

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

**Linear Collider Forum 2018**

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# Introduction

- > Naturalness requires light higgsinos at electroweak scale

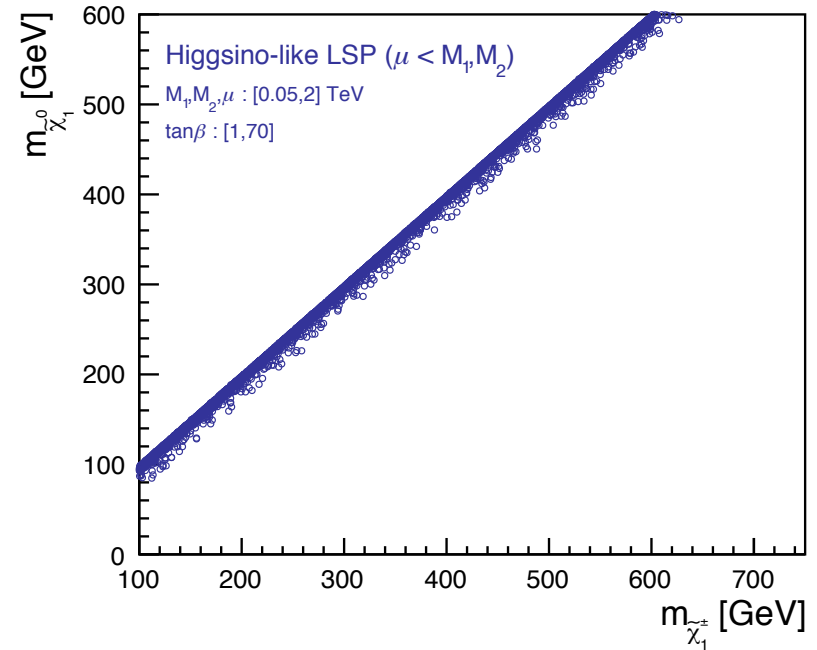
$$m_Z^2 = 2 \frac{m_{H_d}^2 + \Sigma_d^d - (m_{H_u}^2 + \Sigma_u^u) \tan^2 \beta}{\tan^2 \beta - 1} - 2\mu^2$$

- > Natural region is  $\mu = 100\text{-}300$  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

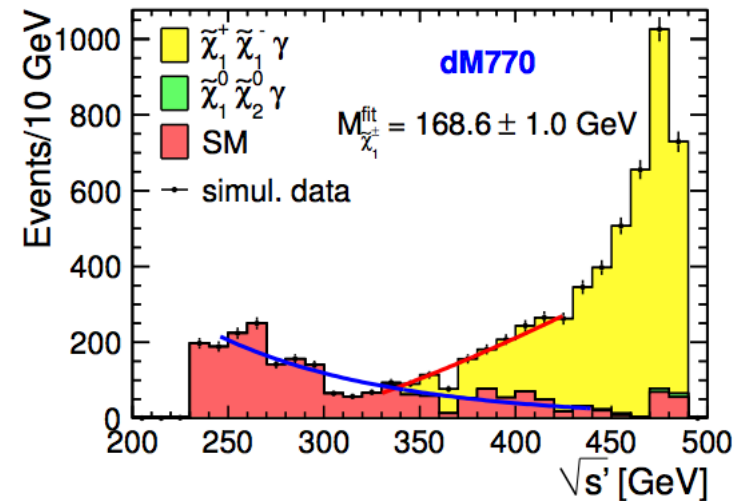
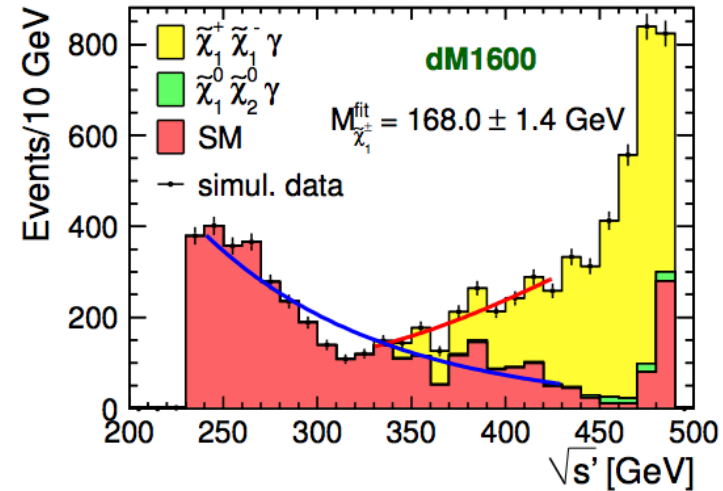
$$\Delta M(\tilde{X}_1^\pm, \tilde{X}_1^0) = 770 \text{ MeV} \Rightarrow \text{dM770}$$

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

> Charginos decay hadronically and leptonically

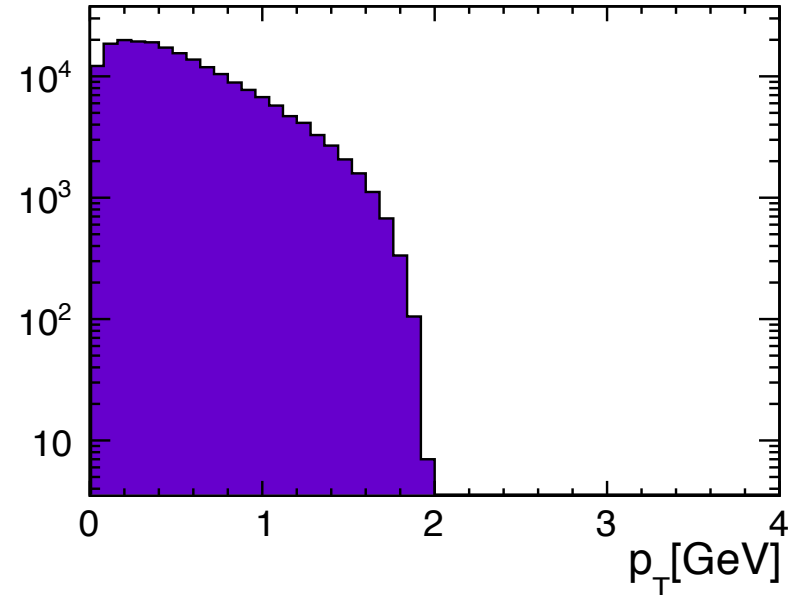
> Studied without the inclusion of

- $\gamma\gamma \rightarrow$  low  $p_T$  overlay
- Pair background



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

- >  $\gamma\gamma \rightarrow$  low  $p_T$  hadron backgrounds is a challenge for some specific cases e.g low  $\Delta M$  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  $p_T$  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\_15\_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



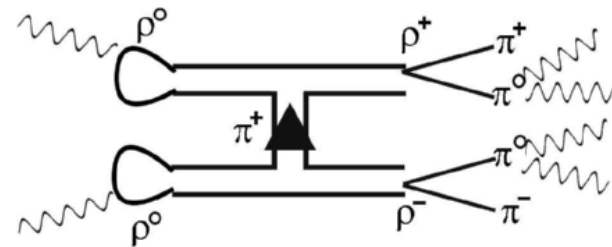
# Possible methods to remove $\gamma\gamma \rightarrow$ low pT hadrons

## > 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  $\gamma\gamma \rightarrow \pi^0\pi^0$

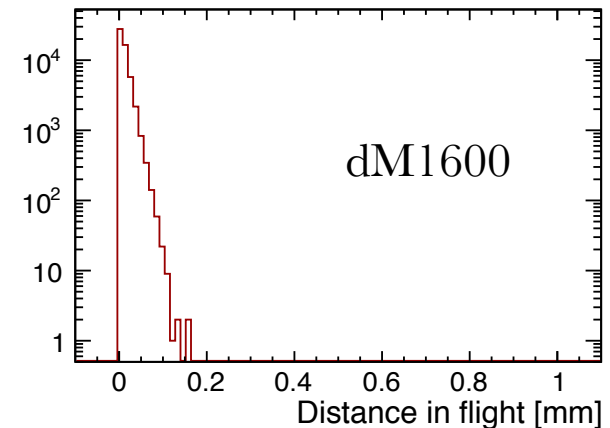
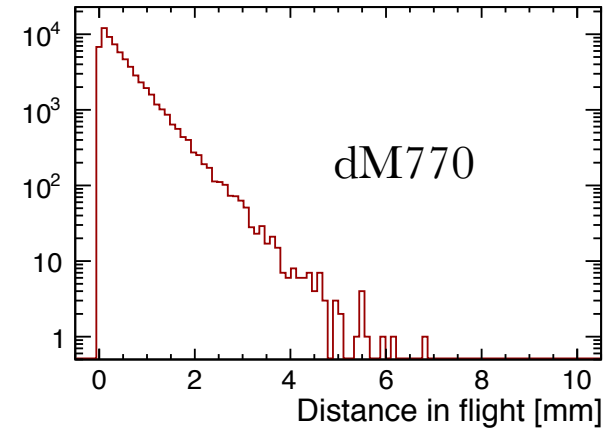
## > Second method:

- 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



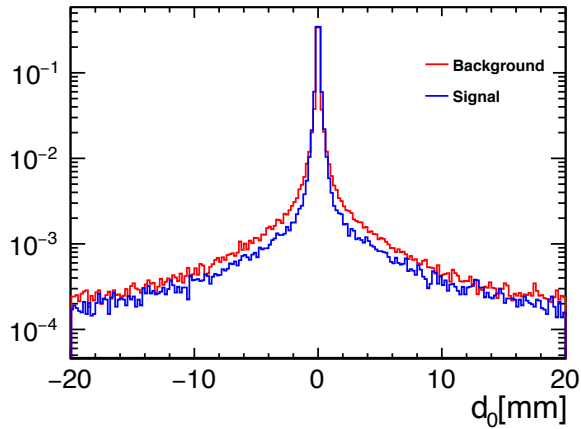
# Reconstruction level and the track parameters

- > 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  $z_0$  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

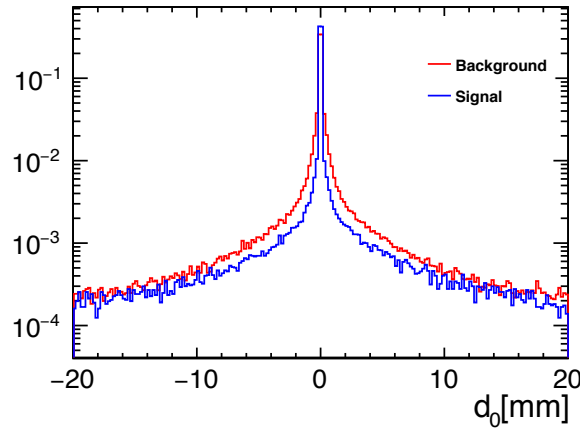


# Detailed study of $d_0$ parameter

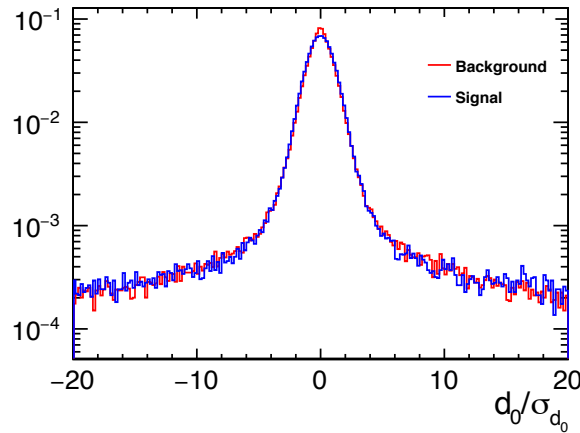
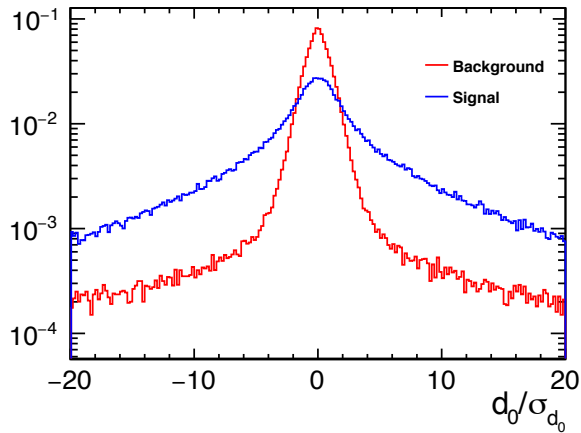
dM 770



dM 1600



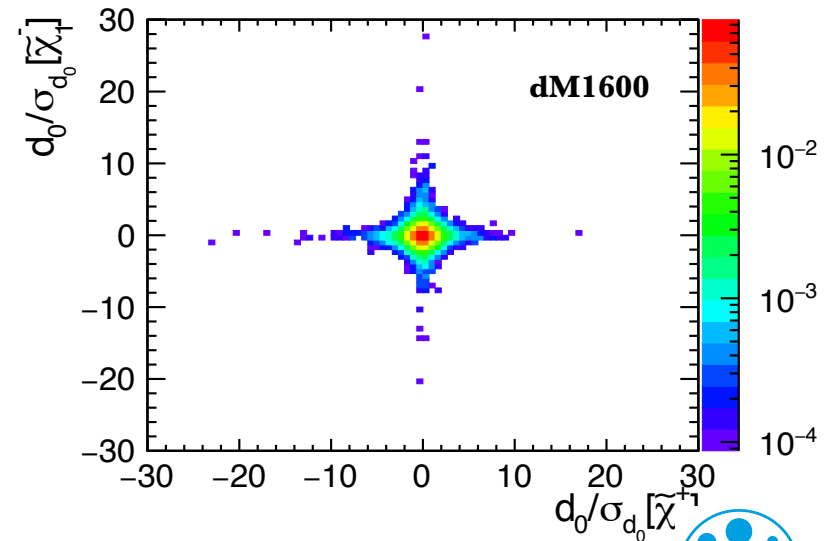
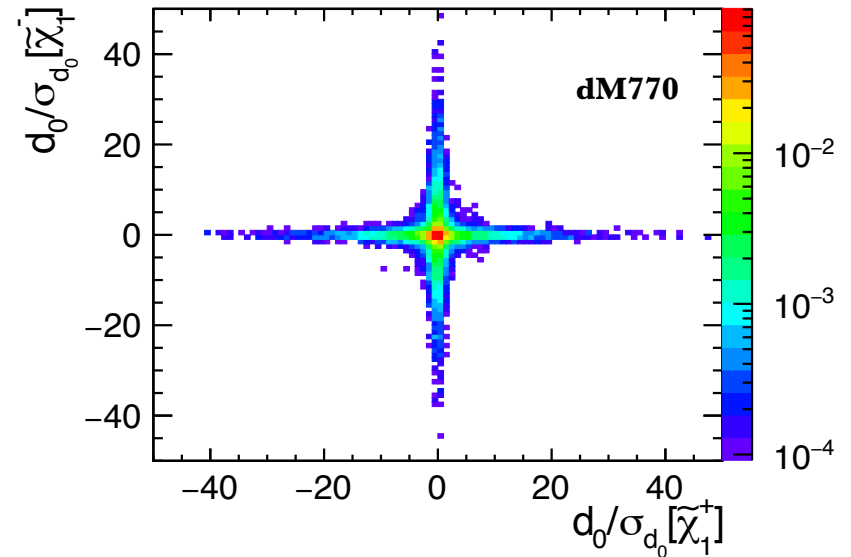
- > With higher mass difference smaller  $d_0$
- > In dM1600  $d_0$  not a handle



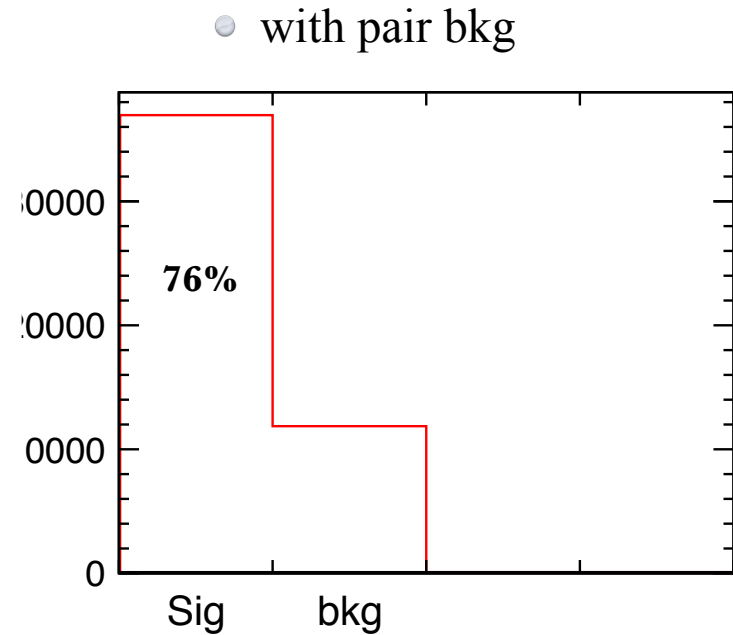
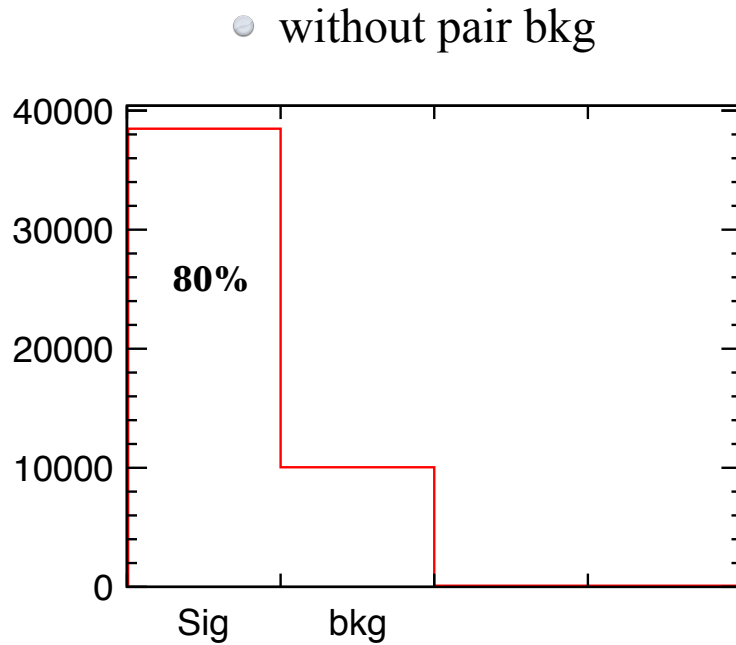
# Removal of high $d_0$ tracks

