Beam possibilities in the North and East Areas

L.Gatignon / EN-EA, Physics Beyond Colliders kickoff workshop, 6-9-2016

With input from J.Bernhard, M.Brugger, N.Charitonidis, A.Fabich, E.Gschwendtner and many other colleagues

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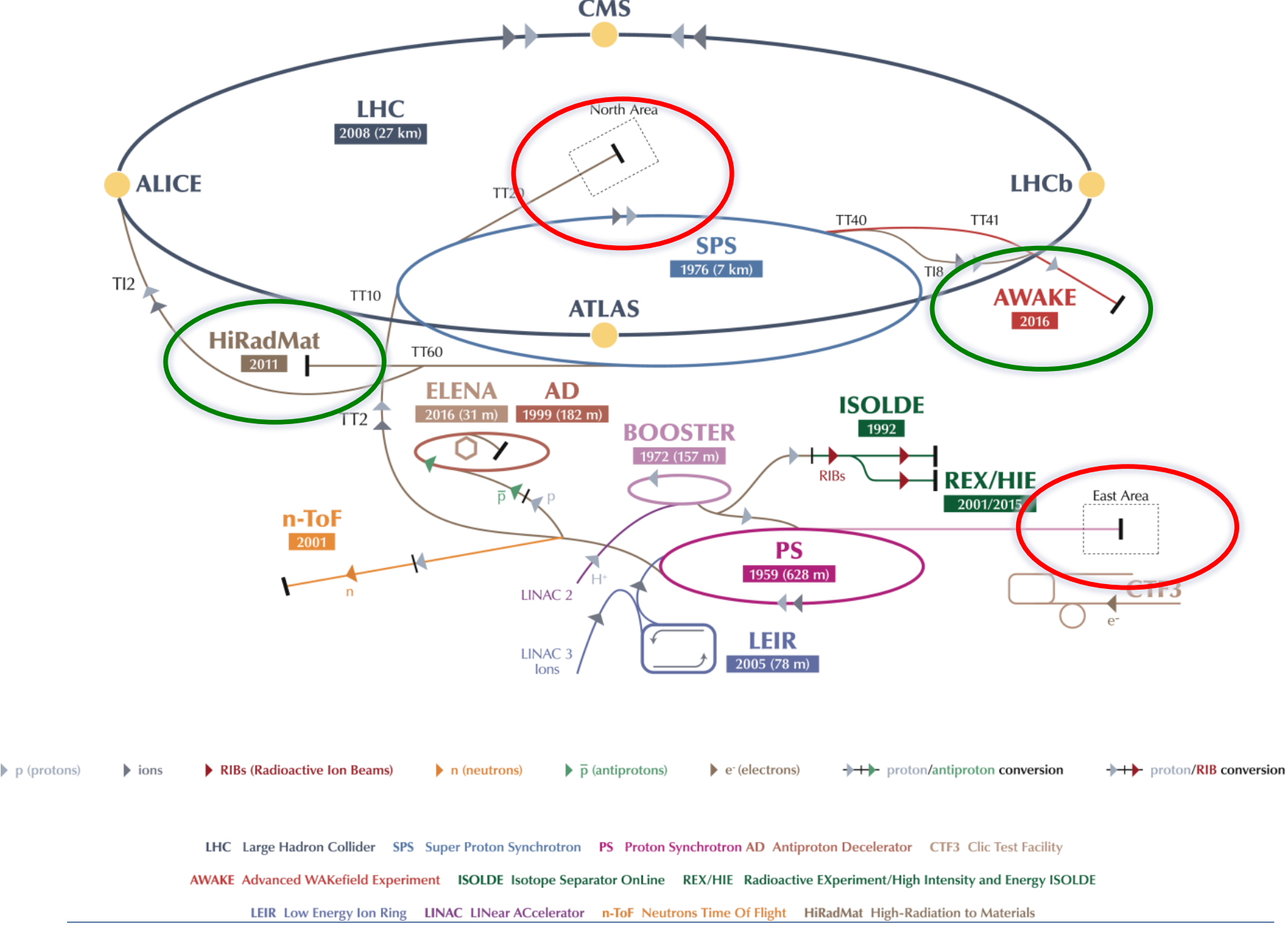
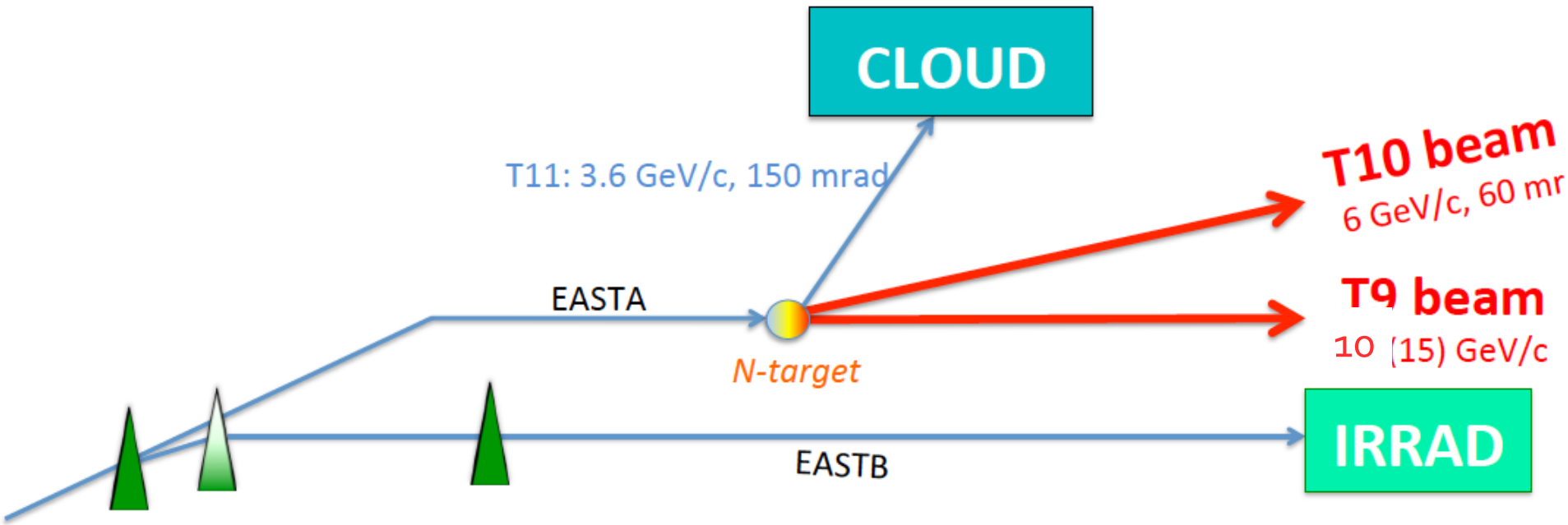
Outline

