Primary Electron Beam Facility at CERN

Daniel Schulte

Facility design (and presentation) by
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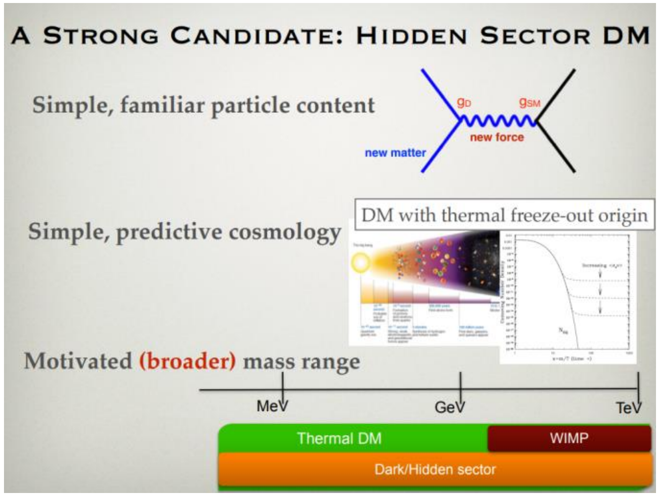
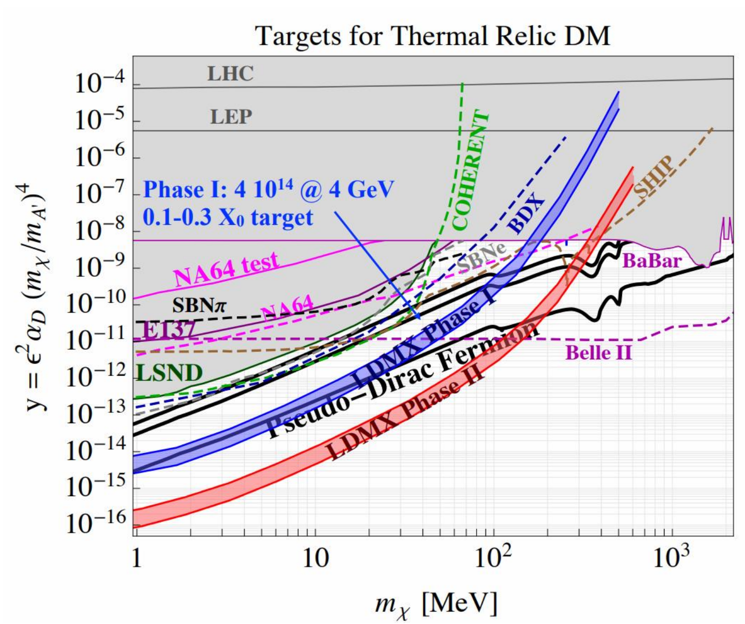
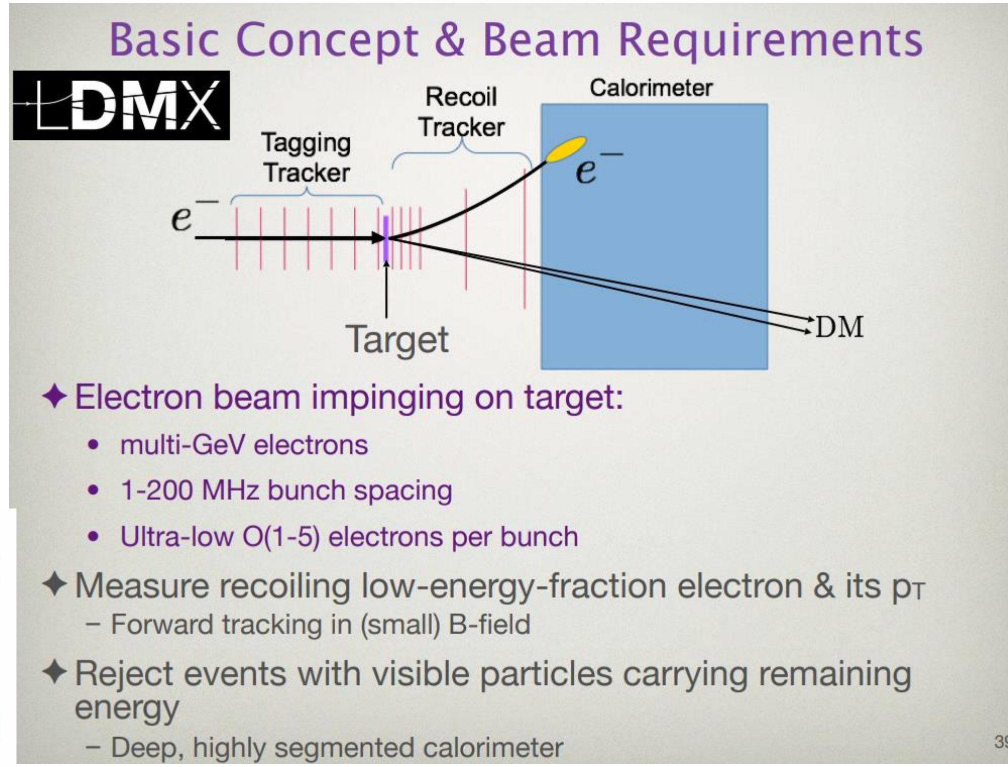
Physics with e-beams, LDMX



