$\gamma\,\gamma$ channel at LHC with NLO computations: user's experience

- Introduction on $\gamma\gamma$ channel for Higgs search. What computations are available ?
- What can be computed with NLO programs:
  - rate
  - event characteristics
- Wish list

(experimentalist's point of view…)

$\gamma\gamma$ channel at LHC for Higgs search

- $H \rightarrow \gamma\gamma$ channel is one of the main channel for discovery of low mass Higgs (115-140 Gev)
- Main background: inclusive production of direct photon pairs

$\Rightarrow$Look for peak in $\gamma\gamma$ invariant mass

- good mass resolution possible (~1.4 GeV in Atlas at 120 GeV)
- background shape is smooth
- background can be measured from data using sidebands

Higgs signal

- Higgs production:
  - g g fusion, computed at LO,NLO,NNLO

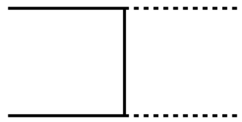
    $\sigma \approx 20, 38, 44$ pb for M_H=120 GeV

    (see for instance Ravindran, Smith and Van Nerven, hep-ph/0302135
    Harlander and Kilgore, hep-ph/0201206)

    $d\sigma/dPt(H)$ also computed at NNLO with resummation
  - Vector Boson Fusion, computed at NLO (K factor « small ») $\sigma_{LO} \approx 4$ pb
  - Associated production WH,ZH,ttH (2.5 pb)
- BR($H \rightarrow \gamma\gamma$) = 0.22% (at M_H=120 GeV)
- To exploit NLO computations of signal would like to have NLO computations of background

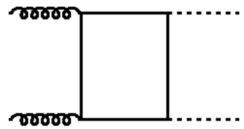
Background processes

- LO diagram: Born $O(\alpha^2)$

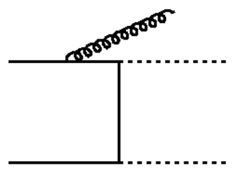


- $gg \rightarrow \gamma\gamma$ through Box has similar rate

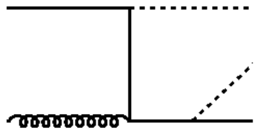
(order $\alpha^2\alpha_S{}^2$ but enhanced by structure functions)



- $\alpha^2\alpha_S$ contributions:
  - Higher order corrections to qq fusion



  - « Bremstrahlung » diagram



« Original sin » : Box (formally NNLO) is comparable to Born (LO).

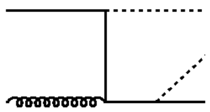
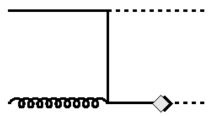
What is a « real NLO » background computation ?

- $\alpha^2\alpha_s$ + BOX
- $\alpha^2\alpha_s$ + BOX + α_s corrections to BOX ($\alpha^2\alpha_s^3$)
- Full $\alpha^2\alpha_s^2$ computation (or even $\alpha^2\alpha_s^3$!?)

Computations used

(not exhaustive review)

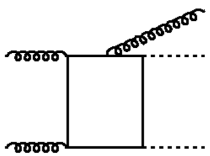
- Diphox (see Binoth,Guillet,Pilon,Werlen in Eur.Phys.J.C16(2000)311): Full $\alpha^2\alpha_S$ computation. Also NLO treatment of colinear brem contribution:

$O(\alpha^2\alpha_S)$  $O(\alpha)$  $+\alpha_S$ corrections

Non perturbative frag. function

- Bern,Dixon,Smidth (Bern,Dixon,Schmidt in hep-ph/0206194)

NLO computation of BOX diagram



+ extra loop diagram

What can be computed ?

