Physics with e-beams (SPS)

Overview of the project

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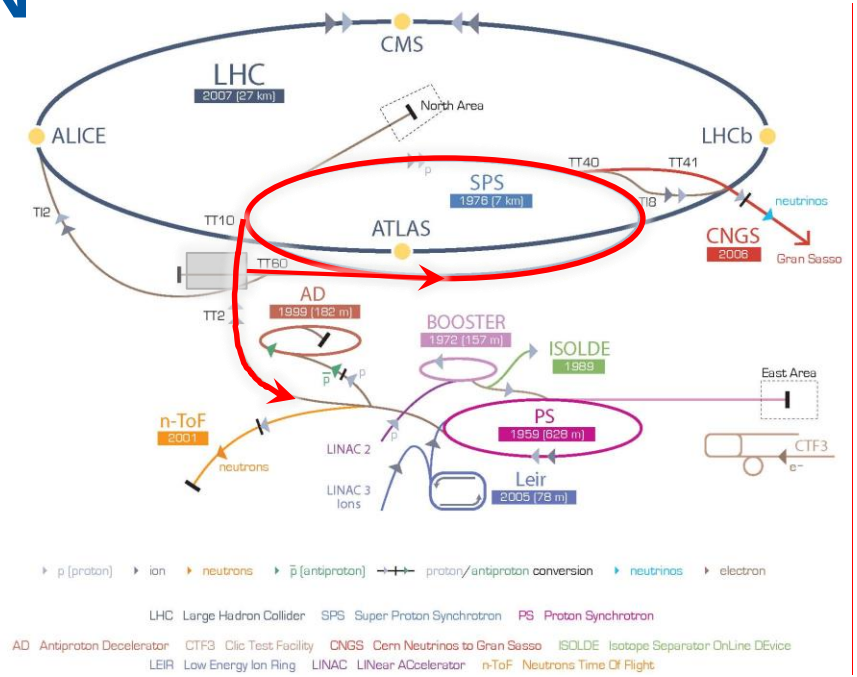
Electrons at CERN

Accelerator implementation at CERN of LDMX type of beam (Physics Beyond Colliders)

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



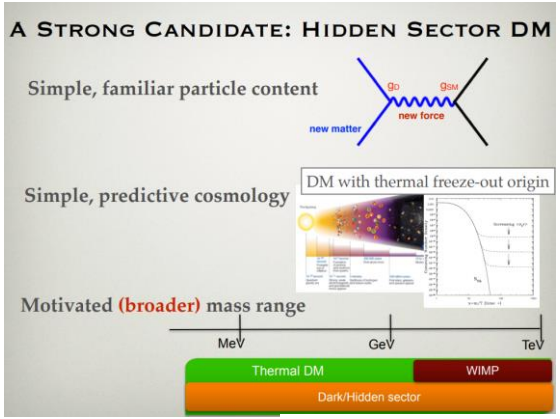
Beyond LDMX type of beam, other physics experiments considered (for example heavy photon searches)

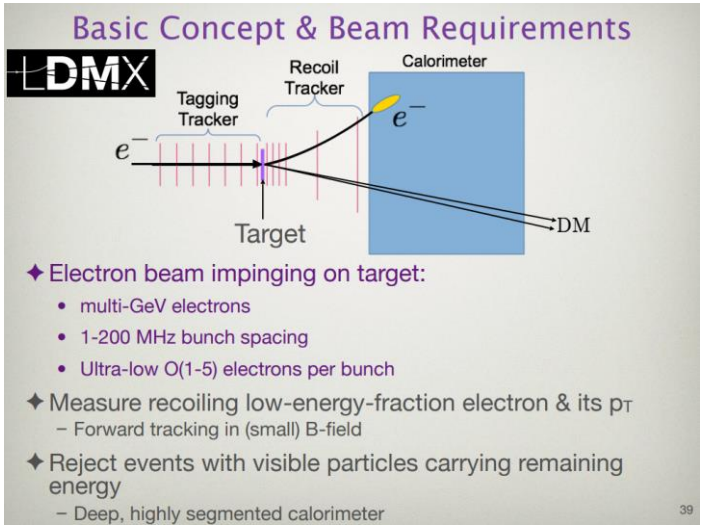
Acc. R&D interests: Overlaps with CLIC next phase (klystron based), FEL linac modules, e-beams for plasma, medical/irradiation/detector-tests/training, impedance measurements, instrumentation. positrons and damping ring R&D

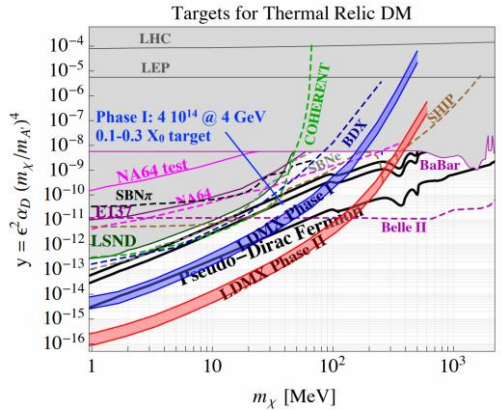
Outline

- Physics case and detector specifics
- Linac design and parameters
- SPS : injection, acceleration and extraction
- Transfer to the target and civil engineering

Physics with e-beams, example of LDMX



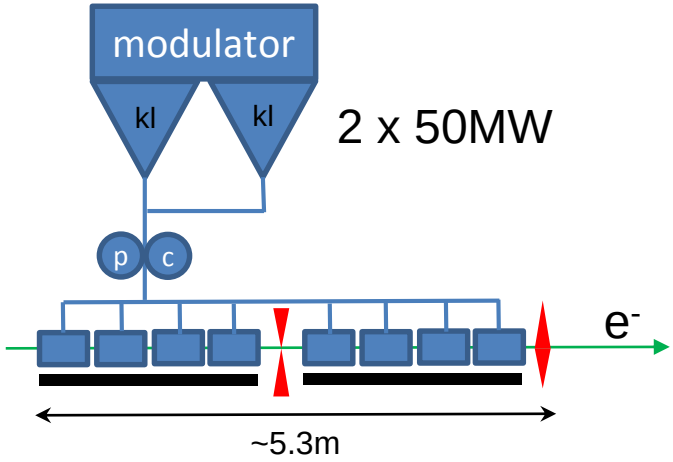




[1]Talk by P. Schuster
Exploring Hidden Sector Physics with an electron beam facility
Physics beyond collider annual workshop
November 21 2017, CERN
indico.cern.ch/event/644287/contributions/2762531/

