A primary electron beam facility at CERN

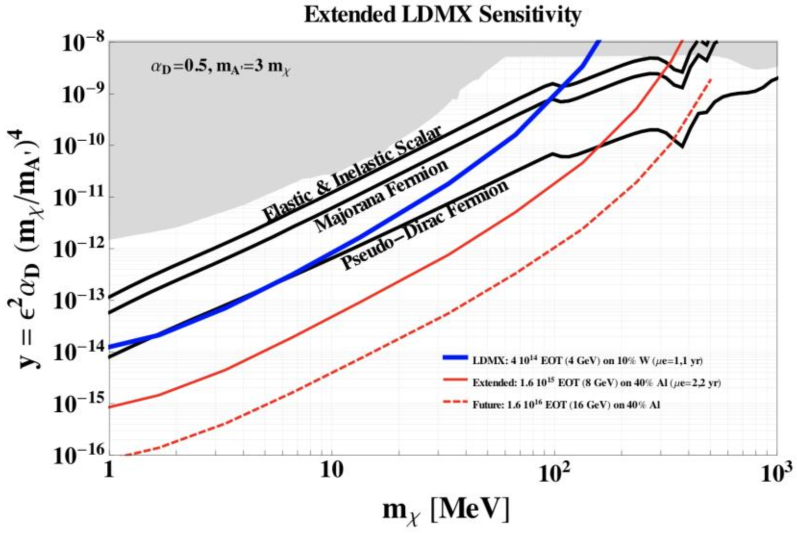
CERN Nov 6th 2019

S. Stapnes

on behalf of the working group PBC-acc-e-beams (email: PBC-acc-e-beams@cern.ch)

Motivations

Physics: Large increasing interest in Light Dark Matter – using e-beams, the original trigger for the "eSPS proposal" – LDMX phys&det talks: Granada slides, EPS slides

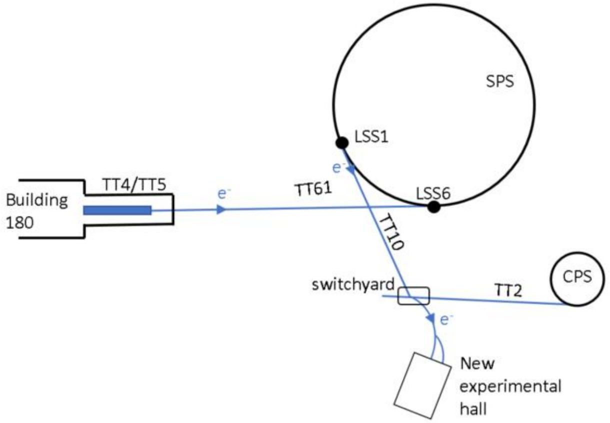


Accelerator R&D:

Any next machine at CERN is "beyond LHC", i.e. 15+ 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, possible RF tests for example
- 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 (ALIC) and CLEARER



Dark Sector Physics with a Primary Electron Beam Facility at CERN

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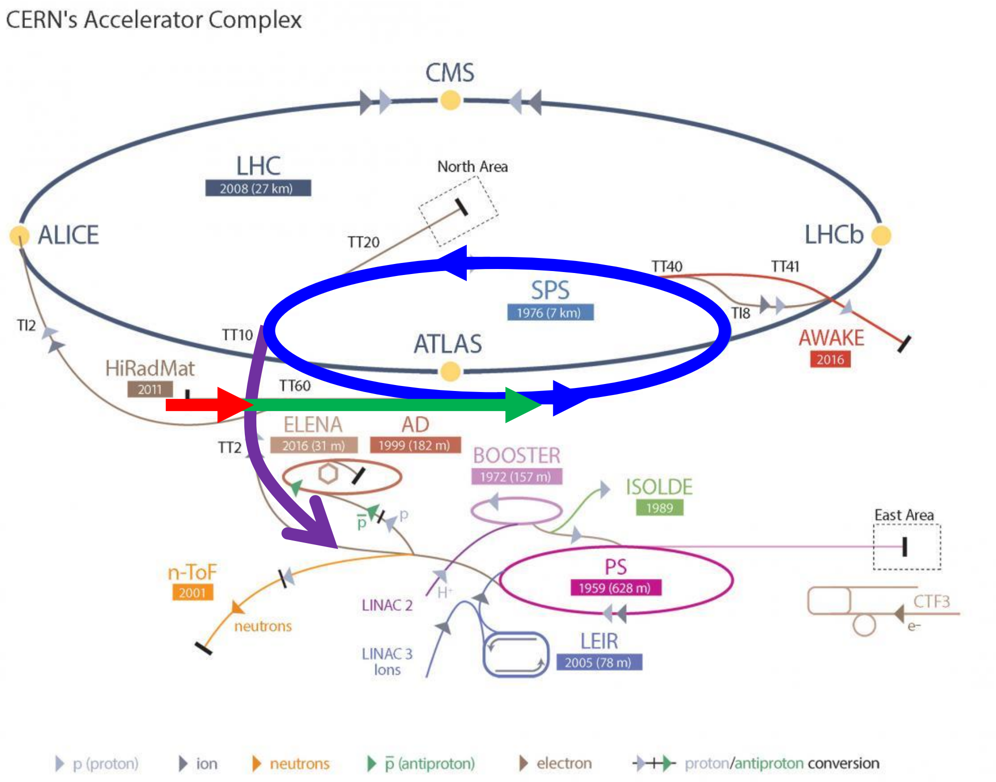
Current work: CDR by end of March 2020

- Updates of all parts including user case studies
- Main updates: Linac infrastructure, SPS RF
- Schedule, cost and implementation planning update

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

Also submitted in "compact form" to ESPP update 18.12:
https://indico.cern.ch/event/765096/contributions/3295600/

