Ferrous Materials

MOLLER Collaboration Meeting – May 2023

ericking@temple.edu

TEMPLE UNIVERSITY
U.S. DEPARTMENT OF ENERGY
Jefferson Lab Exploring the Nature of Matter
Open Science Grid

Ferrous Materials – Rescattering in polarized materials

$$A_{\text{false}} = f_r \; P_e \; P_f \; A_n$$

P_f : Polarization of ferrous material
A_n: Average analyzing power of polz'd scattering processes
P_e: Polarization of the electron
f_r: fraction of detector moller signal

Note: A_{false} is Moller rate but backgrounds come from all processes so there's another factor of ~10^{-4} pops in to adjust for Moller rate.

Design Parameter for MOLLER: $\Delta A_{\text{raw}}[\text{ppb}] \approx 0.54$

We'd like two orders of magnitude cushion on a false asymmetry.

$$A_{\text{false}} \sim 0.1[\text{ppb}](10^{-2})(10^{-4}) \sim 10^{-16}$$

We do make some safe conservative approximations:

P_e ~1
A_n ~10^{-3}

What we're left with is:

$$f_r \propto \frac{A_{\text{false}}}{\chi_f}$$

Material Magnetic Susceptibility

Takeway

$$\chi_f f_r \iff A_{\text{false}}$$

Tolerable Limits

Material	X_r	Spin Polarization P_f	Fraction per e.o.t.	Fraction per Moller
Carbon Steel	2000	1E-02	1E-11	1E-07
Stainless Steel (Worst)	1	1E-05	1E-08	1E-04
Stainless Steel (Ideal)	0.01	1E-07	1E-06	1E-02
Aluminum	0.0001	1E-09	1E-04	1E+00
Inconel 625	0.001	1E-08	1E-05	1E-01
Brass/Bronze (Worst)	0.001	1E-08	1E-05	1E-01

Tungsten, too → Inconel 625

These are the quantities of interest as upper-bounds for ferrous materials scattering in our studies.

- These are the limits that we've set for normalized ferrous materials scattering backgrounds.
- I'm going to try to persuade you into agreeing these are very reasonable upper limits.

Materials: Stainless

Study done for CERN at Los Alamos in the 1990s

MAGNETIC PERMEABILITY OF STAINLESS STEEL FOR USE IN ACCELERATOR BEAM TRANSPORT SYSTEMS*

IV. CONCLUSIONS

The use of 310 with 310 weld rod or 20Cb-3 with 20Cb-3 weld rod appears to produce welds with the required permeability of not greater than 1.02, without the necessity of high-temperature solution annealing of large welded components. The availability of two metal/weld rod combinations allows the fabrication process and material to be selected on basis of cost of fabrication and availability of materials.

Table 1 - Magnetic Permeability - μ

Material	As Received	After Anneal [1]	After Electropolish	Weld Rod	After TIG Welding	Post-Weld Anneal [2]
304L	1.05-1.1	1.02-1.05	<1.01	E/ER 309	2.2-2.5	1.4+
316L [3]	<1.01	<1.01	<1.01	E/ER 316	1.6	1.10-
				E/ER 316L	1.6	1.02-1.05
				E/ER 316L [4]	1.4 [4]	1.02-1.05
				E/ER 310	1.02-1.05	<1.01
20Cb3	1.01-1.02	1.02-1.05	<1.01	E/ER20Cb3	<1.01	<1.01
310	<1.01	<1.01	<1.01	E/ER 310	<1.01	<1.01
Nitronic 33	<1.01	1.02-1.05	<1.01	NIT33	1.1	<1.01
Nitronic 40	<1.01	<1.01	<1.01	NIT40	1.1-1.15	1.02+
317LN	<1.01	<1.01	<1.01	E/ER 317	1.2-1.4	<1.01

1. Anneal conditions: 1800° for 75 min on 20Cb-3, 1980° for 40 min on all other types.
2. Post-weld anneal conditions: 1825° for 60 min in nitrogen at a pressure of approximately 4x10-5 torr on all samples.
3. The same 316L coupons were welded with four different weld rods.
4. Arc welded with coated rod.

