Long-Lived Particle Search with Lepton Colliders

Cen Mo

Shanghai Jiao Tong University

上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

目录 Contents

目录 Contents

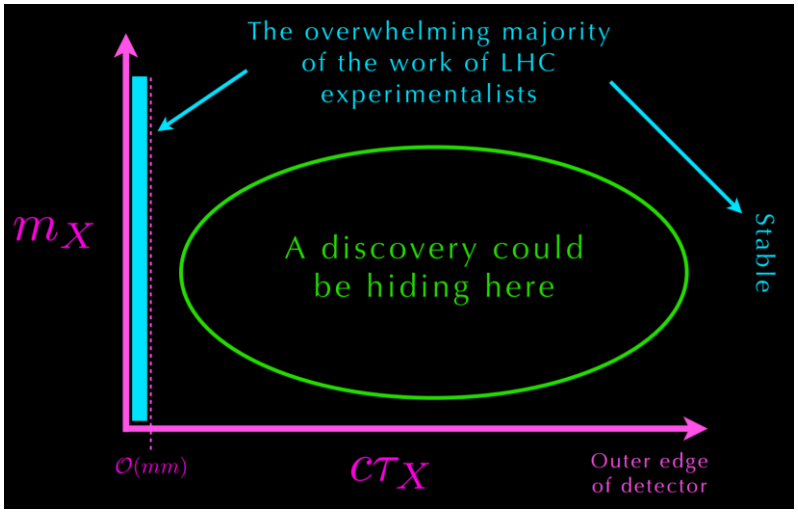
What is long-lived particle?

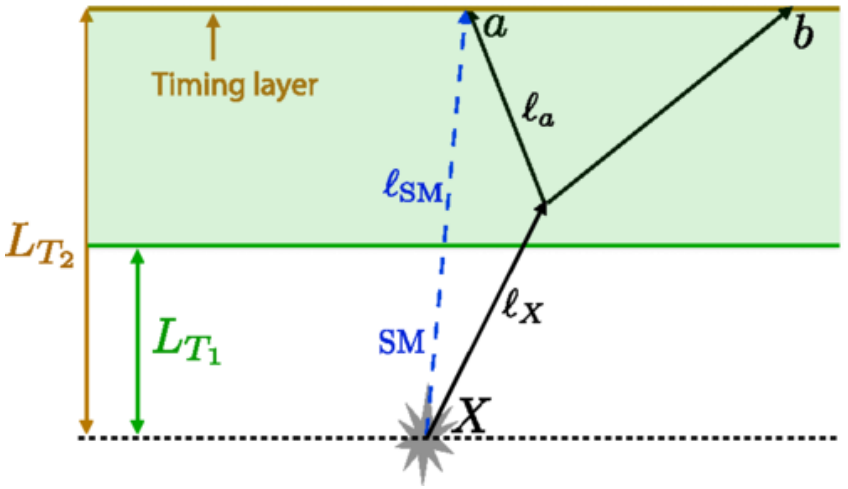
- Long-lived particle (LLP)

Particles decaying a **macroscopic** and **reconstructible** distance from interaction point.

- Signal signature of a neutral long-lived particle:

A burst of energy appearing out of nowhere away from the collision point.

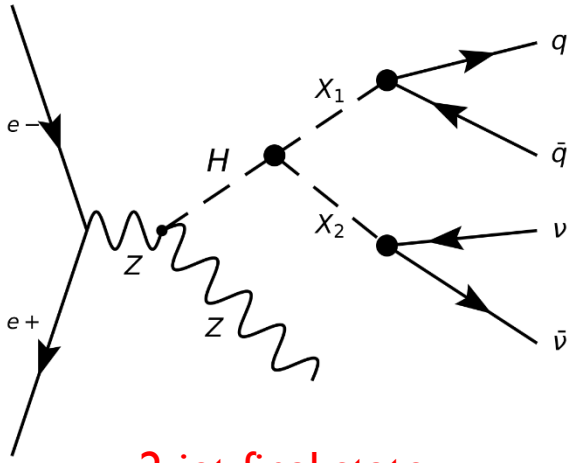




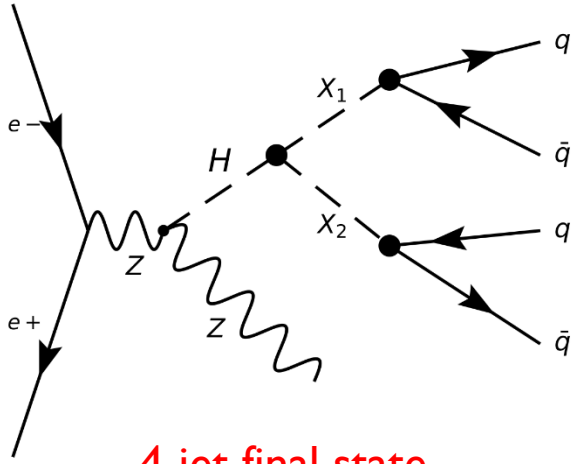
Phys. Rev. Lett. **122**, 131801 – 2019.04.03

