

Report for Simulation Part

The University of Tokyo

Sho Nagao

on behalf of

JLab hypernuclear collaboration

Experimental Readiness Review 2026

Comments and Recommendation

Simulation

The effect of PCS stray fields on ENGE optics must be studied. (Resp. 1)

→ The effect will be included in the Enge calibration. The effect was checked by Geant4 simulation

Are the requirements for the electron beam fulfilled (Resp. 2)

→ The effect was estimated by Geant4 simulation

Manpower

Identification of the manpower and other resources (Resp. 4)

→ Mentors and workers have been assigned. Required computer resources are small

Simulation Overview

Spectrum & Detector response simulation with Geant4

(e,e'K⁺) simulator (HKS-HES-Geant4)

<https://github.com/shonagao-nex/E12-15-008.git>

Decay Pion simulator (Enge-Geant4)

<https://github.com/shonagao-nex/enge.git>

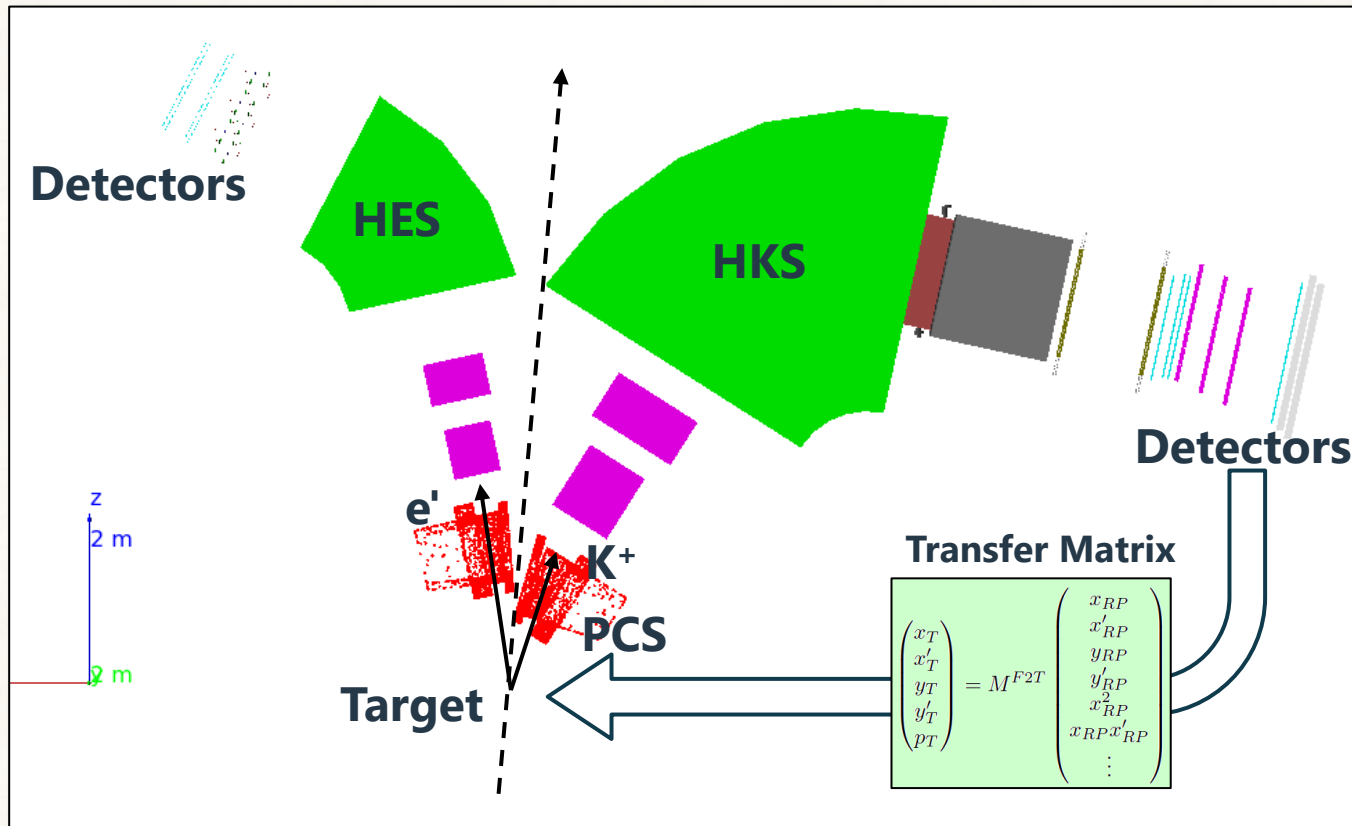
Radiation Dose and Background simulation with Geant4

<https://github.com/shonagao-nex/E12-15-008.git>

Radiation Budget with FLUKA

https://github.com/shonagao-nex/FLUKA_HKS.git

(e,e'K⁺) simulator -- Overview --



Monte Carlo simulator for estimating missing mass distributions in (e,e'K⁺) reactions

Geant4 setup includes:

- Target
- All magnets and TOSCA maps
- All detectors

Reconstruction:

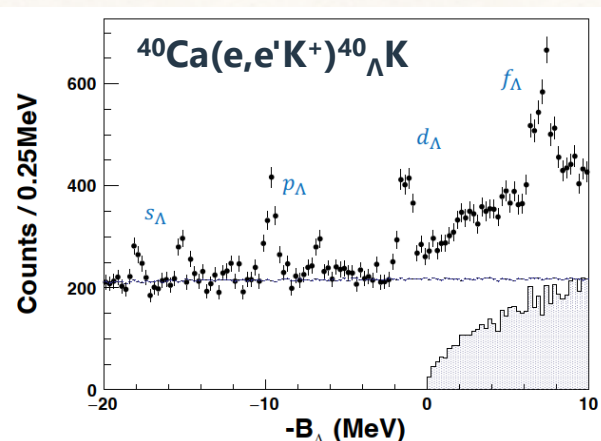
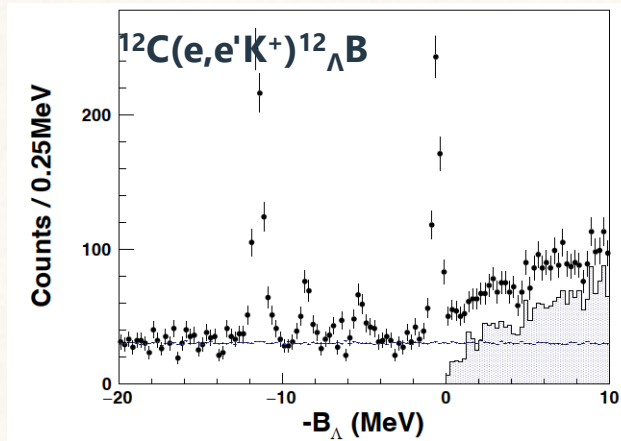
- Backward transfer matrix (6th order max.) from focal-plane observables to target variables.
- Same procedure to the previous Hall-C experiments

Effects included:

- Energy loss, Straggling Multiple scattering, Other electromagnetic interactions
- Particle Decays
- Detector resolution
- Beam size/position etc.

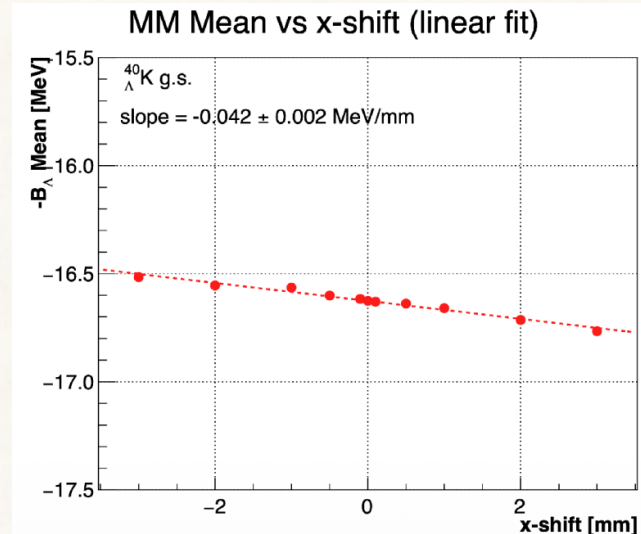
(e,e'K⁺) simulator -- Results --

Expected Spectrum

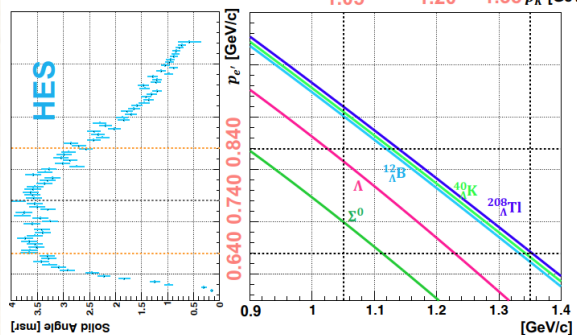


Master's thesis by Tatsu

Beam Position Effect



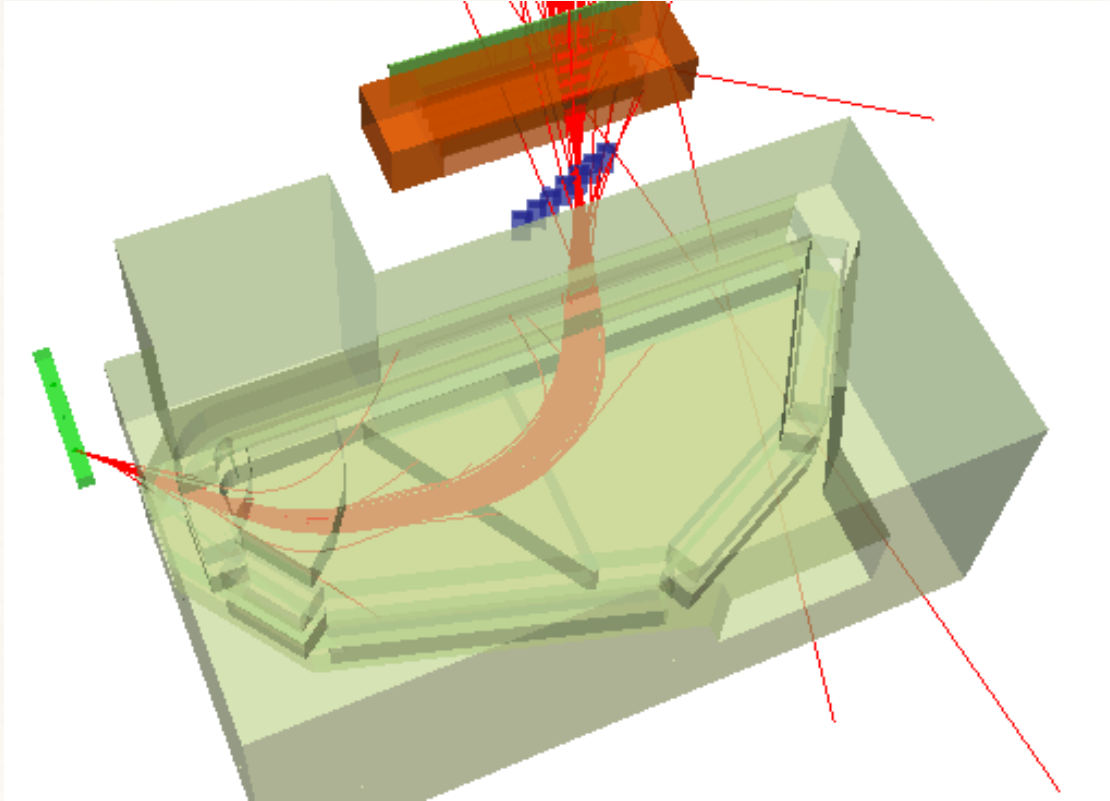
Acceptance Map



Status and Application

- The (e,e'K⁺) simulator has been established.
- Additional functions are being implemented as needed.
- The beam-position requirement was evaluated using the Geant4-based simulator.
- Missing-mass shift: $\Delta\text{MM} = 42 \text{ keV/mm}$
- Since the experimental requirement is $\sim 100 \text{ keV}$, beam-position shifts within $\sim 2 \text{ mm}$ are acceptable.

