New LHC Experiments for Long-lived particles search

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The Lamppost Landscape

- Already Discovered
- Strongly Interacting Heavy Particles
- Weakly Interacting Light Particles
- Impossible to Discover

Coupling Strength

- MeV
- GeV
- TeV

Courtesy Jonathan Feng
The Lamppost Landscape

- **Already Discovered**
- **Weakly Interacting Light Particles**
- **Strongly Interacting Heavy Particles**
- **Impossible to Discover**
- **New Targets of Small Experiments**
- **Traditional Targets of Big Science**

**Axes:**
- **Interaction Strength:** 10^{-3}, 10^{-6}
- **Mass:** MeV, GeV, TeV

Courtesy Jonathan Feng
Long-lived particles are generic

First pixel layer (first layer of detector)

BSM being actively probed

New ideas!

BSM being probed as missing transverse energy or EM charged particles
Hidden sector feeble couplings to SM via various portals, suppressed by the smallness of the couplings

Higgs portal

Dark Photon/Z

Neutrino Portal

Axion Portal

Credit: Zhen Liu
Experiment Landscape - current LHC

LHC coverage
(ATLAS, CMS, LHCb)

Constraints in triggering
Copious QCD background
New LHC projects are complementary to existing experiments at the LHC and elsewhere.

- Aim for low background at trigger level by shielding
- Aim for zero background in analysis
Experiment Landscape

See Ellis Kay’s talk tomorrow

LHC coverage
(ATLAS, CMS, LHCb)

Transverse
(CODEX-b, MATHEUSLA, AL3X, …)

Forward
(FASE-1, SHiP, NA62, …)

See Ellis Kay’s talk tomorrow

1911.00481

Transverse
(CODEX-b, MATHEUSLA, AL3X, …)
A Compact Detector for Exotics at LHC-b

Some specs:
• 10m x 10m x 10m fiducial volume
• 6 RPC layers on each surface
• 5 set of 3 vertical RPC layers in the volume
• 1 cm granularity

From 1708.09395
Massive Timing Hodoscope for Ultra-Stable neutrals

Some specs:
• 200 m x 200 m x 25 m (smaller designs considered)
• Construct in 9 m x 9 m x 25 m modules
• RPC’s for tracking
• Use timing to reject cosmic rays
AN Underground Belayed In-Shaft

Some specs:
- 8m radius (shaft)
- Each tracking station is 30 tons and 230 m$^2$
- RPC’s for tracking
- Use timing to reject cosmic rays
A Laboratory for Long-Lived eXotics

Reuse the L3 magnet and (perhaps) the ALICE TPC

Similar strategy as for CODEX-b: use thick shield with active veto to reduce the backgrounds
A Laboratory for Long-Lived eXotics

Reuse the L3 magnet and (perhaps) the ALICE TPC

Initially, ALICE TPC for tracking and dE/dx

D2 and D4 scintillators to trigger on outgoing charged tracks

D1 and D3 scintillators to veto on incoming charged tracks

40-Å tungsten shield (approx. 40 m$^3$ or 750 ton)

Similar strategy as for CODEX-b: use thick shield with active veto to reduce the backgrounds
See Ellis Kay’s talk tomorrow

**LHC coverage**
(ATLAS, CMS, LHCb)

**Transverse**
(CODEX-b, MATHUSLA, AL3X, …)

**Forward**
(FASER, SHiP, NA62, …)

SCHEMATIC
Beam dump experiment at the SPS accelerator

400 GeV protons

Some specs:
• $10^{20}$ protons on target
• $\sqrt{s} = 20$ GeV
• New beam line needed
• Aiming for 2025 (~ 200 million $)
Fit 5m long detector but less service supports.
ForwArd Search ExpeRiment at the LHC
ForwArd Search ExpeRiment at the LHC

Some specs:
- 20 cm aperture x 5 meters
- ~ 480 meters from IP
- Need small but good tracker
FASER INTEGRATION

L. Dougherty (CERN)
Current Status

Protection

Before

After

2020

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<thead>
<tr>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>April</th>
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Prototype Tracking Layer

First prototype layer produced and mounted in September

Tunnel

Before

After

TDAQ test setup

Calorimeter Module

Calo. built from four spare LHCb outer ECAL modules

Many thanks to LHCb for lending us these modules

Testing lab with LED pulser and cosmic ray test stand setup in building 21

Used to characterize and determine HV working point

Low gain needed to have sufficient range for largest signals

Cosmic ray test stand

Calorimeter Module

PMT Non-linearity [No]l
t
ear

Gain ~300

19

Prototype Tracking Layer

First prototype layer produced and mounted in September

Custom-made flex cables

Tracker board

Digitizer

VME to Ethernet bridge

Tracker board

2020
FASERν: Neutrino measurements in FASER

- Huge flux of neutrinos ($10^{12}$ in Run3) through FASER could allow for interesting neutrino measurements.
- Extend FASER physics program
  * Complementary to existing experiments
  * Measurement at the highest man-made neutrino energies

- Physics case: 1908.02310
  - Complementary to existing experiments
  - Measurement at the highest man-made neutrino energies

- Primary measurement is neutrino cross sections:
  - ~1300 $\nu_e$, mostly from kaon decays
  - ~20k $\nu_\mu$, mostly from pion decays
  - ~20 $\nu_\tau$, mostly from charm decays
Physics Beyond Colliders at the LHC

![Diagram showing coupling strength vs. mass of BSM state](image)

Coupling strength $\log_{10} g/M_{\text{mediator}}$ [GeV$^{-1}$] vs. Mass of BSM state $\log_{10} m_x$ [eV]

- oEDM
- JURA
- IAXO
- Planck Scale

Experiments:
- SHiP
- NA62++
- LDMX
- KLEVER
- FASER
- CODEX-B
- MATHUSLA
- MilliQan
- NA62++
- KLEVER
- REDTOP
- TauFV
- EDM

arXiv 1901.09966
\[ \mathcal{L}_{\text{scalar}} = \mathcal{L}_{SM} + \mathcal{L}_{DS} - (\mu S + \lambda S^2)H^+H \]

- Minimal scenario $\lambda = 0$
- More general scenario $\lambda$ and $\mu$ both non-zero

FASER2, CODEX-b and MATHUSLA cover >4 orders of magnitude in $\sin^2\theta$
<table>
<thead>
<tr>
<th>Project</th>
<th>Higgs decay</th>
<th>B-decay</th>
<th>π,η-decay (dark photon)</th>
<th>Progress</th>
<th>Cost</th>
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<td>Letter of Intent (1811.00927)</td>
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Summary

- Clearly and increased interest in Long-lived particle searches at the LHC
  - LLP BSM White paper [1903.04497]
  - Physics Beyond Collider Report [1901.09966]
  - 6th LLP workshop [https://indico.cern.ch/event/849129/]

- New ideas for additional complementary experiments being constructed or proposed
  - FAER – aiming for data-taking starting in Run3 (2021)
  - MATHUSLA, CODEX-b – expression of interests
  - ANUBIS, AL3X - concept approved
  - Future Beam dump experiments (SHiP)