Status and Prospects of PHYSICS BEYOND COLLIDERS at CERN

Study Group mandated by the CERN Management to prepare the next European HEP strategy update (2019-20)
coordination: J. Jäckel, M. Lamont, C.V.

Excerpt from the PBC mandate:
“Explore the opportunities offered by the CERN accelerator complex to address some of today’s outstanding questions in particle physics through experiments complementary to high-energy colliders and other initiatives in the world.”

Time scale: next 2 decades

pbc.web.cern.ch
KICK-OFF WORKSHOP, CERN, Sept. 6-7, 2016
Call for abstracts → 33 abstracts submitted, 20 selected for presentation

1st GENERAL WORKING GROUP MEETING, CERN, March 1-2, 2017
Identification of main issues to be studied

FOLLOW-UP WORKSHOP, CERN, November 21-22, 2017
https://indico.cern.ch/event/644287/
Working groups project reports
New call for abstracts → 10 abstracts submitted, 7 selected for presentation

NB: credit to Collaborations for the plots shown in this presentation
THE CERN ACCELERATOR COMPLEX

High energy experiments and test beams

Former CNGS extraction line

Antimatter Factory

Low energy experiments and test beams

C. Vallée, DESY, December 2017
A DECADE OF VIBRANT “DIVERSITY” PHYSICS AT CERN!

~1000 physicists on ~20 experiments

Completed

CNGS (ν)
DIRAC (QCD)

Full Swing

COMPASS (QCD)
NA61 (QCD)

Expanding

ANTIMATTER FACTORY (CPT)

Starting

NA62 & NA64 (DM)
ν Platform (det. R&D)
AWAKE (acc. R&D)

Recent stop of major programs (e.g. CNGS) leaves room to new significant initiatives

...+ CAST, OSQAR, etc...
**CERN $\nu_\mu$ beam to Gran Sasso (CNGS)**

optimized for $\nu_\tau$ appearance ($E_\nu \sim 17$ GeV)

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**ICARUS:** limits on sterile neutrinos

**OPERA:** establishment of $\nu_\mu \rightarrow \nu_\tau$ oscillation
NEUTRINO PLATFORM

DUNE LAr-TPC engineering prototypes to be calibrated in low energy beams in a North Hall extension

Prototypes being assembled in hall extension. *Tight schedule to take beam data before LS2*

NB: technology could also be of interest for future DM projects at CERN
R&D for electron acceleration with a plasma cell excited by proton bunches
Plasma self modulation established end 2016 and further studied in 2017

Goal for 2017/18 is first electron acceleration

Post-LS2 program under preparation

A project of interest for future high E / high I electron beams:
Could provide \( \sim 10^{15} \sim 30 \text{ GeV e’s/year in pulsed mode} \)
NB: the former CNGS target+decay tunnel downstream of AWAKE could serve as detector hall for an experimental program
Low E perturbative chiral QCD with mesonic atoms: 
*Discovery of \( \pi K \) atoms and metastable \( \pi\pi \) atoms*

**AFTER LS2: wish to perform similar studies at SPS:**
Increased statistics (\( x \sim 20 \)) would allow quantitative test of chiral \( SU(3)_L \times SU(3)_R \) symmetry breaking with \( \pi K \) atoms

**Main issues:** siting at CERN and strength of Collaboration
NA61/SHINE

Search for QCD Critical Point by scan in the \((T, \mu_B)\) plane

Scan to be completed until LS2

*No indication of CP yet*

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**Diagram Description:**

- **Axes:**
  - Temperature \(T\) [MeV]
  - Net Baryon Density

- **Legend:**
  - **Pb+Pb**
  - **Xe+La**
  - **Ar+Sc**
  - **Be+Be**
  - **p+Pb**
  - **p+p**

- **Scatter Plot:**
  - **\(h^+ + h^-\)**
  - **\(\Sigma_{P,T}^N\)**

- **Colors:**
  - Red
  - Green

- **Data Points:**
  - **2016/18**
  - **2017**
  - **2015**
  - **2011/12/13**
  - **2012/14/16/17/18**
  - **2009/10/11**

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**Graph Details:**

- **Axes:**
  - \(\sqrt{s_{NN}}\) [GeV]
  - Average multiplicity \(\langle W\rangle\)

- **Color Scale:**
  - Red to Blue gradient

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**Note:**

Beyond Co...
AFTER LS2: wish to further study QCD deconfinement with open charm

Would allow to disentangle statistical/dynamical models in complement of J/ψ data from NA38/NA50

Main issues: factor 10 increase in beam intensity and high rate data taking
NA61 large acceptance TPC also unique to constrain $\nu$ beam fluxes.

