FCC-hh injectors and collider beam transfer

scSPS and LHC as injectors incl their transfer lines and injection and beam dump system of the collider

W. Bartmann with valuable input from C. Bracco, E. Carlier, M. Giovannozzi, B. Goddard, G. Perez, F. Velotti, F. Zimmermann CERN

FCC Week, 5-9 June 2023, London

Midterm review deliverable 6.3

topics to cover

- injector possibilties
- transfer lines and their synergy to FCC-ee
- overlap of inj and extr in PB and related difficulties, also news from Sushi magnet test

Injectors

- scSPS at 1.3 TeV[1]
- LHC modified or superferric (4T) ring in LHC tunnel at 3.3 TeV[2]

[1] JAI project report
[2] FCC hadron injector options, FCC week 2018 Amsterdam

scSPS

L. Dyks, D. Posthuma de Boer, A. Ross, M. Backhouse,S. Alden, G. D' Alessandro,D. Harryman

Parameter	Unit	scSPS
Circumference	m	6900
Dipole Bending Radius	m	723
Injection Energy	GeV	25
Maximum Energy	GeV	1300
Minimum Dipole Field	T	0.12
Maximum Dipole Field	T	6
Number of Dipoles		372
Number of Quadrupoles		216
Ramp Rate	T/s	0.35 - 0.5
Number of Bunches per Fill		640
Number of Protons per Bunch		$\leq 2.5 \times 10^{11}$
Dipole Length	m	12.12
Half Cell Length	m	32
Dipoles per Cell		4
Quadrupole Gradient	T/m	146.25
Maximum Beta Function	m	107
Maximum Dispersion	m	4.3
Normalised Emittance $\epsilon_{x,y}$	μm	2.2
$\delta p/p$		5×10^{-4}

Table 2: The baseline parameters for the scSPS as detailed in [2].

Main design points

L. Dyks, D. Posthuma de Boer, A. Ross, M. Backhouse,S. Alden, G. D' Alessandro,D. Harryman

- Lattice has to follow tunnel shape and is kept simple as for the present SPS with missing bend DS
- Layout to include collimation system
- Beam transfer dominated by MP $\rightarrow$ 640 b per inj
- Filling time to be revised in view of reduced number of bunches and possibly higher ramp rate
- Slow extraction for FT program could be considered with crystal extraction only $\rightarrow$ reduction of required aperture
    - now having a spiral step of 20 m which could be reduced to a few mm
- Magnet design crucial

Magnet design

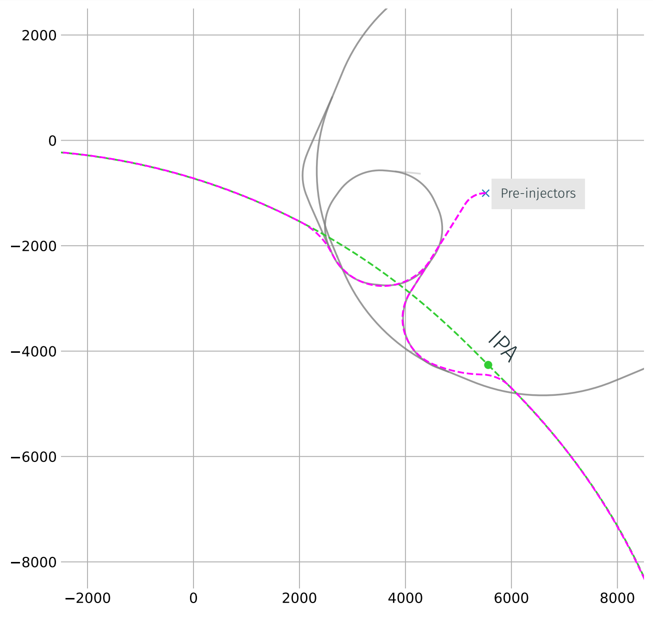
L. Dyks, D. Posthuma de Boer, A. Ross, M. Backhouse,S. Alden, G. D' Alessandro,D. Harryman

- 2D designs for main dipoles and quadrupoles, single and double layer
  - 4.2 K compatible for 2 layer designs (needs optimisation of grading for quads)
  - Enlarged quadrupoles for LSS to be added in design
- Energy swing, field at injection, AC losses would strongly benefit from doubling the injection energy to 50 GeV
- scPS or PS2 to replace >100 year old PS? also get rid of transition crossing
- need to look at full hadron injector chain considering the future needs for FCC and other experimental programs at CERN

