Meeting SHiP-France
Paris – October 11, 2017

Claude Vallée (CPPM/DESY)

Dark Sector & Related Items in 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

PBC EVENTS

KICK-OFF WORKSHOP, CERN, Sept. 6-7, 2016

> 300 registered participants, 3/4 from outside CERN

Agenda :

1. **Theorists wishes**
2. **Accelerator complex opportunities**
3. **Potential future of existing programs**
4. **New ideas: Call for abstracts → 33 abstracts submitted, 20 selected for presentations**

Talks on invitation

1st GENERAL WORKING GROUP MEETING, CERN, March 1-2, 2017

Identification of main issues to be studied

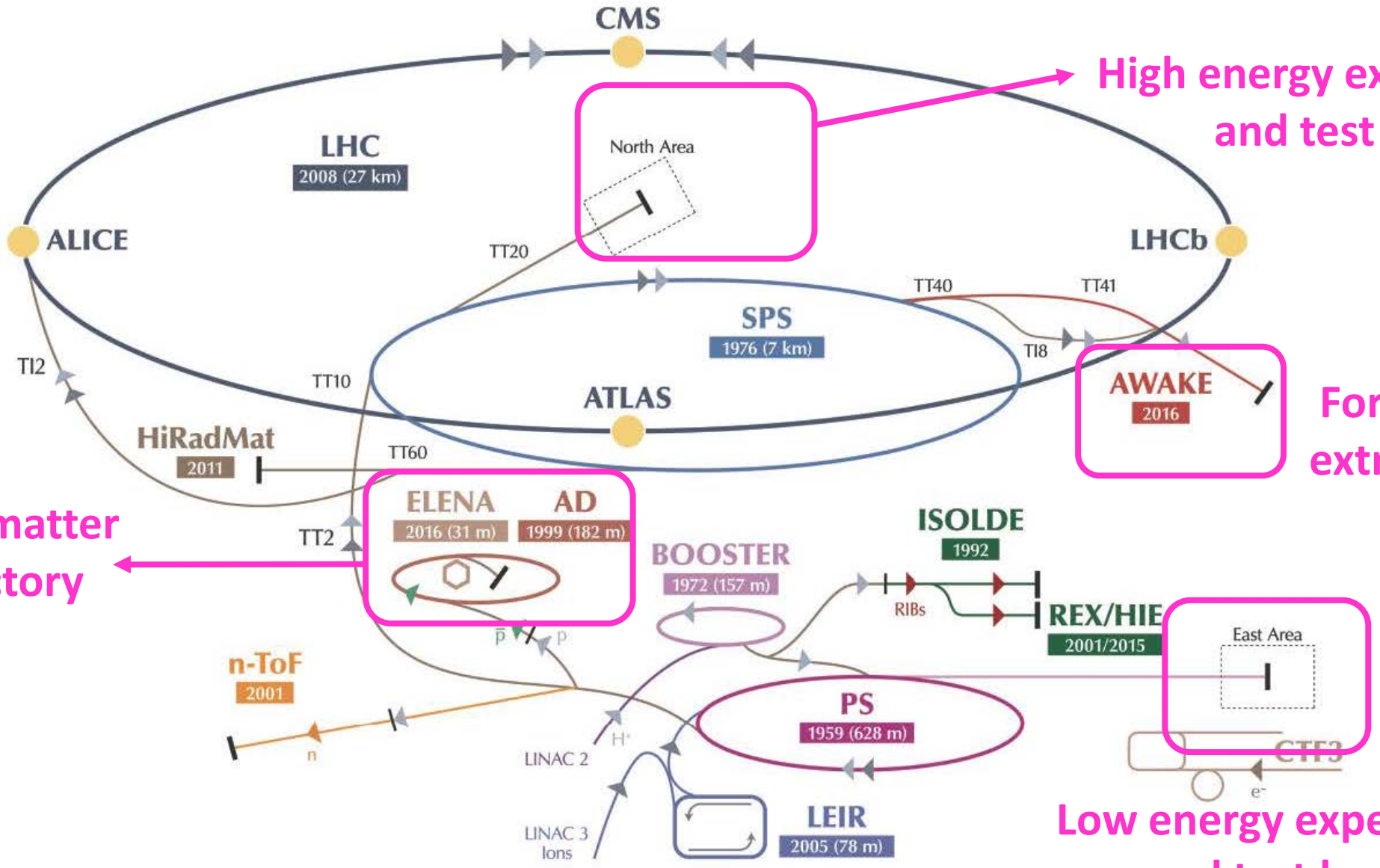
FOLLOW-UP OPEN WORKSHOP scheduled at CERN on November 21-22, 2017

https://indico.cern.ch/event/644287/

Progress on projects and new call for abstracts

NB: credit to Collaborations for the plots shown in this presentation

THE CERN ACCELERATOR COMPLEX



High energy experiments and test beams

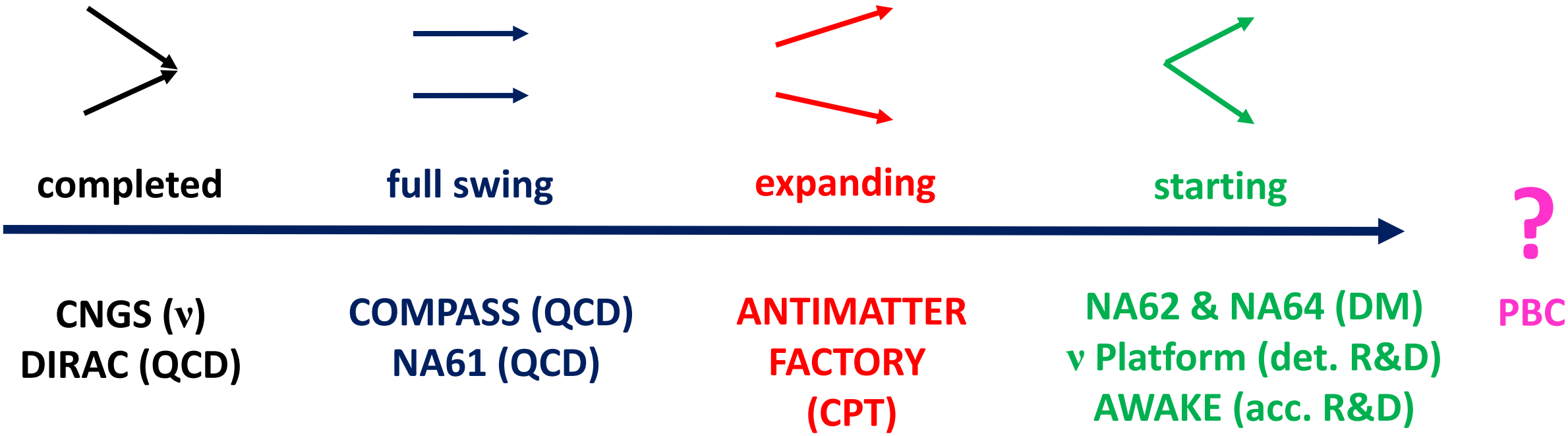
Former CNGS extraction line

Antimatter Factory

Low energy experiments and test beams

A DECADE OF VIBRANT "DIVERSITY" PHYSICS AT CERN !

~1000 physicists on ~20 experiments



...+ CAST, OSQAR, etc...

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

The Hidden Sector

$$L = L_{SM} + L_{mediator} + L_{HS}$$

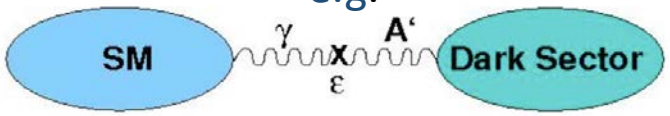
Visible Sector

Hidden Sector

Naturally accommodates Dark Matter (may have rich structure)

Mediators or portals to the HS: vector, scalar, axial, neutrino

e.g.



- *Long-lived objects*
- *Interact very weakly with matter*

Models	Final states
HNL, SUSY neutralino	$l^+\pi^-$, l^+K^-, $l^+\rho^-$ $\rho^+ \rightarrow \pi^+\pi^0$
Vector, scalar, axion portals, SUSY sgoldstino	l^+l^-
HNL, SUSY neutralino, axino	$l^+l^-\nu$
Axion portal, SUSY sgoldstino	$\gamma\gamma$
SUSY sgoldstino	$\pi^0\pi^0$