Heavily used by T2K with p-C and p-replica target data.

Similar program ongoing with the US for LBNF.

LBNF phase space.
Revival of NA60 concept to measure low mass dimuons in heavy ions collisions

New feature: energy scan to revisit QCD phase transition dynamics with a focus on chiral symmetry restoration

Main issues: Experiment siting and strength/resources of the Collaboration
a large acceptance spectrometer in the intermediate $x$-domain between H1/ZEUS and HERMES/JLAB
Muon beam data taking completed in 2012, focused on quark spin contribution to proton spin

**Longitudinal spin**

Improved precision on $g_1$ at low $x$

**Transverse spin**

Non-zero transversity in proton confirmed
COMPASS I(+II) : SPECTROSCOPY AND PRIMAKOV

New isovector meson $a_1(1420)$ $1^{++}$

Pion polarizability with 2009 Primakov data (to be x 5 with 2012 data)
**COMPASS II (2014-18)**

**2016-17: DVCS**: proton tomography with access to orbital momentum of quarks

**2014+15+18: DY**: Transverse Momentum Dependent (TMD) QCD effects in the valence regime

Measurement complementary to SiDIS: opposite asymmetries expected
**COMPASS++ (long term plans > LS3)**

**Wish RF separated antiproton and kaon beams (1 x 50)**

- High statistics strange meson spectroscopy
- Exotic states spectroscopy complementary to LHCb/PANDA
- Kaon and antiproton structure

Main issues: Competition, cost/schedule of RF separated beam, Collaboration support

→ Shorter term LS2↔LS3 program under definition

<table>
<thead>
<tr>
<th>DY statistics</th>
<th>NH$_3$</th>
<th>Al (7cm)</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^-$ beam</td>
<td>14,000</td>
<td>2,800</td>
<td>29,600</td>
</tr>
<tr>
<td>$\bar{p}$ beam</td>
<td>15,750</td>
<td>2,750</td>
<td>22,500</td>
</tr>
</tbody>
</table>

![Diagram showing mass and momentum of particles]
New idea: MUonE
direct measurement of the dominant contribution to the theoretical error on \((g-2)_\mu\) from \(\mu\)-e elastic scattering

High statistics space-like measurement could reduce by factor 2 the current error derived from time-like processes

Full \(t\) range accessible thanks to high energy \(\mu\) beam boost, self normalized measurement
Might be feasible with reasonable resources within the (modified) COMPASS setup

Main issue: systematic effects (control needed at 10\(^{-5}\) level)
Test beam performed to check multiple scattering

GEANT description including tails being quantified

**MUonE systematics**
Fixed Target physics with LHC beams

BEAM SPLITTING
channeled halo to a solid target

STORAGE CELL
unpolarized gas
He, Ne, Ar, ... H2, D2

POLARIZED TARGETS
polarized gas target H, D
guiding magnetic field needed

3 options under study
LHCb:
- SMOG jet target operated.
- SMOG2 storage cell under design (lumi x ~100).
- Polarized target also considered

ALICE: several options under consideration

CRYSTAL:
- Single and double channeling observed (UA9)

Main issue of LHC internal fixed targets: compatibility with other LHC programs/goals
LHC Fixed Target: physics reach

Crystal extraction:
Magnetic and electric moments of short lived baryons
Could test anomalous moments of heavy quarks

Gas target:
p-p: High precision TMD measurements and charm at high x.
p-A: Nuclear PDFs
A-A: HI physics in intermediate range between SPS and RHIC
4 running experiments devoted to Antiproton and Antihydrogen properties

2.5 more in preparation to test gravity of Antihydrogen: AEGIS/GBAR/ALPHA-g
Antiproton Properties

Magnetic moment:
Measured by BASE at same level of precision as for proton

Mass:
Regular ASACUSA progress with cold 1- and 2-photon spectroscopy of antiprotonic Helium

