

A primary electron beam facility at CERN

CLIC PM 7.5

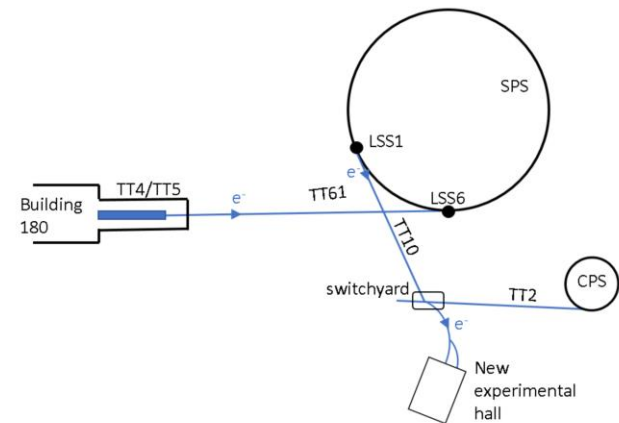
S. Stapnes (CERN)

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



Motivations

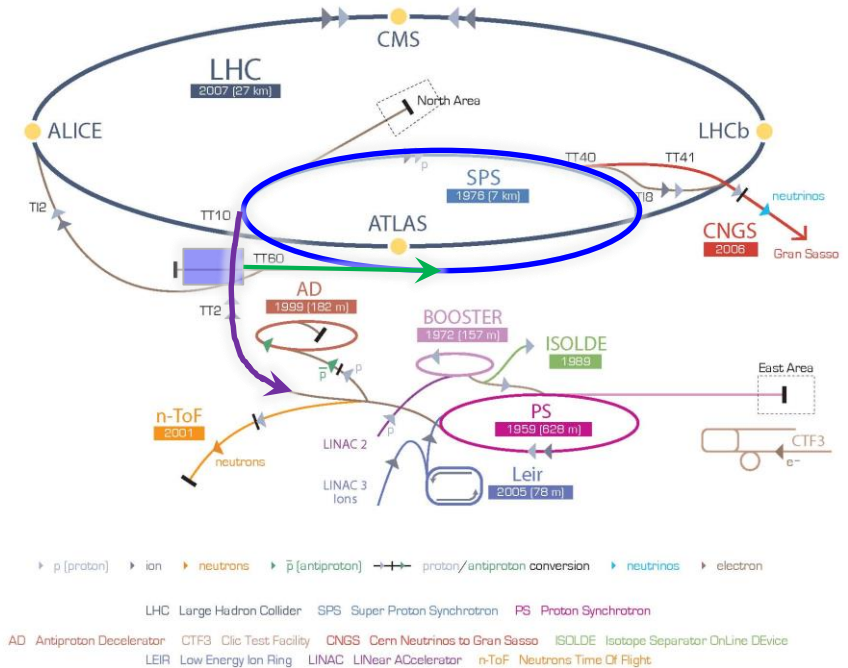
- Physics: Large increasing interest in Light Dark Matter – using e-beams, the key to the “eSPS proposal” – LDMX talk: [slides](#)
- Next step for X-band technology: Any next machine at CERN is beyond LHC, i.e. 15+ years away
 - We have looked carefully at what we could do with CLIC beam and/or drive-beam at a small scale – scaling the industry experience
 - Combining a compact linac with the SPS electron experience provides unique opportunities
- 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

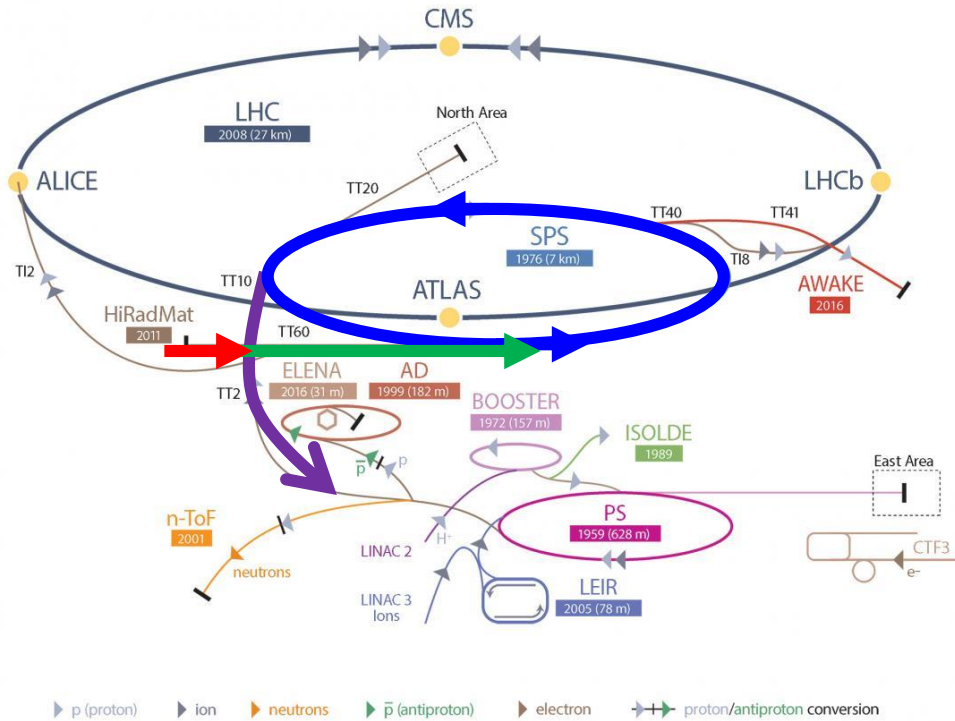


Beyond LDMX type of beam, other physics experiments considered (for example heavy photon searches)

