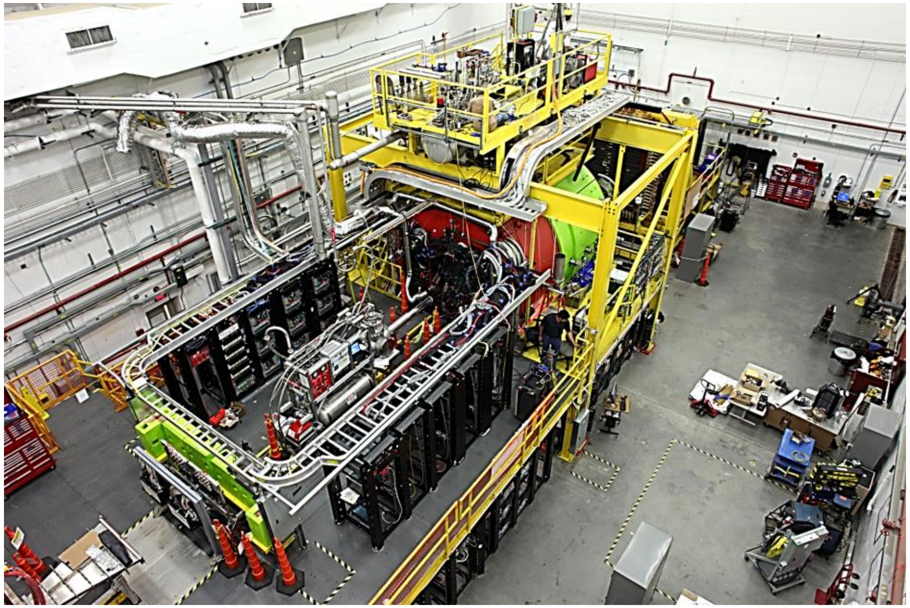
Be-Target Assembly for ERR-I:
Conceptual Design & Radiation Effects

Igor Strakovsky[*)] & *Vitaly Baturin*[**)]

[*)]*The George Washington University*
[**)]*Old Dominion University*



- *ERR-I charge for KPT.*
- *Kaon beamline.*
- *Collimator Hall setting.*
- *Equivalent dose rate for Exp Hall.*
- *Optimization KPT.*
- *Prompt dose rate for Collimator Hall.*
- *Activation dose rate for Collimator Hall.*
- *Radiation budget above ground.*

Supported by DE-SC0016583 DE-FG02-96ER40960

ERR-I Charge for KPT

Experiment Readiness Review Phase I Jefferson Lab, *2023 Charge*

From: **Patrizia Rossi**

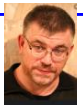
Hall D E12-19-001 *ERR* **Phase I** Jefferson Lab, 2023 Charge

- What is status of *Kaon Production Target* (***KPT***)? Specifically:
  a) Conceptual design.
  b) Evaluation of produced radiation. In particular, following points should be discussed:
    1. Approximations made in *MC* simulations & which code has been used;
    2. Energy deposition & temperature in ***KPT***; → See Tim's report
    3. Prompt dose & activation around ***KPT*** & ***Cave***;
    4. Water-cooling system & possible contaminations. → See Tim's report
- Will civil constructions be needed in ***Cave*** to contain radiation?
- What is decommissioning plans for ***KPT*** & activated components? → See Tim's report as well
  A brief outline is sufficient.

- *Geometry* of *Experimental* & *Collimator Halls* came from *Timothy Whitlatch*.
- *Engineering* design, water cooling, & contamination were done by *Timothy Whitlatch*.
- *RadCon* calculations were under *Pavel Degtyarenko* & *Lorenzo Zana* suggestions.



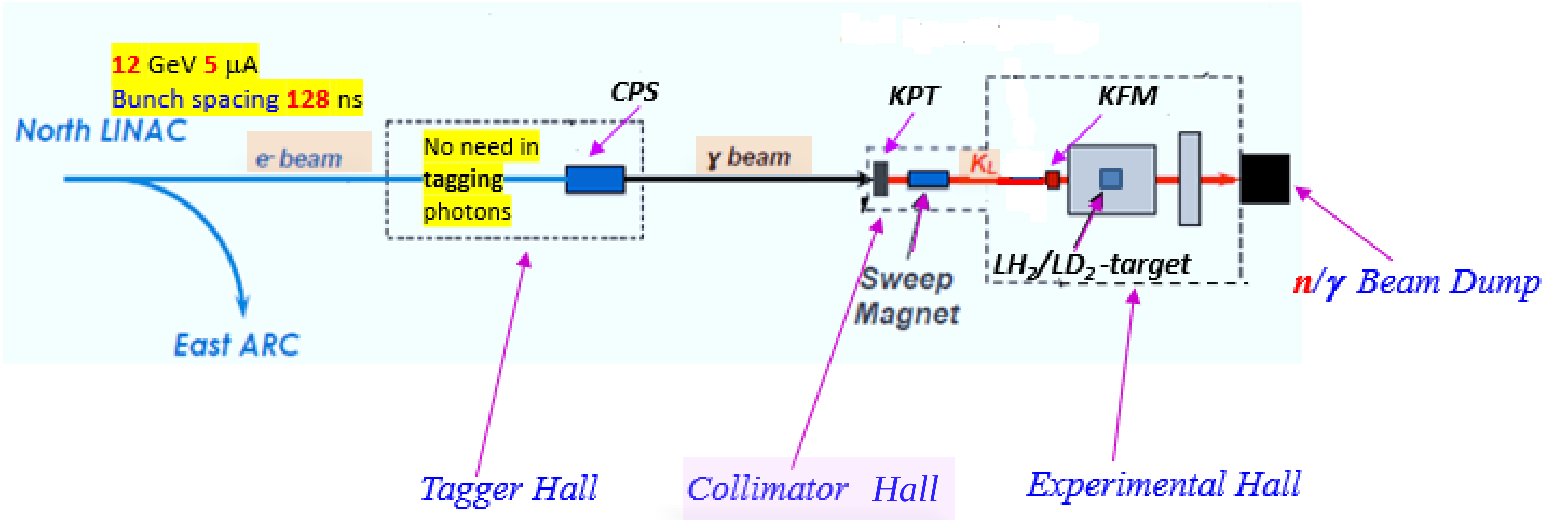
- Following codes were used for MC simulations: MCNP6, FLUKA, GEANT4, Ansys


Kaon Beamline

Hall D: Beam Line for K-long

• Electrons (**3.1 x 10^13** e/sec) are hitting Cu-radiator @ ***CPS*** located in Tagger Hall.

