Long-lived particles at CLIC

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on behalf of the CLICdp collaboration

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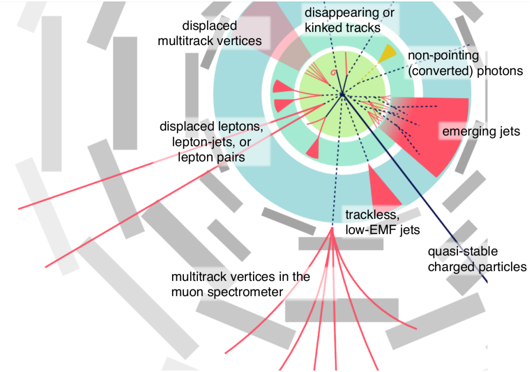
Introduction

Long-lived particles in theory

- Various new physics models predict particles with macroscopic lifetimes
- Example: Small mass splitting/compressed spectra
- "Standard" analyses lack sensitivity
- Variety of signatures in detectors depending on the model (mass, lifetime, boost)
- LHC long-lived particles overview report: 1903.04497
- Many ongoing analyses at the LHC (ATLAS, CMS, LHCb), and dedicated experiments (FASER)

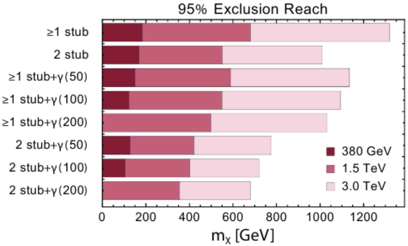


from https://indico.cern.ch/event/607314/contributions/2542309

Long-lived particles at CLIC

- Hidden valley searches in Higgs boson decay
  - displaced multi-track vertices
  - full simulation study with CLIC_ILD CLICdp-Note-2018-001
- Degenerate Higgsino Dark Matter
  - Theory-level study for the CLIC Potential for New Physics yellow report [1812.02093] by N. Craig and S. Alipour-Fard
  - Process: chargino pair production
  - Stub tracks from charged Higgsino with a lifetime of 6.9 mm
  - Decay to pion and neutralino
  - Using geometrical detector acceptance and requirement of at least 4 hits in the CLIC vertex & tracker for the efficiency of reconstructing the stub tracks

- Analysis with 1 or 2 stubs and possibly additional photon at 3 TeV
- Resulting exclusion limits assuming no background:

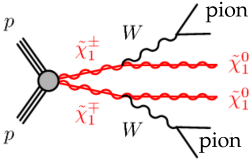


(Fig. 74 from the YR)

- Reach thermal DM mass of $\approx$ 1 TeV

Full simulation of LLP chargino pair production

- Process: chargino pair production, i.e. $e^+e^- \rightarrow \chi_1^\pm \chi_1^\pm$ where the $\chi_1^\pm$ decay to a neutralino and a pion:
  $e^+e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0 \pi^+ \tilde{\chi}_1^0 \pi^-$
- Small mass difference between chargino and neutralino: Chargino mass $m_{\tilde{\chi}_1^\pm} = 1050\,\text{GeV}$, neutralino mass $m_{\tilde{\chi}_1^0} = 1049.8\,\text{GeV}$
- Production chain:
  - Chargino pair production and decay in Whizard
  - Parton shower and hadronization in Pythia
  - Displacement of the decay vertex in Geant4



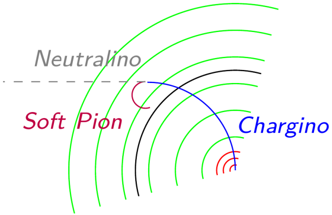
chargino mixing	thermal limit mass	mass difference	lifetime	$c\tau$	Γ
pure higgsino	$\approx$ 1 TeV	355 MeV	0.023 ns	6.9 mm	2.86×10^{-14} eV

- Sample produced for the studies shown here uses lifetime of 600 mm in order to increase the statistics of reconstructable charginos

