CERN Accelerators

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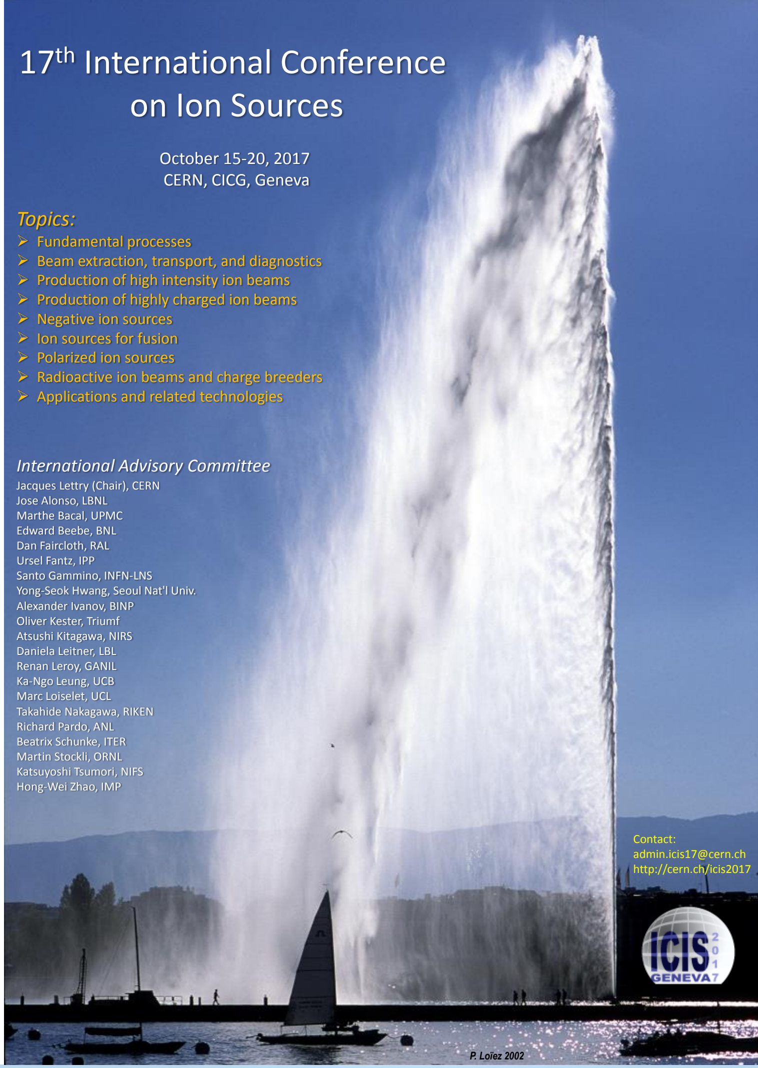
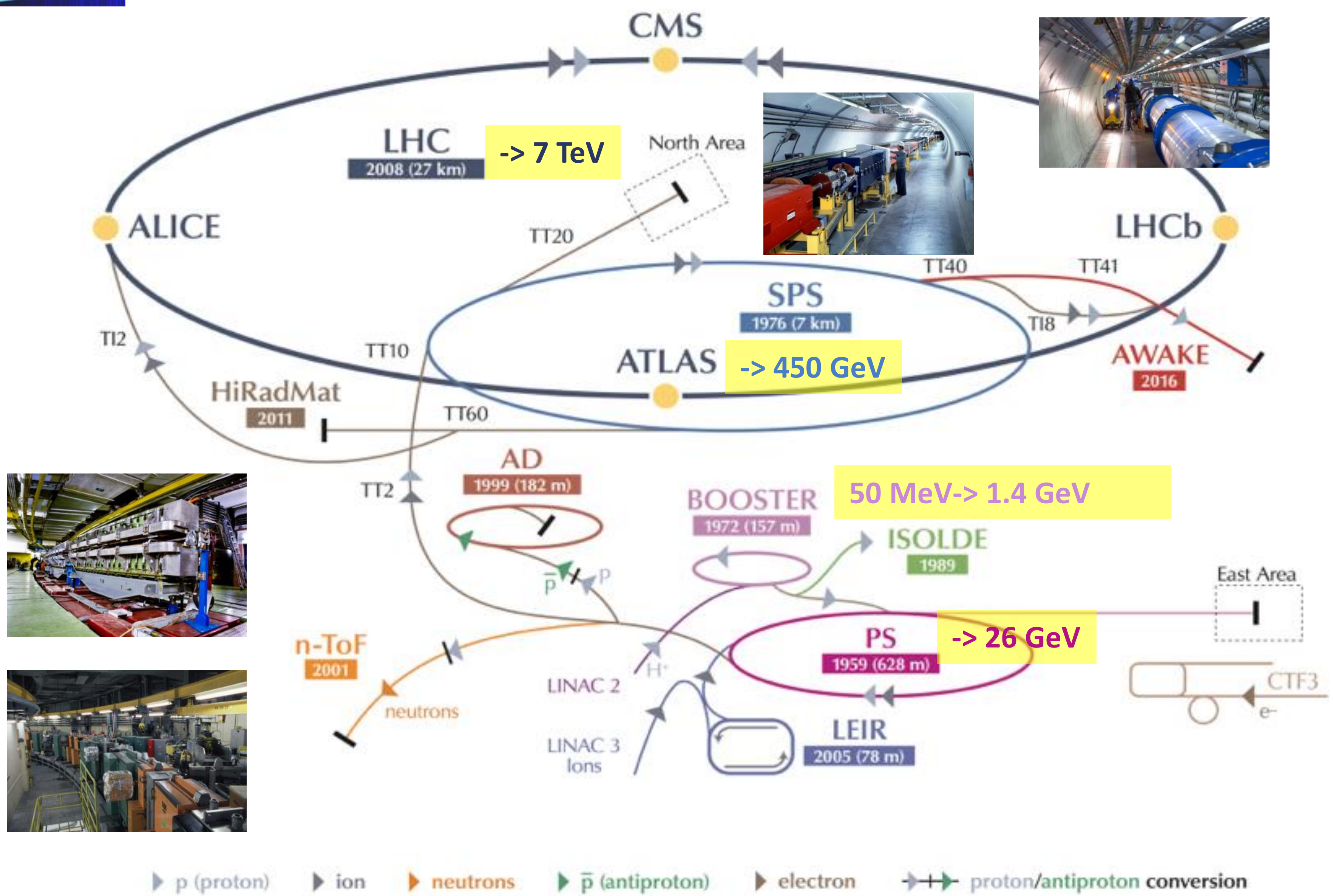
CERN BE/OP



