Primary electron beam facility at CERN

CERN PBC working group
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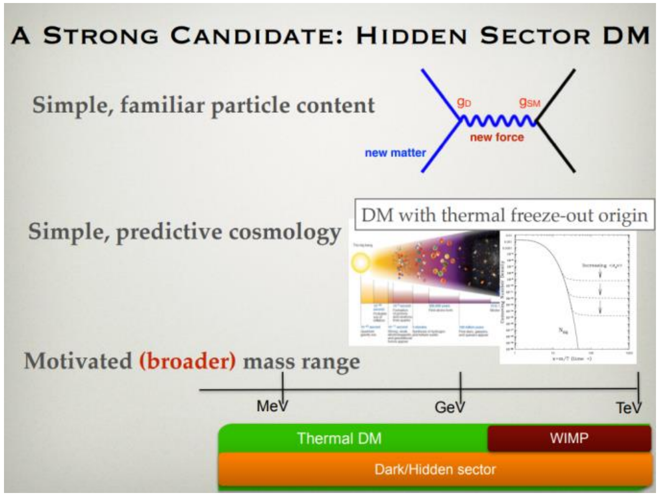
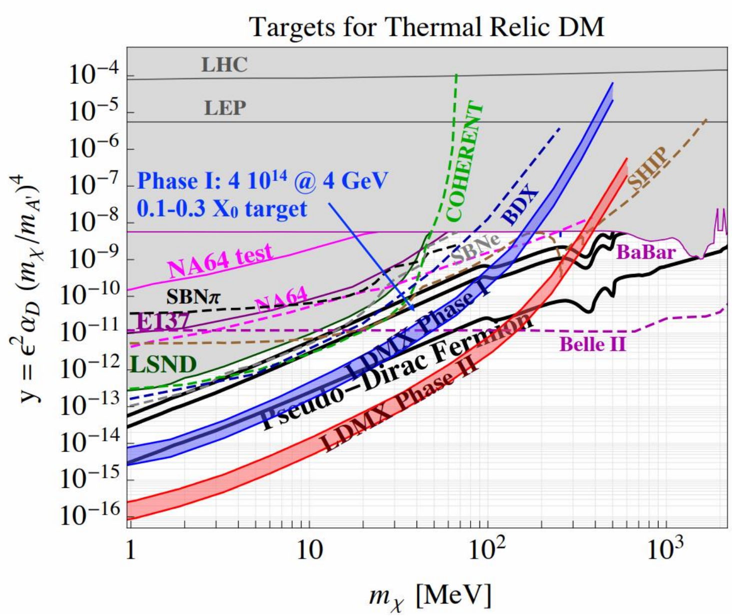
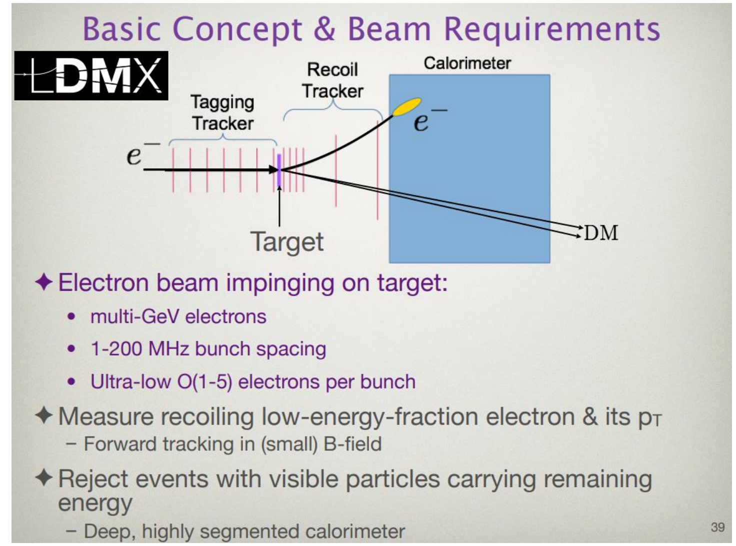
Physics with e-beams, LDMX