Non-accelerator projects

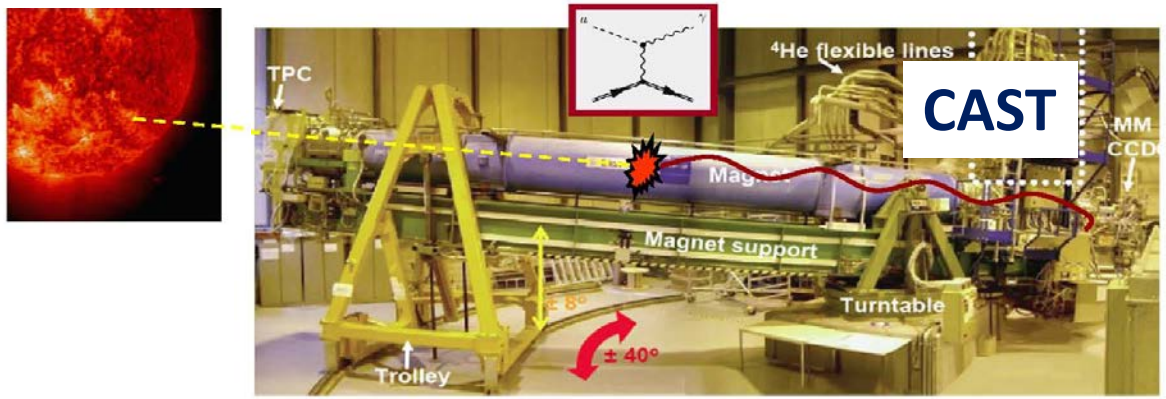
New long term large facilities

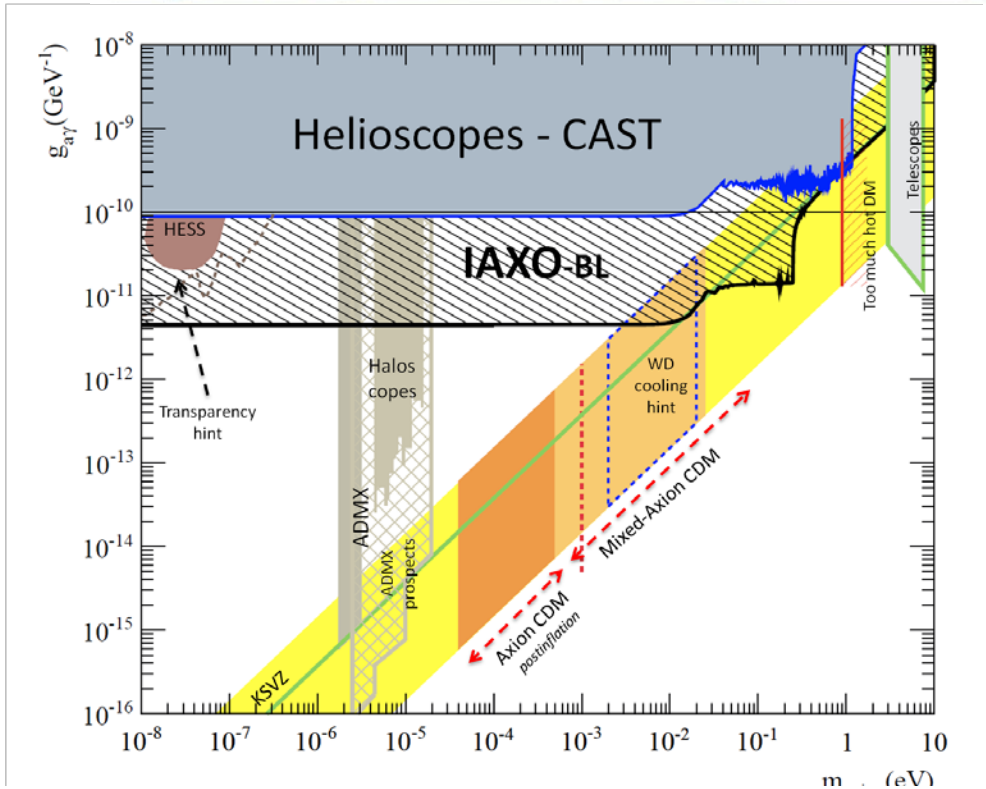
Antimatter factory

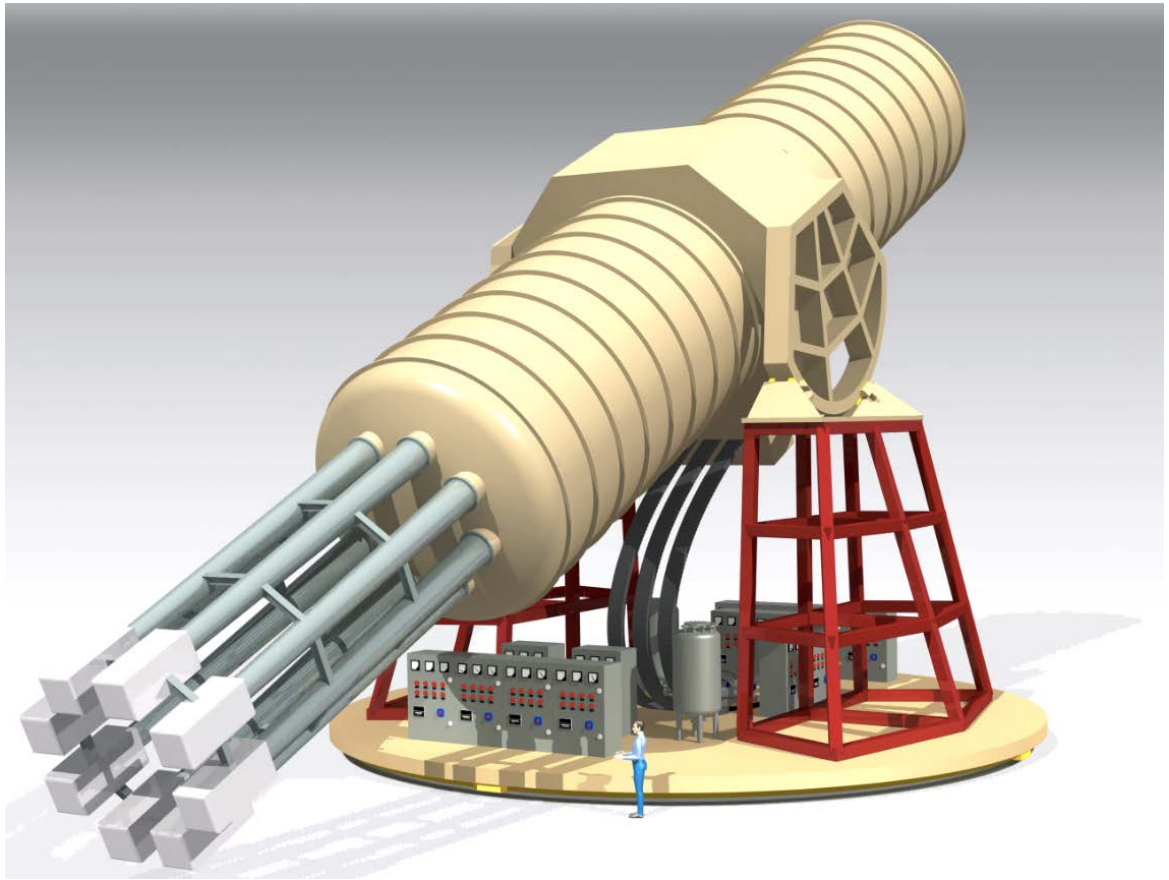
SPS projects

Solar Axions: IAXO

Next generation Axion Helioscope beyond CAST





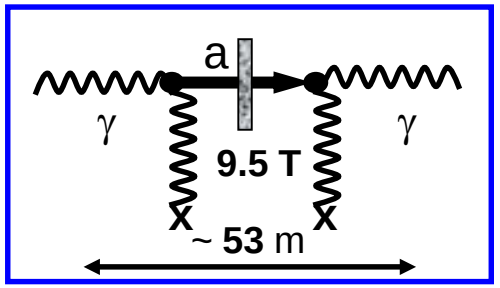


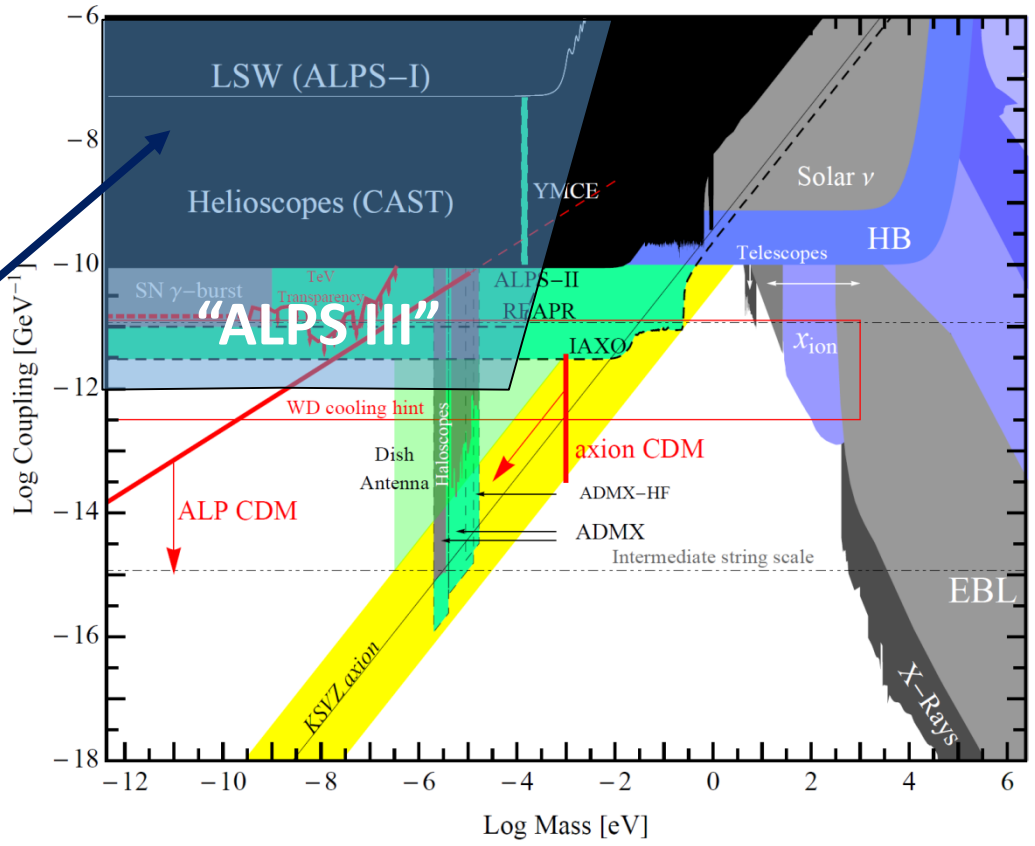
Will profit from CERN magnet expertise (ATLAS-like large bore toroid) for proposal preparation

<u>Main IAXO issues</u>: Collaboration strengthening and helioscope siting (DESY option)

Laboratory Axions: "ALPS III"