17th International Conference on Ion Sources
October 15-20 2017
CERN - CICG - Geneva

The CERN Accelerator Complex

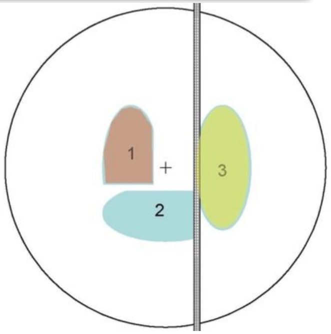


PS Booster

- 1st Synchrotron in the chain with **4 superposed rings**
- **157m** Circumference
- Increases proton energy from **50 MeV to 1.4 GeV** in 1.2s

- LINAC2 pulse distributed over the 4 rings, using kicker magnets
- Each ring will inject over multi-turns, accumulating beam in the horizontal phase space

- => the beam size (transverse emittance) increases when the intensity increases

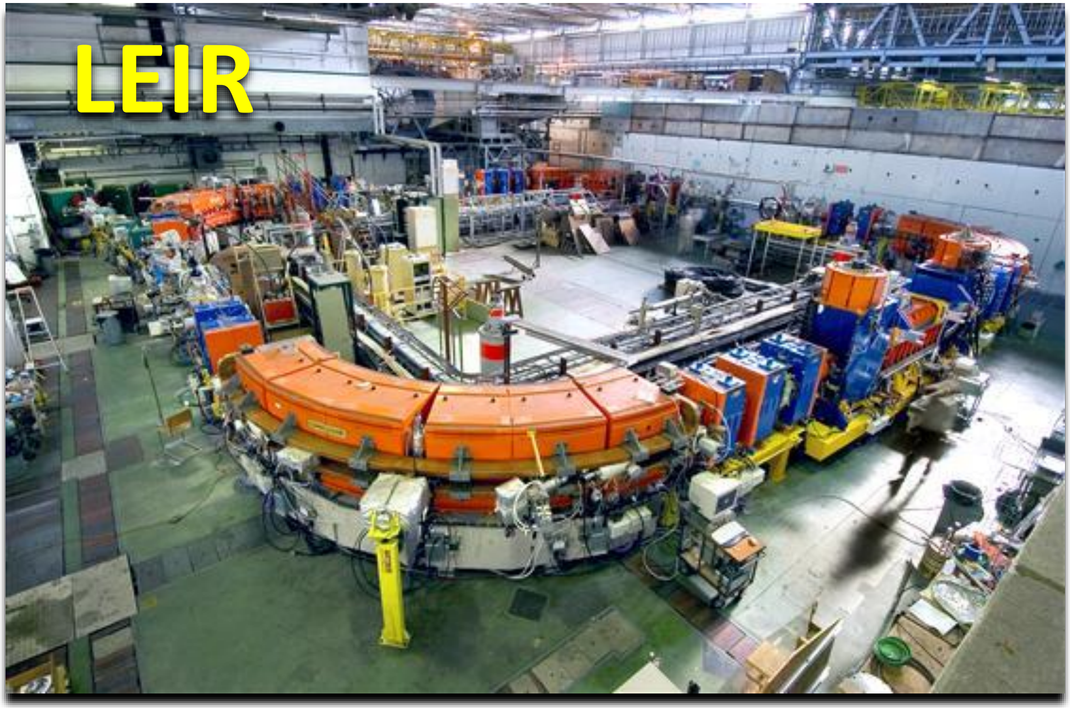


The PS Booster **determines the transverse Brightness** of the LHC beam

ISOLDE & HIE-ISOLDE

- The PSB proton beam impinges on a target producing a range of isotopes
- Two mass separators (GPS & HRS) allow selection of isotopes, which are then transported to the users
- Post-acceleration of isotopes
  - REX, normal conducting accelerating structures
  - HIE-ISOLDE, super conducting LINAC

