Physics Beyond Colliders

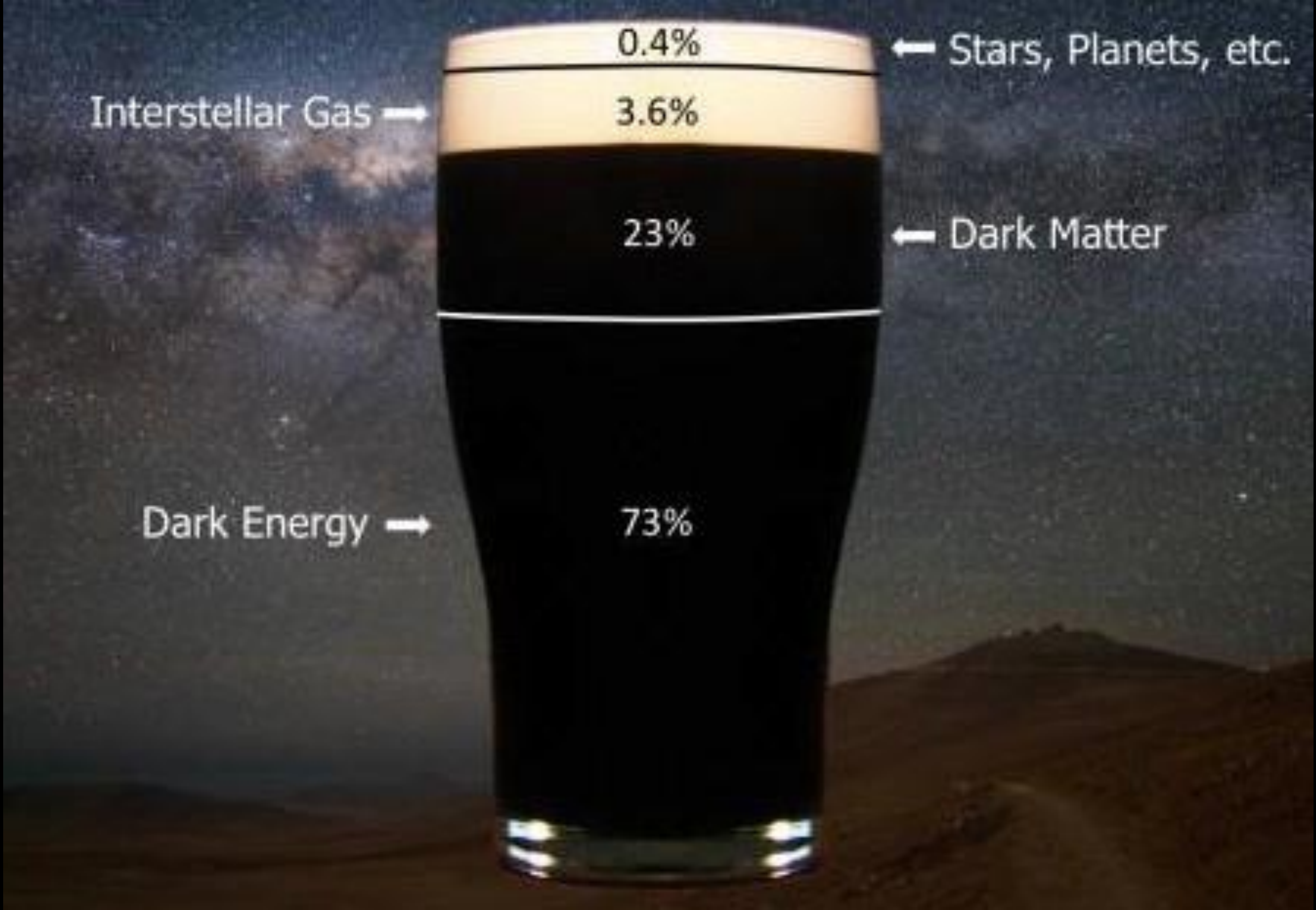
Mike Lamont

Joerg Jaeckel, Claude Vallée

PBC working groups

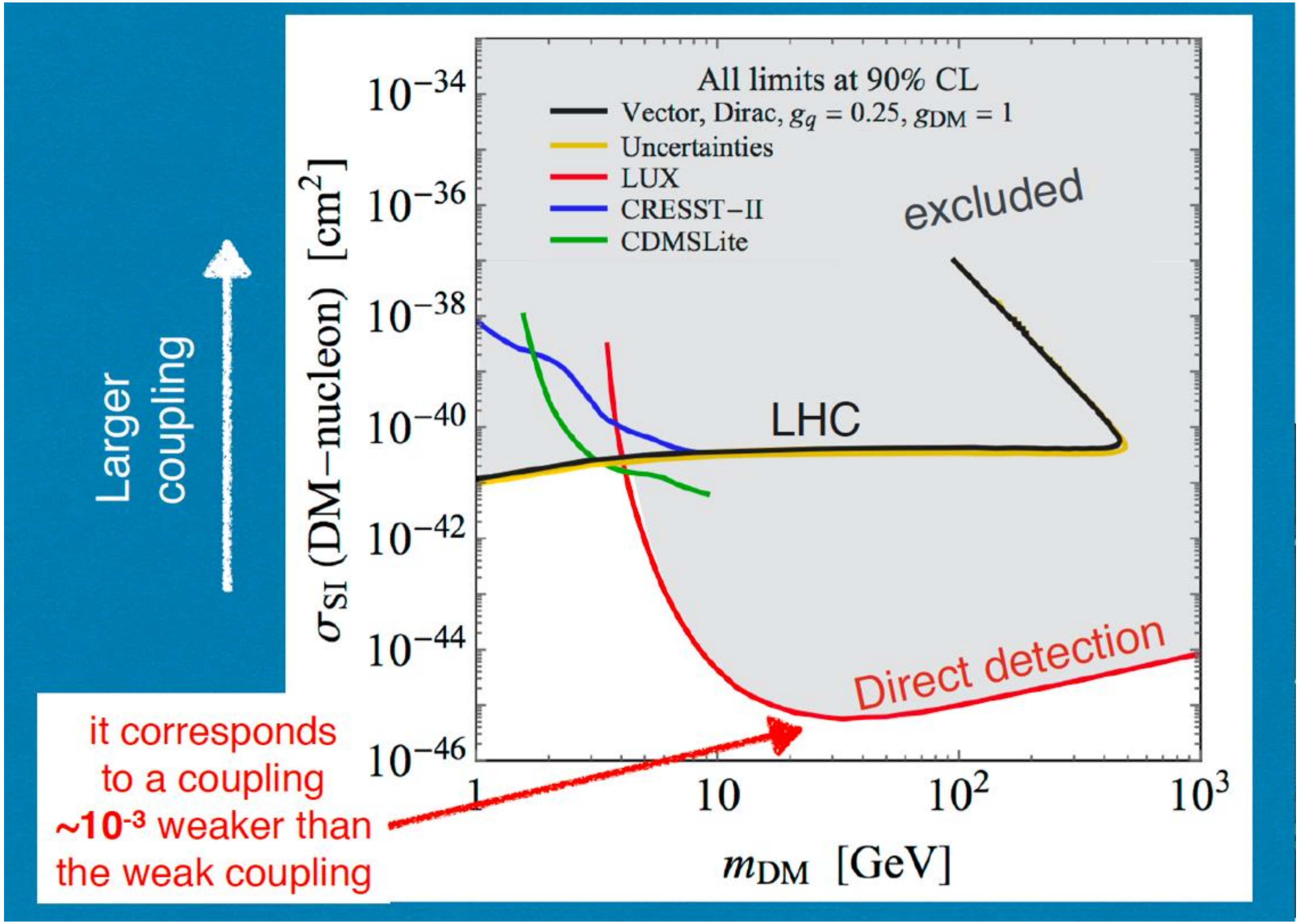
Higgs discovered with mass ~125 GeV.

No new particles found.