The flow



3.5GeV Linac

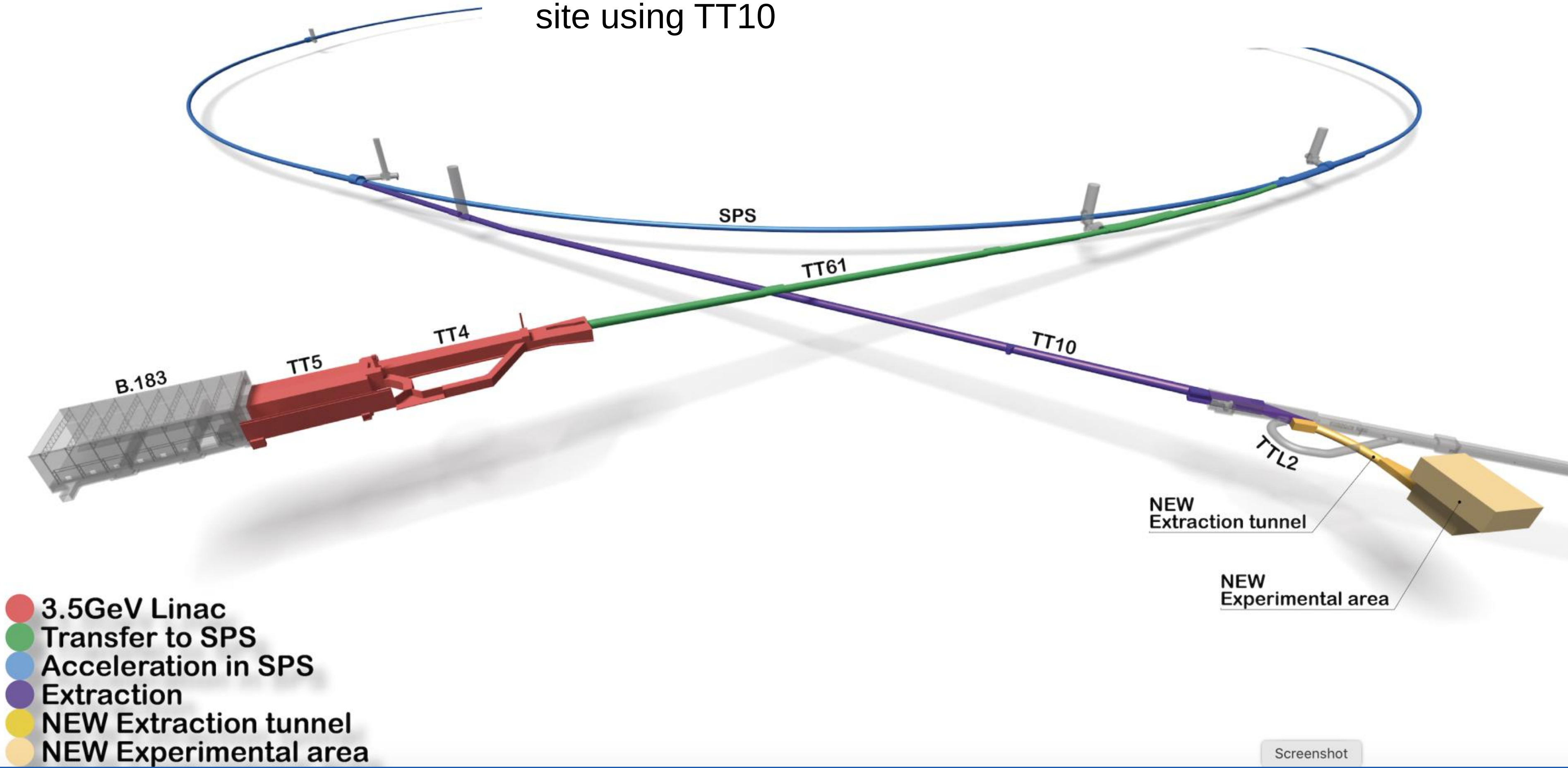
Transfer to SPS

Acceleration in SPS

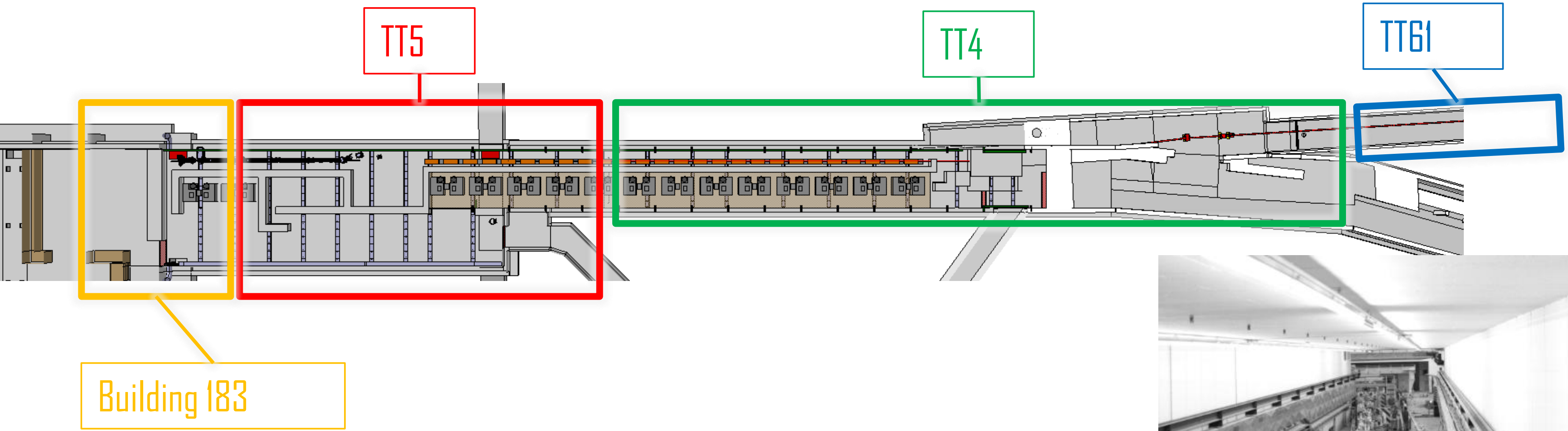
Extraction

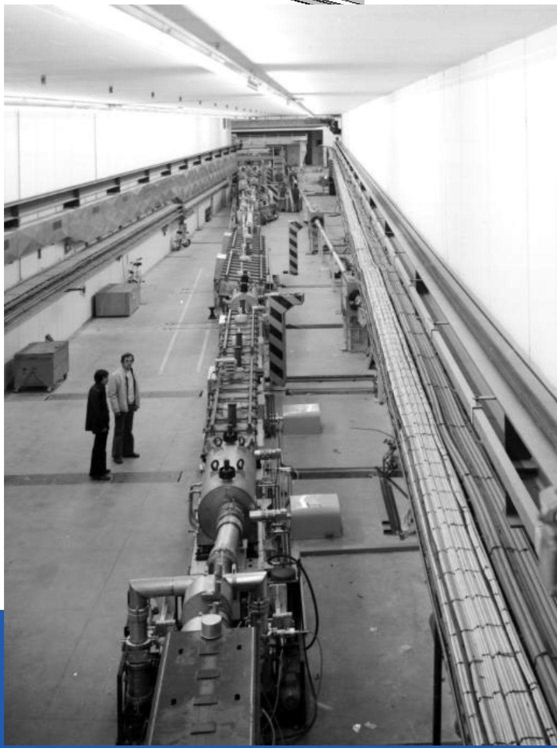
Accelerator implementation at CERN of LDMX type of beam

- X-band based 70m LINAC to ~3.5 GeV in TT4-5
- Fill the SPS in 1-2s via TT60
- Accelerate to ~16 GeV in the SPS (some interest for 20 GeV)
- Slow extraction to experiment
- Experiment(s) considered by bringing beam back on Meyrin site using TT10

