Weizmann Institute of Science - Tel Aviv
ICORE day - December 18, 2017
Claude Vallée (CPPM/DESY)

The Future of Particle Physics Beyond Colliders at CERN

PBC: 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 and infrastructure 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

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

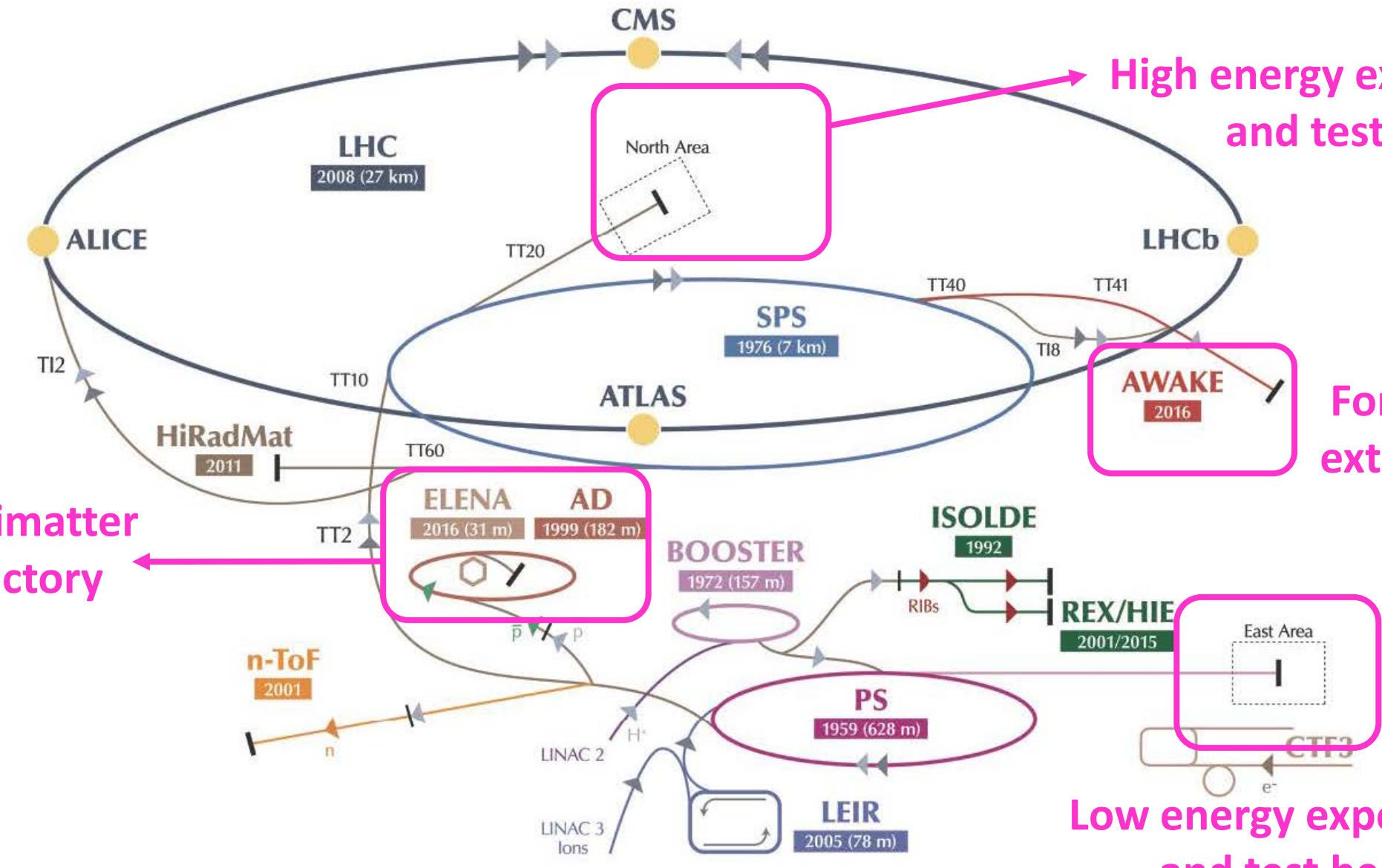
FOLLOW-UP WORKSHOP, CERN, November 21-22, 2017

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

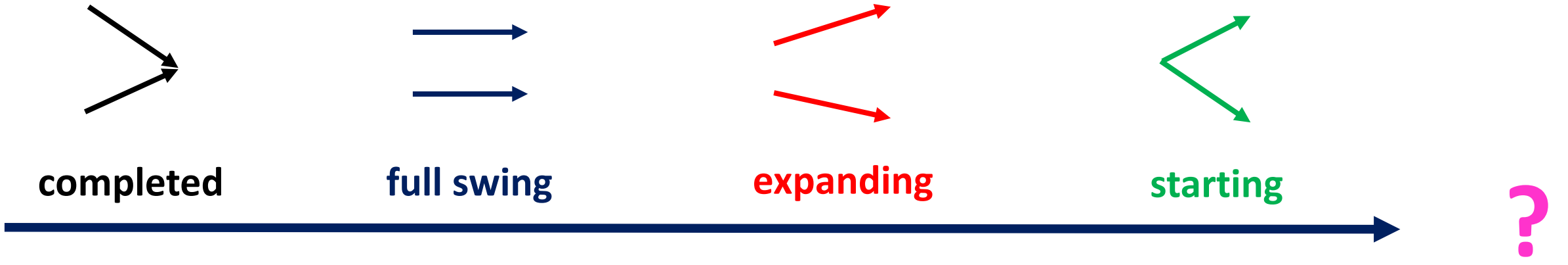
Former CNGS extraction line

Antimatter Factory

Low energy experiments and test beams

PBC BUILDS ON A DECADE OF VIBRANT "DIVERSITY" PHYSICS AT CERN !

~1000 physicists on ~20 experiments



completed	full swing	expanding	starting	PBC
CNGS (ν) DIRAC (QCD)	COMPASS (QCD) NA61 (QCD)	ANTIMATTER FACTORY (CPT)	NA62 & NA64 (BSM) ν Platform (det. R&D) AWAKE (acc. R&D)	

…+ CAST, OSQAR, etc…

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

1) Non-accelerator projects

2) Long term large facilities

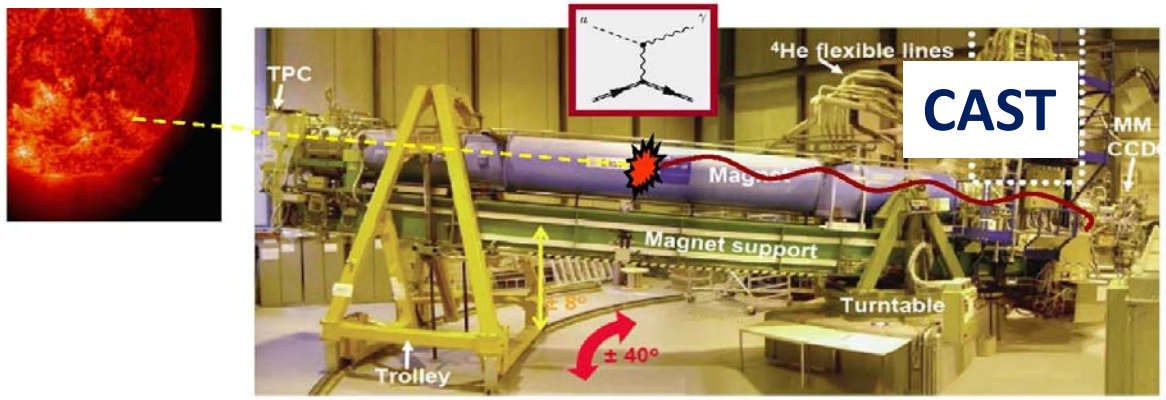
3) Antimatter factory

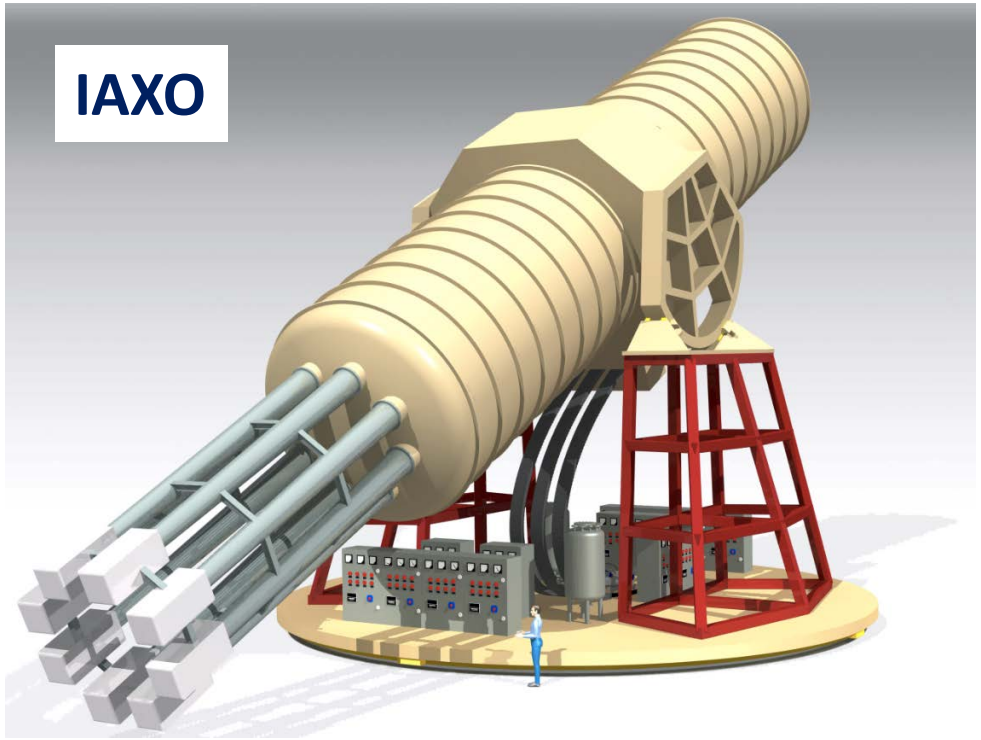
4) QCD Fixed Target

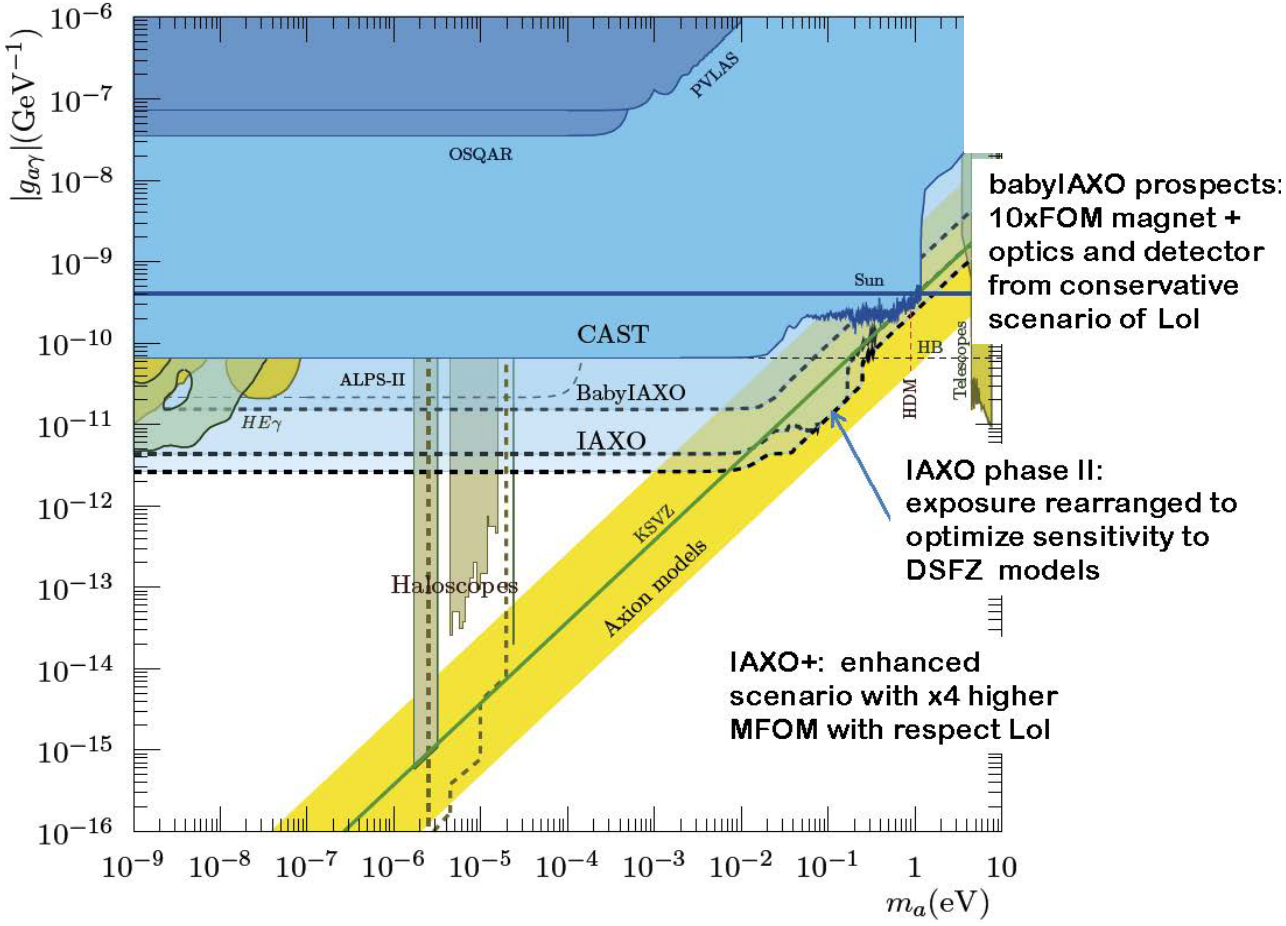
5) BSM Fixed Target

Solar Axions: IAXO

Next generation Axion Helioscope beyond CAST





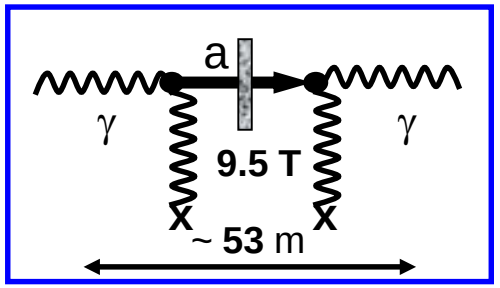


Will profit from CERN magnet expertise for babyIAXO and proposal preparation

Main IAXO issues: Collaboration strengthening and helioscope siting (DESY option)

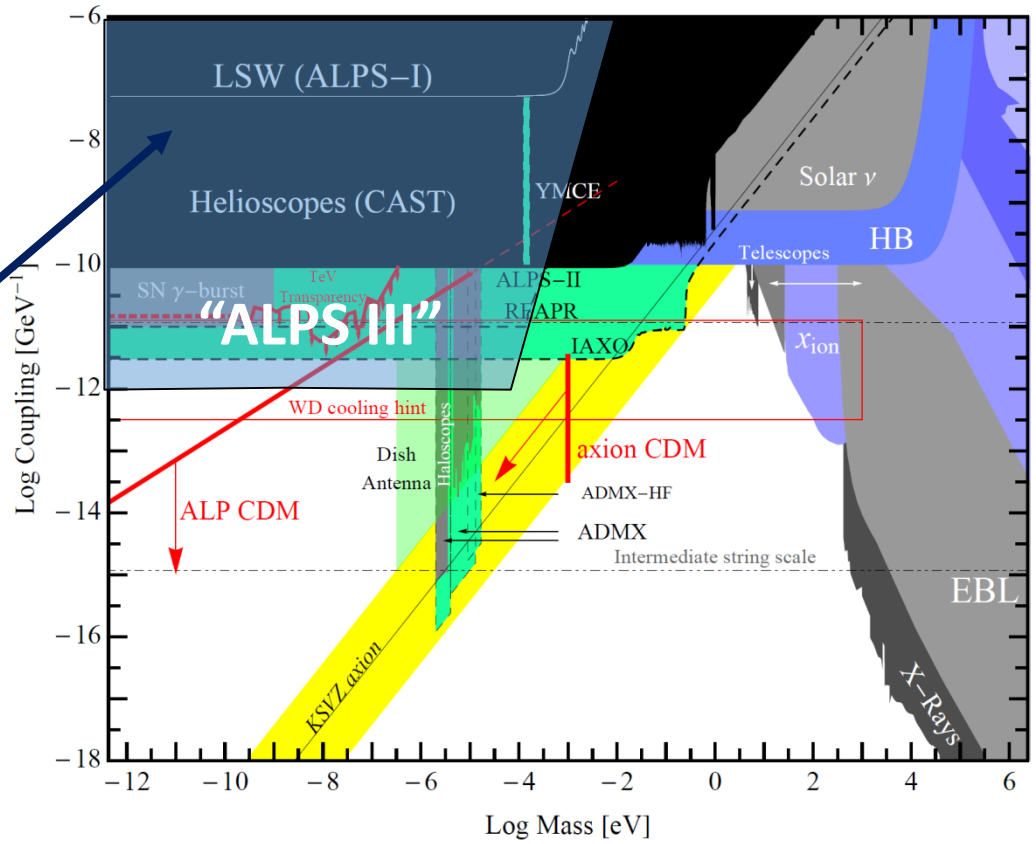
Laboratory Axions: "ALPS III"

Light shining through a wall



Comparable limits obtained by OSQAR@CERN and ALPS@DESY

ALPSII@DESY under construction

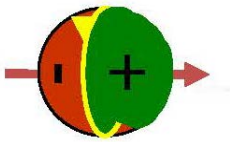


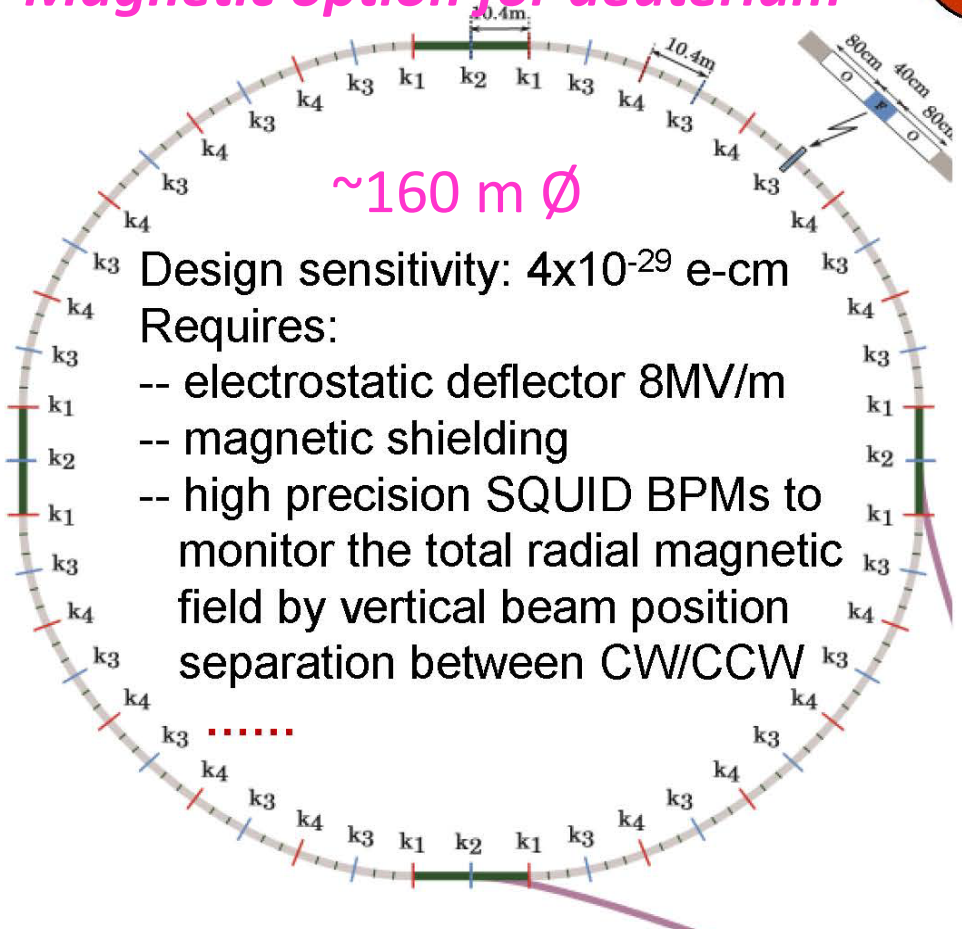
Dipole	Aperture [mm]	Field strength [T]	LSW experiment	Number of used dipoles
HERA (straightened)	50	5.3	ALPS II (DESY)	20
LHC	40	9.0	OSQAR (CERN)	2
"FCC"	100 (40)	13 (20)	"ALPS III"	

