A primary electron beam facility at CERN

EPS Ghent July 12th 2019

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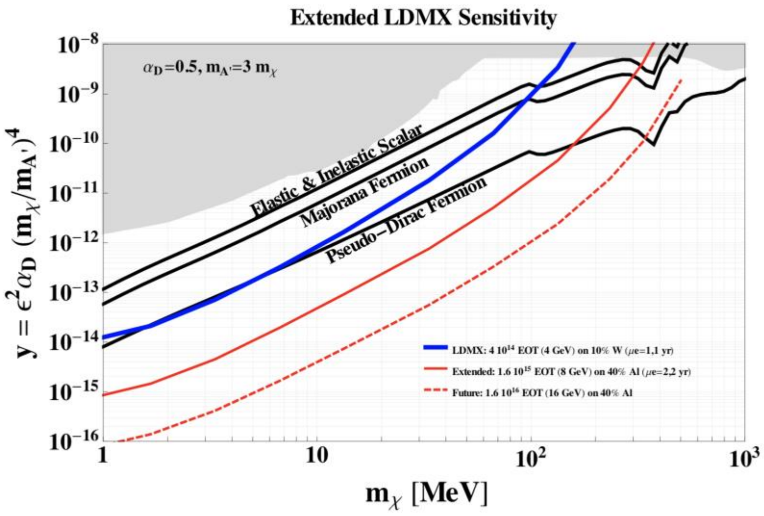
Motivations

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

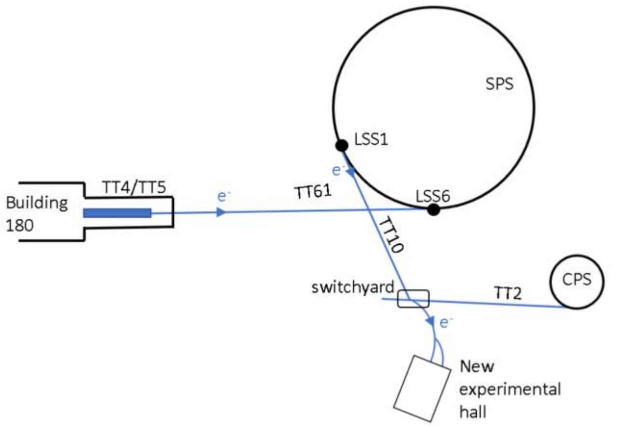


Accelerator R&D:

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

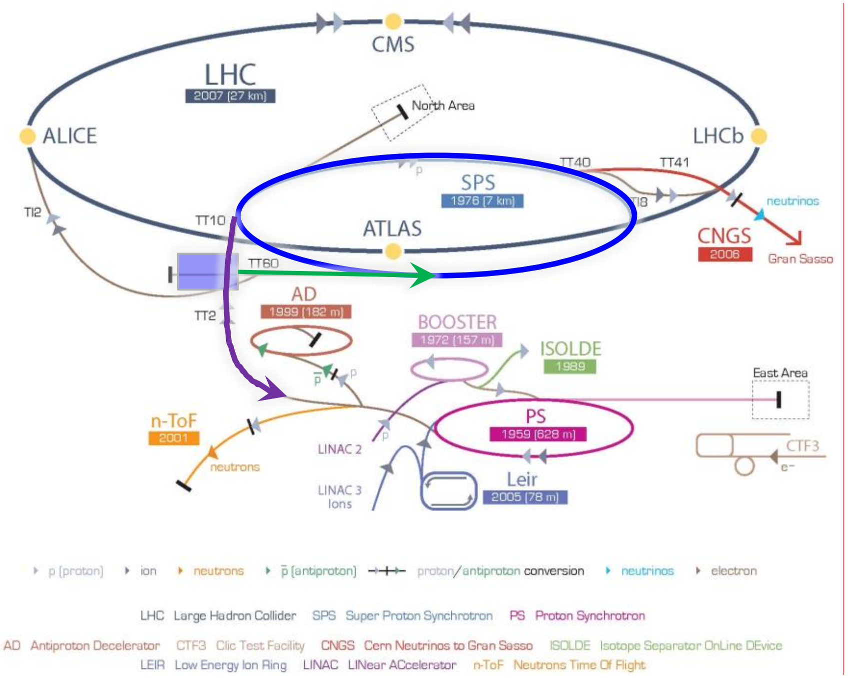
- Future accelerator R&D more generally: Accelerator R&D and project opportunities with e-beams as source
- Main directions: Novel Acc. studies (ALIC) and CLEARER



Electrons at CERN, overview

Accelerator implementation at CERN of LDMX type of beam

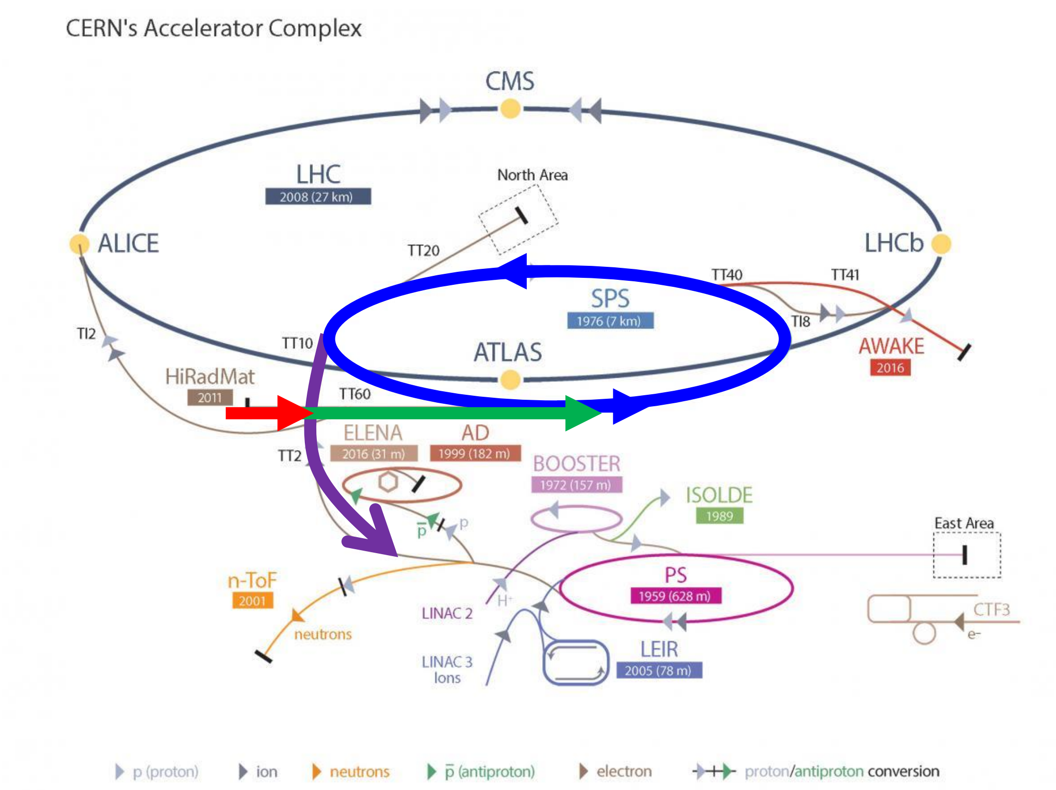
- X-band based 70m LINAC to ~3.5 GeV in TT4-5
- Fill the SPS in 1-2s (bunches 5ns apart) via TT60
- Accelerate to ~16 GeV in the SPS
- Slow extraction to experiment in 10s as part of the SPS super-cycle
- Experiment(s) considered by bringing beam back on Meyrin site using TT10



