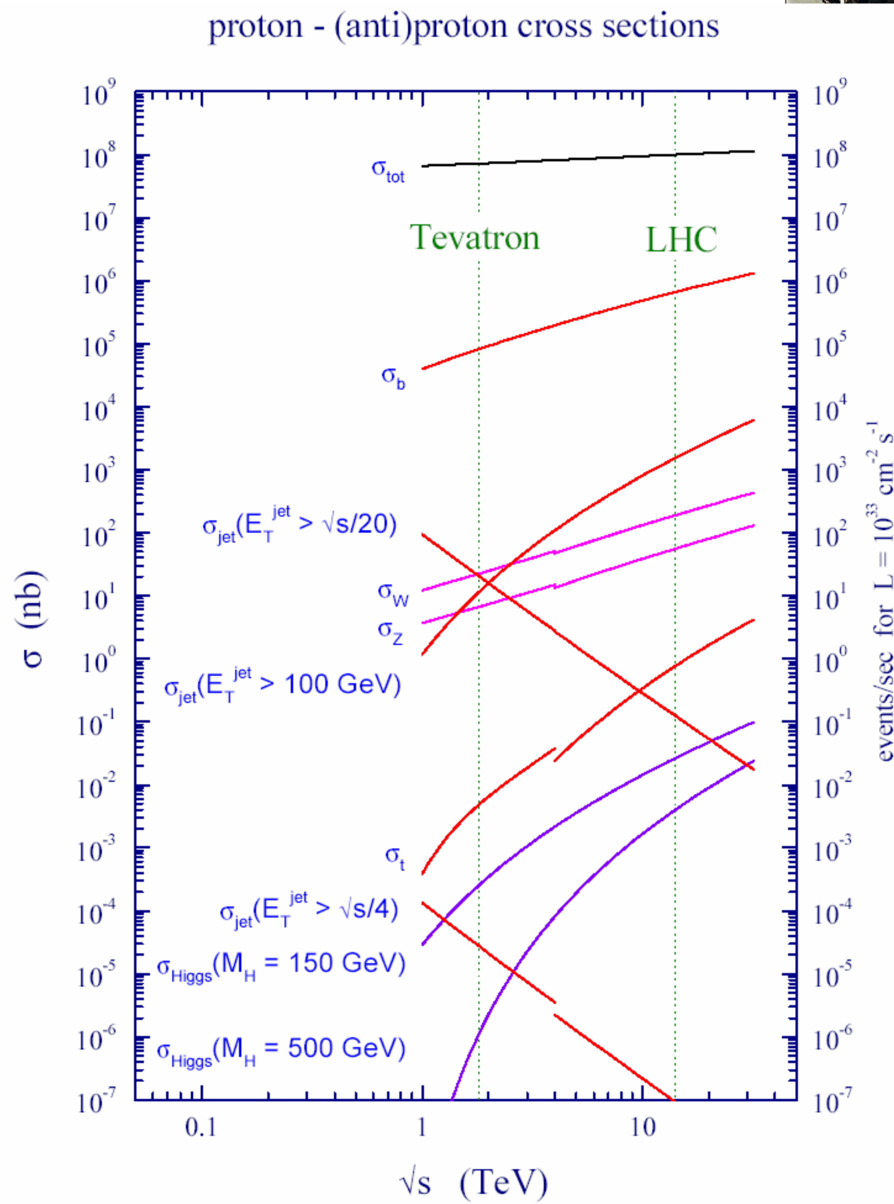
$\Rightarrow$ Low luminosity phase

$10^{33}/cm^2/s = 1/nb/s$

approximately

- 200 W-bosons
- 50 Z-bosons
- 1 tt-pair

will be produced per second!



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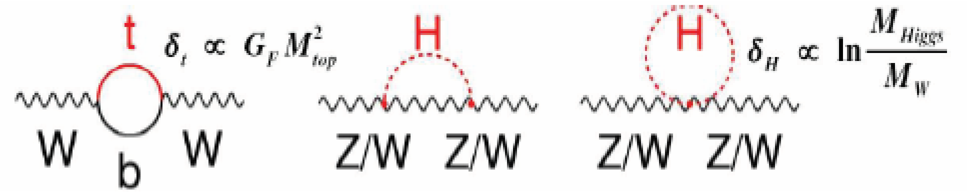
Status of SM model

- **High precision measurements → Test of Standard Model**
- **1000 data points combined in 17 observables calculated in SM**

TOP MASS

– $\alpha_s(M_z)$ precision 2 10^{-2} hadronic observable

M_{top} and M_{Higgs}



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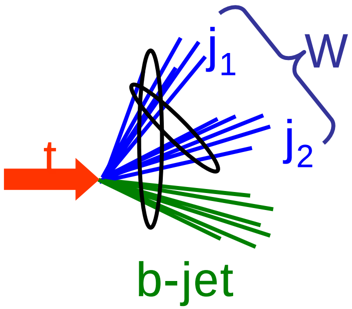
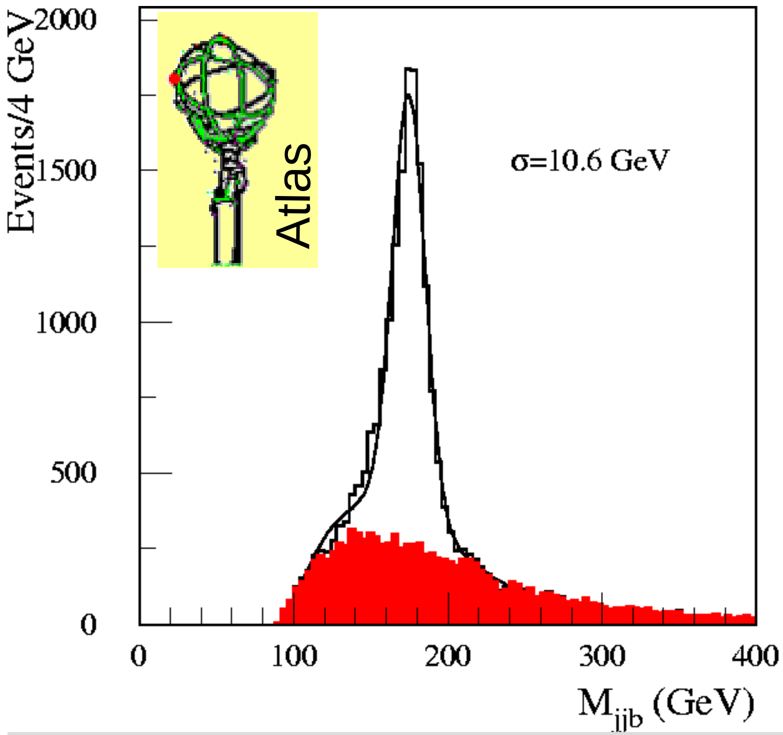
Top Mass from Semi-Leptonic Events

Reconstruct m_t from hadronic W decay
Constrain two light quark jets to m_W



70% top purity - efficiency 1.2 %



- **3.5 million semileptonic events in 10 fb^{-1} (first year of LHC operation)**

$\Rightarrow$ Error on $m_t \approx \pm 1 - 2$ GeV

Dominated by
- **Jet energy scale (b-jets)**
- **Final state radiation**

- Linear with input Mtop
  - Largely independent on Top P_T

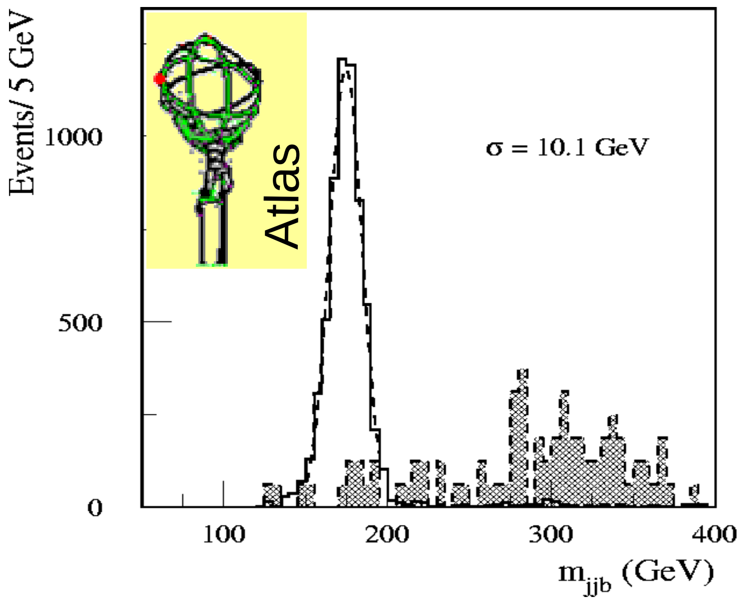
Top Mass from Other Channels

Di-lepton events:
- BR ≈ 5%
- low background
- but two neutrinos in final state

$\Rightarrow \Delta m_t \approx \pm 1.7$ GeV

Fully hadronic events:
- BR ≈ 45%
- difficult jet enviroment

$\Rightarrow \Delta m_t \approx \pm 3$ GeV



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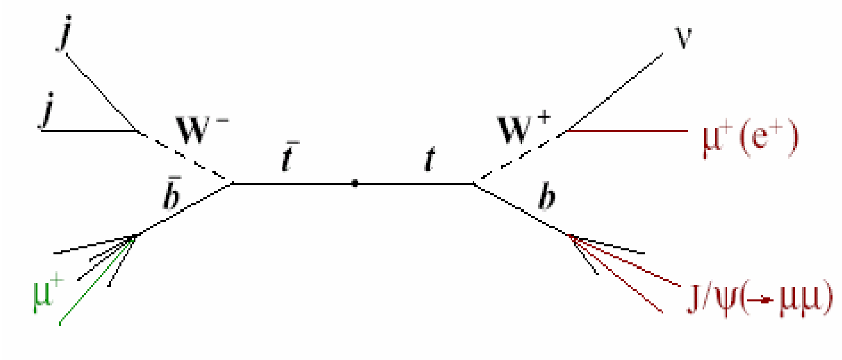
Top Mass from J/Ψ channel

1000 events/y @ 10^{34}

- **Method:**
  Partial reconstruction of top J/Ψ + lepton



- **The lepton from W decay is rather sensitive to m_t**

  $BR(tt \rightarrow Wb+qqJ/\psi \rightarrow \ell\ell) \approx 5\ 10^{-5}$

L $=100fb^{-1}$

- **efficiency ($\varepsilon \sim 30\%$)**

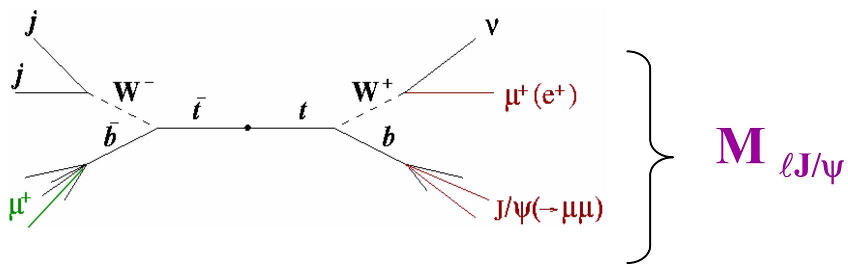
- **Low background**

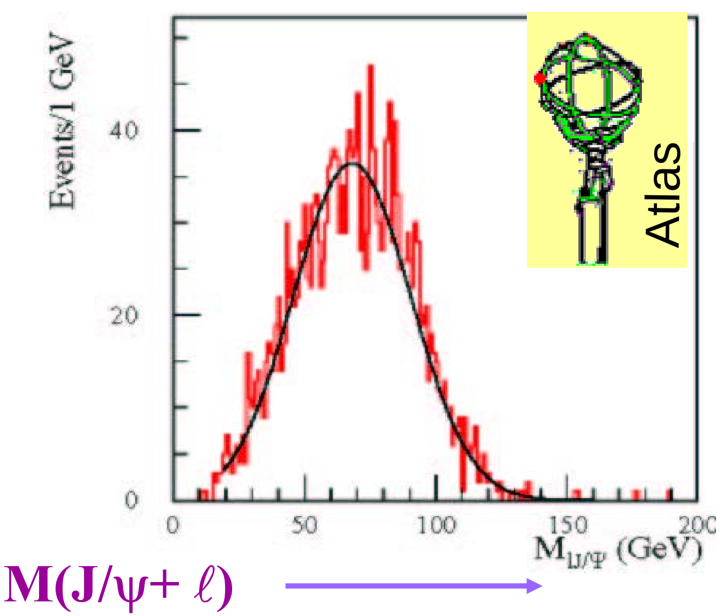
- **Estimated ultimate precision:**

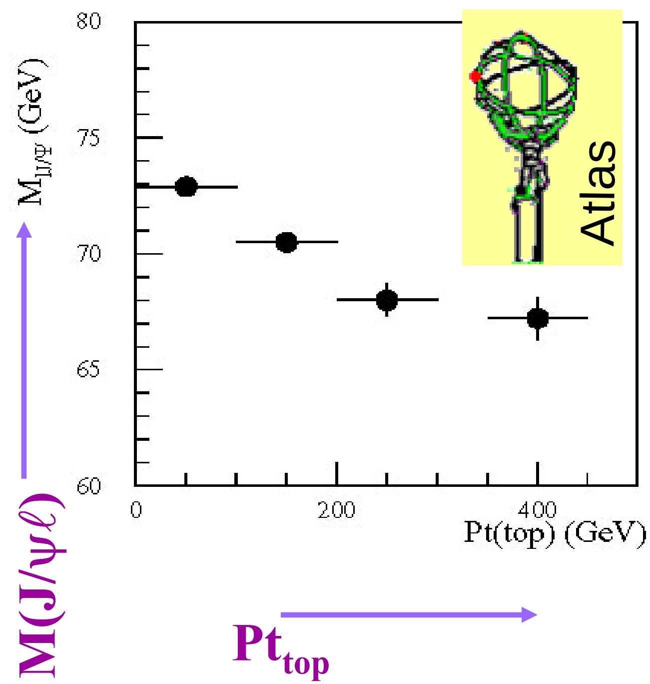
  $\Delta m_t \approx 1$ GeV

- **indipendent of jet energy scale**
- **limited by b fragmentation & needs high luminosity**

Top mass from J/ψ







Different systematics (almost no sensitivity to FSR)

Uncertainty on the b-quark fragmentation function becomes the dominant error

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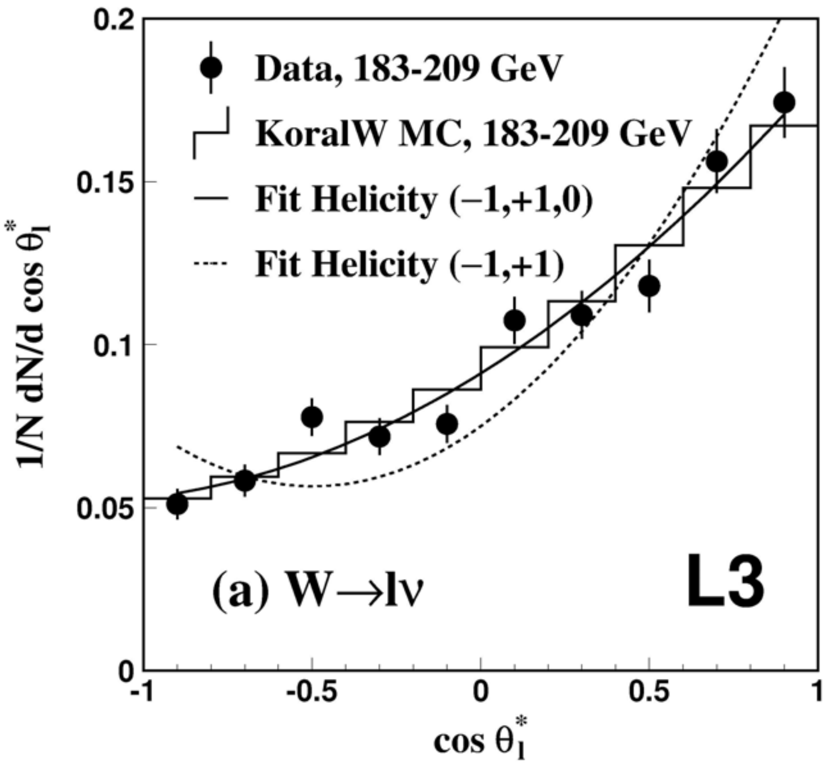
W Polarization

Massive gauge bosons have three polarization states

At LEP in $e^+e^- \to W^+W^-$:

determine W helicity from lepton (quark) decay angle in W rest frame θ^*

- $(1 \pm \cos\theta^*)^2$ transverse
- $\sin^2\theta^*$ longitudinal



$\Rightarrow$

- Fraction of longitudinal W in $e^+e^- \to W^+W^-$

  0.218 ± 0.031

  SM: 0.24

- Tevatron: Longitudinal W in top decays

  0.91 ± 0.52 CDF

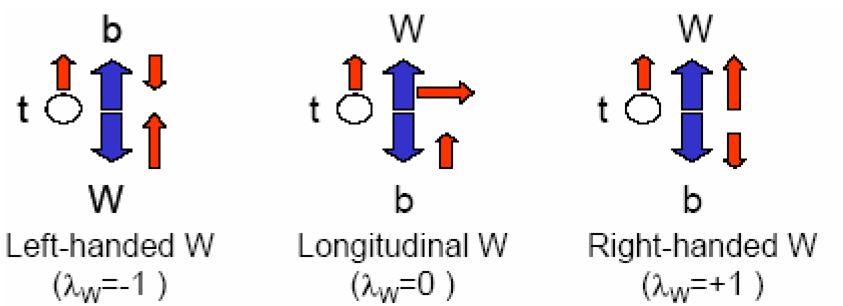
  0.56 ± 0.31 D0

  SM: 0.7

W Polarization in Top Decays

➢Use tt events to study the Lorentz structure of tt

P ossible W configuration in top decays.



$$F_{-} \approx \frac{2M_W^2}{m_t^2 + 2M_W^2} = 0.30 \qquad F_0 \approx \frac{m_t^2}{m_t^2 + 2M_W^2} = 0.70 \qquad F_{+} = 0$$

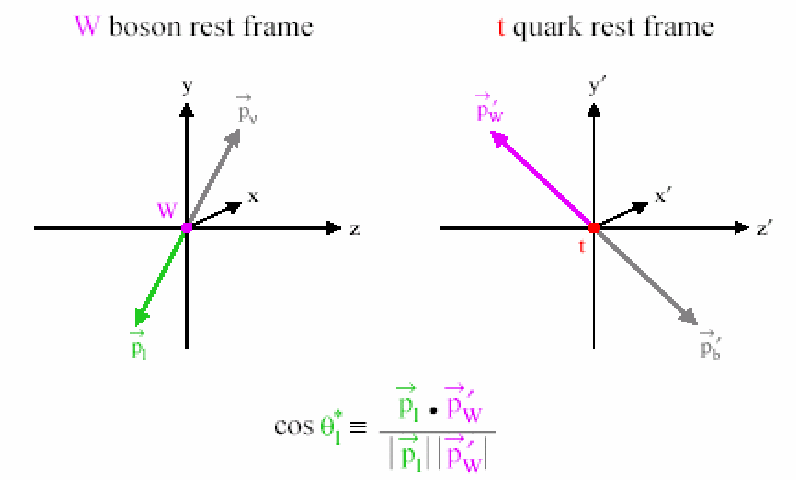
Standard Model

Within SM (V-A coupling) only 2 configuration are

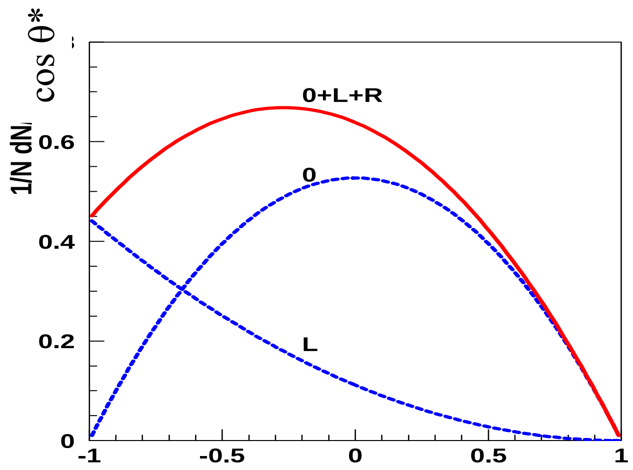
➢Lepton kinematical distribution are rather sensitive to W boson helicity

