Search for a SM Higgs the $H \rightarrow \gamma\gamma$ channel with the ATLAS experiment

Valeria Perez Reale (CERN)
On behalf of the ATLAS Collaboration

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Outline

(I) SM Higgs physics at the LHC

(II) $H\rightarrow\gamma\gamma$ Channel: Introduction and key ingredients

(III) Photon ID with the ATLAS detector and Trigger
(already covered in talk 11/7, "Physics with Photons at the ATLAS experiment")

(IV) Overview of main experimental issues

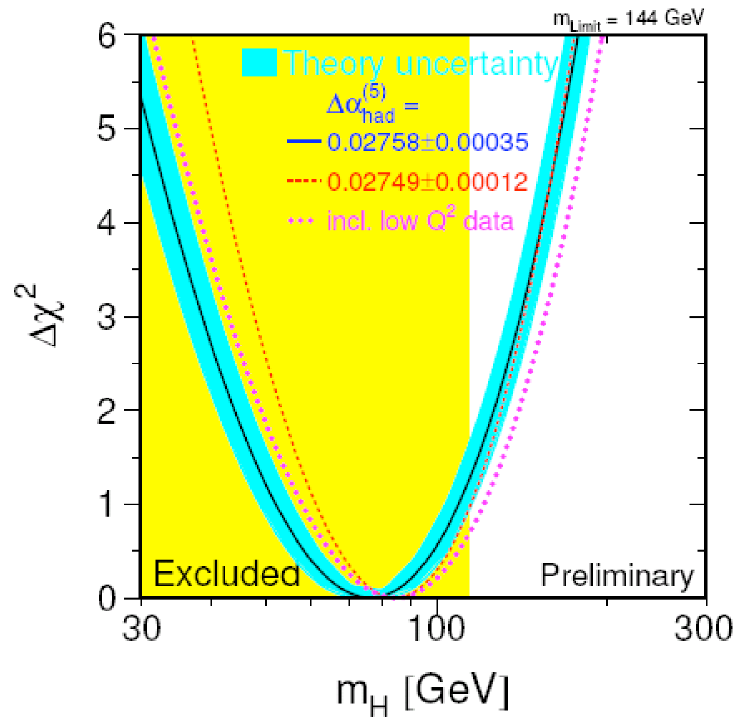
(V) Analysis details and results

(VI) Summary and Conclusions

- Disclaimer: Not covered in this talk are SM Higgs Boson properties and MSSM Higgs model searches

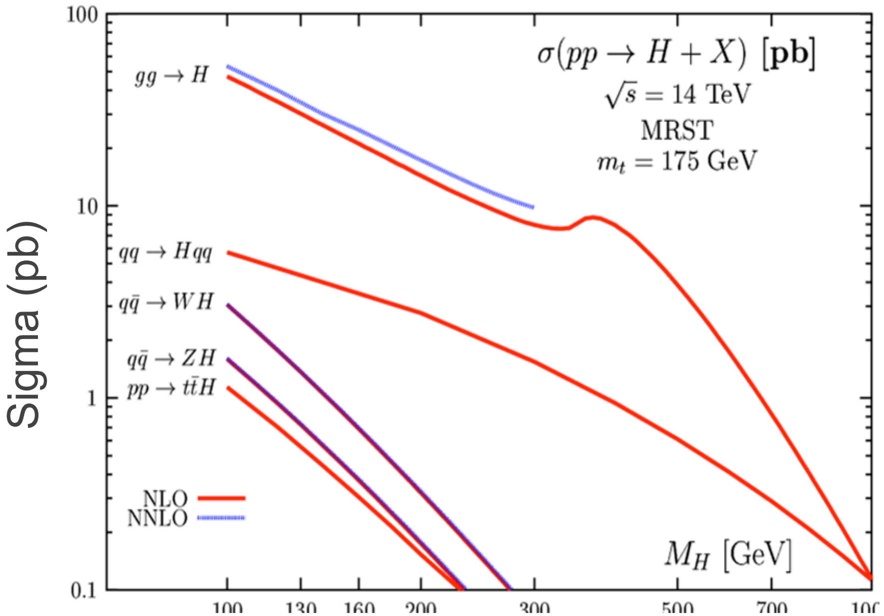
(I) Higgs physics: what do we know?

- m_H > 114.4 GeV from LEP @ 95% confidence level
- m_H < 1 TeV from theoretical contraints (unitarity)
- Global fit to ElectroWeak data:
  - Summer 2003 : M_{top}=174.3 ± 5.1 GeV/c^2 so that M_H<219 GeV/c^2
  - Winter 2005 : M_{top}=178.0 ± 4.3 GeV/c^2 so that M_H<280 GeV/c^2
  - Summer 2005 : M_{top}=172.7 ± 2.9 GeV/c^2 so that M_H<219 GeV/c^2
  - Winter 2007 : M_{top}=170.9 ± 1.8 GeV/c^2 so that M_H<182 GeV/c^2



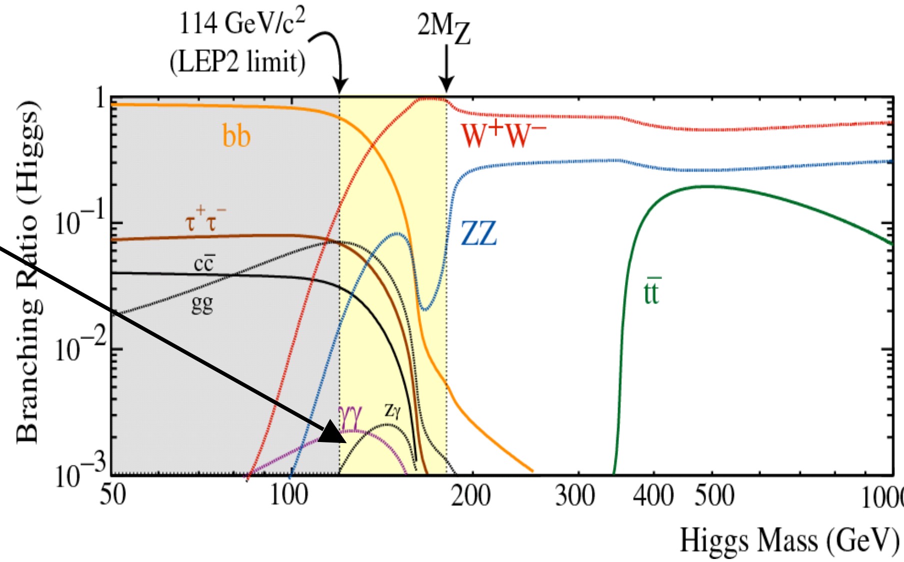
Current indications are for a 'light Higgs' : search for Higgs in mass region 114 < m_H < 200 GeV very important

(II) SM Higgs production and decay



(A. Djouadi) H Mass (GeV)

- Dominant production process is the gluon-gluon fusion (LO ~20 pb for M_H=120 GeV K~1.8)
- Vector Boson Fusion contribution becomes important for higher M_H (but <u>distinctive signature!!</u>) (LO ~4 pb for M_H=120 GeV K=1.06)
- Small contribution from WH,ZH and tt(bar)H (LO ~2.4 pb for M_H=120 GeV K=1.25)



