Ferrous Materials Update

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Rescattering in spin-polarized material

Asymmetry due to spin-dependent rescattering: $A_{false} = f_r \; P_e \; P_f \; A_p$, with

- f_r = fraction of main detector signal from asymmetry process, relative to MOLLER rate.
- P_e = polarization of the incident electron or photon
- P_f = average spin polarization of the electron in the ferromagnetic material
- A_p = average analyzing power of polarized (multiple) scattering process

Calculation requires a bit of care to define and quantify terms, some general limits are easier to set.

Goal:

ΔA_{raw} = 0.54 ppb

Spin-dependent rescattering should be negligible,

so aim for << 0.1 ppb = 10^{-10} with wide margin of 10-100, so aim for 10^{-12}

Moller is ~10^{-4} of electrons-on-Target (eoT), so our goal is $A_p P_e P_f f_r \sim 10^{-16}$ per eoT.

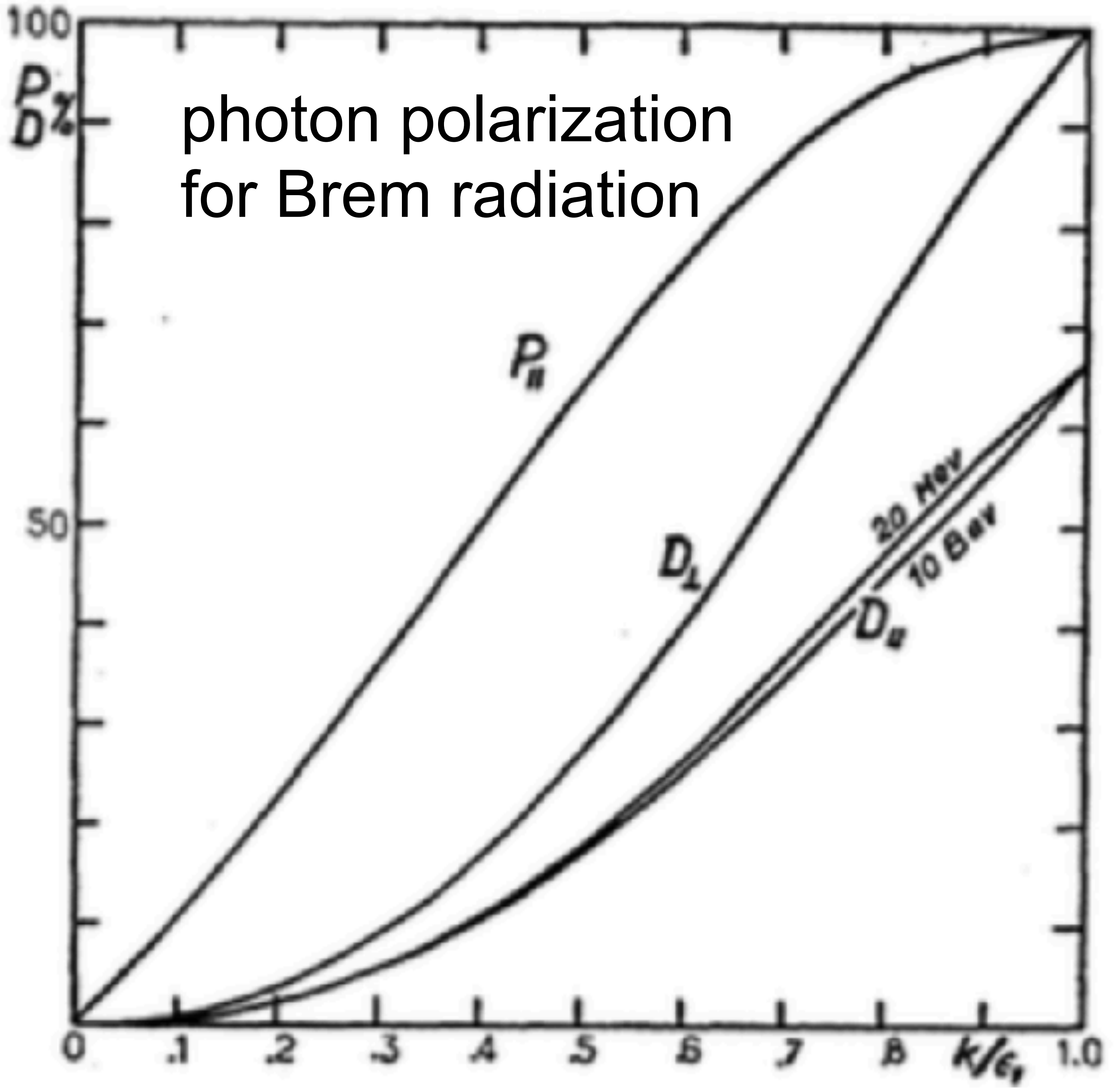
Of course, this probably varies a lot across the detector plane, where rates are < Moller rate but precision is also lower. To keep things simple, we consider all rate in detector rings 1-6 in the above estimate

Which polarized particles do we care about?

Obviously the beam particle is polarized, and remains so for small angle scattering.
But the shower can pick up polarization also, and the beam particle doesn't easily depolarize:

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

Haakon Olsen and L. C. Maximon
Phys. Rev. **114**, 887 – Published 1 May 1959

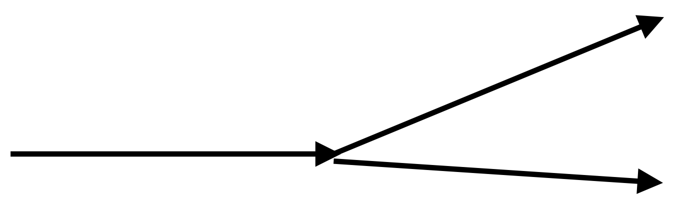


depolarization up to about 70% for full energy loss

We do one simulation considering only the primary electron (where we can guess at the polarization) but also run through all secondaries

What about analyzing power?