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

CERN's Accelerator Complex



3.5 GeV Linac

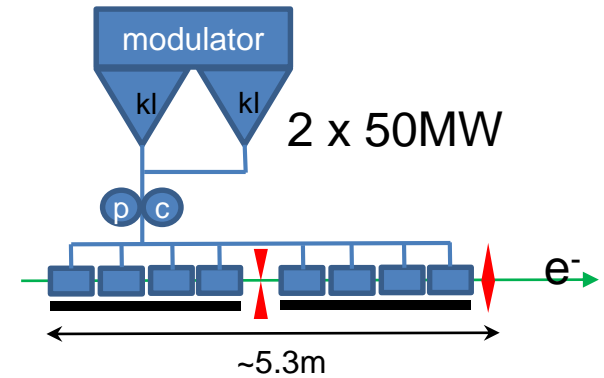
Transfer to SPS

Acceleration in SPS

Extraction

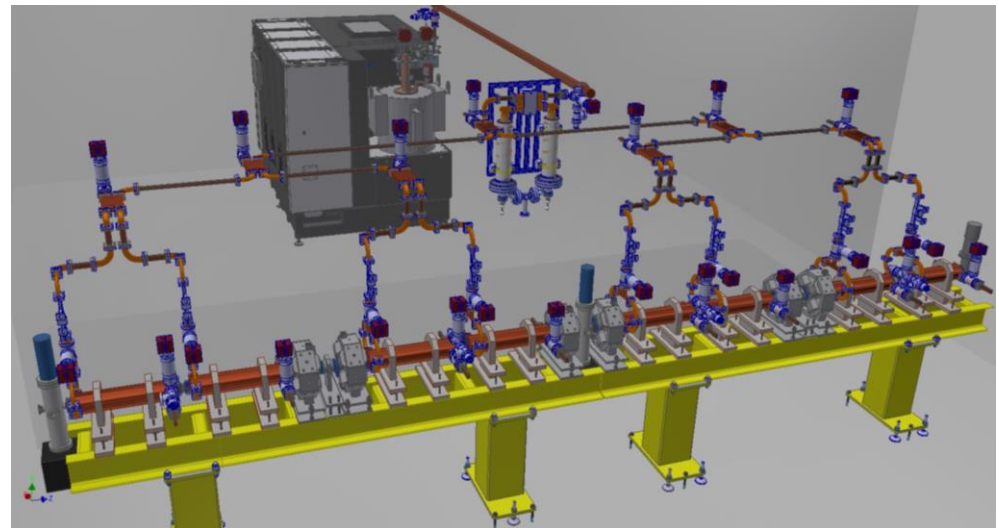
Linac parameters

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



Possible parameters

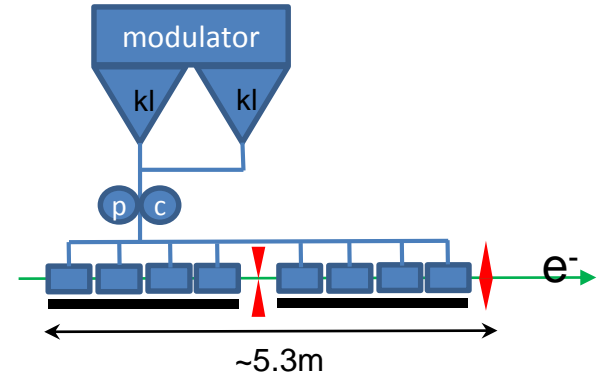
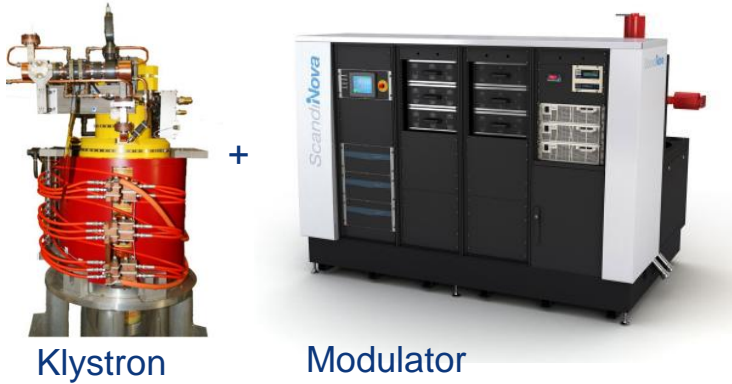
Energy spread (uncorrelated*)	<1MeV
Bunch charge	52 pC
Bunch length	~5ps
Norm. trans emittance	~10um
N bunches in one train	40
Train length	200 ns
Rep. rate	50/100 Hz



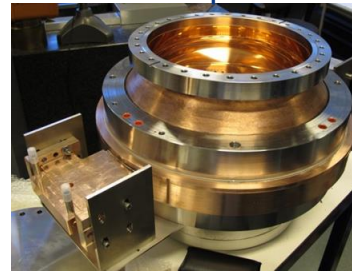
RF design of the X-BAND linac for the EUPRAXIA@SPARC_LAB project
M. Diomedea Et al., IPAC18

