Hadron Production in Photon-Photon Processes at the ILC and the BSM signatures with small mass differences

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DESY

Outline

- Motivation
- DBD simulations for $\gamma\gamma \rightarrow$ low pt hadron events
- Changes and improvements in $\gamma\gamma \rightarrow$ low pt hadron event generators
- Reconstruction efficiency for $\gamma\gamma \rightarrow$ low pt hadron events
- Possible methods to remove the $\gamma\gamma$ overlay
- Summary and Outlook

Motivation

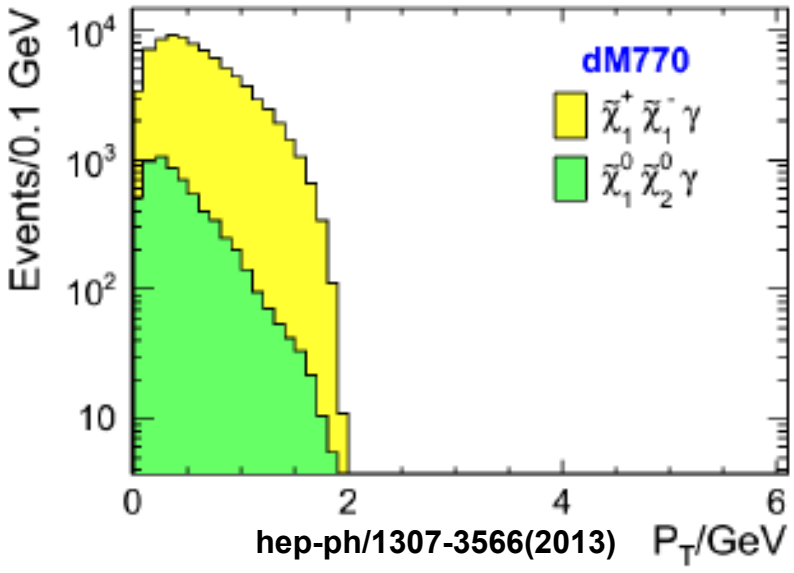
- Low ΔM higgsino analysis studied by Hale Sert - DESY-THESIS-2016-001
- The case was studied at two benchmark scenarios

  $\Delta M(\tilde{X}_1^{\pm}, \tilde{X}_1^0)$ = 770 MeV - dM770

  $\Delta M(\tilde{X}_1^{\pm}, \tilde{X}_1^0)$ = 1.6 GeV - dM1600
- The mass of $\tilde{X}_1^{\pm}$ could be reconstructed with a precision 2 GeV - dM1600 and 1.5 GeV - dM770 and for $\tilde{X}_2^0$ 3.3 GeV - dM1600 and 1.6 GeV - dM770
- The mass difference between the chargino and LSP estimated from energy of decay products of charginos with 270 MeV(dM1600) and 40 MeV(dM770) precision

Motivation

- Hale's study showed that such scenarios can be well observed at the ILC
- Visible decay products very soft and thus similar to $\gamma\gamma \rightarrow$ low pt hadron backgrounds
- The study performed without the inclusion of $\gamma\gamma$ overlay
- Important to study the effect of overlay on the higgsino events

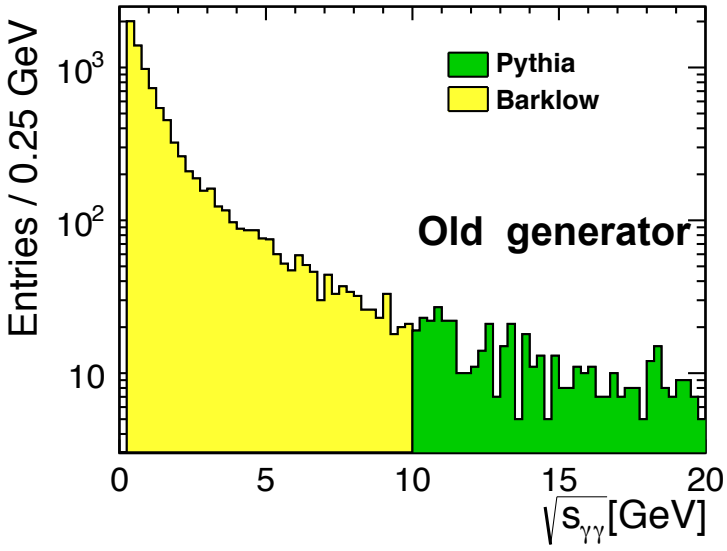


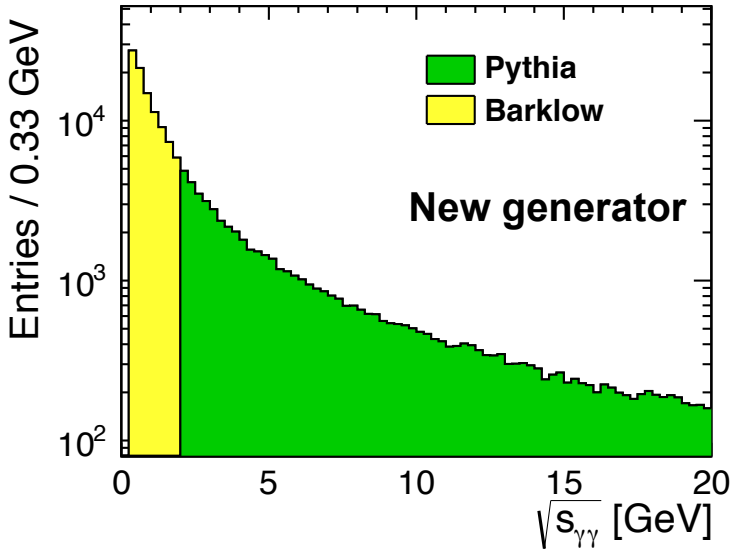
DBD simulations for $\gamma\gamma \rightarrow$ low pt hadron events

- In DBD simulations:
  - Overlaid number of $\gamma\gamma$ events on each physics event (1.7 evnts/BX)
  - $\gamma\gamma \rightarrow$ low p_T hadron event generation by Tim Barklow
    - $\sqrt{s_{\gamma\gamma}}$ < 10 GeV - dedicated generator by Tim (Barklow generator)
    - $\sqrt{s_{\gamma\gamma}}$ > 10 GeV - Pythia
- Removal of $\gamma\gamma$ backgrounds by applied k_T algorithm method
- In most of the cases k_T algorithm method a success to regain the physics performance
- Analysis for higgsinos still an exception to k_T algorithm method - the low pt visible decay products misidentified as $\gamma\gamma$ overlay in exclusive mode and discarded

Monte-Carlo generator for $\gamma\gamma \rightarrow$ low Pt hadron processes

- Until recently a very simpler version of Barklow generator was used - no neutral mesons, no natural width for rho
- $\sqrt{s_{\gamma\gamma}}$ < 10 GeV Barklow generator
- $\sqrt{s_{\gamma\gamma}}$ > 10 GeV Pythia
- Pythia generator - better than Barklow generator
- Pythia cannot generate events below 2 GeV
- **Energy cutoff for Pythia changed from $\sqrt{s_{\gamma\gamma}}$ > 10 GeV to $\sqrt{s_{\gamma\gamma}}$ > 2 GeV**
- $\sqrt{s_{\gamma\gamma}}$ < 2 GeV Barklow generator
- $\sqrt{s_{\gamma\gamma}}$ > 2 GeV Pythia