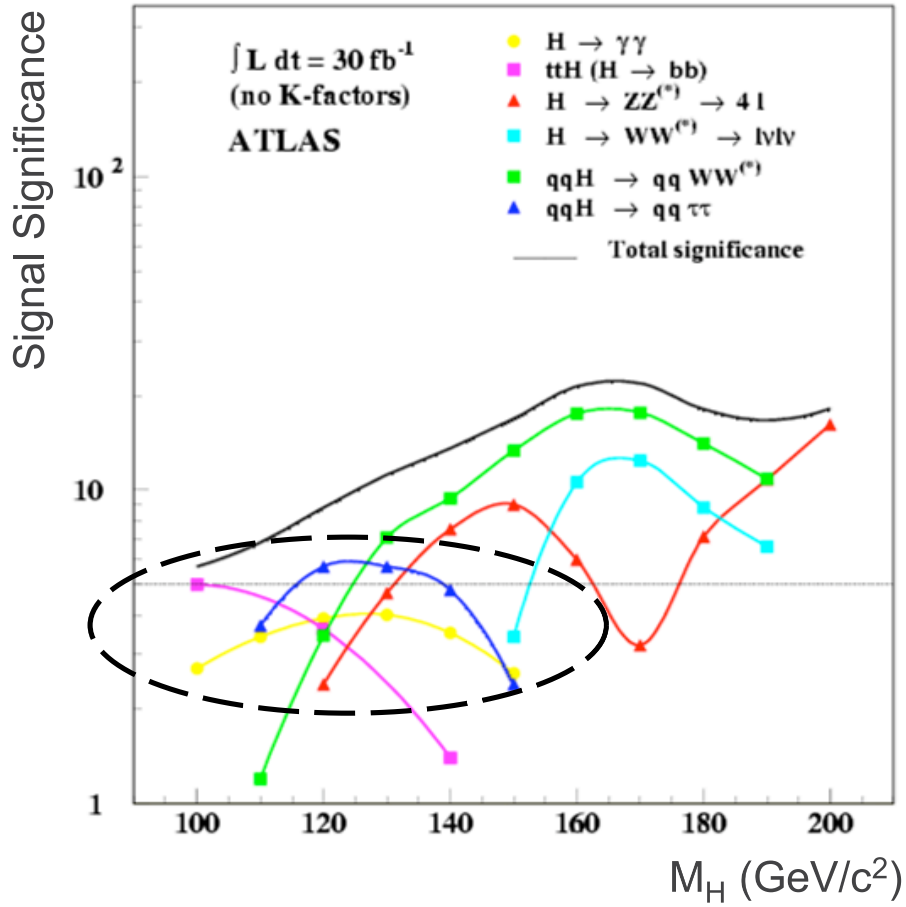
- $H \to \gamma\gamma$ is a rare decay mode with BR ~ 10^{-3} (2.186 10^{-3} for M_H=120 GeV)
- The signal should be visible as a peak above the $\gamma\gamma$ continuum background
- Severe requirements on particle identification capabilities of the detector

(II) Introduction: why the H→γγ channel?

- Current indications are for a ‘light Higgs’ : search for Higgs in mass region 114 < m_H < 200 GeV is crucial

- Although the situation is evolved wrt physics ATLAS TDR the channel is still important in the low mass range (M_H<140 GeV)

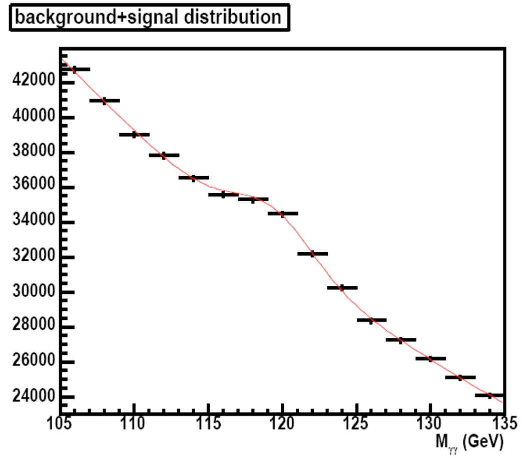
- The inclusive analysis is a base line and there are a number of improvements to it.



(II) Introduction: H→γγ analysis key ingredients

signal

- H→γγ is a rare decay mode with BR ~ 10^{-3} (2.186 10^{-3} for M_H=120 GeV)
- The signal should be visible as a small peak above the γγ continuum background
- Good energy resolution of the EM calorimeter



background

- <u>Irreducible background</u> consists of genuine photons pairs continuum. ~125 fb/GeV @NLO for MH=120 GeV (after cuts and photon efficiency)

- <u>Reducible background</u> comes from jet-jet and gamma-jet events in which one or both jets are misidentified as photons (Reducible / irreducible cross section (LO-TDR) ~$2x10^6$(jj) and ~ $8x10^2$(γj))
  - **Excellent jet rejection factor (> 10^3) for 80% γ efficiency**
  - Severe requirements on particle identification capabilities of the detector especially the em calorimeter

(II) Introduction: what's new?

• Since ATLAS Technical Design proposal in 99 there has been more updated simulations/reconstruction with updated detector geometry

• Lot of improvements in theory and MC:

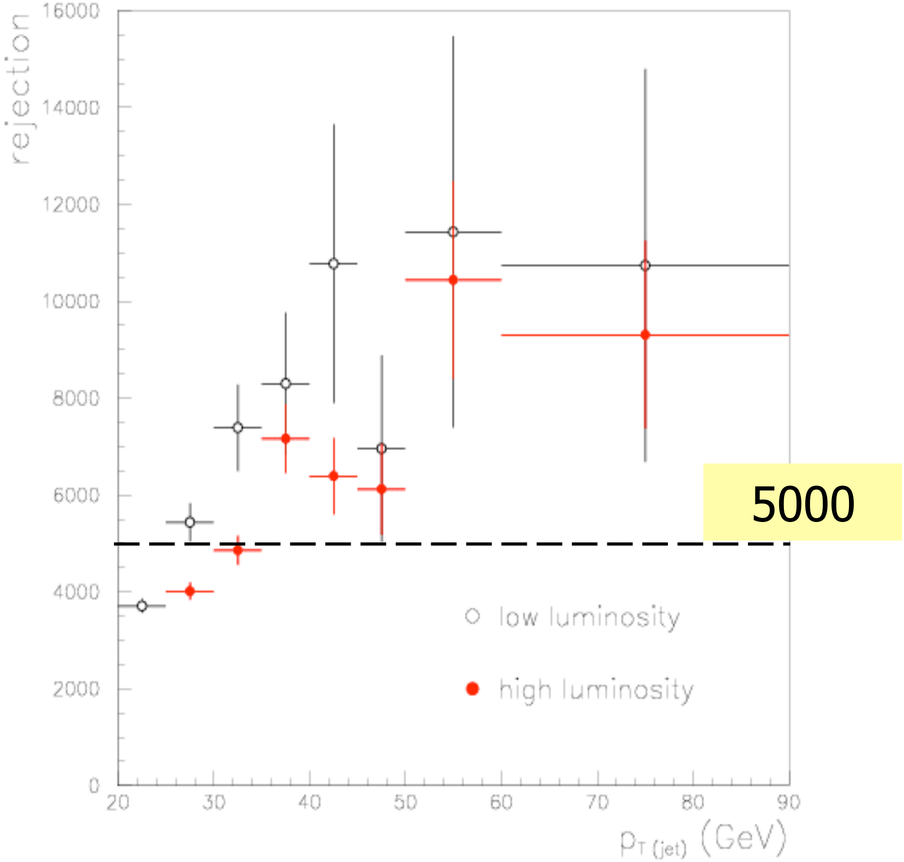
  • New improvements in QCD and EW corrections ($gg \rightarrow H$ is known to QCD NNLO)
  • Signal and backgrounds cross sections known @ NLO
  • New MC tools for the analysis

