Physics Beyond Colliders

Accelerator Complex summary

Mike Lamont
17th January 2019

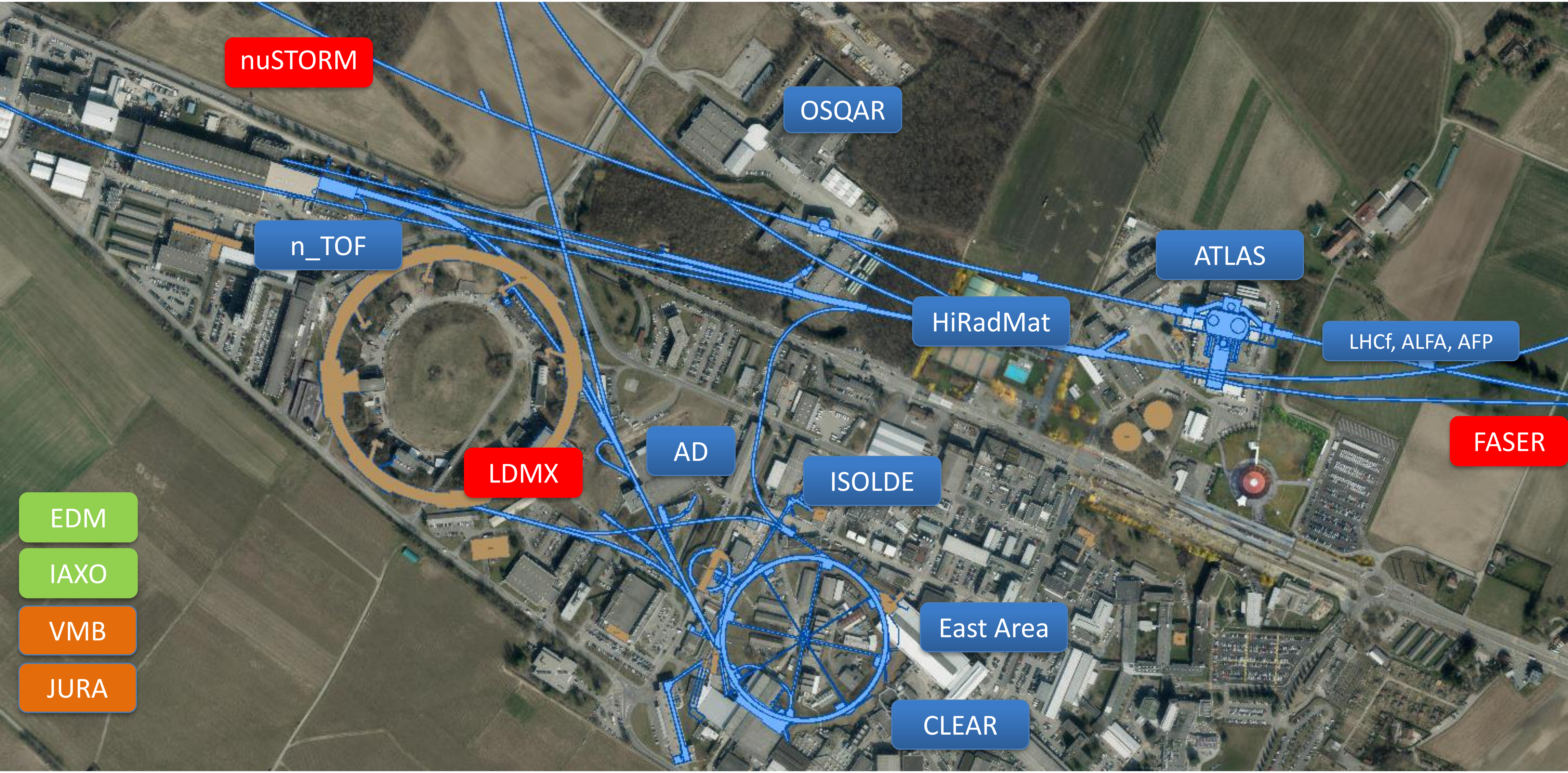
Aim of the exercise

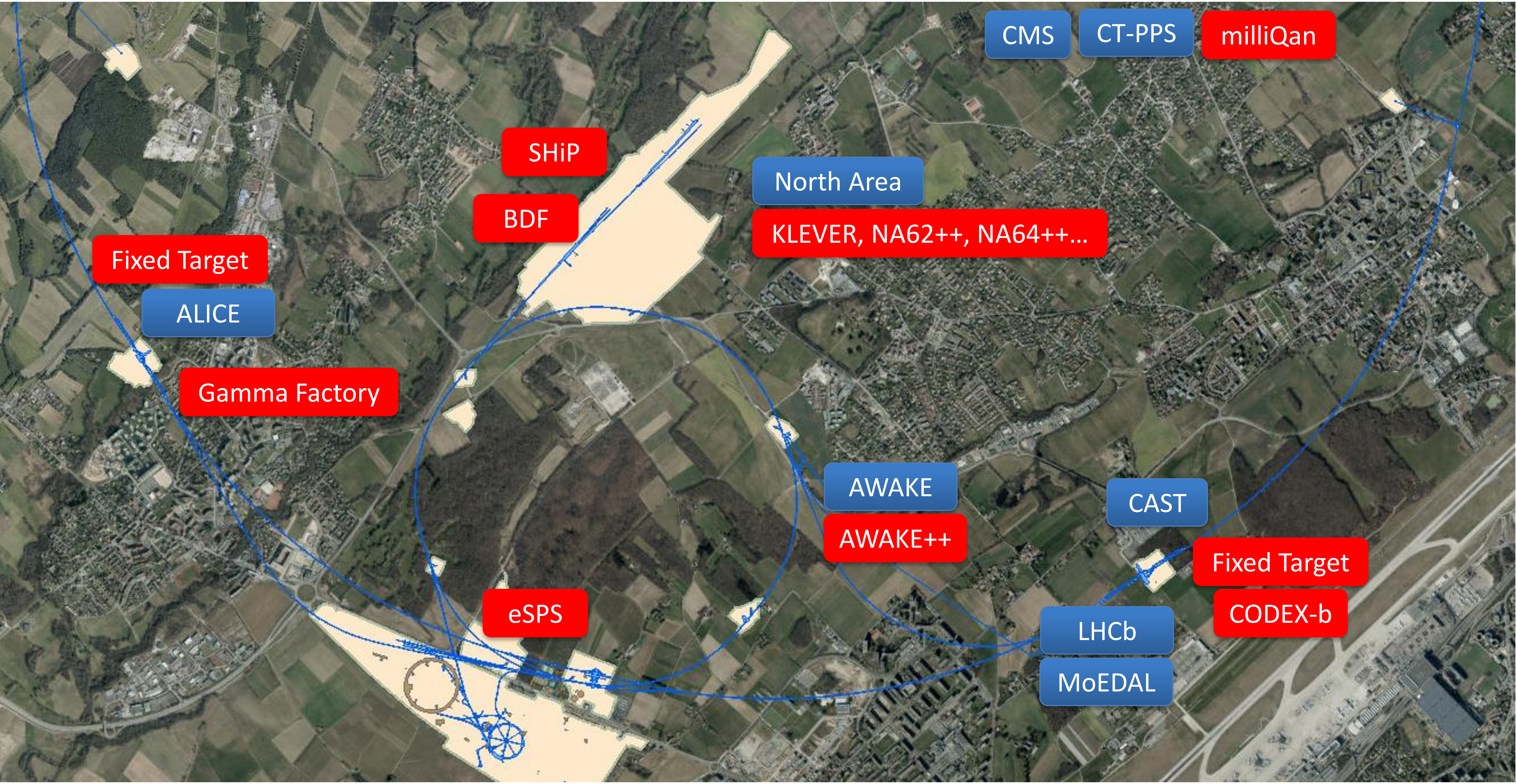
- Maximize physics reach of existing complex
  - New facilities exploiting existing complex
  - Novel exploitation of existing facilities
  - Provide support for novel off-site facilities
  - Harness the existing expertise and resources

