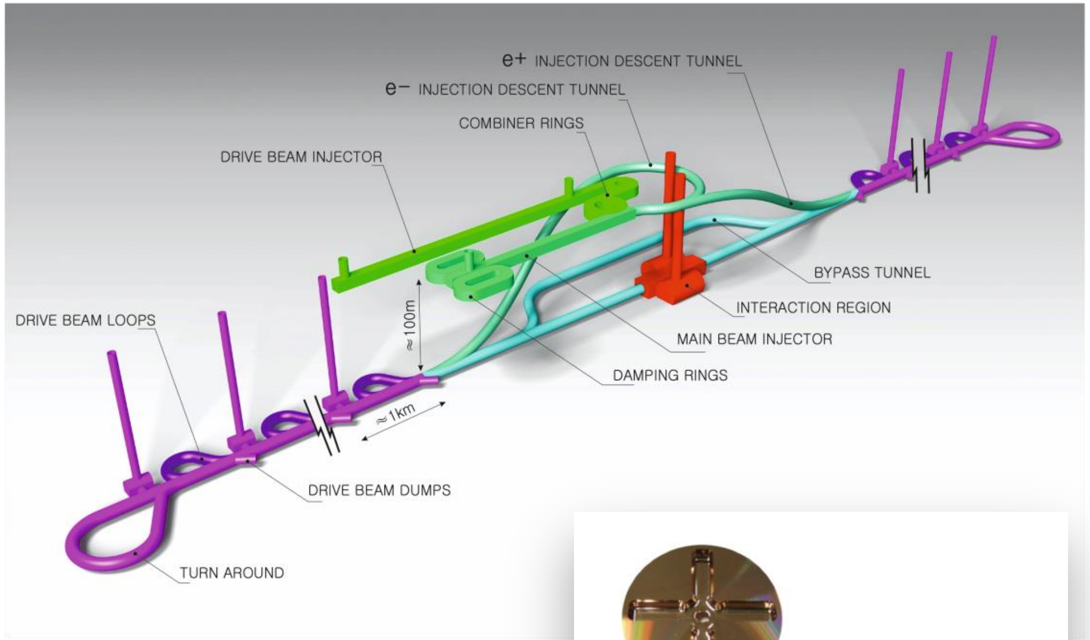
A primary electron beam facility at CERN - eSPS

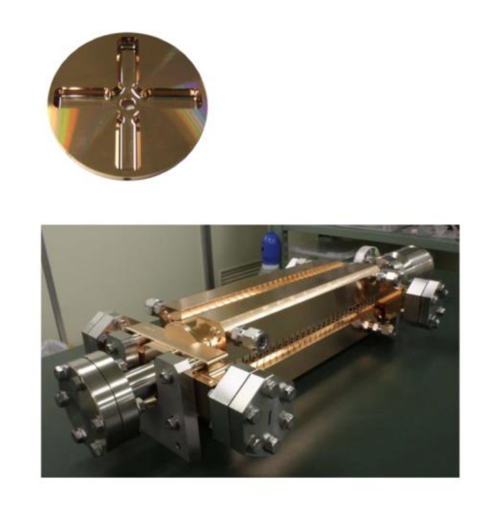
Oxford January 2021

S. Stapnes (CERN)

on behalf of the working group “PBC-acc-e-beams” (eSPS team)

Background: Proposed e^+e^- linear colliders – CLIC





Accelerating structure prototype for CLIC: 12 GHz (L~25 cm)

The Compact Linear Collider (CLIC)

- **Timeline:** Electron-positron linear collider at CERN for the era beyond HL-LHC (~2035 Technical Schedule)
- **Compact:** Novel and unique two-beam accelerating technique with high-gradient room temperature RF cavities (~20'500 cavities at 380 GeV), ~11km in its initial phase
- **Expandable:** Staged programme with collision energies from 380 GeV (Higgs/top) up to 3 TeV (Energy Frontier)

- CDR in 2012. Updated project overview documents in 2018 (Project Implementation Plan). See resource slide.

- **Cost:** 5.9 BCHF for 380 GeV (stable wrt 2012)
- **Power:** 168 MW at 380 GeV (reduced wrt 2012), some further reductions possible

- Comprehensive **Detector and Physics** studies

Motivations

Physics:

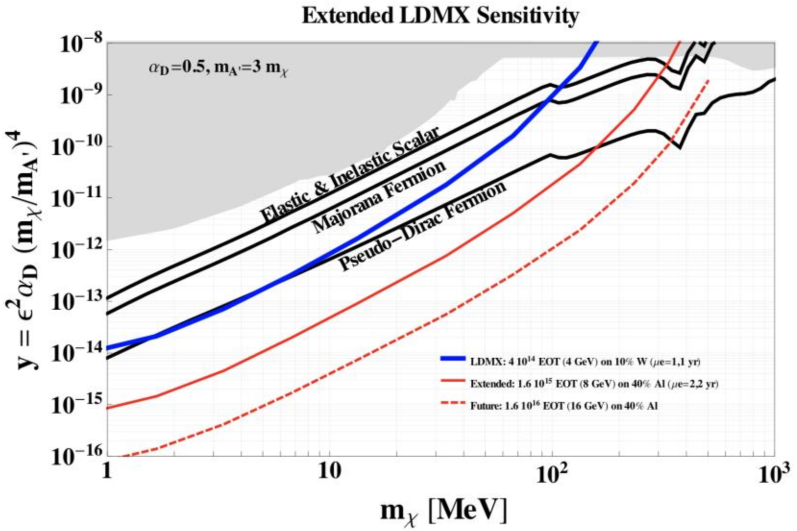
Large increasing interest in Light Dark Matter – using e-beams, the original trigger for the ”eSPS proposal” – LDMX physics & detector talks

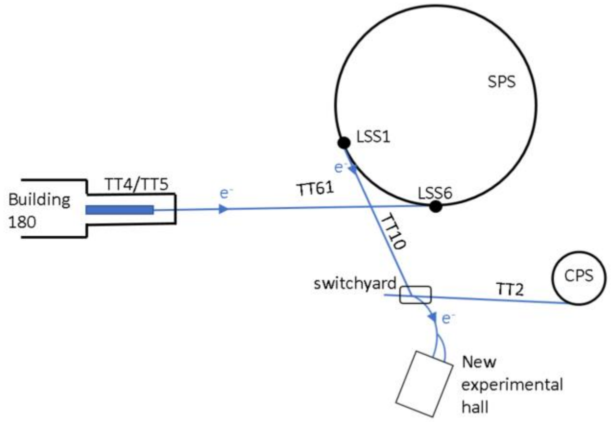
Accelerator R&D:

Any next machine at CERN is “beyond LHC”, i.e. 20+ years away – what can be done using smaller setups on a much shorter timescale ?

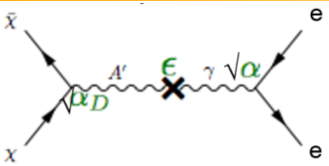
- Linac an important next step for X-band technology
- Relevant for FCC-ee, e.g RF systems needed in the SPS, injectors
- Strategic: Will bring electrons back at CERN fairly rapidly (linacs and rings) – important relevance for the developments and studies needed for future e+e- machines at CERN – being linear or circular

- Future accelerator R&D more generally: Accelerator R&D and project opportunities with e-beams as source
- Main directions: Novel Acc. studies and CLEARER (a higher energy version of CLEAR)





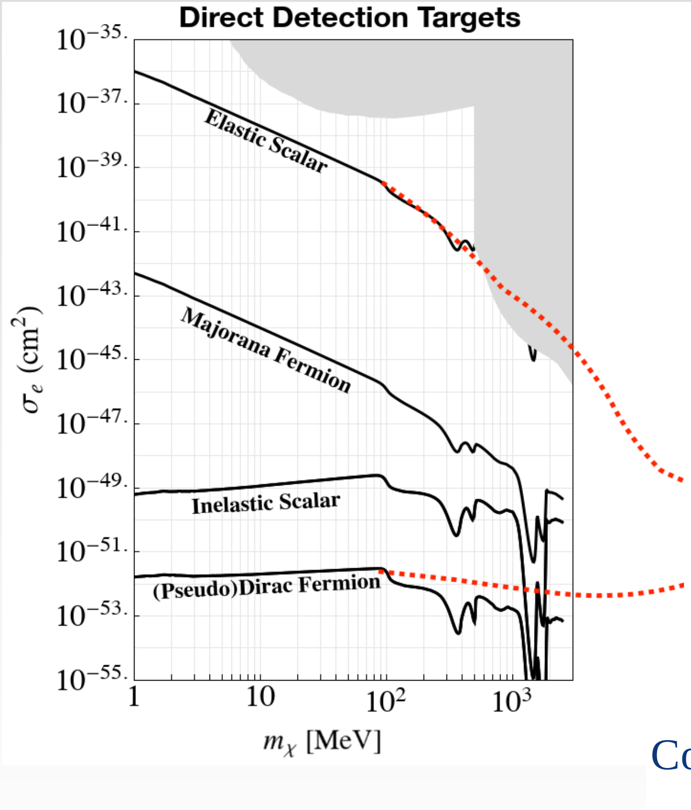
Direct Detection and Accelerator Based Production

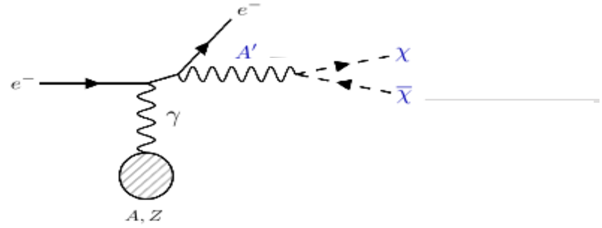


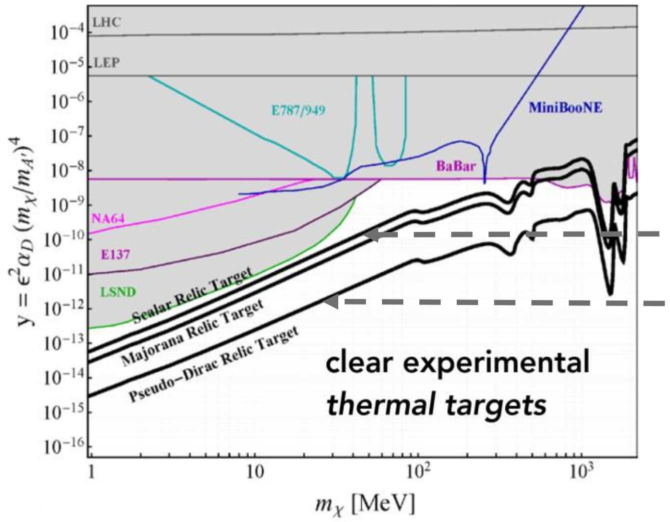
$$\sigma v \sim \varepsilon^2 \alpha_D \frac{m_\chi^2}{m_{A'}^4} = \frac{y}{m_\chi^2};\ y = \varepsilon^2 \alpha_D \left(\frac{m_\chi}{m_{A'}}\right)^4$$

$$\sigma \sim \left(\frac{m_{A'}}{m_\chi}\right)^2 \frac{yZ^2}{\alpha_D m_\chi^2} \Rightarrow y \sim \left(\frac{m_\chi}{m_{A'}}\right)^2 \frac{m_\chi^2 \alpha_D}{Z^2} \sigma$$

But, cross sections can be loop- or velocity- suppressed in the non-relativistic regime of direct detection:





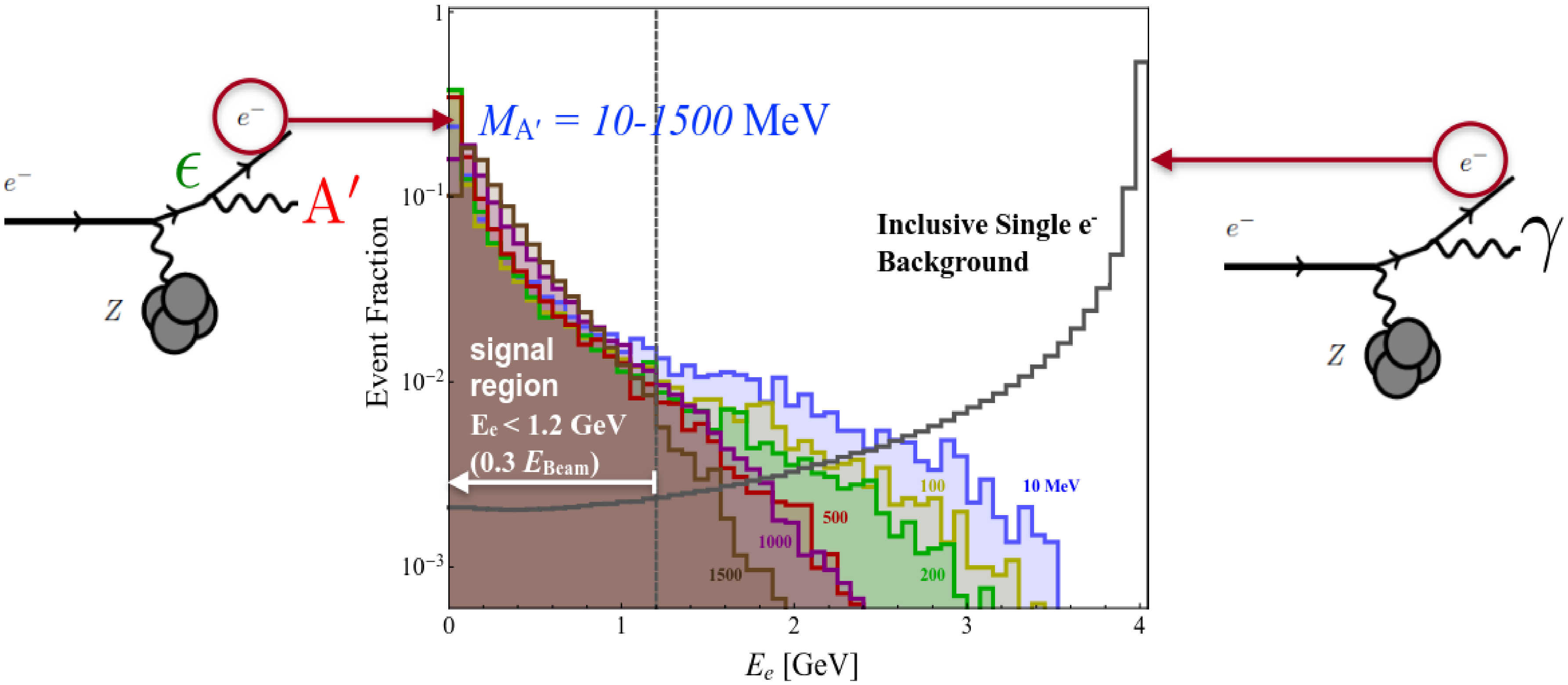


Need 10^{14} e$^-$

Need 10^{16} e$^-$

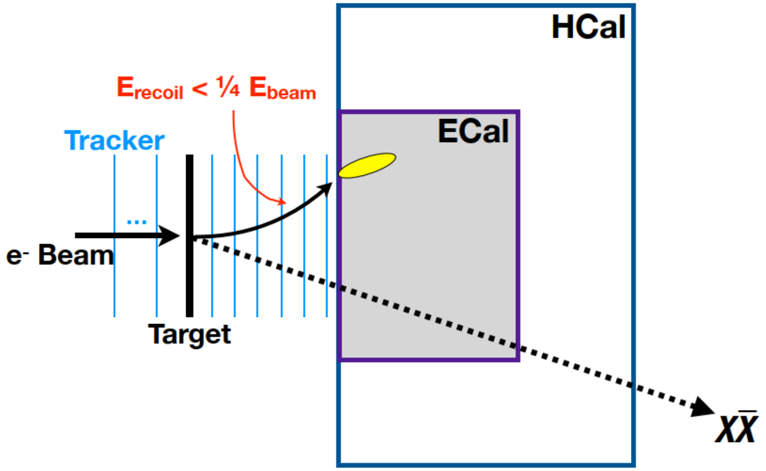
Conservative choice: $\alpha_D = 0.5$ and $m_{A'} = 3m_\chi$

Kinematics: electron energy

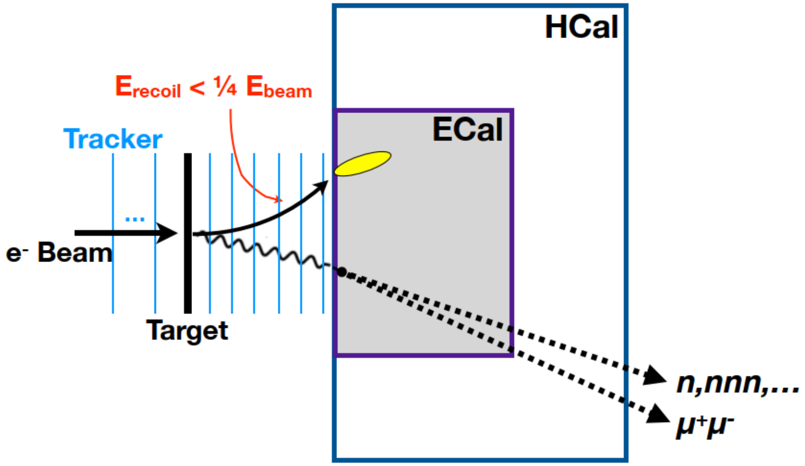


A' created close to threshold in the em-field around the target nucleus, since the A's, heavier that the electrons, take most of the incoming electron energy —> soft recoil electron, large missing energy

Basic task for the experiment



Select these



Reject these

The experiment
is to a big degree
a question of
rejecting these

EoI to the SPSC Oct 2018: https://cds.cern.ch/record/2640784

Dark Sector Physics with a Primary Electron Beam Facility at CERN

Also submitted in "compact form" to ESPP update 18.12.2018 https://indico.cern.ch/event/765096/contributions/3295600/

CDR on arXiv in September 2020

Cornell University

We gratefully acknowledge support from the Simons Foundation and member institutions.

arXiv.org > physics > arXiv:2009.06938

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[Submitted on 15 Sep 2020 (v1), last revised 17 Sep 2020 (this version, v3)]

Conceptual Design Report -- eSPS

M. Aicheler, T. Akesson, F. Antoniou, A. Arnalich, P. A. Arrutia Sota, P. Bettencourt Moniz Cabral, D. Bozzini, M. Brugger, O. Brunner, P. N. Burrows, R. Calaga, M. J. Capstick, R. Corsini, S. Doebert, L. A. Dougherty, Y. Dutheil, L. A. Dyks, O. Etisken, L. Evans, A. Farricker, R. Fernandez Ortega, M. A. Fraser, J. Gall, S. J. Gessner, B. Goddard, J-L. Grenard, A. Grudiev, E. Gschwendtner, J. Gulley, L. Jensen, R. Jones, M. Lamont, A. Latina, T. Lefevre, R. Lopes, H. Mainaud Durand, S. Marsh, G. Mcmonagle, E. Montesinos, R. Morton, P. Muggli, A. Navascues Cornago, M. Nonis, J. A. Osborne, Y. Papaphilippou, A. M. Rossi, C. Rossi, I. Ruehl, S. Schadegg, E. Shaposhnikova, D. Schulte, S. Stapnes, M. Widorski, O. E. Williams, W. Wuensch

The design of a primary electron beam facility at CERN is described. It re-enables the SPS as an electron accelerator, and leverages the development invested in CLIC technology for its injector and as accelerator R&D infrastructure. The facility would be relevant for several of the key priorities in the 2020 update of the European Strategy for Particle Physics, such as an e+e- Higgs factory, accelerator R&D, dark sector physics, and neutrino physics. In addition, it could serve experiments in nuclear physics. The electron beam delivered by this facility would provide access to light dark matter production significantly beyond the targets predicted by a thermal dark matter origin, and for natures of dark matter particles that are not accessible by direct detection experiments. It would also enable electro-nuclear measurements crucial for precise modelling the energy dependence of neutrino-nucleus interactions, which is needed to precisely measure neutrino oscillations as a function of energy. The implementation of the facility is the natural next step in the development of X-band high-gradient acceleration technology, a key technology for compact and cost-effective electron/positron linacs. It would also become the only facility with multi-GeV drive bunches and truly independent electron witness bunches for plasma wakefield acceleration. The facility would be used for the development and studies of a large number of components and phenomena for a future e+e- Higgs and electroweak factory as the first stage of a next circular collider at CERN, and its cavities in the SPS would be the same type as foreseen for such a future collider. The operation of the SPS with electrons would train a new generation of CERN staff on circular electron accelerators. The facility could be made operational in about five years and would operate in parallel and without interference with Run 4 at the LHC.

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Vol. 8 (2020): A primary electron beam facility at CERN—eSPS: Conceptual design report

Editors: Torsten Åkesson and Steinar Stapnes

The design of a primary electron beam facility at CERN is described. The study has been carried out within the framework of the wider Physics Beyond Colliders study. It re-enables the Super Proton Synchrotron (SPS) as an electron accelerator, and leverages the development invested in Compact Linear Collider (CLIC) technology for its injector and as an accelerator research and development infrastructure. The facility would be relevant for several of the key priorities in the 2020 update of the European Strategy for Particle Physics, such as an electron-positron Higgs factory, accelerator R&D, dark sector physics, and neutrino physics. In addition, it could serve experiments in nuclear physics. The electron beam delivered by this facility would provide access to light dark matter production significantly beyond the targets predicted by a thermal dark matter origin, and for natures of dark matter particles that are not accessible by direct detection experiments. It would also enable electro-nuclear measurements crucial for precise modelling the energy dependence of neutrino-nucleus interactions, which is needed to precisely measure neutrino oscillations as a function of energy. The implementation of the facility is the natural next step in the development of X-band high-gradient acceleration technology, a key technology for compact and cost-effective electron/positron linacs. It would also become the only facility with multi-GeV drive bunches and truly independent electron witness bunches for plasma wakefield acceleration. A second phase capable to deliver positron witness bunches would make it a complete facility for plasma wakefield collider studies.

The facility would be used for the development and studies of a large number of components and phenomena for a future electron-positron Higgs and electroweak factory as the first stage of a next circular collider at CERN, and its cavities in the SPS would be the same type as foreseen for such a future collider. The operation of the SPS with electrons would train a new generation of CERN staff on circular electron accelerators. The facility could start operation in about five years, and would operate in parallel and without interference with Run 4 of the LHC.

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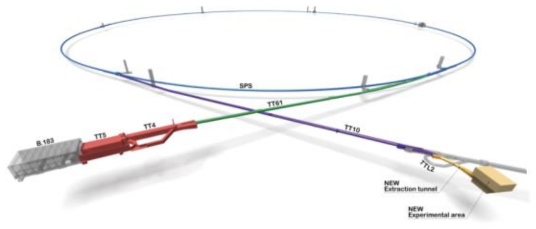
A primary electron beam facility at CERN — eSPS

Conceptual design report



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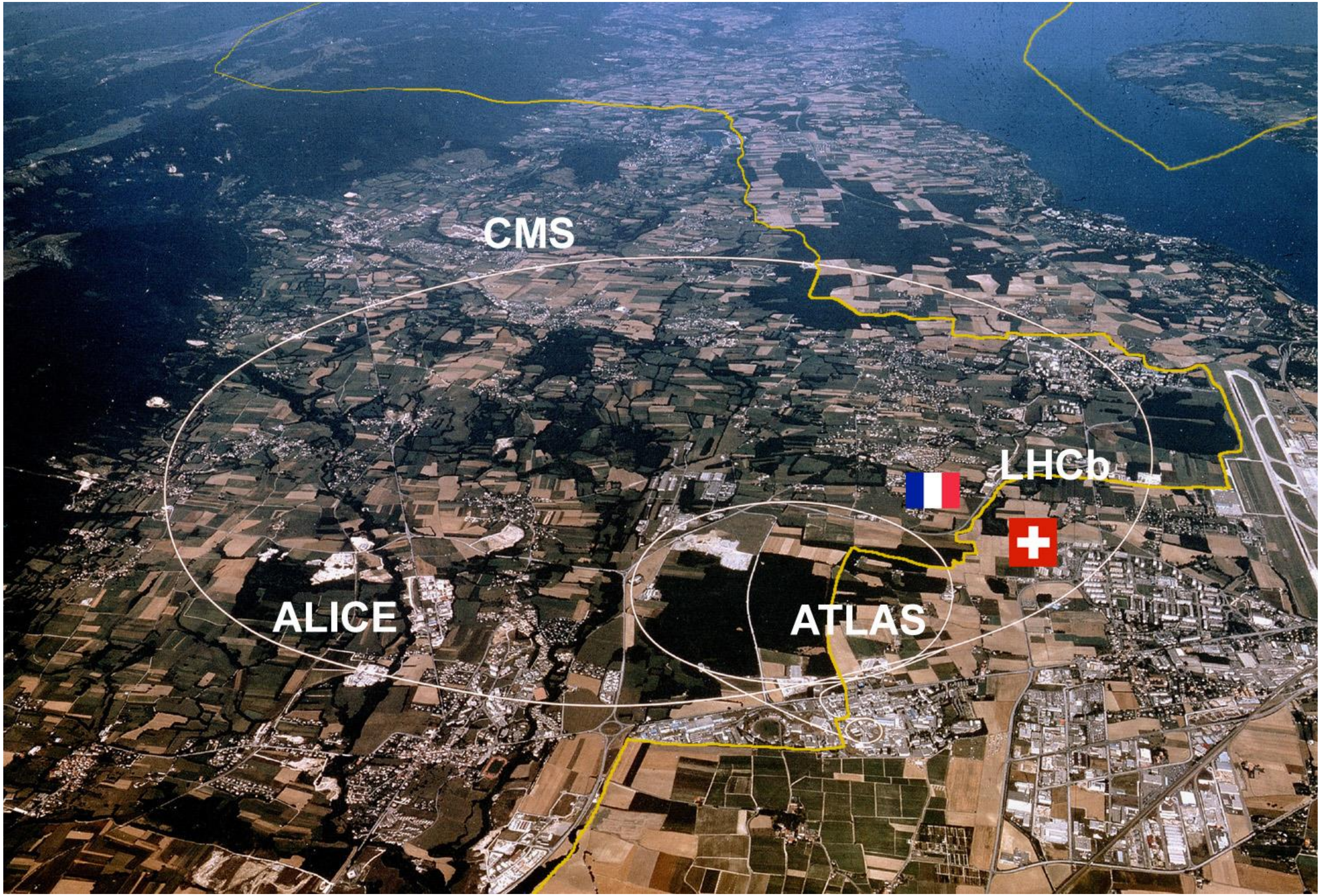
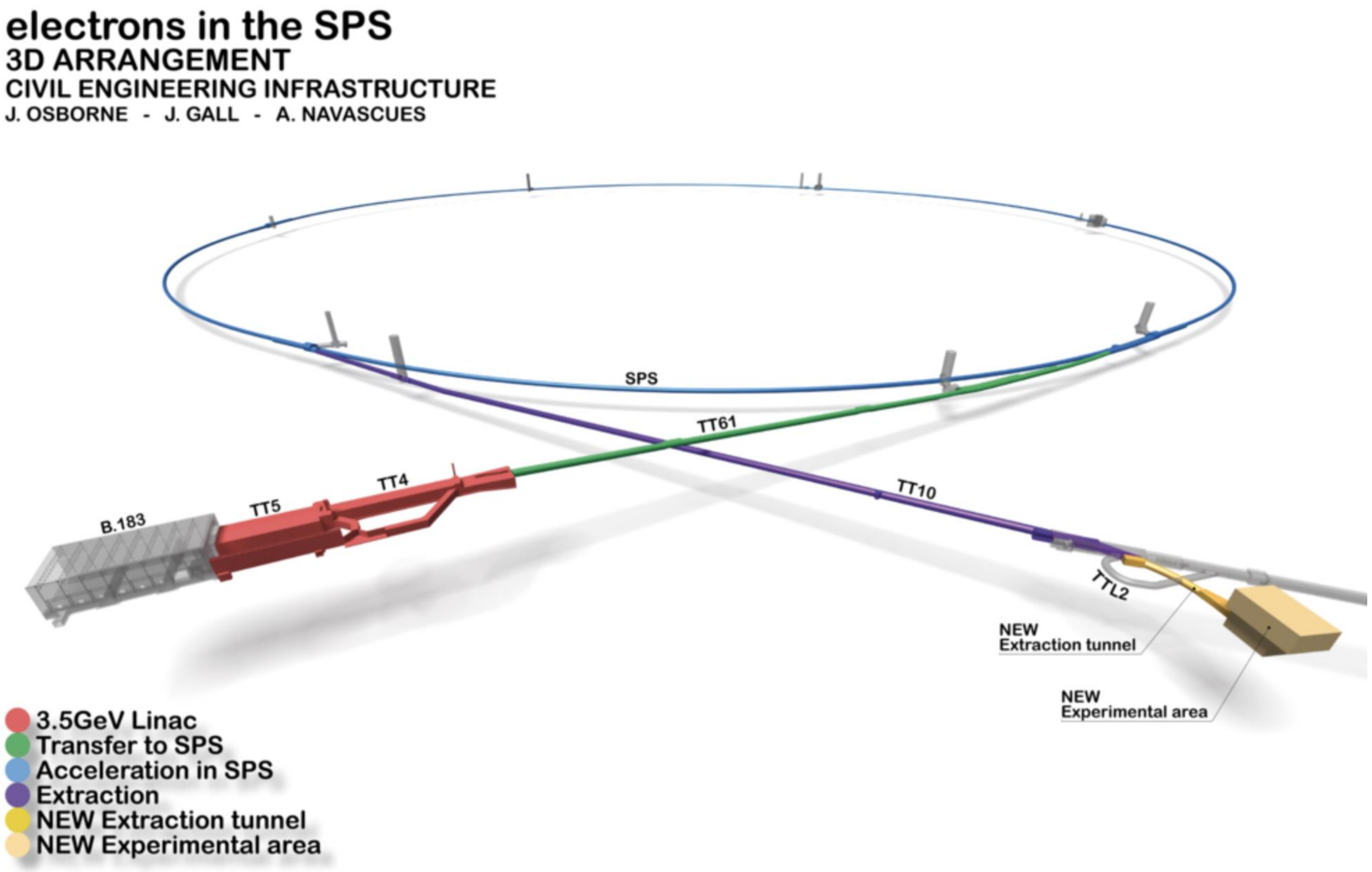