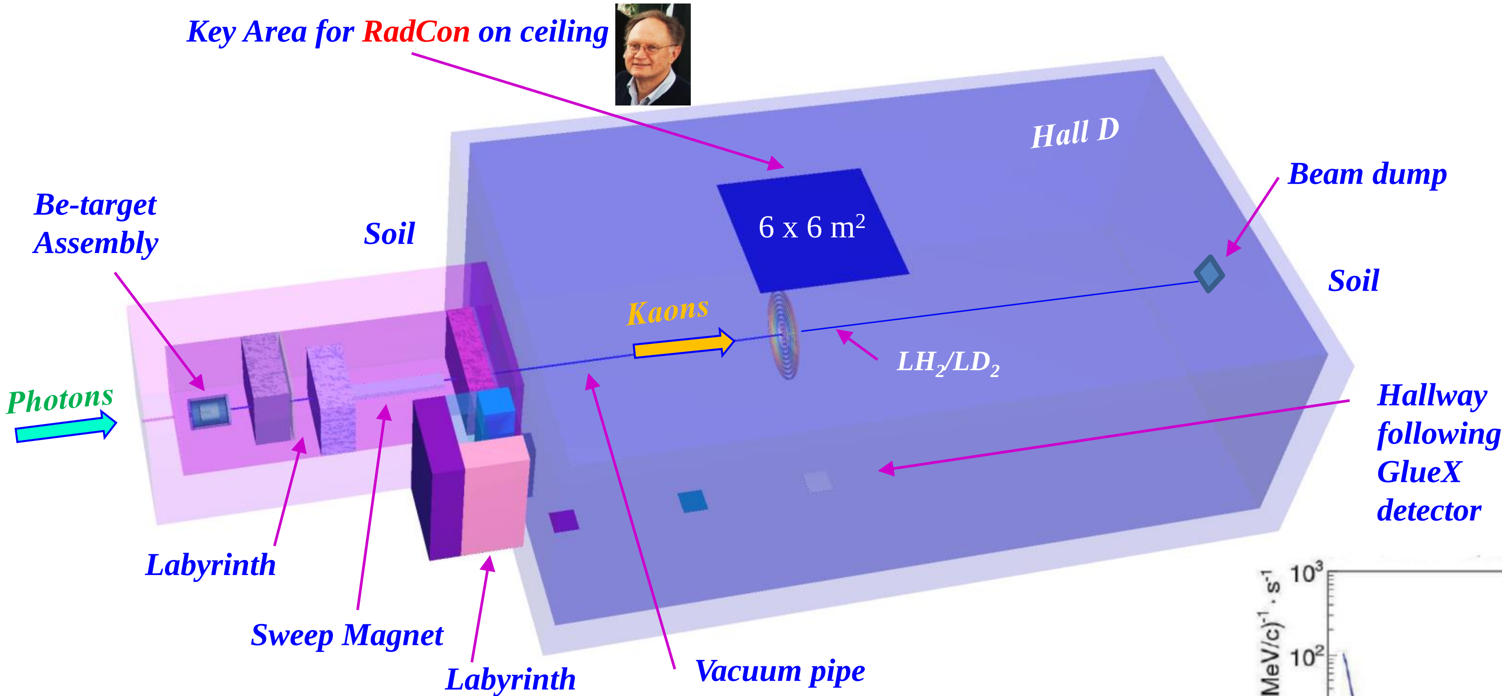


Collimator Hall Setting

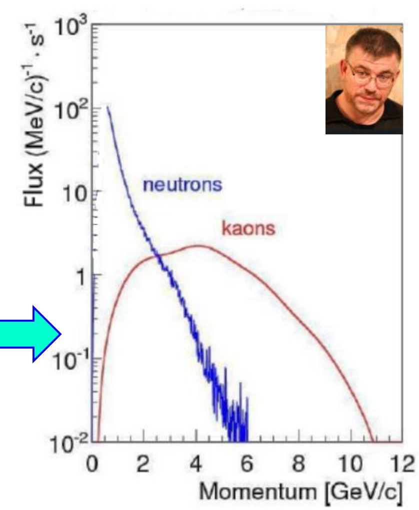
Hall D Setting - 1

RadCon limit =1 mrem/h

- For neutron & gamma calculations, we use MCNP6 *radiation transport code.*



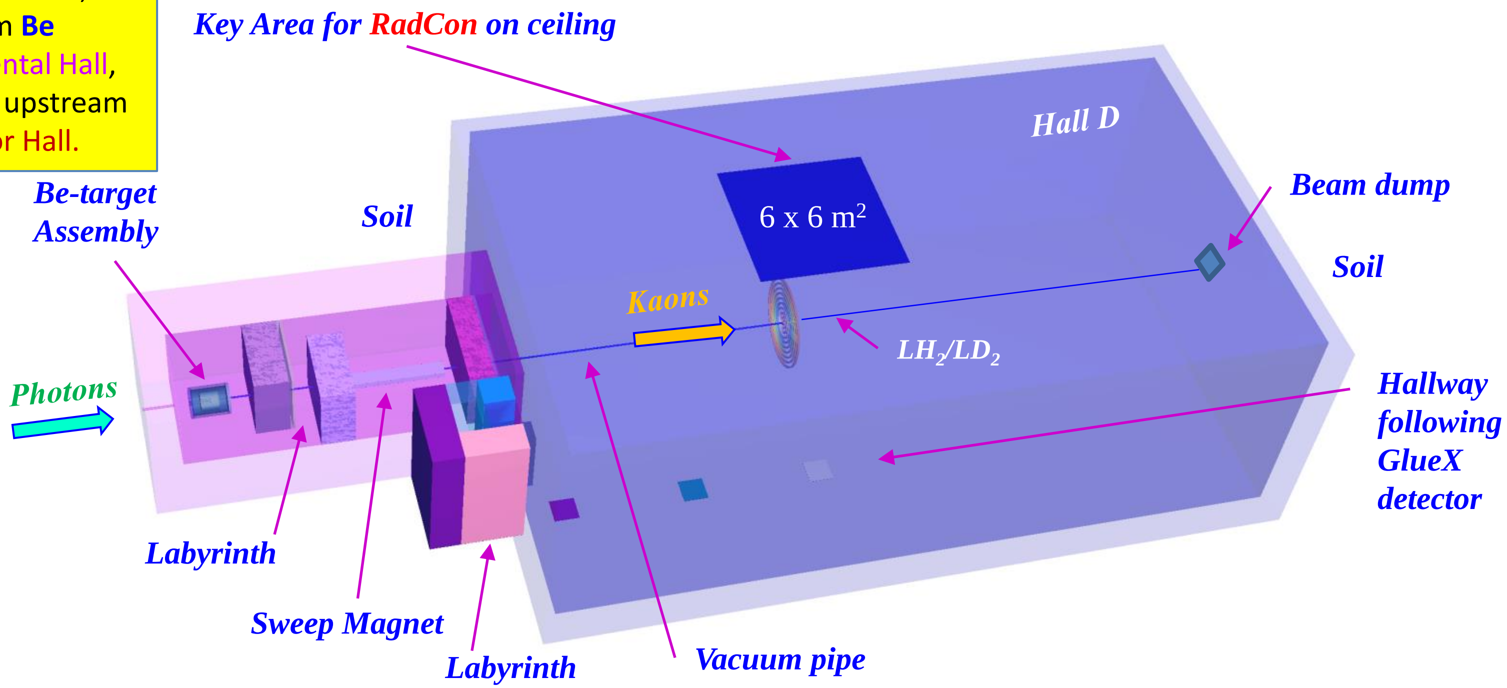
- Most important & unpleasant background for K_L beam comes from neutrons



Hall D Setting - 2

RadCon limit =1 mrem/h

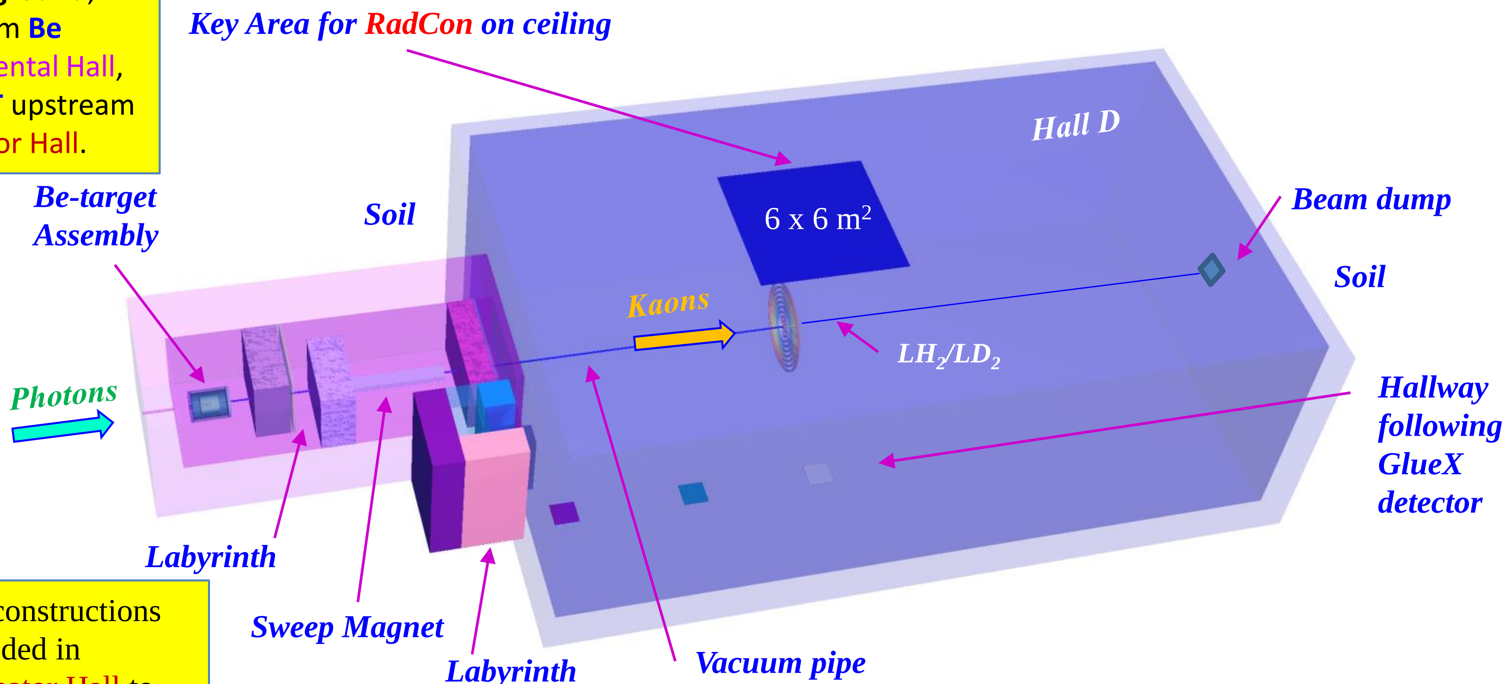
To reduce effect of
n & **γ background**,
coming from **Be**
in Experimental Hall,
we put **KPT** upstream
in Collimator Hall.