W Polarization in Top Decays

➢ A sensitive W spin analyser in top decays is the angle θ* between the charged lepton in W rest frame and W in top rest frame

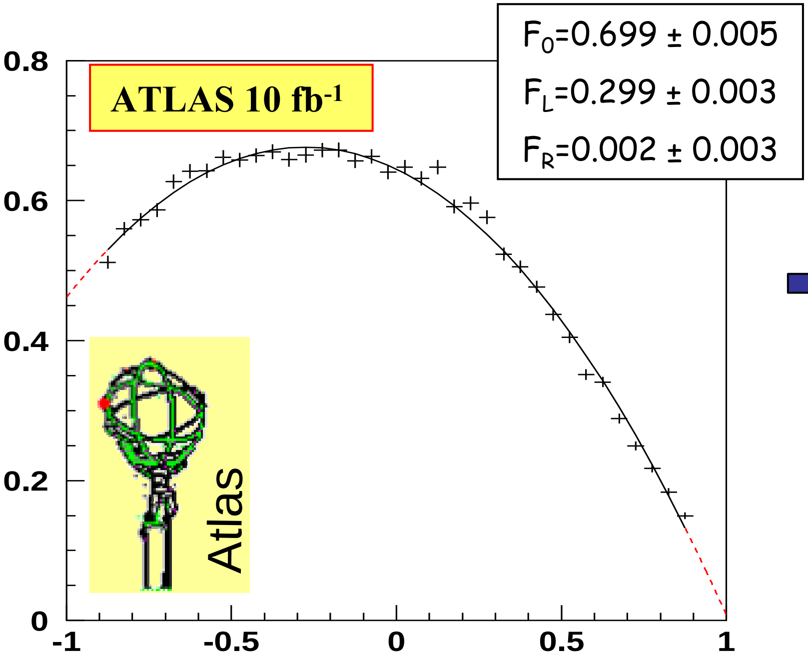


$$\cos\theta_l^* \equiv \frac{\vec{p}_l \bullet \vec{p}'_W}{|\vec{p}_l||\vec{p}'_W|}$$



$$\frac{1}{N}\frac{dN}{d\cos\theta^*} = \frac{3}{2}\left[F_0 \cdot \left(\frac{\sin\theta^*}{\sqrt{2}}\right)^2 + F_L \cdot \left(\frac{1-\cos\theta^*}{2}\right)^2 + F_R \cdot \left(\frac{1+\cos\theta^*}{2}\right)^2\right]$$

W Polarization in Top Decays



	SM	ATLAS (±stat ±syst)
F_0	0.703	± 0.004 ± 0.015
F_-	0.297	± 0.003 ± 0.024
F_+	0.000	± 0.003 ± 0.012

- Systematic dominated by b-jet scale.
- Precision on fraction of long.polarization W~ **0.03 after 10fb^{-1}**

$t\bar{t}$ Spin Correlation

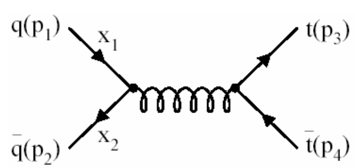
- **Very short lifetime, no top bound states**
- **Spin info not diluted by hadron formation**

•Measure the correlation through the angular distribution of daughter of articles in top rest frame

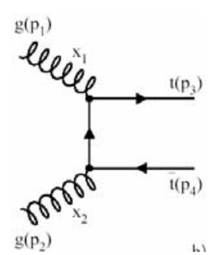
$$\mathcal{A} = \frac{N(t_L\bar{t}_L + t_R\bar{t}_R) - N(t_L\bar{t}_R + t_R\bar{t}_L)}{N(t_L\bar{t}_L + t_R\bar{t}_R) + N(t_L\bar{t}_R + t_R\bar{t}_L)} \qquad \frac{1}{N}\frac{d^2N}{d\cos\theta^*_{\ell+}\, d\cos\theta^*_{\ell-}} = \frac{1}{4}(1 - \mathcal{A}\cos\theta^*_{\ell+}\cos\theta^*_{\ell-})$$

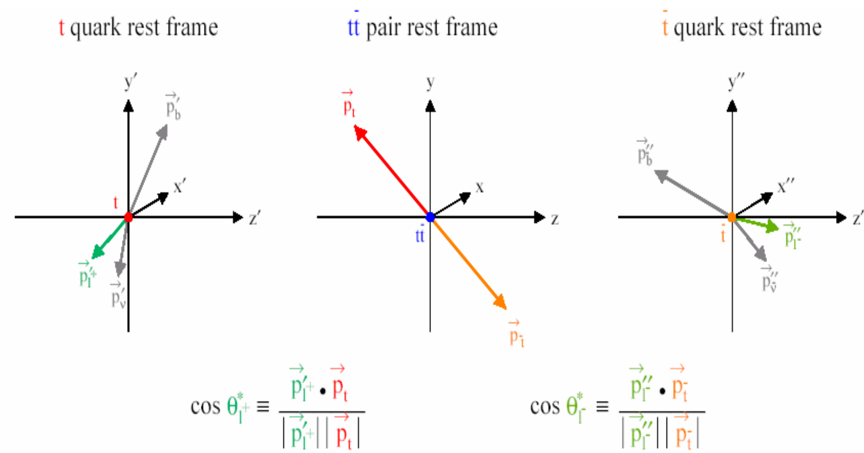
Distinguishes between

- **quark annihilation**
  A = -0.469



- **and gluon fusion**
  A = +0.431

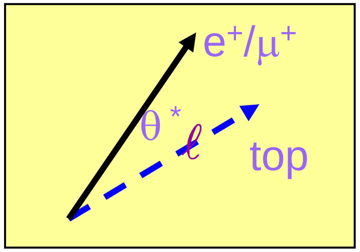




Use double leptonic decays
$t\bar{t} \rightarrow b\bar{b}\, l\nu\, l\nu$

Predicted value A=0.31

tt-correlation dileptonic events



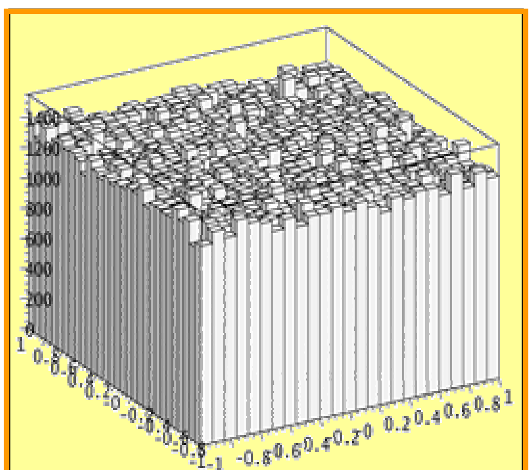
Double leptonic decays
tt → bb lν lν

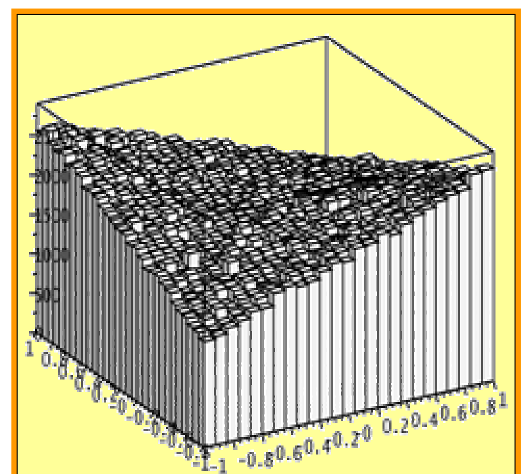
θ^*_ℓ angle of charged lepton in top (or antitop) rest frame

$\langle \cos\theta^{*+}_\ell \cdot \cos\theta^{*-}_\ell \rangle$

$\langle \cos\theta^{*+}_\ell \cdot \cos\theta^{*-}_\ell \rangle$

Without helicity correlation



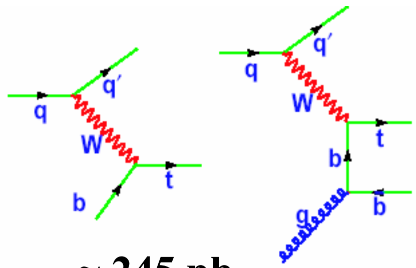


With helicity correlation

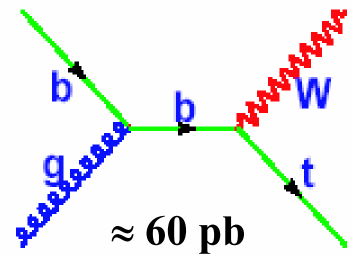
➢ Dilepton and -Semileptonic events analysis with same power to probe SM at 5σ in $10fb^{-1}$

Single Top Production

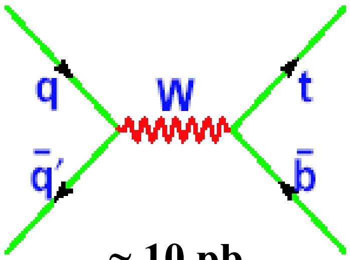
Production mechanisms and cross sections:



≈ 245 pb



≈ 60 pb



≈ 10 pb

1 **2** **3**

- **direct measurement of V_{tb}**

(observable by Tevatron in Run II)

tt final states (LHC,10 fb^{-1})

$W \rightarrow e\nu, \mu\nu$

- process 1 **(0.5M)** : $\ell + \nu$ + 4jets
- process 2 **(0.12M)** : $\ell + \nu$ + 3ets
- process 3 **(0.02M)** : $2\ell + \nu$ + 2jets

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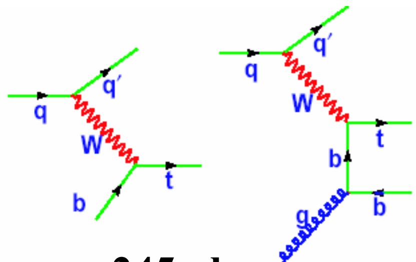
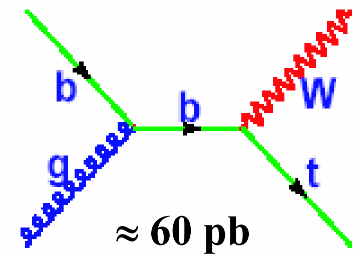
Single Top Production

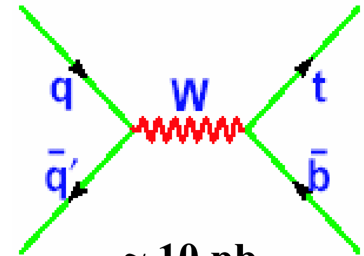
Production mechanisms and cross sections:



≈ 245 pb



≈ 60 pb



≈ 10 pb

Process	δV_{tb} (stat)	δV_{tb} (theory)
1	0.4%	6%
2	1.4%	6%
3	2.7%	5%

- **Selection:**
  $t \rightarrow bW \rightarrow b\, e\nu\ (\mu\nu)$
  b-jet + high p_T lepton
  reconstruction of top mass

- **Background from $t\bar{t}$**
  signal to bkgd. 3.5 : 1

experimental determination of V_{tb} to percent level (with 30 fb^{-1})

EW Single Top Quark Production

Main Background [σxBR(W→ℓν), ℓ=e,μ]:

- tt σ=833 pb [246 pb]
- Wbb σ=300 pb [66.7 pb]
- Wjj $\sigma=18\cdot10^3$ pb [$4\cdot10^3$ pb]

1 [54.2 pb]
2 [17.8 pb]
3 [2.2 pb]

Pre -selection:

≥ 1 isolated lepton Pt>20 GeV

≥ 2 jets Pt>30 GeV

≥ 1 b-tagged jet Pt>50 GeV

+

Njets =2 or 3

Forward jet , pT>50 GeV (for Wg)

N-bjet=1 (for Wt) or =2 (for W*)

Signal unambiguous, after 30 fb-1:

Process	Signal	Bckgnd	S/B
1	27k	8.5k	3.1
2	6.8k	30k	0.22
3	1.1k	2.4k	0.46

Detector performance critical:

Fake ℓ,b-tag, jets calibrations

Top spin correlations

- Also study spin correlations in semi- leptonic events

  Least energetic jet from W decay: κ ~ 0.5

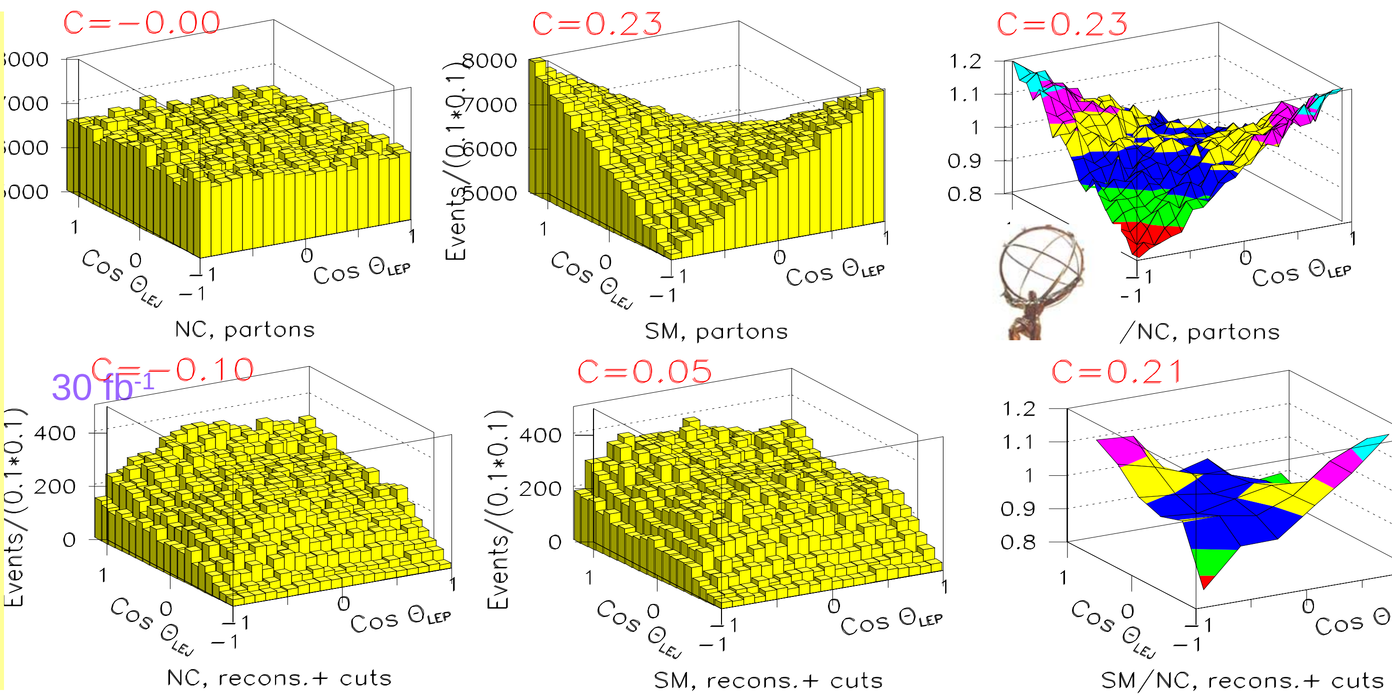
TopReX 4.05 (SM): LO spin correlation simulation

Pythia 6.221 (NC): hadronisation, fragmentation and decays with CTEQ5L structure function, ISR-FSR

AlpGen: used for W+jets background

Tauola+Photos 2.6: t decay and radiative corrections

Atlfast 2.60: ATLAS fast simulation and reconstruction



Results for S + B : 80500 S, S/B=15 with 10 fb^{-1}

C(lej) = **0.21** ± **0.015** ± **0.04** = ~ **5 σ from 0** with 10 fb^{-1}

Determination of Top Charge

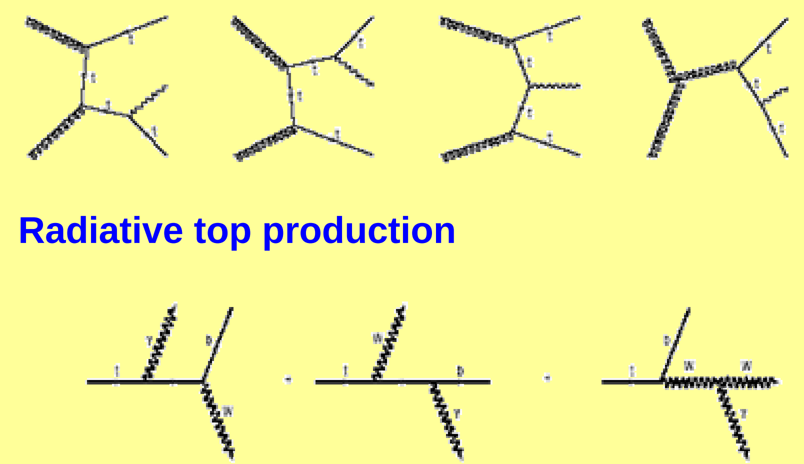
Top charge:

- **$Q_t = +2/3$ not yet established**   **$t \to W^+b$**
- **$Q_t = -4/3$ not yet excluded**   **$t \to W^-b$**

Methods:

- **jet charge determination**. Measure the lepton charge from W decays and distinguish b-quark from anti-b with jet charge determination
- **$tt\gamma$ events .** Final state photon radiation would be more likely if |Q| is larger.