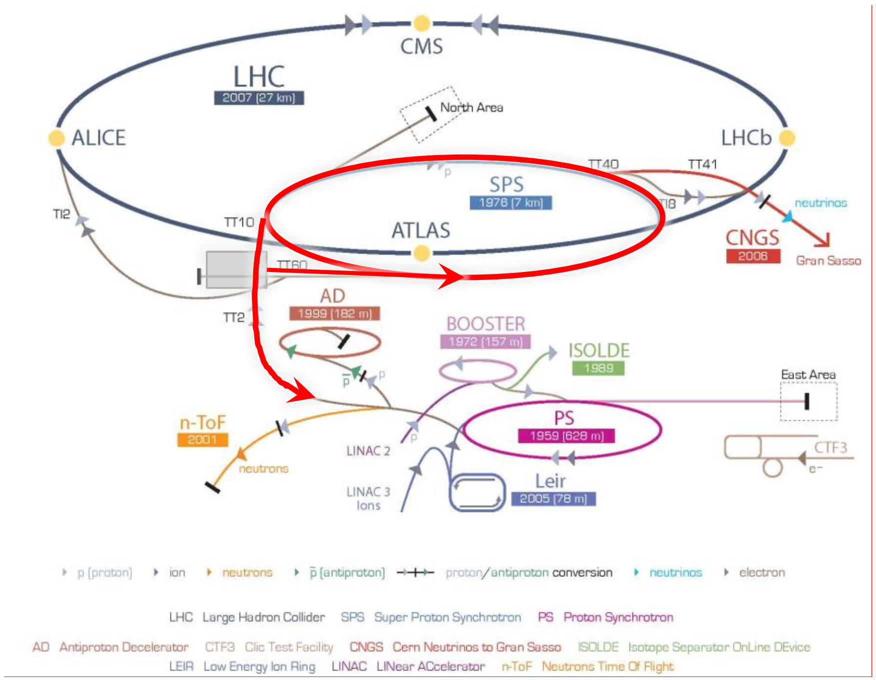


[1]Talk by P. Schuster
Exploring Hidden Sector Physics with an electron beam facility
Physics beyond collider annual workshop
November 21 2017, CERN
indico.cern.ch/event/644287/contributions/2762531/

Electrons at CERN - overview

Accelerator implementation at CERN of LDMX type of beam

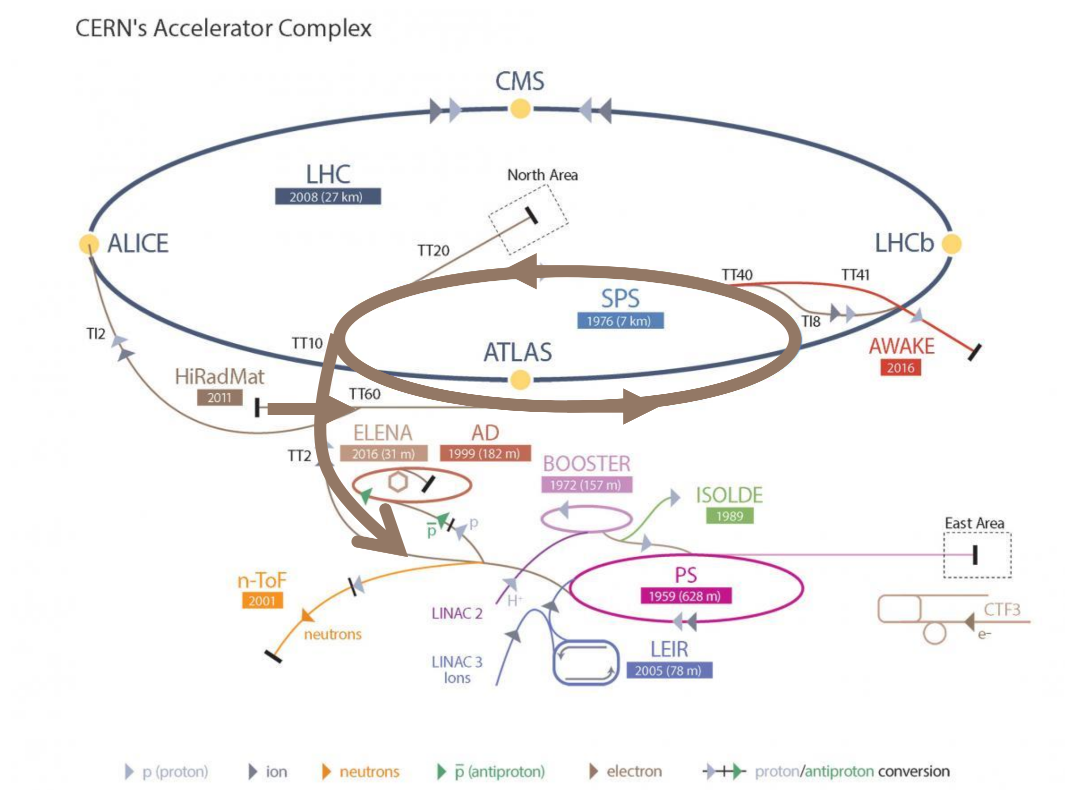
X-band based 70m LINAC to ~3.5 GeV in TT4-5:
- Fill the SPS in 1-2s (bunches 5ns apart) via TT60
- Accelerate to ~16 GeV in the SPS
- Slow extraction to experiment in 10s as part of the SPS super-cycle
- Experiment(s) considered by bringing beam back on Meyrin site using TT10