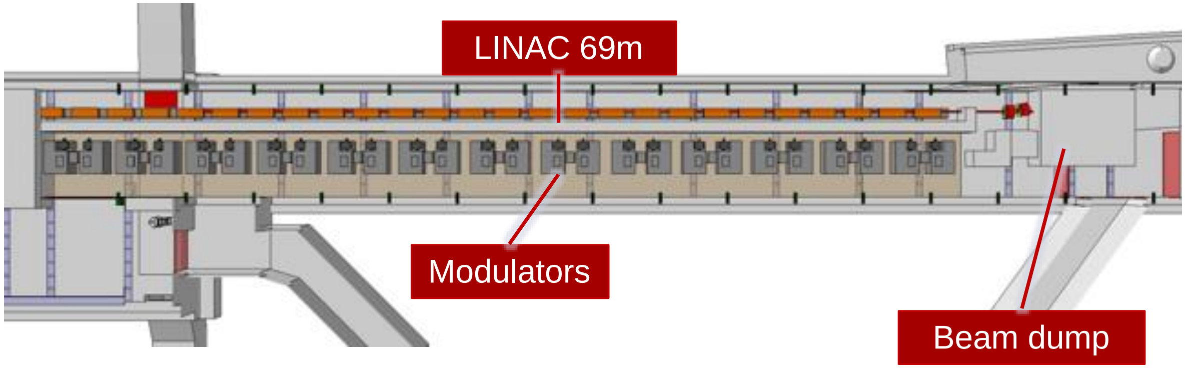


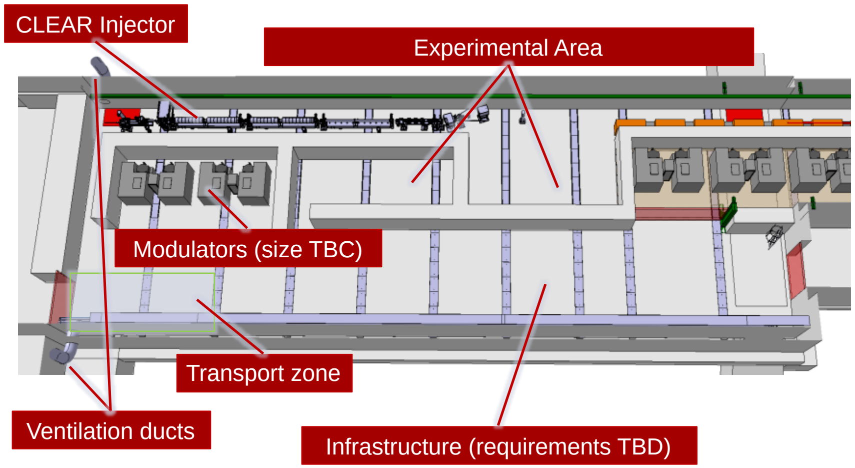
Building 183, TT5, TT4 and TT61



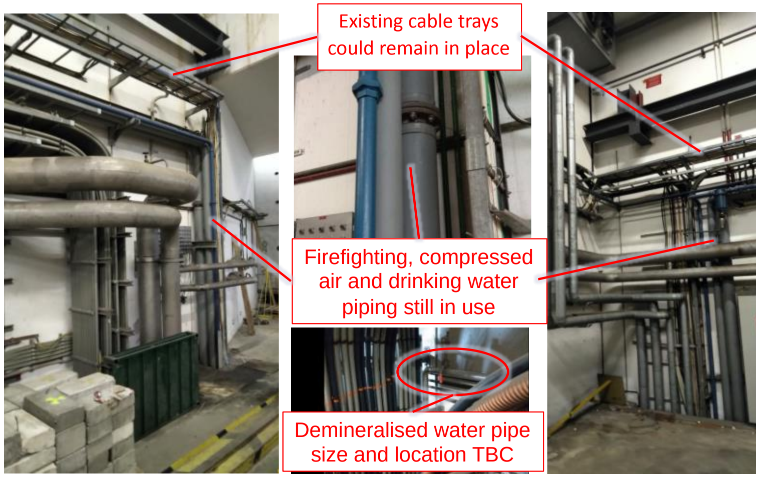


Linac in TT5/TT4



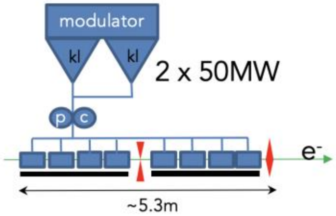


Reviewing: All services, EL, CV, access, safety, shielding/radiation, transport/installation, etc

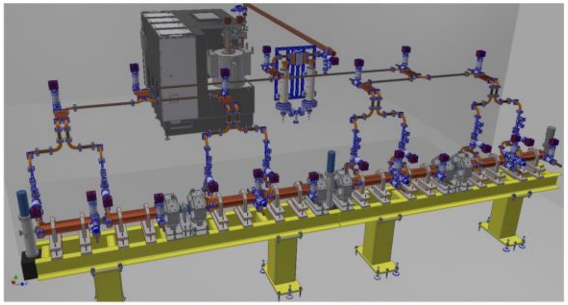


Linac parameters and parts

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



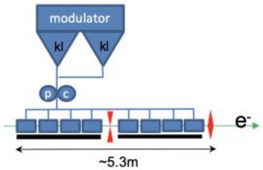
Possible parameters	
Energy spread (uncorrelated*)	<1MeV
Bunch charge	52 pC
Bunch length	~5ps
Norm. trans emittance	~10um
N bunches in one train	40
Train length	200 ns
Rep. rate	50/100 Hz



RF design of the X-BAND linac for the EUPRAXIA@SPARC_LAB project
M. Diomede Et al., IPAC18

- Flexible bunch pattern provided by photo-injector 1.25, 2.5, 5, 10 … 40ns bunch spacing (only constrained by the SPS)
- High repetition rate, for example
  - 200 ns trains at 100 Hz
- To be installed in the available transfer tunnels TT4, in line with the SPS
- Room for accelerator R&D activities at end of linac (duty cycle in many cases low for SPS filling so important potential)

Examples:



One RF unit accelerates 200ns bunch train up to 264 MeV

Pulse compressor

Accelerating structure

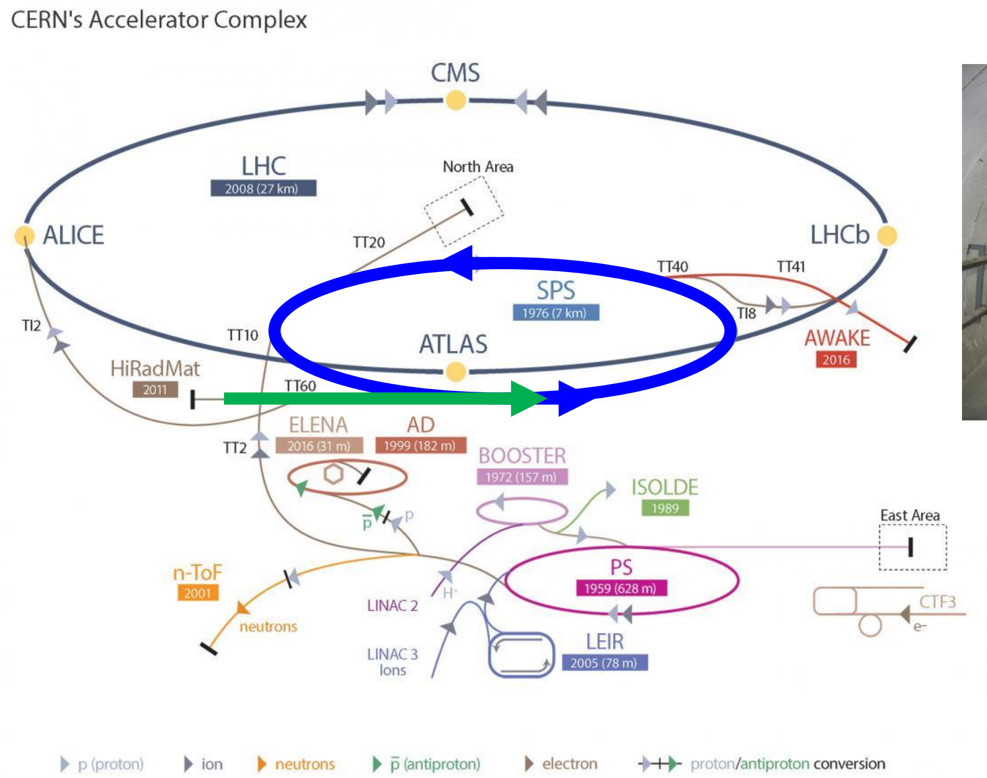
Assembled systems in continues operation at CERN

Transfer tunnel, TT60, from the Linac into the SPS

Injection into the SPS

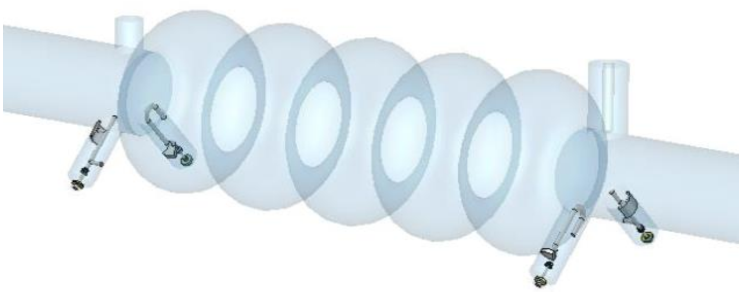
Bunch to bucket injection in the SPS longitudinal RF structure.

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



SPS RF: 800 MHz, 5-Cell

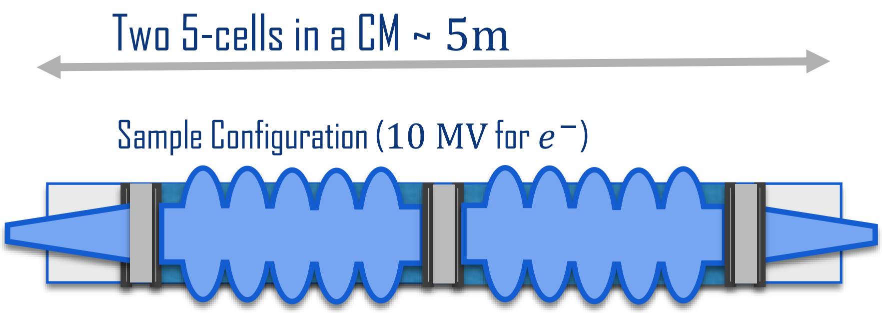
- In mechanical bypass, moved in/out of beam in ~10 min. No proton constraints for beam loading/impedance. Aperture ok for LHC beam
- Moderate HOM damping using 4 LHC-type HOM couplers for electron beam
- Study the feasibility of dynamic by-pass for electrons – equivalent to in line beam