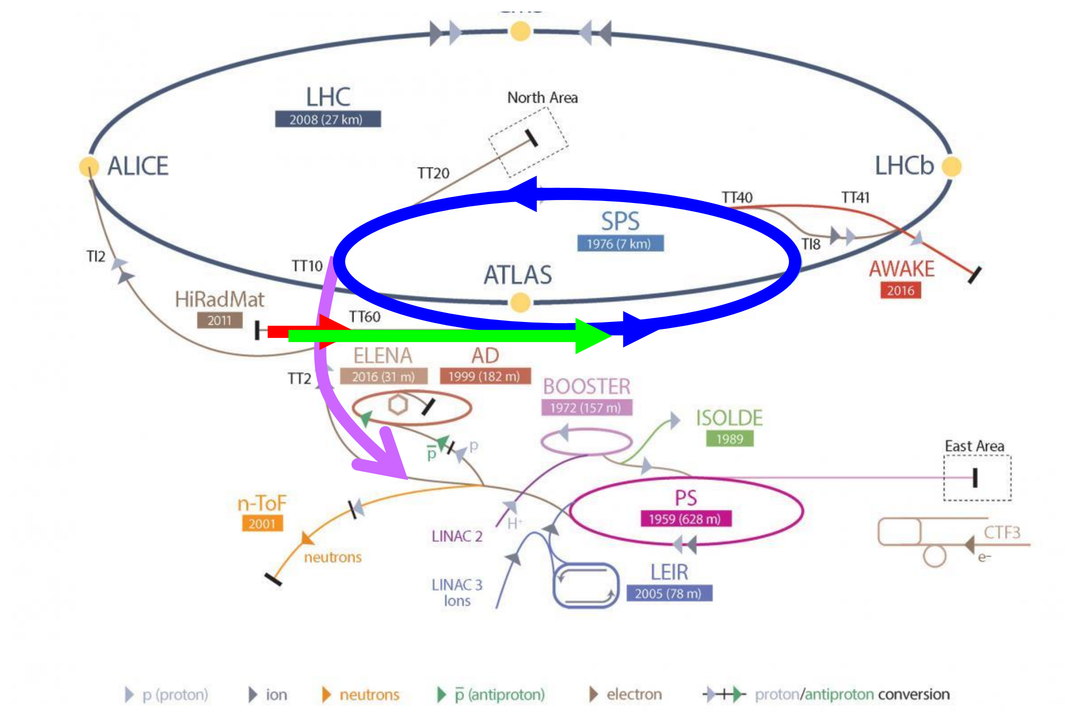




[1]Talk by P. Schuster
Exploring Hidden Sector Physics with an electron beam facility
Physics beyond collider annual workshop
November 21 2017, CERN
indico.cern.ch/event/644287/contributions/2762531/