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

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

Outline



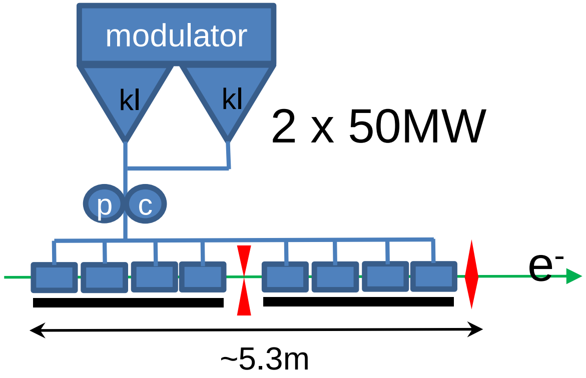
3.5GeV Linac

Acceleration to in SPS

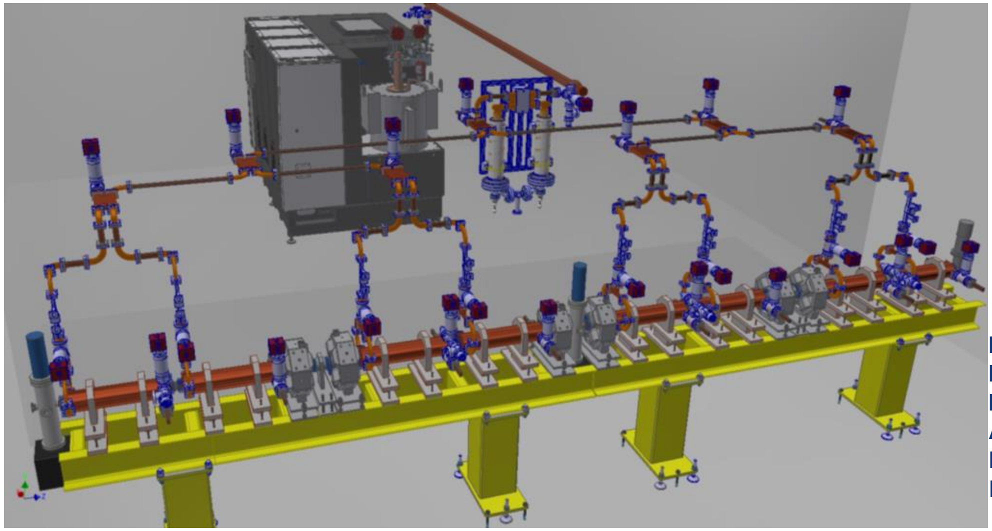
Extraction

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 [1]



