BDF workshop of the German community, Berlin, March 26th 2020

Claude Vallée (CPPM Marseille)

PHYSICS BEYOND COLLIDERS

Excerpt from the 2016 PBC mandate by CERN Management:

"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

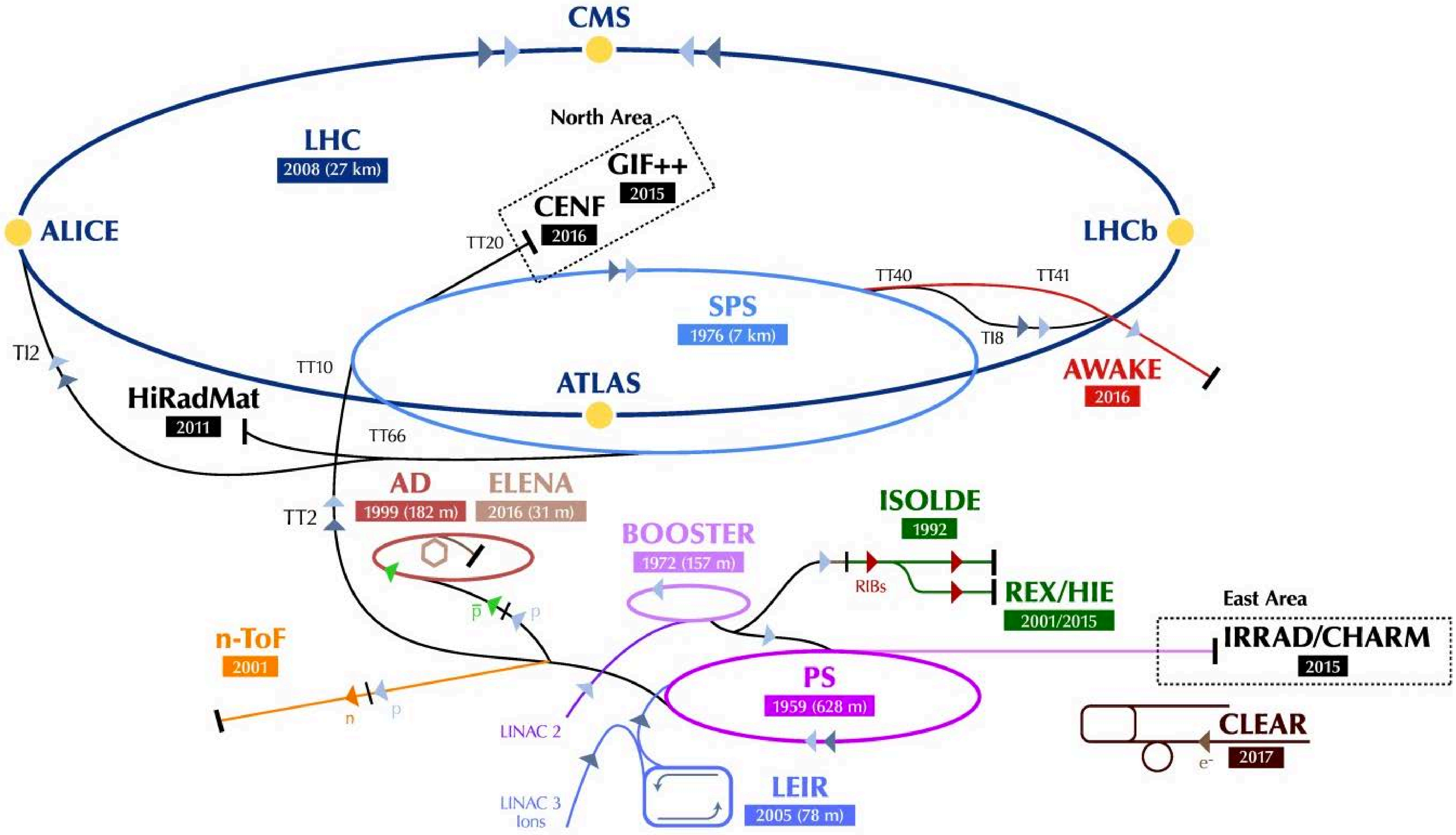
PBC Summary Report: arXiv:1902.00260
PBC BSM Report: arXiv:1901.09966
PBC QCD Report: arXiv:1901.04482
PBC Accelerator Reports:
http://cds.cern.ch/collection/PBC%20Reports?ln=en

Latest status documented in Nov. 2019 PBC WG meeting

https://indico.cern.ch/event/827066/

THE CERN LHC INJECTOR COMPLEX

> 1000 physicists
> 20 projects

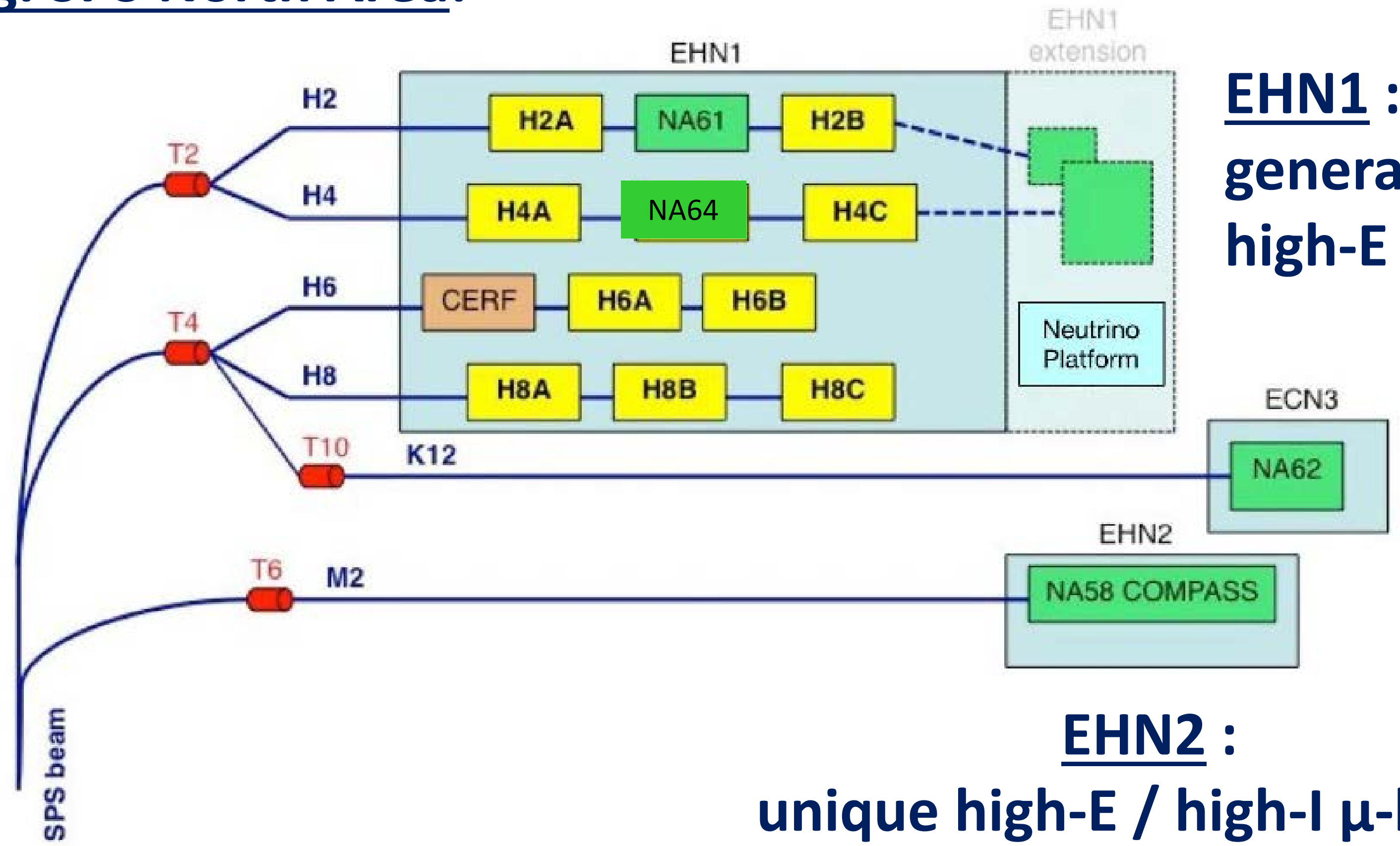


C. Va

IMPLEMENTATION CONSTRAINTS OF NEW PROJECTS

Governed to a great extent by existing beamlines/halls/experiments

e.g. SPS North Area:



EHN1 :
general purpose hall with unique high-E / medium-I beams for all particles

ECN3 :
unique underground hall for high-I hadron beams

EHN2 :
unique high-E / high-I μ-beam

PBC PROJECTS SPECIFICITIES

1) QCD PROJECTS

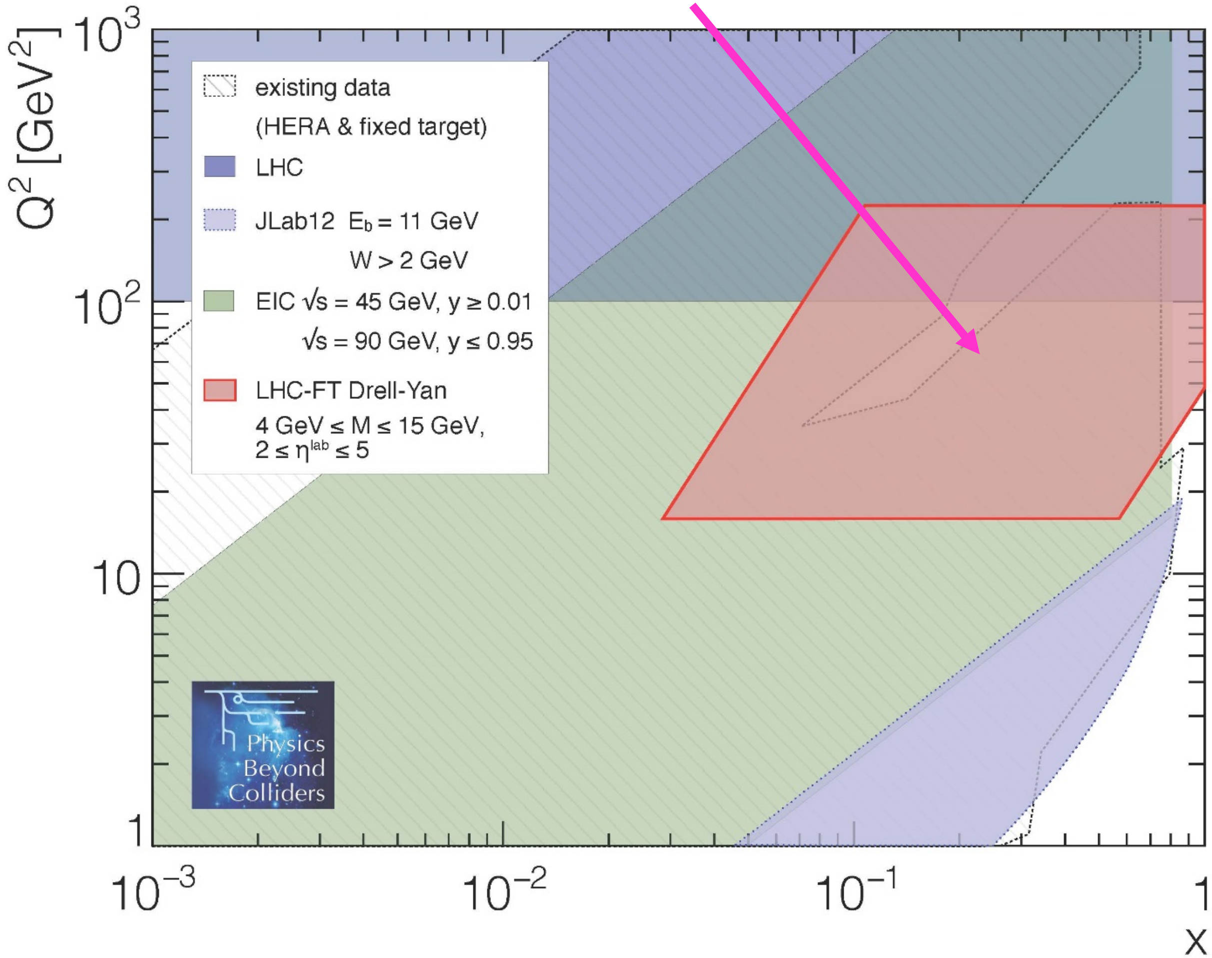
2) BSM PROJECTS

3) BDF/SHiP IN THE GENERAL CONTEXT

PBC QCD PROJECTS IN WORLDWIDE LANDSCAPE

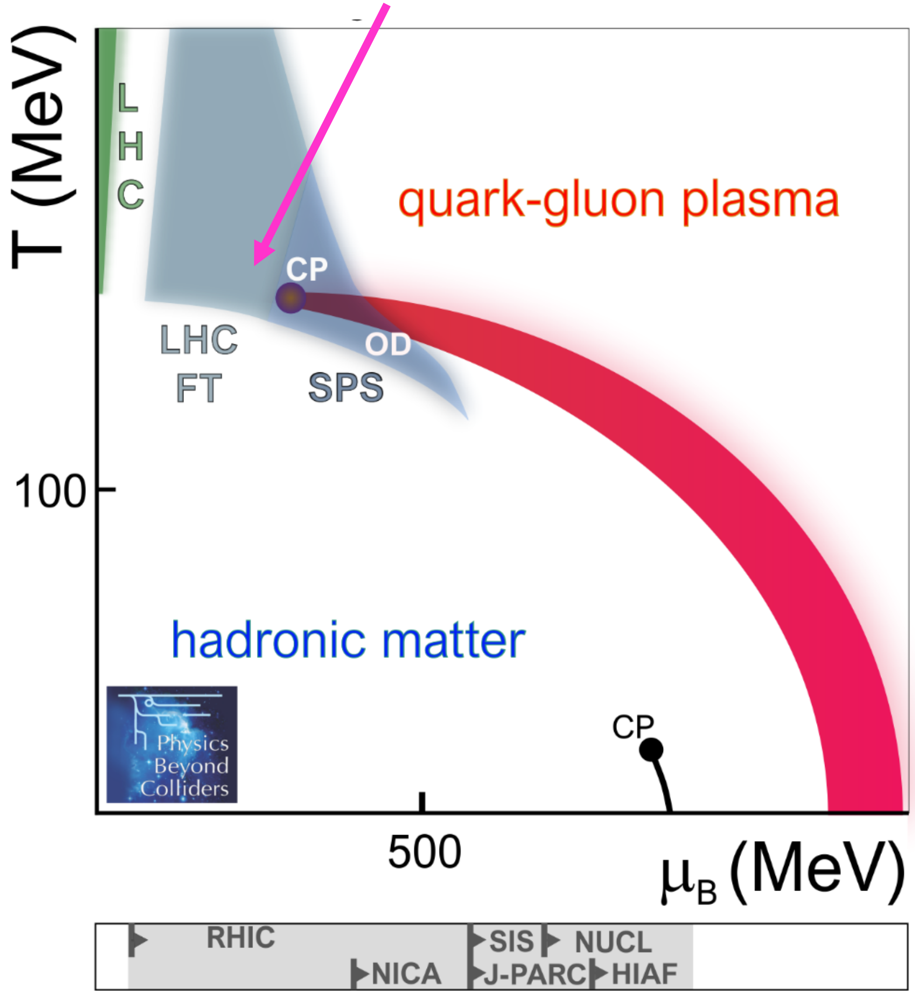
Structure Functions

Unique reach of LHC-FT with high statistics at high-x / high Q^2



QCD Phase Transition

Unique reach of LHC-FT & SPS in transition region to high-μ_B

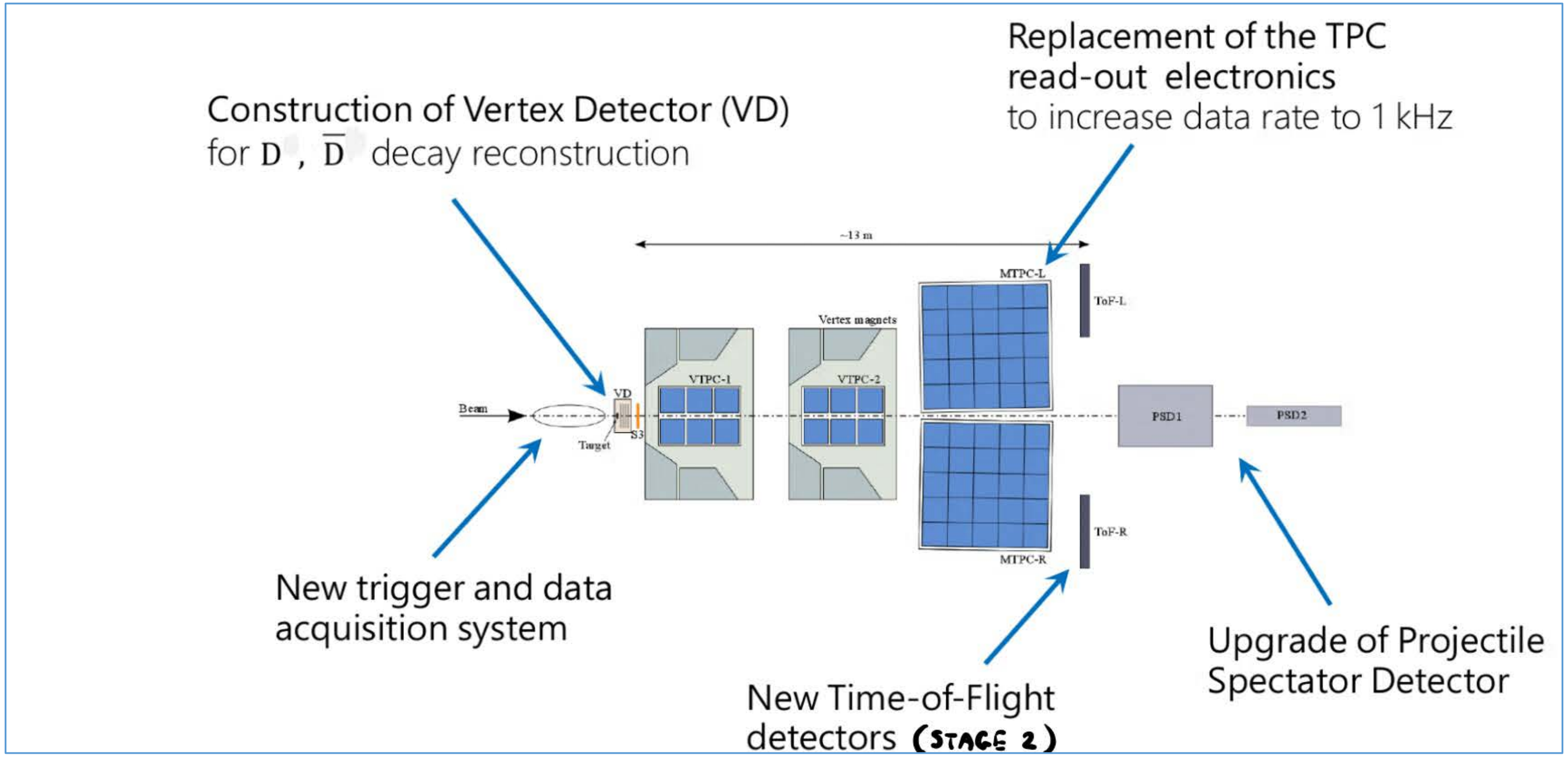


NA61++

Opportunity to study open charm close to expected CP-region.

(was not done by 1st generation SPS QGP-experiments)

Also unique measurements for ν-beams and cosmic rays

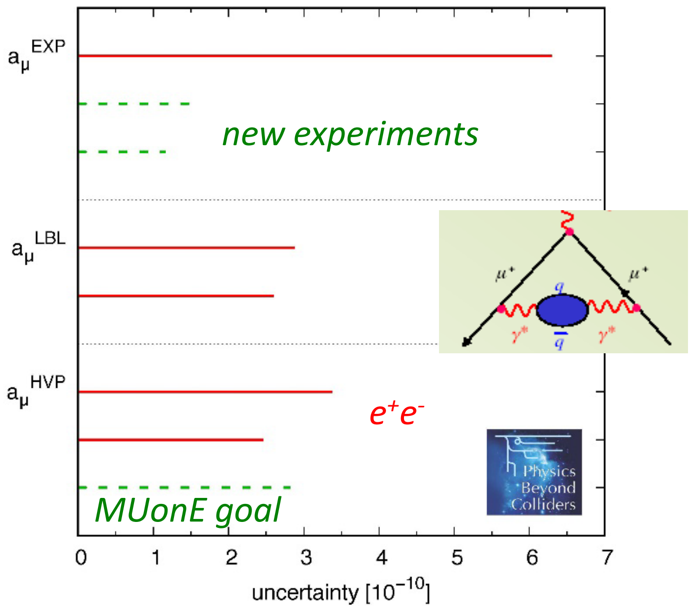


Moderate detector upgrades required, well under control in collaboration with ALICE

Unique physics reach **No new competition on beamline**

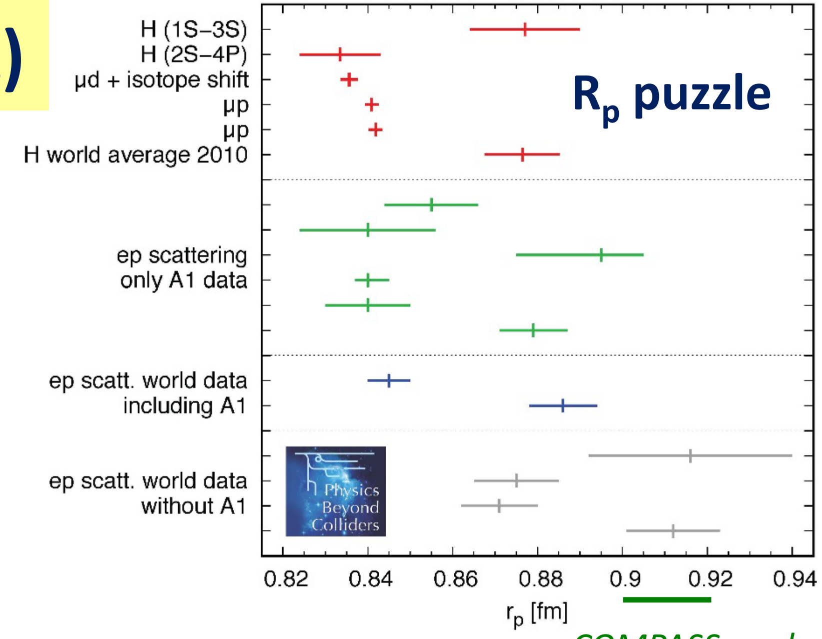
MUonE ↔ COMPASS(R_p)

