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

## International Linear Collider Workshop 2018

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Particles, Strings, and the Early Universe
The Structure of Matter and Space-Time
Deutsche Forschungsgemeinschaft DFG

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES
PIER Partnership of Universität Hamburg and DESY
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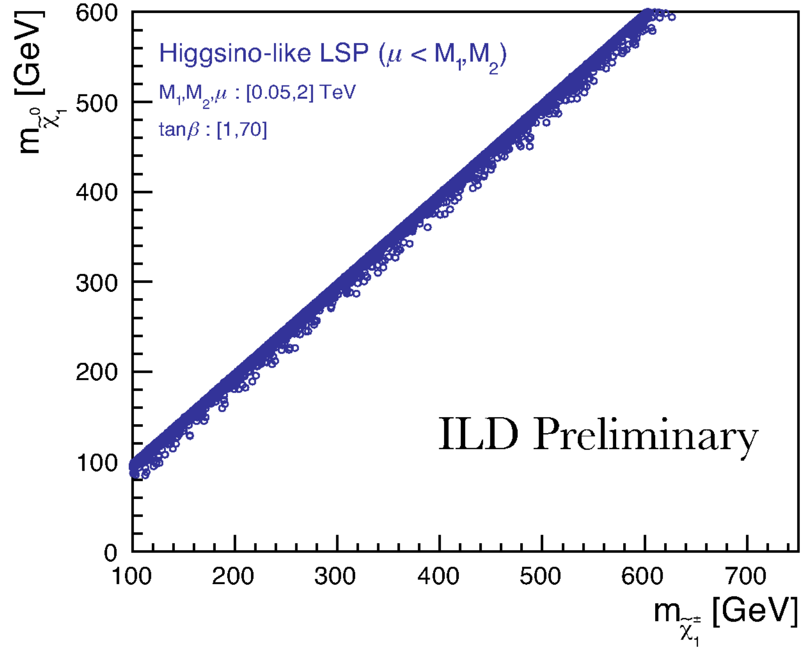
# Introduction

- 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 $\mu$ =100-300 GeV - (accessible for ILC500) [arXiv: 1212.2655, arXiv:1404.7510]
- Light higgsinos - $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^{\pm}$ nearly mass degenerate




Ref: Tomohiko Tanabe

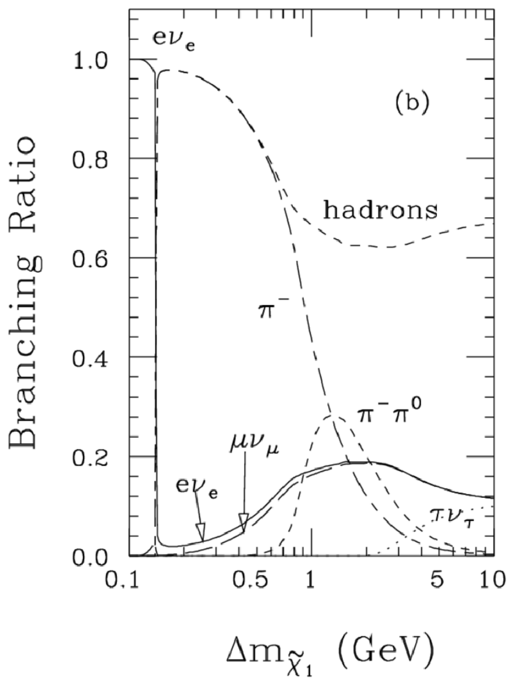
# Benchmark Scenario

- 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

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

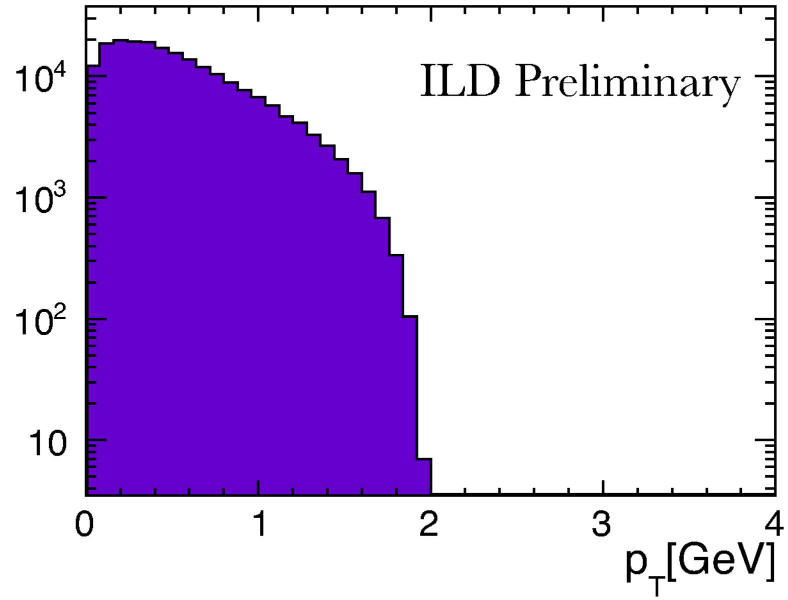
$$\Delta M(\tilde{X}_1^{\pm}, \tilde{X}_1^0) = 1.6 \text{ GeV} \Rightarrow \text{dM1600}$$

- Charginos decay hadronically and leptonically
- Studied without the inclusion of $\gamma\gamma \to$ low pt overlay



# Motivation

- $\gamma\gamma \rightarrow$ low pt 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 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

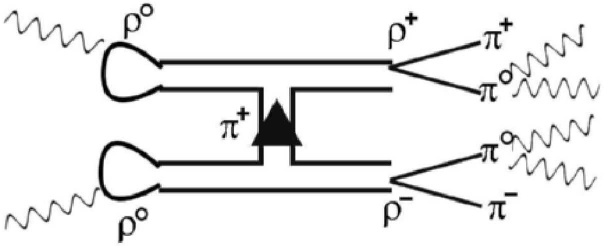
# Possible methods to remove $\gamma\gamma \rightarrow$ low pT hadrons

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

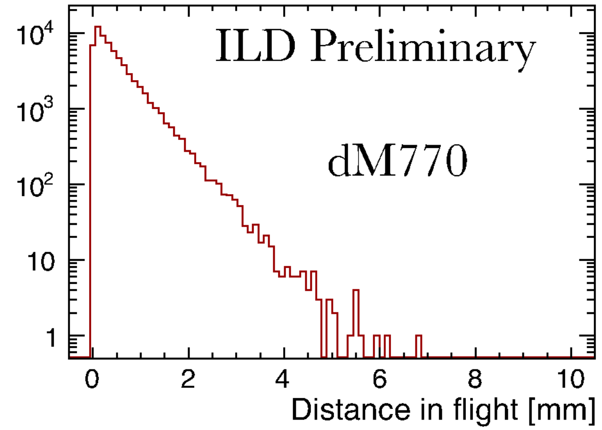
## Second method:

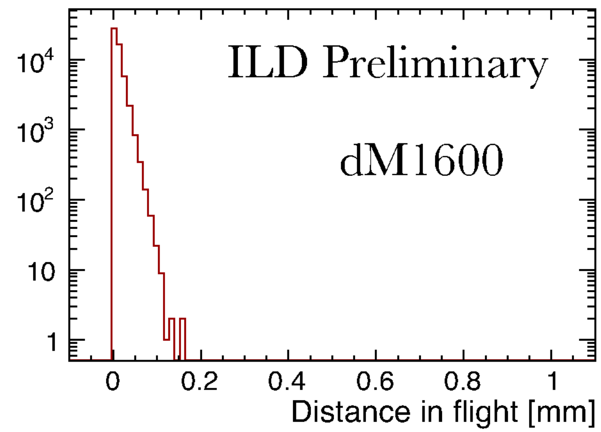
- The invariant mass of decay products of rho meson gives rho mass
- Rho meson used as a tag to remove $\gamma\gamma$ events
- Could be applied on very small event number



# Reconstruction level and the track parameters

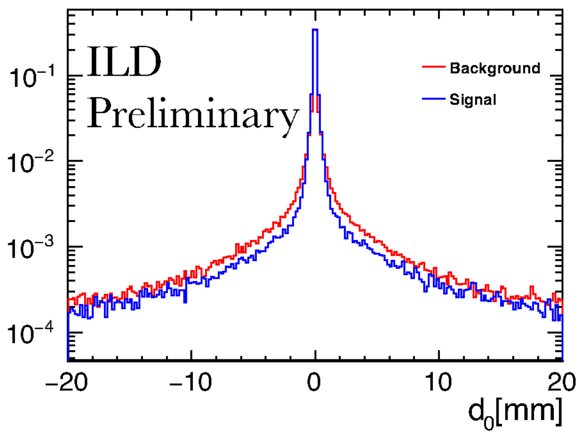
- Standard vertex finding algorithm reconstructs one single primary vertex for each event
- More complex algorithm to group the tracks to find different vertices
- Grouping based on difference in z0 significance
- Unlike the particles in $\gamma\gamma \rightarrow$ low pt hadron events, charginos have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