目录 Contents

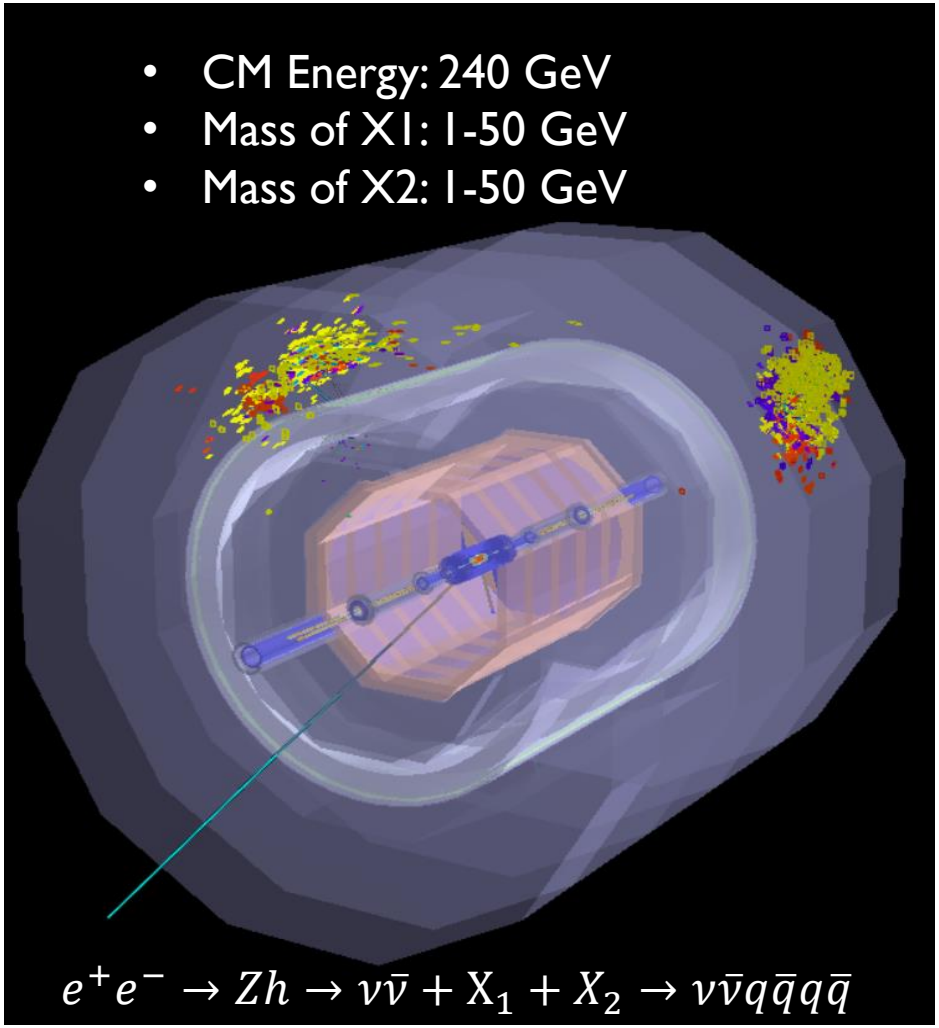
LLPs at future lepton colliders



2-jet final state



4-jet final state



Full simulation setup

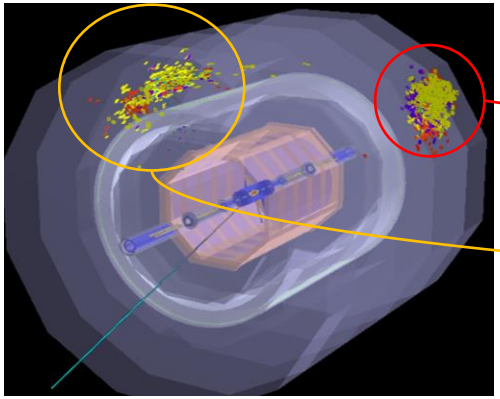
- **Full simulation** with CEPC official software (V4)
- The decay vertex of LLPs: $\mathbf{0 \leq r_{decay} \leq 6\ [m]}$
- Signal sample generated by MadGraph5 and showered by Pythia8