Possible Implementation at CERN

Using existing infrastructure as much as possible



3.5GeV Linac
12 GHz CLIC technology

Transfer to SPS

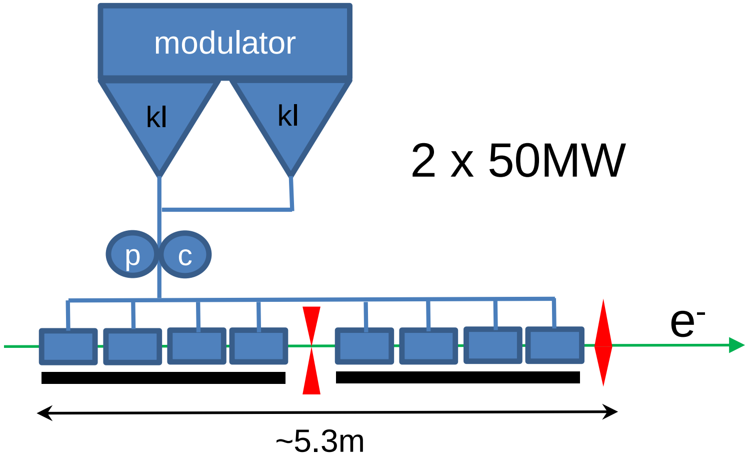
Acceleration to about 16 GeV in SPS

Extraction

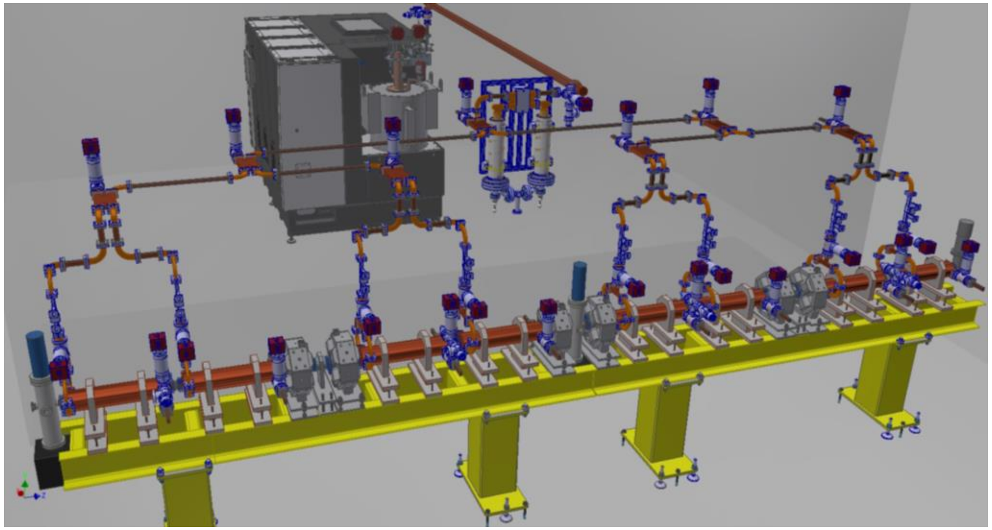
Linac Parameters

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 [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



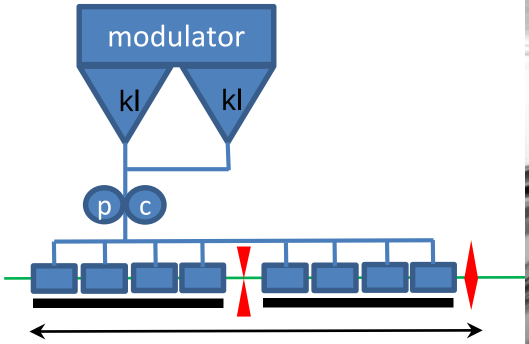
RF DESIGN OF THE X-BAND LINAC FOR THE EUPRAXIA@SPARC_LAB PROJECT
M. Diomede Et al., IPAC18

