A primary electron beam facility at CERN – studies towards ALIC

ALEGRO workshop - March 27th, 2019

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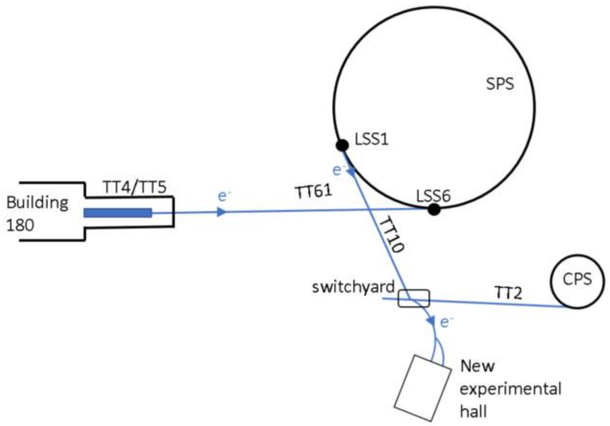
on behalf of the working group PBC-acc-e-beams** (email: PBC-acc-e-beams@cern.ch)

Motivations

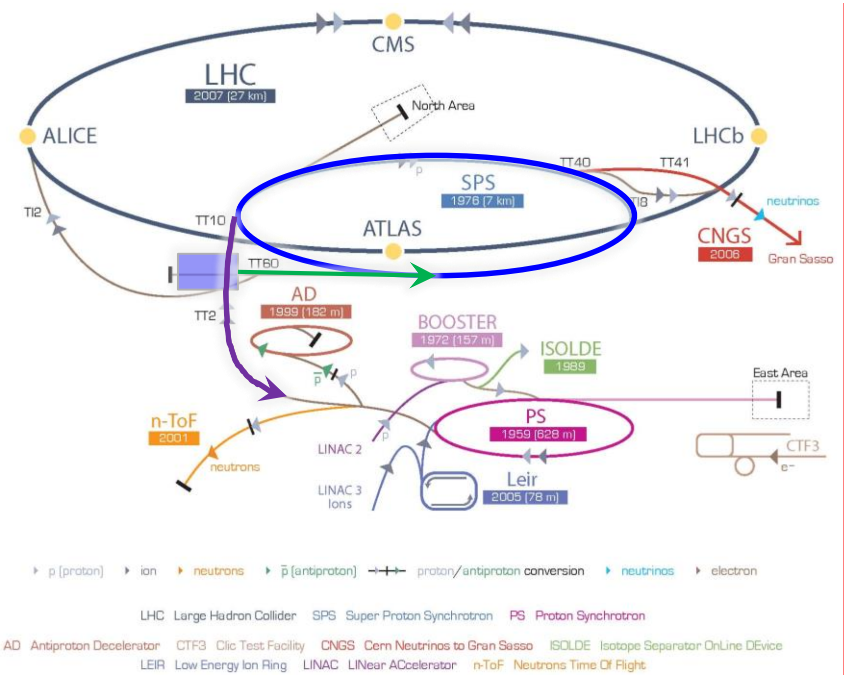
- Physics: Large increasing interest in Light Dark Matter – using e-beams, the key to the ”eSPS proposal” – LDMX talk: slides
- Next step for X-band technology: Any next machine at CERN is beyond LHC, i.e. 15+ years away
  - We have looked carefully at what we could do with CLIC beam and/or drive-beam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

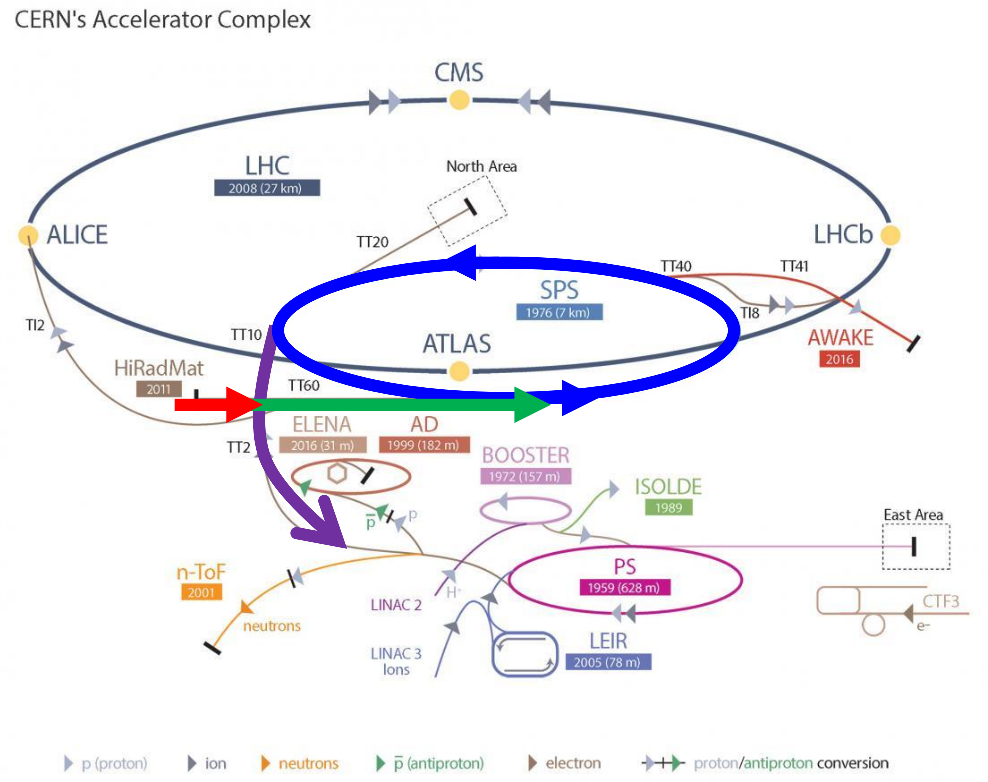
- X-band based 70m LINAC to ~3.5 GeV in TT4-5
- Fill the SPS in 1-2s (bunches 5ns apart) via TT60
- Accelerate to ~16 GeV in the SPS
- Slow extraction to experiment in 10s as part of the SPS super-cycle
- Experiment(s) considered by bringing beam back on Meyrin site using TT10