- The East Area
- The North Area (with protons)
  - EHN1 beams
  - EHN2
  - ECN3
  - Others
- Ion beams
- Studies required for higher intensities


CMS
LHC
2008 (27 km)
North Area
ALICE
LHCb
TT20
TT40
TT41
SPS
1976 (7 km)
TI8
TI2
TT10
ATLAS
AWAKE
2016
HiRadMat
2011
TT60
ELENA
2016 (31 m)
AD
1999 (182 m)
TT2
BOOSTER
1972 (157 m)
ISOLDE
1992
RIBs
REX/HIE
2001/2015
East Area
n-ToF
2001
PS
1959 (628 m)
CTF3
LINAC 2
LINAC 3
Ions
LEIR
2005 (78 m)
p (protons)
ions
RIBs (Radioactive Ion Beams)
n (neutrons)
p̄ (antiprotons)
e⁻ (electrons)
proton/antiproton conversion
proton/RIB conversion
LHC Large Hadron Collider
SPS Super Proton Synchrotron
PS Proton Synchrotron
AD Antiproton Decelerator
CTF3 Clic Test Facility
AWAKE Advanced WAKefield Experiment
ISOLDE Isotope Separator OnLine
REX/HIE Radioactive EXperiment/High Intensity and Energy ISOLDE
LEIR Low Energy Ion Ring
LINAC LINear ACcelerator
n-ToF Neutrons Time Of Flight
HiRadMat High-Radiation to Materials

