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

Linear Collider Forum 2018

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26 Nov 2018, DESY

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

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DESY.

Introduction

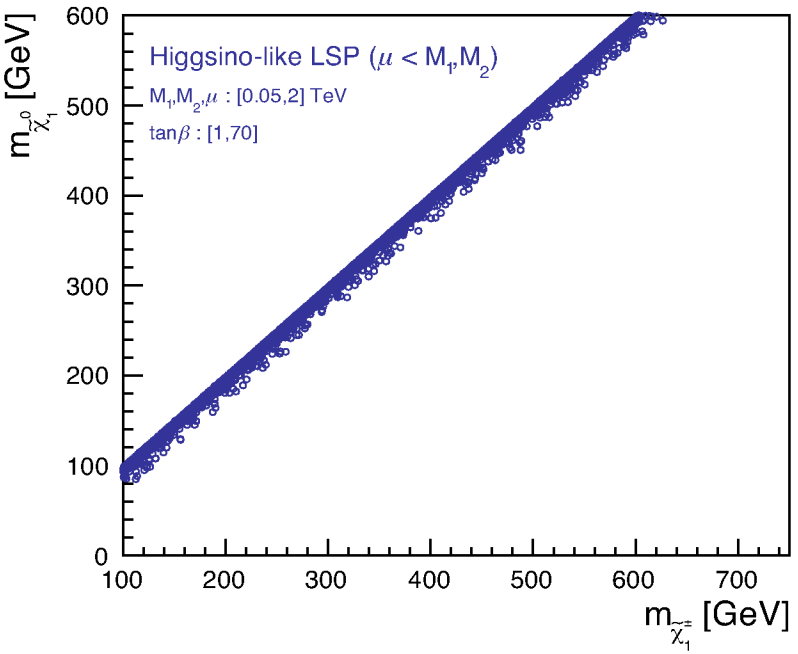
- Naturalness requires light higgsinos at electroweak scale

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

- Natural region is μ =100-300 GeV - accessible for ILC500 and some at 250 GeV
  [arXiv:1212.2655, arXiv:1404.7510]

- Light higgsinos - $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm$ nearly mass degenerate

Courtesy: T. Tanabe



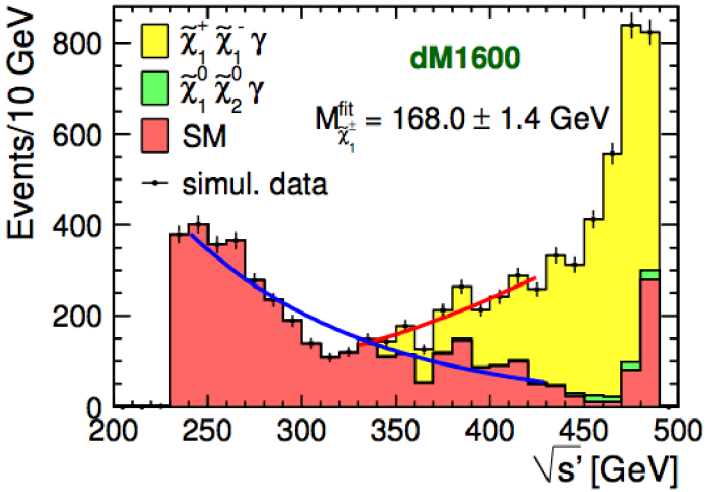
Benchmark Scenario

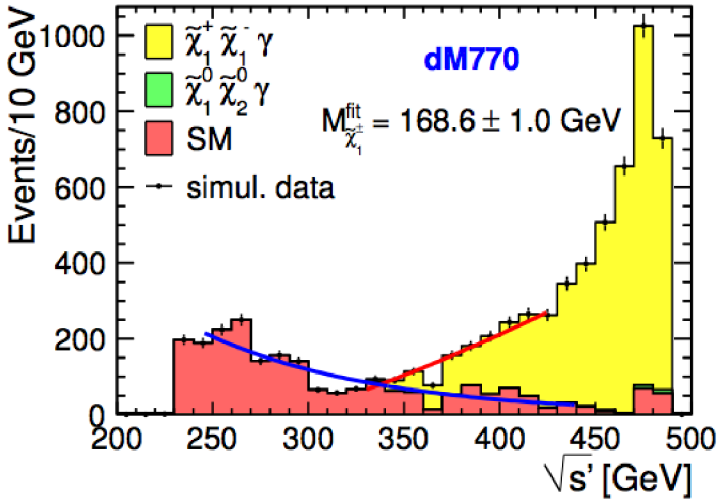
- Light higgsinos $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^{\pm}$ can be discovered/ excluded at ILC - DESY-THESIS-2016-001
- The case was studied at two benchmark scenarios

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

$$\Delta M(\tilde{X}_1^{\pm}, \tilde{X}_1^0) = 1.6 \text{ GeV} \Rightarrow \text{dM1600}$$

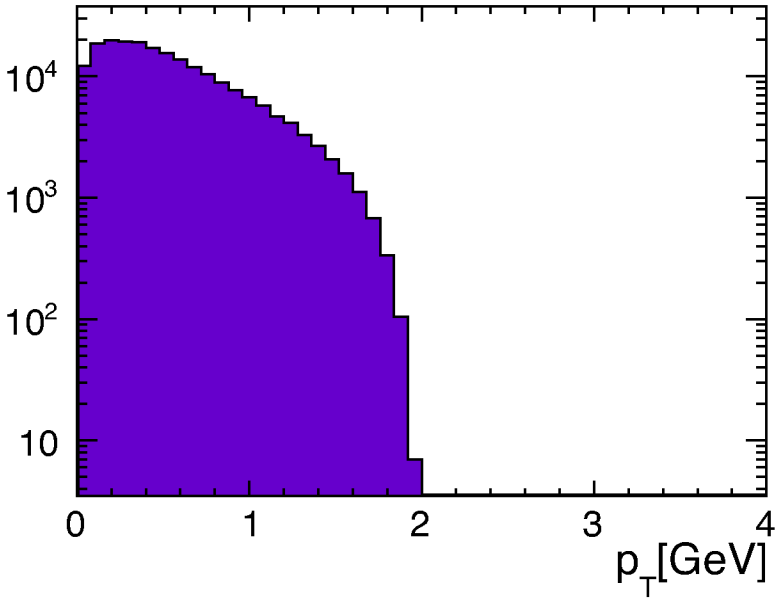
- Charginos decay hadronically and leptonically
- Studied without the inclusion of
  - $\gamma\gamma \rightarrow$ low p_T overlay
  - Pair background





Impact of $\gamma\gamma \rightarrow$ low p_T hadron background

- $\gamma\gamma \rightarrow$ low pt hadron backgrounds is a challenge for some specific cases e.g low ΔM higgsino
- Visible decay products of higgsinos very soft and thus similar to $\gamma\gamma \rightarrow$ low p_T hadron backgrounds
- 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 Whizard 1.95 (500 GeV)
  - $\gamma\gamma$ events from improved Barklow generator and Pythia
- Latest official samples for ILD Monte-Carlo production (2018)
- Simulated $e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-\gamma$ samples (ILD_l5_o1_v02):
  - ILCSoft version: v02-00-01
- Reconstructed $e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-\gamma$ events overlaid with $\gamma\gamma \rightarrow$ low pt hadron events - (1.05 events /BX at 500 GeV)
  - Pair backgrounds too included
  - The signal and background vertices smeared along z axis

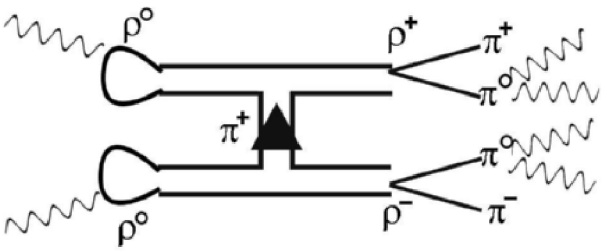
Possible methods to remove $\gamma\gamma \rightarrow$ low pT hadrons

- 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 $\gamma\gamma \rightarrow \pi^0\pi^0$

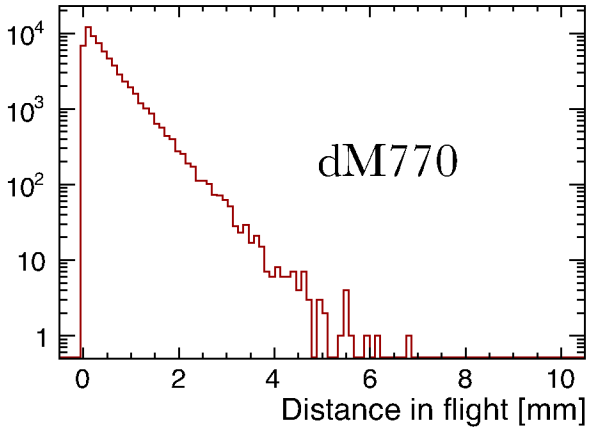
- Second method:

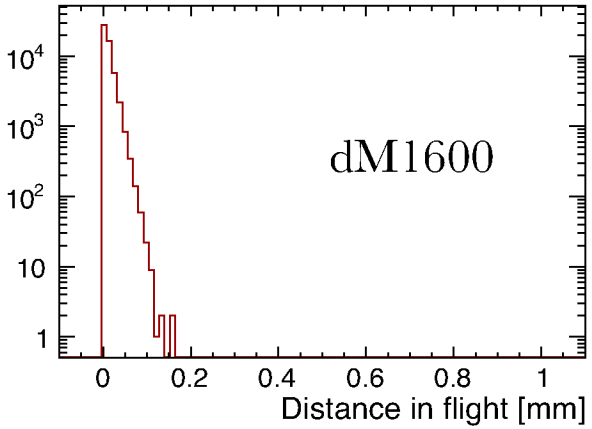
- The invariant mass of decay products of rho meson gives rho mass
- Rho meson used as a tag to remove $\gamma\gamma$ events
- Could be applied on very small event number



