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

International Linear Collider Workshop

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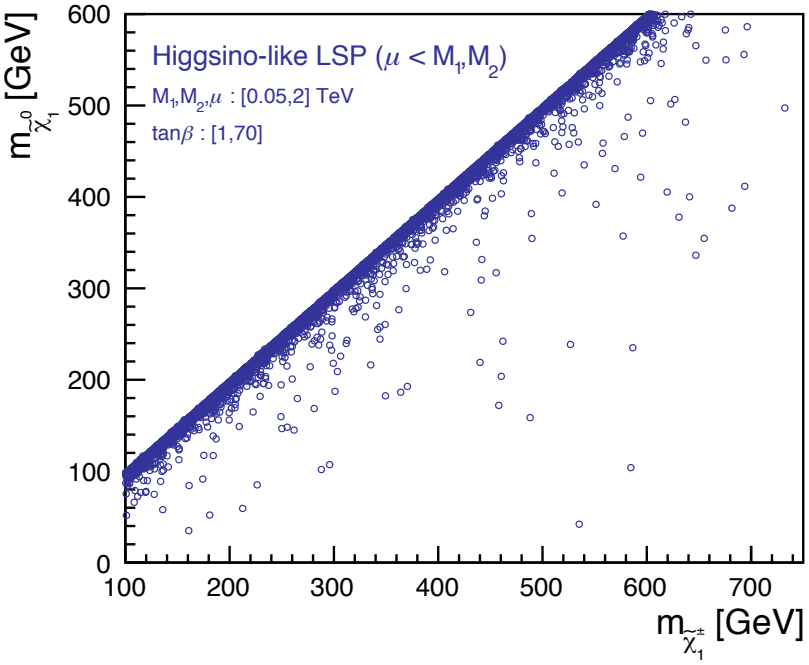
DESY

Motivation

- Issues in Standard model can be solved by Supersymmetry
- Naturalness requires light higgsinos at electroweak scale

$$m_Z^2 = 2\frac{m_{H_d}^2 + \Sigma_d^d - (m_{H_u}^2 + \Sigma_u^u)\tan^2\beta}{\tan^2\beta - 1} - 2\mu^2$$

- Natural region is 100-300 GeV - (accessible for ILC500)
- In certain benchmark scenarios the mass differences are 770MeV - 1.6 GeV



Ref: Tomohiko Tanabe

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 reconstructed as:

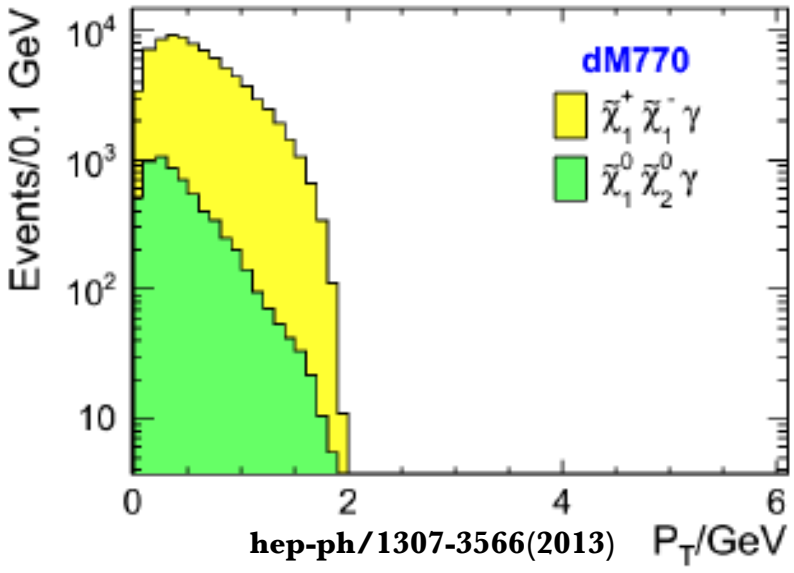
Particle	dM1600	dM770
$\delta\tilde{\chi}_1^{\pm}$	2 GeV	1.5 GeV
$\delta\tilde{\chi}_2^0$	3.3 GeV	1.6 GeV

- The mass difference between the chargino and LSP estimated from energy of decay products of charginos:

dM1600	dM770
270MeV	40MeV

Motivation

- Hale's study showed that such scenarios can be well observed at the ILC
- The study performed without the inclusion of $\gamma\gamma$ overlay - SGV fast simulation
- Visible decay products very soft and thus similar to $\gamma\gamma \rightarrow$ low pt hadron backgrounds
- The standard methods like k_T algorithm method a success to regain the physics performance

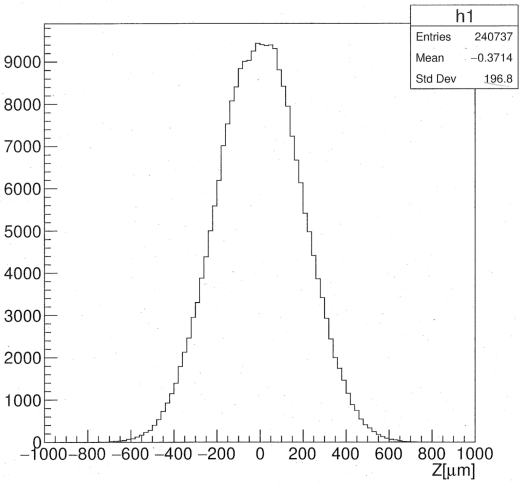


- Analysis for higgsinos still an exception to k_T algorithm method - the low pt visible decay products misidentified as $\gamma\gamma$ overlay in exclusive mode and discarded
- Important to study the effect of overlay on the higgsino events

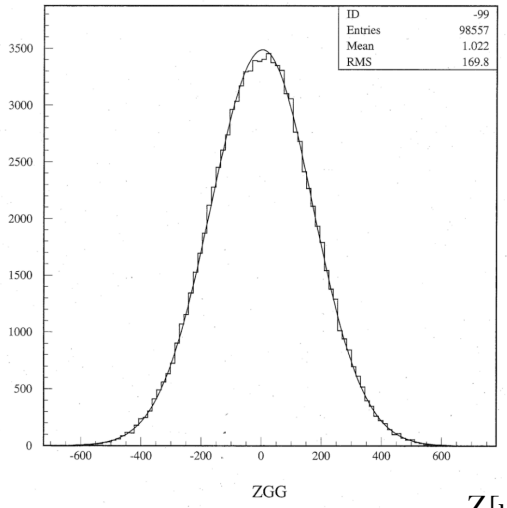
Simulation and Reconstruction

- Study of effect of $\gamma\gamma \rightarrow$ low pt hadron overlay on the higgsino samples, $e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-\gamma$ from Wizhard and $\gamma\gamma$ events from the most improved version of the Barklow generator and Pythia (More details ALWC 2017 talk)
- Simulated $e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-\gamma$ samples with vertex smeared along Z axis - benchmark scenario dM770 (196.8 μm) - ILCSOFT version v01-19-02
- Four different samples of $\gamma\gamma \rightarrow$ low pt hadron events simulated with smeared vertices

