

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

DPG Spring Meeting 2018

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Introduction

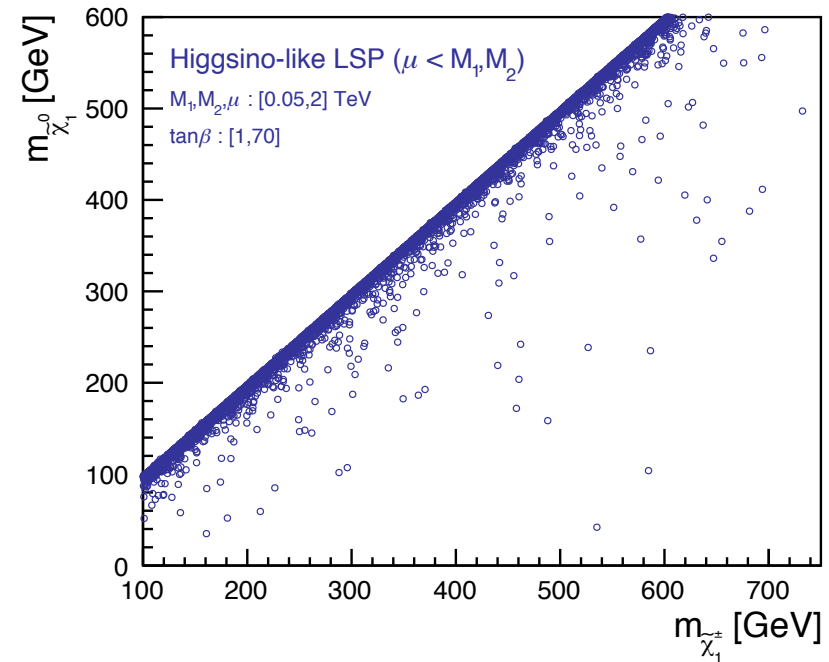
- > Naturalness requires light higgsinos at electroweak scale

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

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

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

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

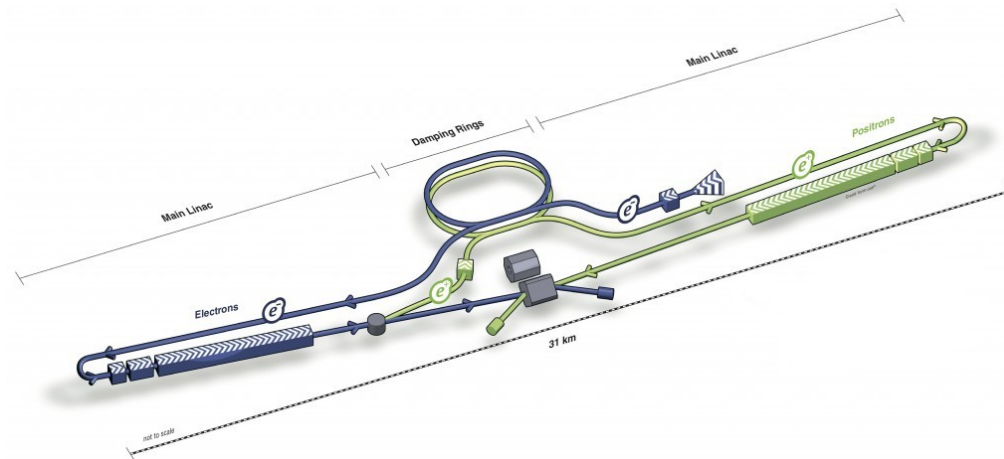
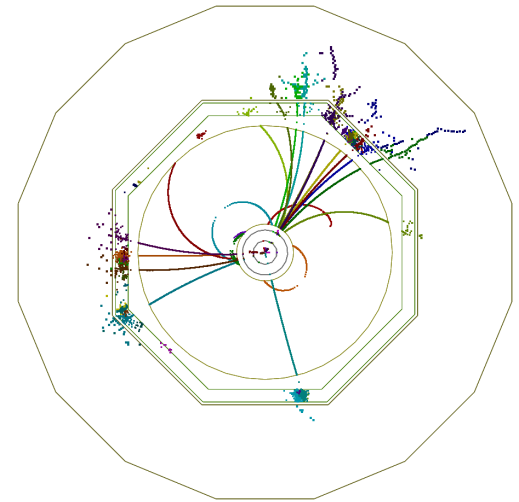


Ref: Tomohiko Tanabe



ILC as a lepton Collider

- > The International Linear Collider (ILC) is a proposed e^+e^- collider
 - ◆ Tunable $\sqrt{s} = 250 - 500$ GeV
 - ◆ Clean and completely reconstructible final states
 - ◆ No trigger - all events included
 - ◆ Japan - under political consideration

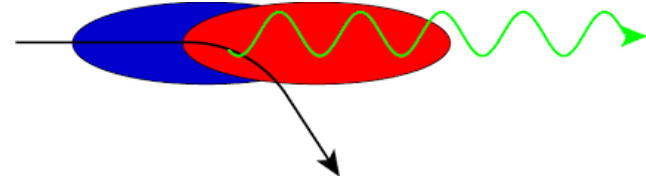


Photons in e^+e^- collider

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

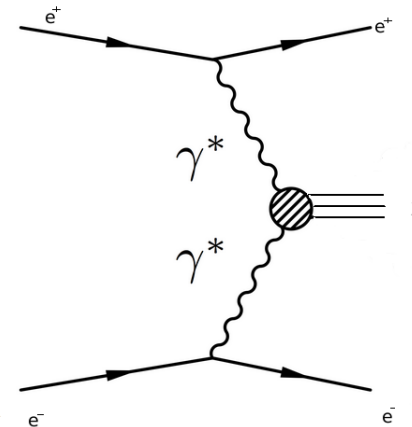
> Real Photons:

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



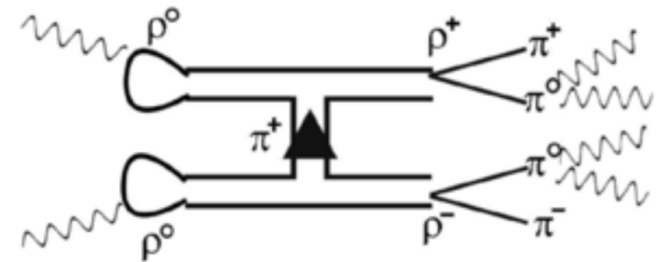
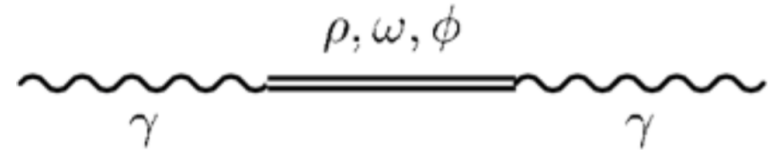
> Virtual Photons:

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



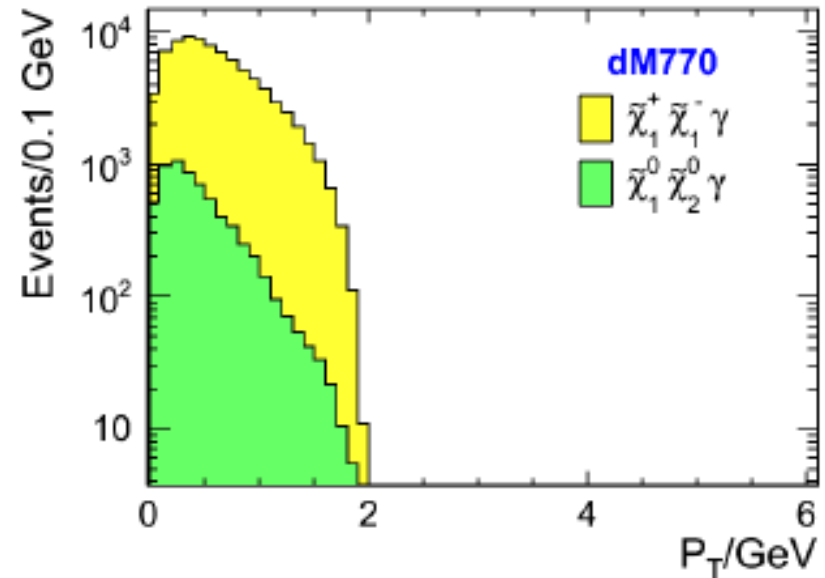
Photon-Photon Interactions

- > Photons from beamstrahlung (real) and Weizacker-Williams (virtual) process
- > Vector meson dominance -Most dominating subprocess $\rho, \omega, \phi, J/\psi, \Upsilon$
- > Photon fluctuates into a vector meson since it has got the same quantum properties
- > Highest probability to fluctuate into rho meson



Motivation

- > $\gamma\gamma \rightarrow$ low p_T 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 (Jet Clustering 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



hep-ph/1307-3566(2013)



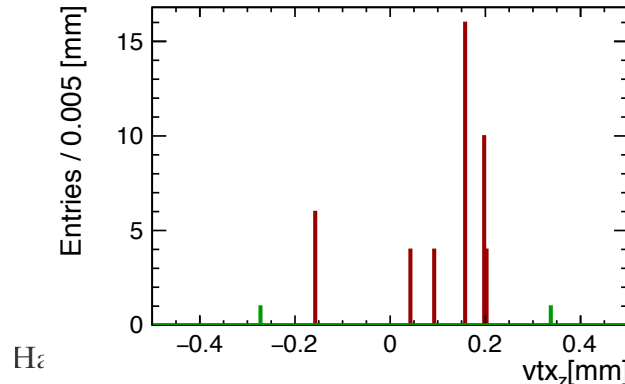
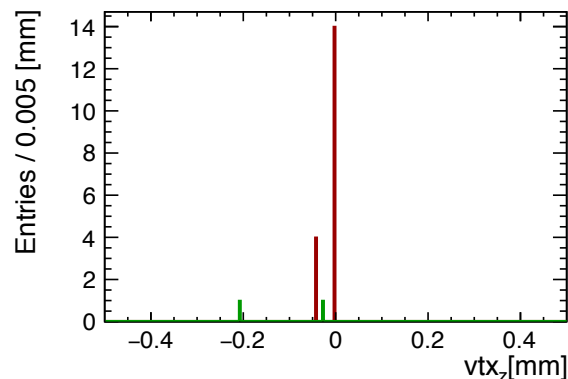
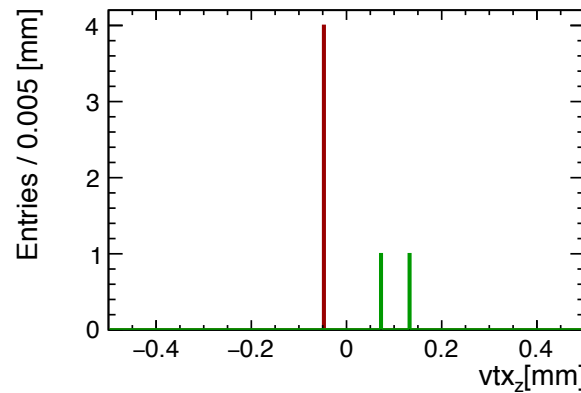
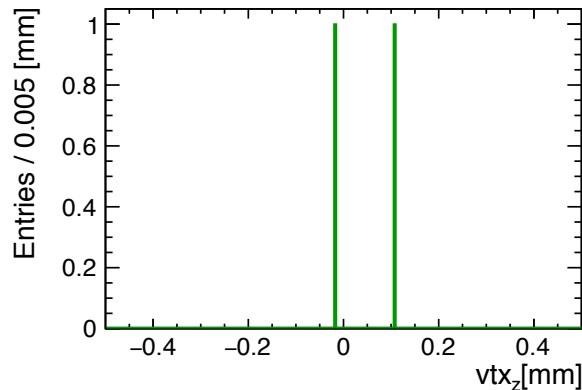
Possible method to remove $\gamma\gamma \rightarrow$ low pT hadrons

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



Z position of MC vertices

- > Every chargino decays to one charged particle and other particles as per the Branching Ratio
- > Signal - green and overlay in reddish-brown
- > At 500 GeV we have 1.05 events/BX

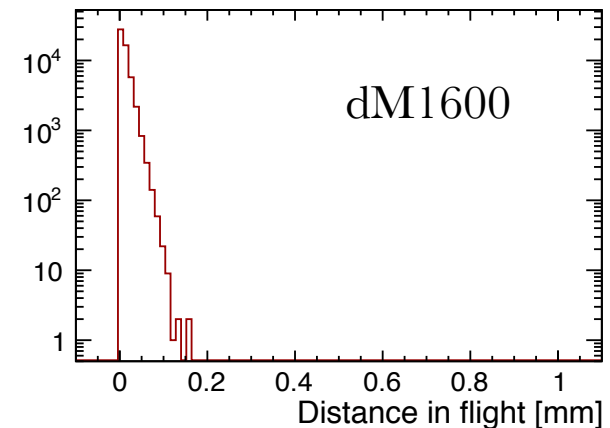
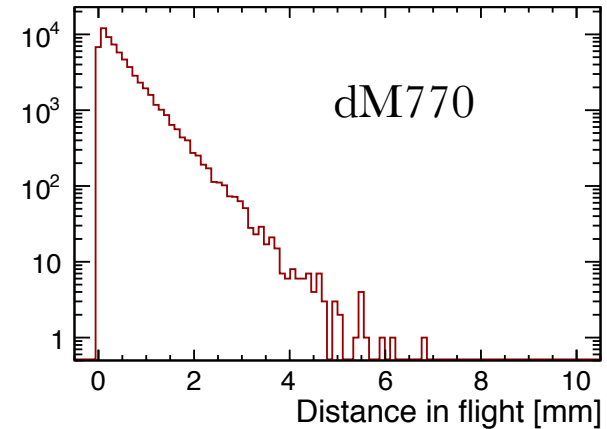


- > Every $e^+e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- \gamma$ gives two tracks
- > Events with different number of $\gamma\gamma$ overlay events shown
- > Vertices for signal and background nicely separated



Reconstruction level and the track parameters

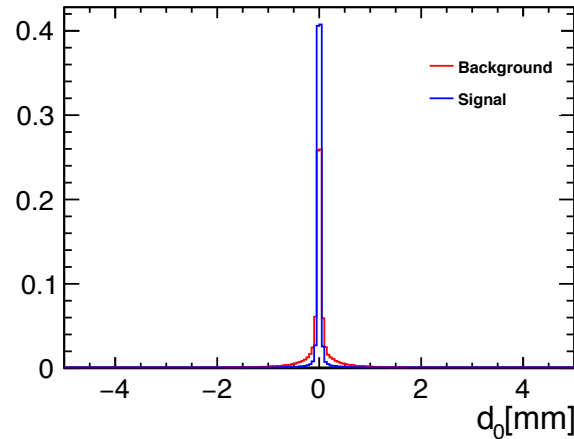
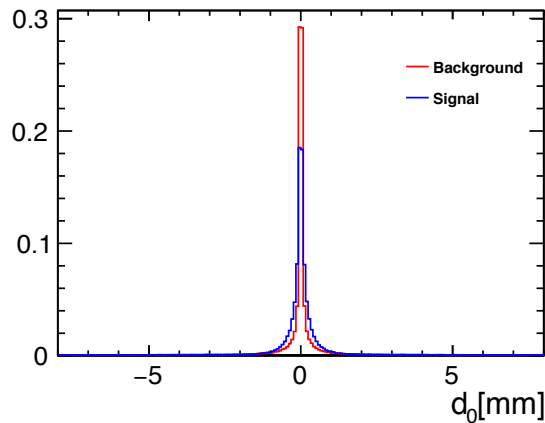
- > Standard vertex finding algorithm reconstructs one single primary vertex for each event
- > more complex algorithm to group the tracks to find different vertices
- > z_0 parameter of the track is important
- > Unlike the particles in $\gamma\gamma \rightarrow$ low pt hadron events, charginos have a finite life time which makes the d_0 parameter important
- > develop a new algorithm which groups the closest tracks to form vertex positions