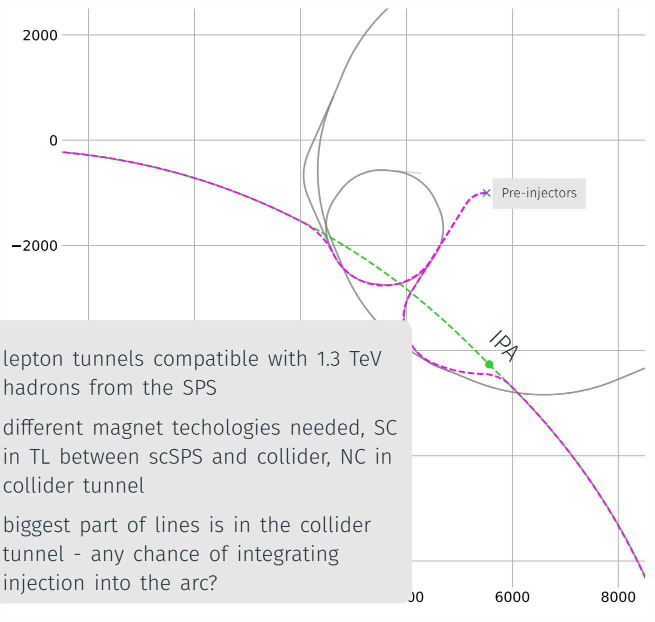
Transfer lines

- cell and basic parameters as shown in previous talk
- result of synergy with lepton lines
- summary for hadron lines
- integration of lines inside the collider tunnel

FCC lines for 1.3 TeV hadrons from scSPS

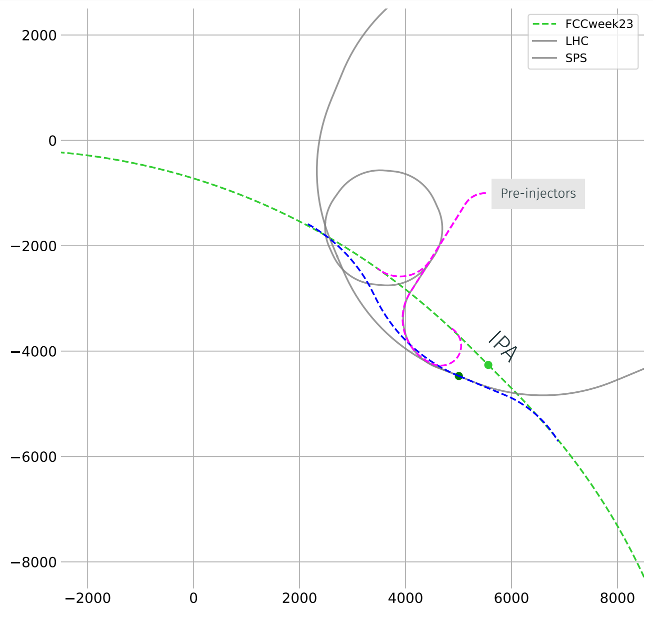


FCC lines for 1.3 TeV hadrons from scSPS

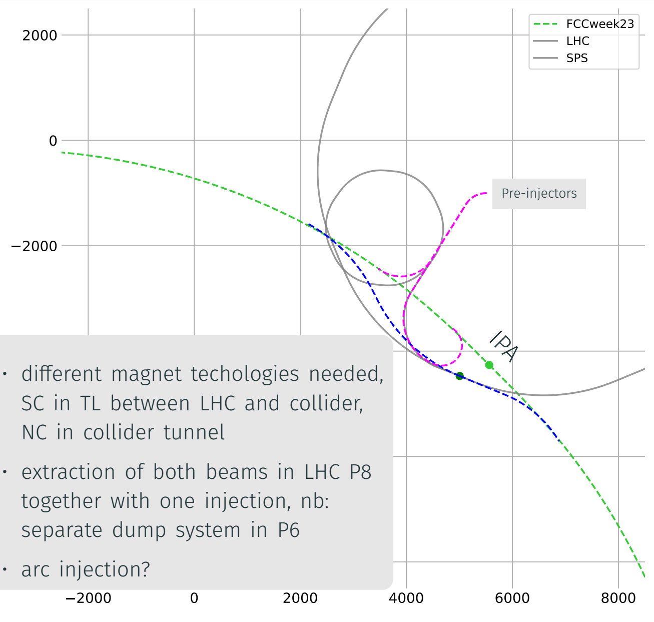


- lepton tunnels compatible with 1.3 TeV hadrons from the SPS
- different magnet techologies needed, SC in TL between scSPS and collider, NC in collider tunnel
- biggest part of lines is in the collider tunnel - any chance of integrating injection into the arc?

