Search for Long-lived Particles at Future Lepton Colliders

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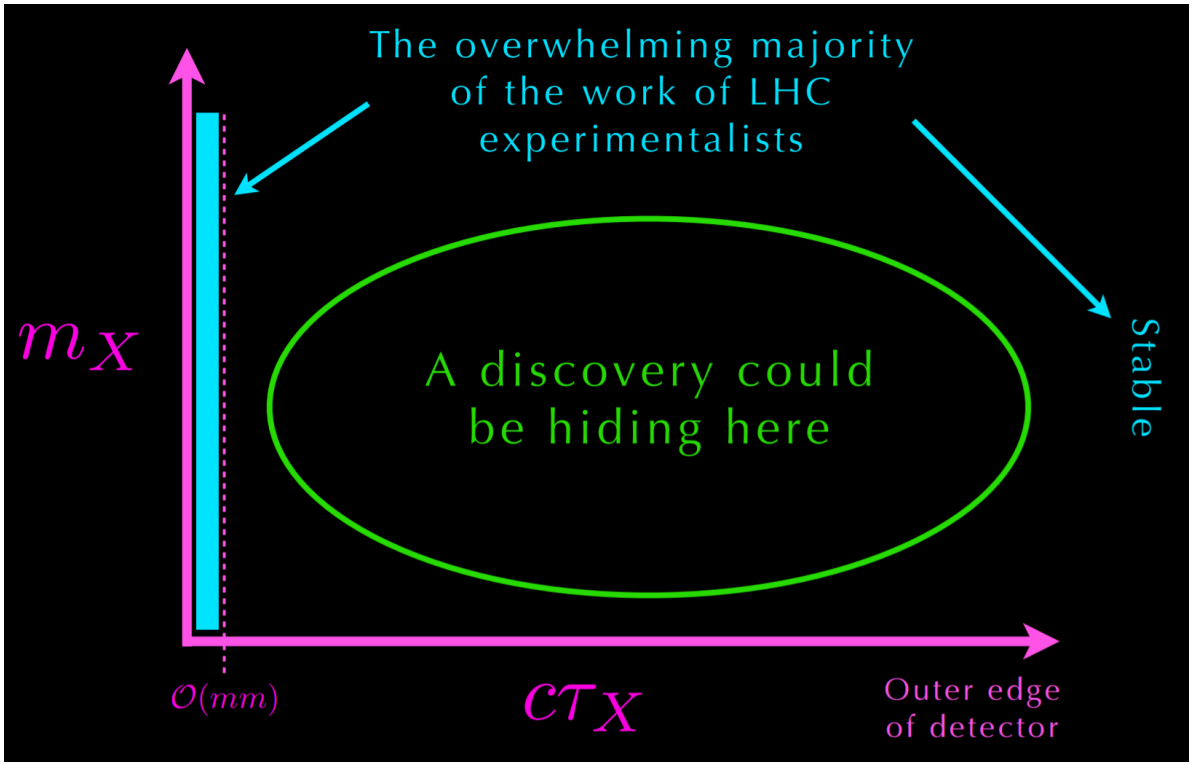
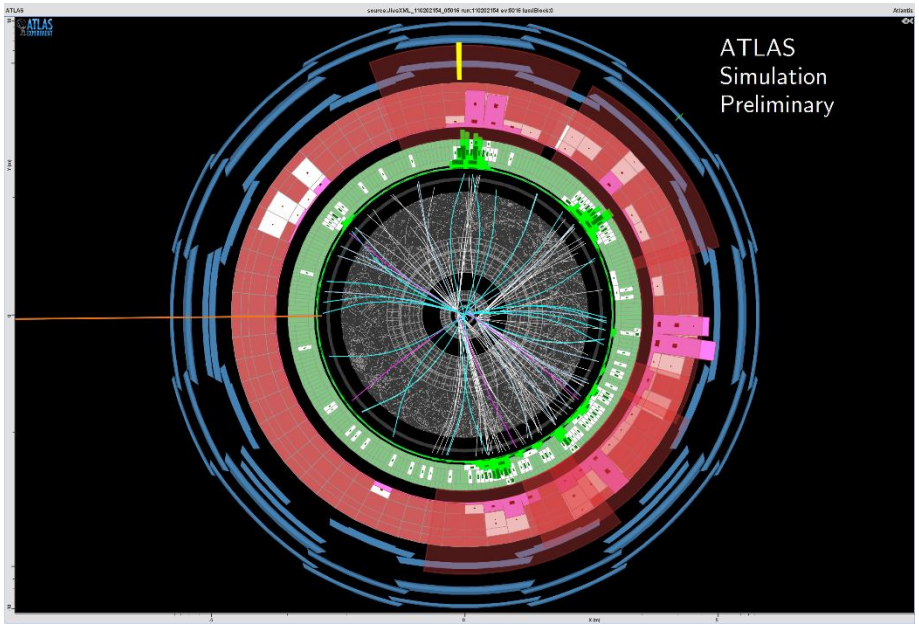
Long-lived Particles Search