cross section proportional to $Q_2^{top.}$



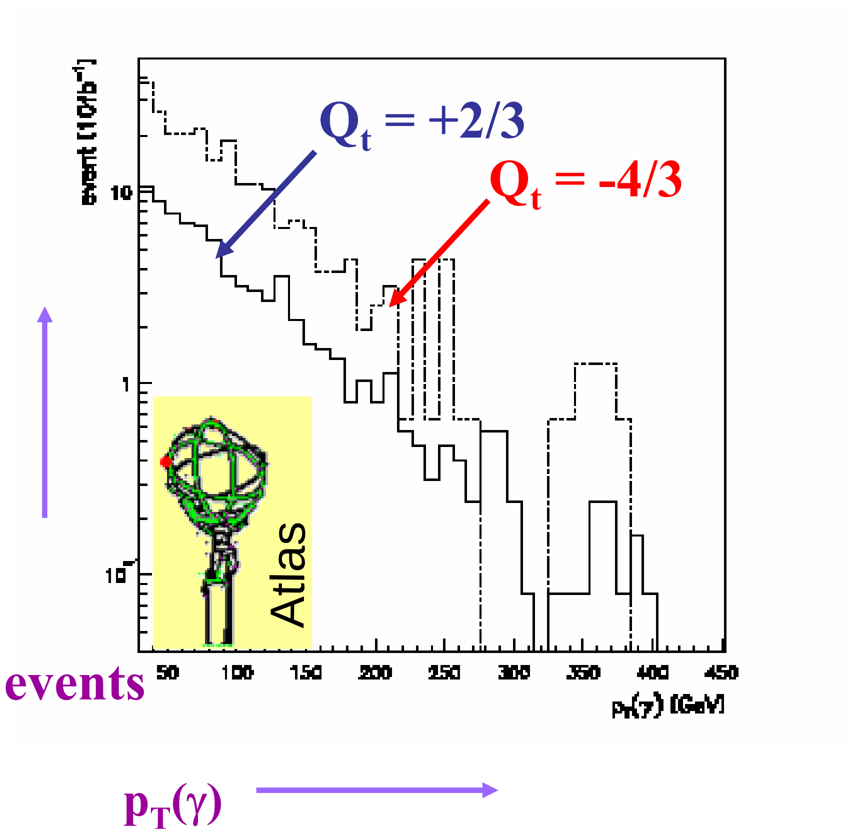
Radiative top production

Radiative top decay

Determination of Top Charge

Determine charge from rate of radiative $t\bar{t}\gamma$ events

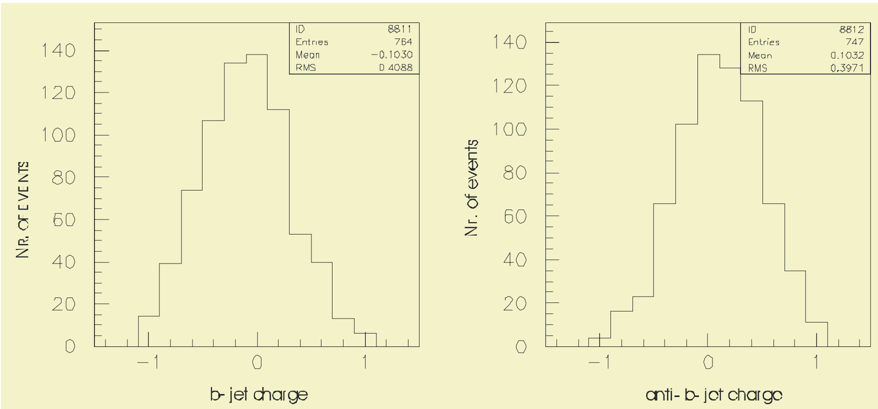
p_T spectrum of photons for 10 fb^{-1}:



	Q=2/3	Q=-4/3
$pp \rightarrow t\bar{t}\gamma$	101 ± 10	295 ± 17
$pp \rightarrow t\bar{t}$; $t \rightarrow Wb\gamma$	6.2 ± 2.5	2.4 ± 1.5
Total background	38 ± 6	

Top Charge Determination

ATL-PHYS-2003-035



$$q_{bjet} = \frac{\sum_i q_i \left| \vec{j} \cdot \vec{p}_i \right|^{\kappa}}{\sum_i \left| \vec{j} \cdot \vec{p}_i \right|^{\kappa}}$$

- Determine charge of b-jet and combine with lepton
  - Use di-lepton sample Investigate ‘wrong’ combination b-jet charge and lepton charge
  - Effective separation b and b-bar possible in first year LHC
  - Study systematics in progress

Measurement of tt cross section

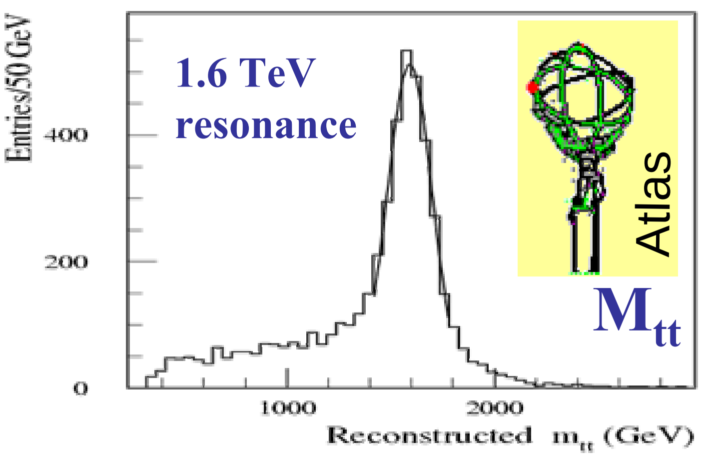
Total cross section:

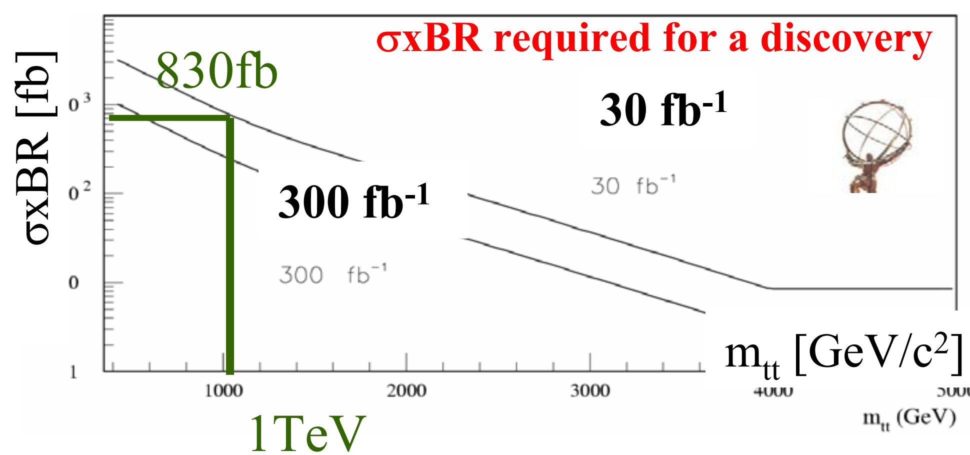
- At 14 TeV interesting in itself
- Sensitive to top mass $\sigma_{tt} \propto 1/m_t^2$

Differential cross sections:

- $d\sigma/dp_T$ checks pdf
- $d\sigma/d\eta$ checks pdf
- $d\sigma/dm_{tt}$ sensitive to production of heavy object decaying to top-pairs X→tt

Atlas





A resonance could be discovered if σxBr >830 fb

Summary & Conclusions

SM physics at the LHC with ATLAS

- Very important in initial phase
  - to check detector
  - to check generators (pdf)
  - to prepare discoveries

- Large potential for precision measurements
  - large cross sections
  - precision limited by systematics
  - use as many different strategies as possible

Standard Model Higgs Search

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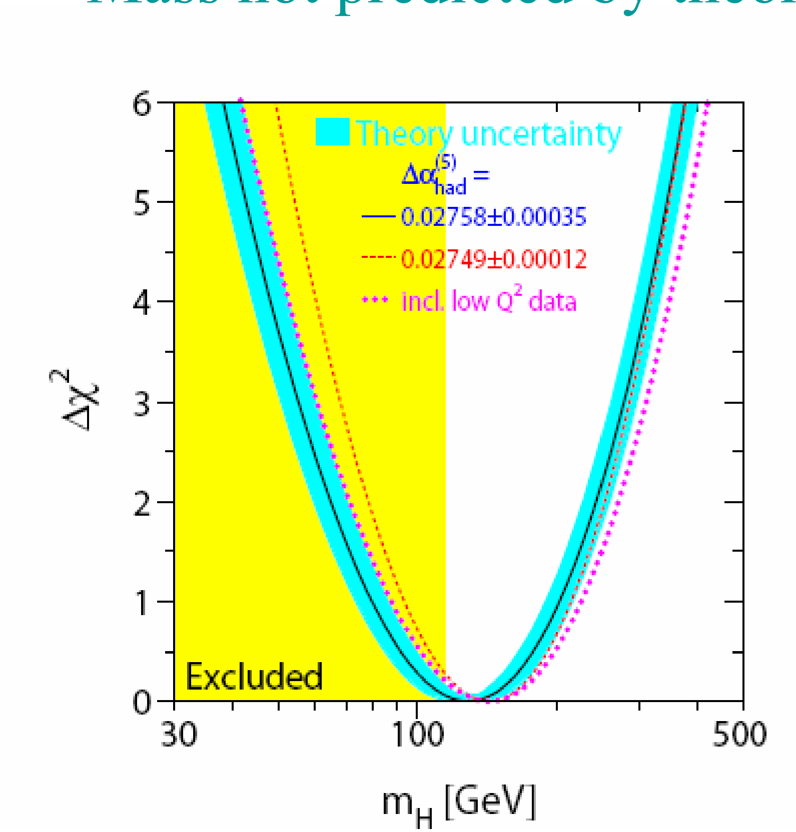
LEP legacy

- Needed to generate particle masses
- Mass not predicted by theory



Direct limit M_H >114.4 GeV

Indirect constraints <208 GeV

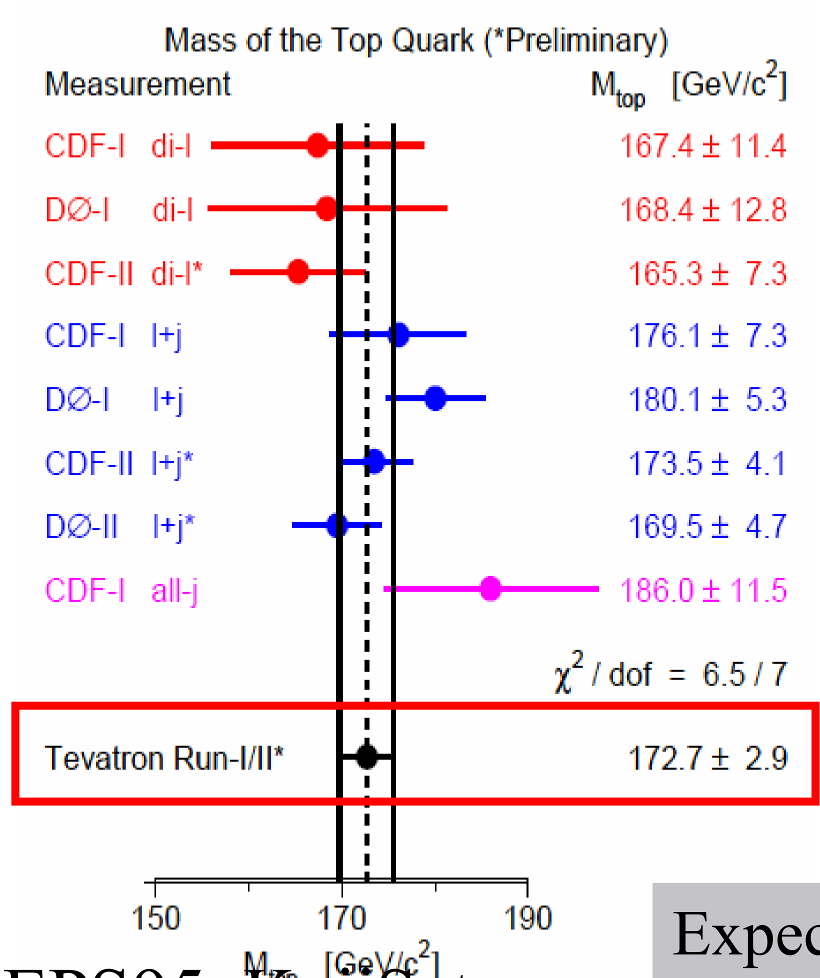
LP2005

With new m_t Tevatron

$M_H = 98^{+52}_{-36}$ GeV

Combination of Measurements

Only best analysis from each decay mode, each experiment.



EPS95 KojiSato

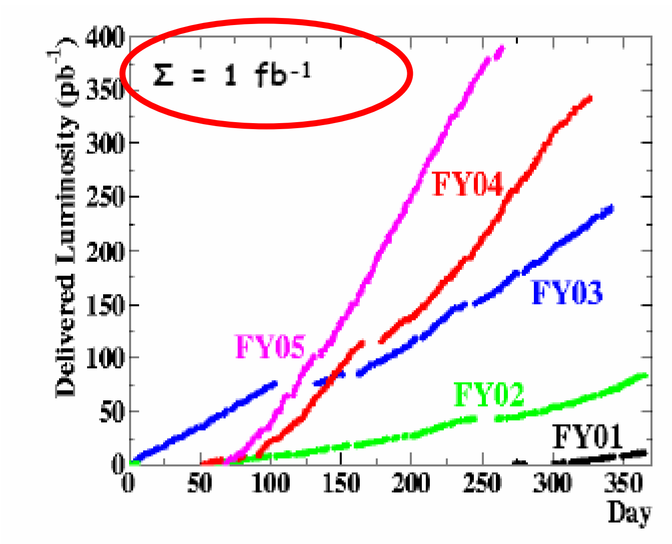
Year	M_{top} [GEV]	M_{Higgs} [GEV]
2003	174.3±5.1	< 219
2004	178.0±4.3	< 251
2005 (june)	174.3±3.4	< 208
2005 (july)	172.7±2.9	?

Expected precision in 2007 at Tevatron: ± ~1GeV

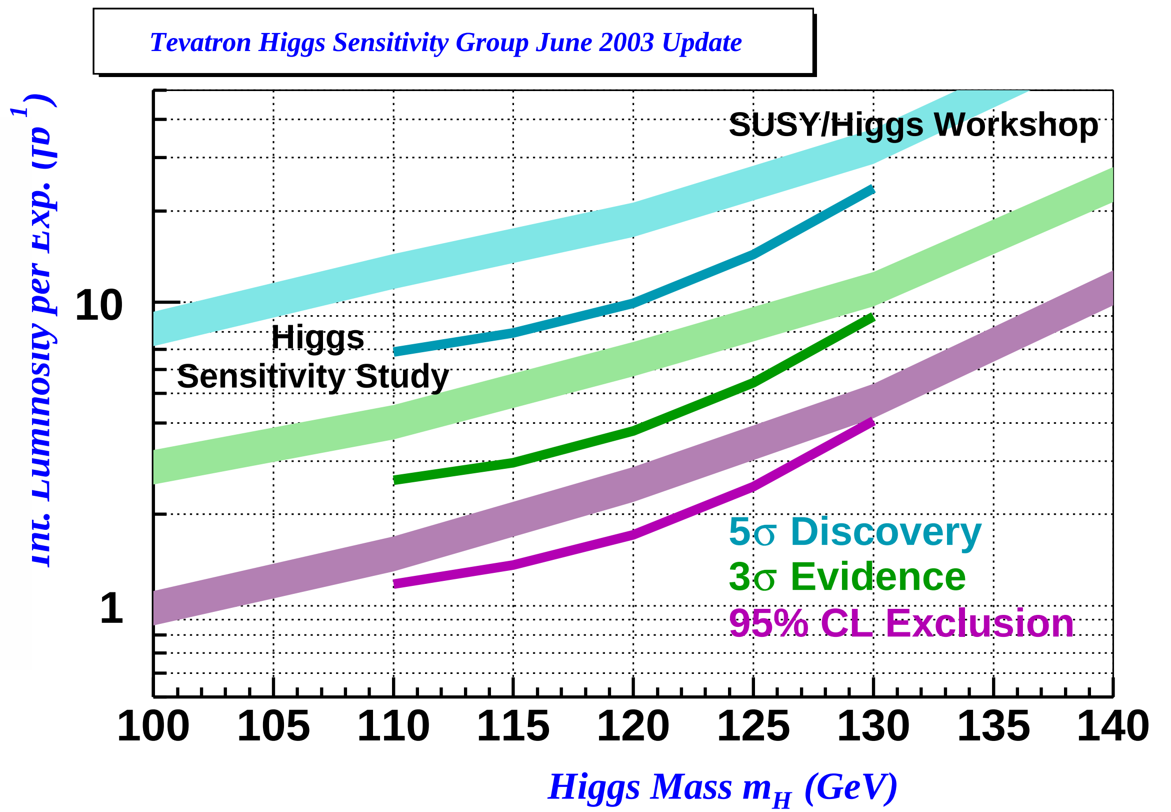
SM Higgs search at Tevatron

Tevatron expected to cover up to 130 GeV/c^2

S.Lammel, Fermilab,LP05



LP05



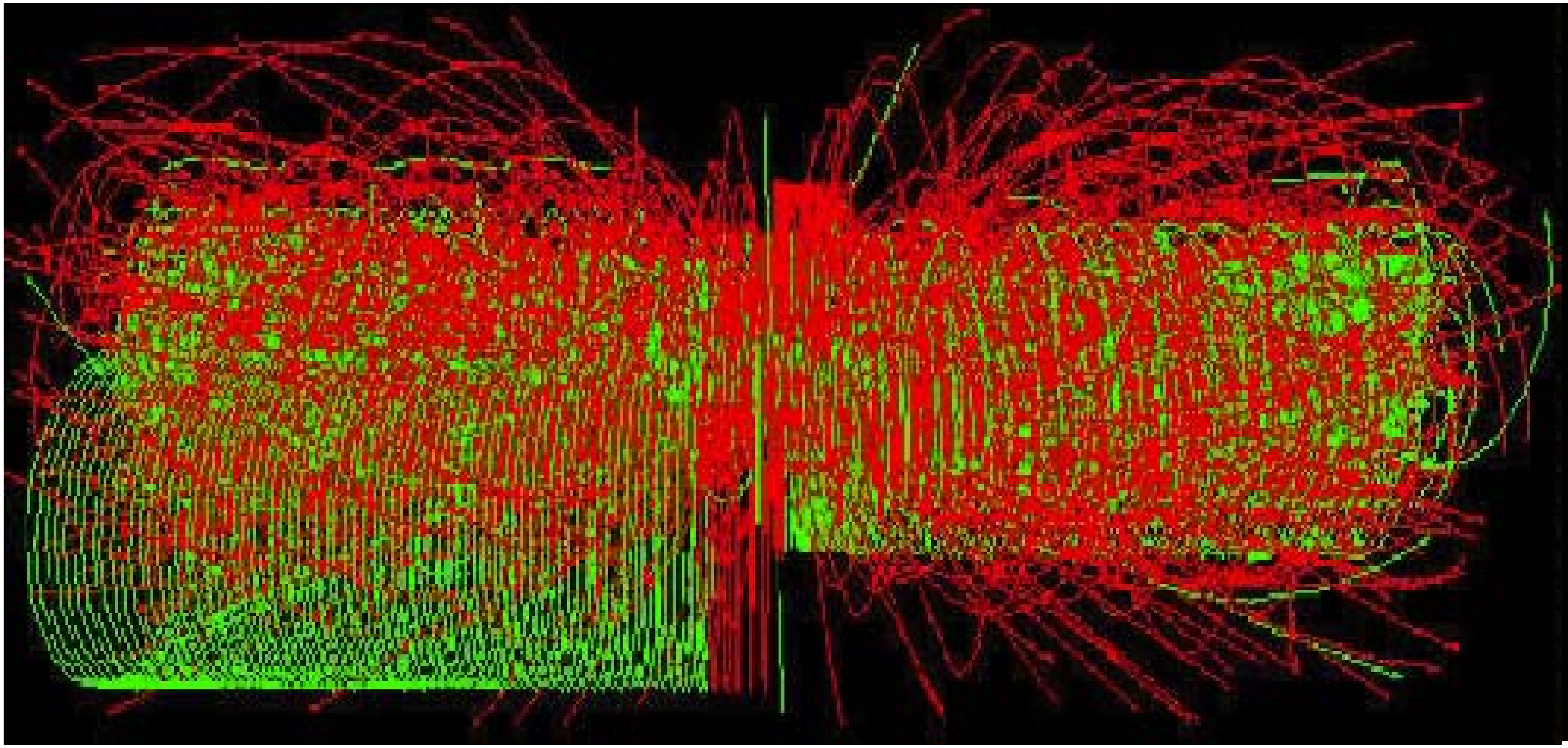
Events Statistics at low luminosity ($L=10^{33}\ cm^{-2}\ s^{-1}$)