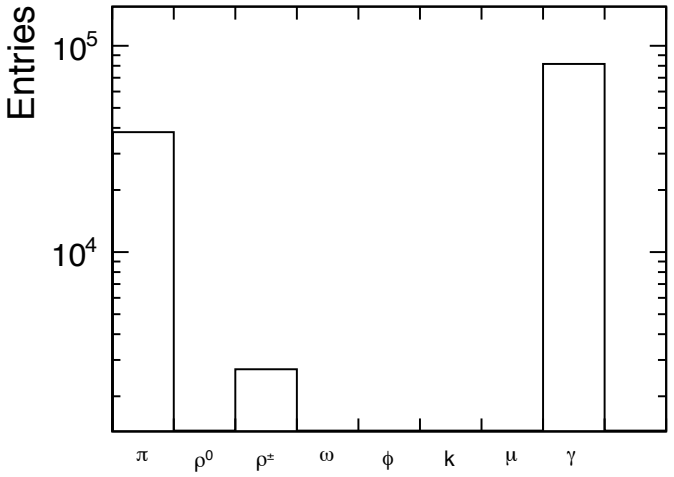


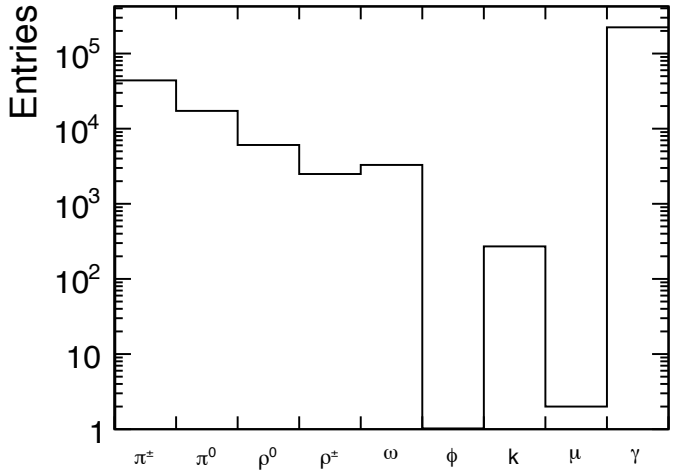


Event Properties of old and new Barklow generator

- Improvements implemented in Barklow generator for $\sqrt{s_{\gamma\gamma}}$ < 2 GeV
- Event Properties before improvements:
  - Barklow generator produced $\gamma\gamma \rightarrow$low Pt hadron processes with very simple events
    - $\pi^+\pi^-$
    - $\pi^\pm\rho^\pm$
    - $\rho^+\rho^-$
  - No neutral mesons included - no ρ^0 or π^0
- Event Properties after improvements:
  - The Barklow generator produces different events like

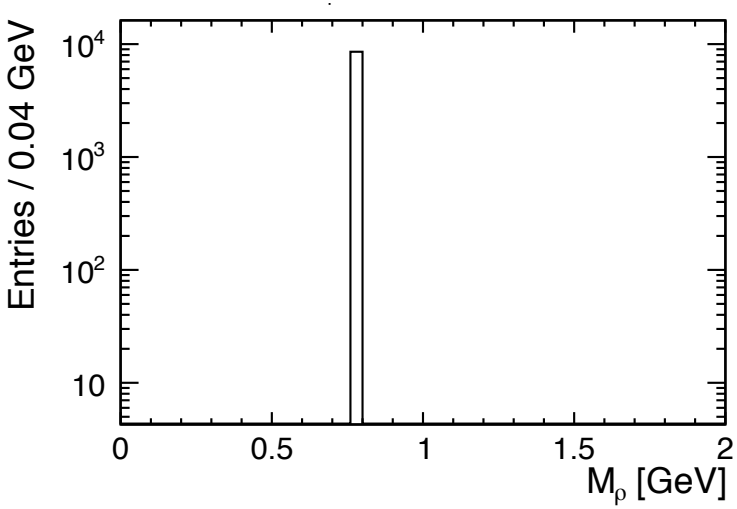
    $\gamma\gamma \rightarrow \pi^0\pi^0, \pi^\pm, \rho^0\rho^0, \rho^\pm, \omega$
  - The cross-sections for producing ρ^0 is greater than that for $\rho^\pm$

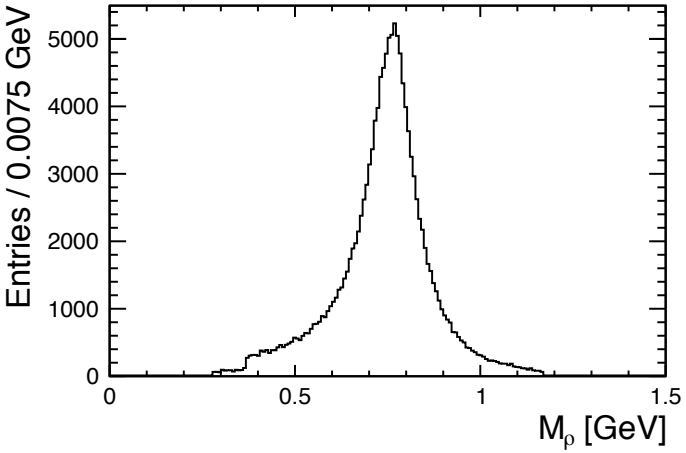




Event Properties of old and new Barklow generator

- PDG: m_ρ = 770 MeV and Γ_ρ = 145 MeV
- Before improvement:
  - Barklow generator produced rho meson without natural width - peaked at 770 MeV
- After improvement:
  - The improved generator now produces rho mesons with full natural width



