Search for a standard model Higgs the $H\rightarrow\gamma\gamma$ channel with the ATLAS detector

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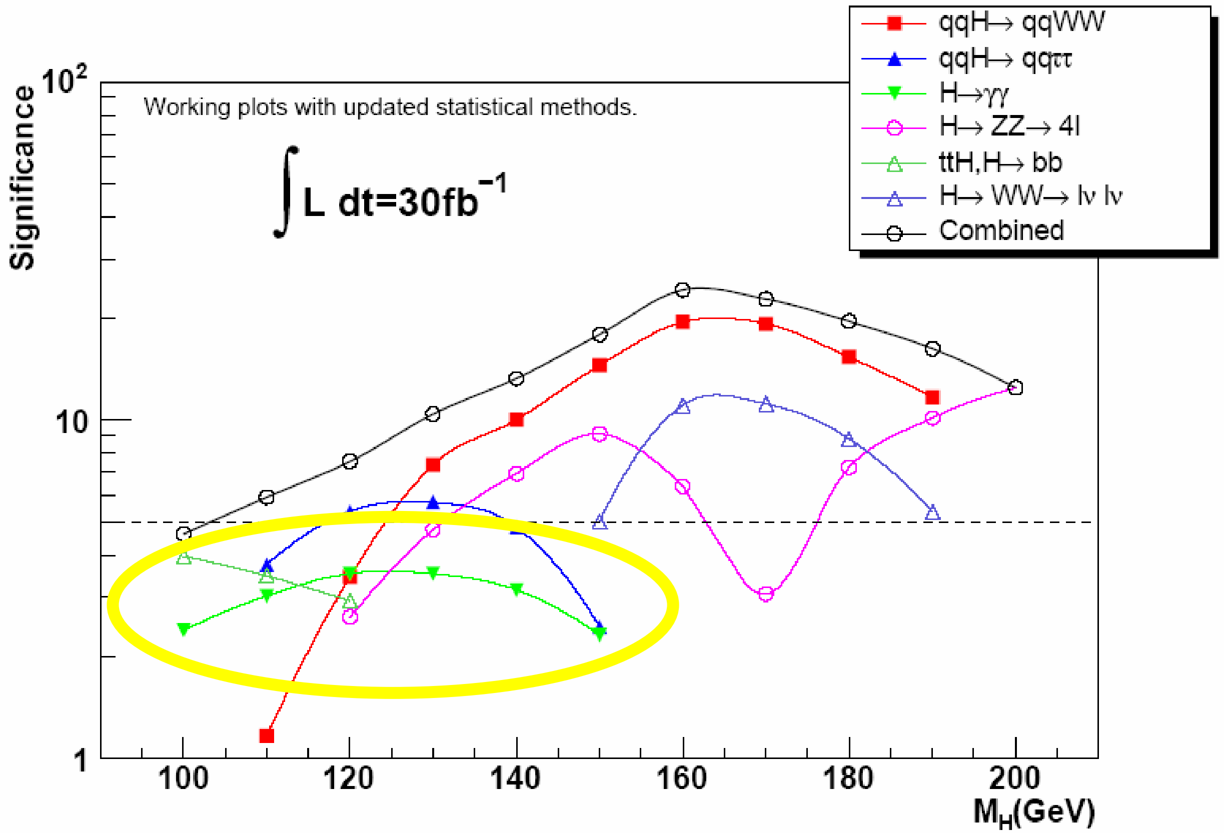
on behalf of the ATLAS collaboration

(I) Introduction: why the $H\rightarrow\gamma\gamma$ 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 TDR the channel is still important in the low mass range (M_H<140 GeV)

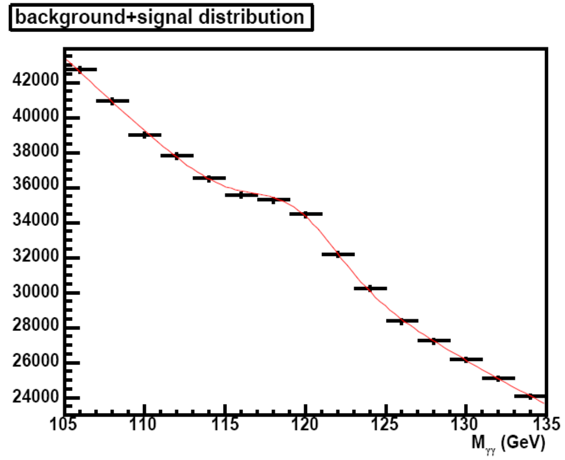


- Inclusive analysis? Robust, less dependent on MC assumptions.

(I) 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 calo



background

- Irreducible background consists of genuine photons pairs continuum. ~125 fb/GeV @NLO for MH=120 GeV (after cuts and photon efficiency)
- Reducible background comes from jet-jet and gamma-jet events in which one or both jets are misidentified as photons (Reducible / irreducible cross section (LO-TDR) ~2×10^6(jj) and ~ 8×10^2(γj))
  - **Excellent jet rejection factor (> 10^3) for 80 % γ efficiency**
  - Severe requirements on particle identification capabilities of the detector especially the em calorimeter

(I) Introduction: what's new?

- Several changes in simulations/reconstruction

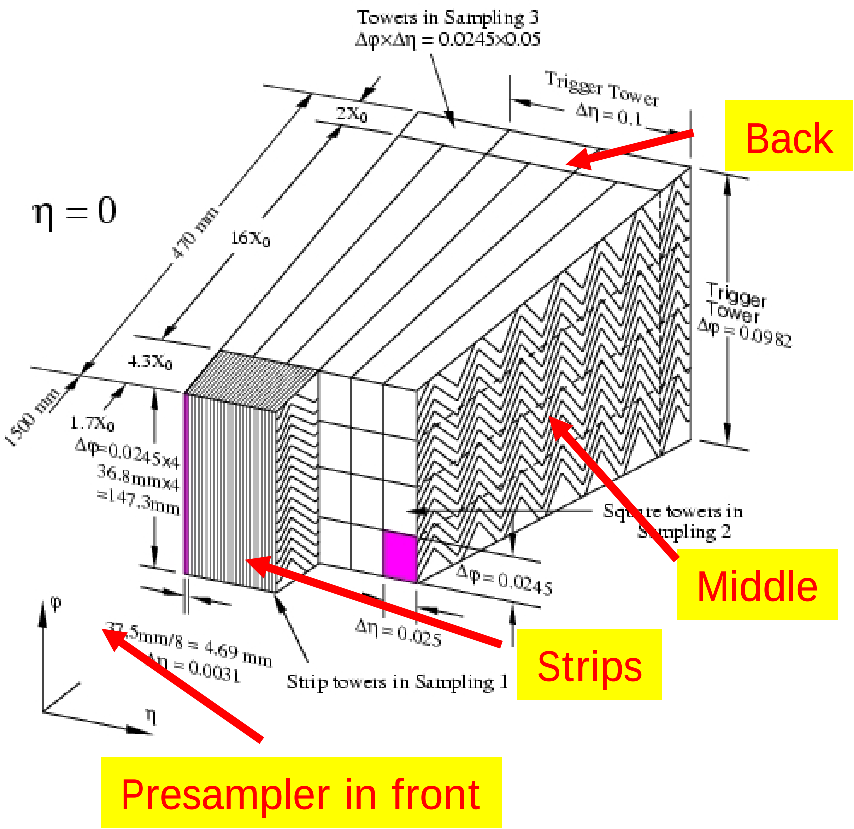
    - Most updated detector geometry
    - Massive MC production (signal + irreducible background) during Data Challenge 1 (~2003)

- Lot of improvements in theory and MC:

    - Newer versions of PYTHIA (6.224) and parton distribution functions sets (CTEQ6L1 – CTEQ6M)
    - Signal and backgrounds cross sections known @ NLO
    - New MC tools for the analysis (ResBos, Diphox)

- Exclusive analyses: studies to test the discovery potential in the H+1 jet, VBF and combined (only mentioned in this talk)

(II) Photon identification / jet rejection



γ candidate

↓

LVL1
EM25i (EM30i)
2EM15i (2EM20i)

↓

Cut on HAD leakage, 2^{nd} sampling of EM — Rejects jets with high energy pions and wide showers

↓

Cuts on 1^{st} sampling of EM calo — Rejects jets with one or more π^0, η,...