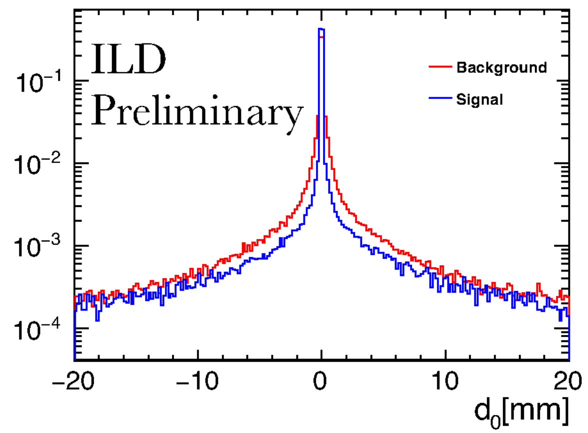


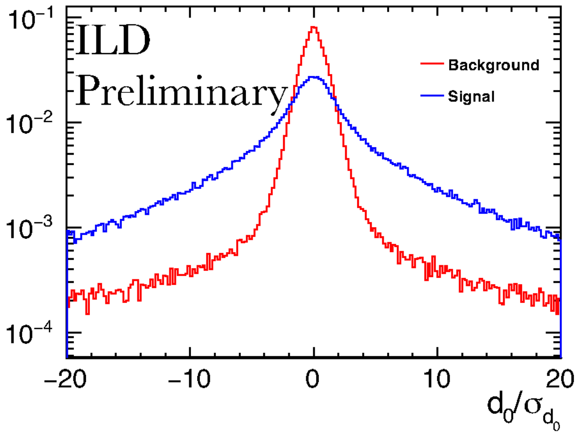



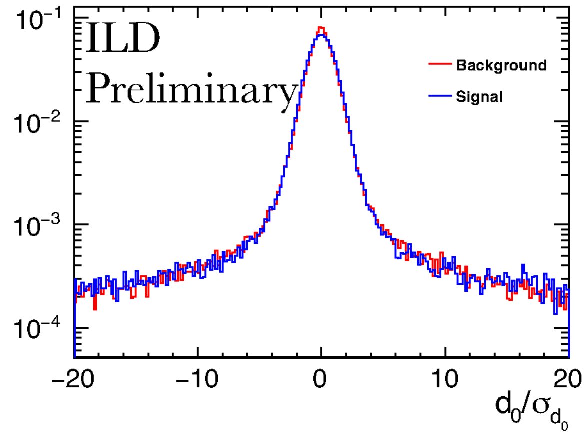
# Detailed study of $d_0$ parameter

dM 770 | dM 1600



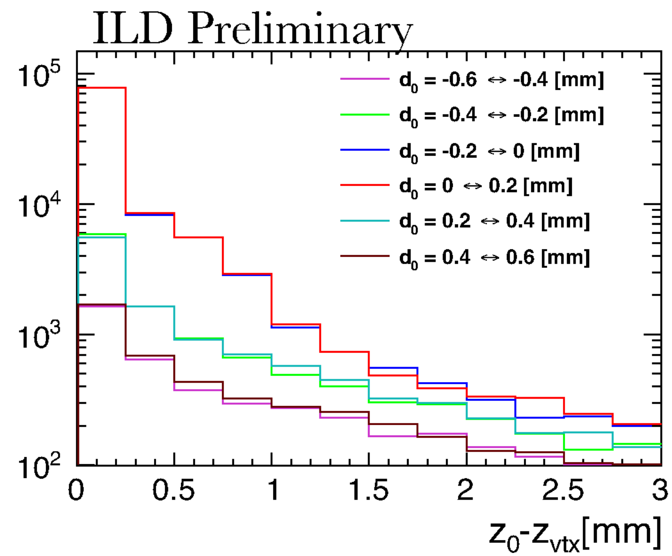



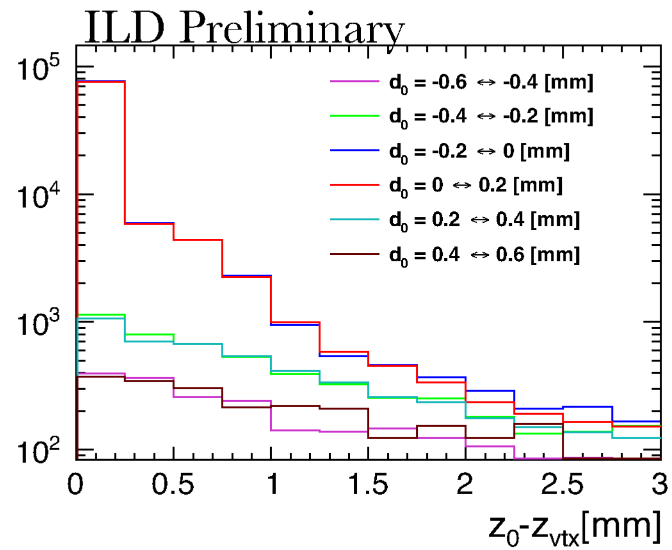

- With higher mass difference smaller $d_0$
- In dM1600 $d_0$ not a handle

# $d_0$ 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**

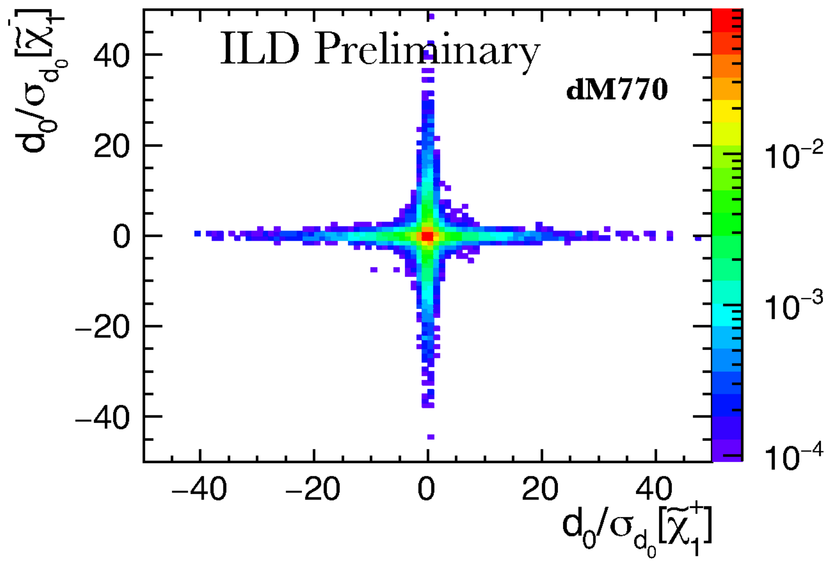


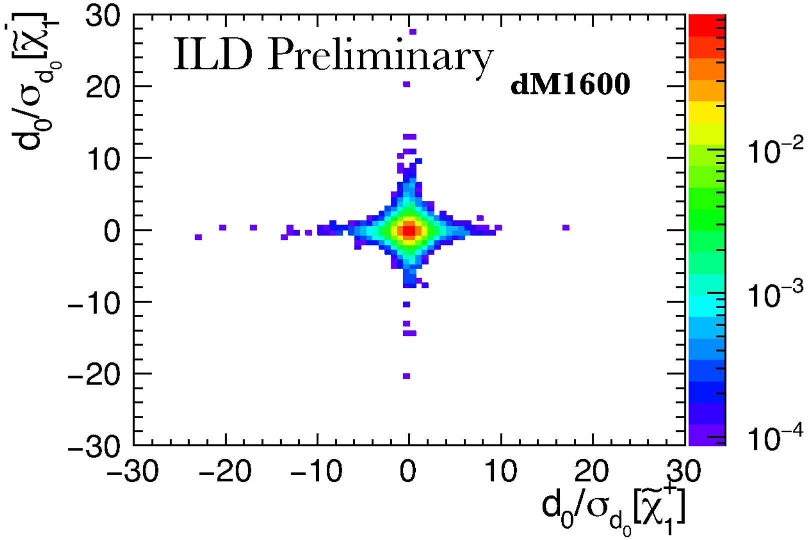

**dM1600**

# 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

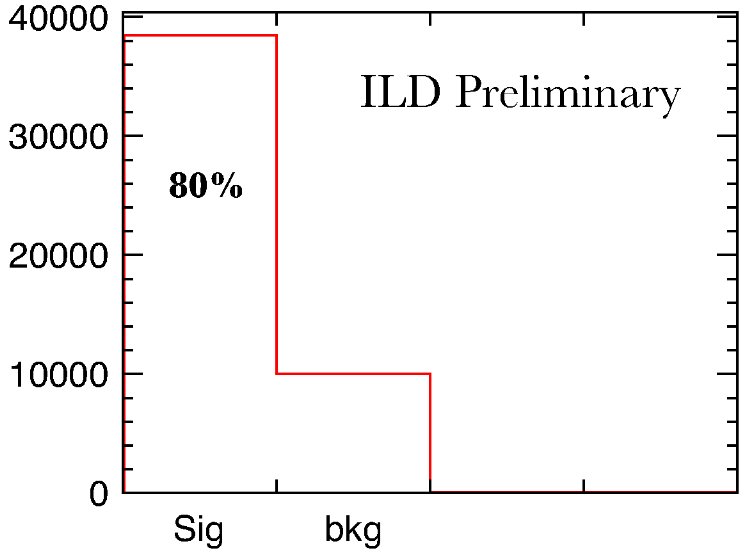
| $\tilde{\chi}_1^+$ decay mode | BR(dM770) |
|---|---|
| $e\nu\tilde{\chi}_1^0$ | 15.0% |
| $\mu\nu\tilde{\chi}_1^0$ | 13.7% |
| $\pi^+\tilde{\chi}_1^0$ | 60.4% |
| $\pi^+\pi^0\tilde{\chi}_1^0$ | 7.3% |
| $\pi^+\pi^0\pi^0\tilde{\chi}_1^0$ | 0.03% |