Light shining through a wall





Comparable limits obtained by OSQAR@CERN and ALPS@DESY

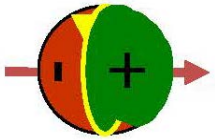
ALPSII@DESY under construction

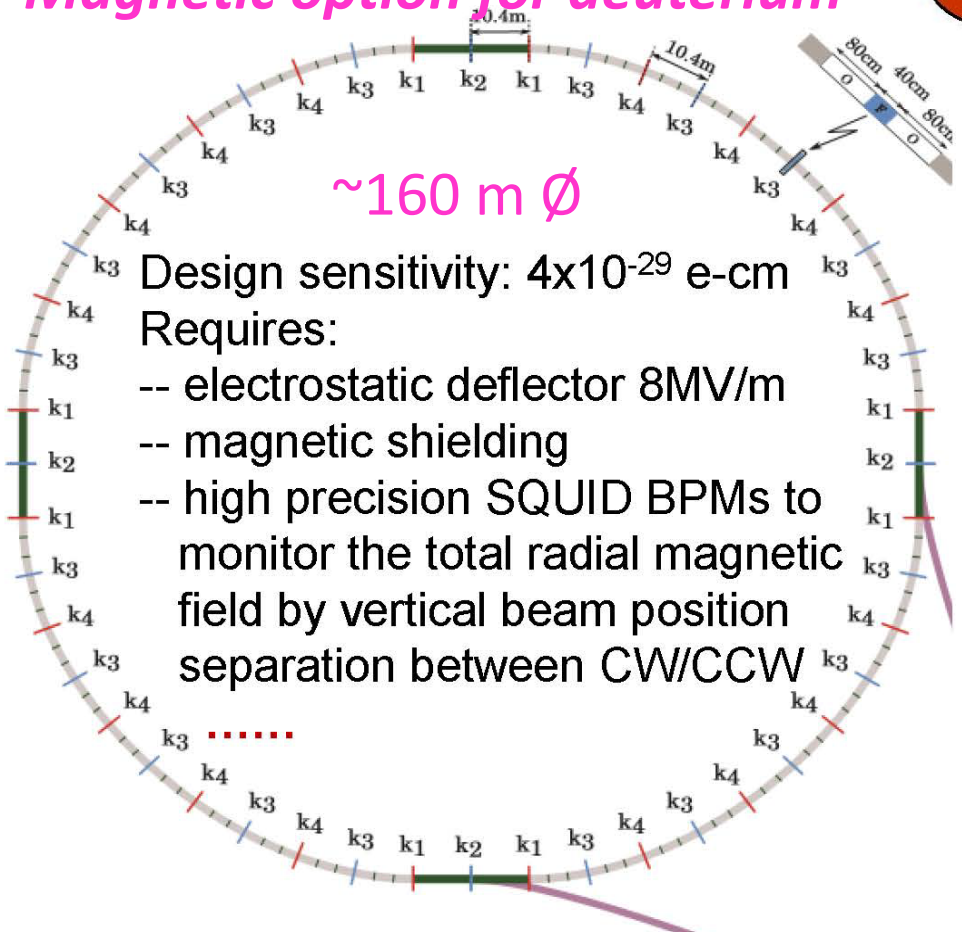
Dipole	Aperture [mm]	Field strength [T]	LSW experiment	Number of used dipoles
HERA (straightened)	50	5.3	ALPS II (DESY)	20
LHC	40	9.0	OSQAR (CERN)	2
"FCC"	100 (40)	13 (20)	"ALPS III"	

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

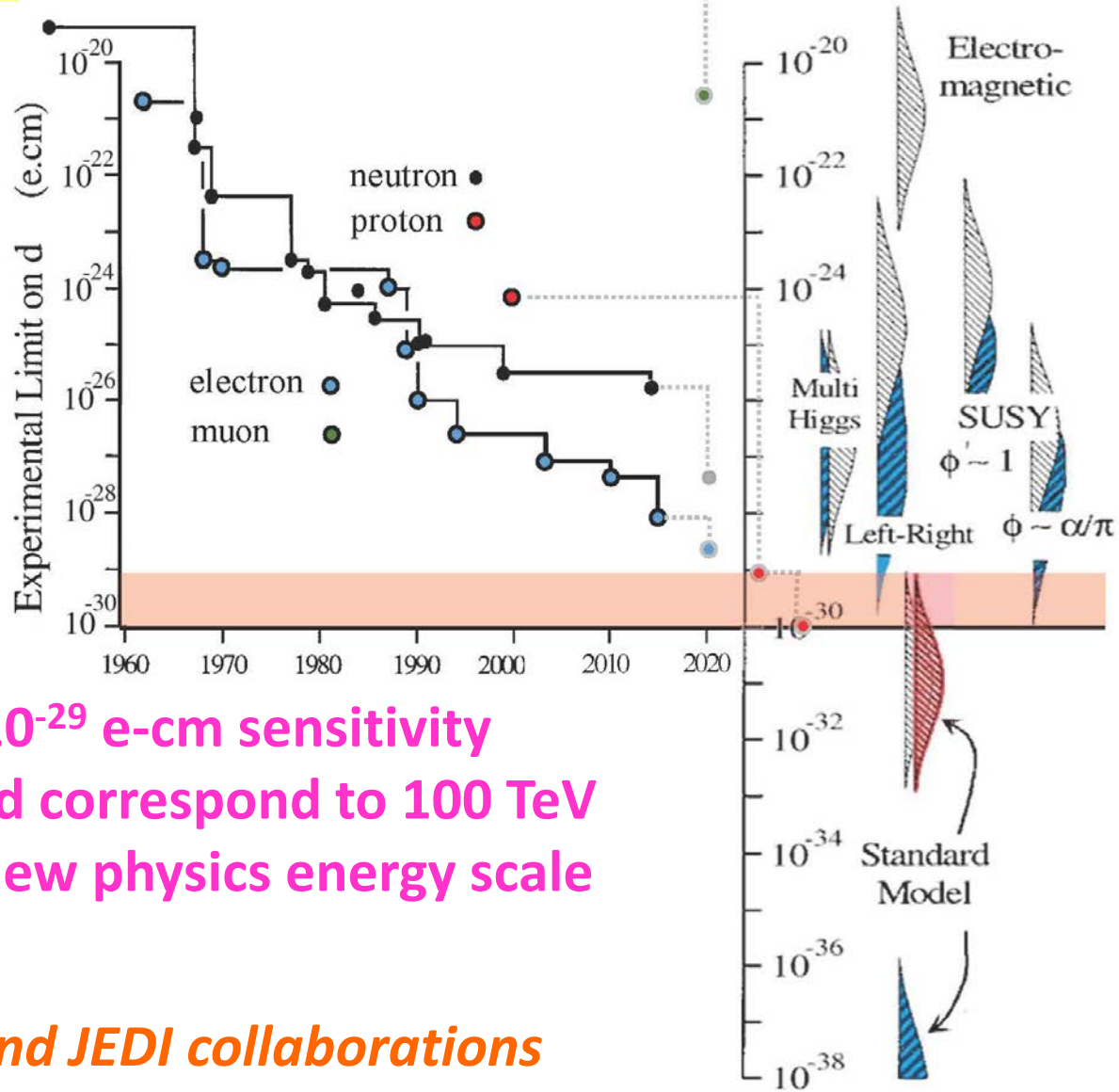




~160 m Ø

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

J.M.Pendlebury and E.A. Hinds, NIMA 440 (2000) 471



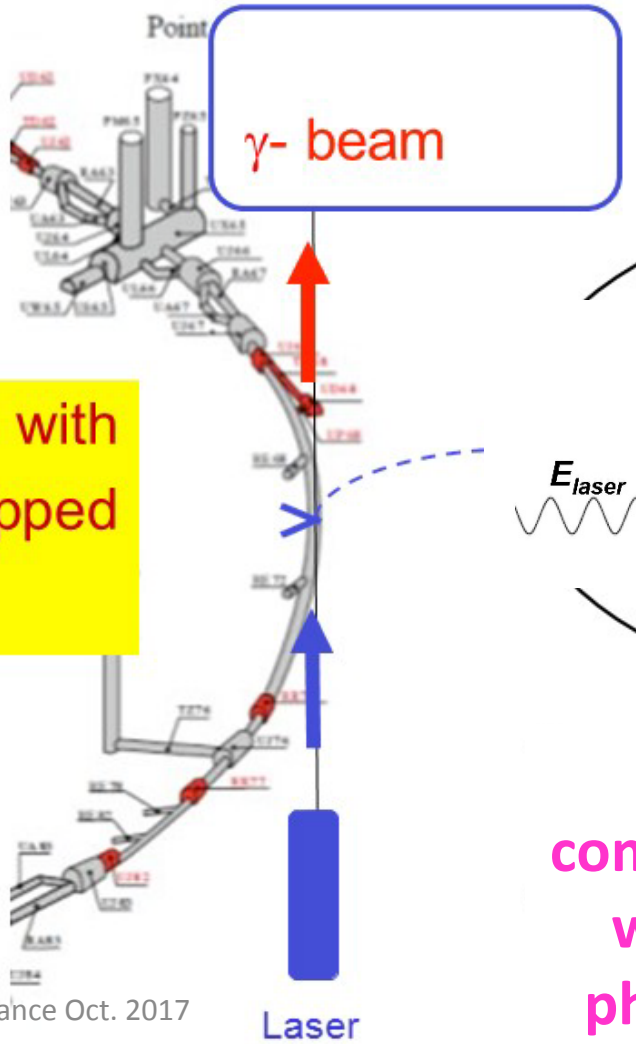
10^{-29} e-cm sensitivity would correspond to 100 TeV for new physics energy scale

Ring design ongoing by CERN with srEDM and JEDI collaborations

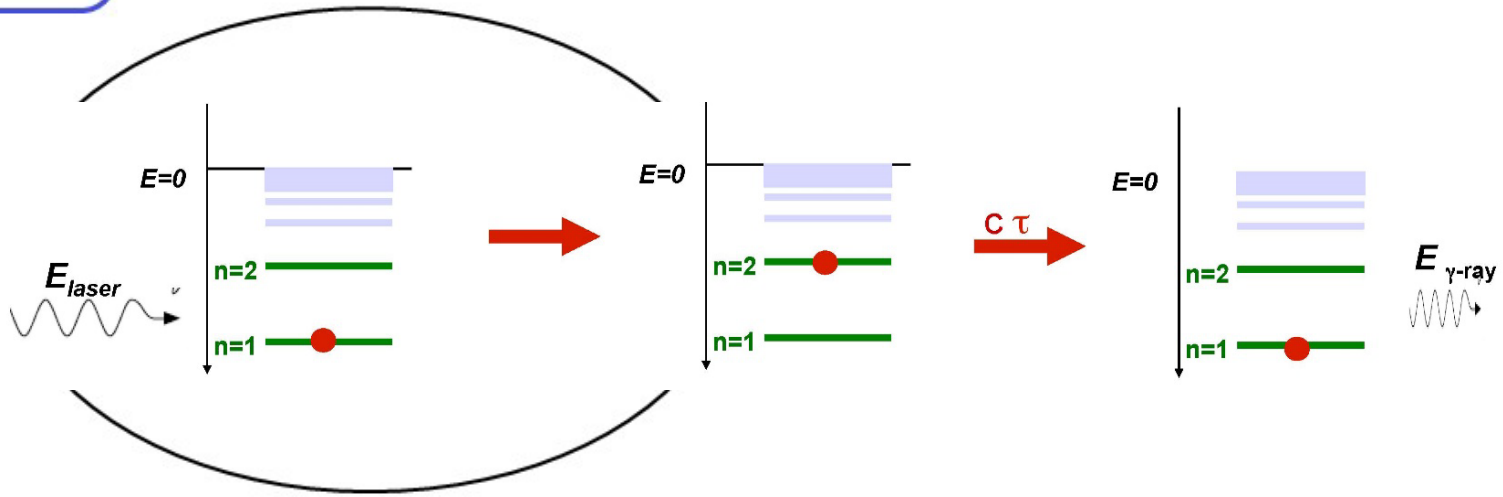
<u>Main issue</u>: control of systematic effects (e.g. B fields)