Analyzing power is complicated, even when considering moderately large energies



2-spin analyzing power A_p makes scattering rate depend on polarization
But… what if events are lost when they scatter? (Asym = -A_p) vs when both are detected (Asym = A_p) or one is detected whether is scatters or not (Asym = 0, regardless of A_p)

Measure the analyzing power with simulation? This is tricky!
- If the polarization dynamics were built into G4, you could run a “beam generator” with difference starting polarization… but we are looking for ~<1e-3 asymmetries, so to measure non-zero result you need >1e6 detected events in each bin
- you could average asymmetry values from a generator, but you need to start with the required initial state and end up with a detected final state, and normalize the separate, asymmetric process to other processes.
- How do you handle multiple scatters?

Naive back-of-the-envelope estimate

Compton scattering:

- spin dependent γe scattering (with polarized brem γ from e polarization)
- best guess from transmission polarimeters may be $A_n < 10^{-3}$ for low energy (and 10^{-4} for high energy), but requires care to extrapolate to our case

Møller scattering:

- spin dependent ee scattering, mostly primary electron (for high polarization)
- if selecting Møller events near 90^o C.o.M. would have $A_n \sim 1$
- what range of CoM does one collect zero, one, or both electrons?
- What is $\sigma_{Møller} / \sigma_{total}$? (we aren't intentionally isolating Moller scattering from this ferrous material)
- Probably ends up 10^{-3} or smaller, but depends on geometry and incident energy and would require individual simulation for any special case

Spin polarization of materials

Saturated iron: $P_f \sim 8\%$

In ambient fields (0.5-2 G measured in Hall A):

Mild steel: $\chi_r \sim 2000$, $P_f \sim$ few x 10^{-3}

Stainless steel: expect this to be history dependent

$\chi_r \sim 1$, $P_f \sim$ few x 10^{-6}

(or with hysteresis, could be 20x higher, so ~10^{-4})

or if well-annealed: $\chi_r \sim 0.01$, $P_f \sim$ few x 10^{-8}

Aluminum (paramagnetic): $\chi_r \sim 10^{-4}$, $P_f \sim$ few x 10^{-10}

For higher fields, assume mild steel is ~ saturated, and others materials scale linearly

Naive back-of-the-envelope estimates

We aim for aim for $\Delta A \sim< 10^{-12}$ when considering just the Moller rate

Moller is $\sim 10^{-4}$ of electrons-on-Target (eoT), so our goal is $A_p P_e P_f f_r \sim 10^{-16}$ per eoT.

Assume $A_n \sim 10^{-3}$ (if it could be much larger than this, people could make better transmission polarimeters)

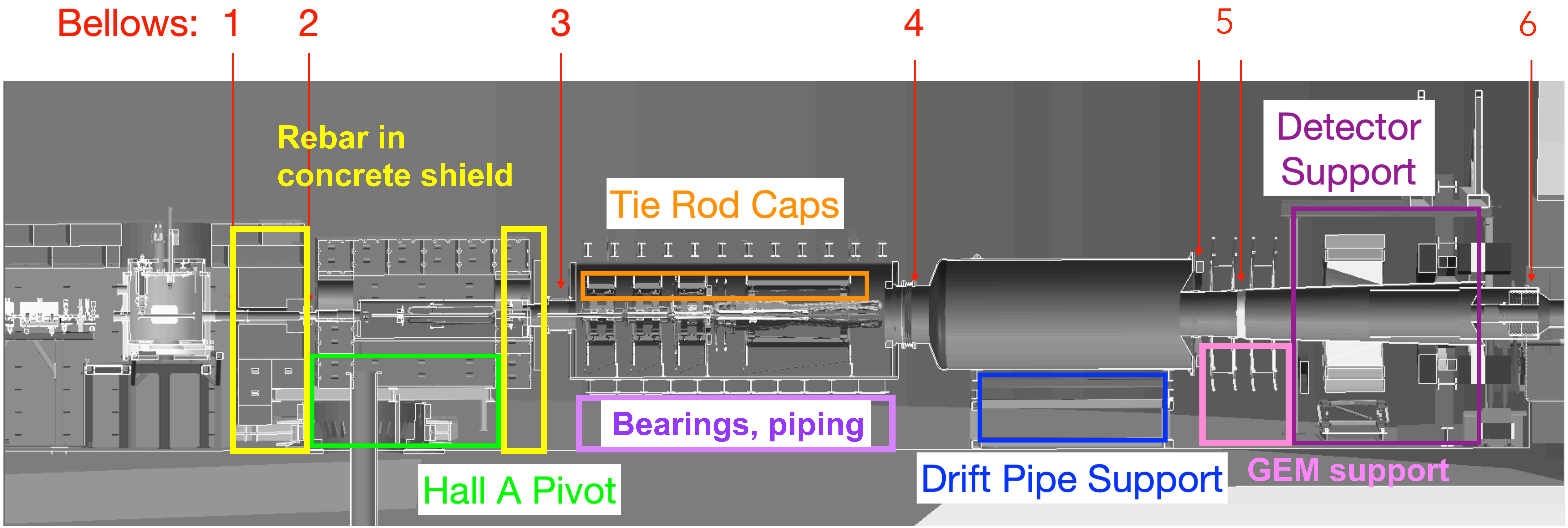
Assume $P_e \sim 1$ (or, use depolarization curve and assume single brem radiation, usually ends up at 1/3)

then $P_f f_r \sim 10^{-9}$ of Møller signal, 10^{-13} per eoT

	χ_r	spin polarization P_f	Fraction of events per Møller event	Fraction of events per eoT
Mild Steel	2000	10^{-2}	10^{-7}	10^{-11}
Stainless Steel (worst case)	1	10^{-5}	10^{-4}	10^{-8}
Stainless Steel (ideal)	0.01	10^{-7}	10^{-2}	10^{-6}
Aluminum	0.0001	10^{-9}	1	10^{-4}