CMS
LHCb
ALICE
ATLAS



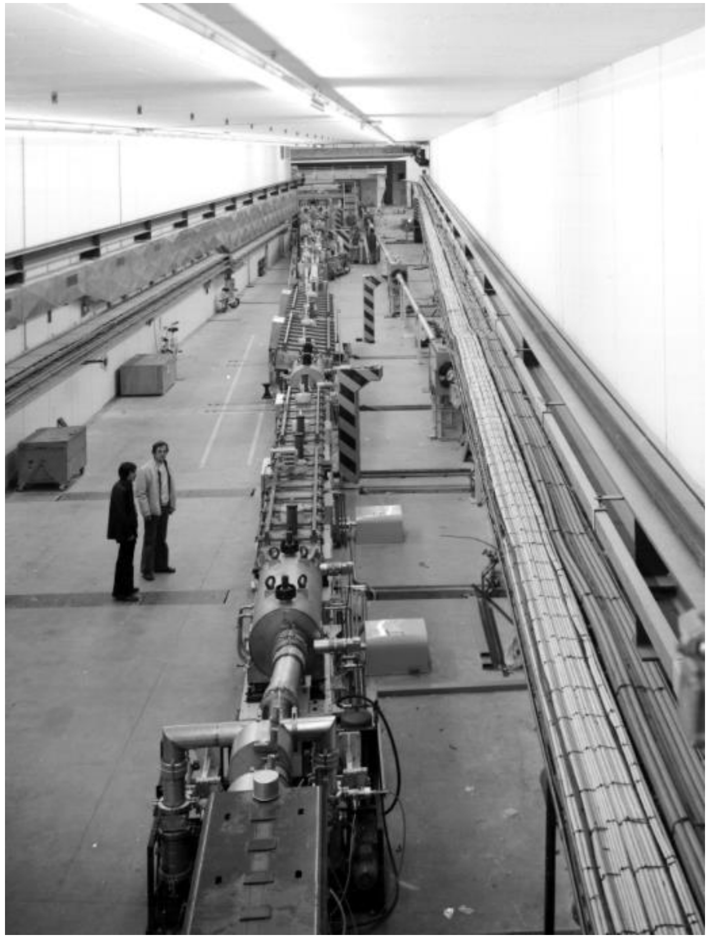
Accelerator implementation at CERN of LDMX type of beam

- X-band based 70m LINAC to ~3.5 GeV in TT4-5
- Fill the SPS in 1-2s (bunches 5ns apart) via TT61
- Accelerate to ~16 GeV in the SPS
- Slow extraction to experiment in 10s as part of the SPS super-cycle, or full use
- Experiment(s) in new hall bringing beam back on Meyrin site using TT10

Parameter	**Accelerating section**		
	S-band linac (Section 3.2)	**X-band linac** (Section 3.3)	**SPS** (Section 4.2)
Energy [GeV]	0.05–0.25	3.5	3.5–18
Electrons per bunch	$10^6 - 10^{10}$	$10^6 - 10^{10}$	10^9
Bunch length [ns]	$10^{-4} - 4 \times 10^{-3}$	$10^{-4} - 2.5 \times 10^{-3}$	$0.15 - < 0.7$
Bunch spacing [ns]	Multiples of 0.33	Multiples of 0.33	5
Bunches per cycle	1 – 200	1 – 200	3×10^3
Cycle length [s]	0.02	0.02	0.02

Linac in TT5/TT4

- Flexible bunch pattern provided by photo-injector
  5ns, 10ns, … 40ns bunch spacing (only constrained by the SPS)
- High repetition rate, for example
  - 200 ns trains at 50 or 100 Hz
- Installed in TT4/TT5, transfer via existing tunnel to the SPS
- Room for accelerator R&D activities at end of linac (duty cycle in many cases low for SPS filling so important potential)



Technology spread

Prototype components

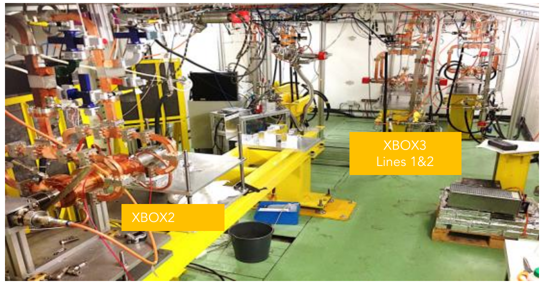
Laboratory with commercial
- Accelerating structures
- pulse compressors
- alignment
- stabilization
- etc.

Full commercial supply
- X-band klystrons
- solid state modulators
- etc.



Systems and 100 MeV-range facilities

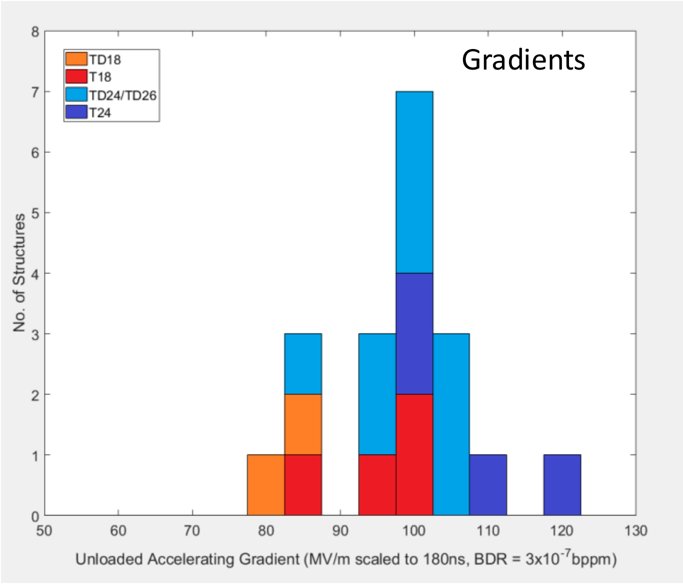
- XBoxes at CERN
- (NEXTEF KEK)
- Test stand at Tsinghua
- Frascati
- NLCTA SLAC
- Linearizers at Electra, PSI, Shanghai and Daresbury
- Deflectors at SLAC, Shanghai, PSI, DESY and Trieste
- NLCTA
- Smart*Light
- FLASH



Normal-conducting, low-emittance GeV-range facilities

Operational
- SACLA
- SwissFEL

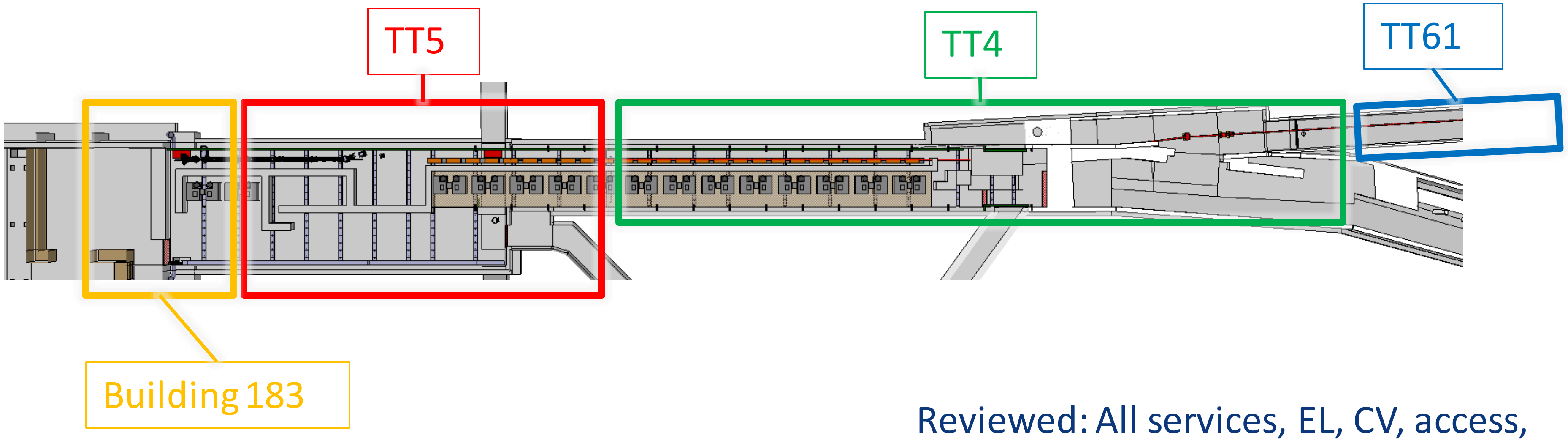
Swissfel: Specs similar, and reached

X-band GeV-range facilities

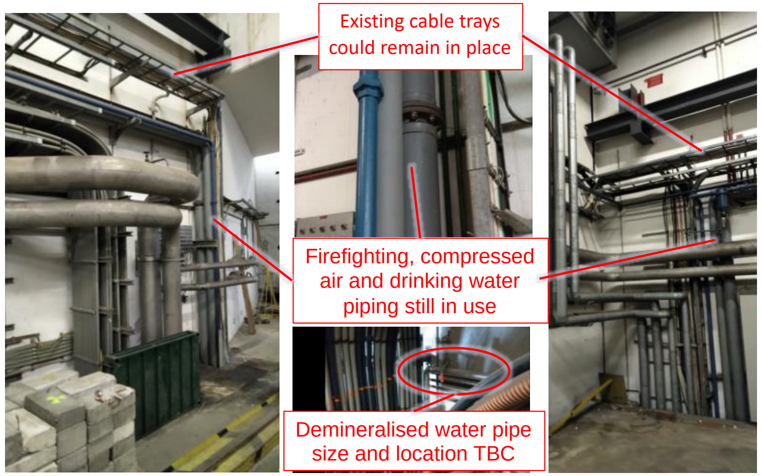
Planning:
- EU-Praxia
- eSPS
- CompactLight
- XARA

