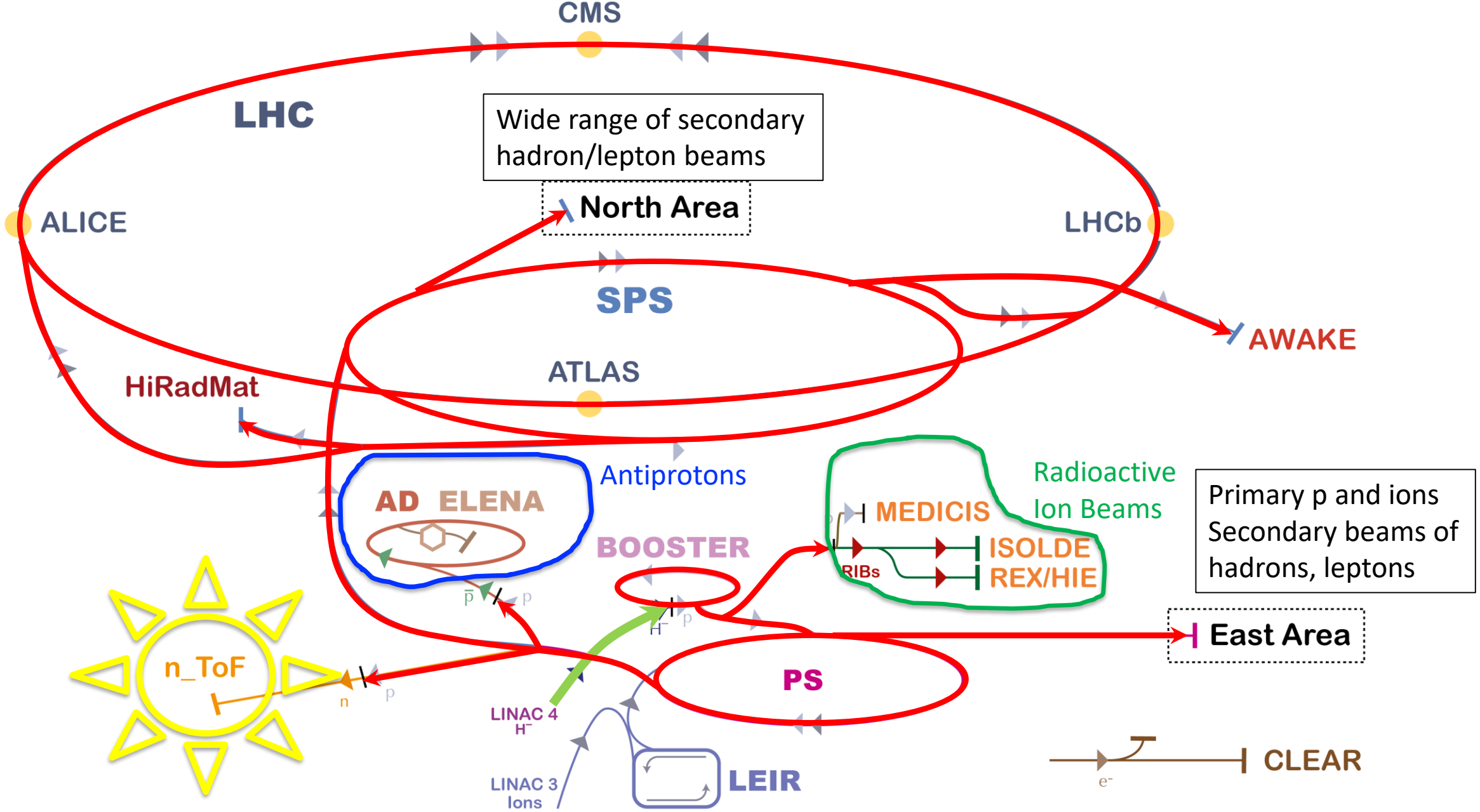
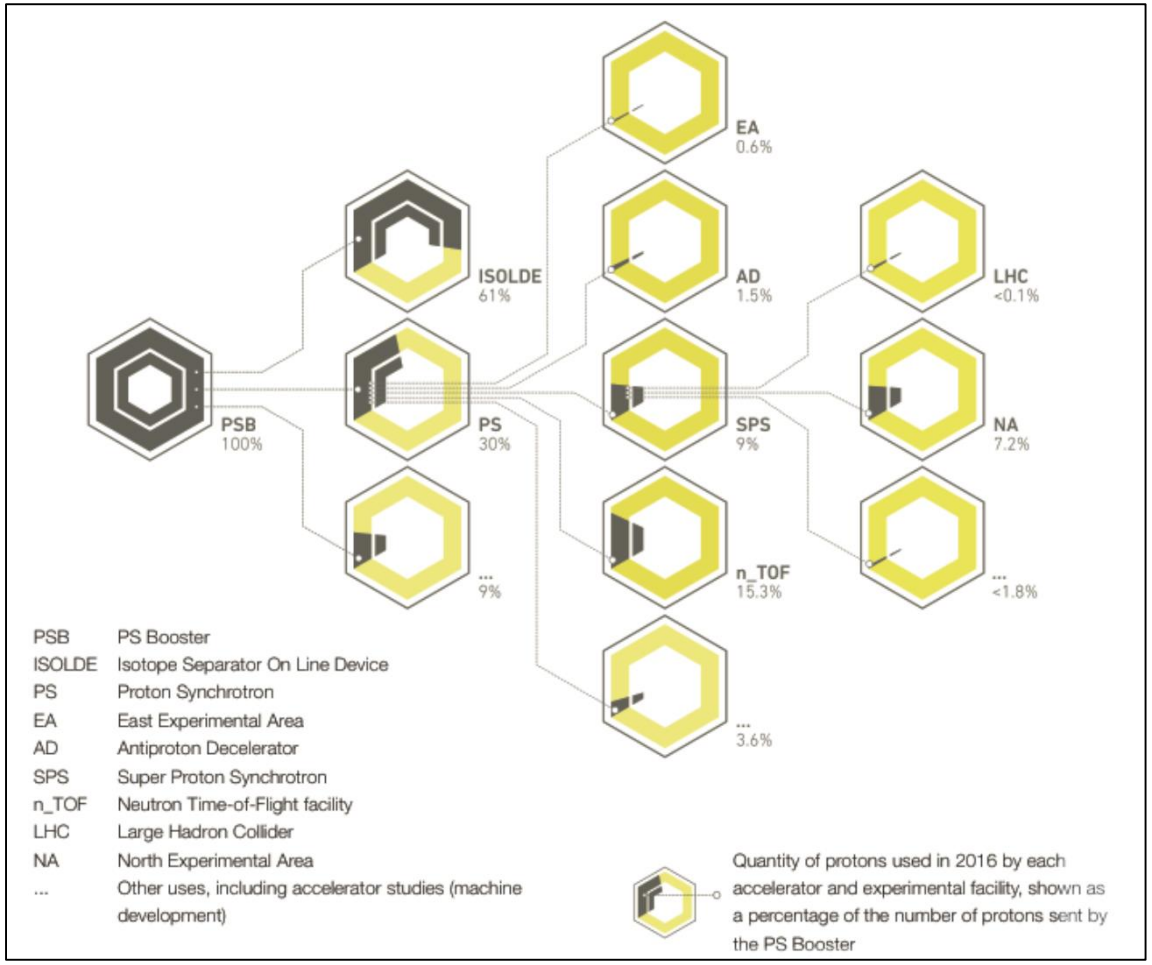
n_TOF at 20: CERN going forward

nTOF



H⁻ (hydrogen anion) | p (protons) | ions | RIBs (Radioactive Ion Beams) | n (neutrons) | $\bar{p}$ (antiprotons) | e^- (electrons)

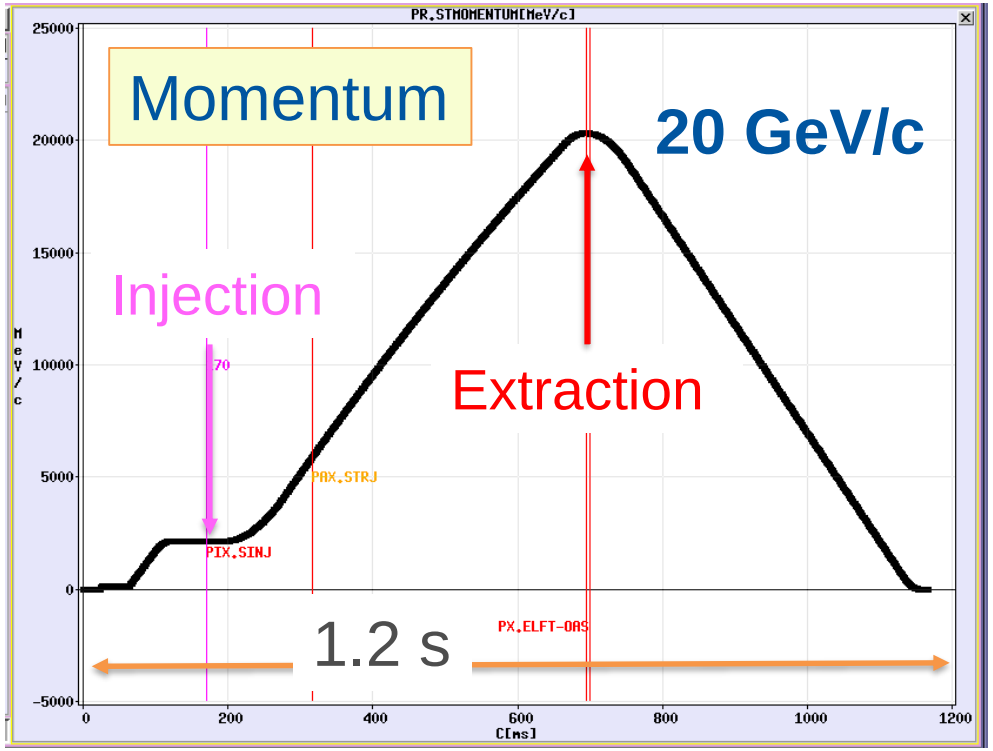
Protons from Booster: <0.1% to LHC



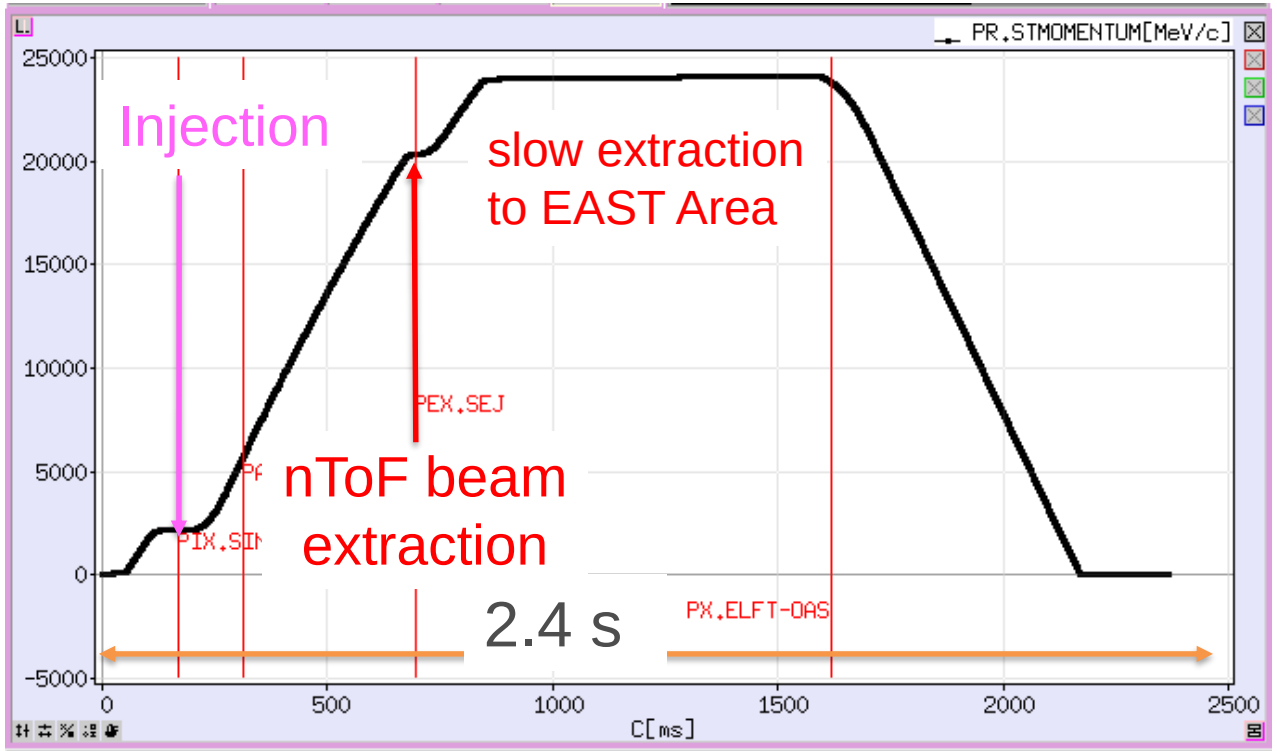
- **ISOLDE**
- **n_TOF**
- **SPS-NA**: COMPASS, NA61, NA62, NA63, NA64, NA65
- **PS-EA**: CLOUD
- **AD/ELENA**: AEgIS, ALPHA, ALPHA-g, ASACUSA, BASE, GBAR
- **Neutrino Platform**: ProtoDUNE
- **Non-accelerator experiments**: CAST, OSQAR
- **AWAKE, HiRadMat**
- Plus a lot of test beam!