Reconstruction level and the track parameters

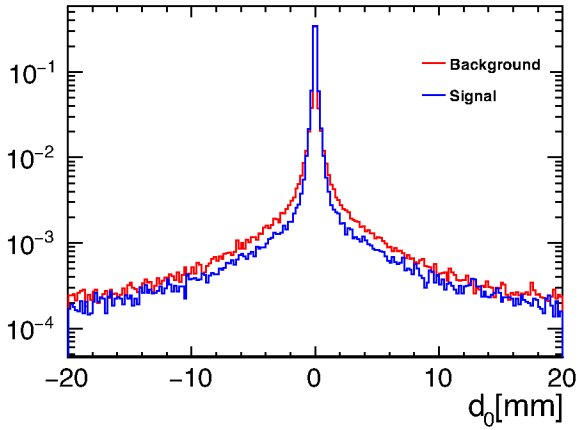
- Standard vertex finding algorithm reconstructs one single primary vertex for each event
- More complex algorithm to group the tracks to find different vertices
- Grouping based on difference in z0 significance
- Unlike the particles in $\gamma\gamma \rightarrow$ low pt hadron events, charginos have a finite life time which makes the d_0 parameter important
- Develop a new algorithm which groups the closest tracks to form vertex positions

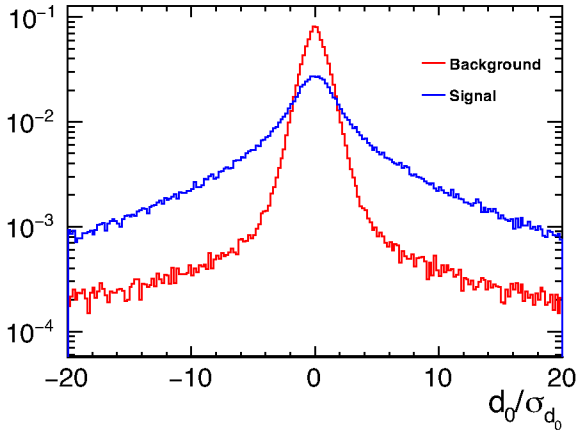




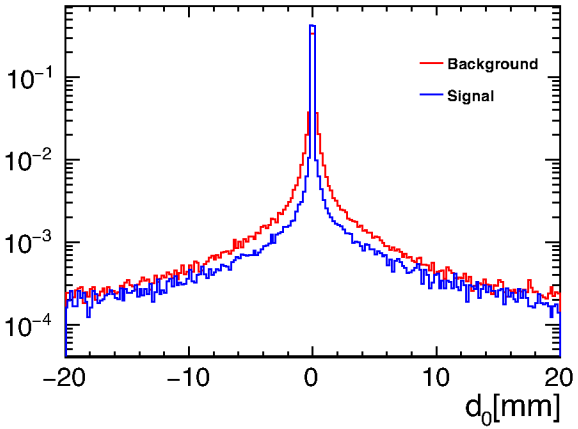
Detailed study of d_0 parameter

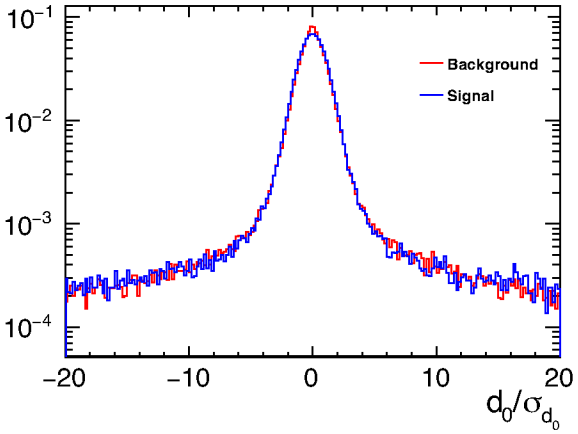
dM 770





dM 1600



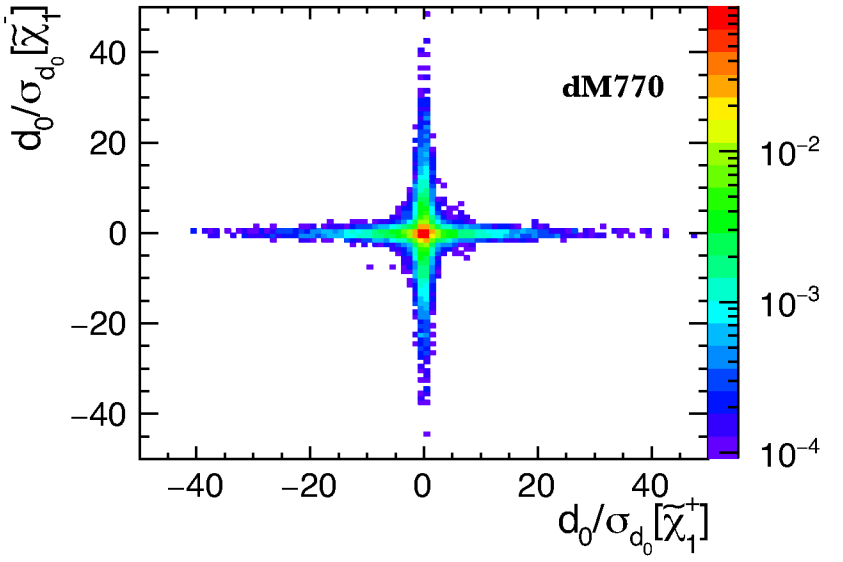


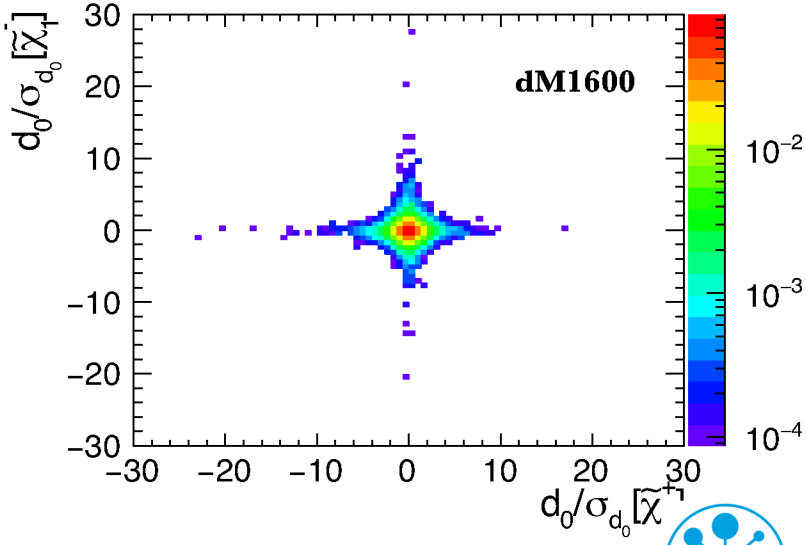
- With higher mass difference smaller d_0
- In dM1600 d_0 not a handle

Removal of high d_0 tracks

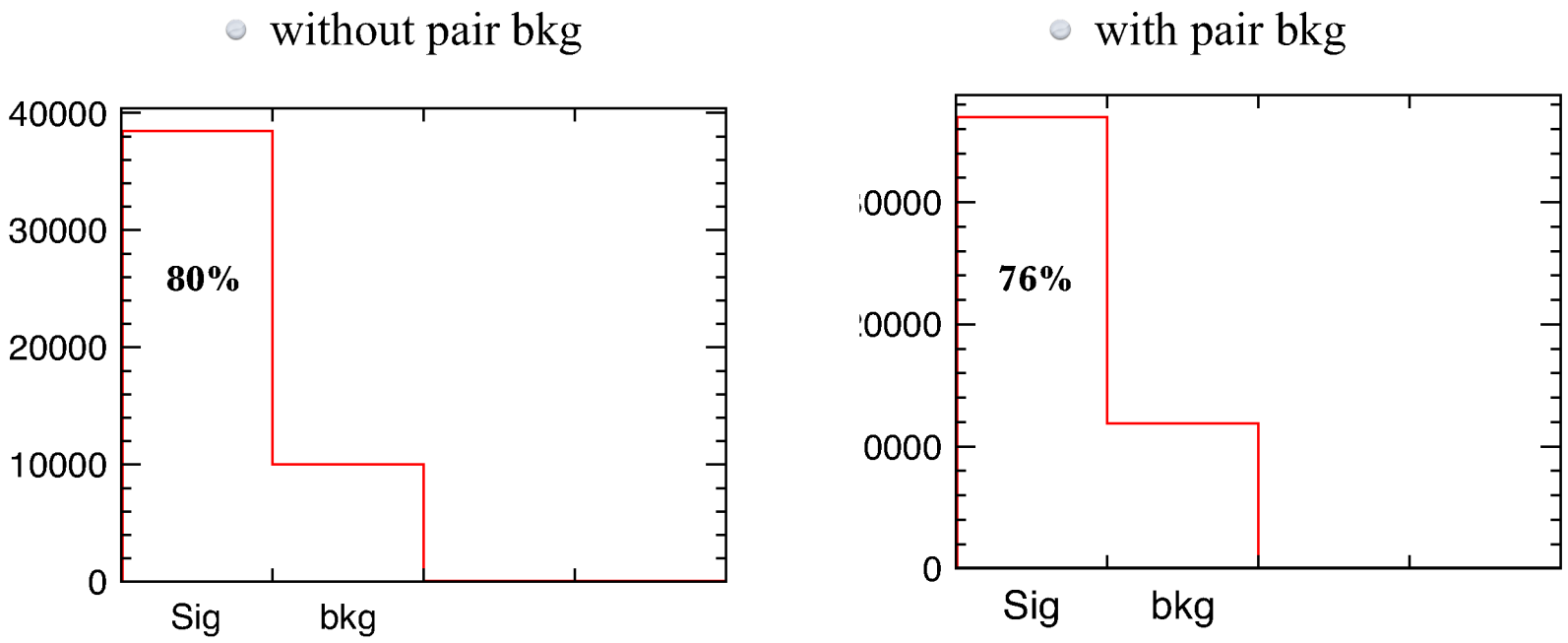
- For dM770 tracks with higher d_0 mostly include signal tracks
- Among the tracks coming from two charginos - one has higher d_0 other lower
- For dM770 track with highest d_0 treated separately assuming to be one signal track