Decay Pion simulator -- Overview --



Monte Carlo simulator for estimating results of decay pion spectroscopy

Geant4 setup includes:

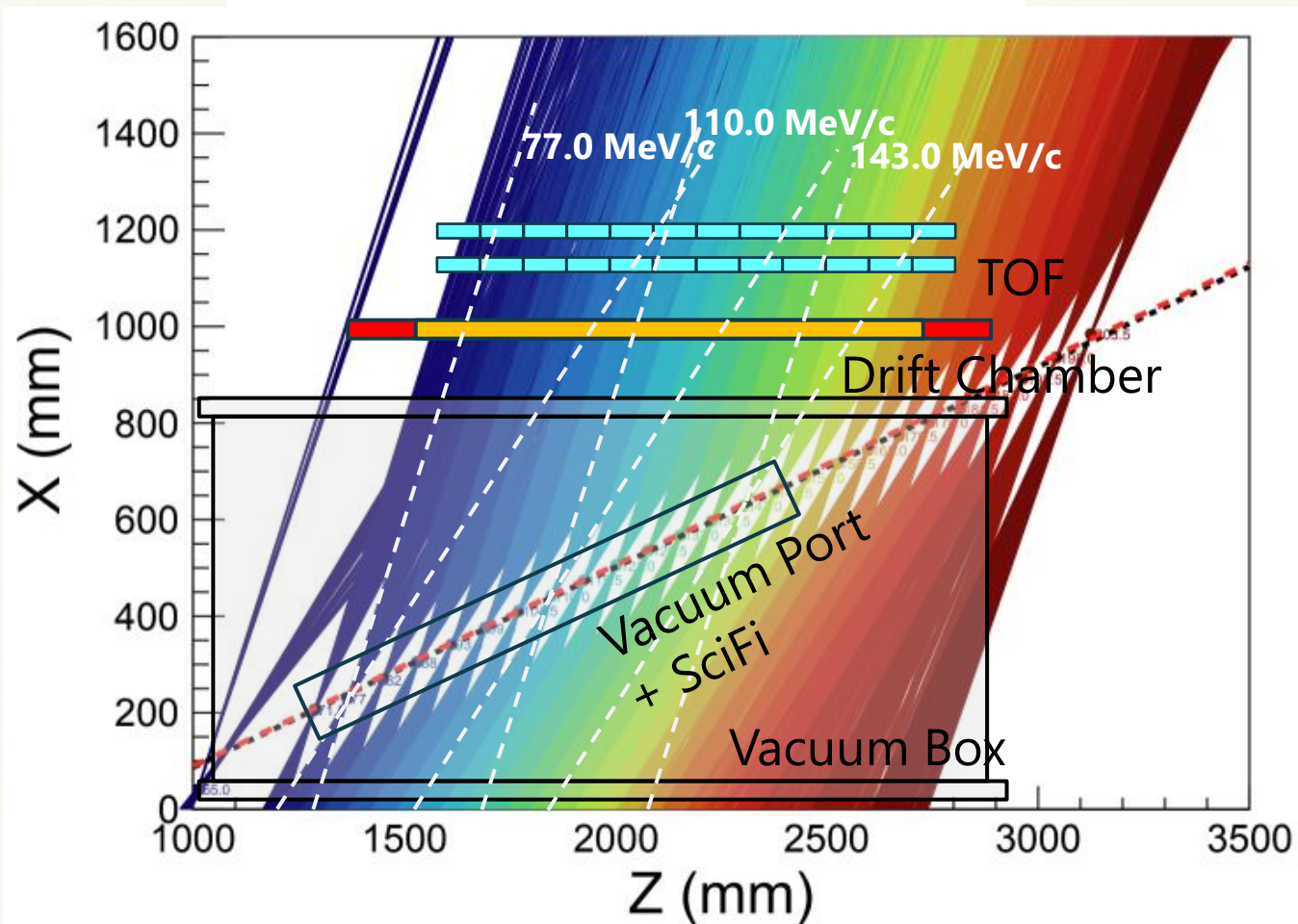
- Target
- PCS Stray Field and Enge Field from TOSCA maps
- All detectors

Effects included:

- Energy loss, Straggling Multiple scattering, Other electro-magnetic interaction
- Particle Decays
- Detector resolution
- Beam size/position etc.

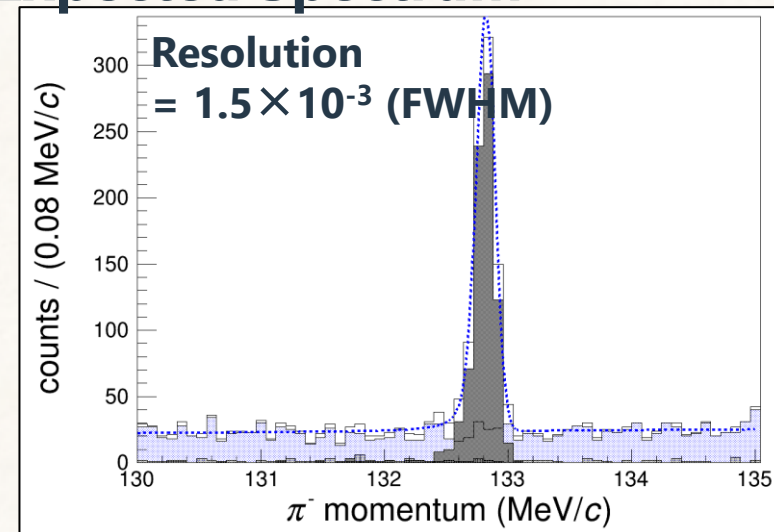
Decay Pion simulator -- Results --

Particle Trajectories 5.5 MeV/c Steps

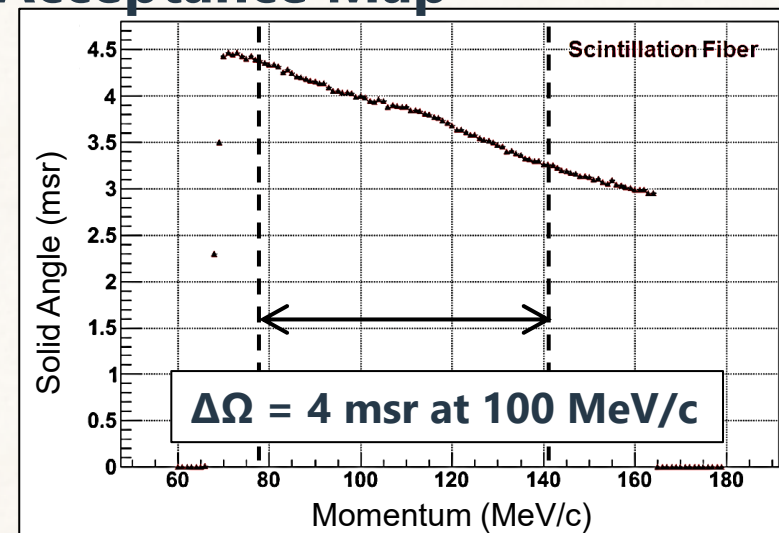


- The Decay Pion simulator has been established.
- Additional functions are being implemented as needed.

Expected Spectrum

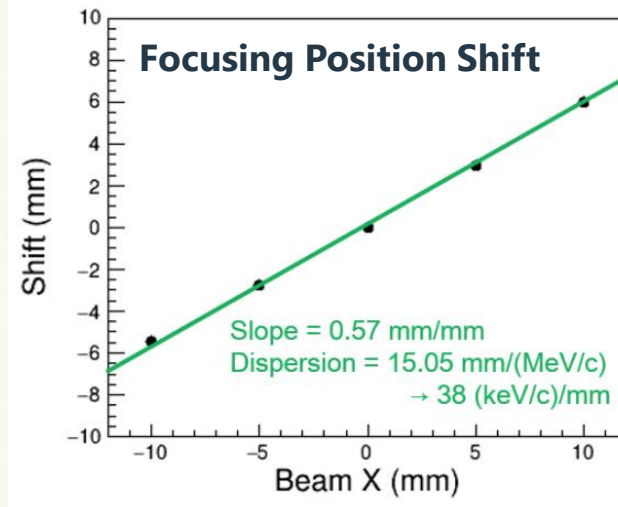
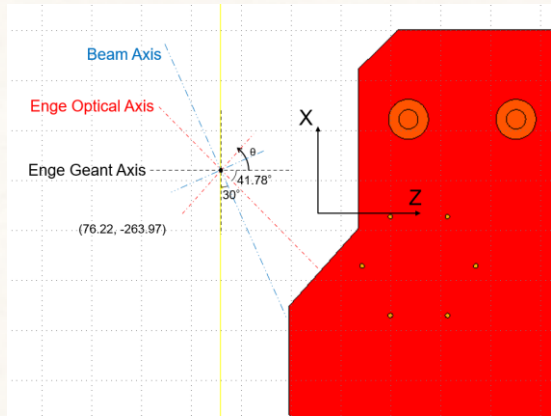


Acceptance Map

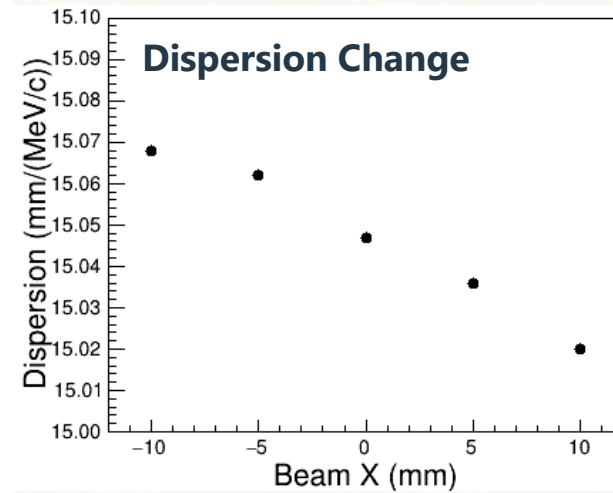


Decay Pion simulator -- Response --

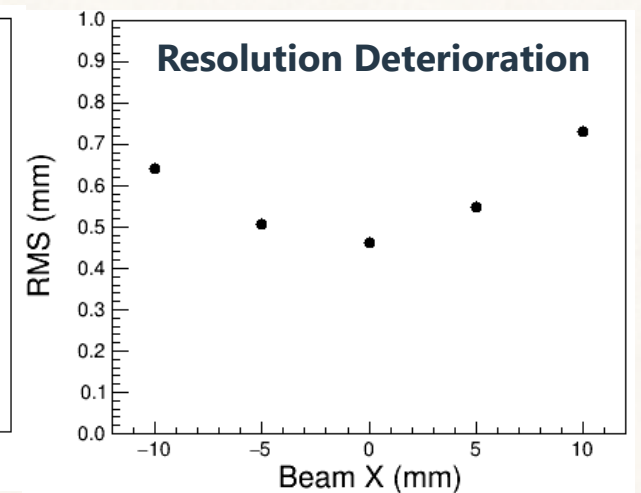
Beam Position Effect



40 (keV/c) shift per mm



0.02% shift per mm



2 keV/c per mm

The production point shift has a non-negligible impact.

Experimental precision target: 10 keV/c → BPM resolution of $\sigma \sim 250 \mu\text{m}$

Resolution: 160 keV/c (FWHM) → beam-size effect is negligible

The PCS stray field has a non-negligible effect: 0.08% \approx 90 keV/c shift.

→ Calibration with alpha sources will be performed with PCS ON/OFF.

→ PCS field monitoring with $\sim 10\%$ precision is sufficient.

Simulation Status and Next Update

Present status

- HKS-HES ($e, e'K^+$) simulator is operational on a consumer-grade PC.
Missing-mass spectra, acceptance, and beam-position effects evaluated
- Enge decay-pion simulator is operational on a consumer-grade PC.
Acceptance, resolution, beam-position effect, and PCS-field effect evaluated
Included PCS stray-field effect in the calibration procedure

Next Update

- Redefine simulation ROOT tree / hit-data structure for the HYPAnalyzer simulation interface
- Prepare HKS-HES and Enge pseudo-data with simulated ADC/TDC hit information
- Test replay chain with simulation files (reconstruction, tracking/PID, monitoring plots etc.)
- These updates and analyzer integration will be completed by summer 2027 in coordination with WG11.