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, FEL linac modules, e-beams for plasma, medical/irradiation/detector-tests/training, impedance measurements, instrumentation, positrons and damping ring R&D

The flow



3.5GeV Linac

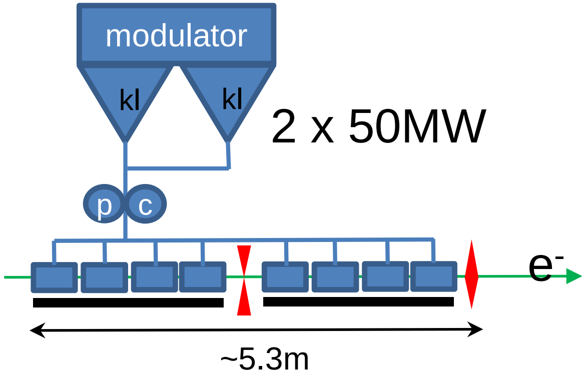
Transfer to SPS

Acceleration in SPS

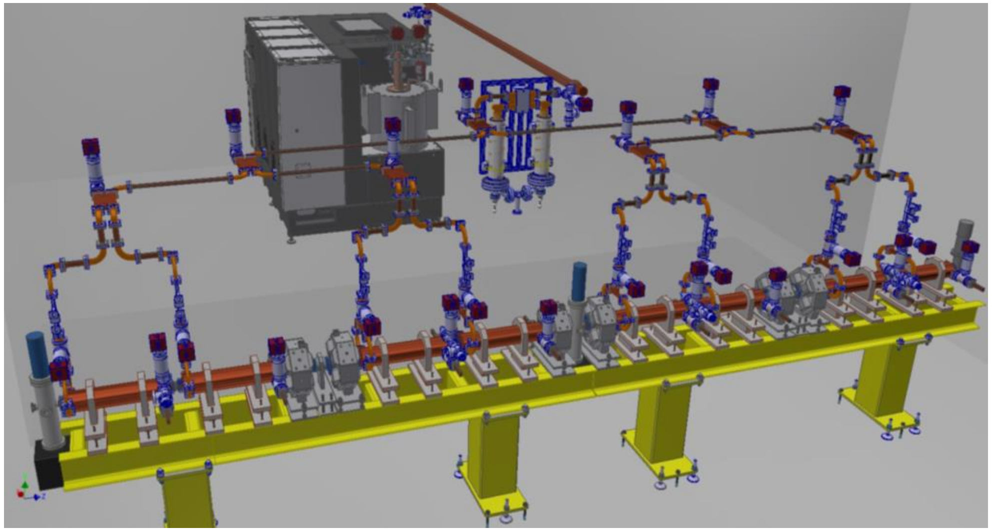
Extraction

Linac parameters

- 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

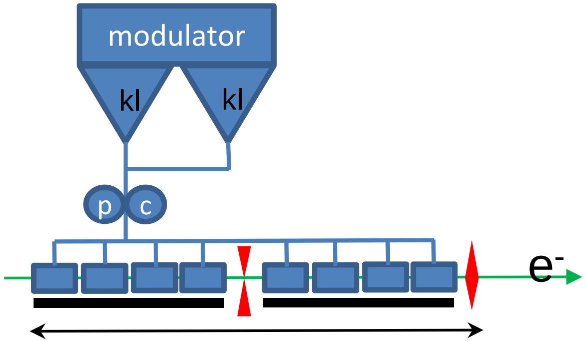


RF design of the X-BAND linac for the EUPRAXIA@SPARC_LAB project
M. Diomede Et al., IPAC18

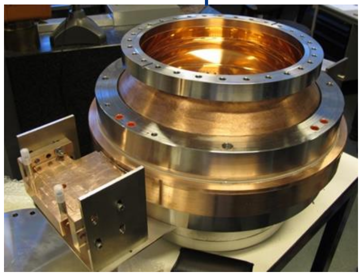
Linac components available

- Examples:

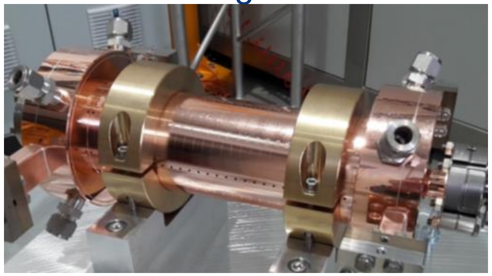
Klystron + Modulator



Pulse compressor

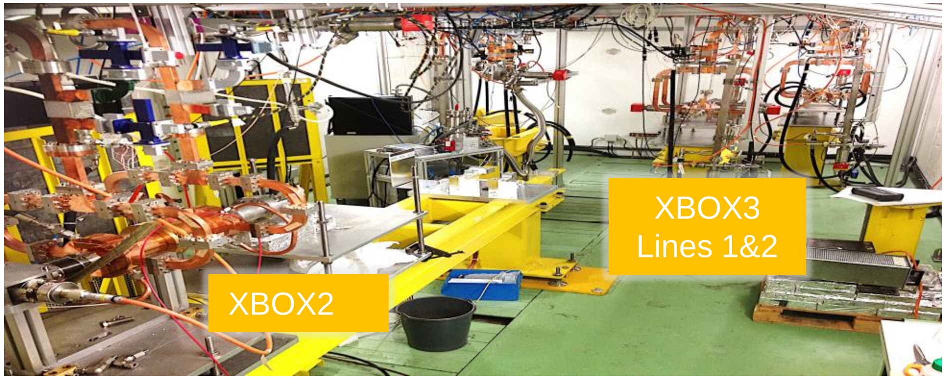


Accelerating structure



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

Assembled systems in continues operation at CERN



Linac in TT5/TT4

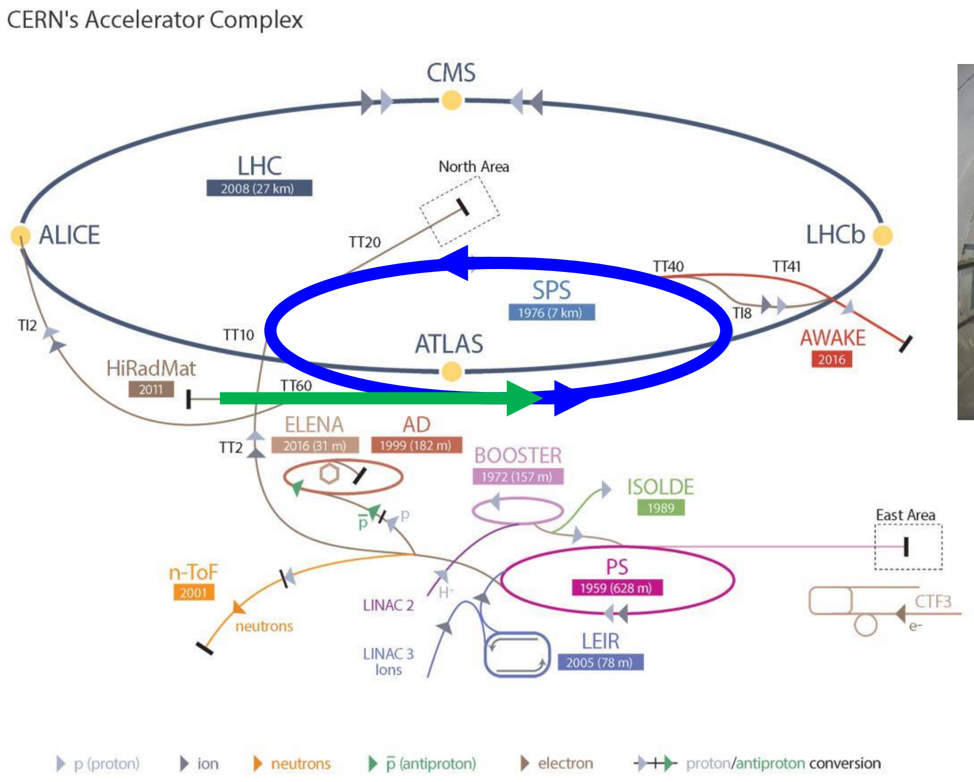
- Flexible bunch pattern provided by photo-injector
  5ns, 10ns, … 40ns bunch spacing (only constrained by the SPS)
- High repetition rate, for example
  - 200 ns trains at 100 Hz
- To be installed in the available transfer tunnels TT4, in line with the SPS
- Room for accelerator R&D activities at end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

Transfer tunnel, TT60, from the Linac into the SPS

Injection into the SPS

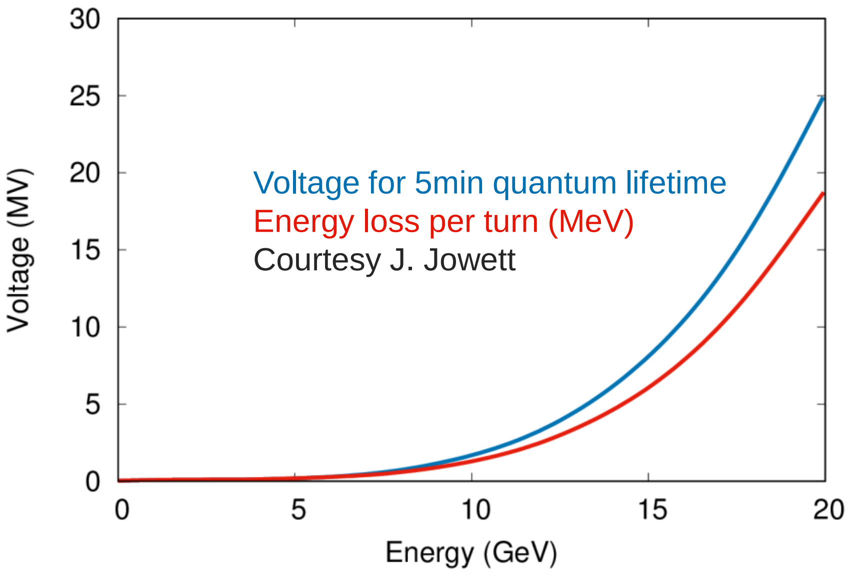
Bunch to bucket injection in the SPS longitudinal RF structure.

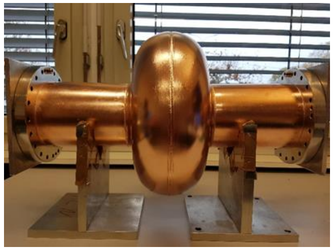
Total of 75 trains of 40 bunches 3000 bunches 10^{12} electrons in the ring



SPS RF system

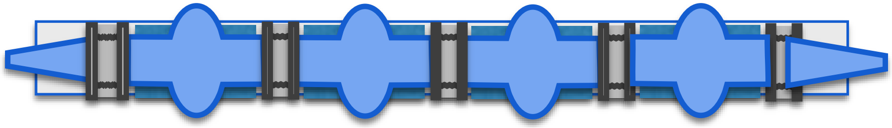
- Acceleration to 16 GeV can safely be achieved, need ~10 MV
- Studies show that a superconducting RF system is the most appropriate. The preferred frequency is 800 MHz – two options seem possible in this case (see below)
- Installation in LSS6 (LHC extraction region) is the preferred location to exploit the existing infrastructure from the crab cavity installation
- Use the mechanical bypass, a pulsed bypass, or inline



