Predictions for the Higgs boson mass measurement precision as a function of its transverse momentum up to 1 TeV for LHC and high luminosity LHC

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Higgs Mass in Standard Model

In an effective-theory approach where momenta of virtual particles are cut off at the scale Λ, the quantum corrections to the physical Higgs mass grow proportionally with Λ:

For scalar particle:

$$m^2 = m_0^2 + \Lambda^2 P(\lambda_0, g) + \underbrace{Q^2 P_1(\lambda_0, g) + O(\log Q)}$$

this effect is not observed could be cancelled by new physics

Q – energy scale, it is ignored in calculations, but could be present

m_0 is a parameter of the Lagrangian,
m the « measured » Higgs mass: m_H,
Λ the scale of new Physics,
P polynomial in couplings.

Giudice: https://arxiv.org/abs/1307.7879
G. Pivovarov and V. Kim: https://arxiv.org/abs/0712.0402

Higgs Mass in Standard Model

- Higgs p_T could be proxy for Q
  → experimental way we could measure the m_H precision as a function of p_T

- Masses are the most precise quantities we measure at the LHC
  (better than any cross section >> 1% precision): m_t ~ 0.3 %, m_W ~ 0.025%, m_H ~ 0.2%

We use gluon fusion Higgs → $\gamma\gamma$ plus 0 and 1 jet, generated in Higgs p_T bins
at 13 TeV pp-collisions to determine mass measurement precision

Higgs: Generation & Parton Shower

Generation: MadGraph5_aMC@NLO, v2.6.5

- NLO generator
- To generate Higgs→ $\gamma\gamma$:
  - p p > h & p p > h j
  - PDF: NNPDF30_nlo_nf_5_pdfas (292200)
  - QCUT - minimum kt jet measure between partons = 10.0 for gen level and 15.0 for pythia8
  - maxjetflavor = 5
  - To generate Higgs in p_T bins, for example in p_T from 120 to 200 GeV:
    {25:120} = pt_min_pdg
    {25:200} = pt_max_pdg

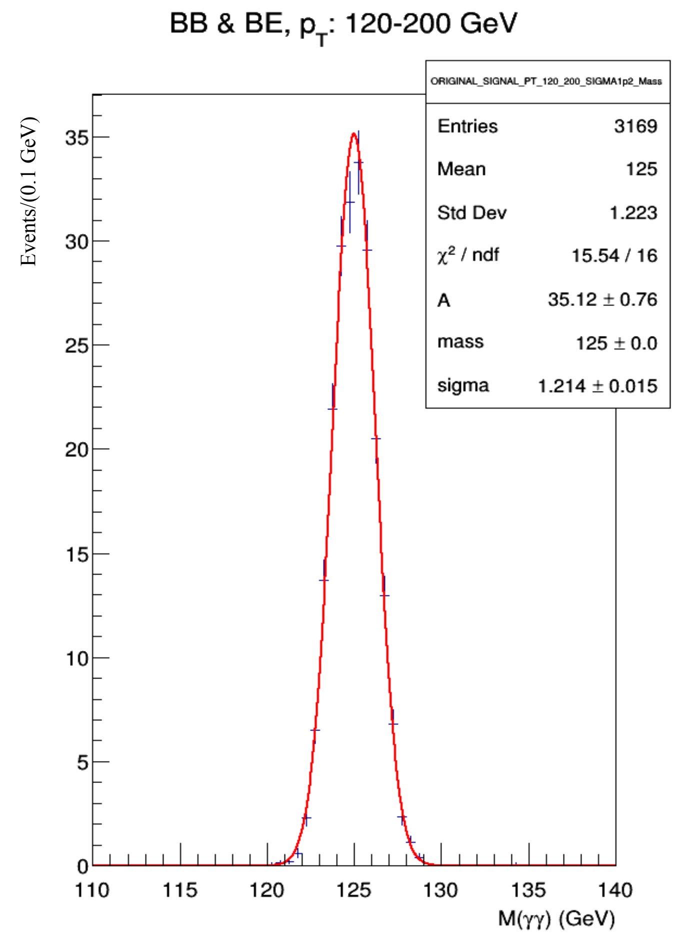
Parton shower: Pythia8 decays H → $\gamma\gamma$

Higgs: Detector Simulation

Detector simulation use Delphes for Run1, CMS

- There are no Delphes cards for Run2 and Run3
  → ECAL response was rescaled according to
  "... detector resolution on the search for Higgs…"
  https://doi.org/10.1140/epjc/s10052-017-4680-5

$$\text{CMS: } \frac{\Delta E}{E} = \sqrt{E^2 * 0.007^2 + E * 0.07^2 + 0.35^2}, E \text{ in GeV.}$$

