Magnetic field in ArgonCube?

Alan Bross

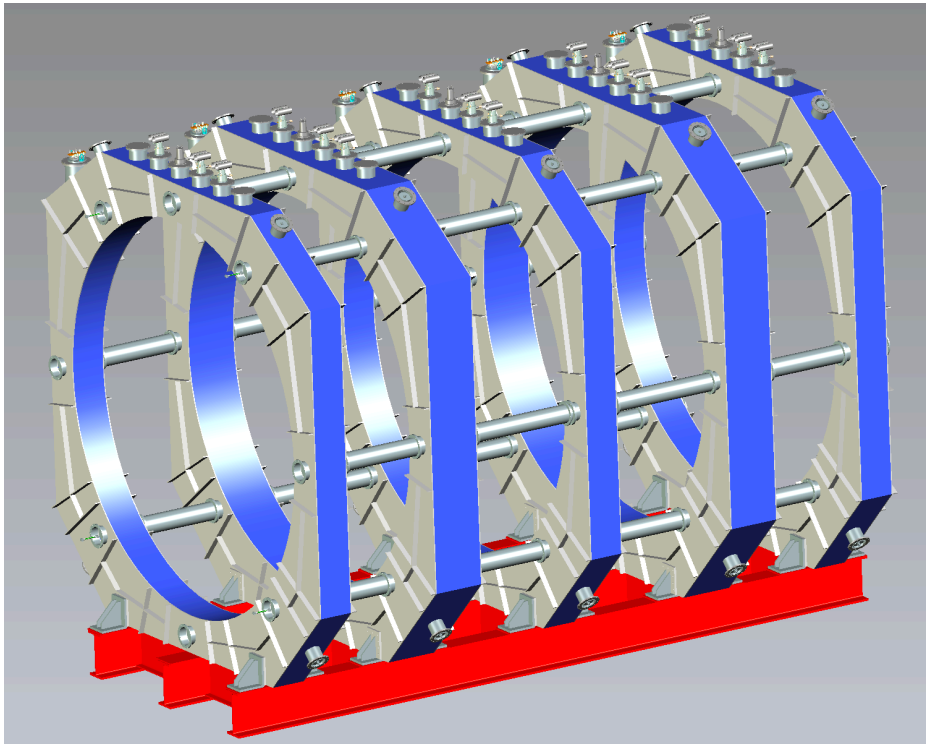
ArgonCube Collaboration Meeting

December 8-10, 2019

To B or not to B?

- The presentation here comes out of discussions on the MPD magnet regarding its reference design and possible options
- The ArgonCube collaboration has not considered the advantage or disadvantage of living with B field in the detector to any extent up to now
- Given the status of the MPD magnet design work, it is appropriate for the ArgonCube Consortium to give this some thought now

MPD magnet reference design



MPD magnet
Reference design

- The Reference Design for the magnet for the MPD is
  - 5-Coil Helmholtz
  - Central field = 0.5T
- Meets requirements for μ spectrometer to assist LAr
  - Large acceptance for particles leaving LAr
  - Present minimal mass
- The design is very mature
- Does produce a rather large stray field, however
- Good or Bad for LAr?

Magnetic tracking in ArgonCube

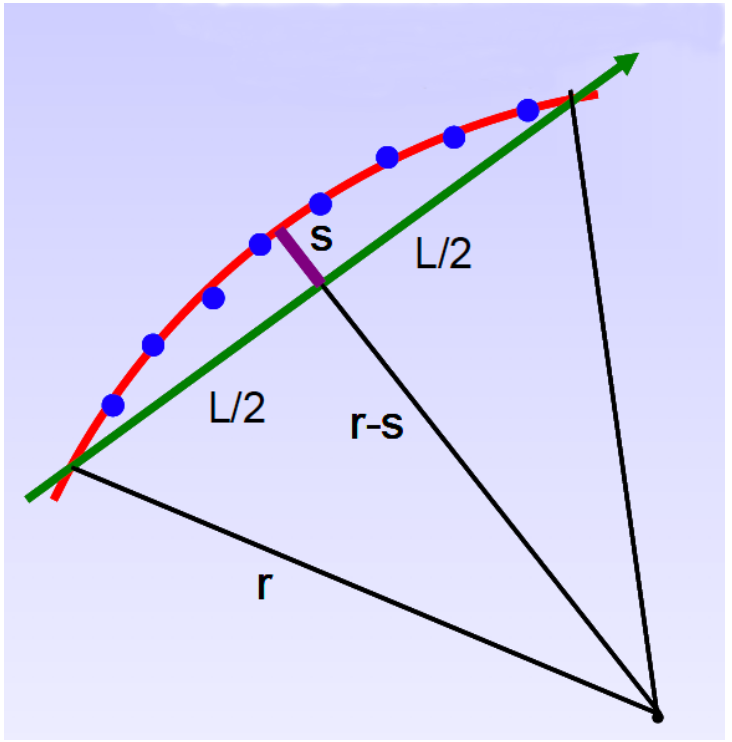
- Should magnetic tracking capability be an input to the requirements for the MPD magnet?
- Tracking in B field basics

$$p_t\,[GeV/c] = 0.3 \times B[T] \times r[m]$$

$$\sigma_s = \sqrt{\frac{A_N}{N+4}} \times \frac{\sigma_{r\varphi}}{8}$$

Gluckstern, NIM 24
A_N = 720

$$\frac{\sigma_p}{p} = \frac{8 p_t}{0.3 B L^2} \times \sigma_s$$



- Assume
  - $\sigma_{r\phi}$= 4mm/√12; L=1m, N=200, B=0.05

$$\frac{\sigma_p}{p} \simeq 15\% p$$

Sign determination?