A combined project ("ALPS III") could benefit from CERN high field magnet developments

Storage Ring for proton/deuterium EDM

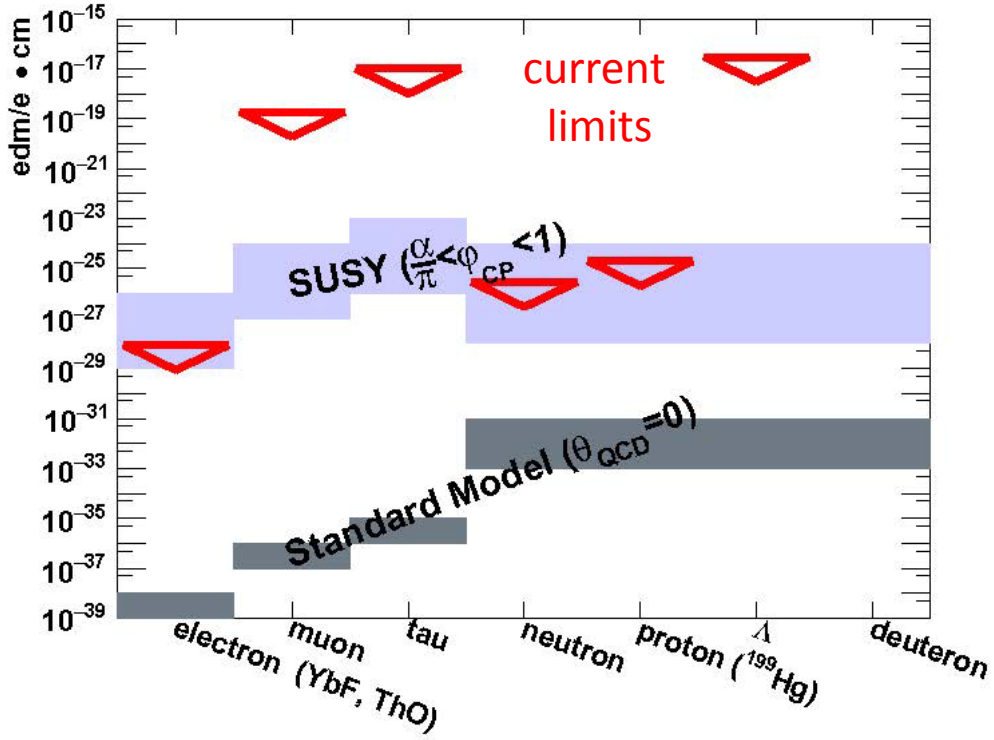
Electrostatic option for proton
Magnetic option for deuterium





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



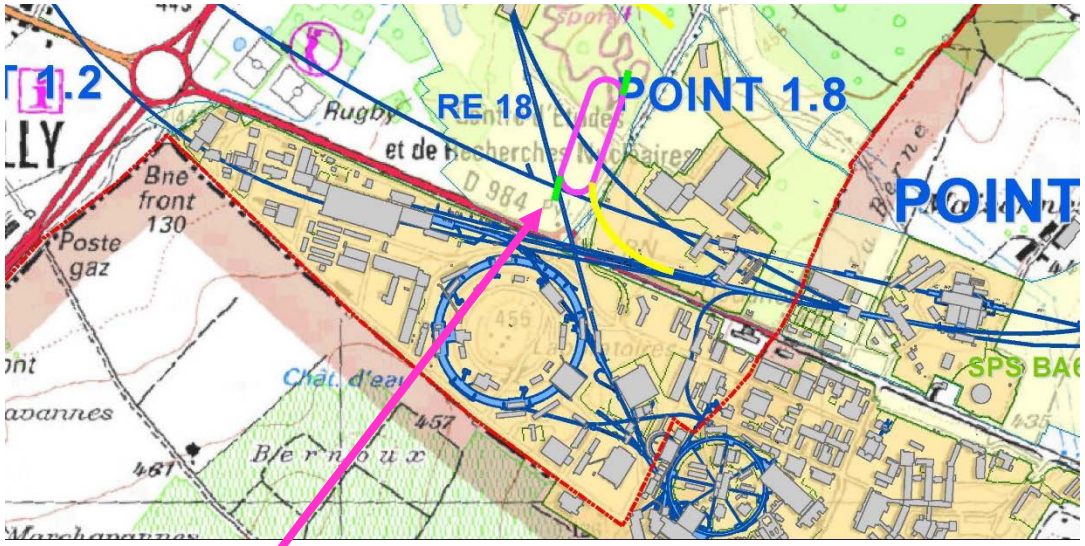
Ring design ongoing by CERN with srEDM and JEDI collaborations

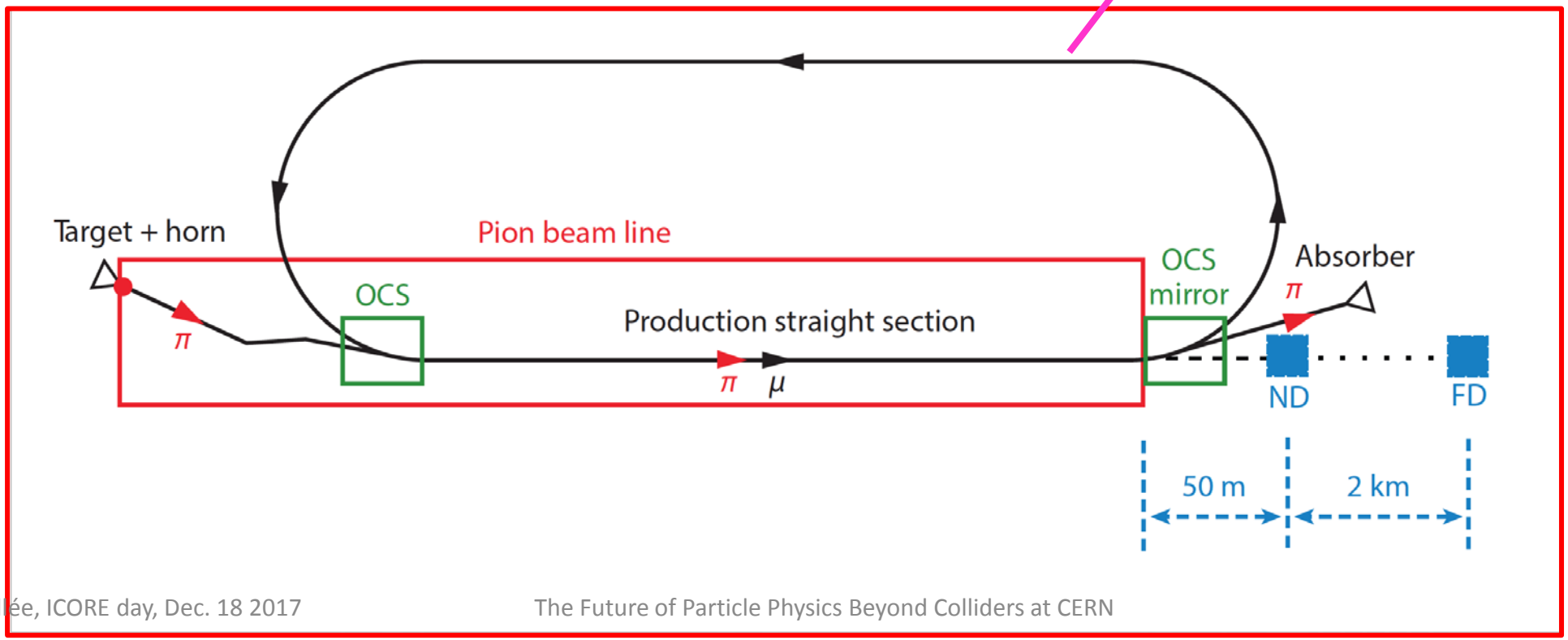
<u>Main issue</u>: control of systematic effects (e.g. B fields)

NuSTORM

Well controlled ν beam from a μ storage ring.

Would allow precise σ(ν) measurements.
Also a path towards a ν factory or a μ collider.

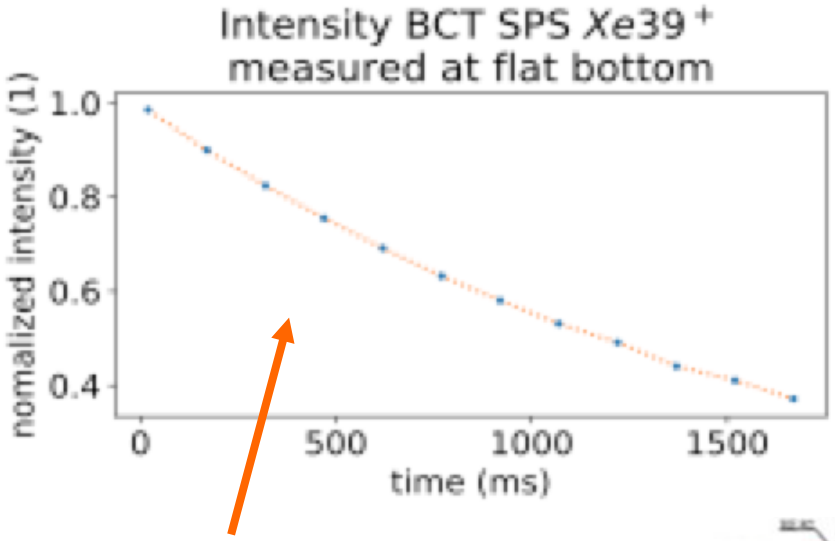




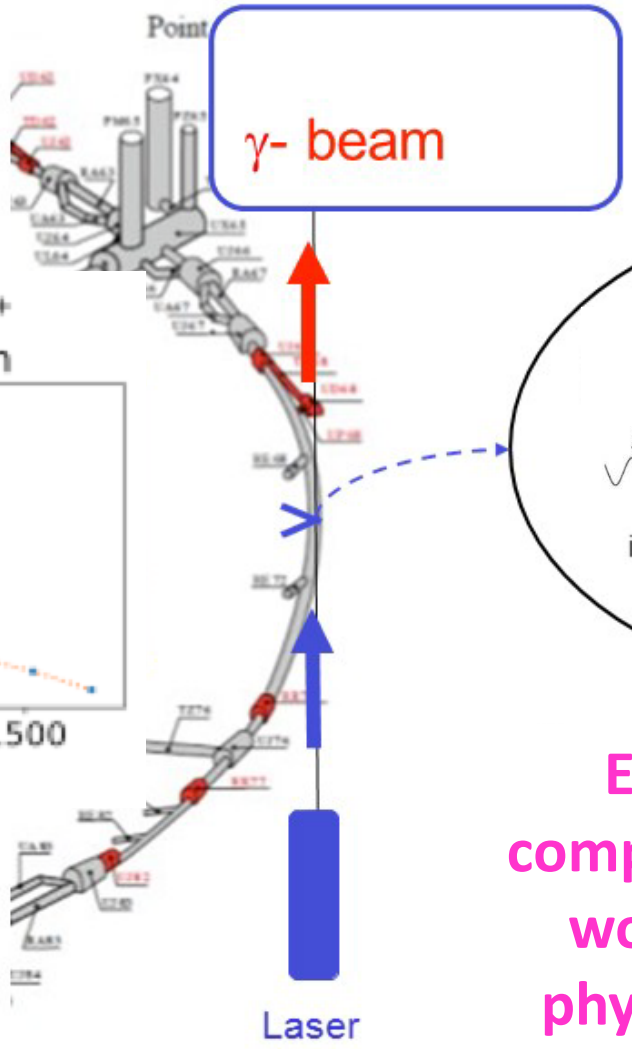
New idea: Gamma Factory

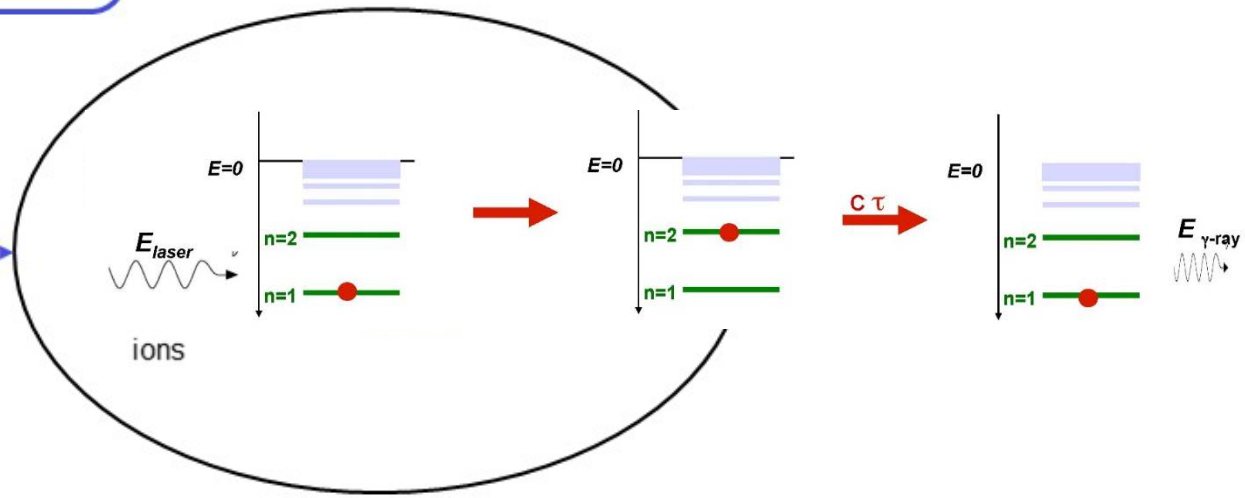
Use LHC beam to convert laser photons into 0.1 - 400 MeV γ rays

LHC filled with Partially Stripped Ions

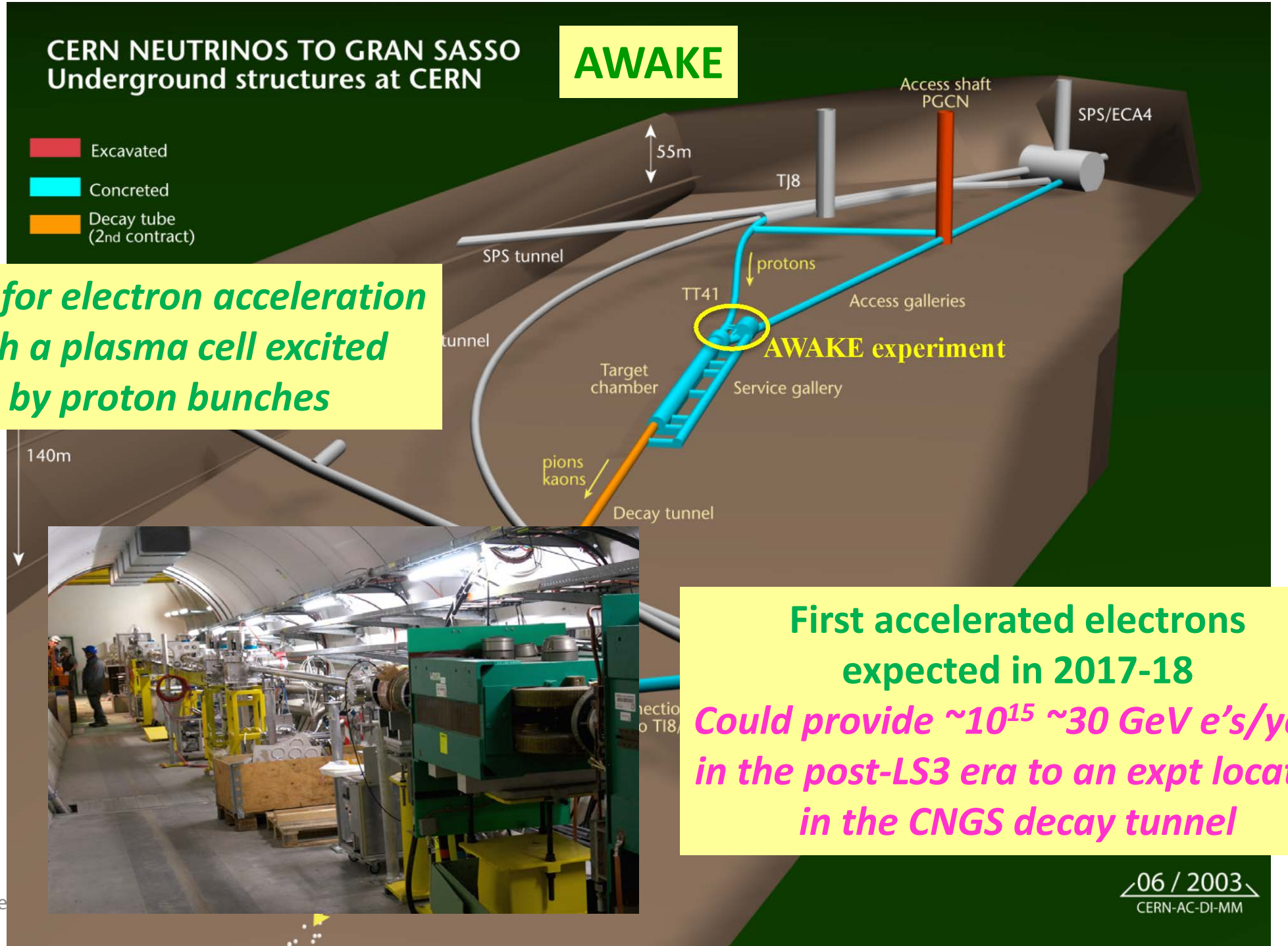


NB: encouraging lifetime > 1s measured in SPS for 39+Xe PSI





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.