Linac components available

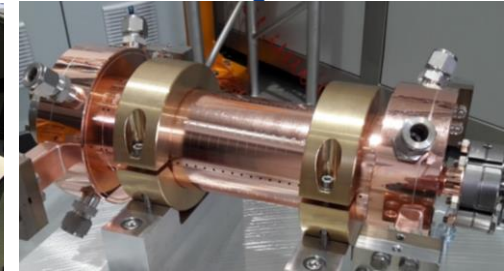
Examples



Pulse compressor

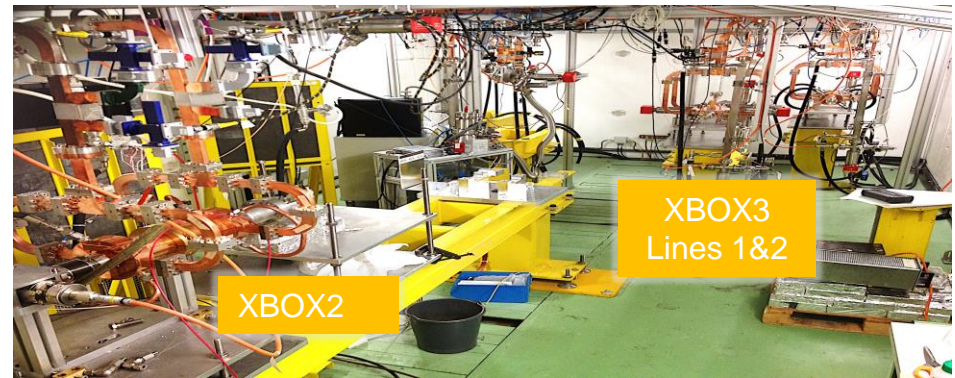


Accelerating structure



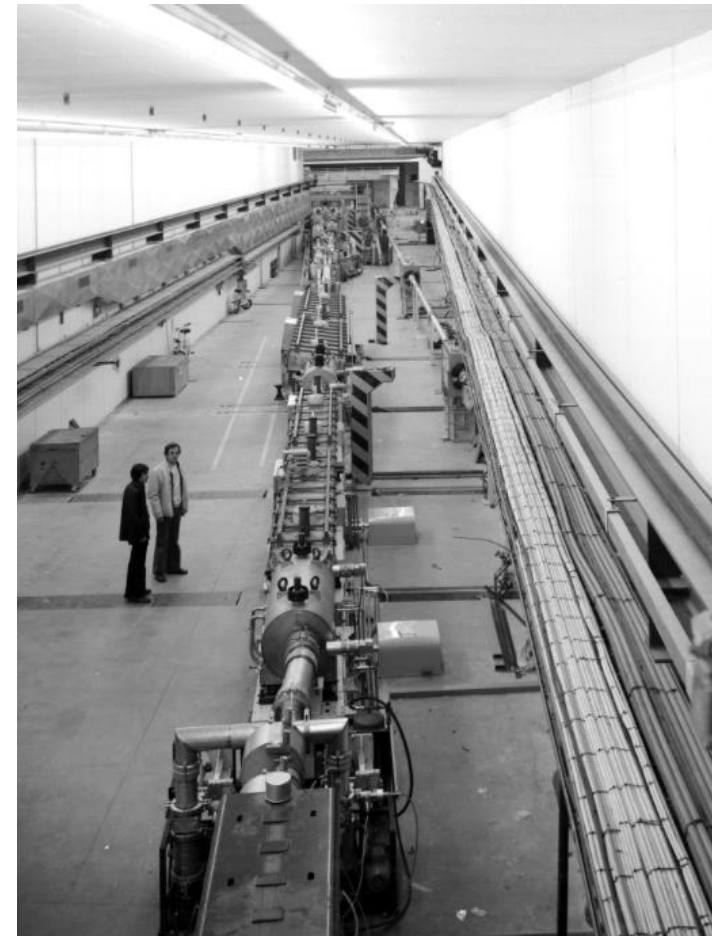
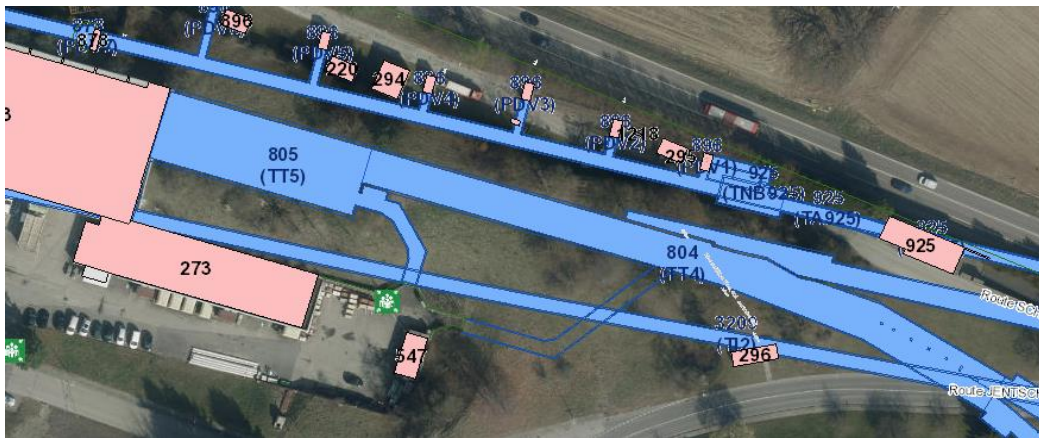
One RF unit accelerates
200ns bunch train up
to 264 MeV

Assembled systems in
continues operation at CERN



Linac in TT5/TT4

- Flexible bunch pattern provided by photo-injector
5ns, 10ns, ... 40ns bunch spacing
- High repetition rate
 - 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)



Beam to/in/from the SPS – see backup slides

Transfer tunnel, TT60, from the Linac into the SPS

Injection into the SPS

Bunch to bucket injection in the 200MHz SPS longitudinal RF structure.

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

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SPS RF system

- Acceleration to 16 GeV can safely be achieved
- Existing 200 MHz cavities from LEP era to be re-installed
 - Need 10MV for 16GeV electrons (12 + 1) 200 MHz Standing Wave Cavities [1 MV per cavity] available
- Space is available to install them
 - 5ns, 10ns, ... 40 ns longitudinal structure is imposed by the available cavities
- Trains of 200ns (linac) separated by 100ns gaps (injections kicker)

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Slow extraction to experiments

Extraction

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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

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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

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Extracted beam and experimental area

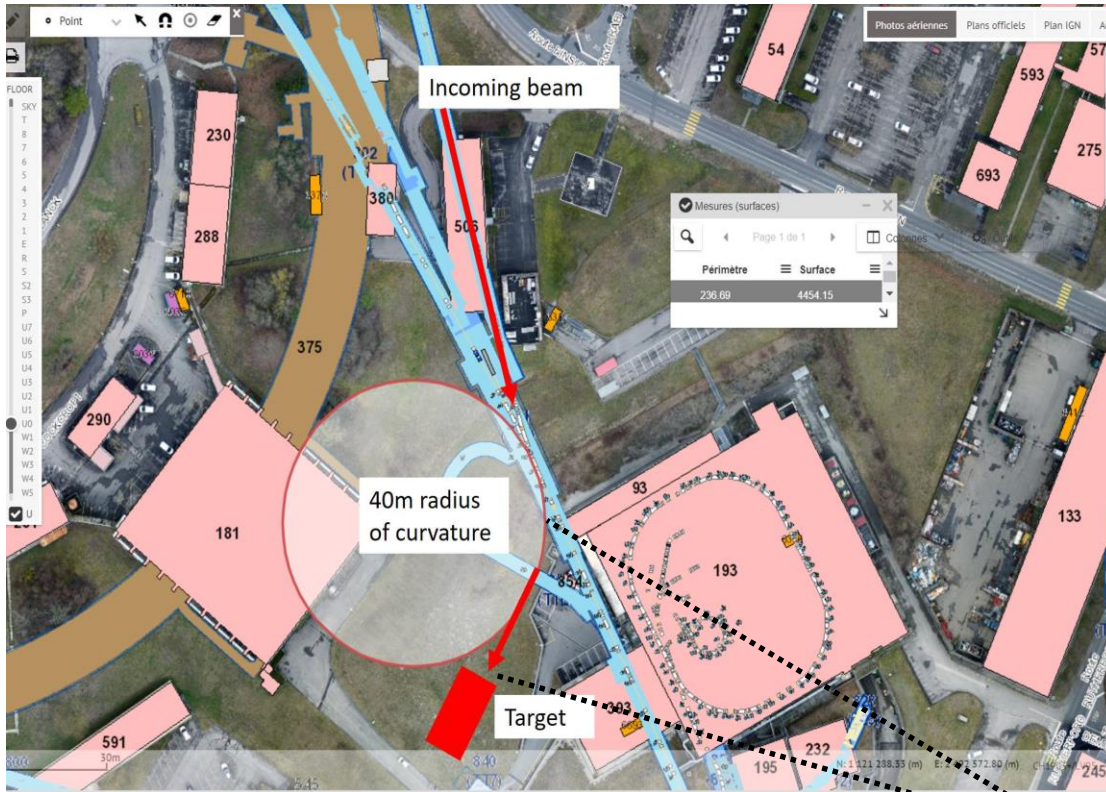


FIG. 43: Visualisation of the proposed underground (shown in blue) and overground (shown in red) facilities

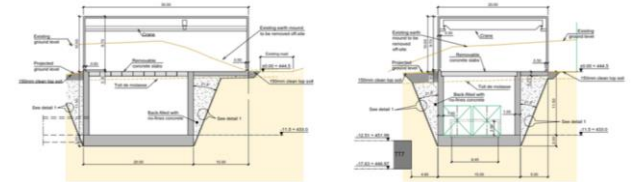


FIG. 41: Typical Sections through the experimental hall parallel to the beam-line (left) and transverse to the beam-line (right)

