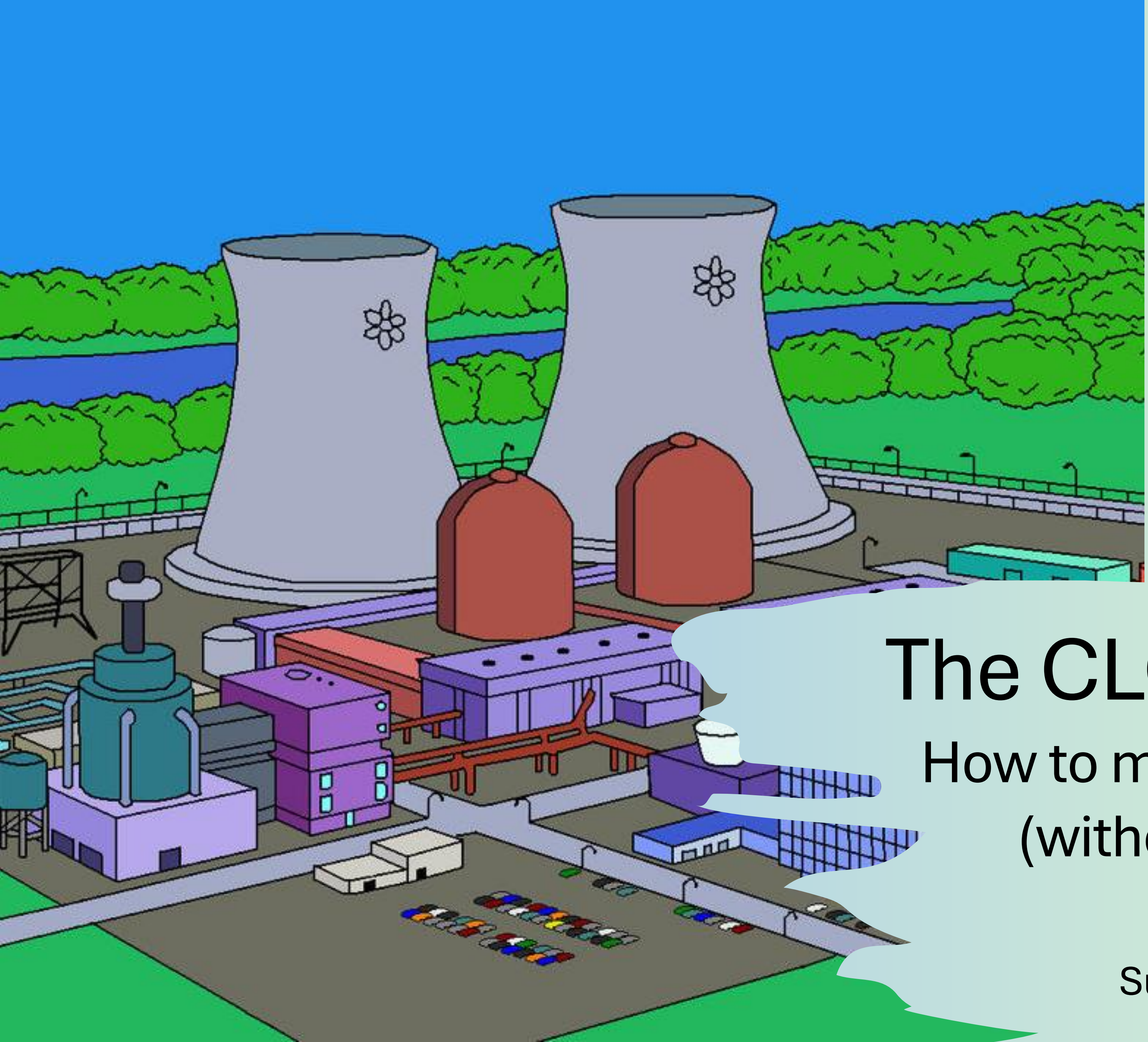


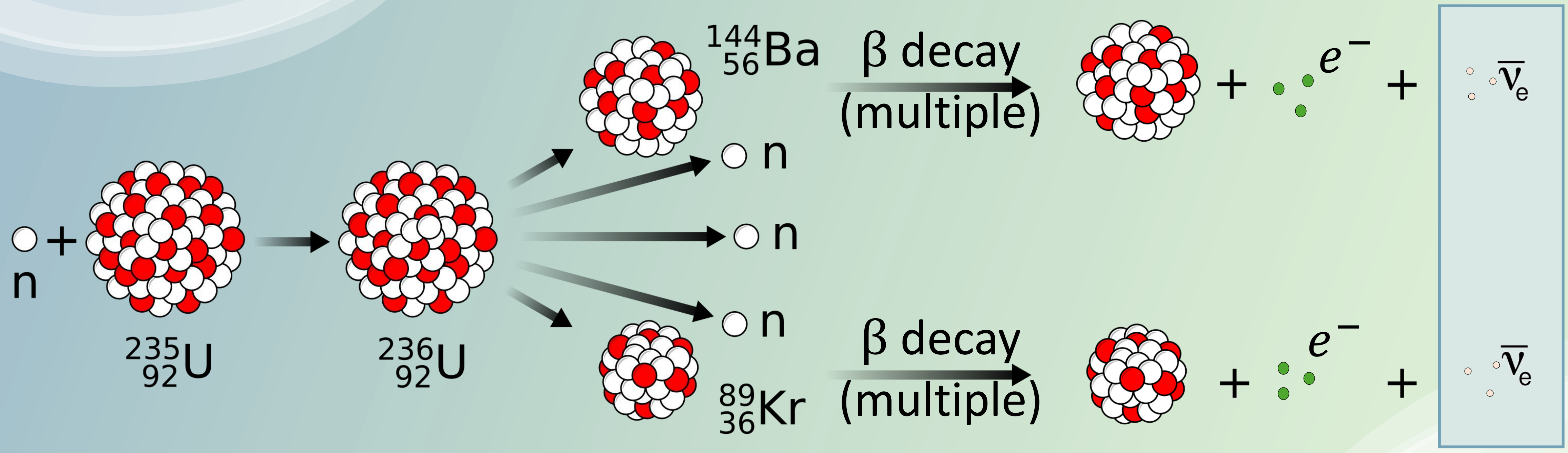
The CLOUD Experiment

How to monitor a nuclear reactor (without getting arrested)

Susie Wakely

Supervisor: Alfons Weber

What happens in a nuclear reactor?



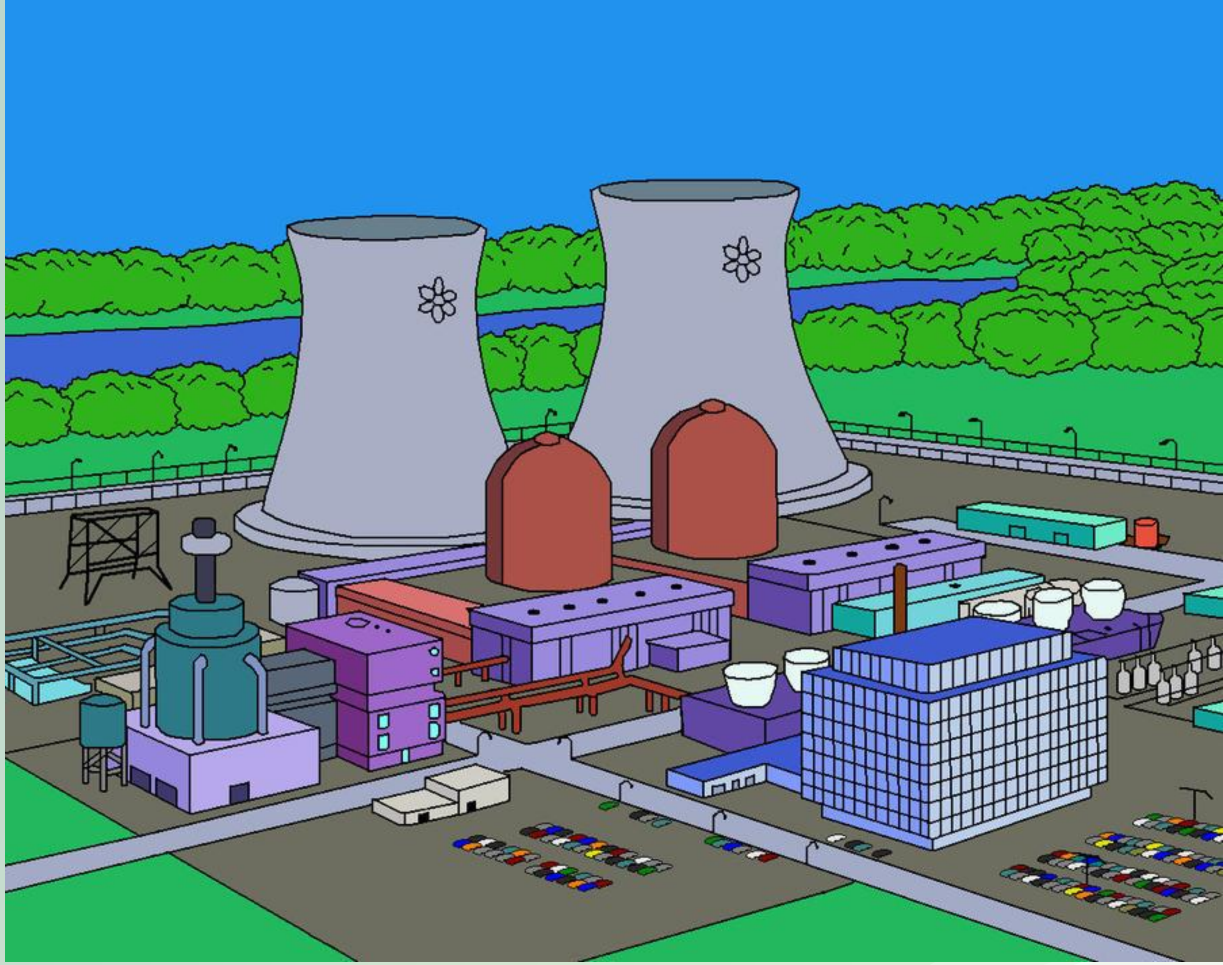
Aim: detect particles that escape the reactor.

Detecting neutrinos

Detector

Aims:

- As many interactions as possible:
  - Large neutrino flux (close to source)
  - Large detector (more target material)
- Background reduction:
  - Deep underground (block cosmic rays)
- Background discrimination:
  - **Particle identification**



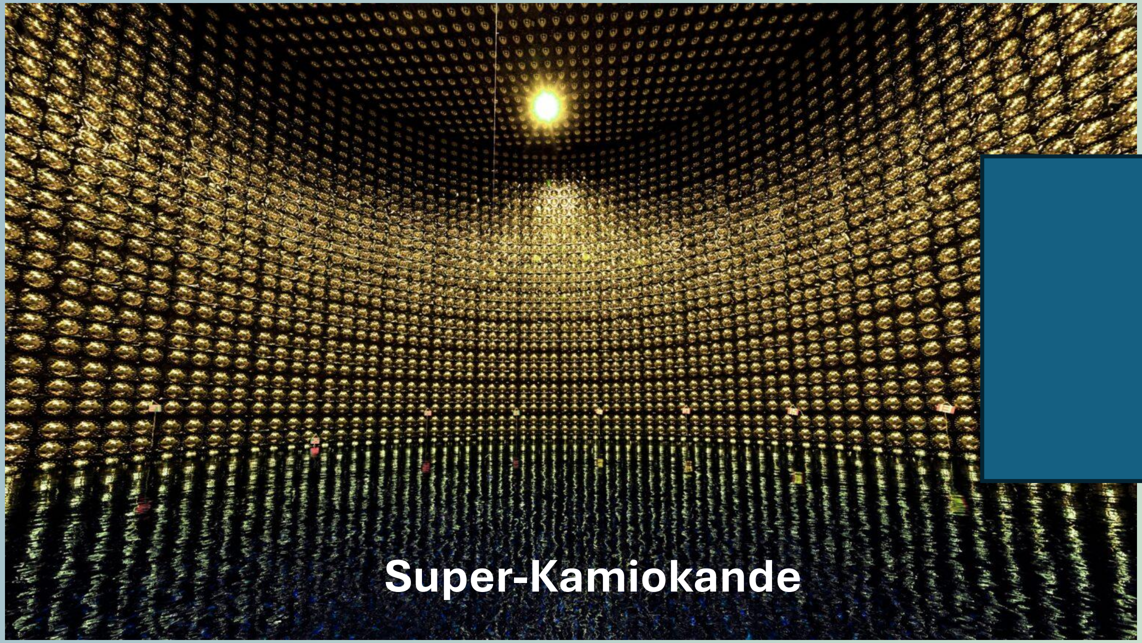
Signal	Background
Positrons (Inverse beta decay, IBD)	**Muons** **Electrons** **Gammas**

Scintillator detectors

Scintillator: material that produces light when a charged particle travels through it.