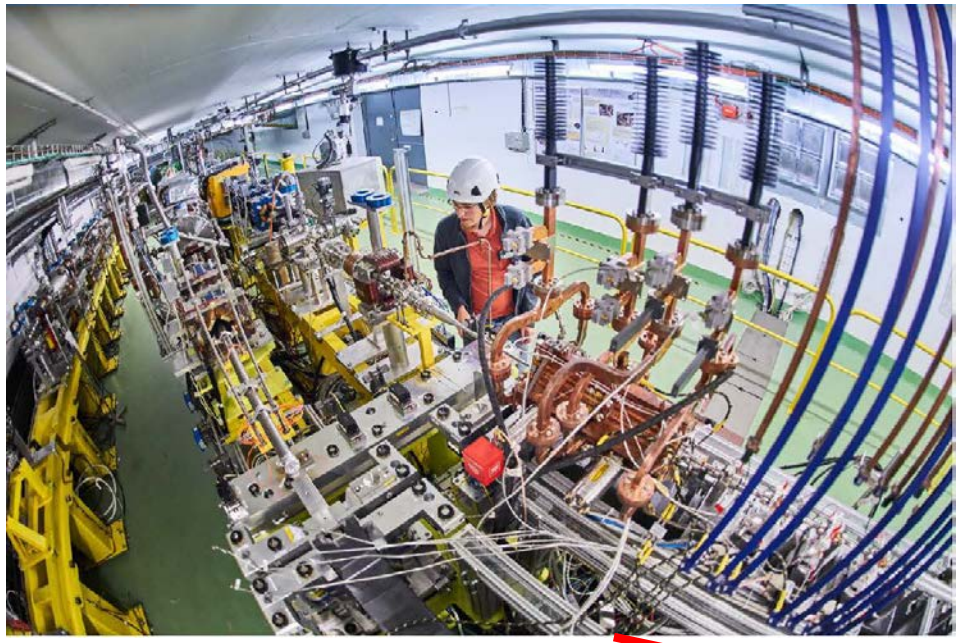
R&D for electron acceleration with a plasma cell excited by proton bunches

First accelerated electrons expected in 2017-18

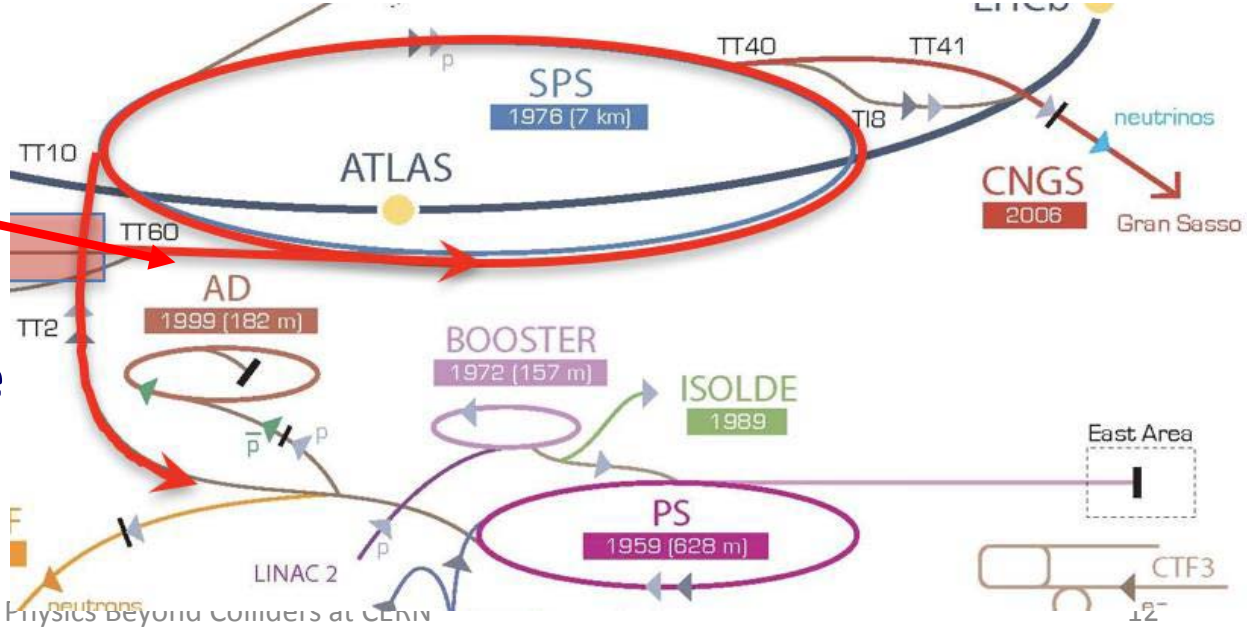
Could provide ~10^{15} ~30 GeV e's/year in the post-LS3 era to an expt located in the CNGS decay tunnel

New idea: CLEAR++

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



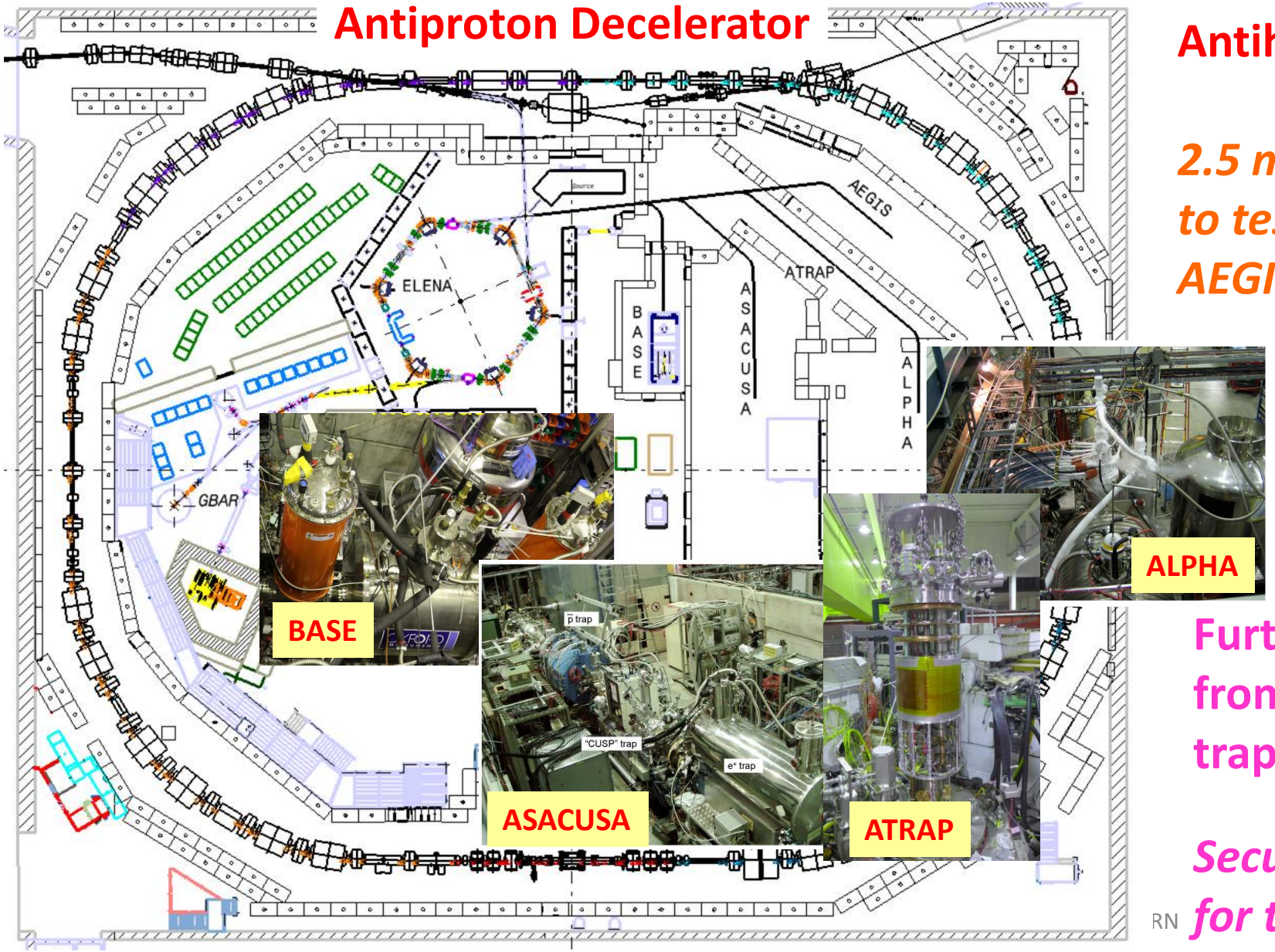
Would provide a unique testbed for R&D on linear acceleration techniques



Slow extraction from SPS would allow hidden sector searches in the invisible mode (~10^{16} e/year to expts à la NA64/LDMX)

ANTIMATTER FACTORY

Antiproton Decelerator



4 running experiments devoted to Antiproton and Antihydrogen Properties

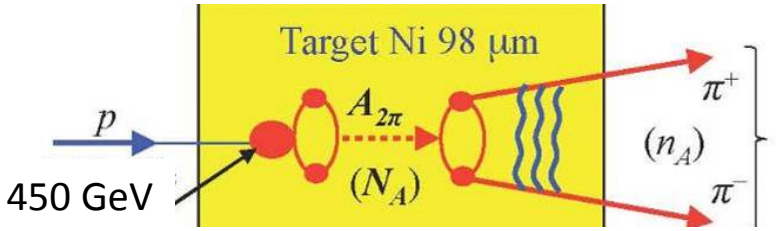
2.5 more in preparation to test gravity of Antihydrogen: AEGIS/GBAR/ALPHA-g

AFTER LS2:* ELENA *(under commissioning)

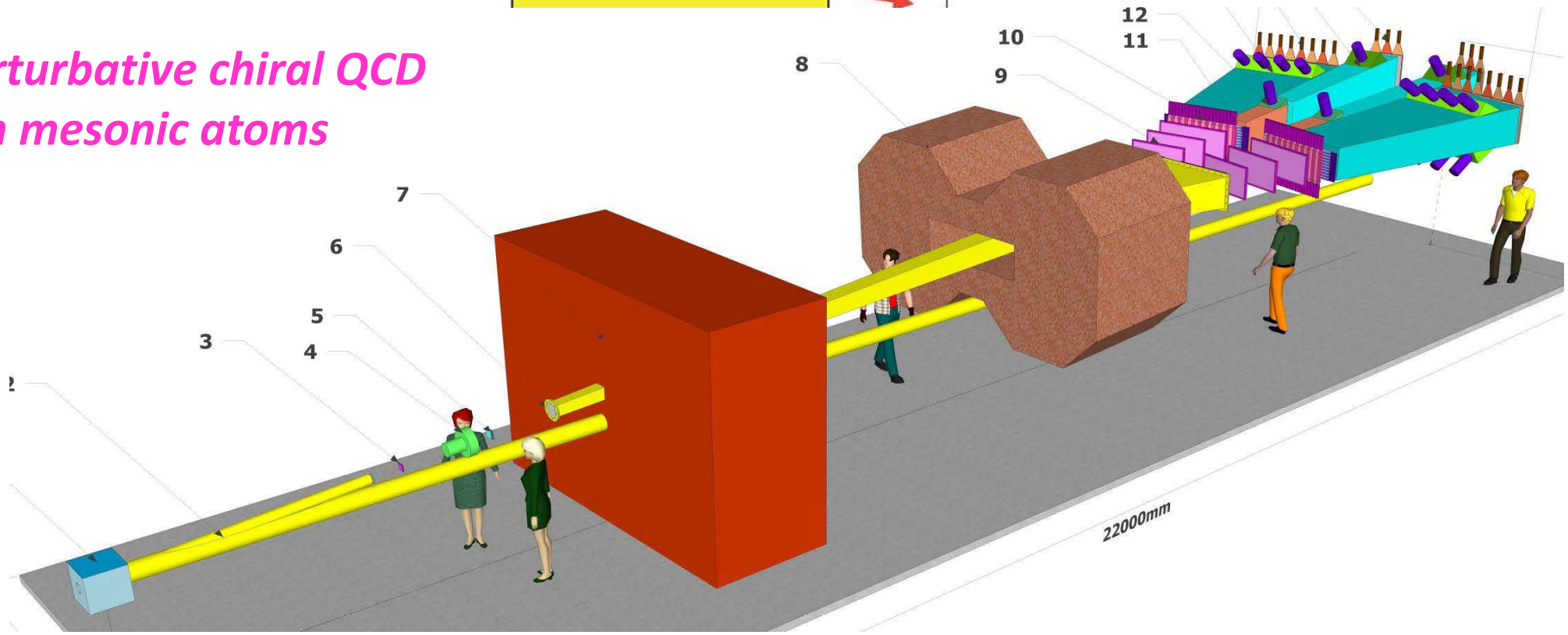
Further deceleration of pbar from 5 MeV to 100 KeV → trapping efficiency x ~100

Secures antimatter physics for the next decade

DIRAC@SPS

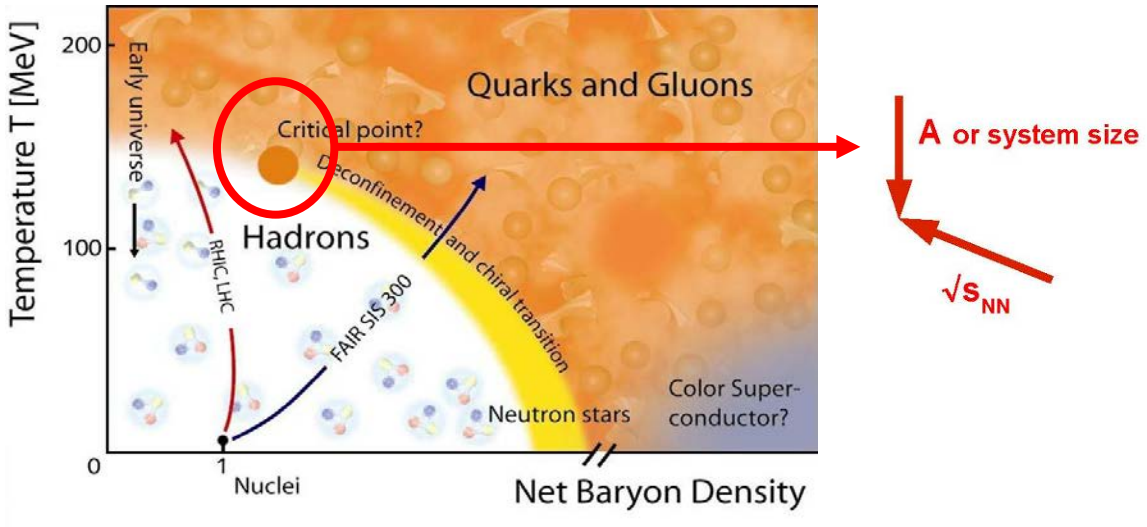


Low E perturbative chiral QCD with mesonic atoms



Improved statistics at SPS (~PSx20) would allow precision measurement of πK atoms for quantitative test of chiral $SU(3)_L \times SU(3)_R$ symmetry breaking