Linac parameters

- 0.1GeV S-band injector
- 3.4GeV X-band linac
  - 13 RF units to get 3.4 GeV in ~70 m [1]



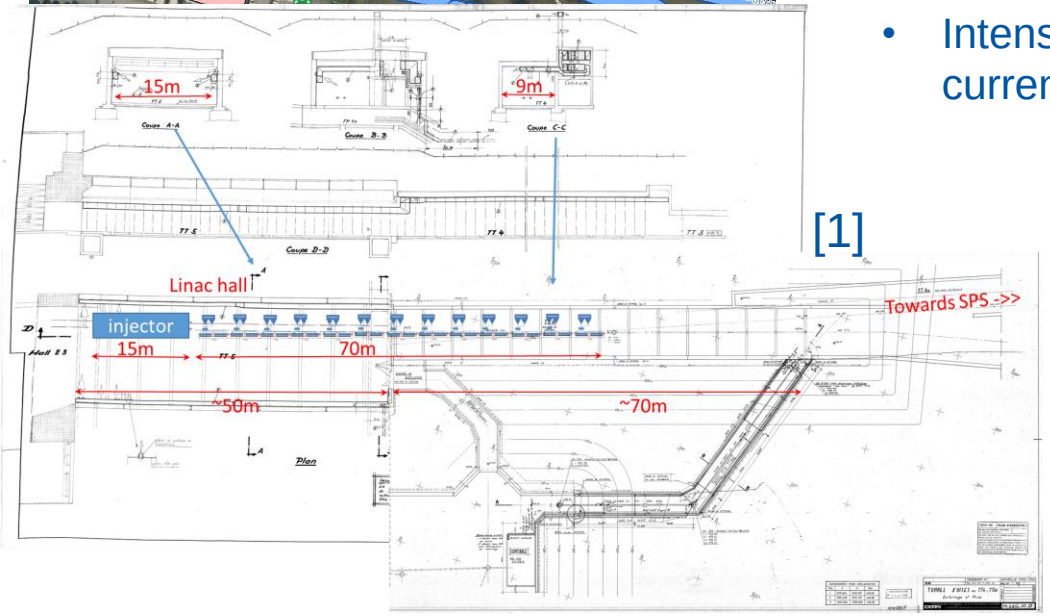
Possible parameters consistent with what is achieved in CLEAR (to be checked)	
Energy spread (uncorrelated*)	<1MeV
Bunch charge	52 pC
Bunch length	~5ps
Norm. trans emittance	~10um
N bunches in one train	40
Train length	200 ns
Rep. rate	50/100 Hz

[2]

Certainly, some parameters can be improved if needed

* Correlated energy spread along the bunch (1st and 2nd order) may appear due to RF voltage and/or wakes. Should be discussed in detail and specified what is acceptable

[1] Talk by A. Grudiev, Linac layout and cost, March 20th 2018, CERN indico.cern.ch/event/715324/
[2] Talk by A. Grudiev, Linac parameters, February 2nd 2018, CERN indico.cern.ch/event/701603/



[1]

Beam instrumentation [2]:

- Position : CTF3 inductive pick-ups or simple button BPMs
- Beam size : OTR screens
- Intensity : CTF3 inductive pick-ups or standard current transformer

[1] Talk by A. Grudiev, Linac layout and cost, March 20th 2018, CERN indico.cern.ch/event/715324/
[2] R. Jones, Instrumentation challenges, March 1st 2018, indico.cern.ch/event/703049/

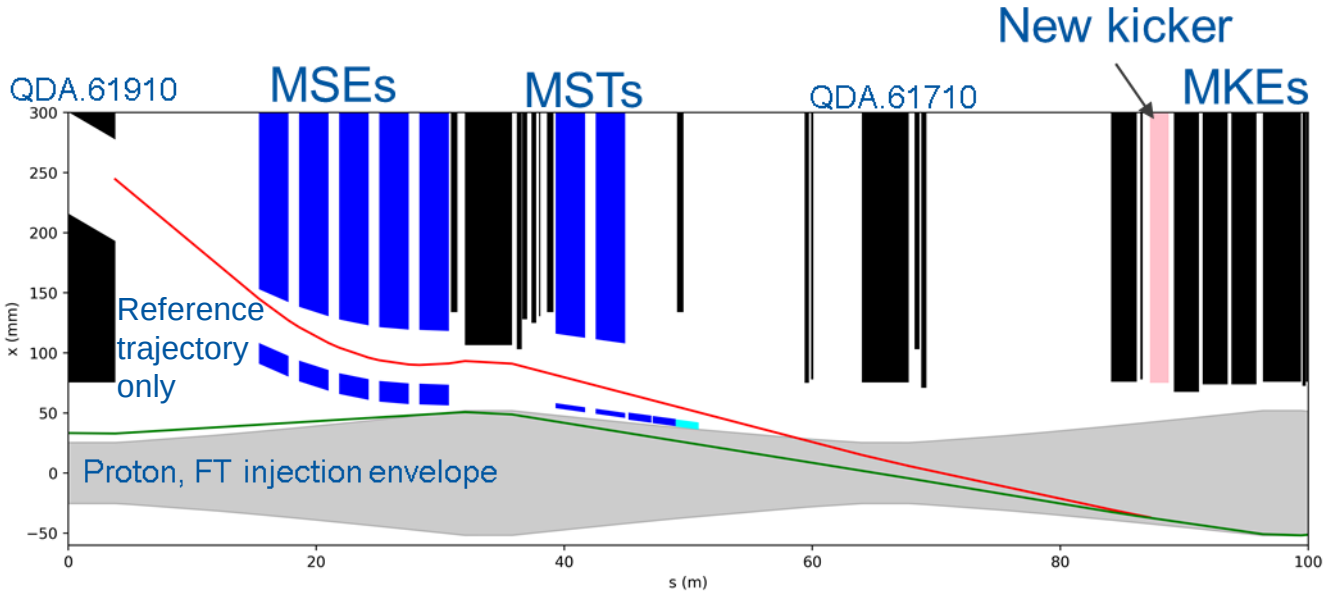
SPS injection in LSS6

- Fast injection of 200ns trains into SPS 200MHz buckets
  - 40 bunches per train and 75 trains for 3000 bunches
- Fast kicker with 50 to 100Hz repetition rate and 100ns rise time

Realistic kicker specifications using conventional technologies

The specifications proposed for the injection kicker are [5]:

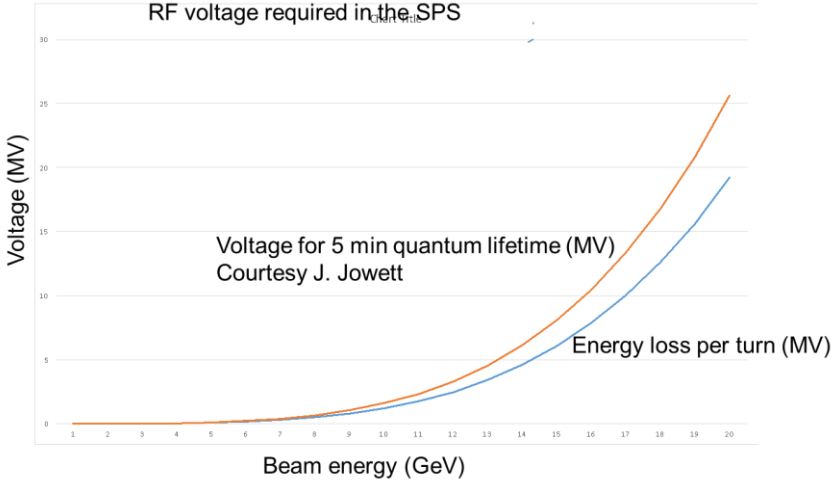
- located just upstream the MKE.6163
- Transmission line magnet with 1.0 m yoke length but modeled using a 1.5 m long element
- Vertical aperture 60 mm
- Horizontal aperture 150 mm
- Total inductance 1.57 μH
- Total capacitance 2.5 nF
- 25 Ω characteristic impedance
- Rise time $\simeq$ 100 ns
- semiconductor switching technology (e.g. inductive adder or Marx) and 12.5 kV



[1] Y. Dutheil , SPS electron slow extraction, March 1st 2018, CERN indico.cern.ch/event/703049/

SPS RF system

- 200 MHz cavities from LEP era
  - Need 10MV for 16GeV electrons
  - We have kept (12 + 1) * 200 MHz Standing Wave Cavities [1 MV per cavity] in storage area, in very good condition.
  - We only have few of the peripherals (amplifiers + HOM couplers + FPC + Tuners), but these can be rebuilt within 2-3 years if needed

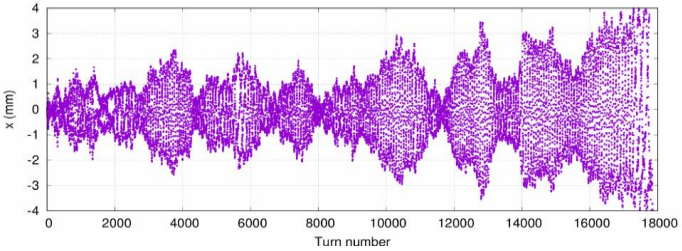


- Preliminary estimate of longitudinal broadband impedance
  - It is based on the numbers from SL-note-96-49 by Linnecar and Shaposhnikova
  - 12 cavities will increase Z/n of SPS by about 10% (with fundamental mode dampers/plungers in)

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

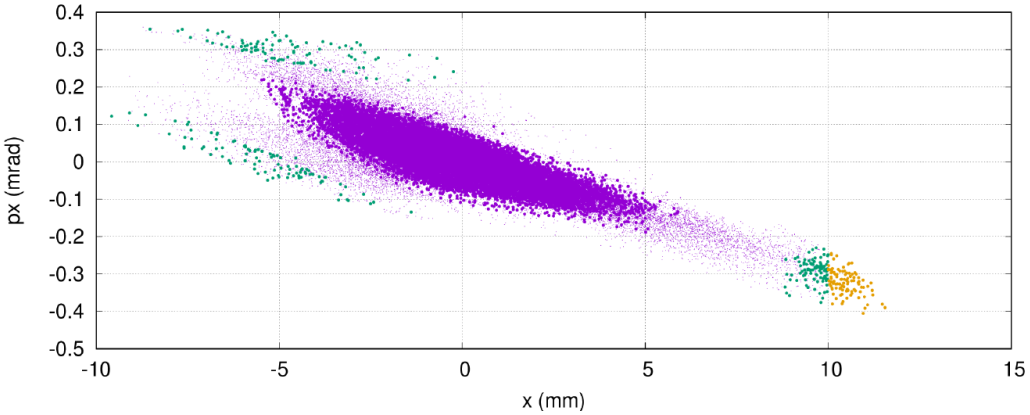
SPS slow extraction driven by quantum diffusion

Stochastic motion of a single particle in presence of synchrotron damping and quantum excitation.



Quantum excitation provides the stochastic process for extraction. Control of extraction rate through the distance to resonance in tune space.
Analytical model being developed for extraction rate and power supply ripple effect (J. Prieto, TE-ABT-BTP).

Particles in orange are kicked by the septum and extracted while their position on the 3 previous turns are showed in green.
In purple is the position of the particles during the 1000 turns before extraction.



Using the statistical definition we find that the characteristics of the extracted beam are:

- $\epsilon = 1.01 \times 10^{-8}$ mrad
- $\beta = 11$ m
- $\alpha = 0.5$

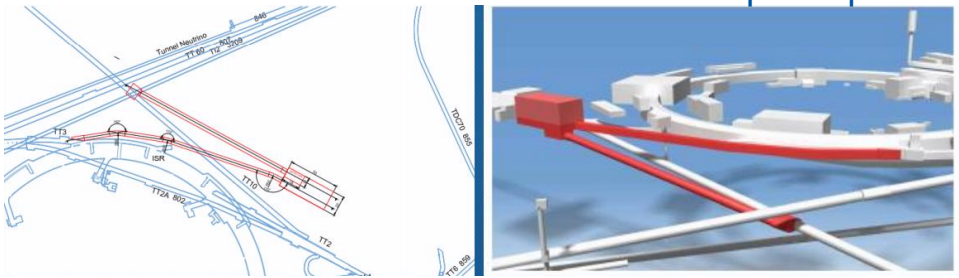
Very low emittance and flat beam extracted

[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/
[2] Y. Dutheil , SPS electron slow extraction, March 1st 2018, CERN indico.cern.ch/event/703049/

