

PAUL SCHERRER INSTITUT



Riccardo Zennaro :: on behalf of the P³ Team :: Paul Scherrer Institute

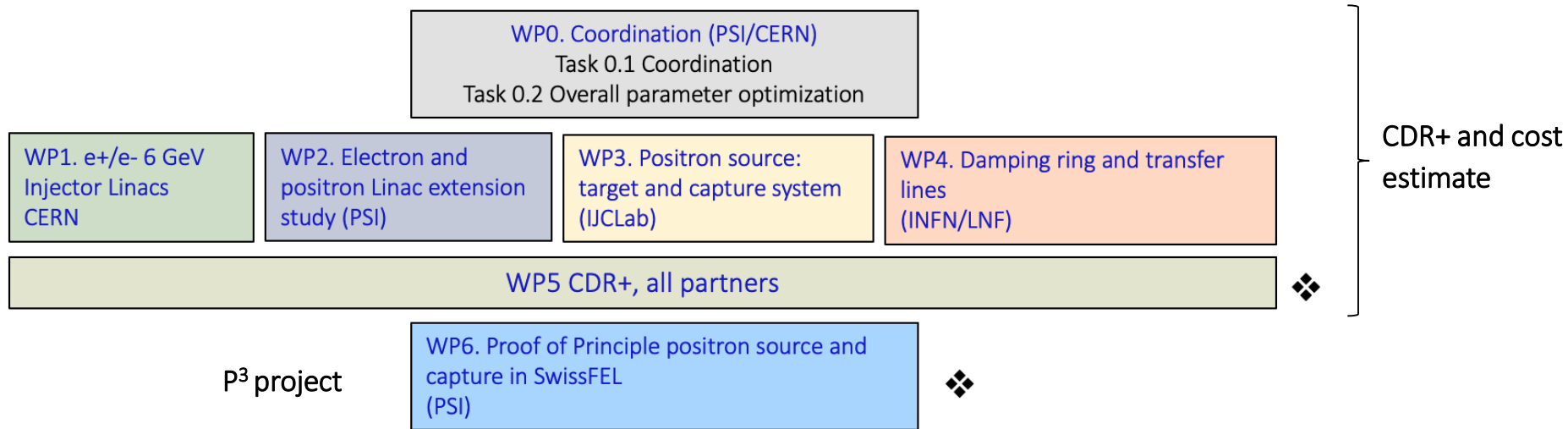
FCC-ee Injector design and the PSI Positron Production project

LLRF Workshop 2022 at PSI, 10.10.2022

FCC-ee injector study (Project in CHART)

Collaboration between PSI and CERN with external partners:

CNRS-IJCLab (Orsay), INFN-LNF (Frascati), SuperKEKB as observer (also interested in the P³ project), INFN-Ferrara – radiation from crystal





- **CHART (Swiss Accelerator Research and Technology): umbrella collaboration for accelerator research and technology activities in Switzerland**
- **The mission is to support the future oriented accelerator project FCC at CERN and development of accelerator concepts beyond the existing technology**
- **The activities are focused on the support of the FCC project. I.e. High-field magnet R&D complemented by beam dynamics studies for FCC-ee, FCC-hh and FCC-ee Injector and positron production test facility**
- **CHART is contributing to the FCC Feasibility Study to be delivered in 2025**

Injector Parameters and Main Options

	Baseline	HE Linac	Unit
Ring for injection	SPS/PBR	BR	
Injection energy	6	20	GeV
Bunch population both species	5.55	5.0	(nC)
Repetition rate	200	200	Hz
Number of bunches	2	2	
Bunch spacing	17.5-50	17.5-50	ns
Normalized emittance (x, y) (rms)	50, 50	50, 50	mm.mrad
Bunch length (rms)	~1	~1	mm
Energy spread (rms)	<0.1	<0.1	%

Other important requests:

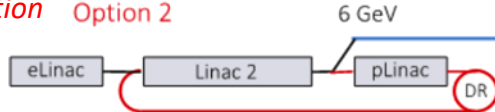
- The bunch by bunch intensity will **randomly vary 0 to 100%**, depending on the intensity balance between the collider rings
- **Bunch-by-bunch injection intensity fluctuation: 3%.**

Baseline

Option 1



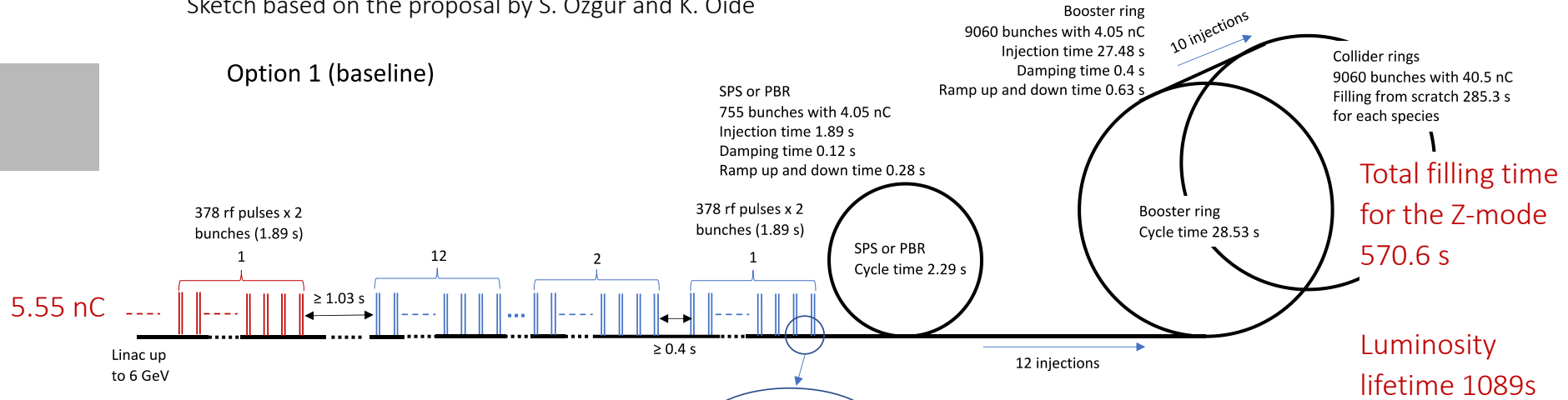
20 GeV Linac option Option 2



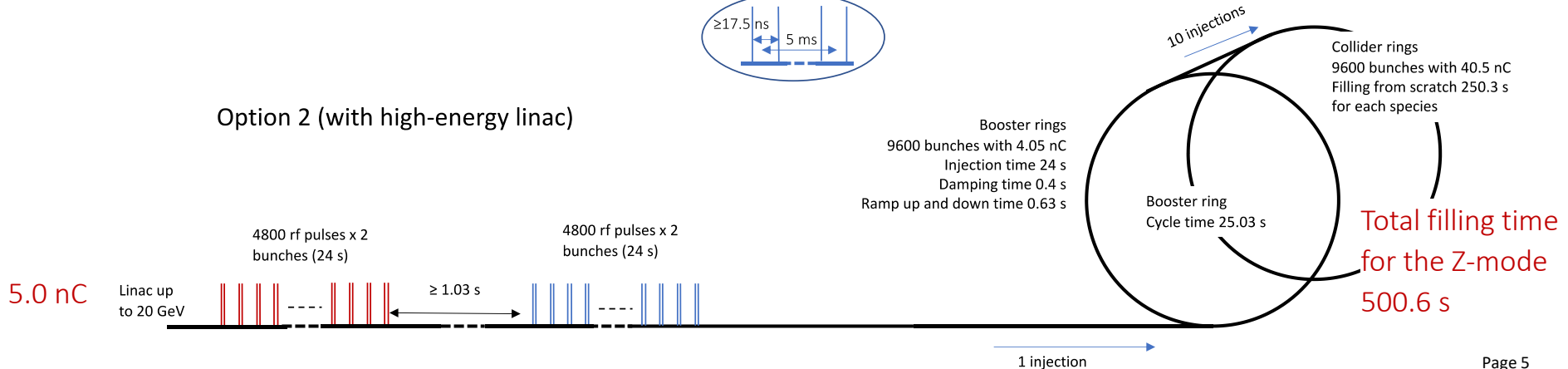
Filling Pattern for the Z-Mode

Sketch based on the proposal by S. Ozgur and K. Oide

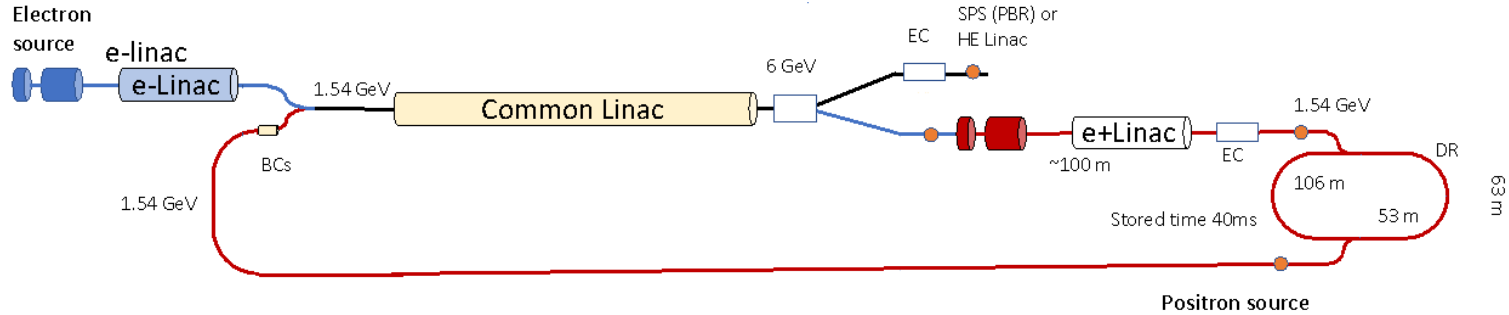
Option 1 (baseline)



