STUDY OF DIRECT PHOTON AT CMS

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OUTLINE

- Direct Photon – Motivation
- Direct Photon Physics – Signal & Background
- Event Generation
- S/B optimization studies
- Summary
- Conclusions

MOTIVATION

Direct Photons are those which emerge directly from the hard scattering of the partons so they provide a clean signature of the underlying hard scattering dynamics. Study Direct Photon

- To validate perturbative QCD
- To study gluon distribution of proton
- Background to many SM and BSM processes such as

  a) Intermediate mass SM Higgs (100 GeV – 130 GeV) - H→ $\gamma\gamma$

  b) Diphoton processes for new physics
    - Quark Compositeness signature : qqbar→ q^*→ $\gamma\gamma$
    - Randall-Sundrum Graviton signature : G→ $\gamma\gamma$

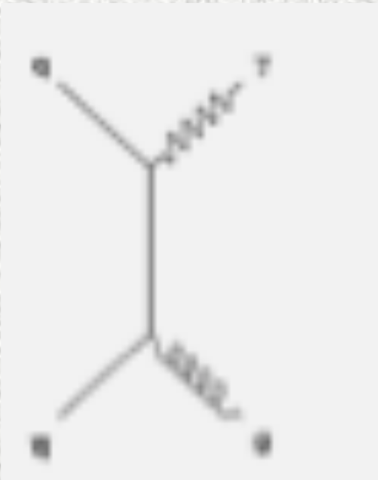
  c) γ + $\not{E}_T$ process for new physics
    - γ + $\not{E}_T$ As a signature of ADD Graviton
    - Quark Compositeness signature : qg →q^*→ γ + jet

Importance of Direct Photon Physics

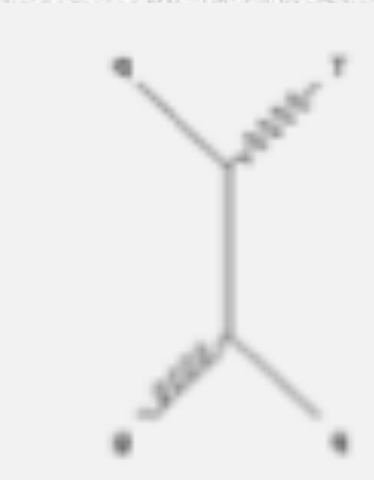
- As Direct Photon will test the SM, is background for SM Higgs$\rightarrow\gamma\gamma$ and will be a signature of new physics such as Quark Compositeness, ADD Graviton or Extra dimensions etc. **So an understanding of Direct photon is very important at CMS.**

Signal and Background processes

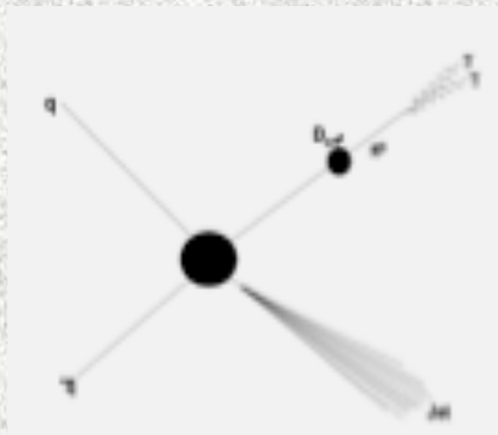
Signal Processes	Background Processes



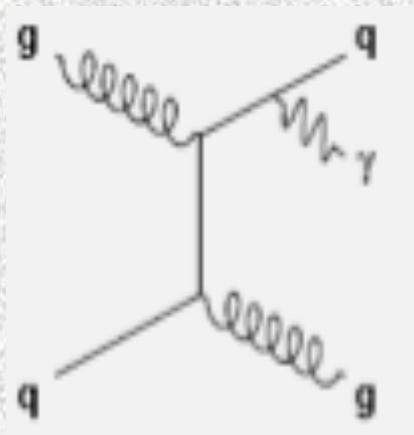
Annihilation Diagram



Compton Diagram



Background contributions from EM jets.



Photons from Bremsstrahlung in jet-jet events

At LHC,
Annihilation Diagram Cross Section is ~ 10 - 25 %
Compton process Cross Section is ~ 75 - 90 %

Generation of events

EVENT GENERATORS Used:-

a)ALPGEN

- Dedicated to the study of Multiparton hard processes in hadronic collisions (2 → n process)
- Tree level Matrix Element Generator
- Interfaced to Pythia for full showering and Hadronization of event

b)MADGRAPH

- Tree Level Matrix Element Generator
- Interfaced to Pythia for full showering and Hadronization of event

c)PYTHIA

- Used to generate high-energy physics events , i.e. sets of outgoing particles produced in the interactions between two incoming particles

CMSSW

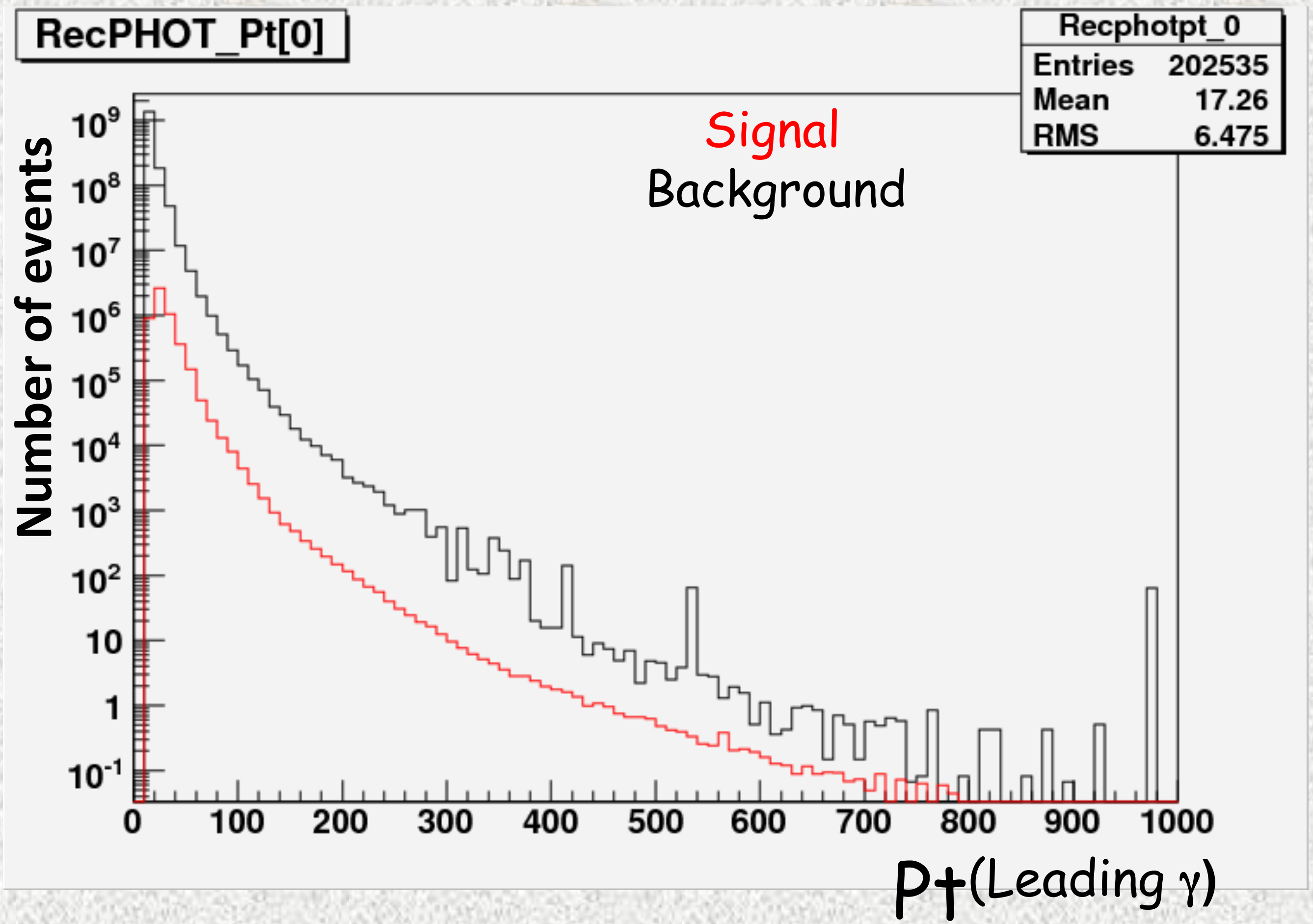
- Software used for simulation of detectors, reconstruction and to analyse data in CMS

S/B optimization studies

Results with ALPGEN generated samples

- Centre of mass energy = 14 TeV
- Signal :- Photon+Njets (N = 1, 2, 3 & 4)
- Background – Njets (N = 2,3,4,5 & 6)
- CMS Software Version used for analysis - CMSSW_1_6_12
- # of events analysed in signal = 240000
- # of events analysed in background = 234000
- CUTS Applied – Pt(Photon) ≥ 10 GeV   Pt(Jet) ≥ 10 GeV
  Eta(Photon) ≤ 2.7   Eta(Jet) ≤ 5.0

SIGNAL & BACKGROUND (Without Any Isolation Cut)



