PAUL SCHERRER INSTITUT

Nicolas Vallis (PSI / EPFL) on behalf of FCC-ee Injector WP6

The P³ experiment: a Positron Source Demonstrator for FCC-ee

eeFACT Workshop - Frascati, 15 September 2022

The P^3 project
PSI Positron Production

1. Introduction
    1. FCC-ee and P^3
    2. e+ production at SwissFEL

2. Key Technology and Beam Dynamics
    1. AMD
    2. RF Cavities
    3. Solenoid around RF Cavities
    4. The P^3 beam

3. Beam Diagnostics

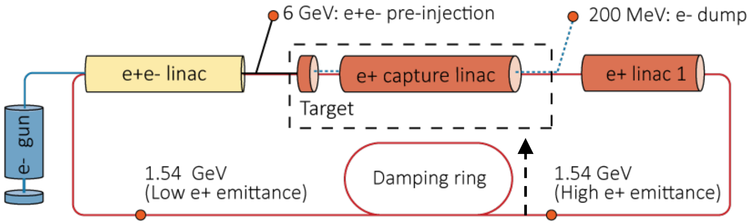
4. Project Status and Conclusion

FCC-ee Injector Study

- Work package in FCC collaboration.

- Two deliverables included in FCC feasibility study:
  - Design proposal for FCC-ee Injector.
  - Proof-of-principle experiment for novel positron source (P^3).

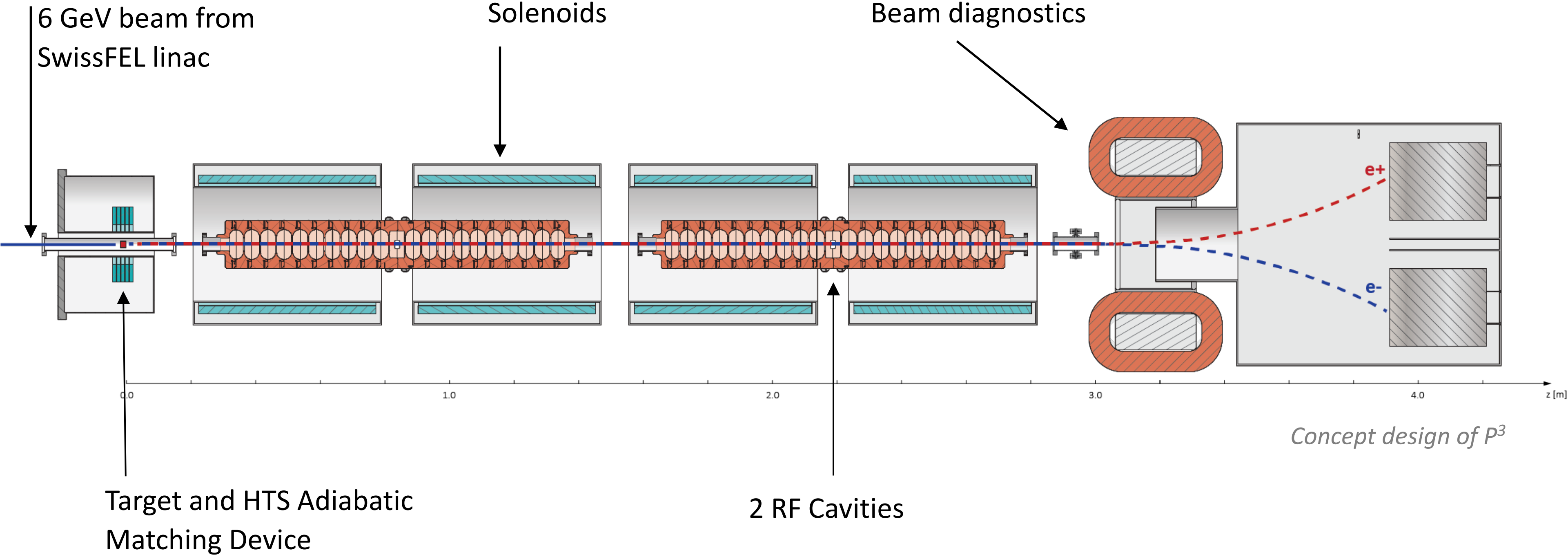
- Due to FCC-ee high current requirements
  - Only target-based e+ production schemes considered.
  - Vast production of e+, poor transport efficiency to DR
  - Use of **HTS solenoids for the AMD** proposed for higher efficiency.



Schematic of FCC-ee Injecor Complex

- Target
- Adiabatic Matching Device
- 10 RF Cavities surrounded by solenoids

The PSI Positron Production (P3) Experiment



Concept design of P^3

Goals of P³

- References for yield value:

SuperKEKB Factory (State of the art, 3 GeV) [1]	0.5
FCC-ee requirements [2]	1 (plus safety factor 2)
P^3 simulations	8

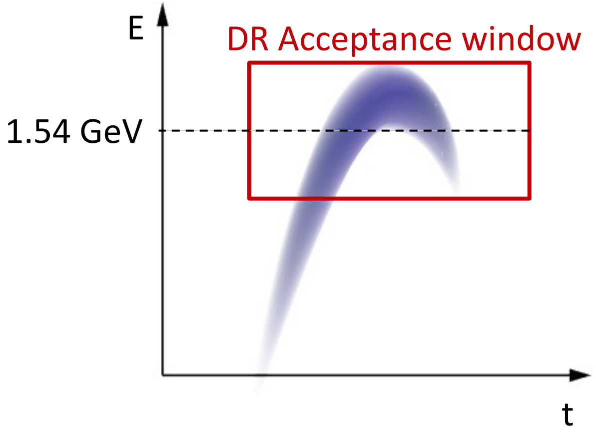
[1] K. Akai, K. Furukawa, and H. Koiso, "Superkekb collider", 2018.

[2] I. Chaikovska et al., "Positron source for FCC-ee", 2019.

$$Yield = \frac{Ne^{+} accepted\ by\ DR}{Ne^{-} primary\ beam}$$

- Main goal is to provide first experimental validation of such a yield.

- But a compact positron source at PSI can:
  - Host further experiments/tests
  - Contribute to other future positron machines



Impression of the a e+ beam at entrance of DR and DR acceptance window

e+ Source at SwissFEL

- SwissFEL linac can provide high quality 6 GeV electron beam.

- Strict radiation limits do not allow for high bunch charges and rep. rates.

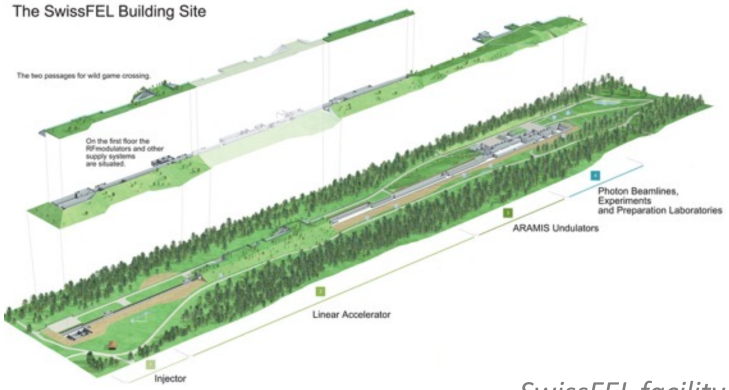
  – beam dynamics insensitive of electron charge and time structure.

  – thermomechanical study of the target excluded from P3.

Table 1: Main drive linac parameters

	FCC-ee	P^3 (SwissFEL)
Energy [GeV]	6	
$\sigma_{x,RMS}$ [mm]	0.5 - 1.0	
Q_{bunch} [nC]	0.88 - 1.17[1]	0.20
Reptition rate [Hz]	200	1
Bunches per pulse	2	1

[1]Based on 5.0 - 5.5 nC requirements at booster ring and preliminary yield estimations of 4.7 - 5.7 N_{e+}/N_{e-}.

