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Precision 3D scan, Alignment and MCNP Simulation of a 100 µm Neutron Collimator at DICER

--- When modern engineering is applied to a legacy facility

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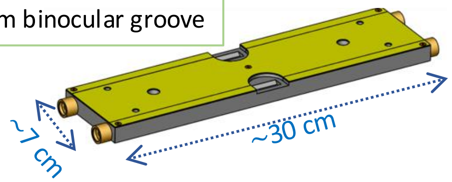
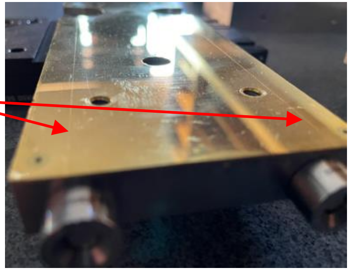
Introduction: Motivation

- We are installing 100 μm collimator in Lujan Center, inside FP13 (DICER)
- Legacy facility design introduces many geometric uncertainties—especially impactful for fine spallation target configurations and precise collimation systems.
- A new spallation target design was installed in 2022 and accurate understanding of the as-built facility through 3D scanning has proven essential.
- Our workflow spans from 3D scanning to MCNP modeling—culminating in geometry potential optimization.

CAD model of collimator
- 100μm binocular groove

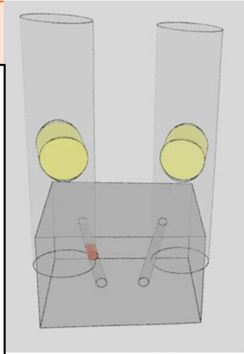


Photograph of collimator
- 100μm binocular groove



DICER instrument

- Neutron beamline at LANSCE designed for indirect capture experiments on radionuclides
- Enables high-precision cross-section measurements using neutron transmission
- Supports low-activity samples and reduced radiation risk through optimized collimation



A. Stamatopoulos et al., "New capability for neutron transmission measurements at LANSCE: The DICER instrument", Nucl. Instrum. Meth. A, 1025 (2022) 166166, 10.1016/j.nima.2021.166166
A. Stamatopoulos et al., "First study of 88 Zr + n at DICER at LANSCE at energies up to 500 eV and relevance to explosive environments", Phys. Rev. C (2025) CW10809

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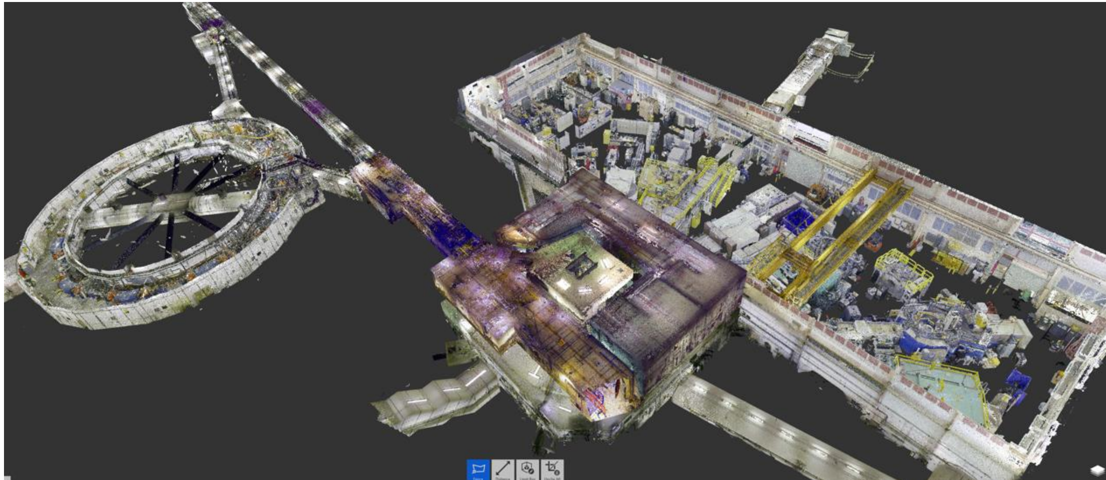
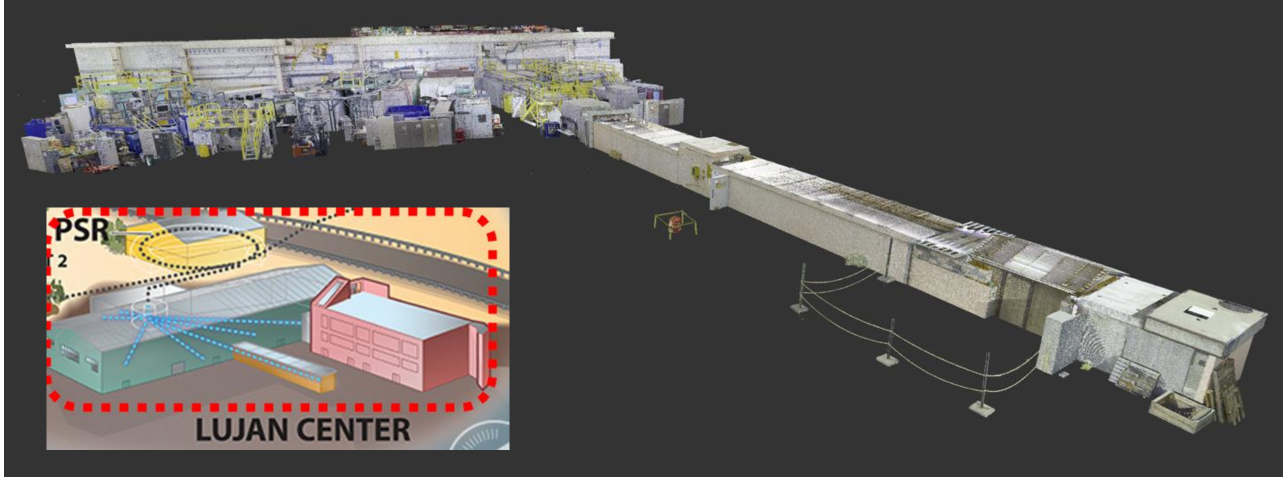
Acknowledgement:
Kenny Feller & Martha Gomez – Legacy LiDAR
Brad DiGiovine & Andrew Cooper – Legacy LTS



FP13 100 μm collimator:

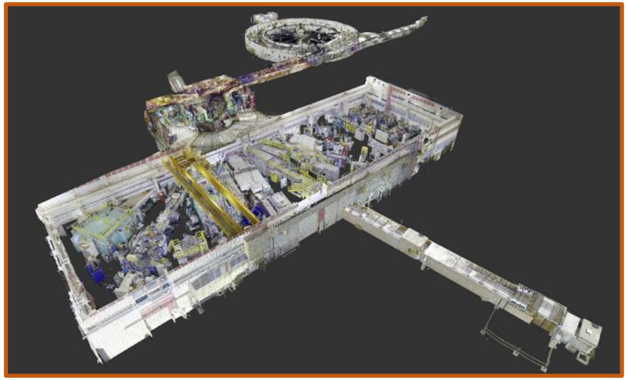
Legacy Facility, Modern Demands

FP13 – DICER (Device for Indirect Capture Experiments on Radionuclides)



Short analogy:

Documents → digitized → searchable
Facilities → scanned → analyzable



- High-fidelity MCNP requires **accurate starting geometry**
- Legacy documentation → **incomplete and unreliable geometry**
- We build a pipeline: **3D scan** → **CAD** → **MCNP** with a goal: **3D scan** → **MCNP**
- <u>Key challenge: **turning scan data into simulation-ready geometry**</u>

Accurate neutron simulations require accurate geometry—and legacy facilities don't have it. We built a full pipeline from scan → CAD → MCNP → alignment to fix that.