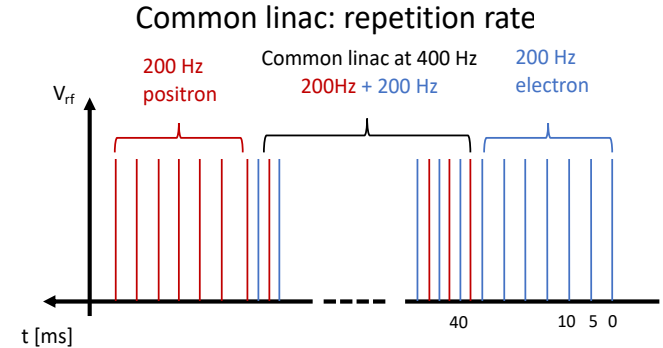
Option 2 (with high-energy linac)



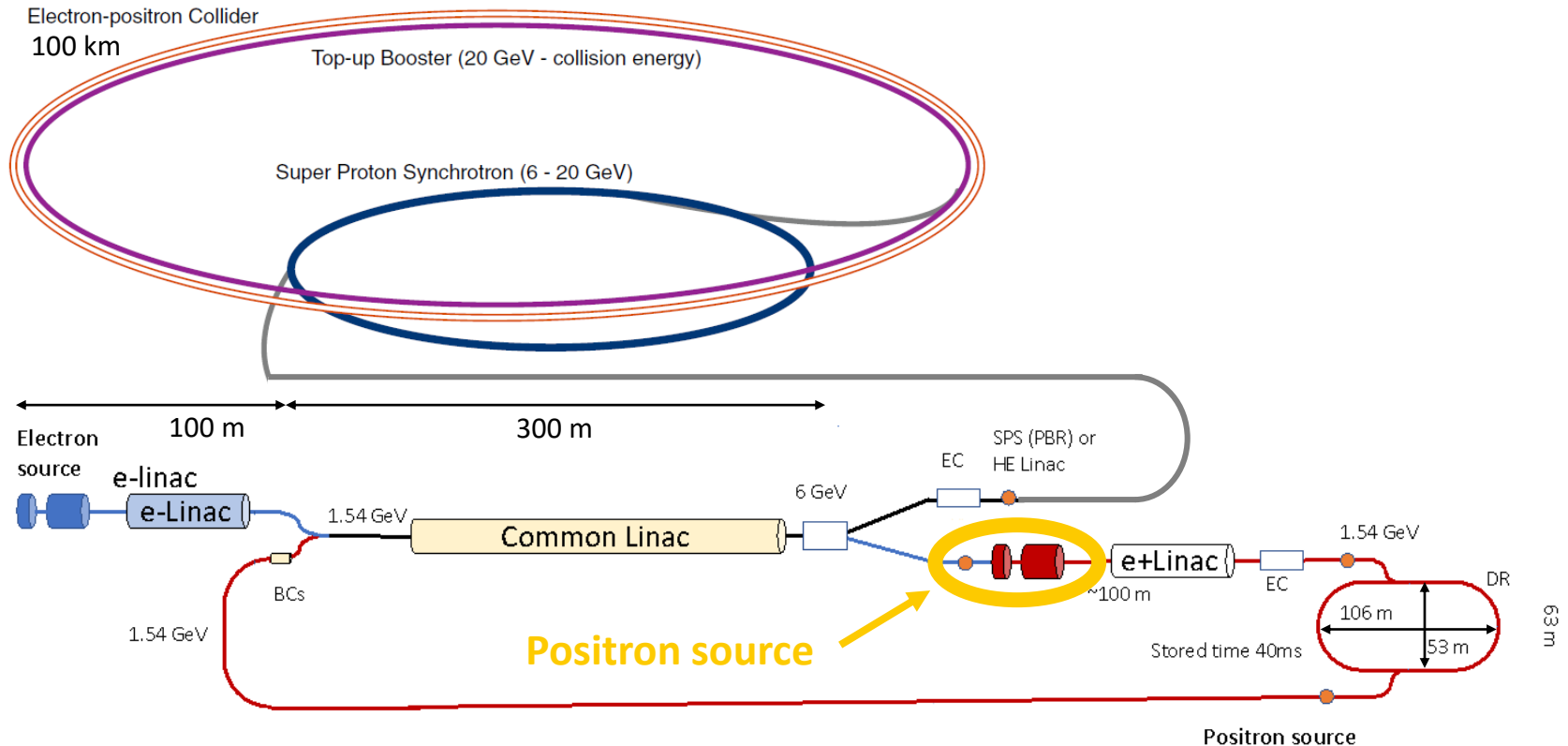
Injector overview



- Common linac at 200 Hz (electrons) + 200 Hz (positrons) when positron are generated
- DR has to provide a delay of 2.5 ms to allocate the positron bunches on the on the right rf bucket
- e- linac and common linac at 2.0 GHz or 2.8 GHz, conventional TW structure design
- e+ linac at 2.0 GHz with nose-shaped irises

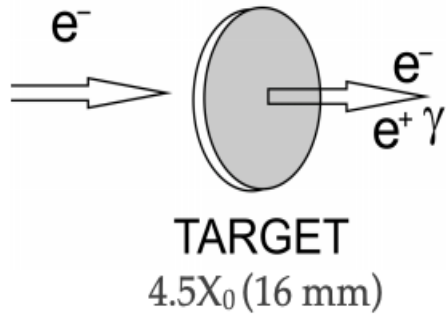


P³ as Positron Source Demonstrator for FCC-ee

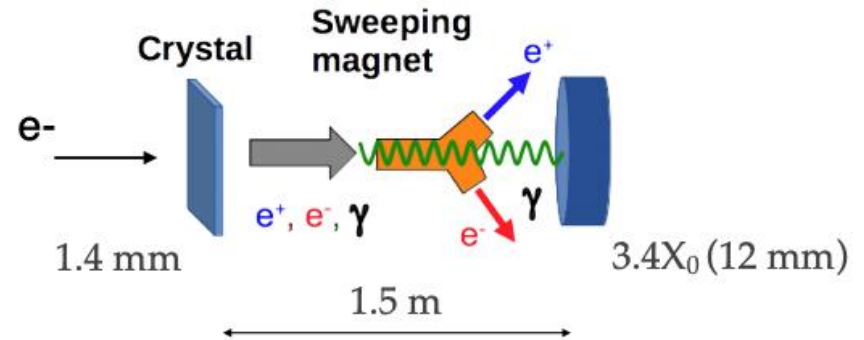


Generation of Positrons

Conventional target (P³ phase 1)



Hybrid scheme (P³ phase 2?)



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

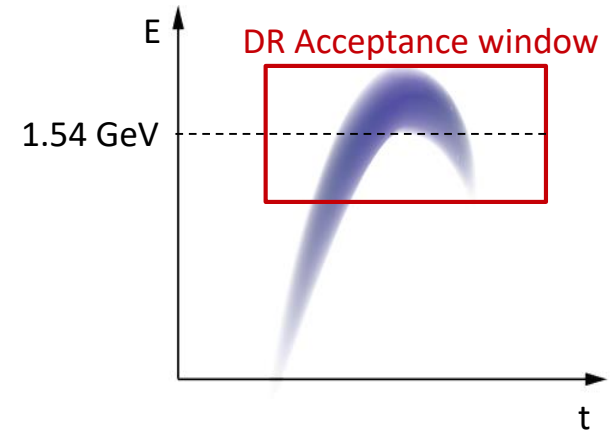
[1] K. Akai, K. Furukawa, and H. Koiso, "Superkekb collider", 2018.