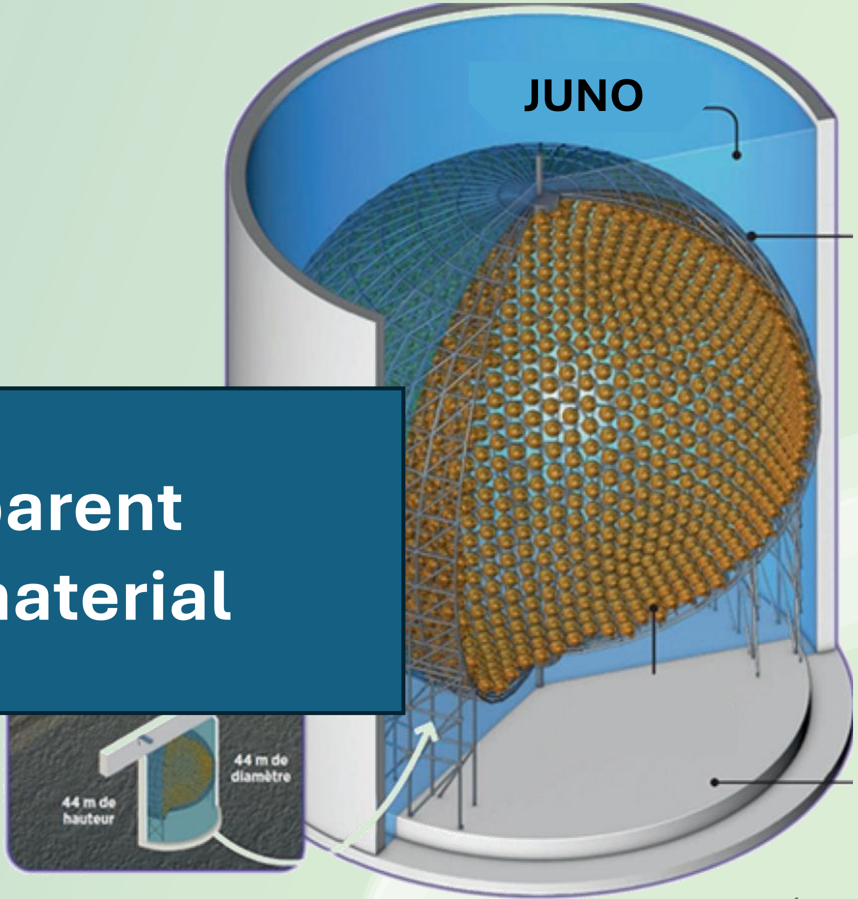
Detector design:

- Tank full of scintillator **(photon production),**
- Photosensors on tank walls **(photon detection).**



(not a scintillator detector but similar design)

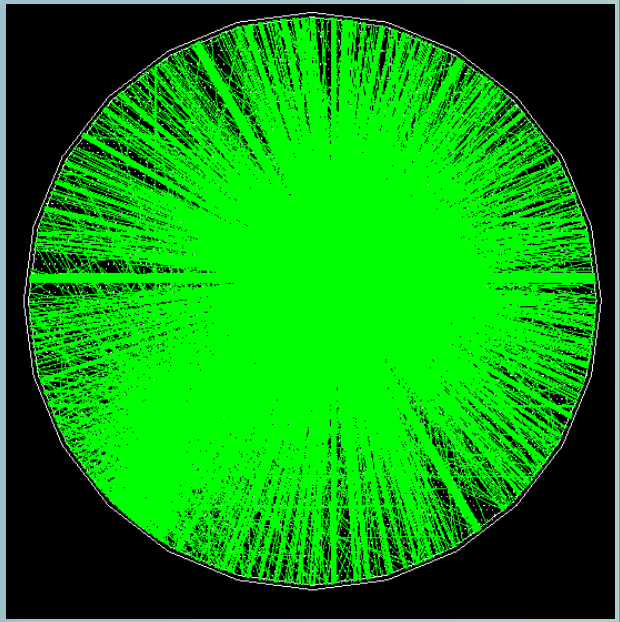
Transparent target material



Particle interactions – Transparent Scintillator

Scintillator: material that produces light when a charged particle travels through it.

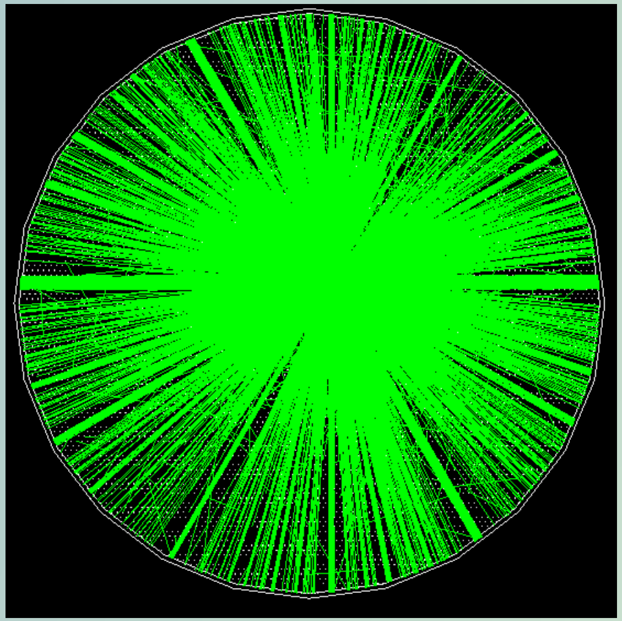
Signal



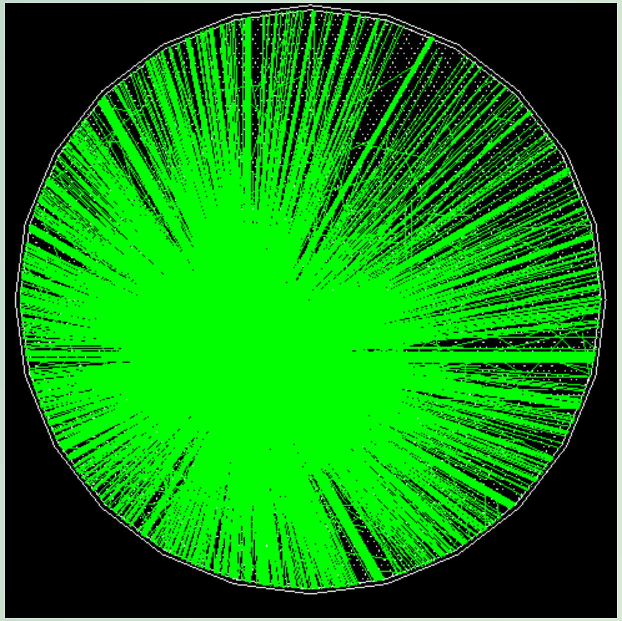
Positron

Background

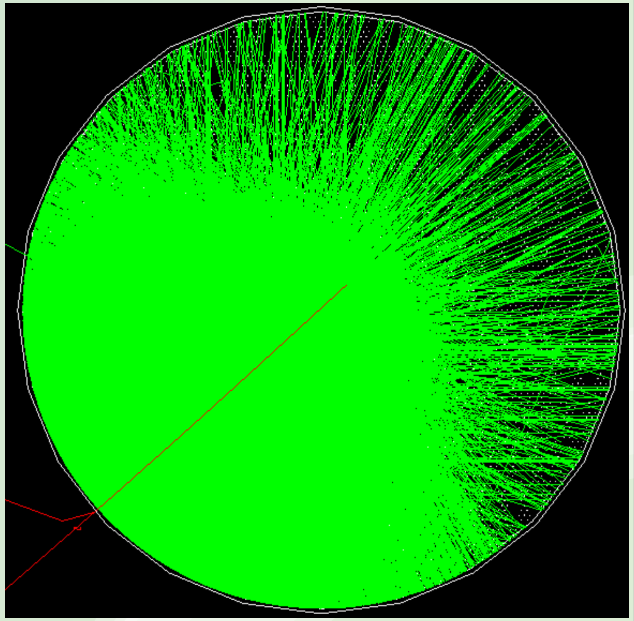
Geant4 simulations



Electron

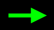
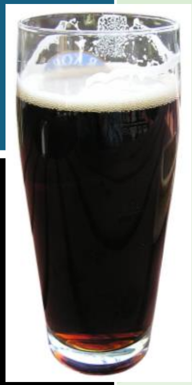
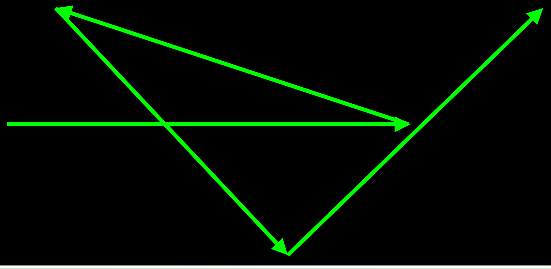
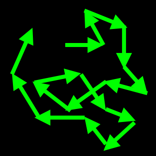


Gamma
Compton scattering



Muon

Opaque Scintillator (Liquid-O)

	Long	Short
Absorption Length **(photon absorbed)**	 	 
Scattering Length **(photon changes direction)**		 

Particle interactions – Liquid-O Scintillator

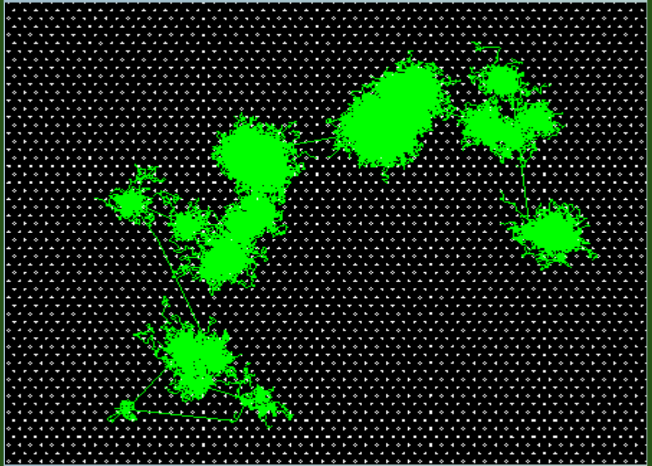
Scintillator:

A material that produces light when a charged particle travels through it.

Liquid-O:

Short scattering length,
Long absorption length.