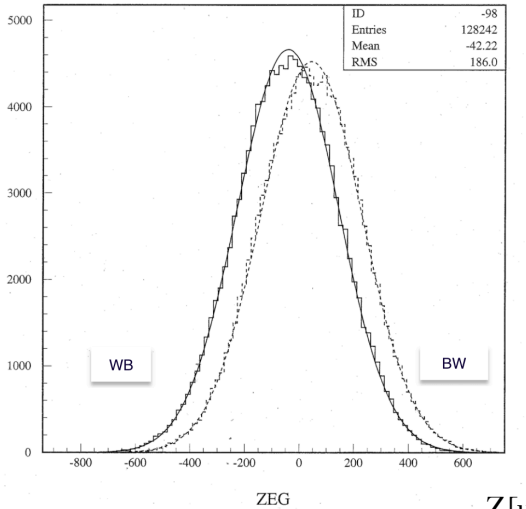
WW-196um



BB -169um



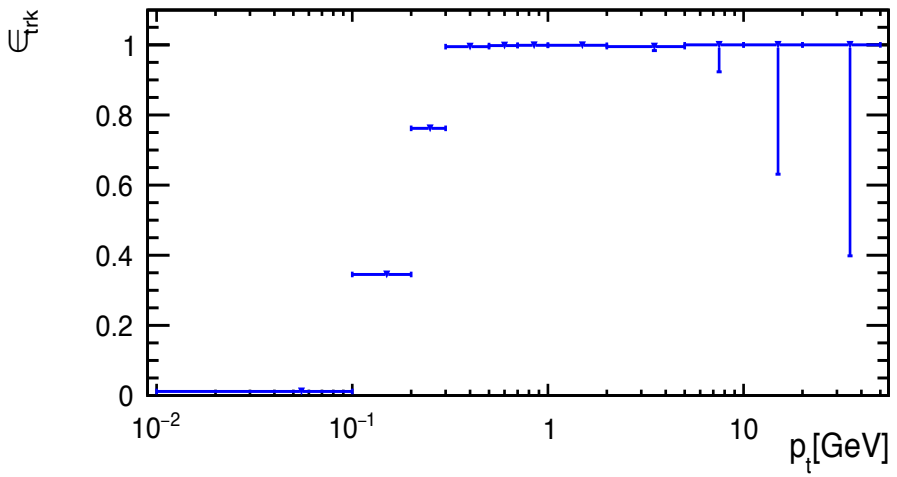
WB/BW -186um +/- 42um

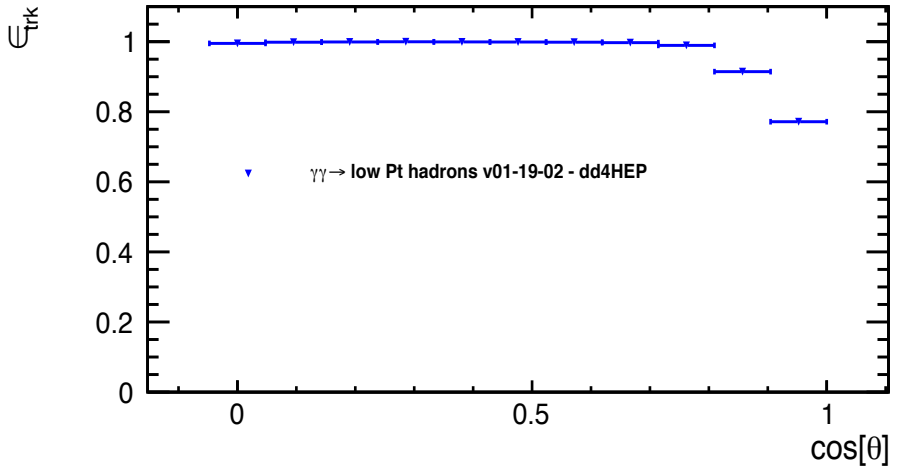


- $e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-\gamma$ events overlaid with $\gamma\gamma \rightarrow$ low pt hadron events - (1.05 events /BX at 500 GeV) - ILCSOFT version v01-19-03

Reconstruction efficiency for $\gamma\gamma \rightarrow$ low pt hadron tracks

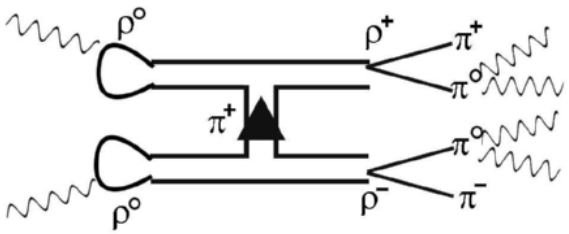
- ILD performance -Diagnostics package used for tracking efficiency
- https://confluence.desy.de/display/ILD/Reconstruction#Reconstruction-ILCSoftv01-19-01-preandILDConfig_HEAD
- Tracking Efficiency of the detector studied with detector model - ILD_l1_v01_dd4hep and ILCsoft version v01-19-03
- Reconstruction efficiency for the low pt hadron events above 70%
- Important to develop method to remove $\gamma\gamma \rightarrow$ low pt hadron events





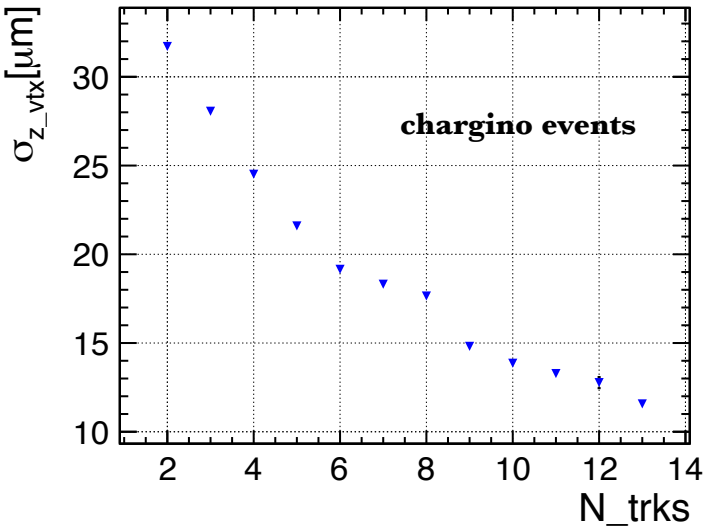
Possible methods to remove $\gamma\gamma \rightarrow$ low pT hadrons

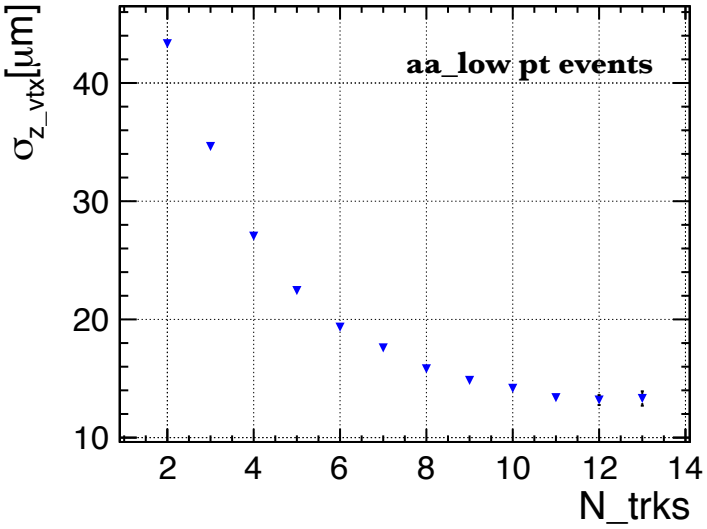
- First Method:
- Displacement of vertices in z direction
- Vertices of $\gamma\gamma$ overlay events displaced from that of signal vertices
- Identifying the tracks coming from such vertices and removing them would be an effective method
- This method cannot be used for purely neutral events like $\gamma\gamma \rightarrow \pi^0\pi^0$
- 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



Detector Resolution for vertices

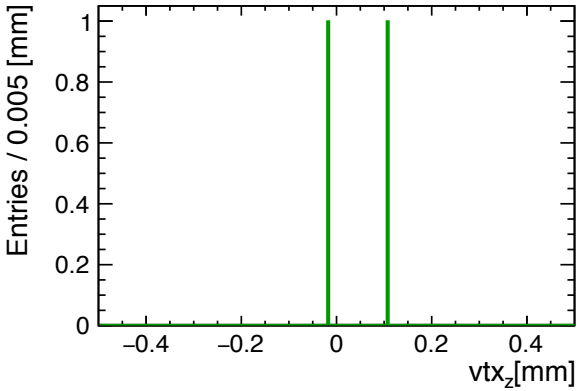
- Vertices of $\gamma\gamma$ overlay events displaced from that of signal vertices in z
- z_vtx resolution studied for vertices having 2 or greater than 2 tracks associated
- With increasing number of tracks in the primary vertex the resolution for vertex z position gets better by $\sqrt{N_{trk}}$ as expected
- For the signal events 60% of the events - z_vtx resolution ~ 35μm or better
- For the overlay events 60% of the events - z_vtx resolution ~ 40μm or better
- 40% events - either neutral events or events with 1 track or no tracks - only cluster information