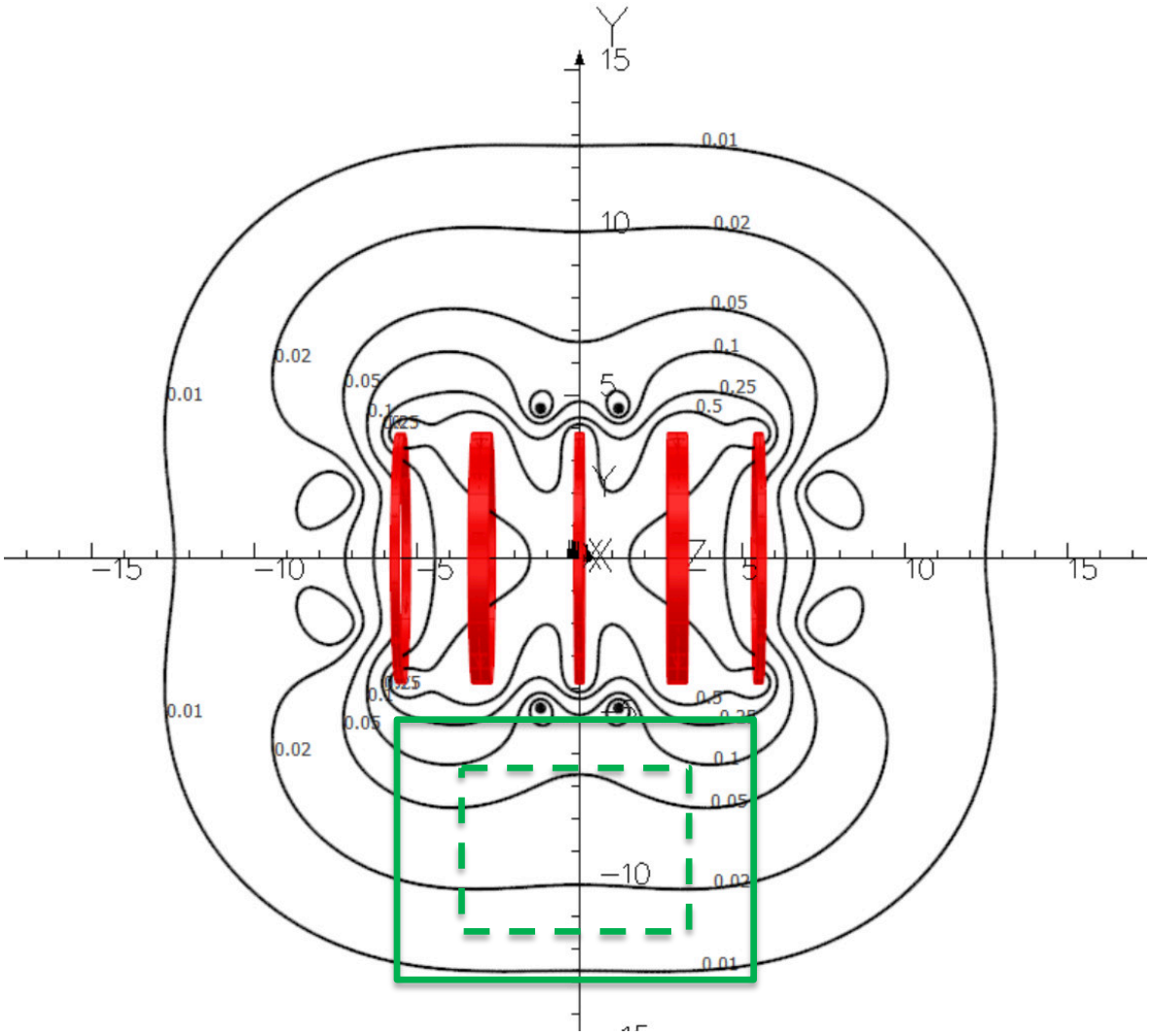
Basic tracking: MCS limit

$$\frac{\delta p}{p} = \frac{21(MeV/c)}{\beta \sin\theta} \frac{10}{3} \left(\frac{Tm}{GeV/c} \right) \frac{1}{B} \sqrt{\frac{C_N}{2LX_{rad}}}$$

- From Blum and Rolandi
- Example: B=500G, 1m track length, C_N = 1.4 since # measurments >> 5, X_{rad} = 14cm
  - $\delta p/p$ = 50%
- **Full track reconstruction with detailed field map is needed to fully tell the story**