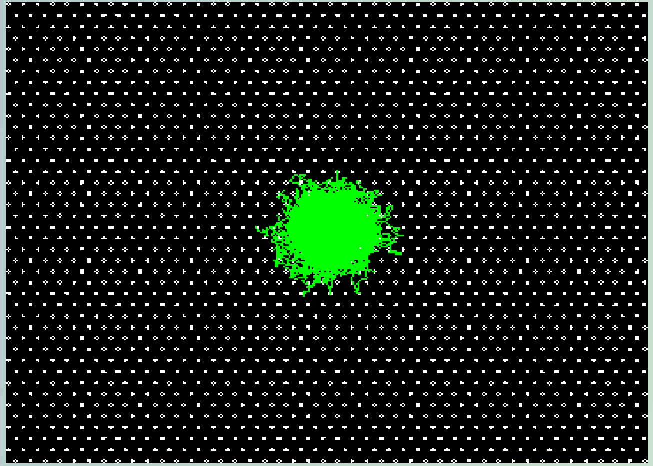
Signal



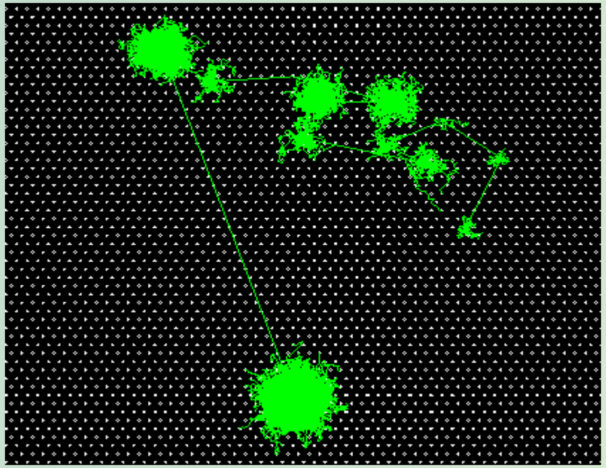
Positron

Background

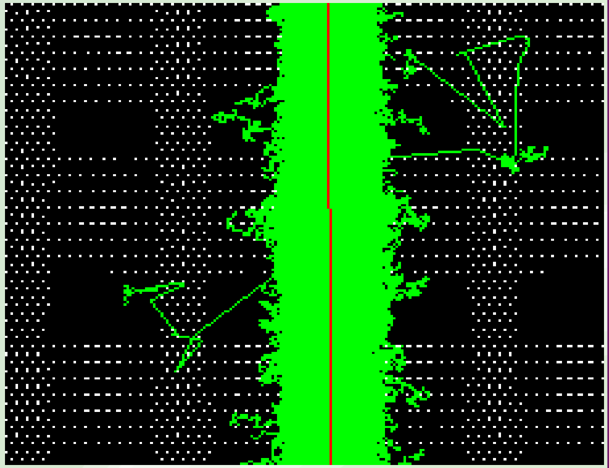
Geant4 simulations



Electron

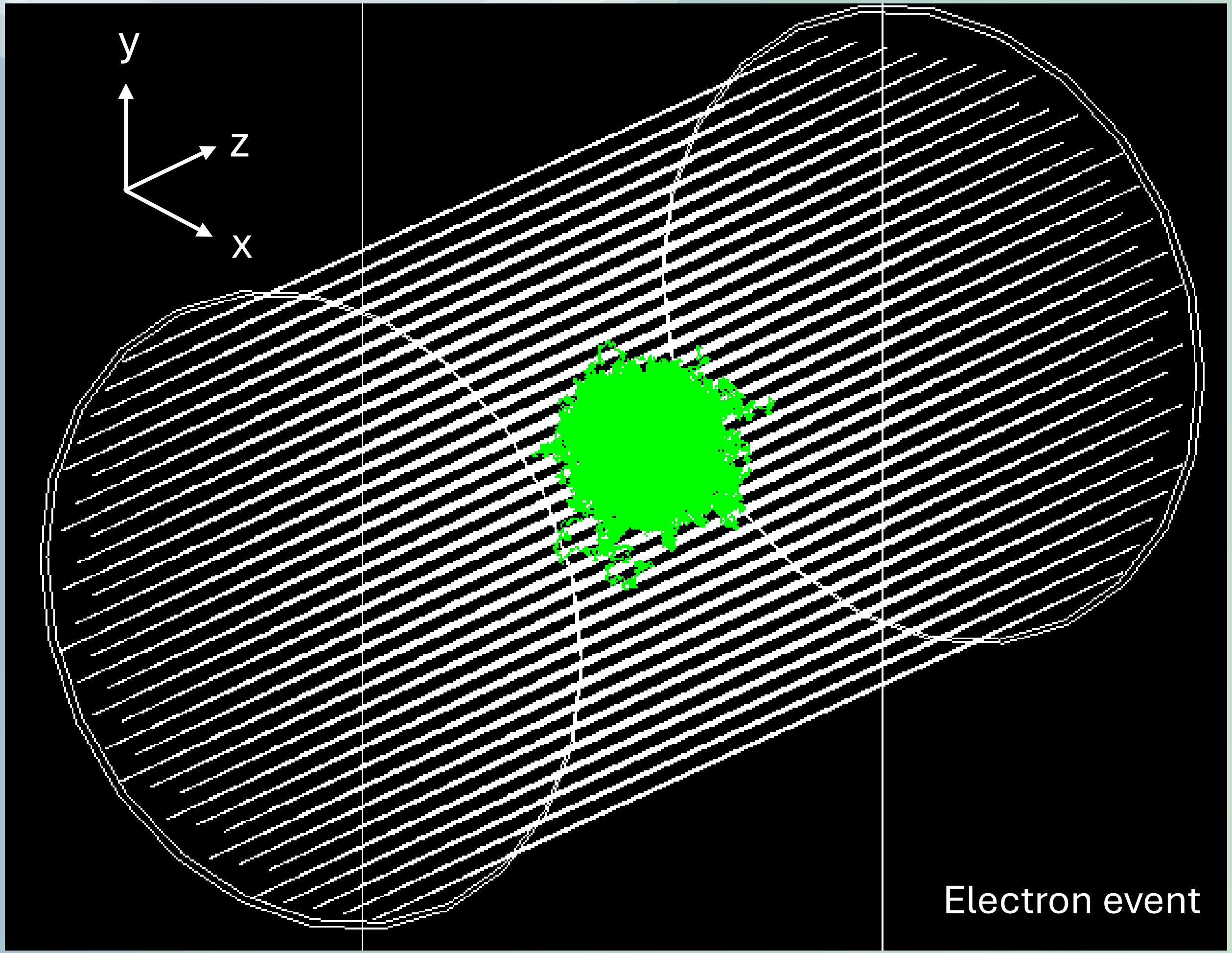


Gamma
Compton scattering



Muon

LiquidO Detector Design

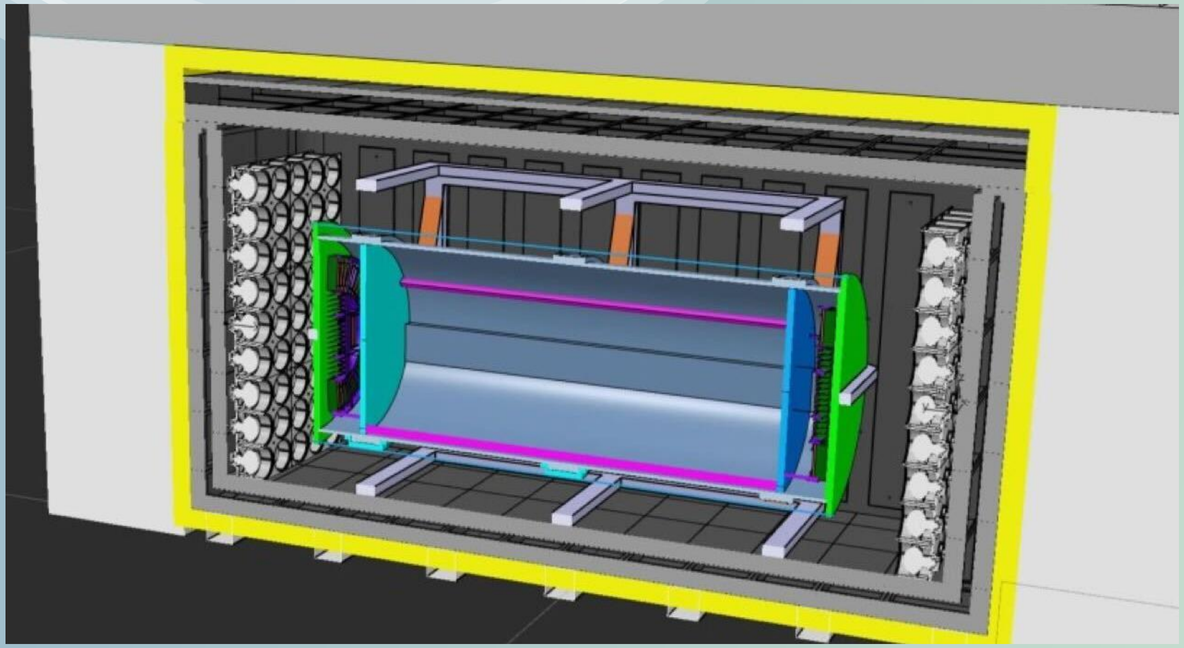


Detector design:

- Tank of LiquidO scintillator
  - **(photon production),**
- Wavelength shifting fibres
  - **(photon collection/transport),**
- Photosensors on tank walls
  - **(photon detection).**

CLOUD Experiment

Chooz Liquid-O Ultra-near Detector



Potential physics

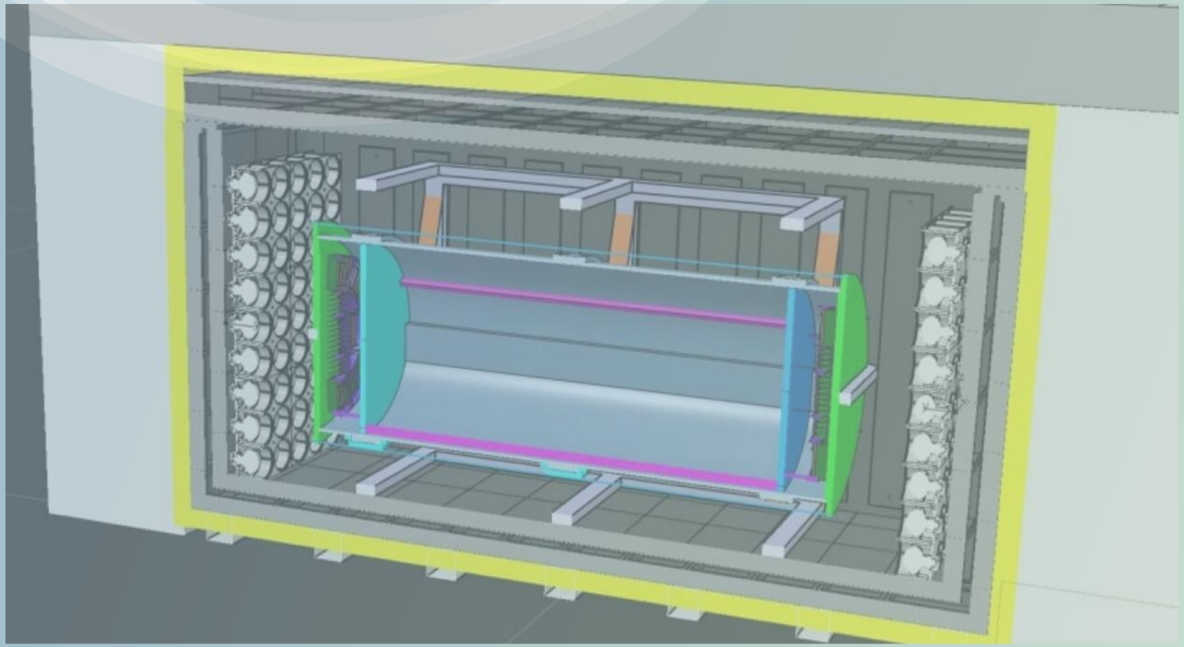
Reactor monitoring, Neutrino oscillation (near detector for Super Chooz)

Currently being designed

- Next generation 5-10 ton detector
- ~30m from reactor
- 10 000 WLS fibres (< 2cm spacing)
- Expected to see ~10 000 IBD events per day

CLOUD Experiment

Chooz Liquid-O Ultra-near Detector



Potential physics

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Currently being designed

- Next generation 5-10 ton detector
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- **10 000 WLS fibres (< 2cm spacing)**
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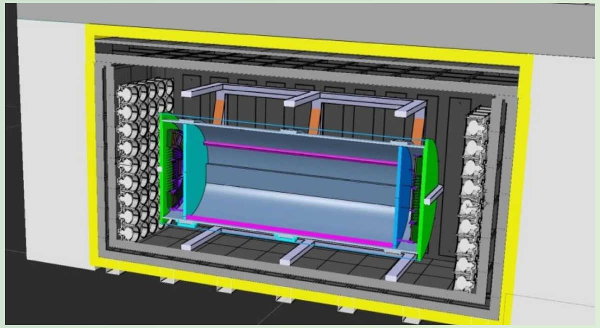
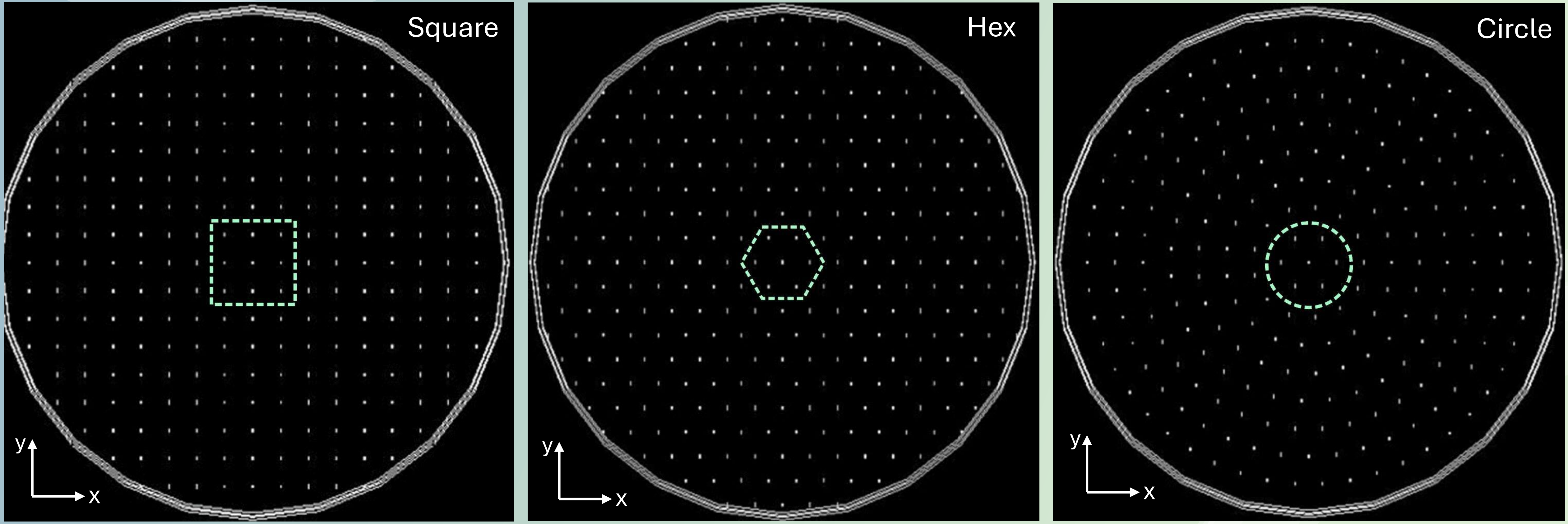
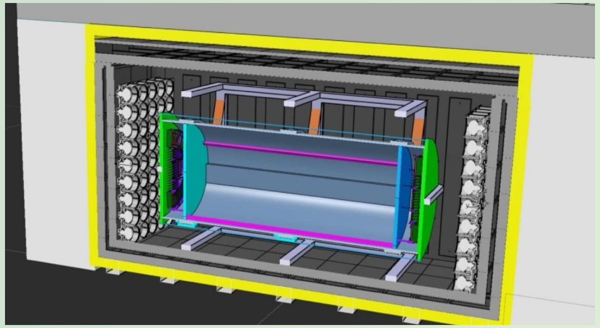
Fibre Array Geometry



