PPG12: Isolated Prompt Photons in p+p collisions at 200 GeV

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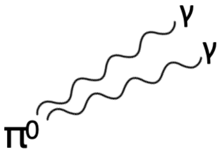
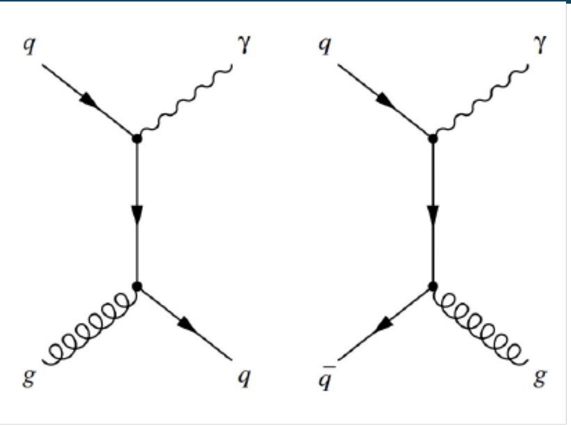
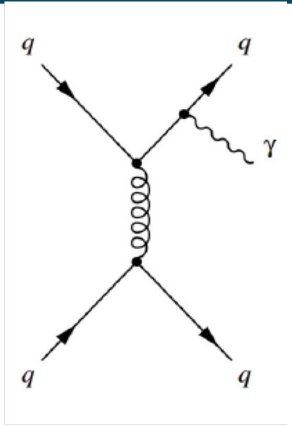
For PPG 12

Isolated Prompt Photons

- **Direct photon**
  - produced from **primary vertex**
  - Processes : Compton scattering, Annihilation
- **Fragmentation photon**
  - radiated from partons after the primary hard scattering
- **Decay photon**
  - decayed from hadrons, such as π_0-> $\gamma+\gamma$
  - **major background**







Compton scattering Annihilation Fragmentation

Direct photons

Prompt photons

= Direct + Fragmentation photons

Event and Data/Simulation Samples

Data

- DST: DST_JETCALO ana462 p010 v001
- Run range: 47289 - 53880
- Total luminosity: ~16pb^{-1}

Signal MC

- Pythia photon+jet 5, 10, and 20 GeV

Background MC

- Pythia inclusive jet 10, 20, and 30 GeV

Event Selections

- | MBD vertex z | < 30 cm
- MBD hits north >= 1 && MBD hits south >= 1
- Photon 4 GeV + MBD N&S trigger (bit 26)

Object Selection Summary

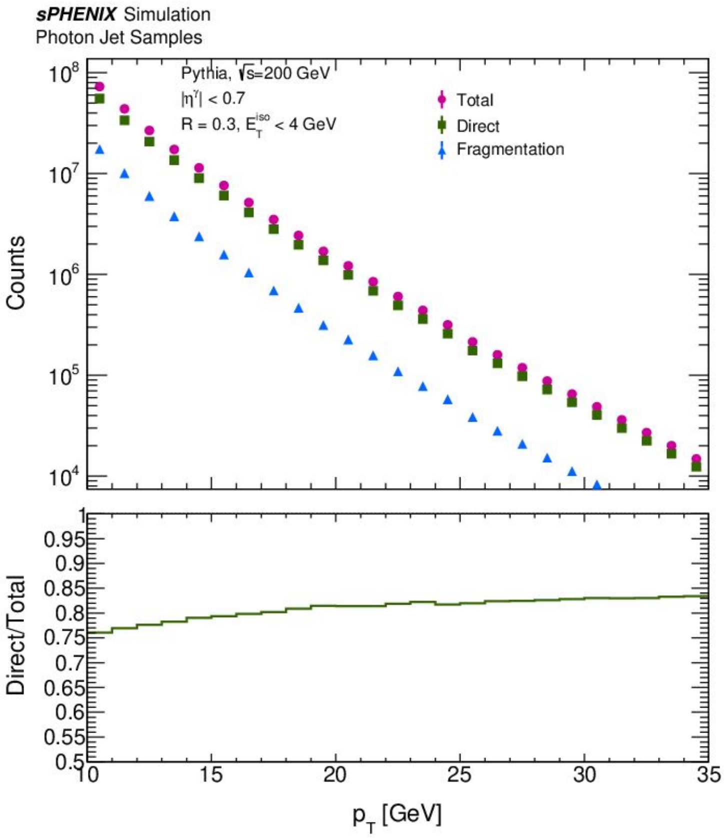
Isolated prompt photon truth-level definition:

- |eta|<0.7
- Direct or fragmentation photons
  - Back trace the photon history (skipping the vertices for frame transformation) to find the first production vertex of photon. Direct photons are from 2 to 2 vertex with q or g as input. Fragmentation photons are from 1 to 2 vertex with q as input.
- Truth-level isolation energy (= sum of transverse energy of final-state truth particles in a cone of R=0.3) less than 4 GeV
- Truth-reco matching to reco-level cluster (dR<0.05, best match cluster based on g4eval)

Reconstruction-level signal selection:

- EMCal template-based cluster
- |eta|<0.7
- Photon ID conditions (see later slides)
- Isolation transverse energy (E_T^{iso})in a R=0.3 cone less than a variable pT-dependent cut (see later slides)

Direct and Fragmentation Photons



- Isolated prompt photons are defined as **direct** or **fragmentation** photons with truth isolation transverse energy below 4 GeV in a cone of R=0.3

- About 80% of direct photons

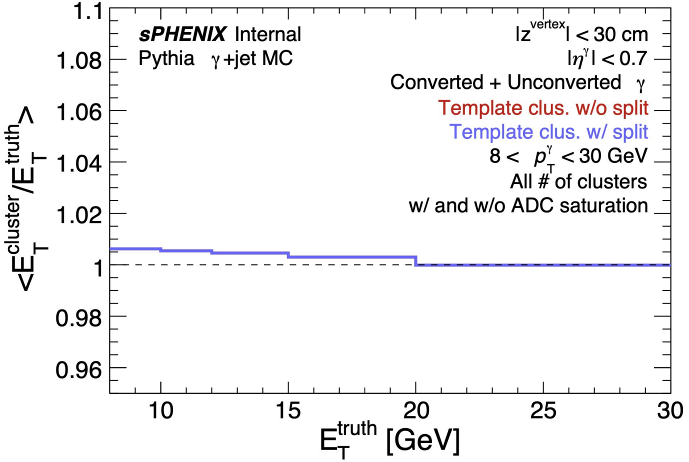
Clustering Algorithm

Utilizing existing RawClusterBuilder module without splitting

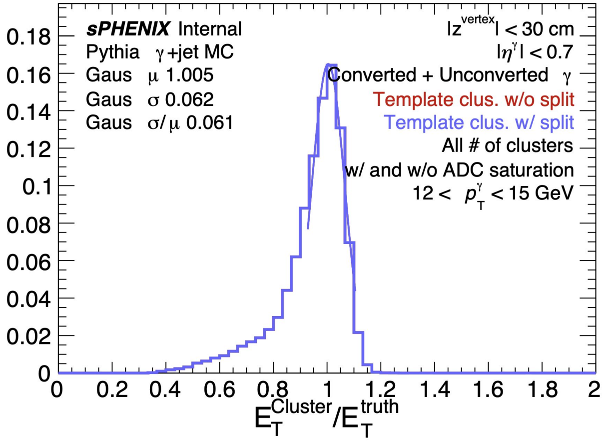
- All adjacent towers above a 70 MeV threshold are clustered together
- Towers passing the isGood quality selection
- Using reco clusters above 5 GeV