$(g-2)_\mu$ uncertainties

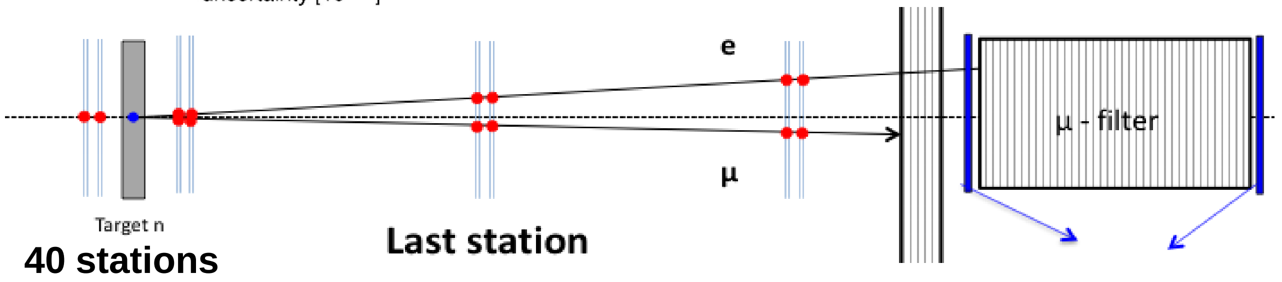


μ-e ↔ μ-p
elastic scattering

In competition on same μ-beam in EHN2



COMPASS goal



→ COMPASS spectro

Suitable MUonE position identified upstream of COMPASS

new COMPASS TPC

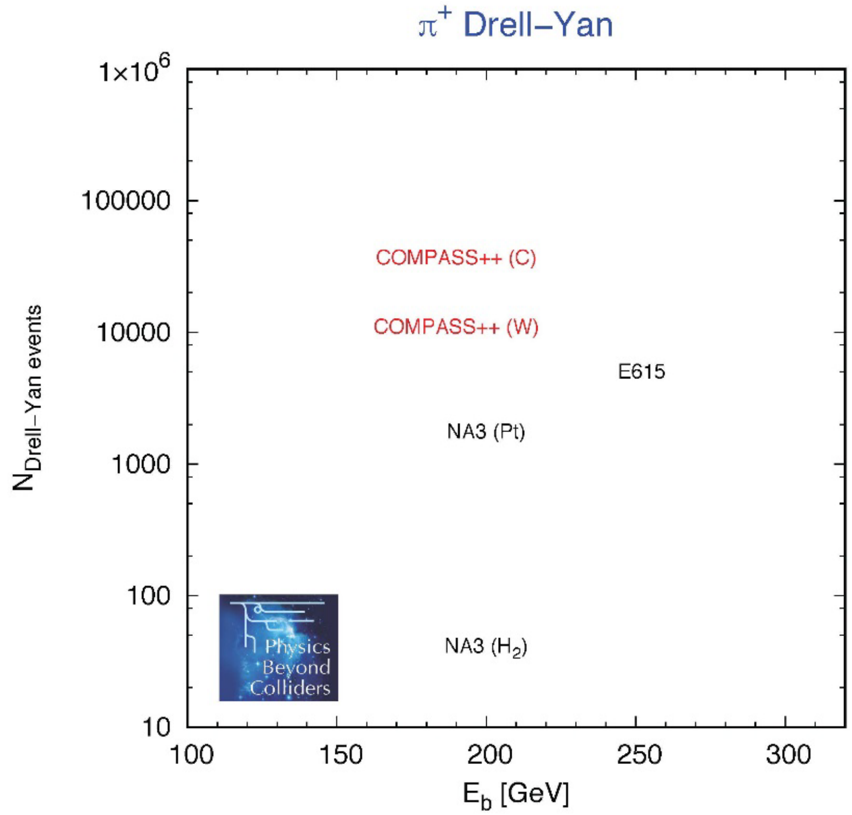
Convincing physics motivation

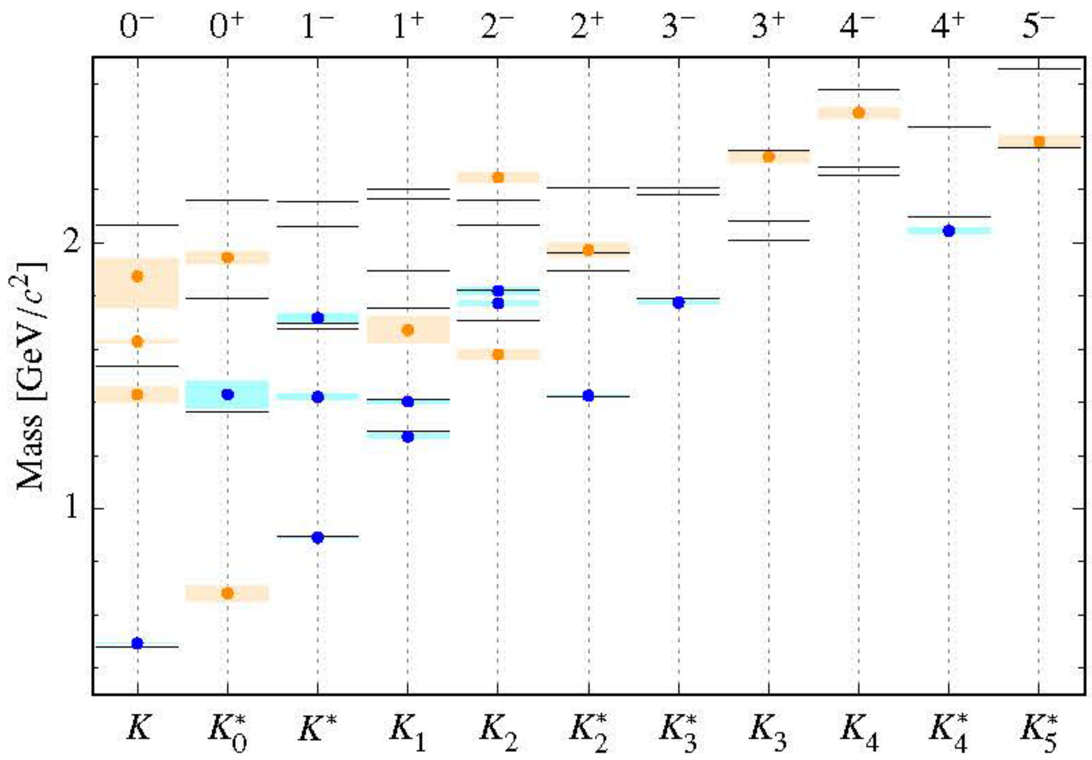
Both projects still need better quantification of feasibility and precision as well as studies for common siting and/or operation

COMPASS++/AMBER "QCD FACILITY"

Competition from growing number of QCD facilities worldwide

Some highlights identified by PBC





With existing beams:

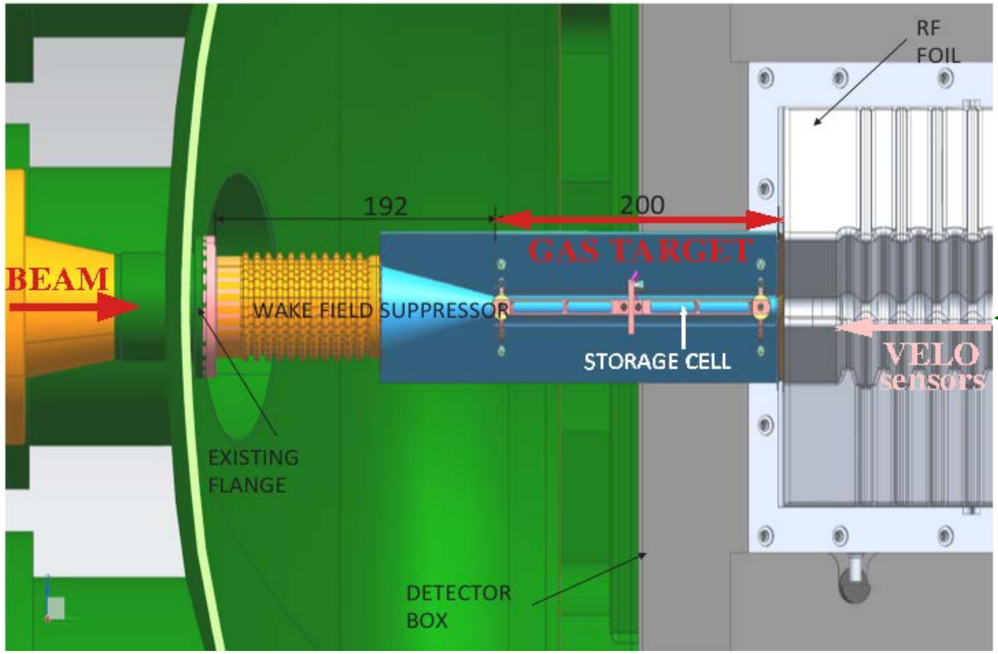
Unique opportunity for higher precision pion structure measurements

With new RF-separated K-beam:

(significant investment possible for post-LS3):

Comprehensive measurement of strange spectroscopy

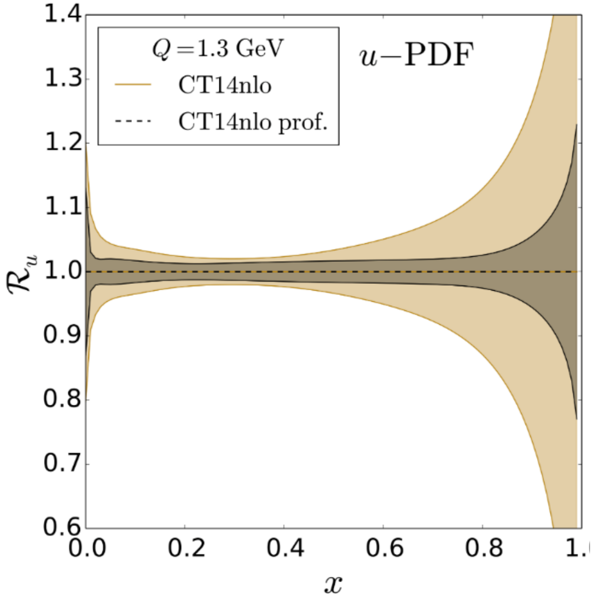
LHC FIXED TARGET

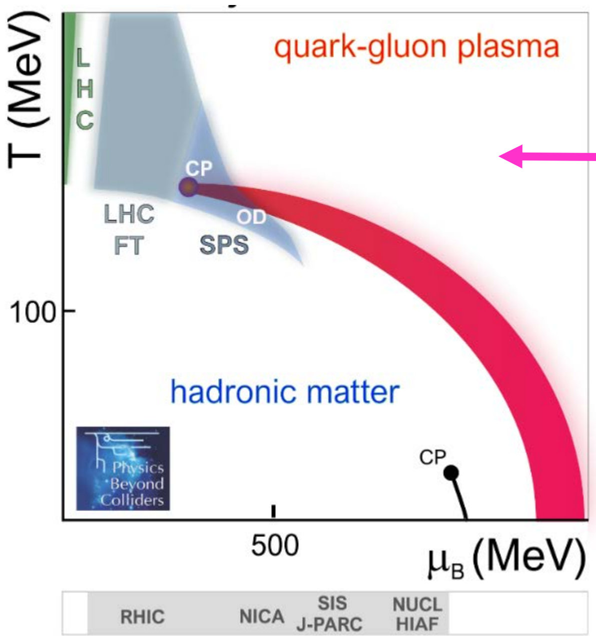


Already started by LHCb in run 2 with SMOG.
Promising SMOG2 storage cell development:
FT lumi x ~100 in run 3

ALICE also interested

R&D ongoing on polarized gas targets
and double-crystal set-ups





“Simple” storage cells already open
unique opportunities in both
hadron and QGP physics

Optimization of FT- and collider-operation
required to maximize LHC-FT physics reach

PBC PROJECTS SPECIFICITIES

1) QCD PROJECTS

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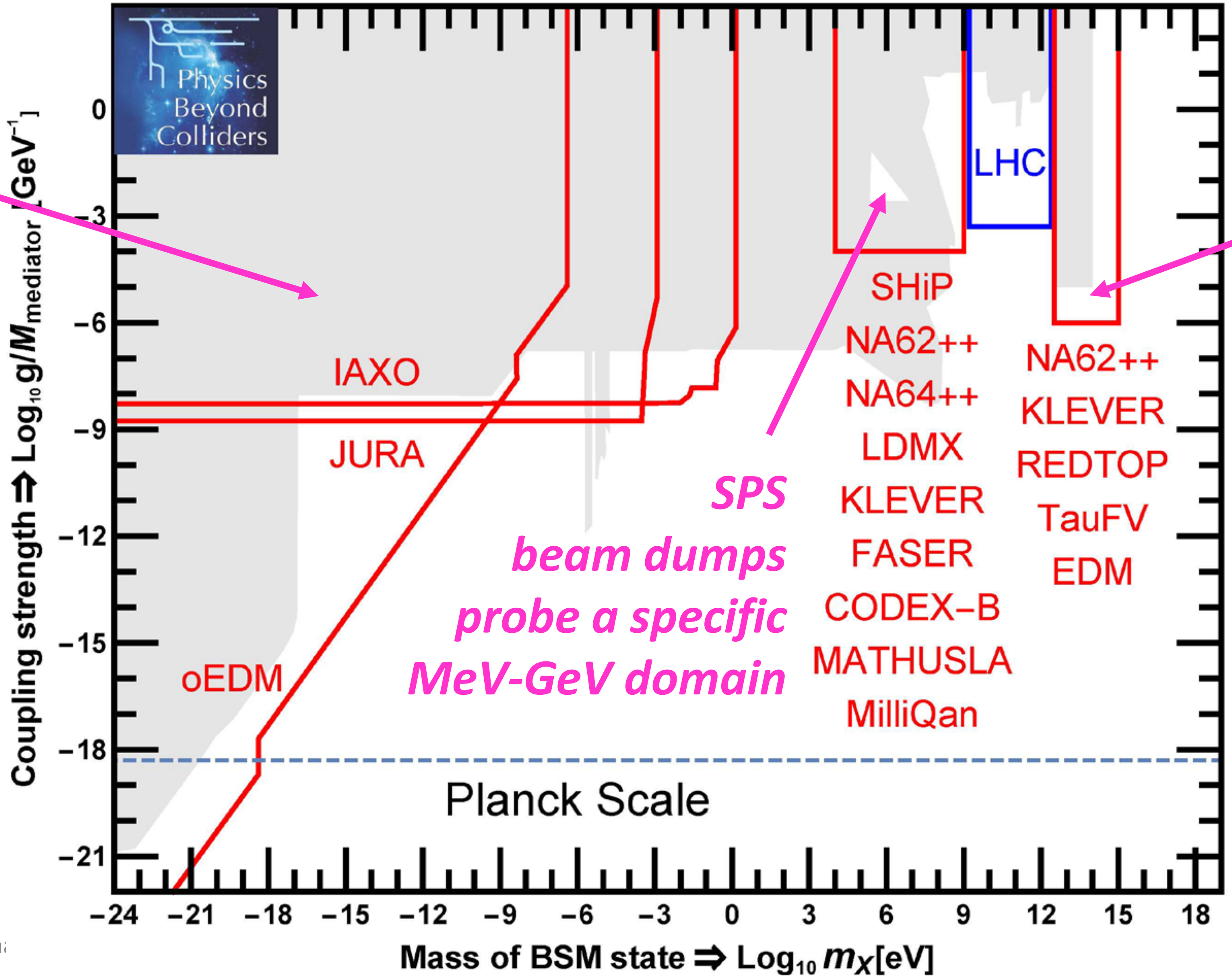
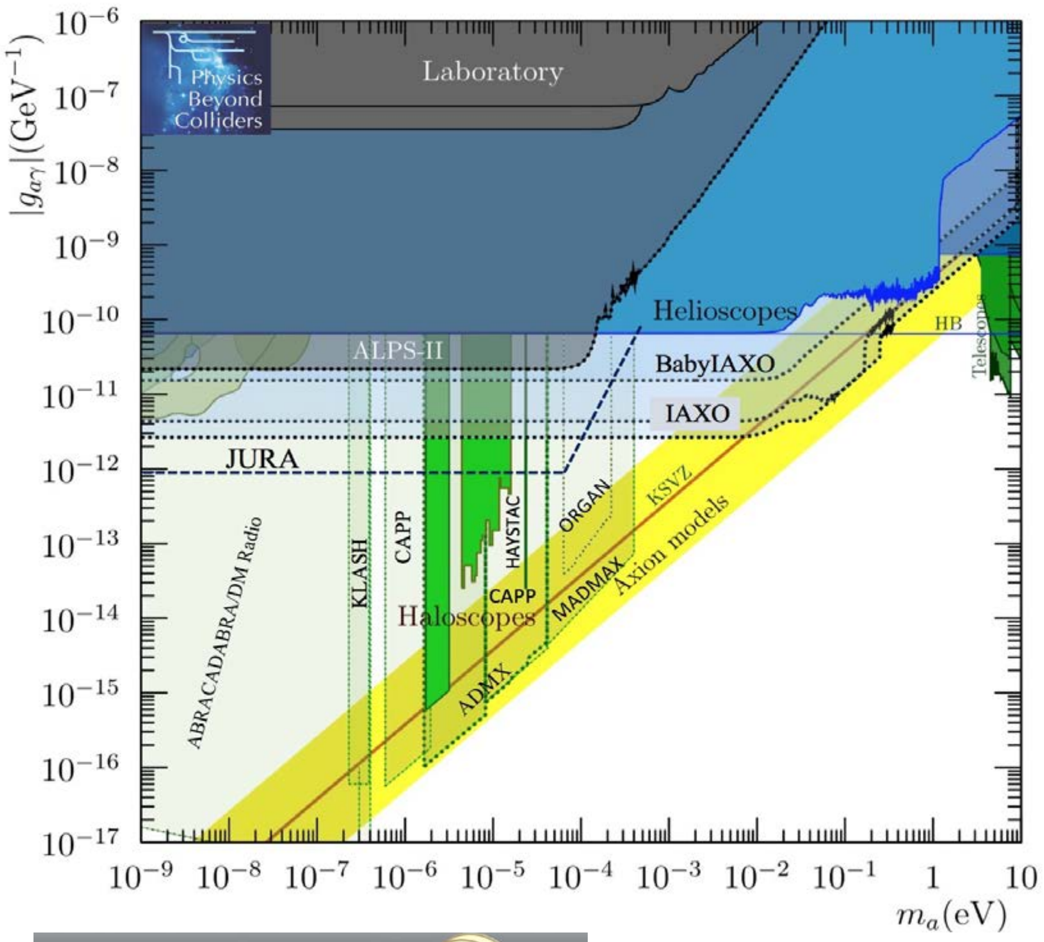
PBC BSM PROJECTS IN WORLDWIDE LANDSCAPE

EDM & non-accelerator projects cover the very low-mass domain



Precision experiments extend reach of high-E colliders



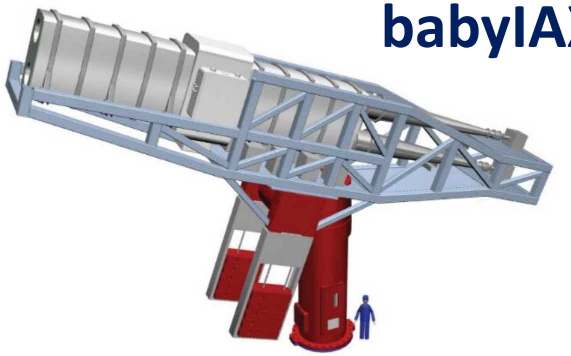
NON-ACCELERATOR PROJECTS

Unique sensitivity to low-mass ALPs

(Baby)IAXO (helioscope successor of CAST) supported by CERN for magnet design

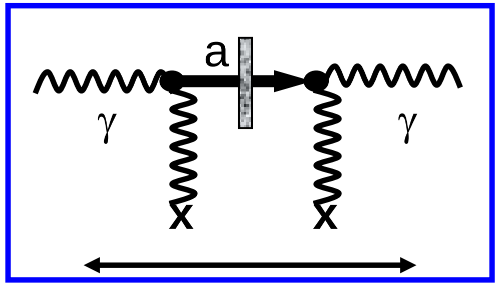
In approval stage at DESY

JURA possible long term LSW experiment combining state-of-the-art ALPS II optics and CERN high-field magnets



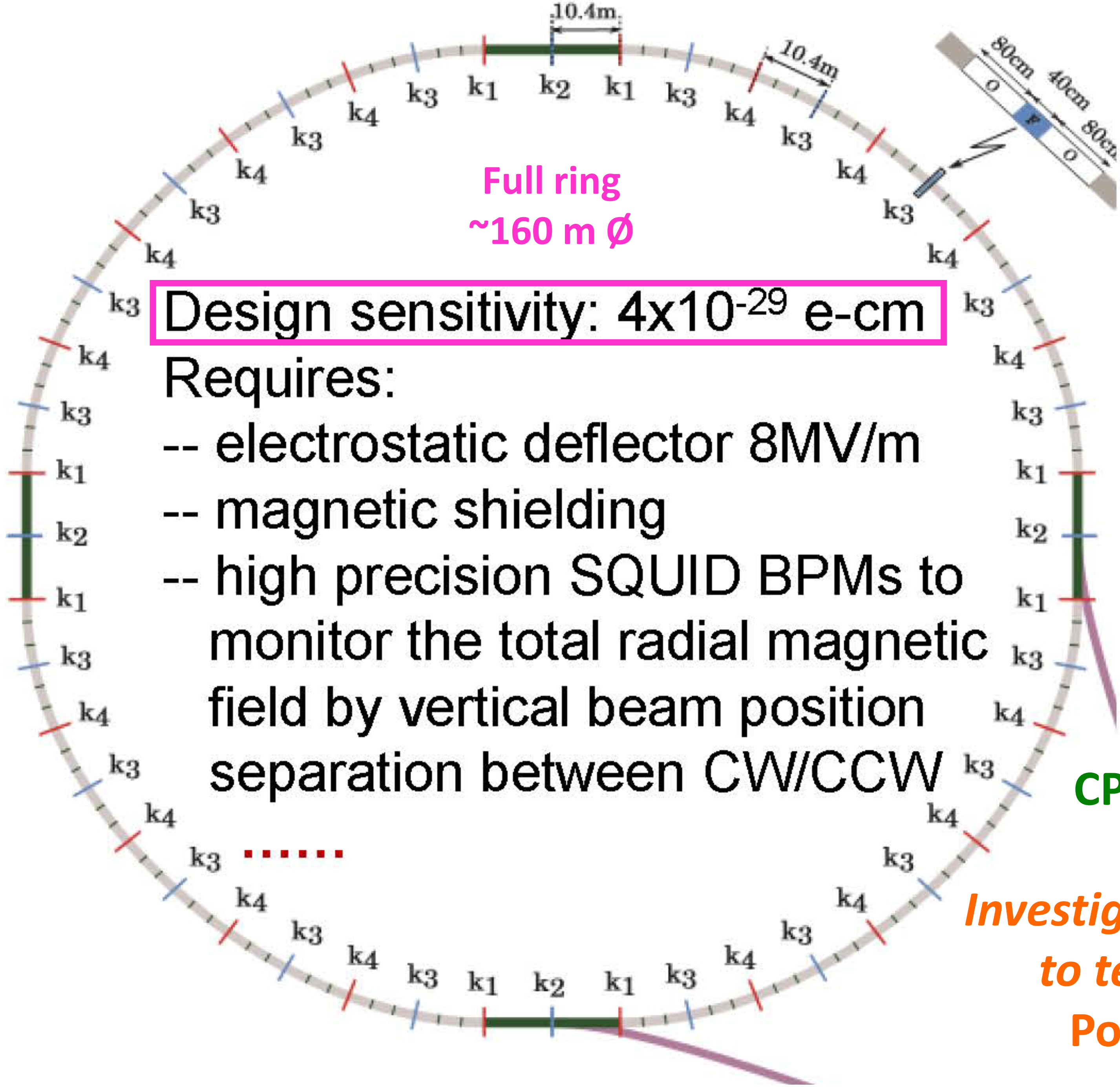
babyIAXO

JURA



PROTON EDM RING

New method aiming at breakthrough in hadron EDM measurement



Design sensitivity: 4×10^{-29} e-cm

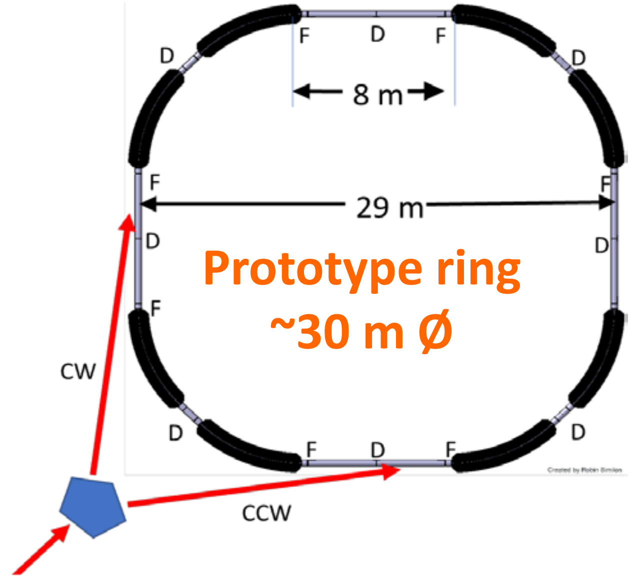
Requires:

-- 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

......

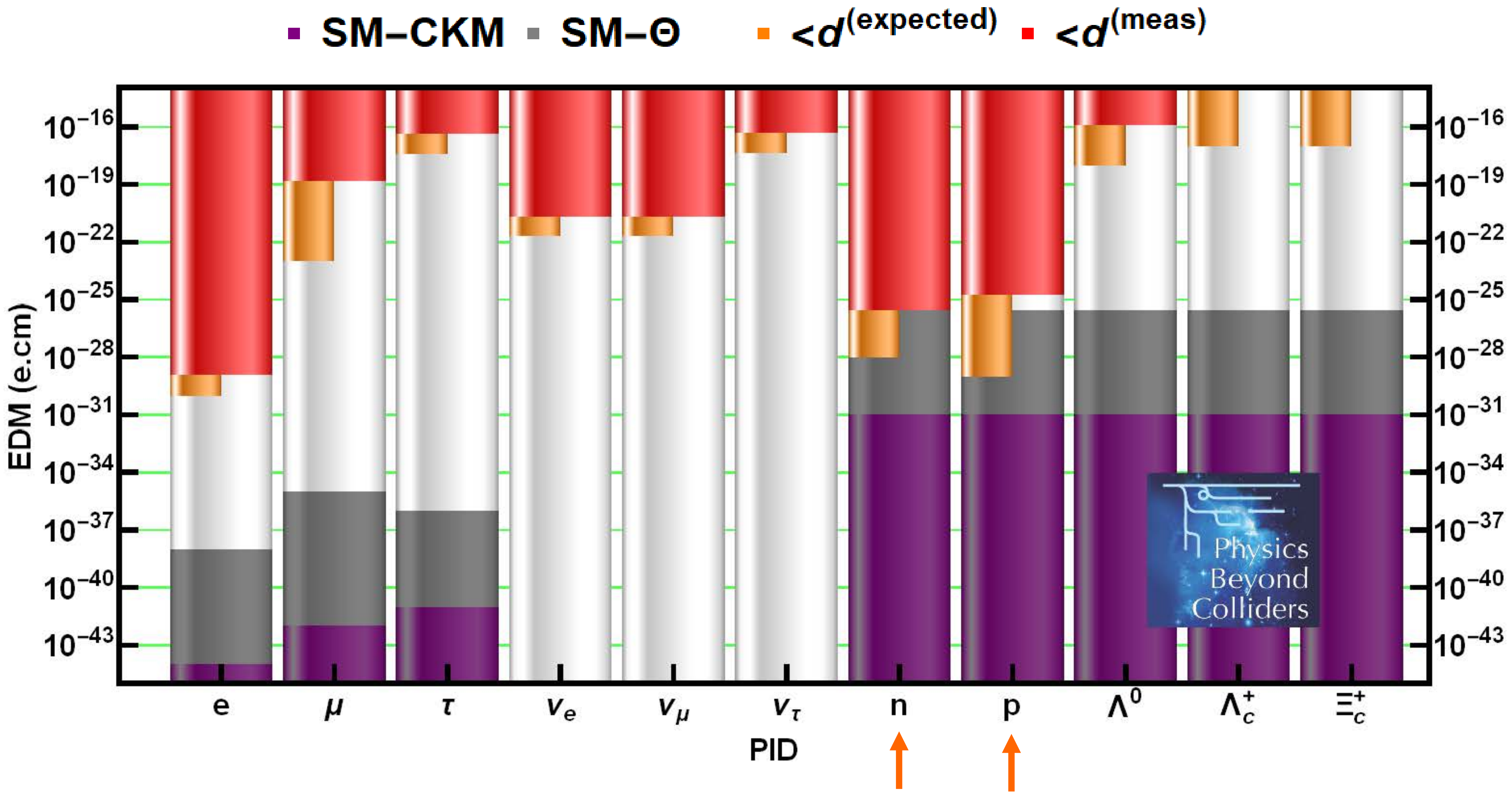


CPEDM Collaboration built within PBC

Investigations revealed need of a prototype ring to test and finalize control of systematics.