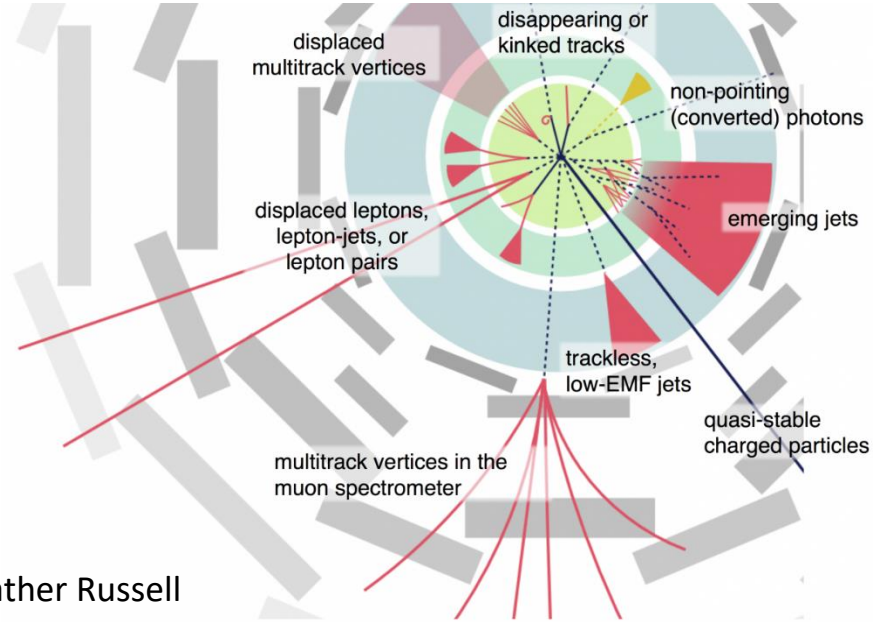


Leave no stone unturned:

- **New particles might have non-prompt decays and long lifetime**
- **Timing information important in detector design**
- **Energy information complementary**
- **Charged and neutral signals**

Long-lived Particles Search at Hadron Collider





Heather Russell

Journal of Physics G: Nuclear and Particle Physics

LHC LLP Community white paper

- arXiv:1903.04497
- 226 pages
- 201 authors
- 104 citations (today)

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Searching for long-lived particles beyond the Standard Model at the Large Hadron Collider

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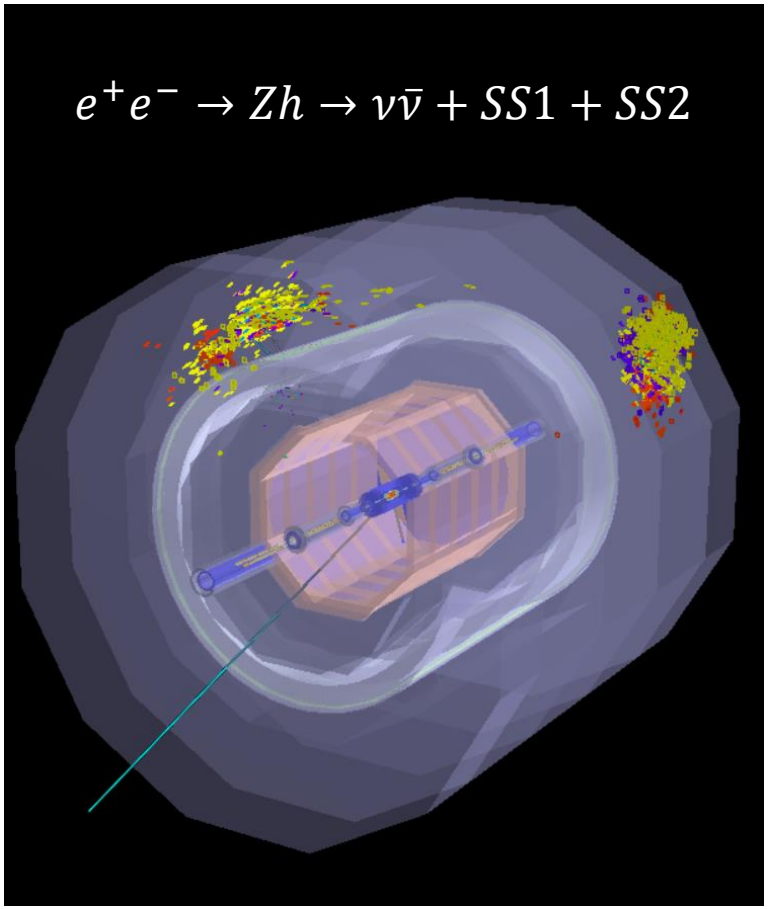
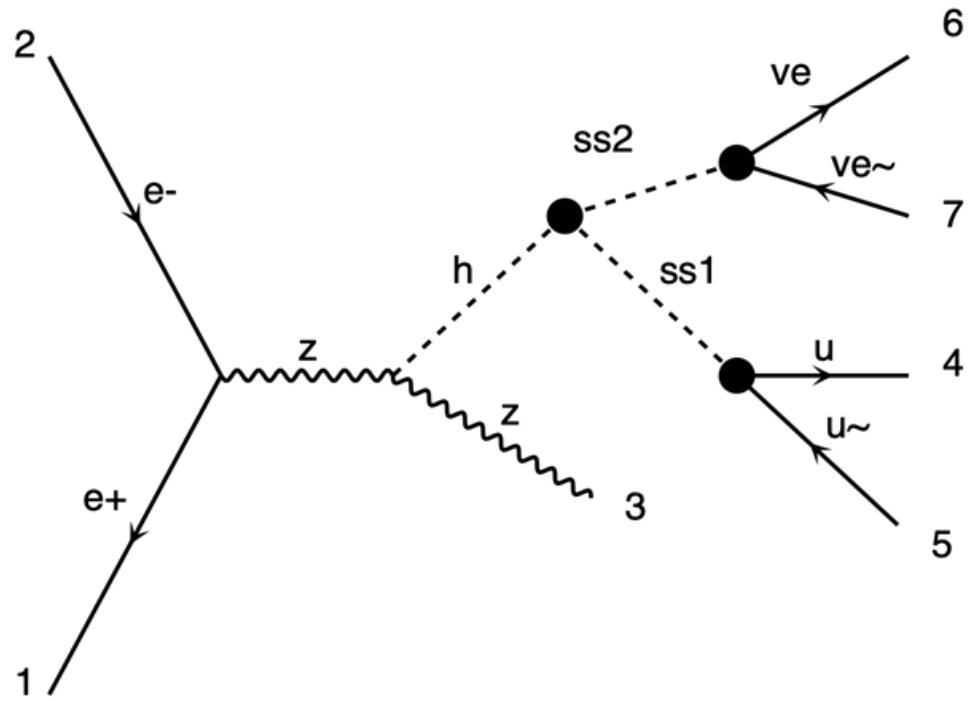
Long-lived Particles Search at Lepton Collider