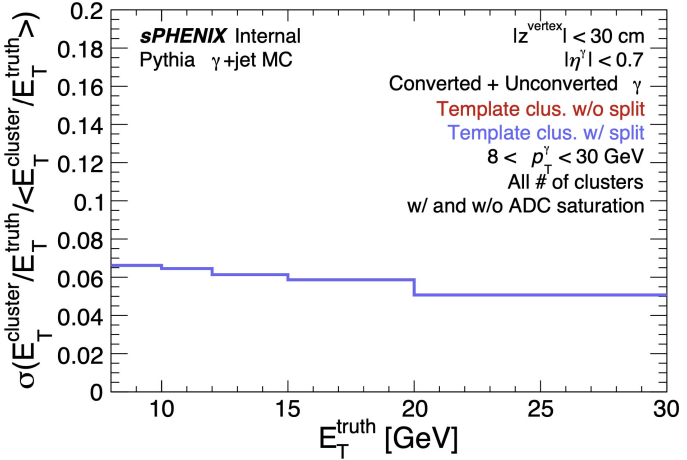
Photon Energy Scale and Resolution

- lower E_T^{reco}/E_T^{truth} tail from absence of the position-dependent calibration (aiming for post-QM)
- Photon energy scale and resolutions are obtained with Gaussian fits of E_T^{reco}/E_T^{truth} at the peak region



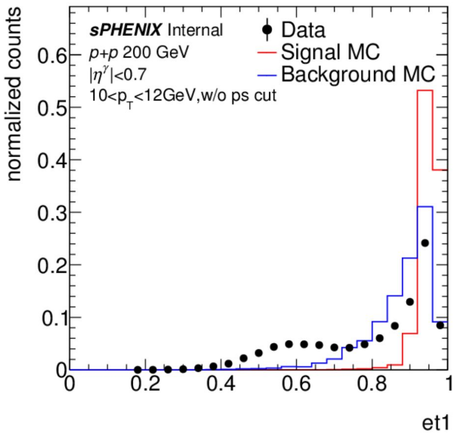
e.g. truth photon 12-15 GeV

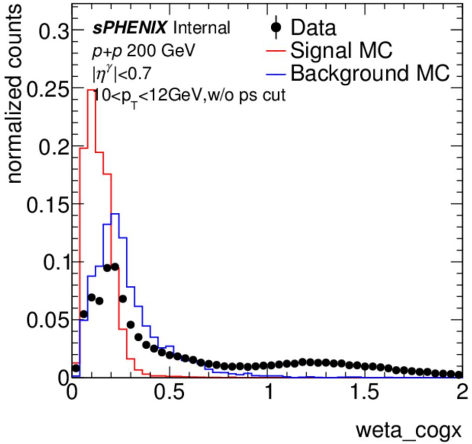


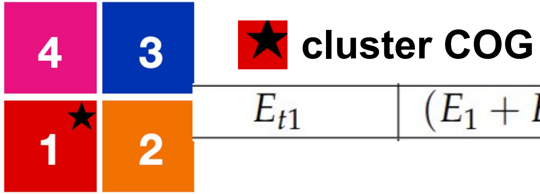


Photon Shower Shapes

- A set of cluster moments and energy ratios, collectively referred to as shower shapes, are used to select signal photons.
- Below, 2 example shower shapes compared to signal and background MC
- Shower shapes statistically separate S/B
- Clear excess et1=0.4-0.8, weta_cogx=1-1.5 which arises from non-physics beam related backgrounds





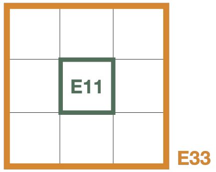


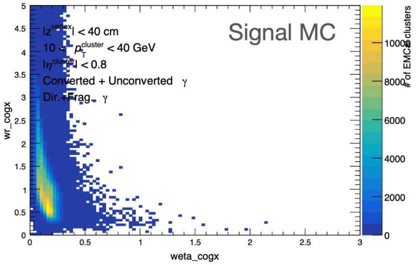
E_{t1}	$(E_1 + E_2 + E_3 + E_4)/E_{tot}$

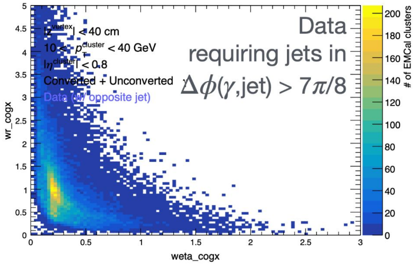
$w^{\mathrm{COGX}}_{\eta(\phi)}$	energy weighted second moment of $\eta(\phi)$ from all towers in a given cluster excluding the tower containing the center of gravity.

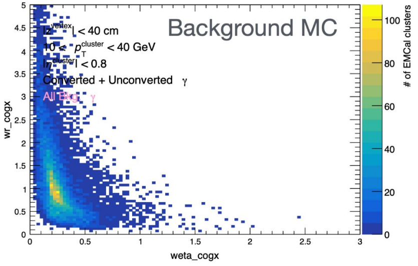
Non-Physics Background Removal

- It is common for beam backgrounds to enter the EMCal and fire the photon trigger. These backgrounds are of high enough rate that a coincident physics collision (or other background) also triggering the MBD N&S trigger is common.
- A set of cuts on shower shape variables are derived to prevent these clusters from entering the sideband regions
  - (wphi_cogx/weta_cogx < 0.4) && (weta_cogx > 0.9) ; to remove streak beam background
  - E11/E33<0.98 ; to remove hot towers