↓

Isolation cuts (ID or EM calo) — Rejects low multiplicity π^0 jets

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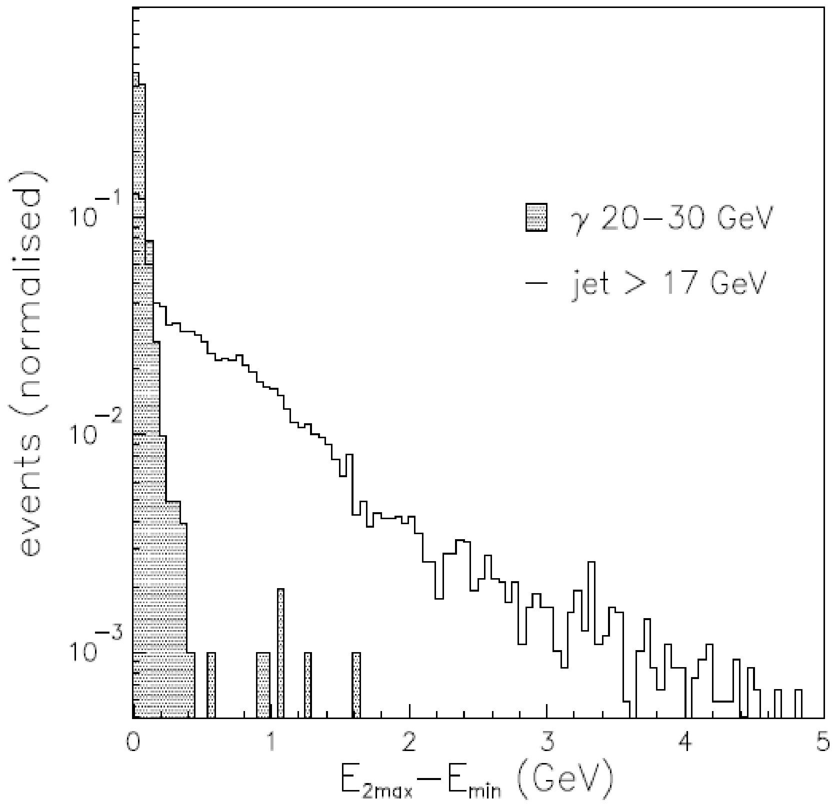
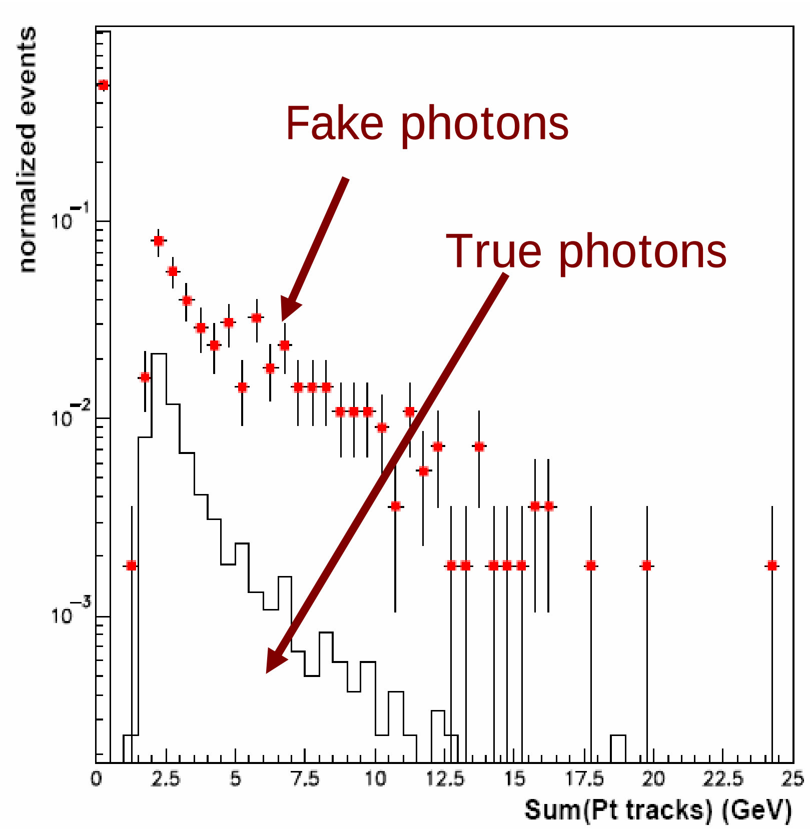
(II) Photon identification / jet rejection

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



Effect of track isolation

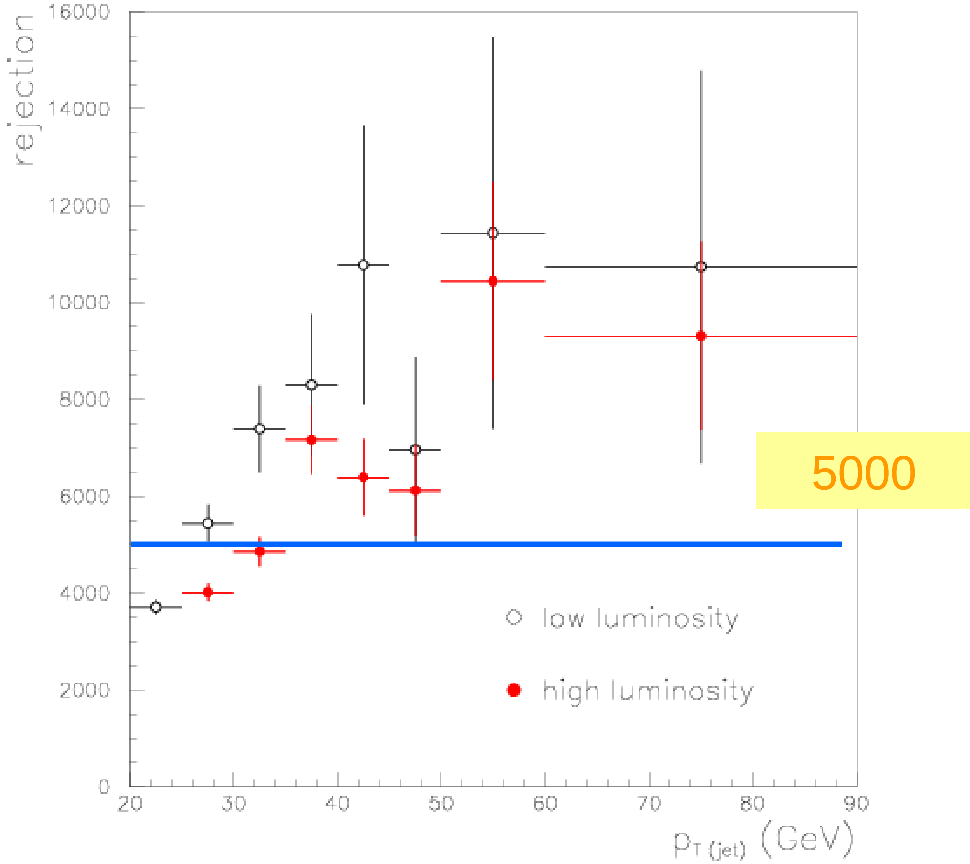


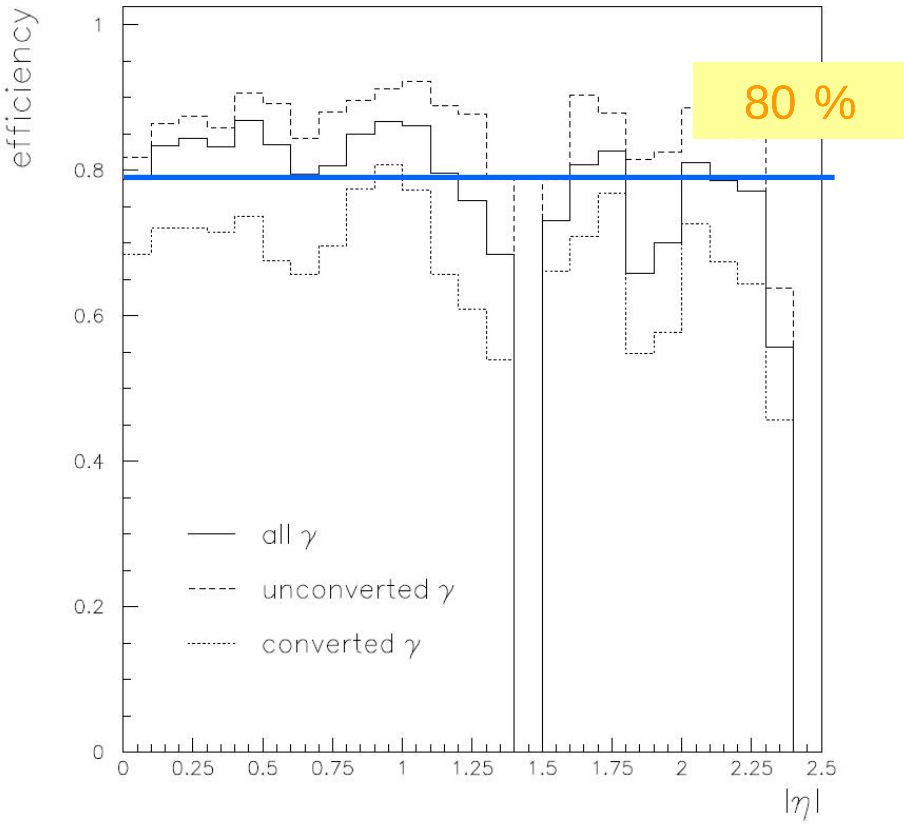
(II) DC1 inclusive analysis: photon identification / jet rejection

- Higher rejection against gluon initiated jets than quark initiated jets

Jet rejection ~5000 (P_T> 25 GeV)

80% average photon efficiency





(II) DC1 inclusive analysis: photon calibration

- Fixed cone clusters have been used: 3x7 (middle granularity) for converted photons while 3x5 (5x5) for 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

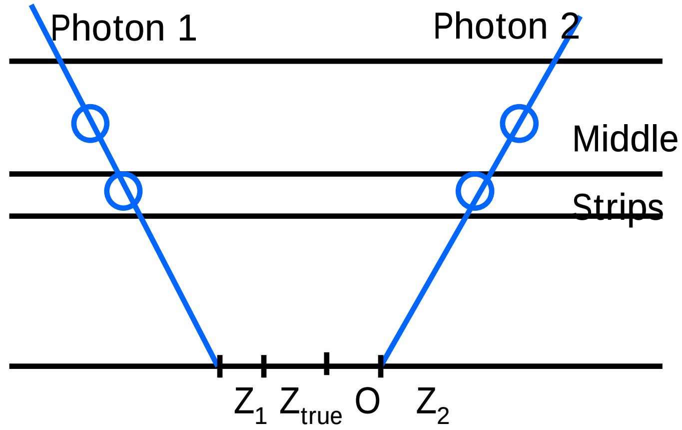
- The P_T > 25 GeV cut protects against linearity problems

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

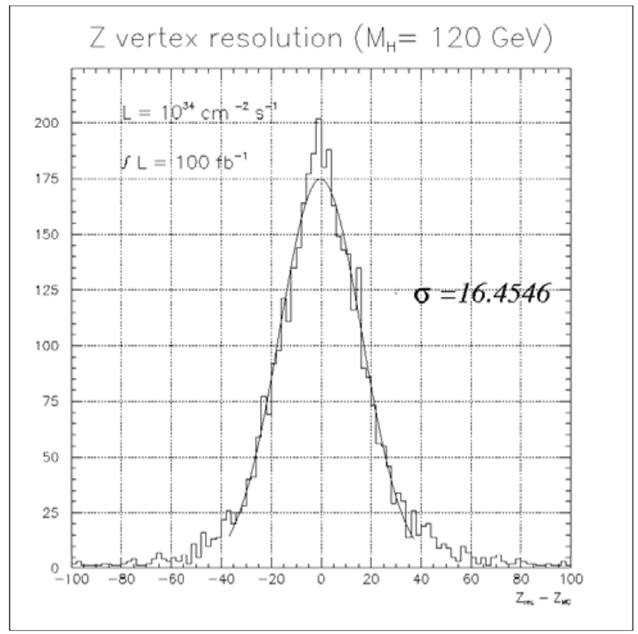
- Refined position using the following corrections:
  - S – shape for for strips and middle
  - Phi offset (middle only)