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



3.5GeV Linac

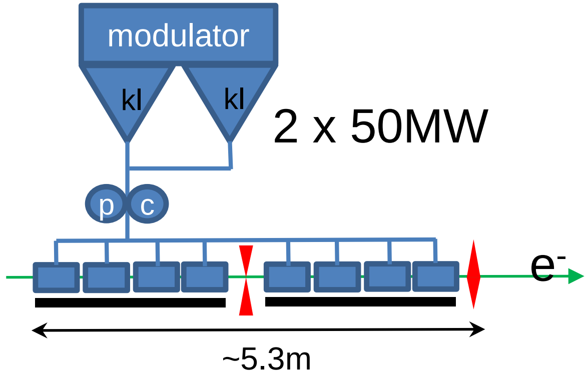
Transfer to SPS

Acceleration in SPS

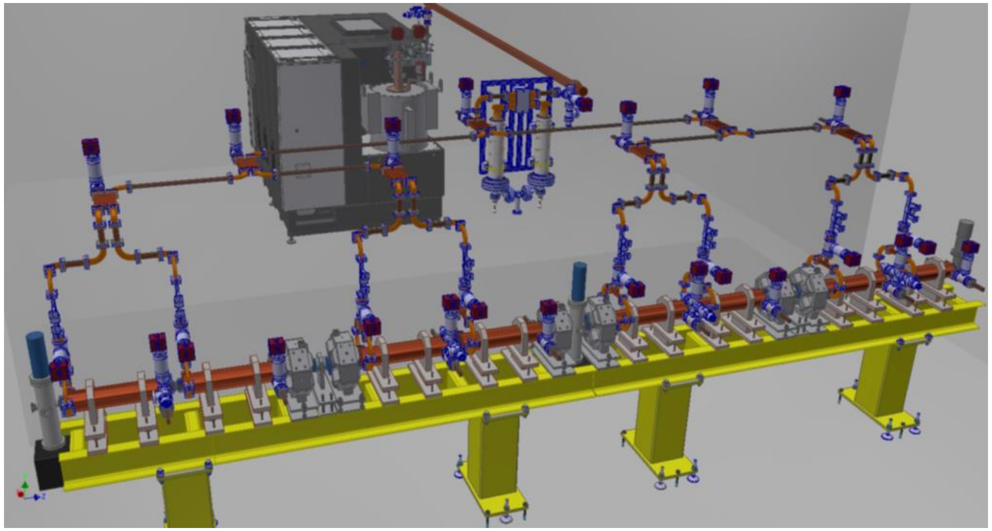
Extraction

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

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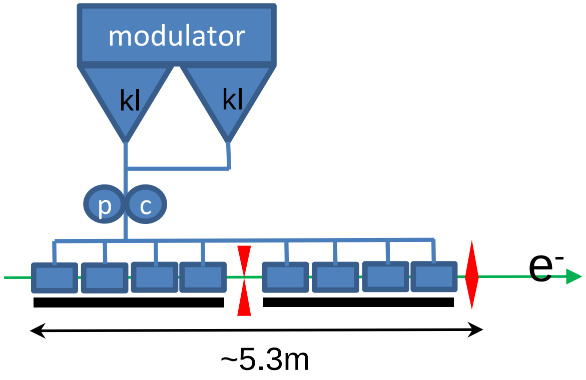
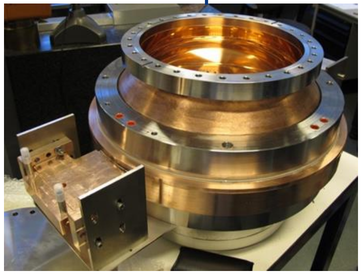
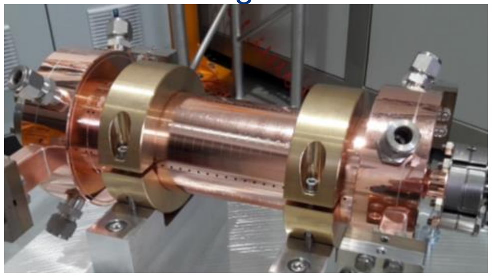
Modulator



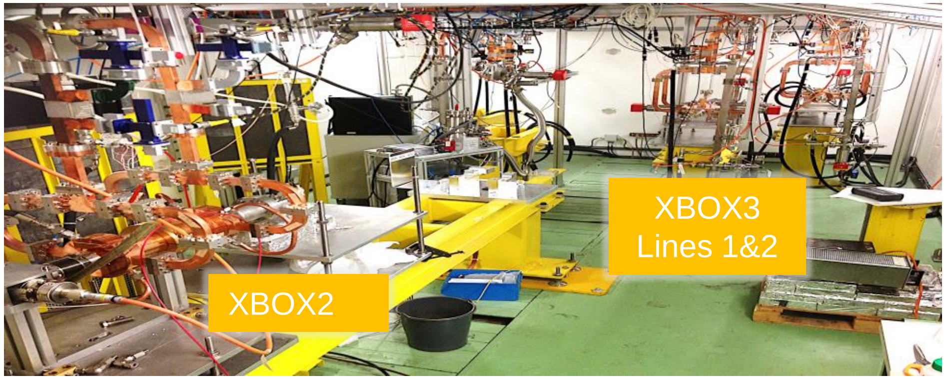
Pulse compressor



Accelerating structure



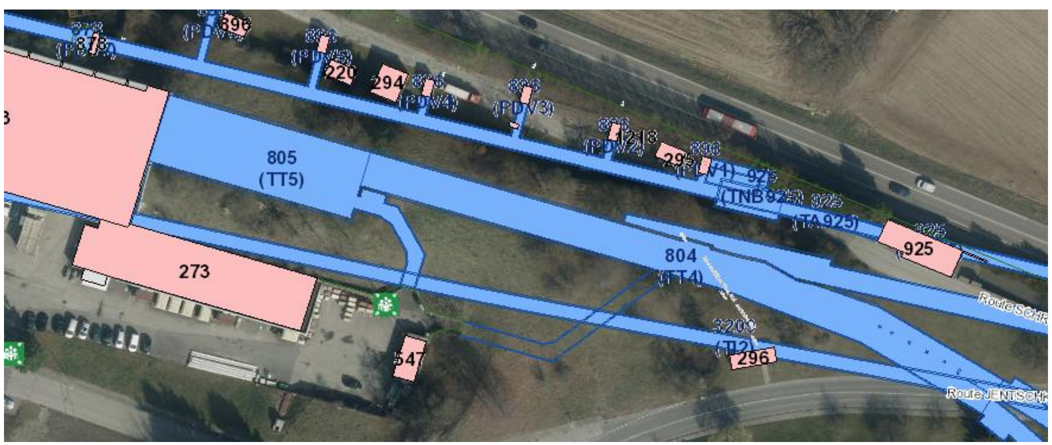
- One RF unit accelerates 200ns bunch train up to 264 MeV