$\tilde{\chi}_1^+$ decay mode	BR(dM770)
$e\nu\tilde{\chi}_1^0$	15.0%
$\mu\nu\tilde{\chi}_1^0$	13.7%
$\pi^+\tilde{\chi}_1^0$	60.4%
$\pi^+\pi^0\tilde{\chi}_1^0$	7.3%
$\pi^+\pi^0\pi^0\tilde{\chi}_1^0$	0.03%





Separated highest d_0 track



- The track with highest d0 significance value in dM770
- 76% - (including pair bkg)
- 80% - (without pair bkg)

Pre-cuts to the algorithm

>dM 770 :

- track with highest d_0 removed
- d0 < 0.3 mm
- z0 < 15 mm

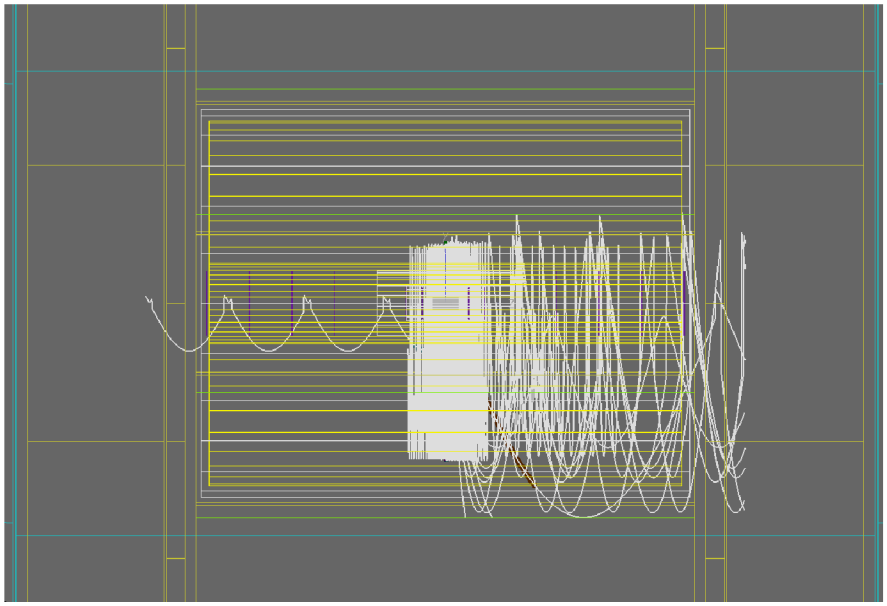
>dM 1600 :

- d0 < 0.2 mm
- z0 < 15 mm

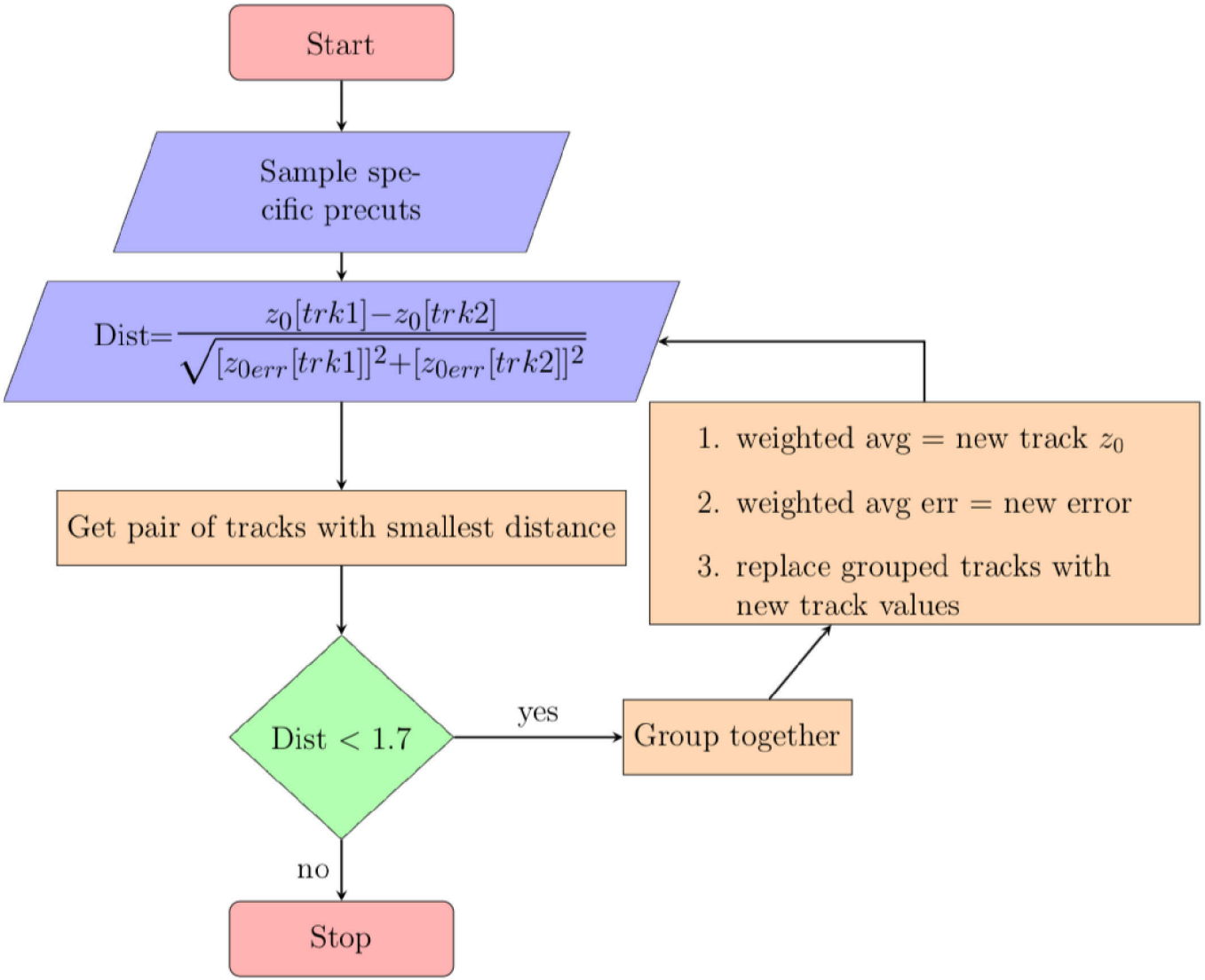
>No of tracks < 13

- Curling of low p_T tracks

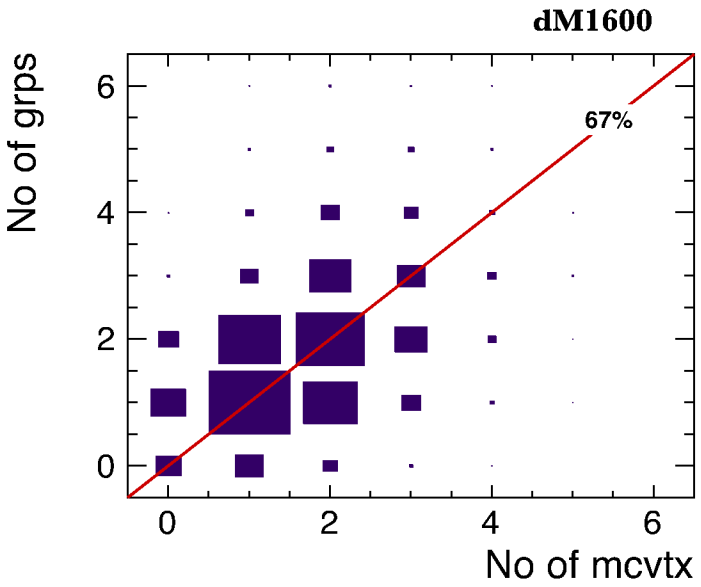
>Events with minimum 2 signal tracks reconstructed