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

(*) with 1.5 T SC solenoids around RF cavities, ~2.8 with 0.4 T NC solenoids

- Main goal is to provide first experimental validation of such a yield
- P³ can not provide equivalent average beam power as FCC (thermal and radiation aspects)

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



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

The 6 GeV Electron Beam of SwissFEL @ PSI



	FCC-ee	SwissFEL	P ³ (*)
Beam energy	6 GeV		
RMS beam size	~ 0.5 mm		
Rep. rate	200 Hz	100 Hz	1 Hz
Bunch charge	~ 5 nC	0.2 nC	0.2 nC
Bunches/pulse	2	2	1

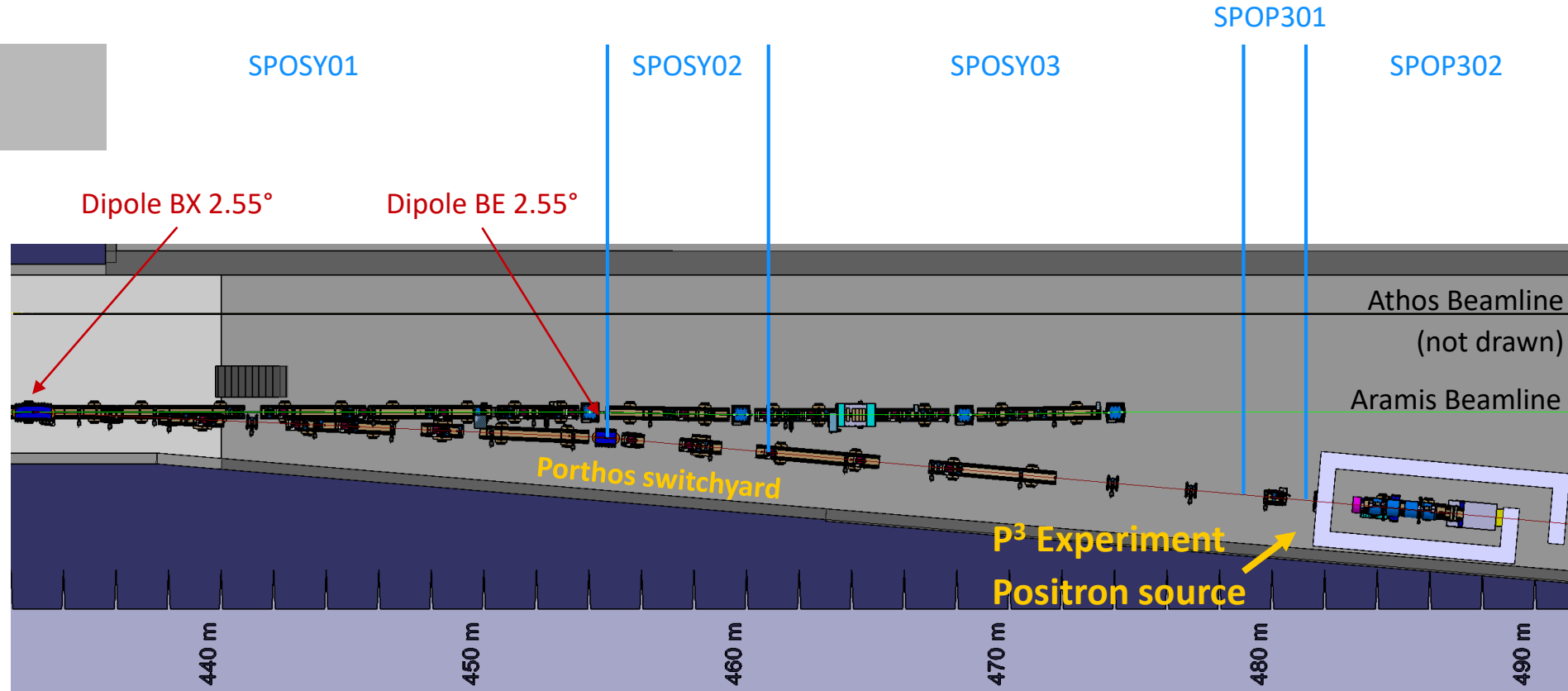
(*) for radiation reasons we must limit the average beam current of P³

Space for a 3rd Beamline in SwissFEL (Porthos)

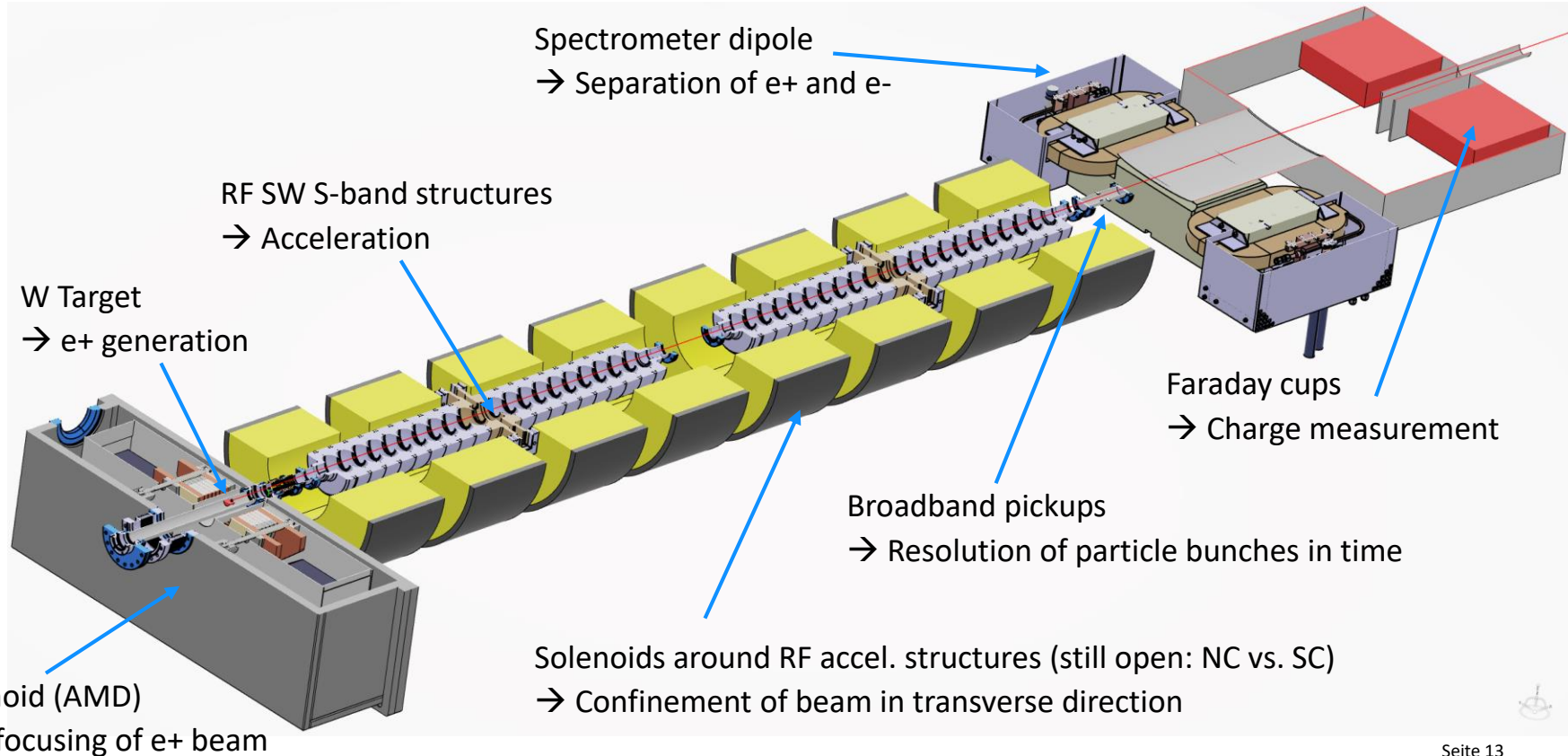


- SwissFEL building has been designed to allocate a future beam line (Porthos)
- Perfect location for P³