Detailed study of d_0 parameter

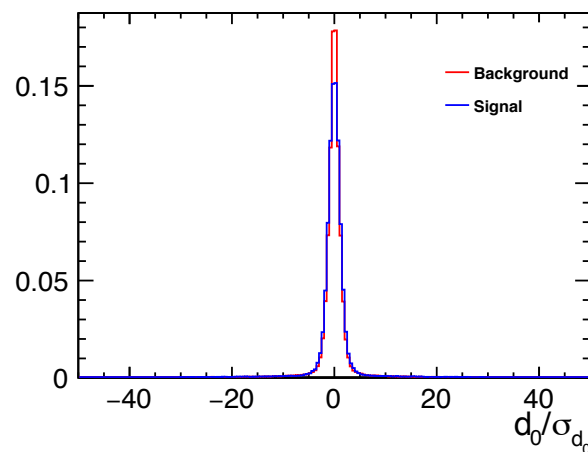
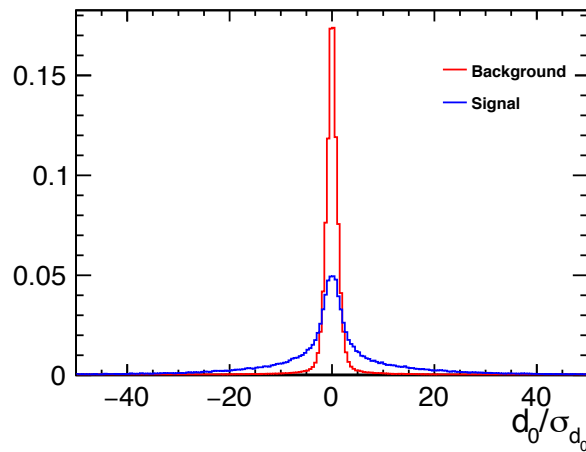
dM 770