*Table copy courtesy of Don

Materials: Brass/Bronze

Worst case brass/bronze susceptibility is ~10-3

Note: Ignoring 'free cutting brass'

Measured X_rs:

Silicon Brass: (consistent) $<10^{-3}$
Brass 485: (consistent) $<10^{-3}$

Brass 360:
Inconsistent upperbound as much as $2(10^{-2})$

Magnetic Susceptibility

Room Temp

C10100	OXYGEN FREE COPPER	8.94	-9.37E-6	-2.98E-6	D
[illegible]	[illegible]	8.92	3.22E-5	2.53E-5	P
[illegible]	[illegible]	8.89	-4.44E-6	4.96E-4	D-P
[illegible]	[illegible]	8.97	7.47E-5	6.74E-5	P
C17200	BERYLCO 25	8.33	1.56E-3	1.82E-3	P
C18200	CHROME COPPER	8.94	-3.60E-6	7.51E-5	D-P
C18700M	DEOXIDIZED C18700	8.95	2.76E-4	-4.01E-3	P-D
C18900	HIGH COPPER ALLOY	8.89	2.36E-4	2.59E-3	P
C22000H	COMMERCIAL BRONZE	8.80	-5.69E-6	7.63E-6	D-P
C22600	JEWELRY BRONZE 87.5	8.83	-3.19E-6	1.26E-5	D-P
C230001	RED BRASS 85	8.76	-5.85E-6	3.38E-5	D-P
C260002	CARTRIDGE BRASS 70	8.52	-3.48E-6	-6.14E-5	D
C31600	LEADED BRONZE W NI	8.86	-7.86E-6	-1.26E-2	D
C34000	MEDIUM LEADED BRASS 64	8.48	9.42E-5	-8.36E-3	P-D
C35300	HIGH LEADED BRASS 62	8.50	3.36E-3	-2.37E-2	P-D
~~C36000~~	~~FREE CUTTING BRASS~~	~~8.52~~	~~1.12E-2~~	~~1.40E-2~~	~~P-D~~
C44300	ADMIRALTY BRASS AS	8.55	-1.27E-5	-2.62E-5	D
C46400	NAVAL BRASS UNINHIBITED	8.43	6.64E-4	7.85E-3	P
C46400H	NAVAL BRASS	8.40	5.54E-4	1.17E-3	P
C48200	NAVAL BRASS MED LEAD	8.44	5.63E-5	-1.81E-3	P-D
C48500	NAVAL BRASS HIGH LEAD	8.50	5.80E-4	-2.21E-2	P-D
C50700	PHOSPHOR BRONZE 1.25	8.95	-5.98E-6	-3.98E-6	D
C51000	PHOSPHOR BRONZE 5 A	8.95	-5.86E-6	-5.56E-6	D
C61000	ALUMINUM BRONZE	7.88	-9.02E-6	-1.12E-5	D
C64700	SILICON BRONZE	8.91	4.04E-6	7.95E-5	P
C65100	LOW SILICON BRONZE B	8.75	2.85E-5	2.09E-3	P
C655001	HIGH SILICON BRONZE A	8.56	2.30E-4	8.02E-3	P
C65600	SILICON BRONZE	8.54	2.84E-4	8.67E-3	P
C66100	SILICON BRONZE	8.55	1.30E-4	4.48E-3	P
C77300	NICKEL SILVER	8.44	4.96E-6	1.42E-4	P

I've placed these slides towards the beginning just in case we are really crunched for time.

Main Points

General Points

- Stainless steel components are okay so long as they're not in a high field and there's no straight LoS to the detectors.
- Inside the spectrometer we're going to need to use the ferromaster to check SS and brass components.
- We've made conservative estimates to set our tolerable ferrous background limits.

I’ve placed these slides towards the beginning just in case we are really crunched for time.

Main Points

On the limits

- We’ve made conservative estimates to set our tolerable ferrous background limits.
- Additionally,
    1. We don’t calculate the effects of depolarization (Maximon & Olsen paper) in our analysis.
    2. Field weighting doesn’t take into field directions.
    3. We also don’t account for spin precession of e- while in the fields.

Collectively (as these should all work in our favor were we to calculate them), this all suggests that what I referred to as ‘Tolerable Limits’ are prudently set and safe upper bounds.

Process: Simulation

(1) Run simulations of ***beam on target***
   (a) Volumes of interest are first placed in parallel world as SD volumes.
   (b) Typically run 10B events
      (i) Under 1 MeV? StopAndKill
      (ii) No hits? Don't record event in ROOT file.

