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

Linear Collider Forum 2017

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27^{th}-29^{th} Nov 2017

HELMHOLTZ | ASSOCIATION

Collaborative Research Centre 676
Particles, Strings, and the Early Universe
The Structure of Matter and Space-Time
Deutsche Forschungsgemeinschaft DFG

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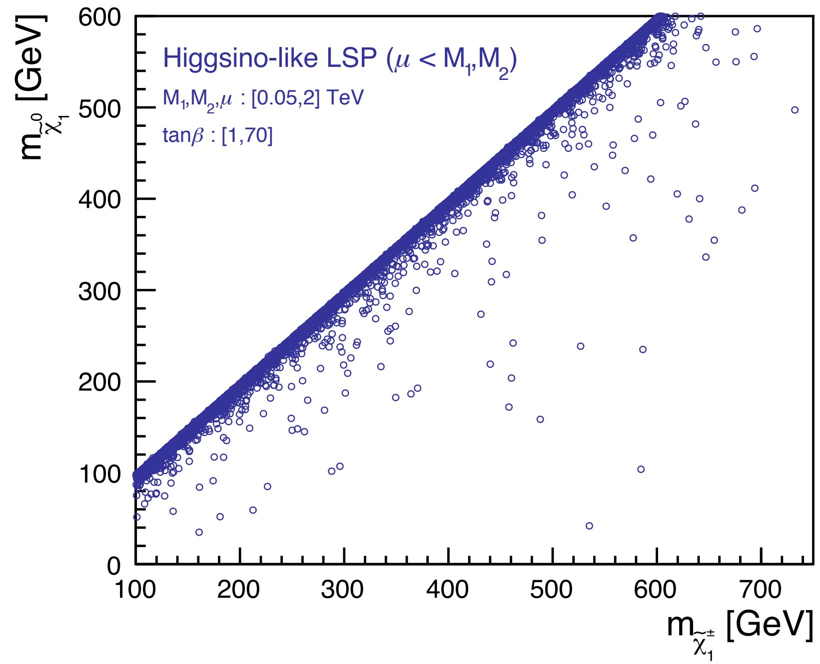
DESY

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) [arXiv: 1212.2655, arXiv:1404.7510]
- Light higgsinos - $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^{\pm}$ nearly mass degenerate
- Mass degeneracy depends on Bino (M_1) and Wino(M_2) mass parameters



Ref: Tomohiko Tanabe

Benchmark Scenarios

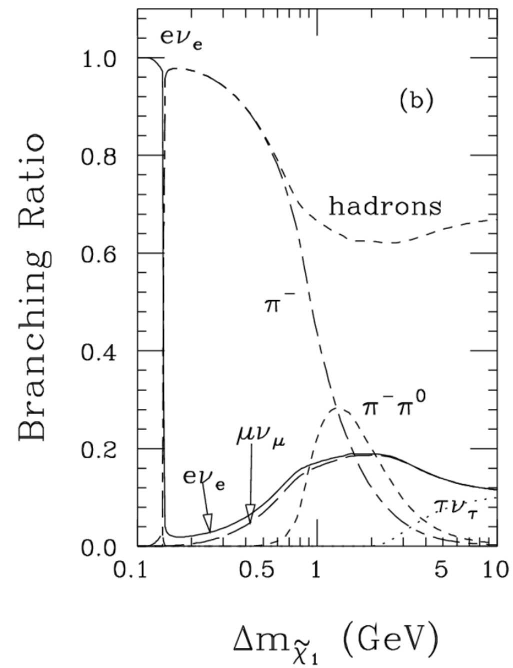
- Low ΔM higgsino analysis performed by Hale Sert - DESY-THESIS-2016-001
- The case was studied at two benchmark scenarios

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

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

- Charginos decay hadronically and leptonically
- Hale's study showed that such scenarios can be well observed at the ILC
- Case studied with Fast Simulation
- The study performed without the inclusion of $\gamma\gamma$ overlay

hep-ph/9512230 [hep-ph]



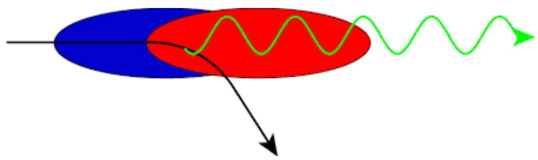
$\tilde{\chi}_1^+$ decay mode	BR(dM770)
$e\nu\tilde{\chi}_1^0$	15.0%
$\mu\nu\tilde{\chi}_1^0$	13.7%
$\pi^+\tilde{\chi}_1^0$	60.4%
$\pi^+\pi^0\tilde{\chi}_1^0$	7.3%
$\pi^+\pi^0\pi^0\tilde{\chi}_1^0$	0.03%

Photons in e^+e^- collider

> e^+e^- beams accompanied by photons:

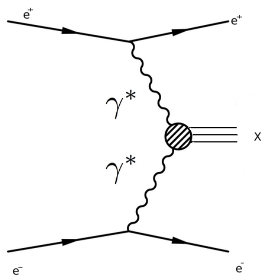
> **Real Photons:**

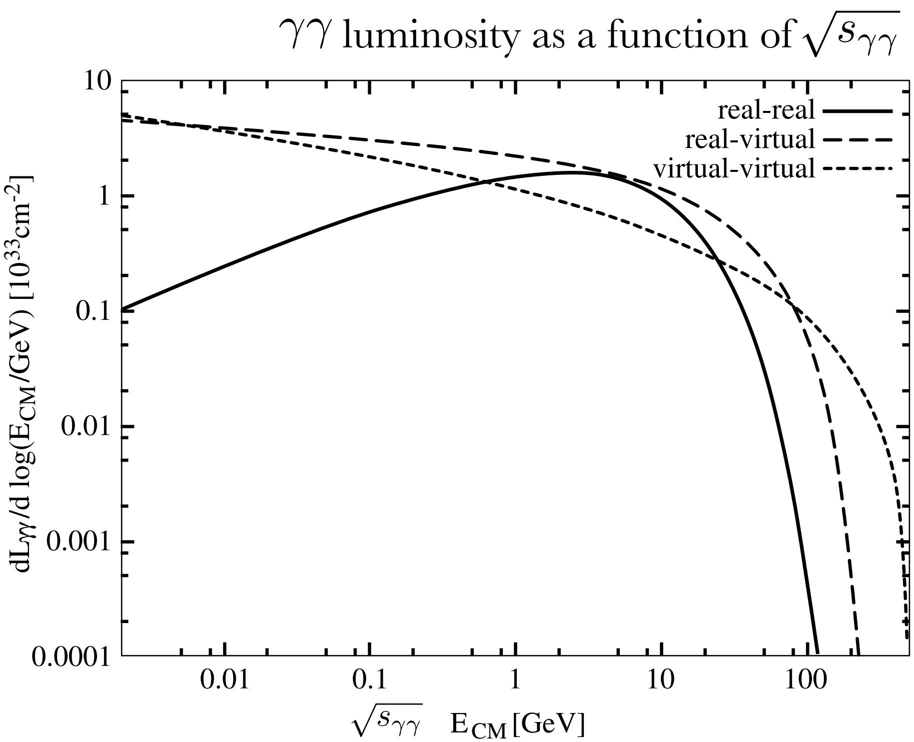
- Beamstrahlung - emission of real photons in high electrical field of oncoming bunch



> **Virtual Photons:**

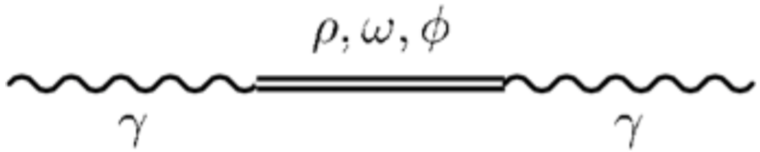
- Weiszaecker-Williams process - emission of virtual photons interacting with oncoming photon or electron

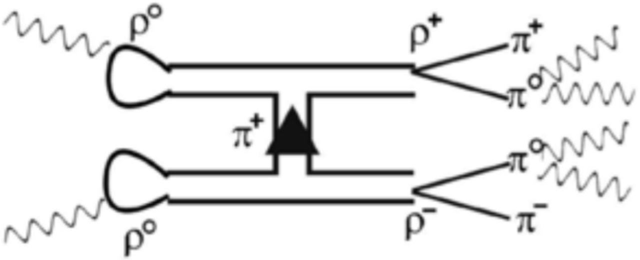




Photon-Photon Interactions

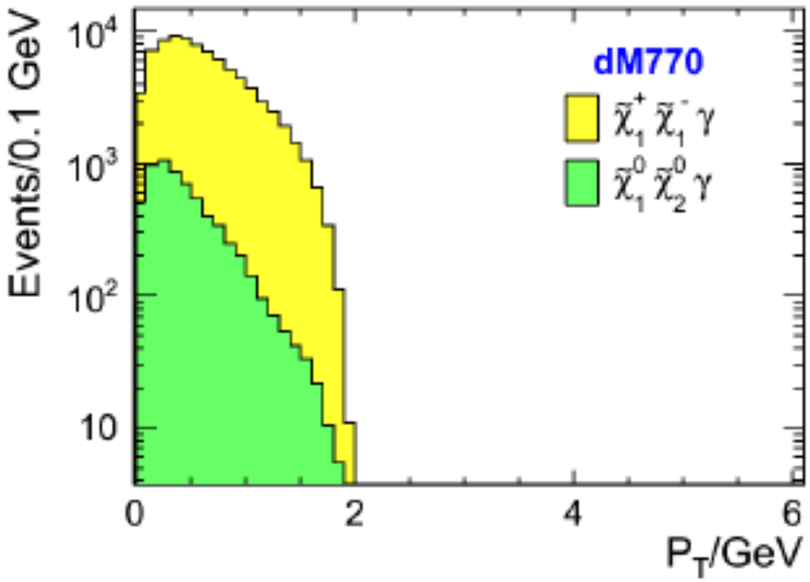
- Photons interact in different ways
- Vector meson dominance -Most dominating subprocess
- What are vector mesons? - $\rho, \omega, \phi, J/\psi, \Upsilon$
- Photon fluctuates into a vector meson since it has got the same quantum properties
- Photon is a hadron 1/400 of the time
- Highest probability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