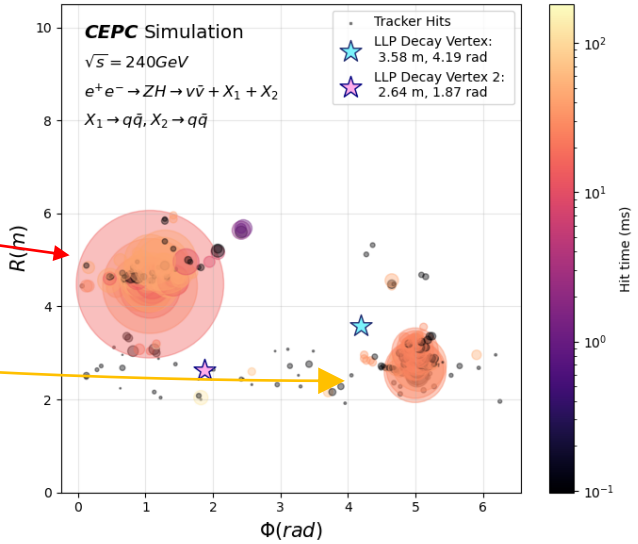
Process	# of Events simulated
Signal: $Z \to \bar{q}q, h \to SS1 + SS2$ (2-jet)	$\sim 5.0 \times 10^5$
Signal: $Z \to \bar{\nu}\nu, h \to SS1 + SS2$ (2-jet)	$\sim 5.0 \times 10^5$
Signal: $Z \to \bar{q}q, h \to SS1 + SS2$ (4-jet)	$\sim 5.0 \times 10^5$
Signal: $Z \to \bar{\nu}\nu, h \to SS1 + SS2$ (4-jet)	$\sim 5.0 \times 10^5$
$e^+e^- \to q\bar{q}$	$\sim 0.99 \times 10^7$
$e^+e^- \to Zh$ (Standard Model)	$\sim 1.37 \times 10^6$
$e^+e^- \to W/Z$	$\sim 1.3\times 10^7$

目录 Contents

Configuration

- Mapping the **raw detector information** to a 2D image
- Input Format: image with resolution of $(\mathrm{R}, \phi) = 200 \times 200$ and 2 channel(s)
  - $R_i = i \times \Delta R_i$, R starts from 0 m to 8 m.
  - ϕ starts from $-\pi$ to π





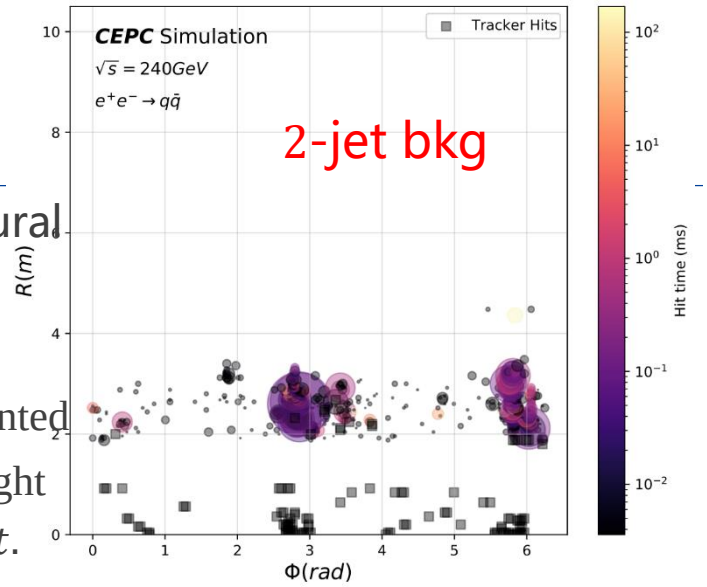
- CNN Model: ResNet18
- **Cross Entropy Loss:** $loss = -[\omega_0 * y_0 \log(x_0) + \omega_1 * y_1 \log(x_1) + \omega_2 * y_2 \log(x_2)]$

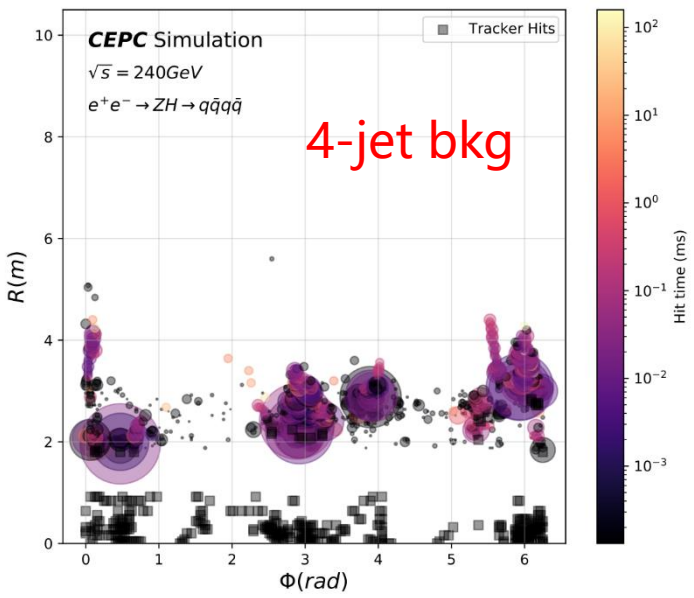
Class 0: 2-fermion bkg	Class 1: 4-fermion bkg	Class 2: LLP Signal
$\omega_0 = 0.25$	$\omega_1 = 0.25$	$\omega_2 = 0.5$

