Fermilab

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The EMPHATIC Magnet

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EMPHATIC Director's Review

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Topics

- Requirements
- Design & mapping
- Safety considerations
- 2020 experience
- Cost, schedule and risks

Requirements

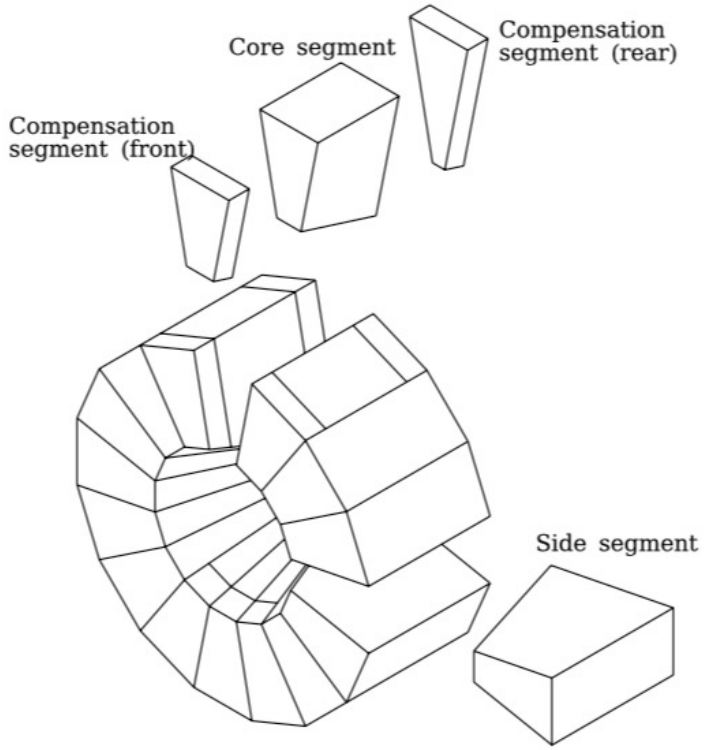
- ± 350 mrad opening angle
- $\int B \cdot d\ell = (1\ \mathrm{T})\ (0.2\ \mathrm{m})$ to within ~5% of design [scale]
- Tracking does not depend critically on uniformity (AP-STD will measure field)
- Stray fields as low as reasonably possible (safety)
- Position measurement tolerances relative to field measurement position depend on field uniformity,

$$\Phi = \frac{1}{\int B \cdot d\ell} \left[\frac{d \int B \cdot d\ell}{d(\vec{x}_\perp)} \right]$$