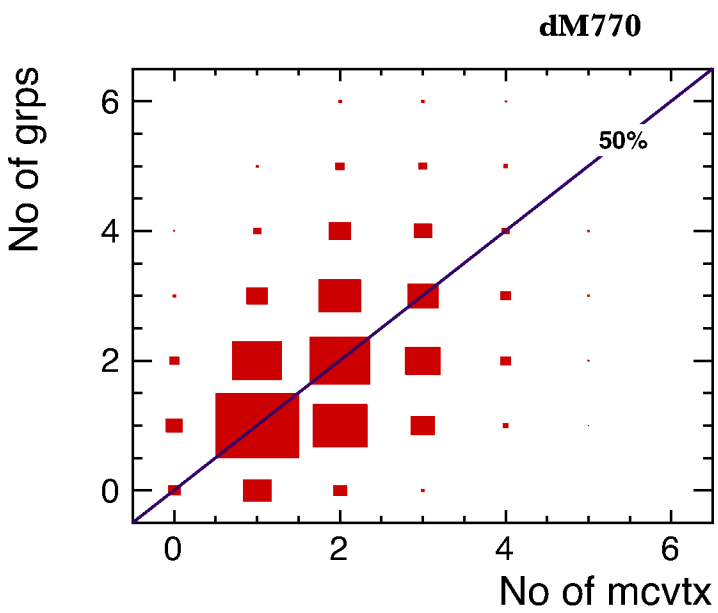


Algorithm - flowchart



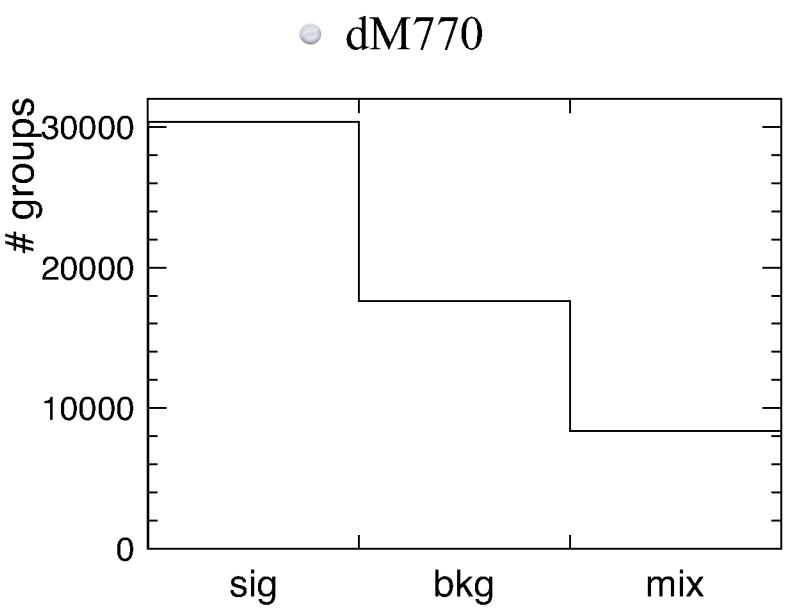
Results from the algorithm

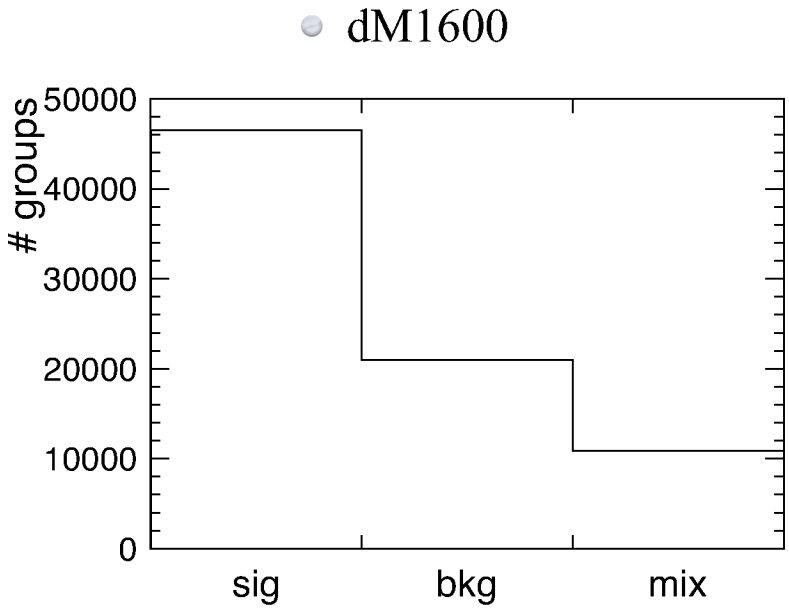




- No. of groups created with algorithm compared with no of Mcvtx
- MC vertices very close and within the detector impact parameter resolution are combined together

Algorithm Performance (without pair bkg)

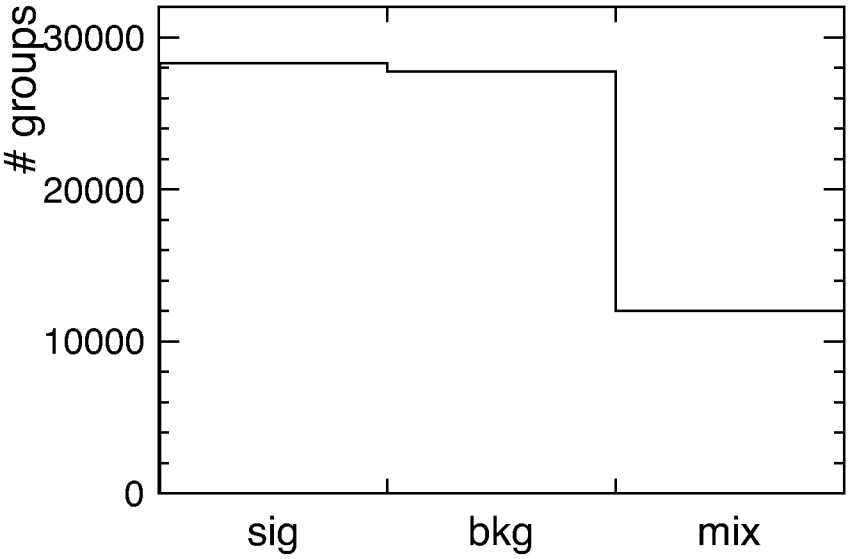




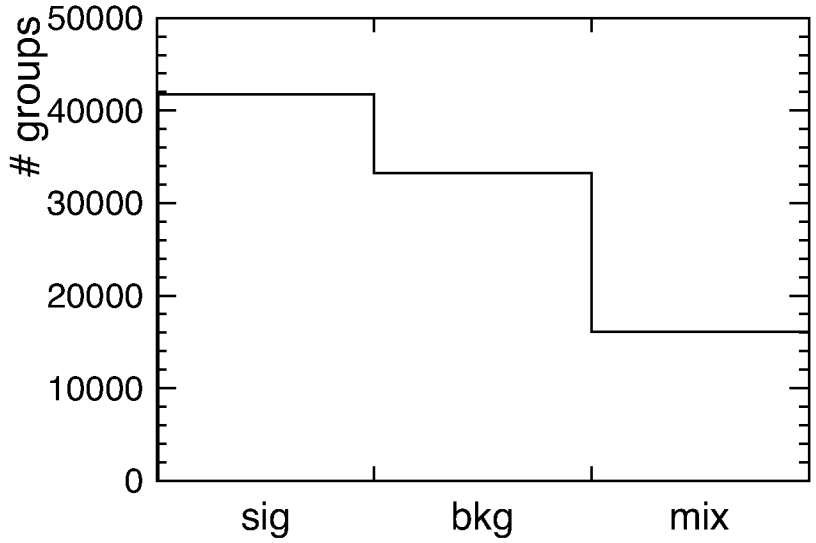
- Signal and background nicely separated
- No. of groups having signal and background mix is meagre

Algorithm Performance (with pair bkg)

- dM770



- dM1600



- Grouping done without the exclusion of pair background
- Inclusion of pair background doesn't degrade purity of group much

Conclusion and Outlook

- Impact of $\gamma\gamma \rightarrow$ low pt hadron overlay on the higgsino events very important
- 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
- Results very encouraging!!
- Identification of group and application on full analysis - work in progress.

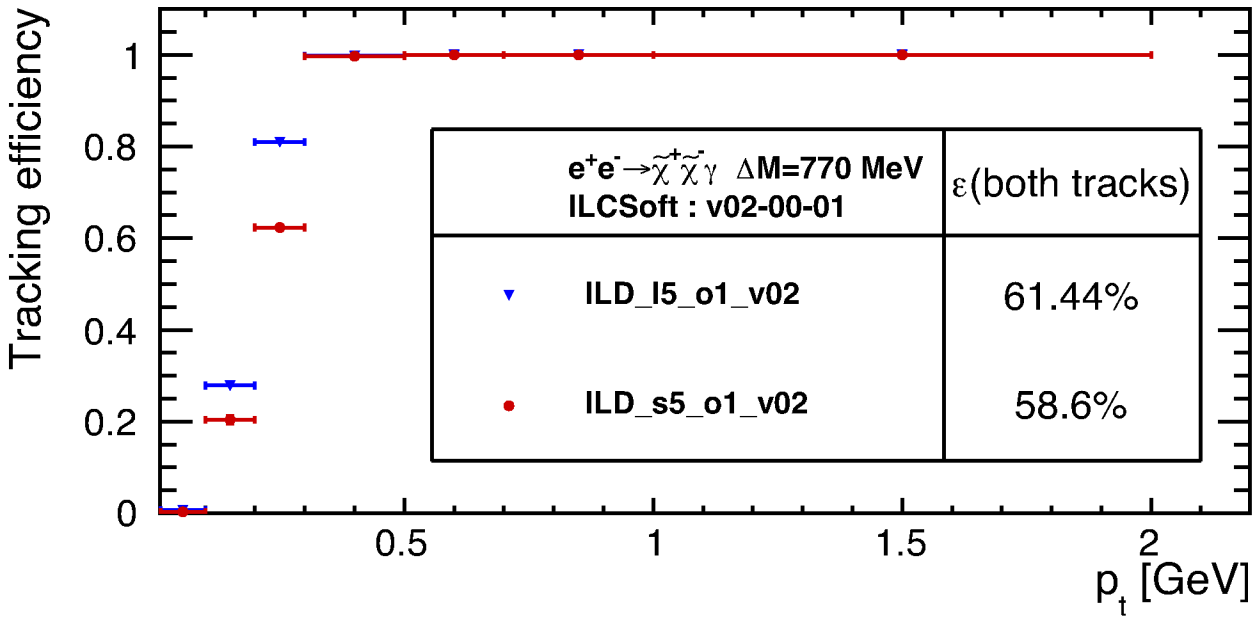
Questions??