FCC lines for 3.3 TeV hadrons from LHC



FCC lines for 3.3 TeV hadrons from LHC



- different magnet techologies needed, SC in TL between LHC and collider, NC in collider tunnel
- extraction of both beams in LHC P8 together with one injection, nb: separate dump system in P6
- arc injection?

Summary table for hadron lines

1.3 TeV (SPS)	TL length [km]	tunnel [km]	dipole fields [T]	Comments
PB	12.9	1.8	4.2/0.5	from SPS-LSS4 via TI8 to PB
PL	6.9	0.9	7.4/0.5	from SPS-LSS6 to PL

Summary table for hadron lines

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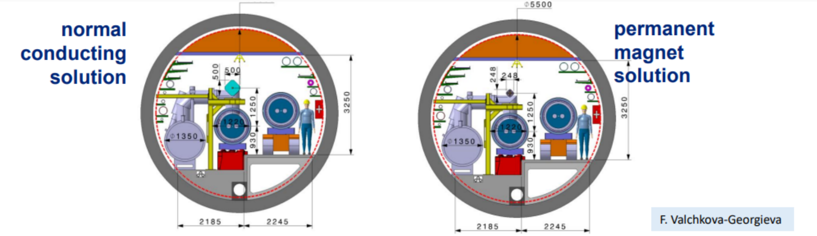
3.3 TeV (LHC)	TL length [km]	tunnel [km]	dipole fields [T]	Comments
PB	8.6	1.6	8/1.1	from LHC-P8 to PB
PL	9.8	3.8	6/1.1	from LHC-P8 to PL