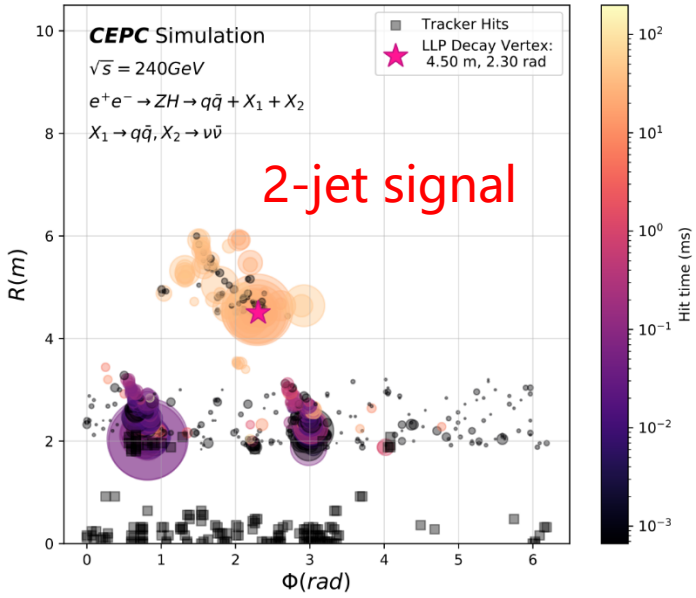
Image

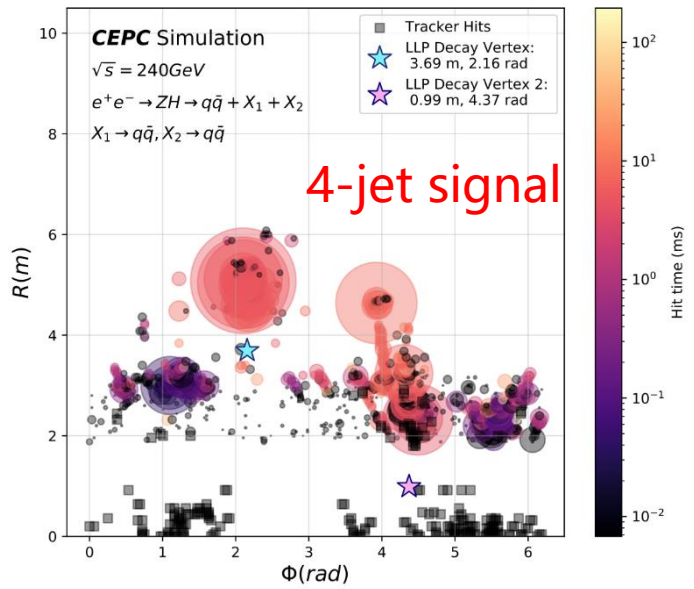
Images received by neural network.

- $\Delta t = t_{hit} - \frac{R}{c}$ is represented by the color of circle: light color represents large Δt.
- Energy deposition is illustrated as the size of circle: bigger circle represents more energy.



