Radiation Shielding and Background caclulation on long beamlines

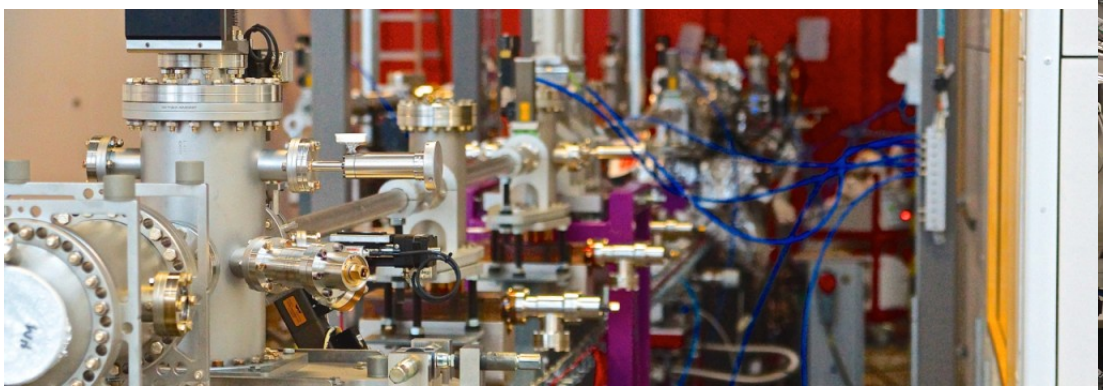
Stuart Ansell

MAX IV Laboratory, Lund University, Sweden.

November 19, 2019

Beamlines Complexity

- X-ray instruments are now denser and more complex systems at **both** larger and smaller scale lengths.
- Signal / Incoming photon ratio getting much smaller.

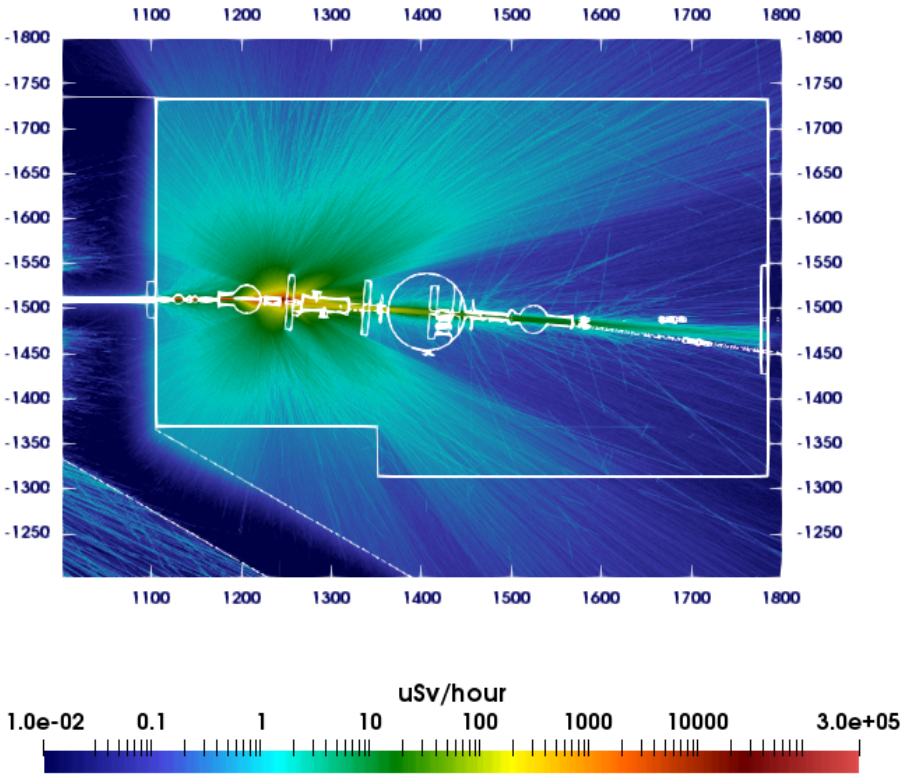


- Simulation model complexity **must** reflect the new world

MAX IV LABORATORY

The Fundermental Issue

- How much detail is required to simualate the background photons on a beamline?



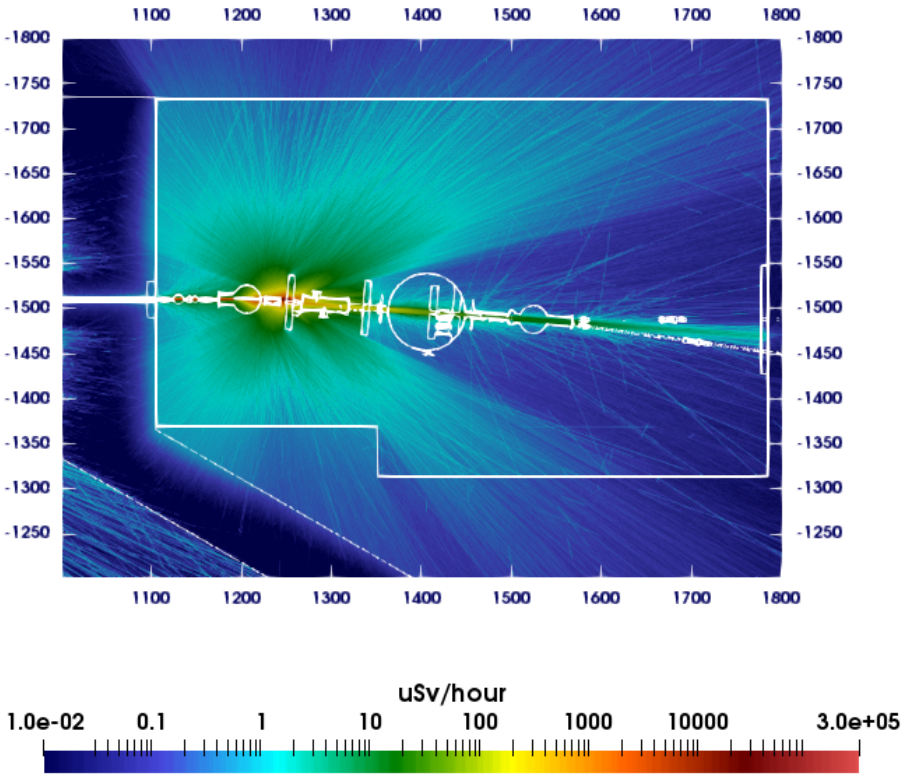
- How much detail can we sensibly model?
- What is the start point?
- How much detail can we compute?