Motivation

- 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 in full simulation scenario

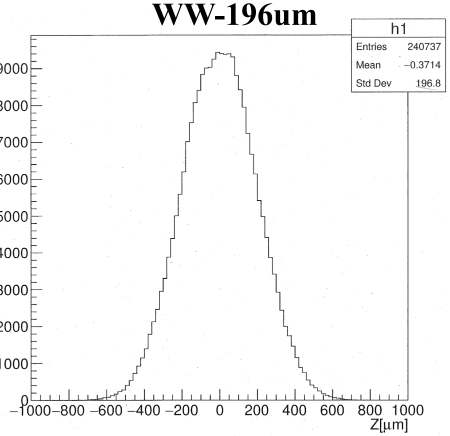


hep-ph/1307-3566(2013)

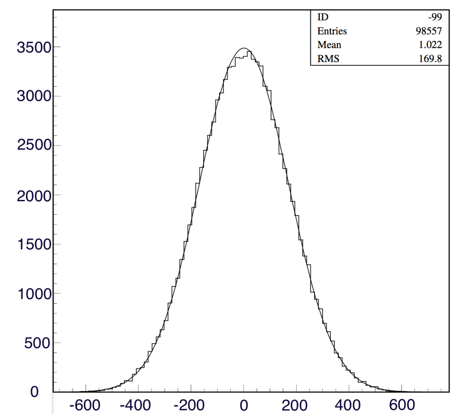
Simulation and Reconstruction

- 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
  - $\gamma\gamma$ events from improved Barklow generator and Pythia
- Simulated $e^{+}e^{-} \rightarrow \tilde{\chi}_1^{+}\tilde{\chi}_1^{-}\gamma$ samples with vertex smeared along z axis - benchmark scenario dM770 (196.8 μm)
- Four different samples of $\gamma\gamma \rightarrow$ low pt hadron events simulated with smeared vertices - Guinea Pig

WW-196um

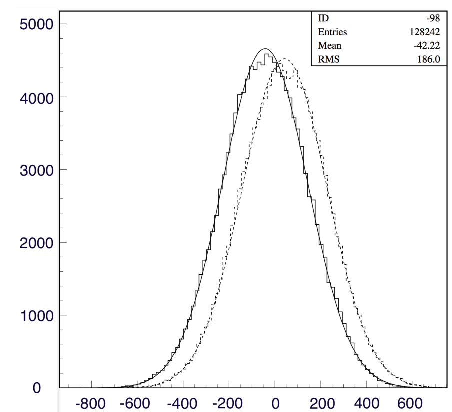


BB -169um



Z[um]

WB/BW -186um +/- 42um

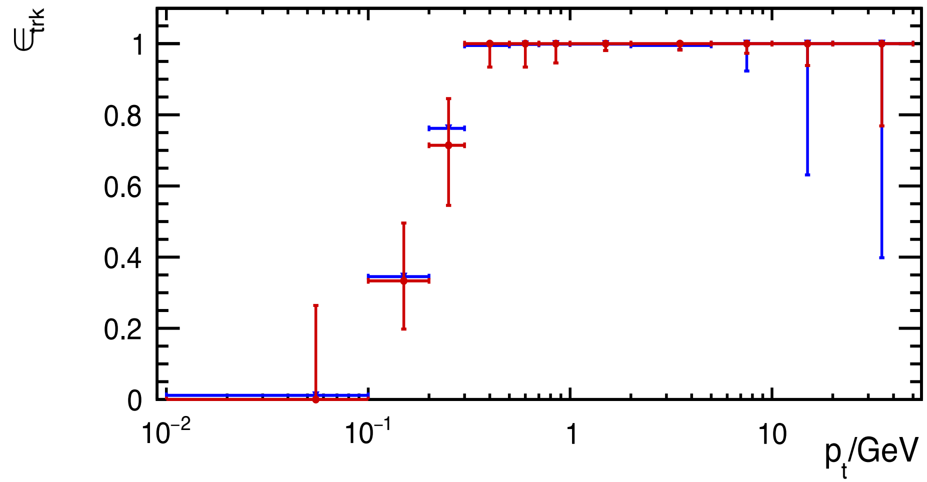


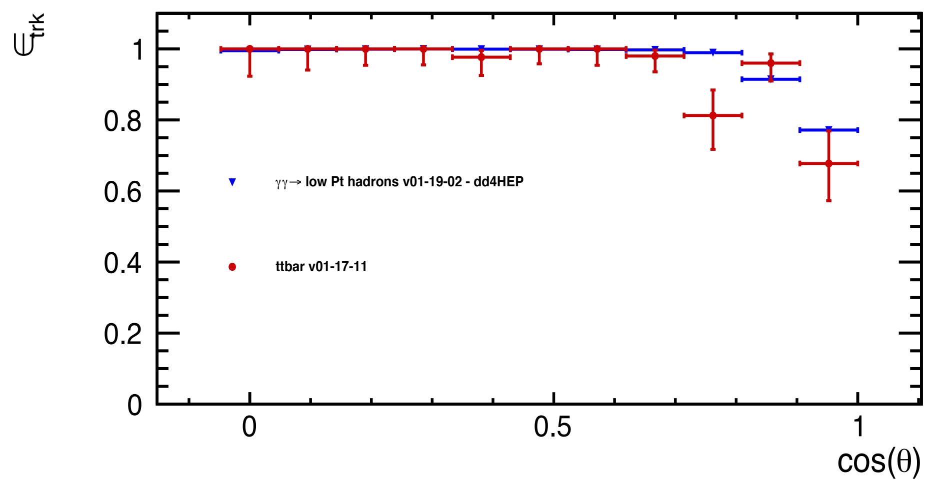
Z[um]

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

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





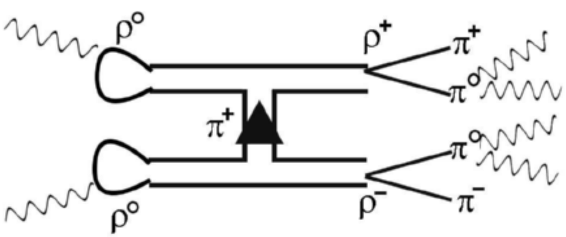
Possible methods to remove $\gamma\gamma \rightarrow$ low pT hadrons

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

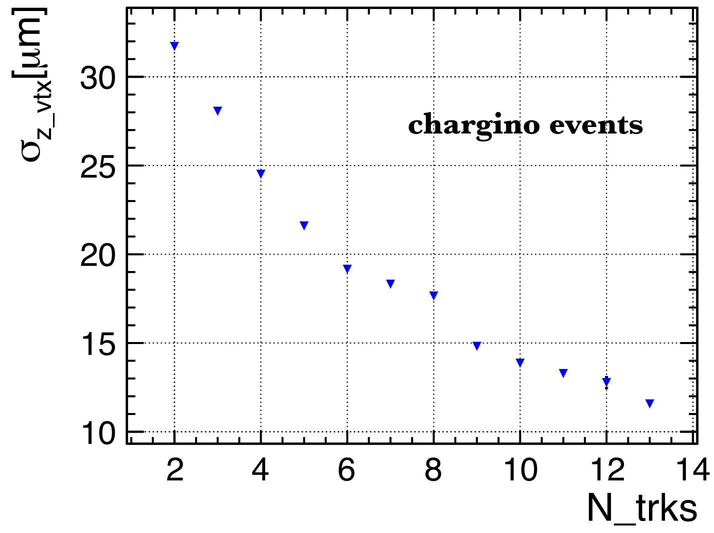
Second method:

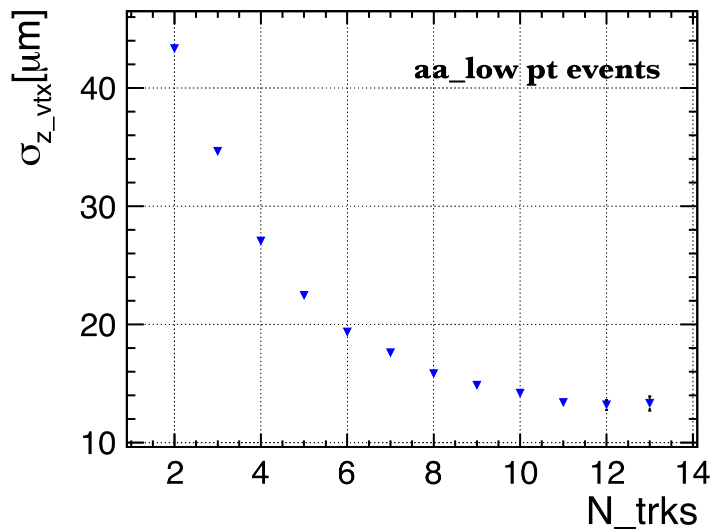
- The invariant mass of decay products of rho meson gives rho mass
- Rho meson used as a tag to remove $\gamma\gamma$ events
- Could be applied on very small event number