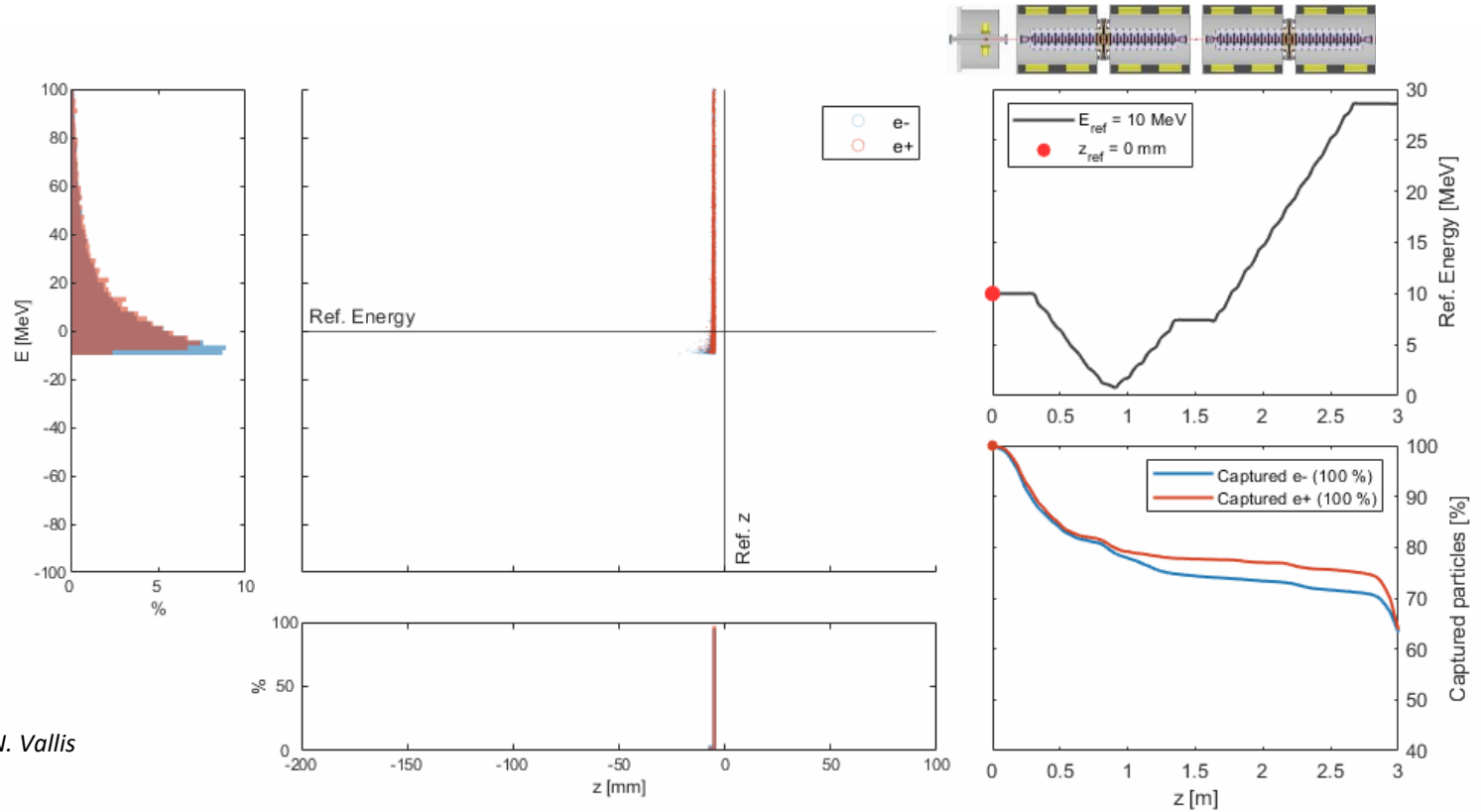
Position of the P³ Experiment in SwissFEL



P³ = PSI Positron Production

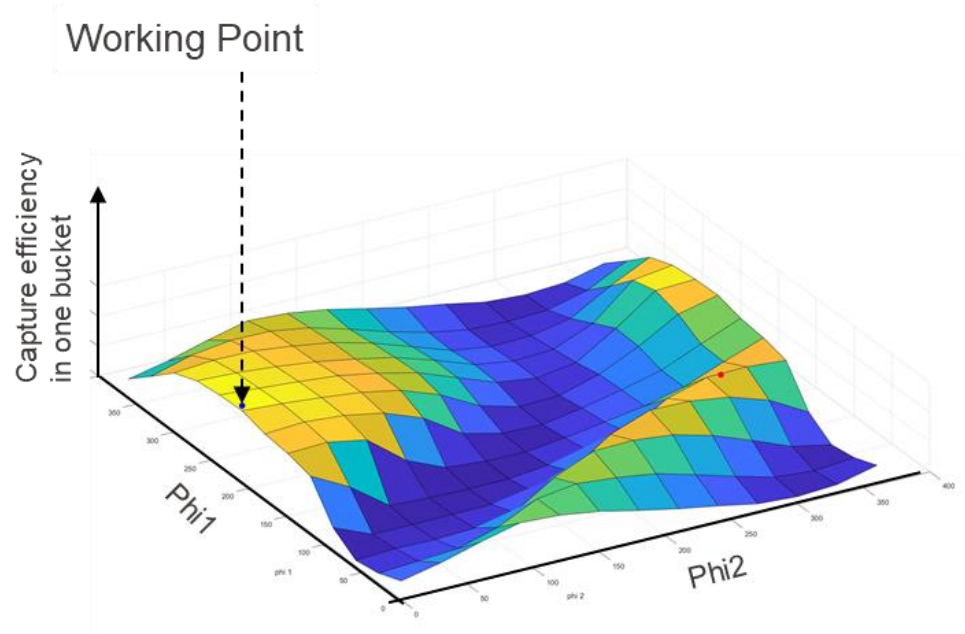


Beam Dynamics Along the Experiment

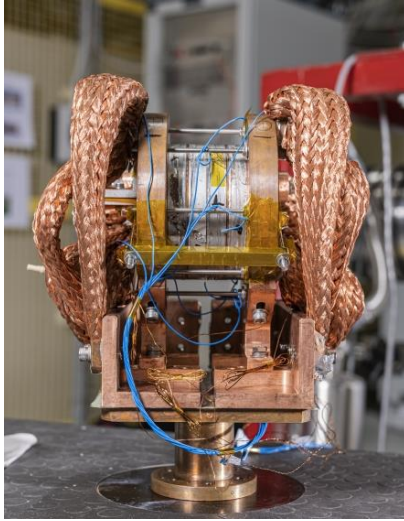


Courtesy of N. Vallis

- Ideally, RF Structures should be able to:
 - Capture a large part of the beam
 - **Bunch most positrons in one RF bucket**

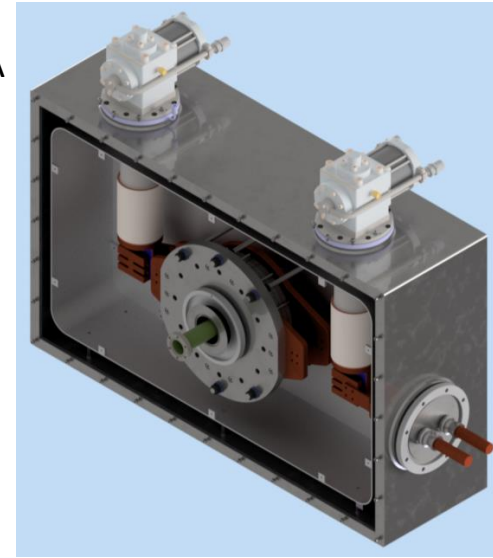
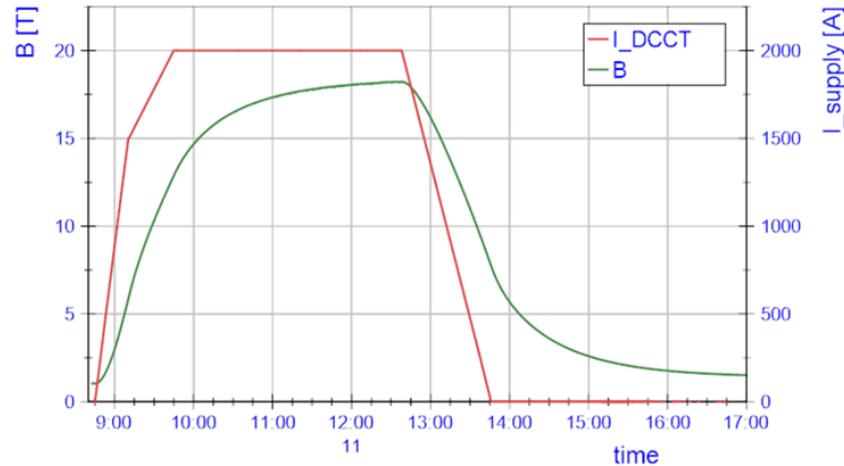


HTS Solenoid as Adiabatic Matching Device (AMD)



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

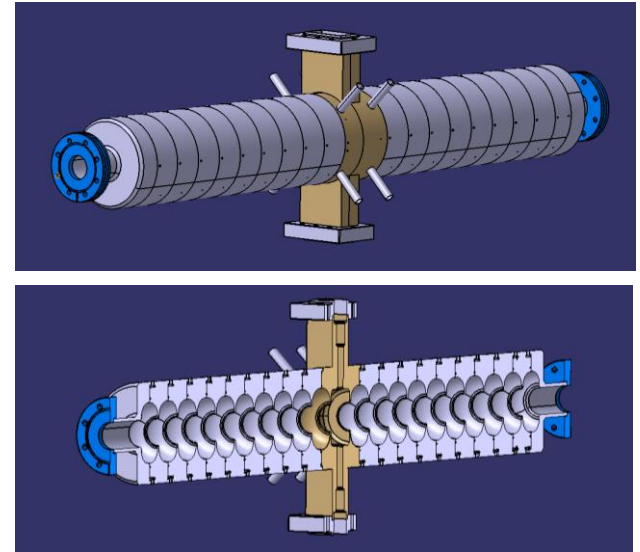
- HTS demonstrator developed at PSI (left)
 - 4 ReBCO (*Rare-earth barium copper oxide*) tape coils at 2kA
 - Operation at 18.2 T, on-axis peak
 - Temperature 20 – 30 K, no need of He cooling
- Technical design of cryostat for P³ in development at PSI (right)
- CW operation, ramp-up time of magnetic field ~ 2 days