(II) DC1 inclusive analysis: 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**

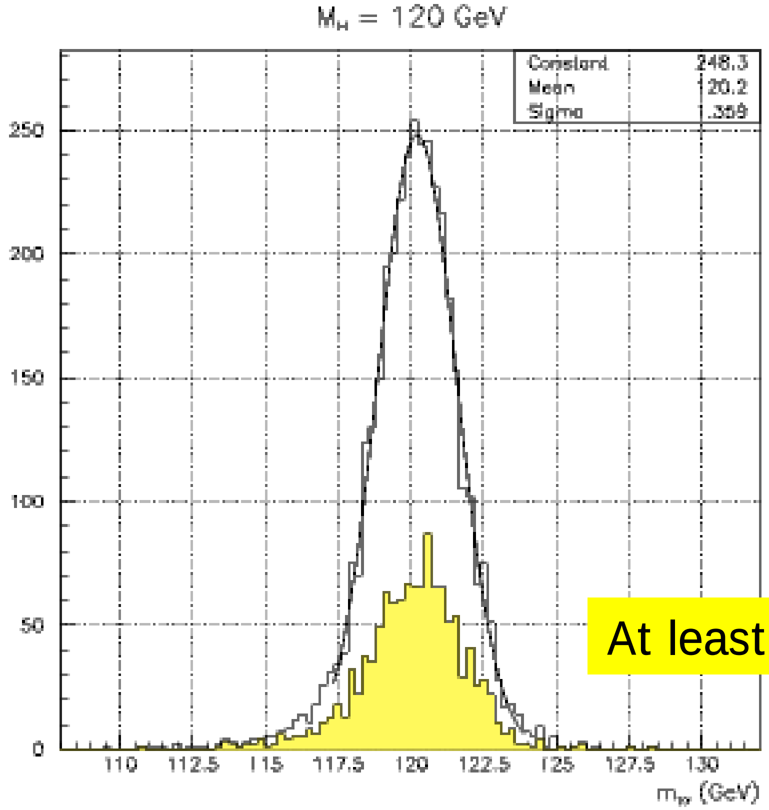
(III) Analysis cuts and reconstruction:

Analysis flow:

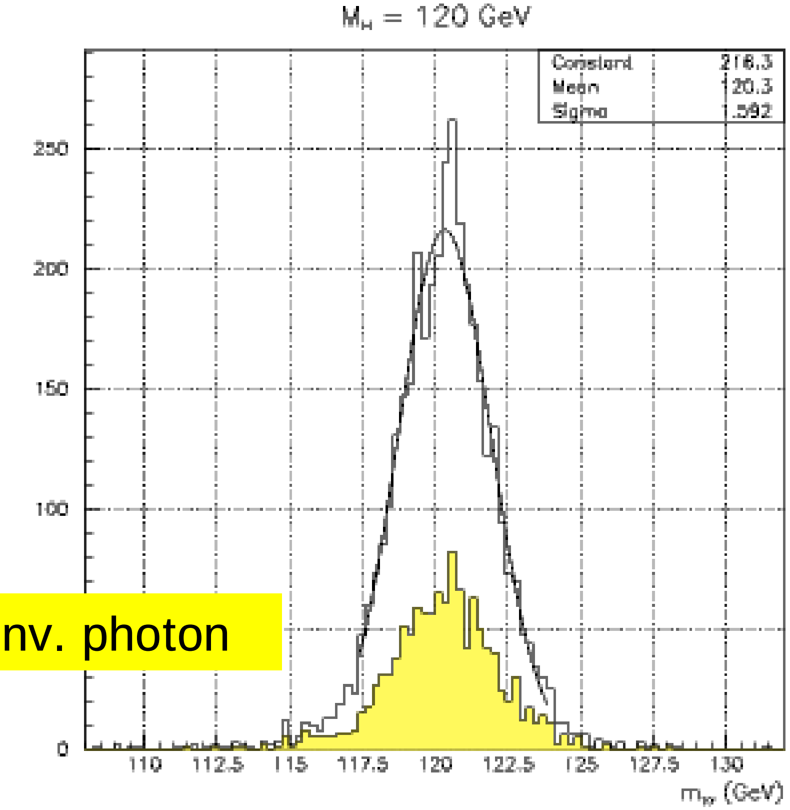
- Events with 1 γ in the electromagnetic calorimeter cracks excluded (bad energy resolution):
  - $|\eta|<0.05$, $1.4<|\eta|<1.55$ and $|\eta|>2.45$
- Transverse momentum cuts (background rejection):
  - $p_T(1)>40$ GeV, $p_T(2)>25$ GeV
- Photon identification cuts applied to all egamma candidates
- Photon reconstruction and calibration
- 0.7% constant term to the photons reconstructed energies added (mechanics, calibration, HV variations...not included in the detector simulations yet). Work in progress for “as built as installed” simulations
- The direction of both photons is corrected for the primary vertex position
- Invariant mass distribution of the two photons is reconstructed

(III) Higgs invariant mass reconstruction

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



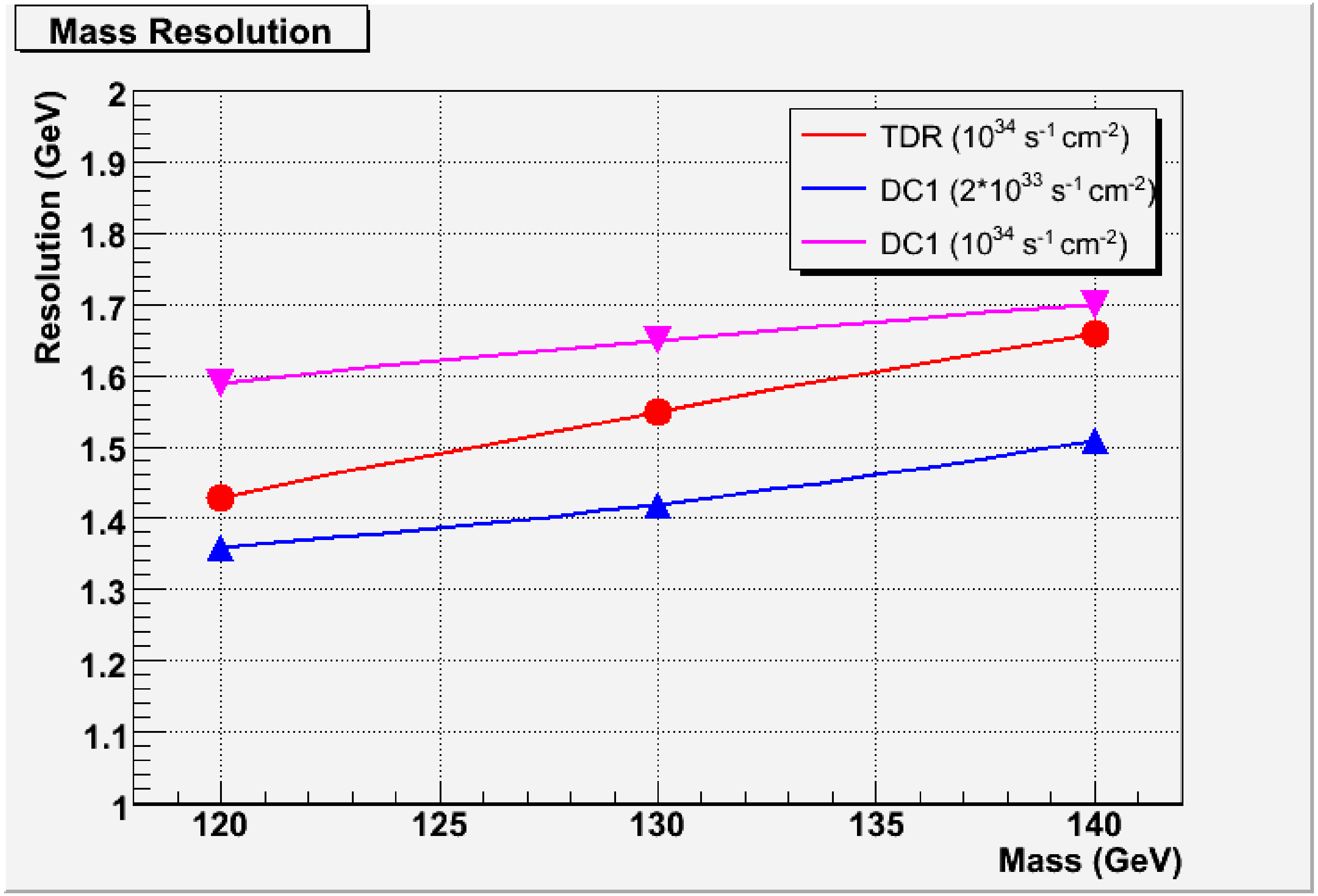
High lumi: 1.59 GeV
80.9% inside +- 1.4 σ



At least 1 conv. photon

(identification cuts applied to the photons)

(III) Higgs invariant mass reconstruction



(III) 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 (from ResBos and HiGlu)
- Associated production from PYTHIA (LO)
- $H\rightarrow\gamma\gamma$ branching ratio of PYTHIA corrected with HDecay

Irreducible background

- DIPHOX and ResBos : treatment of the background at NLO
- Increase of 47 % due to the LO -> 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.