Hall D Setting - 3

RadCon limit =1 mrem/h

To reduce effect of **n** & **γ background**, coming from **Be** in Experimental Hall, we put **KPT** upstream in Collimator Hall.

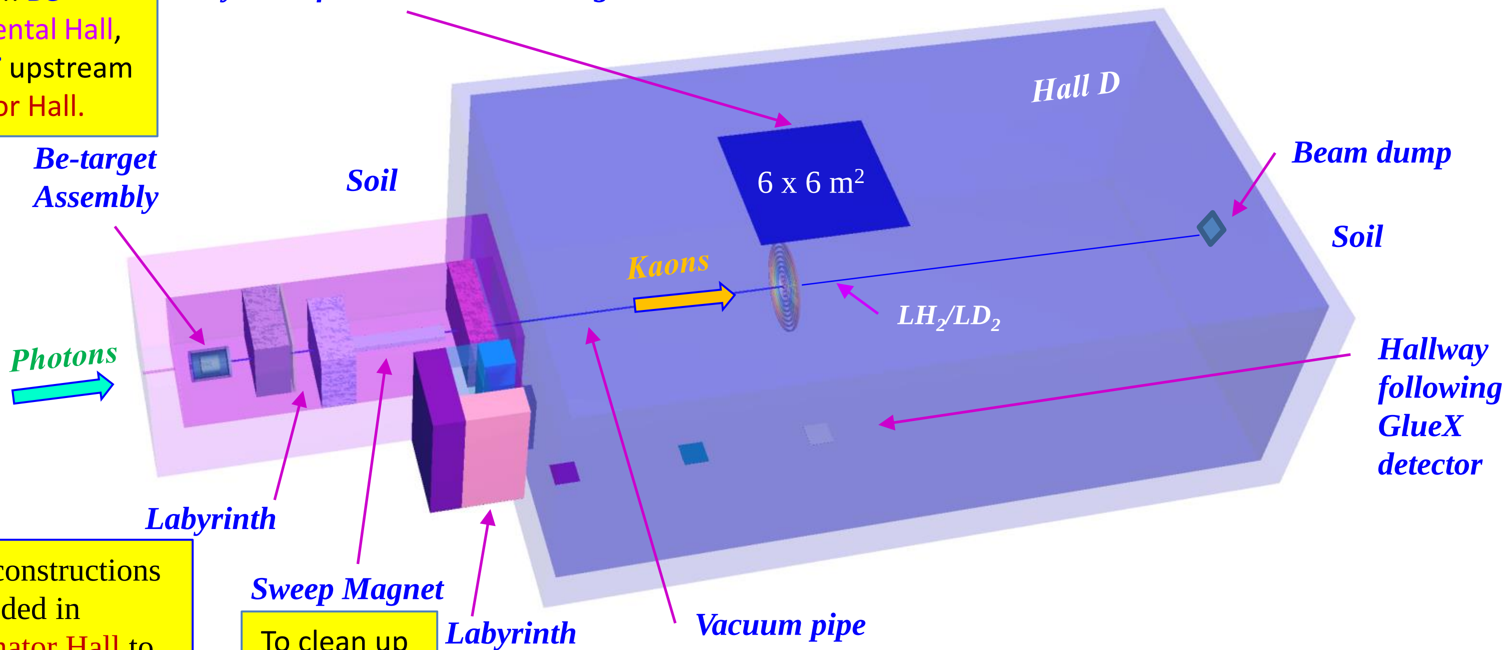


Civil constructions be needed in Collimator Hall to contain radiation to minimize **n** & **γ** **background** in Experimental Hall.

Hall D Setting - 4

RadCon limit =1 mrem/h

To reduce effect of **n** & γ **background**, coming from **Be** in Experimental Hall, we put **KPT** upstream in Collimator Hall.



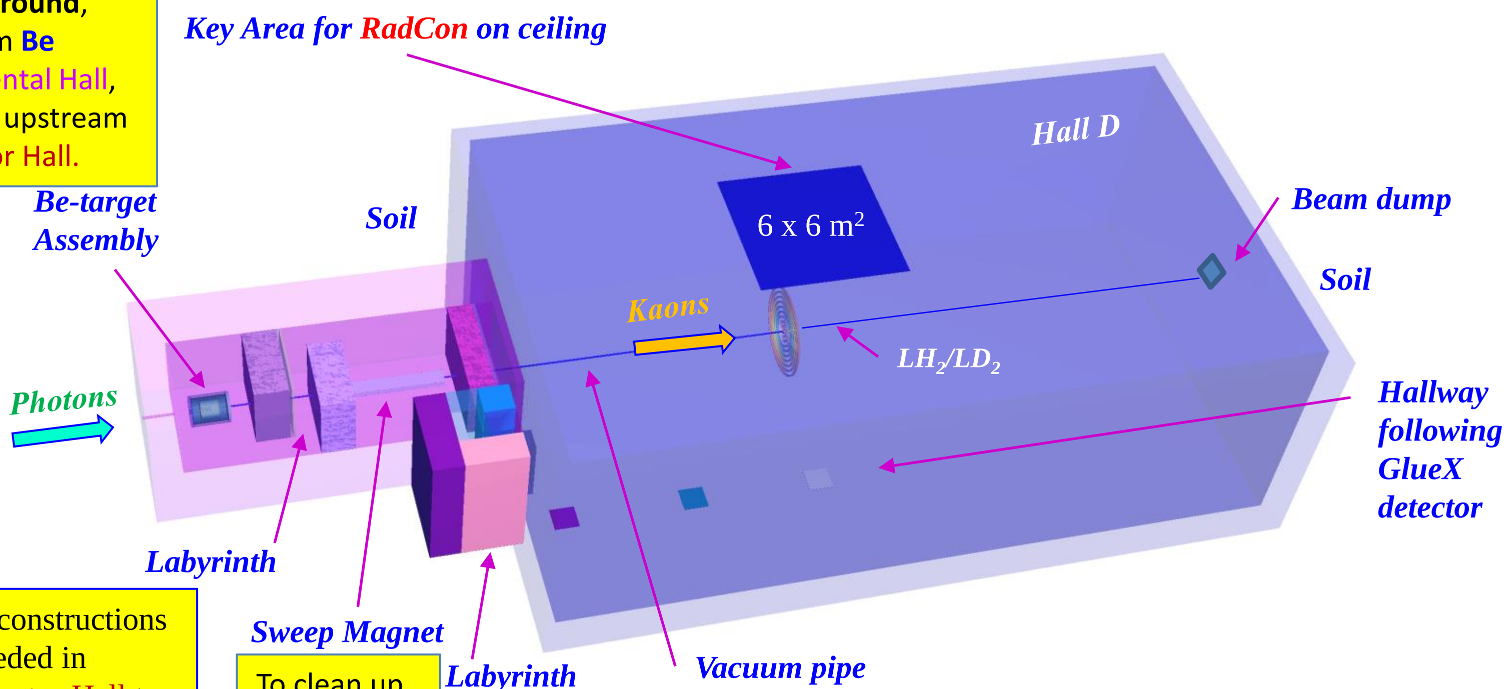
Civil constructions be needed in Collimator Hall to contain radiation to minimize **n** & γ **background** in Experimental Hall.