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 ~ 5m

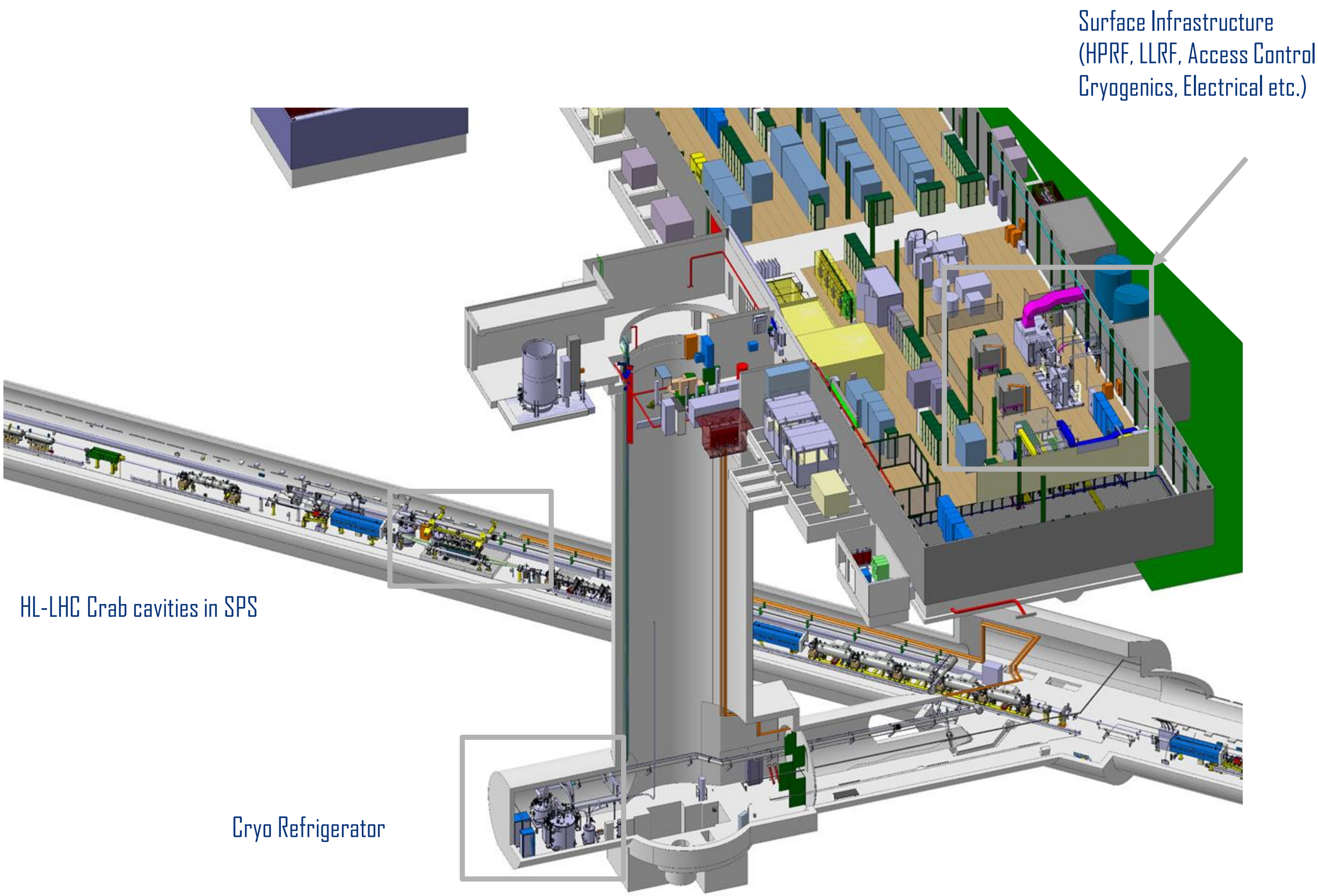
Sample Configuration (10 MV for e^-)



FCC-800 MHz prototype

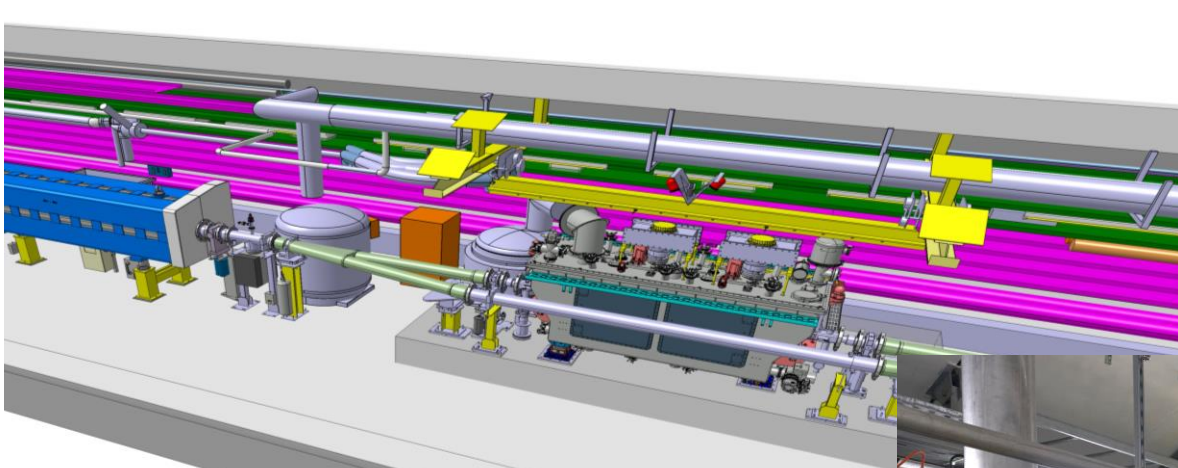
* First approximation – requires detailed study to optimize RF system

Crab Cavity Bypass – SPS-LSS6



Crab Cavity Bypass – SPS-LSS6

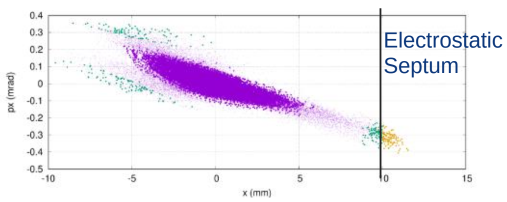
- Movement in/out of SPS-ring by 510mm – movement approx. 10 min with 2K Helium (~30 W)
- Independent vacuum system
- As mentioned, look also as longer dynamic by pass giving more flexibility

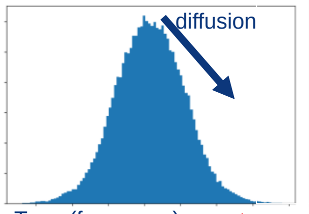


SPS, transfer lines and exp. area

Slow extraction principle, in frequency space

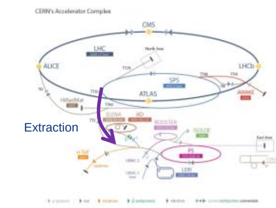
- Spread in oscillation frequency within the beam follows
  - Transverse distribution
  - Longitudinal distribution in presence of chromatic lattice
- Position of the resonant condition is set by the machine
- Synchrotron radiation constantly diffuse the particles to fill the tail in the distribution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

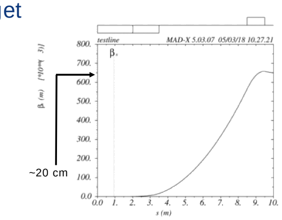




Electron beam transfer line from the SPS to experiments

- 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/cm²/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





Extracted beam and experimental area

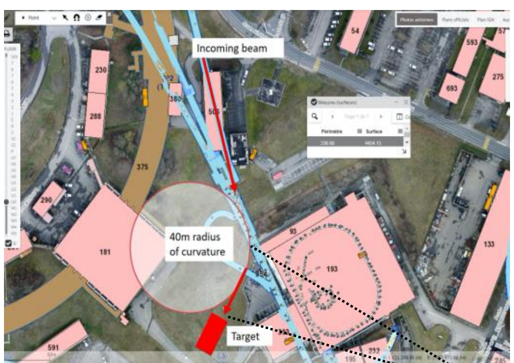
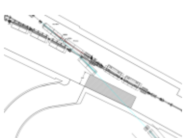


FIG. 43: Visualisation of the proposed underground (shown in blue) and overground (shown in red) facilities