New idea: Gamma Factory

Use LHC beam to convert laser photons into 0.1 - 400 MeV γ rays

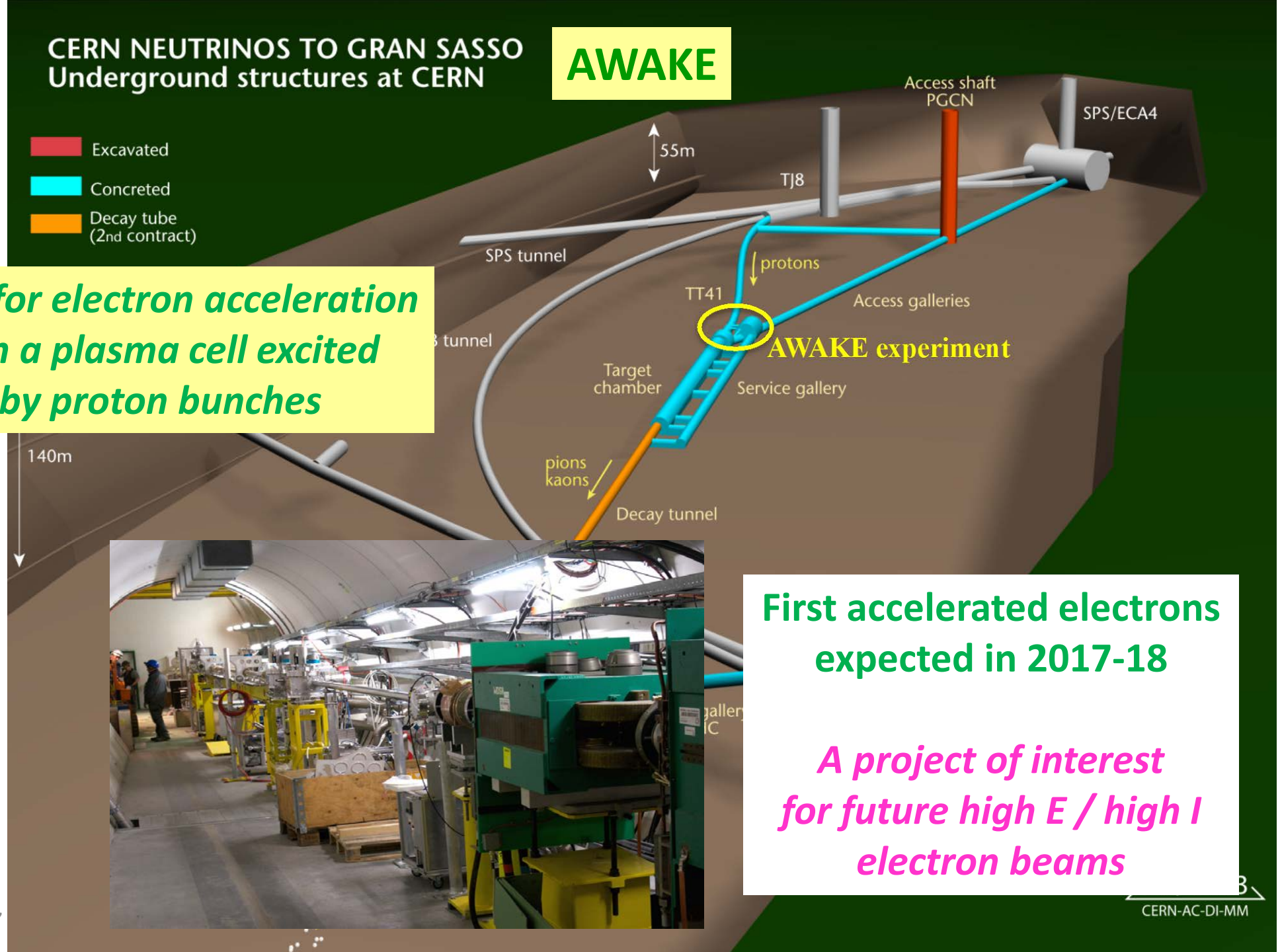


LHC filled in with partially stripped ion beams



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

AWAKE



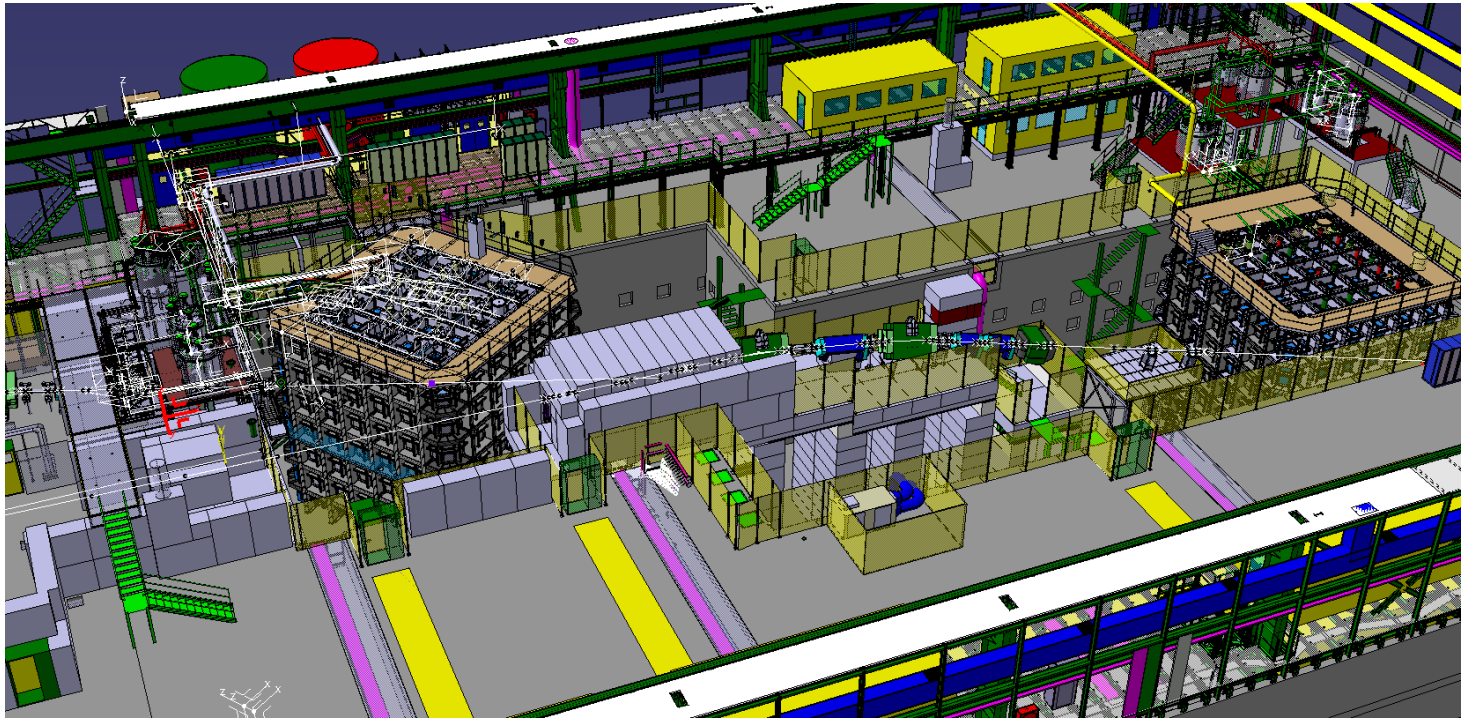
R&D for electron acceleration with a plasma cell excited by proton bunches

First accelerated electrons expected in 2017-18

A project of interest for future high E / high I electron beams

NEUTRINO PLATFORM

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



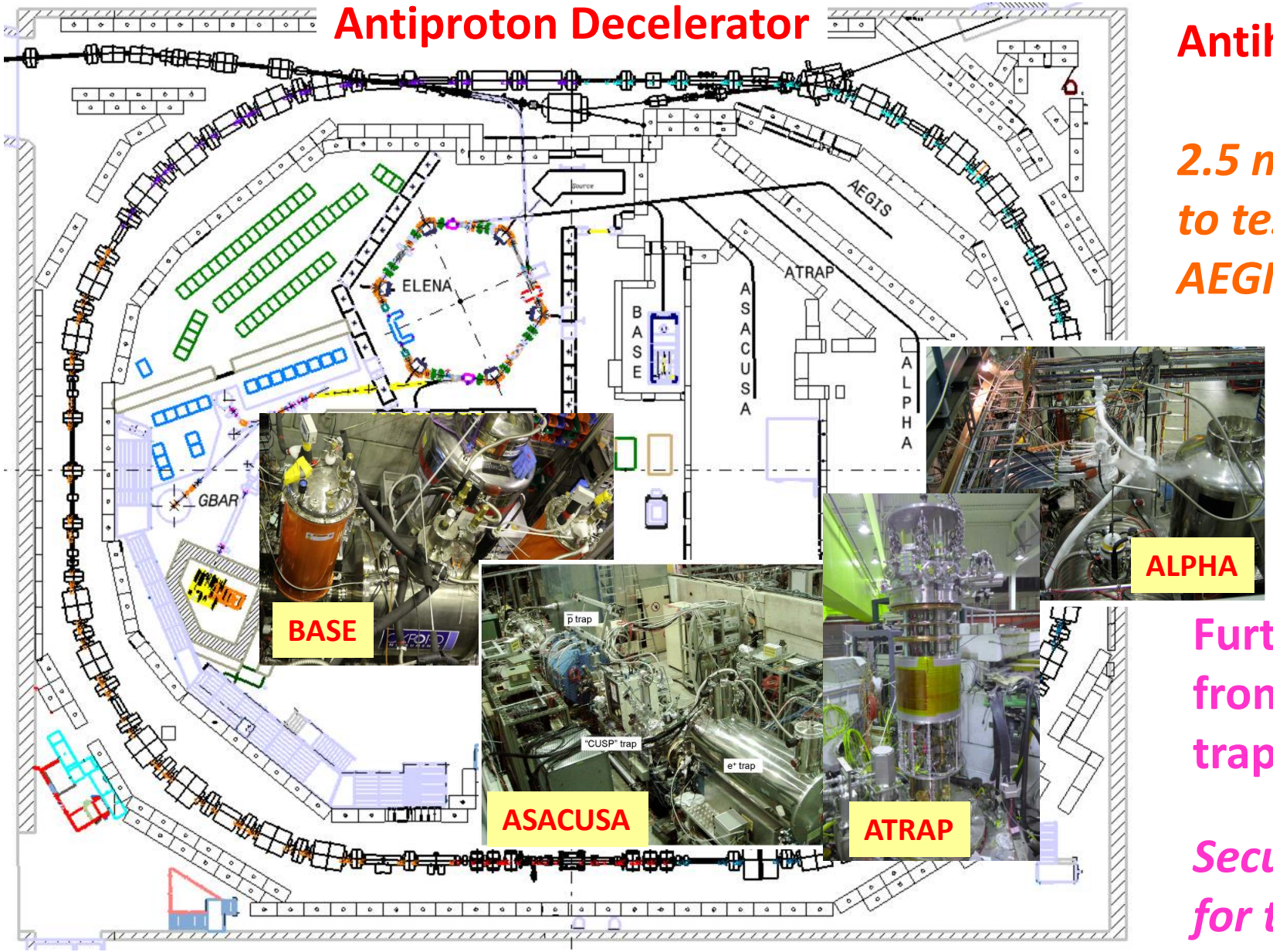
Hall extension built and prototype assembly started