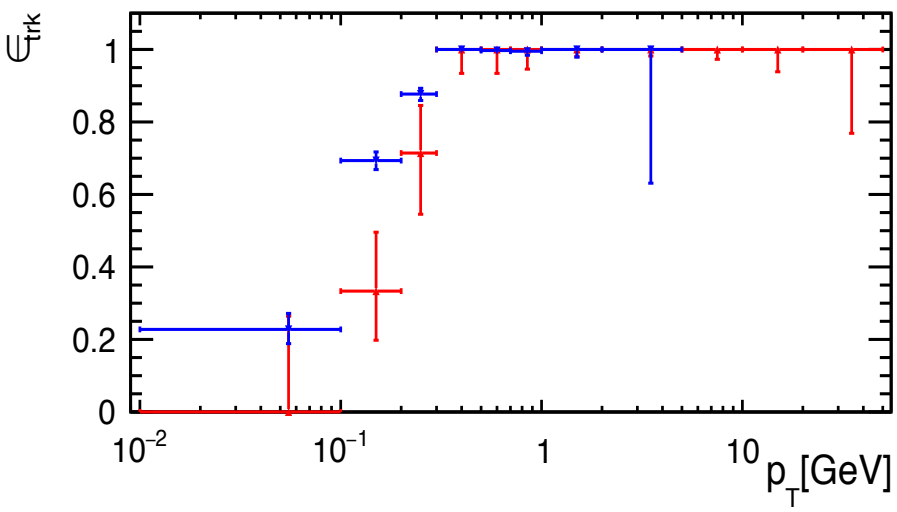


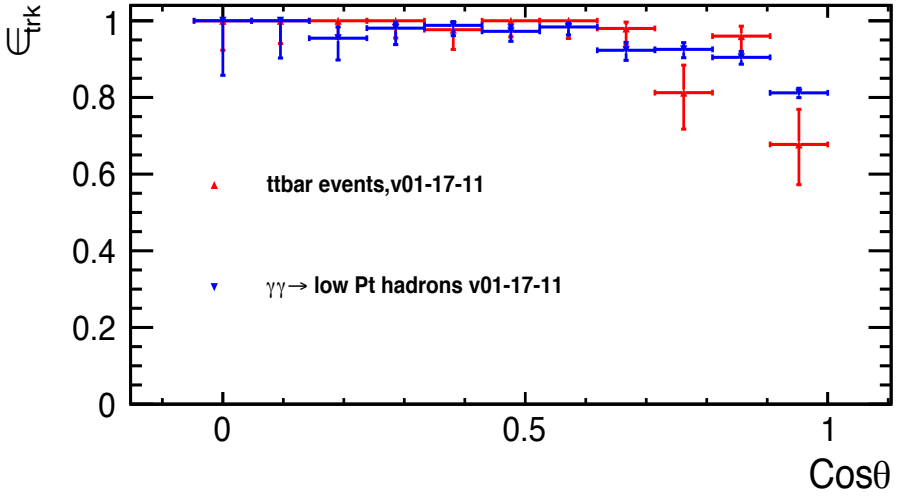
Cross sections for Barklow generator events

- Barklow generator events takes relative cross sections for different processes from different sources
- Measured cross sections from different experiments like Argus, Crystal Ball and other e^+e^- experiments at PETRA and PEP
- For each process β/s dependence for the cross section is used to determine relative weights of different processes at given E_{cm}
- The sources of cross sections for different processes are different from that used in old generator
- The cross sections for single processes have changed than before but the total cross section remains the same
- To do:
  - Recheck folding of total cross section with luminosity spectrum
  - $\gamma\gamma$ luminosity calculated wrongly in DBD - 1.7 events/BX
  - Average number of events per BX to 1.2 events

Reconstruction efficiency for tracks

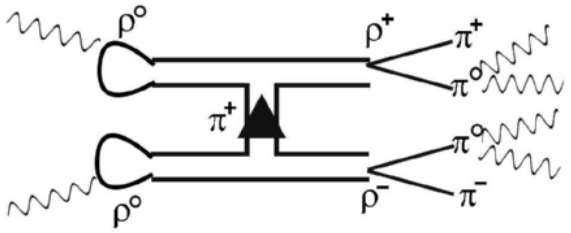
- ILD performance -Diagnostics package used for tracking efficiency
- https://confluence.desy.de/display/ILD/Reconstruction#Reconstruction-ILCSoftv01-19-01-preandILDConfig_HEAD
- Tracking Efficiency of the detector studied with detector model - ILD-o2-v05 and ILCsoft version v01-17-11
- Reconstruction efficiency for $\gamma\gamma \rightarrow$ low pt hadron events is consistent with the reconstruction efficiency for $t\bar{t}$ events
- Important to develop method to remove $\gamma\gamma \rightarrow$low pt hadron events





Possible methods to remove $\gamma\gamma \rightarrow$ low pT hadrons

- First Method:
- Displacement of vertices in z direction - 300 μm bunch length
- Vertices of $\gamma\gamma$ overlay events displaced from that of signal vertices
- Identifying the tracks coming from such vertices and removing them would be an effective method
- This method cannot be used for purely neutral events like $\pi^0\pi^0$
- Second method:
- The invariant mass of decay products of rho meson gives rho mass
- Rho meson used as a tag to remove $\gamma\gamma$ events
- Could be applied on very small event number



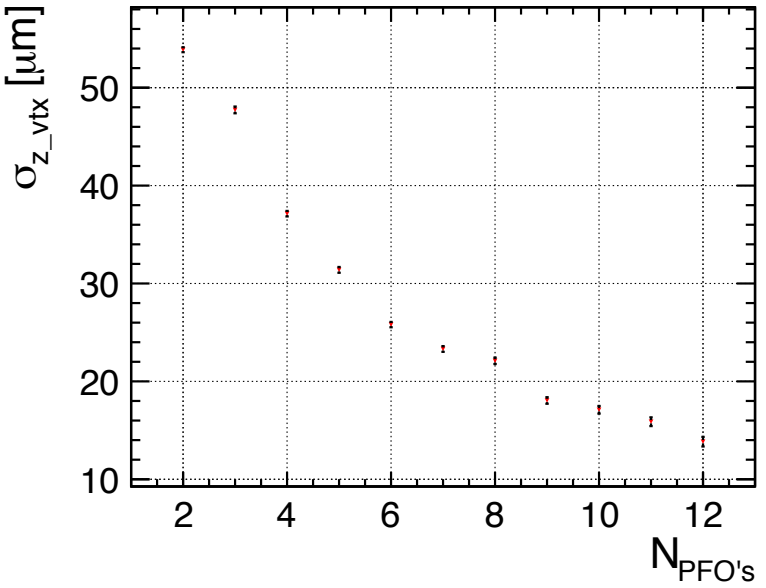
Method Development to remove backgrounds

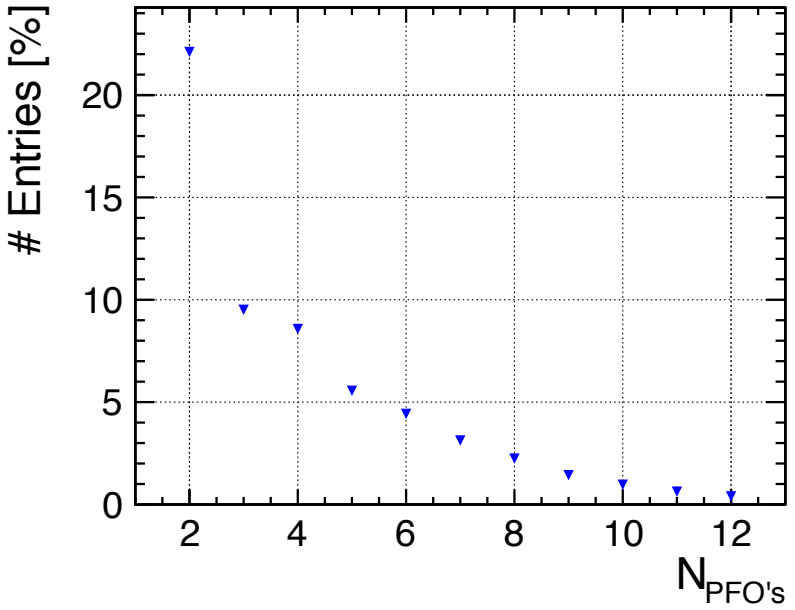
- Primary step - separating events as in table
  - Pythia events complex - 55 % events - good chances for finding vertex
  - Only Separating Barklow events as below - 45 %