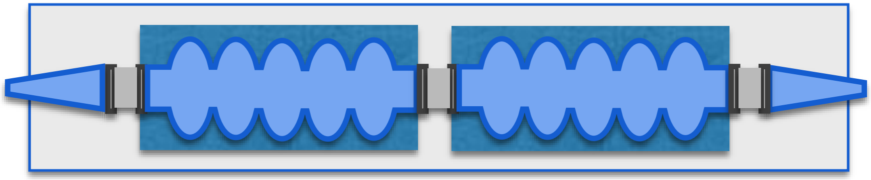


FCC-800 MHz prototypes

Sample Configuration (10 MV)

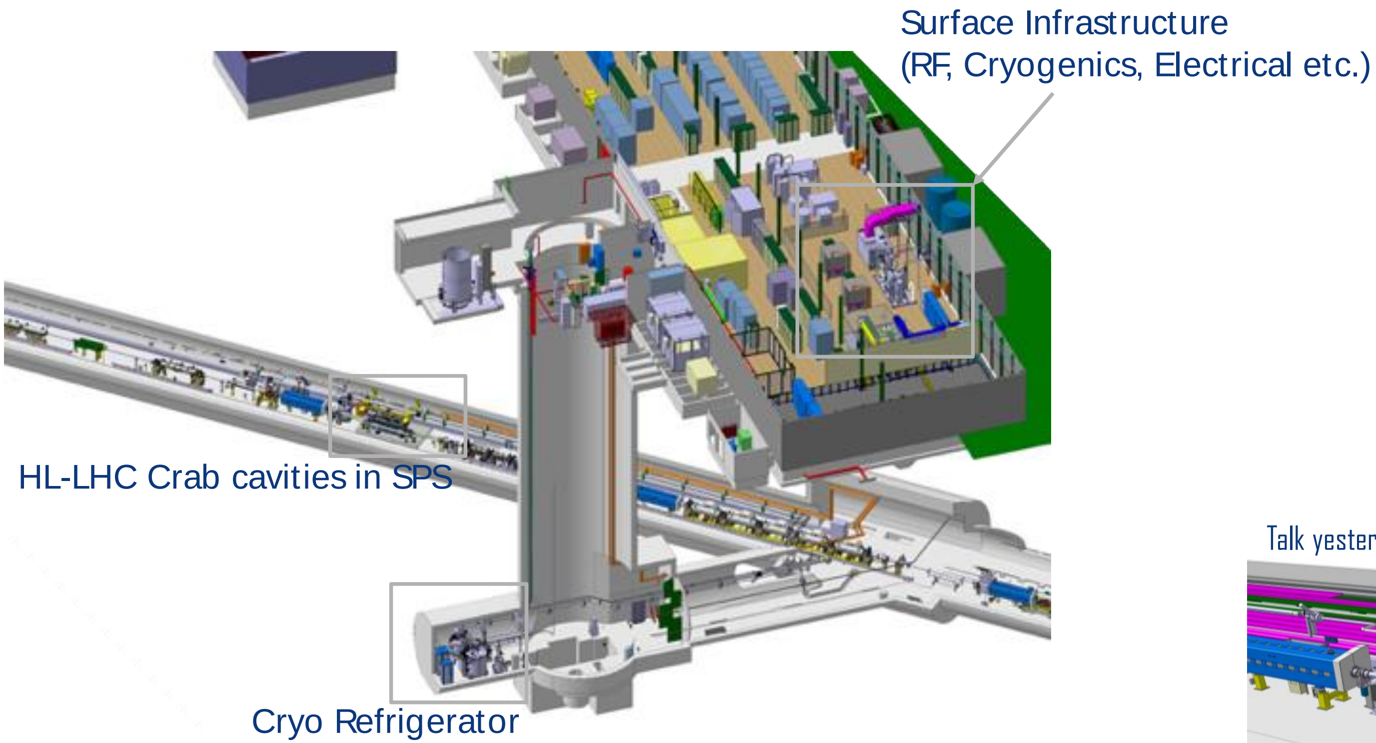


Four 1-cell in a CM ~ 5m

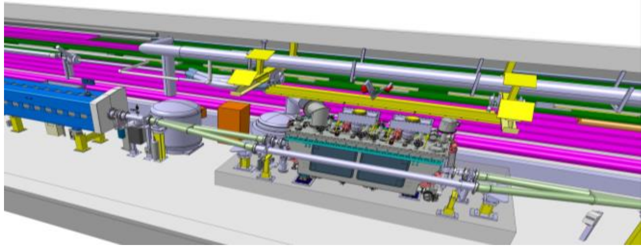


Two 5-cells in a CM ~ 5m

RF: use Crab Cavity Bypass – SPS-LSS6



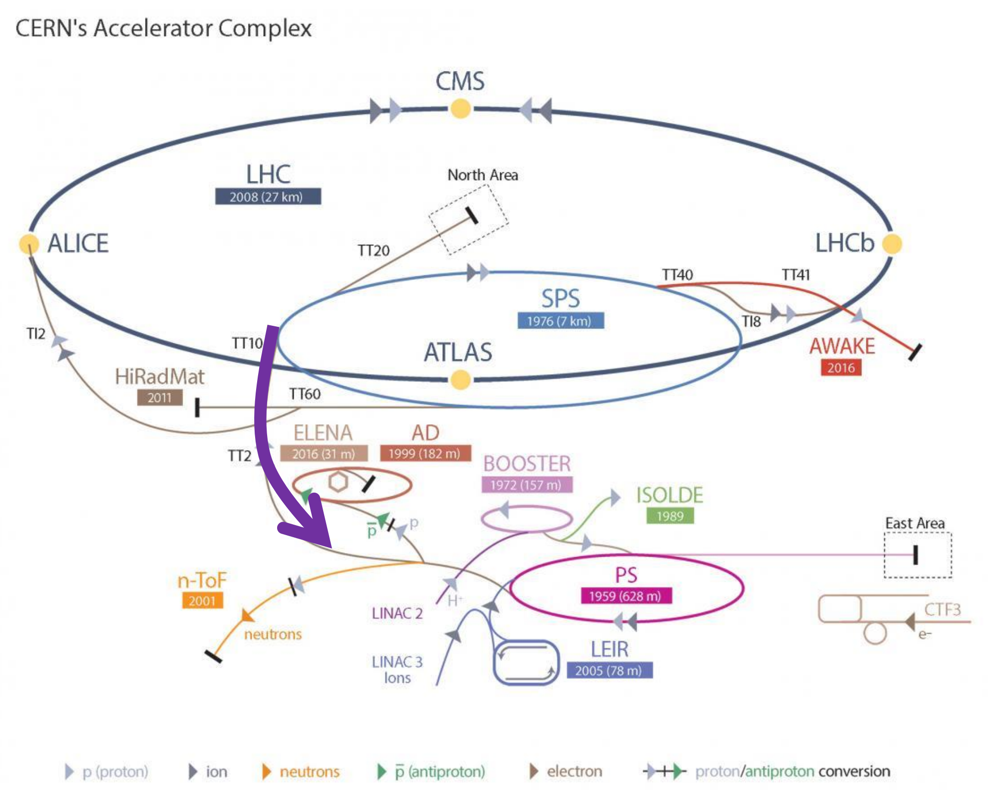
Talk yesterday by Rama Calaga: (LINK)