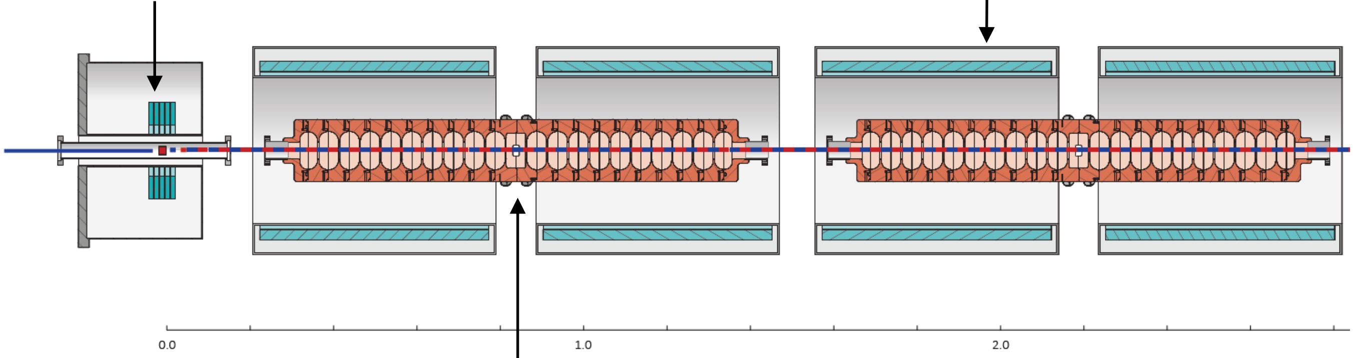


SwissFEL facility

II. Key Technology and Beam Dynamics

High temperature superconductor-based AMD (12.7 T peak on-axis)

NC or SC solenoids (0.4 to 1.5 T peak on-axis)



SW, S-band Cavities with large iris aperture 40 mm

PAUL SCHERRER INSTITUT PSI

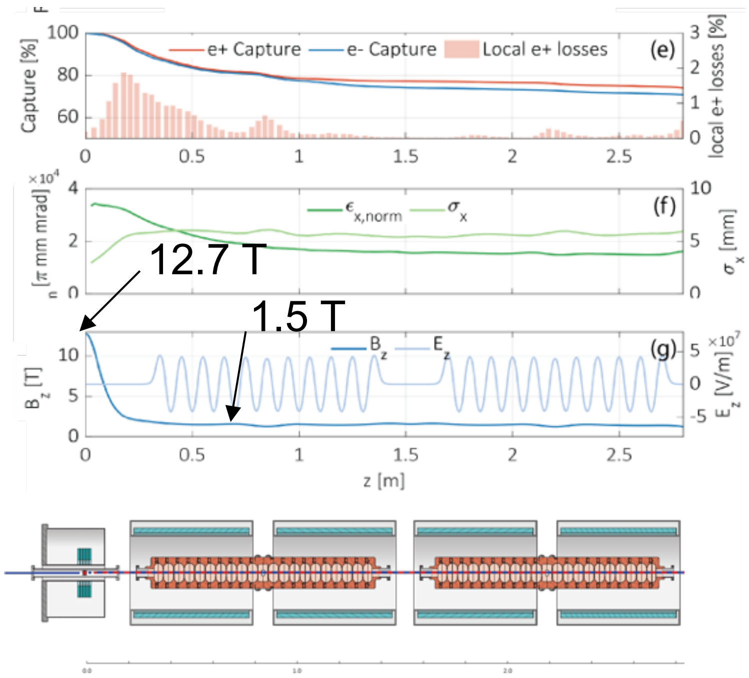
EPFL FUTURE CIRCULAR COLLIDER

Solenoids: Beam Matching and Confinement

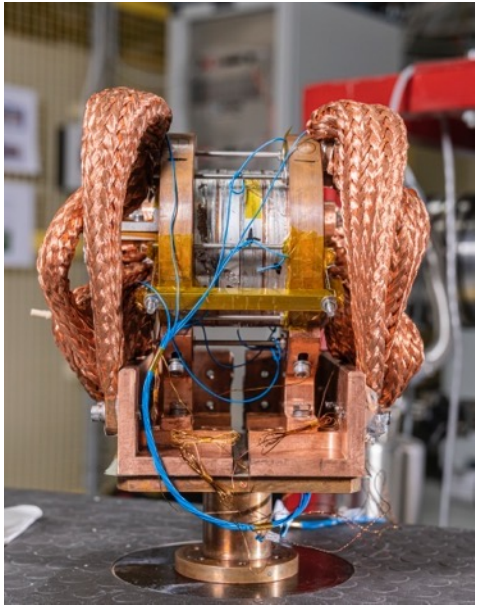
- Baseline:
  - High temperature SC based Adiabatic Matching Device (12.7 T)
  - SC solenoids around cavities (1.5 T) or NC solenoids around cavities (0.4 T).

- AMD matches the e+ beam into capture system. Part of the beam is lost and norm. transverse emittance decreases over first RF cells.

- SC solenoids contain the matched beam. Capture efficiency and emittance stabilize.



HTS Adiabatic Matching Device

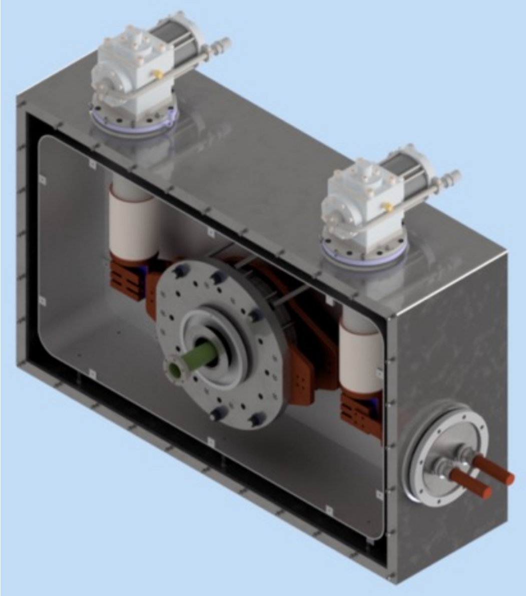


HTS demonstrator at PSI (M. Duda et al.)

- HTS demonstrator built at PSI:
  - 4 ReBCO tape coils at 2kA
  - Operation at 18.2 T, on-axis peak
  - Temperature 20 – 30 K, no need of He cooling
  - No insulation, quench self-protected

- Simulation study at CERN found no critical machine protection issues [1]

- Technical design of cryostat in development at PSI

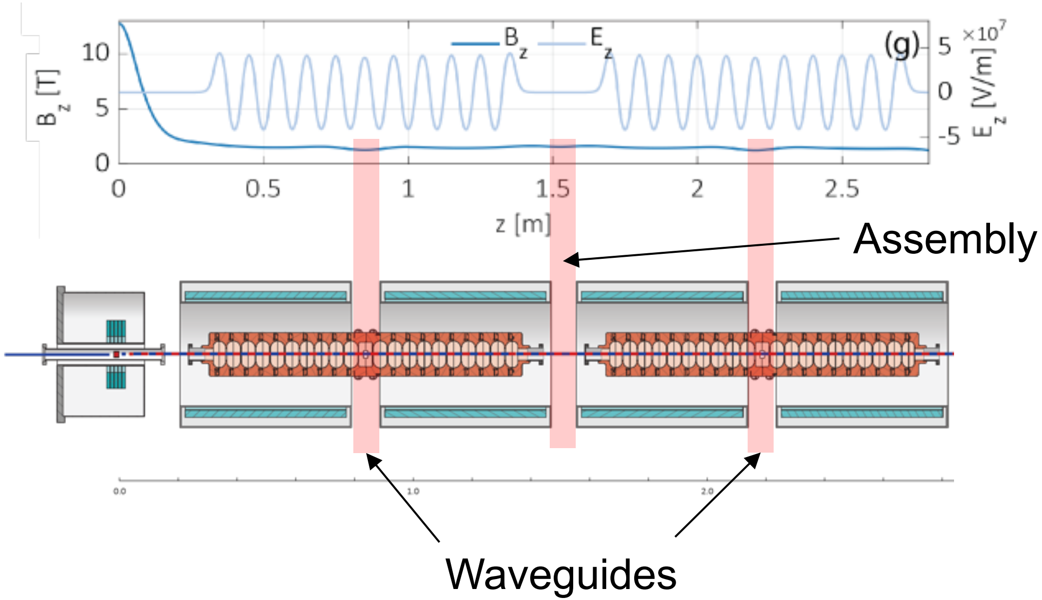


Preliminary model of the AMD, including cryostat (H. Garcia Rodrigues)

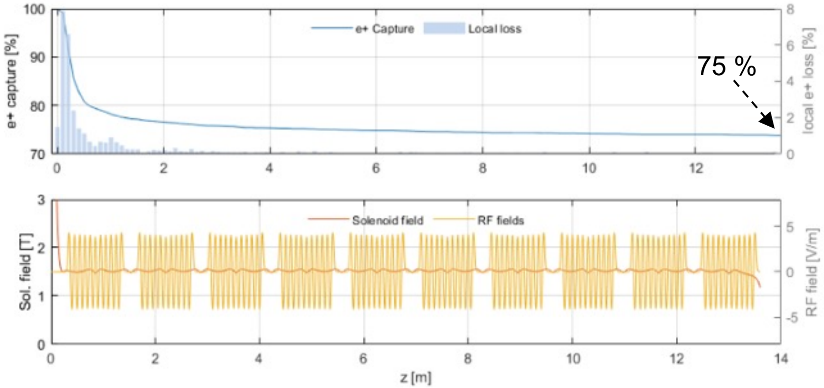
[1] B. Humann et al., Radiation Load Studies for the FCC-ee Positron Source with a Superconducting Matching Device, 2022.