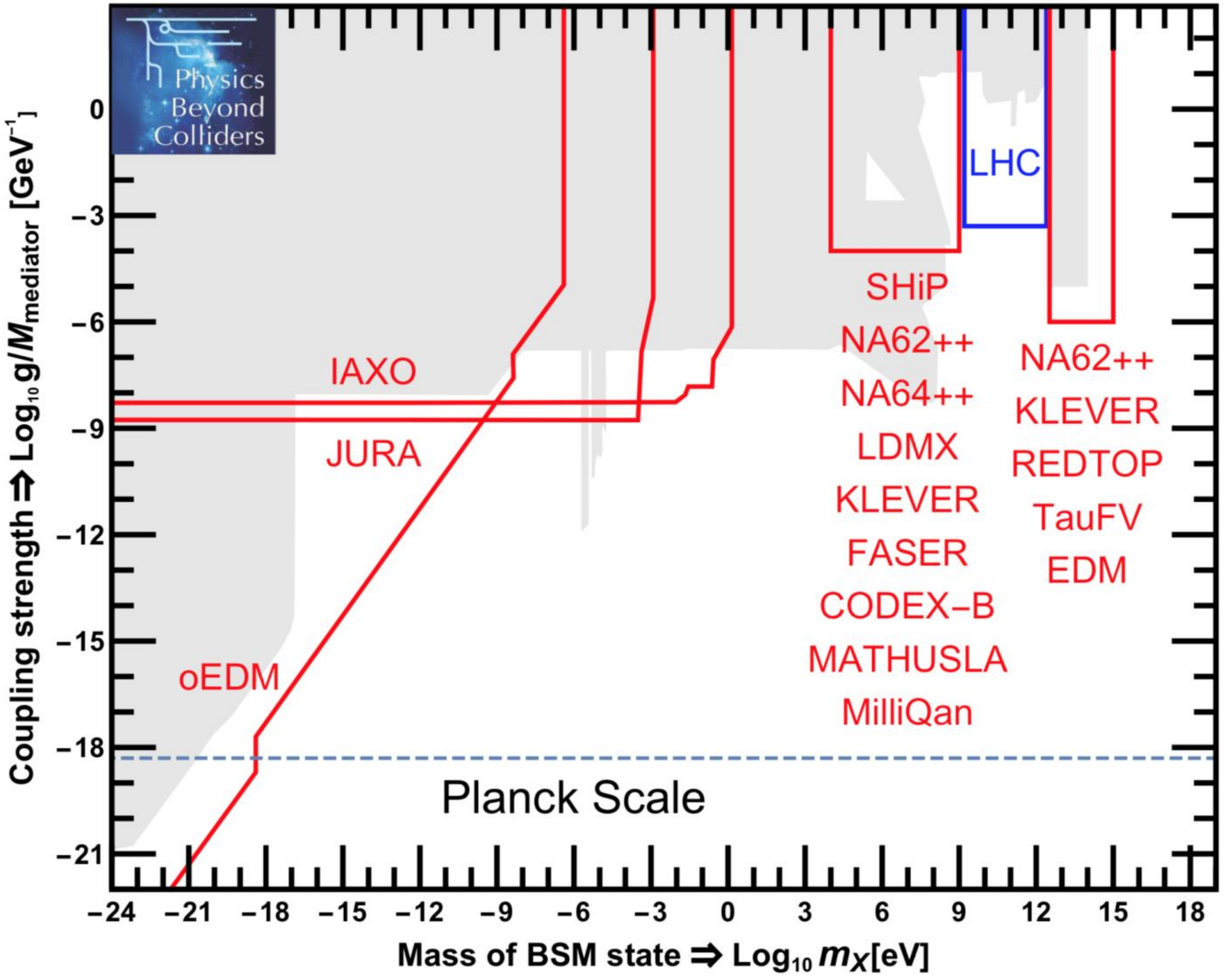


Stefania Gori

Direct detection – WIMP searches



Strong motivation to extend the search



- **Sub-eV:** axions, axion-like particles
- **MeV – GeV:** RH neutrinos below the EW scale, Axion-Like Particles, Light Dark Matter
- **>>TeV:** search for NP in clean and very rare flavour processes or in EDMs

PBC - Brief

- **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 technology and expertise

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

Evaluate these options motivation and competitiveness in a world wide scape

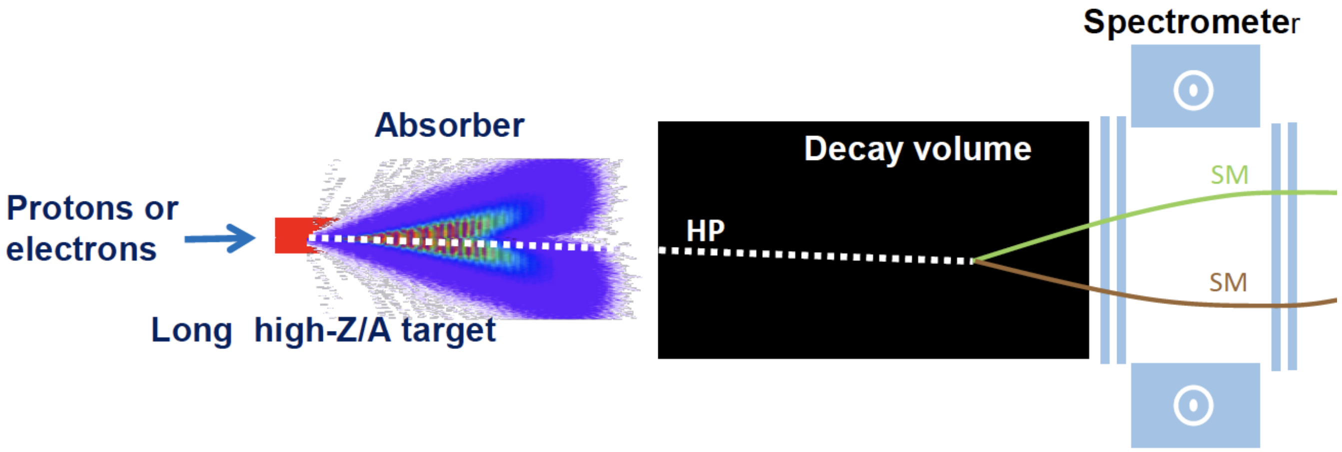
PBC accelerator side - main themes

- Exploitation of SPS/North Area
  - Conventional North Area beams, BDF for SHiP/TauFV, nuSTORM
    eSPS[1] for LDMX
- Novel approaches
  - EDM proton storage ring, Gamma Factory[2], AWAKE++[3]
- LHC
  - LHC fixed target (gas, crystals)[4] , Long Lived Particles
- Technology
  - Various options (Helioscopes, "light-shining-through-walls"…)