Analysis strategy

Signal selection

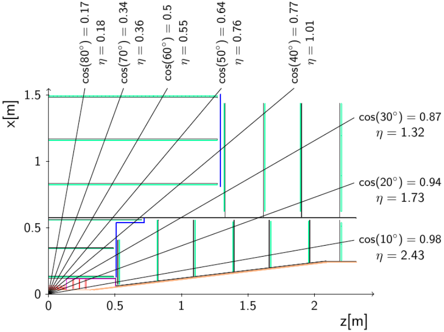
- Stub track candidate definition:
  - at least four hits in the tracking system
  - disappearing within the tracking system volume
  - no energy deposition in the calorimeter
  - isolated track
  - minimum transverse momentum
  - possibly: dE/dx requirement
- At least one stub candidate per event
- Possibly: Requirements on soft displaced pion(s)
- Possibly: Requirements on additional photons



Backgrounds:

- Beam-induced $\gamma\gamma \rightarrow$ hadrons:
  - algorithmic
  - split tracks
  - conversion
- final states with low multiplicity of isolated leptons

Track reconstruction for the analysis

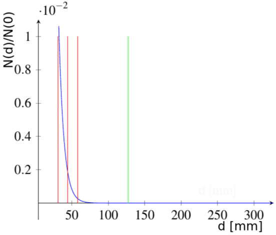


2 challenging types of objects for track reconstruction:

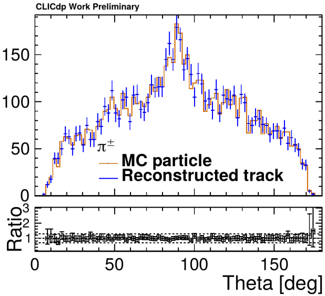
- Stub track reconstruction
  - in many cases too short to be reconstructable
  - at CLIC 3 TeV: E = 1.5 TeV, m = 1.05 TeV $\Rightarrow$ p = 1.07 TeV

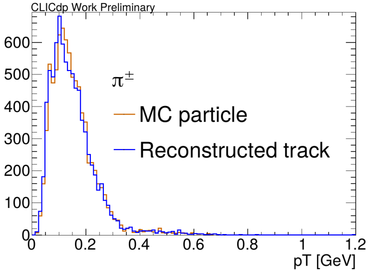
  $\Rightarrow$ chargino gives very straight and short track $\Rightarrow$ difficult to reconstruct track parameters
- Displaced pions
  - very soft
  - displaced

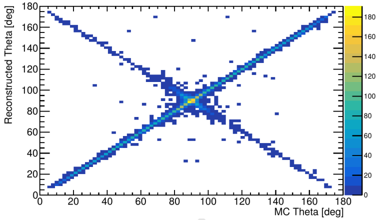
chargino lifetime distribution:



Track reconstruction of soft displaced pions





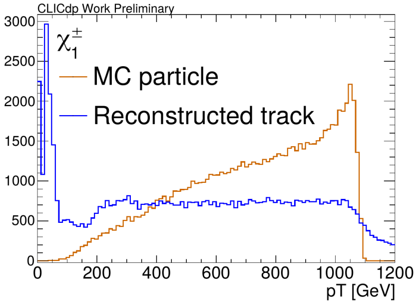


- Soft displaced pions are well reconstructed (pT)
- Reconstruction efficiency is ≈ 60 %
- Polar angle:
  - significant contribution of flipped θ due to helix fit of the central soft objects
  - excess in central region

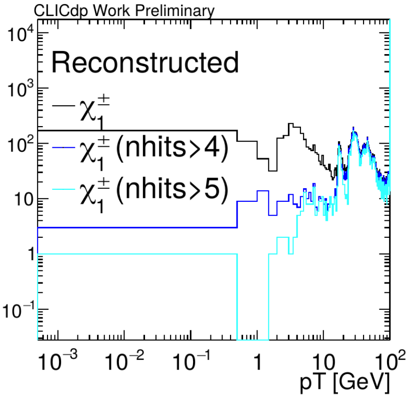
Track reconstruction of stub tracks

- Sensitivity to the curvature of a particle in a given magnetic field depends on the length of the track (d) and the sagitta (s)