Preliminary model of the AMD for P³
(H. Garcia Rodrigues)

Acceleration with RF SW S-Band Structures

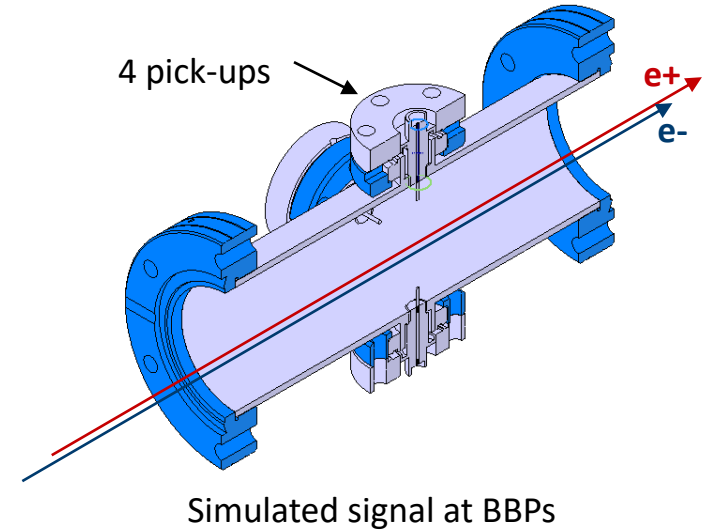
Length	1.2 m
RF Frequency	2.9988 GHz
Gradient	~ 18 MV/m
N cells	21
Q-factor	21600
R/L	13.9 MOhm/m
Aperture	40 mm
Mode Separation	5.3 MHz (π mode)
Coupling factor	2



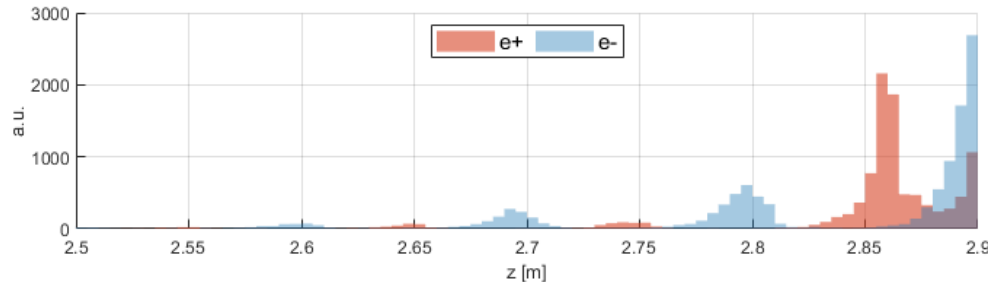
Under production at VDL, brazing at PSI

Time Res. Of Bunches With Broadband Pick-Ups

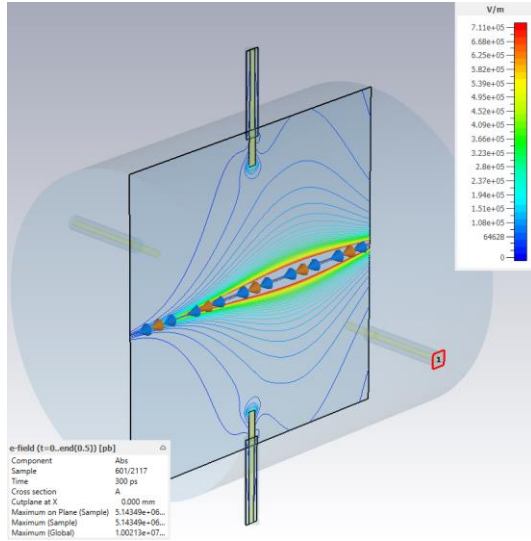
- Very broadband pickups (bandwidth > 40 GHz) can measure the time structure of the beam
- e+ and e- buckets are separated by 167 ps
- Based on SuperKEKB factory diagnostic



Time structure of the beam

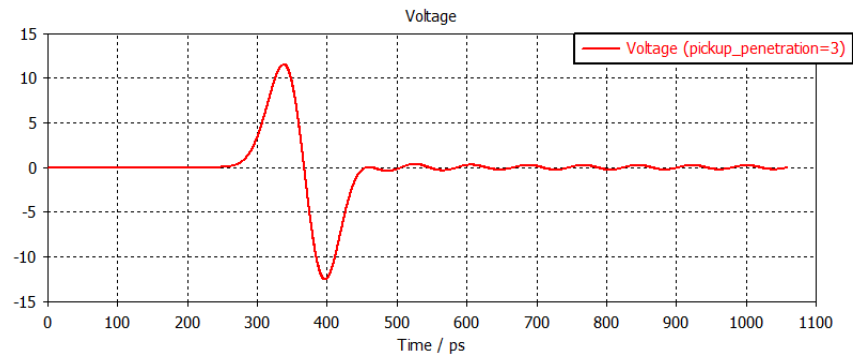


Broadband Pick-Ups 2



Feedthroughs from Allectra GmbH

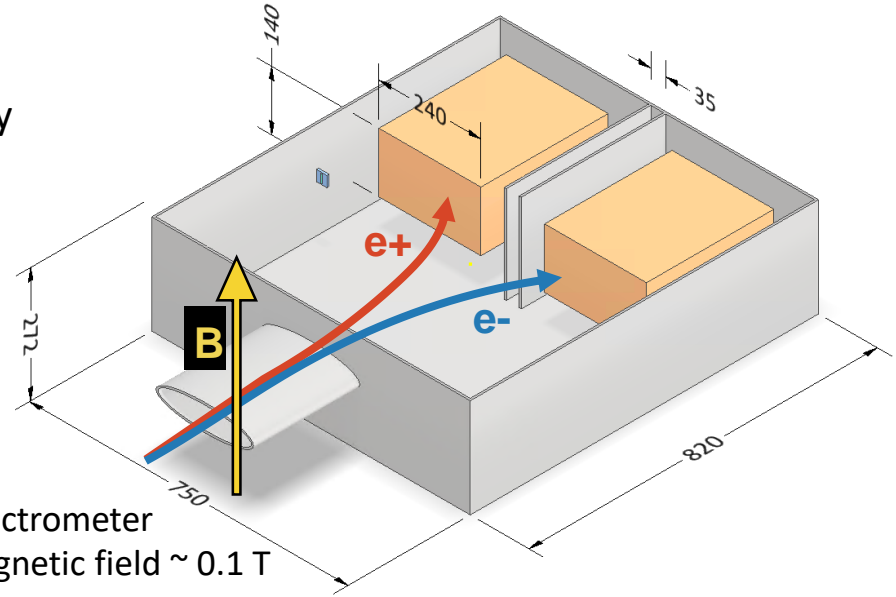
- A gaussian approximation of the main e+ bunch is simulated with CST wakefield solver over vacuum chamber.
- Pick-up geometry optimized:
 - Maximum peak voltage
 - Minimum signal tail
- Pick-up geometry optimized:
 - Maximum peak voltage
 - Minimum signal tail



Courtesy of N. Vallis

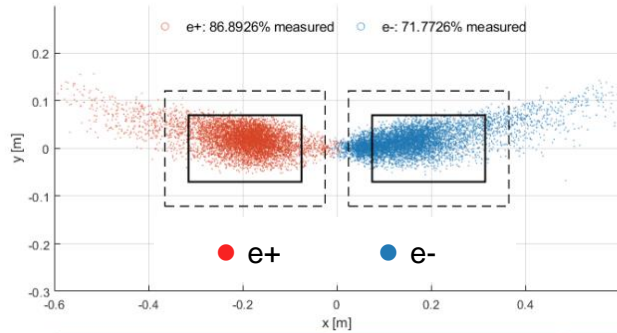
Charge Measurement with Faraday Cups

- Measurement of e^+ and e^- charge separately
- 2 parallel 25 Ohm connectors each
- Negligible backscattering



Spectrometer
magnetic field ~ 0.1 T

Optimized dimensions of diagnostics chamber.