Basically, what is the trade off between complexity, time and human effort?

MAX IV LABORATORY

The Fundermental Issue

- How much detail is required to simualate the background photons on a beamline?

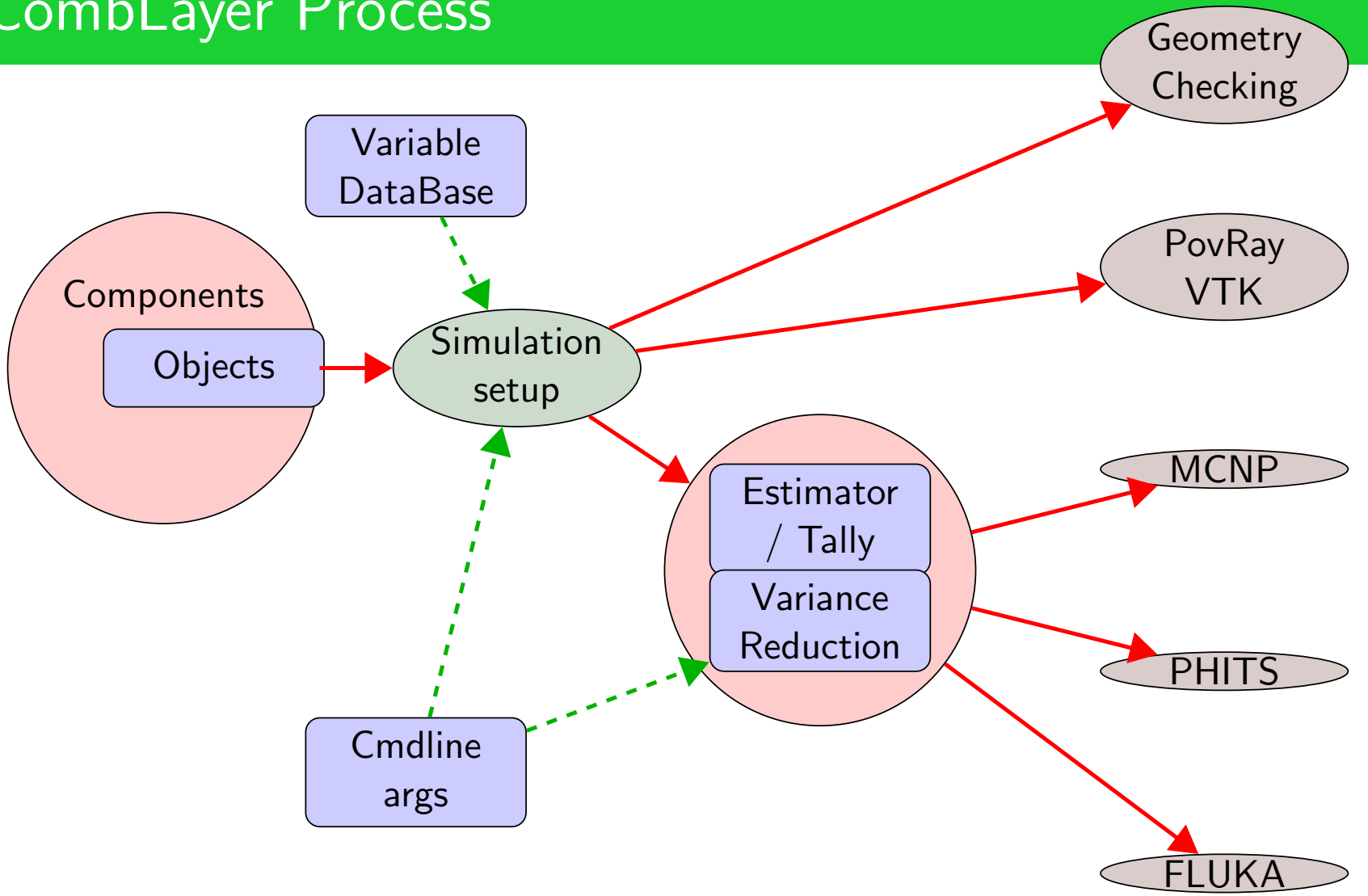


- How much detail can we sensibly model?
- What is the start point?
- How much detail can we compute?

Basically, what is the trade off between complexity, time and human effort?