Plot normalised for 1 fb^{-1}

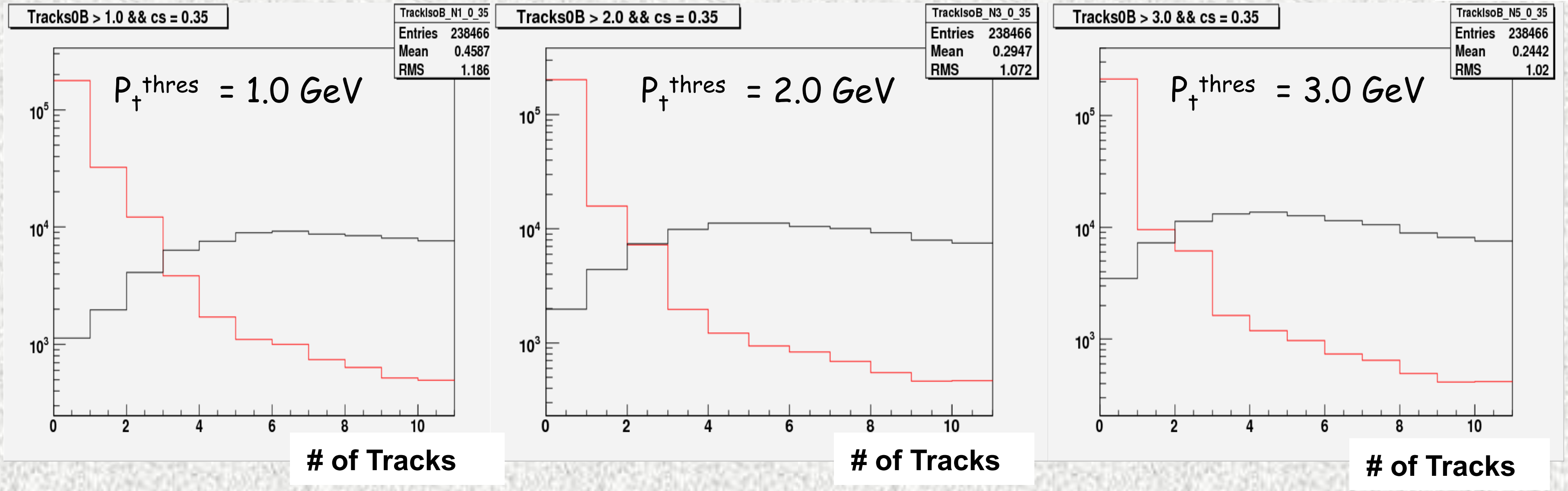
Isolation Variables Studied

- Tracker isolation : the number of tracks which have $P_T > P_T^{thres}$ (which has been taken as 1.0 GeV, 2.0 GeV & 3.0 GeV) lying in the Cone Size R around the photon candidate should be less than the threshold value.

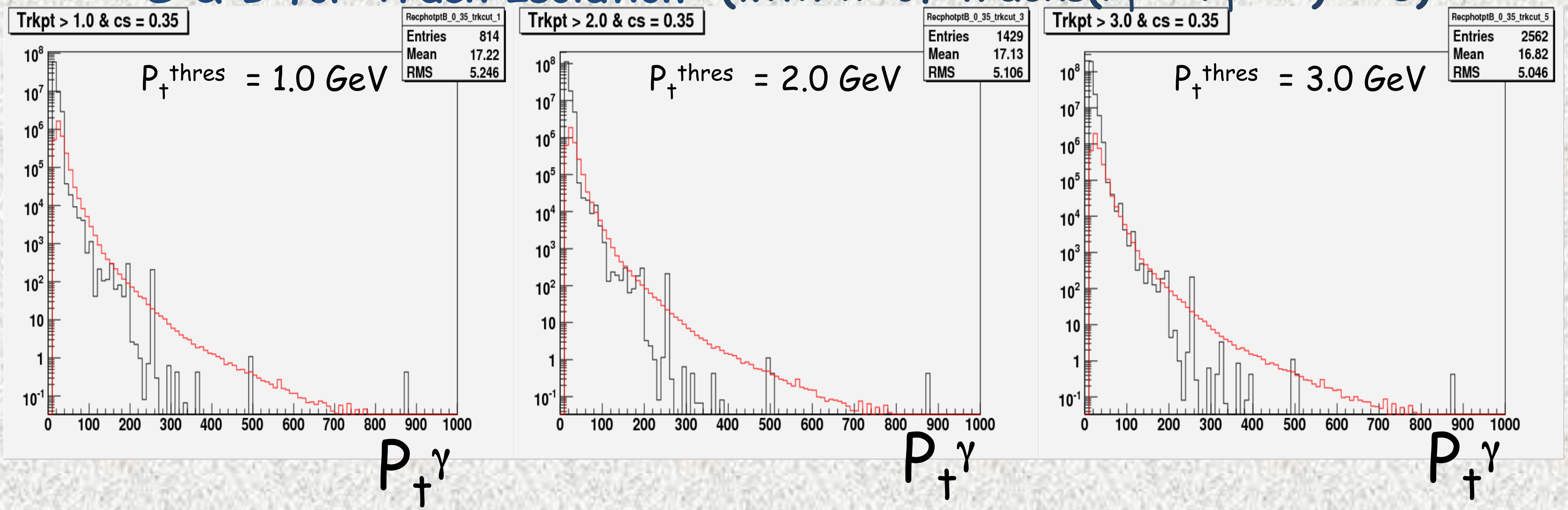
- ECAL isolation : the sum of the transverse energy of all the basic clusters lying in the Cone size R around the photon candidate should be less than the threshold value.

- HCAL isolation : the sum of the transverse energy of all the particles depositing energies in the HCAL should be less than the threshold value lying in the Cone Size R around photon candidate.

No of Tracks With $P_T > P_t^{thres}$ for Cone Size = 0.35 (Barrel)



S & B for Track Isolation (with # of tracks($P_t > P_t^{thres}$) = 0)



After optimizing the cuts on these variables, we decided on the following values for the cuts which gave a better S/B ratio-

Isolation Cuts

CUT A

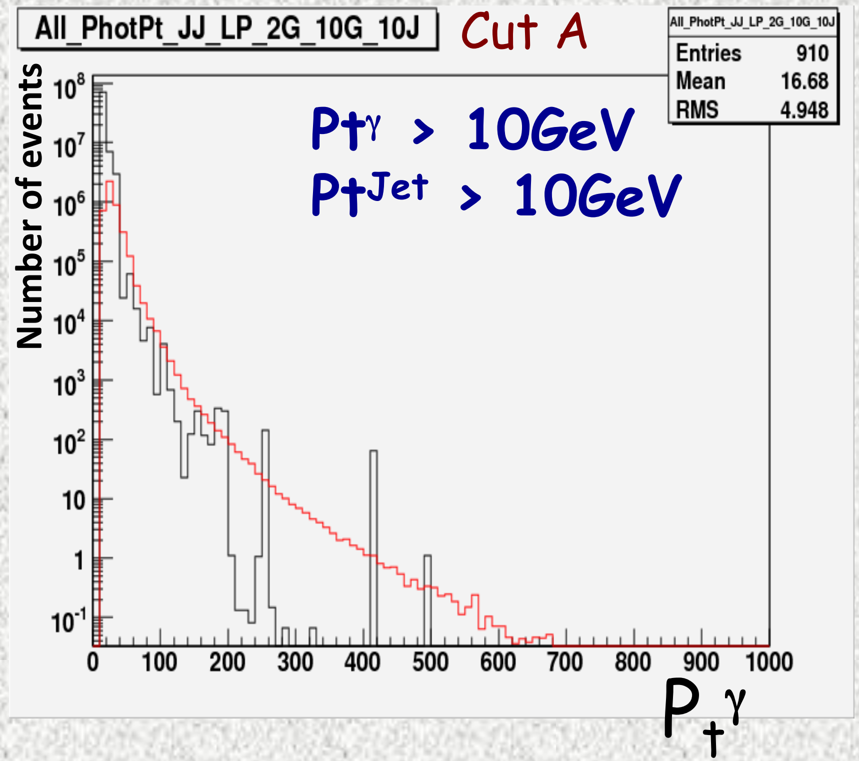
- No of tracks around photon (Trackmin_Pt = 2GeV) = 0
- E_{TH}(Ecal) ≤ 2 GeV
- E_{TH}(Hcal) ≤ 6 GeV

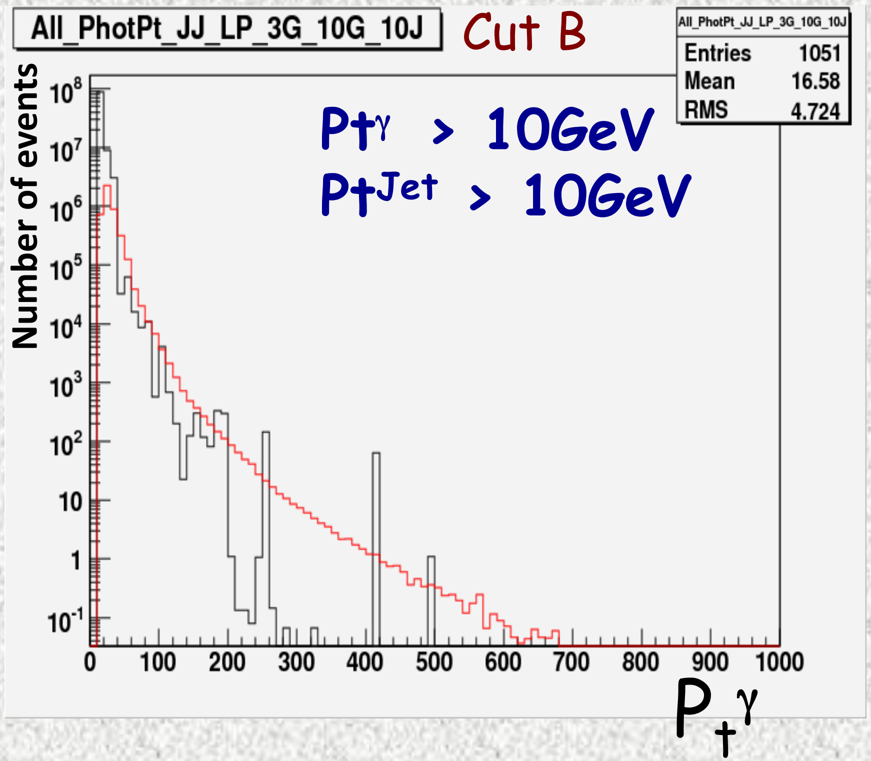
CUT B

- No of tracks around photon (Trackmin_Pt = 2GeV) = 0
- E_{TH}(Ecal) ≤ 3 GeV
- E_{TH}(Hcal) ≤ 6 GeV

COMBINATION OF DETECTORS
S & B

Red – Signal & Black – Background





The signal becomes dominant only after $P_T^{\gamma} \sim 40$ GeV even after applying either of the set of cuts

The ΔØ Cut

Usually γ + jet events are produced back to back, but this condition is disturbed by initial and final state radiations. So the condition of P_T^{γ} being back to back with P_T^{jet} within $\Delta\phi$ can be given by the equation:

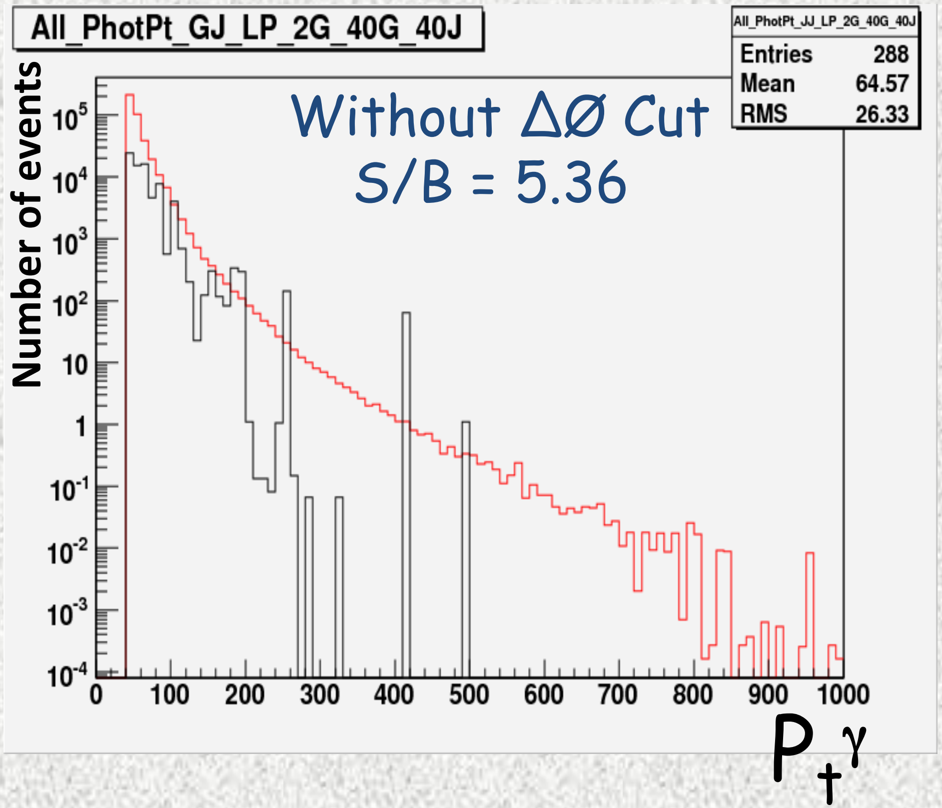
$$\Phi(\gamma, jet) = 180° \pm \Delta\phi$$

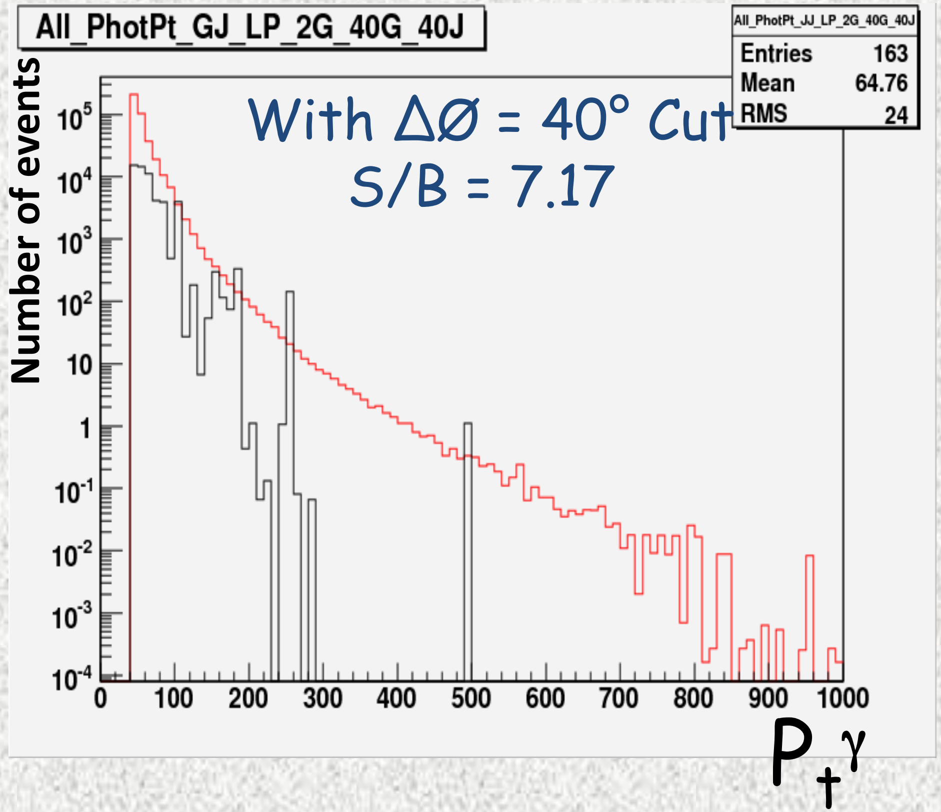
where $\Phi(\gamma, jet)$ is the angle between P_T^{γ} and P_T^{jet} . The $\Delta\phi$ cut has been applied after applying all the isolation conditions.

"Obviously the back to back condition exploits the γ + 1jet topology in the event"

SIGNAL & BACKGROUND (After Isolation Cut A)

$Pt^{\gamma} > 40GeV$ & $Pt^{Jet} > 40GeV$





Work Published as CMS Analysis Note-

CMS AN-2009/117 -- First Look at Photon + NJet(s) at CMS

SUMMARY

- Due to large QCD backgrounds, we observe that Background dominates over signal (when no isolation cut is applied).
- In photon isolation studies , while studying the effect of the isolation parameters separately , we observe that Tracker isolation parameter gives maximum background rejection after which HCAL isolation becomes somewhat redundant.
- After combining the effect of the all the three isolation variables together (choosing Cut A or Cut B), we observe that signal overtakes background only after 40GeV. For Pt^{γ} below 40Gev S/B is less than 1.0.
- As we increase cut on Pt^{γ} & Pt^{Jet} we observe that the S/B ratio increases.
- The ΔØ Cut further enhances the S/B ratio with minimal loss in signal.

S/B optimization studies
Results with MADGRAPH samples

- Centre of mass energy = 10 TeV
- Signal – Photon+NJets
- Background – NJets
- CMS Software Version used for analysis – CMSSW_2_2_9
- # of events analysed in signal = 8318607
- # of events analysed in background = 23606565
- CUTS Applied – Pt(Photon) ≥ 10 GeV   Pt(Jet) ≥ 10 GeV
  Eta(Photon) ≤ 2.5   Eta(Jet) ≤ 5.0

ANALYSIS

For the analysis,

1. Looked at the leading reconstructed photon in each event.
2. Further only the leading reconstructed photons which have a generated matched particle were stored.
3. Then the loose photon criteria was applied

   Sum of pt of tracks in a cone around photon candidate in tracker < 9

   Et sum of hits around photon candidate in ECAL < $5+0.15*P_T^{\gamma}$

   Et sum of hits around photon candidate in HCAL < 7

   hadronicOverEm < 0.1
4. Then the Tight photon criteria was applied

   Sum of pt of tracks in a cone around photon candidate in tracker < 5

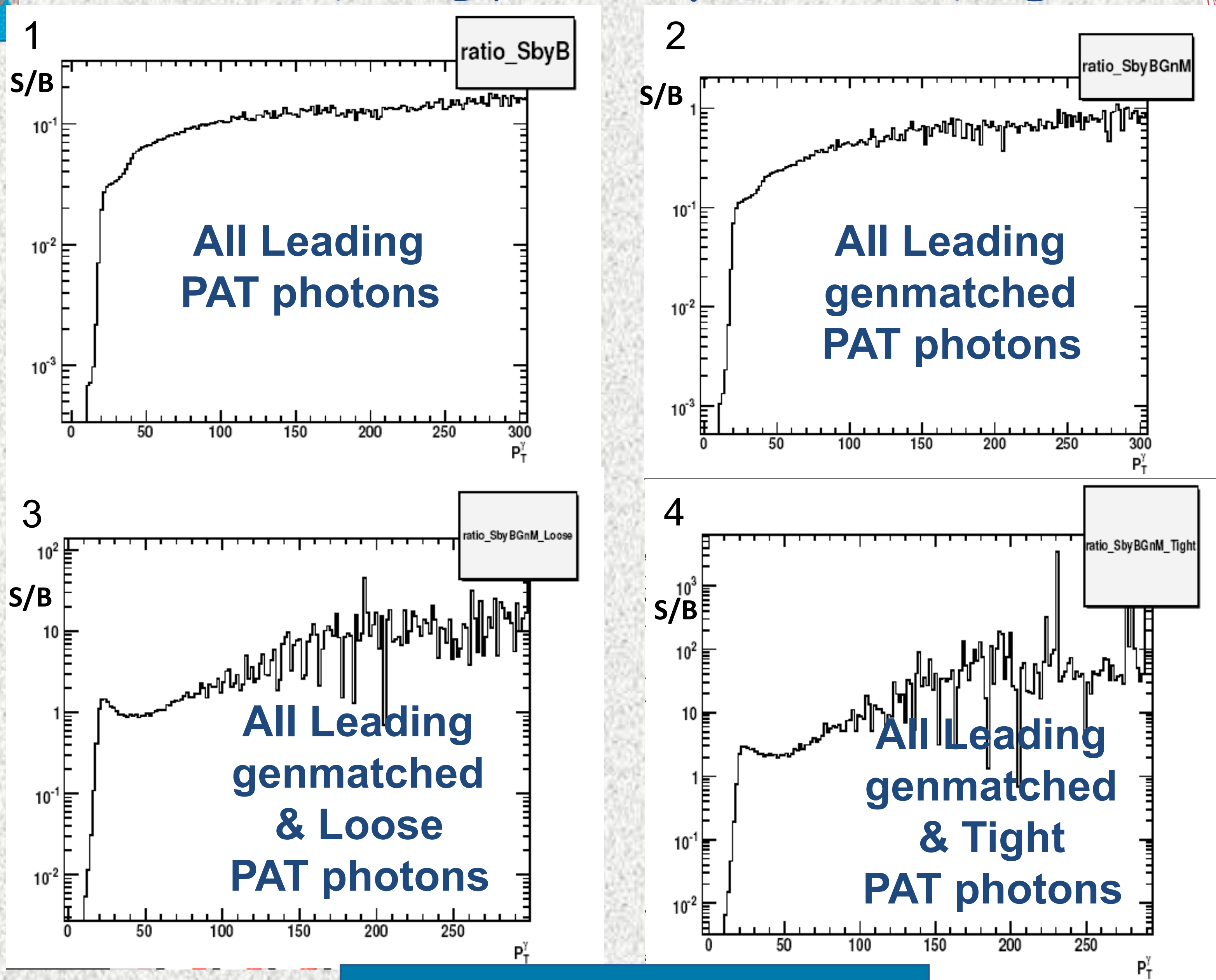
   Et sum of hits around photon candidate in ECAL < $8+0.0073*P_T^{\gamma}$

