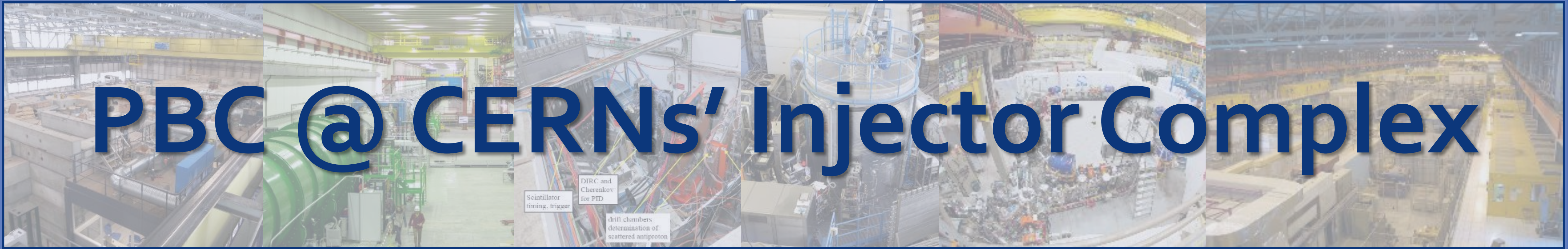
PBC @ CERNs' Injector Complex



Accelerator/Infrastructure/Technology

in the setting of Injectors & Fixed Target Physics…

M. Brugger on behalf of **PBC & The Many Study/Equipment/Service/Support Teams/Groups**

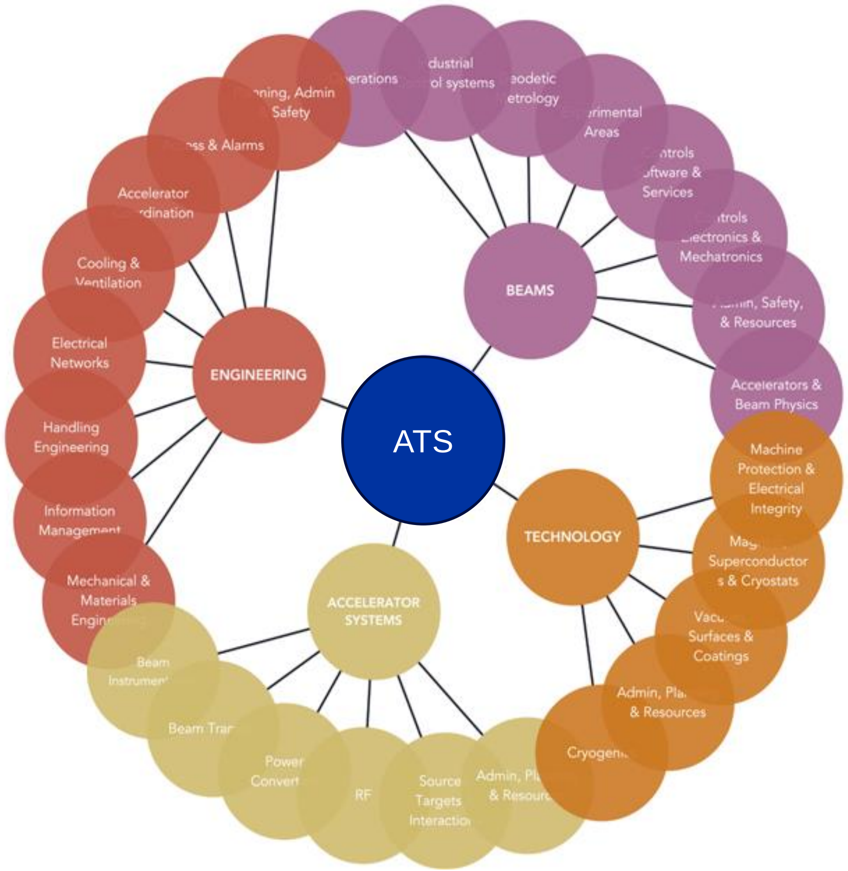
November 8th 2023

Research in Particle Physics needs:

- Theories
- Accelerators – Engineering – Infrastructure
- Experiments – Computing – Services
- Projects
- People
- People
- People

CERN

THANKS TO an Enormous Amount of Work by CERN Groups/Teams/Projects



EP

SME

DT

Department of Theoretical Physics

Radiation Protection

Raising awareness of radiation protection

Occupational Health and Safety

Advice and Support in matters of Occupational Health and Safety

Environmental Protection

Committed to limiting CERNs impact on the environment

EAST AREA RENOVATION

ELENA

NA cons

ACC-CONS

Physics Beyond Colliders

...etc.

Driven by Ideas from Experiments/Collaborations/Researchers

AWAKE		Advanced WAKEfield Experiment
NA58	COMPASS	Common Muon and Proton Apparatus for Structure and Spectroscopy
NA61	SHINE	Study of Hadron Production in Hadron-Nucleus and Nucleus-Nucleus Collisions at the CERN SPS
NA62		Proposal to Measure the Rare Decay K+ -> pi+ nu nu at the Cern SPS
NA63		Electromagnetic Processes in strong Crystalline Fields
NA64		Search for dark sectors in missing energy events
NA65	DsTau	Study of tau neutrino production
NA66	AMBER	Apparatus for Meson and Baryon Experimental Research

EP SME DT

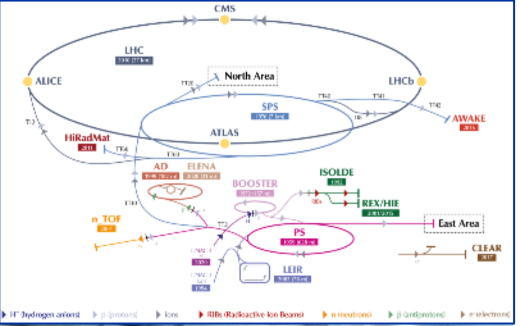
Department of Theoretical Physics

AD-3	ASACUSA	Atomic Spectroscopy and Collisions Using Slow Antiprotons The ASACUSA Collaboration
AD-5	ALPHA	Antihydrogen Laser PHysics Apparatus
AD-6	AEGIS	Antihydrogen Experiment Gravity Interferometry Spectroscopy
AD-7	GBAR	Gravitational Behaviour of Anti-Hydrogen at Rest
AD-8	BASE	Baryon Antibaryon Symmetry Experiment
AD-9	PUMA	Antiprotons and radioactive nuclei

ISOLDE	ISOLDE

PS212	DIRAC	Lifetime Measurements of pi+ pi- and pi+- K-+ Atoms to Test Low-Energy QCD Predictions
PS215	CLOUD	A Study of the Link between Cosmic Rays and Clouds with a Cloud Chamber at the CERN PS
nTOF COLLABORATION		Neutron Time-Of-Flight (n_TOF) experiment

...etc.

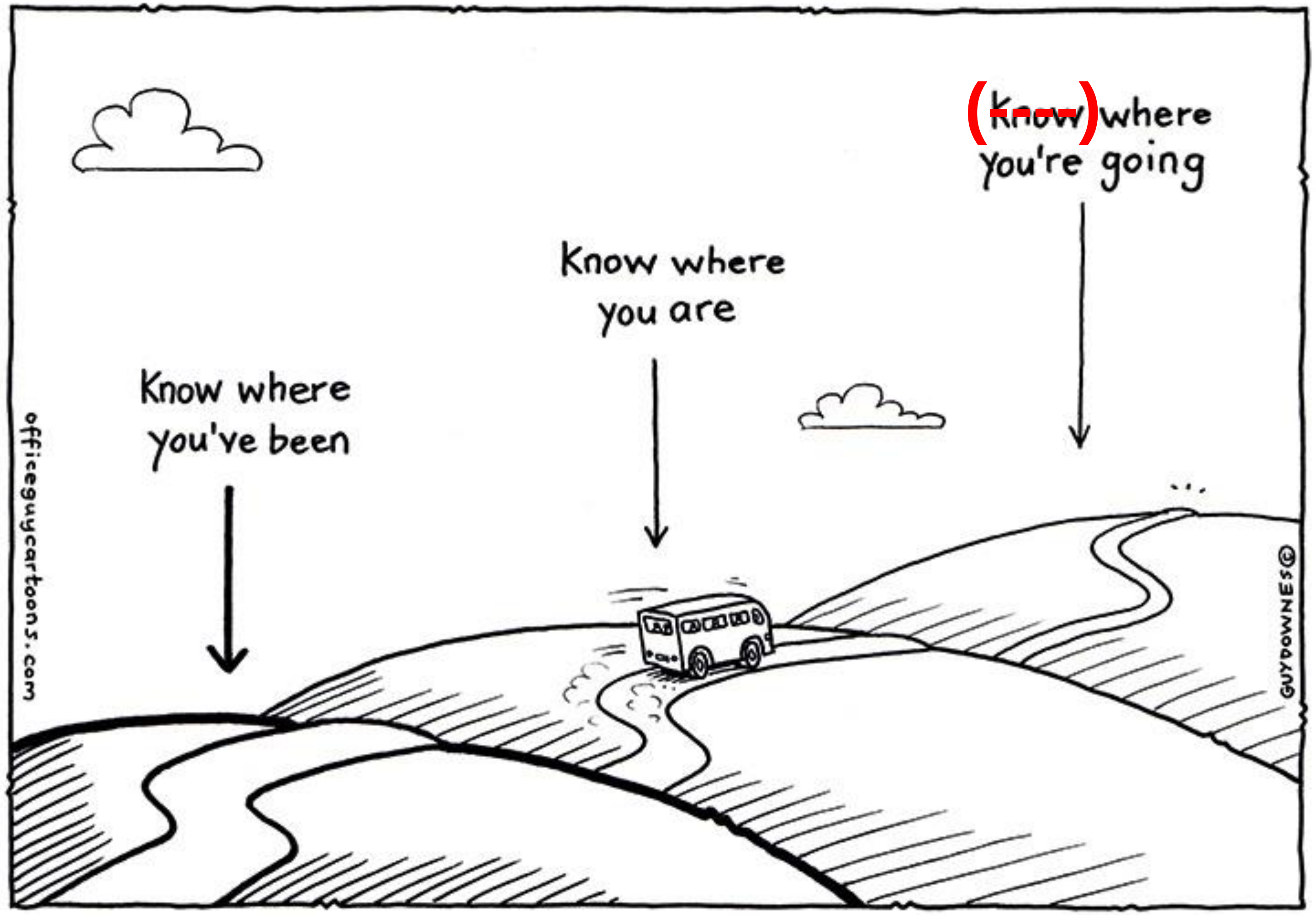


An (incomplete!) ? 50' Story Line

The CERN Accelerator Injector Complex & Its Experimental Areas

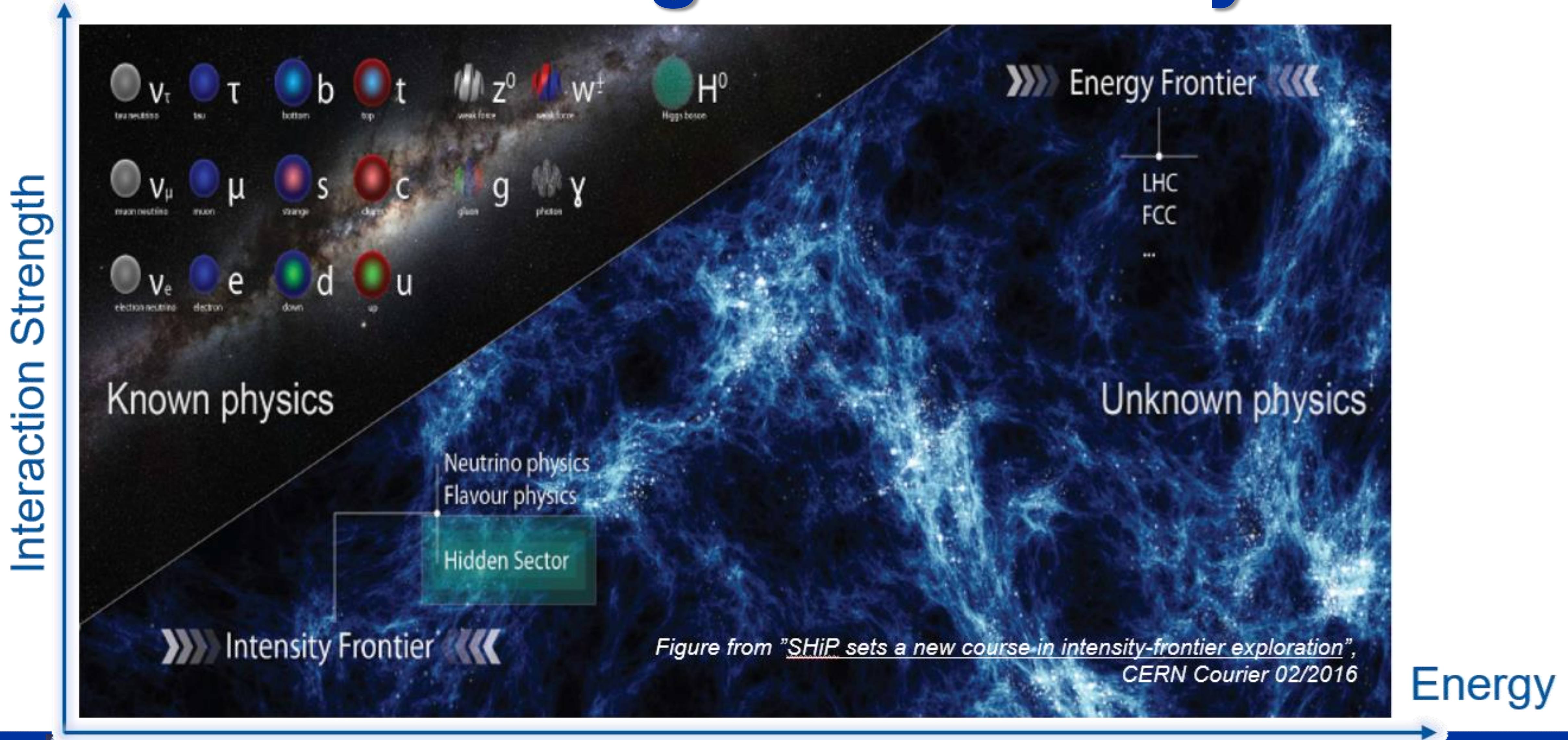
What's needed – based on a selection of on-going/planned/proposed Experiments (North Area Focus)

In the context of Mid/Long-term perspectives of concerned Experimental Areas


(Know) where you're going
Know where you are
Know where you've been
officeguycartoons.com
GUYDOWNES©


SCHULZ

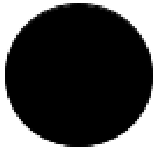
Claude: Probing What is Beyond

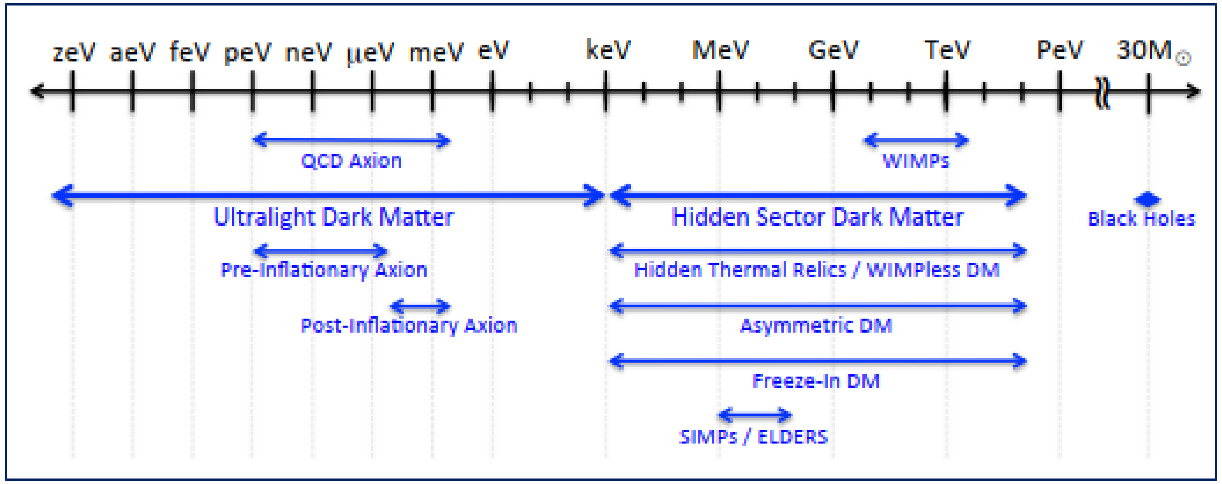


Probing What is Beyond

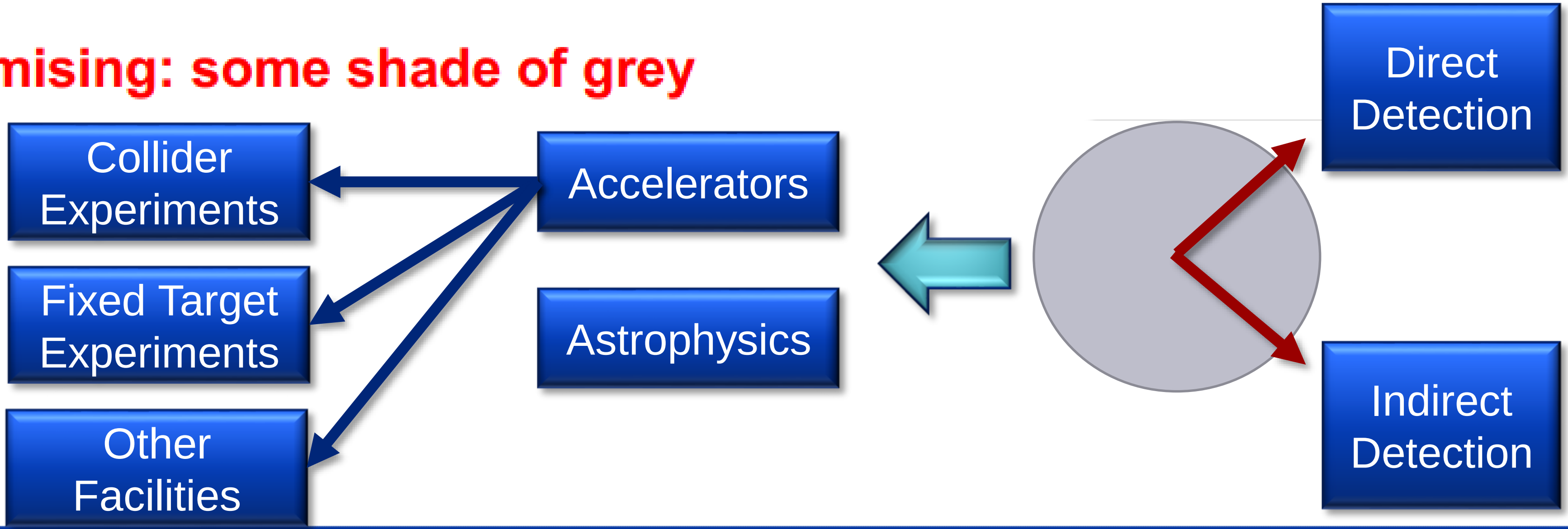
© U. Wiedemann

- An experimental fact & yet, still a total mystery
  - And masses span over 80 orders of magnitude
- Nightmare scenario: totally dark
  - Only Gravity to play with…

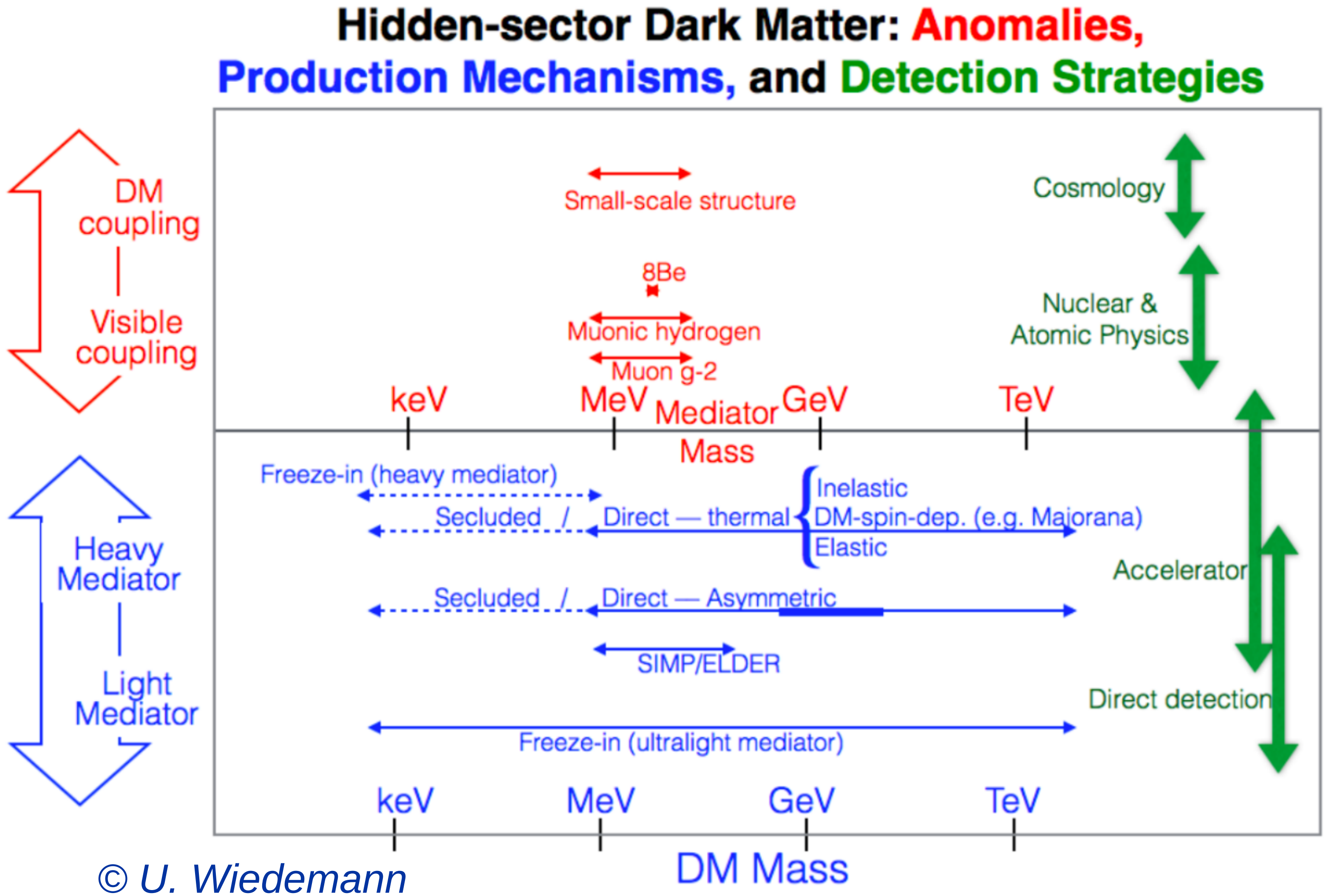




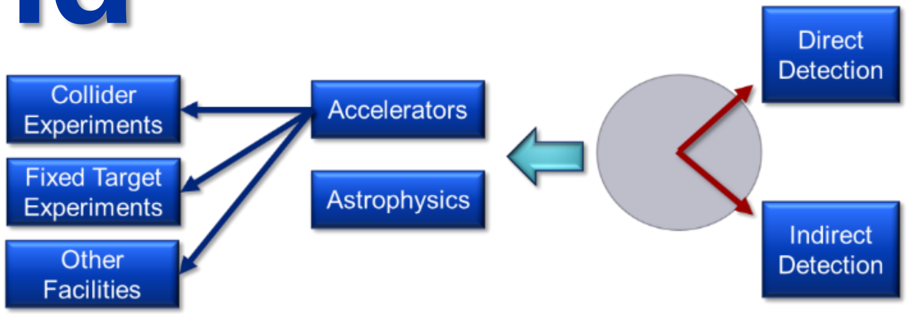
- More promising: some shade of grey



Probing What is Beyond



© *U. Wiedemann*



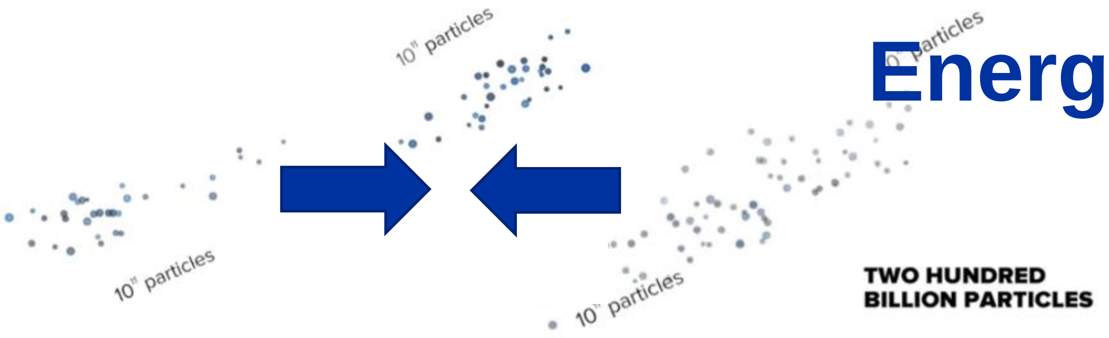
- No "no-lose" theorem, nor "easy focus"
- Many Open **Questions**
- Enormous Amount of **Ideas**
- Vast Physics **Opportunities**

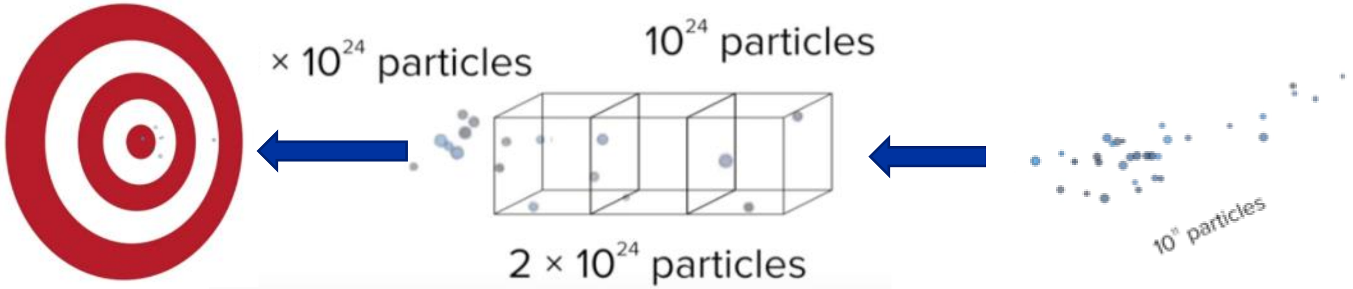
Fresh From The Press

https://edition.cnn.com/2023/11/07/world/euclid-telescope-first-images-scn/index.html

Collider vs Fixed Target Physics

Energy & Luminosity





$E_{cms} \sim E_{beam}$

e.g.: LHC: 13600 GeV

Few particle types:

Protons (+ ions)

$$\mathcal{L} = \frac{N_1 N_2 f n_b}{4\pi\sigma_x\sigma_y}$$

$$\underbrace{\Phi\,\rho_T\,l}_{L}\;\sigma_p$$

$E_{cms} \sim \sqrt{2 m_P E_{beam}}$

e.g.: SPS: 27 GeV

Many particle types:

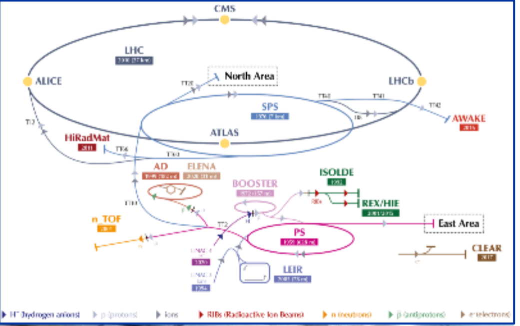
e.g. p, π, K, e, μ, ..

Discovery machines:

e.g. Higgs…

Precision experiments:

Rare events, e.g. Kaons & CP violation…



Let’s Get Started

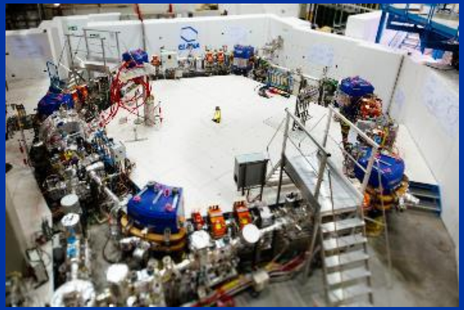
The CERN Accelerator Injector Complex & Its Experimental Areas

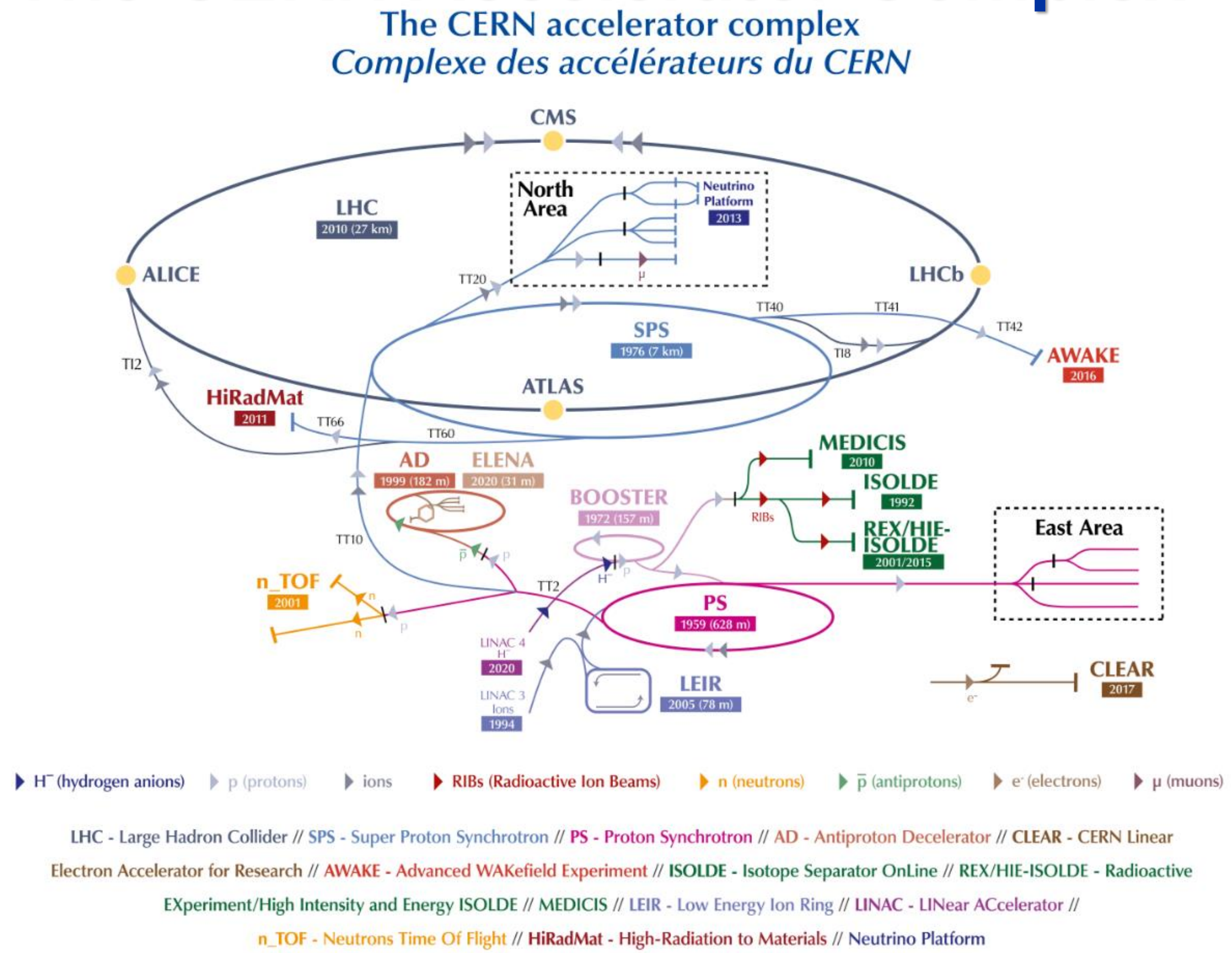
What’s needed – based on a selection of on-going/planned/proposed Experiments (North Area Focus)