- Event rate

Pt(γ1)>40 GeV, Pt(γ2)>25 GeV |η| < 2.4

ΔM ±2 GeV around M=120 GeV

100 fb^{-1}, ε=80% per photon, Isolation:Et<5GeV in DR=0.4

≈ 47000 events

- **11000 Born LO + 4000 Born HO**
- **11000 BOX LO + 2500 BOX HO** (LO/HO depends on α_S definition and structure function NLO/LO in computing BOX LO)
- **18000 Bremstrahlung**

$\alpha^2\alpha_S/\alpha^2$ only = factor 3 (>4 if includes BOX)

NLO « traps »

- Be careful when separating background in various components:
- Brem = direct + fragmentation, separation somewhat arbitrary, only sum is « physical »
- Example: tighter isolation cut => direct contribution increases ! But frag and sum decreases (as expected)
- Similar behaviour when changing factorisation/renormalisation scale
- Explained in Diphox paper

- Event characteristics:
  - Motivation: Use more information than $M\gamma\gamma$
  - H events have more jet(s) than background
  - Angular distribution, etc…
- Shape of background different at LO and NLO (obvious for $Pt(\gamma\gamma)$ pair for instance, also angular distributions are not the same).
- In this case, cannot just use LO+Parton shower MC « normalized » to NLO σ

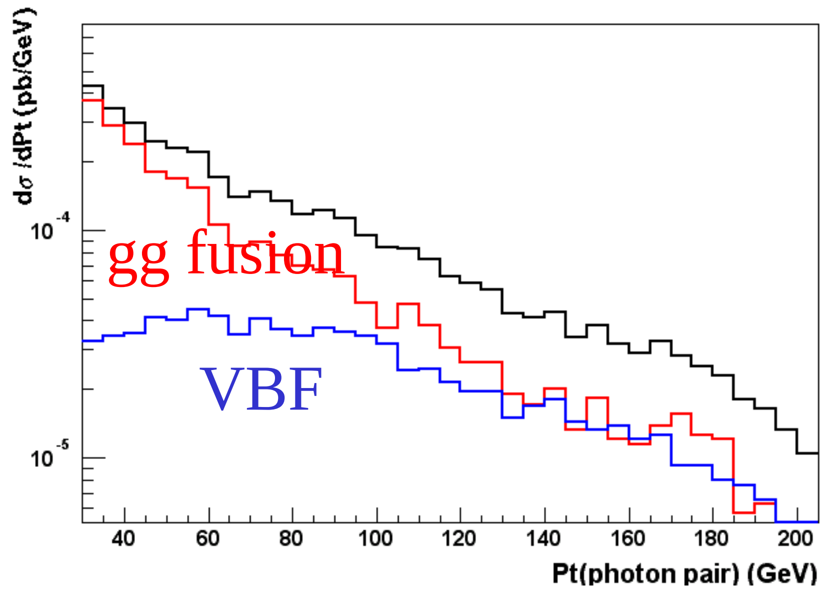
Example: $\gamma\gamma$+jet vs $\gamma\gamma$

- « K factor » for signal large => Higgs often produced at high Pt (in association with jet)
- $\gamma\gamma$+jet events may also have experimental advantages (production vertex determined easily from tracks in jet)
- What is the change in S/B and S/$\sqrt{B}$ when applying for instance a cut on Pt($\gamma\gamma$) ?
- Need full NLO computation to compare to no cut case (tree level matrix elements are not enough)