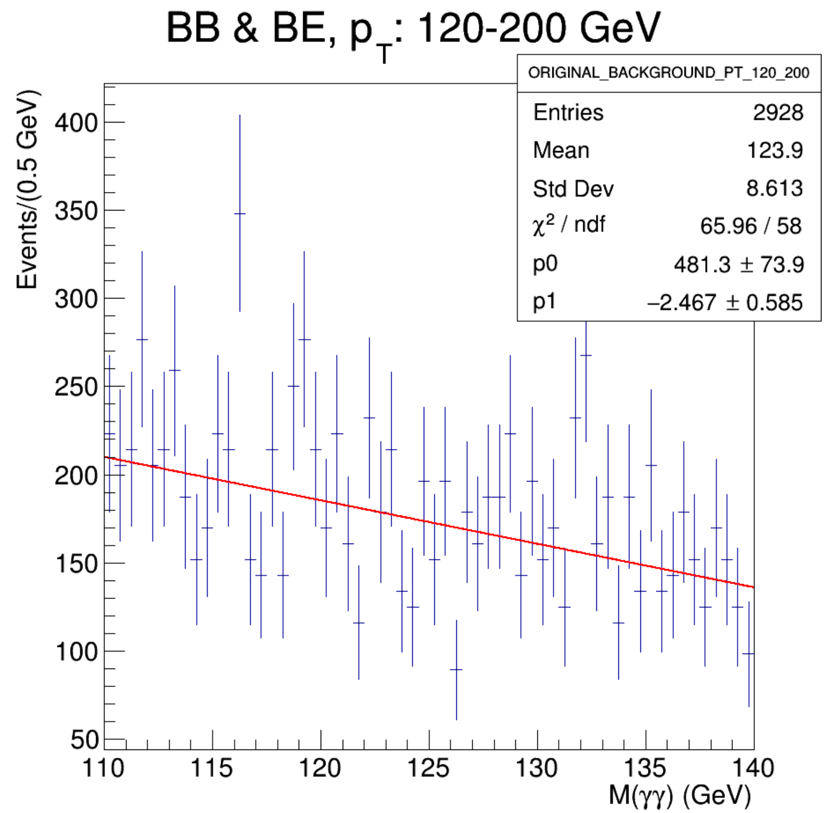


Simulation for $\gamma\gamma$ Background

Use the same Delphes detector model as for Signal:

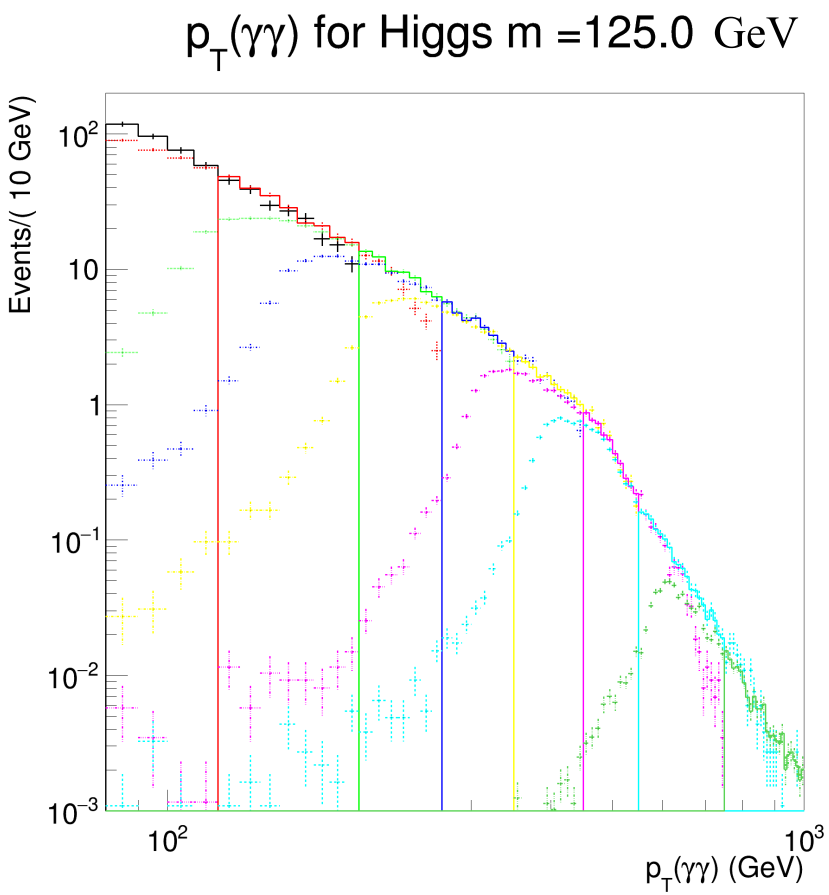
- p p > $\gamma\ \gamma$ QCD=99 QED=99
  & p p > $\gamma\ \gamma$ j QCD=99 QED=99

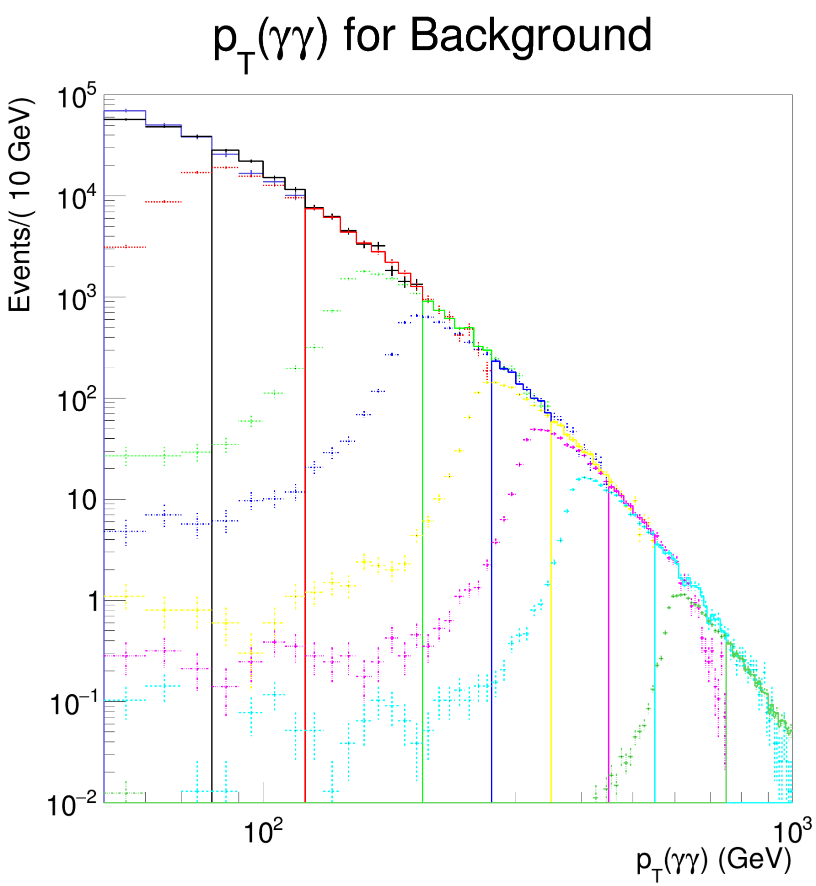
- To generate $\gamma\gamma$ in $p_T(\gamma\gamma)$ bins, for example in p_T from 120 to 200 GeV, using cut on jets:
  120 = htjmin (minimum jet HT=Sum(jet pt))
  200 = htjmax (maximum)



