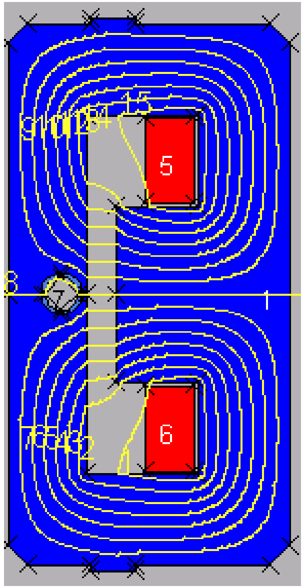
High field massless septa

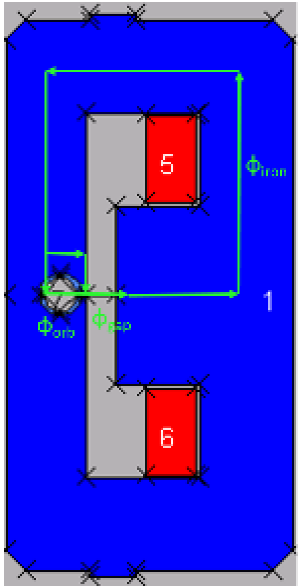
A. Sanz Ull

Outline

- Lambertson limitations.
  - Injection proposal using Lambertson septa.
- Pacman as a massless septum solution.
  - Comparison with previously reported massless septa.
- Double Pacman.
- Stealth dipole proposal and massless variant.
- Truncated cosine theta septum.
- Other novel superconducting topologies.
- Conclusions.

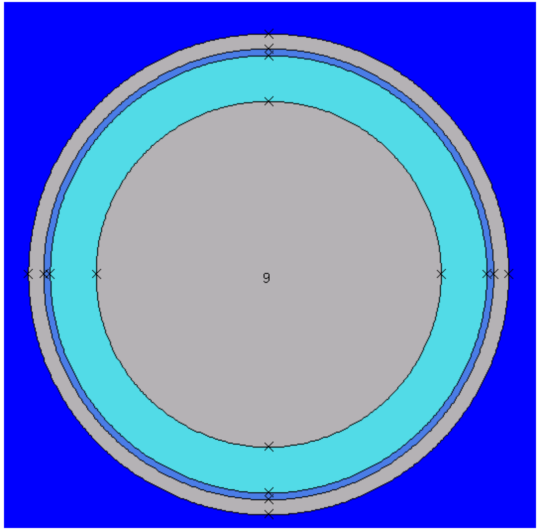
LHC Lambertson septa limits





0.9 mm sheet of Mumetal around the vacuum chamber (7 mm thick in total)

The maximum field reachable is 1.39 T with a 25 mm apparent septum thickness while respecting the leak field requirements



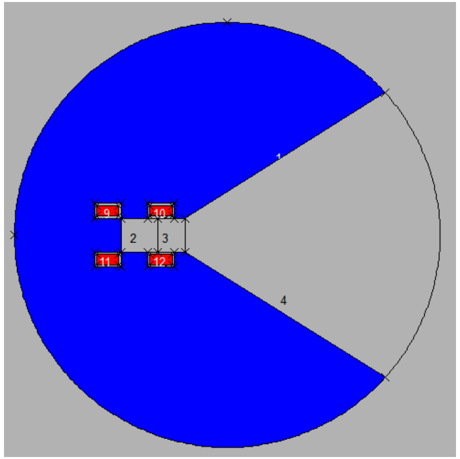
Proposed injection for FCC: Lambertson septa

Parameter	Unit	FCCA	FCCB	FCCC
Magnetic field integral	Tm	5.6	24	62.4
Nominal magnetic field	T	0.7	1	1.2
Number of magnets per extraction line	-	2	6	13
Apparent septum thickness	mm	8	12	18
Current	A	1043	1043	1043
Coil turns	-	12	17	21
Orbiting beam gap (h/v)	mm	9/14	9/14	9/14