<u>Main issues</u>: siting at CERN and strength of Collaboration

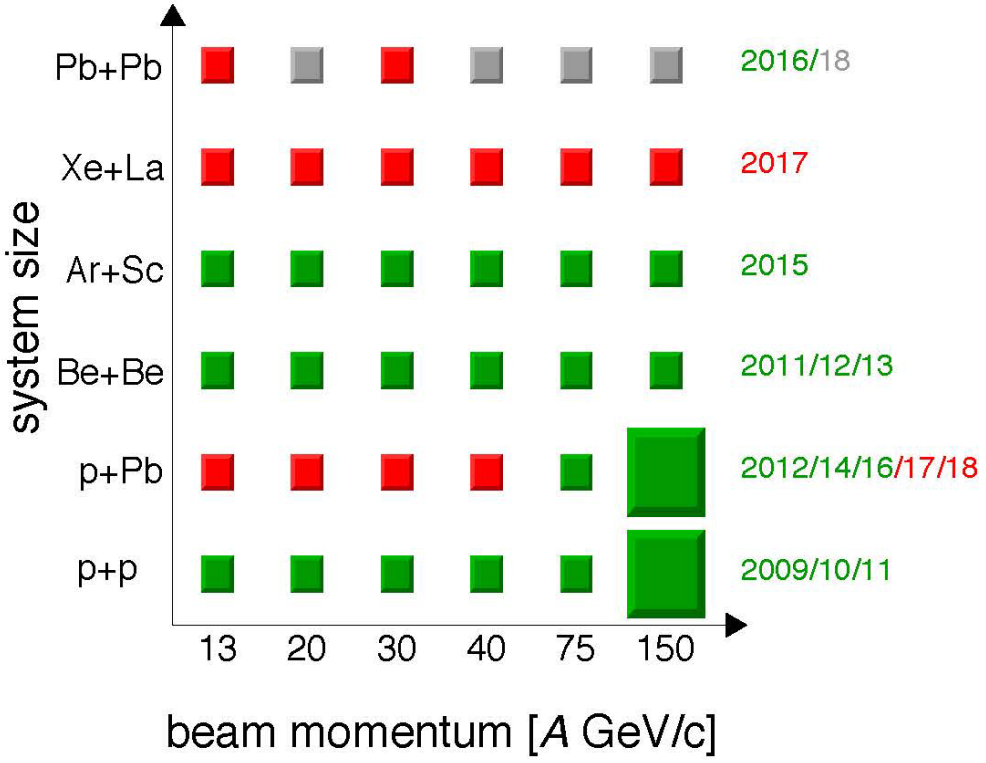


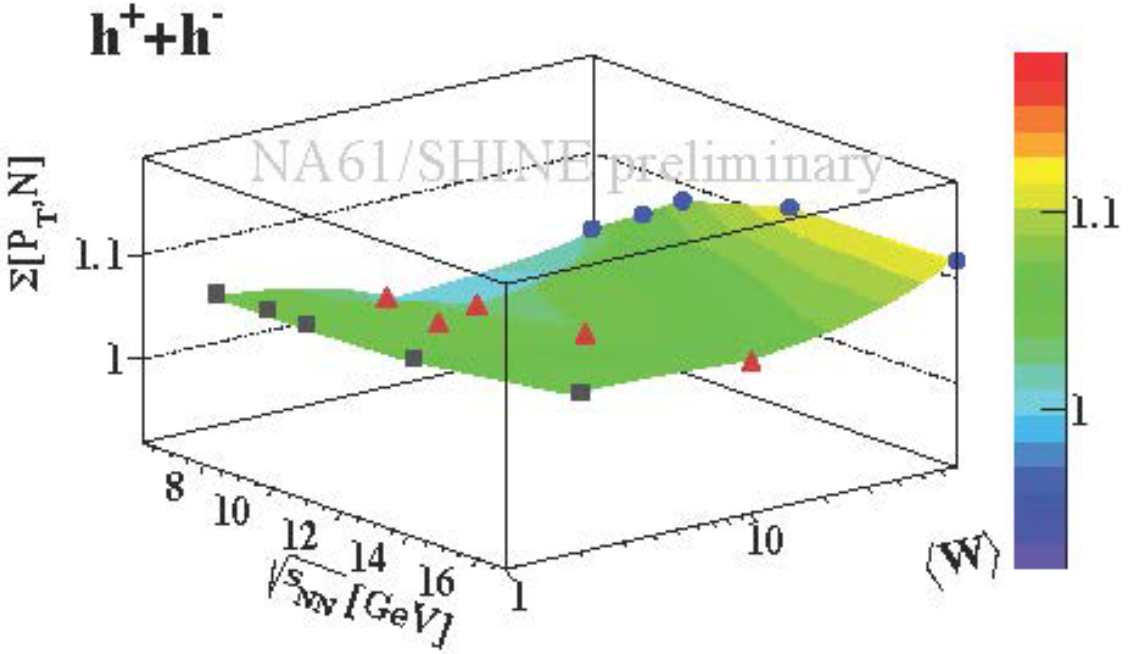
NA61/SHINE

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

Scan to be completed until LS2

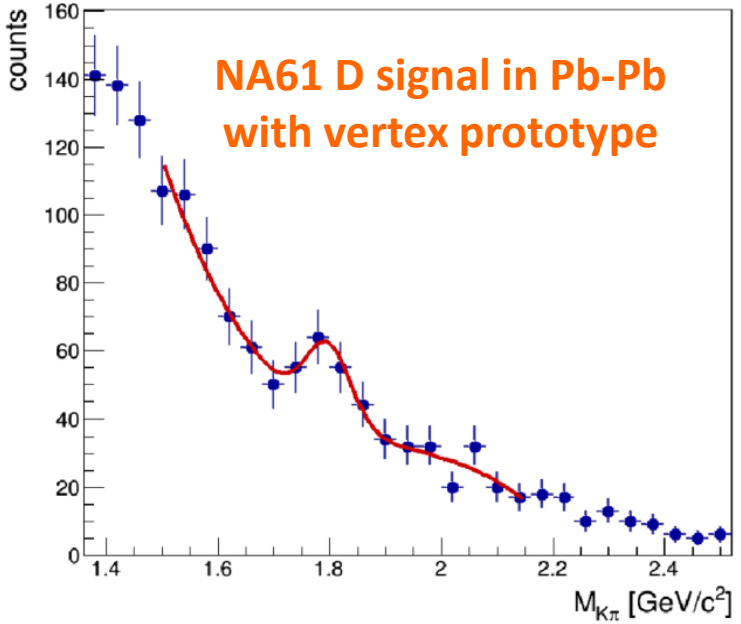
No indication of CP yet



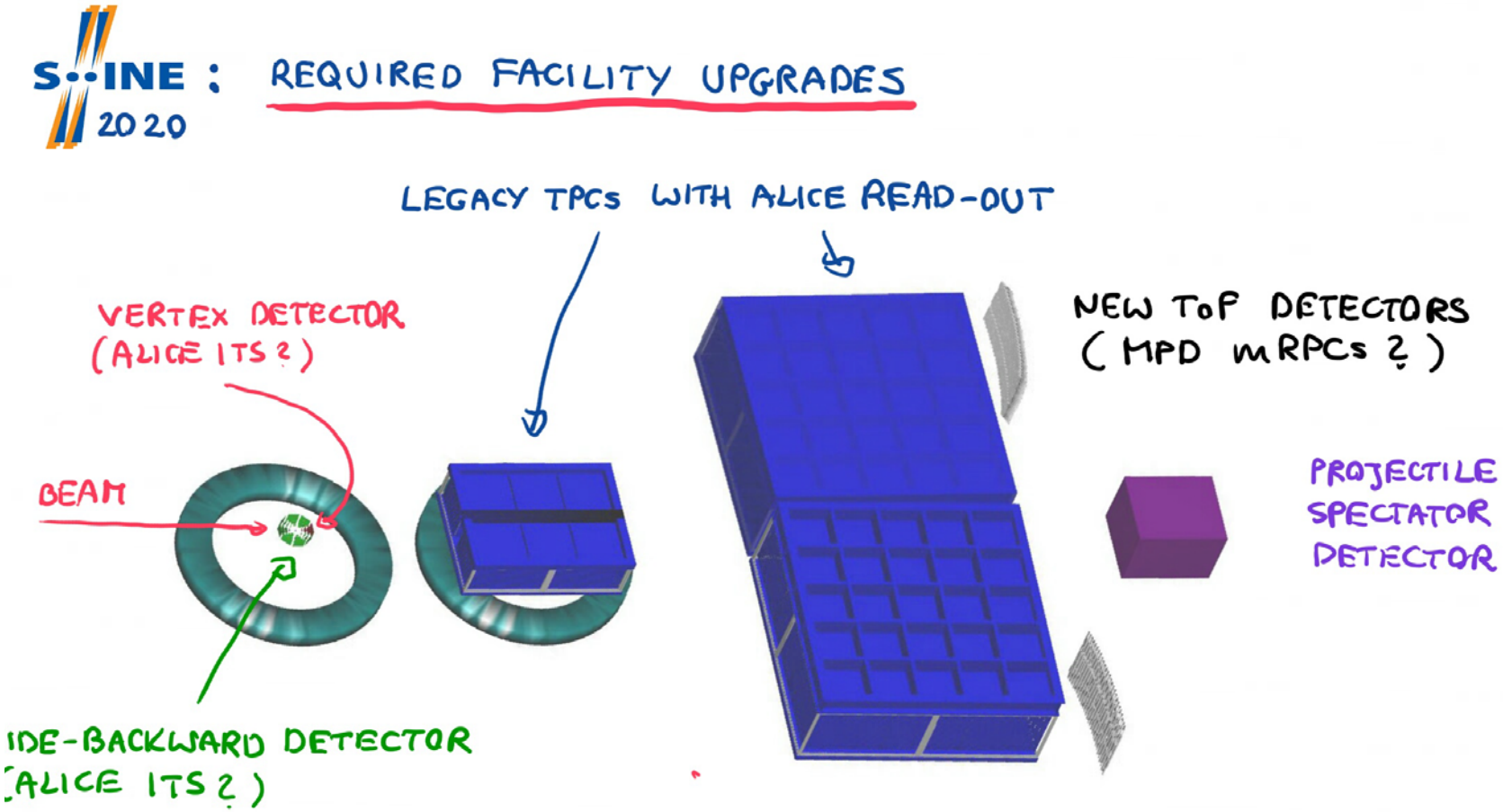


NA61/SHINE

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



NA61 D signal in Pb-Pb with vertex prototype



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

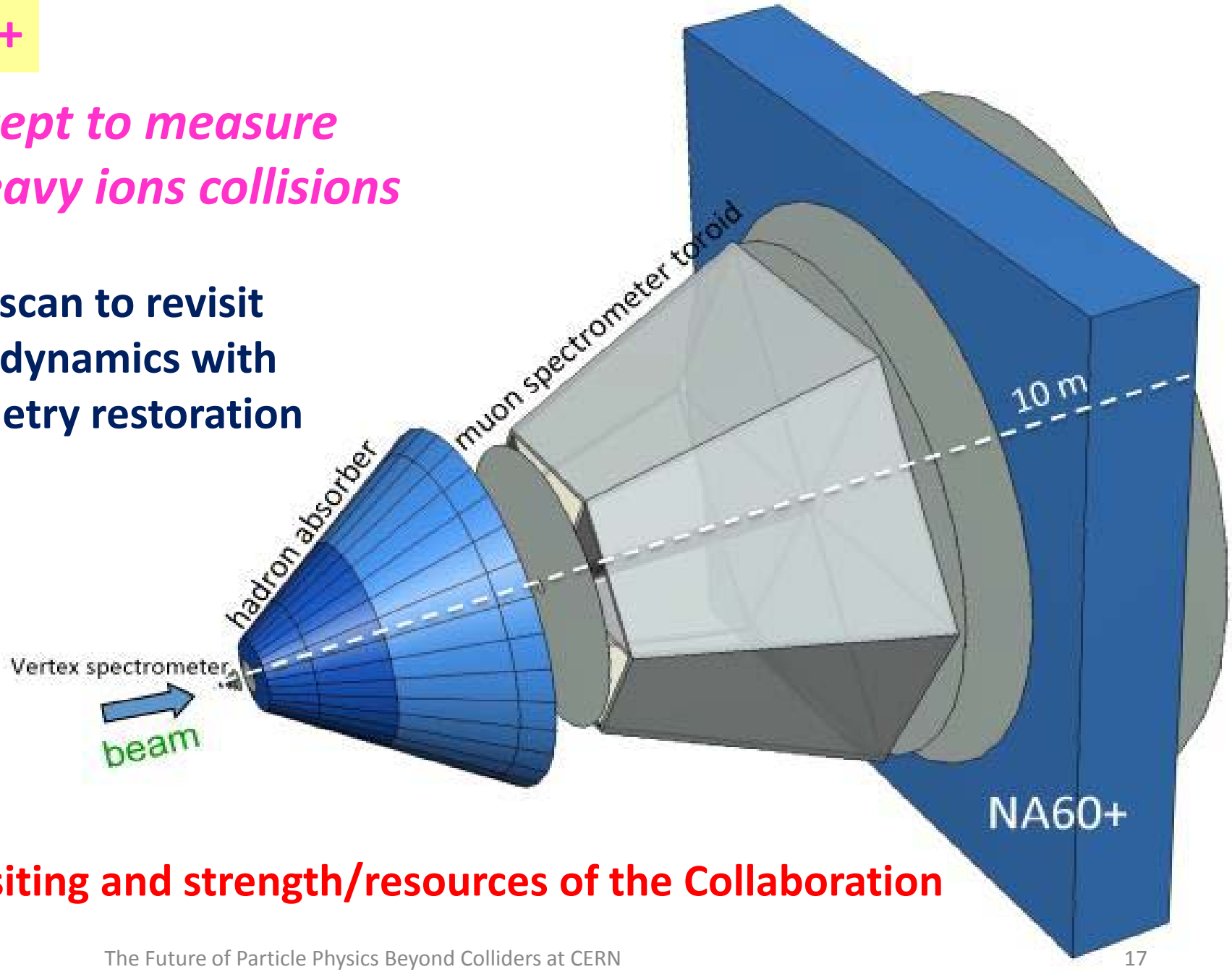
Main issues: factor 10 increase in beam intensity and high rate data taking

NB: NA61 large acceptance TPC still unique after LS2 to constrain ν beam fluxes

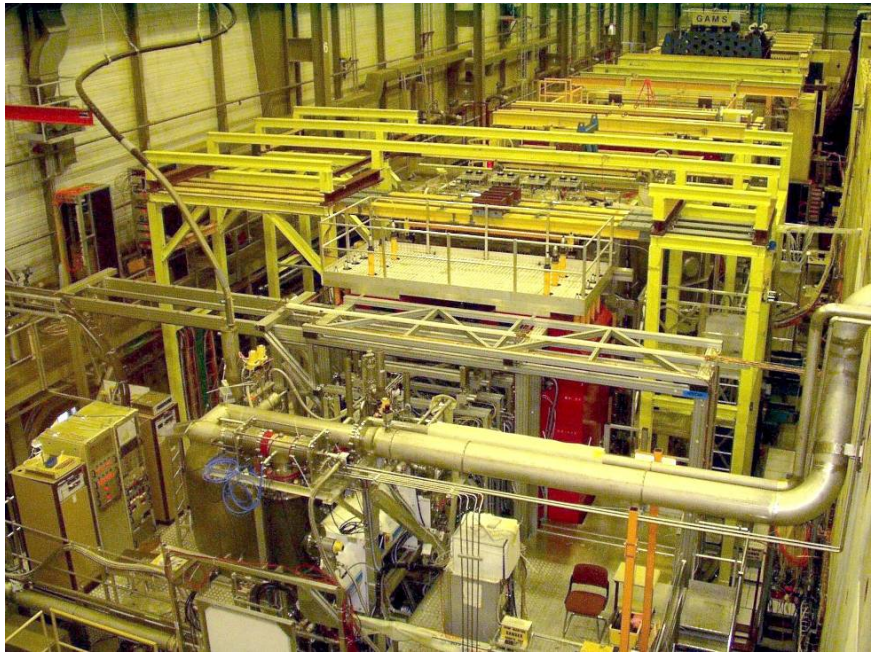
NA60++

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

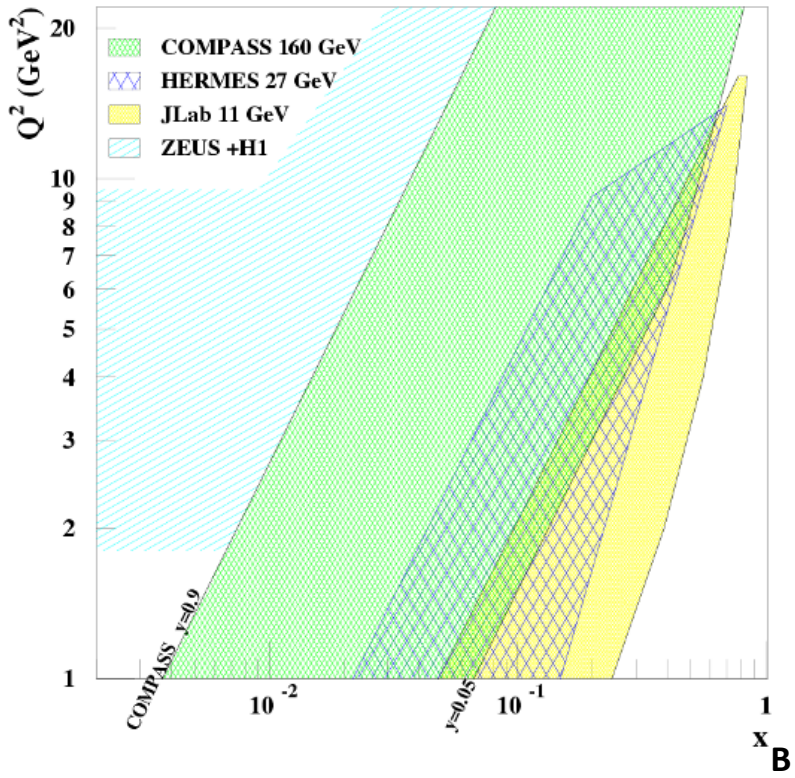


<u>Main issues</u>: Experiment siting and strength/resources of the Collaboration



COMPASS

a large acceptance spectrometer in the intermediate x-domain between H1/ZEUS and HERMES/JLAB

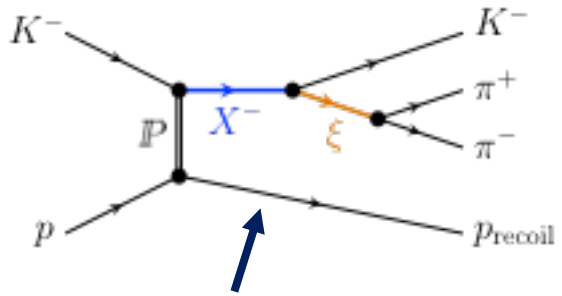


COMPASS I (< 2012): Spin content of the proton constituents with polarized DIS

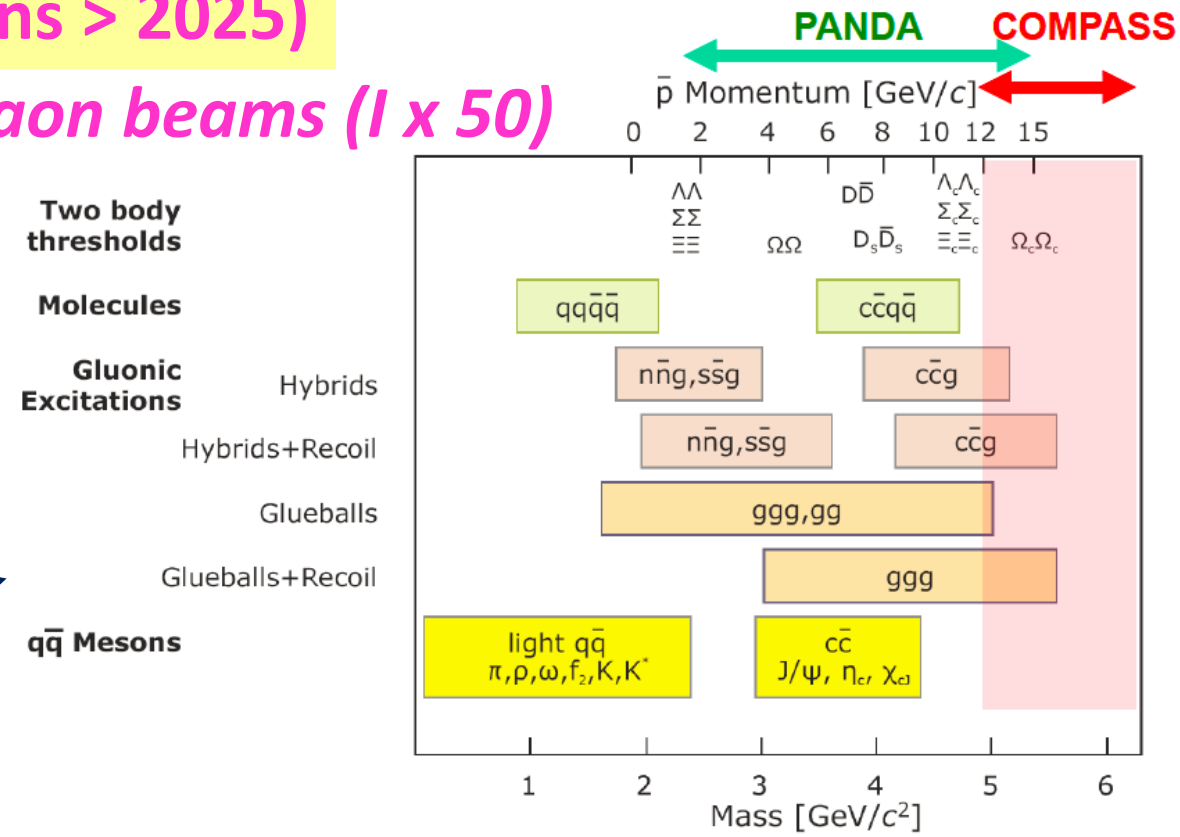
COMPASS II (2014-18): Orbital momentum with DVCS
TMD effects with polarized DY

COMPASS++ (long term plans > 2025)

Wish RF separated antiproton and kaon beams (I x 50)



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



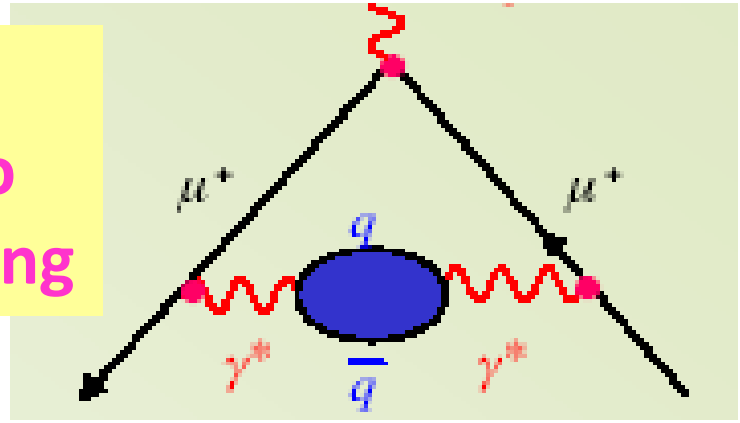
DY statistics	NH_3	Al (7cm)	W	NA3	NA10	E537	E615
K^- beam	14,000	2,800	29,600	700			
$\bar{p}$ beam	15,750	2,750	22,500			387	

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

→ Shorter term LS2↔LS3 program under definition

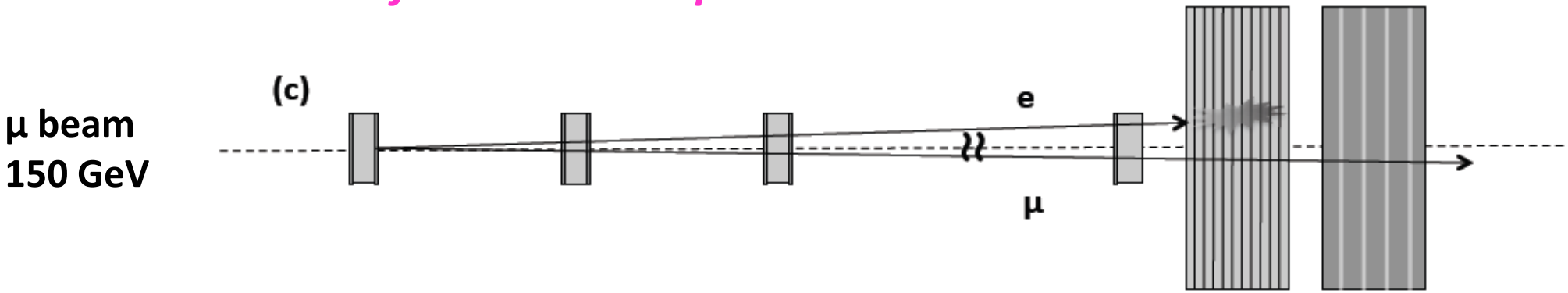
MUonE

Direct measurement of the dominant contribution to the theoretical error on $(g-2)_\mu$ from μ-e elastic scattering



