LONG-LIVED PARTICLE RECONSTRUCTION AT CLIC

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on behalf of the CLICdp collaboration

- Long Lived Particles
- Simulated Signal
- Reconstructed Stub Tracks
- Reconstructed Pion Tracks
- Signal + Overlay
- Conclusions and outlooks

Signal process:

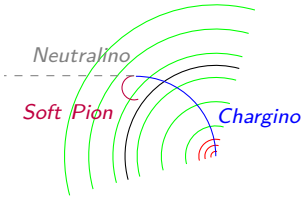
$$e^+e^- \to \widetilde{\chi}_1^+\widetilde{\chi}_1^- \to \widetilde{\chi}_1^0\pi^+\widetilde{\chi}_1^0\pi^-$$

@ 3 TeV

Long Lived Particles

- Particles with half-life time at mm scale are predicted by several theories.
- A LLP candidate (in a BSM scenario) is the chargino ($\chi_1^{\pm}$) that together with the neutralino (χ_1^0) composes the higgsino multiplet.
- Because of the small chargino-neutralino mass difference, chargino is long lived.
- emitted pions in the chargino decay are soft (narrow phase-space)
- Dark matter-motivated pure Higgsino mass $\approx 1\,\text{TeV}$ (required to explain relic abundance).
  $\rightarrow$ Charginos can be produced at CLIC third energy stage (3 TeV)

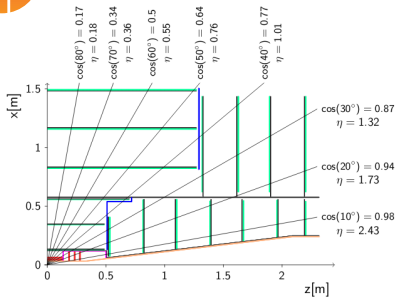
CERN-2018-009-M,
CERN-TH-2018-26721,
Dec. 2018



- Model parameters:

case	thermal limit mass	mass difference	lifetime	$c\tau$	Γ
pure higgsino	$\approx 1\,\text{TeV}$	355 MeV	0.023 ns	6.9 mm	2.86×10^{-14} eV

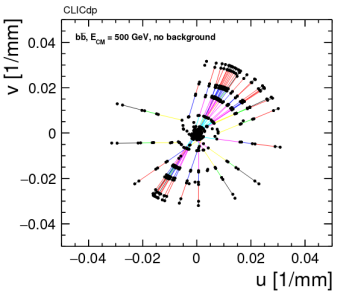
Research Tools



CLICdet

- Tracker system is divided into two all-silicon subdetectors:
  - Vertex: double layers in 3 barrels and 3 spirals.
  - Tracker: single layers in 6 barrels and 11 endcaps.

- *Conformal Tracking* performs pattern recognition in the conformal plane, where prompt tracks are translated in straight lines.
- *Pandora Particle Flow Algorithm* performs jet energy reconstruction at the calorimeter level.



Analysis Strategy for Long-Lived Charginos

Signal selection:

- Stub track candidate definition:
  - At least four hits in the tracking system;
  - Disappearing within the tracking system volume;
  - No energy deposition in the calorimeter;
  - Isolated.
- At least one stub candidate per event;
- Requirements on the soft pion(s) production point (additional);
- Photon requirements (additional).

Backgrounds:

- $\gamma\gamma \rightarrow$ hadrons main background:
  - algorithmic;
  - split tracks;
  - conversion.
- final state with low multiplicity of isolated leptons.

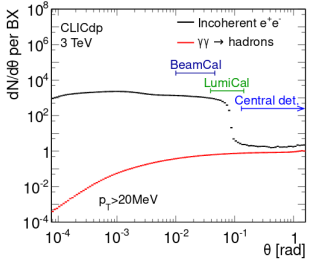
Simulated Signal

Signal

- 50k events;
- 3 TeV CoM;
- ISR;
- beamspectrum;
- negative beam polarization: $P(e^-) = -80\,\%$;
- chargino mass: 1050 GeV;
- neutralino mass: 1049.645 GeV;
- chargino mean lifetime: 600 mm.
  $\rightarrow$ hugely overestimated for statistical reasons.
  Reweight charginos based on their decay length to the physical lifetime distribution.