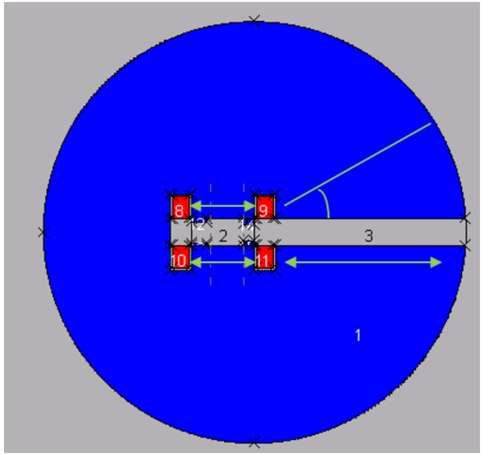
Thin septum

Introducing the Pacman septum (massless)

Pacman concept



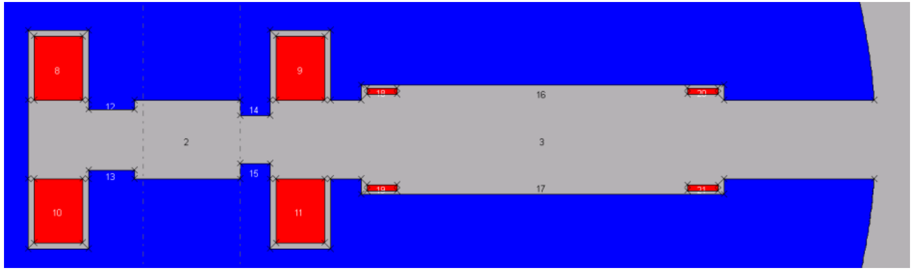
Optimized cross-section



- Geometry optimization, compensation coils and shimming
- Can be massless or close the yoke (shunt the magnetic circuit around both beams)

Optimised massless Pacman septum

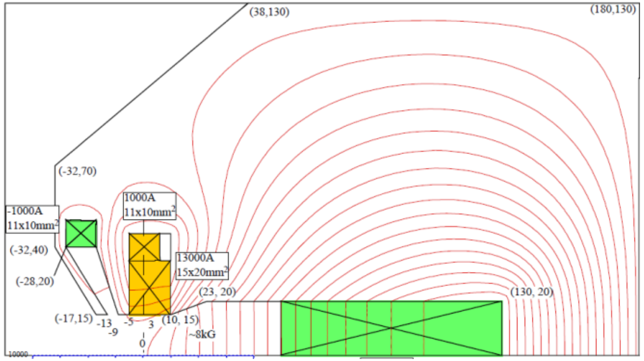
- Apparent septum thickness ≈ 1.8 x h (h = gap height) i.e. 34 instead of required to 25 mm. Low sensitivity to field level.
- B < 2 T and Leak field ≈ 1e-3 T
- Closing the gap reduces the leak field level, not the transition region width.
- If a shield is used, it is not a massless septum.
- Can be built also normal conducting.

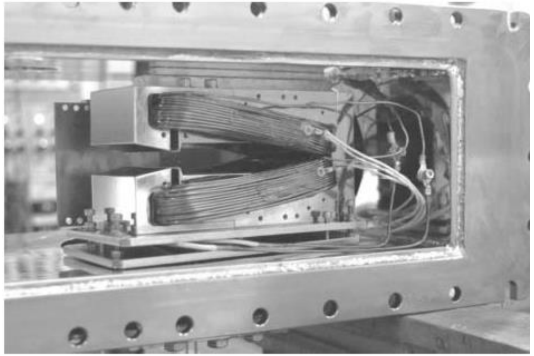


Optimised to achieve:
B_0 = 1.8 T
B_{leak} = 10^{-3} T
Resulting septum width (1 – 99%): 34 mm

Previously reported massless septa

Iwashita (Simulations) [1]