MAX IV LABORATORY

CombLayer Process

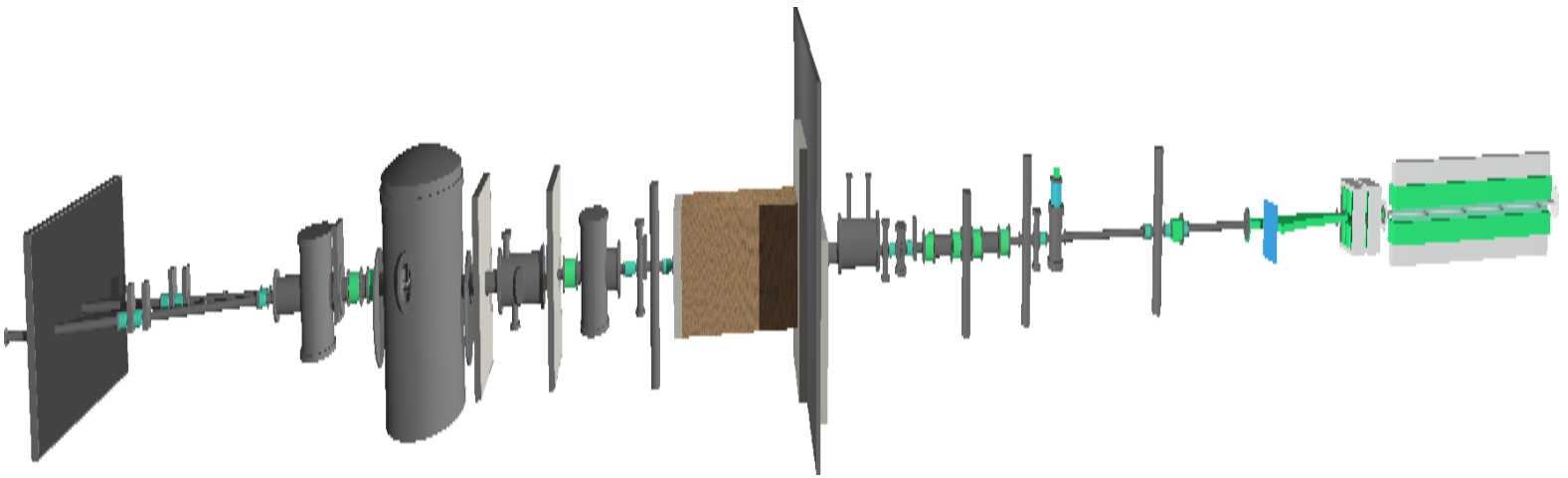


CombLayer : https://github.com/SAnsell/CombLayer

MAX IV LABORATORY

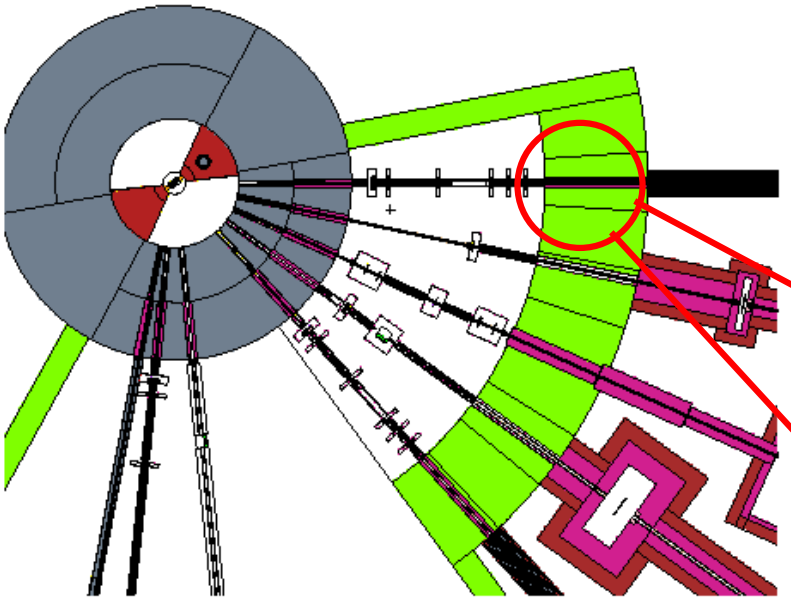
Link Objects together based on exit points

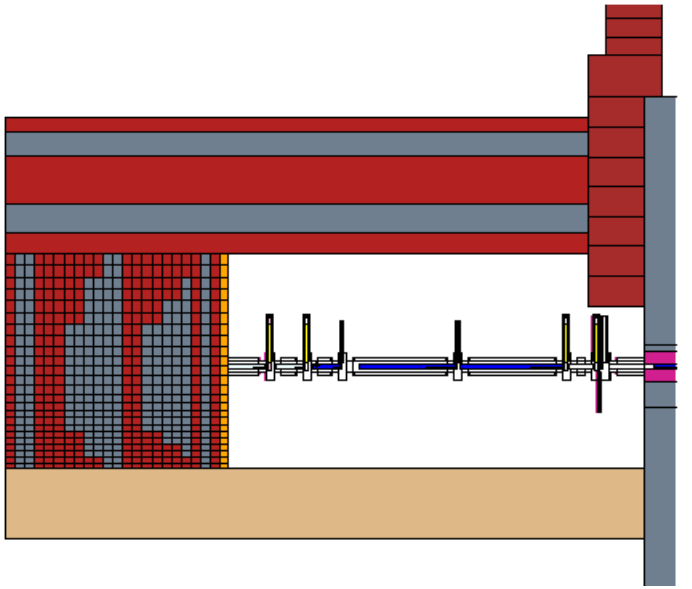
- All objects have local basis set
- Constructed relative to another objects linkpoint
- Quaternion based rotation and translatoin so robust.