Linac in buildings 183, TT5, TT4 and TT61

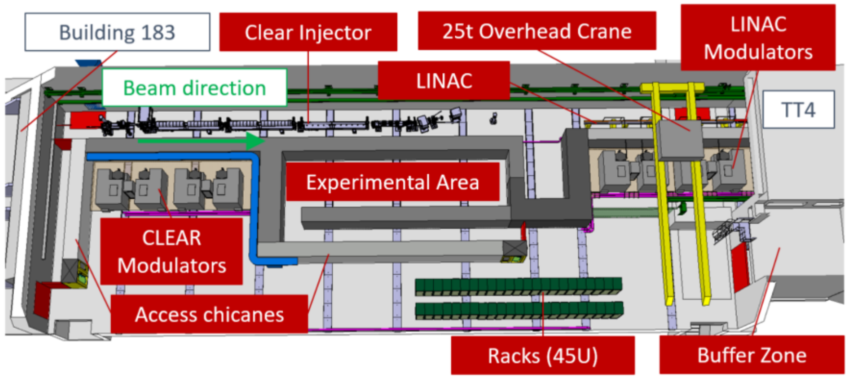


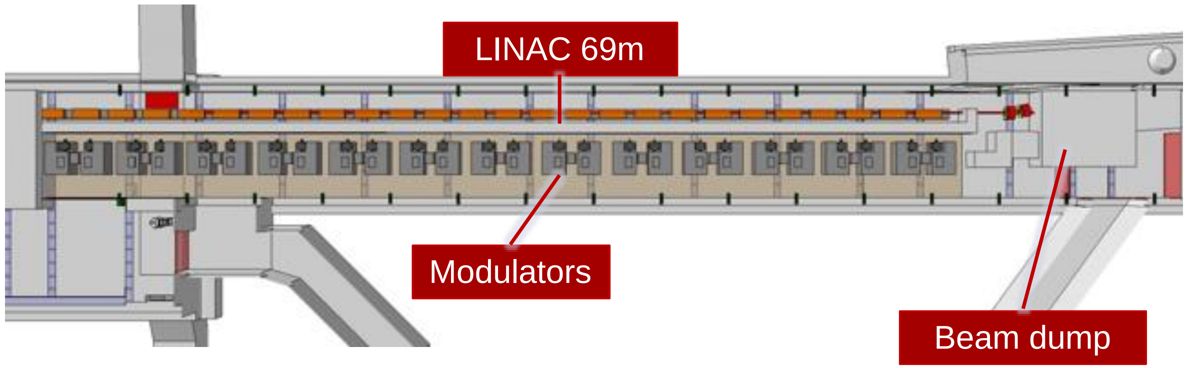
Reviewed: All services, EL, CV, access, safety, shielding/radiation, transport/installation, etc

- 0.1GeV S-band injector
- 3.4GeV X-band linac
  - High gradient CLIC technology
  - 24 RF units to get 3.4 GeV in ~70 m



Linac in TT5/TT4





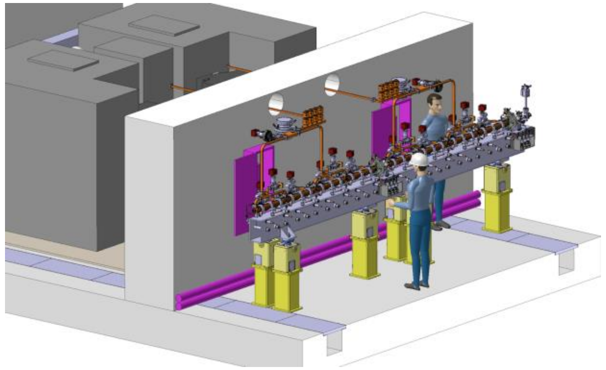


Table 3.3: Beam parameters at the end of the CLEAR injector.

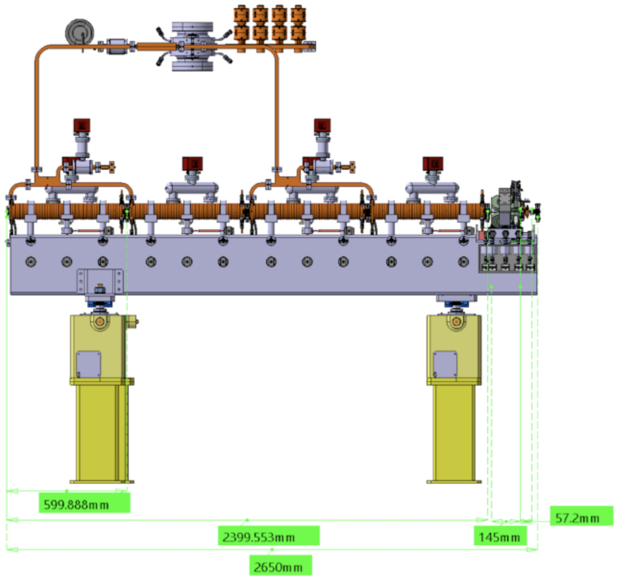
Parameter	**Value range**	**Value for eSPS**
Energy [MeV]	50 to 250	200
Bunch charge [nC]	0.001 to 1.5	0.05
Norm. emittance [μm]	$\sim$3 for 0.05 nC/bunch	3
	$\sim$20 for 0.4 nC/bunch	
Bunch length rms [mm]	0.3 to 1.2	0.8
Energy spread rms [%]	below 0.2	0.1
Number of bunches	1 to 200	40
Micro-bunch spacing [ns]	multiple of 0.33	5

Table 3.6: Parameters of the X-band accelerating structure.

Parameter	**First cell**	**Last cell**
Aperture iris radius [mm]	3.7	2.7
Iris thickness [mm]	1.35	1.35
Q-factor	7090	7020
Group velocity [% of c]	3.6	1.34
R'/Q [kΩ/m]	14.3	17.5
Number of cells	69	
Active length [mm]	575	
Input power for <60MV/m> [MW]	30.5	
Rise time (1/bandwidth) [ns]	12	
Filling time [ns]	88	

Linac components "available"

- Examples:

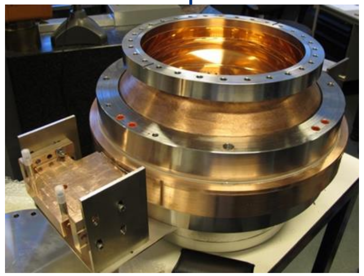


+

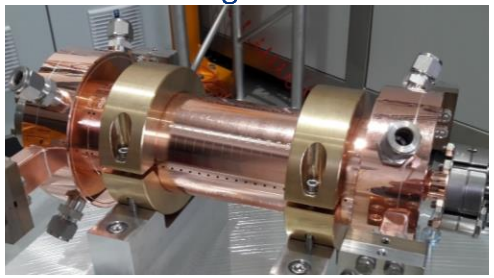
Klystron

Modulator

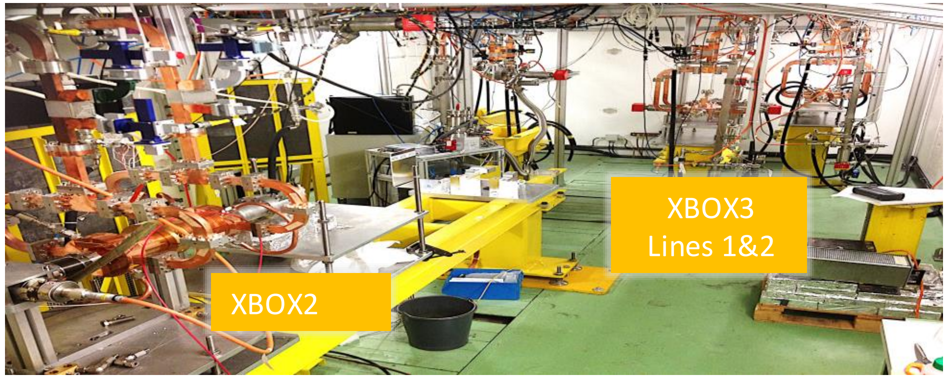
Pulse compressor



Accelerating structure



Assembled systems in continues operation at CERN

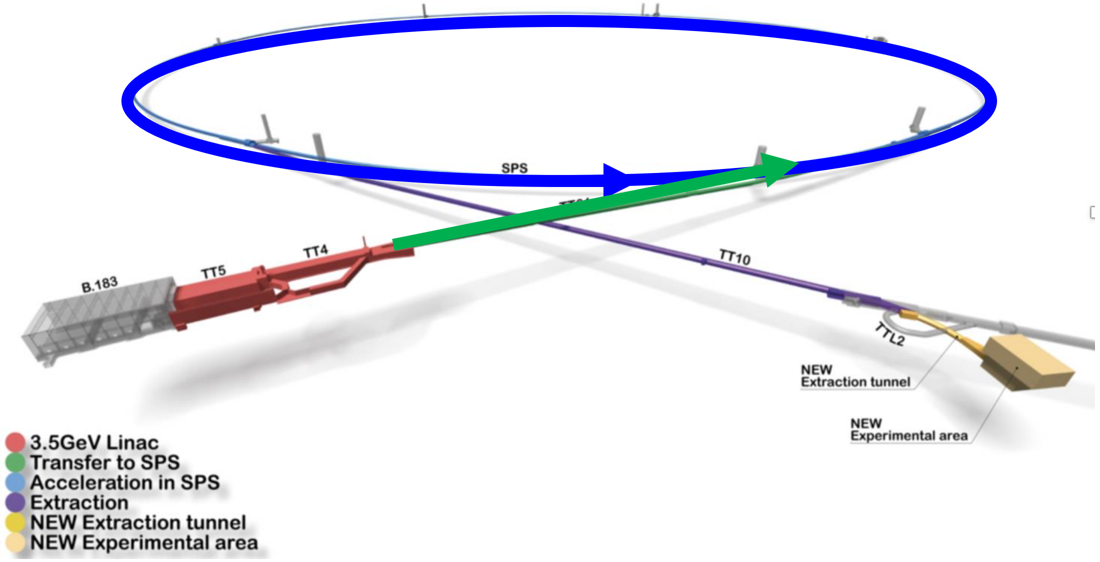


Transfer tunnel, TT61, from the Linac into the SPS

Injection into the SPS

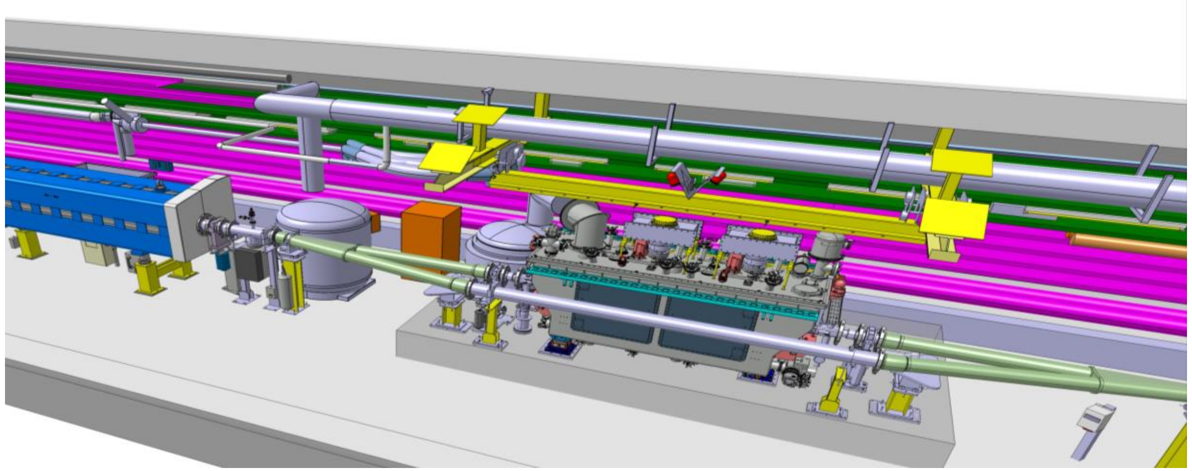
Bunch to bucket injection in the SPS longitudinal RF structure.

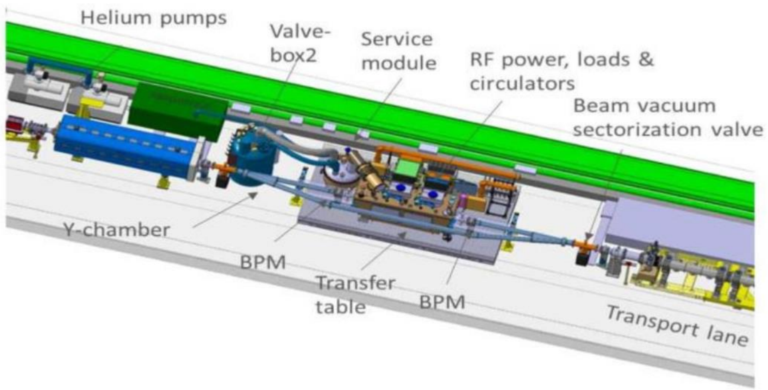
For example: total of 75 trains of 40 bunches
3000 bunches
10^{12} electrons in the ring



SPS RF, use Crab Cavity Bypass in SPS-LSS6

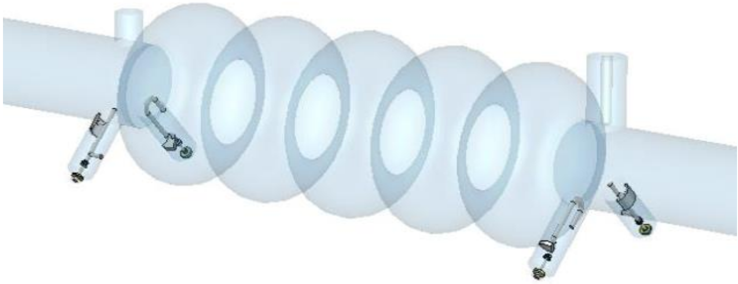
- Movement in/out of SPS-ring by 510mm – movement approx. 10 min with 2K Helium (~30 W)
- Independent vacuum system
- Look also as longer dynamic by pass giving more flexibility





SPS RF: 800 MHz, 5-Cell

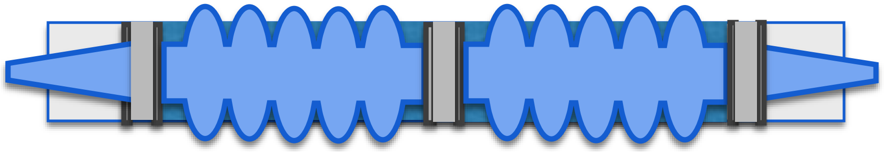
- In mechanical bypass, moved in/out of beam in ~10 min. No proton constraints for beam loading/impedance. Aperture ok for LHC beam
- Moderate HOM damping using 4 LHC-type HOM couplers for electron beam
- As mentioned, study the feasibility of dynamic by-pass for electrons – equivalent to in line beam



per cavity	unit	value
Frequency	[MHz]	801.58
Voltage	[MV]	5.0
R/Q	[Ω]	196
Epk, Hpk	$[\mathrm{m}^{-1}, \mathrm{mT/MV}]$	30, 60
RF Power	[kW]	~ 50