Process	Events/s	Events/year	Other machines
$W \to e\nu$	15	10^8	10^4 LEP / 10^7 Tev.
$Z \to ee$	1.5	10^7	10^7 LEP
$t\bar{t}$	0.8	10^7	10^4 Tevatron
$b\bar{b}$	10^5	10^{12}	10^8 Belle/BaBar
$\tilde{g}\tilde{g}$ (m=1 TeV)	0.001	10^4	—
H (m=0.8 TeV)	0.001	10^4	—
QCD jets $p_T > 200$ GeV	10^2	10^9	10^7

→ LHC is a B-factory, top factory, W/Z factory, Higgs factory, SUSY factory

The Challenge

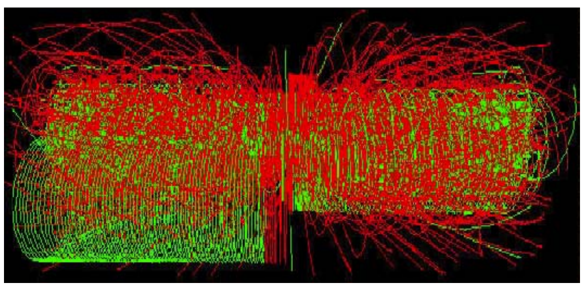
How to extract this... ... from this …



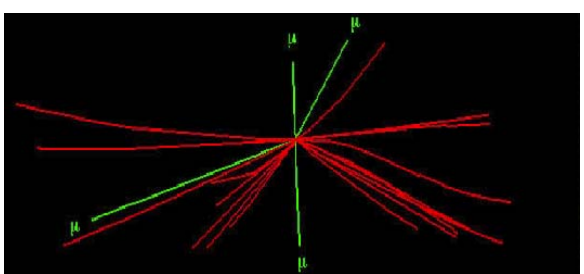
Higgs -> 4μ +30 MinBias

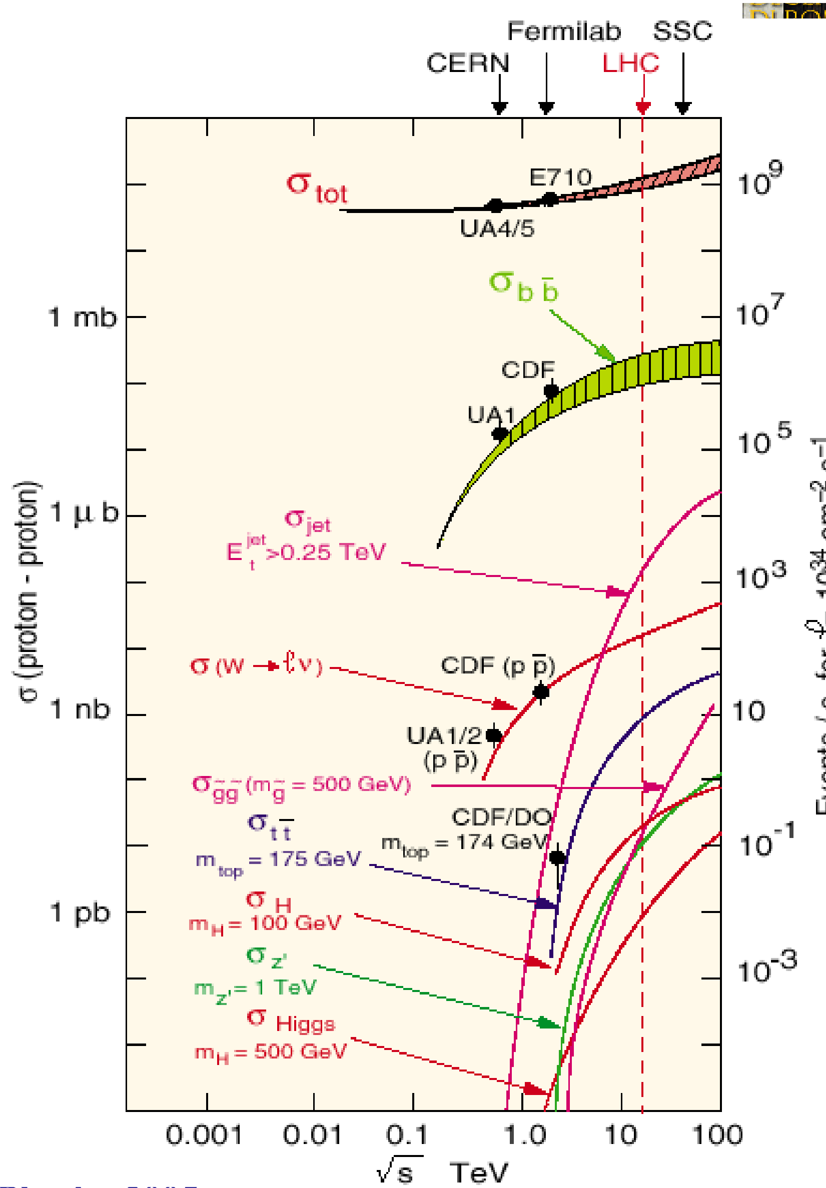
The Challenge

Knowing that there are 10 thousands billions of:

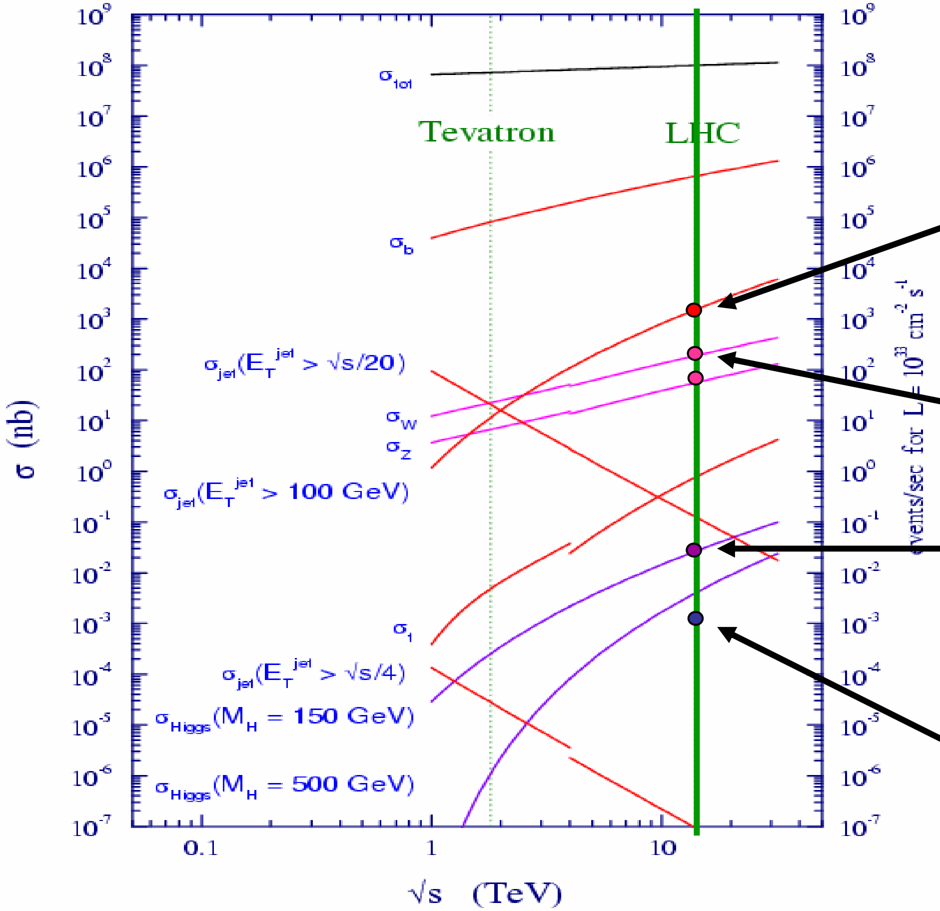


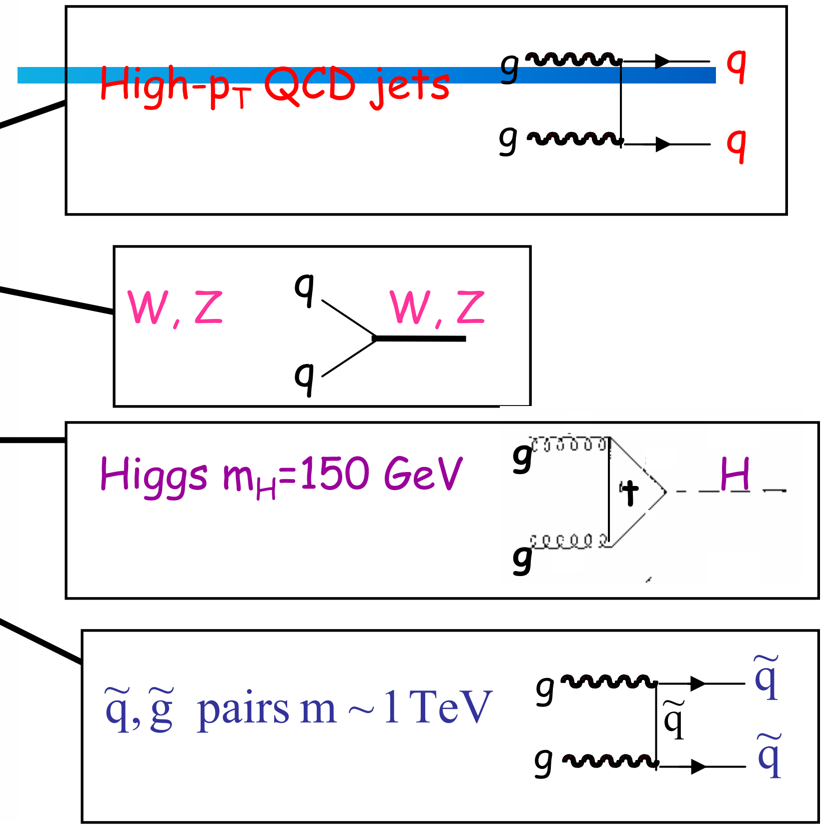
for ONE of:





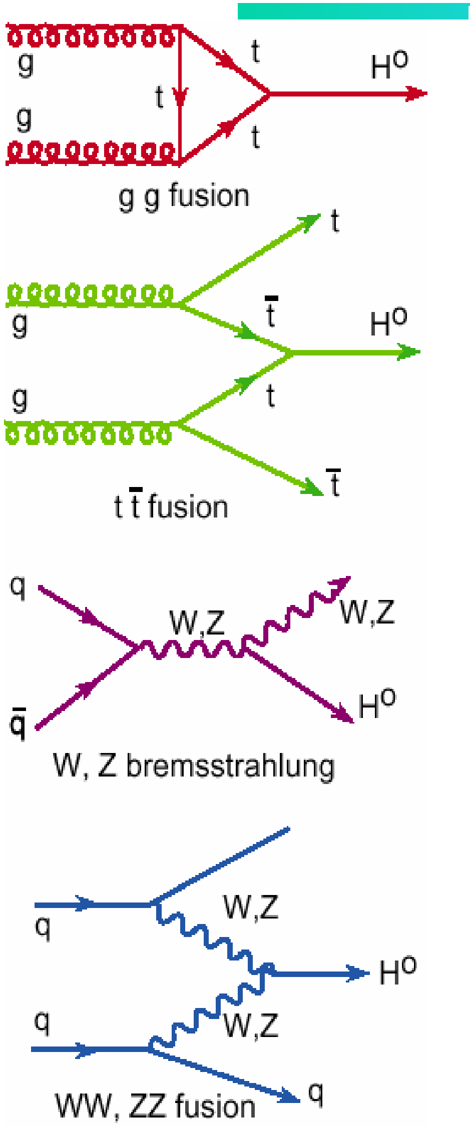
Huge (QCD) backgrounds

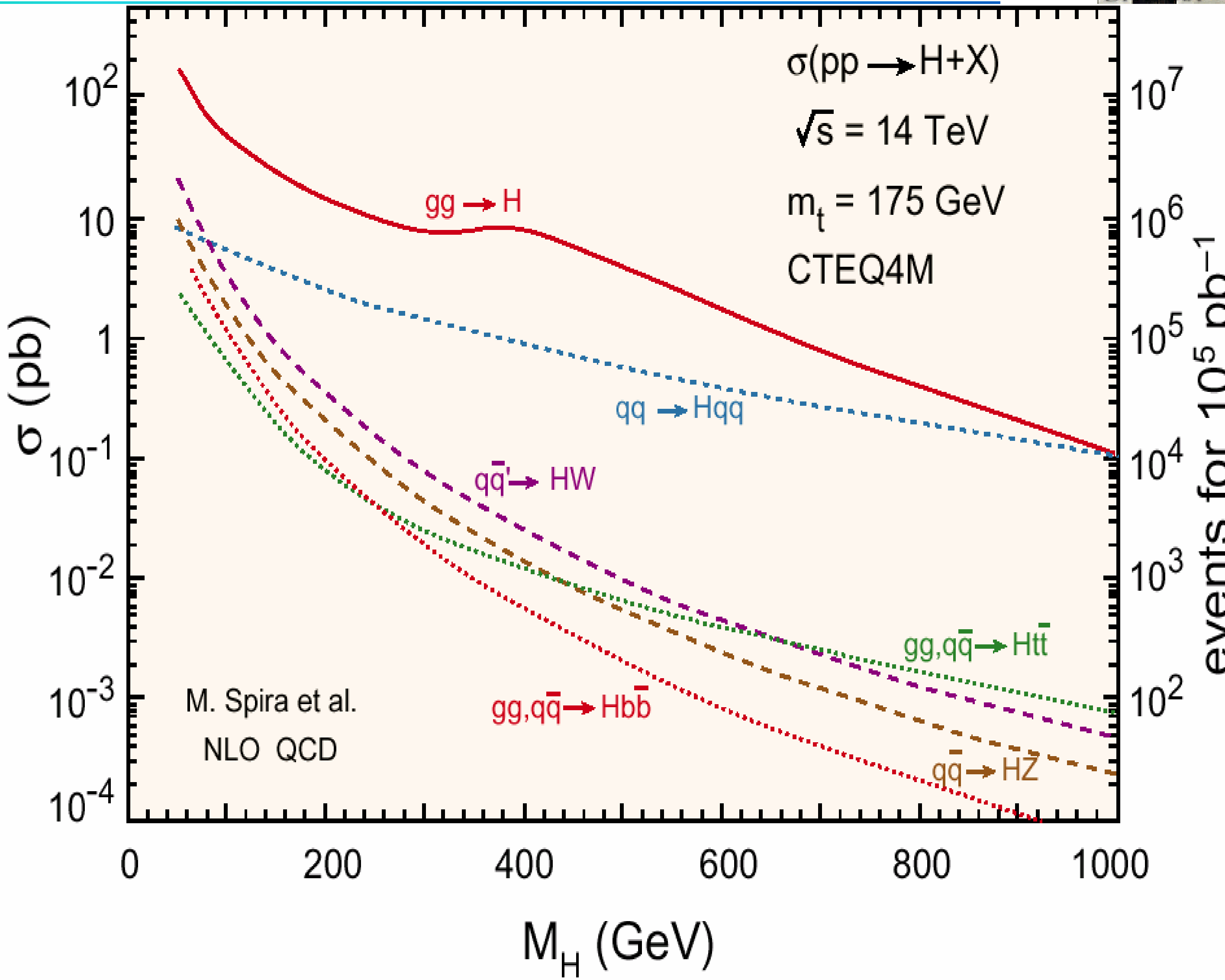




- No hope to observe the fully-hadronic final states → **rely on ℓ, γ**
- **Fully-hadronic** final states only with **hard O(100 GeV) p_T cuts**
- **Mass resolutions of ~1% (10%) needed for ℓ, γ (jets)**
- Excellent particle identification: e.g. **e/jet ratio p_T > 20 GeV is 10^{-5}**

Higgs Production Mechanism@ LHC





4 production mechanisms ➡ key to measure H-boson parameters

Standard Model Higgs production

- **Direct production**

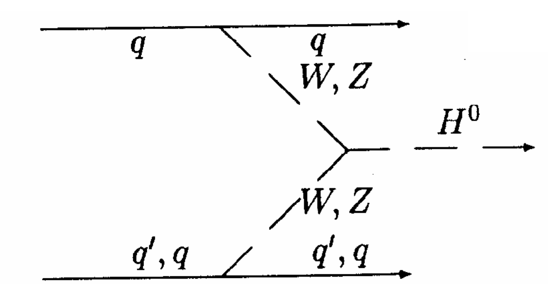
  gg fusion

gg fusion dominant

- **WW/ZZ fusion**

VectorBosonFusion 20% of gg at 120 GeV

•2 jets @ large η



- **Associated production**

  tt H, WH, ZH :

1-10% of gg fusion

•isolated lepton from W decay

• reconstruct top-quarks

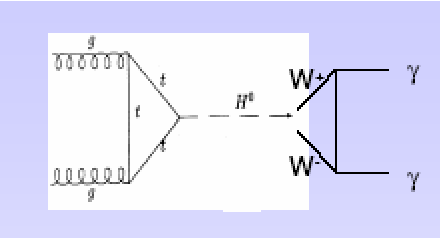
Simonetta Gentile
Gomel School of Physics 2005

Properties of Higgs boson

➢The Higgs boson couples to particles proportionally their mass
→ preferred decays in heaviest particle allowed.