To clean up charged component of beam (including muons).

Hall D Setting - 5

RadCon limit =1 mrem/h

To reduce effect of **n** & **γ** **background**, coming from **Be** in Experimental Hall, we put **KPT** upstream in Collimator Hall.



Civil constructions be needed in Collimator Hall to contain radiation to minimize **n** & **γ** **background** in Experimental Hall.

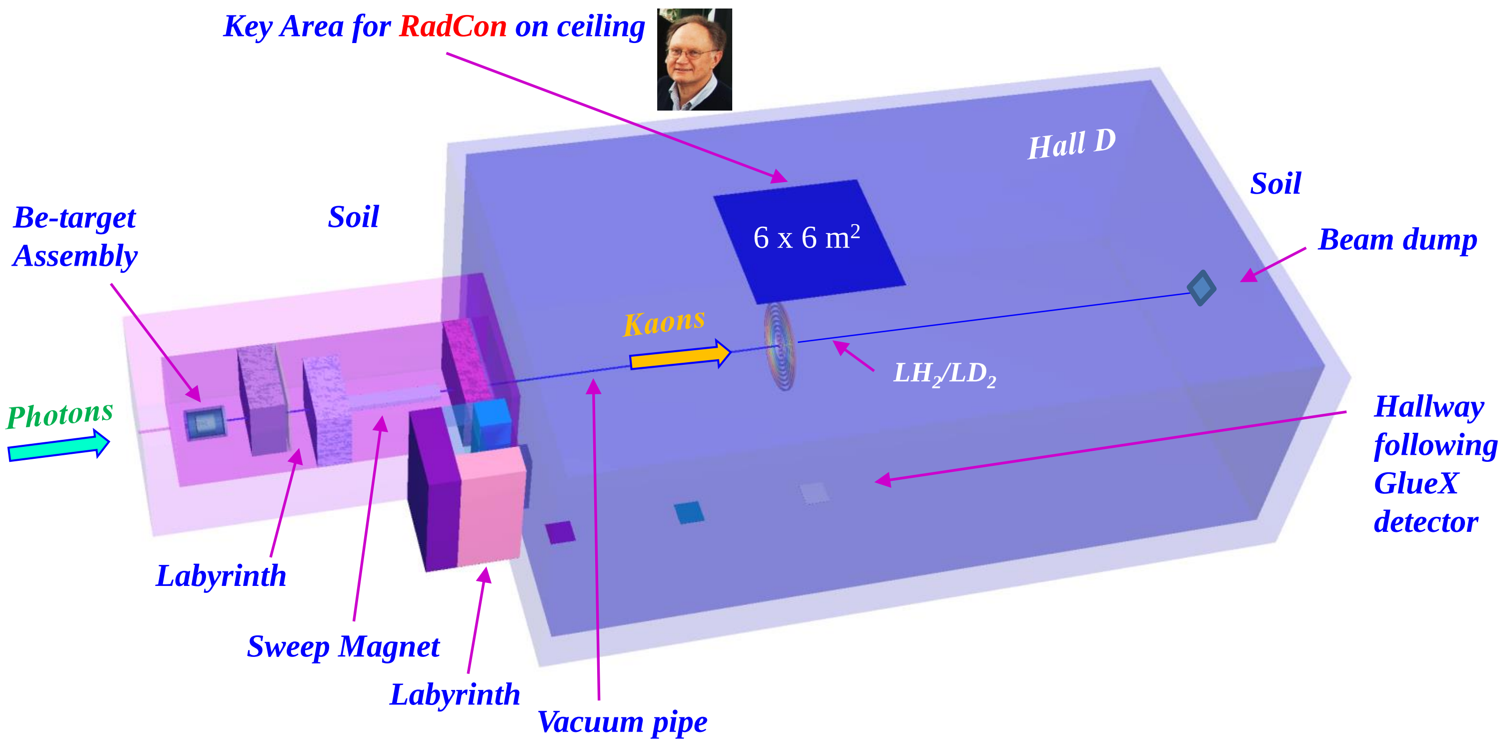
To clean up charged component of beam (including muons).

Vacuum beam pipe prevents neutrons re-scattering in air.

Equivalent Dose Rate for Experimental Hall

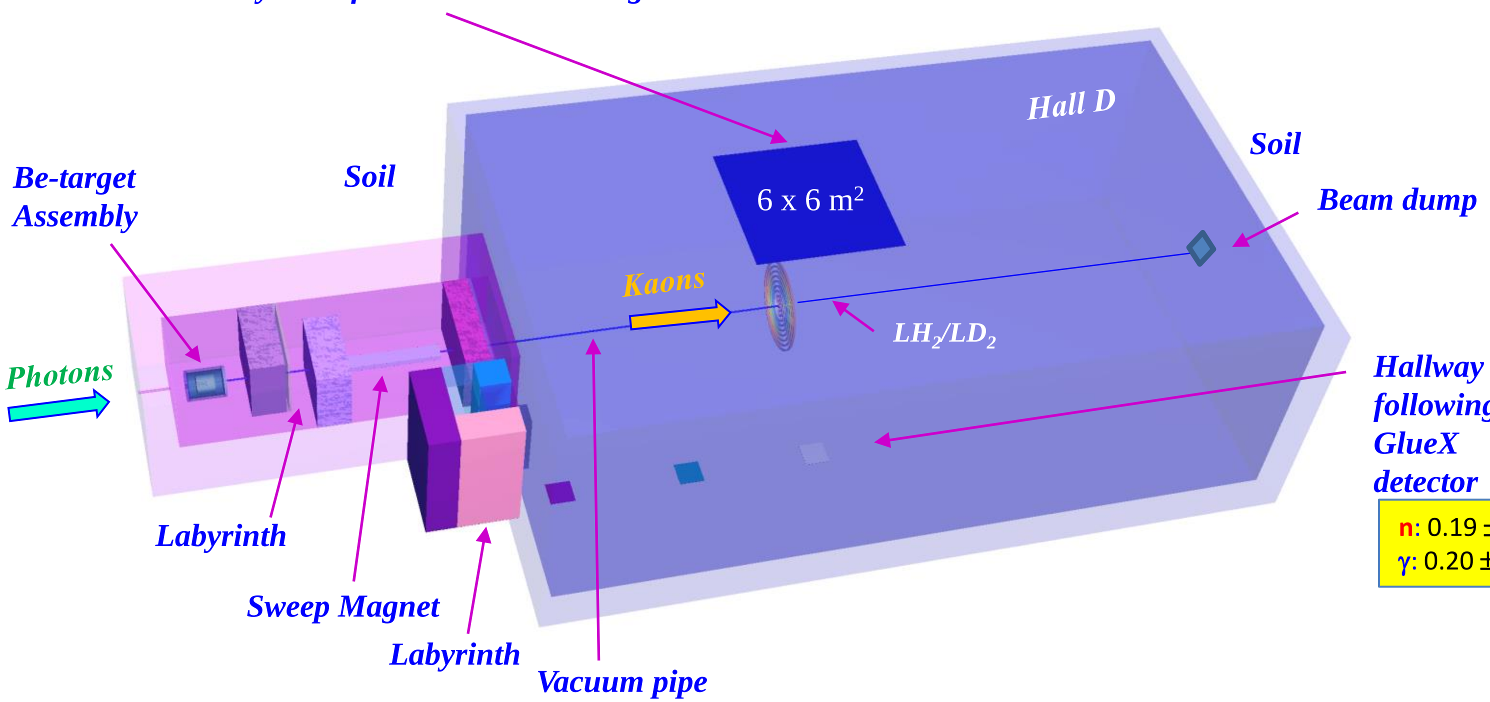
Hall D Setting & Equivalent Dose Rate - 1