Detector Resolution for vertices

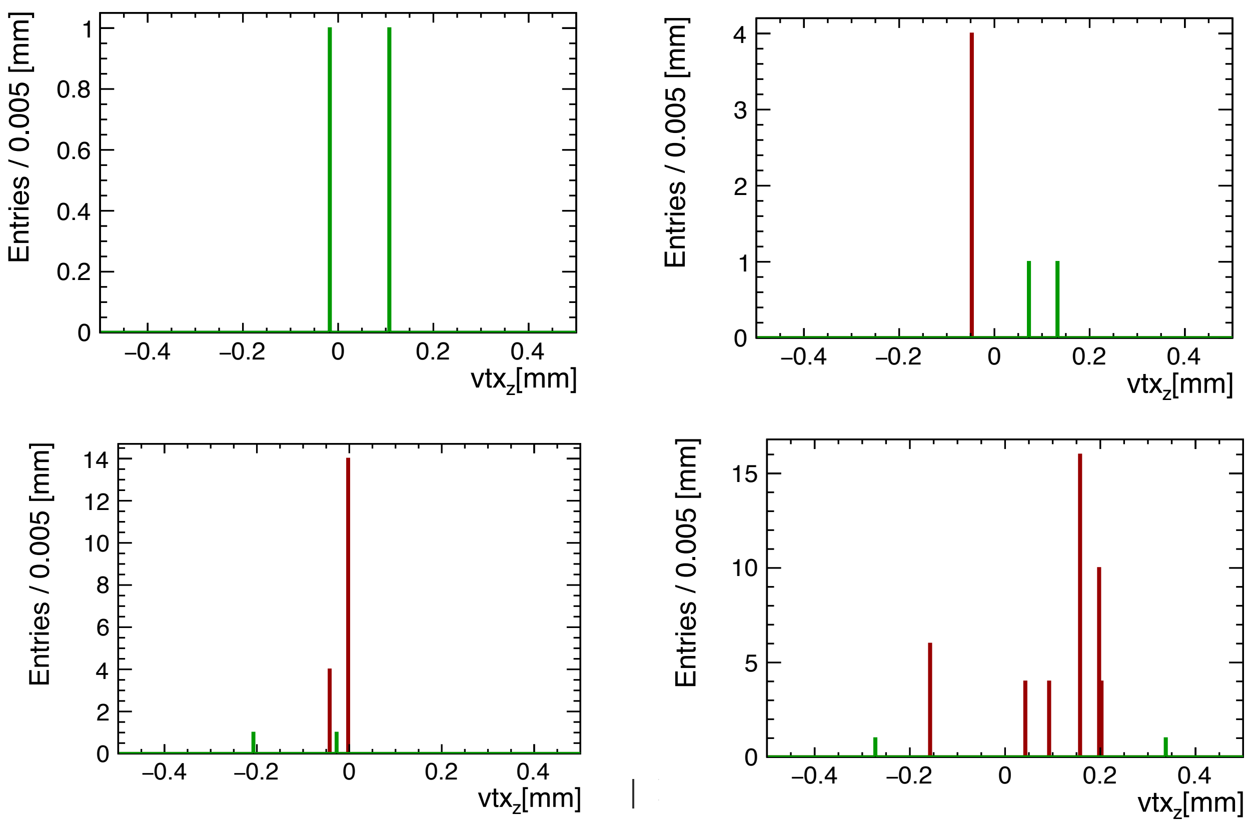
- Vertices of $\gamma\gamma$ overlay events displaced from that of signal vertices in z
- z_vtx resolution studied for vertices having 2 or greater than 2 tracks associated
- With increasing number of tracks in the primary vertex the resolution for vertex z position gets better by $\sqrt{N_{trk}}$ as expected
- For the signal events 60% of the events - z_vtx resolution ~ 35 μm or better
- For the overlay events 60% of the events - z_vtx resolution ~ 43 μm or better
- 40% events - either neutral events or events with 1 track or no tracks - only cluster information





Z position of MC vertices

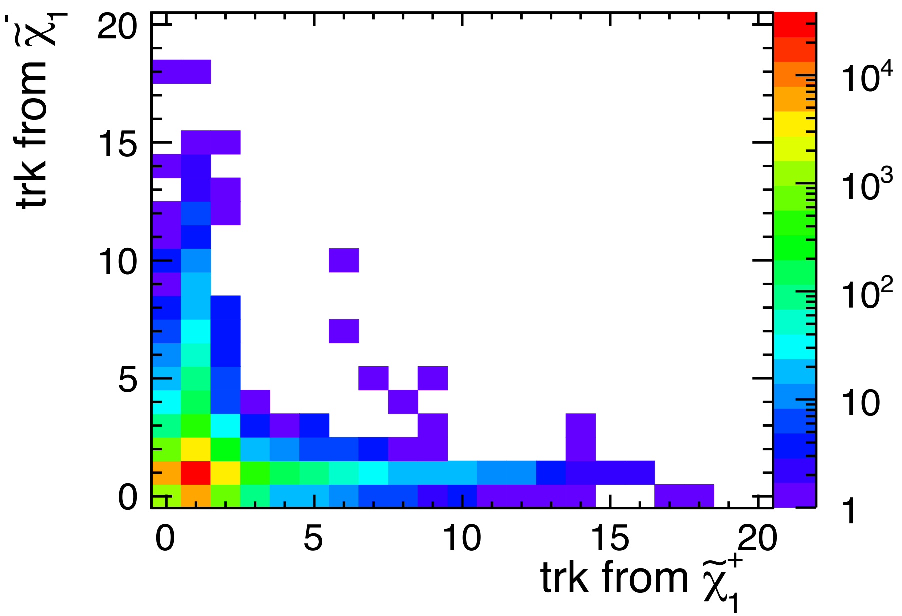
- Every chargino decays to one charged particle and other particles as per the BR
- Signal - green and overlay in reddish-brown
- At 500 GeV we have 1.05 events/BX - Poissonian distribution - 0,1,2,3 etc $\gamma\gamma$ events



- Every $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-\gamma$ gives two tracks
- Events with different number of $\gamma\gamma$ overlay events shown
- Vertices for signal and background nicely separated

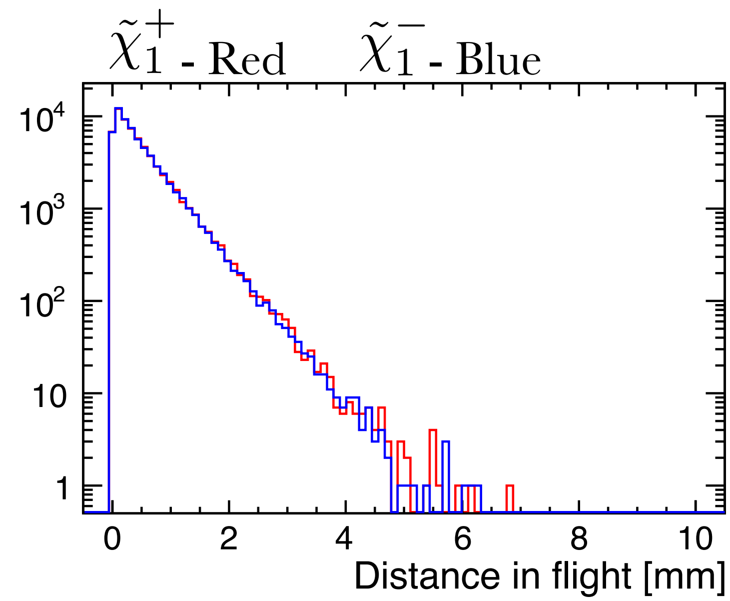
Reconstruction of signal tracks

- Every event has 2 signal tracks - from $\tilde{\chi}_1^+$ and $\tilde{\chi}_1^-$
- 60% of events both tracks from signal reconstructed
- 22 % events only one track found
- 15 % events tracks split due to vigorous curling
- 2% no tracks reconstructed



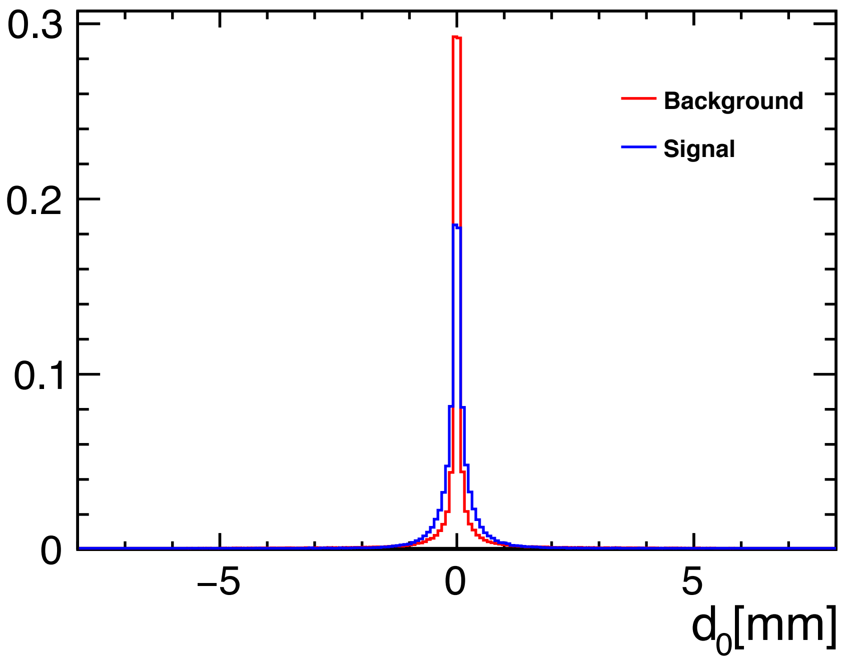
Reconstruction level and the track parameters