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



In total ~50 m new tunnel

FIG. 38: Plan view of proposed layout

Instrumentation

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

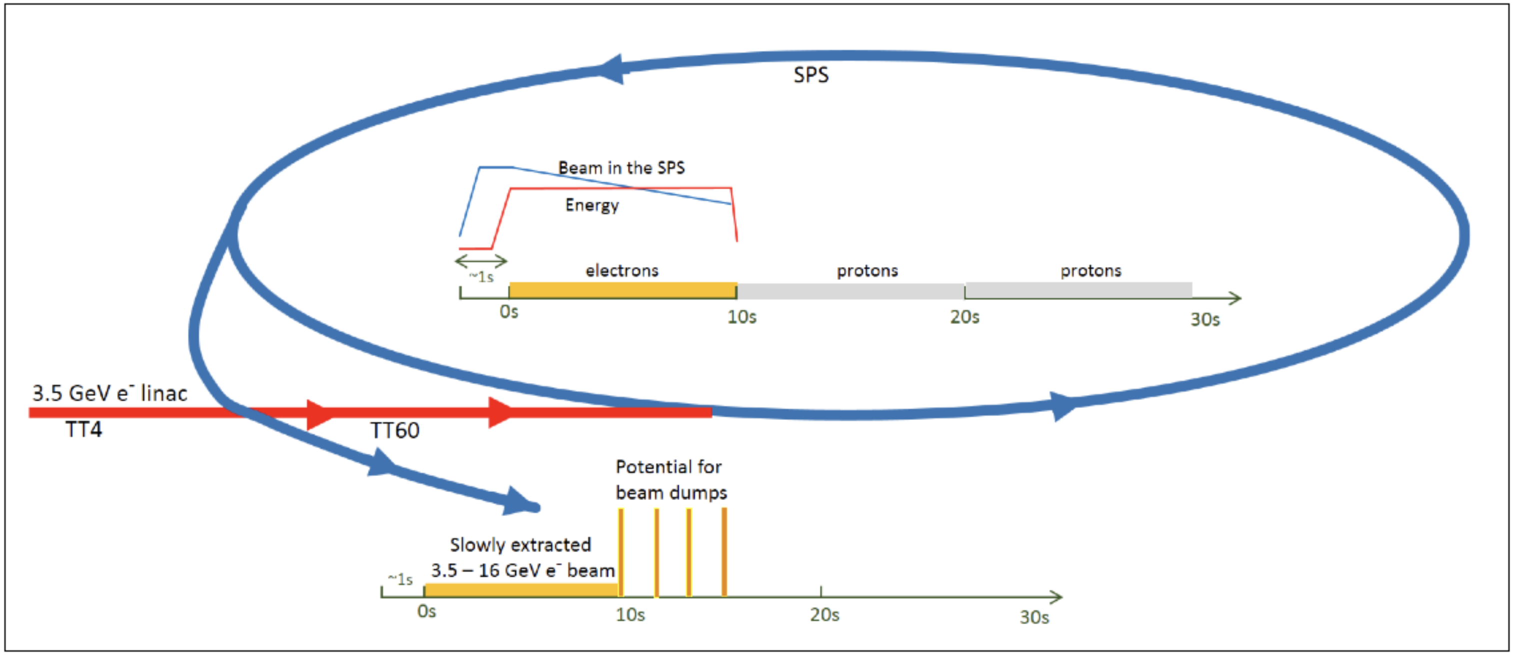
The challenge of measuring very low intensity beam can be circumvented using a higher intensity for beam setup

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:

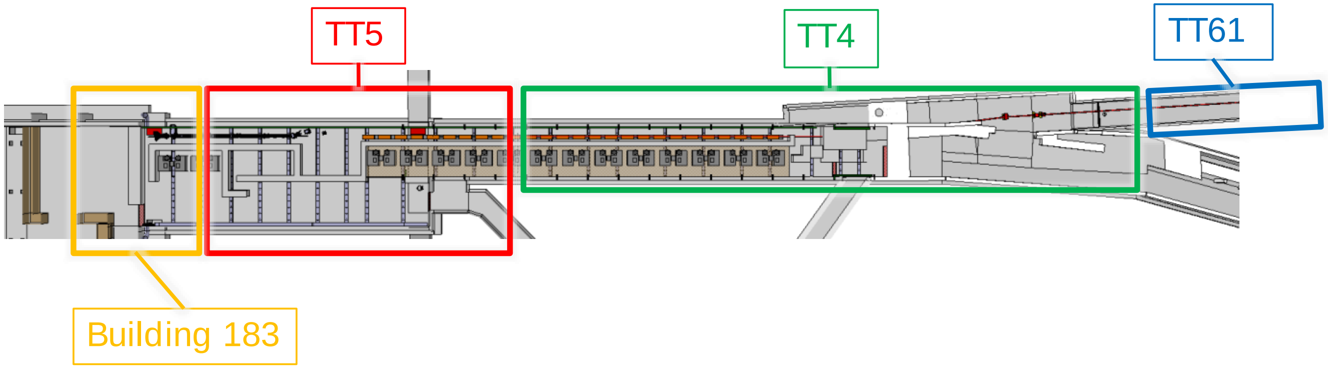


Potential use of such a facility

(linac more than 90% free)

Physics:

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



Accelerator physics opportunities (not all studied currently)

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 for other potential future facilities using electrons (rings) considered at CERN, for example the RF systems

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. Recent results: https://acceleratingnews.web.cern.ch/article/first-experimental-results-clear-facility-cern

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

Also to be updated

Costs from EoI

Sources

- Industrial (e.g. RF components, structures for linacs)
- "Standard" rates (e.g. civil engineering)
- PBS with ~80 items, estimates from technical responsible

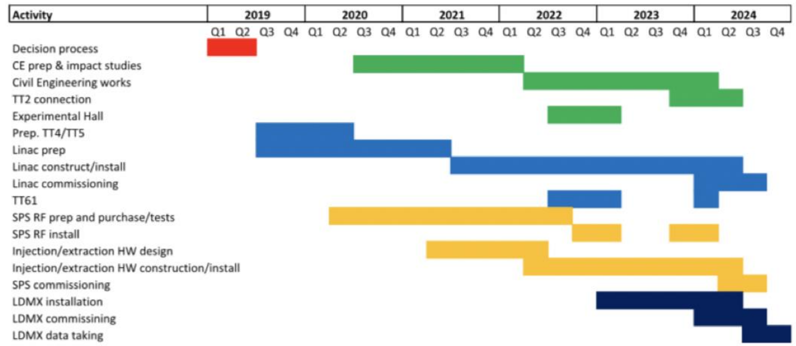
TABLE I: Cost summary

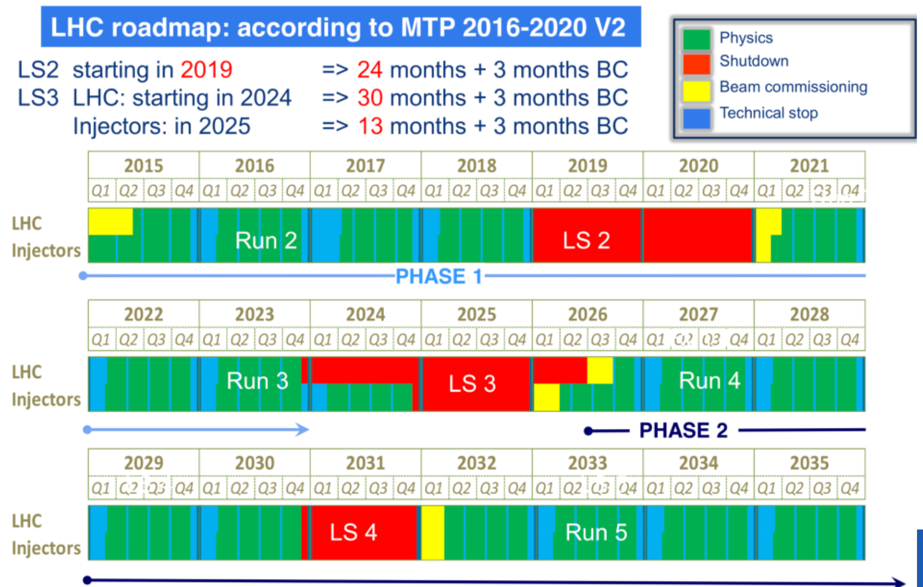
PBS	Item	Cost MCHF
1.1	Source	6.0
1.2	X-band linac	34.1
2.1	Linac to SPS transfer	4.6
2.2	SPS fast injection	3.4
2.3	SPS ring	10.5
2.4	SPS slow extraction	3.3
2.5	Transfer SPS to Exp. Area	4.2
3.2	Civil Engineering	11.4
3.3	Exp. Area infrastructure	2.0
	Sum	**79.5**