Detector Simulation

- Signal with Higgs mass 123, 125 and 127 GeV (Background) is generated in 8 bins of Higgs p_T ($p_T(\gamma\gamma)$) with 50 kEvents in each sample
- Bins were reweighted to the cross-section





Smooth transition from one p_T bin to another is observed

Event Selection

Event selections as at CMS for 2016 data "Higgs boson properties in H→ $\gamma\gamma$…" (10.1007/JHEP11(2018) 185):

- Barrel (B): $|\eta_\gamma| < 1.44$
  Endcap (E): $1.57 < |\eta_\gamma| < 2.5$
  Select $\gamma\gamma$ only with BB or BE

- leading $p_T(\gamma) > m(\gamma\gamma)/3$
  sub leading $p_T(\gamma) > m(\gamma\gamma)/4$

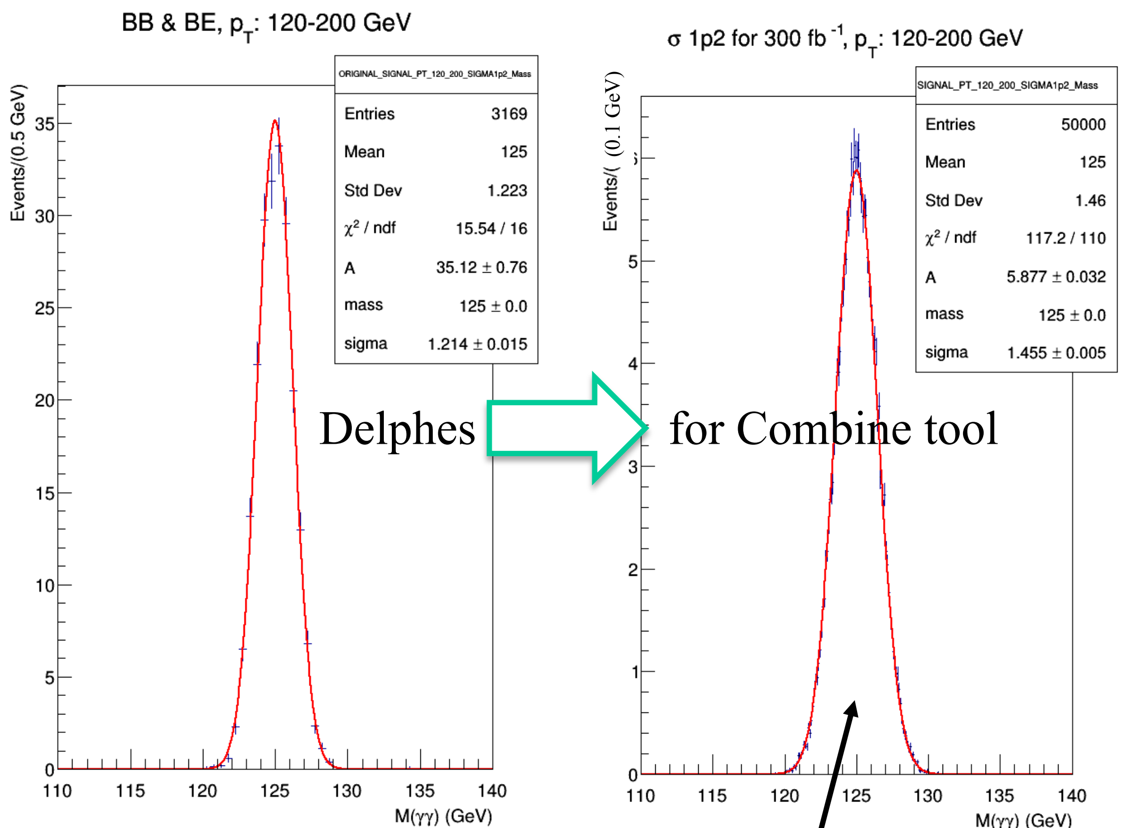
- p_T leading jet > 30 GeV

Combine Tool

For the mass estimation, CMS Higgs Combine tool is used:
https://github.com/cms-analysis/HiggsAnalysis-CombinedLimit

- Build statistical binned likelihood
- Inject 125 GeV SM signal (Higgs)
- Scan likelihood as function of Higgs mass hypothesis
- Using templates interpolated from 123-125-127 GeV
- Higgs mass precision was estimated in 7 Higgs p_T bins:
  0-120-200-270-350-450-550-INF GeV