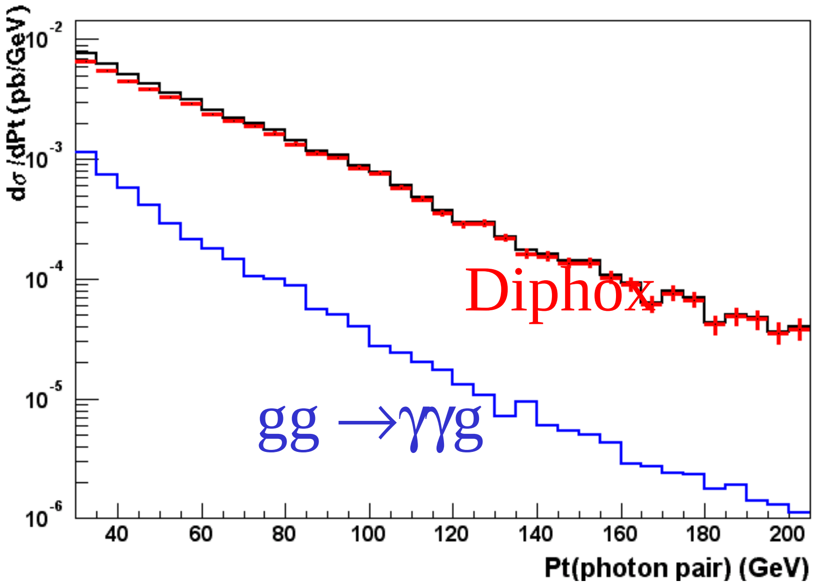
Distributions of Pt(γγ)

Fixed order matrix element computation => computation not reliable at « low Pt »

Signal

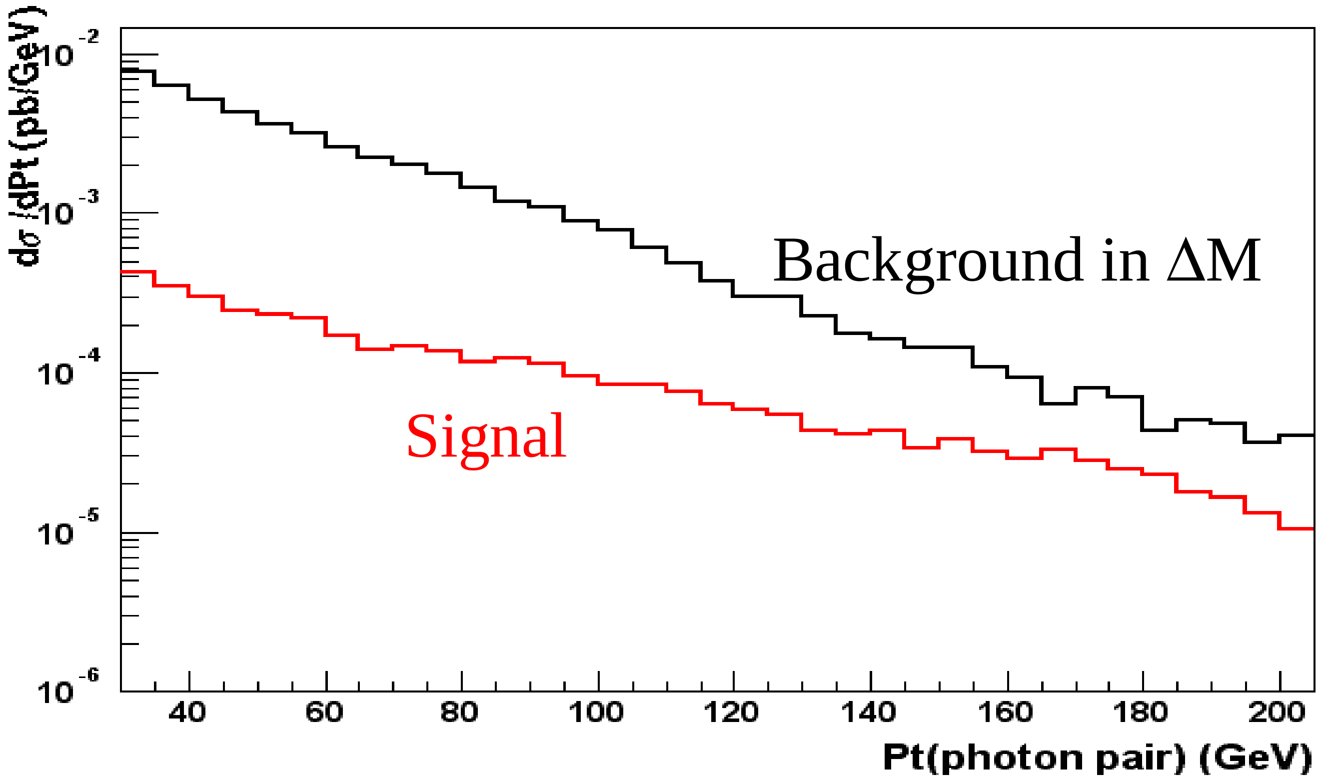


background



Background dominated by brem. contribution qg →γγq

Pt(γγ) signal vs background



Cut on Pt(pair) ⇒ Significant improvement in S/B (by ~3-5)