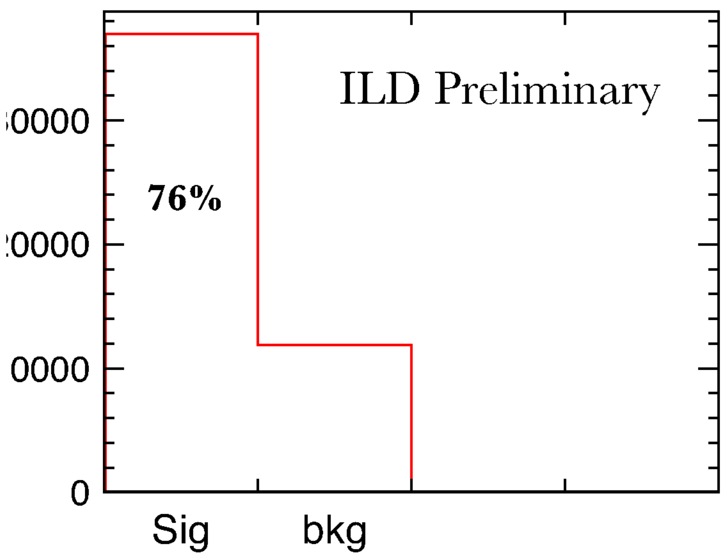



# Separated highest $d_0$ track

- without pair bkg




- with pair bkg



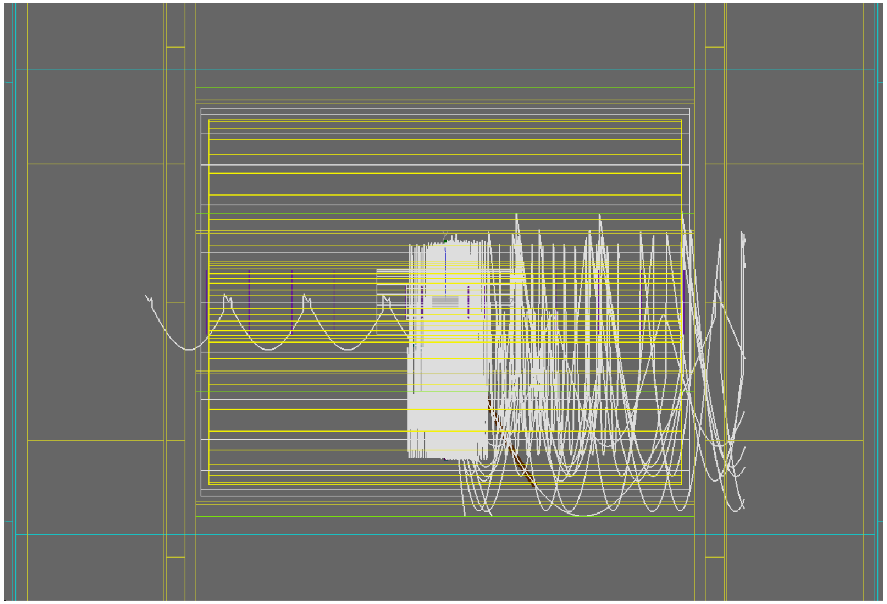

- The track with highest d0 significance value in dM770
- 76% - (including pair bkg)
- 80% - (without pair bkg)

# Pre-cuts to the algorithm

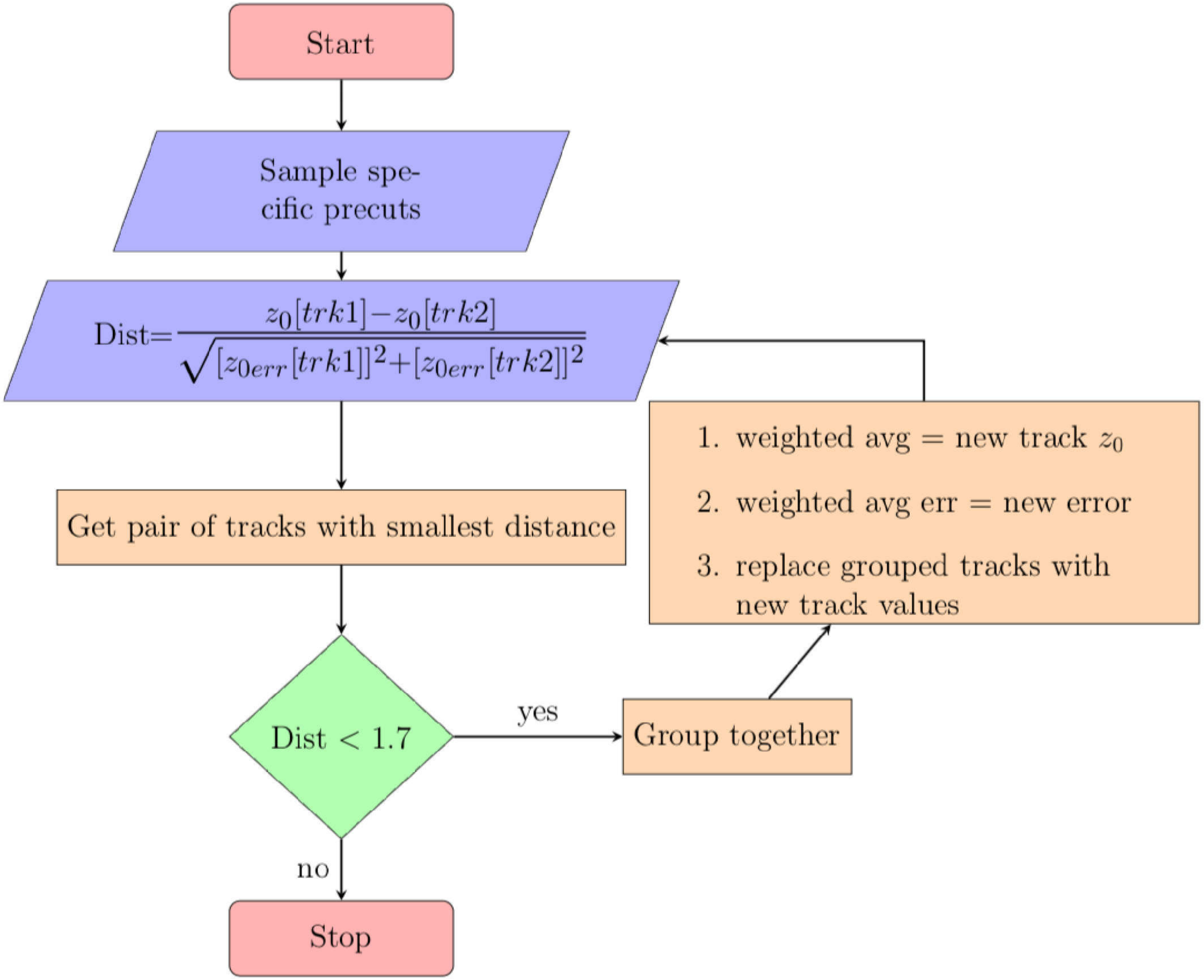
| **> dM 770 :** | **> dM 1600 :** |
|---|---|
| • track with highest $d_0$ removed<br>• d0 < 0.3 mm<br>• z0 < 15 mm | • d0 < 0.2 mm<br>• z0 < 15 mm |

> No of tracks < 13
  - Curling of low $p_T$ tracks

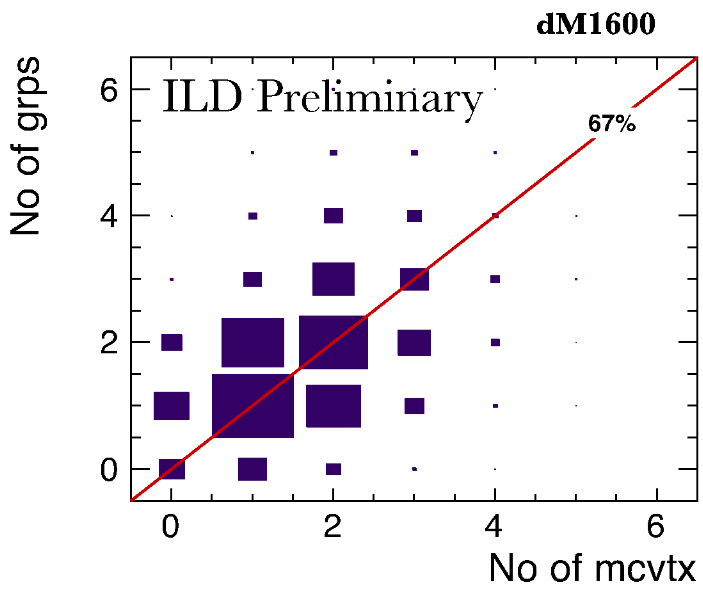
> Events with minimum 2 signal tracks reconstructed