Energy: 240 GeV
Mass of SS1: 1-50 GeV
Mass of SS2: 1-50 GeV

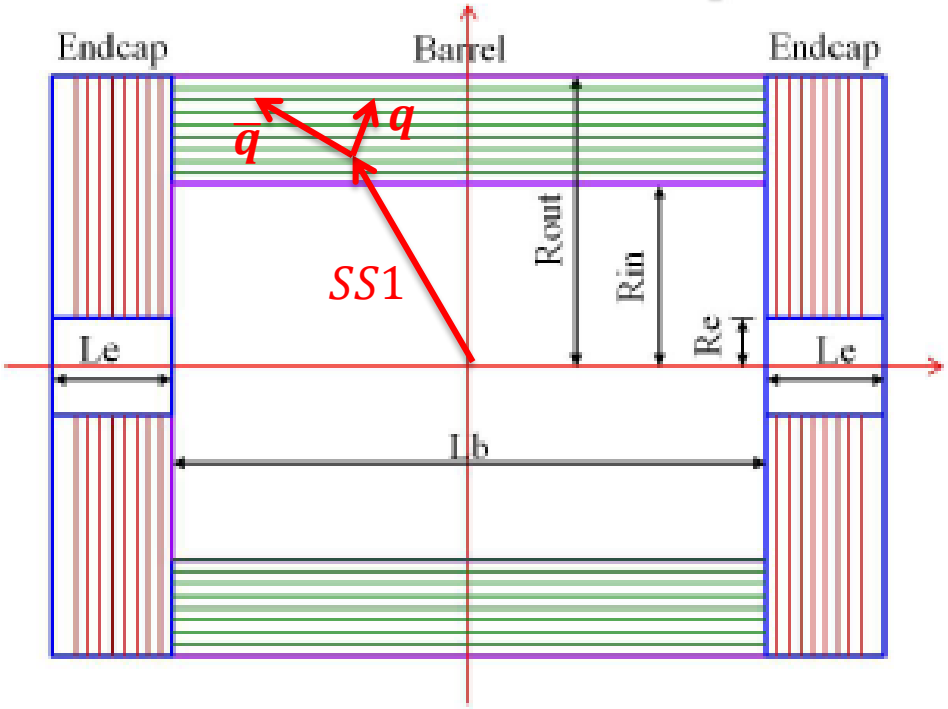
Lepton collider uniqueness

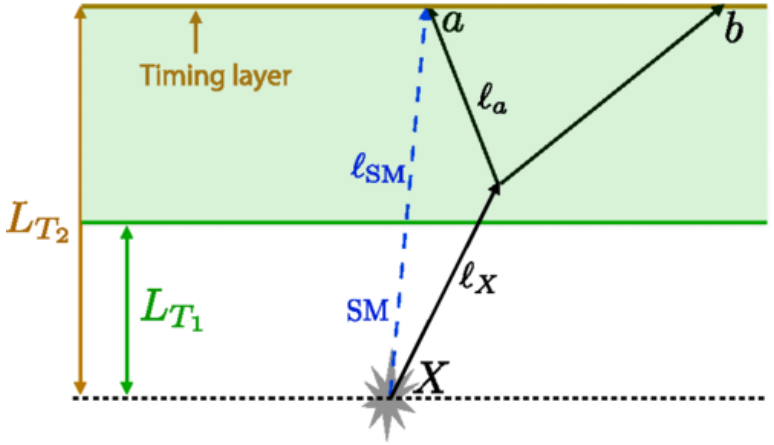
- **Clean environment**
- **Time of flight**
- **Energy deposition**