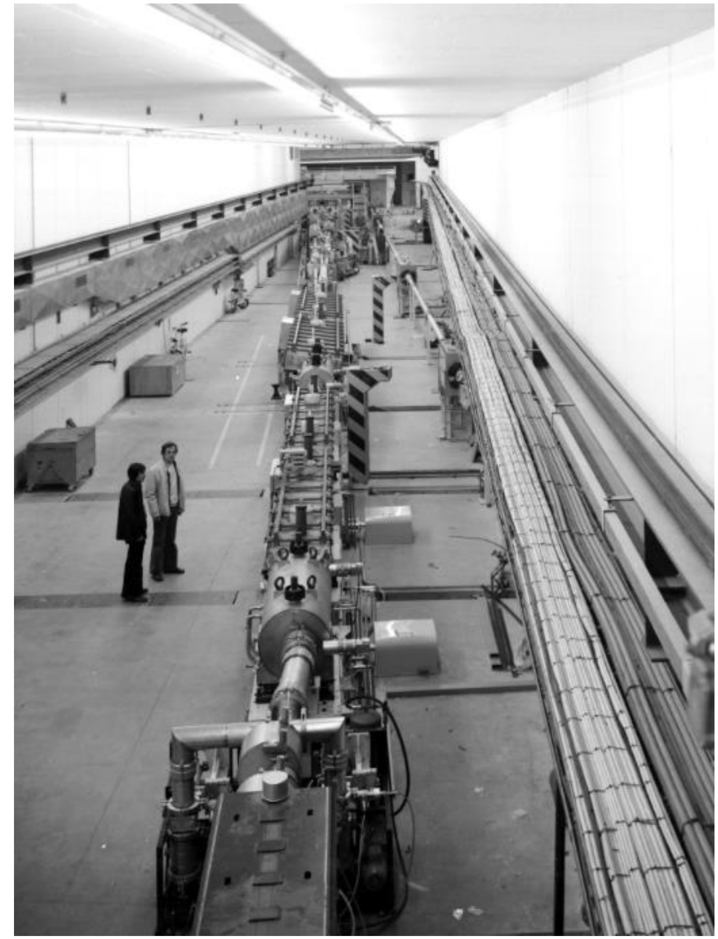


Assembled systems in continues operation at CERN

Linac in TT5/TT4

- Flexible bunch pattern provided by photo-injector
  5ns, 10ns, … 40ns bunch spacing
- 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)





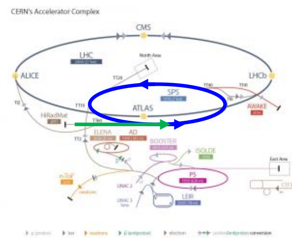
Beam to/in/from the SPS – see backup slides

Transfer tunnel, TT60, from the Linac into the SPS

Injection into the SPS

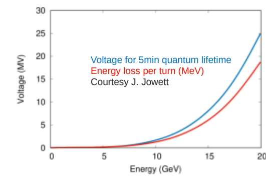
Bunch to bucket injection in the 200MHz SPS longitudinal RF structure.

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



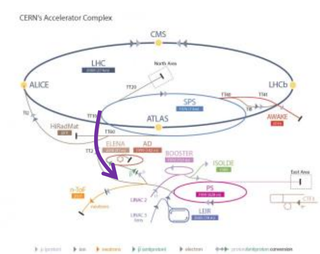
SPS RF system

- 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)



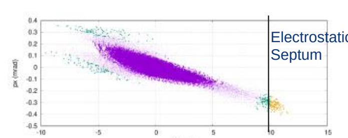
Slow extraction to experiments

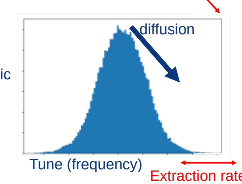
Extraction



Slow extraction principle, in frequency space

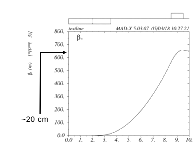
- Spread in oscillation frequency within the beam follows
  - Transverse distribution
  - Longitudinal distribution in presence of chromatic lattice
- Position of the resonant condition is set by the machine
- Synchrotron radiation constantly diffuse the particles to fill the tail in the distribution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



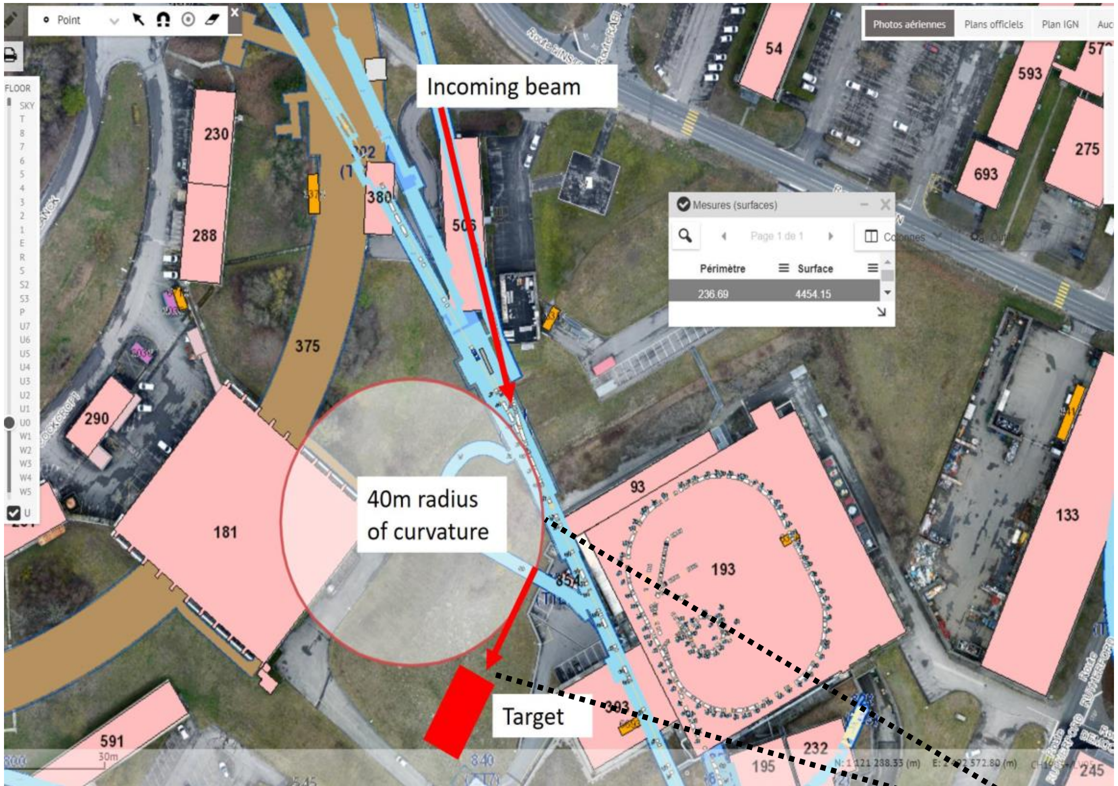


Electron beam transfer line from the SPS to experiments

- 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/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



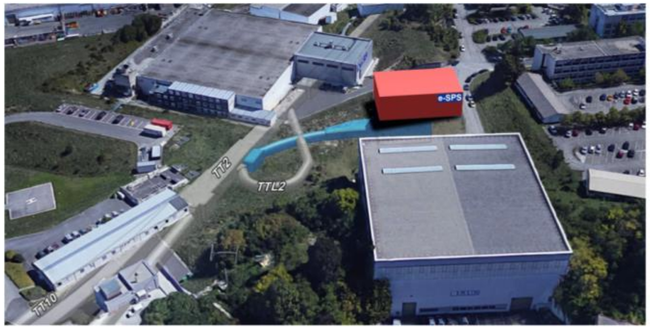


FIG. 43: Visualisation of the proposed underground (shown in blue) and overground (shown in red) facilities

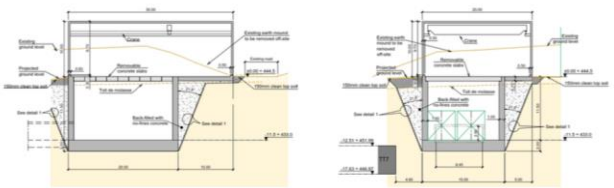


FIG. 41: Typical Sections through the experimental hall parallel to the beam-line (left) and transverse to the beam-line (right)