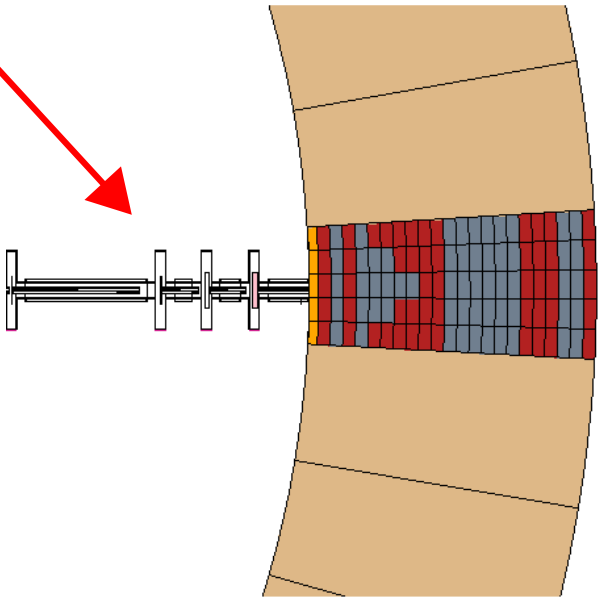


MAX IV LABORATORY

Cell Sub-Division



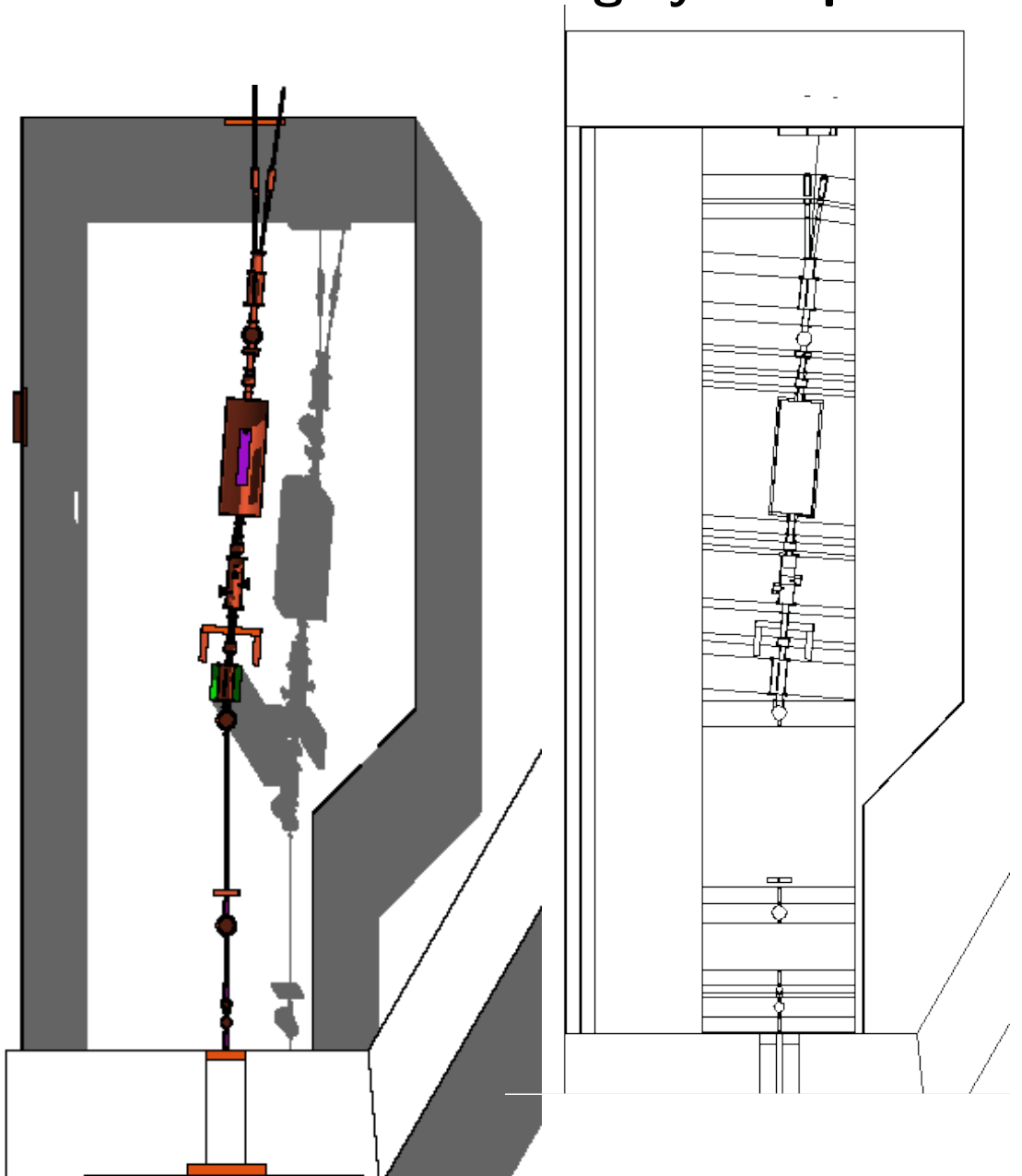




- Any generic cell can be split in N dimesions
- XML file of materials for each cell segment

CombLayer: Cell Problem

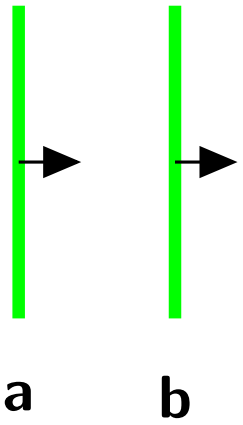
Fluka does not allow highly complex cells



1. Simple insertion of objects into a hutch cause the hutch inner volume to be to complex
2. The cells must be divided efficiently into sub-cells of <20 surfaces
3. Surface refinement automatic done for >5000 cells