Within the limits posed by an already vibrant and diverse physics program

What has CERN got to offer?

- Existing accelerator complex and associated infrastructure
  - Wide range of beams, intensities, energies, facilities
- Technical expertise and experience
  - Vacuum, magnets, power converters, RF, instrumentation, beam transfer, targets, cryogenics, accelerator physics, engineering…
- Support
  - workshops, test facilities, engineering support, manufacturing
- Resources, size, and flexibility
- Wise and beneficent management

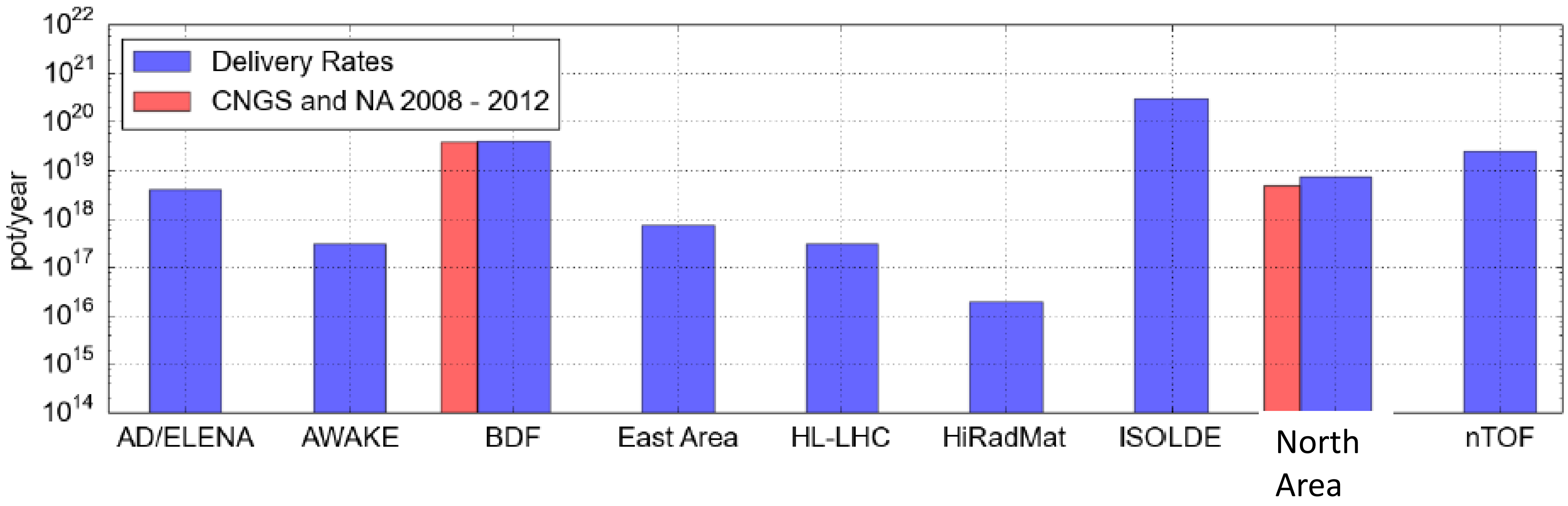

nuSTORM
OSQAR
n_TOF
ATLAS
HiRadMat
LHCf, ALFA, AFP
AD
LDMX
ISOLDE
FASER
EDM
IAXO
VMB
JURA
East Area
CLEAR



CMS
CT-PPS
milliQan
SHiP
BDF
North Area
KLEVER, NA62++, NA64++...
Fixed Target
ALICE
Gamma Factory
AWAKE
AWAKE++
CAST
Fixed Target
CODEX-b
eSPS
LHCb
MoEDAL

Complex already heavily solicited

- (HL)LHC will continue to dominate
- Diverse forward looking program already in place!



