PBC Technology Working Group

Andrzej Siemko and Babette Döbrich for the Working Group

CERN, June 2018
Mandate and goals of the Technology Working Group
- Initiatives integrated into the Technology WG
- Physics landscape
- Analysis of initiatives and their potential benefit from CERN expertise and technologies (selected examples)
- Analysis of synergies
- Status of the report and outlook
The PBC Technology WG

Core members:

Giovanni Cantatore (aKWISP), Dimitri Delikaris (CERN), Babette Döbrich (CERN), Livio Mapelli (DARKSIDE), Antonio Polosa (Nanotubes), Pierre Pugnat (LSW/OSQAR), Joern Schaffran (DESY/ALPS), Andrzej Siemko (CERN), Paolo Spagnolo (STAX), Herman ten Kate (CERN/IAXO), Guido Zavattini (PVLAS)

Mandate of the Techno working group

"Exploration and evaluation of possible technological contributions of CERN to non-accelerator projects possibly hosted elsewhere: survey of suitable experimental initiatives and their connection to and potential benefit to and from CERN; description of identified initiatives and how their relation to the unique CERN expertise is facilitated."
Goals of the Techno Working Group

- Establish a list of non-accelerator proposals and all known new initiatives
- Address the physics case of the proposed initiatives in the worldwide landscape
- Address their feasibility and possible implementation at CERN (or elsewhere)
- Make a link between interested projects/experiments and CERN experts
- Identify requests to CERN for help and contribution
- Evaluate what sounds reasonable in order to put in balance wishes on one side and interest, availability and constraints on the other side, in particular CERN contributions to the preparation of the projects and, possibly, their future realisation at or outside CERN
- Help the preparation of the projects facilitating access to the unique expertise at CERN in various technologies
- Analyse synergies between different proposals and existing experiments in collaboration with other working groups
- Identify technologies that might be of interest for CERN in mid- and longer-term future
Initiatives integrated into the Techno WG

- Haloscope
  - LNCMI-Grenoble

- aKWISP

- Helioscope
  - IAXO

- DarkSide proto

- New QED-VMB Experiment at CERN

- ALPS III

- HALOSCOPE
  - STAX

- Nanotube Based DM Detector

- New LSW Experiment at CERN OSQAR+
Physics Landscape in the Technology Working Group

1. Direct detection of Dark Matter
   a. Ultralight (sub-eV) DM candidates like axions and ALPs (physics potential of respective experiments evaluated by BSM WG).
      Initiatives concerned: IAXO, ALPS-III, STAX, OSQAR+, Grenoble Haloscope
   b. WIMPs: nuclear recoil. Initiatives concerned: DARKSIDE, Nanotubes

2. Test of density-dependent fields. Initiatives concerned: aKWISP

3. Fundamental tests of QED: Vacuum magnetic birefringence. Initiatives concerned: OSQAR+, PVLAS

Details on initiatives presented in November: https://indico.cern.ch/event/644287/contributions/2724494/
### Initiatives and their potential benefit from/to CERN