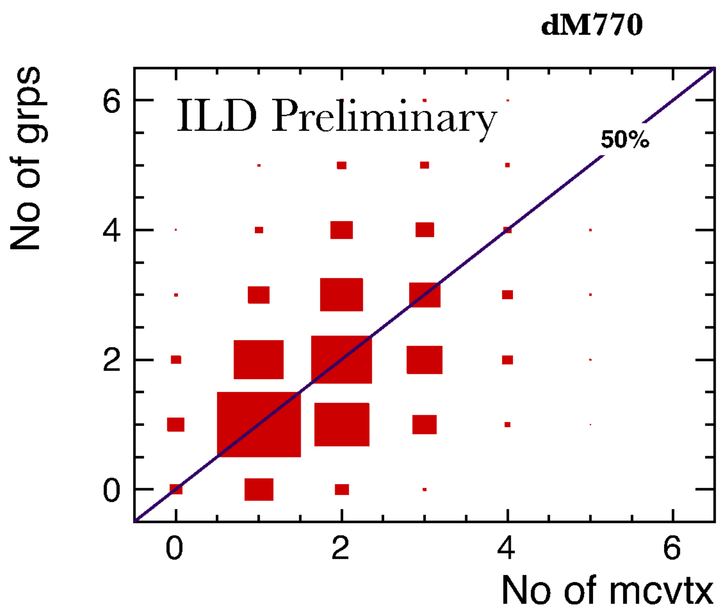


# Algorithm - flowchart



# Results from the algorithm

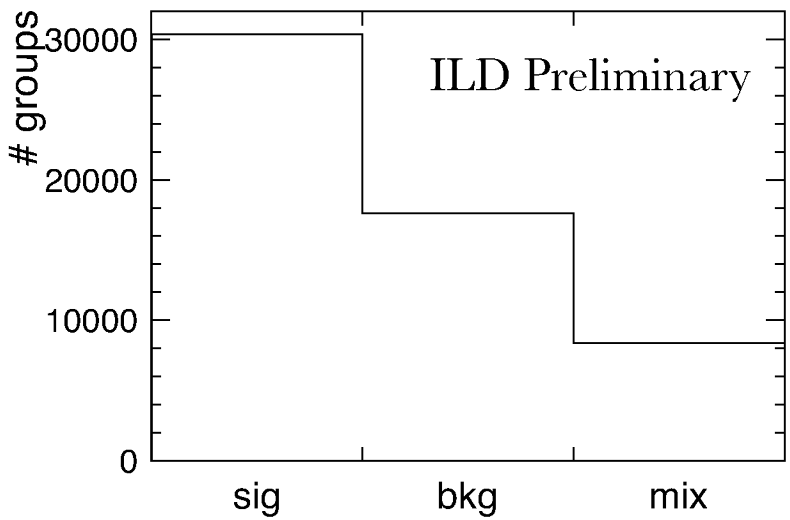


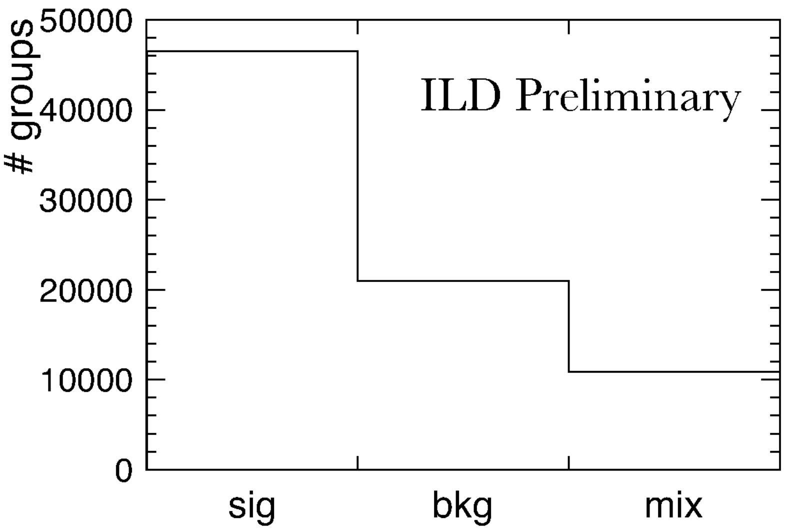

- No. of groups created with algorithm compared with no of Mcvtx
- MC vertices very close and within the detector impact parameter resolution are combined together

# Algorithm Performance (without pair bkg)

- dM770




- dM1600

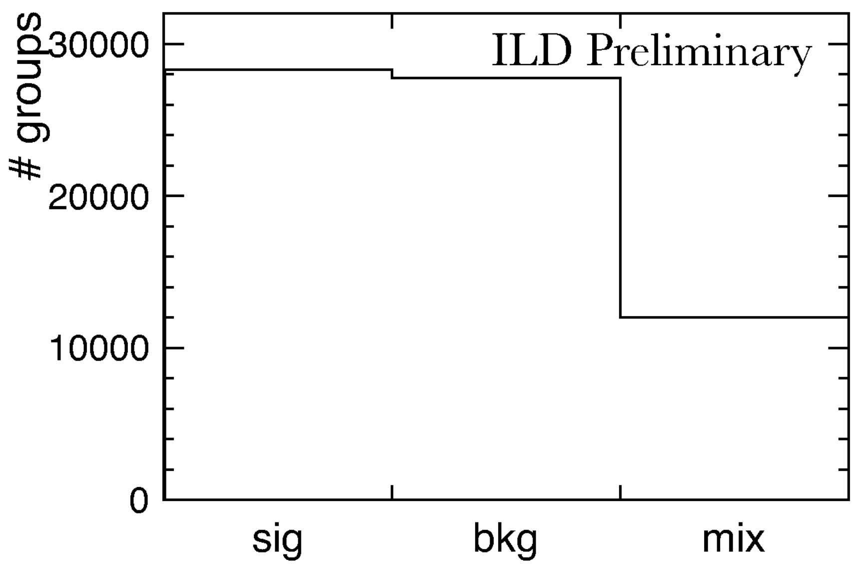



> Signal and background nicely separated

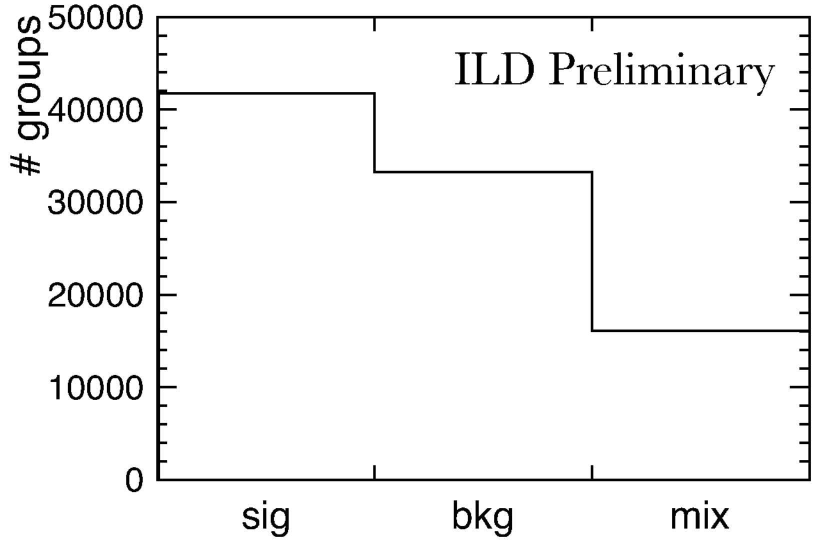
> No. of groups having signal and background mix is meagre

# 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.

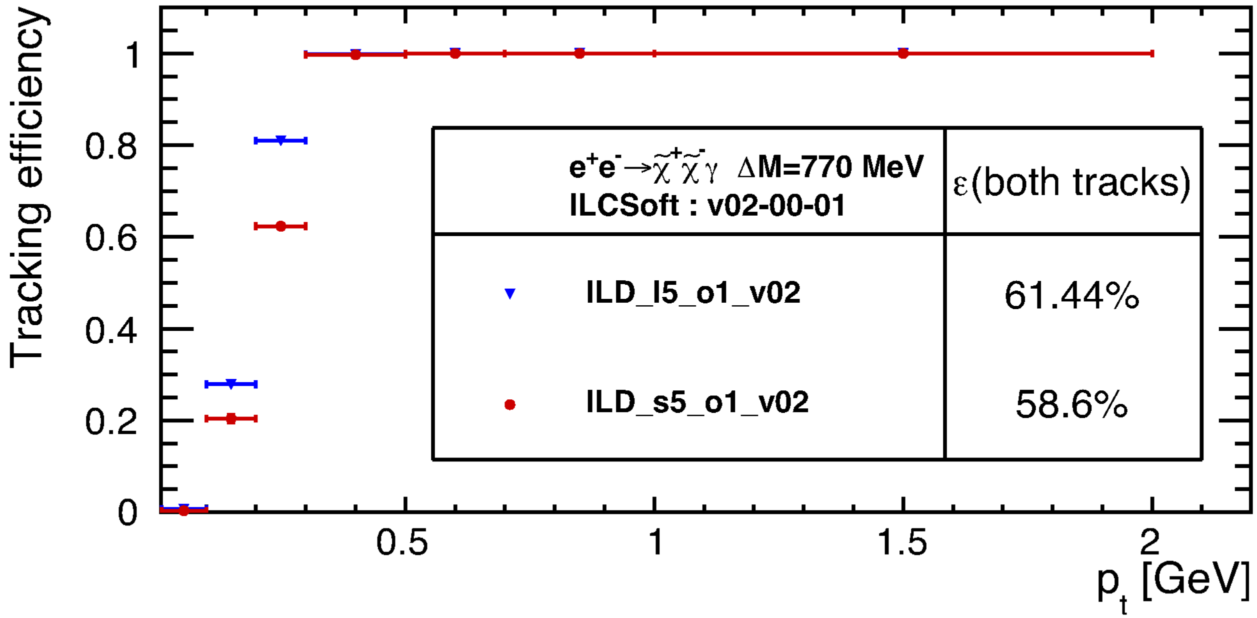
# Questions??