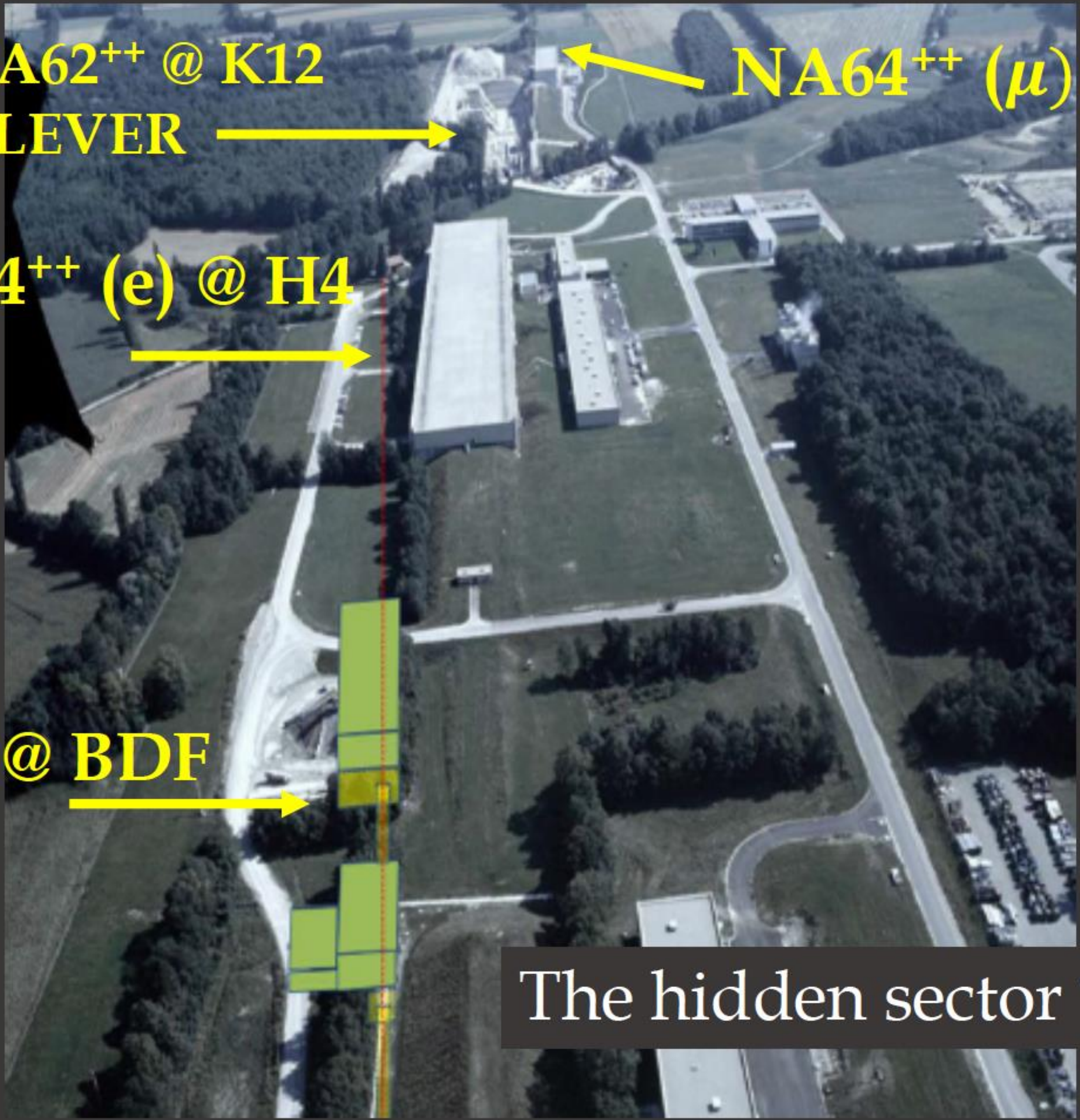
Nonetheless…

Main themes

- Exploitation of SPS/North Area (HSC)
  - options, required developments, compatibility
- Novel approaches
  - Gamma Factory, storage ring pEDM, AWAKE++
- LHC
  - LLP, LHC-FT
- Technology
  - many and various options

- Studies clearly at different stages
- Nothing too radical - such as a new proton driver (SPL, PS2 etc.)…
- appropriate given the medium to long term priorities of the lab

Aerial picture of the North Area



HSC

The hidden sector "campus"

Conventional beams at the North Area

Good progress on all fronts - healthy mix of HS/QCD

NA62++	Optimise conditions for NA62 in beam dump mode for Hidden Sector searches
NA64++ (e,h)	Increase electron flux and optimise hadron beams in the H4 line
NA64++ (u)	Study the possibility to install and run a NA64-like experiment with muons in EHN2
KLEVER	Study a new beam for a KL → pi0nunu experiment at very high proton flux in ECN3
COMPASS++	Study new requests from COMPASS, including a RF separated beam
MUonE	Study the possibility to implement the MuonE experiment in the M2 beam for operation with μ and e beams
DIRAC++	Study implementation options for a DIRAC follow-up experiment at the SPS
NA60++	Study implementation options for a NA60 follow-up experiment with heavy ion beams
NA61++	Run NA61/SHINE at higher intensity and with better protection

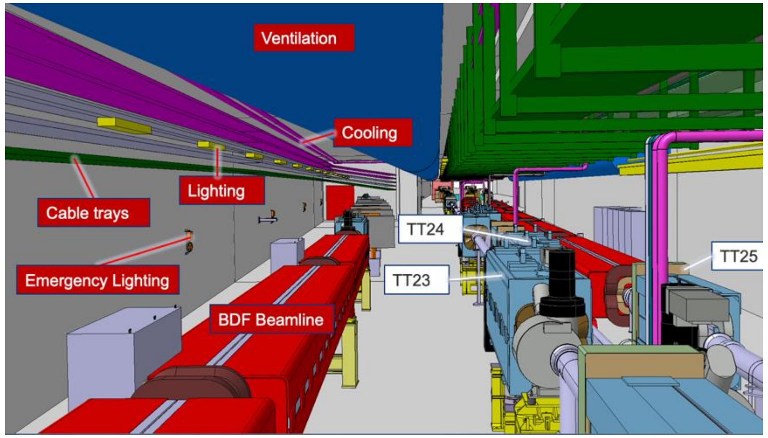
D.Banerjee, J.Bernhard, M.Brugger, N.Charitonidis, G.L.d'Alessandro, N.Doble, M.van Dijk,
L.Gatignon, A.Gerbershagen, E.Montbarbon, M.Rosenthal
on behalf of the Conventional Beams working group