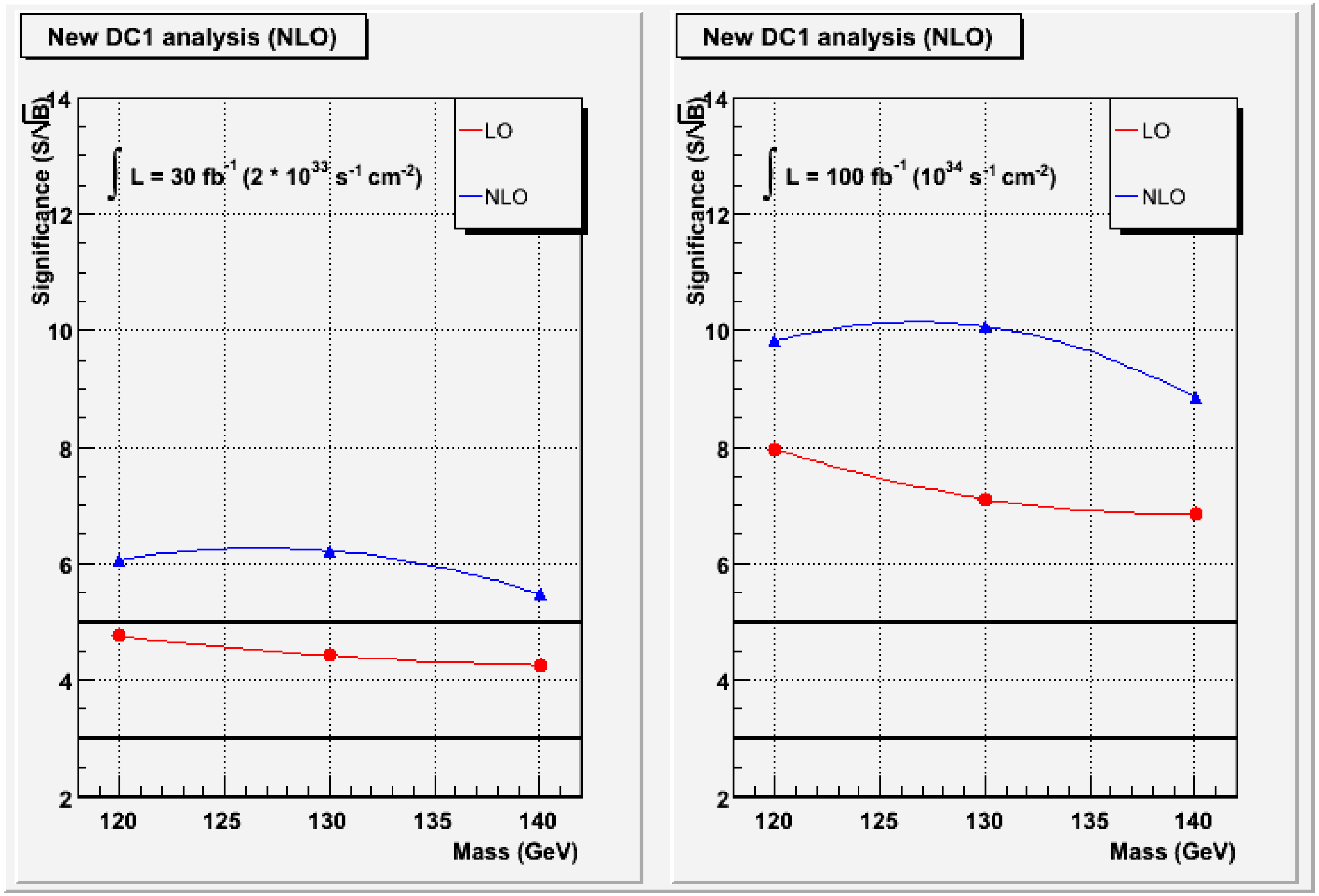
(III) Inclusive analysis results (NLO)

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

Mass (GeV)	120	130	140
σ (GeV)	1.36	1.42	1.51
Signal	815	758	610
Birreducible	14100	11472	9552
Breducible	3967	3396	2839
$S/\sqrt{(B)}$	6.06	6.22	5.48

(III) Inclusive analysis results (NLO)

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



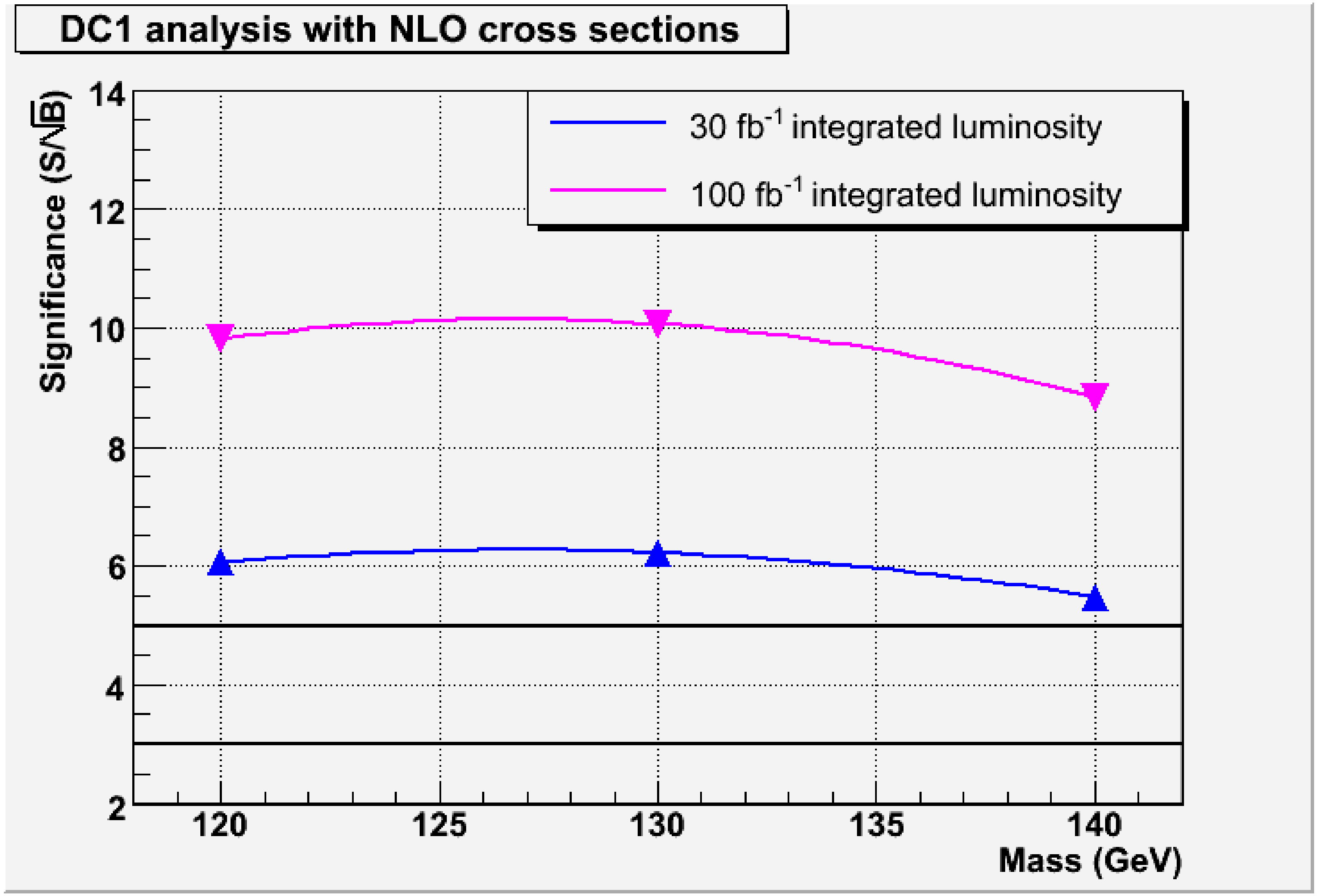
(III) Inclusive analysis results (NLO)

- Contributions to the uncertainty on the significance have been estimated:
  - 37 % on the signal (parton density functions, order of perturbative development, scale dependence)
  - 18 % on the irreducible background
  - A factor of 3 on γ/jet and 5 on jet/jet background: mainly from fragmentation (tipically $\pi^0 \rightarrow \gamma\gamma$), detector effects, higher order corrections to cross sections.

- Systematic uncertainty on the significance ~30 %

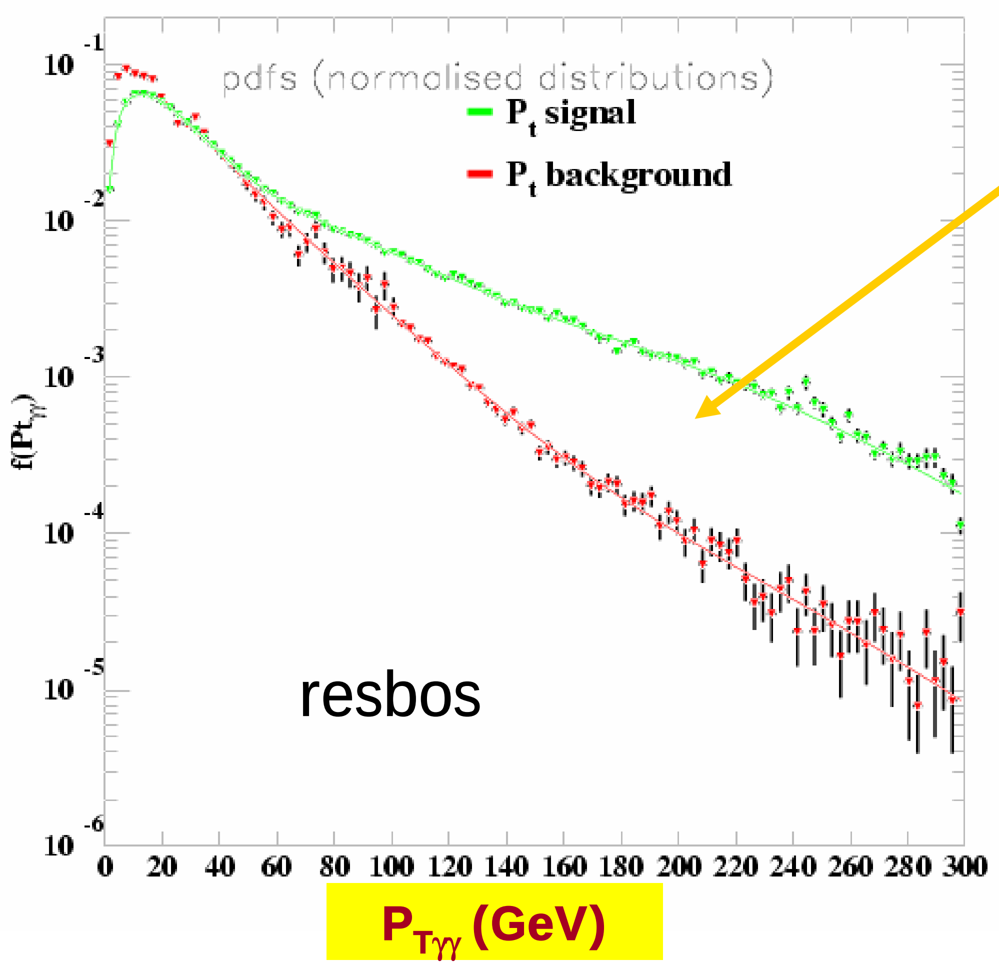
- An additional 10% lowering factor from background subtraction using sidebands

(IV) Summary of inclusive analysis in one picture



(III) 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 $\cos\theta^*$ (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.