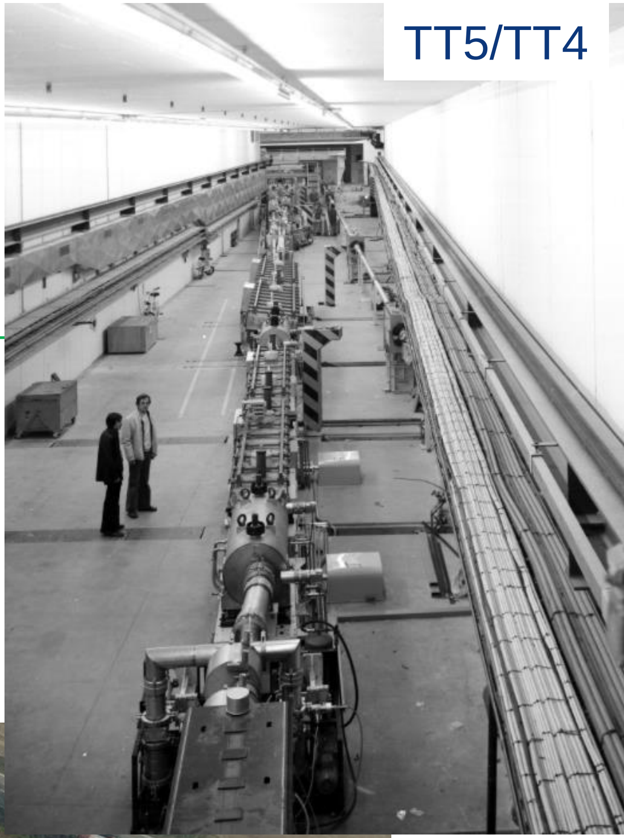
Linac Components and Site Available

Klystron

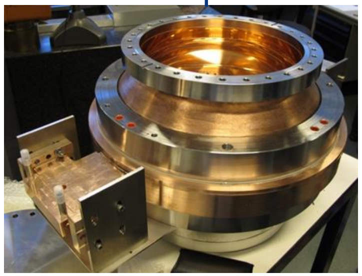
+

Modulator



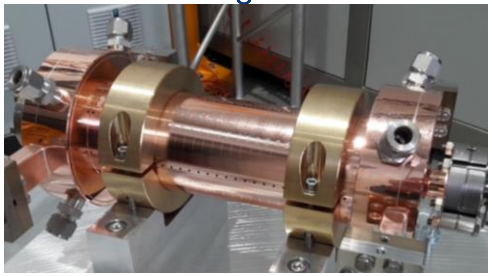


Pulse compressor



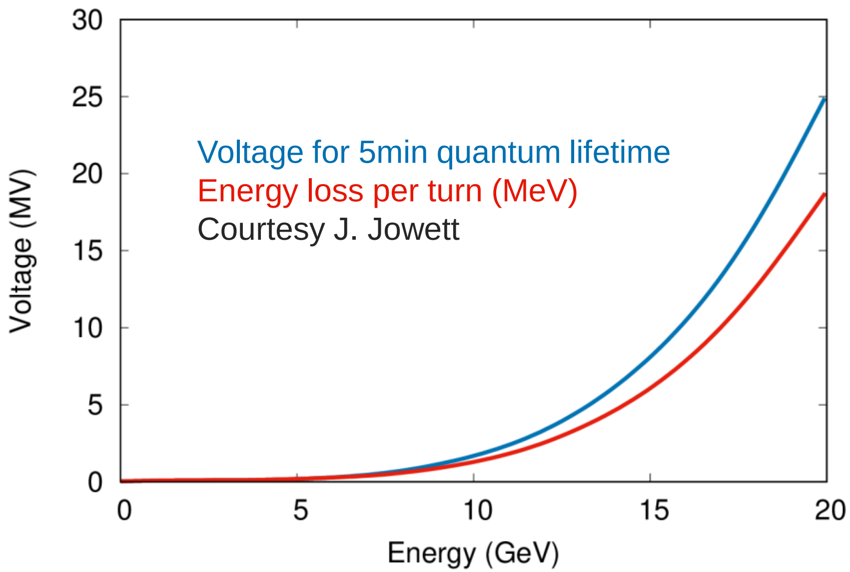
One RF unit accelerates 200ns bunch train up to 264 MeV

Accelerating structure



SPS

Transfer to SPS through TT60



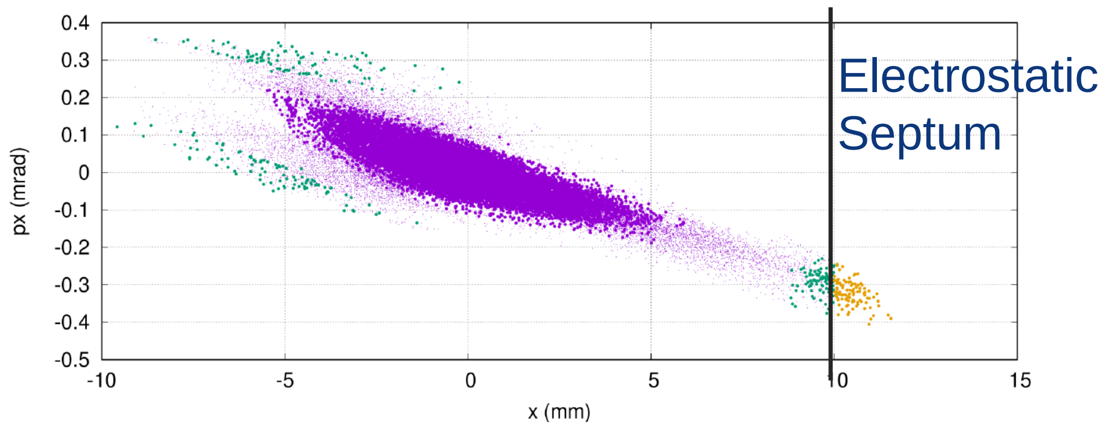
Bunch to bucket injection in the 200 MHz SPS longitudinal RF structure.

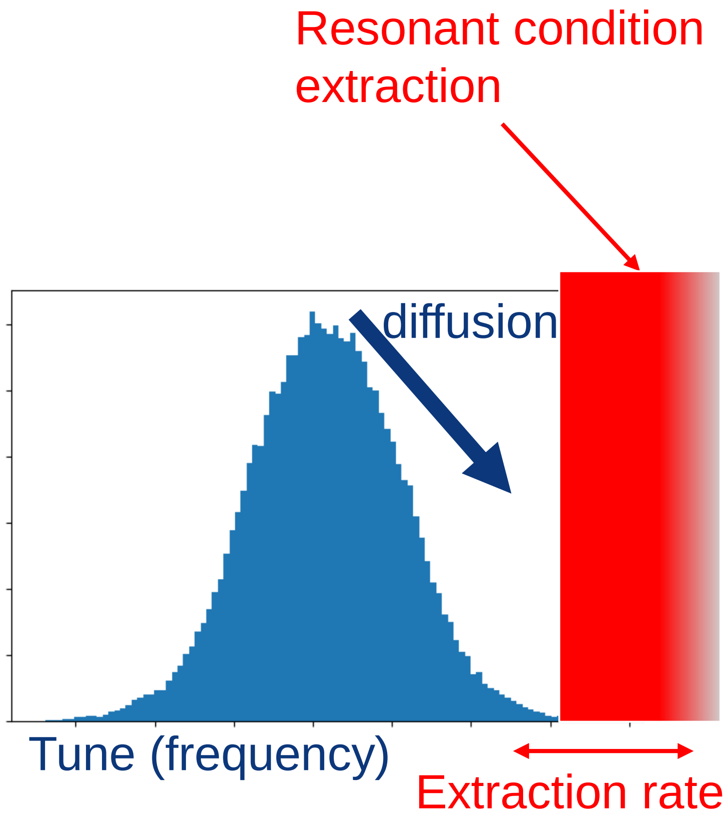
Total of 75 trains of 40 bunches
3000 bunches, 10^{12} electrons in the ring