(2) Skim electrons–beam electron or daughter of beam electron– that pass through ferrous volumes being studied.
   (a) Only count any given electron once on initial entry into a ferrous volume.
   (b) Skimmed events are stored in ROOT file to be used in secondary simulation.

(3) Secondary simulations run with input from skimmed ROOT file.
   (a) Sensitive detector volumes for the main detector and cylindrical volume encasing the PMT region (SD for this region overestimates hits).
   (b) Number of events can vary. I default to ~100K. Although, I try to make sure that sample the primary simulation hits a sufficient number of times in the secondary simulations so it can be 500K or 1M events.

(4) Analyze!

Analysis

If secondary simulation event results in a hit(s):

(1) Check to see if vertex originated in magnetic field – if so then assign weight equal to field strength in gauss (Default weighting for events is 1 assuming ~1 gauss ambient field)

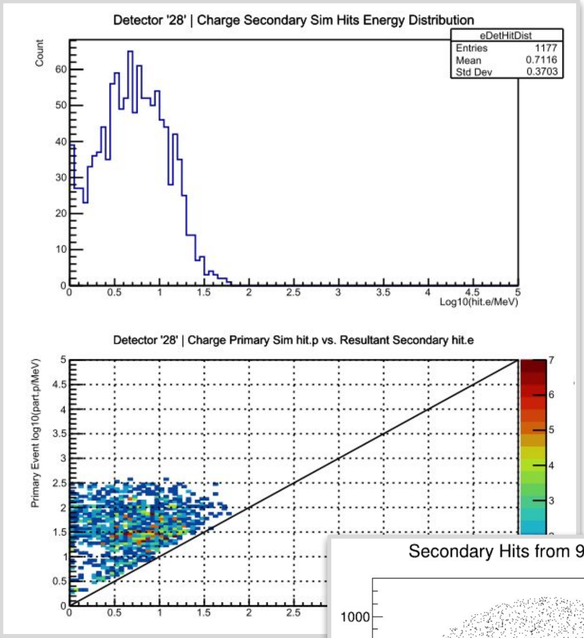
(2) Take results and normalize against total generated vertex weight.

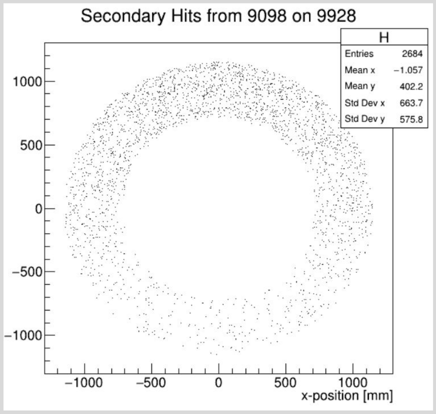
(3) Hits < 1 MeV are not counted.

(4) Output select histograms and csv file.

Calculating total beam on target event fraction:

⇒ Multiply secondary simulation fractional hit rate by primary simulation fractional hit rate to get total 'simulated' fractional hit rate.





Sample images from recent barite wall simulations

We've previously looked at many different histograms but we're ideally down to energy distributions and hit locations on the detector volumes.

Analysis

If secondary sim

(1) Check to see
if so then ass
gauss (Defau
gauss ambie

(2) Take results o
vertex weigh

(3) Hits < 1 MeV

(4) Output selec

Calculating tota

⇒ Multiply secon
primary simulation
'simulated' fractional

We do not take depolarization into account

This works in our favor with an overestimate of the ferrous scattering background.

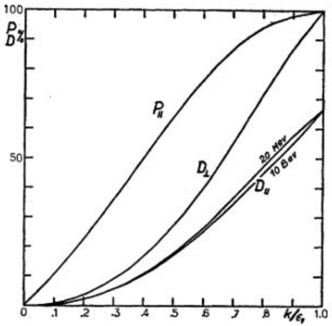


FIG. 5. Circular polarization of bremsstrahlung beam from longitudinally polarized electrons,

$$P_{\parallel}=P(\mathbf{p}_1,\zeta_{1\,\text{long}},\mathbf{e}_{\text{circ}}),$$

and depolarization of longitudinally polarized electrons,

$$D_{\parallel}=D(\mathbf{p}_1,\zeta_{1\,\text{long}})$$

and of transversely polarized electrons, $D_{\perp}=D(\mathbf{p}_1,\zeta_{1\,\text{trans}})$. Coulomb and screening effects are included. The curves for $P_{\parallel}$ and $D_{\perp}$ are valid for all elements and for any incident electron energy above ≈20 Mev. $D_{\parallel}$ depends slightly on the electron energy; curves are shown for incident electron energies 20 Mev and 10 Bev.