In total ~50 m new tu

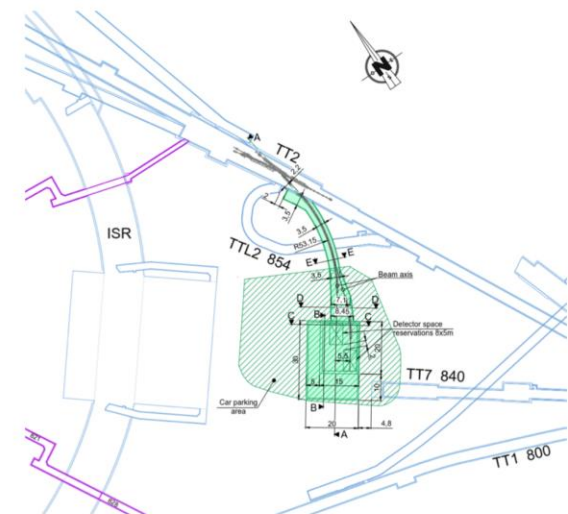
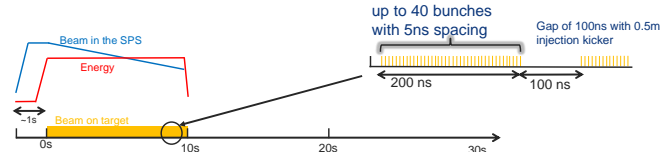


FIG. 38: Plan view of proposed layout



Beams in exp. area – instrumentation (see backup slides)

Structure of extracted beam

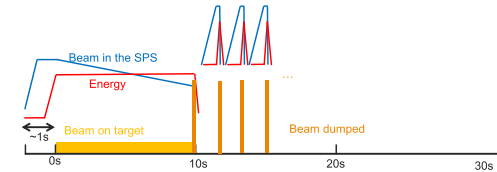


- Flexibility
 - Bunch spacing 5ns, 10ns, ... 40ns
 - Average electrons per bunch can be chosen from <math><1</math> to anything
 - Transverse beam spot on target from very small up to hundred cm^2
- This flexibility can deliver the needs of LDMX
 - Phase 1 : 10^{14} electrons
 - Phase 2 : 10^{16} electrons



Beamdump experiments possible

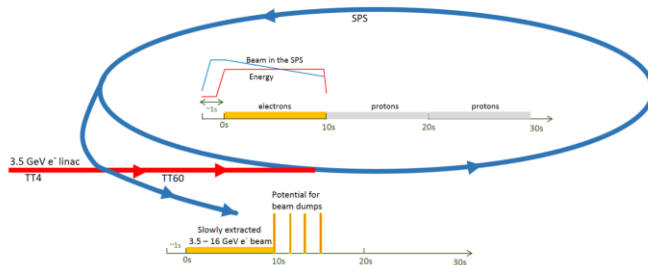
- After this beam has been delivered there is still a lot of electrons in the SPS
- These can quickly be dumped into a separate beam line
 - 10^{12} electrons within $23\mu\text{s}$, possibly up to 4 times more



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 \sim year or a few years as part of super-cycle



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 $\sim 5e8$)
- Beam Size
 - Wire scanners
 - 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



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 for other potential future facilities using electrons (rings) considered at CERN

Plasma studies with electrons

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

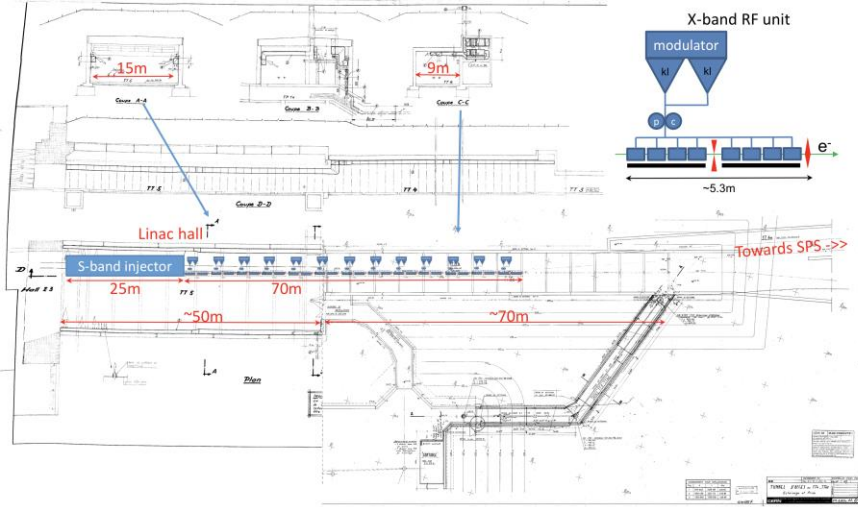
General acc. R&D as in CLEAR – existing ~200 MeV linac - today (<https://clear.web.cern.ch>)

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 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



List of Linac “users” and what they get

	Required bunch population	bunch population from the linac	Destination
LDMX	1.5E7@5ns (Lyn, March 2018)	~1e8	SPS
Beam Dump experiment	As much as possible? @5ns	3.3e8	SPS
CLEAR++	As flexible as possible?		R&D area(s)
CLIC	5.2E9 @0.5ns (CLIC380)	5.2E9 single bunch 2E9 @5ns	SPS ?
FCC-ee(Z)	To be checked	6E9 single bunch	SPS
Plasma driver	1.1E10 (EOI)	6E9	Plasma
Positron driver	1.1E10 (EOI)	6E9	Positron source

Proposed ICE Mandate



General Objective

- Develop the existing layouts for the project from a civil engineering and technical infrastructure point of view, and work with the various actors towards a realistic design and project planning as needed for the conceptual design report (CDR).

Specific Responsibilities

- Coordinate input from the required disciplines to produce a detailed conceptual design incorporating all of the main requirements for infrastructure and civil engineering (ICE) including:

- Civil Engineering
- Cooling and Ventilation
- Electricity
- Transport and Handling
- Integration
- Safety systems engineering

- Liaise with other disciplines such as survey, beam transfer, optics, machine, radiation protection, coordination, experiment etc. to ensure all constraints and requirements are understood and accounted for.

- Study environmental aspects of the project eg spoil, contamination, wider environmental considerations.

Produce Schedule and Cost Estimates

- Coordinate input as above to produce a cost estimate and schedule covering ICE packages.