Z-parallel: fibres parallel to the tank walls



Fibre Array Geometry



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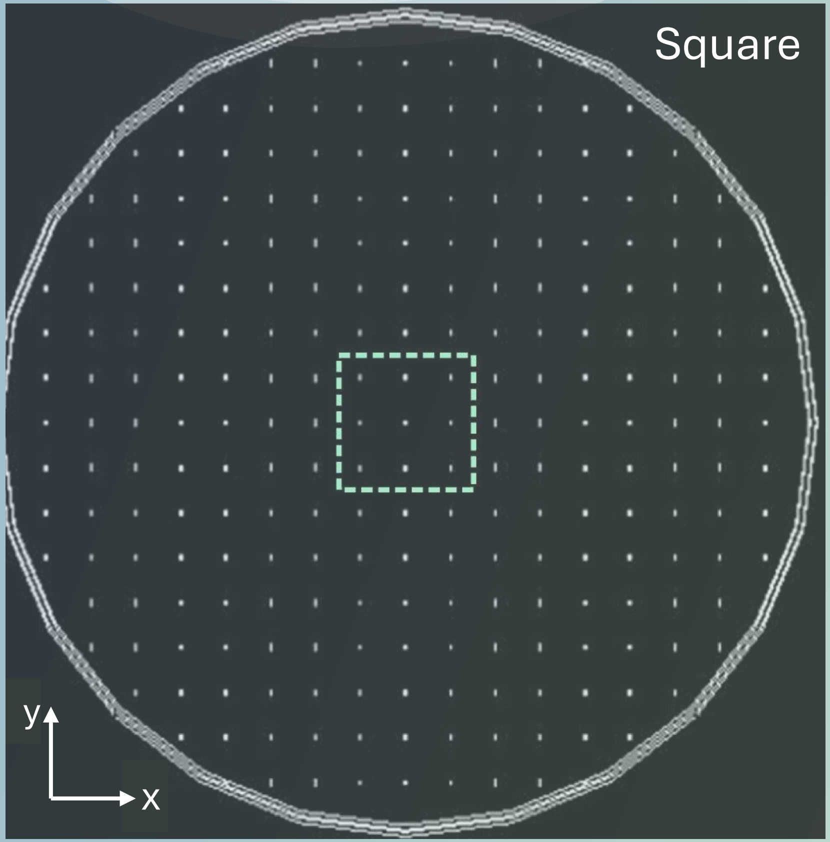
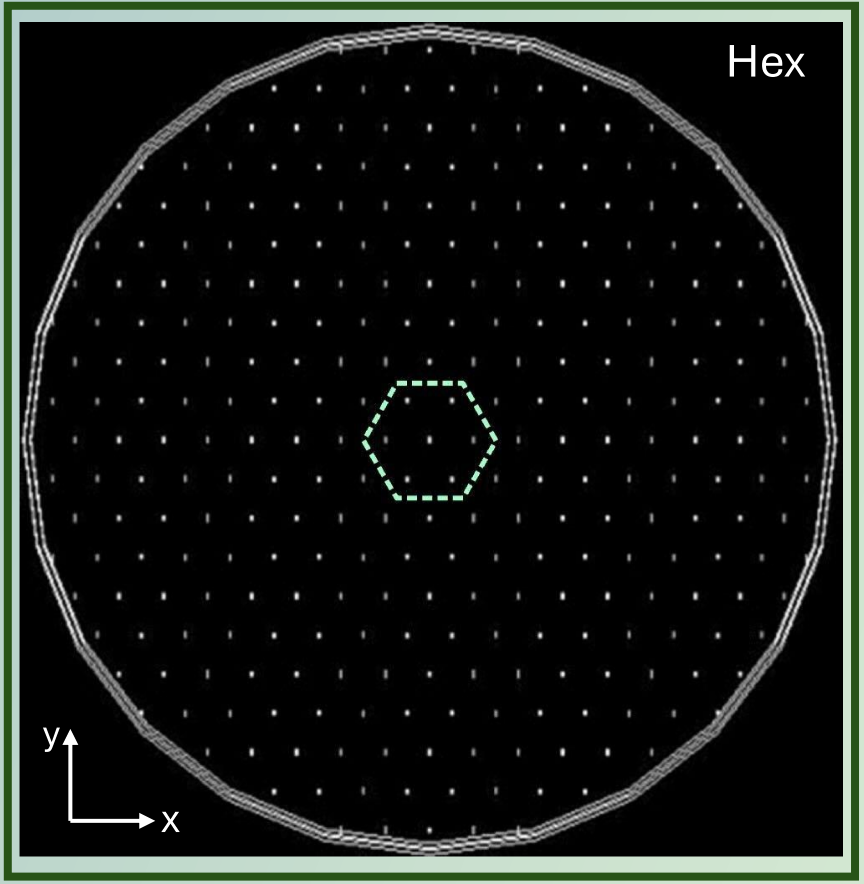
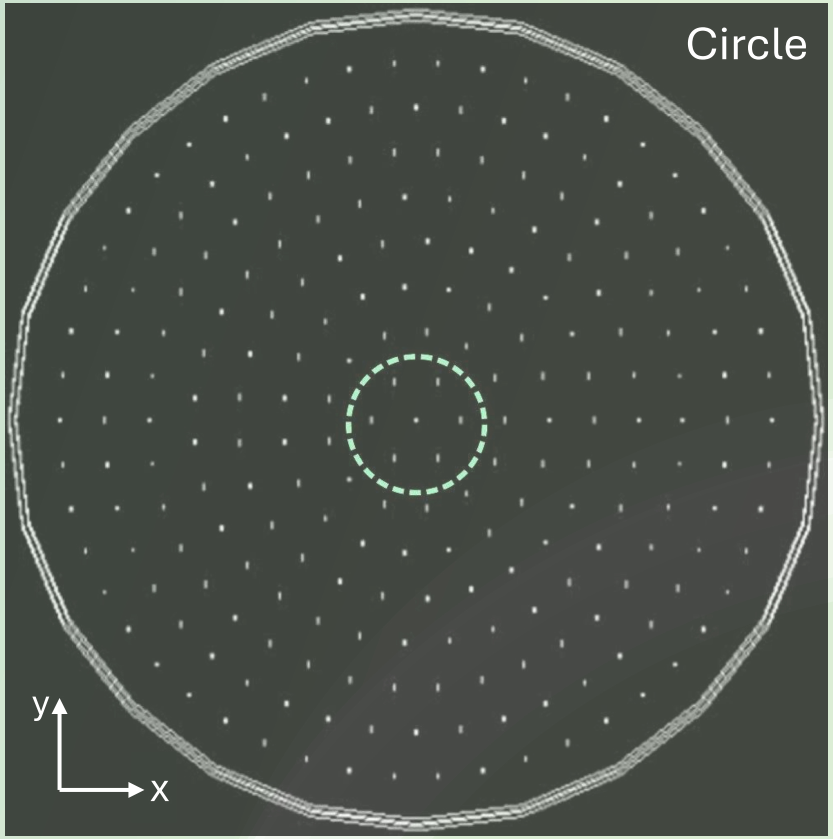
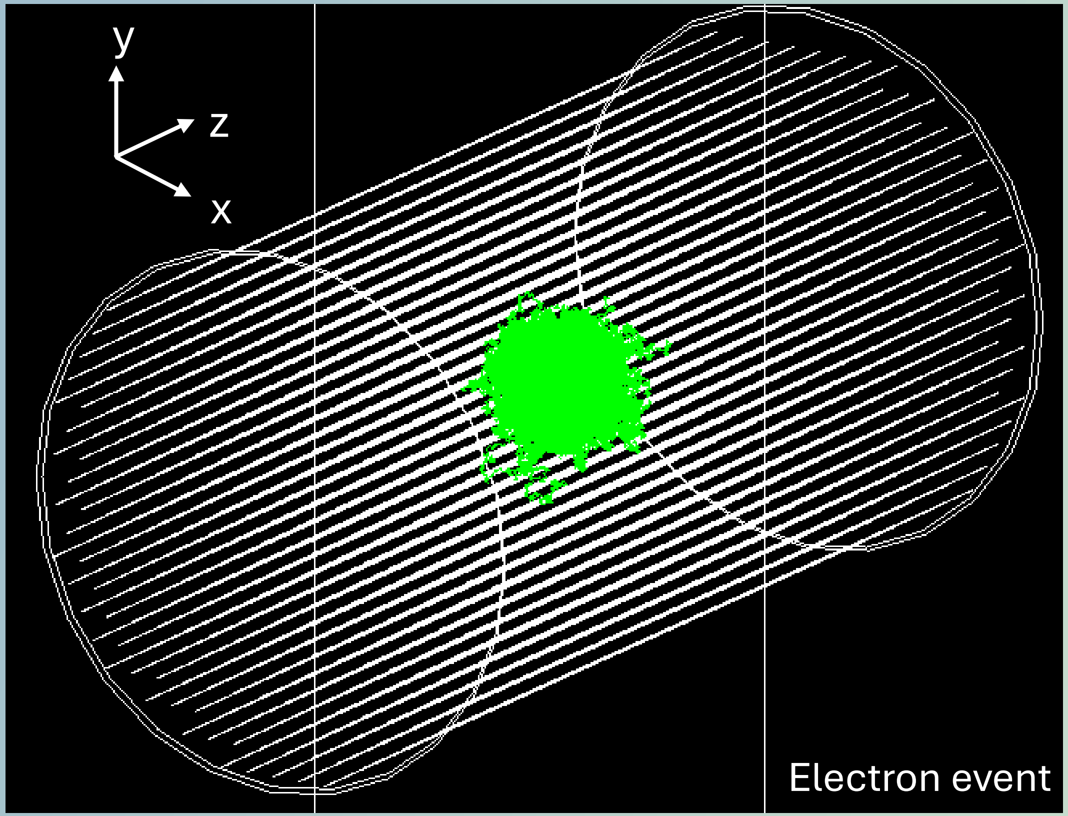






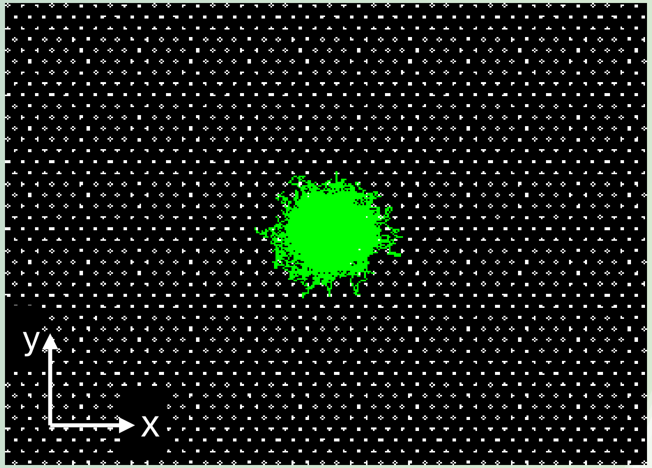
Fibre Array Geometry

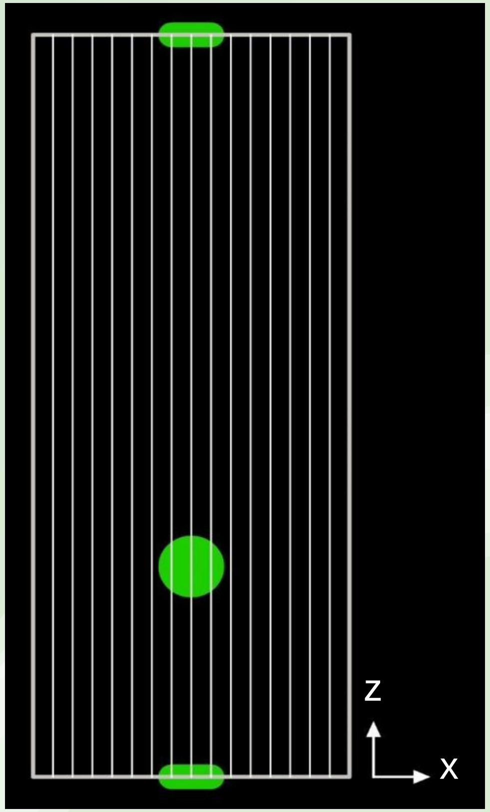
What is the best way to arrange the wavelength shifting fibres?



Position resolution:

- x & y, the position is determined from **which fibres are hit**. Position resolution ~ 1mm (or less).
- z, the position is determined from the **timing difference** of the signals readout at either end of the detector. Position resolution ~ few cm.





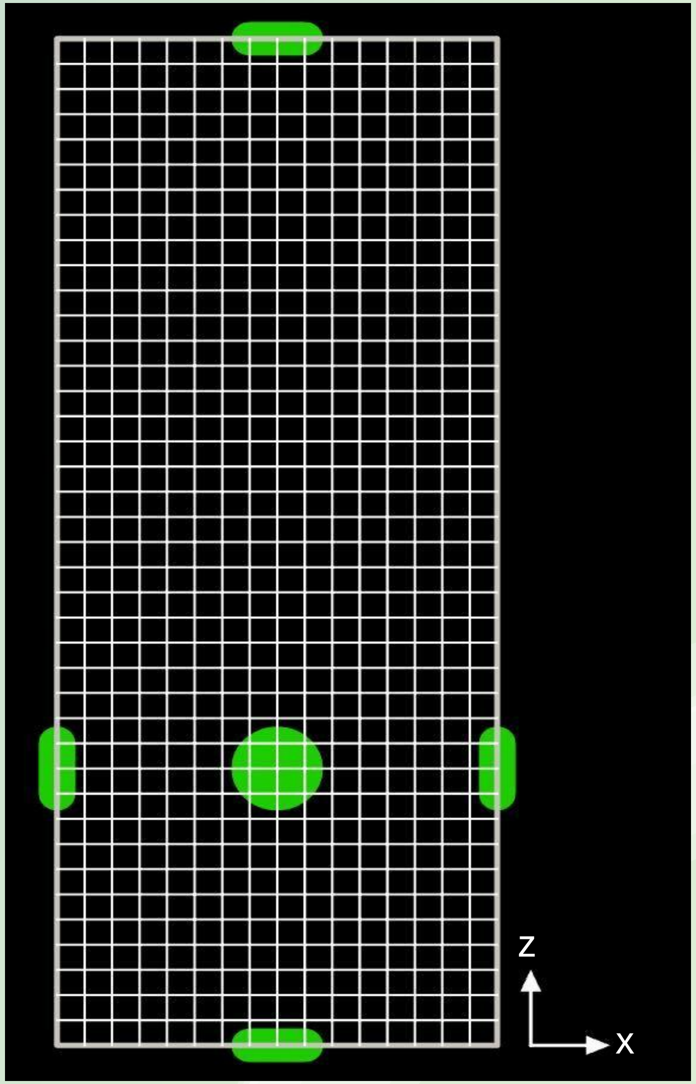
Fibre Array - Stereo Geometries

Can we improve z-resolution?