Field Maps ➛

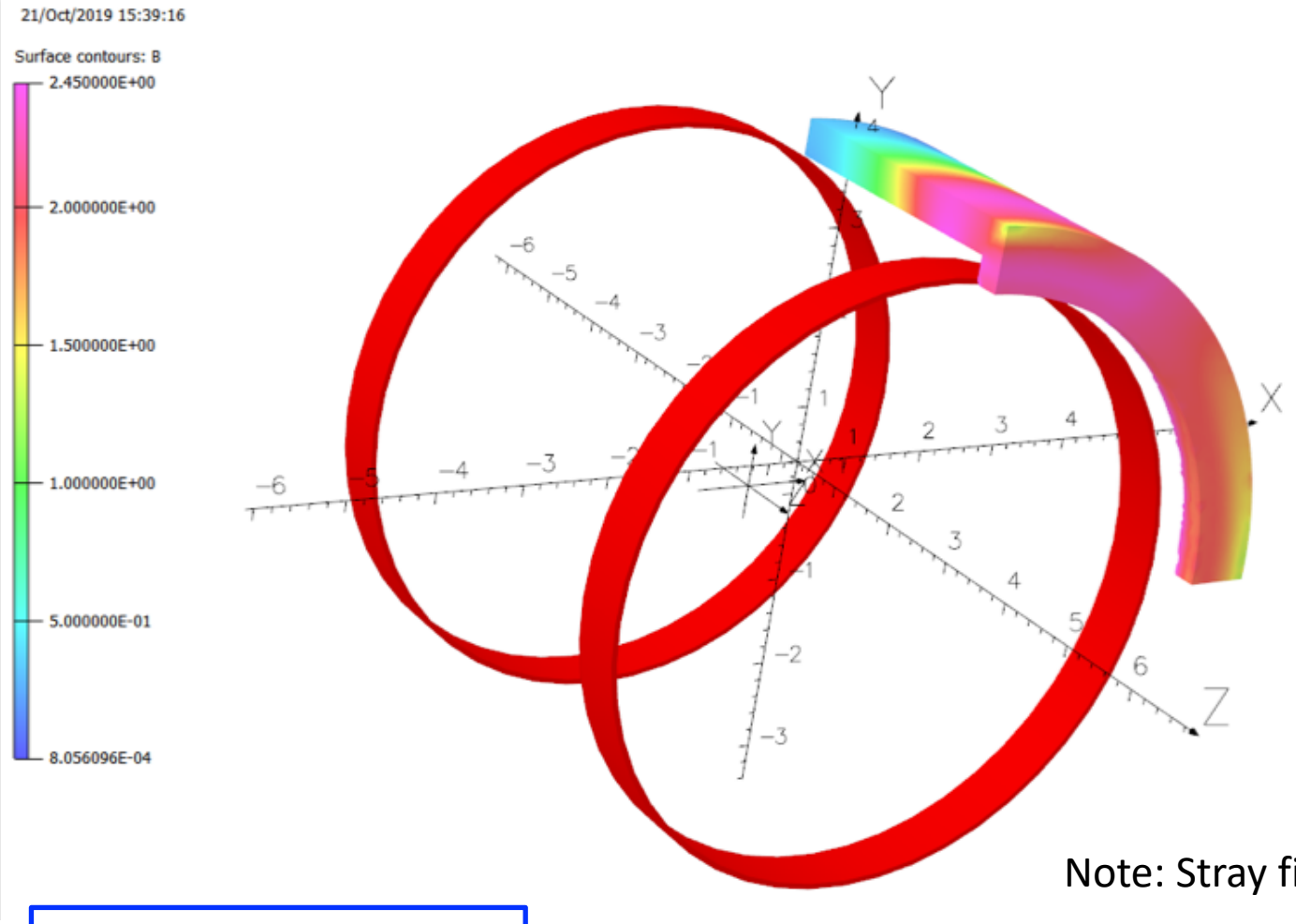
Stray field: Reference design magnet



Magnet Options

- At the DESY WS, it was decided to freeze the reference design in its current form and move onto alternate designs
- Motivation
  - Save space along beam direction
    - 8.4m ➛ ~ 7.5m
    - Reduce cost
- Taking two forward
  - 2-coil Helmholtz design with partial return yoke (PRY)
  - Solenoid with PRY (SPY)
  - Note: Double-dipole option dropped
- In both stored E ~ 40% of reference design
  - Remember Cost ~ $(E)^{0.8}$

