Multi-physics considerations of NI HTS Solenoid

for PSI Positron Production Experiment

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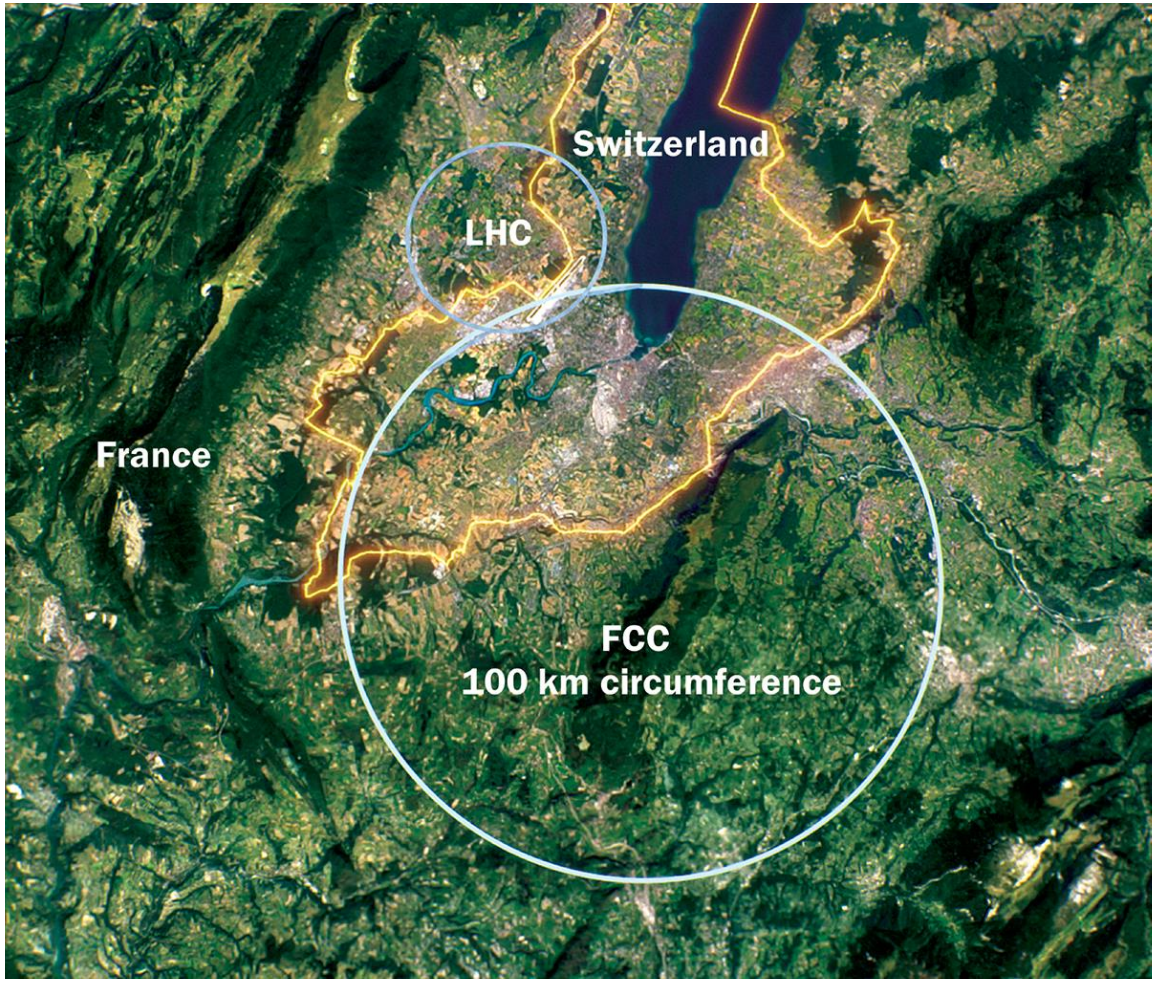
- PSI positron production experiment
- EM/thermal design
- Mechanical design
- Conclusion

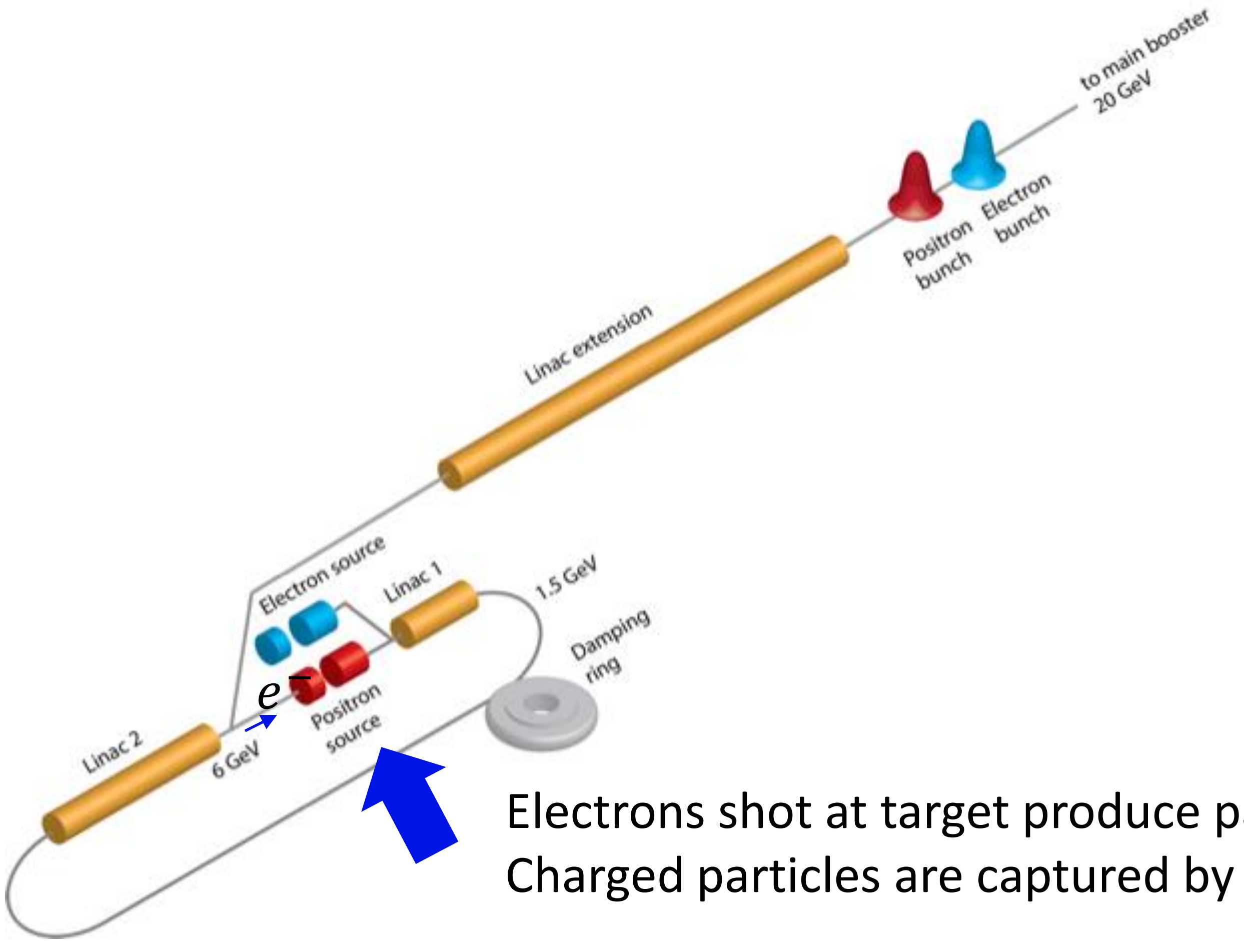
FCC-ee: electron-positron collider



"A 100 km tunnel hosting a ***circular electron–positron collider*** *as a first stage towards a 100 TeV proton–proton collider would* ***probe new phenomena coupled to the Higgs and electroweak sectors*** *with unparalleled precision."* [1]

[1] https://cerncourier.com/a/fcc-ee-beyond-a-higgs-factory/

FCC-ee injector



Electrons shot at target produce particles
Charged particles are captured by a magnet

"portions of the same linac are used for multiple purposes" [2]

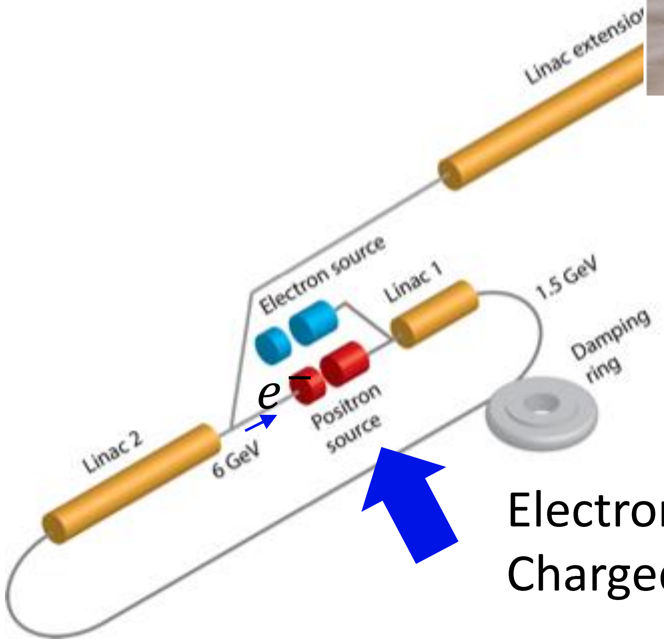
6 GeV e^- available as a precursor for e^+ beam

[2] P. Craievich, https://www.psi.ch/en/gfa/fcc-ee-injector-design-and-psi-positron-source-pss-project