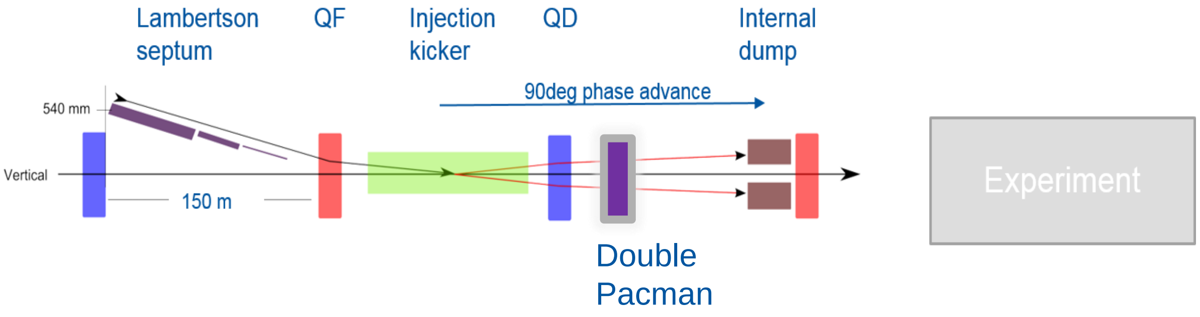


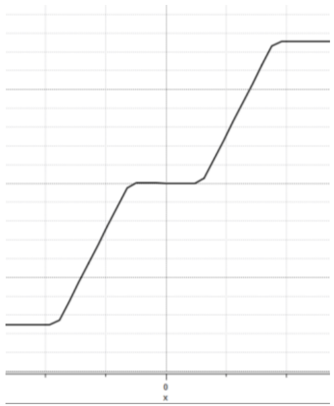
Yonemura (built) [2]

	Unit	Pacman	Iwashita	Yonemura
Magnetic field	T	1.8	0.8	0.1
Leak field	mT	8	~0.01	~0.01
Apparent septum thickness	mm	35	40	33
Gap height	mm	19	30	20
Apparent septum thickness/ Gap height	-	1.8	1.3	~1.6

Converge to Pacman geometry if pushed to high fields (2 T)

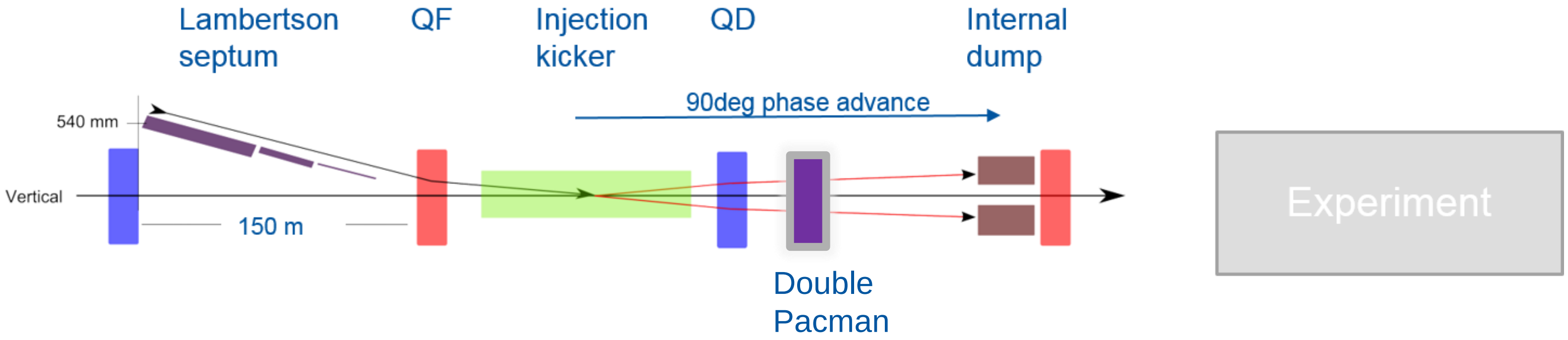
Double Pacman. Massless as a protection device





- Use a massless opposite fields septum to kick a mis-injected beam into a TDI.
- Option A→ Same function as a defocusing quadrupole but with a zero field region at the centre instead of a point. No impact on the optics of mis-steered beam.
- ~100 m length required. (Preliminary)
- Tolerances of zero field region and steep slope are challenging to combine