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Simulation Challenge & Approach (FP13 – DICER)

Key Challenges

Unknown facility geometry
- Proton beam shape & position
- Target position and FP axis
- Upstream collimator effects

Unknown collimator geometry
- Exact position
- As-built shape

Extreme conditions
- 100 µm aperture at ~15 m
- Non-uniform neutron source

Our Approach

- Comprehensive 3D scanning
- Target, shutter ports, flight path, detectors
- LiDAR + Laser Tracker + optical scans
- Precise alignment
- Monument-based Laser Tracker system
- Collimator tightly referenced to beam axis
- Simulation-ready modeling
- As-built geometry → CAD → MCNP
- Pixelized neutron source for non-uniform emission

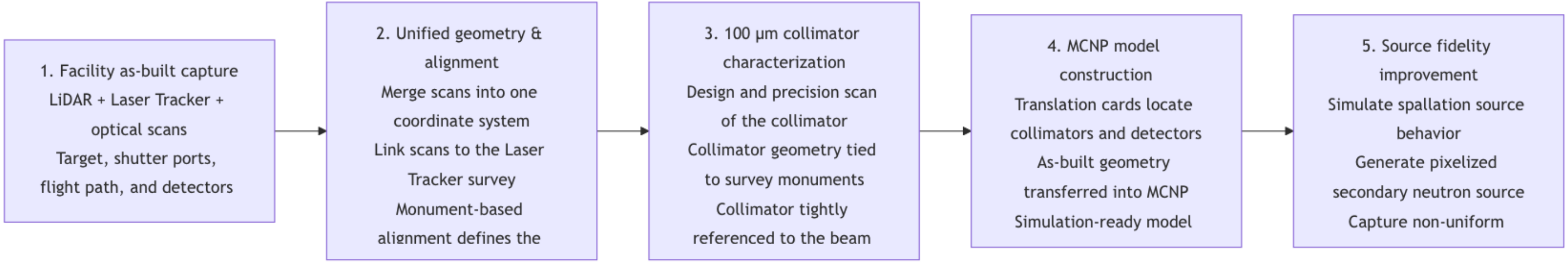
High-fidelity MCNP simulation – legacy facility constrains

<u>Before building a high-fidelity model, we must ask:</u>

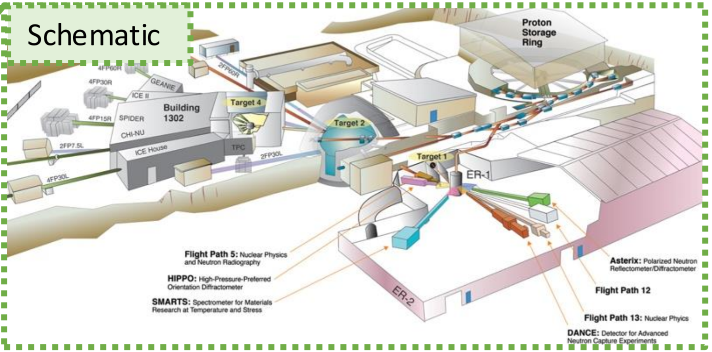
- ❖ What do we *actually* know about geometry?
- ❖ What are the tolerances?
- ❖ Was the *as-designed* geometry validated?
  - LiDAR
  - Laser Tracker Survey
    - Direct Scan (Point Cloud)
    - Spatial Scan (Measured Points of Reflective Sphere)
  - Optical Scan (Structured–light)
  - Profilometer
- ❖ How can we use these data for *as-built* MCNP geometry?
  - Constructive Solid Geometry (CSG)
  - Unstructured Mesh (UM)
  - Hybrid approaches (CSG+UM)

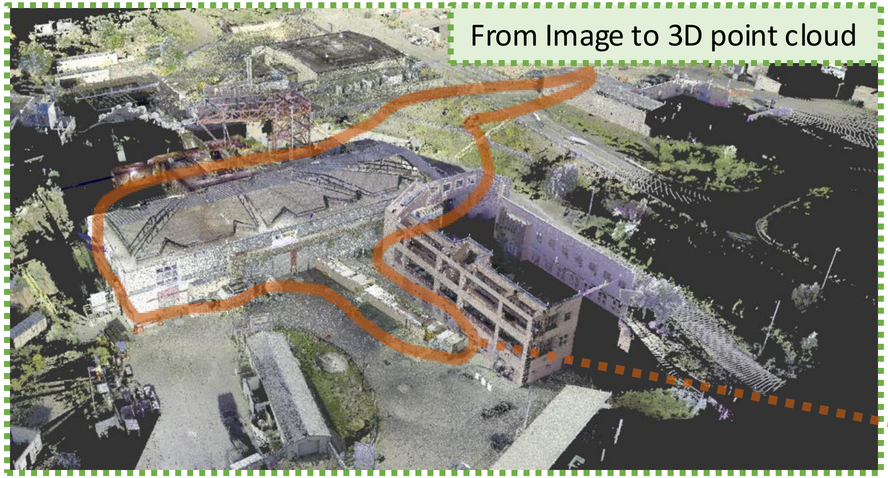
From Legacy Facility to High-Fidelity Simulation

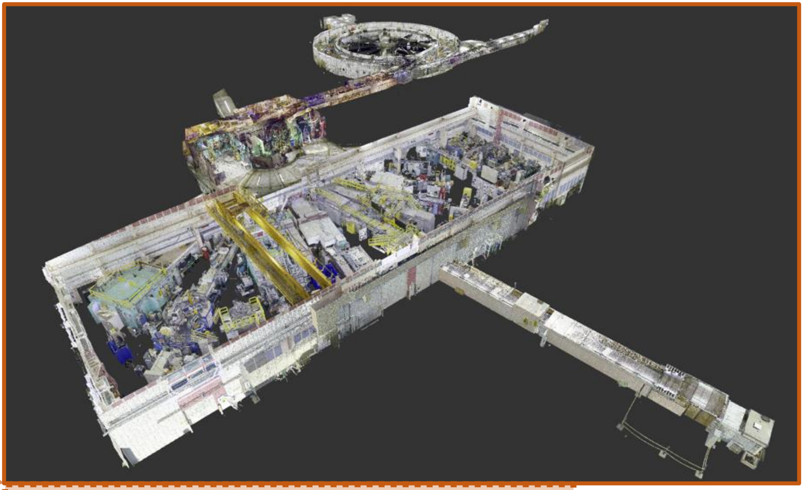
- High-fidelity MCNP requires **accurate starting geometry**
- Legacy documentation → **incomplete and unreliable geometry**
- We build a pipeline: **3D scan → CAD → MCNP**
- Key challenge: **turning scan data into simulation-ready geometry**



From image to terrestrial LiDAR scan (3D point cloud)