- > 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  $d_0$  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
- $d_0 < 0.3$  mm
- $z_0 < 15$  mm

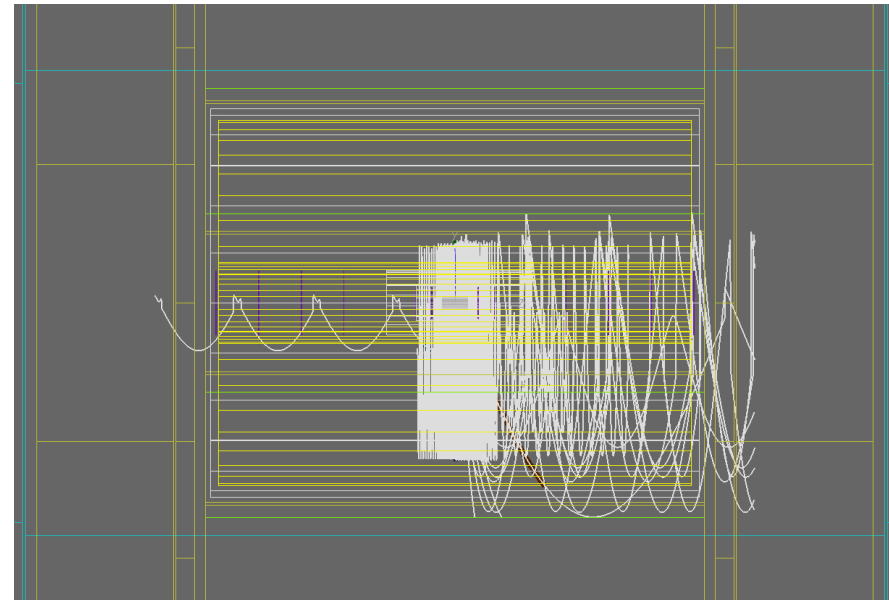
## > dM 1600 :

- $d_0 < 0.2$  mm
- $z_0 < 15$  mm

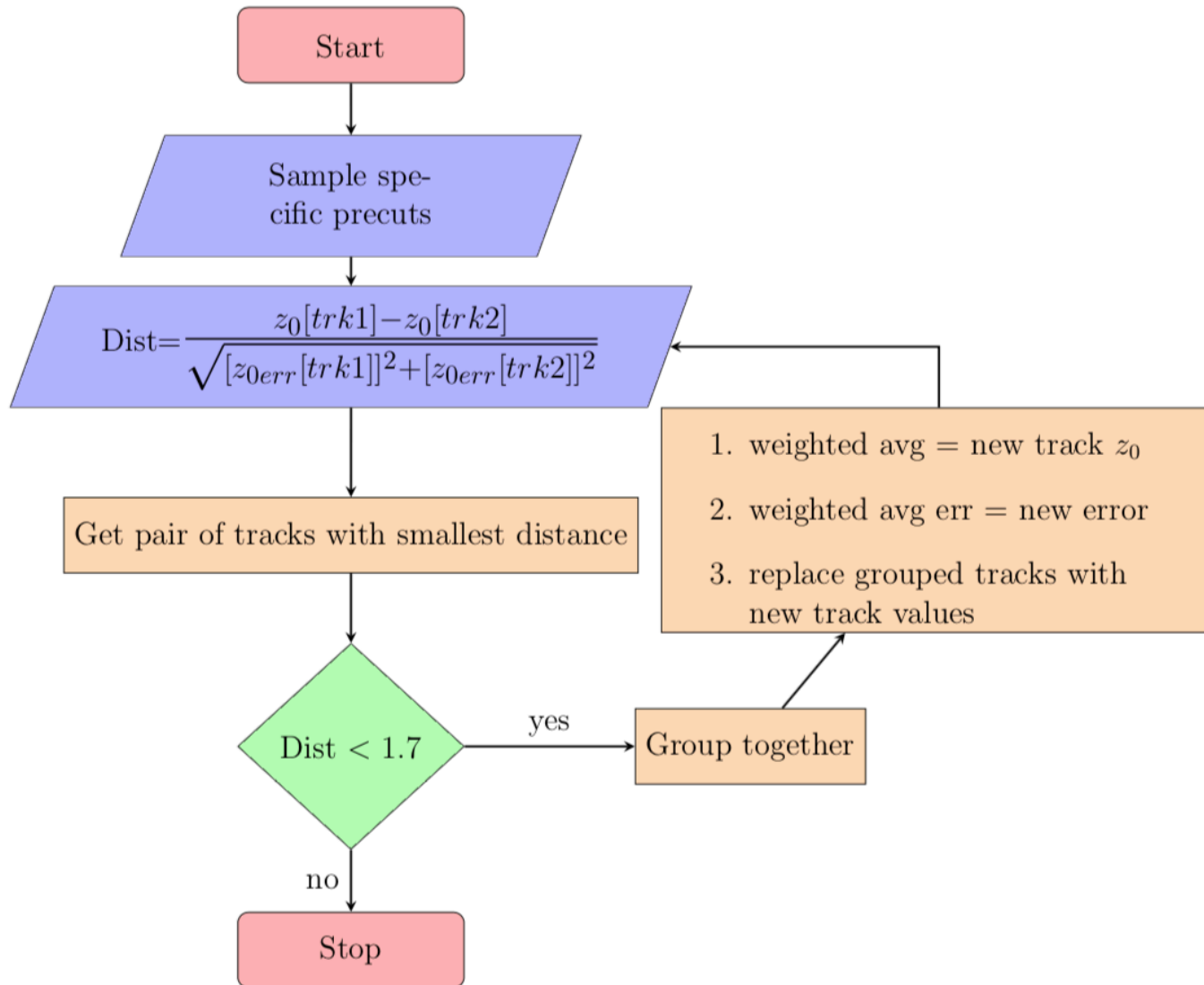
## > No of tracks $< 13$

- Curling of low  $p_T$  tracks

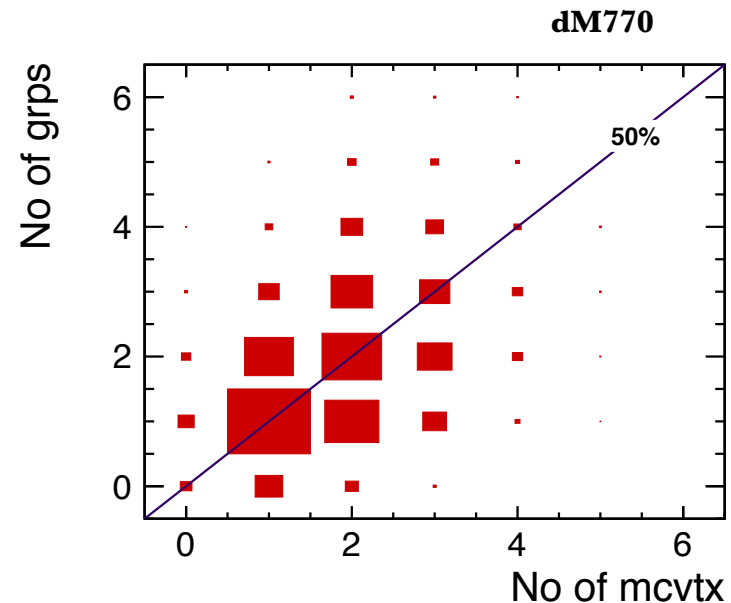
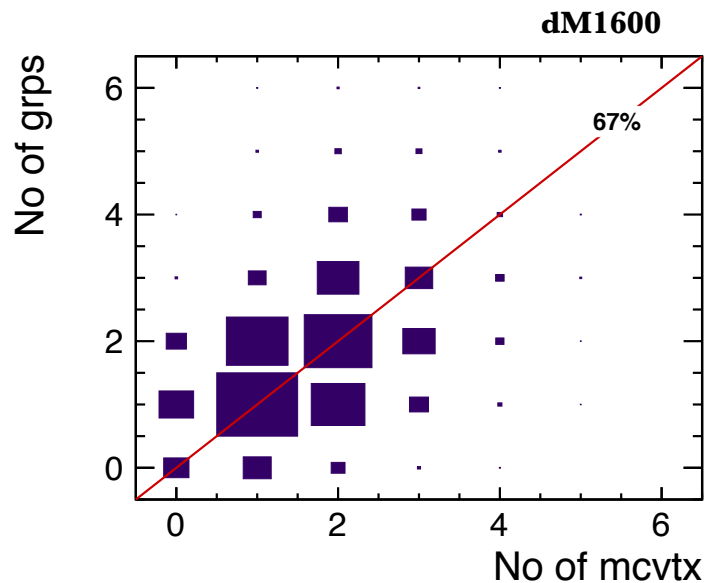
## > Events with minimum 2 signal tracks reconstructed