Somewhat Worse $S/\sqrt{B}$ (by ~0.6)

Can also cut on Pt(jet) + M(γ–γ–jet)

(cf S.Abdullin et al, Phys.Lett.B431(1998)410)

At high Pt($\gamma\gamma$) NLO of inclusive = LO of high Pt
What about NLO corrections to $\gamma\gamma$ at high Pt(pair) ?

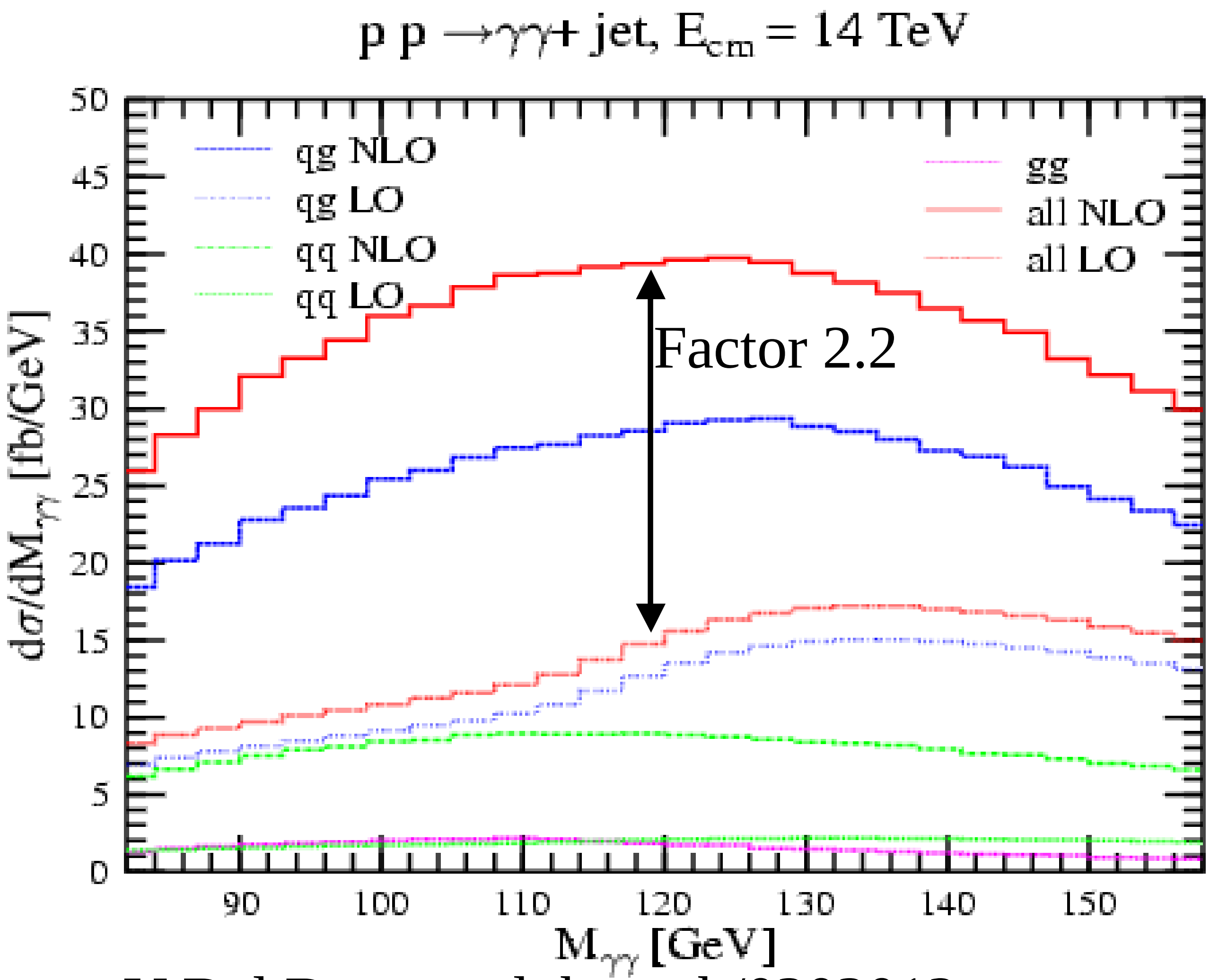
Signal: K factor for gg fusion at high Pt computed, ~1.8