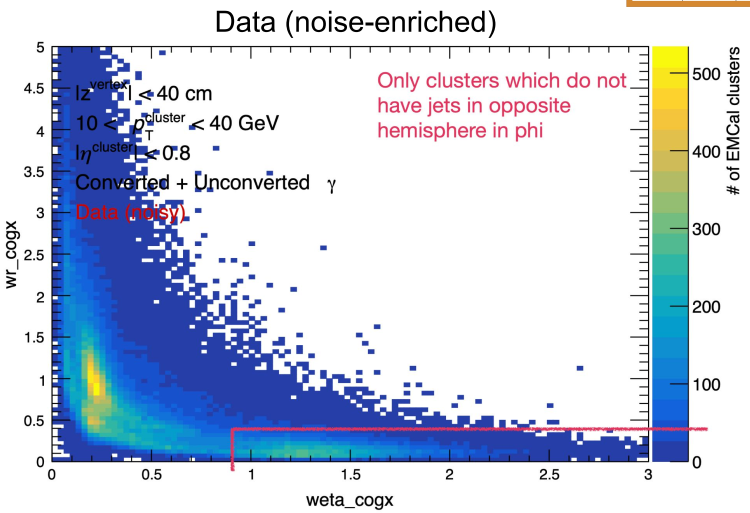






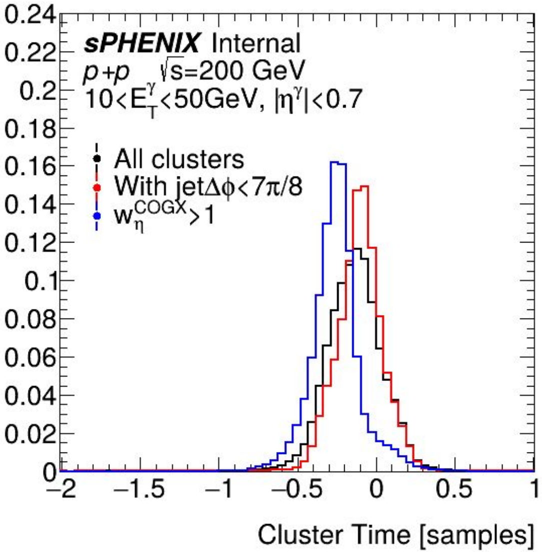


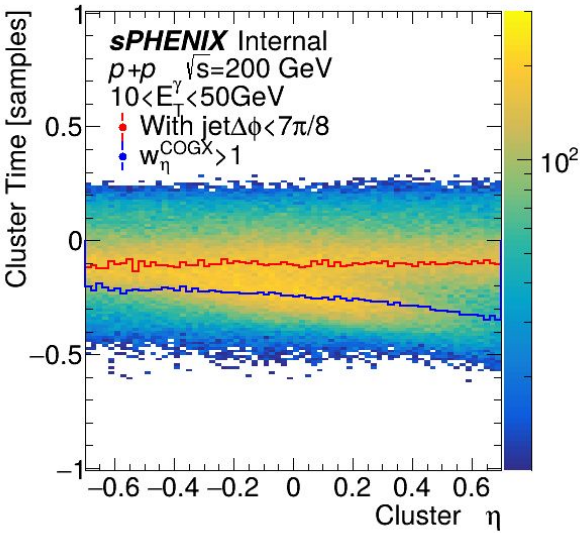
- weta_cogx (wphi_cogx) = energy weighted second moment of eta (phi) from all towers in a given cluster
- wr_cogx: wphi_cogx/weta_cogx

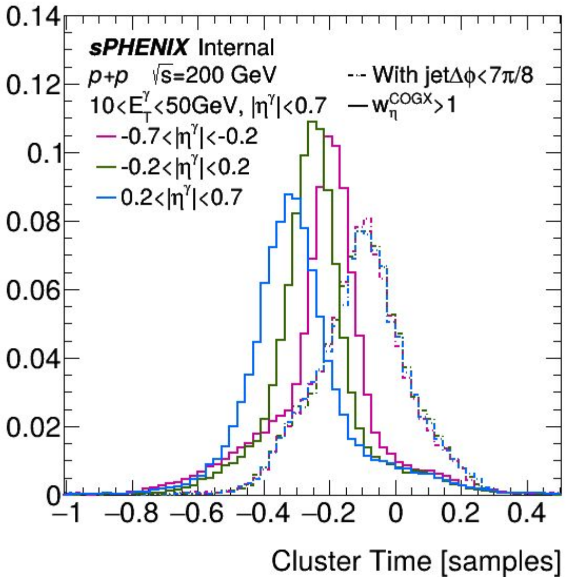


Non-Physics Background Removal

The non-physics background seems to be in-time with the collision and travel with the beam from +z to -z.
Working on selecting the background with timing cut and study their showershape and isolation E_T .

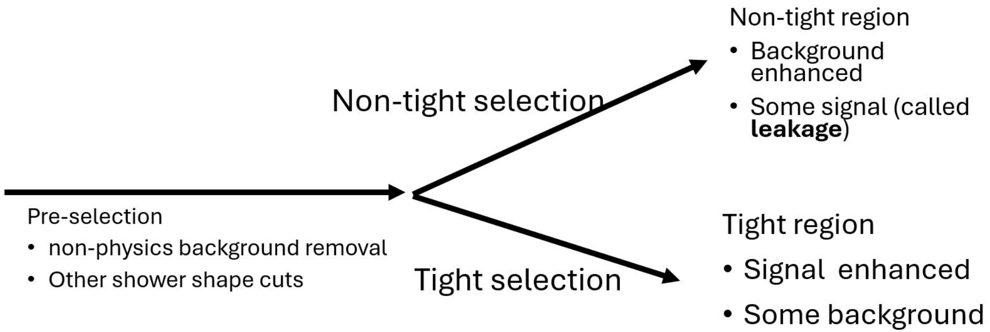






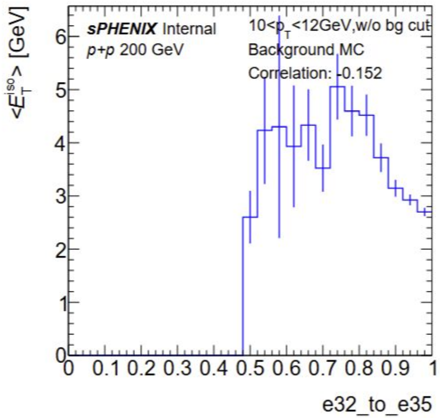
Photon Identification (2)

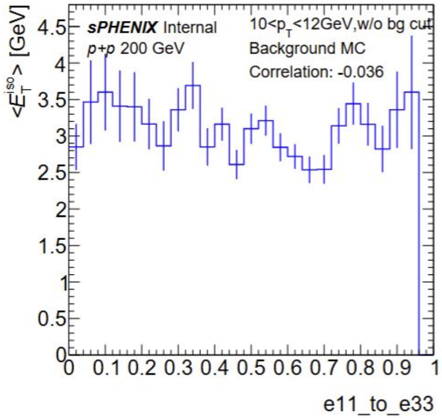
- The set of shower shape selections used to select signal photons are known as the ***tight*** selection
- These selections enhances the purity in the signal region but there is a large irreducible physics background e.g. high-pT pi0s.
- Shower shapes are also used to measure background yields in control regions for a data-driven physics background removal procedure (described in latter slides). This background shower shape selection is referred to as the ***non-tight***   selection.
- **Pre-selection** cuts are applied in both the tight and non-tight selections and removes non-physics backgrounds as does some initial physics background removal (discussed in following slide).



Correlation between Photon-ID and Isolation ET

- The background estimation procedure used in this analysis (see following slides) **relies on the independency of isolation energy and photon criteria** (shower shape signal and background cuts).
- There are intrinsic physics correlations in some processes between E_T^{iso} and some shower shapes (which are still useful to for increasing signal purity). These shower shape cuts are applied to both signal and background and are added to the preselection.
- Below are the average E_T^{iso} as a function of shower shape, for a correlated (leaft) and less-correlated (right) shower shape
- The left plot demonstrates a shower shape used for the pre-selection cuts and the right is used in the tight and non-tight separation.