MAX IV LABORATORY

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

MAX IV LABORATORY

Fundamental Simulation problem

We start with $>10^{18}$ particles per second. **Interested in:**

- Dose at outside a wall (100 particles/sec/cm^2)
- Signal to noise ratio (S/N) ($\approx$ 1 particles/sec/cm^2)

The mean primary particle

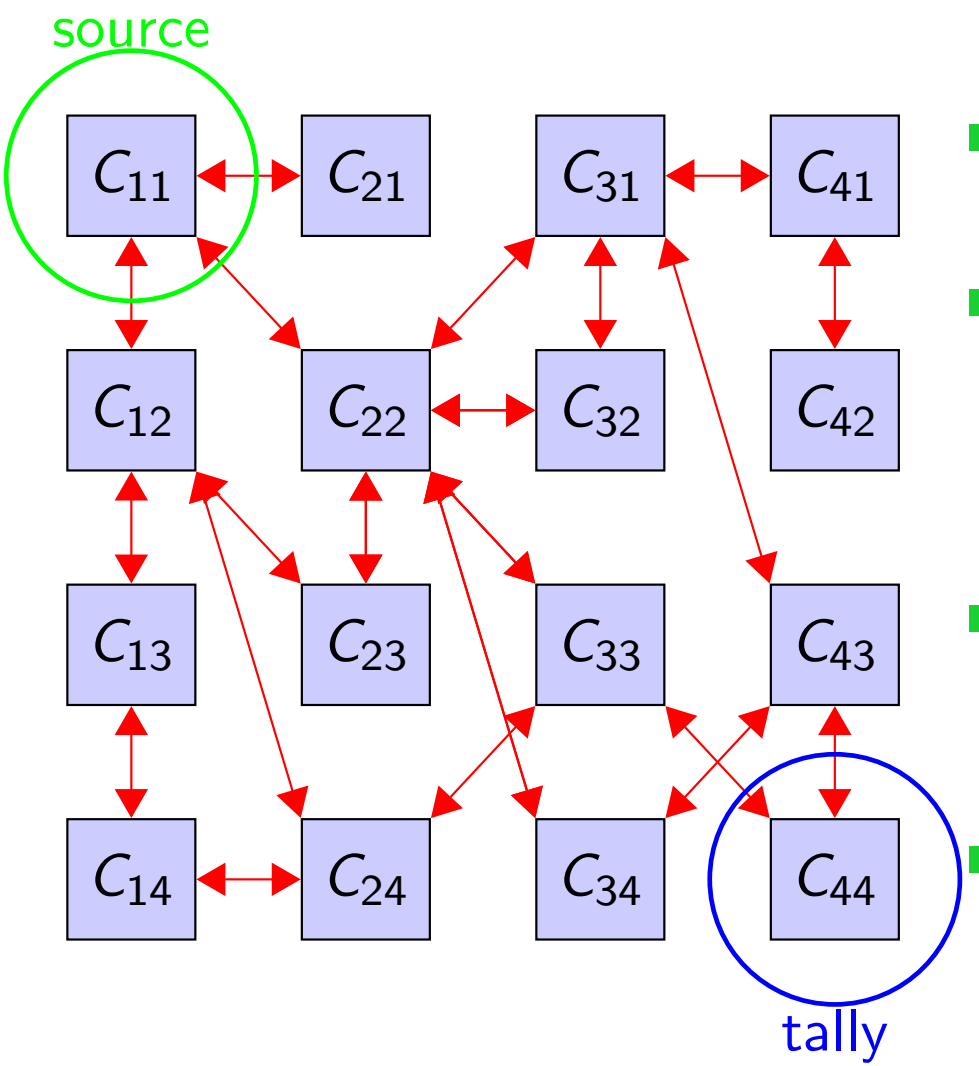
- Photon : 7 collision through 40 cells
- Neutron : 150 collision in 480 cells
- Electron : 3,000,000 collision [8000 CH] in 25 cells

Computational time for 10% statistics in the WHOLE problem at once is on IBM Summit [122.3 PFLOPS]: 3.16 billion years – $\sim$ Age of the solar system

Directional variance reduction is essential.