• <u>Disclaimer</u>: Exclusive analyses studies to test the discovery potential in the H+1 jet, VBF and combined are only mentioned in this talk

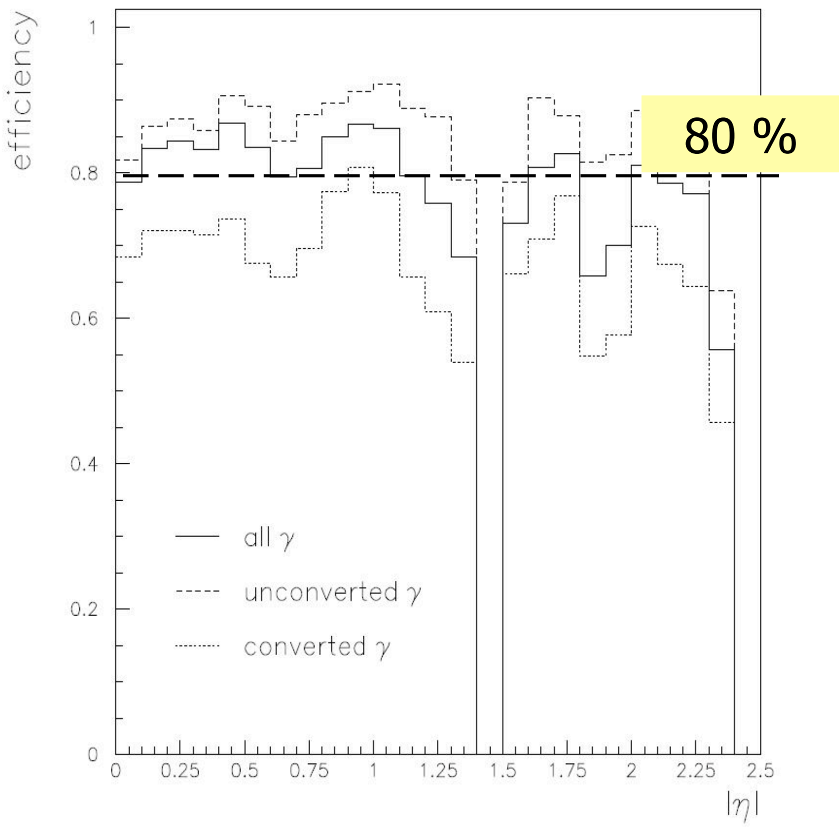
(III) Photon ID/ jet rejection

- Higher rejection against gluon initiated jets than quark initiated jets

Jet rejection ~5000 (P_T> 25 GeV)



80% average photon efficiency



(IV) Photon calibration

- Fixed cone clusters have been used for converted photons and unconverted photons in the barrel (endcap)

$$E_{rec} = \lambda \cdot (w_{ps} E_{ps} + E_{str} + E_{mid} + w_{back} E_{back})$$

- Weight for the presampler and back to correct for upstream material energy losses and longitudinal leakage

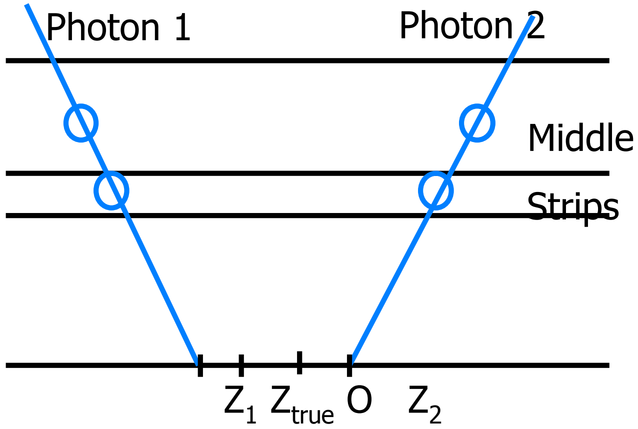
- The P_T > 25 GeV cut protects against linearity problems

- Refined energy after corrections :
  - ❑ out of cone (shower lateral containment)
  - ❑ accordion modulation corrections (phi)

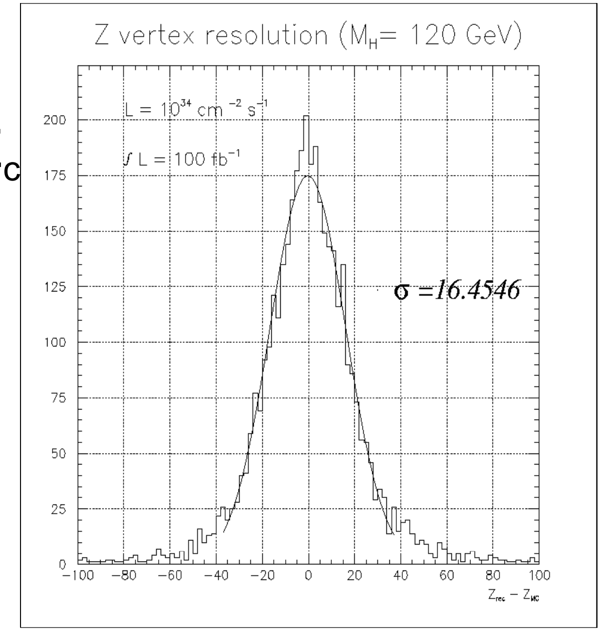
- Refined position using the following corrections:
  - ❑ S – shape for for strips and middle
  - ❑ Phi offset (middle only)

(IV) Primary vertex reconstruction

- Low luminosity:
  - Use calorimeter η measures from strips and middle + Z_v measure from ID (σ_z=40 μm)
- High luminosity:
  - Conservative : no use of ID. Photons direction obtained with calorimeter information only: crucial role for fine η segmented strips layer



- For early conversions (R_c<40 cm and $|Z_c$ <220 cm) the vertex also included in both cases:



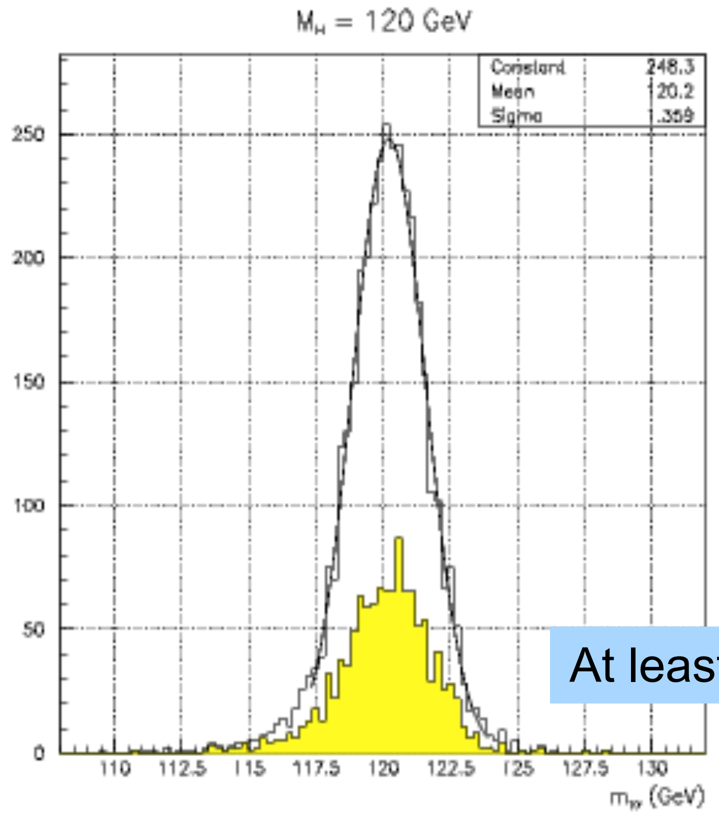
- Primary vertex resolution with em calorimeter only : **~ 16.5 mm**