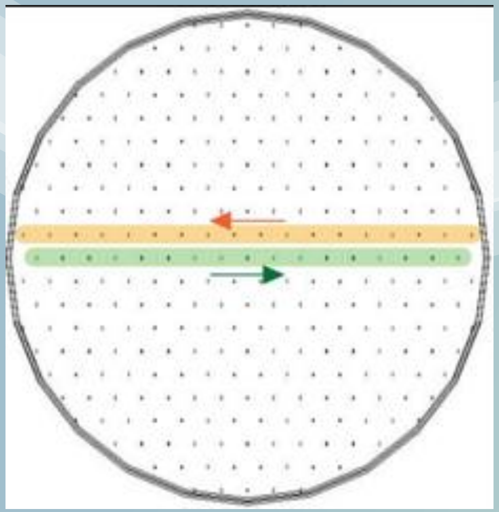
Yes! Cross the fibres.

Orthogonal crossing:

- Ideal: z-resolution = x-resolution = y-resolution,
- Very expensive!

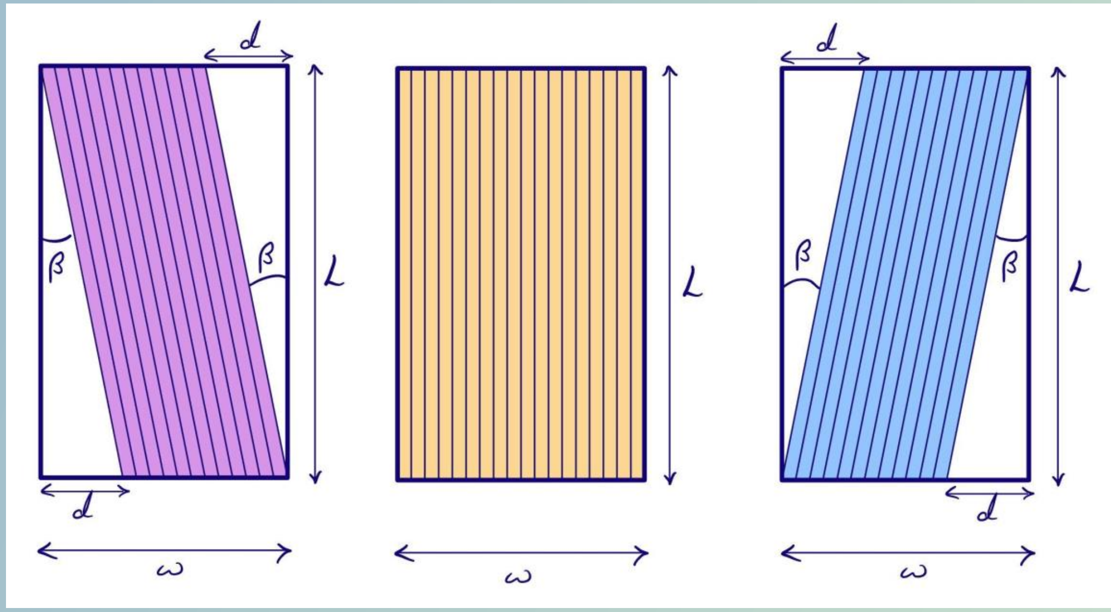


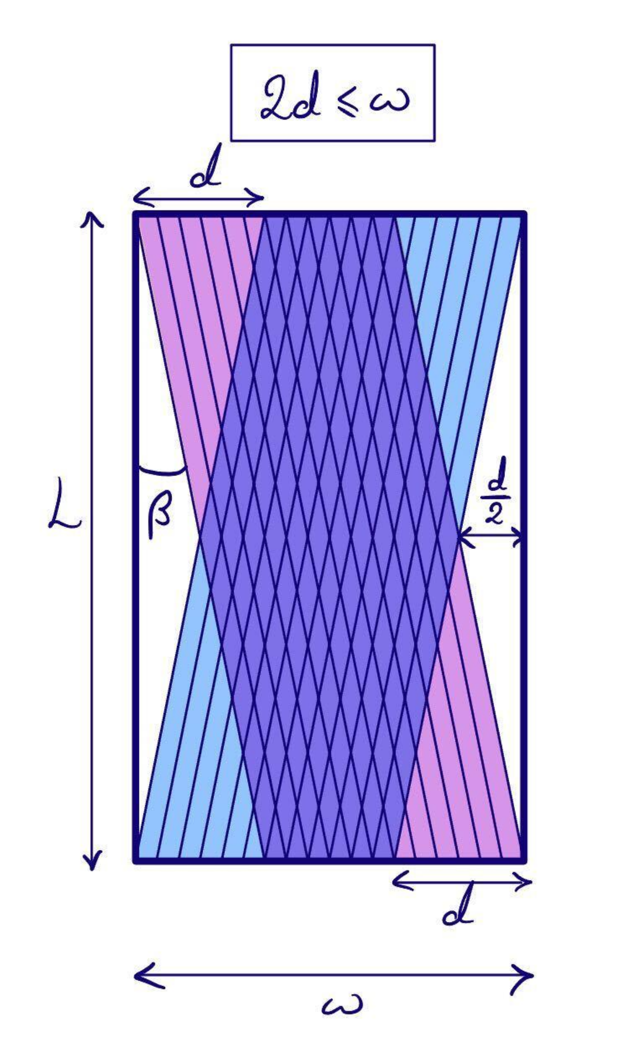
Fibre Array - Stereo Planes

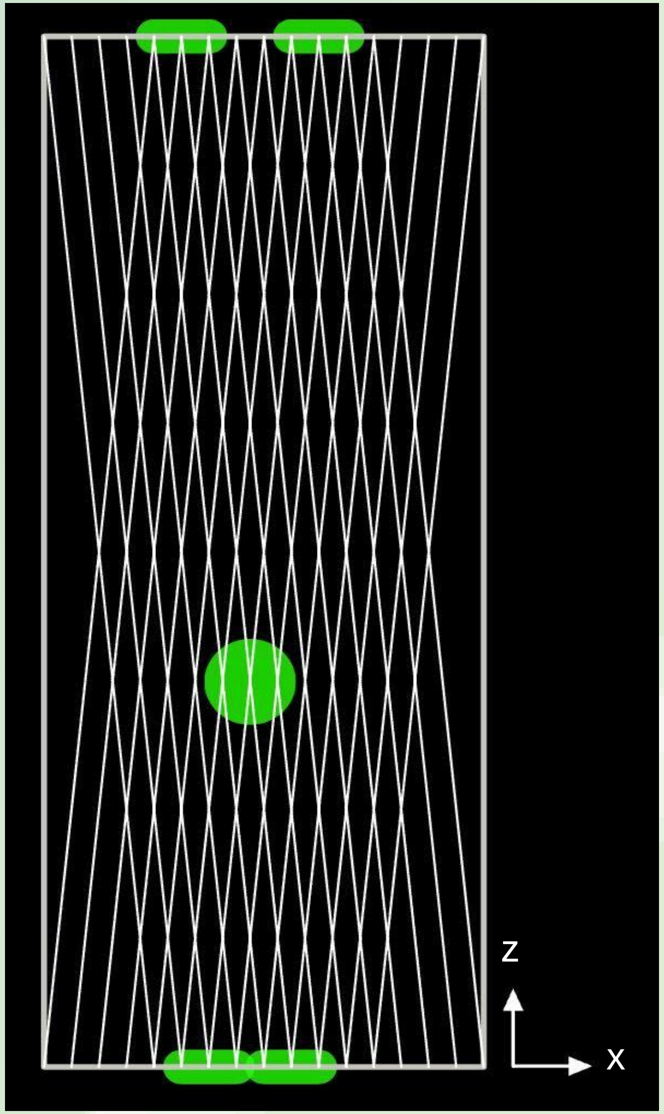


Uninstrumented space

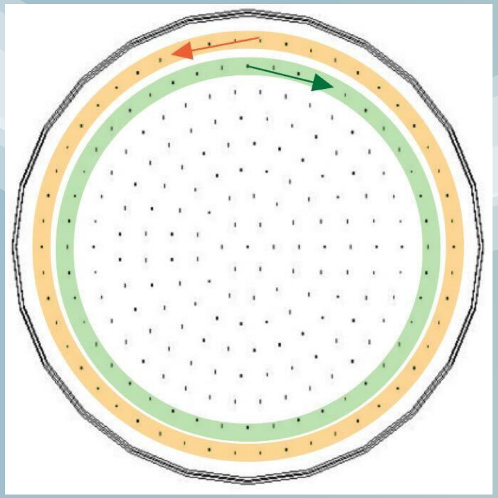
= lost signal



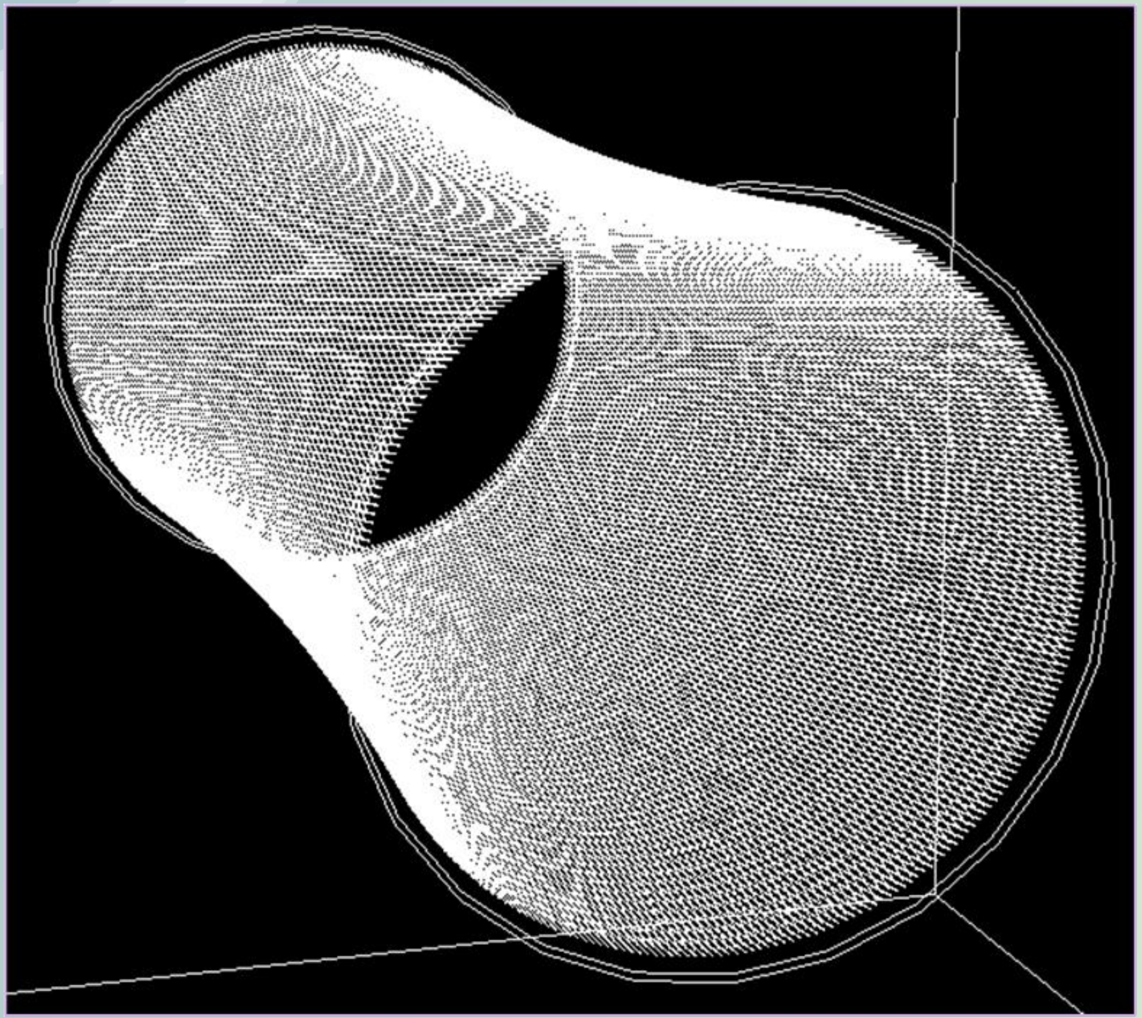


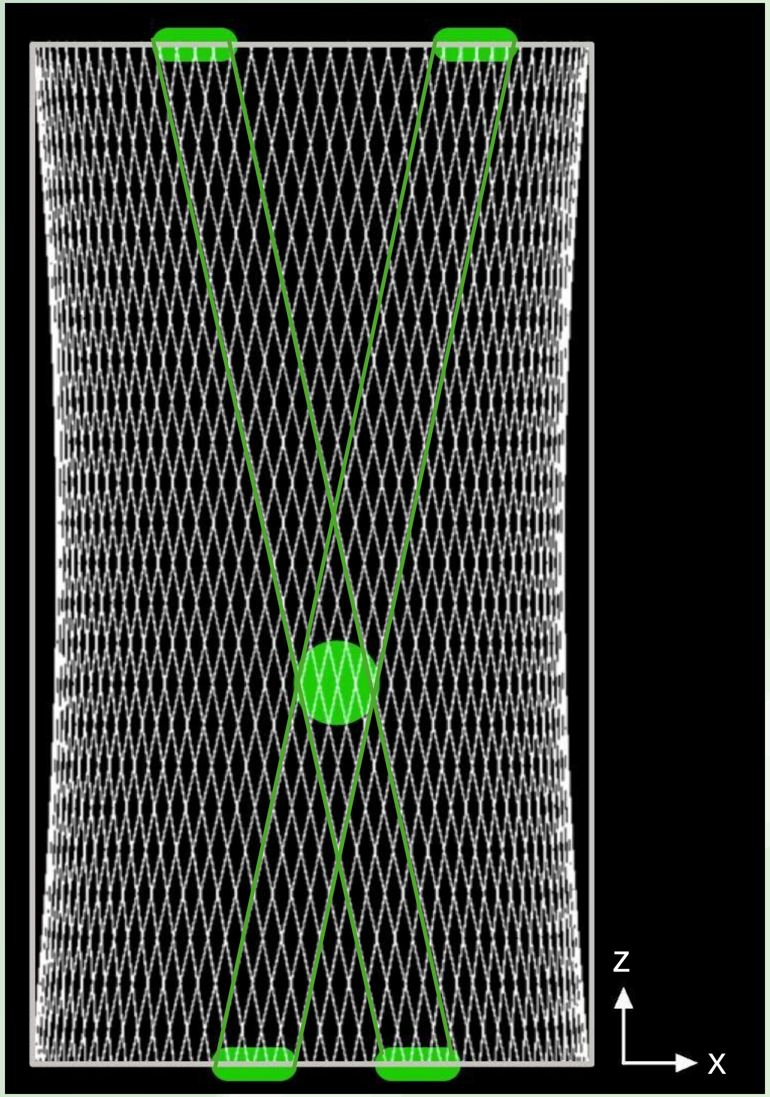


Fibre Array – Rotated Shells

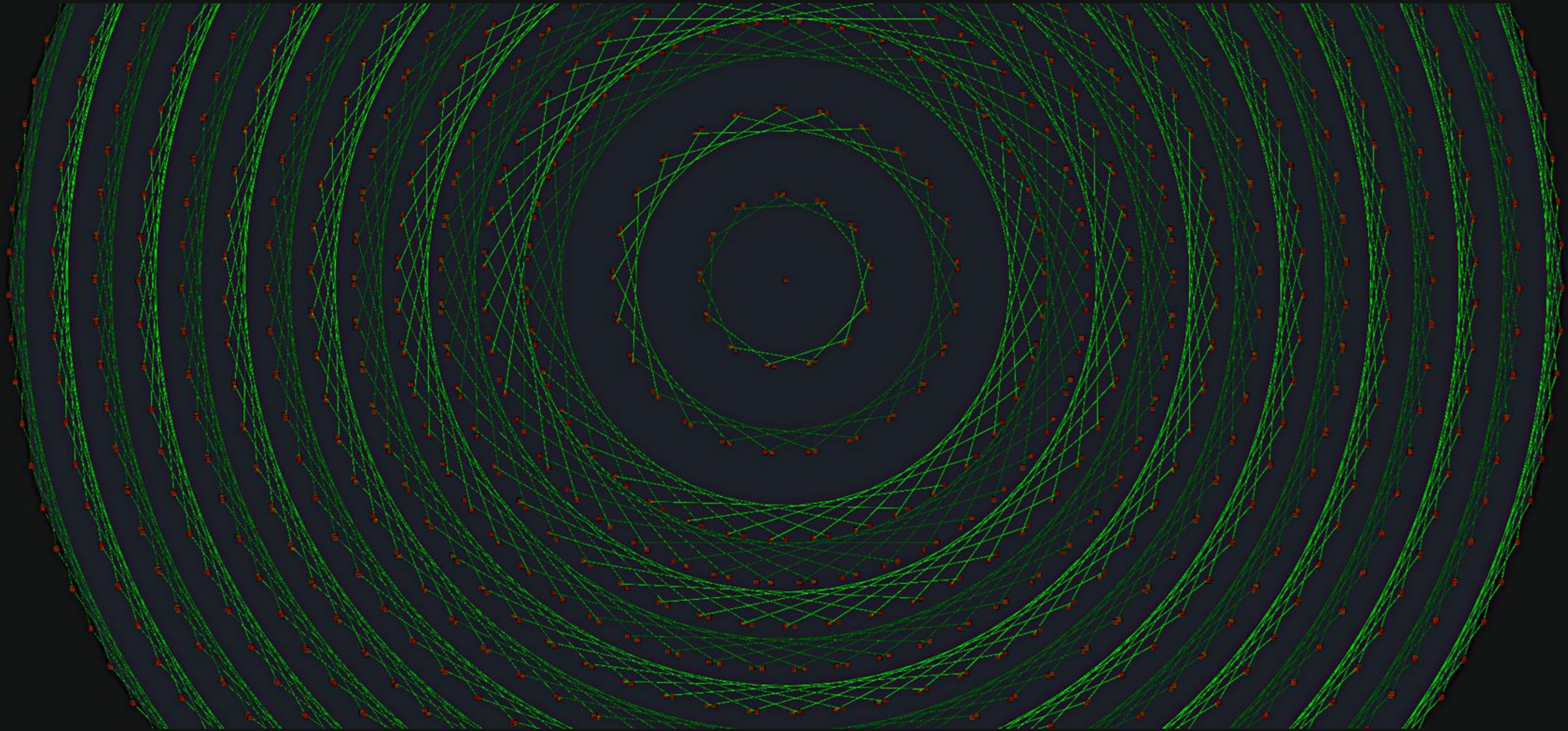