Beam-induced Background

- $\gamma\gamma \rightarrow$ hadron overlay (simulated);
  $\rightarrow$ dominant in the silicon tracker.
- Incoherent e^+e^- (not simulated).
  $\rightarrow$ dominant in the vertex and the very forward region.



$$e^+ + e^- \rightarrow \widetilde{\chi}^+\widetilde{\chi}^- \rightarrow \widetilde{\chi}^0 u\bar{d}\widetilde{\chi}^0 d\bar{u} + \text{PS and hadronization (Pythia6) + detector interaction (Geant4)}$$

Whizard Whizard Whizard

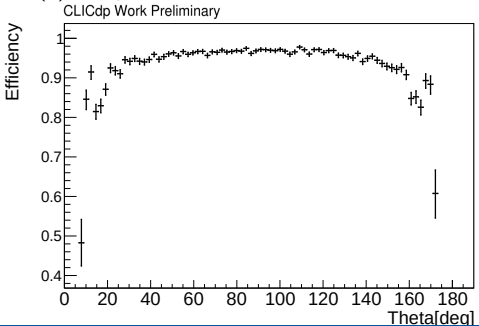
Reconstructed Chargino Tracks

* Stub tracks reconstruction is a hard challenge for the algorithm.

- Tracking efficiency $\approx 96\,\%$ for chargino tracks in central detector region.
- Efficiency has been computed as follows:

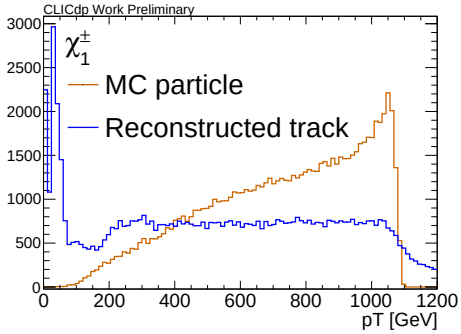
$$\frac{\text{reconstructed}}{\text{reconstructable}^{*}}$$

(*) MC particles with at least four hits



- PT reconstruction limited by the pixel single point resolution in the sagitta evaluation.
  $\rightarrow$ discrepancies between MC value and reconstructed one.

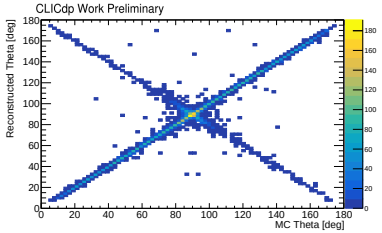
$$p_{\mathrm{T}} = 0.3B\frac{\left(\frac{d}{2}\right)^2 + s^2}{2s}$$

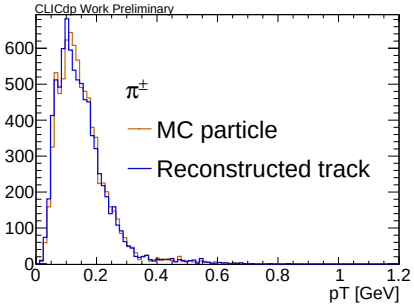


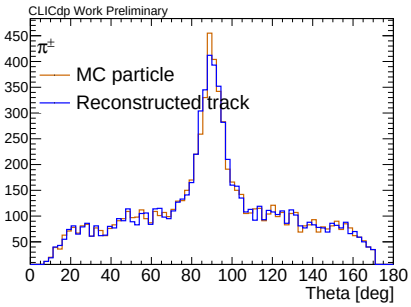
Reconstructed Pion Tracks

Preliminary Analysis

- Excellent performances in reconstructing pT.
- Polar angle distribution different from what we expected.
  → Anomalous peak in the central theta region.
  → Anomalous anticorrelation between MC theta and reconstructed theta.