Background: Recent computation of NLO corrections to $\gamma\gamma$ + jet
(include real corrections from $\gamma\gamma$ + 2 jets and loop effects)

=> K factor can be large (close to 2)
Depends on photon isolation cut

Does this suggest NNLO/NLO for inclusive is large ?
(for Higgs, NNLO/NLO is $\approx$1.2)

Pt(γ) > 40 GeV, Pt(jet seen)>40 GeV, Isolation in 0.4 cone



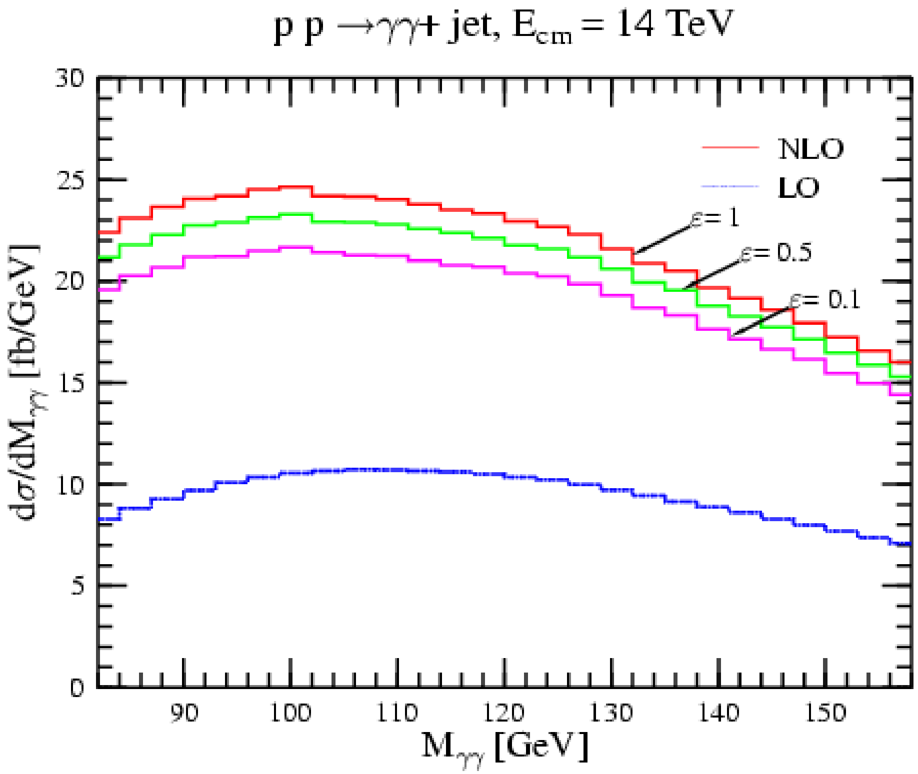
From V.Del Duca et al, hep-ph/0303012

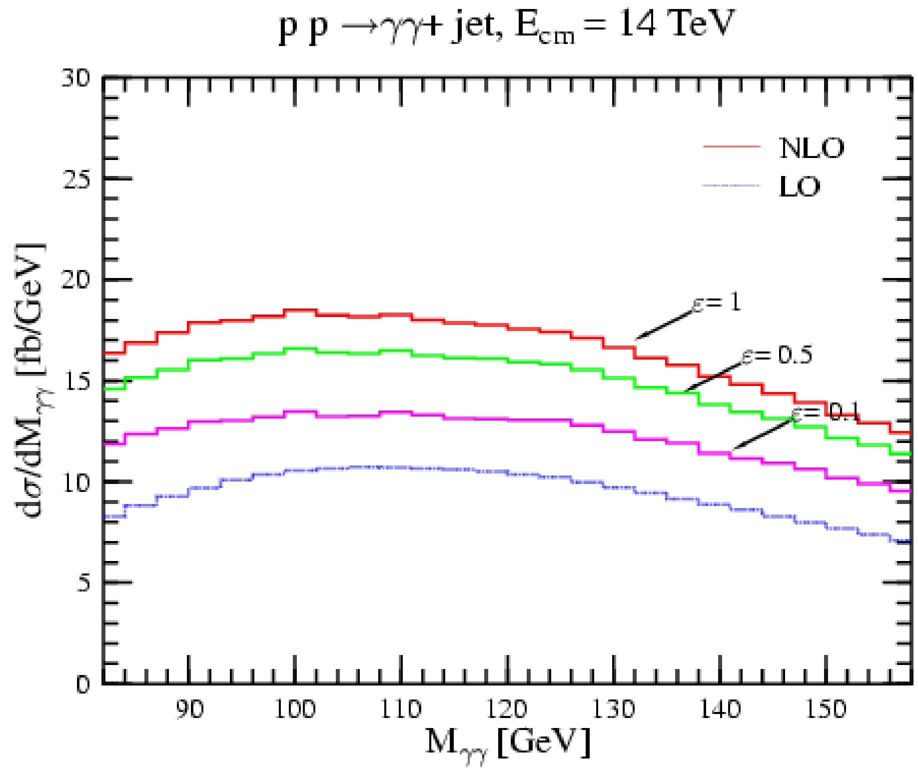
Isolation cut effect:

Pt(γ) > 40 GeV, Pt(jet)> 40 GeV DR(γ-observed jet)>1.5

Compare isolation in cone 0.4 and cone 1.0

=> significant variations in K factor (~2.2 => ~1.3 to 1.5)





Et < ε Et(γ) (1-cos(ΔR))/(1-cos(ΔRmax)) =>ε=0.1 and ΔRmax=1 most likely unrealistic

Going to γγ+2 jets final state

- Motivation: optimise cuts to select VBF events (2 « forward » jets)
- cf study by Rainwater and Zeppenfeld (hep-ph/9712271)
- Background computation:
  - need tree level matrix elements for γγ+2jets (including EW contribution) => Madgraph,Comphep,…
  - Study of central jet veto challenging (need to estimate γγ+3jets/γγ+2jets ratio, which is expected to be large when 2 jets are « tagged » back to back in η)
- S/B could be close to 0.5 to 1 => very complementary to inclusive analysis.