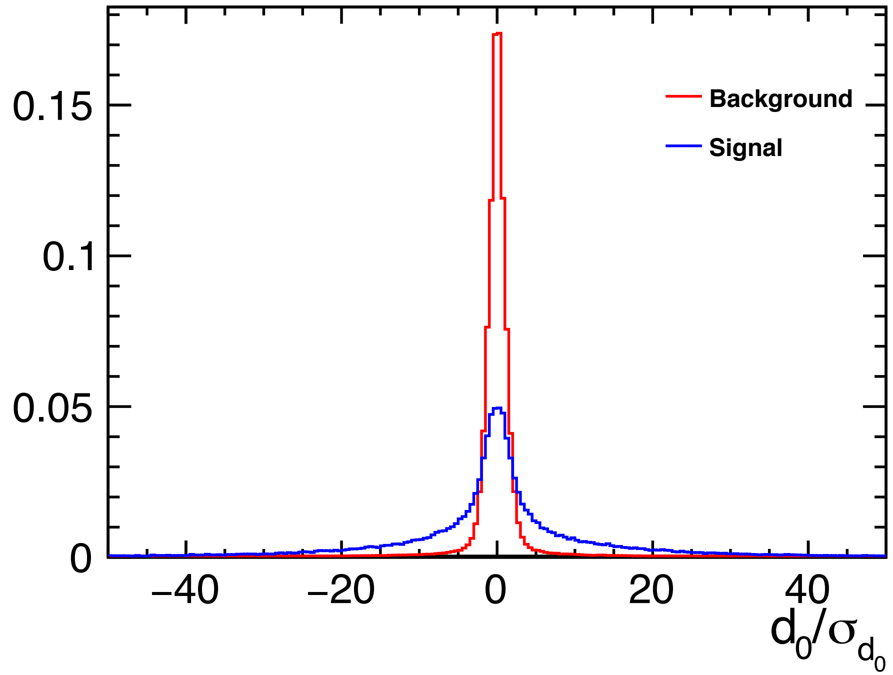
- Standard vertex finding algorithm reconstructs one single primary vertex for each event
- With smeared vertices important to have a more complex algorithm to group the tracks to find different vertices
- This algorithm can be developed with the track parameters as the important tools
- Knowledge of displaced vertices along the z axis
  - z_0 parameter of the track is important
- Unlike the particles in $\gamma\gamma \to$ low pt hadron events, charginos have a finite life time which makes the d_0 parameter important
- Using this parameters we try to develop a new algorithm which groups the closest tracks to form vertex positions



Detailed study of d_0 parameter

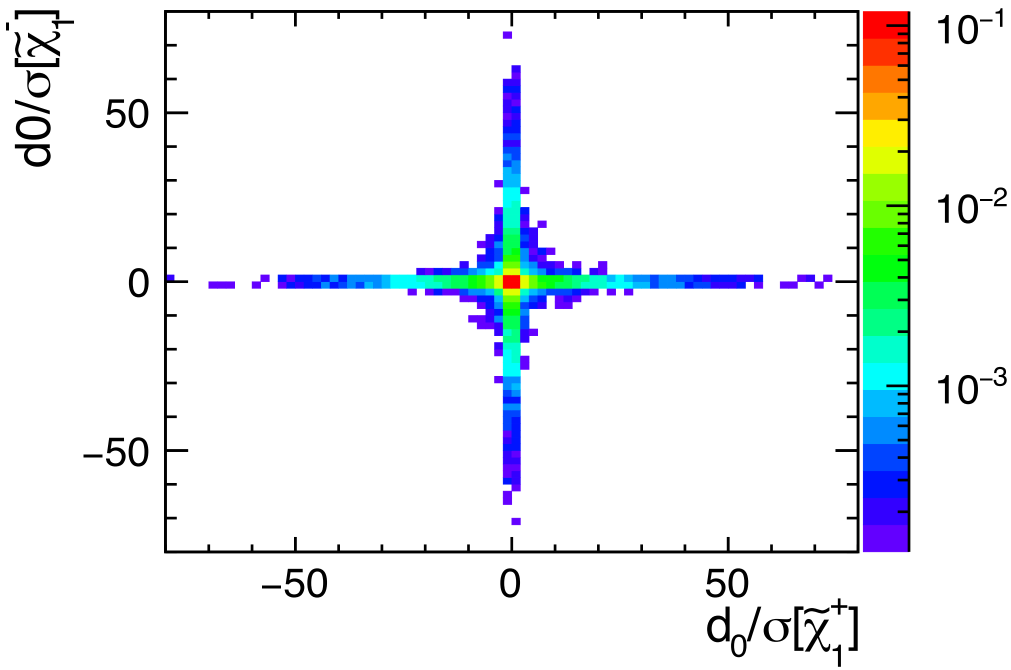
- d_0 and the d_0 significance of the of the pure signal and pure $\gamma\gamma$ events plotted as below
- d_0 and d_0 significance for the signal much wider than the background
- Due to higher spread d_0 significance would be more relevant than the use of pure d_0