Photon Identification Criteria

Preselection cuts

Non-physics background removal cuts

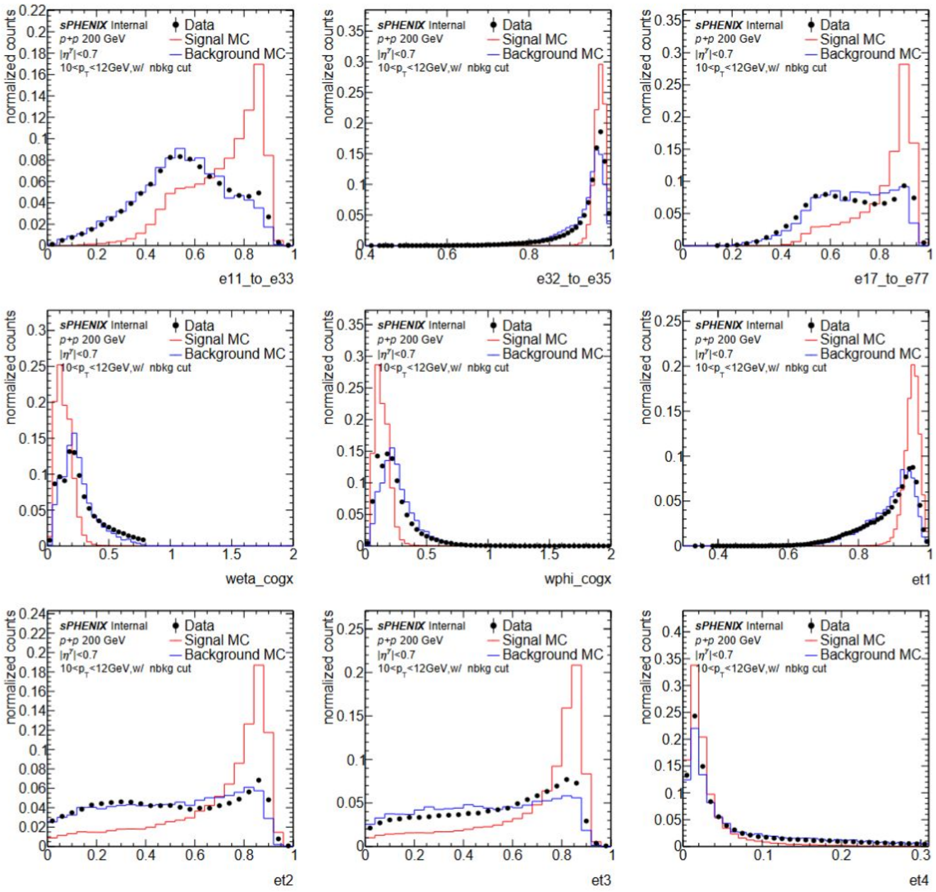
- E11/E33 < 0.98
- weta_cogx < 0.8
- 0.9 < et1 < 1.0
- 0.92 < E32/E35 < 1.0

Tight (while passing common cut):

- 0 < weta_cogx < 0.15
- 0.5 < E11/E33 < 0.98
- 0 < et4 < 0.2
- 0 < w32 < 0.4

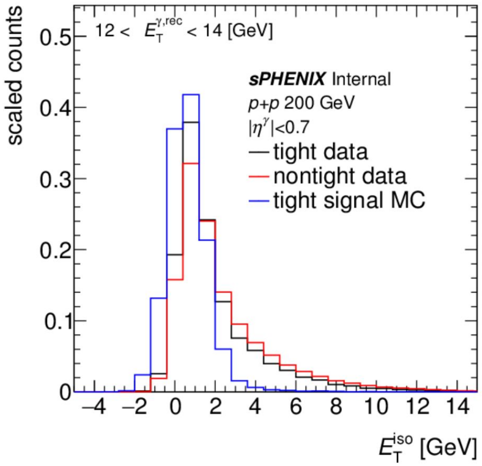
Non-tight (for background photons): pass 0.3 < weta_cogx < 0.8 && any 1 other cuts failing

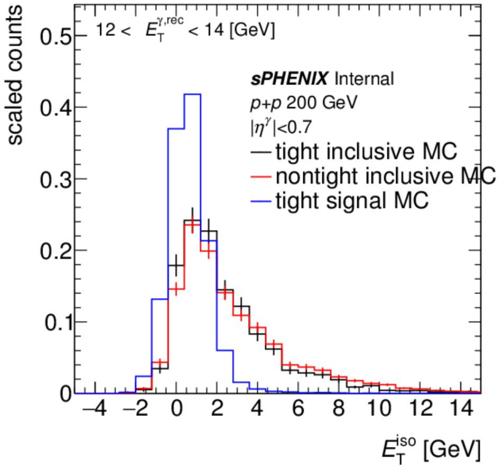
Plots are shown for with the non-physical background removal cuts



Isolation Energy distributions

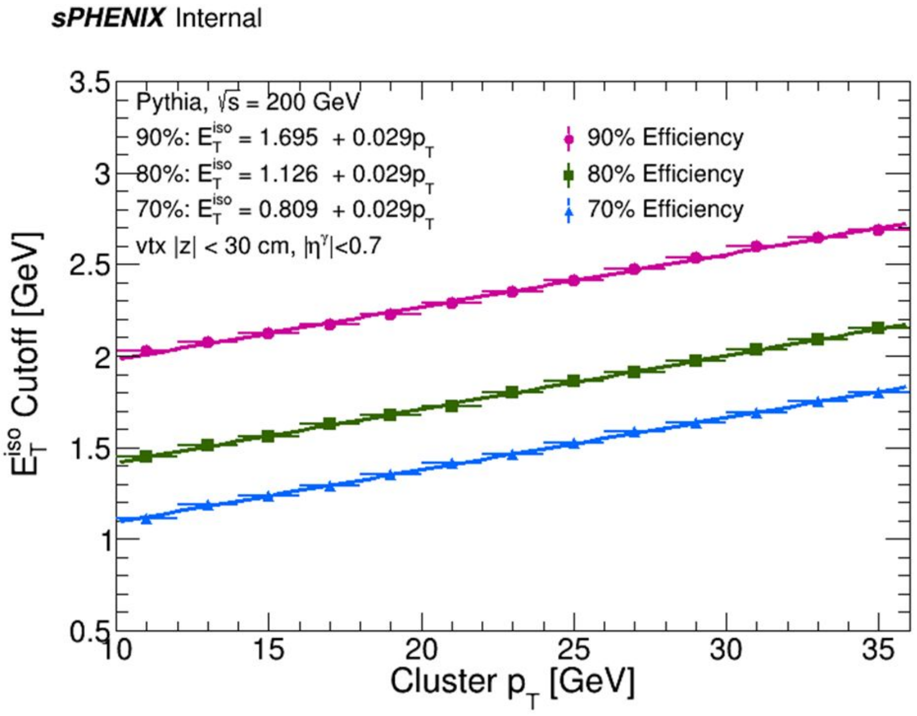
- Isolation energy distributions for tight vs. non-tight selections show difference related to more signal in the tight selection.
- A rather low purity can be seen and thus a systematic sensitivity to the correlation of the background isolation energy shape and the tight and non-tight definition.
- A comparison to inclusive MC (pythia jet sample) is shown and demonstrates that a low purity is expected (at these pTs direct photons are only 10-25% of the pi0 yield)





Considering using Isolation energy calculation with tower minimum energy threshold.