The East Area



East Area beam lines

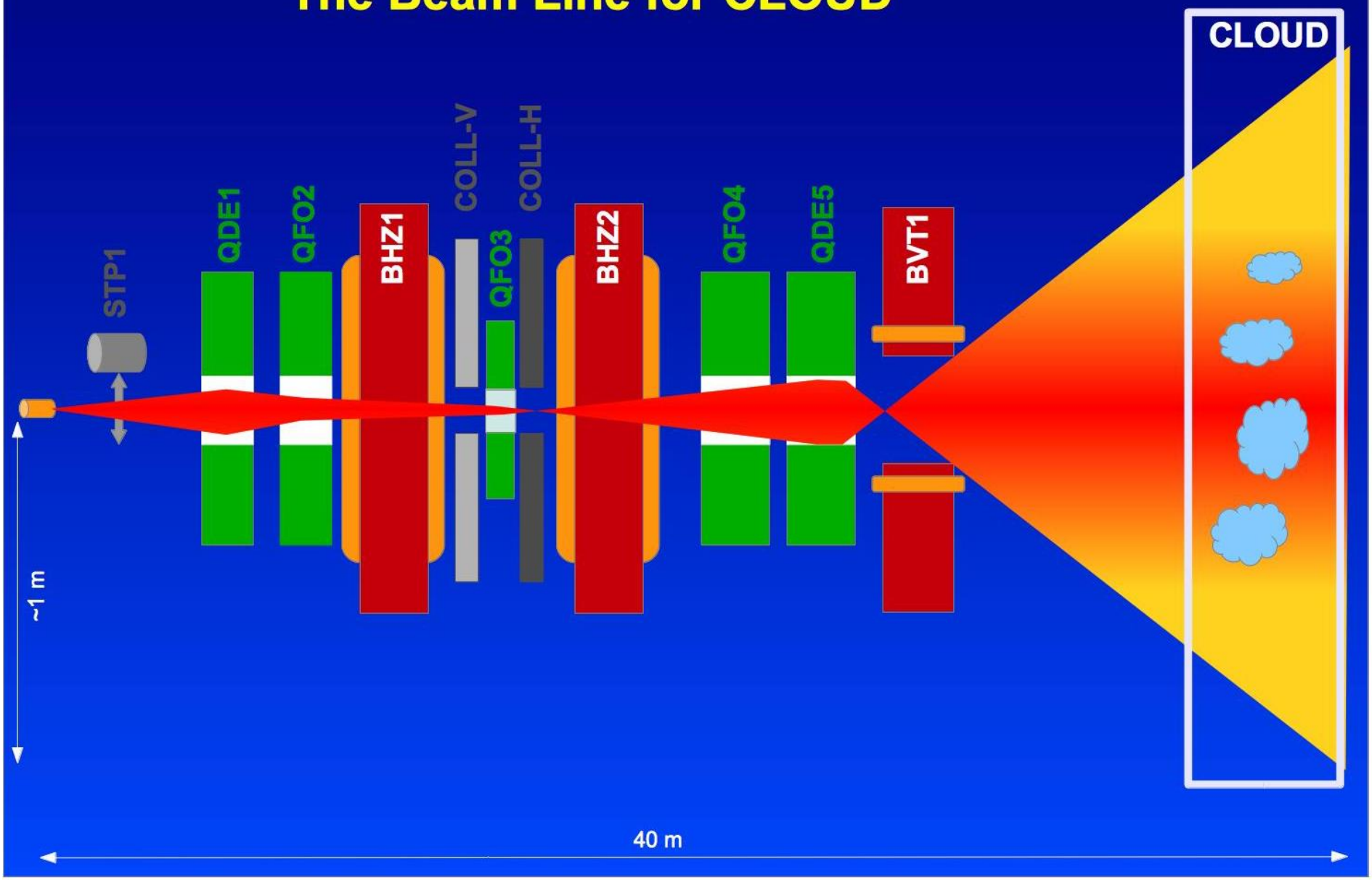
- One of the oldest complexes at CERN (110x44 m^2). Full renovation during LS2 has been approved.
- **IRRAD** and **CHARM** radiation facilities for proton and mixed field facility. Installed during LS1. Up to 5 10^{11} protons per spill, 10^{18} protons per year. Performance and facility layout not affected by LS2 renovation.
- **T9 and T10** flexible test beams with intensities between 10^3 and 10^6 ppp, depending on momentum, sign and particle type. RP limits to 10^6 ppp. Beam momentum range:

Beam	Design momentum	Present range	Momentum Post-LS2
T9	0.5 to 15 GeV/c	0.5 to 10 GeV/c	0.5 to 15 GeV/c
T10	0.5 to 7 GeV/c	0.5 to 6 GeV/c	0.5 to 12 GeV/c