Charge/Mass:
High precision BASE measurement with cyclotron frequency
Antihydrogen Properties

Hbar trapping established by 3 experiments

ALPHA
ASACUSA
ATRAP

On-resonance interactions cause ejection of Hbar from trap

First Hbar microwave and laser spectroscopy performed by ALPHA

<table>
<thead>
<tr>
<th>Type</th>
<th>Number of detected events</th>
<th>Background</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off resonance</td>
<td>159</td>
<td>0.7</td>
<td>13</td>
</tr>
<tr>
<td>On resonance</td>
<td>67</td>
<td>0.7</td>
<td>8.2</td>
</tr>
<tr>
<td>No laser</td>
<td>142</td>
<td>0.7</td>
<td>12</td>
</tr>
</tbody>
</table>
Antihydrogen Properties cont’d: gravitation

2.5 experiments now devoted to a direct measurement

AEGIS
in-flight deviation of Hbar atoms by gravitation

GBAR: Hbar free fall using ELENA

ALPHA-g
Statistical method for a first measurement of the sign
**AFTER LS2: ELENA**

Further deceleration of antiprotons from 5 MeV to 100 KeV kinetic energy

Will increase by 2 orders of magnitude the antiproton trapping efficiency

Under commissioning for first connection to GBAR in 2017

Secures antimatter physics for the next decade
Rare $K$ decays

$K \rightarrow \pi \nu \bar{\nu}$ (BR $\sim 10^{-11}$)

NA62

1 GHz 75 GeV unseparated beam, 11 MHz $K^+$ decays in detector

Signal regions

From concept…
Detector fully operational in 2016, first year of quasi-nominal operation

Signal regions: ~100 evts expected until LS2

NA62

Rare K decays

νπν→K (BR ~ 10^{-10})

After many years of intensive construction and commissioning

5% 2016 data
NA62 Preliminary

...to reality!
New idea: $K^0 \rightarrow \pi^0\nu\nu$ rare decay (KLEVER)

$K^0$ decays complementary to $K^+$ decays for the CKM matrix and BSM searches.

Would require a new high intensity $K^0$ beam.

~50 events could be collected with a similar but basically new detector.

Competition from starting KOTO at JPARC:

few events expected in coming years, upgrade by factor ~10 foreseen > 2025

Detector layout for $K_L \rightarrow \pi^0\nu\bar{\nu}$

Similar to NA62 but basically new detector

Main issues: actual sensitivity vs competition, cost of new beam and upgraded detector
Intermezzo: the Hidden Sector

\[ L = L_{SM} + L_{\text{mediator}} + L_{HS} \]

Visible Sector

- Mediators or portals to the HS: vector, scalar, axial, neutrino (e.g.)

Hidden Sector

Naturally accommodates Dark Matter (may have rich structure)

- Long-lived objects
- Interact very weakly with matter

<table>
<thead>
<tr>
<th>Models</th>
<th>Final states</th>
</tr>
</thead>
<tbody>
<tr>
<td>HNL, SUSY neutralino</td>
<td>( l^+ \pi^-, l^+ K^-, l^+ \rho^- \rho^+ \rightarrow \pi^+ \pi^0 )</td>
</tr>
<tr>
<td>Vector, scalar, axion portals, SUSY sgoldstino</td>
<td>( l^+ l^- )</td>
</tr>
<tr>
<td>HNL, SUSY neutralino, axino</td>
<td>( l^+ l^- \nu )</td>
</tr>
<tr>
<td>Axion portal, SUSY sgoldstino</td>
<td>( \gamma \gamma )</td>
</tr>
<tr>
<td>SUSY sgoldstino</td>
<td>( \pi^0 \pi^0 )</td>
</tr>
</tbody>
</table>
Intermezzo cont’d: the Hidden Sector

Production + decay of new particle:  
2 couplings $\rightarrow$ needs high intensity  

Invisible decay of new particle:  
accommodates lower intensity

A similar situation as the search for neutrino oscillations in the 70 – 80’s:  
do not know if they exist and where they stand!