dM 1600

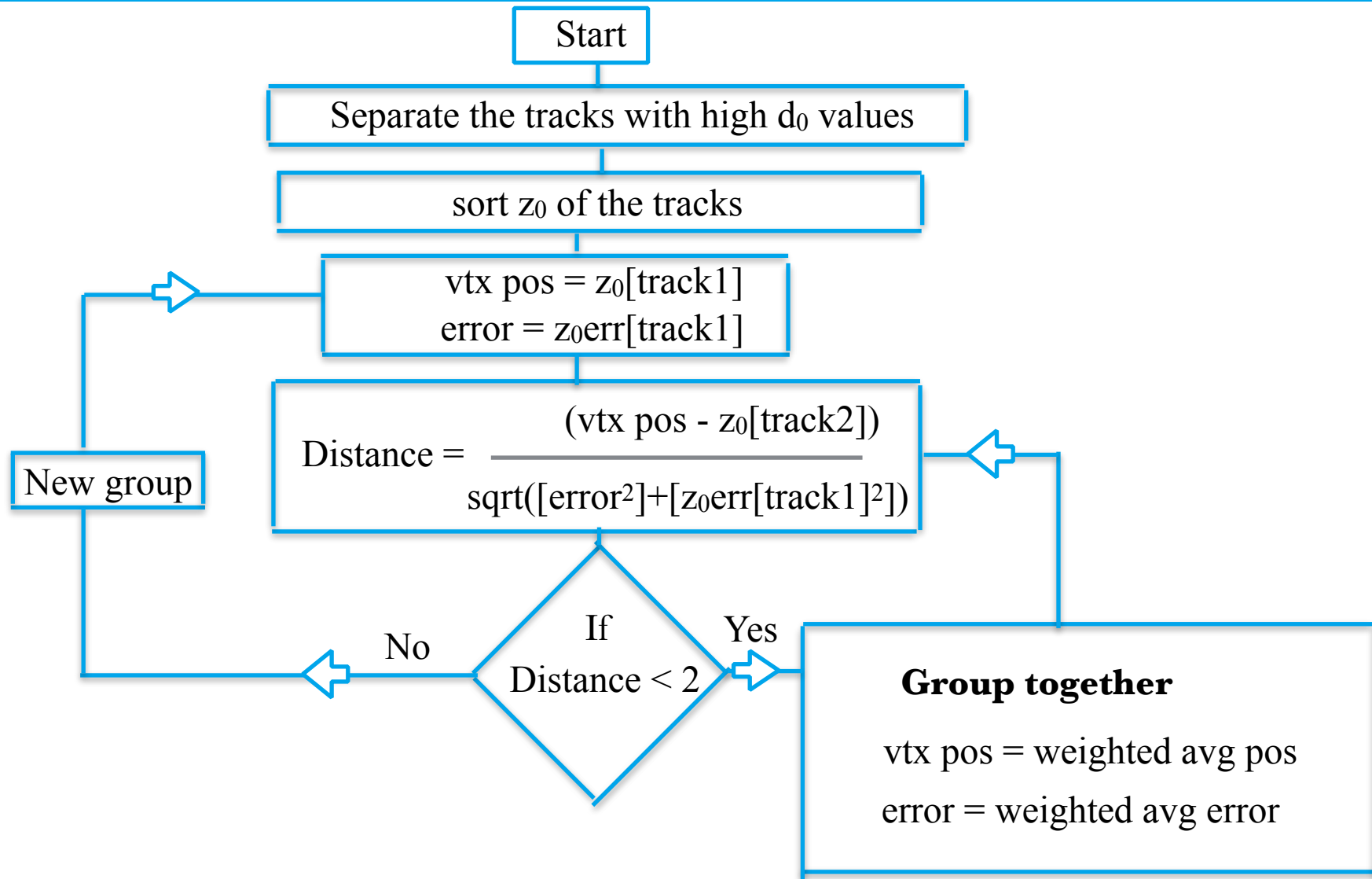


> With higher mass difference smaller d_0

> In dM1600 d_0 not a handle

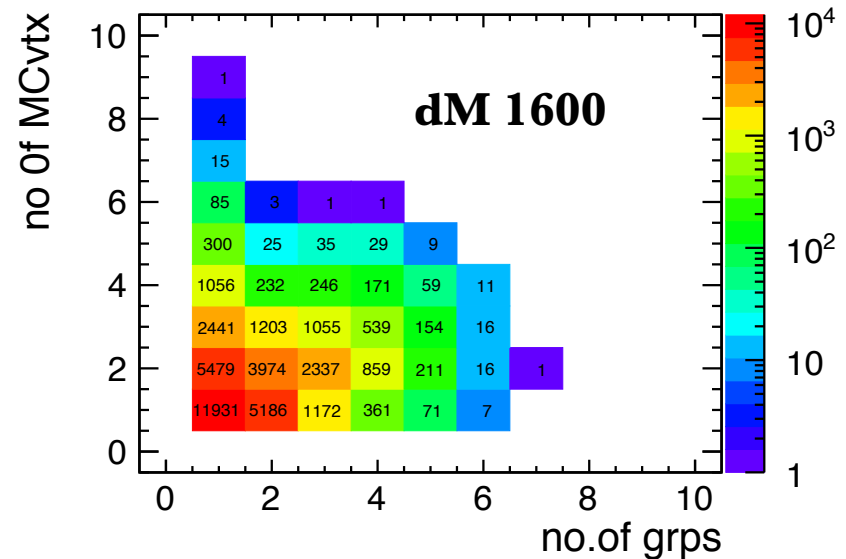
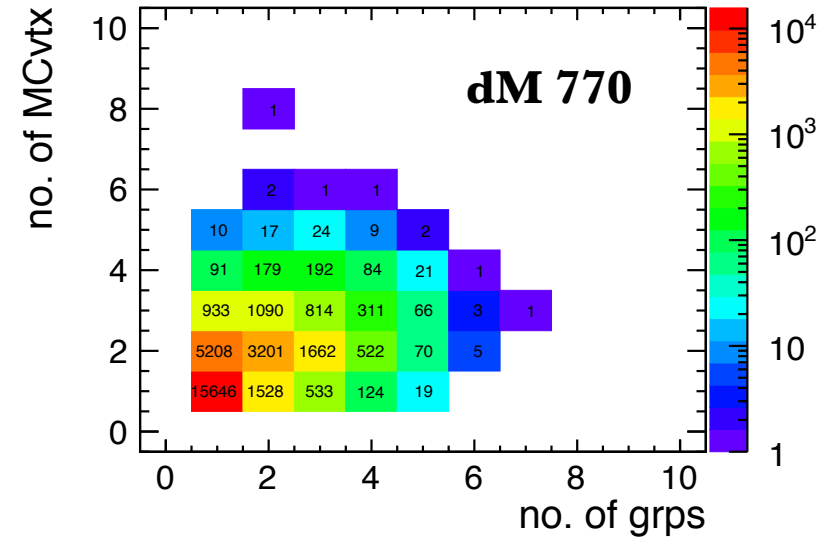


Algorithm



Results from the algorithm

- > d_0 method only partially used for dM770 - highest d_0 track removed
- > d_0 separation still not used in dM1600
- > 80% of tracks separated using d_0 parameter for dM770 - charginos !!! 😊
- > 60% of the events (dM770) - diagonal



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 using d0 separation
 - Check total charge of a group
 - To identify groups (background or signal)



Questions??



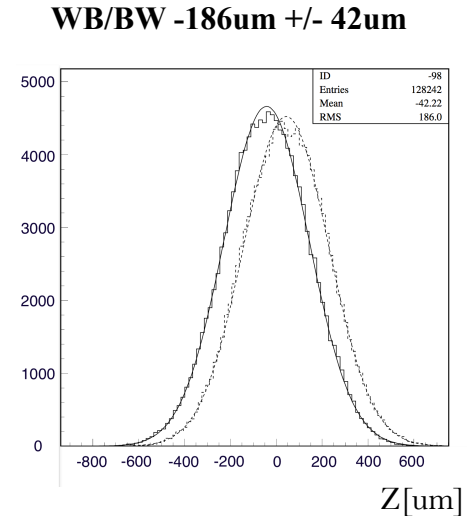
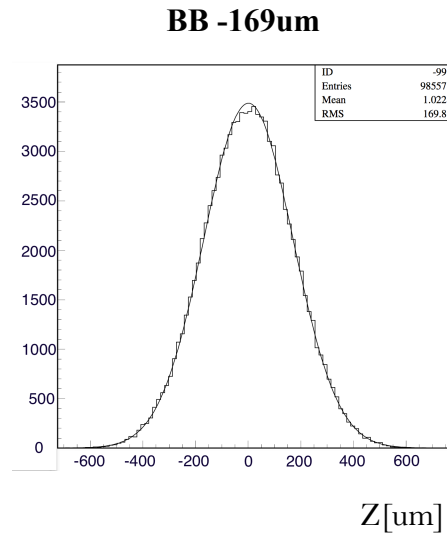
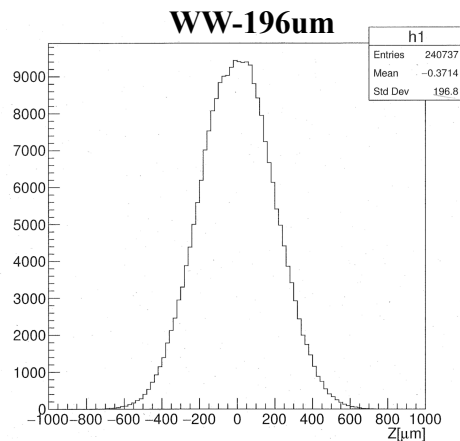
> Weighted avg position = $\sum_i \frac{Z0[track_i]}{Z0[error_i]} / \sum_i \frac{1}{Z0[error_i]}$

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



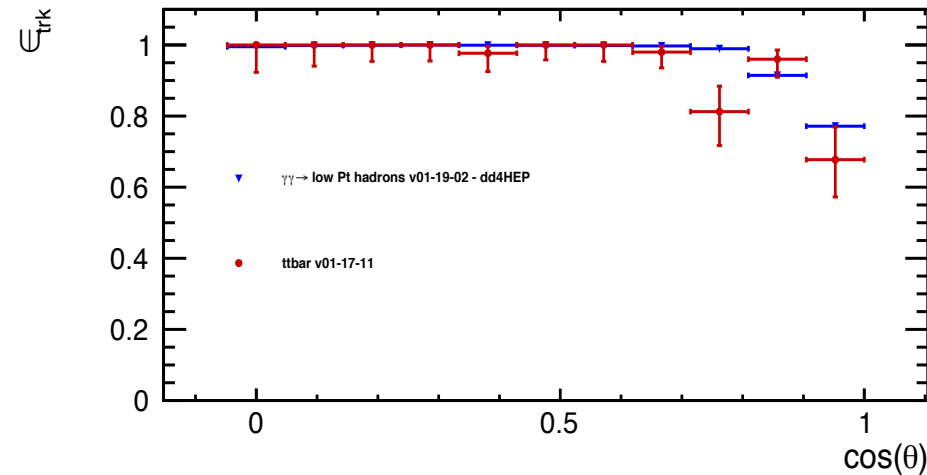
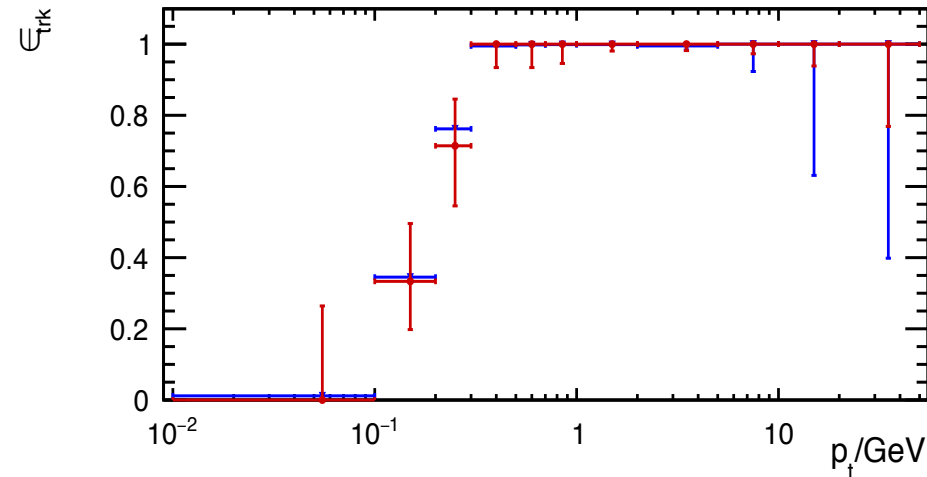
Vertex Smearing