In the context of Mid/Long-term perspectives of concerned Experimental Areas

The CERN Accelerator Complex

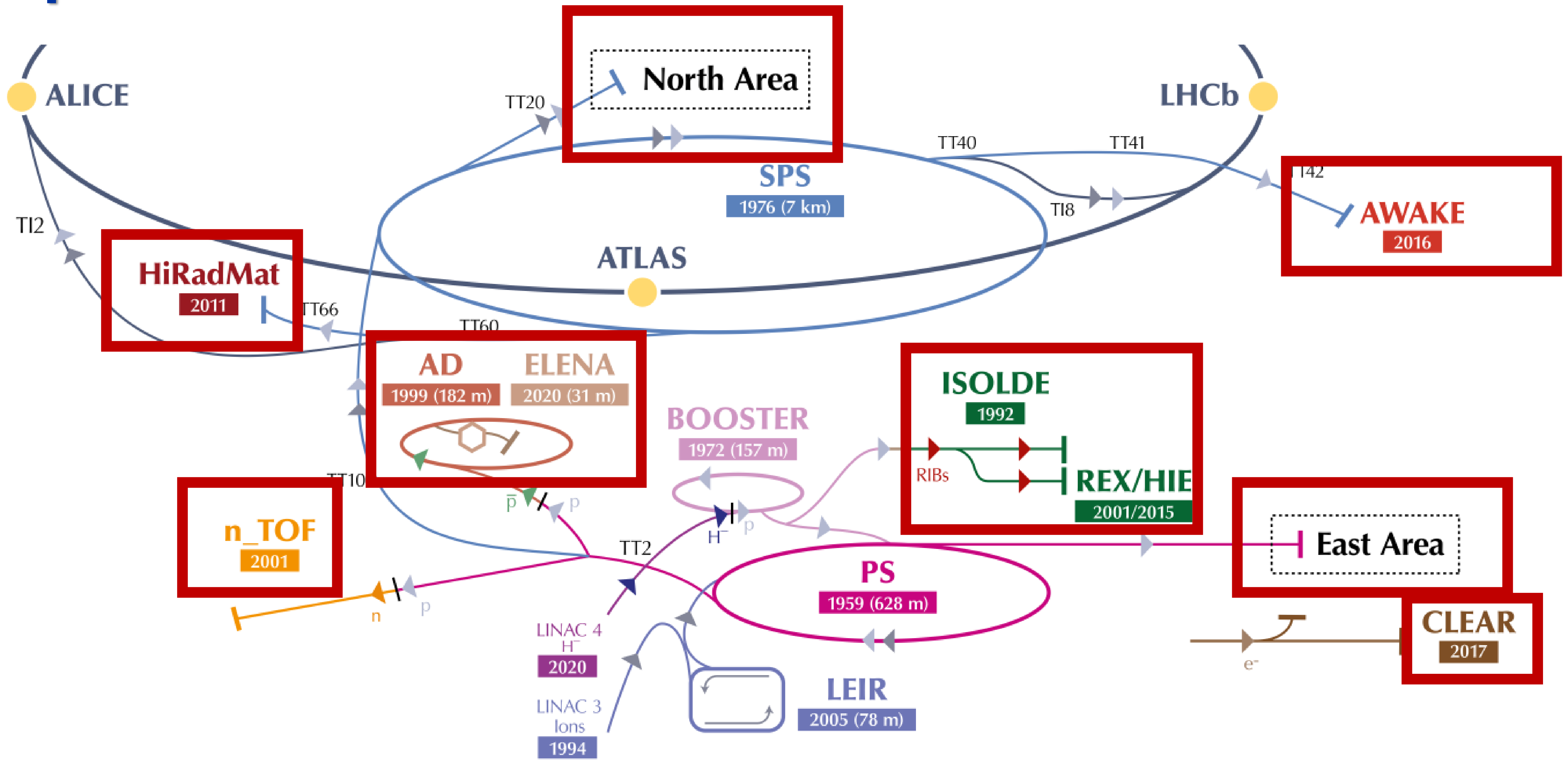







Experimental Areas

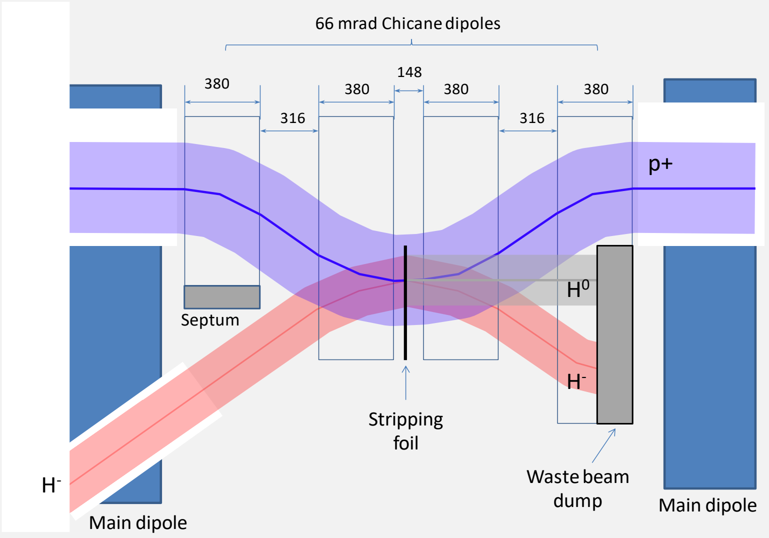


Linac 4

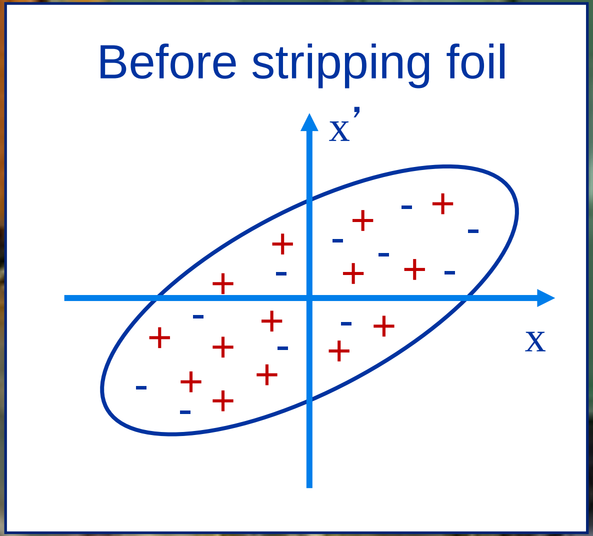
- H^- ion source at 45 keV
- Accelerates beam up to **160 MeV**
- The chopping scheme allows removing some of the Linac bunches to make the beam fit into the PS Booster RF buckets
- **Pulse rate 1.2 s**

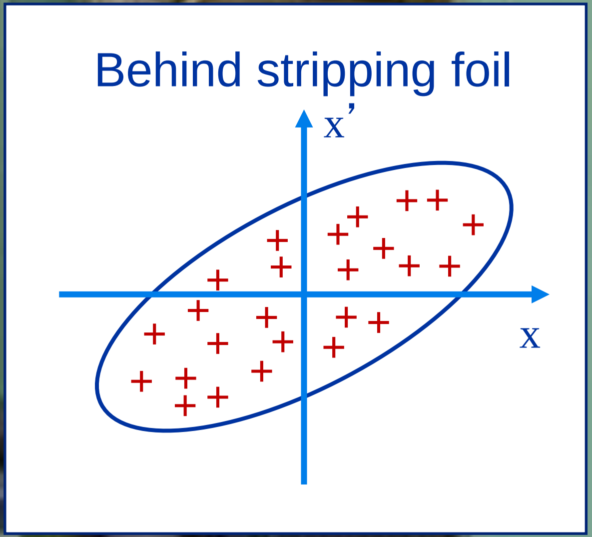
PS Booster

- 1st Synchrotron, unique, with **4 superposed rings**
- Circumference of 157 m
- Proton energy from 160 MeV to **2 GeV**
- Can cycle every 1.2 s
- Each ring will inject over multi-turns, using charge exchange injection

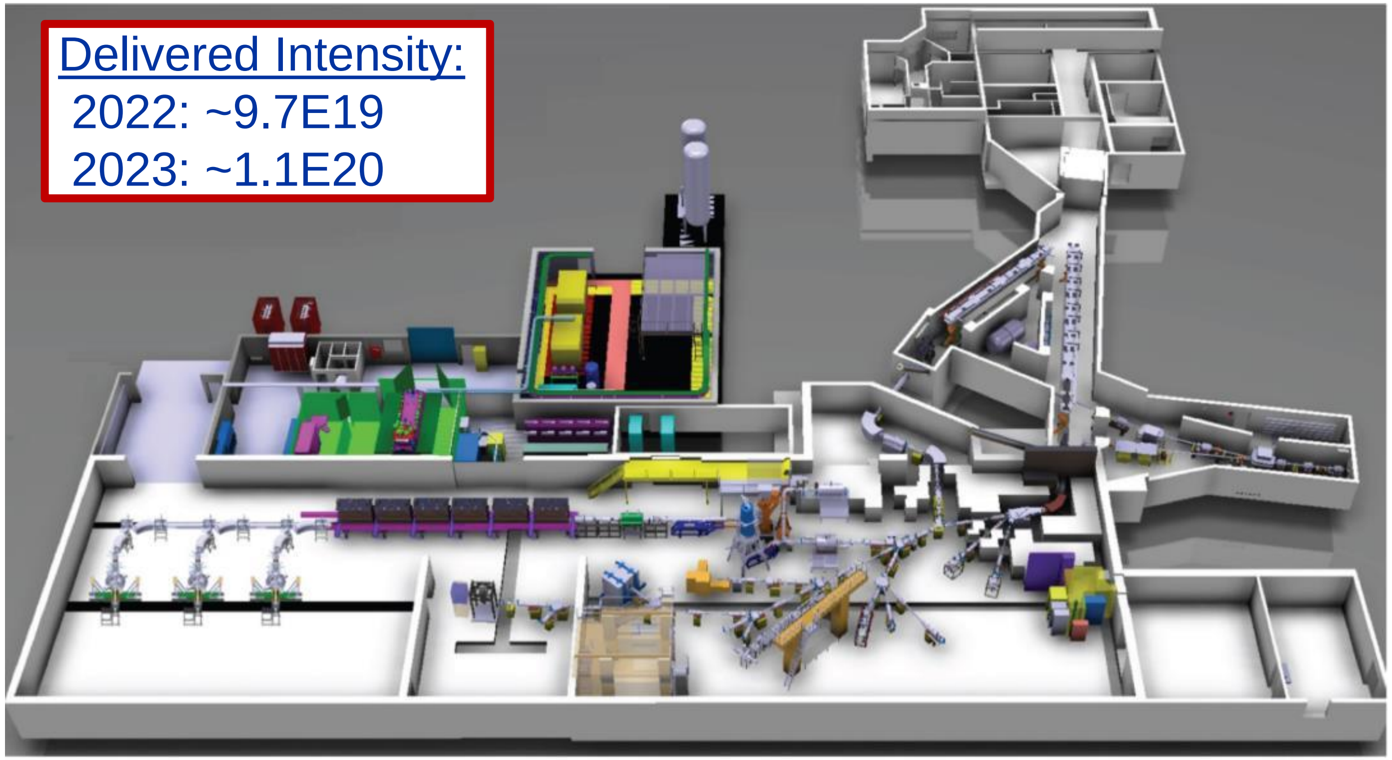


Injected Intensity:
2022: ~1.7E20
2023: ~1.7E20





ISOLDE / HIE-ISOLDE



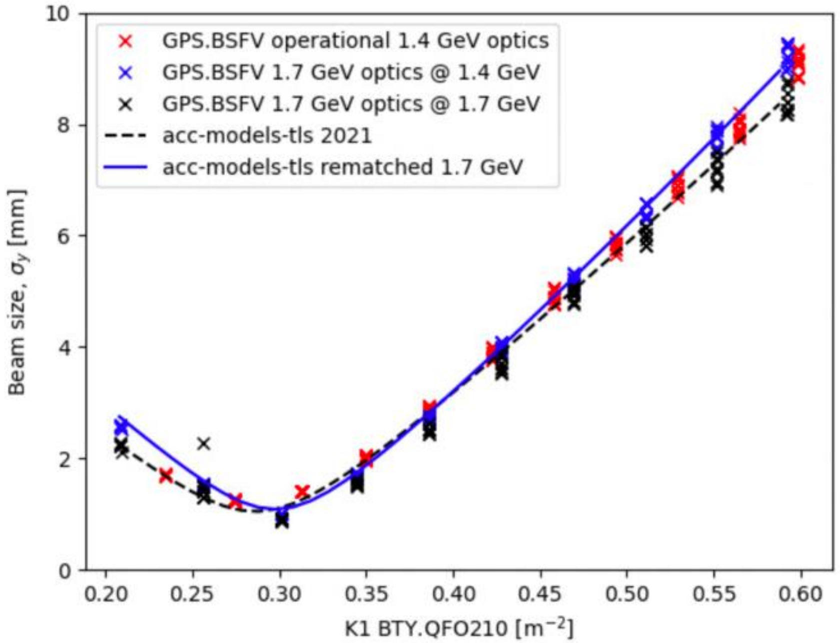
- **PSB proton beam impinges on a target producing a range of isotopes**
- **mass separators (GPS & HRS) allow selection of isotopes**
- **Post acceleration of isotopes**
  - REX, normal conducting accelerating structures
  - HIE-ISOLDE, super conducting LINAC

https://isolde.cern

-> BTY 2 GeV upgrade study
-> Beam Dumps exchange
-> Fire/RP/REX-HIE Consolidation

ISOLDE Beam Perspectives

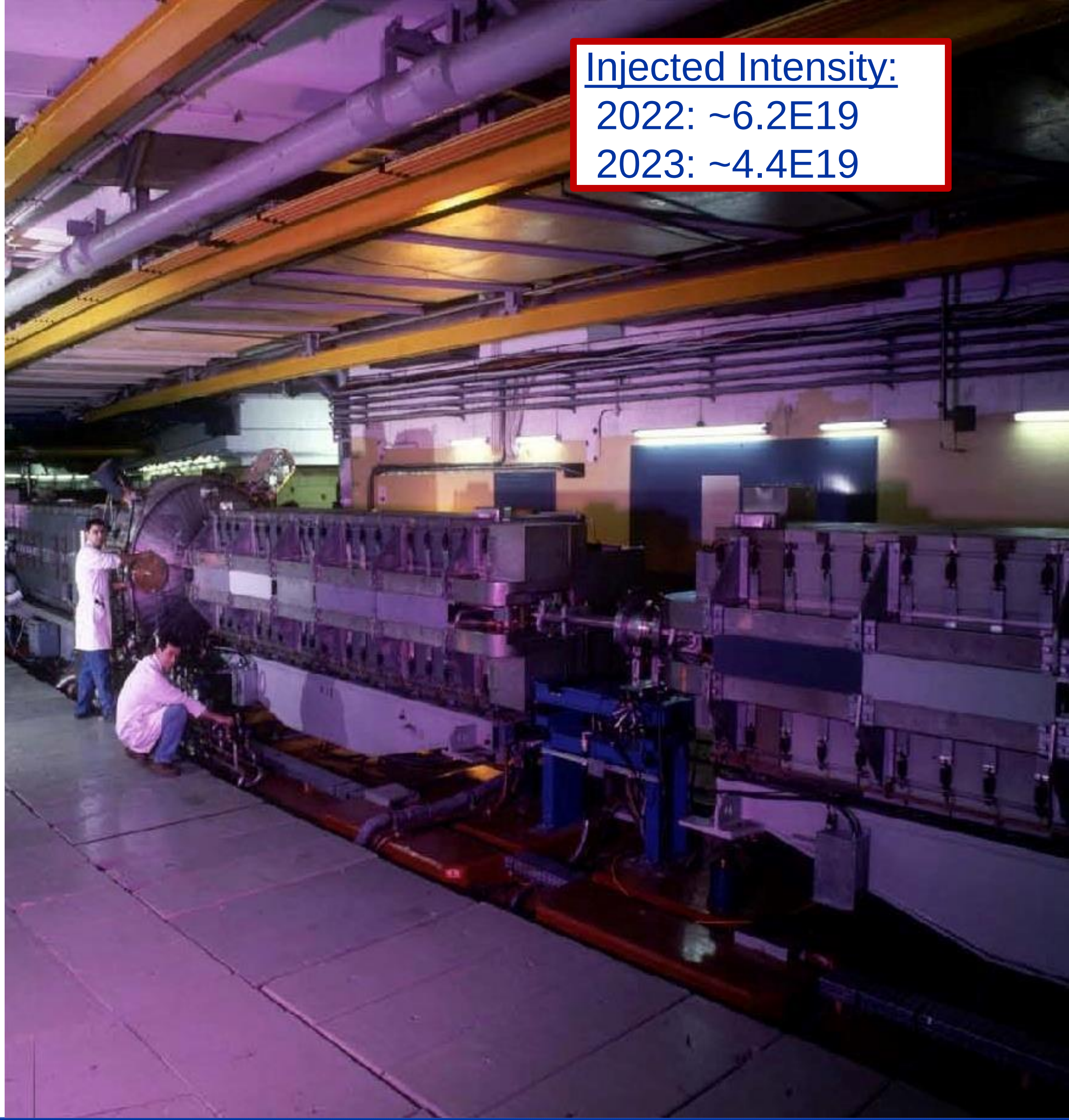
- **PSB upgrade opened the path to ISOLDE beam beyond the pre-LS2 1.4GeV limit**
- **Today limited to 1.7 GeV by power converter current in BTY vertical dipoles**
- **Optics rematched to keep all quadrupole settings within power converter limits for 1.7 GeV**
- **First (ever) ISOLDE run at 1.7 GeV done in 2022**
- **Operation up to 2GeV is technically possible but requires hardware changes**



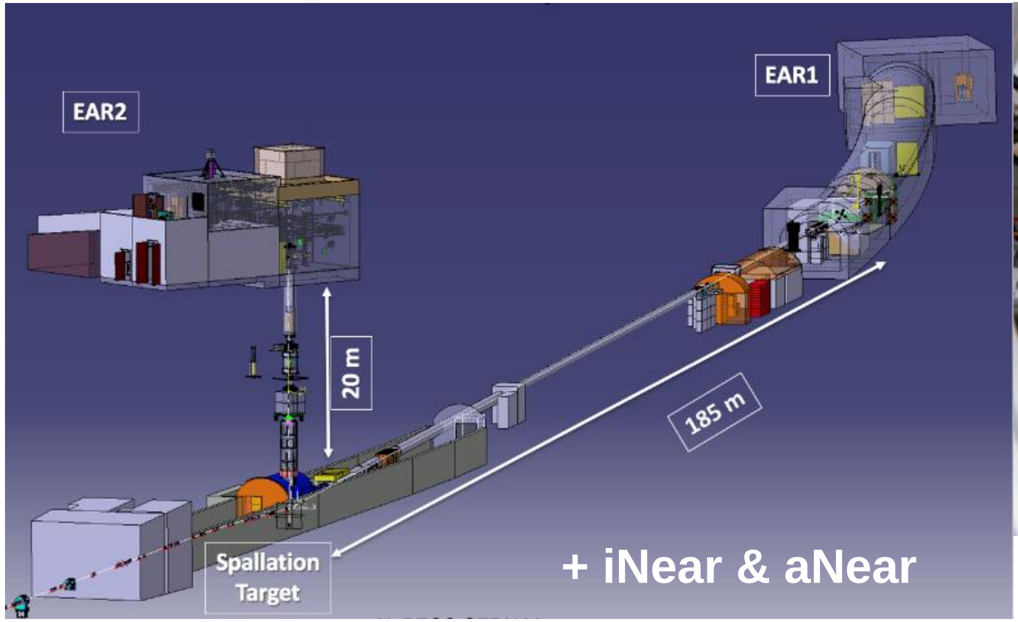
Mini-workshop on ISOLDE consolidation and improvement https://indico.cern.ch/event/1208149
L4/PSB MPC #81 https://indico.cern.ch/event/1179484/#5-psb-status
CERN-PBC-Notes-2022-008 https://cds.cern.ch/record/2838061
Status of the PSB instabilities studies, https://indico.cern.ch/event/1179487

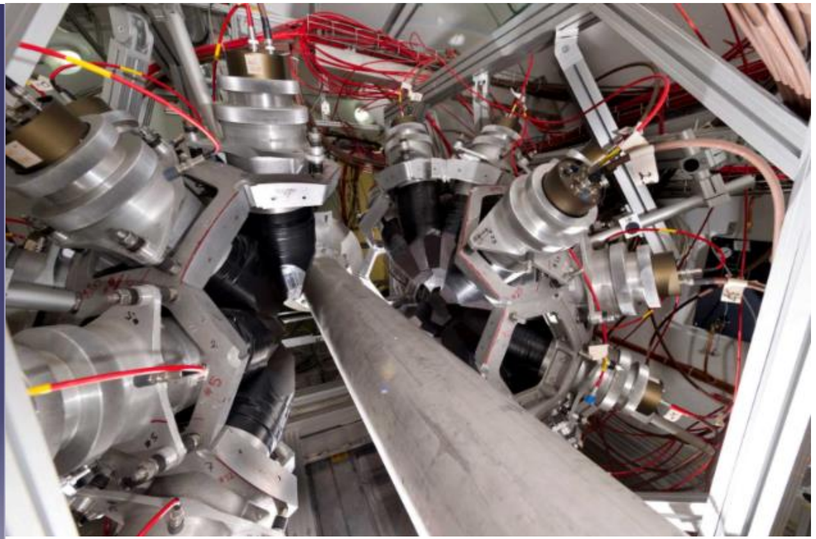
PS

- **The oldest operating synchrotron at CERN**
- **Circumference of 628m**
  - 4 x PSB circumference
- **Increases proton energy from 2 GeV to max. 26 GeV**
- **Cycle length ranges from 1.2s to 3.6s**
- **Many RF systems allow for complex RF gymnastics**
- **Various types of extractions:**
  - Fast extraction
  - Multi-turn extraction (MTE)
  - Slow extraction



nToF @various Flavors





https://ntof-exp.web.cern.ch/

Delivered Intensity:
2022: ~2.6E19
2023: ~2.4E19

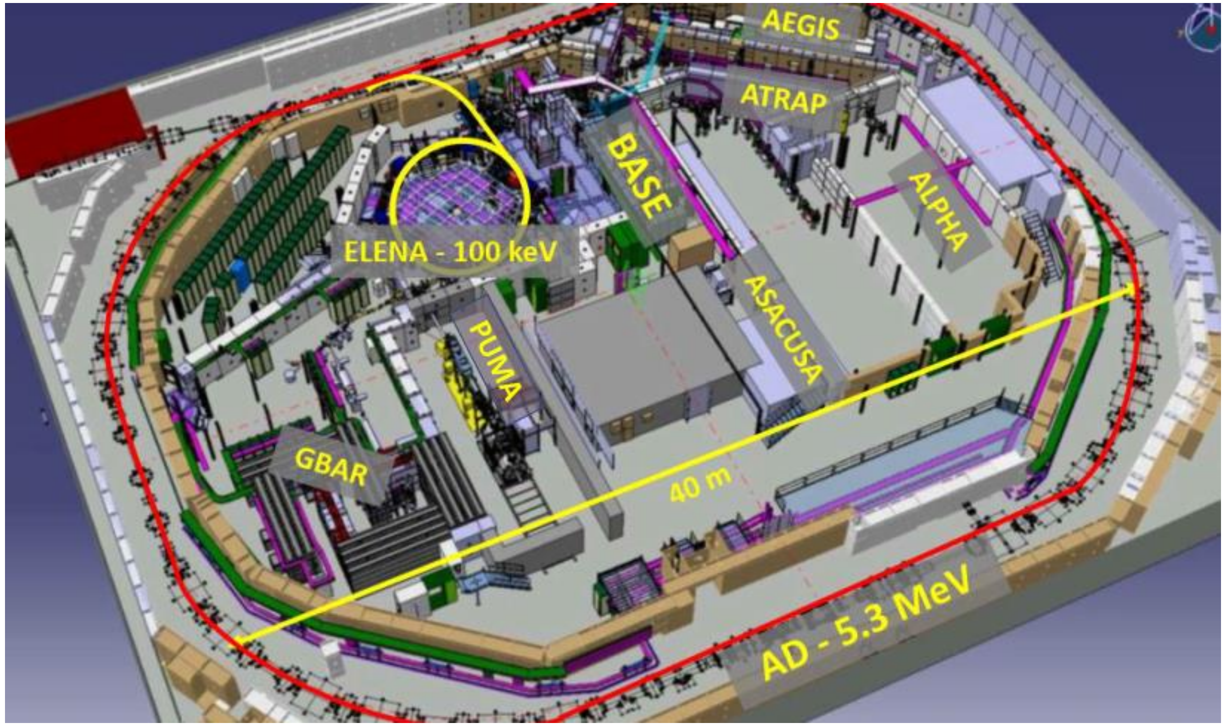
nTOF (neutron time-of-flight)

- **Neutron cross-section measurements**
  - Astrophysics
  - Nuclear Physics
  - Medical Applications
  - Nuclear Waste Transmutation

- **FTN WG -> path to higher flux operation**
  - **Double batch TOF beam (single PS cycle with 2 bunches extracted 1.2s apart to allow for increased flux)**
  - **Flexible adaptation of the SC to exploit maximum flux reach (work ongoing, full implementation LS3)**
  - Max. bunch intensity of PS TOF beam can be explored
  - Maximum intensity of parasitic TOF on EAST cycles can be explored in the PS

AD-ELENA

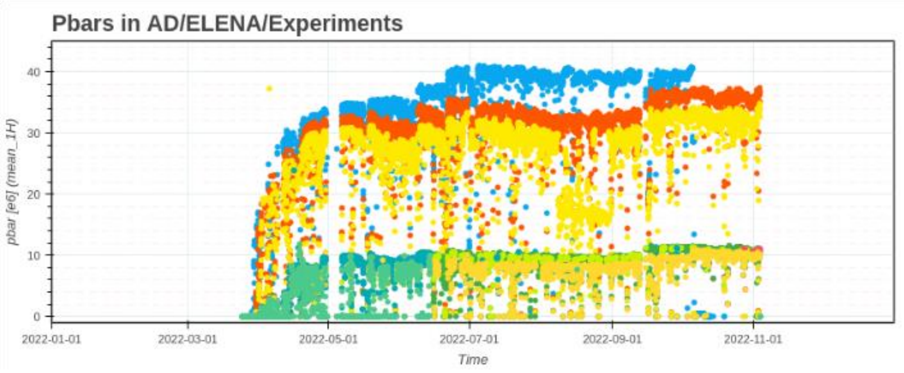
- **Receives fast extracted proton beam from PS at 26 GeV/c on a target**
- **One out of a million protons yields about one usable antiproton at 3.5 GeV/c.**
- **AD decelerates beam in stages down to 5.3 MeV**
- **ELENA further decelerates down to 100 keV**
- **Experiments:**
  - ASACUSA, ALPHA, AEGIS, BASE, GBAR, PUMA, BASE-STEP

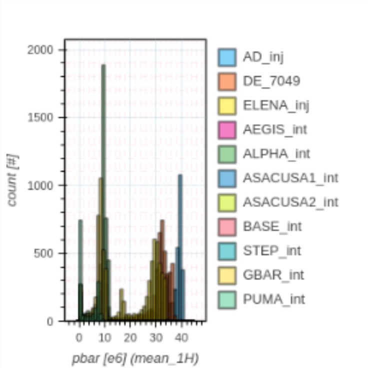


Injected Intensity:
2022: ~2.2E18
2023: ~1.8E18

AD-ELENA

- running full steam with 4 bunches delivered to 4 different experiments at the same time
- higher intensities than design in ELENA
- 2 new lines commissioned in 2022 for PUMA and BASE-STEP in addition to the 5 regular users
- Parallel operation with H^- in ELENA for machine studies and experiments setting-up





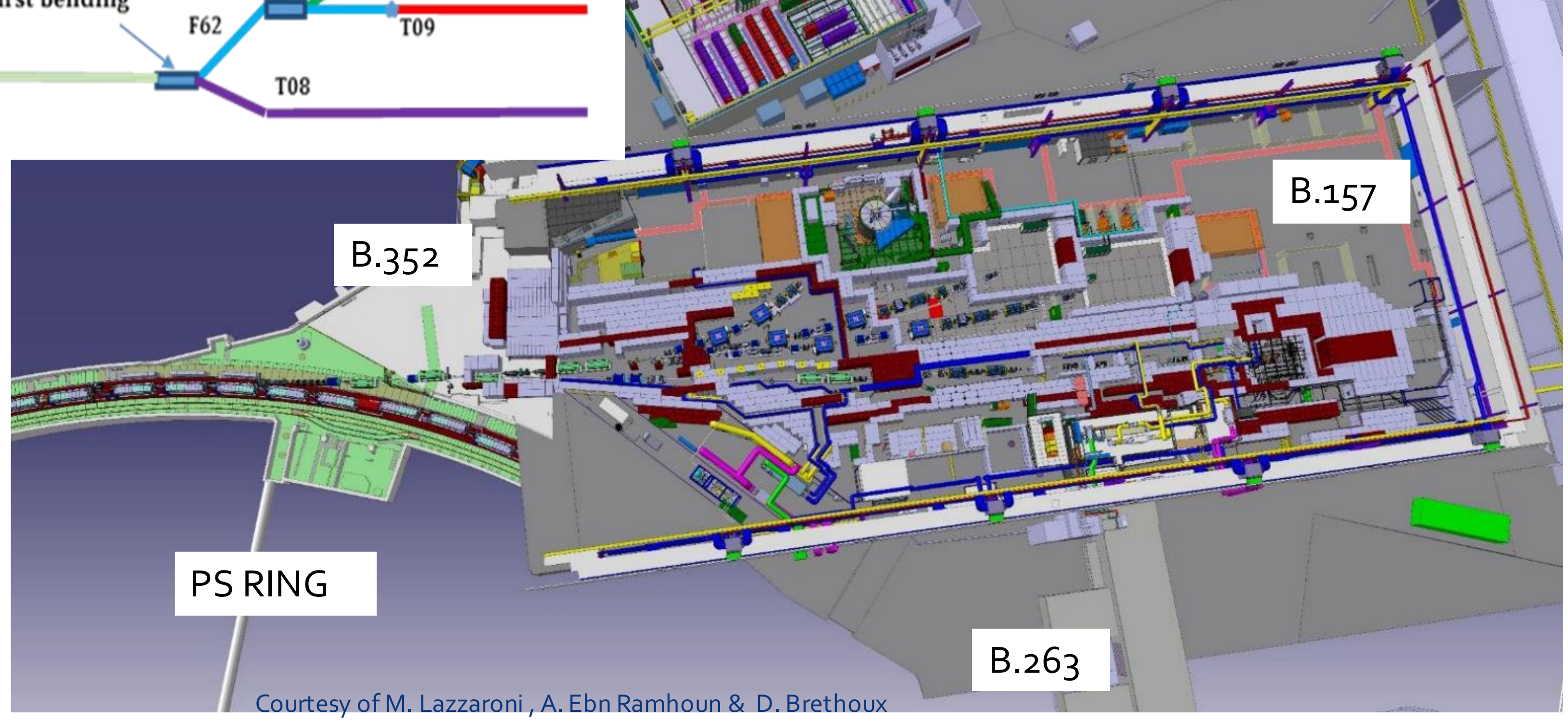
LATEST – Nature:
https://home.cern/news/news/physics/alpha-experiment-cern-observes-influence-gravity-antimatter

We're Save
10^9 years
@ full steam
or
10^{16} years
for todays experiments

East Area

- **Since the 1960's, the CERN East Area is a beam facility using protons derived from the Proton Synchroton (PS) for:**
  - Irradiation facilities
  - R&D tests of detectors
  - Experiments (CLOUD)
  - Outreach

- **An important consolidation program (EAR) has been completed during LS2**



Delivered Intensity:
2022: ~9.6E17
2023: ~8.8E17

EAR: 2 years in 2 Minutes (link)

CLOUD Experiment, T11

2009 – 2019

CLOUD during beam run in 2017

2020 - 2021

East Area Renovation with CLOUD Upgrade

2022 –

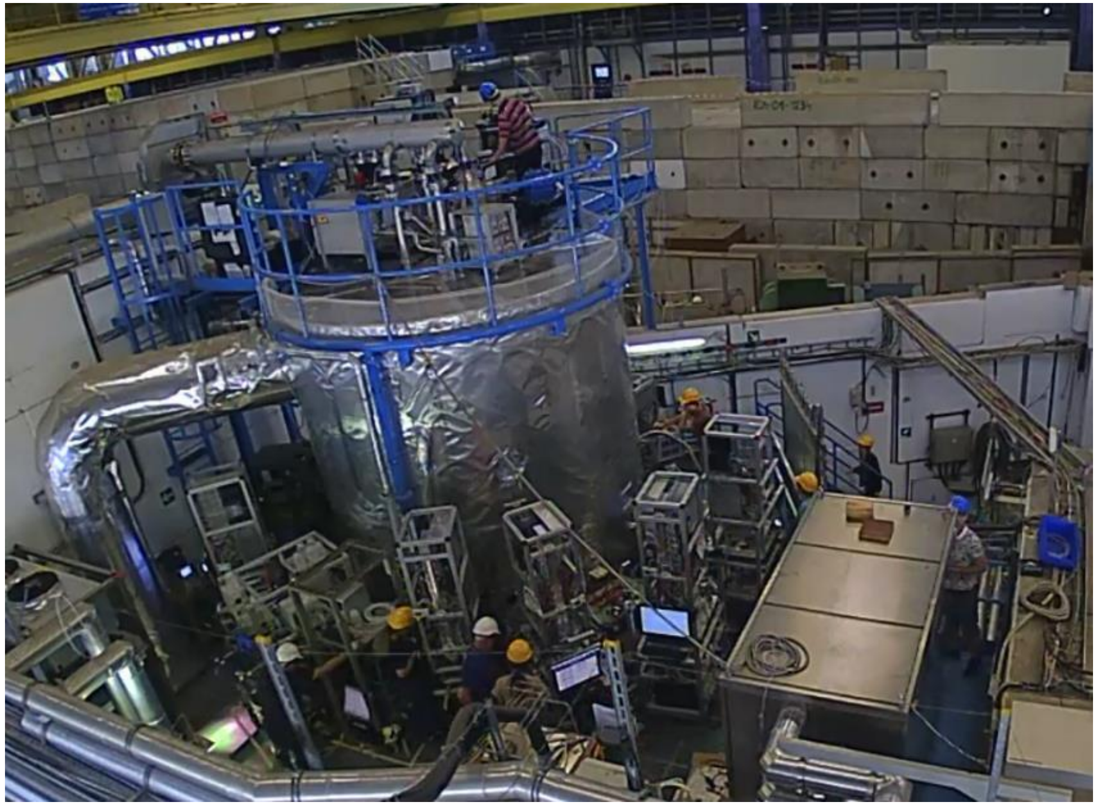
- **Enlarged T11 beam area**
- **Larger platforms and better accesses**
- **Control + Rack room & Chemistry lab**
- **Gas system**
- **Electrical power and IT networks**
- **HVAC systems**

New and improved →

Big thanks to all CERN service & support groups involved in BE, EN, EP, HSE, IT, SCE,…

CLOUD

- Study aerosol formation and cloud formation
- The beam simulates cosmic radiation
- The chamber contains air from pure N2 and O2, with controlled injection of other gases
- Very important inputs for climate research
- Profit from CERN beam and expertise, as well as CERN collaboration mechanisms (e.g. Common Fund)
- Largest ad cleanest chamber in the world
- Many Nature publications
- Recent Upgrade: FLOTUS (pre-age stage)



https://home.cern/news/news/experiments/flotus-aerosol-precursor-vapours-age-more-quickly