But tight schedule to take beam data before LS2

NB: technology could also be on interest for future DM projects at CERN

ANTIMATTER FACTORY

Antiproton Decelerator



4 running experiments devoted to Antiproton and Antihydrogen Properties

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

***AFTER LS2:* ELENA**
(under commissioning)

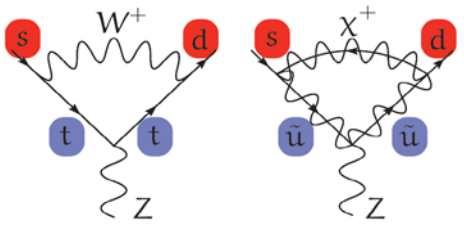
Further deceleration of pbar from 5 MeV to 100 KeV → trapping efficiency x ~100

Secures antimatter physics for the next decade

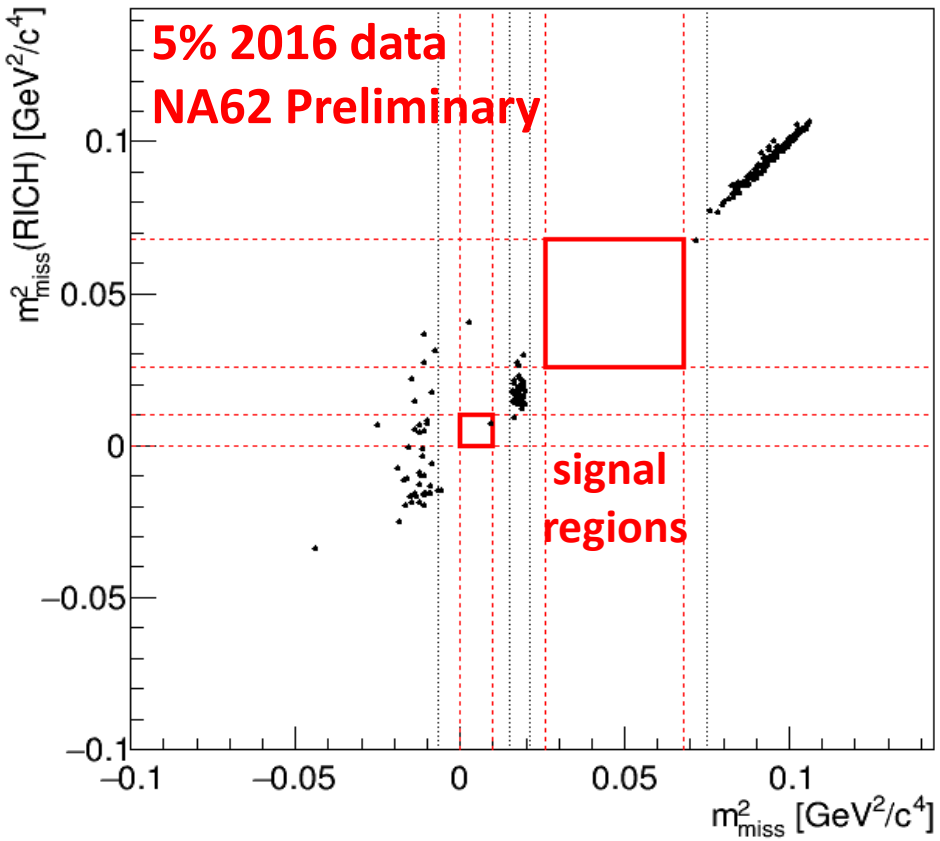
$K \to \pi \nu \bar{\nu}$ (BR ~ 10^{-10})

NA62

Rare K decays



Regular data taking starting after many years of intensive construction and commissioning



Signal regions: ~100 evts expected until LS2

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

New idea: $K^o \rightarrow \pi^o \nu\nu$ rare decay (KLEVER)

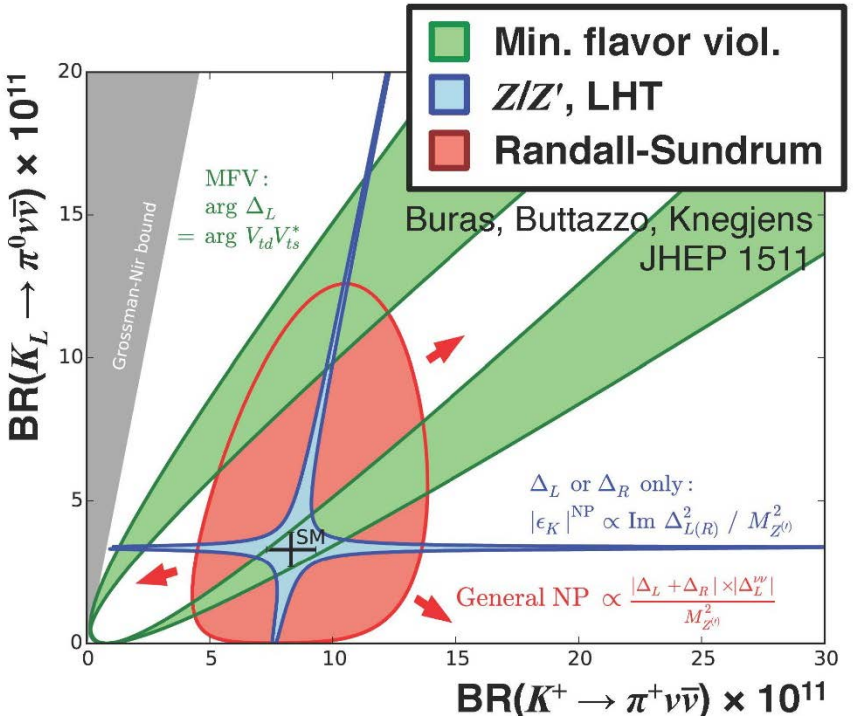
K^0 decays complementary to K^+ decays for the CKM matrix and BSM searches.

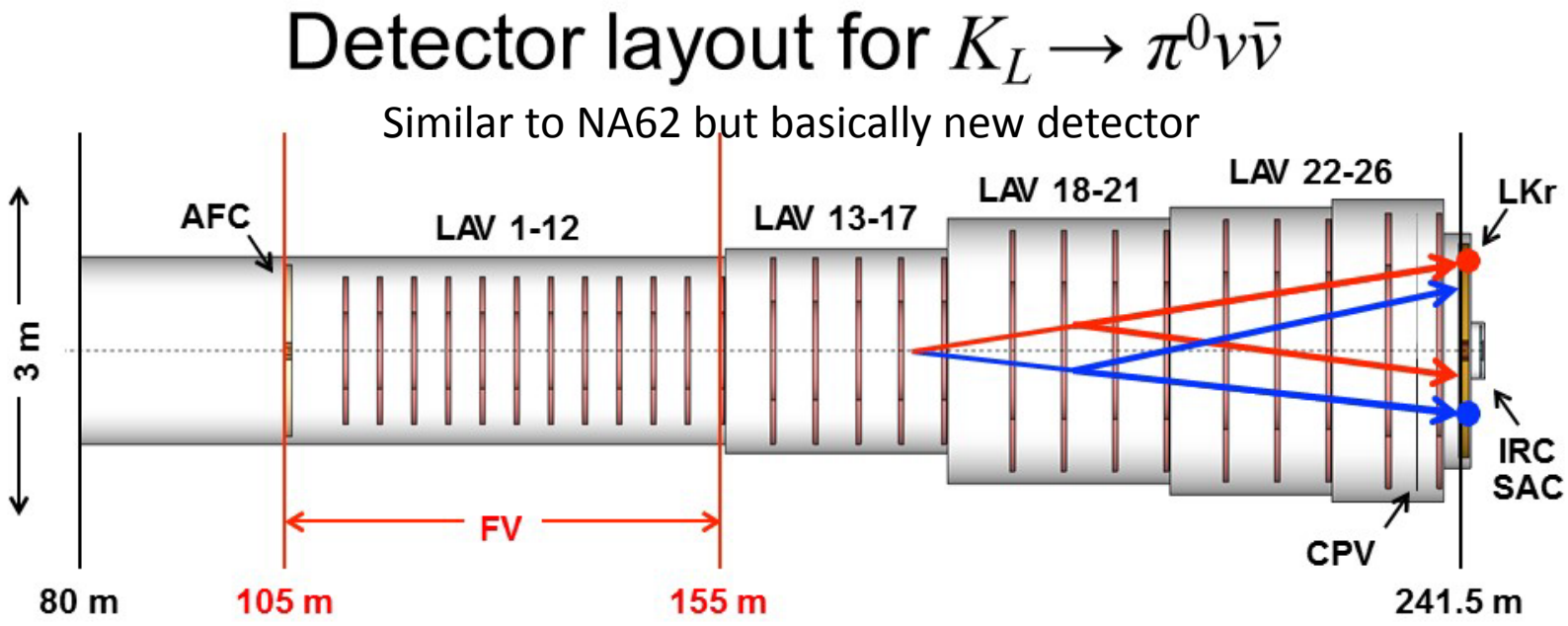
Would require a new high intensity K^o beam.