Average position and error

- Weighted avg position = $\Sigma_i \frac{Z_0[track_i]}{Z_0[\sigma_i]} / \Sigma_i \frac{1}{Z_{0[\sigma_i]}}$

- Weighted Avg Error = $1/\Sigma_i \sqrt{\frac{1}{Z_0[\sigma_i]}}$

Tracking Efficiency



- 100 % tracking efficiency above 300 MeV
- 72 % of total tracks have p_T above 300MeV
- Only events with both tracks reconstructed considered

$\tilde{\chi}_1^+$ decay mode	BR(dM770)
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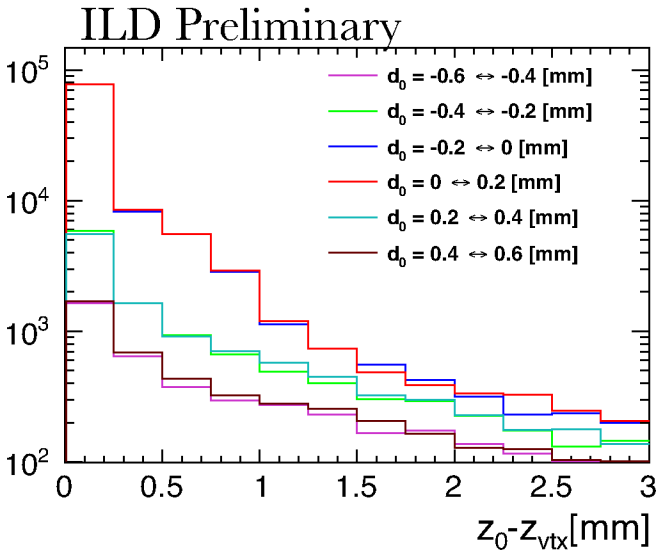
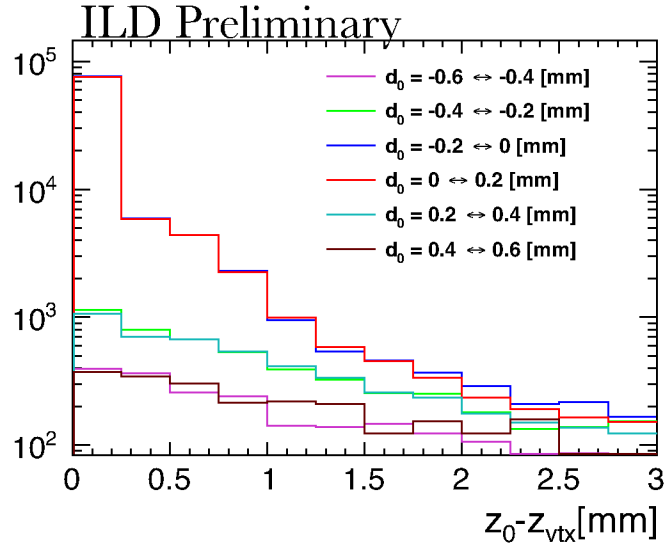
$\mu\nu\tilde{\chi}_1^0$	13.7%
$\pi^+\tilde{\chi}_1^0$	60.4%
$\pi^+\pi^0\tilde{\chi}_1^0$	7.3%
$\pi^+\pi^0\pi^0\tilde{\chi}_1^0$	0.03%

d_0 projection on z_0-z_{vtx}

- Group tracks with z_0
- For z_0 to be comparable with z_{vtx} track required to be closest to z-axis
- Tracks with higher d_0 are away from z-axis
- Tracks above certain d_0 threshold value to be treated differently



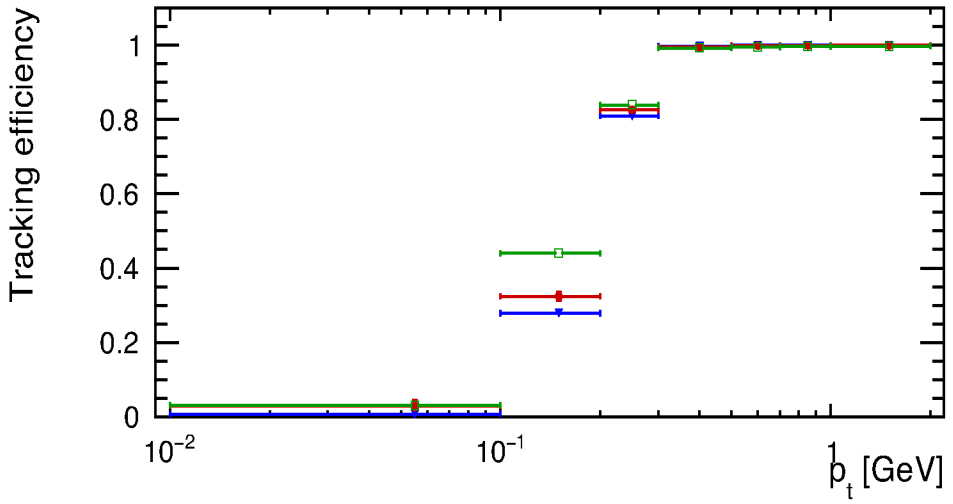
dM770

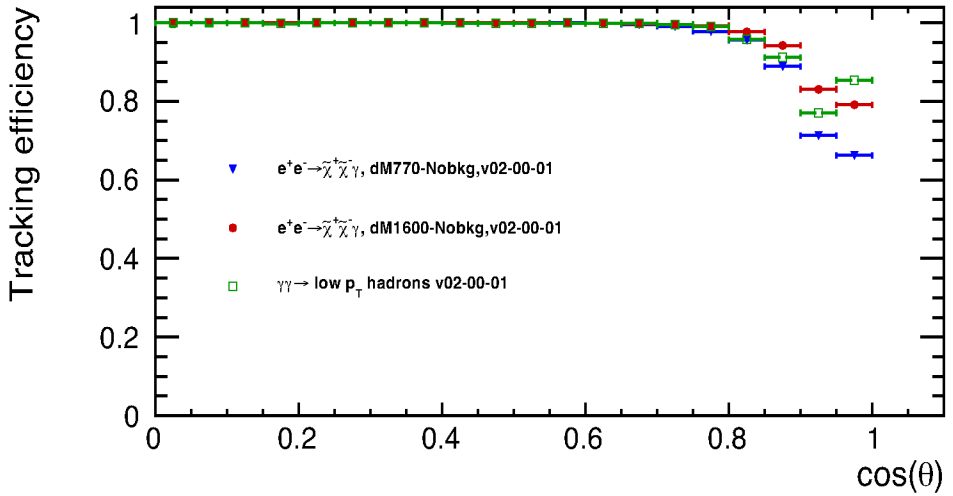


dM1600

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

- ILDPerformance -Diagnostics package used for tracking efficiency
- Silicon Tracking algorithm used to reconstruct tracks
- Reconstruction efficiency of $\gamma\gamma \rightarrow$ low p_T hadron events consistent with $t\bar{t}$ events
- Reconstruction efficiency for the low pt hadron events
  - Above 300 MeV and at higher angles 99%
- Important to develop method to remove $\gamma\gamma \rightarrow$ low pt hadron events





N4 C2+, C2- Wino-like M_2 ~ 500-1000 TeV

N3 Bino-like M_1 ~ 250-500 TeV

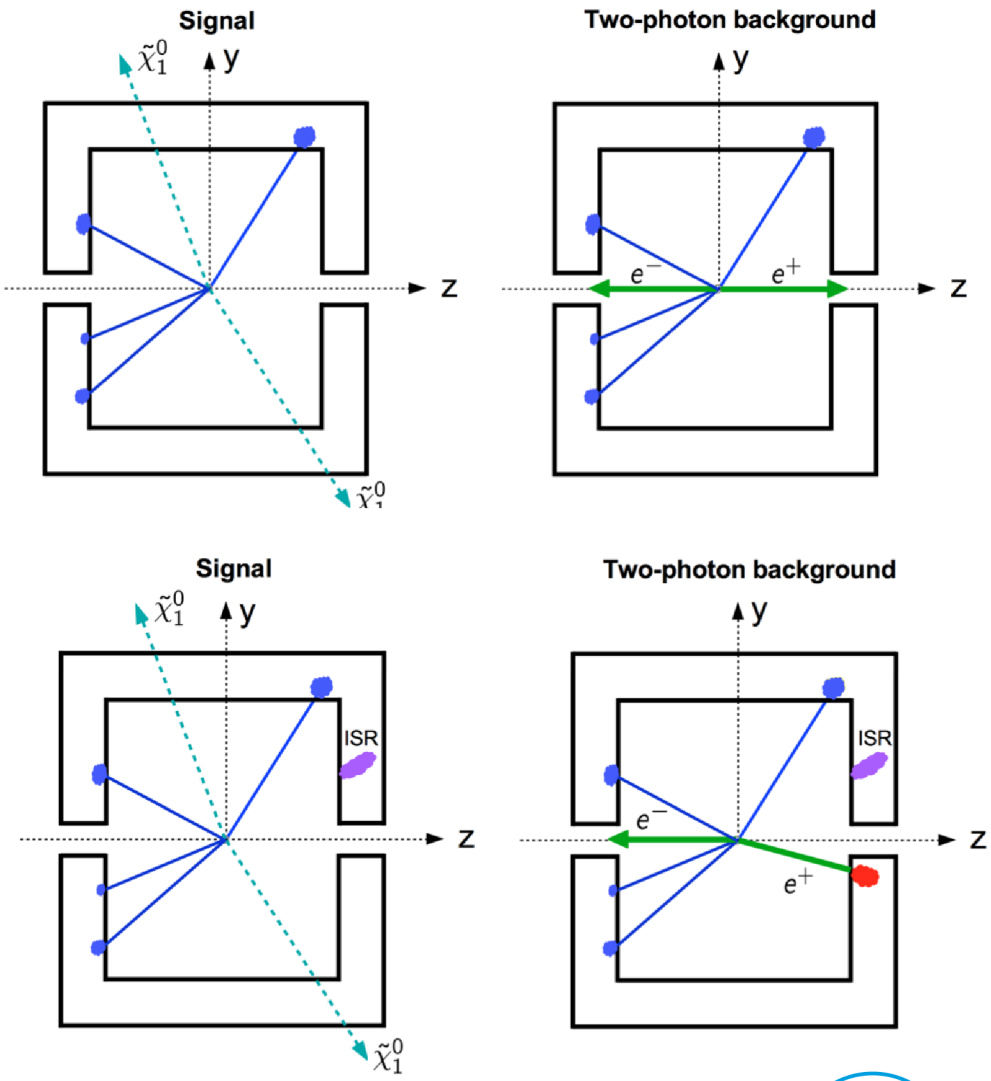
N2 N1 C1+, C1- Higgsino-like μ ~ 100-150 GeV