Photon Isolation Condition



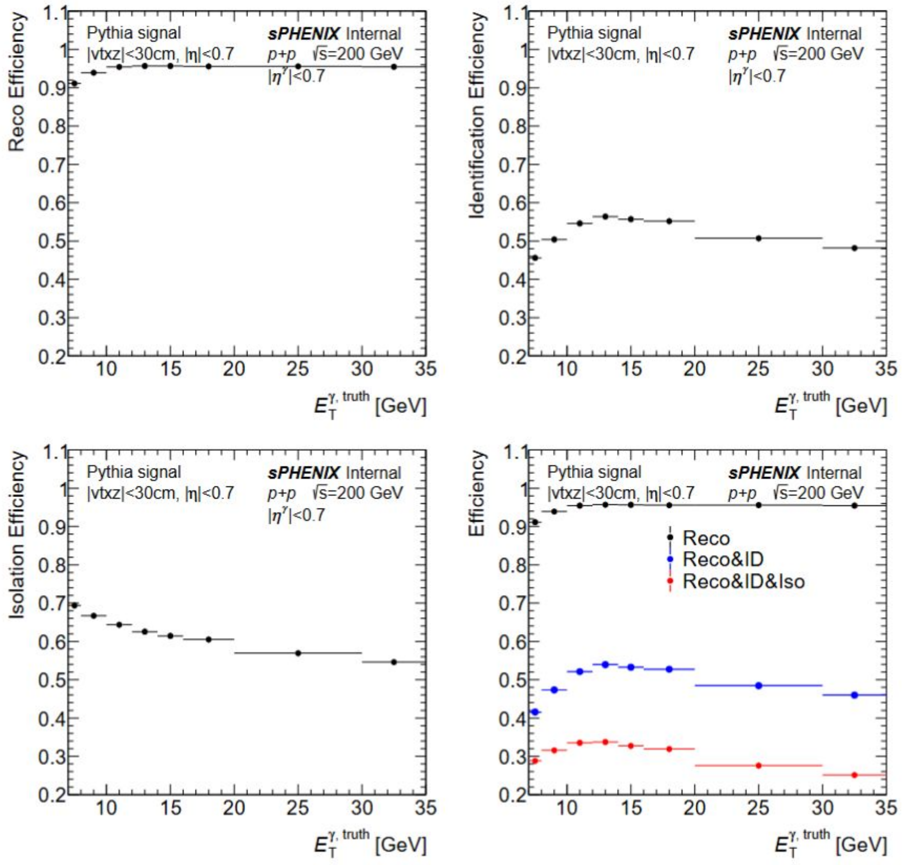
For signal photon MC, the E_T^{iso} cut for 90%,80%,70% efficiency are calculated as a function of photon E_T.

Fit function corresponds to 70% efficiency is used for this analysis.

$$E_T^{iso} < 0.809 + 0.029*E_T$$

e.g. for 10 GeV photon, E_T^{iso} < 1.099

Photon Efficiency



Reconstruction Efficiency

- defined as (# truth photon matched to reconstructed photons) / (# of truth photons)
- Truth-reco photon matching criteria imposed
- Efficiency is corrected bin-by-bin after unfolding

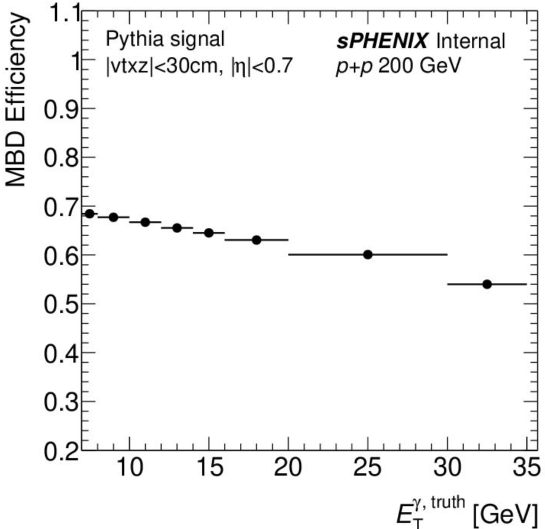
Working on deriving pT dependent photon id cut to increase efficiency at higher energy.

Trigger Efficiency

- (Photon 4 GeV + MBD N&S>=1) trigger (bit 26) is used

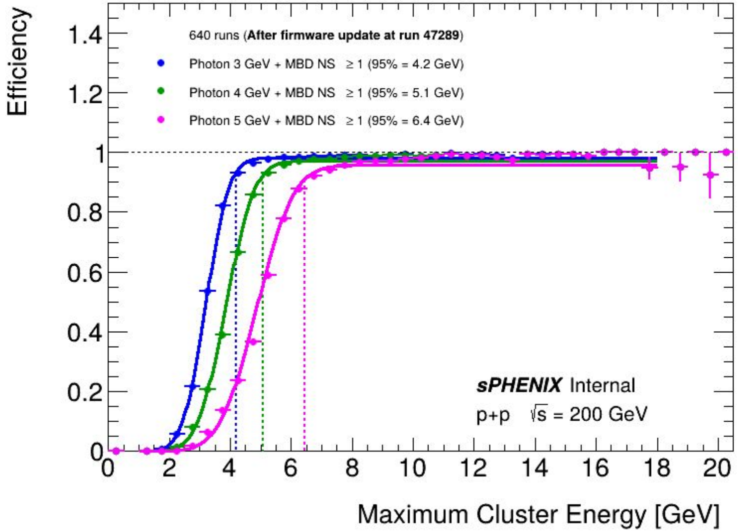
MBD trigger efficiency

- For signal photons with truth vertex within 30cm how many of them pass the event level cut of having MBD vertex within 30cm and have (mbdnorthhit >=1 && mbdsouthhit>=1).
- Here MBD hit is define when calibrated (to nMIPs) MBD charge >0.4



Photon trigger efficiency

- Photon 4 GeV trigger is well within the (almost) fully efficient plateau region for clusters of 8 GeV or more



Photon Purity Estimation

- After “tight” identification and isolation selections, there are still significant amount of background contribution (mostly from neutral mesons decay into two photons and being merged as one EM cluster)
- Purity is estimated with double-sideband data-driven method
- Assume that the isolation profile for the background for those that fail the identification are the same for those that pass the identification
    - A: signal region
    - B, C, D: controlled region (sideband region)

$$N_A^{\mathrm{sig}} = N_A - N_B \frac{N_C}{N_D}$$

To correct for signal leakage to the controlled region

$$N_A^{\mathrm{sig}} = N_A - (N_B - c_B N_A^{\mathrm{sig}}) \frac{(N_C - c_C N_A^{\mathrm{sig}})}{(N_D - c_D N_A^{\mathrm{sig}})}$$

