CombLayer : Method of making full scale models

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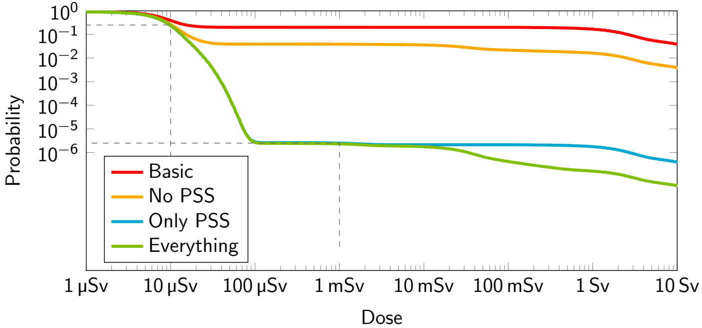
Probabilty of a dose per year (highest person dose)

The upper bound of probability of the dose is a key metric of a safety analysis

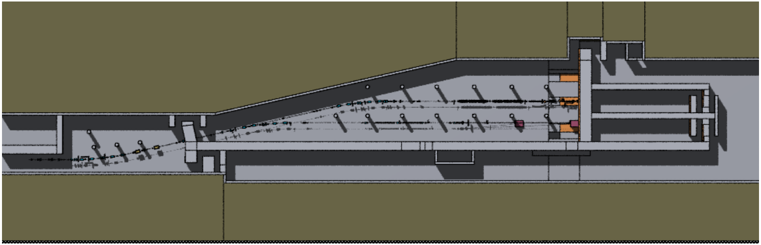


What is needed....

1. Scenario list of events
2. Probability distribution of events (and duration)
3. Probability distribution of personnel
4. Expected radiation field associated with events
5. Any expected change in human behaviour when the event takes place.

Overview Model

Example : Transverse Deflecting Cavity [TDC]

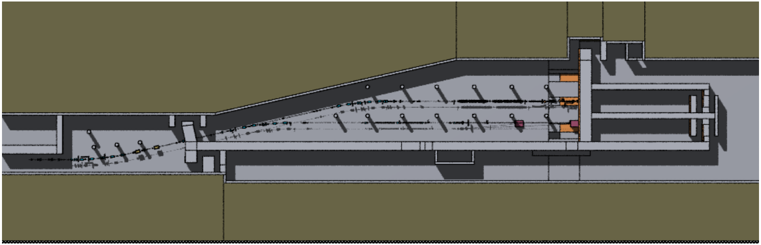


$\sim$ 100m

- The TDC is an electron line added to the short pulse facility
- Transport electrons all at 3GeV
- Kicks the beam with two 60MeV R.F. cavities
- At least 500 different ways something can go wrong...

Modeling part..

Example : Transverse Deflecting Cavity [TDC]



∼ 100m

- At this level you are seeing 90 magnetic component (corrector magnets/dipoles/quadrupole etc).
- Multiple beam (valid) paths.
- Multiple -bespoke- local shielding

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Modeling part..

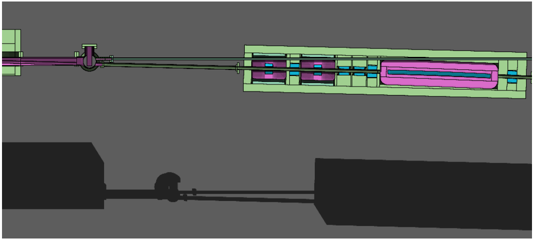
Think like a software engineer

- DRY : **Don't Repeat Yourself**
- Break object into component and subcomponents
- Have ability to unit test all components
- Moment a component gets complex make it sub-components

Think like a mathematian

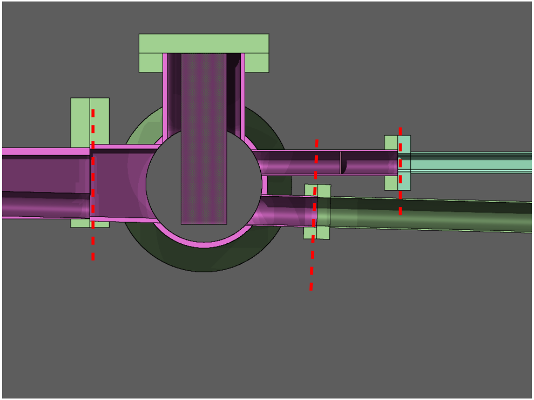
- Geometric algebra e.g. quaternion rotations, bivectors etc.
- Boolean algebra description allowing optimization
- Multiple basis set geometry description