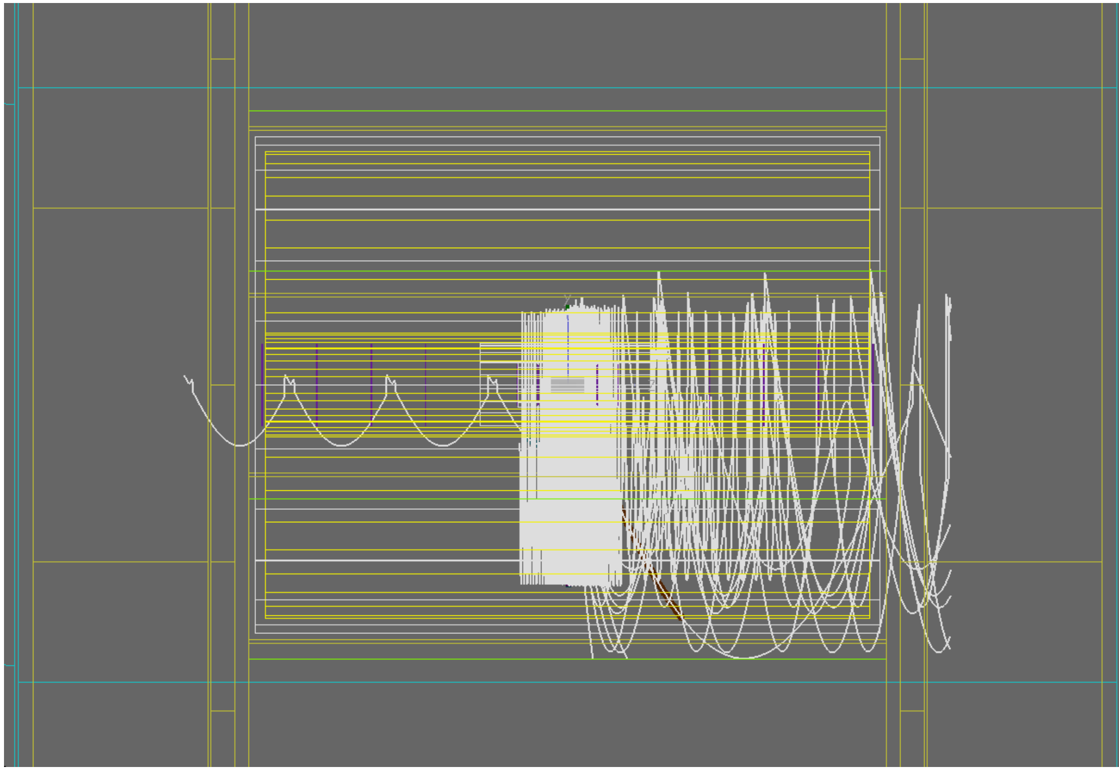
Detailed study of d_0 parameter

- 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

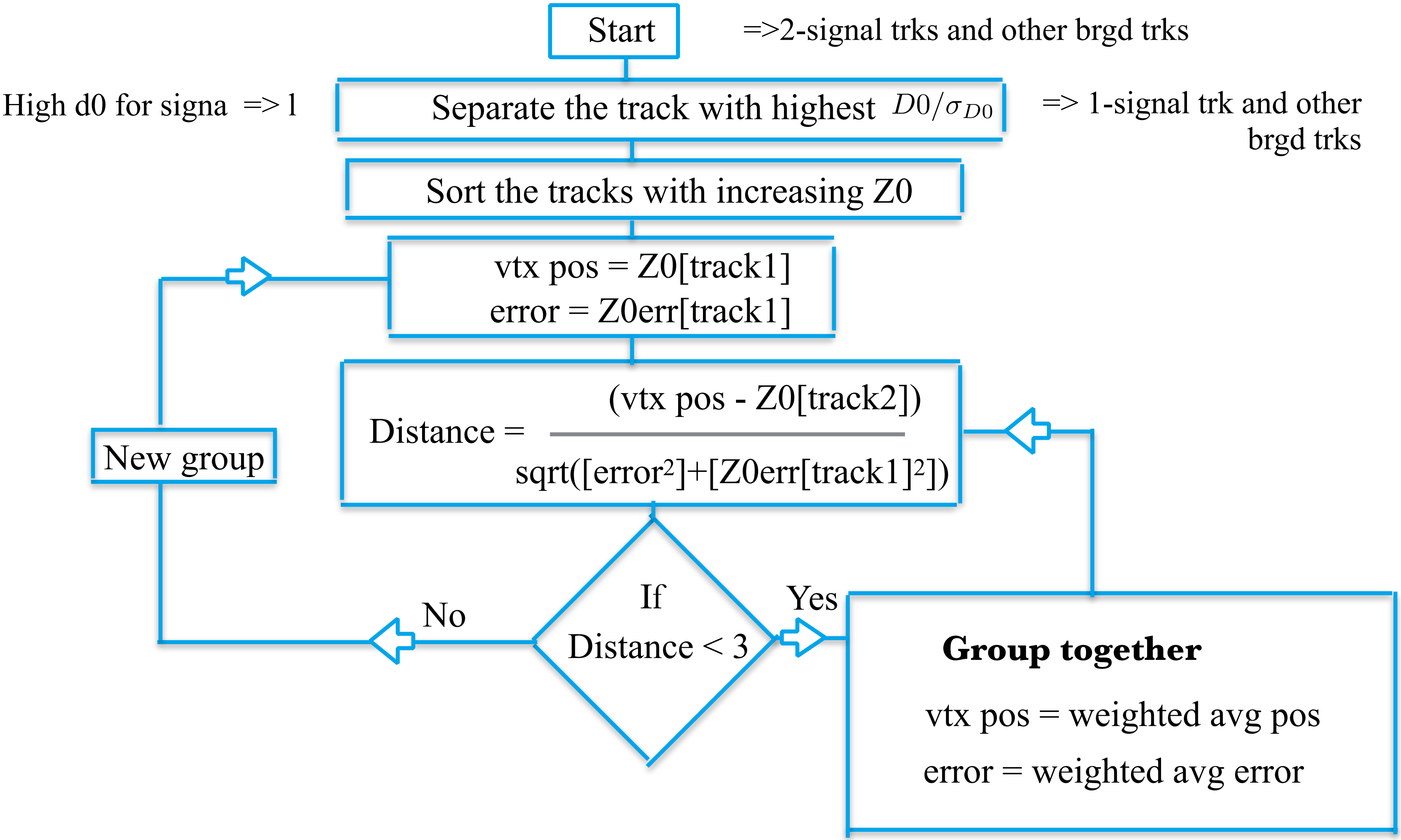


Precuts for the algorithm

- A cut of $N_{trks} < 12$ is applied
  - 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
- Z_0 of the track should be less than 15 mm
  - $Z_0 > 15$ can be particles created from the detector material

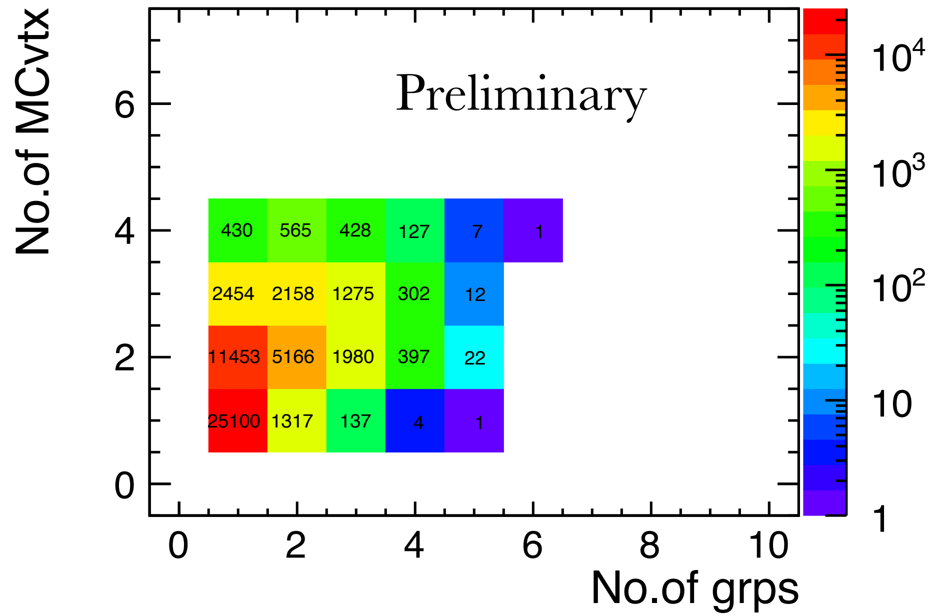


Algorithm


Start
=>2-signal trks and other brgd trks
High d0 for signa => 1
Separate the track with highest $D0/\sigma_{D0}$
=> 1-signal trk and other brgd trks
Sort the tracks with increasing Z0
vtx pos = Z0[track1]
error = Z0err[track1]
Distance = $\frac{\text{(vtx pos - Z0[track2])}}{\text{sqrt([error}^2\text{]+[Z0err[track1]}^2\text{])}}$
New group
If
Distance < 3
No
Yes
Group together
vtx pos = weighted avg pos
error = weighted avg error

Results from the algorithm

- 80% of tracks separated using d_0 parameter - charginos !!! 😃
- No. of groups made by the algorithm compared to true number of vertices
- Very preliminary study
- 60% of the events - diagonal
- Count on true no of vertices not always right due to secondary vertices - complex events
- Work in progress



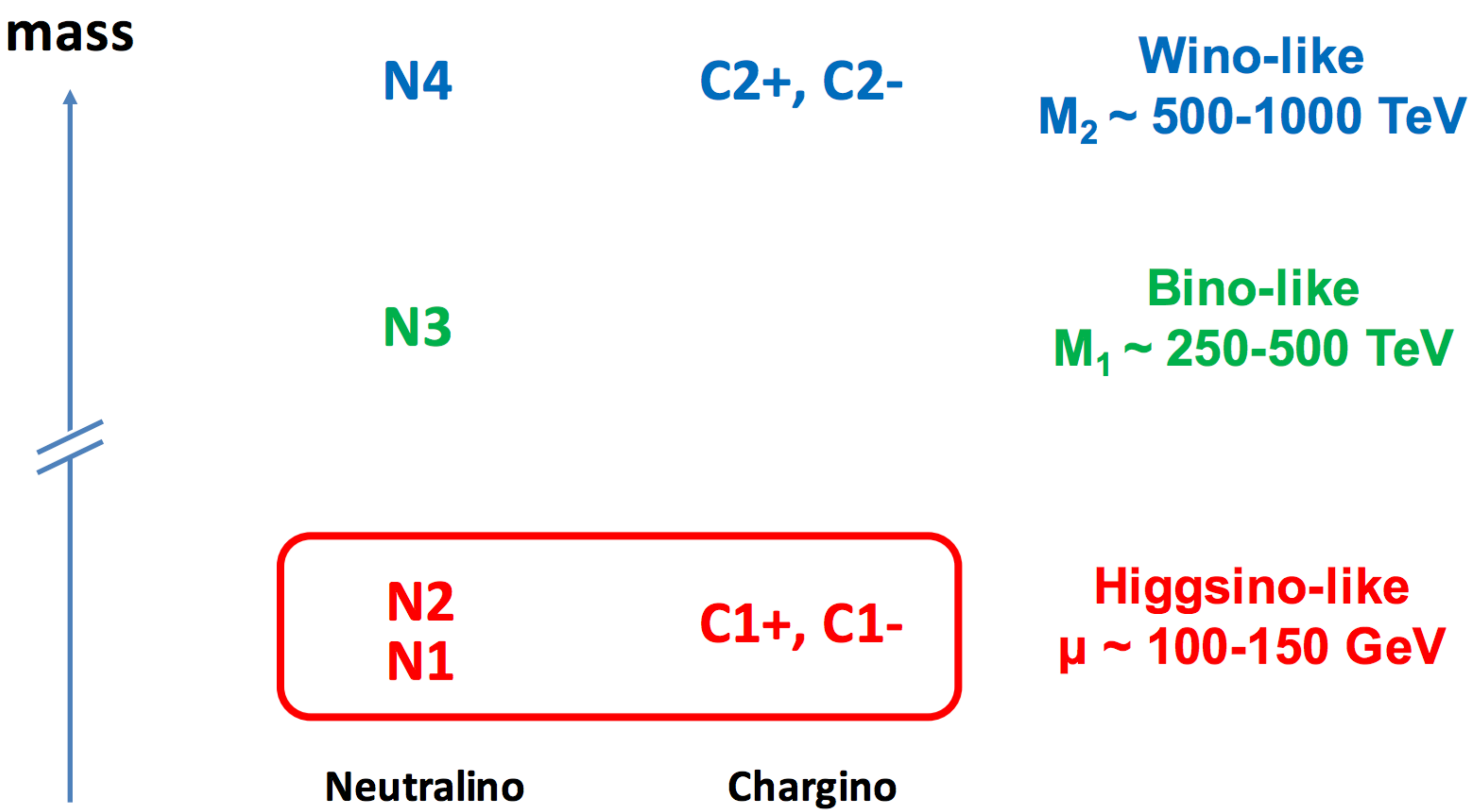
Conclusion and Outlook

- 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 cut

Questions??