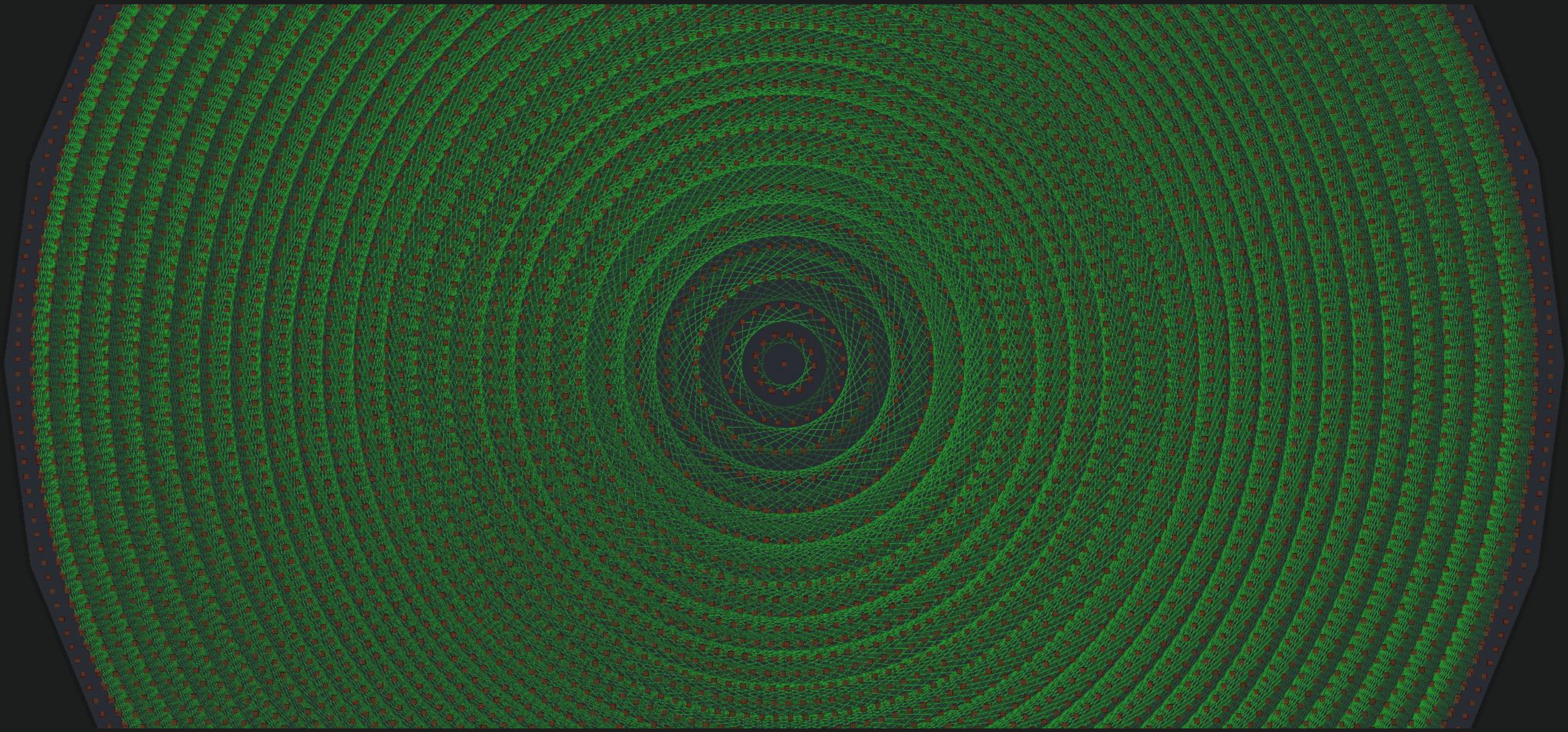
- Full volume instrumented
- Much more complicated:
  - To simulate
  - To optimise
  - To build
  - To trigger
  - To reconstruct





But: z-resolution is much improved!





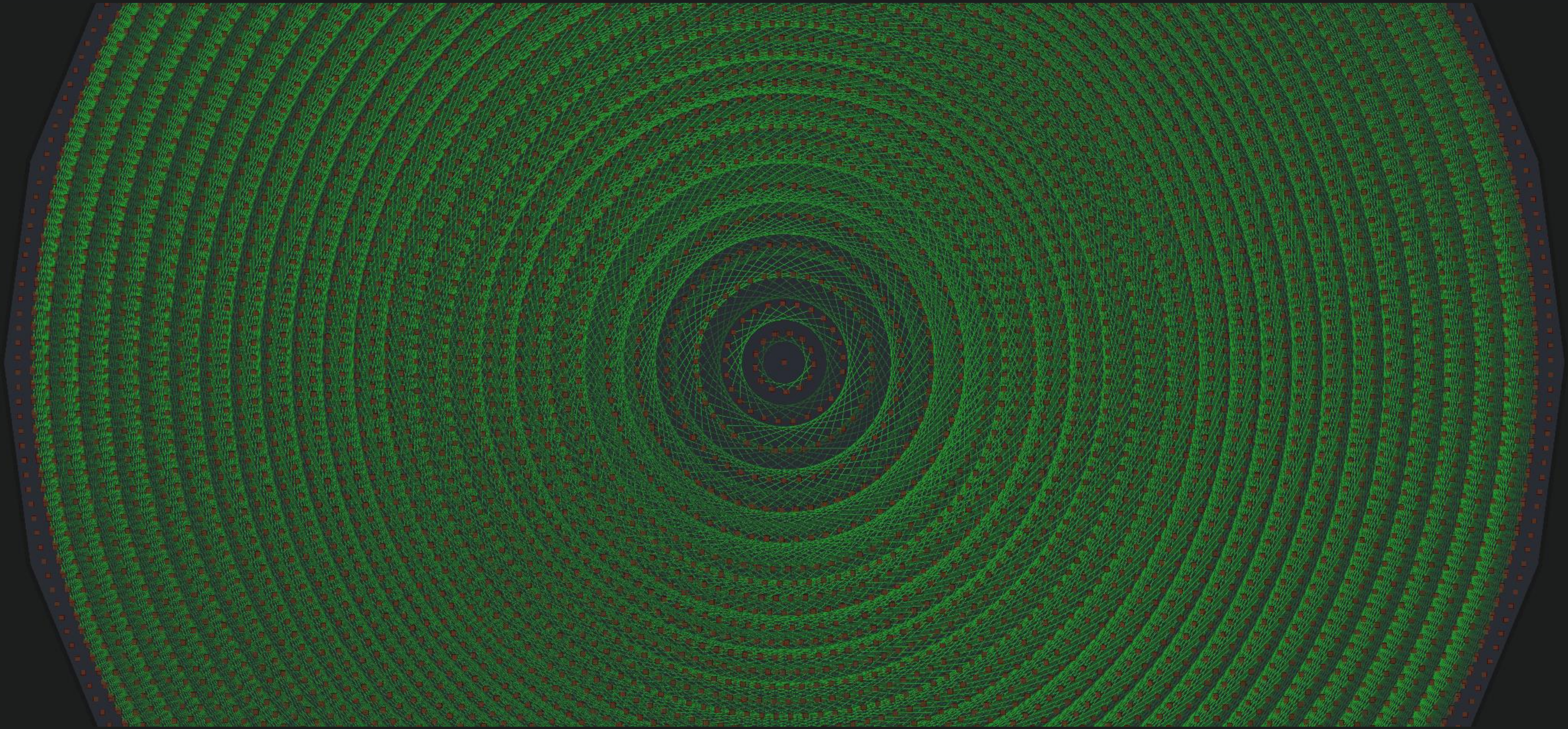
Conclusion

How to monitor a nuclear reactor:

- Detect the neutrinos.
- Maximise neutrino flux - get as close as possible.
- Background reduction and/or background discrimination.
- Liquid-O technology works well for this.
- Designing a fibre array is more complicated than you'd think!