Neutralino Chargino

ref. Tomohiko Tanabe

Precuts for the Algorithm

- The event should have a hard ISR photon with E > 10 GeV
- ISR photon gives a pt kick to the beam electron - beam electron within detector acceptance
- Missing energy from beam particles - overlay events
- For signals - the pt kick balanced by the invisible neutralinos
- No effect on the signal decay products or the beam electron

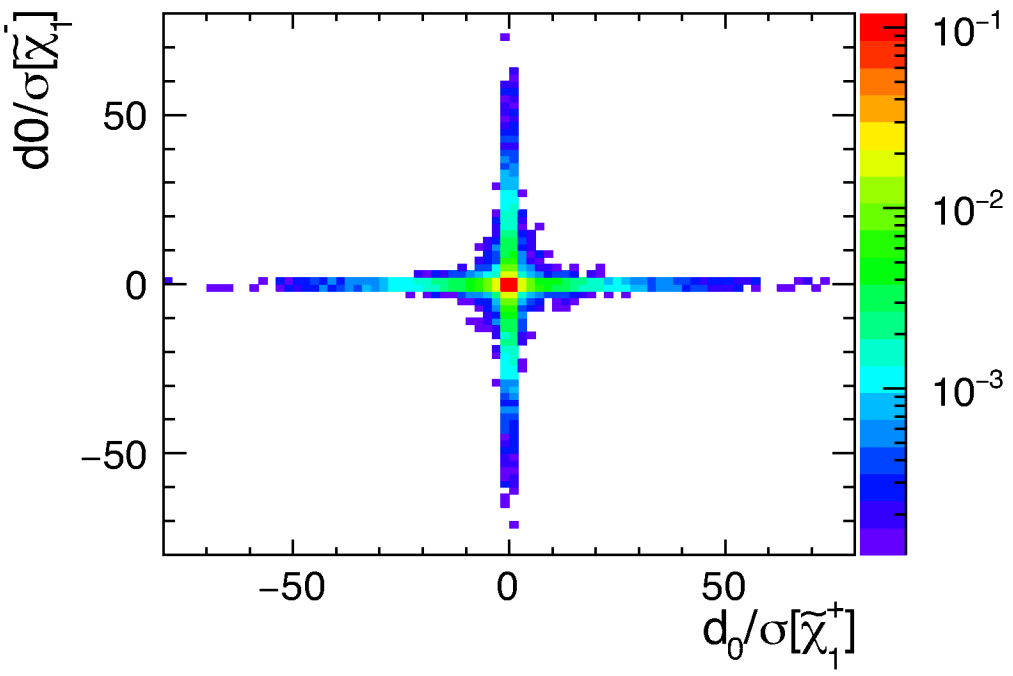


Summary and Outlook

- 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

Detailed study of d_0 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 d_0 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 d_0 significance for both tracks are similar



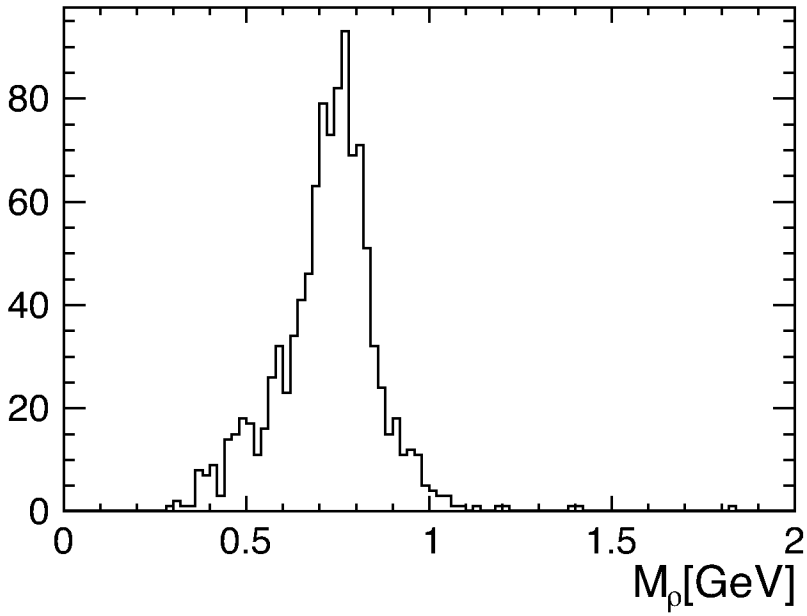
Method Development to remove backgrounds

- 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 - 770 145 MeV
  - Only 0.54% events reconstructed exactly as 2 +ve and 2 -ve tracks



Event Properties of Pythia

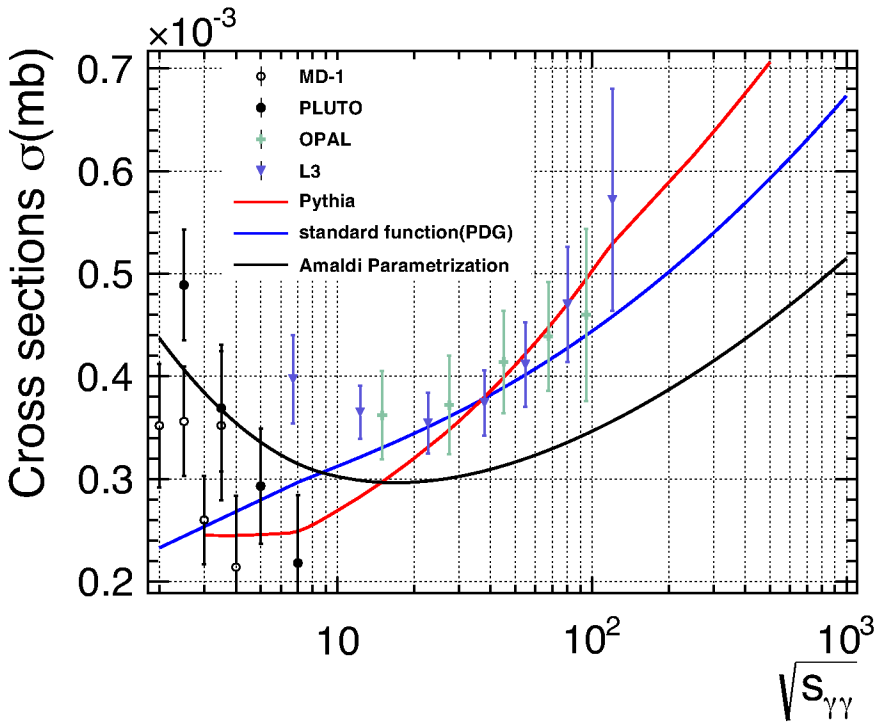
- Direct Interactions(DIR) - Real photons interacts directly
- Vector Meson Dominance(VMD) - Photon fluctuates into a vector meson
- Anomalous Interactions(GVMD) - Photon fluctuates into a $q\bar{q}$ pair of larger virtuality
- Deep inelastic Scattering(DIS) - A process of probing the Hadrons with very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

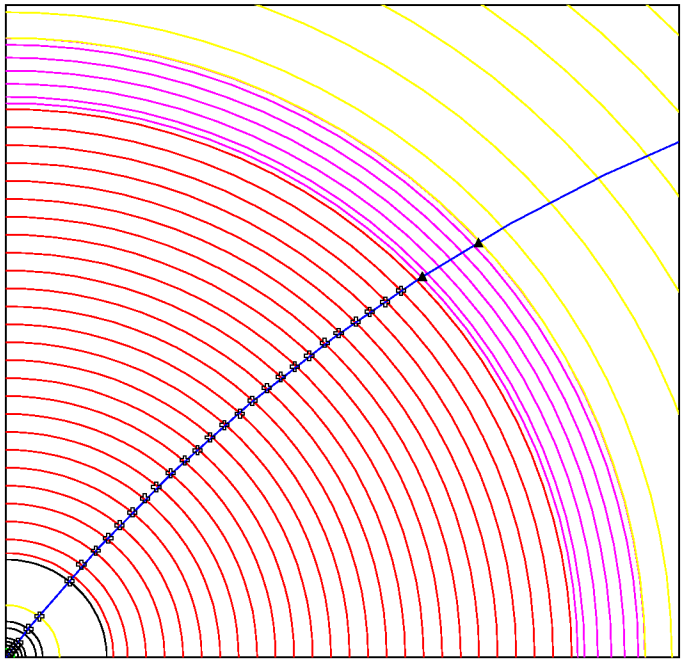
Cross sections for Pythia events

- Comparison of $\gamma\gamma$ 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



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”