Transfer line integration

Integration needs to take into account margin for avoiding cross-talk

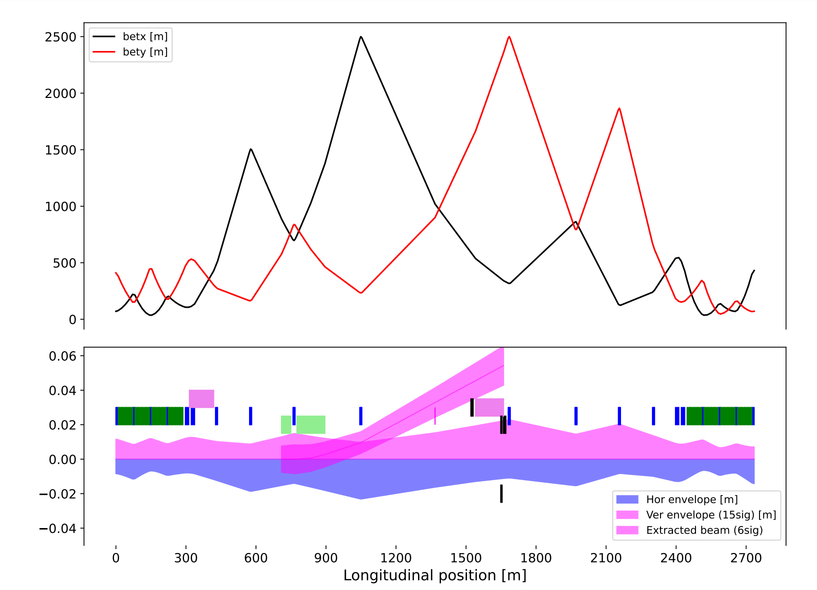


Injection and dump in PB

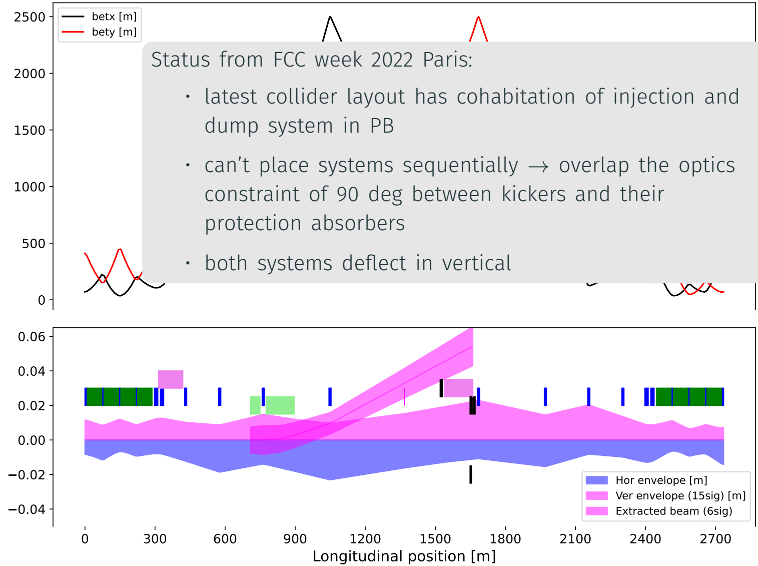
- general specs of dump system unchanged wrt CDR, ie externally triggered, extract full beam at once, dilute and absorb on external dump, use several abort gaps
- main characteristics are reliability and availability
- overall concept and HW design driven by machine protection and 'satellite' approach, high segmentation, simple units, hot spares, remote control/exchange[3]

[3] E.Renner et al. FCC week 2018, Amsterdam

Injection and dump in PB



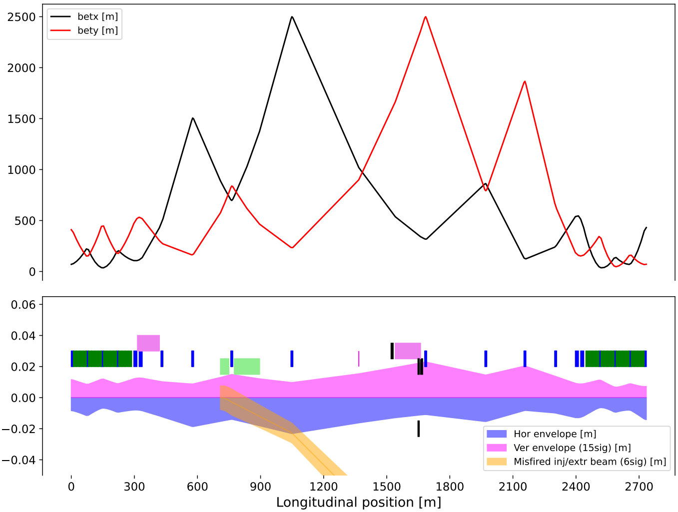
Injection and dump in PB



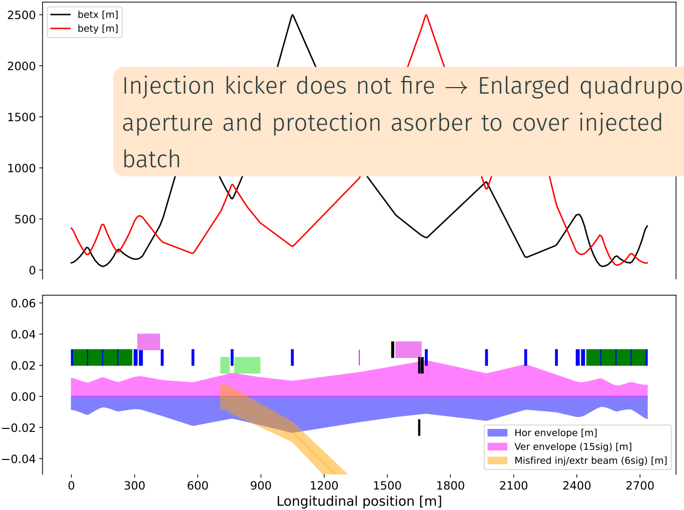
Status from FCC week 2022 Paris:

- latest collider layout has cohabitation of injection and dump system in PB
- can't place systems sequentially → overlap the optics constraint of 90 deg between kickers and their protection absorbers
- both systems deflect in vertical