Where $c_K \equiv \frac{N_K^{\mathrm{sig}}}{N_A^{\mathrm{sig}}}$ accounts for truth signal leakage to controlled region

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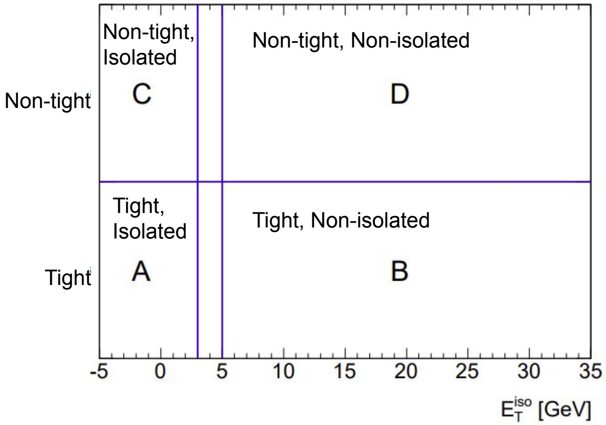
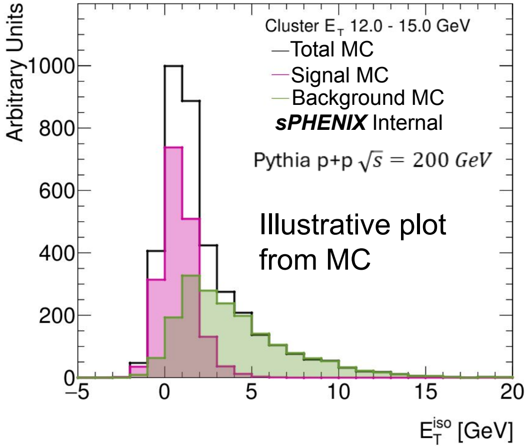
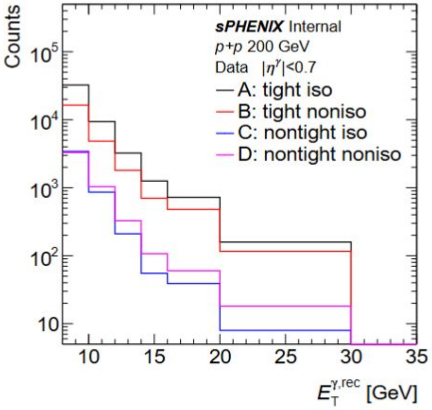
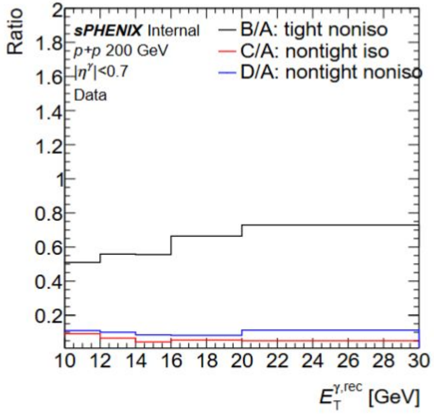




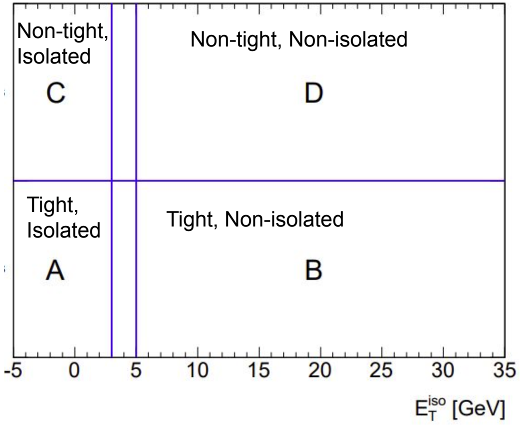
Purity Estimation (2)

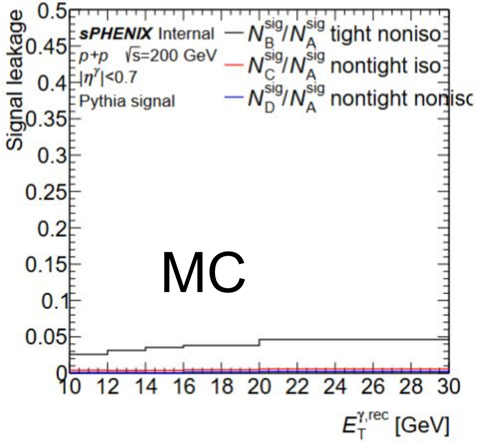
- Distributions of the number of clusters in different sideband region.
- Distribution doesn't show any odd features as a function of pT.
- Important balancing the statistics in different regions for smaller statistical uncertainties after sideband subtraction.
- Still working on optimizing the cuts to balance the statistics.





Data



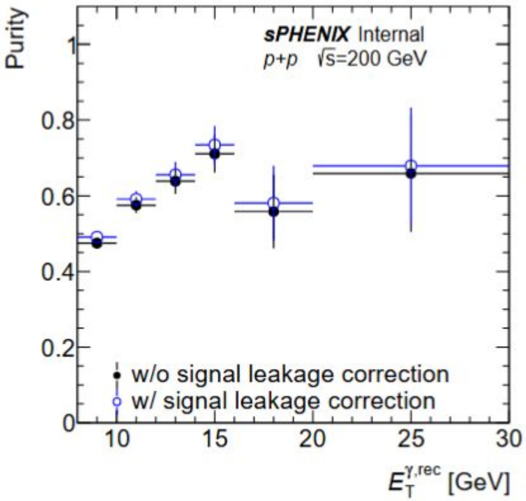


MC

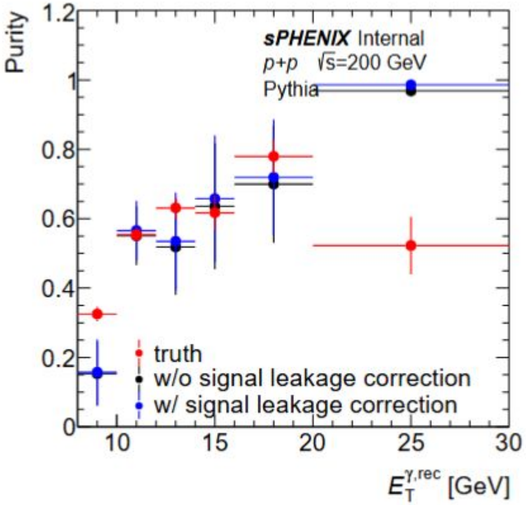
Purity

Since the majority of signal leakage is to the region C(tight, non-iso). Applying the leakage correction gives higher purity. Applying the same method to inclusive MC sample shows the leakage correction gives purity closer to MC ground truth.