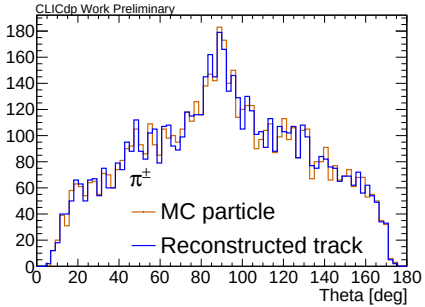


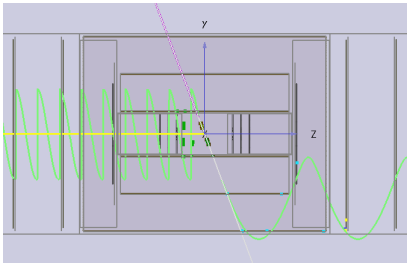


Reconstructed Pion Tracks

Duplicates

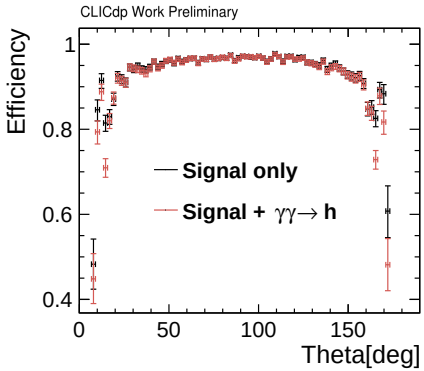
- Conformal Tracking algorithm tends to split looping tracks, reconstructing them in pieces.
  $\rightarrow$ same MC information stored more than once, associated to several different reconstructed polar angles.
  $\rightarrow$ More duplicates in the central theta region: These tracks leave more hits in the Tracker.
- Theta plot with no MC particle doubled. The associated track has been chosen on the closeness between its reconstructed theta and the simulated one.
- Anticorrelation given by the helix flipping made by the algorithm. Not completely removed.
- Remaining peak in the central theta region not yet investigated.

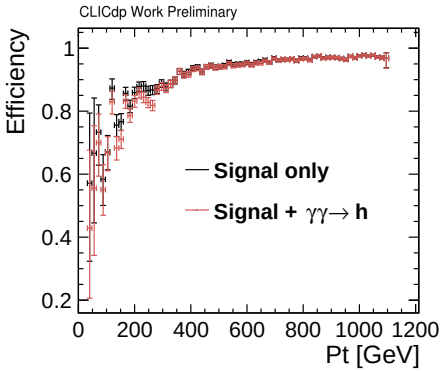




Signal $+\gamma\gamma \rightarrow$hadron Overlay Analysis

Chargino Efficiencies

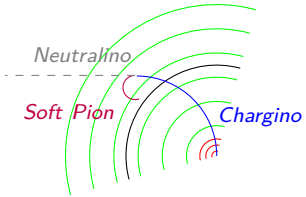




- Efficiency $= \frac{\text{reconstructed}}{\text{reconstructable}^*}$. For MC information. (*) MC particles with at least four hits.
- Efficiency decreases slightly at low pT and in the detector very forward regions when the overlay is introduced.

Signal $+\gamma\gamma \rightarrow$hadron Overlay Analysis

Definition of a Stub



- Track

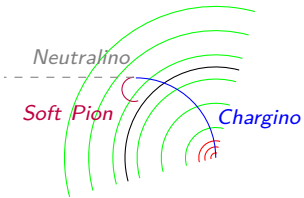
A good definition of stub track is the one that maximize the efficiency of recognizing a chargino track and minimize the number of fakes at the same time.
Hence, we should find in what charginos* and the other event tracks** are different.