Possible prototype site: COSY in Jülich

EDM LANDSCAPE



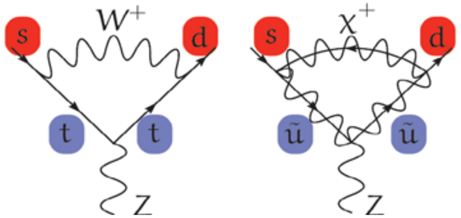
Neutron EDM is leading the field for hadrons

Catching up in precision is a challenge for the proton

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

NA62

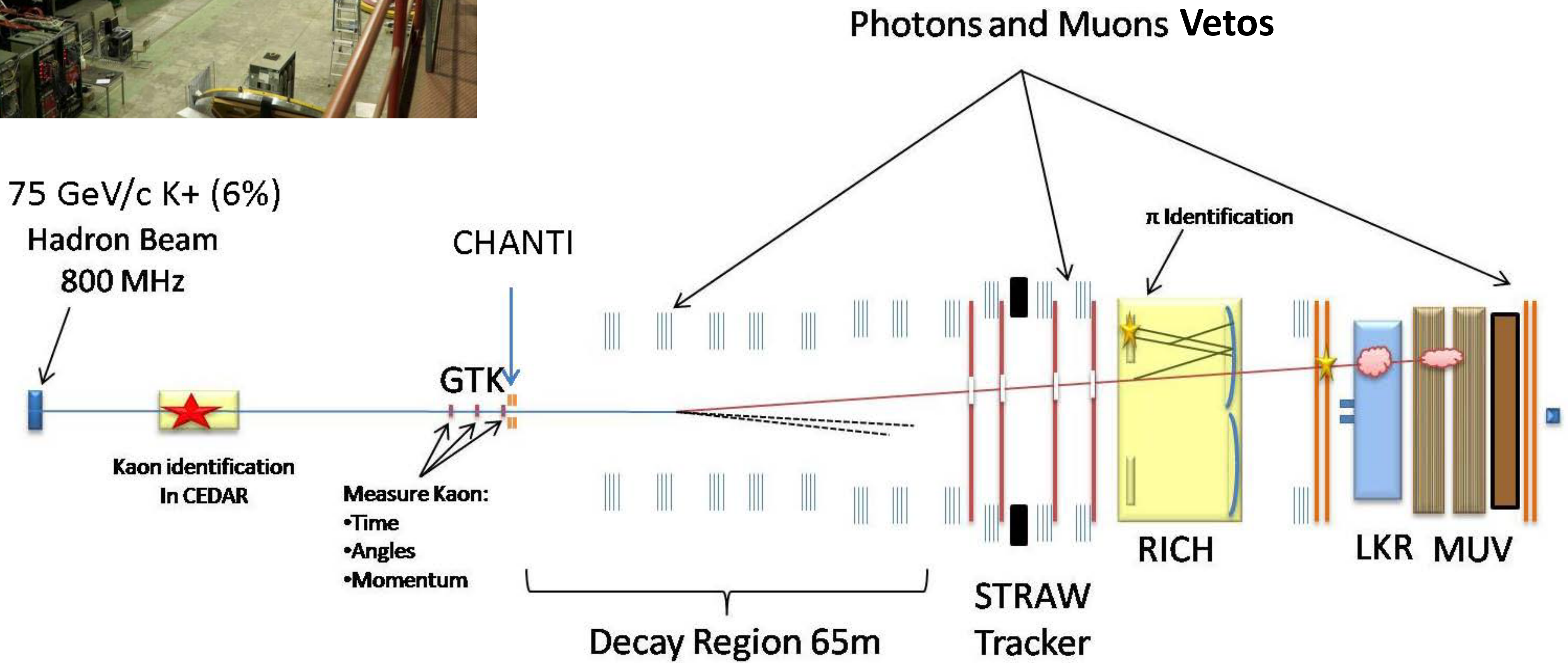
ultra-rare K^+ decays



Regular data taking started in 2016

3 candidates released in agreement with SM

aim at ~100 signal events



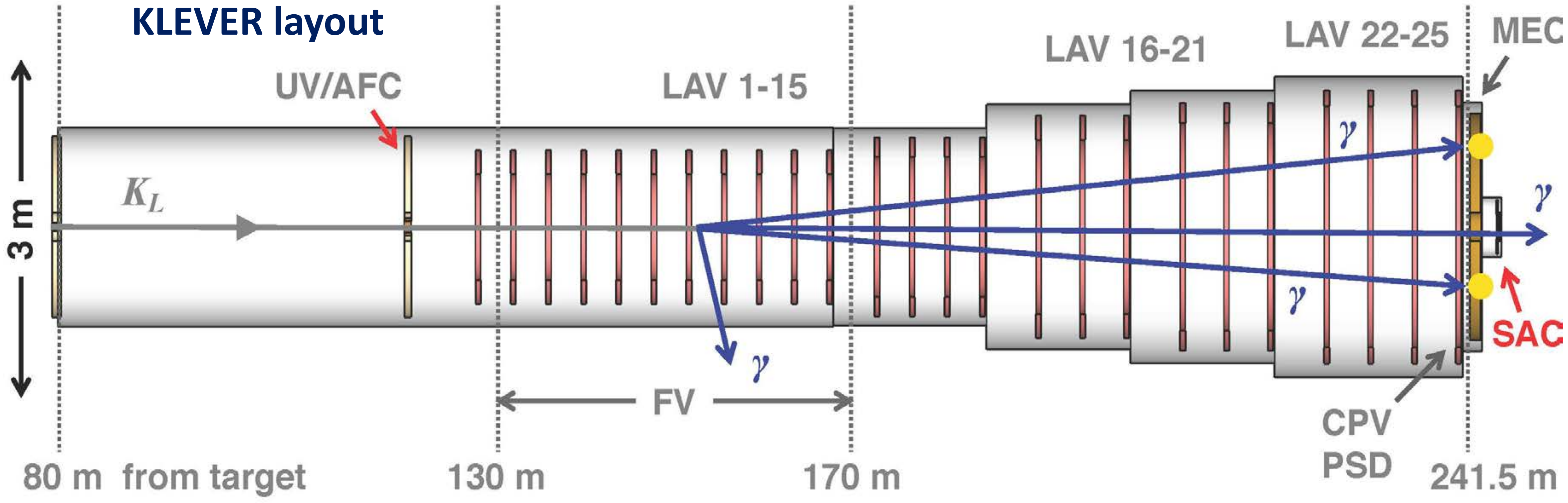
KLEVER: $K^o \to \pi^o\nu\nu$ rare decay

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

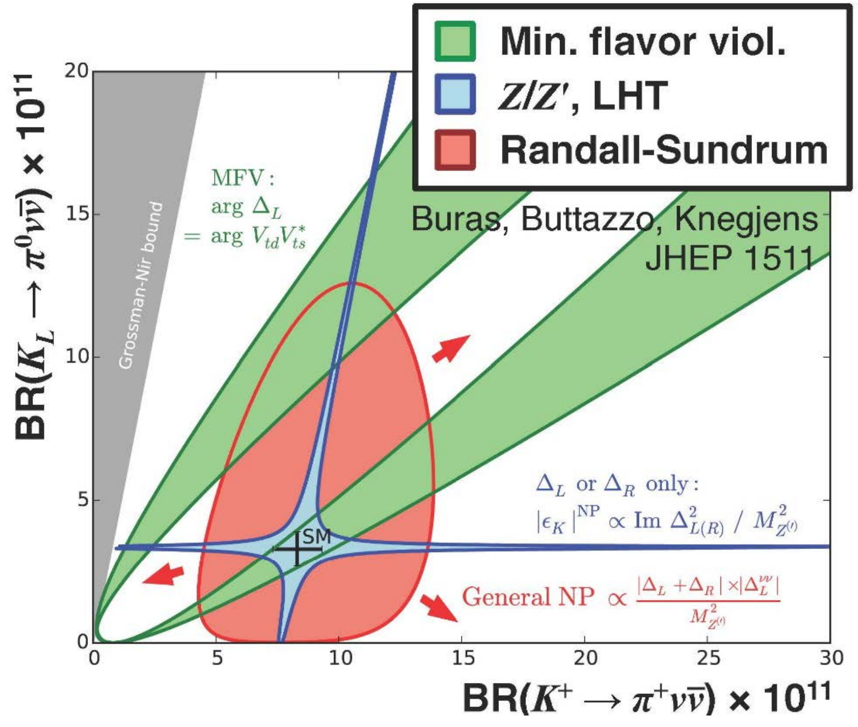
Would require a new high intensity K^o beam.

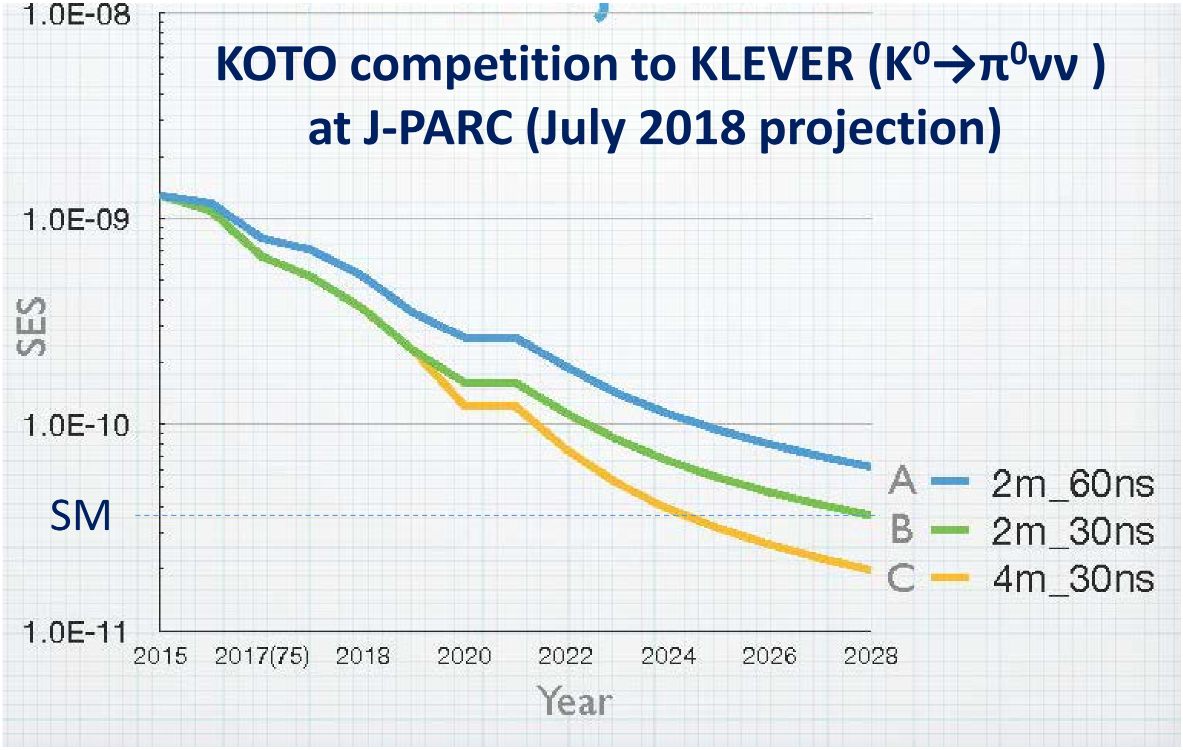
~50 events could be collected with a new detector similar to NA62

KLEVER layout



ULTRA-RARE KAON DECAYS: NA62 (K^+) ↔ KLEVER (K^0)





complementary sensitivity to BSM models

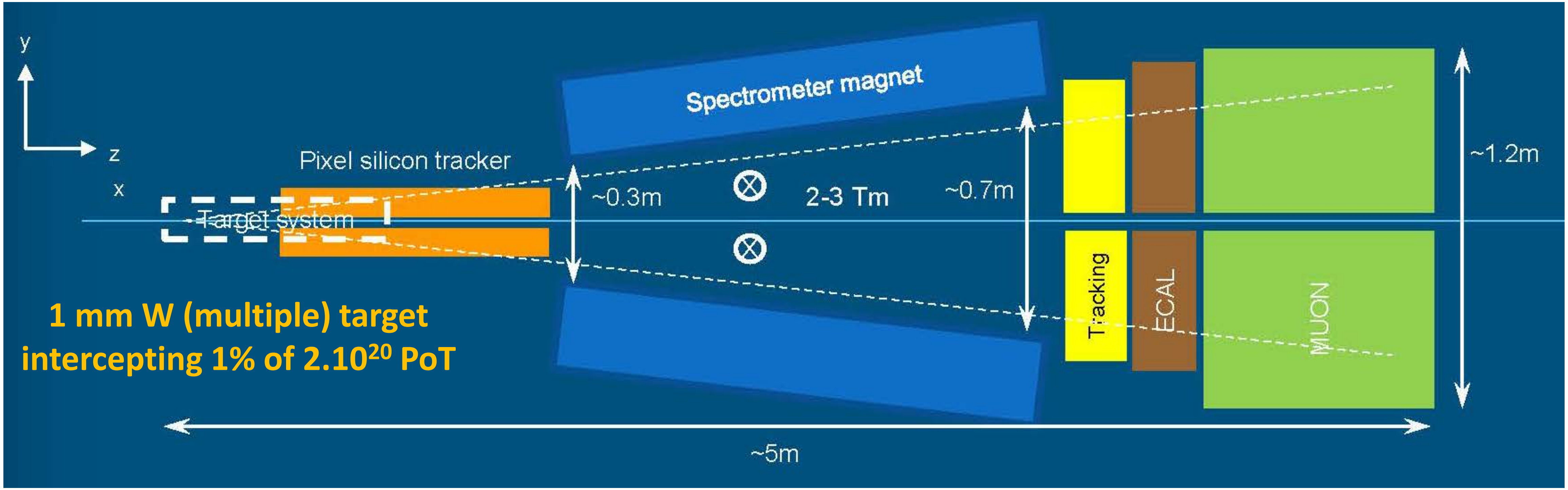
Strong improvement of KOTO performance expected in the coming decade… *and possibly later.*

Phasing of KLEVER in NA62 hall is a multi-parameter issue:
K^+ results ↔ K^+/K^0 sensitivity ↔ B-anomalies ↔ KOTO

TauFV

Interception of small BDF beam fraction to look for $\tau \rightarrow 3\mu$ decays

Could set limits on branching ratio better than 10^{-10} level (~BELLE-II reach)



Implementation layout under study *(see talk by Guy Wilkinson)*

A small exp. hall upstream of BDF target could trigger a unique rare decay facility

PBC PROJECTS SPECIFICITIES

1) QCD PROJECTS

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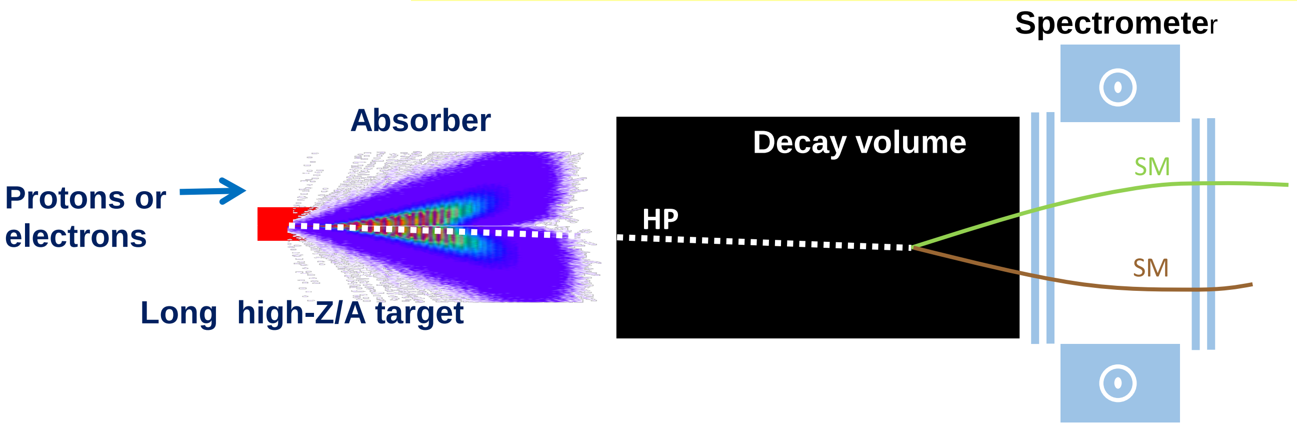
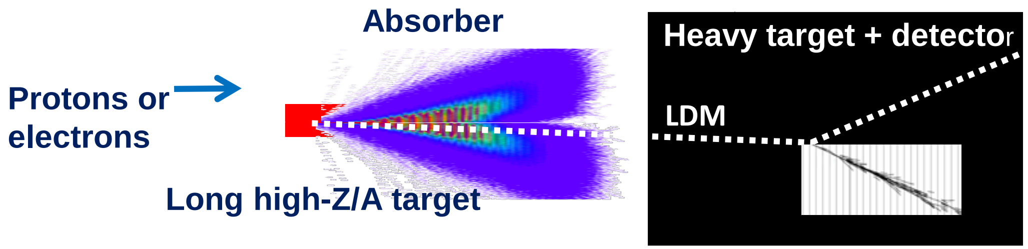
BEAM DUMP EXPERIMENTAL METHODS



Visible decay to SM particles

$$signal \propto \epsilon^4$$

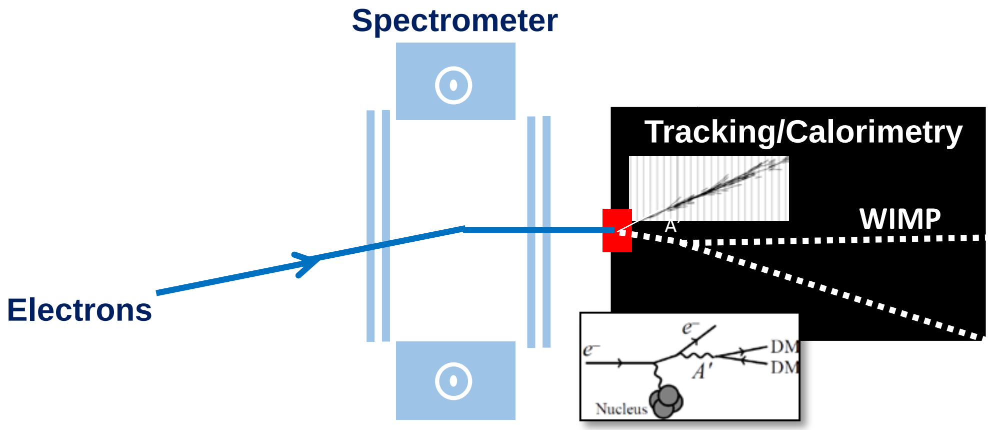
Critical: BG control



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

Graphics Courtesy Richard Jacobson

NB: reach in (m,ε) depends on many parameters:
beam energy & intensity, decay length, signatures, background …

MAIN PAST BEAM DUMP PROJECTS

DP = Dark Photon
DS = Dark Scalar
HNL = Heavy Neutral Lepton
ALP = Axion-Like Particle

EXPERIMENT	PERIOD	BEAM	PARTICLES ON TARGET	SIGNATURE	MODELS
E137 @SLAC	80's	e 20 GeV	$2\ 10^{20}$	recoil e	DP, ALPs
E141 @SLAC	80's	e 9 GeV	$2\ 10^{15}$	visible e^+e^-	DP, ALPs
E774 @FNAL	80's	e 275 GeV	$5.2\ 10^{9}$	visible e^+e^-	DP
NuTeV @FNAL	90's	p 800 GeV	$2\ 10^{18}$	visible μ	HNL
NUCAL @Serpukhov	80's	p 70 GeV	$1.7\ 10^{18}$	visible $\gamma\gamma$, e^+e^-, $\mu^+\mu^-$	DP, DS, ALPs
PS191 @CERN	80's	p 19 GeV	$0.8\ 10^{19}$	visible	HNL
CHARM @CERN	80's	p 400 GeV	$2.4\ 10^{18}$	visible $\gamma\gamma$, e^+e^-, $\mu^+\mu^-$	DP, DS, HNL

NB: most past beam dumps were "cheap" by-products of other experiments

MAIN CURRENT BEAM DUMP PROJECTS OUTSIDE CERN

DP = Dark Photon
DS = Dark Scalar
HNL = Heavy Neutral Lepton
ALP = Axion-Like Particle

EXPERIMENT	PERIOD	BEAM	PARTICLES ON TARGET	SIGNATURE	MODELS
HPS @JLAB	2016-20	e 2-6 GeV	$\sim 10^{20}$	visible e^+e^-	DP, ALPs
APEX @JLAB	2018-19	e 1-4.5 GeV	$\sim 10^{20}$	visible e^+e^-	DP, ALPs
BDX @JLAB	~2022	e 12 GeV	$\sim 10^{22}$	recoil e	DP, ALPs
LDMX @SLAC	> 2022	e 4-8 GeV	$2\ 10^{16}$	invisible	DP, ALPs
MiniBooNe @FNAL	2013-14	p 8 GeV	$1.8\ 10^{20}$	recoil e, N	DP
SBND @FNAL	>2020	p 8 GeV	$6\ 10^{20}$	recoil Ar	DP
SEAQUEST @FNAL	2021-30	p 120 GeV	$10^{18} \rightarrow 10^{20}$	visible e^+e^-	DP, DS, HNL
LBND @FNAL	>2025	p 120 GeV	$\sim 10^{21}$	recoil e, N	DP, DS, HNL

Recent dedicated experiments demonstrate a regain of interest for beam dumps

Flavour factories (BELLE II, …) have also some sensitivity from exotic decays

DP = Dark Photon
DS = Dark Scalar
HNL = Heavy Neutral Lepton
ALP = Axion-Like Particle

BEAM DUMP PROJECTS AT CERN

EXPERIMENT	PERIOD	BEAM	PARTICLES ON TARGET	SIGNATURE	MODELS
NA64++(e)	2015-24	e 100 GeV	~5 10^{12}	invisible & visible e^+e^-	DP, ALPs
eSPS/LDMX	> 2026	e 16 GeV	10^{16}	invisible	DP, ALPs
AWAKE++	> 2026	e ~50 GeV	~10^{15}	visible e^+e^-	DP, ALPs
NA62++	> 2022	p 400 GeV	10^{18}	visible	DP, DS, HNL, ALPs
SHiP	> 2026	p 400 GeV	2 10^{20}	recoil & visible	DP, DS, HNL, ALPs
NA64++(μ)	> 2022	μ 160 GeV	5 10^{13}	invisible	DZ_{μ} , ALPs

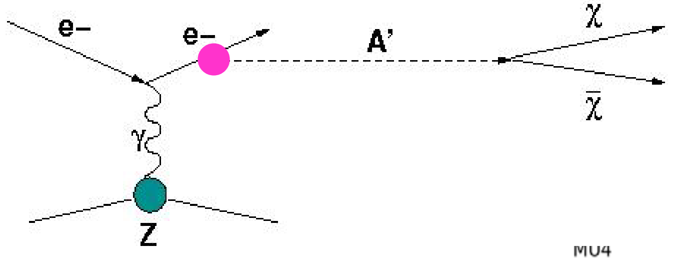
NB: CERN offers unique opportunities with both lepton and hadron beams

LHCb and LHC-LLP dedicated projects (FASER, milliQan, CODEX-b, MATHUSLA) have also sensitivity in similar mass range