Injection and dump in PB - failure scenarios

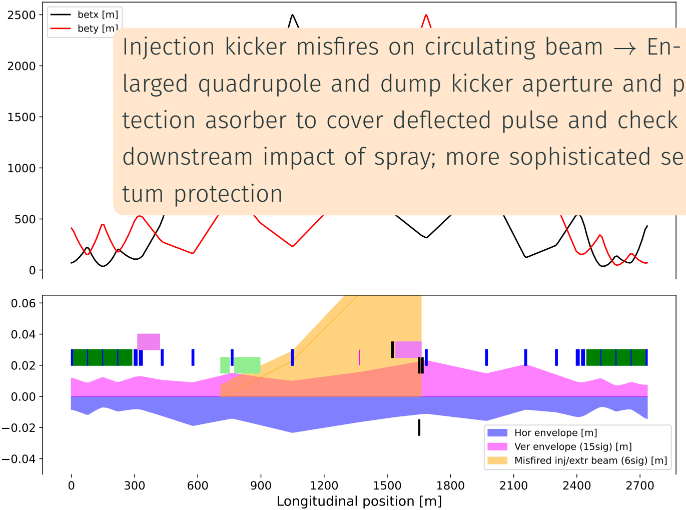


Injection and dump in PB - failure scenarios



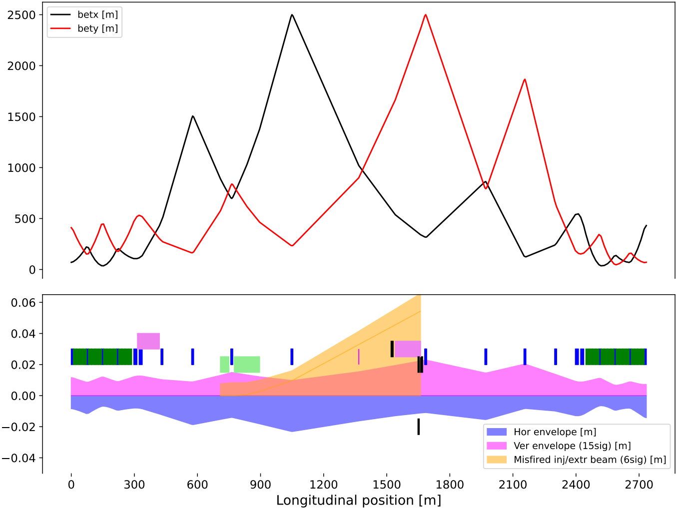
Injection kicker does not fire → Enlarged quadrupole aperture and protection asorber to cover injected batch

Injection and dump in PB - failure scenarios

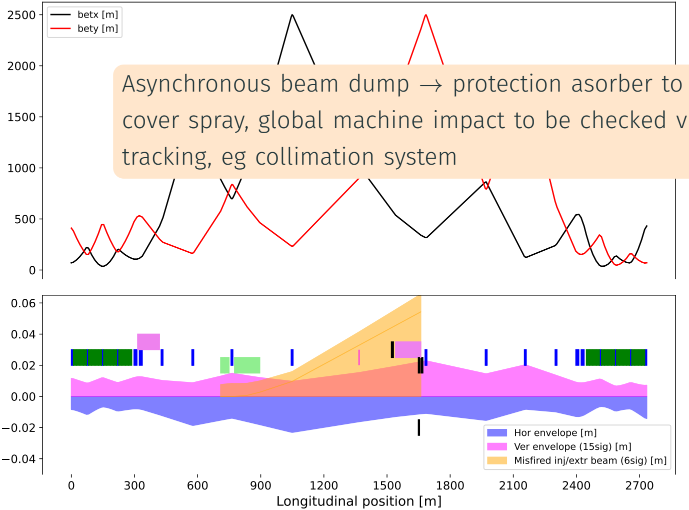


Injection kicker misfires on circulating beam → Enlarged quadrupole and dump kicker aperture and protection asorber to cover deflected pulse and check for downstream impact of spray; more sophisticated septum protection