Again: these are conservative estimates - we could do better, but it would take work

Ferrous materials



Bellows: inconel 625

Hall A Pivot: mild steel

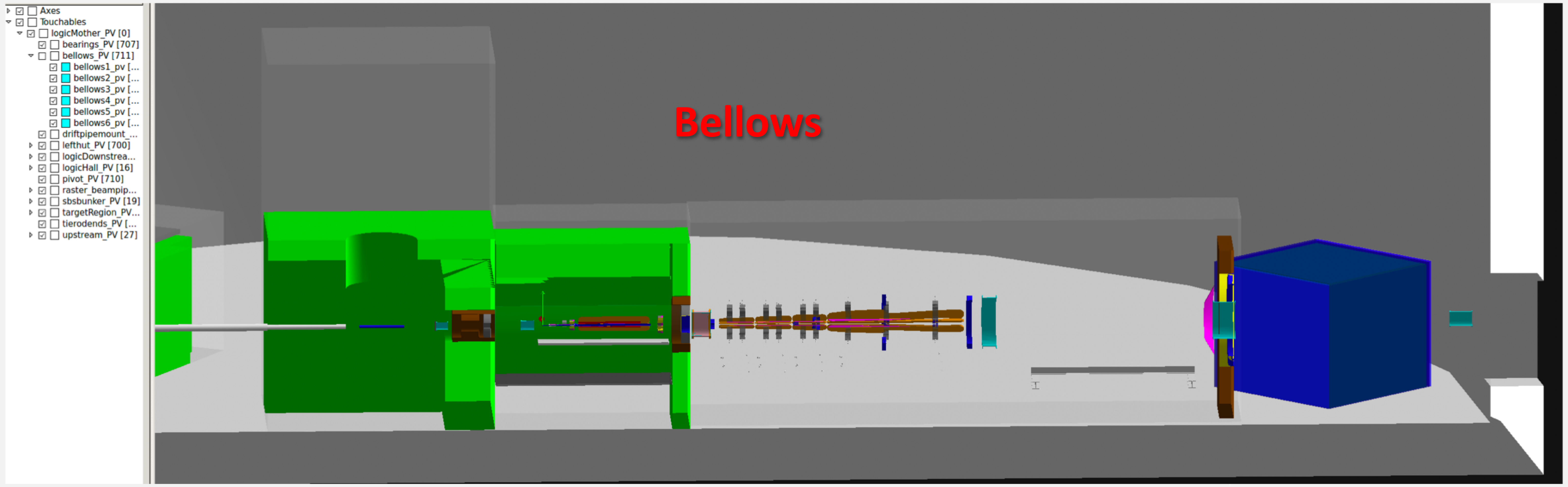
Supports for drift pipe and downstream torus support, GEM and Detector support

Tie Rod ends: stainless?

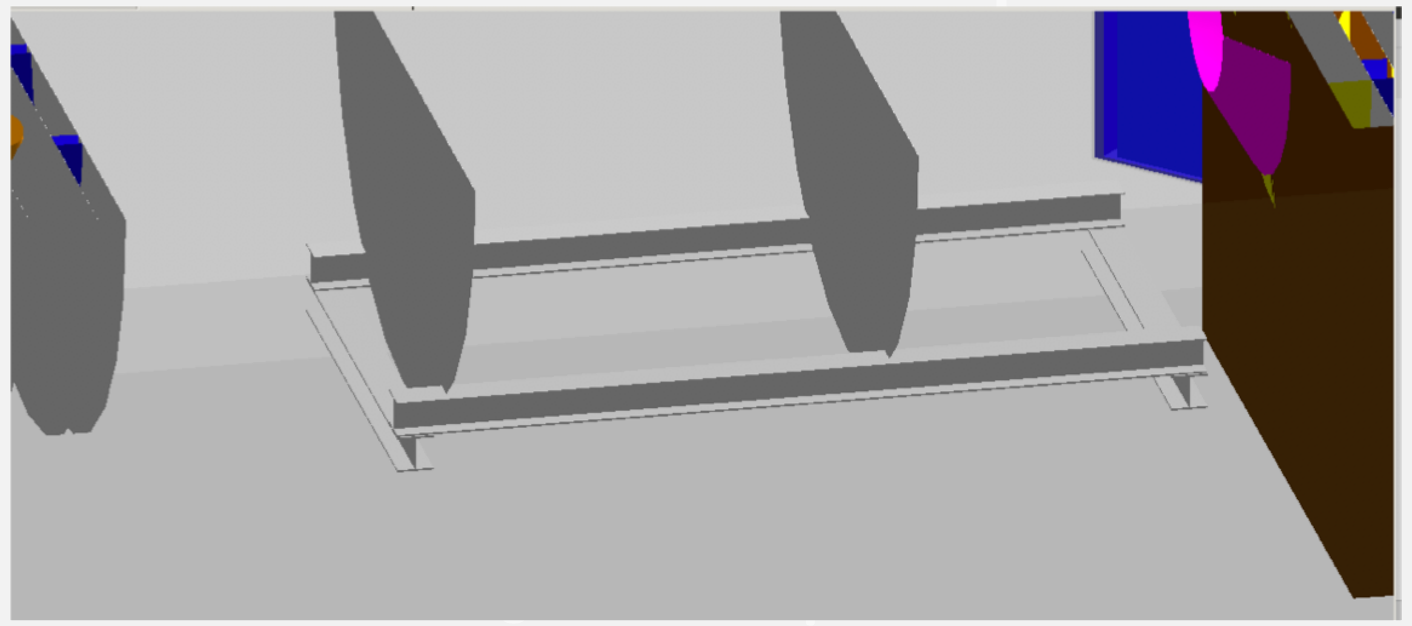
Bearings: stainless **Rebar:** stainless? **GEM support:** stainless?