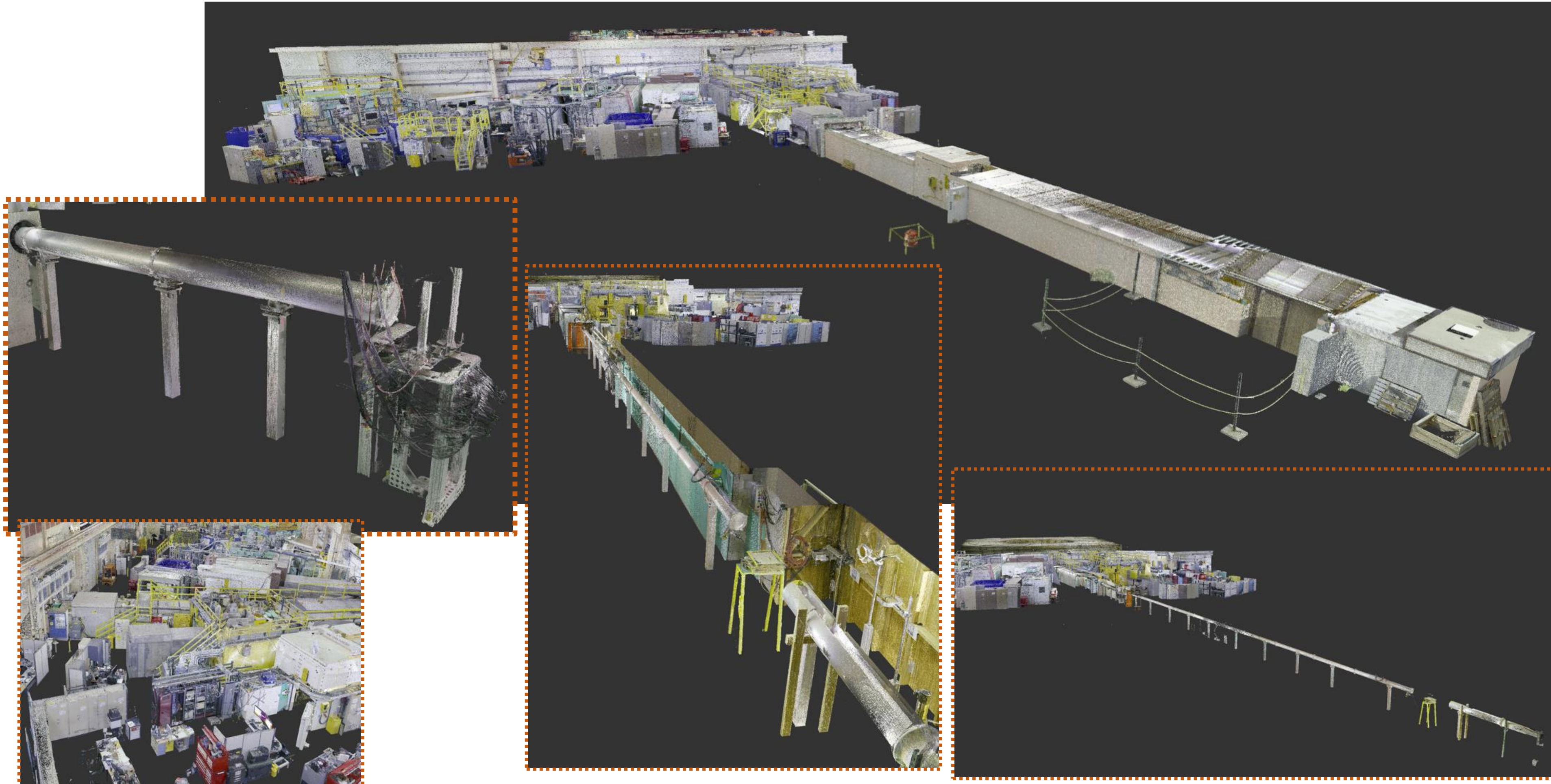






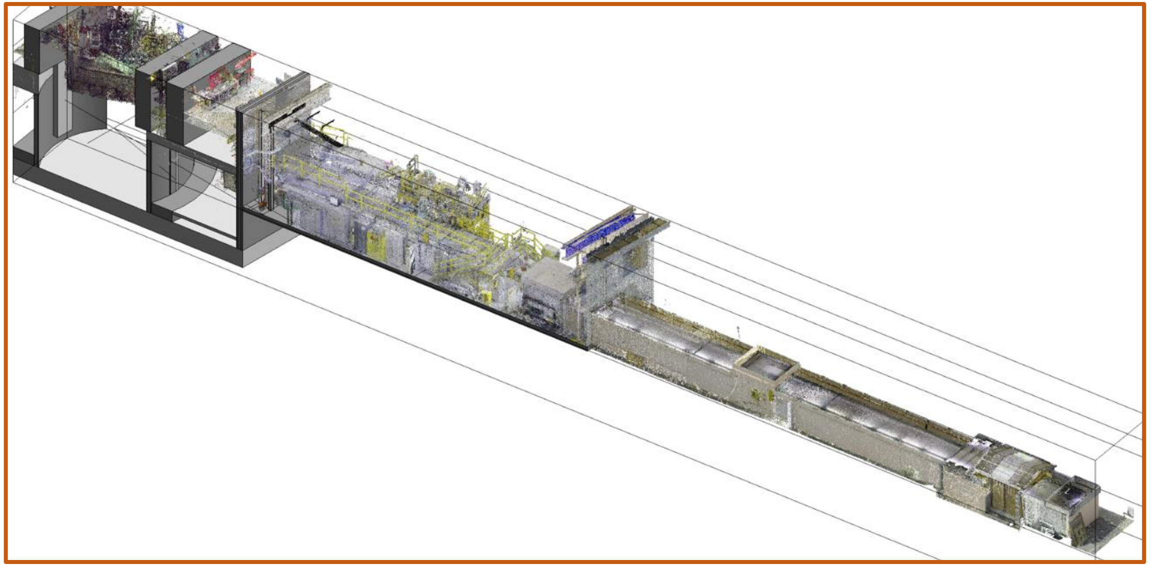
From RAW 3D scan to clean Point Cloud

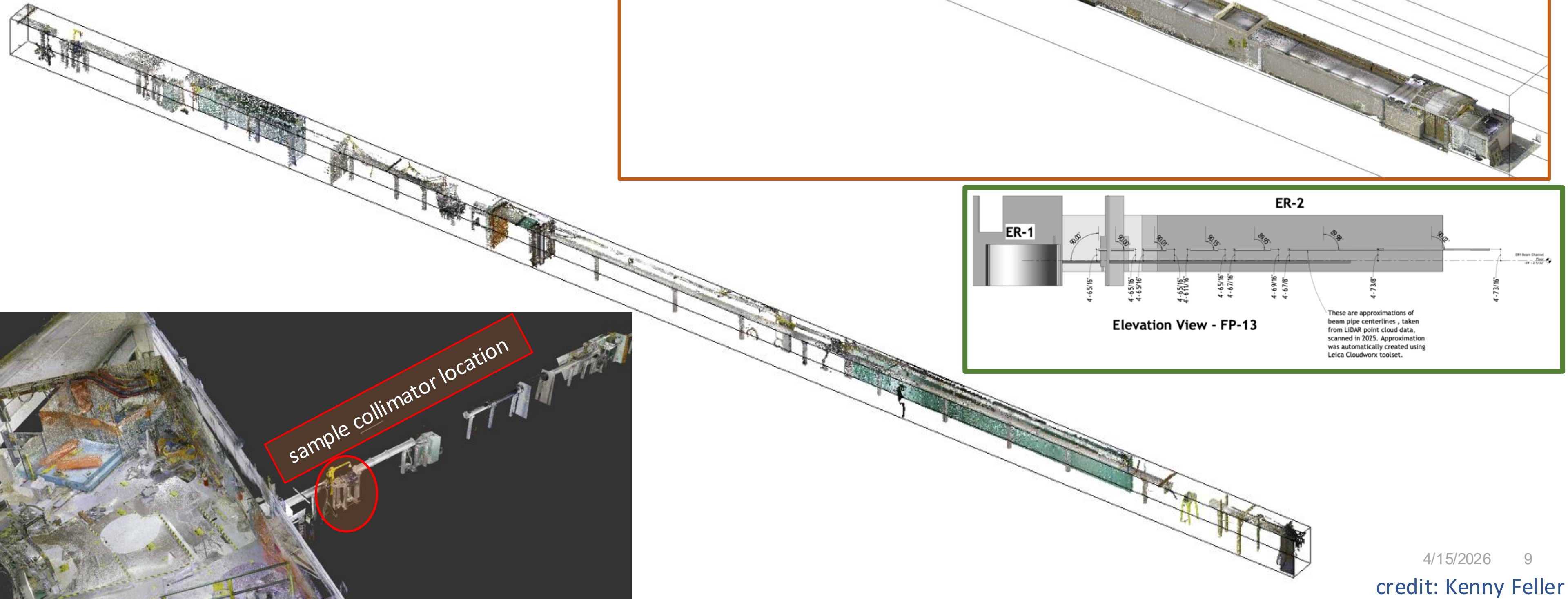
From As-Built Facility Scans to Flight Path 13 Modeling