Dark Sector Physics with a Primary Electron Beam Facility at CERN

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¹³California Institute of Technology, Pasadena, CA 91125, USA

¹⁴SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA

¹⁵University of Minnesota, Minneapolis, MN 55455, USA

¹⁶Santa Cruz Institute for Particle Physics,

University of California at Santa Cruz, Santa Cruz, CA 95064, USA

¹⁷Sofia University, Bulgaria

¹⁸Fermi National Accelerator Laboratory, Batavia, IL 60510, USA

¹⁹INFN- Sezione di Catania, Italy

²⁰Dipartimento di Fisica, Sapienza Università di Roma and INFN Roma, Italy

²¹Department of Physics, University of Oslo, Postbox 1048, 0316 Oslo, Norway

²²Perimeter Institute for Theoretical Physics, Waterloo ON N2L 2Y5, Canada

²³INFN Roma, Italy

V. A primary electron beam facility at CERN

A. Introduction and overview

B. Electron linac

1. S-band electron injector

2. High gradient X-band linac

3. Beam stability

C. Electron beam in the SPS

1. Linac to SPS

2. RF system

3. Beam dynamics and stability

D. Beam delivery and parameters

1. SPS slow extraction

2. SPS to target

E. Instrumentation

1. Source and Linac systems

2. Linac transfer and SPS injection

3. SPS ring systems

4. SPS Extraction and TT10 Transfer Line

F. Civil engineering and experimental area

1. Location

2. Proposed facilities

3. Construction Methods

4. Recommendations for work at the next stage of project development

VII. CERN and R&D on acceleration technology

A. Introduction

1. Studies with relevance for future facilities

2. Plasma acceleration

3. General accelerator R&D

4. The SPS electron beam

B. Large scale X-band linac prototype

C. Other future machines needing electrons

D. Plasma studies using electrons

1. Introduction

2. General beam and plasma parameters requirements

3. Witness bunch

4. Simulation results

5. Plasma source

6. Experimental area

7. Conclusion

E. A future high energy CLEAR facility

F. Added capabilities: Positron production and studies with positrons

1. Studies for future lepton colliders

2. The LEMMA muon collider

3. Plasma wakefield experiments with a positron beam

4. Physics of Positron Acceleration in Plasma

5. Crystal undulators and photon production

G. Summary and user community

The accelerator community involved as developers or users

VIII. Conclusions

A. Schedule and cost

1. Electron beam facility

2. LDMX

References

Costs

Sources

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

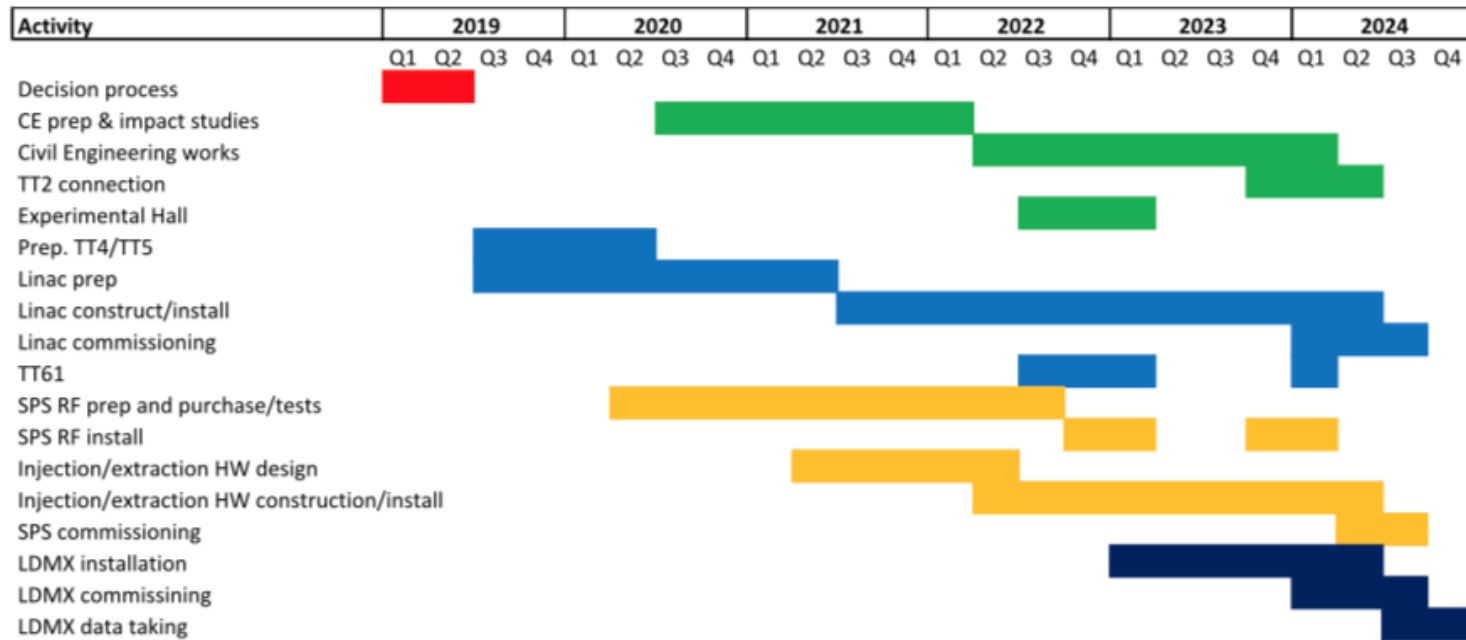
TABLE I: Cost summary

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 Eol

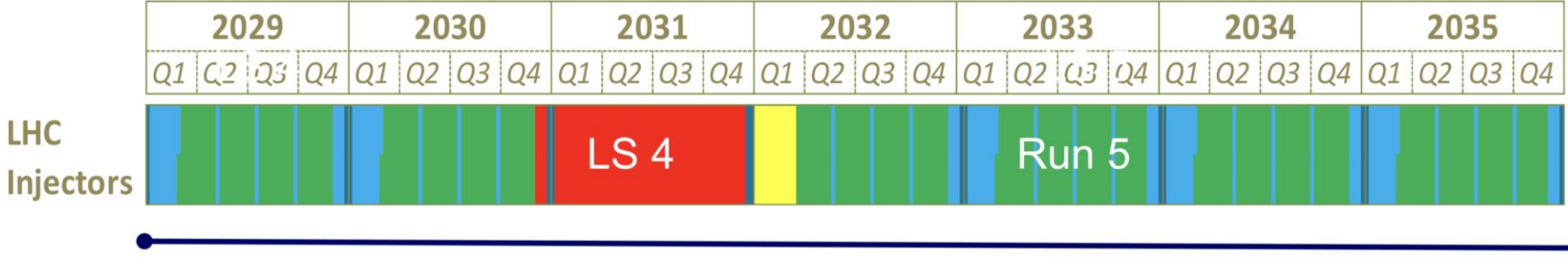
Technically based ... however

- 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/priorityv 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



Towards a CDR this year ?