$$\text{purity} = \frac{N_A^{sig}}{N_A}$$

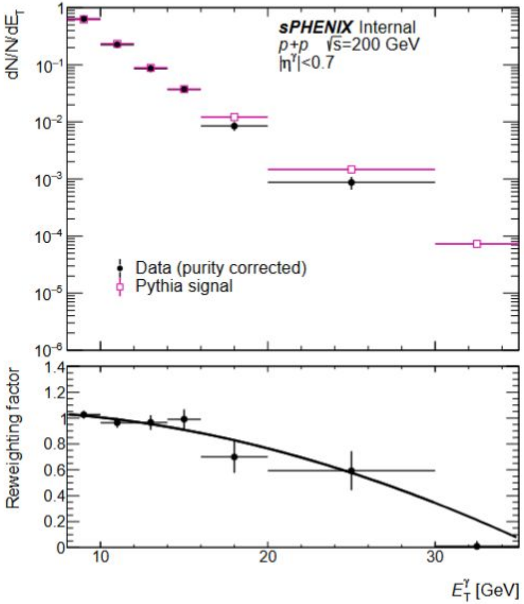


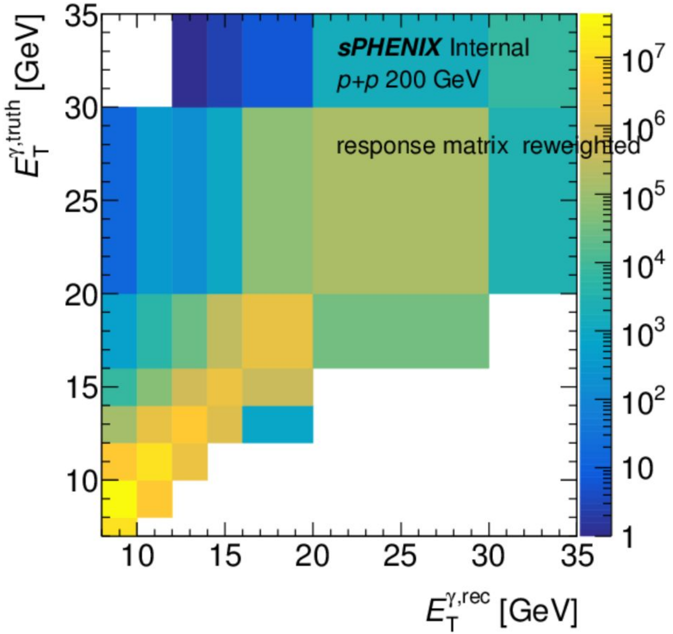
Inclusive MC Closure test



Unfolding

- Unfolding is performed with D'Agostini Bayesian method using RooUnfold
- truth ET bins [7,8,10, 12, 14, 16, 20, 30, 35] GeV
- reco ET bins [8,10, 12, 14, 16, 20, 30, 35] GeV
- fiducial bins [10, 12, 14, 16, 20, 30] GeV





Analysis Procedure

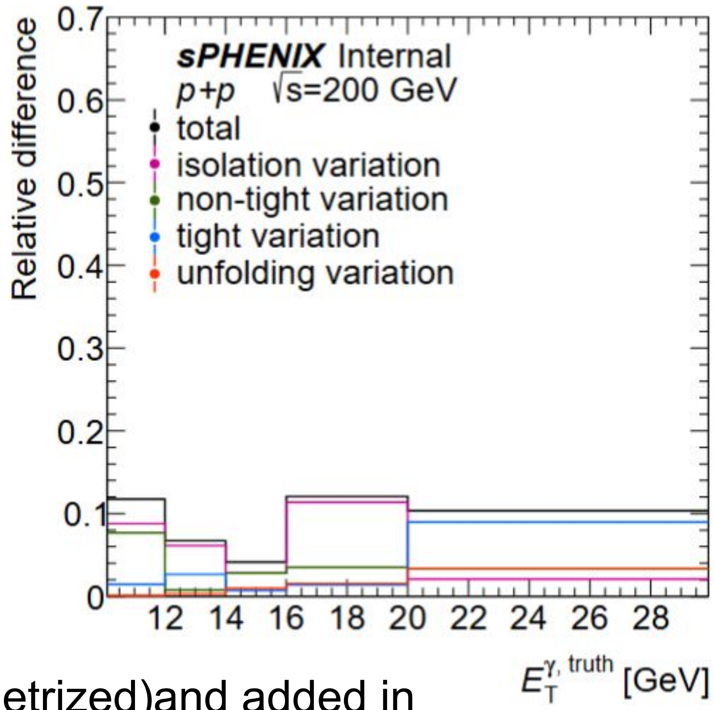
- Photon **Identification** using EMCal shower shapes
- Photon **Isolation** significantly rejects background photons
- After identification & isolation, the remaining background photons (decay photons from neutral mesons) contribution is estimated (purity) and corrected for
  - **Purity** estimation with data-driven double sideband method
- **Unfold** for E_T^{γ}
- **Efficiency** correction

$$\frac{dY^{\mathrm{rec}}}{dE_{\mathrm{T}}^{\gamma}} = \mathrm{Unfolded}\left[\frac{dN^{\mathrm{tight,iso}\,\gamma}}{dE_{\mathrm{T}}^{\gamma}} \times \mathcal{P}(E_{\mathrm{T}}^{\gamma})\right]$$

$$\frac{d\sigma}{dE_{\mathrm{T}}^{\gamma}} = \frac{1}{\mathscr{L}} \frac{dY^{\mathrm{rec}}/dE_{\mathrm{T}}^{\gamma}}{\mathcal{E}(E_{\mathrm{T}}^{\gamma})}$$