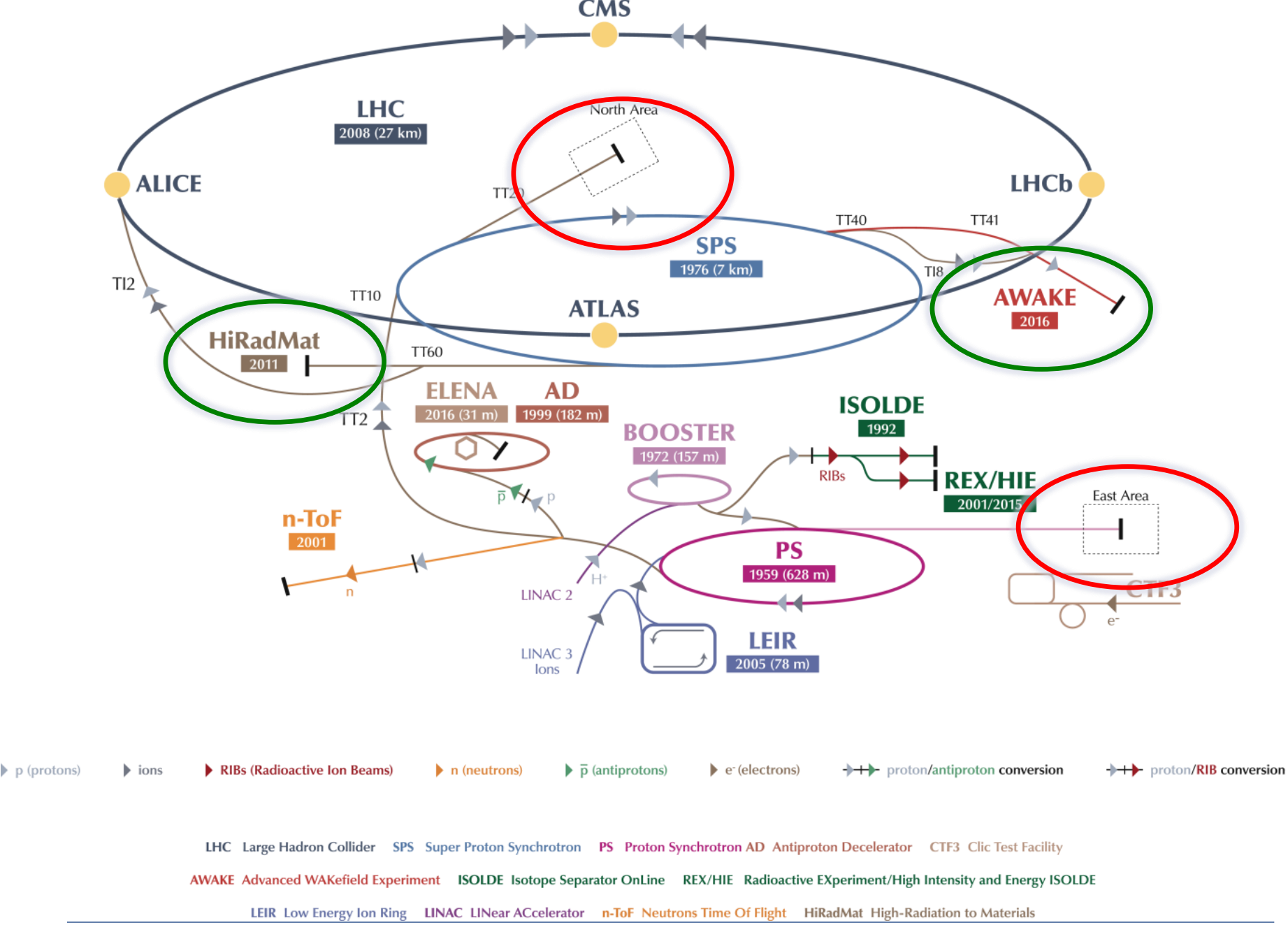
After upgrade: more control over particle type, in particular for T9.

- T11 dedicated very wide beam for **CLOUD** at 3.5 GeV/c, max. 10^6 ppp
  Can work as test beam (0.3 to 3.5 GeV/c) but interferes with CLOUD experiment.
- Protons in competition with nTOF. Isolde, AD. Also limited by RMS power in PS