n_TOF beam production

Dedicated TOF cycle



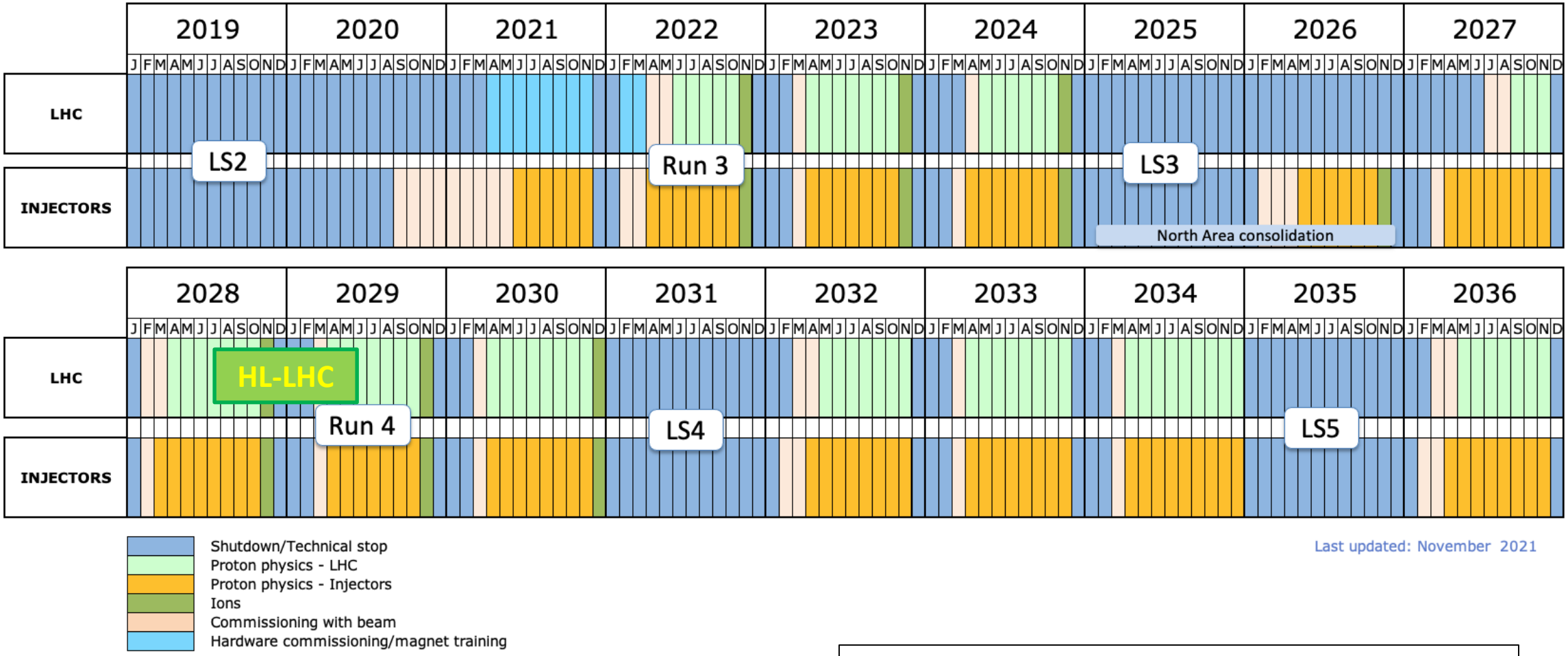
Parasitic EAST/TOF cycle



Present n_TOF beam

- **Dedicated** n_TOF beam (1.2 s), **parasitic** on EAST cycles (2.4 s)
- Beam momentum **20 GeV/c**
- Maximum intensity per pulse
  - **Dedicated** beam: up to **$8.5*10^{12}$ p/pulse**
  - **Parasitic** beam: **$3.5*10^{12}$ p/pulse**
- Single bunch, **25 ns (4σ)** bunch length
- Minimum repetition rate 1.2 seconds, average repetition rate 4.8 s
- Beam spot on target of **30 x 7 mm (1σ)** in H and V (dedicated)
- Momentum spread: $3.8*10^{-3}$ @2σ (dedicated), $2.8*10^{-3}$ @2σ (parasitic)

Long-term Schedule



HL-LHC nominally operational out through 2038 to deliver 3 ab^{-1} to both ATLAS and CMS

LIFE AFTER 40?

1972

(800 MeV - 0.59 T)

1988

(1 GeV - 0.69 T)

1999

(1.4 GeV - 0.86 T)

2013 - 40 years of operation

2020

(2 GeV - 1.12 T)

Recently…

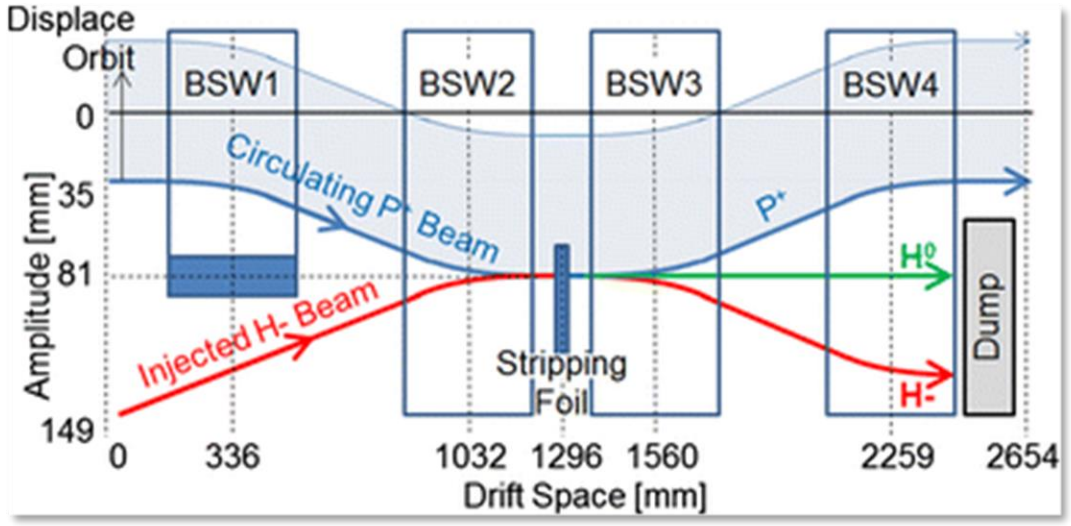
There has been a major investment in the injector complex

- Connection of Linac4 to Booster
- Deployment of LHC Injectors Upgrade (LIU) project
- Wide ranging consolidation programme
- Completion of East Area Consolidation
- Upgrades to facilities:
  - n_TOF, ISOLDE, AD-ELENA

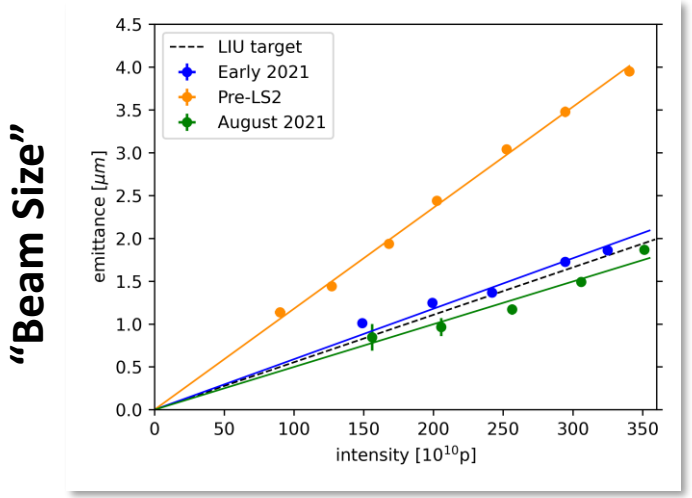
Booster

- Connection of Linac4: H^- at 160 MeV
- H^- charge exchange injection
- Increase of extraction energy to PS to 2 GeV

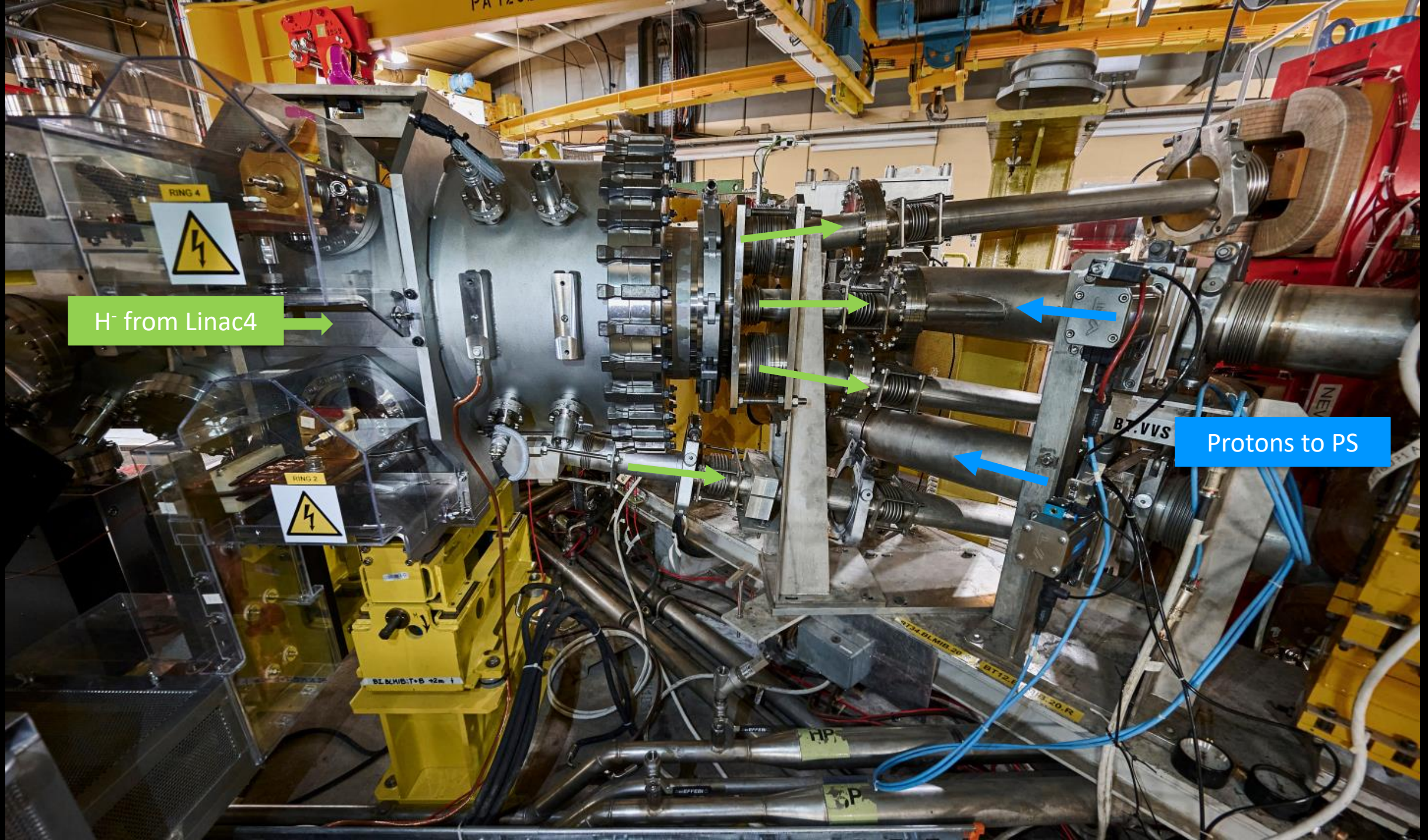
The key measures



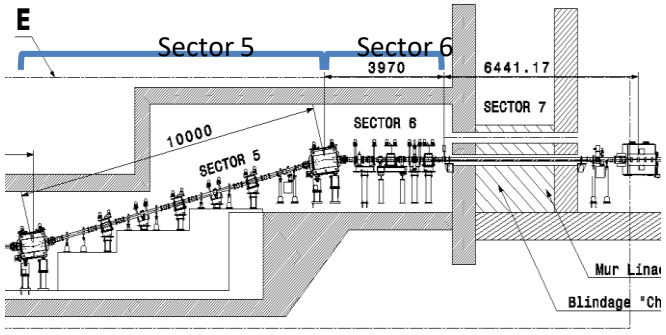
Aim is to double intensity and brightness for LHC beams to meet the HL-LHC requirements