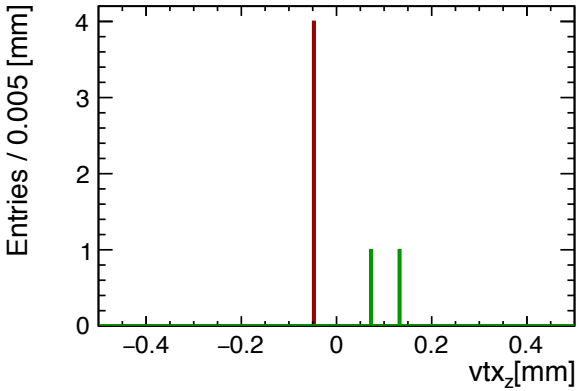


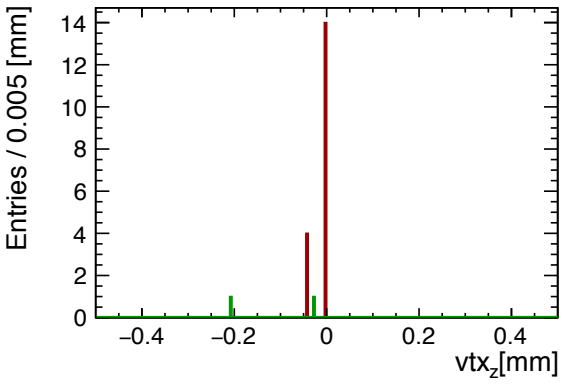


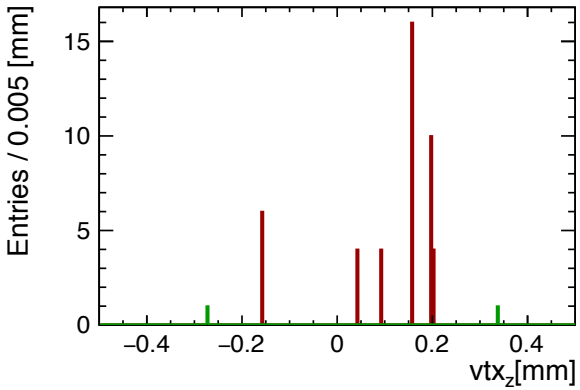
Z position of MC vertices

- Every chargino decays to one charged particle and other particles as per the BR
- Signal - green and overlay in reddish-brown
- Vertices of charged stable particles plotted





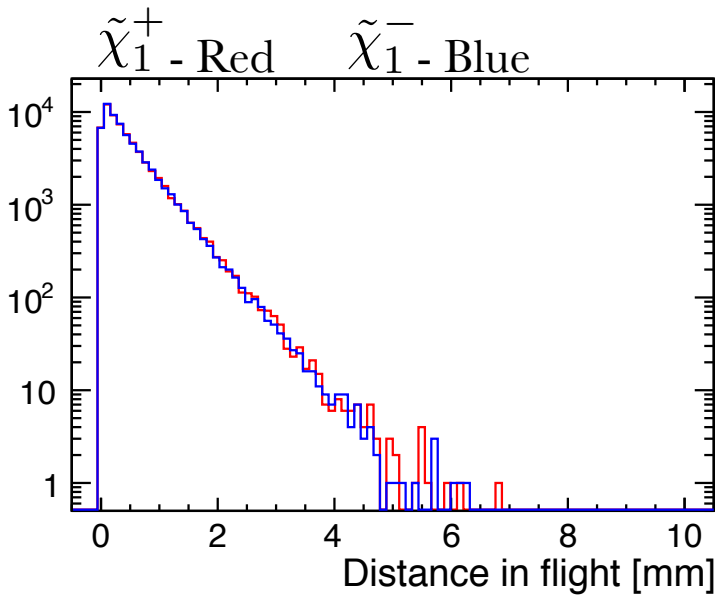




- Every $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-\gamma$ gives two tracks
- Events with different number of $\gamma\gamma$ overlay events shown

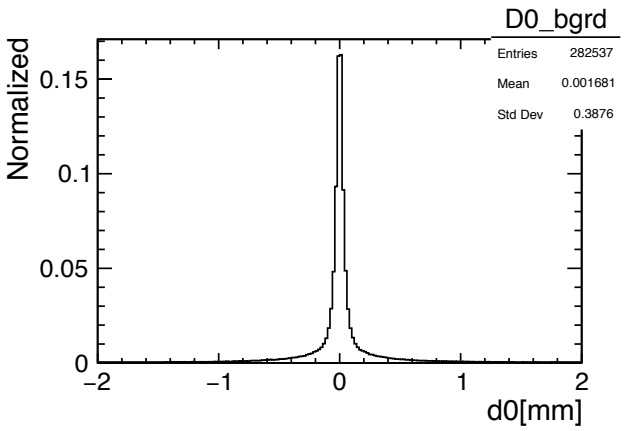
Reconstruction level and the track parameters

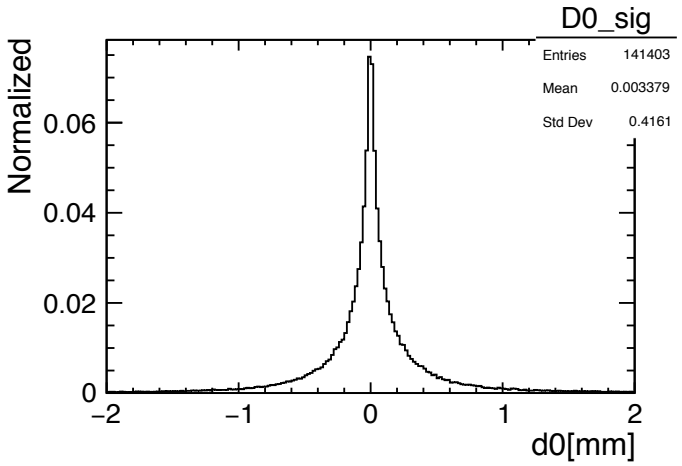
- Standard vertex finding algorithm reconstructs one single vertex for each event
- With smeared vertices it is important to have a more complex algorithm which could group the tracks to find different vertices
- This algorithm can be developed with the track parameters as the important tools
- Knowledge of displaced vertices along the z axis
  - Z0 parameter of the track is important
- Unlike the particles in $\gamma\gamma \rightarrow$ low pt hadron events, charginos have a finite life time which makes the d0 parameter important
- Using this parameters we try to develop a new algorithm which groups the closest tracks to form vertex positions

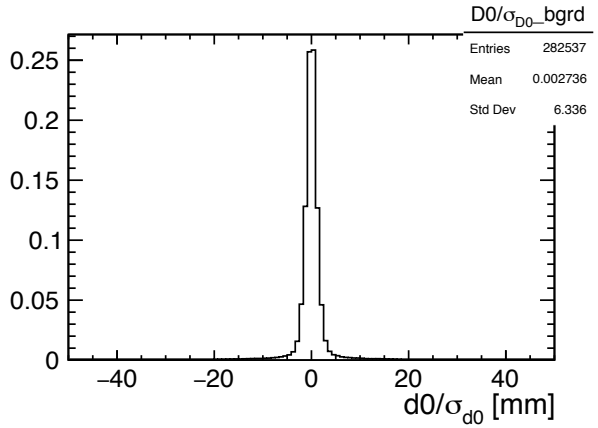


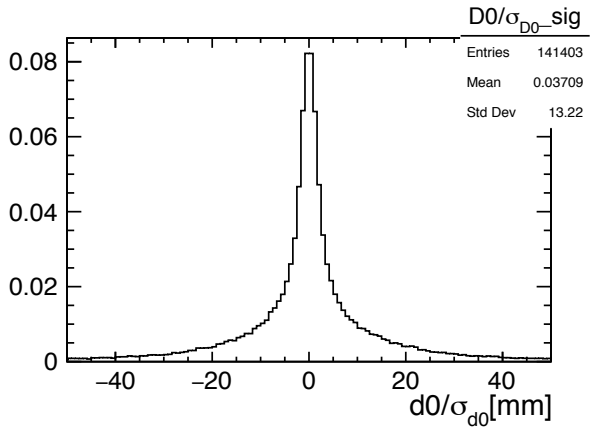
Detailed study of d0 parameter

- d0 and the d0 significance of the of the pure signal and pure $\gamma\gamma$ events plotted as below
- d0 and d0 significance for the signal much wider than the background
- Due to higher spread d0 significance would be more relevant than the use of pure d0