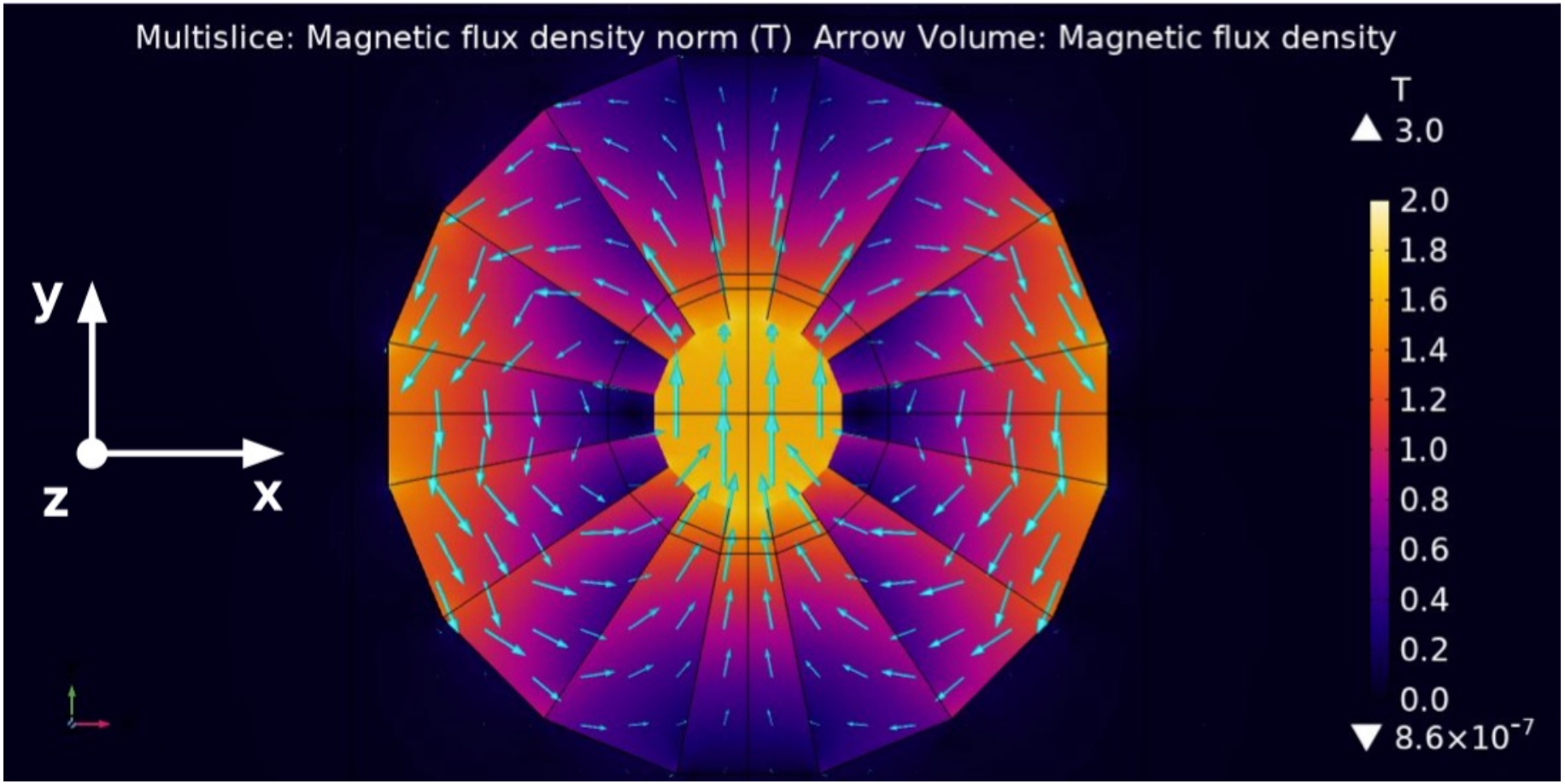
Design	Φ	Transverse δ(x,y)	Roll δφ	Pitch δθ
Compensated	~1 m^{-1}	0.1% ⇒ 1 mm	1 mm/r = 12 mrad	1 mm/ℓ = 7 mrad
Uncompensated	~4 m^{-1}	¼ mm	3 mrad	2 mrad

Design & Mapping

- N52 Neodymium permanent magnets in a Halbach array
- $B = 1.44$ T in the NdFeB
- Max operating temp 80ºC
- Compensated design has ~3% uniformity [vs ~12%], lower stray fields and similar cost
- Our COMSOL 5.4 simulation does not allow for epoxy volume, we expect measured field lower than design by ~5%
- AP-STD can map to 0.1% in mm scale steps in a day or so



Design & Mapping



Safety Considerations

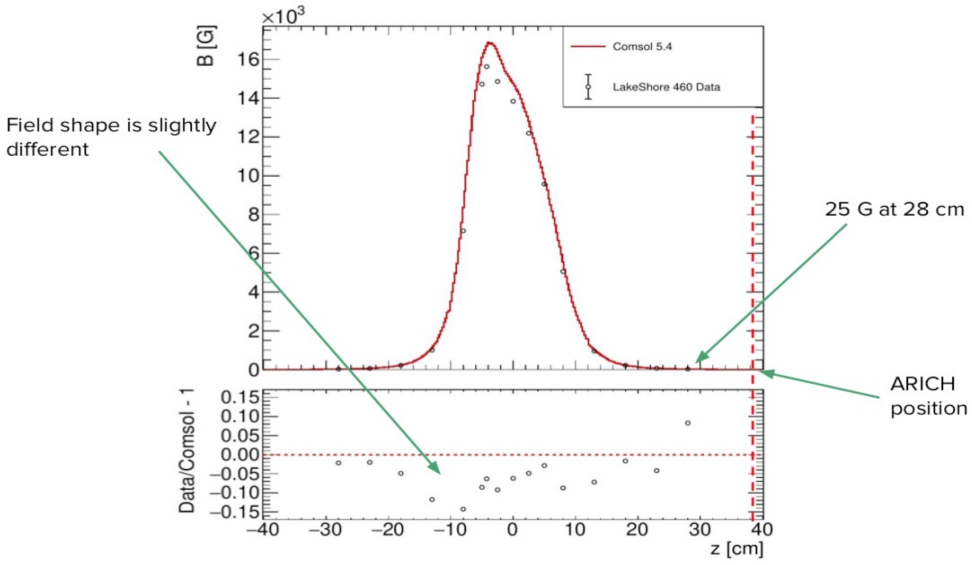
- Mass is $\gtrsim 100\ \mathrm{kg}$
  ⇒ If dropped, some risk of shattering
  ⇒ Shattered pieces could fly out at speed
  ⇒ Mechanical handling requires HA