   Et sum of hits around photon candidate in HCAL < $5+0.002*P_T^{\gamma}$

   hadronicOverEm < 0.05

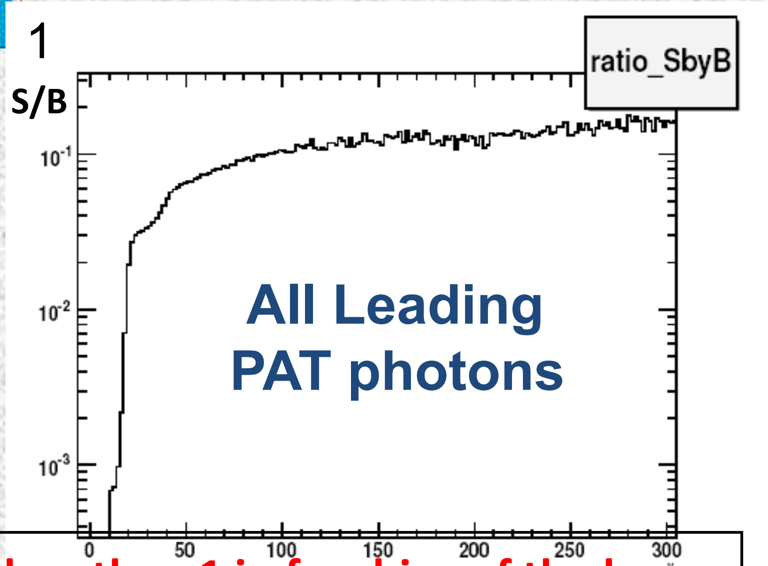
The Loose and Tight criteria have been optimised by egamma group in CMS for this particular version of CMS software.

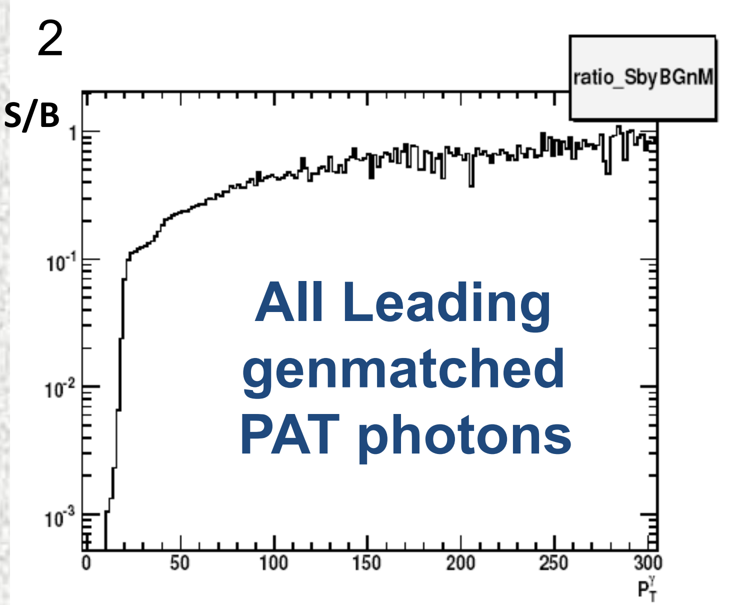
SIGNAL/BACKGROUND



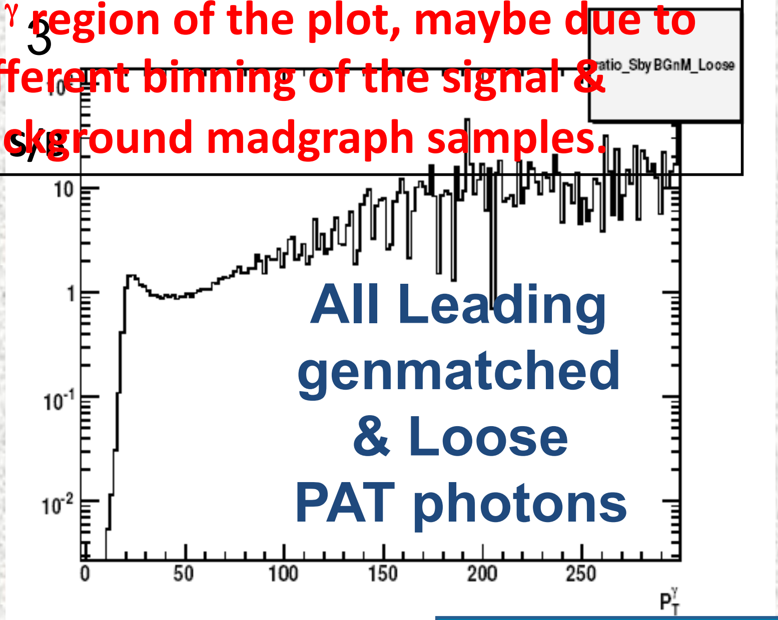
Plot normalised for 100 pb^{-1}

SIGNAL/BACKGROUND

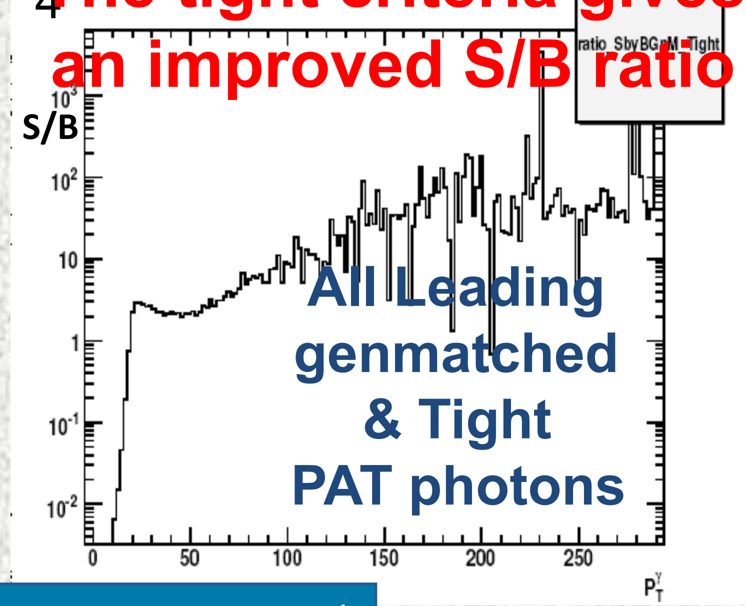




S/B is less than 1 in few bins of the low P_T^{γ} region of the plot, maybe due to different binning of the signal & background madgraph samples.

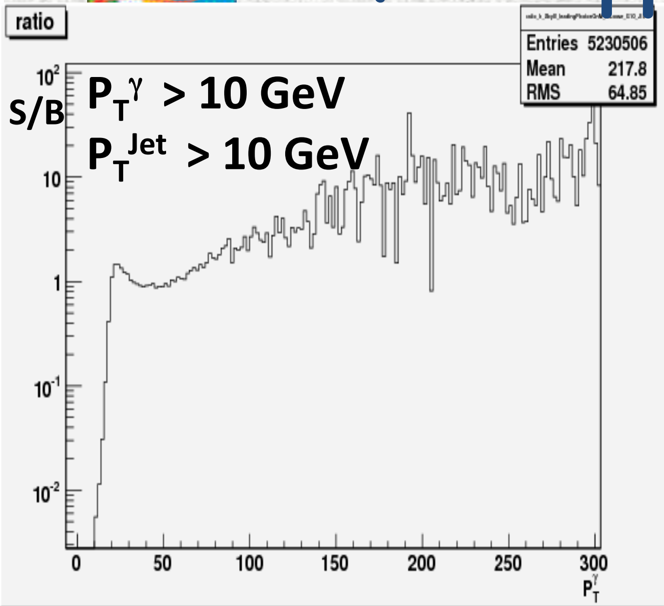


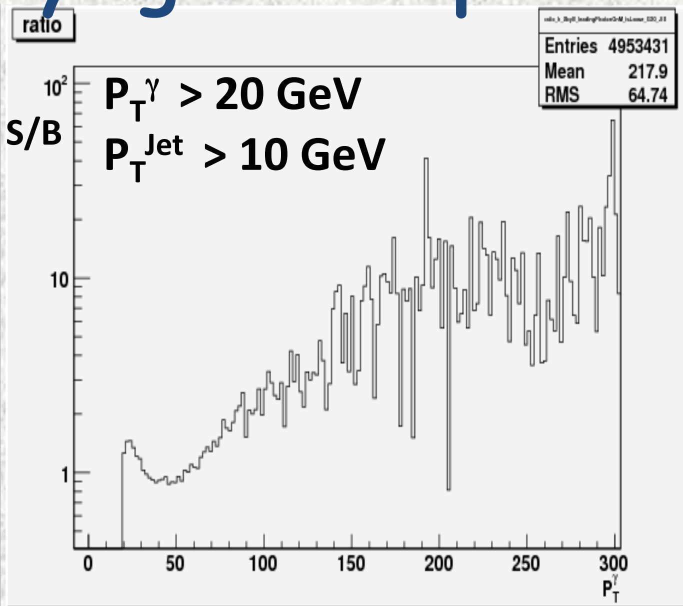
The tight criteria gives an improved S/B ratio