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

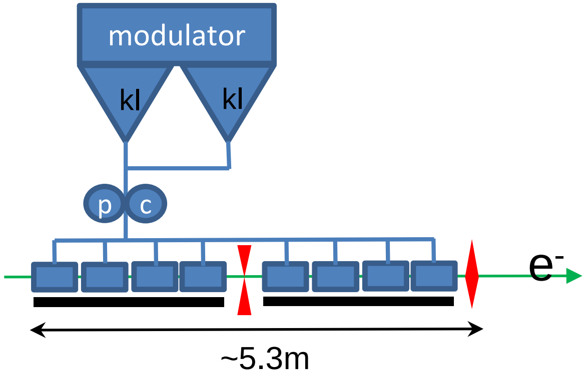
Linac components available

- Examples

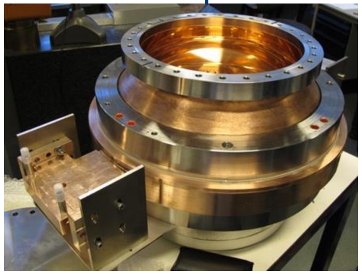
\+

Klystron

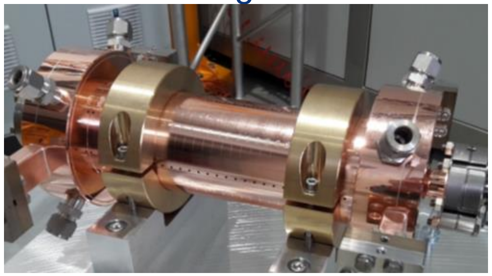
Modulator



Pulse compressor



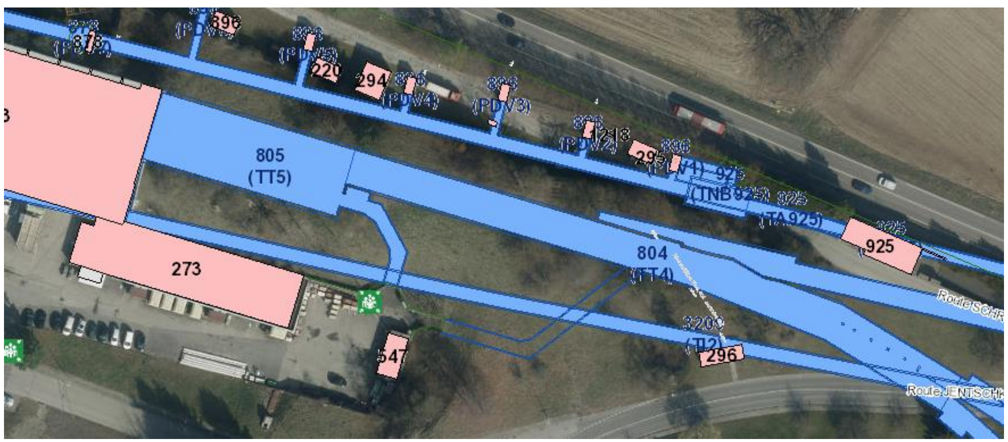
Accelerating structure

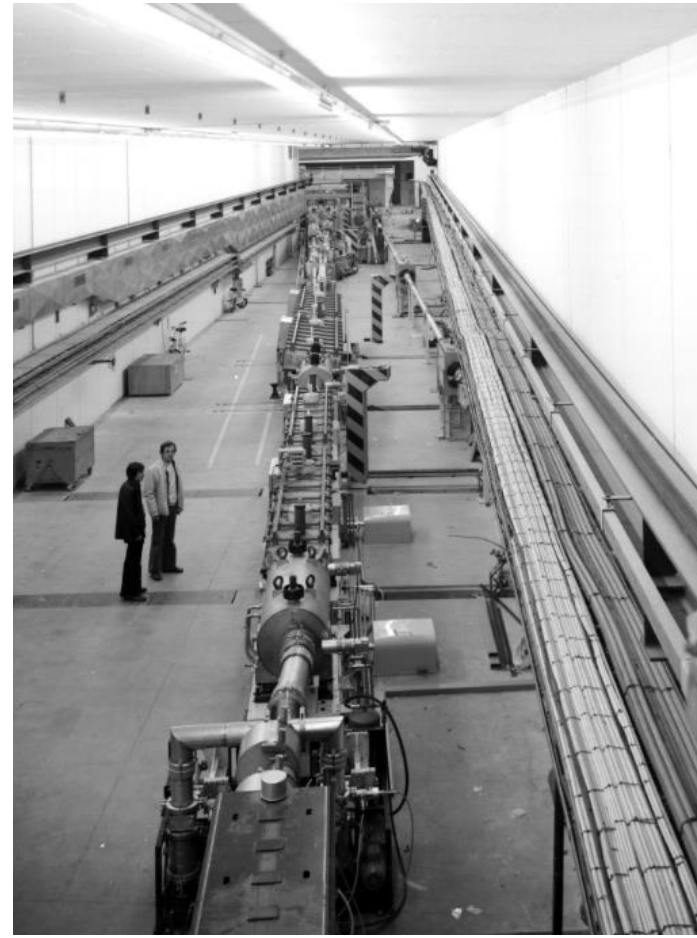


- One RF unit accelerates 200ns bunch train up to 264 MeV

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





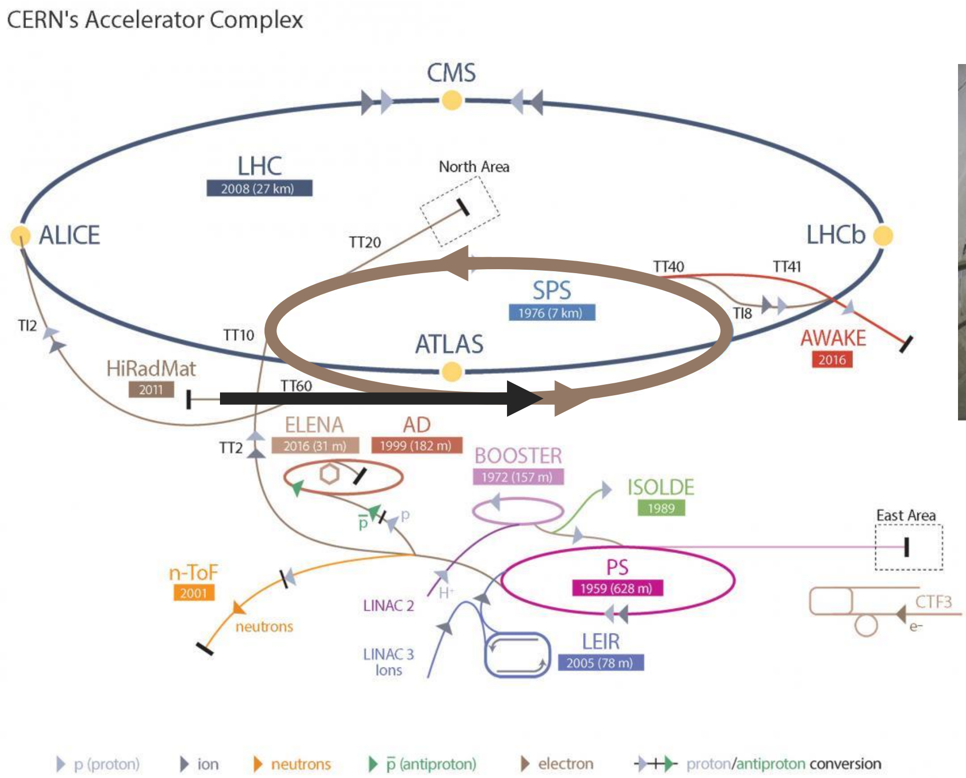
[1] Talk by A. Grudiev, Linac layout and cost, March 20th 2018, CERN
indico.cern.ch/event/715324/