Radiation Simulation with Geant4 -- Overview --

A Monte Carlo code has been prepared for

- Cross-checking with FLUKA simulations
- Detector-response estimation with background particles
- Beam-transport studies

$$H = \sum_{\gamma, e^{\pm}, n, p, \dots} \Phi(E) \cdot w(E)$$

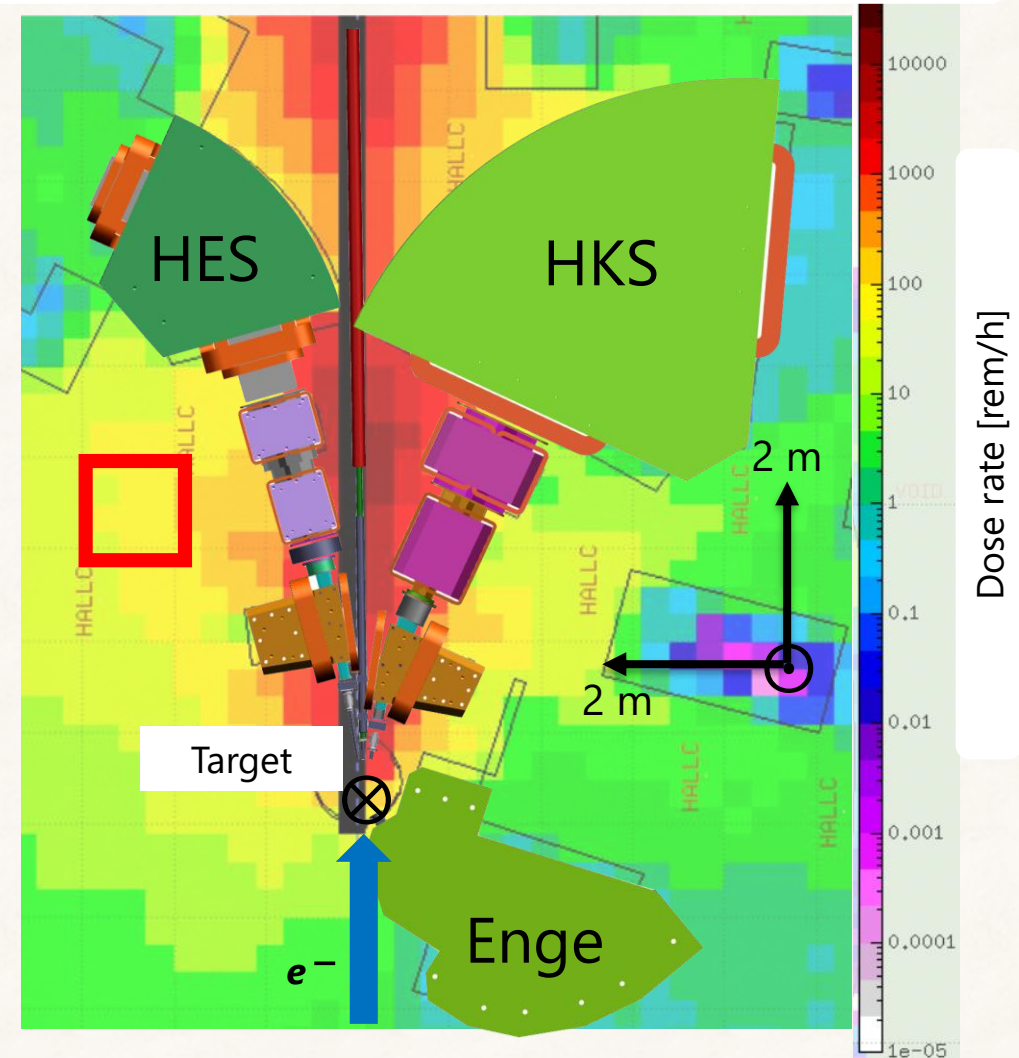
Fluence [cts/cm²]

Conversion Factor
Fluence → Equivalent Dose

The simulation has been developed with Geant4 11.03.

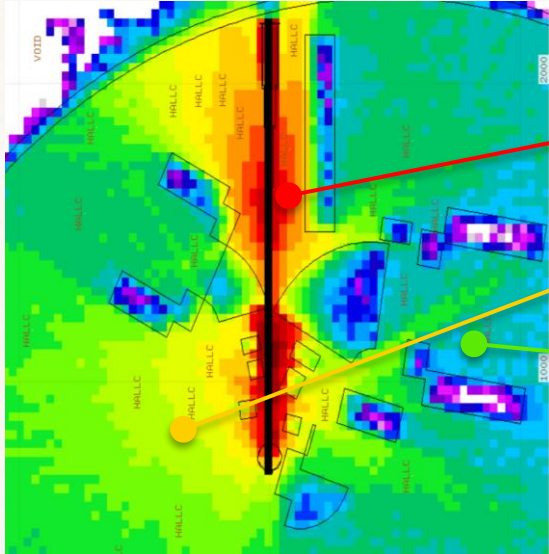
- Includes all EM interactions and the updated shielding physics
- Tracks all secondary particles except neutrinos
- Magnetic fields from Enge, PCSs, corrector, and HKS-HES

Dose rate map near the Target



FLUKA and Geant4

FLUKA



- Radiation / Shielding Optimization
- Macroscopic dose evaluation over long timescale
- Reliable for area dose estimates

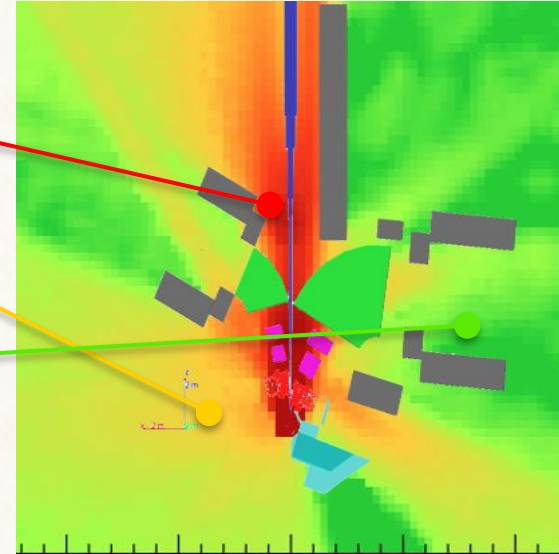
In the Exp. area,

$\sim 10^4$ rem/h

$\sim 10^2$ rem/h

~ 1 rem/h

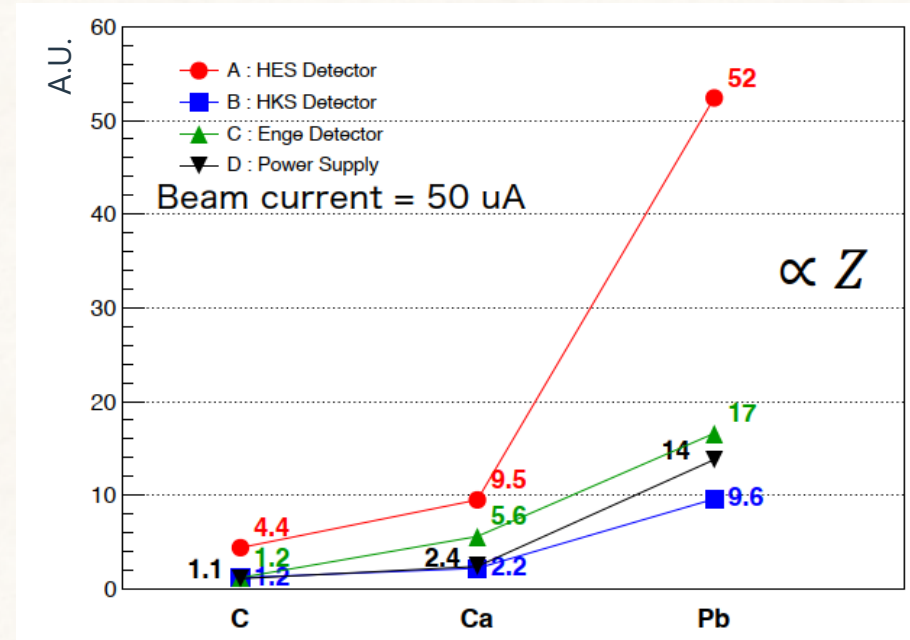
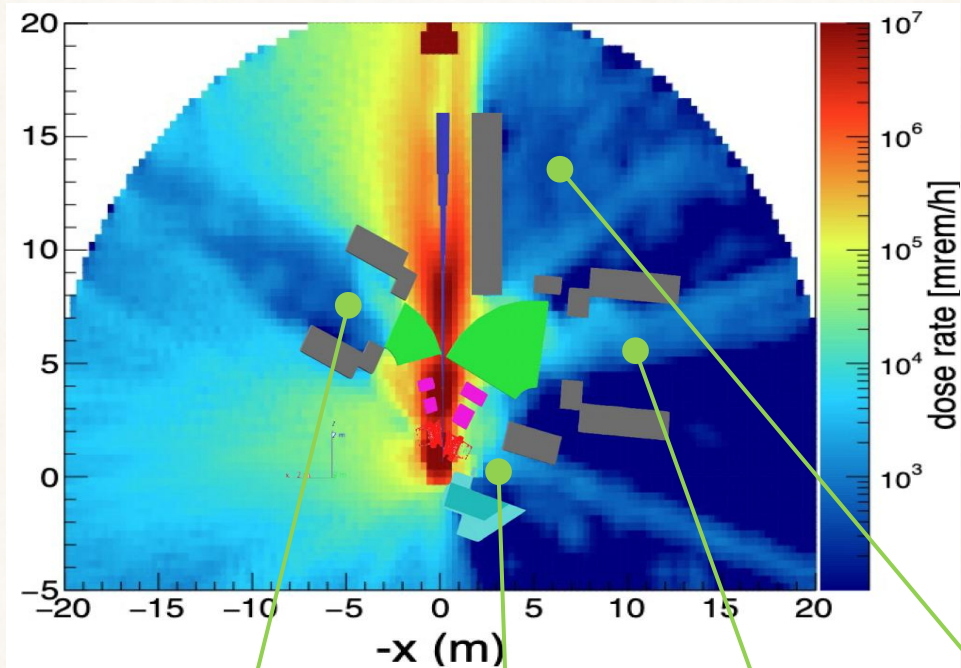
Geant4



- Detector response / Background evaluation
- Event-by-event microscopic particle tracking
- Validated for detector response studies

The two independent simulations give consistent radiation levels, supporting the robustness of the shielding and background evaluation.

Radiation Dose Estimation



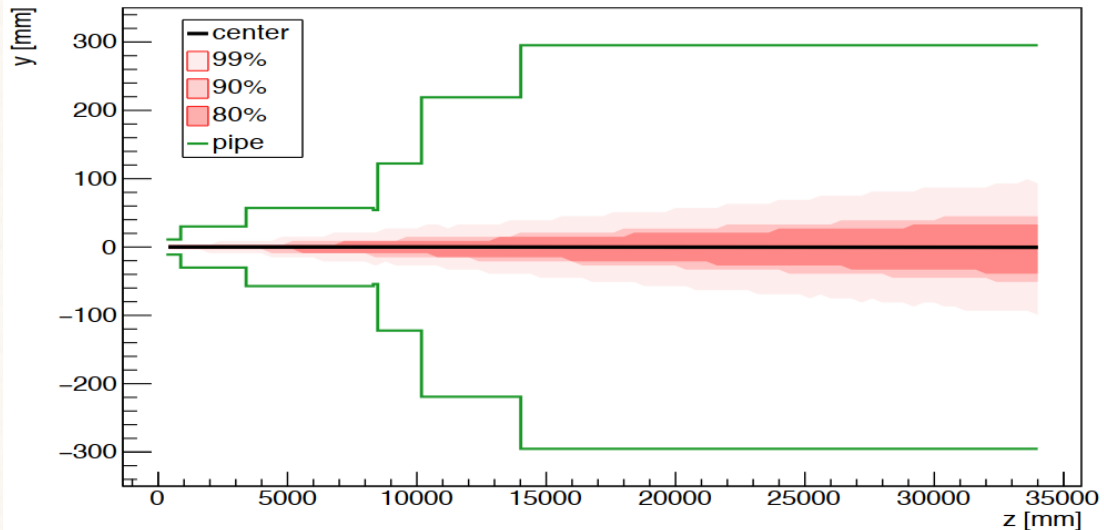
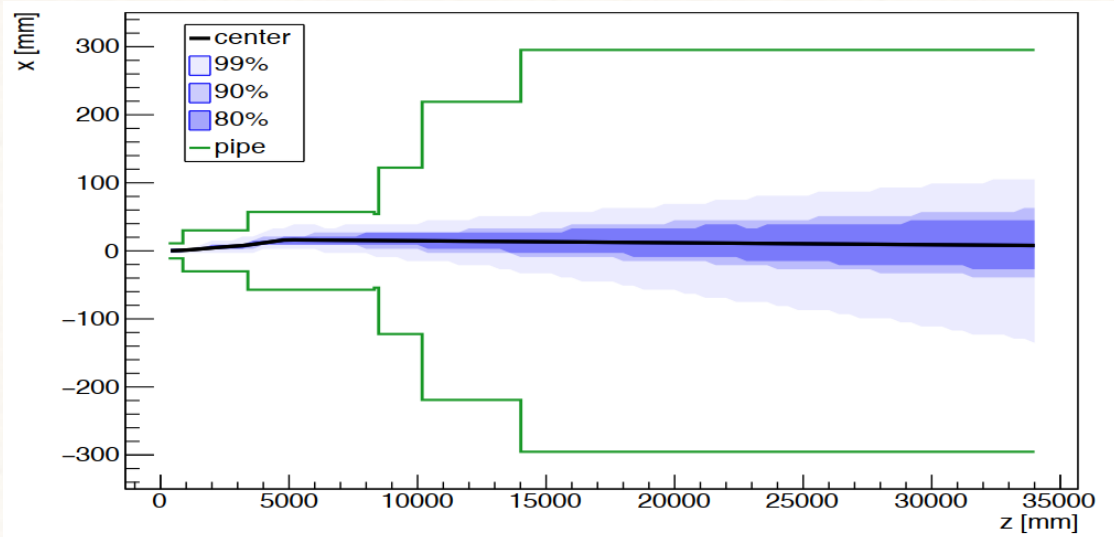
	HES	ENGE	HKS	PSU
e^\pm	150	1600	40	40
gamma	30	100	30	50
neutron	1	15	<1	<1
SUM	180	1700	70	90