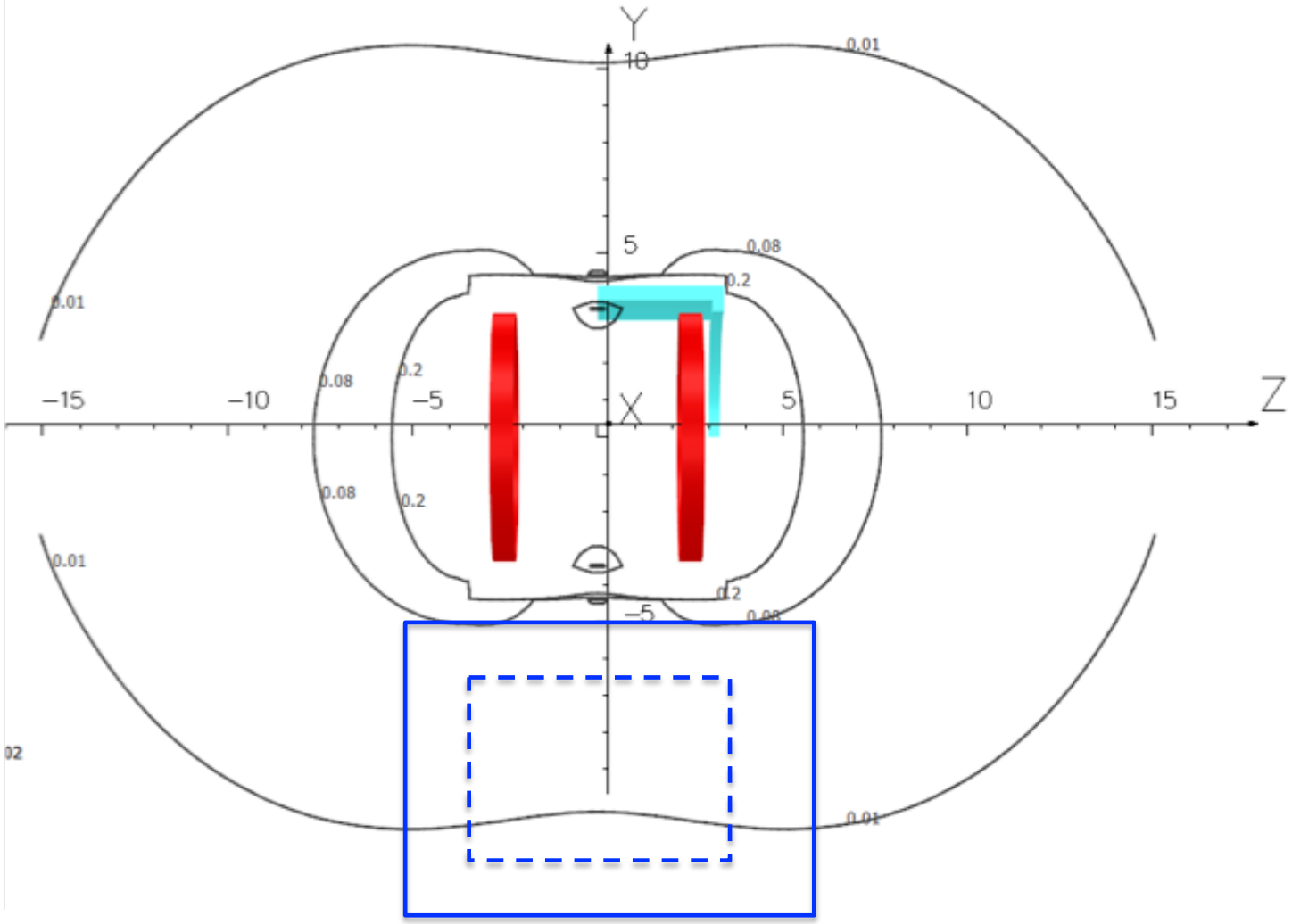
2-coil with partial return yoke



Note: Stray field

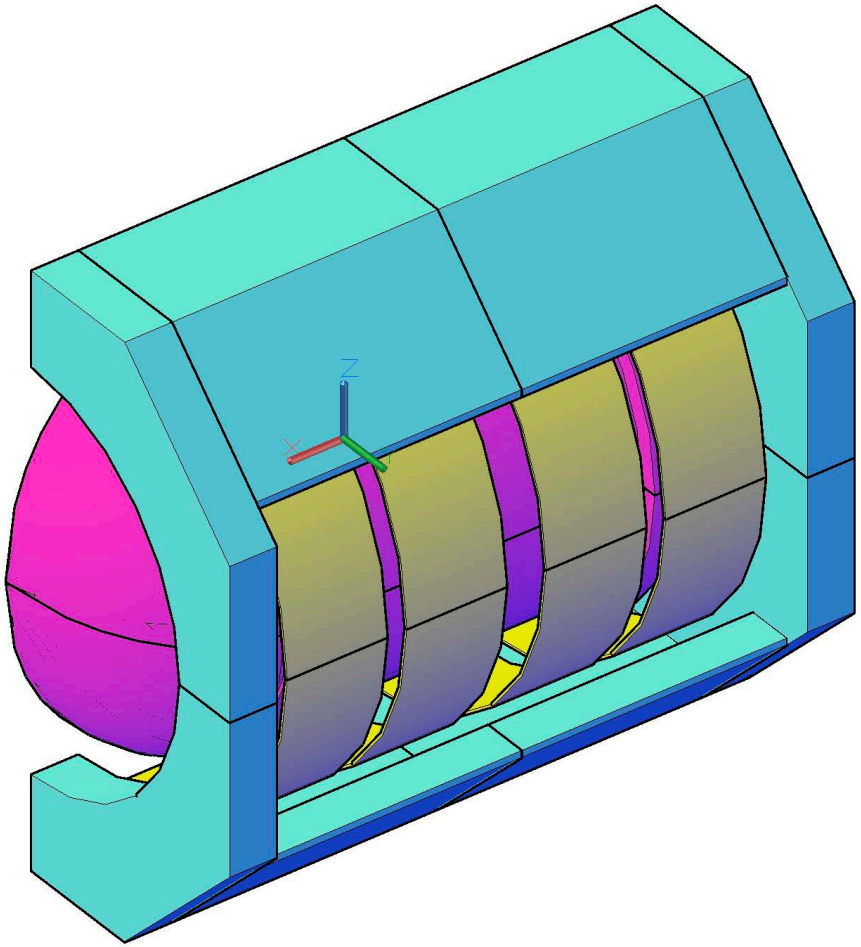