Talk by
Maria Jose Garcia Borge

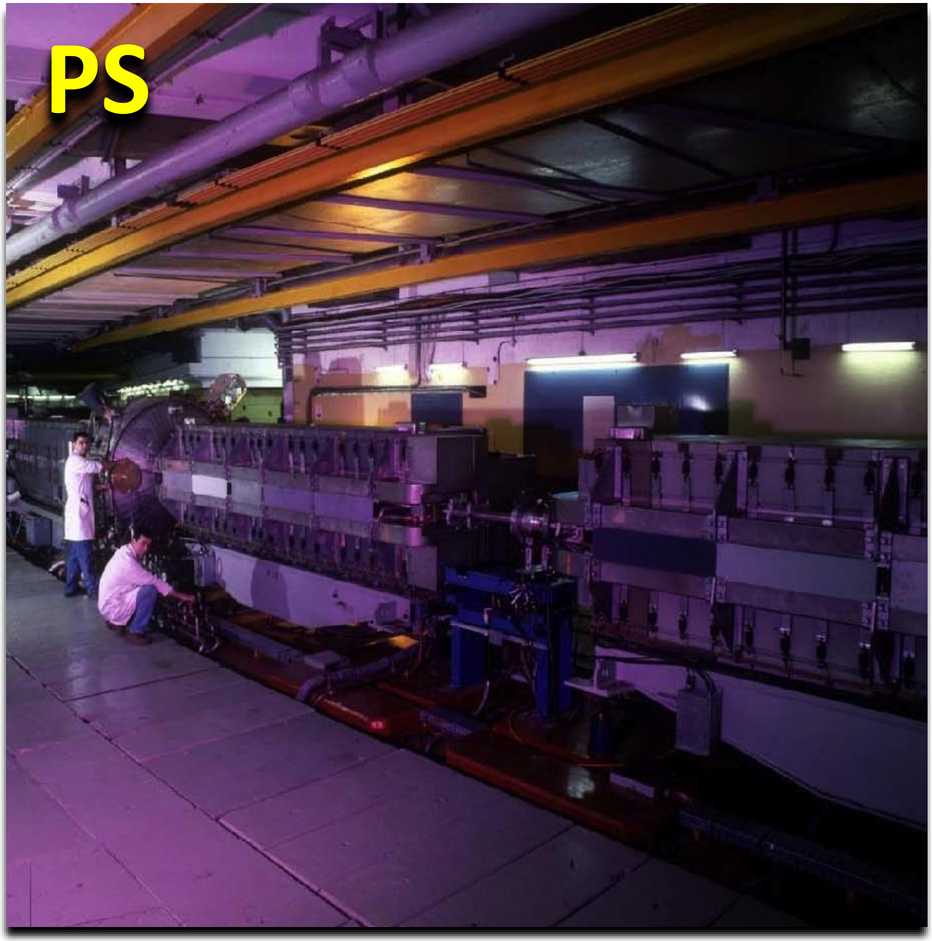


- Receives beam from **LINAC3**
- Different ion species:
  - Pb (lead)
  - Ar (Argon)
  - In (Indium)
  - Xe (Xenon)
  - …
- The LEIR cycle length is 3.6s

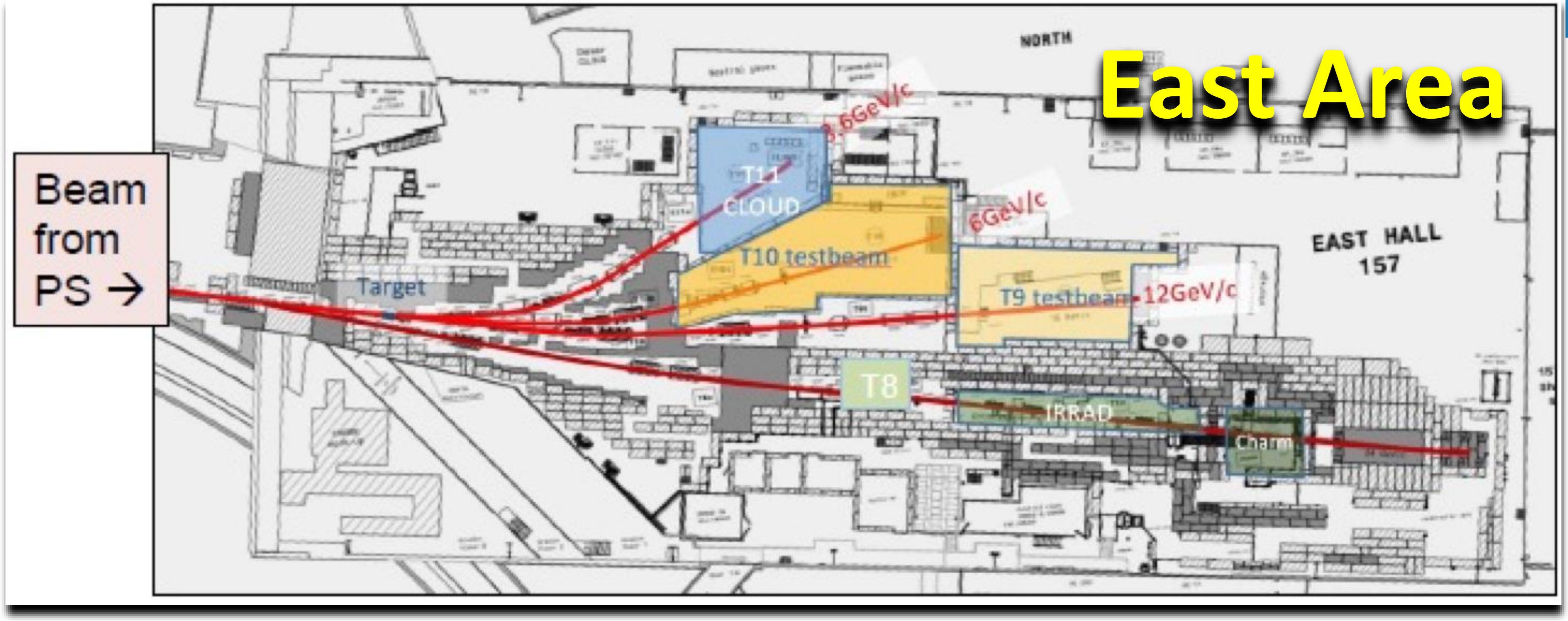
- Performs multi-turn injection at a rate of 200 ms
- Uses stochastic and electron cooling to reduces transverse and longitudinal beam dimensions
- Sends the beam to the PS that feeds it in to the SPS for delivery to the LHC and the North Area

- Oldest operating synchrotron at CERN
- Circumference **628m (2πx100m)**
  - 4 x PSB circumference
- Increases proton energy from 1.4 GeV to a range of energies **up to 26 GeV**
- Cycle length depending on the final energy, ranges from 1.2s to 3.6s

- The **many different RF systems** allow for complex RF gymnastics:
  - 10 MHz, 13/20 MHz, 40 MHz, 80 MHz, and 200 MHz
- Various types of extractions:
  - Fast extraction
  - Multi-turn extraction (MTE)
  - Slow extraction