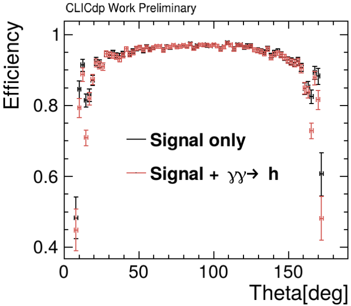
$$p_T = 0.3B\frac{\left(\frac{d}{2}\right)^2 + s^2}{2s}$$

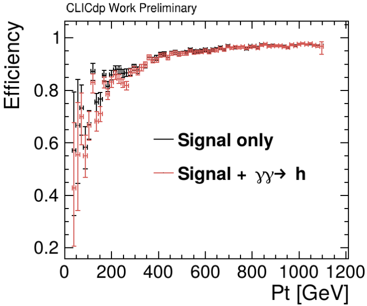


$\Rightarrow$ pT reconstruction of short, straight tracks is limited by the single point resolution



Efficiency for stub tracks



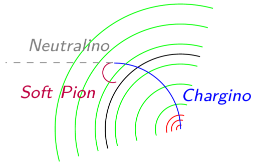


Efficiency: $\epsilon = \frac{N_{\text{reconstructed}}}{N_{\text{reconstructable}}}$

reconstructable: $\geq$ 4 hits in the detector

- Efficiency decreases slightly at low pT and in the detector very forward regions when the overlay is introduced

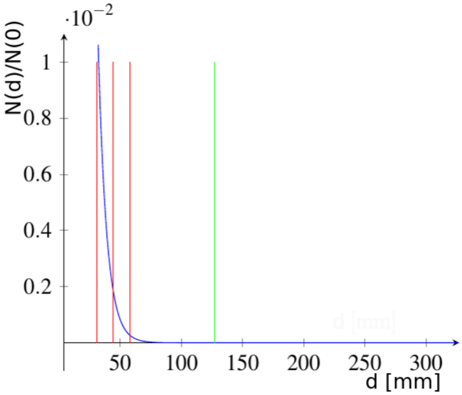
Stub track definition



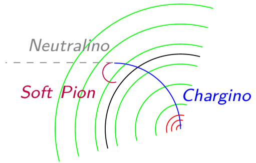
- Track

reconstructable: at least 4 hits

chargino lifetime distribution:

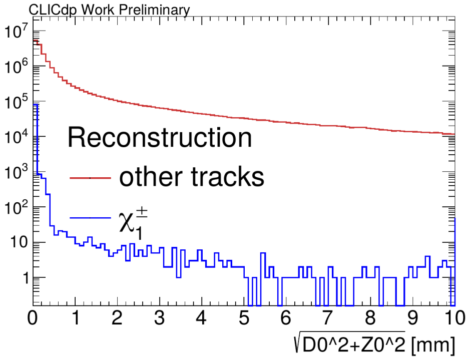


Stub track definition

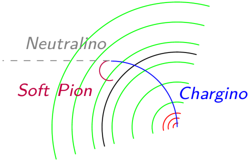


- Track
- Prompt

stub tracks are prompt → possible cut $\sqrt{d_0^2 + z_0^2} < 0.5\,\mathrm{mm}$

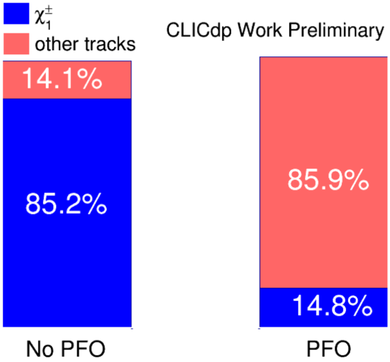


Stub track definition



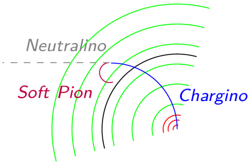
- Track
- Prompt
- No PFO association

Stub tracks are not associated to a PFO



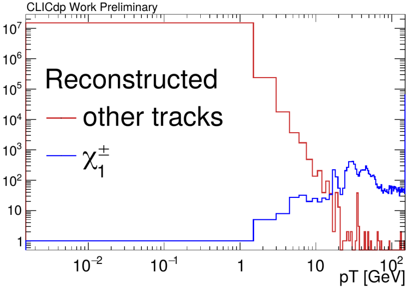
(the 14.8 % include PFOs below 1.5 GeV which are standalone tracks, as well as the overestimate of the lifetime in the given sample)