Preliminary study with outer detector

Long-lived Particles Search at Lepton Collider

Phys. Rev. Lett. 122, 131801





$$\Delta t = t_{signal} - t_{SM}$$

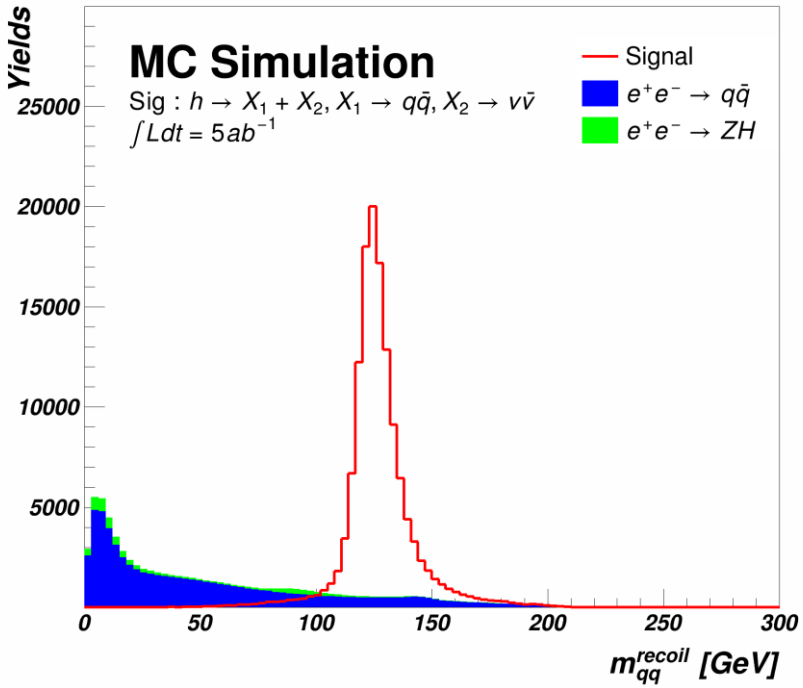
Select signal events with muon detector

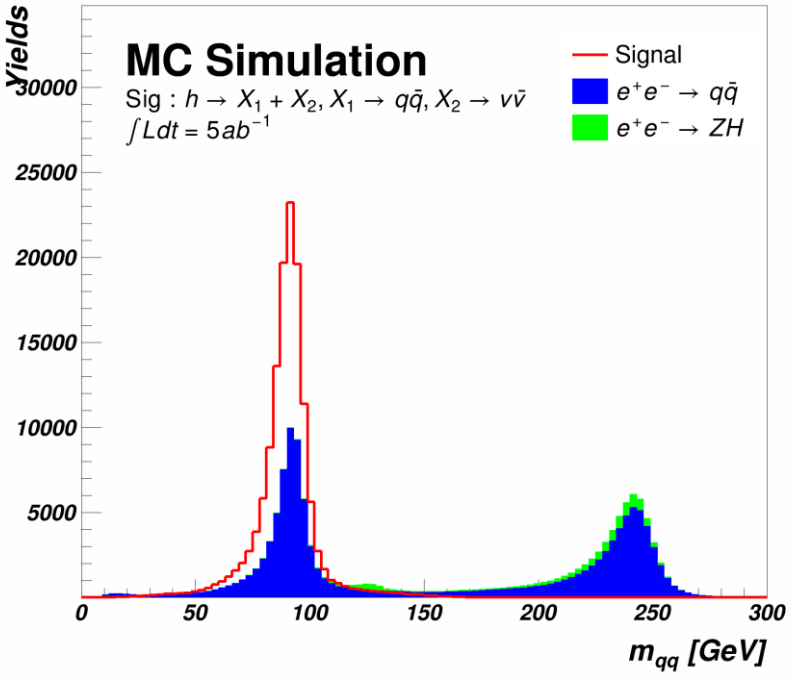
- $\Delta t = t_{Hit} - r_{Hit}/c$, R_{out} ~ 6m (CEPC baseline)
- consider 2 non-prompt jets final state (for simplicity) with possible Z-tagging

Dominant background

- $ZH \rightarrow \nu\nu bb, \nu\nu jj$
- $e^+e^- \rightarrow qq$ (ISR/FSR)