Transfer tunnel, TT60, from the Linac into the SPS

Injection into the SPS

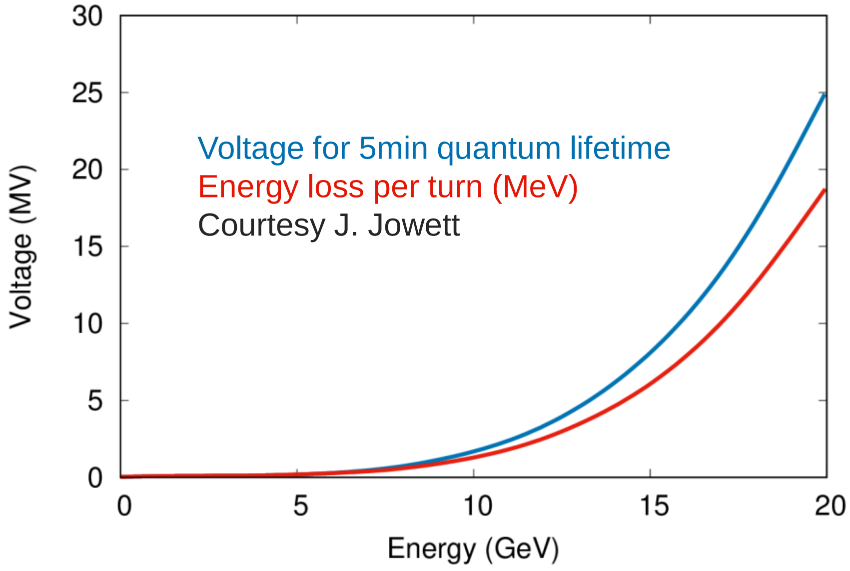
Bunch to bucket injection in the 200MHz SPS longitudinal RF structure.

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



SPS RF system

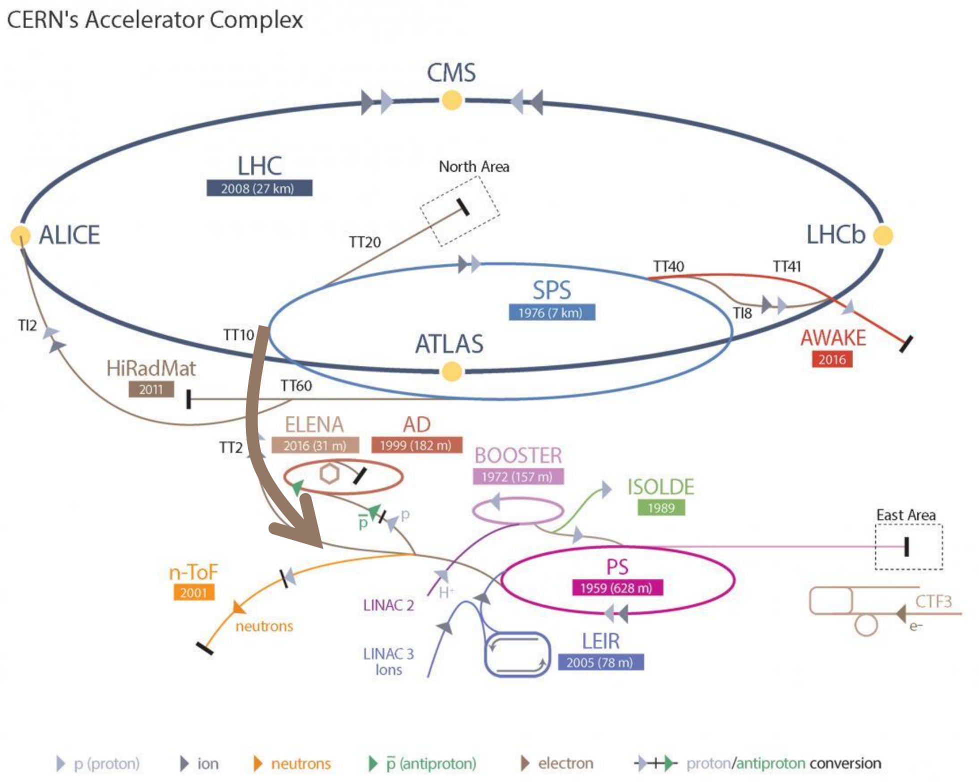
- Acceleration to 16 GeV can safely be achieved
- Existing 200 MHz cavities from LEP era to be re-installed
  - Need 10MV for 16GeV electrons
  - (12 + 1) 200 MHz Standing Wave Cavities [1 MV per cavity] available
- Space is available to install them
- 5ns, 10ns, … 40 ns longitudinal structure is imposed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