RadCon limit =1 mrem/h



Hall D Setting & Equivalent Dose Rate - 2

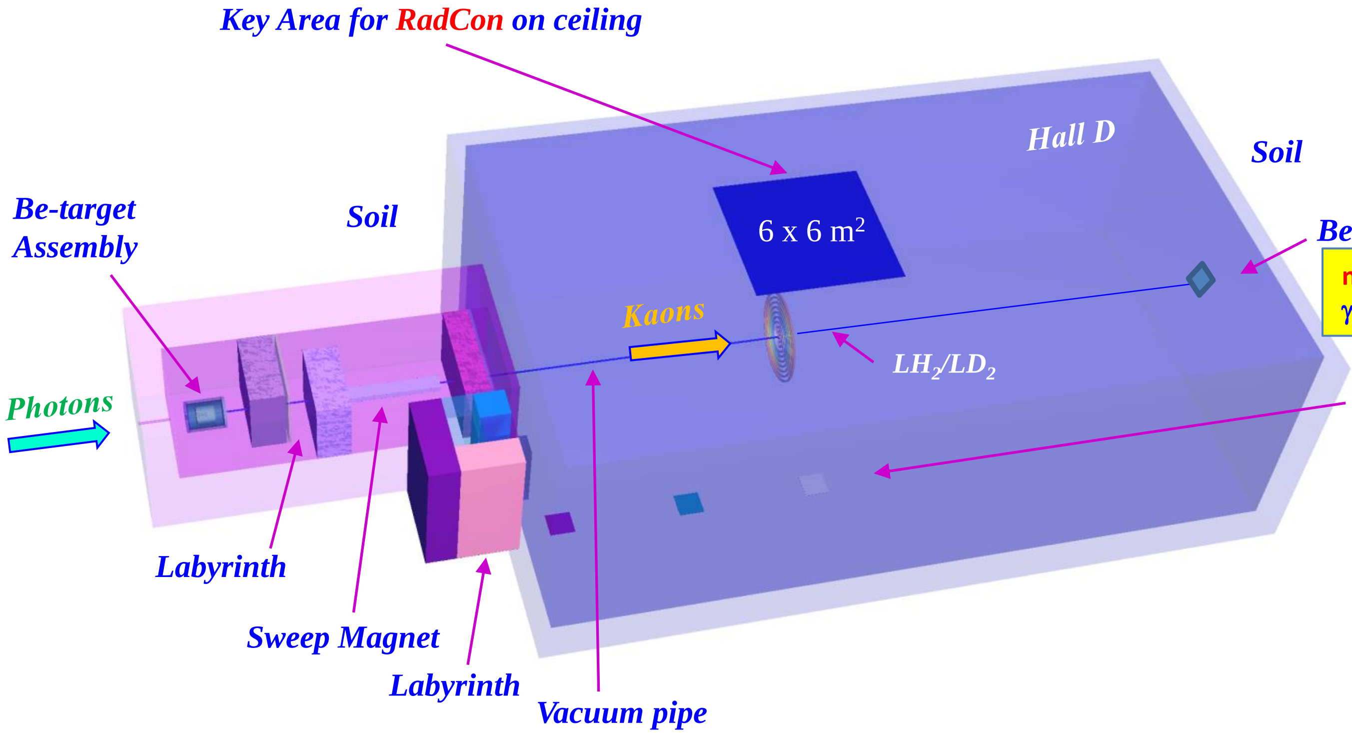
RadCon limit =1 mrem/h



n: 0.19 ± 0.19 mrem/h
γ: 0.20 ± 0.19 mrem/h

Hall D Setting & Equivalent Dose Rate - 3

RadCon limit =1 mrem/h

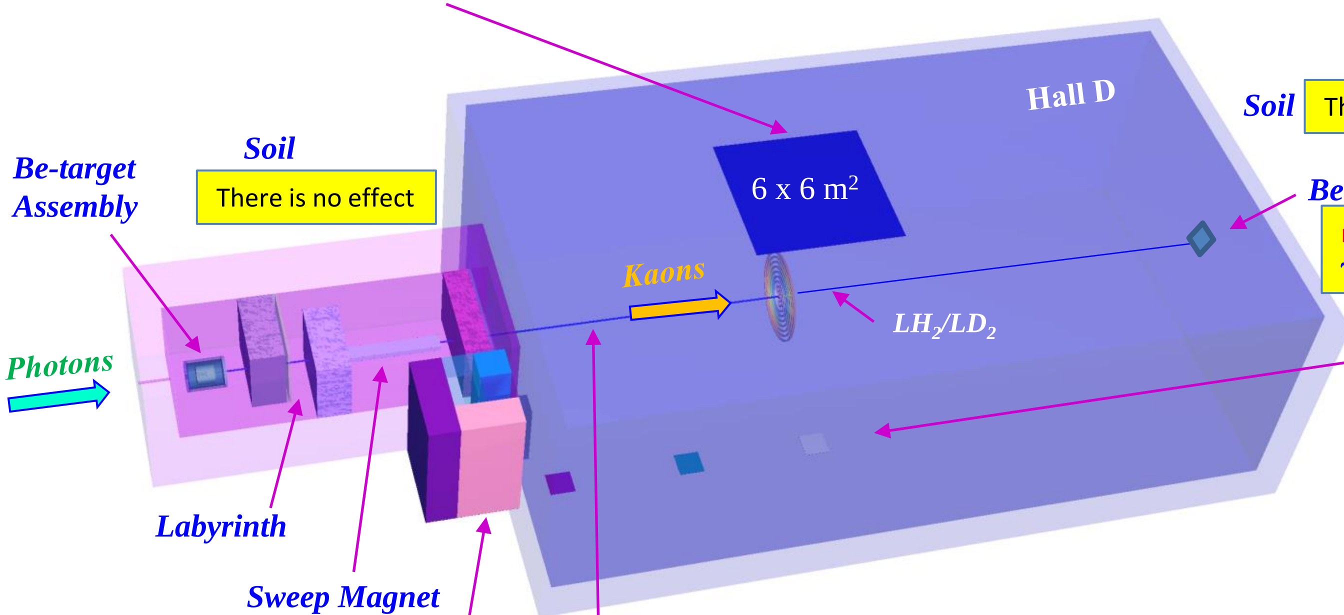


Beam dump:
n: 0.20 ± 0.20 mrem/h
γ: 1.25 ± 0.10 mrem/h

Hallway following GlueX detector:
n: 0.19 ± 0.19 mrem/h
γ: 0.20 ± 0.19 mrem/h

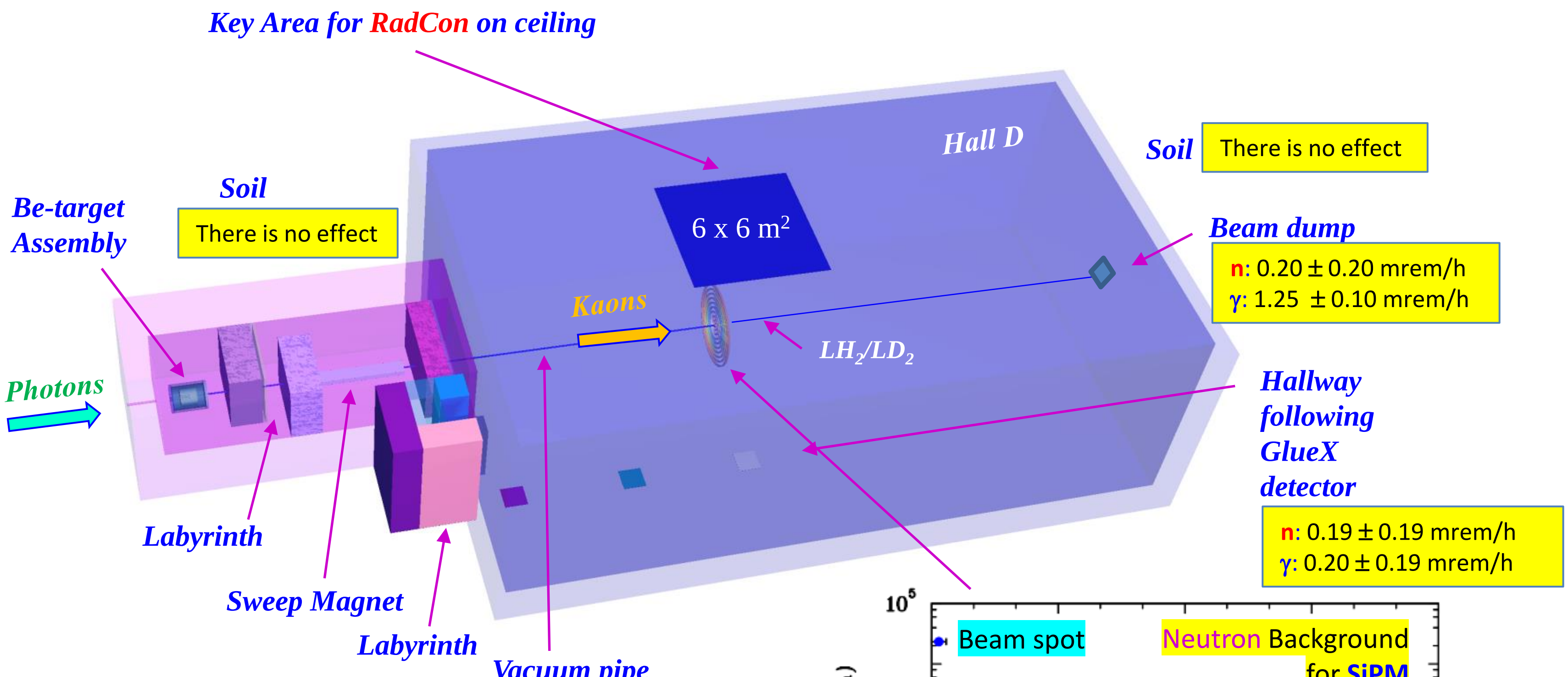
Hall D Setting & Equivalent Dose Rate - 4

