

#### JOHANNES GUTENBERG UNIVERSITÄT MAINZ

### Testing Light, Hidden New Physics at CEPC

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JHEP06(2017)077 [arXiv:1704.00730] Collaborated with Jia Liu and Felix Yu



### A. Evidence:





### A. Evidence:

**B. Search:** 





### A. Evidence:

**B. Search:** 





## Motivation

### **Dark Portals**

1. Vector  $B_{\mu\nu}Z'^{\mu\nu}$ 2. Higgs  $|S|^{2}H^{\dagger}H$ 3. Axion  $\frac{a}{f_{a}}F_{\mu\nu}\tilde{F}^{\mu\nu}$ 

4. Neutrino LHN







### **★**Direct Detection

**★Indirect Detection** 

### **★**Collider Search

- LEP & LHC Constraint
- Future CEPC



$$\begin{aligned} \mathcal{L} \supset &-\frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} W^{i}_{\mu\nu} W^{i,\mu\nu} - \frac{1}{4} K_{\mu\nu} K^{\mu\nu} + \frac{\epsilon}{2\cos\theta_W} B_{\mu\nu} K^{\mu\nu} \\ &+ |D_{\mu}H|^2 + \mu_H^2 |H|^2 - \lambda_H |H|^4 + |D_{\mu}\Phi|^2 + \mu_D^2 |\Phi|^2 - \lambda_D |\Phi|^4 - \lambda_{HP} |H|^2 |\Phi|^2 \\ &+ \bar{\chi} (i\gamma^{\mu} D_{\mu} - m_{\chi}) \chi \end{aligned}$$

$$\mathcal{L} \supset -\frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} W^{i}_{\mu\nu} W^{i,\mu\nu} - \frac{1}{4} K_{\mu\nu} K^{\mu\nu} + \frac{\epsilon}{2\cos\theta_W} B_{\mu\nu} K^{\mu\nu} + |D_{\mu}H|^2 + \mu_H^2 |H|^2 - \lambda_H |H|^4 + |D_{\mu}\Phi|^2 + \mu_D^2 |\Phi|^2 - \lambda_D |\Phi|^4 - \lambda_{HP} |H|^2 |\Phi|^2 + \frac{1}{\chi} (i\gamma^{\mu}D_{\mu} - m_{\chi})\chi$$



$$\begin{aligned} \mathcal{L} \supset &-\frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} W^{i}_{\mu\nu} W^{i,\mu\nu} - \frac{1}{4} K_{\mu\nu} K^{\mu\nu} + \frac{\epsilon}{2\cos\theta_W} B_{\mu\nu} K^{\mu\nu} \\ &+ |D_{\mu}H|^2 + \mu_H^2 |H|^2 - \lambda_H |H|^4 + |D_{\mu}\Phi|^2 + \mu_D^2 |\Phi|^2 - \lambda_D |\Phi|^4 - \lambda_{HP} |H|^2 |\Phi|^2 \\ &+ \bar{\chi} (i\gamma^{\mu}D_{\mu} - m_{\chi})\chi \end{aligned}$$

$$\mathcal{L} = \tilde{Z}_{\mu} \left( gJ_{Z}^{\mu} - g_{D} \frac{m_{Z, \text{SM}}^{2} t_{W}}{m_{Z, \text{SM}}^{2} - m_{K}^{2}} \epsilon J_{D}^{\mu} \right)$$
  
+  $\tilde{K}_{\mu} \left( g_{D} J_{D}^{\mu} + g \frac{m_{K}^{2} t_{W}}{m_{Z, \text{SM}}^{2} - m_{K}^{2}} \epsilon J_{Z}^{\mu} + e\epsilon J_{\text{em}}^{\mu} \right)$   
+  $\tilde{A}_{\mu} e J_{\text{em}}^{\mu}$ 

$$\begin{aligned} \mathcal{L} \supset &-\frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} W^{i}_{\mu\nu} W^{i,\mu\nu} - \frac{1}{4} K_{\mu\nu} K^{\mu\nu} + \frac{\epsilon}{2\cos\theta_W} B_{\mu\nu} K^{\mu\nu} \\ &+ |D_{\mu}H|^2 + \mu_H^2 |H|^2 - \lambda_H |H|^4 + |D_{\mu}\Phi|^2 + \mu_D^2 |\Phi|^2 - \lambda_D |\Phi|^4 - \lambda_{HP} |H|^2 |\Phi|^2 \\ &+ \bar{\chi} (i\gamma^{\mu} D_{\mu} - m_{\chi}) \chi \end{aligned}$$