"Cheap" setup implemented in 2015 on H4 e test beam

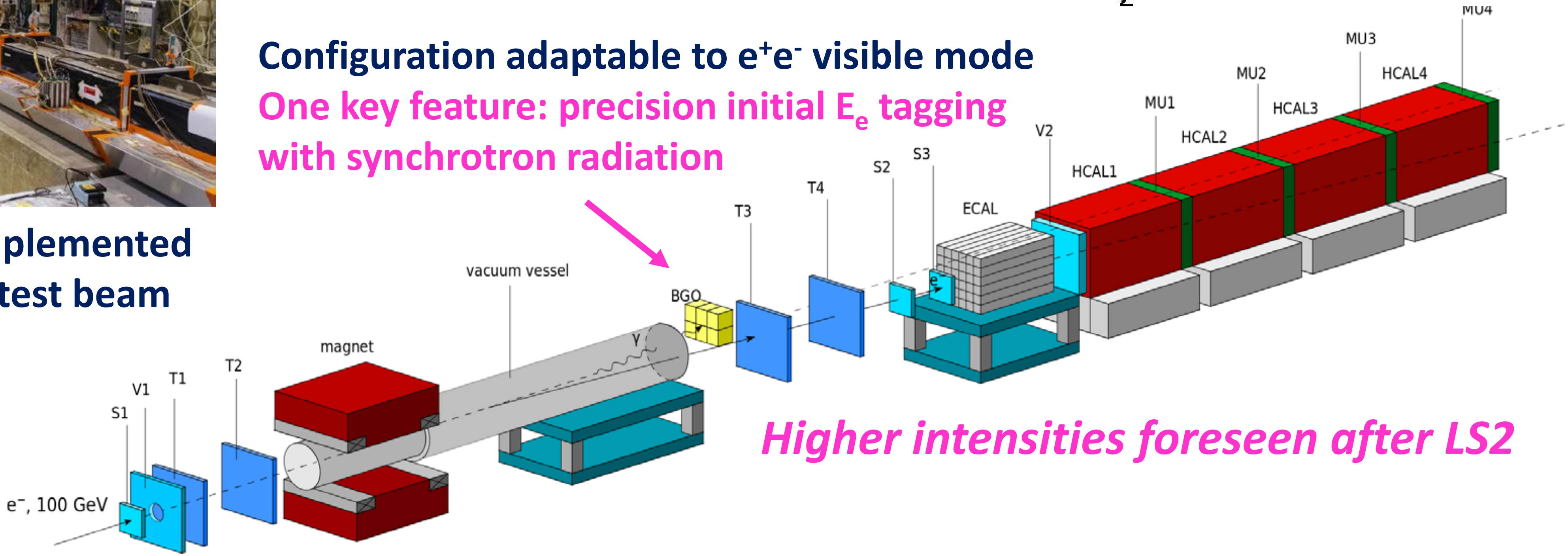
NA64++

Dark Photon search from invisible decays with missing energy



Configuration adaptable to e^+e^- visible mode

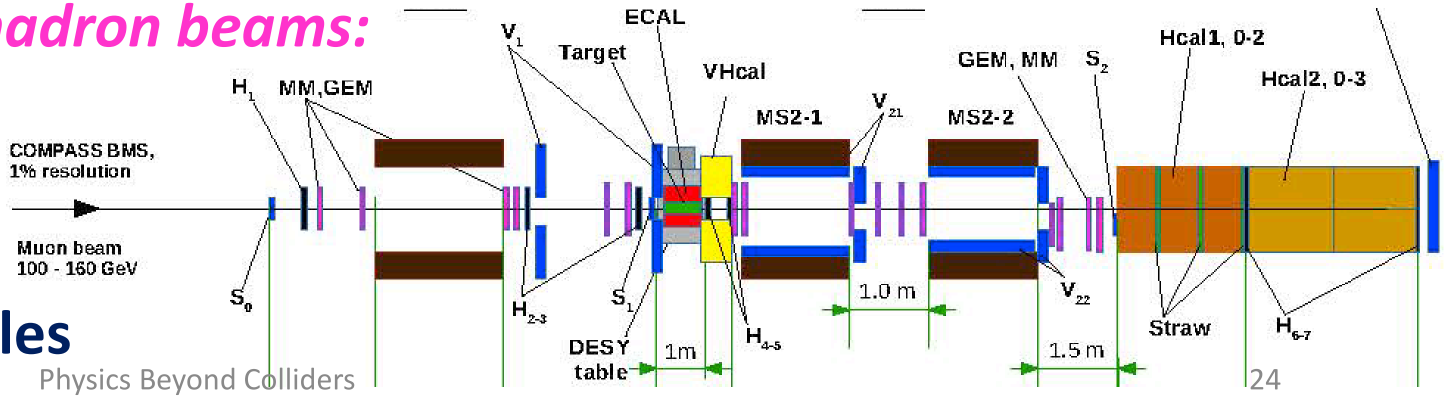
One key feature: precision initial E_e tagging with synchrotron radiation



Higher intensities foreseen after LS2

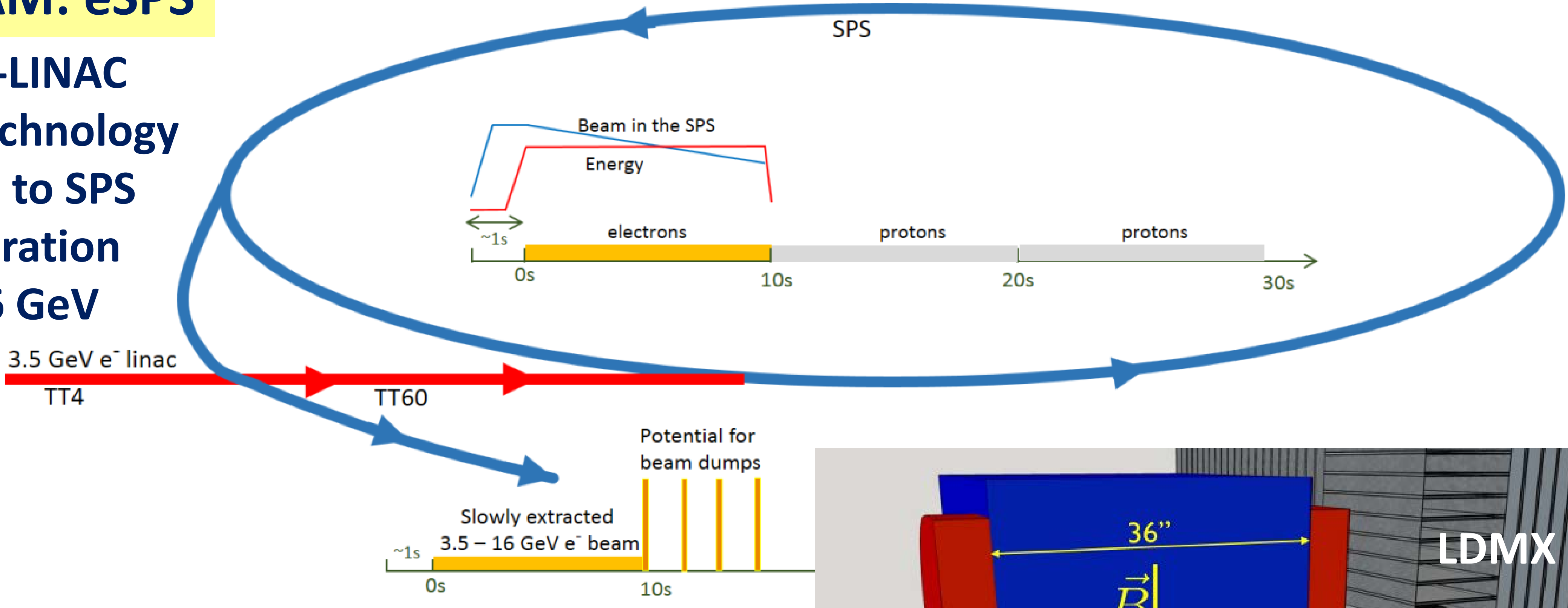
Wish also to extend the method to μ / hadron beams:

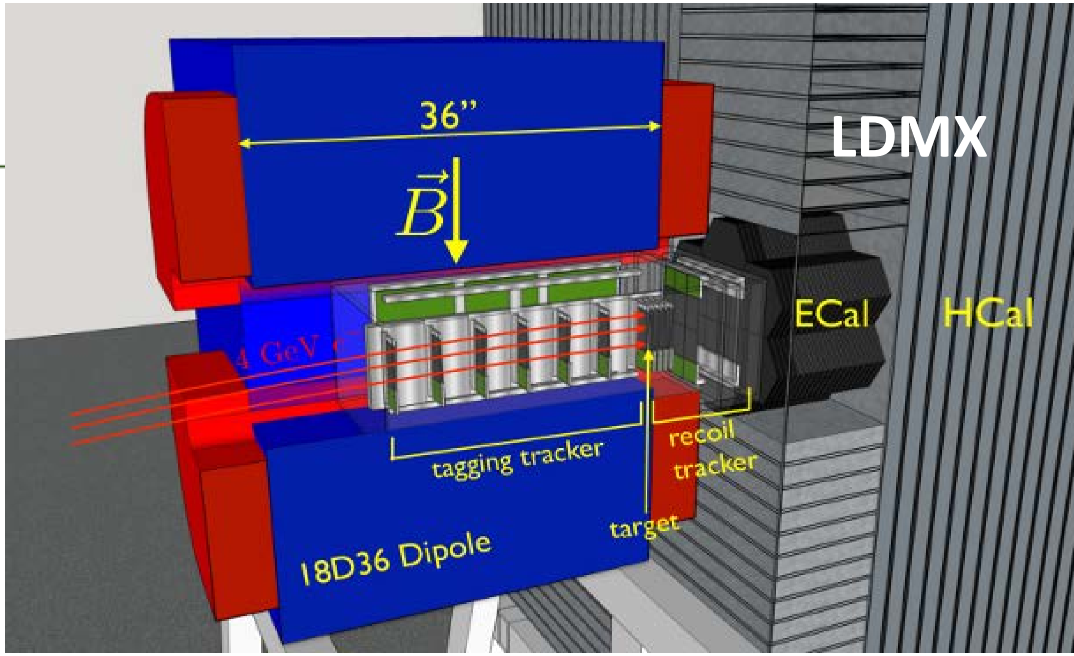
- Few months of μ beam would test a $(g-2)_\mu$ interpretation
- Few years of μ beam would improve limits on millicharged particles



NEW e-BEAM: eSPS

3.5 GeV e-LINAC
with CLIC technology
connected to SPS
for acceleration
up to 16 GeV



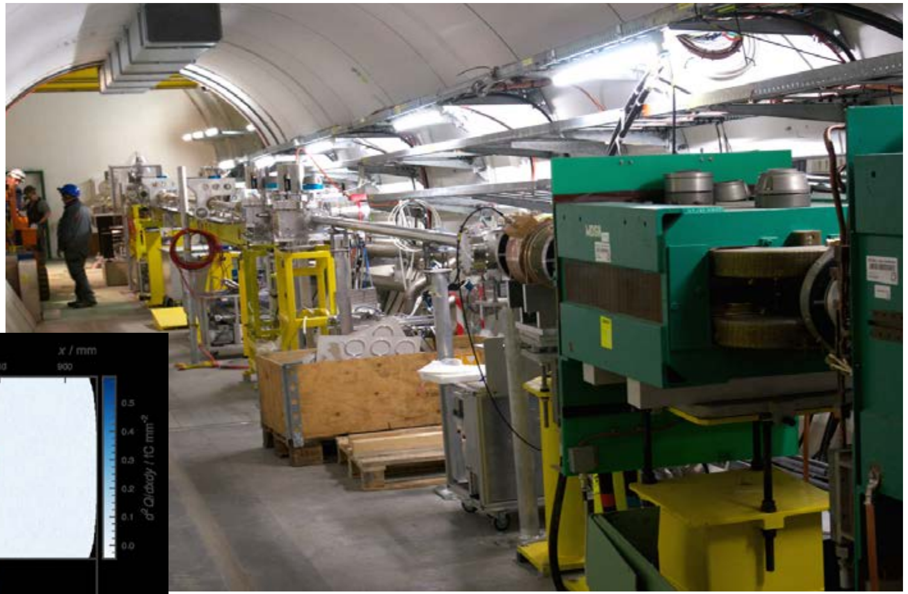


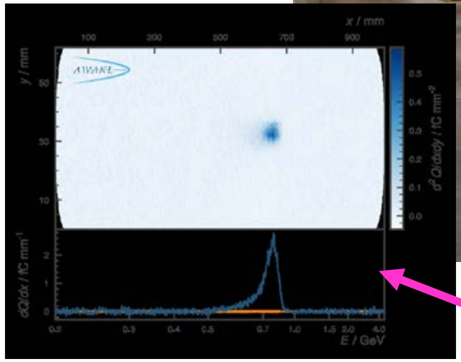
Slow extraction of up to ~10^{16} e/year
if 1/3 of SPS duty cycle reserved to project

Would allow hidden sector searches
in the invisible mode with a LDMX-like detector

NEW e-BEAM: AWAKE++

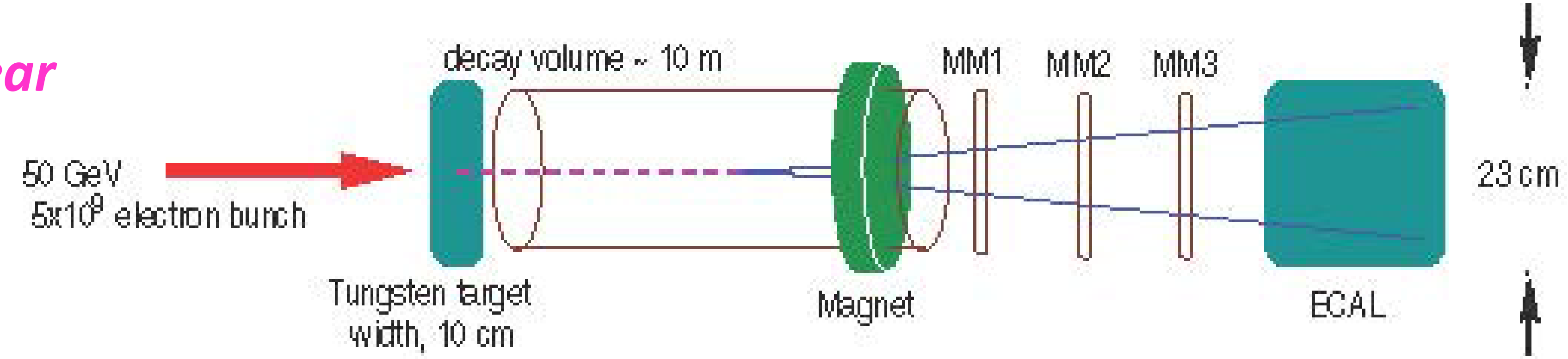
electron acceleration with a plasma cell excited by proton bunches





First accelerated e seen in 2018 (~2 GeV) - Phase 2 (~10 GeV) in preparation for run3

Could provide ~10^{15} ~50 GeV pulsed e's/year in the post-LS3 era for e^+e^- visible searches by an experiment located in the CNGS decay tunnel



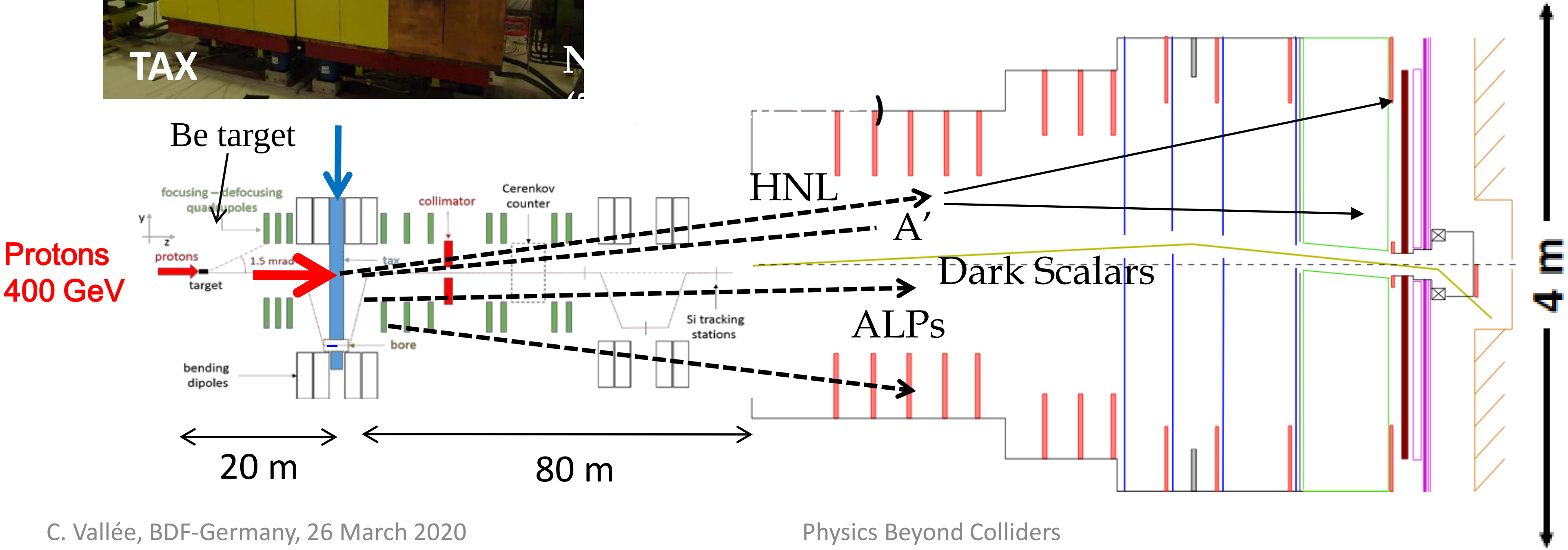
NA62 BEAM DUMP

Some NA62 data taking in beam dump mode under consideration for run 3

Achieved by closing the TAX collimator

1 year would correspond to ~10^{18} PoT

Instrumentation of NA62 decay vessel well adapted to searches in visible mode



A potential precious source of information to final SHiP optimization

BDF/SHiP

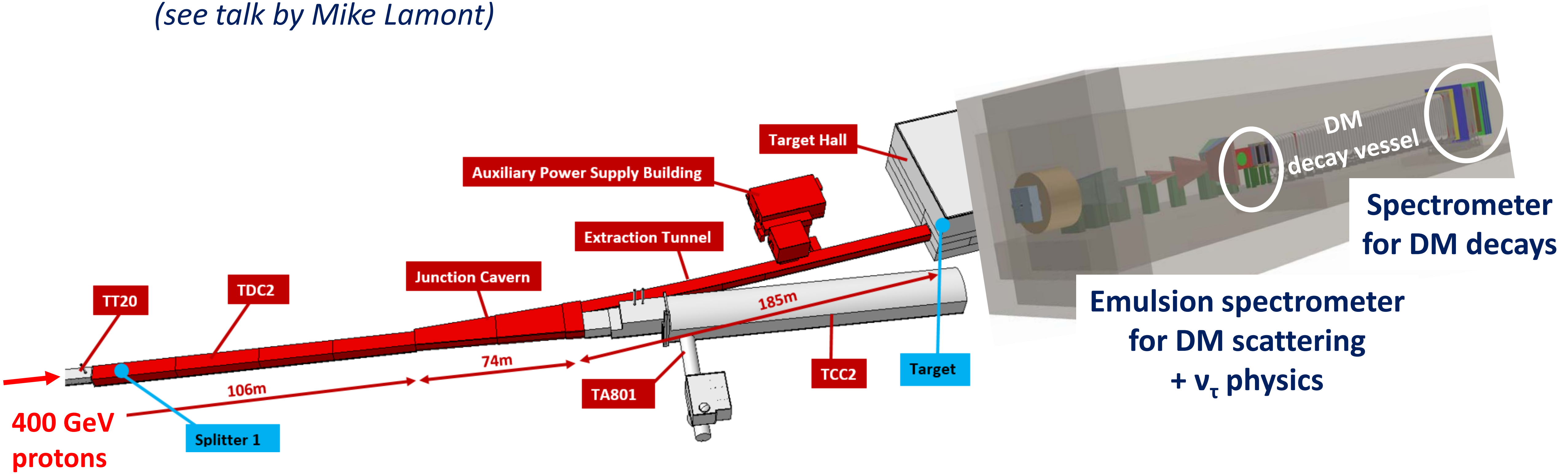
BEAM DUMP FACILITY:

Comprehensive Design Study done

(see talk by Mike Lamont)

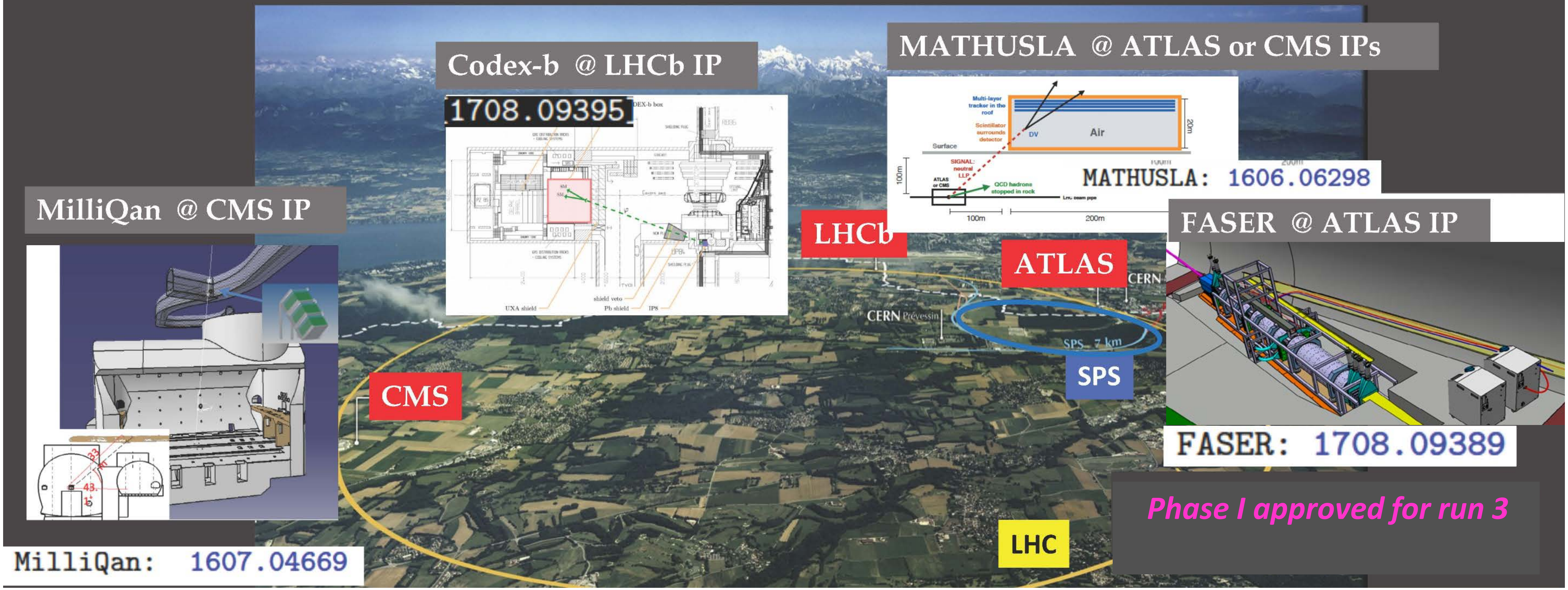
SHiP:

Dual spectrometer



LHC-LLP DEDICATED PROJECTS

MilliQan, MATHUSLA, FASER, Codex-b @ the LHC IPs



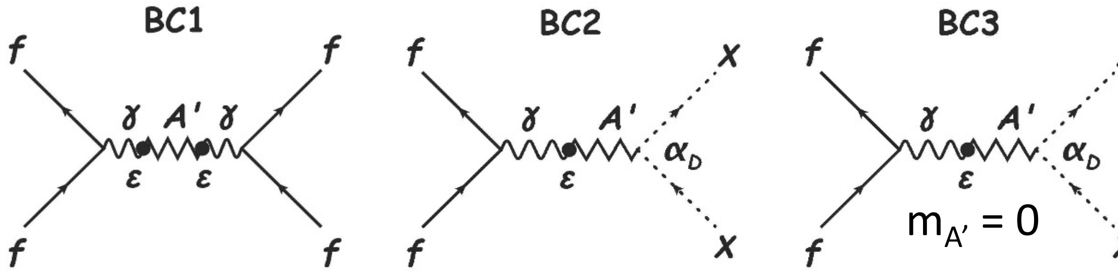
Phase I approved for run 3

NB: all are "small scale" projects except MATHUSLA

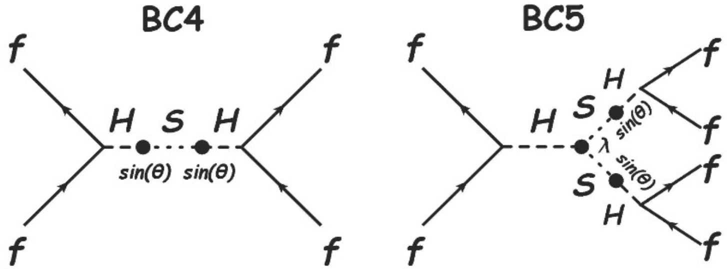
PBC BENCHMARK MODELS FOR HIDDEN SECTOR

defined to cover most signatures and compare reach of projects under same assumptions