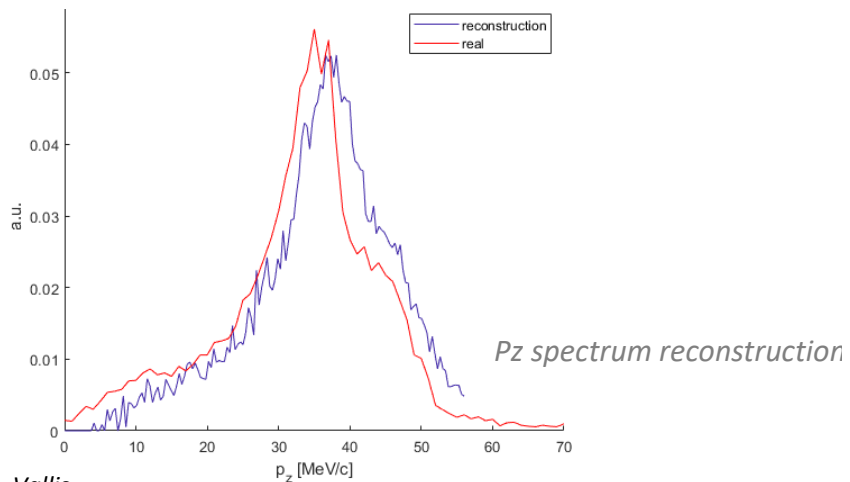


e^+e^- beam at faraday cups

Courtesy of N. Vallis

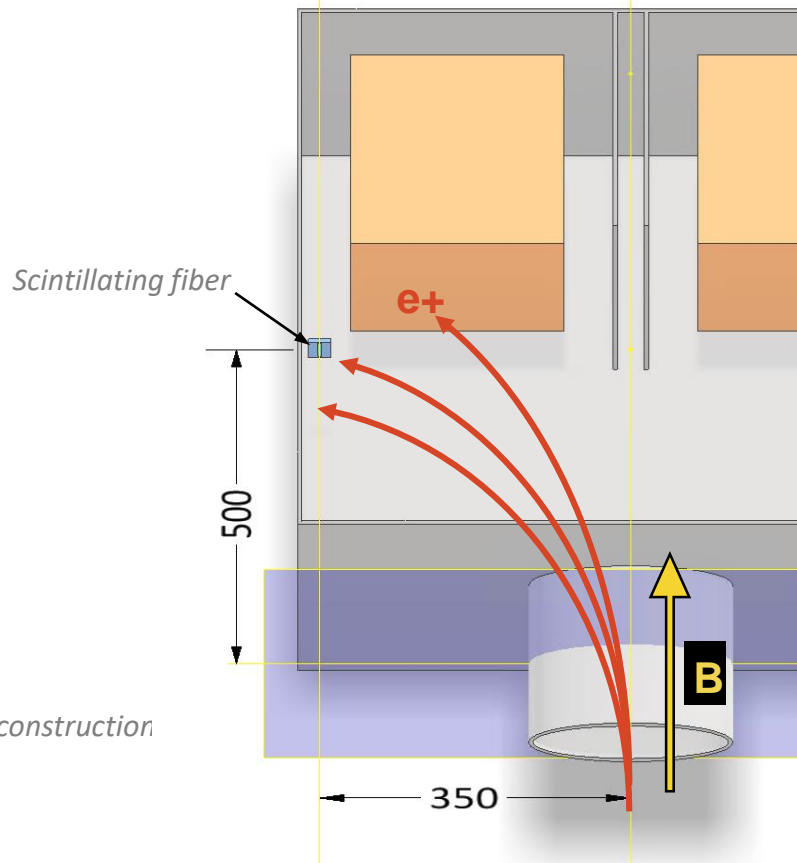
Spectrometer and energy spectrum

- Dipole strength scanned to measure e^+ energy profile
- e^+ at different p_z detected by scintillating fiber



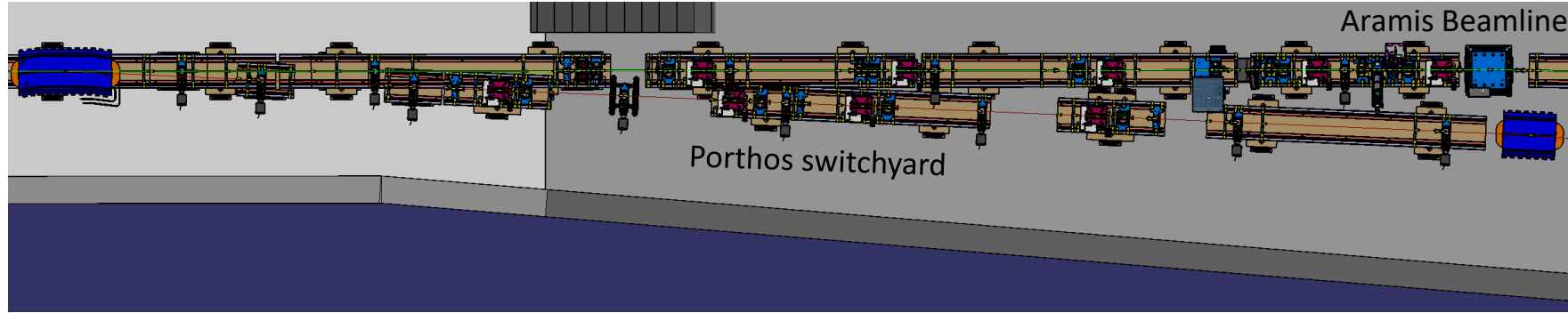
Courtesy of N. Vallis

Schematic of energy spectrum measurement

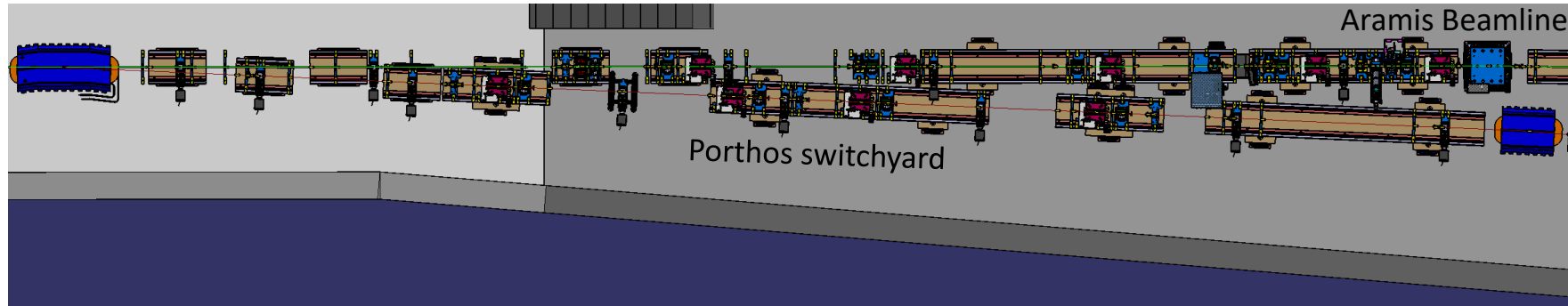


Modification of Aramis Beamline

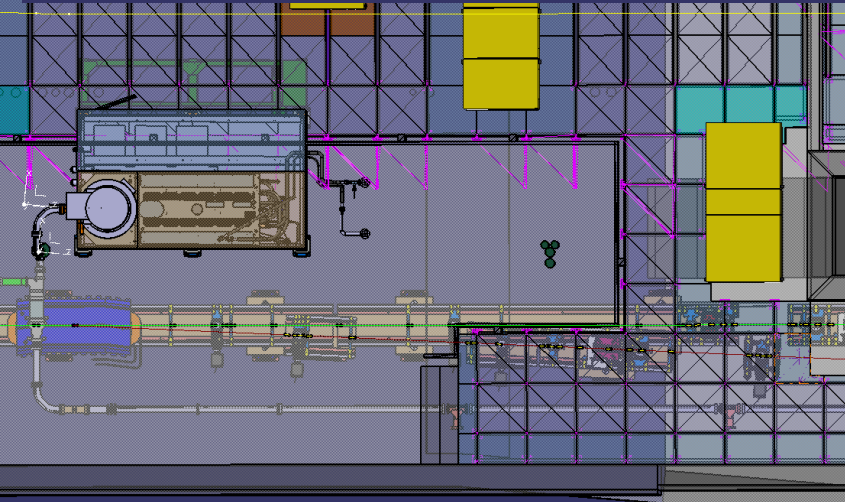
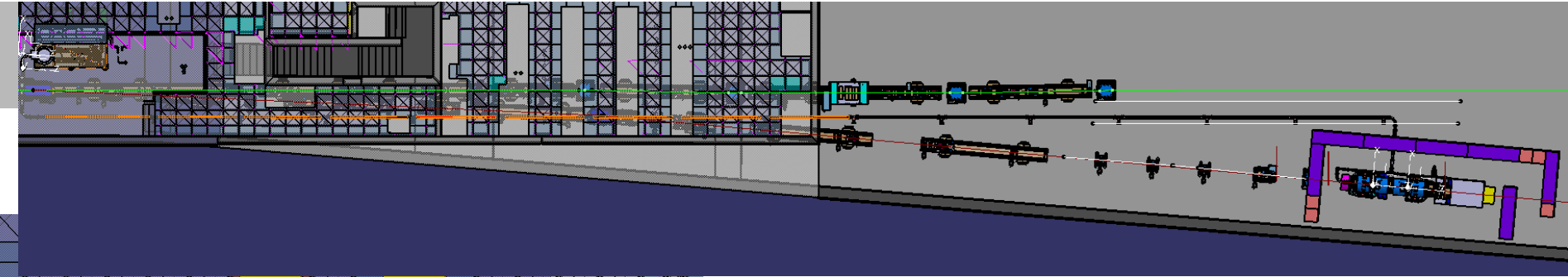
Current status (Aramis) → Conflicts with new Porthos switchyard