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

- 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)

Summary

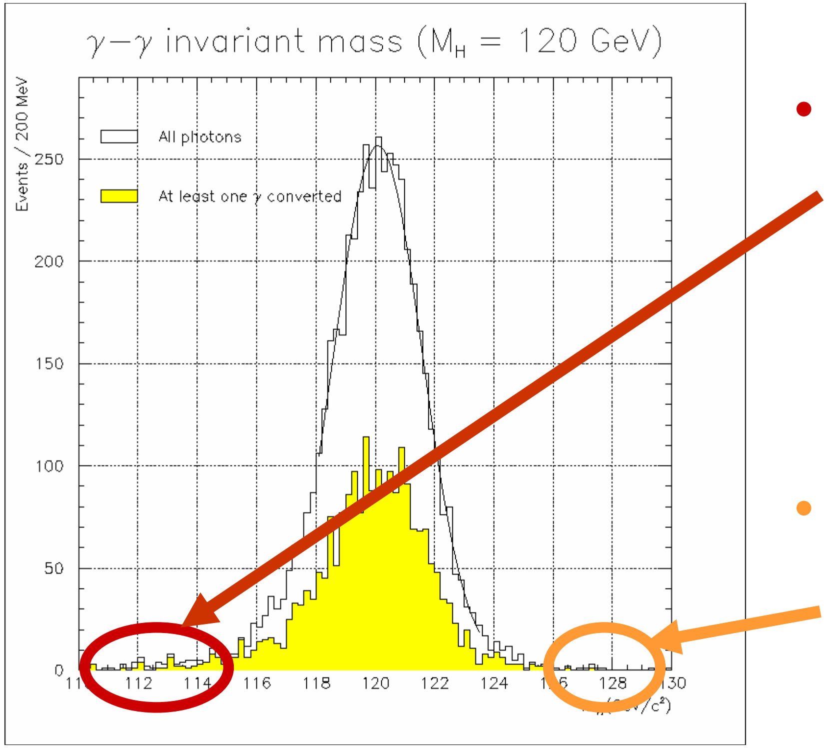
- Impact of the detector performance on the discovery potential has been readdressed with the most updated detector knowledge: only a slight degradation wrt TDR (<10%) has been observed.

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

- 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

(III) Adressing experimental issues

Study of the tails is important to understand reco problems.



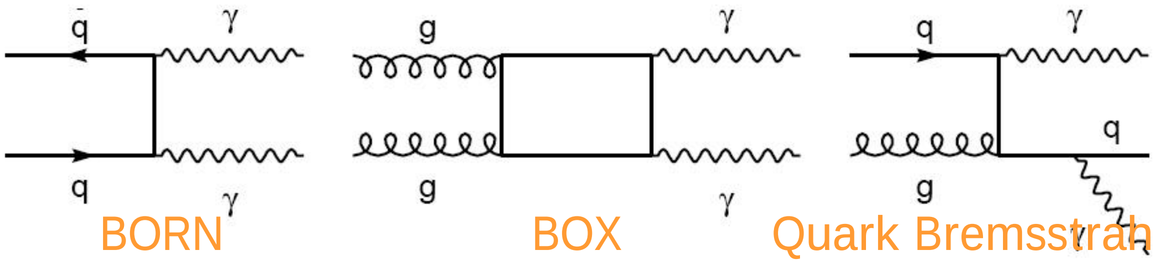
Example on 120 GeV low luminosity

- Low energy tail ($M_h^{rec} < M_H - 5$ GeV) : 48 events
  - 87 % are events with converted photons:
    - ~ 50 % of these events one conversion is not reconstructed
    - ~ 50 % one early conversion (R_C< 40cm)
- High energy tails ($M_h^{rec} > M_H - 5$ GeV) : 16 events
  - 70 % events with bad reconstructed vertex. Mainly both photons in the endcap.

- Main problems: handling converted photons and direction reconstruction in the endcap: items to be considered carefully

BACKUP SLIDES

Irreducible background:

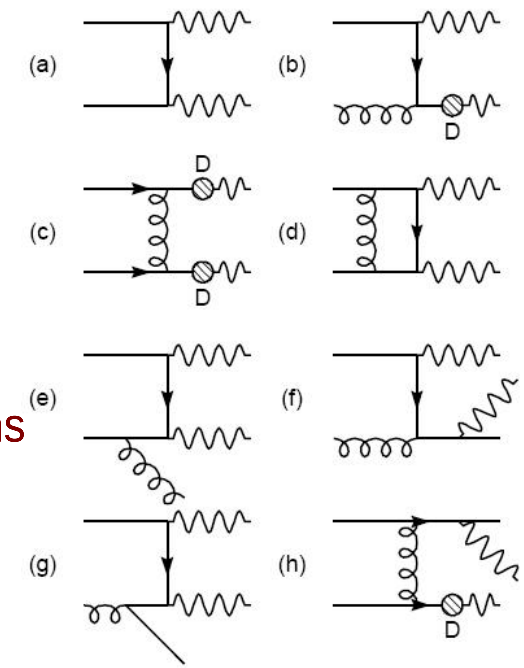


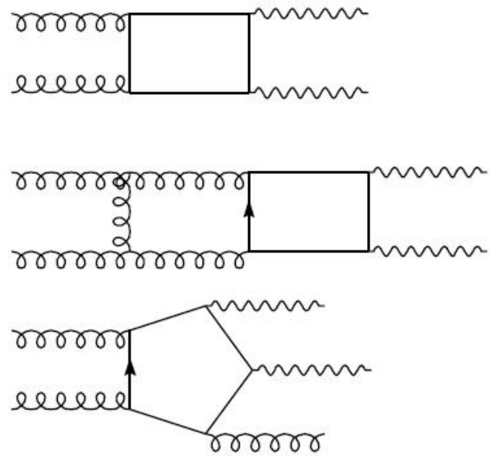
BORN BOX Quark Bremsstrahlung

Irreducible background
a' la TDR

Resbos :

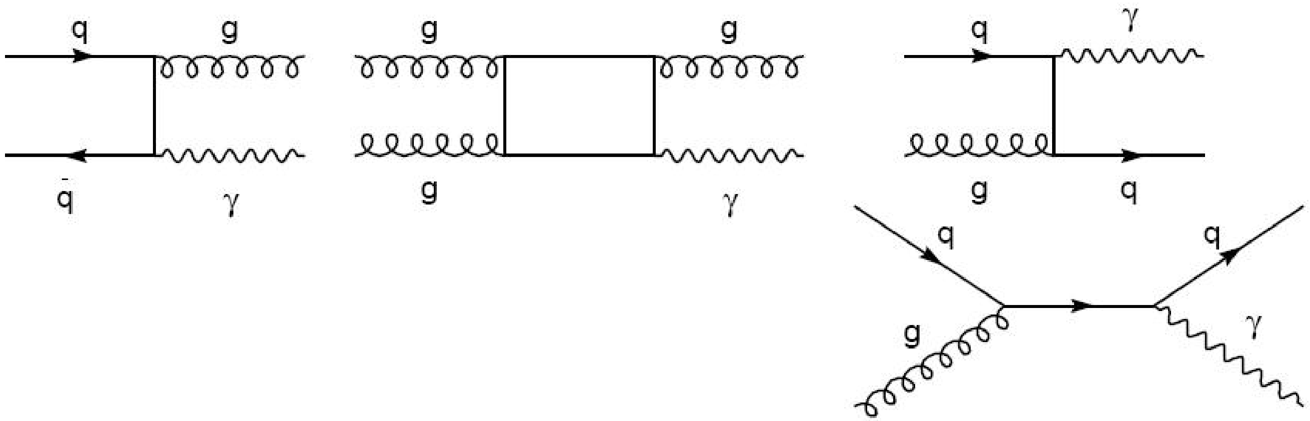
- Only unique fragmentation implemented
- Fragmentation at LO
- Resummation of soft gluons



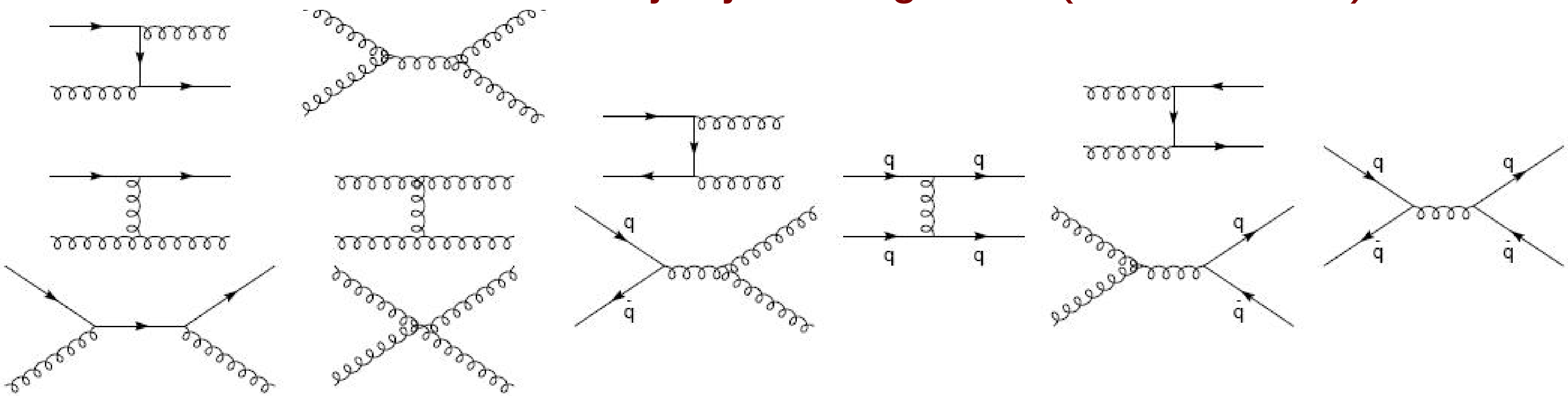


Reducible background:

γ/jet background (PYTHIA - LO)



jet/jet background (PYTHIA – LO)



$H \to \gamma\gamma$: conversion reconstruction

~ 40 % of $H \to \gamma\gamma$ events will have at least one converted photon:

• Fraction of converted photons in the fiducial region $R_C < 80$ cm and $|z| < 280$ cm

TDR	DC1	Rome
22%	24 %	21%

❑ TDR: track based conversion reconstruction algorithm optimized for $R_C < 80$cm

- ❑ Overall efficiency ~80% almost flat in R_C (up to 80 cm) , η and P_T
- ❑ Resolution on the reconstructed Z vertex : σ_Z =0.3 mm for $R_C < 20$ cm and σ_Z=5.3 mm for $20 < R_C < 40$)

❑ DC1: vertexing algorithm for conversion reconstruction implemented into Athena but not optimized (G. Gorfine). In the analysis TDR efficiencies have been used.