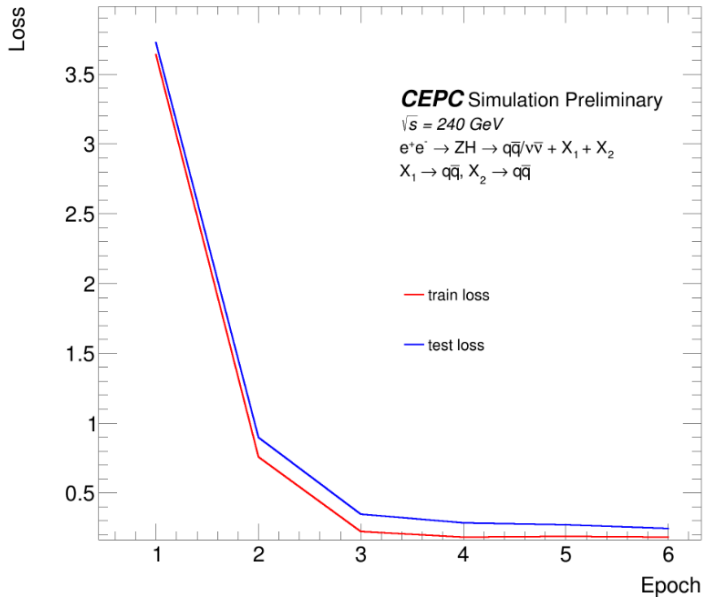


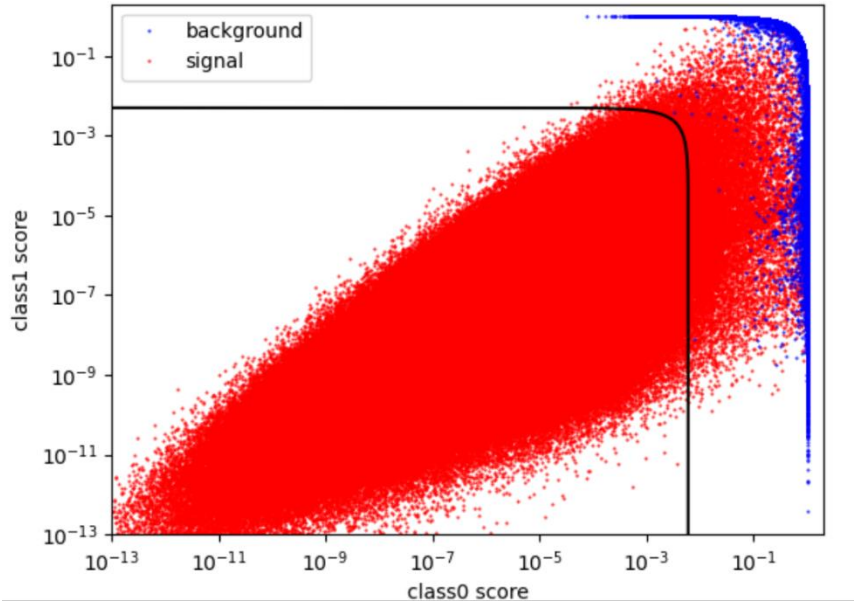




目录 Contents

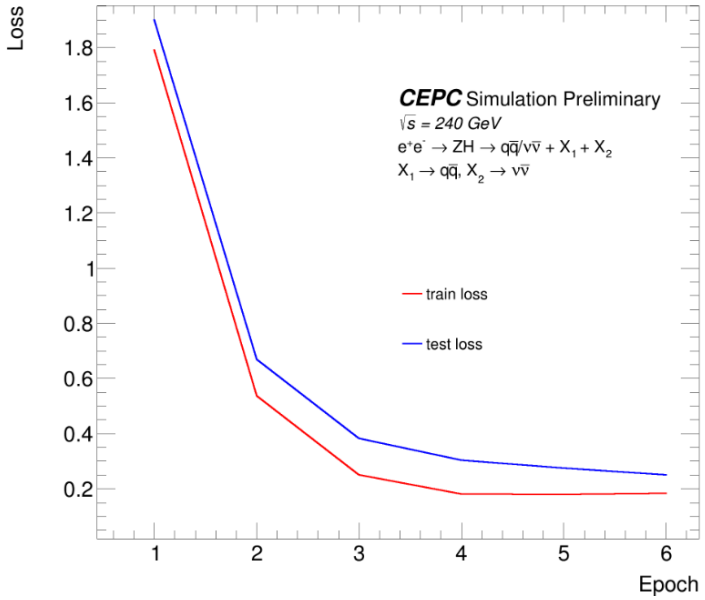
Training of 4-jet

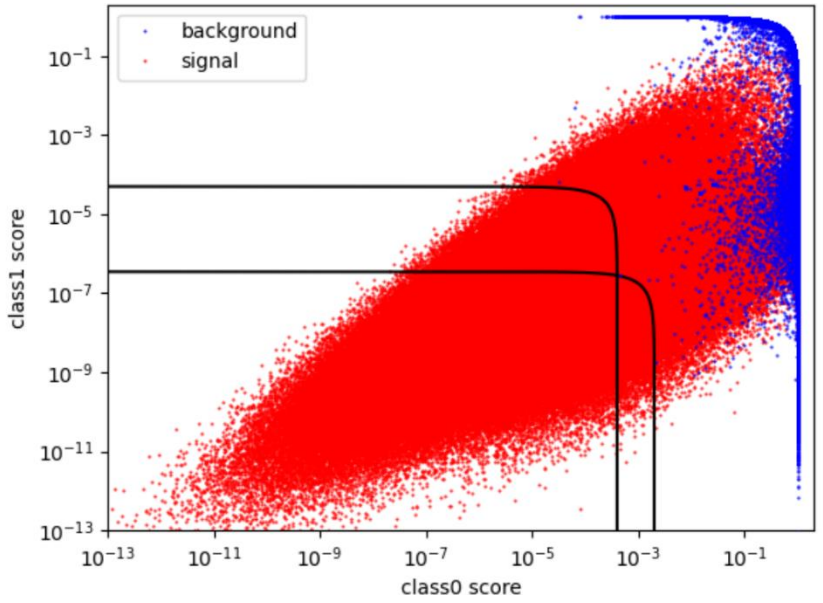




	Total Event	Passed Event	ϵ
Signal: $e^+e^- \to \boldsymbol{ZH} \to SS1 + SS2$ (4-jet)	926,427	909,620	98.18%
Class 0: 2-fermion background	1,425,628	0	0%
Class 1: 4-fermion background	893,984	0	0%