> Weighted avg position = $\Sigma_i \frac{Z0[track_i]}{Z0[error_i]} / \Sigma_i \frac{1}{Z0[error_i]}$

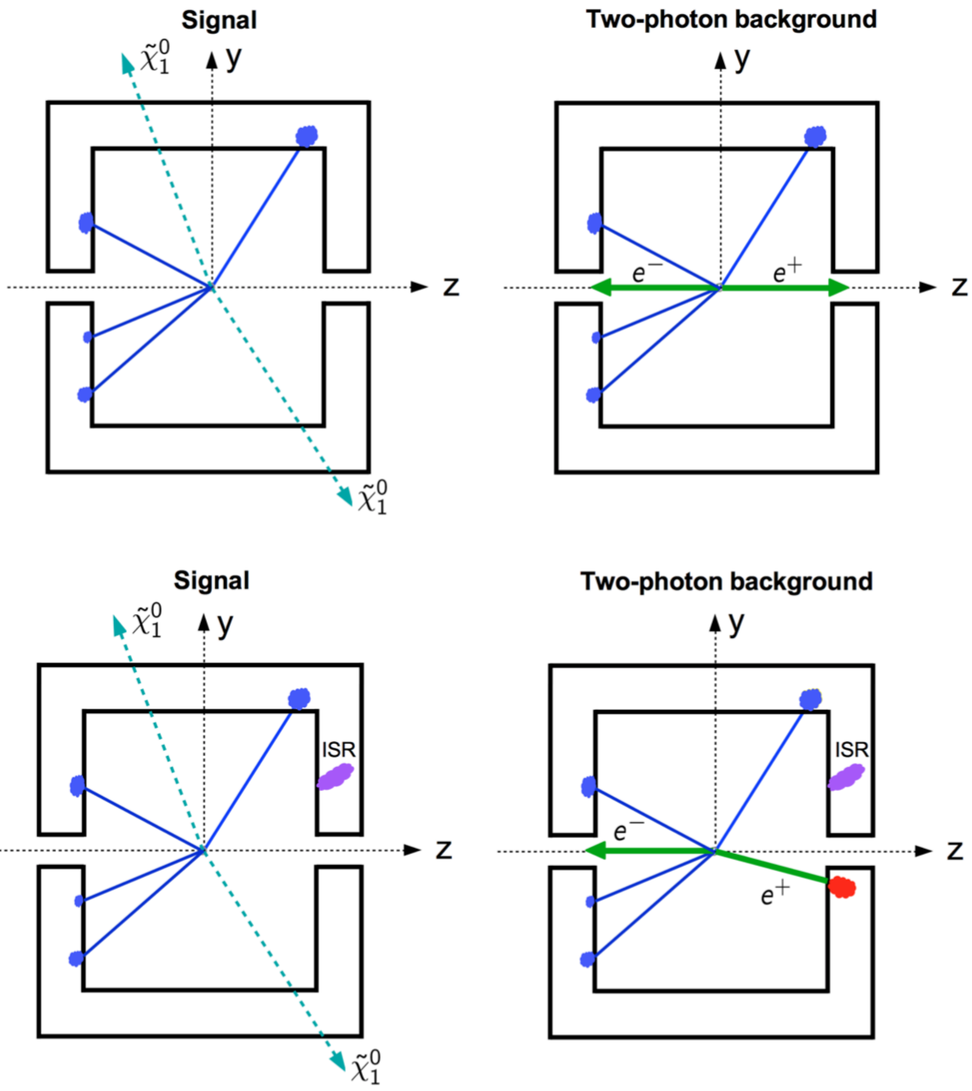
> Weighted Avg Error = $1/\Sigma_i \frac{1}{Z0[error_i]}$



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

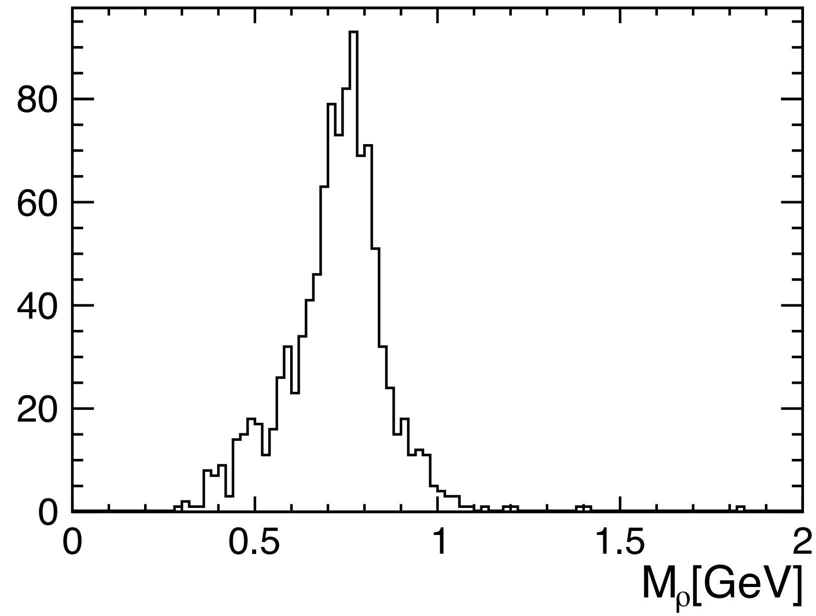
Method Development to remove backgrounds

- 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

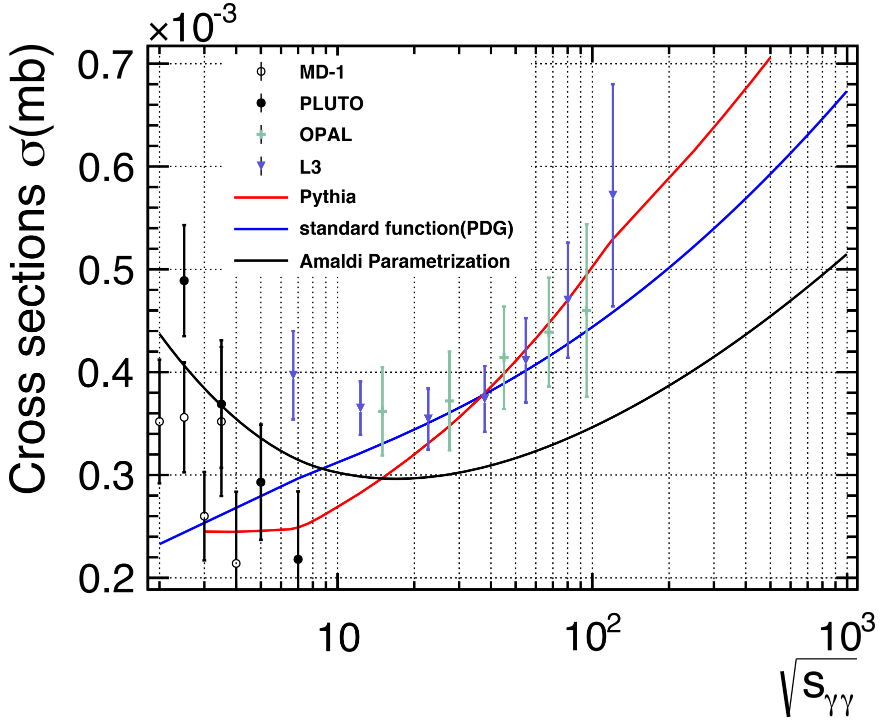
- Direct Interactions(DIR) - Real photons interacts directly
- Vector Meson Dominance(VMD) - Photon fluctuates into a vector meson
- Anomalous Interactions(GVMD) - Photon fluctuates into a $q\bar{q}$ pair of larger virtuality
- Deep inelastic Scattering(DIS) - A process of probing the Hadrons with very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

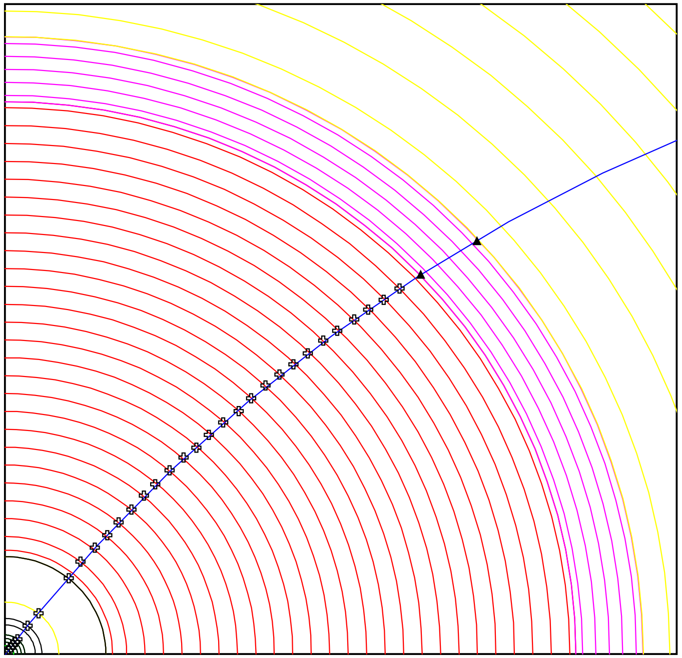
Cross sections for Pythia events

- Comparison of $\gamma\gamma \to$ 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



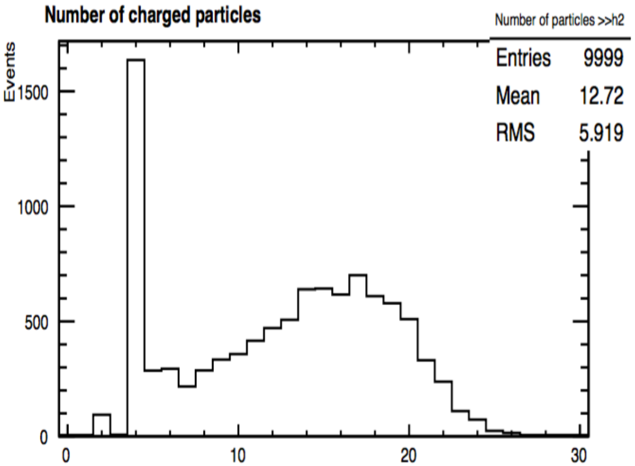
Does $\sqrt{s_{\gamma\gamma}} < 1$ GeV matter?

