The neutrino/LDM detector: towards the CDS and beyond

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Project involving many groups from several Countries:
Bulgaria, Germany, Italy, Japan, Korea, Russia and Turkey
+ interest from France
Detector Optimization

Neutrino Detector closer to the proton target

Muon shield ~30 m

Vacuum vessel ~45 m
FairShip implementation (A. Buonaura)  
emulsion target magnetised
FairShip implementation (A. Buonaura)
emulsion target non magnetised
$$\nu_\tau$$ detection

- Micrometric accuracy for $\tau$ identification
- Momentum and charge measurement for $\tau^+/\tau^-$ separation in hadronic decays
- Muon identification and momentum/charge measurement
Charm production for QCD measurements

Measuring $s$-quark content of the nucleon
Interactions with atoms (electrons and nucleus) of any weakly interacting particle

Typically without any muon in the final state
Dark matter interaction with electrons: $\nu_e$-like event

- Micrometric accuracy
- Emulsion films alternated with lead
- Electron identification and energy measurement

High granularity sampling calorimeter

See A. Ustyuzhanin’s talk for machine learning techniques

See Valeri’s talk for the test-beam program
Pentaquark (with open charm) production in neutrino interactions

Depending on the mass, $\theta^0_c$ can decay weakly.
Proton identification ($dE/dx$) to tag unambiguously this particle.
Other exotic particles

Emulsion target

$\mu^+$

$\mu^-$
**The Emulsion Target**

**Magnetised**
- 6 columns, 14 rows, 11 walls
- 12 Target Trackers layers
- 924 bricks
- 0.8 x 1.6 x 2 m³
- ~6900 m² emulsion films

**Non-magnetised**
- 9 columns, 20 rows, 20 walls
- 21 Target Trackers layers
- 3600 bricks
- 1.12 x 2.04 x 2.68 m³
- ~25600 m² emulsion films

Assume 10 times replacement (depending on the muon flux)

**OPERA 110000 m²!**

by Fujifilm
Comments on the emulsion target

- Tau neutrino topology in emulsion: first signal/noise discrimination
- OPERA as a demonstrator (no challenge)
- Important difference is the high muon flux → film replacement
- Define the replacement frequency (part of the test program)
- Now assume twice a year, replacement easy but expensive
- Japanese groups committed for the production of emulsions as needed in the baseline option (~7000 m²)
- Exploring production/pouring in other facilities (Slavich, Moscow)
- Full volume emulsion scanning won’t be an issue in ten years from now.
- Common project with MISiS (Andrey is PI). Emulsion Spectrometer is one of the four sub-projects of "Prospective technological, methodical and material solutions for searches of new physical effects"
Compact Emulsion spectrometer

NIM A 592 (2008) 56–62

DATA

MC

2 GeV/c

10 GeV/c
Preliminary results – CES, Naples, Japan, Russia

- Rohacell gaps demonstrated to be unsatisfactory (high deformability)
- New options under study → test beam activity

See Komatsu’s presentation for further results
Comments on the magnet

• Emulsion target defined by the physics sensitivity

• Design of the magnet linked to the available space cleaned by the muon sweeper

Options
  – Reshape the magnet to avoid intercepting the muon flux
  – Place the magnet a few m downstream
Magnetised versus non-magnetised

• Magnetised version:
  – Pros: measure the charge also in hadronic decay channels → reduce the target mass and films with comparable physics output
  – Contras: add the complication (heating, insulation, mechanics design, passive material, …) of the surrounding magnet
  – Challenge: demonstrate that the charge and momentum can be measured for particles up to 10^{-12} GeV

• Non magnetised version:
  – Pros: simplified detector concept without the CES and without the magnet
  – Contras: increase the target mass (and density) and emulsion film production for a comparable physics output
Target tracker

• Time stamp to the event and high spatial resolution to separate tracks within the same event