# Algorithm - flowchart



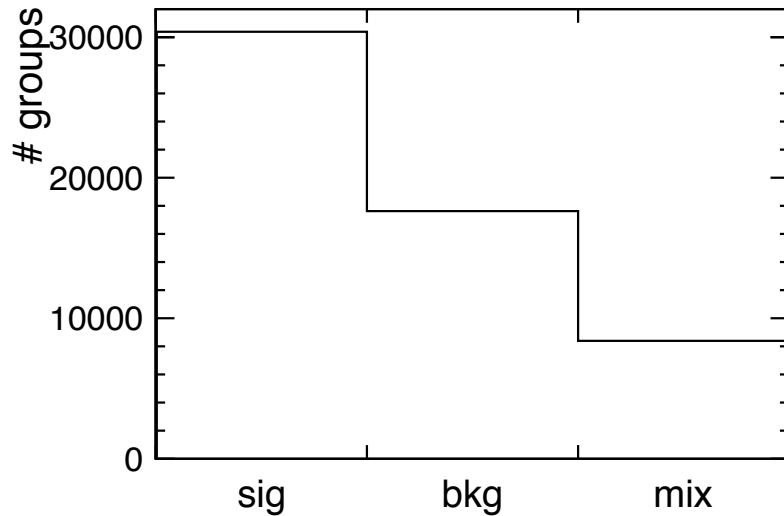
# Results from the algorithm



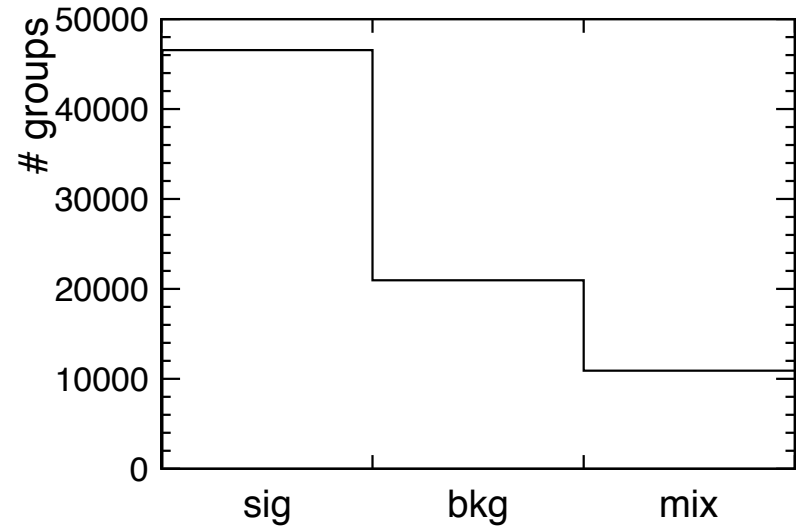
- > No. of groups created with algorithm compared with no of Mcvtx
- > MC vertices very close and within the detector impact parameter resolution are combined together

# Algorithm Performance (without pair bkg)

● dM770



● dM1600

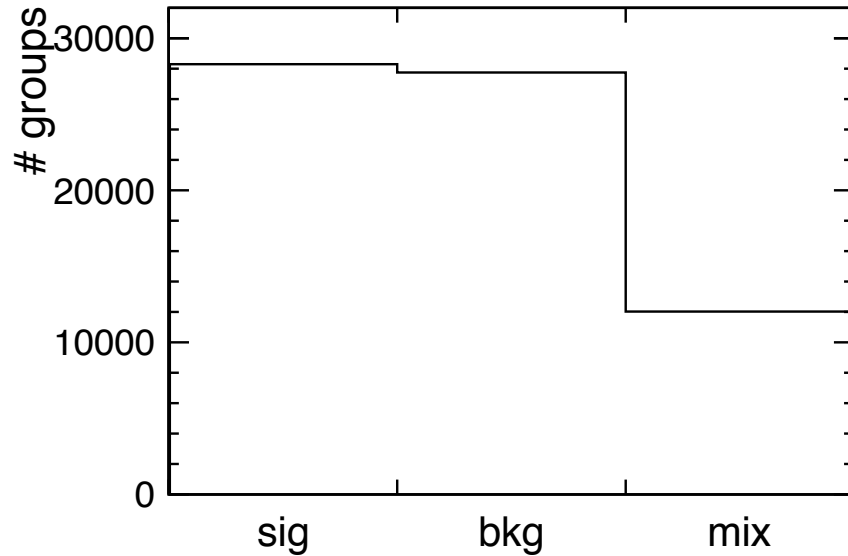


- > Signal and background nicely separated
- > No. of groups having signal and background mix is meagre

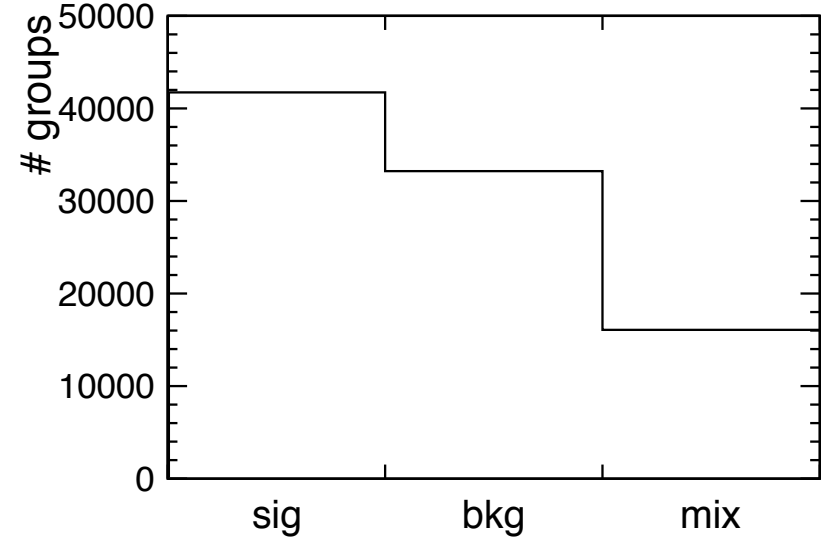


# Algorithm Performance (with pair bkg)

● 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??



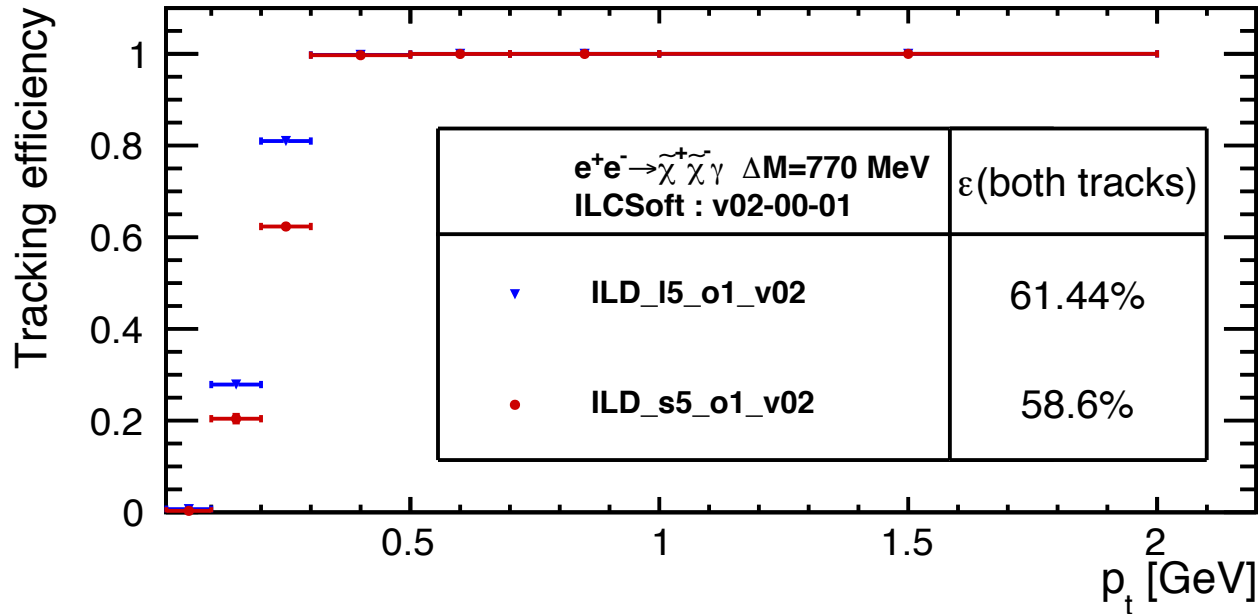
# Average position and error

> Weighted avg position =  $\sum_i \frac{Z_0[\text{track}_i]}{Z_0[\sigma_i]} / \sum_i \frac{1}{Z_0[\sigma_i]}$