- > Beam spot not a perfect spot - has a spread
- > Simulated $e^+e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- \gamma$ samples with vertex smeared along z axis - benchmark scenario dM770 (196.8)
- > Four different samples of $\gamma\gamma \rightarrow$ low pt hadron events simulated with smeared vertices - Guinea Pig



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 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

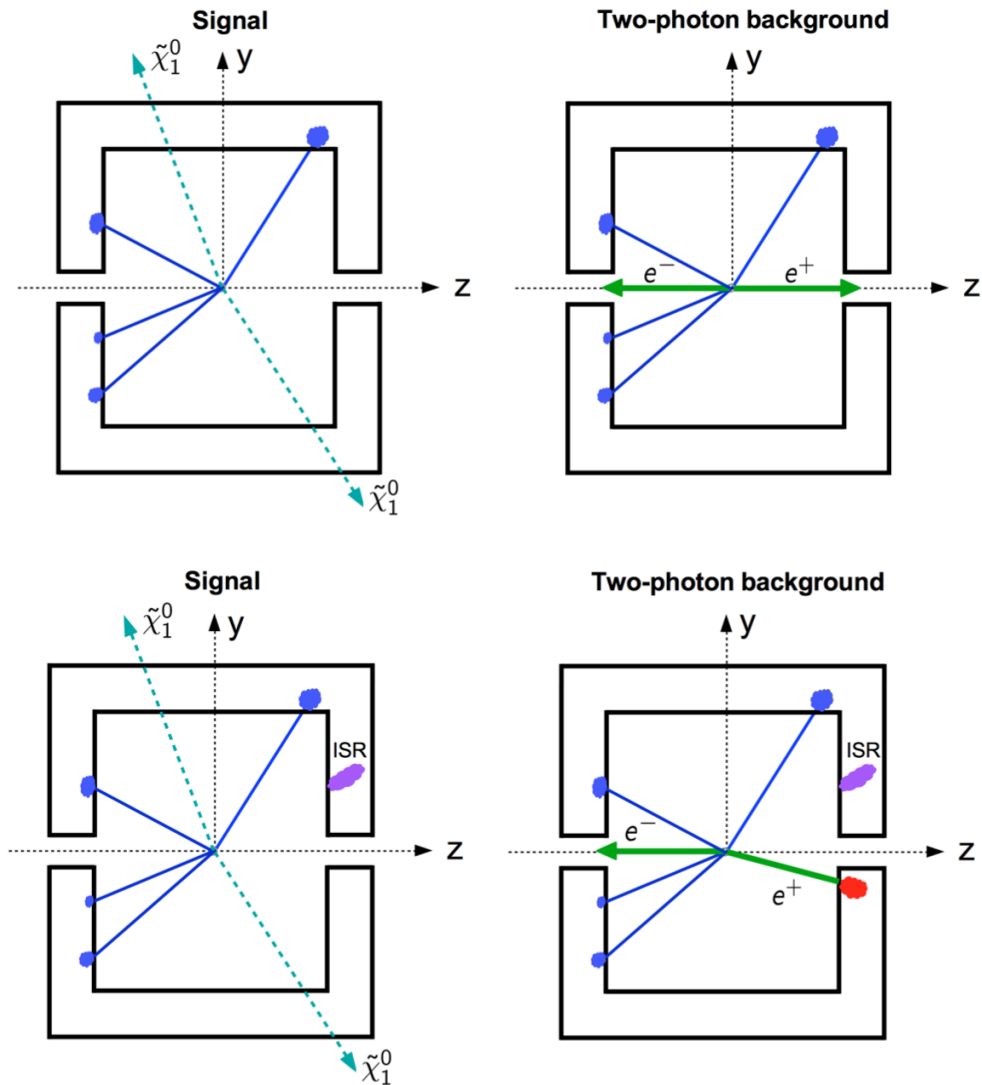
Chargino

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



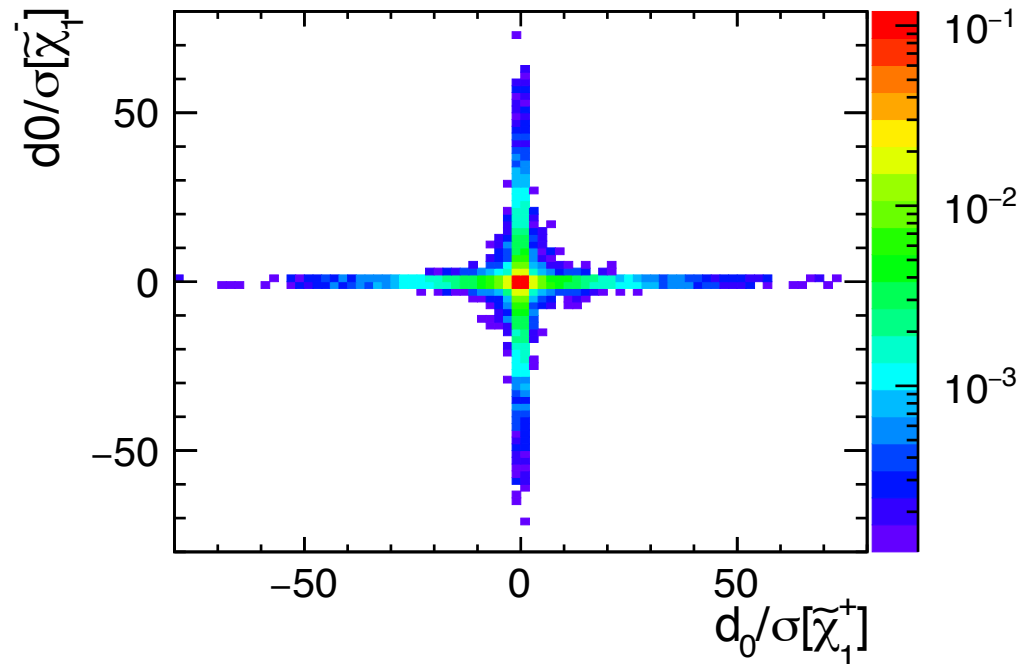
Summary and Outlook

- > 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_{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

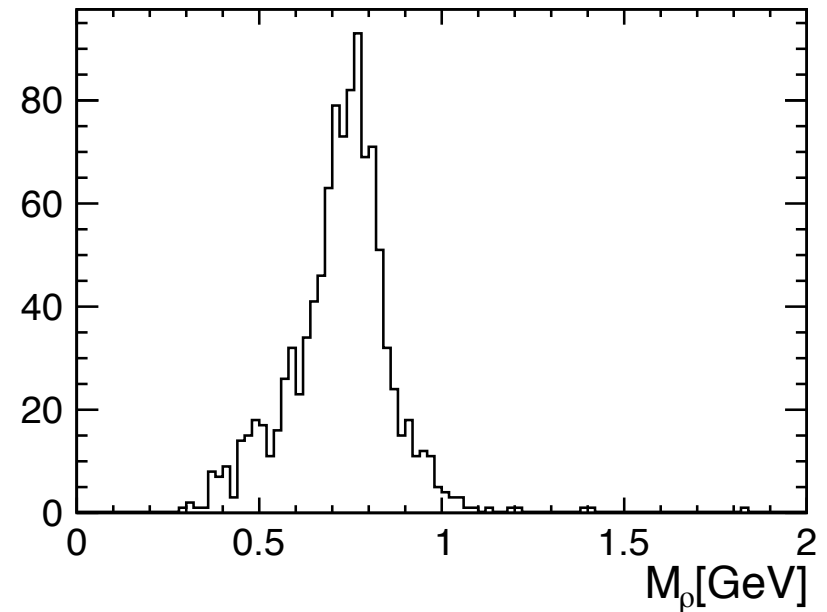
- Primary step - separating events as in table
 - Pythia events complex - 55 % events - good chances for finding vertex
 - Only Separating Barklow events as below - 45 %

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 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.