Full Simulation Comparison

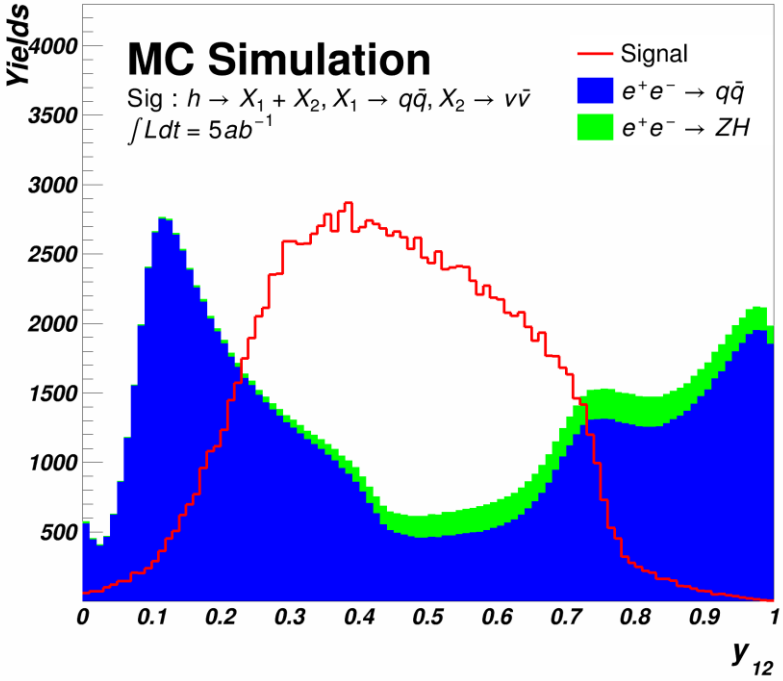


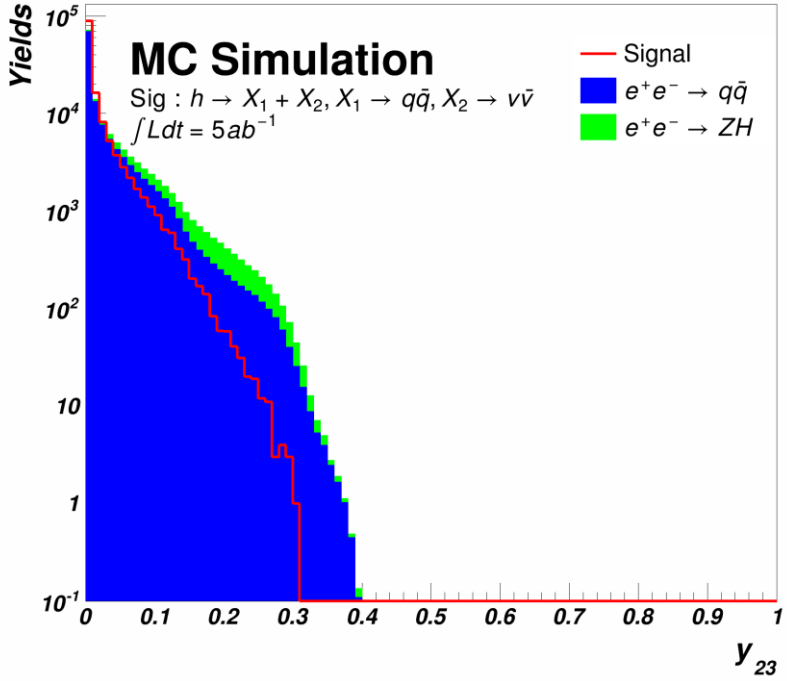


Mass of Two Prompt Jets

- **Reconstructed via anti-K_T algorithm (inclusive)**
- **ISR/FSR included for $e^+e^- \to qq$**
- **Background normalized to signal to compare shape**

Full Simulation Comparison

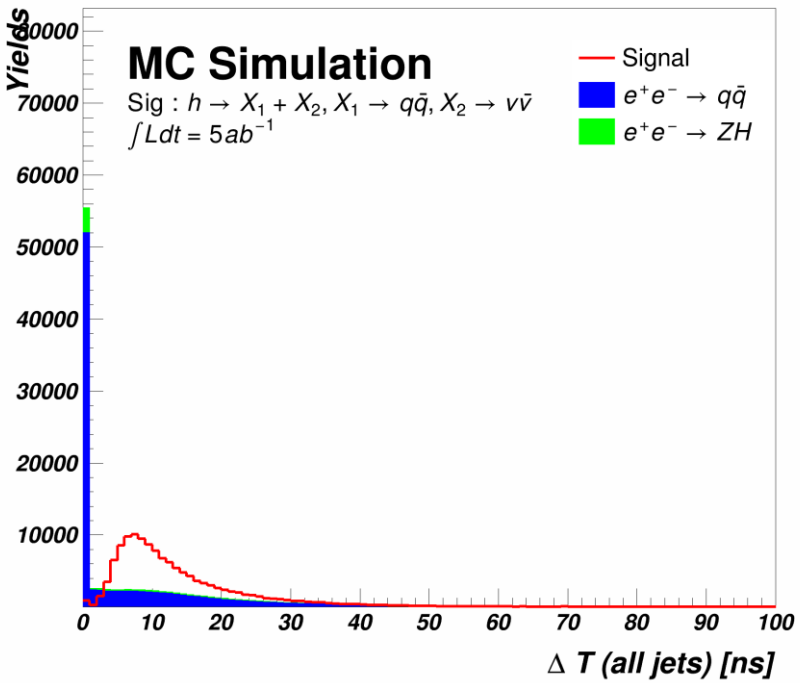


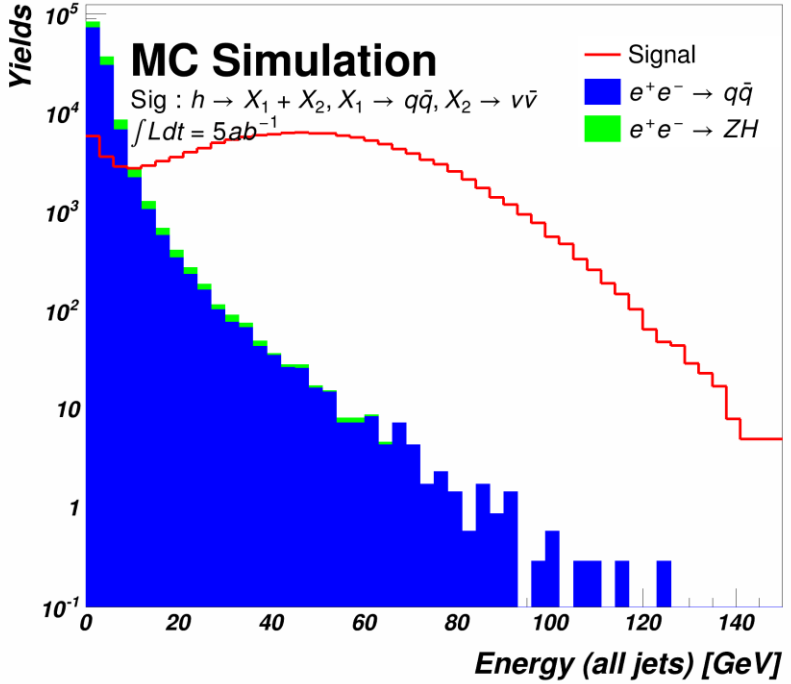


Shower distance of sub-jets

- **Reconstructed via anti-K_T algorithm (inclusive)**
- **Background normalized to signal to compare shape**