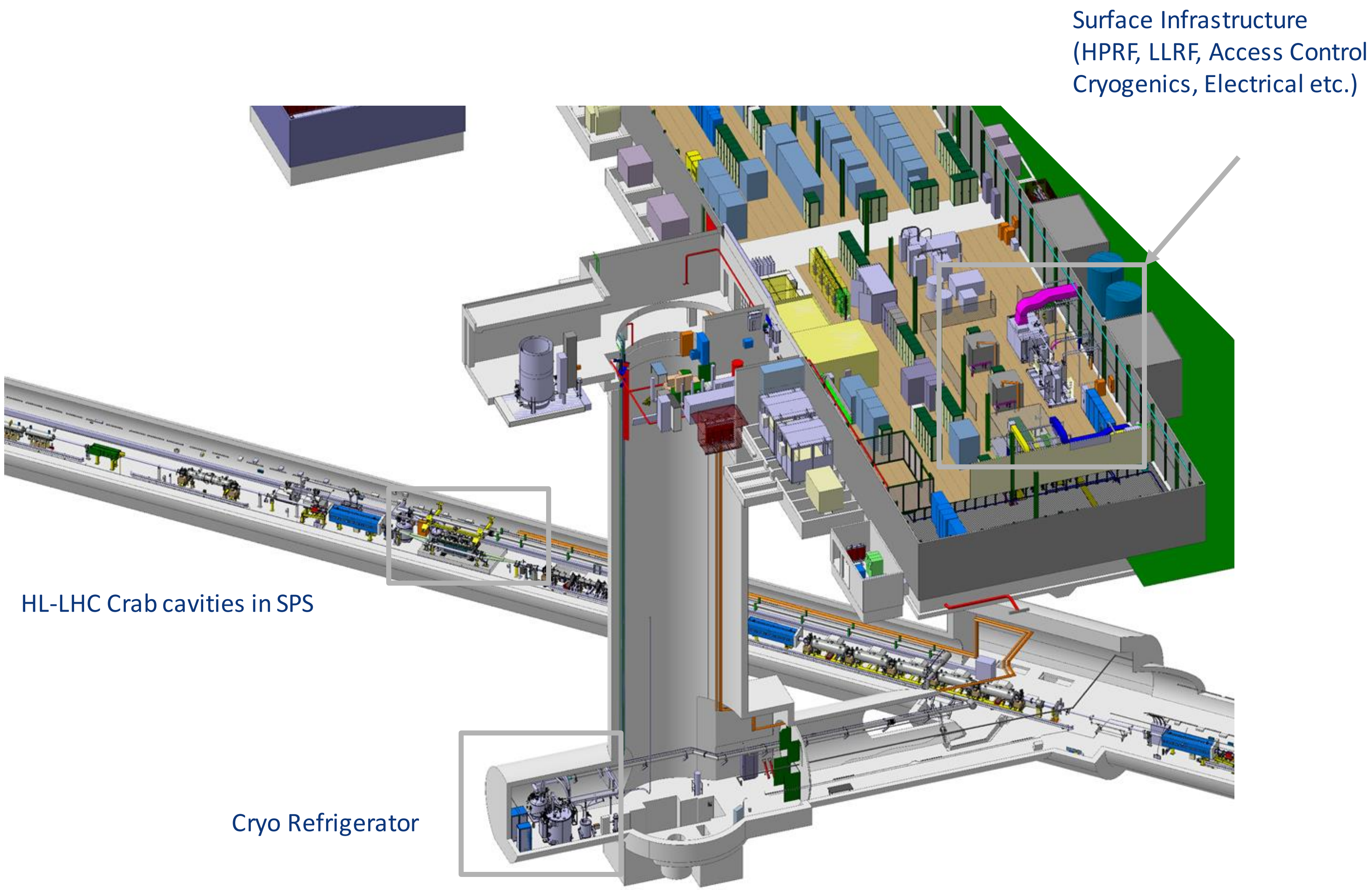
Two 5-cells in a CM ~ $5\mathrm{m}$

Sample Configuration (10 MV for e^{-})

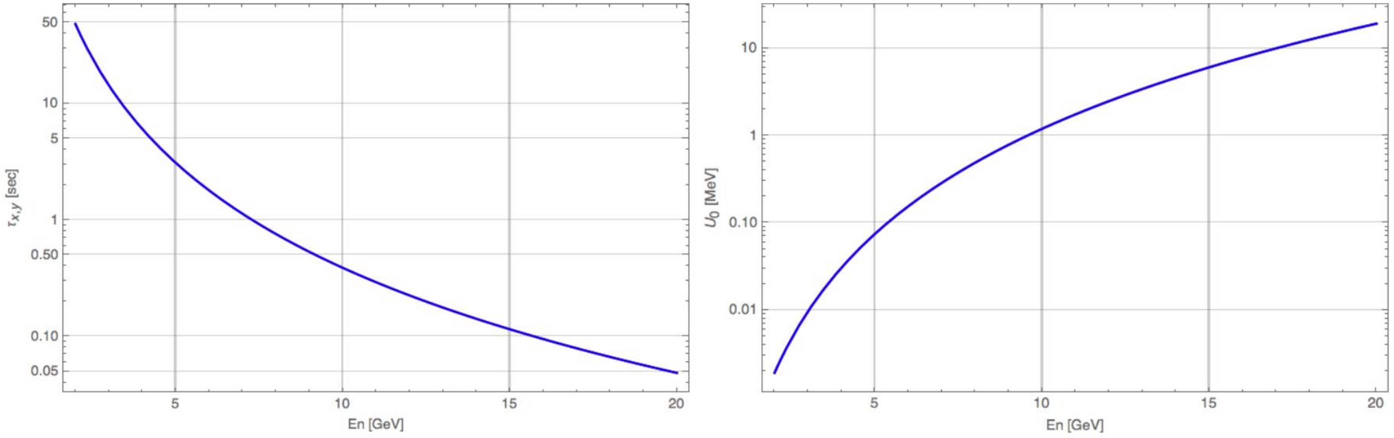


FCC-800 MHz prototype

Crab Cavity Bypass – SPS-LSS6



Many other SPS issues addressed in the EoI and CDR: beam-stability, energy losses, internal beam dump, injection, instrumentation, magnetic field stability, etc



(a) (b)

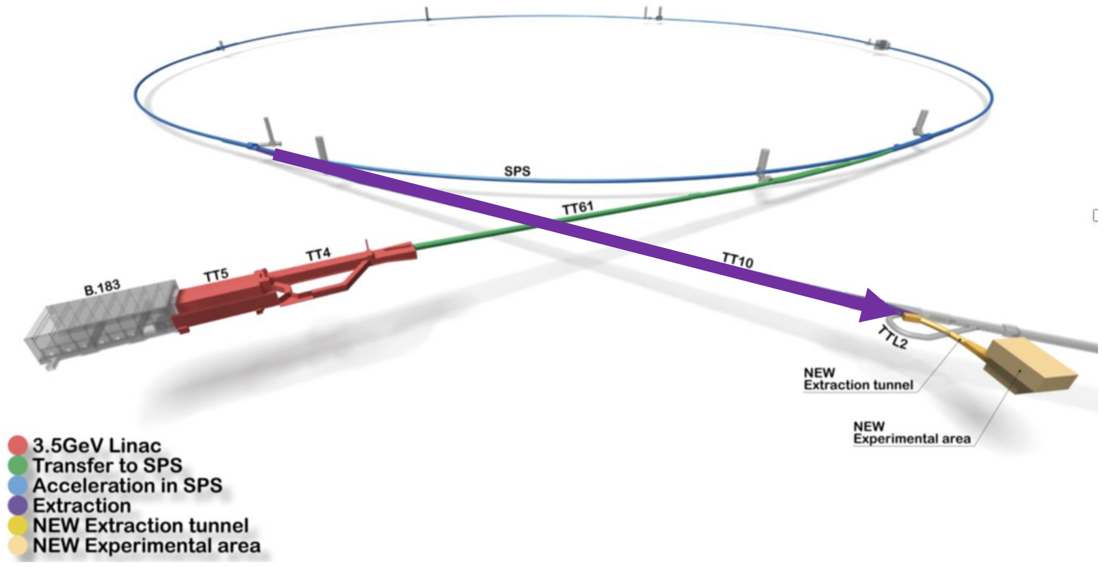
Figure 4.7: Transverse damping times (a) and energy loss per turn (b) versus electron energy in the SPS.

Table 4.3: Collective effects estimations for the eSPS.

Parameters and thresholds	**Q40**	**Q26**
Phase advance (h/v)	$135^\circ/90^\circ$	$90^\circ/90^\circ$
Eq. hor. emittance @ injection. [nm.rad]	1.62	3.56
Eq. hor. emittance @ extraction [nm.rad]	34.7	74
Eq. Bunch length [mm]	10	14
Injected hor. emittance [nm.rad]	0.43	
e^- per bunch	10^8	
Bending radius [m]	70.1	
Average chamber radius [m]	0.04	
Longitudinal impedance [Ω]	6.4	
Transverse impedance [MΩ/m]	9.77	
SC tune shift @ injection [10^{-4}]	4	4
SC tune shift @ equilibrium [10^{-4}]	8	3
SC tune shift @ extraction [10^{-7}]	1.2	0.6
LMI impedance threshold @ injection [Ω]	17912	33988
LMI impedance threshold @ equilibrium [Ω]	21.67	41.12
LMI impedance threshold @ extraction [Ω]	682	1294
TMCI impedance threshold @ injection [MΩ/m]	5060	6900
TMCI impedance threshold @ equilibrium [MΩ/m]	506	690
TMCI impedance threshold @ extraction [MΩ/m]	1121	1612
Tune shift due to ions [10^{-5}]	4	4
FII rise time [t_{rev}]	6.7	15
CSR LMI bunch length threshold @ injection [m]	0.41	1.76