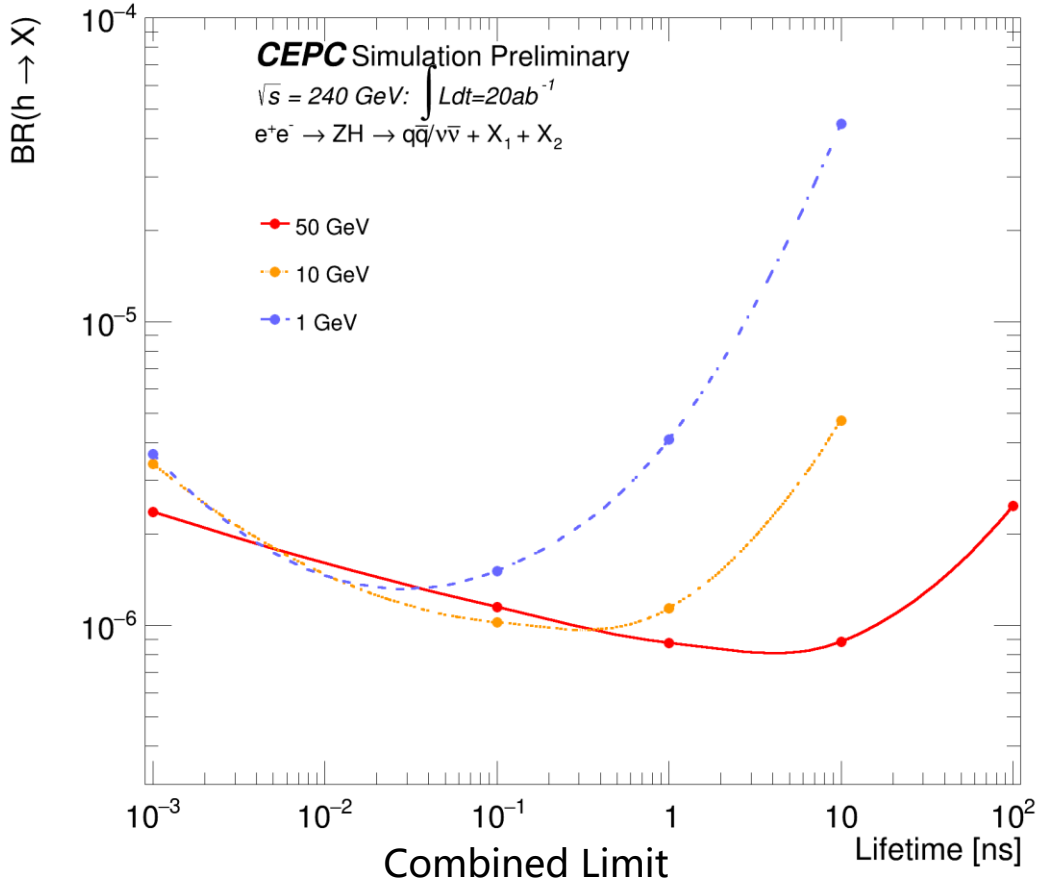
Training of 2-jet

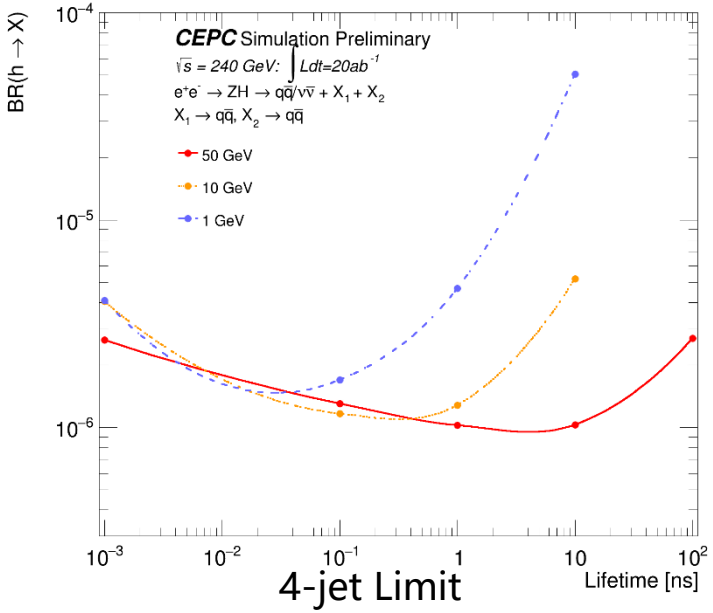


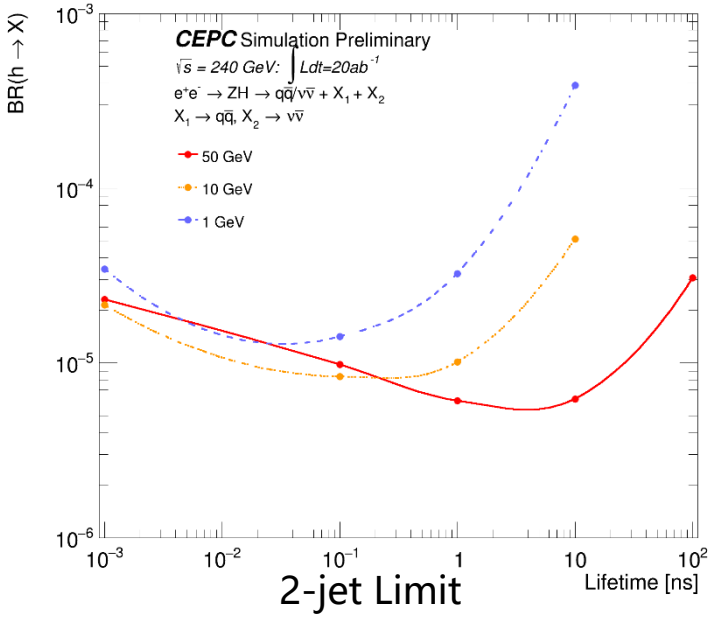


	Total Event	Passed Event	ϵ
Signal: $e^+e^- \to \boldsymbol{ZH} \to