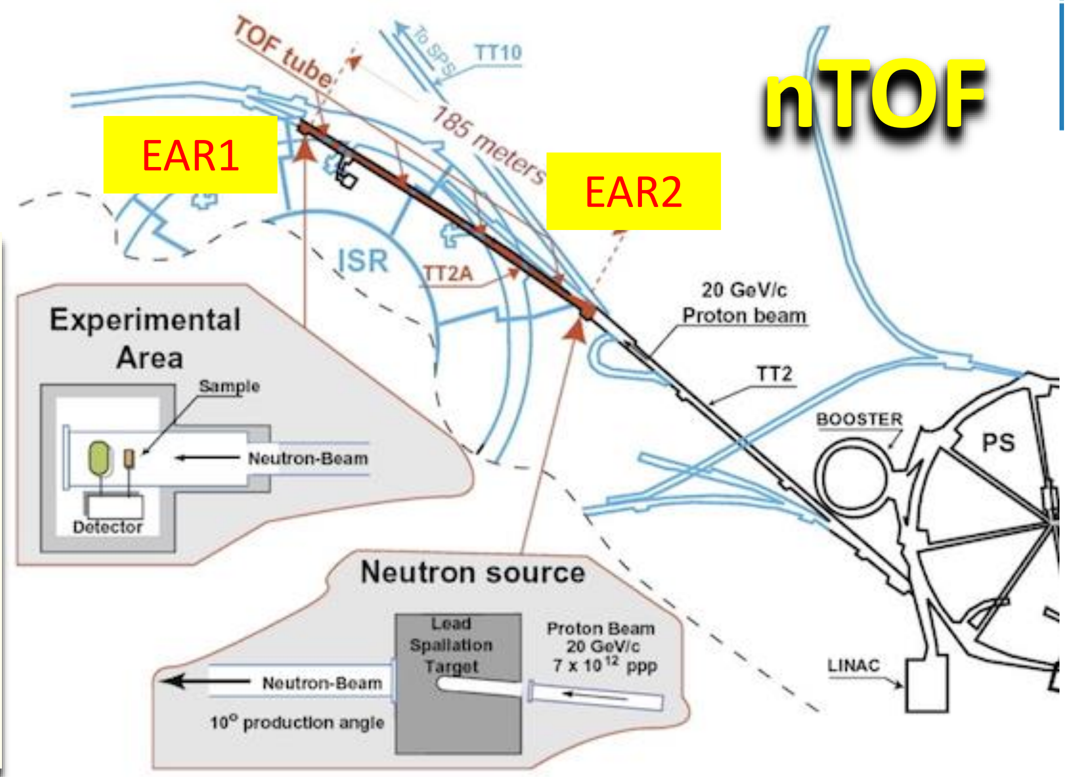


East Area



- Receives slow extracted beam from the PS at 24 GeV/c
  - Beam pulse length ~400 ms for a cycle length 2.4s
- Secondary particle beams:
  - From 1 GeV to ~ 15 GeV with ~ 10^6 particles
  - Protons, Electrons, Muons, Pions
- Experiments: CLOUD, previously DIRAC, HARP, ...
- Test beams: LHC, COMPASS, BabyMind, SHiP, AMS, ...
- Irradiation Facilities: IRRAD & CHARM

nTOF



- **N**eutron **T**ime **of F**light
- Fast-extracted single proton bunch from PS at **20 GeV/c** on a lead **spallation target**
- Every proton yields about 300 **neutrons**, spanning an energy range from the MeV region up to the GeV region (slow and fast)

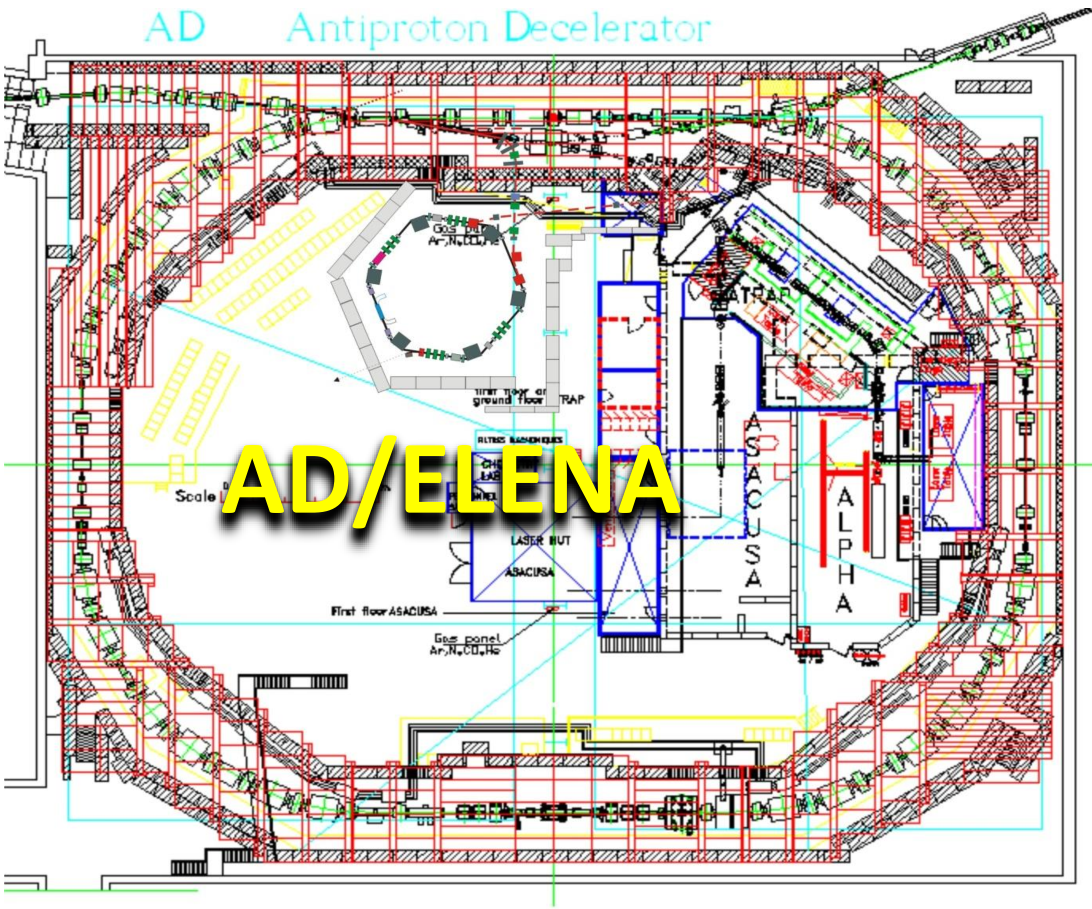
- Experimental area 1 (EAR1):
  - Horizontal beam line with 185 m drift tube
- Experimental area 2 (EAR2):
  - Vertical beam line above the target with 20m drift tube