- Acceleration to 16 GeV can safely be achieved
- Existing 200 MHz cavities from LEP era to be re-installed
  - Need 10 MV for 16 GeV 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)

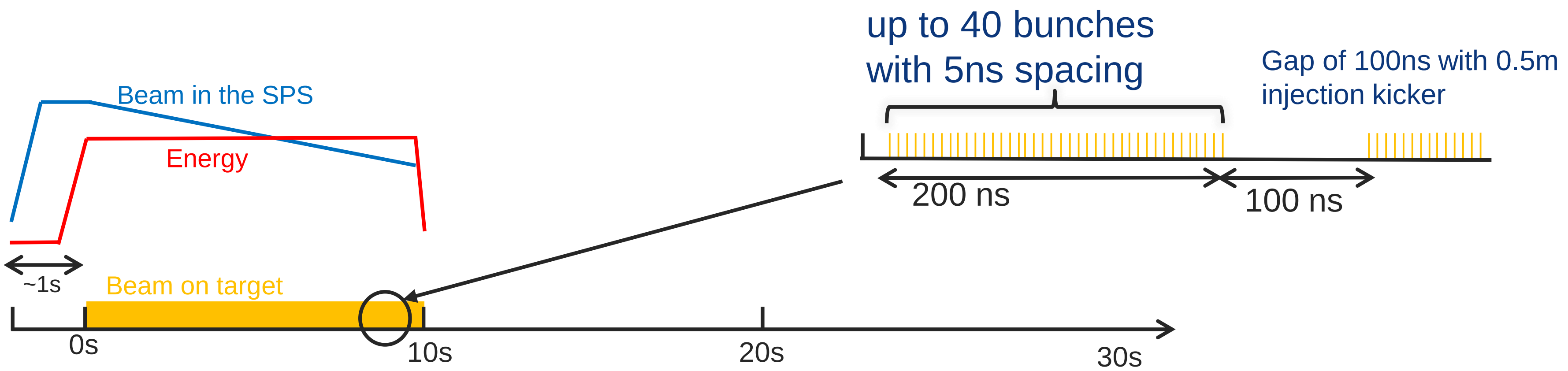
Slow Extraction Principle, in Frequency Space

- 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

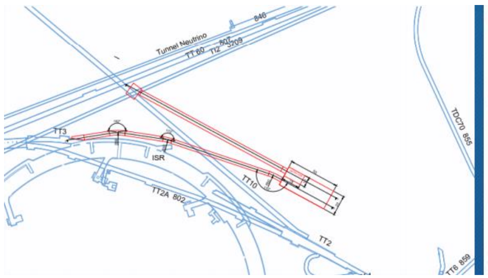
Can also delivery beam for dump experiments

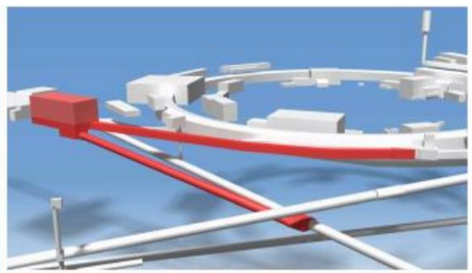
Experiments

Several options considered

SPS beam extracted and transported through TT10

3.5 GeV beam can be used in different area





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

Example User Groups for CERN Primary Electron Beam Facility

Physics

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

Accelerator physics

- CLIC: Linac goes 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, instrument., 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 ….