Schedule in the EoI

Technically based … however

- Respects that efforts during LS2 has to be limited
- No major spending or commitments until Spring/mid 2020 (ESU completion) -> need significant resources from then
- Final connection after end of LHC run in 2023
- Can run during LS3 when/if the SPS is available
- Need to decide now if we move ahead towards a CDR or similar in a years time – resource/priority issue





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
  - LDMX interest in pursuing this option as beam close to ideal

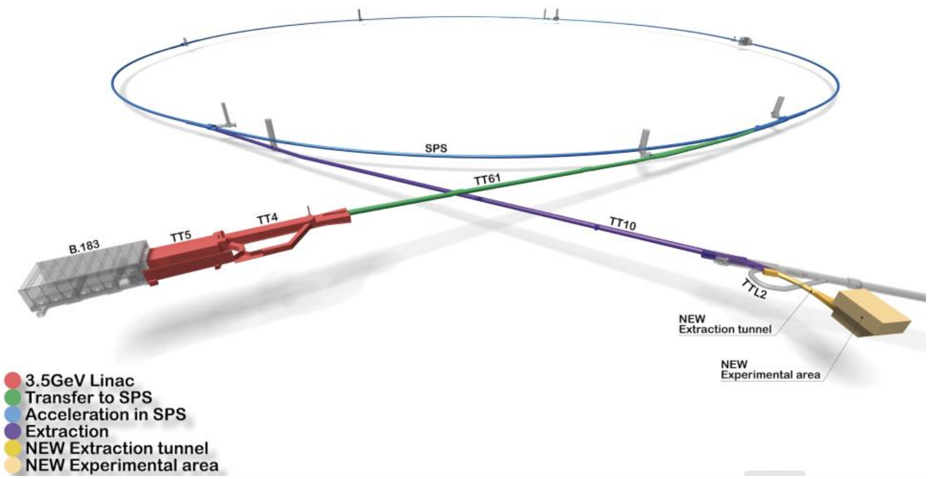
- Will also provide many opportunities for important and strategic accelerator R&D at CERN – and opens the door to future electron facilities in general

- Currently updating the EoI document with special emphasis on the SPS RF, civil engineering and infrastructure, implementation planning – aim to complete CDR by end March 2020

eSPS, overview

Accelerator implementation at CERN of LDMX type of beam

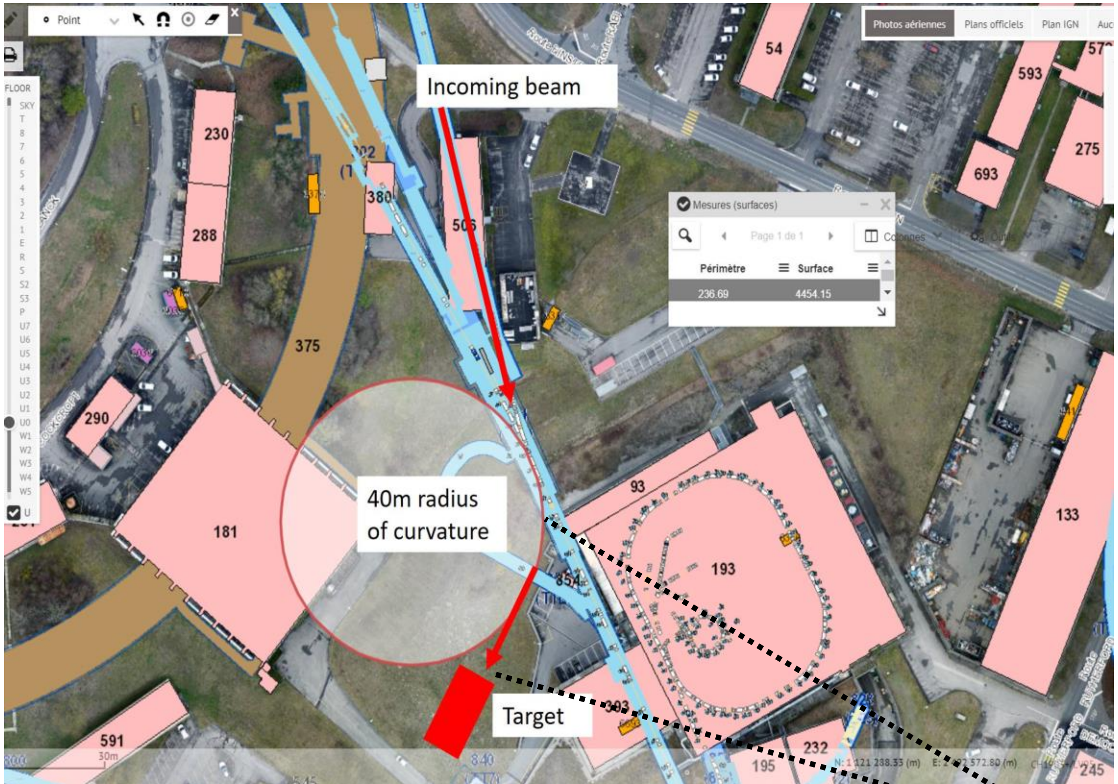
- X-band based 70m LINAC to ~3.5 GeV in TT4-5
- Fill the SPS in 1-2s via TT60
- Accelerate to ~16 GeV in the SPS
- Slow extraction to experiment
- Experiment(s) considered by bringing beam back on Meyrin site using TT10

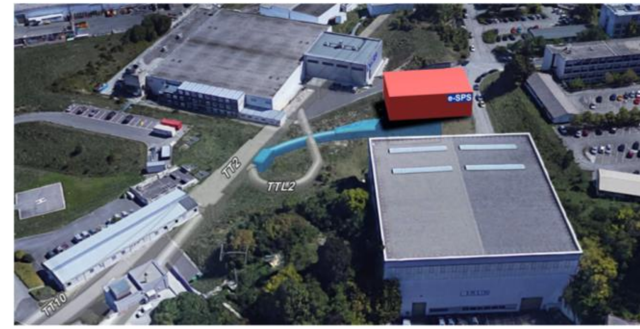


Beyond LDMX type of beam, other physics experiments considered (for example heavy photon searches)

Acc. R&D interests (see later): Overlaps with CLIC next phase (klystron based), future ring studies (FCC-ee), FEL linac modules, e-beams for plasma, medical/irradiation/detector-tests/training, impedance measurements, instrumentation, positrons and damping ring R&D

Extracted beam and experimental area





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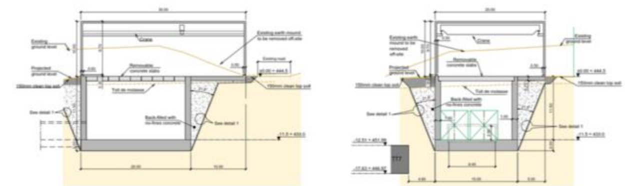

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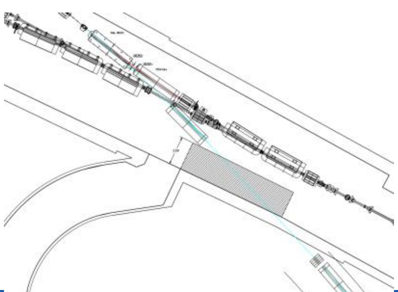