❑ Rome: preliminary results obtained for $R_C < 20$ cm conversions (D. Joffe) (~80% for 100 GeV photons).

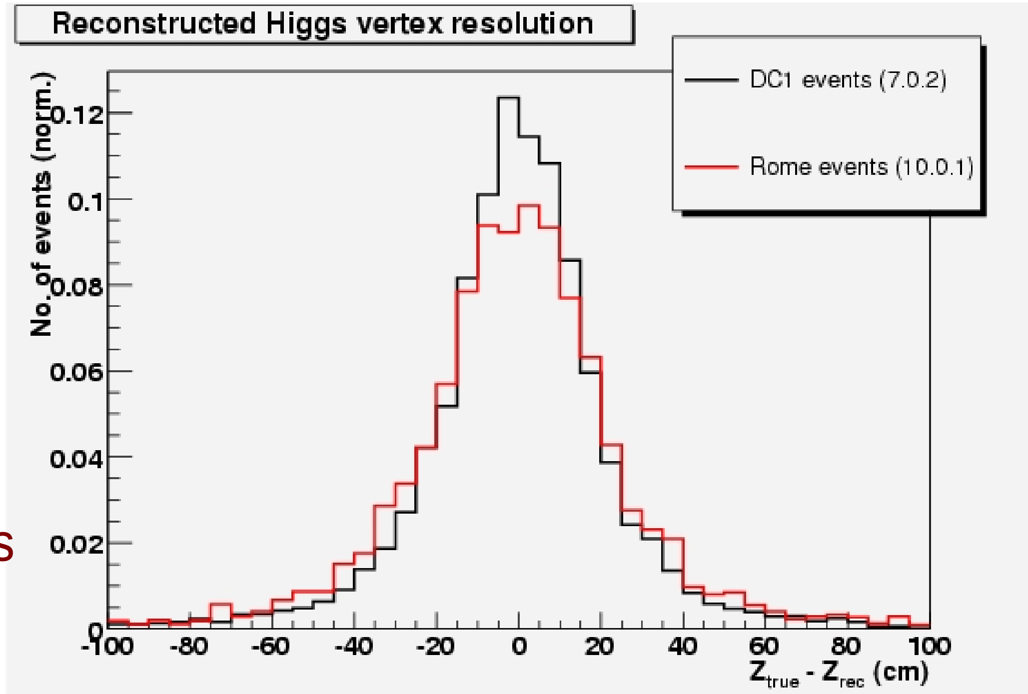
Need to asses a track reconstruction strategy and optimal cuts for conversions especially at high radii as was done in the TDR

H→γγ: primary vertex reconstruction

Impact of primary vertex reconstruction on the mass resolution (DC1) no pileup and no const term smearing

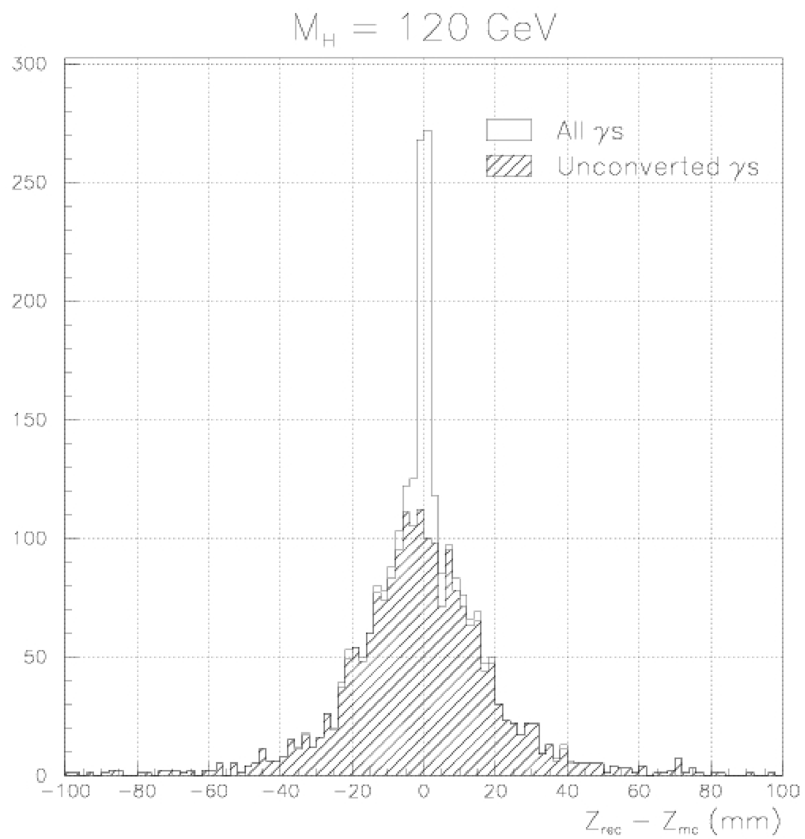
	σ (GeV)
Uncorrected	~ 2.00
After calo pointing	~ 1.48
Direction from Truth	~ 1.30

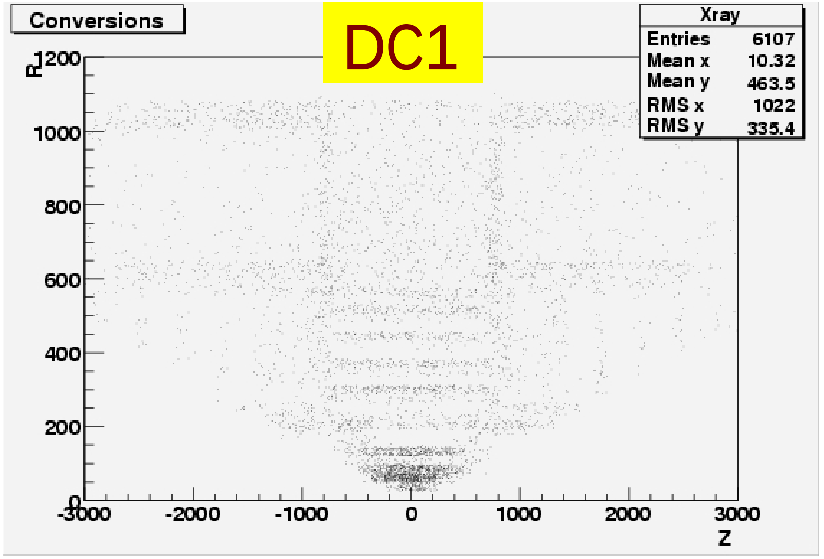
- Primary vertex provided by Inner Detector with a resolution of 40 μm
- The photons direction can be measured from em-calo standalone leading to a Z vertex resolution of
  - TDR ~ **1.33 cm**
  - DC1 ~ **1.67 cm**
  - Rome ~ **1.94 cm**
- DC1/Rome: non optimal η corrections
- Conversion vertex can be used in the direction fit to improve the resolution

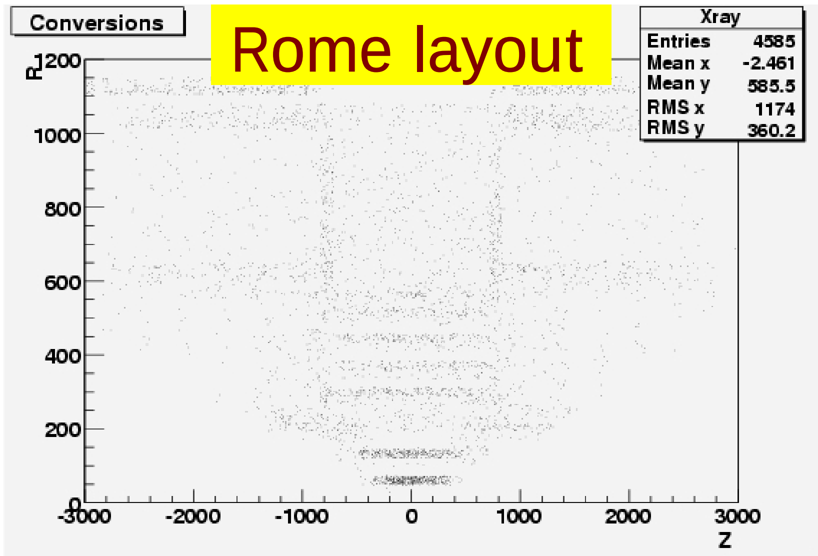


Conversion vertex in the direction fit

Use conversion vertex in the direction fit







Analysis cuts and reconstruction:

- Events with 1 γ in the electromagnetic calorimeter cracks excluded (bad energy resolution):
  - $|\eta|<0.05$, $1.4<|\eta|<1.55$ and $|\eta|>2.45$
- Transverse momentum cuts (background rejection):
  - $p_T(1)>40$ GeV, $p_T(2)>25$ GeV
- 0.7% constant term to the photons reconstructed energies added (mechanics, calibration, HV variations...not included in the detector simulations)
- Conversions found from MC taking into account 80 % efficiency (flat in eta and p_T)
- Different cluster size for converted (3x7) and unconverted photons (3x5):
- The direction of both photons is corrected for the primary vertex position using a weighted least squares fit and a simple GEANT 3 parametrization of the shower depth