Unit: mrem/h

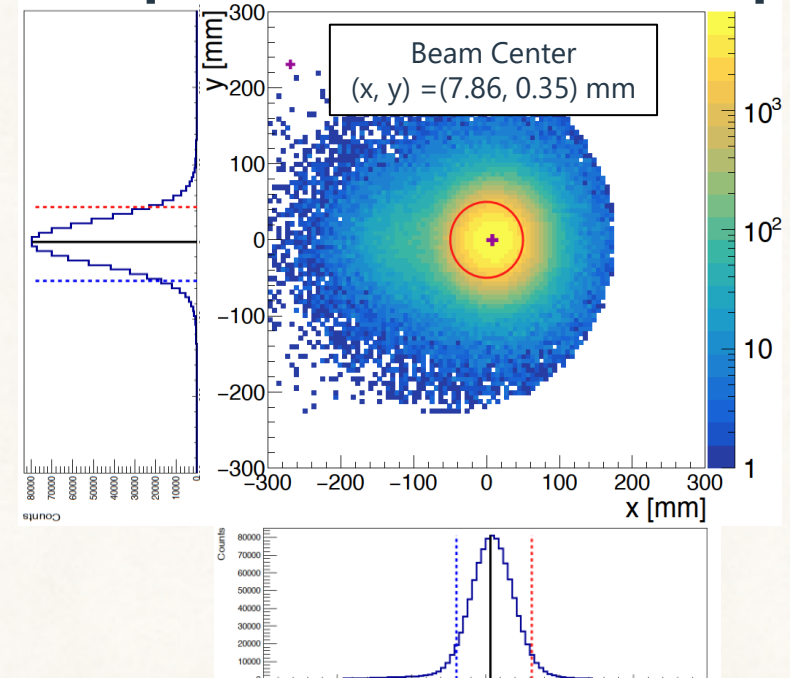
- Geant4-based dose-rate estimation
- Shielding locations were implemented based on the CAD model
- The current simulation provides a basis for radiation protection planning

Beam Tracking (Lead target, 150 mg/cm²)

Beam trajectory

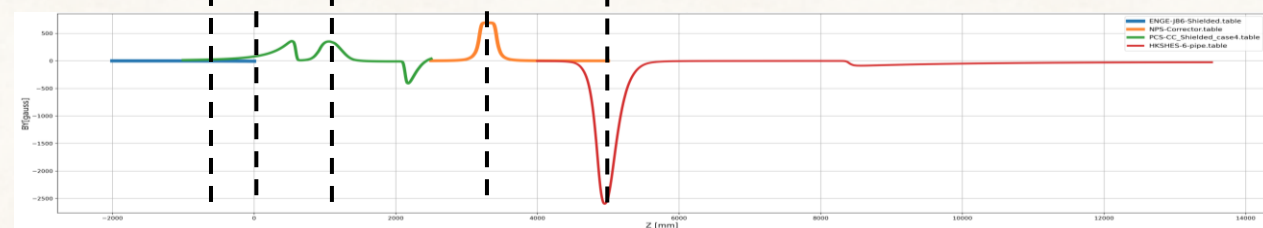
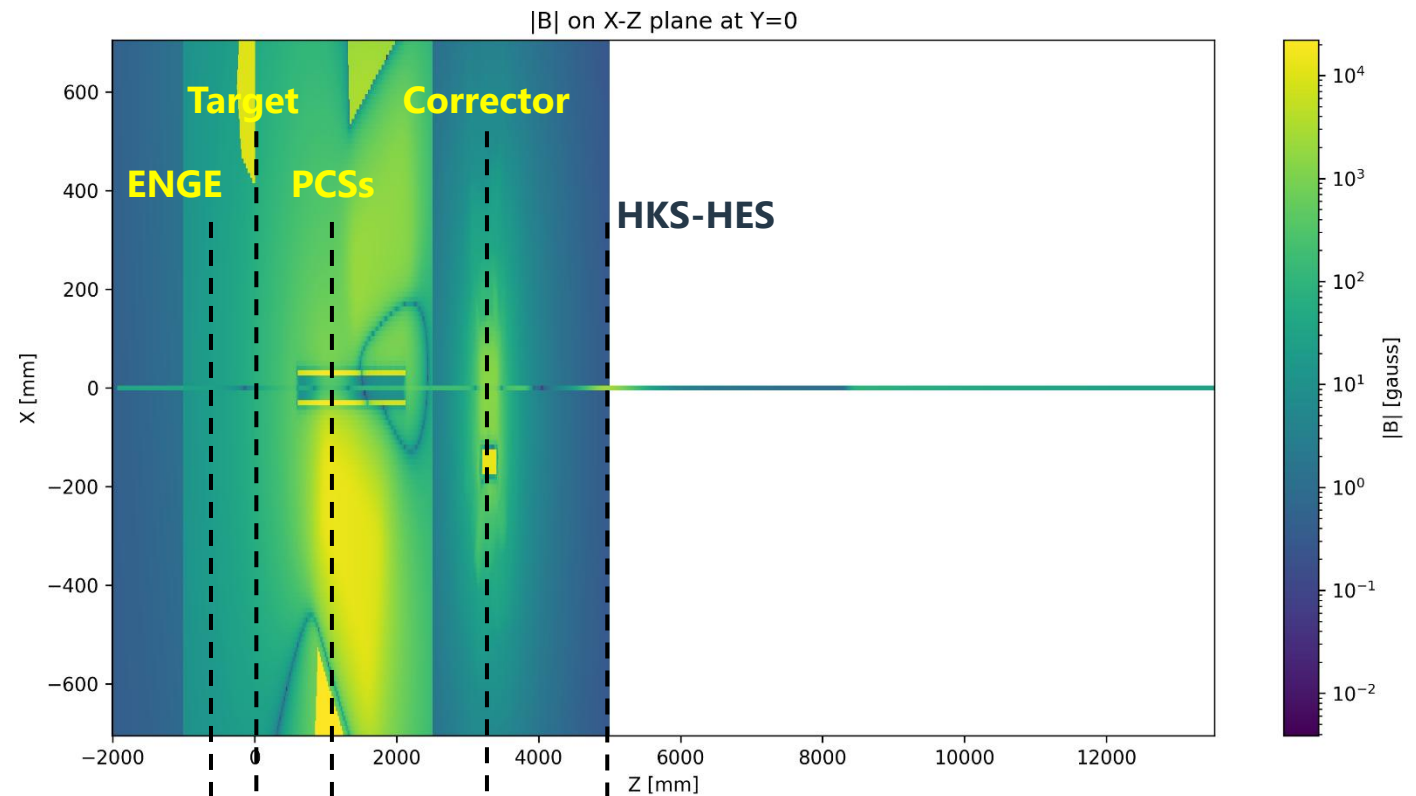


Beam profile at the beam dump



- TOSCA-based stray fields were included in the beam tracking simulation
- Corrector tuning compensates for the integrated stray field effect along the beam line
- The simulated beam profile remains acceptable at the beam dump

Magnetic Field from TOSCA calculation



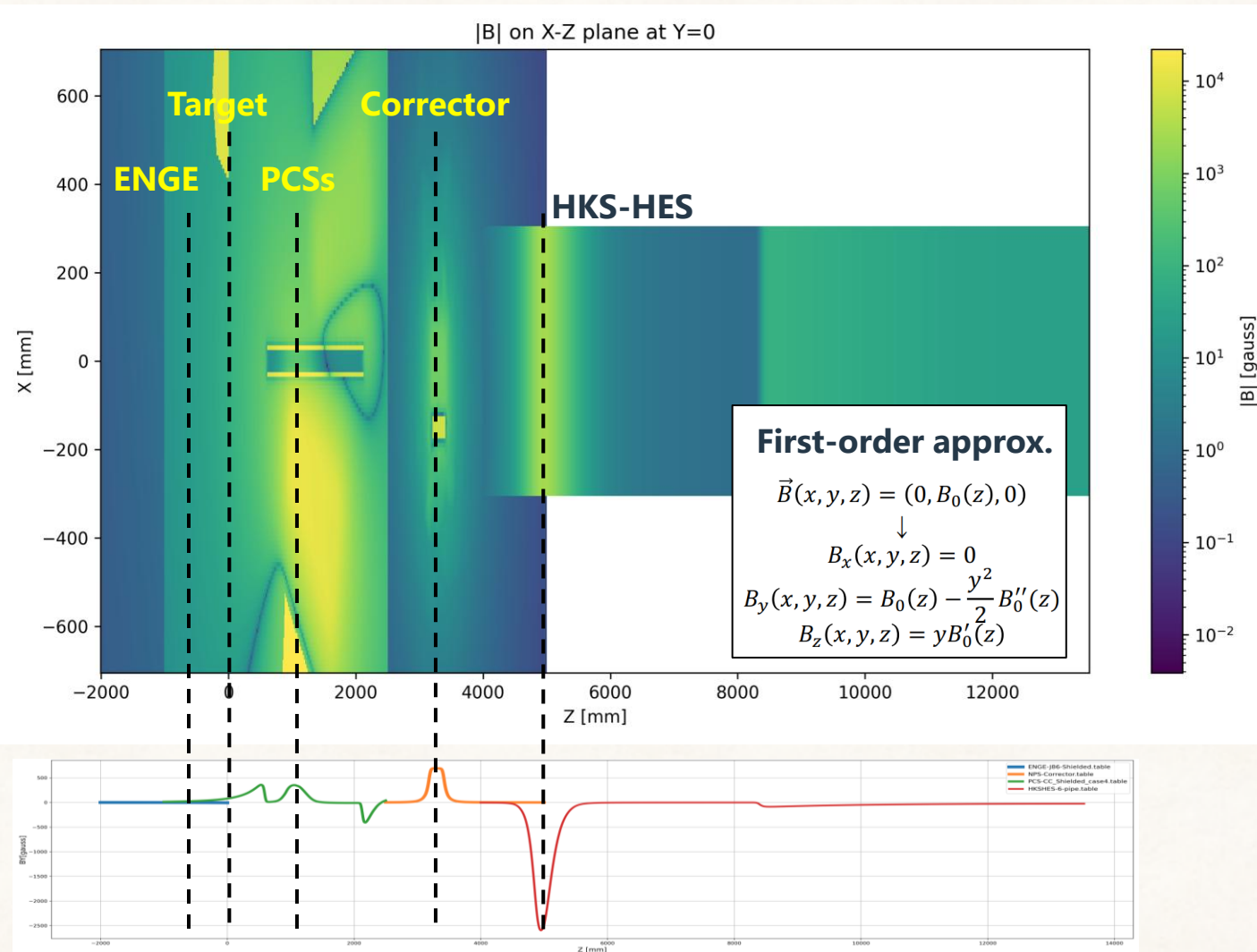
Stray Fields Summary [T.m]

Pipe Shielding	No	No	No	Yes x3	Yes x3	Yes x3	Yes x3	Yes/No/Yes
ENGE	-0.00104	-0.00104	-0.00104	-0.00113	-0.00113	-0.00113	-0.00113	-0.00113
PCS Case #	1	2	3	4	5	6	4	1
CC Polarity	PCS Neg CC	PCS No CC	PCS +CC	PCS Neg CC	PCS No CC	PCS +CC	PCS Neg CC	PCS Neg CC
PCS Both	0.1244	0.3427	0.5604	0.0921	0.2875	0.2666	0.0921	0.1244
HKS/HES Case #	3	3	3	4	4	4	4	4
HKS/HES	-0.3700	-0.3700	-0.3700	-0.1700	-0.1700	-0.1700	-0.1700	-0.1700
NPS Corrector							0.0424	0.0424
SUM	-0.2466	-0.0283	0.1894	-0.0791	0.1163	0.0954	-0.0366	-0.0043

TOSCA stray-field result

- Original TOSCA field map by S. Lassiter
- Integral BdL evaluated along the beam trajectory
- For the HKS-HES region, the available TOSCA result was limited to the beam-axis field
- Corrector magnet setting estimated from the integrated field
- Beam transport to the dump is feasible with tuning