The Beam Line for CLOUD



East Area Layout after LS2)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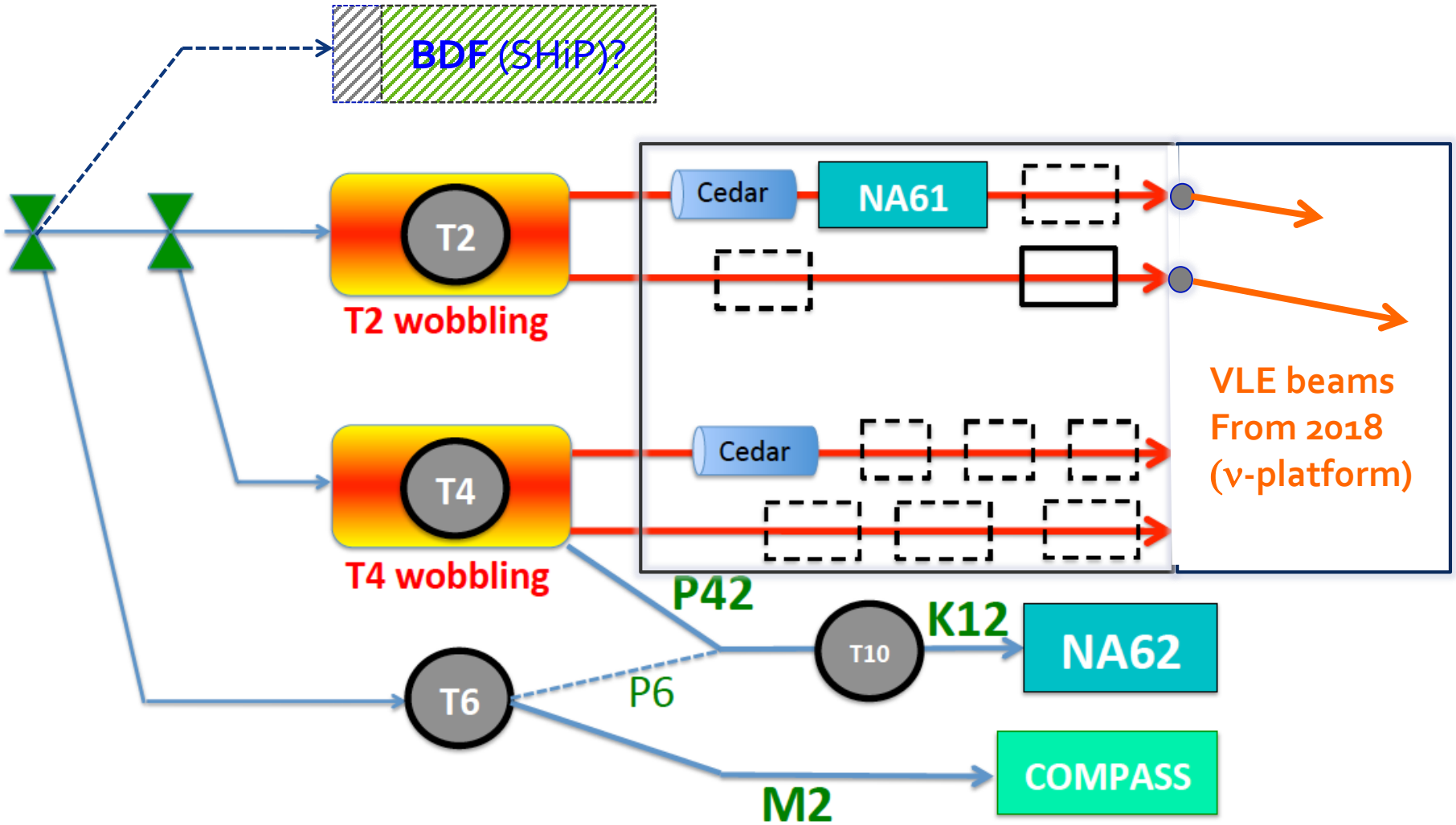
The North Area



North Area beam lines

The present North Area comprises 3 experimental halls / caverns:

- **EHN1:** surface hall, 270 x 50 m^2, with 4 beam lines running in parallel. Presently a 60 m hall extension is under construction, with two beam line extensions providing low-energy and low-intensity test beams from 2018 onward.
- **EHN2:** 100 x 30 m^2 surface hall housing the COMPASS experiment, served by the M2 line, which can provide high-energy high-intensity muon and hadron beams.
- **ECN3:** An underground cavern housing the NA62 experiment and the K12 beam designed for a high-intensity 75 GeV/c mixed hadron beam, optimised for the NA62 physics program.

North Area (SPS)

THE EHN1 HALL

The beams in EHN1

- The EHN1 beam lines serve mostly test beam activities, but also several experiments, such as NA61 (H2), NA63 and NA64 (H4) and UA9 (H8).
- Typical beam parameters are listed in the table below.

Beam	p-range (GeV/c)	Particle choice	Special remarks
H2	10-400	e, h, μ	NA61, tests. Particle identification.
H4	10-400 (450)	e, h, μ	NA63 and NA64, GIF, tests. Good electrons.
H6	5-205	e, h, μ	Tests. Secondary hadrons, flexible tertiaries
H8	10-400 (450)	e, h, μ	UA9, tests. Microbeam option. Threshold Cer.