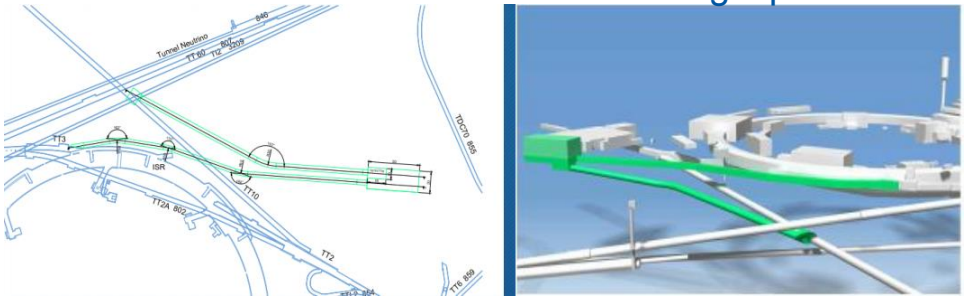
Civil engineering for target and transfer

- 2 options considered

Option 1 – ‘Helipad Option’



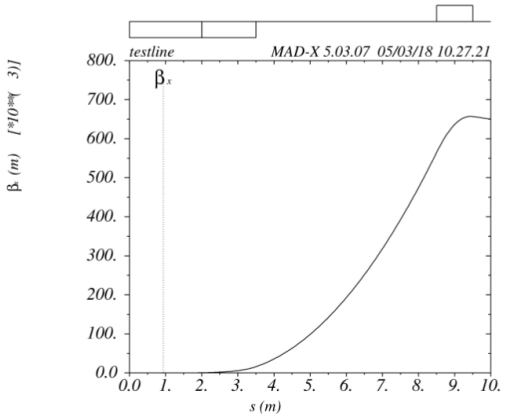
Option 2 – ‘AD building Option’



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

SPS to target transfer line

- Uses TT10 line, specifics remain to be studied
- Extracted beam would be small and very flat
- Collimation in the line for control of beam size and intensity
- Instrumentation:
  - Very low intensity for operation could be measured in intensity and position using fiber monitors[1]
  - Setup could be done at higher intensity using higher extraction rate
- Beam size could be increased at the target to increase maximum rate per bunch.
  For instance a 20cm wide beam is feasible



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

User groups and communities

- Physics (main driver)
  - LDMX
  - Other experiments, incl. dump-type experiments using available higher intensity
- Plasma studies with electrons
  - Use rlectron (3.5GeV) beam as driver and/or probe – AWAKE WG (P. Muggli)
- CLIC : Linac goes a long way towards a TDR verification of a klystron based CLIC
- Plasma community in general and Linear Colliders: Positron production and studies (talk in next WG meeting 26.4)
- Linear Collider related studies
  - e-SPS as damping ring (also relevant for FCC-ee) and extracted beam for final focus studies (beyond ATF2)
- General acc. R&D as in CLEAR today (plasma-lenses, impedance, high grad, medical, training, instrumentation, THz, ESA irrad.) ..

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

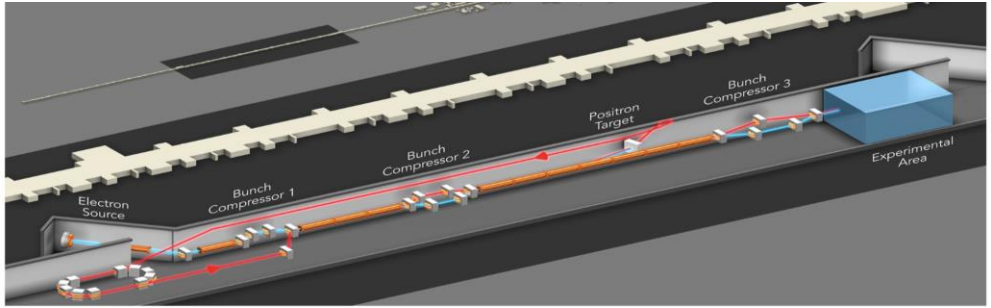
Positron PWFA Research Facilities

There are only been two facilities that have provided positron beams for PWFA experiments: FFTB and FACET, both at SLAC.

FACET-II is under construction at SLAC and will also provide positron beams for PWFA experiments.

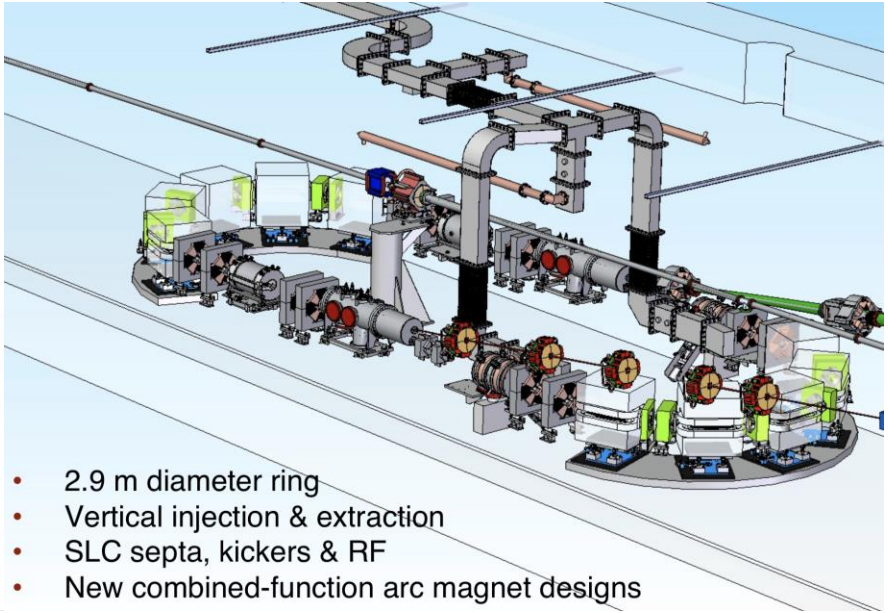
There have been no laser-driven positron acceleration experiments to date.

Positrons at FACET-II



Electron Beam Parameter	Baseline Design	Operational Ranges
Final Energy [GeV]	10	4.0-13.5
Charge per pulse [nC]	2	0.7-5
Repetition Rate [Hz]	30	1-30
Norm. Emittance $\gamma\varepsilon_{x,y}$ at S19 [μm]	4.4, 3.2	3-6
Spot Size at IP $\sigma_{x,y}$ [μm]	18, 12	5-20
Min. Bunch Length σ_z (rms) [μm]	1.8	0.7-20
Max. Peak current I_{pk} [kA]	72	10-200

Positron Beam Parameter	Baseline Design	Operational Ranges
Final Energy [GeV]	10	4.0-13.5
Charge per pulse [nC]	1	0.7-2
Repetition Rate [Hz]	5	1-5
Norm. Emittance $\gamma\varepsilon_{x,y}$ at S19	10, 10	6-20
Spot Size at IP $\sigma_{x,y}$ [μm]	16, 16	5-20
Min. Bunch Length σ_z (rms)	16	8
Max. Peak current I_{pk} [kA]	6	12



- 2.9 m diameter ring
- Vertical injection & extraction
- SLC septa, kickers & RF
- New combined-function arc magnet designs

FACET-II uses existing infrastructure to generate positrons from a high-Z target. The beam is captured and returned to a damping ring before being reaccelerated in the linac.