# Average position and error

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

- 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

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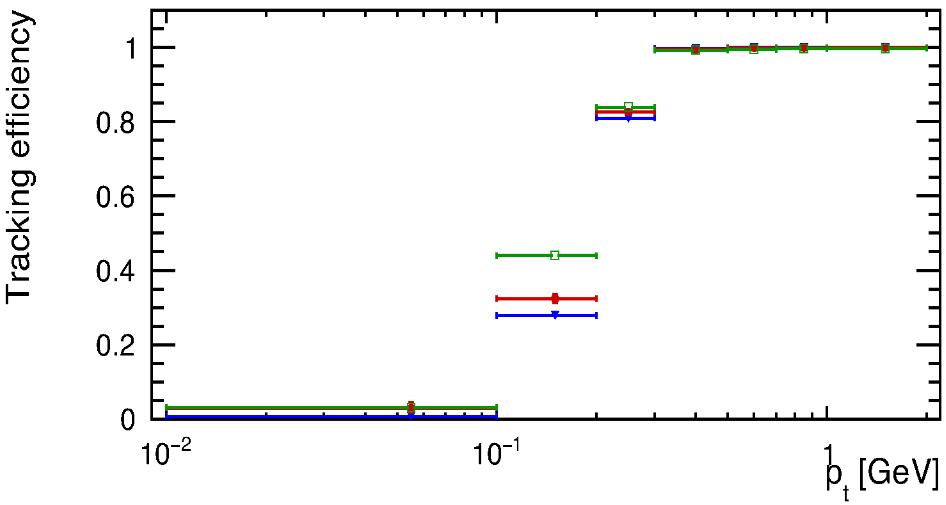
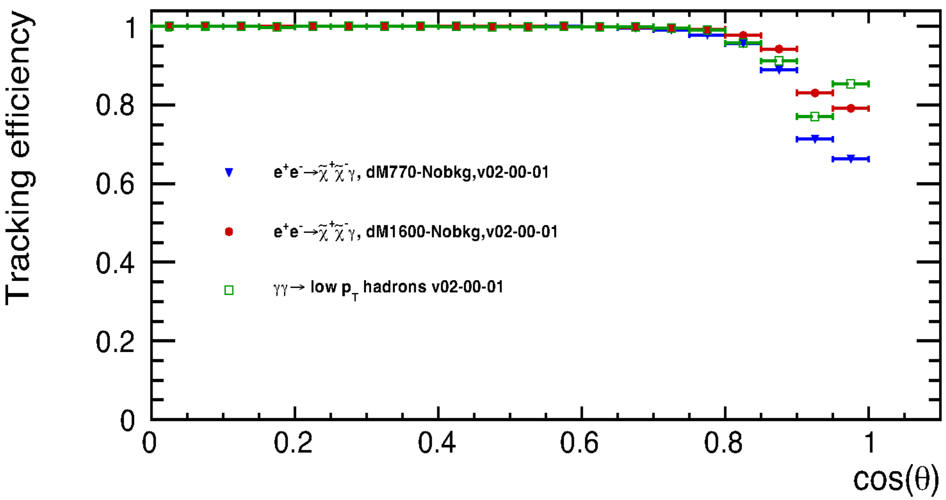
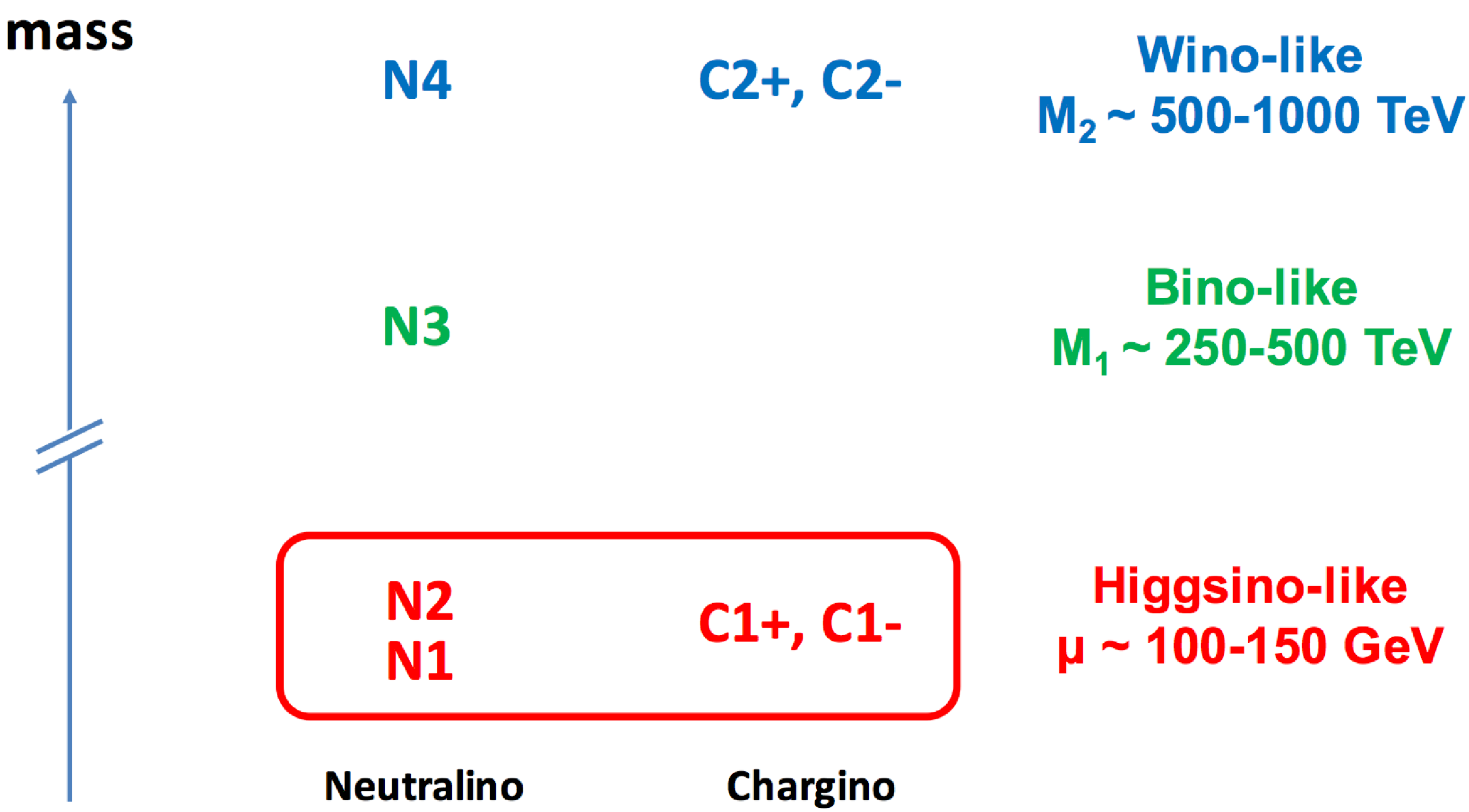
# Reconstruction efficiency for $\gamma\gamma \to$ low pt hadron tracks

- ILDPerformance -Diagnostics package used for tracking efficiency
- Silicon Tracking algorithm used to reconstruct tracks
- Reconstruction efficiency of $\gamma\gamma \to$ 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 $\gamma\gamma \to$ low pt hadron events