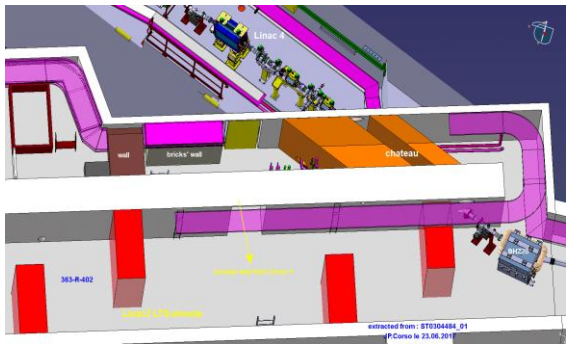


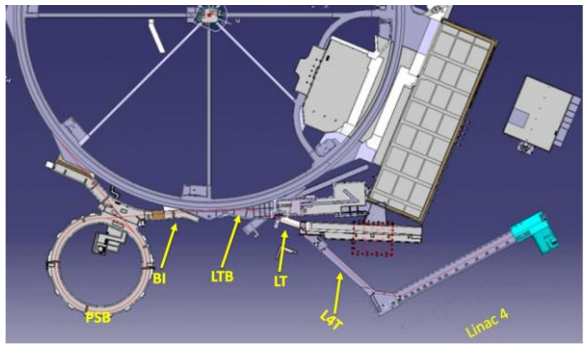
Protons per bunch

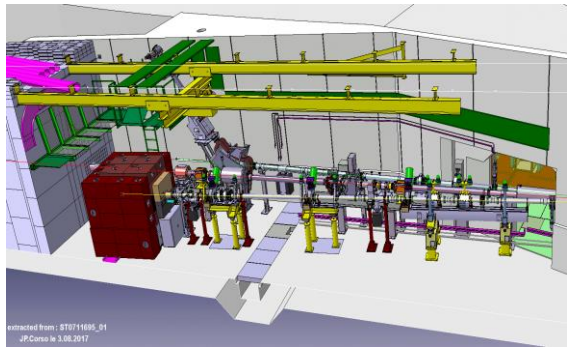

RING 4
RING 2
H- from Linac4
Protons to PS

LINAC4 connection

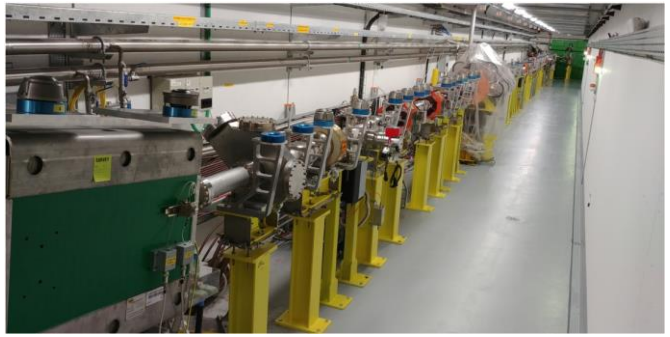






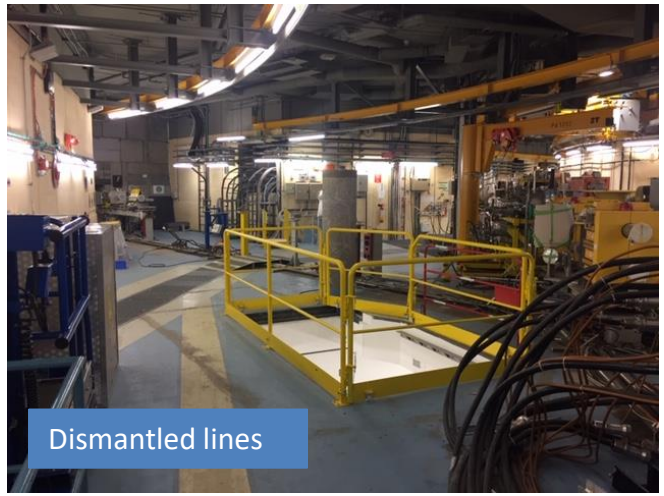


Connection of the Linac4 to the LT.BHZ20 and Reconfiguration of the Beam Emittance measurement Line (LBE) in the PS Switch Yard

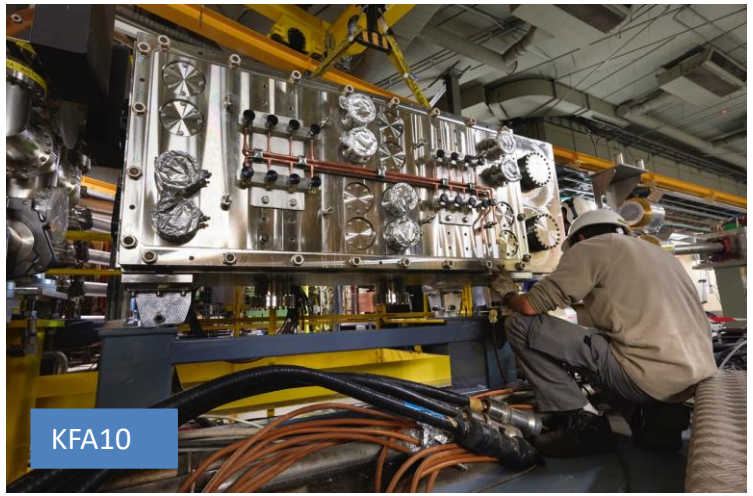


Courtesy of: S. Mataguez and J. Coupard

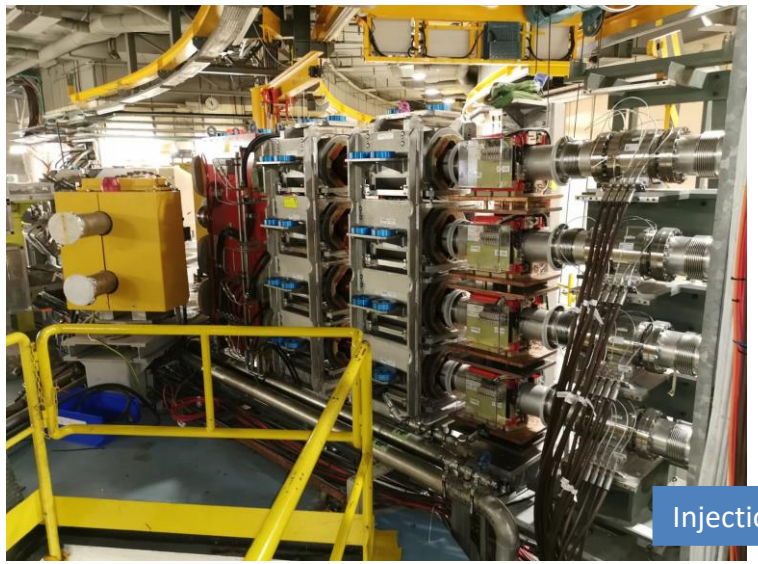
PSB LS2 works in pictures

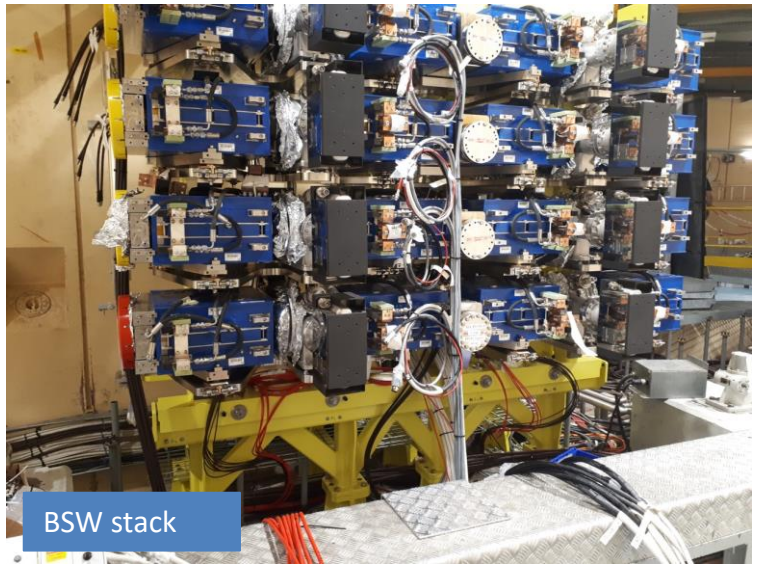

Dismantled lines


Beam stoppers


KFA10


BSW transformers

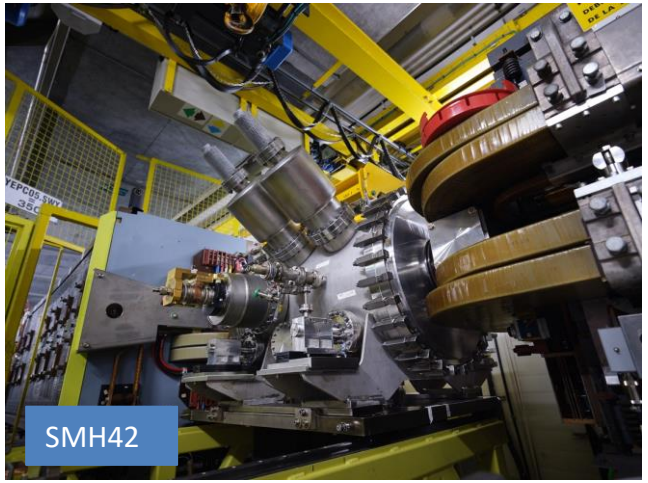

Injection Line

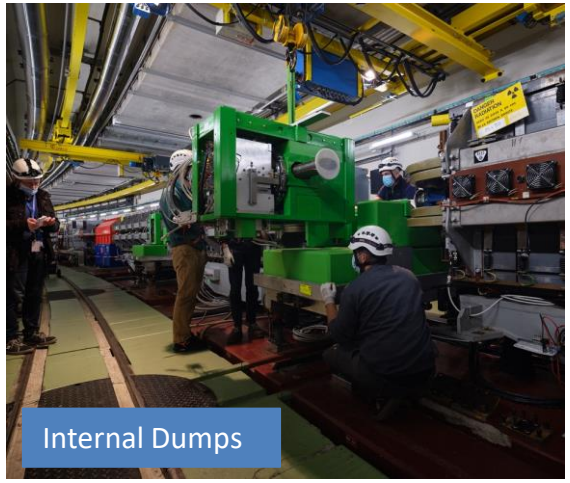

BSW stack

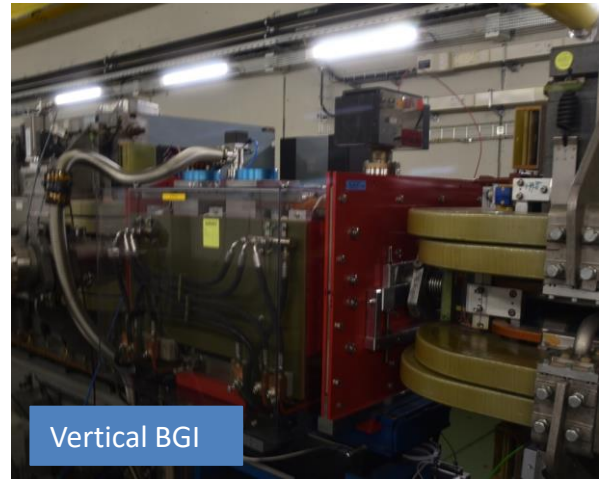
Courtesy of: D. Hay

PS&TT2 LS2 works

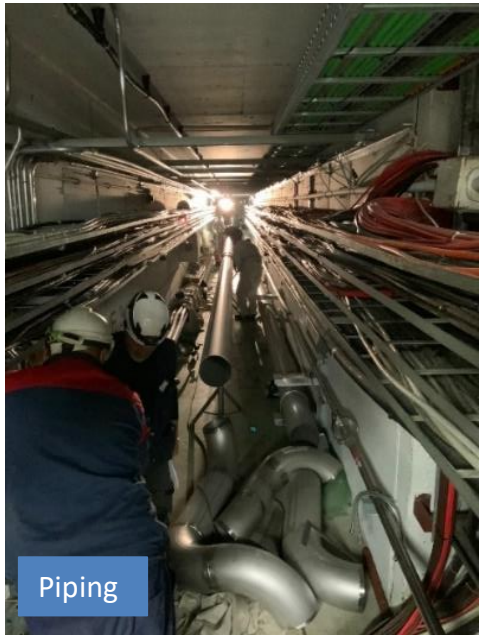

Booster to PS Line


SMH42


Internal Dumps


Vertical BGI


KFA45


Piping


10 MHz amplifiers


Wire scanners

Longitudinal damper

PS&TT2 LS2 works (consolidation)