FCC-ee injector

Flux Concentrator (FC)
Pulsed copper device

P. Martyshkin, BINP



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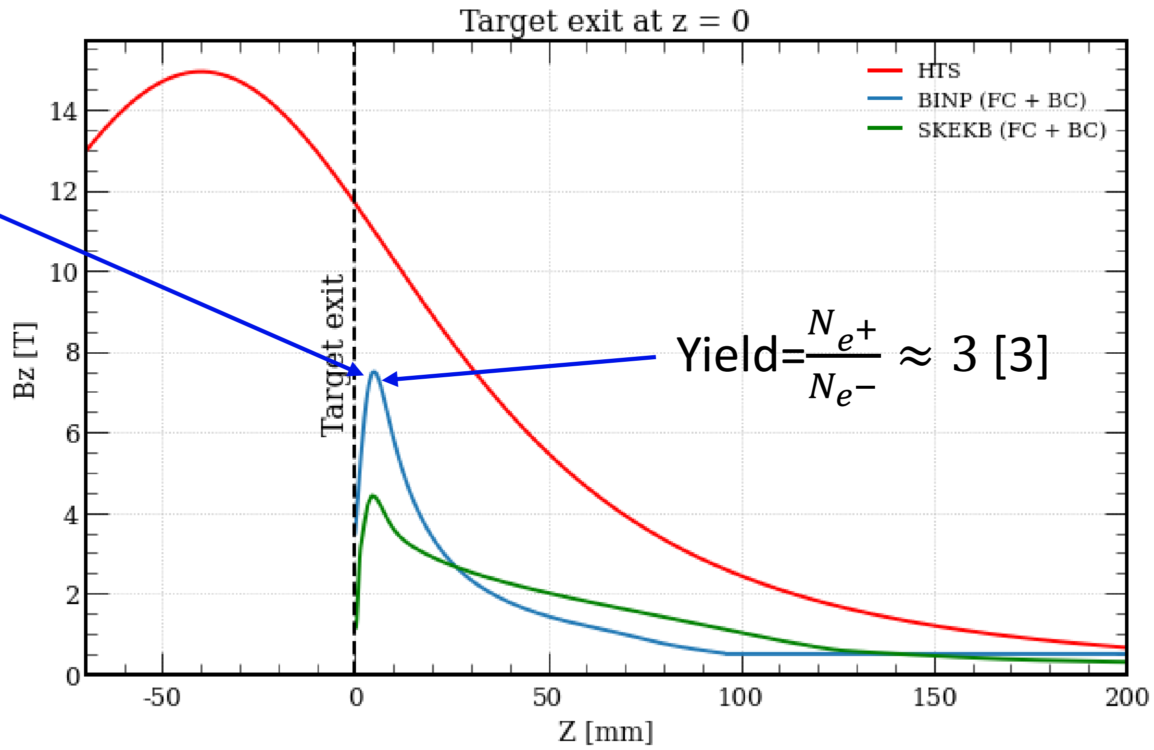
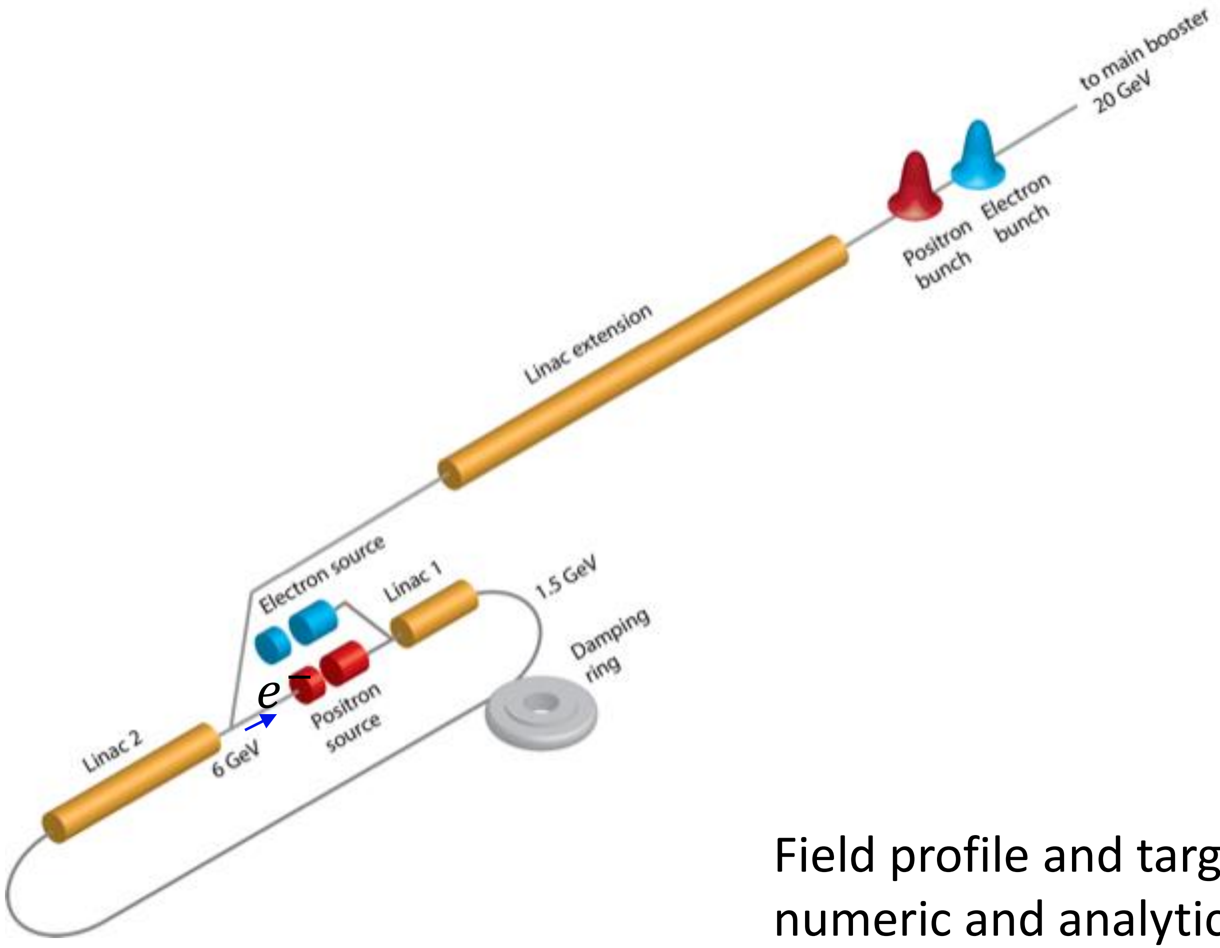


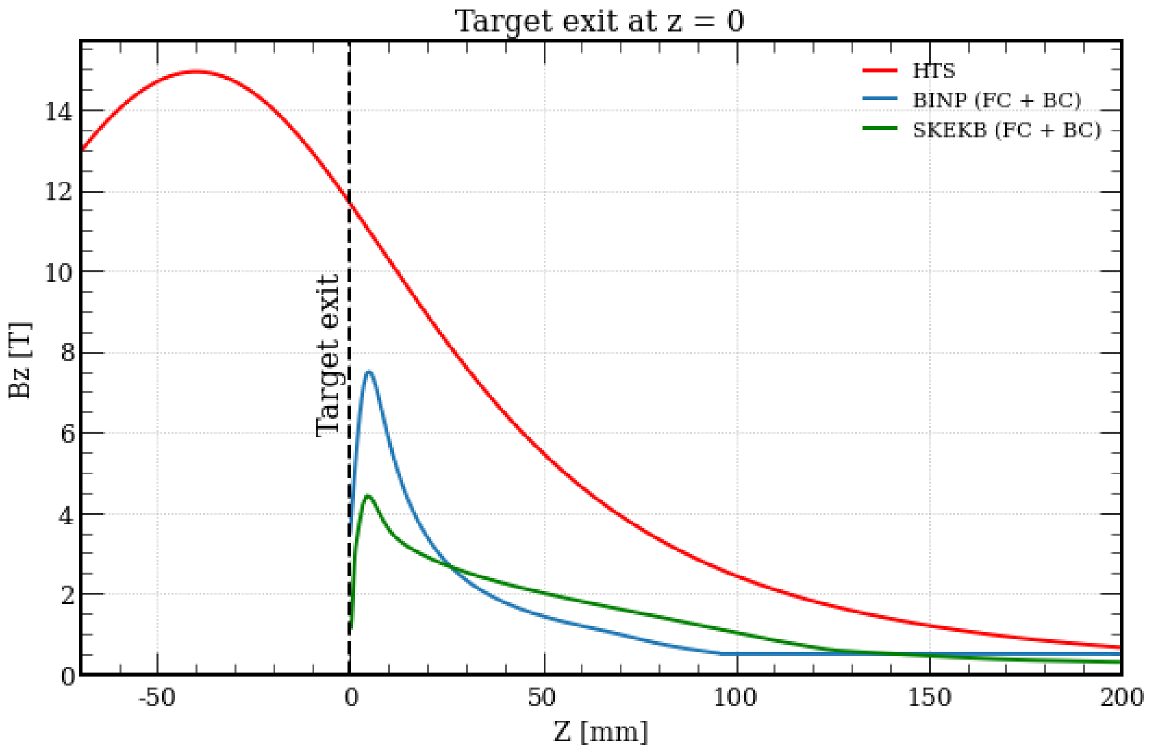
We want to do better by using HTS

Yield=$\frac{N_{e^+}}{N_{e^-}} = 7$ [3]

[3] N. Vallis https://doi.org/10.18429/JACoW-LINAC2022-TUPORI16

FCC-ee injector





Field profile and target location result from numeric and analytical optimization

- *Y Zhao. Optimisation of the FCC-ee Positron Source Using a HTS Solenoid Matching Device, 2022.*
- *Y Zhao. Comparison of Different Matching Device Field Profiles for the FCC-ee Positron Source, 2021.*
- *R. Chehab et al., "An adiabatic matching device for the Orsay linear positron accelerator", IEEE Trans. Nucl. Sci., 1983.*