1. Overall	
2. Physics goals and justifications for beams	
3. Linac	
	3.1 Gun and Injector
	3.2 X-band LINAC
	3.3 Positron production and DR
4. SPS	
	4.1 Transfer to SPS
	4.2 Injection
	4.3 RF
	4.4 Extraction
	4.5 Transfer and delivery to EA
	4.6 Electron beam performance
	4.7 Impedances and hadron compatibilites
5. CE and infrastructure	
	5.1 CE including Exp.Hall
	5.2 CV
	5.3 EL
	5.4 General infrastructure TT4/5, refurbishment
	5.5 Integration
4. Instrumentation	
	4.1 Linac and positrons
	4.2 Transfer line and SPS
	4.3 Extraction line and beam-delivery
5. Radiation studies and protection	
6. Accelerator R&D	Intro
	6.1 Linac related
	6.2 Ring related (FCC-ee)
	6.3 Plasma
	6.4 CLEARER
	6.5 Positrons
7. Implementation plans	Schedules, Resources, Costs, Power



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, 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

More information



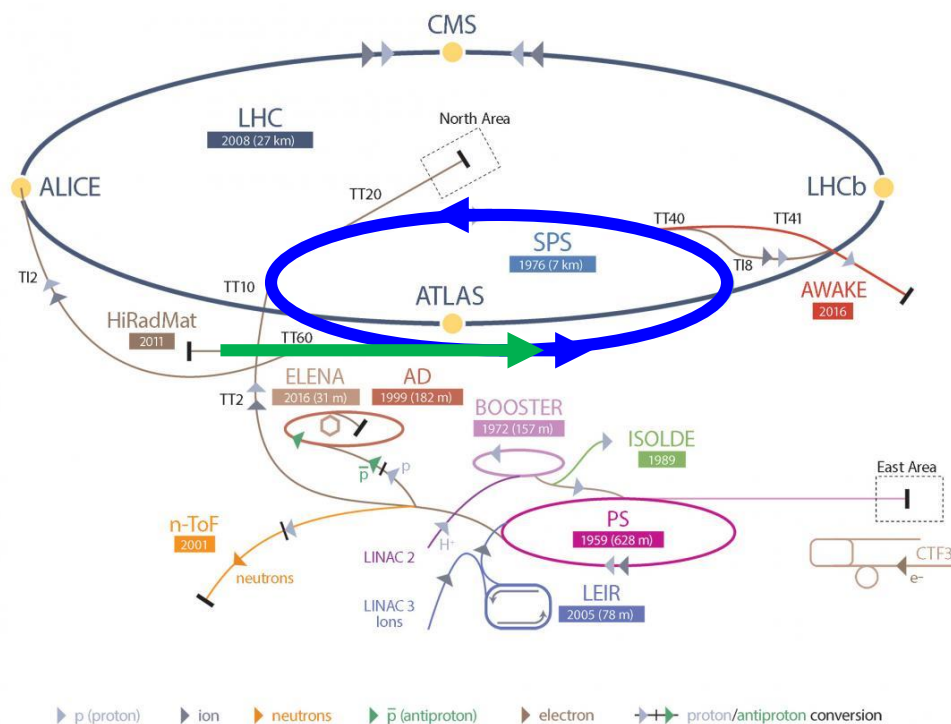
Transfer tunnel, TT60, from the Linac into the SPS

Injection into the SPS

Bunch to bucket injection in the 200MHz SPS longitudinal RF structure.

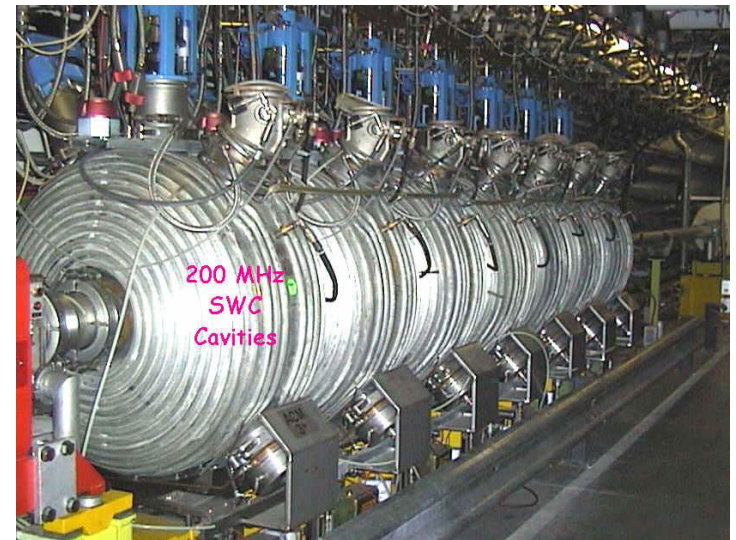
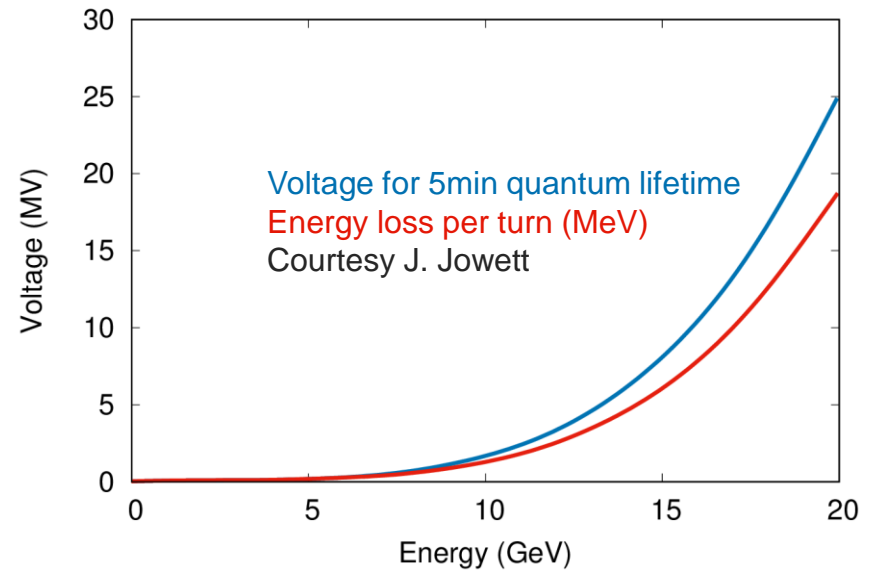
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CERN's Accelerator Complex