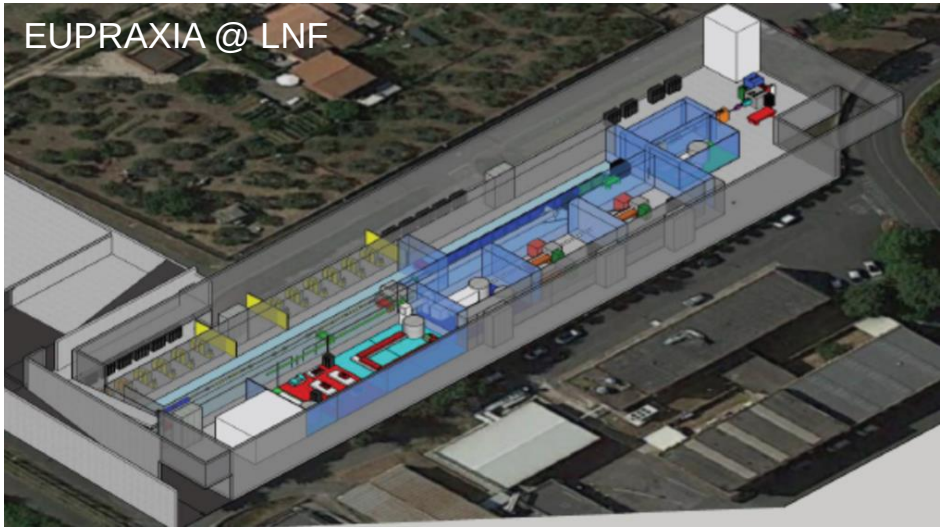
The compact damping ring is a new feature. It is 2.9 meters in diameter and hangs from the ceiling of the tunnel.

Positrons at EUPRAXIA

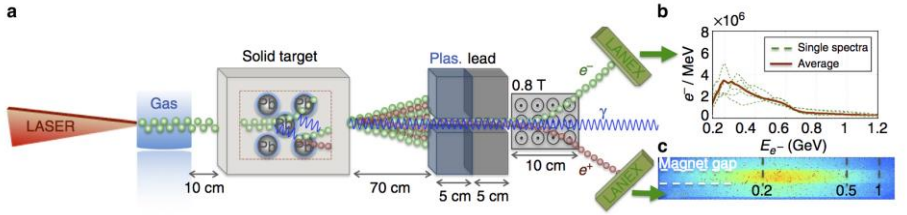
EUPRAXIA combines high-power laser technology with an x-band accelerator.

There is interest in generating positrons by using a laser to accelerate electrons in plasma, and collide the accelerated electrons into a high-Z target.

The positrons produced this way have a spectra that extends to the GeV-level and beyond depending on the laser parameters.



G. Sarri, Nat. Comm., 6747, 2015



A Dedicated Positron PWFA/LWFA Research Facility

ALEGRO will provide input to the European Strategy Group.

A facility that can provide positrons for PWFA/LWFA research is a top priority!