PSI Positron Production (P^3) Experiment @ SwissFEL

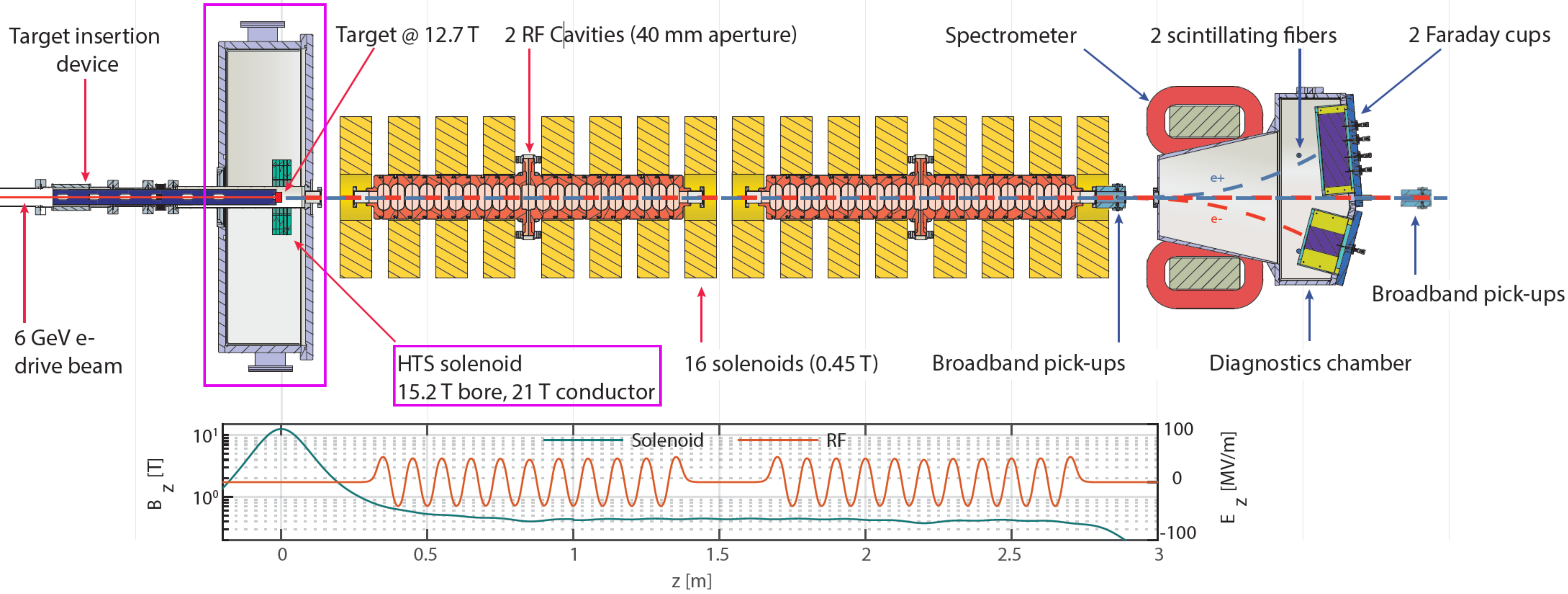
PSI

CHART
Swiss Accelerator Research and Technology

Aims to demonstrate high yield positron source in 2026

PSI Positron Production (P^3) Experiment

Aims to demonstrate high yield positron source



Magnet to be tested by end of 2024

P^3 experiment operational 2026

N. Vallis, https://doi.org/10.1103/PhysRevAccelBeams.27.013401

Solder-potted NI HTS: an attractive option

- DC application
- Loose magnetic field quality requirement
- No risk of insulation radiation damage
- Mechanically strong
- Good thermal conductivity
- Compact

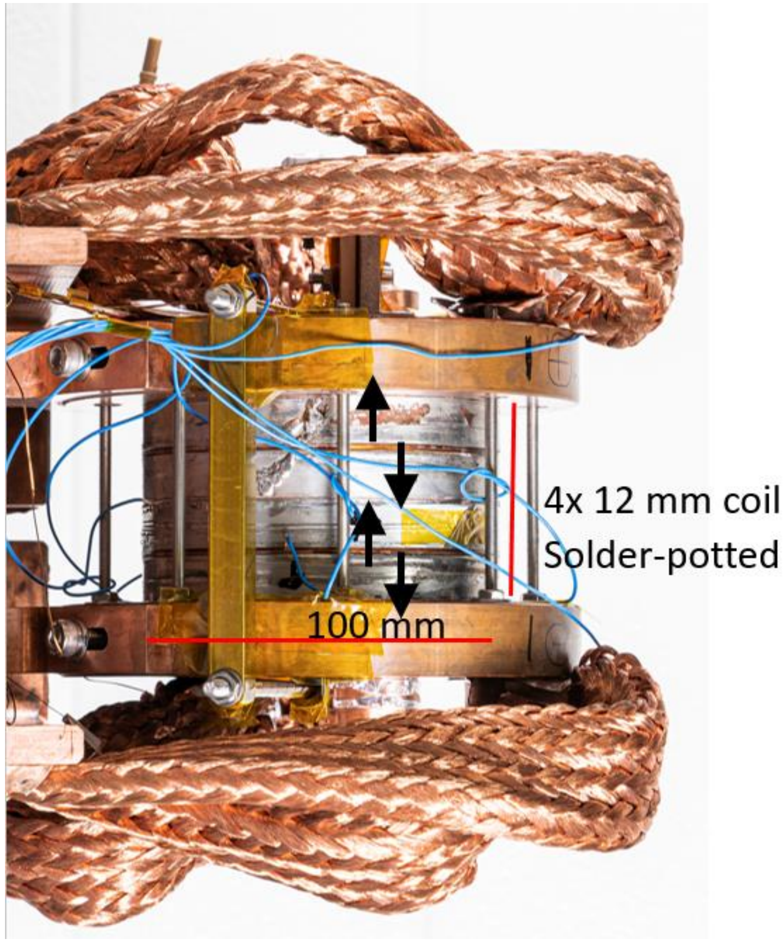
Upscaled version of 18 T PSI NI solenoid

18 T 50 mm cold bore → 15 T 72 mm warm bore

4 coils	5 coils
Built&tested	Under construction

Experimental results of 18 T stack used as P^3 simulation input

Current injection method
& parts of soldering technology via
licensing agreement with
Tokamak Energy