Talk by Maria Jose Garcia Borge

- Measurement of neutron cross sections relevant for nuclear waste transmutation and for nuclear astrophysics
- Neutrons as probes for fundamental nuclear physics

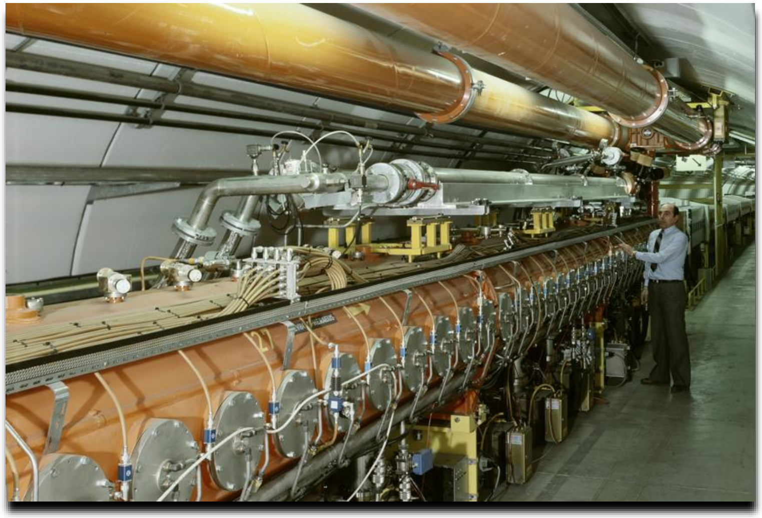
Antiproton Decelerator/ELENA

- Receives fast-extracted proton beam from PS at 26 GeV/c on a tungsten target
- **Every million protons** yields about **one** usable **antiproton** at 3.5 GeV/c.
- AD decelerates beam in stages down to **5.3 MeV**
- Experiments:
  - ASACUSA, ALPHA, ATRAP, AEGIS



- Presently the **ELENA ring** is under commissioning
  - Decelerates further down to **100 keV**
  - Beam intensity ~ $3x10^7$ antiprotons

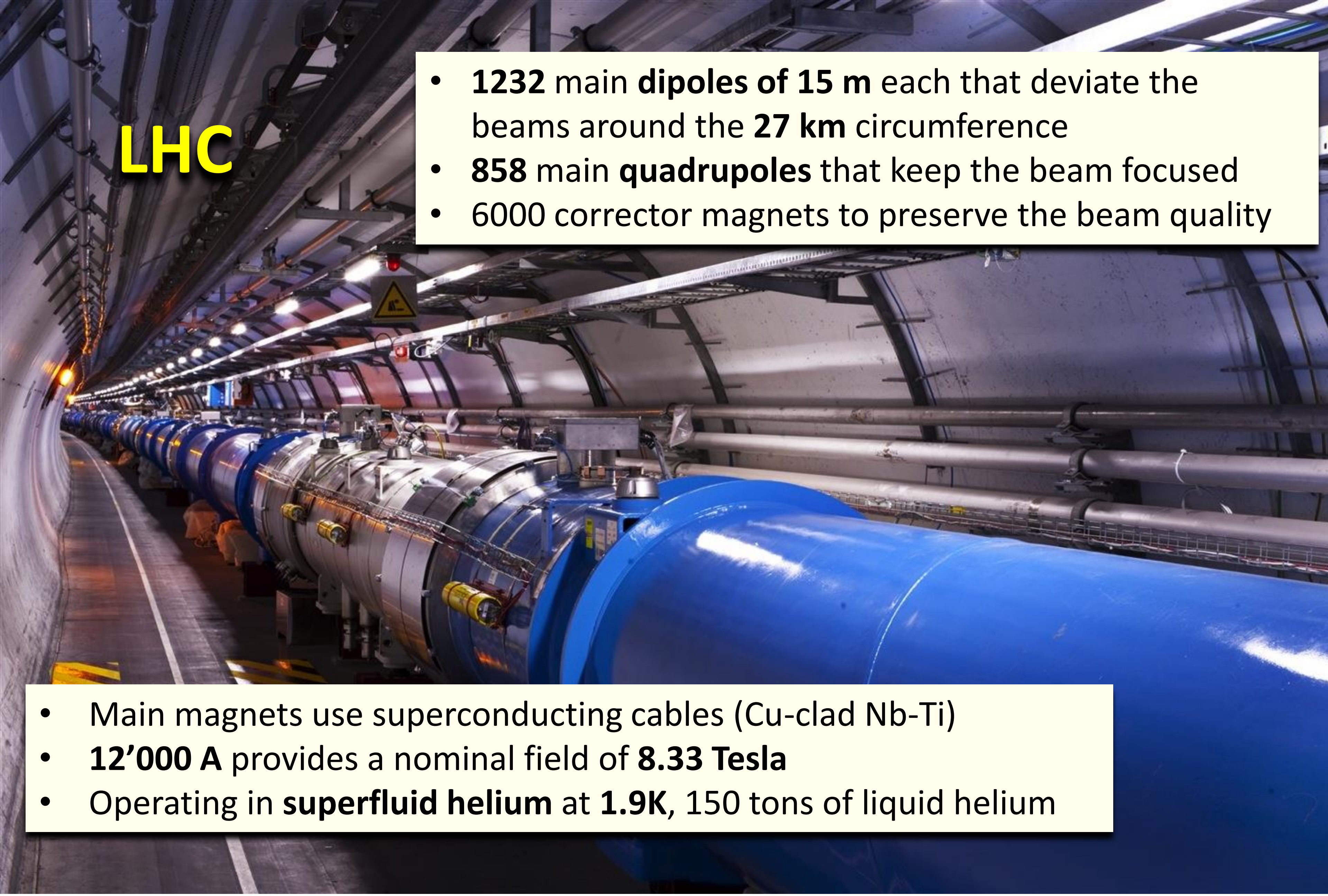
- about 30m under ground
- Circumference **6.9 km**
  - 11 x PS circumference
- Increases proton beam energy **up to 450 GeV** with up to ~5x10^{13} protons per cycle