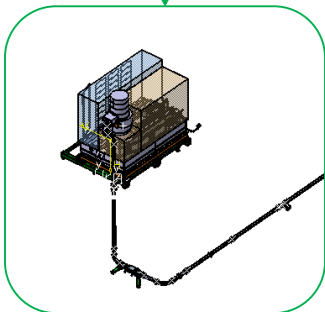
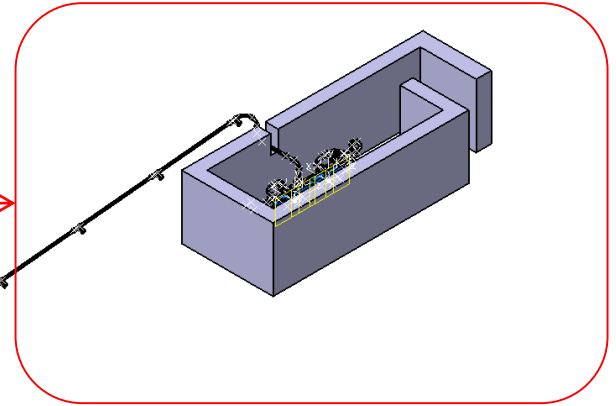
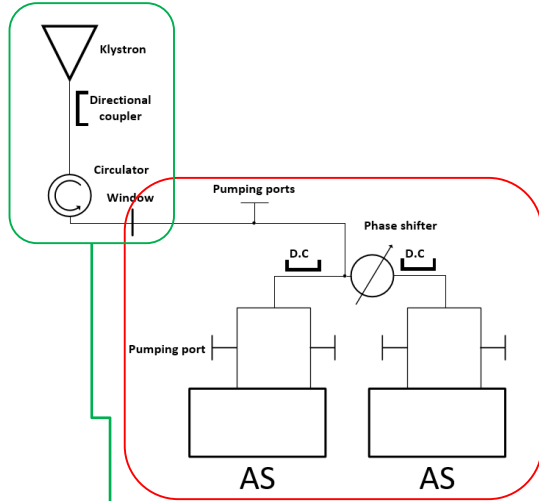
After modifications with shorter, alternating girders → Conflicts solved



S-Band RF System, Tunnel / Technical Gallery



Overview S-Band RF System

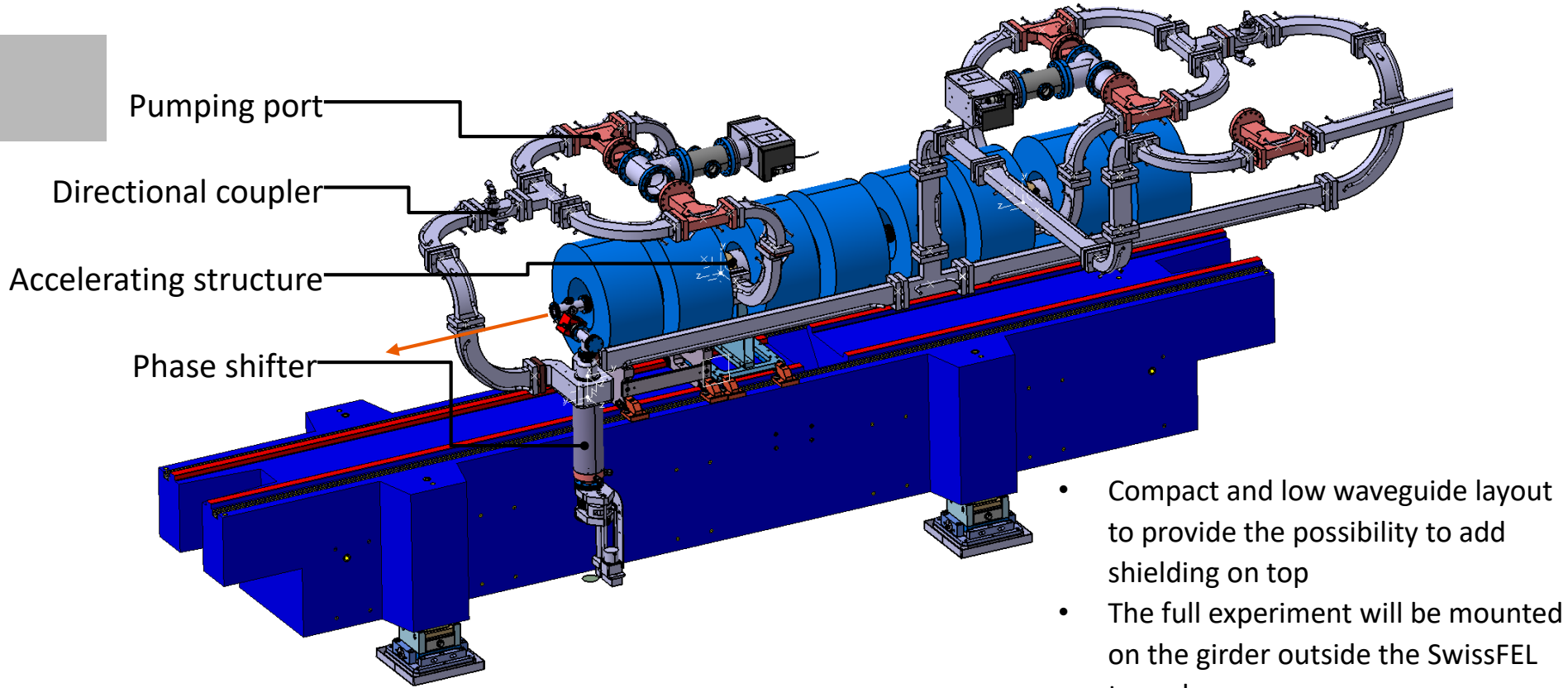


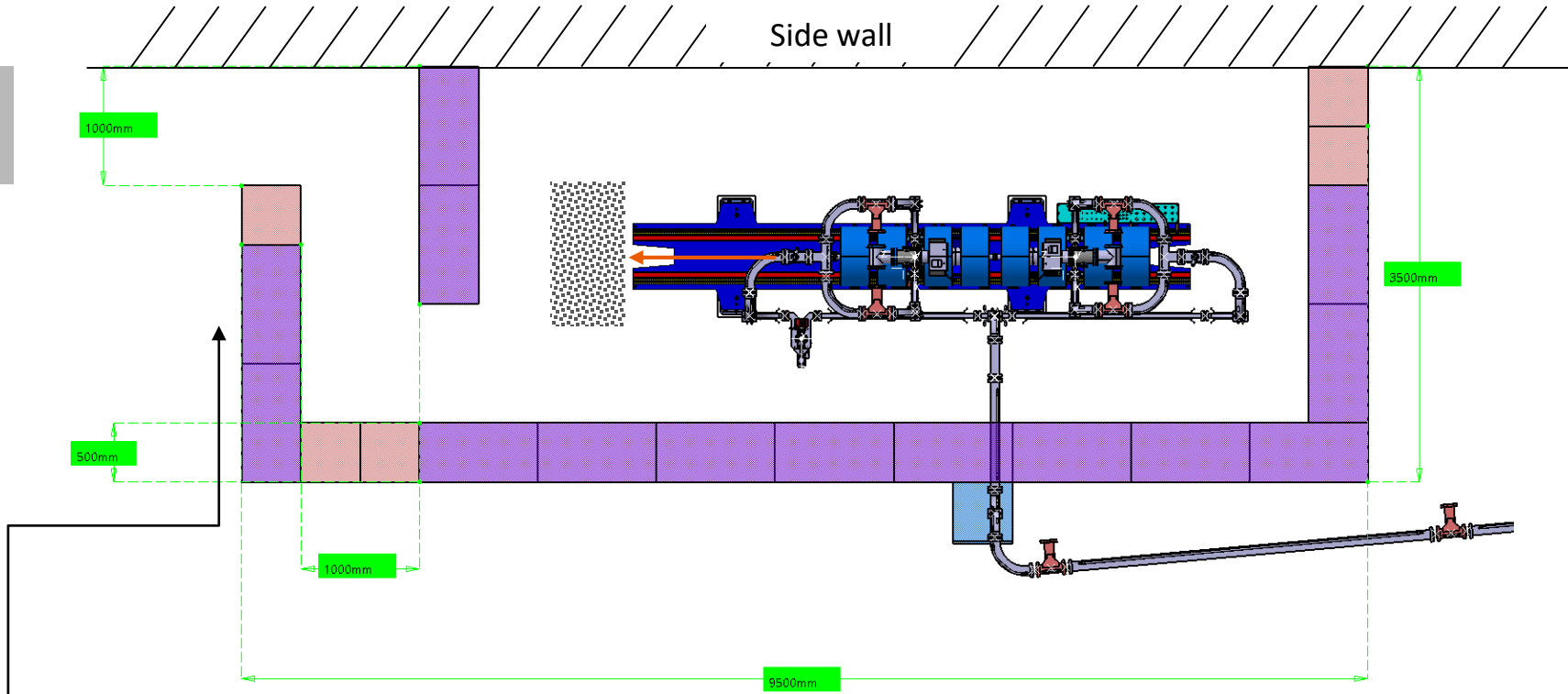
About 59 m waveguides needed,
will be borrowed from CERN