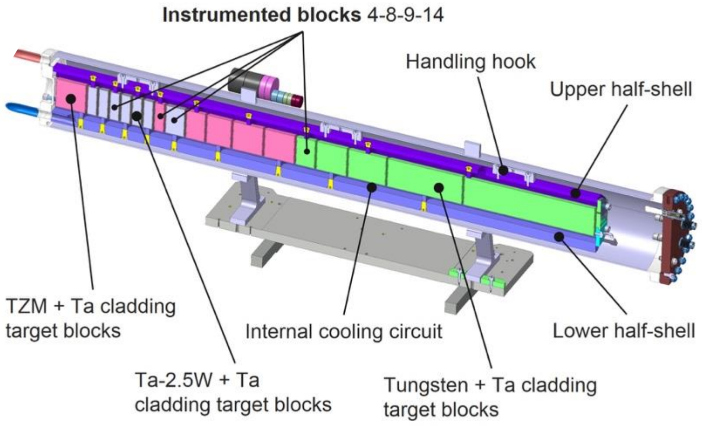
Beam Dump Facilities

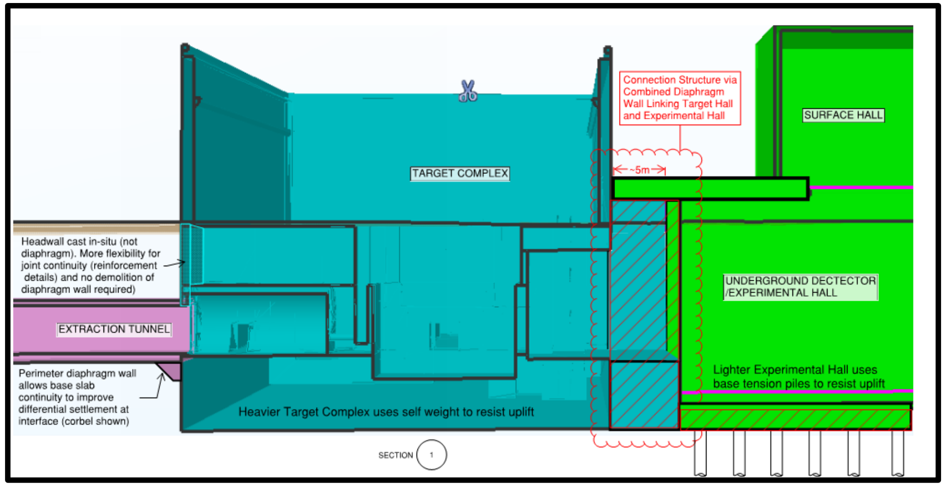
- BDFs ideal for exploring light super-weakly interacting particles and Light Dark Matter
  - **Luminosity** (yield of π, K, D, B decay and photons):
    - HL-LHC: ~10^{35} $cm^{-2}s^{-1}$ x 10^7 s = **10^{42} cm^{-2}**
    - SPS (1 m long high A/Z target): 4*10^{13} x 6*10^{24} cm^{-3} x 10^2 cm x 10^6 ~ **2*10^{46} cm^{-2}**
    - Superior luminosity compensates for lower energy (e.g. yield of charm hadrons ~10^{16}@HL-LHC vs ~10^{18}@SPS)
  - **Geometrical acceptance**
  - **Long lifetimes**
  - **Background suppression**

BDF (SHiP, tauFV)

- Excellent progress, CDS in preparation
- Technically feasible, operationally interesting
- Time-line: ideally start CE before LS3
- Material cost: ~160 MCHF

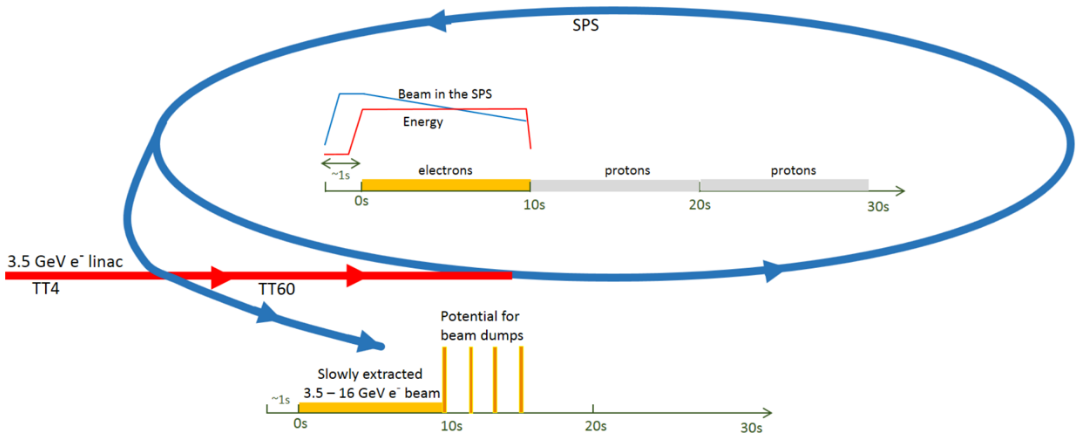






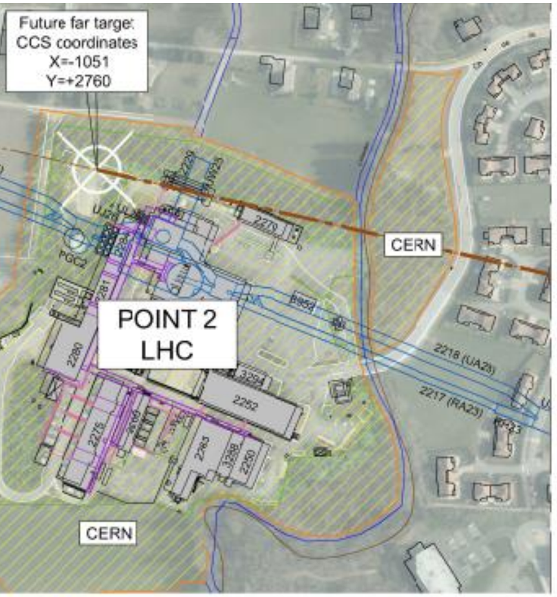
eSPS/LDMX

- Linac/SPS – looks feasible
- + electron beam facility
- TT10 back to Meyrin
  - relatively inexpensive, small foot print
- Timeline: ideally pre-LS3
- Material cost: ~80 MCHF
- SPS cycle sharing implications