Injection and dump in PB - failure scenarios

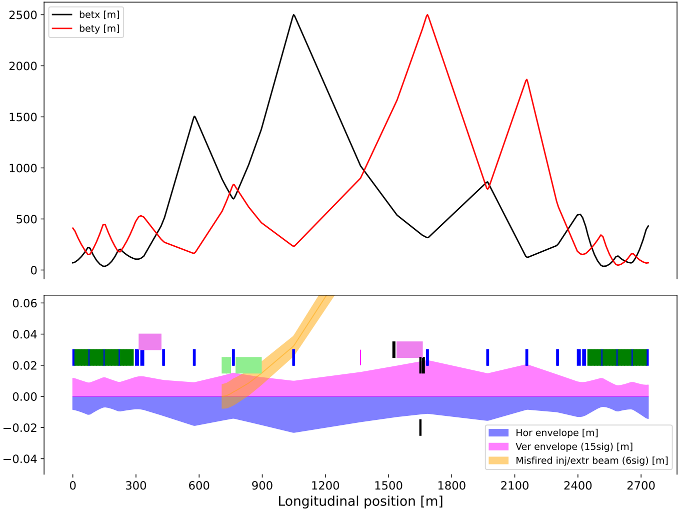


Injection and dump in PB - failure scenarios

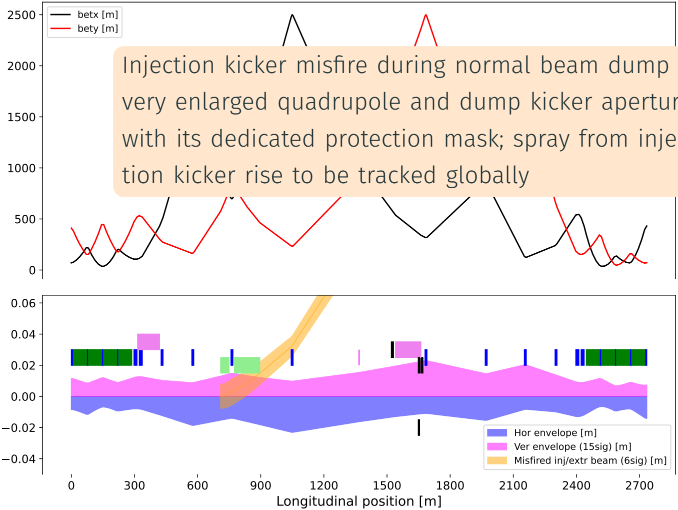


Asynchronous beam dump → protection asorber to cover spray, global machine impact to be checked via tracking, eg collimation system

Injection and dump in PB - failure scenarios



Injection and dump in PB - failure scenarios



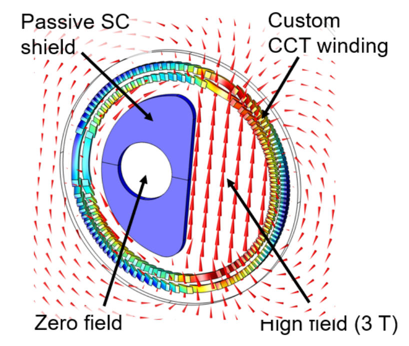
Injection kicker misfire during normal beam dump → very enlarged quadrupole and dump kicker aperture with its dedicated protection mask; spray from injection kicker rise to be tracked globally

Failure scenarios summary

- for sake of simplicity only one side of the dump system is shown - symmetric arrangement around LSS centre $\rightarrow$ needs careful look into integration of injection vs dump lines
- Certain failure scenarios independent of overlap in PB, eg asynchronous dump
- Most of the scenarios impact common (quadrupole) and other system equipment (aborbers)
- so far refrain from linking the injection and dump system which would allow to actively suppresse some of the failure scenarios since this would almost certainly compromise the reliability of dump system
- I recommend to have another look on the layout if the dump and injection system can be separated

Superconducting Shield (SUSHI) dump septum[4]

D. Barna, M. Atanasov, J. Borburgh, K. Brunner, F. Lackner, T. Bagni, K. Sugita

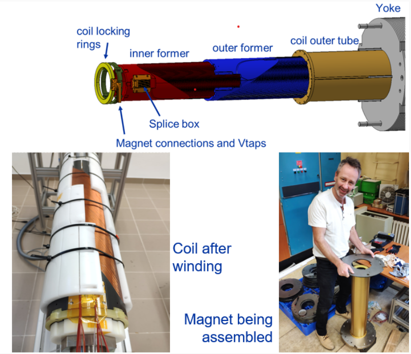


- Very simple (canted cosine theta) winding topology
- Bulk SC septum wall, small thickness
- Perfectly zero field for circulating beam

[4] DOI:10.1109/TASC.2022.3149726

Sushi prototyping progress

D. Barna, M. Atanasov, J. Borburgh, K. Brunner, F. Lackner, T. Bagni, K. Sugita



- Modified CCT dipole magnet design, eg wax impregnation
- A half moon shaped bulk MgB2 sc shield manufactured in industry
- CCT magnet without shield was tested successfully up to nominal current without quenching
- Next: Install shield and perform magnetic measurements, then repeat with NbTi/Cu multilayer shield

Conclusions

- review of scSPS as injector, will be useful to look at status and needs of full hadron injector complex given the time scale
- transfer lines at 1.3 TeV from SPS and 3.3 TeV from LHC calculated with magnet technology presently in reach and well in synergy with the lepton lines - injection into arc unfavourable or to be checked?
- overlaying injection and dump system creates delicate failure scenarios, with risk of compromising the dump system reliability $\rightarrow$ layout to be checked