Aligned point cloud with Revit CAD structure

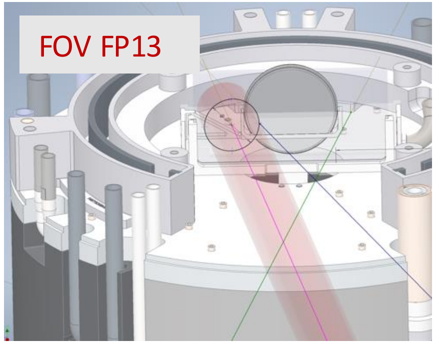
→ informing “as-built” CAD drawings

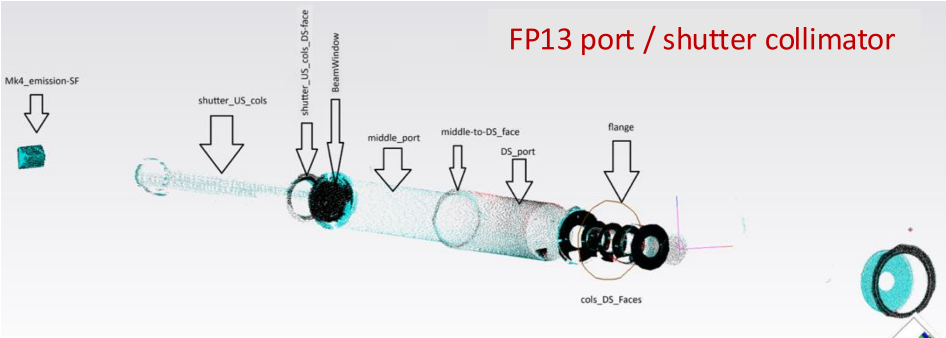


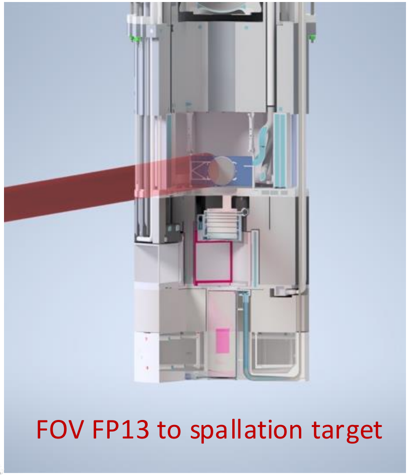


credit: Kenny Feller

Target and FP13 port with shutter collimator

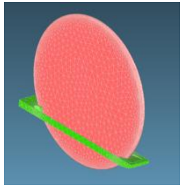


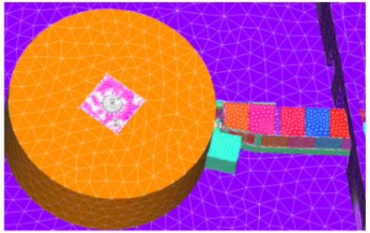




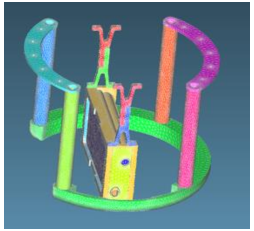
- Complex geometry transfer from CAD / SCAN to CSG / UM
- Unstructured Mesh benefits / costs (below)

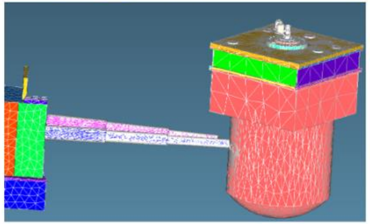
upper target W disc

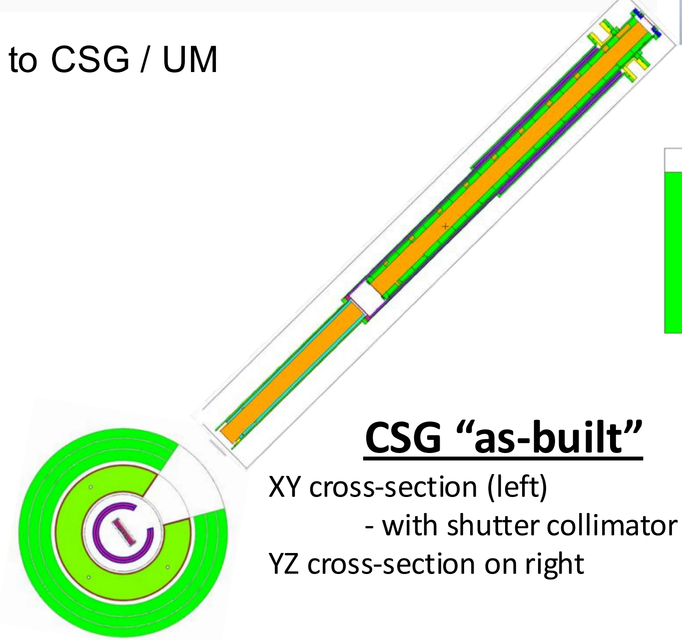


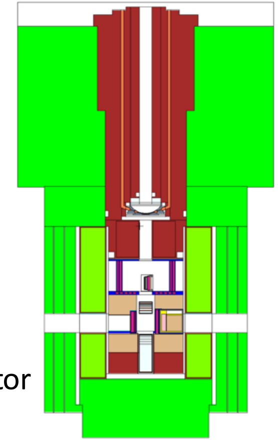


upper-tier target assembly







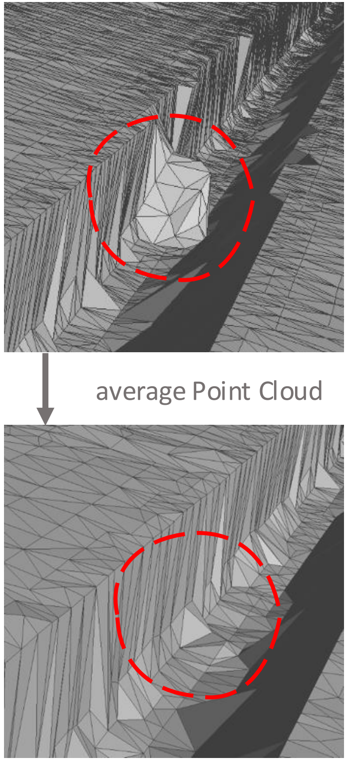


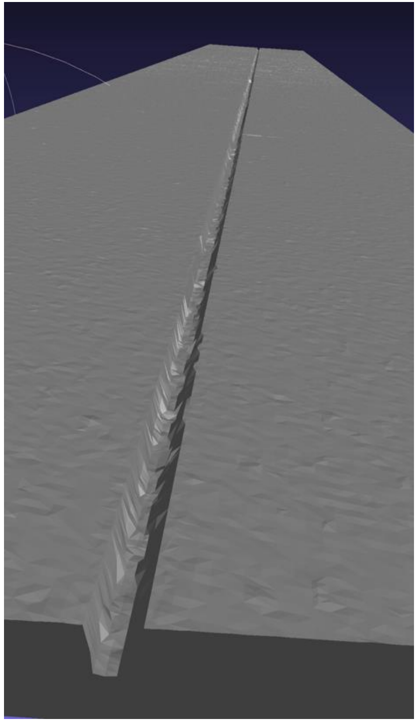
CSG "as-built"

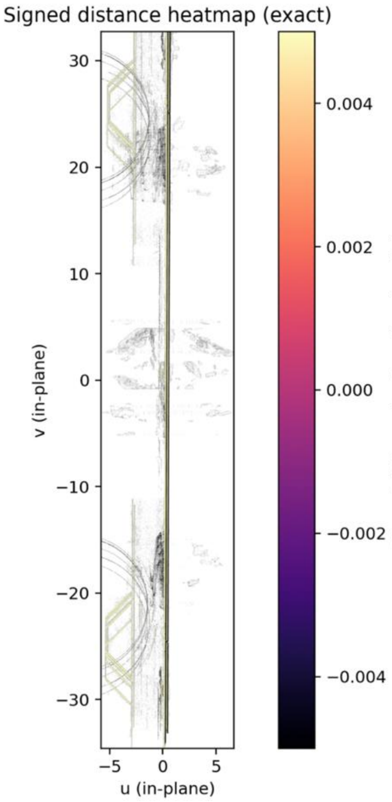
XY cross-section (left)
- with shutter collimator