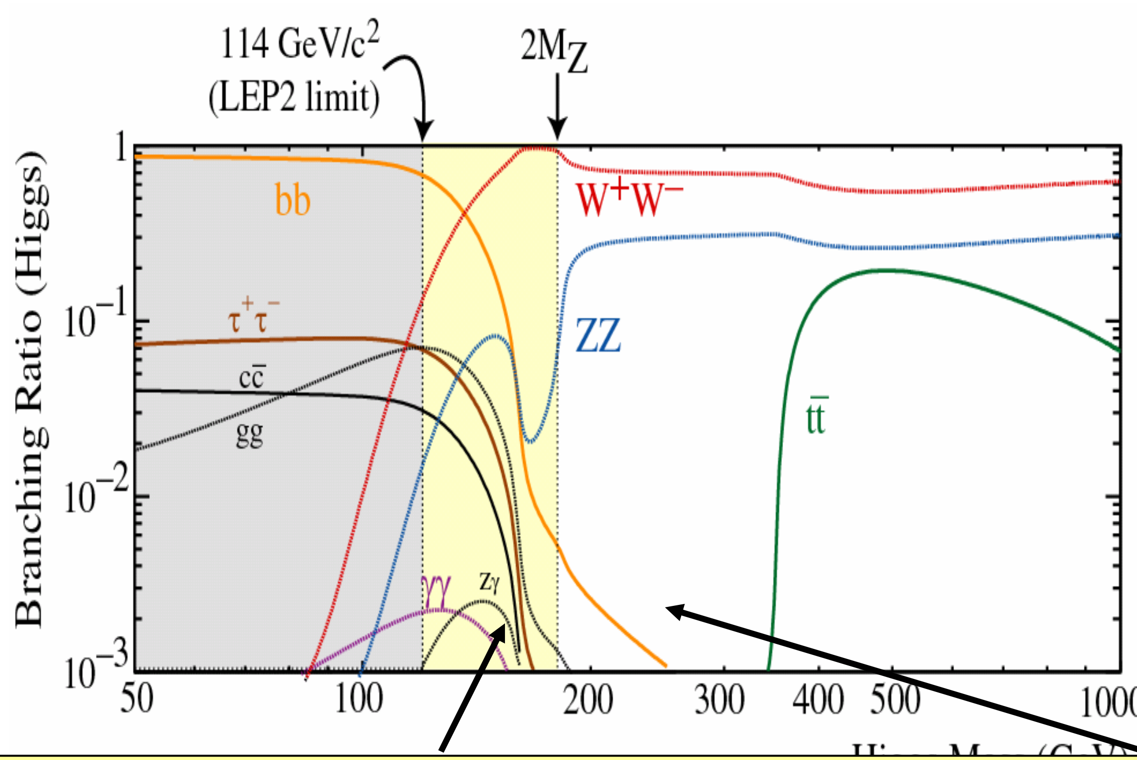
H → W^+, Z, t,b,c, τ^+ …. γ

H → W^-, Z, t,b,c, τ- …. γ



•Lepton & photons are essential final state against QCD background
bb decay mode only possible in associated production tt…

Higgs Discovery Channels at LHC



Dominant BR for $m_H < 2m_Z$:
σ (H → bb) ≈ 20 pb;
σ (bb) ≈ 500 μb
for m(H) = 120 GeV
→ no hope to trigger or extract fully hadronic final states
→ **look for final states with ℓ, γ (ℓ = e,μ)**

Low mass region: m(H) < 2 m_Z :

H → γγ : small BR, but best resolution

H → bb : good BR, extract backg➔ ttH, WH

H → ZZ* → 4ℓ

H → WW* → ℓνℓν or ℓνjj : via VBFand direct production

H → ττ : via VBF

m(H) > 2 m_Z :

H → ZZ → 4ℓ

qqH → ZZ → ℓℓ νν *

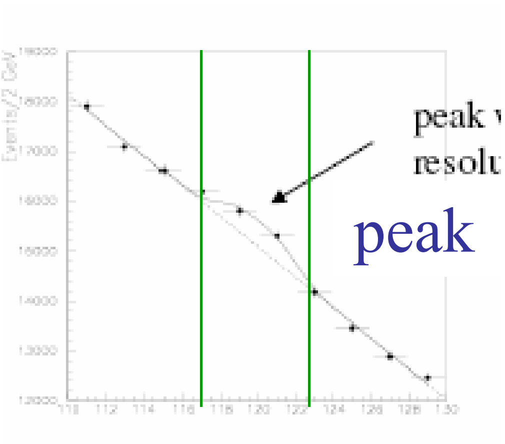
qqH → ZZ → ℓℓ jj *

qqH → WW→ ℓνjj *

* for m_H > 300 GeV forward jet tag

Discovery in a channel

➢ **Particle decaying in X → μμ**



$m_{\mu\mu}$

Signal significance

$$S = \frac{N_s}{\sqrt{N_b}}$$

N_s= number of signal events
N_b= number of background events

} In the signal region

$\sqrt{N_b}$ Error on number of background events (for large statistics, for low Poisson statistics)

➢ **S > 5 : signal larger 5 times error on background. Gaussian probability that background fluctuates up more than 5 σ is 10^{-7} → DISCOVERY**

Considerations

➢Detector resolution

If the detector resolution became worst σ_μ . To keep the same number of signal events, N_s , the region has to be 2 times larger to keep the same number of events.

If background flat →→ N_b ,increases ~ 2

$$S = \frac{N_s}{\sqrt{N_b}} \longrightarrow \text{decrease} \longrightarrow \sqrt{N_b} \approx \sqrt{2} \approx \sqrt{\sigma_\mu}$$

An high resolution detector has better chance for a discovery

- If $\Gamma_H << \sigma_m$ (if the width particle X is broad of detector resolution this comment is not important)

Remind : $m_H = 100$ GeV → $\Gamma_H \sim 0.001$ GeV
$m_H = 200$ GeV → $\Gamma_H \sim 1$ GeV
$m_H = 600$ GeV → $\Gamma_H \sim 100$ GeV $\Gamma_H \sim m^3$

Considerations

- **Luminosity**

$N_s \sim L$
$N_b \sim L$ } → $S \sim \sqrt{L}$

The Challenge

Theoretical limits:

M(Higgs) < 1 TeV

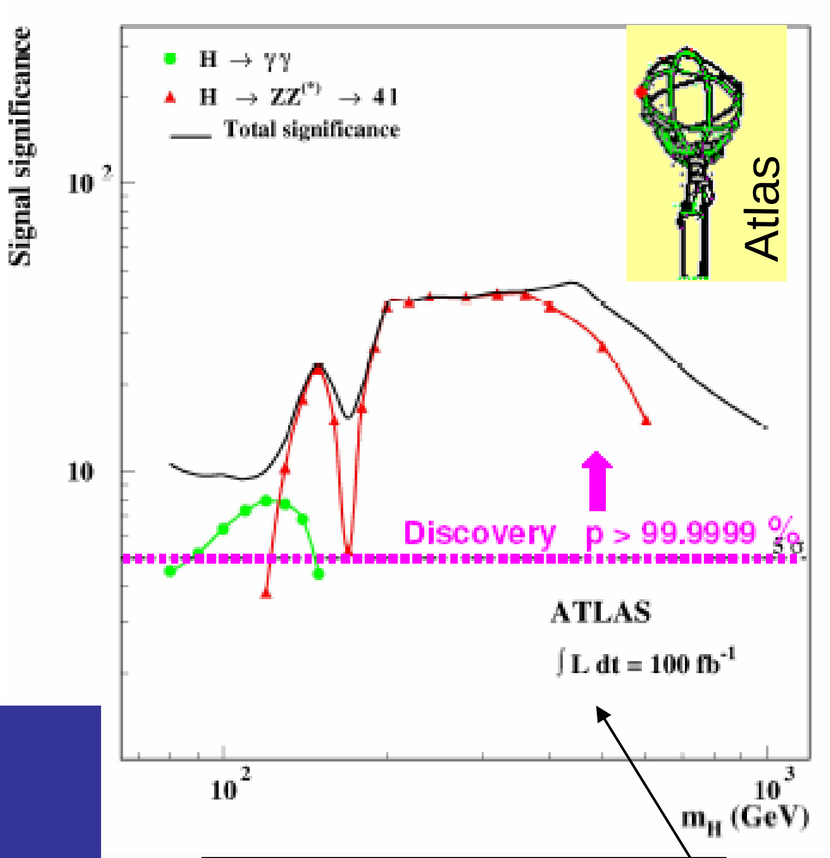
LEP

Experimental limits:

M(Higgs) > 114.4 GeV

Indirect constraints:

M(Higgs) < 208 GeV



Safe channels:

$H \rightarrow \gamma\gamma$

$H \rightarrow ZZ \rightarrow \ell\ell\ell\ell$

here discovery "easy" with $H \rightarrow 4\ell$

Prospects for Standard Model Higgs searches

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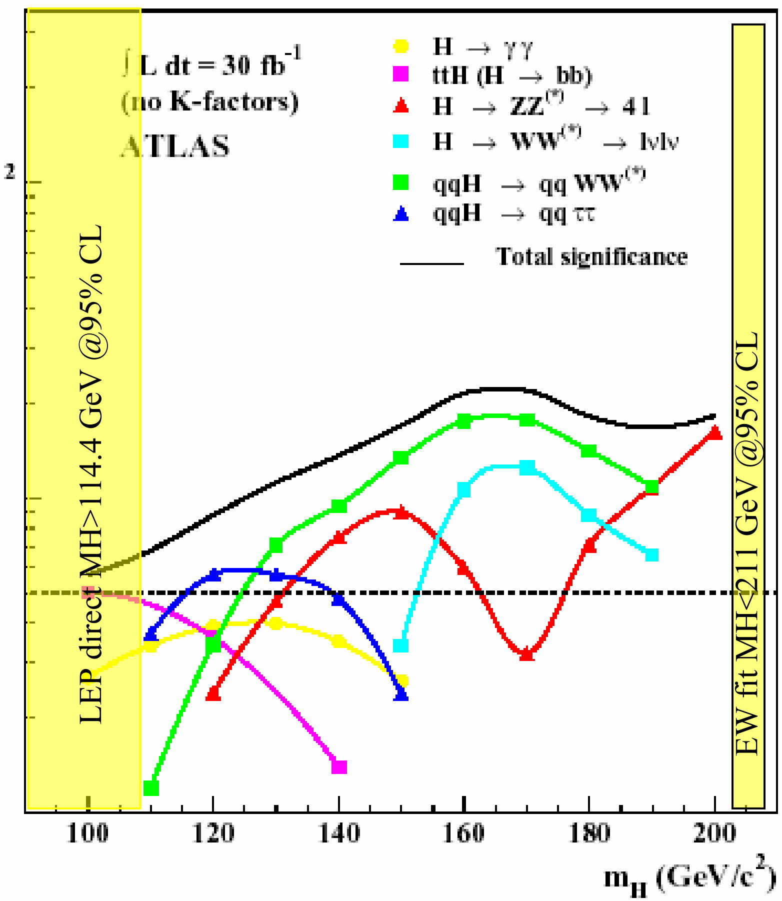
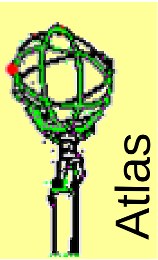




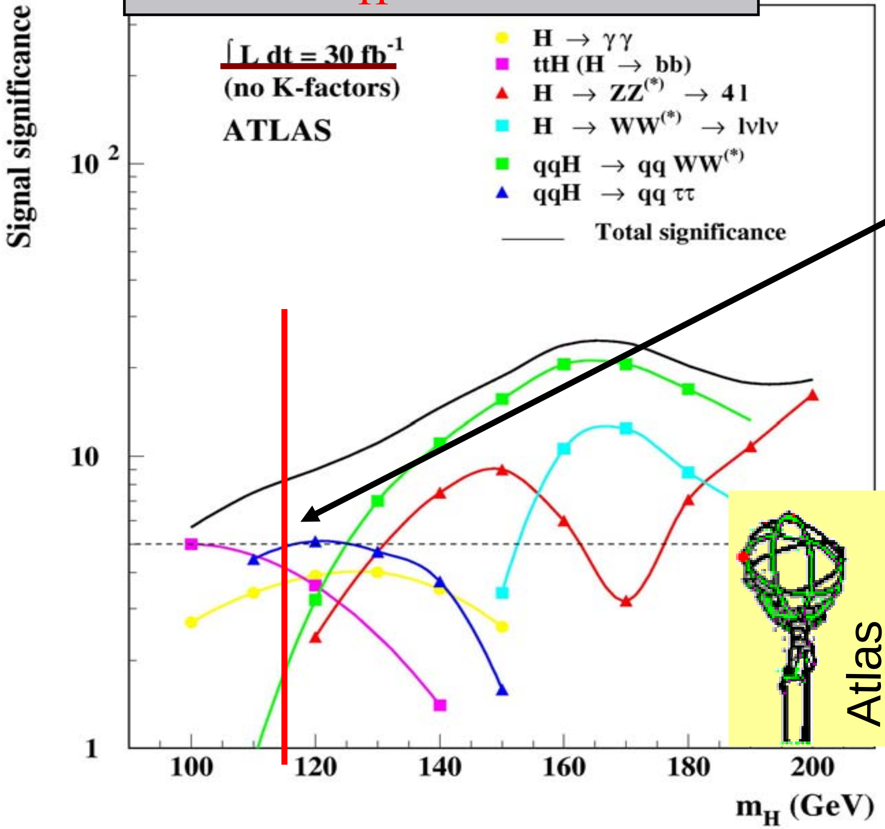
- **Discovery: several complementary channels.**
  - some channels with very **exclusive topologies** (large bgd. suppression).
  - **Coupling** measurements @ $30 fb^{-1}$.
  - Mass, width (direct and indirect).
- **Detector performance is crucial:** **b-tag, ℓ/γ, E-resolution, γ/j separation, E_T^{miss} resolution, forward jet tags, central jet-veto, τ–reconstruction.**

Expected results discussed at Integrated Luminosity of $10 fb^{-1}$ $30 fb^{-1}$ $100 fb^{-1}$.

SM-like Higgs searches early reach

Low mass

LEP : $m_H > 114.1$ GeV



$m_H \sim 115$ GeV

•**observation of all channels important to extract convincing signal 4-5 σ significance in first year**

(Several channels give ~ 2 σ significance 10 fb^{-1})

→H → γγ relies only on electromagnetic calorimeter, (constant term < 0.7 %)

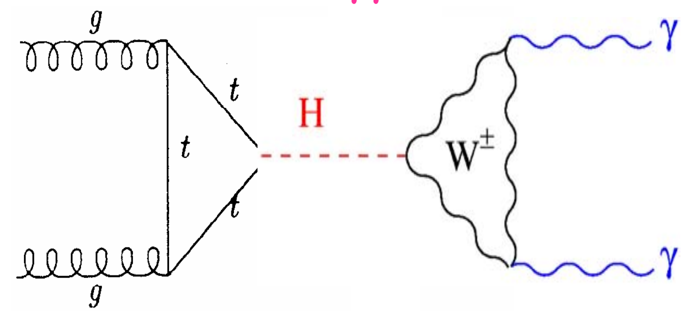
$M_H = 115$ GeV

	$H \rightarrow \gamma\gamma$	$ttH \rightarrow ttbb$	$qqH \rightarrow qq\tau\tau$ ($\ell\ell$ + ℓ-had)
S	150	15	~ 10
B	3900	45	~ 10
S/B	0.04	0.33	
Signif.	2.4	2.1	3.5
CLb	$9\ 10^{-3}$	$2\ 10^{-2}$	$4\ 10^{-3}$

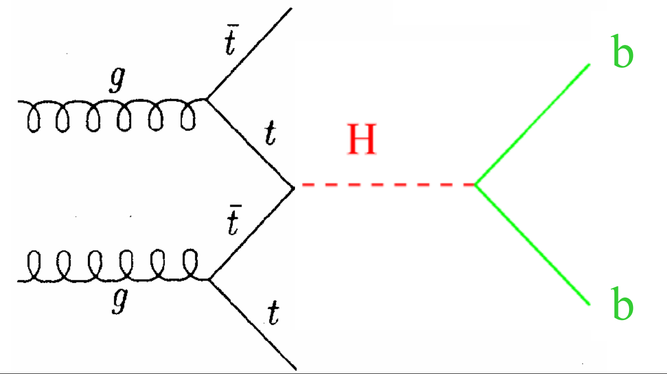
$$K-\text{factor} \equiv \frac{\sigma_{NLO}}{\sigma_{LO}} \approx 2 \quad \text{not included}$$

Total $S/\sqrt{B}$ for 10 fb^{-1} and complete detector: ~ 4.2 σ

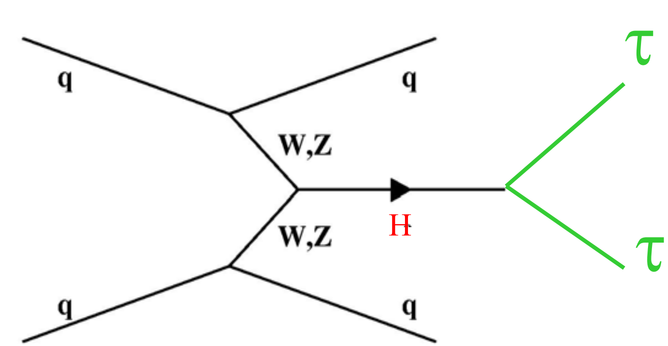
$H \rightarrow \gamma\gamma$



$ttH \rightarrow tt\ bb \rightarrow b\ell\nu\ bjj\ bb$



$qqH \rightarrow qq\tau\tau$



SM-like Higgs searches early reach

Inter mass

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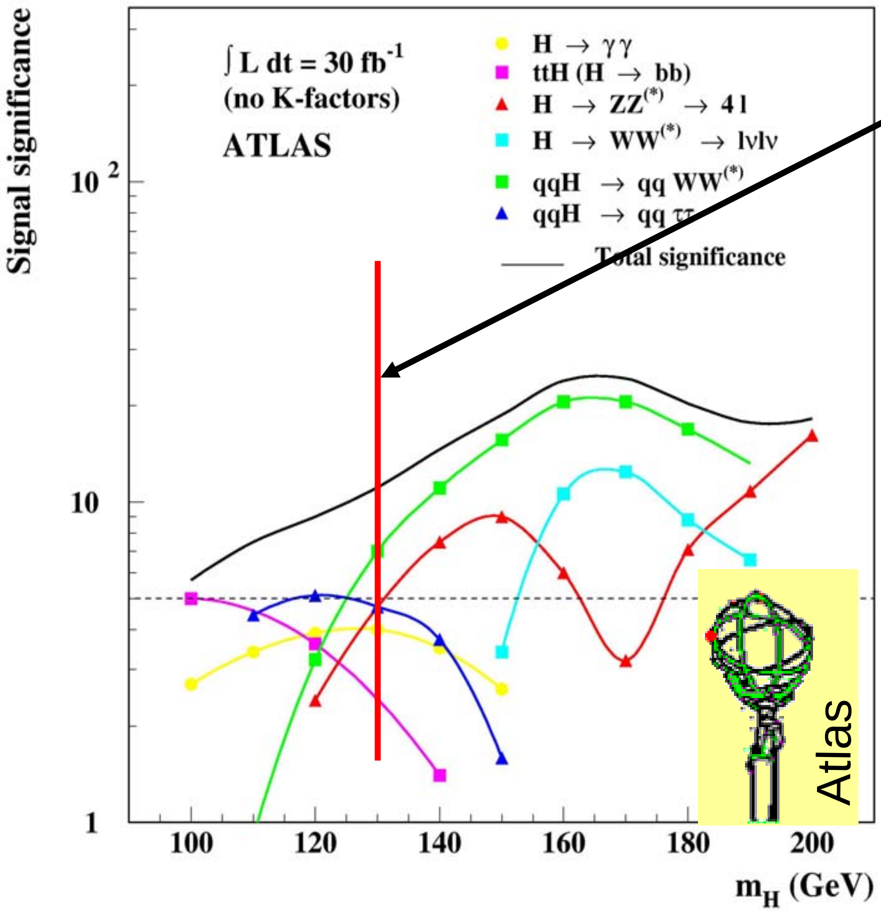
$m_H \sim 130$ GeV



•observation of all channels important to extract convincing signal 6 σ significance in first year (Several channels give

<3 σ significance 10 fb^{-1})

•4 complementary channels → robustness

→ $H \to 4\ell$: low rate but very clean (large S/B, narrow mass peak)
< 3σ significance per channel
(except qqWW counting channel)

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M_H= 130 GeV

Intemediate mass

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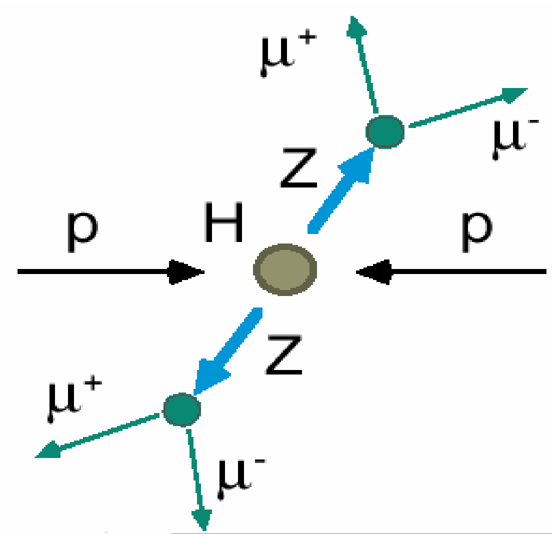
10 fb^{-1} complete detector