$$\begin{aligned} \mathcal{L} \supset -\frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} W^{i}_{\mu\nu} W^{i,\mu\nu} - \frac{1}{4} K_{\mu\nu} K^{\mu\nu} + \frac{\epsilon}{2\cos\theta_W} B_{\mu\nu} K^{\mu\nu} \\ + |D_{\mu}H|^2 + \mu_H^2 |H|^2 - \lambda_H |H|^4 + |D_{\mu}\Phi|^2 + \mu_D^2 |\Phi|^2 - \lambda_D |\Phi|^4 - \lambda_{HP} |H|^2 |\Phi|^2 \\ + \bar{\chi} (i\gamma^{\mu}D_{\mu} - m_{\chi})\chi \end{aligned}$$

$$sin \alpha$$
  
 $S$   $H_0$ 

$$\begin{aligned} \mathcal{L} \supset &-\frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} W^{i}_{\mu\nu} W^{i,\mu\nu} - \frac{1}{4} K_{\mu\nu} K^{\mu\nu} + \frac{\epsilon}{2\cos\theta_W} B_{\mu\nu} K^{\mu\nu} \\ &+ |D_{\mu}H|^2 + \mu_H^2 |H|^2 - \lambda_H |H|^4 + |D_{\mu}\Phi|^2 + \mu_D^2 |\Phi|^2 - \lambda_D |\Phi|^4 - \lambda_{HP} |H|^2 |\Phi|^2 \\ &+ \bar{\chi} (i\gamma^{\mu}D_{\mu} - m_{\chi})\chi \end{aligned}$$

$$\begin{aligned} \mathcal{L} \supset m_{Z,\mathrm{SM}}^2 \frac{\cos \alpha}{v_H} \tilde{Z}_{\mu} \tilde{Z}^{\mu} H_0 - m_K^2 \frac{\sin \alpha}{v_D} \tilde{K}_{\mu} \tilde{K}^{\mu} H_0 \\ &+ 2\epsilon t_W \frac{m_K^2 m_{Z,\mathrm{SM}}^2}{(m_{Z,\mathrm{SM}}^2 - m_K^2)} \left( \frac{\cos \alpha}{v_H} + \frac{\sin \alpha}{v_D} \right) \tilde{Z}_{\mu} \tilde{K}^{\mu} H_0 \\ &+ m_{Z,\mathrm{SM}}^2 \frac{\sin \alpha}{v_H} \tilde{Z}_{\mu} \tilde{Z}^{\mu} S + m_K^2 \frac{\cos \alpha}{v_D} \tilde{K}_{\mu} \tilde{K}^{\mu} S \\ &+ 2\epsilon t_W \frac{m_K^2 m_{Z,\mathrm{SM}}^2}{(m_{Z,\mathrm{SM}}^2 - m_K^2)} \left( -\frac{\cos \alpha}{v_D} + \frac{\sin \alpha}{v_H} \right) \tilde{Z}_{\mu} \tilde{K}^{\mu} S \end{aligned}$$



### **★**Parameters

 $\{m_{\chi}, m_{\tilde{K}}, m_S, \epsilon, \sin \alpha, g_D\}$ 

### ★Mass Hierarchy

 $m_{\chi} < m_{ ilde{K}}/2$  $m_{ ilde{K}} < m_S/2$  $m_S < m_{H_0}/2$ 

## **Direct Detection**

Direct Detection



Annihilation





## **Direct Detection**

Direct Detection



Annihilation





## **Direct Detection**



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## **Indirect Detection**

#### • CMB

$$p_{\mathrm{ann}} = rac{1}{m_{\chi}} \sum_{i} f^{i}_{\mathrm{eff}} \left\langle \sigma v \right\rangle_{i}$$

Fermi-LAT, Dwarf

Gamma ray constraint

### · AMS-02

Electron-positron measurement



## **Indirect Detection**

#### • CMB

$$p_{\mathrm{ann}} = rac{1}{m_{\chi}} \sum_{i} f^{i}_{\mathrm{eff}} \left\langle \sigma v \right\rangle_{i}$$

### Fermi-LAT, Dwarf

Gamma ray constraint

### · AMS-02

Electron-positron measurement



# JGU Collider Phenomenology

Pheno	$\sin lpha$	$\epsilon$			
Electroweak Precision	$e^+e^- \to \tilde{Z}S$	$e^+e^- \to f\bar{f}$			
	LEP	LEP			
	$H_0 \to SS \to 4(\chi \bar{\chi})$ , $H_0 \to \tilde{K}\tilde{K} \to 2(\chi \bar{\chi})$				
Higgs	LHC				
Droll-Van		$p\bar{p} \to \tilde{Z}, \tilde{K} \to l^+ l^-$			
Dren-Tan		LHC			
Radiative		$e^+e^- \to \tilde{A}\tilde{K}$			
		Babar			