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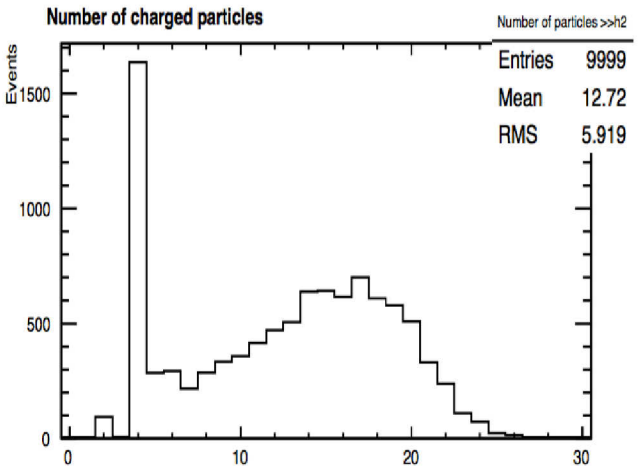
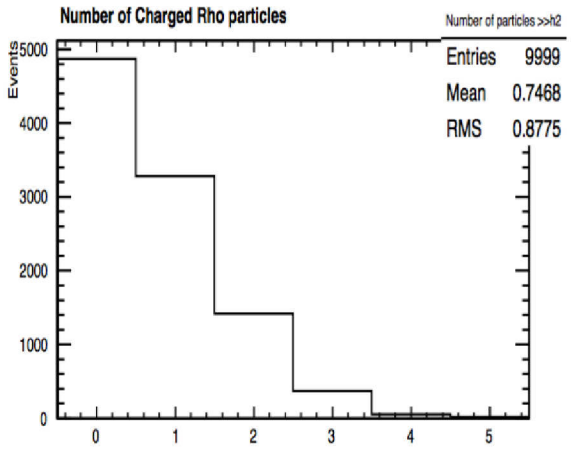
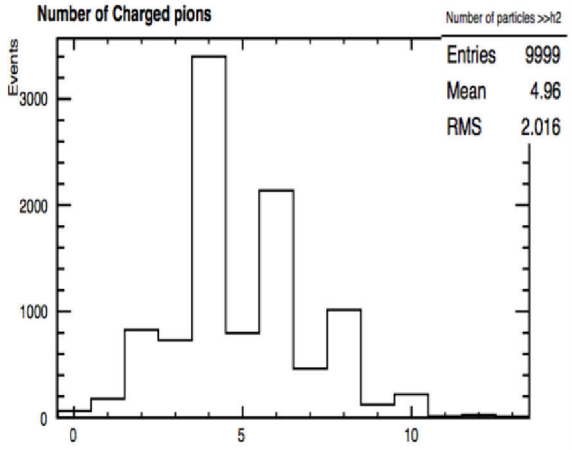
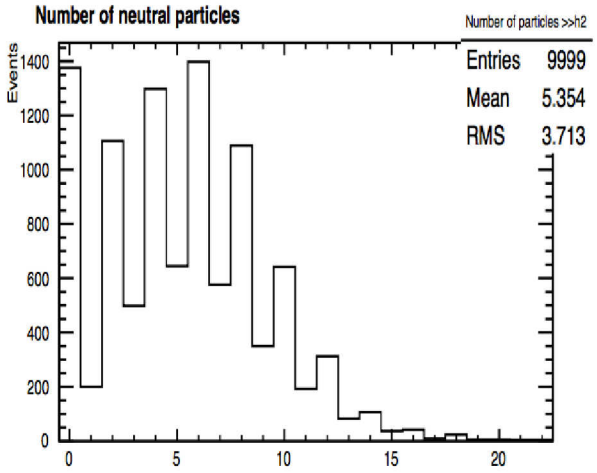
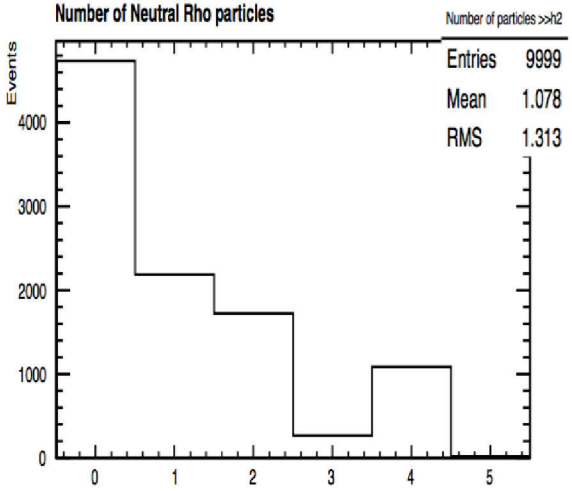
Event Properties of Pythia

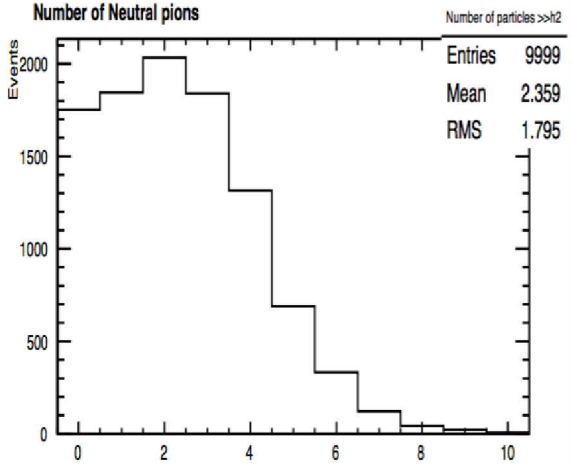






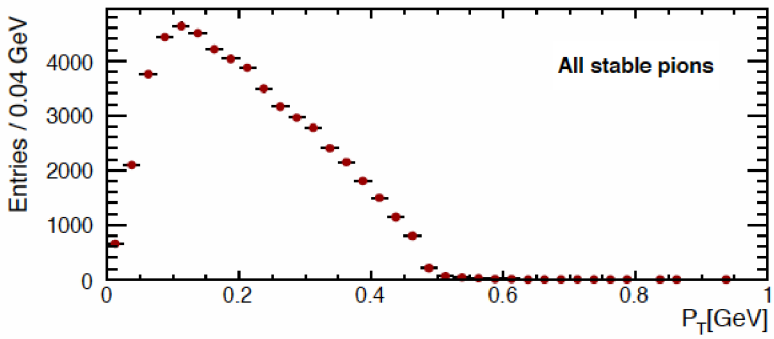


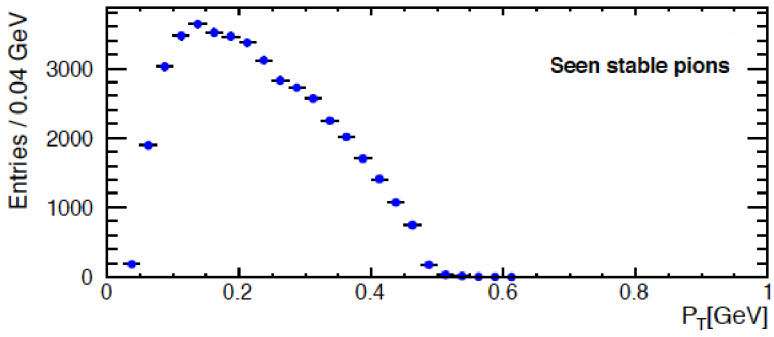


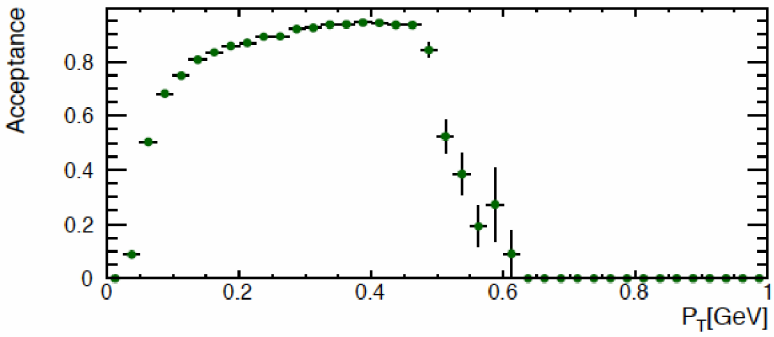


Pythia could be used to simulate events down upto $\sqrt{s_{\gamma\gamma}} = 2$ GeV