RadCon limit =1 mrem/h



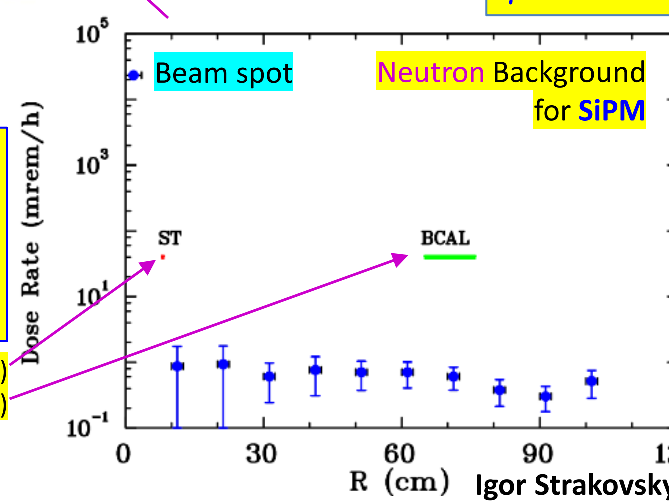
Hall D Setting & Equivalent Dose Rate - 5

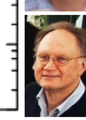
RadCon limit =1 mrem/h



Previous studies stand that dose rate of 30 mrem/h increases dark current @ **SiPM** by factor of 5 after 75 days of running period.

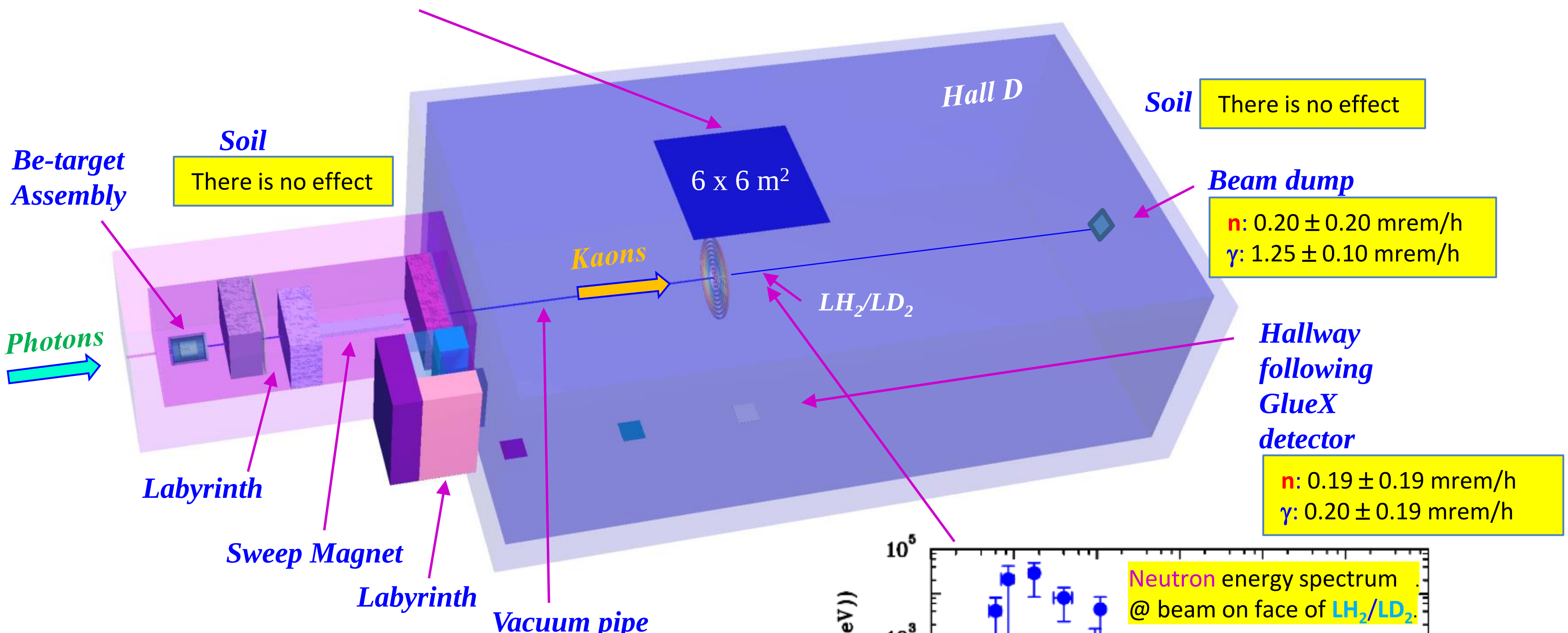
SC: E. Pooser *et al*, Nucl Instrum Meth A **927**, 330 (2019)
BCAL: T.D. Beattie *et al*, Nucl Instrum Meth A **896**, 24 (2018)