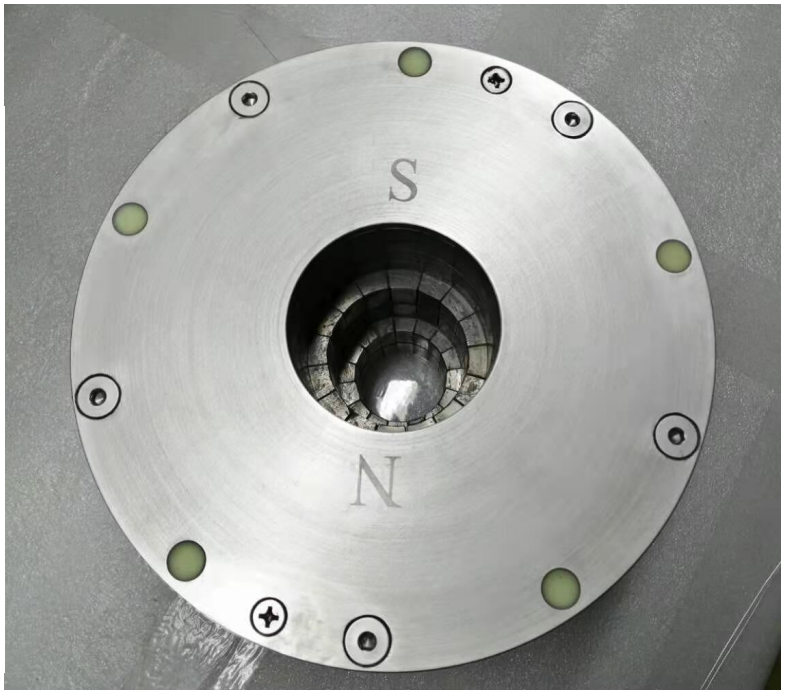
- Stray field is $\sim 0.2\mathrm{T}$ at aperture
  ⇒ No magnetic tools allowed in work area
  ⇒ Protective cover over aperture when not running beam

- Warning signs – pacemaker, metal tools

2020 Experience

- A smaller, lower cost magnet was available for the 2020 engineering run
- Run was cancelled but experience was valuable esp. re safety