PSI 18 T solenoid

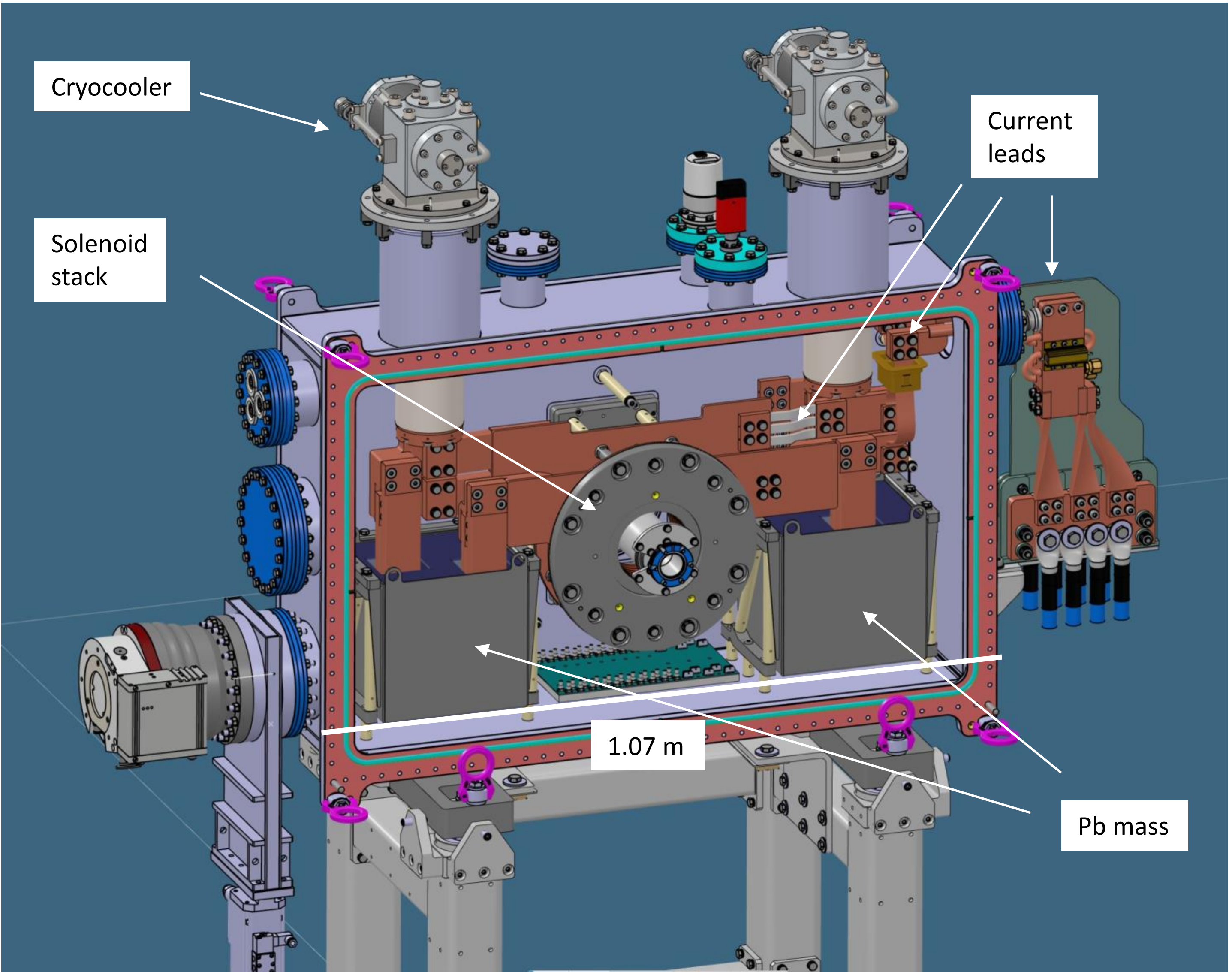
Radiation

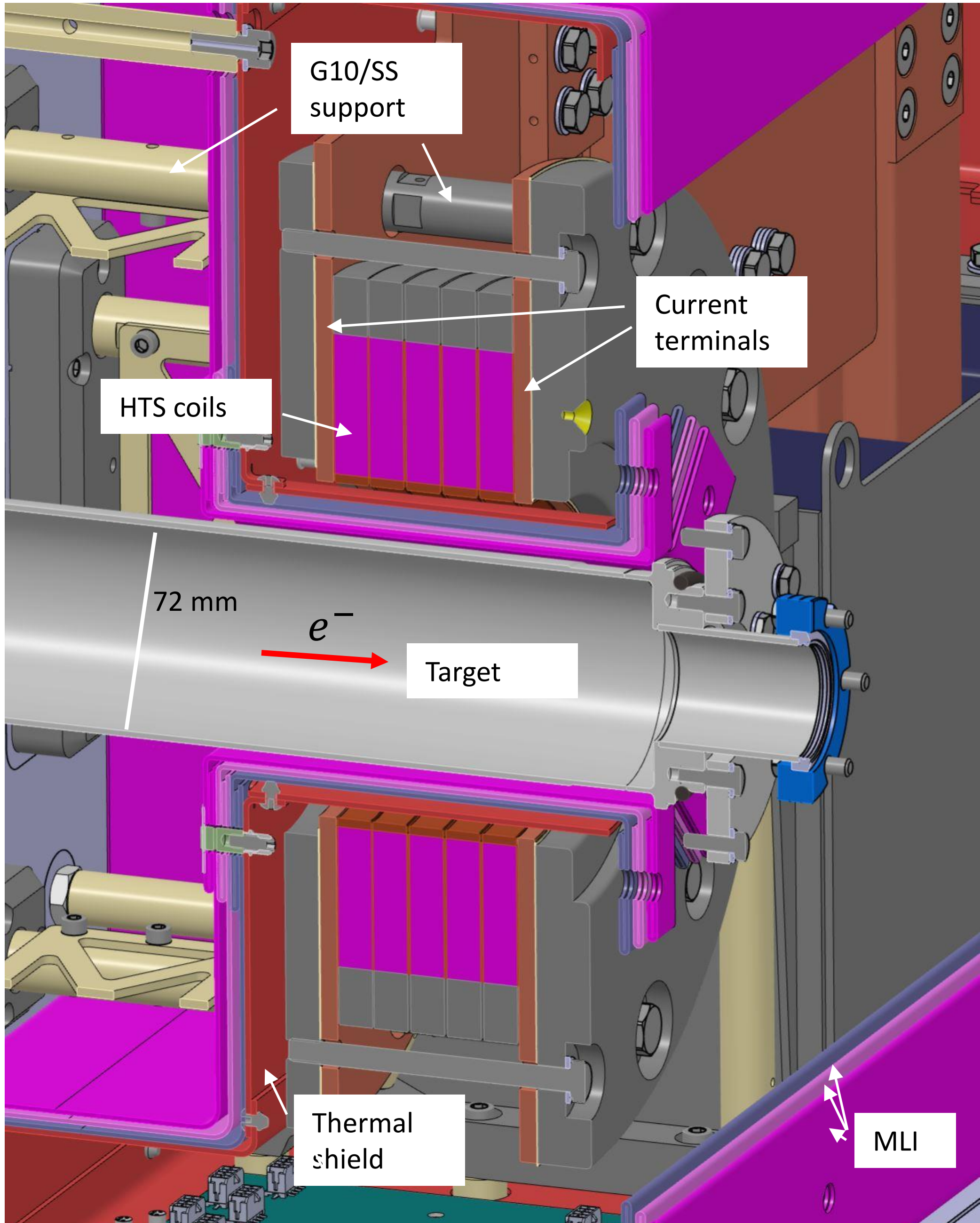
P^3 will demonstrate high yield,
but not radiation robustness

P3 (unshielded)	**FCC-ee (2 cm Tungsten)**
18 kGy/year	23 MGy/year
10^{-8} DPA/year	$2 \cdot 10^{-4}$ DPA/year

B. Humann, doi:10.18429/JACoW-IPAC2022-THPOTK048

Conduction-cooled system
15 T bore, 20 T conductor @ 1.2 kA, 15 K





Electromagnet/thermal simulation

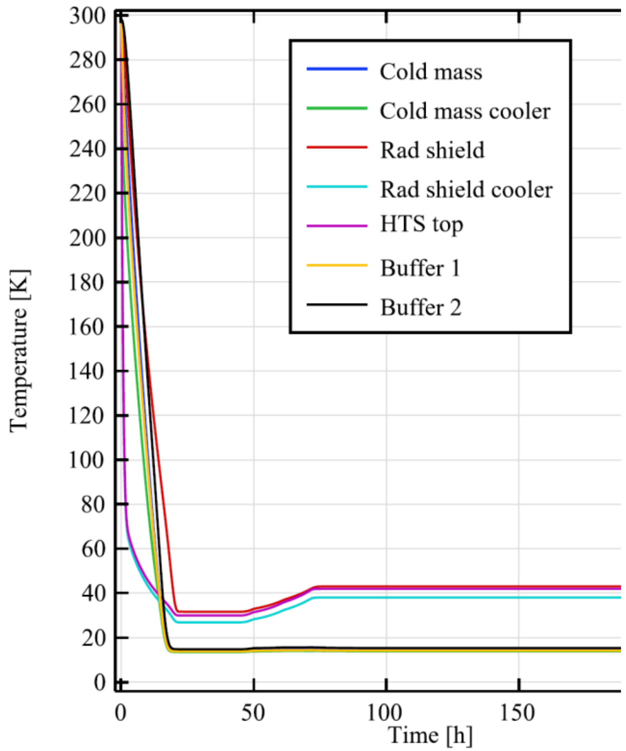
2D axisymmetric H-formulation,

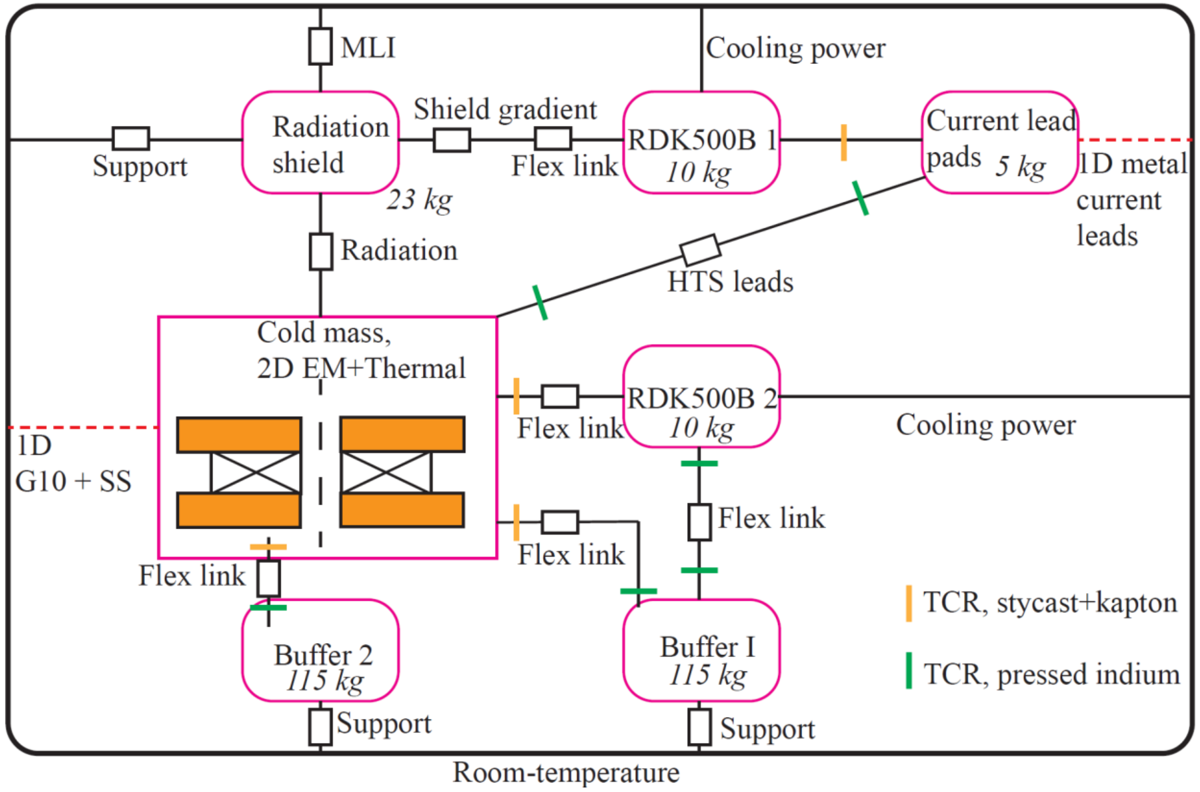
- homogenized winding pack,
- Anisotropic resistivity matrix with off-diagonal terms to account for the spiral nature of the coils [5]

+2D thermal

+ thermal network

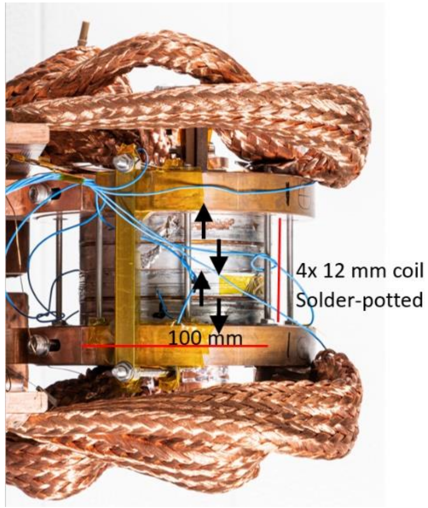
$$\boldsymbol{\rho}_{\text{coil}} = g\boldsymbol{\rho}' g^{-1} = \begin{bmatrix} \rho_{\text{rr}} & \rho_{\text{r}\phi} & 0 \\ \rho_{\phi r} & \rho_{\phi\phi} & 0 \\ 0 & 0 & \rho_{\text{z}} \end{bmatrix}_{\hat{r},\hat{\phi},\hat{z}}$$