In total ~50 m new tu

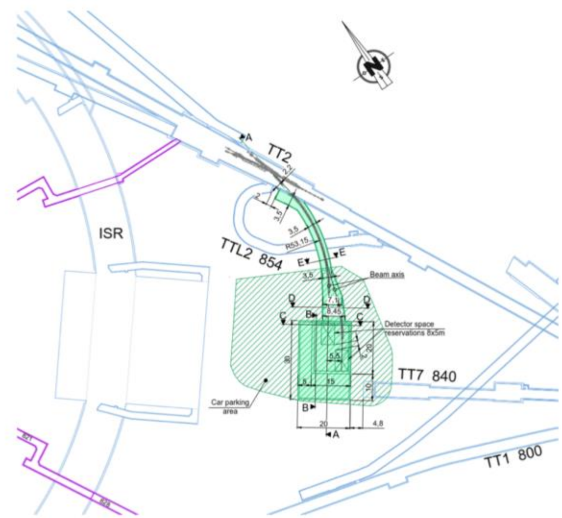
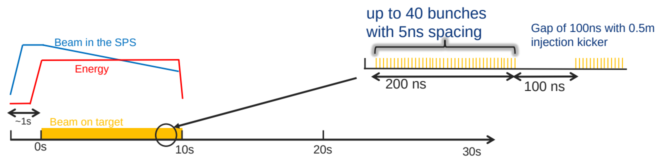


FIG. 38: Plan view of proposed layout

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

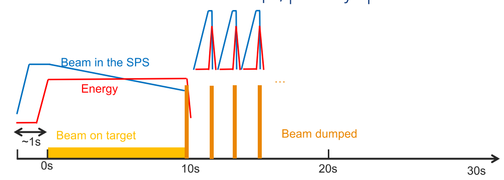
Structure of extracted beam



- Flexibility
  - Bunch spacing 5ns, 10ns, … 40ns
  - Average electrons per bunch can be chosen from <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

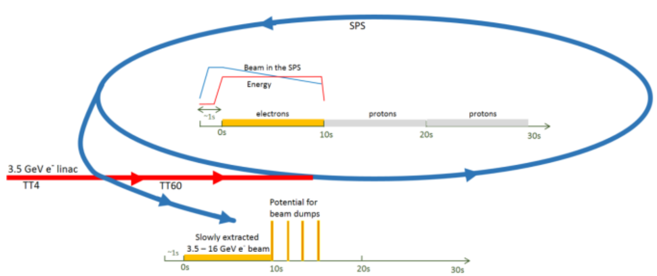
Beamdump experiments possible

- 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 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

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

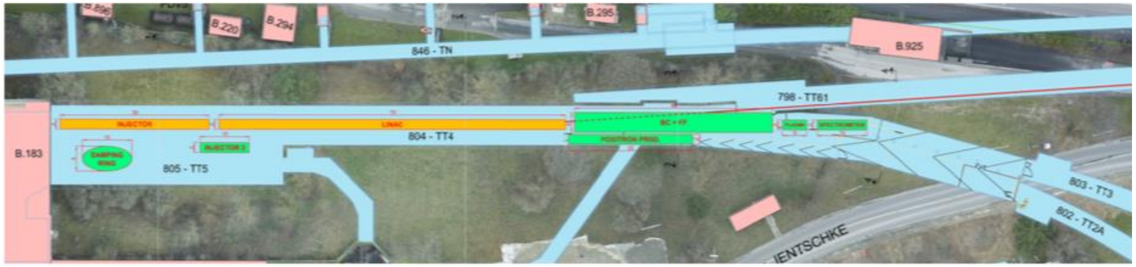
The challenge of measuring very low intensity beam can be circumvented using a higher intensity for beam setup

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)

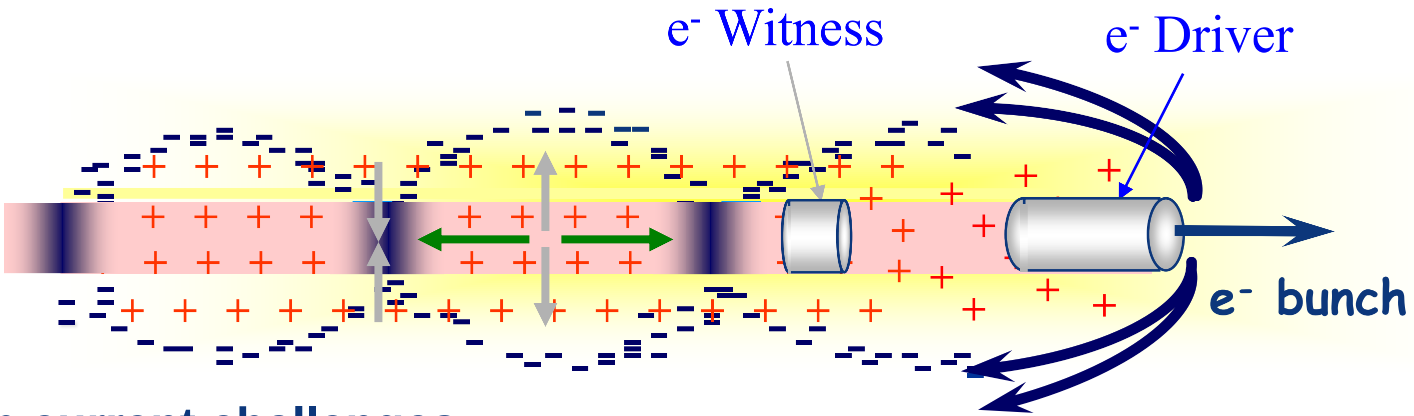
Plasma-lenses, impedance, high grad studies, medical (electron irradiation), training, instrumentation, THz, ESA irradiation. Recent results: https://acceleratingnews.web.cern.ch/article/first-experimental-results-clear-facility-cern

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

PLASMA WAKEFiELD ACCELERATOR (e^-)



Main current challenges

- ✧True D-bunch/W-bunch experiments
- ✧Demonstrate emittance preservation (at the mm-mrad level)
- ✧Reach low energy spread (%-level)
- ✧Reach high energy transfer efficiency
- ✧Repeat with e^+
- ✧Staging
- ✧Collider parameters …

✧ Quality of the results limited by the drive (D) and witness (W) bunch parameters available

eSPS MOTiVATiONS

Goal: study accelerator-related PWFA topics

- ✧Provide quality accelerated bunch, same $\Delta E/E$ and ε_N as injected one
- ✧Aim for energy gain on the order of incoming energy, 3.5GeV
- ✧Aim for >1GeV/m accelerating gradient
- ✧Operate with independent D and W bunches, D=3.5GeV, W=CLEAR++
- ✧Matching of the W-bunch to the plasma

May still be the only facility with GeV drive bunch and independent D+W bunch

Possible studies:

- ✧Emittance preservation (in the blow-out regime)
- ✧Narrow final energy spread => beam loading
- ✧D-bunch energy depletion, energy transfer efficiency
- ✧Beam/plasma matching
- ✧Bunch shaping for >2 transformer ratio and energy transfer efficiency
- ✧Effect of drive bunch train on wakefields and plasma as a fct of time
- ✧Effect of plasma "quality", longitudinal density profile, ramps, reproducibility, etc.
- ✧Test bed for plasma sources: helicon source, discharge source, etc.