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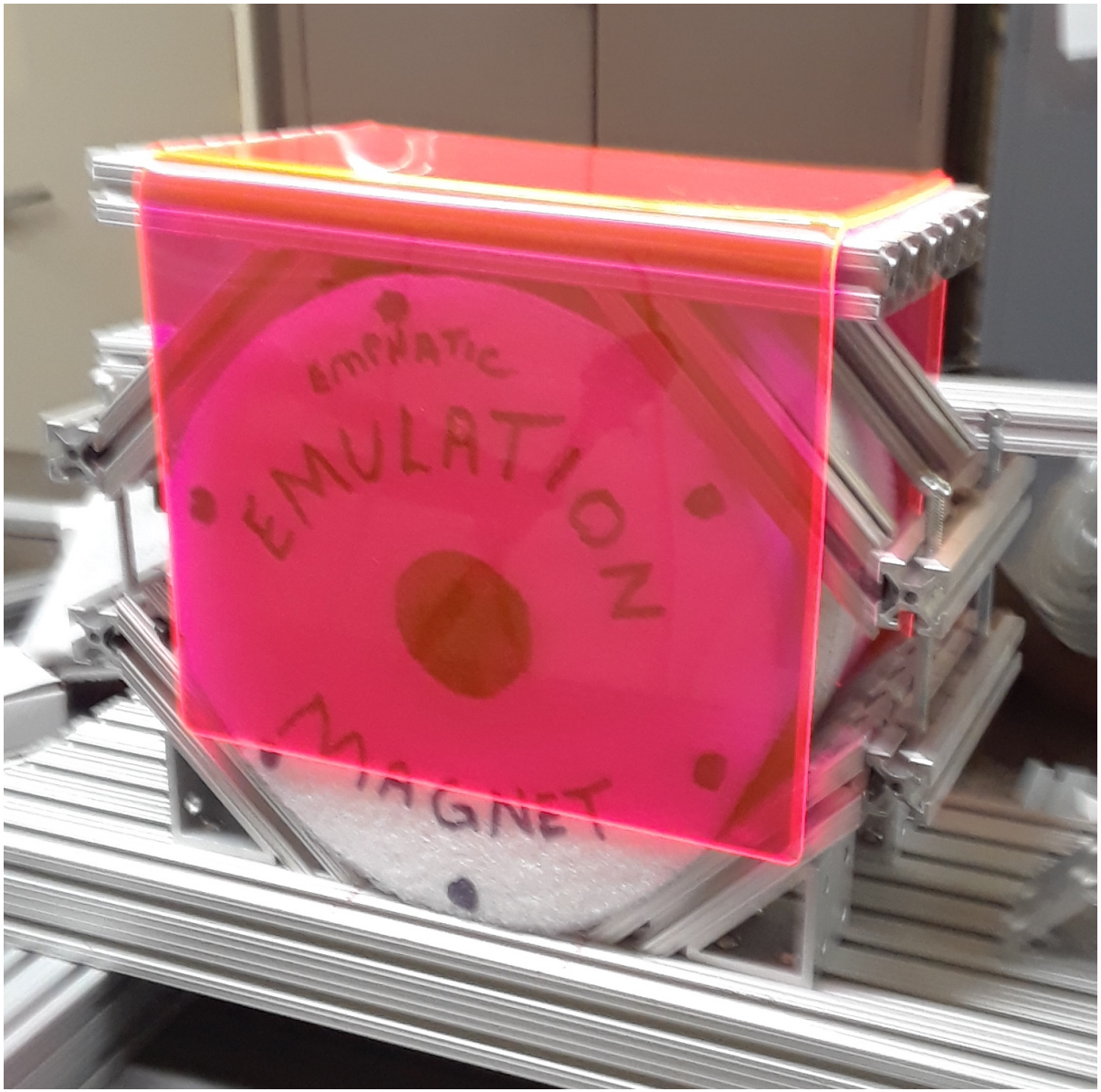

2020 Experience

- Manufacturer should provide more than magnet itself; we want some quantification re stresses inside the structure
- Need to pay attention to steel shell design for installation / positioning issues
- If US manufacture, could enquire about their handling procedure [European, Japanese procedures also informative]
- Must get stay-away signs up immediately upon delivery
- 5% spec easy to make

Cost, Schedule and Risks

- 4 quotes received during 2020
- Prices 75k$ - 138k$
- Compensated designs not much higher and we strongly prefer it
- Delivery 12 – 20 weeks [2020 magnet took 16 weeks]; we wrote 23 weeks into our schedule including post-award engineering and delivery
- Allow 9 weeks to clarify existing quotes, write detailed vendor spec
- Add 10 weeks for FNAL procurement

Cost, Schedule and Risks

- Magnet is dropped
  - Magnet is heavy and can cause injury if dropped on someone
  - If the structure containing the magnet fails, parts could fly out at high speed
  - Administrative controls for crane operation & moving heavy objects have proven reliable in FNAL operations generally.
  - Mechanical review of the support structure is planned.
- Loose ferromagnetic objects too close to the magnet accelerate into the core of the magnet, causing damage to personnel or magnet
  - Mitigation is to have a protective shield on the magnet when not running beam and to keep ferromagnetic objects out of the enclosure.
  - Can draw on previous FNAL experience with strong magnets
  - If only magnet is damaged, we might be able to re-map it after the run. The tracking depends more crucially on knowing the actual field than upon the uniformity of the field.

Conclusions

- Magnet design to meet specs exist
- Cost and schedule estimates based on industry input
- Safety issues have input from previous experience and all have operational-level mitigations