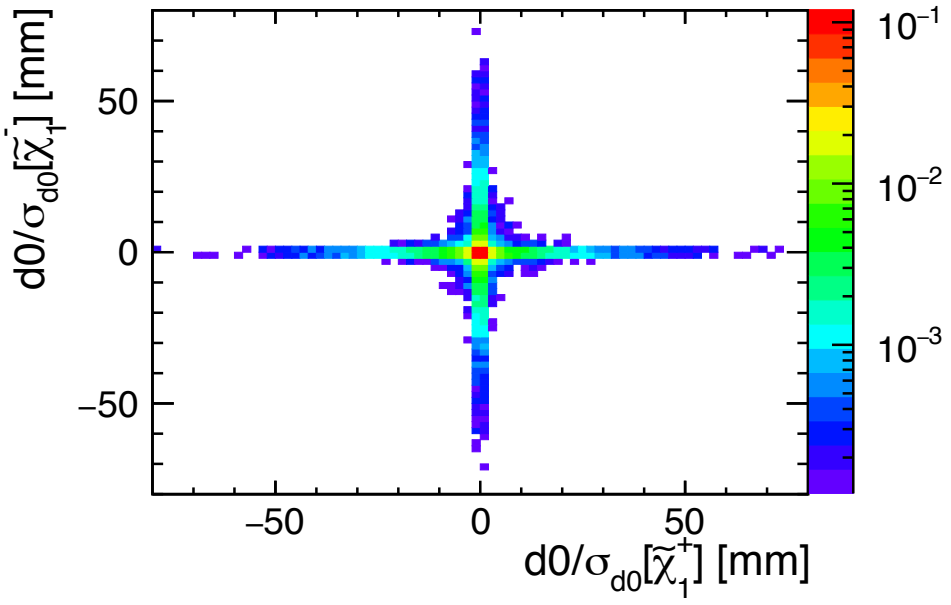






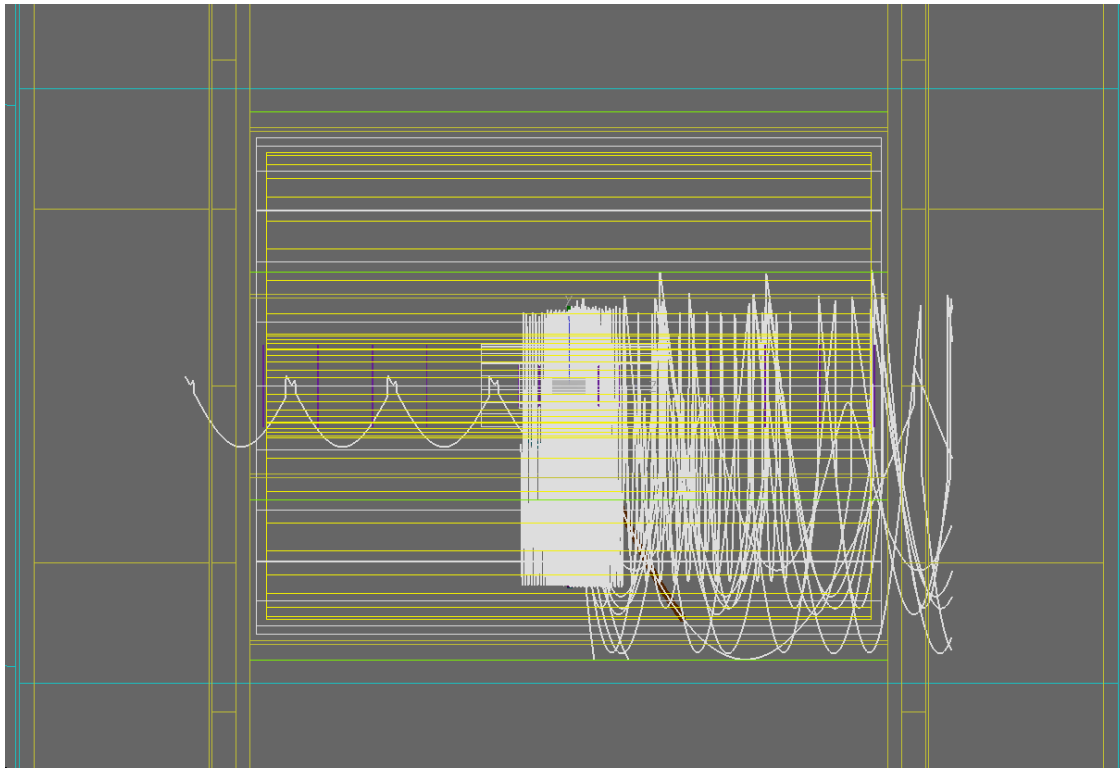
Detailed study of d0 parameter

- Chargino - different branching ratios but always decays into one charged particle
- Every event should have two tracks from the signal $(\tilde{\chi}_1^+, \tilde{\chi}_1^-)$
- The d0 significance of the two tracks of the signal are plotted
- 60 % cases one track has high value of d0 significance and other is smaller
- Rest 40 % cases d0 significance for both tracks are similar



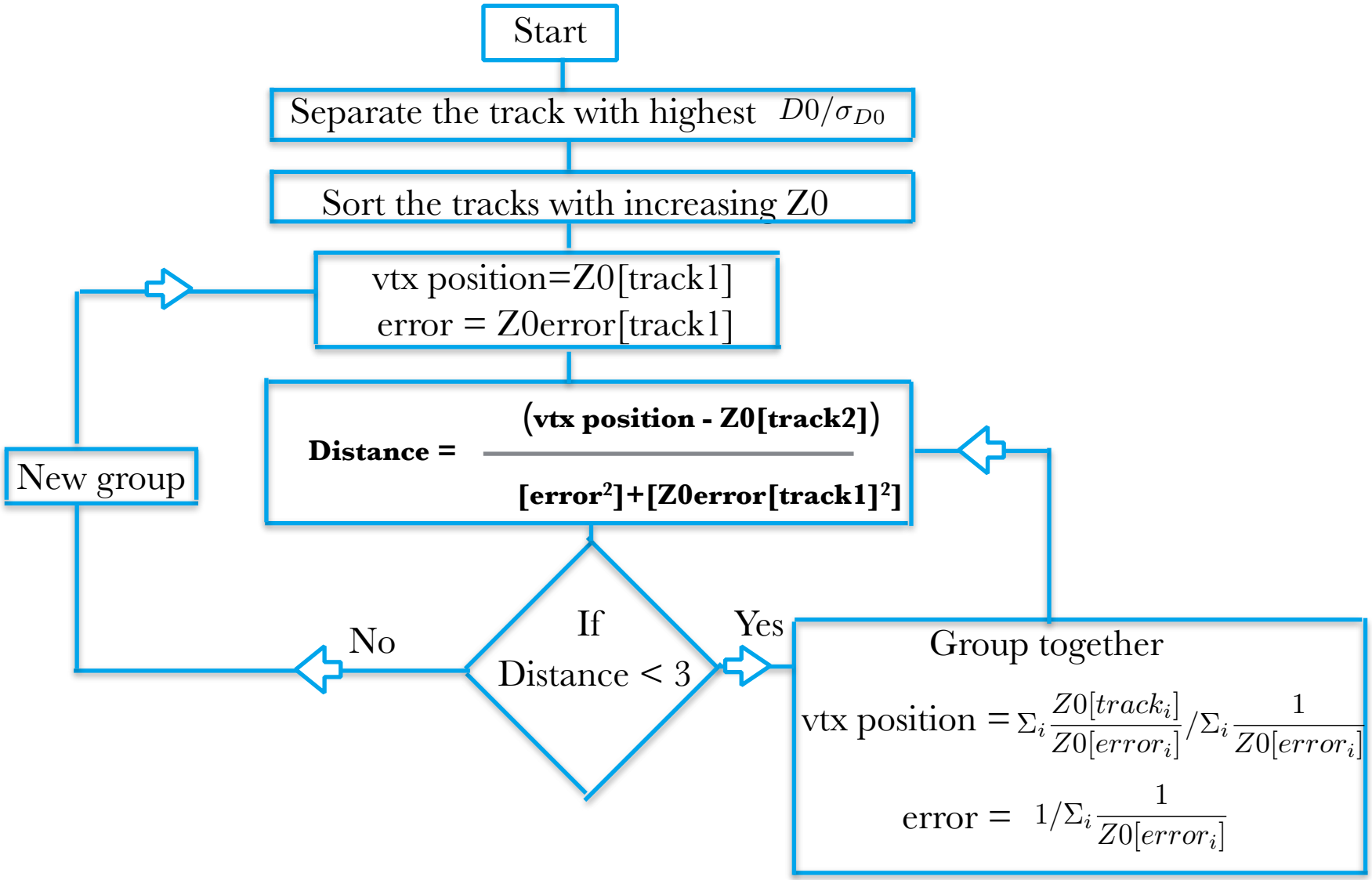
Precuts for the algorithm

- Tracks curling vigorously perpendicular to the z axis entering the TPC
- Challenging for the tracker to identify the hits from a single track
- Many tracks reconstructed in such cases
- To avoid such events a cut of Ntrks < 12 is applied
- The event should have a hard ISR photon with E > 10 GeV
- ISR photon gives a pt kick to the beam electron -
  - missing energy from beam particles - overlay events