Fixed Target searches complementary to others
AFTER LS2 : NA62++

Wish to run ~1 year in beam dump mode to look for Heavy Neutral Leptons

→ possible intermediate step towards a more ambitious beam dump facility

Compact beam dump: ~11 λ Cu-based beam-defining collimator (TAX)
radioprotection-compliant even if target removed

Decay volume ~ 60 m long (in vacuum):
reasonable acceptance to long-lived states
Flagship program for a comprehensive investigation of the Hidden Sector in the few GeV domain

Similar layout as NA62, with larger acceptance to reach the c/b mass range

An opportunity for a new post-CNGS high intensity general facility at CERN

Significant progress in detector design and optimisation
Foreseen to be sited close to the North Area
Conceptual design ongoing at CERN.

Magnetized hadron absorber and light weight active muon shield minimize punch through in decay volume

Muon yields and charm cross sections to be measured in test beams
Main issue: maximize physics reach to justify high investment of a new beamdump facility

- **Scalar with Yukawa-like couplings**
- **Dark photon**
- **Heavy neutral leptons**
- **SHiP physics reach**
- **Significant & mostly unique extension of reach for many channels**

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**C. Vallée, DESY, December 2017**

**Physics Beyond Colliders at CERN**
Recently revived idea to intercept small beam fraction to look for $\tau \rightarrow 3\mu$ decays

_Could set limits on branching ratio at $10^{-10}$ level_

E.g. 1mm W (multiple) target system intercepting 1% of $2 \times 10^{20}$ pot

Possibility of implementation upstream of BDF target to be studied
NA64

Hidden sector search from invisible decays with missing energy

First implementation in 2016 on an electron test beam

Fast analysis excluding \((g-2)_\mu\) interpretation confirms the potential of the method
AFTER LS2: NA64++

Wish to extend the method to $\mu / \pi / K / p$ beams

<table>
<thead>
<tr>
<th>Beam and process</th>
<th>Motivation</th>
<th>Required number of POT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. $e^- Z$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$A' \rightarrow$</td>
<td>S, V mediator of light DM</td>
<td>$\sim 5 \times 10^{12}$ EOT</td>
</tr>
<tr>
<td>invisible</td>
<td>production</td>
<td></td>
</tr>
<tr>
<td>$X(16.7), A' \rightarrow e^+e^-$</td>
<td>$^8$Be anomaly,</td>
<td></td>
</tr>
<tr>
<td>invisible</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$a \rightarrow$</td>
<td>Leptonic pseudogoldstone,</td>
<td></td>
</tr>
<tr>
<td>$\gamma\gamma$</td>
<td>ALP decays, milli-Q</td>
<td></td>
</tr>
<tr>
<td>invisible</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\text{milli-Q}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mu^- Z$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Z_{\mu^+} \rightarrow$</td>
<td>New gauged</td>
<td></td>
</tr>
<tr>
<td>$\nu\nu, \mu^+\mu^-$</td>
<td>symmetry $L_{\mu}-L_{\tau}$,</td>
<td></td>
</tr>
<tr>
<td>invisible</td>
<td>Leptonic pseudo-goldstone,</td>
<td></td>
</tr>
<tr>
<td>$\mu \rightarrow \tau$</td>
<td>LFV</td>
<td></td>
</tr>
<tr>
<td>conversion</td>
<td></td>
<td>$10^{12} - 10^{13}$ MOT</td>
</tr>
<tr>
<td>$\pi (K) p \rightarrow M^0 n + E_{\text{miss}}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$K_L \rightarrow$</td>
<td>NHL, $\phi\phi$,</td>
<td></td>
</tr>
<tr>
<td>invisible</td>
<td>Bell-Steinberger Unitarity,</td>
<td></td>
</tr>
<tr>
<td>$K_S \rightarrow$</td>
<td>CP, CPT symmetry</td>
<td></td>
</tr>
<tr>
<td>invisible</td>
<td></td>
<td>$\sim 5 \times 10^{12}$ P(K)OT</td>
</tr>
<tr>
<td>$\pi^0, \eta, \eta \rightarrow$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>invisible</td>
<td></td>
<td>$\sim 5 \times 10^{12}$ POT</td>
</tr>
</tbody>
</table>

Main issues: e beam intensity and CERN siting for other beams
NA64++ expected sensitivities

Electron beam
appearance mode

\[ \chi, A' \to e^+e^- \]