Processes	No. events [%]	Methods to tackle
$\gamma\gamma \to \pi^+\pi^-$	33.43 %	displaced vertices
$\gamma\gamma \to \pi^0\pi^0$	5.68 %	only photons 😕
$\gamma\gamma \to \rho^+\rho^-$	1.26 %	displaced vertices & rho tag
$\gamma\gamma \to \rho^0\rho^0$	2.68 %	displaced vertices & rho tag
$\gamma\gamma \to \rho^0\omega$	0.7 %	displaced vertices & rho tag

Method - Displaced vertices for $\gamma\gamma$ events

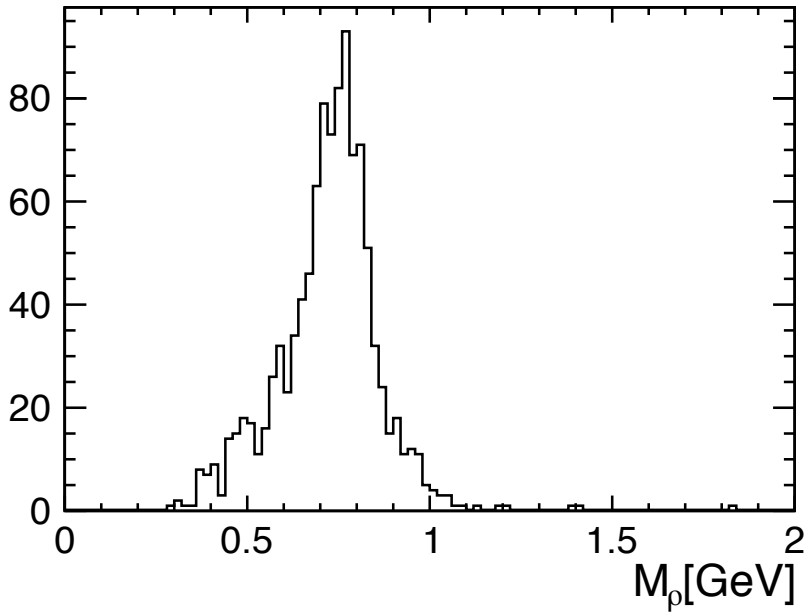
- Vertices of $\gamma\gamma$ overlay events displaced from that of signal vertices in z
- z_vtx resolution studied for vertices having 2 or greater than 2 tracks associated
- With increasing number of tracks(PFO's) in the primary vertex the resolution for vertex z position gets better
- For 60% of the events - z_vtx resolution ~ 50μm or better
- 40% events - either neutral events or events with 1 track or no tracks - only cluster information ☹





Method - Using Rho meson tag

- $\gamma\gamma \to \rho^0\rho^0$ events - rho meson decay to two π^+ and two π^- (2.68 %)
  - Events with exactly 2 $^{+ve}$ and 2 $^{-ve}$ tracks selected
  - Invariant mass calculated from two different combinations
  - mass closest to rho meson chosen and plotted
  - The pion combinations give rho mass - 770 $\pm$ 145 MeV
  - Only 0.54% events reconstructed exactly as 2 $^{+ve}$ and 2 $^{-ve}$ tracks



Summary and Outlook

- Although physics environment at ILC is very clean $\gamma\gamma$ backgrounds is still important
- The impact of this overlay is found on a very few specific but important events
- A better generator to produce $\gamma\gamma \rightarrow$ low pt hadrons was developed with more realistic particle contents for events
- Investigating whether different z_vtx position and vector meson tag can be used to remove the backgrounds
- Work in progress!!
- OUTLOOK:
  - The method developed will be applied on higgsino samples and Hale Sert's study would be repeated but with inclusion of $\gamma\gamma$ overlay

Questions??

Event Properties of Pythia

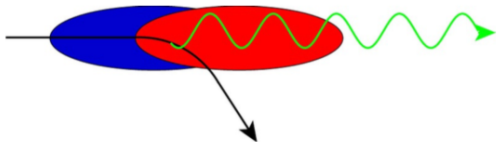
- Direct Interactions(DIR) - Real photons interacts directly
- Vector Meson Dominance(VMD) - Photon fluctuates into a vector meson
- Anomalous Interactions(GVMD) - Photon fluctuates into a $q\bar{q}$ pair of larger virtuality
- Deep inelastic Scattering(DIS) - A process of probing the Hadrons with very high energy leptons.

Subprocesses	Cross-sections (nb)
VMD * VMD	239.2
DIR * VMD	87.52
GVMD * DIR	9.77
GVMD * GVMD	12.05

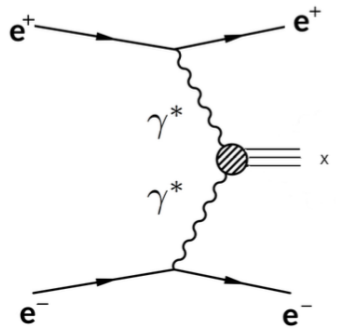
> Pythia cannot simulate below 2 GeV

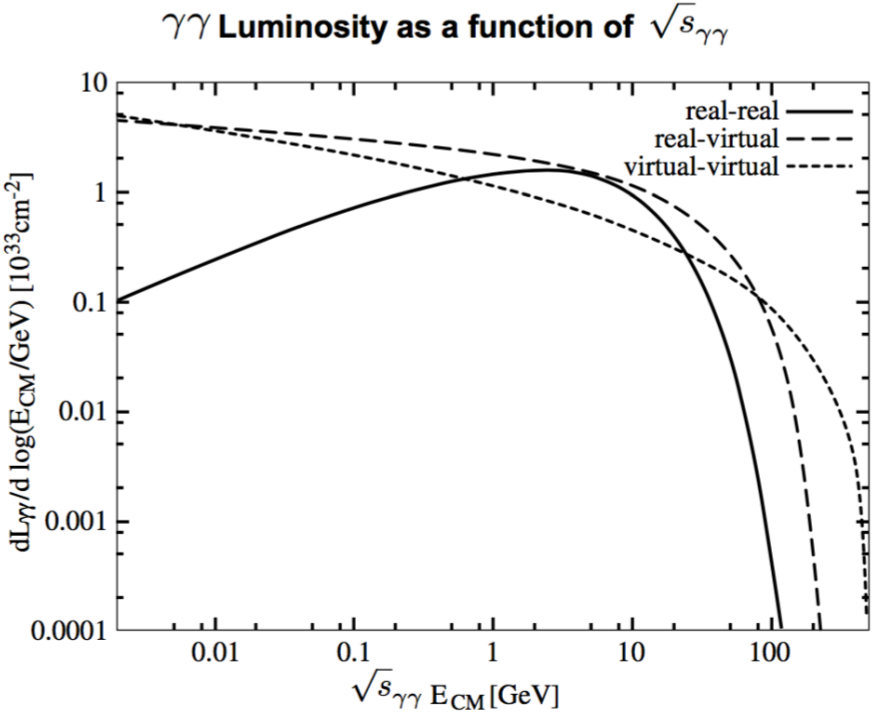
Photon Sources

- $e^+ e^-$ beams are accompanied by :
- **Real photons $f_r(x)$:**
  - Beamstrahlung - emission of **real** photons in high electrical field of oncoming bunch



- **Virtual photons $f_v(x)$:**
  - Weizsaecker-Williams process - emission of **virtual** photons which can interact with an oncoming photon or an electron