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

Competition from starting KOTO at JPARC:

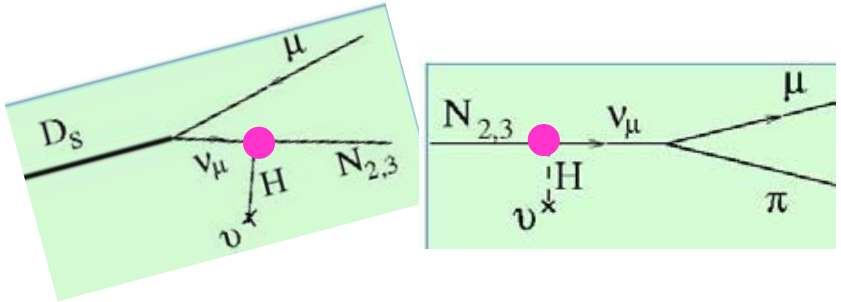
few evts expected in coming years, upgrade by factor ~10 foreseen > 2025



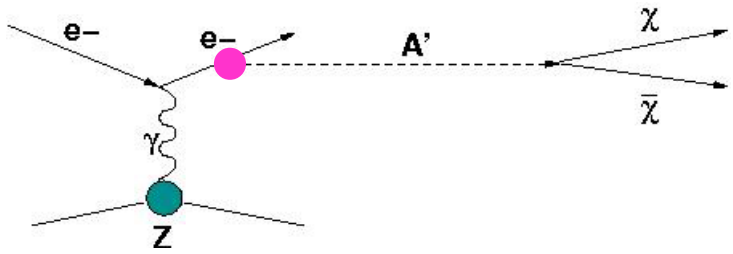


<u>Main issues</u>: actual sensitivity vs competition, cost of new beam and upgraded detector

Exploration of the Hidden Sector with Fixed Targets



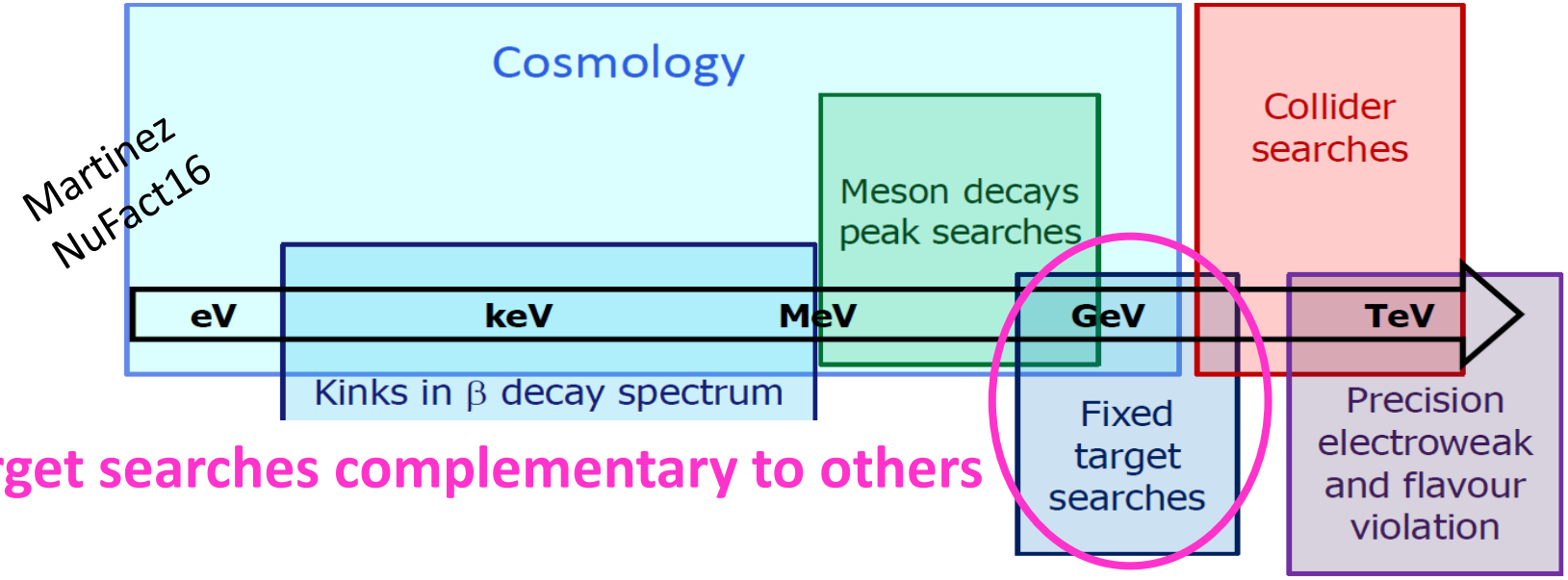
2 methods



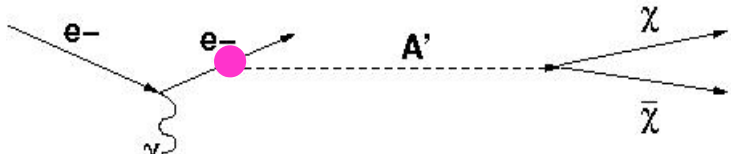
Production + decay of new particle:
2 couplings → needs high intensity

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 !



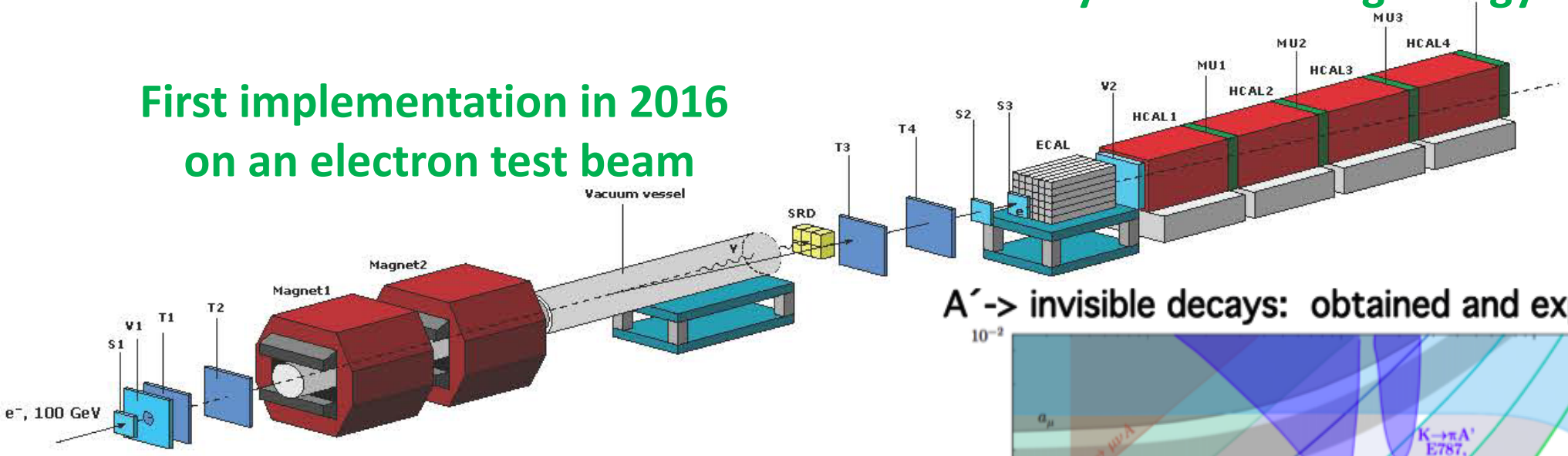
Fixed Target searches complementary to others



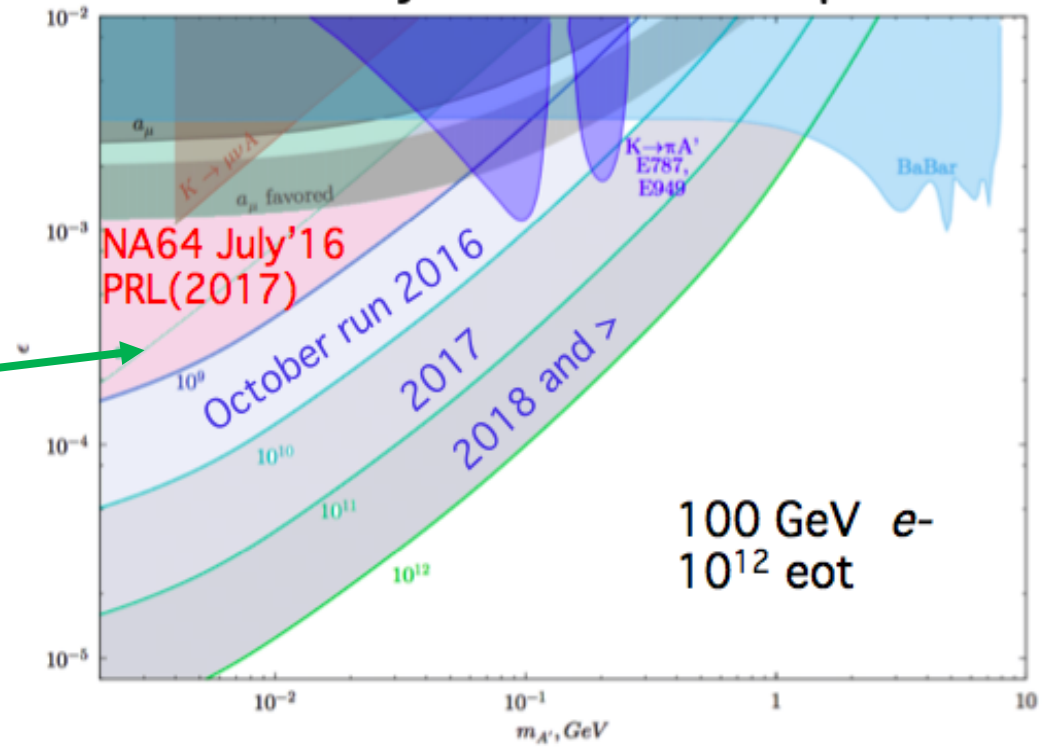
NA64

Hidden sector search from invisible decays with missing energy

First implementation in 2016 on an electron test beam



A´-> invisible decays: obtained and expected limits

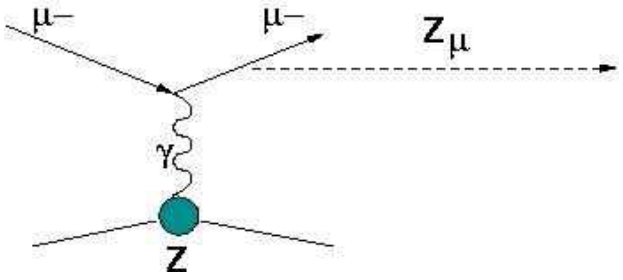


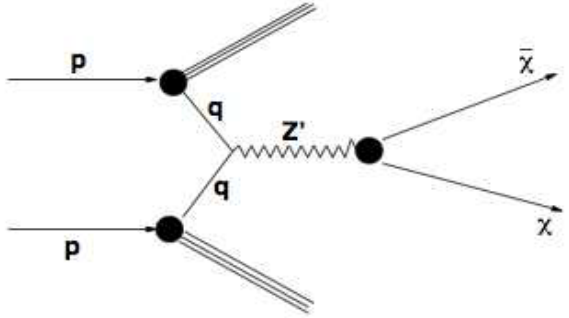
Exclusion of $(g\text{-}2)_\mu$ interpretation with 1 day of data taking confirms the potential of the method

(more data under analysis)