• Expected rate $\sim 0.4 \nu$/spill over a muon rate of $\sim \text{kHz/m}^2$

• Target tracker: 100 $\mu$m or better, time sensitive
  – Scintillating Fibres: robust technology
  – Gas chambers: cheaper, test beams to demonstrate technological challenges in magnetic field

\[ \nu \quad \text{e.g. charm production in neutrino interactions for QCD measurements} \]
\[ D_0 \]
An event with electromagnetic shower

Tracks at the TT surface

- **μon**
- **hadron**
- **e^+/e^-**
- **vertex**

**ID 169**

- \(N_{\text{tracks}}\) in TT = 18
- \(N_{\text{e^+/e^-}}\) in TT = 13
- **Area** = 15.44 cm\(^2\)
- Track density = 1.2/cm\(^2\)

Occupancy of the emulsion films largely dominated by the \(\mu/e\) flux
Target Tracker resolution

• Requirement: TT-Emulsion alignment with high (>98%) purity and (>90%) efficiency
• 2 mm gap between CES and TT
• In the early studies, 100 GeV muons assumed to be at zero angle uniformly distributed on the surface → Test this assumption with current muon Monte Carlo samples
• Relationship between single point and fitted position resolution to be assessed

<table>
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<th>Density (muons/mm²)</th>
<th>Average track distance (μm)</th>
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<tbody>
<tr>
<td>1000</td>
<td>30</td>
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Note: muon tracks passing through can be discarded. Remaining one are due to tracking inefficiency. Electrons matter

Need to reduce the muon (and electron!) density
GEM/emulsion chamber (LNF, Naples, Nagoya)

Micro-TPC mode not used yet (planned)

Micro RWells: to be tested in October with LNF group

<table>
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<th>θ (°)</th>
<th>B = 0T</th>
<th>B = -1T</th>
<th>B = 1T</th>
<th>B = 0T</th>
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<tbody>
<tr>
<td>0°</td>
<td>54±2</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>7.5°</td>
<td></td>
<td>221±13</td>
<td>132±6</td>
<td>154±15</td>
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<tr>
<td>15°</td>
<td>369±36</td>
<td>63±2</td>
<td>218±17</td>
<td></td>
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Different Target Tracker option

- **Emulsion clock**
  - 3 stages, each moving cyclically at a different speed
  - Track displacement linked to the recorded time
  - Operate in magnetic field
  - Test program in 2017 (see Valeri’s talk)
Muon spectrometer

High precision trackers
Straw tubes

Coils

Coarse trackers (RPC)
Inside magnetised iron

High precision trackers (see Daniel’s talk)
Interesting synergy emerged with the straw tracker of the hidden sector
Similar resolution (~150 microns)
Coarse tracking in the muon spectrometer

• Based on RPC
  – Available from OPERA
  – Magnet originally ~ same height

• New configuration requires new chambers

• Their characteristics (electronics, resistivity, ...) being defined through a number of tests (see Saverio’s talk)

• RPC technology suitable in environments with $\gamma$ and neutron background
Issues to be addressed: highly non uniform rates

• High rates at the edge

- Muons: $\sim 1\div5$ Hz/cm$^2$ in the last (first) RPC layer, with a sizeable ($\sim50\%$) low momentum component
- Electrons (mostly from muon bremsstrahlung): $\sim 2\div60$ Hz/cm$^2$ in the last (first) RPC layer
Shielding electrons with Pb Shield (A. Buonaura)

lead attached to both sides of the spectrometer

\[ R = \frac{\text{Rates without Pb shield}}{\text{Rates with Pb Shield}} \]
Final considerations

- Emulsion target being optimised according to the physics sensitivity
- Options with and without magnets are being compared
- Wide test-beam program on-going and planned
- Machine learning techniques very promising
- Avoid low energy muons and large non-uniformities in the rates for all detectors
- Magnet design still to be optimised (avoid intercepting the muon flux)
- True also for the muon spectrometer
- Lead shield around the spectrometer helps but it might be a fine tuning rather than the solution
- The Emulsion Spectrometer optimisation will largely benefit from the project "Prospective technological, methodical and material solutions for searches of new physical effects"