First of all, it should be a track, which means that it is associated to at least four hits in the tracking system. (Minimum number of hits required for the reconstruction of prompt tracks).

(*) This study has been performed looking at PDG Ids associated to the tracks.
(**) Tracks from $\gamma\gamma \rightarrow$hadrons in the same events. Normalisation not correct

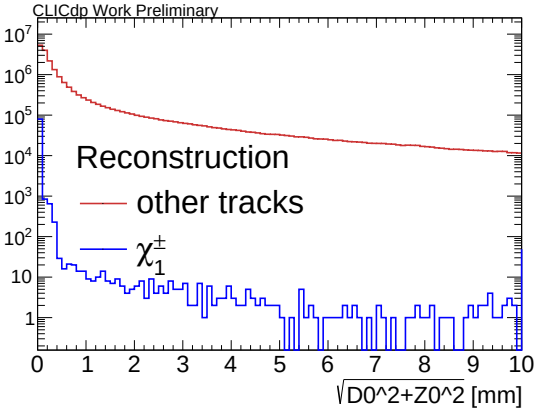
Signal $+\gamma\gamma \rightarrow$hadron Overlay Analysis

Definition of a Stub



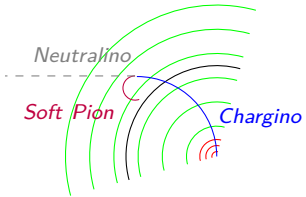
- Track
- Prompt

Stub tracks are prompt $\rightarrow$ Possible cut at $\sqrt{D0^2 + Z0^2} > 0.5\,\text{mm}$.



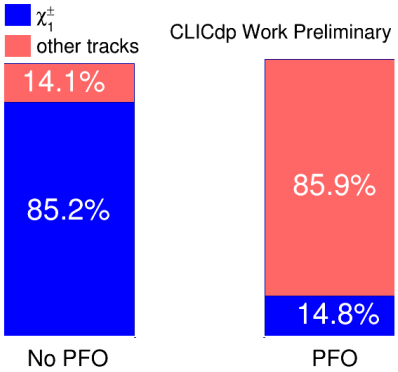
Signal $+\gamma\gamma \rightarrow$hadron Overlay Analysis

Definition of a Stub



- Track
- Prompt
- No PFO association

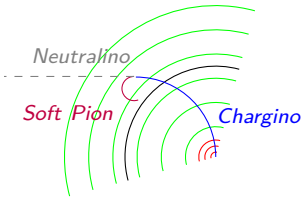
Stub tracks are not associated to PFO.
(PandoraPFOs LCIO collection)



Only not related PFO tracks are considered.

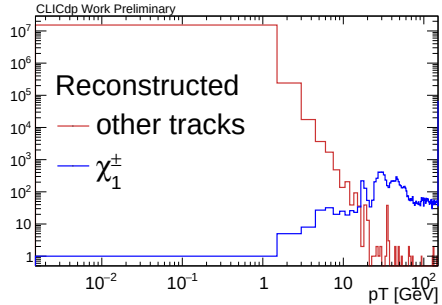
Signal $+\gamma\gamma \rightarrow$hadron Overlay Analysis

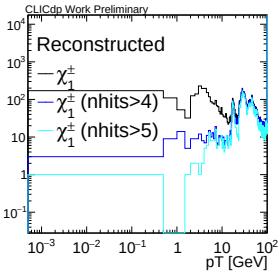
Definition of a Stub



- Track
- Prompt
- No PFO association
- Pt requirements

Charginos have higher pT than background tracks
$\rightarrow$ Cut at pT$=$ 10 GeV.

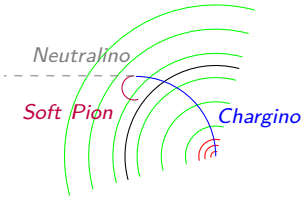




The plot on the left takes into account tracks with more than 5 hits only.