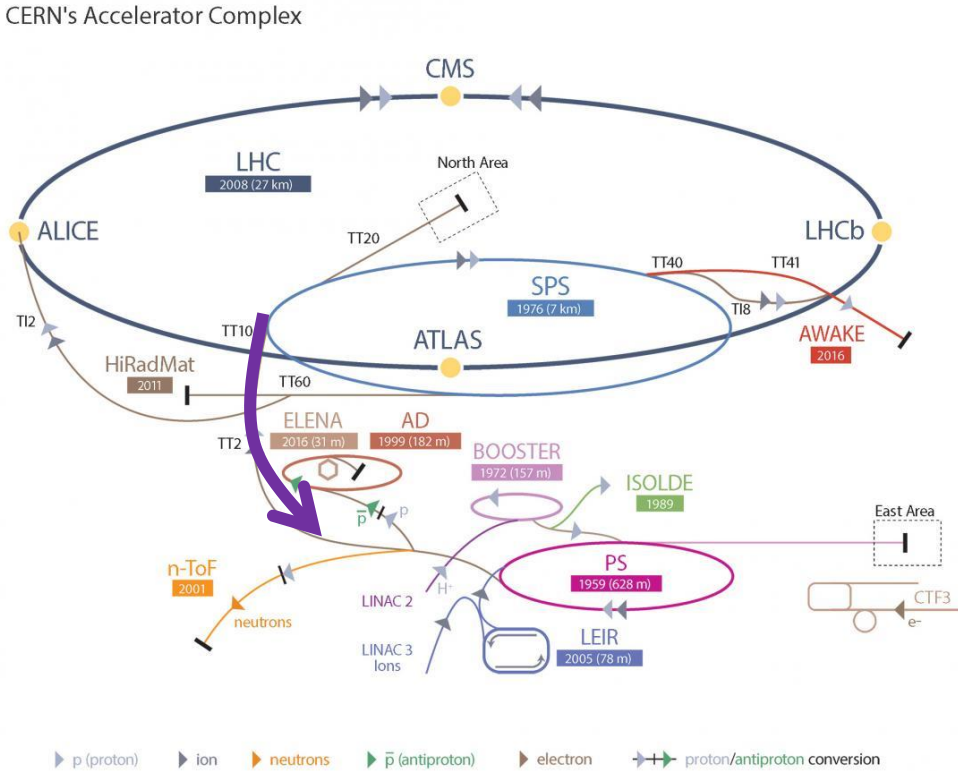
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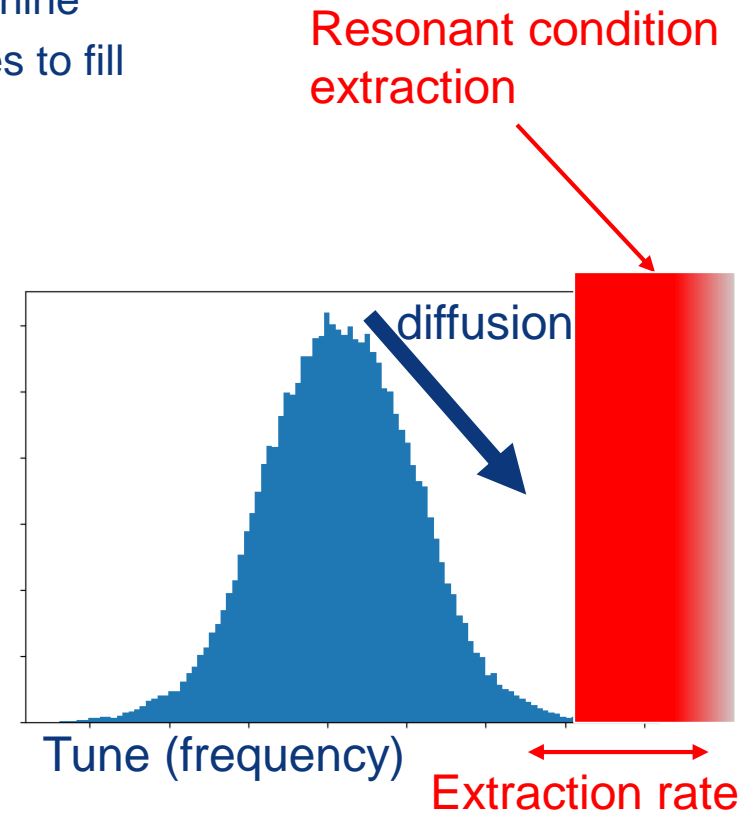
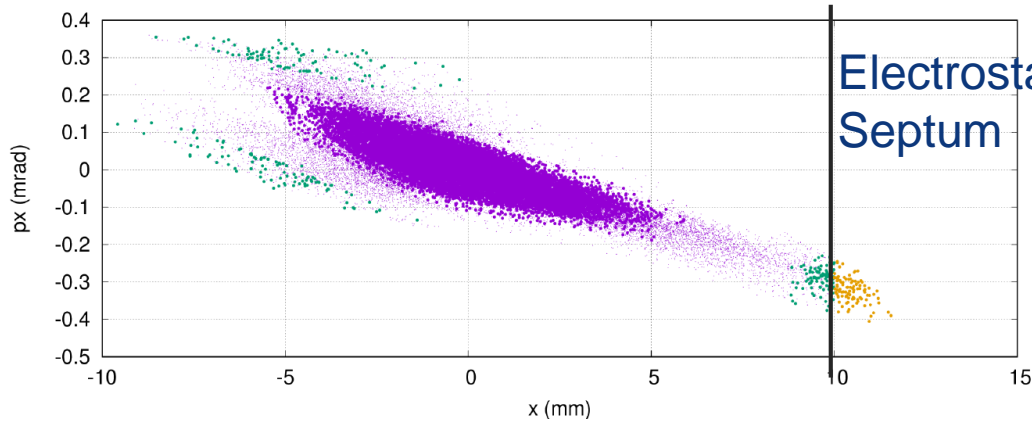
Slow extraction to experiments

Extraction



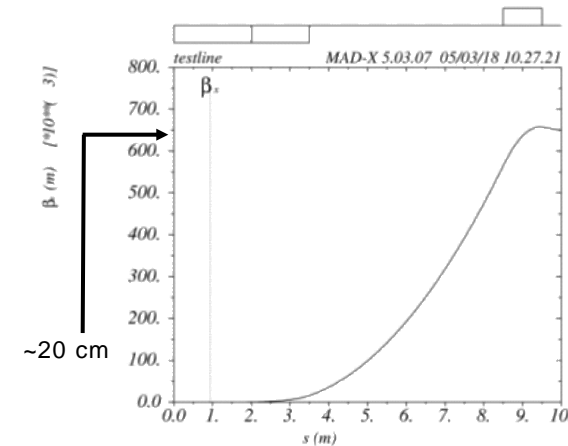
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Linac:

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- Intensity
 - Re-use of CTF3 inductive pick-up or standard beam current transformers

SPS:

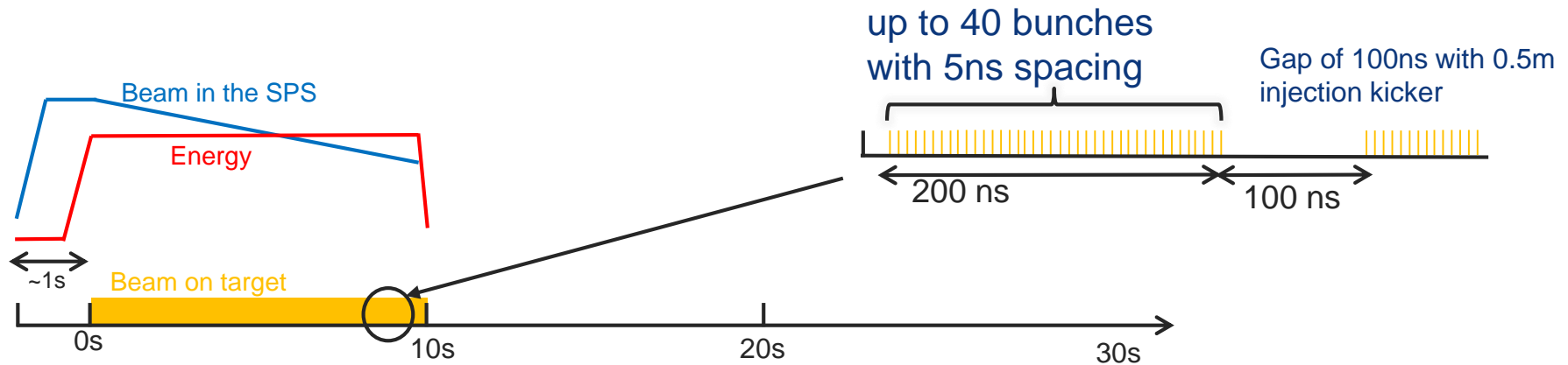
- Position
 - Standard orbit system (consolidated in LS2)
 - Should be able to measure to $1e9$ (limit $\sim 5e8$)
- Beam Size
 - Wire scanners
 - Possible use of synchrotron radiation
- Intensity
 - DC Transformer OK for total current
 - Fast BCT does not distinguish 5ns spaced bunches
 - Could do batch 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

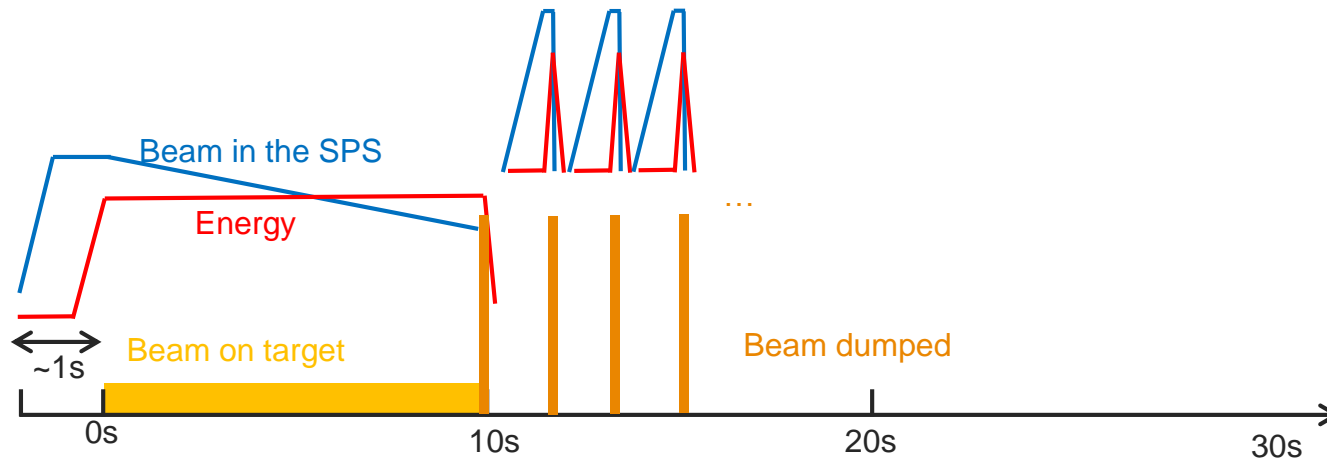
Structure of extracted beam



- Flexibility
 - Bunch spacing 5ns, 10ns, ... 40ns
 - Average electrons per bunch can be chosen from <1 to anything
 - Transverse beam spot on target from very small up to hundred cm²
- This flexibility can deliver the needs of LDMX
 - Phase 1 : 10^{14} electrons
 - Phase 2 : 10^{16} electrons

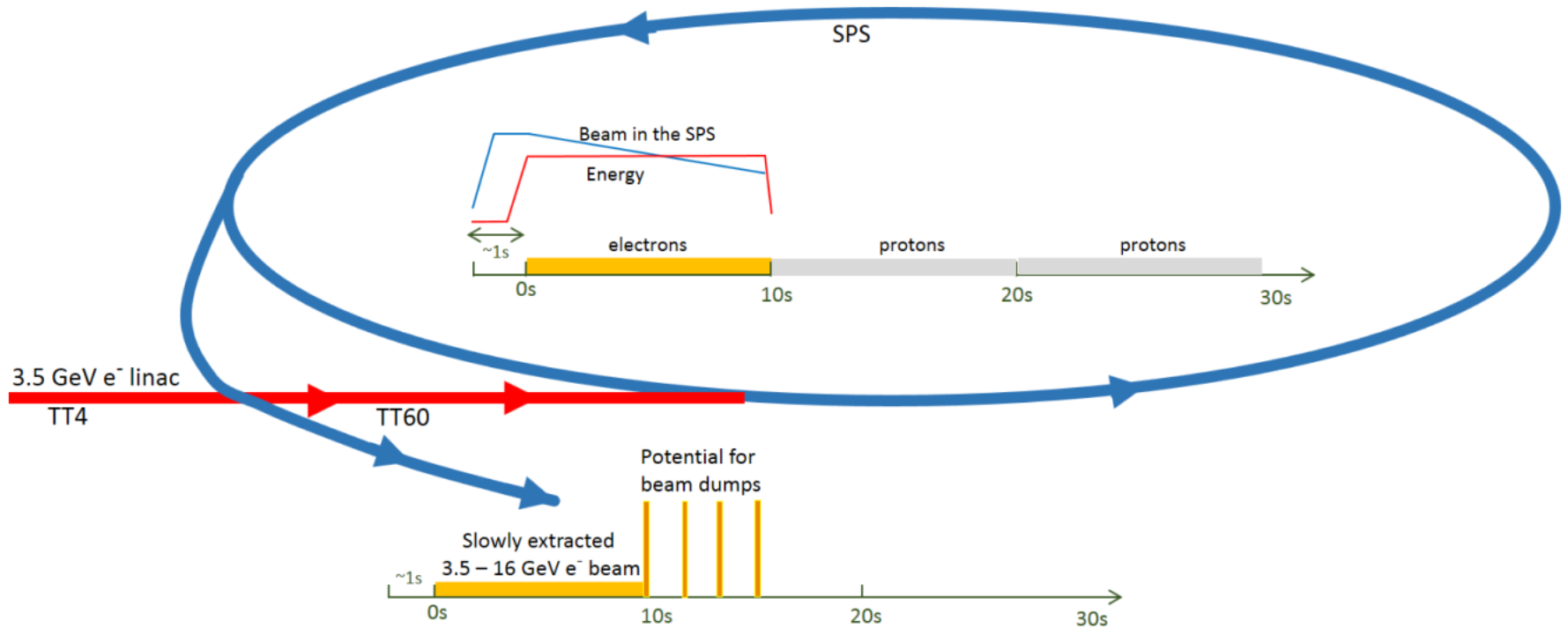
Beamdump experiments possible

- 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 $23\mu\text{s}$, 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 \sim year or a few years as part of super-cycle