- Movement in/out of SPS-ring by 510mm – movement approx. 10 min with 2K Helium
- Independent vacuum system

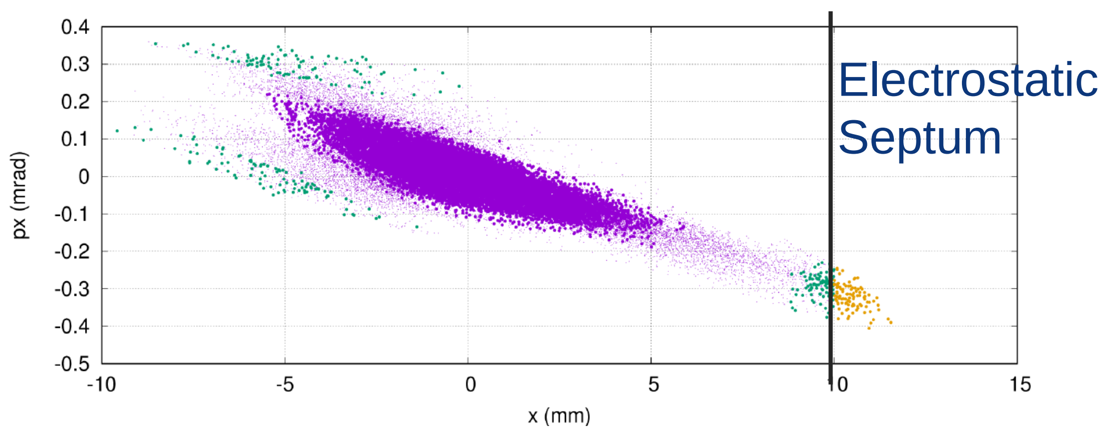
Slow extraction to experiments

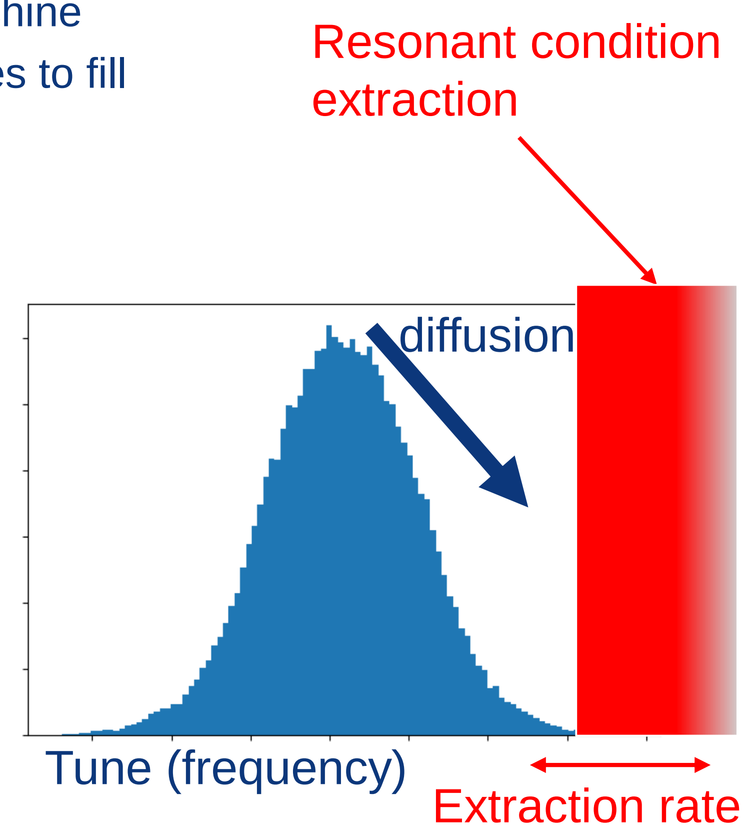
Extraction



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



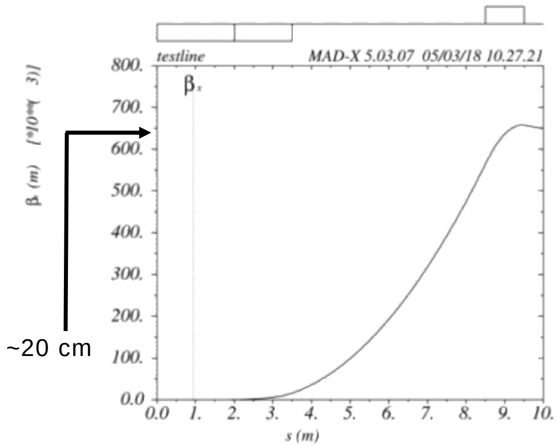


Electron beam transfer line from the SPS to experiments

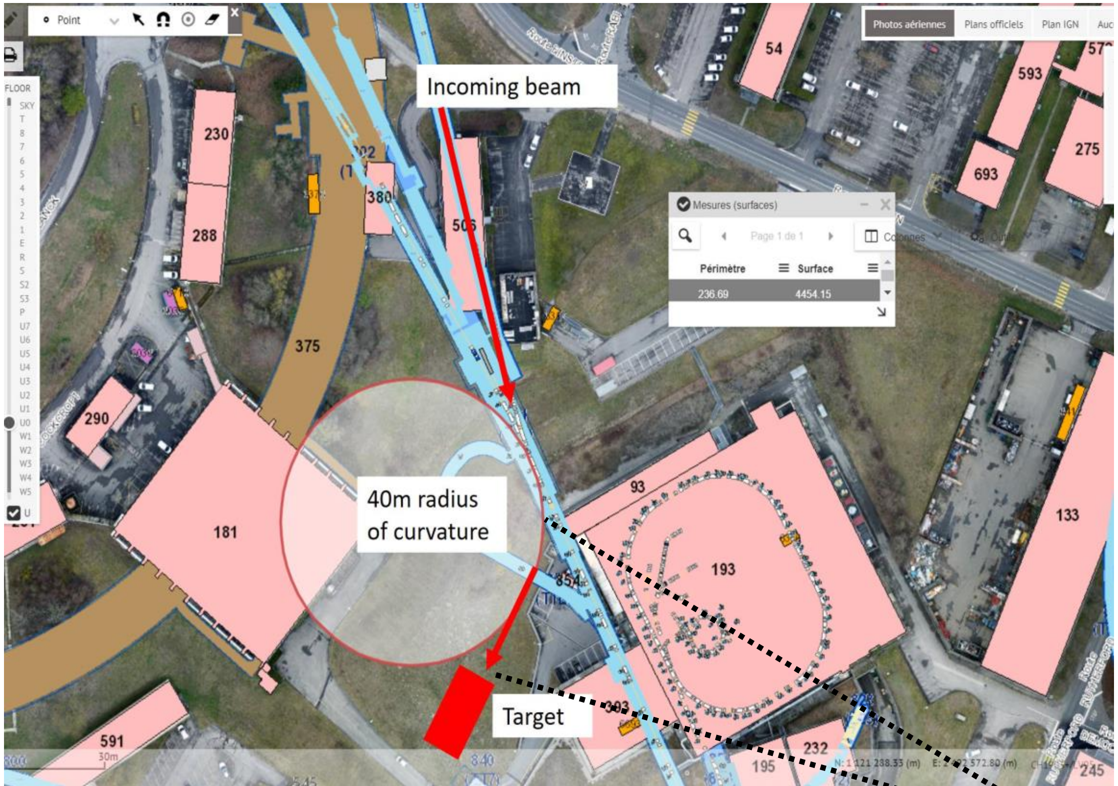
- Uses existing TT10 line, designed to transport 10/20 GeV beams

- 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



Extracted beam and experimental area



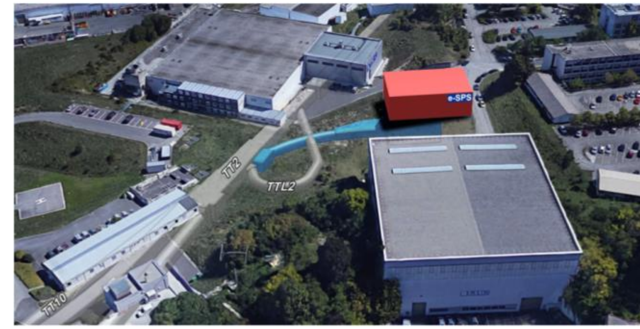


FIG. 43: Visualisation of the proposed underground (shown in blue) and overground (shown in red) facilities

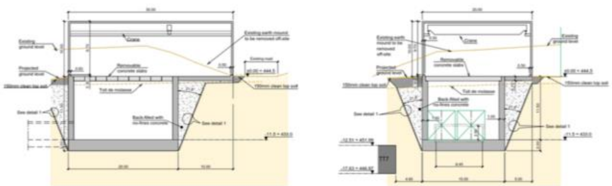