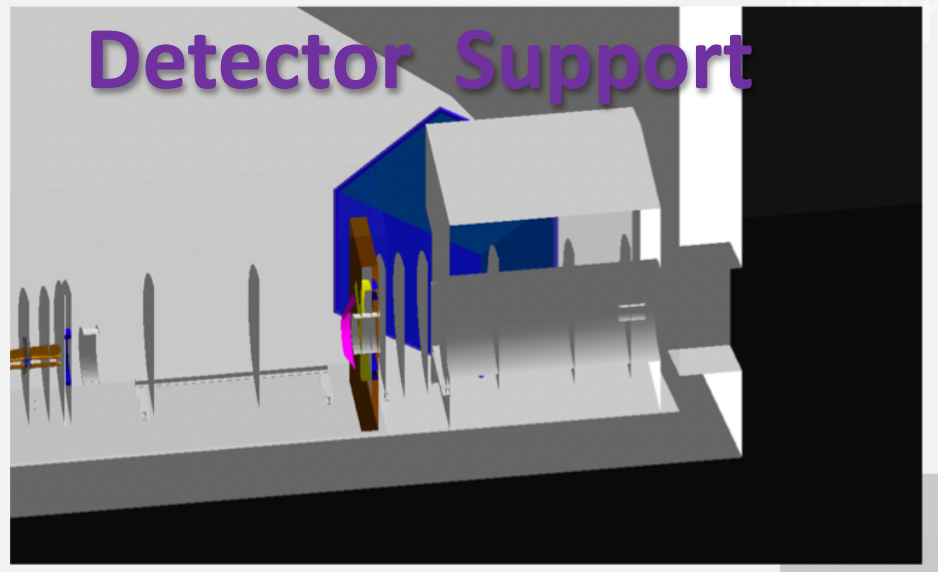
Simulation: Put virtual shapes in as detectors

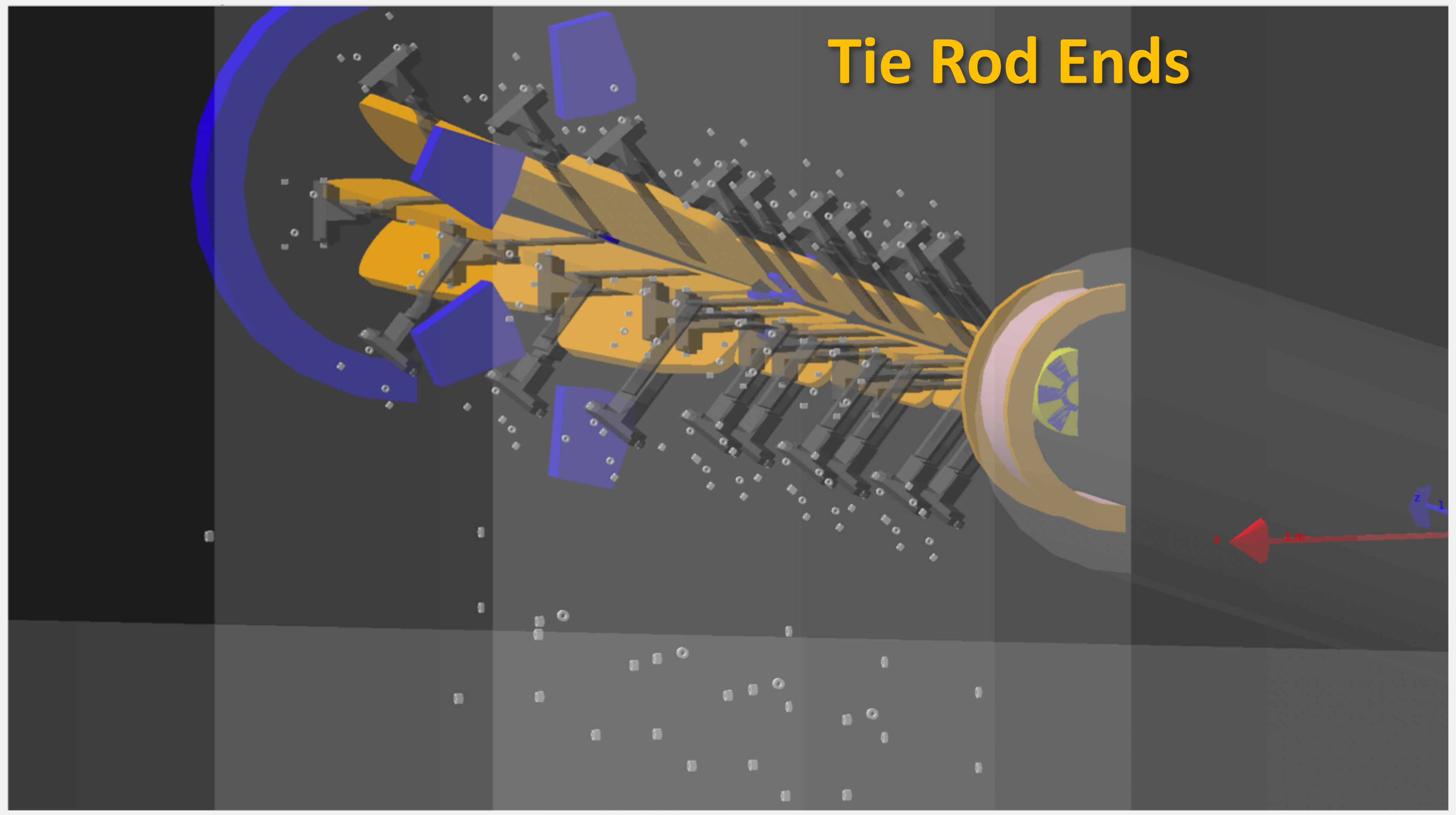
- Add virtual components to featurePhotonBlocker (Chandan branch)
- Collect beam electrons which are incident upon each virtual component