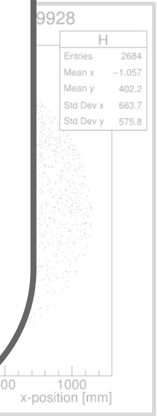
Photon and Electron Polarization in High-Energy Bremsstrahlung and Pair Production with Screening*

HAAKON OLSEN, *Fysisk Institutt, Norges Tekniske Høgskole, Trondheim, Norway*

AND

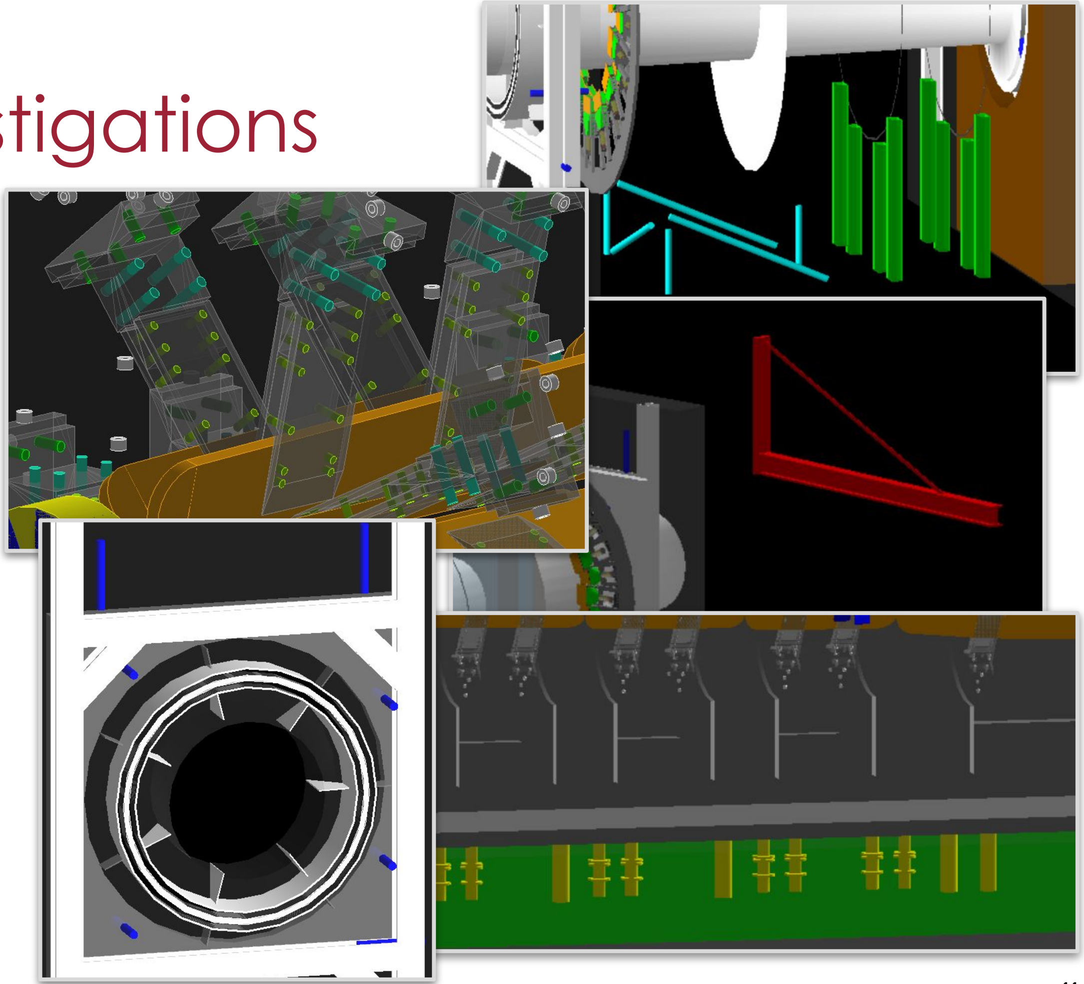
L. C. MAXIMON,† *Fysisk Institutt, Norges Tekniske Høgskole, Trondheim, Norway and Department of Theoretical Physics, The University, Manchester, England*