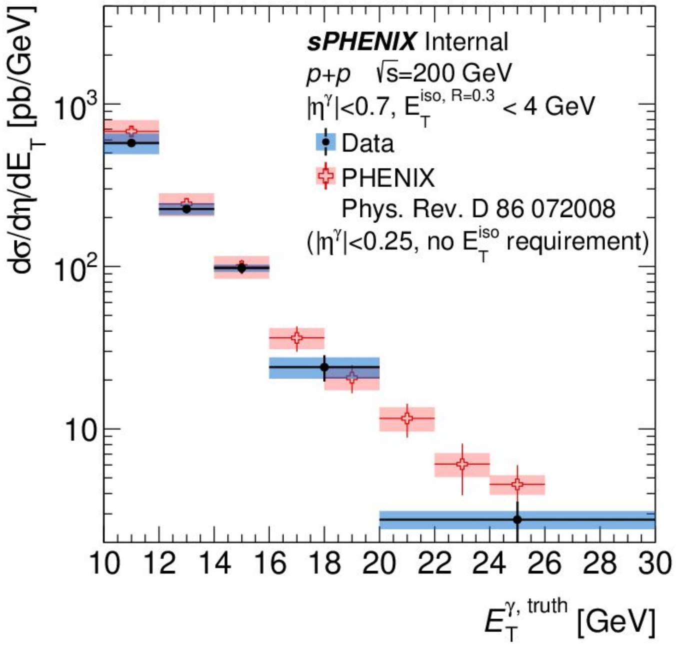
Systematic uncertainties

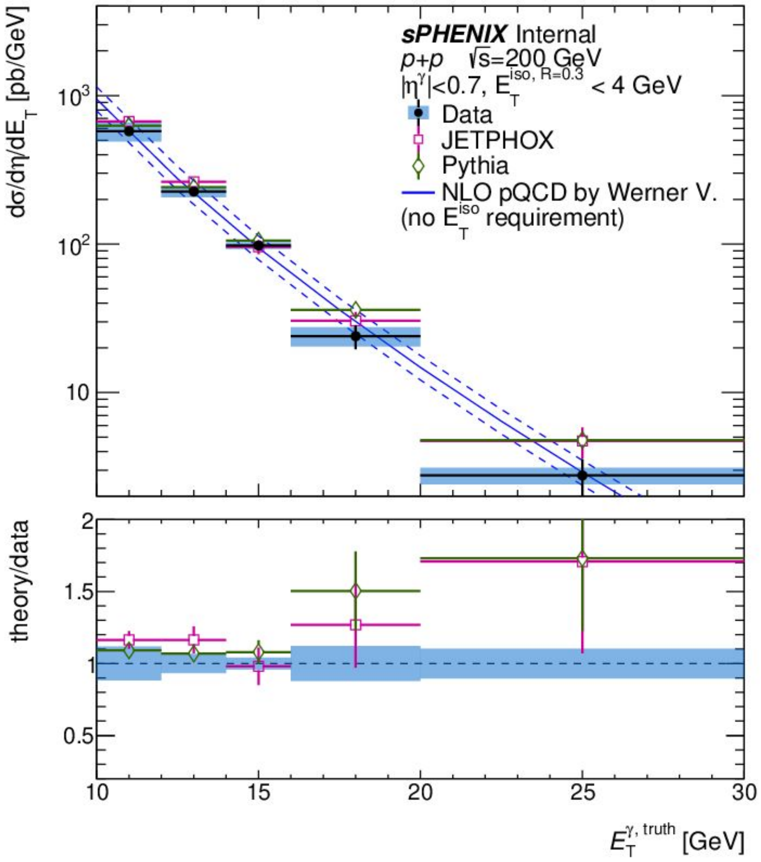
- Photon energy response(work in progress)
- Photon identification efficiency
  - Tight condition
  - Fudging showershape(not yet implemented)
- Photon Purity
  - Non-tight condition
  - Non-iso condition
- Unfolding
  - Without reweighting response matrix
- Luminosity
  - MBD cross-section
  - Pileup correction



Currently bin by bin variations are calculated (and symmetrized)and added in quadrature.
Working on more compete variations.

Results





- Current state final result is compared to theory and PHENIX result.

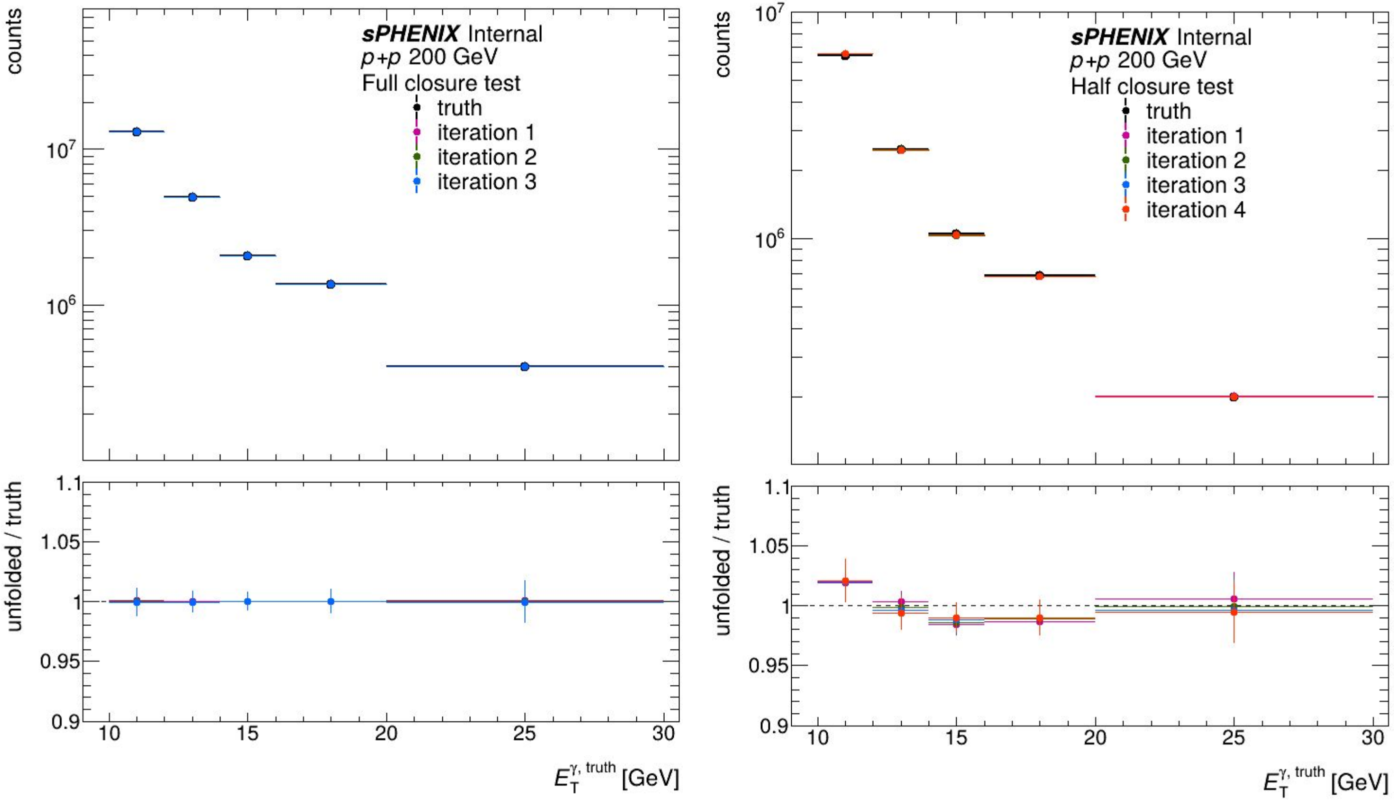
Todos

sPHENIX

- Cluster E_T dependent id cut.
- Cut optimization to balance statistics in the sideband region.
- Look into the effect of non-physics background to E_T^{iso} and showershapes
- Consider E_T^{iso} calculation with tower energy threshold imposed.
- Sample more complete systematic uncertainty variations.
    - Positive & negative variation for efficiency and purities.
    - Systematic from energy scale and energy resolution

backup

Unfolding Closure Test



To demonstrate the unfolding machinery, two closure tests are done.

Both shows acceptable closure.