Vacuum polarisation

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

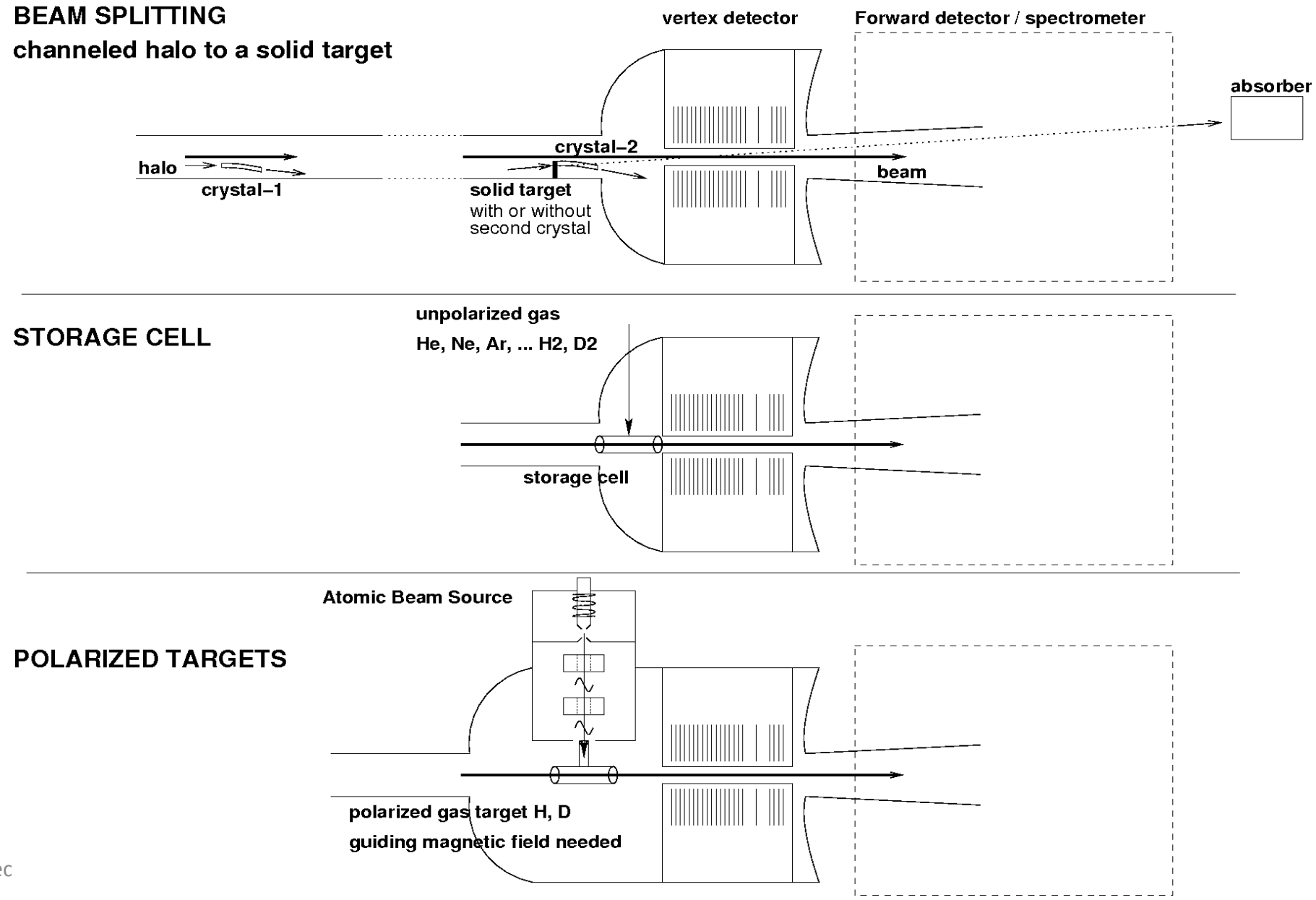


Full t range accessible thanks to high energy μ beam boost, self normalized measurement
Might be feasible with reasonable resources within the (modified) COMPASS setup

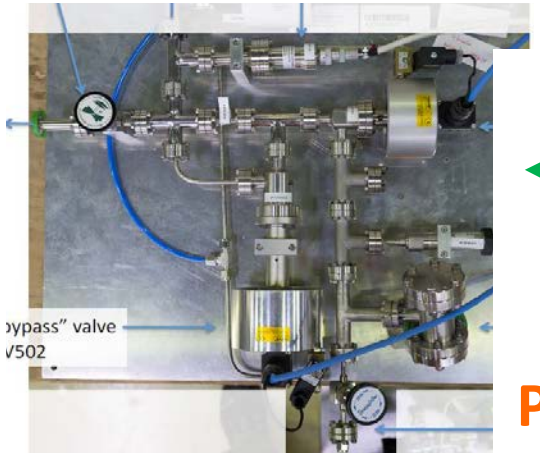
<u>Main issue</u>: systematic effects (control needed at 10^{-5} level)

Fixed Target physics with LHC beams

3 options under study



LHC Fixed Target: ongoing studies



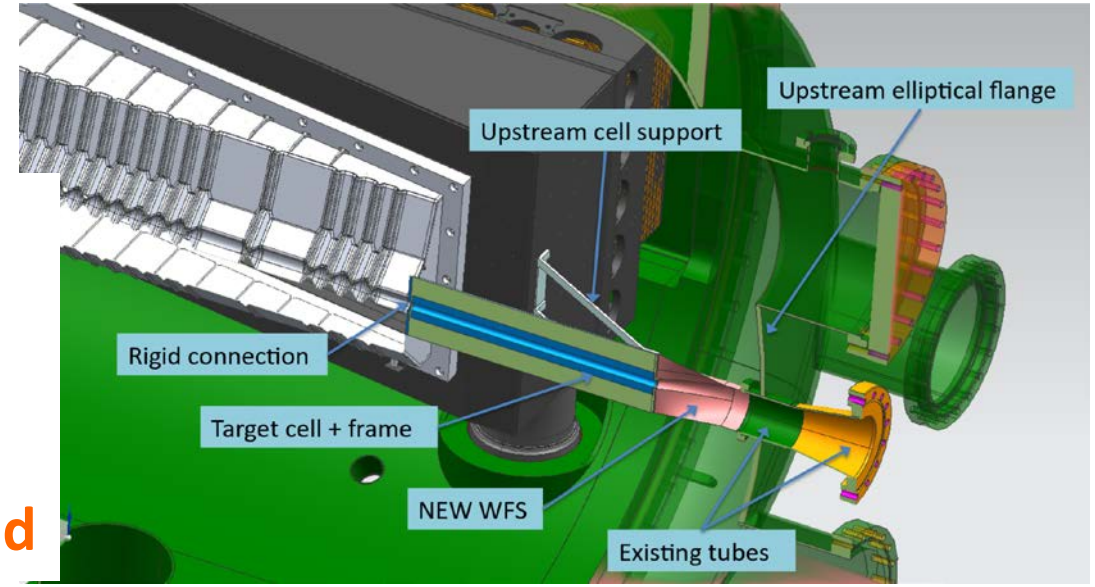
LHCb:

← SMOG jet target operated.

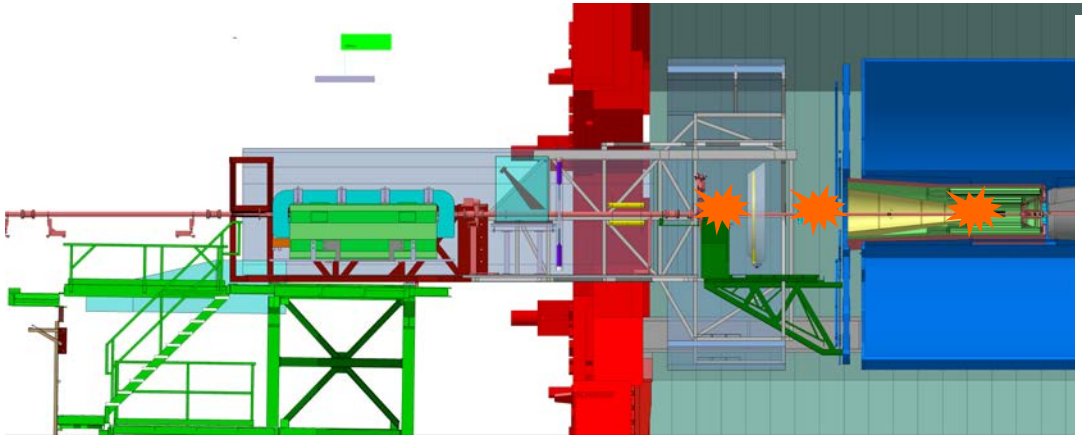
SMOG2 storage cell →

under design (lumi x ~100).

Polarized target also considered

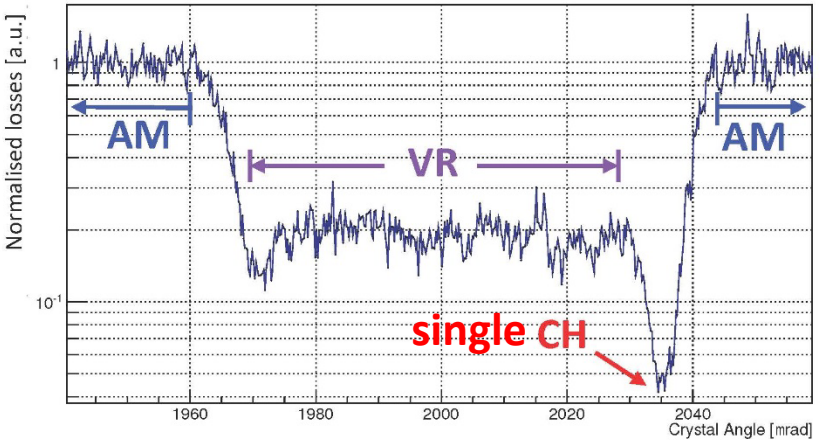


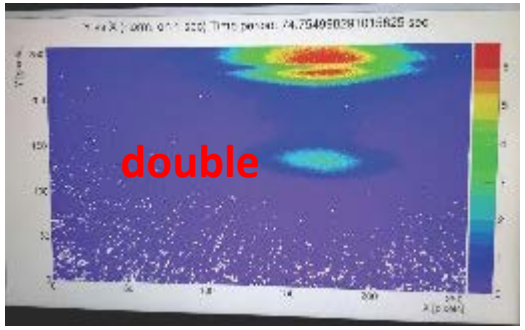
ALICE: several options under consideration



CRYSTAL:

single and double channeling observed (UA9)





Main issue of LHC internal fixed targets: compatibility with other LHC programs/goals

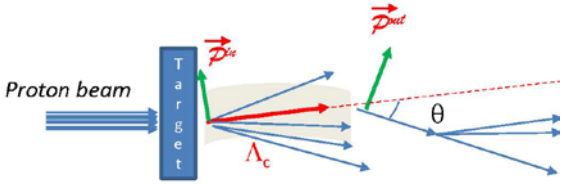
LHC Fixed Target: physics reach

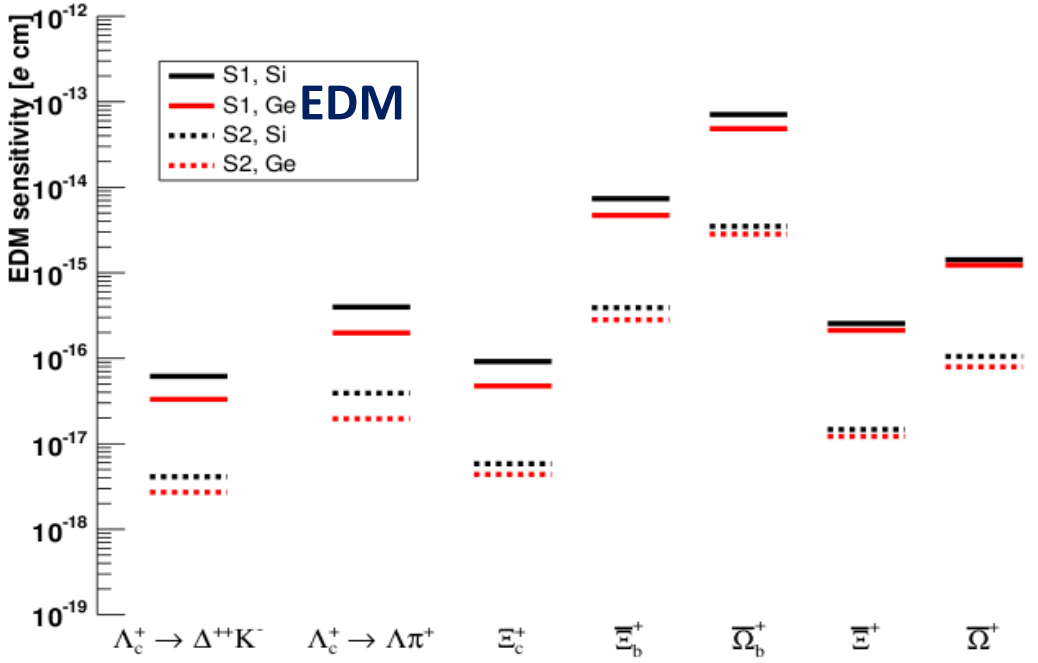
Crystal extraction:

Magnetic and electric moments of short lived baryons

Could test anomalous moments of heavy quarks

$$\frac{dN_i}{N_{0i}\, d\cos\theta_i} = \frac{1}{2}(1+\alpha P_i \cos_i\theta_i)$$



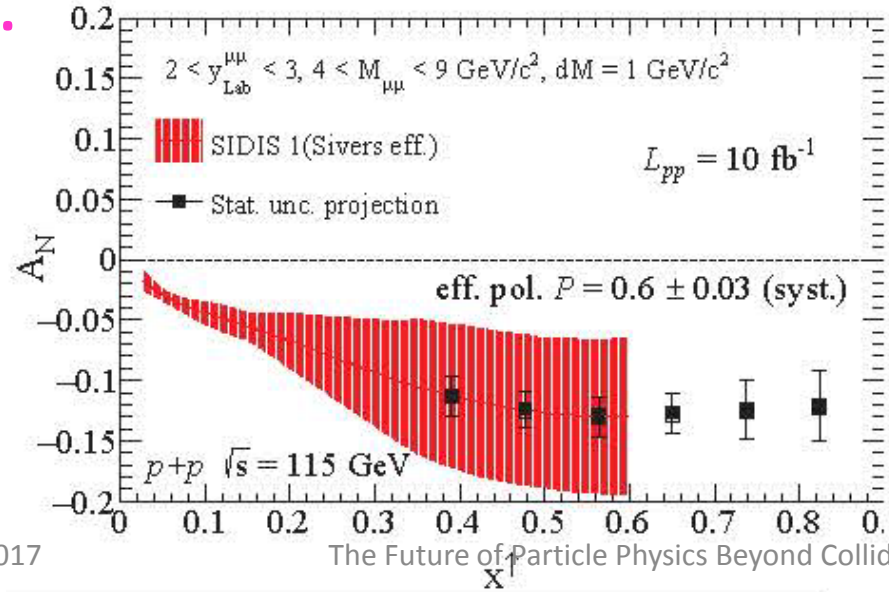


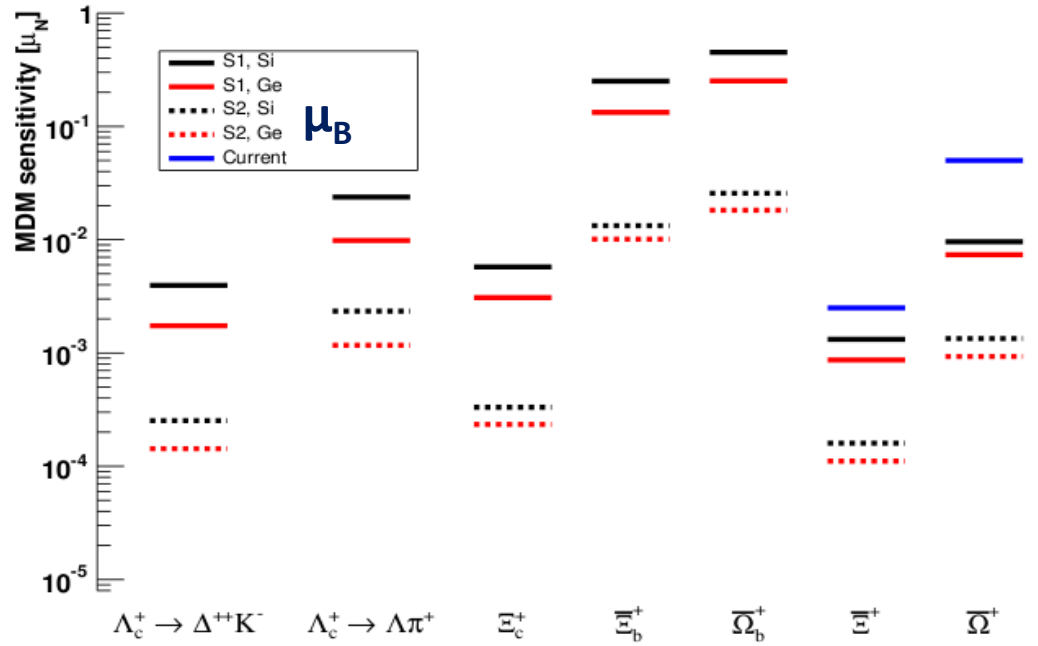
Gas target:

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

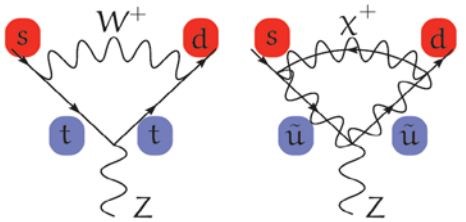




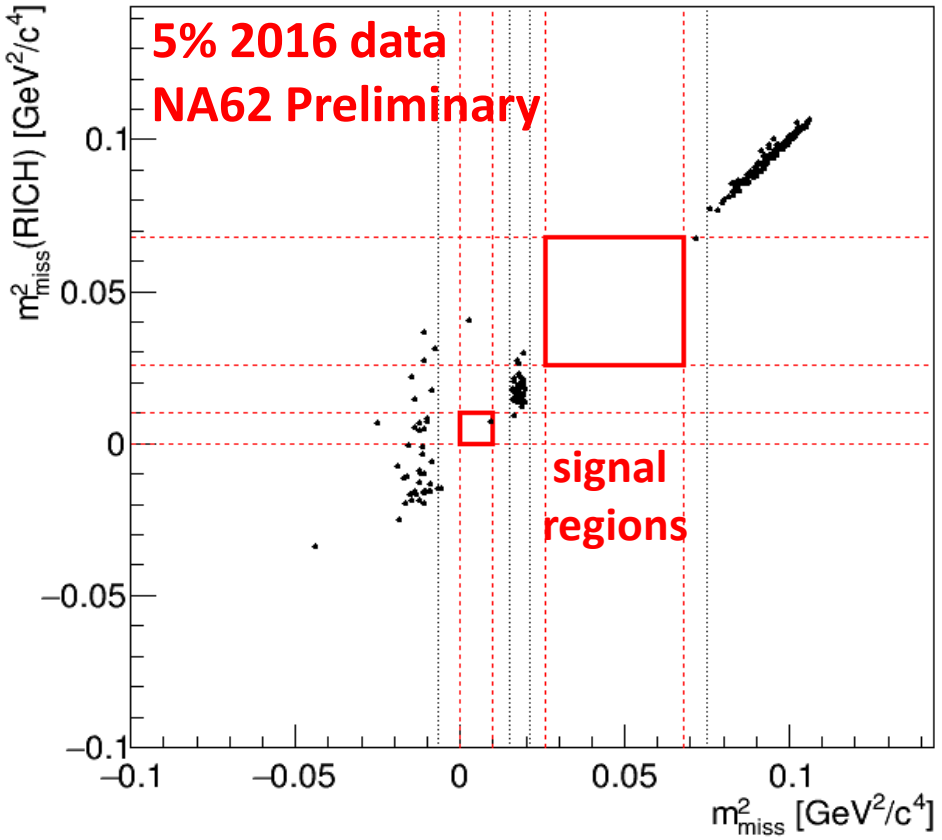
$K \to \pi\nu\bar{\nu}$ (BR ~ 10^{-10})

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

Extension to other rare decays: KLEVER ($K^o \to \pi^o\nu\nu$)

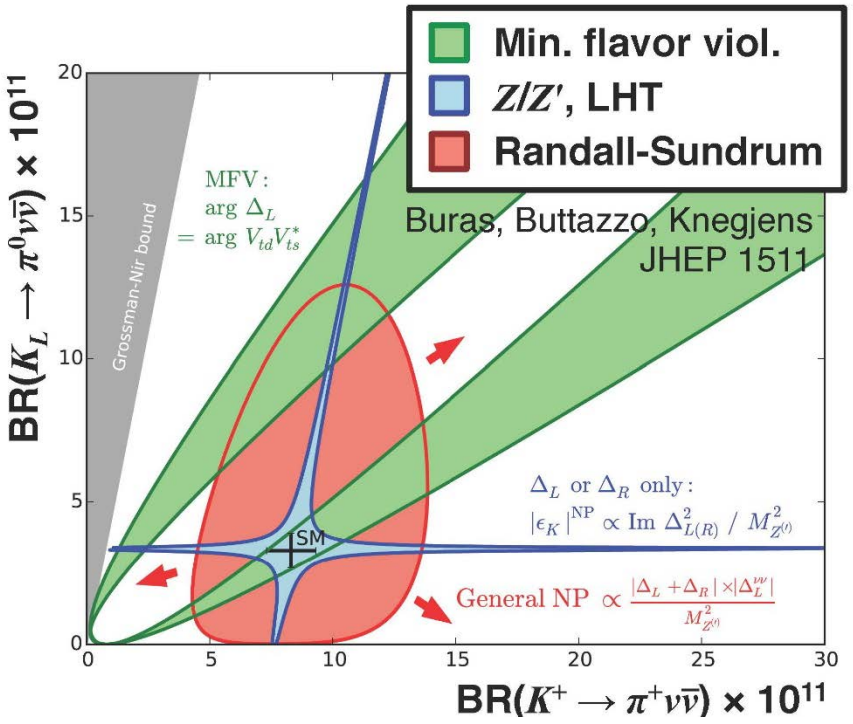
K^0 decays complementary to K^+ decays for the CKM matrix and BSM searches.

