SHiP status report

E. Graverini for the SHiP collaboration

Physics Beyond Colliders annual workshop: January 16, 2019
Hidden sector at the BDF

- NP should exist, but we don’t know its scale
- Many theories predict light weakly interacting LLPs
  - Light dark matter
  - Hidden sector: neutrino, vector, scalar, axion portals
- Production $\mathcal{B} \sim 10^{-10}$, decay to SM:
  - high-intensity beam
- **BDF @ CERN SPS:**
  - $\chi_{c\bar{c}} \sim 2 \times 10^{-3}$, $\chi_{b\bar{b}} \sim 2 \times 10^{-7}$
2 × 10^{20} \textit{pot} in 5 years: > 10^{18}D, > 10^{16}\tau

- zero background beam dump expt. with spectrometry and PID
- large geometrical acceptance: long volume close to dump
- complementary detectors for scattering/decay signatures
Muon shield

- magnetized hadron stopper: immediately separate $\mu^\pm$
  $\implies$ reduce length of magnet system
- magnetic field configuration optimised with ML
  $\implies$ $\mu$ rate reduced to $\sim 25$ kHz
- note: $\mu$ spectrum validated with dedicated expt. (see later)
Scattering and Neutrino Detector: $\nu$ physics

- distinguish $e$, $\mu$, $\tau$ and hadrons
- major revision following muon shield optimization: $80 \times 80 \times 300$ cm$^3$, simplified detector
- Target (Emulsion Cloud Chamber + Compact Emulsion Spectrometer) + Downstream Tracker

<table>
<thead>
<tr>
<th></th>
<th>$\bar{E}$ [GeV]</th>
<th>CC DIS int.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu_e$</td>
<td>59</td>
<td>$1.1 \times 10^6$</td>
</tr>
<tr>
<td>$\nu_\mu$</td>
<td>42</td>
<td>$2.7 \times 10^6$</td>
</tr>
<tr>
<td>$\nu_\tau$</td>
<td>52</td>
<td>$3.2 \times 10^4$</td>
</tr>
<tr>
<td>$\bar{\nu}_e$</td>
<td>46</td>
<td>$2.6 \times 10^5$</td>
</tr>
<tr>
<td>$\bar{\nu}_\mu$</td>
<td>36</td>
<td>$6.0 \times 10^5$</td>
</tr>
<tr>
<td>$\bar{\nu}_\tau$</td>
<td>70</td>
<td>$2.1 \times 10^4$</td>
</tr>
</tbody>
</table>
Scattering and Neutrino Detector: LDM

- light dark matter scattering in the emulsion spectrometer
- $\bar{\nu}_e p \rightarrow e^+ n$ background reduced using correlation between $e^+$ angle and energy
Scattering Spectrometer: status

- CES tested at CERN PS in 2017
- $\mu$-RWELL or SciFi for tracking, both tested on beam (2018)
- $\mu$ ID system: RPC tested in CERN H4 in summer 2018
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Decay Spectrometer

- surround background tagger
- straw spectrometer
- EM calorimeter
- Timing detector
- Muon detector

- 0 background $\rightarrow$ 2 candidates are a discovery
- measure candidates mass and identify final state
  $\rightarrow$ narrow down physics models
Decay Spectrometer: status

**SBT** Several improvements \( w.r.t. \) TP. Tested on beam Oct. 2018

**SST** Straw \( \phi \) increased to 20mm. Tested on beam: \( \sigma_{\text{hit}} \approx 120 \mu \text{m} \)

**TD** Plastic scint + large-area SiPMs feasible, large-scale prototype yields \( \sigma_t \approx 80 \text{ps} \). RPC alternative tested Oct. 2018 with \( \sigma_t \approx 54 \text{ps} \)

**ECAL** SplitCal with 3 high-res layers for \( ALP \rightarrow \gamma \gamma \) (\( \sigma_\theta \sim \text{few mrad} \))
- measure barycentre at 3 depths with MPGDs; \( > 1 \text{ m lever arm} \)

**MUON** move to scintillating tiles with SiPM readout. Beam test Oct. 2018, aim at \( \sigma_t < 200 \text{ps} \)
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SHiP simulation / validation