- Intensities are mostly limited by radiation protection, around 10^6 particles per spill in the open areas. In the upstream zones, roof shielded, intensities can be higher, typically up to 10^8 per spill.
- H2 and H4 are optimised for electrons (by γ conversion), whilst H8 can deliver low emittance attenuated primary proton beams (e.g. for UA9).

EHN1 extension

- An extension to the EHN1 hall (by 60 m) is being completed. It will house two large cryostats for the neutrino platform (initially NP02/WA105 and NP04/ProtoDune).
- Extensions of the H2 and H4 lines will provide low-energy, low-intensity test beams for the neutrino platform.
- The H2 momentum range is from 0.4 to 12 GeV/c, the H4 momenta range from 0.4 to 7 GeV/c. Intensities are a few 100 Hz.
- Beams will be available from summer 2018.
- Their operation is in alternation with traditional H2, H4 users.

Beams for EHN2

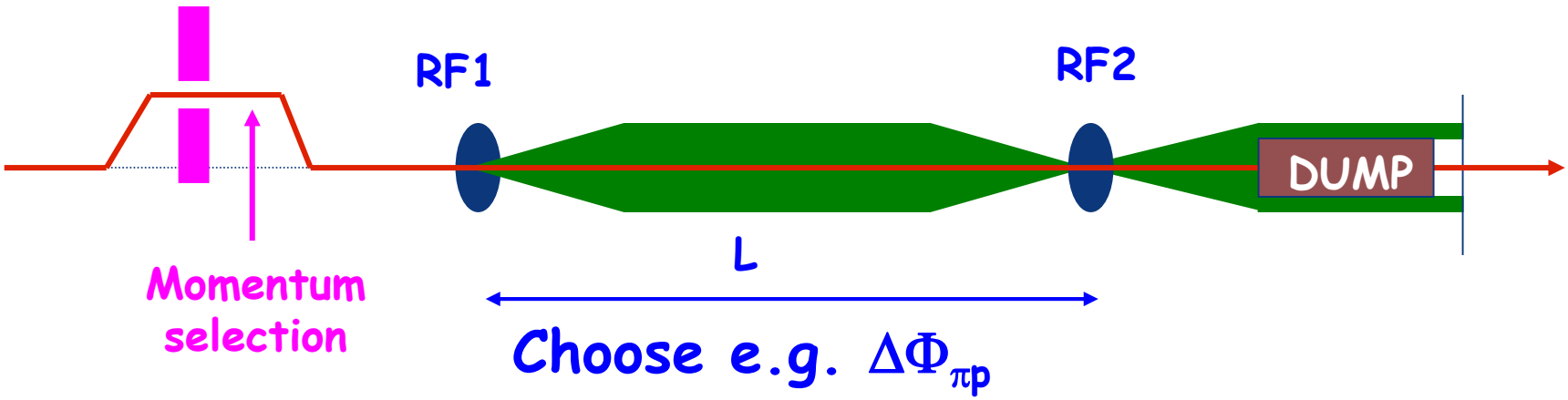
- The M2 beam can provide a high-energy, high-intensity muon beam from 60 to 280 GeV/c or secondary hadron beams up to 280 GeV/c.
- Typical beam parameters are given below (for 4.8 s spills):

Beam type	p (GeV/c)	Flux	p on T6	Limitations
Muons	160	$3\ 10^8$	$150\ 10^{11}$	RP
Hadrons	-190	$4\ 10^8$	$120\ 10^{11}$	RP, Cedar
Electrons	10 to 40	Few 10^3	$100\ 10^{11}$	production

- Rates are limited by radiation protection (surface hall, extraction, target cavern) and equipment survival considerations (transfer line, target, TAX, etc) as well as by proton delivery and sharing. Maximum rate $3\ 10^8$ muons per spill or $4\ 10^8$ hadrons per spill (the latter strongly depending on experimental and shielding configuration)

Prospects for M2 ?

- For hadron beams the wanted species are often a minority (K, pbar).
- The limitations come from RP and particle identification at high rates.
- Therefore COMPASS proposes an RF separated beam that needs a full study (feasibility to start with) and a full rebuild of the beam (1100 m).