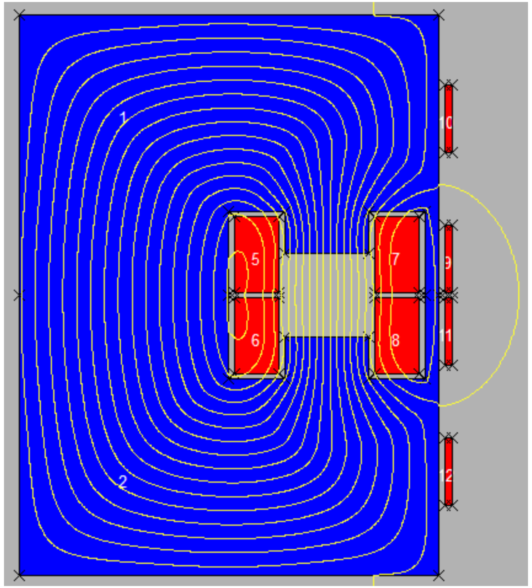
Double Pacman. Massless as a protection device

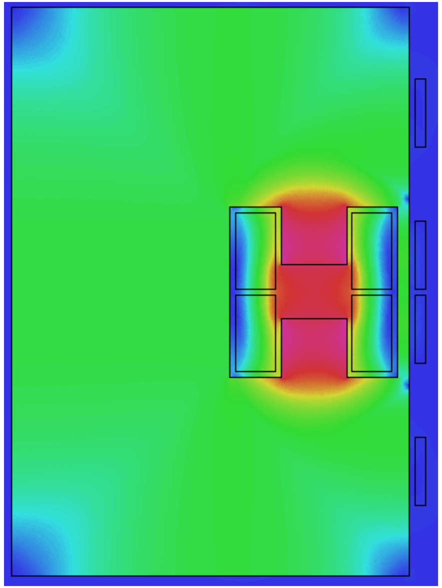


- Use a massless opposite fields septum to kick a mis-injected beam into a TDI.
- Option B→ Use gradient to increase deflected beam size at TDI.
- ~10 m length required (preliminary)
- Zero field region is challenging.