Possibility to have suitable positron (e^+) bunch for De^-/We^+-PWFA studies

Fits the ALEGRO roadmap

All knowledge at CERN, including CLEAR++, AWAKE, plasma source, etc.

CERN-SPSC-2018-023 / SPSC-EOI-018
05/10/2018

Dark Sector Physics with a Primary Electron Beam Facility at CERN

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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

Sources

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

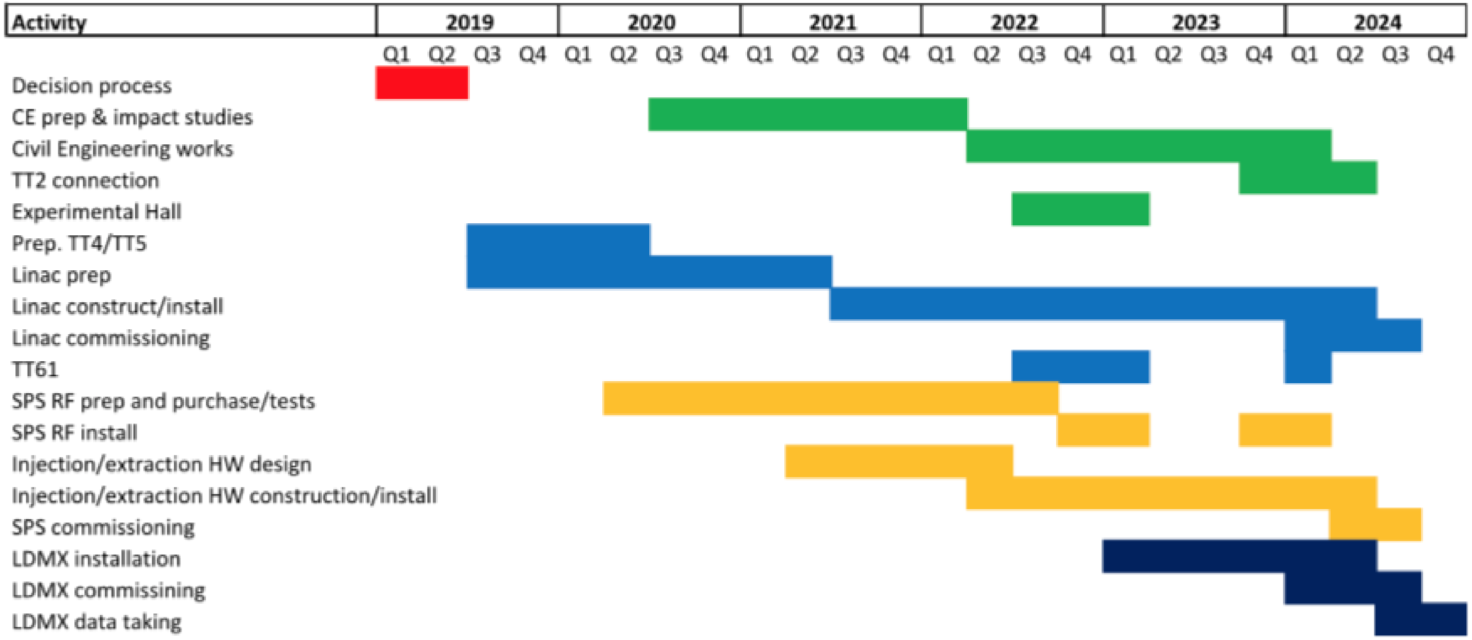
TABLE I: Cost summary

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

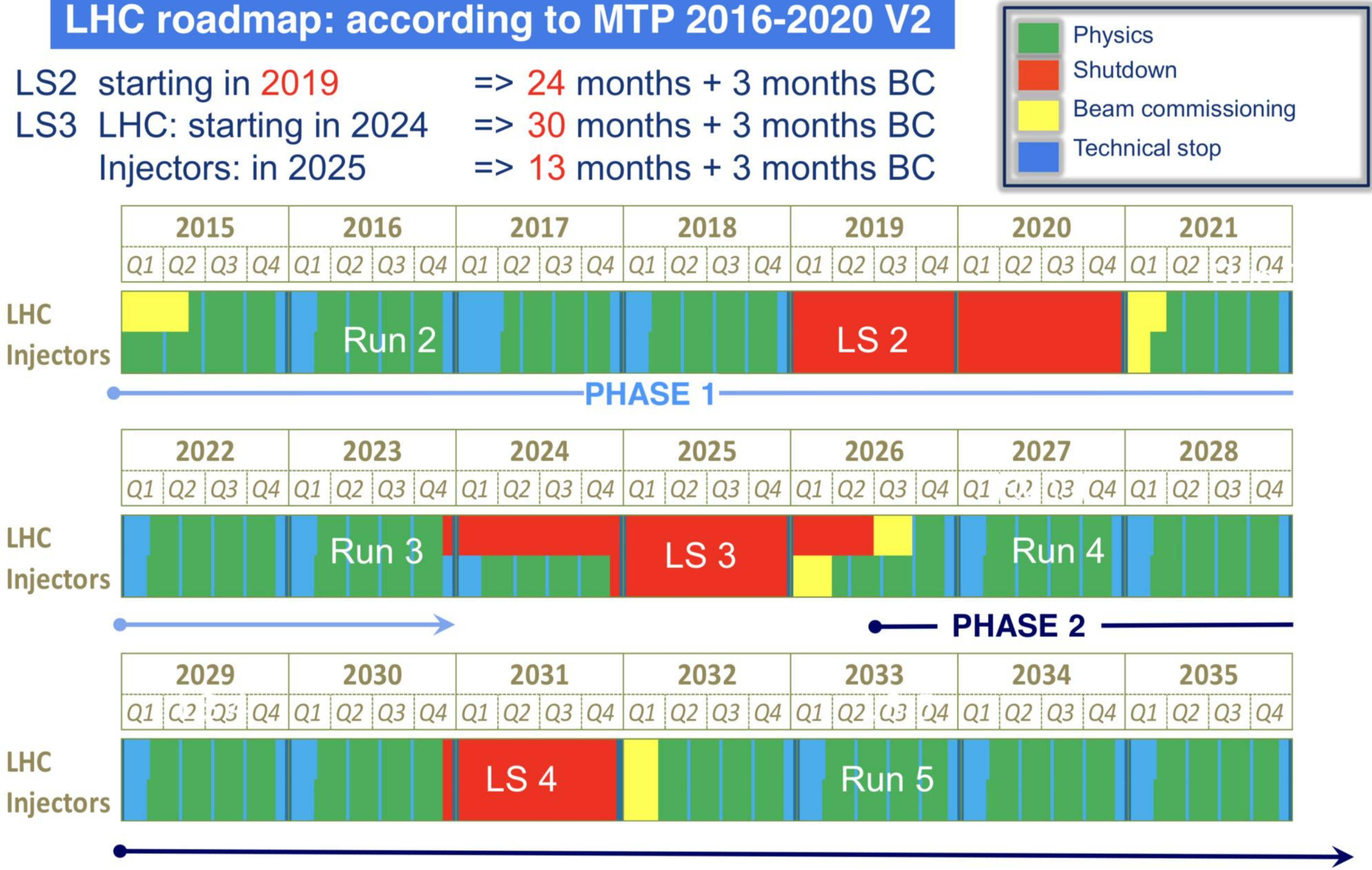