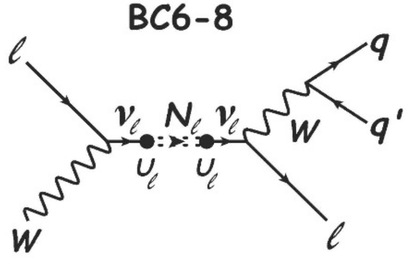
Dark Photons, Dark Matter & millicharged particles



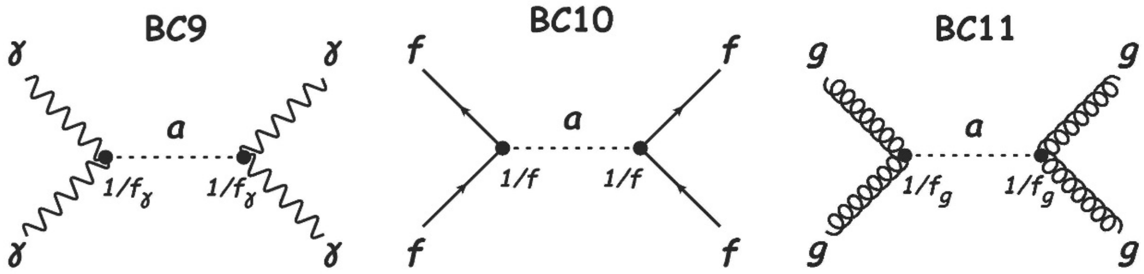
Dark Scalars



Heavy Neutral Leptons

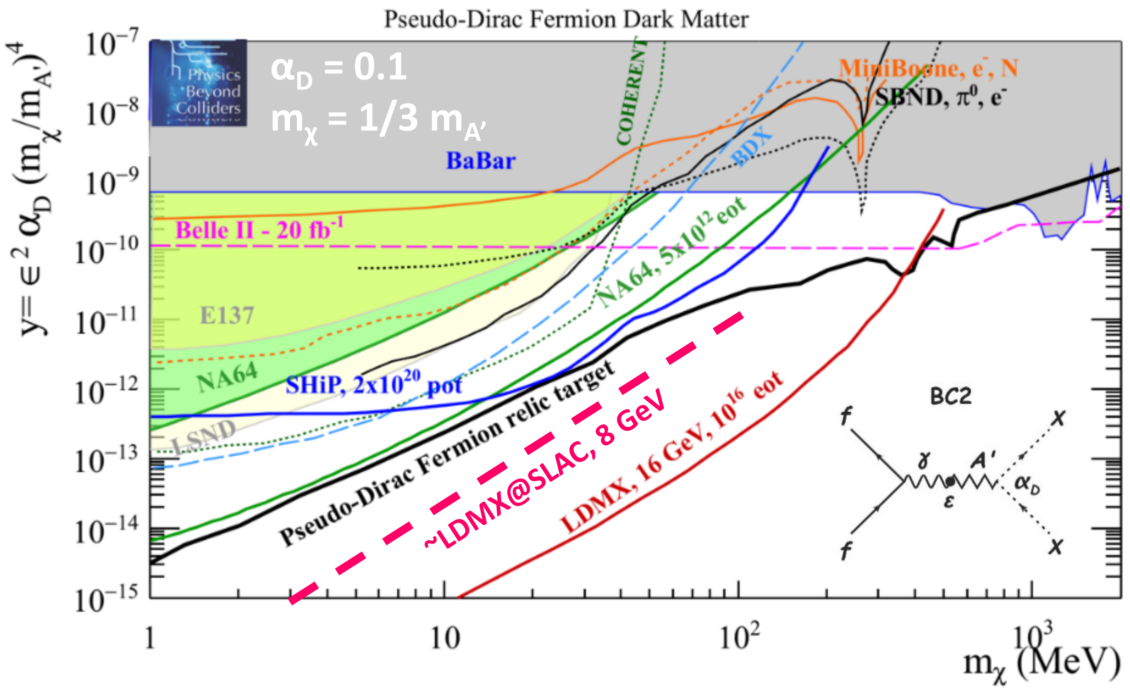


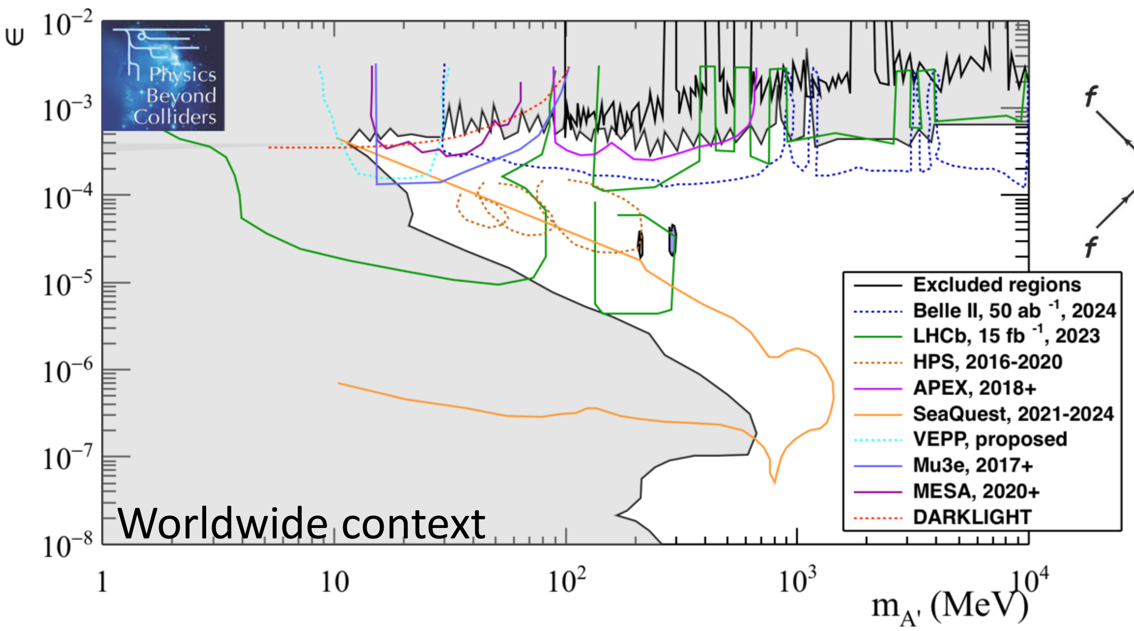
Axion-Like Particles

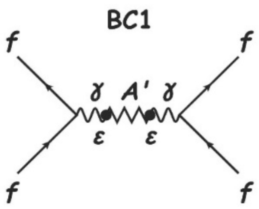


SENSITIVITIES TO DARK PHOTONS

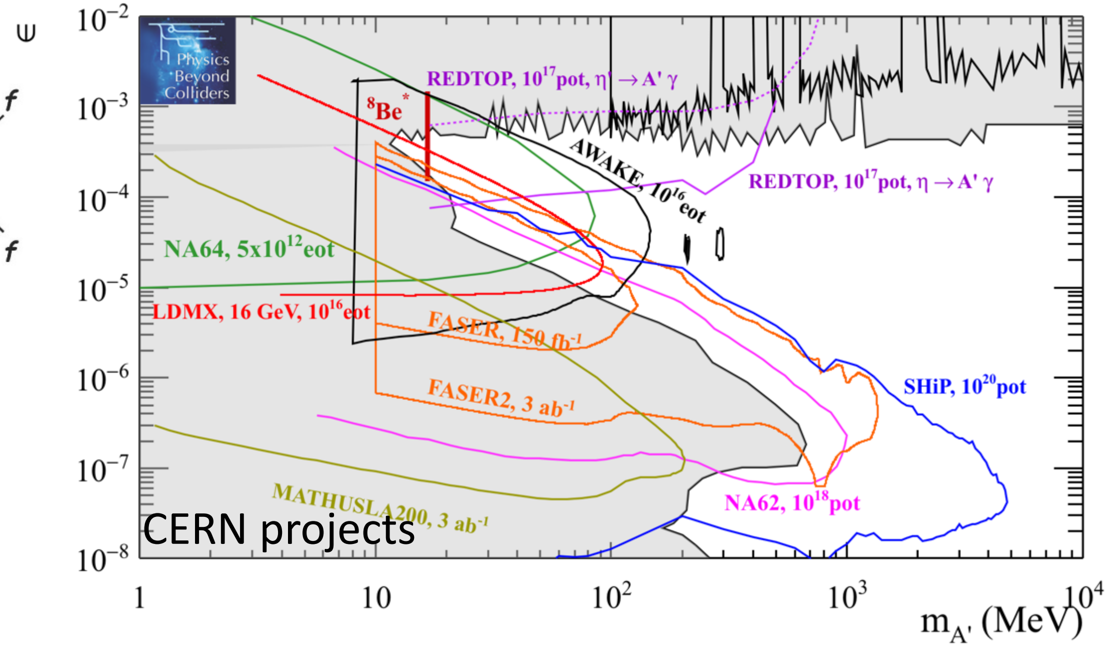
- A significant part of the LDMX potential can be covered at SLAC (in final approval stage)
- AWAKE++ domain expected to be covered by the competition in the coming decade
- NA64++ has a unique short term potential
- SHiP has the highest long term potential at high mass / low couplings



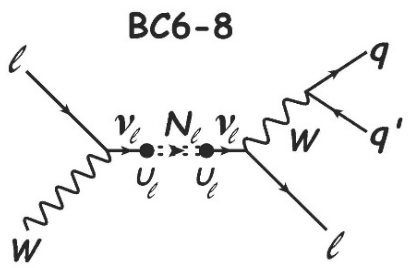




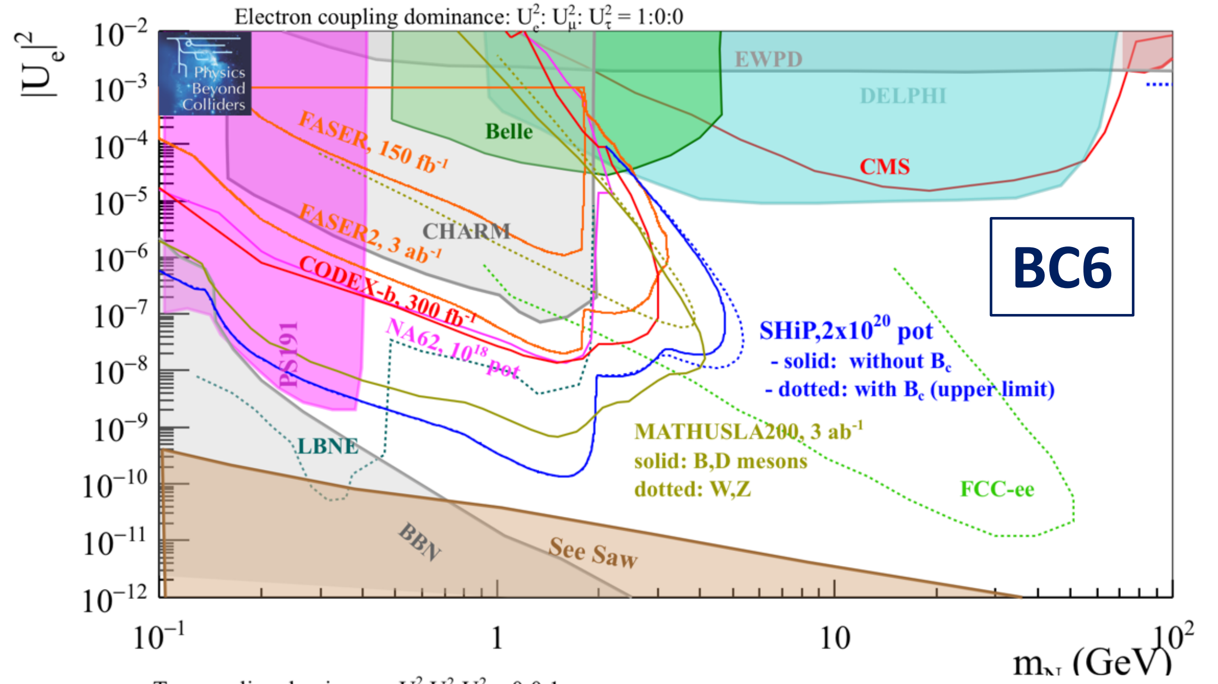
Beyond Collid

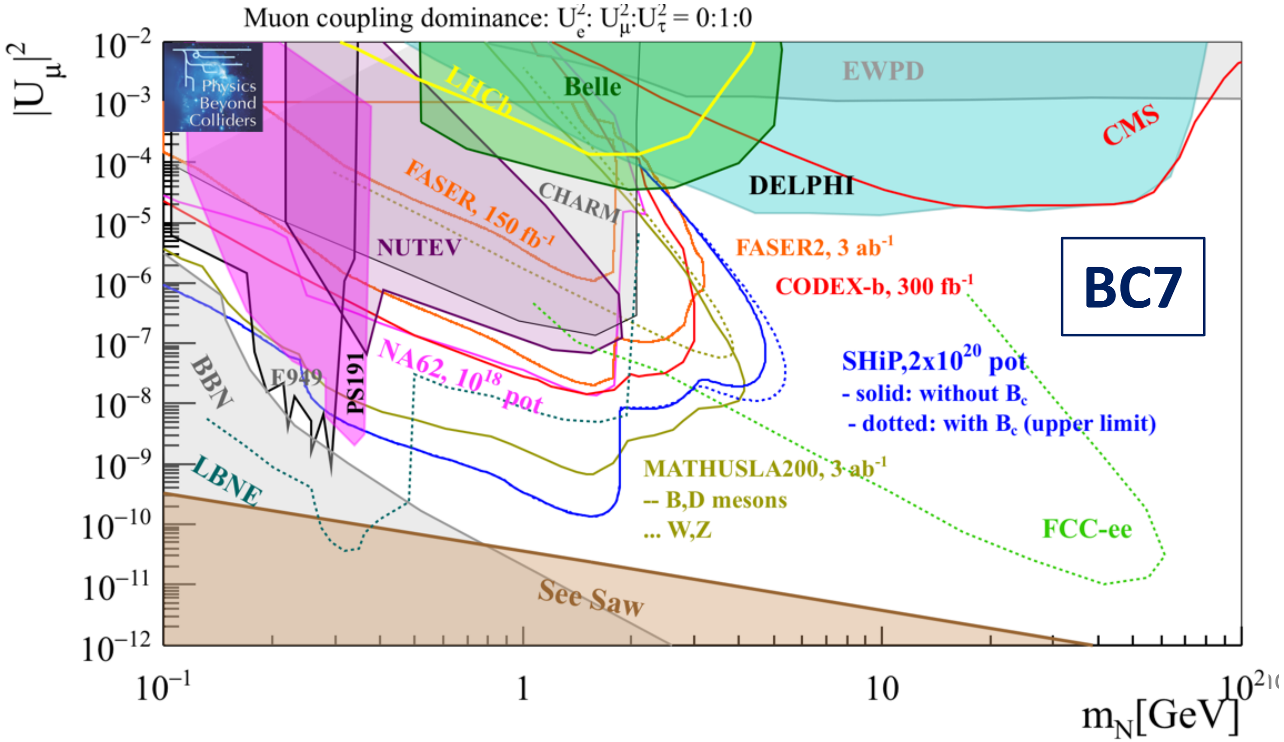


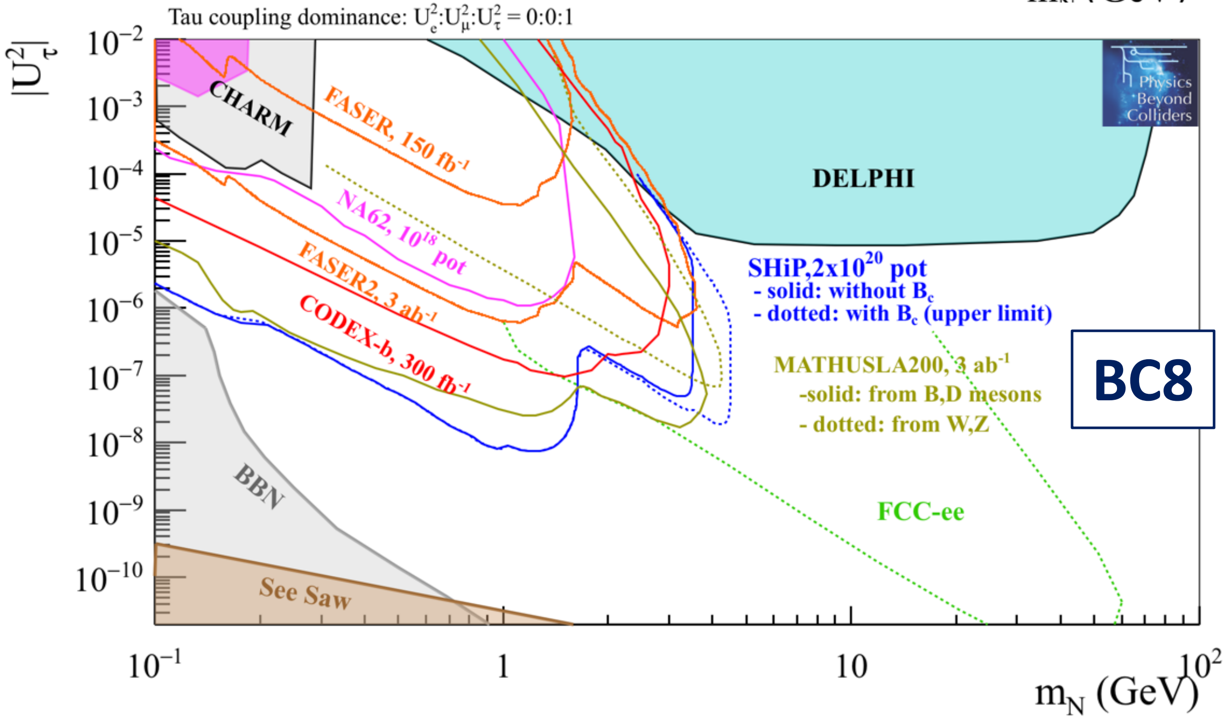
SENSITIVITIES TO DARK FERMIONS (HNL's)



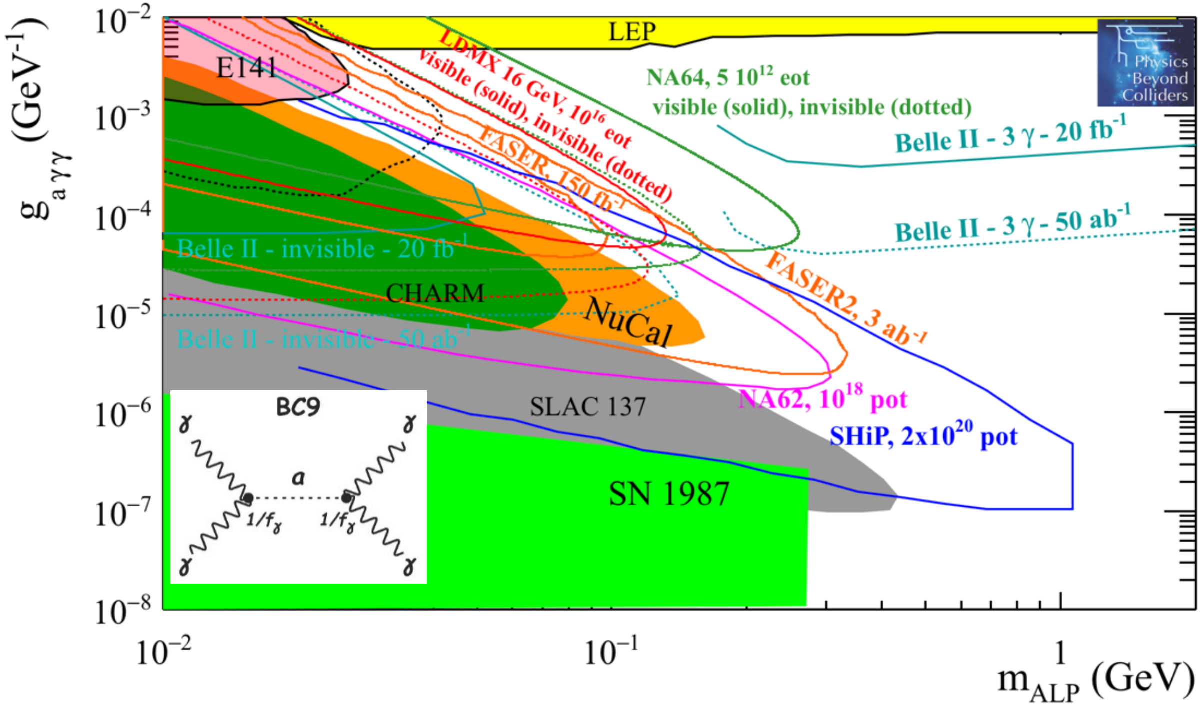
- Unique short term opportunities with NA62 Beam Dump and FASER
- SHiP has the highest reach on the long term

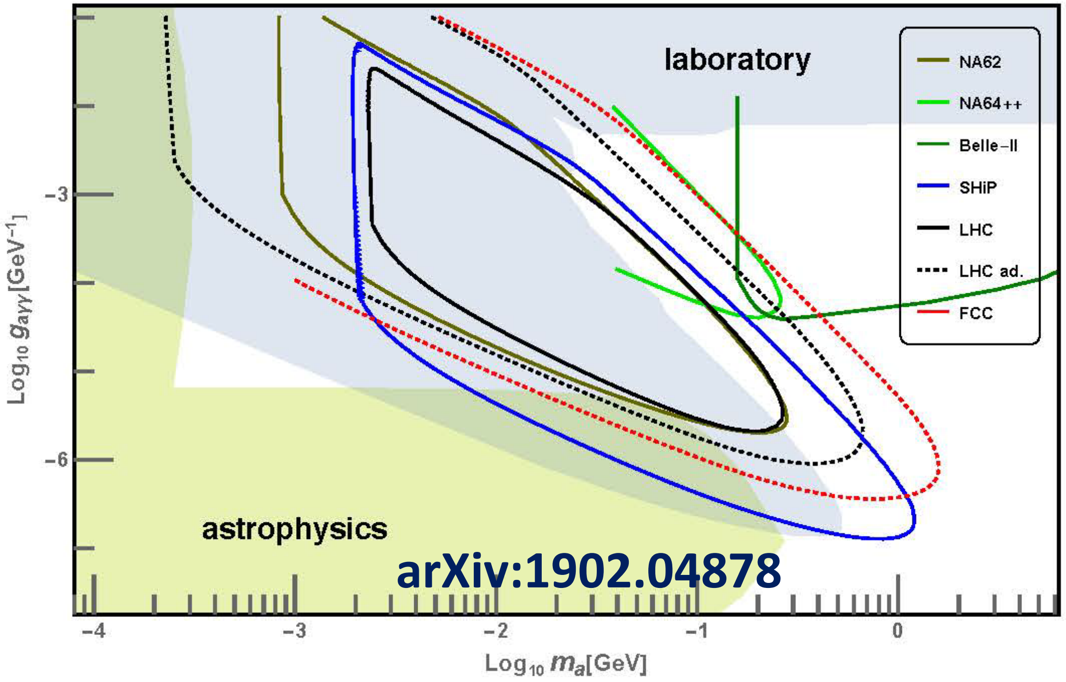






EXPLORATORY STUDY OF HIGHER-ENERGY BEAM DUMPS POTENTIAL
the example of ALPS





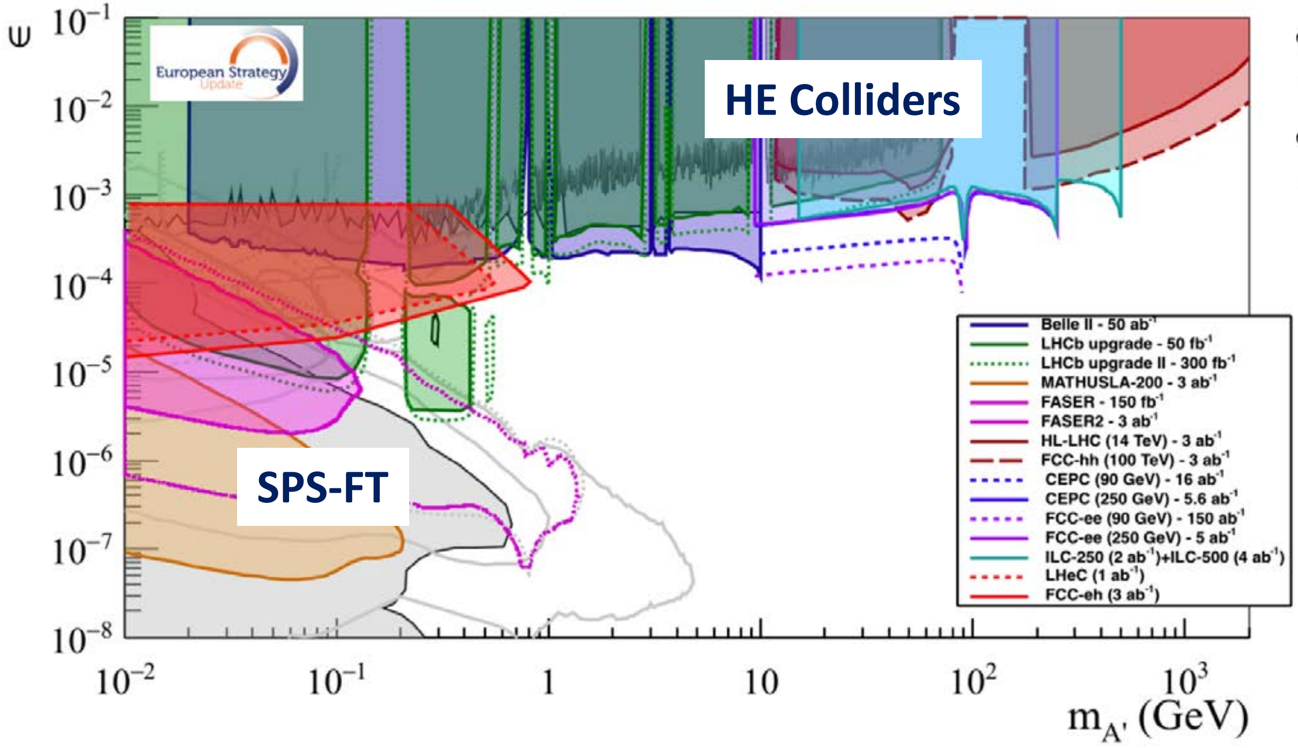
PBC projects have a similar reach as for visible A'
(similar signatures $\gamma\gamma$ and e^+e^-)