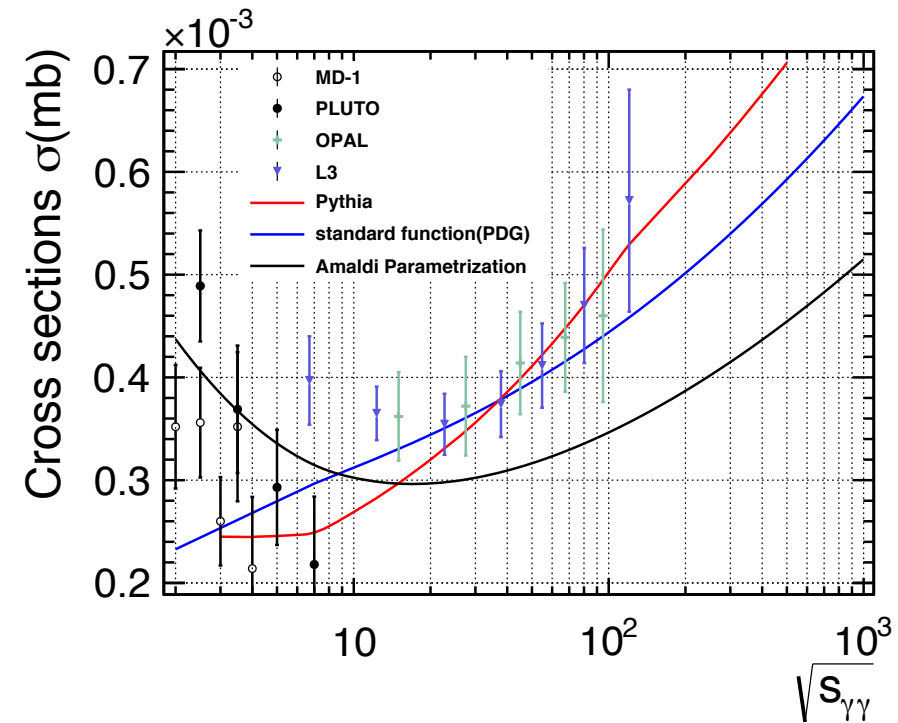
Subprocesses	Cross-sections (nb)
VMD * VMD	239.2
DIR * VMD	87.52
GVMD * DIR	9.77
GVMD * GVMD	12.05

> Pythia cannot simulate below 2 GeV



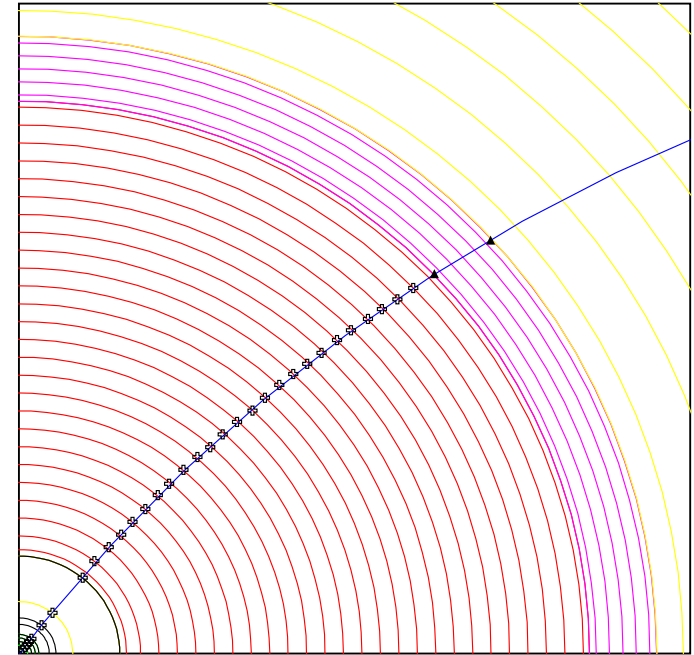
Cross sections for Pythia events

- > 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



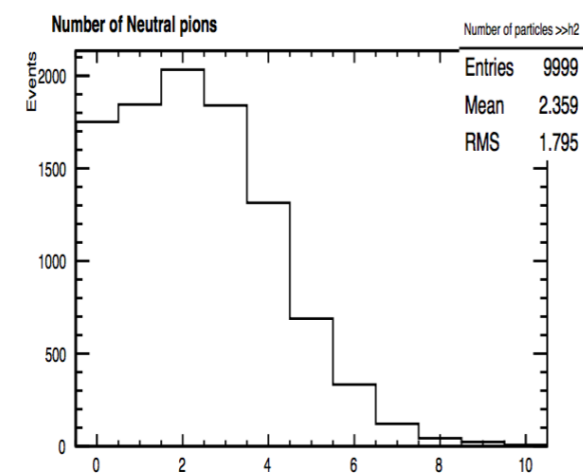
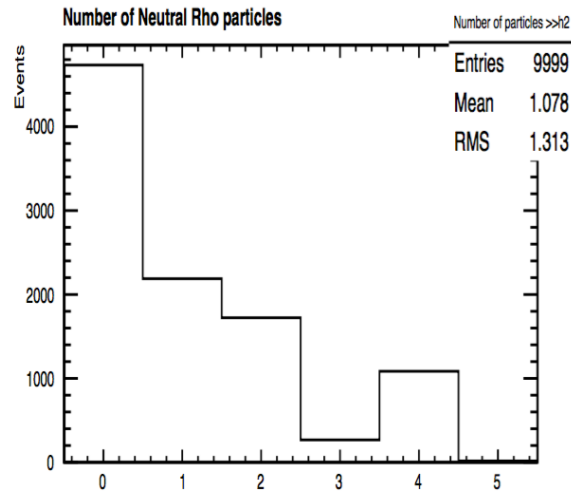
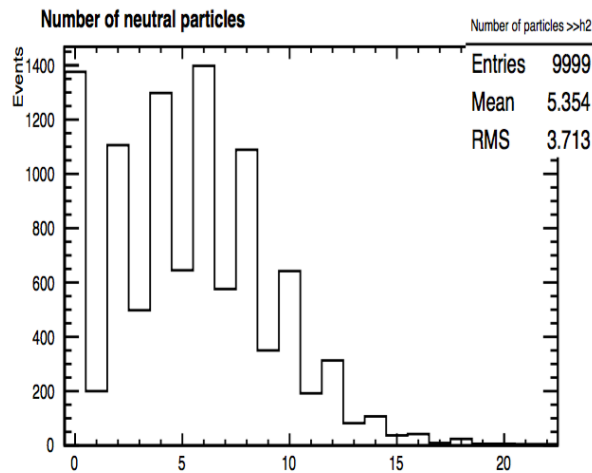
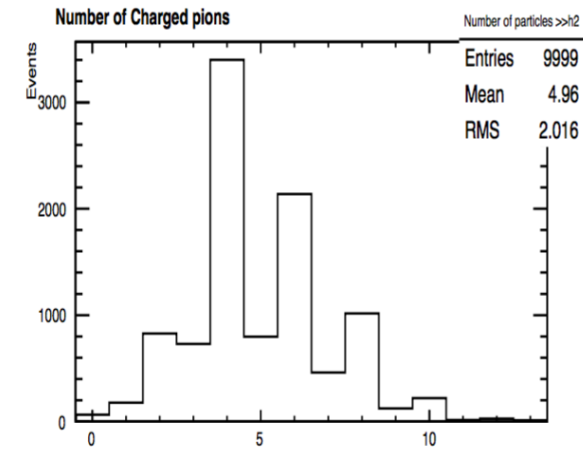
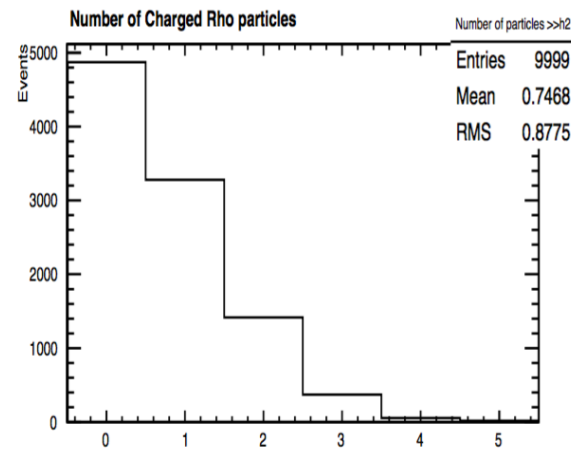
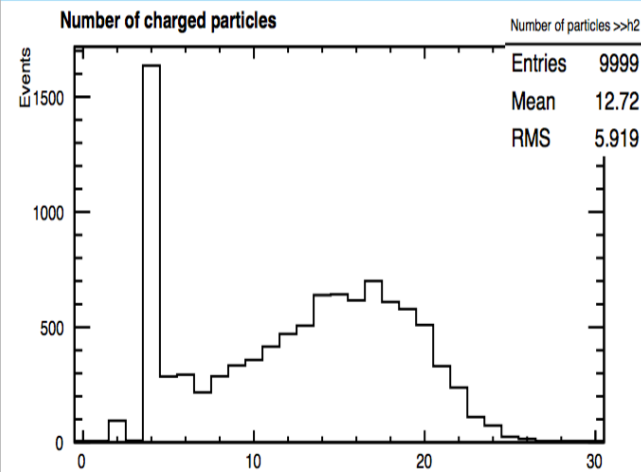
Does $\sqrt{s_{\gamma\gamma}} < 1 \text{ GeV}$ matter?