EAR Project Finished -> NA-CONS Starting

EAR Project Finished -> NA-CONS Starting

HVAC & Cooling

Radiation Protection

Vacuum Installation

Integration

Magnet System

Power Converters

Beam Studies

EAR : Survey Activities

New Beam Instrumentation

Safety Systems

Beam Stoppers

Handling/Transport

IT Systems

Collimators & BIDs in general

Planning

Control Systems

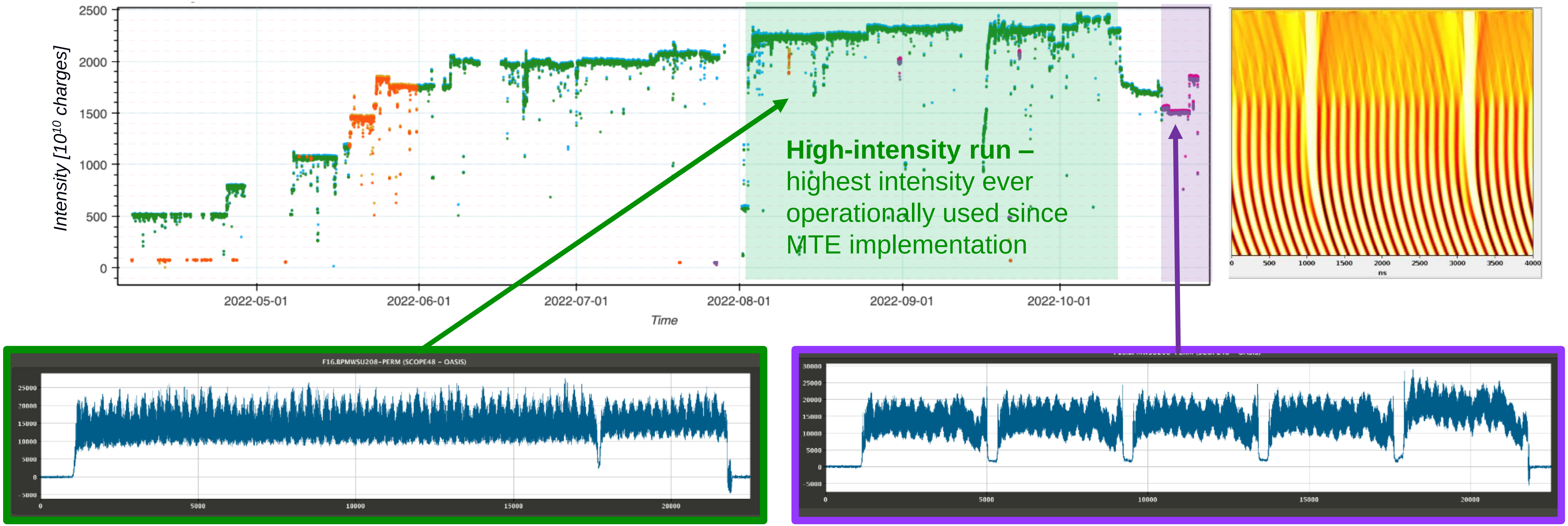
Electrical Distribution & Cabling

Configuration Management

Gas Distribution

Warm Magnet Interlock Controller (WIC)

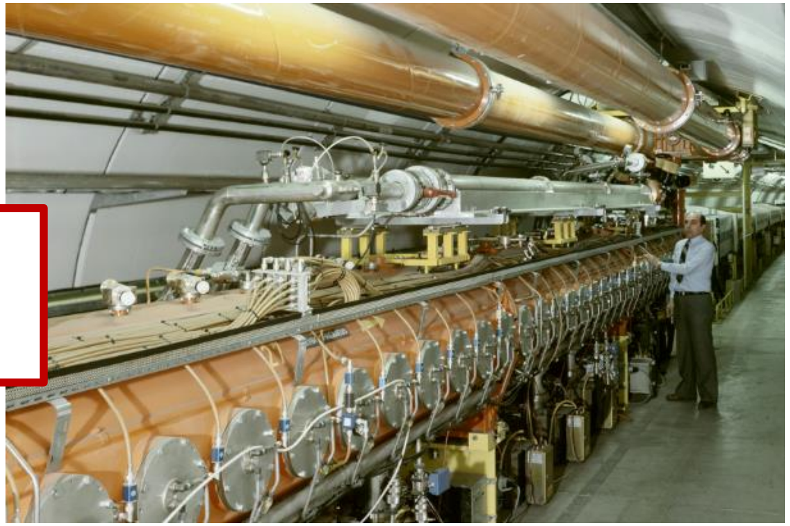
PS High-Intensity Beam for North Area



- **Barrier bucket beam production scheme for PS extraction loss reduction**

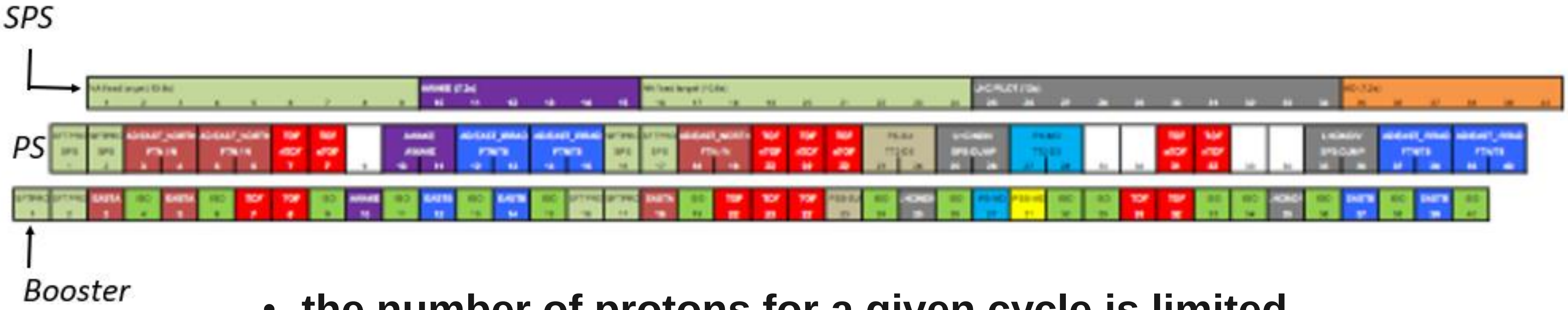
SPS

- **The first synchrotron in the chain at ~30m under ground**
- **Circumference of 6.9 km**
  - 11 x PS circumference
- **Increases proton beam energy up to 450 GeV with up to ~4-5x10^{13} protons per cycle**
- **Provides slow extracted beam to the North Area**
- **Provides fast extracted beam to LHC, AWAKE and HiRadMat**



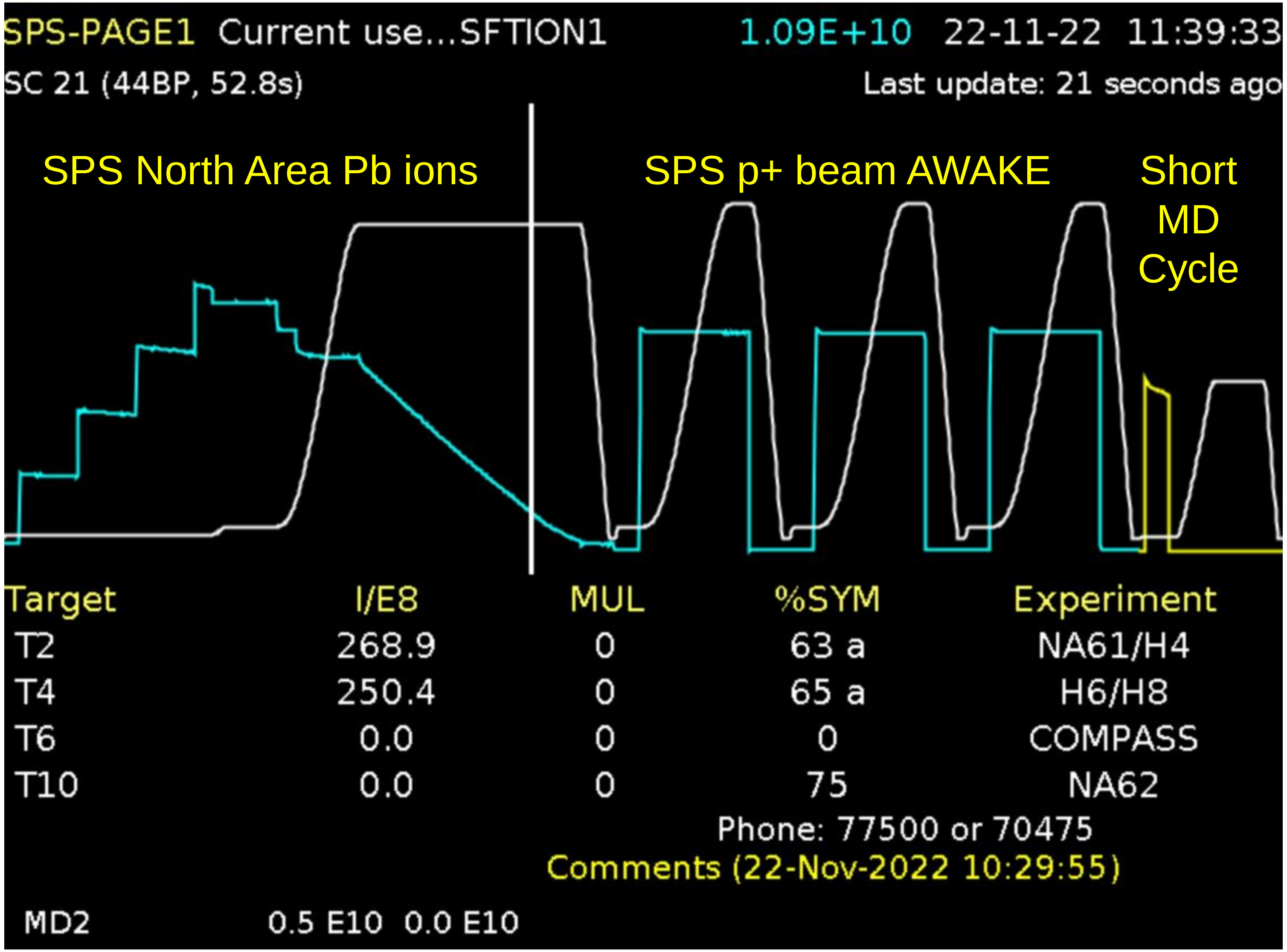
Injected Intensity:
2022: ~2.4E19
2023: ~1.4E19

The versatile PSB / PS / SPS Super cycle Chain

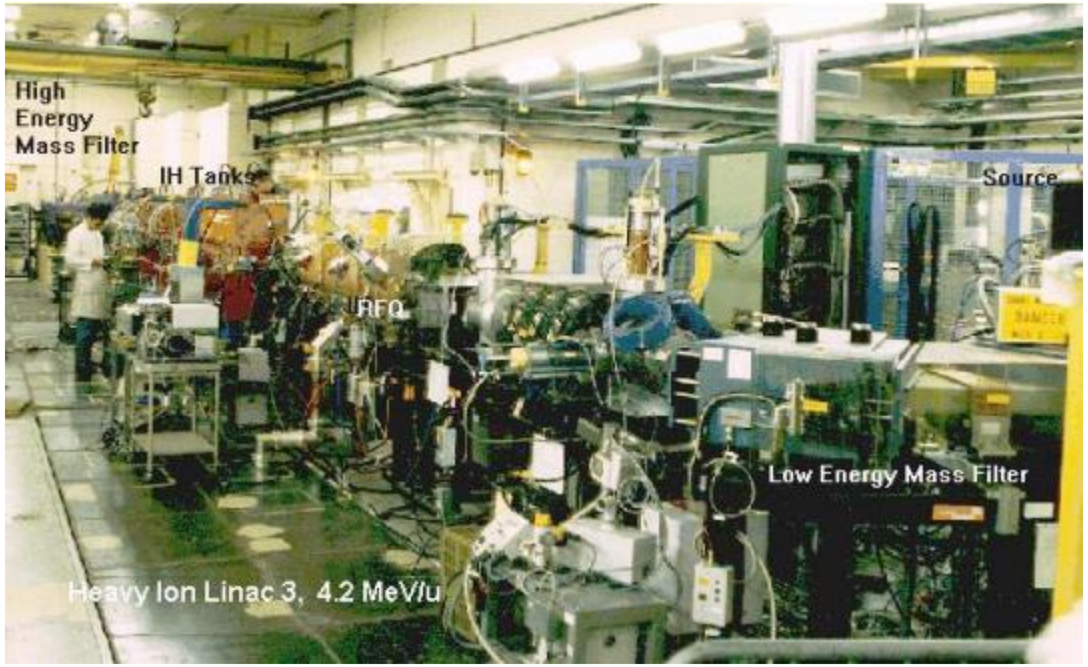


- the number of protons for a given cycle is limited
- Composition of cycles/super-cycles define sharing among experimental areas and users/experiments
- Very flexible and changes possible (almost) on the fly
- lot of effort by the CERN accelerator teams to optimise the delivery rate

The versatile SPS Super cycle



Not Forgetting about LINAC-3 & LEIR

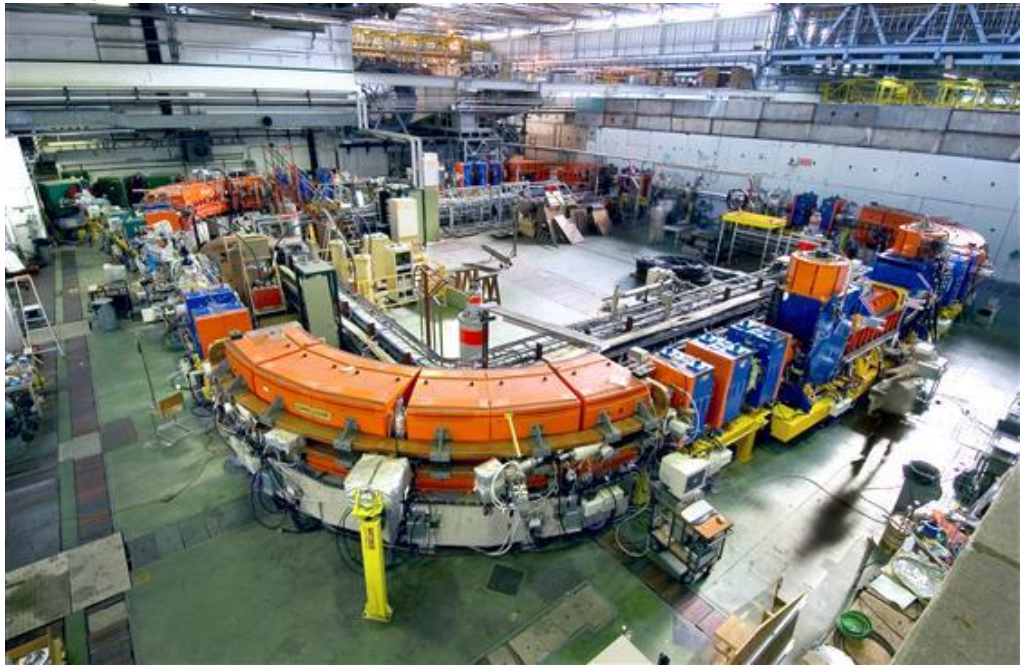


Linac3: the heavy ion source
(Commissioned in 1994)

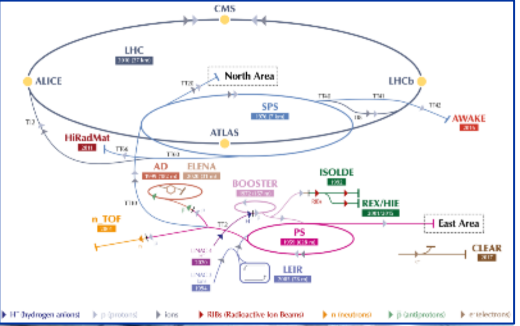
- Total length: ~12 m + short transfer line
- 4.2 MeV/N
- **25 µA Pb^{54+}**
- **+ Ar, Xe and soon O beams**

The LEIR machine
(circumference is about 80 m)

Uses a multi-turn injection from Linac3, normally Pb^{54+}, or lighter isotopes (e.g. Ar, Xe or O) ->accelerated to 72 MeV/u, then further accelerated by the PS and fully stripped before being sent to the SPS or the EA



Let’s Look into some Details



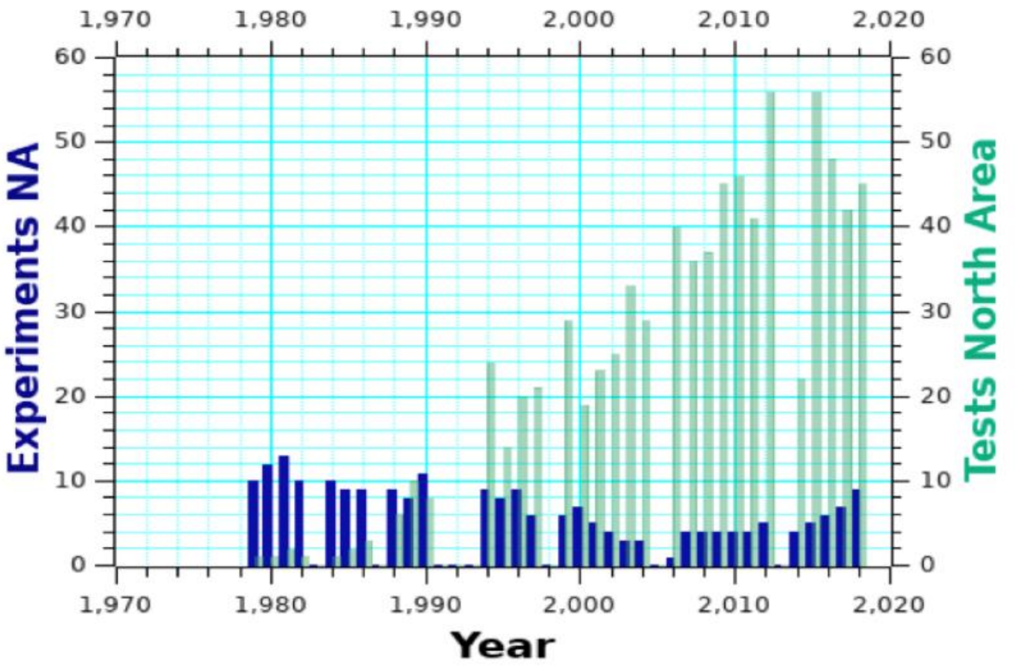
The CERN Accelerator Injector Complex & Its Experimental Areas

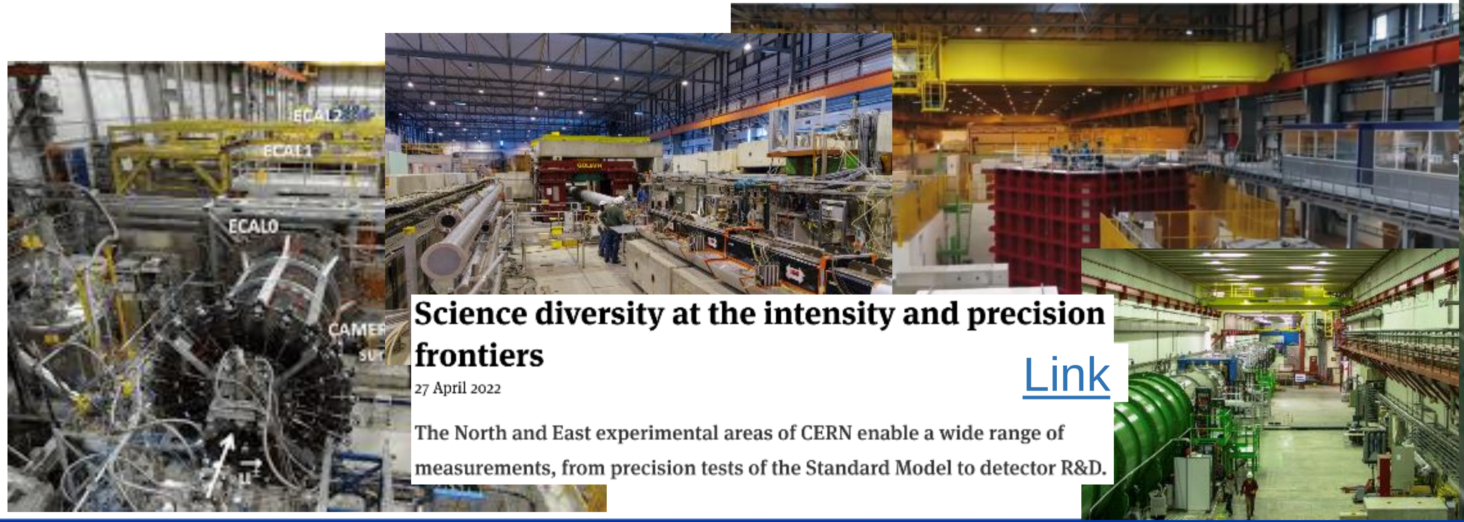
What’s needed – based on a selection of on-going/planned/proposed Experiments (North Area Focus)

In the context of Mid/Long-term perspectives of concerned Experimental Areas

Science Diversity at the CERN North Area

- The North Area at CERN is one of the most diverse experimental facilities that currently exists, serving **proton, hadron, electron, muon, and ion beams** to yearly over **200 user teams** for **detector R&D** and to the NA58/COMPASS, NA62, NA63, NA64e, NA64mu, NA65/DsTau and NA66/AMBER **experiments,** the two large **neutrino platform** cryostats**,** as well as to the GIF++ and CERF **irradiation facilities**, with combined **more than 2000 users**.



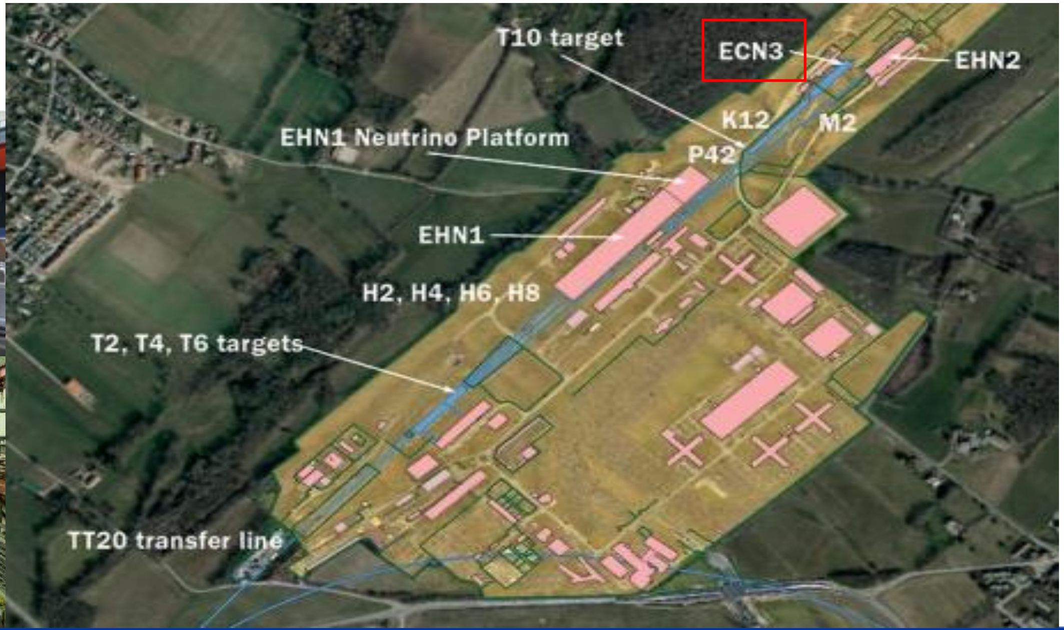


Science diversity at the intensity and precision frontiers

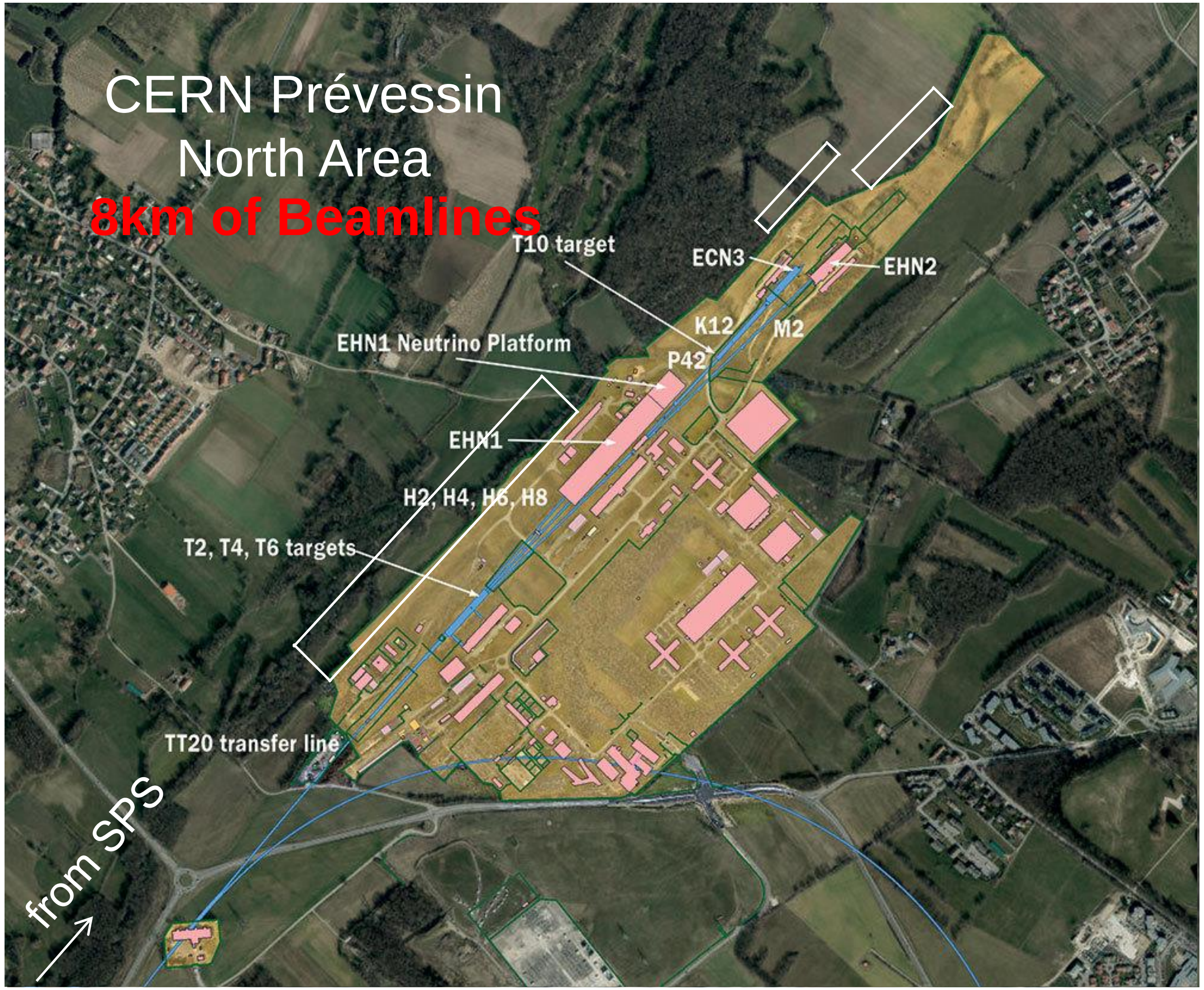
27 April 2022

[Link]

The North and East experimental areas of CERN enable a wide range of measurements, from precision tests of the Standard Model to detector R&D.



FT Physics @ SPS



Experimental Areas:

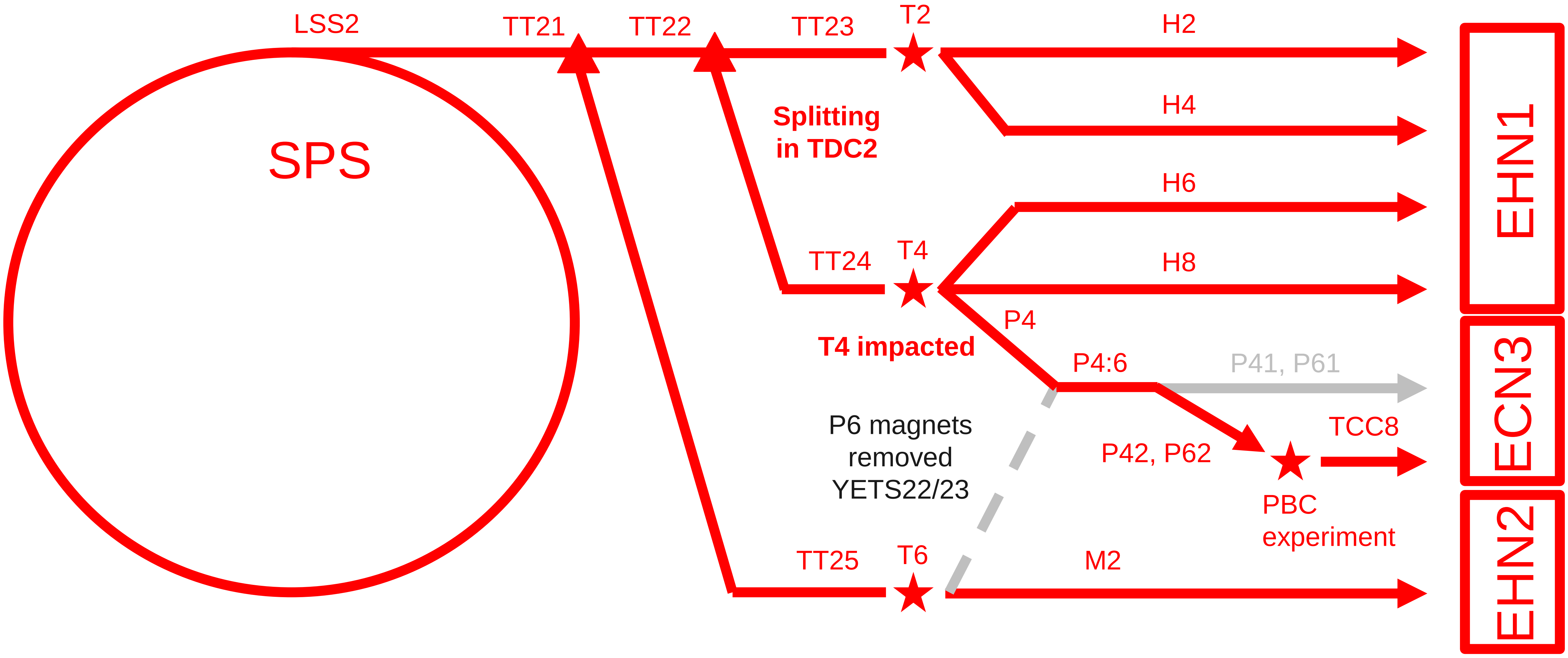
- EHN1 (surface building)
- EHN2 (surface building)
- ECN3 (underground cavern)

Main Users:

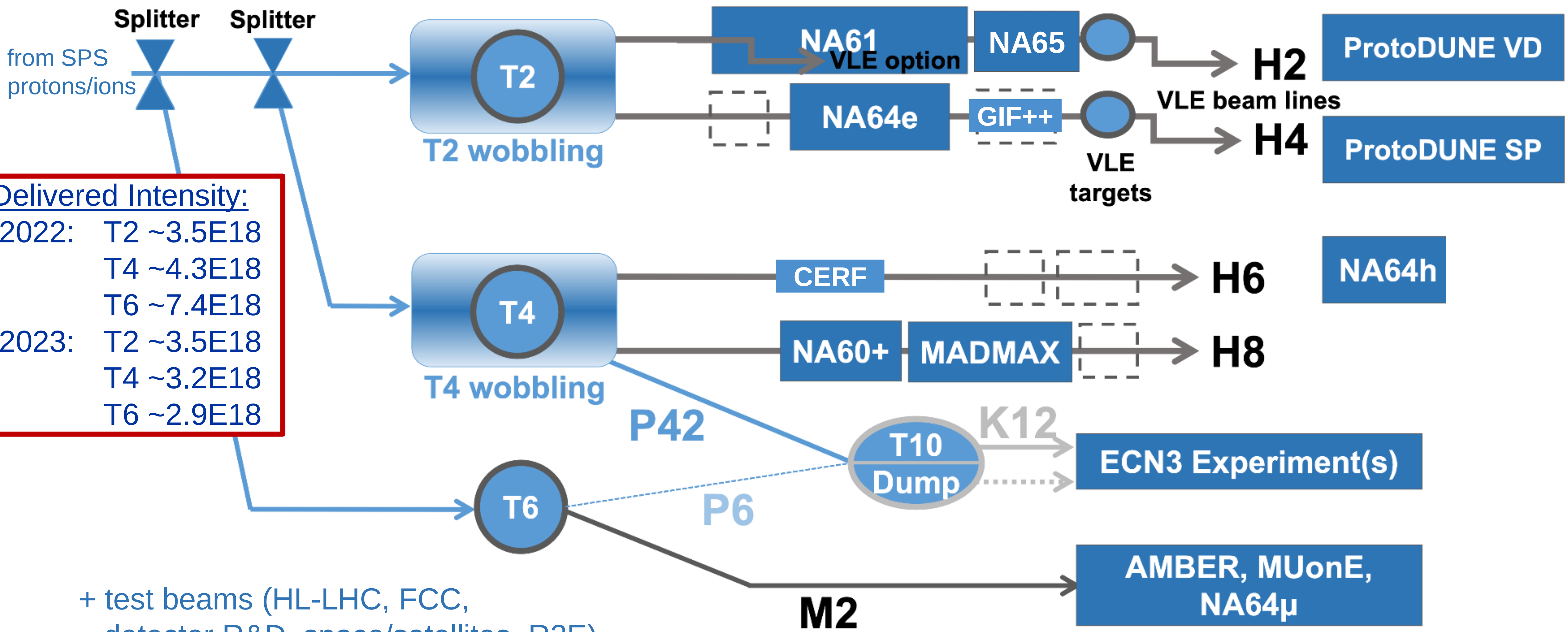
- Fixed Target Experiments
- Variety of Test Beam Users

Beam Delivery Scenarios: SHARED

(à la SFTPRO)