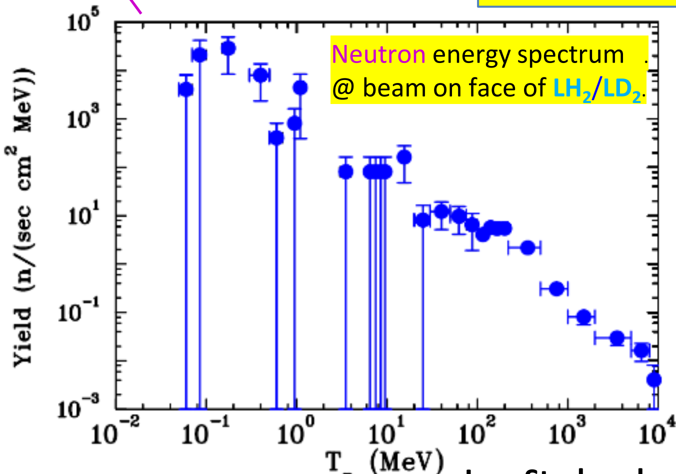




Hall D Setting & Dose Rate - 6

RadCon limit =1 mrem/h

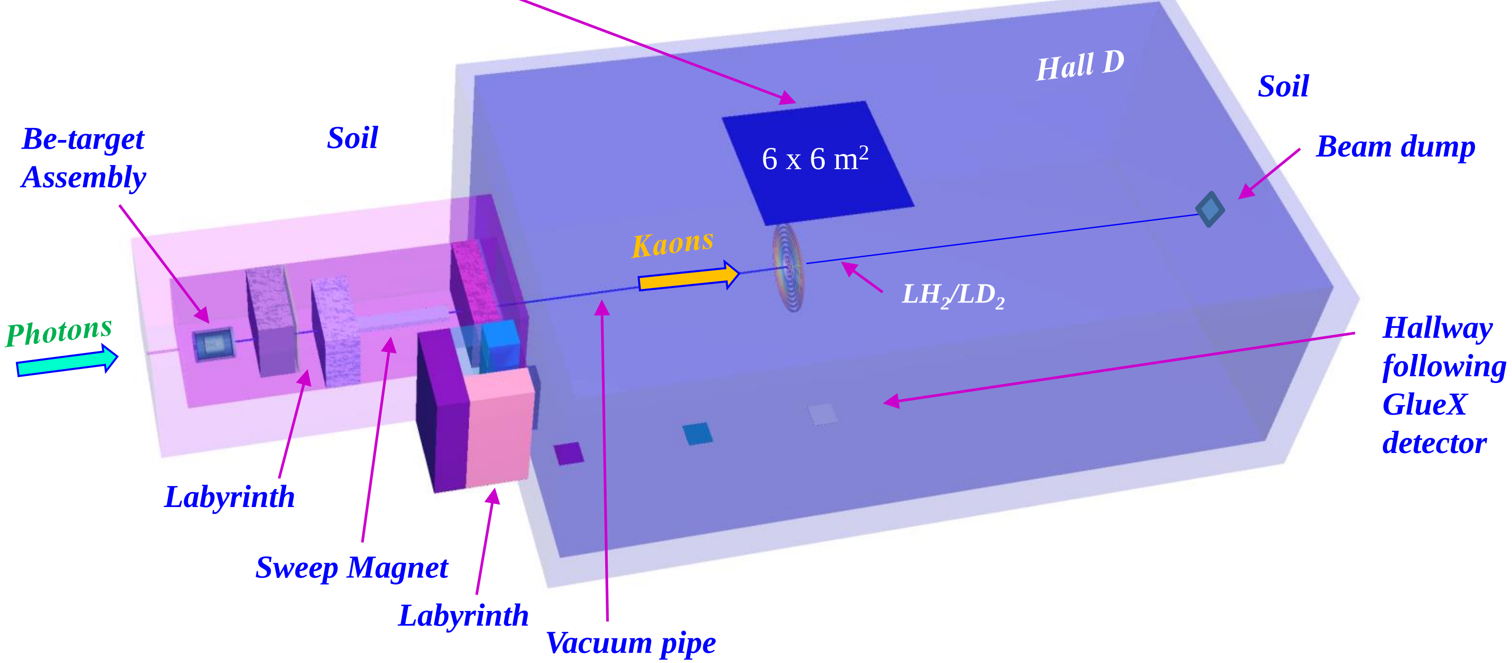




Hall D Setting & Equivalent Dose Rate – 7 [Final]

RadCon limit =1 mrem/h

n: 0.27 ± 0.08 mrem/h
γ: 0.065± 0.002 mrem/h



• Radiation in ***Experimental Hall*** is under *allowed* limits.