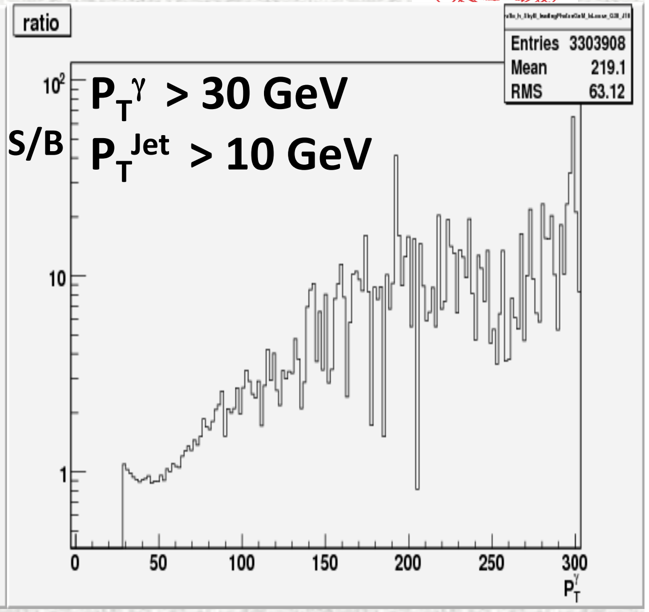


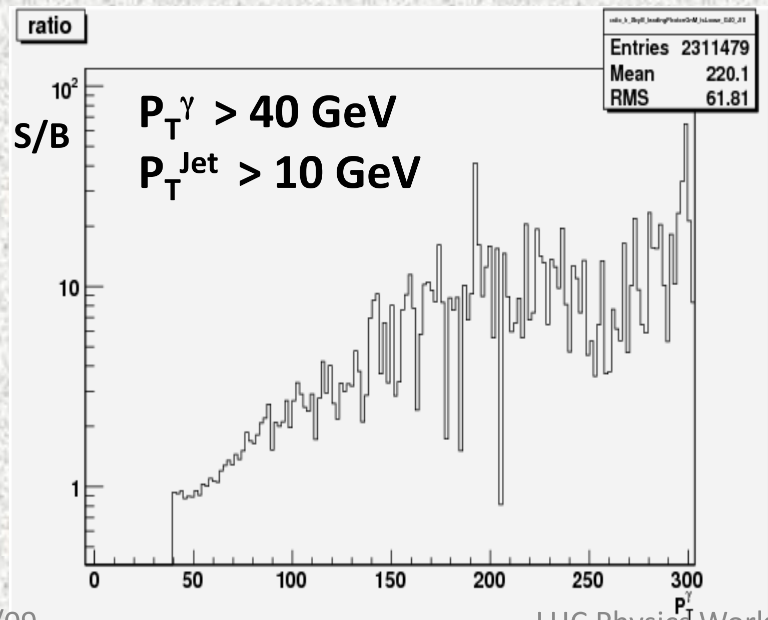
Plot normalised for 100 pb^{-1}

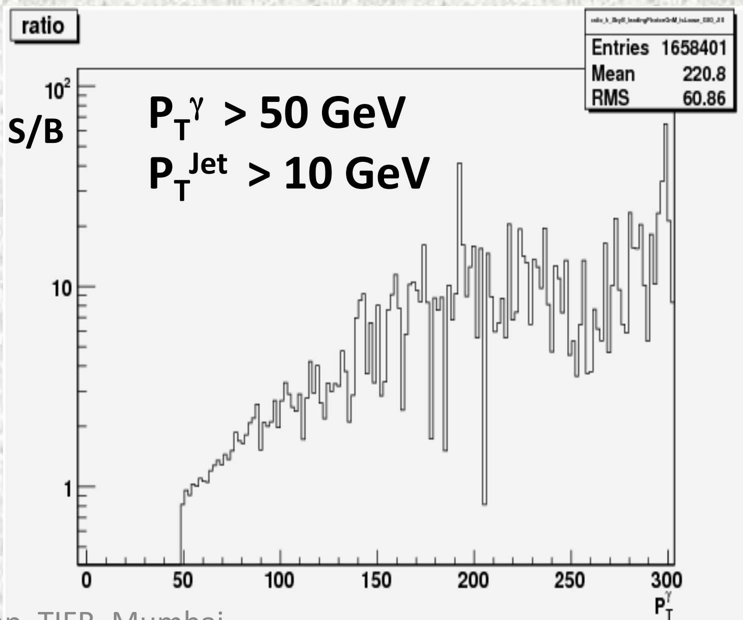
S over B & its dependence on P_T^{γ} after applying Loose photon criteria



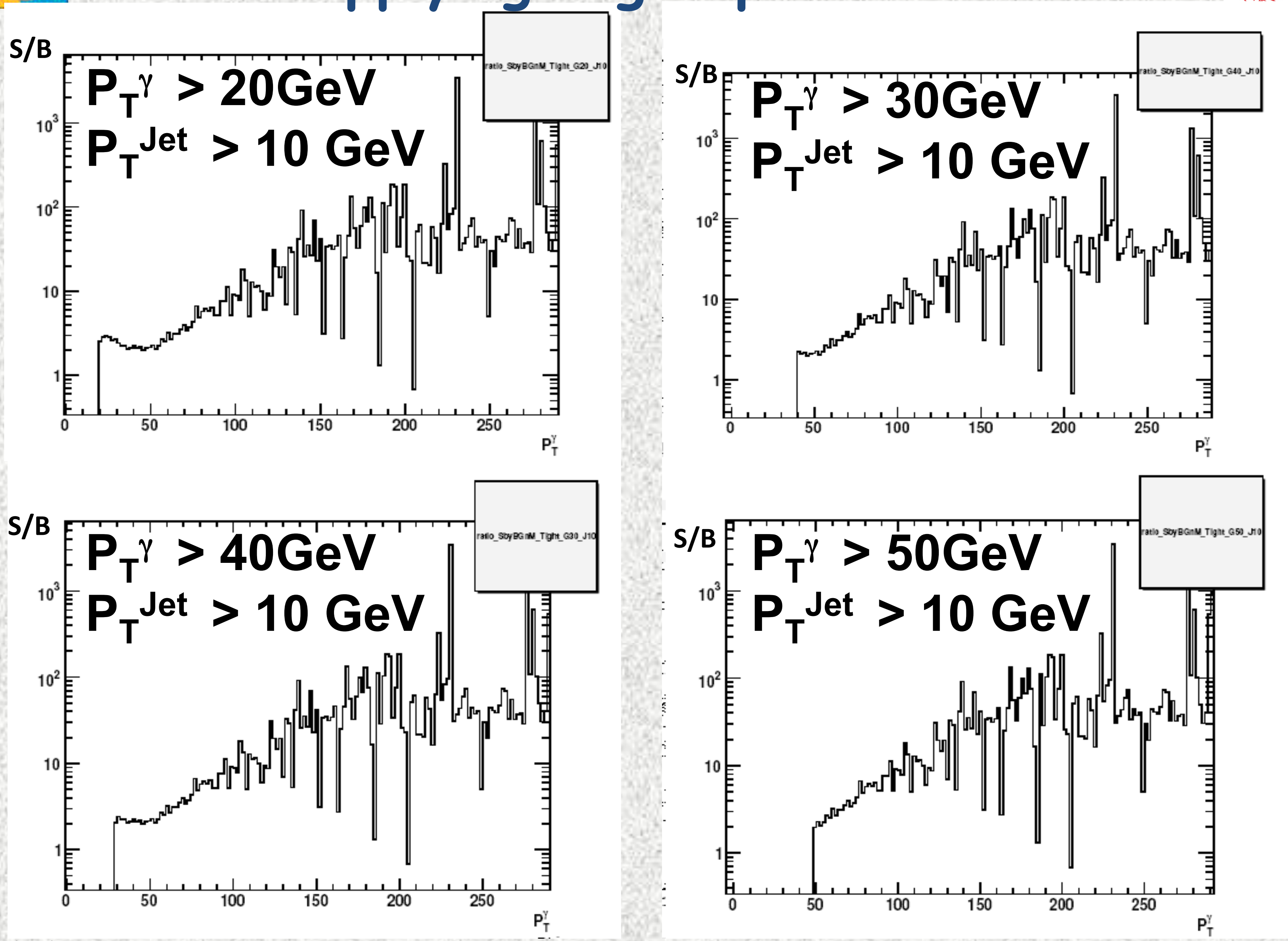








S over B & its dependence on P_T^γ after applying Tight photon criteria



SUMMARY

- Studied the S/B ratio applying various levels of cuts
  - a) Generator matching
  - b) Loose Photon Cut
  - a) Tight Photon Cut
- The tight photon selection gives a better S/B ratio.