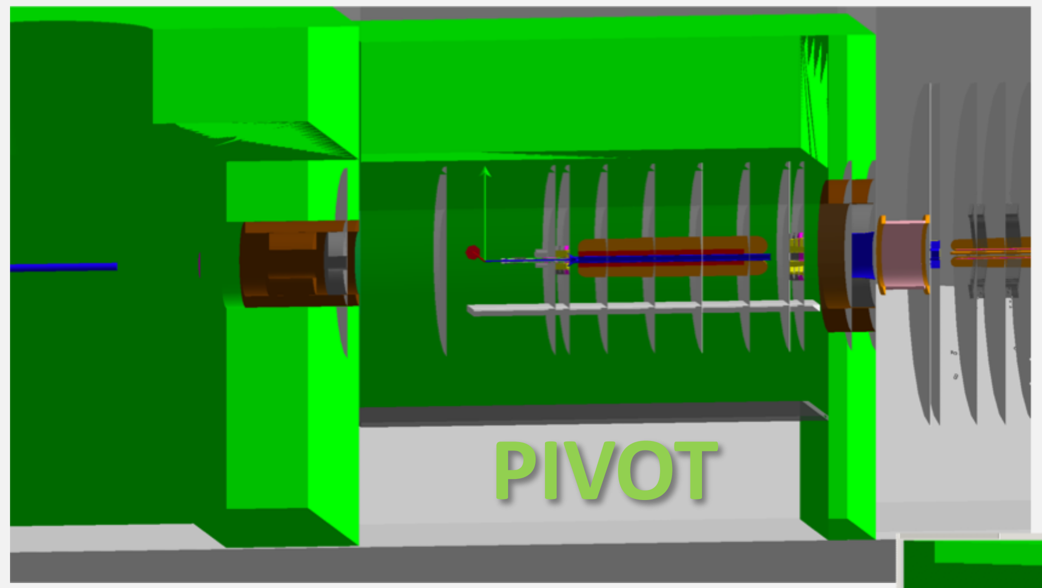


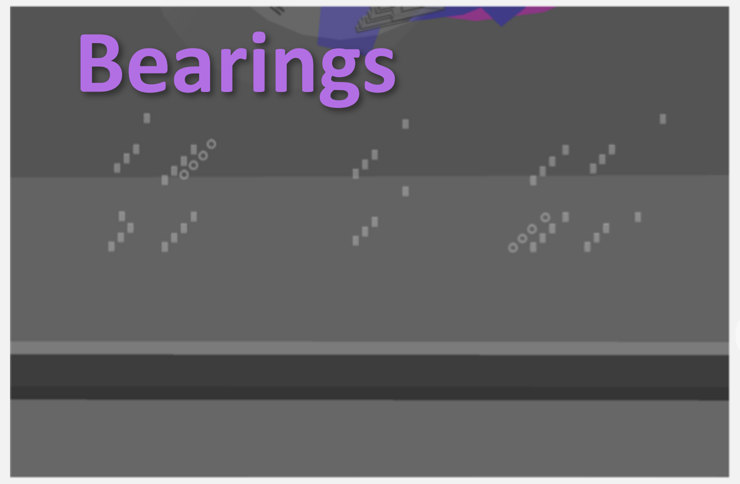
Drift pipe support



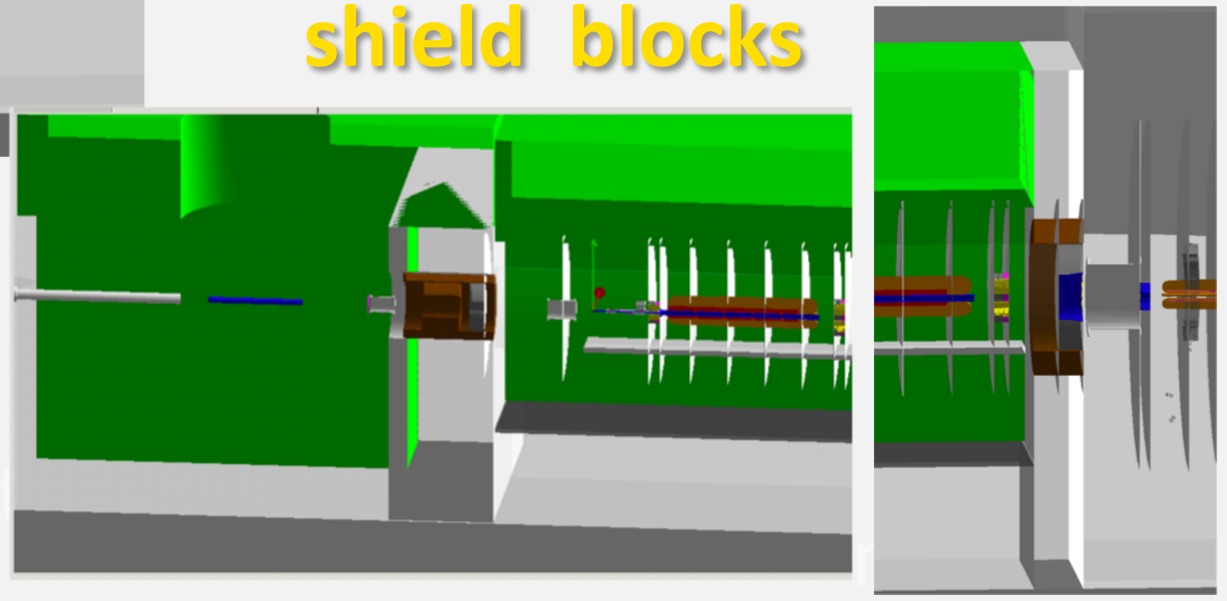




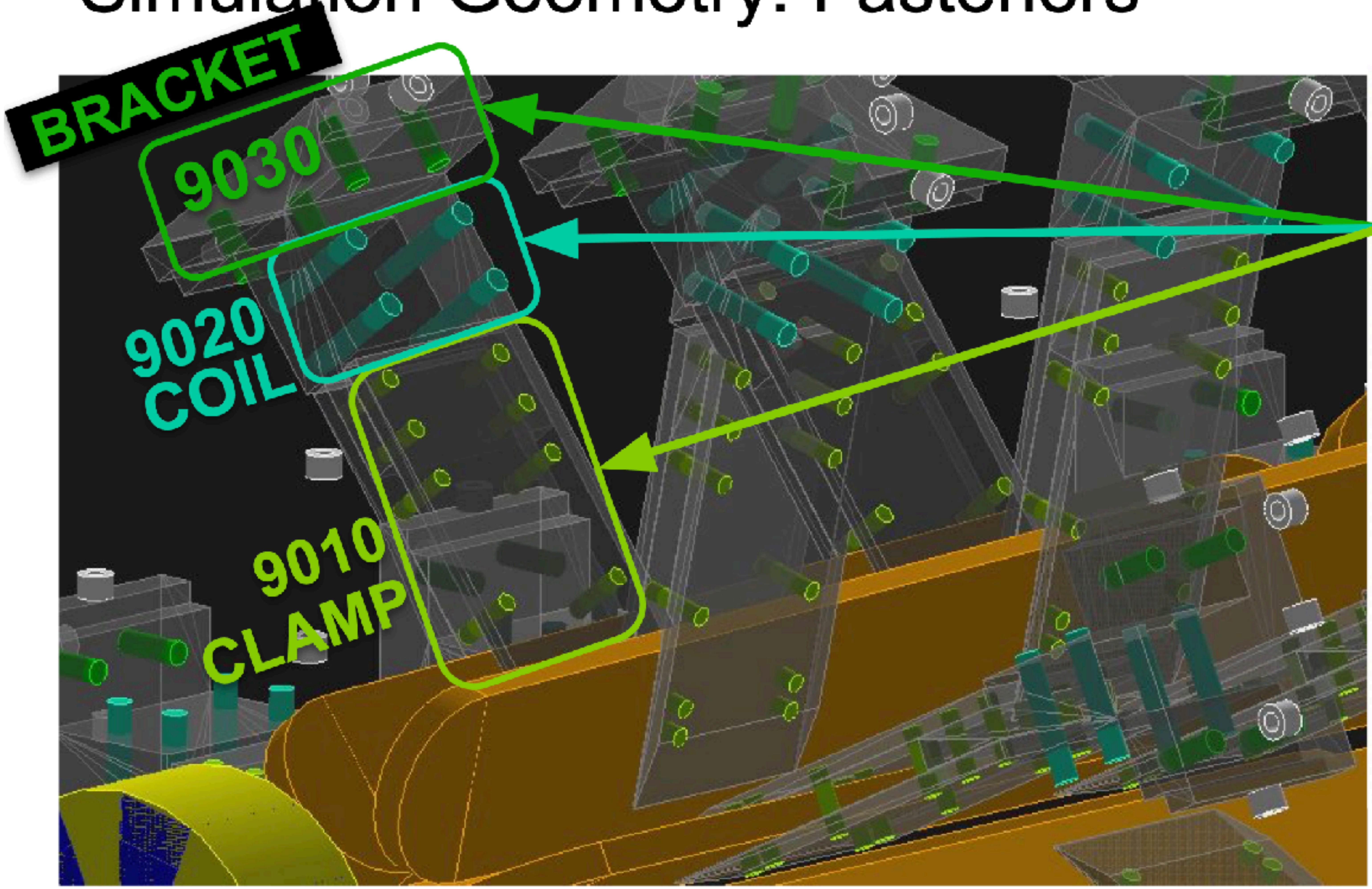




Rebar in concrete shield blocks



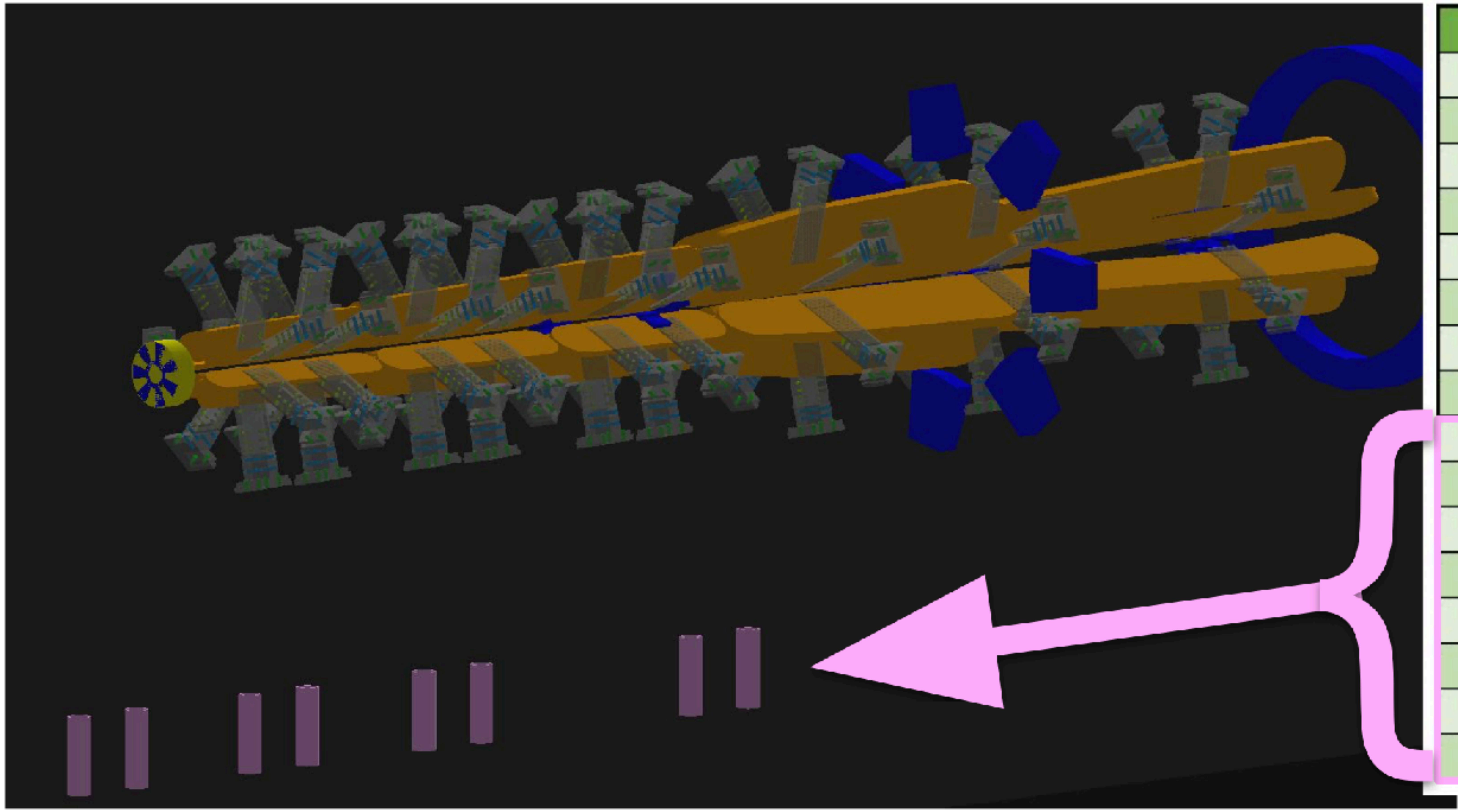
Simulation Geometry: Fasteners



Detectors	
9001	PIVOT
9010	Fasteners Plate
9020	Fasteners Coil
9030	Fasteners Brackets
9040	Fasteners Outer (Debug Geo)
9060	Tierod Ends
9099	Drift Pipe Mount
9100	Drift pipe vacuum pipe
9101	Water-cooled Leads DS Mag T1 Supply
9102	Water-cooled Leads DS Mag T1 Return
9103	Water-cooled Leads DS Mag T2 Supply
9104	Water-cooled Leads DS Mag T2 Return
9105	Water-cooled Leads DS Mag T3 Supply
9106	Water-cooled Leads DS Mag T3 Return
9107	Water-cooled Leads DS Mag T4 Supply
9108	Water-cooled Leads DS Mag T4 Return

[Eric King, docdb:891]