(naive) wish list

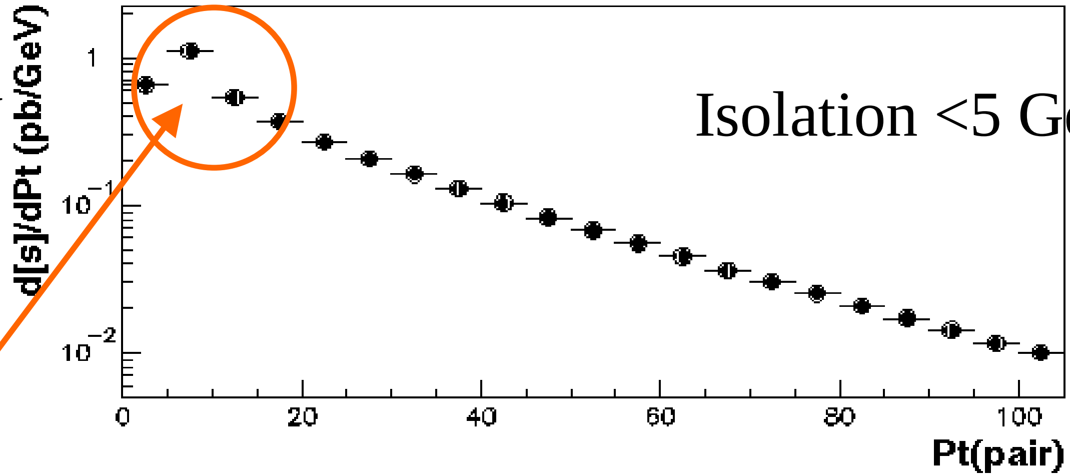
- intrinsic limitations of fixed order matrix element computations: « Low » Pt part not well described => Resummation

(see for instance Resbos program from Balazs/Yuan, hep-ph/9905551). Up to which Pt are these effects important ?

- parton level limitations: Isolation cut « crudely » modelled. Would need fragmentation+underlying event +… to do a better job
- Put NLO into parton shower program ?
  - **Fix (at least partially) low pt part**
  - **Isolation better described**
  - **$\gamma\gamma$ case probably complicated (fragmentation contribution and brem vs QED radiation in shower, …)**

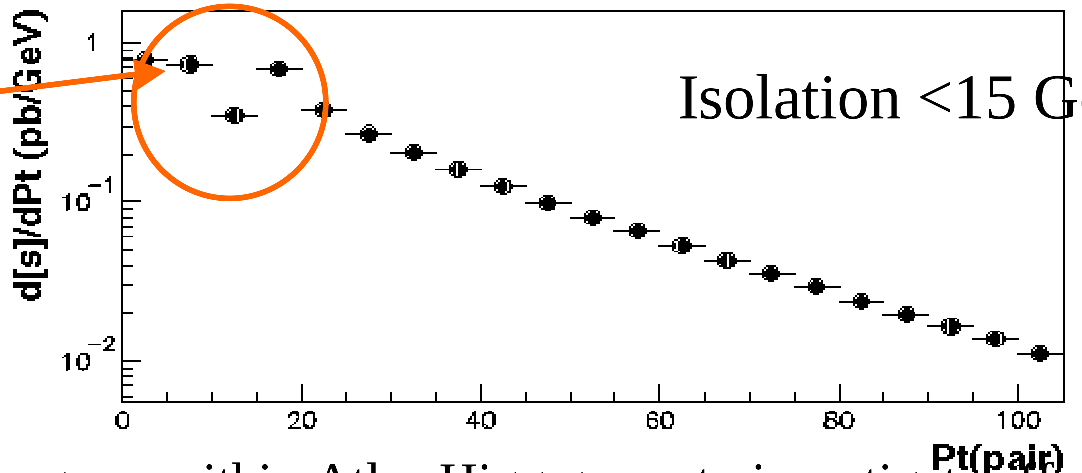
Pt(γγ) in Diphox

Pt(γ)>25 GeV
80<M<140 GeV
|η|<2.4



Isolation <5 GeV in ΔR=0.4

Region with
Pt(γγ)<< M



Isolation <15 GeV in ΔR=0.4

(studies in progress within Atlas Higg group to investigate effect of resummation a la Resbos (M.Escalier, B.Laforge)

Do we really care ?

- Total rate of Higgs background=> best extracted directly from data

(direct photon production is however a interesting QCD test per se. Is NNLO useful/needed ?)

- Modelling of various variables: Can probably improve sensitivity to Higgs (i.e. less luminosity to have significant excess). Most probably many things can also be derived from data, but at the beginning (low data stat) MC can be useful (also should not be biased too much by data).
- If Higgs found, need good MC for signal to derive informations from observed rate (couplings, …)