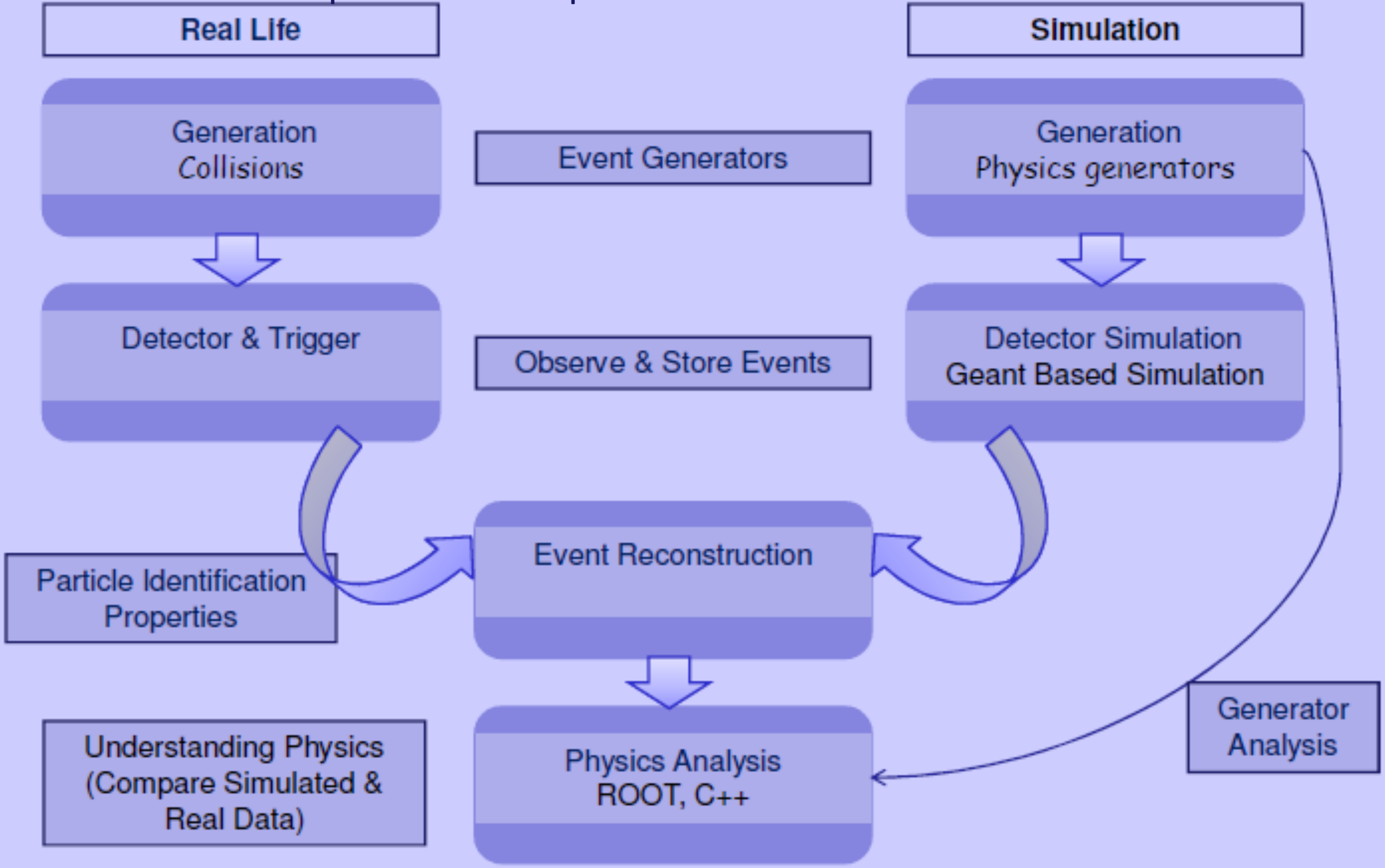
CONCLUSIONS

- Direct Photon is an important channel at CMS.
- Jet production rates are a factor 10^3 – 10^4 times more than direct photon signal and so background contribution becomes comparable to the signal.
- Thus the signal needs to be well distinguished from the background, which is done using certain detector isolation criteria.
- The S/B ratio is then well optimised.
- We look at photons with P_T between 10 GeV & 200 GeV.
- This analysis is foreseen for the first data set of CMS.
- The study can be done with few pb^{-1} of initial data.

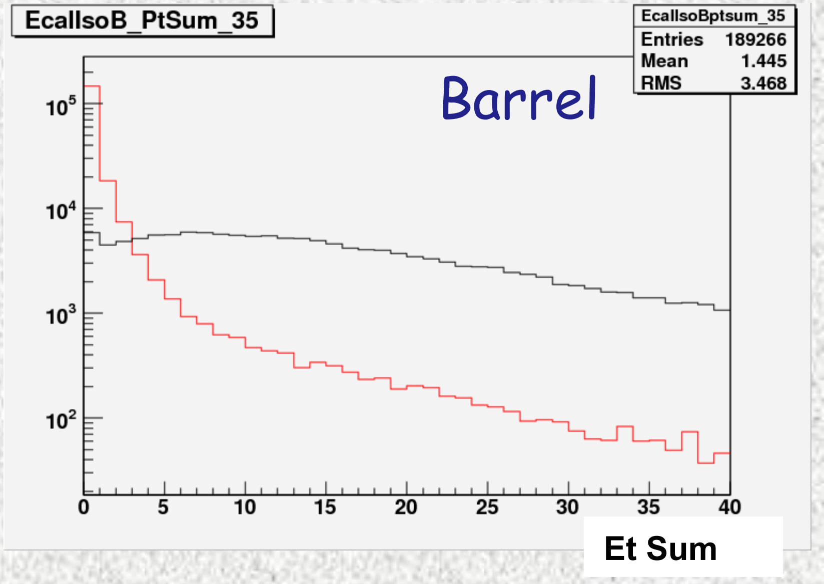
BACK UP

SIMULATION PROCESS

Simulations are performed to predict how an event looks in the detector..

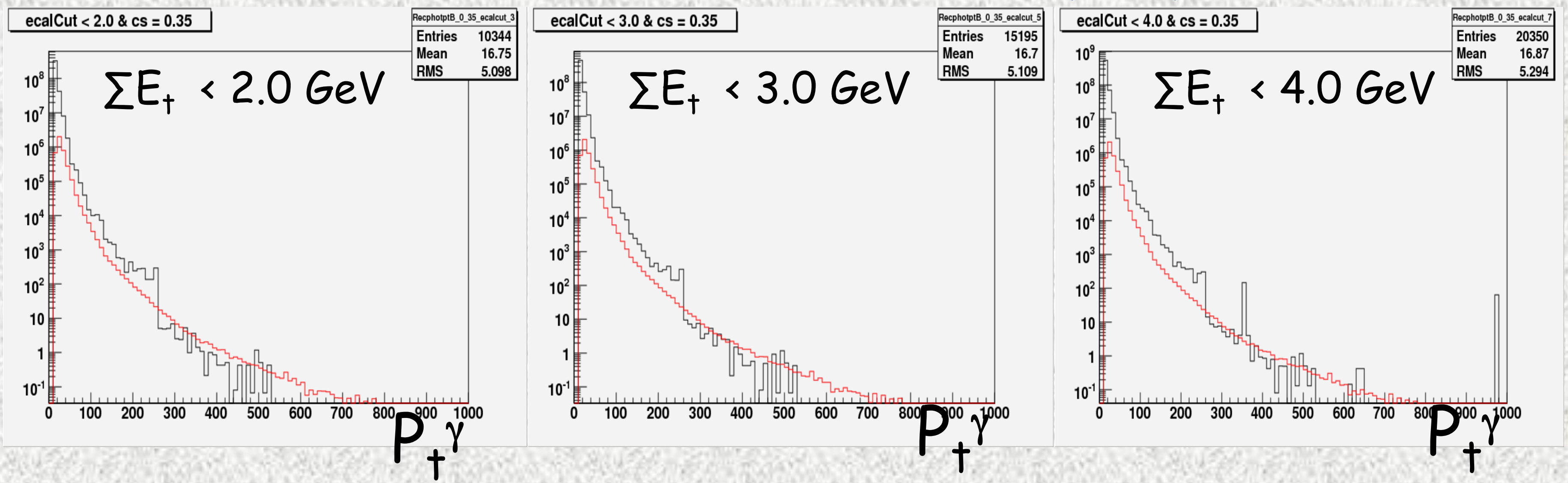


Ecal Isolation Variable

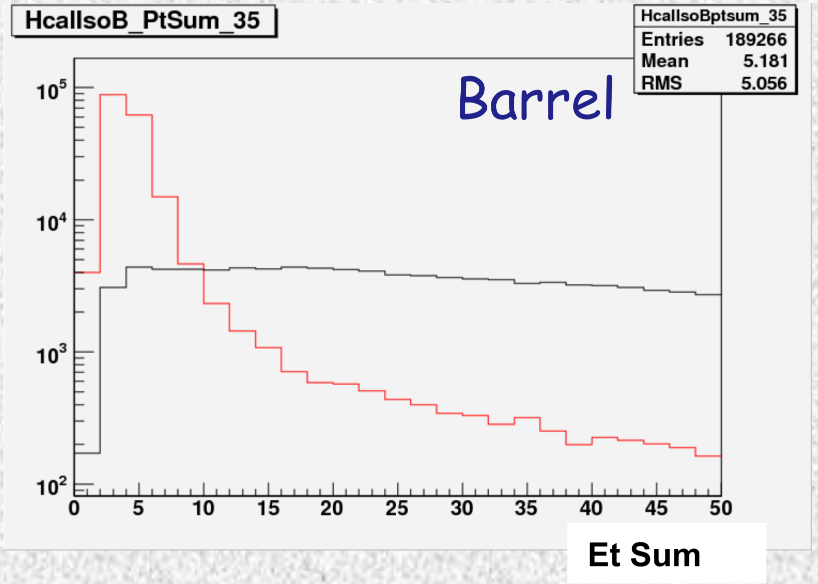


Sum of transverse energy of all basic clusters lying in a cone size R (0.35 here) around photon candidate

S & B for Ecal Isolation(Barrel) (ΣE_t < E_t^{thres})

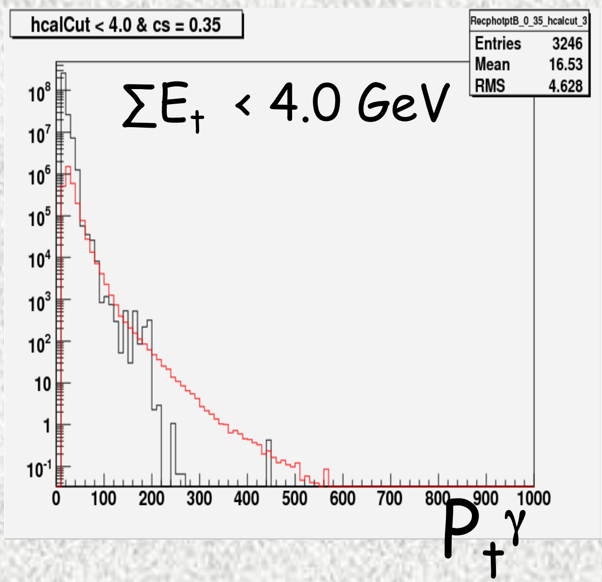


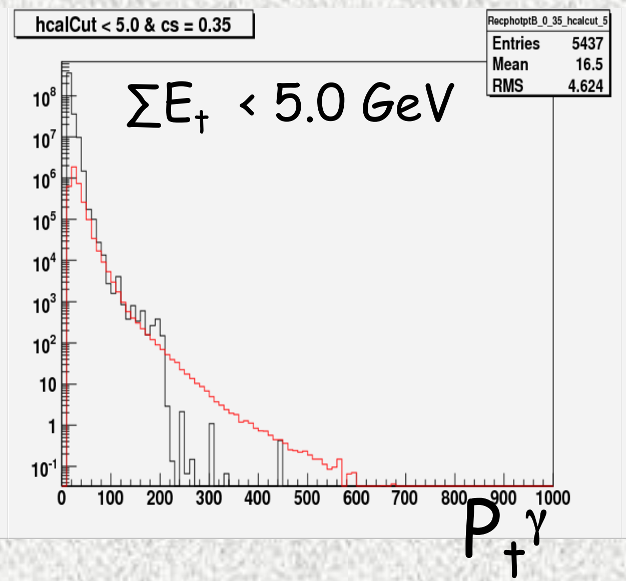
Hcal Isolation Variable

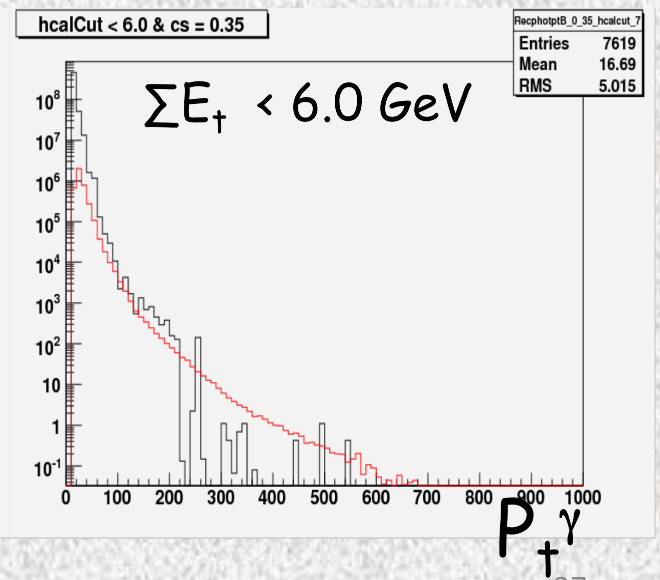


the sum of the transverse energy of all the particles depositing energies in the HCAL in a cone size R(0.35 here) around photon candidate