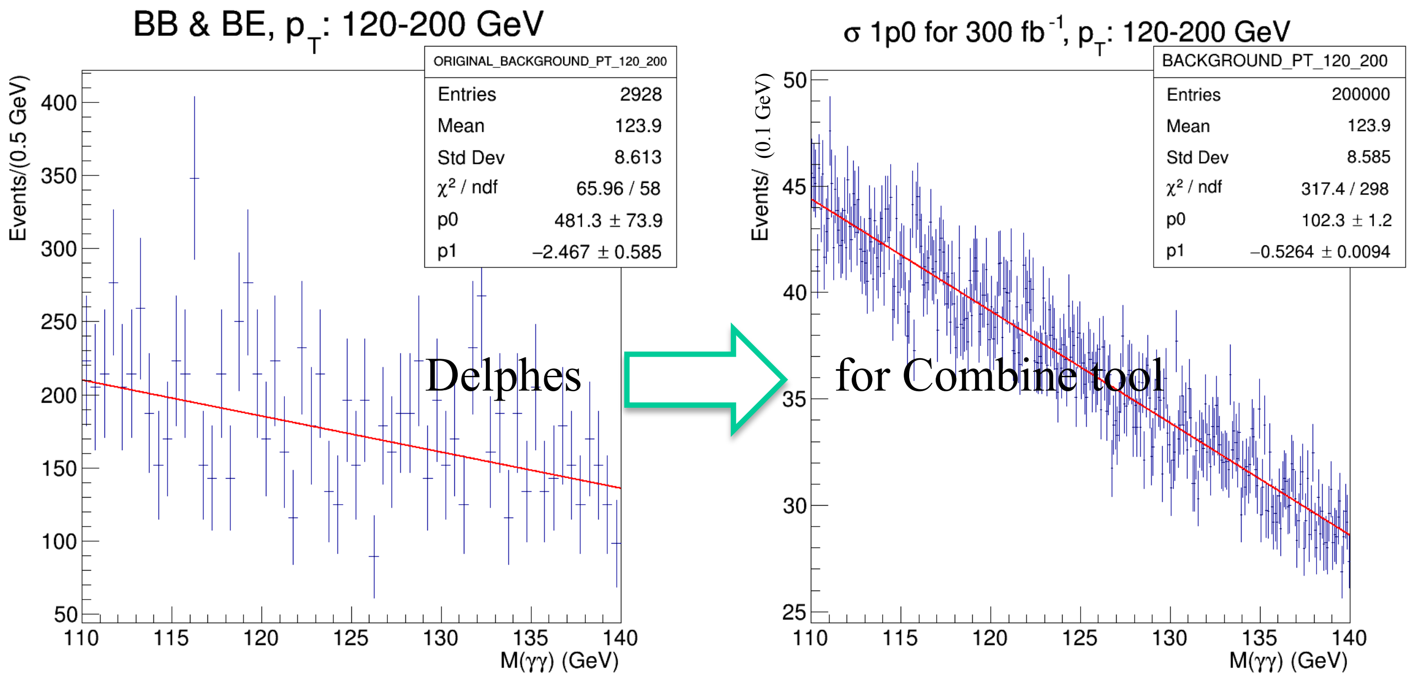
Higgs Signal Modification



Higgs in Delphes:

- Higgs is fit by Gaussian : resolution is the same for BB and BE regions (not the case for data) → combined to one sample BB & BE.
- Higgs resolution is ~20% better than in CMS paper → scale it.
- Regenerated for Combine tools with Gaussian shape (1.2σ), smaller binning (500 MeV → 100 MeV) and higher statistics, but keep rescaled to 300 fb^{-1}.

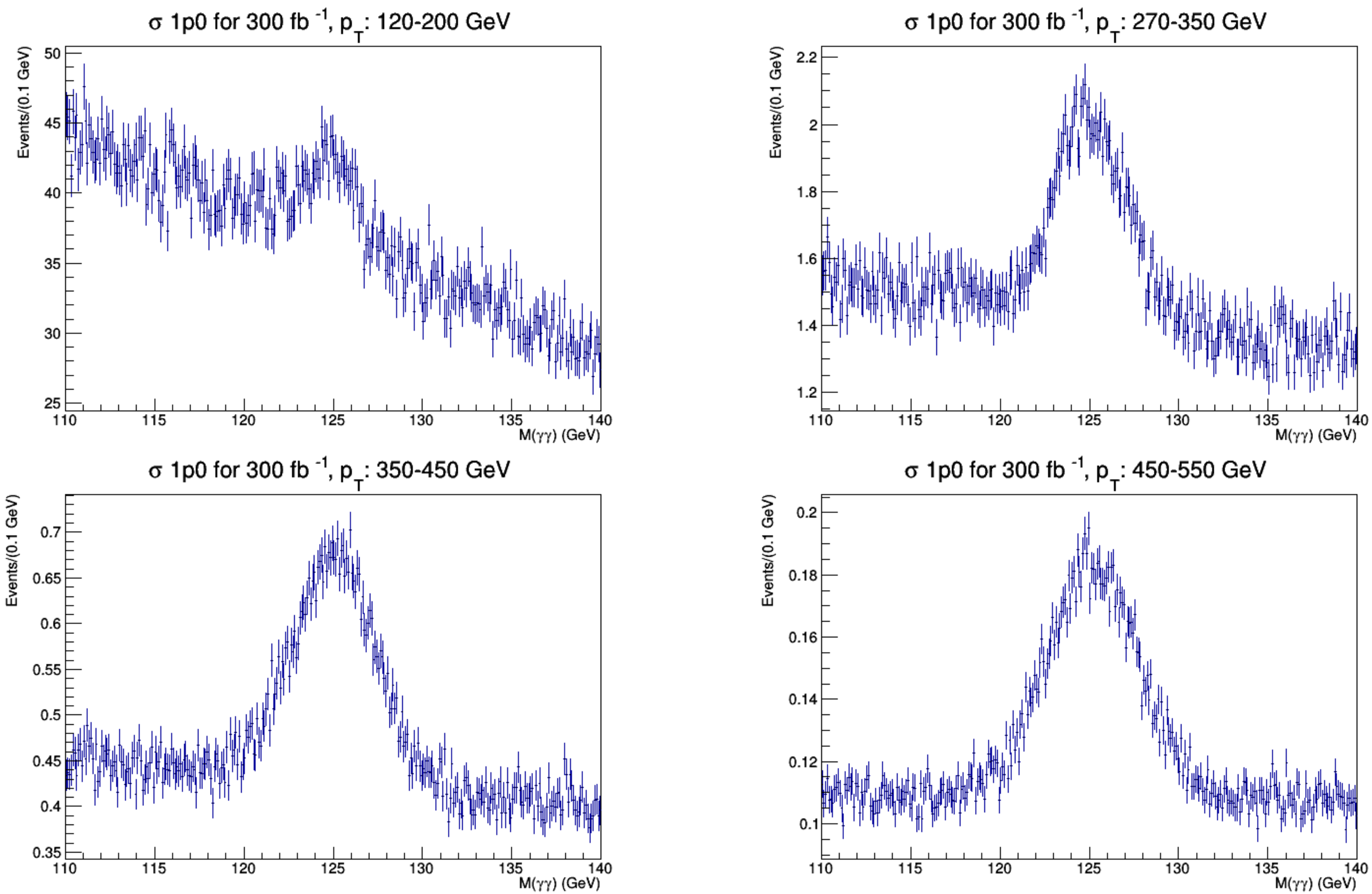
Background Modification



$\gamma\gamma$ background in Delphes:

- Background is fit by the polynomial of 1st degree: use BB & BE.
- Regenerated for Combine tools using polynomial of 1st degree, smaller binning (500 MeV → 100 MeV) and higher statistics, but keep rescaled to 300 fb^{-1}.

Shapes: Higgs + Background for 300 fb^{-1}



Signal to background ratio is increasing with increasing Higgs p_T

Cross Section Scaling

Higgs scaling:

- To make prediction for HL-LHC, 13 TeV Higgs simulation was scaled to 14 TeV Madgraph prediction: it varies from 1.14 to 1.29 from lowest to highest Higgs p_T bin.

Background scaling:

- Currently, no scaling is applied.
  We checked the effect of a larger background, and plan to further explore
  γ-jet and jet-jet contributions.

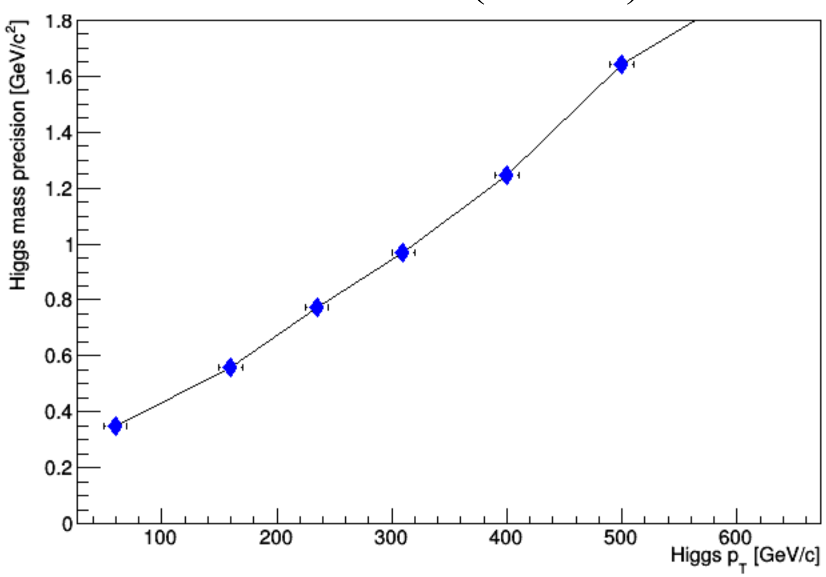
Higgs Mass Precision

Expected number of Higgs and background for HL-LHC 3000 fb^{-1} (14 TeV):

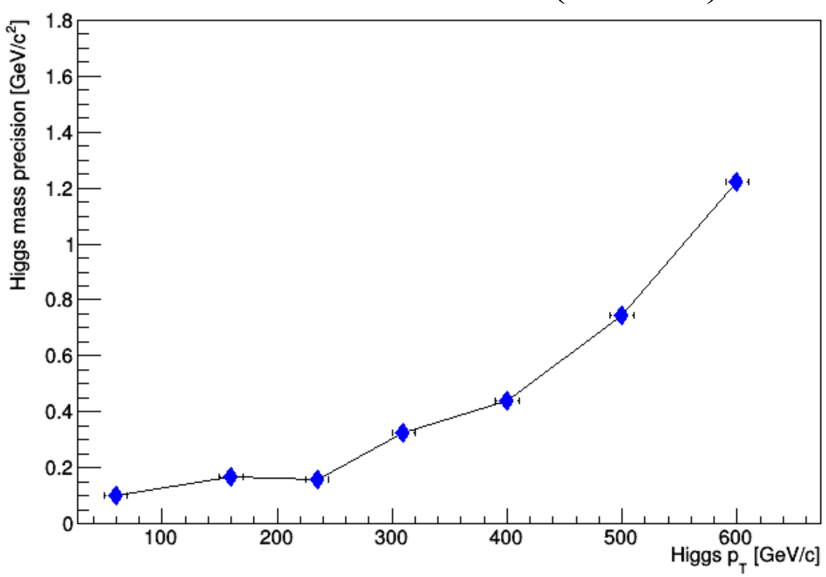
Higgs p_T [GeV/c]	0-120	120-200	200-270	270-350	350-450	450-550	550-INF
#Higgs	16 100	2 500	1 200	350	180	61	20
#Background $120<m_{\gamma\gamma}<130$ GeV/c^2	469 000	31 000	4 600	1 360	410	110	48

1st results for expectation of Higgs mass precision without systematic estimation:

LHC: 300 fb^{-1} (13 TeV)



HL-LHC: 3000 fb^{-1} (14 TeV)



Summary

- 1st preliminary results for 300 fb^{-1} LHC and 3000 fb^{-1} HL-LHC for the CMS detector are presented.

- In run 3, could be sensitive to mass differences of 1.2 GeV up to a Higgs p_T of 350-450 GeV.
  At HL-LHC, we could reach the same mass precision for Higgs p_T above 550 GeV.

Plans:

- Switch to HL-LHC Delphes configuration built for CERN Yellow Report for European Strategy I 2019.