#### Summary table

<table>
<thead>
<tr>
<th>Technology concerned</th>
<th>Benefit from CERN</th>
<th>Benefit to CERN</th>
<th>How to facilitate?</th>
<th>Experiments concerned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnet, concretely: high-field, large-bore</td>
<td>availability of strong fields, CERN expertise to build custom magnets</td>
<td>make optimal use of magnet resources (spares)</td>
<td>advertise existing magnet usage, provide expertise in magnet design, PBC-fellow</td>
<td>IAXO, OSQAR, ALPS, STAX, PVLAS</td>
</tr>
<tr>
<td>Optics/Optics sensing, concretely: Fabry Perot, membranes</td>
<td>surface coating, possibility to combine magnet with optics</td>
<td>integrate local expertise on optics technologies</td>
<td><code>optics hub</code>, as described in the document</td>
<td>aKWISP, PVLAS, ALPS</td>
</tr>
<tr>
<td>Radiofrequency cavities, concretely: design for axion searches</td>
<td>experience in design and production</td>
<td>new cavity designs for non-accelerator purposes, tuning in cold</td>
<td>mandate for cavity experts to aid in design</td>
<td>Grenoble initiative and other Haloscope operating already at CERN (CAST-CAPP), STAX</td>
</tr>
<tr>
<td>Cryogenics, concretely: large-scale: helium, argon, krypton from 120K to mK</td>
<td>availability of cryogenic facilities</td>
<td>participate in research beyond collider</td>
<td>through TE-CRG</td>
<td>DarkSide, aKWISP, OSQAR-VMB, IAXO</td>
</tr>
<tr>
<td>Vacuum, concretely: large-scale leak testing, surface coating</td>
<td>experience and availability</td>
<td>participate in research beyond collider</td>
<td>through TE-VSC</td>
<td>DarkSide, OSQAR, aKWISP, Nanotubes</td>
</tr>
</tbody>
</table>
Magnets example: Design of baby-IAXO magnet

Introduction: Previous meeting, magnet designs considered

Saddle coil dipole ($h, \alpha$)
- Optimized geometry for both BabyIAXO and IAXO
- Problematic manufacturing

Block coil dipole ($h, L, w$)
- Less efficient than saddle coils
- Less appealing when considered for IAXO due to bulky ends

Common coil dipole ($h, g, w$)
- Presumably, the only option that hits available budget
- Thus, it has been selected for further design optimization...

Next: Towards second construction proposal

<table>
<thead>
<tr>
<th>design layout</th>
<th>magnet length, L</th>
<th>10 m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>winding height, h</td>
<td>50 mm</td>
</tr>
<tr>
<td></td>
<td>pole gap, p</td>
<td>100 mm</td>
</tr>
<tr>
<td></td>
<td>winding width, w</td>
<td>710 mm</td>
</tr>
<tr>
<td></td>
<td>distance between coils</td>
<td>880 mm</td>
</tr>
<tr>
<td>bore</td>
<td>bore inner diameter</td>
<td>700 mm</td>
</tr>
<tr>
<td>MFOM 3-0</td>
<td>48.8 Tm$^2$</td>
<td></td>
</tr>
<tr>
<td>MFOM 2-0</td>
<td>714 mH</td>
<td></td>
</tr>
<tr>
<td>MFOM 2-0</td>
<td>913 A/mm$^2$</td>
<td></td>
</tr>
<tr>
<td>current density</td>
<td>radial number of turns, $N_r$</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>number of layers, $N_L$</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>using of shims</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>operating current</td>
<td>12 kA</td>
</tr>
<tr>
<td></td>
<td>total length</td>
<td>9.79 km</td>
</tr>
<tr>
<td></td>
<td>cable width</td>
<td>8.75 mm</td>
</tr>
<tr>
<td></td>
<td>cable height</td>
<td>16.7 mm</td>
</tr>
<tr>
<td></td>
<td>thickness of insulation</td>
<td>0.25 mm</td>
</tr>
<tr>
<td></td>
<td>number of strands</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>cross-section of NbTi</td>
<td>7.14 mm$^2$</td>
</tr>
<tr>
<td></td>
<td>cross-section of Al</td>
<td>118 mm$^2$</td>
</tr>
<tr>
<td></td>
<td>cross-section of Cu</td>
<td>8.52 mm$^2$</td>
</tr>
<tr>
<td></td>
<td>cross-section of Ka</td>
<td>12.5 mm$^2$</td>
</tr>
<tr>
<td>cable</td>
<td>strand diameter</td>
<td>1 mm</td>
</tr>
<tr>
<td></td>
<td>Cu/NbCu ratio</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Thanks to: Nikolay Bykovskiy, Alexey Dudarev, Helder Silva and Herman ten Kate
RF example: Key RF components for Axion Haloscopes

RF cavities of various dimensions & geometries (cylindrical, rectangular) for the range (0.3-30 GHz) @ T < 40 mK