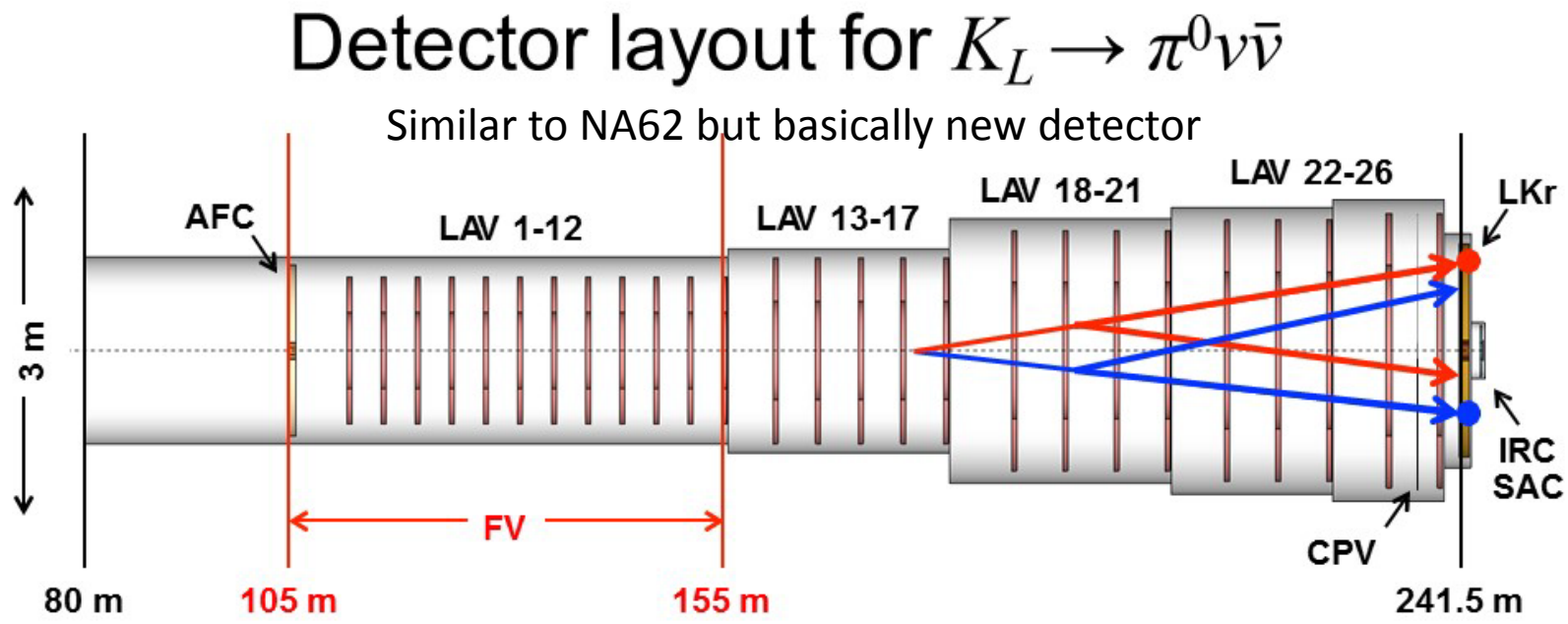
Would require a new high intensity K^o beam.

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

Competition from starting KOTO at JPARC:

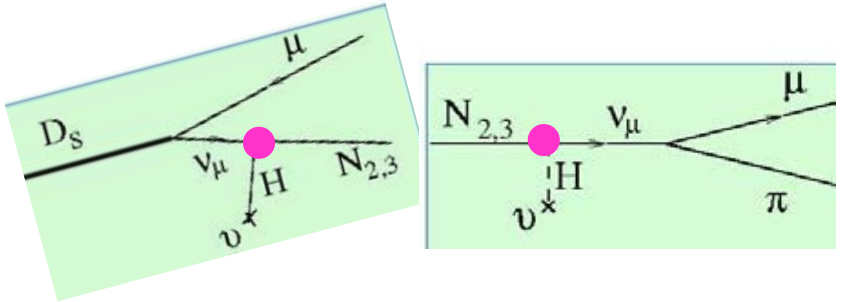
few events expected in coming years, upgrade by factor ~10 foreseen > 2025



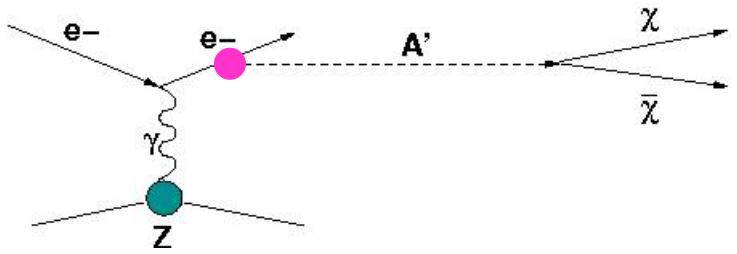


<u>Main issues</u>: actual sensitivity vs competition, cost of new beam and upgraded detector

Exploration of the Hidden Sector



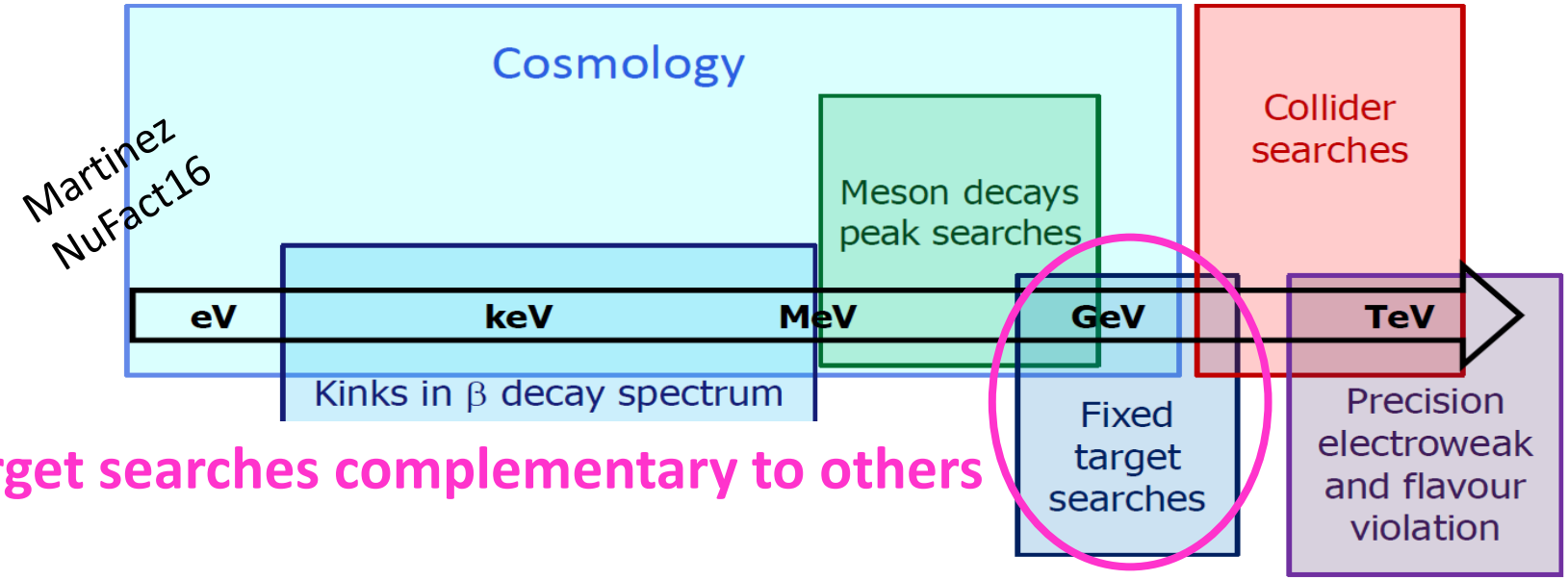
2 methods



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 !

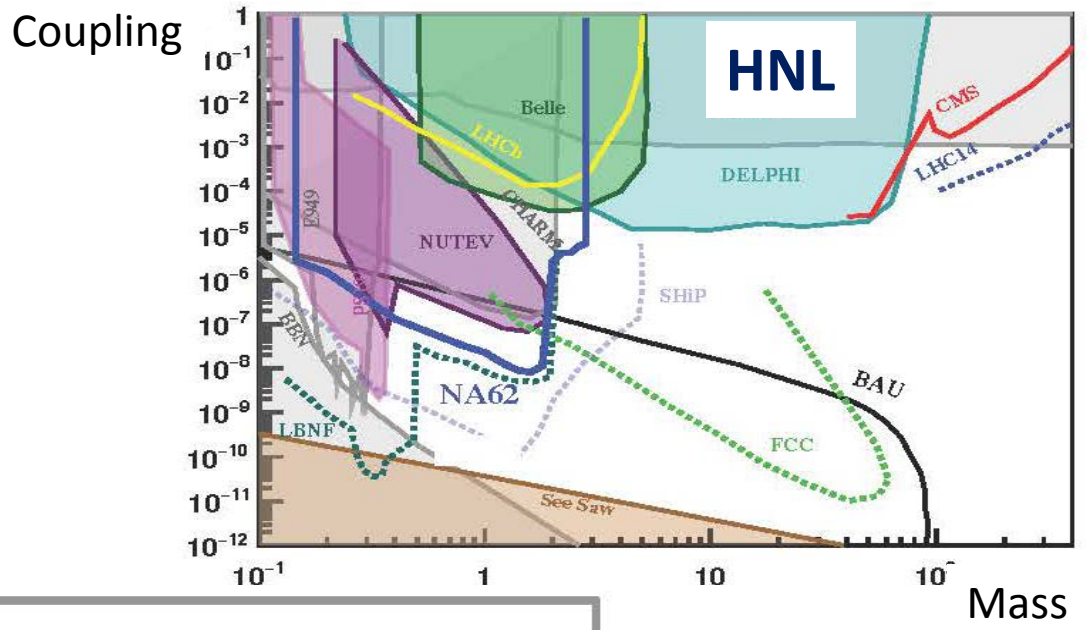


Fixed Target searches complementary to others

AFTER LS2 : NA62++

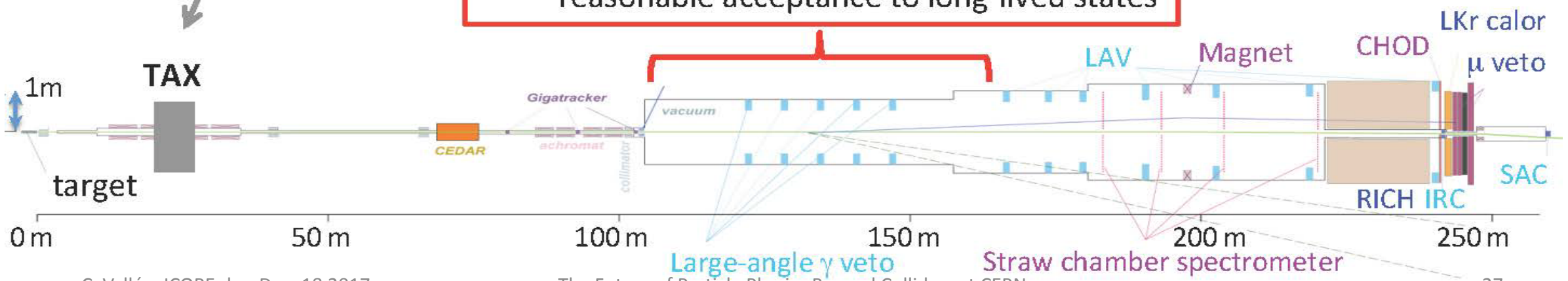
Wish to run ~1 year in beam dump mode to look for Heavy Neutral Leptons

→ 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

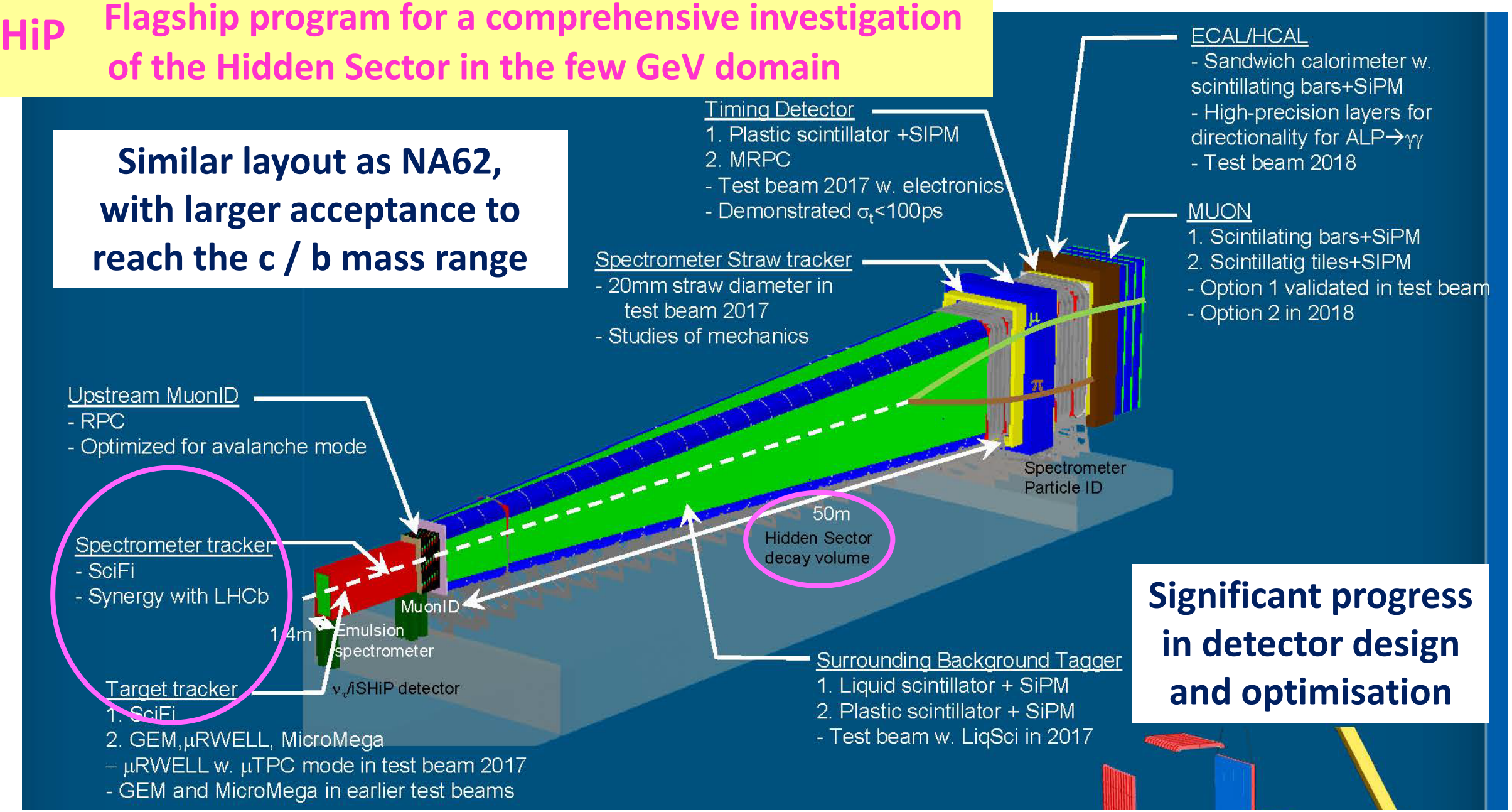
Decay volume ~ 60 m long (in vacuum):
reasonable acceptance to long-lived states



SHiP

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

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



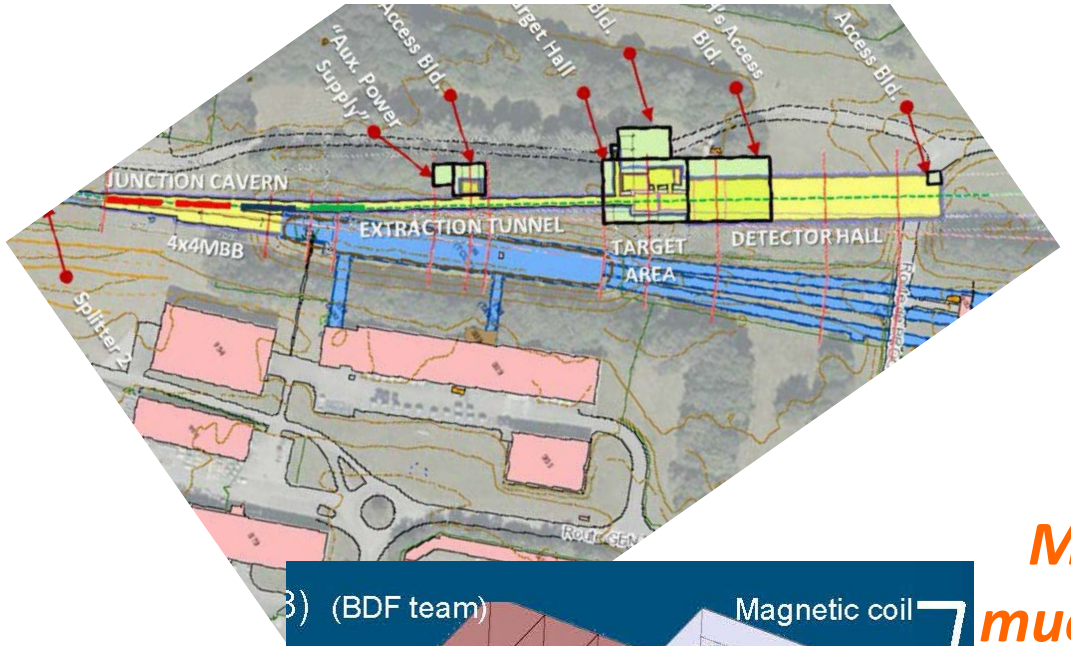
Significant progress in detector design and optimisation