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

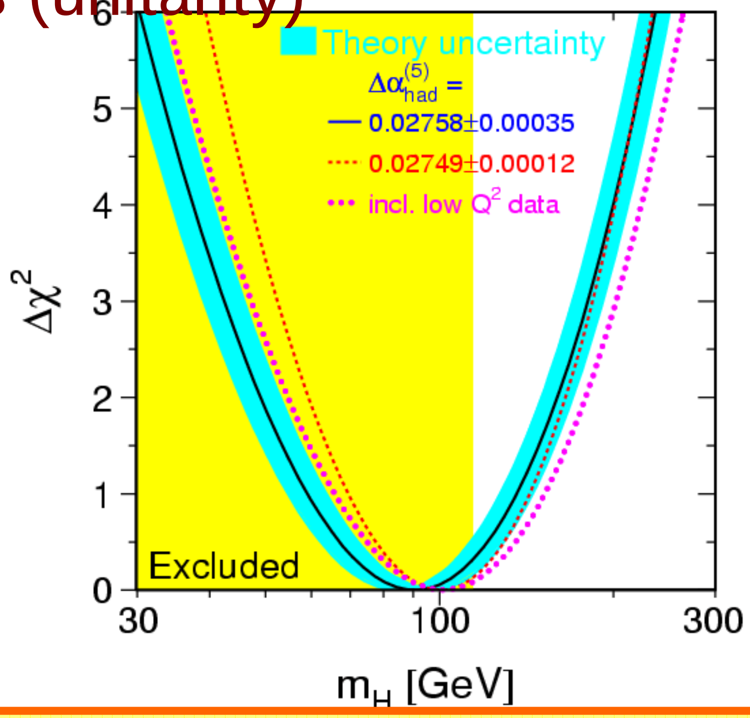
Contributions to the calorimeter resolution

$$\frac{\sigma_E}{E} = 0.7\% \oplus \frac{10\%}{\sqrt{E}} \oplus \frac{300 MeV}{E}$$

	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**

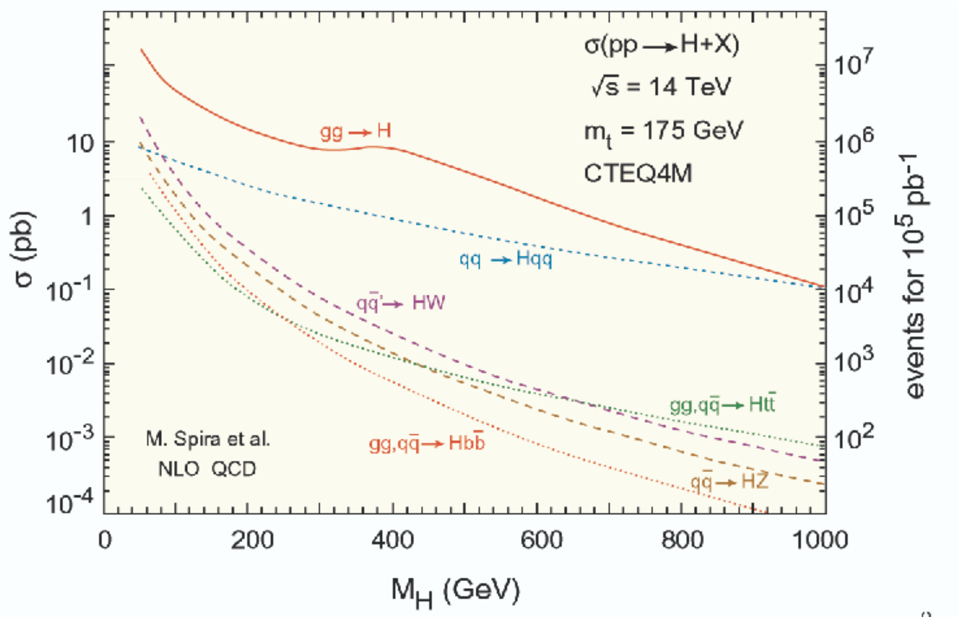
Higgs physics: what do we know?

- 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

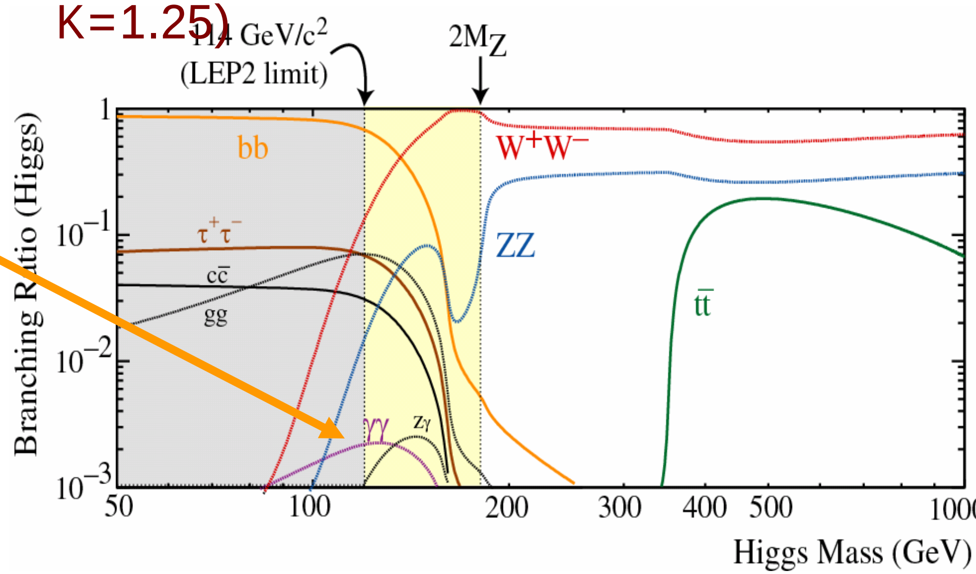


Anyway, current indications are for a 'light Higgs' : search for Higgs in mass region 114 < m_H < 200 GeV very important

SM Higgs production and decay:



- Dominant production process is the gluon-gluon fusion (LO ~20 pb for M_H=120 GeV K=1.9)
- 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)

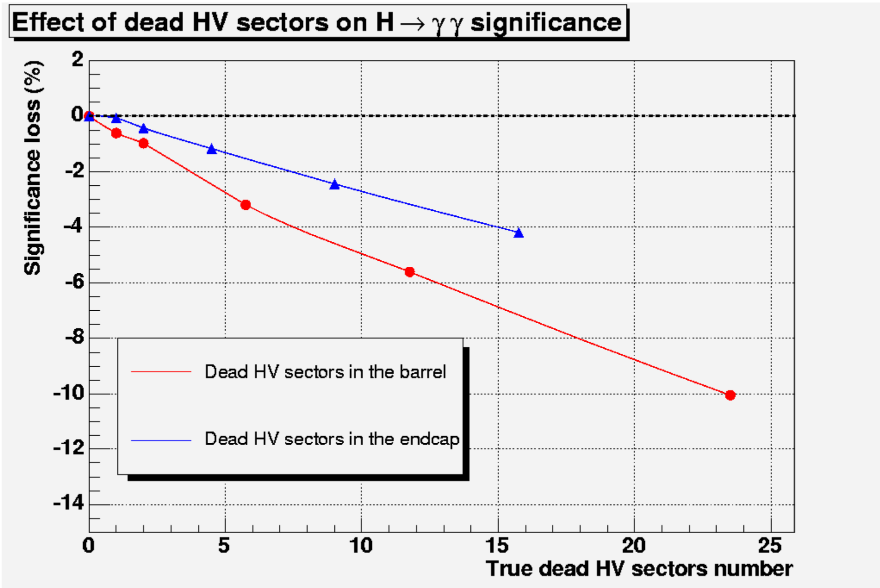


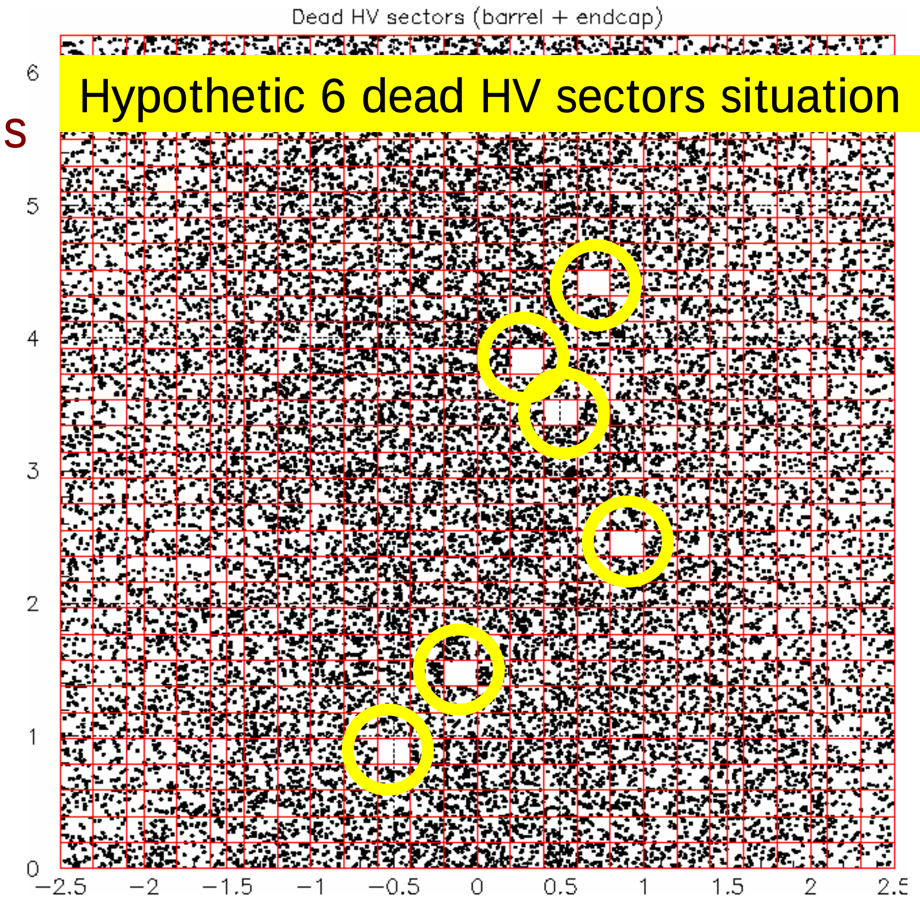
- $H\to\gamma\gamma$ is a rare decay mode with BR ~ 10^{-3} (2.186 10^{-3} for M_H=120 GeV)
- The signal should be visible as a peak above the $\gamma\gamma$ continuum background
- Severe requirements on particle identification capabilities of the detector

DC1 data: a bricolage approach to the 'as built detector' project

Milano

- Study performed on M_H=120 GeV sample (no noise and no pileup): the HV problems simulated at the reconstruction stage.