Covered briefly in this talk

Covered in this session: [1]Steinar, [2]Yann, [3]Anthony, [4]Stefano

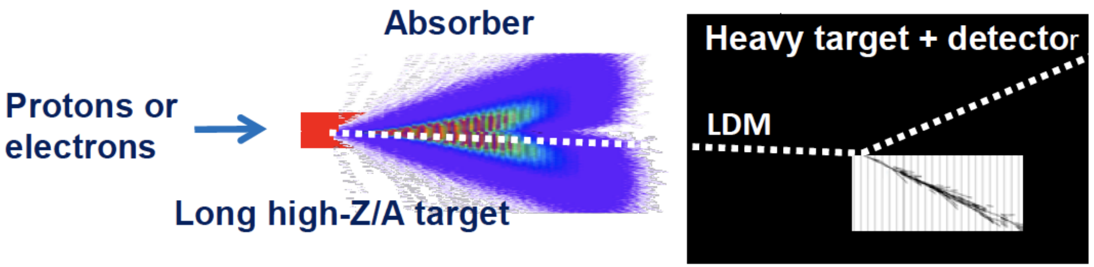
Beam Dump experiments



Visible decay to SM particles

$signal \propto \epsilon^4$

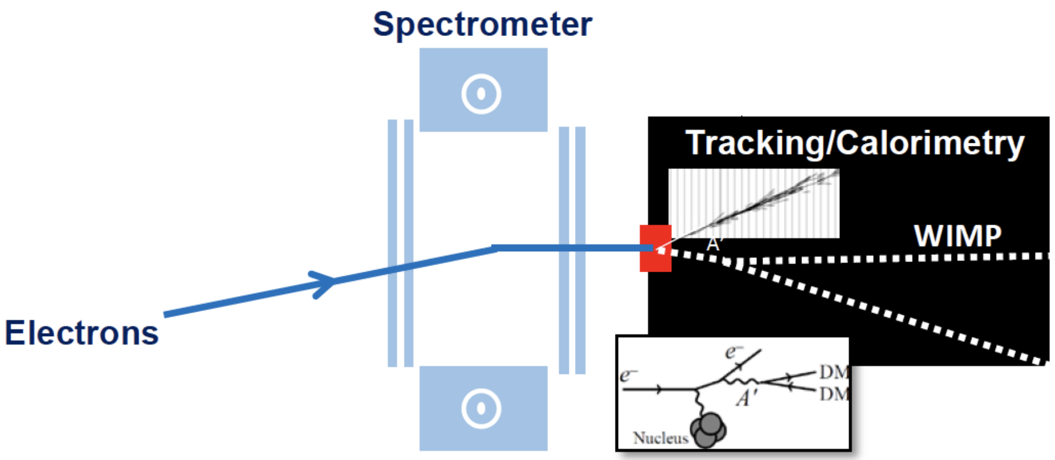
Critical: BG control



Recoil e/N from rescattering

$signal \propto \epsilon^4$

Critical: BG control

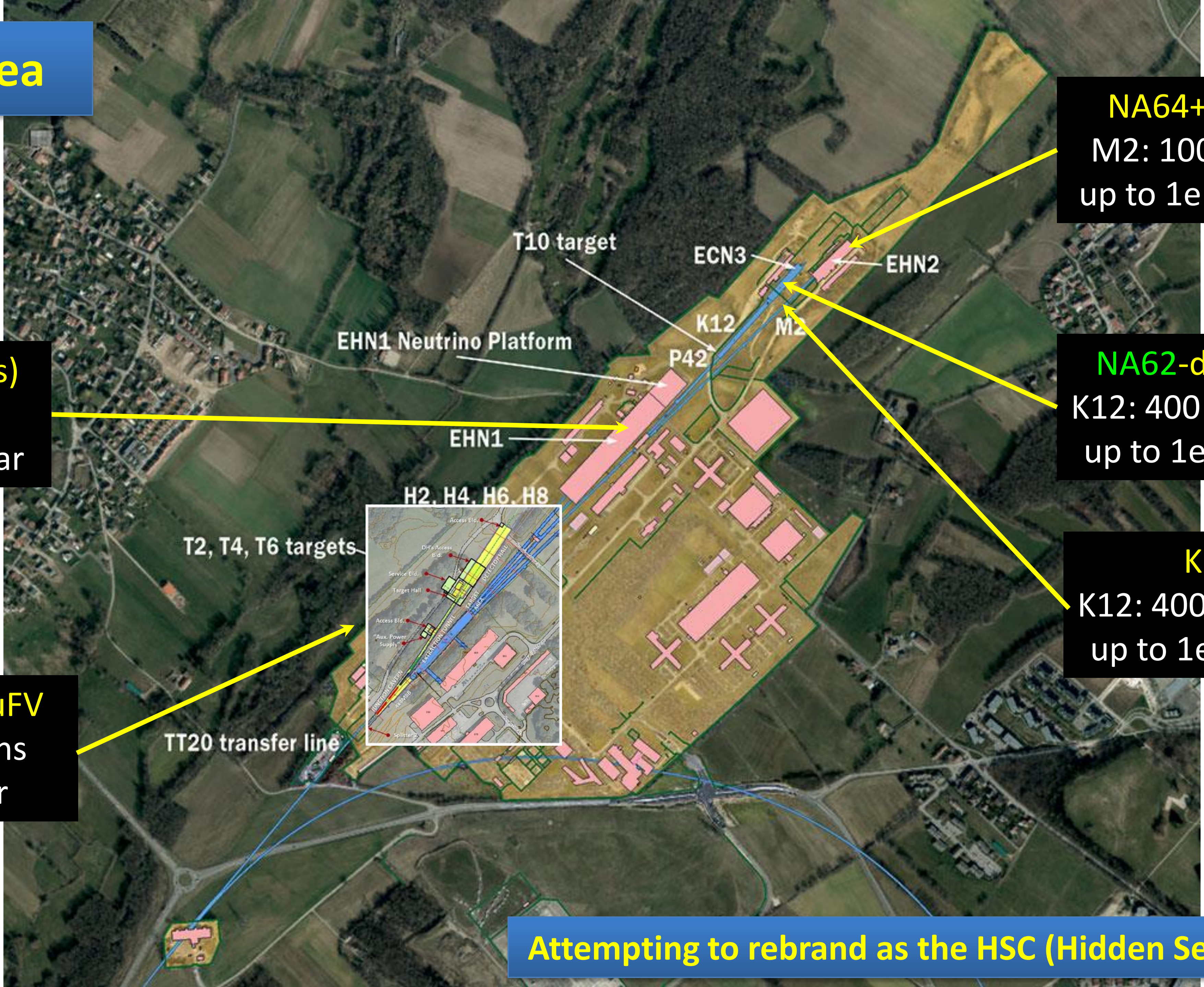


Missing energy from invisible decays

$signal \propto \epsilon^2$

Critical: initial particle and pileup control

North Area



NA64++ (muons)
M2: 100 – 160 GeV
up to 1e13 mot/year

NA64++ (electrons)
H4: 100 GeV
up to 5e12 eot/year

NA62-dump mode
K12: 400 GeV protons
up to 1e19 pot/year

KLEVER
K12: 400 GeV protons
up to 1e19 pot/year

BDF -> SHiP, TauFV
400 GeV protons
4e19 pot/year

Attempting to rebrand as the HSC (Hidden Sector Campus)

Conventional Beams at the North Area

Proposals followed by the CB WG - healthy mix of HS/QCD

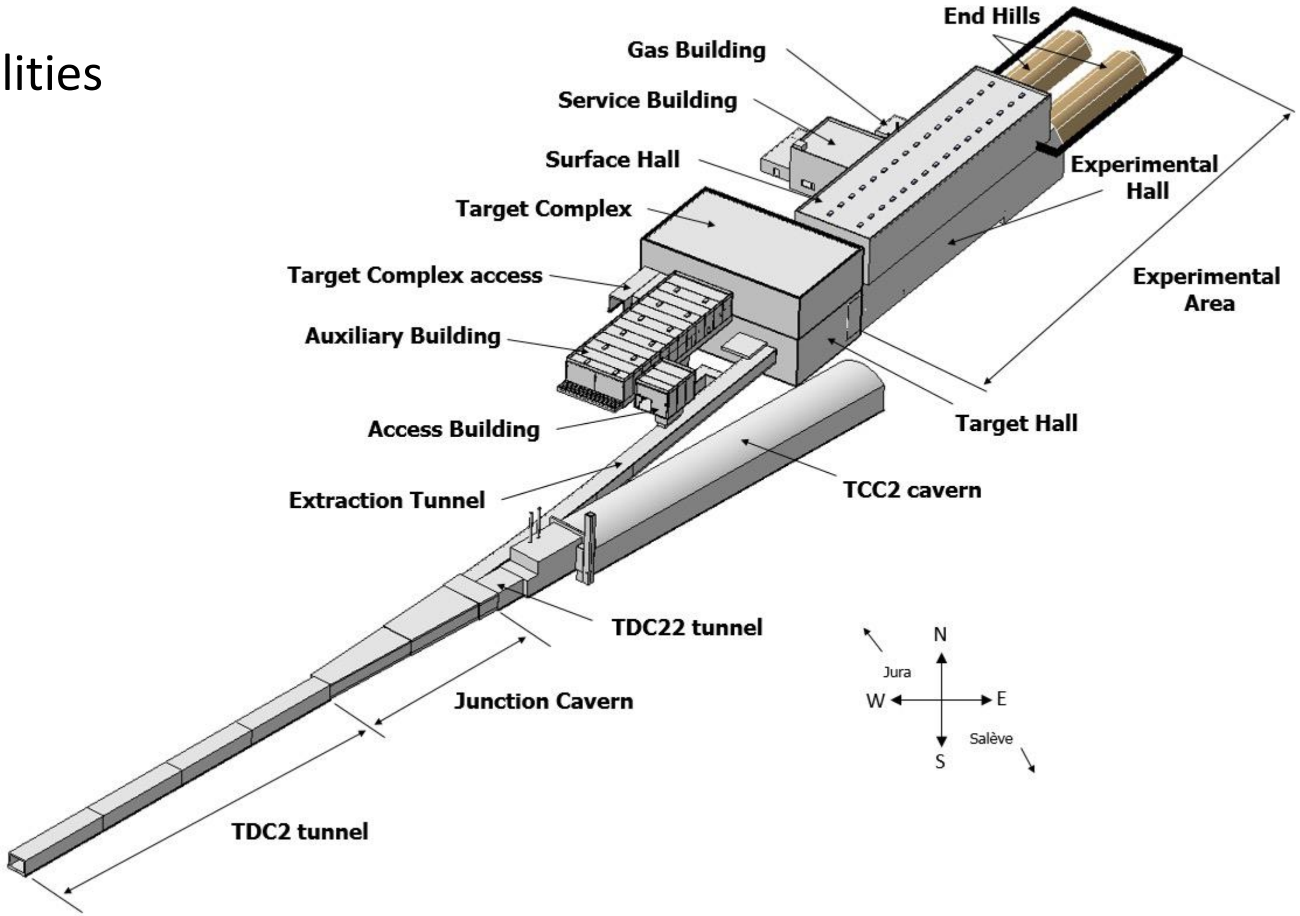
NA62-beam dump	Dark Sector
NA64++ (e,h)	Dark Sector
NA64++ (u)	Dark Sector
KLEVER	Rare decays: $K_0 \rightarrow \pi^0 \nu\bar{\nu}$
MUonE	Hadronic Vacuum Polarization for (g-2_μ)
NA61++	QGP charm
COMPASS++	Full QCD program
DIRAC++	Chiral QCD
NA60++	QGP phase