Vladimir Kashikhin, FNAL

2-coil Helmholtz



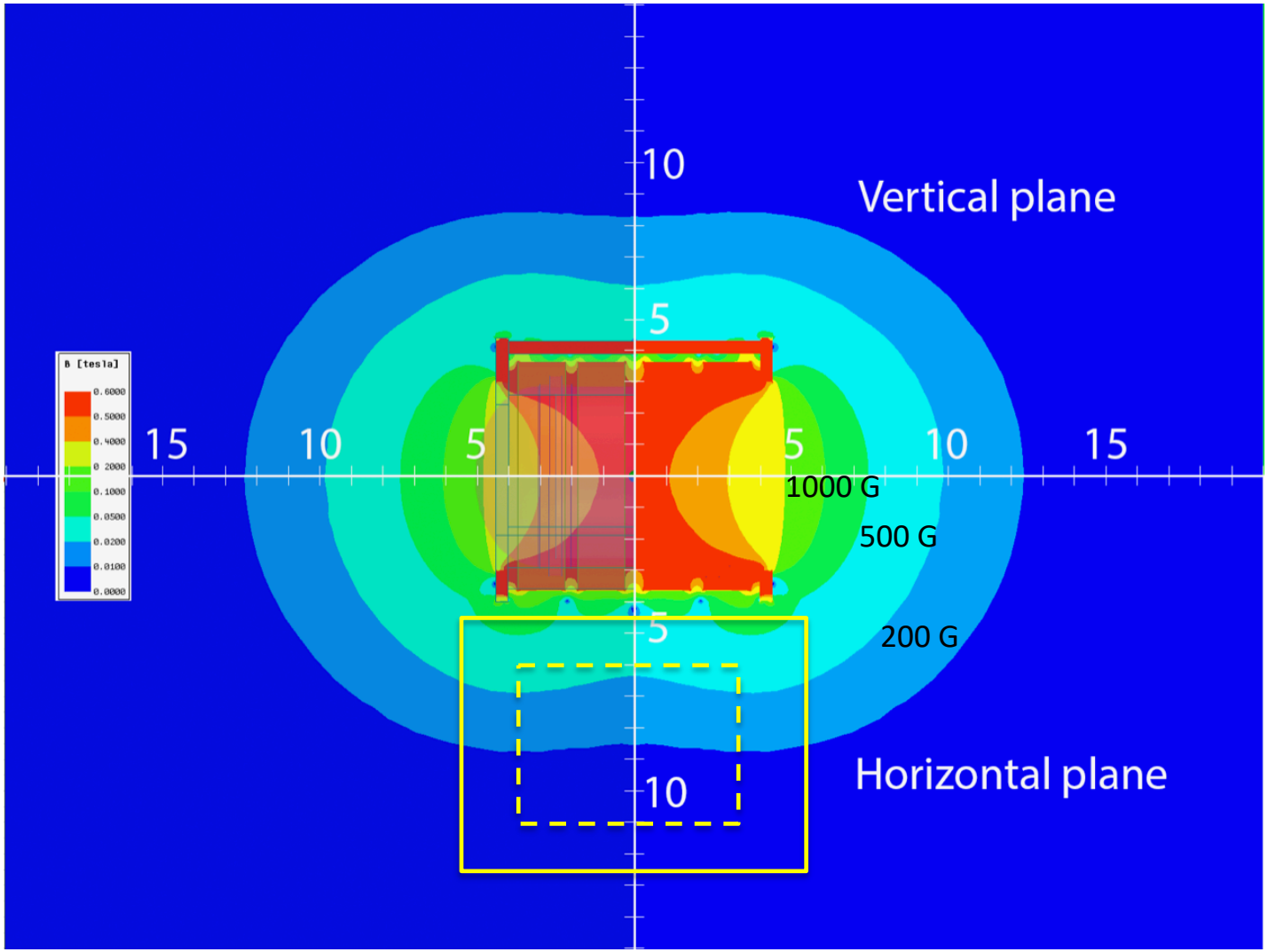
Solenoid with Partial Yoke (SPY)