FIG. 41: Typical Sections through the experimental hall parallel to the beam-line (left) and transverse to the beam-line (right)

In total ~50 m new tu

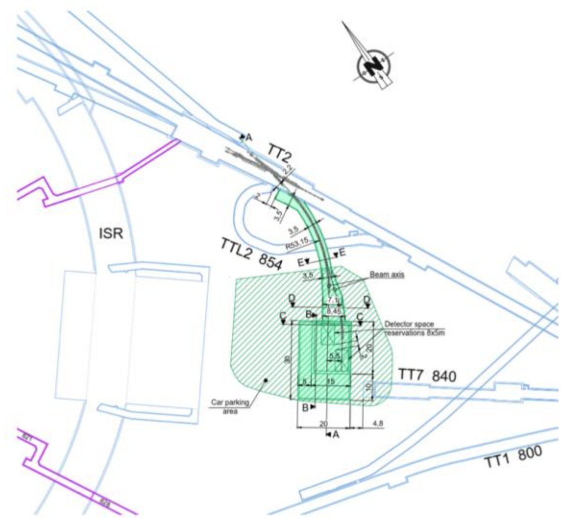


FIG. 38: Plan view of proposed layout

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

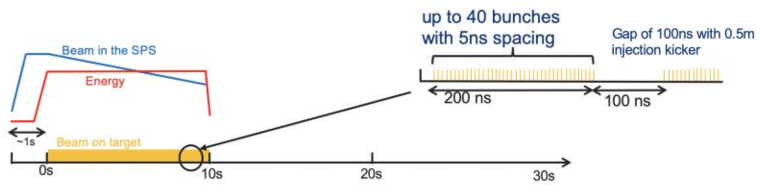
SPS:
- Position
  - Standard orbit system (consolidated in LS2)
  - Should be able to measure to 1e9 (limit ~5e8)
- Beam Size
  - Wirescanners
  - Possible use of synchrotron radiation
- Intensity
  - DC Transformer OK for total current
  - Fast BCT does not distinguish 5ns spaced bunches
  - Could do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

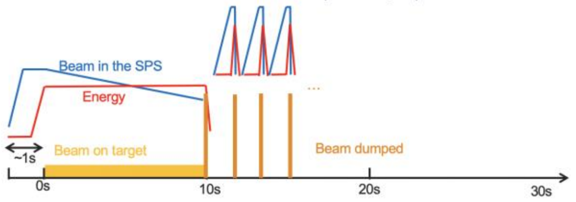
Structure of extracted beam as part of super cycle