Technically based … however

- 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



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

- Thank you -

More information

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Injection into the SPS

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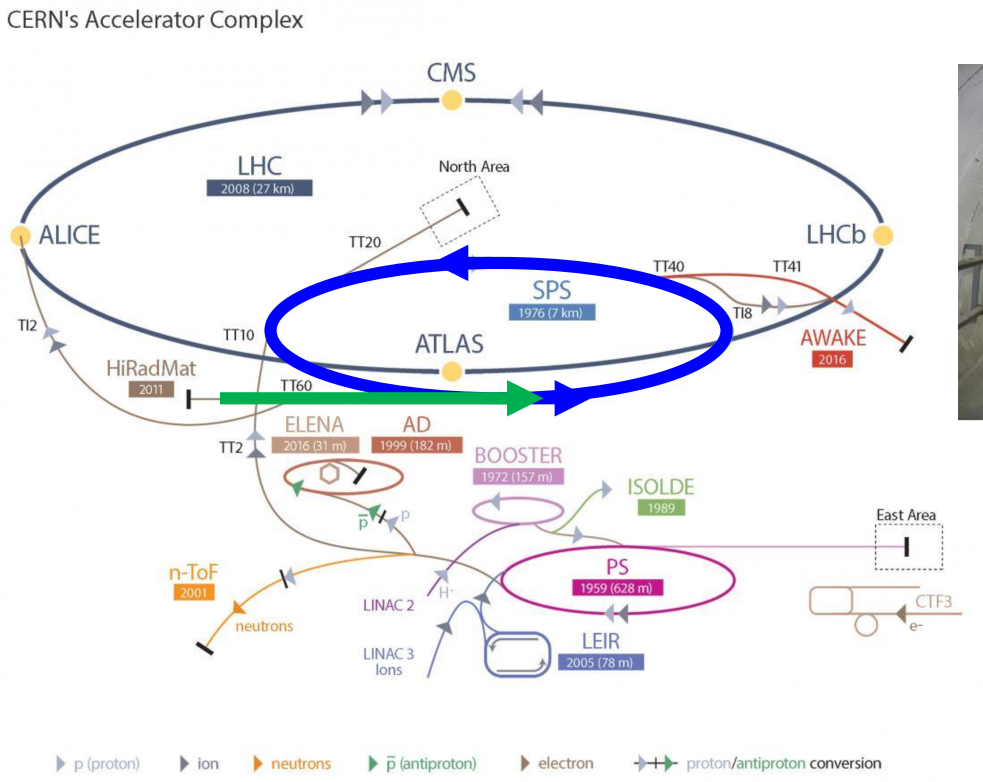

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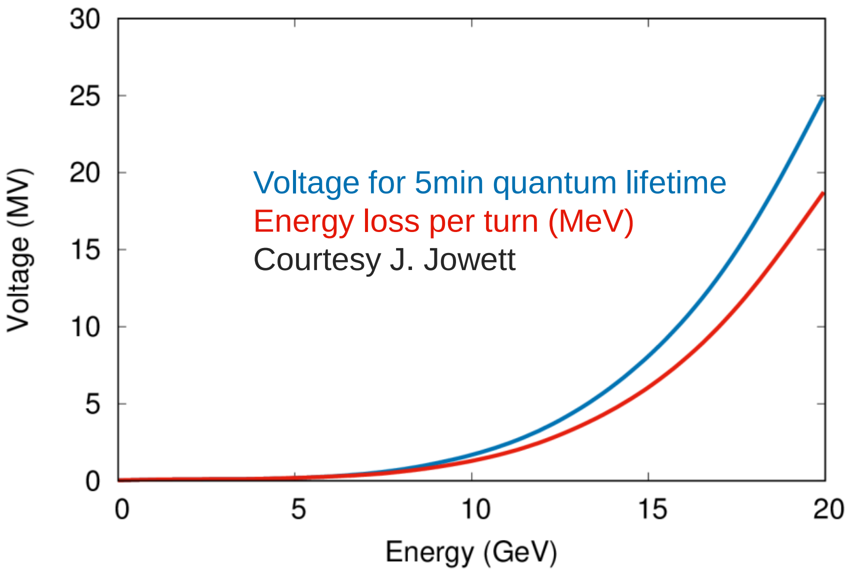
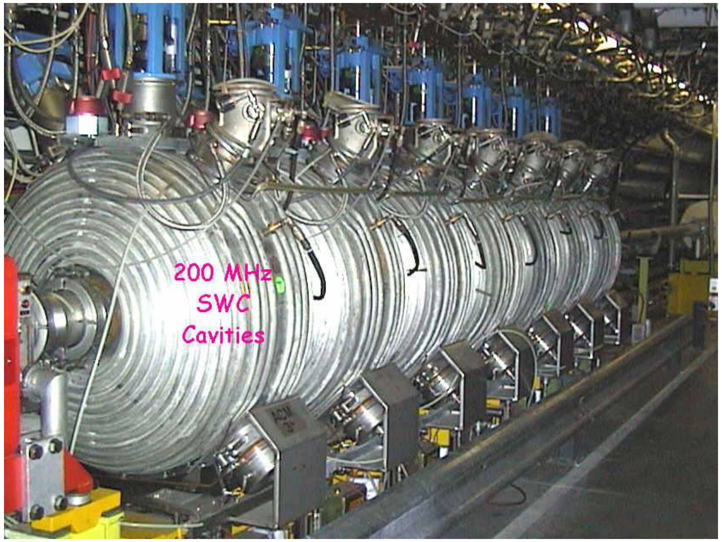
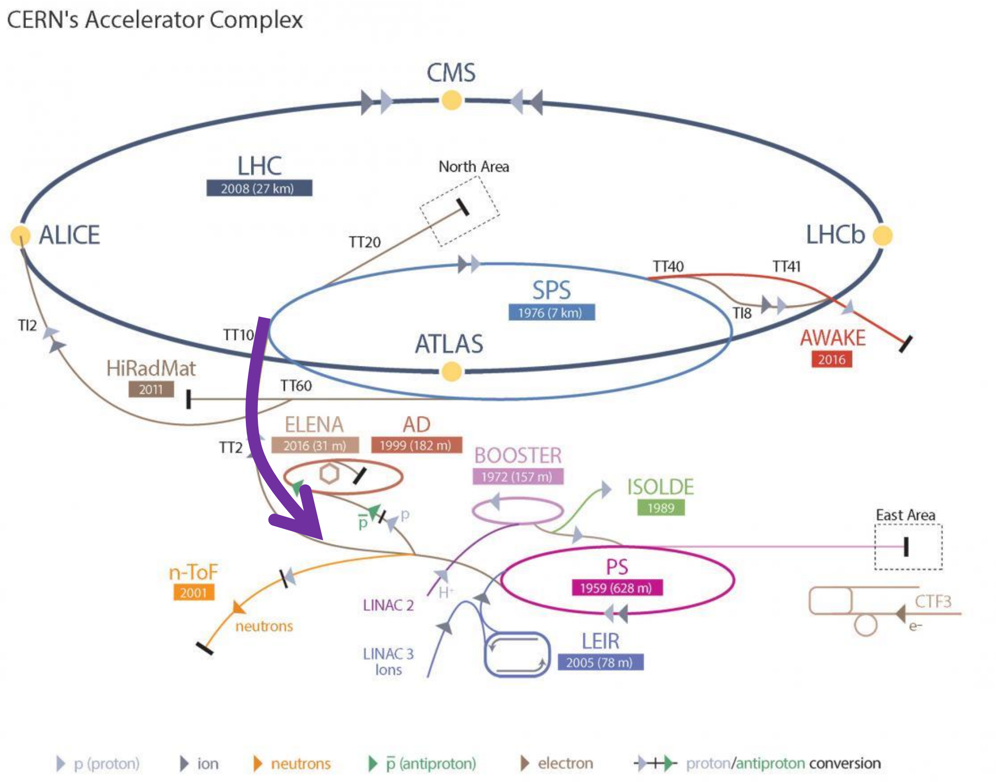
- Trains of 200ns (linac) separated by 100ns gaps (injections kicker)