- Provides fast-extracted beam to LHC, AWAKE (PWFA tests) and HiRadMat
- Provides slow-extracted beam to the North Area

- Receives slow extracted proton beam from the SPS at **400 GeV/c**
- Beam spill of ~4.5 s for a cycle length of 10.8s
- Various targets
- 7 beam lines with a total length of nearly 6 km
- 3 experimental halls

- Uses nearly every year also ion beams from the SPS for a rich primary and secondary ion physics program



LHC

- **1232** main **dipoles of 15 m** each that deviate the beams around the **27 km** circumference
- **858** main **quadrupoles** that keep the beam focused
- 6000 corrector magnets to preserve the beam quality

- Main magnets use superconducting cables (Cu-clad Nb-Ti)
- **12’000 A** provides a nominal field of **8.33 Tesla**
- Operating in **superfluid helium** at **1.9K**, 150 tons of liquid helium

LHC: Luminosity

$$LUMINOSITY = \frac{N_{event/\sec}}{\ldots} = \frac{N_1 N_2 f_{rev} n_b}{\ldots} F$$

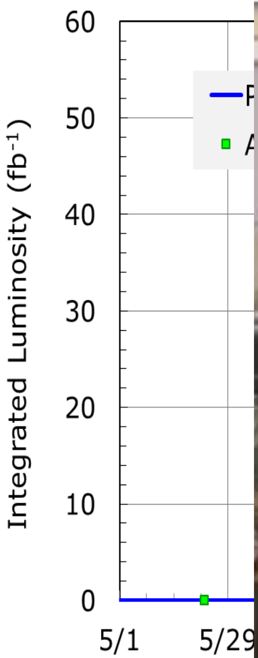
Intensity per bunch

Number of bunches

Geometrical Correction factors

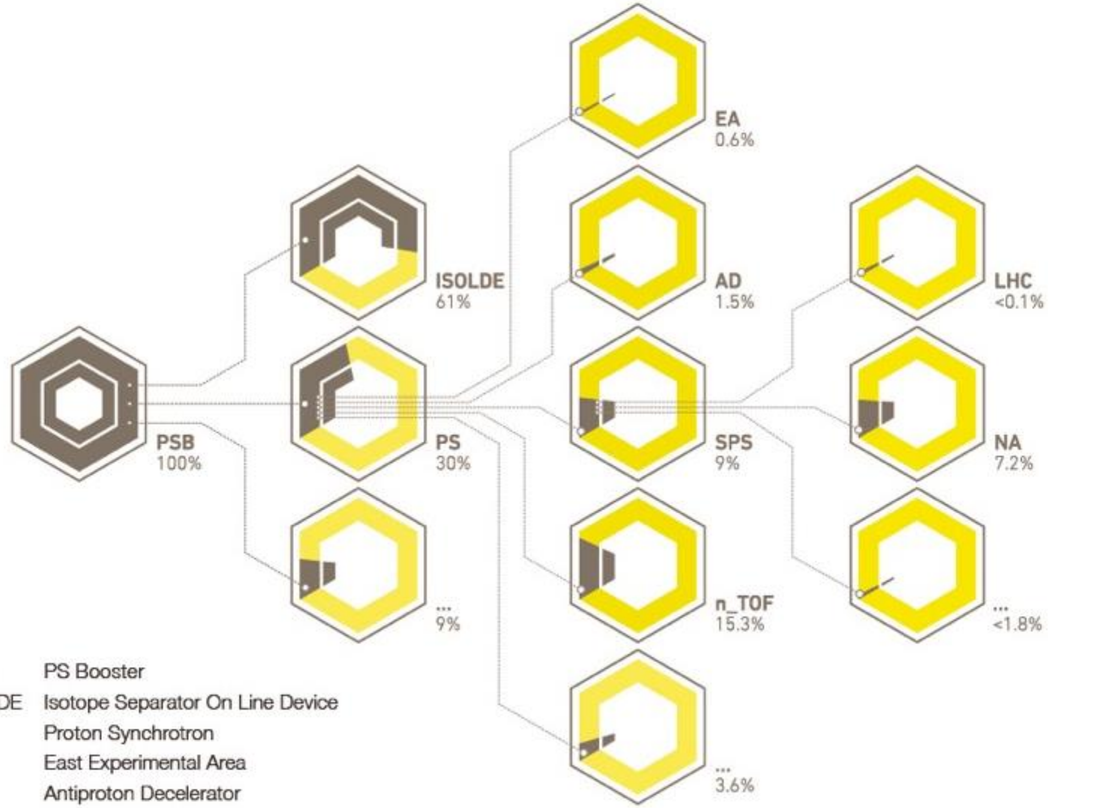
ns

points



134 000 000 000 000 000 000 protons

- 1.34 x 10^{20} protons in 2016
- only mass of **ONE grain of sand** accelerated per year!
- Only a tiny fraction of <0.1% to LHC

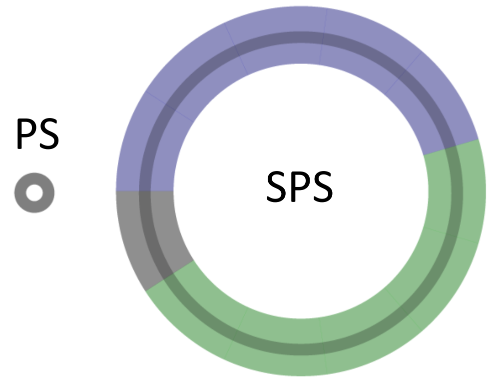


PSB	PS Booster
ISOLDE	Isotope Separator On Line Device
PS	Proton Synchrotron
EA	East Experimental Area
AD	Antiproton Decelerator
SPS	Super Proton Synchrotron
n_TOF	Neutron Time-of-Flight facility
LHC	Large Hadron Collider
NA	North Experimental Area
...	Other uses, including accelerator studies (machine development)

