THE SHiP EXPERIMENT AND THE RPC TECHNOLOGY

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On behalf of the SHiP Collaboration
**MOTIVATION**

- The **Standard Model** provides an explanation for most of subatomic processes

- Although very successful, it fails to explain many observed phenomena
  - **Dark Matter**
  - **Neutrino Oscillation and masses**
  - **Matter/antimatter asymmetry in the Universe**

- **A Hidden Sector (HS)** of weakly-interacting BSM particles as an explanation

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**Energy Frontier:**
Heavy particles → high energy collisions

**Intensity Frontier:**
Very weakly interacting particles → high intensity beam
THE SHiP PROJECT

• SHiP (Search for Hidden Particles) in a proposed fixed target experiment at CERN SPS
• Collaboration of 250 members from 49 institutes, 17 countries
• Technical Proposal
• Physics case prepared by 80 theorists
• Positive SPSC recommendation
• Comprehensive Design Study by 2019
  \rightarrow \textit{decision about approval in 2020}
• Important actor in the CERN Physics Beyond Colliders study group
**SHiP Detector Layout**

Muon shield ~30m

Vacuum vessel ~50m

Neutrino/iSHiP detector

Hidden Sector/ dSHiP detector

- **24 RPC planes** 214 x 490 cm²
  - Acting as:
    - Muon Tagger for iSHiP detector
    - Upstream Veto System for dSHiP detector

Multigap Resistive Plate Chambers
- possible option for dSHiP Timing Detector
- Required time resolution: <100 ps
- Transverse size: 5x10 m²

p 400 GeV
SHiP sensitivity to Hidden Sector

Based on $2 \times 10^{20}$ pot @400 GeV in 5 years

- Vector Portal
- Scalar Portal
- Neutrino Portal
- Axion Portal
The Timing Detector implementation based on MRPCs. Schematic drawing (Alberto Blanco and Paulo Fonte)

- Modules composed of two 6 gaps RPCs sensitive volumes.
- Strip (placed in the middle of two sensitive volumes) readout on both sides
- Active area of $1500\times1200$ mm$^2 = 1.8$ m$^2$
- Good time resolution, < 100 ps $\sigma$.
- Good efficiency, > 95 %
- Easy to build.
- Low multiplicity, few particles per module.

Area to be covered 10x5 m$^2$
$\Rightarrow$ 40 MRPC modules with overlap
Ongoing optimization on the size
The Timing Detector implementation based on MRPCs.
Schematic drawing (Alberto Blanco and Paulo Fonte)

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Module

6 gaps RPC sensitive volume

Strip readout

Readout on both ends
The Timing Detector implementation based on MRPCs.
Schematic drawing (Alberto Blanco and Paulo Fonte)

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A sensitive volume contains the glass and HV electrodes enclosed in a plastic gas tight box with feed-throughs for gas and High Voltage.

Easy to build completely gas tight, no gas leaks
Testing MRPCs (Alberto Blanco and Paulo Fonte)

All systems borrowed from the HADES-TOF

- FEE, time ($\sigma_t \sim 40$ps) and charge measurement in one single channel.
- Strips are readout in both sides

One central FPGA with trigger management capabilities plus 4 sockets with capability to operate.

- 4 X 32 Multi-hit TDC
  - Time precision < 20 ps

And much more
First prototype just assembled and instrumented few days ago

- Time resolution and efficiency under evaluation.
In the magnetized region:
- ECC walls and target trackers, followed by tracker stations.

Outside the magnet:
- Muon detector
**F₄ and F₅ Structure Functions**

First evaluation of F₄ and F₅, not accessible with other neutrinos

\[
\frac{d^2\sigma^{\nu(\bar{\nu})}}{dx dy} = \frac{G_F^2 M E_\nu}{\pi(1 + Q^2 / M_W^2)^2} \left( (y^2 x + \frac{m_\tau^2 y}{2 E_\nu M}) F_1 + \left[ (1 - \frac{m_\tau^2}{4 E_\nu^2}) - (1 + \frac{M x}{2 E_\nu}) \right] F_2 \right)
\]

\[
\pm \left[ x y (1 - \frac{y}{2}) - \frac{m_\tau^2 y}{4 E_\nu M} \right] F_3 + \frac{m_\tau^2 (m_\tau^2 + Q^2)}{4 E_\nu^2 M^2 x} \left( F_4 - \frac{m_\tau^2}{E_\nu M} F_5 \right),
\]

- \( F_4 = F_5 = 0 \)

**F₄ = F₅ = 0**

**CC interacting \( \bar{\nu}_\tau \)**

- At LO \( F_4 = 0, 2x F_5 = F_2 \)
- At NLO \( F_4 \sim 1\% \) at 10 GeV

**SM prediction**

\( E(\bar{\nu}_\tau) < 38 \text{ GeV} \)
**Tau Neutrino Magnetic Moment**

A massive neutrino may interact e.m. → magnetic moment proportional to its mass

\[ \mu_\nu = \frac{3e G_F m_\nu}{8 \pi^2 \sqrt{2}} \simeq (3.2 \times 10^{-19}) \left( \frac{m_\nu}{1 \text{ eV}} \right) \mu_B \]