- Flexibility
  - Bunch spacing 5ns, 10ns, … 40ns (with 800 MHz can go down to 1.25ns)
  - Average electrons per bunch can be chosen from <1 to anything
  - Transverse beam spot on target from very small up to hundred cm^2
- This flexibility can deliver the needs of LDMX
  - Phase 1 : 10^{14} electrons
  - Phase 2 : 10^{16} electrons

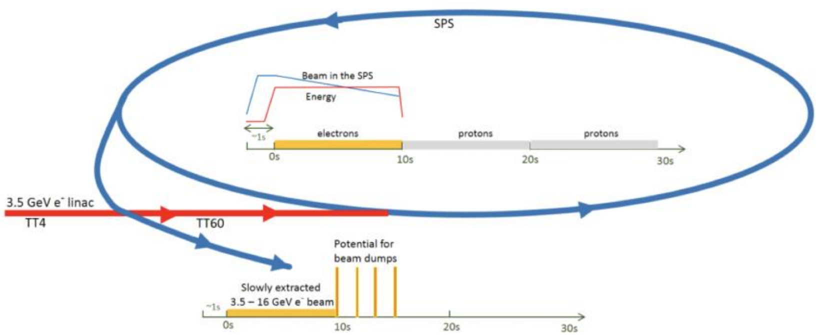
Beamdump experiments possible

- After this beam has been delivered there is still a lot of electrons in the SPS
- These can quickly be dumped into a separate beam line
  - 10^{12} electrons within 23μs, possibly up to 4 times more



If there would be a high priority the dump can be repeated every 2 s

An Electron Beam Facility at CERN



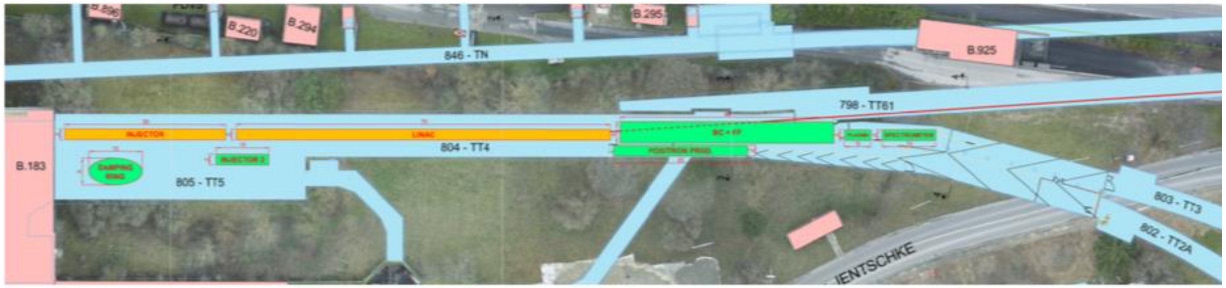
Capability:
Extracting ~10 electrons per 5 ns means 10^{16} electrons in ~80 days
Including up-times and efficiencies: a dedicated ~year, or a few years as part of super-cycle

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 (electron irradiation), training, instrumentation, THz, ESA 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

Dark Sector Physics with a Primary Electron Beam Facility at CERN

Torsten Åkesson,[1] Fabio Bossi,[2] Antonio Boveia,[3] Massimo Brugger,[4] Lene Bryngemark,[1] Philip N. Burrows,[5,4] Massimo Carpinelli,[6,7] Nuria Catalan,[4] Riccardo Catena,[8] Augusto Ceccucci,[4] James Chappell,[9] Owen Colegrove,[10] Giulia Collura,[10] Jan Conrad,[11] Karel Cornelis,[4] Roberto Corsini,[4] Hans Danielsson,[4] Dominik Dannheim,[4] Steffen Doebert,[4] Caterina Doglioni,[1] E. C. Dukes,[12] Yann Dutheil,[4] Valentina Dutta,[10] Bertrand Echenard,[13] Lyn Evans,[4] Matthew A. Fraser,[4] Alexander Friedland,[14] Jonathan Gall,[4] Jake S. Gessner,[4] Brennan Goddard,[4] Norman Graf,[14] R. C. Group,[12] Alexej Grudiev,[4] Edda Gschwendtner,[4] Vincent Hedberg,[1] Joshua Hiltbrand,[15] David Hitlin,[13] Joseph Incandela,[10] Lars Jensen,[4] Robert Johnson,[16] Rhodri Jones,[4] Venelin Kozhuharov,[17] Gordan Krnjaic,[18] Mike Lamont,[4] Andrea Latina,[4] Thibaut Lefevre,[4] Emanuele Leonora,[19] Lucie Linssen,[4] Fabio Longhitano,[19] Olle Lundh,[1] Else Lytken,[1] Jeremiah Mans,[15] Takashi Maruyama,[14] Jeremy McCormick,[14] Gerard Mcmonagle,[4] Eric Montesinos,[4] Omar Moreno,[14] Patric Muggli,[4] Geoffrey Mullier,[1] Timothy Nelson,[14] Gavin Niendorf,[10] John A. Osborne,[4] Yannis Papaphilippou,[4] Reese Petersen,[15] Ruth Pöttgen,[1] Javier Prieto,[4] Mauro Raggi,[20] Nunzio Randazzo,[19] Alexander Read,[21] Philipp Roloff,[4] Carlo Rossi,[4] Andre Sailer,[4] Daniel Schulte,[4] Philip Schuster,[14,22] Eva Sicking,[4] Valeria Sipala,[6,7] Steinar Stapnes,[4] Igor Syratchev,[4] Natalia Toro,[14,22] Nhan Tran,[18] Domenico D'Urso,[6,7] Paolo Valente,[23] Andrew Whitbeck,[18] and Walter Wuensch[4]