Beams for ECN3

- The K12 beam has been redesigned and rebuilt during LS1 to optimally fit the NA62 requirements: aim to collect 100 events of $K^+ \rightarrow \pi^+ \nu\nu$ over 2 yrs
- Nominal rate 2.2 10^9 particles per 4.8 sec flat top (750 MHz effective rate). Protons not interacting in the T4 target are transported over almost 900 m to the T10 target to produce a hadron beam with ~6% K^+ content.
- Proton requirement: 3.3 10^{12} ppp on T10 from 8 10^{12} on T4 (100 mm Be target)
- The nominal beam performance has been demonstrated in 2015.
- Limitations come from:
  - T4 and T10 intensity limitations for target longevity,
  - Ripples and spikes in instantaneous beam intensity,
  - Ventilation of T10 cavern and proton beam tunnel (> 800 m),
  - Radiation levels from T4,
  - Competition for protons in case of longer spill.

Intensity increase would require major upgrades of beams & infrastructure

Prospects for kaon program

- The KLEVER proposal asks for a high-intensity K_L beam for a dedicated $K_L \rightarrow \pi^0 \nu\nu$ experiment
- This requires **2.4 10^{13} protons** on the K_L production target over 4.8 s.
- A rebuild of the K12 beam is in principle possible, but in the present locations this would imply major works:
  - This flux would require substantially higher flux on T4 (~4 10^{13})
  - This is the full flux possible today from the SPS
  - Limitations on extraction, proton transport, targets, TAX
  - Need further improved interlocks and machine protection
  - Many RP issues, lead to strongly reduce losses
- Need many studies, e.g. an option to have vertically wide beam at T4, such that most of the protons would not hit (by-pass) the T4 target head
- May have to look for different location (BDF like?)

Other beams

- The SPS also provides beam to

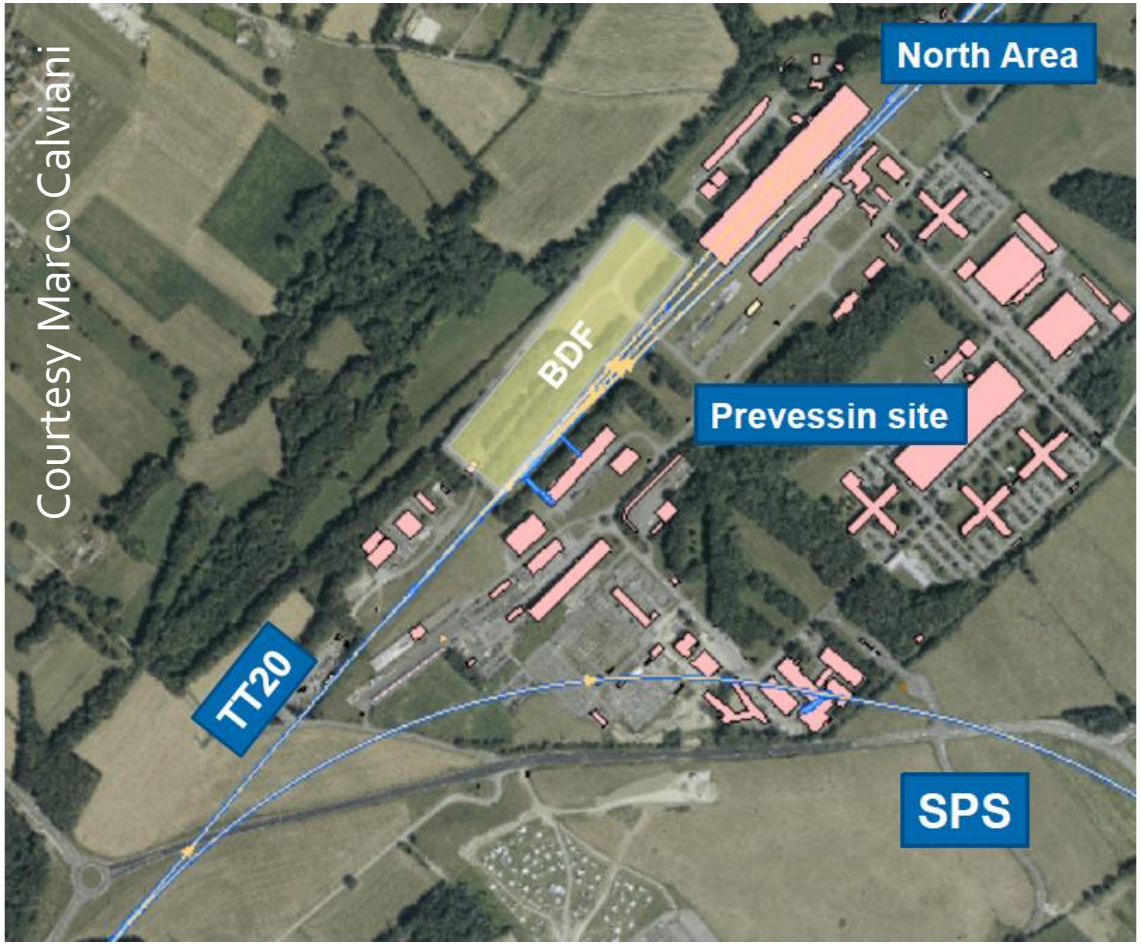
HiRadMat - a proton irradiation and material test facility for fast extracted beams
- does not use large integrated proton flux or beam time.