Muon beam
invisible mode

Hadron beams
invisible mode

\[ B(K_{L} \to \phi\phi) \text{ Krasnikov'16} \]

\[ B(K_{L} \to \nu\nu) \text{ Abada et al. (2016)} \]
Another possible source of hidden particles:

**Axions from the sun**

CAST: Instrumented LHC magnet pointed to the sun to convert Axions into X rays

$^3$He and $^4$He scans completed, start to bite into QCD models

Vacuum runs continued with “IAXO pathfinder” detection system

R&D on new detection techniques going on CAST CERN setup
Collaboration formally founded in July 2017, funding being secured to prepare TDR. Prototypes of IAXO detector under preparation. Support from CERN for magnet design granted within PBC. Baby-IAXO intermediate option may offer optimal sensitivity/cost ratio.

Main IAXO issues: Collaboration strengthening and helioscope siting (DESY interest)
Laboratory Axions: “ALPS III”

Light shining through a wall

Comparable limits obtained by OSQAR@CERN and ALPS@DESY
ALPSII@DESY under construction

<table>
<thead>
<tr>
<th>Dipole</th>
<th>Aperture [mm]</th>
<th>Field strength [T]</th>
<th>LSW experiment</th>
<th>Number of used dipoles</th>
</tr>
</thead>
<tbody>
<tr>
<td>HERA (straightened)</td>
<td>50</td>
<td>5.3</td>
<td>ALPS II (DESY)</td>
<td>20</td>
</tr>
<tr>
<td>LHC</td>
<td>40</td>
<td>9.0</td>
<td>OSQAR (CERN)</td>
<td>2</td>
</tr>
<tr>
<td>“FCC”</td>
<td>100 (40)</td>
<td>13 (20)</td>
<td>“ALPS III”</td>
<td></td>
</tr>
</tbody>
</table>

A combined project (“ALPS III”) could benefit from CERN high field magnet developments
Storage Ring for proton/deuterium EDM

**Electrostatic option for proton**
**Magnetic option for deuterium**

~160 m Ø

Design sensitivity: $4 \times 10^{-29}$ e-cm
Requires:
- electrostatic deflector 8 MV/m
- magnetic shielding
- high precision SQUID BPMs to monitor the total radial magnetic field by vertical beam position separation between CW/CCW

$10^{-29}$ e-cm sensitivity would correspond to 100 TeV for new physics energy scale

+ recent idea to look for axion DM through oscillating EDMs

**Ring design ongoing by CERN with srEDM and JEDI collaborations**

**Main issue:** control of systematic effects (e.g. B fields)
COSY ring in Jülich used for R&D on components, could host a demonstrator ring for e.g. oscillating EDMs

Possible siting at CERN: inside ISR ring
New idea: Gamma Factory

Use LHC beam to convert laser photons into 0.1 - 400 MeV $\gamma$ rays

Expect factor $10^7$ intensity increase compared to present e-driven $\gamma$ ray beams, would open a completely new field of physics measurements and applications.

LHC filled with Partially Stripped Ions

NB: encouraging lifetime > 1s measured in SPS for 39+Xe PSI

C. Vallée, DESY, December 2017
Well controlled $\nu$ beam from a $\mu$ storage ring.

Would allow precise $\sigma(\nu)$ measurements. Also a path towards a $\nu$ factory or a $\mu$ collider.
New idea: CLEAR++

3 GeV e-LINAC with CLIC technology
Connected to SPS for acceleration to ~10 GeV

Would provide a unique testbed for R&D on linear acceleration techniques

Slow extraction from SPS would allow hidden sector searches in the invisible mode (~10^{16} e/year to experiments à la NA64/LDMX)
THE CERN LANDSCAPE AFTER 2025?