PBC (including studies) FT Physics @ SPS



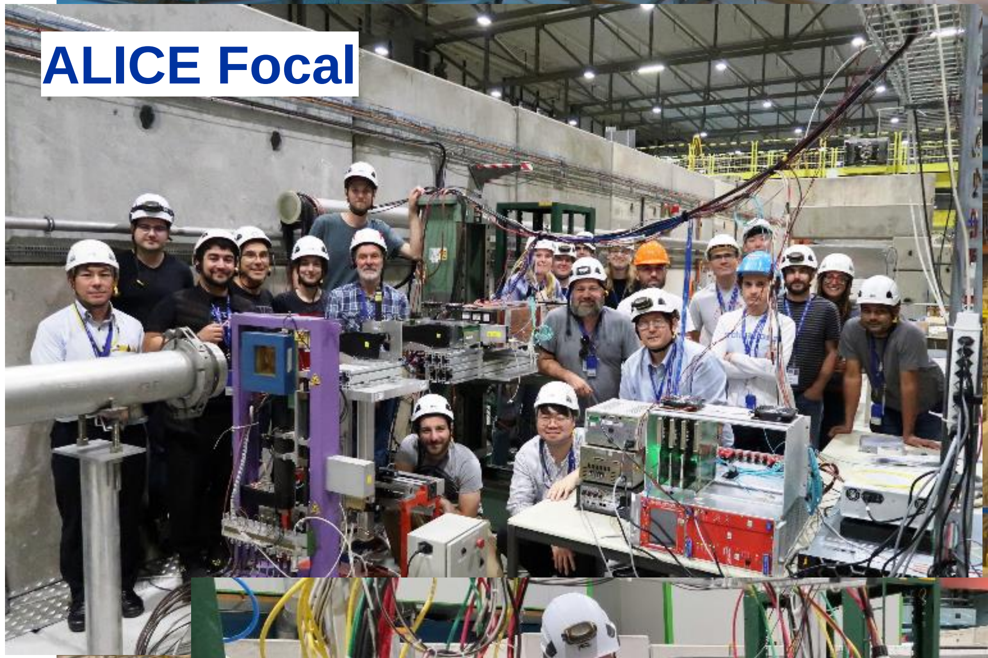
Delivered Intensity:

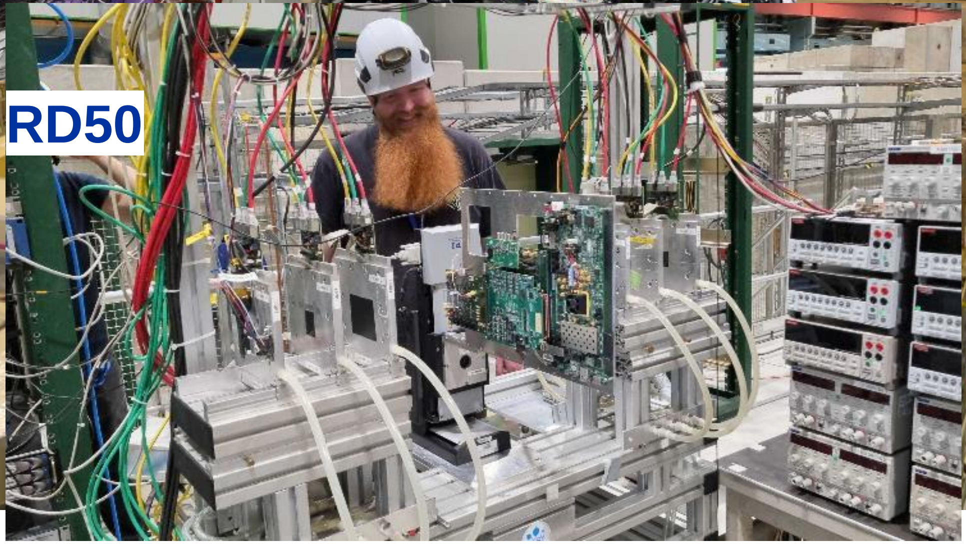
2022:	T2 ~3.5E18
	T4 ~4.3E18
	T6 ~7.4E18
2023:	T2 ~3.5E18
	T4 ~3.2E18
	T6 ~2.9E18

+ test beams (HL-LHC, FCC, detector R&D, space/satellites, R2E)

The EHN1 Hall: Test-Beams

Beam	Momentum	Particle types
H2	≤ 400 GeV/c	p,e, h, μ, ions*)
H4	≤ 450 GeV/c	p,e, h, μ, ions*)
H6	≤ 205 GeV/c	e, h, μ
H8	≤ 450 GeV/c	p,e, h, μ, ions*)





Maximum fluxes depend strongly on the momentum, charge, particle type, production angle, layout, shielding, etc.
-> typically 10^5-10^7 per pulse
(but can be higher with more shielding)

[coupling between beamlines
from the same target – Wobbling]

*) Up to LS1, only fragmented ion beams can be provided
After LS1, primary Pb, Ar and Xe beams are possible

Excursion: Test Beams

All experiments need test beam time for detector R&D, proof of their concepts and validation of their backgrounds

PBC contributes to the general need for detector R&D as was just stated by ECFA: “It is recommended that the structures to provide Europe-wide coordinated infrastructure in the areas of: test beams, large scale generic prototyping and irradiation be consolidated and enhanced to meet the needs of next generation experiments…” – P. Allport

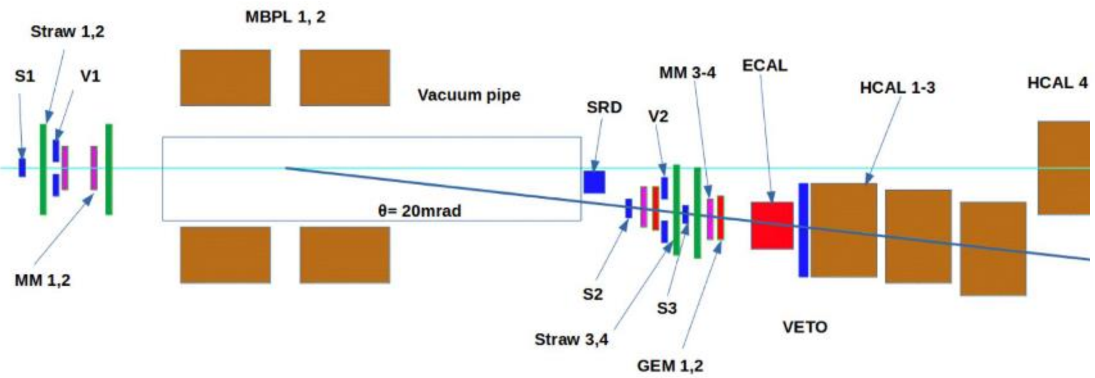
With the consolidation efforts (e.g. East Area, NACONS) we go in the right direction, very much appreciated by the community. We have more than 1100 users per year with increasing number of requests

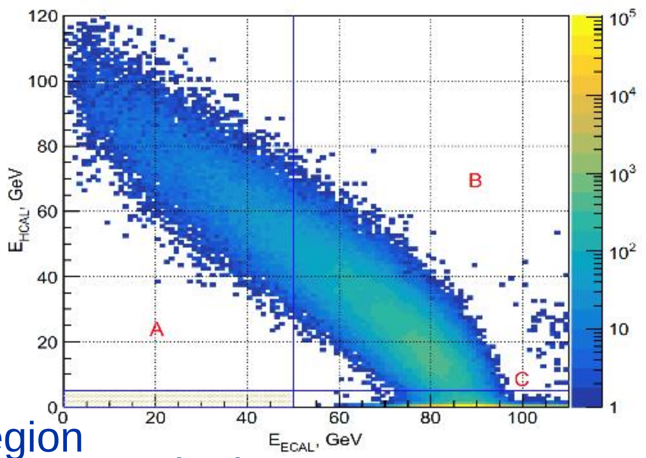
NA64

NA64 is designed to search for dark sector physics in missing-energy events with mainly electron and muon beams.

Unlike classical beam dump experiments, NA64 uses an active target, i.e. a detector in which dark matter particles are potentially produced. This results in a high sensitivity for certain channels.

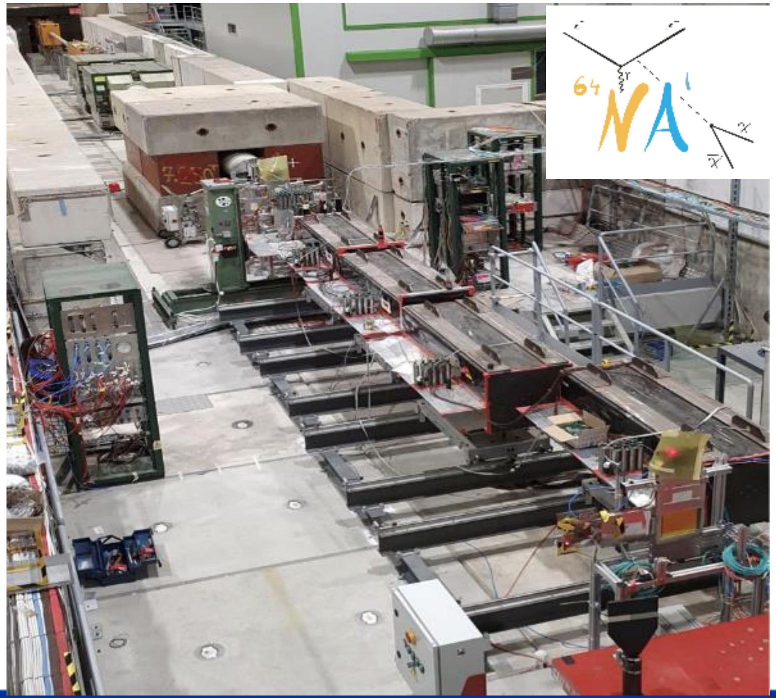
Suppression and control of the backgrounds to a high level is essential to the experiment



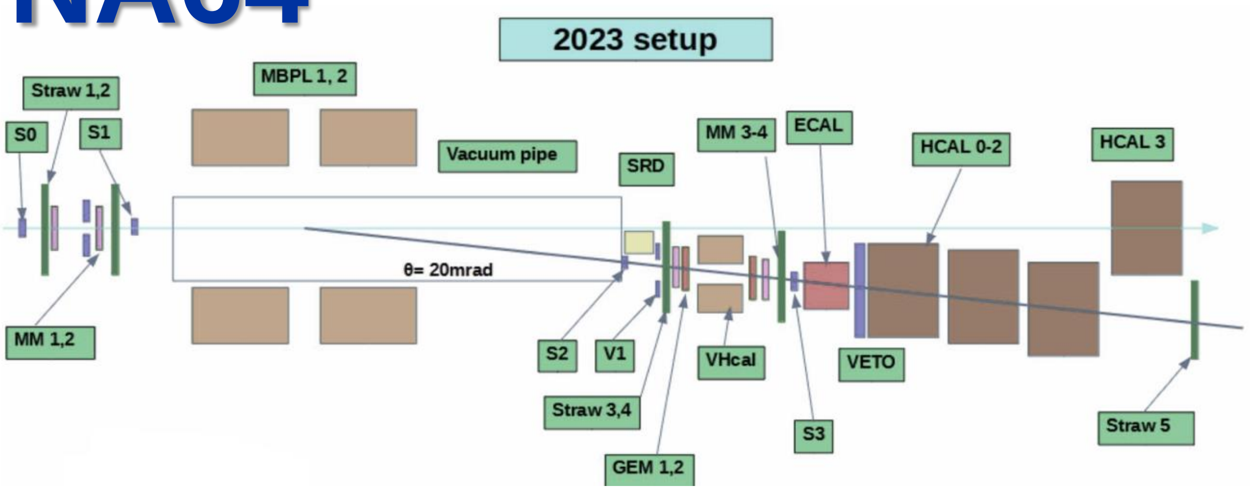


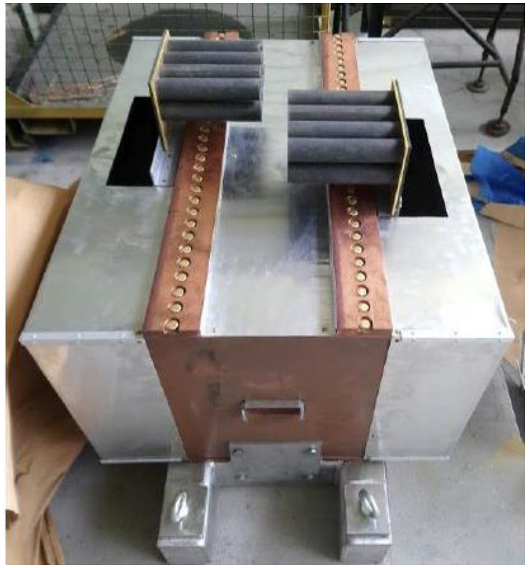
Signal Region
(box size increased vertically for visibility)

Missing energy



NA64





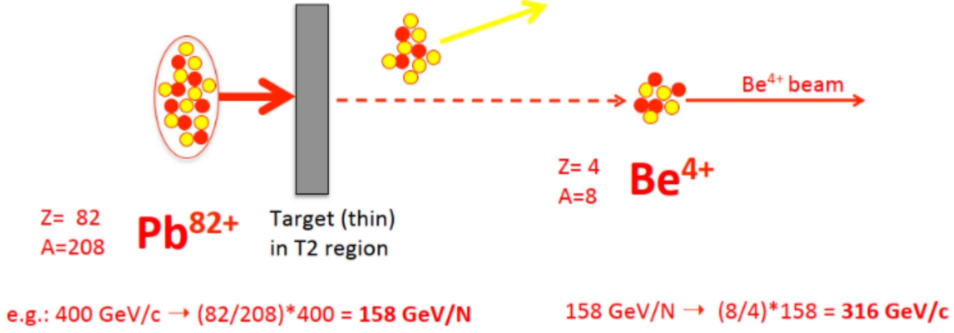
- A **new veto hadronic calorimeter (VHCAL)** was installed in front of ECAL to further suppress upstream electro-nuclear reactions with large-angle neutral hadrons.
- Excellent beam quality in 2023 with further **reduction of hadronic contamination down to 0.3%**.
- About 6 weeks physics run in May/June with ~ $6.5 \cdot 10^6$ electrons/spill
  → **Increase total available statistics on invisible mode by $5.1 \cdot 10^{11}$ electrons on target.**

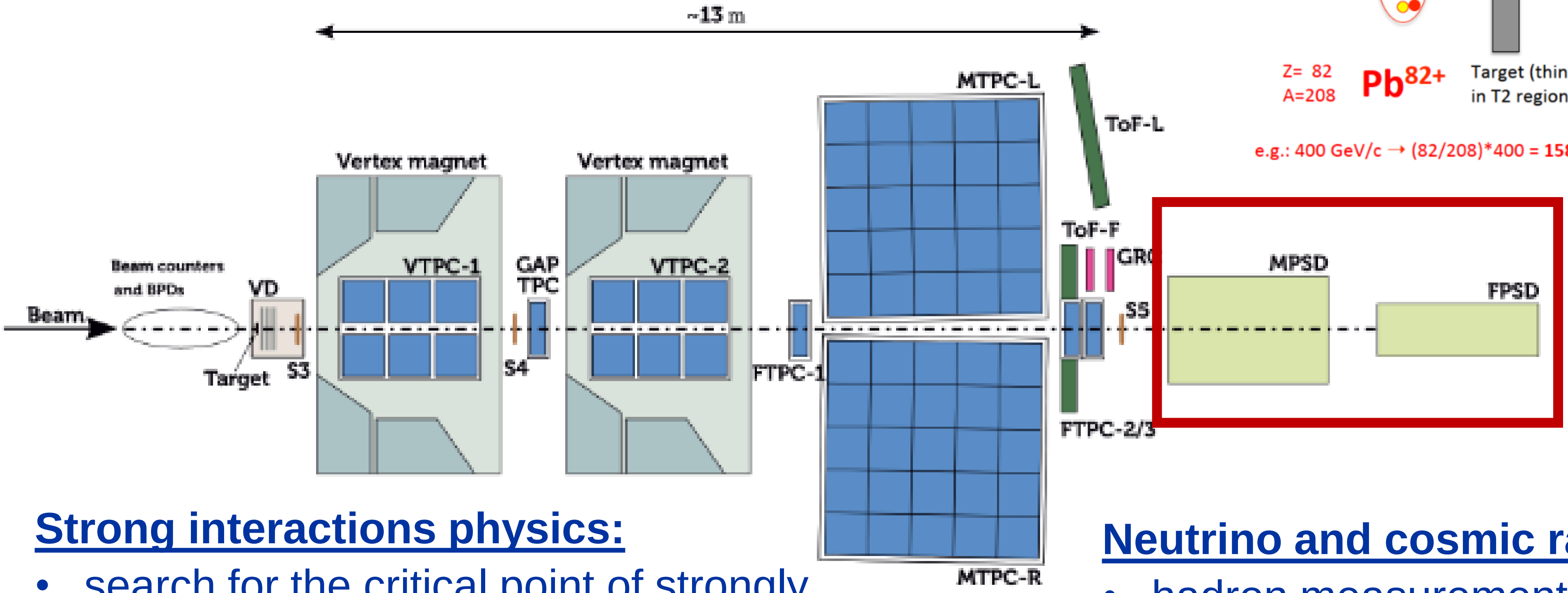
-> First tests with Positron Beams

POKER
POsitron resonant annihilation into dar**K** matt**ER**

- The **A' Bremsstrahlung** production mechanism scales with $1/m^2_{A'}$, hence is **suppressed towards higher masses**
- **First Test Run!** → Plan to start a dedicated positron beam campaign.

NA61





Shielding Improvement:

- Early PBC
- Allowing for 10x more intensity during this run period

Strong interactions physics:

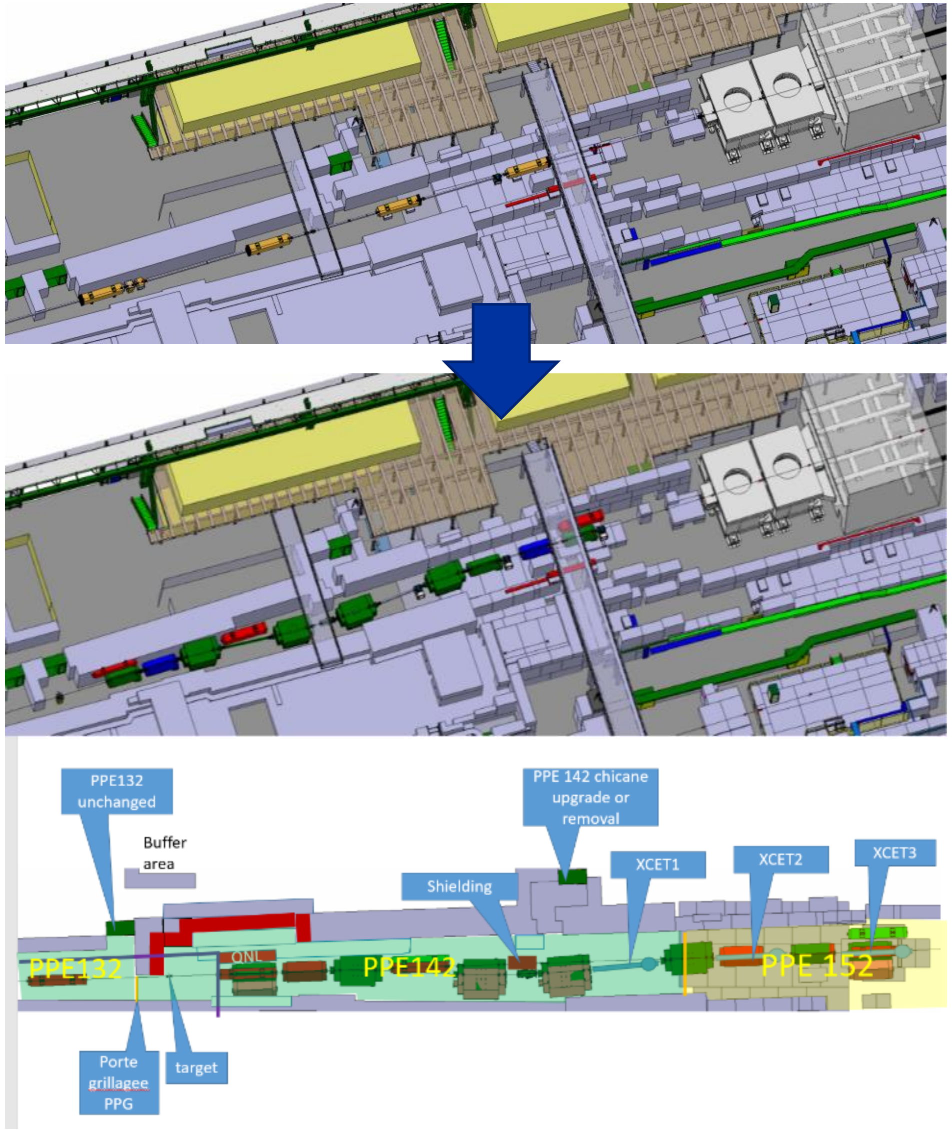
- search for the critical point of strongly interacting matter
- study of the properties of the onset of deconfinement
- heavy quarks: direct measurement of open charm at SPS energies

Neutrino and cosmic ray physics:

- hadron measurements for the J-PARC and Fermilab neutrino program
- measurements for cosmic ray physics
- measurements of nuclear fragmentation cross sections of intermediate mass nuclei needed to study cosmic rays in our Galaxy

NA61 Low-E Beamline

- **Requirements**
  - low-momentum (2-13 GeV/c) beam proposed by and extended NA61 physics program
  - **Studied a new tertiary branch of the H2 line (located in PPE132-142-152 zones) in front of the NA61/SHINE TPC**
  - new magnets and modifications to existing power supplies powering the H2-VLE line of the neutrino platform
  - extra shielding, and rail systems allowing the transition between the existing H2 line and this low-energy configuration
- **Remarks**
  - **H2 VLE beamline motivated by NA61 TPC location and unique capabilities**
  - **Tertiary beam possible, however starting from SPS beam energies not optimal (in terms of production/intensity)**



The M2 Beam

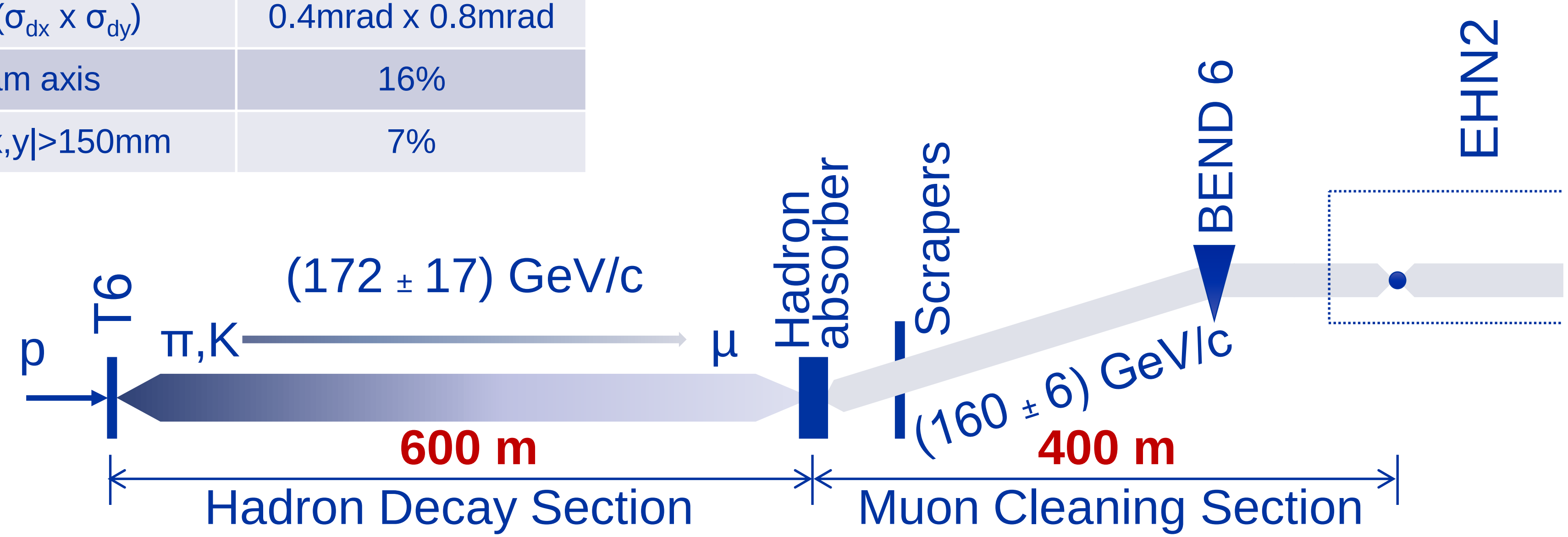
Three main operation modes:

- **High-energy, high-intensity muon beam**. Normally for muon momenta up to 200 GeV/c. Higher momenta up to 280 GeV/c are possible, but the flux drops very rapidly with beam momentum.
- **High-intensity secondary hadron beam** for momenta up to 280 GeV/c with radiation protection constraints.
- **Low-energy, low-intensity (and low-quality) in-situ electron calibration beam.**

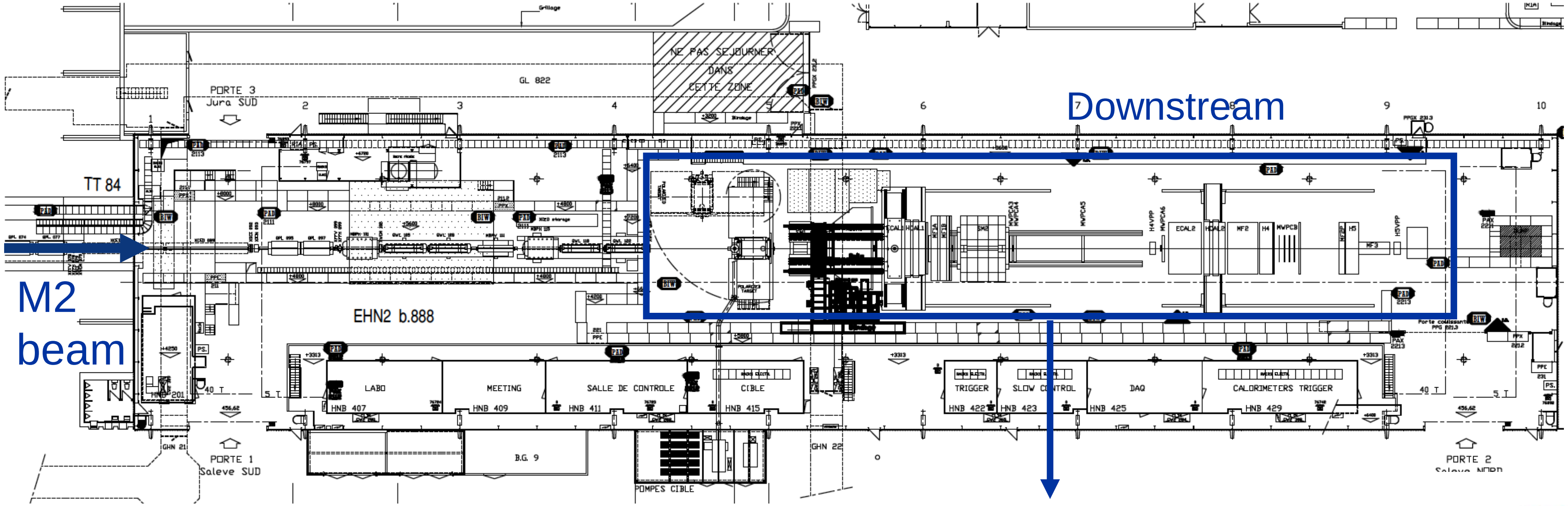
Beam Mode	Momentum (GeV/c)	Max. Flux (ppp / 4.8s)	Typical $\Delta p/p$ (%)	Typical RMS spot at target	Polarisation	Absorber (9.9 m Be)
Muons	+208/190 +172/160	~10^8 2.5 10^8	3%	8 x 8 mm	80%	IN 10^{-5} impurity
Hadrons	+190 -190 Max. 280	10^8 (RP) 4 10^8 (with dedicated dump)	-	5 x 5 mm	-	OUT
Electrons	-10 to -40	< 2 10^4	-	> 10 x 10 mm	-	OUT

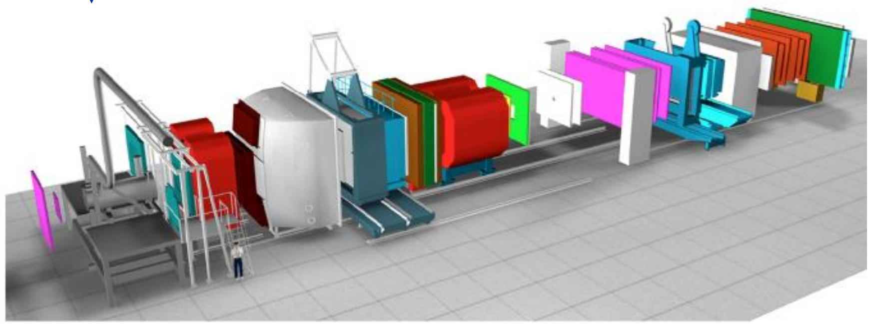
The M2 Muon Beam

Beam Parameters for COMPASS	Measured
Beam momentum p_μ/p_π	160 / 172 GeV/c
Proton flux on T6 per SPS cycle	1.5 10^{13}
Muon flux at COMPASS per SPS cycle	2.5 10^8
Beam polarisation	-80% ± 4%
Spot size at COMPASS target (σ_x x σ_y)	8mm x 8mm
Divergence at COMPASS target (σ_{dx} x σ_{dy})	0.4mrad x 0.8mrad
Muon halo within 50mm from beam axis	16%
Halo in experiment (6 x 4m^2) at |x,y|>150mm	7%



The EHN2 Experimental Area

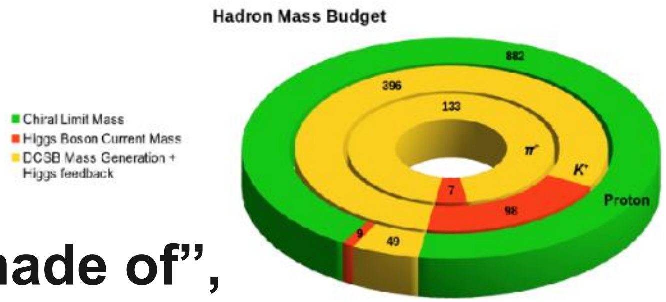




- **Large surface experimental area**
- Houses currently the
  AMBER, NA64μ and MUonE experiments

AMBER

The new question
is not "what is matter made of",
but rather "how did it emerge" and
"do we understand the structure of what is visible"



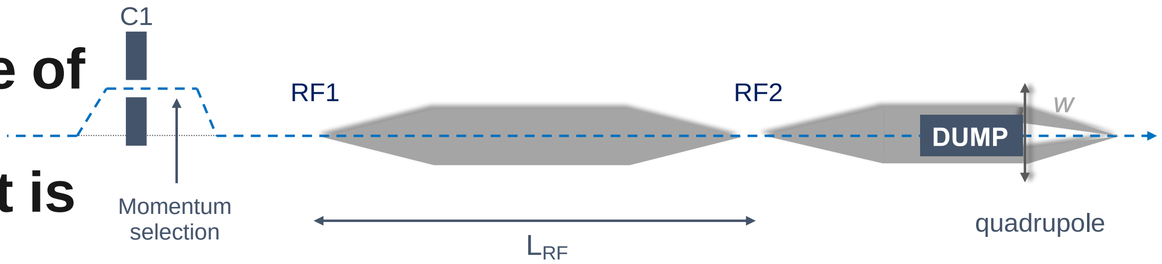
AMBER is a QCD facility, aiming at understanding open issues such as the proton radius puzzle (different proton sizes seen depending on the probe and method used)

Phase 1 aims at exploiting the conventional muon and hadron beams and is already largely approved

Phase 2 requires high purity kaon and antiproton beams at high energies, for which the technique of RF-separation is being studied. A dedicated workshop has taken place and a pre-CDR report is aimed for before LS3.

Program	Physics Goals	Beam Energy [GeV]	Beam Intensity $[s^{-1}]$	Trigger Rate [kHz]	Beam Type	Target	Earliest start time, duration	Hardware additions
muon-proton elastic scattering	Precision proton-radius measurement	100	$4\cdot10^6$	100	$\mu^\pm$	high-pressure H2	2022 1 year	active TPC, SciFi trigger, silicon veto,
Hard exclusive reactions	GPD E	160	$2\cdot10^7$	10	$\mu^\pm$	$NH_3^\uparrow$	2022 2 years	recoil silicon, modified polarised target magnet
Input for Dark Matter Search	$\overline{p}$ production cross section	20-280	$5\cdot10^5$	25	p	LH2, LHe	2022 1 month	liquid helium target
$\overline{p}$-induced spectroscopy	Heavy quark exotics	12, 20	$5\cdot10^7$	25	$\overline{p}$	LH2	2022 2 years	target spectrometer: tracking, calorimetry
Drell-Yan	Pion PDFs	190	$7\cdot10^7$	25	$\pi^\pm$	C/W	2022 1-2 years	
Drell-Yan (RF)	Kaon PDFs & Nucleon TMDs	~100	10^8	25-50	$K^\pm, \overline{p}$	$NH_3^\uparrow$, C/W	2026 2-3 years	"active absorber", vertex detector
Primakoff (RF)	Kaon polarisability & pion life time	~100	$5\cdot10^6$	>10	K^-	Ni	non-exclusive 2026 1 year	
Prompt Photons (RF)	Meson gluon PDFs	≥100	$5\cdot10^6$	10-100	$K^\pm$ $\pi^\pm$	LH2, Ni	non-exclusive 2026 1-2 years	hodoscope
K-induced Spectroscopy (RF)	High-precision strange-meson spectrum	50-100	$5\cdot10^6$	25	K^-	LH2	2026 1 year	recoil TOF, forward PID
Vector mesons (RF)	Spin Density Matrix Elements	50-100	$5\cdot10^6$	10-100	$K^\pm, \pi^\pm$	from H to Pb	2026 1 year	

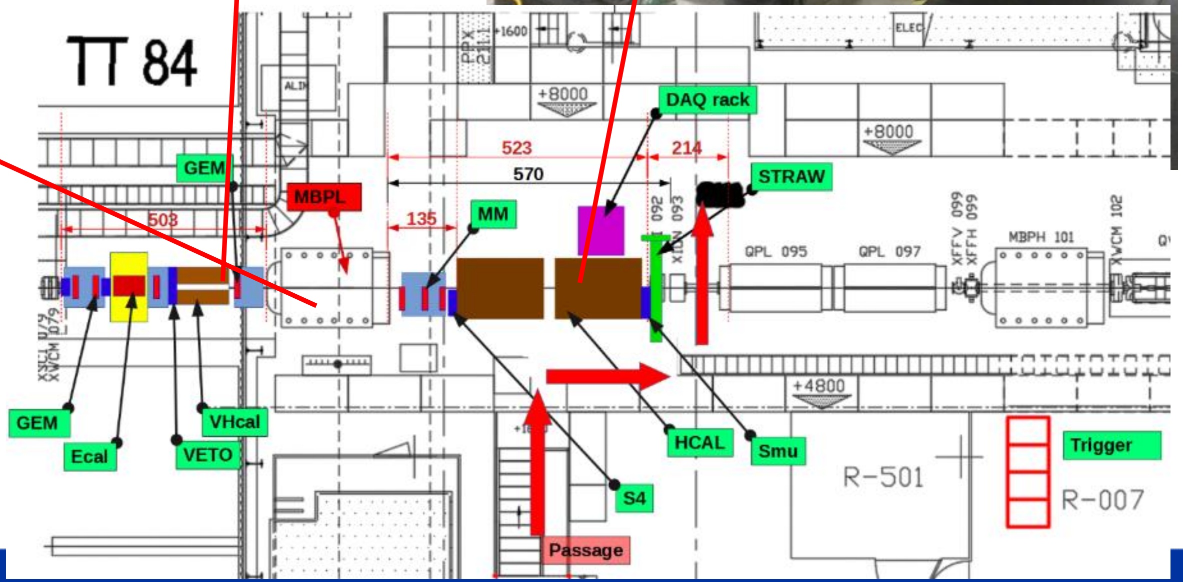
Table 2: Requirements for future programmes at the M2 beam line after 2021. Muon beams are in blue, conventional hadron beams in green, and RF-separated hadron beams in red.