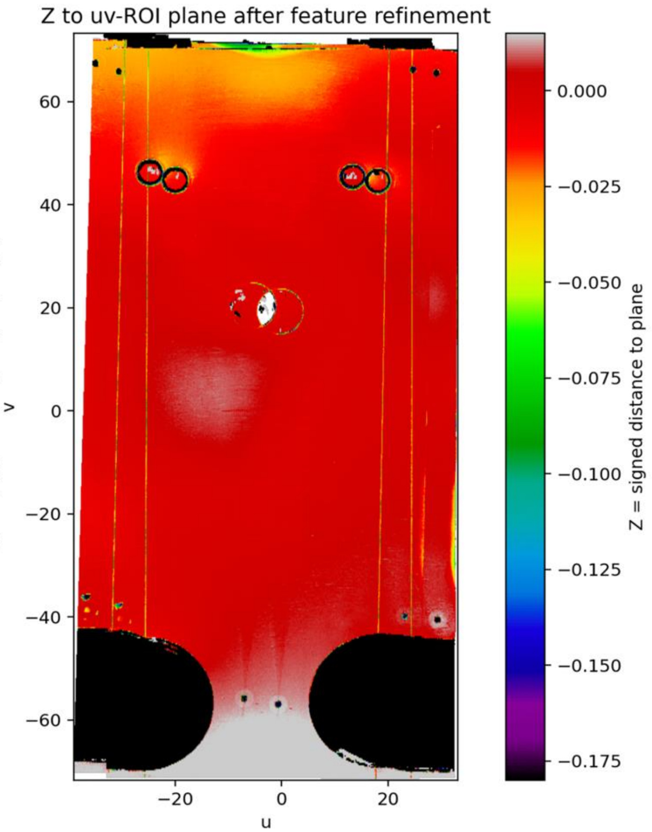
YZ cross-section on right

Collimator 3D Scans – Custom Script for Scan Merging (python)



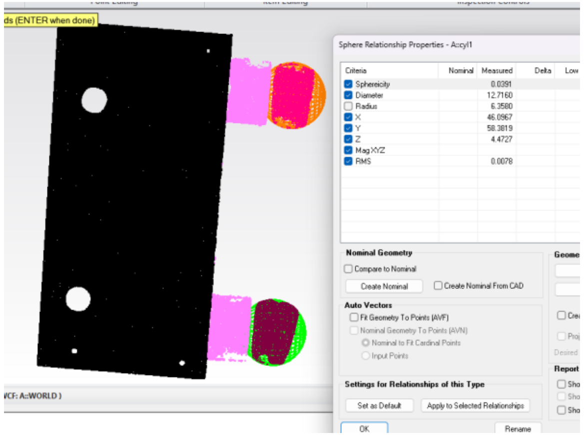


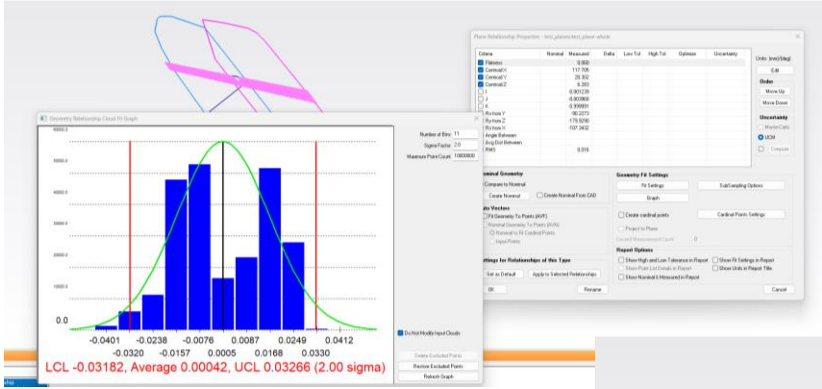


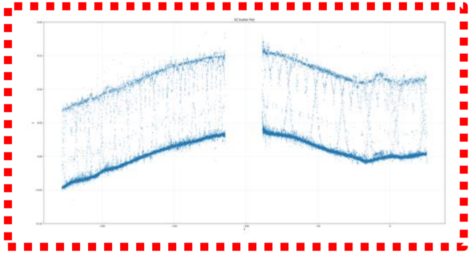


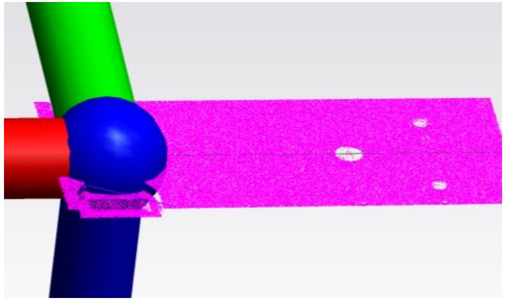
Multiple scans prior to alignment — improving fidelity through point cloud averaging

Manual Alignment of Scan Segments in Spatial Analyzer Using Point Cloud Fitting

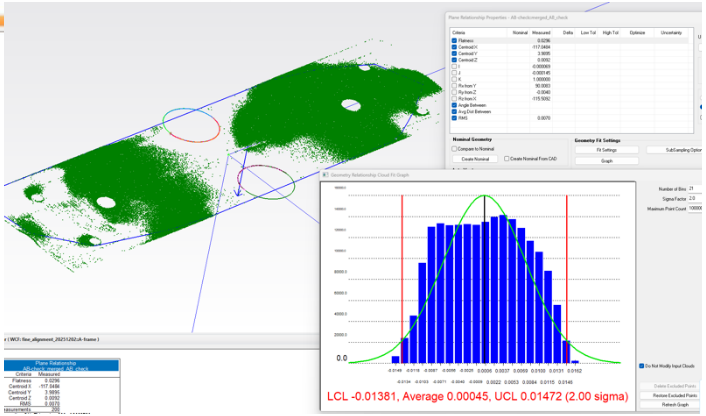




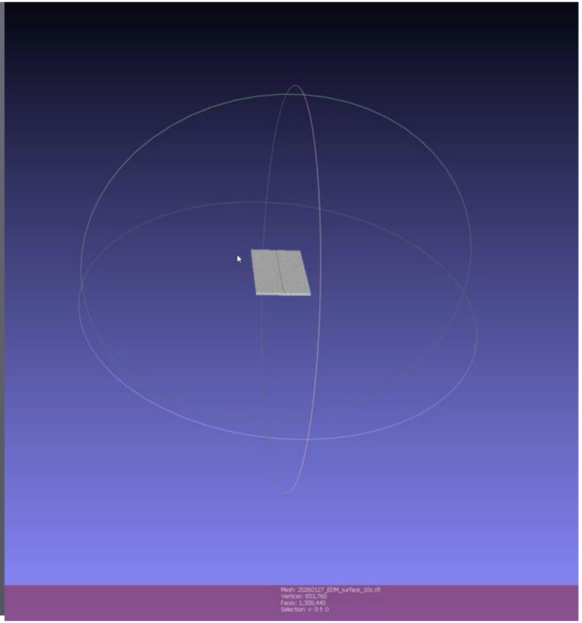




Collimator Scan Merging and Manufacturing Quality Control in SA



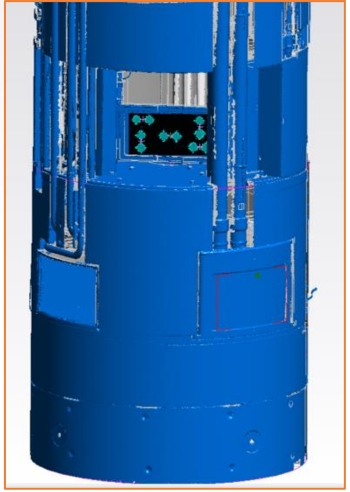
100 µm Collimator Scan

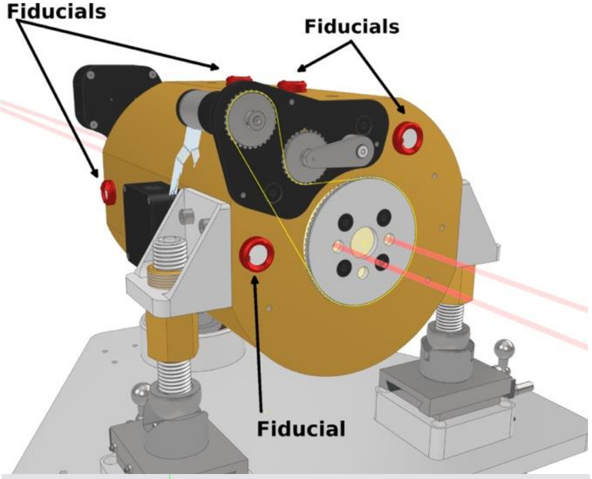


Collimators Alignment in Spatial Analyzer (SA)