[5] R Mateira, DOI 10.1088/1361-6668/ab9688

Experiment vs model

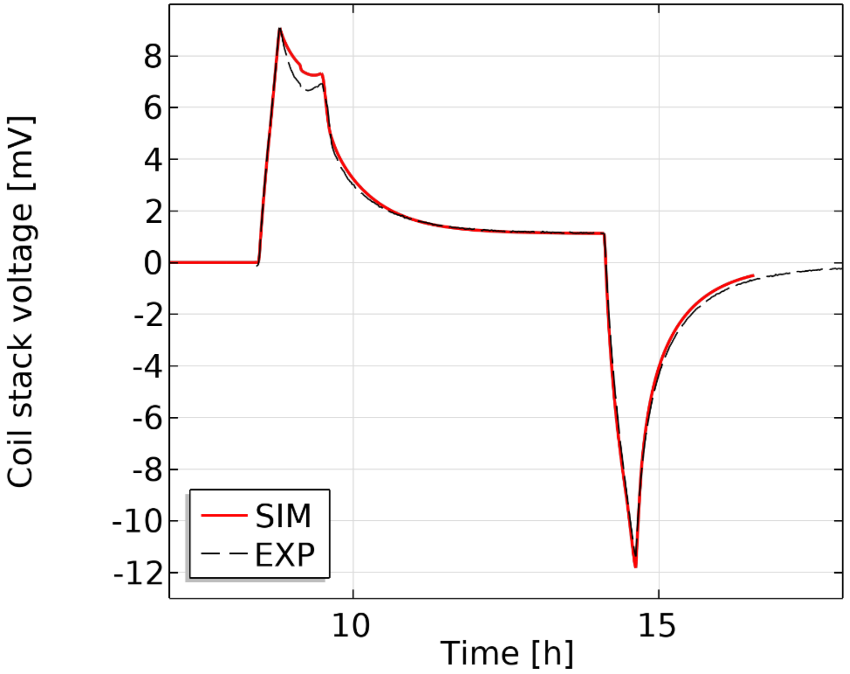


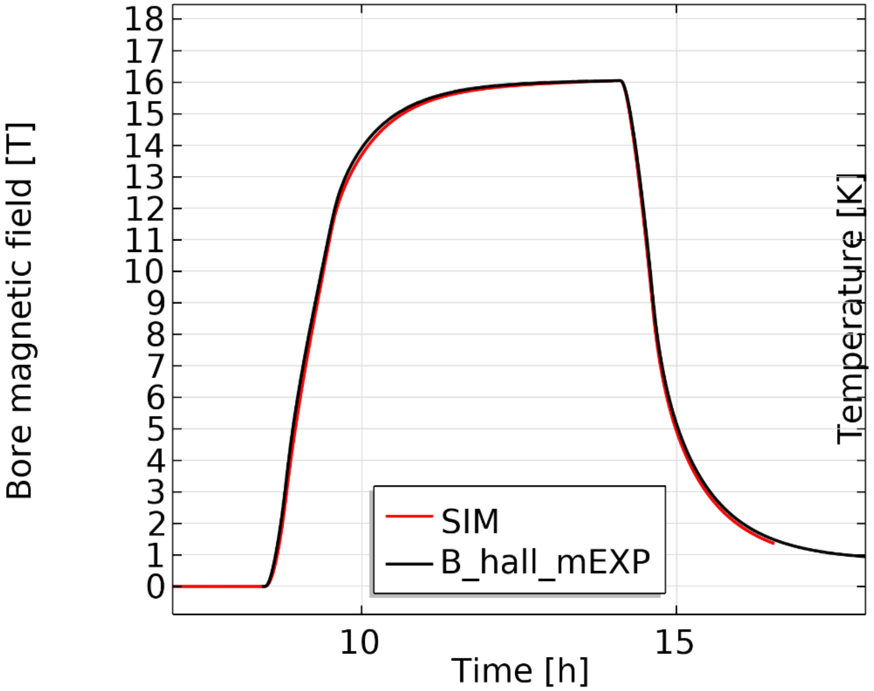
Turn-turn resistance used a fitting parameter

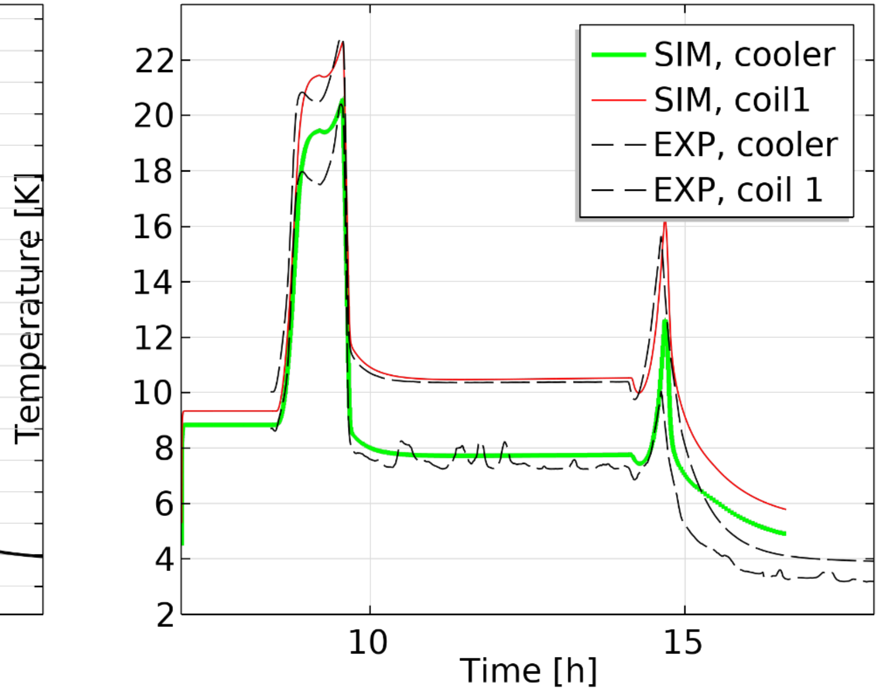
$\rho_{turnturn} \propto \rho_{copperRRR20}(B,T)$

Works reasonably over a 15-77 K range

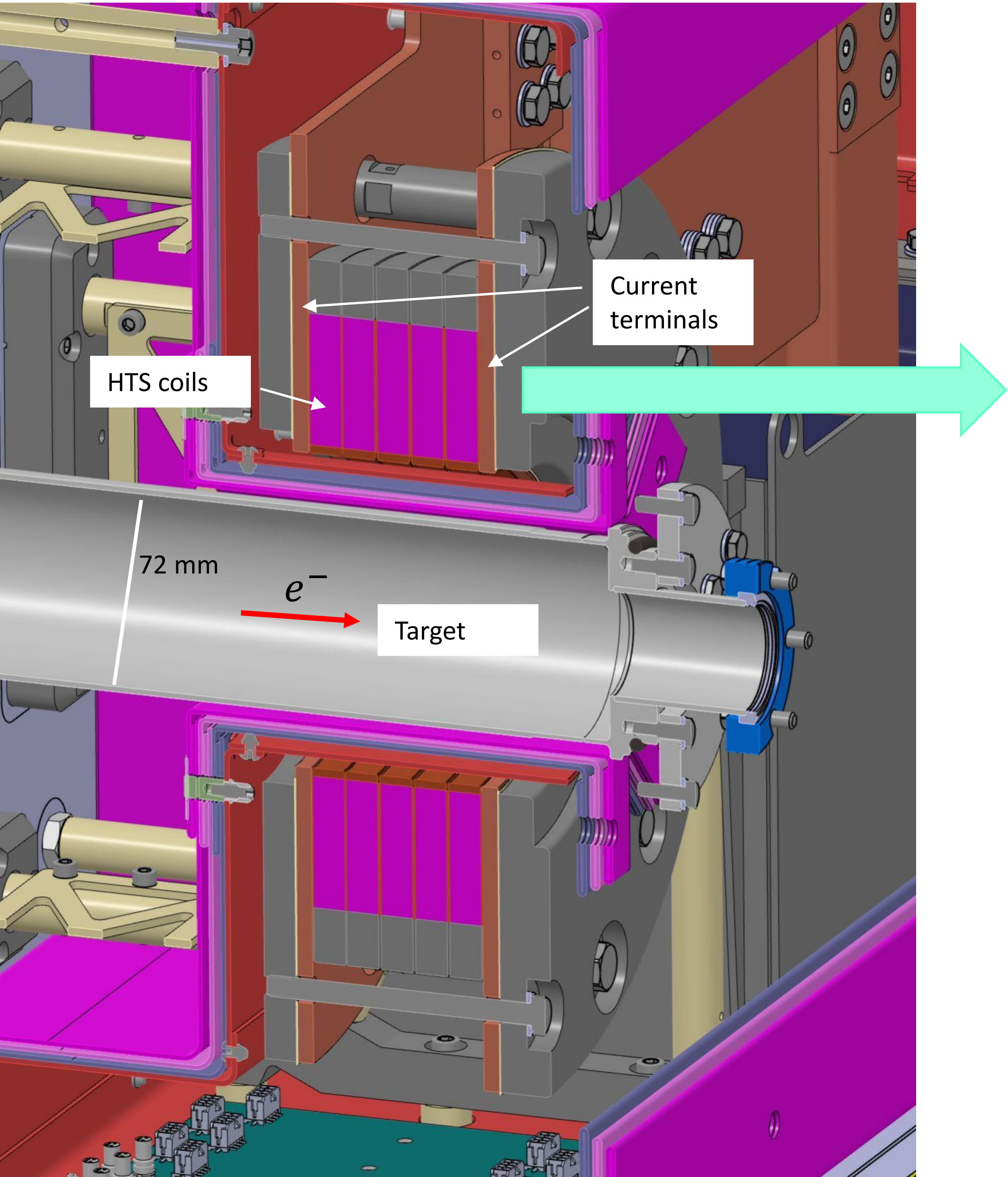
Example: 1.8 kA at 15 K in cryogen-free setup