AFTER LS2: NA64++

Wish to extend the method to μ / π / K / p beams





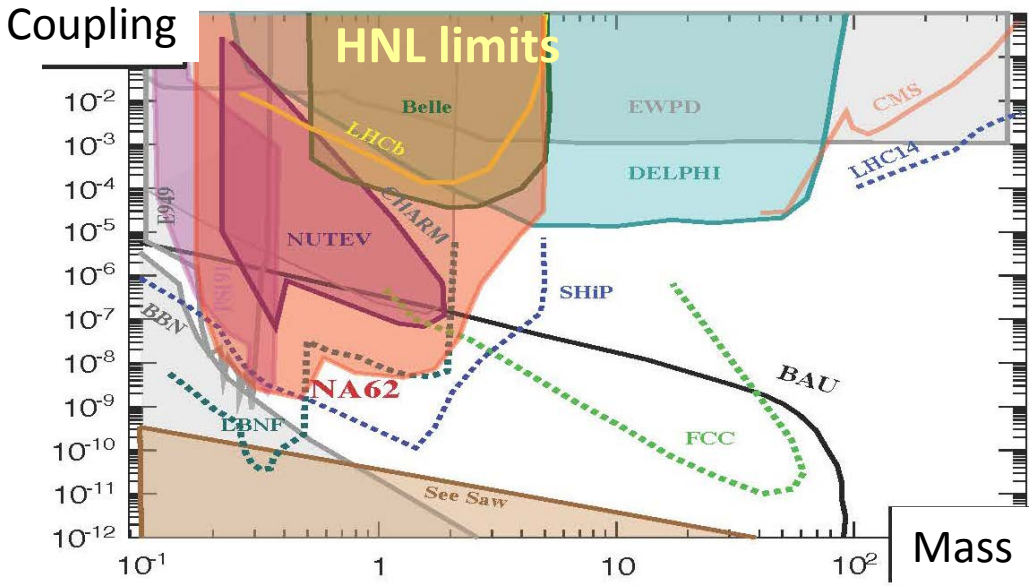
Process	New Physics	Sensitivity
1. $e^-Z \to e^-Z + E_{miss}$		
✧ $A' \to e^+e^-$ ✧ $A' \to$ invisible ✧ alps ✧ milli-Q	Dark Sector: Dark Photons and DM New light states (V,S) weakly coupled to e- ^{8}Be excess	$10^{-3} < \varepsilon < 10^{-6}$ $M_{A'} \sim$ sub-GeV mQ $< 10^{-5}$-10^{-7} e $M_{mQ} \sim$ sub-GeV
2. $\mu^- Z \to \mu^- Z + E_{miss}$		
✧ $Z_\mu \to \nu\nu$, $\mu^+\mu^-$ ✧ a_μ ✧ $\mu \to \tau$ conversion	$(g-2)_\mu$ anomaly, New Z_μ from L_μ-L_τ gauged symm., scalars coupled to μ LFV	$\alpha_\mu < 10^{-11}$-10^{-9} $\sigma_{\mu\tau}/\sigma_\mu < 10^{-9}$-$10^{-8}$
3. π (K)p-> M^0n + E_{miss}		
✧ K_L-> invisible ✧ K_S-> invisible ✧ π^0, η, η'-> invisible	CP, CPT symmetry Bell-Steinberger Unitarity, new WC particles: NHL, $\phi\phi$, VV	Br $< 10^{-8}$-10^{-6}, Complementary to $K \to \pi\nu\nu$ Br$< 10^{-8}$-10^{-7}
4. pA -> Z′ + E_{miss}		
✧ leptophobic Z′	~ GeV DM	$\sigma_{Z'} < 10^{-7}$-10^{-8} /p

Main issues: e beam intensity and CERN siting for other beams

AFTER LS2 : NA62++

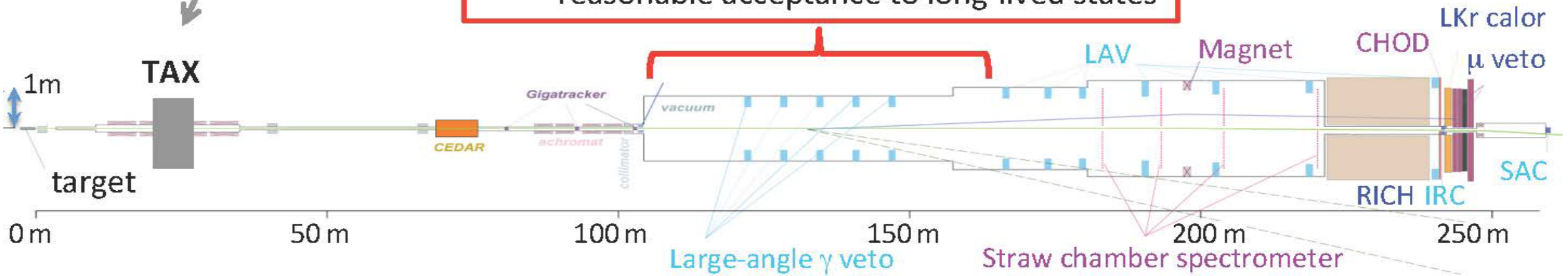
Wish to run ~1 year in beam dump mode to look for Heavy Neutral Leptons

→ possible intermediate step towards a more ambitious beam dump facility



Compact beam dump: ~11 λ_I 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

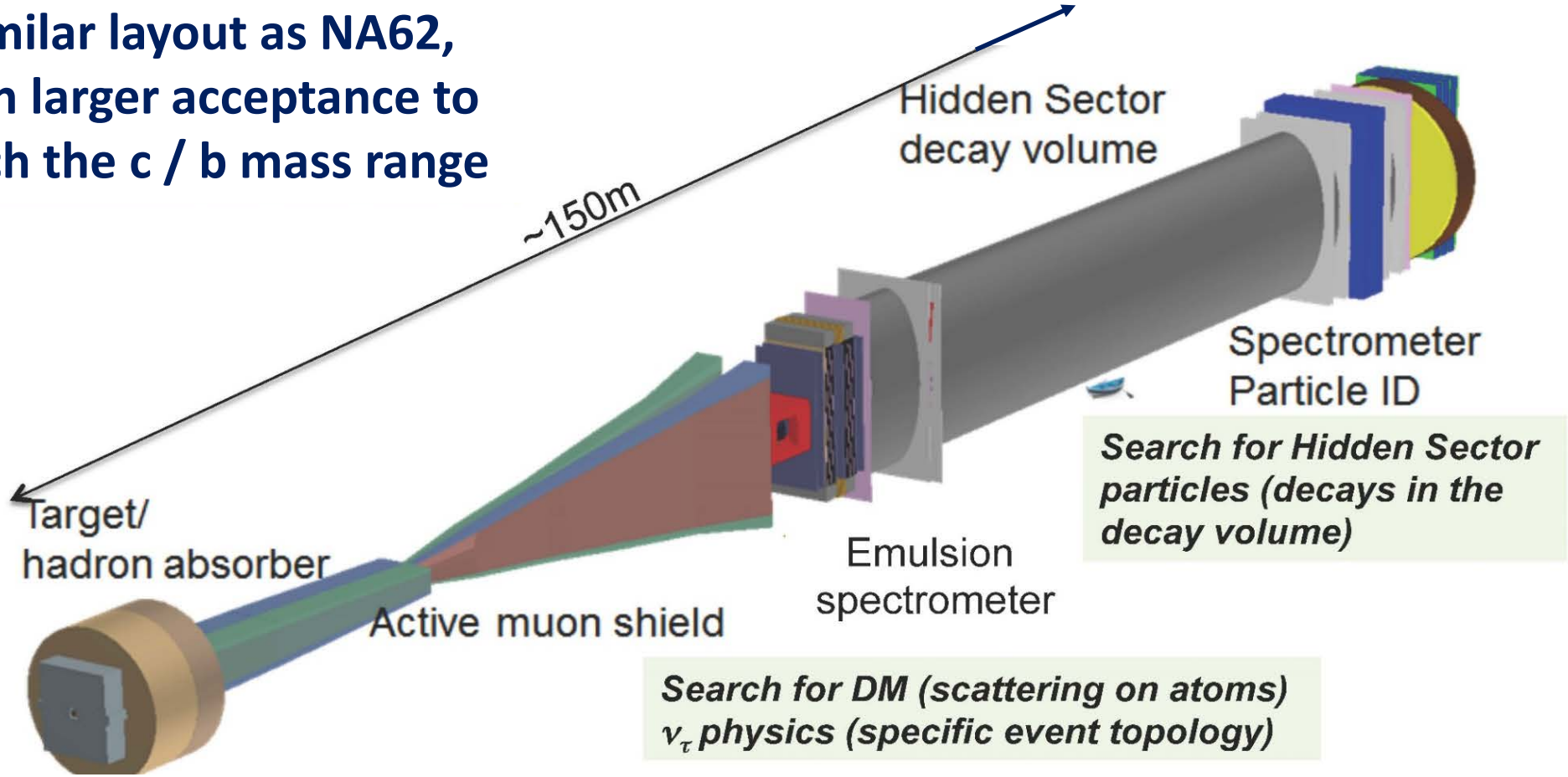


SHiP

Flagship program for a comprehensive investigation of the Hidden Sector in the few GeV domain