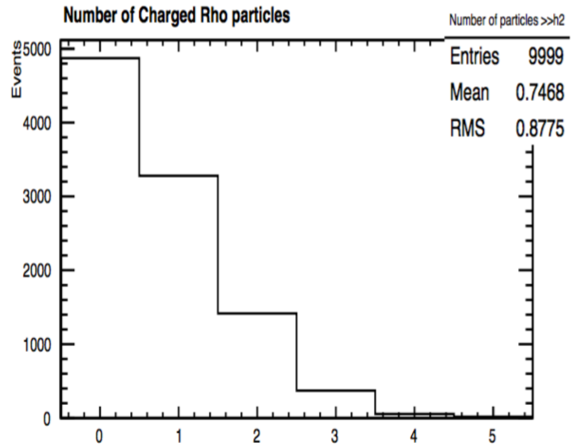
- Detector acceptance for $\sqrt{s_{\gamma\gamma}} \lesssim 1$ GeV
  - Select events $\sqrt{s_{\gamma\gamma}} < 1$ GeV
  - Events generated from real-real, real-virtual and virtual-virtual photon collisions
  - Simulate ILD in SGV fast simulation
- Reconstruction in SGV
  - Particles having $\gtrsim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

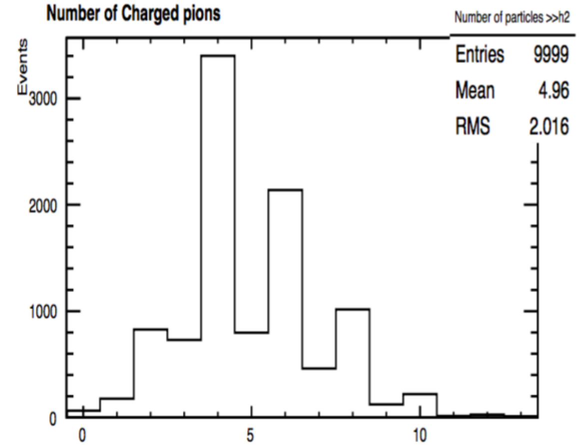


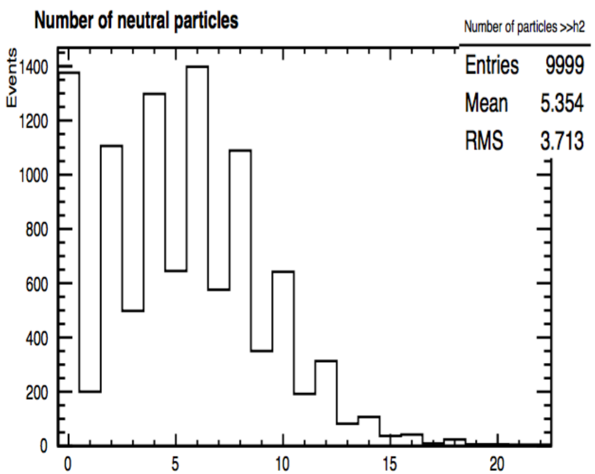
Ref: archiv:1203.0217v1

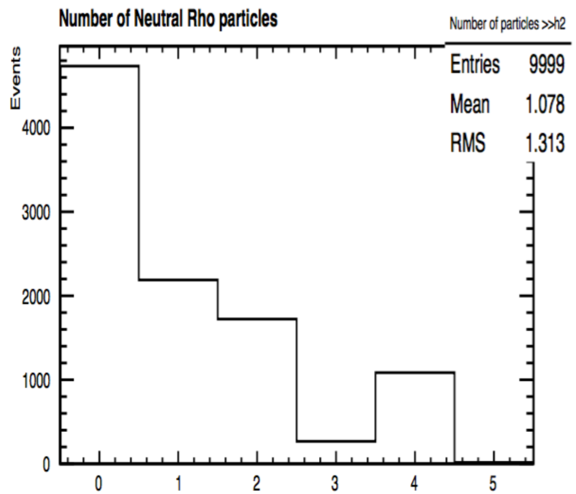
Event Properties of Pythia

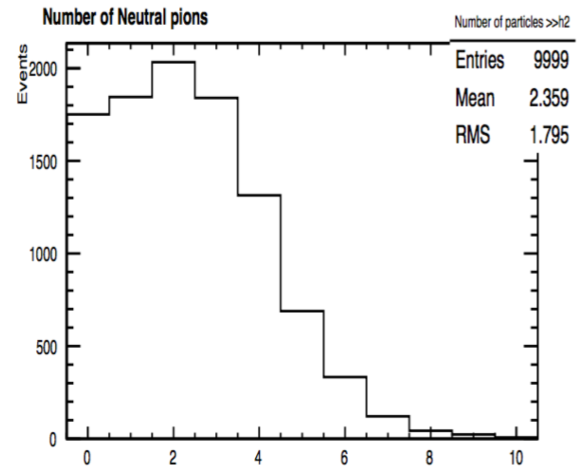






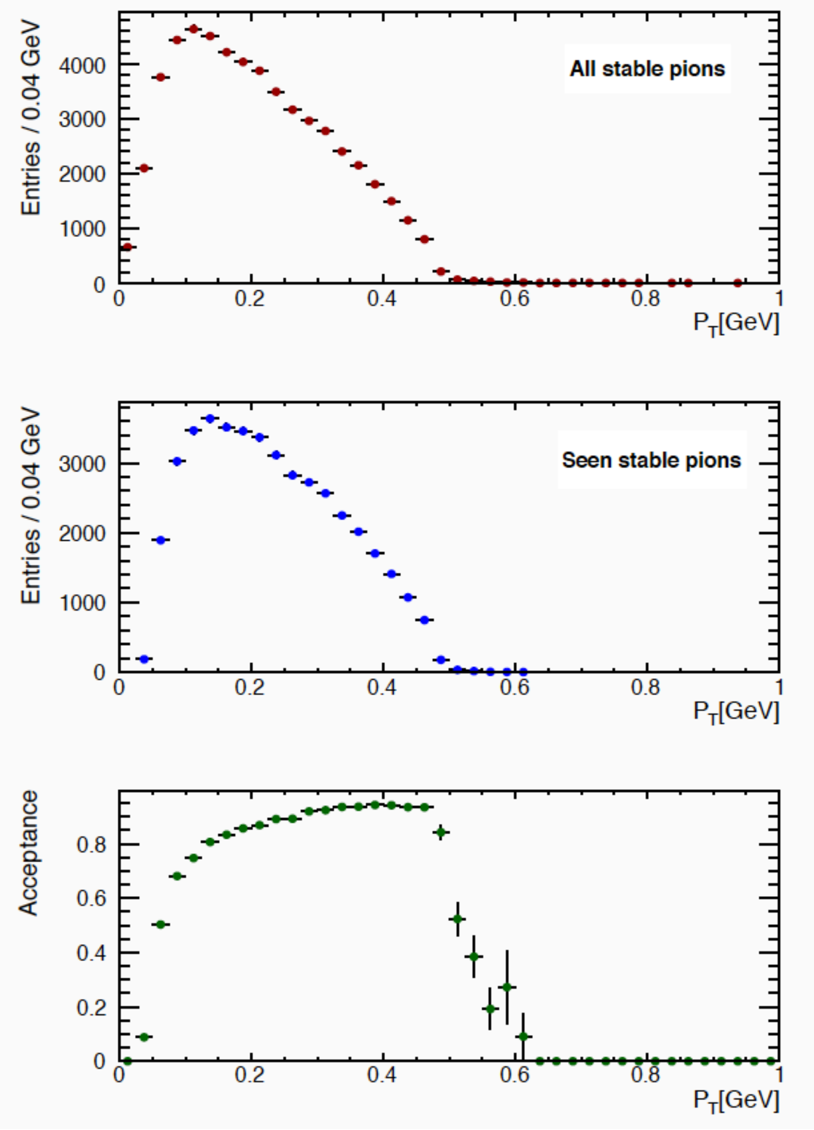




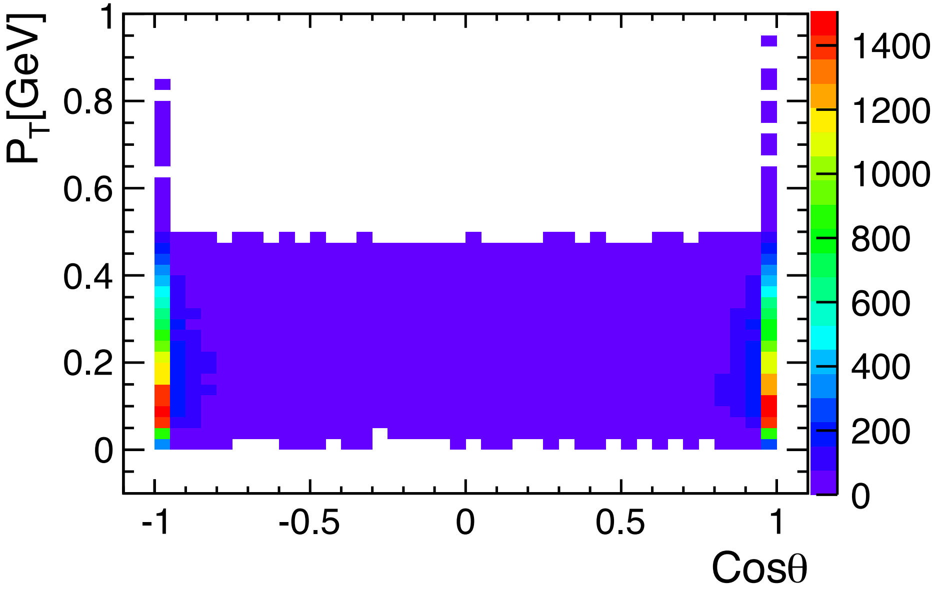


Pythia could be used to simulate events down upto $\sqrt{s_{\gamma\gamma}} = 2$ GeV