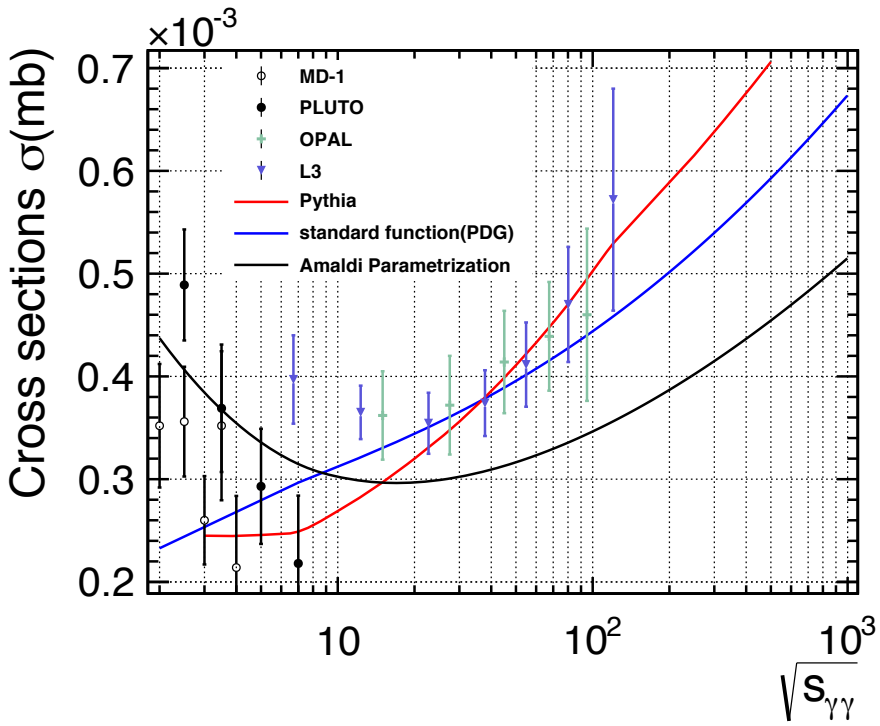




Ref:hep-ph/0406010v1(2004)

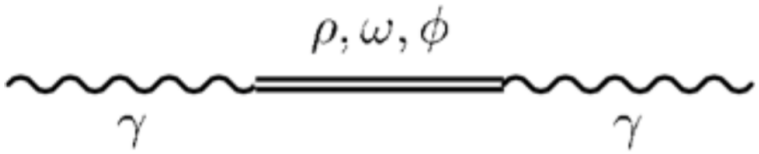
Cross sections for Pythia events

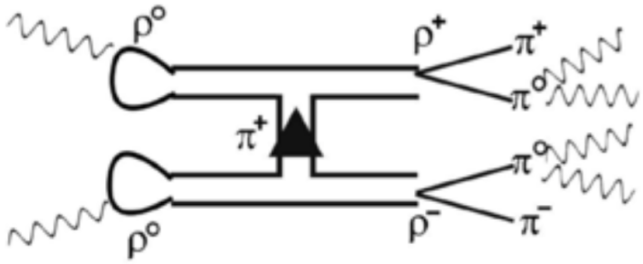
- Comparison of $\gamma\gamma \rightarrow$ low Pt hadron process cross sections from Pythia with PDG, Amaldi et.al(hep-ph/9305247) and data from LEP,PETRA and VEPP
- $\sqrt{s_{\gamma\gamma}}$ > 10 GeV : Good description of LEP data with Pythia
- $\sqrt{s_{\gamma\gamma}}$ < 10 GeV: Measurements have large uncertainties and widespread
- Pythia event properties studied in detail for better understanding



Photon-Photon Interactions

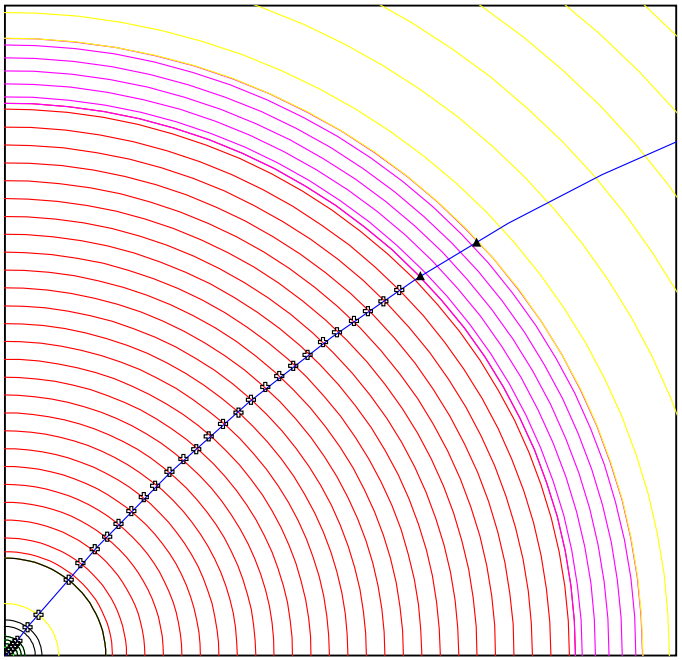
- Photons interact in different ways
- Vector meson dominance -Most dominating subprocess
- What are vector mesons? - $\rho, \omega, \phi, J/\psi, \Upsilon$
- Photon fluctuates into a vector meson since it has got the same quantum properties
- Photon is a hadron 1/400 of the time
- Highest probability to fluctuate into rho meson
- Production of huge amount of low Pt hadrons





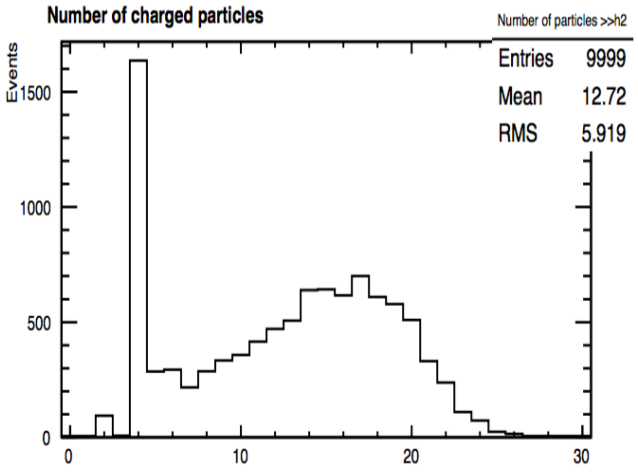
Does $\sqrt{s_{\gamma\gamma}}$ < 1 GeV matter?