No real breakthrough of LHC/FCC beam dumps:
SPS seems to offer a quite optimal energy-intensity mix in the present context

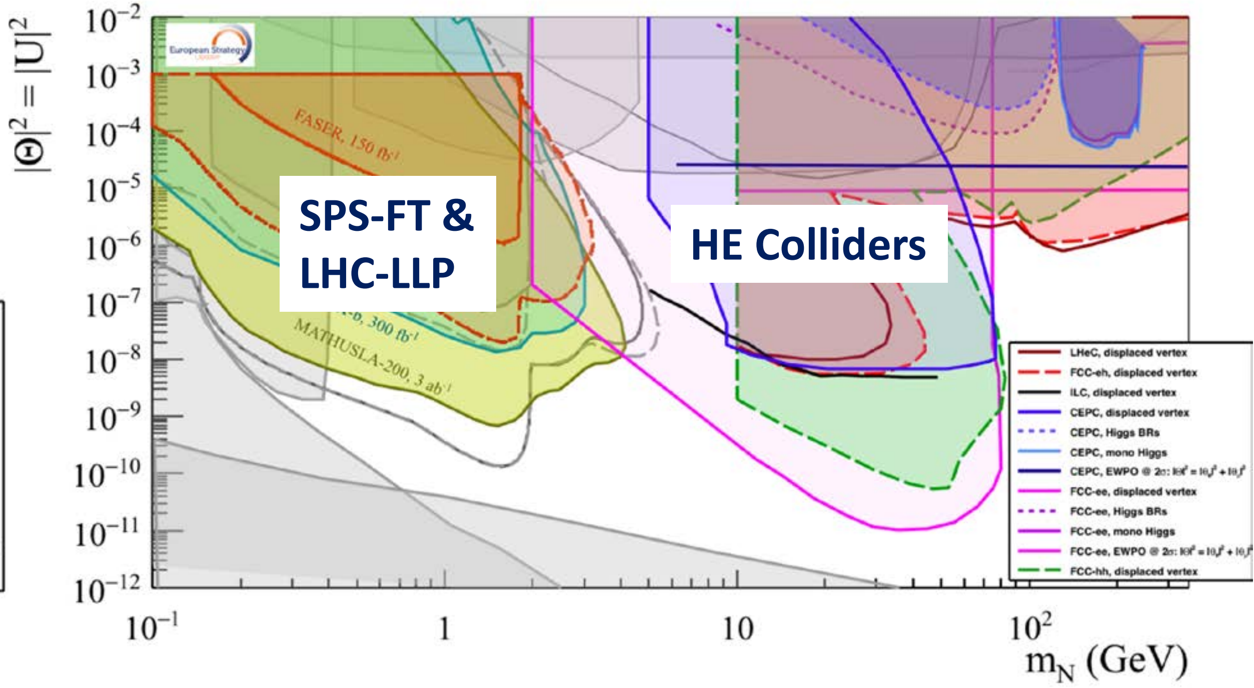
Comparison of SPS FT and HIGH-ENERGY COLLIDERS for hidden searches

(courtesy Gaia Lanfranchi, see EPPSU Briefing Book)

Dark Photons



HNLs



Different domains of similar "sizes" explored by the various facilities

→ all approaches needed to cover the full landscape

SUMMARY AND OUTLOOK

The PBC study has shown that:

- **SHiP has the highest potential for hidden sector searches among worldwide fixed target projects;**
- **The SPS has an optimal energy/intensity mix for a proton beam dump;**
- **The BDF exploration of the hidden sector is fully complementary to non-accelerator and high-energy frontier collider projects.**

The BDF/SHiP design explores the new paradigm of a state-of-the-art dedicated proton beam dump w.r.t previous opportunistic beam dumps.

The future now lies in the hands of the EPPSU. My personal opinion: BDF/SHiP is the most promising among CERN mid-size new facilities considered by EPPSU for the future.

EXTRA SLIDES

HISTORY OF PBC EVENTS

PBC KICK-OFF WORKSHOP, CERN, September 2016

Call for abstracts → 20 selected for presentation

1st GENERAL WORKING GROUP MEETING, CERN, March 2017

Identification of main issues to be studied

2nd PBC WORKSHOP, CERN, November 2017

Working groups project reports

New call for abstracts → 7 selected for presentation

2nd GENERAL WORKING GROUP MEETING, CERN, June 2018

Status of studies for PBC deliverables

3rd PBC WORKSHOP: CERN, January 16-17, 2019

Summary of inputs to EPPSU and survey of future studies

3rd GENERAL WORKING GROUP MEETING, CERN, 5-6 November 2019

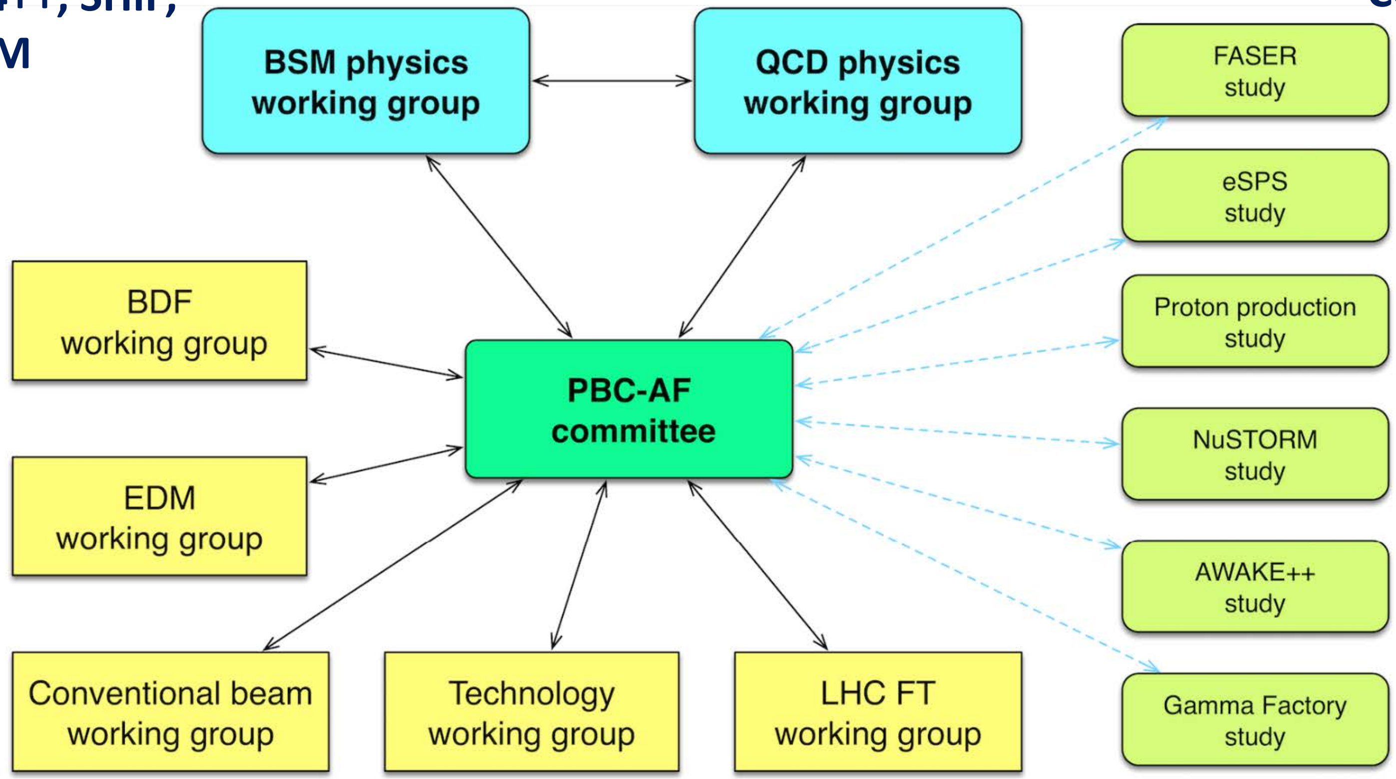
Updated status of projects before EPPSU drafting session

PBC WORKING GROUP STRUCTURE

Main coordinators: J. Jaeckel, M. Lamont, C. Vallée

BSM conveners: C. Burrage, G. Lanfranchi, S. Rozanov, G. Ruoso
+ ext. experts + projects representatives:
NA62++, KLEVER, NA64++, SHiP,
LDMX, IAXO, JURA, EDM

QCD conveners: M. Diehl, J. Pawlowski, G. Schnell
+ ext. experts + projects representatives:
COMPASS++, MUonE, DIRAC++
AFTER, CRYSTAL,
LHCb-FT, ALICE-FT
NA61++, NA60++



~100 core members in the Working Groups **> 200 WG meetings in the past 3 years**

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

PBC DELIVERABLES: ACCELERATOR WGs

Working group	10 pager for ESPP for 18th December - WG dependent	Possible proponents/clients submitting 10 pager to ESPP	PBC deliverable for 18th December * (referenced by 10 pager)
AWAKE++	Y	Proposed client experiment	Exploratory study
BDF	Y	SHiP, tauFV	Comprehensive Design Study - tauFV as appendix
Conventional beams	Y	NA61, NA62++, KLEVER etc.	Description of the conventional beam upgrades associated to the proposed projects
EDM	Y		3 appendices: COSY; prototype; full ring (feasibility study).
eSPS	Y	LDMX,BD	Technical report on possible implementation at CERN
FASER acc.	N	FASER	Technical report on possible implementation in LHC
Gamma factory	Y		Exploratory study
LHC FT	N	AFTER@LHC, LHCspin, MDM/EDM	Technical study of feasibility
nuSTORM	Y		Broad outline of a possible nuSTORM implementation at CERN
Perf post-LIU	N		Injector complex performance after LIU
Technology	Y	IAXO et al	Exploration and evaluation of possible technological contributions of CERN to non-accelerator projects possibly hosted elsewhere

Reports publicly available on CERN CDS: http://cds.cern.ch/collection/PBC%20Reports?ln=en

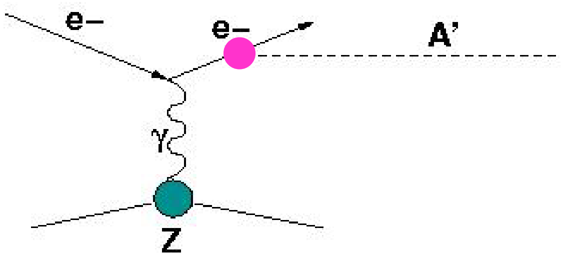
EXPERIMENTS READINESS

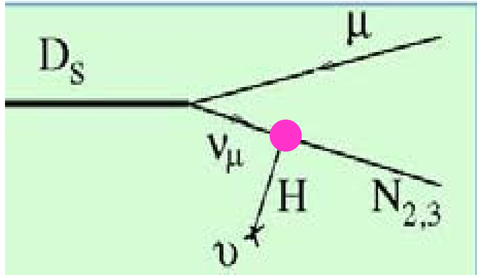
Summarized in a semi-quantitative table

Quote:	A B C	ready need upgrade to be built	ready under design need R&D	adequate to strengthen to be built	< 10 M€ 10-50 M€ > 50 M€	Run 3 Run 4 Run 5
Project	**Physics highlight**	**Beam requirement**	**Detector maturity**	**Collaboration**	**Cost beam+det**	**Earliest operation**
NA61++	QGP Charm	B	B	A	A	A
COMPASS+	R_p & QCD	A	B	A	A	A
COMPASS++	QCD	B	B	B	B	B
MUonE	HVP(g-2)$_\mu$	A	B	B	A	A
LHC-FT	QCD	A	B	B	A	A
LHC-FT++	spin/MM/EDM	A	C	B	A	B
NA60++	QGP phase	C	B	C	B	B
DIRAC++	chiral QCD	C	B	C	B	B
NA62++	dark sector	B	A	A	A	A
KLEVER	$K^0 \to \pi^0\nu\bar{\nu}$	B	C	B	B	B
NA64++	dark photon	A	B	A	A	A
SHiP	dark sector & ν_τ	C	B	A	C	B
TauFV	$\tau \to 3\mu$	C	C	B	C	C
REDTOP	η decays	B	C	B	B	B
EDM ring	p EDM	C	C	B	C	C
eSPS	dark photon	C	B	B	C	B
AWAKE++	dark photon	C	B	A	B	B
nuSTORM	$\sigma(\nu)$	C	C	B	C	B
γ-Factory	high rate γ	C	C	C	-	C

New projects also constrained by existing beamlines/halls/experiments

HIDDEN SECTOR MAIN PRODUCTION MODES





Primakov/Bremstrahlung:

Mass reach mainly in sub-GeV domain, weakly dependent on beam energy

Meson decays:

Mass reach in multi-GeV domain dependent on accessible meson mass thresholds (K,D,B)

EXPERIMENTAL SIGNATURES

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	$\gamma\gamma$

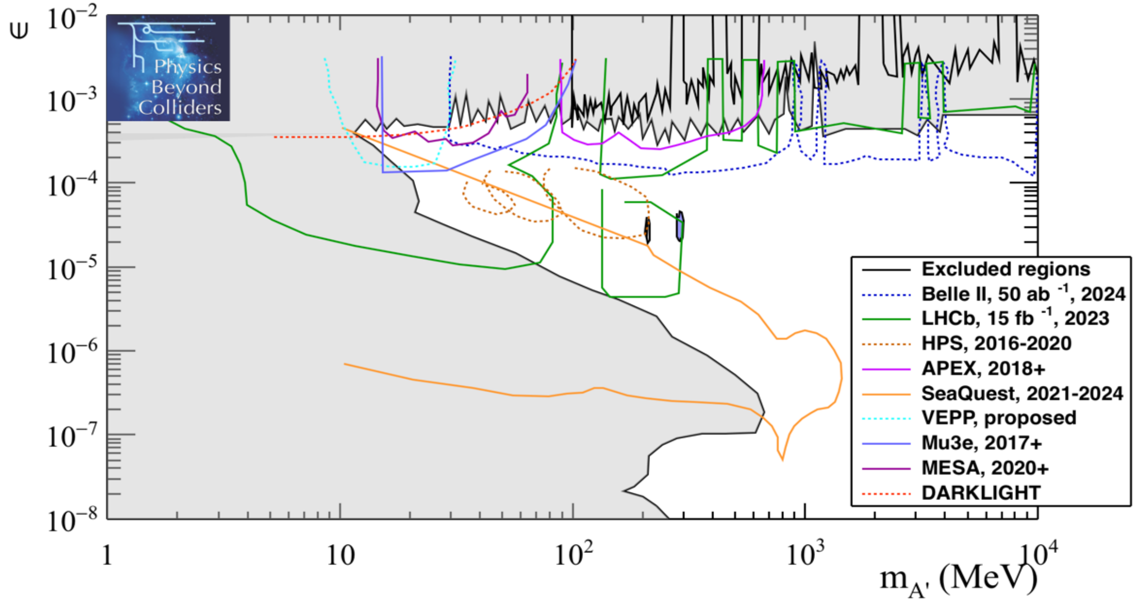
+ recoil particles or missing energy for rescattering / missing energy methods

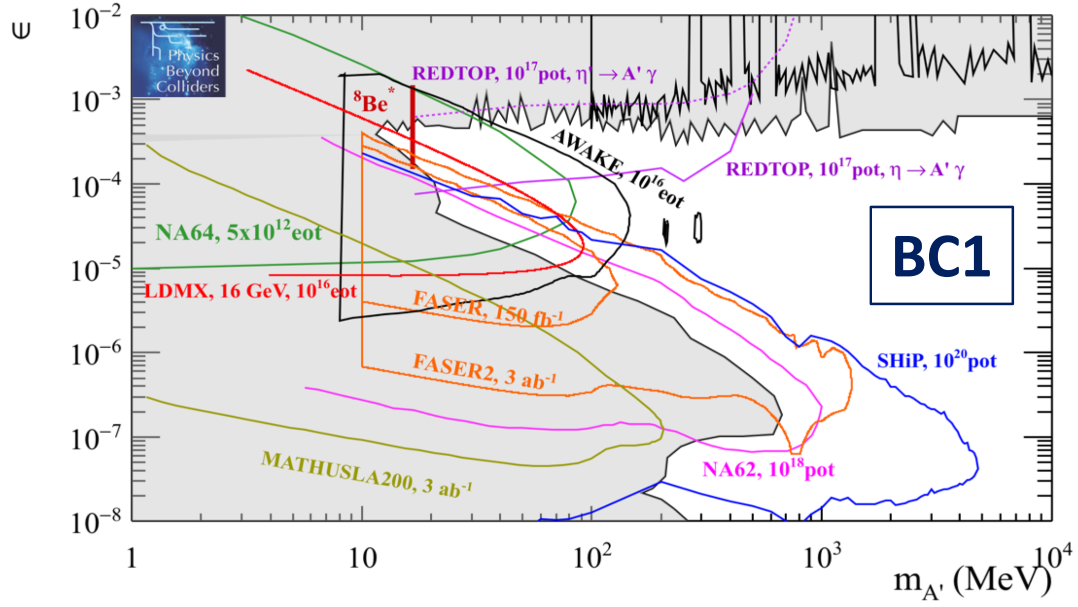
LEVEL OF MATURITY OF SENSITIVITY ESTIMATIONS

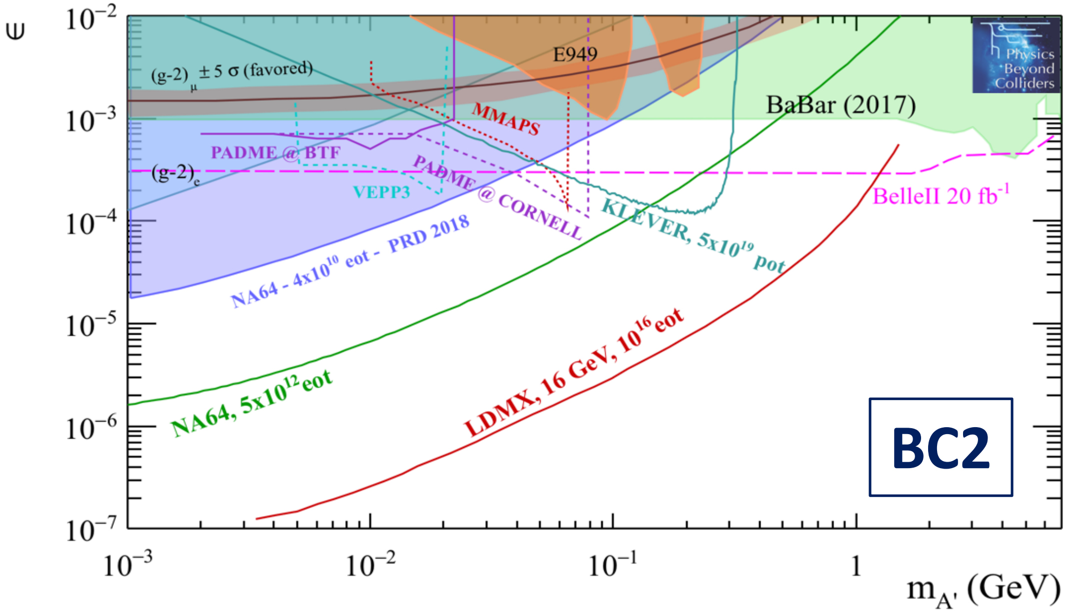
Project	Background	Efficiency	Inputs
NA62++	0-BG assumed	partly included	10^{16} PoT run in BD mode
KLEVER	partly included	included	fast simulation
REDTOP	included	included	full simulation
NA64++(e)	included	included	real data
NA64++(μ)	0-BG assumed	100 % assumed	M2 μ beamtest
eSPS/LDMX	included	included	full simulation at 4 GeV
AWAKE++	0-BG assumed	100 % assumed	toy model
SHiP	0-BG assumed	included	full simulation
CODEX-b	0-BG assumed	included	full simulation
FASER	0-BG assumed	100 % assumed	BG simulations & in situ measurements
MATHUSLA200	0-BG assumed	100 % assumed	cosmic & LHC BG fluxes
milliQan	included	included	full simulation