	$H \to \gamma\gamma$	$qqH \to qq\tau\tau$ ($\ell\ell + \ell$-had)	$H \to 4\ell$	$qqH \to qqWW$
S	120	~ 8	~ 5	18
B	2500	~ 6	< 1	15
S/B	0.05		~ 5	~ 1
Signif.	2.4	~ 2.7	3.2	3.9
CLb	$9\ 10^{-3}$	$4\ 10^{-3}$	$6\ 10^{-4}$	$4\ 10^{-5}$

Total $S/\sqrt{B}$ for 10 fb^{-1} and complete detector: ~ 6.5 σ

Light Higgs Search: H -> ZZ* ->4 leptons



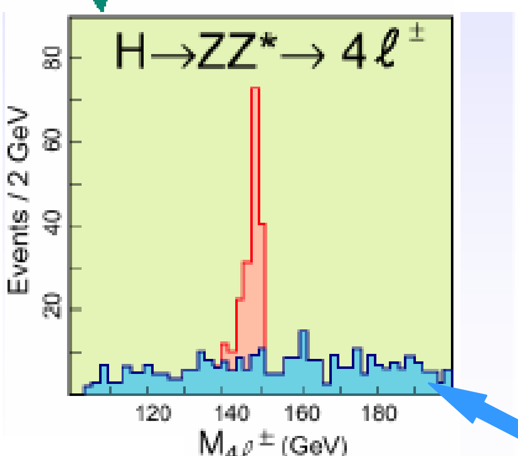
σ Br = 5.7 fb (m_H =100 GeV)

Example of

- P_T of 2 most energetic μ > 20 GeV
- P_T of 2 less energetic μ > 7 GeV
- |η|<2.5 (barrel)

Invariant mass constraints

- $M(\ell\ \ell) \sim M_Z$
- $M(\ell\ \ell) < M_Z$



background

L =100 fb^{-1}

Light Higgs Search: H -> ZZ* ->4 leptons

background

•Top production

$t\bar{t} \rightarrow W\,b\;\;W\,b \rightarrow \ell\nu\;c\ell\nu\;\;\ell\nu\;c\ell\nu$

W b W b

$\sigma\,Br \approx 1300$ fb

•Associated production of Zbb $\sigma\,Br(Z\rightarrow\mu\mu) \approx 22.8$pb

$Zbb \rightarrow \ell\ell c\;\ell\nu\;c\ell\nu$

To reject the background:

1. leptons from b-quarks decays are not isolated
2. don't originated from primary vertex ($\tau_b \sim 1.5$ ps)

• ZZ background $\sigma\,Br(Z\rightarrow bb)$

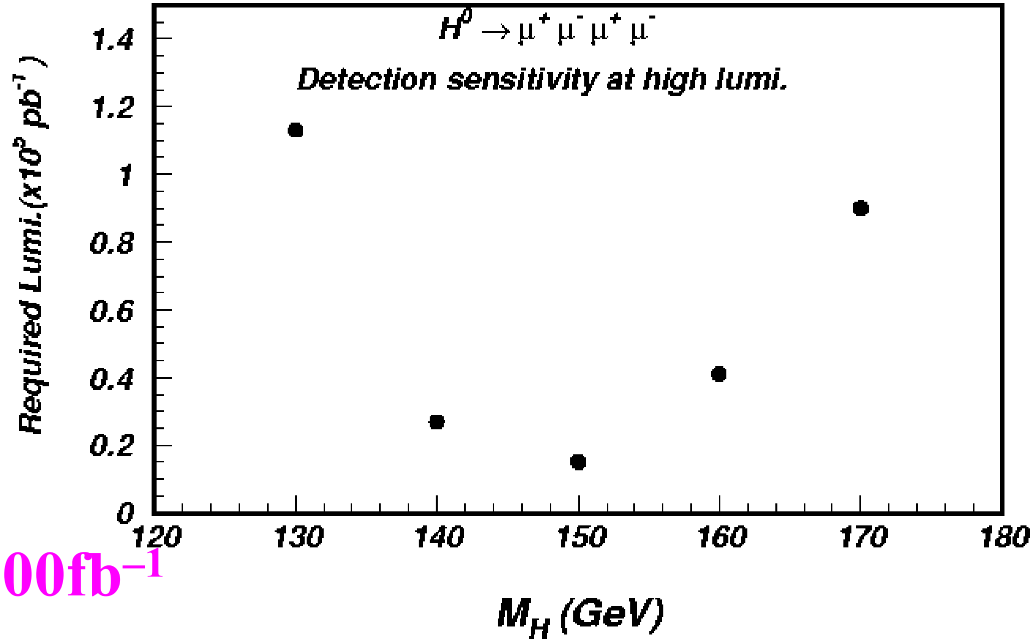
after isolation cut continuum $Br(Z\rightarrow\mu\mu) \approx 0.15$pb

Discovery potential in mass range from ~ 130 GeV to 600 GeV

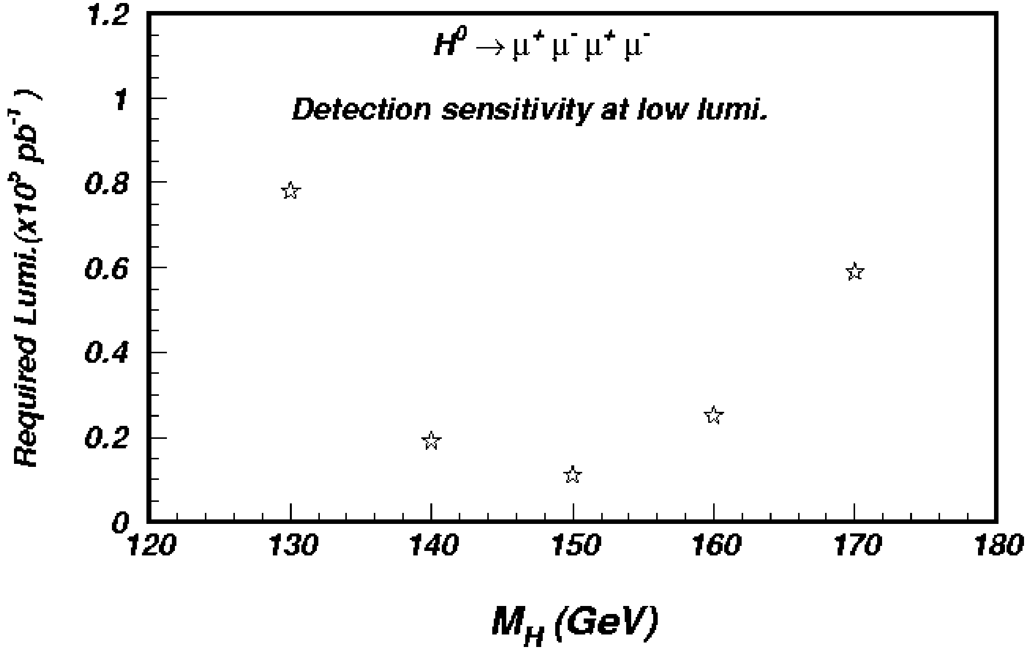
Light Higgs Search: H -> ZZ* -> 4μ

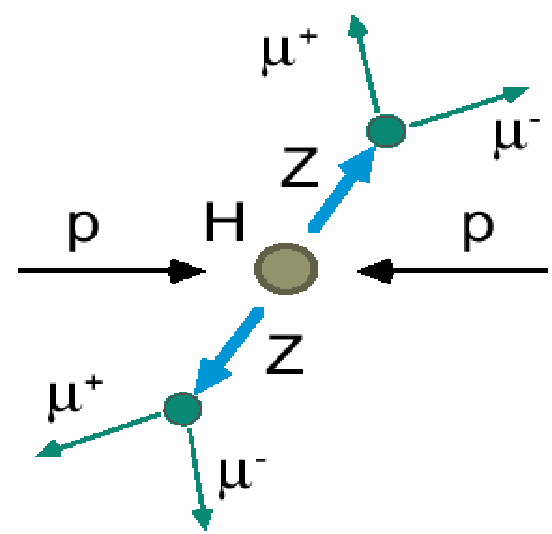
100fb^{-1}

required lumi for discovery



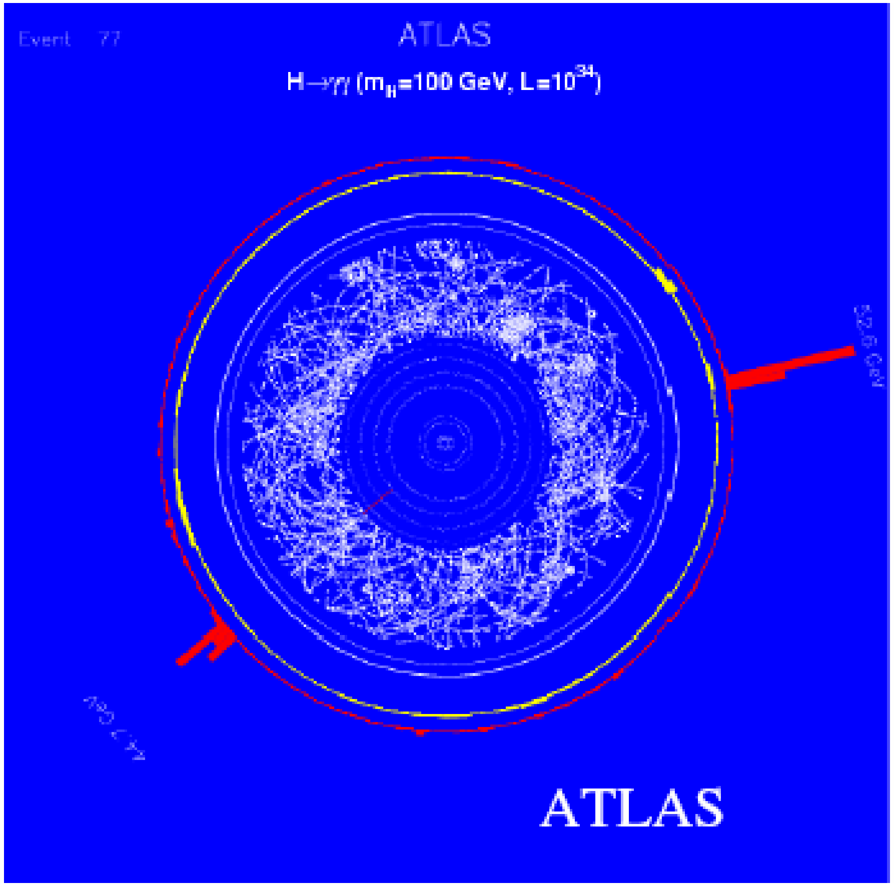
100fb^{-1}



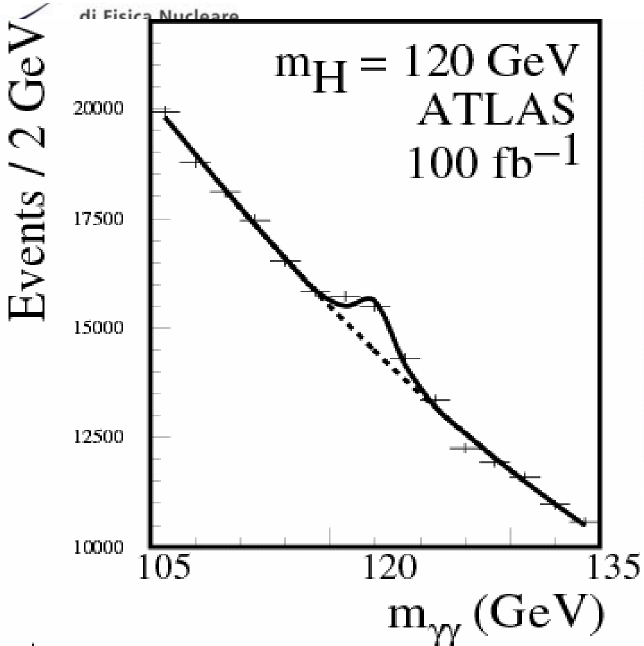


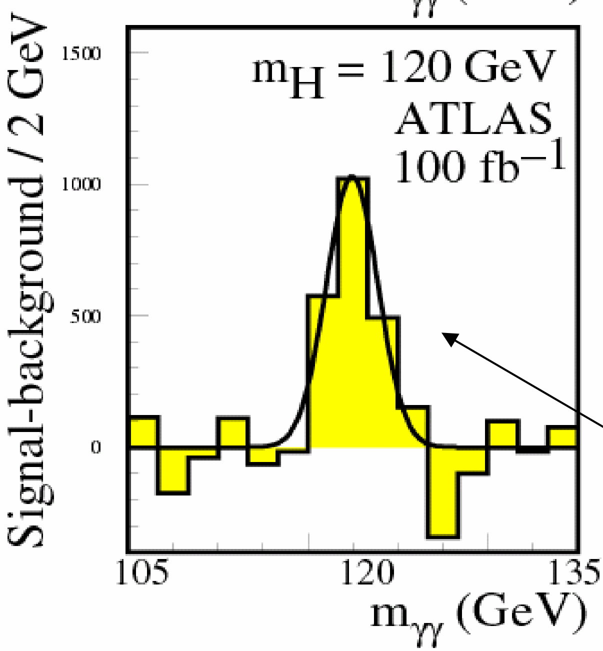
S Gomel

H→γγ



Light Higgs Search: γγ, ttH channels





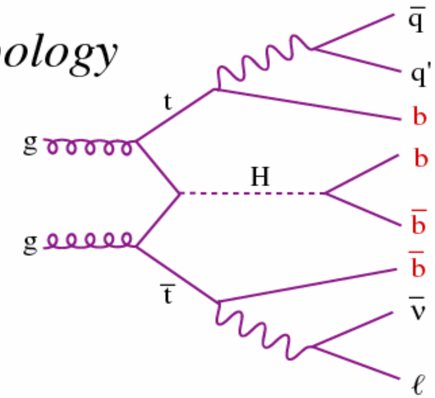
Challenging and complex topology

4 b-jets, 2 jets, 1 lepton

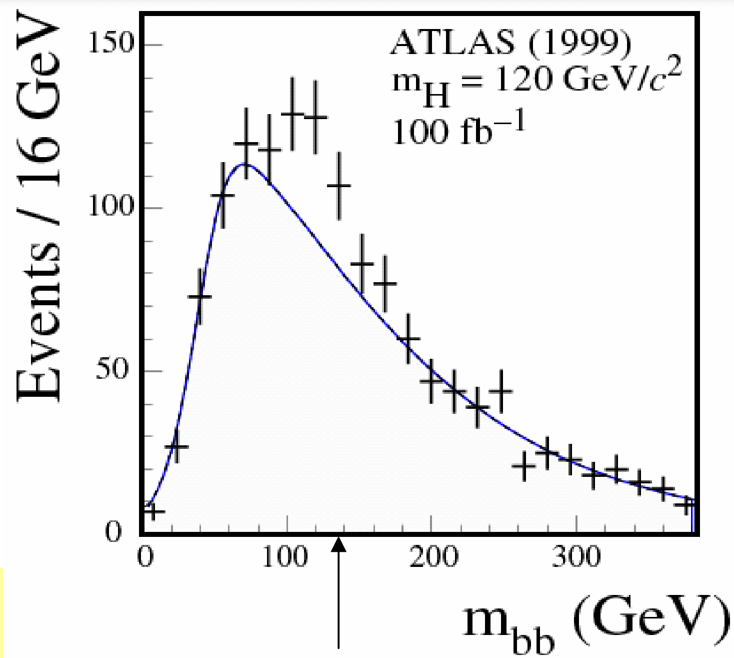
$H \rightarrow bb$

$t \rightarrow bqq'$

$t \rightarrow b\ell\nu$



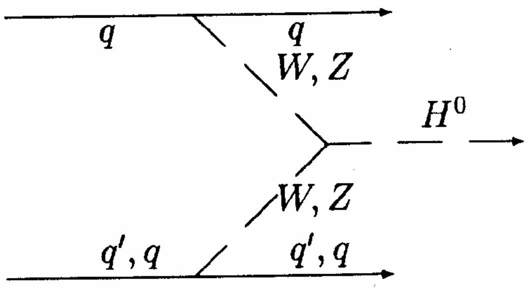
$100fb^{-1}$



Significance:
2.8 to 4.3σ for
$100\ fb^{-1}$

Signal significance (5σ) :
m_H < 120 GeV needs $100\ fb^{-1}$

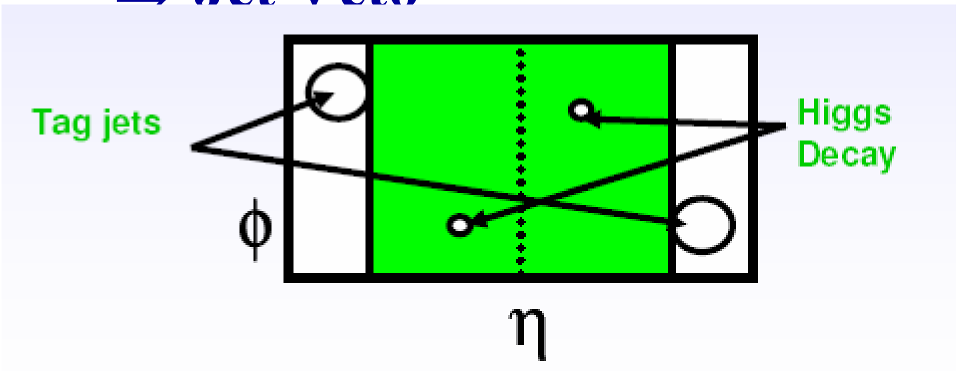
VBF Higgs boson production at low mass



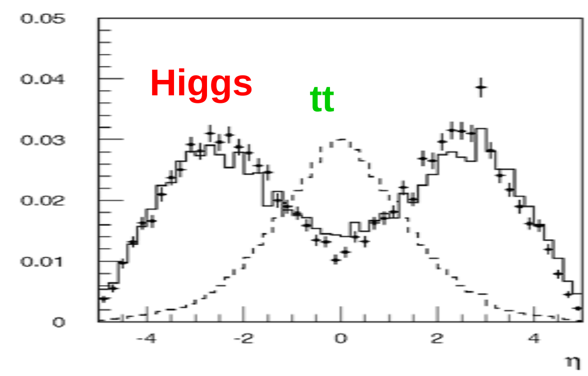
Distinctive Signature of:

- two high P_T forward jets
- little jet activity in the central region

$\Rightarrow$ Jet Veto



Rapidity distribution of tag jets
VBF Higgs events vs. tt-background



η jet

Channels studied:

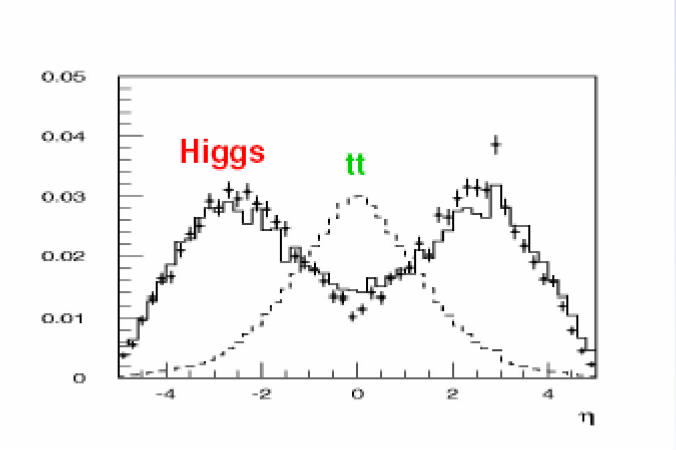
$qqH \to qqWW^* \to qq\,\ell\nu\;\ell\nu$