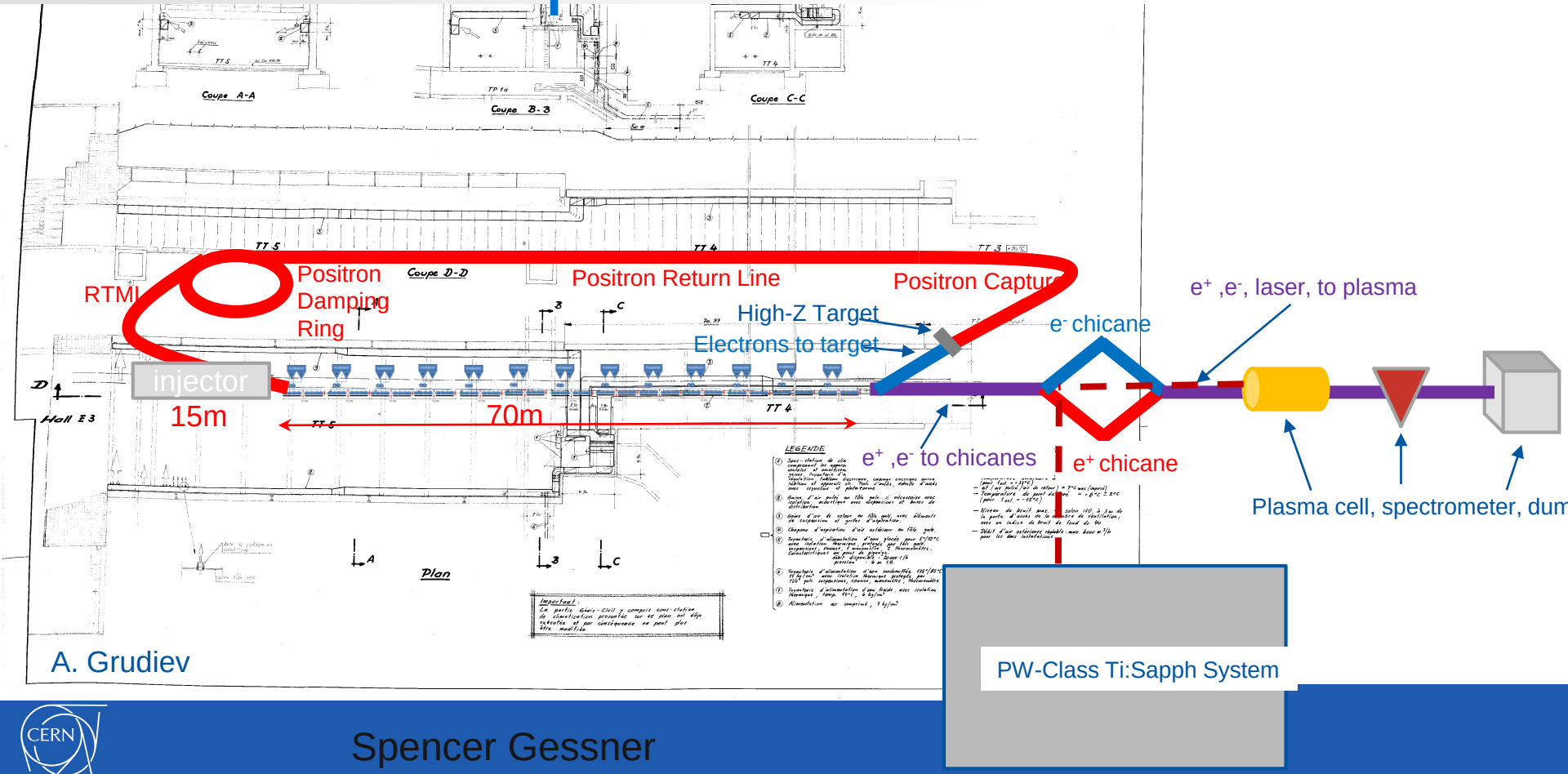
Proposed statement on positron sources

ALEGRO 2018

ALEGRO has identified a clear need to develop plasma based technology to make positron beams for particle physics.
As EuPRAXIA is planning to have a dedicated electron beam to create a positron source, there is an opportunity for an international project to work on a positron beam alongside EuPRAXIA.
The idea of such a project has full support of ALEGRO.
Plasma based technology to make positron beams for particle physics is vital for plasma based colliders. A facility of this type would complement very well FACET-II program at SLAC and could lead to very much needed industrial applications.

B. Cros, ALEGRO Summary

CERN Concept



Why CERN?

There are already many “customers” for novel, compact, electron accelerators:

- X-Ray diagnostics
- Medical physics
- FEL science

Groups throughout Europe are racing to develop PWFA/LWFA technologies with these applications in mind.

The only reason to generate high-energy positrons is for high-energy physics.

CERN is the only laboratory in Europe (the world?) dedicated to energy frontier physics. If CERN supports novel acceleration research in general, CERN should support positron acceleration research in plasma.

Conclusion

- Prospects of LDMX-type experiments at CERN was particularly well received by the physics and LDMX community
  - Many interesting accelerator R&D prospects
- Studies so far show no major issues to provide 16GeV electrons at CERN
- Studies encounter large resonance in many groups and interest might well increase as investigations continue
  - In particular other experiments such as dump-type high intensity at 16GeV or at 3.5GeV will be investigated

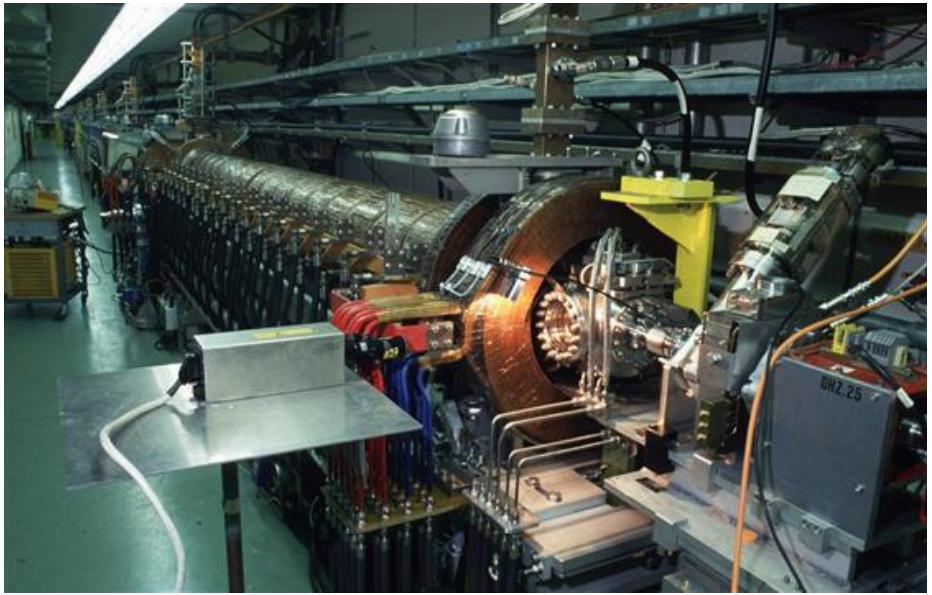
An opportunity for ILC R&D

- A 3.5 GeV electron beam would be a great opportunity for R&D towards a ILC positron source.
- Target experiments could be envisaged
- What else ?

CLIC news

- Mainly busy with preparing the project implementation plan (PIP)
  Focusing on optimized 380 GeV first stage of the machine
  Cost and Power update
  Input for the European strategy update
- Continue to work on positron source optimization (see Yanliang's talk)

POSIPOL 2018 at CERN
September 3rd – 5th



Back to the roots / rocks !

POSIPOL 2018 at CERN

New topics to enlarge scope of the meeting

- Other projects needing positrons: LHeC, FCC-ee, GBAR at CERN
- Positrons for Plasma acceleration, Alegro
- Target testing and simulations as well for non positron applications
- Muon-collider, high energy positrons to produce good quality Muons
- Othere related facilities, ThomX, …

POSIPOL 2018 at CERN
September 3rd – 5th

Save the date
Registration will open soon :

https://indico.cern.ch/event/727621/

Thank you

Asian Linear Collider workshop, Fukuoka

SPS considerations

- Preliminary results predict no stability issues for the intensities considered[1]
  - TMCI threshold is one order of magnitude away
- Total supercycle of 40s possible [2]
  - <1s injection with 100Hz linac repetition rate
  - 1s for acceleration and deceleration
  - 10s slow extraction
- Possible Beam Instrumentation for Circulating Beam [3]
  - Position : standard system down to 1e9 (limit ~5e8)
  - Beam Size : Wire scanner and possibly SR
  - Intensity : DC Transformer for total current

[1] Talk by Y. Papaphilippou, SPS beam stability, March 20th 2018, CERN indico.cern.ch/event/715324/
[2] L. Evans, Parameter overview, March 1st 2018, indico.cern.ch/event/703049/
[3] R. Jones, Instrumentation challenges, March 1st 2018, indico.cern.ch/event/703049/