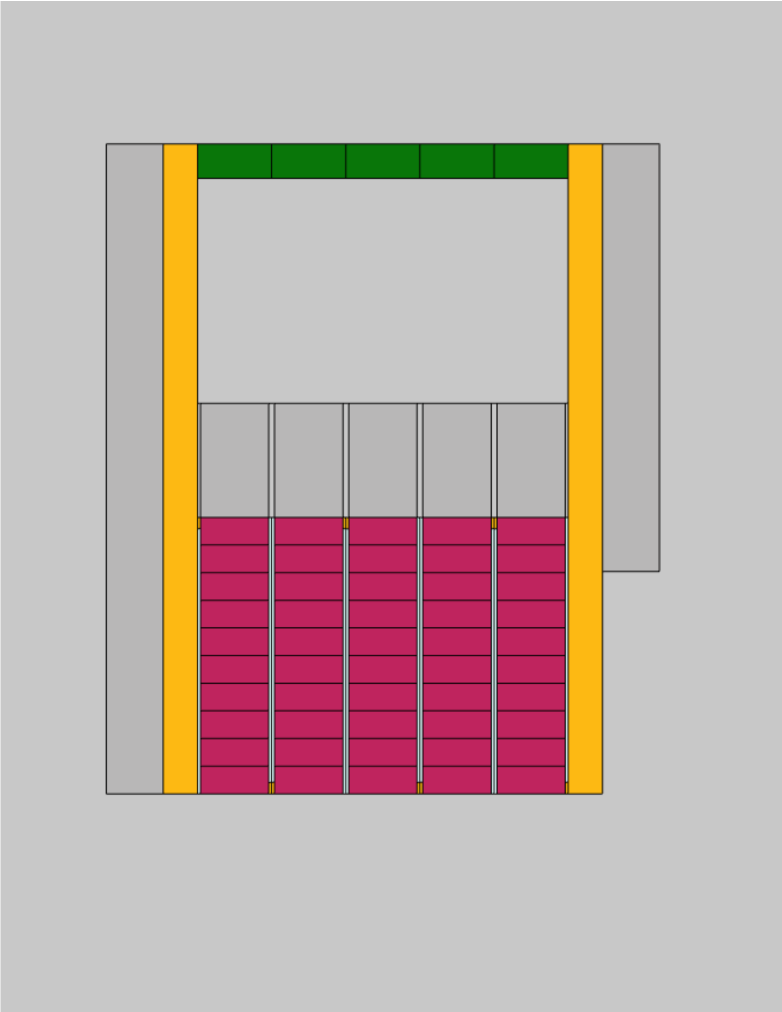




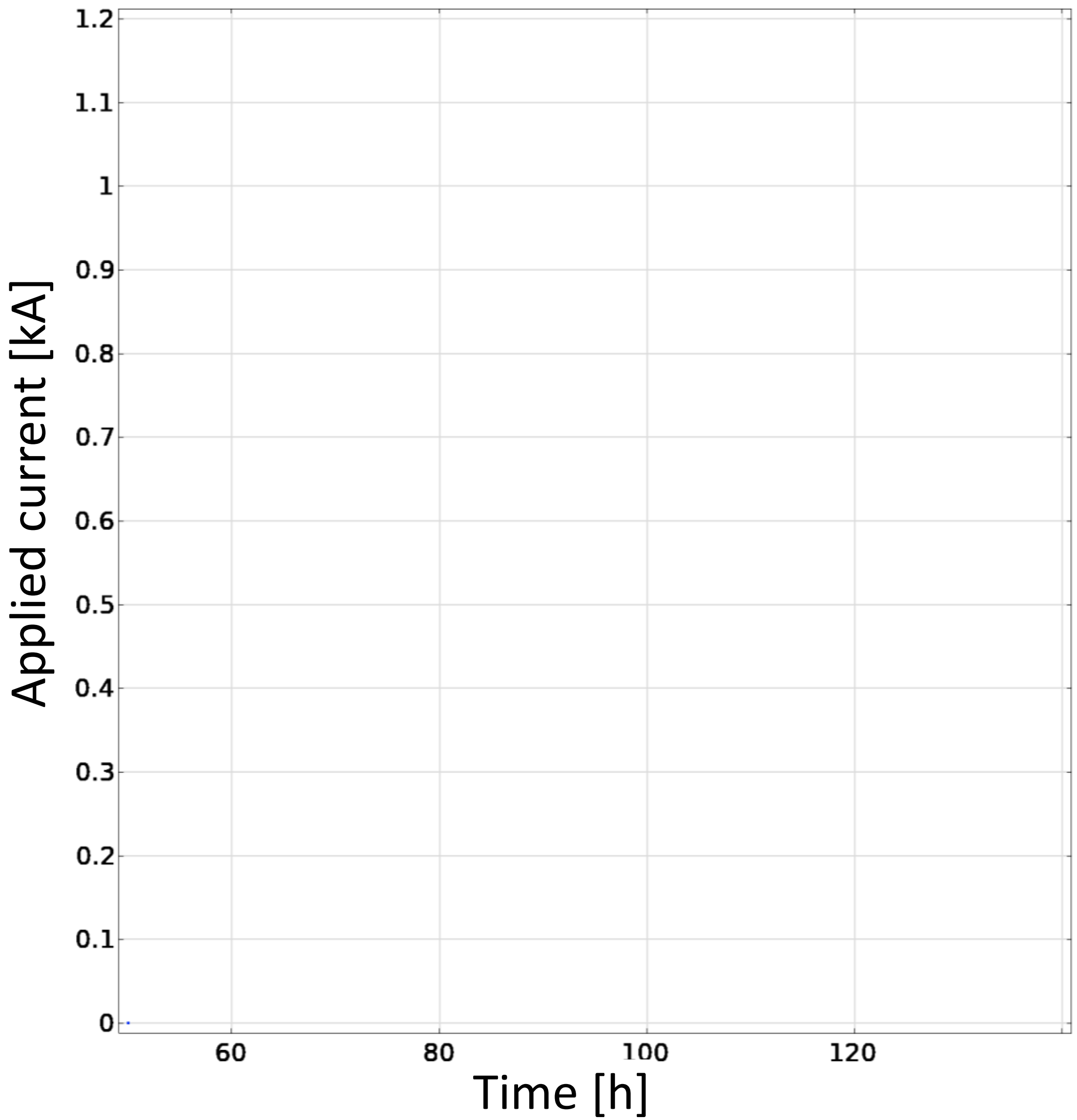


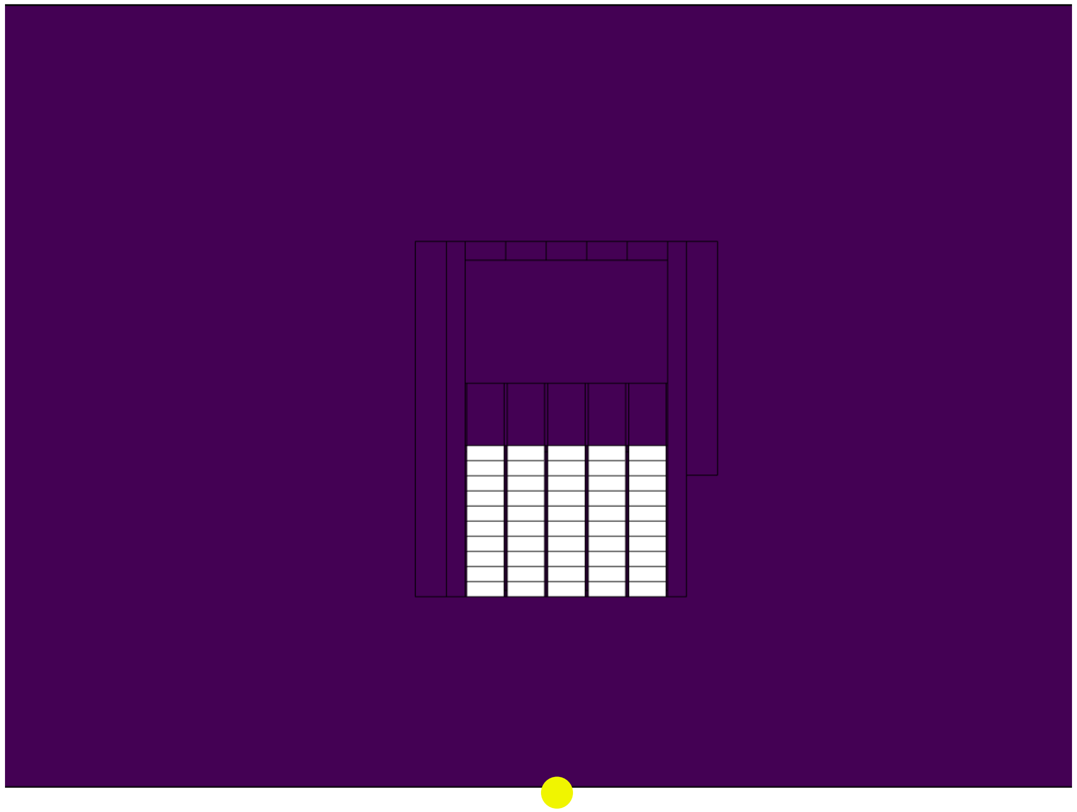
P3 simulation geometry



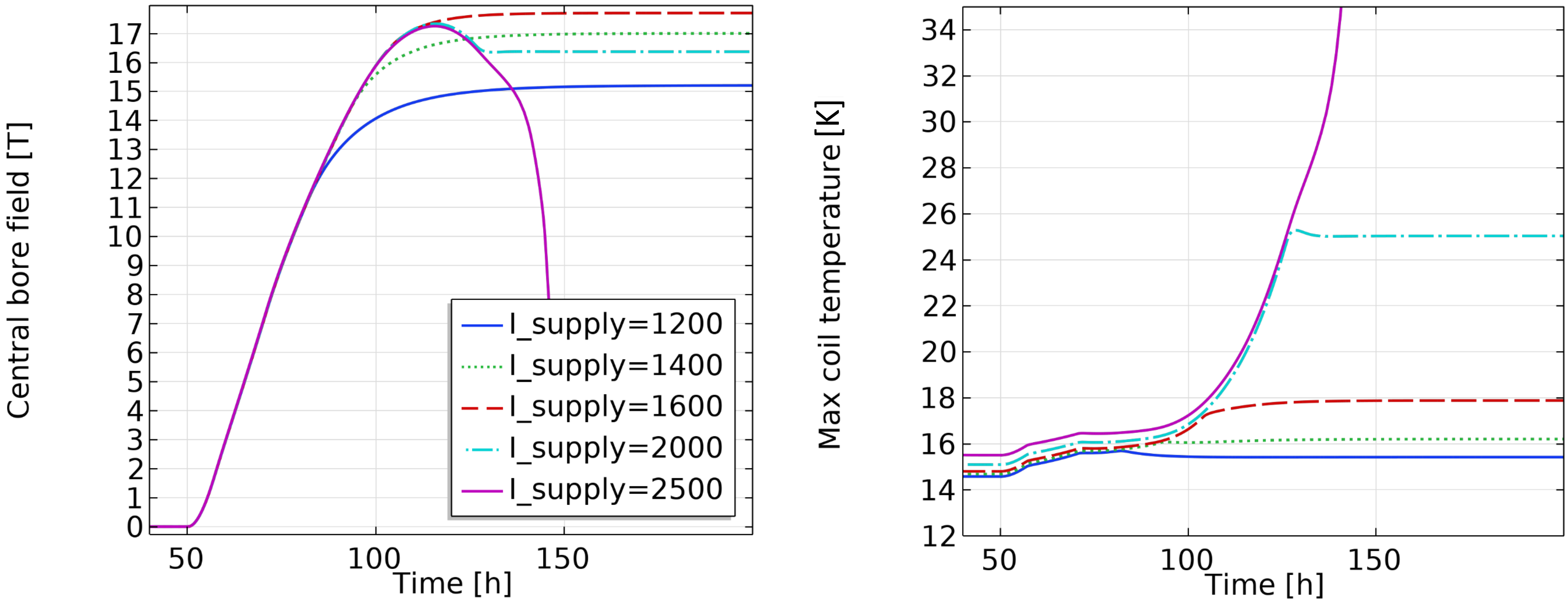


Magnet charging





Obtainable field strongly depends on thermal aspects