Exploits the unique high-E/ high-I SPS features

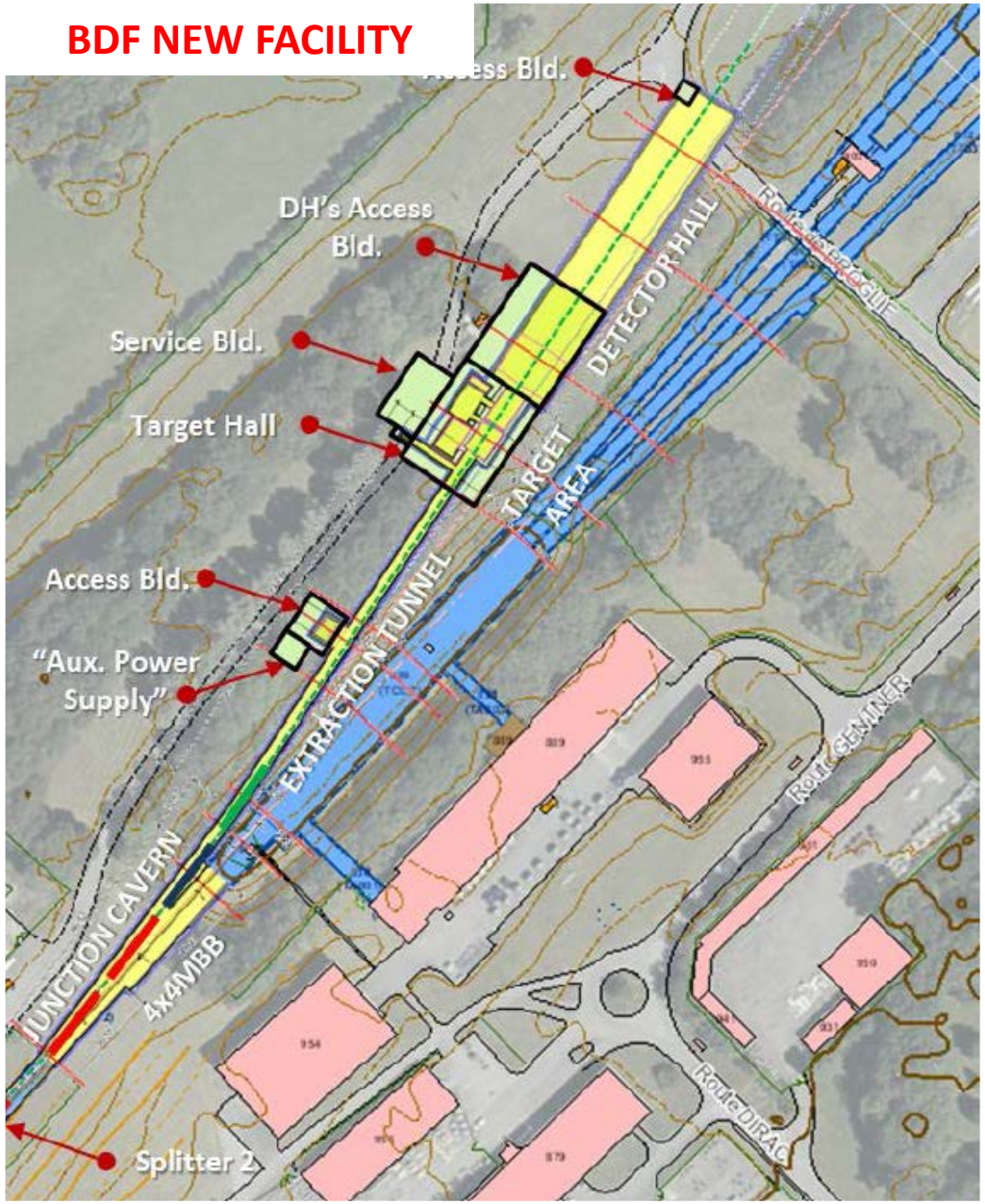
Similar layout as NA62, with larger acceptance to reach the c / b mass range



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

<u>Main issue</u>: maximize physics reach to justify high investment of a new beamdump facility

BDF NEW FACILITY



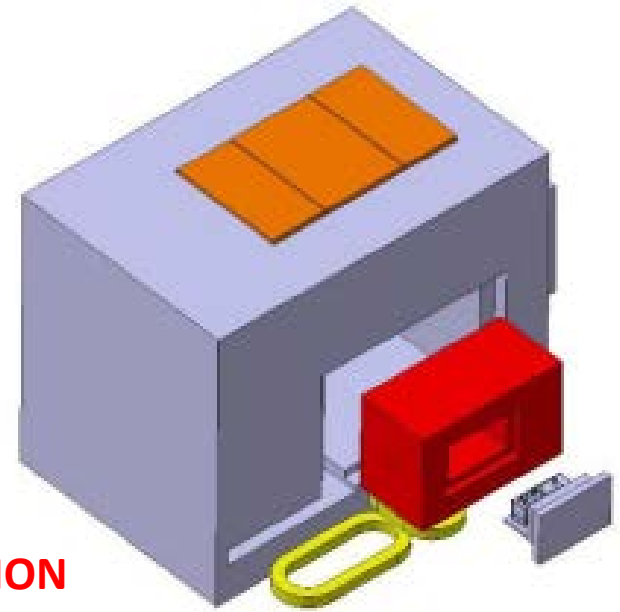
BEAM DUMP FACILITY

Conceptual design ongoing at CERN

with significant resources!

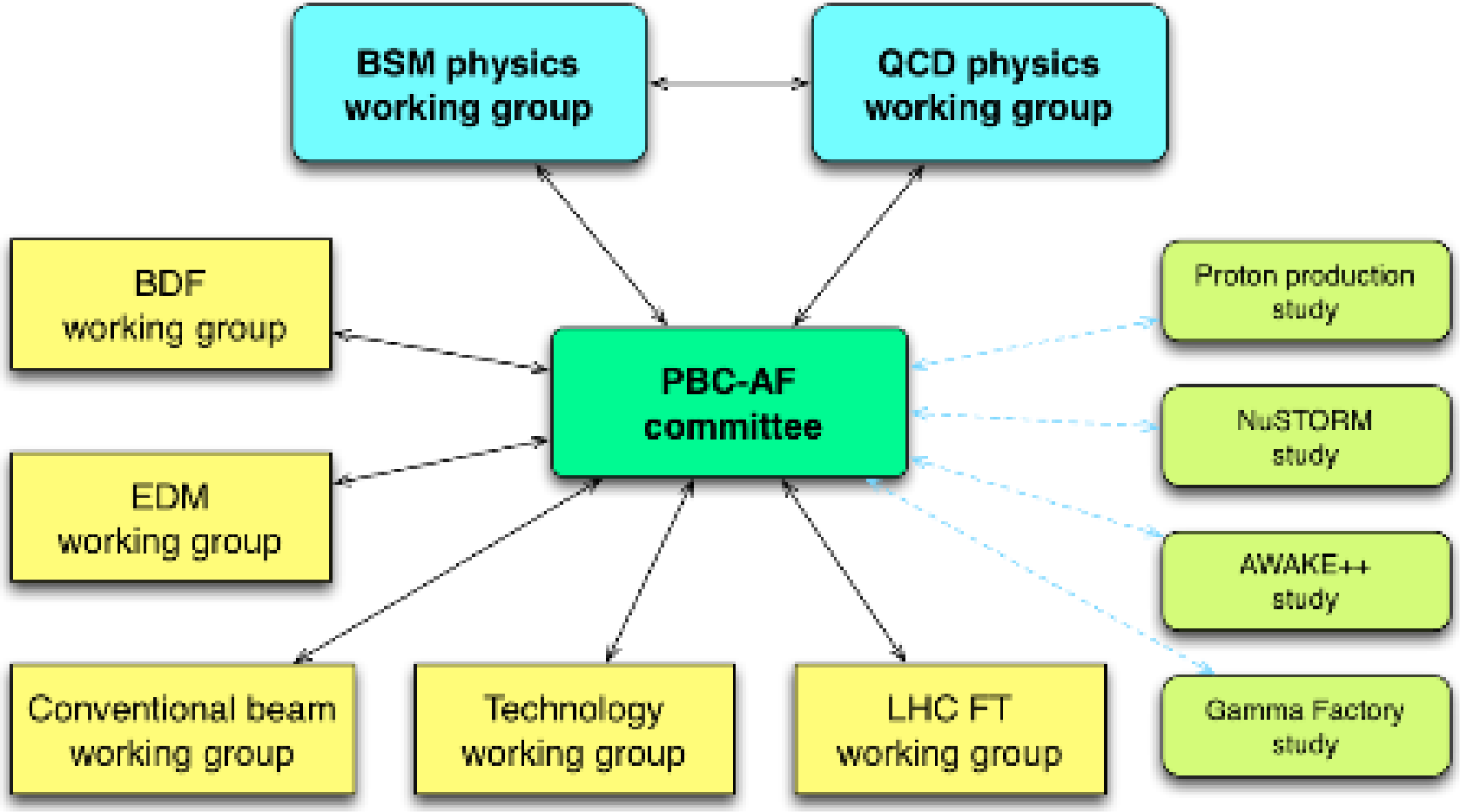
Foreseen to be sited close to the North Area

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



TARGET STATION

PBC WORKING GROUP STRUCTURE



Organisation and follow-up of activities documented on http://pbc.web.cern.ch/

PBC DELIVERABLES

One main overview document supplemented by experiment documents
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

Context Documents

DOCUMENT	EDITORS	AUTHORS	CONTENT
Main (30-50 pages)	PBC coordinators	PBC WGs	Highlights of the physics case of the proposed PBC experiments at CERN, and how they can address it: *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.
BSM context	BSM WG conveners	BSM WG *+ possible externals as appropriate*	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 LSW searches vs EDM limits via axion-like particle models, p/d vs n EDM,…); indication of mass and coupling ranges favored by current observations (DM amount, experimental&astrophysical hints, …); general suggestions for possible extension of the PBC projects discovery reach.*

Project-oriented Documents

Experiments contributions	Proponents	Proponents	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. ---------- Documents are also expected from the Collaborations with a level of details matched to the maturity of their project: *physics motivation; expected sensitivity; detector layout; estimated timeline and cost; Collaboration structure.* NB: these documents stay under responsibility of the Collaborations and can be the basis for possible future consideration of the projects by the SPSC and LHCC.

Complex Performance	Complex study group	Complex study group	Injector complex performance after LIU: *proton delivery through the CERN accelerator complex in view of the potential provided by LIU; intensity limitations and possible mitigation; considerations on the optimization of the delivery rates.*
BDF Comprehensive Design Study	BDF WG	BDF WG	Conceptual design of the Beam Dump Facility: *complete technical feasibility studies, layout and performance from SPS extraction to experimental hall; siting and civil engineering; interconnection to the SHiP detector and to possible additional detectors; possible longer term use as a general high-intensity facility; construction schedule and costing.*

ADDITIONAL SLIDES

More details on PBC deliverables

ACCELERATOR SUB GROUPS DELIVERABLES

Subgroups:		**Deliverable:**
Beam Dump Facility	:	Technical feasibility of BDF as input to SHiP CDS
EDM ring	:	Fully developed feasibility study incl. preliminary costing
Conventional beams	:	Study upgrades for NA62++, NA64++, COMPASS++, DIRAC++ beams
LHC Fixed Target	:	CDR putting together UA9, LHC Collimation, AFTER…
Technology	:	Evaluation of possible CERN contributions to non-acc. projects

Studies:

Complex performance	:	Performance plan in LIU era and exploration of new proton driver
AWAKE	:	Exploratory study of possible applications of AWAKE concept
NuSTORM	:	Broad outline of possible implementation at CERN
Gamma Factory	:	Exploratory study incl. initial tests

PHYSICS SUB GROUPS DELIVERABLES

Deliverables 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

BSM subgroup : SHiP/NA64++/NA62++/IAXO/LSW/EDM …

QCD subgroup : COMPASS++/μ-e/LHC-FT/DIRAC+/NA60++/NA61++ …