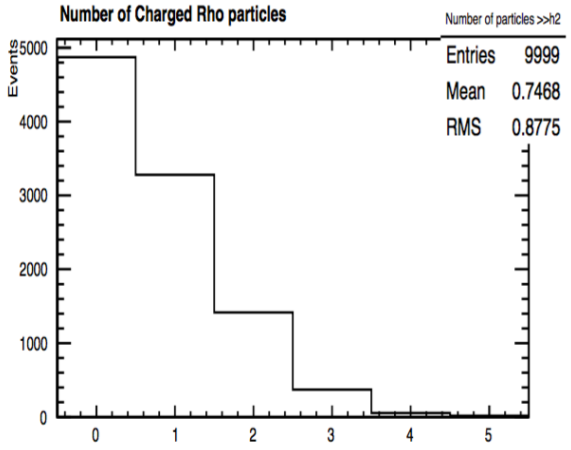
- Detector acceptance for $\sqrt{s_{\gamma\gamma}}$ <1 GeV
  - Select events $\sqrt{s_{\gamma\gamma}}$ < 1 GeV
  - Events generated from real-real, real-virtual and virtual-virtual photon collisions
  - Simulate ILD in SGV fast simulation
- Reconstruction in SGV
  - Particles having $\geq$ 3 layer hits : “Charged”
  - Particles hitting calorimeter : “Neutral”

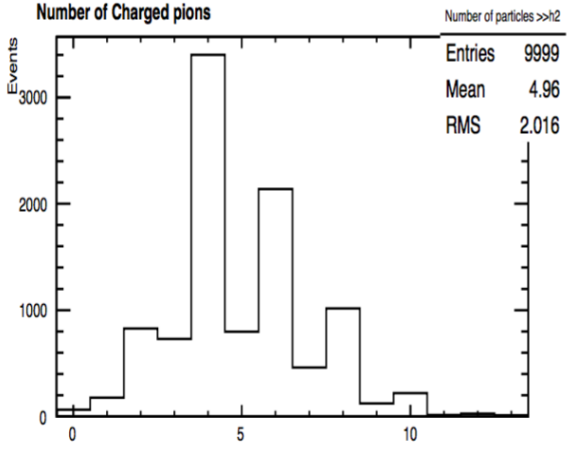


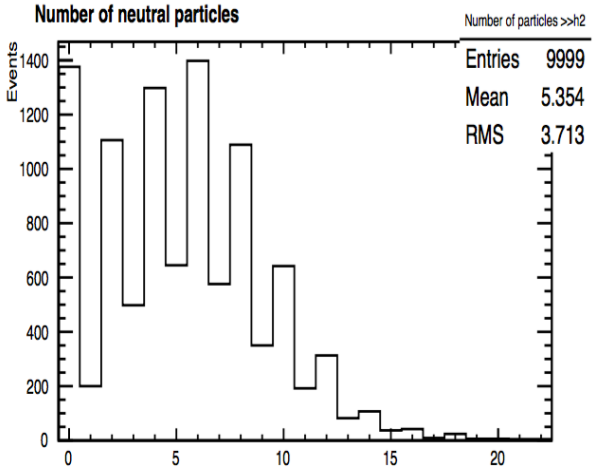
Ref: archiv:1203.0217v1

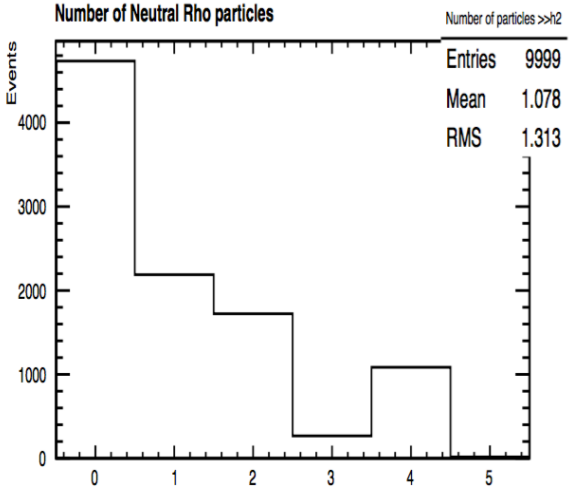
Event Properties of Pythia

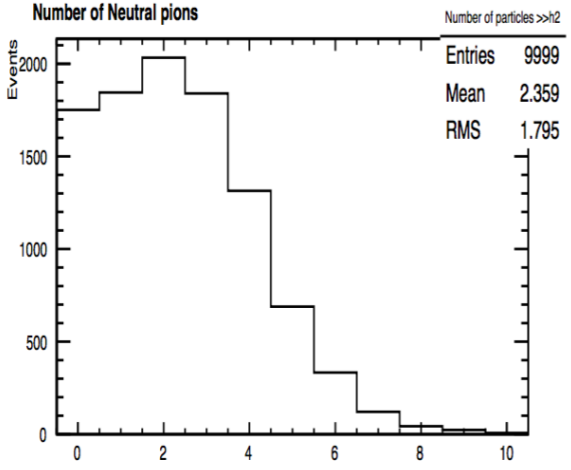






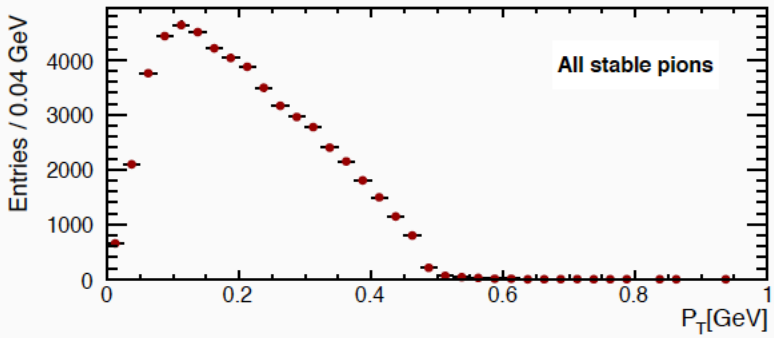


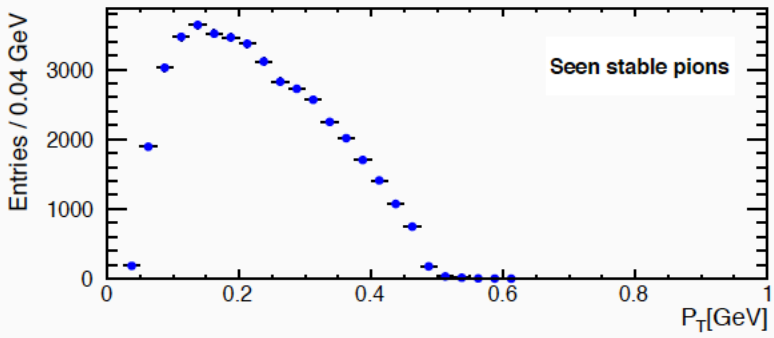


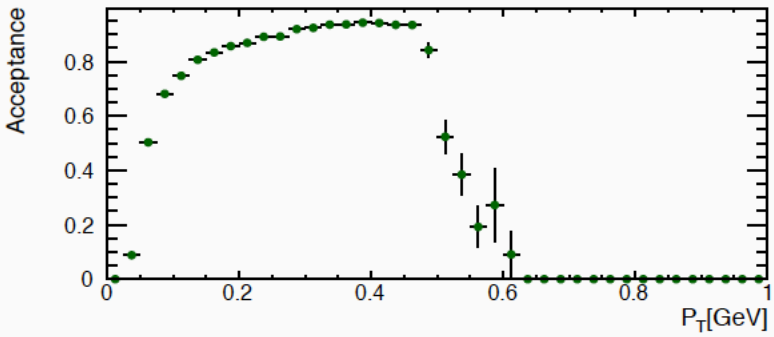


Pythia could be used to simulate events down upto $\sqrt{s_{\gamma\gamma}}$ = 2 GeV