- Estimate contribution to the background from γ-jet and jet-jet parts.

- Estimate systematic uncertainties.

Thanks to NSF support

Motivation for this measurement built in collaboration with G. Pivovarov and V.Kim

Back up slides

Detector Simulation

- Signal with Higgs mass 123, 125 and 127 GeV (Background) is generated in 8 bins of Higgs p_T ($p_T(\gamma\gamma)$) with 50 kEvents in each sample
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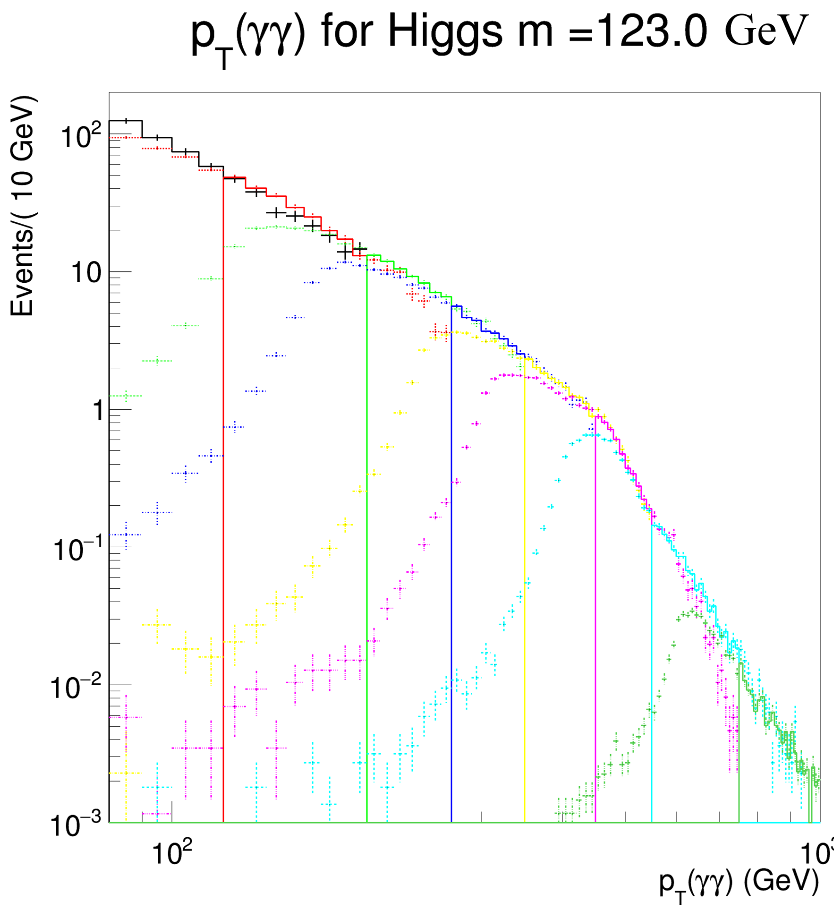