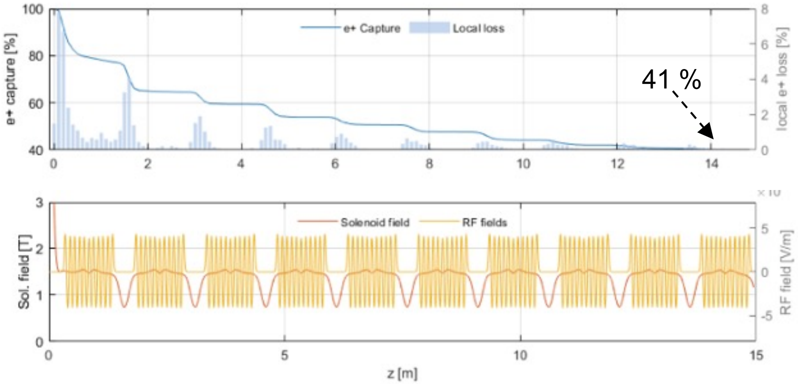
Solenoids Around RF Cavities (I)

- Solenoids must create strong and flat magnetic channel.
- Mechanical constraints exist, separation must be provided for waveguides and installation



Solenoids Around RF Cavities (II)

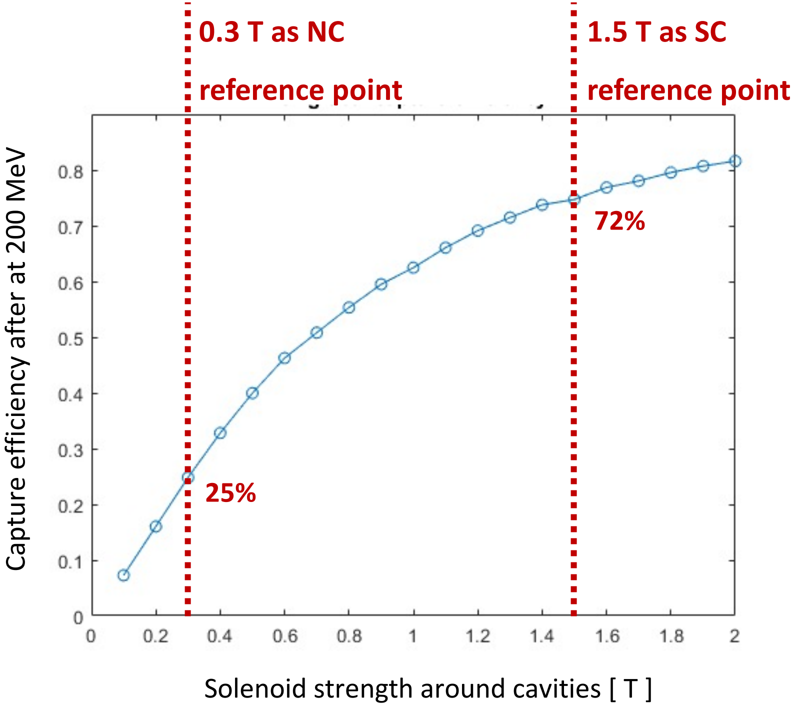




Extended simulations over 10 RF Cavities with optimized (left) and breached (right) magnetic channels.

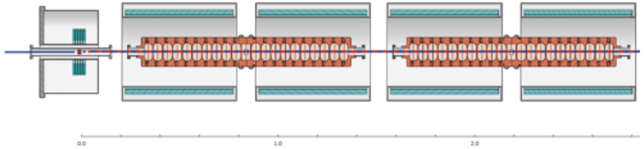
Solenoids Around RF Cavities (III)

- Two baseline options for P-cubed:
  - Superconducting
    - NbTi
    - 1.5 T on axis
  - Normal Conducting
    - Copper
    - 0.4 T on axis



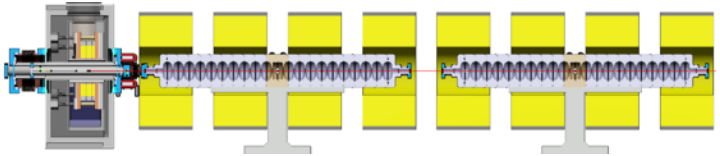
Solenoids Around RF Cavities (IV)

Superconducting (NbTi, 1.5 T)



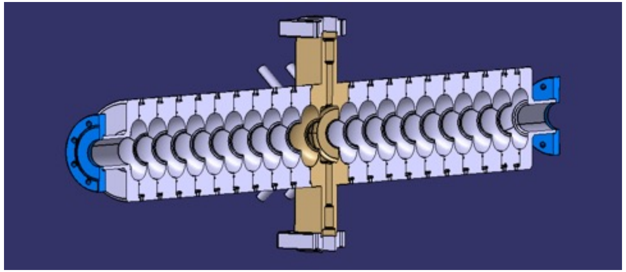
- Superconducting:
  - Extremely high yield provided (8.0)
  - Lower power consumption
  - High cost (above tender call limit 230 kCHF)

Normal Conducting (Copper, 0.4 T)



- Normal conducting:
  - Lower yield (3.1), sufficient for FCC-ee requirements
  - Extremely high power consumption (>100 kW), large amount of copper required
  - Lower cost, conventional technology

RF Cavities

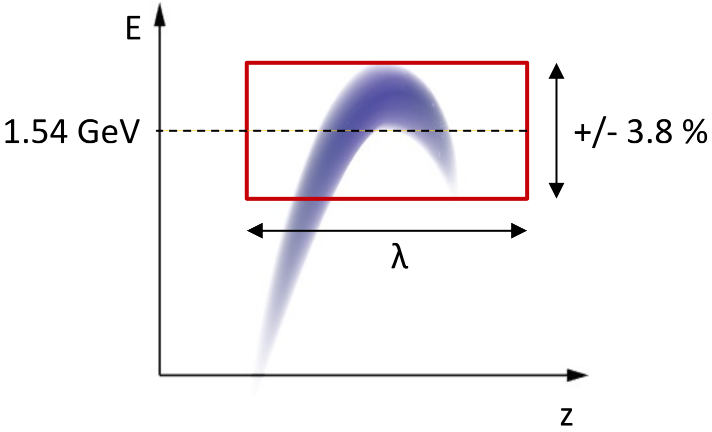


Mechanical model of RF Cavities (R. Zennaro)

Table 2: Main parameters of the SW Cavities

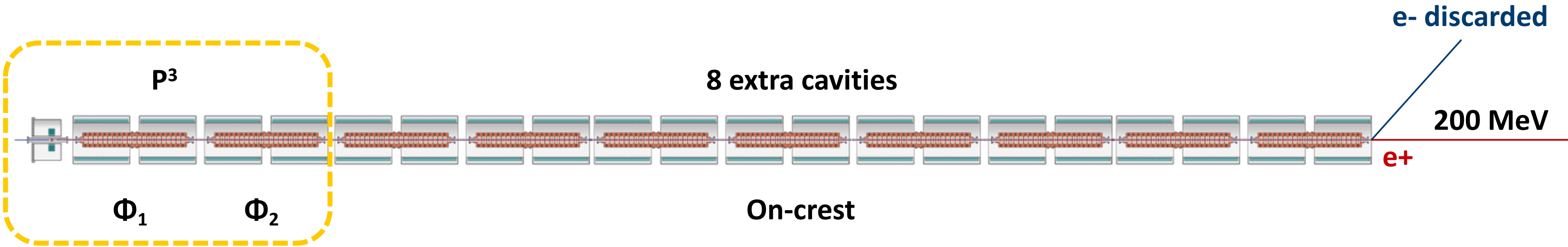
Length [m]	1.2
RF frequency [GHz]	2.9988
Nominal gradient [MV/m]	18
Number of cells	21
R/L	13.9 MΩ/ m
Aperture [mm]	40
Mode separation (in π mode) [MHz]	5.3
RF Pulse length [μs]	3
Coupling factor	2