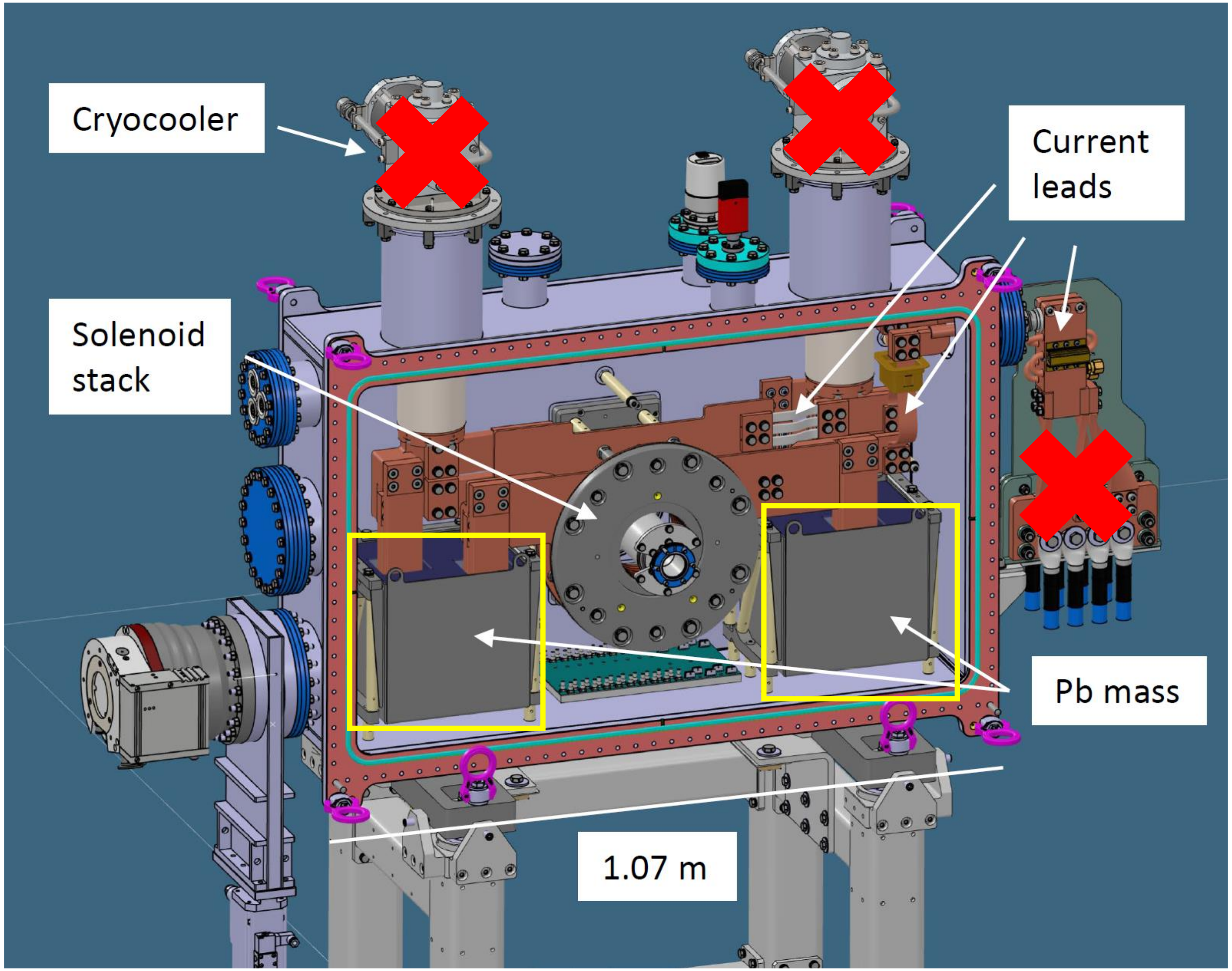
17 T reachable*, but magnet at risk of quenching during failure

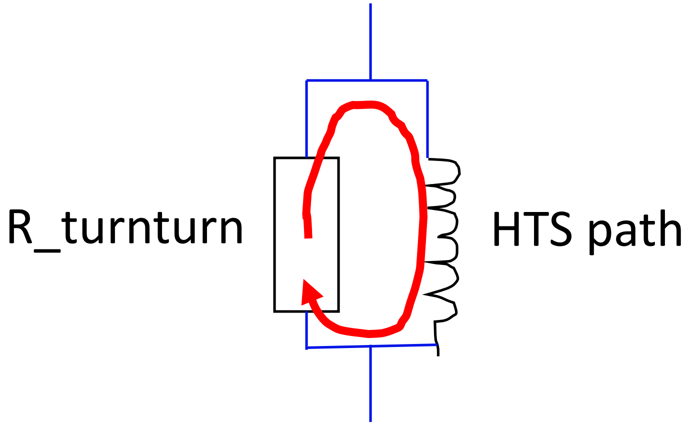
[5] R Mateira, DOI 10.1088/1361-6668/ab9688

*Not considering mechanical

Fault scenario:

Coolers stop

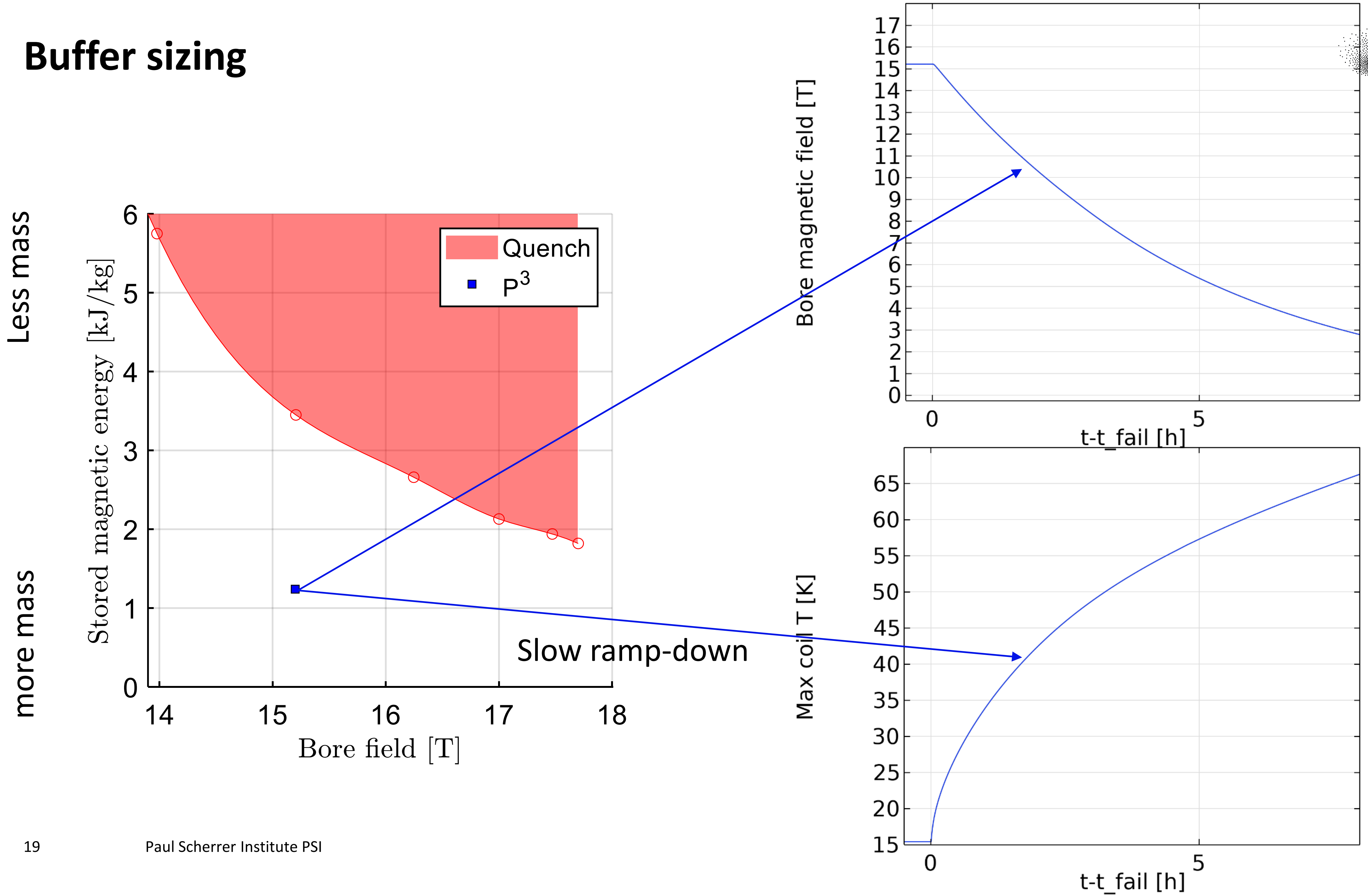




Open circuit

Stored energy gets dissipated in coils+buffers

Buffer sizing



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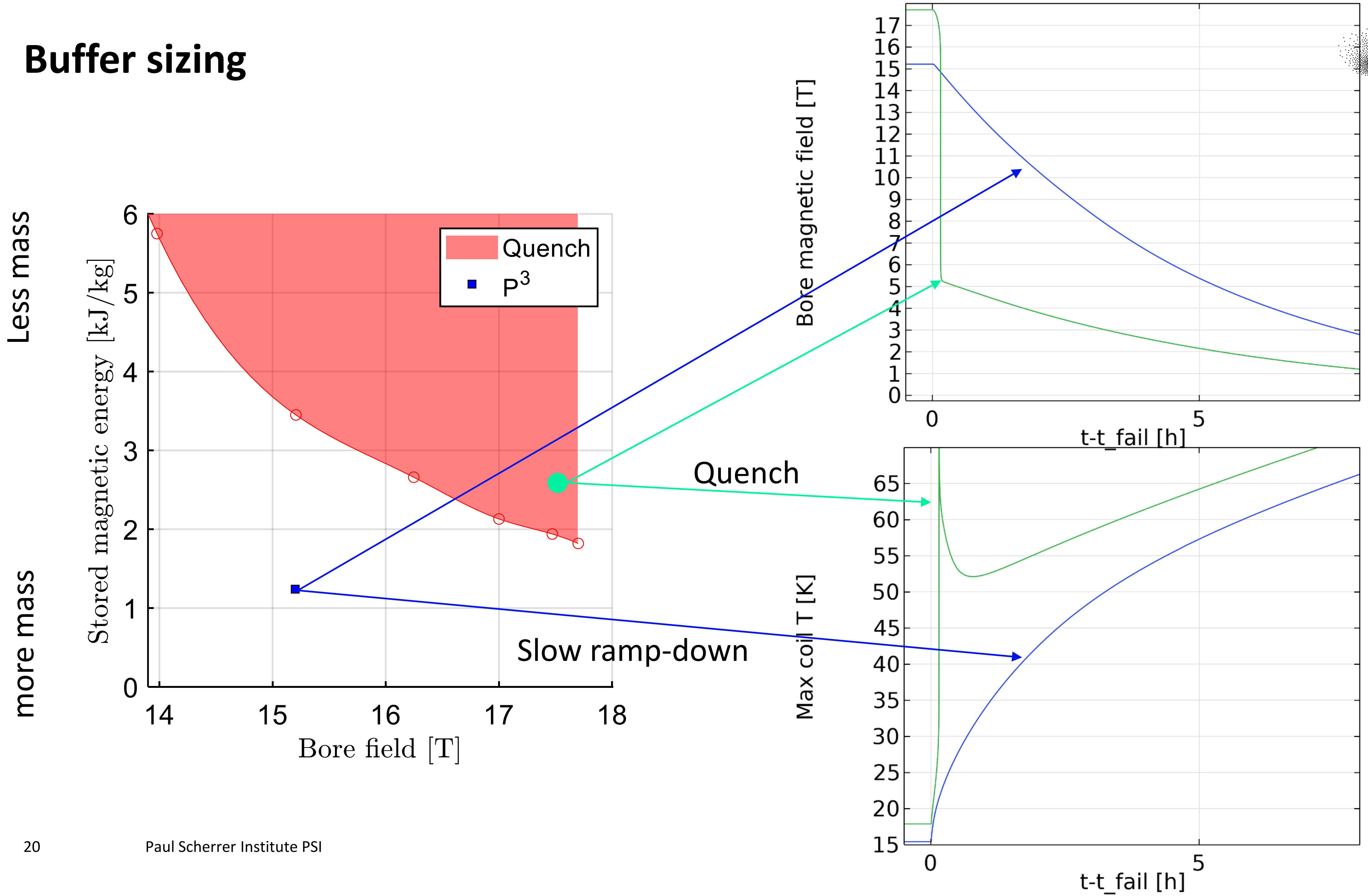
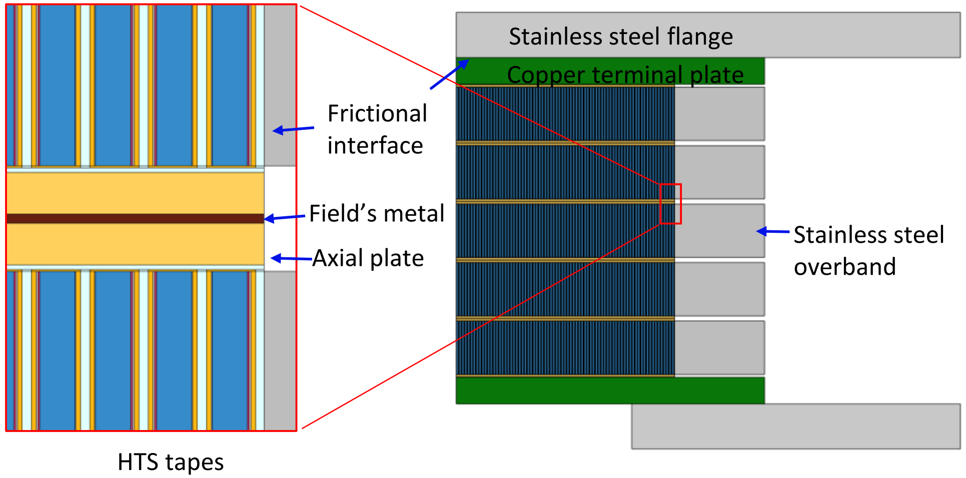
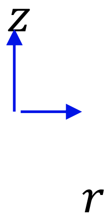
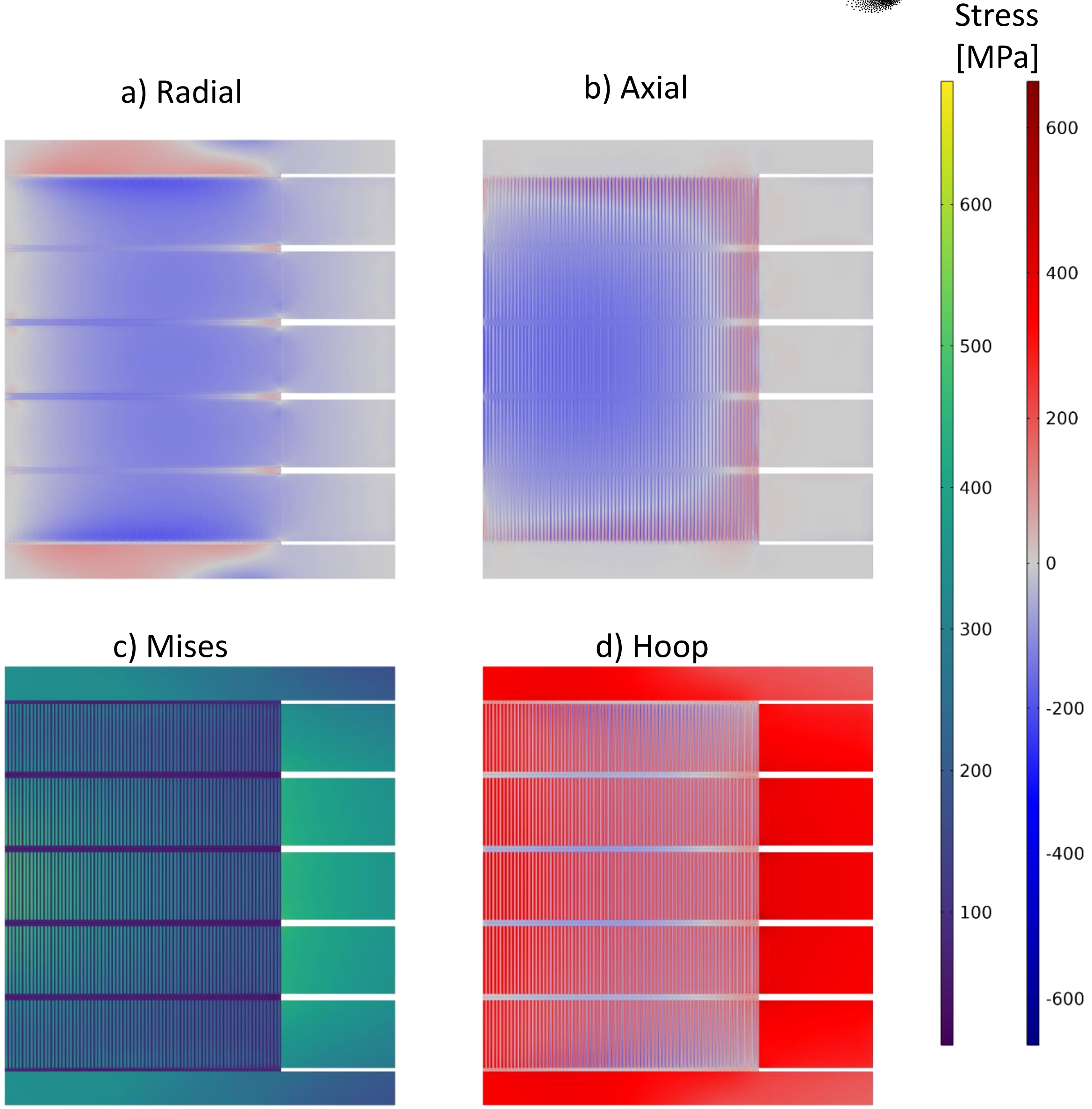


Mechanical







Tape structure explicitly modeled to capture
-differential thermal contraction
-plasticity

Max	radial stress	2	MPa
Min	axial stress	-150	MPa
Max	hoop stress (substrate)	373	MPa

Conclusions

- P^3 experiment aims to demonstrate high yield positron source

- Positron source ideal application for NI HTS

- P^3 experiment will feature a NI HTS solenoid, 15 T bore,
at 15 K, 1.2 kA, conduction-cooled in cryogen-free cryostat

- Extra thermal mass can help prevent quenches in case of external faults

- Magnet under construction, scheduled for test in 2024