- **Maturity of proposals and the effort required varies considerably**
- **Follow-up dictated by collaboration strength and CERN side resources; overseen by CERN committees**

SPS Beam Dump Facility (BDF)

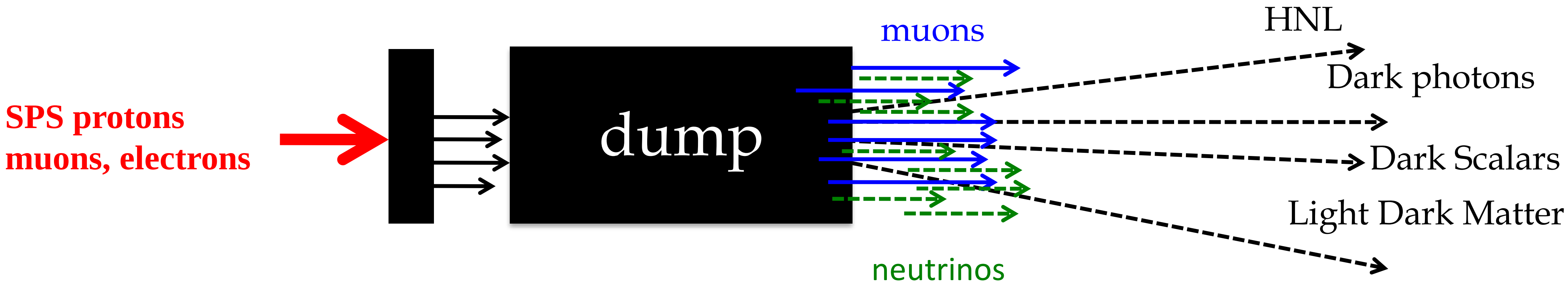
- Slow extraction from SPS into existing TT20 transfer line
- Switch to new transfer line at existing North Area splitters
- Heavy target plus hadron absorber
- Target complex with sophisticated handling capabilities
- Underground Experimental Hall

Momentum	400 GeV/c
Beam intensity on target per cycle	4.0e13
Cycle length	7.2 s
Spill duration	1 s
Avg. power on target	355 kW
Avg. power on target during spill	2560 kW
Protons on target (PoT) per year	4e19
PoT in 5 years' data taking	2.0e20



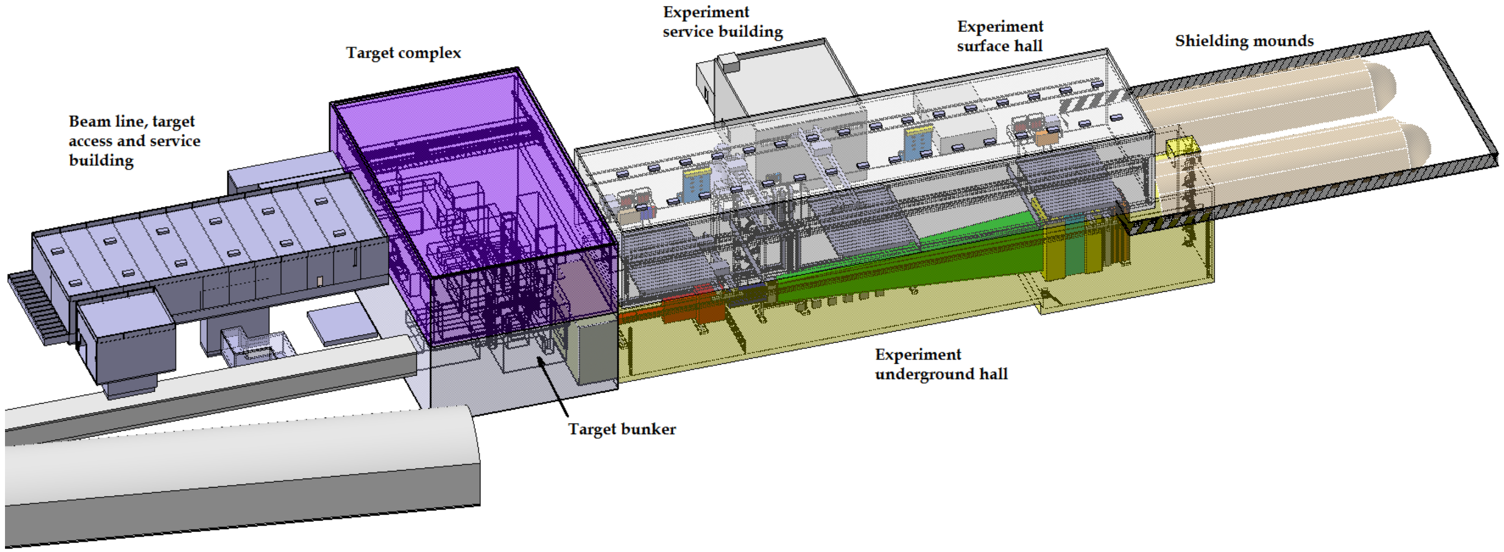
Beam Dump Facilities

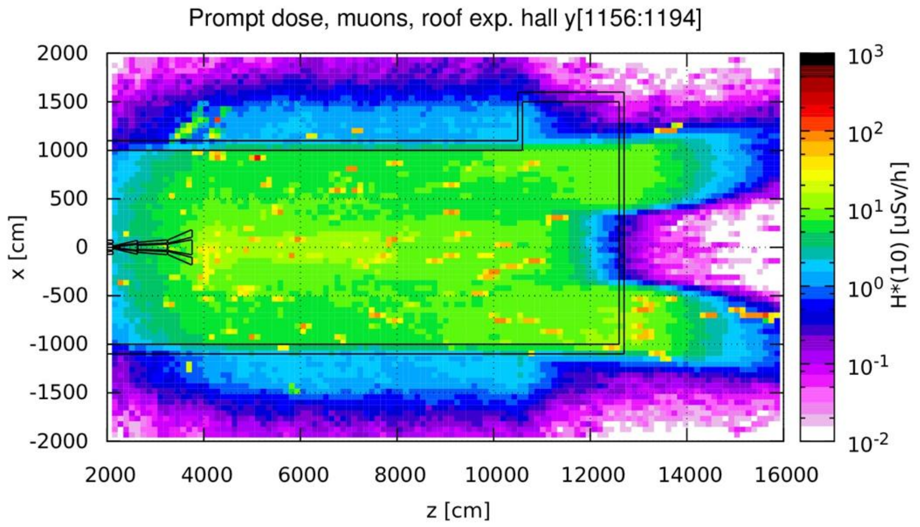
- BDFs ideal for exploring light feebly interacting particles and Light Dark Matter
  - **Luminosity** (yield of π, K, D, B decay and photons):
    - HL-LHC: ~10^{35} $cm^{-2}s^{-1}$ x 10^{7} s = **10^{42} cm^{-2}**
    - SPS (1 m long high A/Z target): $4*10^{13}$ x $6*10^{24}$ cm^{-3} x 10^{2} cm x 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 Study

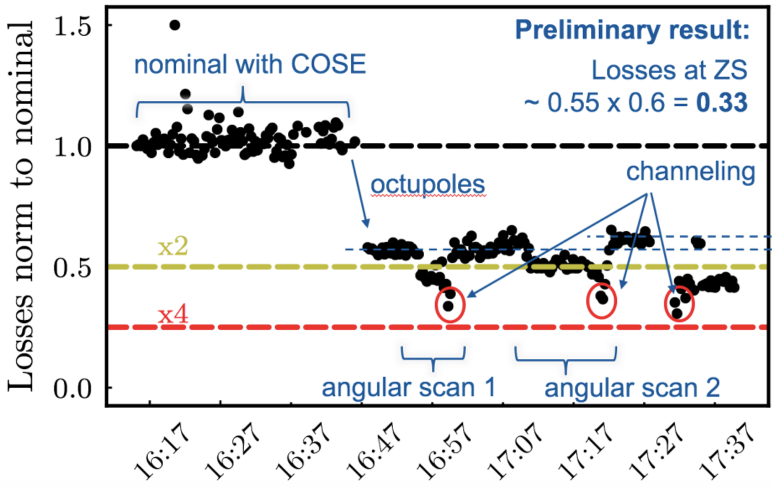
- 2016-2018: **3 year feasibility study** following work since EoI 2013
  - extraction, beamlines, target, target complex, experimental hall, integration, civil engineering, safety, and radiation protection
- BDF Comprehensive Design Study in pre-publication