Magnetic Field from TOSCA calculation

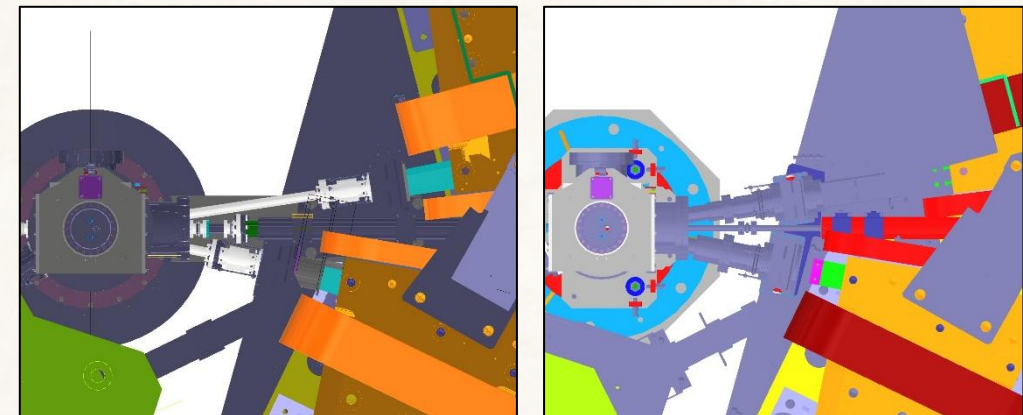


Present Status

- Tracking based on available TOSCA stray fields
- HKS-HES field limited to beam-axis information
- Off-axis components complemented by first-order approximation

Next update

- Update TOSCA model to the latest beam pipe and shielding geometry
- Regenerate refined field maps and repeat full tracking simulation
- Completion expected within the next two months



Schedule and FTEs

Coordinator: S. Nagao (U. Tokyo)

Deputy Coordinator: M. Ichikawa (RIKEN)

Item	Task	Personnel	Target
(e,e'K ⁺) / Decay pion simulation	Redefine ROOT tree + Pseudo-data preparation	S. Nagao (U. Tokyo, 0.2 FTE) T. Gogami (Shiga U.) T. Ishige (Tohoku U. , 0.1 FTE) K. Higashimoto (U. Tokyo, 0.1 FTE) K. Ishido (Kyoto U. 0.05 FTE)	March 2027
	Test simulation data in analyzer	M. Ichikawa (RIKEN, 0.2 FTE) K. Ishido (Kyoto U. , 0.1 FTE) K. Higashimoto (U. Tokyo, 0.05 FTE) J. Takahashi (U. Tokyo, 0.1 FTE) + WG11 (analyzer)	June 2027
Radiation simulation	Update TOSCA	J. Benesch (JLab) T. Gogami, S. Nagao, P. Medeiros (JLab)	July 2026
	Update dose estimation (FLUKA)	P. Degtiarenko (JLab) J. Takahashi (U. Tokyo, 0.1 FTE)	Mid. August 2026
	Update dose estimation (Geant4)	J. Takahashi (U. Tokyo, 0.1 FTE)	Mid. August 2026
	Update beam tracking	J. Takahashi (U. Tokyo, 0.05 FTE)	Early August 2026

Summary

Status

Three Monte-Carlo simulation codes (Spectrometer, G4 radiation, FLUKA)

- Code developments are almost completed
- Spectrometer performance and beam fulfilled have been checked
- Expected background rate has been estimated
- Beamline and TOSCA map update will be completed

Response

The effect of PCS stray fields on ENGE optics must be studied. (Resp. 1)

→ The effect will be included in the Enge calibration. The effect was checked by Geant4 simulation

Are the requirements for the electron beam fulfilled (Resp. 2)

→ The effect was estimated by Geant4 simulation

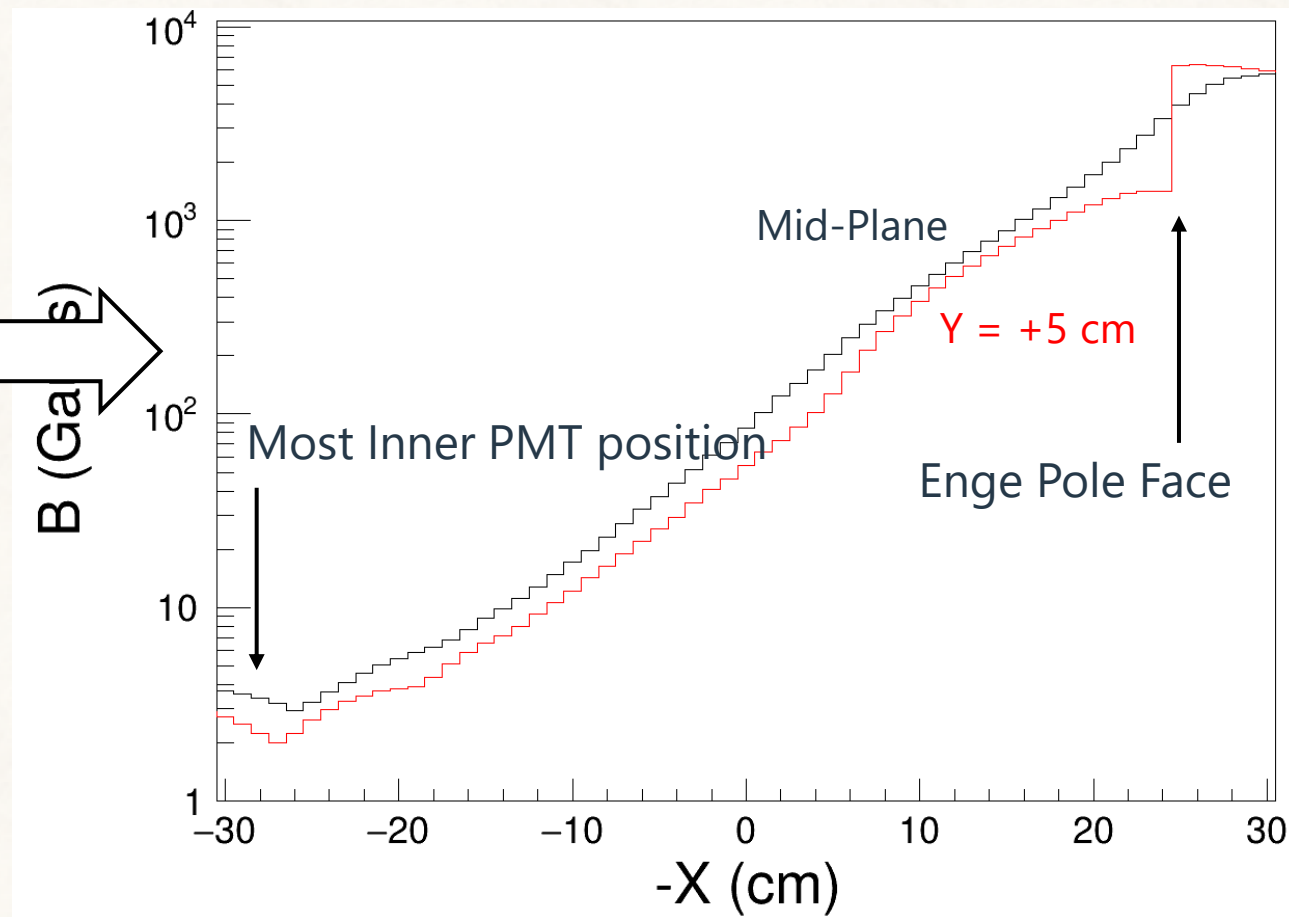
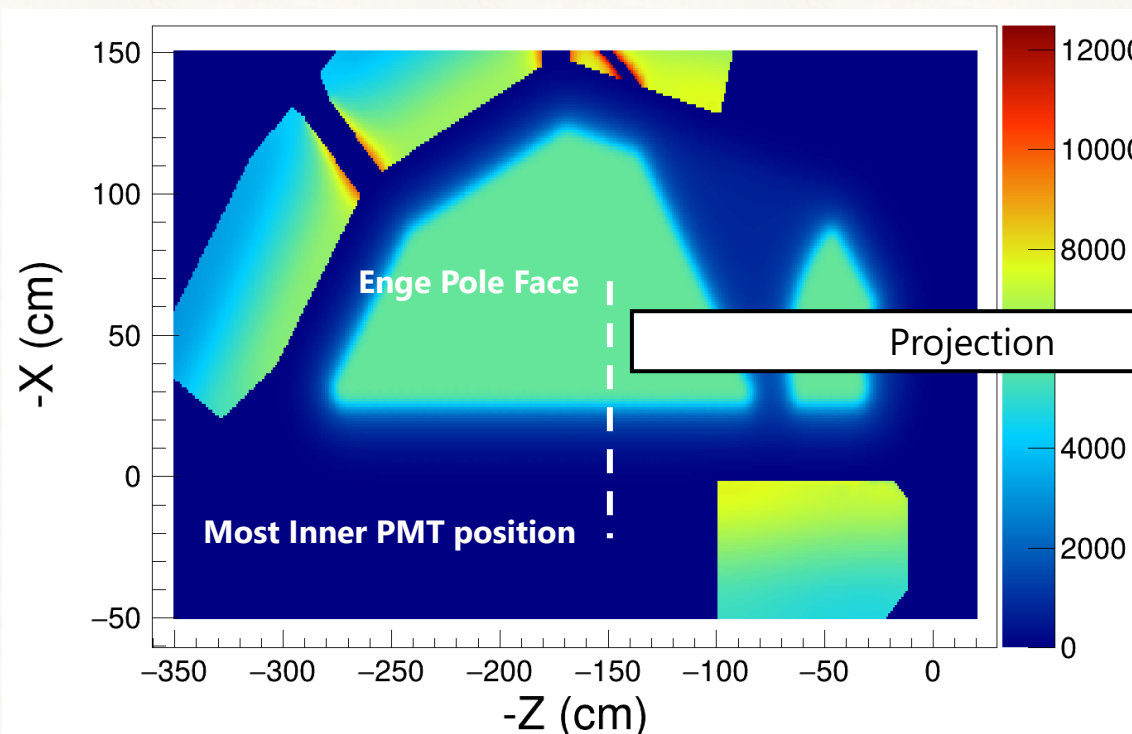
Manpower

Identification of the manpower and other resources (Resp. 4)