(Received November 24, 1958)



List of Recent Investigations

- Fasteners in toroid region
- Collimators 1 & 2
- Drift pipe vacuum pipe
- Detector Supports
- Concrete Scraping
- Pion-donut tie rods
- Jib crane
- Power leads
- GEM supports
- Collar 2 barite wall
- Bellows (done by Ryan)



Components which aren't a concern

- Fasteners in toroid region
- Collimators 1 & 2←**Not a concern**
- Drift pipe vacuum pipe←**Not a concern**
- Detector Supports ←**Not a concern**
- Concrete Scraping←**Not a concern**
- Pion-donut tie-rod ends←**Not a concern**
- Jib crane←**Not a concern**
- Power leads←**Not a concern**
- GEM supports←**Not a concern**
- Collar 2 barite wall
- Bellows (done by Ryan)

(For example) Jib Crane SensDet 9209

Primary Events	9,850,000,000

Primary Counts			
Det/mTrid	0	1	TOT
9209	1434	3795	5229

Primary Fractional			
Det/mTrid	0	1	TOT
9209	1.5E-07	3.9E-07	5.3E-07

Secondary (Beam Only)			
Total Events	500000	Sec Fractional	Total Fractional
[9928] Charges > 1MeV	38	7.6E-05	2.9E-11
[9928] Gammas > 1MeV	92	1.8E-04	7.1E-11
[9911] Charges > 1MeV	337	6.7E-04	2.6E-10
[9911] Gammas > 1MeV	491	9.8E-04	3.8E-10

Secondary (Beam and daughter e-)			
Total Events	500000	Sec Fractional	Total Fractional
[9928] Charges > 1MeV	54	1.1E-04	5.7E-11
[9928] Gammas > 1MeV	27	5.4E-05	2.9E-11
[9911] Charges > 1MeV	366	7.3E-04	3.9E-10
[9911] Gammas > 1MeV	137	2.7E-04	1.5E-10

Material	X_r	Spin Polarization P_f	Fraction per e.o.t.	Fraction per Moller
Carbon Steel	2000	1E-02	1E-11	1E-07
Stainless Steel (Worst)	1	1E-05	1E-08	1E-04
Stainless Steel (Ideal)	0.01	1E-07	1E-06	1E-02
Aluminum	0.0001	1E-09	1E-04	1E+00
Inconel 625	0.001	1E-08	1E-05	1E-01
Brass/Bronze (Worst)	0.001	1E-08	1E-05	1E-01

Components which require care

- **Fasteners in toroid region** →
- Collar 2 barite wall
- Bellows (done by Ryan)
- HRS steel floor tracks

Fasteners:
- Proper material selection is important.
- Ferrous simulations highlight the importance of measuring each of these components with a ferromaster to ensure quality.
- Fasteners in TM4-region account for most of the backgrounds.

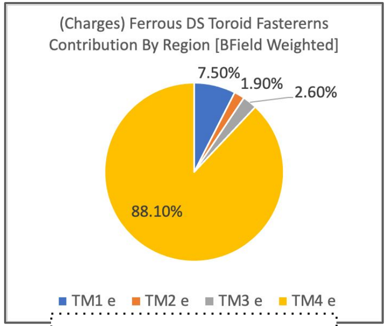
Radius from coils: $r_{9010} < r_{9020} < r_{9030}$ (See backup slide if needed)

Zone	Primary (per e.o.t.)	Secondary (per primary)	Total fraction (per e.o.t.)	Mean B-field at vertex	B-field scaled fraction (per e.o.t.)	Allowable X_r
9010	2.1E-05	4.2E-04	8.7E-09	270 G	2.3E-06	4e-3
9020	2.7E-05	1.7E-03	4.6E-08	38 G	1.8E-06	6e-3
9030	1.3E-05	5.5E-04	7.2E-09	11 G	8.0E-08	0.1

Table taken from slides Kent made

There's a need for quality brass here.