SS1 + SS2$ (2-jet)	879,823	708,224	80.49%
Class 0: 2-fermion background	1,425,628	0	0%
Class 1: 4-fermion background	893,984	0	0%

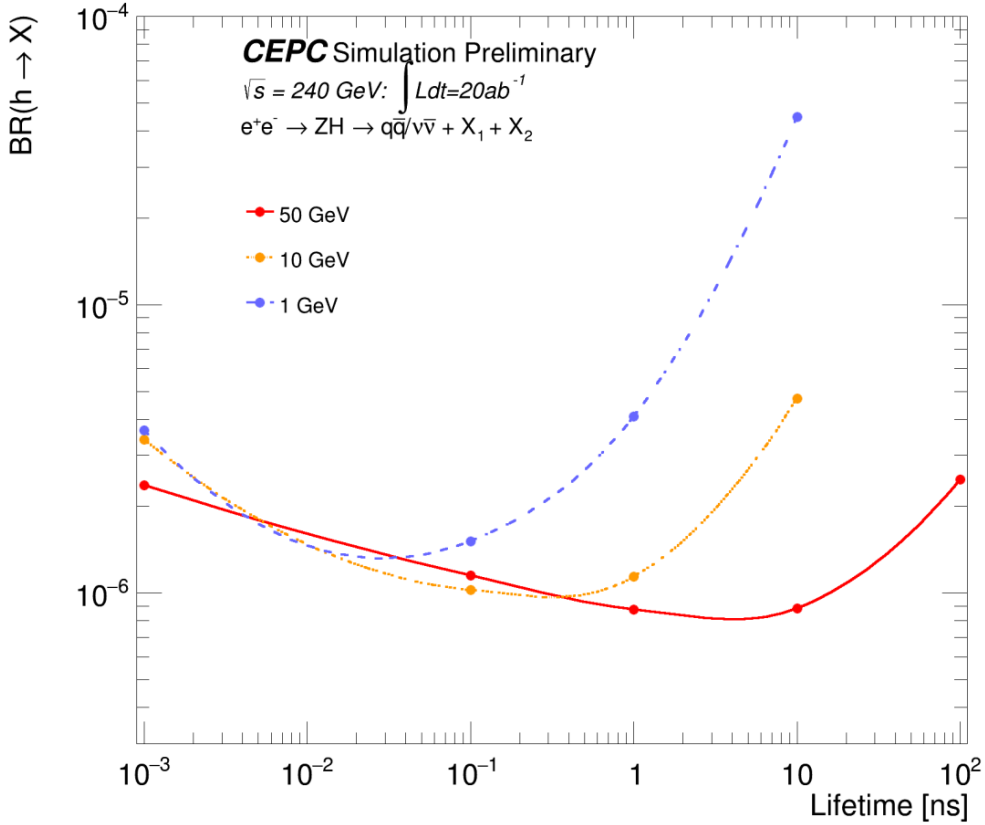
Exclusion Limit (95% CL)