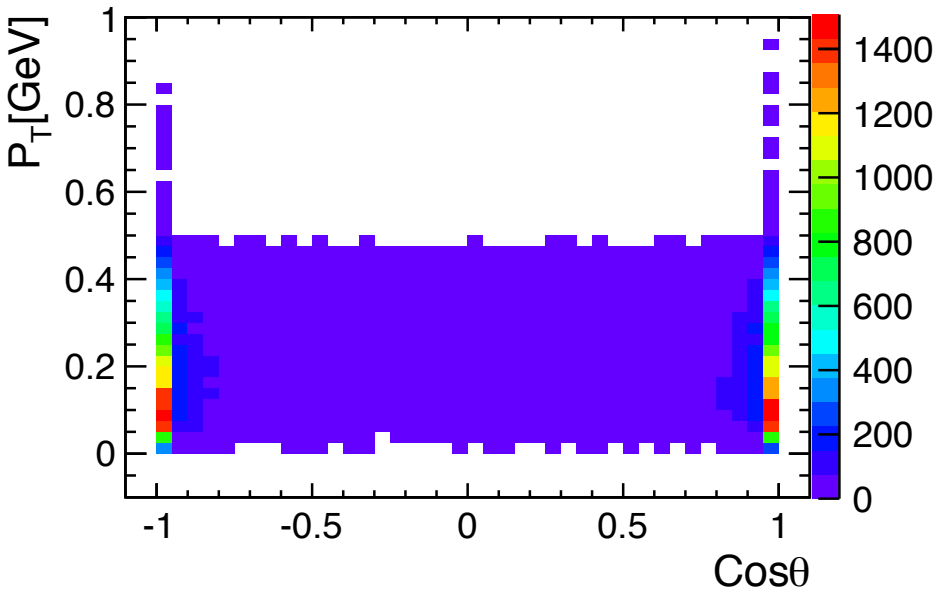
Momentum acceptance for Pions





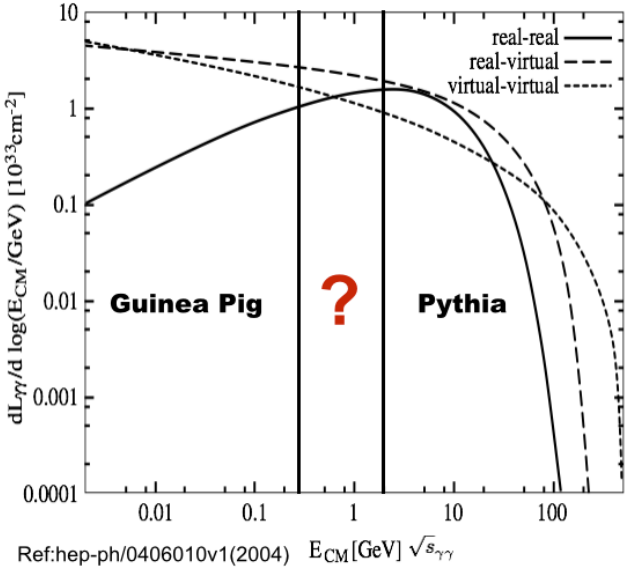


- Momentum acceptance:
  - Dividing seen stable pions with all true pions
  - The acceptance for most particles > 80%
  - Particles with high Pt but moving in forward direction - low acceptance

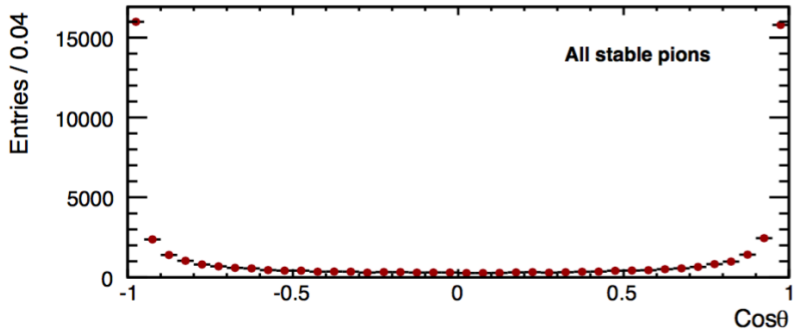


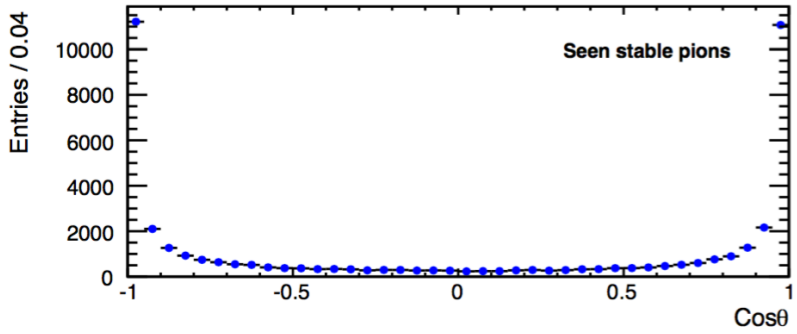
A dedicated event generator for $\gamma\gamma$ processes

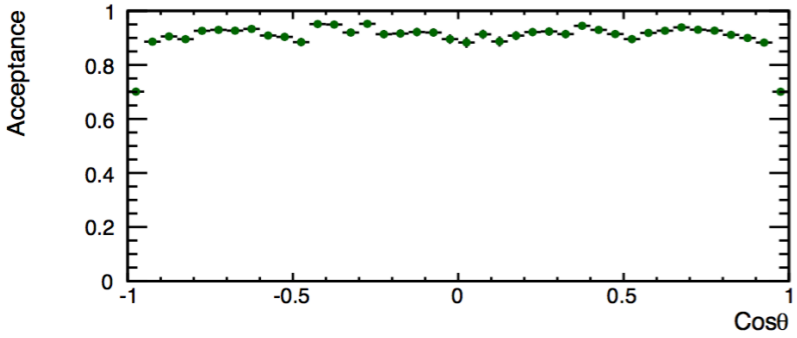
- For $\sqrt{s_{\gamma\gamma}}$ > 2 GeV Pythia 6 used to simulate $\gamma\gamma \rightarrow$ low pT hadron processes
- Below $2\pi_m$ pure QED beam-beam interactions modeled by dedicated programs - Guinea Pig
- Need to evaluate the impact of uncovered region - how can it be modeled?
- Dedicated generator developed in ILC community to study low energy region by Tim Barklow
- The particles below 2 GeV - Very low Pt
- Could these particles be observed in the detector?
- How important is it to model this area?