See talk by E. Renner. FCC-hh transfer line and injection

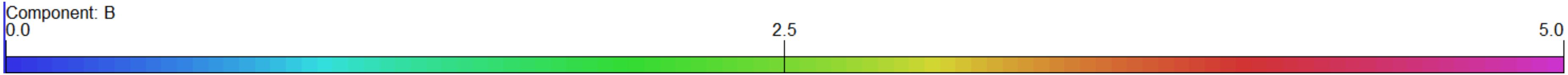
Stealth dipole proposal



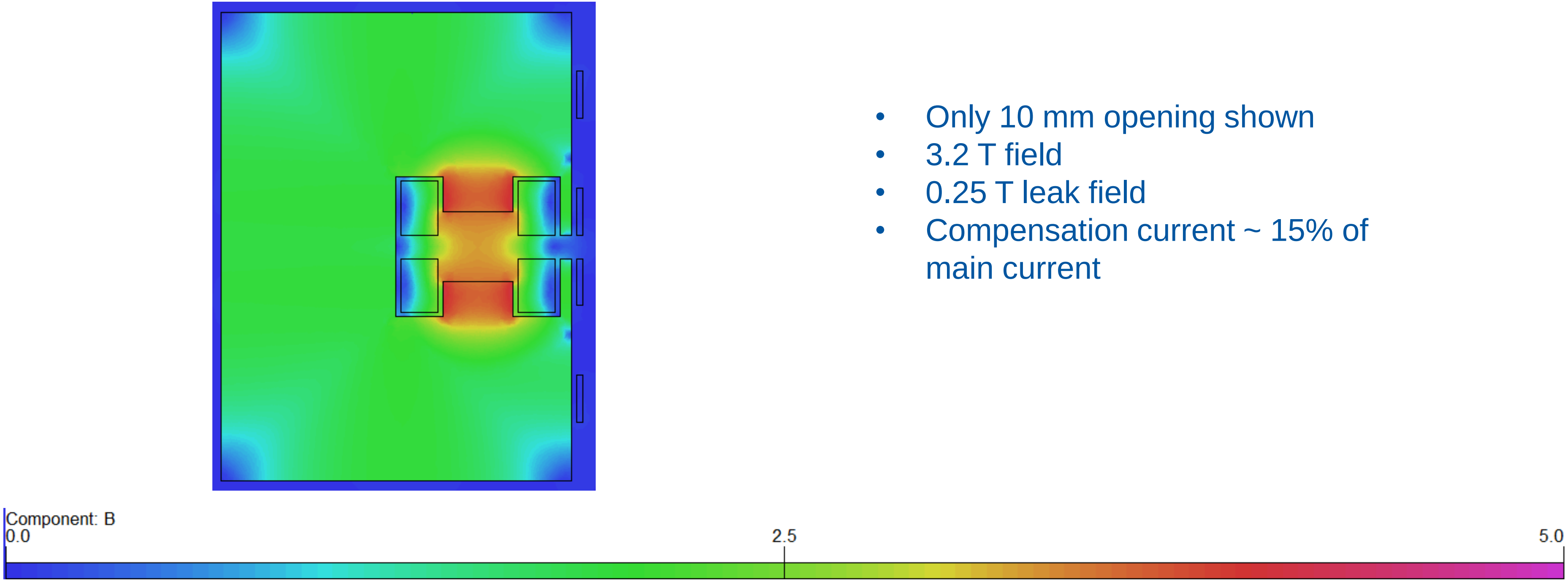


Texas A&M (Peter McIntyre and Akhdiyor Sattarov)

- 4 T field
- 0.1 mT leak field if shielded
- 25 mm apparent septum thickness
- Compensation current ~ 2% of main current
- Designed for cable in conduit
- B vs. I not linear

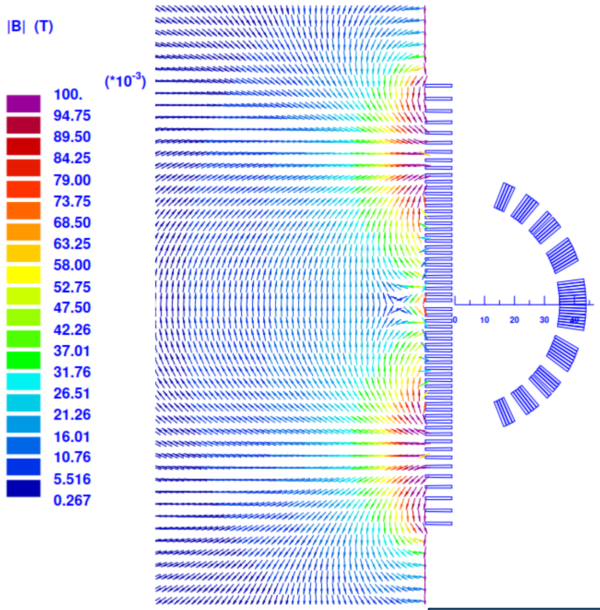


Massless variant of Stealth Dipole



- Only 10 mm opening shown
- 3.2 T field
- 0.25 T leak field
- Compensation current ~ 15% of main current

Truncated Cosine Theta

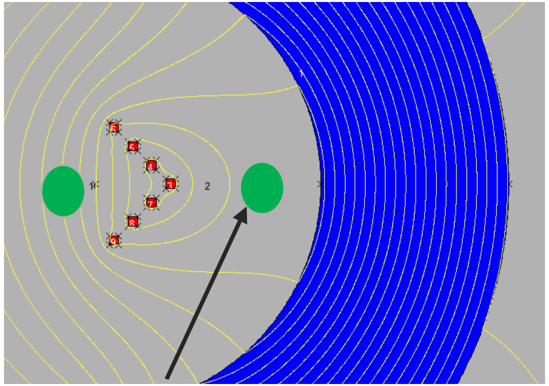


Magnitude	Value
B [T]	4
B_{leak} bare geometry [mT]	20
B_{leak} with magnetic shielding [mT]	<0.1
Apparent septum thickness [mm]	30
Cable type [-]	Rutherford (NbTi)
Current [A]	6284
Number of turns/pole [-]	31
Magnetic length [m]	4

See [4,8] and Kei Sugita's talk: Status of truncated cosine-theta septum magnet study.