Cell Construction



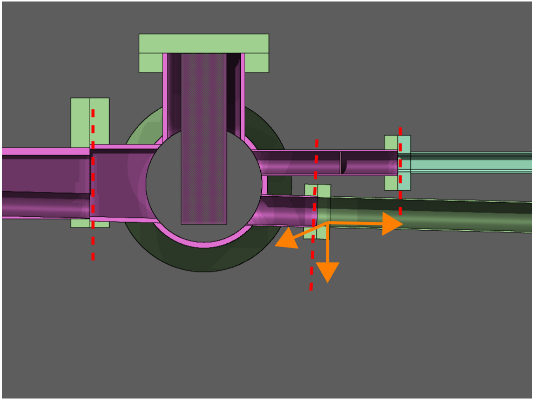
- Connections to an object can be at point and surface
- On-going objects use that connection basis vector set as their initial basis set
- Anything can join to anything else

Cell Construction



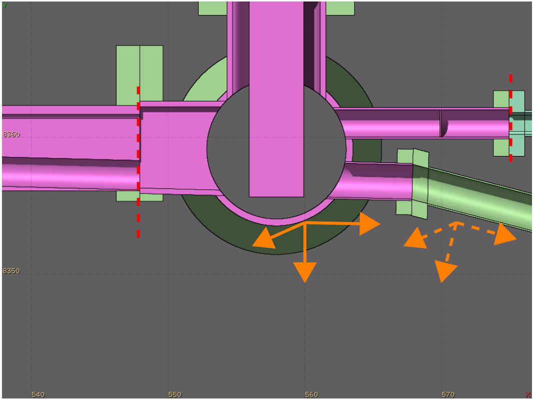
- There are three (active) joining surfaces

Cell Construction

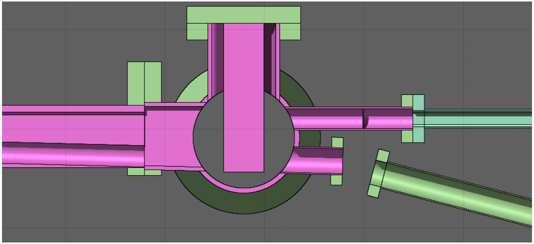


- There are three (active) joining surfaces
- Each join also constructs an independent basis set for the ongoing object

Cell Construction



- There are three (active) joining surfaces
- Each join also constructs an independent basis set for the ongoing object
- New object can apply rotations to the new basis set



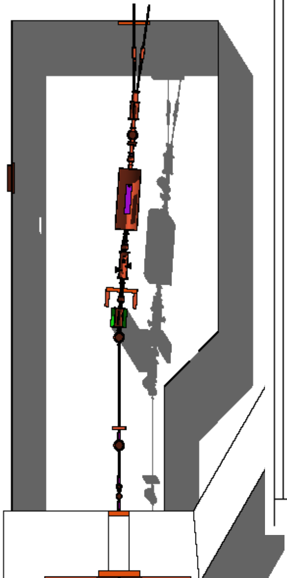
C++ construction code:

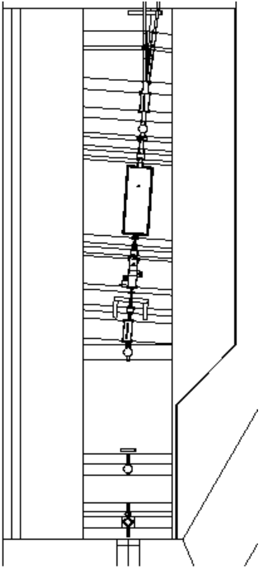
```
eTransPipe->setFront(*chokeChamber,"electron");
eTransPipe->setBack(*magBlockU1,"voidFront");
eTransPipe->createAll(System,*chokeChamber,"electron");
```

Code on command line to adjust the transfer pipe:

```
~/CombLayerGit/Master/maxiv   \
   --defaultConfig Single FORMAX  \
   -va FormaxFrontBeamETransPipeZAngle -13.0 \
   -va FormaxFrontBeamETransPipeXStep 5.0 \
   -va FormaxFrontBeamETransPipeYStep 3.0 \
    TestModel
```

Cell Optimization





- The cells can be divided efficiently into sub-cells
- This is automatic

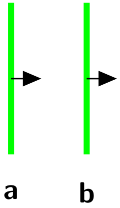
Shannon Introduction

- The geometry for all Monte-Carlo codes is a (truncated) boolean algebra.
- **HUGE** amounts of effort have/are being spent on optimizing boolean algebras to run fast *Semiconductor industry*.
- If we reexpress our geometry as as formal boolean algebric expressions, we can simply use their work.