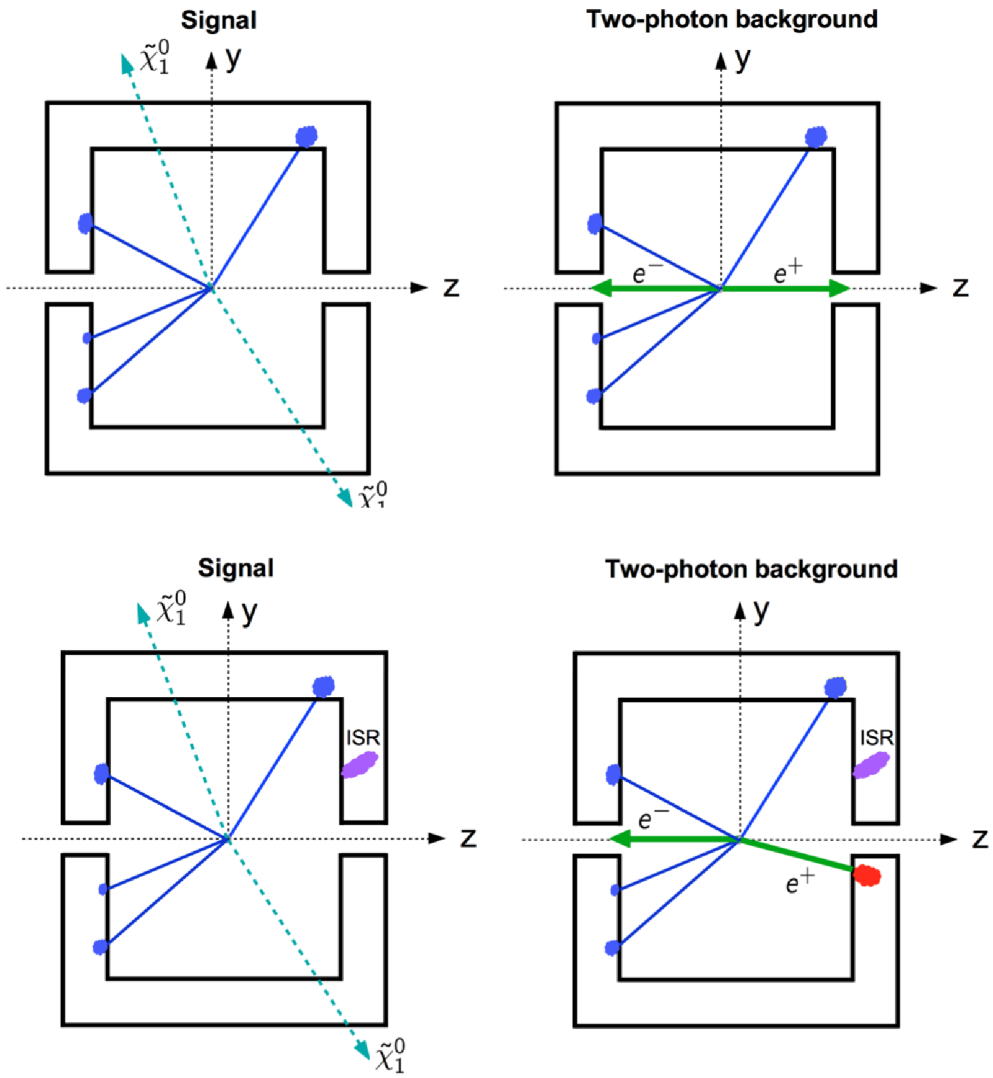






**ref. Tomohiko Tanabe**

# 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

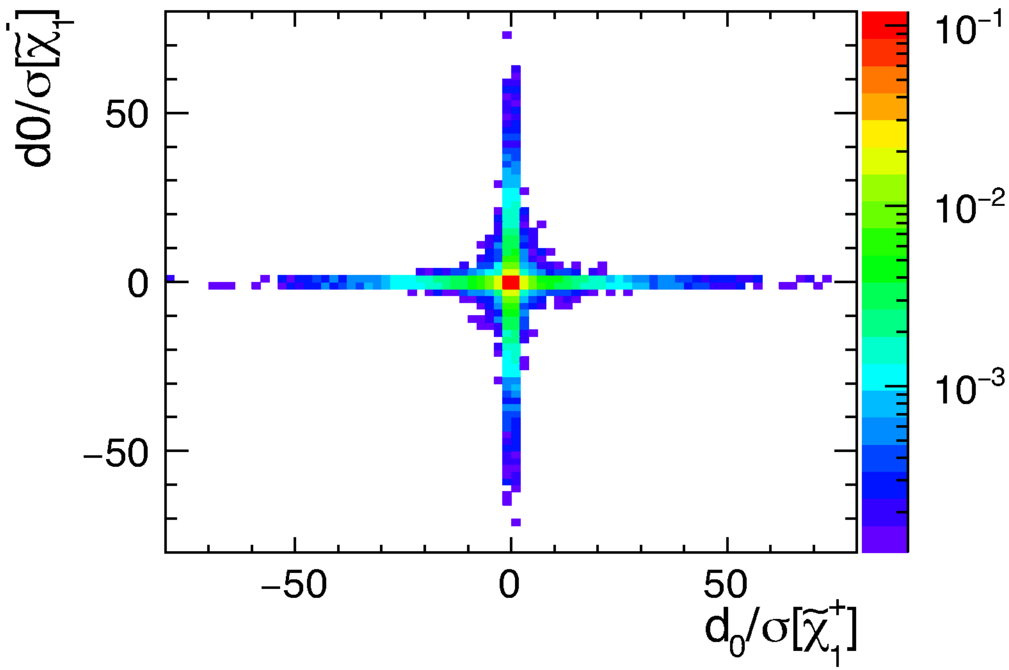


# Summary and Outlook

- 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



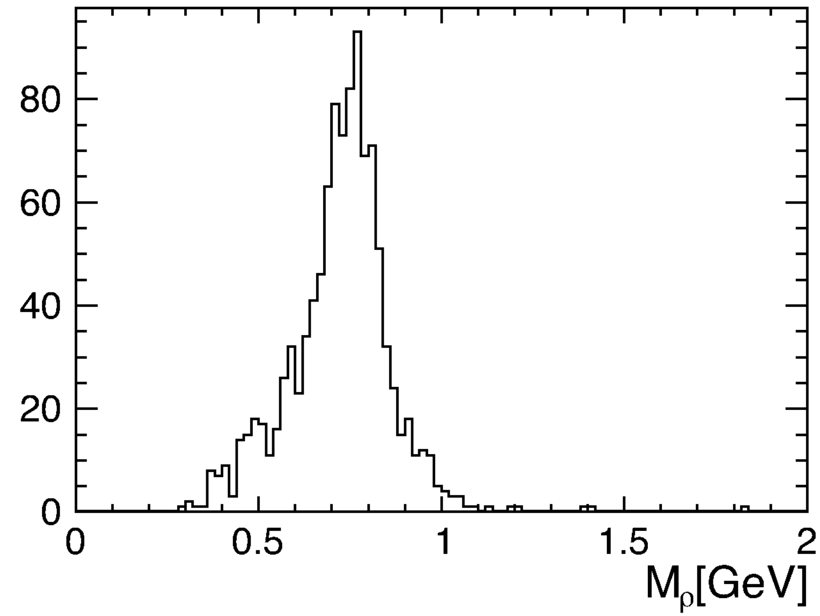
# Method Development to remove backgrounds

- 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 |
|---|---|---|
| $\gamma\gamma \rightarrow \pi^+\pi^-$ | 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 - $770 \pm 145$ MeV
  - Only 0.54% events reconstructed exactly as 2 $^{+ve}$ and 2 $^{-ve}$ tracks



# Event Properties of Pythia

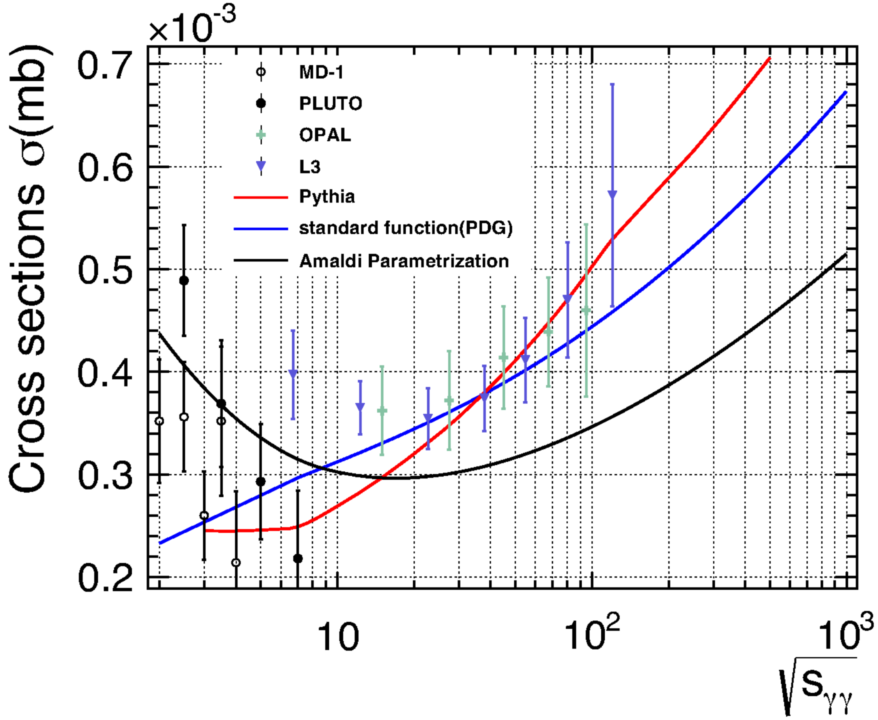
- Direct Interactions(DIR) - Real photons interacts directly
- Vector Meson Dominance(VMD) - Photon fluctuates into a vector meson
- Anomalous Interactions(GVMD) - Photon fluctuates into a $q\bar{q}$ pair of larger virtuality
- Deep inelastic Scattering(DIS) - A process of probing the Hadrons with very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