Full Simulation Comparison



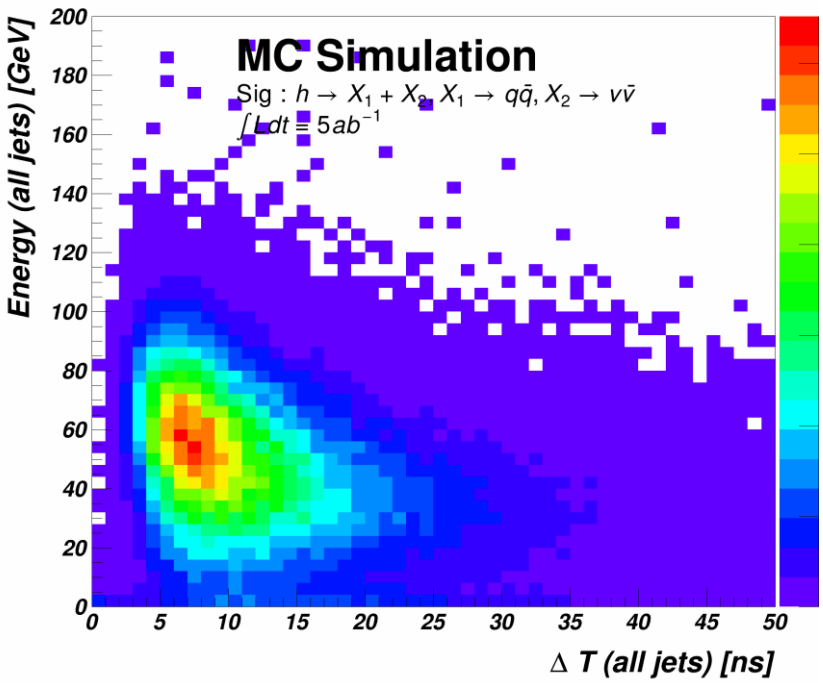


Time and Energy Distributions

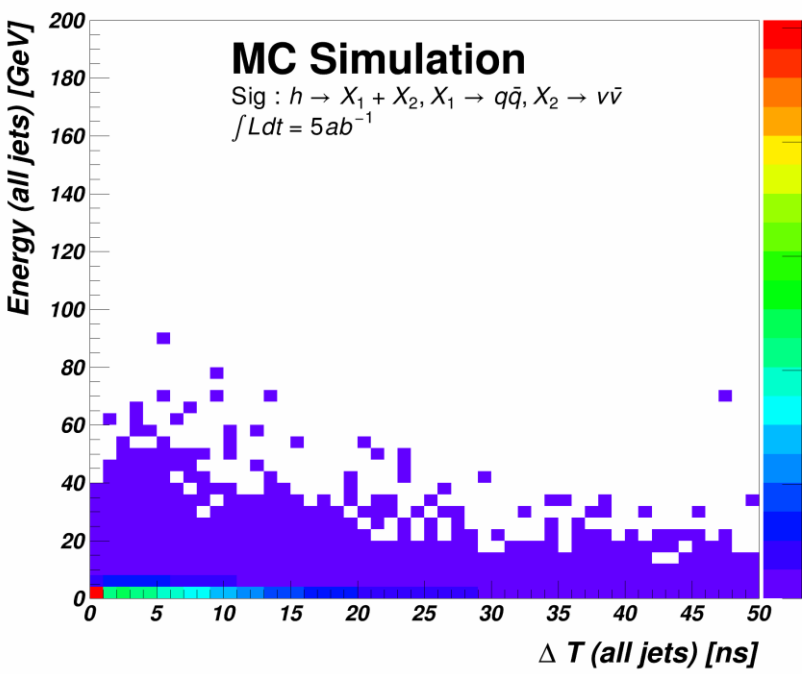
- **Energy deposition in muon detector**
- **Background normalized to signal to compare shape**

Full Simulation Comparison

Signal



Background



2D Time and Energy Distributions

- **Clear signal presence**
- **Optimized 2D selections**

Z→qq + 2 non-prompt jets channel

	Signal: $Z \to \bar{q}q$	$e^+e^- \to q\bar{q}$	$e^+e^- \to Zh$	Total
# of Events in 5.6 ab^{-1}		2.0×10^8	1.0×10^6	2.01×10^8
# of Events simulated	$\sim 1.3 \times 10^6$	$\sim 0.99 \times 10^7$	$\sim 1.37 \times 10^6$	$\sim 2.87 \times 10^6$
Decay in Muon Detector	134,559	6,516,657	796,596	7,313,253
$\lvert m_{qq} - m_Z \rvert \leq 15$ GeV	113,723	4,013,875	39,631	4,053,506
$\lvert m_{qq}^{rec} - m_h \rvert \leq 15$ GeV	104,942	229,703	26,862	256,565
$0.23 \leq y_{12} \leq 0.72$	93,517	129,546	20,041	149,587
$E_{2j} \geq 30$ GeV	69,468	72	16	88
$\min(\Delta T_{j_1}, \Delta T_{j_2}) > 3$ ns	68,368	50	11	61
Efficiency	50.80%	0.00077%	0.0014%	0.00083%

Full simulation study

- **Large sample required for $e^+e^- \to qq$ background estimation**
- **2D energy and time selections**