Nr	S-band Components	Qty	Units
1	Splitter	3	Pieces
2	H-bend	14	Pieces
3	E-bend	11	Pieces
4	Directional coupler	3	Pieces
5	Window	1	Pieces
6	Circulator	1	Pieces
7	Pumping port	4* or 18**	Pieces
8	Phase shifter	1	Pieces
9	Waveguides	58687	Length (mm)

* SF6 vs. ** Vacuum solution

P³ Experiment, S-Band RF Network

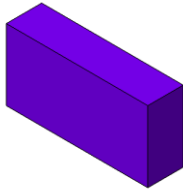




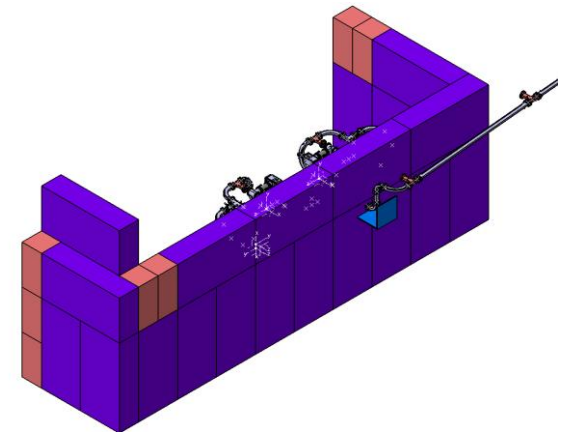
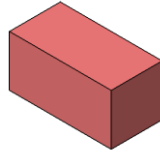
Chicane will be mounted at the end, really needed?

P³ Bunker

1 m x 0.5 m x 2 m

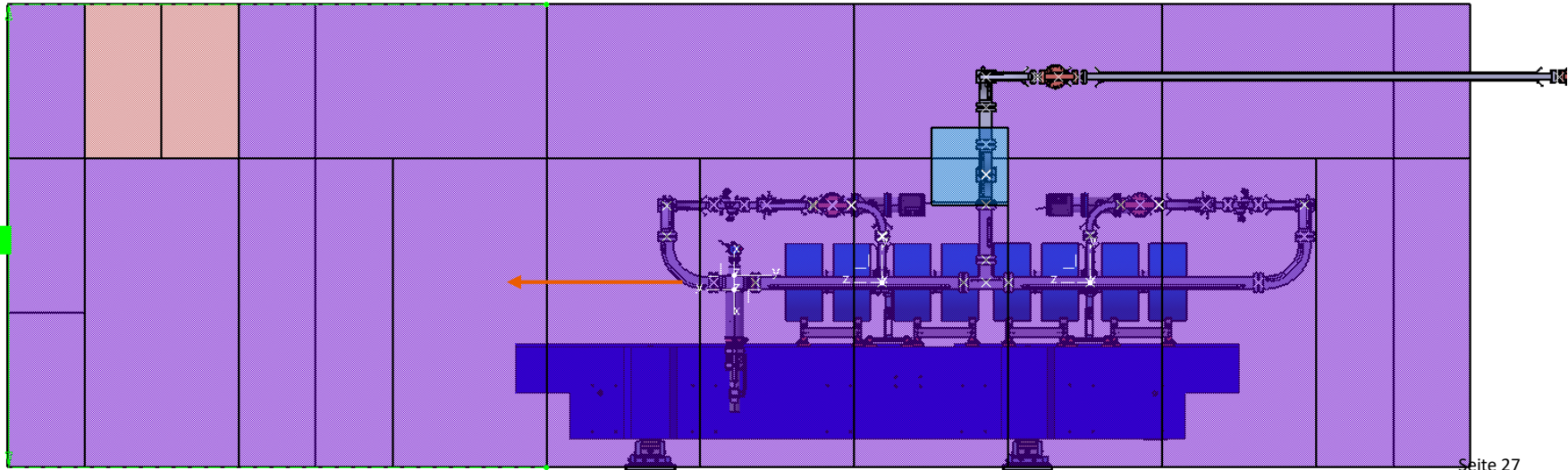


0.5 m x 0.5 m x 1 m



Tunnel height 3210 mm

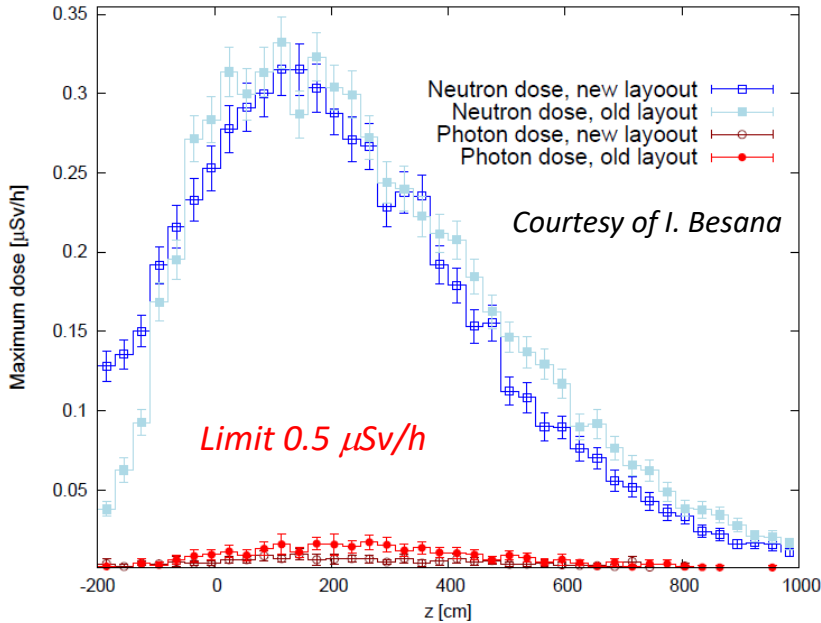
3000mm



Main critically: radiation above the roof → Average beam current limitation
Probably no need of chicane

Values for 0.2 pC/bunch 1 Hz, 1 bunch/pulse

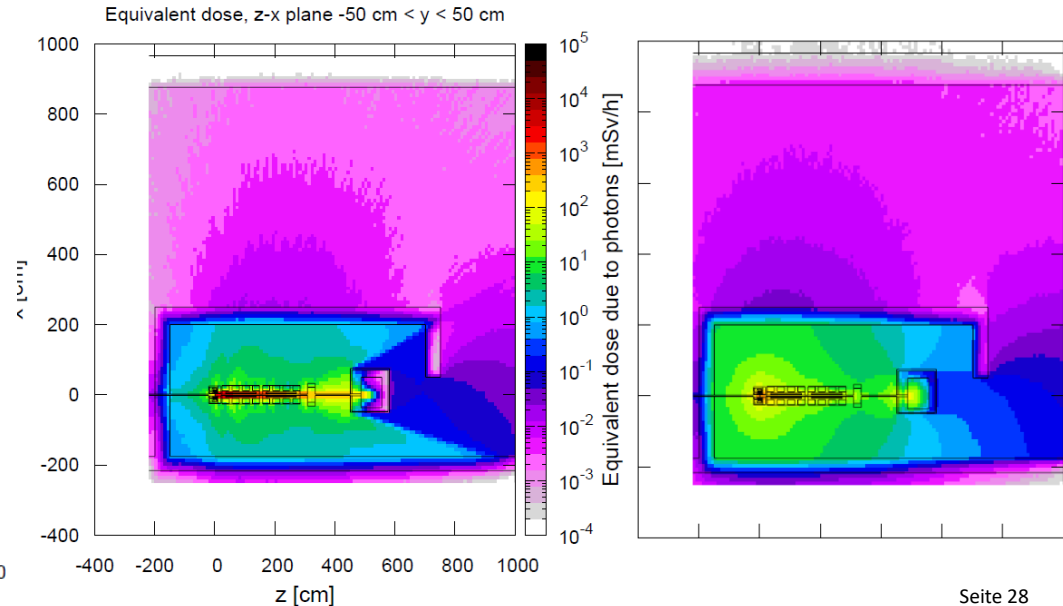
Above the roof (including 0.4 m soil)



Neutrons

Limit 1 mSv/h

Photons



Time Schedule



Special thanks to..

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



Swiss Accelerator
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