Quantity of protons used in 2016 by each accelerator and experimental facility, shown as a percentage of the number of protons sent by the PS Booster

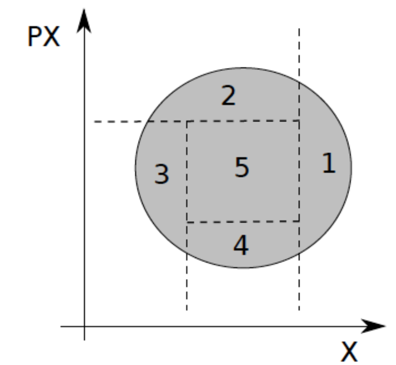
MTE – Multi Turn Extraction

- **SPS North area - fix target beam**
- $L_{SPS} = 11 * L_{PS}$
- How to fill 10/11 of the SPS from the PS? (remaining ‘hole’ for extraction kicker)



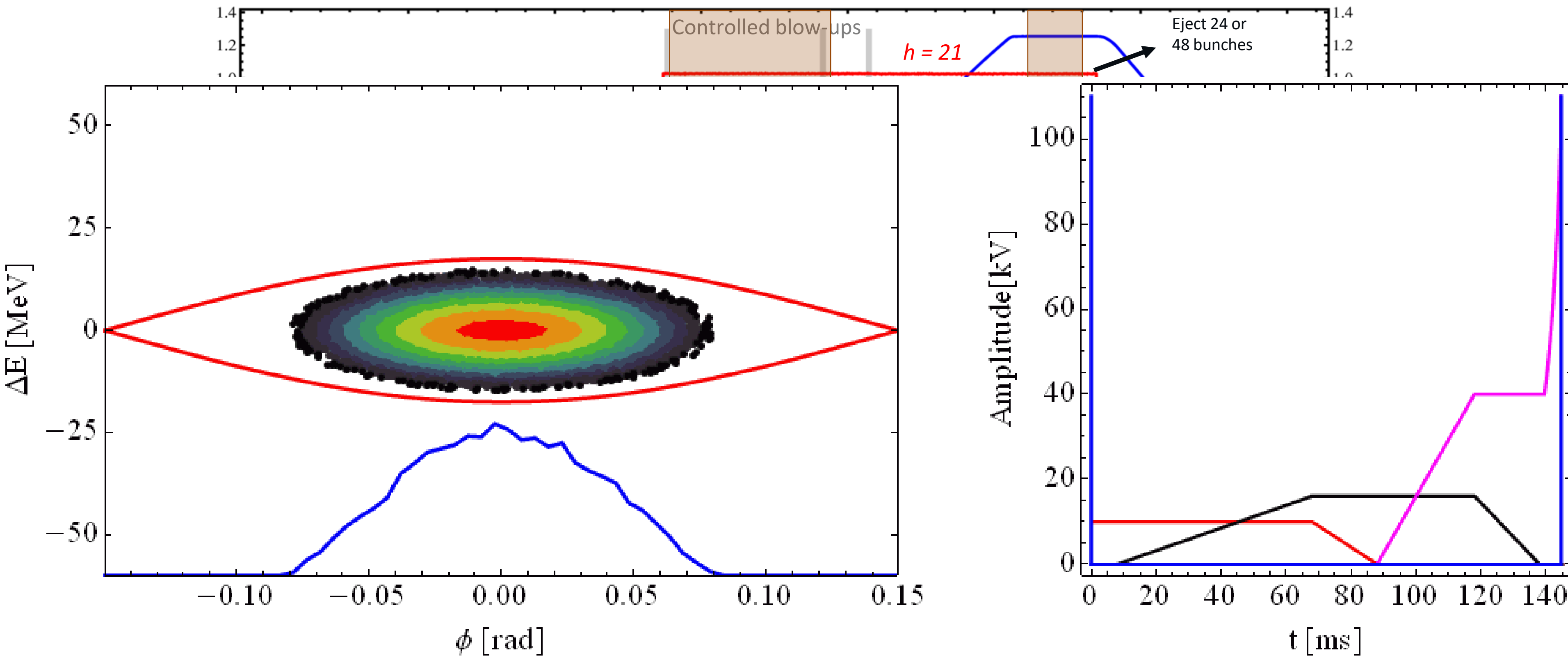
- Split the beam in the PS in 5, inject twice!
- **Continuous Transfer (CT)** was mechanically splitting the beam (transversely) with significant losses

Horizontal Phase Space



- **‘Multi-Turn Extraction’ (MTE)** uses nonlinear elements (sextupoles and octupoles) to create **4 islands** in the horizontal phase space and extracts them successively followed by the **core**

PS bunch splitting for LHC



- BCMS beam: 8 instead of 6 bunches from PSB
  => lower charge/bunch in PSB
- lower transverse emittance
  => higher LHC luminosity!

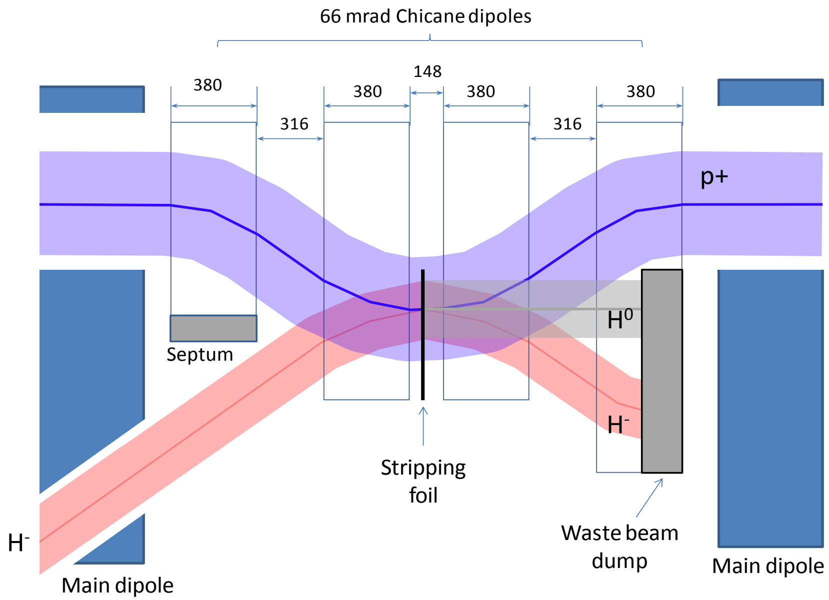
Standard: 72 bunches @ 25 ns
BCMS: 48 bunches @ 25 ns
+various other schemes