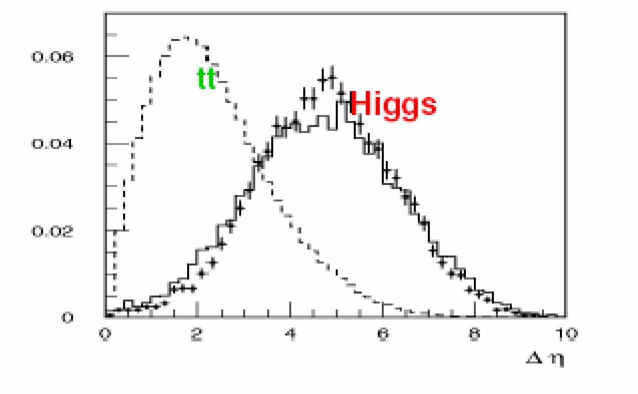
$qqH \to qq\,\tau\;\tau \to qq\,\ell\nu\nu\;\ell\nu\nu$

$\to qq\,\ell\nu\nu\;\text{had}\,\nu$

Hard leptons with distinctive kinematics;
Full H->tt reconstruction possible

Forward jet tagging





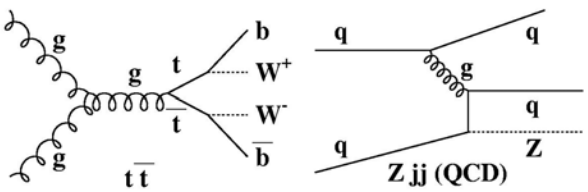
Rapidity distribution of tag jets
VBF Higgs events vs. tt-background

Rapidity

Background

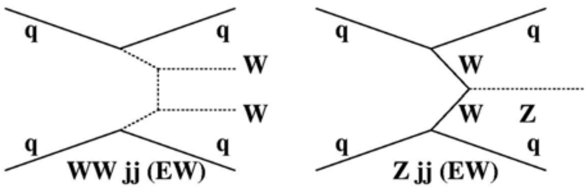
QCD backgrounds:

tt production — Z + 2 jets



el.weak background:

WW jj production — Z + 2 jets

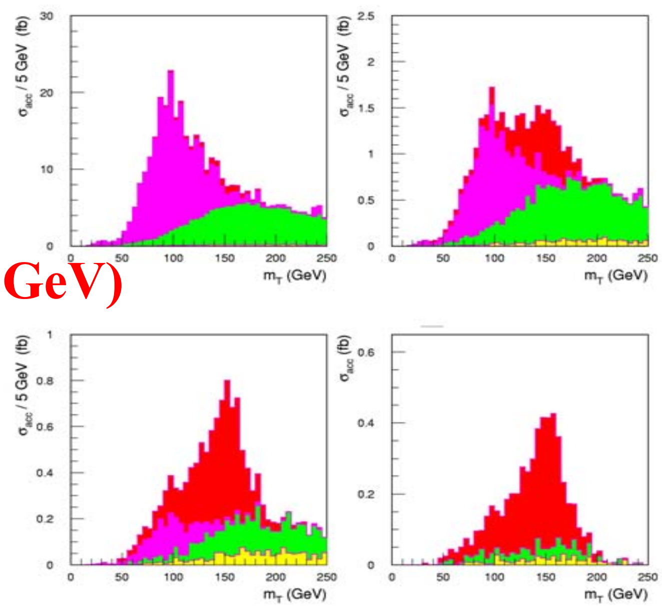


Background rejection:

qqH → qqWW* → qq l ν l ν

- Lepton P_T cuts and tag jet requirements ($\Delta\eta$, P_T)
- Require large mass of tag jet system
- Jet veto
- Lepton angular and mass cuts

$$M_T = \sqrt{(E_T^{ll} + E_T^{\nu\nu})^2 - (\vec{p}_T^{\,e\mu} + \vec{p}_T^{\,miss})^2}$$



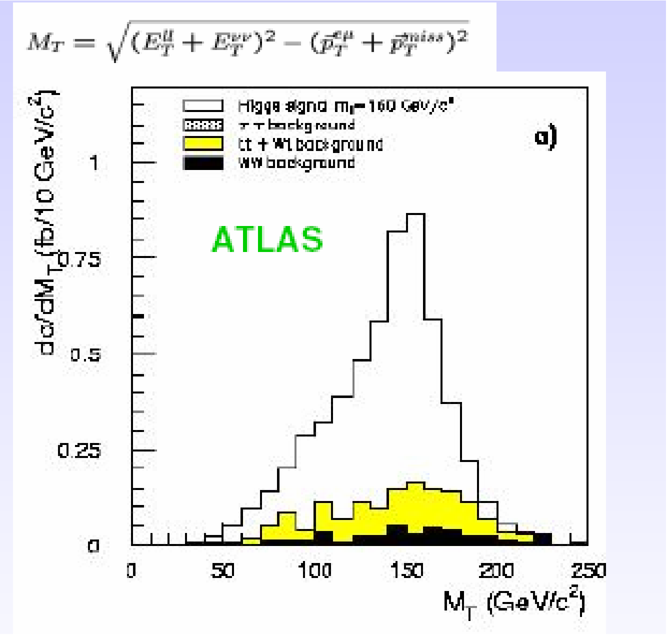
Higgs boson (m_H = 160 GeV)

tt background

γ* / Z + jets

el.weak WW jj

qq→qq W W*→qq ℓ ν ℓ ν



Transverse distribution excess
On the background tt -production

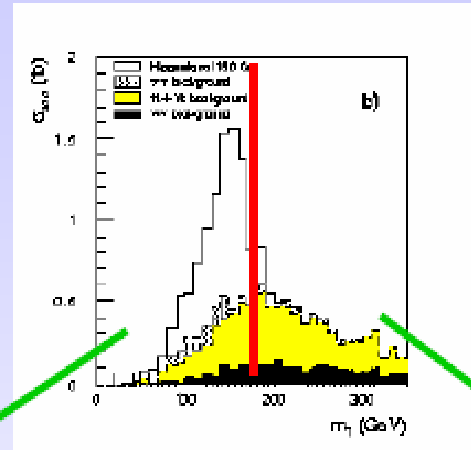
$qq \to qq\, W\, W^* \to qq\, \ell\, \nu\ \ \ell\, \nu$

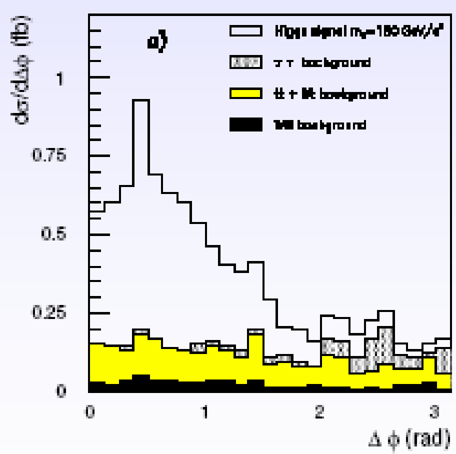
Evidence for spin-0 of the Higgs boson

Spin-0 → WW → ℓνℓν expect leptons to be close by in space

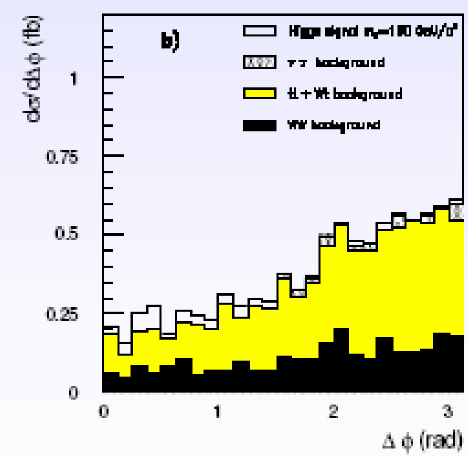
K.Jacobs

Azimuthal difference Between the two leptons





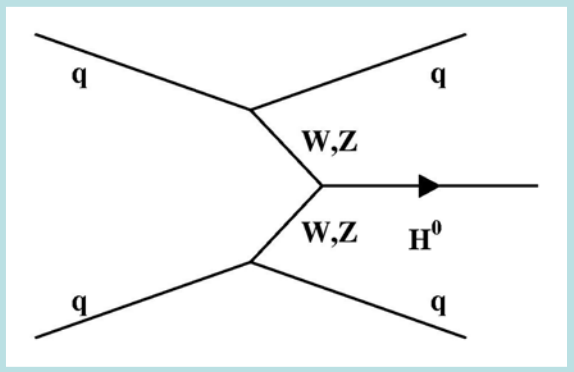
signal region



background region

qqH :Signal and background rates

SIGNAL: qq →qqH

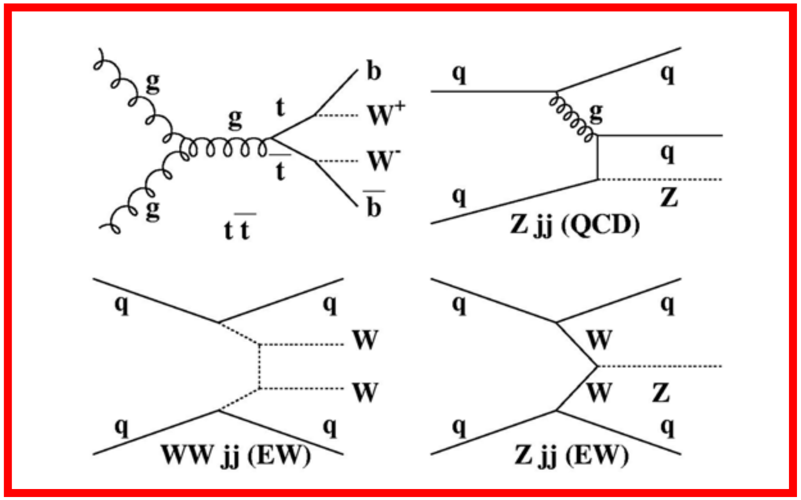


m_H = 120 – 180 GeV

σ(qqH) = 4.4 – 2.8 pb

σ x BR (qqH -> WW*) = 530 – 2600 fb
σ x BR (qqH -> ττ) = 300 – 2 fb

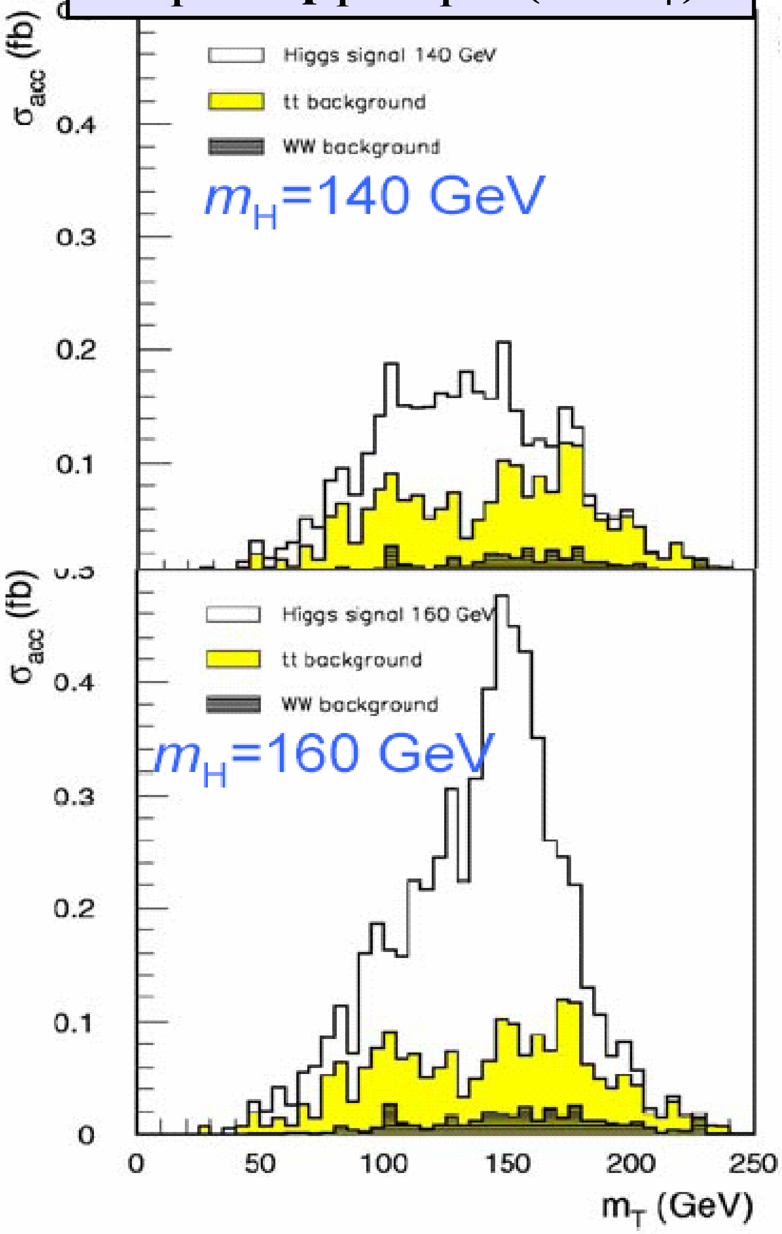
BKG



$t\bar{t}$	55 pb
QCD $WW + jets$	17 pb
$Z/\gamma^* + jets,\ Z/\gamma^* \to \tau\tau$	2600 pb
EW $WW + jets$	82 fb
EW $\tau\tau + jets$	170 fb
$Z/\gamma^* + jets,\ Z/\gamma^* \to ee/\mu\mu$	5300 pb
ZZ	38 pb

$H \to WW^* \to \ell\nu\ell\nu$

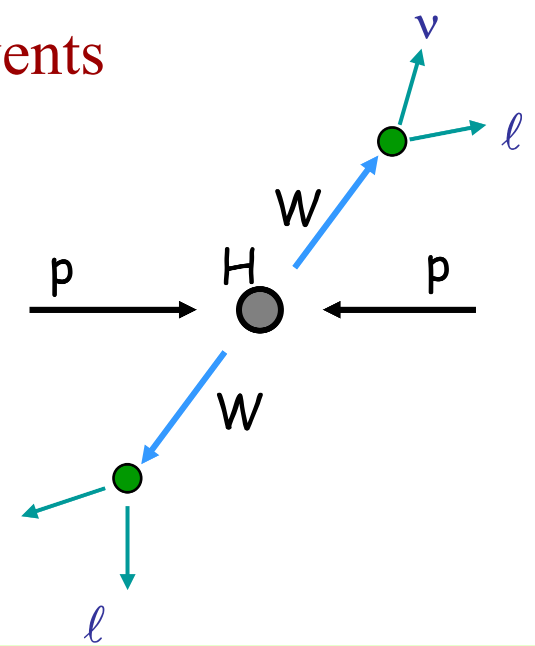
$m_T = \sqrt{2 p_T^{\ell\ell} E_T^{miss}(1-\cos\phi)}$



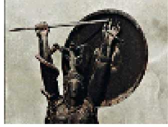
Observe excess in transverse mass distribution

S ~ 10-40 events for **$10fb^{-1}$**

B ~ 10-15 events



- **Two isolated leptons**
- **Two forward tag jets**
- **Central jet veto: p_T<20 GeV**
- **lepton angular correlation**

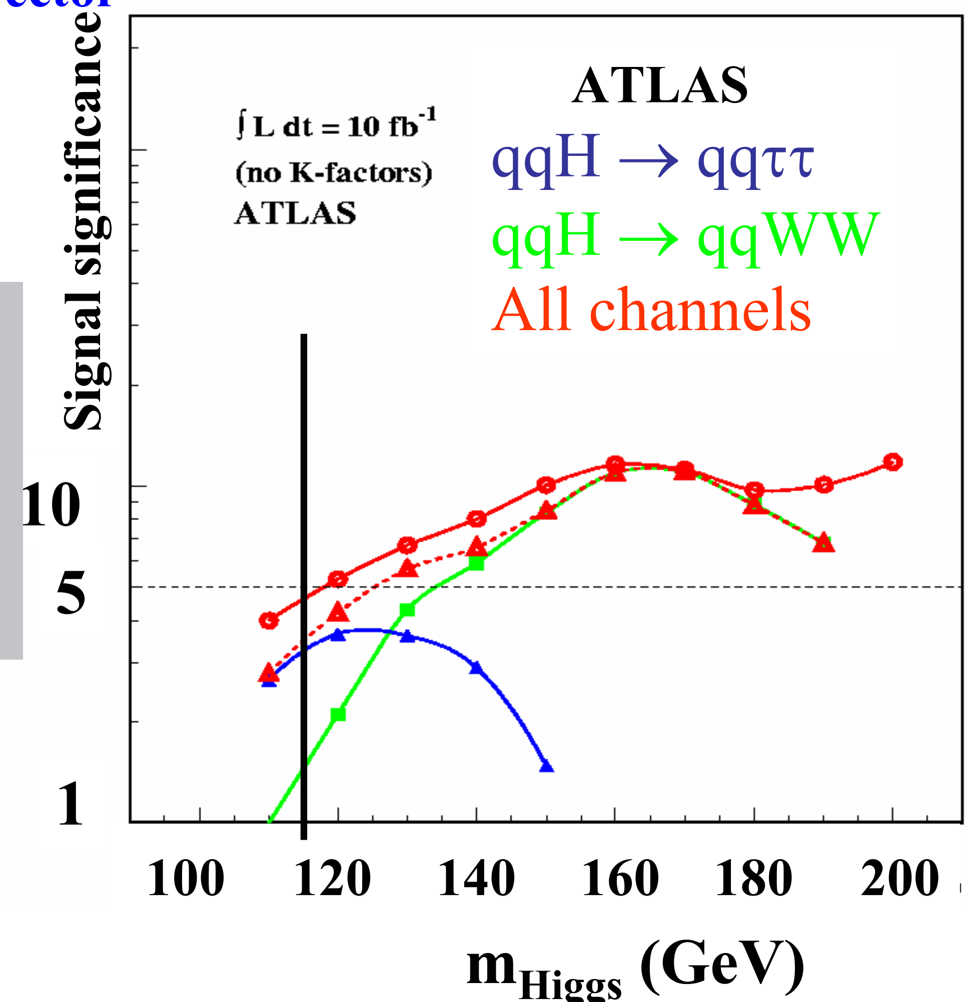


Vector Boson Fusion

These studies demonstrate that vector boson fusion channels may be accessible in the low mass region already in the first year.