1. Decompose all regions into infinite surfaces
2. Assign a token name to all surfaces in a region
3. Define implicates

For surfaces a,b, we evaluate them as true or fasle
Using the normal boolean algebra expression, a+b is OR, and ab is implicit AND, a' is NOT
A region $F(a, b, c, \cdots)$, which is dependent on the state of a point/line etc relative to a surfacecd

Object Decomposition



- Use can be made of $b \implies a$ and $a' \implies b'$
- b $\implies$ a := b'+a

Shannon expansion gives us:

$$F = abF(a=1,b=1) + ab'F(a=1,b=0) + \\ a'bF(a=0,b=1) + a'b'F(a=0,b=0) \quad (1)$$

And given b $\implies$ a and a' $\implies$ b' eliminates term 3, and if either remaining terms are null we can eliminate a literal
Allows ARBITRARY splitting of a cell to decrease complexity

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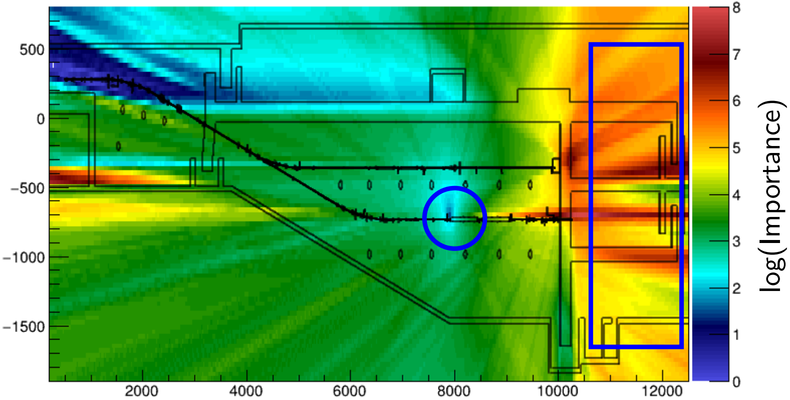
Variance Reduction Map

Corrector magnet miss-steer



Solves the double eigenfunction for source at circle and and estimator in rectangle. Two step Markov chain used.

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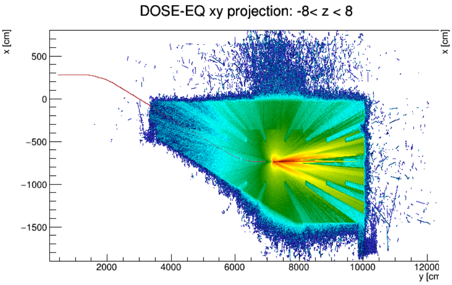
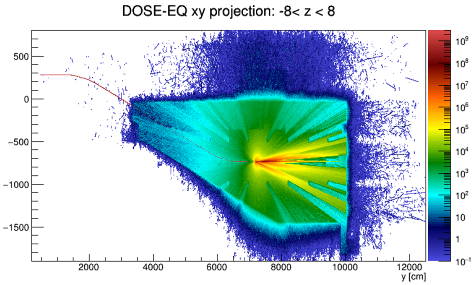
Variance Reduction Map





No variance reduction

Variance reduction

Short 2 hour total CPU time runs:

- Regions of importance are better sampled – other stuff is LESS sampled.

Theory

As early as 1946 neutron adjoint variance reduction was formulated
The detector/tally response is:

$$R = \int_{\mathbf{P}} \phi(\mathbf{P})\sigma_{det}(\mathbf{P})d\mathbf{P}$$

where $\mathbf{P}$ is all phase space $(\mathbf{r}, E, \hat{\Omega})$
And in the adjoint form:

$$R = \int_{\mathbf{P}} \phi^{\dagger}(\mathbf{P})q(\mathbf{P})d\mathbf{P}$$

$$\text{weight}(\mathbf{P}) = R/\phi^{\dagger}(\mathbf{P})$$

The only difficulty was creating a $q(\mathbf{P})$ that reflect the *source* reponse function.