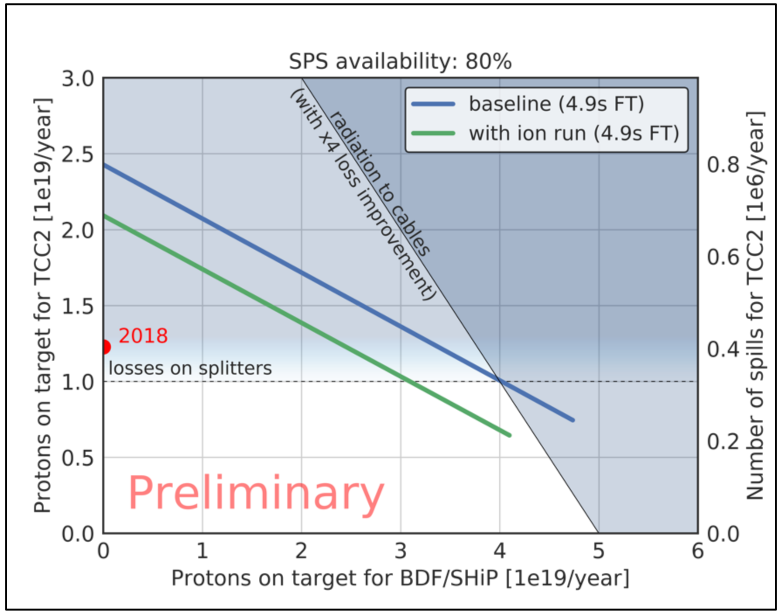
nuSTORM

- SPS can provide the beam and fast extraction, target is familiar territory, muon decay ring – interesting technology (SC FFA)
- Preliminary analysis - no show stoppers
- Approx. material cost: 150 – 200 MCHF



Potential major SPS/HSC users

	Momentum GeV/c	Int/Cycle	Flat top length	POT/year
NA CB	400	2 – 4.9e13	4.8	~1e19
SHiP	400	4e13	1.2	4e19
KLEVER	400	~2e13	4.8	1e19
ENUBET	400	4.5e13	4.8	5.2e19
nuSTORM	100	4e13	1.0	4e19
eSPS	16	~3.1e11	10.0	1e18 EOT

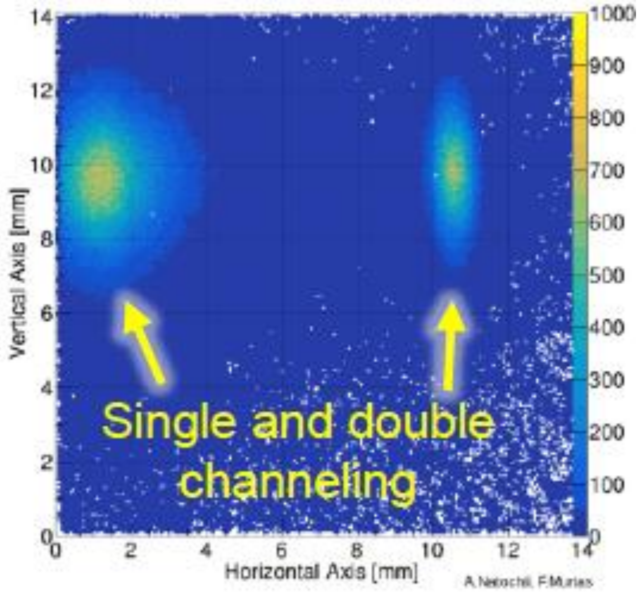


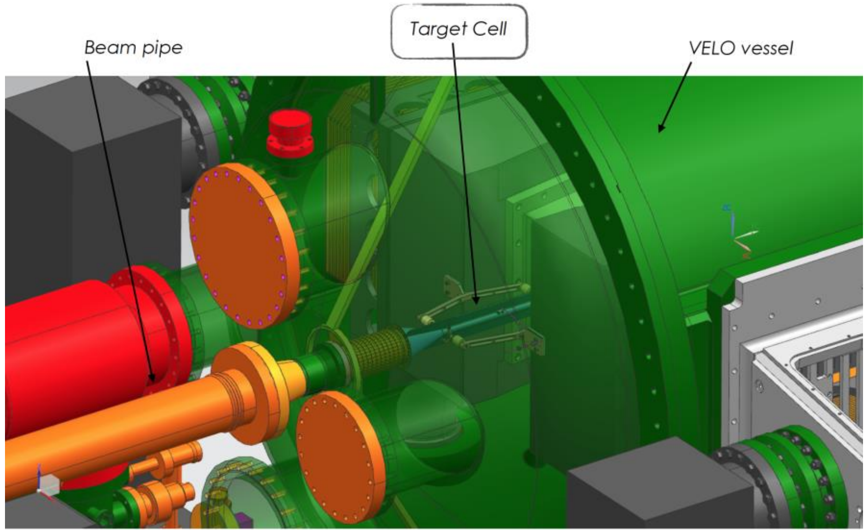
- Standard NA operations compatible with BDF for SHiP
- Another major user would imply compromise or temporal separation

LHC Fixed Target

Synergy with ongoing efforts (UA9, Collimation, SMOG2, LHCb, AFTER…) – significant progress

- Crystals
  - double crystal: LHCb, LHC IR3, SPS
  - single crystal to target: ALICE
  - triple crystal (Ds -> tau)
  - very nice results in 2018; now addressing key feasibility aspects;
    - E.g. Double-channeling experiment in the SPS and the characterization of large bending angle crystals [UA9/W. Scandale]
- Standard and polarized gaseous targets
  - gaseous targets plans well established; SMOG2 for installation in LS2…