- Up to now only 2 (endcap) fully dead sectors have been observed at cold
- Not dramatic: from our simulation 2-3% loss in significance for up to 6 fully dead HV sectors

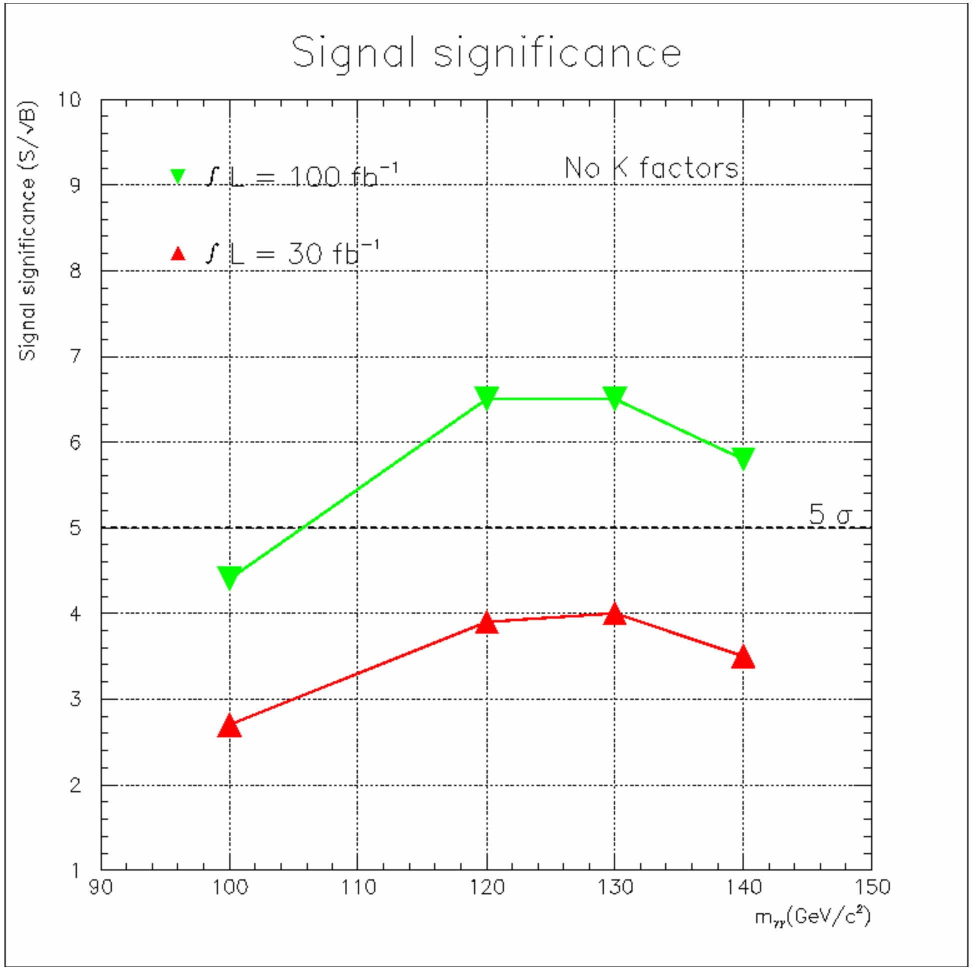
(I) What we knew @ the TDR time about the channel

- Signal: Use of LO cross-sections for signal PYTHIA 5.7 (with CTEQ2L) and GEANT 3 - Atrecon based analysis
  - σ x BR ~50 fb for M_H=120 GeV
  - Acceptance of kinematical cut ~ 50 %

- Irreducible $\gamma\gamma$ background (not in full simulation)
  - Born (LO) + Box (higher order but enhanced by structure functions)
  - Some estimate of 'bremstrahlung' contribution
  - Born+Box ~0.7 pb/GeV before kinematical cuts (~10% acc) and photon efficiency (~2 x 80%) for M_H=120 GeV + quark bremsstrahlung (~ 50% of the Born+box).

- Reducible background from jet-jet and γ-jet events in which one or both jets are misidentified as photons from full simulation: Reducible / irreducible cross section ~$2x10^6$(jj) $8x10^2$(γj) with large uncertainties
  - Excellent jet rejection factor (~10^3) for 80% γ efficiency required : after all cuts the reducible background ~20% of the irreducible

(I) What we knew @ the TDR time about the channel

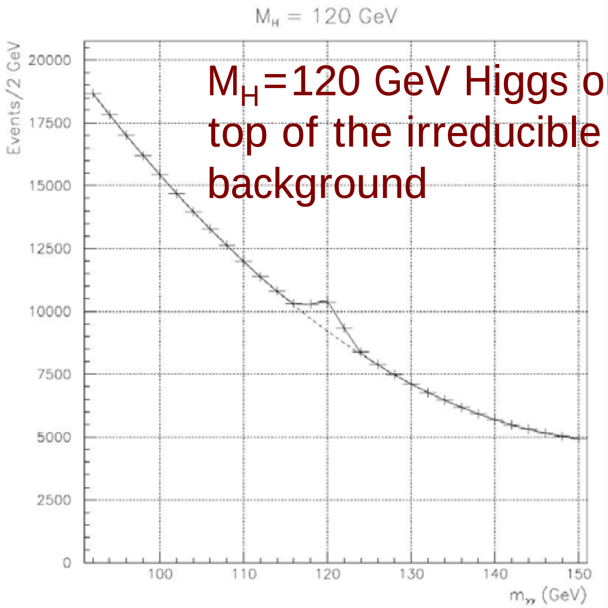


- 100 fb^{-1} collected in high luminosity conditions (10^{34} cm^{-2} s^{-1})
- 30 fb^{-1} collected in low luminosity conditions (10^{33} $cm^{-2}s^{-1}$)
- Associated production (HW, HZ and Httbar) analysis: ~ 4 σ achieved with 100 fb^{-1} of integrated luminosity. This analysis has not been updated yet.
- H+Jet(s): no definite conclusion in TDR because of lack of full NLO computations

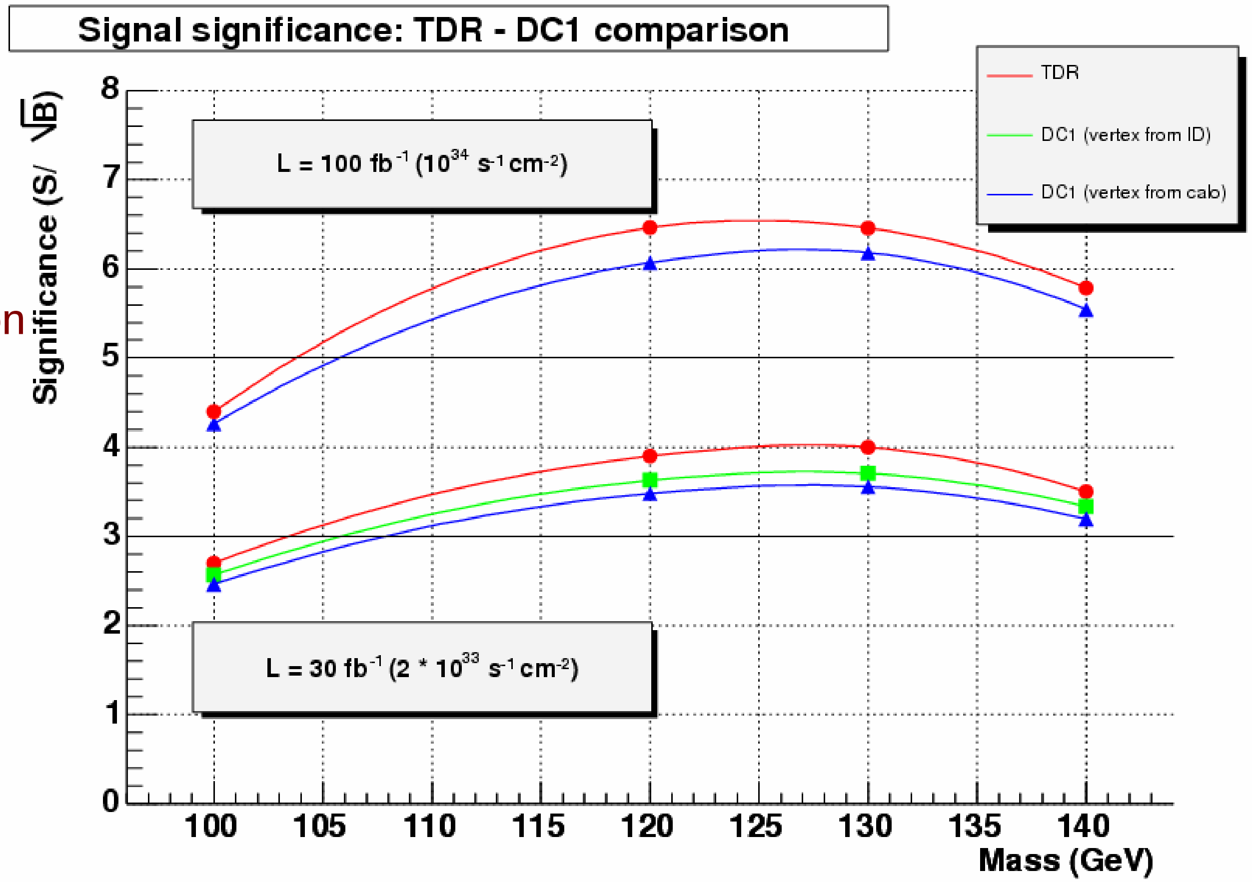
(III) DC1 inclusive analysis: DC1 results

- Direct TDR/DC1 comparison of significance with same cross-sections (LO)
  - Naïve estimation of significance = $N_S/\sqrt{N_B}$ in 1.4 σ mass bin
  - Slight degradation (< 10%) in the new detector layout mostly due to worse Higgs mass resolution
  - No photon ID cuts

(80% flat efficiency)



M_H=120 GeV Higgs on top of the irreducible background



(III) DC1 inclusive analysis: results (LO)

- Re-evaluation of signal significance with state of the art LO cross-sections, branching ratios and DC1 resolution

  - ❑ New LO cross sections for signal and background (PITHYA 6.224 and CTEQ6L1)
  - ❑ Photon identification cuts have been applied
  - ❑ Irreducible background a' la TDR
  - ❑ Reducible background reevaluated