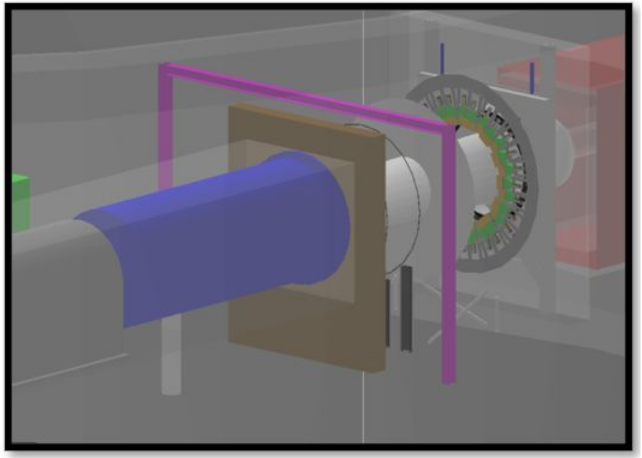
Refer back to earlier brass slide.



Backup slide for breakdowns if anyone is interested.

Components which require care

- Fasteners in toroid region
- **Collar 2 barite wall**
- Bellows (done by Ryan)
- HRS steel floor tracks



- First-round ferrous simulations used simpler 'older' barite wall support idea.
- Simulations with more accurate design underway (I'm building the GDML).
  - Top portion will be shielded but there will be more 'leg mass' (so outcome uncertain)
- Takeaway: Care in material and perhaps design is likely key here.

Results of this basic geometry model suggest material sensitivity

(9928 MainDet) Total Fractional - 0&1		
Secondaries	Electrons	Gammas
9098	3.02E-09	3.85E-09

(9911 PMT Region) Total Fractional - 0&1		
Secondaries	Electrons	Gammas
9098	1.15E-08	1.46E-08

Material	X_r	Spin Polarization P_f	Fraction per e.o.t.	Fraction per Moller
Carbon Steel	2000	1E-02	1E-11	1E-07
Stainless Steel (Worst)	1	1E-05	1E-08	1E-04
Stainless Steel (Ideal)	0.01	1E-07	1E-06	1E-02
Aluminum	0.0001	1E-09	1E-04	1E+00
Inconel 625	0.001	1E-08	1E-05	1E-01
Brass/Bronze (Worst)	0.001	1E-08	1E-05	1E-01

Components which require care

- Fasteners in toroid region
- Collar 2 barite wall
- **Bellows (done by Ryan)**

Bellows:

- Ryan's recent simulations continue to support the need for high-quality materials for the bellows.
- Collar 1 design improvements (Ryan has already or will give this talk) *should* further tamp down ferrous backgrounds from the bellows.

Final Slide

(1) We're happy to field questions about components.

- ➢ No SBS over the late-spring and early-summer so I have some time.