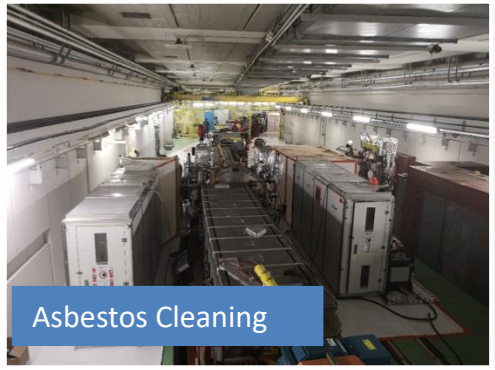

F61 line – PS to East Area


De-cabling


Duct Replacement


Vacuum system


WIC


Asbestos Cleaning


PFW replacement in 43/100 MUs


Large MAD


F16 Beam Stoppers


Slabs

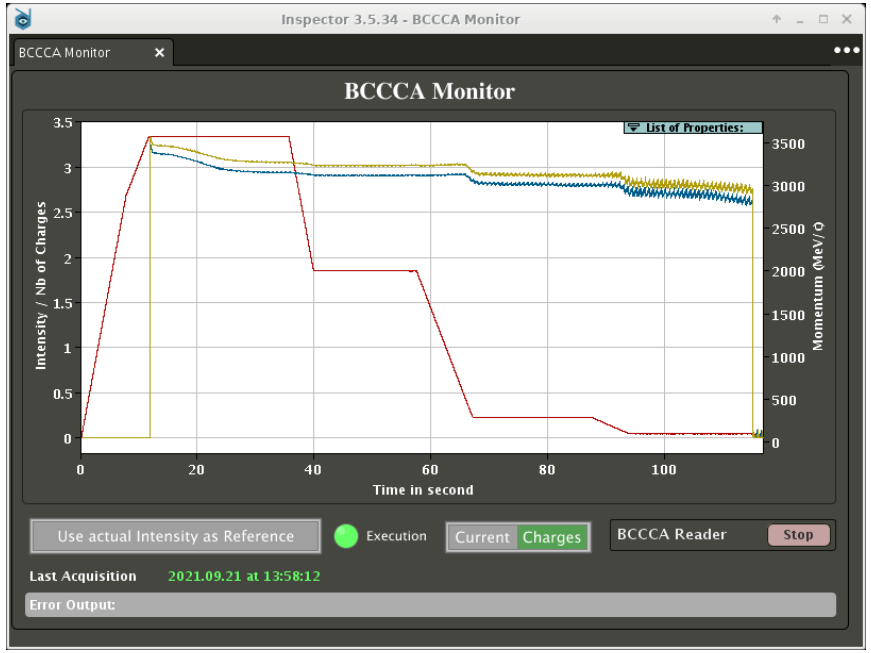

PS SWY evacuation path


PS to SPS through TT2 and TT10

AD and ELENA

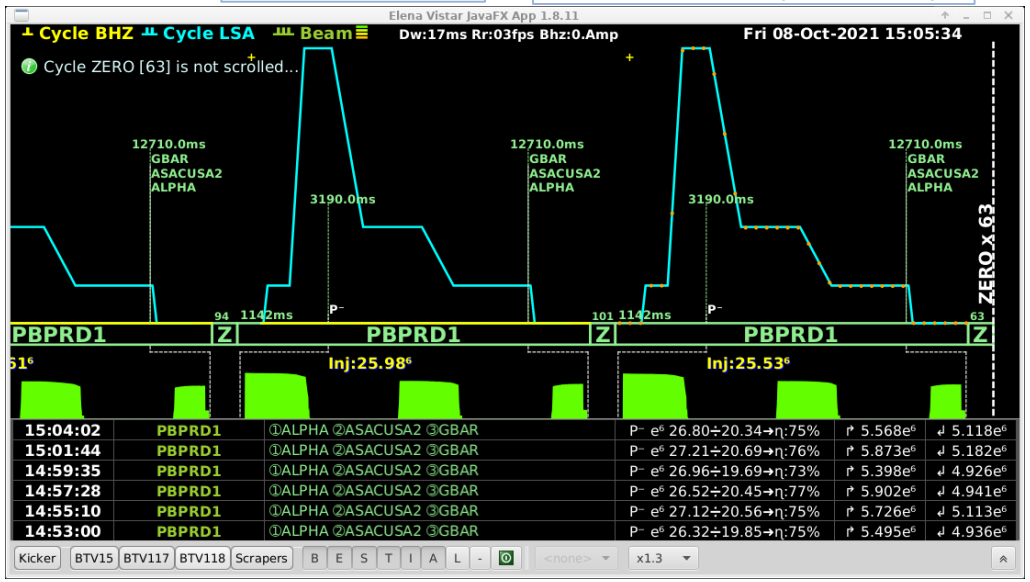
3.5 GeV/c

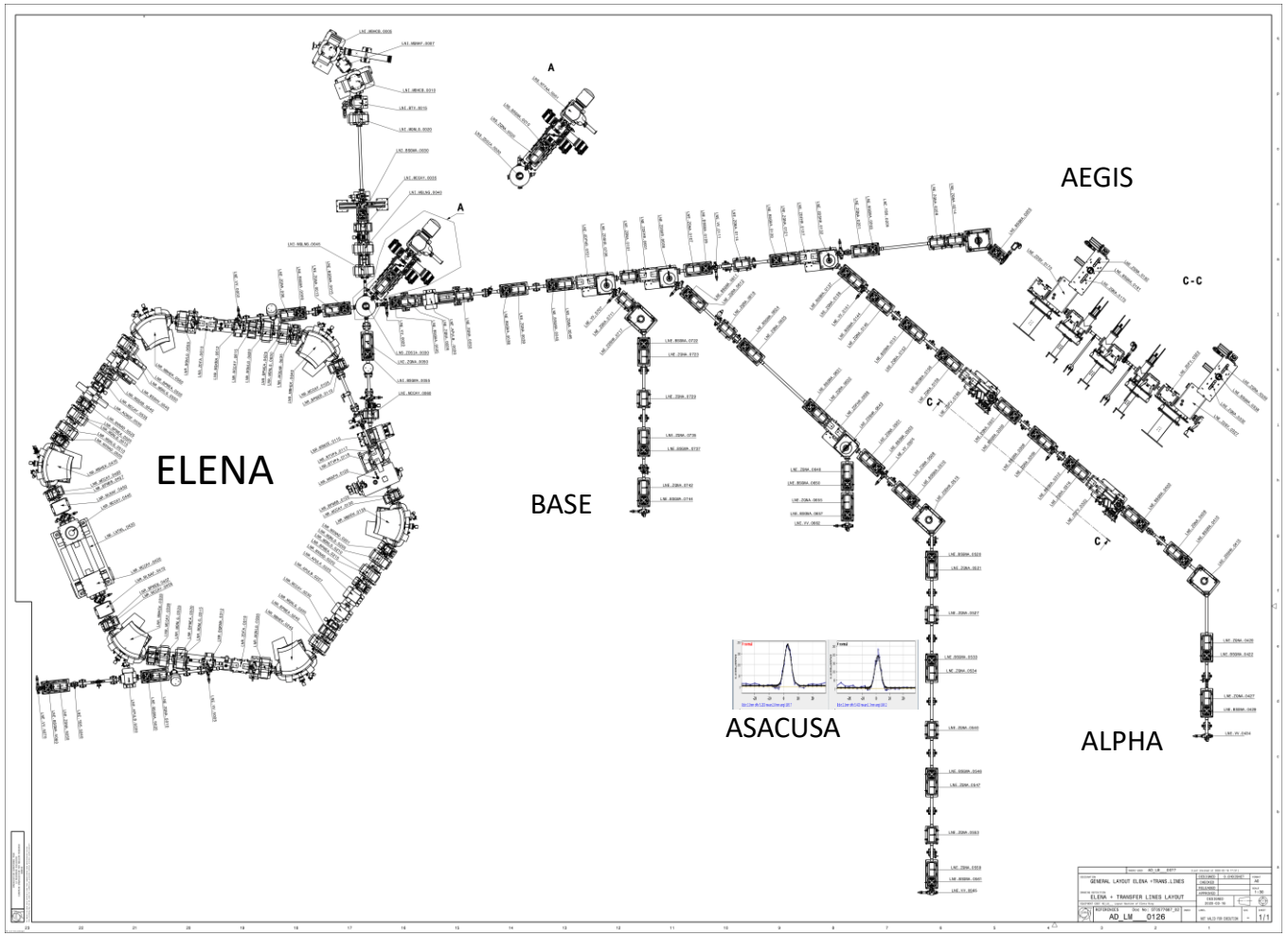
100 MeV/c **(5.3 MeV)**



100 MeV/c

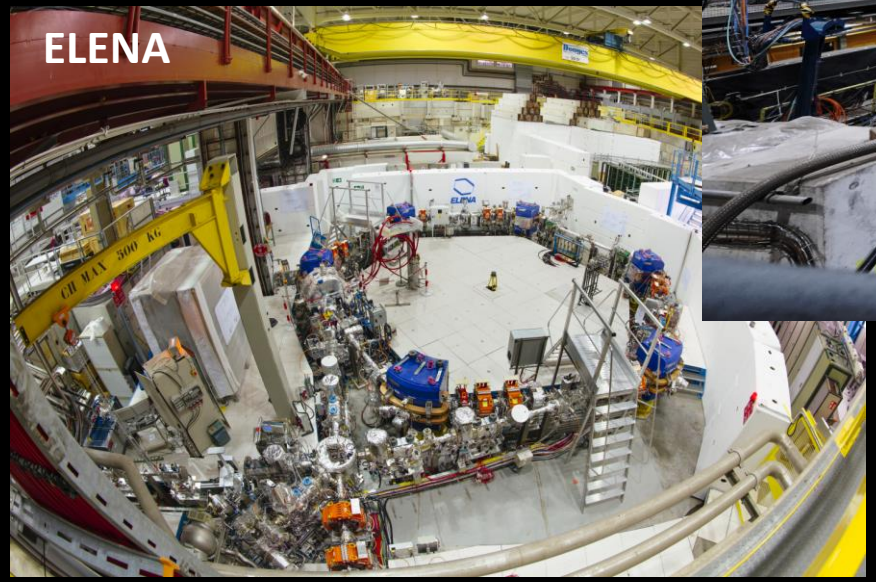
13.7 MeV/c **(100 keV)**



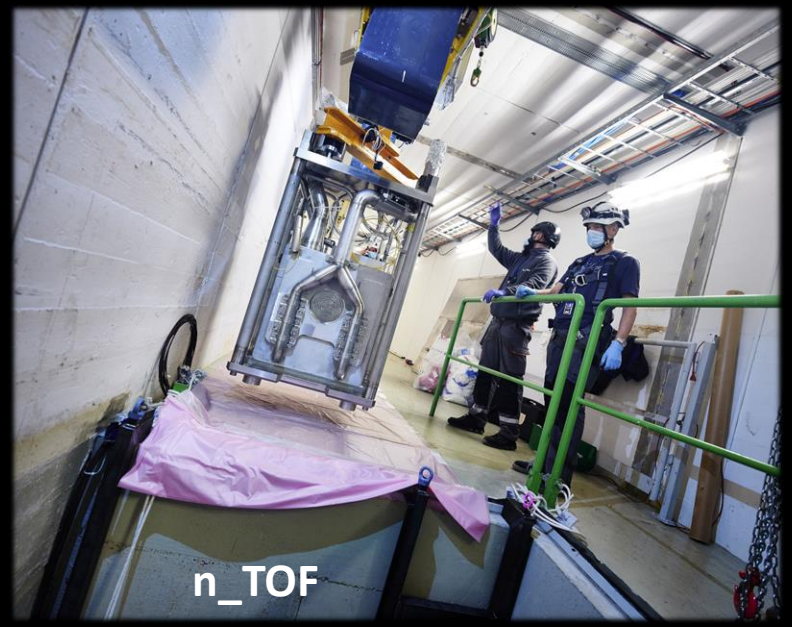


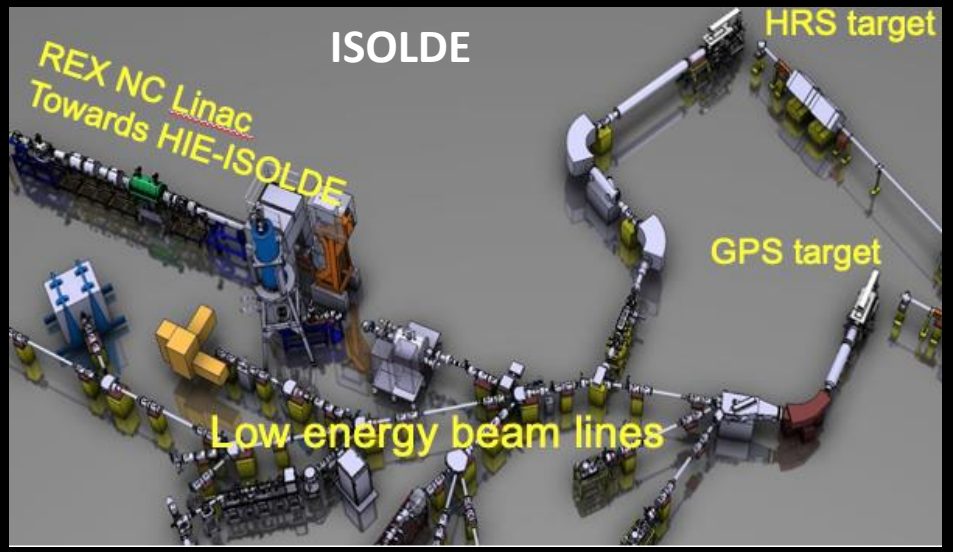
Impressive achievement opening the way to a full and wide-ranging physics program