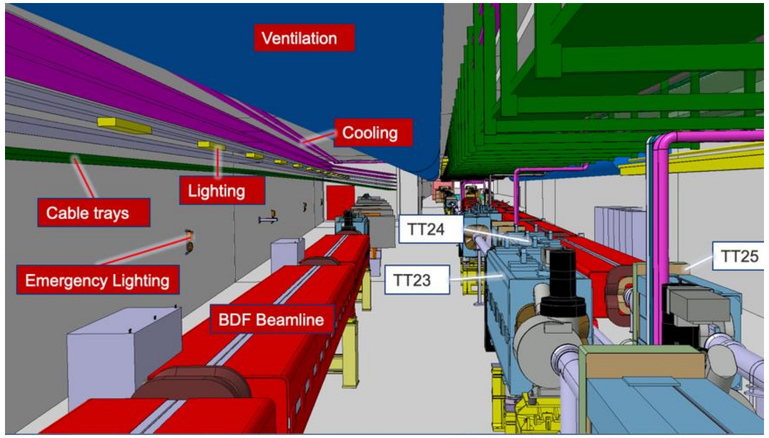


BDF Study

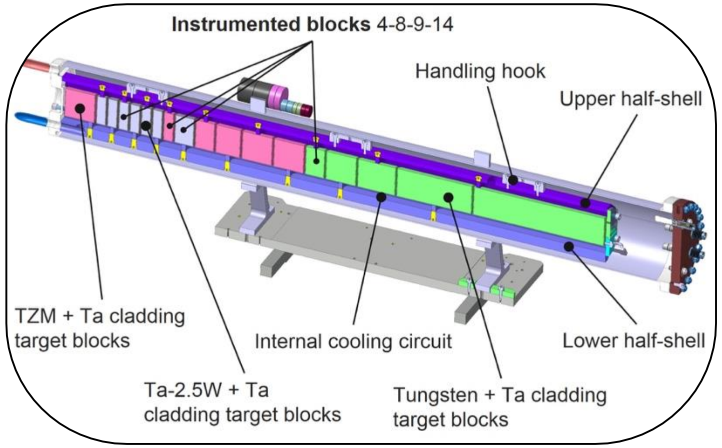
- **Feasibility confirmed:**
  - factor 3 reduction in SPS slow extraction losses demonstrated – confident to reach required x4
  - transfer line and dilution – well within CERN's established capabilities
  - target – challenging – extensive studies – prototype built and tested with beam
  - fully developed target complex study in collaboration with external company
  - phase 1 civil engineering and integration studies completed
  - RP studies showed the general feasibility in terms of radiation/radiological impact on the environment



Extraction losses



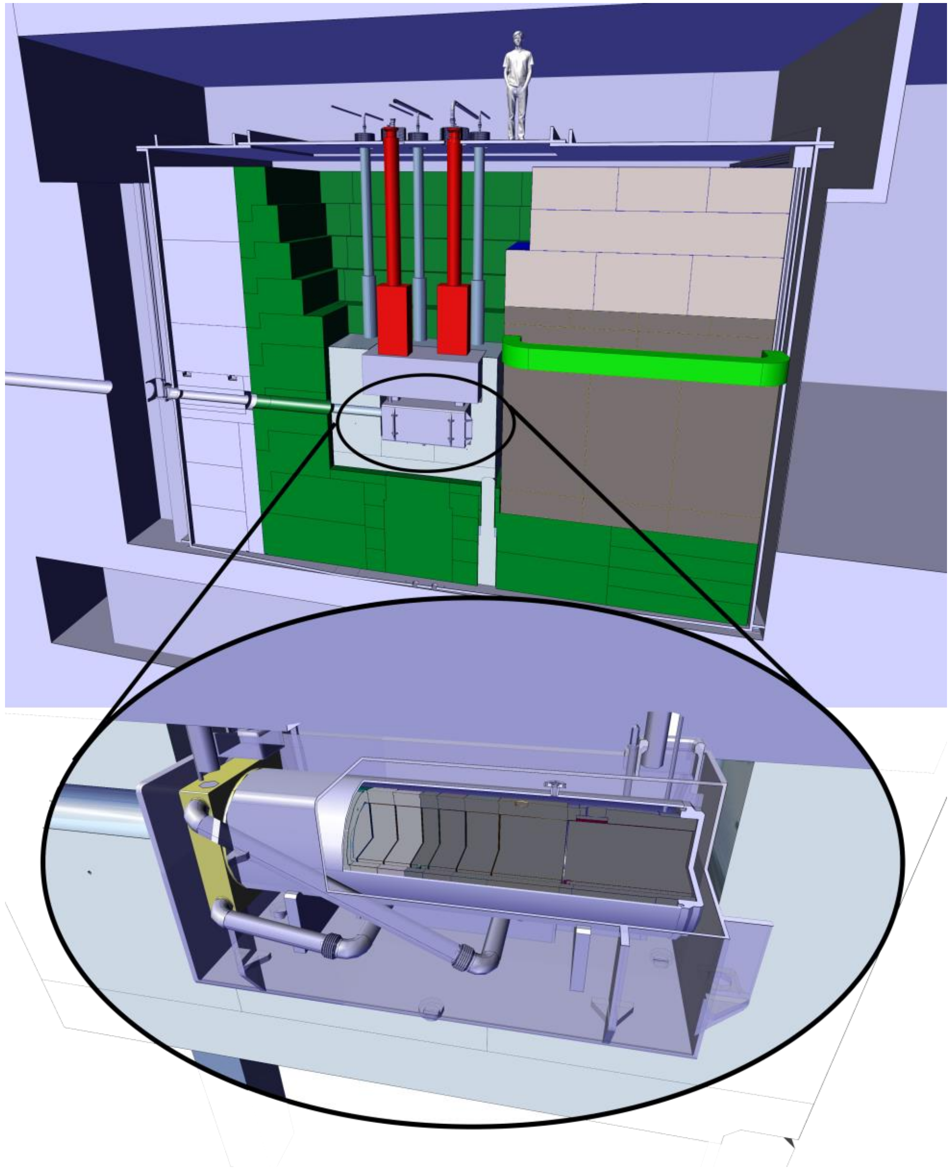
New BDF beamline



Target prototype

BDF - Summary

BDF/SHiP are mature proposals, ready to move into the TDR phase, and are targeting construction/start of data taking in the next decade.