Super conducting geometry

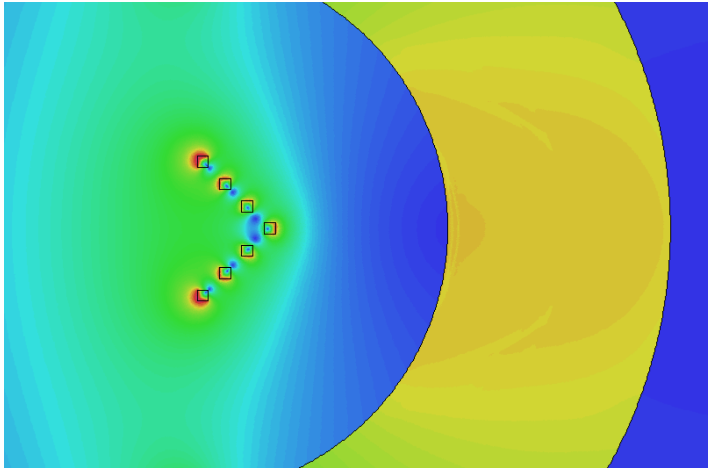
Super ferric magnet obtained using analytic algorithm that determined location of conductors as a function of the required field profile. (Useful as a first iteration [5, 6])



Orbiting beam gap

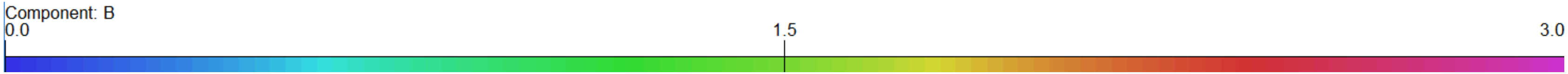
Unipolar configuration

- Can it act as a massless septum?
- Close the coil outside the yoke (not shown)



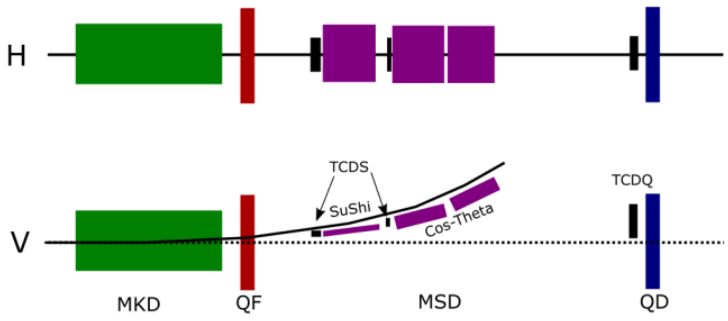
Bipolar configuration

- Same case as TCT.



Conclusions

- FCC injection to be done using three families of Lambertson septa.
- Beam dump septa system is feasible with various alternatives.
- Even if using a massless variant, beam impact on the septum, or absorber is still to be studied for the CDR.
- Use a staged approach: first SuShi, followed by Truncated Cosine-Theta (showers can quench both septa, even with absorbers).



Kei Sugita’s talk: Status of truncated cosine-theta septum magnet study.
Daniel Barna’s talk: Superconducting shield (SuShi): towards a full prototype

Figure: E. Renner

Thank you

References

[1] I. Iwashita et al. Massless septum with hybrid magnet. EPAC 98, Luzern.
[2] Y. Yonemura et al. Beam extraction of the pop ag with a massless septum. Proceedings of the PAC 2003.
[3] A. Yamamoto et al. The superconducting inflector for the BNL g^{-2} experiment. Nuclear Instruments and Methods in Physics Research A 491 (2002)
[4] K. Sugita et al. Basic design aspects for superconducting high field septa. Submitted to PRAB special issue FCC Week 2016
[5] S. Fartoukh. A semi-analytical method to generate an arbitrary 2D magnetic field and determine the associated current distribution. LHC project report 1012, 2007.
[6] A. Sanz Ull. Note on the application of fartoukh's algorithm. TE-ABT Internal note, 2016
[7] D. Barna. High field septum magnet using a superconducting shield for the Future Circular Collider. PRAB April 2017. https://link.aps.org/doi/10.1103/PhysRevAccelBeams.20.041002
[8] A. Sanz Ull. et al. Comparison of superconducting septa topologies and parameter space exploration. IPAC proceedings 2018.