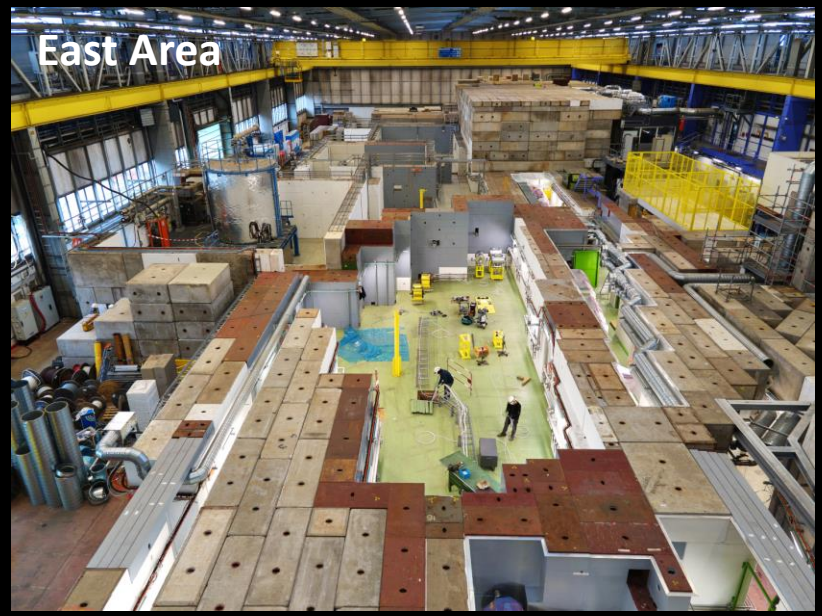

North Area


ELENA

PHYSICS!


n_TOF


ISOLDE
HRS target
REX NC Linac
Towards HIE-ISOLDE
GPS target
Low energy beam lines


East Area

Message

- LIU targeted HL-LHC but is also (very) beneficial for other users
- Wide ranging consolidation programme
  - East Area complete, North Area foreseen for LS3
- Major upgrades of existing facilities
  - n_TOF, AD-ELENA, ISOLDE

- Huge effort to assure the effective future exploitation of the complex until at least circa 2038…

In conclusion, in almost twenty years of operation n_TOF has been one of, if not the, most productive neutron facility in the world, with forefront research being performed thanks to the innovative features of the neutron beams and the synergy of groups with various competences and expertise. As new needs of nuclear data for fundamental and applied science are continuously emerging, the facility has all potentialities to continue play in the future a world-leading role in the field of neutron physics with accelerators.

Basic science at n_TOF & Plans

Explored

Cosmochronology (nuclear clocks) : Re/Os clock
: the cosmological lithium problem (CLiP)

Planned

NN-scattering length : charge-symmetry breaking in QCD

To be explored

X17 ($n+^{3}He$, $n+^{7}Be$) : dark photons/fifth force (?)

- Experiments (single measurements) at n_TOF are evaluated by the INTC (Isolde and n_TOF Experiments Committee). Plans for the next ≅ two years of run already approved

- The new target station (3rd generation) is supposed to last for **10 years**.
Activities can, in principle, continue for this whole period, i.e. beyond LS3

Courtesy Alberto Mengoni

ISOLDE

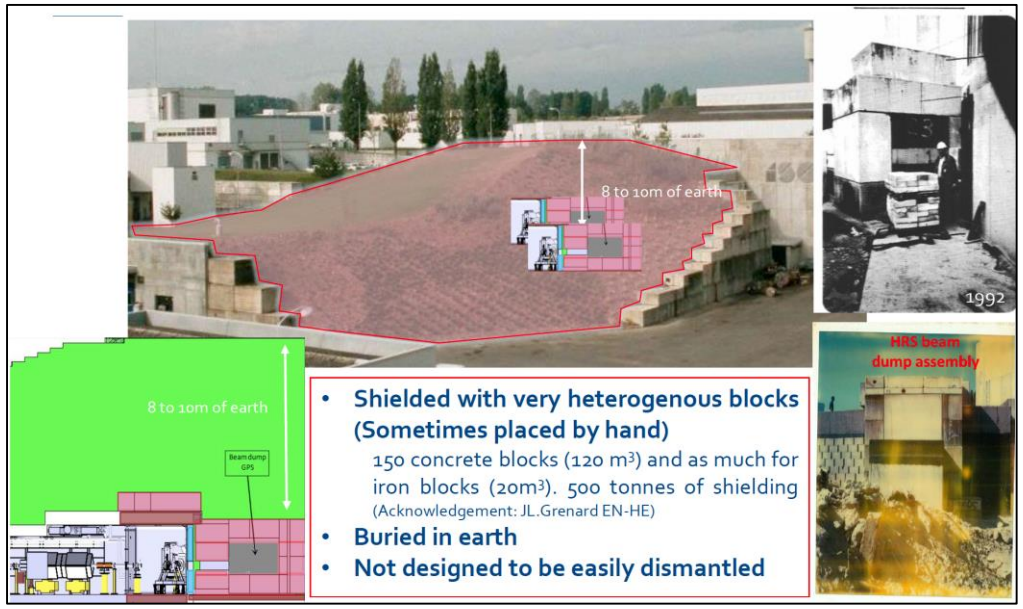
Medium-term facility upgrade (possible horizon LS3) to fully profit from LIU-PSB improvements:

- ISOLDE @ 2 GeV
- Increased POT

Upgrade needed :

- Rebuilding of PSB-ISOLDE transfer line
- Rebuilding of ISOLDE beam dumps
- Validate new targets and future FEs

Not yet approved!



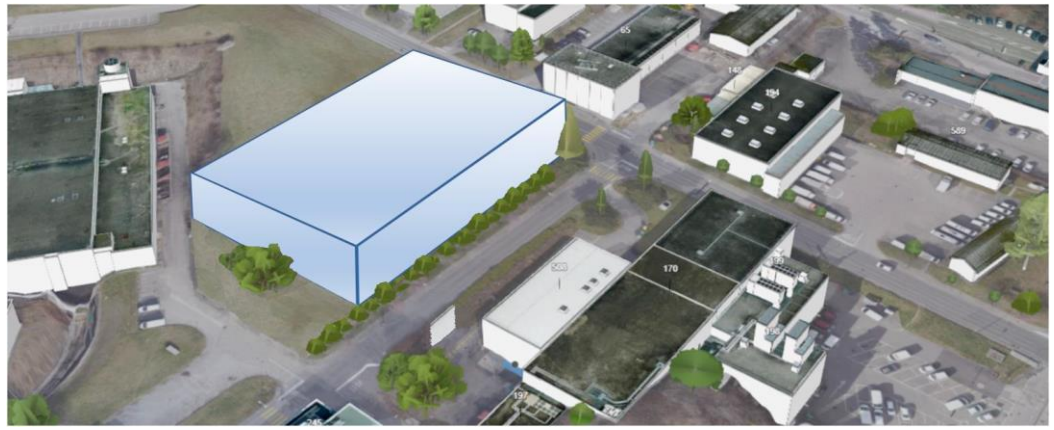
EPIC (Exploiting the Potential of ISOLDE at CERN)

Ambitious future program proposed following the long-term tradition of the ISOLDE community/facility

- Increase integrated intensity to final users
- Increase possible experiments -> New experimental hall
- New physics opportunities -> Isotope storage ring

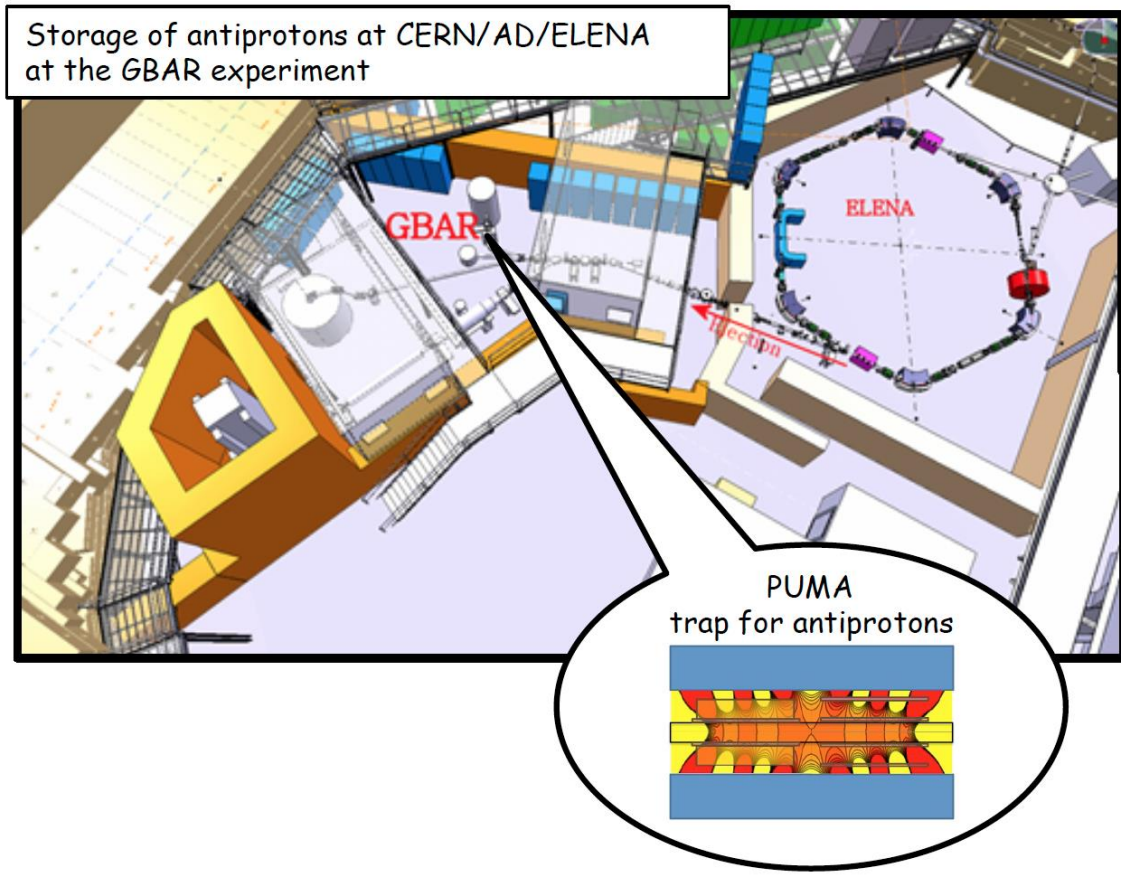
Explore synergies with other CERN physics programs: such as n_TOF and AD-ELENA…