MAX IV LABORATORY

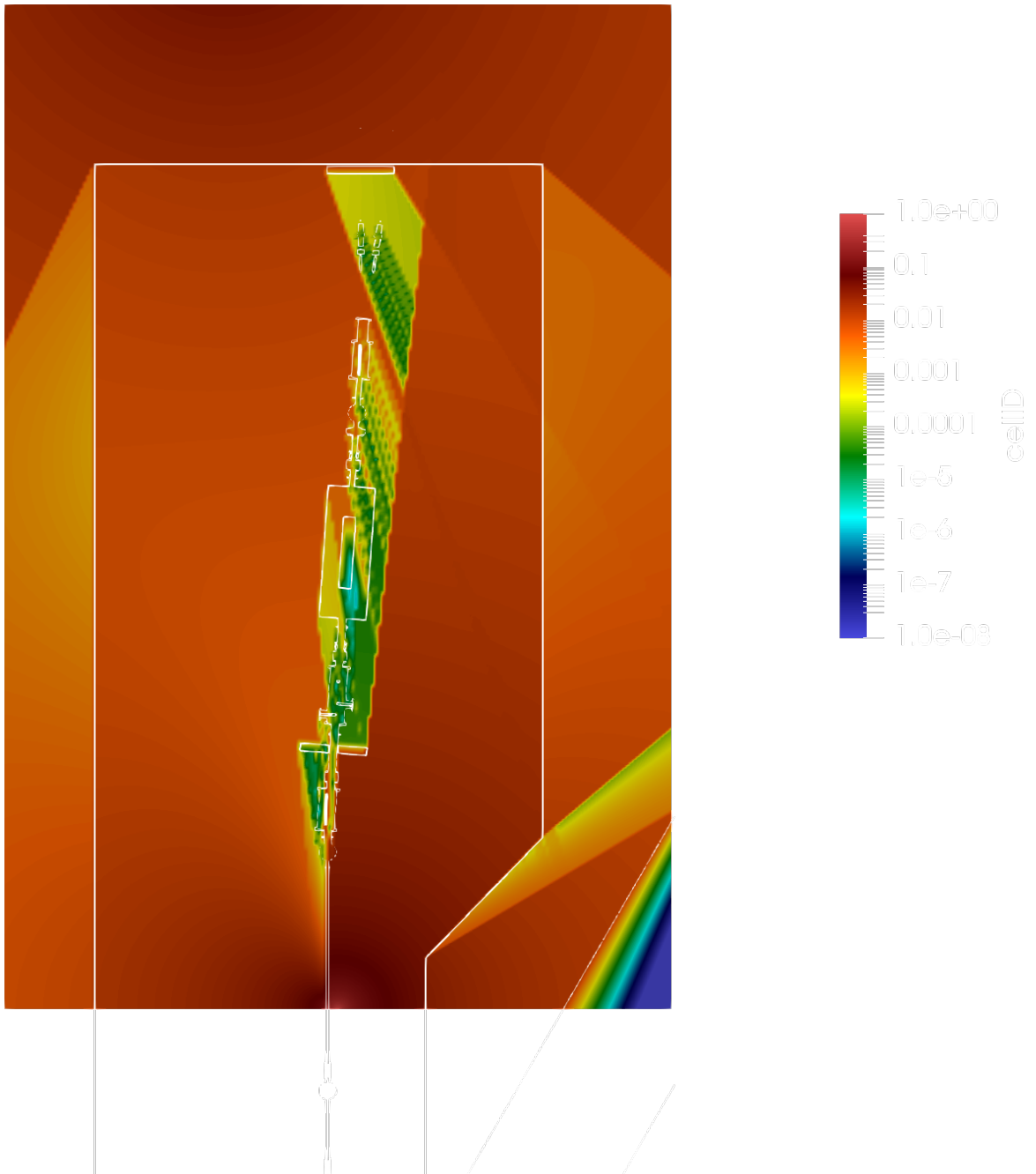
Variance reduction: Semi-Adjoint processing



- Create the object connections
- Calculate the attenuation and $1/r^w$ from cell centre to cell centre for each
- Evolve the Markov Chain cell interaction probability
- Normalize by the fraction that moves from source to tally

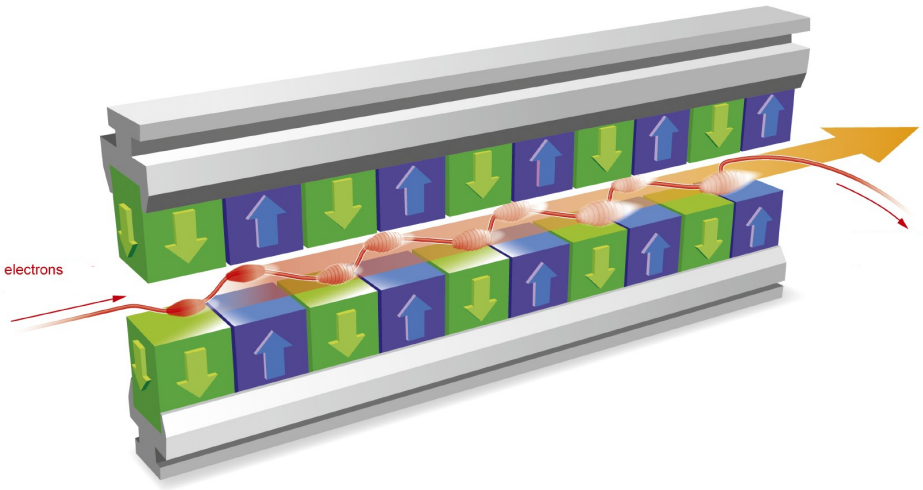
MAX IV LABORATORY

Weight Window for Optics hutch back-wall transit



- Weight Windows are in 6 dimensions (x,y,z,px,py,pz) + Energy functional
- Adds a $\sim 10^{12}$ performance gain
- Automated checking minimizes the old issue of implicit bias
- Intrisically unstable – requires more effort than all other parts of the process