S & B for Hcal Isolation(Barrel) ($\Sigma E_t < E_t^{thres}$)







Alpgen DATASETS USED : Signal

/ph1j_20_60-alpgen/CMSSW_1_6_7-CSA07-1201165474/RECO
/ph1j_60_120-alpgen/CMSSW_1_6_7-CSA07-1202106391/RECO
/ph1j_120_180-alpgen/CMSSW_1_6_7-CSA07-1200559977/RECO
/ph1j_180_240-alpgen/CMSSW_1_6_7-CSA07-1200560452/RECO
/ph1j_240_300-alpgen/CMSSW_1_6_7-CSA07-1200560052/RECO
/ph1j_300_7000-alpgen/CMSSW_1_6_7-CSA07-1203060287/RECO
/ph2j_20_60-alpgen/CMSSW_1_6_7-CSA07-1200560085/RECO
/ph2j_60_120-alpgen/CMSSW_1_6_7-CSA07-1200561475/RECO
/ph2j_120_180-alpgen/CMSSW_1_6_7-CSA07-1200560242/RECO
/ph2j_180_240-alpgen/CMSSW_1_6_7-CSA07-1200559924/RECO
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/ph4j_20_60-alpgen/CMSSW_1_6_7-CSA07-1201165529/RECO
/ph4j_60_120-alpgen/CMSSW_1_6_7-CSA07-1200561528/RECO
/ph4j_120_180-alpgen/CMSSW_1_6_7-CSA07-1200560294/RECO
/ph4j_180_240-alpgen/CMSSW_1_6_7-CSA07-1202106442/RECO
/ph4j_240_300-alpgen/CMSSW_1_6_7-CSA07-1200560189/RECO
/ph4j_300_7000-alpgen/CMSSW_1_6_7-CSA07-1201630273/RECO

Alpgen DATASETS USED : Background

/Njet_2j_20_80-alpgen/CMSSW_1_6_7-CSA07-1199459756/RECO
/Njet_2j_80_140-alpgen/CMSSW_1_6_7-CSA07-1200571375/RECO
/Njet_2j_140_5600-alpgen/CMSSW_1_6_7-CSA07-1199459808/RECO
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/Njet_3j_80_140-alpgen/CMSSW_1_6_7-CSA07-1201165693/RECO
/Njet_3j_140_180-alpgen/CMSSW_1_6_7-CSA07-1201011815/RECO
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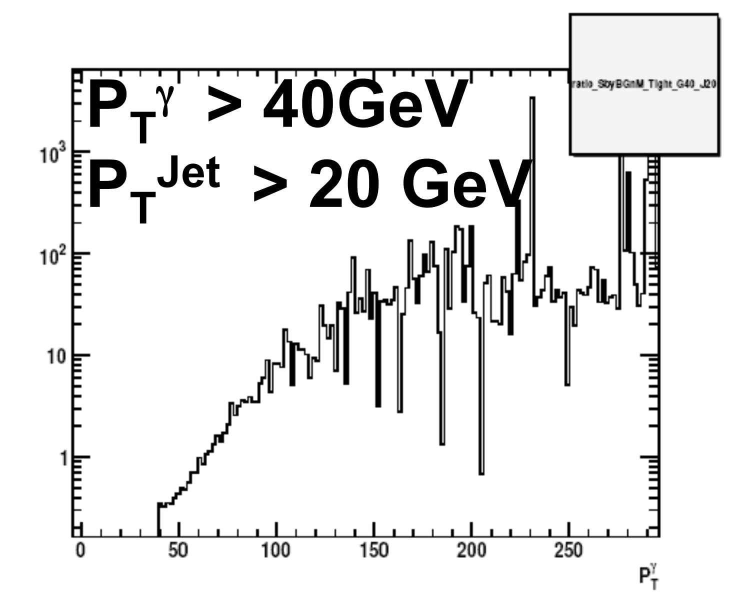
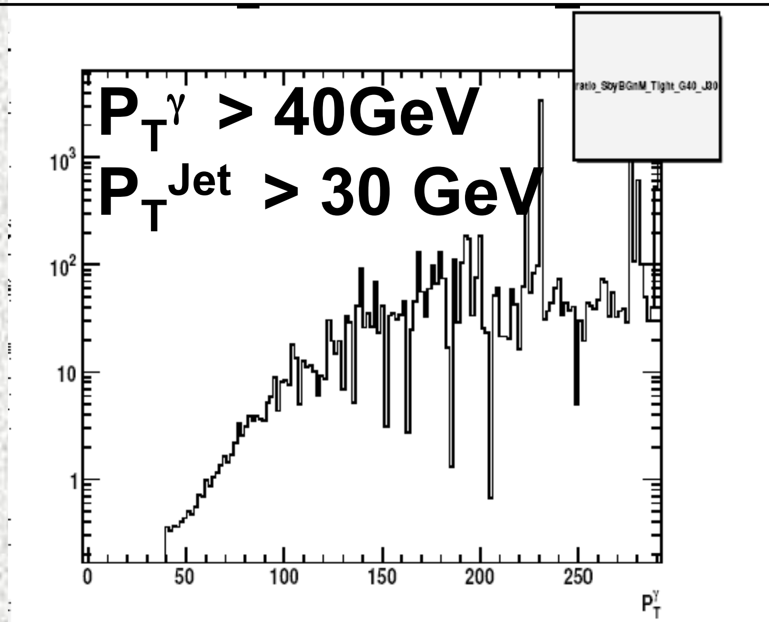
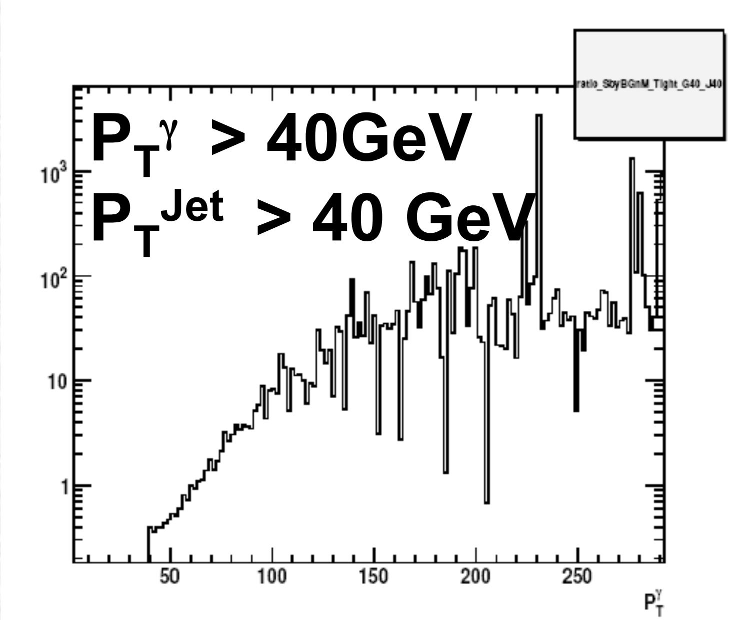
Madgraph DATASETS USED

- Signal
  - /PhotonJets40to100-madgraph/Fall08_IDEAL_V11_redigi_v2/GEN-SIM-RECO
  - /PhotonJets100to200-madgraph/Fall08_IDEAL_V11_redigi_v2/GEN-SIM-RECO
  - /PhotonJets200toInf-madgraph/Fall08_IDEAL_V11_redigi_v2/GEN-SIM-RECO
- Background
  - /QCD100to250-madgraph/Fall08_IDEAL_V11_redigi_v1/GEN-SIM-RECO
  - /QCD250to500-madgraph/Fall08_IDEAL_V11_redigi_v1/GEN-SIM-RECO
  - /QCD500to1000-madgraph/Fall08_IDEAL_V11_redigi_v1/GEN-SIM-RECO
  - /QCD1000toInf-madgraph/Fall08_IDEAL_V11_redigi_v1/GEN-SIM-RECO