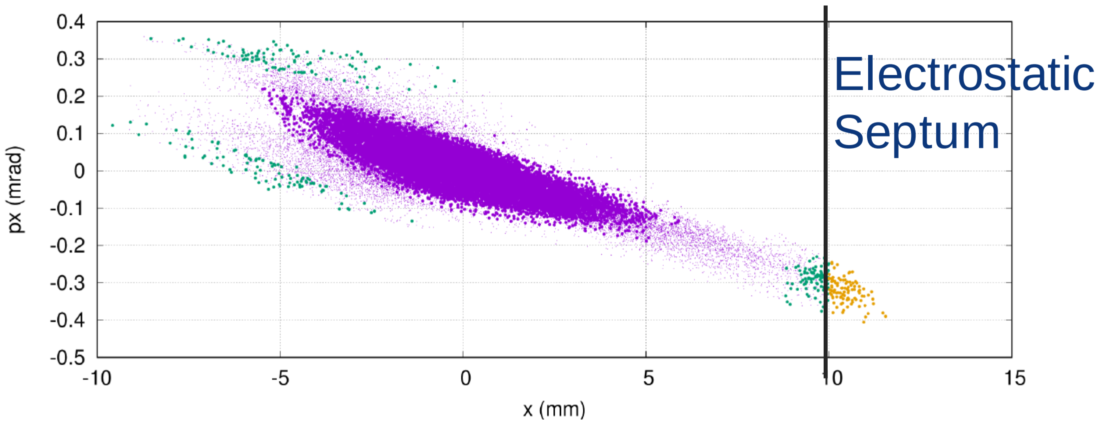
Slow extraction to experiments

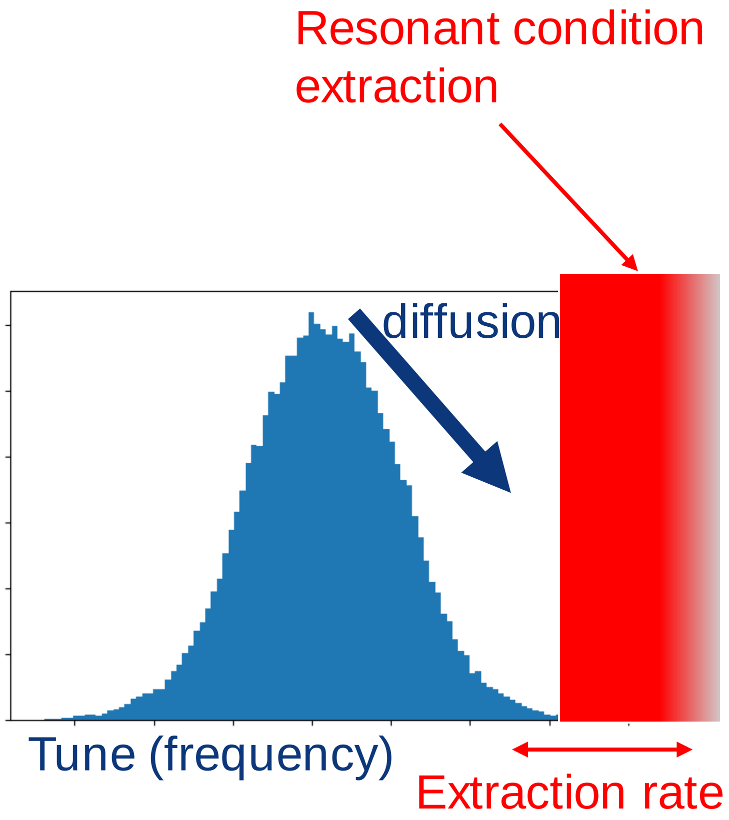
Extraction

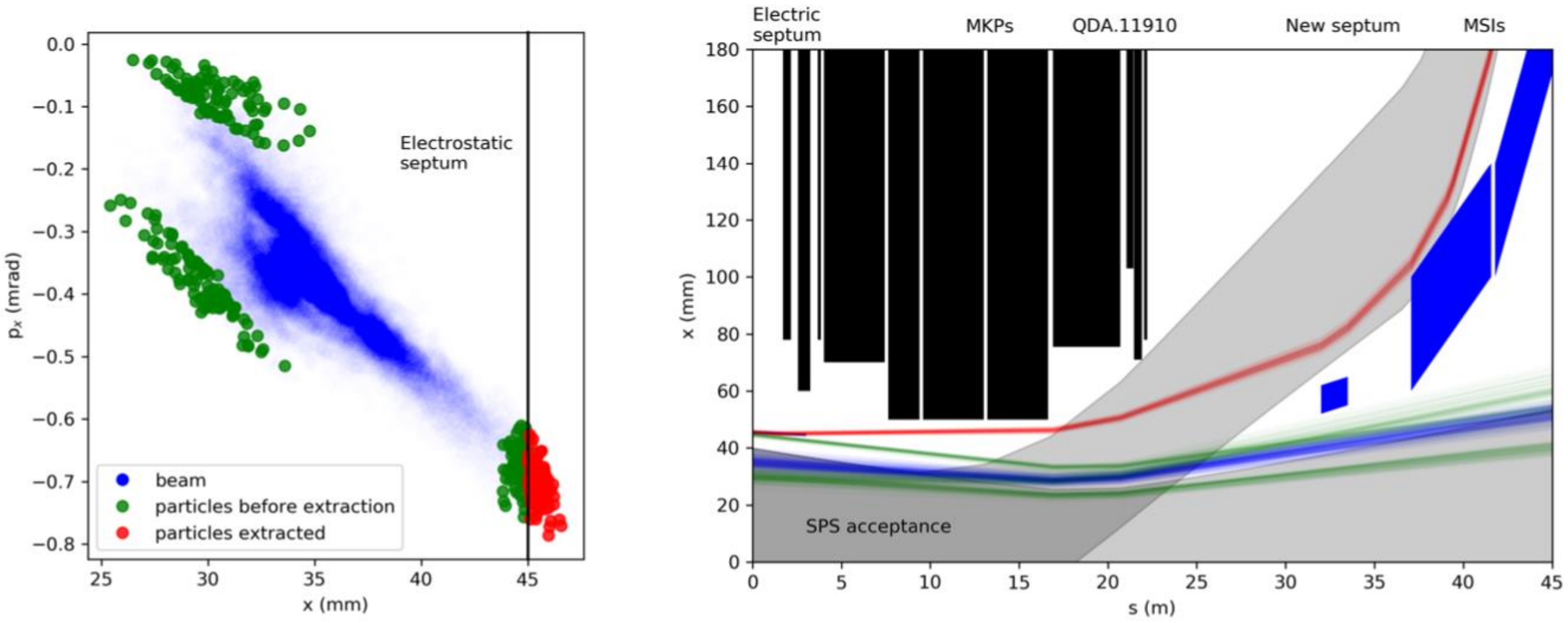


Slow extraction principle, in frequency space

- Spread in oscillation frequency within the beam follows
  - Transverse distribution
  - Longitudinal distribution in presence of chromatic lattice
- Position of the resonant condition is set by the machine
- Synchrotron radiation constantly diffuse the particles to fill the tail in the distribution
- The extraction rate can be controlled by changing the position of the resonant condition







(a) (b)

Figure 4.9: Extraction process in the horizontal phase space at the electric septum (a). Particle trajectories in the transverse horizontal space in the extraction region with apertures and the injected 14 GeV/c proton beam envelope in grey (b).

Electron beam transfer line from the SPS to experiments

- Uses existing TT10 line, designed to transport 10/20 GeV beams
- Collimation in the line for control of beam distribution and intensity
  - ~ Gaussian beam can be made almost flat by careful collimation
- Beam size might be increased greatly at the target
  - Size of beam-spot chosen to deliver number of electrons/cm^2/bunch-crossing on target
  - For instance a 2cm vertical and 20cm horizontal beam is feasible
  - There is flexibility on the choice of both horizontal and vertical beam sizes

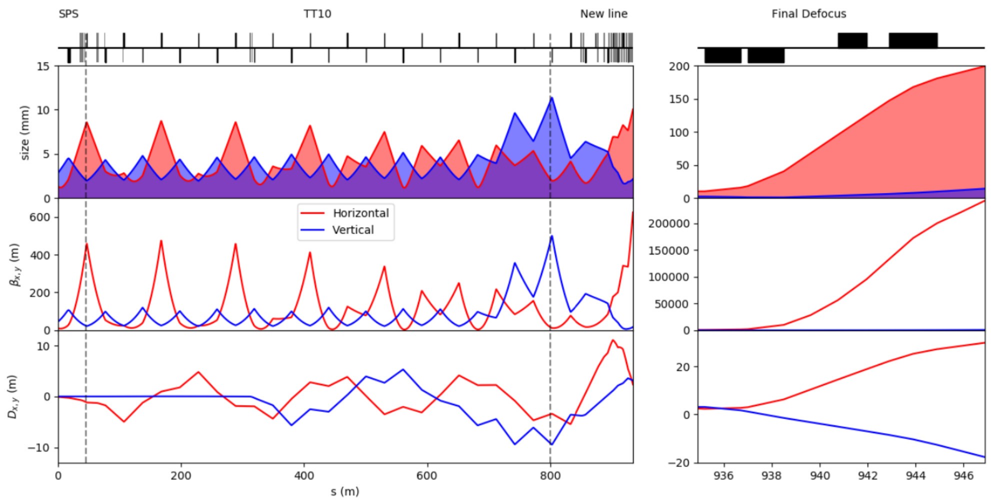


Figure 4.10: Beam sizes and optical functions from the SPS to the experimental target.

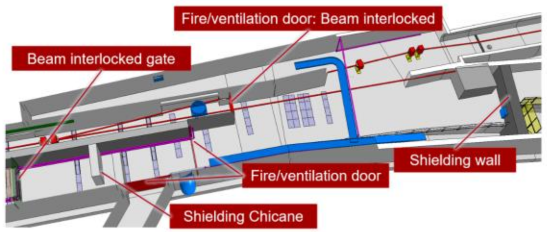


Figure 5.26: Access control layout in TT4.

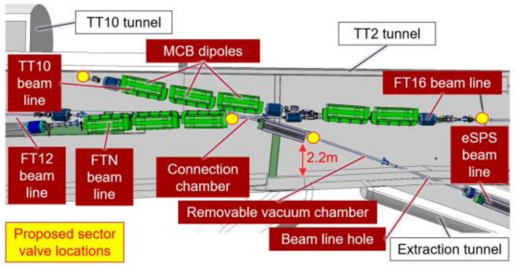
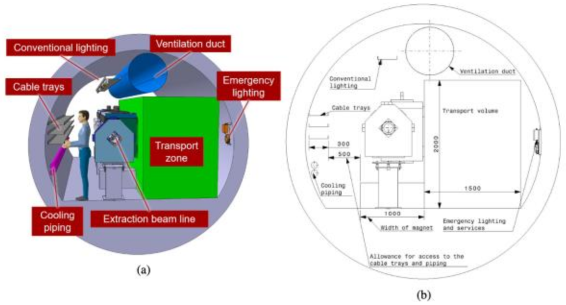


Figure 5.74: Integration layout of TT2.



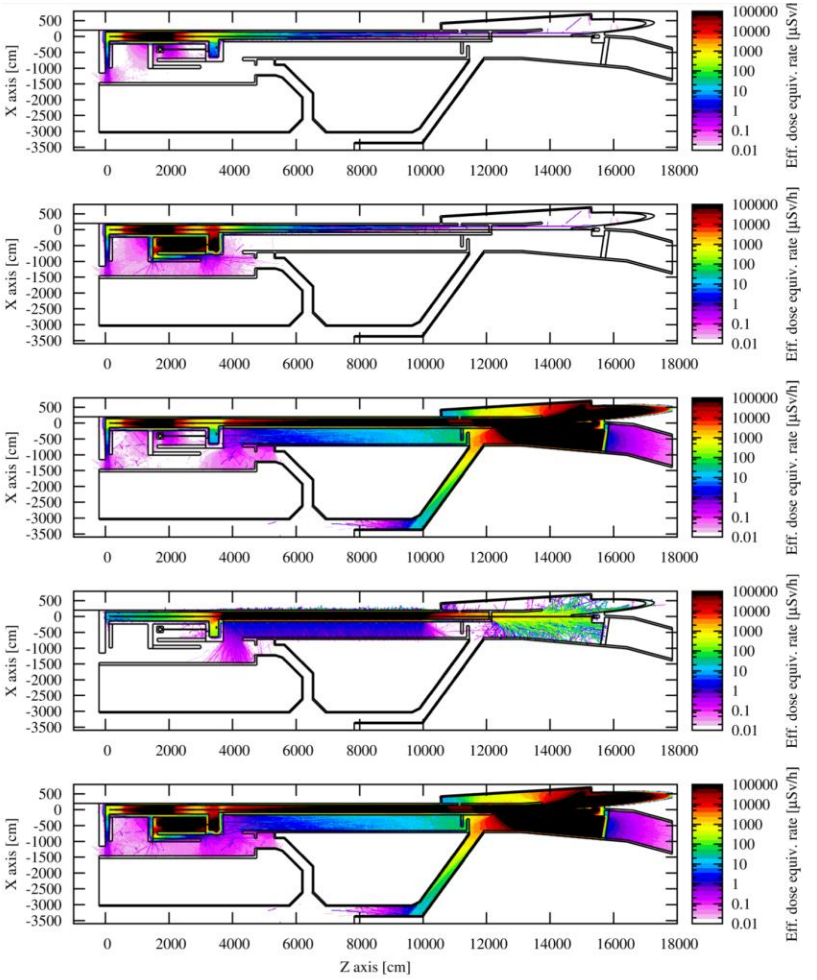
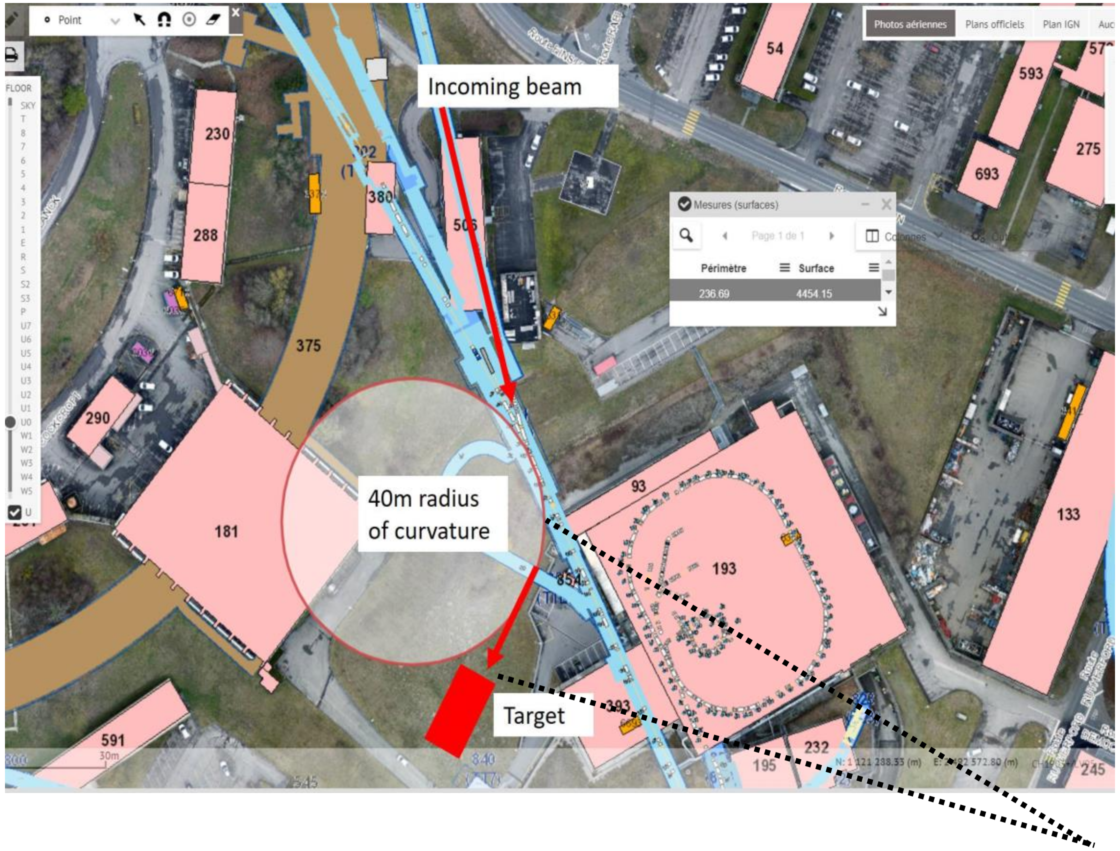


Figure 5.39: Dose rate levels for different loss scenarios. From top to bottom: S-Band linac operation, low energy experimental area operation, X-Band linac operation to the high energy experimental area, X-Band linac RF conditioning, simultaneous beam operation to both experimental areas with maximum nominal beam losses.