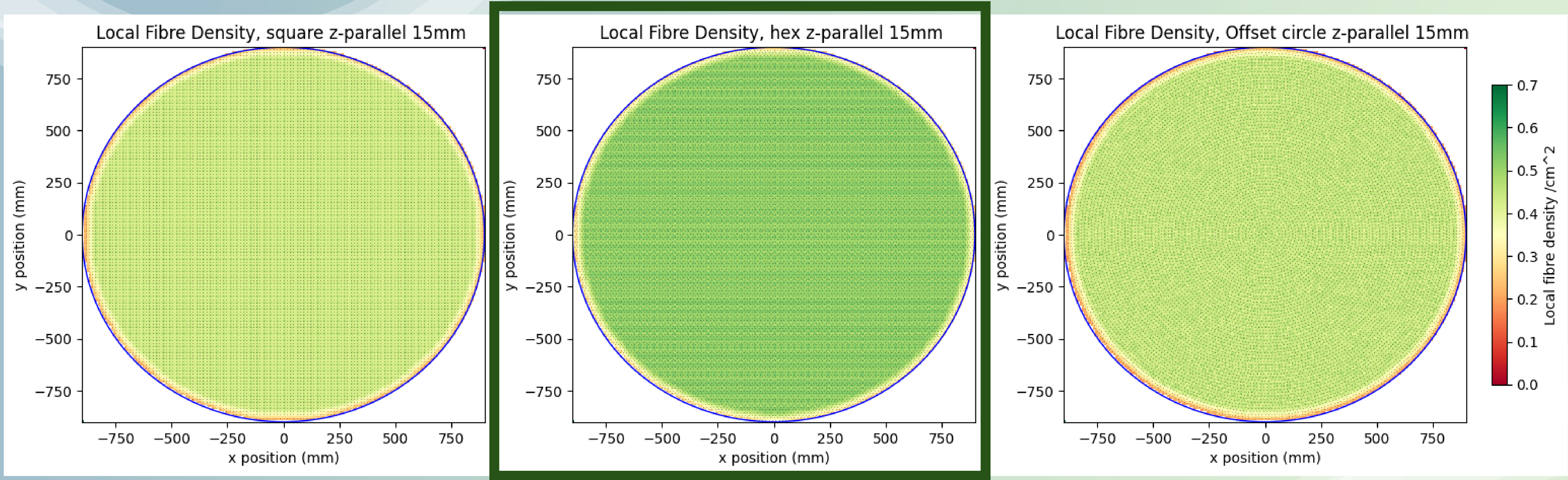
Without getting arrested:

- Don't tunnel under a nuclear reactor!



Backup Slides

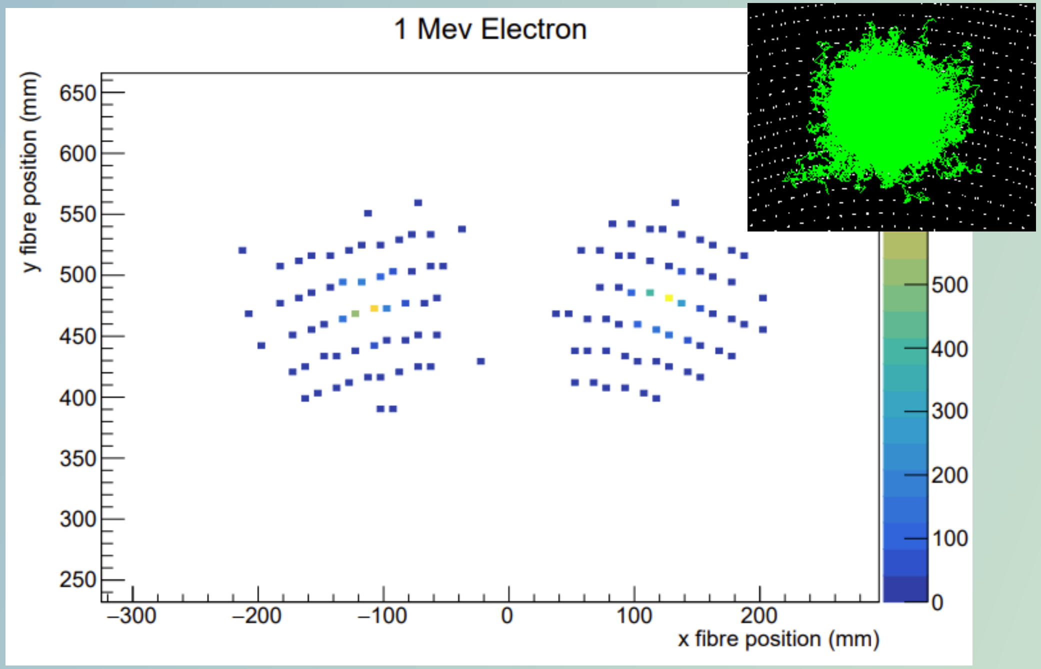
Z-Parallel

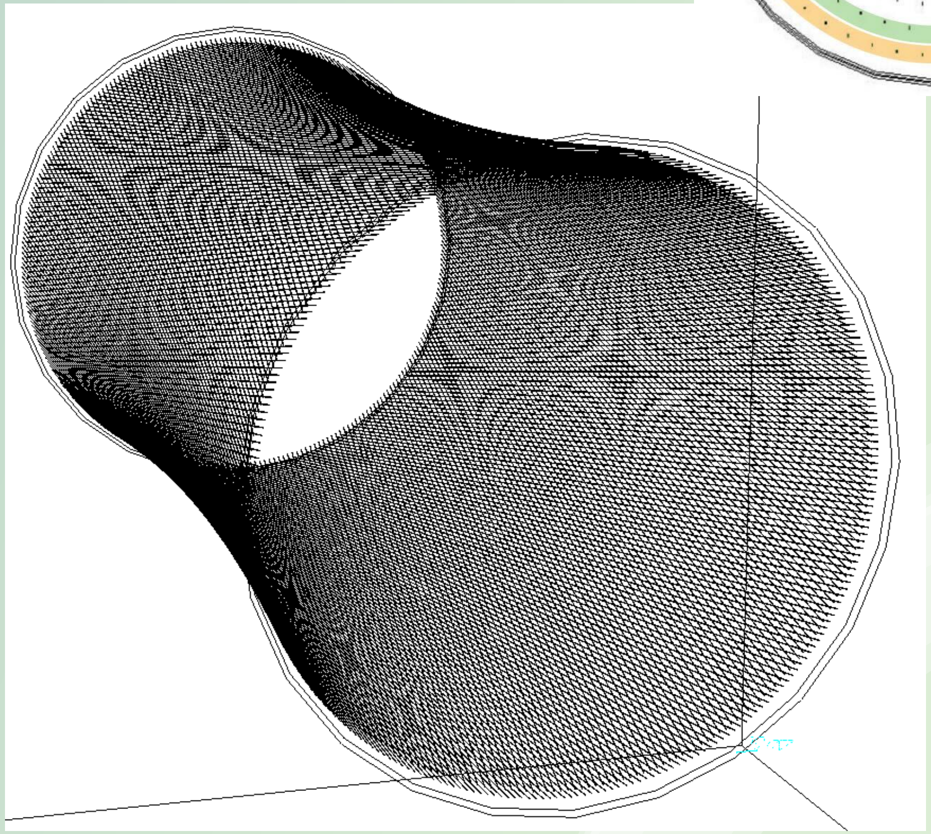


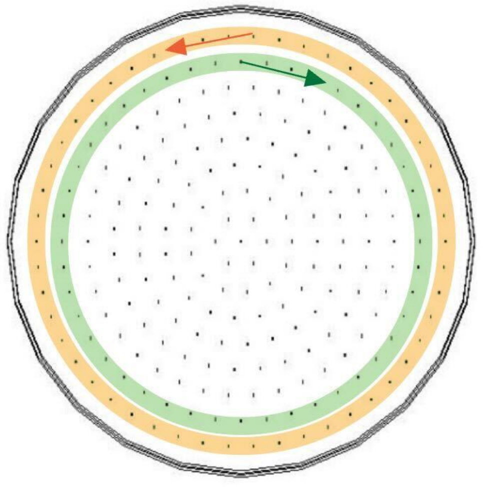
- Local fibre density: number of fibres per cm^2 within a chosen radius.
- As high as possible (money allowing)
- Uniform across the detector volume