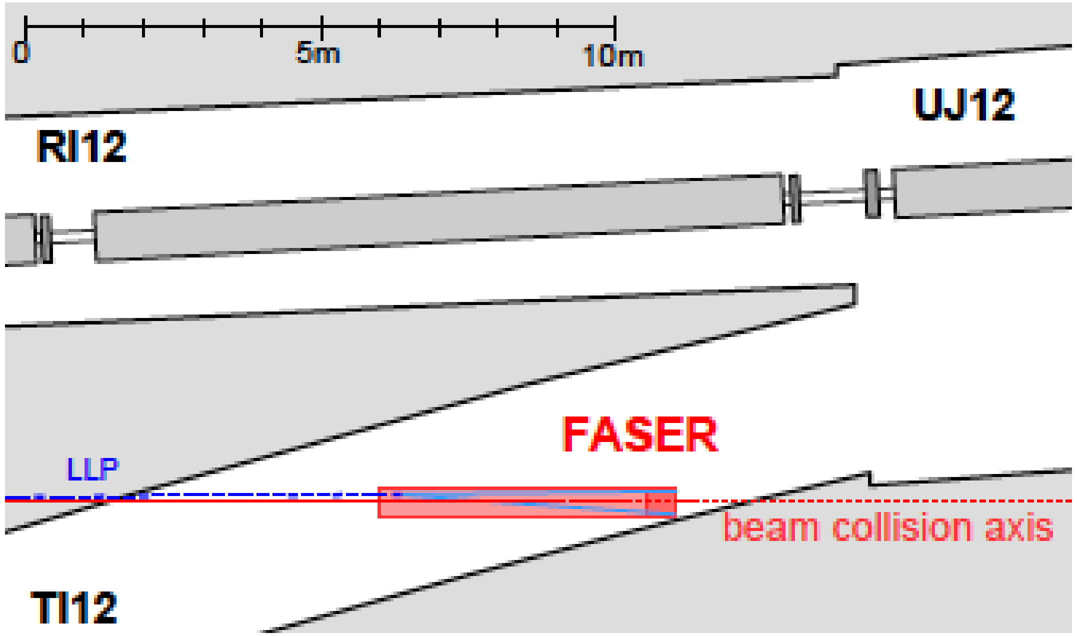
Massi, Stefano

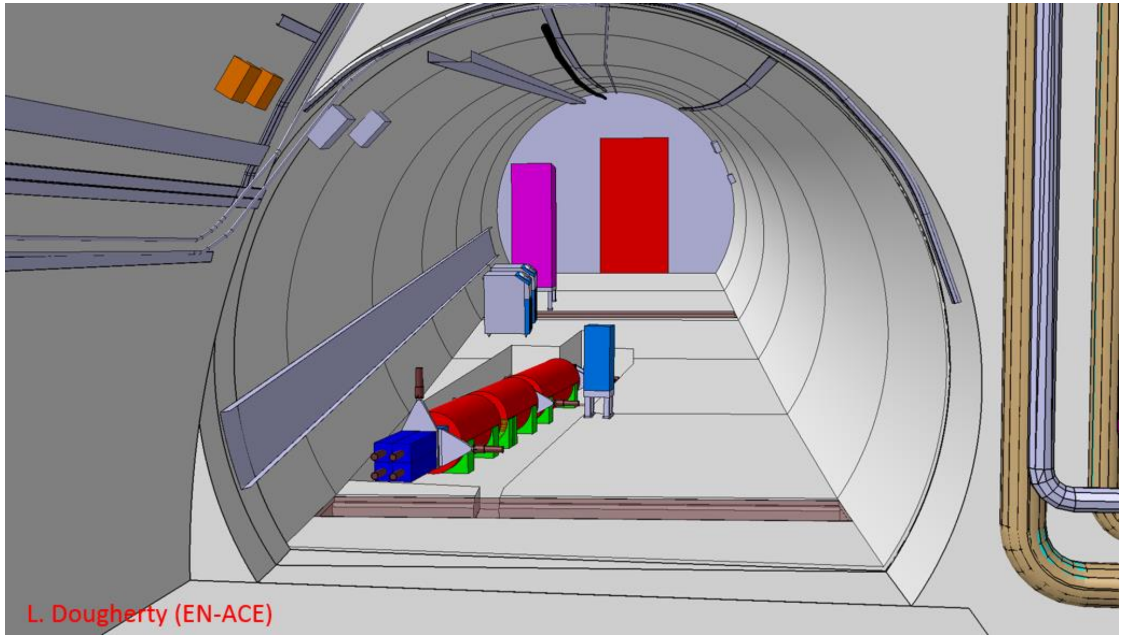
LHC-LLP

- Approval for installation of FASER 1 in LS2 at LMC yesterday

3 ab^{-1} is a lot of collisions!

Big thanks from FASER to CE, FLUKA, Transport, Integration, Magnets, BI, Survey, Safety…





Jamie Boyd, Brian Petersen

Gamma Factory

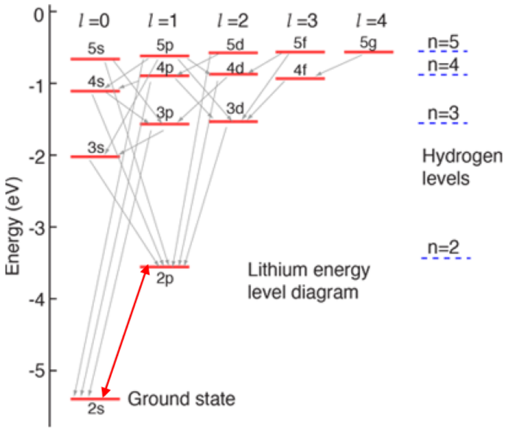
- Cool!
- Well developed program in place
  - next step Proof of Principle in the SPS ++

SCIENCE / PHYSICS

CERN's Large Hadron Collider Accelerates its First 'Atoms'

Physicists from CERN spent a few special days testing the possibilities of transforming the LHC into a gamma ray factory.

- (Almost) head-on laser-PSI interaction, maximising spatial and temporal overlap functions and relativistic Doppler-boost
- Pb+79 (Li-like) PSI, SPS rigidity ~790 Tm (~236 GeV proton), $\gamma = 96$
- 2s → 2p transition, 230 eV calculated for Pb79+ (cf 1.85 eV for Li)



- Laser: $230/(\gamma(1+\beta\cos\theta))$ eV ≈ $230/1.985\gamma$ ≈ 1.2 eV (1030 nm)
- Interaction angle as small as possible compatible with physical layout: 6°