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



# Tracking Efficiency



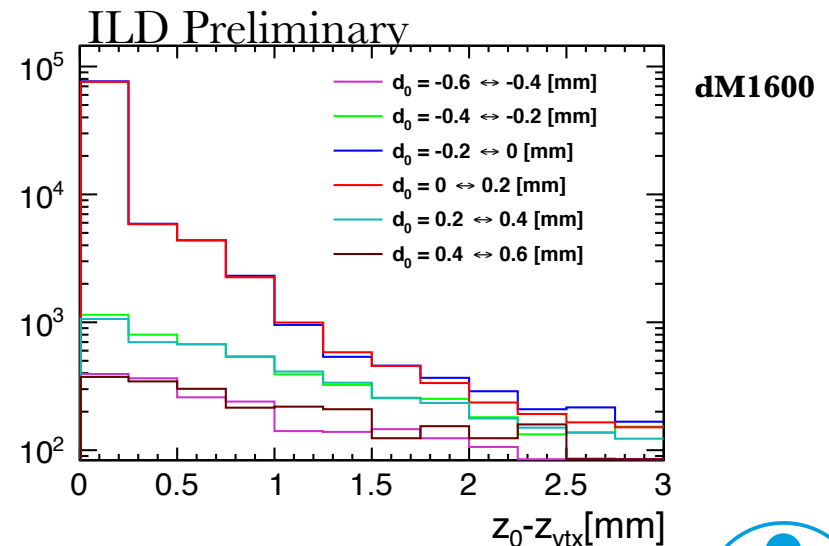
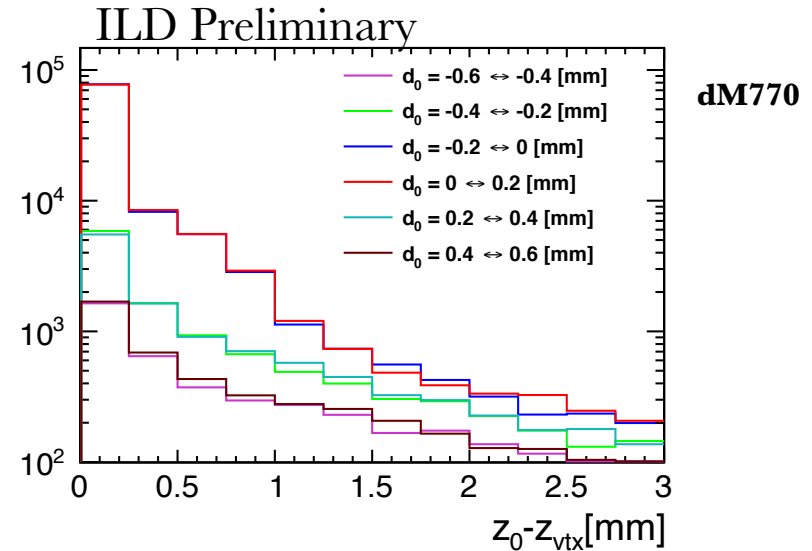
- > 100 % tracking efficiency above 300 MeV
- > 72 % of total tracks have  $p_T$  above 300MeV
- > Only events with both tracks reconstructed considered

$\tilde{\chi}_1^+$ decay mode	BR(dM770)
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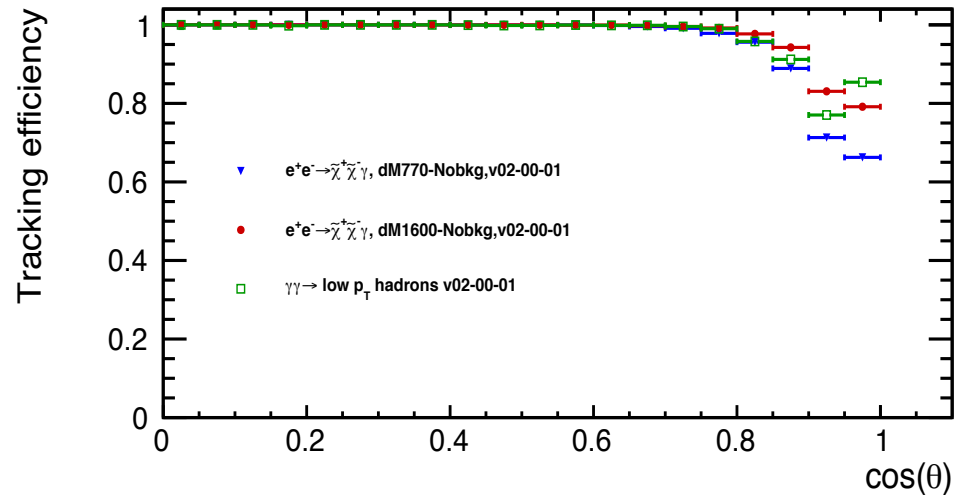
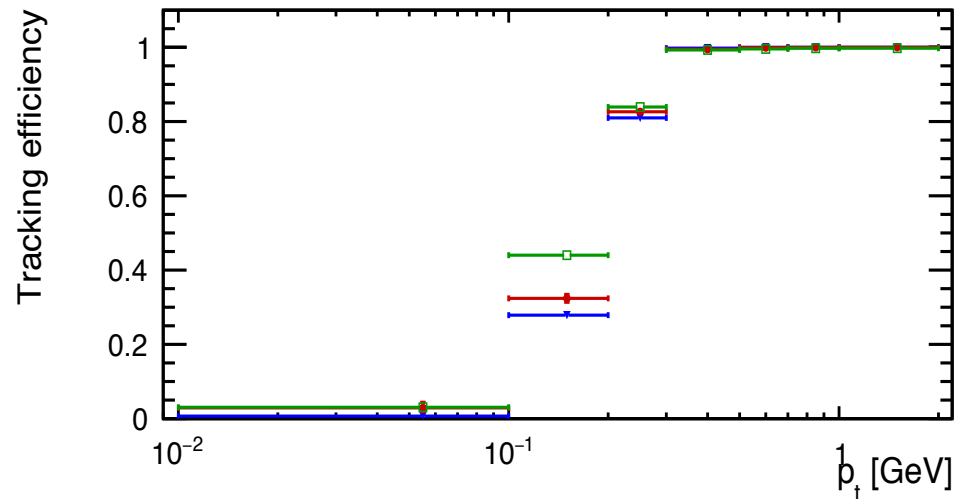
# $d_0$ projection on $z_0$ - $z_{\text{vtx}}$

- > Group tracks with  $z_0$
- > For  $z_0$  to be comparable with  $z_{\text{vtx}}$  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



# Reconstruction efficiency for $\gamma\gamma \rightarrow$ low $p_T$ 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  $p_T$  hadron events
  - Above 300 MeV and at higher angles 99%
- Important to develop method to remove  $\gamma\gamma \rightarrow$  low  $p_T$  hadron events