SPS extraction requirements

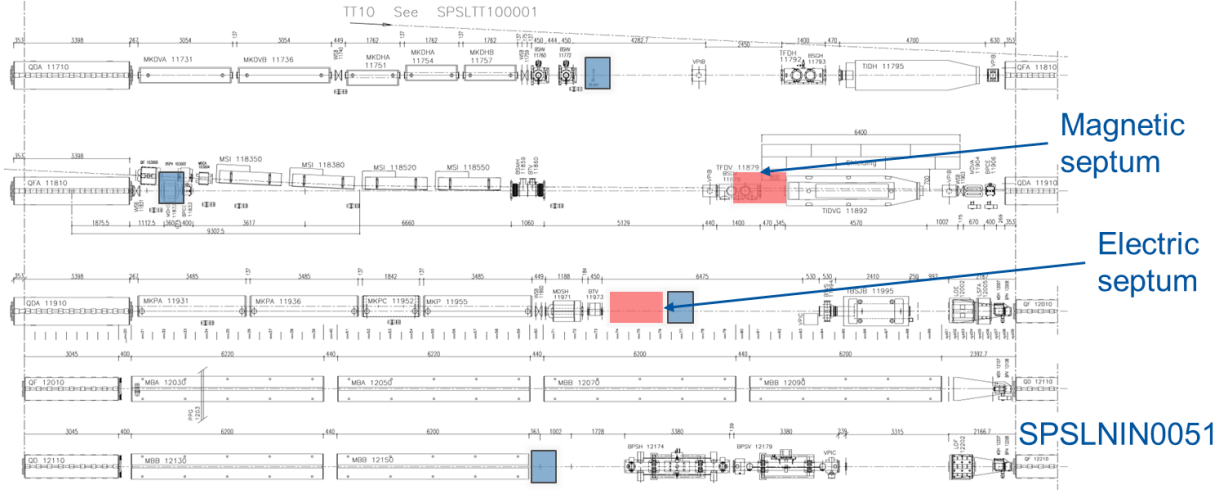
- The detector requires very low intensity, in the order of a few electrons per bunch per turn[1]

- Slow extraction is investigated. In general low and regular extraction rates are achieved by use of diffusion processes[2]
  - Bunched extraction is mandatory. SR losses are too important and the beam would be lost immediately
  - Chromatic extraction and RF noise to diffuse particles out of the bucket can be investigated
  - Particle dynamic undergo stochastic motion due to the equilibrium between synchrotron damping and quantum excitation. The synchrotron radiation acts as a diffusion mechanism of particle actions. This was studied

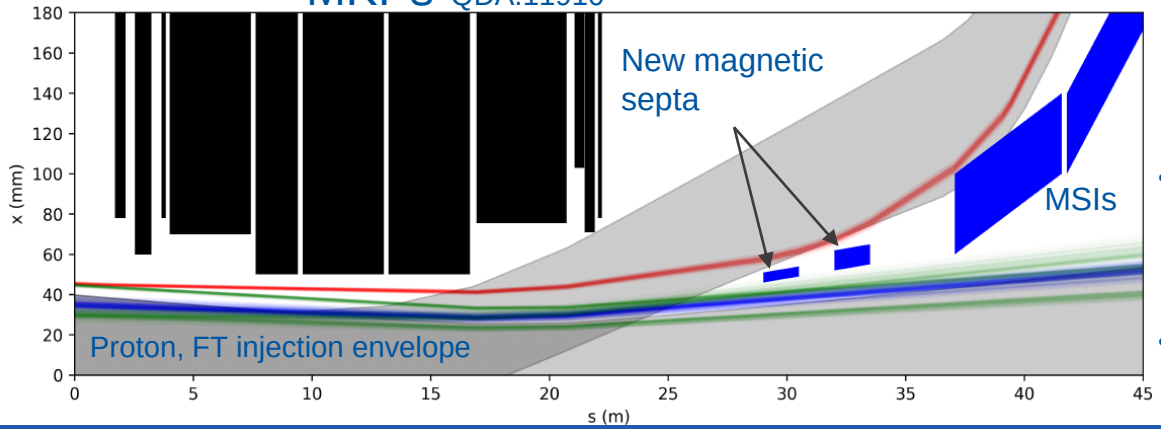
[1]Talk by P. Schuster
Exploring Hidden Sector Physics with an electron beam facility Physics beyond collider annual workshop, November 21 2017, CERN indico.cern.ch/event/644287/contributions/2762531/
[2] Y. Dutheil , SPS electron slow extraction, March 1st 2018, CERN
indico.cern.ch/event/703049/

SPS slow extraction in LSS1

Extracted trajectories are in red while the 3 turns leading to extraction are showed in green. Blue trajectories correspond to circulating beam.
Electric septum is at s=0m.
Injected and circulating FT proton beam at 14GeV with margins is showed in grey.