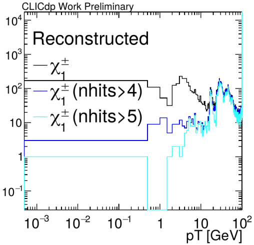
Stub track definition



- Track
- Prompt
- No PFO association
- p_T requirement

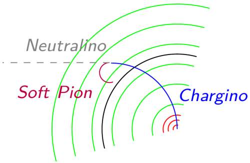
Charginos have higher pT than background tracks → preliminary cut at 10 GeV





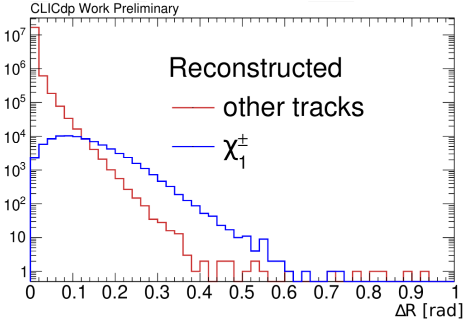
Note that this removes shorter tracks → under investigation

Stub track definition



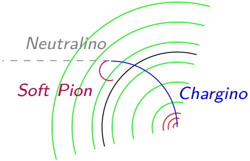
- Track
- Prompt
- No PFO association
- p_T requirement
- Isolation requirement

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



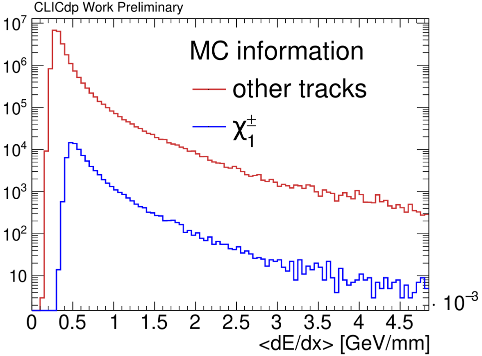
Other isolation criteria are under investigation, e.g. pT sum in a cone.

Stub track definition



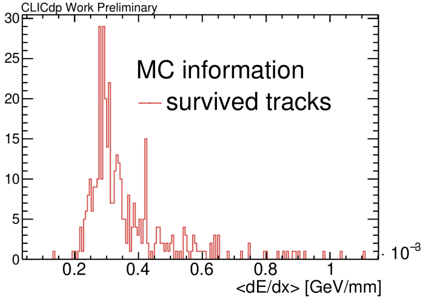
- Track
- Prompt
- No PFO association
- p_T requirement
- Isolation requirement
- dE/dx requirement

dE/dx distribution for charginos is shifted to higher values



Preliminary background study

- $\gamma\gamma \rightarrow$ hadrons-only sample is used to study the main background
- Efficiency of 0.32 % by requiring at least on stub candidate with
  - $\sqrt{d_0^2 + z_0^2} < 0.5\,\text{mm}$
  - $p_T > 10\,\text{GeV}$
  - No PFO association
- Additional cut could be on dE/dx $\longrightarrow\longrightarrow\longrightarrow$

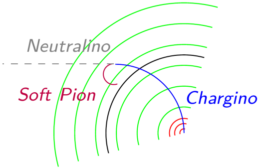


$\Rightarrow$ ongoing study to further understand and suppress the background

- dE/dx resolution
- additional requirement on pions
- possibility to add photons

Conclusions and outlook

- Long-lived particles signatures = unexplored avenues for searches for new physics
- Charged long-lived particles at CLIC benefit from clean environment and high precision of the track reconstruction
- Investigated a sample of long-lived chargino pair production
- Track reconstruction of stub tracks quite efficient, p_T reconstruction limited by length of the track
- Preliminary background study shows handle on $\gamma\gamma \rightarrow$ hadrons by optimizing stub track definition and dE/dx criterion
  $\Rightarrow$ **to be continued**



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