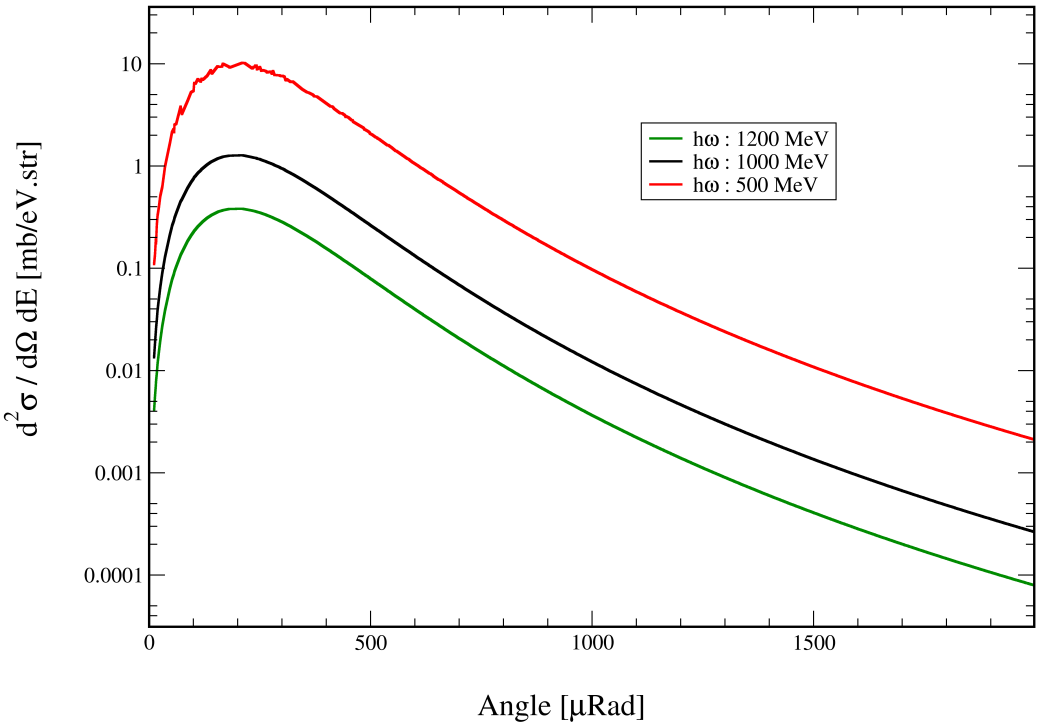
MAX IV LABORATORY



- Closed undulator causes the electron beams direction to change by $>500\mu$Rad.
- Acceptance collimator is $40\mu\text{Rad} \times 40\mu\text{Rad}$.
- This broadens the bremsstrahlung by 30x at the acceptance angle of the primary collimator

Integrated cross section into the FM mask from 1.5 GeV photons.

MAX IV LABORATORY

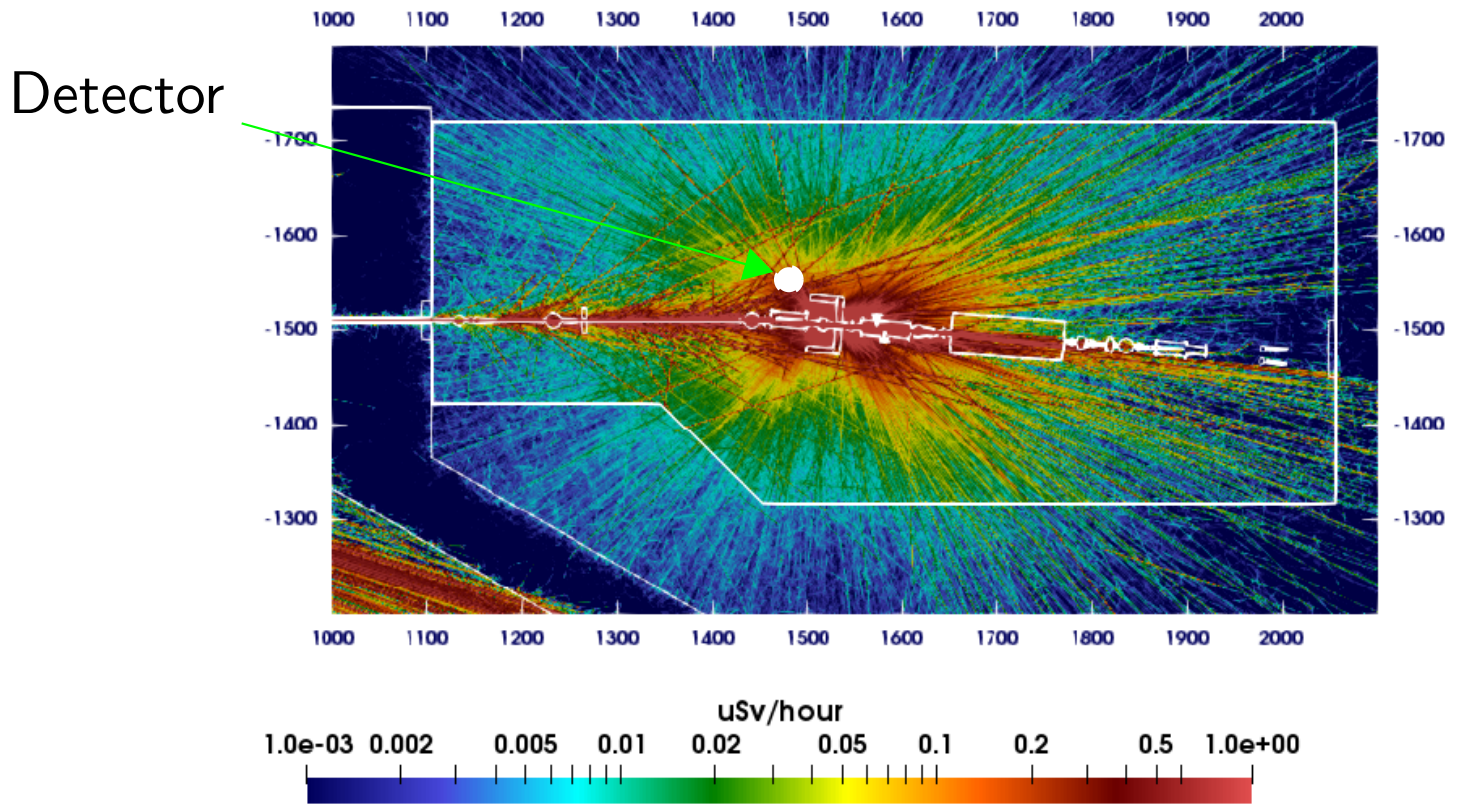


Integrated cross section at different angles from a 1.5 GeV electron-proton interaction