S over B & its dependence on P_T^{Jet} with P_T^{γ} fixed



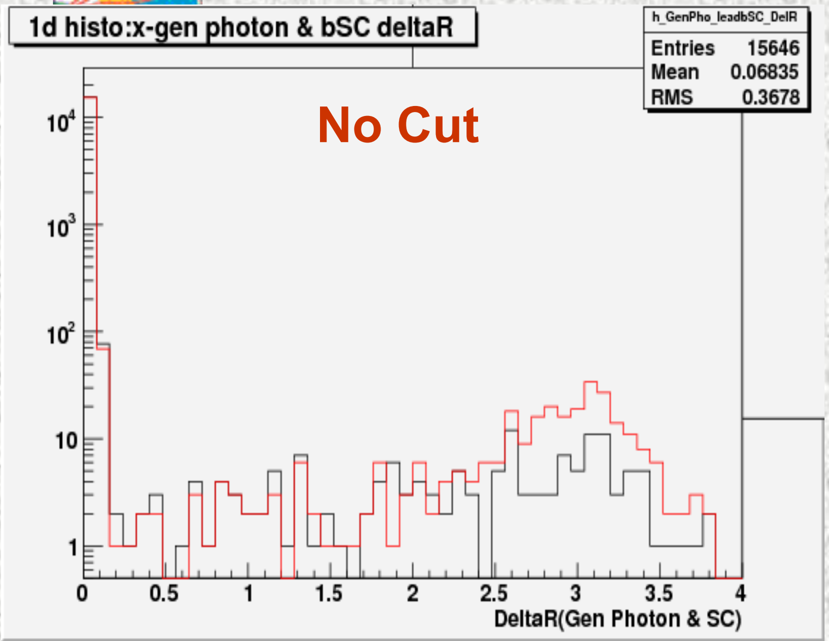




MC Efficiency studies
Preliminary Results with Pythia samples

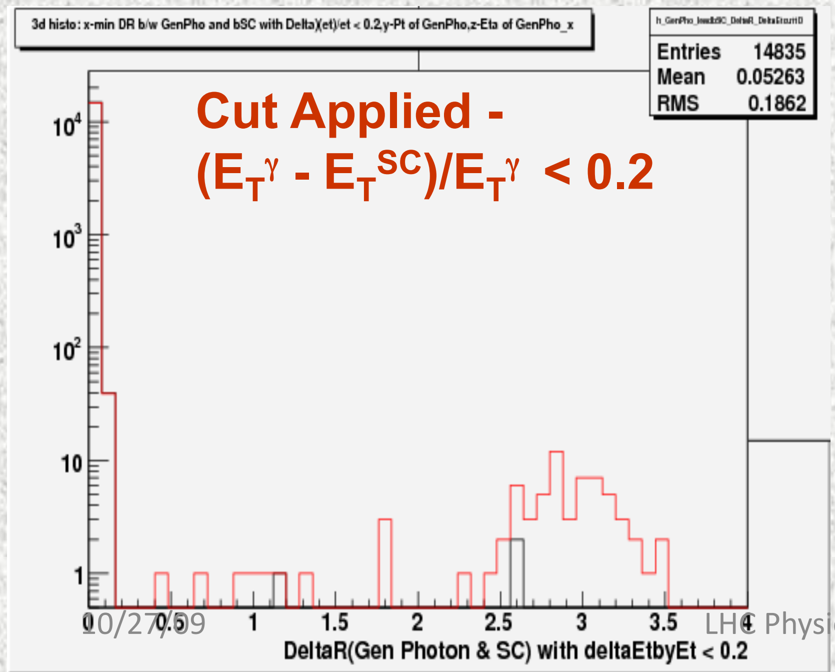
- Centre of mass energy = 10 TeV
- Sample used – Photon+Jet
- CMS Software Version used for analysis – CMSSW_3_1_2

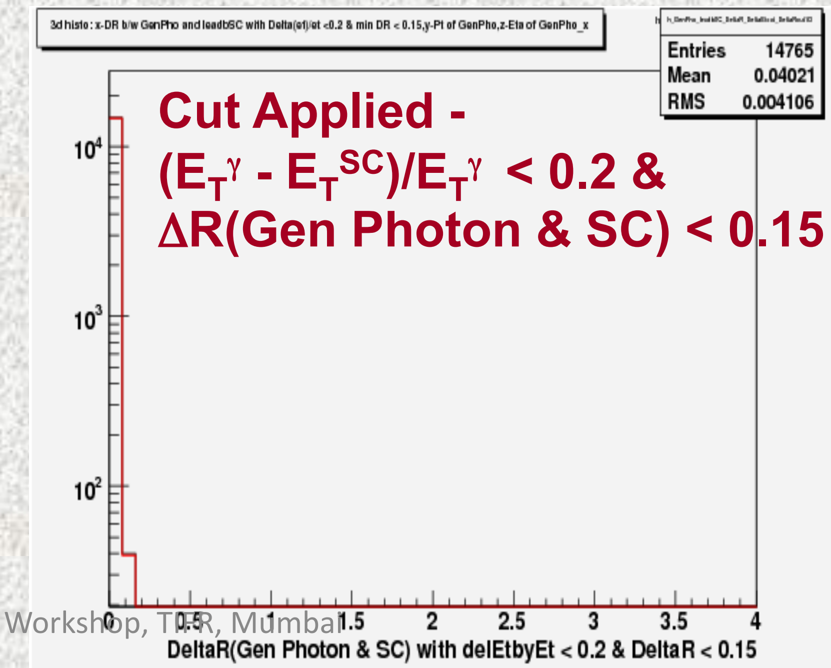
ΔR between generated γ and SC – Effect of cuts



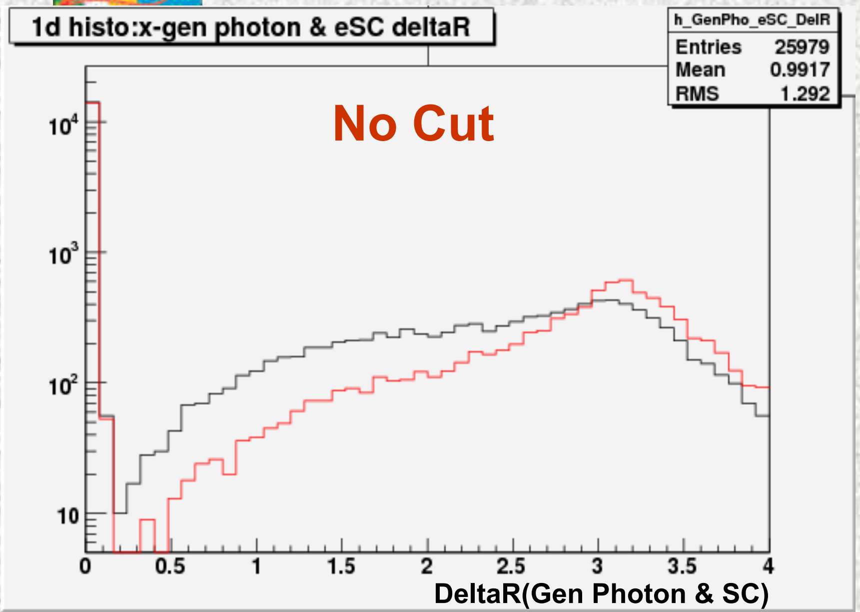
BARREL

Black – with Nearest SC
Red – with Leading SC





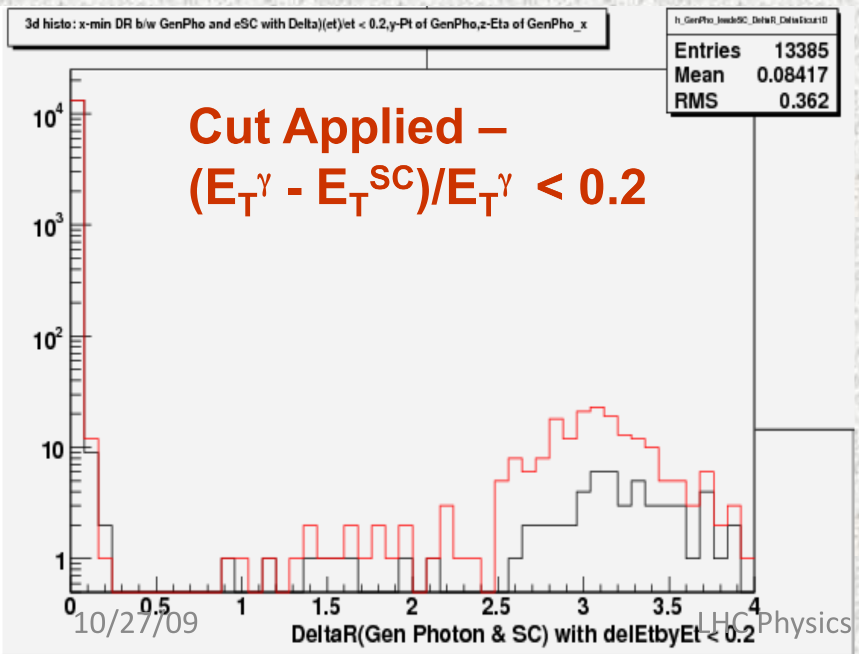
ΔR between generated γ and SC – Effect of cuts

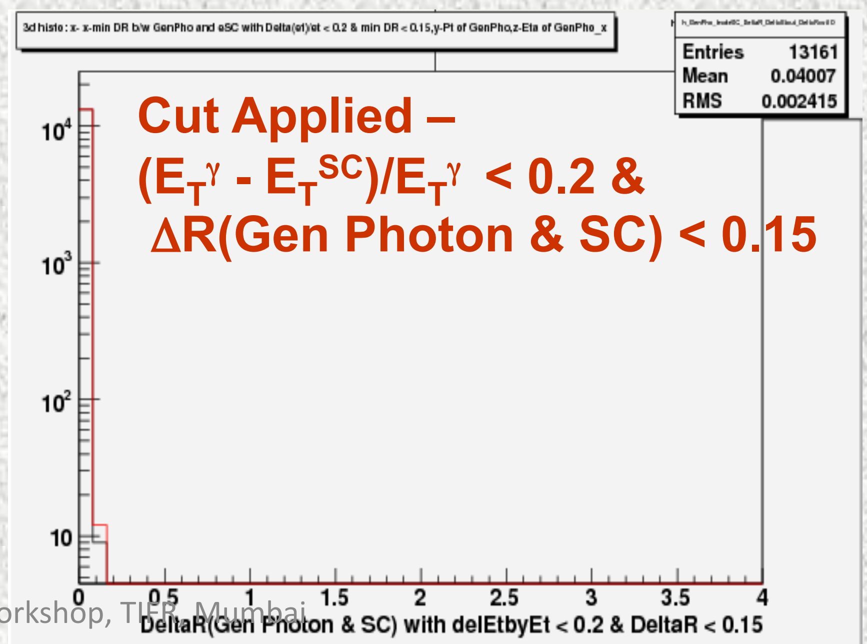


ENDCAPS

Black – with Nearest SC

Red – with Leading SC





Efficiency of cuts

- **Barrel**

After applying the $(E_T^{\gamma} - E_T^{SC})/E_T^{\gamma} < 0.2$ Cut ~ 95 %

After applying the ΔR(Gen Photon & SC) < 0.15 Cut ~ 100 %

- **Endcaps**

After applying the $(E_T^{\gamma} - E_T^{SC})/E_T^{\gamma} < 0.2$ Cut ~ 51 %

After applying the ΔR(Gen Photon & SC) < 0.15 Cut ~ 100 %

(Numbers given are similar for both nearest & leading SC)

Pythia DATASETS USED

- /PhotonJet_Pt15/Summer09-MC_31X_V3-v1/GEN-SIM-RECO