Impression of the a e+ beam at entrance of DR and DR acceptance window



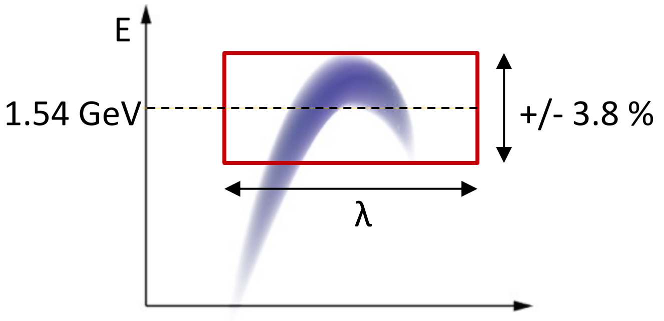
- Ideally:
  - High capture efficiency
  - Low energy spread
  - Positrons in one bucket

Estimation of the Yield at DR

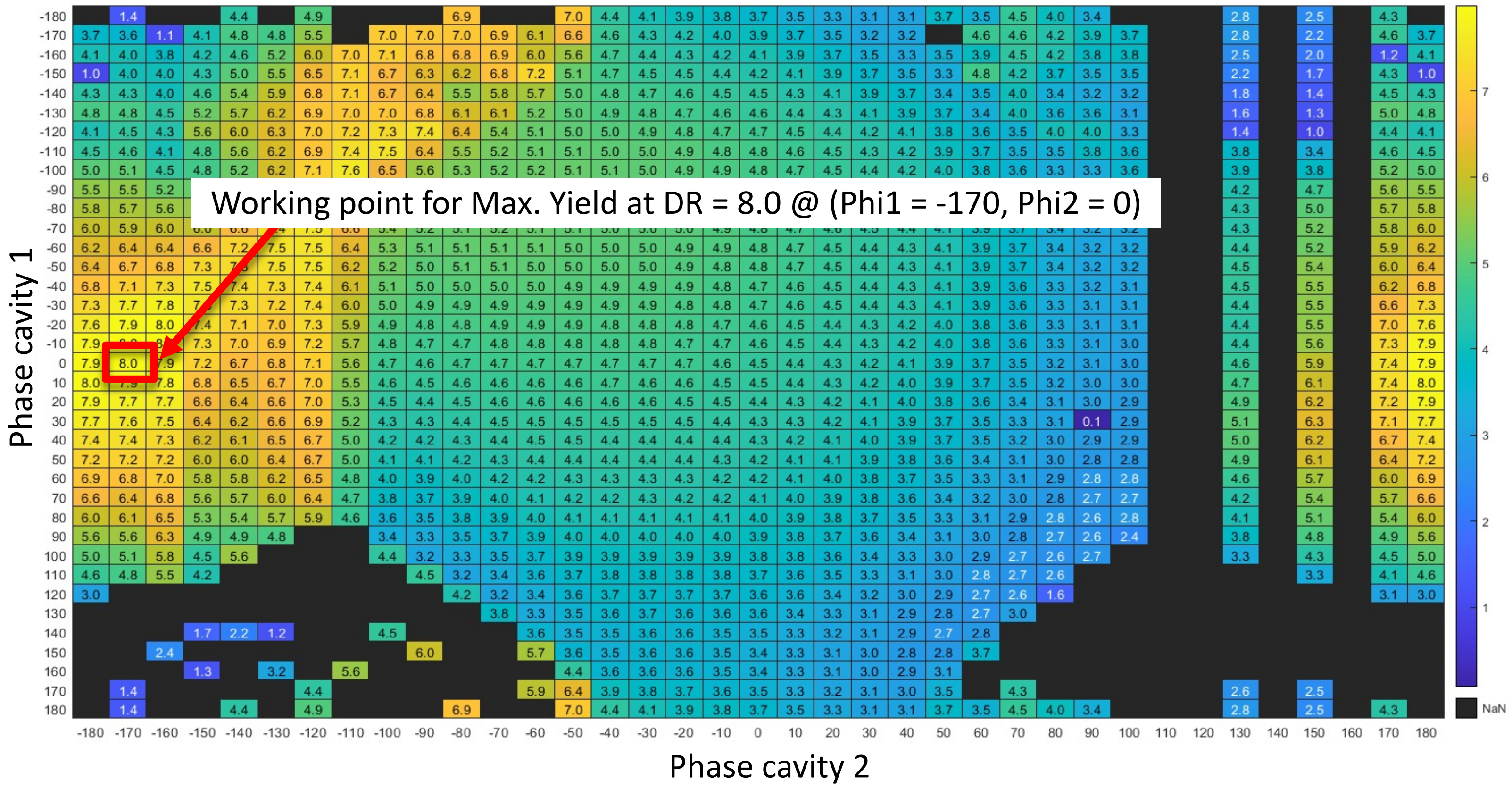


200 MeV