[1] Talk by A. Grudiev and E. Montesinos, SPS RF for e-update, March 1st 2018, CERN indico.cern.ch/event/703049/

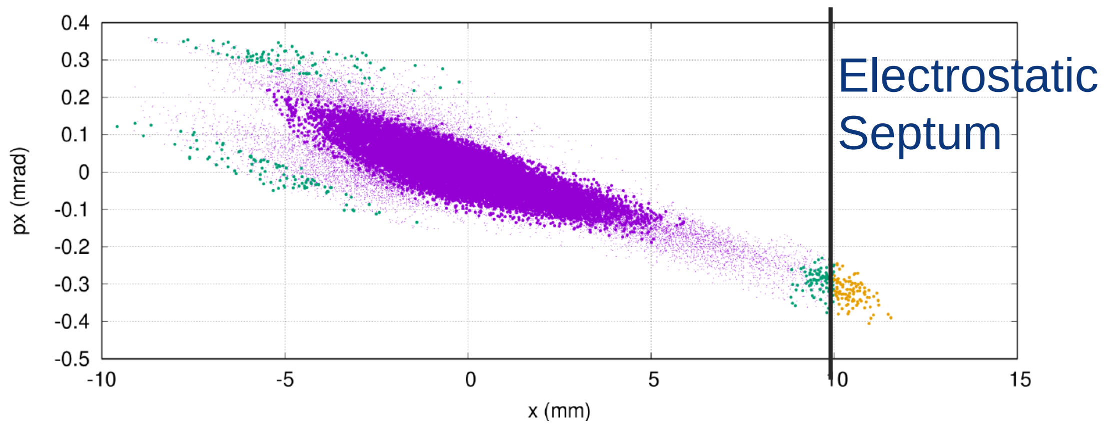
Slow extraction to experiments

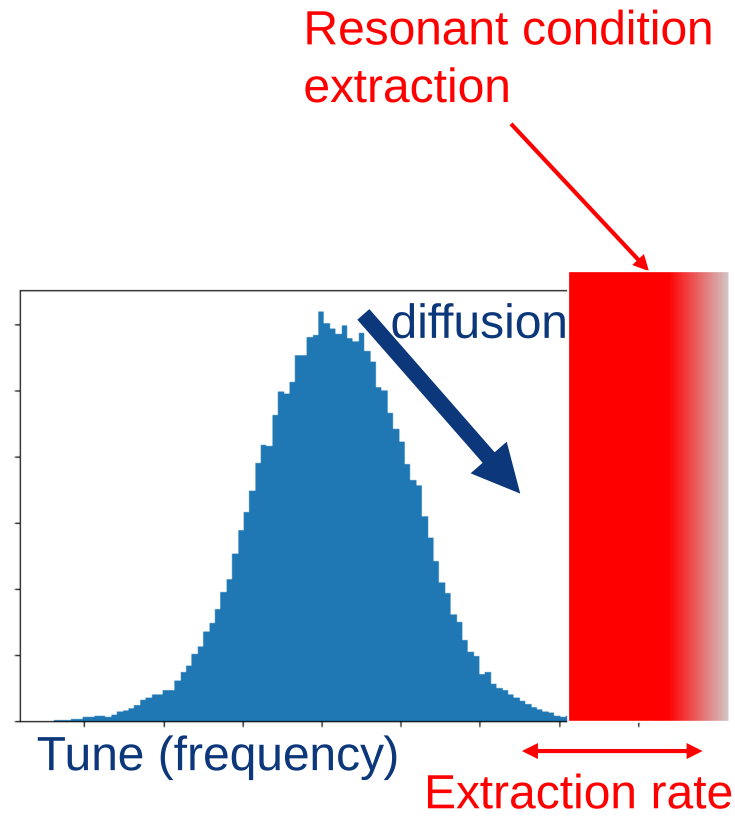
Extraction



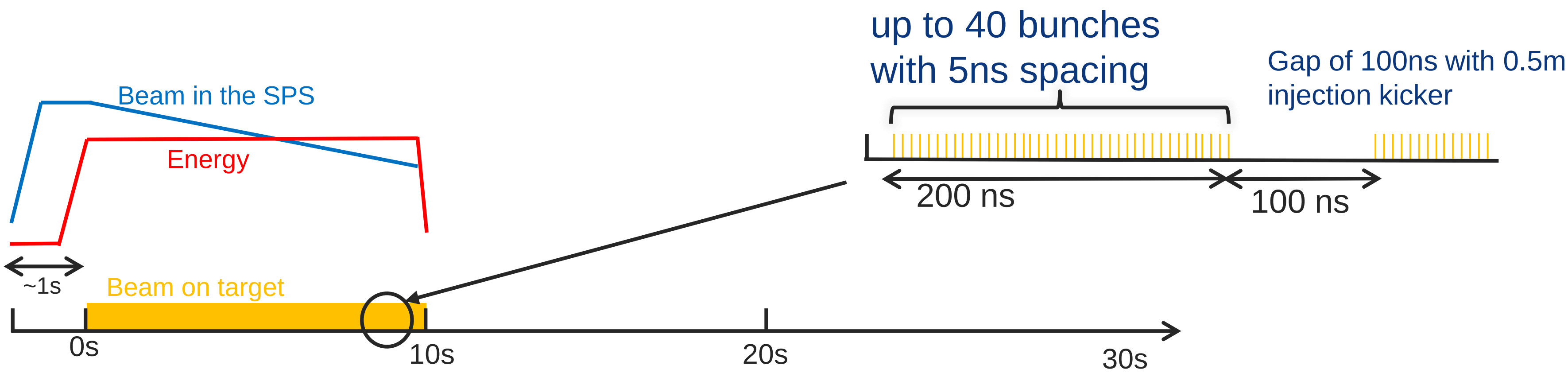
Slow extraction principle, in frequency space

- 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