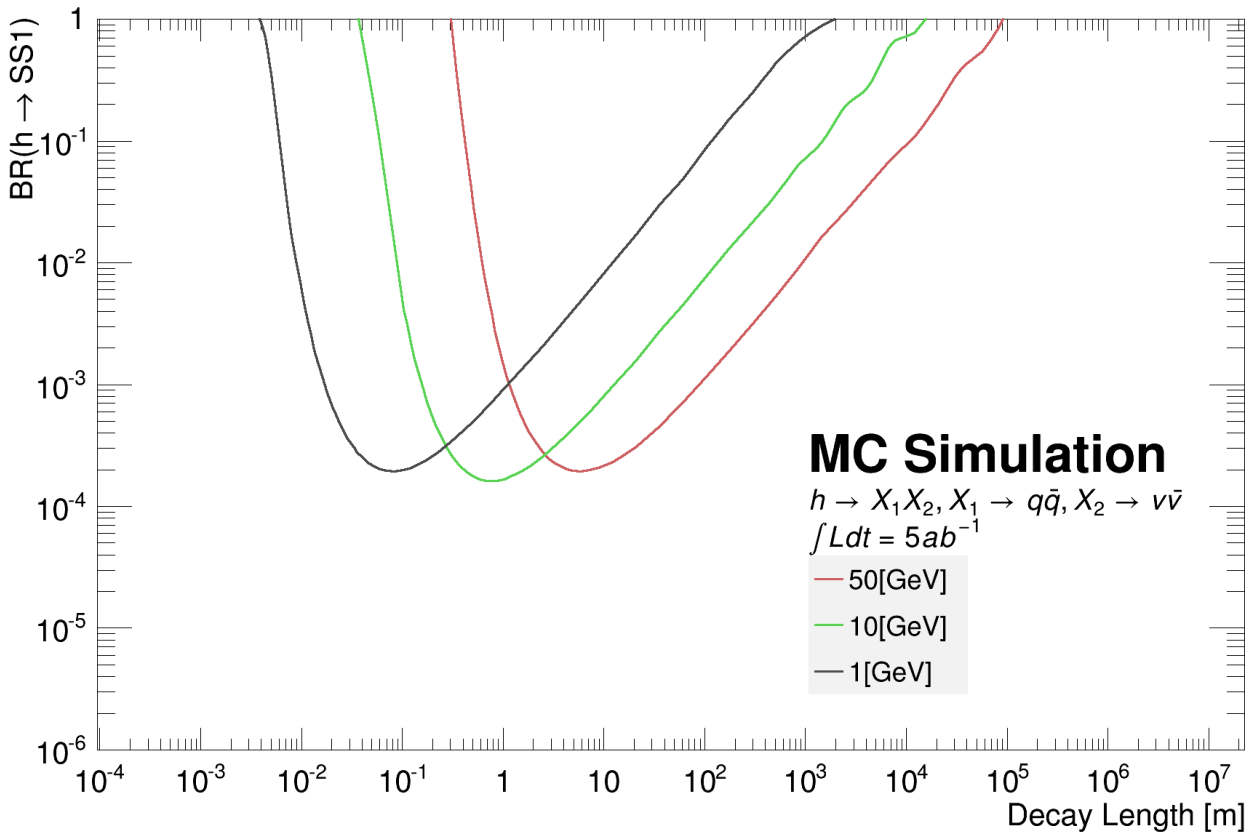
Z→νν + 2 non-prompt jets channel

	Signal: $Z \to \bar{\nu}\nu$	$(e^+e^- \to q\bar{q})^*$	$e^+e^- \to Zh$	Total
# of Events in 5.6 ab^{-1}		2.0×10^8	1.0×10^6	2.01×10^8
# of Events simulated	$\sim 1.0 \times 10^6$	$\sim 0.99 \times 10^7$	$\sim 1.37 \times 10^6$	$\sim 2.87 \times 10^6$
Decay in Muon Detector	89,757	6,516,657	796,596	7,313,253
$E_{missing} > 190\ GeV$	89,437	463,421	6,413	469,834
$n_{rec} < 8$	88,103	281,897	3,901	285,798
$E_{2j} \geq 30$ GeV	67,244	0	0	0
$\min(\Delta T_{j_1}, \Delta T_{j_2}) > 3$ ns	66,325	0	0	0
Efficiency	73.89%	–	–	–

Full simulation study

- **Large sample required for $e^+e^- \to qq$ background estimation**
- **Clean signal (no energy from inner detector)**
- **Cosmic ray background under investigation**

Preliminary Expected Sensitivity



Two non-prompt jets results

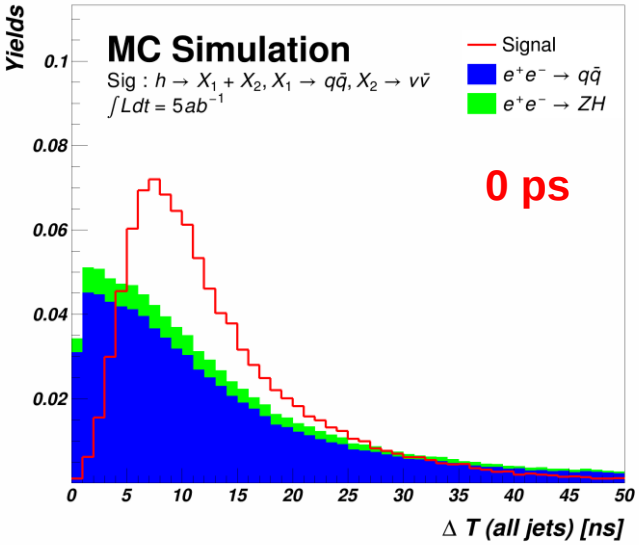
- **Signal scan: 1-50 GeV (assuming same signal efficiency)**
- **Complementary to LHC, especially at low energy**