For 10 fb^{-1} in ATLAS:

5 σ significance for $120 \le m_H \le 190$ GeV



Results are conservative:

- K-factor not included
- very simple analyses used

Low mass remarks

The 3 channels are complementary → robustness:

- different production and decay modes
- different backgrounds
- different detector/performance

requirements:

-- ECAL crucial for $H \to \gamma\gamma$
(in particular response uniformity) :
$\sigma/m \sim 1\%$ needed

-- b-tagging crucial for ttH :
4 b-tagged jets needed to reduce combinatorics

-- efficient jet reconstruction over $|\eta| < 5$
crucial for $qqH \to qq\tau\tau$:
forward jet tag and central jet veto needed against background

Note :
all require "low" trigger thresholds.

e.g. ttH analysis cuts :

$p_T(\ell) > 20$ GeV,
$p_T(\text{jets}) > 15\text{-}30$ GeV

200 GeV<M_H<600 GeV

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Large mass

complete detector

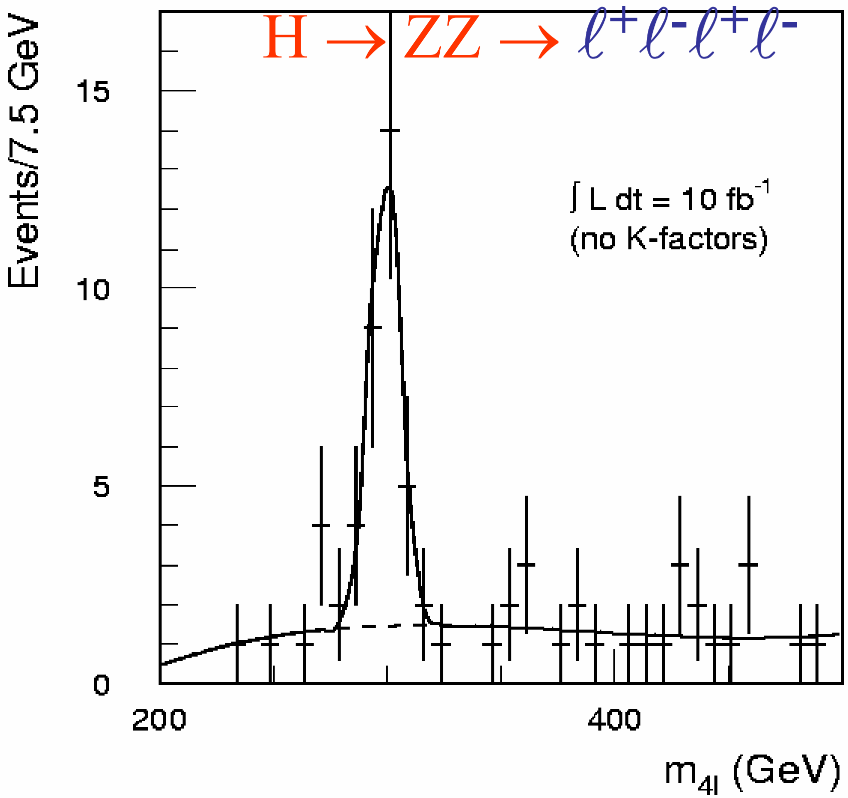
10 fb^{-1}

200 GeV < m(Higgs) < 600 GeV:

- discovery in $H \to ZZ \to \ell^+\ell^-\ell^+\ell^-$

background smaller than signal, Higgs natural width larger than experimental resolution (m_{Higgs} > 300 GeV)

- confirmation in $H \to ZZ \to \ell^+\ell^- jj$ channel



m(Higgs) > 600 GeV:

4 lepton channel statistically limited

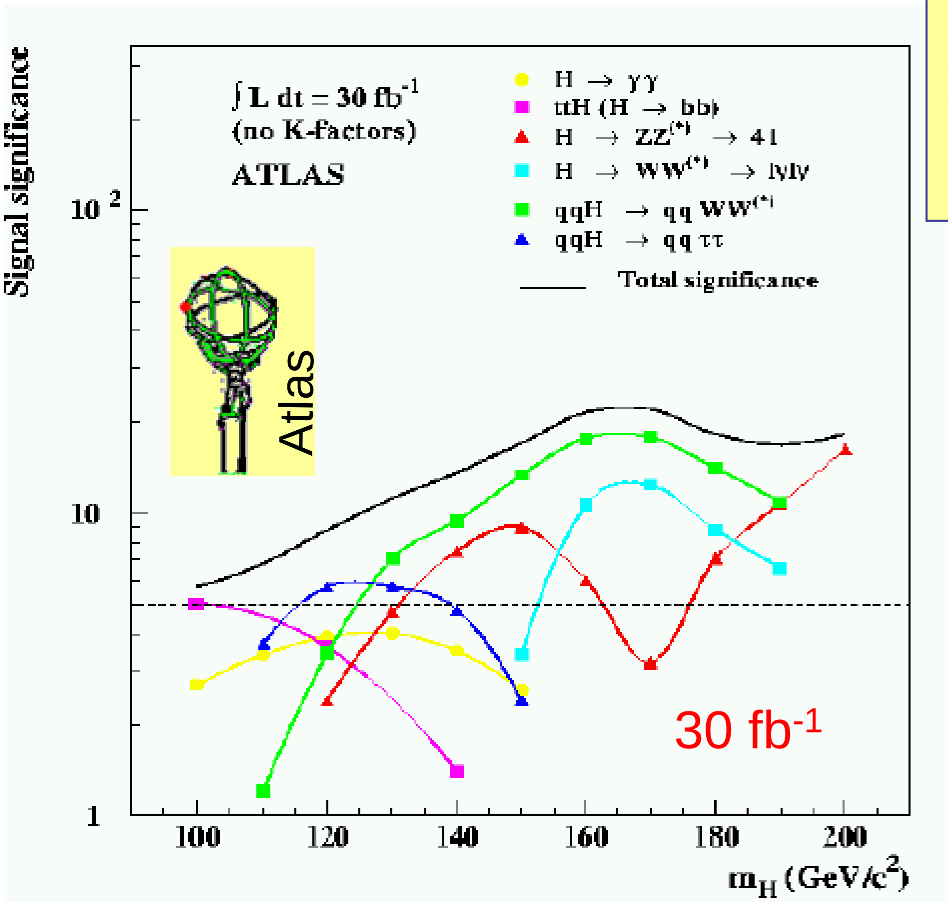
$H \to ZZ \to \ell^+\ell^- \nu\nu$

$H \to ZZ \to \ell^+\ell^- jj$, $H \to WW \to \ell^+\nu jj$ (150 times larger BR than 4l channel)

Event signature: high p_T lepton, two high p_T jets

Combination of analyses allows Higgs discovery in full mass range

Higgs signal in ATLAS



LHC can probe entire set of "allowed" Higgs mass values (100 GeV – 1 TeV)

✓at least 2 channels for most of range

Full mass range can be covered After few years at low

Discovery potential

All channels together

- **For most of the mass range at least two channels available**
- **Good sensitivity over the full mass range from ~ 100 GeV to ~ 1TeV**

- **m_H<180 GeV: several complementary channels ($\gamma\gamma$, ttbb, $2\ell E_T^{miss}$, $3\ell E_T^{miss}$, 4 ℓ, tt)**
- **m_H>180 GeV: easy with gold-plated $H \rightarrow ZZ^* \rightarrow 4\ell$**

Challenging channels (multijets…, WH) not included

Standard Model Higgs

Once Higgs boson has been discovered measure its properties:

Measurement of the Higgs boson mass

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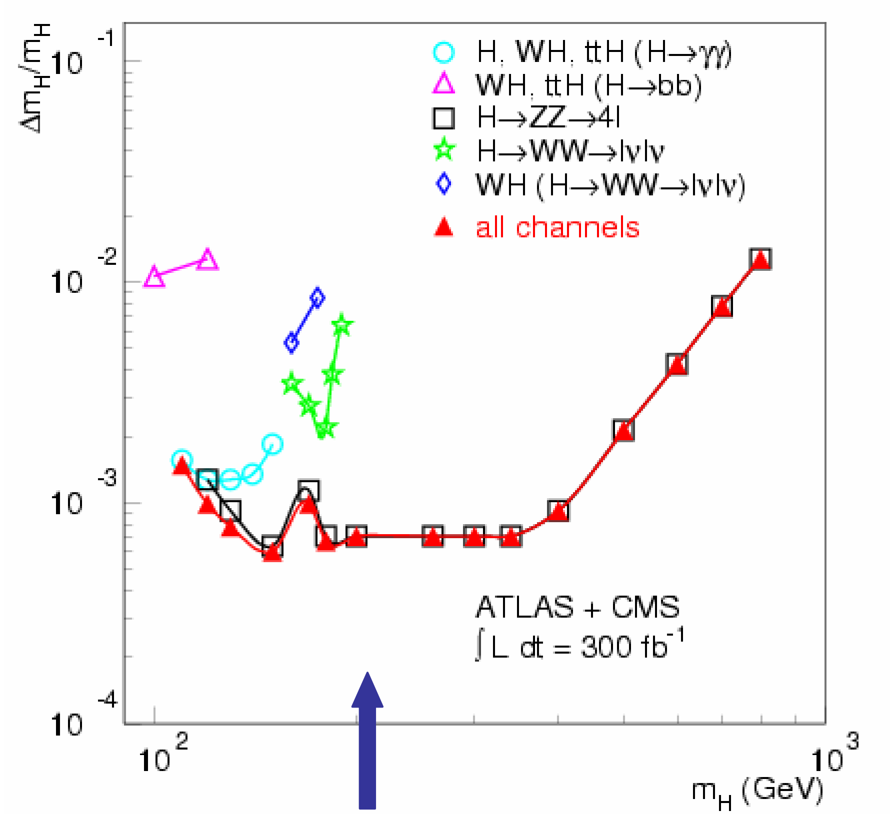


Dominated from ZZ→4 ℓ **and H → γ γ**

- **No theoretical error**
- **Dominant systematic uncertainty: γ /ℓ, E scale.**

Assumed 1‰

Goal 0.2‰

Scale from Z → ℓℓ (close to light Higgs)

Assumed 1% jets

Resolution for

γ γ & ℓ ℓ 1.5 GeV/c²

bb 15 GeV/c²

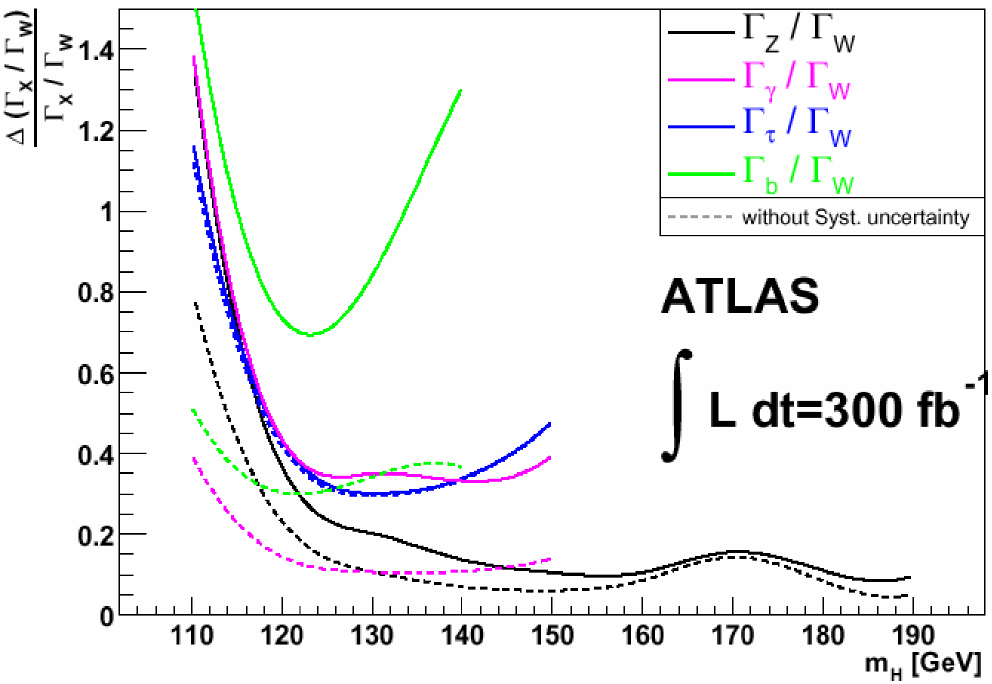
At large masses decreasing precision due to large Γ_H

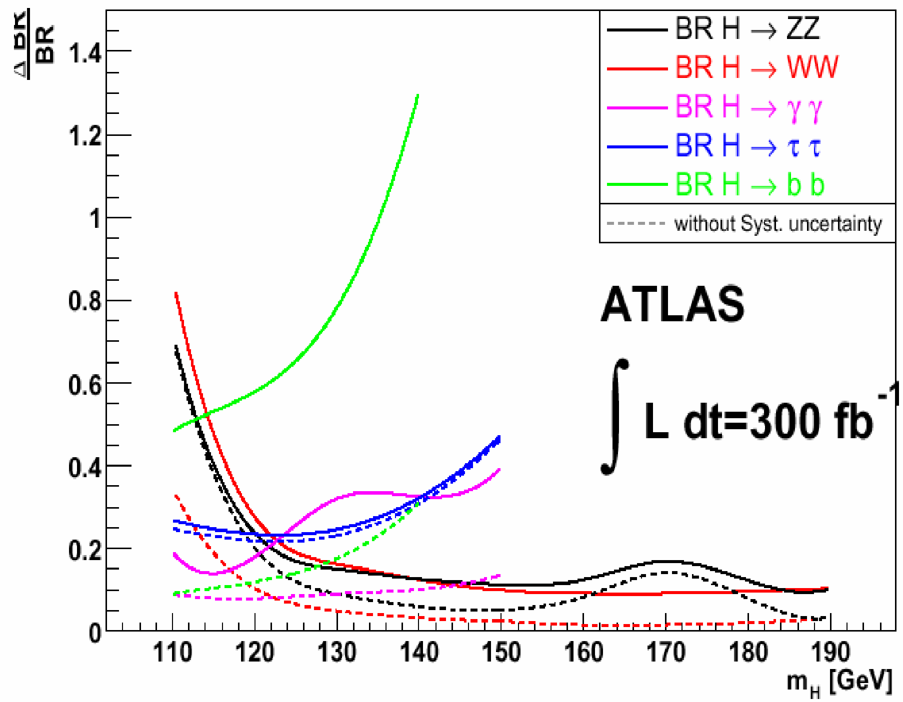
Higgs boson mass can be measured with a precision of 0.1% over a large mass range (130 - ~450 GeV / c²)

Measurement of Branching Ratios

- Measurement of relative branching ratios
- Fitting Br(H->XX) (assume Higgs production works as in SM)

- Fit of BR($H \to ZZ$), BR($H \to WW$), BR($H \to \gamma\gamma$), BR($H \to \tau\tau$) and BR($H \to b\bar{b}$)
- $(\sigma \cdot \mathrm{BR})_j\,(\vec{x}) = \sigma_j \cdot \mathrm{BR_j}$



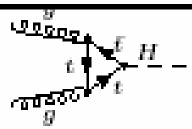
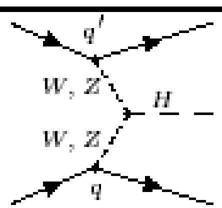
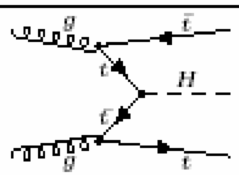
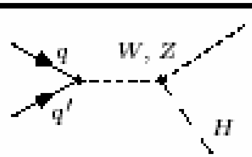


Higgs Searches at the LHC

- Measurement of coupling-parameters (110 GeV $\leq m_H \leq$ 190 GeV) -

Global Fit to all ATLAS studies

- Maximum Likelihood Fit
- Systematic uncertainties are taken into account

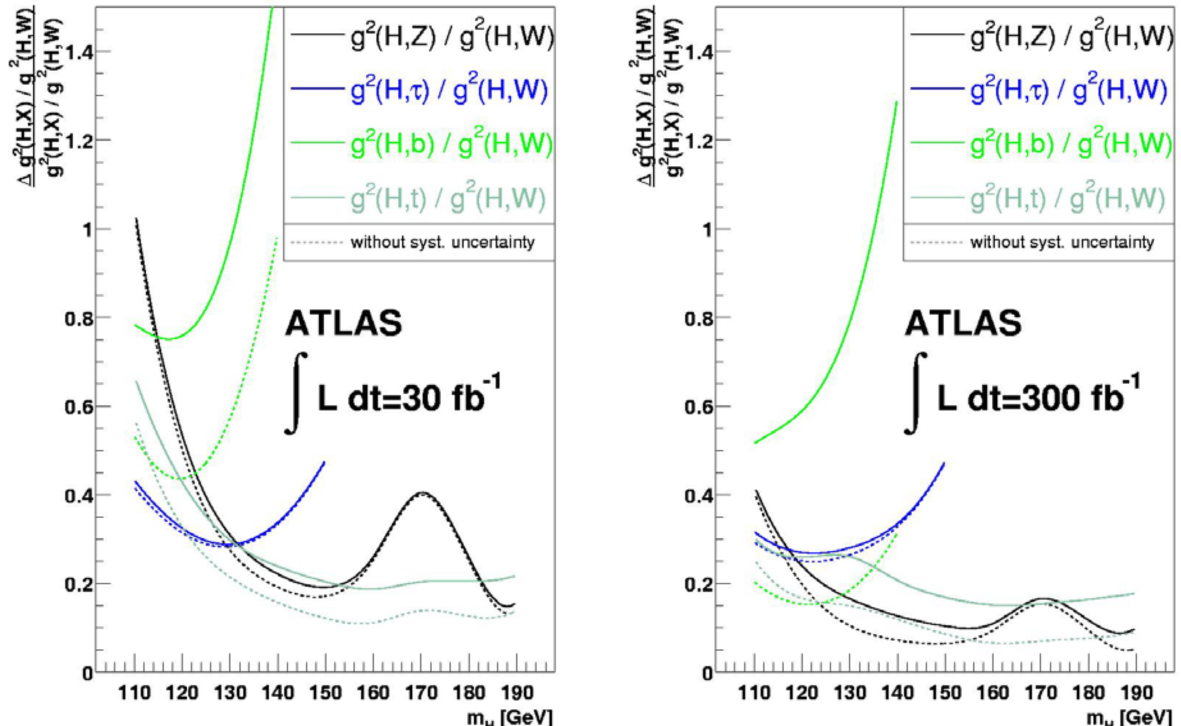
Production		Decay	mass ranges
	Gluon-Fusion ($gg \to H$)	$H \to ZZ \to 4l$	110 GeV - 200 GeV
		$H \to WW \to l\nu\, l\nu$	110 GeV - 200 GeV
		$H \to \gamma\gamma$	110 GeV - 150 GeV
	WBF ($qq\,H$)	$H \to ZZ \to 4l$	110 GeV - 200 GeV
		$H \to WW \to l\nu\, l\nu$	110 GeV - 190 GeV
		$H \to \tau\tau \to l\nu\nu\, l\nu\nu$	110 GeV - 150 GeV
		$H \to \tau\tau \to l\nu\nu\, \text{had}\nu$	110 GeV - 150 GeV
		$H \to \gamma\gamma$	110 GeV - 150 GeV
	$t\bar{t}H$	$H \to WW \to l\nu\, l\nu\, (l\nu)$	120 GeV - 200 GeV
		$H \to b\bar{b}$	110 GeV - 140 GeV
		$H \to \tau\tau$ (not included)	110 GeV - 150 GeV
		$H \to \gamma\gamma$	110 GeV - 120 GeV
	WH	$H \to WW \to l\nu\, l\nu\, (l\nu)$	150 GeV - 190 GeV
		$H \to \gamma\gamma$	110 GeV - 120 GeV
	ZH	$H \to \gamma\gamma$	110 GeV - 120 GeV

Measurement of Higgs Boson Couplings

•Global likelihood-fit (at each possible Higgs boson mass)

Input: measured rates, separated for the various production modes

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



Relative couplings can be measured with a precision of **10-20% (for 300 fb^{-1})**

Conclusions to the SM part

Inclusion of VectorBosonFusion channels improves SM Higgs discovery potential:

- ~10 fb^{-1} needed for 5σ discovery over the full (interesting) mass range
- At least 3 channels with 3σ sign for 30 fb^{-1} for each mass: more robust result

Conclusions on the SM Higgs

Inclusion of Vector Boson Fusion channels improves SM Higgs discovery potential:

~10 fb^{-1} needed for **5σ discovery** over the full (interesting) mass range

30 fb^{-1} more robust result