Backup. Leak field calculation

$$B\rho_{LHC} = 11e3 \; and \; 1501 \; at \; extraction \; and \; injection \text{ (TDR)}$$

$$B\rho_{FCC} = 166Tkm \cdot \frac{3.3TeV}{50TeV} = 11Tkm$$

From LHC Lambertson: Bleak= 2.1 mT (I take it as a homogeneus leak value. It's very conservative). 15 MSD, 4 m long each (magnetic)

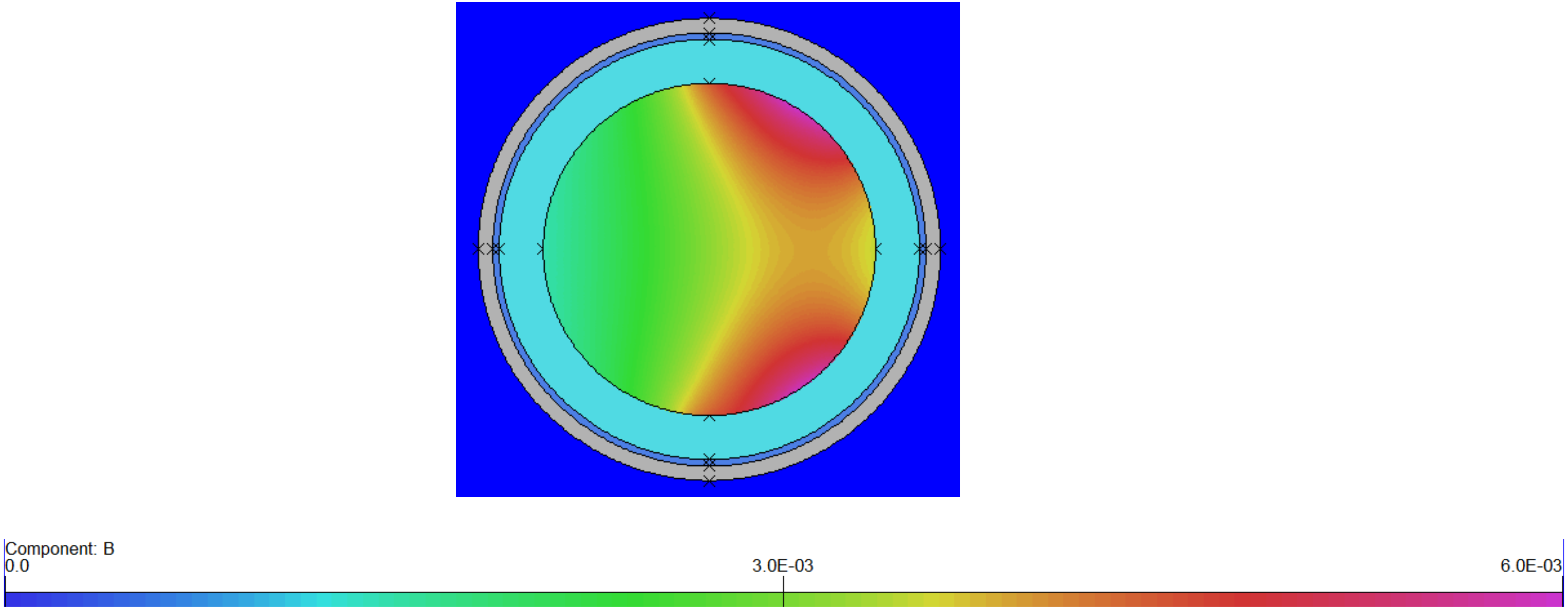
$$\int B_{leakLHC} = 2.1\, mT \cdot 15 magnets \cdot 4m/magnet = 126mT \cdot m$$

Now we scale that leak field with the beam rigidities to obtain the TOTAL leak field allowed for FCC dump septa