Momentum acceptance for Pions

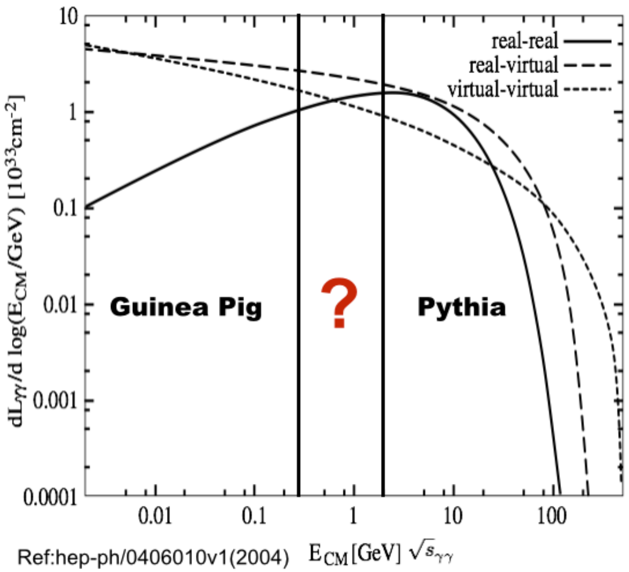


- Momentum acceptance:
  - Dividing seen stable pions with all true pions
  - The acceptance for most particles > 80%
  - Particles with high Pt but moving in forward direction - low acceptance



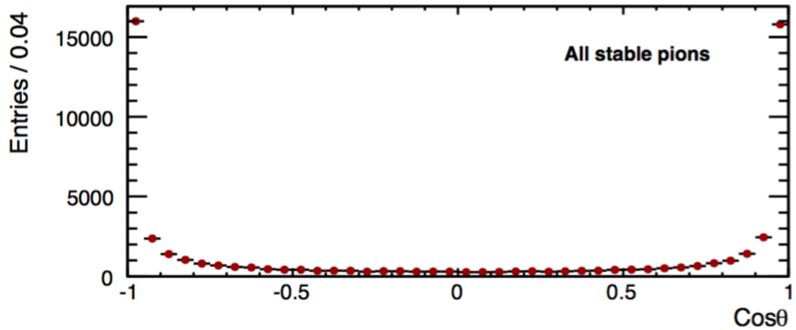
A dedicated event generator for $\gamma\gamma$ processes

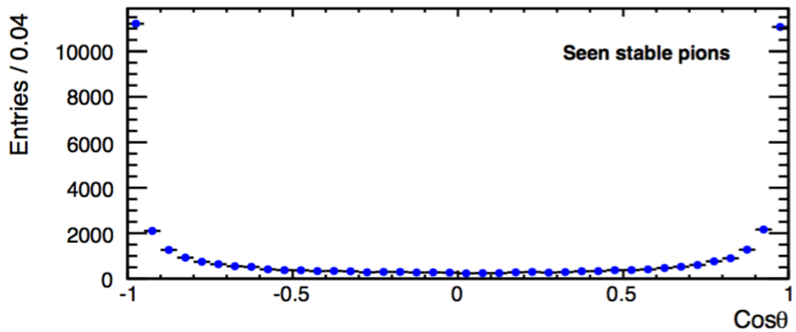
- For $\sqrt{s_{\gamma\gamma}} > 2$ GeV Pythia 6 used to simulate $\gamma\gamma \rightarrow$ low pT hadron processes
- Below 2 π_m pure QED beam-beam interactions modeled by dedicated programs - Guinea Pig
- Need to evaluate the impact of uncovered region - how can it be modeled?
- Dedicated generator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

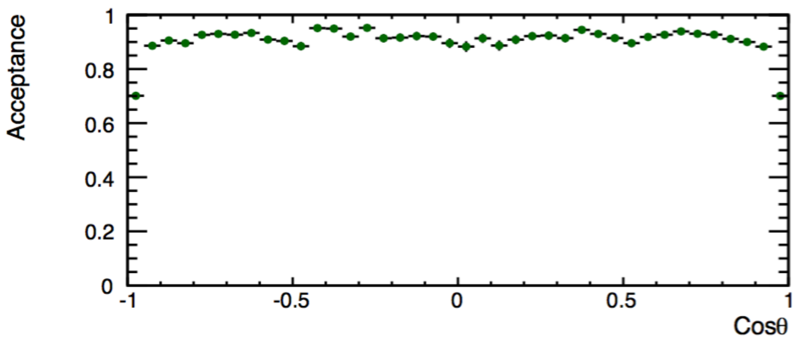


Ref:hep-ph/0406010v1(2004)

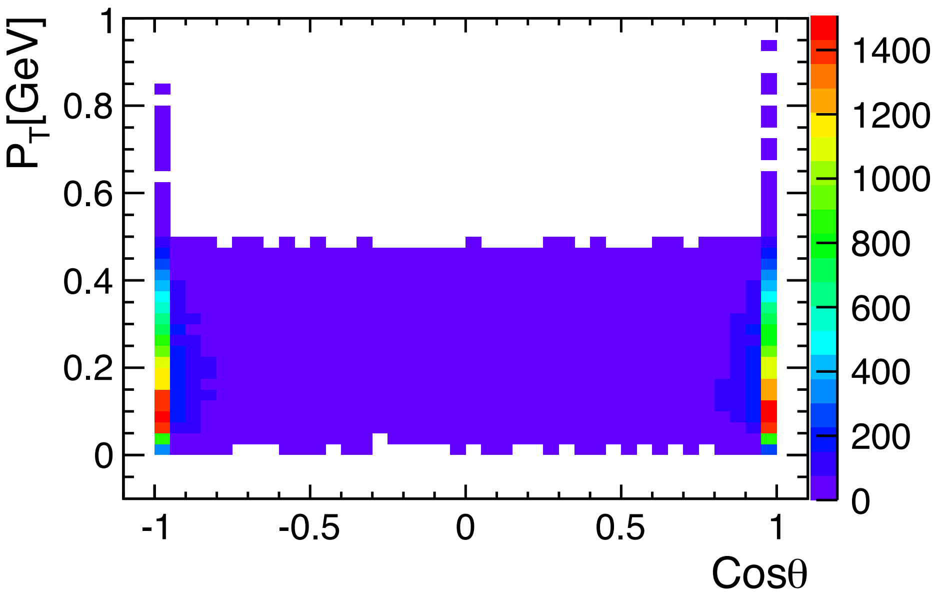
Angular acceptance for Pions





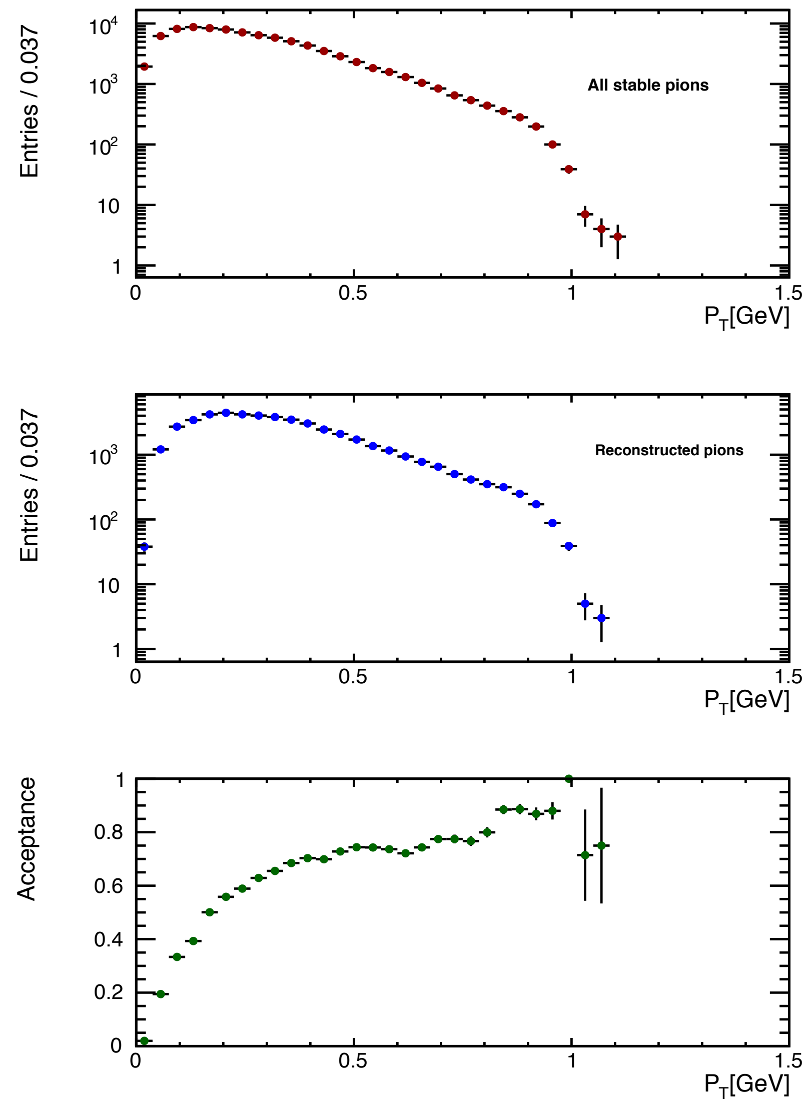


- Angular acceptance:
  - Dividing seen stable pions with all true pions
  - The acceptance for most particles > 80%
  - Particles with high Pt but moving in forward direction - low acceptance



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!!!