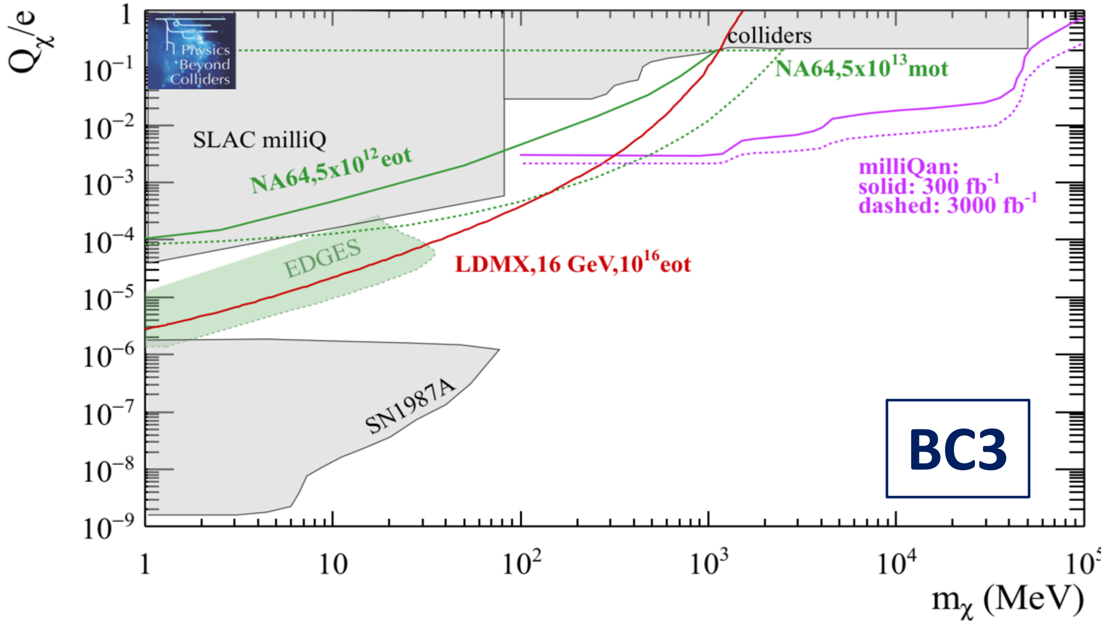
DARK VECTORS

BC1 worldwide context



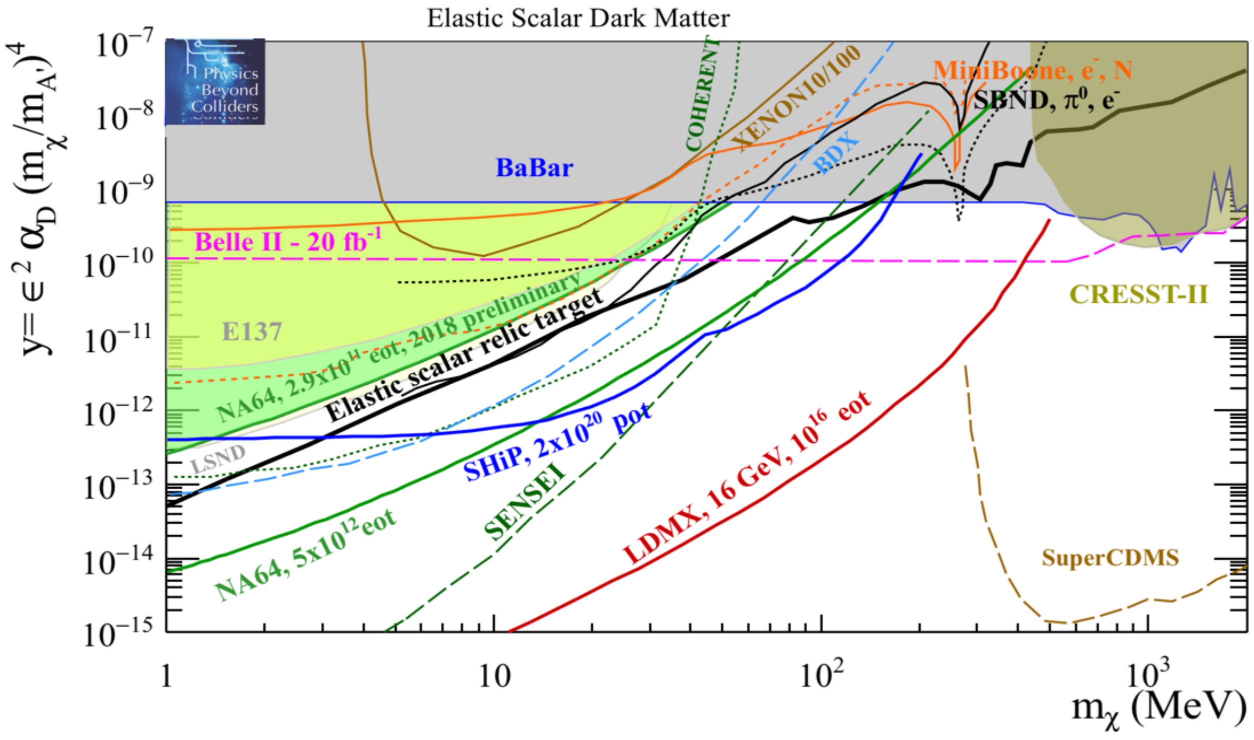


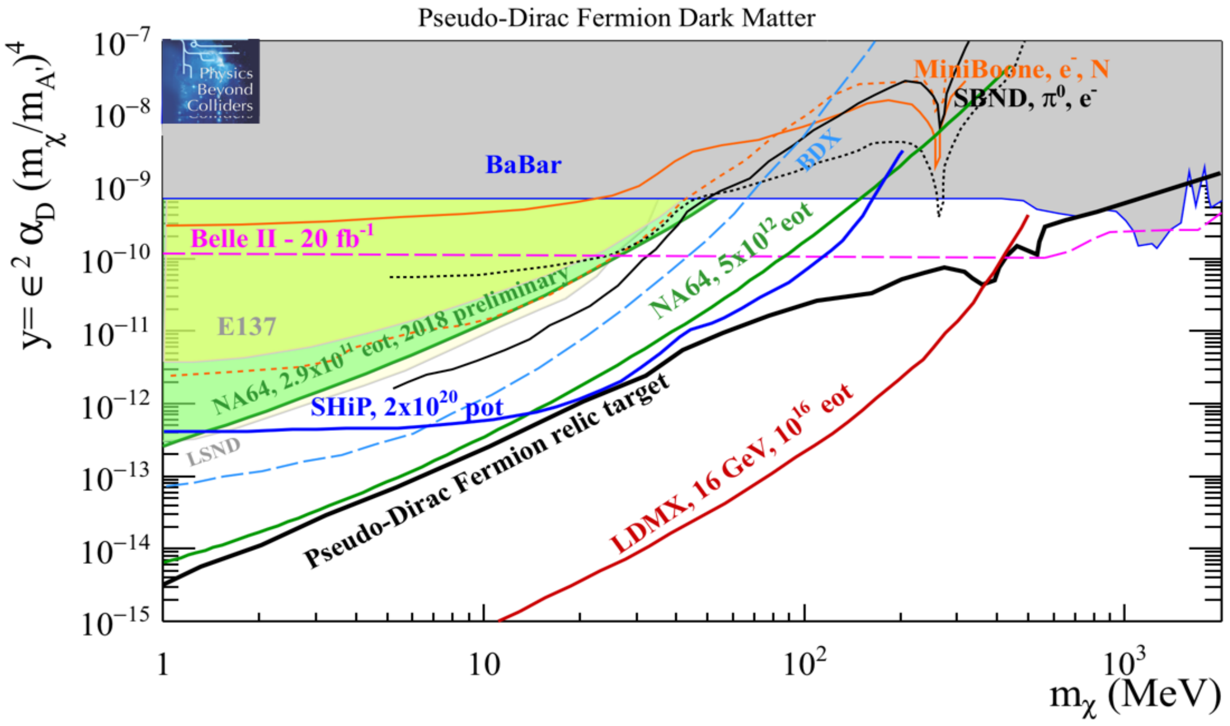




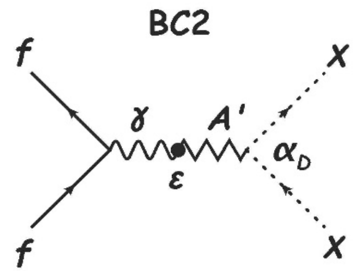
DARK VECTORS IN DM PARAMETER SPACE (BC2)

$\alpha_D = 0.1 \qquad m_\chi = 1/3\ m_{A'}$

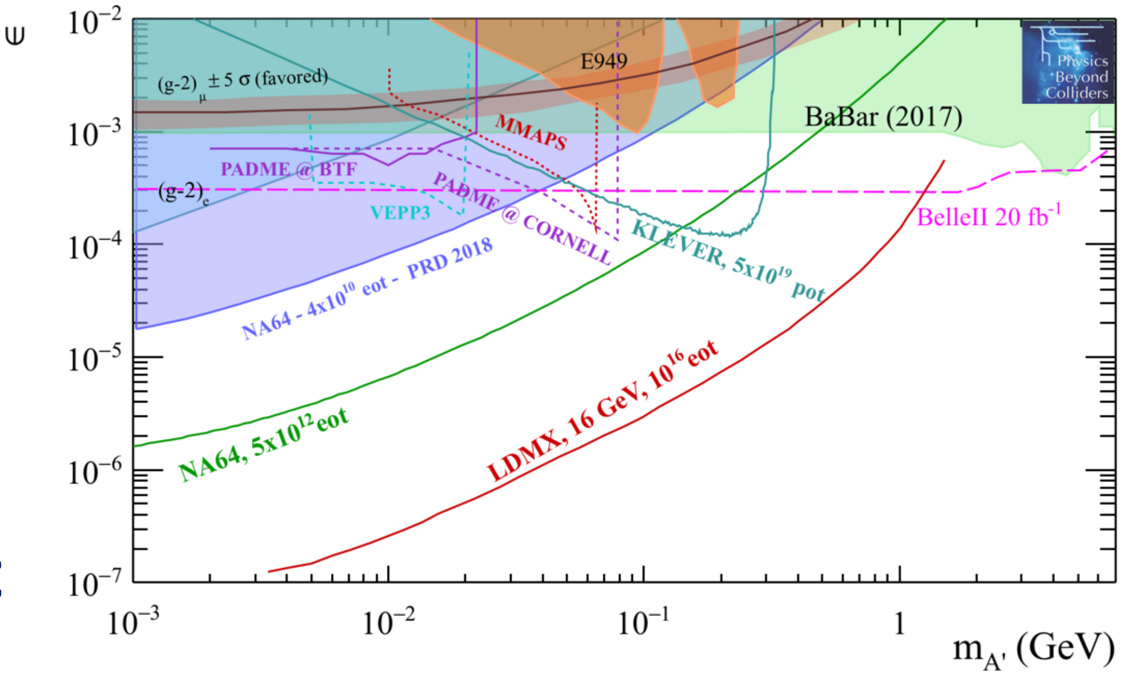


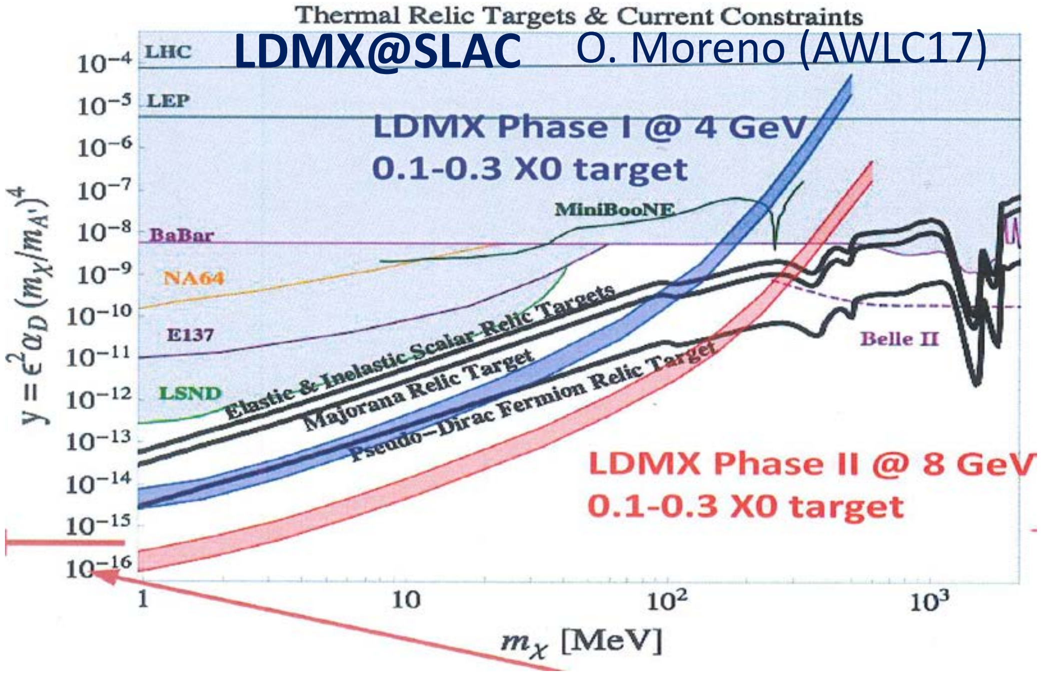


Dark Photon invisible mode



- **Unique NA64++(e) short term opportunity to explore the relevant DM parameter space**
- **Significantly higher reach of LDMX@eSPS, to be put in regard with a possible faster&cheaper implementation of LDMX at SLAC** ***(pending approval of LCLS-II beam extraction)***