Analytical transformation in longitudinal plane. Transverse losses neglected



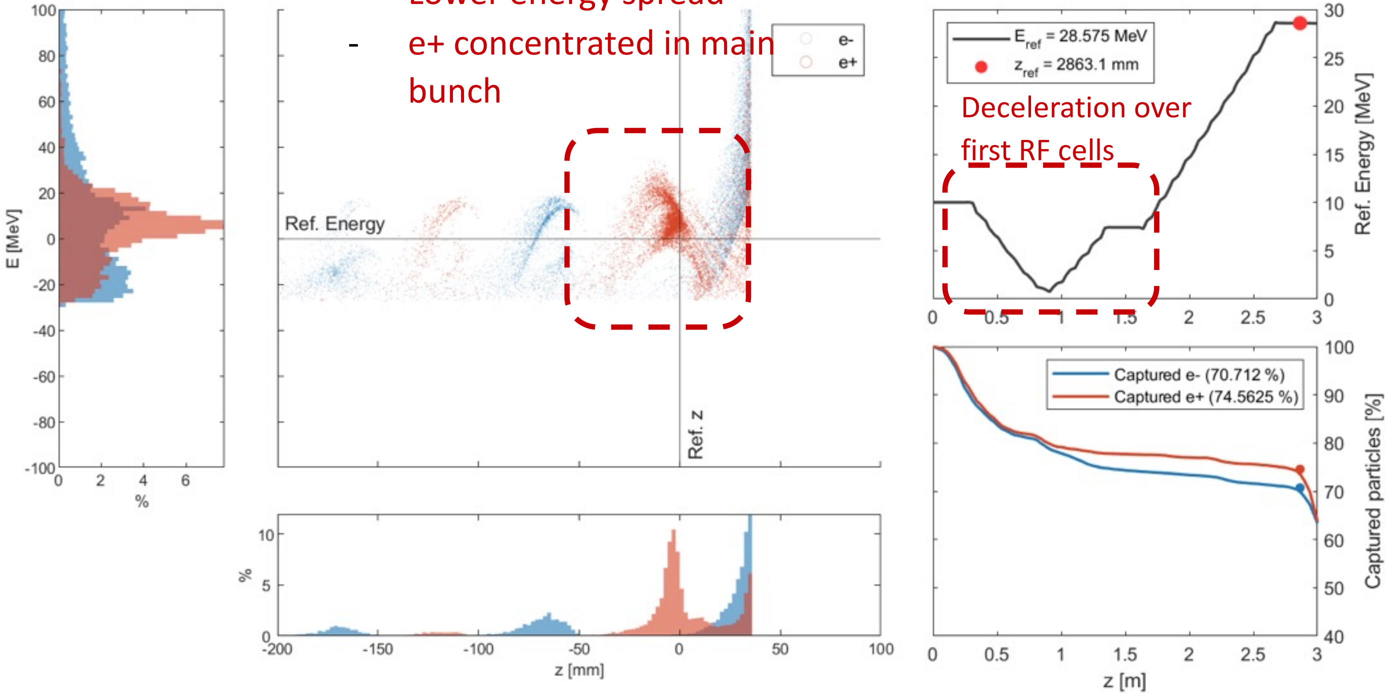
RF Working Points



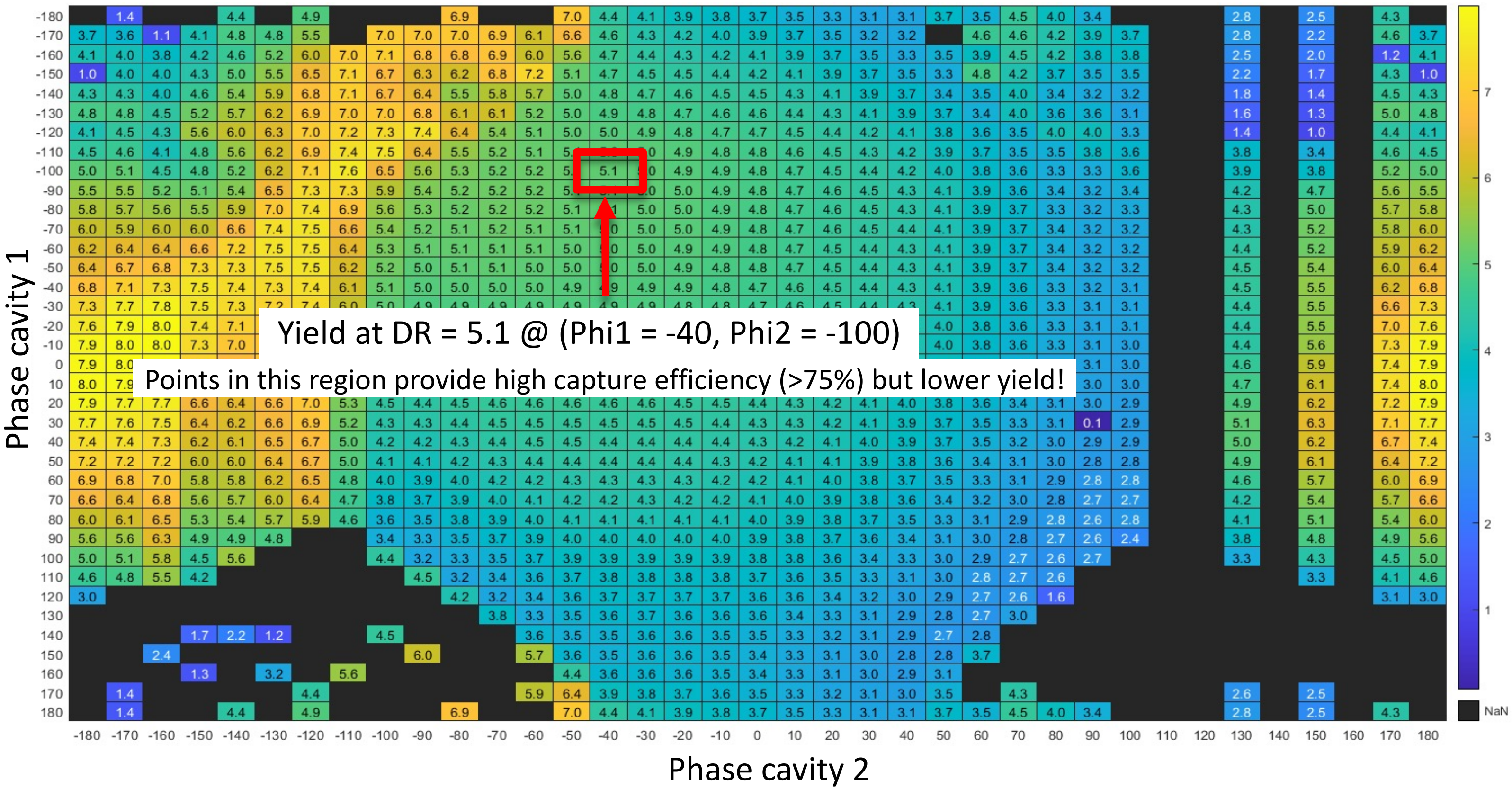
RF Working Points (II)

Second bucket:

- Lower energy spread
- e+ concentrated in main bunch

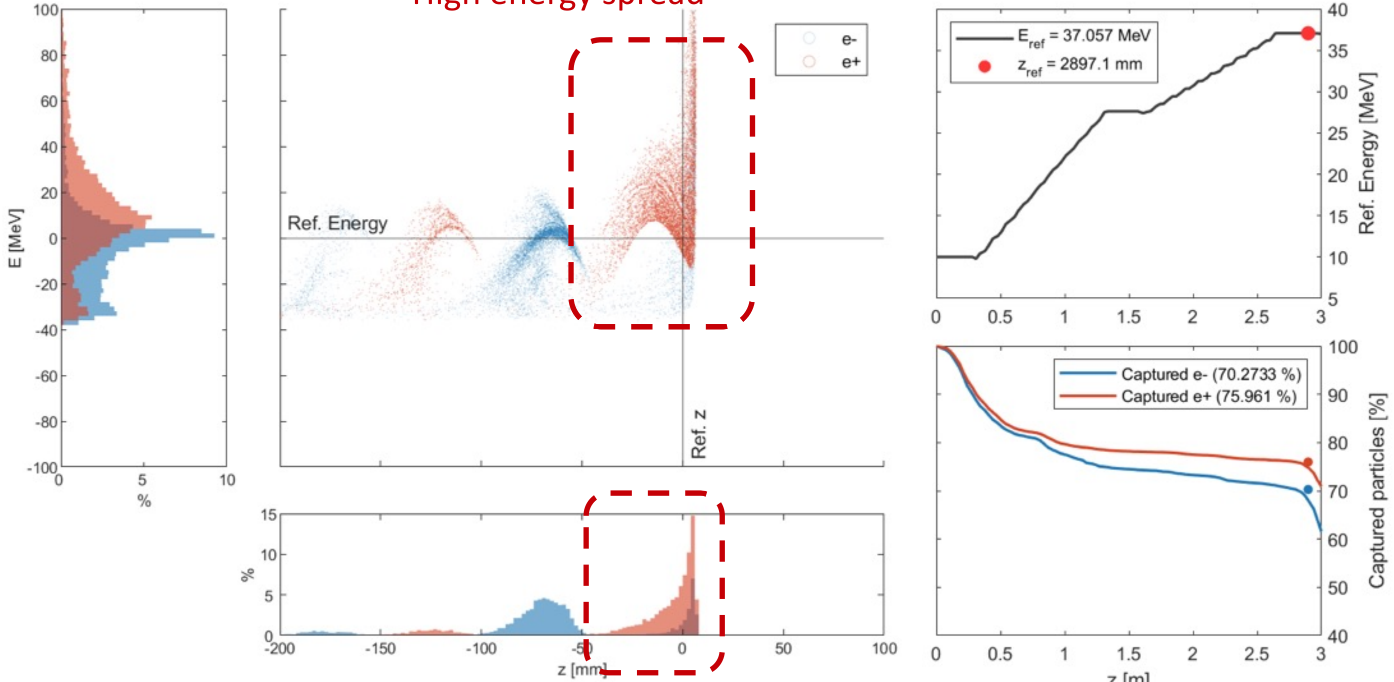


RF Working Points



RF Working Points (III)