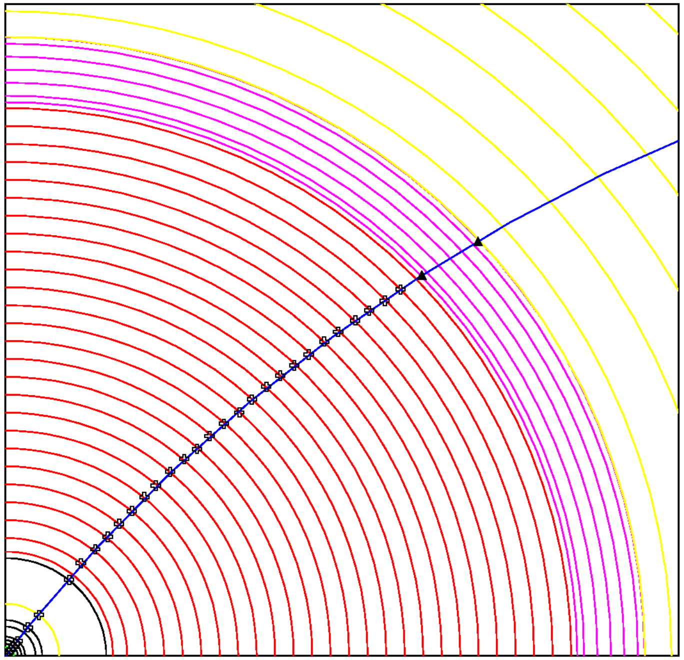
# Cross sections for Pythia events

- Comparison of $\gamma\gamma \to$ 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



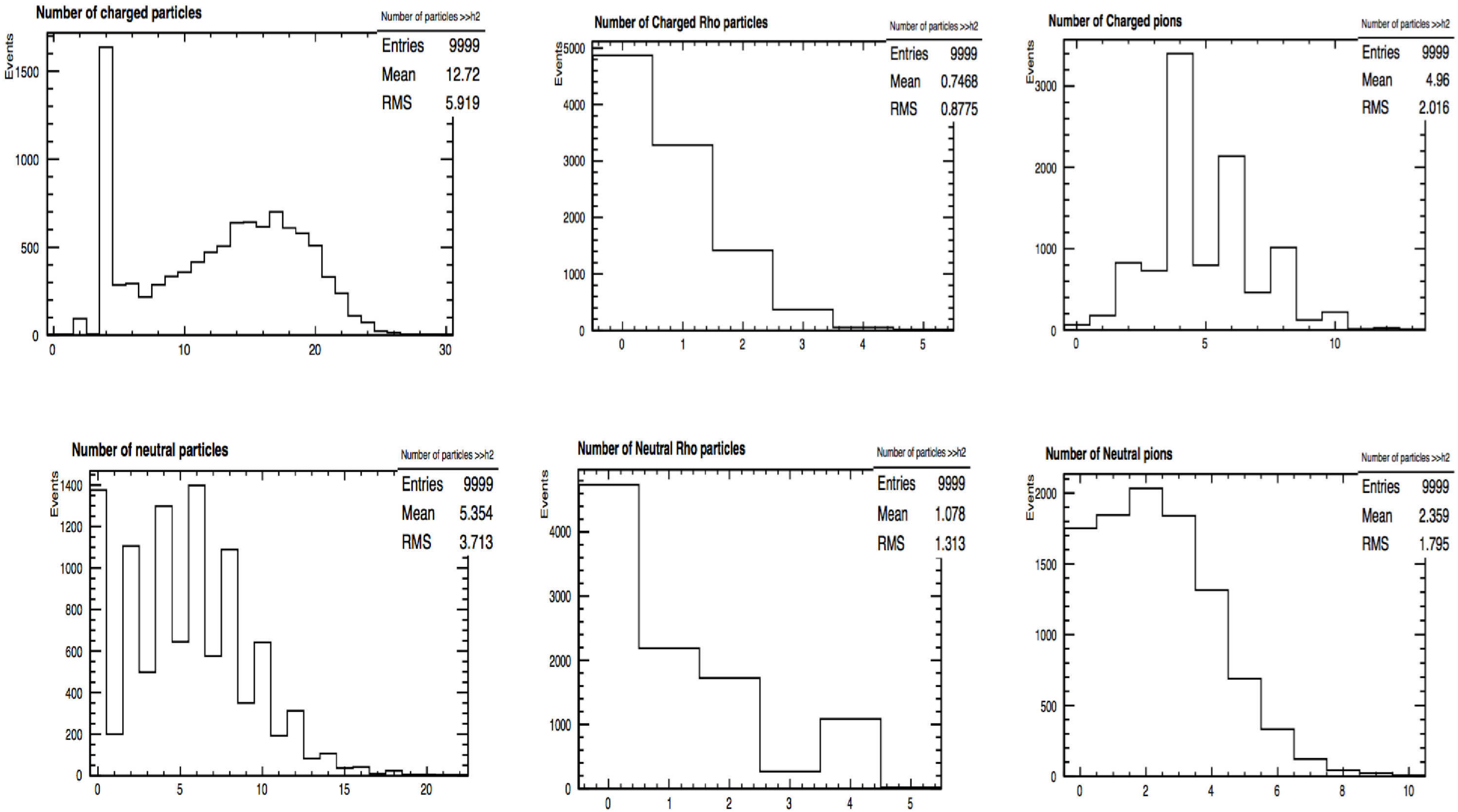
# Does $\sqrt{s_{\gamma\gamma}}$ < 1 GeV matter?

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



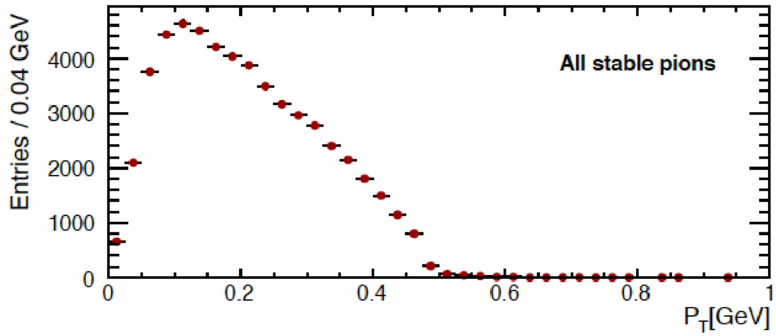
Ref: archiv:1203.0217v1

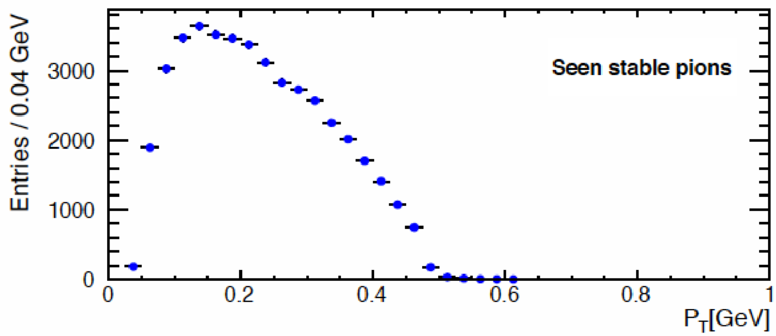
# Event Properties of Pythia

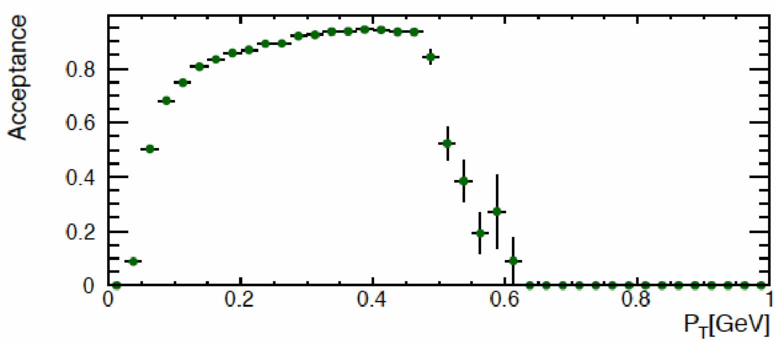



Pythia could be used to simulate events down upto $\sqrt{s_{\gamma\gamma}} = 2$ GeV

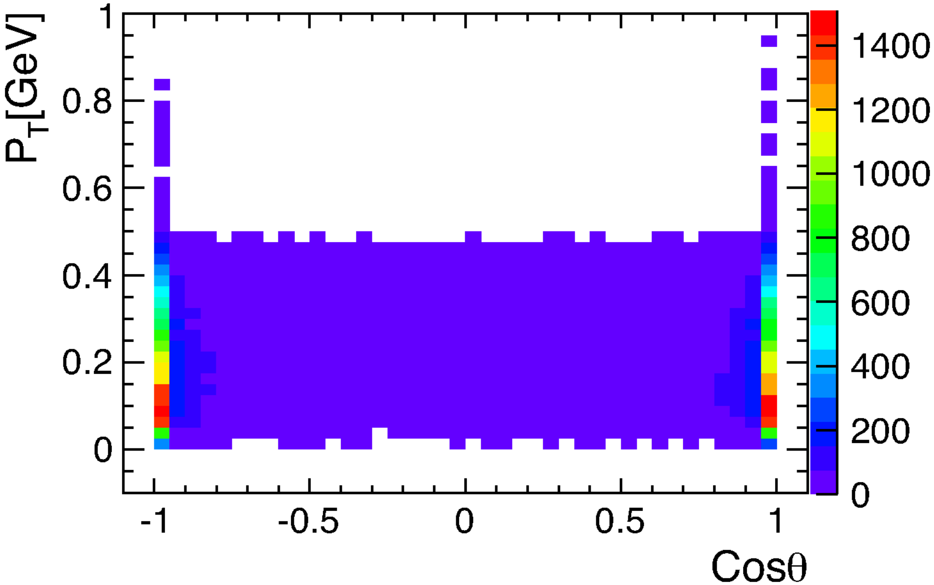
# Momentum acceptance for Pions



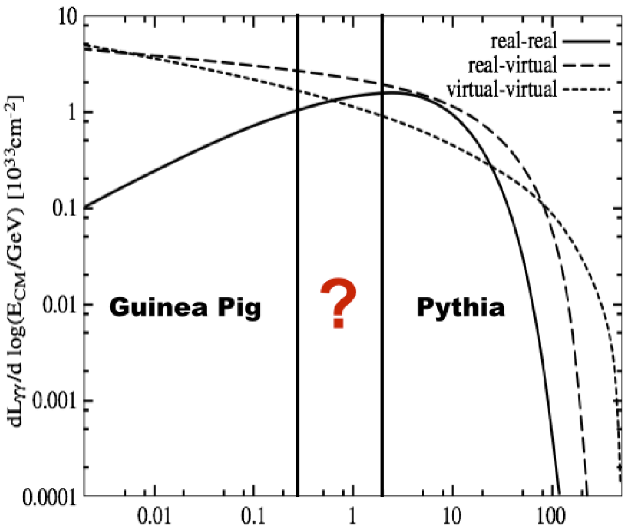




- Momentum acceptance:
  - Dividing seen stable pions with all true pions
  - The acceptance for most particles > 80%
  - Particles with high Pt but moving in forward direction - low acceptance