Fixed Target
ALICE
Gamma factory
EDM
CLEAR++
SHiP
BDF
North Area
Klever, NA62++, NA64++...
AWAKE
AWAKE++
LHCb
MoEDAL
Fixed Target
PBC WORKING GROUP STRUCTURE

PBC DELIVERABLES

One main overview document supplemented by CDR/CDS at a level of details matched to the maturity of the projects

To be submitted end 2018 as input to the next European Particle Physics strategy update

NB: no arbitration between projects to be done by PBC

Guidelines will come later from the Strategy update

One of the main added values of PBC: a forum for exchanges between communities with similar motivations, under CERN “umbrella”:

SHiP/NA62, COMPASS/LHC-FT, COMPASS/MUonE,
NA60/NA61/LHC-FT, JEDI/srEDM, OSQAR/ALPS, etc…
ADDITIONAL SLIDES
To be submitted end 2018 as input to the next European Particle Physics strategy update

Guidelines for structure and content distributed to all participants

<table>
<thead>
<tr>
<th>DOCUMENT</th>
<th>EDITORS</th>
<th>AUTHORS</th>
<th>CONTENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main (30-50 pages)</td>
<td>PBC coordinators</td>
<td>PBC WGs</td>
<td>Highlights of the physics case of the proposed PBC experiments at CERN, and how they can address all physics orientations in the worldwide landscape, uniqueness of CERN context, compatibility of projects, technical feasibility, timelines and financial implications. The content of this document will be supported by the detailed information provided in the ancillary documents listed hereafter.</td>
</tr>
<tr>
<td>BSM context</td>
<td>BSM WG conveners</td>
<td>BSM WG + possible externals as appropriate</td>
<td>Worldwide BSM physics landscape with a focus on how the proposed PBC projects fit in term of theoretical motivation and experimental sensitivity; overview of experimental physics processes (direct production modes, decay signatures, indirect searches); reach in term of new particle types, masses and couplings; comparison and complementarity of their sensitivities via common simplified BSM models (e.g. accelerator WIMP searches vs recoil experiments via effective operator and simple mediator test models, helioscope and CSL vs EDMs via axion-like particle models, p/π vs n EDM,...); indication of mass and coupling ranges favored by current observations (DM amount, experimental astrophysical limits, ...); general suggestions for possible extension of the PBC projects discovery reach.</td>
</tr>
<tr>
<td>QCD context</td>
<td>QCD WG conveners</td>
<td>QCD WG + possible externals as appropriate</td>
<td>Worldwide QCD physics landscape with a focus on how the proposed PBC projects fit in term of theoretical motivation and experimental sensitivity; QCD fundamental open questions and measurements of interest for other domains.</td>
</tr>
<tr>
<td>Experiments contributions</td>
<td>Proponents</td>
<td>Proponents</td>
<td>Experiments contribute to the BSM and QCD context documents by providing their sensitivity curves within the commonly agreed models and assumptions for comparison with past, present and future experiments.</td>
</tr>
<tr>
<td>Technical support</td>
<td>Technology WG</td>
<td>Technology WG</td>
<td>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 fostered.</td>
</tr>
<tr>
<td>AWAKE</td>
<td>AWAKE study group</td>
<td>AWAKE study group</td>
<td>Exploratory study of possible applications of the AWAKE concept: development of physics cases and experimental design; accelerator systems and realistic range of parameters; possible infrastructure and siting.</td>
</tr>
<tr>
<td>nuSTORM</td>
<td>nuSTORM study group</td>
<td>nuSTORM study group</td>
<td>Updated broad outline of a possible nuSTORM implementation at CERN.</td>
</tr>
<tr>
<td>γ Factory</td>
<td>γ Factory study group</td>
<td>γ Factory study group</td>
<td>Exploratory study of the concept feasibility: results of initial tests and extrapolated performance; elaboration on the corresponding physics reach.</td>
</tr>
</tbody>
</table>
One main overview document supplemented by:

**Accelerator documents:**
- Beam Dump Facility: Conceptual Design of the BDF
- EDM ring: Fully developed feasibility study including preliminary costing
- Conventional beams: Study beam upgrades for extended or new fixed target projects
- LHC Fixed Target: Conceptual design of LHC internal crystal and gaseous targets
- Technology: Evaluation of possible CERN contributions to non-acc. projects
- Complex performance: Injector complex performance after LIU
- AWAKE++: Exploratory study of possible applications of the AWAKE concept
- NuSTORM: Updated broad outline of a possible implementation at CERN
- Gamma Factory: Exploratory study of the concept feasibility

**BSM and QCD context documents with for each proposed project:**
- Evaluation of the physics case in the worldwide context
- Possible further optimization of the detector
- For new projects: investigation of the uniqueness of CERN siting

NB: no arbitration between projects to be done by PBC!