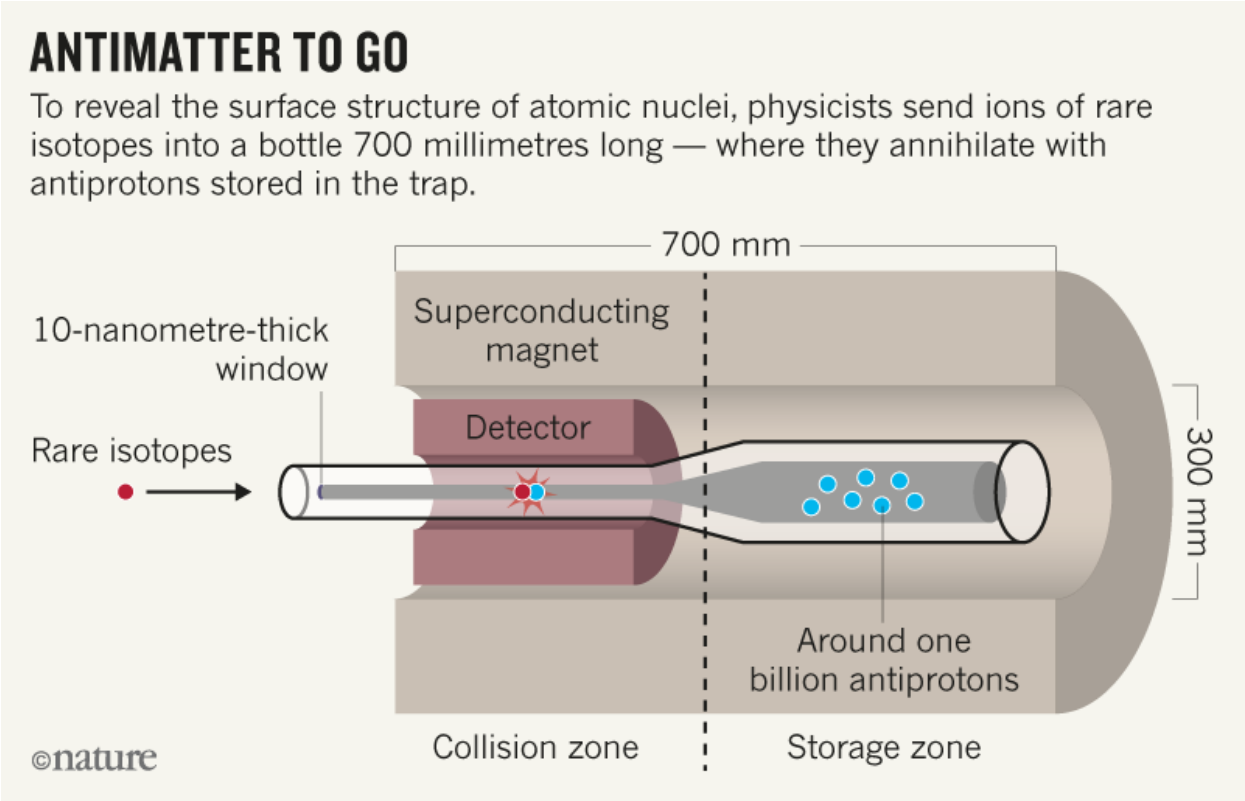
Exploratory!



PUMA – “Hauling antiprotons around in a van”

One of the most fascinating quantum phenomena in nuclear physics is the occurrence of neutron halos and neutron skins in very neutron rich atomic nuclei…





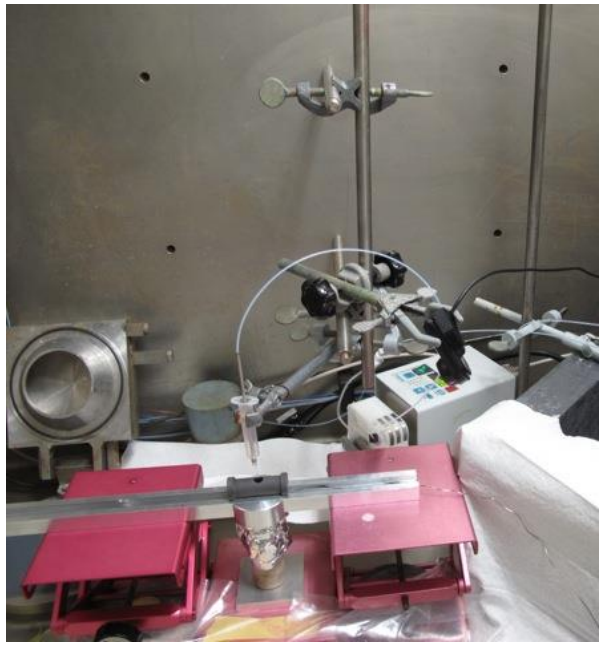
$^{7}Be(n,p)^{4}He$

L A Damone et al. (The n_TOF Collaboration)
Phys. Rev. Lett. **121** (2018) 042701

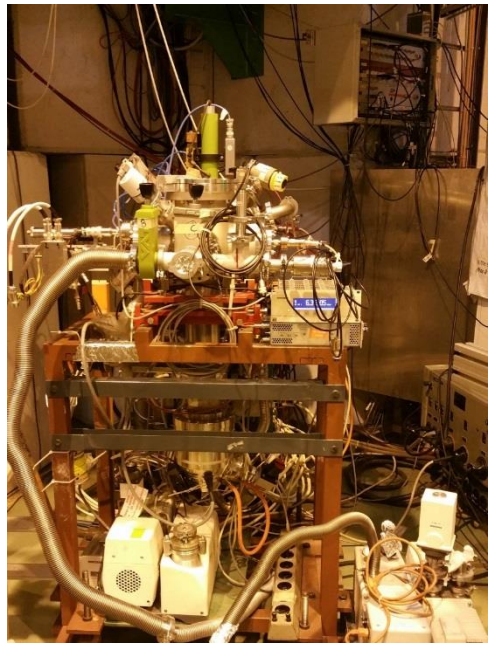
A three-step experiment:

- Extraction of 200 GBq material from water cooling of SINQ spallation source at PSI
- Implantation of the 30 keV (~45 nA) ^{7}Be beam on suited backing using **ISOLDE-GPS separator and RILIS**
- Measurement at n_TOF-EAR2 using a silicon telescope (20 and 300 mm, 5x5 cm^2 strip device)

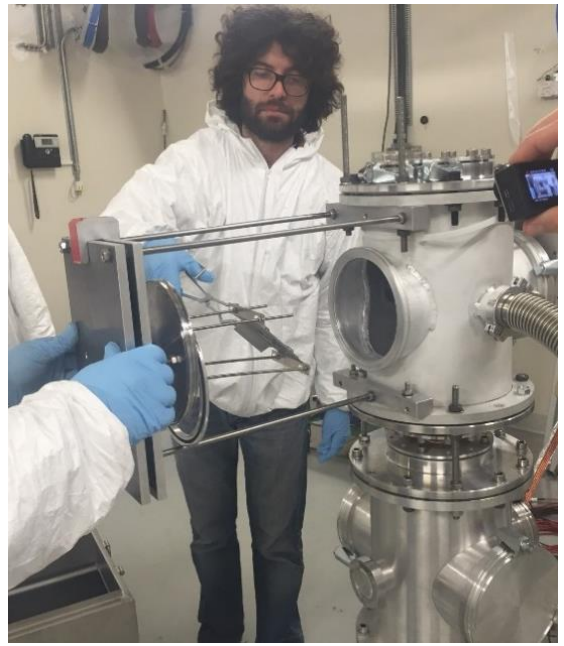
PSI hot-cell



ISOLDE - GLM



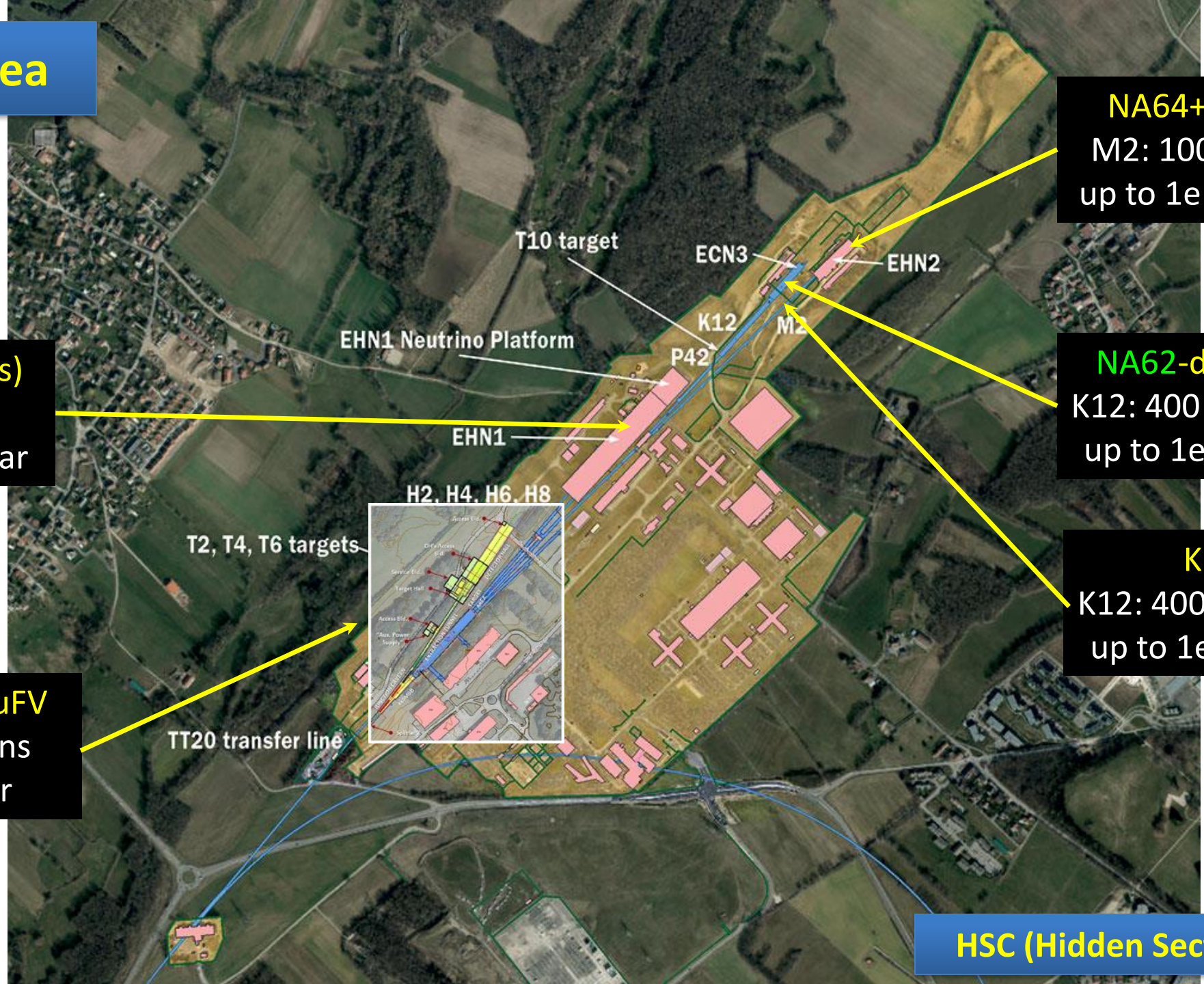
n_TOF EAR2



E. Maugeri *et al.* (The n_TOF Collaboration), Nucl. Instr. and Meth. A **889** (2018) 138
M. Barbagallo *et al.* (The n_TOF Collaboration), Nucl. Instr. and Meth. A **887** (2018) 27-3

Courtesy Alberto Mengoni

North Area



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

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

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

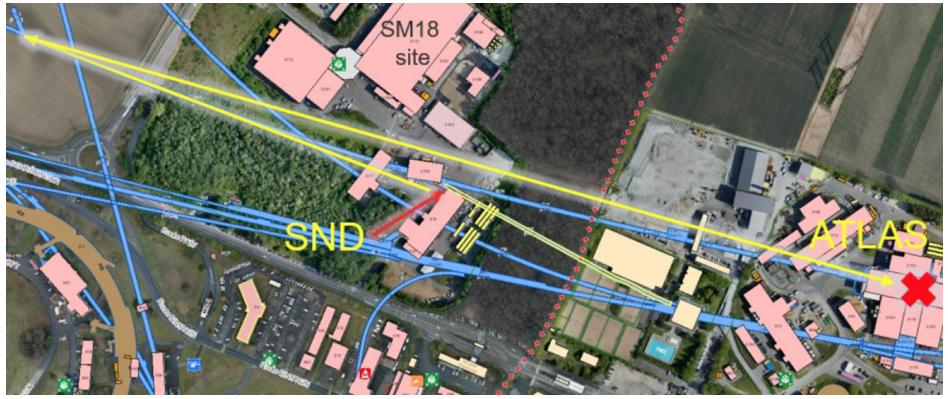
KLEVER
K12: 400 GeV protons
up to 1e19 pot/year