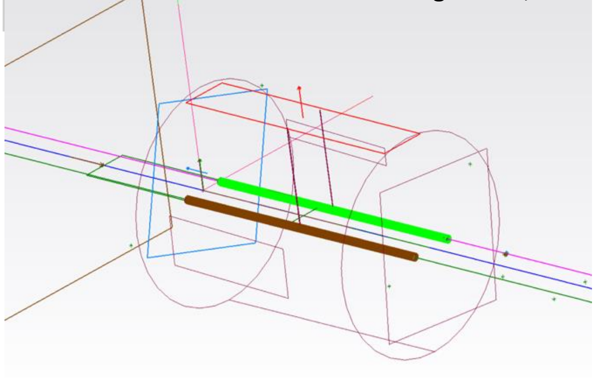
Spallation Target Assembly 3D scan
-fitted spatial scan

Optical Scan of Mark-IV

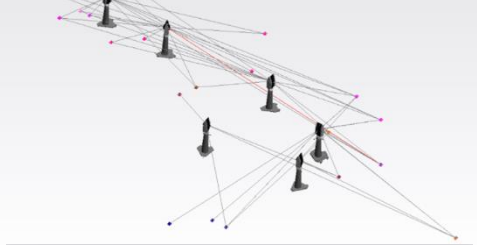




Beam Blocker Alignment, SA



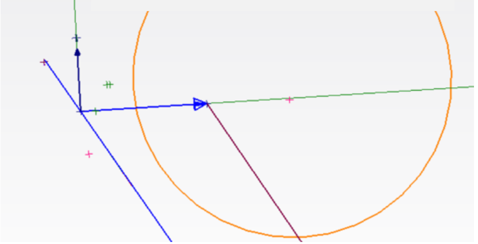
USMN – monuments network from target to experimental cave



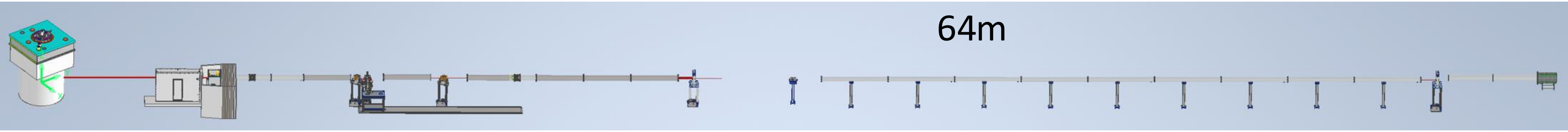
Frames: AS BODY FRAME to AS BODY FRAME2

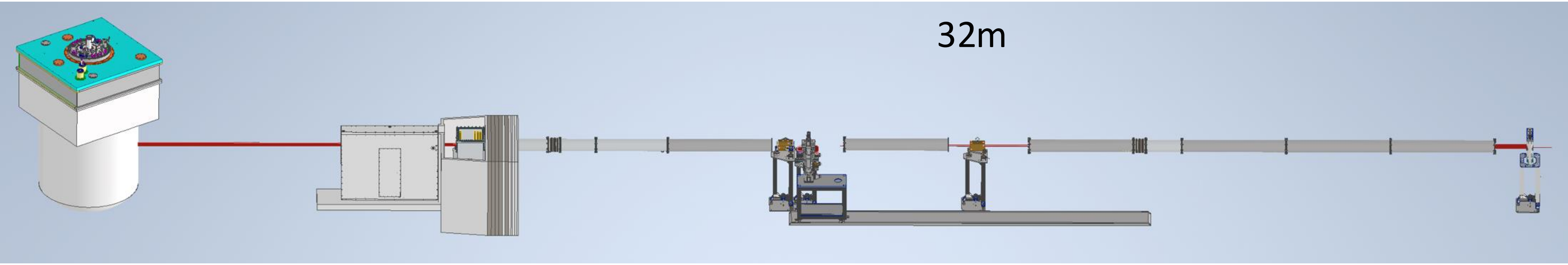
X	0.007	Rx	0.0019
Y	0.005	Ry	-0.0044
Z	-0.115	Rz	-0.0057
d	0.115	TAng	0.0075
	Units: (mm)	/	(deg)

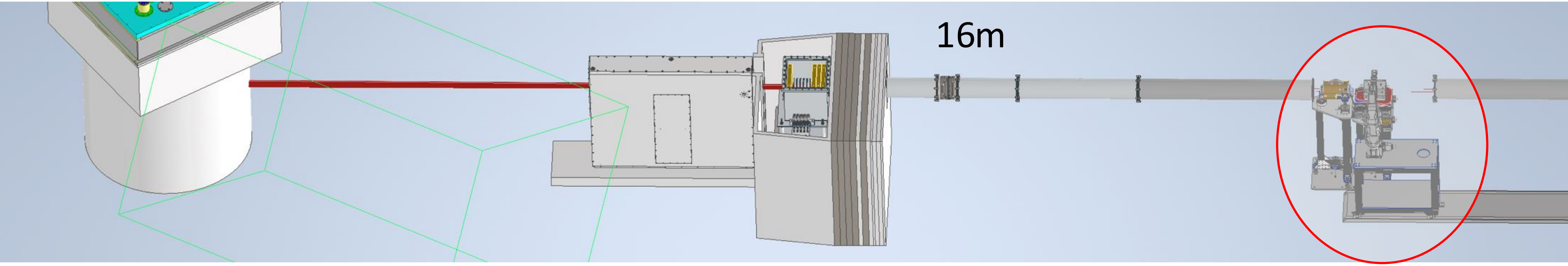
All Collimators alignment to new axis to increase flux

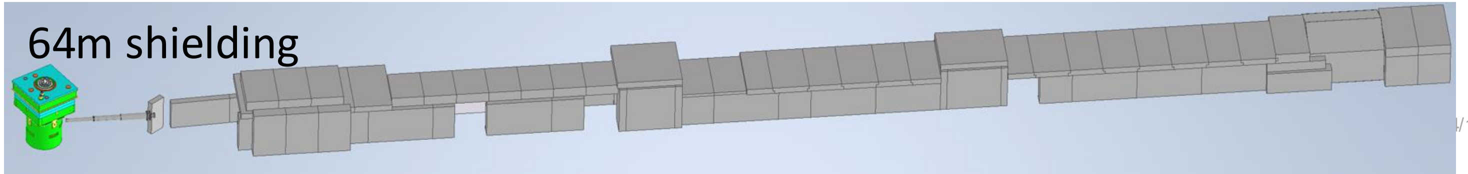


Scan to as-built CAD model









Higher Fidelity ≠ Linear Effort

What's easy (already solved):

- CSG (as-designed) models
  - for dose, flux, fmesh, time-emission
- CAD → MCNP conversion
  - GEOUNED (CAD → CSG)
  - Attila4MC (CAD → UM)

What's hard (this work):

- Converting *as-built scans* into MCNP geometry
  - Point cloud as reference → adjust CSG geometry
  - Point cloud → rebuild CAD → convert again
  - Alignment + consistency across datasets

Geometry is no longer idealized—it's measured, noisy, and misaligned

Collimator Alignment: LTS → MCNP

Setup

- Sample collimator (1 mm / 100 μm) with fiducials (SMR nests)
- Laser Tracker defines beam-axis reference
  - Origin: (0, 0, 31.8 cm) {*31.8cm is upper-target level; our target has 2 flight-paths level}