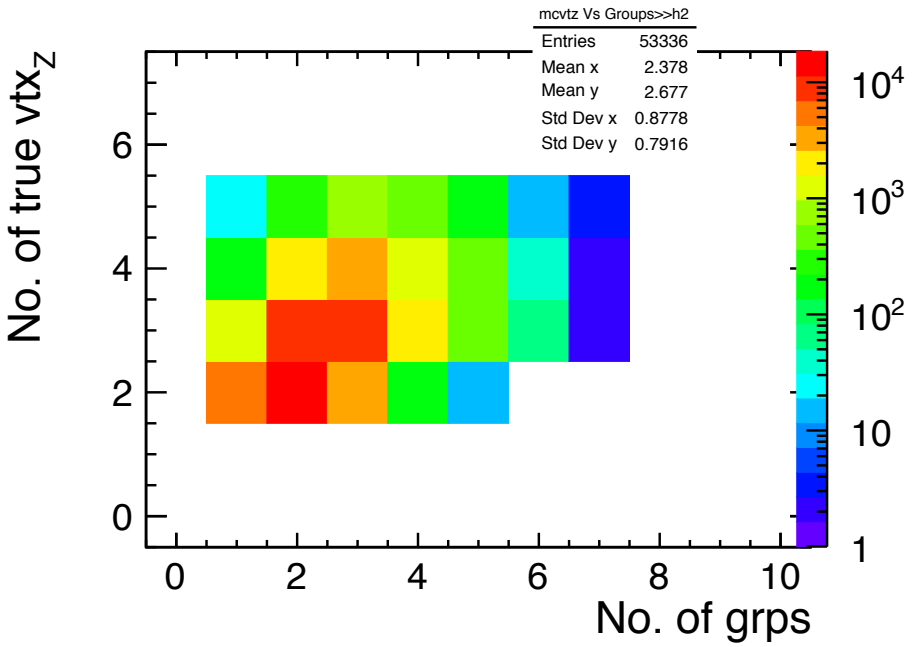
- Z0 of the track should be less than 15 mm as the others can be particles created from the detector material

Algorithm


Start
Separate the track with highest $D0/\sigma_{D0}$
Sort the tracks with increasing Z0
vtx position=Z0[track1]
error = Z0error[track1]
Distance = (vtx position - Z0[track2]) / [error²]+[Z0error[track1]²]
If Distance < 3
No
New group
Yes
Group together
vtx position $= \Sigma_i \frac{Z0[track_i]}{Z0[error_i]} / \Sigma_i \frac{1}{Z0[error_i]}$
error $= 1/\Sigma_i \frac{1}{Z0[error_i]}$

True no. of vertices Vs no. of groups

- No. of groups made by the algorithm compared to true number of vertices
- Very preliminary study
- ~70 % of the events - diagonal
- 60% - both charginos reconstructed
- 15 % one track, 22 % tracks split tracks due to curling
- Count on true no of vertices not always right due to secondary vertices - complex events
- Work in progress



Conclusion and Outlook

- Impact of $\gamma\gamma \rightarrow$ low pt hadron overlay on the higgsino events very important
- Existing standard methods to remove these backgrounds remain inefficient in this case
- Displaced vertices for the signal and background events and the finite life time of the charginos very important factors to develop new method
- New algorithm leading towards the method to remove the $\gamma\gamma \rightarrow$ low pt hadron events developed
- Work in progress!!!
- OUTLOOK:
  - Algorithm is to be optimized with better track quality cuts
  - Different track groups given by the algorithm identified as the signal or background using the ISR photon cut and the PID's of the particles

Questions??

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

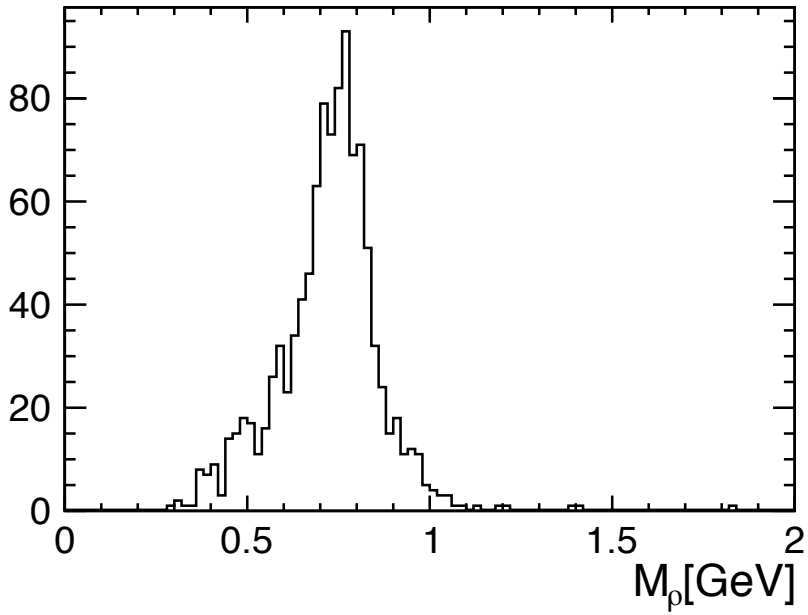
Method Development to remove backgrounds

- 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 - Using Rho meson tag

- $\gamma\gamma \rightarrow \rho^0\rho^0$ 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



Event Properties of Pythia

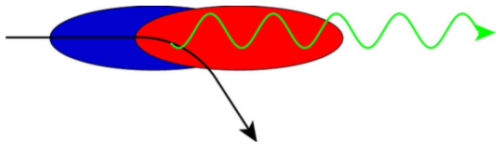
- Direct Interactions(DIR) - Real photons interacts directly
- Vector Meson Dominance(VMD) - Photon fluctuates into a vector meson
- Anomalous Interactions(GVMD) - Photon fluctuates into a $q\bar{q}$ pair of larger virtuality
- Deep inelastic Scattering(DIS) - A process of probing the Hadrons with very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