MKPs QDA.11910

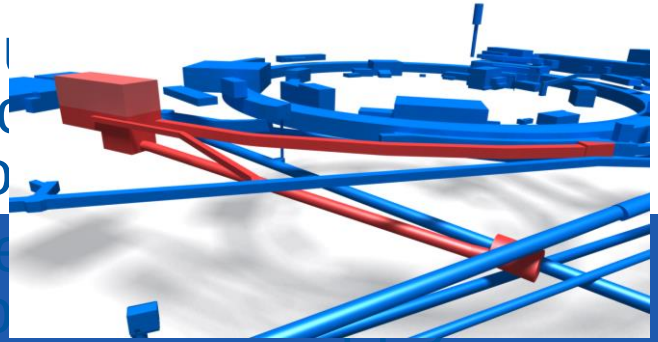


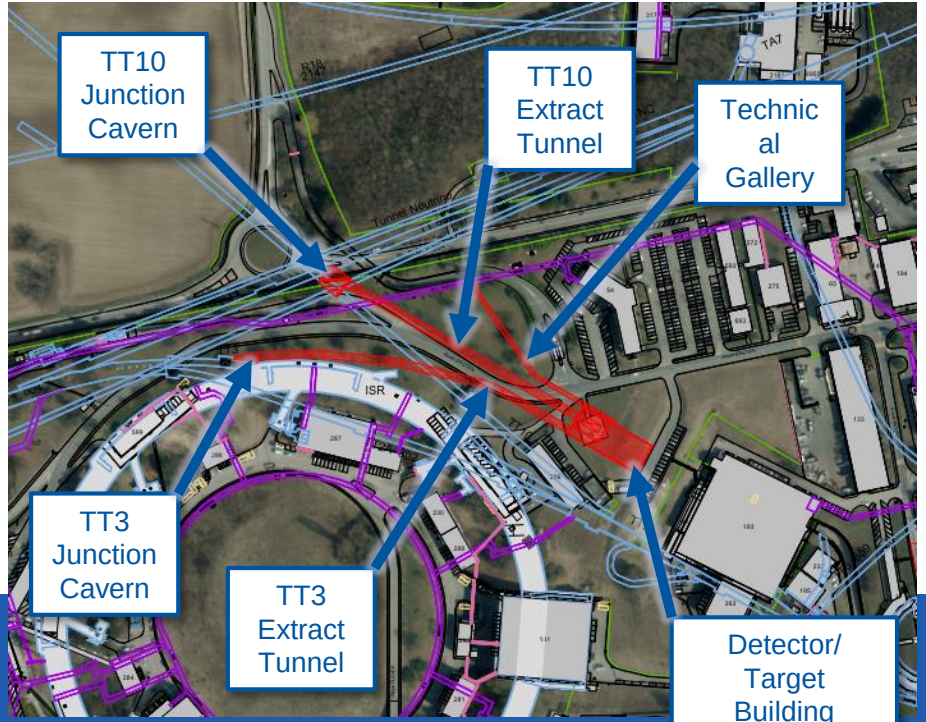
New elements

- Electrostatic septum 1.5m long and 5.0MV/m to provide 0.46875mrad kick at 16GeV
- 2 magnetic septa with realistic characteristics

Chosen option – Option 1 - ‘Helipad Option’

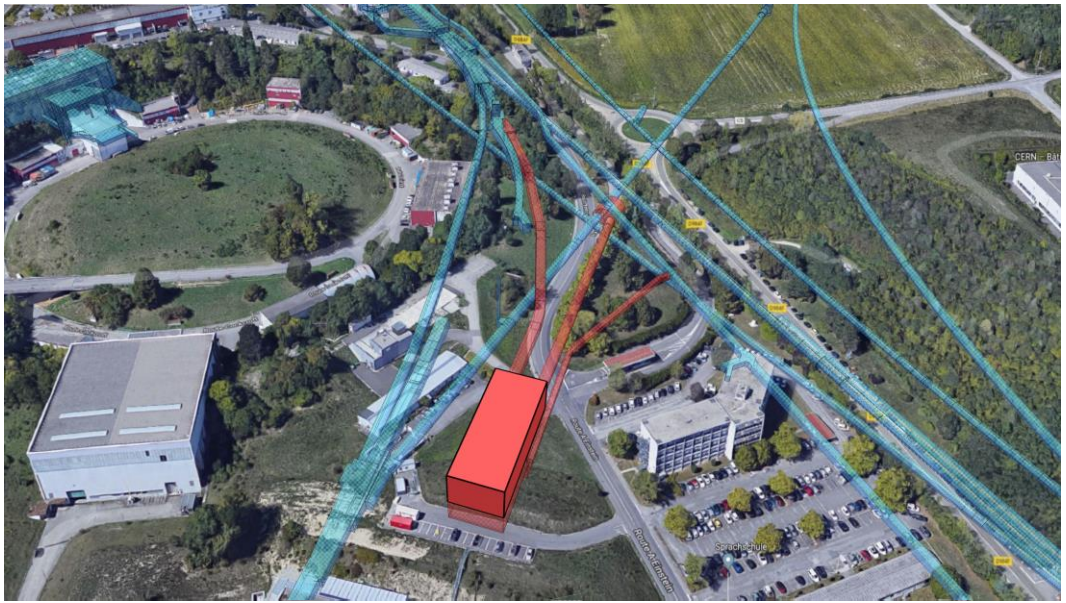
- Next iteration details:
  - Junction caverns estimated
  - Tunnels in molasse and moraines
  - Bu
    ac
    fo
  - Te
    fo





Next Steps – Civil Engineering

- Any further requirement from civil engineering for European Particle Physics Strategy submission?
- Conceptual design report
  - Further design refinement
  - Construction sequence feasibility
  - Route Einstein Diversion and phasing to consider
  - Service diversions to cost in some detail
  - Discussion with adjacent building users to understand constraints
  - Feedback to consider from all study group members



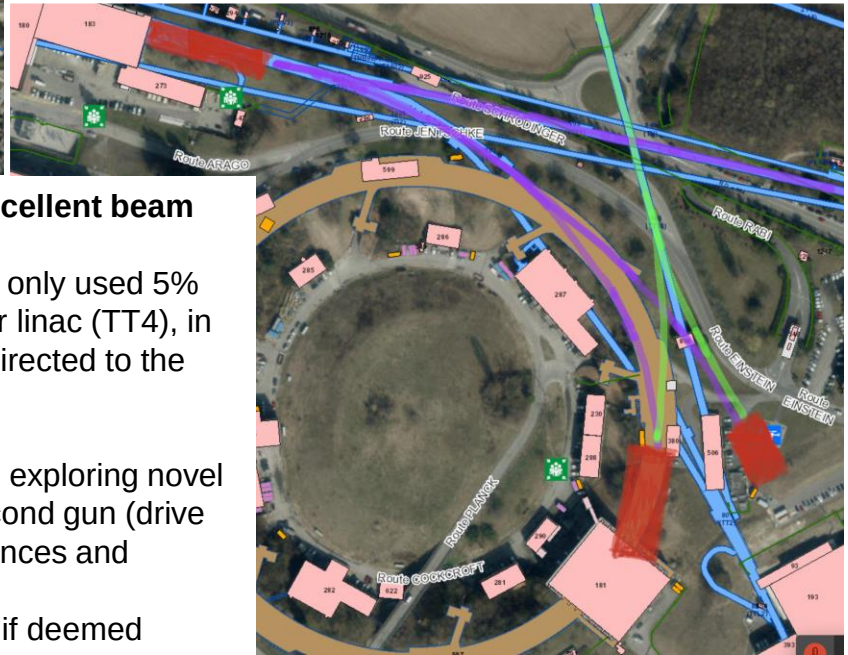
Four/five users groups:

- Physics
- CLIC TDR overlap large
- e-AWAKE
- CLEAR(er)
- DR, positrons and ATF-like studies (possible)

GREEN: ~16 GeV electron beam in SPS

Acc. in SPS, can also be a damped small emittance beam. Long bunches.

- Extracted to Meyrin side for LDMX like experiment.
- Can also – possibly – be guided to AWAKE.
- Other uses, either extracted or circulating to be worked out.



PURPLE: 3.5 GeV x-band linac with excellent beam quality

Short bunch electrons from X-band linac, only used 5% for filling the SPS. Can be used right after linac (TT4), in new experimental area, and/or possibly directed to the current AWAKE area.

- CLEAR type of research progamme.
- Electrons for drive and/or probe beam exploring novel accelerating techniques, including second gun (drive and probe bunches with variable distances and charges).
- Longer term possibilities for positrons if deemed