- New concept from INFN
- Solenoid with a "window" in the yoke
  - closing the magnetic circuit with iron
  - does not affect particles
- Good for
  - reducing stray field
  - reducing stored energy
  - having uniform material budget
    - May be important for DUNE PRISM
- Bad for
  - heavier
  - ~10cm of aluminum along particles path (outside the calorimeter)

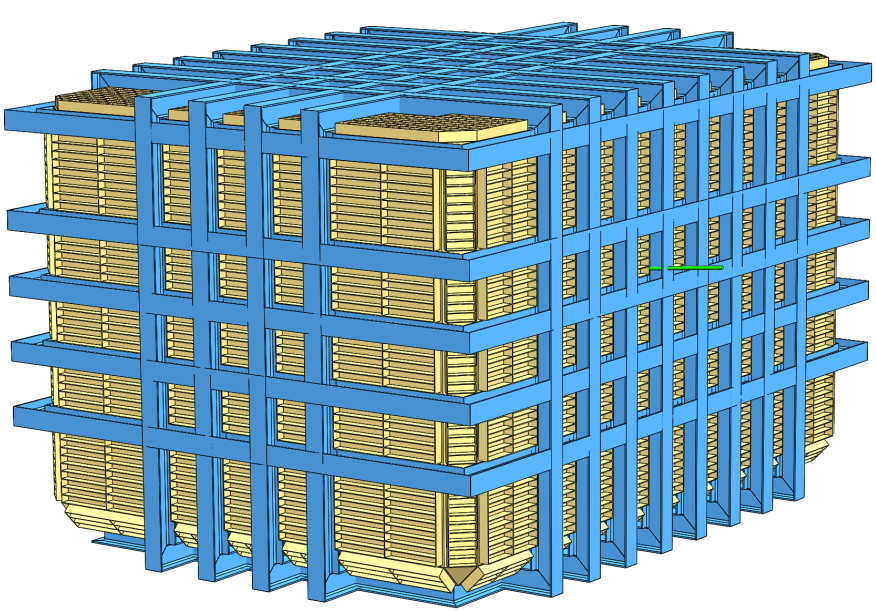


Andrea Bersani, INFN Genoa

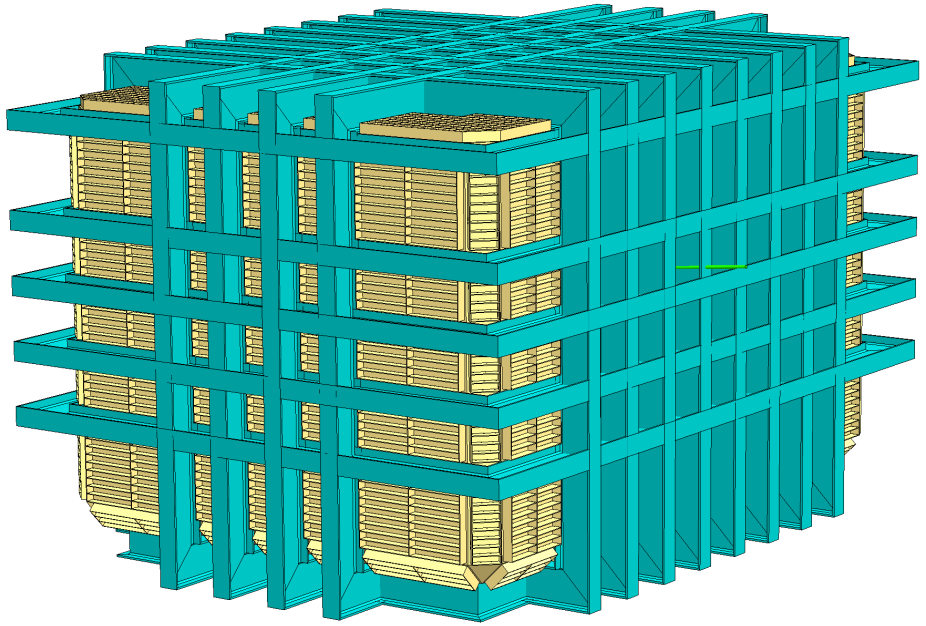
Stray field SPY



Comments on cryostat design w/r to B



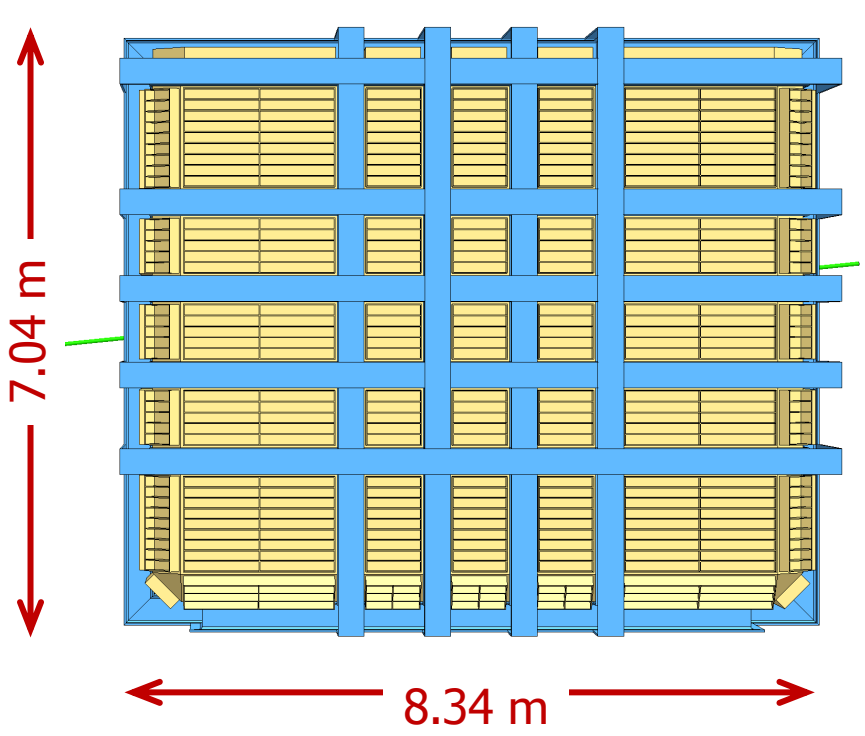
Steel Beams
(Beam Structure Weight = 87 tonne)



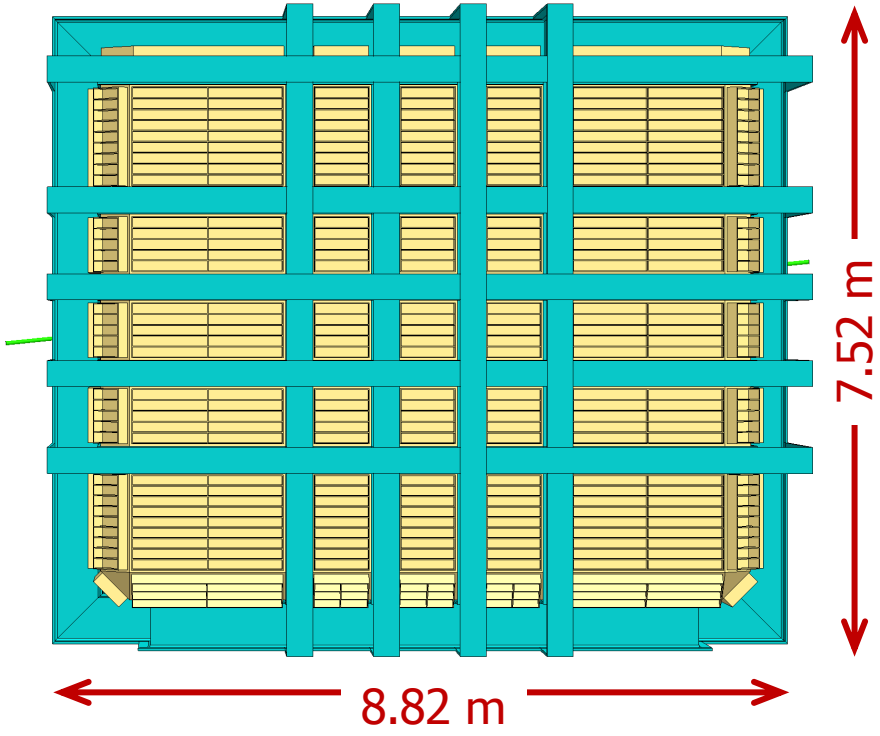
Aluminum Beams
(Beam Structure Weight = 45 tonne)

- This is based on SBND/Proto-DUNE/DUNE design
- Not “purpose-designed” for near detector
  - Material thickness and uniformity presented to muons exiting LAr
  - No B field considerations