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

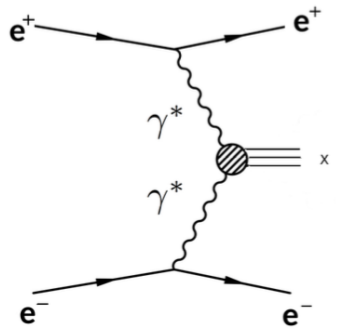
> Pythia cannot simulate below 2 GeV

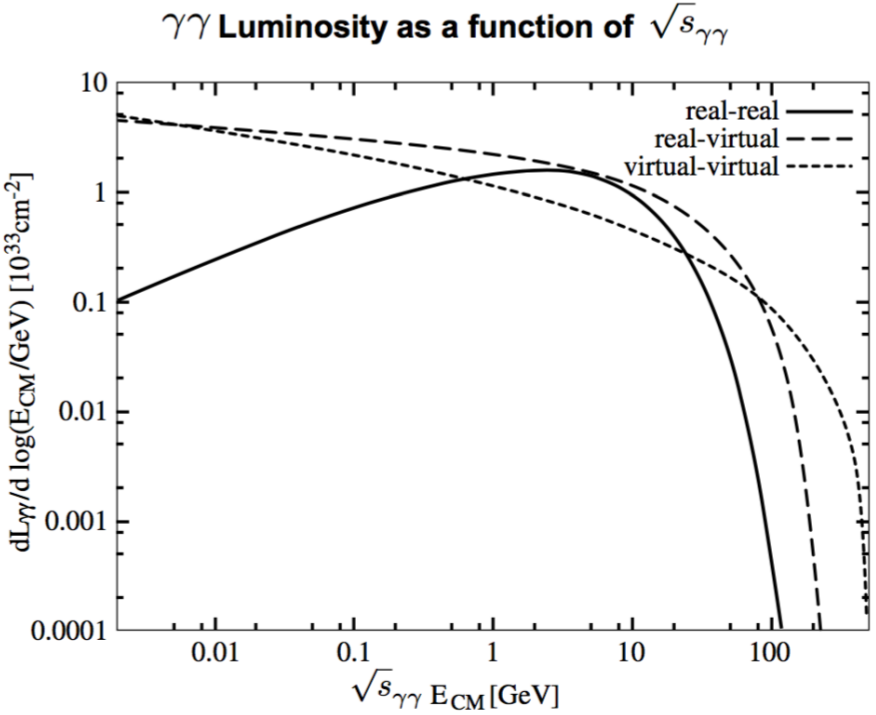
Photon Sources

- $e^+ e^-$ 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

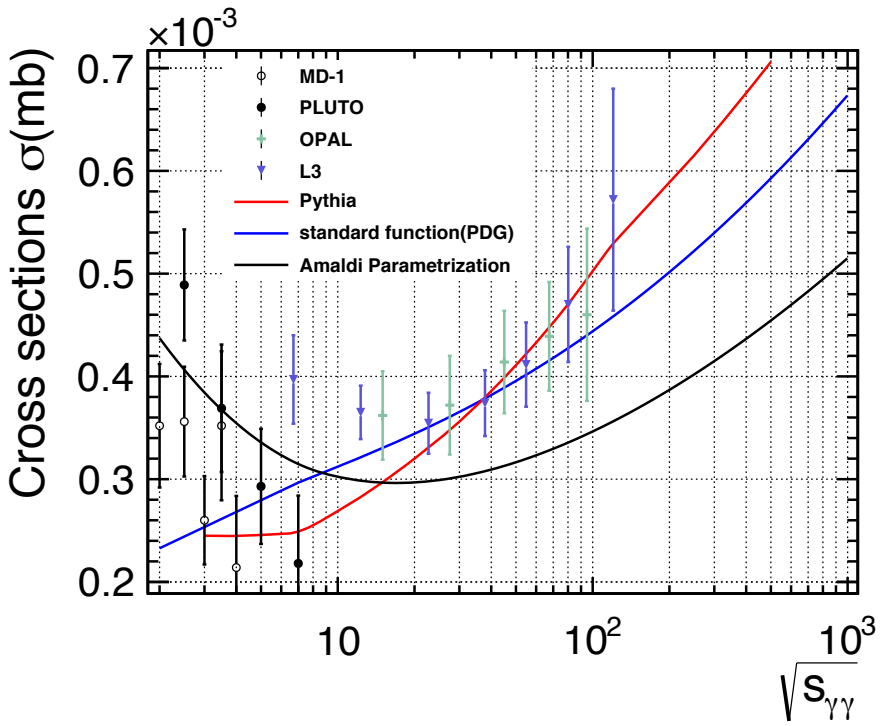




Ref:hep-ph/0406010v1(2004)

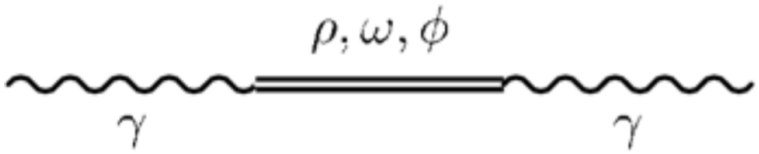
Cross sections for Pythia events

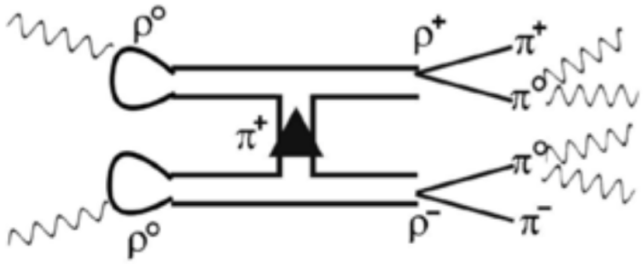
- Comparison of $\gamma\gamma \rightarrow$ low Pt hadron process cross sections from Pythia with PDG, Amaldi et.al(hep-ph/9305247) and data from LEP,PETRA and VEPP
- $\sqrt{s_{\gamma\gamma}} >$ 10 GeV : Good description of LEP data with Pythia
- $\sqrt{s_{\gamma\gamma}} <$ 10 GeV: Measurements have large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



Photon-Photon Interactions

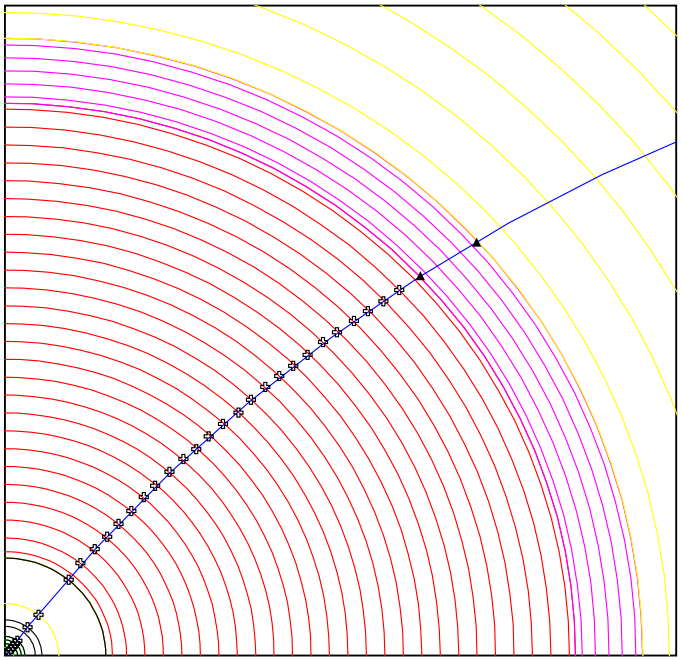
- Photons interact in different ways
- Vector meson dominance -Most dominating subprocess
- What are vector mesons? - $\rho, \omega, \phi, J/\psi, \Upsilon$
- Photon fluctuates into a vector meson since it has got the same quantum properties
- Photon is a hadron 1/400 of the time
- Highest probability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





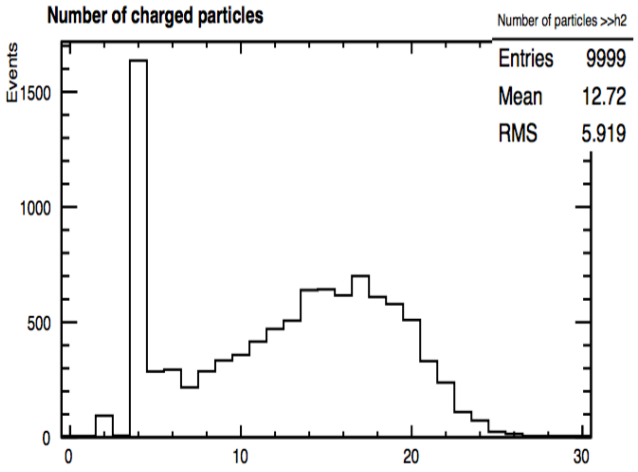
Does $\sqrt{s_{\gamma\gamma}}$ < 1 GeV matter?

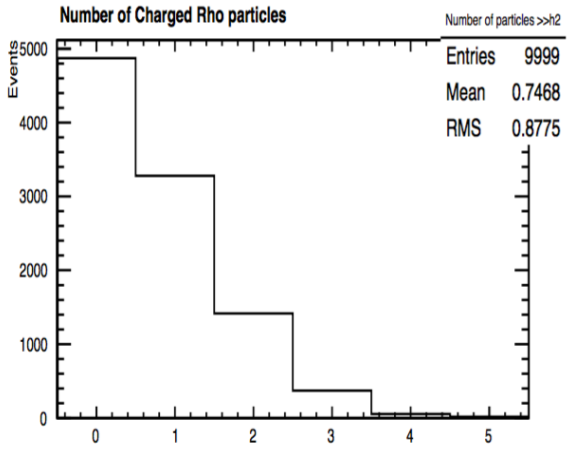
- Detector acceptance for $\sqrt{s_{\gamma\gamma}} < 1$ GeV
  - Select events $\sqrt{s_{\gamma\gamma}} < 1$ GeV
  - Events generated from real-real, real-virtual and virtual-virtual photon collisions
  - Simulate ILD in SGV fast simulation
- Reconstruction in SGV
  - Particles having ≥ 3 layer hits :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