Technologies:
- Al, Cu, (Sc?)
- Quality Factor $10^5-10^6$
- Cavity arrays with same frequency & phase matching
- Tuning systems

CAST/CAPP Haloscope

RADES project
arXiv:1803.01243v1, 3 March 2018
Vacuum example: ARIA facility for DarkSide 20k

ARIA

350-m LAr cryogenic distillation tower to purify and isotopically separate argon from other elements for DS20k

Full tower - 30 modules

Tested at CERN – 11 modules

On Friday, 24 November, ARIA’s top and bottom modules plus one standard module were brought to Building 180 and lined up to precisely test their alignment and interconnections. (Image: Max Brice/CERN)

Thanks to: Livio Mapelli
Analysis of synergies among LSW and VMD initiatives

The main characteristics of different Light Shining through the Wall and Vacuum Magnetic Dichroism initiatives

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Light Shining through the Wall (LSW)</th>
<th>Dichroism</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ALPS IIc</td>
<td>OSQAR+</td>
</tr>
<tr>
<td>Magnet assembly</td>
<td>10 + 10</td>
<td>4 + 4</td>
</tr>
<tr>
<td>HERA</td>
<td>10 + 10</td>
<td>4 + 4</td>
</tr>
<tr>
<td>Field length $L_B$ [m]</td>
<td>88 + 88</td>
<td>57+57</td>
</tr>
<tr>
<td>$B$ [T]</td>
<td>5.3</td>
<td>9</td>
</tr>
<tr>
<td>Photons/s, $R$ [s$^{-1}$]</td>
<td>$1.6 \times 10^{20}$</td>
<td>$1.6 \times 10^{20}$</td>
</tr>
<tr>
<td>Photon energy, $\omega$ [eV]</td>
<td>1.17</td>
<td>1.17</td>
</tr>
<tr>
<td>$N_1$</td>
<td>5000</td>
<td>5000</td>
</tr>
<tr>
<td>$N_2$</td>
<td>40000</td>
<td>40000</td>
</tr>
<tr>
<td>Background, $B$ [s$^{-1}$]</td>
<td>$10^{-6}$</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>Shot-Noise floor, $NF$</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>$g_{a\gamma\gamma}$ [GeV$^{-1}$]</td>
<td>$&lt; 2 \times 10^{-11}$</td>
<td>$&lt; 2 \times 10^{-11}$</td>
</tr>
<tr>
<td>$m_a$ [eV]</td>
<td>$&lt; 1 \times 10^{-4}$</td>
<td>$&lt; 1.3 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

N1 and N2 are the amplification factors of the generation and regeneration cavities.

Regeneration rate signal: $S = RN_1N_2 \left( \frac{g_{a\gamma\gamma}BL}{4} \right)^4$

Rotation due to dichroism $\phi = N_1 \left( \frac{g_{a\gamma\gamma}BL}{4} \right)^2$

Mass limits have been set from $m_a < \sqrt{\frac{4\omega}{L}}$.

Limits on $g_{a\gamma\gamma}$ have been obtained by setting $S = B$ for the LSW cases and $\phi = NF$ for VMD

Everywhere $1 \text{T} = \sqrt{\frac{\hbar^2 e^2}{2\mu_0}} = 195 \text{ eV}^2$

$1 \text{ m} = \frac{e}{\hbar c} = 5.06 \times 10^6 \text{ eV}^{-1}$

Thanks to: Guido Zavattini
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Appendices: Description of all initiatives, plans, collaboration, time-lines...
Status of the Report and Outlook

- The technological contributions and future expectations from 9 new initiatives: **Grenoble-haloscope, STAX, aKWISP, DarkSide, IAXO, new QED-VMB experiment at CERN (OSQAR-PVLAS), nanotube DM detector, ALPS III and OSQAR+** were categorized and are being documented.

- The working group's job is now to complete analysis of synergies and develop a form of executive summary with a proposal of recommendations for the future.

- The Technology WG report is well advanced and will be submitted with a number of appendices describing all initiatives/experiments assigned to this WG.