- Broadening by the undulator is sufficient to reduce direct scattering by an order of magnitude.
- Secondary scattering from pair production due to electron-wall interactions are moved close to the undulator

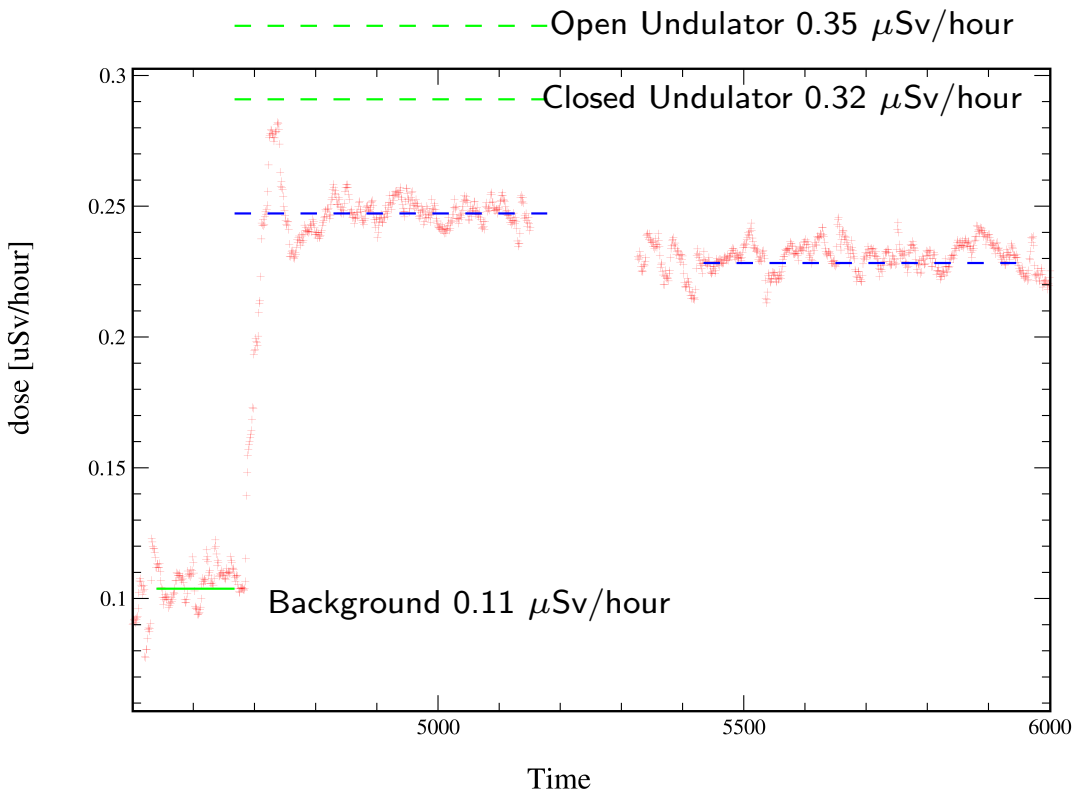
MAX IV LABORATORY

Experiment



- Dose infront of first Bremsstrahlung shield
- No possible synchrotron radiation
- Calculated at 1e-9 mBar

MAX IV LABORATORY

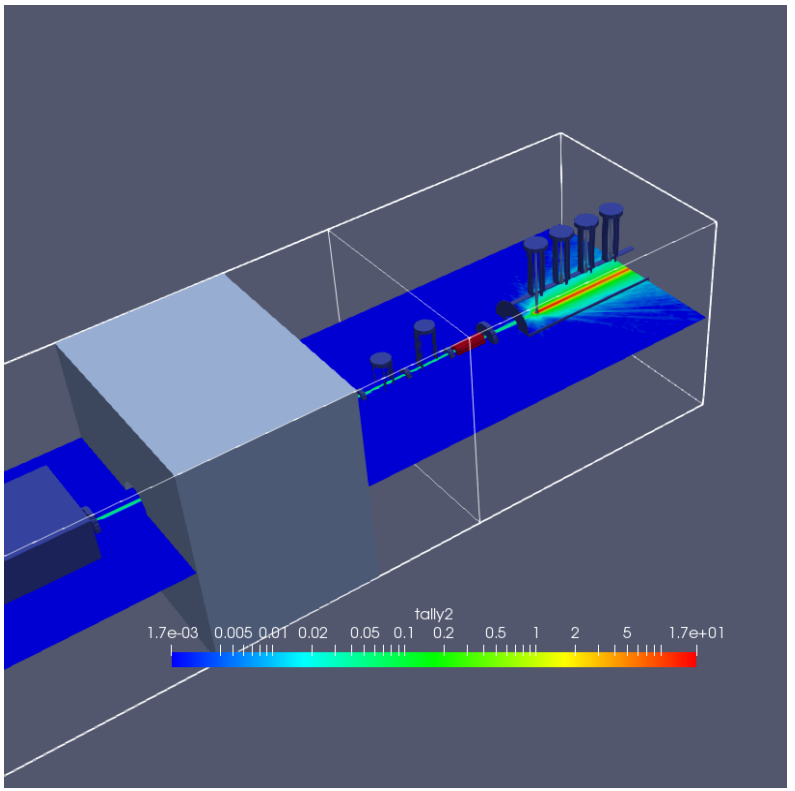


- Green as calculated [over by 1.5x]
- Blue corrected for open undulator
- Absolute accuracy not great
- Relative effect good(ish)

MAX IV LABORATORY

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

MAX IV LABORATORY