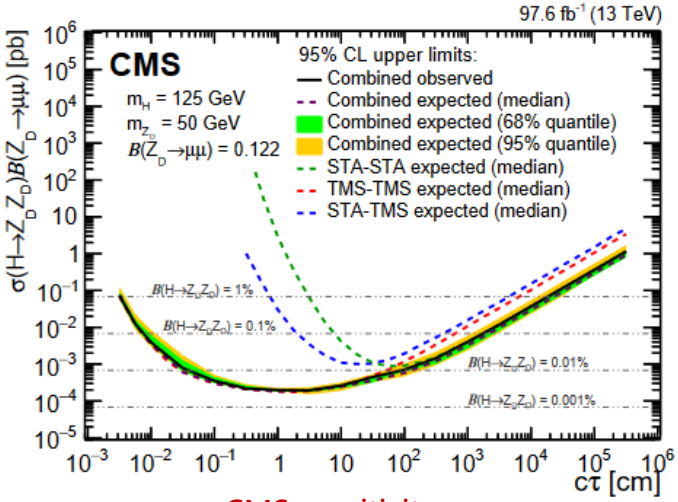




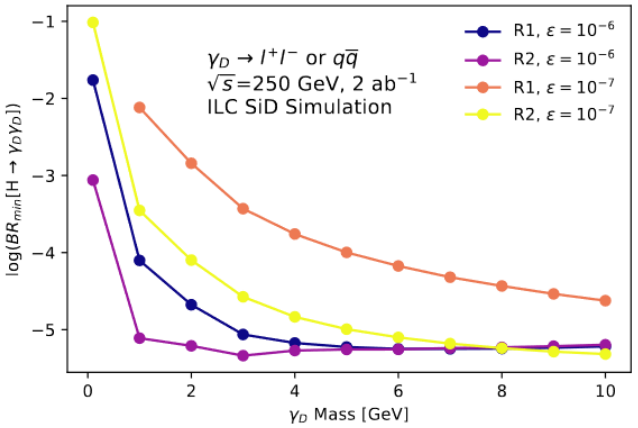
Sensitivity (compared with others)



Combined Limit
(95% CL)



CMS sensitivity



baseline ILC sensitivity
arXiv:2203.08347

目录 Contents

Summary

- Long-Lived Particle (2-jet and 4-jet final states) study done with future lepton collider
  - current results are based on CEPC_v4 geometry setup
- First attempt to apply AI image recognition techniques to raw detector hits
  - Very good sensitivity reached $(\sim 10^{-6})$ with (expected) 4×10^6 Higgs statistics (comparable to current ILC result) .
- Faraway detector can further improve geometry acceptance and exclusion limit.

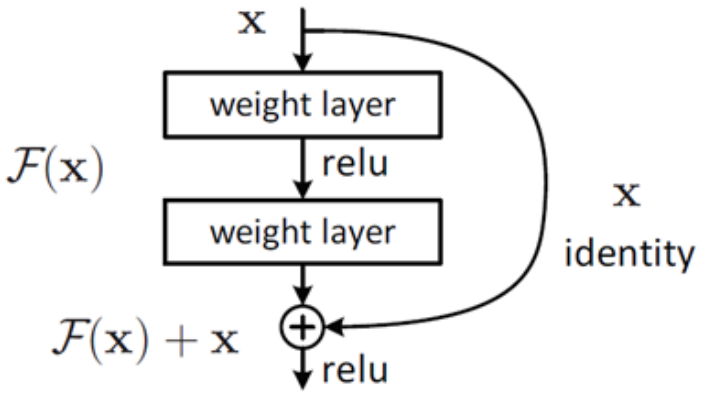
Thanks

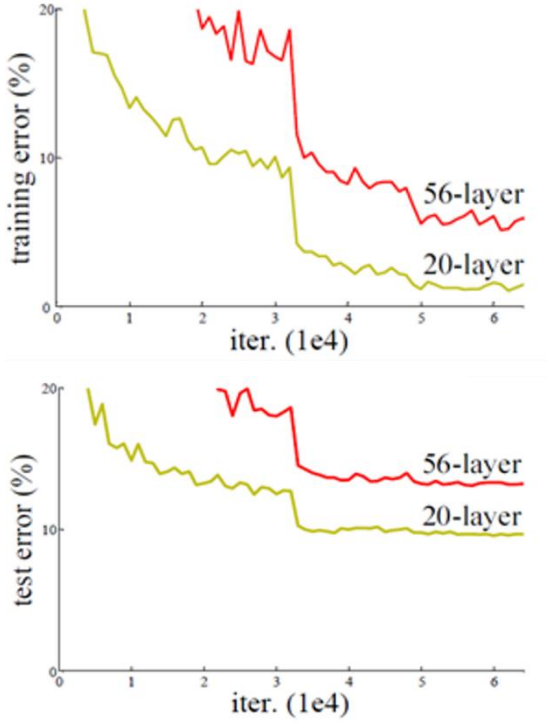
Cen Mo

✉ mo_cen@sjtu.edu.cn

Deep Residual Network, ResNet

- Firstly appeared in the ILSVRC 2015 classification challenges (ImageNet Large Scale Visual Recognition Challenge)
- Skip connections or shortcuts are used to jump over some layers.
- ResNet18, ResNet50, ResNet101…





Expected background events

	# of Events simulated	# of Events in 20 ab^{-1}
$e^+e^- \to q\bar{q}$	$(\sim 0.99 \times 10^7)$	1.0×10^9
$e^+e^- \to Zh$ (Standard Model)	$\sim 1.37 \times 10^6$	4.0×10^6
$e^+e^- \to W/Z$	$\sim 1.3 \times 10^7$	6.4×10^7