(V) Inclusive Analysis and reconstruction

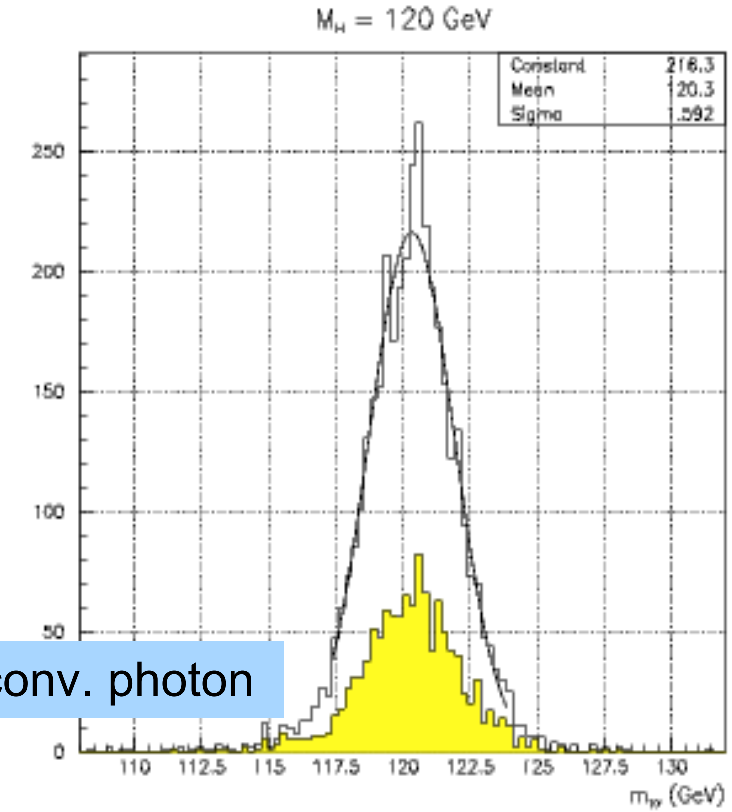
- Trigger selects events with 2γ with $E_T > 20$ GeV in $|\eta|<2.4$
- Events with 1 γ in the electromagnetic calorimeter cracks excluded (bad energy resolution):
    - $|\eta|<2.4$ excluding crack region and $|\eta|\sim1.4$
- Transverse momentum cuts (background rejection):
    - $p_T(\gamma1)>40$ GeV, $p_T(\gamma2)>25$ GeV
- Photon identification cuts applied to all egamma candidates
- Photon reconstruction and calibration
- The direction of both photons is corrected for the primary vertex position
- Invariant mass distribution of the two photons is reconstructed

(V) Higgs invariant mass reconstruction

Low lumi: 1.36 GeV
80.9% inside +- 1.4 σ



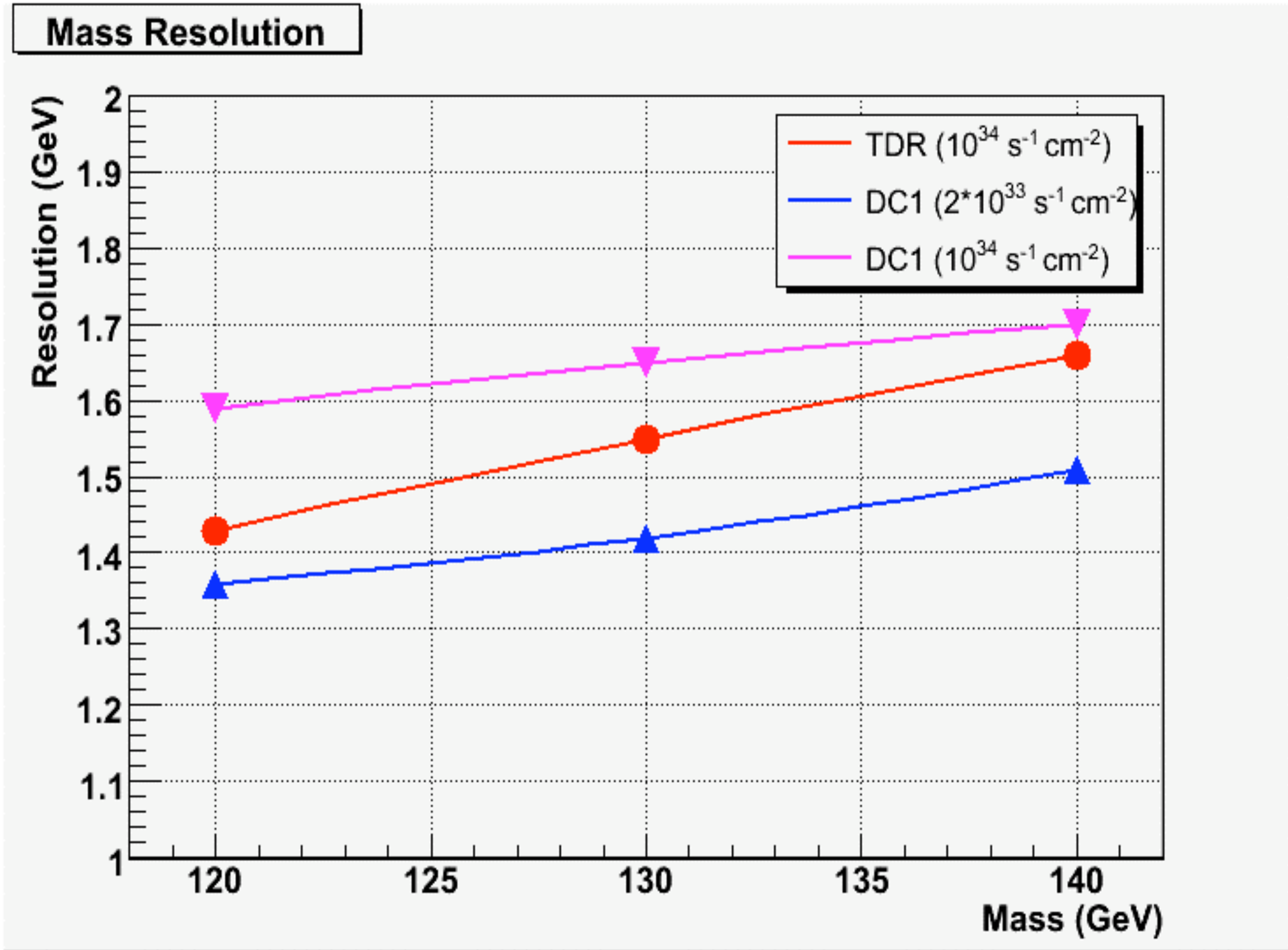
High lumi: 1.59 GeV
80.9% inside +- 1.4 σ



At least 1 conv. photon

- The ATLAS realistic detector layout will lead to more photon conversions therefore identifying conversions is very important for the analysis

(V) Higgs invariant mass reconstruction



(V) NLO cross sections

Signal

- Gluon-gluon fusion events generated from ResBos (K factor ~ 1.8)
- VBF from PYTHIA 6.224 (LO)+ 1.04 K factor
- Associated production from PYTHIA (LO)
- $H\rightarrow\gamma\gamma$ branching ratio with HDecay