The PS **defines** the **longitudinal** beam **characteristics**

High Luminosity LHC (HL-LHC) / LIU

- aims at integrated luminosity of 3000 fb^{-1}
- many upgrades of the LHC (magnets, cryogenics, ...) and detectors
- also needs higher brightness and intensity from the injectors => **LHC Injector Upgrade (LIU)**
- LINAC4: increases injection energy into PSB from 50 to 160 MeV => lower space charge problems
- H- injection into PSB => no emittance blow-up
- PSB extraction to PS from 1.4 to 2.0 GeV => lower space charge
- plus other upgrades in PSB, PS, and SPS

Principle of H- injection in the PSB



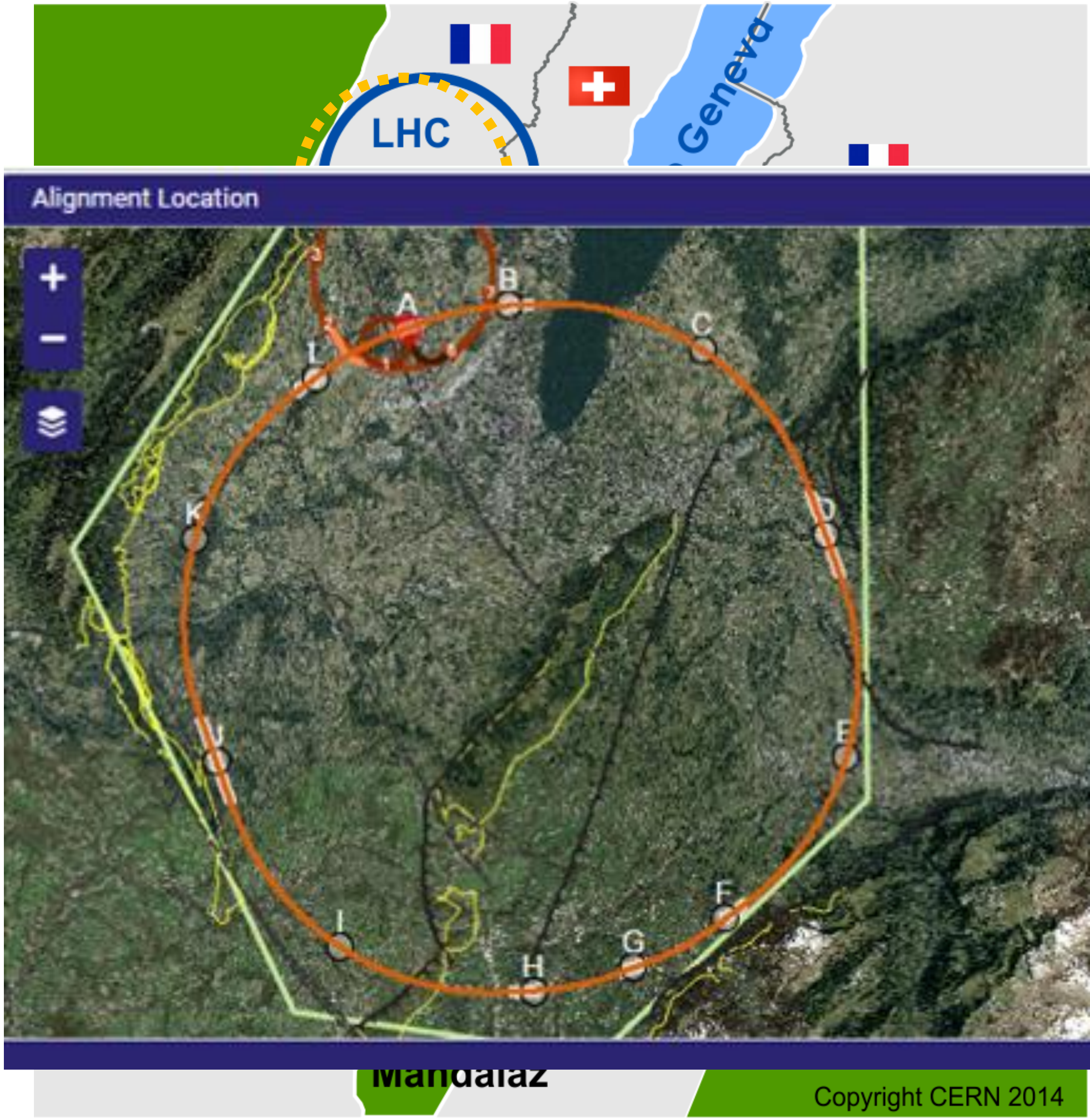
Future Circular Collider (FCC) study

International collaboration :

- ***pp*-collider (*FCC-hh*)** → defining infrastructure requirements

~16 T ⇒ 100 TeV in 100 km
~20 T ⇒ 100 TeV in 80 km

- including ***HE-LHC*** option: 16-20 T in LHC tunnel
- ***e*$^+$*e*$^-$ collider (*FCC-ee*)** as potential intermediate step
- ***p-e* (*FCC-he*) option**
- **100 km infrastructure** in Geneva area



Thank you very much for your attention!

Acknowledgements

- Many thanks for material from
  - Rende Steerenberg
  - Paul Collier
  - Alexander Huschauer
  - Heiko Damerau
  - Daniel Dominguez
  - Johannes Rothe