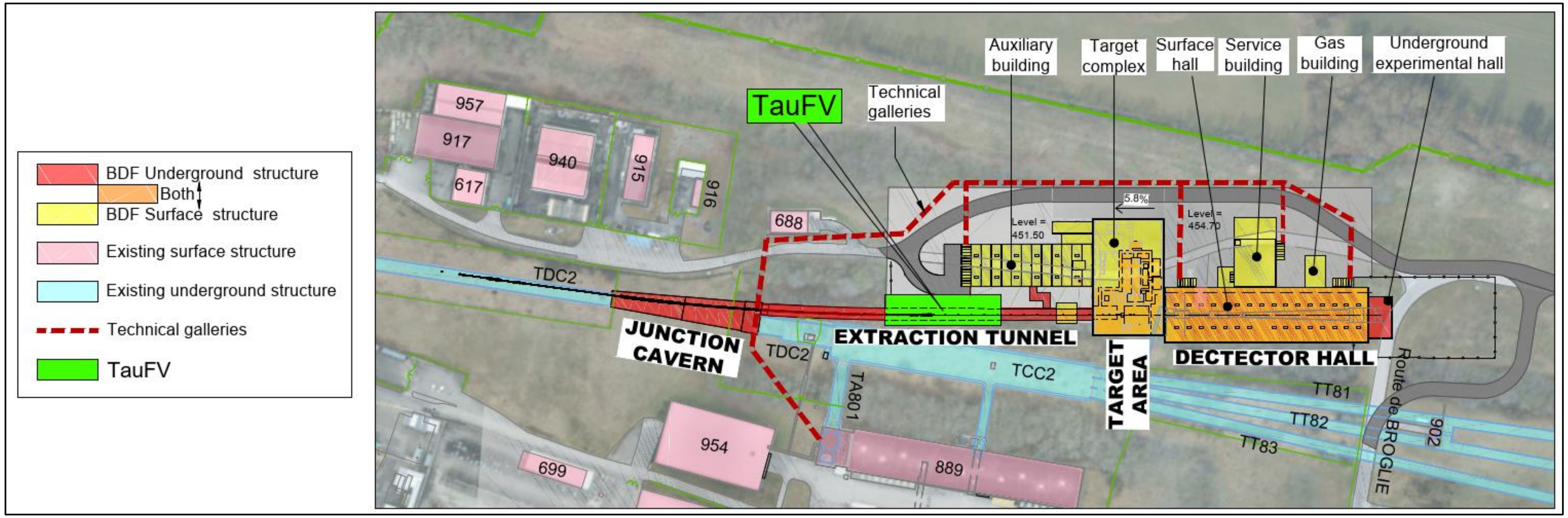


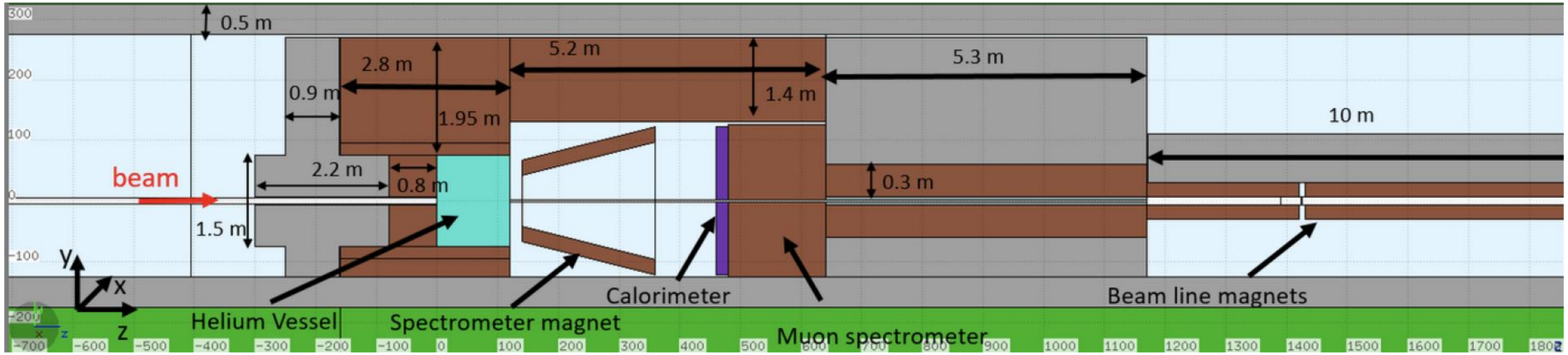
TauFV

Search for Lepton Flavour Violation and rare decays

Using a thin in-line target to intercept about 2% of the intensity delivered to the SHiP target

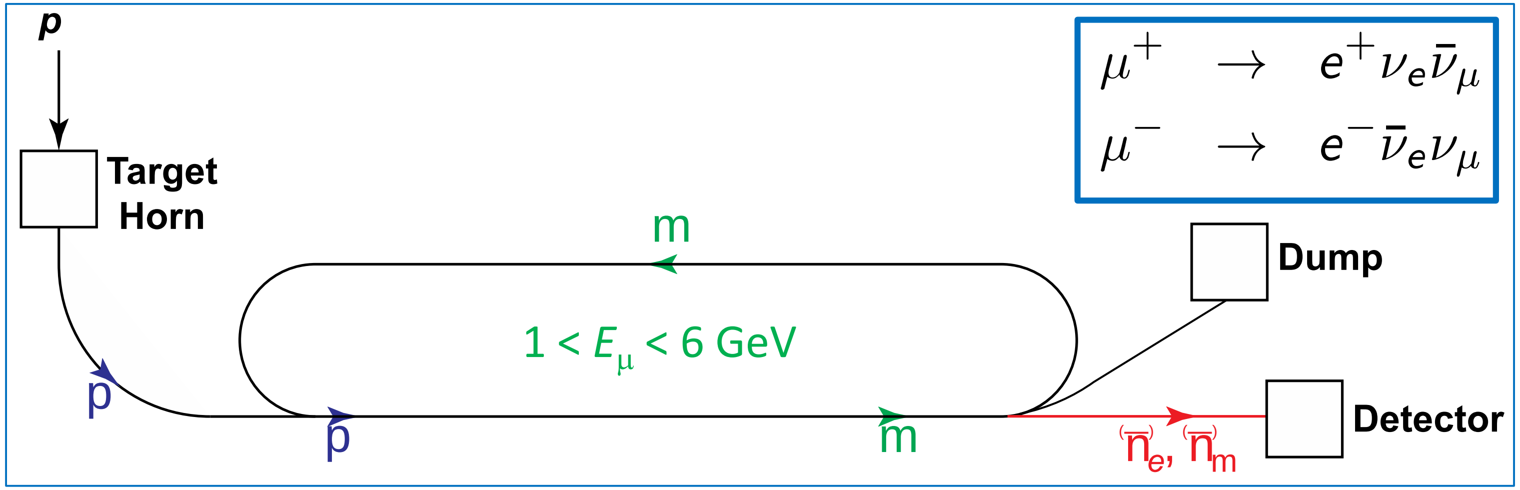
Would have access to close to 8e13 tau lepton and 5e15 D_0 meson decays





TauFV in feasibility study phase at present - well motivated complement to SHiP

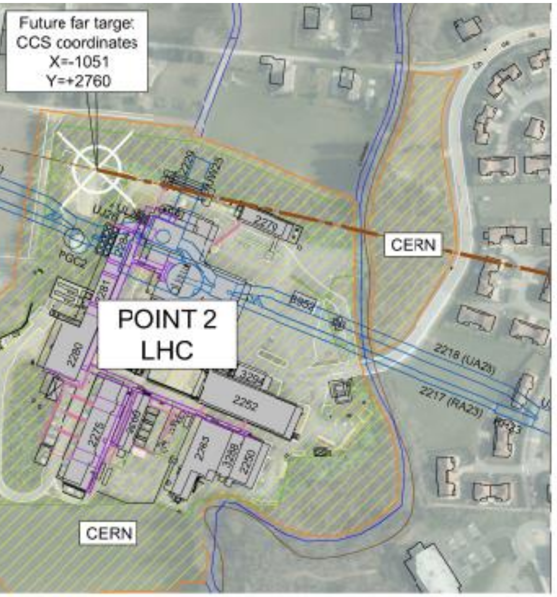
nuSTORM

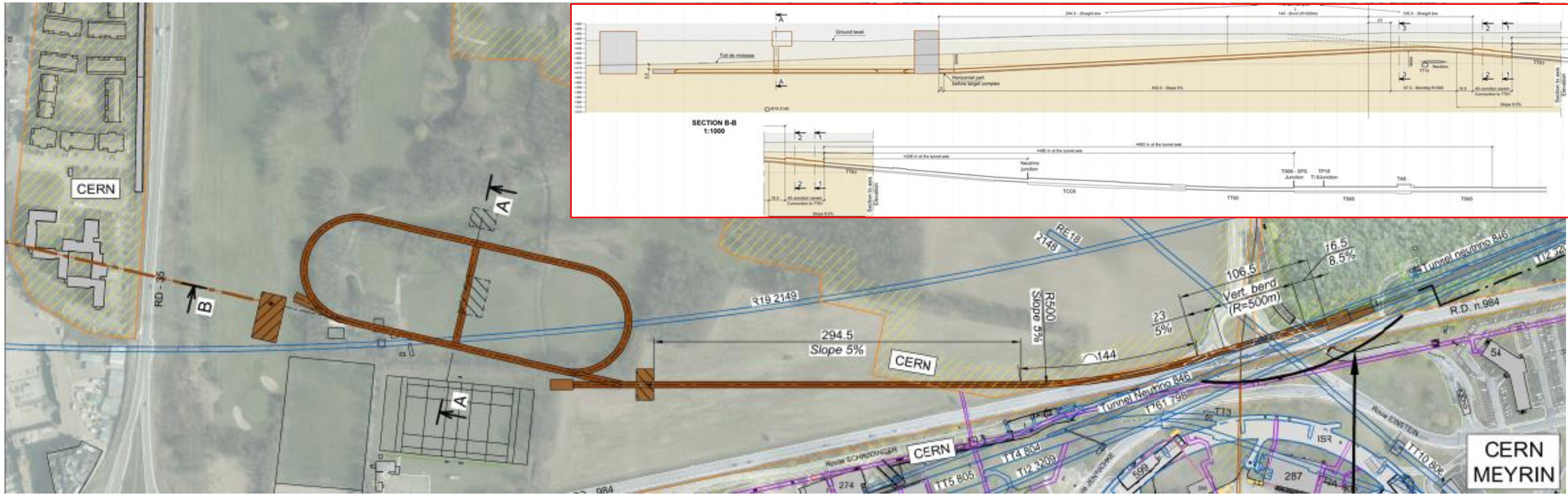


- **Well developed proposal for possible siting at FNAL circa 2013**
- **Siting at CERN – exploratory study:**
  - Via existing fast extraction system at SPS point 6 into a new transfer line
  - Graphite target, magnetic horn
  - Target complex based on extensive work done for CENF
  - Containment and transport of pion beam under study
  - New design for the decay ring (SC FFA):
    - Central momentum between 1 GeV/c and 6 GeV/c;
    - Momentum acceptance of up to ±16%

nuSTORM

- Fast extraction, transfer, target/horn within CERN's established expertise
- Potential green field site with appropriate geology identified
- Study in early stage. Muon storage ring is certainly challenging.