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



Ref: [archiv:1203.0217v1](#)

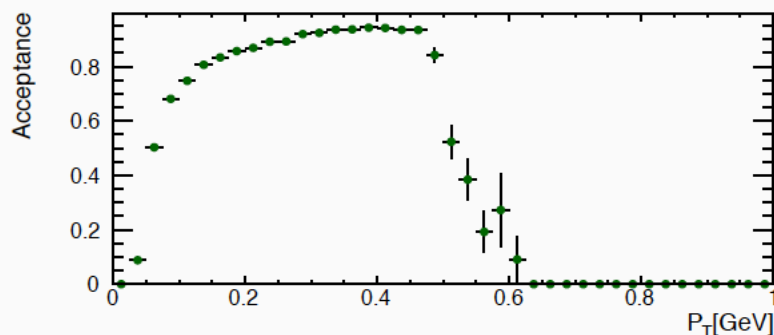
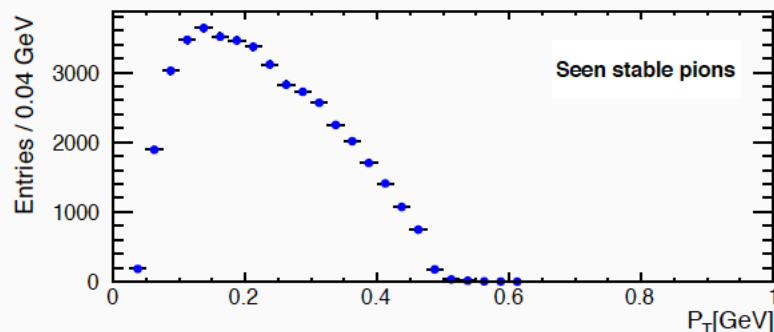
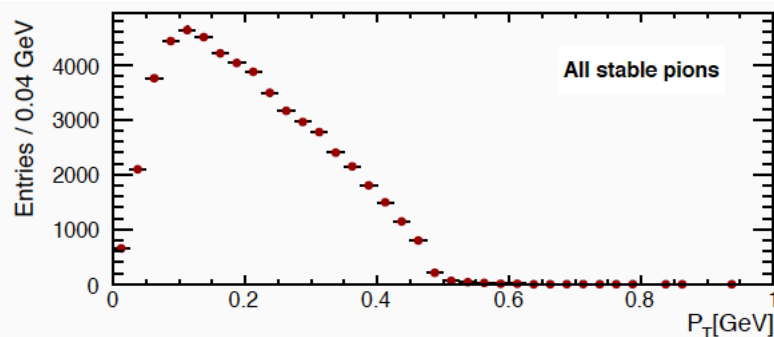
Event Properties of Pythia



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

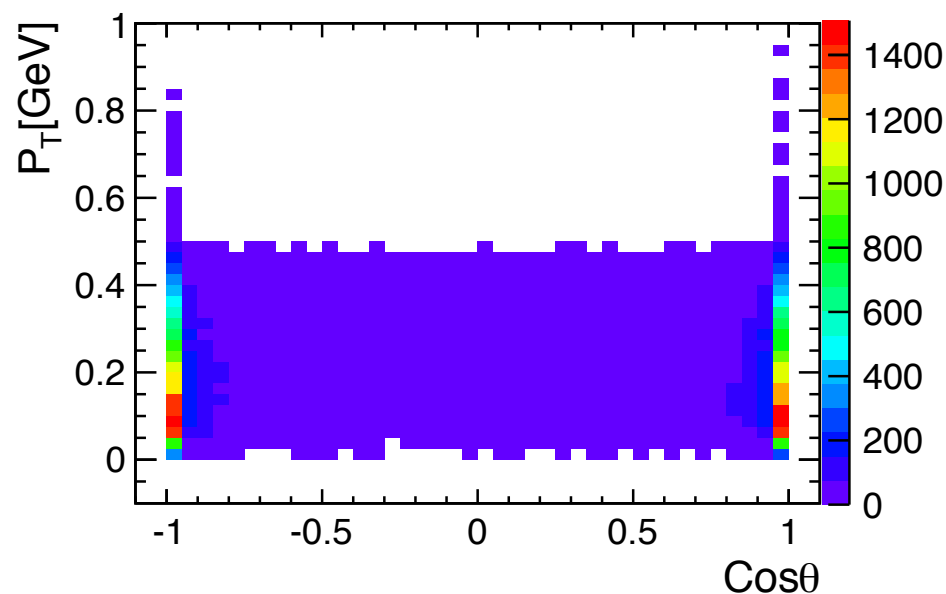


Momentum acceptance for Pions



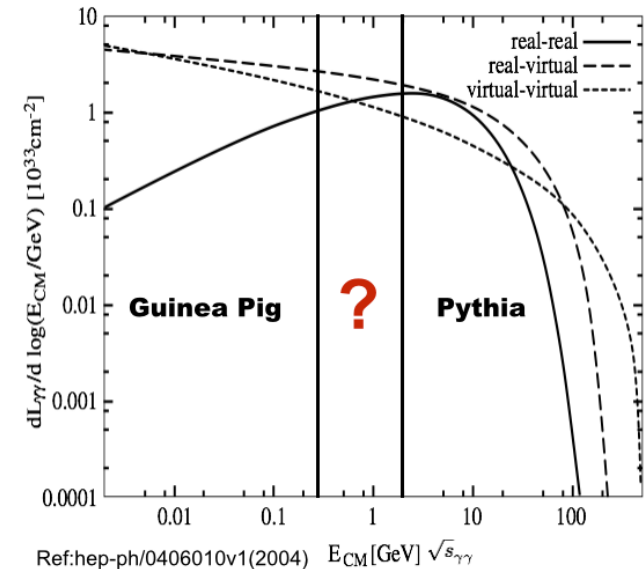
> Momentum acceptance:

- 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

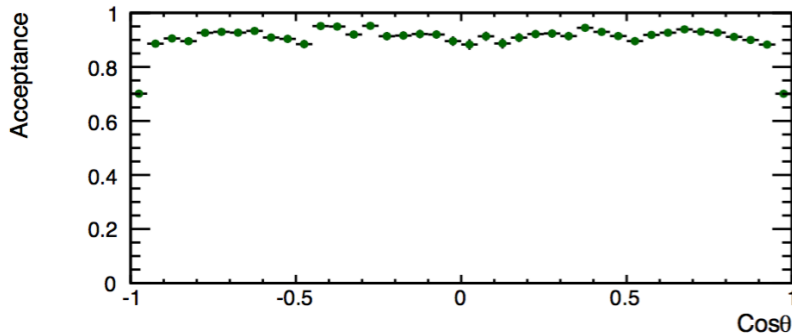
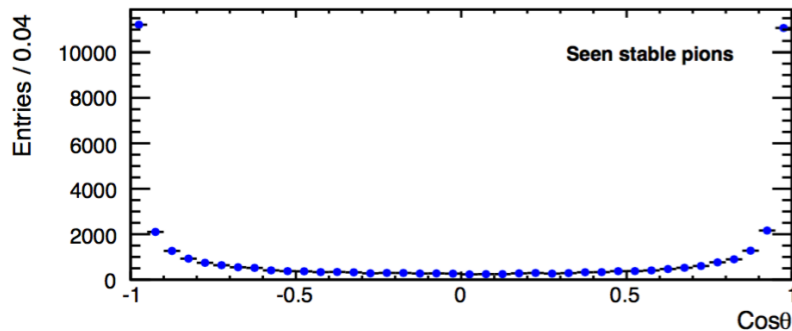
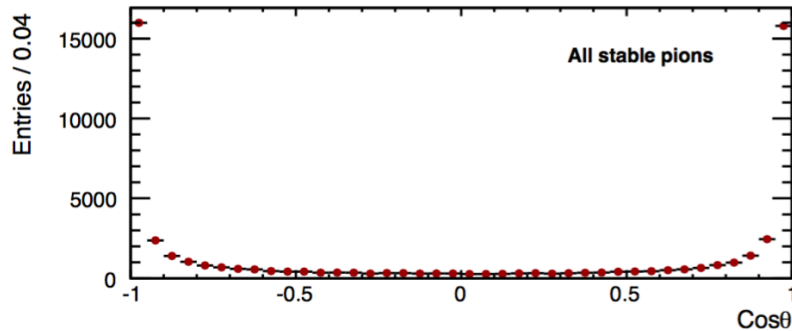


A dedicated event generator for $\gamma\gamma$ processes

- > 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?

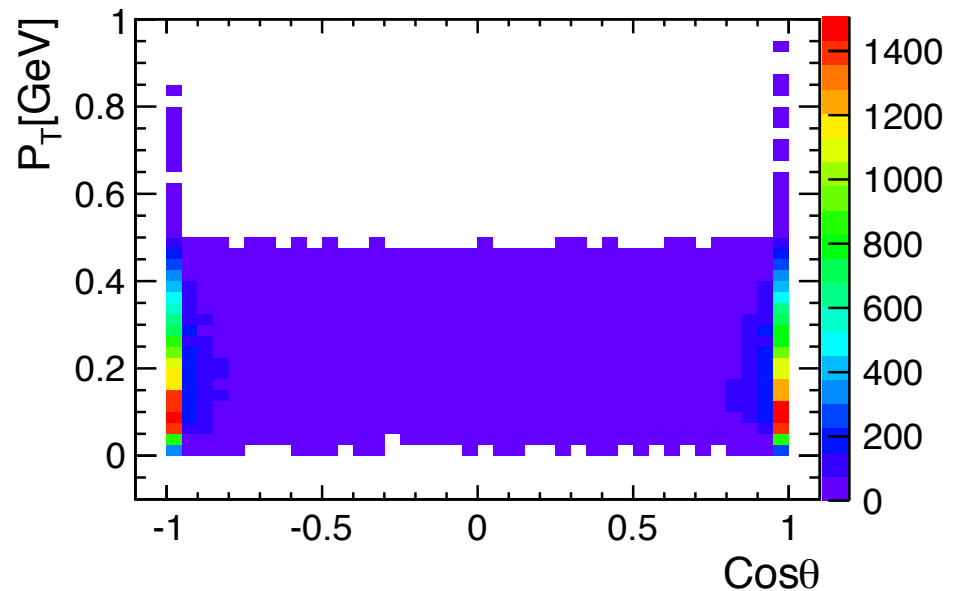


Angular acceptance for Pions



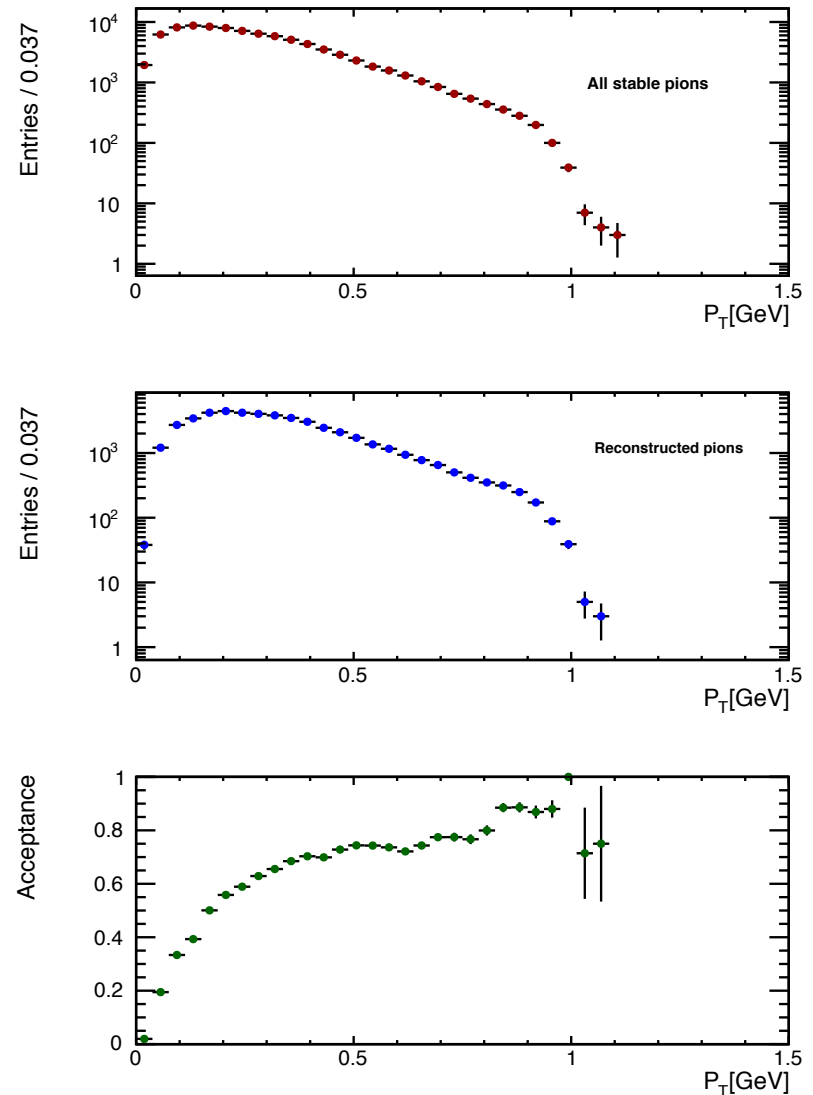
> Angular acceptance:

- Dividing seen stable pions with all true pions
- The acceptance for most particles $> 80\%$
- Particles with high P_t 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 $\sqrt{s}=2$ 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^\pm is greater than ρ^0
- > A better version of the generator was thus developed correcting the issues in older version- big progress!!!