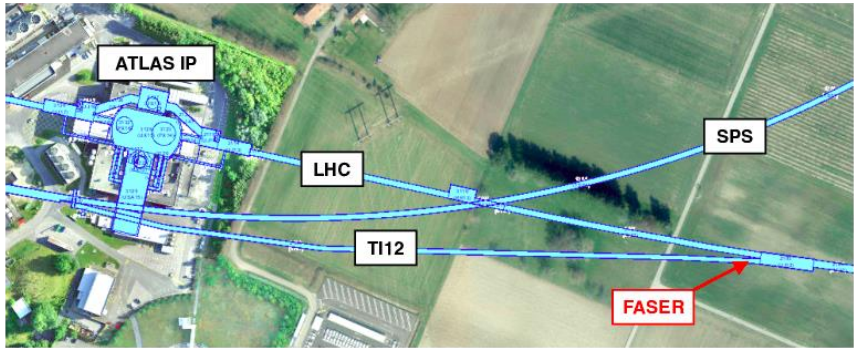
BDF -> SHiP, TauFV
400 GeV protons
4e19 pot/year

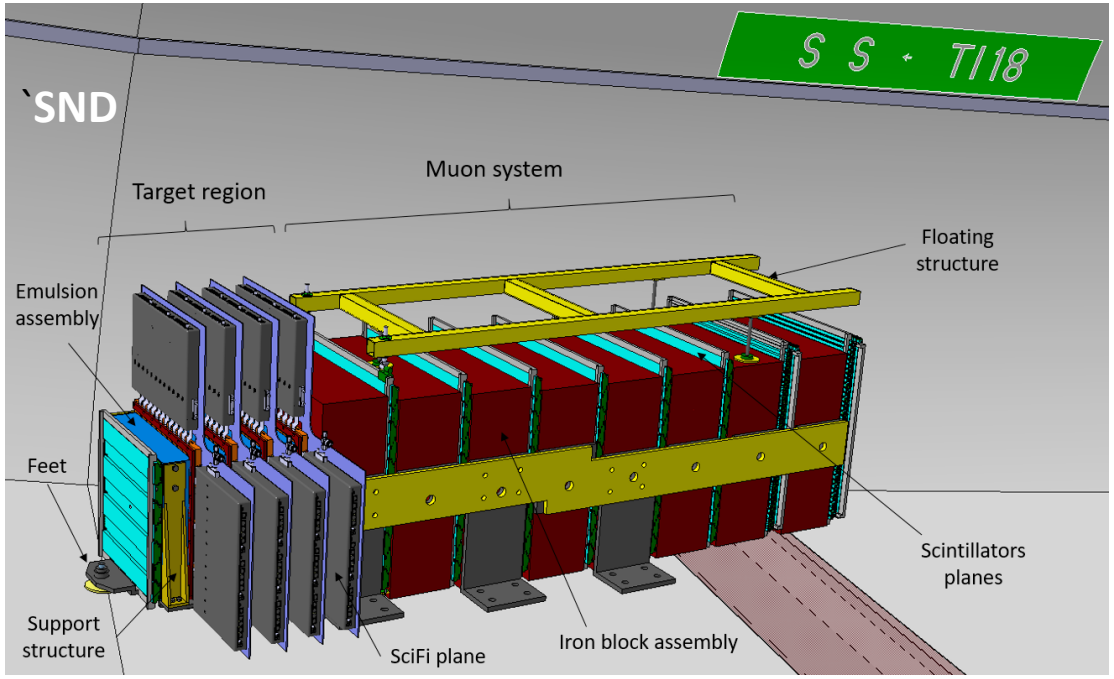
HSC (Hidden Sector Campus)