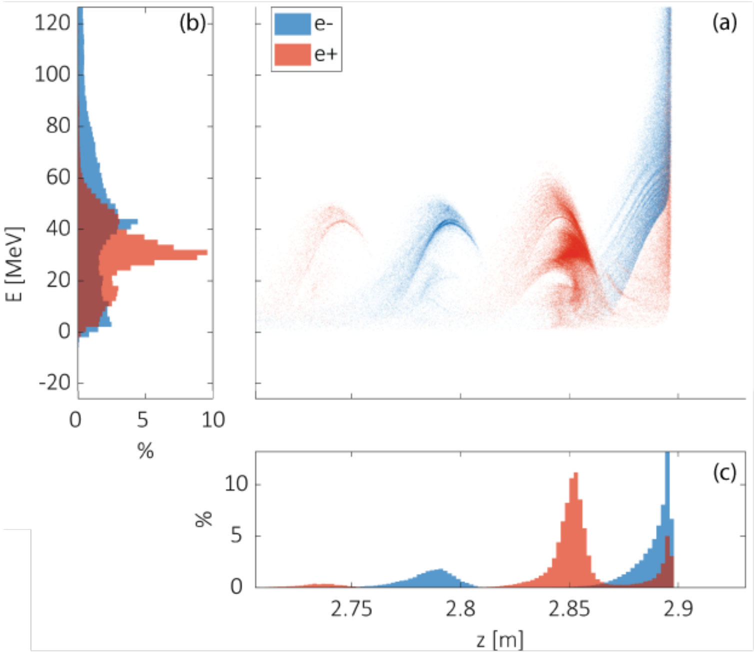
First bucket:
- High energy spread

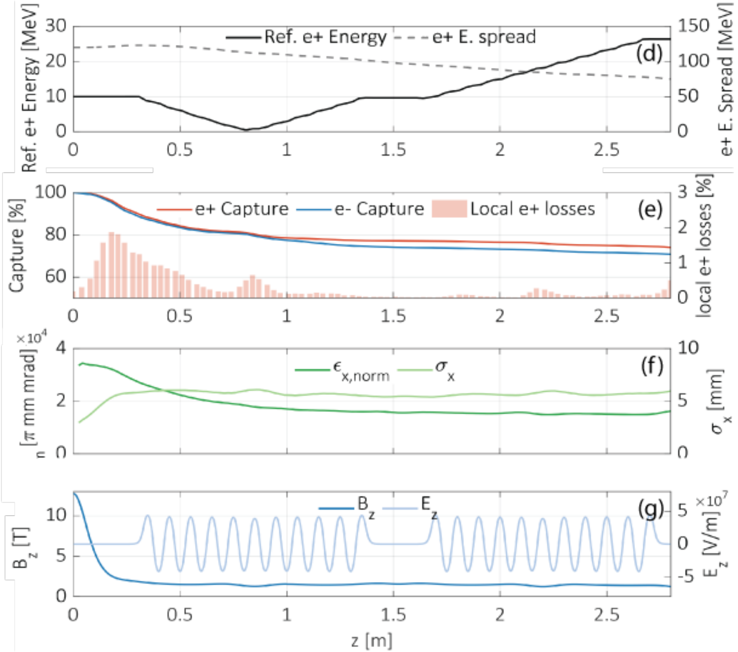


Many electrons in first bucket

The p3 beam (I)

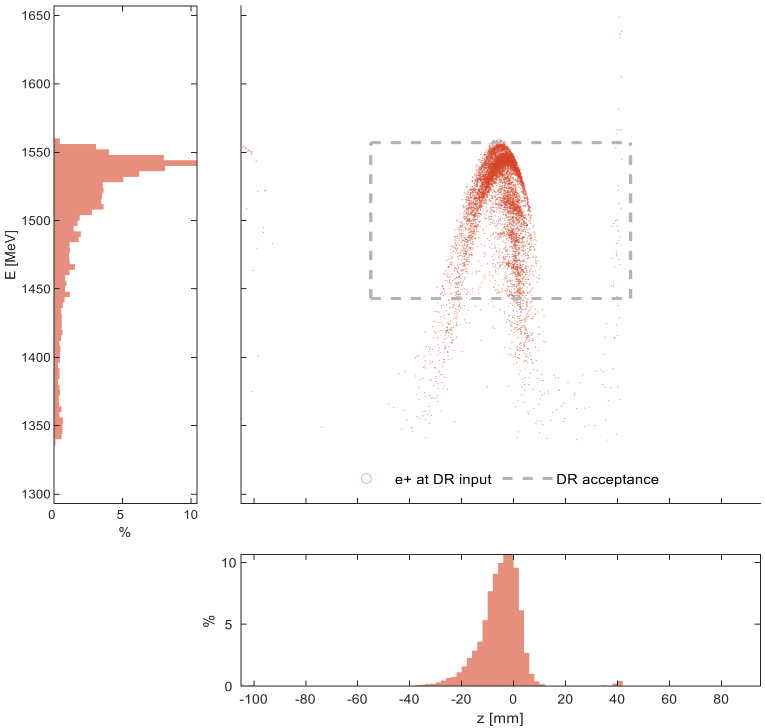
AMD max.	12.7	T
Solenoids max.	1.5	T
e+ capture efficiency	74	%
Energy Spread	92	MeV
Norm. emittance	15157	pi mm mrad





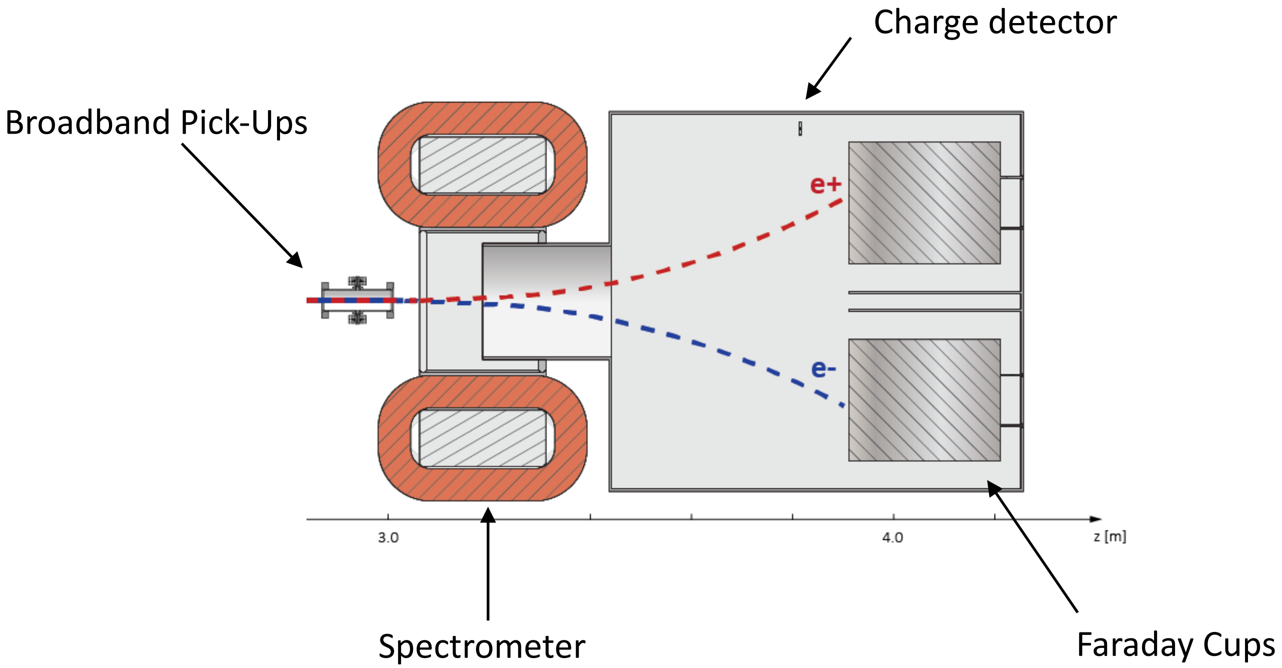
The P3 Beam (II)

Longitudinal profile of e+ beam at DR entrance



	Yield at DR	**8.0**	
	AMD max.	12.7	T
	Solenoids max.	1.5	T
@ 200 MeV	Capture efficiency	72	%
	Energy Spread	66	MeV
	Norm. emittance	14667	pi mm mrad