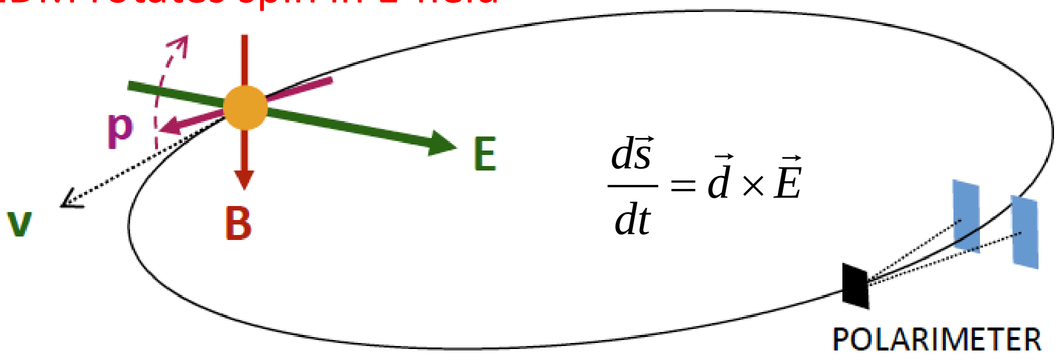




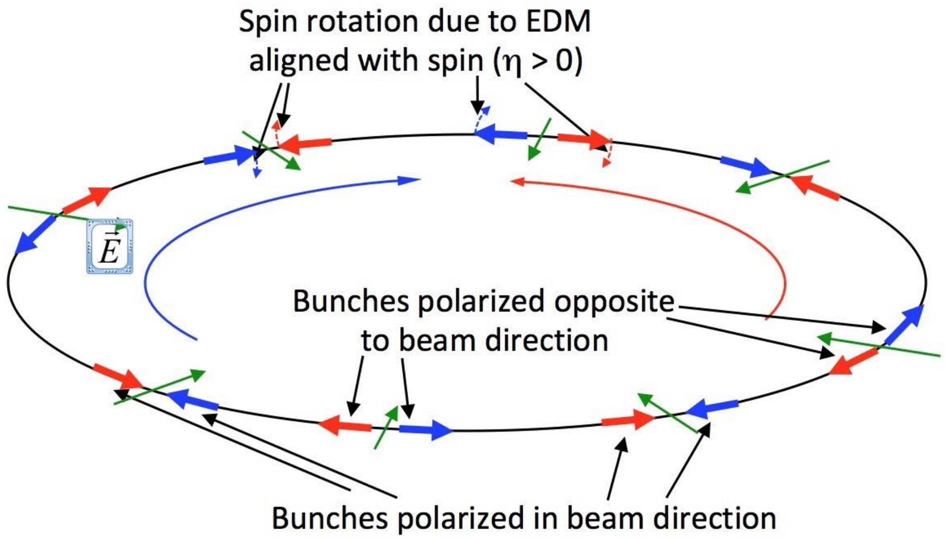
EDM Storage Ring

- Principles of **all electric proton storage ring with frozen spin at "magic momentum"** well established
- Interesting potential statistical sensitivity (~10^{-29} e.cm)
- **Challenging systematics**
  - in particular parasitic radial magnetic field (~10 aT mimics 10^{-29} e.cm)
- **Extensive studies by EDM community**:
  - Polarimetry, deflectors, magnetic shielding, instrumentation
  - Optics, lattice, ring design, beam dynamics
  - Systematics and proposed mitigation measures, simulations

EDM rotates spin in E-field



EDM induced rotation detected here



EDM Roadmap

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 - Radiofrequency (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 (TDR) Start construction > 2022	After construction and operation of prototype > 2027

Impressive “precursor” results at COSY with polarized deuterons in a magnetic storage ring

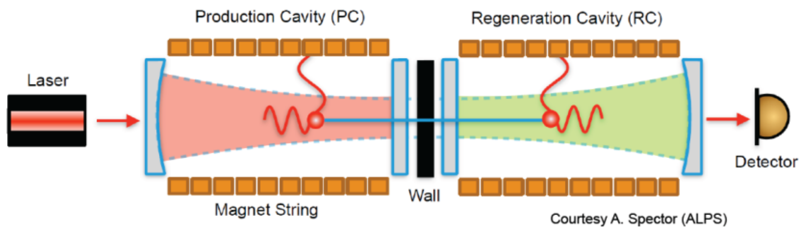
PROTOTYPE SEEN AS ESSENTIAL NEXT STEP

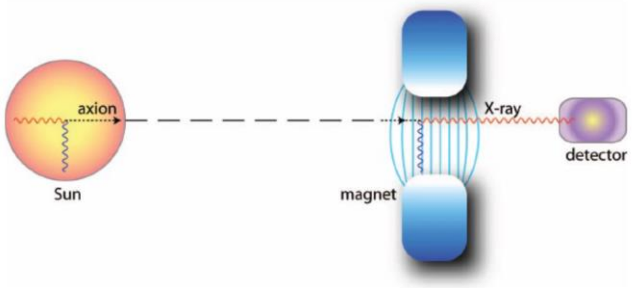
- Small (100 m circum.) designed to operate 2 modes: all-electric at 30 MeV; and combined electric and magnetic fields to allow frozen spin operation at 45 MeV.
- If the prototype is at COSY, takes advantage of the existing facility for the production of polarized proton (and deuteron) beams, beam bunching, and spin manipulation.

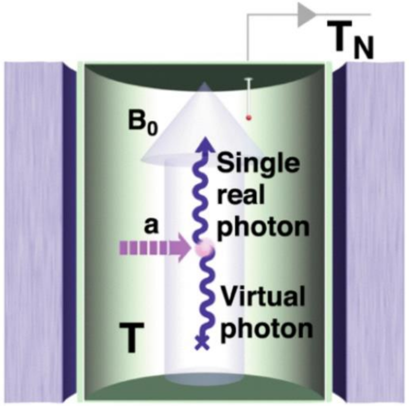
Yellow report in pre-publication – includes preliminary design of prototype

Technology

Exploration and evaluation of possible technological contributions of CERN to non-accelerator projects possibly hosted elsewhere



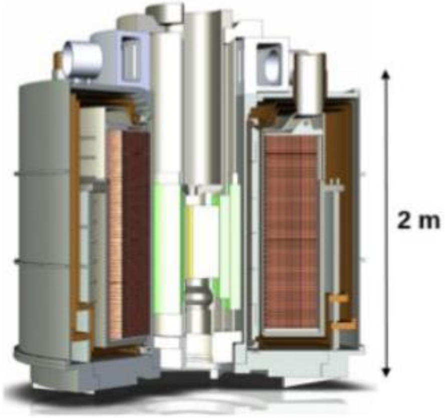




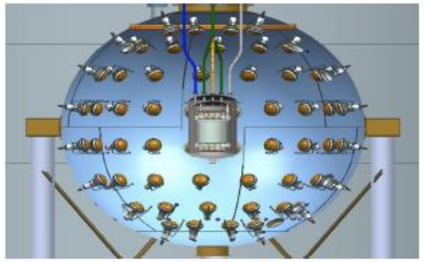
Initiative	Physics		Technology	CERN?
VMB@CERN	VMB	Search for Vacuum Magnetic Birefringence	optics, magnets	Y
JURA	LSW/ALPS	Via optics, detector development at ALPS II + FCC magnets	magnets	Y
STAX	LSW/ALPS	Transition-edge-sensors (TES); high Q Fabry-Perot cavities	magnets, cryo, RF	P
BabyIAXO/IAXO	Axions	Next generation helioscope - independent collaboration	magnets	N
DarkSide	WIMPs	Independent collaboration	vac, cryo, SIPM	N
Carbon Nano Tubes	CNB, DM	Electron recoils in large arrays of // carbon nanotubes - DM target for PTOLEMY	new material studies, neutrons	N
aKWISP	Chameleons	short-distance interactions at sub-micron scales	cryo, thin films..	N