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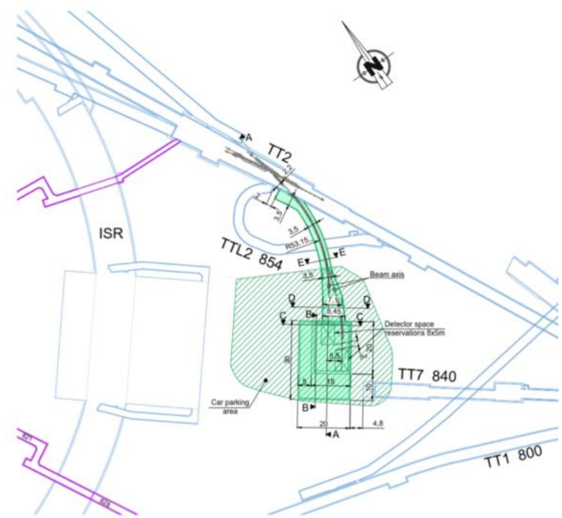

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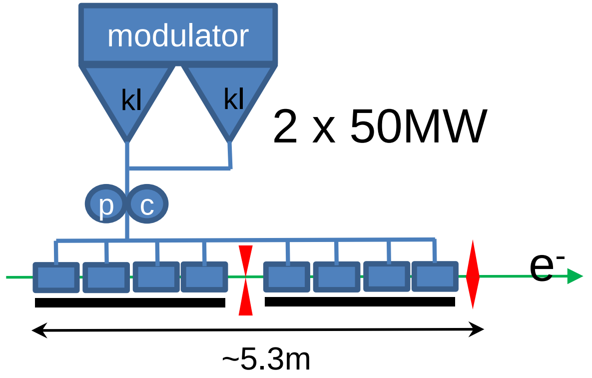

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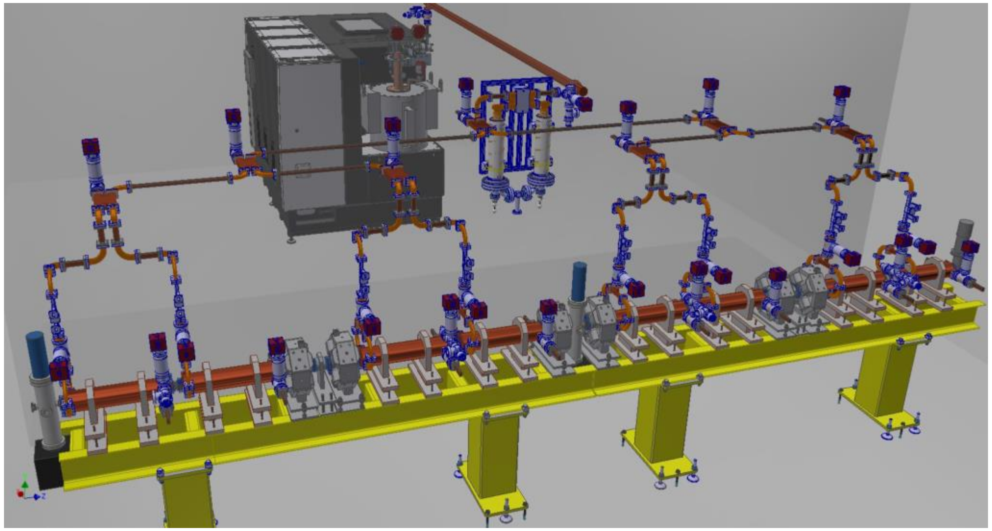
Rep. rate	50/100 Hz



RF design of the X-BAND linac for the EUPRAXIA@SPARC_LAB project
M. Diomede Et al., IPAC18

Costs from EoI

Sources

- Industrial (e.g. RF components, structures for linacs)
- ”Standard” rates (e.g. civil engineering)
- PBS with ~80 items, estimates from technical responsible

TABLE I: Cost summary

PBS	Item	Cost MCHF
1.1	Source	6.0
1.2	X-band linac	34.1
2.1	Linac to SPS transfer	4.6
2.2	SPS fast injection	3.4
2.3	SPS ring	10.5
2.4	SPS slow extraction	3.3
2.5	Transfer SPS to Exp. Area	4.2
3.2	Civil Engineering	11.4
3.3	Exp. Area infrastructure	2.0
	Sum	**79.5**

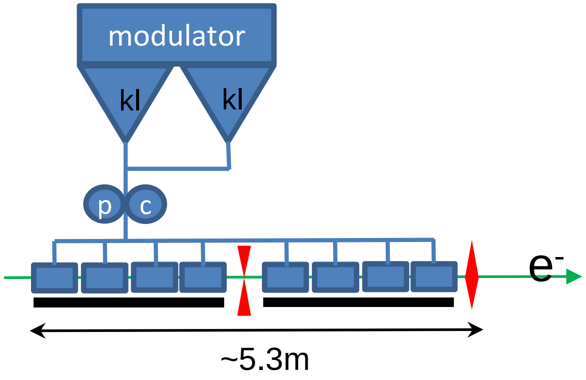
Linac components available

- Examples:

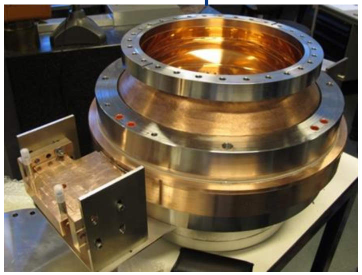
Klystron

+

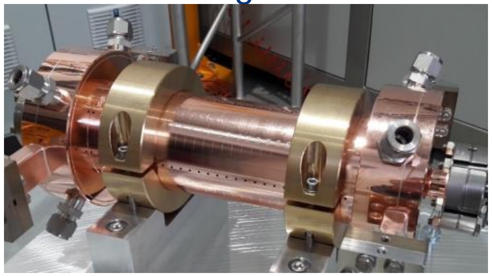
Modulator



Pulse compressor

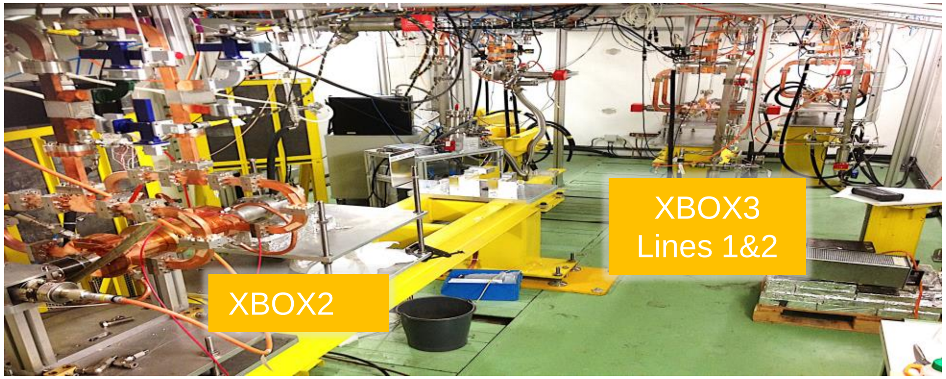


Accelerating structure



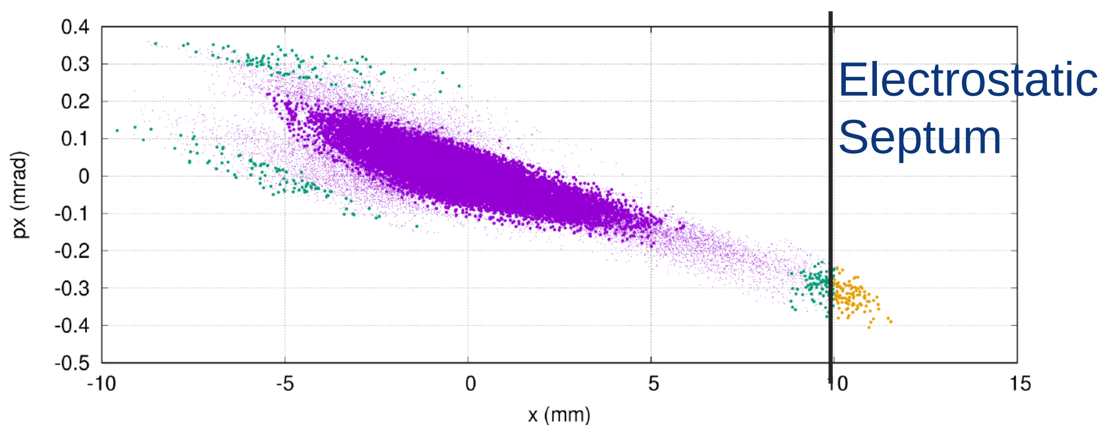
- One RF unit accelerates 200ns bunch train up to 264 MeV