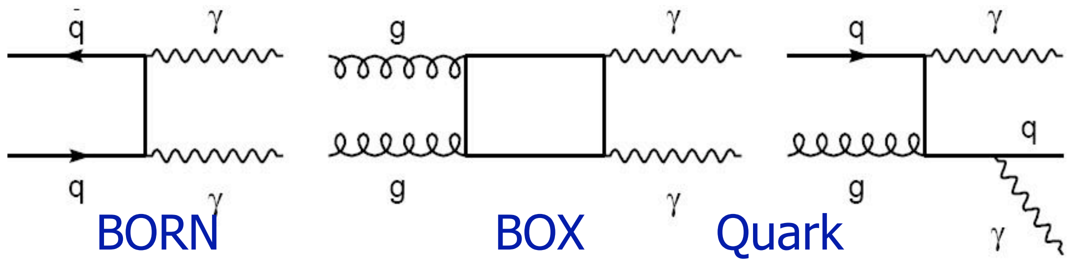
Irreducible background

- DIPHOX and ResBos : treatment of the background at NLO
- Increase of ~50 % due to the “LO” $\rightarrow$ NLO transition
- @NLO ~125 fb/GeV for M_H=120 GeV (after cuts and photon efficiency)

Reducible background

- jet/jet events dominated by gluon initiated jets (easier to reject) while γ/jet events dominated by quark initiated jets
- the total contribution @LO is close to TDR although dominated by γ/jet : ~ 20 fb/GeV
- K factor ~ 1.7: at NLO ~30 % of irreducible back.

(V) Irreducible background

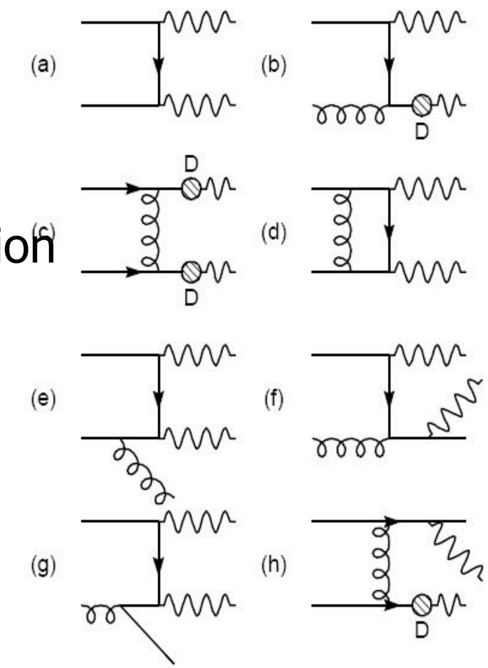


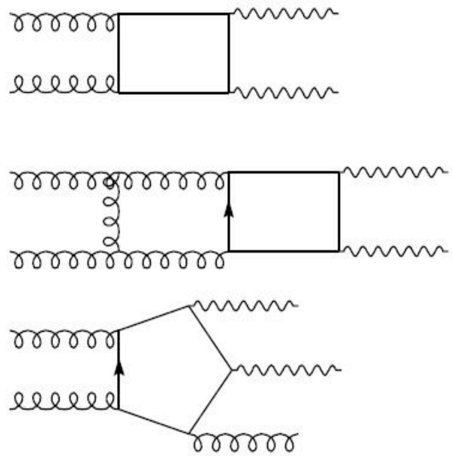
BORN BOX Quark Bremsstrahlung

Irreducible background a’ la ATLAS TDR

Resbos :

- Only unique fragmentation implemented
- Fragmentation at LO
- Resummation of soft gluons





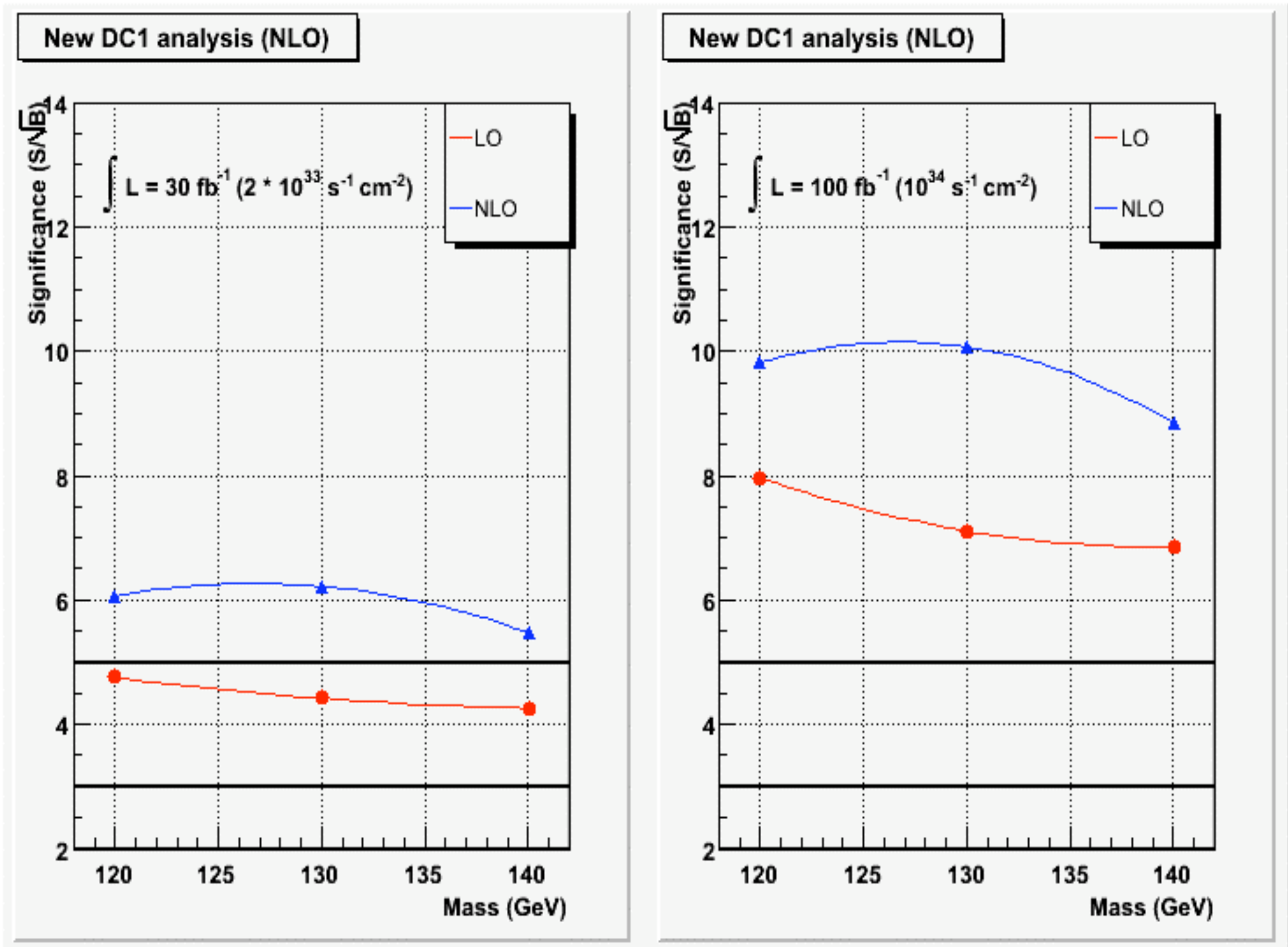
(V) Inclusive analysis results (NLO)

Signal and background rates: NLO low lumi (30fb-1)