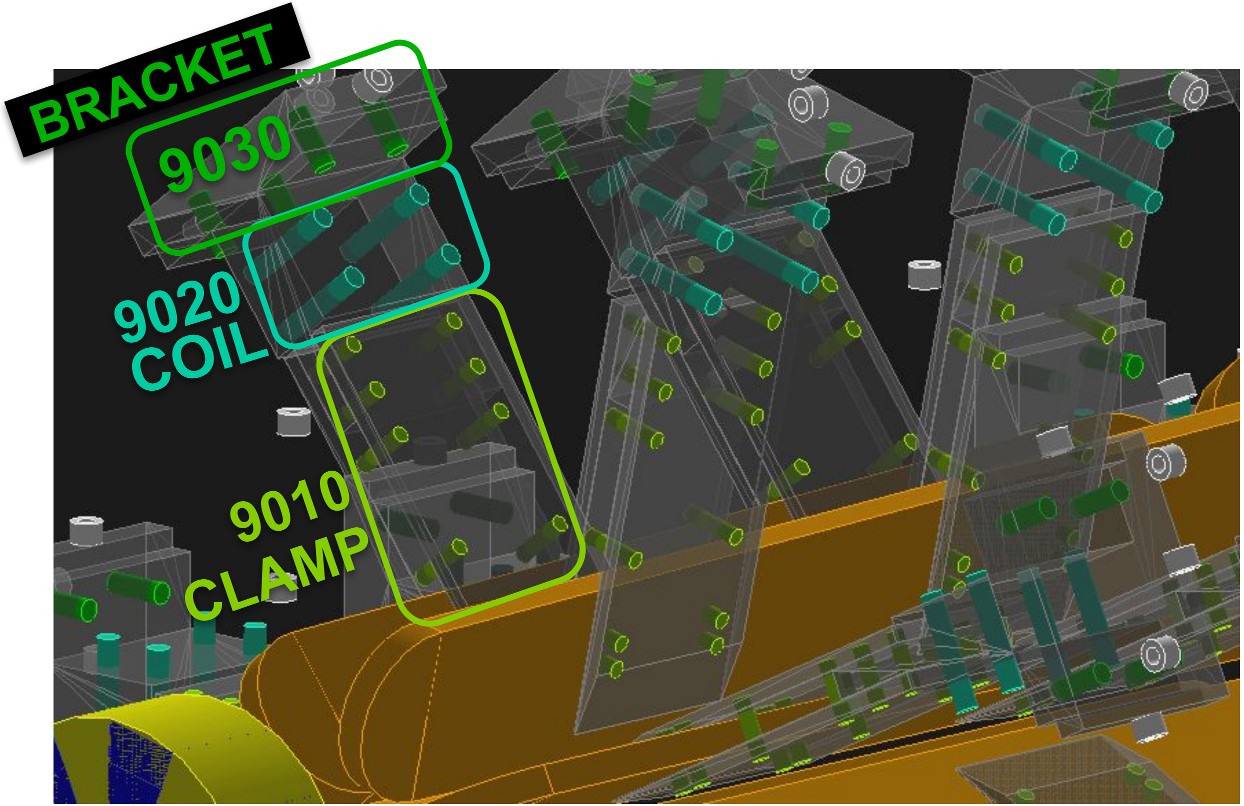
(2) I hope I've convinced or at least persuaded people into the idea that we've set prudent upper-bounds on ferrous scattering.

(3) There is no #3. Just see #1 and #2 again.

Questions?

Comments?

Fastener Reference Slide



Backup Slide: Tabled Fastener Results

TM1 Region Contribution				
Type:	Charges		Gammas	
Det	Frac Total	Frac Wtd	Frac Total	Frac Wtd
9010	2.5%	7.5%	10.7%	23.4%
9020	0.1%	0.0%	0.9%	0.0%
9030	0.0%	0.0%	0.2%	0.0%
TM1 SUMS	**2.7%**	**7.5%**	**11.9%**	**23.4%**

TM2 Region Contribution				
Type:	Charges		Gammas	
Det	Frac Total	Frac Wtd	Frac Total	Frac Wtd
9010	1.3%	1.8%	5.2%	6.2%
9020	2.3%	0.1%	5.8%	0.2%
9030	1.3%	0.0%	2.5%	0.1%
TM2 SUMS	**4.9%**	**1.9%**	**13.5%**	**6.4%**

TM3 Region Contribution				
Type:	Charges		Gammas	
Det	Frac Total	Frac Wtd	Frac Total	Frac Wtd
9010	0.7%	1.2%	2.7%	4.6%
9020	6.4%	1.1%	9.0%	1.4%
9030	4.4%	0.2%	5.0%	0.2%
TM3 SUMS	**11.5%**	**2.6%**	**16.8%**	**6.2%**

TM4 Region Contribution				
Type:	Charges		Gammas	
Det	Frac Total	Frac Wtd	Frac Total	Frac Wtd
9010	11.1%	50.9%	11.0%	41.6%
9020	55.0%	34.1%	37.2%	20.6%
9030	14.9%	3.1%	9.6%	1.7%
TM4 SUMS	**80.9%**	**88.1%**	**57.9%**	**63.9%**

Mean Magnetic Field at Detector Event 'Vertices' in Gauss					
Det/Type	TM1	TM2	TM3	TM4	ALL
9010/e	204.8	91.3	117.6	313.9	268.4
9020/e	1.7	2.6	12.1	42.5	37.9
9030/e	1.8	1.7	3	14.4	11.2
9010/g	172.1	93.3	134	297.6	201.4
9020/g	1.8	2.7	12.2	43.8	33.2
9030/g	1.7	1.7	2.9	13.9	8.9

↑ Mean magnetic fields

← Background contributions