Measurement → Model pipeline

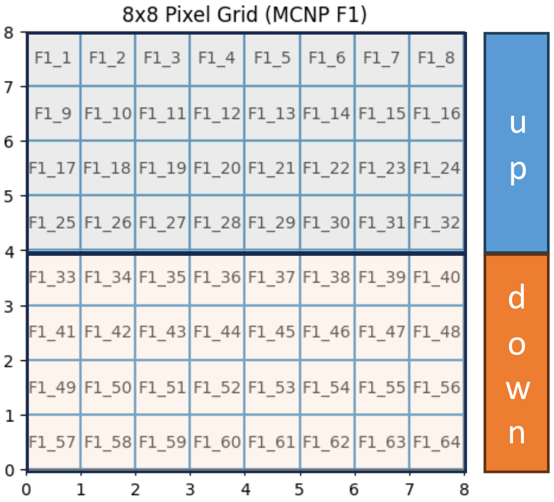
- Spatial Analyzer exports fiducial coordinates
- CAD model aligned using scanned fiducials
- Python workflow converts measurements → MCNP transformation card (TR)
  - Beam blocker
  - Sample collimator
  - Aperture stop
- **Result**
  - Direct mapping of measured positions into MCNP geometry

Outcome
Physically aligned model (not idealized)
Enables first-pass optical / transport simulations with real geometry

MCNP pixelized F1 source

Transporting spallation neutrons over 32 m through a 100 µm sample collimator is extremely challenging.

secondary neutron source (SDEF)



energy binning

angular binning

```
c --- Surface definitions (RPP) --- Python script for F1 pixels definition by D. Kral
c
c generated: 2026-03-05 13:50:25
c orientation: YZ  rows: 8  cols: 8  total: 64
c total_x: 17.4626  total_y: 17.4626  thickness: 1.0  start: 101.0c --- Tally definitions -----
surfaces
c 64 pixels definition
---- cells
c 64 F1 tallies with binning energy and cosines
c
c generated: 2026-03-05 13:50:25
c orientation: YZ  rows: 8  cols: 8  total: 64
E0 1e-9 1e-8 1e-7 1e-6 1e-5 1e-4 1e-3 1e-2 1e-1 1 10 100 800
*C0 90.000 2.000 1.500 1.400 1.300 1.200 1.100 1.000 0.900 0.800 0.750 0.700
    0.650 0.600 0.550 0.500 0.450 0.400 0.350 0.300 0.250 0.200 0.150 0.100
    0.050 0.000 t
FQ0   e c
```

- SDEF pos=d1 y=fpos=d2 z=fpos=d3 vec=fpos=d4 dir=fpos=d5 erg=fpos=d6 tr=13 par=n
  - wgt=1.717616E-02 [down]
  - wgt=1.855102E-02 [up]

2 x 5072 lines definition due to limit 999 in MCNP definition {historical limit, reported to developers}

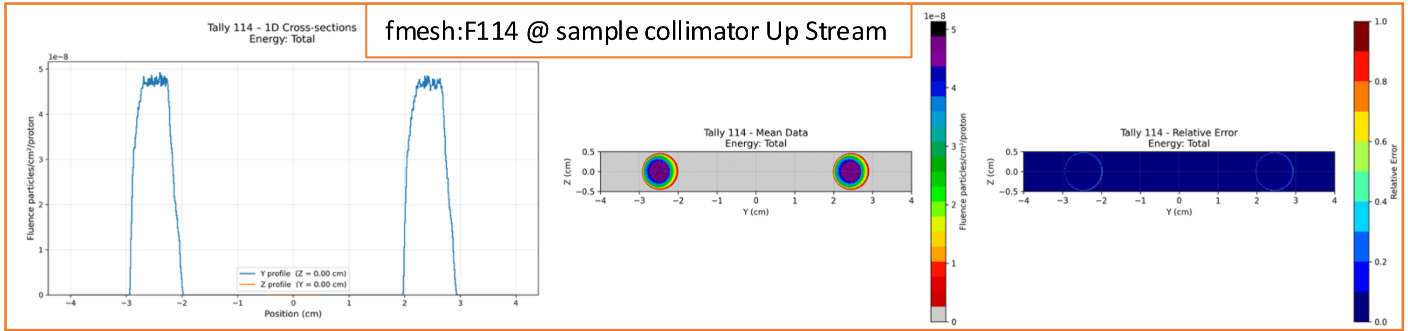
credit: Dusan Kral, P-2

MCNP parallelization of SDEF – “quick” optics

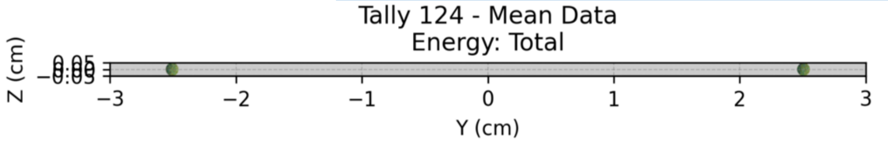
- imp:n =0 of all collimators for quick beam spot visualization and flux estimation – MCNP63

SDEF - MCNP63; NPS = 2e11			
Nodes	Cores	Clock Delta	Scaled 1core [h]
1	64	8:23:06	537
2	128	4:25:34	567
3	192	2:57:41	569
4	256	2:12:59	567
5	320	1:47:12	571
8	512	1:06:36	568
16	1024	0:34:01	580

fmesh:F114 @ sample collimator Up Stream

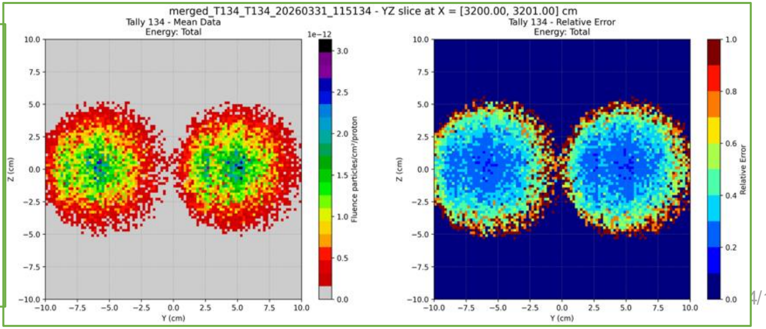


fmesh:F124 @ sample collimator Down Stream



- We are currently looking for faster optical transport – McStas ?
- MCNP is overly robust for these simplified simulations; however, it enables immediate transition to full particle interactions and supports direct comparison across multiple tallies

fmesh:F134 @ 32 m detector position



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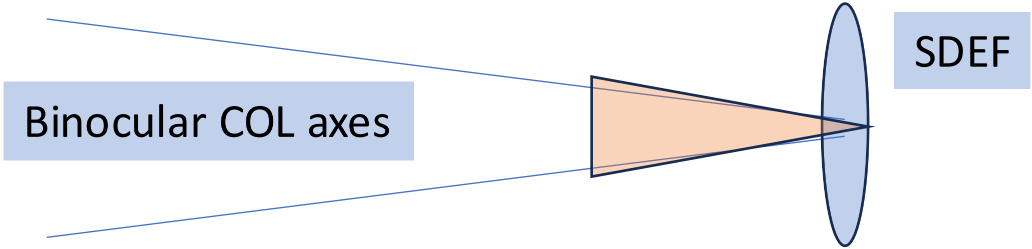
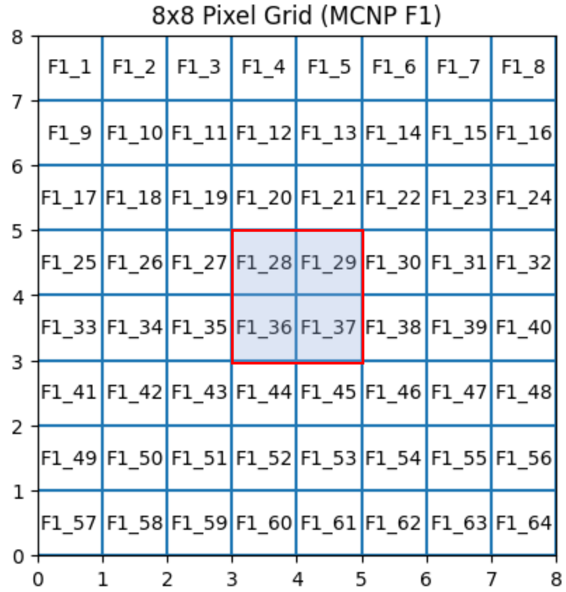
Manual Source Biasing - Variance Reduction ---