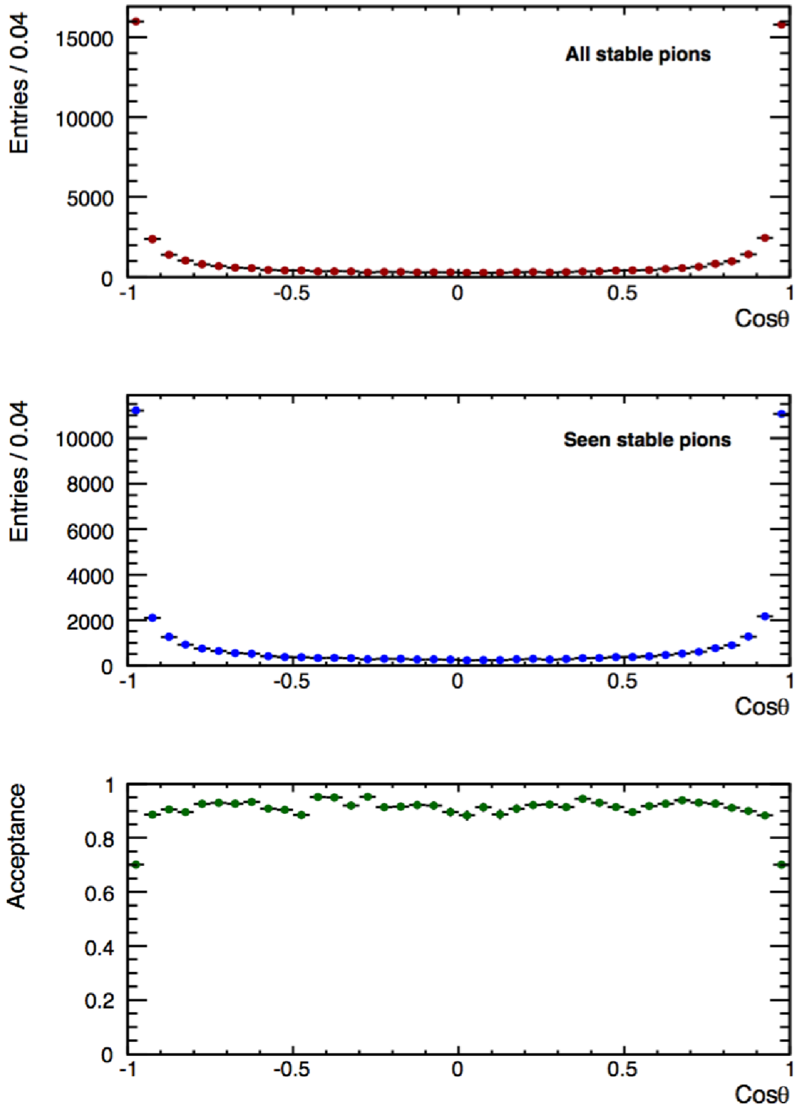
# A dedicated event generator for $\gamma\gamma$ processes

- 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?




Ref:hep-ph/0406010v1(2004)

# Angular acceptance for Pions

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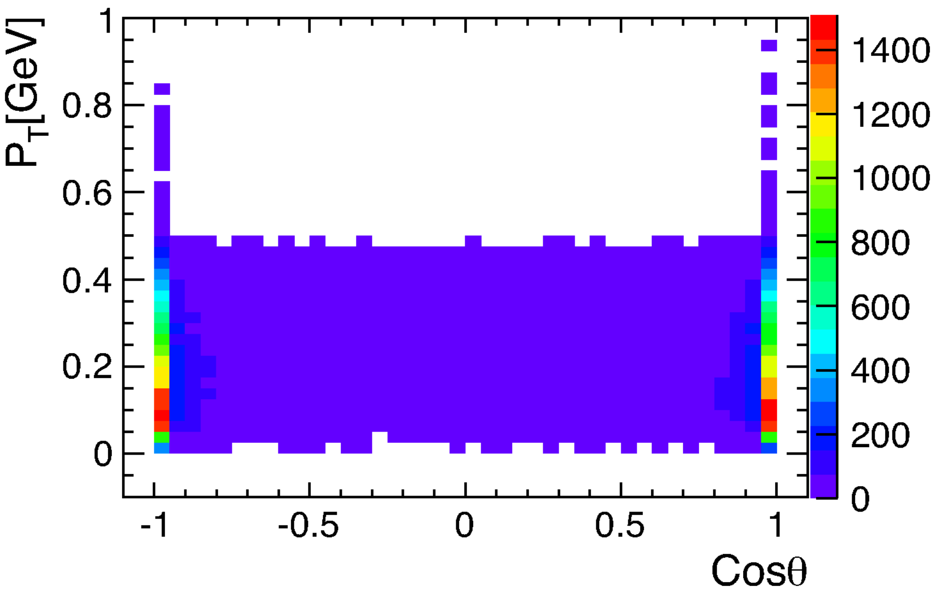
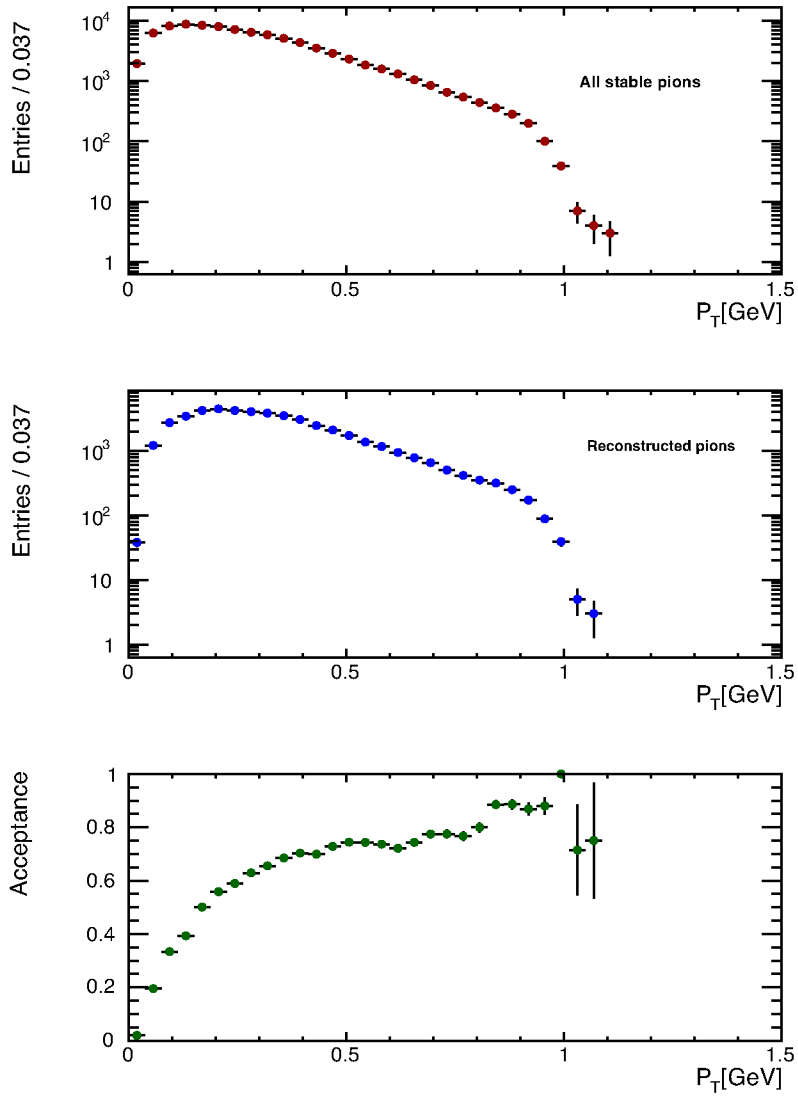


# Momentum acceptance of pions with full simulation

- 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 $\rho^0$ is greater than $\rho^{\pm}$
- A better version of the generator was thus developed correcting the issues in older version- big progress!!!