Extracted beam and experimental area



In total ~50 m new tun

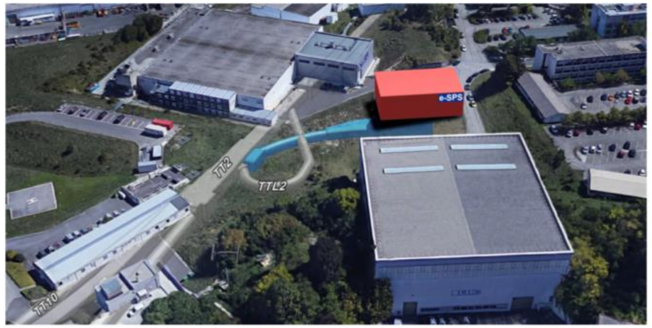


FIG. 43: Visualisation of the proposed underground (shown in blue) and overground (shown in red) facilities

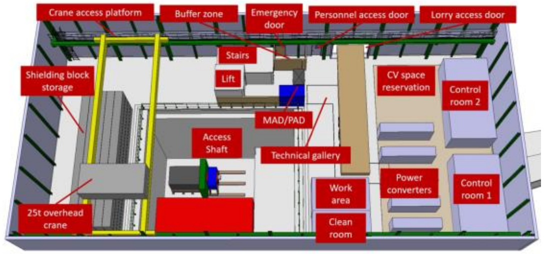


Figure 5.87: Integration layout of the surface building.

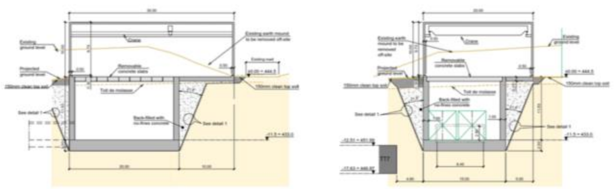


FIG. 41: Typical Sections through the experimental hall parallel to the beam-line (left) and transverse to the beam-line (right)

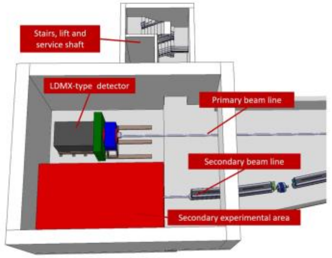


Figure 5.88: Integration layout of the experimental hall.

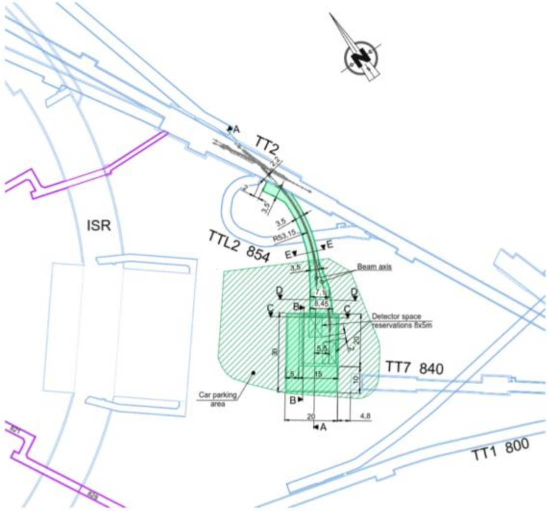


FIG. 38: Plan view of proposed layout

Instrumentation (from EoI)

Linac:

- Position
  - Re-use of CTF3 inductive pick-ups
  - Simple button BPMs would also do the job
- Beam Size
  - OTR screens (can also be combined with streak camera for bunch length)
- Intensity
  - Re-use of CTF3 inductive pick-up or standard beam current transformers

SPS:

- Position
  - Standard orbit system (consolidated in LS2)
  - Should be able to measure to 1e9 (limit ~5e8)
- Beam Size
  - Wirescanners
  - Possible use of synchrotron radiation
- Intensity
  - DC Transformer OK for total current
  - Fast BCT does not distinguish 5ns spaced bunches
  - Could do batch by batch but at limit of resolution (tbc)

Extracted beam:

- Position & Intensity
  - Use of fibre monitors.
    - Developed for new EHN1 (neutrino platform) secondary lines
    - Scintillating (or Cherenkov) fibres
    - Low material budget
    - > 90% efficiency for single particles demonstrated
  - R&D required to make them UHV compatible

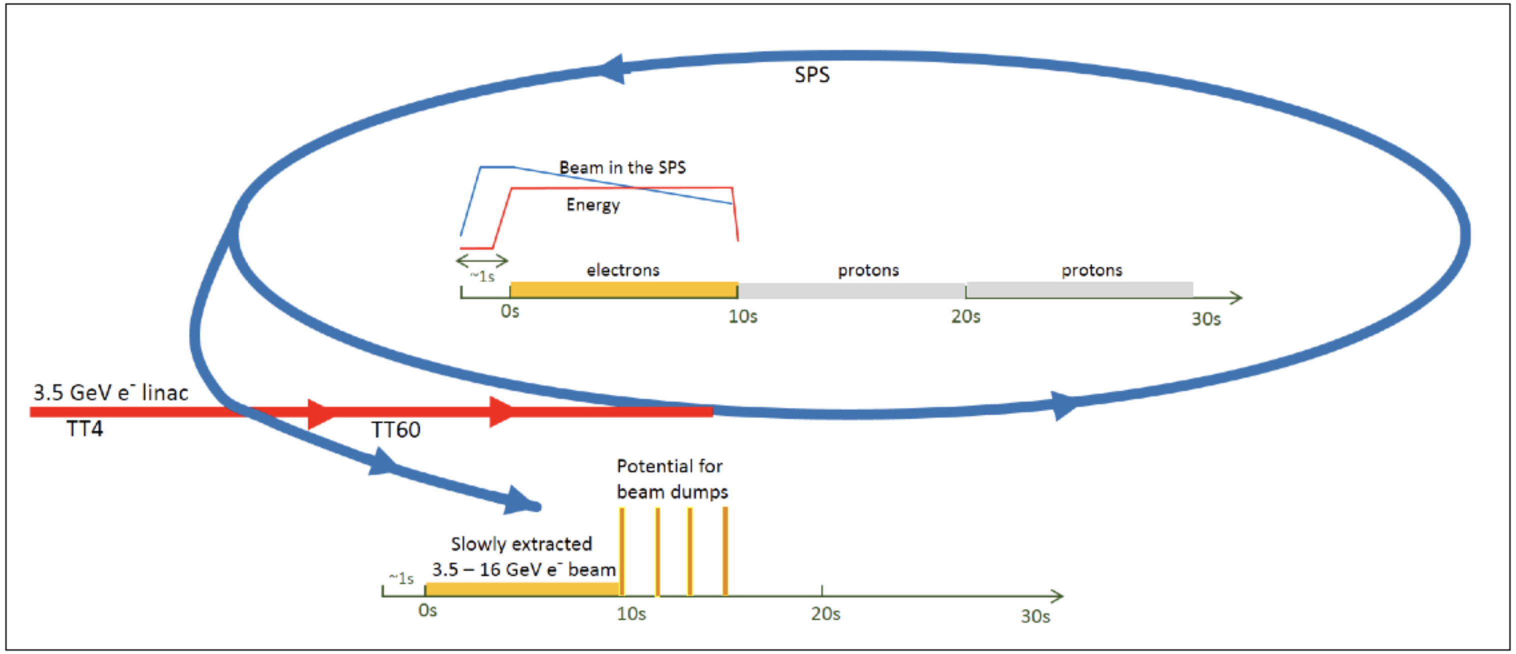
The challenge of measuring very low intensity beam can be circumvented using a higher intensity for beam setup

Beam structures

Capability stand-alone:
Extracting ~10 electrons per 5ns means 10^{16} electrons in ~ 80 days
Including up-times and efficiencies: dedicated year overall

Using 800 MHz and/or more electrons per extraction will increase rate

Or as part of super-cycle, or extract entire beam every 1-2s (beamdump)

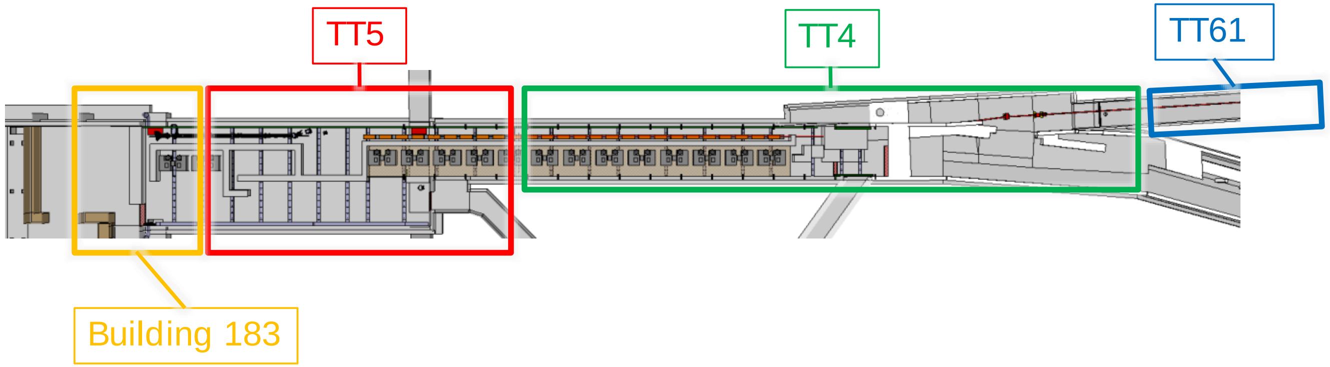


Potential use of such a facility

(linac more than 90% free)

Physics:

LDMX - Other hidden sector exp., incl. dump-type experiments using the available electrons - Nuclear physics



Accelerator physics opportunities:

CLIC: Linac goes a long way towards a natural next step for use of technology (collaborate with INFN and others also using technology for X-band linacs in coming years)

Relevant also FCC-ee, for example theRF systems, injector, etc

Plasma studies with electrons

Use electron (3.5 GeV) beam as driver and/or probe – studied by AWAKE WG

General acc. R&D as in CLEAR – existing ~200 MeV linac - today (https://clear.web.cern.ch)

Plasma-lenses, impedance, high grad studies, medical (electrons), training, instrumentation, THz, ESA and detector irradiation. Some results: https://acceleratingnews.web.cern.ch/article/first-experimental-results-clear-facility-cern (new article in preparation)

Positron production (interesting for linear or circular colliders and plasma) and studies with positrons for plasma, and possibly LEMMA concept for muon collider

General Linear or Ring related Collider related studies using SPS beam

Example: damped beam for final focus studies (beyond ATF2), FCC-ee related studies

Plasma studies

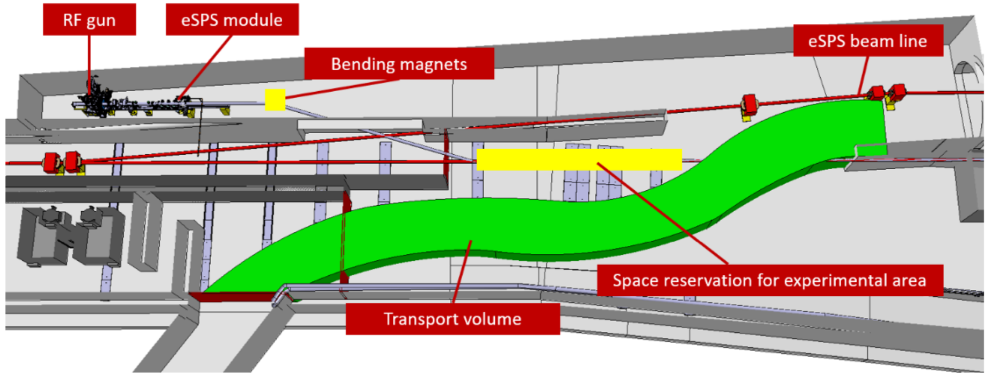


Figure 3.15: Schematic layout for a second injector dedicated for plasma wakefield acceleration research. The injector could be installed at the beginning of TT61 and connected via a dogleg to an experimental area at the end of the linac.

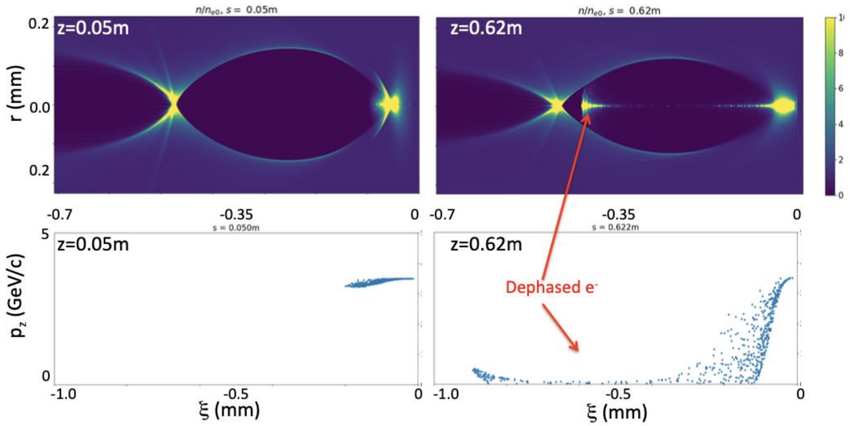
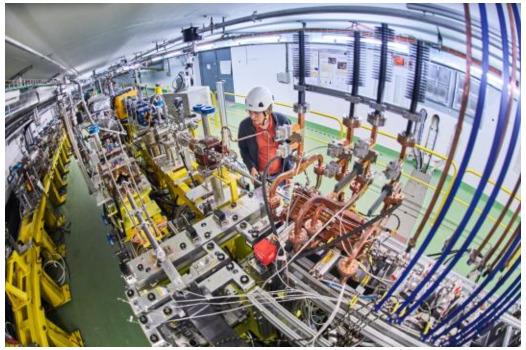


Figure 6.3: Top panels: snapshots of the drive bunch ($-0.1 \leq \xi \leq 0.0$ mm) and plasma densities (no witness bunch, colour scale for n_e/n_{e0}) at two locations along the plasma ($z = 5$ and 62 cm). Bottom panels: corresponding snapshots of the drive bunch electrons longitudinal momentum. The simulation parameters used were: $n_{e0} = 5.6 \times 10^{15}\,\text{cm}^{-3}$, $\sigma_z = 100\,\mu$m, $\sigma_r = 70\,\mu$m, $N = 4.3 \times 10^{10}$ ($n_b/n_e = 1$), thus $E_{WB} = 7.24$ GeV/m.