Initiatives integrated into the Techno WG

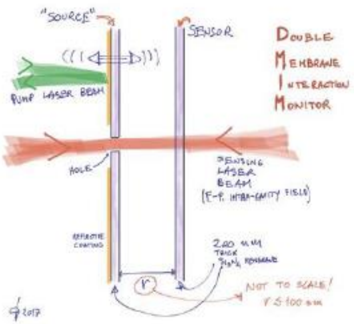
1) Haloscope LNCMI-Grenoble



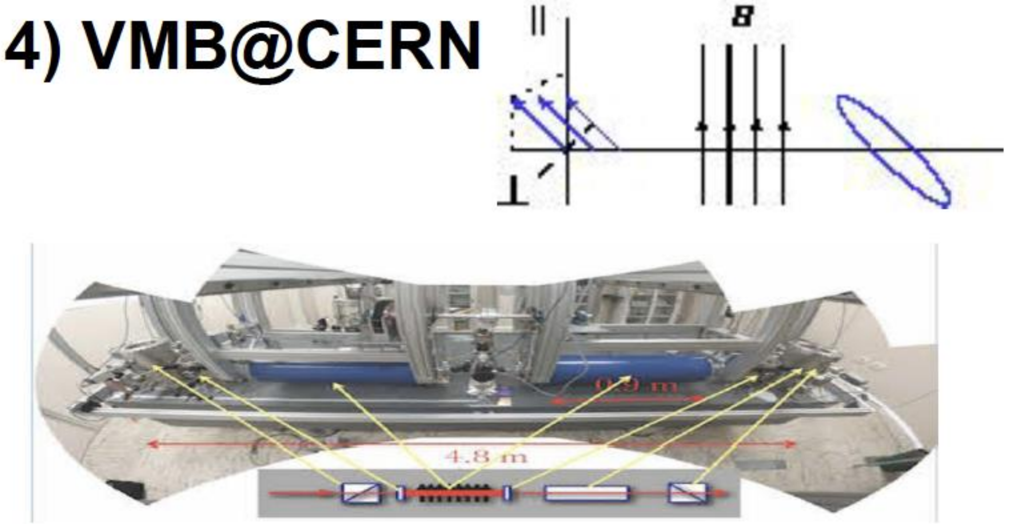
2) DarkSide



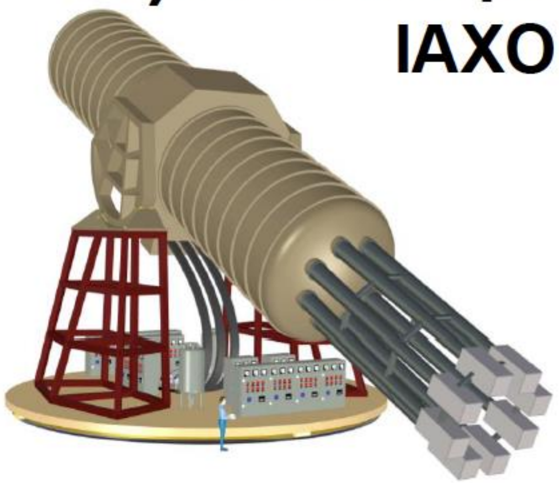
3) aKWISP



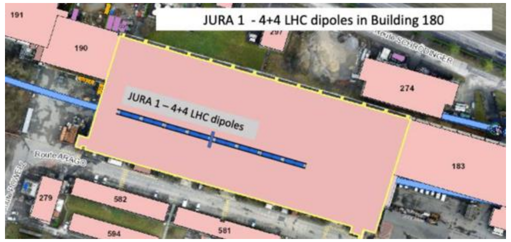
4) VMB@CERN



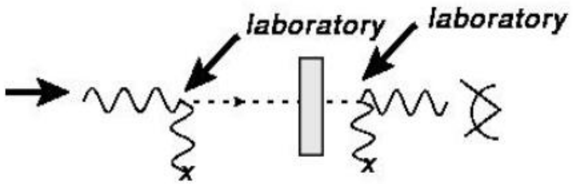
5) Helioscope IAXO



6) JURA (LSW combining ALPS-III and OSQAR+)

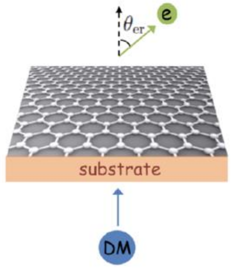


7) LSW-STAX



8) CNT Based DM Detector

PTOLEMY



Also considered

- **LHC Long Lived Particles**
  - FASER – for installation in LS2
  - MATHUSLA, CODEX-b, milliQan considered by BSM WG
- **REDTOP**
  - eta factory, possible at PS but PoT demand would conflict with existing users
- **LHC fixed target, Gamma Factory, AWAKE++, eSPS…**

Main message

This is what we should be doing in the medium term!

Well motivated, competitive, cost-effective options, making good use of CERN's existing complex, beams, and expertise.

Rare decays and precise measurements
KLEVER ($K^0_L \rightarrow \pi^0 \nu\nu$)
TauFV@BDF: $\tau \rightarrow 3\mu$
REDTOP (η decays)
MUonE (hadronic vacuum polarization for ($g\text{-}2_\mu$))
EDM proton storage ring

Long-lived particles from LHC collisions
FASER, MATHUSLA, CODEX-b, milliQAN

Other facilities:
γ-factory from Partially Stripped Ions;
nuSTORM

QCD measurements
COMPASS++, DIRAC++
NA61++, NA60++
Fixed target (gas, crystals) in ALICE & LHCb

Hidden sector with "beam dumps"
NA64++ (e,μ)
NA62++
Beam Dump Facility at North Area (SHiP)
LDMX@eSPS
AWAKE++

Non-accelerator projects
Exploit CERN's technology (RF, vacuum, magnets, optics, cryogenics) for experiments possibly located in other labs.
E.g. axion searches: IAXO (helioscope), JURA (Light Shining through Wall)

Conclusion from PBC BSM report

- The absence, so far, of unambiguous signals of NP from
  - direct searches at the LHC,
  - indirect searches in flavour physics,
  - and direct detection Dark Matter experiments,
  - along with the absence of a clear guidance from the theory about the NP scale,

  motivates today, more than ever, the broadening of the experimental effort in the quest for NP and exploring different ranges of interaction strengths and masses with respect to what is already covered by existing or planned in initiatives.
- CERN could offer an unprecedented variety of high-intensity, high energy beams and scientific infrastructures that could be exploited to this endeavour.
- This effort would nicely complement and further broaden the already rich physics programme ongoing at the LHC and HL-LHC.

BACKUP

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

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

Reports

Submission to ESPP update/recent summary as appropriate

Document	Submitted by	Link to document
Summary Report of Physics Beyond Colliers at CERN	PBC coordination	CDS arXiv
Physics Beyond Colliders QCD Working Group Report	QCD Working Group	CDS arXiv
Report of the BSM Working Group of the Physics Beyond Colliders at CERN	BSM Working Group	CDS arXiv
SPS Beam Dump Facility Comprehensive Design Study	BDF Working Group	CDS (to be published)
Report from the Conventional Beams Working Group	Conventional Beams Working Group	CDS
AWAKE++: The AWAKE Acceleration Scheme for New Particle Physics Experiments at CERN	AWAKE++ Working Group	CDS (to be published)
PBC technology subgroup report	Technology Working Group	CDS
Dark Sector Physics with a Primary Electron Beam Facility at CERN	eSPS	CDS
Report from the LHC Fixed Target working group of the CERN Physics Beyond Colliders forum	Fixed Target Working Group	CDS
TECHNICAL PROPOSAL: FASER, THE FORWARD SEARCH EXPERIMENT AT THE LHC	FASER collaboration	CDS
The CERN Gamma Factory Initiative: An Ultra-High Intensity Gamma Source	Gamma Factory collaboration	IPAC (report in prep.)
Feasibility Study for a storage ring to search for an Electric Dipole Moment of charged particles	CPEDM	CDS (to be published)
nuSTORM at CERN: Feasibility Study	nuSTORM Working Group	CDS (to be published)
SPS Operation and Future Proton Sharing scenarios for the SHiP experiment at the BDF facility	Proton perf. post-LIU WG	CDS

see http://pbc.web.cern.ch/

A number of teams* submitted 10 page summary proposals to the ESPP update, some referencing the documents above.

*AWAKE++, BDF, CB, EDM, eSPS, Gamma factory, nuSTORM, Technology