mass



N4

C2+, C2-

**Wino-like**  
 $M_2 \sim 500-1000 \text{ TeV}$

N3

**Bino-like**  
 $M_1 \sim 250-500 \text{ TeV}$

N2  
N1

C1+, C1-

**Higgsino-like**  
 $\mu \sim 100-150 \text{ GeV}$

Neutralino

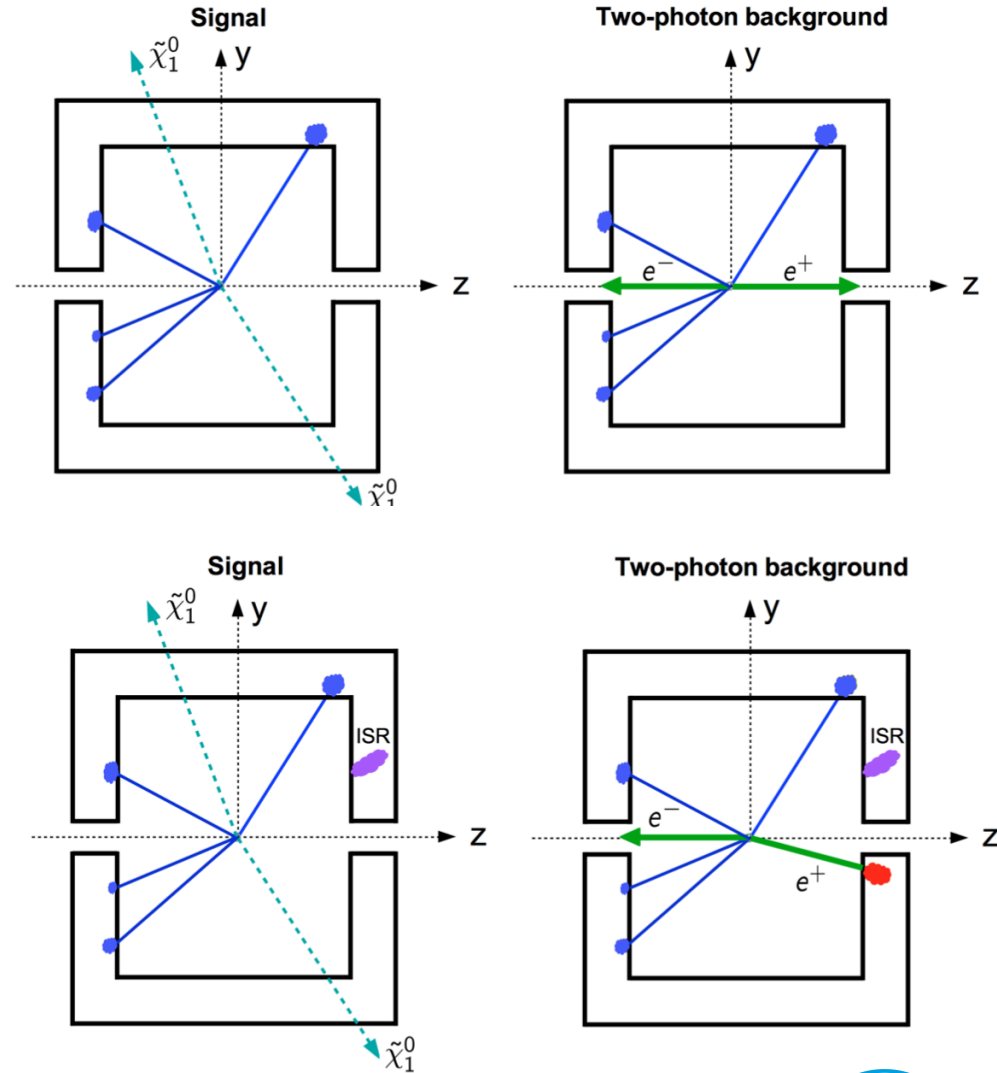
Chargino

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



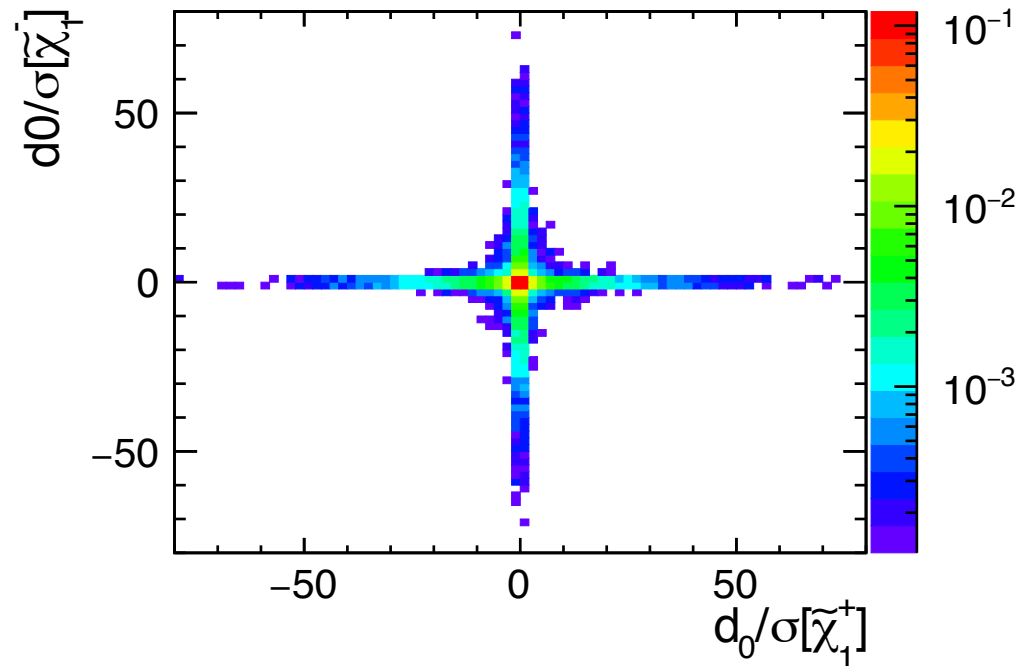
# Summary and Outlook

- 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  $z_{\text{vtx}}$  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  $d_0$  significance and other is smaller
- > Rest 40 % cases  $d_0$  significance for both tracks are similar



# Method Development to remove backgrounds

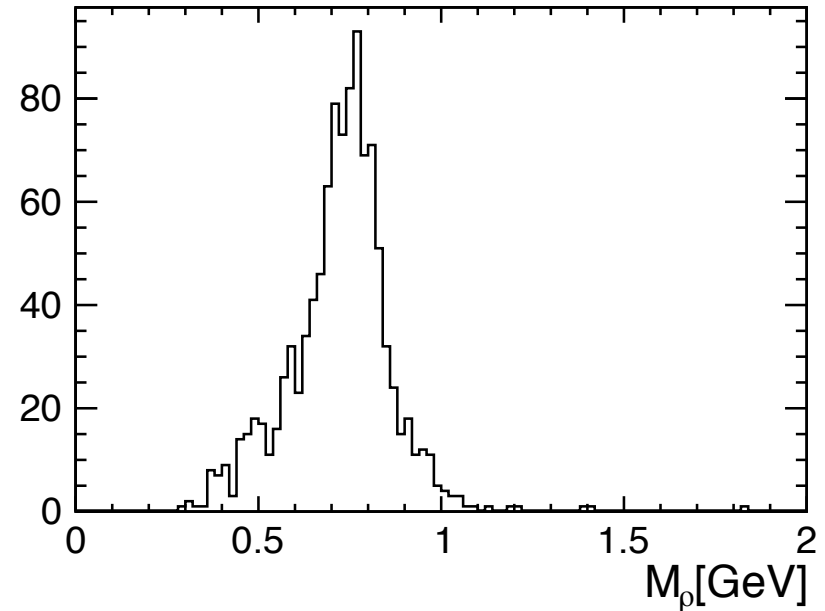
- > Primary step - separating events as in table
  - Pythia events complex - 55 % events - good chances for finding vertex
  - Only Separating Barklow events as below - 45 %

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



# Method - Using Rho meson tag

- >  $\gamma\gamma \rightarrow \rho^0 \rho^0$  events - rho meson decay to two  $\pi^+$  and two  $\pi^-$  (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.

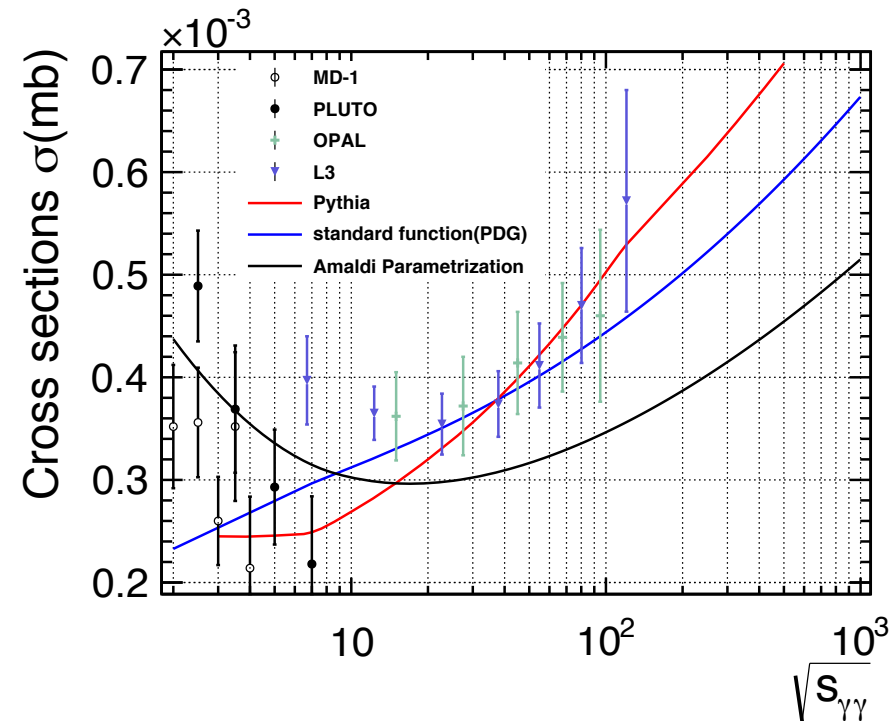
Subprocesses	Cross-sections (nb)
VMD * VMD	239.2
DIR * VMD	87.52
GVMD * DIR	9.77
GVMD * GVMD	12.05