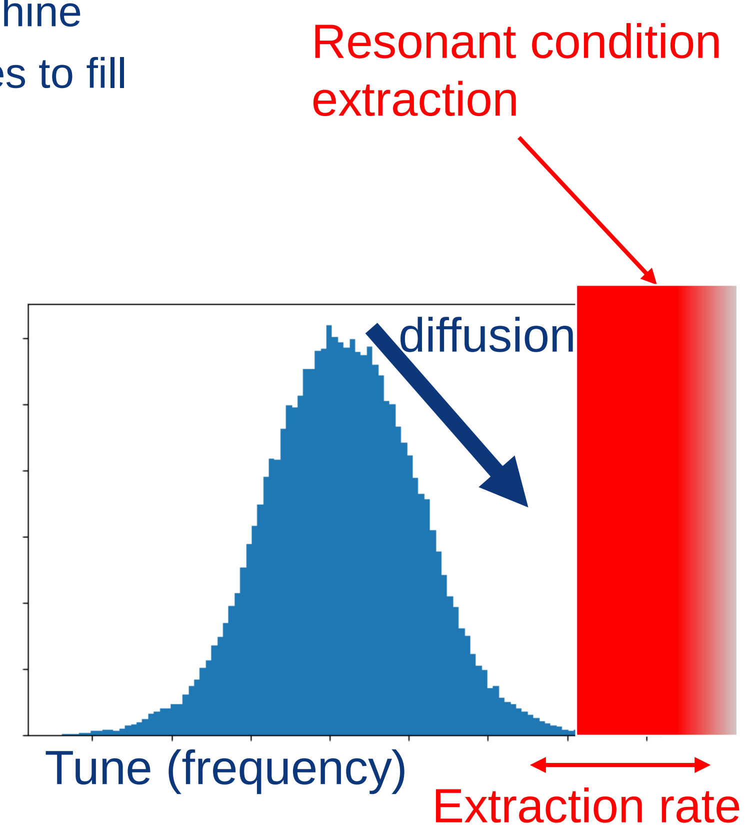
Assembled systems in continues operation at CERN



Slow extraction principle, in frequency space

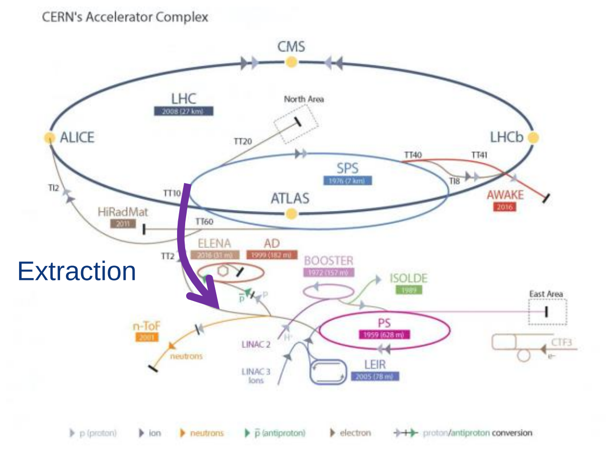
- Spread in oscillation frequency within the beam follows
  - Transverse distribution
  - Longitudinal distribution in presence of chromatic lattice
- Position of the resonant condition is set by the machine
- Synchrotron radiation constantly diffuse the particles to fill the tail in the distribution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

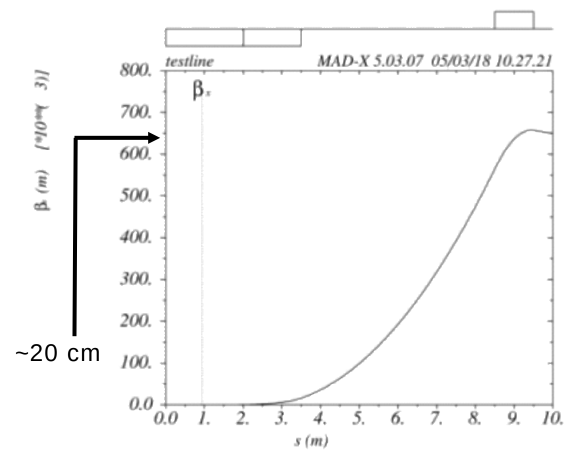




Electron beam transfer line from the SPS to experiments

- 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





Instrumentation

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:

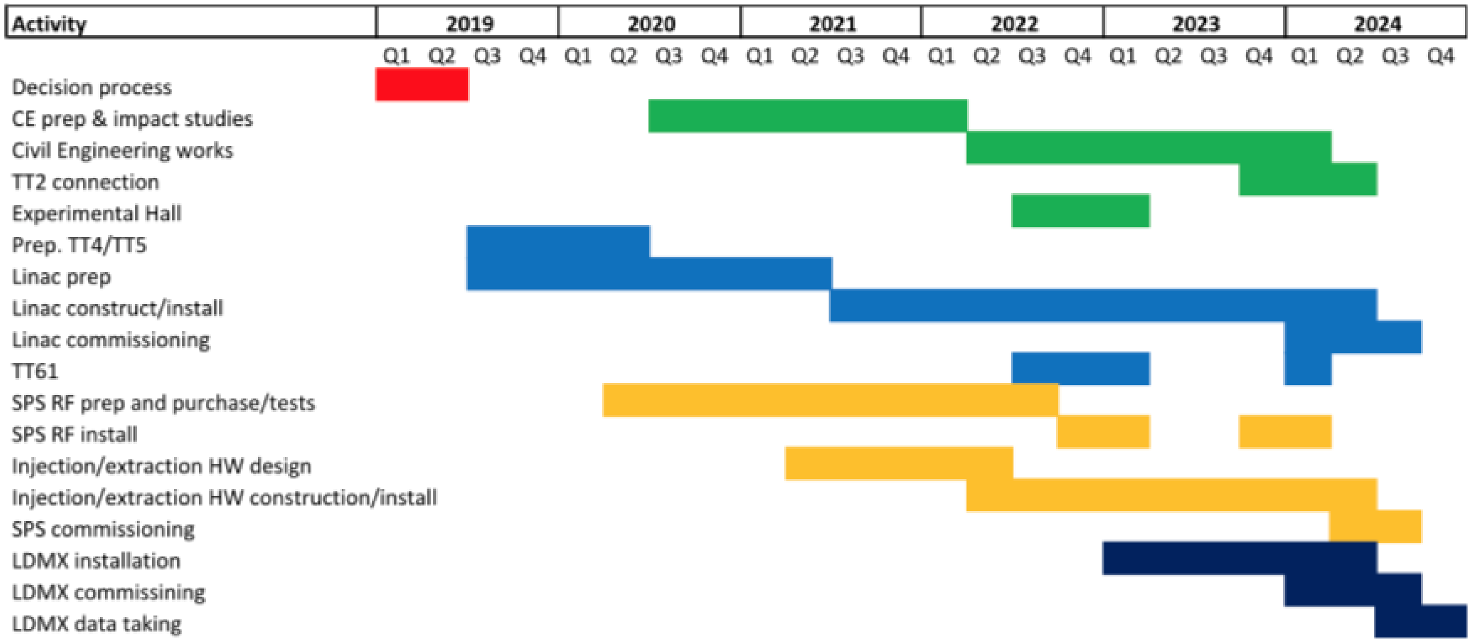
- Position & Intensity
  - Use of fibre monitors.
    - Developed for new EHN1 (neutrino platform) secondary lines
    - Scintillating (or Cherenkov) fibres
    - Low material budget
    - > 90% efficiency for single particles demonstrated
  - R&D required to make them UHV compatible

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

Schedule in the EoI

Technically based … however

- Respects that efforts during LS2 has to be limited
- No major spending or commitments until Spring/mid 2020 (ESU completion) -> need significant resources from then
- Final connection after end of LHC run in 2023
- Can run during LS3 when/if the SPS is available
- Need to decide now if we move ahead towards a CDR or similar in a years time – resource/priority issue



LHC roadmap: according to MTP 2016-2020 V2

LS2 starting in 2019 => 24 months + 3 months BC
LS3 LHC: starting in 2024 => 30 months + 3 months BC
Injectors: in 2025 => 13 months + 3 months BC