Aluminum is out, since it adds ~ 0.5m along beam

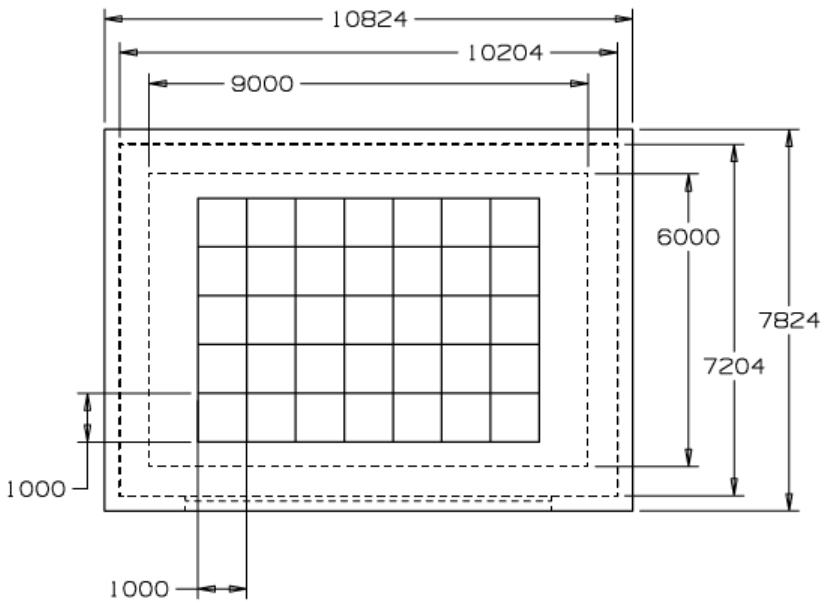


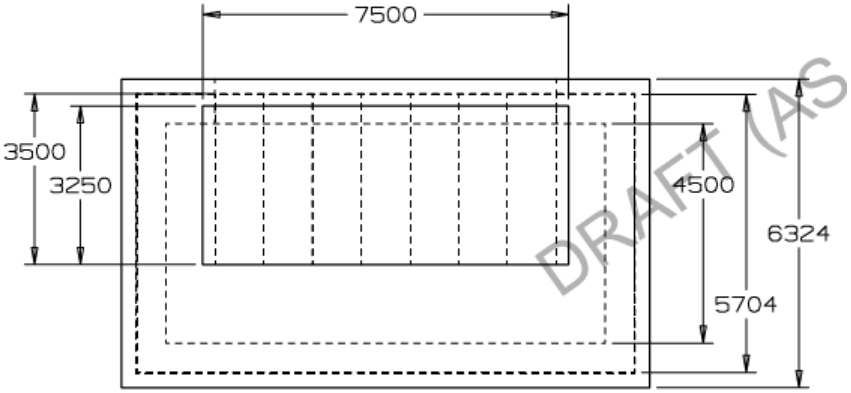
360 mm Depth Steel Beams



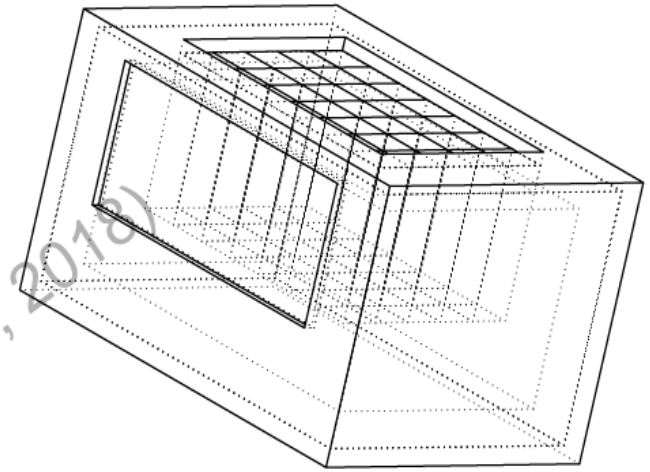
600 mm Depth Aluminum Beams

But the good news is that ML seems to have double-counted the thickness of support structure





ArgonCube Modules in 5 x 7 Configuration



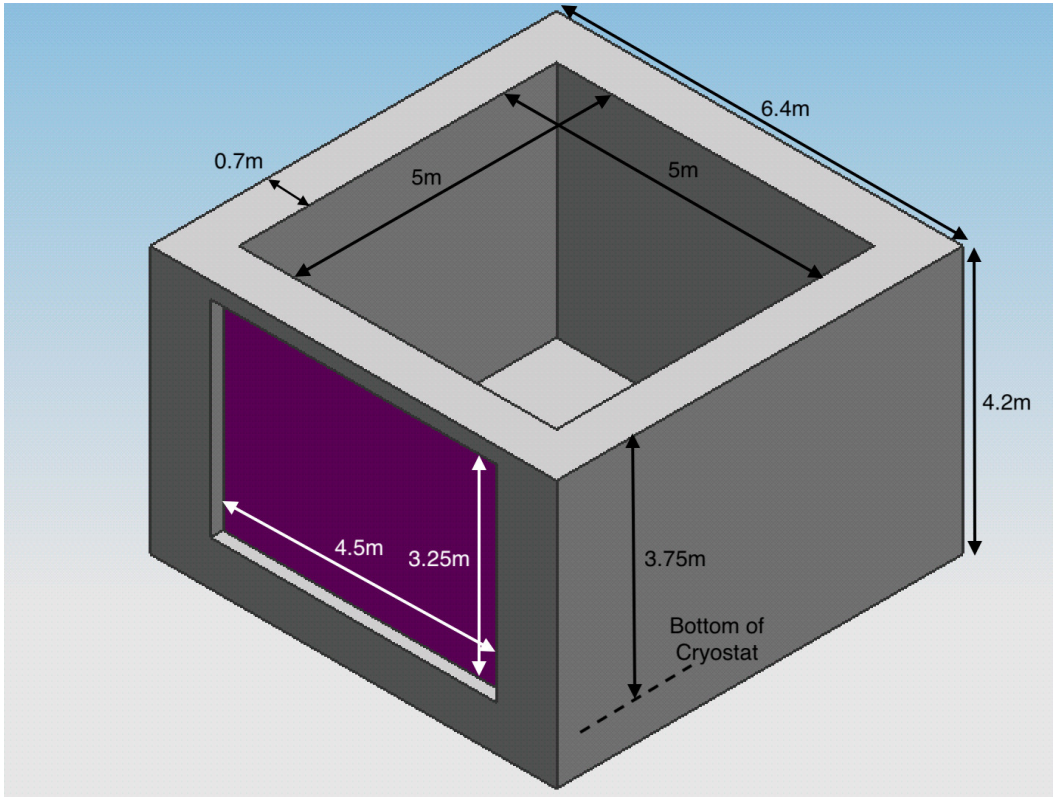
DRAFT (AS OF OCT. 31, 2018)

Cryostat Design Parameters

Cryostat Internal Dimension (between Flat Surfaces)	9000 (W) x 6000 (L) x 4500 (H)
Thickness of Insulation (including Membrane Liner and Secondary Barrier)	602
Thickness of Support Structure (including Vapor Barrier) : Concrete or Steel	310