- Quantum excitation constantly diffuse the particles, hence frequencies, within the beam
- The extraction rate can be controlled by changing the position of the resonant condition





Structure of extracted beam

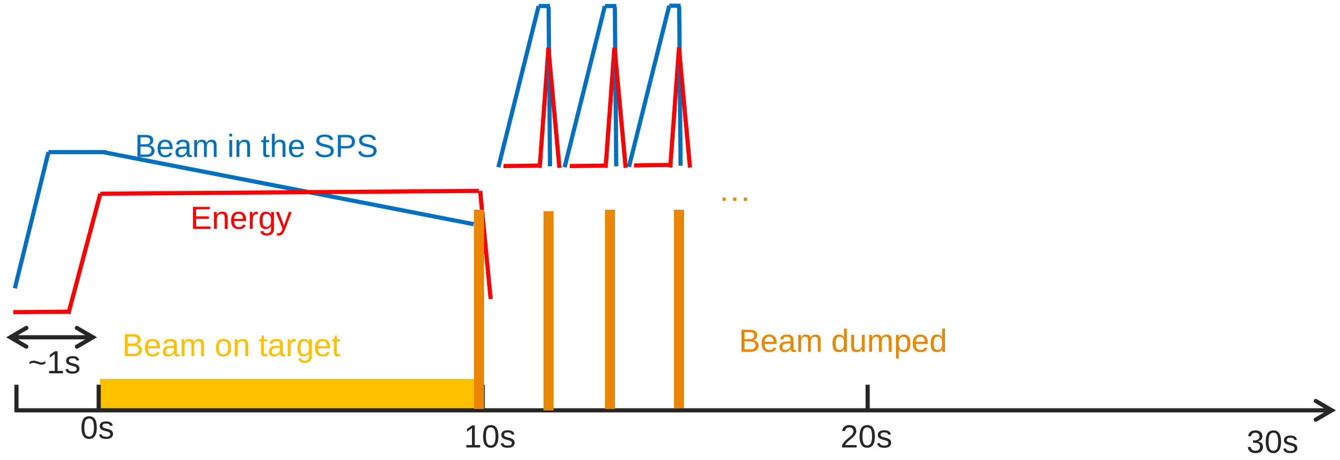


- Flexibility
  - Bunch spacing 5ns, 10ns, … 40ns
  - Average electrons per bunch can be chosen from <1 to anything
  - Transverse beam spot on target from very small up to hundred cm^2