Fibre Array Geometry - Rotated Shells The Maths

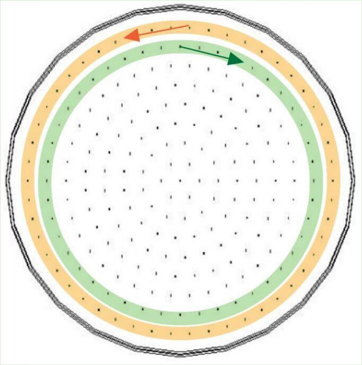
Cnaojc jsbcjabckasjc

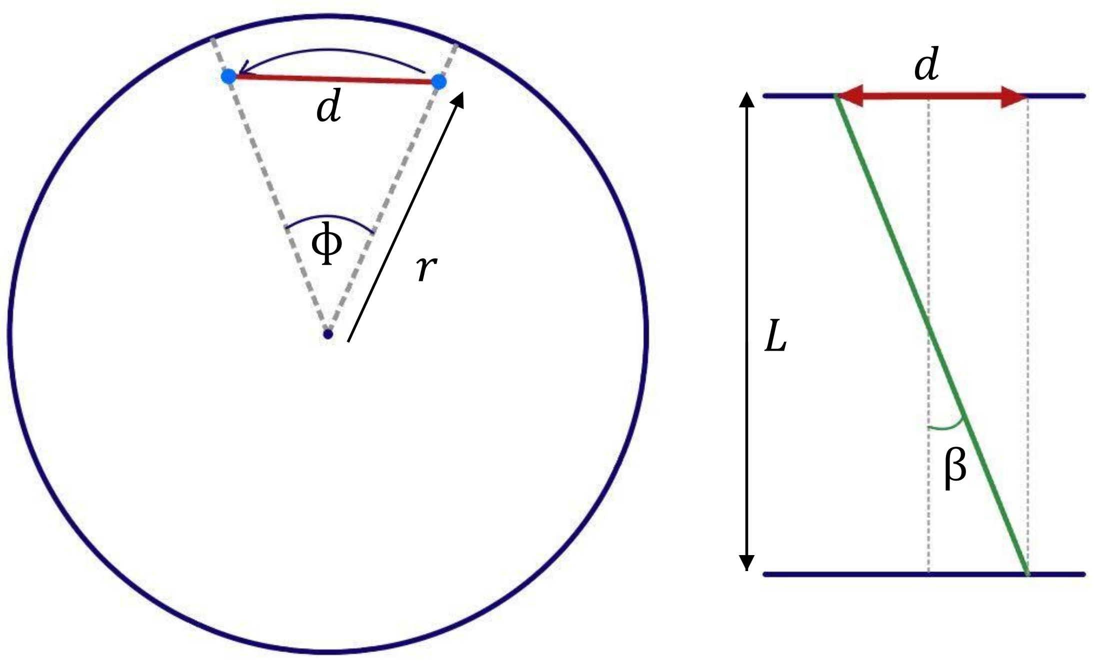






Fibre Array Geometry - Rotated Shells
The Maths



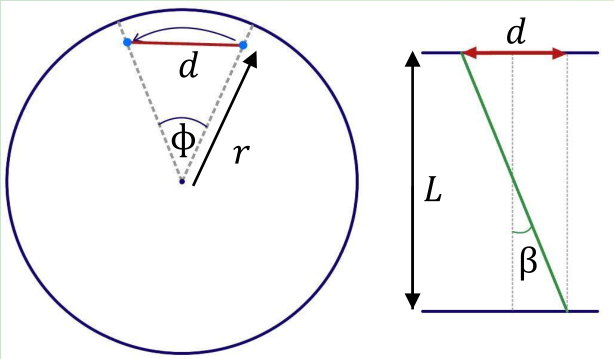


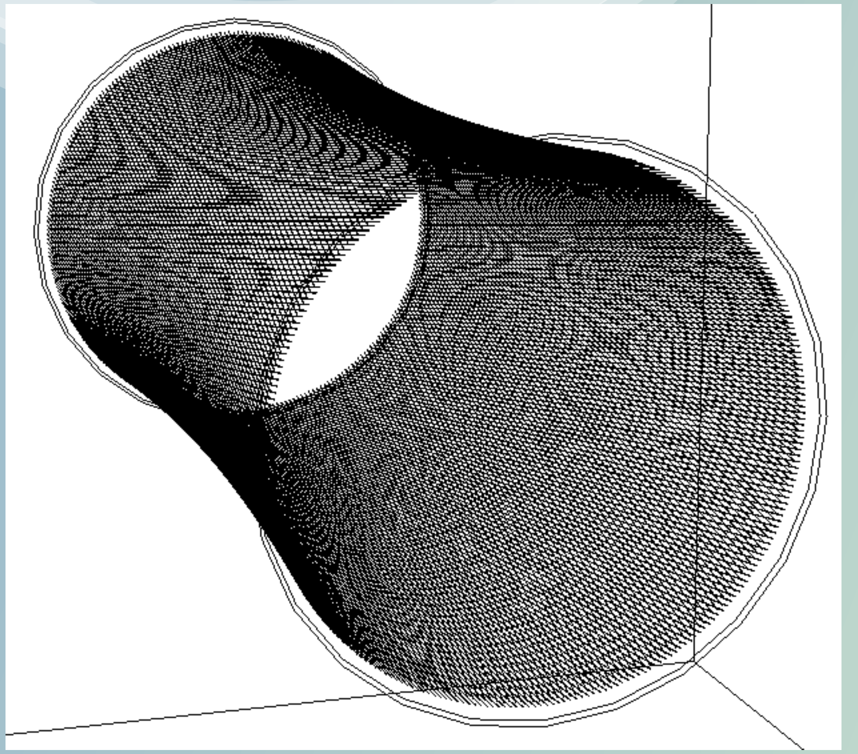
Inner Detector: End view   Top view

$$d = 2r \sin\frac{\phi}{2} = L \tan\beta$$

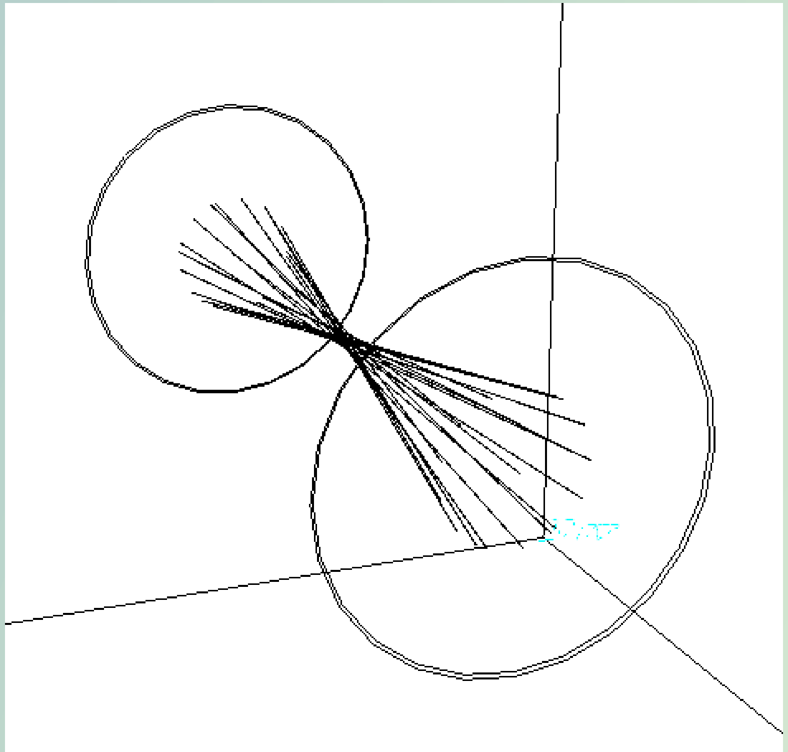
- Rotation Methods:
- Constant ϕ
- **Constant β**

Fibre Array Geometry - Rotated Shells
The Small r Problem





The two outermost shells of fibres in constant beta geometry.



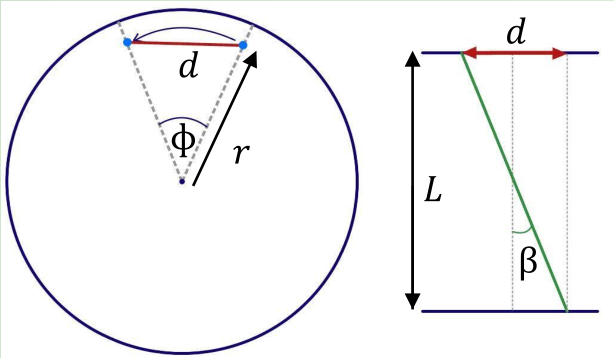
The two innermost shells of fibres in constant beta geometry.

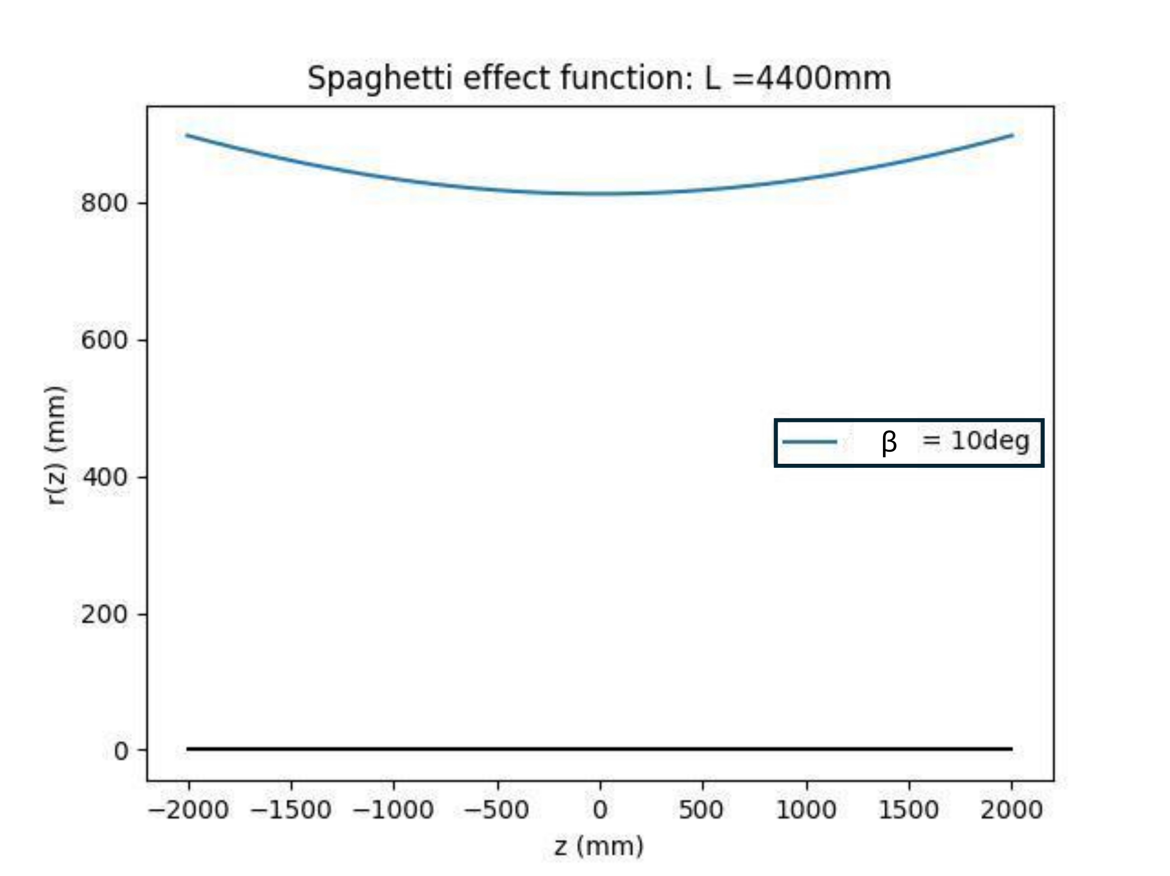
No fibres = no signal

Constant β is only viable for shells above a certain radius.

Constant ϕ must be used at small radii.

Fibre Array Geometry - Rotated Shells
The Spaghetti Effect

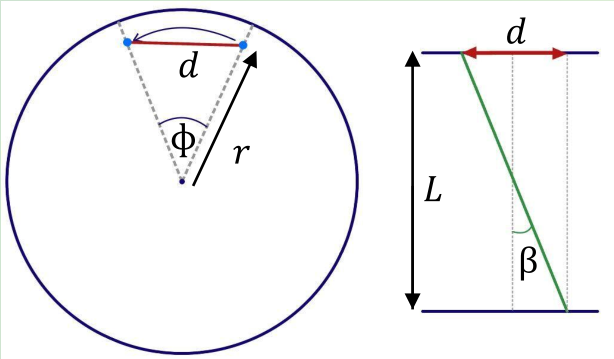




- **Uninstrumented volume** around the edge of the detector.
- **No fibres = no signal**

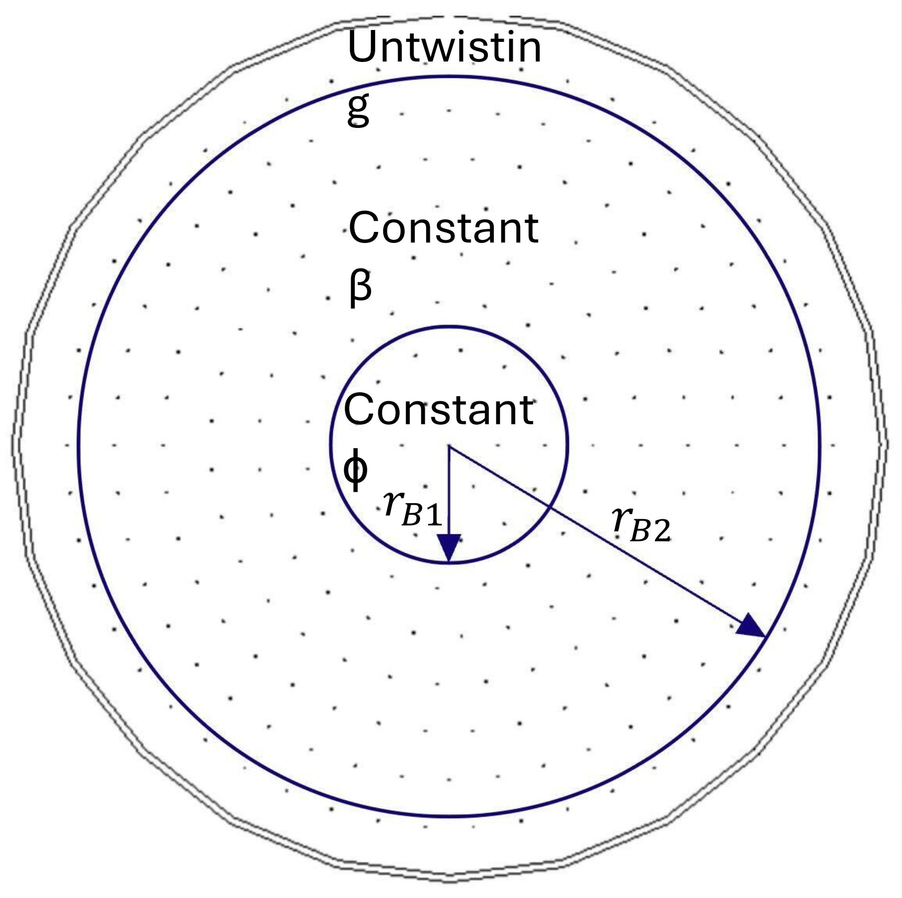
- Solution: **Untwisting region**, gradually untwist outermost shells.

Fibre Array Geometry - Rotated Shells
The Hybrid Design



- This geometry is non-trivial for construction, triggering and reconstruction.

- **Is it worth it?**



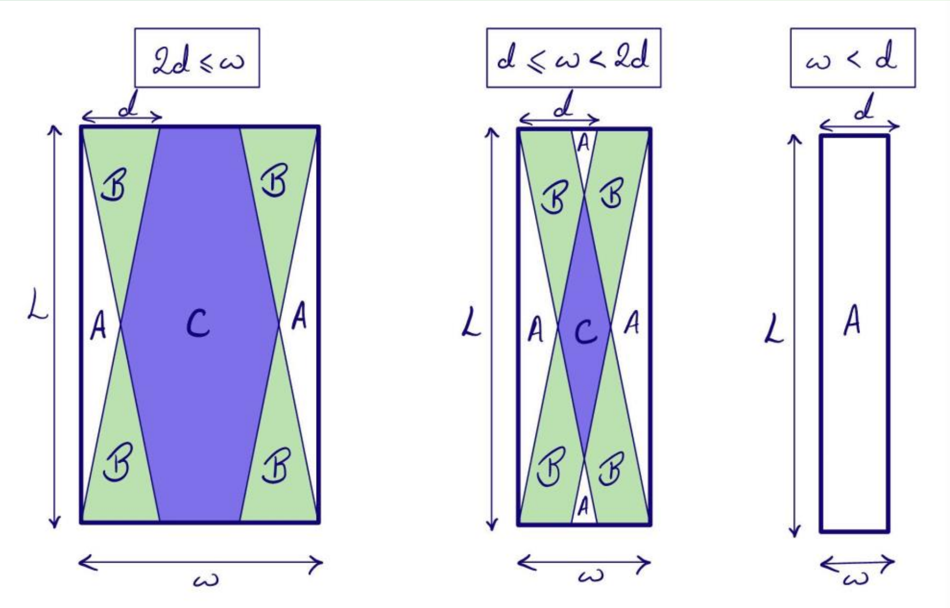
Stereo Planes

Zone C is covered by all layers

Zone B is covered by 2/3 layers

Zone A is covered by 1/3 layers

beta (deg)	A (%)	B (%)	C (%)	zSpacing/fibreSpacing)
10	27.6	20.3	52.1	5.7
9	24.2	19.1	56.6	6.3
8	21.1	17.6	61.3	7.1
7	18.2	15.9	65.9	8.1
6	15.4	14.0	70.7	9.5
5	12.7	11.9	75.5	11.4
4	10.0	9.6	80.3	14.3
3	7.5	7.3	85.2	19.1
2	5.0	4.9	90.1	28.6
1	2.5	2.5	95.1	57.3



- Volume of zones as a % of the total volume of the detector