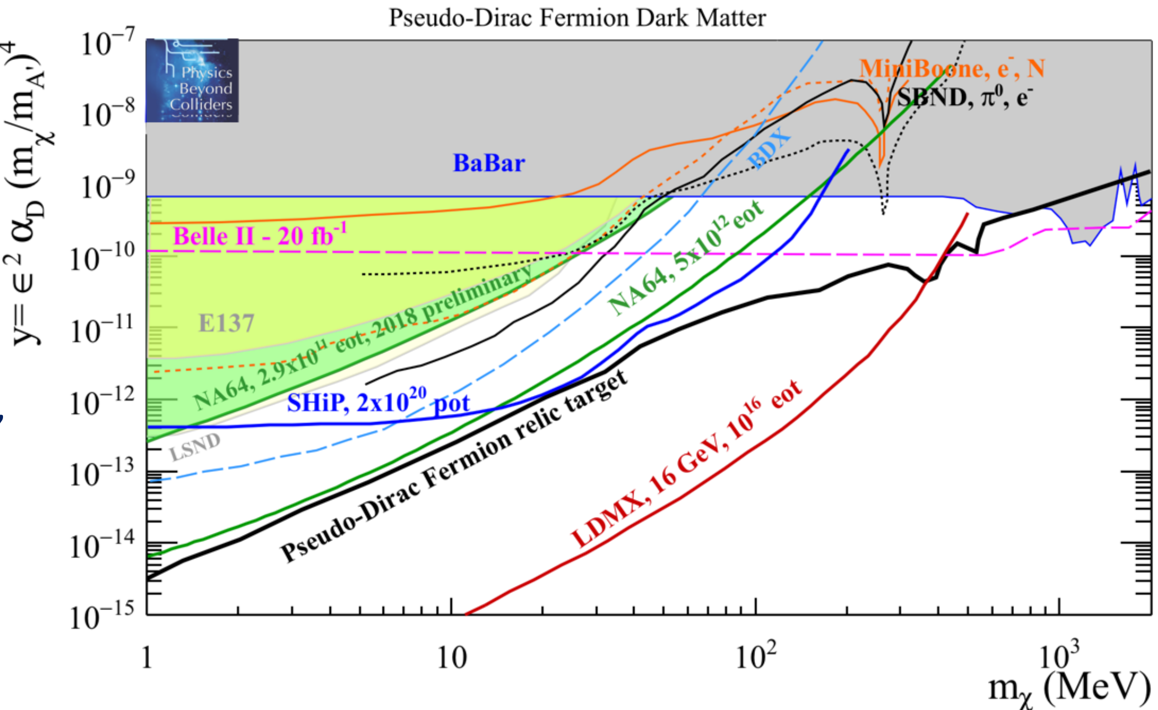




$\alpha_D = 0.1$

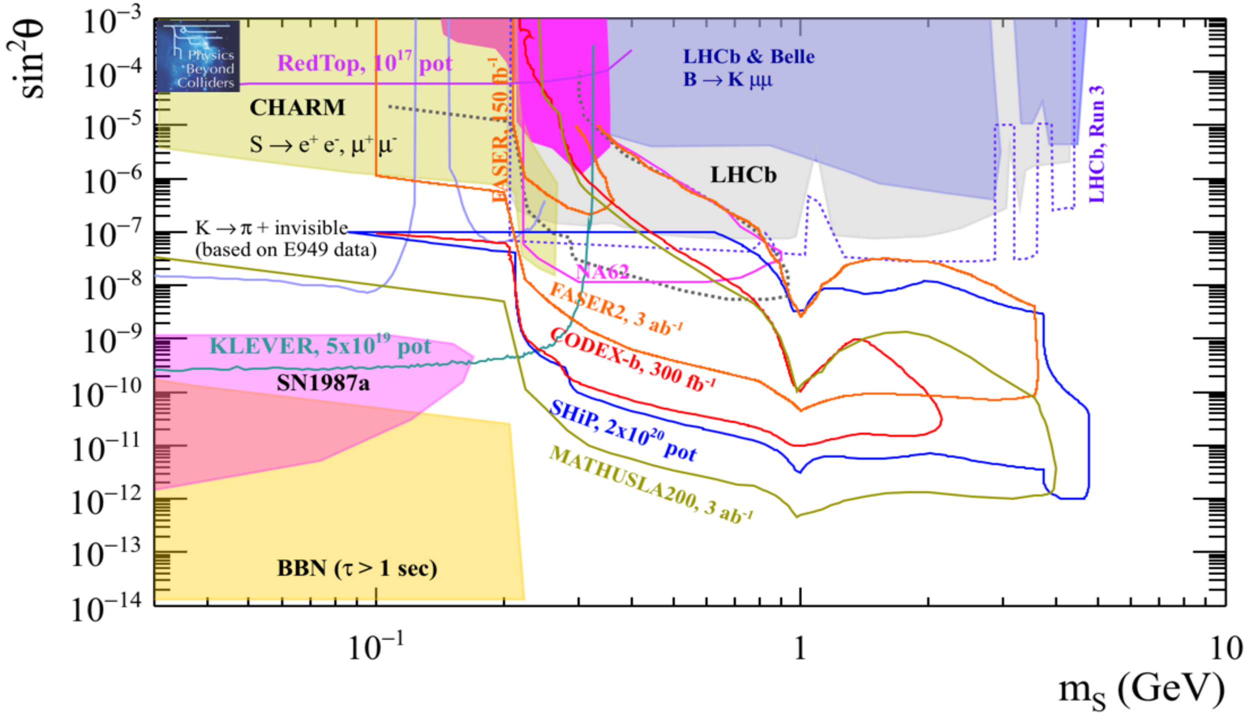
$m_\chi = 1/3\ m_{A'}$

Physics Beyond Coll

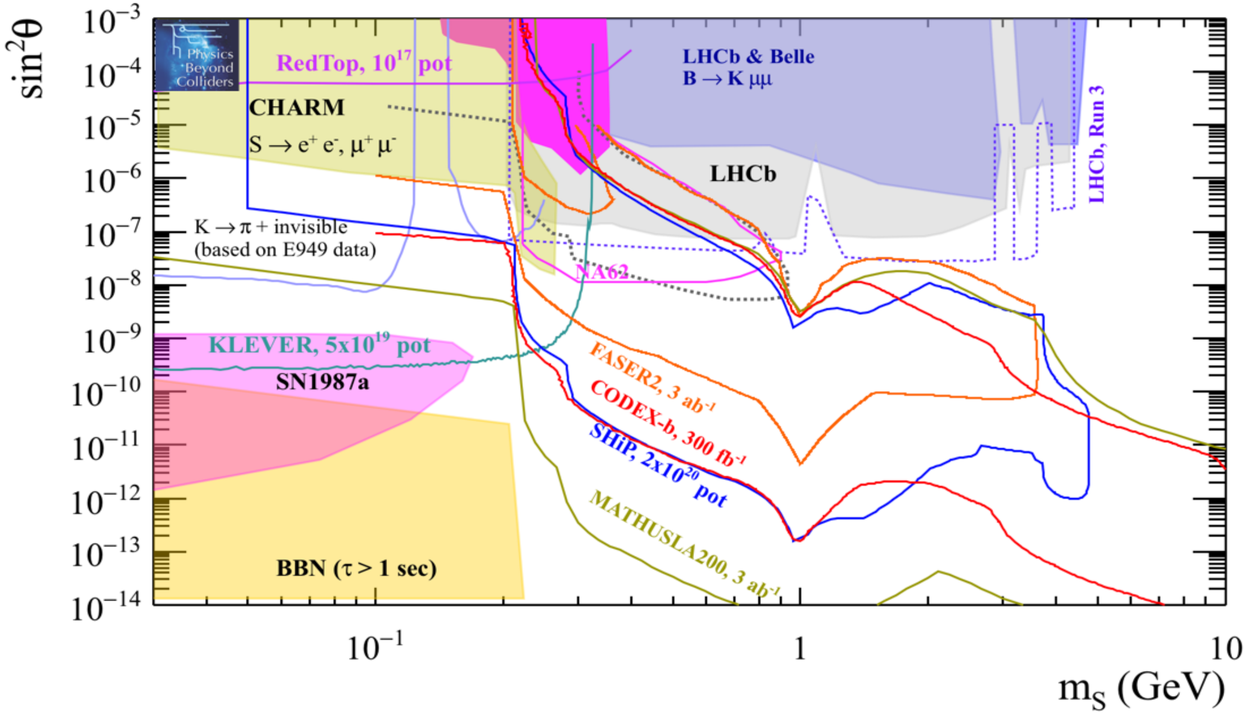


DARK SCALARS

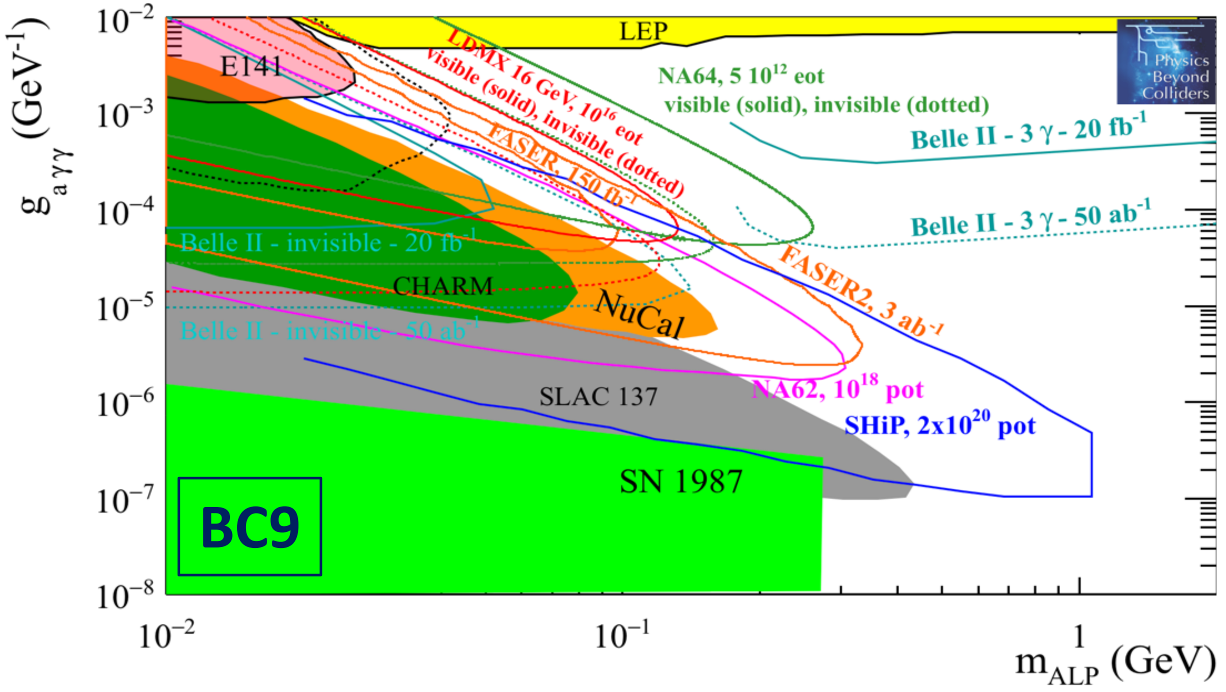
BC4

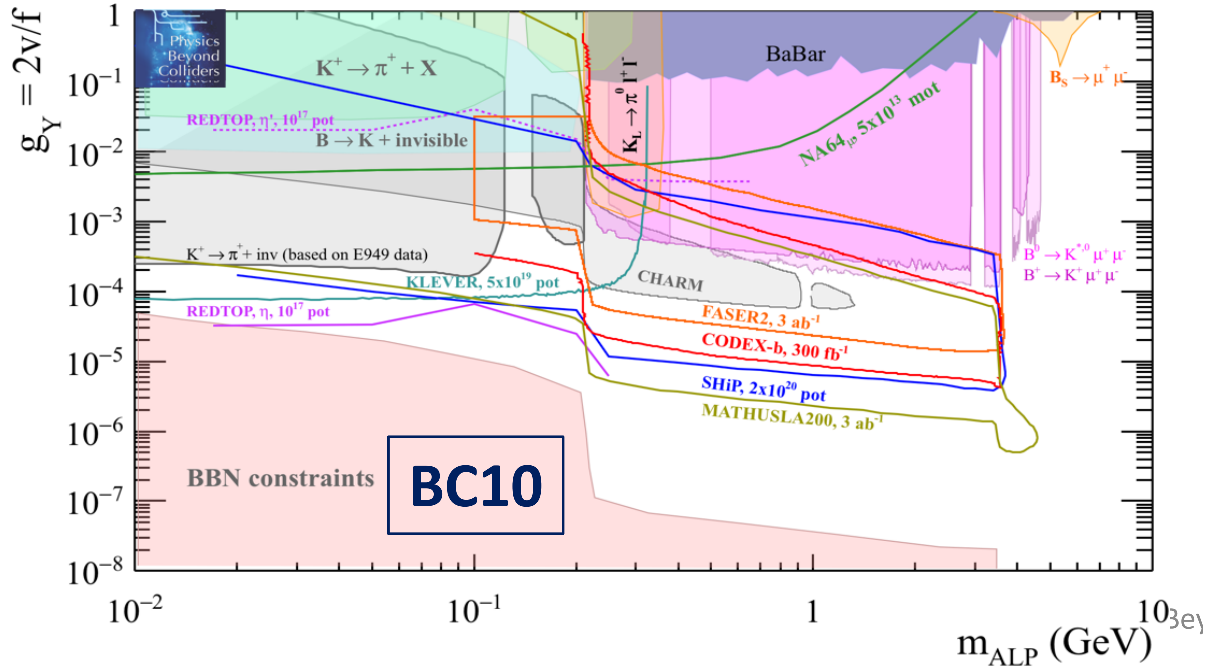


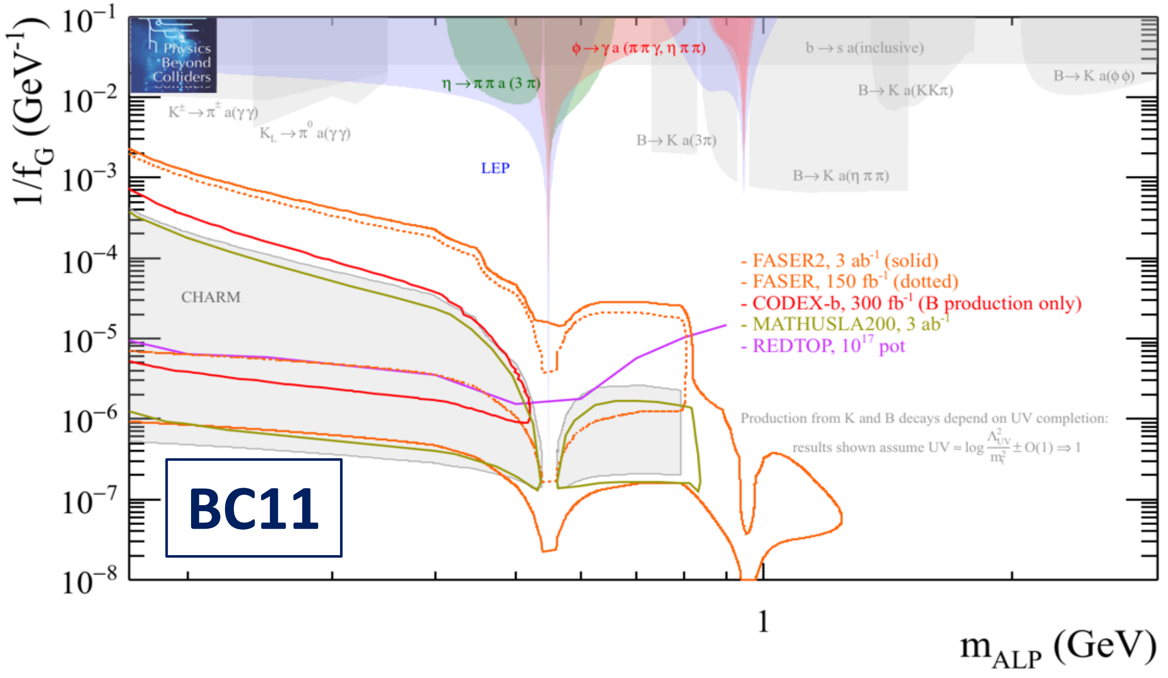
BC5



ALPS IN BEAMDUMPS







NA60++ and DIRAC++

Unique physics reach for both

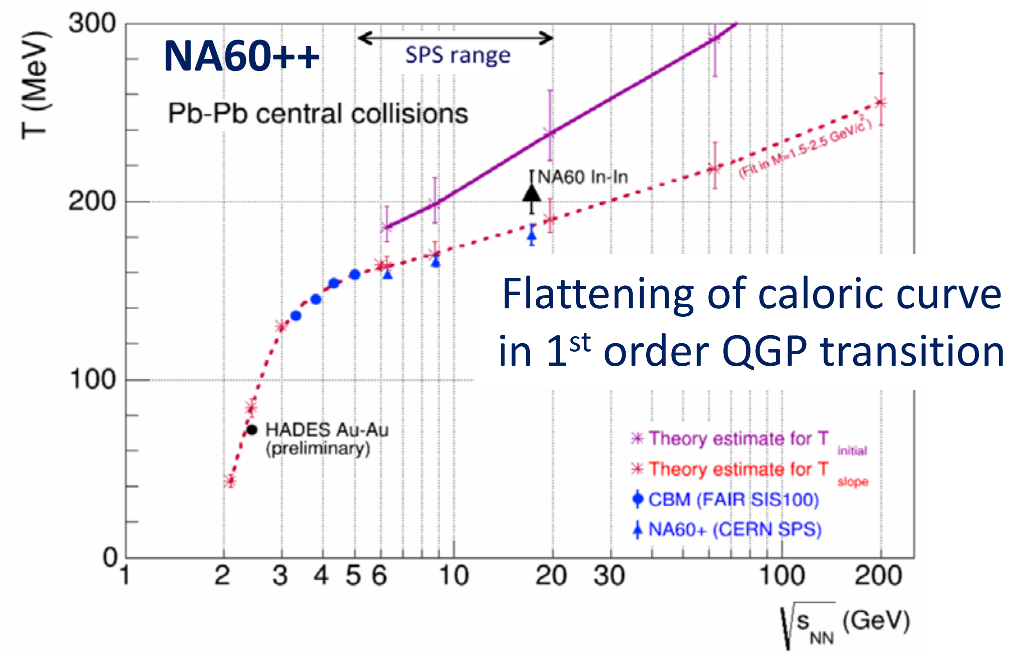
High hadron beam intensities

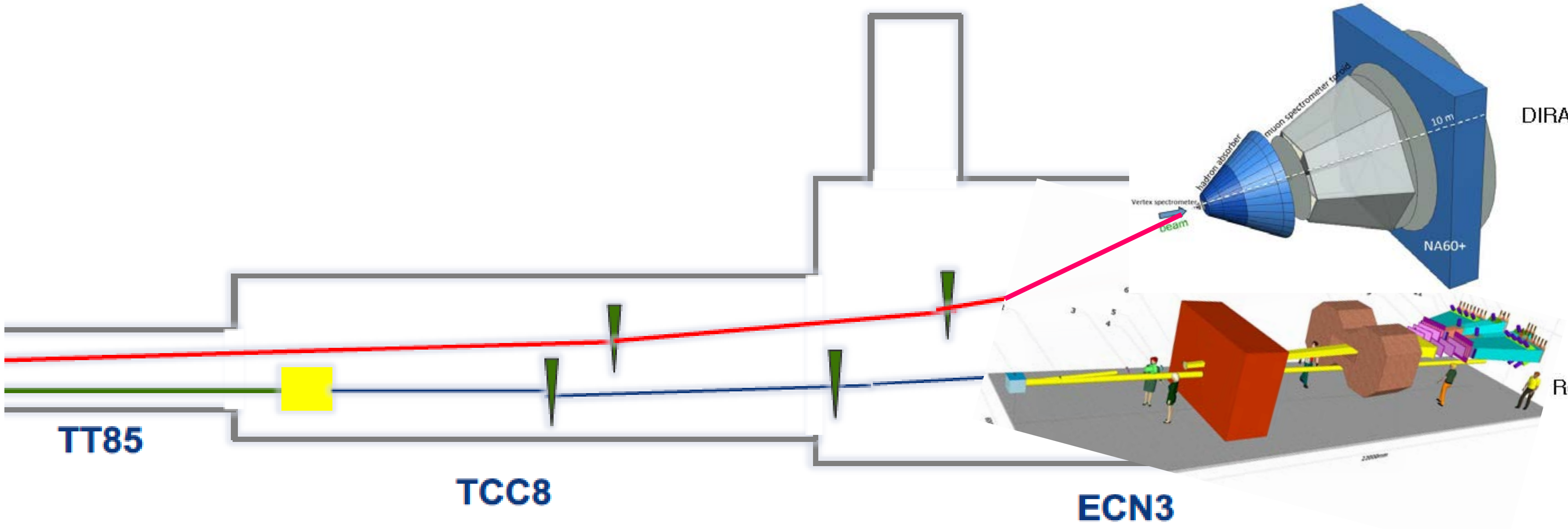
→ only reasonable implementation is in ECN3

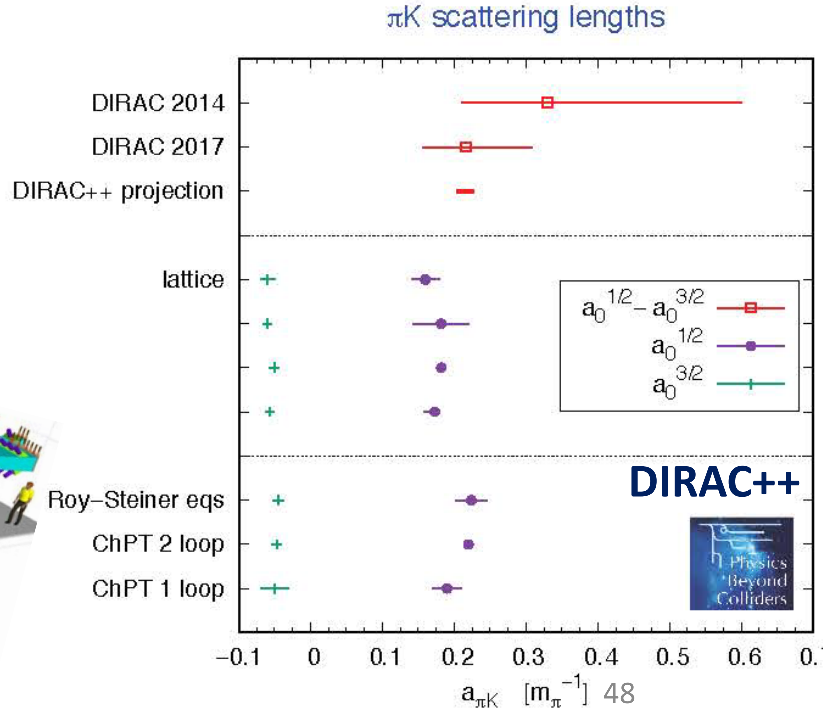
Both beams could fit together in ECN3

But implementation can be done only

once NA62 has freed the hall

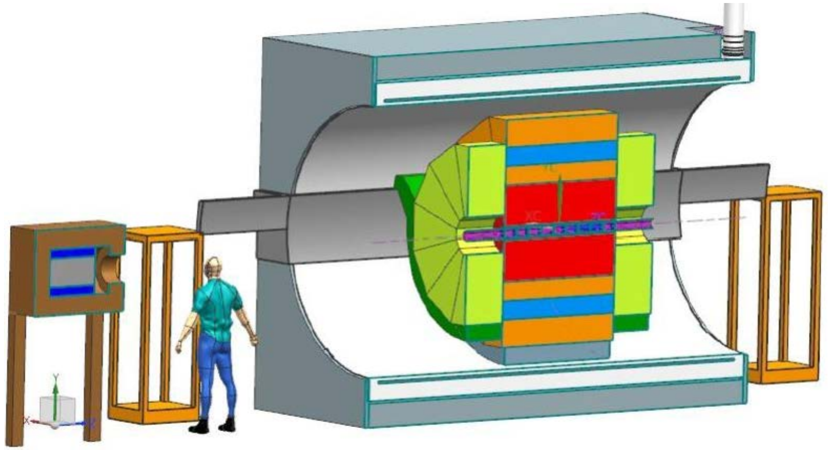






REDTOP η – η’ factory

Also in discussion at FNAL



It is a Goldstone boson → Symmetry constrains its QCD dynamics

It is an eigenstate of the C, P, CP and G operators (very rare in nature): $I^G J^{PC} = 0^+ 0^{-+}$ → It can be used to test C and CP invariance.

All its additive quantum numbers are zero (very clean state)
$Q = I = j = S = B = L = 0$
→ Its decays are not influenced by a change of flavor (as in K decays) and violations are “pure”

All its possible strong decays are forbidden in the lowest order by P and CP invariance, G-parity conservation and isospin and charge symmetry invariance.

EM decays are forbidden in lowest order by C invariance and angular momentum conservation

→ It is a very narrow state (Γ_η=1.3 KeV vs Γ_ρ=149 MeV)

Contributions from higher orders are enhanced by a factor of ~100,000

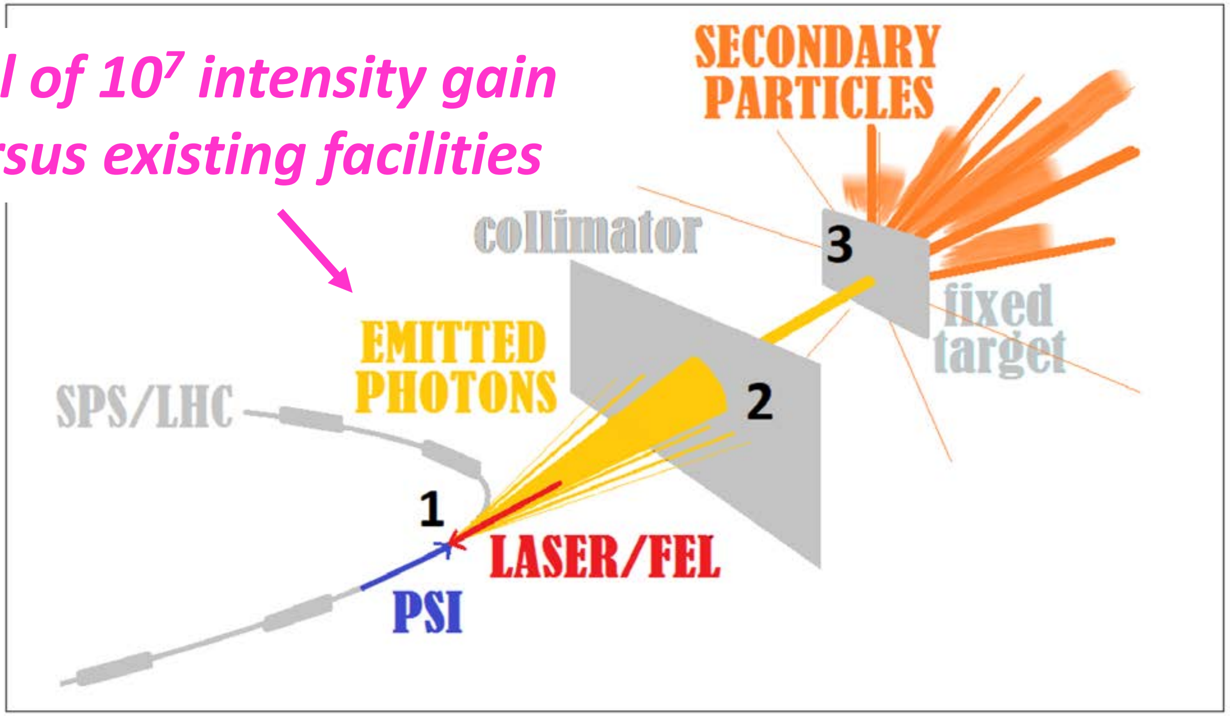
Excellent for testing invariances

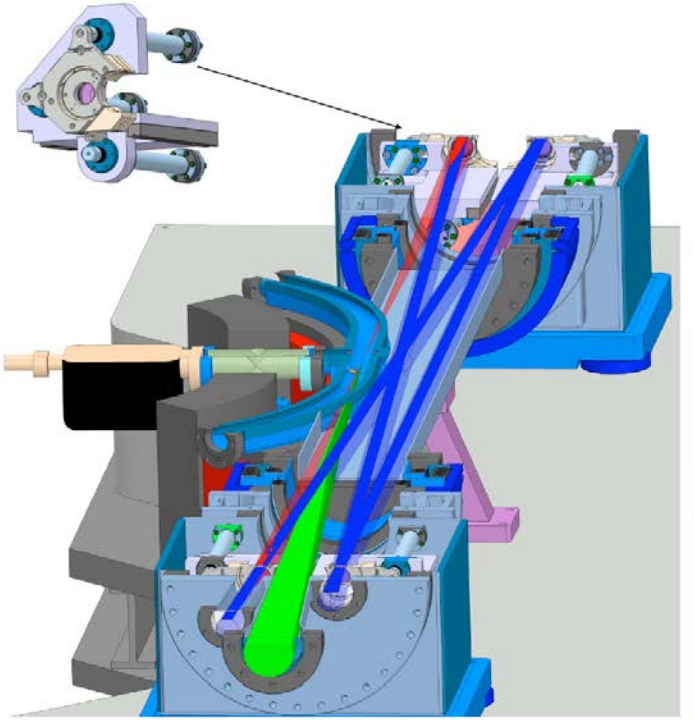
Main issues:

- **2 GeV continuous proton beam (PS best option but non-nominal for REDTOP)**
- **Demanding detector technology (Optical TPC and dual readout calorimetry)**

GAMMA FACTORY

Goal of 10^7 intensity gain versus existing facilities





Important milestone reached within PBC with successful acceleration and storage of Partially Stripped Ions in LHC

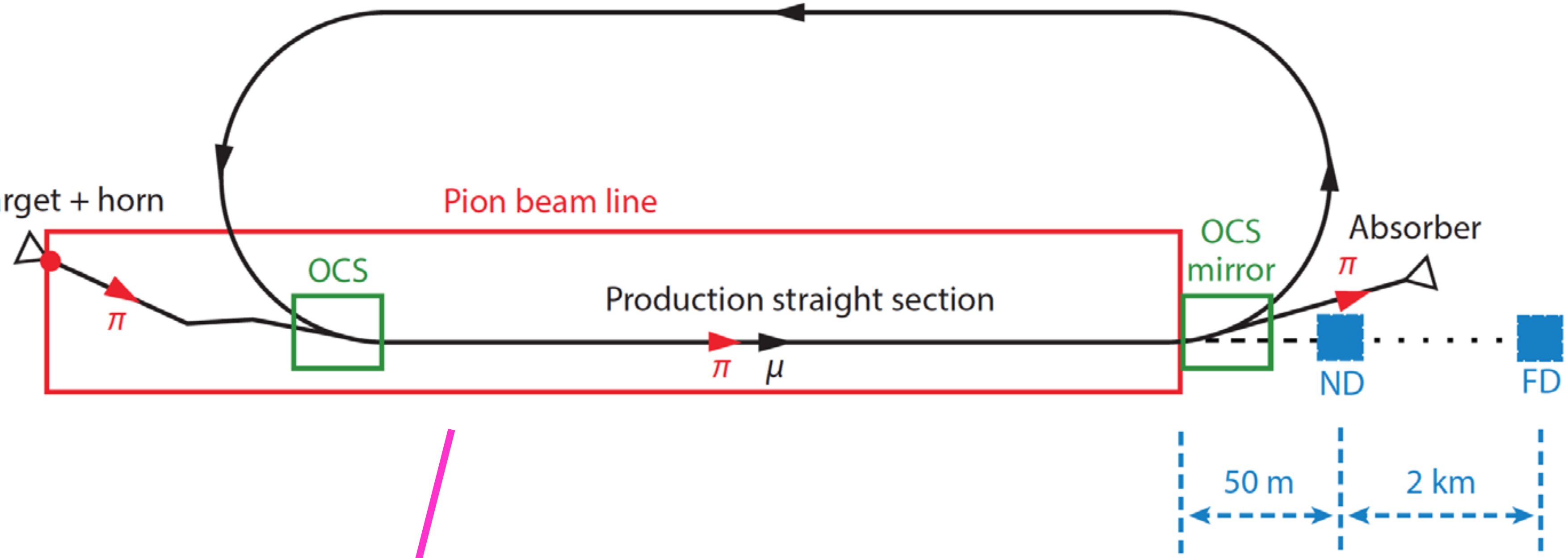
Proof of Principle experiment with full configuration foreseen at SPS after LS2

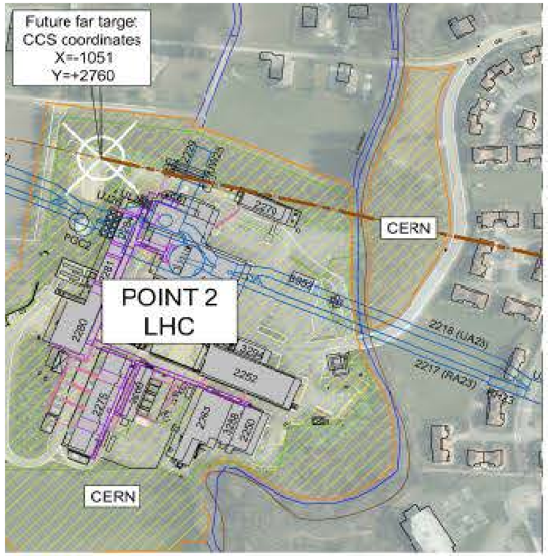
NB: physics reach to be quantified once all ingredients are better understood

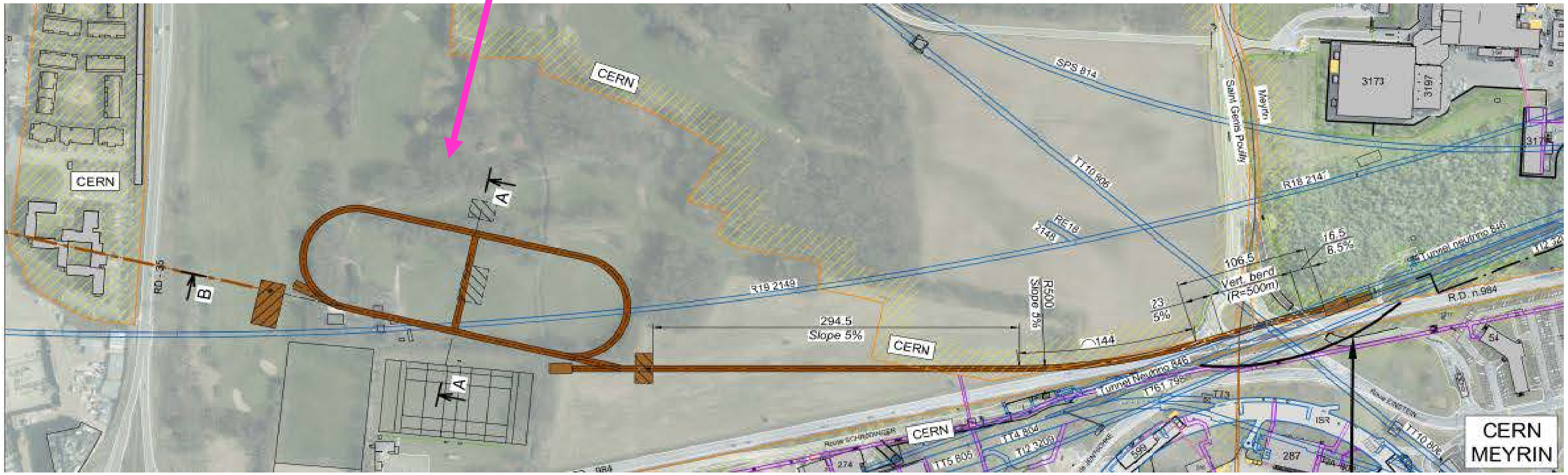
NuSTORM

Well controlled ν beam from a μ storage ring

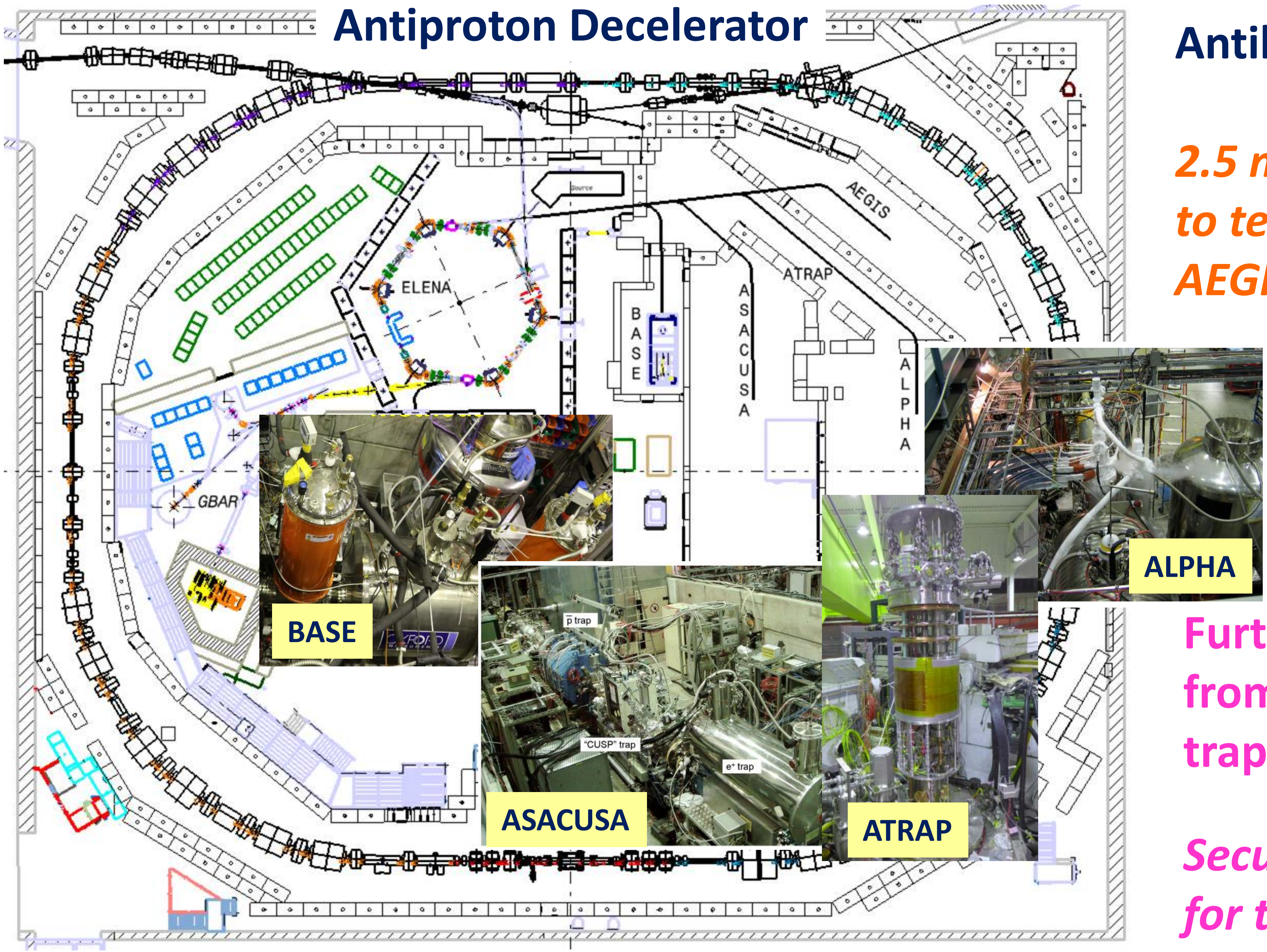
Precise σ(ν) measurements and a path towards a ν factory or a μ collider.







ANTIMATTER FACTORY



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**

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

Secures antimatter physics for the next decade