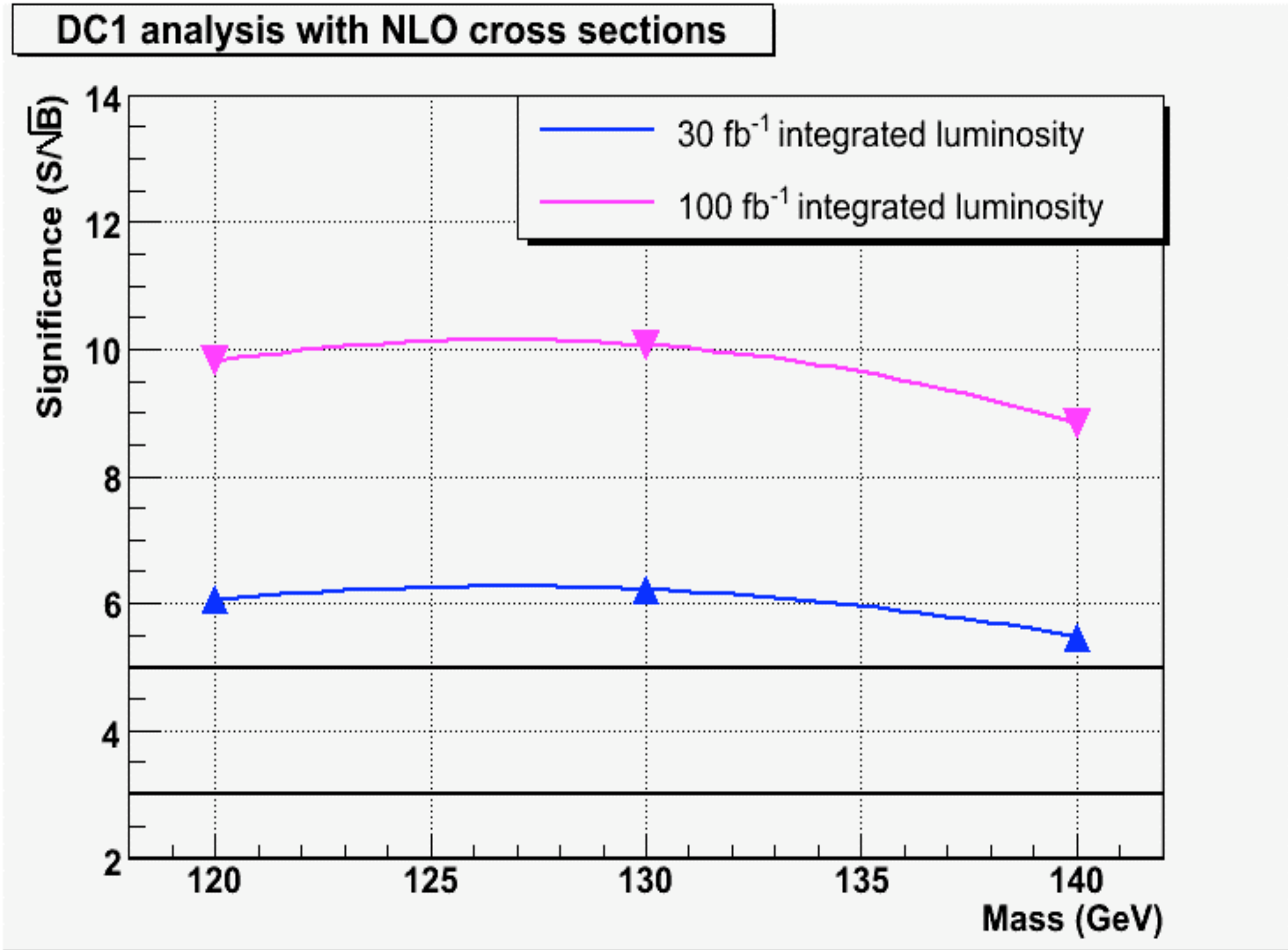
Mass (GeV)	120	130	140
σ (GeV)	1.36	1.42	1.51
S_{ignal}	815	758	610
$B_{irreducible}$	14100	11472	9552
$B_{reducible}$	3967	3396	2839
$S/\sqrt{(B)}$	**6.06**	**6.22**	**5.48**

(V) Inclusive analysis results (NLO)

Signal significance for counting experiment: $S/\sqrt{B}$



(V) Summary of inclusive analysis



What at the beginning of data taking?

Difficult to say...

- In a basic inclusive analysis at least 10 fb^{-1} are required to have a > 3 σ signal significance
- The clasification of events in the inclusive analysis, including discrimination variables has the potential to add sensitivity
- With 10 fb^{-1} a 5 σ signal significance only achievable using additional kinematical assumptions such as a likelihood ratio method or in combined analysis (VBF + H+1Jet + Inclusive)

(VI) Conclusions

- A Complete NLO study of the $H \rightarrow \gamma\gamma$ channel available: K factors included in the analysis and uncertainties on the discovery potential estimated
  - Possible discovery for > 10 fb^{-1}
  - Uncertainties are large (~30%)

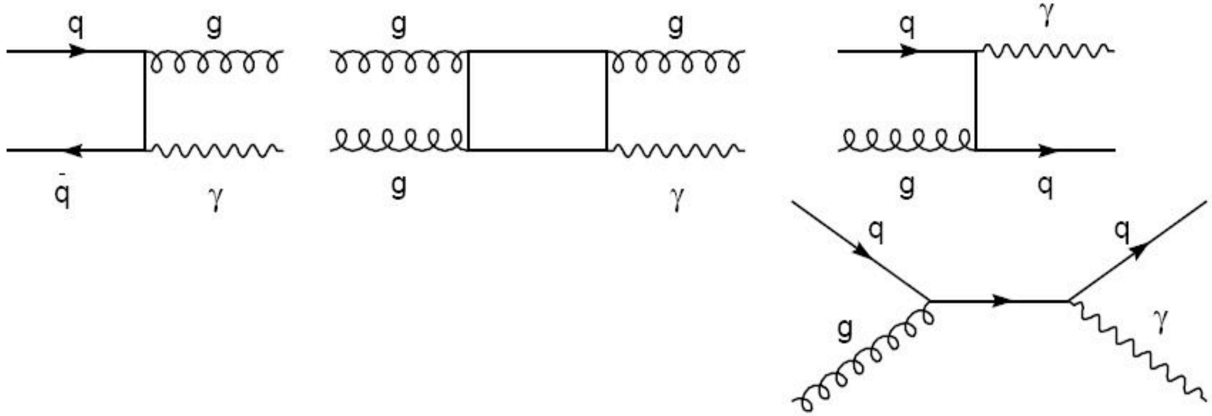
- Impact of the detector performance on the discovery potential has been readressed with the most updated detector knowledge: only a slight degradation wrt first studies (ATLAS TDR 99) (<10%) has been observed.