Simulation Geometry: Water-cooled Leads

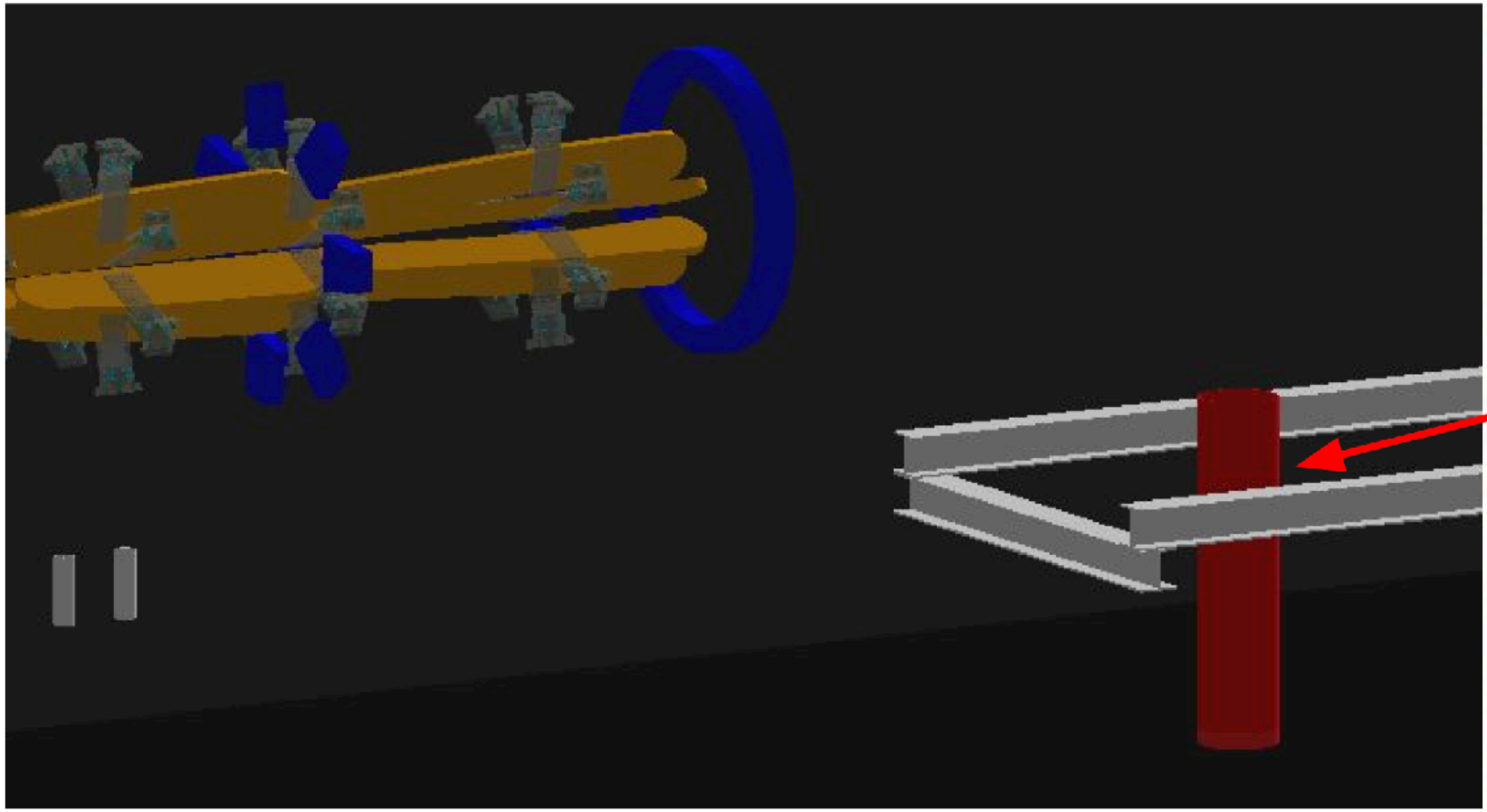


Detectors	
9001	PIVOT
9010	Fasteners Plate
9020	Fasteners Coil
9030	Fasteners Brackets
9040	Fasteners Outer (Debug Geo)
9060	Tierod Ends
9099	Drift Pipe Mount
9100	Drift pipe vacuum pipe
9101	Water-cooled Leads DS Mag T1 Supply
9102	Water-cooled Leads DS Mag T1 Return
9103	Water-cooled Leads DS Mag T2 Supply
9104	Water-cooled Leads DS Mag T2 Return
9105	Water-cooled Leads DS Mag T3 Supply
9106	Water-cooled Leads DS Mag T3 Return
9107	Water-cooled Leads DS Mag T4 Supply
9108	Water-cooled Leads DS Mag T4 Return

**Geometries per David Kashy*

[Eric King, docdb:891]

Simulation Geometry: Drift pipe vacuum pipe



Detectors	
9001	PIVOT
9010	Fasteners Plate
9020	Fasteners Coil
9030	Fasteners Brackets
9040	Fasteners Outer (Debug Geo)
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9105	Water-cooled Leads DS Mag T3 Supply
9106	Water-cooled Leads DS Mag T3 Return
9107	Water-cooled Leads DS Mag T4 Supply
9108	Water-cooled Leads DS Mag T4 Return

**Geometry per Cip (bottom of drift pipe to floor)*

Specs: (IR) 19cm; (OR) 20cm; (Length) 172cm [bottom of drift pipe to floor in simulation]
Simulation Material: ***G4_Stainless-Steel***

[Eric King, docdb:891]

Results

Reminder for background per e.o.t. goals:

SS (ideal): 10-6
SS (worst): 10-8

Brass/Bronze (worst): 10-5

(Normalized) Bfield Weighted Charge Detections at DetNo 28									
DetNo	ExtGenN	<1MeV	1-10M	10-100M	.1-1G	1-10G	>10GeV	TOTAL	PER EOT
9010	100000	4.4E-02	1.1E-01	3.2E-01	2.7E-01	0.0E+00	0.0E+00	7.4E-01	3.6E-06
9020	100000	2.5E-02	7.1E-02	3.7E-01	2.5E-01	2.2E-03	0.0E+00	7.2E-01	2.6E-06
9030	100000	5.7E-03	1.4E-02	6.2E-02	2.6E-02	0.0E+00	0.0E+00	1.1E-01	2.2E-07
9060	100000	1.8E-03	5.7E-03	1.5E-02	4.8E-03	0.0E+00	0.0E+00	2.7E-02	4.3E-08
9099	100000	1.4E-04	4.8E-04	2.3E-04	0.0E+00	0.0E+00	0.0E+00	8.5E-04	4.5E-09
9100	100000	8.7E-05	4.3E-04	1.6E-04	0.0E+00	0.0E+00	0.0E+00	6.8E-04	7.4E-10
9102	100000	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
9103	100000	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
9104	100000	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
9105	100000	0.0E+00	1.7E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.7E-05	2.2E-13
9106	100000	0.0E+00	3.5E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.5E-05	1.7E-13