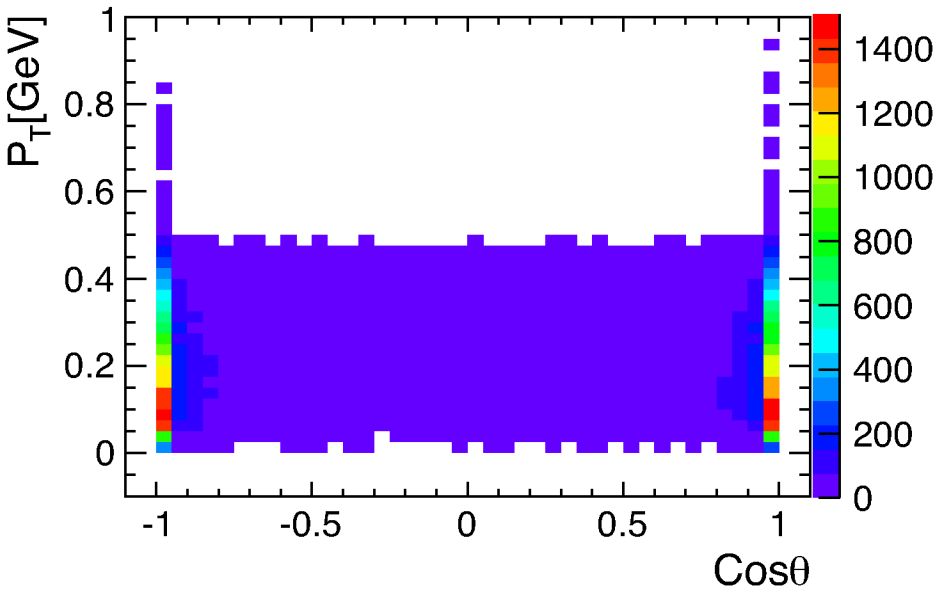
Momentum acceptance for Pions





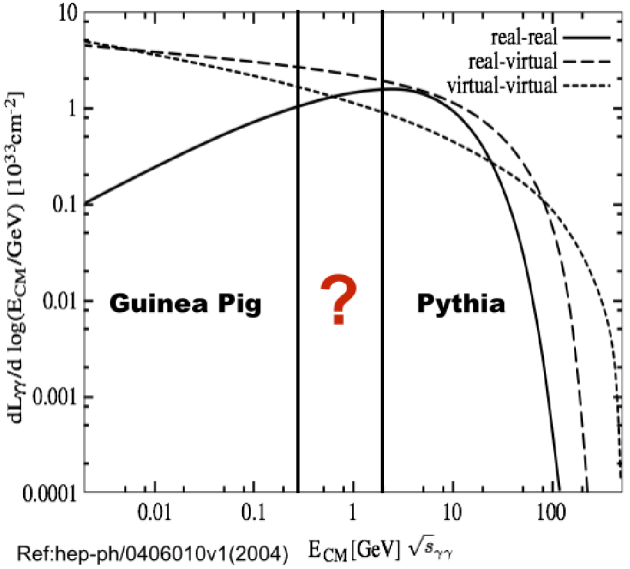


- Momentum acceptance:
  - Dividing seen stable pions with all true pions
  - The acceptance for most particles > 80%
  - Particles with high Pt but moving in forward direction - low acceptance

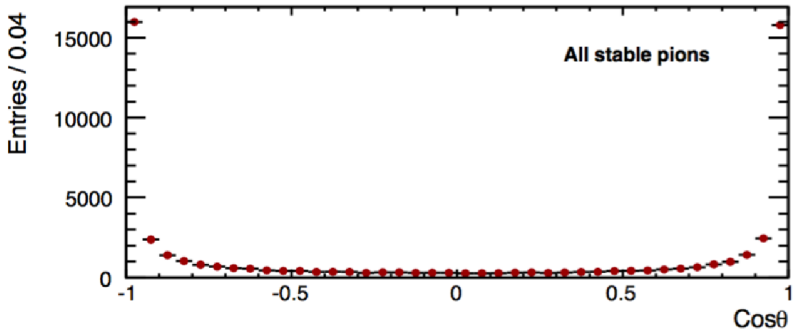


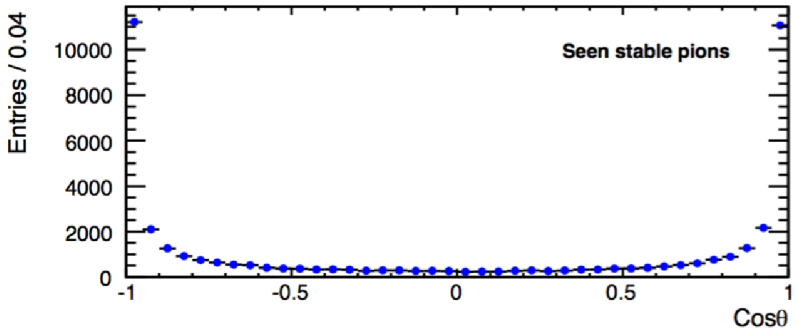
A dedicated event generator for $\gamma\gamma$ processes

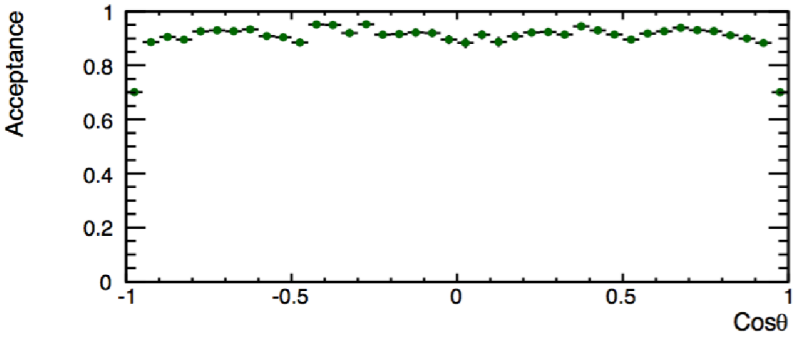
- For $\sqrt{s_{\gamma\gamma}} > 2$ GeV Pythia 6 used to simulate $\gamma\gamma \rightarrow$ low pT hadron processes
- Below 2 π_m pure QED beam-beam interactions modeled by dedicated programs - Guinea Pig
- Need to evaluate the impact of uncovered region - how can it be modeled?
- Dedicated generator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



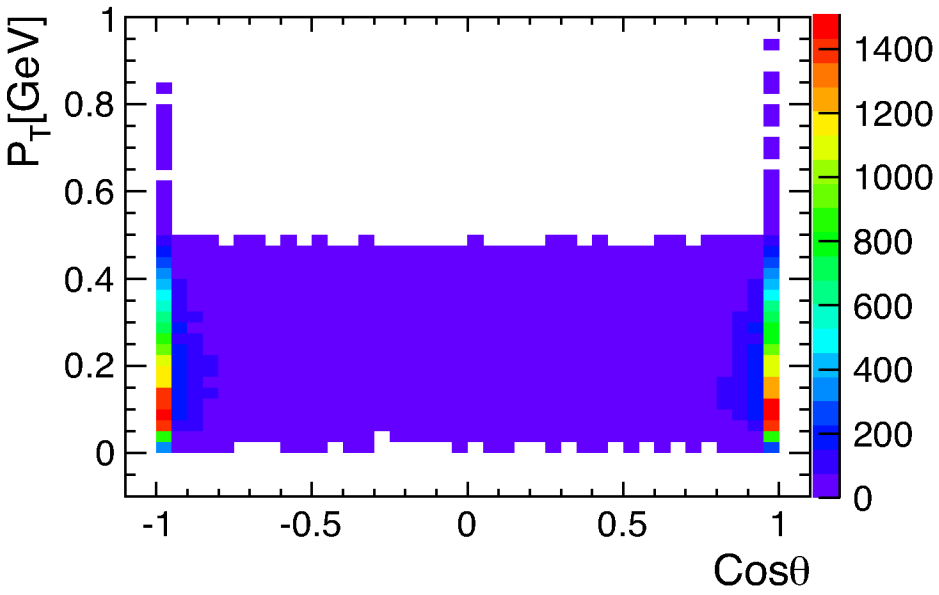
Angular acceptance for Pions





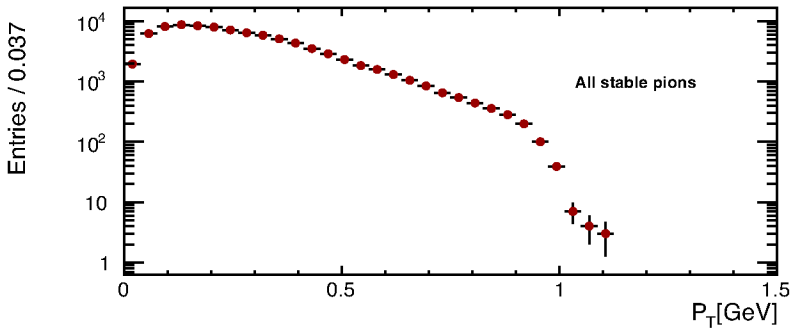


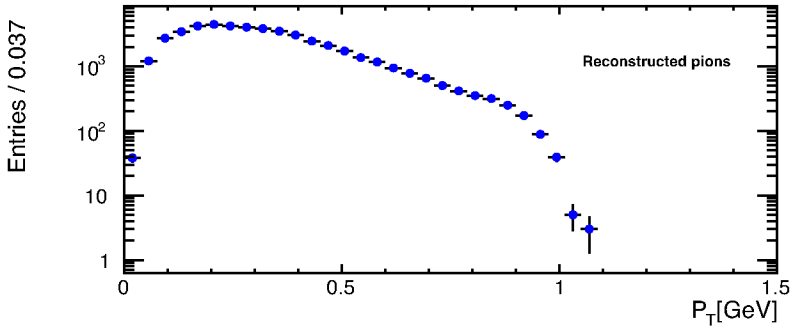
- Angular acceptance:
  - Dividing seen stable pions with all true pions
  - The acceptance for most particles > 80%
  - Particles with high Pt but moving in forward direction - low acceptance

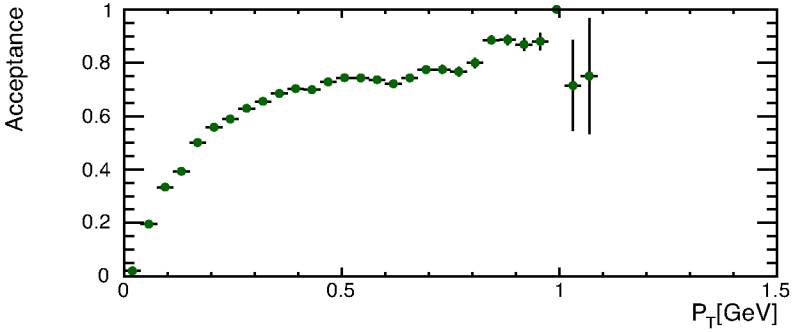


Momentum acceptance of pions with full simulation

- Cross checked the results with full simulation
- acceptance for pions at $\sqrt{s_{\gamma\gamma}}$ 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!!!