CLEAR



A recent report about 2020 (link)

[...]
2020
- 2337478 (v.1) 18-Calibrate Gafchromic EBT3
- 2337479 (v.1) 19-Response of secondary standard ionisation chambers to VHEE
- 2337580 (v.1) 20*-CHUV
- 2337586 (v.1) 21-light yield and spectrum of Chromox screens
- 2337591 (v.1) 22-Optical Transition Radiation Interferometry (OTRI) and Digital Micro-mirror Device (DMD)
- 2337596 (v.1) 23-Dosimetry control and characterisation for R2E + ESA Monitors
- 2337890 (v.1) 24-IRRAD BPM test
- 2337894 (v.1) 25-Fiber optic dosimetry
- 2337898 (v.1) 26-R2E impact of neutrons
- 2337902 (v.1) 27-radiation damage and stuck bits in SDRAMs
- 2337905 (v.1) 28-Yield of the Cherenkov radiation within soft X-ray
- 2337909 (v.1) 29-Coherent Cherenkov diffraction radiation by Surface Plasmon Polariton
- 2337910 (v.1) 30-Coherent Cherenkov diffraction radiation in dielectrics
- 2337913 (v.1) 31-CLIC wake field monitor studies
- 2337914 (v.1) 32-Plasma Lens Studies
- 2337918 (v.1) 33-CLIC Cavity BPMs
- 2337920 (v.1) xx-Test of new Rad-tolerant cameras from Microcameras
- 2337922 (v.1) xx-EOS bunch length measurement for AWAKE
- 2337924 (v.1) xx-Impedance studies on Coherent Cherenkov radiation
- 2337926 (v.1) xx-JUAS
- 2396415 (v.1) 38-Machine Learning for beam imaging system
- 2396850 (v.1) 39-Investigation on Degradation of Irradiated EPI (epitaxial) Silicon Pad Diodes

Providing a test facility at CERN with high availability, easy access and high quality e- beams.

Performing R&D on accelerator components, including innovative beam instrumentation prototyping, high gradient RF technology realistic beam tests and beam-based impedance measurements.

Providing an irradiation facility with high-energy electrons, e.g. for testing electronic components in collaboration with ESA or for medical purposes(VHEE), possibly also for particle physic detectors.

Performing R&D on novel accelerating techniques – electron driven plasma and THz acceleration. In particular developing technology and solutions needed for future particle physics applications, e.g., beam emittance preservation for reaching high luminosities.

Maintaining CERN and European expertise for electron linacs linked to future collider studies (e.g. CLIC and ILC, but also AWAKE and FCC-ee injectors), and providing a focus for strengthening collaboration in this area.

Using CLEAR as a training infrastructure for the next generation of accelerator scientists and engineers.

Experiments/Activities in 2019 – 38 weeks

(Possibly not a complete list)

- JUAS Practical Work Days
- NPL – Irradiation/dosimetry
- CHUV – FLASH dosimetry
- AWAKE Cherenkov BPM
- CLIC Wake-Field Monitors
- EOS bunch length monitor
- Inductive BPMs
- CLIC Structure wake-field kicks
- THz Smith-Purcell radiation
- THz high power generation/bunch length monitoring
- Ionization chambers dosimetry (Oldenburg U. /PTW)
- R2E Irradiation studies SEU-SEE
- R2E – ESA monitor flash
- R2E – displacement damage
- Plasma Lens (Oslo, DESY, Oxford U.)
- VHEE radiobiology/plasmid irradiation (Manchester U.)
- AWAKE spectrometer calibration
- Cryogel radiation length evaluation (FCC detectors R&D)
- Cherenkov X-ray pre-tests (Belgorod)
- RP measurements/neutrons
- Double-bunch generation
- High Charge bunch compression
- Irradiation of DCDC converters for detectors (EP/ESE group)
- IRRAD Beam Profile Monitors prototype tests
- WSM-BPR diagnostics tests
- Cherenkov Plasmonic

Positrons (not part of cost and schedule below)

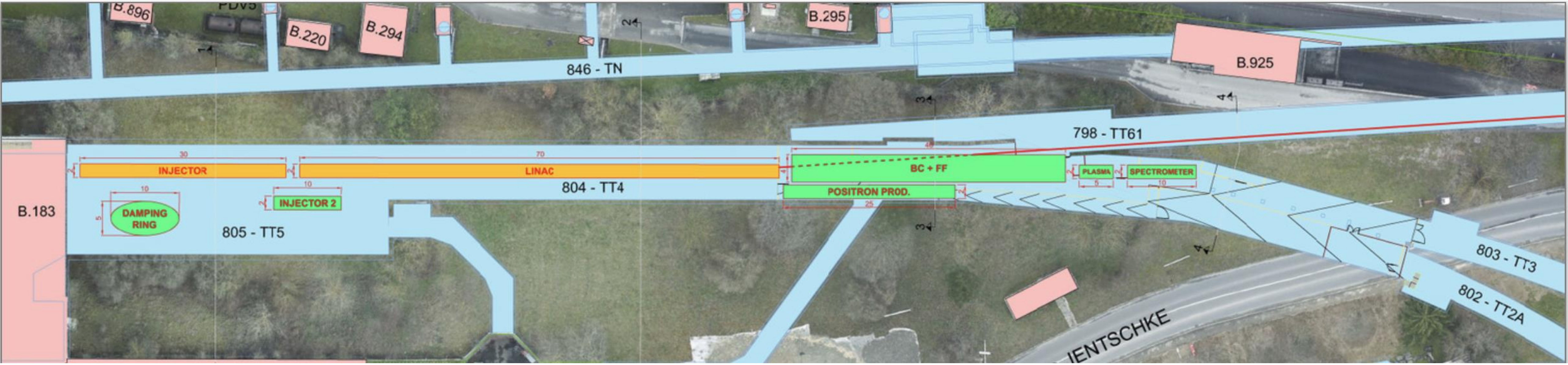
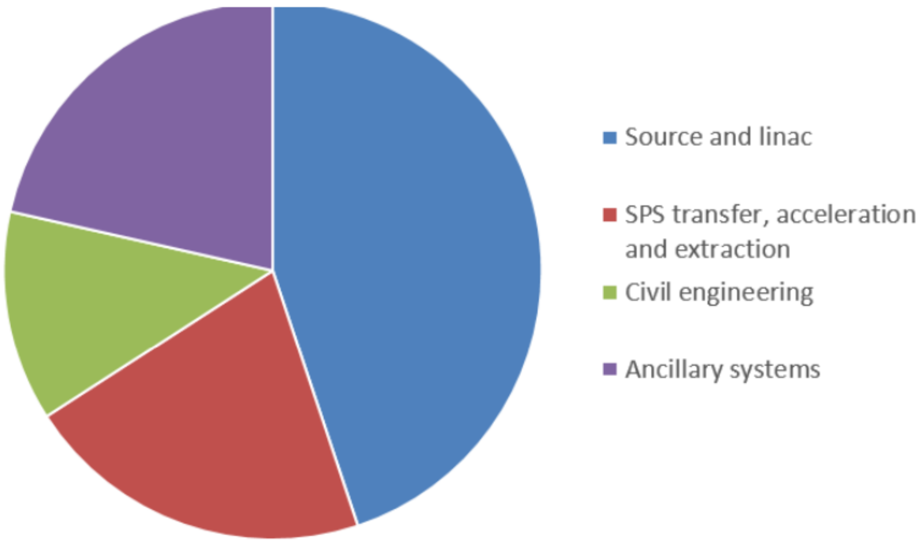


Table 6.3: Possible parameters for positron production.

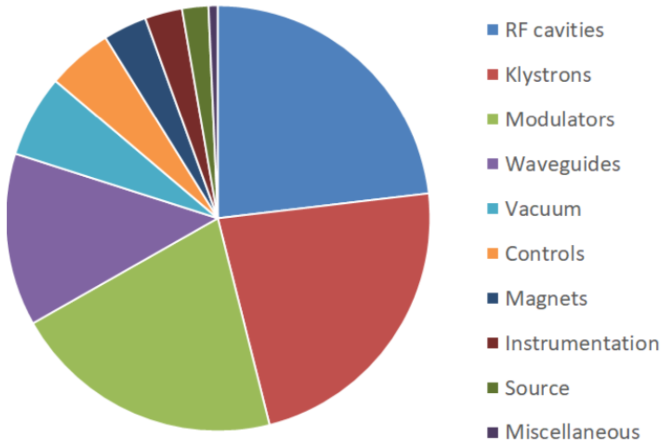
Parameter	Symbol	Value
Electron drive bunch		
Energy	W_0	3.5 GeV
Charge	Q	1.7 nC
Bunch rms length	σ_z	200 μm
Positron bunch		
Energy	W_0	3.5 GeV
Charge	Q	$>$ 1 nC
Bunch rms length	σ_z	200 μm
Capture energy	W_c	335 MeV
Final emittance	ε	$<$ 20 mm mrad

Total costs from CDR – example of breakdown for Linac



Item	cost [MCHF]
Source and linac	49.8
SPS transfer, acceleration and extraction	23.4
Civil engineering	14.0
Ancillary systems	23.8
Sum	111.0

Figure 7.2: Summary of the cost estimate for the project.



Item	cost [MCHF]
RF cavities	11.52
Klystrons	11.42
Modulators	10.32
Waveguides	6.53
Vacuum	3.12
Controls	2.47
Magnet	1.66
Instrumentation	1.41
Source	1.00
Miscellaneous	0.35
Sum	49.80

Figure 7.3: Summary of the linac and source cost estimate.

Schedule in the CDR

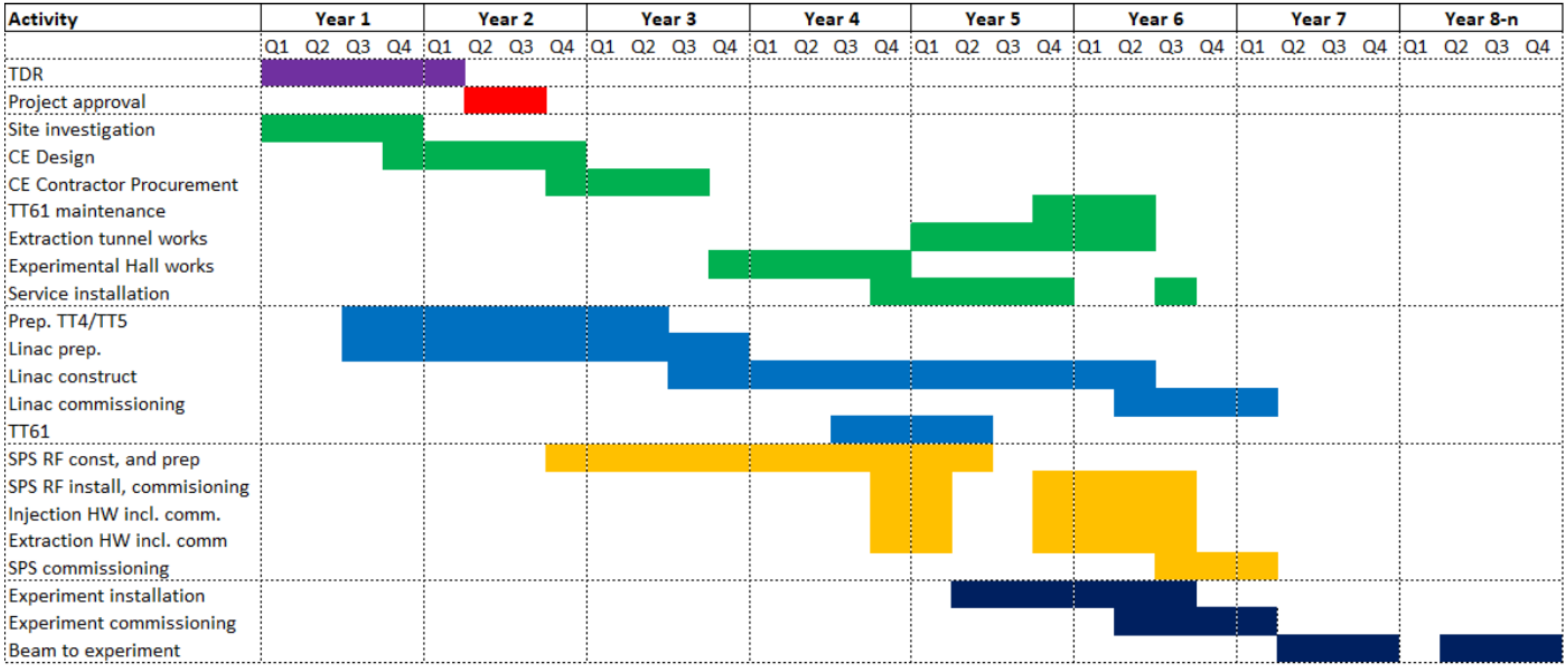


Figure 7.1: Possible eSPS implementation schedule.

Concluding remarks

- Important physics opportunities with e-beams at CERN
- Based on previous usage of the CERN accelerator complex, and building on the accelerator R&D for CLIC and HiLumi/FCC, an electron beam facility would be a natural next step
  - No show-stoppers have been found when exploring this option
  - Interest in pursuing this option as beam close to ideal for LDM searches of this type

- Will also provide many opportunities for important and strategic accelerator R&D at CERN – and opens the door to future electron facilities in general

- CDR completed and on the arXiv (link), CERN Yellow Report published in Dec 2020 (minor changes wrt arXiv version)

- Can this be implemented ? Further progress resource limited (or priority limited) at CERN ..
- Can (some of) this be done elsewhere?
- Clear common features with 1 GeV X-band linac at LNF – and we will continue to collaborate for this project
- We also hope LDMX at SLAC (starting at 4 GeV) can be done ….

With warm thanks to the entire eSPS team