AWAKE - proton driven plasma wakefield acceleration studies
- in the old CNGS location
- modest proton intensities, running occasionally with one spill per super-cycle

and perhaps later

BDF (SHiP?) - proposal recommended and approved for conceptual design study. New beam taken from NA extraction and proton transfer line TT20 (see other talks).
Major user of protons, similar to CNGS
This would require to go back to **long (9.6 s?) flat top** for the NA fixed target program, requiring almost 2x more protons per FT spill. Hence increased losses, etc.

Beam Dump Facility (e.g. for SHiP)



- Use existing extraction, shared with the North Area
- New beam line from first splitter/switch magnets
- High-intensity target, followed by hadron stop and muon sweeping
- Underground facility, civil engineering
- Very high rates possible

See dedicated presentation by Marco Calviani

Ion beams

- Ion beams are not considered for the East Area secondary lines. However, partly stripped Pb and Xe beams are under study for 2017 in the IRRAD and CHARM facilities. The shielding is sufficient.
- Primary and fragmented ion beams are delivered regularly to H2, H4 and H8 in EHN1. In the past primary ion beams have also been delivered to ECN3, but this is of no interest for NA62 today.
  In general the intensity is limited by shielding and radiation protection restrictions (except in ECN3), typically up to 10^5 ions per spill in open areas. Higher intensities would need detailed shielding studies.
- For the moment the ion program is driven by NA61. Isotopes delivered recently or considered include fully stripped Pb, Xe, Ar as well as various lighter species as fragmented beam (e.g. Be), Energies range from 13 to 158 GeV/n.

Studies needed for intensity increases

- Go to long flat top whilst maintaining instantaneous rates
- Detailed radiation protection studies
- Loss reduction at extraction and along proton transport
- Reduce splitter losses, or go to different splitting approach (crystals, RF switching magnets, etc)
- North Area consolidation (immediately after East Area renovation)
- Upgrades of targets, beam dumps
- Improved machine protection systems
- Move to underground areas for higher intensities
- Significant injector upgrades may be required for some new ideas.
- Some former beam areas (e.g. West Area) would have been useful now

Summary and Outlook

- The East and North Areas at CERN provide powerful and flexible facilities for test beams and physics experiments.
- However, many new ideas require more space and much higher intensities, often incompatible with operation in the present surface areas.
- An additional high-intensity underground facility (such as the proposed Beam Dump Facility) and new approaches (for splitting, bypassing the T4 target, and so forth) may provide the possibility to fully exploit the potential of the SPS for many years to come.

Thanks for your attention!

Some scenarios for proton fluxes in NA

Proton fluxes (after losses at extraction and splitting) per flat top in units of 10^{12}

Scenario	FT	*T10*	T2	T4	T6	Total	p/year
Nominal 2017	4.8 s	*3.3*	2	8	15	25	$2.4\ 10^{19}$
Nominal 2017 with long flat top	9.6 s	*6.6*	3	16	25	44	$1.4\ 10^{19}$
As 2017, but with KLEVER	4.8 s	*24*	2	48	15	65	$6.4\ 10^{19}$
Idem with T4 by-pass beam	4.8 s	*24*	2	30	15	47	$4\text{-}5\ 10^{19}$
With KLEVER and long flat top	9.6 s	*48*	3	96	25	124	$3.8\ 10^{19}$
Idem with by-pass beam	9.6 s	*48*	3	60	25	88	$2.8\ 10^{19}$

↑ In SPS ring

Assume a year of 200 days with 80% efficiency; 20% losses before target

Duty cycle:

For short flat top could reach 2x4.8 s per 36 s, i.e. 26.7%

Short flat top plus 4 SHiP cycles + MD: 4.8 / (10.8+28.8+12) = 9.3%

With long flat top + 4 SHiP cycles +MD: ~9.6 / (15.6+28.8+12) = 17%

KLEVER difficult after NA targets