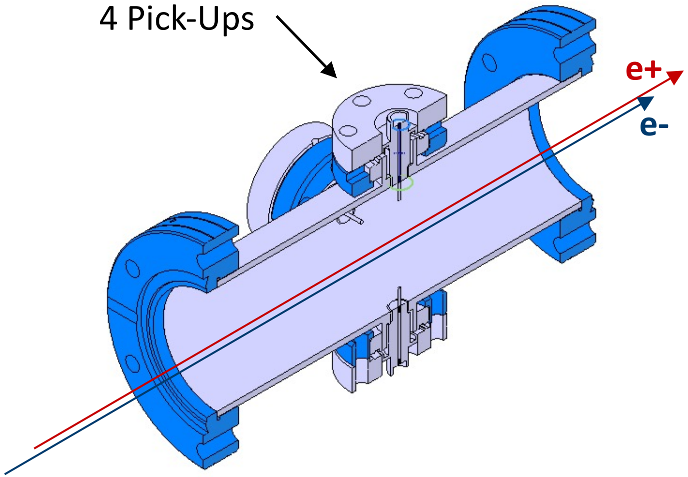
II. Beam Diagnostics

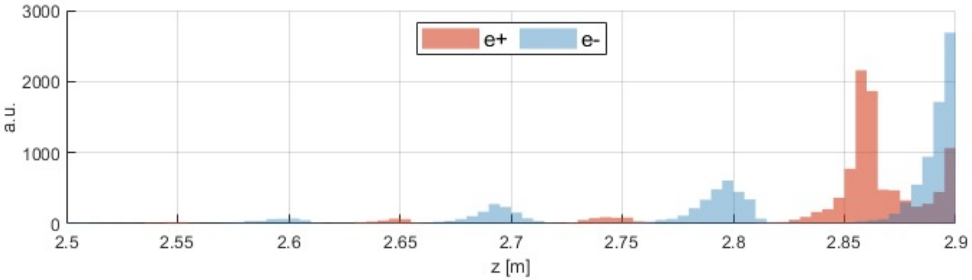


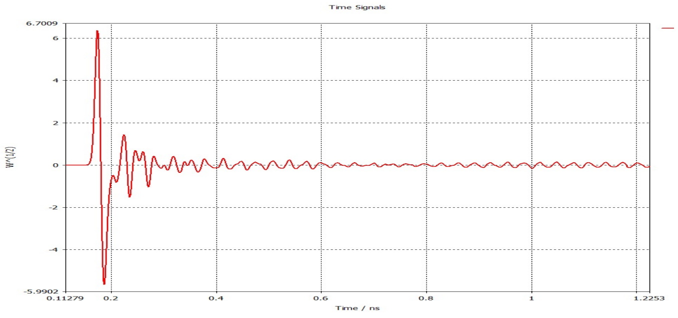
Broadband Pick-Ups

- BBPs measure time structure of the beam after second cavity.
- Broadband operation and high sampling frequency (40 GHz) required to differentiate e+ and e- bunches.
- Based on SuperKEKB factory diagnostic [1].

[1] T. Suwada et al., "First simultaneous detection of electron and positron bunches at the positron capture section of the SuperKEKB factory", Sci. Rep., vol. 11, 2011.



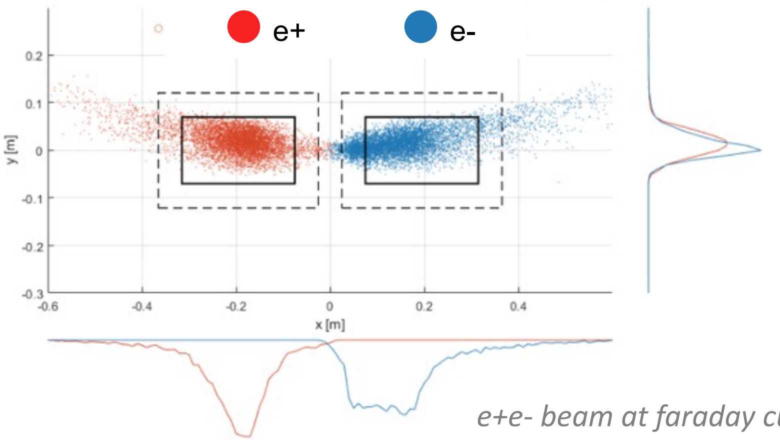




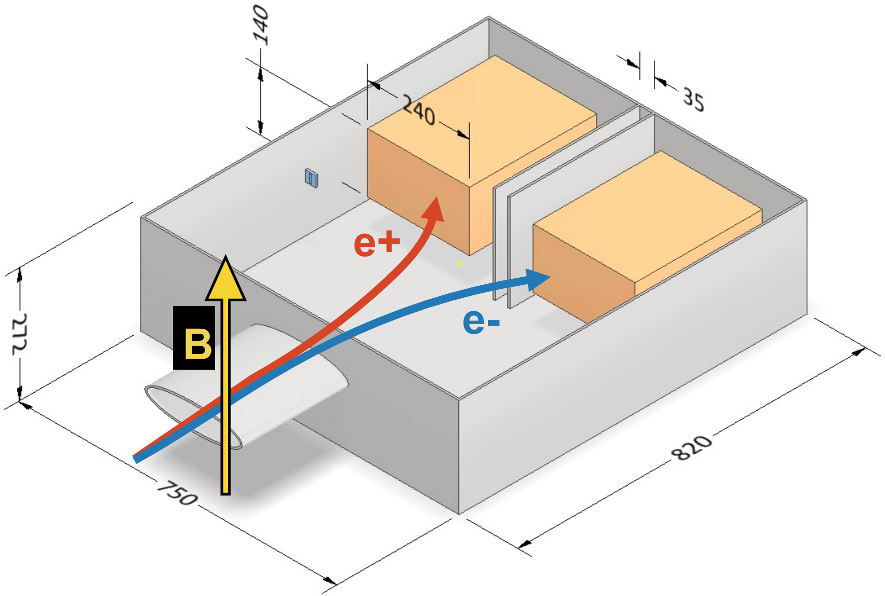
Simulated signal at BBPs (E. Ismaili)

Faraday Cups

- Measurement of e+ and e- charge separately.
- Alluminum FCs at 25 Ohm. Matching to 50 Ohm through 2 parallel coax cables
- Negligible electron backscattering



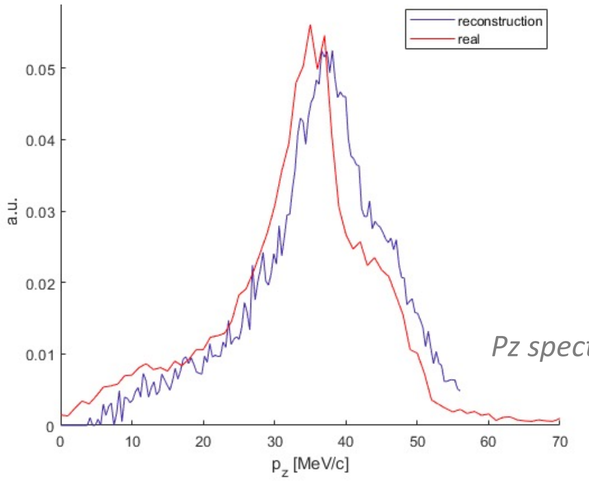
e+e- beam at faraday cups



Optimized dimensions of diagnostics chamber.

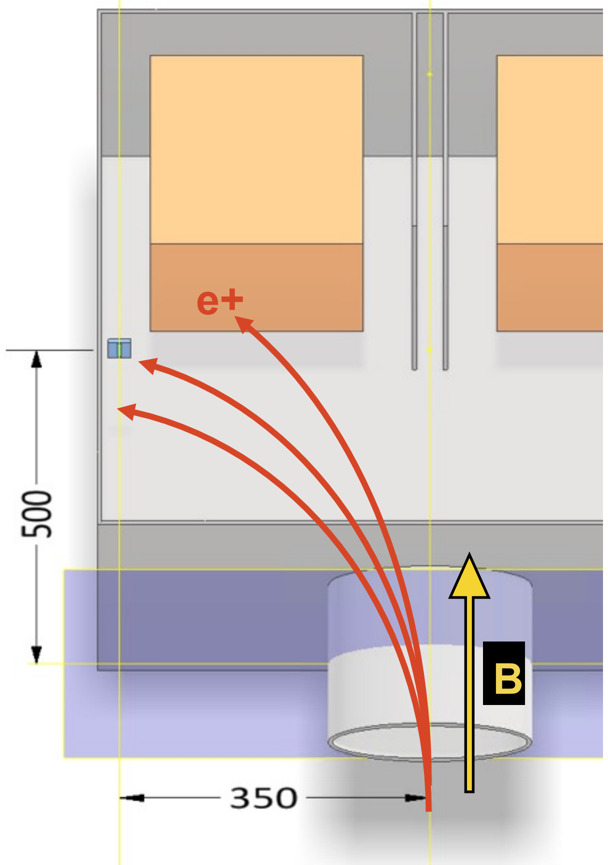
Spectrometer and Charge Detector

- Dipole strength scanned to measure e+ energy profile
- e+ at different p_z detected by narrow screen
- Technology of the detector t.b.d.!