9107	100000	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
9108	100000	3.5E-05	1.2E-04	3.5E-05	0.0E+00	0.0E+00	0.0E+00	1.9E-04	4.3E-12

This includes fields, does not include ~60% depolarization (~3x improvement)

Fasteners: ok as brass/bronze

Water cooled leads: SS is fine

Drift-pipe vacuum-pipe: SS is fine

[Eric King, docdb:891]

Various components

Done

- Bellows 1-6 (Inconel 625) [docdb:860]
  - Bellows gasket Nimonic-90 ok, but probably will be EPDM [docdb:889]
- Drift Pipe Support
- Tie rod ends (cannot be mild steel, some could be S.S. but needs to be near ideal) [docdb:871]
- Bearings, under magnets (done, SS ok)
- Fasteners (Brass, ok) [docdb:891]
- DS torus water leads, Drift-region vacuum pipe [docdb:891]
- Pivot (mild steel, done, ok with shield wall)
- Target keep out zone (done based on geometric argument, simulation to be done)

In progress

- Concrete/rebar US (almost done)
- Concrete/rebar DS (almost done)
- GEM supports (almost done)
- Verify bellows with new geometry, asymmetric fields, secondary flux

To Do

- Detector frame elements
- Pion detector support
- water cooling lines
- collimator material
- Upstream beam pipe/halo models

Closing thoughts / Summary

- We are attempting to catalog all ferrous or potentially ferrous material
  - keep track of approvals/considerations/assumptions. Sometimes it is clearly fine, based on other calculations, we just want to keep notes.
  - Plans to improve documentation
  - Also, helps keep track of multiplicity of items that are close to the limit
  - First note (mostly bellows, pivot) to try to summarize technique is close to ready

- A number of components have been checked and verified, and in some cases less expensive options have been ruled out (SS bellows, chrome-moly tie rod ends) or shielding required (shield wall after US torus)
- If expense or engineering requires, a more careful (i.e. less conservative) estimation for analyzing power (or, spin precession, etc) is possible, but it requires more work

- Many components require quality control. Need to develop both a plan and documentation
- Some materials may have very stringent limits (for example, collimator or exit window aluminum). We haven't made a Q.C. plan for this yet.
  - These may be places where a more careful analyzing power estimate is required