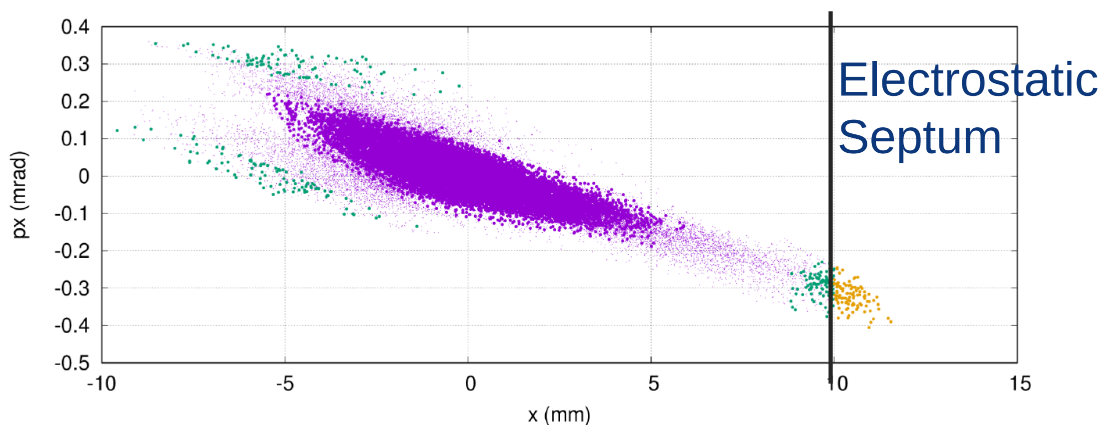
Slow extraction to experiments

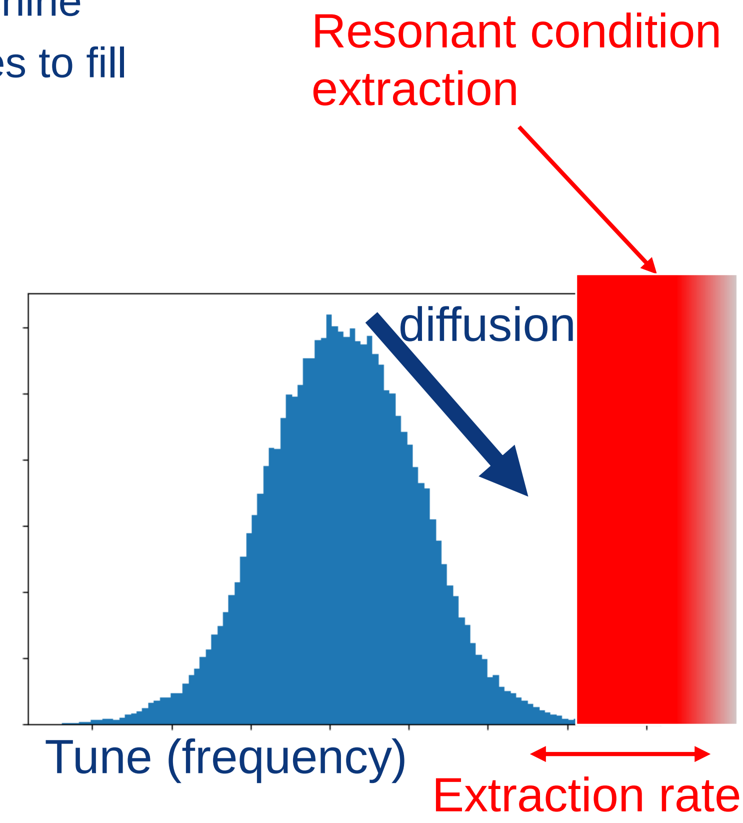
Extraction



Slow extraction principle, in frequency space

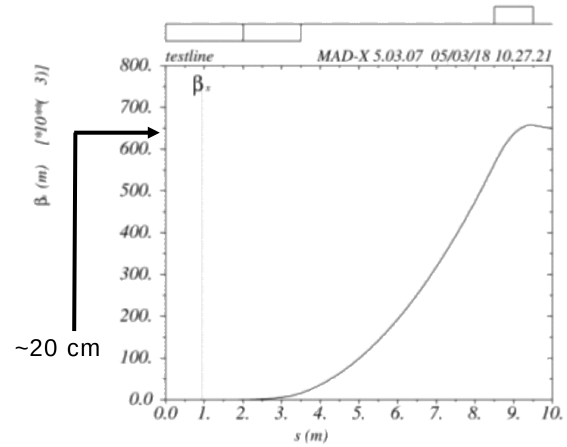
- Spread in oscillation frequency within the beam follows
  - Transverse distribution
  - Longitudinal distribution in presence of chromatic lattice
- Position of the resonant condition is set by the machine
- Synchrotron radiation constantly diffuse the particles to fill the tail in the distribution
- 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