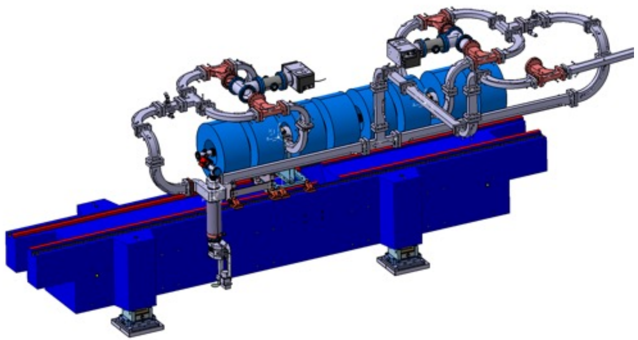


Pz spectrum reconstruction

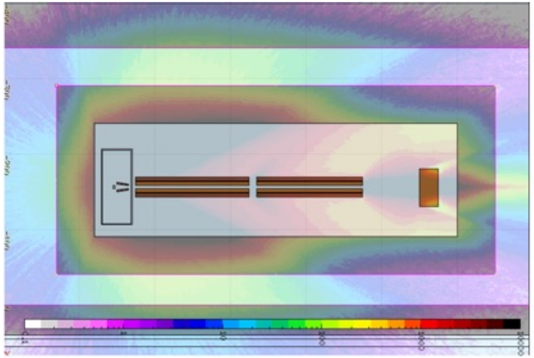
Schematic of energy spectrum measurement



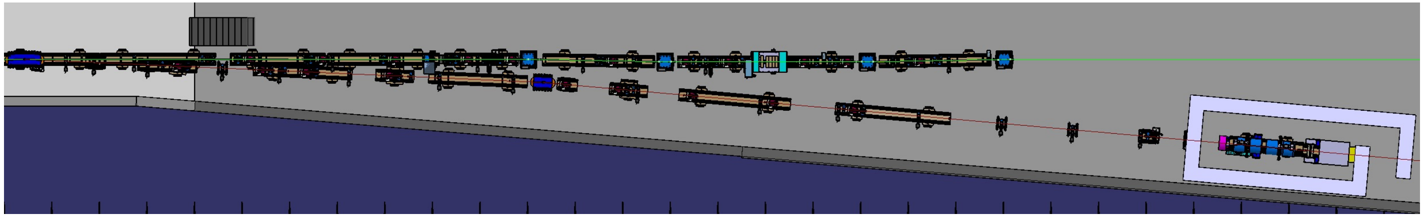
IV. Project Status



Mechanical design of P^3 and RF network (A. Magazinik)

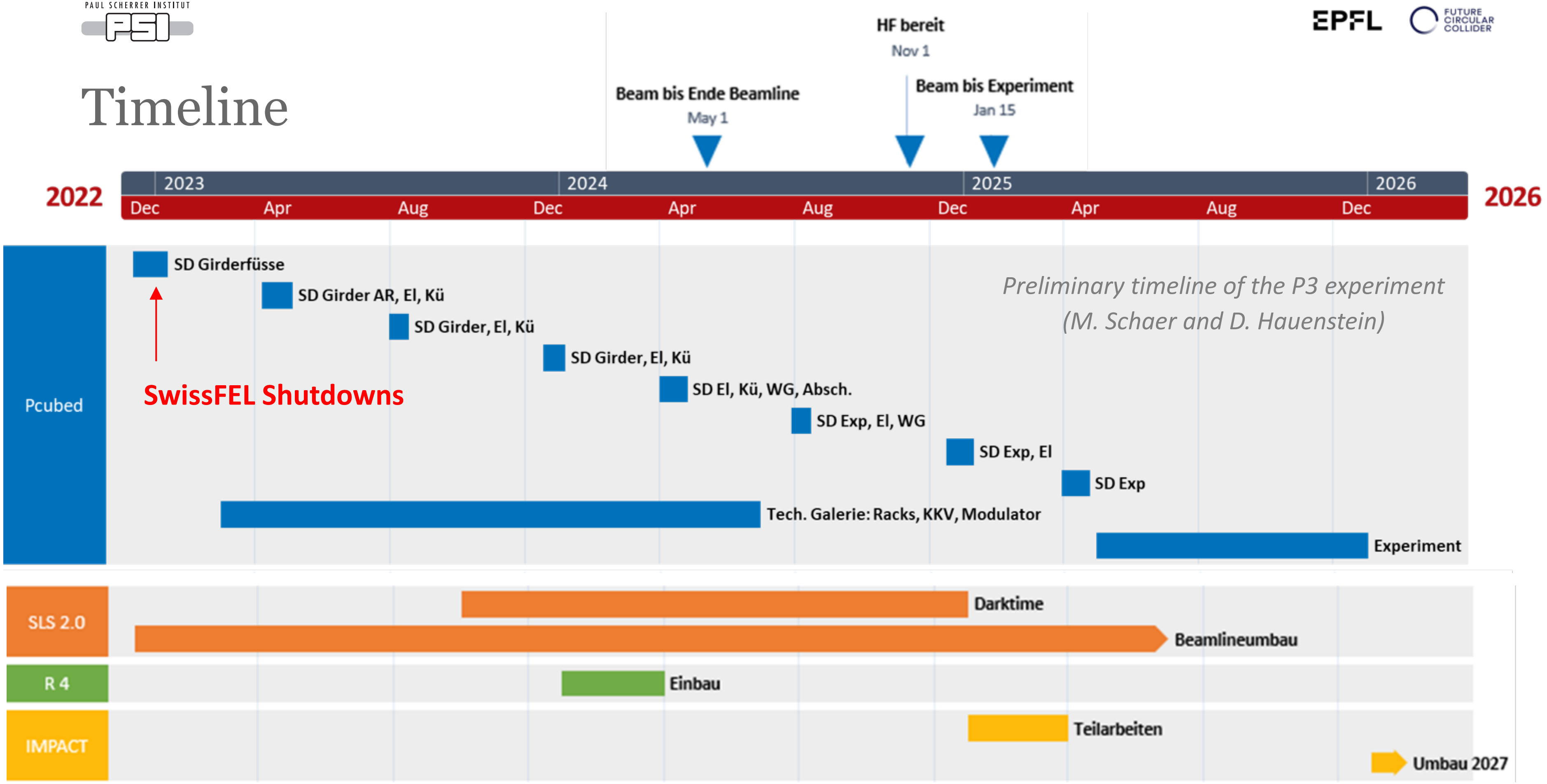


Radioprotection studies (I. Besana)



Design of the extraction line and P3 bunker at SwissFEL (D. Hauenstein and M. Schaer)

Timeline



HF bereit
Nov 1
Beam bis Ende Beamline
May 1
Beam bis Experiment
Jan 15
2022
2023
2024
2025
2026
2026
Dec
Apr
Aug
Dec
Apr
Aug
Dec
Apr
Aug
Dec
Pcubed
SD Girderfüsse
SD Girder AR, El, Kü
SD Girder, El, Kü
SD Girder, El, Kü
SD El, Kü, WG, Absch.
SD Exp, El, WG
SD Exp, El
SD Exp
Tech. Galerie: Racks, KKV, Modulator
Experiment
SwissFEL Shutdowns
Preliminary timeline of the P3 experiment
(M. Schaer and D. Hauenstein)
SLS 2.0
Darktime
Beamlineumbau
R 4
Einbau
IMPACT
Teilarbeiten
Umbau 2027

Status of Experiment Design

	Target	Concept design defined.
	RF Structures	Ready for copper purchase.
Magnets	**AMD**	HTS tape to be purchased shortly. Design of cryostat almost complete.
Magnets	**Solenoids around RF structures**	NC and SC options presented.
Beam diagnostics	**Faraday Cups and diagnostics chamber**	Dimensions optimized. Backscattering simulations performed.
Beam diagnostics	**Broadband pick-ups**	Feedthroughs to be purchased and tested shortly. Optimization of pickups in progress.
Beam diagnostics	**Spectrometer**	Baseline design complete. Mechanical modification of existing dipole in progress.
Beam diagnostics	**Charge detector**	Technology under discussion.

- Purchase phase
- In progress
- Concept design

Final Remaks

- P^3 is at advanced design stage and on-schedule. Final design expected for 2023 Q1.

- Experiment to take place in 2025. Eventual delays might occur due to installation and integration issues.

- Make the most of our compact positron source at PSI:
  - A demonstrator for all future e+e- colliders and positron machines.
  - Possible host to further experiments and tests.

- Open to new ideas and collaborators!

Acknowledgements

Mike Seidel (thesis advisor)

Paolo Craievich

Riccardo Zennaro

Mattia Schaer

Anastasiya Magazinik

Fabio Marcellini

Erisa Ismaili

Michal Duda

Jaap Kosse

Henrique Garcia Rodrigues

Swiss Accelerator Research and Technology

This work was done under the auspices of CHART (Swiss Accelerator Research and Technology) Collaboration, https://chart.ch