Also note that concrete somewhat thinner than steel, based on 35t design rules

Concrete design with window

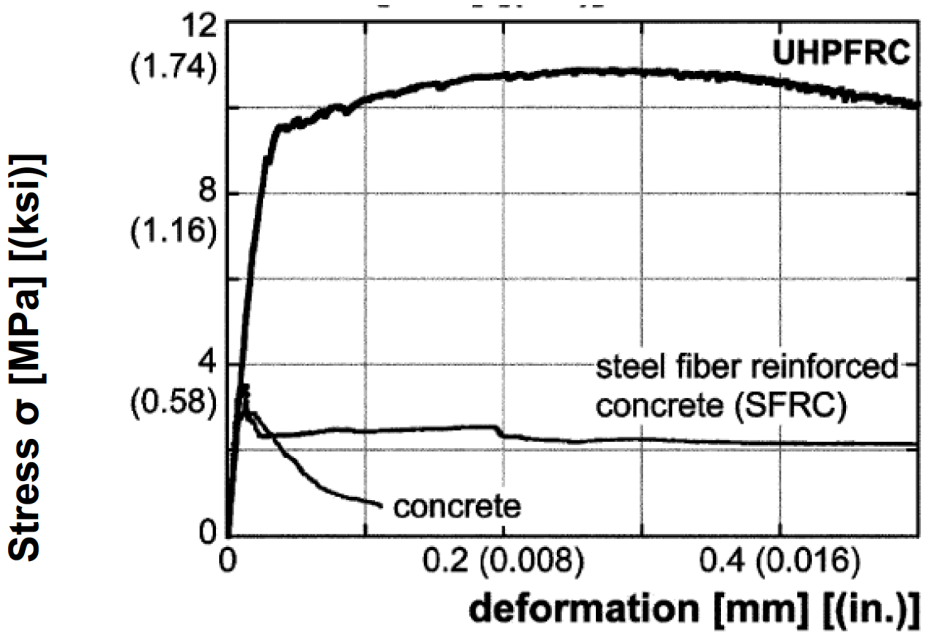


- Things have changed in the ~ two years since this was done
- But concept still looks promising for ND LAr
- Take another look
  - Window design
  - Use of UHP concrete pre-fab

Layer	Material	Thickness (mm)
Membrane	304 Stainless Steel	2
Fireproof board	Calcium Silicate board	10
GRE/GRU	Glass reinforced epoxy/glass reinforced urethane	0.5
Insulation	High temperature polyurethane foam	190
GRE/GRU	Glass reinforced epoxy/glass reinforced urethane	0.5
Insulation	High temperature polyurethane foam	200
Moisture Barrier	Carbon Steel	1.2
Reinforced Concrete	Reinforced concrete	300

Ultra-high-performance concrete

- Ultra-high-performance fiber reinforced concrete (UHPFRC) has widespread use in construction applications due to its superior mechanical properties.
- UHPFRC provides solutions for structures where high strength, ductility and durability properties are required
- Fibers
  - Steel
  - Glass
- Pre-fab panels available



Ultra-high-performance concrete

Table 1. Typical UHPC composition.

Material	Amount (kg/m^3 (lb/yd^3))	Percent by Weight
Portland Cement	712 (1,200)	28.5
Fine Sand	1,020 (1,720)	40.8
Silica Fume	231 (390)	9.3
Ground Quartz	211 (355)	8.4
Superplasticizer	30.7 (51.8)	1.2
Accelerator	30.0 (50.5)	1.2
Steel Fibers	156 (263)	6.2
Water	109 (184)	4.4

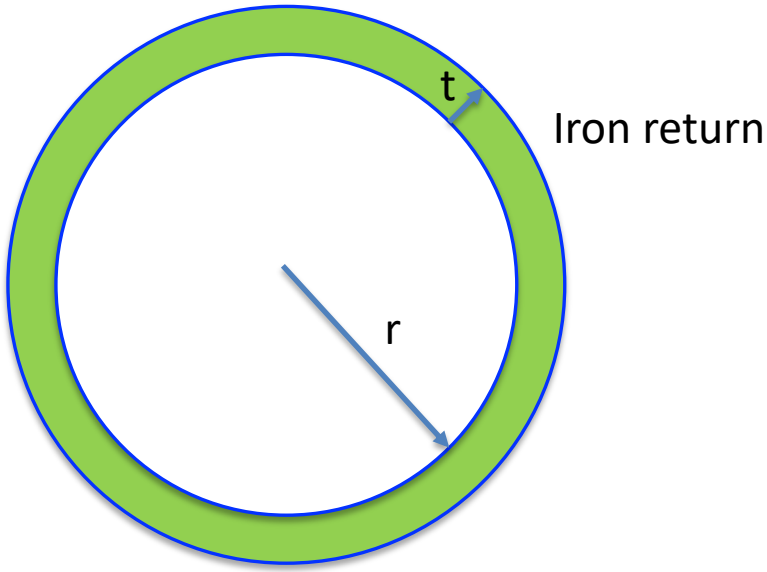
Conclusions

- All MPD magnet designs will produce some field in the LAr
- Down-select for magnet design at next DUNE CM is the goal
  - Difficult, but could happen
- The reference design probably gives the most flexibility w/r to delivering some specification for the B in the LAr while still providing appropriate field for the HPgTPC
- Overall optimization of an “Integrated Argon Detector” is complicated
  - MPD magnet
  - Partial return yoke
  - LAr cryostat support structure
  - Tracking in HPgTPC and LAr

Discussion

- To determine if B is good or bad will require simulation
  - Also some thought to determine if there are components of ArgonCube that may not operate correctly in the field
- If the conclusion is that B in LAr is bad
  - MPD magnet design(s) that minimize B in LAr are then obviously preferred
  - This probably is most straightforward path forward
- If the conclusion is that B in LAr is good
  - Stray field analysis becomes more complicated
    - Must include full reco & tracking in LAr with proper field map
  - Cryostat support structure needs study & its effect on B
  - Set benchmark(s) for “extra” physics obtained with B
  - **This is a Heavy Lift**

BACKUP

Capturing flux lines

- Assumptions
  - Central field = 0.5T
  - Iron saturates at 2T
  - r=3.5m; L=6m
- Then in order to capture all the flux
  - $\pi r^2/4 \cong \pi rt$
  - $t = r/4 \cong 0.9m$
  - Almost a kt of steel