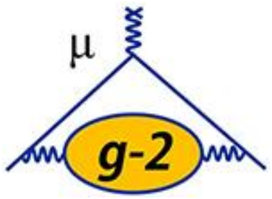
NA64μ

An experiment to search for dark sector particles weakly coupled to muon at the SPS as well as test the $(g\text{-}2)_\mu$ anomaly.

Installation of rails for the MBPL magnet as well as all upstream components.



MUonE

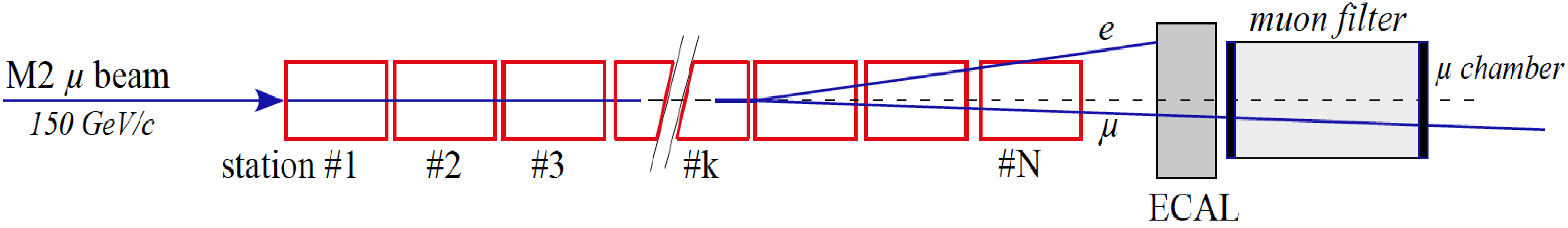


One of the few hints for new physics comes from the tension of the g_{μ}–2 measurements with respect to the SM prediction -> Theory Uncertainties

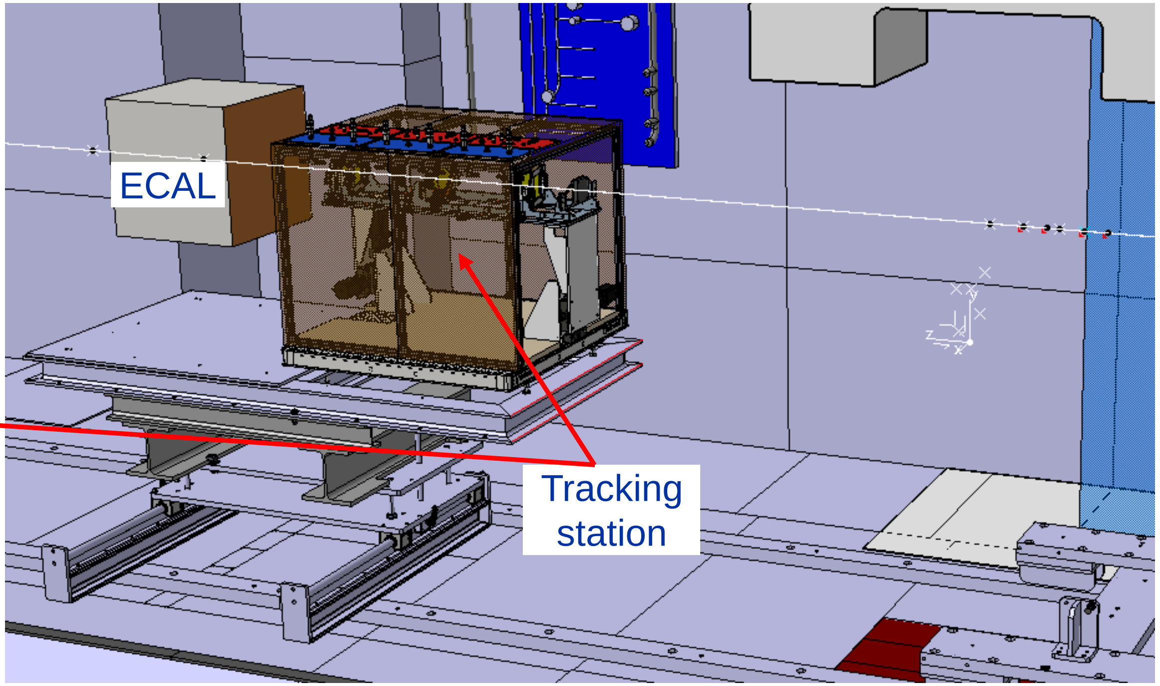
While the measurement reached a new level of precision, theory rapidly caught up – missing just one important ingredient for an even better prediction, the hadronic vacuum contribution

MUonE offers a complementary way of measuring this with the help of elastic muon on electron scattering, which needs to be done at an unprecedented precision and stability (order 10^{-5})

https://cerncourier.com/a/getting-to-the-bottom-of-muon-g-2/



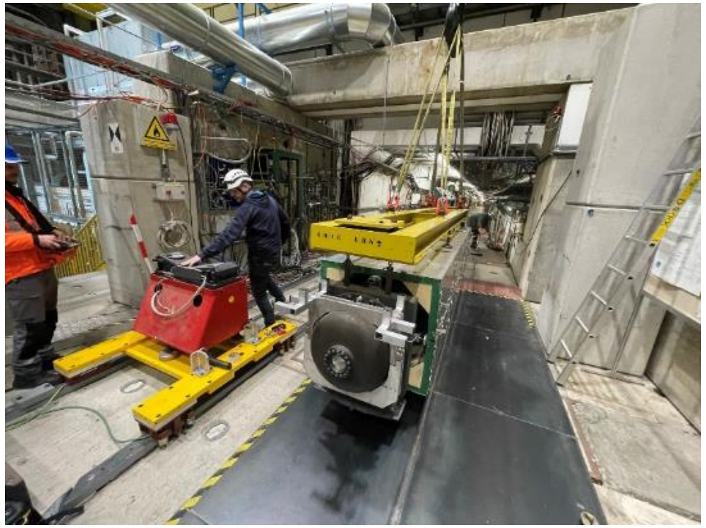
MUonE

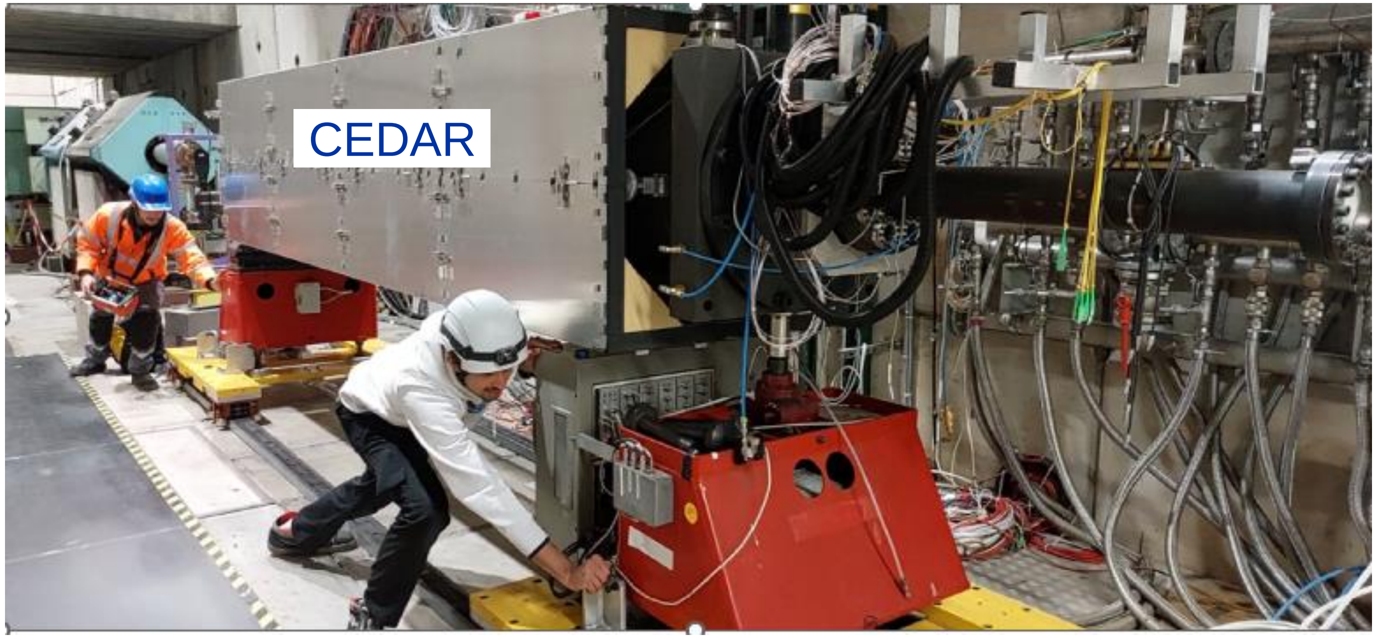


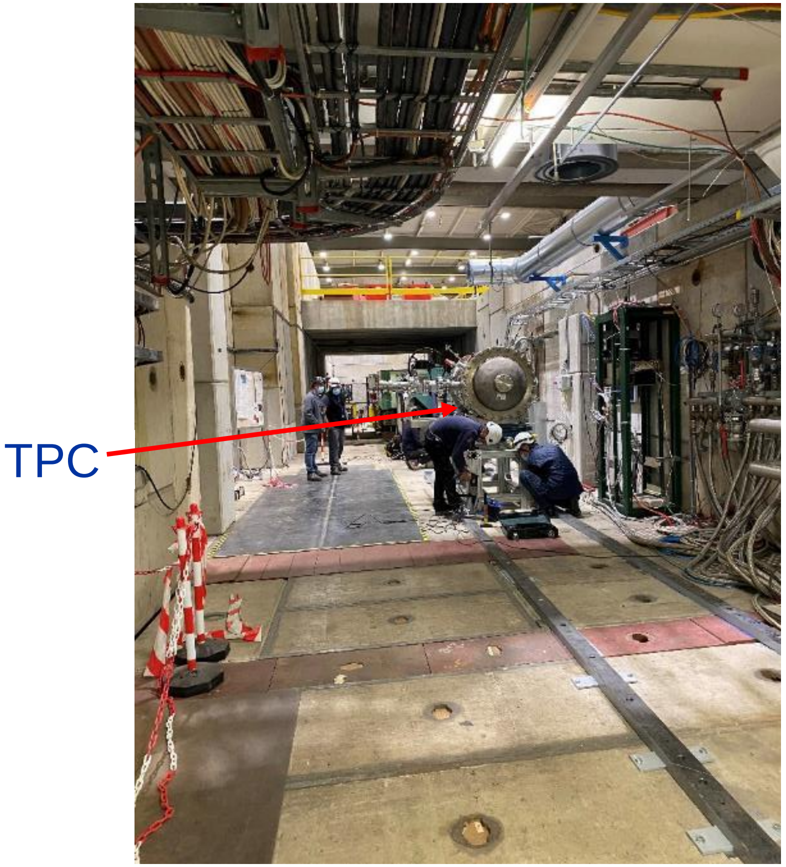
Design and installation of the blue trolley for easy changeover of MUonE during the COMPASS/AMBER polarisation periods for tests

Final installation with 40 such stations (10 in 2025!)
Experiment aims at an independent and precise determination of the leading hadronic contribution to the muon anomalous magnetic moment $a_\mu=(g_\mu-2)/2$.

Infrastructure allowing for fast reconfiguration







Installation of TPC on the rails for the **proton radius measurement,** one ingredient to understand where **98% of the mass of the visible universe** comes from.

Excursus: Stability

Many experiments rely on stable conditions during their physics run as they try to exploit the absolute maximum of their data taking capabilities

Each proton counts to reach the physics goal, but the steadier they come, the less often interruptions occur, and more data can be taken

A high duty cycle is a guarantee for reaching the physics goals of the experiments. Often it is even more helpful to communicate early any change, so the data taking strategy can be adapted

Stability is defined over several time scales: From short fluctuations in the spill structure, even to weeks of data taking, during which experiments try to balance between configurations in order to decrease their systematic errors

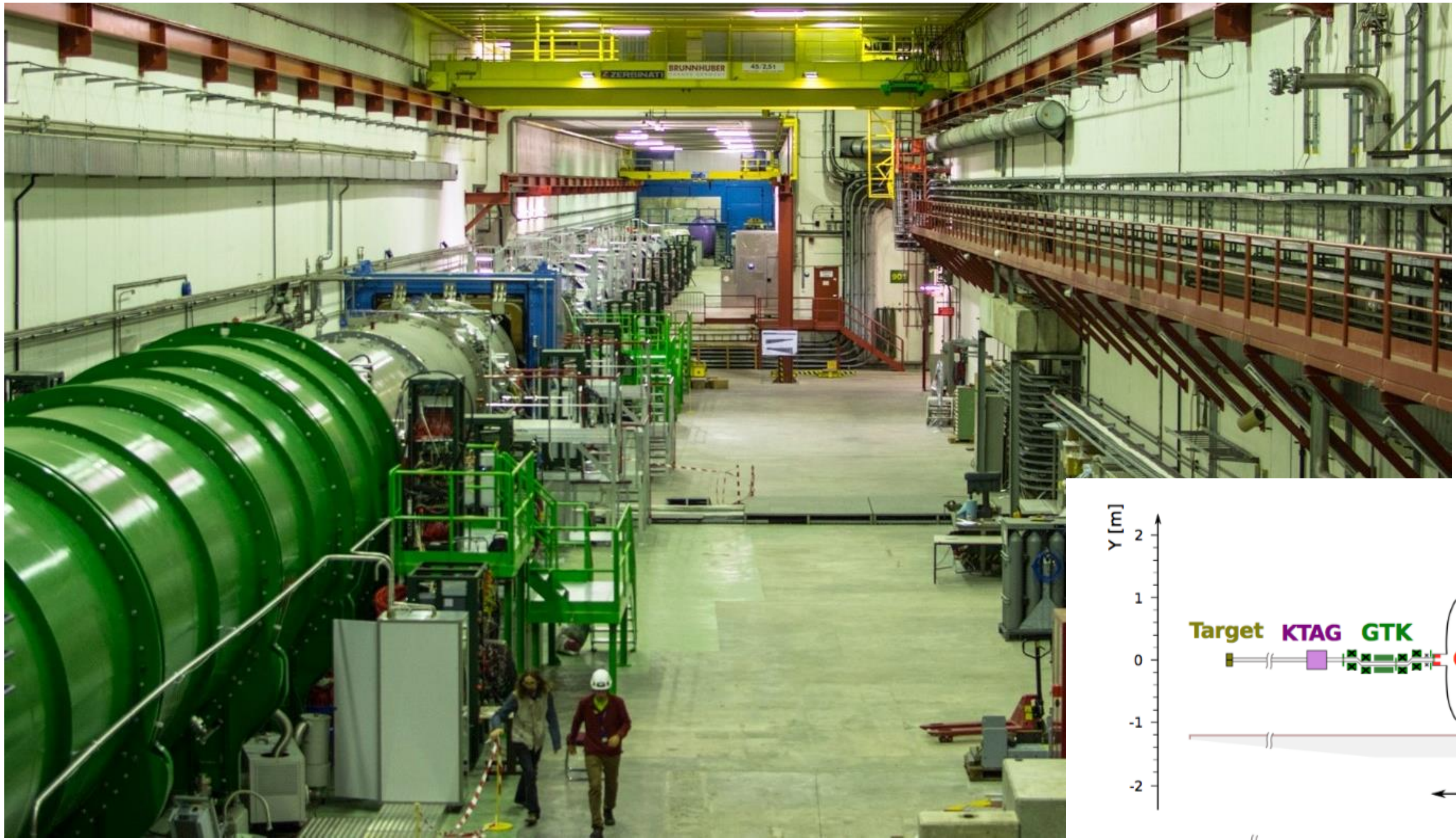
Beam instrumentation is essential: accurate and absolute intensity measurement per beam line and an accurate and fast spill structure monitoring -> ideally from which information should be available directly to experiments for logging with their data

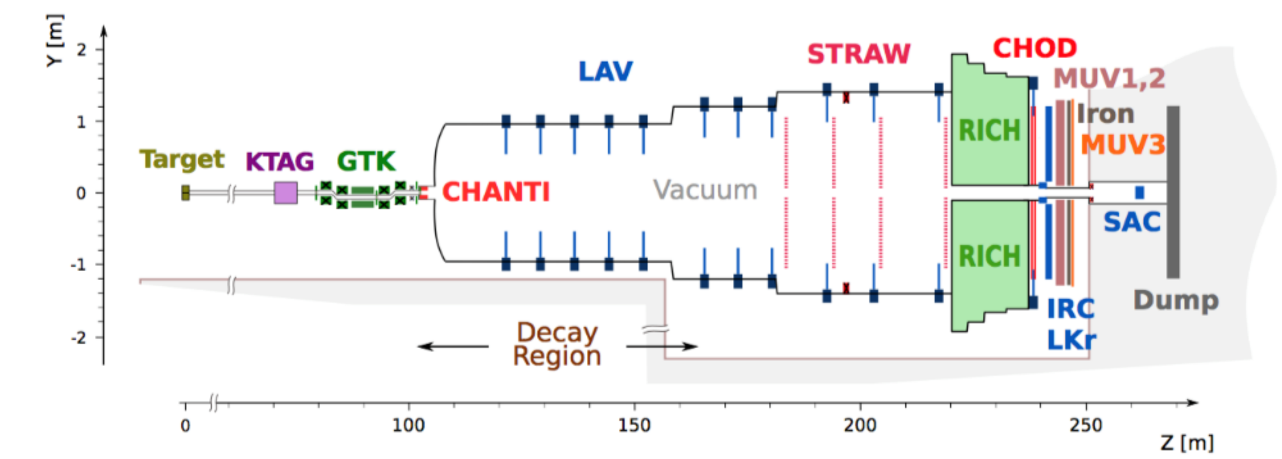
ECN3 -> today: NA62

studies very rare K^+ decay -> $\pi^+\nu\nu$

very small (~10^{-10}) branching ratio and calculable with very good precision in the Standard Model
-> Probing New Physics

- It can also look for other rare K decays (e.g. LFV)
- NA62 spends part of its beam time in looking for Dark Matter, dark photon and axions.



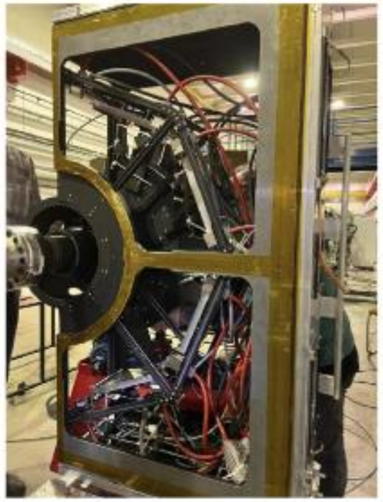


CEDAR – A Special Tool -> Now with Hydrogen

New optics

CEDAR-H installed in K12

Light box installed



KTAG Cabled

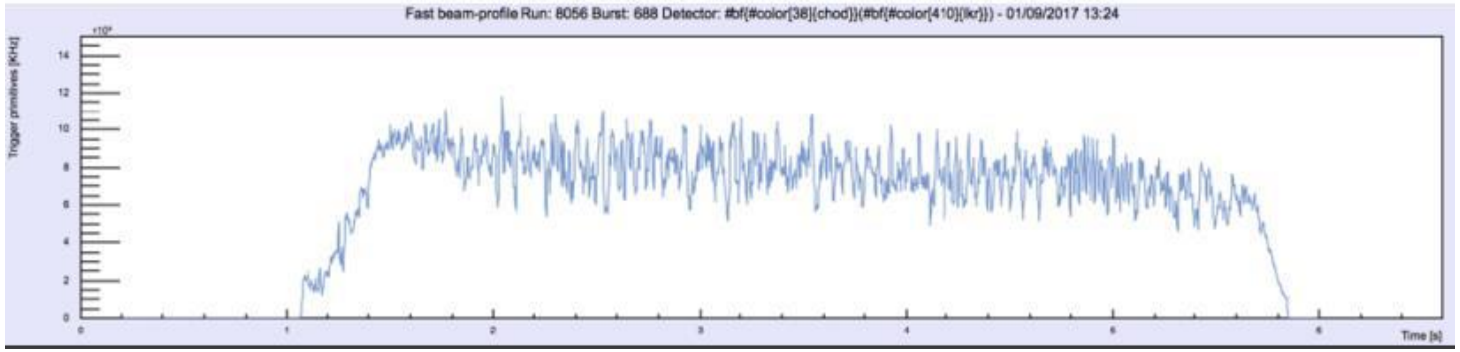
Excursus: Spill Structure

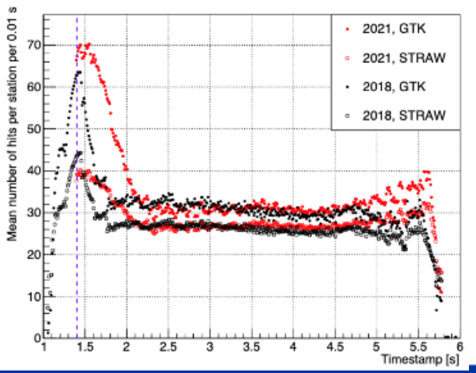
Precision Experiments rely critically on slow extraction -> sensitive to intensity fluctuations

High frequencies (e.g. f_{rev}) **lead typically to a shorter effective spill length**. Large effect: 1% shorter effective spill needs typically an additional 1.5 days **more data taking per year** to compensate -> also leads to **pile-up**: very dangerous as it **mimics good physics signals**

Low frequencies lead typically to problems in the data acquisition and to fluctuations in the gain of some detectors, and thus their efficiency and stability -> for experiments without good online data quality control this is hard to spot and seen normally at the analysis level

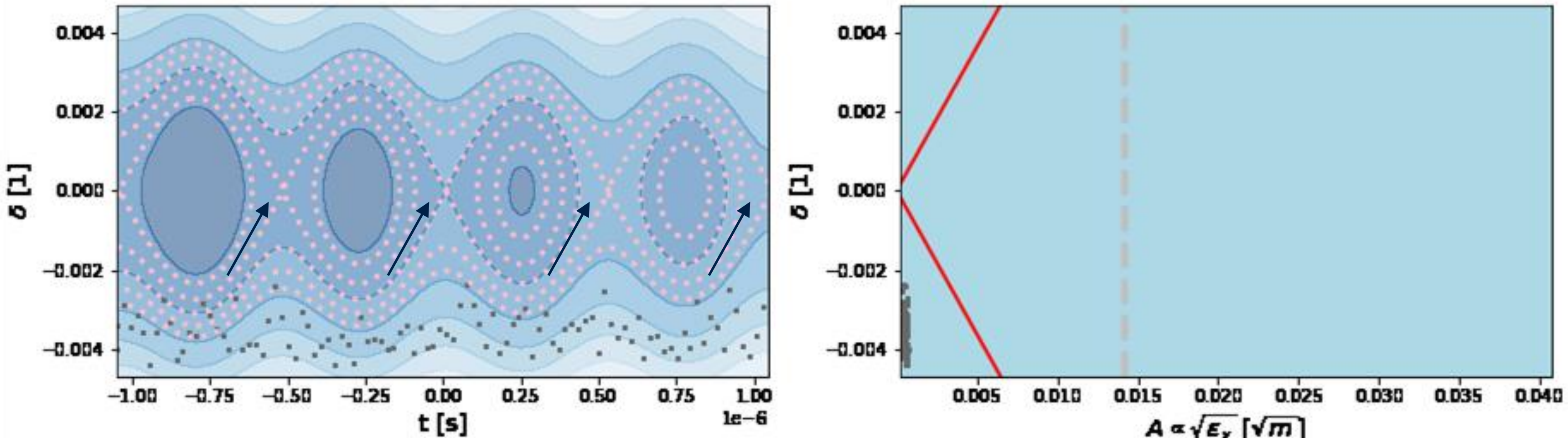
Spikes can trip or even destroy detectors if the amplitude is high -> often spikes lead to a crash of detector readout and data acquisition, which takes some time to recover

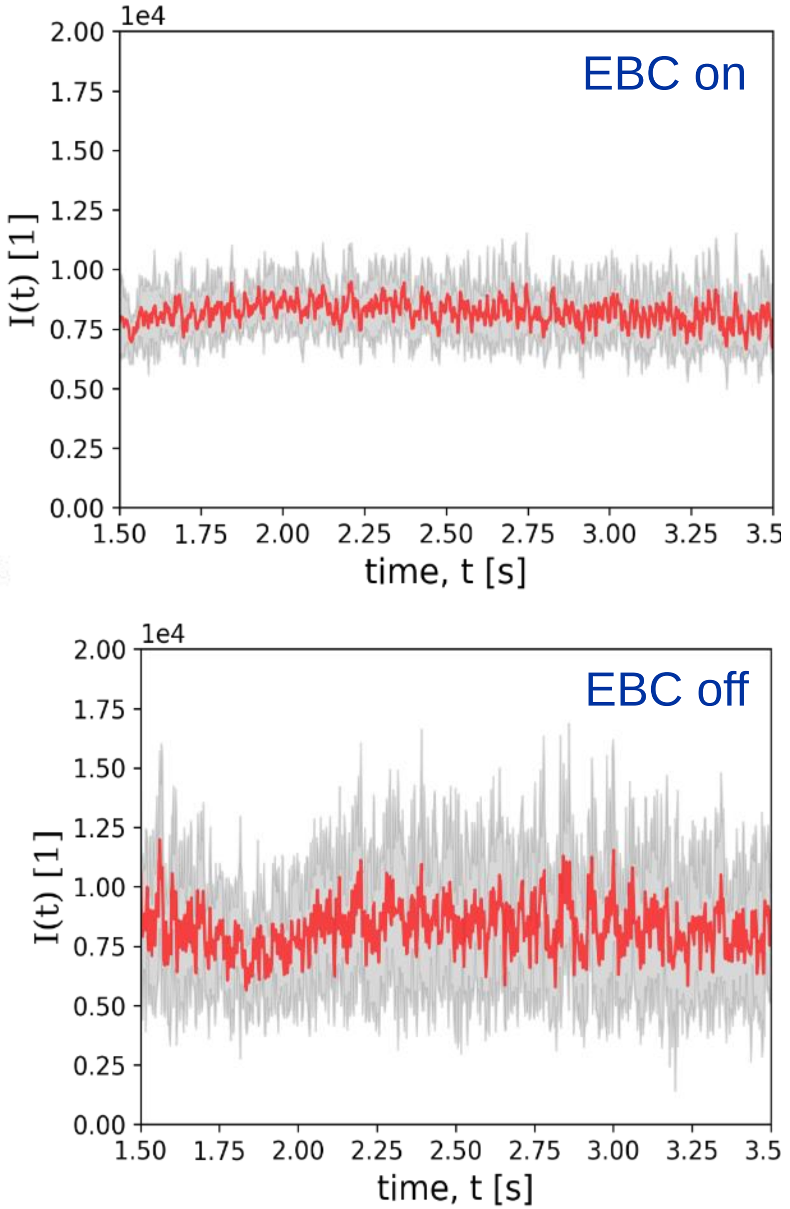




Extraction Quality

P. Arrutia (CERN)

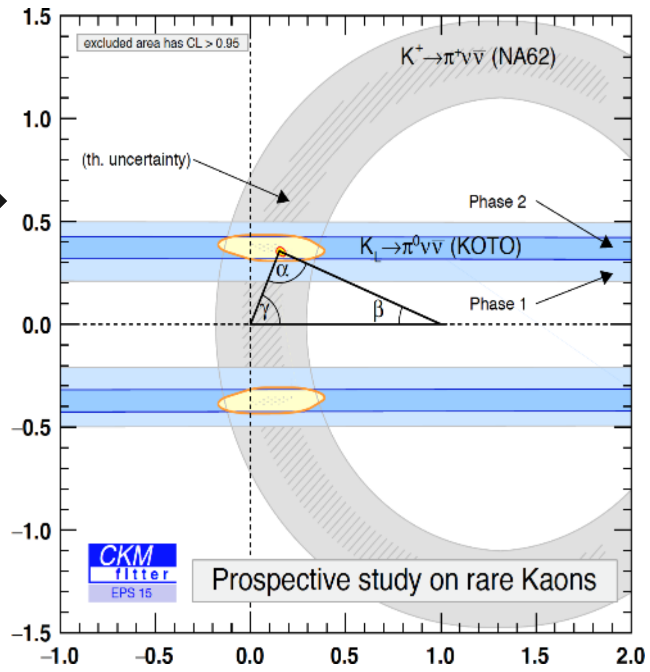




- Especially time structures at 50 Hz and 150 Hz, introduced via power converters, can easily lead to data acquisition issues due to peaks in the instantaneous intensity
- **Amongst several improvements on the hardware and controls-side, empty bucket channelling proved very helpful: the de-bunched beam is forced up and "channelled" between the empty buckets**

- **Pablo A. Arrutia Sota thesis** (funded by PBC), Keble College, University of Oxford
  Advanced RF techniques for CERN's future slow-extracted beams
  (to be submitted for the degree of DPhil, 2024)

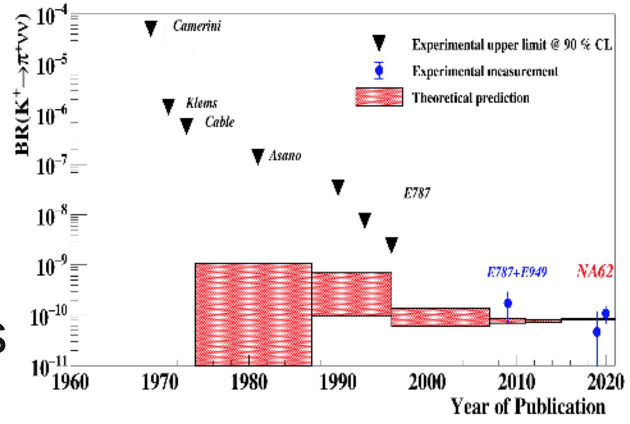
NA62 and Beyond



Extremely rare decays with rates are very precisely predicted in SM, example: the kaon decay to πνν, either with a charged kaon/pion (→ NA62) or with a neutral kaon/pion (→ KLEVER) [golden channel]

Due to the small branching ratio in the order of 10^{-11}, stable high-intensity beams are a must. In order to reach a measurement precision of e.g. 5%, the current intensity for NA62 would need to be quadruplicated

As the branching ratio for the neutral channel is even smaller, the intensity for KLEVER would need to be at least sixfold of what is available now, i.e. 2.10^{13} protons per spill. With an assumed 1.5 10^{13} protons for T6/M2 and some 0.8 10^{13} for T2, this could bring us to the need of providing a total of more than 4.10^{13} protons



Such measurements are comparable to a sensitivity at the O(100 TeV) mass scale for new physics searches -> **precision means true complementarity to measurements at highest energies**

Excursus: The Quest for Higher Intensities

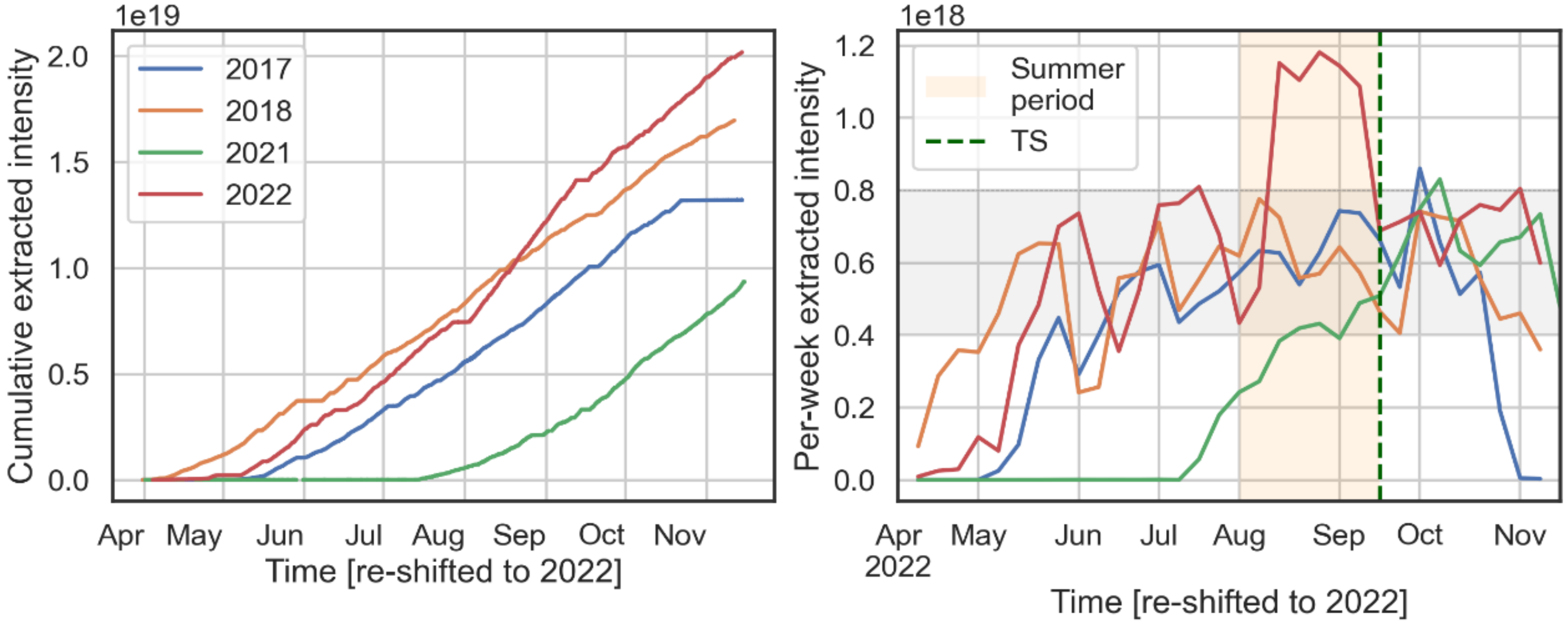
Basically all newly proposed experiments want to push the limits of precision aiming at either excluding new physics at a certain scale or even making a discovery of new physics (e.g. SHiP/HIKE/SHADOWS). This means clearly higher intensities are needed, none the less to serve the demand of having more high intensity users at the same time. This happened already 2021 with NA64, NA62 and Compass wanting to run simultaneously

Slow extraction of high proton intensities at a high quality is one of the major features that makes CERN unique, and which is even constantly improving (remarkable progress by SLAWG-driven ideas)

Higher intensities means overcoming several challenges: Radiation protection issues, adapting beam intercepting devices (especially target and XTAX), providing and transporting the required intensity from the machine to the targets -> all this was studied in PBC, in particular within the Accelerator Complex Capabilities WG, BDF WG, Conventional Beams WG and many more

High intensities come at the cost of higher backgrounds -> **advanced muon shielding designs and simulation of muon backgrounds at more than 11 orders of magnitude**

Pushing Proton Intensities



K. Li

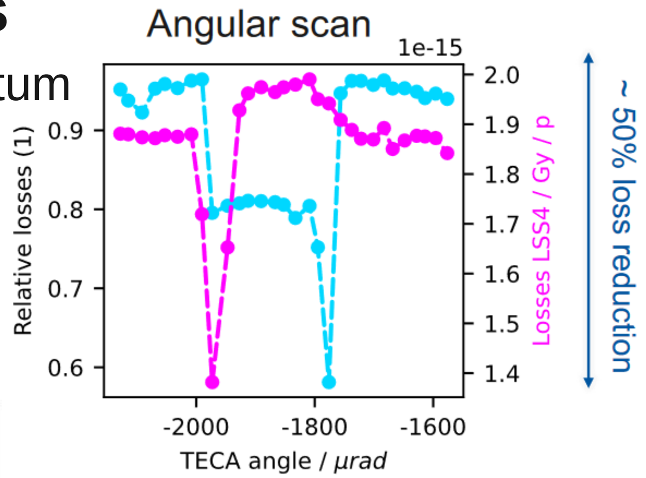
- The demand for **higher intensities** and the **increasing number of users** requesting beam time confirms the attractiveness of the North Area, but also becomes more and more challenging on the accelerator side.
- For test beam users, **beam lines** are already **overbooked**, sometimes with 20 parallel user set-ups in one line.
- **In 2022, the three major experiments Compass, NA62, and NA64e** required running at the same time with high intensities, leading to an **all-time intensity record** for the North Area – however also with **record activation of the beam line elements, potentially leading** to equipment failures.