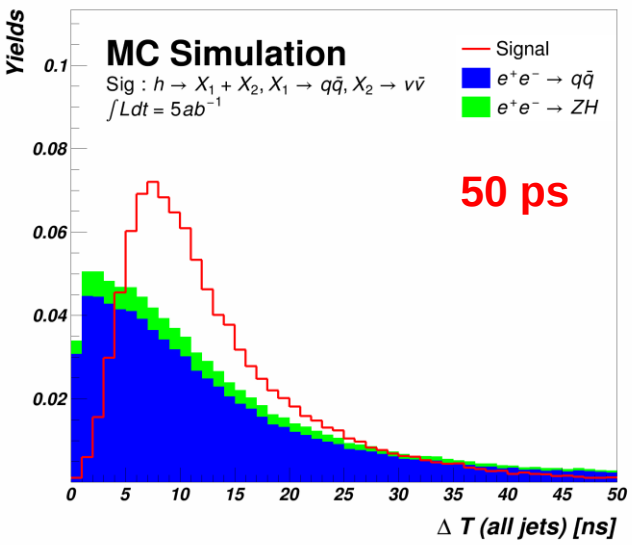
Muon Detector Recommendation

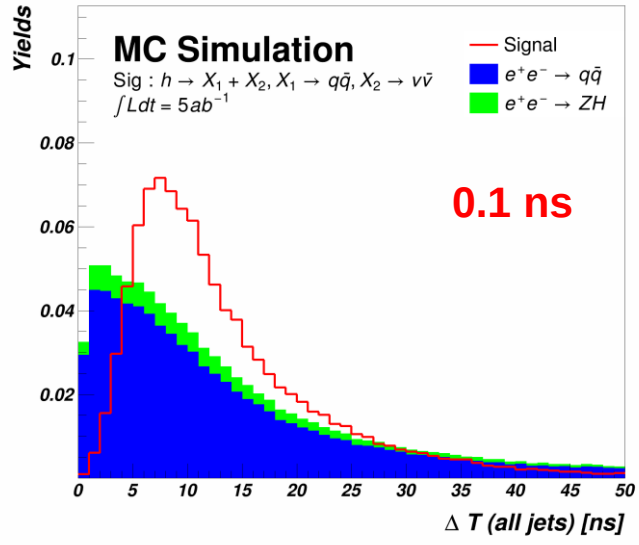
Sensitivity study related to muon detector optimization

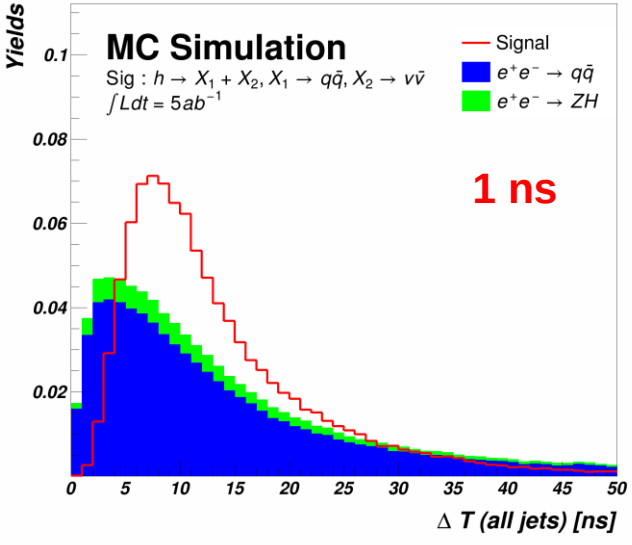
- **Timing resolution**
- **Detector size, number of layers etc.**

Timing Resolution Study









Timing Resolution Study

Sensitivity study related to muon detector optimization

- **Timing resolution**
  - **For signals at muon detector, the peak of time delay is around 10 ns, which is much larger than the time resolution range tested (1ps-1ns).**
  - **We don't expect the effect of time resolution to be significant for LLPs studies with muon detector.**

Increase Muon Detector Size

Muon Outer Radius (m)	Expected Limits (BR)
6	$\sim 10^{-4}$
8	$\sim 5 \times 10^{-5}$
10	$\sim 4 \times 10^{-5}$

Sensitivity study related to muon detector optimization

- **Detector size, number of layers etc.**
  - **Current CEPC muon detector geometry size: 4-6m.**
  - **Increasing detector length would increase signal acceptance and yield better sensitivity.**
  - **Energy and time information not very sensitive to the number of layers, under investigation.**

Summary and Outlook

✓ **Preliminary LLPs study done using full simulation samples**

- **First look at outer detector for lepton colliders**
  - **Time and energy information with good separation power**
  - **Detector timing resolution: ~ 1 ns**
  - **Energy threshold: ~ 30 GeV**
  - **Inner detector study ongoing**
    - **More complicated reconstruction with displaced vertex**
- **Complementary to hadron colliders**
  - **Low energy signal region**
- **Further optimization and more thorough understanding of backgrounds needed**
  - **Looks promising: clean signal with no major backgrounds**