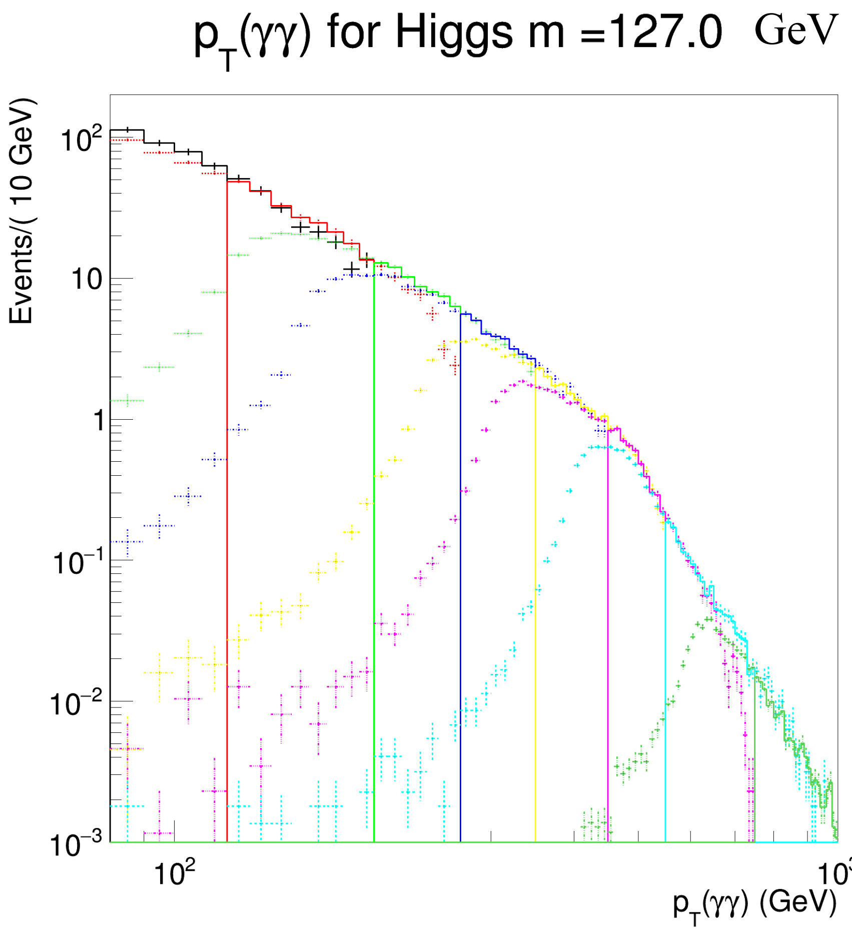

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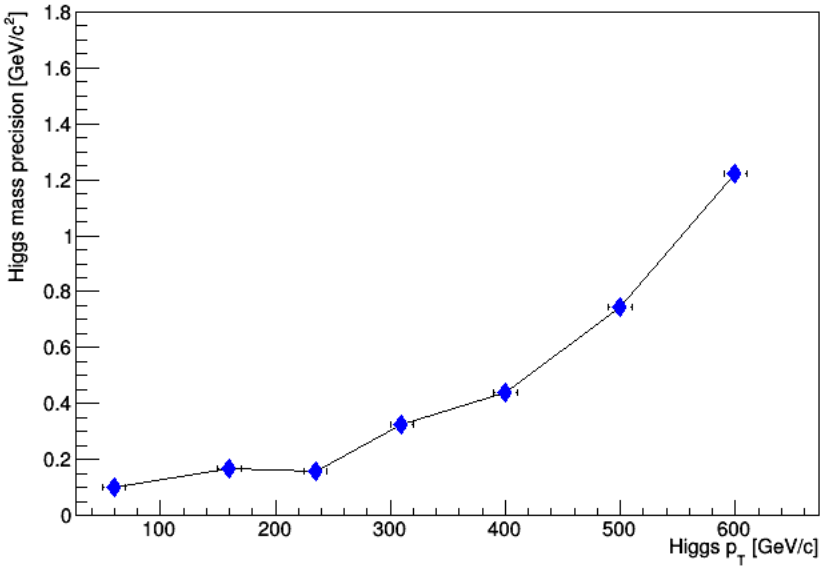
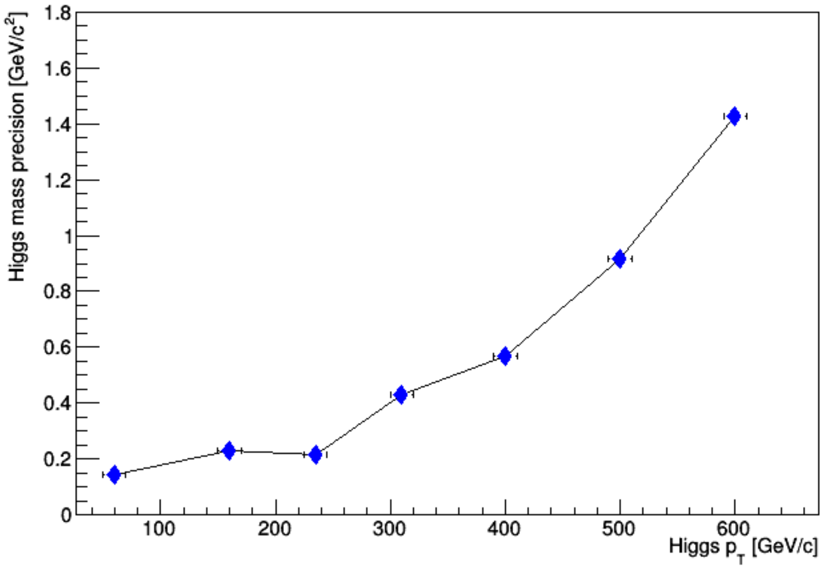
Higgs Mass Precision

1st preliminary results for expectation of Higgs mass precision without systematic estimation:

HL-LHC: 3000 fb^{-1} (14 TeV)