Cutting the secondary neutron source to optimized pixels and cosines

- Pushing neutrons through 100 μm opening @ 15m from spallation source is challenging without f5 tally or DXT, postprocessed pixelized SDEF helps



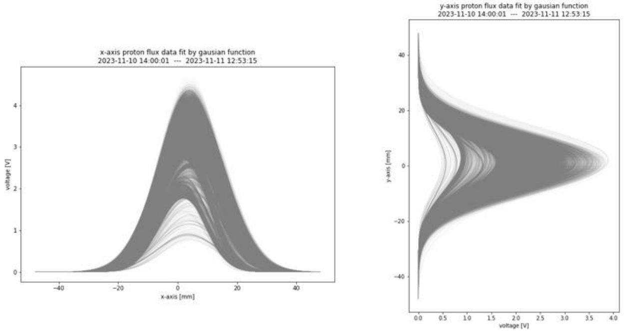


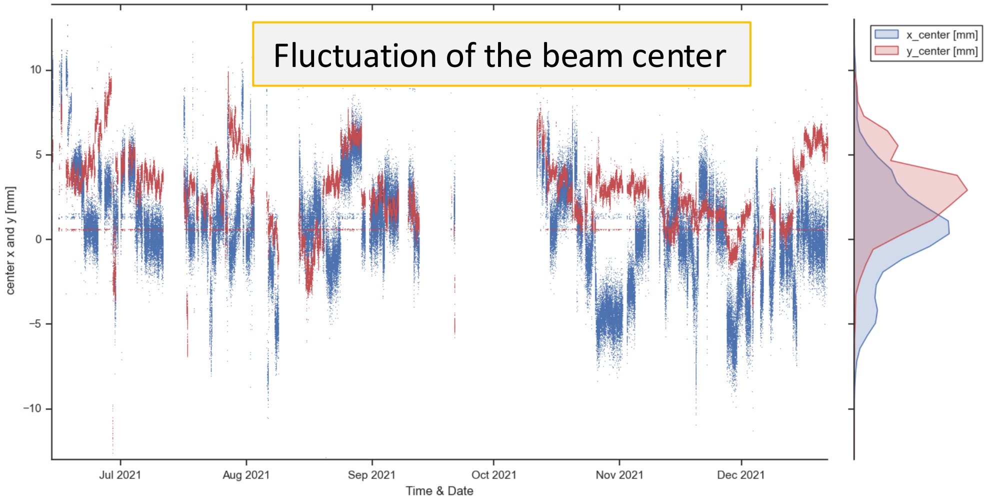
i01r									NPS-SDEF	v
1901	************	4.08E+12	0	0.00E+00	5.85E-04	2.50E+00	3.43E-05		4.08E+12	
1301	0	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	based on 2x2 p	
1302	0	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
1321	488918205	488918205	0	0.00E+00	4.21E-04	1.48E+00	3.43E-05	1.20E-04		
1322	487137669	487137669	0	0.00E+00	4.16E-04	1.50E+00	3.43E-05	1.19E-04		
1323	448605100	448605100	0	0.00E+00	4.22E-04	1.49E+00	3.43E-05	1.10E-04		
1324	446390129	446390129	0	0.00E+00	4.15E-04	1.50E+00	3.43E-05	1.09E-04		
1331	70638	70638	0	0.00E+00	4.17E-04	1.43E+00	3.43E-05	1.73E-08	1.58E-04	
1332	70824	70824	0	0.00E+00	4.17E-04	1.48E+00	3.43E-05	1.74E-08		
1333	724	724	0	0.00E+00	6.57E-04	2.15E+00	3.43E-05	1.77E-10		
1334	614	614	0	0.00E+00	2.46E-04	9.78E-01	3.43E-05	1.50E-10		

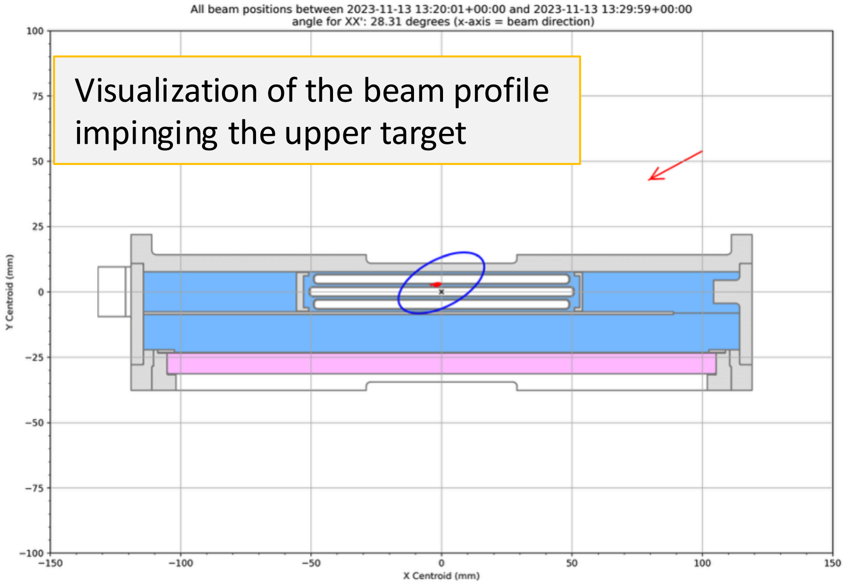
input-name	NPS-SDEF	wgt	protons	ctm	hits in col	note
i01p	9.60E+12	1.86E-02	5.17E+14	1.52E+06	1224	based on 8x8 pixels without any cosines cuts
i01q	5.28E+12	9.37E-03	5.64E+14	9.06E+05	1667	based on 4x4 pixels and cosines cuts to 0.5deg
i01r	4.08E+12	3.43E-05	1.19E+17	7.27E+05	70824	based on 2x2 pixels and cosines cuts to 1.5deg

Proton Beam Position and Shape

- In addition to geometric discrepancies, neutron flux and background levels depend on the proton beam's position and shape
- We post-process each proton bunch using HARP monitor data to adjust the simulations

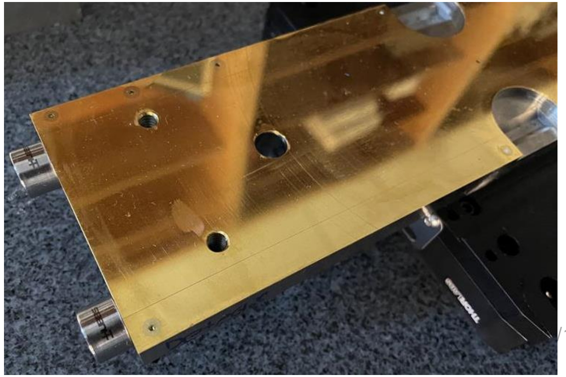






Summary – DICER - 100 μm collimator

- We redesigned the DICER collimator to minimize sample activity, dose, and measurement cost while maintaining high precision.
- We are developing a full pipeline:
  3D scanning → alignment → ~~CAD~~ → MCNP, enabling accurate *as-built* geometry in simulations.
- We integrate LiDAR, laser tracker, and optical scans to achieve **precise, measurement-based alignment** of all components.
- The spallation target is modeled as a **pixelized neutron source**, capturing spatial non-uniformity and enabling fast simulations.
- Transporting neutrons through a **100 μm collimator over 32 m remains challenging**, requiring precise alignment and modeling.
- Ongoing work focuses on **automation and closed-loop integration** (scan → model → simulation → update).
- First experiment is planned for this run cycle (2026)
- High demand for a new MCNP feature: direct STL geometry import (anticipated in MCNP6.4).



Thank you for your attention.

P-2, LANL

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on behalf of DICER Team