Witek Krasny, Reyes Alemany, Brennan Goddard et al

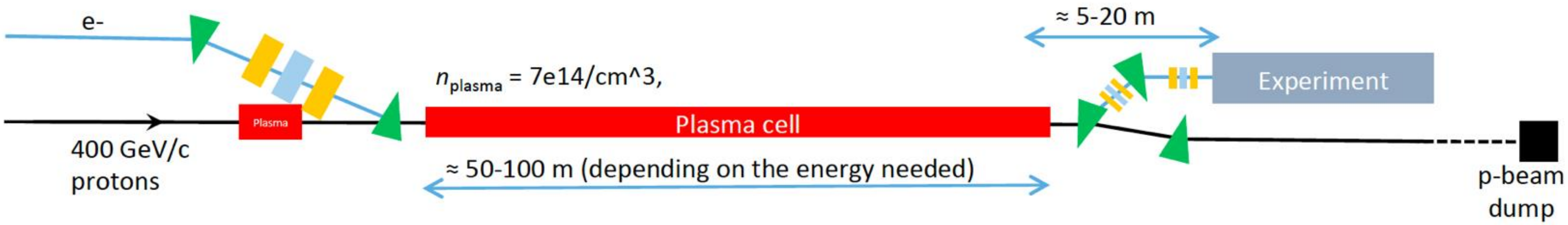
EDM

- Challenging systematics – important input from CERN
- Valuable experience being gained at COSY
- Prototype regarded as key step – favoured location COSY at IKP Juelich

1 Precursor Experiment →	2 Prototype Ring →	3 All-electric Ring
dEDM proof-of-capability (orbit and polarization control; first dEDM measurement)	**pEDM proof-of-principle** (key technologies, first direct pEDM measurement)	**pEDM precision experiment** (sensitivity goal: 10^{-29} e cm)
- Magnetic storage ring - Polarized deuterons - d-Carbon polarimetry - Additional E-field by RF Wien-filter	- High-current all-electric ring - Simultaneous CW/CCW op. - Frozen spin control (with combined E/B-field ring) - Phase-space beam cooling	- Frozen spin all-electric (at p = 0.7 GeV/c) - Simultaneous CW/CCW op. - B-shielding, high E-fields - Design: cryogenic, hybrid, …
Ongoing at COSY (Jülich) 2014 → 2021	Ongoing within CPEDM 2017 → 2020 (CDR) → 2022 (TRD) Start construction > 2022	After construction and operation of prototype > 2027?

AWAKE++

- Run 2 (2021 - 2024) - demonstrate the scalability and the acceleration of electrons to high energies while maintaining the beam quality
- Application for fixed target experiments for dark photon searches ++



Baseline scenario (based on AWAKE Run 2 parameters)

- **50 m** long plasma accelerator
- **33 GeV/c electrons, ΔE/E = 2%, ~100 pC**
- For 100 m accelerator: 53 GeV/c e, ΔE/E=2%, ~130 pC

Edda Gschwendtner, Matthew Wing

Technology working group

Physics Beyond Accelerators

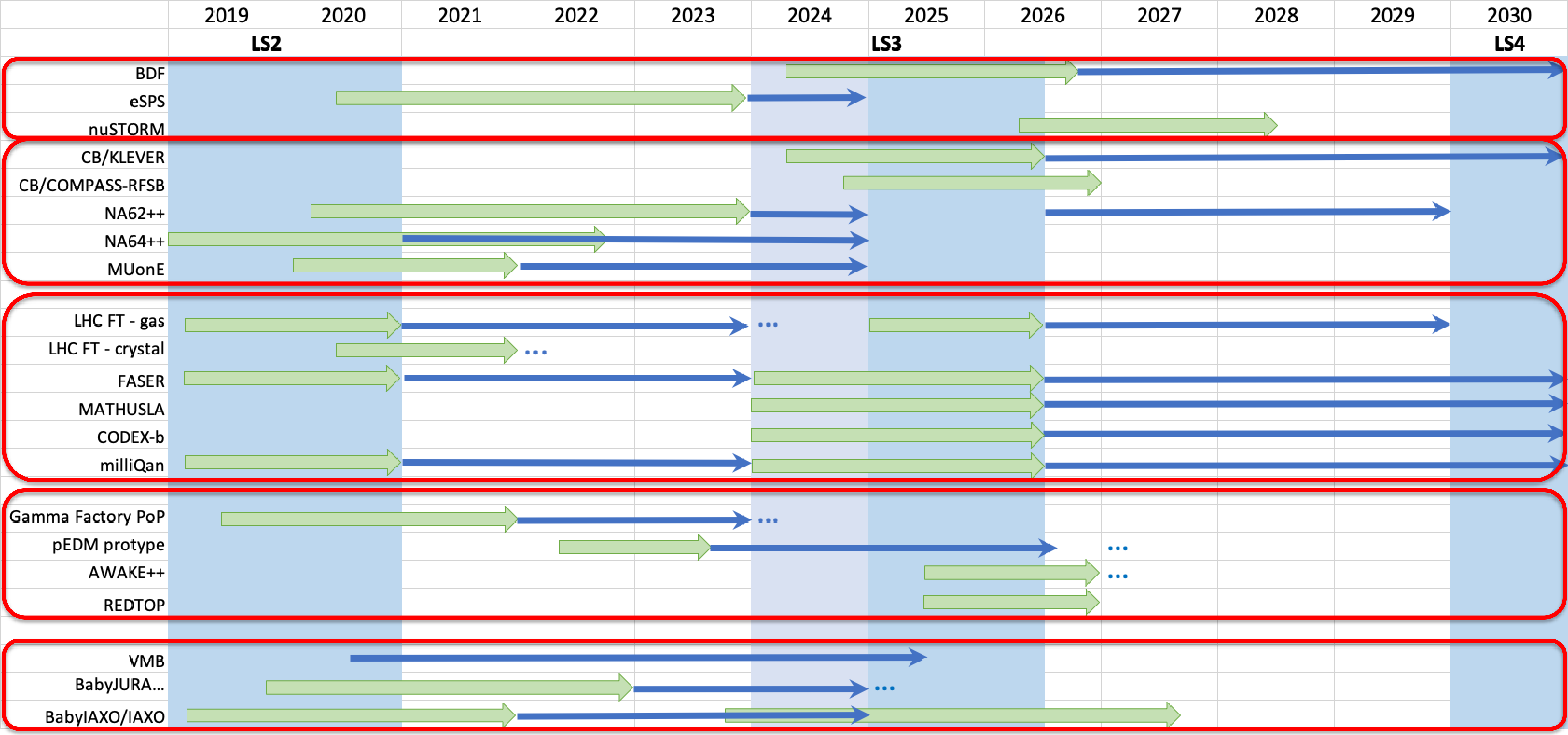
Our aim is to review only the initiatives that have sought to profit via PBC from CERN technology.
(magnets, RF, optics, cryogenics, vacuum)

- Great job pulling together some very diverse possibilities and taking some interesting initiatives:

Optics Technology Hub	Advanced optics technologies
VMB@CERN	Vacuum Magnetic Birefringence
JURA (Baby, 1, 2)/STAX	Optics and detector development at ALPS II + future dipole magnets
BabyIAXO/IAXO	Independent collaboration - magnets
DarkSide	Independent collaboration – vacuum, cryogenics, SiPM
CNT	DM target in PTOLEMY, neutrons, vacuum
aKWISP	Optical interferometric read-out of nano-membranes, cryo, thin films..