▶ based on FairRoot, uses:
  – Pythia8 for \( p \)-on-target collisions, tuned to include production of \( c, b \) mesons from secondaries
  – Geant4 for propagation through the target and detector material. \( V^0 \to \mu\mu, \gamma \to \mu\mu, ee \to \mu\mu \) activated and boosted
  – Genie for neutrino interactions
▶ several HS models added/extended (HNL, \( \gamma' \), \( S \), RPV \( \tilde{\chi}^0 \) ...)
▶ \( 1.8 \times 10^9 / 6.5 \times 10^{10} \) \textit{pot} simulated with \( E_{th} = 1 / 10 \) GeV
▶ \( \mu \) MS and catastrophic energy loss validated with existing data

**Data from HYPERON**

![Data from HYPERON](image)

**NA62 LKr**

![Data from NA62 LKr](image)
Charm / $\mu$ flux measurements (July 2018)

- replica of BDF target + drift tube spectrometer + RPC $\mu$ tagger
- $\sim 6 \times 10^{11}$ pot recorded, analysis ongoing

- measure of charm production essential for HS and $\nu_\tau$ studies
- lead target + ECC. $1.6 \times 10^6$ pot + 10× run after LS2
Hidden sector: physics performance

- setup ideally suited for any weakly interacting LLP

<table>
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<tr>
<th>Cut</th>
<th>Value</th>
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<tr>
<td>Track momentum</td>
<td>&gt; 1.0 GeV/c</td>
</tr>
<tr>
<td>Children distance of closest approach</td>
<td>&lt; 1 cm</td>
</tr>
<tr>
<td>Decay vertex position</td>
<td>(&gt; 5 cm from inner wall)</td>
</tr>
<tr>
<td>IP w.r.t. target (fully reconstructed)</td>
<td>&lt; 10 cm</td>
</tr>
<tr>
<td>IP w.r.t. target (partially reconstructed)</td>
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- event selection: high signal efficiency + redundant BG suppression
- common selection (model independent search)
- redundancy cuts:
  - associated activity in VETO systems
  - PID cuts
  - time coincidence (suppress combinatorial background)
  - opening angle (reject events from $\gamma$ conversions in the material)
Hidden sector: backgrounds

- **Muon combinatorial:**
  - $10^{16}$ selection $\rightarrow 10^9$ $\Delta t < 340 \text{ps}$ $\rightarrow 10^{-2}$ candidates in 5 years @ 90%CL
  - ML used to generate large sample of dangerous $\mu$

- **Muon inelastic:**
  - 5 years of SHiP operation simulated
  - correlation between VETO and selection: $< 6 \times 10^{-4}$ @ 90%CL

- **$\nu$ interactions:**
  - 10 years of SHiP simulated, increasing to 100
  - $\nu$-air: $< 10^{-2}$ in 5 years with pressure $\sim 1$ mbar
  - $\nu$-material: $5 \times 10^5$ cuts (fully reco) $\rightarrow 0$
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  [JHEP11(2018)032]
- cascade production of charm and beauty
  [SHiP-NOTE-2015-009]
- flavour-independent sensitivity matrix including $B_c$ contribution
- HNL identification and discovery reach close to seesaw limit
- great sensitivity also in $U^2_\tau$-enhanced scenario
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[hep-ph/1811.00930] [PBC-REPORT-2018-007]

[SHiP-NOTE-2015-009]

[JHEP11(2018)032]
Physics performance

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  - meson decays, proton bremsstrahlung, $qq \rightarrow \gamma'$
  - expect improvements at low mass from:
    - cascade production
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- **Dark scalar:**
  - couple to Higgs in FCNC $K$ and $B$ decays

- **Axion-like particles:**
  - couple to fermions and to photons
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- preparation of CDR (submission to SPSC in fall 2019)
- continue phase 2 module-level prototyping for test beams
  - at DESY (2019-2010)
  - at CERN (2021)
- prepare complete meas. of charm production at CERN in 2021
- detector engineering design and preparation of TDR
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**Conclusions + Outlook**

- major design changes since TP
- all sub-detector’s phase 1 prototypes tested with nice results
  - schedule driven by SPS/LHC schedule: installation LS3
  - phase 2 prototyping → TDR second half of 2021
- many improvements on background evaluation and sensitivities
  - working hard to simulate more rare events

- comprehensive search for weakly interacting LLPs @ SPS
- complement CERN’s energy frontier and flavour programme
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