- Finding the Higgs requires excellent understanding of the detector: extensive work needed to understand the detector as soon as the first data will become available
  - LAr calorimeter: γ energy calibration, γ direction reconstruction, γ/jet separation
  - Inner detector: Primary vertex reconstruction, Conversion reconstruction, γ isolation
  - Trigger Efficiencies

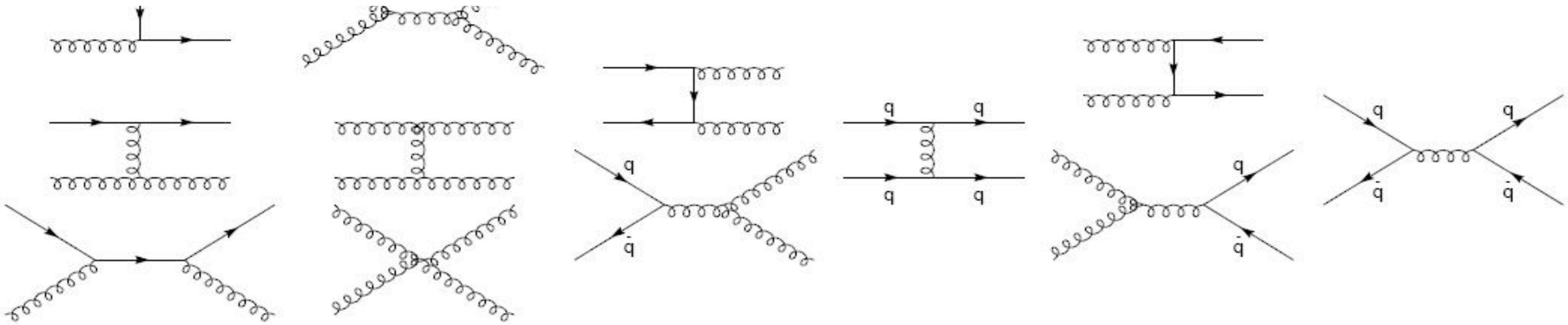
BACK-UP SLIDES

Reducible Background

γ/jet background (PYTHIA - LO)

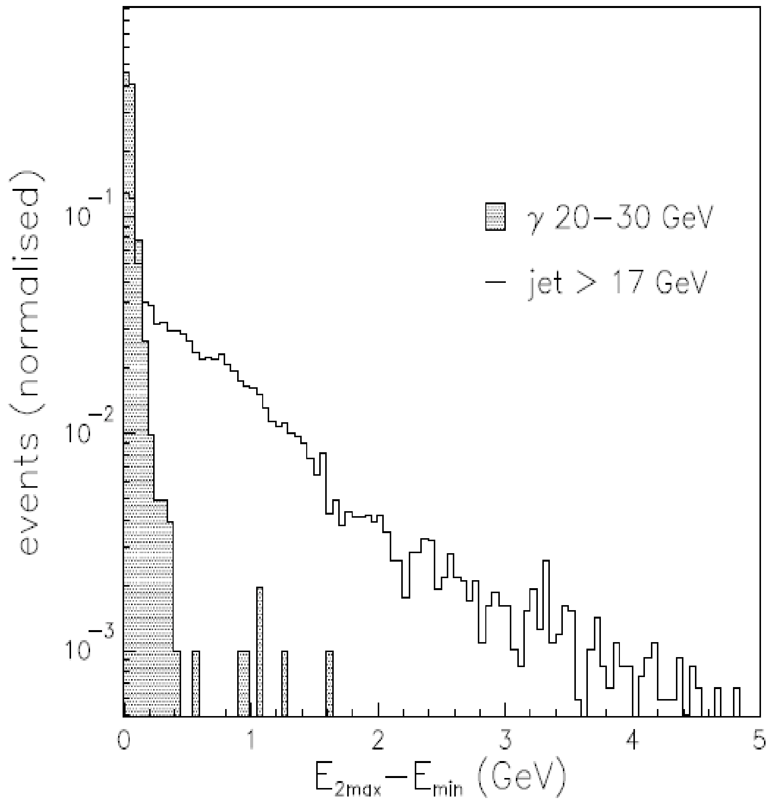


jet/jet background (PYTHIA – LO)

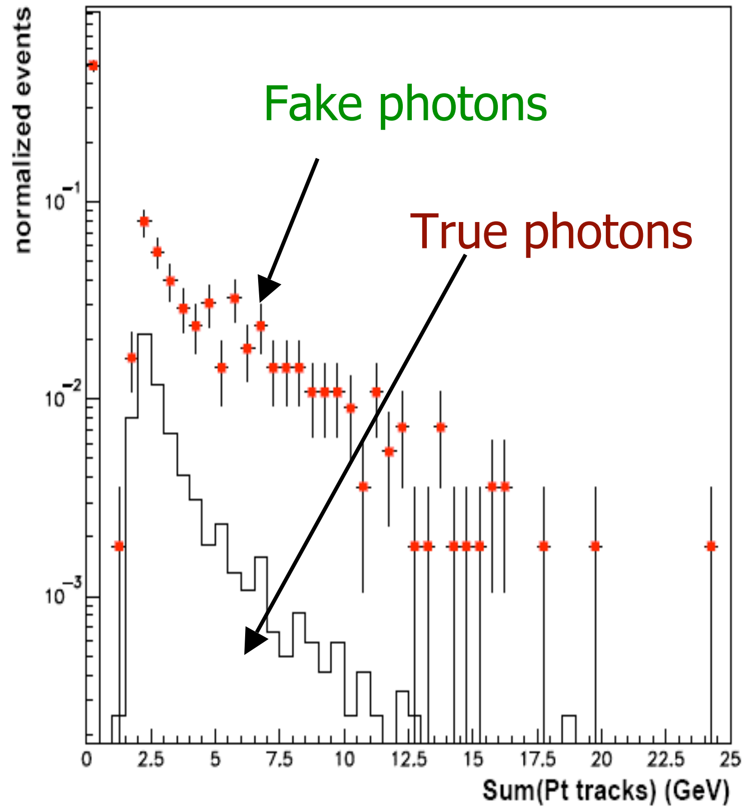


Photon identification / jet rejection

Effect of the strips: presence of a second maximum ($\Delta\eta$ = 0.003)



Effect of track isolation



Full simulation details: mass resolution contributions

The various contribution to the Higgs mass have been estimated: example reported for the high luminosity case

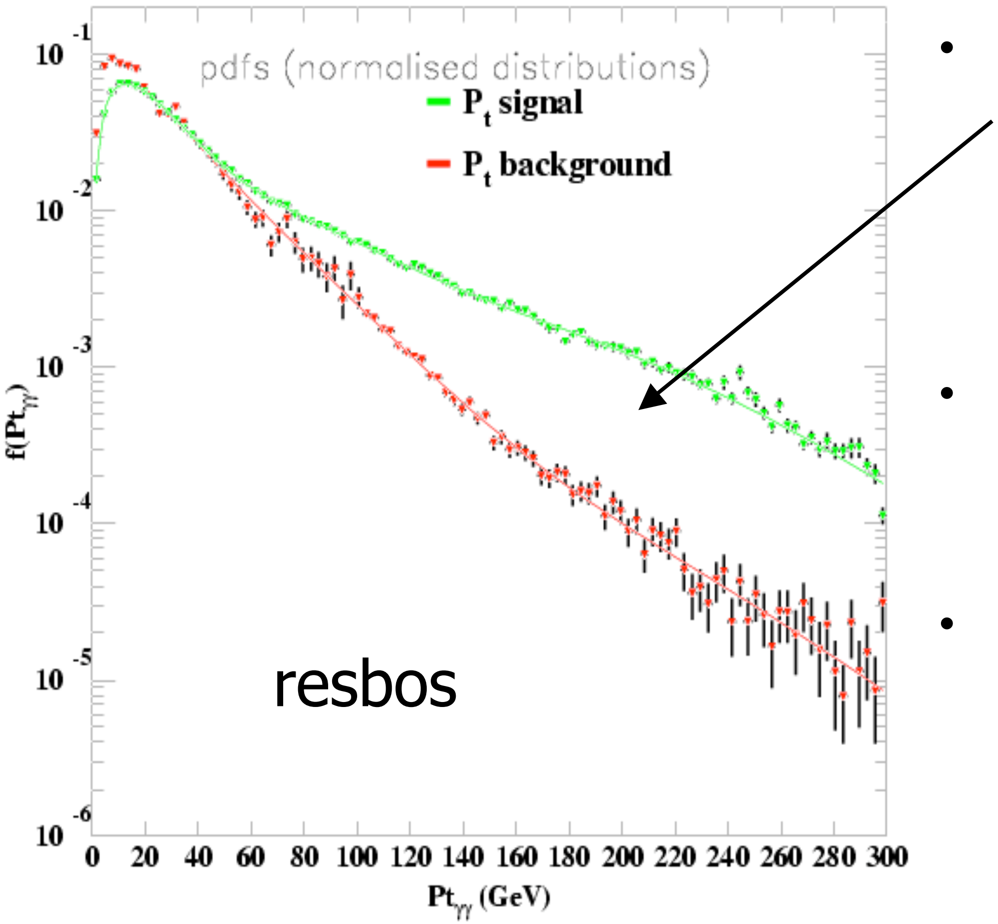
$$\frac{\sigma_m}{m} = \frac{1}{2}\left(\frac{\sigma_{E_1}^2}{E_1^2} + \frac{\sigma_{E_2}^2}{E_2^2} + \frac{\sigma_\alpha^2}{\tan^2(\alpha/2)}\right)$$ ⇦ *Contributions to the Higgs invariant mass*