Andrzej Siemko, Babette Dobrich et al

Approximate "ideal" timelines



Summary

HSC	Status	Deploy	Cost	Physics
BDF/SHiP,tauFV	CDS	LS3+	C6	Hidden Sector
eSPS/LDMX	EoI	<LS3	C5	DM
nuSTORM	→CDS	LS3++	C6	Neutrinos
CB/KLEVER	EoI	LS3+	C3	Precision
CB/COMPASS-RFSB	EoI/proposal	LS3+	C4	QCD
NA62++	studies	Run 3	C1	Hidden Sector
NA64++	OP	Run 3	C1	DM
MUonE	proposal	Run3	C2	muon anomaly
LHC				
LHC FT - gas	TP	Run 3	C1	PDF,DY,spin
LHC FT - crystal	proto	Run 3	C2	MDM/EDM
FASER	TP/approval	Run 3	C2	LLP
MATHUSLA	LOI	LS3	C5	LLP
CODEX-b	LOI	LS3	C3	LLP
milliQan	demo	Run 3	C2	LLP
NOVEL				
Gamma Factory PoP	→EoI	Run 3	C2	PSI/Laser
pEDM protype	→CDS	2022	C4	EDM
AWAKE++	exploratory	LS3+	C4	DM
PS				
REDTOP	proposal	LS3+	C3	BSM+
TECHNOLOGY				
VMB	LOI	Run 3	C2	VMB
BabyJURA, JURA1, JURA 2	proposal	2023	C2,C2,C4	ALPs
BabyIAXO/IAXO	advanced	2023	C3,C4	Axions

- Class 4 for BDF, eSPS;
- Preliminary for nuSTORM
- Conventional beams – see PBC report
- Technology – all options – see PBC report

Extended Gatignon Cost Scale

C1	< few 100 kCHF
C2	From few 100 KCHF to 1-2 MCHF
C3	From 1-2 to 5-10 MCHF
C4	~10-50 MCHF
C5	> 50 MCHF
C6	> 150 MCHF

Class 5
Conceptual estimate
Pre-design estimate
Preliminary estimate
Pre-budget estimate
Evaluation estimate
SD estimate
Parametric estimate
Rough order-of-magnitude (ROM) estimate
Very rough order-of-magnitude (VROM) estimate
SWAG (scientific, wild-ass guess) estimate
PIDOOMA (pulled-it-directly-out-of-my-ass) estimate

Possible PBC post ESPP – overview

WG	Comment	Possible support next 1-2 years
AWAKE++	Exploratory – conditional on Run 2	Low level continued
BDF	On track for construction	Fellows/material towards TDR
EDM	Support prototype off-site	Component dev.; studies (systematics…)
Conventional beams	Individual physics cases evaluated Imagine on-going PBC support for some options	Manpower: fellow(s), associates, Ph.D. (see Lau)
eSPS	Could be done, towards CDR?	ABT, CE, ABP, PBC towards CDR
Gamma factory	Novel with potential	Towards proof of principal expt. - material/associate support
LHC fixed target	Well developed: options to be evaluated	Maintain WG? Possible M&P support
Technology	Interesting options – some to be developed	Fellows/material
Protons post LIU	ABP continued	Roll-out post-LS2
nuSTORM	Could be done, towards CDR?	Generic PBC support towards CDR
FASER	TP submitted, final approval pending	Installation in LS2 - PBC support

PBC acc - general remarks

It's been very interesting exercise (so far)!

- Framework for initiatives
- Channeling and sharing resources
- Incubation - provided an effective way of supporting initiatives
- Fostered innovation (technology, new methods etc.)
- Forum for communication and scrutiny, engaging the community and establishing synergies

Thanks!

BDF	Marco Calviani, Brennan Goddard, Richard Jacobsson
Conventional beams	Lau Gatignon, Markus Brugger
Protons post LIU	Giovanni Rumulo, Hannes Bartosik, Eirini Koukovini Platia
LHC FT	Massi Ferro-Luzzi, Stefano Redaelli
EDM	Hans Ströher, Yannis Semertzidis, Christian Carli
Gamma factory	Witek Krasny, Reyes Alemany, Brennan Goddard
Technology	Andre Siemko, Babette Döbrich
AWAKE++	Edda Gschwendtner, Matthew Wing
nuSTORM	Ken Long, Jonathan Gall
FASER	Jamie Boyd, Brian Peterson
eSPS	Steinar Stapnes, Lyn Evans, Thorsten Akesson

Huge thanks to the conveners and the members of the working groups for their uptake and collaboration – always in addition to existing workloads and with only limited injection of additional resources

Thanks!

2019: BDF/PBC Fellows

Group			Subject
EN-CV	Pietro	Avigni	Target and target complex
EN-MME	Josep	Busom Descarrega	Target and target complex
EN-STI	Edmundo	Lopez Sola	Target and target complex
TE-MSC	Jakub	Kurdej	Splitter design
EN-EA	Pablo	Santos Díaz	Integration
EP-ADO	Nikolay	Bykovskiy	**PBC** Technology (IAXO)
HSE-RP	Mirko	Casolino	**BDF/PBC** Radiation Protection
EN-EA	Liam	Dougherty	**BDF/PBC** Integration
TE-ABT	Yann	Dutheil	**BDF/PBC** extraction/beamline
SMB-SE	Jonathan	Gall	**BDF/PBC** Civil engineering
BE-ABP	Malek	Haj Tahar	**PBC** EDM
BE-ABP	Eirini	Koukovini Platia	**PBC** Complex performance

Truly impressive – the future's in good hands.