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	Parameter		Signal process	I	Background (pb)	Signal region	
			$\tilde{Z} \to \bar{\ell} \ell  \tilde{K} \to \bar{\gamma} \gamma$	$\bar{\ell}\ell\bar{\nu}\nu$	$0.929 \ (250 \ {\rm GeV})$	$N_{\ell} \ge 2,  m_{\ell\ell} - m_Z  < 10 \text{ GeV},$	
<i>S ϵ</i> <i>sin α</i>		ĨŔ ₋			$0.545 \ (500 \ {\rm GeV})$	and $ m_{\rm recoil} - m_{\tilde{K}}  < 2.5 {\rm ~GeV}$	
			$\tilde{Z} \to \bar{\ell}\ell,  \tilde{K} \to \bar{\ell}\ell$	ĒŀĒŀ	$0.055 \ (250 \ {\rm GeV})$	$N_{\ell} \ge 4,  m_{\ell\ell} - m_Z  < 10 \text{ GeV},$	
					$0.023 \; (500 \; {\rm GeV})$	and $ m_{\ell\ell} - m_{\tilde{K}}  < 2.5 \text{ GeV}$	
		$\epsilon \qquad \begin{array}{c} \tilde{K} \text{ inclusive decay} \\ \tilde{A}\tilde{K} \\ \tilde{K} \rightarrow \bar{\ell}\ell \\ \\ \tilde{K} \rightarrow \bar{\chi}\chi \end{array}$	$ ilde{K}$ inclusive decay $\gamma ar{f} f$	$\sqrt{f}f$	$23.14 \ (250 \ {\rm GeV})$	$N_{\gamma} \geq 1$ , and	f
	$\epsilon$			$\gamma J J$	$8.88 \ (250 \ {\rm GeV})$	$ E_{\gamma} - (\frac{\sqrt{s}}{2} - \frac{m_{\tilde{K}}^2}{2\sqrt{s}})  < 2.5 \text{ GeV}$	$\langle , J \rangle$
			$\tilde{K} \to \bar{\ell} \ell$	$\gamma \bar{\ell} \ell$	12.67 (250 GeV)	$N_{\gamma} \ge 1, N_{\ell} \ge 2,$ $ E_{\gamma} - (\frac{\sqrt{s}}{2} - \frac{m_{\tilde{K}}^2}{2\sqrt{s}})  < 2.5 \text{ GeV},$	
					4.38 (500 GeV)	and $ m_{\ell\ell} - m_{\tilde{K}}  < 5 \text{ GeV}$	$\overline{f}$
			$\tilde{K}  ightarrow ar{\chi} \chi$	$\gamma \bar{ u}  u$	3.45 (250 GeV)	$\begin{vmatrix} N_{\gamma} \ge 1, \\  E_{\gamma} - \left(\frac{\sqrt{s}}{2} - \frac{m_{\tilde{K}}^2}{2\sqrt{s}}\right)  < 2.5 \text{ GeV}, \end{vmatrix}$	$\chi, J$
				2.92 (500  GeV)	and $\not\!\!\!E > 50~{\rm GeV}$	$\chi, f$	
		$\begin{bmatrix} \tilde{Z}H_0 \\ \tilde{K} \to \bar{\chi}\chi, \ \tilde{Z} \to \bar{\ell}\ell \end{bmatrix}$	$H_0 \to \tilde{K}\tilde{Z}$ with	0000	$1.8 \times 10^{-5} (250 \text{ GeV})$	$N_{\ell} \ge 4,  m_{\ell\ell} - m_Z  < 10 \text{ GeV},$	
			LLLP D	$3.5 \times 10^{-4} (500 \text{ GeV})$	and $ m_{\rm recoil} - m_{\tilde{K}}  < 2.5 {\rm ~GeV}$		
	$\sin \alpha \qquad \tilde{Z}S$	ĩs	$\tilde{Z}  ightarrow \bar{\ell} \ell$	<u>_</u> 0	0.87 (250 GeV)	$N_{\ell} \ge 2,  m_{\ell\ell} - m_Z  < 10 \text{ GeV},$	
		$S \rightarrow$	$S \to \tilde{K}\tilde{K} \to 4\chi$	ινν	0.87 (250  GeV)	and $ m_{\rm recoil} - m_S  < 2.5 { m GeV}$	



### Constraint on $\epsilon$



### **Prospects for CEPC**

### Constraint on $\sin \alpha$





### Summary