→ Mentors and workers have been assigned. Required computer resources are small

Backup

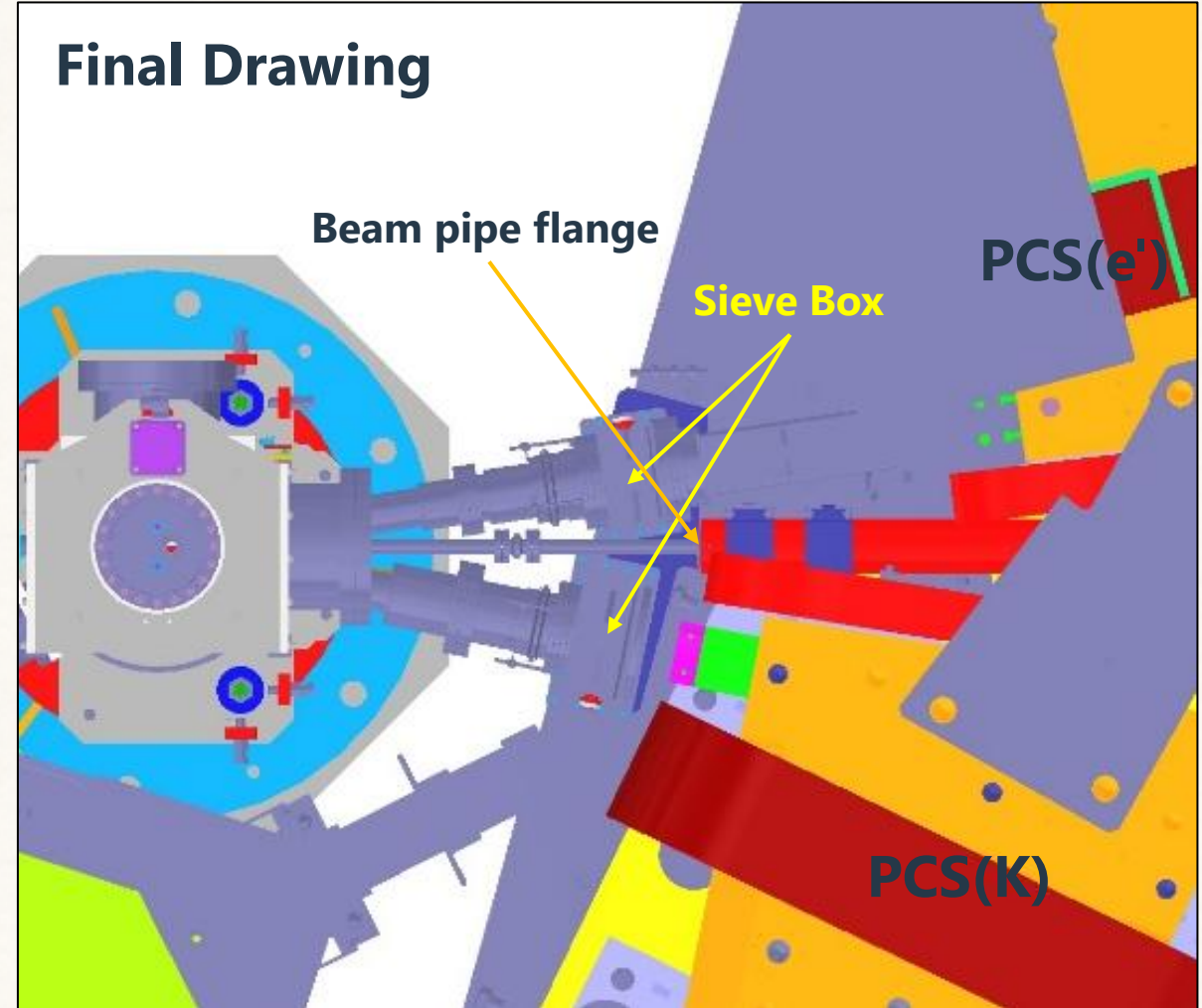
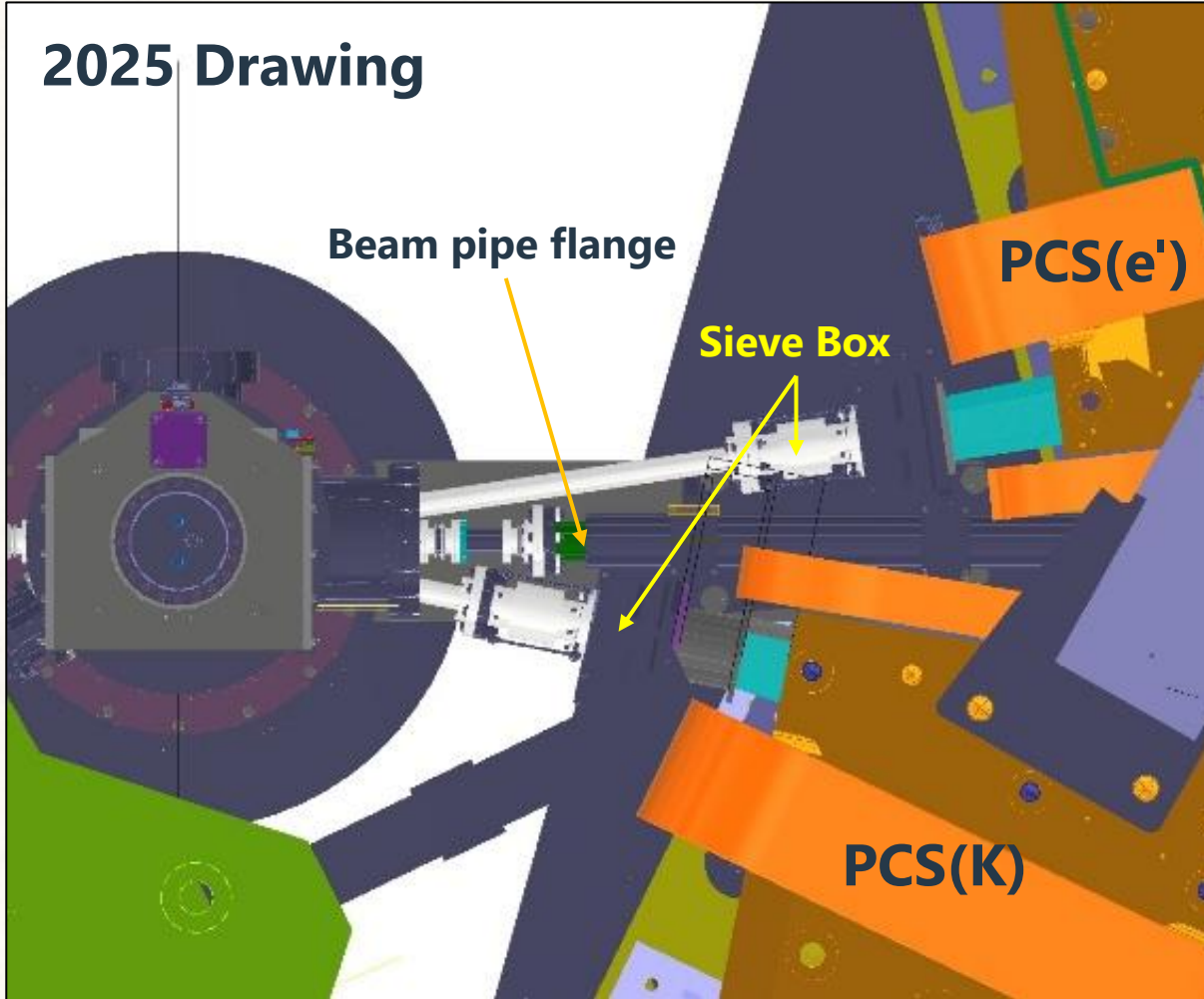
Enge Fringe Field (by TOSCA)



Expected Field will be 2~3 Gauss at $(-X, Y) = (-30, 5)$ cm.

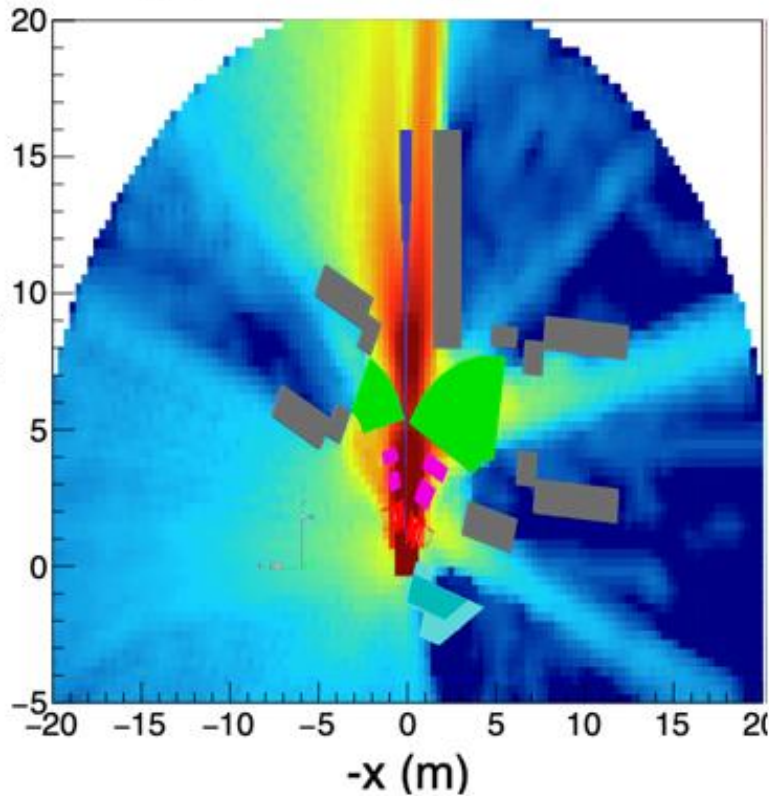
The most Inner PMT position is $(-X, Y) = (-29, 30)$ cm

Update Drawing

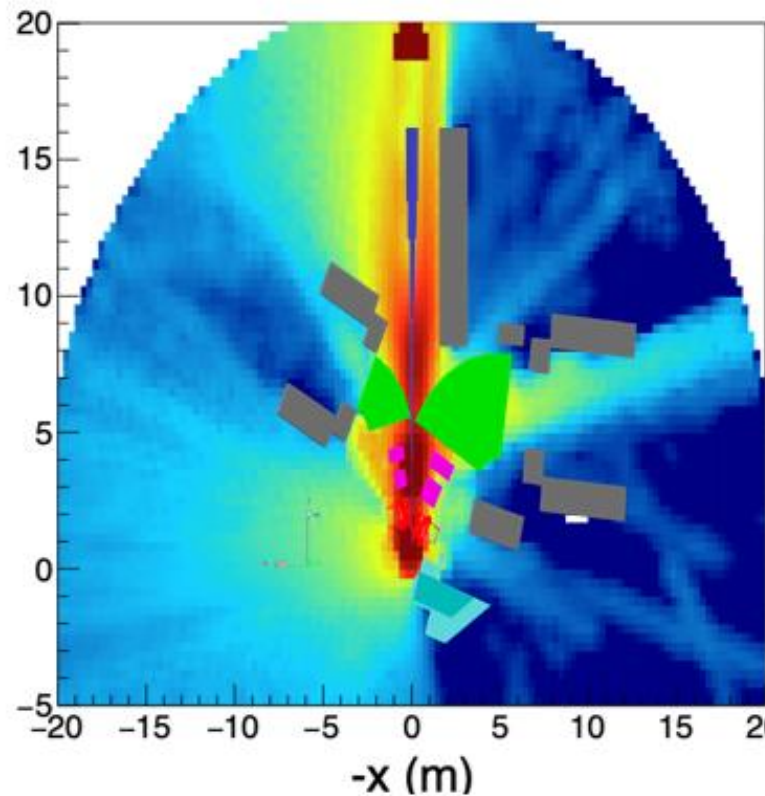


Results (Sum the doses for all particle types)