Instrumentation

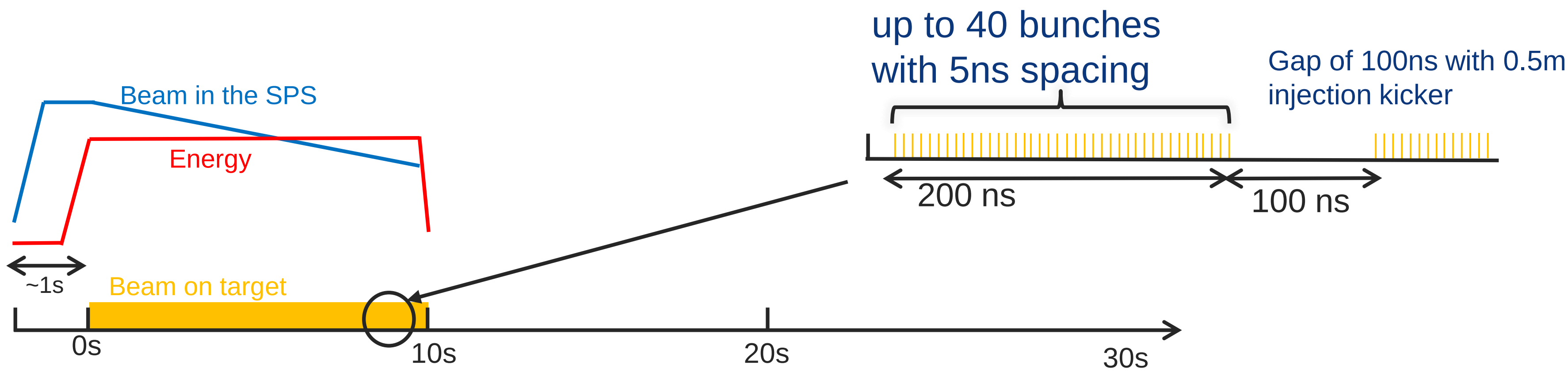
Linac:
- Position
  - Re-use of CTF3 inductive pick-ups
  - Simple button BPMs would also do the job
- Beam Size
  - OTR screens (can also be combined with streak camera for bunch length)
- Intensity
  - Re-use of CTF3 inductive pick-up or standard beam current transformers

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

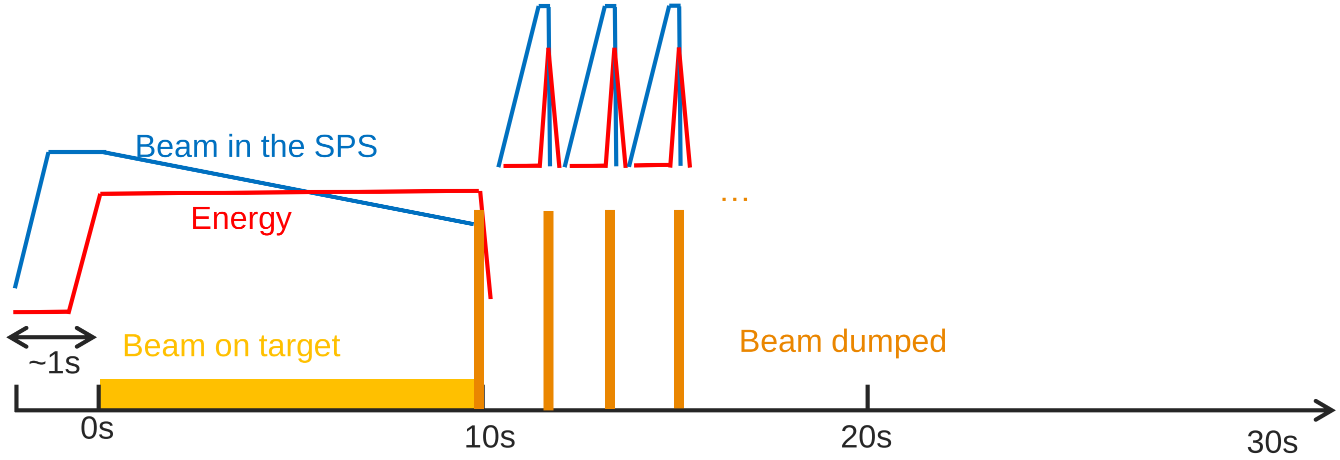
Structure of extracted beam



- 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 cm^2
- This flexibility can deliver the needs of LDMX
  - Phase 1 : 10^{14} electrons
  - Phase 2 : 10^{16} electrons

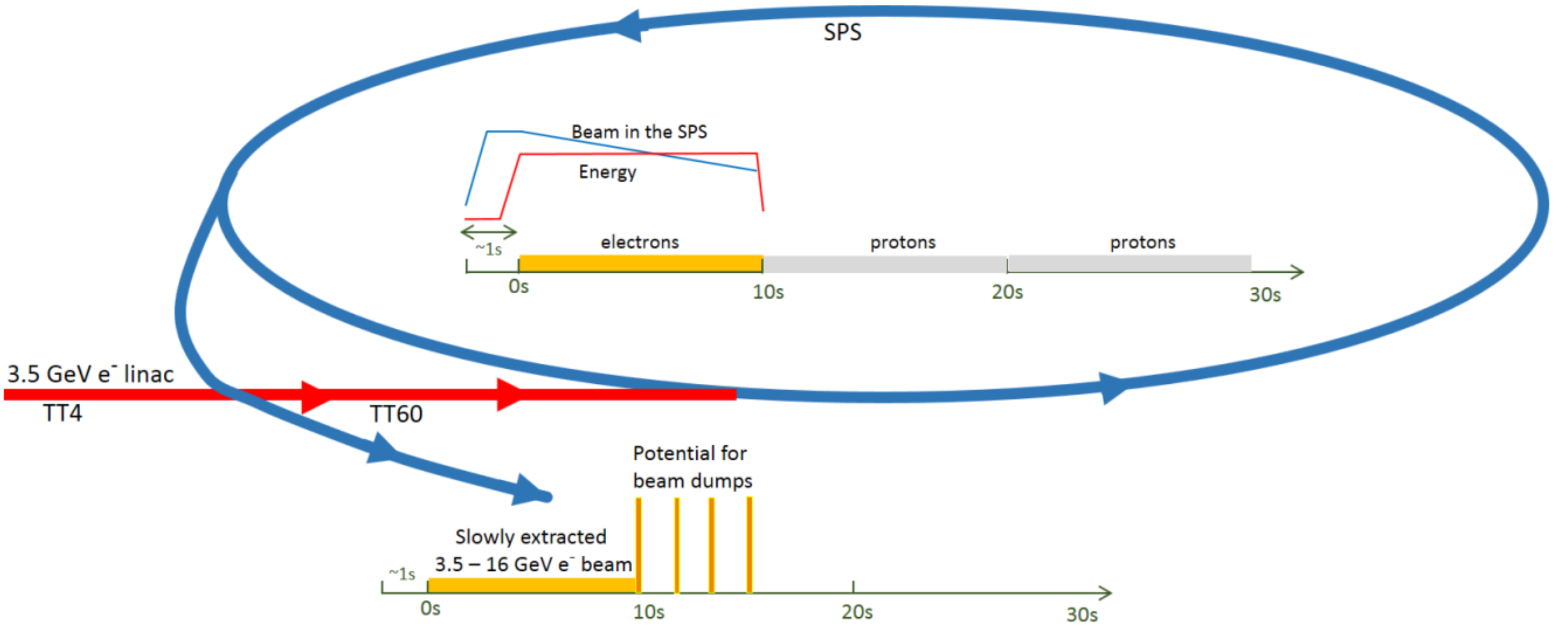
Beamdump experiments possible

- 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