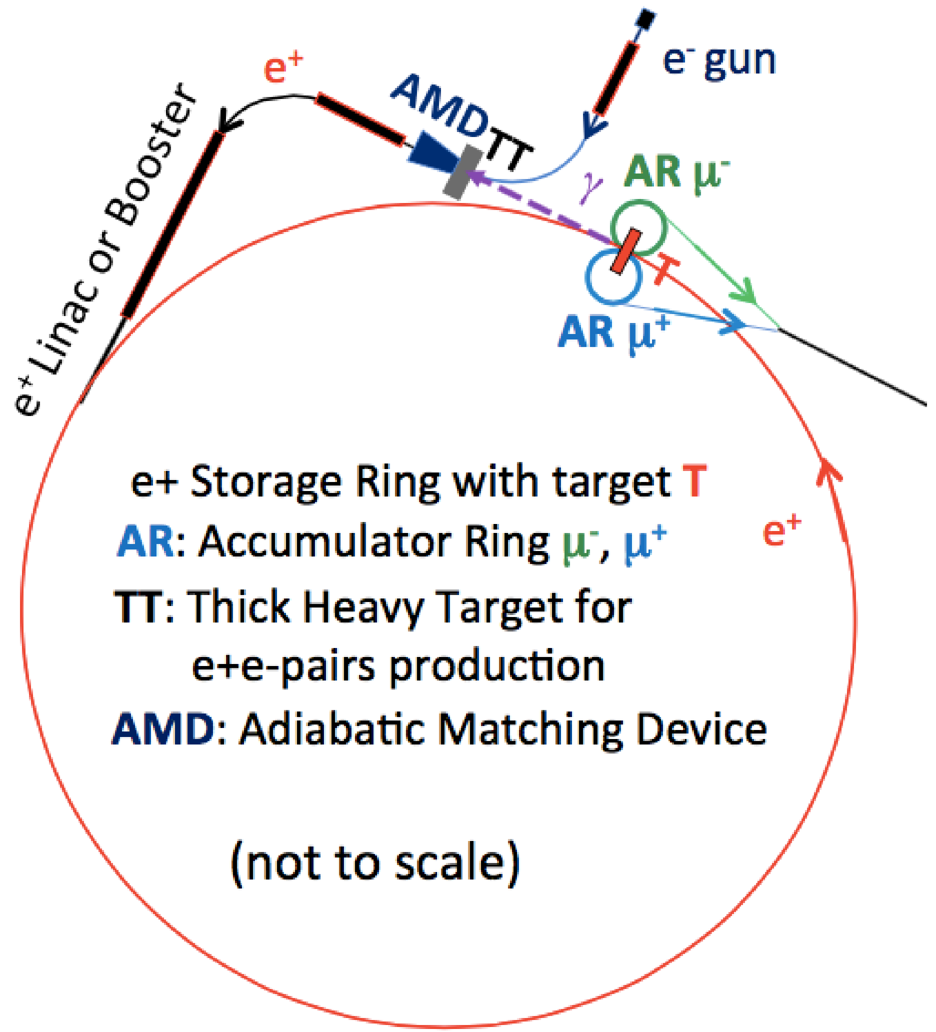
The LEMMA in a Nutshell

Developed by M. Boscolo et al.

Use positron storage ring at 45 GeV to produce low-emittance muon beam in a thin target

Muon beams make 2500 turns in rings then are accelerated

=> 2000 bunches per second



Year of the Strategy Input

Observation: Existing SPS and LHC rings give long-term perspective to pursuit of LEMMA scheme

Thinking strategy
L. Evans, S. Stapnes,
D. Schulte

- LHC tunnel ideal to house 45 GeV positron ring
- SPS requires much more installed voltage and power
- SPS tunnel can house 3+3 TeV muon collider
- LHC tunnel can house 7+7 or 14+14 TeV muon collider
- LEP3 collider in LHC tunnel is consistent with doing muon production studies, spot on for Z production

Considered phased approach:

- Phase 1: eSPS would be entry point for all options
- Phase 2: LEP3 or CLIC (use to test and develop muon production)
- Phase 3: Muon collider in SPS or LHC tunnel
- Allows to develop all technologies and wait for physics input to define energy scales and choices

Relevance of eSPS for Muon Colliders

This facility could potentially be of interest for muon collider development

Some examples, based on the LEMMA scheme

- Target
- Acceleration
- Collision
- Warning: These are fun examples made up by me to illustrate where maybe tests could help. Better examples in this workshop.

Can a muon collider with proton-based source learn something from eSPS?

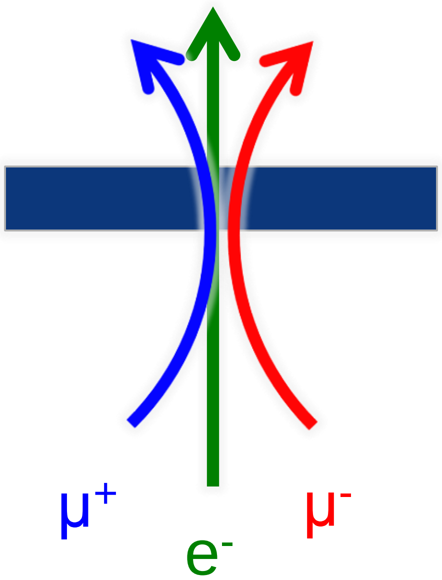
Target Issue to be Addressed

Target survival is important
Potentially fluid target is required

Muon beam passes 2500 times through target

- Each time additional muons are produced
- Multiple scattering increases muon beam emittance
- Optimum beta-function for target with thickness L is waist at the centre with $\beta = L / \sqrt{12}$
- 3 mm Be means $\Delta\varepsilon \approx 600$ nm (normalised)

Note: goal is $\varepsilon = 40$ nm



Note: target thickness does not matter for constant circulating positron beam

$L = a N^2 / \varepsilon$, $\varepsilon = b L^2$, $N = c L$, => $L = \text{const}$