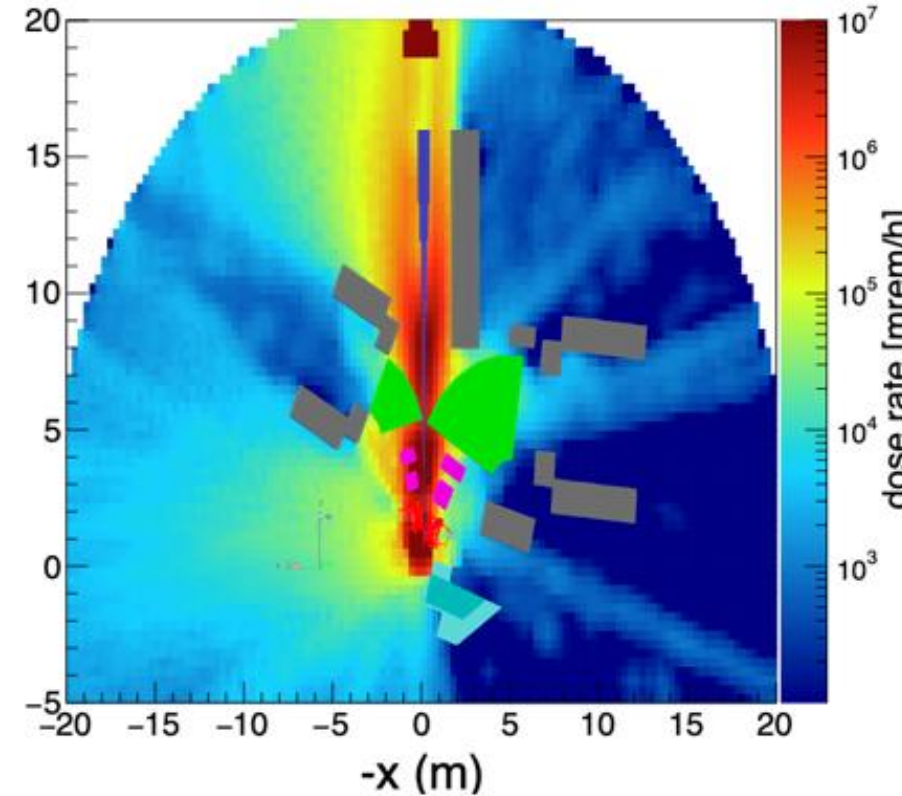
Case1.
Old pipe+Old Mag field



Case2.
New pipe+Old Mag field

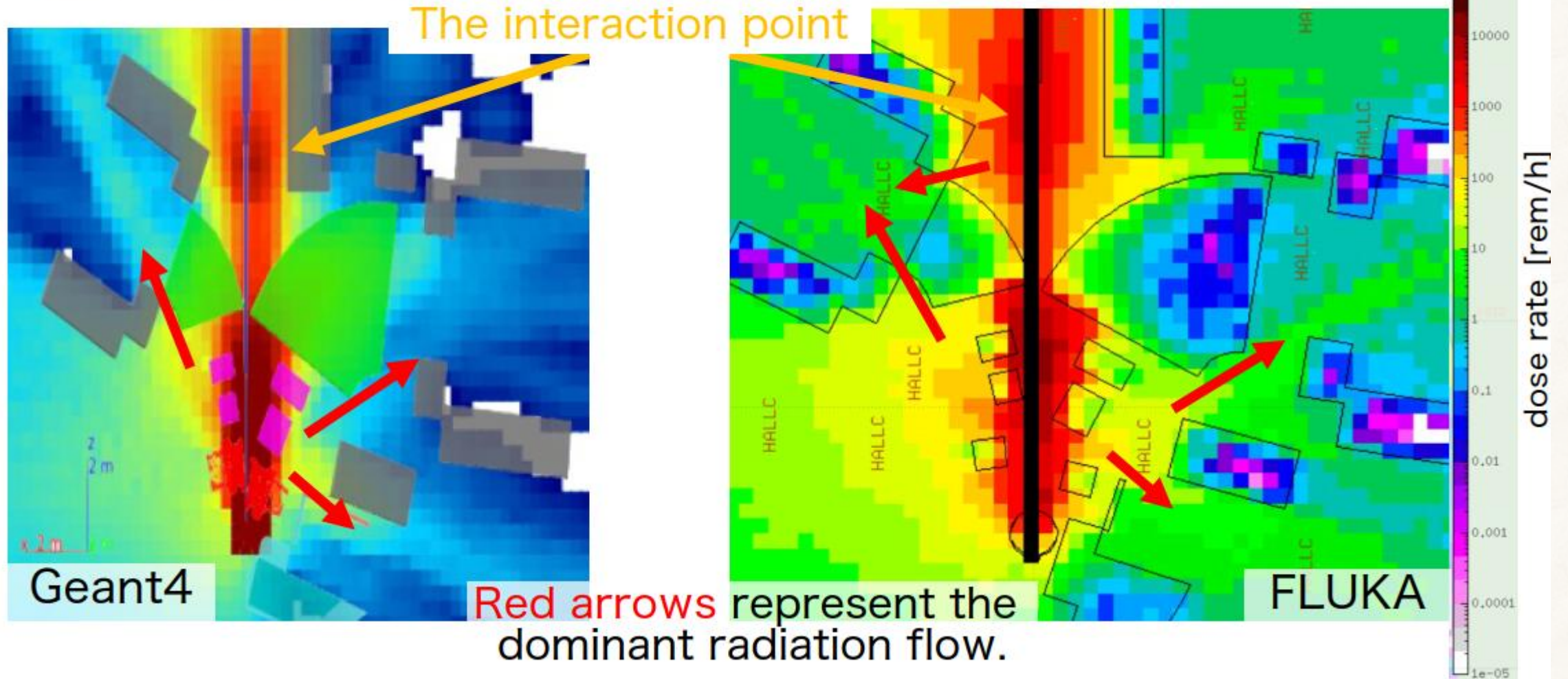


Case3.
New pipe+New Mag field



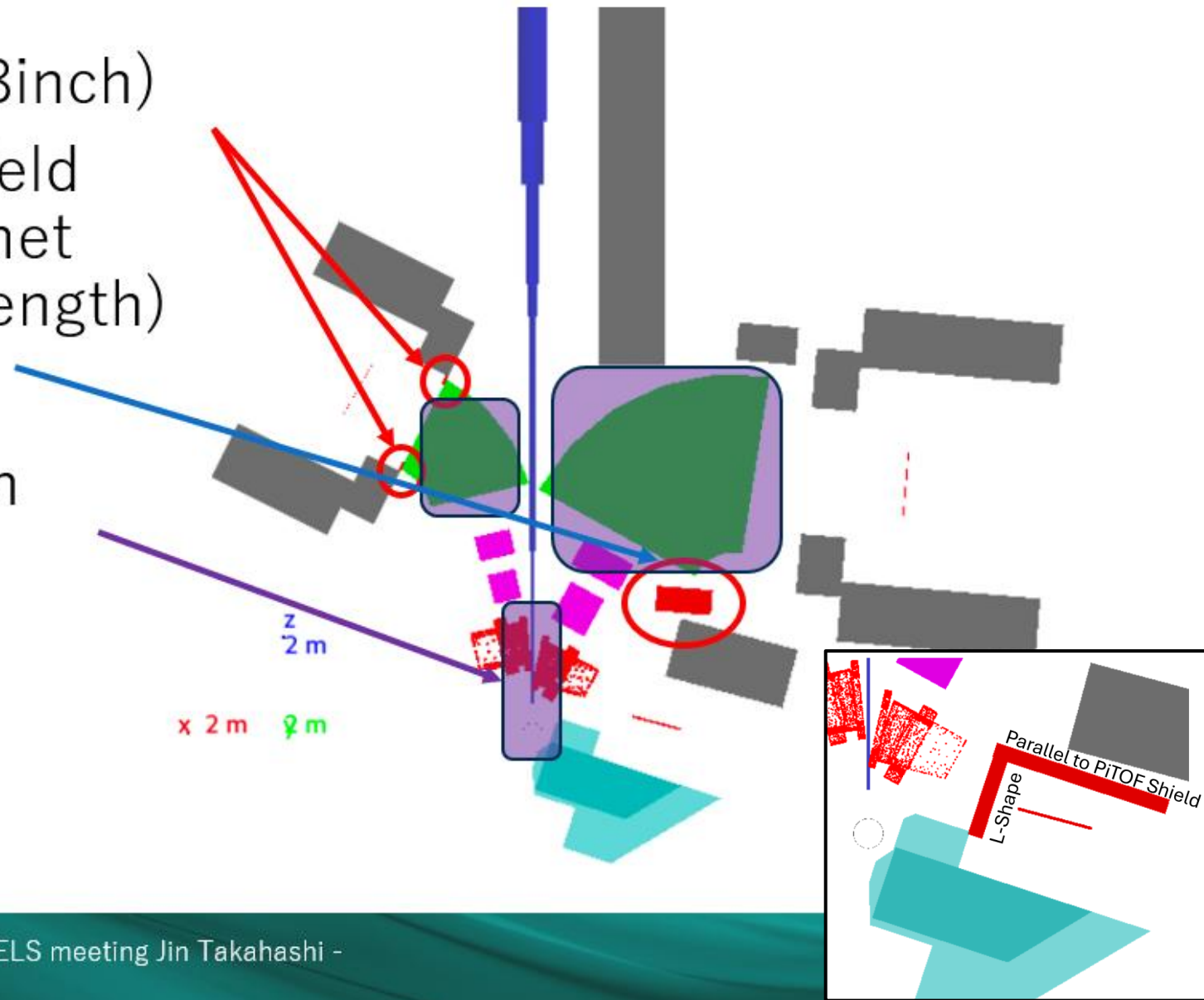
Dominant radiation flow

Beam current = 25 uA
Pb Target with Shielding

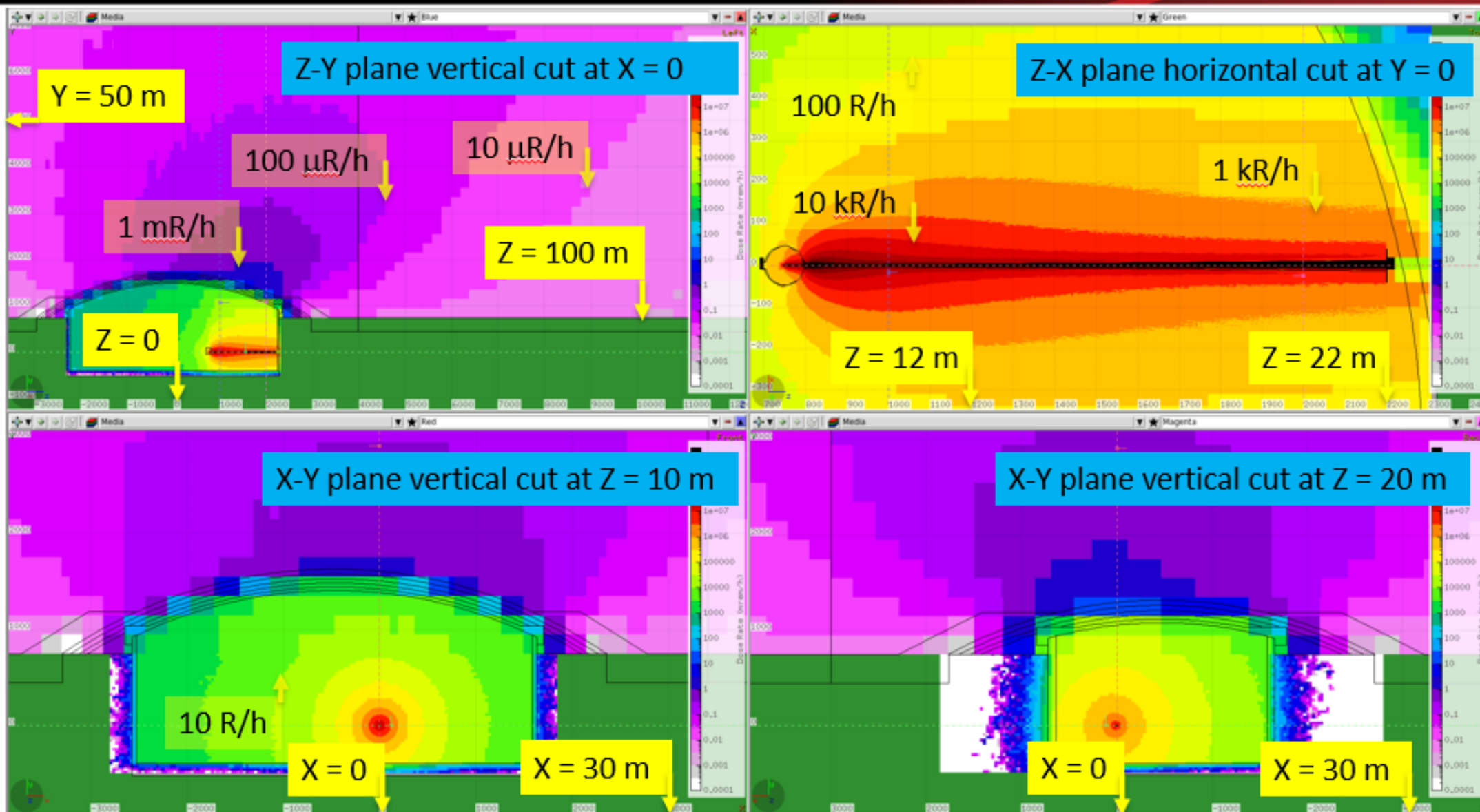


Condition

1. HES Pb Block Shield (8inch)
2. Place the Concrete shield in front of HKS D Magnet (50cm Thickm 1.1 m Length)
3. HKS, HES D Magnet on Beamline B Field on