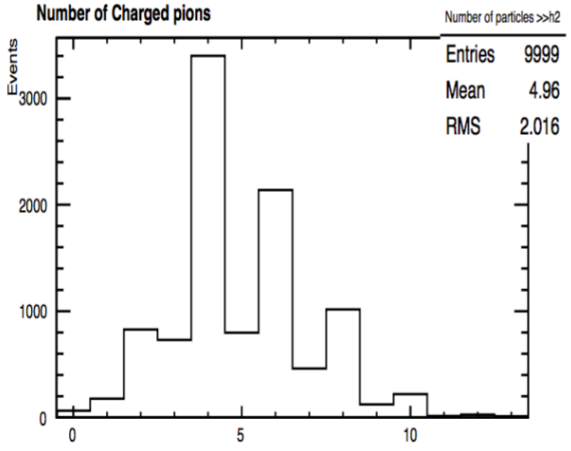


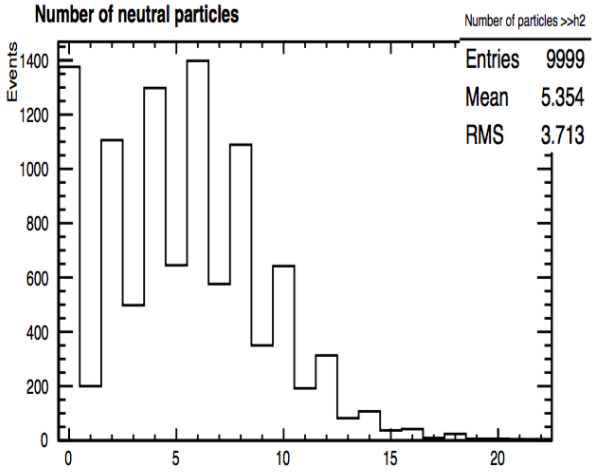
Ref: archiv:1203.0217v1

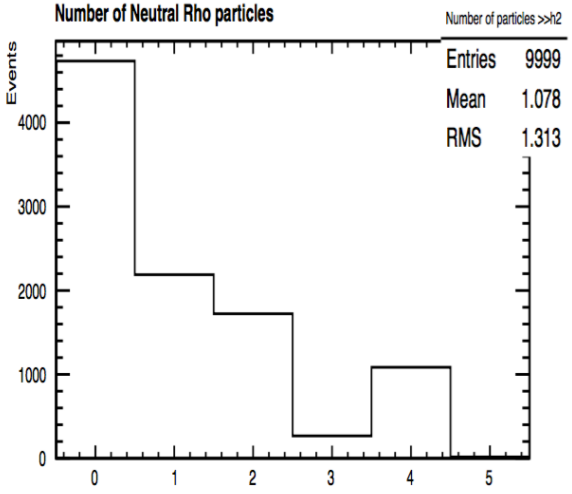
Event Properties of Pythia

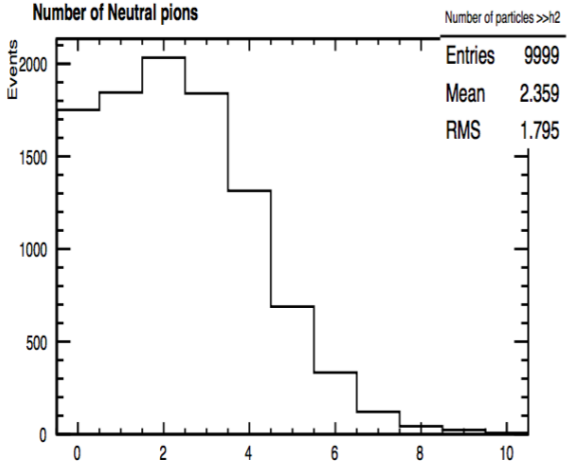






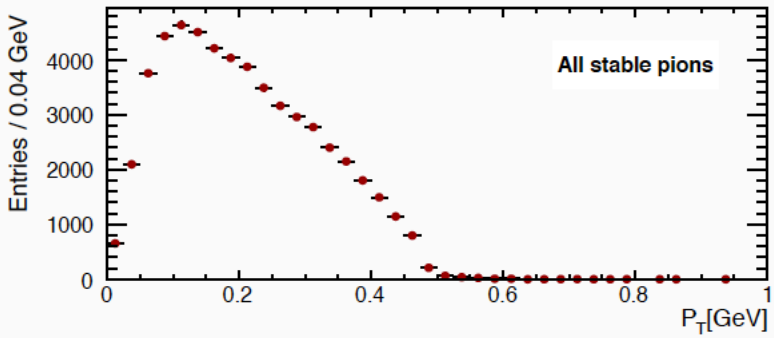


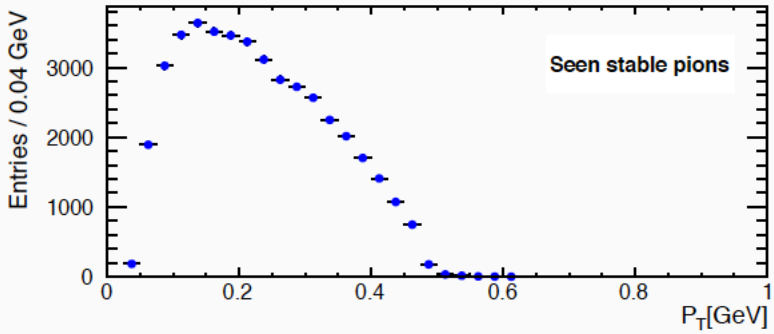


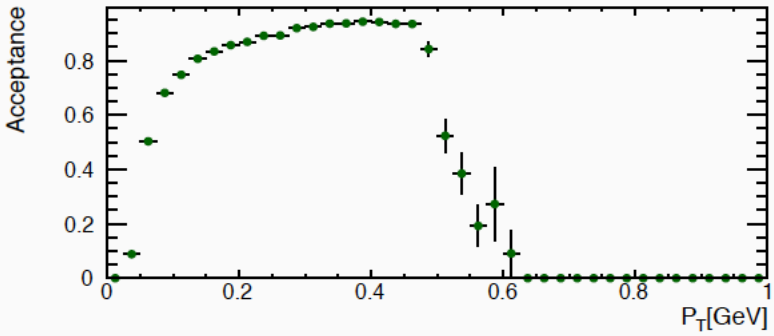


Pythia could be used to simulate events down upto $\sqrt{s_{\gamma\gamma}} = 2$ GeV

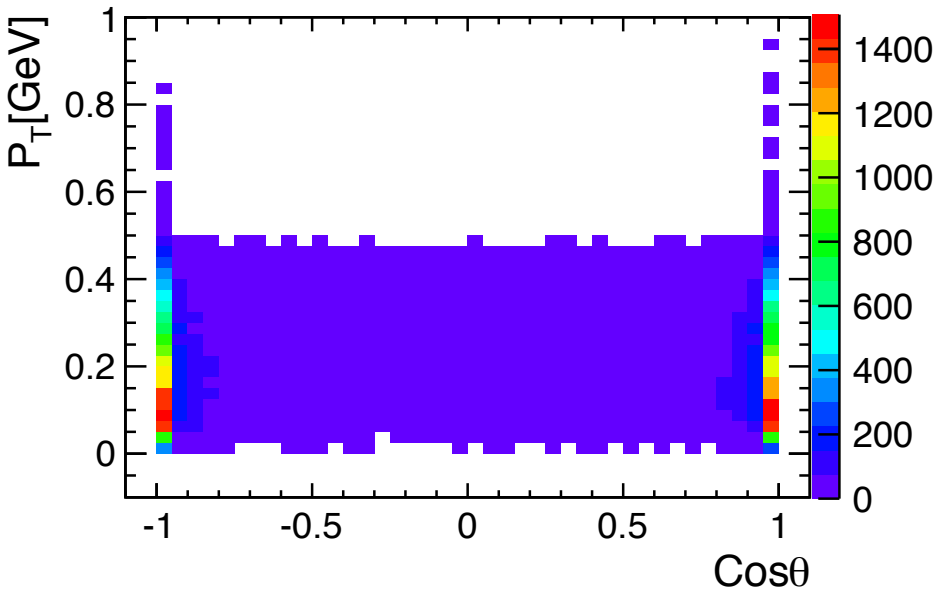
Momentum acceptance for Pions





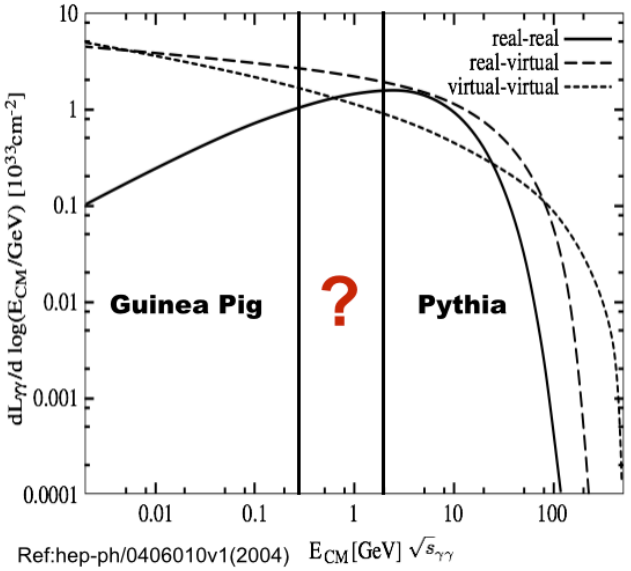


- Momentum acceptance:
  - Dividing seen stable pions with all true pions
  - The acceptance for most particles > 80%
  - Particles with high Pt but moving in forward direction - low acceptance