Angular acceptance for Pions







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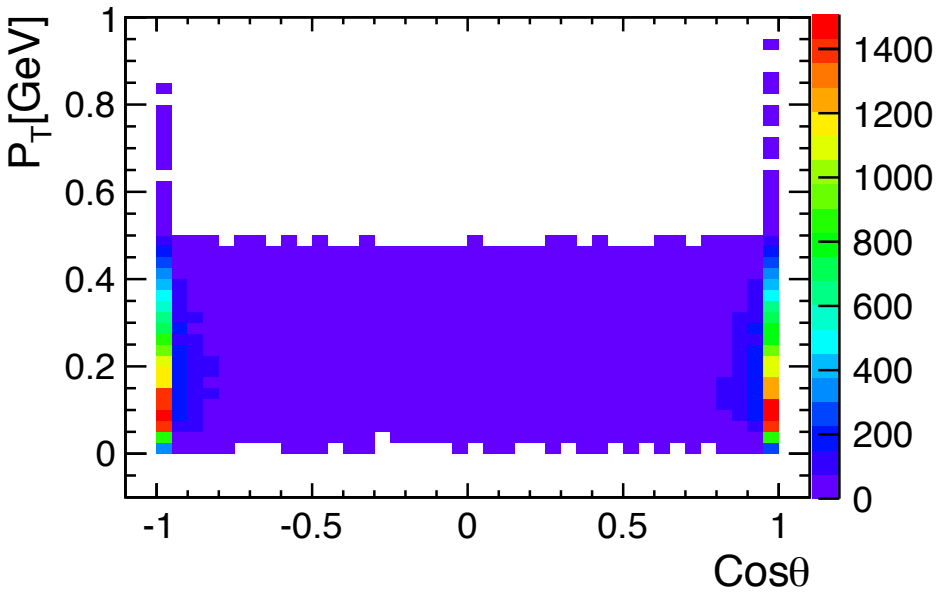
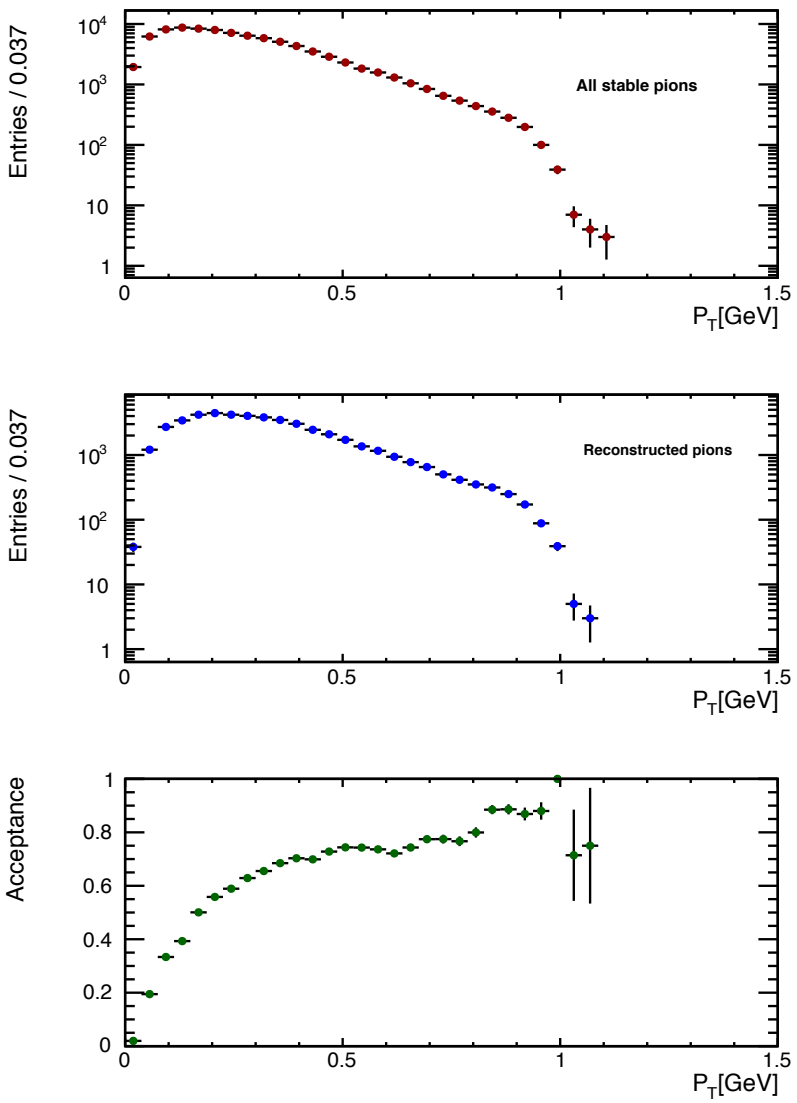
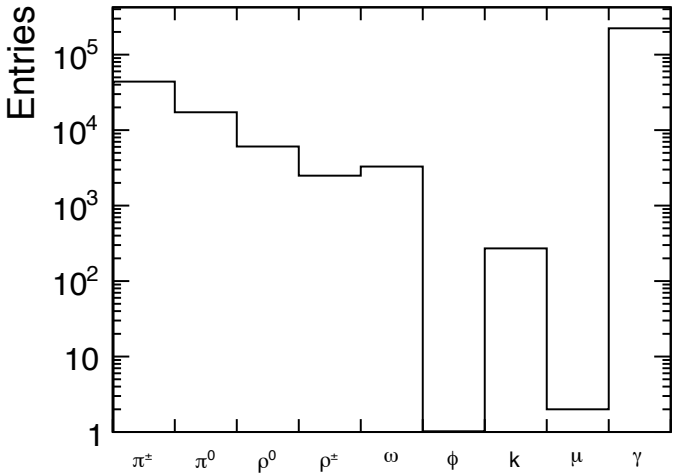
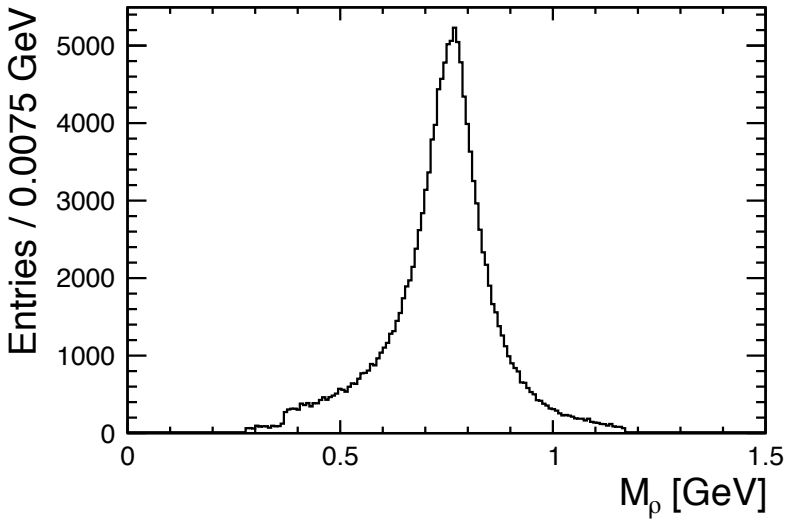


Momentum acceptance of pions with full simulation

- Cross checked the results with full simulation
- acceptance for pions at $\sqrt{s_{\gamma\gamma}} < 2$ GeV
- Acceptance reasonable enough to model the region below 2 GeV
- Work under progress to confirm the results



Modeling the low energy regime

- The issues discovered studied and conveyed to the author
- As expected from Chiral sum rule and Regge theory the generator now produces large variety of events
- The cross-sections for producing ρ^0 is greater than $\rho^{\pm}$
- A better version of the generator was thus developed correcting the issues in older version- big progress!!!