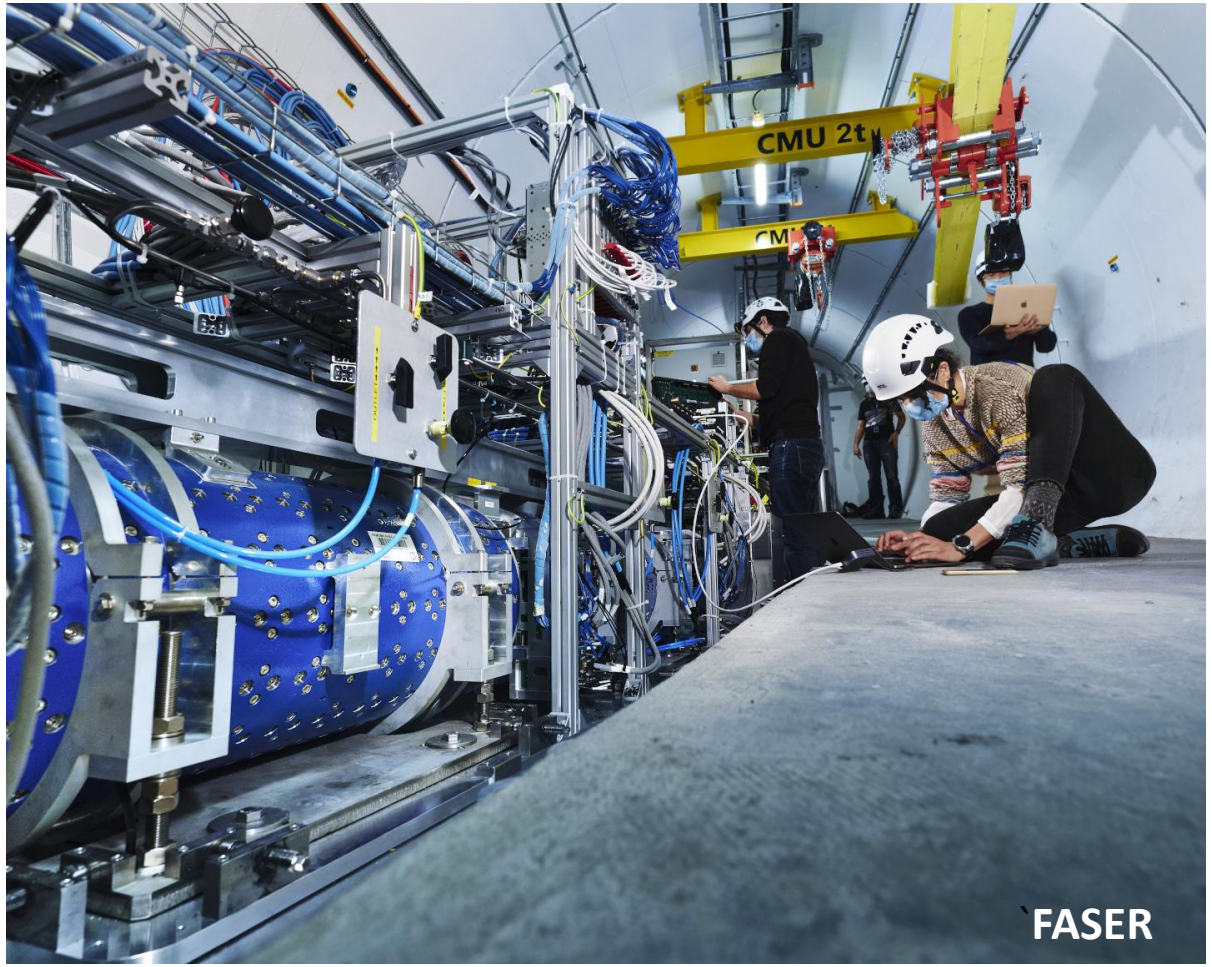
LHC - diversification

Neutrinos and long-lived particles

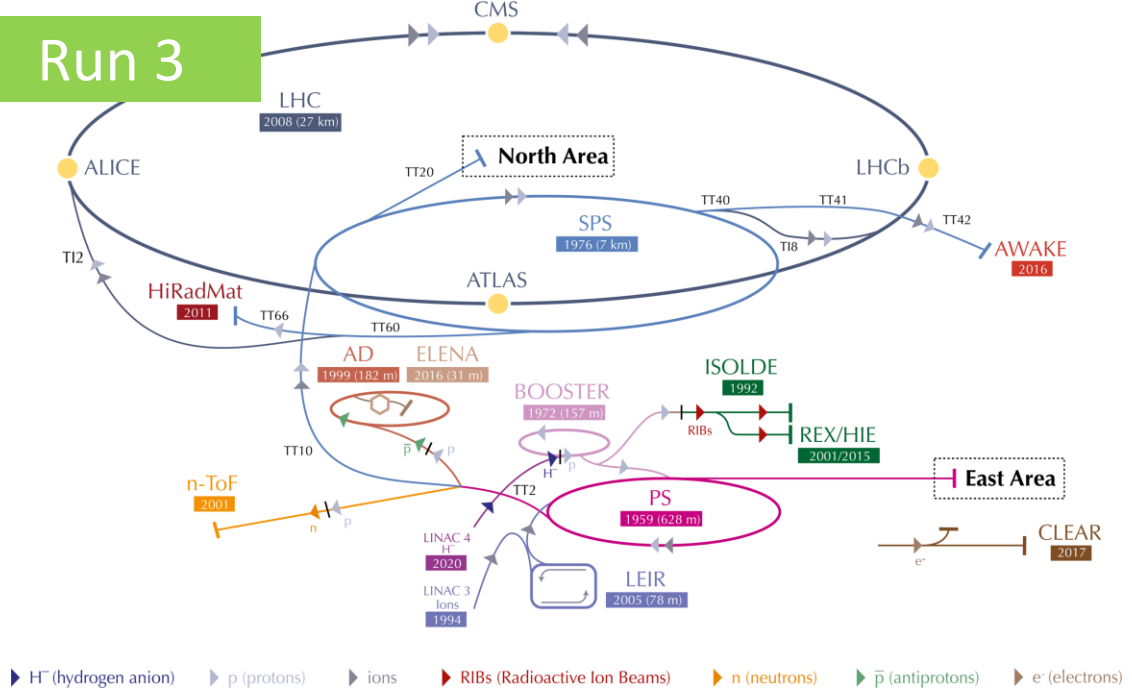




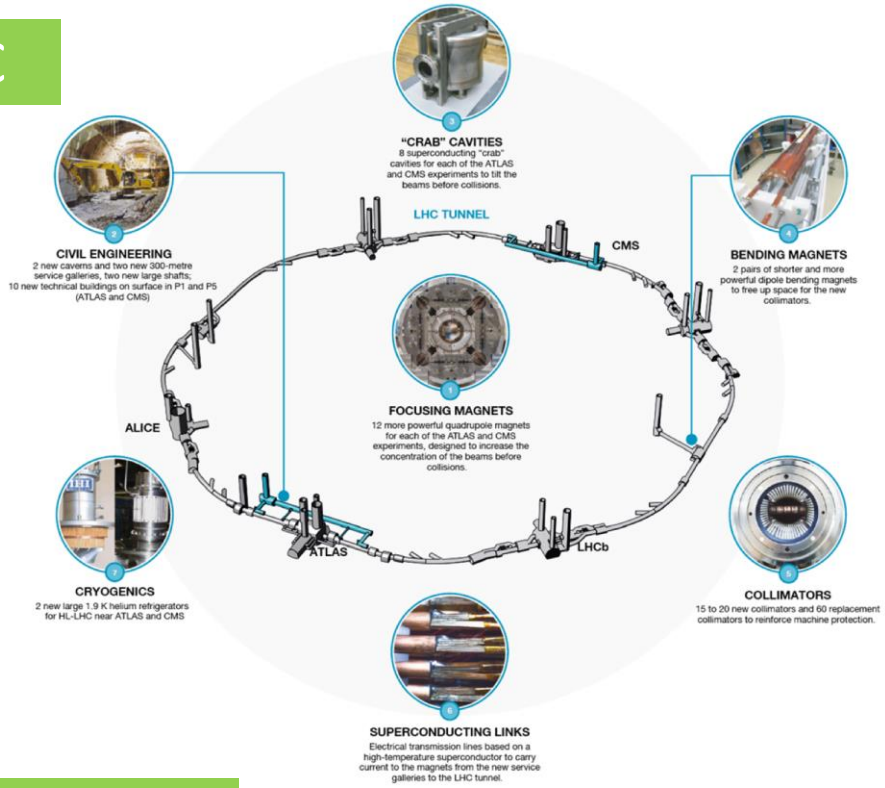




Run 3



HL-LHC



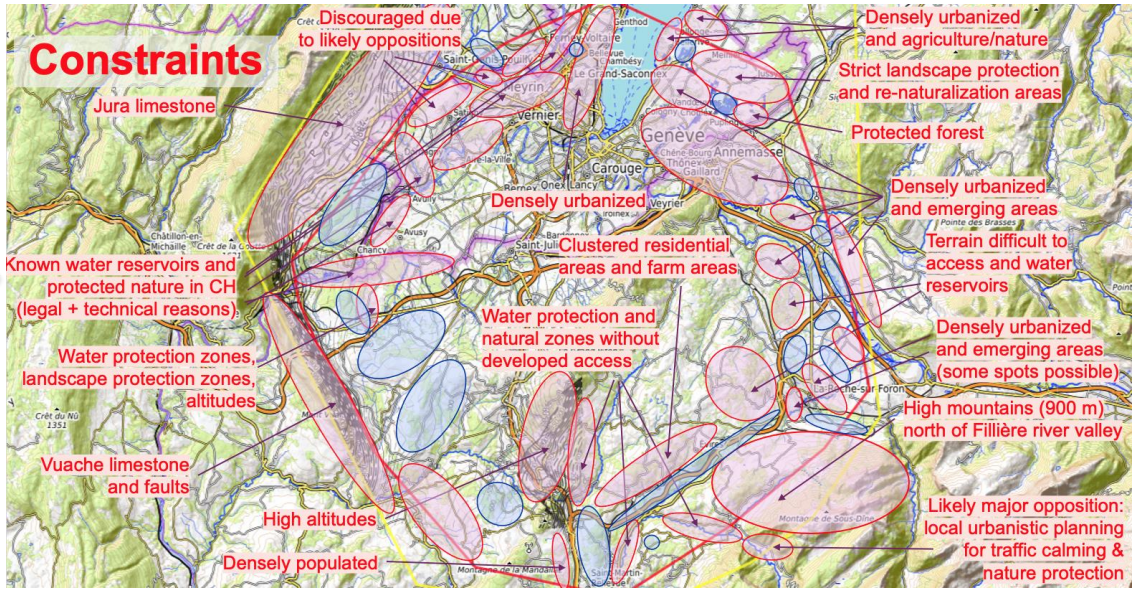
Future Options

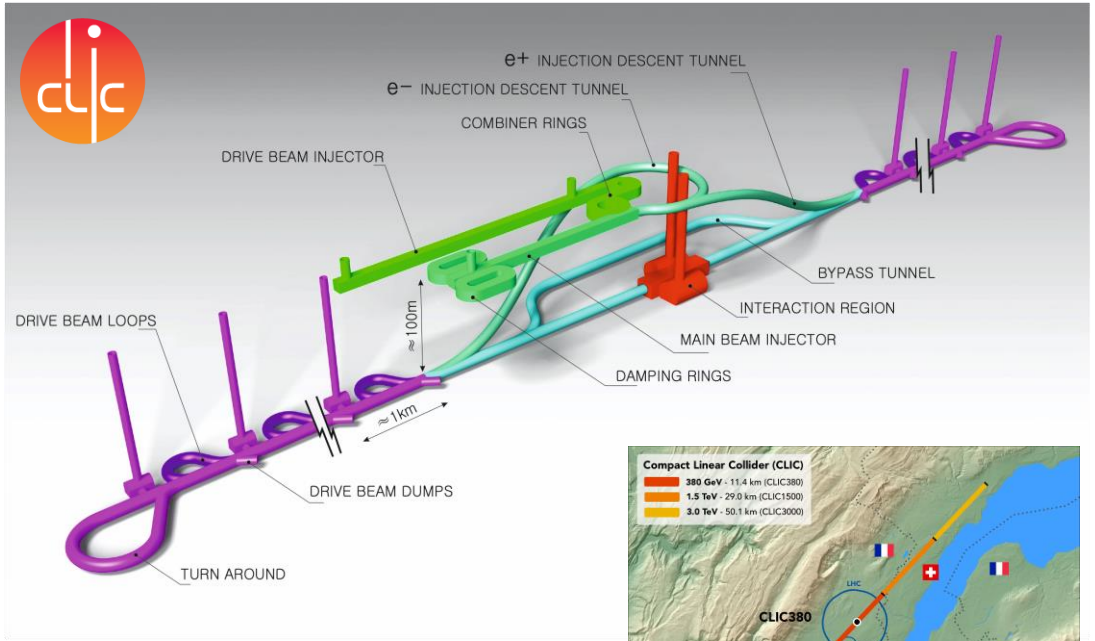
Technology/R&D

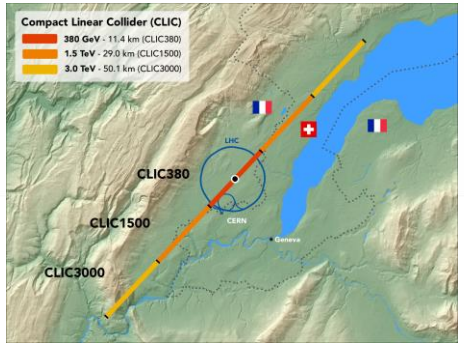
Collider studies

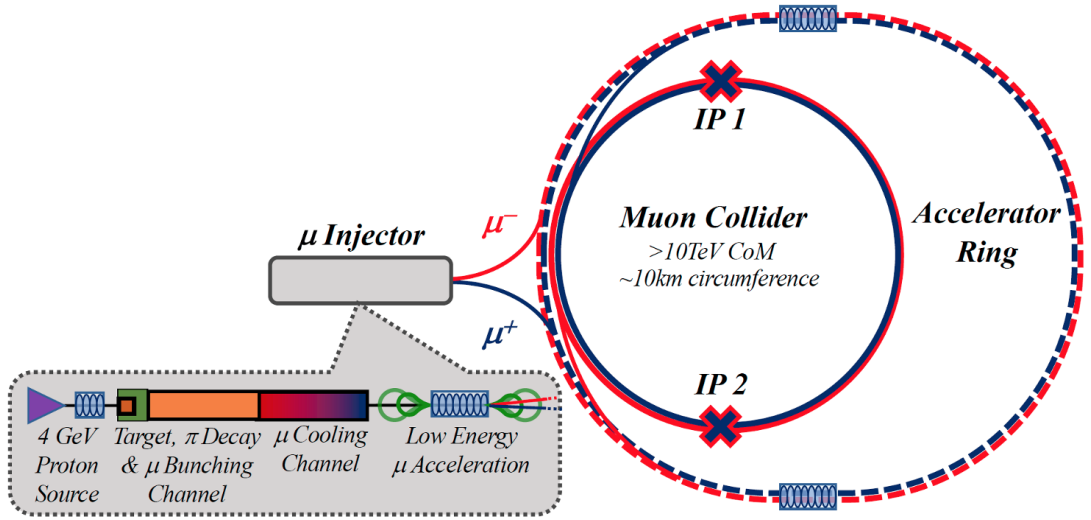
ESPP: “Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage”

FCC



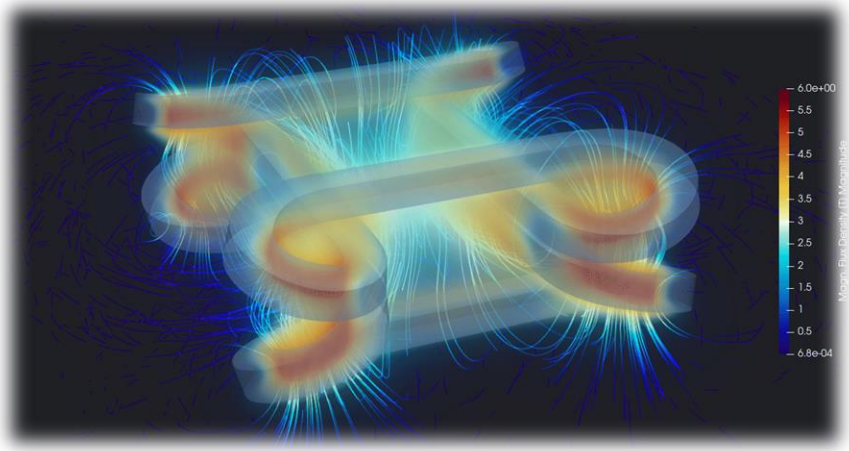




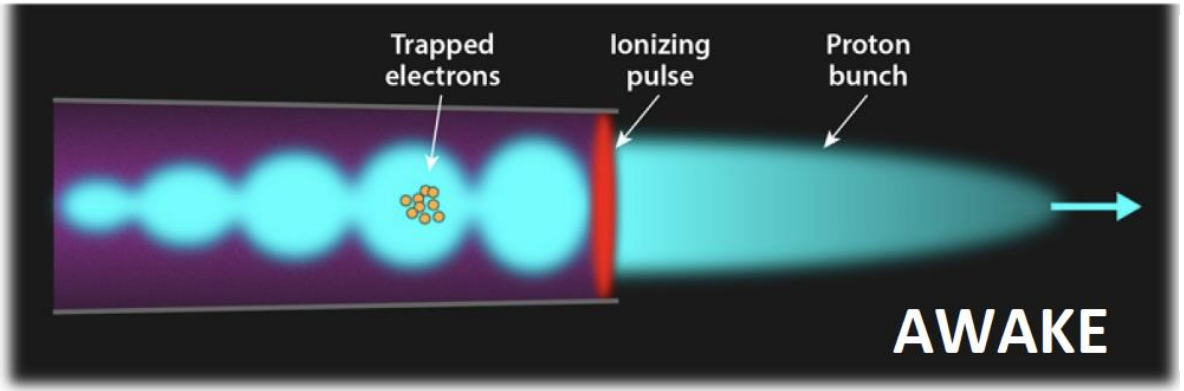


Accelerator Technologies

High-Field Magnets (LTS/HTS)

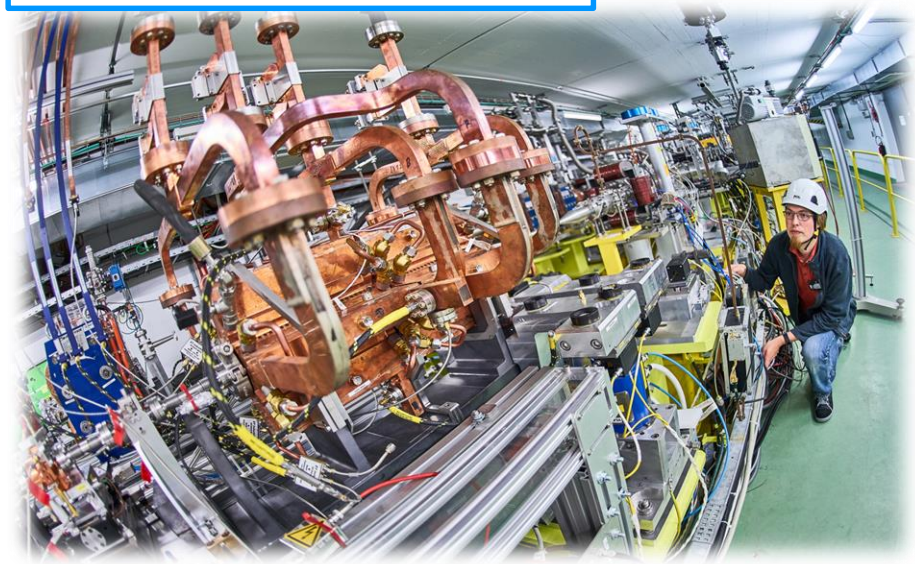


Plasma Wakefield Acceleration

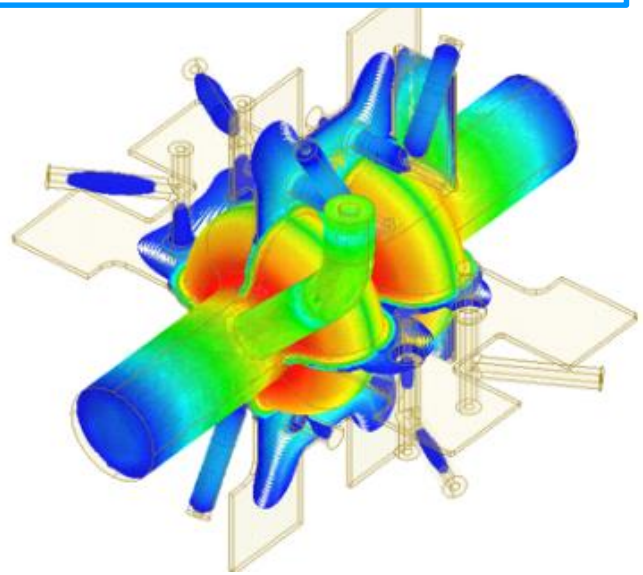


APS/Alan Stonebraker

X-band RF (CLIC)



SRF (LHC, FCC-ee, thin film…)



Final remarks

- CERN’s accelerator complex always an ongoing exercise, but looking good for another 20 years.
- “Diversity” is a key element of CERN’s scientific programme and full exploitation of the complex’s potential is a must.
- This in parallel with other major projects that are coupled with targeted accelerator technology R&D.

10 years ago - many congratulations on the first 20!

Carlo Rubbia, the creator of the n_TOF experiment
Enrico Chiaveri, Spokesperson of n_TOF Experiment
Enrique Gonzalez-Romero, Chairman of Collaboration Board