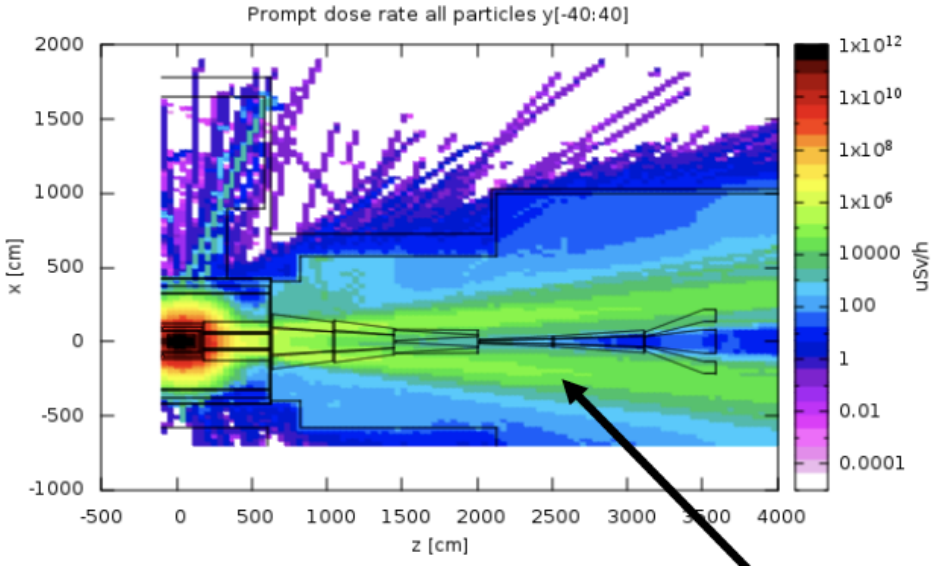
BEAM DUMP FACILITY

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

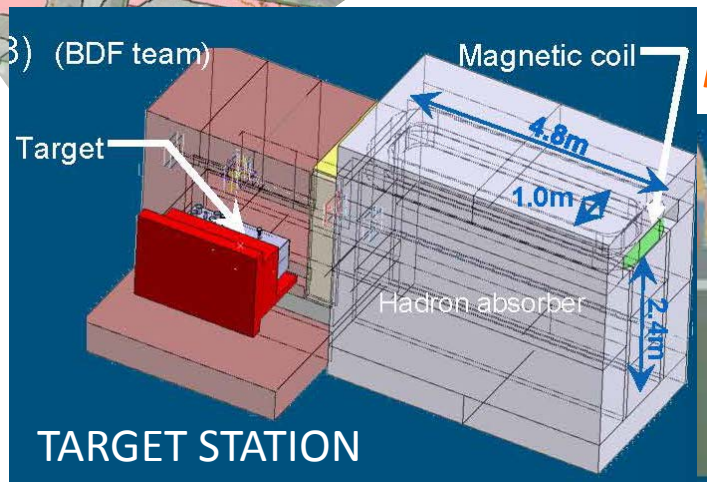
Foreseen to be sited close to the North Area

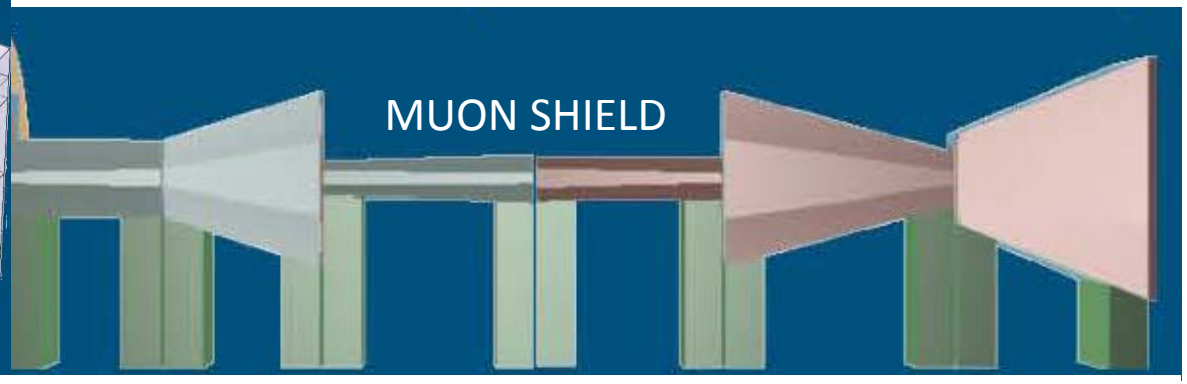
Conceptual design ongoing at CERN.



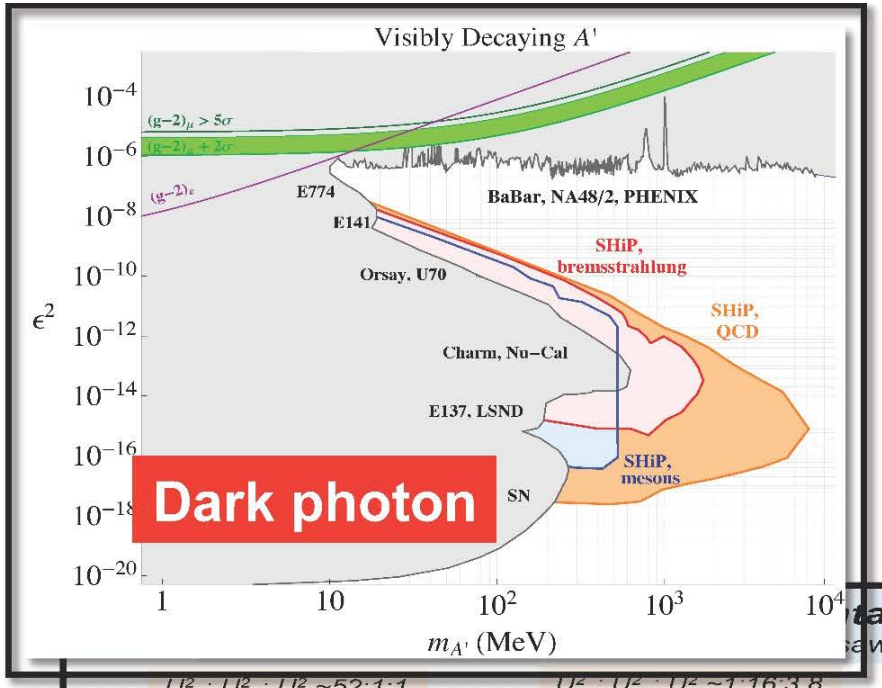


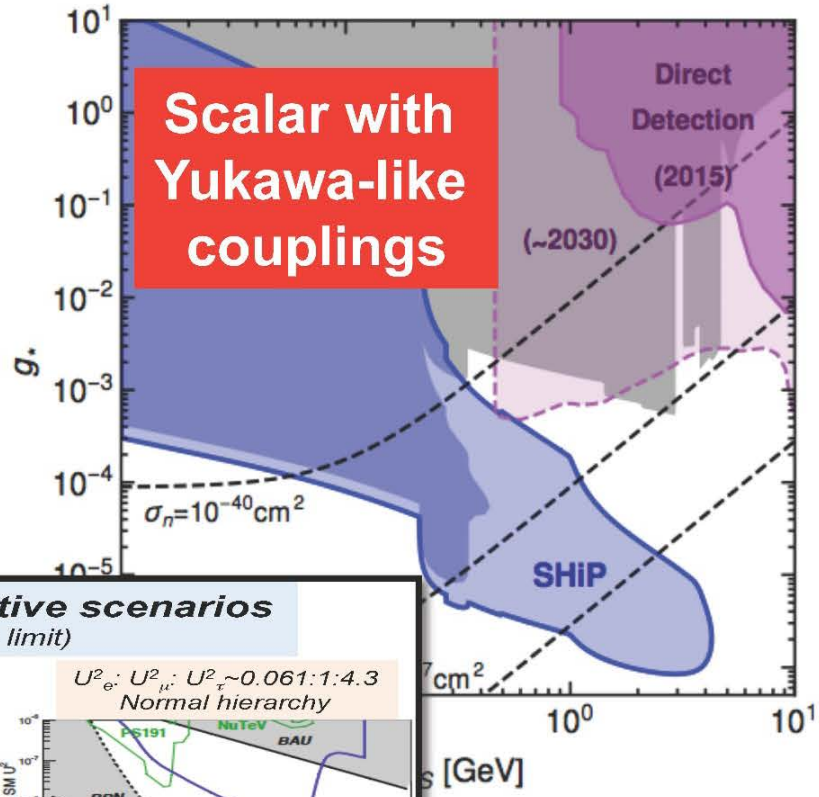
Magnetized hadron absorber and light weight active muon shield to minimize punch through in decay volume



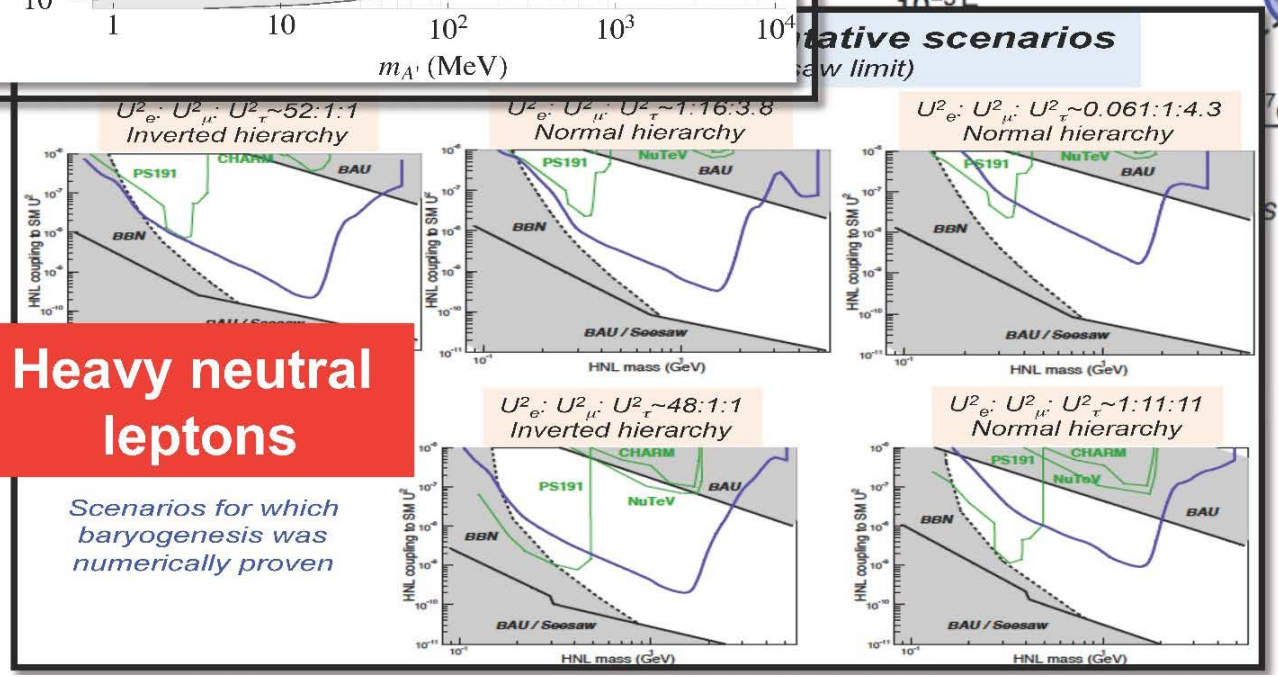


Muon yields and charm cross sections to be measured in test beams





SHiP physics reach



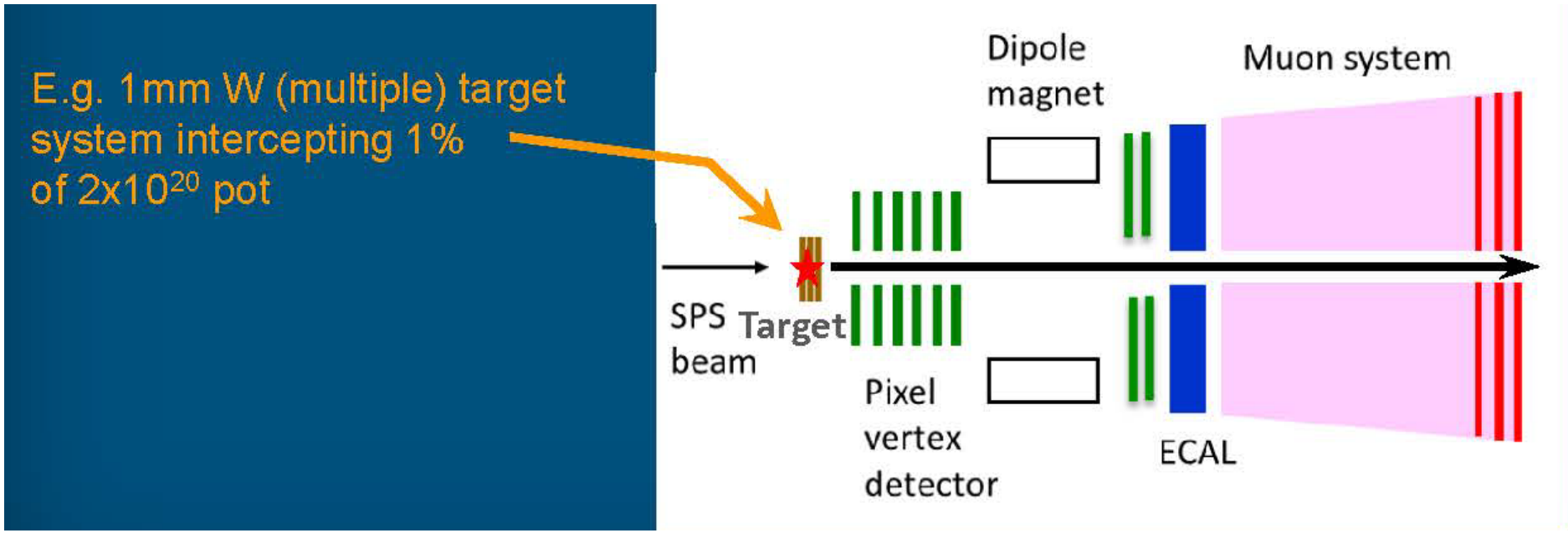
Significant & mostly unique extension of reach for many channels

Main issue: maximize physics reach to justify high investment of a new beamdump facility

"τ-SHiP"

Recently revived idea to intercept small beam fraction to look for τ → 3μ decays

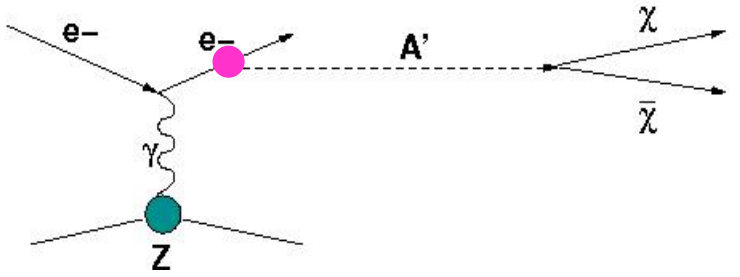
Could set limits on branching ratio at 10^{-10} level



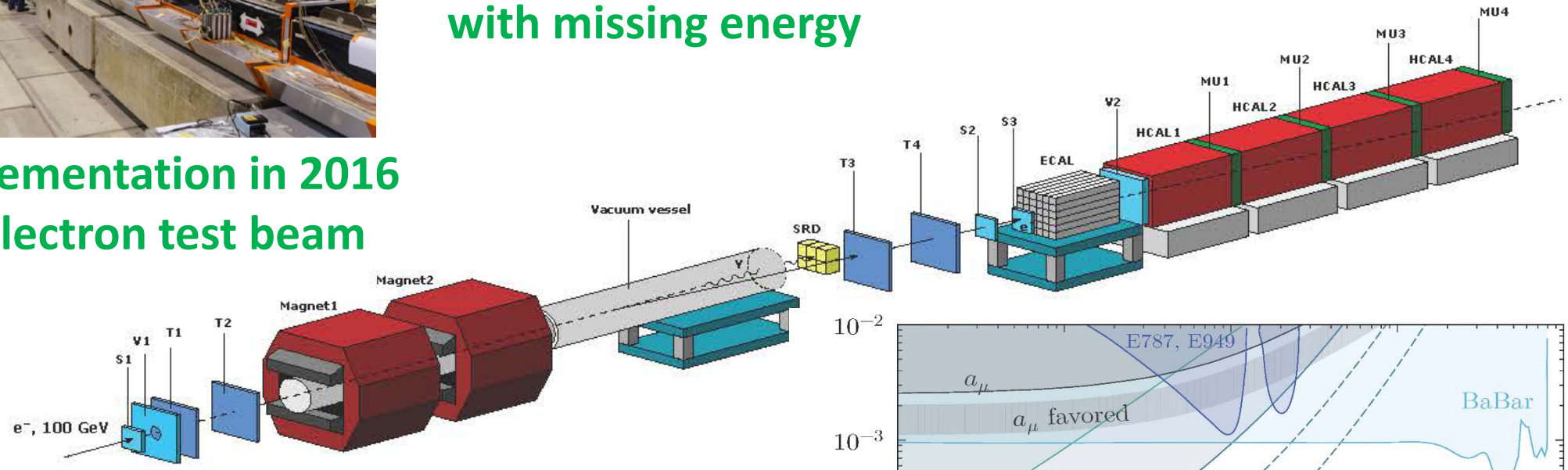
Possibility of implementation upstream of BDF target to be studied

NA64

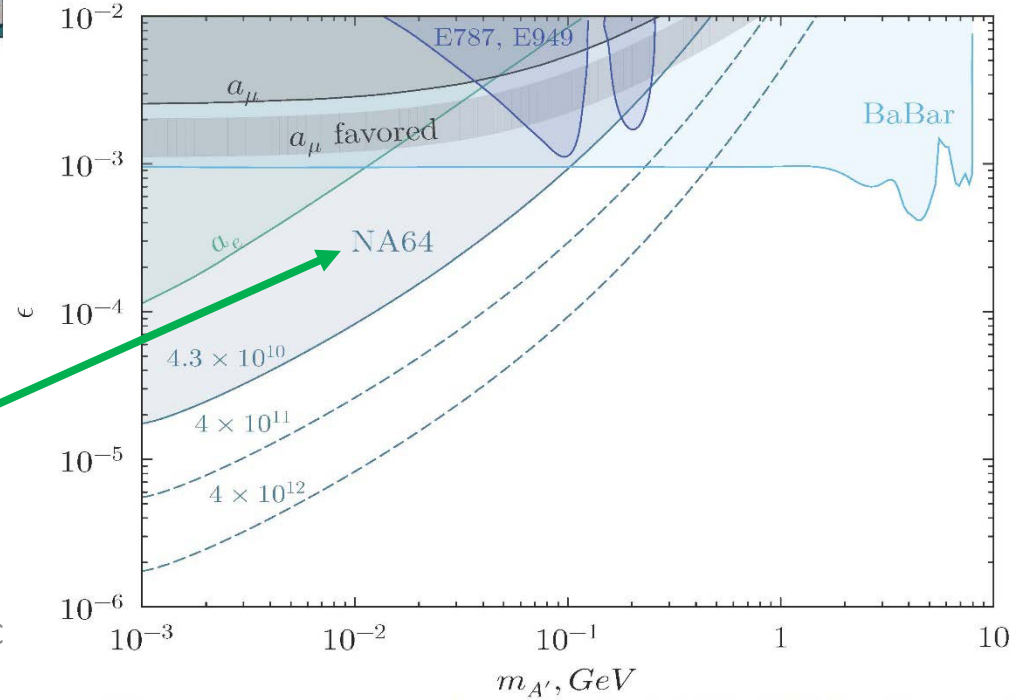
Hidden sector search from invisible decays with missing energy