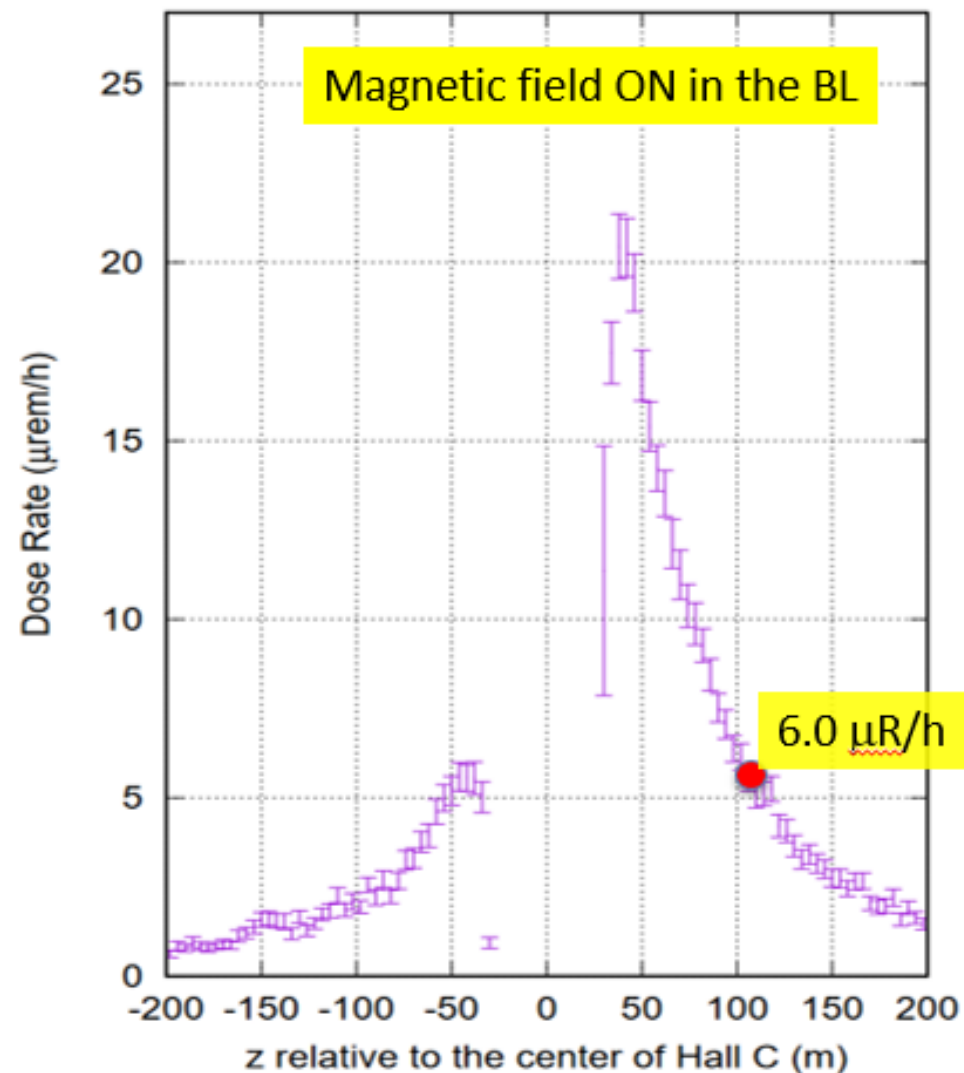
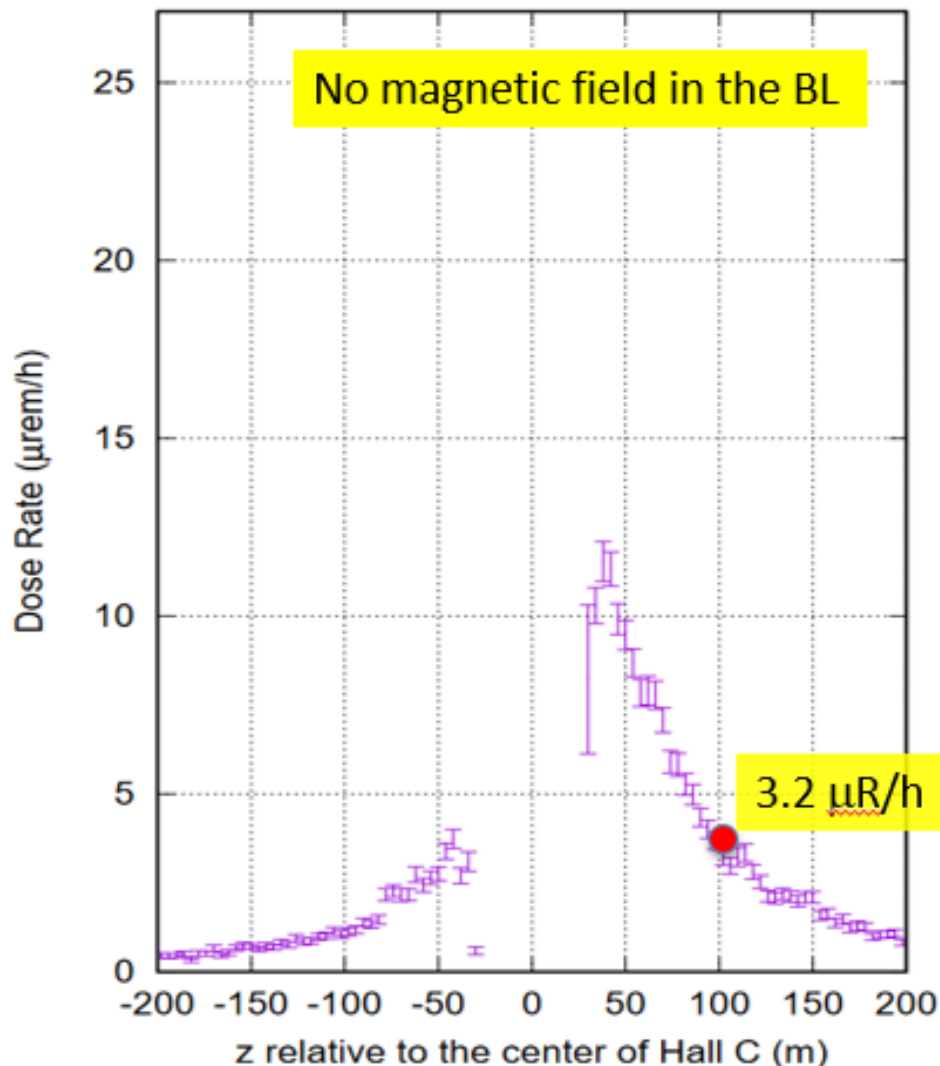
Prompt Dose Rates During Setup #9



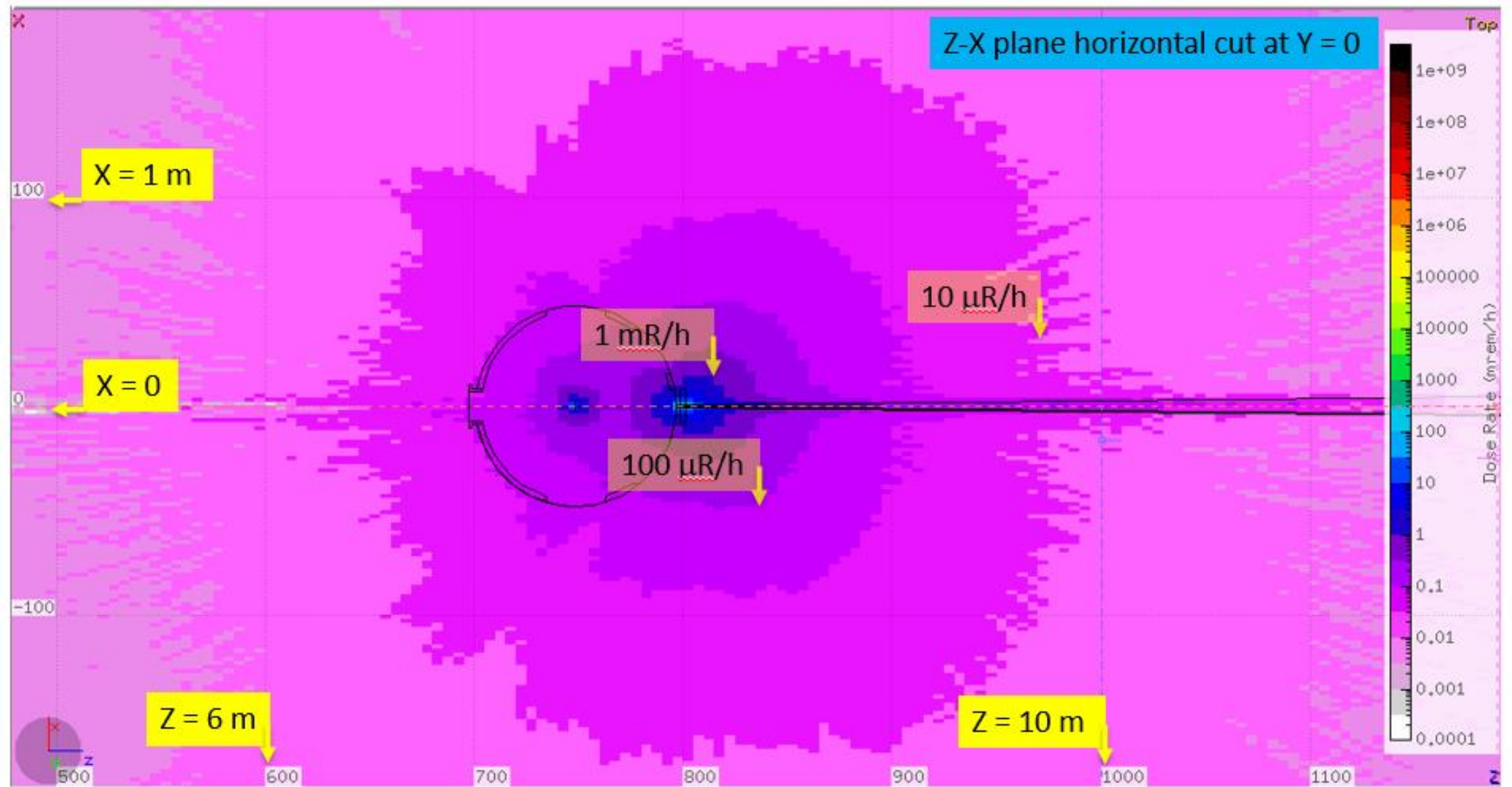
Boundary Dose Rates During HKS Setup #9

A factor of ~ 2 increase when the stray fields are taken into account

Dose rates along Z in 2 m thick, 4 m wide air layer above ground in the vicinity of Hall C



Activation in the Hall 1 hour after stop



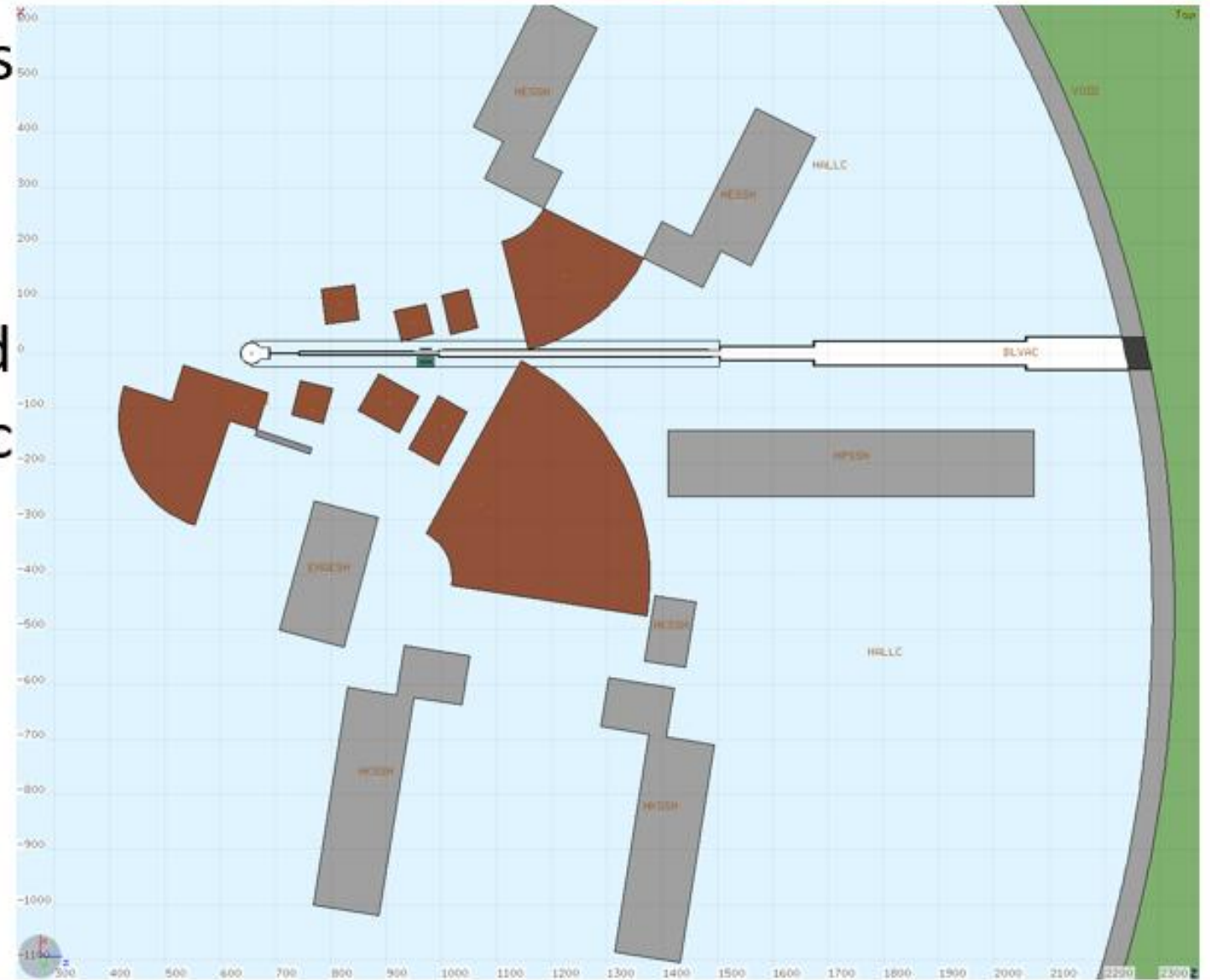
ERR Charge #6

- Are the radiation levels expected to be generated in the hall acceptable?
 - First preliminary evaluations tell Yes, however the final beam line design still needs to be evaluated
- Is any local shielding required to minimize the effects of radiation in the equipment?
 - The answer is also Yes. It will be dependent on the final design of the beam line and detailed calculations taking into account stray magnetic fields.
 - Damage to electronics and materials in the Hall need to be evaluated by the Experiment
- Dose rate accumulation at the CEBAF boundary is expected to be reasonable for 2-yr operations, and could be optimized

May 2026 Update

New beam line geometry is implemented in FLUKA

- Wider beam pipe, shifted location, longer magnetic shielding



Expected Background Rate and Trigger Rate

Assuming

Layer Coincidence Window = 24 ns

Spectrometer Coincidence Window = 200 ns

pi rejection efficiency (HKS) = 99%

Target [thickness / mg/cm ²]	Beam current / μ A	Rate / kHz												
		HES			HKS					Enge			Coincidence	
		e'	Accidental	Total	pi ⁺	K ⁺	p	Accidental	Total	pi ⁻	Accidental	Total	CP	Kaon Trigger
Graphite [100]	50	130	42	170	18	0.22	23	0.3	23	41	52	93	3.8	1.2
⁴⁰ Ca [150]	50	770	210	980	23	0.27	29	1.5	31	52	110	160	46	6.9
²⁰⁸ Pb [150]	25	1200	1300	2500	9	0.11	11	10	21	20	1700	1700	840	18