Theory-2

- FW/CADIS system [1] showed how to normalize $q(\mathbf{P})$. [position only]
- Extended FW/CADIS-Ω [2] form integrated over angle

$$\phi^{\dagger}(\mathbf{r}, E) = \frac{\int_{\Omega} \phi(\mathbf{r}, E, \hat{\Omega})\phi^{\dagger}(\mathbf{r}, E, \hat{\Omega})}{\int_{\Omega} \phi(\mathbf{r}, E, \hat{\Omega})} \tag{2}$$

[1] J.C. Wagner *et al* Trans. Amer. Nucl Societ. **97** 603 (2007)
[2] M. Munk *et al* Nucl. Sci Eng. (2017)

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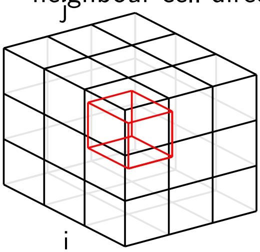
Theory-3

At this point if you know the flux (everywhere), you can calculate the perfect variance reduction

- The accuracy of the forward and adjoint flux calculations **for the weight windows** do not need to be high.
- CombLayer uses a simple source-to-cell population followed by Markov Chain iteration (effective multi-scatter)
- Insuffcent memory for the angle component when doing big models.

Theory-4

- CombLayer **APPROXIMATES** the angle term by nearest neighbour cell directions



$$\phi^{\dagger}(\mathbf{r}, E) = \frac{\int_{\Omega} \phi(\mathbf{r}, E, \hat{\Omega})\phi^{\dagger}(\mathbf{r}, E, \hat{\Omega})}{\int_{\Omega} \phi(\mathbf{r}, E, \hat{\Omega})}$$

Angular parts proportionate as:

$$\phi(\mathbf{r}, E, \hat{\Omega_{ijk}}) = \frac{\phi_{000}(\phi_{000} + (\phi_{ijk} - \phi_{-i-j-k})/2)}{26\phi_{000}}$$

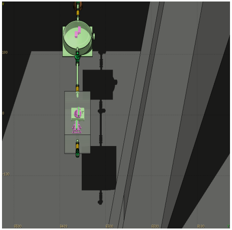
Remember to allow a transport flux in void cells in the Markov-Chain approximation

CombLayer Program

CombLayer *C++ code (450k lines)*

- Fully interchangable/connectable component geometry
- Variable driven
- Variance reduction
- Open source

Writes MCNP/Fluka/PHITS input decks



This allows the rapid development of complete semi-engineering models.

https://github.com/SAnsell/CombLayer

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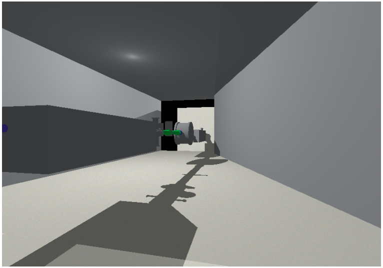
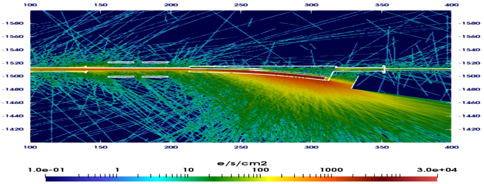
Current Status





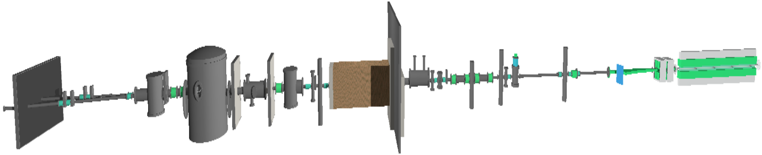
Current Baseline :

- Tools to deal with complex geometry
- Tools to deal with magnetics
- Tools for variance reduction
- Library of many standard components with full parametization

Conclusions

Conclusions

- Detailed modeling is essential to reproduce experimental results.
- Tools are available to get you there quickly.



https://github.com/SAnsell/CombLayer
https://plone.esss.lu.se