Contributions to the calorimeter resolution ⇨ $$\frac{\sigma_E}{E} = 0.7\% \oplus \frac{10\%}{\sqrt{E}} \oplus \frac{300MeV}{E}$$

	100 GeV	120 GeV	130 GeV	140 GeV
Sampling term (MeV)	1060	1180	1250	1300
Constant term (MeV)	460	500	540	600
Poyinting (MeV)	670	650	630	690
Electronic noise	520	590	550	550
Pile-up	490	610	630	590
Total width (GeV)	**1.52**	**1.67**	**1.72**	**1.78**

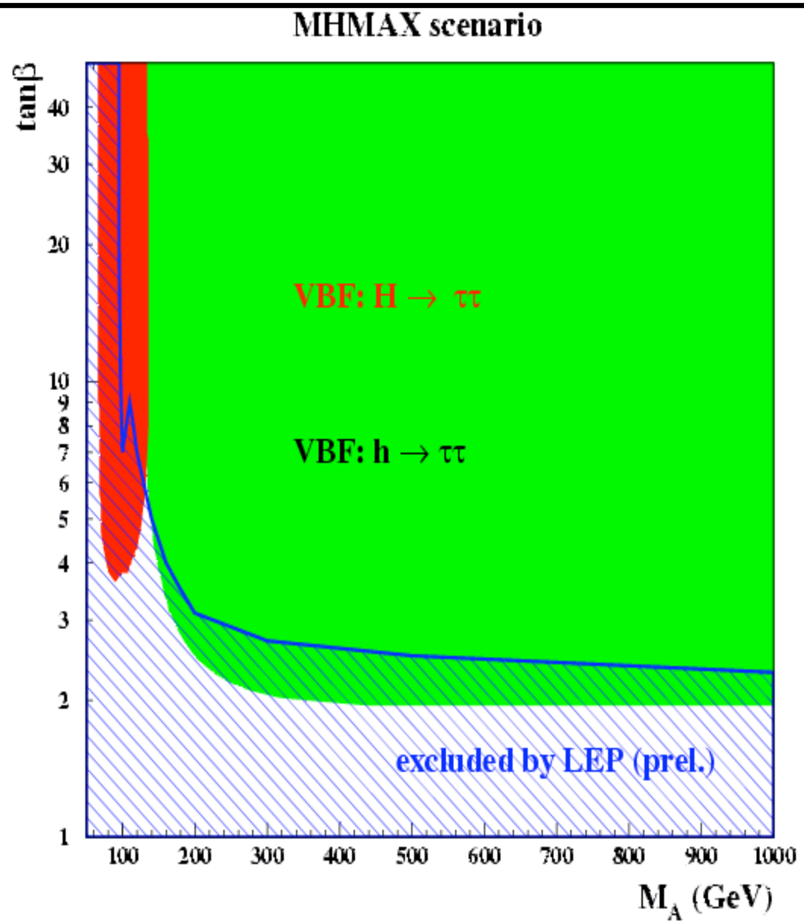
Improvements to the standard inclusive analysis

- Improve the discovery potential using the shape of kinematical variables:. One has to assume some theoretical knowledge



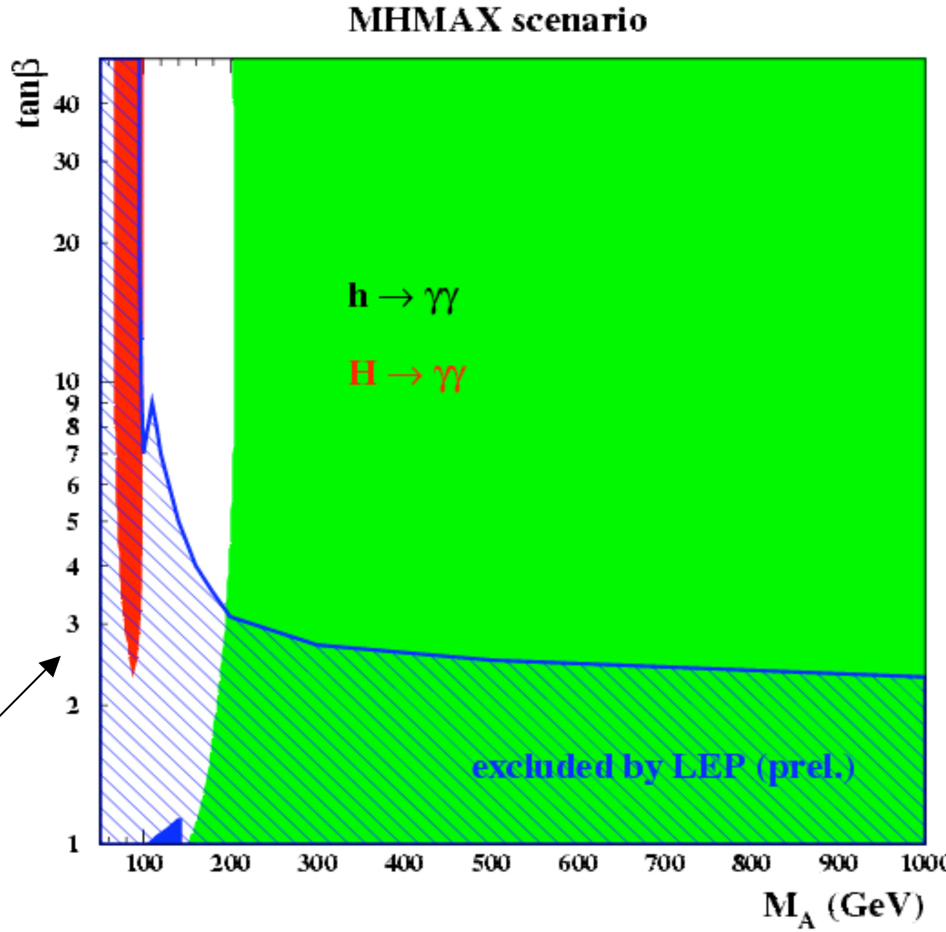
- Likelihood ratio method based on P_T and cosq* (well predicted in NLO calculations) of signal and background
- Each event is weighted by the likelihood ration
- With a likelihood analysis a further 30-40% improvement in the discovery potential has been reported.

Application of SM Higgs searches



VBF H,h -> ττ
with 30 fb^{-1} (ATLAS)

Difficult channel: tagging jet, Etmiss resolution, tau identication



H,h ->γγ
with 300 fb^{-1} (ATLAS)