Pushing Proton Intensities – LSS2/TT20

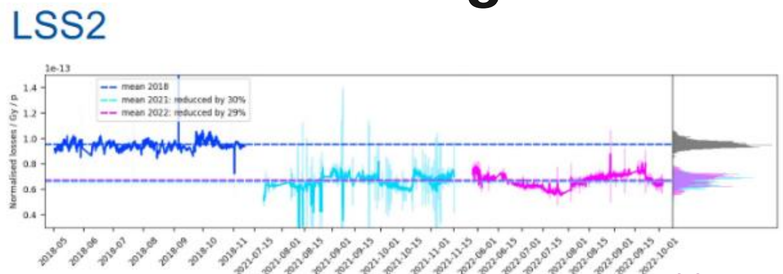
- **Beam loss per extracted proton has been improved since LS2**
  - 30% lower at ZS (**LSS2 crystal in VR** and optimization together with new ZS)
  - 10% lower at TCSC (optimisation and alignment)
  - first results from **LSS4 crystal in CH** indicate about 50% lower at ZS

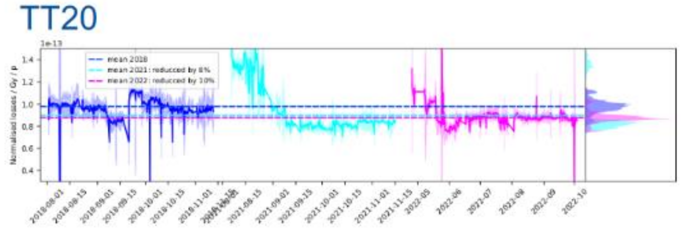
F. Pirozzi et al. *https://indico.cern.ch/event/1249260/*

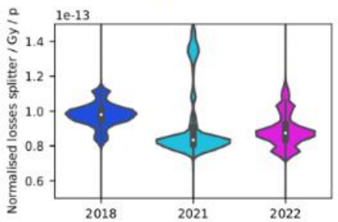
- **Use of lower density (“low-Z”) materials in the extraction equipment to reduce the induced radiation levels**
  - PBC Fellow ABT-SE working on ZS anode straightness and a prototype low-Z septum to be installed in LS3
  - improved procedures and handling to reduce dose in SLAWG



- **TSCS re-design in NA-CONS** (+use of remote handling)

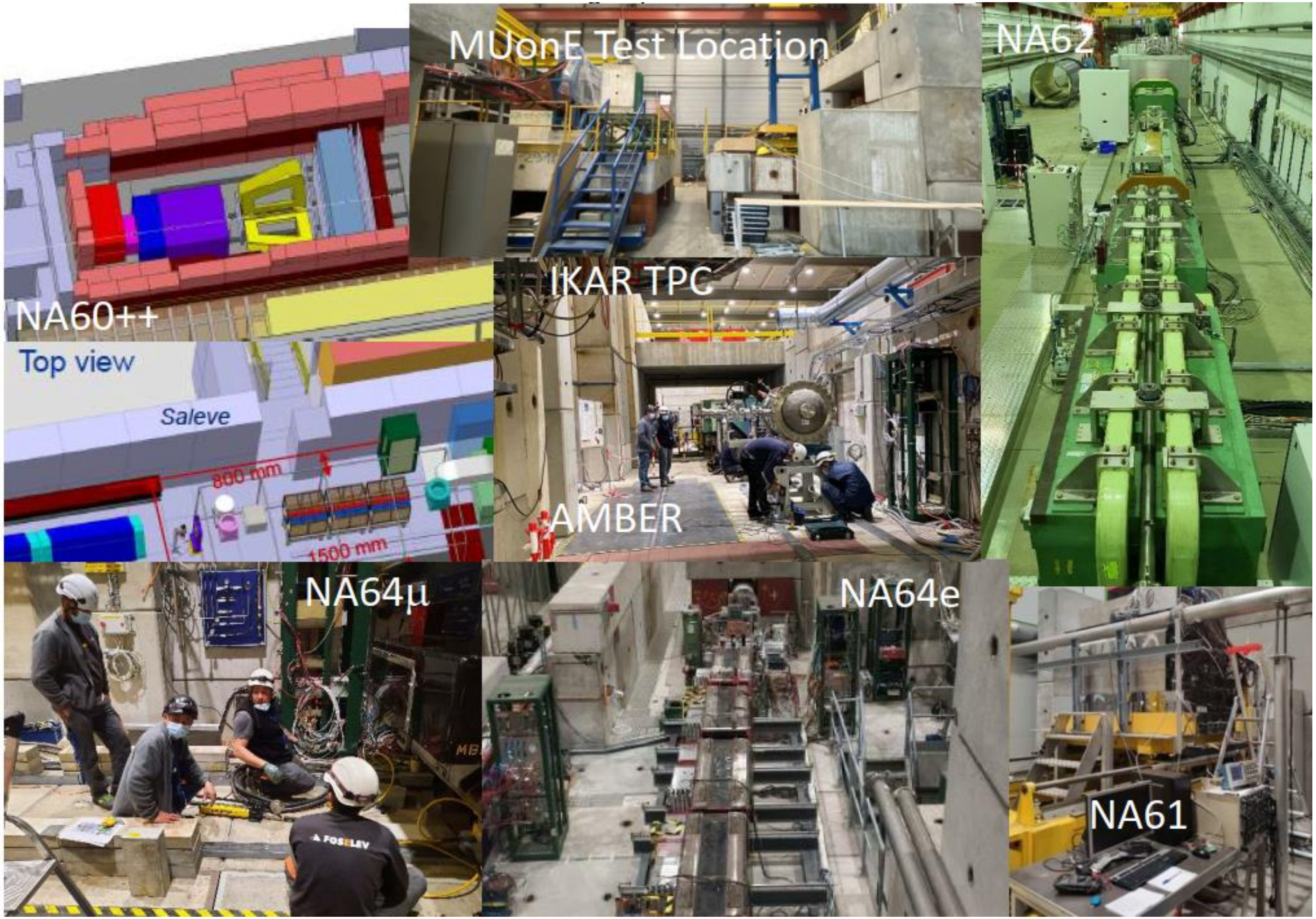


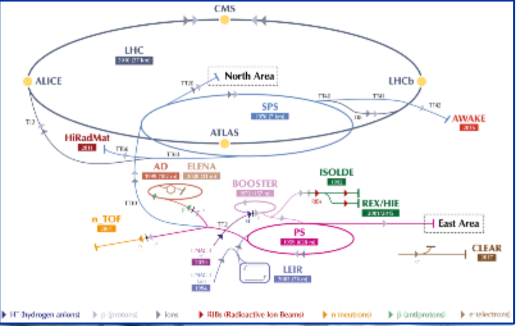




F. Velotti et al., https://journals.aps.org/prab/pdf/10.1103/PhysRevAccelBeams.22.093502

The Many Helping Hands





Let’s Look Beyond

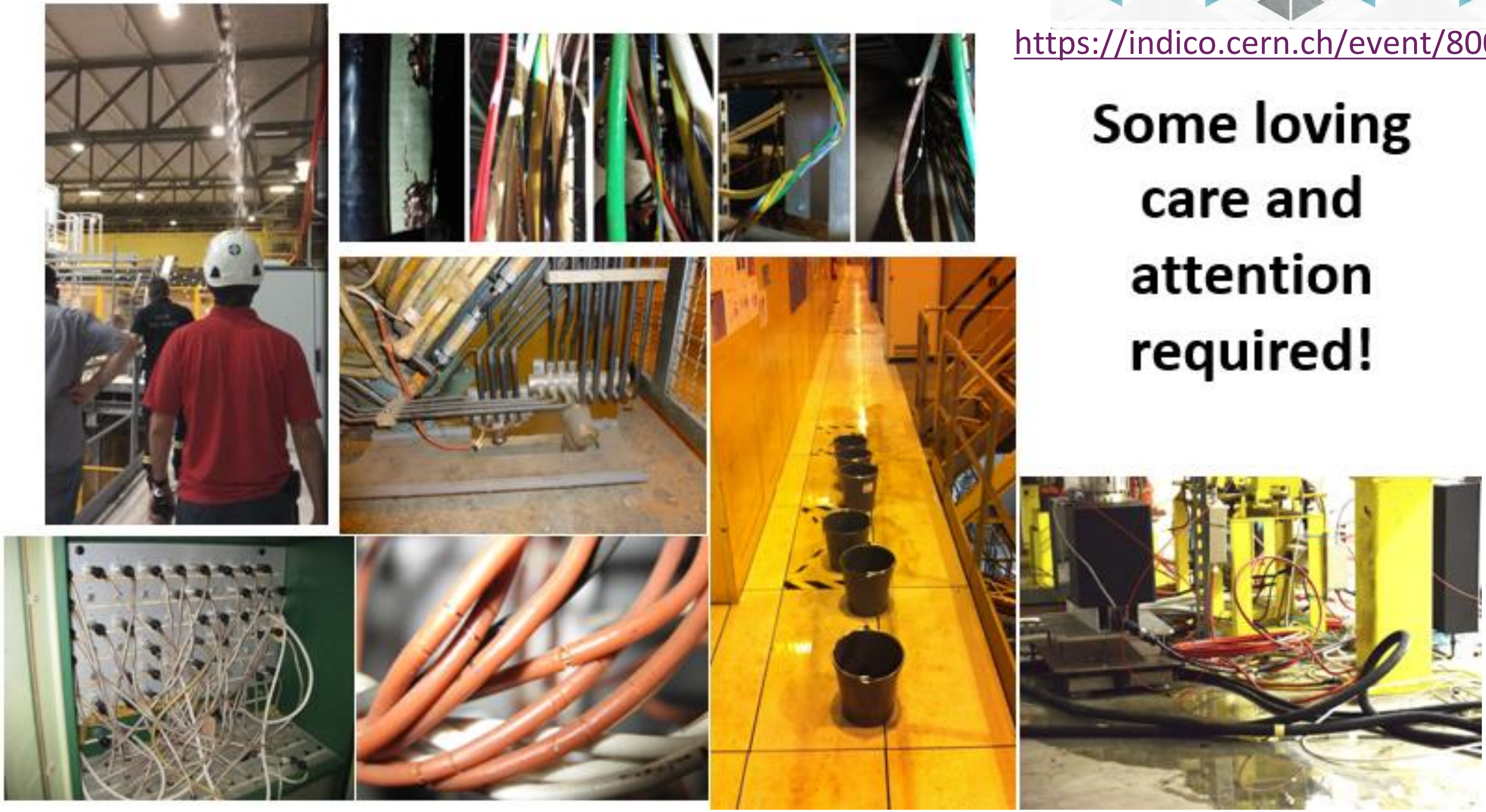
The CERN Accelerator Injector Complex & Its Experimental Areas

What’s needed – based on a selection of on-going/planned/proposed Experiments (North Area Focus)

In the context of Mid/Long-term perspectives of concerned Experimental Areas

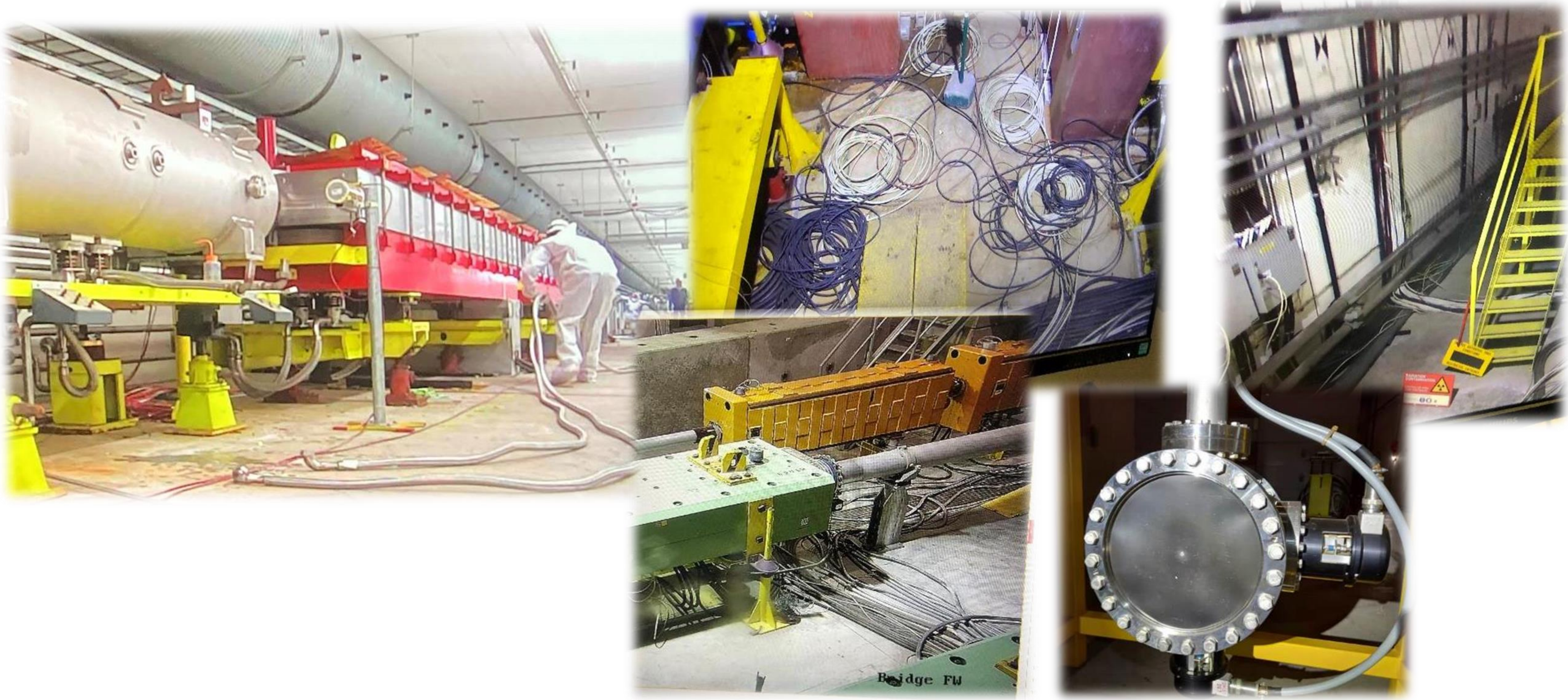
North Area – 40+ years

https://indico.cern.ch/event/800748/timetable/



Some loving care and attention required!

North Area – 40+ years



NA-CONS Project Timeline/Roadmap

Pre-Phase I			Phase I						Phase II			
LS2			Run 3			LS3			Run 4		LS4	
2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031

Pre-Phase I

Power Converter Consolidation study

Beam Instrum:
Review & analysis
Crates consolidation
AFT implemented
Electrical non conformities

Civil Eng.:
roof of gas barracks
BA gate doors

Tech.Services:
CT2, cooling plant,
Chilled water piping,
Irrad cables TDC2,
Lift for TCC8

Safety:
Gas network,
Gas detection,
ATEX ventil.
SUSI 918, EHN2
video ECN3, EHN2
Elec. non conform.

Phase I

Power Converters in BA80:
- PC & E.E. for vertex1&2 + H8 Morpurgo (YETS 21/22)
- 50% of the power converters
- 50% of availability recovered (TT20, TDC2, start of NA)

Beam Instrumentation: 60% of consolidation
- Primary beam area : BSI, BSP, BTV, BLM, P42 SEM, ...
- XBPF, electronics, ...

Civil Engineering: BA80, 5th cell for CT2
Light repairs elsewhere

Technical Services:
EL: BA80, TDC2, TCC2, UPS, secured network
CV: underg. ventil, chilled water, cooling station,CT2,
new cooling station for converters in BA80

Safety (95%):
- Underground & Surface Fire detection & Alarm.
- Fire detection in false floors BA80
- Sprinklers underground (shafts)
- Fire detection EHN2 galleries
- Pilot test for new access control system

Phase II

Power Converters BA81 & BA82:
- 50% of the power converters
- 100% of availability recovered

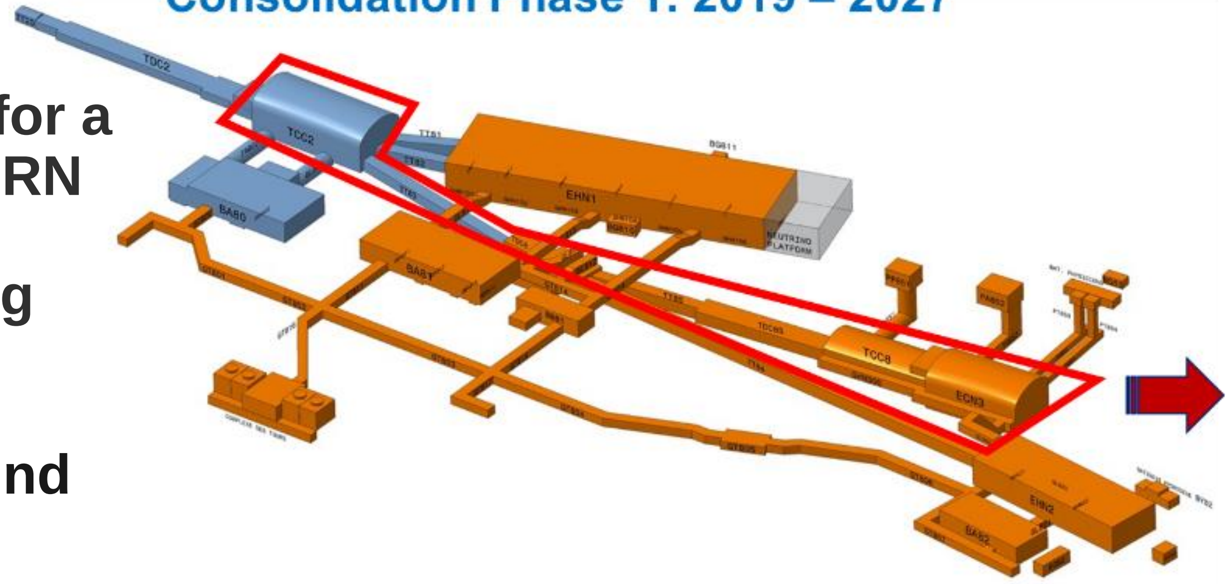
Consolidation & Upgrade for higher intensity: remaining 40%
Essentially secondary beamlines

Civil Eng.: EHN1, EHN2, ECN3, BA81, BA82

Technical Services:
EL: BA81, BA82, EHN1, EHN2, ECN3
CV: ventil. surf bldg., primary pumps circuits, new cooling station in BA81 and 82 (for PC)
CRG: centrifugal helium pumps

Safety (remaining 5%):
- Fire detection in ventilation and in false floors for BA81 & BA82
- Access system deployment

North Area High Intensity Beams - ECN3



SPS North Area is the workhorse for a diverse physics programme at CERN

Consolidation programme ongoing

New proposals requiring higher intensities in the ECN3 underground cavern post-LS3

Beam loss/radiation control, beam quality (reproducibility, spill structure etc.) are challenging future requirements

Identified synergies and implications of a future ECN3 High Intensity programme on North Area Consolidation -> ECN3-HI Upgrade Program (Initial Phase Approved)

https://cerncourier.com/a/pushing-the-intensity-frontier-at-ecn3/

ECN3 High Intensity – Experiment Proposals

Possible Scenario

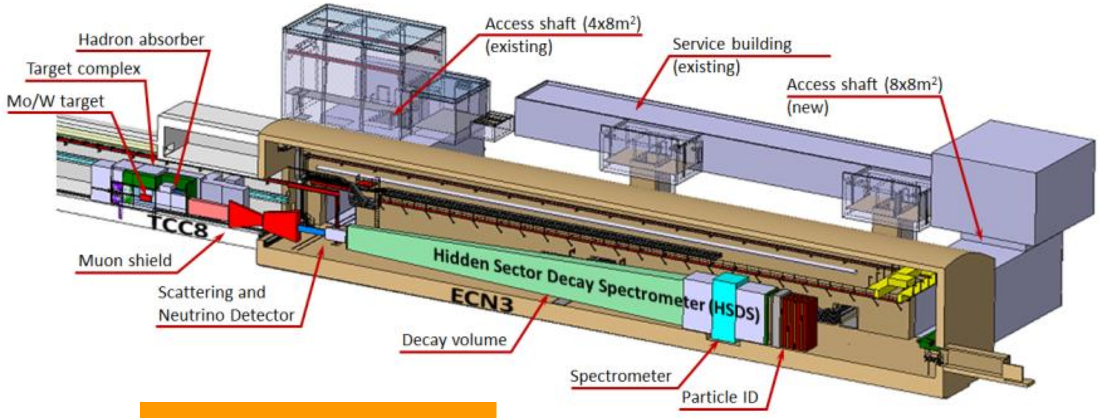
- **SHiP** (Search for Hidden Particles) is a general-purpose beam dump experiment proposed to **search for feebly interacting particles (FIPs)**. Highlights of the physics programme would be ability to search for a variety of FIPs, i.e., heavy neutral leptons, dark photons, dark scalars, axion-like particles, and light supersymmetric particles. **Access an abundance of tau and muon neutrinos**.
  Several extensions possible, e.g. adding an irradiation facility, adding an LAr TPC to search for milli-charged particles.

Possible Scenario

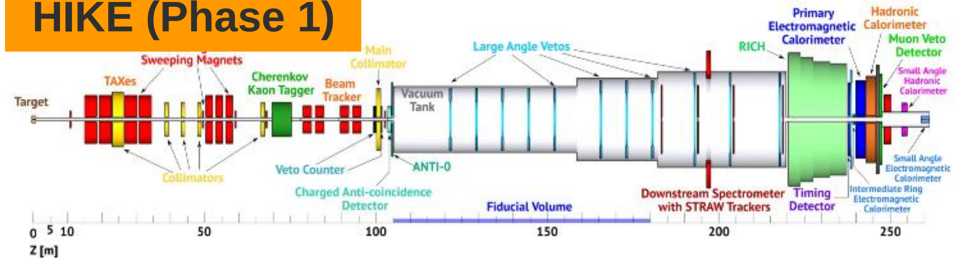
- **High intensity Kaon Experiment (HIKE)** with a programme to study **Ultra Rare Kaon decays (e.g. $K \rightarrow \pi\nu\bar{\nu}$ - BR~10^{-10})** complemented by the search for visible decays of **Feebly-Interacting Particles (FIP) in Beam Dump mode** on-axis

- **SHADOWS** (Search for Hidden And Dark Objects With the SPS) to search for **FIP visible decays in Beam Dump (BD) mode off-axis**. Running in parallel to HIKE when operated in BD mode

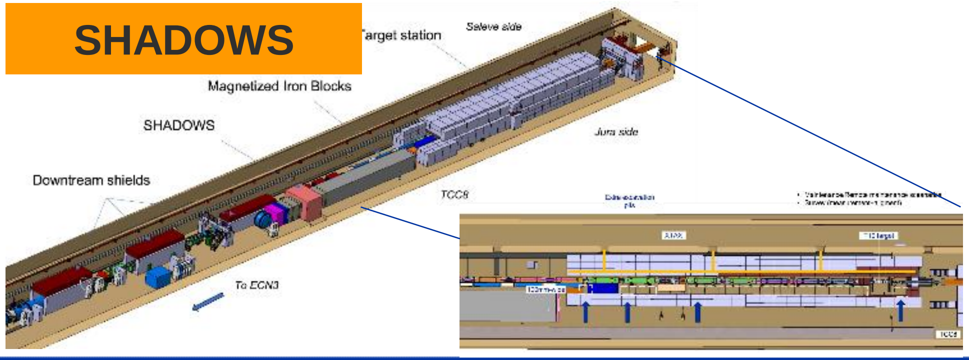
BDF/SHiP@ECN3



HIKE (Phase 1)



SHADOWS

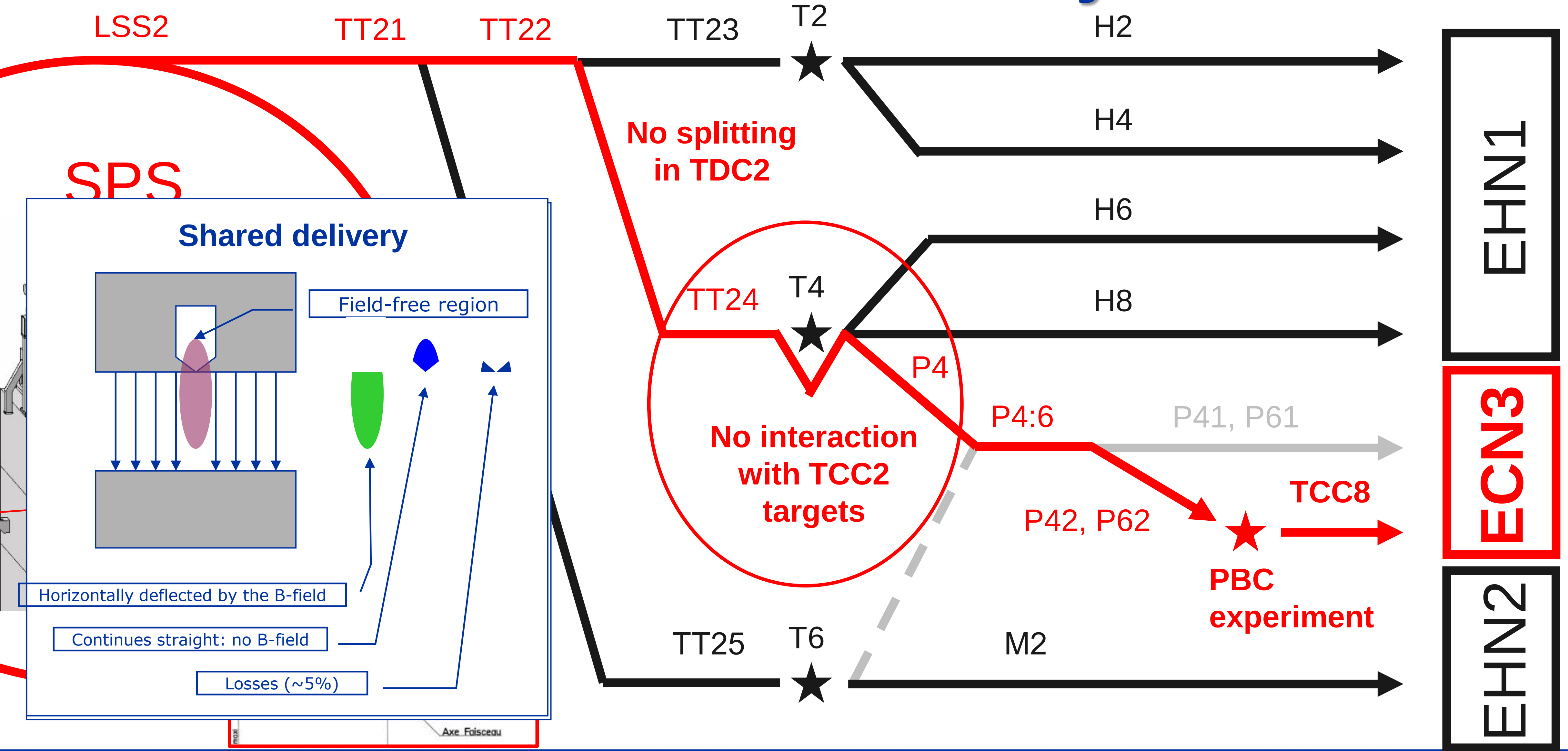


Intensity Requirements

	PoT/spill	Spill duration [s]	PoT / nominal operation year	# nominal operation years	Total PoT
HIKE Phase 1 (K^+)	1.2×10^{13}	≥ 4.5	0.72×10^{19}	5	3.6×10^{19}
HIKE Phase 2 (K^0)	2.0×10^{13}	≥ 4.5	1.2×10^{19}	6	7.2×10^{19}
HIKE/SHADOWS BD	2.0×10^{13}	≥ 4.5	1.2×10^{19}	4	5×10^{19}
BDF/SHiP	4.0×10^{13}	≥ 1.0	4×10^{19}	15	60×10^{19}

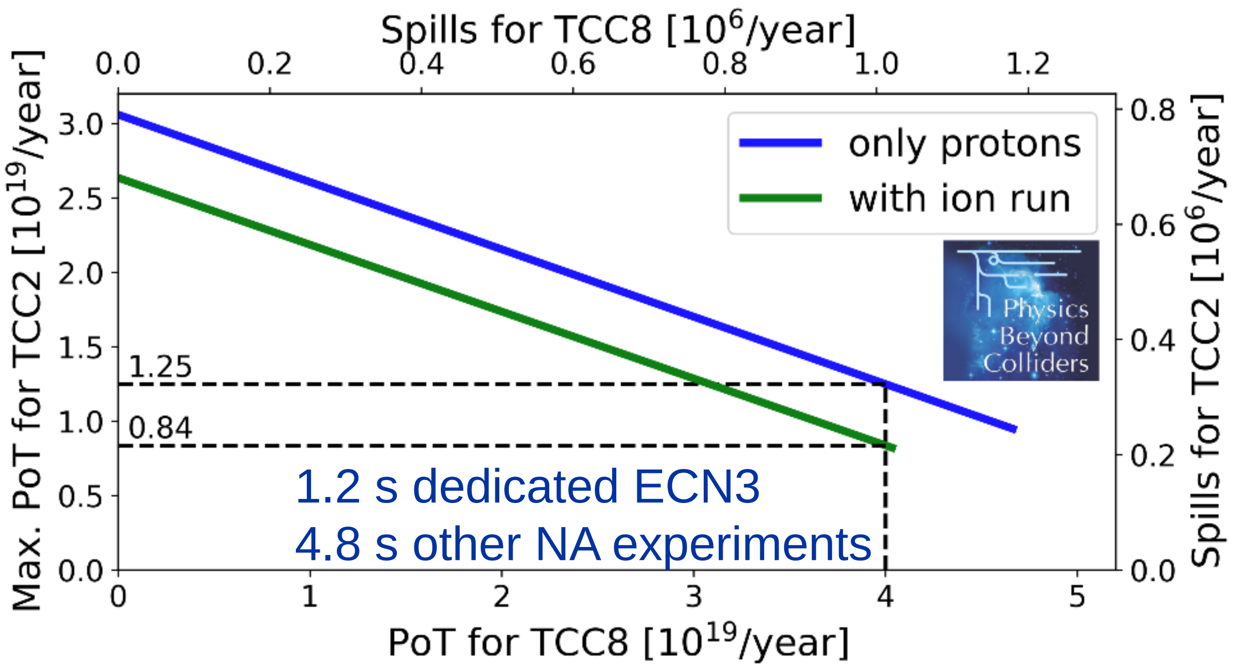
factor 6 to 12 increase in p/spill
factor 6 to >20 increase in p.o.t./year