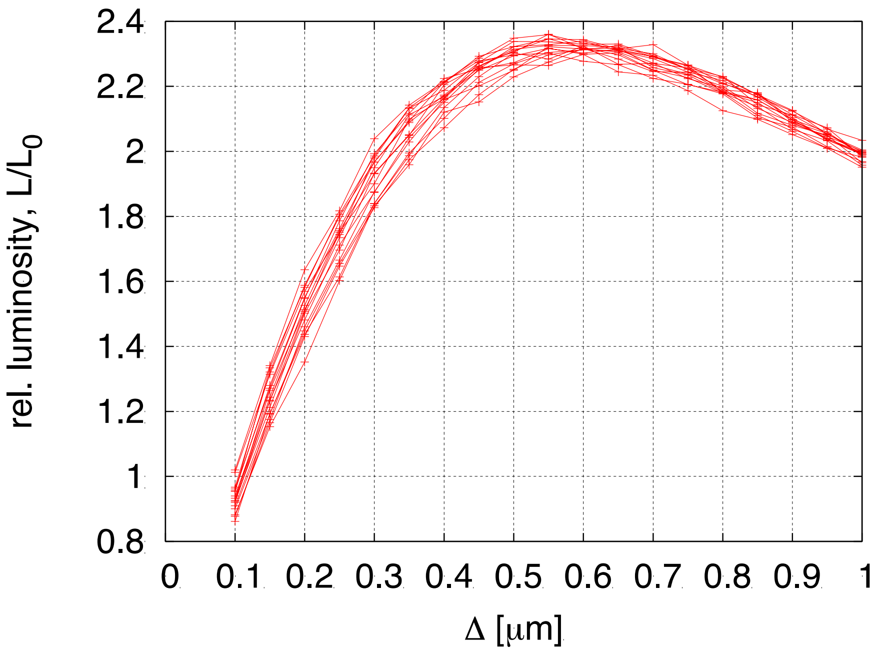
Also positron beam will experience emittance growth, but smaller due to damping and higher energy

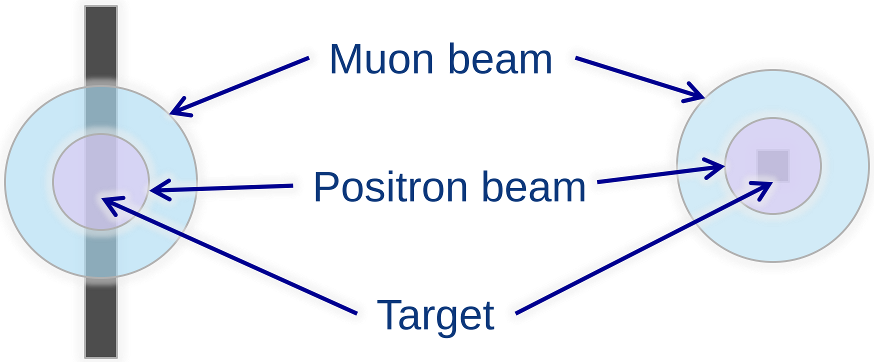
Fun Example Consideration

Consider target with limited transverse extensions

- If muons reach large action they scatter less often
- Also reduces the emittance growth of the positron beam

Hold target with foam, thin wires, … ?
Liquid target? Large heating per shot might require this anyway.





Only factor 2 gain in simulation with only multiple scattering

Much better ideas should be possible
Lots of fun in design to be had

Beam Collisions

Very small beta-function is the goal (0.2 mm), even smaller than in FCC-ee

- Test of beam quality in multi-turn
- Lattice tests?

Micro-focusing tests

Comments: I do not understand LEMMA scheme to combine bunches at collision energy

- Eager to learn how this could be done

Emittance growth from beam-beam seems large (O(8nm/collision) for 40 nm beams)

If one combines n bunches, luminosity increases by factor n

(luminosity is proportional to $f_r N^2 = f_{r0}/n (N_0 n)^2 = n f_{r0} N_0^2$

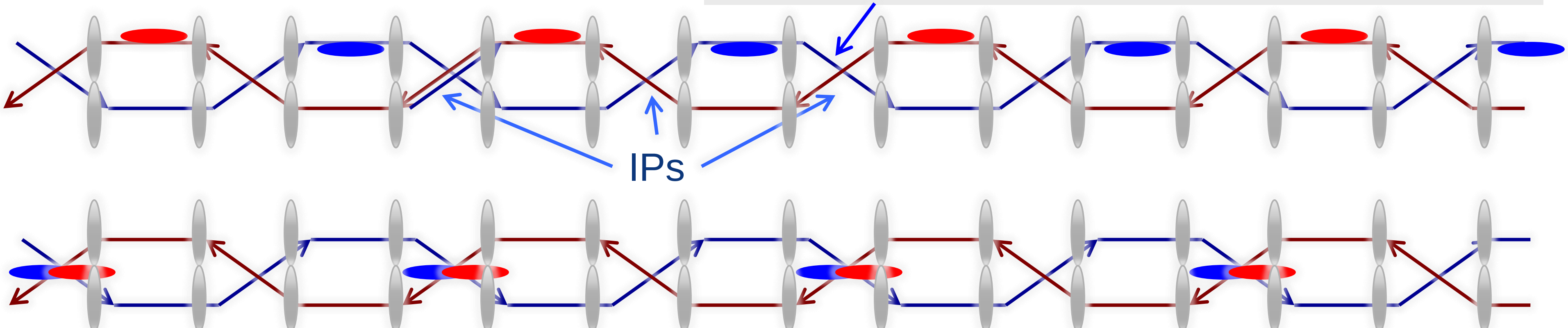
- Lack of ability to combine would reduce luminosity