> Pythia cannot simulate below 2 GeV



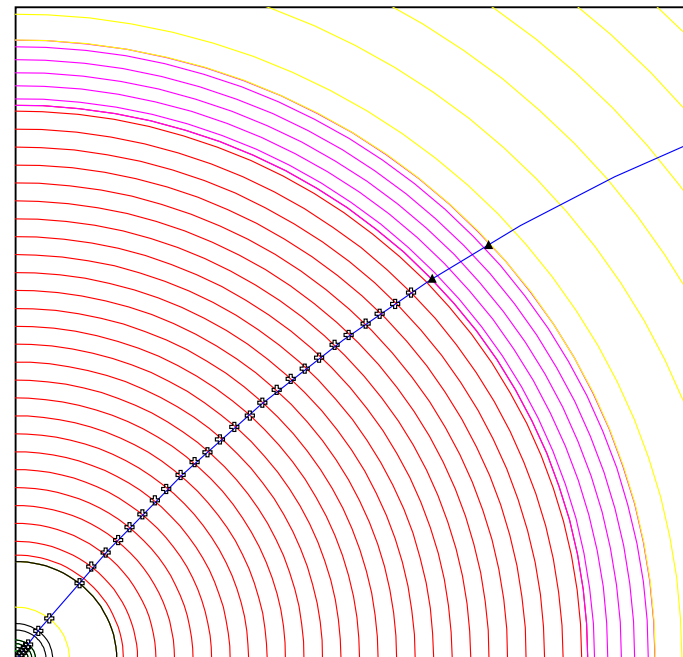
# Cross sections for Pythia events

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



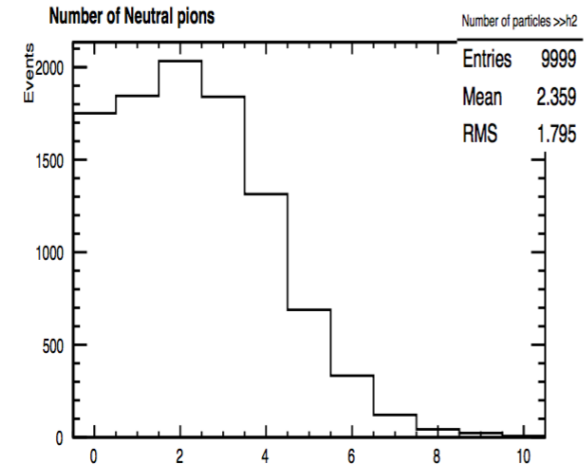
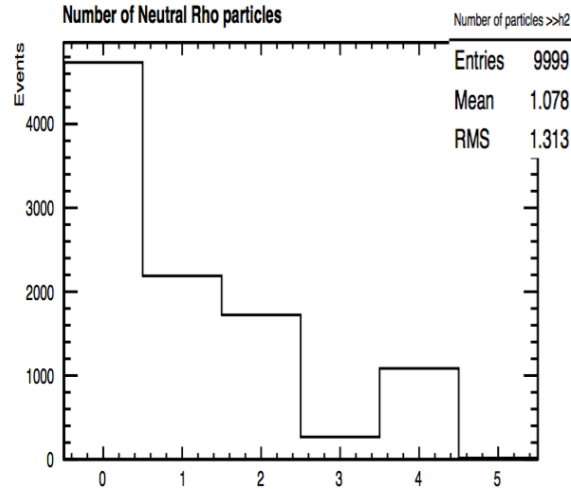
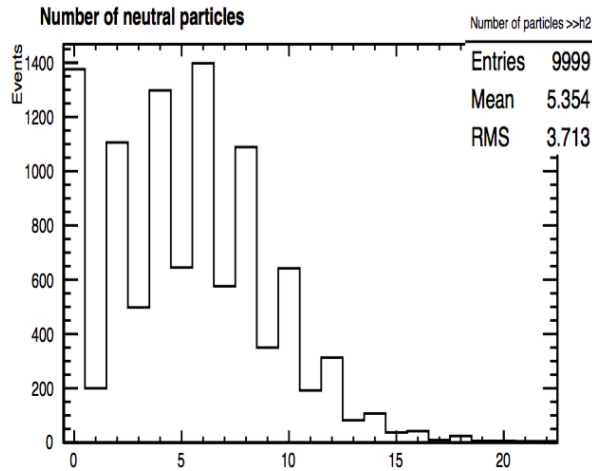
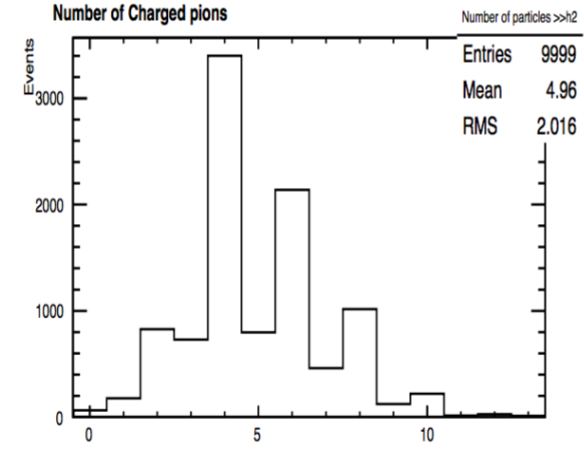
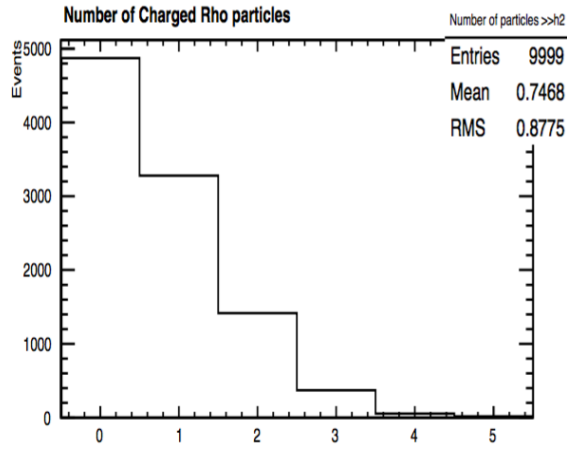
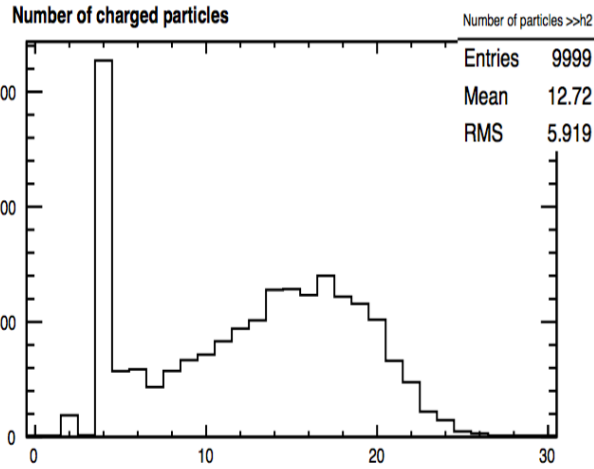
# Does $\sqrt{s_{\gamma\gamma}} < 1$ GeV matter?

- 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  $\geq 3$  layer hits : “Charged”
  - Particles hitting calorimeter : “Neutral”



Ref: [archiv:1203.0217v1](https://arxiv.org/abs/1203.0217v1)

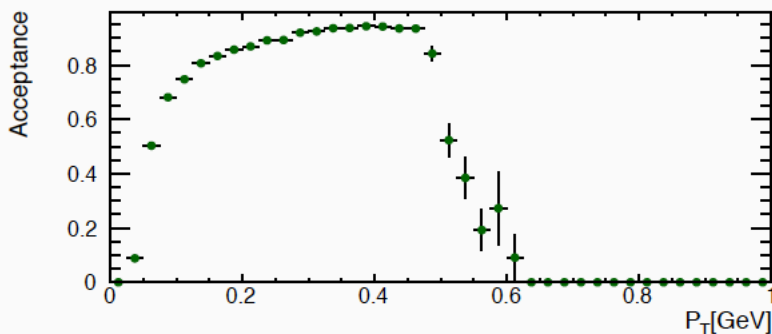
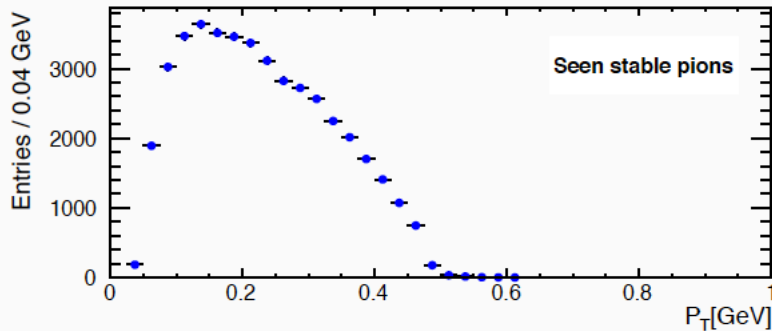
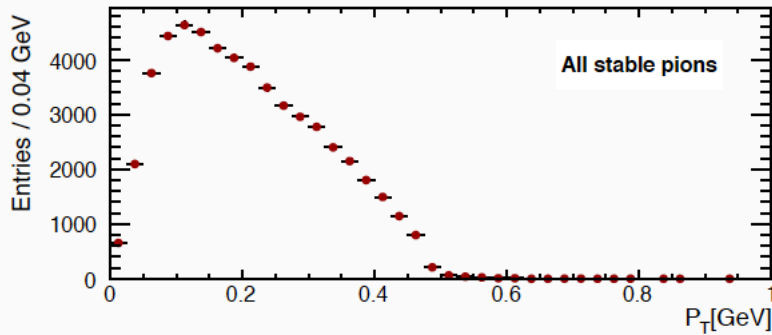
# Event Properties of Pythia