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

In addition

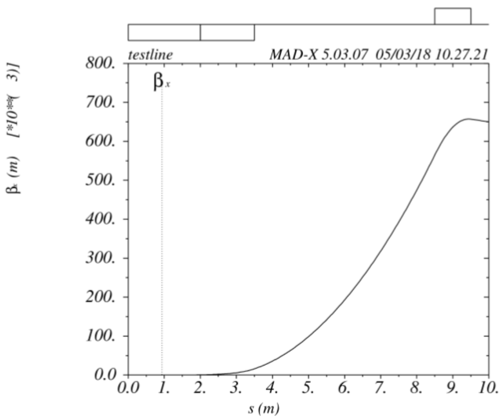
- After this beam has been delivered there is still a lot of electrons in the SPS
- These can quickly be dumped into a separate beam line
    - 10^{12} electrons within 23μs, possibly up to 4 times more



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

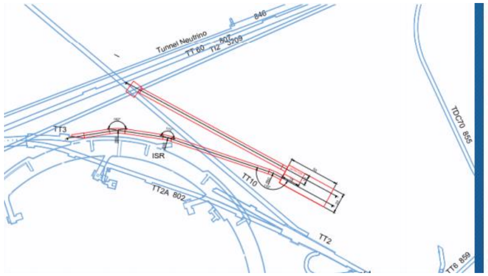
Electron beam transfer line from the SPS to experiments

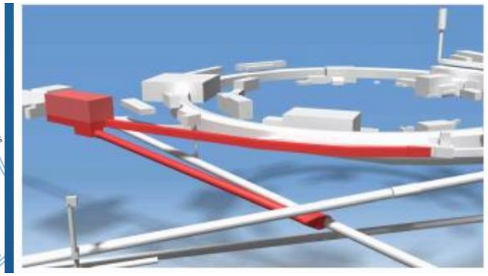
- Uses existing TT10 line, designed to transport 10/20 GeV beams
- Collimation in the line for control of beam distribution and intensity
  - ~ Gaussian beam can be made almost flat by careful collimation
- Beam size might be increased greatly at the target
  - Size of beam-spot chosen to deliver number of electrons/cm^2/bunch-crossing on target
  - For instance a 2cm vertical and 30cm horizontal beam is feasible
  - There is flexibility on the choice of both horizontal and vertical beam sizes



Civil engineering for experiments

- Several options considered
- Use of 3.5 GeV beam (see later) and physics programme using SPS beam can use different areas – see below two possible location of an experimental hall for experiments





[1] J.A. Osborne and J. Gall, Civil engineering – experimental hall, March 20th 2018, CERN, indico.cern.ch/event/715324/

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.

[1] R. Jones, Instrumentation challenges, March 1st 2018, indico.cern.ch/event/703049/

Example of user groups for the CERN primary electron beam facility

Physics

- LDMX
- Other hidden sector experiments, incl. dump-type experiments using available higher intensity
- Nuclear physics

Accelerator physics

- 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 (FCC-ee)
- Plasma studies with electrons
  - Use electron (3.5GeV) beam as driver and/or probe – study by AWAKE WG
- Positron production (interesting for LC and plasma) and studies with positrons (plasma), LEMMA concept for muon collider
- General acc. R&D as in CLEAR today (https://clear.web.cern.ch)
  - Plasma-lenses, impedance, high grad, medical, training, instrumentation, THz, ESA irrad.
- General Linear Collider related studies
  - Example: damped beam for final focus studies (beyond ATF2)

….. in all cases we have representatives in e-SPS WG ….

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 (LDMX beam: https://arxiv.org/abs/1805.12379)

- Work well underway to write this up and conclude on outstanding points, including a cost estimate
  - Some user cases will need further studies

- Working group meets ~monthly, next meeting 21.6
- Representation across user groups, machines, technical systems and CE/infrastructure
  - Mailing list : PBC-acc-e-beams (electron beam in SPS) <PBC-acc-e-beams@cern.ch>
  - Collaborative space : espace.cern.ch/test-ESEWG (access rights with mailing list)
  - Indico branch in PBC projects : indico.cern.ch/category/10055/

Possible program quantities to deliver phase 1

- 12s cycle
  - <2s for injection, acceleration and reset
  - 10s slow extraction
  - 83% duty in-cycle
- ~33% duty cycle to work along LHC and proton fixed target program
- 65% of ring occupied (with 100ns injection kicker rise time)
- 150 days/year
- 1e per bunch (20ns spacing or 50MHz) per turn
- 1.15×10^{14} electrons per year on target

Possible program quantities to deliver phase 2

- 12s cycle
  - <2s for injection, acceleration and reset
  - 10s slow extraction
  - 83% duty in-cycle
- ~33% duty cycle to work along LHC and proton fixed target program
- 65% of ring occupied (with 100ns injection kicker rise time)
- 150 days/year
- 22e per bunch (5ns spacing or 200MHz) per turn
- Beam-spot surface area chosen to deliver acceptable number of electrons/cm^2/bunch-crossing
- 10^{16} electrons per year on target