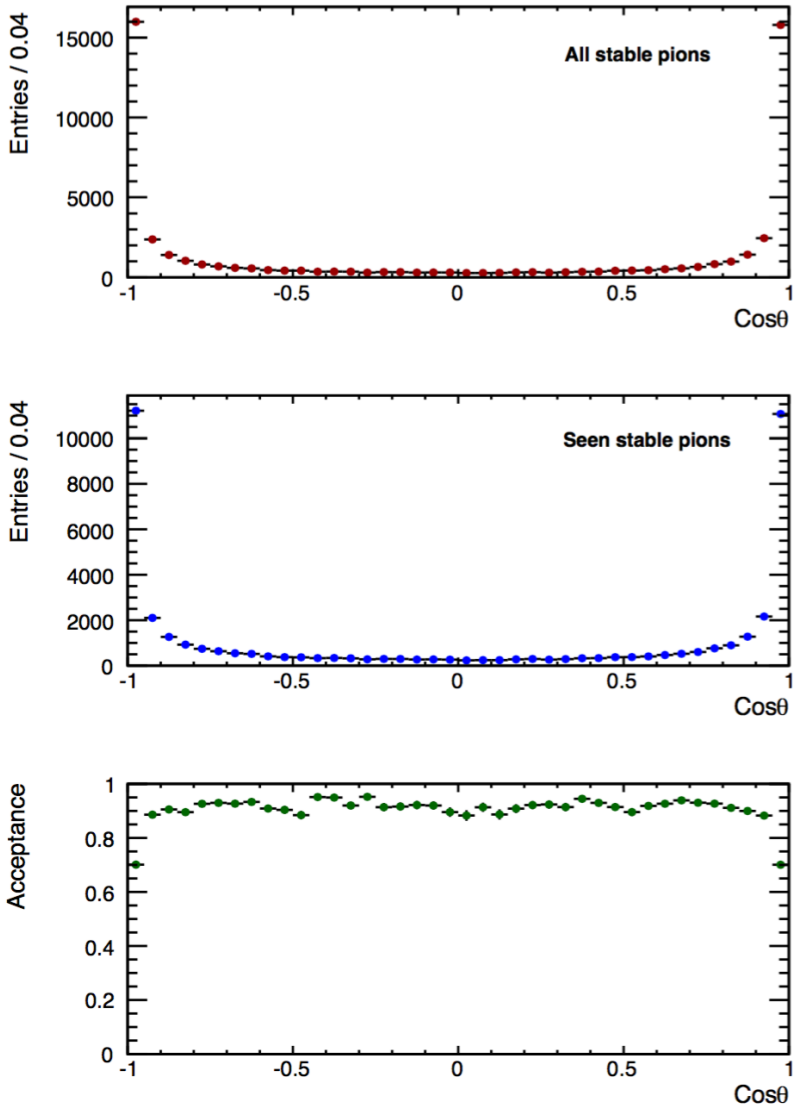


A dedicated event generator for $\gamma\gamma$ processes

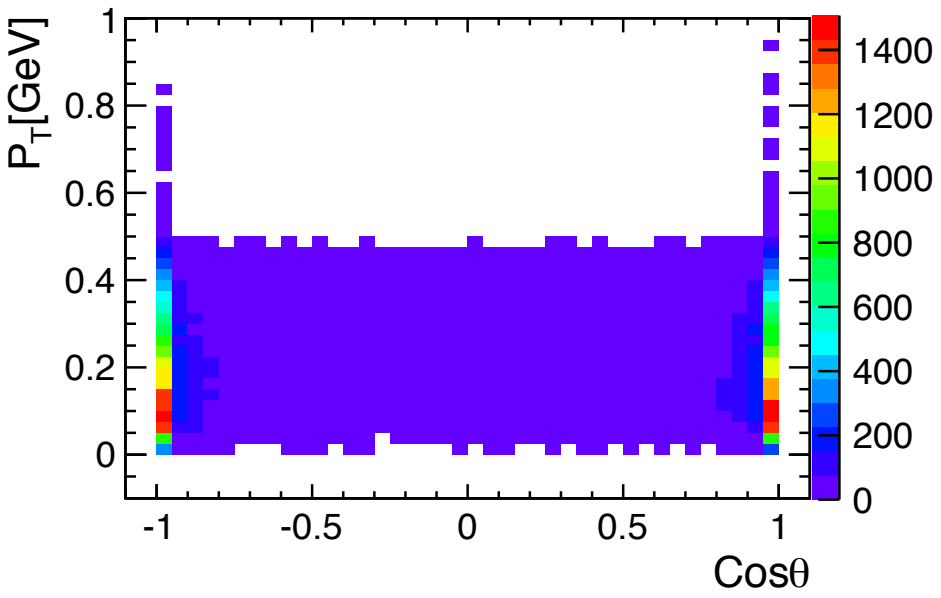
- For $\sqrt{s_{\gamma\gamma}}$> 2 GeV Pythia 6 used to simulate $\gamma\gamma \rightarrow$ low pT hadron processes
- Below 2 π_m pure QED beam-beam interactions modeled by dedicated programs - Guinea Pig
- Need to evaluate the impact of uncovered region - how can it be modeled?
- Dedicated generator 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

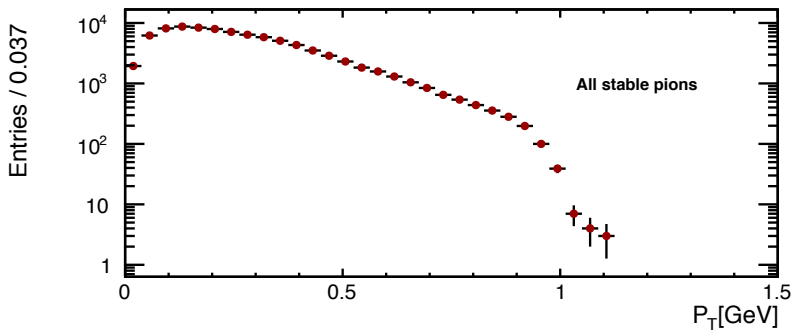


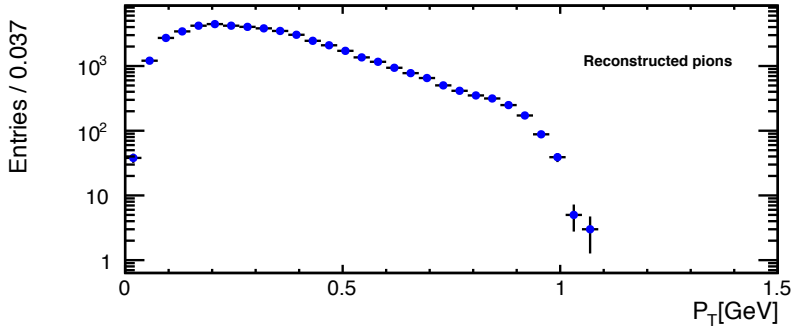
- Angular acceptance:
  - Dividing seen stable pions with all true pions
  - The acceptance for most particles > 80%
  - Particles with high Pt but moving in forward direction - low acceptance

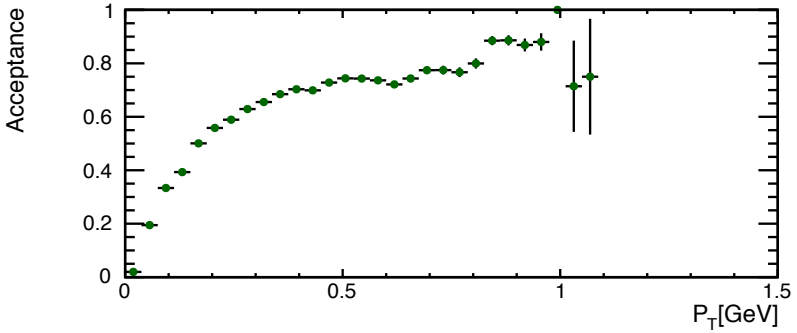


Momentum acceptance of pions with full simulation

- 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!!!