Signal $+\gamma\gamma \rightarrow$hadron Overlay Analysis

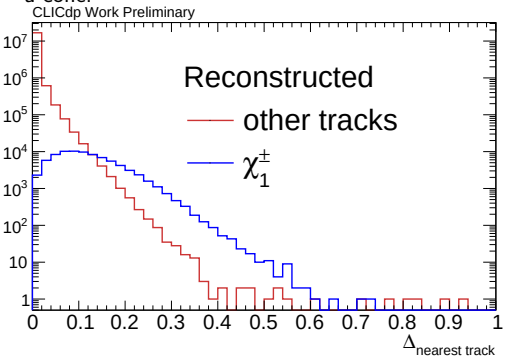
Definition of a Stub



- Track
- Prompt
- No PFO association
- Pt requirements
- Isolation

Chargino stub tracks are isolated tracks, their $\Delta_{nearest\ track}$ distribution is peaked at higher values.

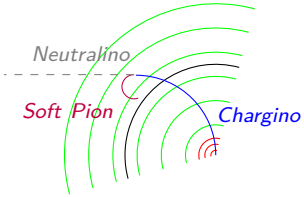
Other isolation criteria are under investigation, i.e. pT sum in a cone.



$$\Delta_{nearest\ track} = min(\sqrt{\Delta\phi^2 + \Delta\eta^2})$$

Signal $+\gamma\gamma \rightarrow$hadron Overlay Analysis

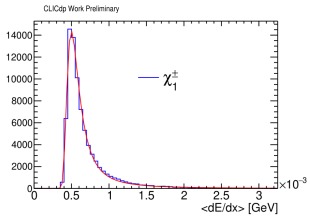
Definition of a Stub

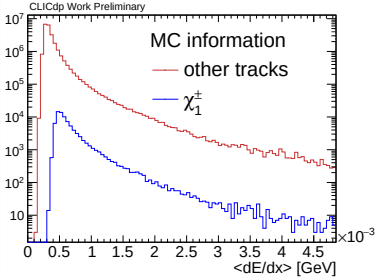


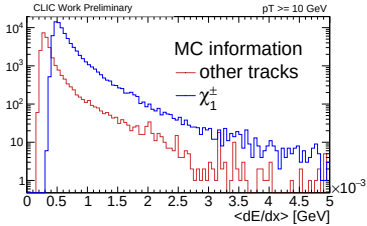
- Track
- Prompt
- No PFO association
- Pt requirements
- Isolation
- dEdx identification

Chargino <dE/dx> Landau distribution maximum is shifted to the right with respect to the one of other tracks distribution.

Possible cut at <dE/dx> = 0.5 MeV.







Conclusions and Outlooks

- The analysis performed suggests that a stub candidate can be identified under several aspects:
  - Promptness
  - PFO
  - PT
  - Isolation
  - dEdx Identification

- Fake stubs study will be performed:
  - Study on fake rate;
  - Behavior of fake stub tracks;
  - Suppression of fake stub background.

  $\Big\}$ $\longrightarrow$ Estimation of the total background of fake stub tracks to this analysis.

- Cuts efficiency will be analyzed.
- Other possible cuts will be investigated (i.e. track length, pT cut depending on number of hits, ...).

BACKUP

Preliminary Study on Background

- Analyzed data-set: $e^+ + e^- \rightarrow \nu\ \nu$ + Overlay. (123k event).

- After having applied the following cuts:
  - no PFO track selection
  - pT $> 10\,\text{GeV}$
  - $\sqrt{D0^2 + Z0^2} < 0.5\,\text{mm}$
- We obtained the plot on the right. (only 405 tracks selected).
- If the $\frac{dE}{dx}$ identification will be possible, we would be able to remove a non-negligible part of background. (Cut proposed before: $< dE/dx > > 0.5\,\text{MeV}$).