First implementation in 2016 on an electron test beam

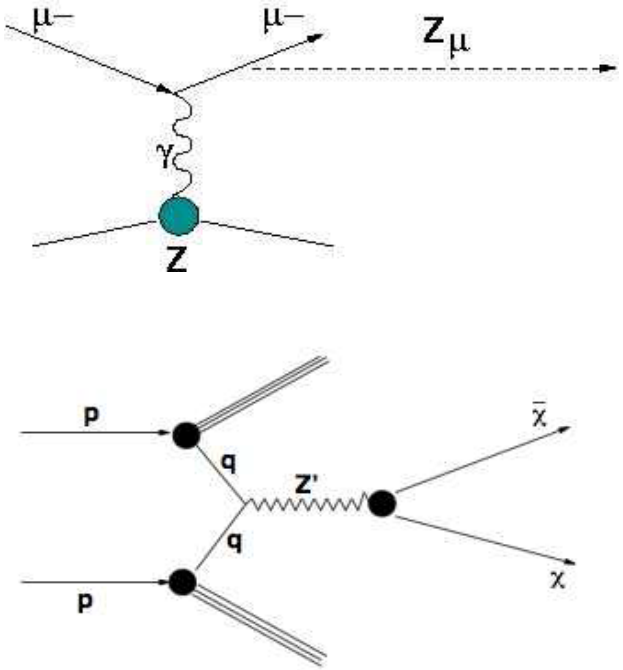


Fast analysis excluding (g-2)$_\mu$ interpretation confirms the potential of the method



AFTER LS2: NA64++

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



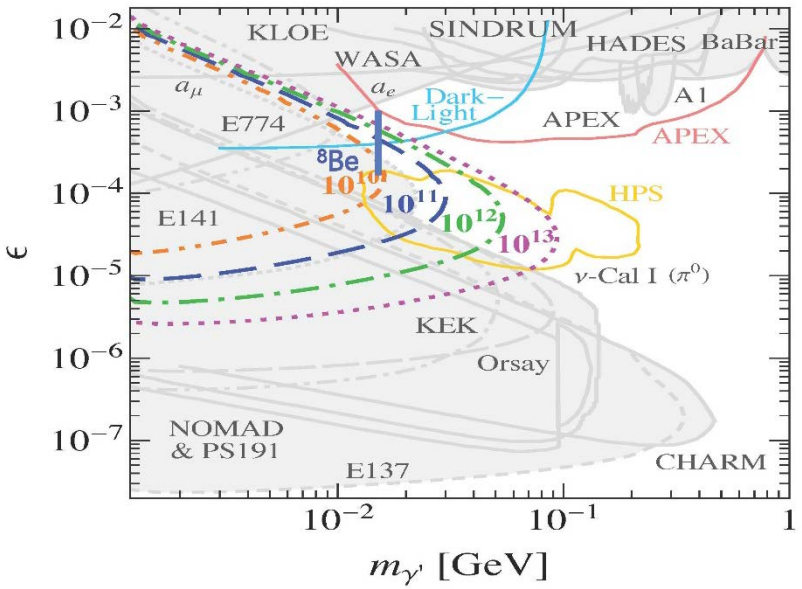
Beam and process	Motivation	Required number of POT
1. e^- Z		
✧ A´-> invisible ✧ X(16.7), A´ -> e^+e^- ✧ pseudoscalar ->invisible ✧ a -> γγ ✧ milli-Q	S,V mediator of light DM production ^{8}Be anomaly, Leptonic pseudogoldstone, ALP decays, miii-Q	~5x10^{12} EOT ~5x10^{12} EOT
2. μ^- Z		
✧ $Z_{\mu\tau}$ -> νν, $\mu^+\mu^-$ ✧ pseudoscalar -> invisible ✧ μ->τ conversion	$(g-2)_\mu$, New gauged symmetry L_μ-L_τ. Leptonic pseudo-goldstone, LFV	10^{12}-10^{13} MOT
3. π (K) p-> M^0 n + E_{miss}		
✧ K_L-> invisible ✧ K_S-> invisible ✧ π^0, η , η -> invisible	NHL, φφ, Bell-Steinberger Unitarity, CP, CPT symmetry	~5x10^{12} P(K)OT
4. p A -> X+ E_{miss}		
✧ leptophobic X	~ GeV DM	~5x10^{12} POT

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

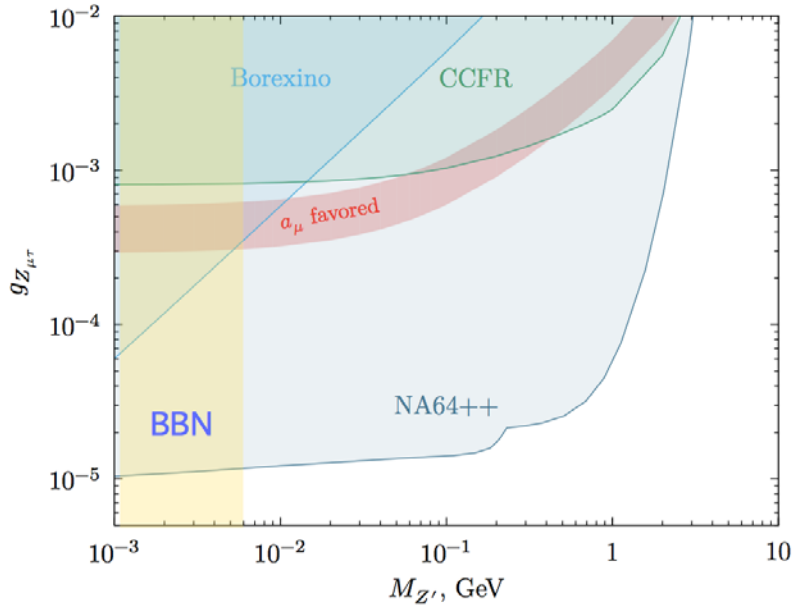
NA64++ expected sensitivities

Electron beam
appearance mode

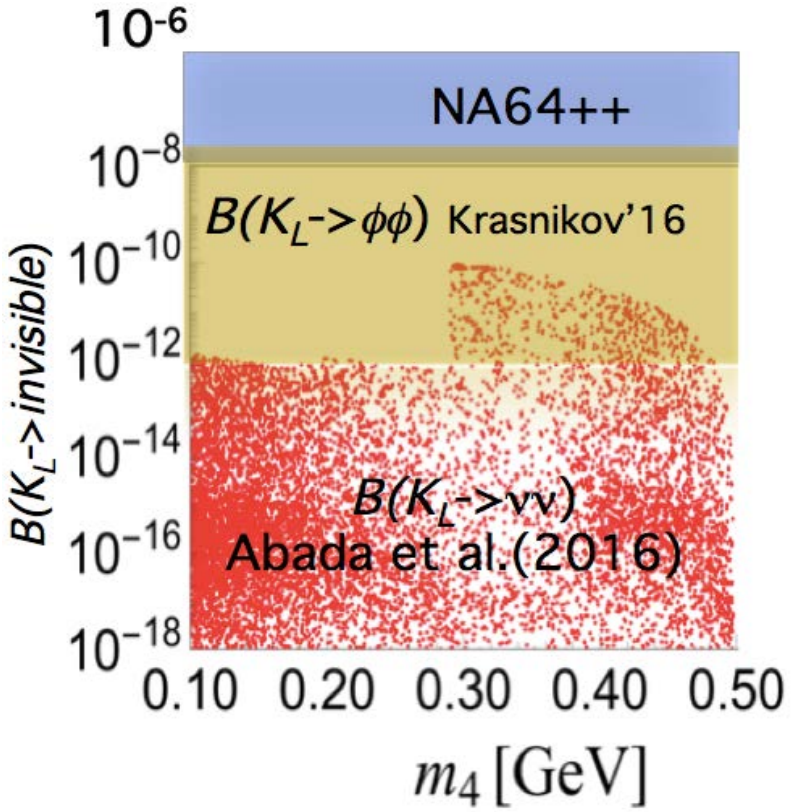
X, A´ → e^+e^-

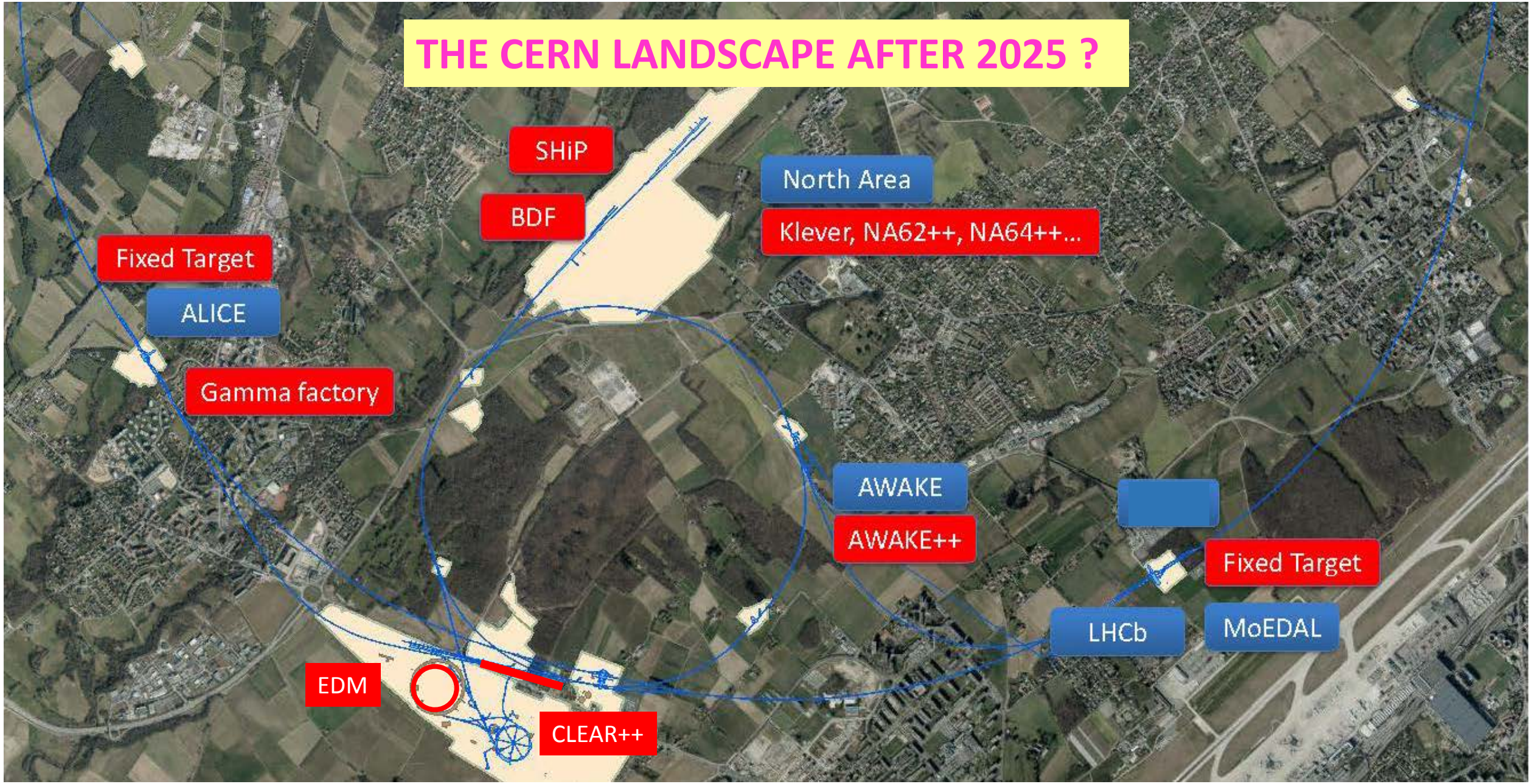


Muon beam
invisible mode

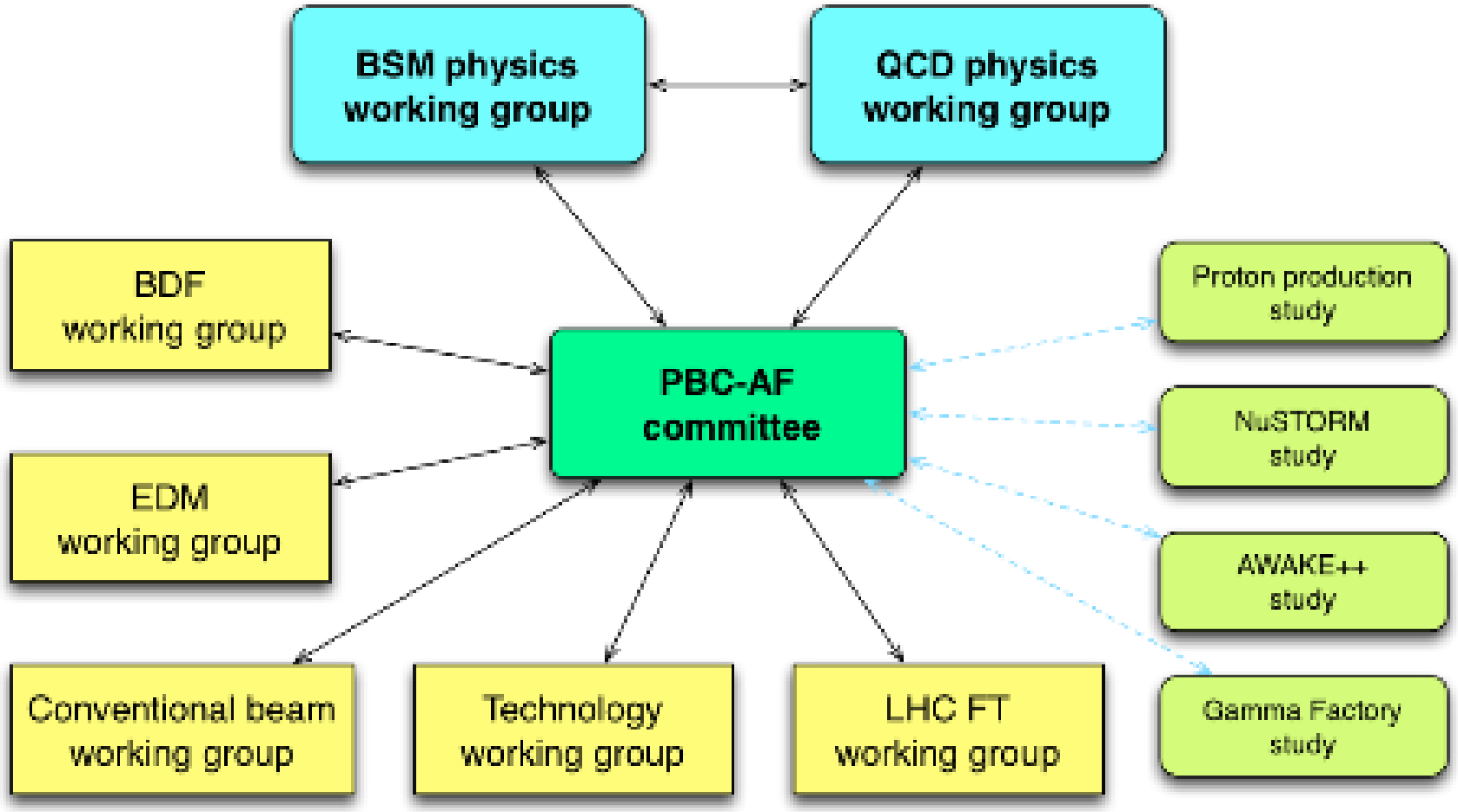


Hadron beams
invisible mode




THE CERN LANDSCAPE AFTER 2025 ?
SHiP
BDF
North Area
Klever, NA62++, NA64++…
Fixed Target
ALICE
Gamma factory
AWAKE
AWAKE++
Fixed Target
LHCb
MoEDAL
EDM
CLEAR++

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 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…

SOME STRATEGIC ISSUES
(personal view)

QCD

CERN future competitiveness vs dedicated “QCD facilities” worldwide (FAIR, JLAB, JPARC…)
& complementarity between COMPASS++/NA60++/NA61++/LHC-FT projects at CERN for p/ions measurements
→ Should CERN focus on LHC-FT as a worldwide-unique QCD program maximizing long term LHC physics yield?

BSM

Motivation for K rare decays and precision studies as function of evolution of current B anomalies
Specificity of the CERN SPS-FT hidden sector mass window in the overall landscape
Added value of a p/d EDM ring versus lower cost n EDM projects worldwide

CERN specific

Optimization of use of existing experimental halls for new projects (e.g. COMPASS hall for MUonE/NA64++ ?)
Flexibility of the Antimatter Factory availability for future (short term) new ideas
Possible recycling of neutrino LAr-TPC prototypes for physics projects
Level of CERN support to & involvement in outside (non-accelerator) projects

ADDITIONAL SLIDES

PBC DELIVERABLES

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

Guidelines for structure and content distributed to all participants

STRUCTURE OF PBC DELIVERABLES

The following table describes the overall spirit, content and relationship of the documents expected at the term of the PBC study. The PBC working groups are in charge of defining the detailed structure and content of their own deliverables along these lines.

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.*
QCD context	QCD WG conveners	QCD WG *+ possible externals as appropriate*	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.*
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.*
EDM	EDM WG	EDM Collab.	Fully developed feasibility study of the proton/deuteron EDM storage ring: *ring layout options; experimental aspects of the EDM measurement (e.g. systematics); initial civil engineering studies for a possible siting at CERN; timeline and cost estimate; collaboration structure.*
Conventional Beams upgrades	CB WG	CB WG	Description of the conventional beam upgrades associated to the proposed projects: *technical feasibility; schedule and cost; identification of potential areas of conflict between projects siting in available experimental halls.* Level of details to be matched to the available manpower for the studies, with a priority to implementations possible after LS2: *NA62++ beam dump, NA64++ and MUE muon beams, NA61++ higher intensity ion beam. Reliable estimates of the orders of magnitude of the costs of the COMPASS RF-separated beam and of the KLEVER K^0 beam are also needed.*
LHC Fixed Target	LHC-FT WG	LHC-FT WG	Study of the implementation of LHC internal fixed targets in the LHCb and ALICE areas: *technical description of the discussed options (gas targets with and without polarisation, crystals, etc…); estimation of the maximal luminosities achievable for each option, compatible with the experiments and LHC constraints.*
Technology support	Technology WG	Technology WG	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.*
AWAKE	AWAKE study group	AWAKE study group	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.*
nuSTORM	nuSTORM study group	nuSTORM study group	Updated broad outline of a possible nuSTORM implementation at CERN.
γ Factory	γ Factory study group	γ Factory study group	Exploratory study of the concept feasibility: *results of initial tests and extrapolated performance; elaboration on the corresponding physics reach.*

PBC DELIVERABLES in short

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 !