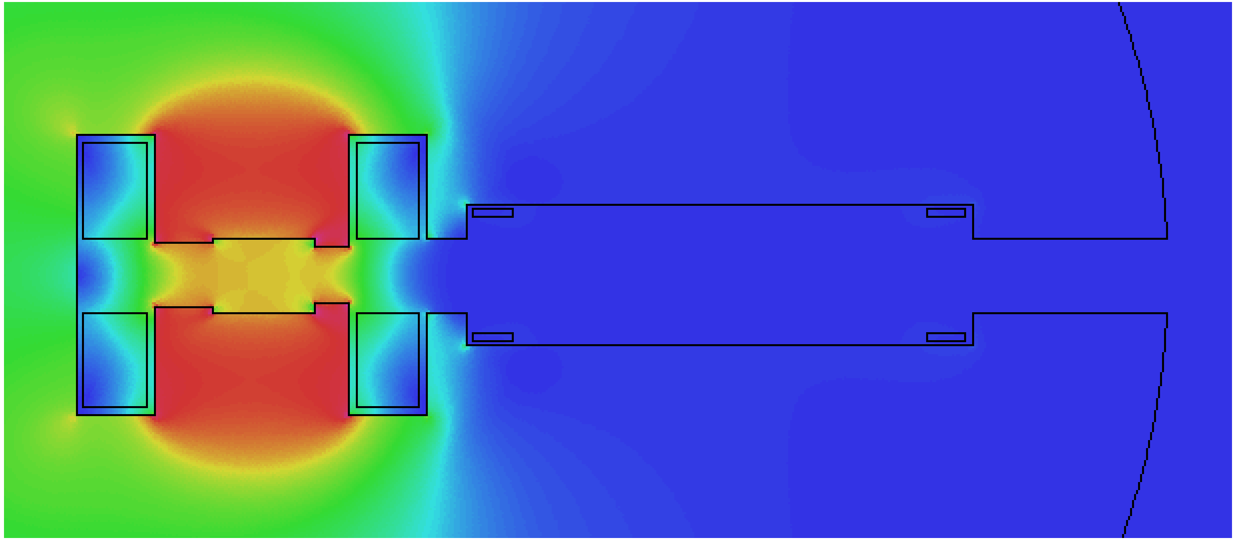
$$\int B_{leakFCC} = 126mT \cdot m \cdot \frac{11e3\; T \cdot m}{1501\; T \cdot m} = 924\; mT \cdot m$$

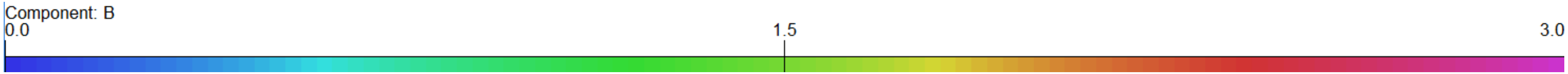
And this leak field, since it's integrated, we do the inverse sequence as before. Divide it by N magnets, Y m long each (35 magnets, 4 m for FCC Lambertsons=6.6 mT)

Backup. Lambertson leak field map



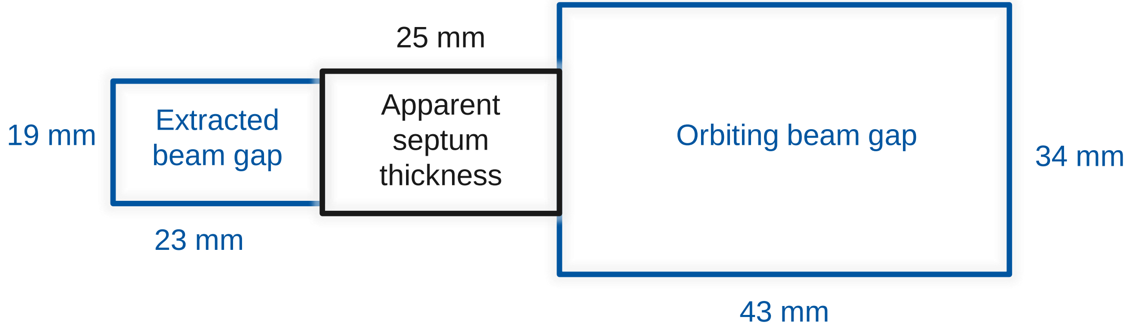
Backup. Pacman leak field map





FCC gap and septum blade dimensions

Assuming injection at 3.3 TeV.
Extraction septa dimensions.



Parameter	Unit	Value
Available length	m	120
Magnetic field integral	Tm	190
Total deflection	mrad	1.15
Blade thickness	mm	25
Good field region (hor/ver)	mm	19
Leak field integral	mTm	924
Total dump line length	km	2.8

Picture to scale

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