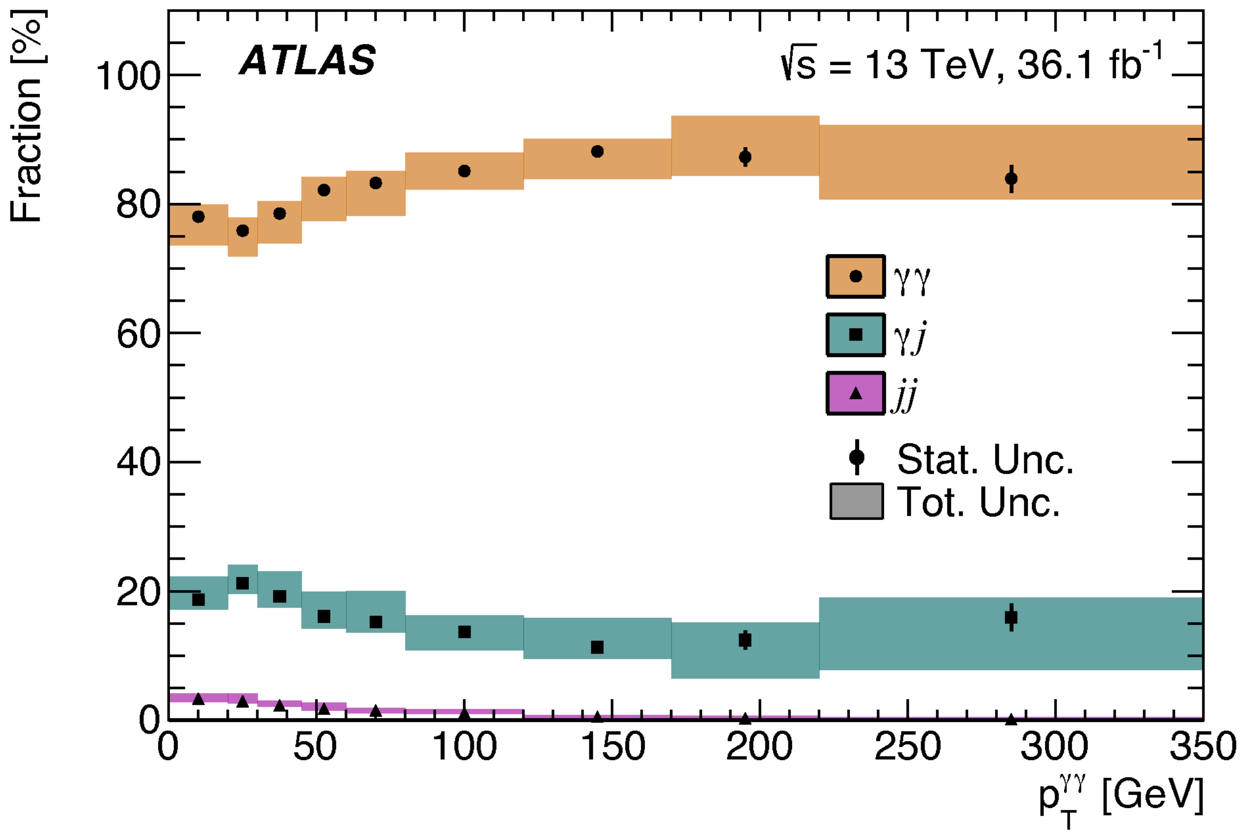


HL-LHC: 3000 fb^{-1} (14 TeV) and doubled background

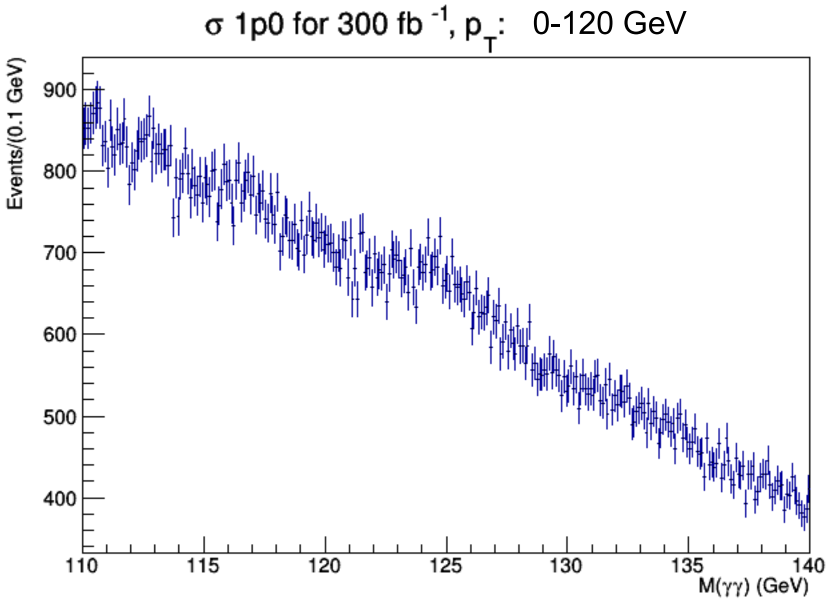


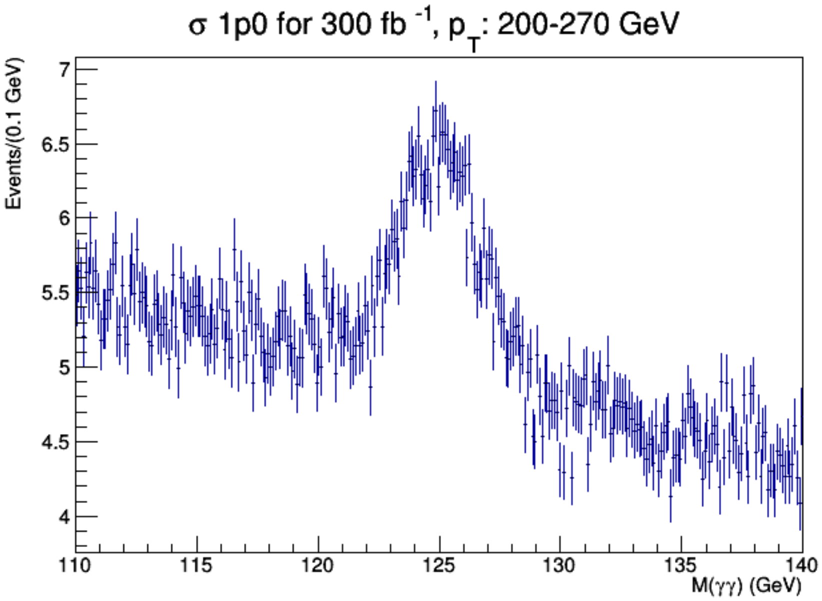
Fake Rate

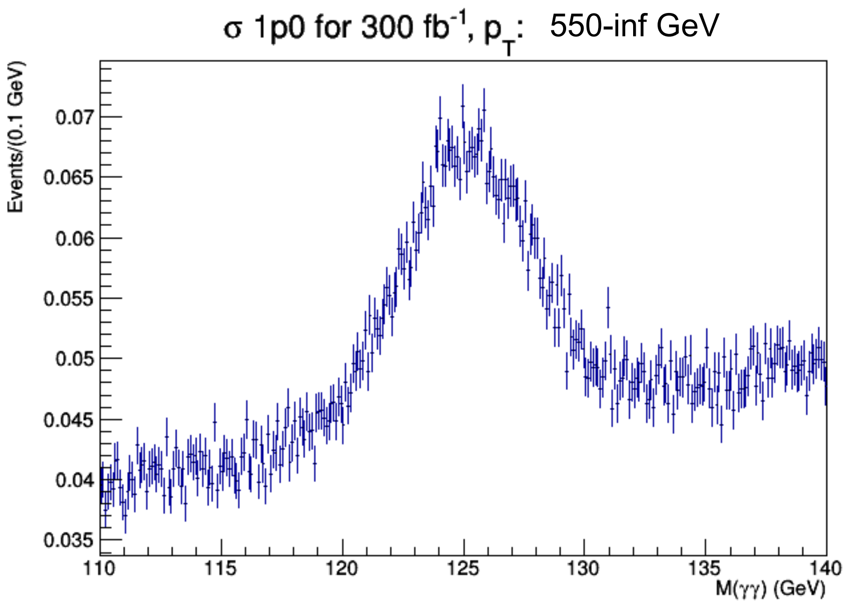
Fake rate from γ-jet and jet-jet background:



Shapes: Higgs + Background for 300 fb^{-1}







Signal to background ratio is increasing with increasing Higgs p_T