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05/10/2018

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/

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

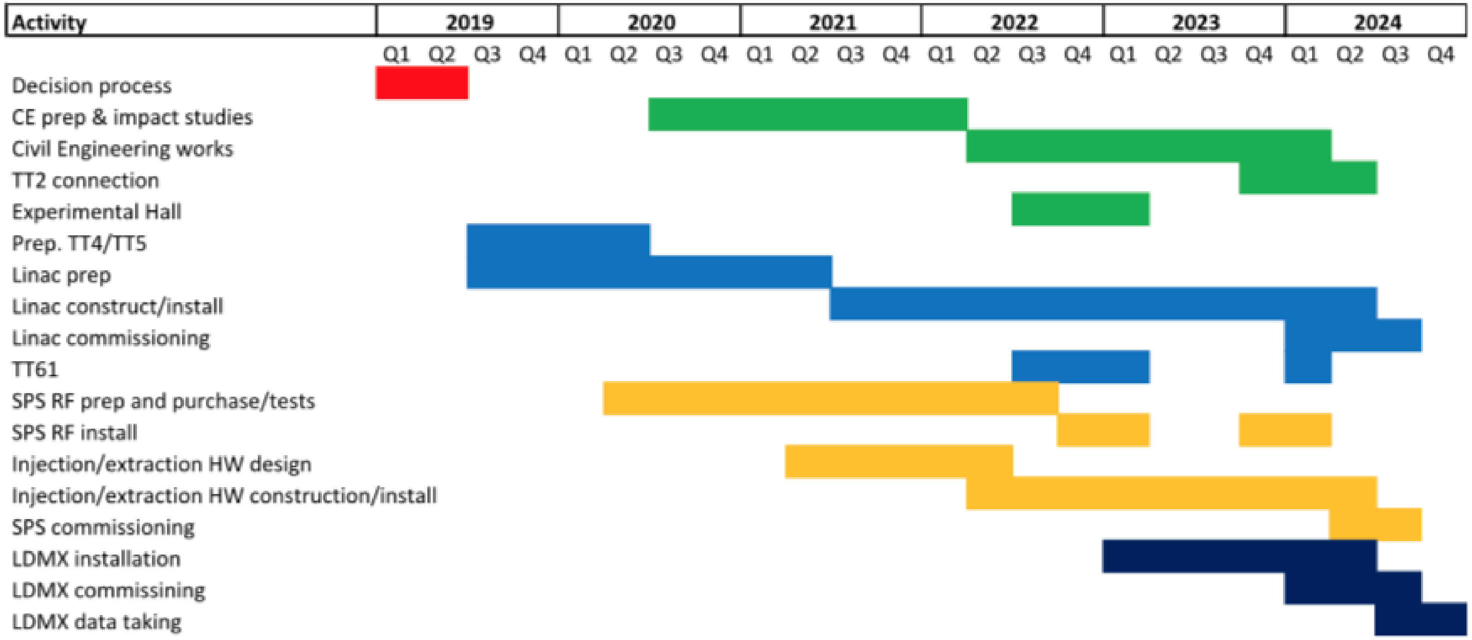
TABLE I: Cost summary

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

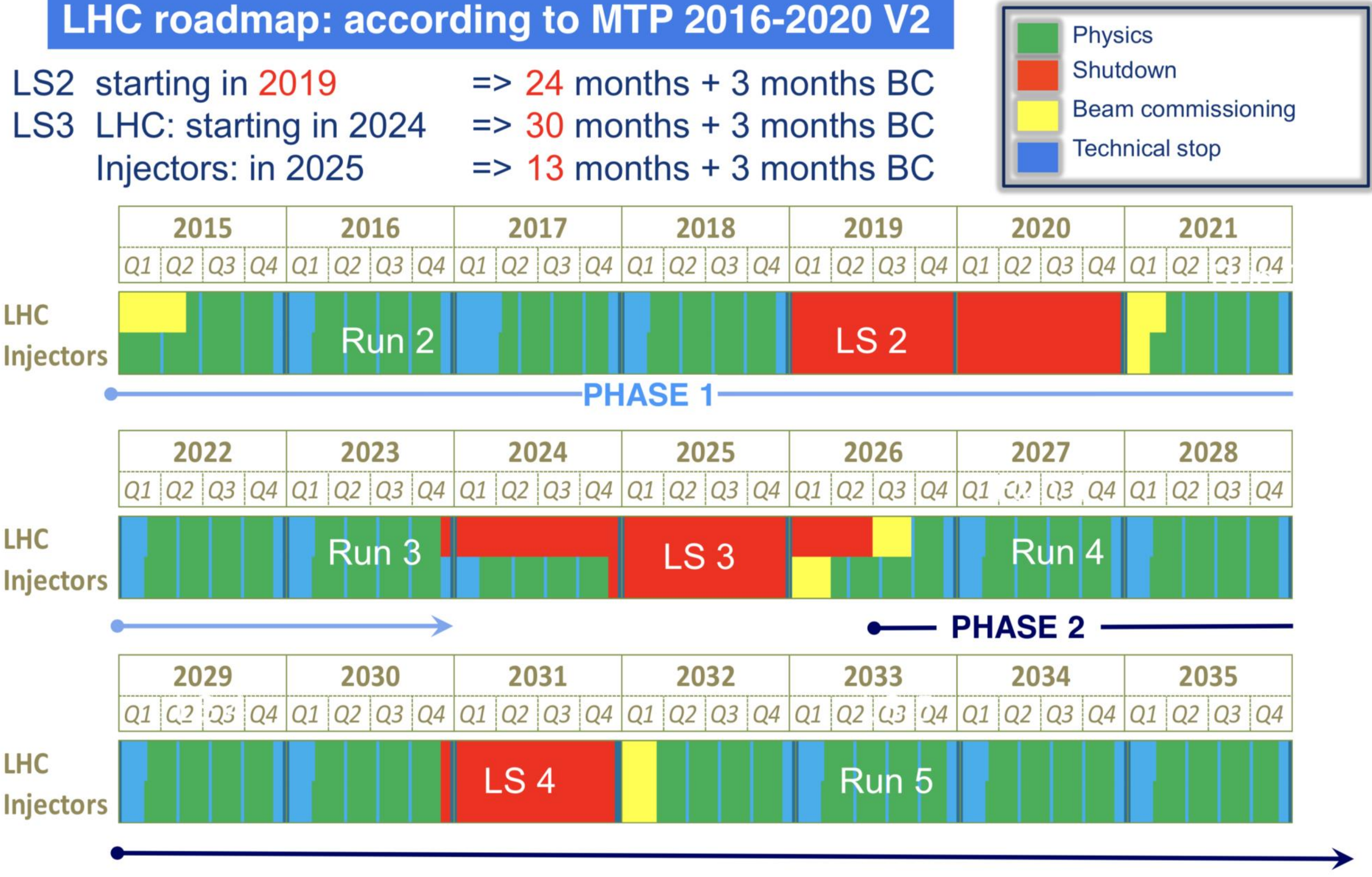
Technically based … however

- 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



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



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 this year