Current limits

\[ \begin{align*}
(\nu_e) & \quad \mu_\nu < 2.9 \cdot 10^{-11} \mu_B \\
(\nu_\mu) & \quad \mu_\nu < 6.9 \cdot 10^{-10} \mu_B
\end{align*} \]

\[ \theta_{\nu-e}^2 < 2m_e / E_e \]

**SIGNAL SELECTION**

\[ \theta_{\nu-e} < 30 \text{ mrad} \]

\[ E_e > 1 \text{ GeV} \]

**BACKGROUND PROCESSES**

- \[ \nu_x(\bar{\nu}_x) + e^- \rightarrow \nu_x(\bar{\nu}_x) + e^- \] NC
- \[ \nu_e + e^- \rightarrow e^- + \nu_e \] CC
- \[ \nu_e + n \rightarrow e^- + p \] QE
- \[ \bar{\nu}_e + p \rightarrow n + e^+ \] QE
- \[ \nu_e(\bar{\nu}_e) + N \rightarrow e^- (e^+) + X \] DIS

\[ n_{\text{evt}} = \frac{\mu_\nu^2}{\mu_B^2} \int \Phi_{\nu_\tau} \sigma^\mu N_{\text{nucl}} dE = 4.3 \times 10^{15} \frac{\mu_\nu^2}{\mu_B^2} \]

Assuming 5% systematics from DIS measurements

SHiP can explore a region down to

\[ \mu_\nu = 1.3 \times 10^{-7} \mu_B \]
SHiP Physics Program for Neutrino/iSHiP

- Strange quark content of the nucleon
- Light Dark Matter search

Strange quark content
MEASUREMENT OF MUON FLUX IN JULY 2018

- **SHIP target replica**, TZM 58 cm-thick + Tungsten 58 cm-thick
- **Spectrometer** to measure momentum and charge of the muons
- **Muon tagger** to identify muons

$10^{11}$ pot $\rightarrow$ 100 events in the dangerous corner

Validate simulation
CHARM MEASUREMENTS IN JULY 2018

- Measurement of inclusive $d^2\sigma/\text{d}E\text{d}\theta$ charm cross section in thick target
- Validation of cascade production in the target (factor $\sim 3$)

- **Lead target**, $12.5 \times 10$ cm$^2$ Pb plates interleaved with emulsion to identify charmed hadrons
- **Spectrometer** to measure momentum and charge of charm daughters
- **Muon tagger** to identify muons

$5 \times 10^7$ pot $\rightarrow \sim 10000$ charmed hadron pairs
**MUON TAGGER**

- 5 Iron walls
- 5 RPC planes

- Iron blocks assembled in order to have a 5x5cm$^2$ hole along beam direction
**Muon Tagger**

**Muon identification**

- Number of RPC planes crossed by muons produced in charm decays
- Normalization: muons entering the Muon Tagger

<table>
<thead>
<tr>
<th>RPC planes crossed</th>
<th>Fraction of muons</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 2</td>
<td>0.82</td>
</tr>
<tr>
<td>≥ 3</td>
<td>0.77</td>
</tr>
<tr>
<td>≥ 4</td>
<td>0.72</td>
</tr>
<tr>
<td>≥ 5</td>
<td>0.69</td>
</tr>
</tbody>
</table>

**Muon isolation**

- Muon isolation in > 2 RPC planes for muon tracking and for the measurement of its slope
- Muon isolation criteria: at least 1 cm distance (strip width) both in x and y coordinates with respect to the closest hit in the same RPC plane

Requirement to build a muon track: at least two RPC planes where muon is isolated
Status of RPC production (KODEL)

Sung Park
Kyong Sei Lee

Gaps at CERN

Strip panel
RPC mechanical structure

Stiffener Panel
Aluminum Honeycomb
30 mm thick

Standard BOSCH
Tubular Aluminum Frame

Preamplifiers - FEERIC11
Cards

Prototype

Mechanics Service INFN - Bari
RPC mechanical structure

- Stiffener Panel
- Aluminum Honeycomb 30 mm thick
- Standard BOSCH Tubular Aluminum Frame
- Preamplifiers - FEERIC11 Cards

Prototype
 RPCs Frontend Electronics

R. De Asmundis, INFN - Napoli

- Frontend electronics: 112 cards (16 channels each), FEERIC 11 – ALICE
- Cards were delivered in Naples in December
- Preparation of FE card test (including slow control) in progress in Naples
Readout boards: new firmware block scheme (Saverio Simone, Bari)

- Input signals (after masking) are stored in a circular buffer (pipeline) at 100MHz (all boards are synchronised at 100MHz).

- The 100MHz internal clock can be *synchronised* with an external signal through the Trigger Supervisor board.

- Upon arrival of a trigger signal, the 64-bit hit map corresponding to a pre-determined latency + trigger number (12bit) + time stamp (12bit) are written to a FIFO.
Schedule optimized to avoid interference with operation of North Area

Four separate work packages (junction cavern, beam line, target complex and detector hall)

Use LS3 for junction cavern and first short section of SHiP beam line

Positive recommendation by the SPSC in January 2016 to prepare a Comprehensive Design Study 2016-2018

CERN DG launched the “Physics Beyond Colliders” Working Group

Outcome of the WG at the European HEP strategy in 2020

Construction/production 2021-

Data taking 2026

RPCs may play an important role (your contribution is very welcome!)