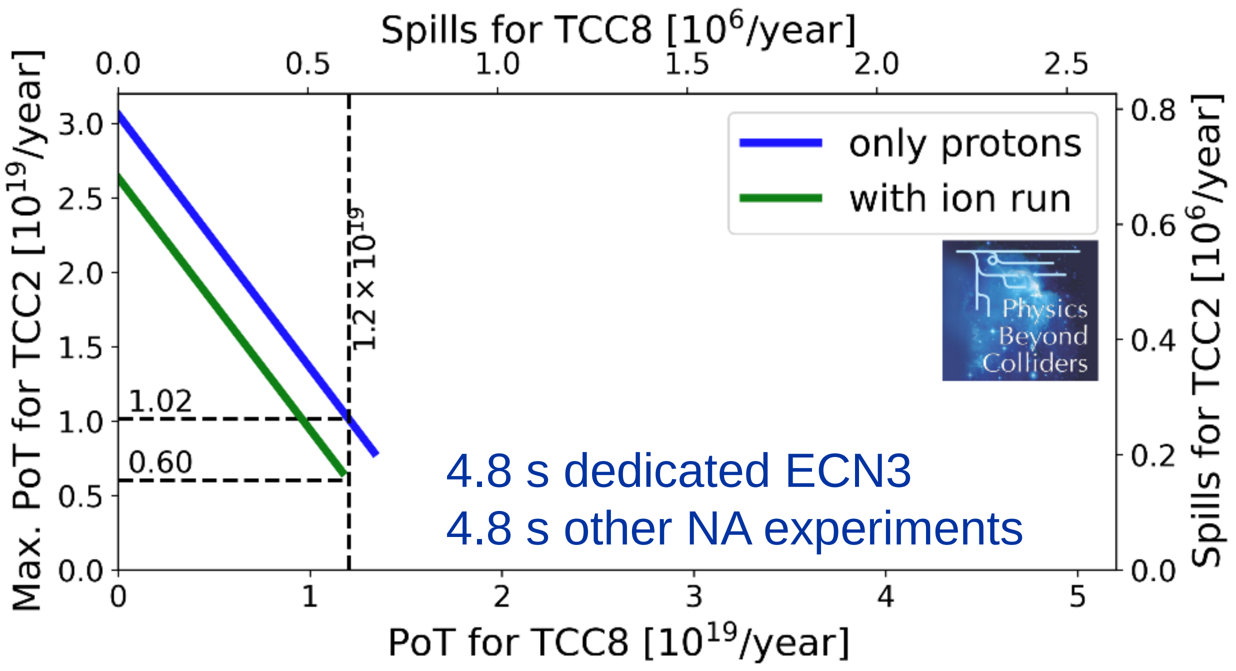
ECN3 Dedicated Beam Delivery

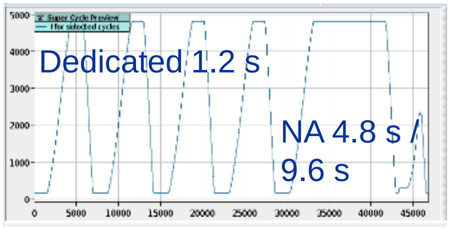


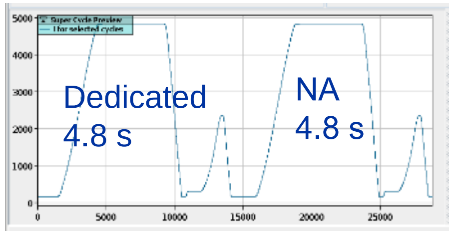
Proton Sharing

SPS Operation and Future Proton Sharing Scenarios for the ECN3 facility
Prebibaj, Tirsi et al., CERN-PBC-Notes-2023-001
https://cds.cern.ch/record/2848908





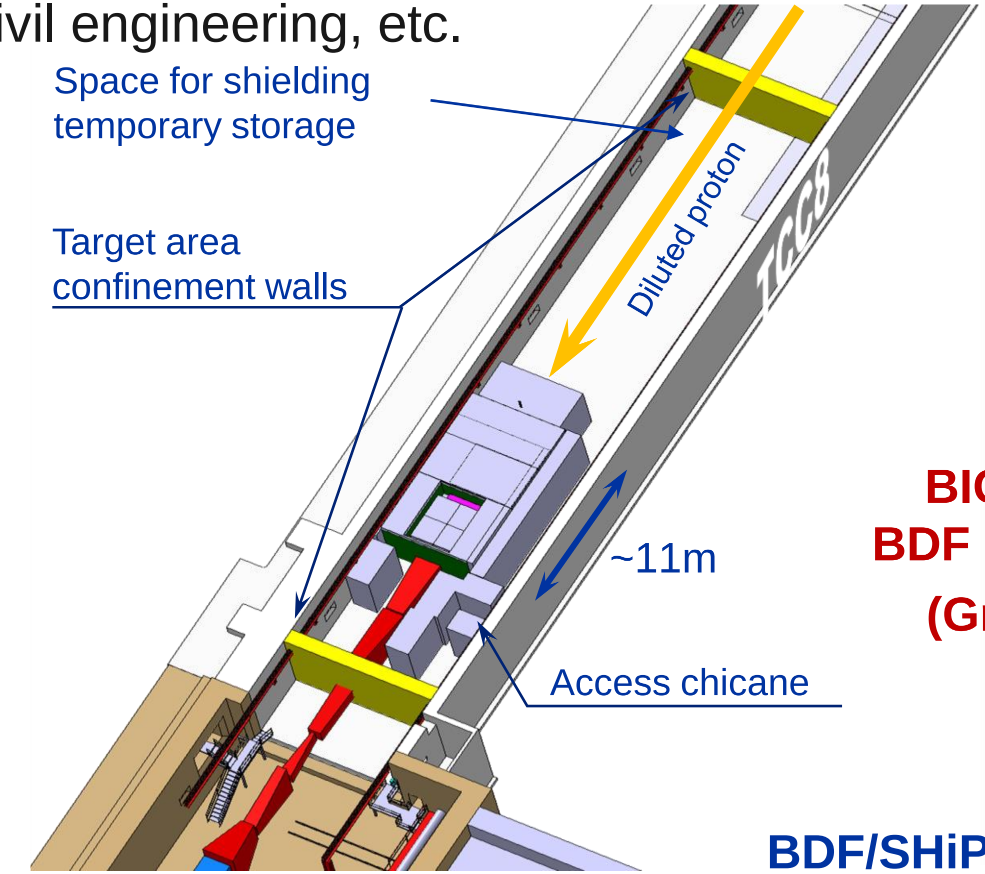




- With a new ECN3 high-intensity facility, there would be a dedicated extraction only to ECN3, interleaved with extractions serving the other NA experiments and test beam users.
- Proton sharing computed to max. TCC2 POT: SFTPRO with 4.2×10^{13} ppp and with 4.8 s FT

TCC8 Target Complex

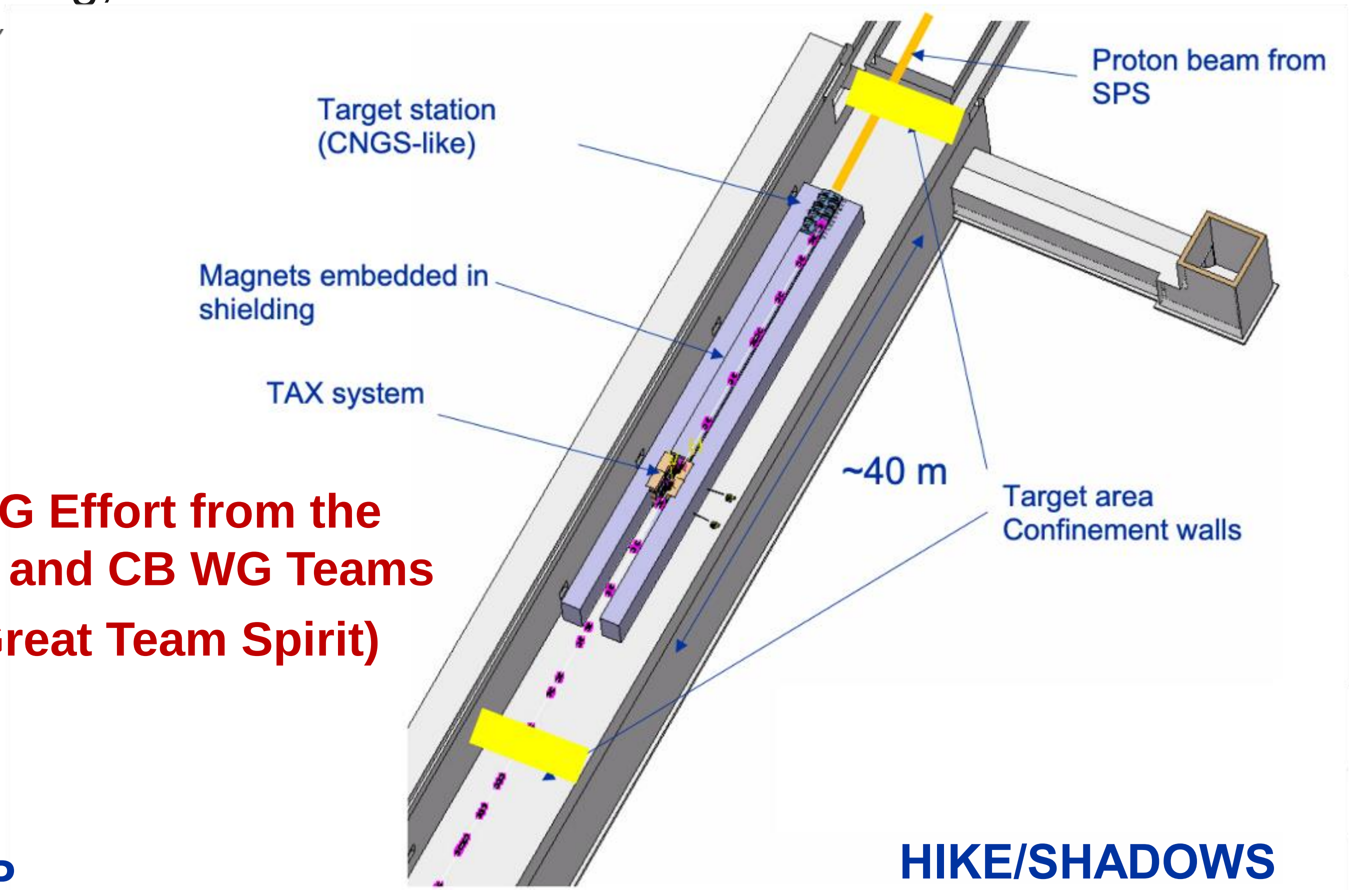
- a new target complex will make sure that the new intensity step can be optimally exploited while upgrading the facility to **modern radiation protection and handling standards**
- **challenging design** and infrastructure, shielding, service constraints
- + civil engineering, etc.



BDF/SHiP

BIG Effort from the BDF and CB WG Teams

(Great Team Spirit)

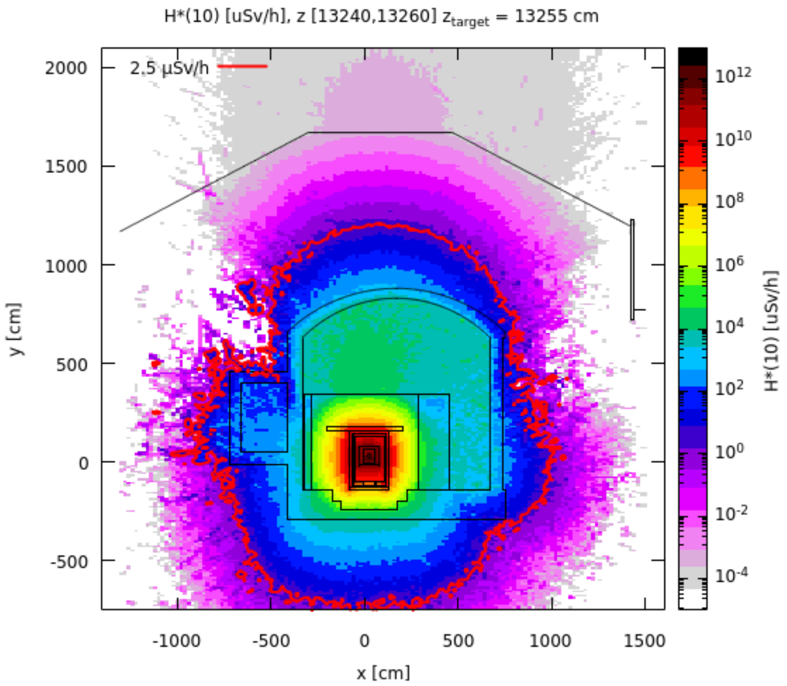


HIKE/SHADOWS

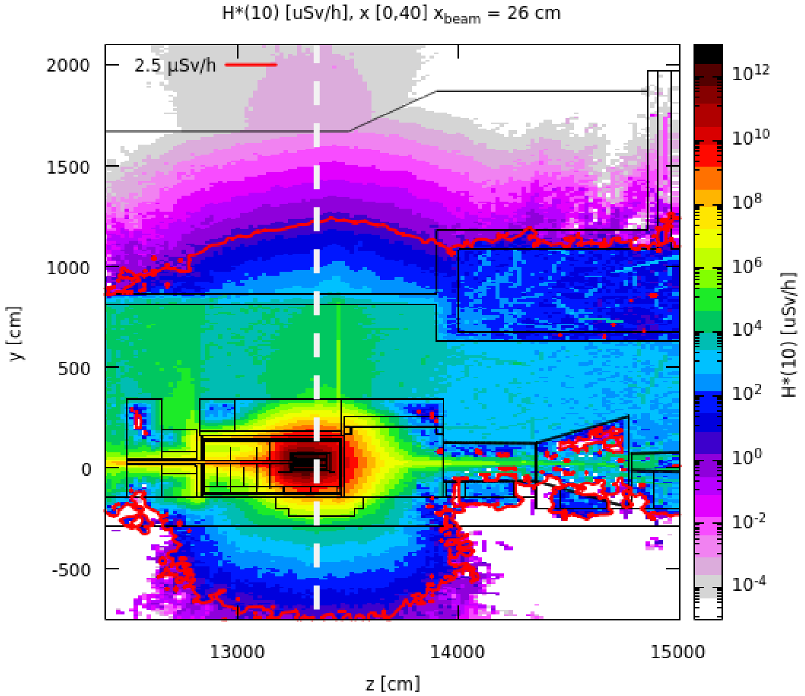
An Example of Radiation Protection Challenges

BDF/SHIP prompt radiation in target area

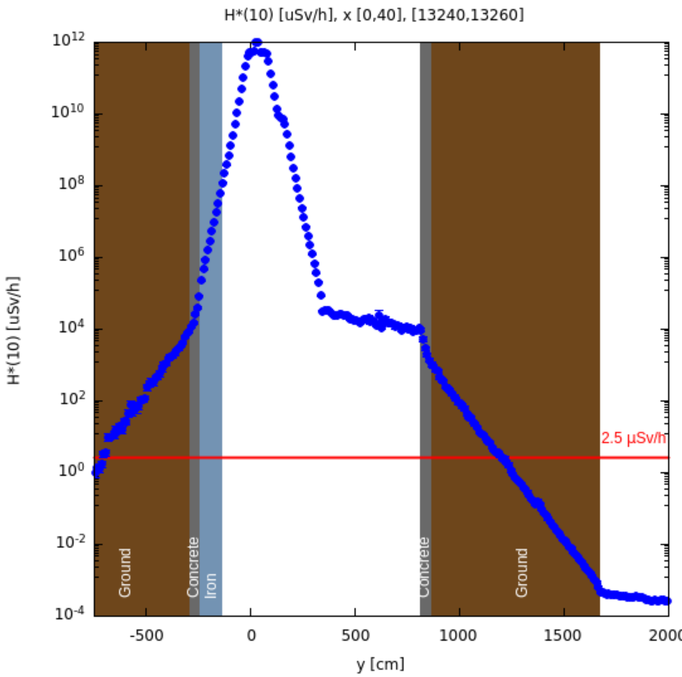
Side view



Cross-sectional view



Along y-axis



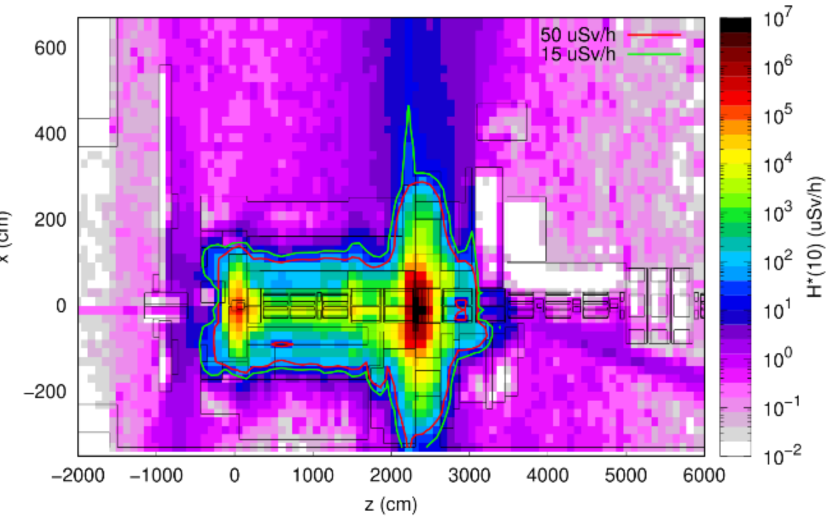
- ➢ **Shielding design is optimized for the prompt radiation**
- ➢ **Thanks to shielding reinforcements towards the bottom, no increase of soil activation expected**

An Example of Radiation Protection Challenges

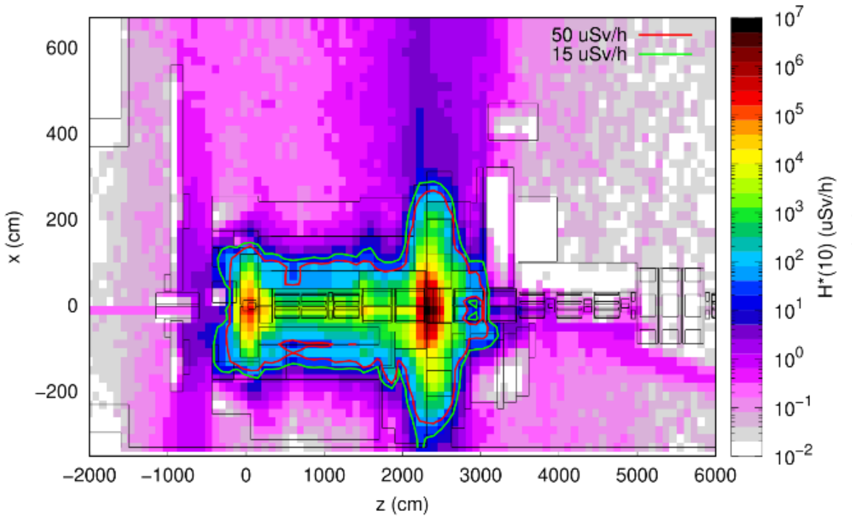
HIKE residual radiation in Target/TAX area

Cross-sectional view, target level

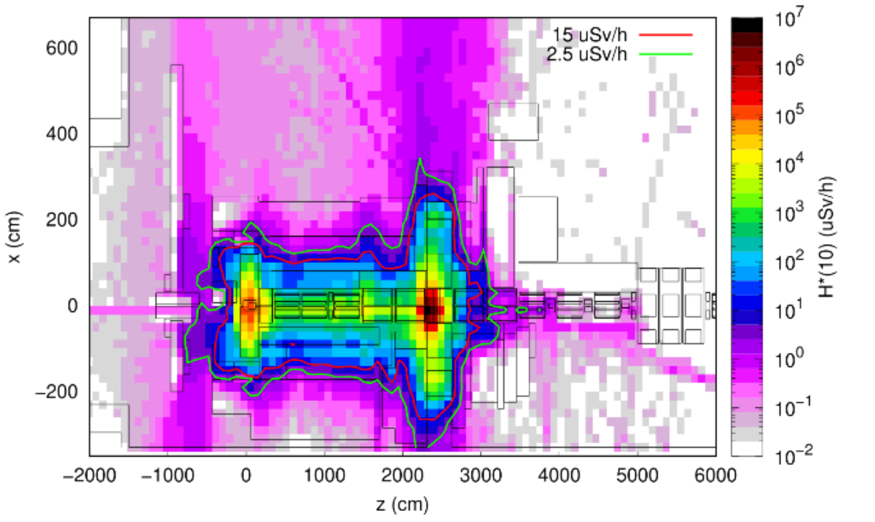
1 hour cool-down



1 day cool-down



1 week cool-down

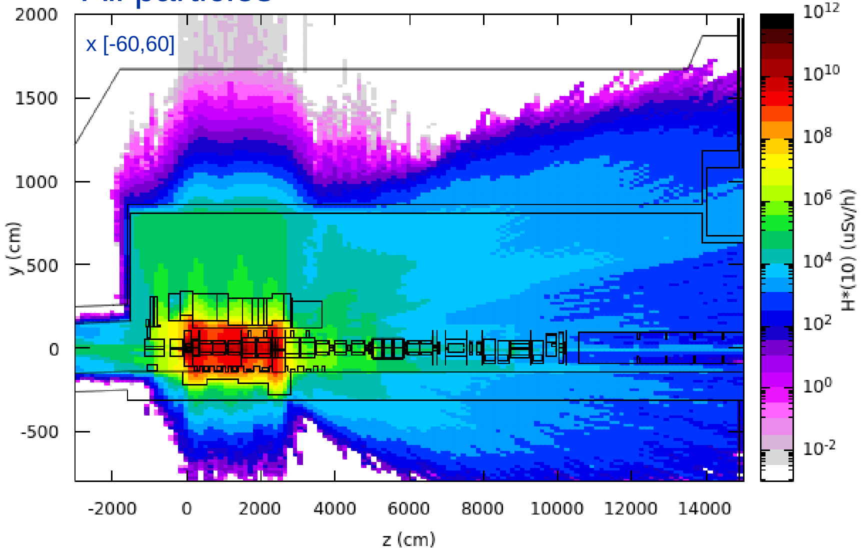


- **Challenging Target and especially TAX area**
  -> high residual dose rates even after significant cooling times (not shown here)
- Residual dose rates well contained within shielding allowing for a Supervised Radiation Area in SHADOWS experimental area
- High residual dose rates in secondary beamline requiring optimisation of interventions
  (e.g. remote operations, quick connections, cool-down, etc.)

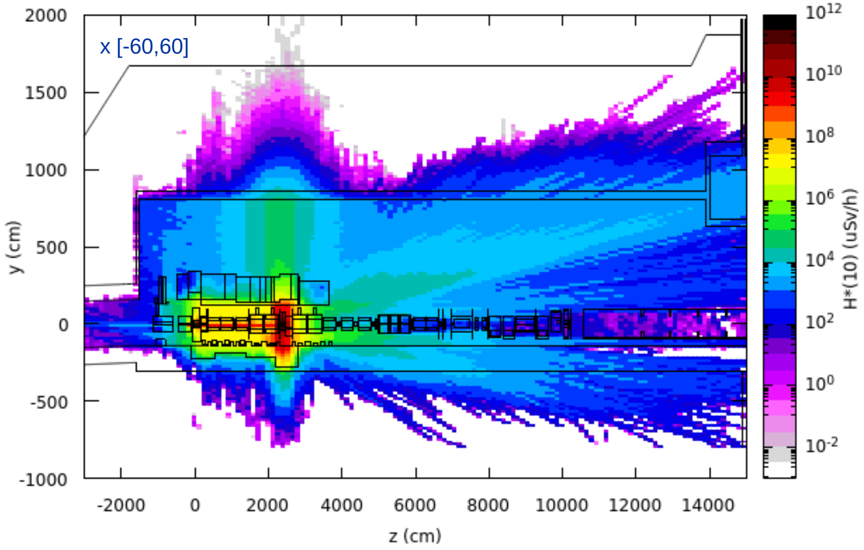
An Example of Radiation Protection Challenges

HIKE prompt radiation in Target/TAX area

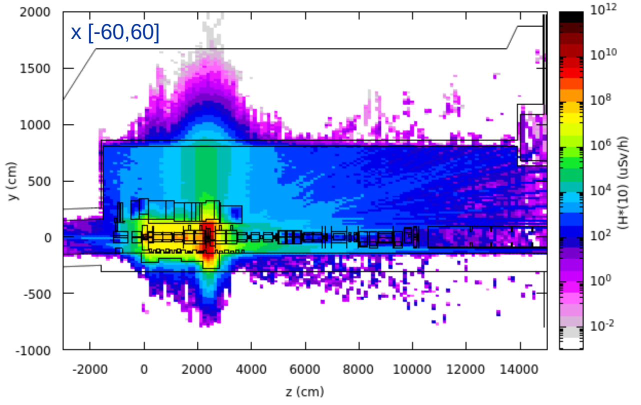
HIKE Phase 1
Side view
All particles



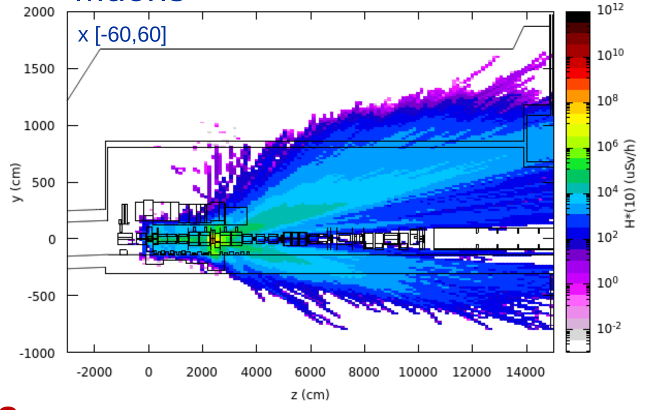
HIKE BD/SHADOWS
Side view
All particles



Neutrons



Muons



- **High radiation levels in region between target and TAX (equipment life-time constraints!)**
- **Prompt radiation sufficiently reduced for a Non-designated Area above target-TAX area**
- Prompt radiation dominated by neutrons in target-TAX area and by muons downstream

First Indicative Schedule -> Beyond HL-LHC !

	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
HIKE	Detector / Beam Commissioning		K+ / BD	K+ / BD	LS4	K+ / BD	K+ / BD	K+ / BD	K+ / BD	K+ / BD
SHADOWS	Installation & Detector / Beam Commissioning		BD	BD	LS4	BD	BD	BD	BD	BD
SHiP/BDF	Installation & Detector / Beam Commissioning		BD	BD	LS4	BD	BD	BD	BD	BD

Possible LS at the HL-LHC

	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048
HIKE	LS5	K+ / BD	K+	Installation & Detector / Beam Commissioning	K0	K0	K0	K0	K0	K0
SHADOWS	LS5	BD								
SHiP/BDF	LS5	BD	BD	Extension & Detector / Beam Commissioning	BD	BD	BD	BD	BD	BD

Indicative

Decision Timeline: ECN3

ECN3 TaskForce -> Report

SPSC Taskforce established

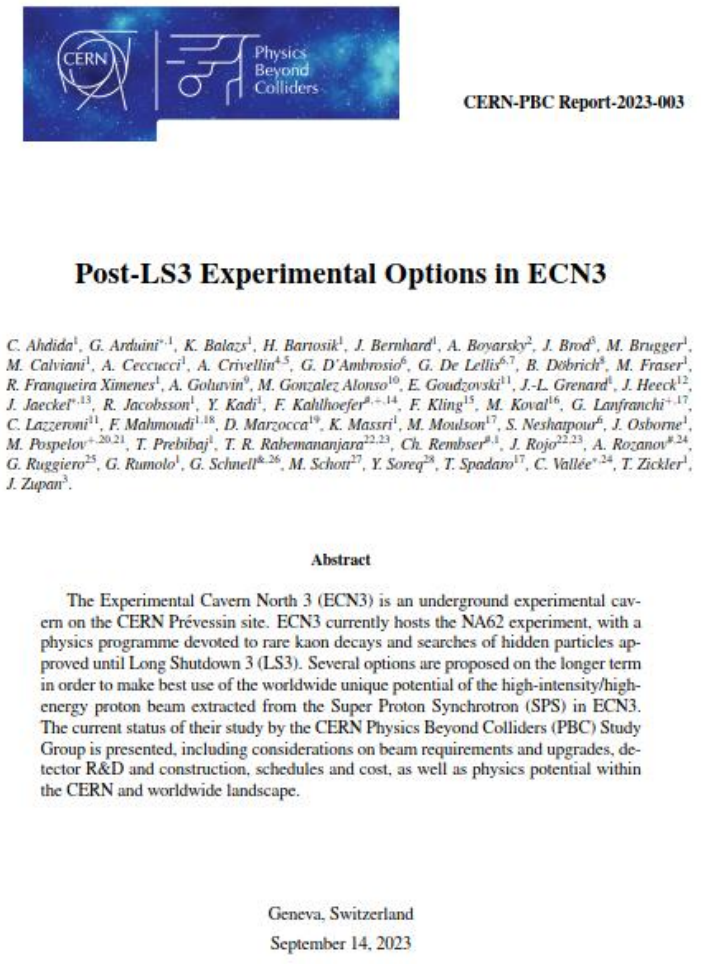
Positive recommendation for a high intensity facility from SPSC -> allocation of budget to continue the studies in time for possible implementation in LS3 (NA-CONS + ECN3-HI)

PBC document on ECN3 options post-LS3 to SPSC and management on 15/9/2023

Final recommendation/decision on which experiment to host - SPSC & RB November/December 2023

Presentation to Council

Aim for inclusion in MTP 2024



CERN-PBC Report-2023-003

Post-LS3 Experimental Options in ECN3

C. Ahdida[1], G. Arduini[*,1], K. Balazs[1], H. Bartosik[1], J. Bernhard[1], A. Boyarsky[2], J. Brod[3], M. Brugger[1], M. Calviani[1], A. Ceccucci[1], A. Crivellin[4,5], G. D'Ambrosio[6], G. De Lellis[6,7], B. Döbrich[8], M. Fraser[1], R. Franqueira Ximenes[1], A. Goluvin[9], M. Gonzalez Alonso[10], E. Goudzovski[11], J.-L. Grenard[1], J. Heeck[12], J. Jaeckel[*,13], R. Jacobsson[1], Y. Kadi[1], F. Kahlhoefer[#,+,14], F. Kling[15], M. Koval[16], G. Lanfranchi[+,17], C. Lazzeroni[11], F. Mahmoudi[1,18], D. Marzocca[19], K. Massri[1], M. Moulson[17], S. Neshatpour[6], J. Osborne[1], M. Pospelov[+,20,21], T. Prebibaj[1], T. R. Rabemananjara[22,23], Ch. Rembser[#,1], J. Rojo[22,23], A. Rozanov[#,24], G. Ruggiero[25], G. Rumolo[1], G. Schnell[&,26], M. Schott[27], Y. Soreq[28], T. Spadaro[17], C. Vallée[*,24], T. Zickler[1], J. Zupan[3].

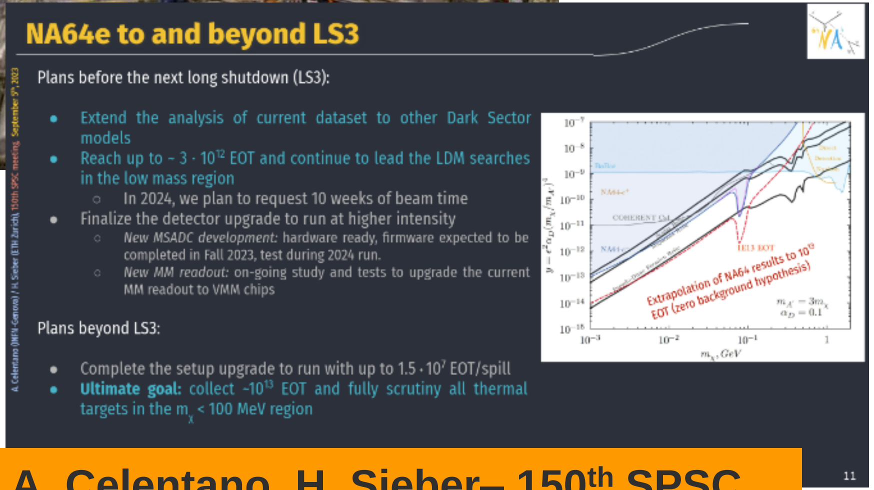
Abstract

The Experimental Cavern North 3 (ECN3) is an underground experimental cavern on the CERN Prévessin site. ECN3 currently hosts the NA62 experiment, with a physics programme devoted to rare kaon decays and searches of hidden particles approved until Long Shutdown 3 (LS3). Several options are proposed on the longer term in order to make best use of the worldwide unique potential of the high-intensity/high-energy proton beam extracted from the Super Proton Synchrotron (SPS) in ECN3. The current status of their study by the CERN Physics Beyond Colliders (PBC) Study Group is presented, including considerations on beam requirements and upgrades, detector R&D and construction, schedules and cost, as well as physics potential within the CERN and worldwide landscape.