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

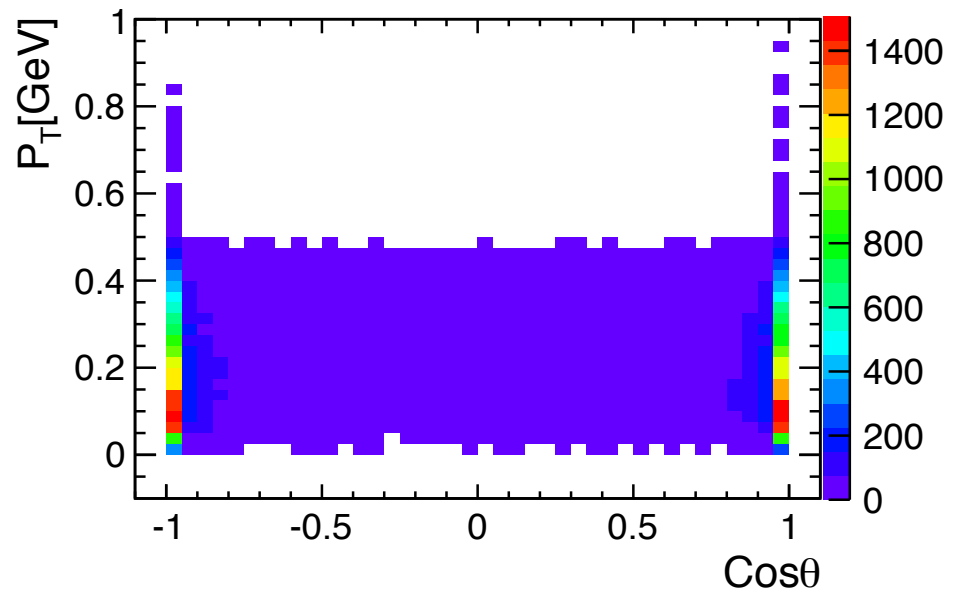


# Momentum acceptance for Pions



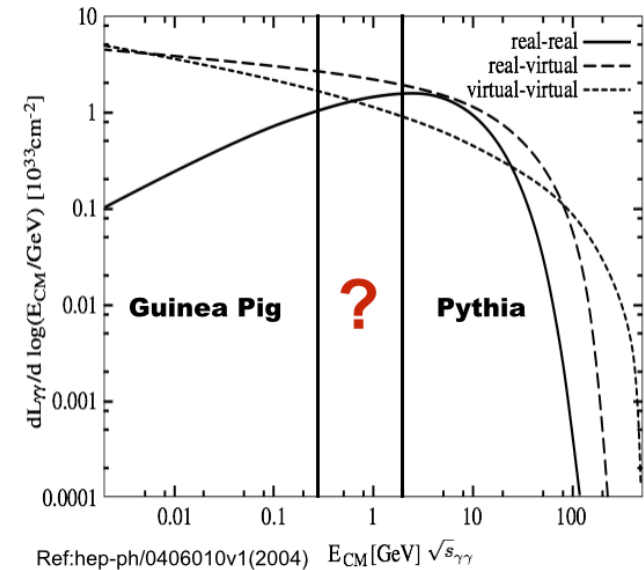
## > Momentum acceptance:

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

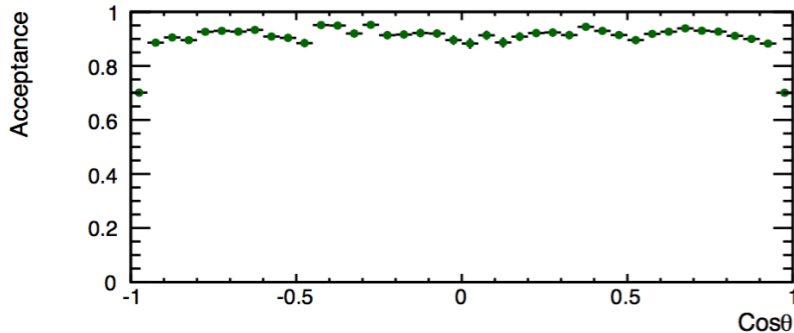
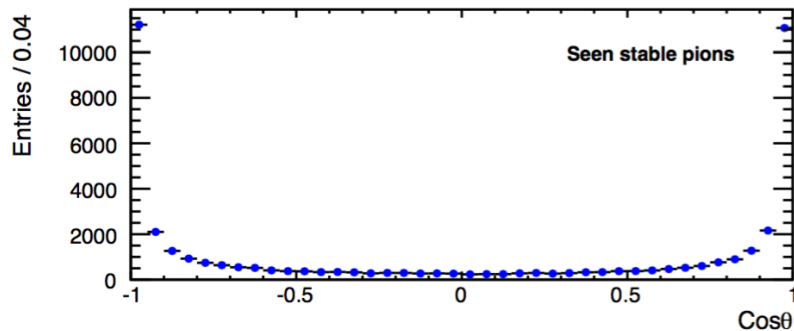
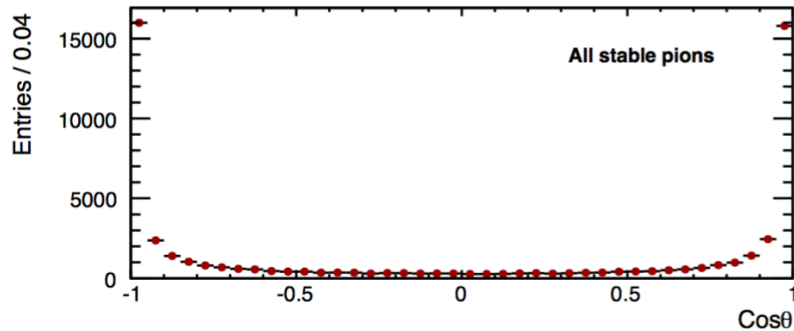


# A dedicated event generator for $\gamma\gamma$ processes

- 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?

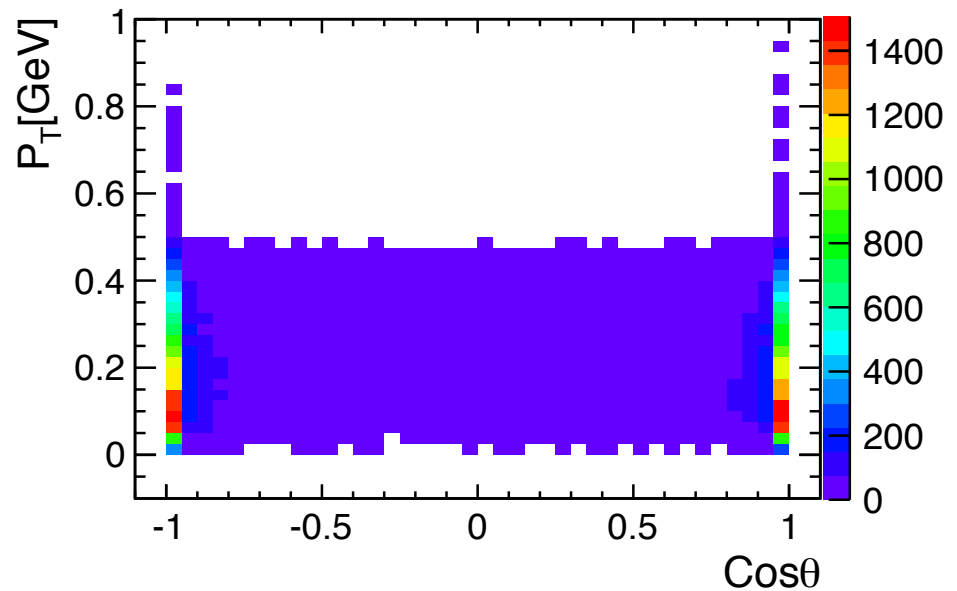


# Angular acceptance for Pions



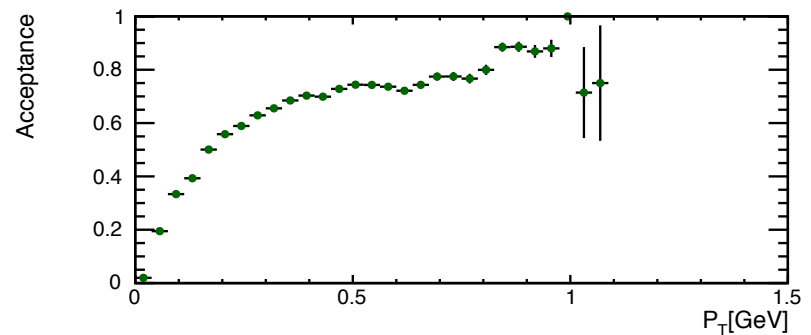
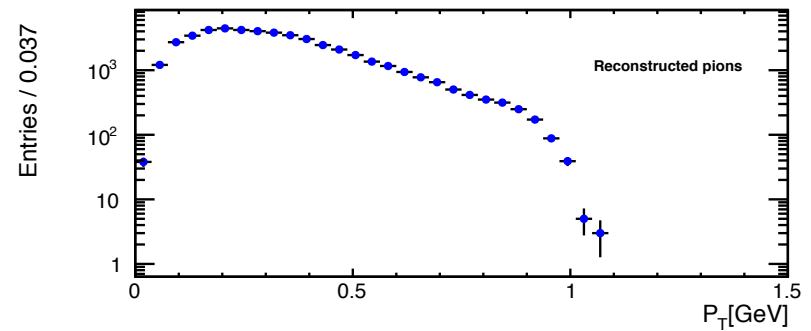
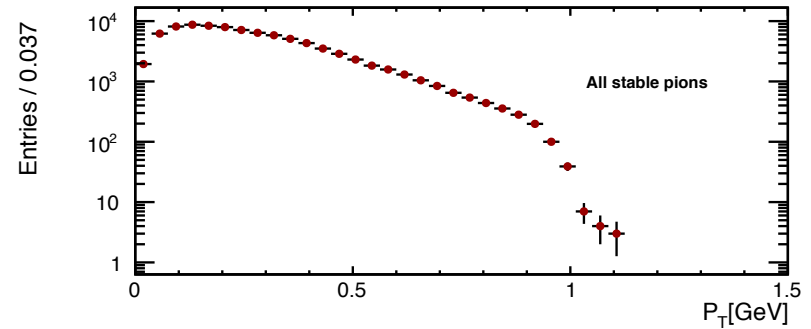
## ➤ Angular acceptance:

- 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  $\rho^\pm$  are greater than  $\rho^\pm$
- A better version of the generator was thus developed correcting the issues in older version- big progress!!!