Consideration

Potential approach: combine bunches to train not single bunch

- Very short bunch spacing (mm) due to ultra-fast kicker (to be developed)
- Multi-interaction point in stretch-limousine detector
- All bunches collide with all
- Betafunction can be small

At least few mm distance to increase beta-function to level that it is channeled
e.g. in diamond $\beta>2$cm for $\varepsilon=40$ nm @ 7 TeV



Very short focusing systems are required

- Crystals, beams, plasma could be options
- But need strong focusing, maybe not possible

But few points of collision would already help

Is this insane?
Very well possible

Note scheme could also improve production
Few thinner targets in a row

Muon Acceleration

Muon acceleration to final energy, e.g. 7 TeV

- A ring requires very fast magnet ramping (several Hz to kHz)
  - Difficult with superconducting ring
  - Or use large normal-conducting ring
- Recirculating linac
  - A few turns possible, still important voltage needed
- Plasma acceleration
  - Plasma is good at high gradient
  - Not so clear are high efficiency and high beam quality
  - Muon bunch charge is low and emittance large
    - 2000 bunches/second at $5x10^7$ muons
      - Beam stability is much easier
    - 40 nm is equivalent to 8 μm at electron mass, compared to 10 nm for linear collider
      - Much less concern for emittance preservation
    - Efficiency requirement is much relaxed (LEMMA example: 2000 bunches/second at $5x10^7$ muons to 7 TeV at 1% efficiency requires only 11 MW)
      - May even be OK for μ^+

Concluding remarks

- Important physics opportunities with e-beams at CERN
- Based on CERN accelerator complex and R&D for CLIC an electron beam facility would be a natural next step
  - No show-stoppers found
  - LDMX interest in pursuing this option as beam close to ideal (LDMX beam: https://arxiv.org/abs/1805.12379)

- Preparing write-up, including a cost estimate
  - Some user cases will need further studies
  - Interest for muon collider R&D should be identified
    - Target work
    - Plasma acceleration?
    - Compact focusing?
    - …

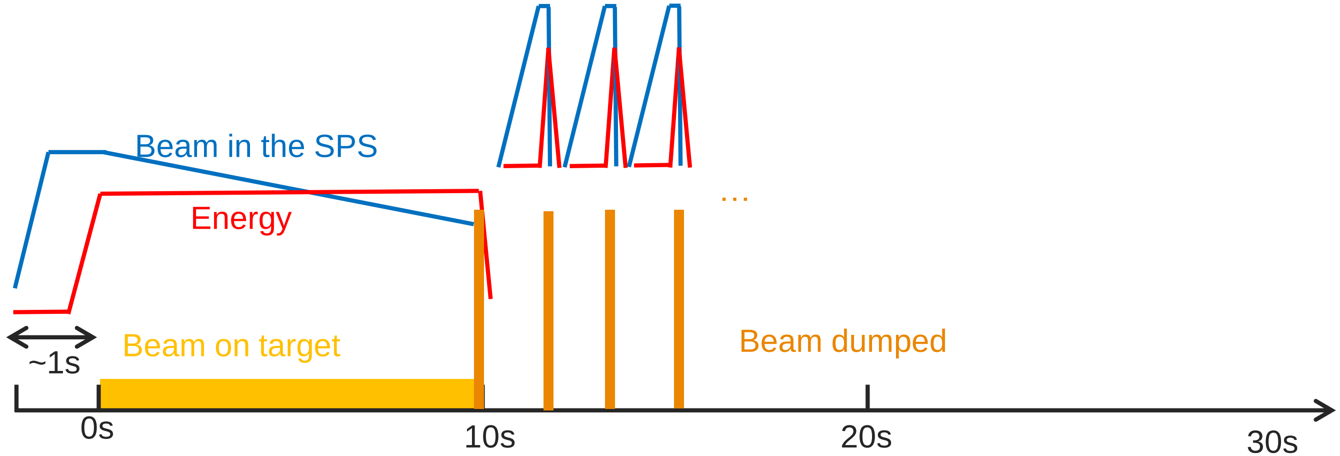
Many thanks to M.Boscolo and P. Raimondi for discussions on LEMMA

- 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/

Reserve

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