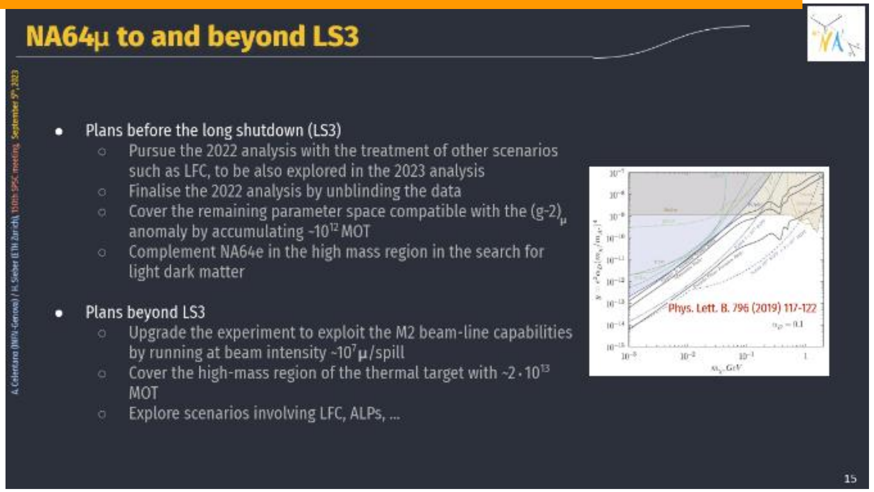
Geneva, Switzerland
September 14, 2023

NA64x -> Post LS3

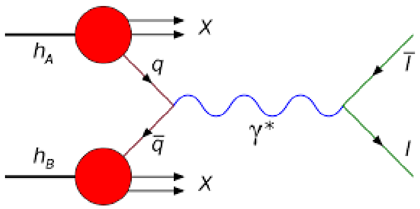
- **NA64(e):** Optimized for invisible production, currently leading the field for dark photon searches
- Aiming for × 2-3 electron beam intensity post-LS3
  - Needs to be studied taking into account the limitations in intensity for T2 TAX and target
- **NA64(μ)**: test of $(g\text{-}2)_{\mu}$ interpretations and μ-coupled dark sector
- Aiming for × 3-4 muon beam intensity post-LS3
- **NA64(e^+):** being also considered after pilot run in 2022
- **NA64(h)**: use decays of hadrons from a hadron beam to look for FIPs



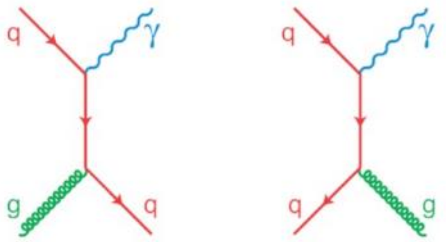
A. Celentano, H. Sieber– 150th SPSC



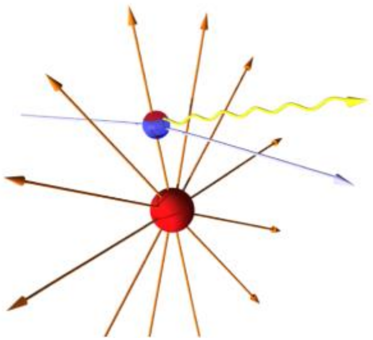
AMBER Upcoming



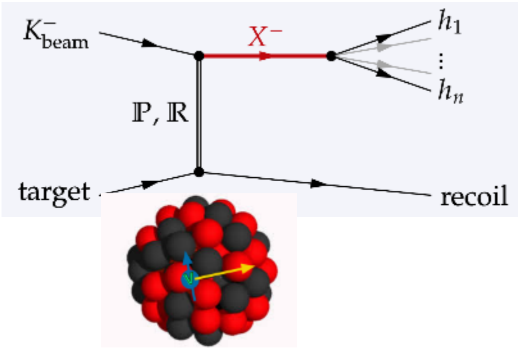
- **Kaon structure via the Drell-Yan process**
  (Post LS3 -> 2y running)



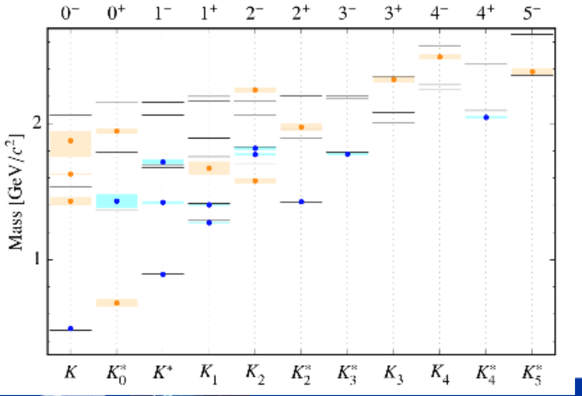
- Gluon structure of pions and kaons via prompt photons



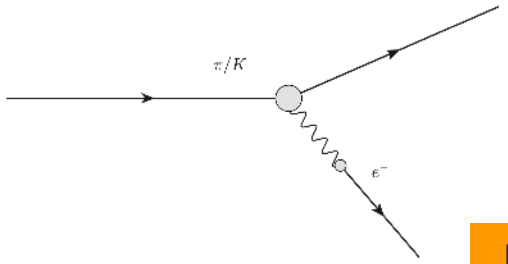
- Primakoff reactions to investigate Kaon-photon coupling: Kaon polarisability, $F_{KK\pi}$



- Diffractive production of vector mesons and di-jets to study distribution amplitudes



- Spectroscopy of mesons with strangeness



- Meson charge radii via electron scattering in inverse kinematics

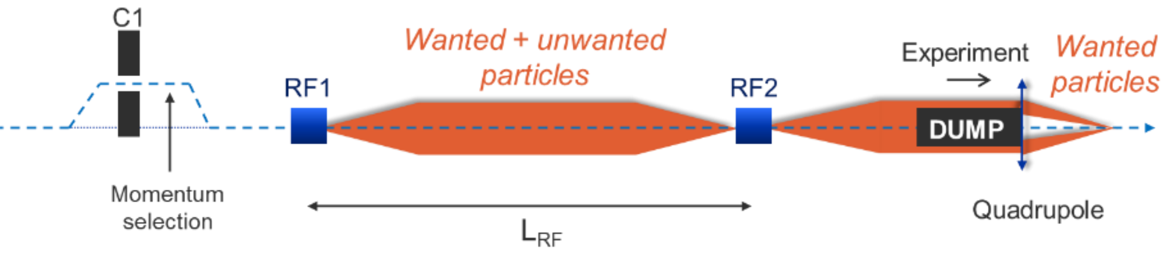
J. Friedrich – PBC Annual WS 2022

A Long-Term Perspective
-> Leading to A Shorter Term Improvement

AMBER
Apparatus for Meson and Baryon Experimental Research

Requirement of increased purity K beam with no or limited reduction in intensity –> two options studied:

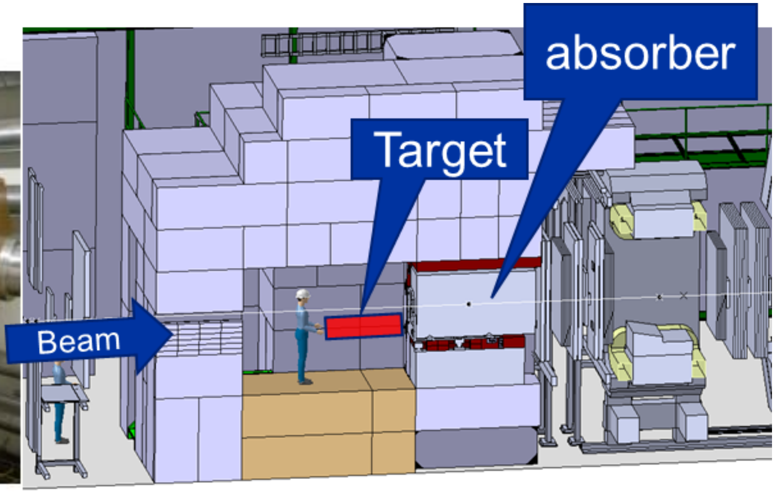
RF separated beams



- **Feasibility study (see PBC CB Workshop)**
- Studies indicate that physics requirements cannot be (easily) met with present technology
- RF cavities parameters not achievable
- Significant cost and complexity

General beam line improvements

- **Completing the vacuum in the line**
- **Improving the divergence at the CEDARs with optics and an additional collimator.**
- **Increasing the number of accumulated hadrons**



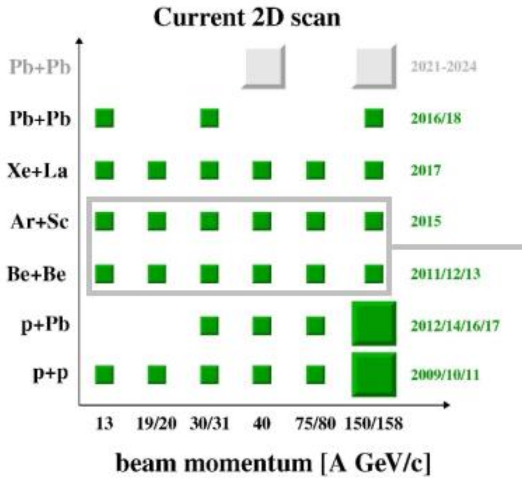
Ion experiments' proposals post-LS3

NA61++ aiming to explore onset of fireball **with lighter ions**

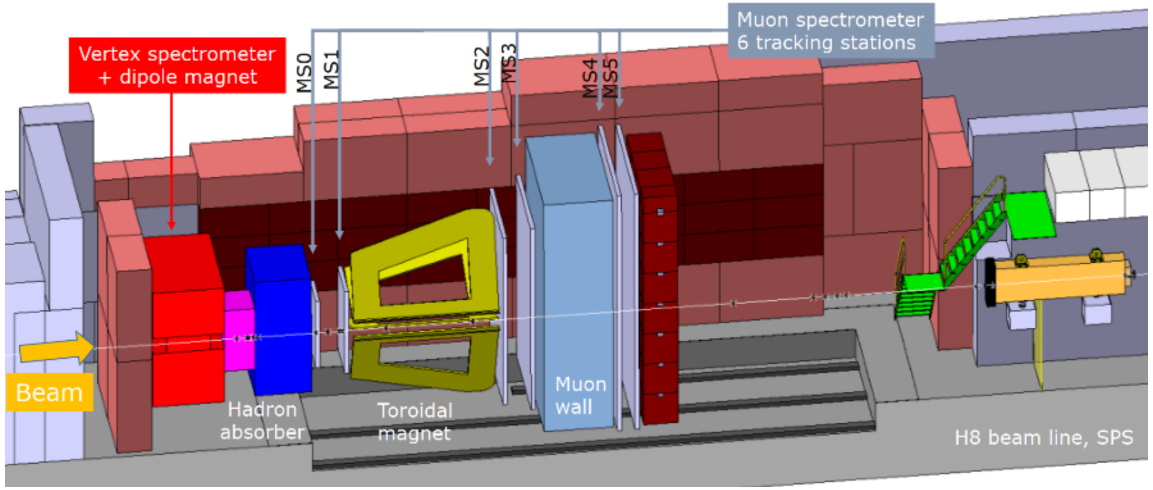
- requires production and acceleration of lighter ions
- **Studies ongoing: appears to be feasible**

Pb Ions for NA60++ to measure the caloric curve of the QCD phase transition:

- **pre-study & location identified in H8 (EHN1)**
- support for integration and muon toroidal spectrometer design
- soon with SPSC



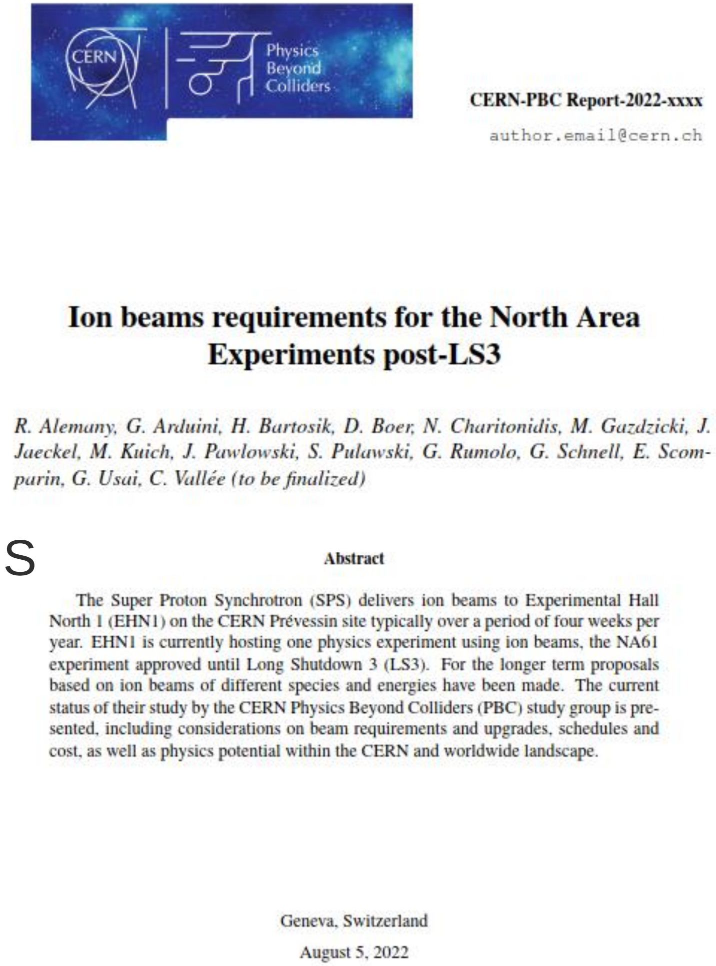
p_{beam} $(AGeV/c)$	$\sqrt{s}_{NN}$ (GeV)	^{10}B # days	^{16}O # days	^{24}Mg # days
13	5.1	7	7	7
30	7.6	7	7	7
150	16.8	7	7	7



North Area Ions post-LS3

Review of the ion beam requirements post-LS3:

- Summary of requirements (NA61++, NA60++):
  -> **ion species and beam characteristics**
- **Conceptual feasibility (ion sources, accelerator capabilities)**
- **Operational scenarios and expected performance**
- Implications on the accelerator/experimental area infrastructure/NA-CONS
- Necessary studies/R&D, technically driven time scale, cost class
- Physics potential within CERN and worldwide context
- Synergies with other future programmes (e.g. @ LHC)



CERN-PBC Report-2022-xxxx

author.email@cern.ch

Ion beams requirements for the North Area Experiments post-LS3

R. Alemany, G. Arduini, H. Bartosik, D. Boer, N. Charitonidis, M. Gazdzicki, J. Jaeckel, M. Kuich, J. Pawlowski, S. Pulawski, G. Rumolo, G. Schnell, E. Scomparin, G. Usai, C. Vallée (to be finalized)

Abstract

The Super Proton Synchrotron (SPS) delivers ion beams to Experimental Hall North 1 (EHN1) on the CERN Prévessin site typically over a period of four weeks per year. EHN1 is currently hosting one physics experiment using ion beams, the NA61 experiment approved until Long Shutdown 3 (LS3). For the longer term proposals based on ion beams of different species and energies have been made. The current status of their study by the CERN Physics Beyond Colliders (PBC) study group is presented, including considerations on beam requirements and upgrades, schedules and cost, as well as physics potential within the CERN and worldwide landscape.

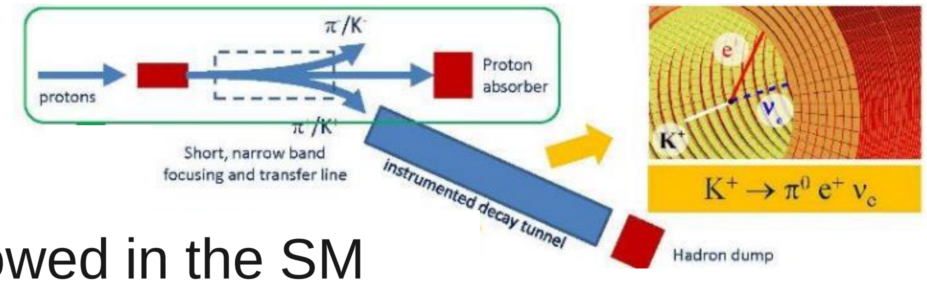
Geneva, Switzerland

August 5, 2022

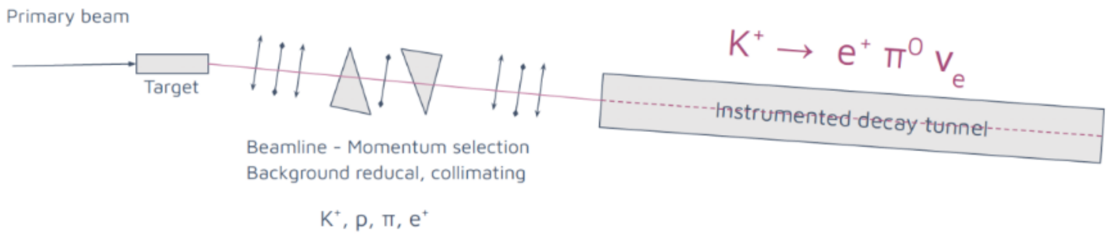
Input for SPSC and CERN Management

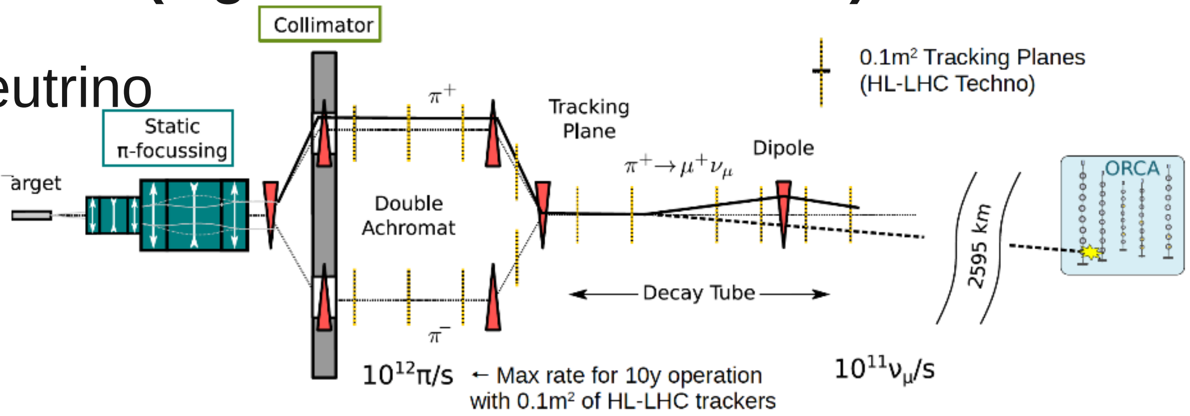
Time scale: March/April 2024

Tagged Neutrino Beams



- Studying neutrino oscillations and therefore their masses
  gives an important access to new physics as this is not allowed in the SM
- **Experiments measure nowadays easily the arriving neutrino**
- **it is hard to say with which flavour the neutrino started from**
  -> hence, the community looks into **tagging of the neutrino beams close to their source**
- **ENUBET and NUTAG study identifying neutrinos coming from kaons decaying into neutrinos and other particles at the same time (e.g. muons and electrons)**
- Measuring means tagging of the outgoing neutrino
  on a **particle-by-particle basis**

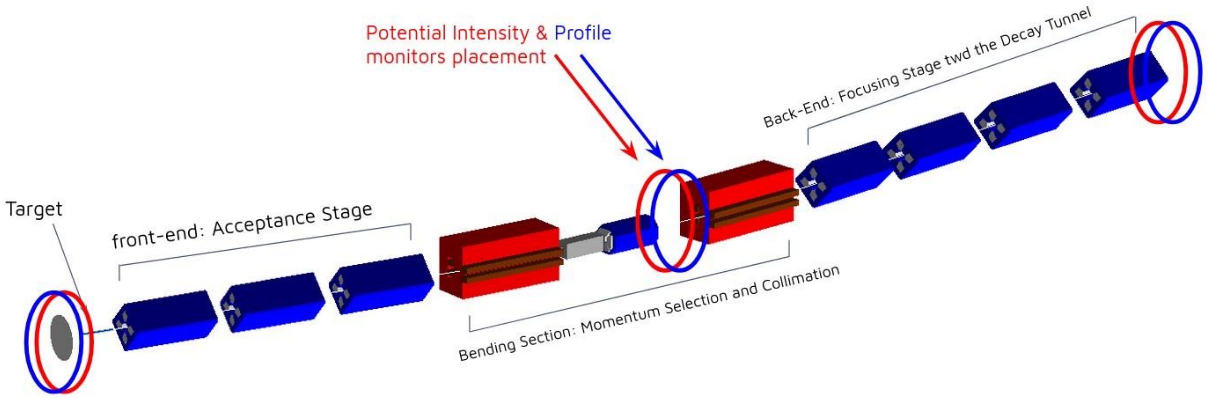


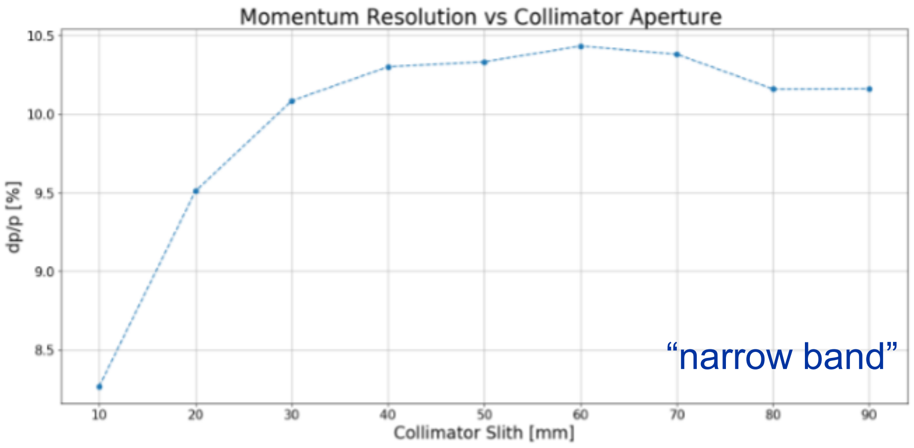


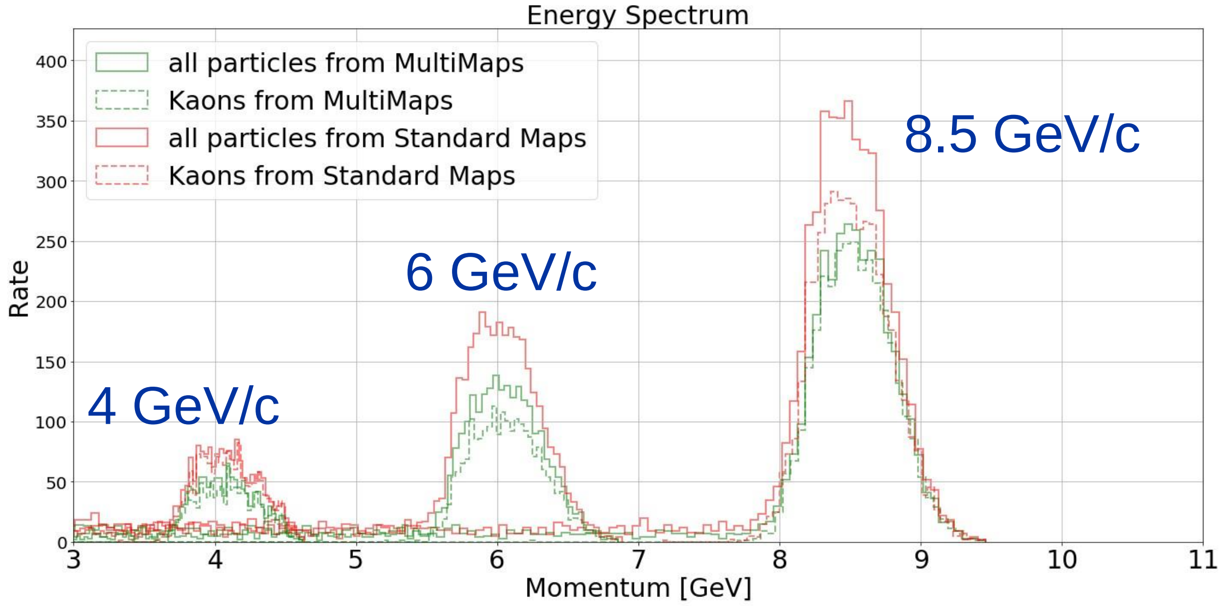
Efforts towards a short-baseline proposal that combines both projects with a reasonable number of POT/y.
Studies within the Conventional Beams – Neutrino Beams WG (https://indico.cern.ch/category/14358/)

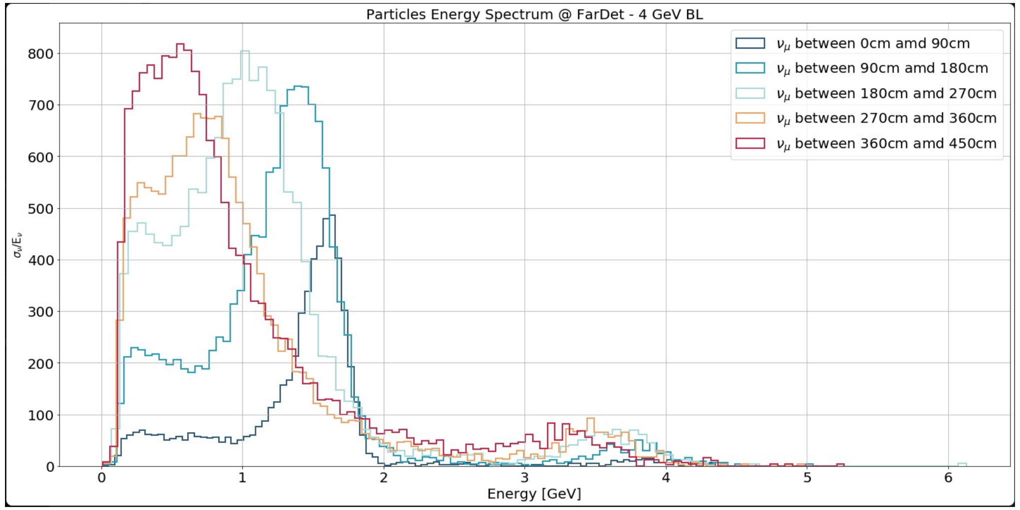
ENUBET – Multi-Momentum beam line performance

E. Parozzi

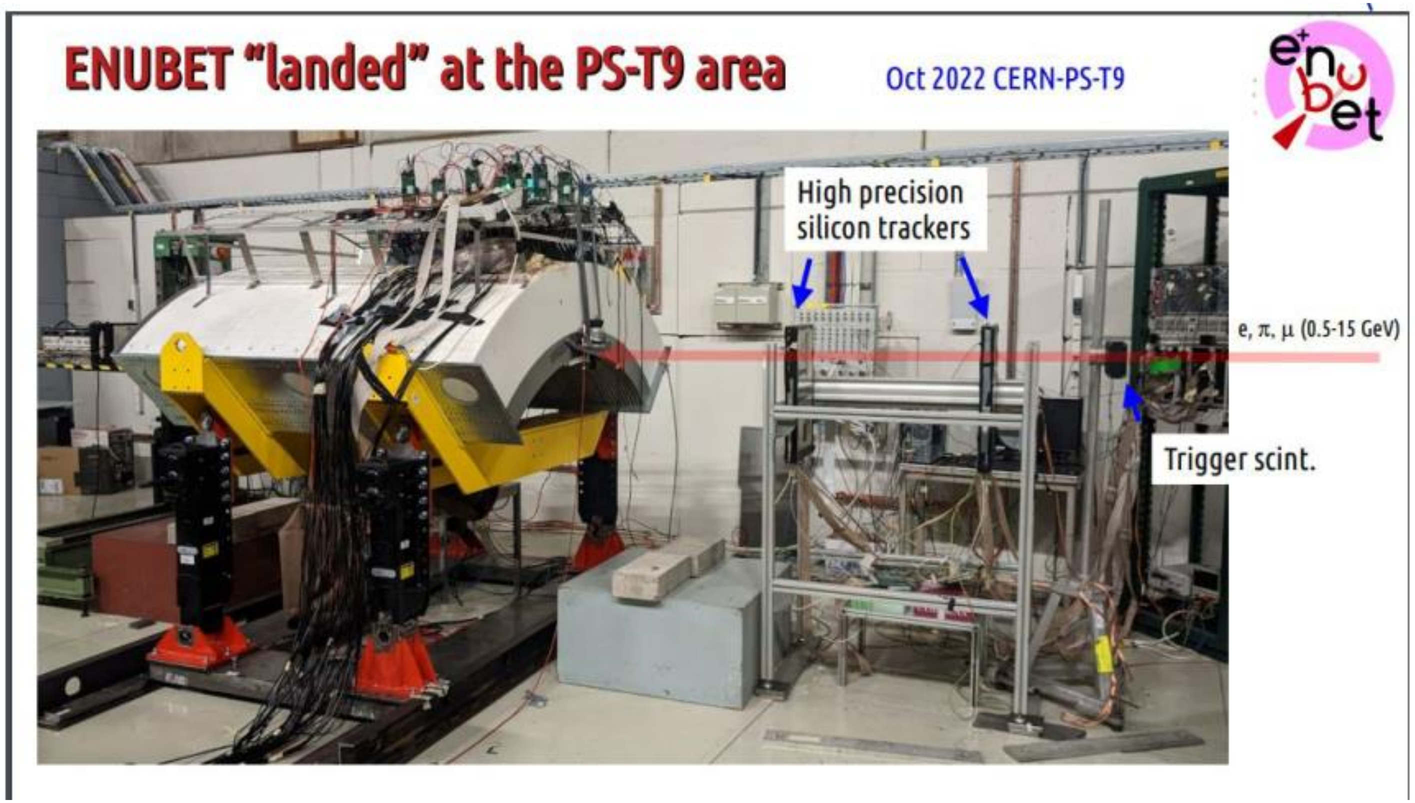




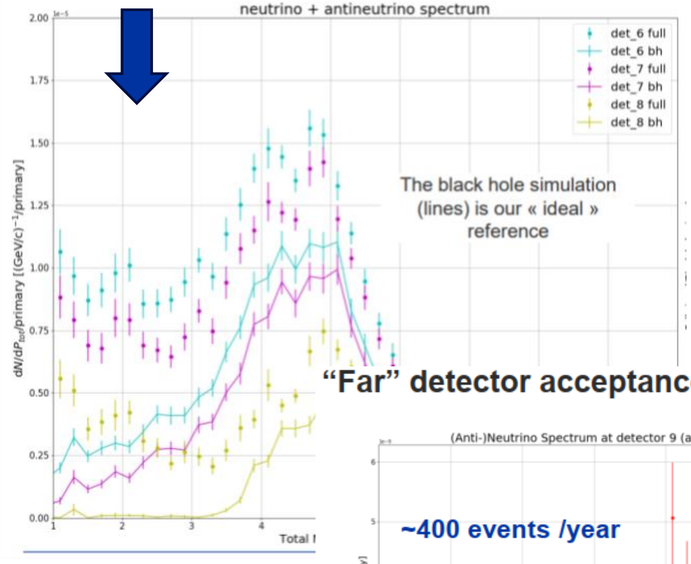




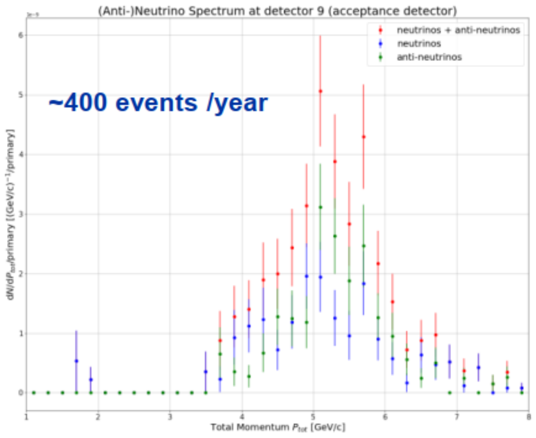
ENUBET – Demonstrator – ERCs - +…



Some background neutrinos in lower momenta reach the near detector



"Far" detector acceptance first estimates



"TRITON" has submitted an ERC grant application for the continuation of the studies

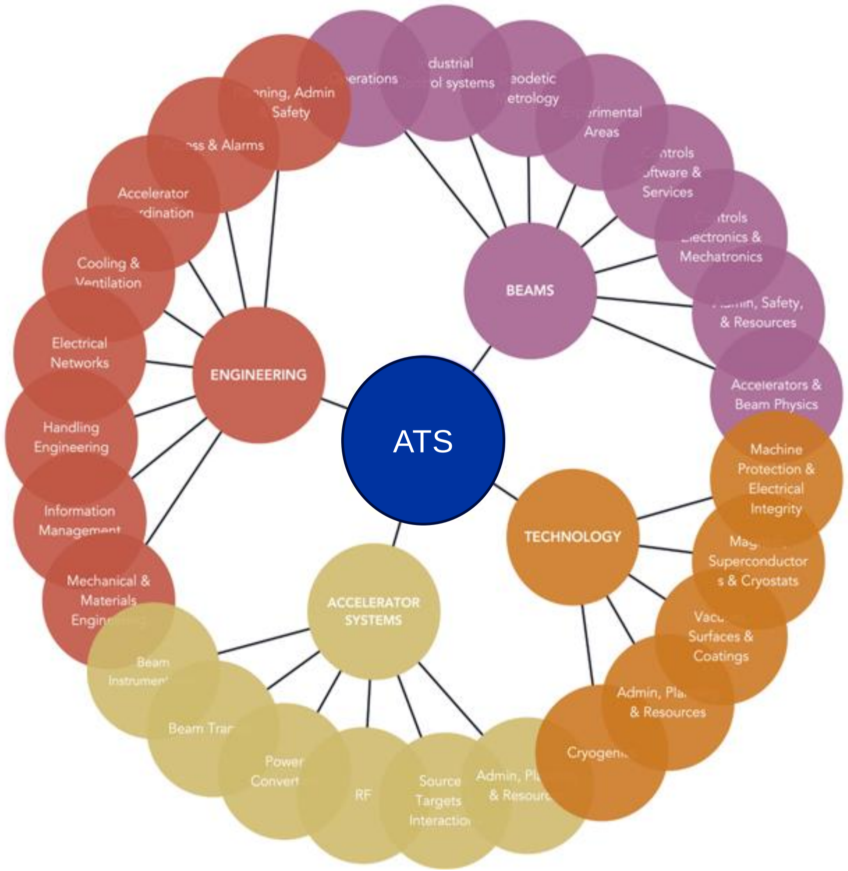
What We Didn't Have Time to Look At

Touched upon by Claude yesterday…

Each worth an academic lecture by its own

- **TauFV**
- **AWAKE and AWAKE++**
- **Gamma Factory**
- **EDM**
- **PBC Technology WG**
- **AD Experiments, ISOLDE Facilities & Experiments, nToF, etc…**

THANKS TO an Enormous Amount of Work by CERN Groups/Teams/Projects



EP SME DT

Department of Theoretical Physics

Radiation Protection
Raising awareness of radiation protection

Occupational Health and Safety
Advice and Support in matters of Occupational Health and Safety

Environmental Protection
Committed to limiting CERNs impact on the environment

EAST AREA RENOVATION

ELENA

ACC-CONS

NA cons

AD

Physics Beyond Colliders

…etc.

Driven by Ideas from Experiments/Collaborations/Researchers

AWAKE		Advanced WAKEfield Experiment
NA58	COMPASS	Common Muon and Proton Apparatus for Structure and Spectroscopy
NA61	SHINE	Study of Hadron Production in Hadron-Nucleus and Nucleus-Nucleus Collisions at the CERN SPS
NA62		Proposal to Measure the Rare Decay K+ -> pi+ nu nu at the Cern SPS
NA63		Electromagnetic Processes in strong Crystalline Fields
NA64		Search for dark sectors in missing energy events
NA65	DsTau	Study of tau neutrino production
NA66	AMBER	Apparatus for Meson and Baryon Experimental Research

EP SME

DT

Department of Theoretical Physics

AD-3	ASACUSA	Atomic Spectroscopy and Collisions Using Slow Antiprotons The ASACUSA Collaboration
AD-5	ALPHA	Antihydrogen Laser PHysics Apparatus
AD-6	AEGIS	Antihydrogen Experiment Gravity Interferometry Spectroscopy
AD-7	GBAR	Gravitational Behaviour of Anti-Hydrogen at Rest
AD-8	BASE	Baryon Antibaryon Symmetry Experiment
AD-9	PUMA	Antiprotons and radioactive nuclei

ISOLDE	ISOLDE

PS212	DIRAC	Lifetime Measurements of pi+ pi- and pi+- K-+ Atoms to Test Low-Energy QCD Predictions
PS215	CLOUD	A Study of the Link between Cosmic Rays and Clouds with a Cloud Chamber at the CERN PS
nTOF COLLABORATION		Neutron Time-Of-Flight (n_TOF) experiment

...etc.


Enjoy the journey as
much as the destination.
Marshall Sylver
quotefancy

MANY THANKS

FOR YOUR INTEREST

AND the MANY

Experiments, Users, Equipment/Service/Support Groups