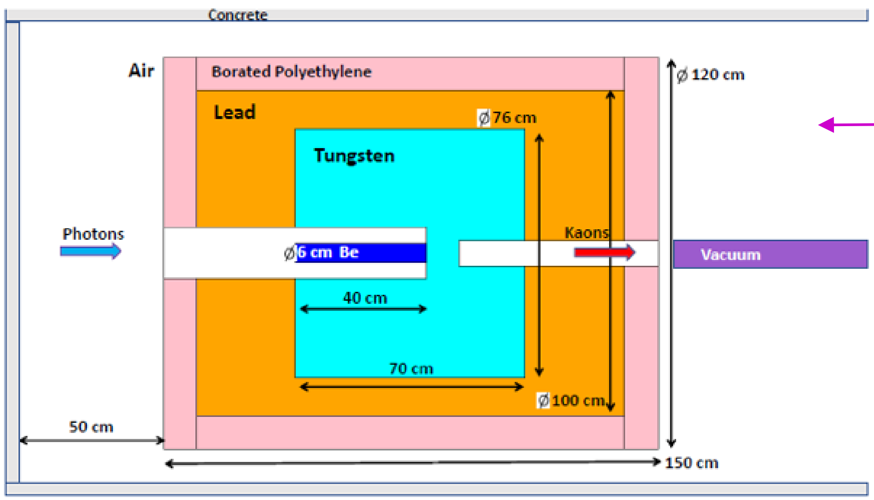
Optimization KPT

Be-Target Assembly - 1

RadCon limit = 1 mrem/h

xy-cross section, x-dimension

Concrete walls are out of scale

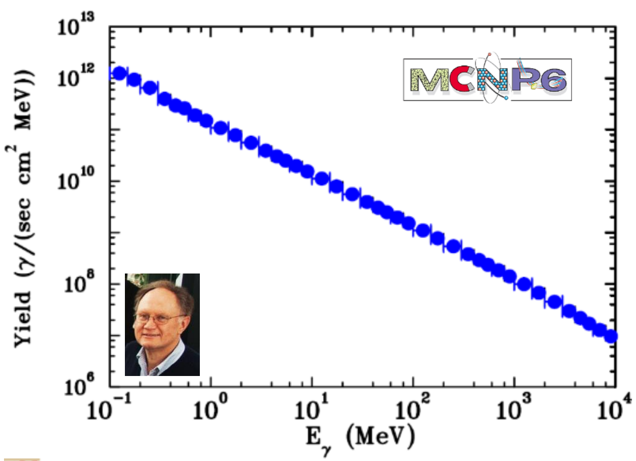


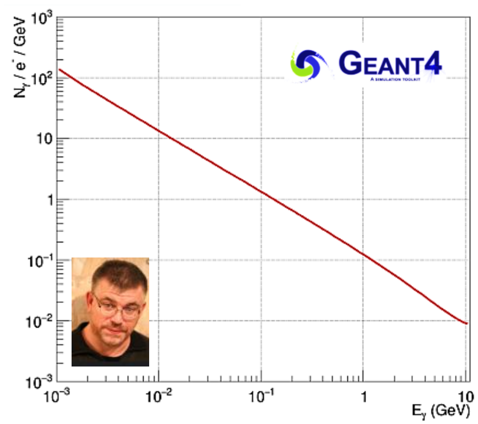
At key area for RadCon on ceiling

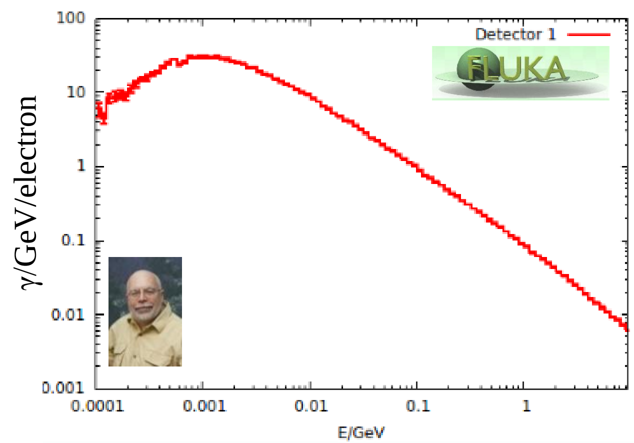
Pb & W

n: 0.35 ± 0.17 mrem/h
γ: 0.078±0.005 mrem/h

Gammas on face of Be-target



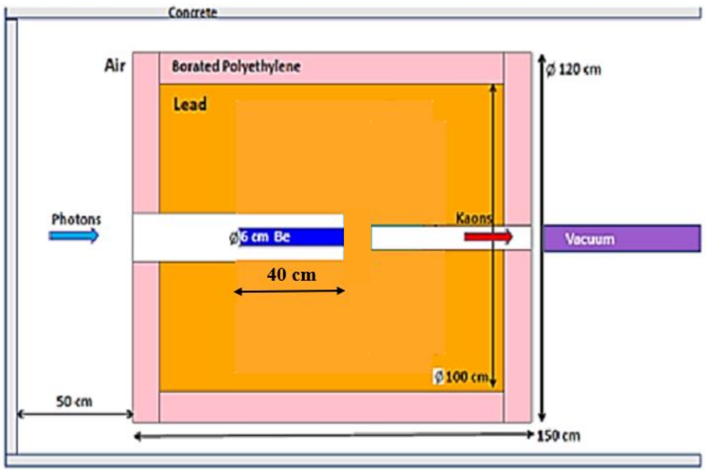




Be-Target Assembly - 2

RadCon limit =1 mrem/h

xy-cross section, x-dimension

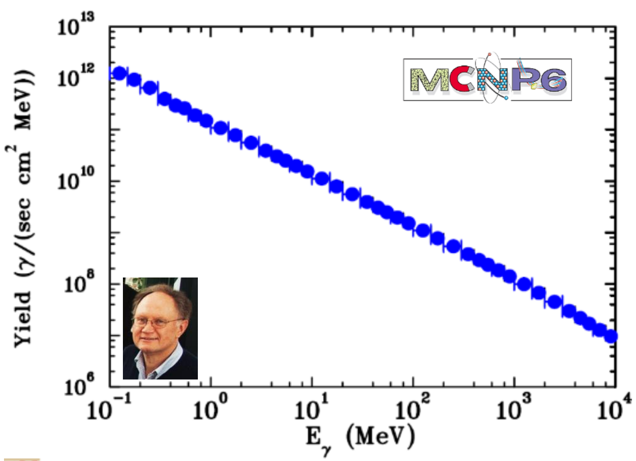


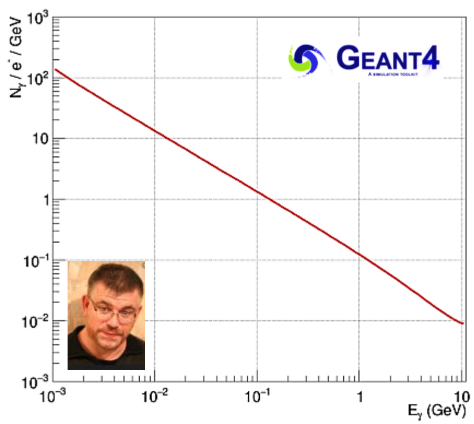
Concrete **walls** are out of scale

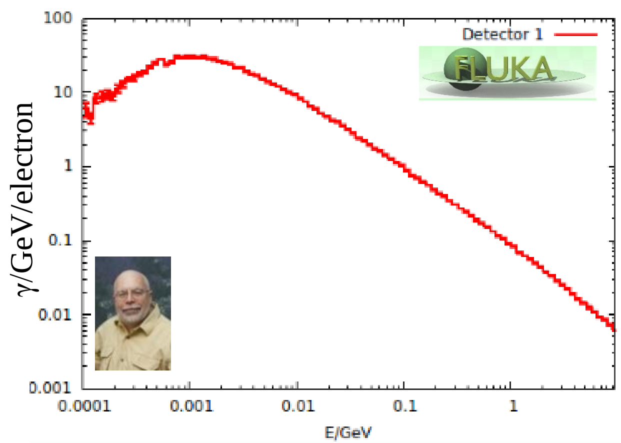
At key area for RadCon on ceiling

Pb & W	**n**: 0.35 ± 0.17 mrem/h γ: 0.078±0.005 mrem/h
Pb & no W	**n**: 0.61 ± 0.25 mrem/h γ: 0.527±0.006 mrem/h

Gammas on face of Be-target



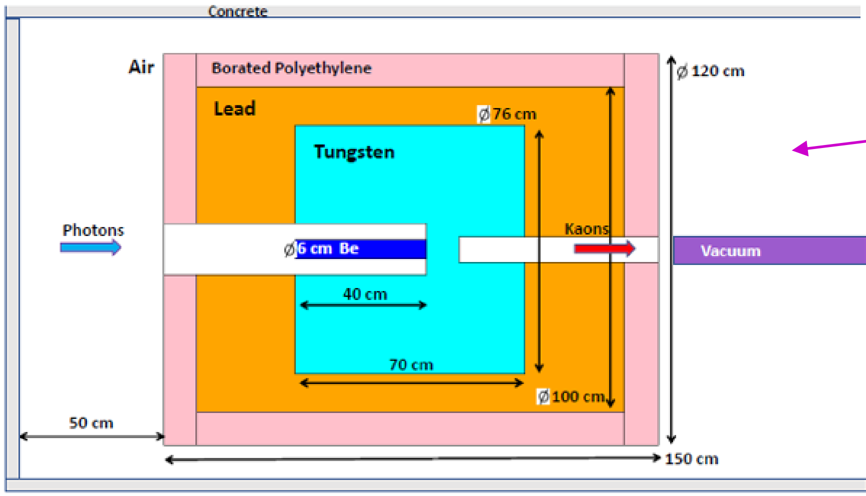




Be-Target Assembly - 3

RadCon limit =1 mrem/h

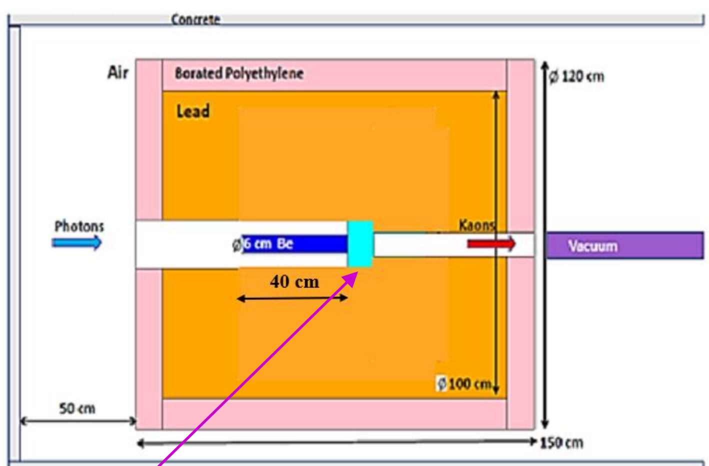
xy-cross section, x-dimension



Concrete **walls** are out of scale

At key area for RadCon on ceiling

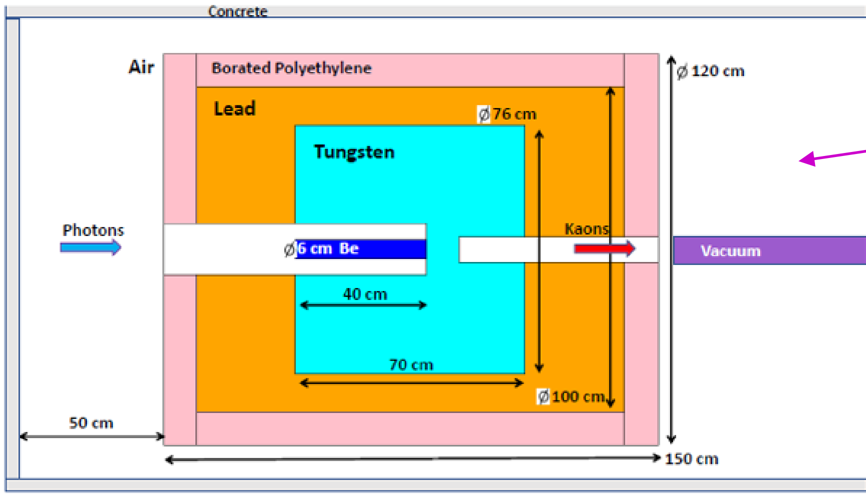
Pb & W	n: 0.35 ± 0.17 mrem/h γ: 0.078±0.005 mrem/h
Pb & no W	n: 0.61 ± 0.25 mrem/h γ: 0.527±0.006 mrem/h
Pb & W-plug	n: 0.27 ± 0.08 mrem/h γ: 0.065±0.002 mrem/h



W-plug
16 cm in **diam**
10 cm in **length**

RadCon limit =1 mrem/h

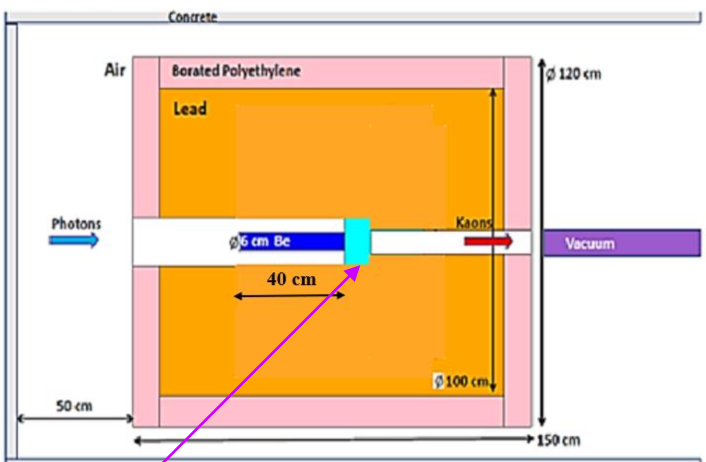
xy-cross section, x-dimension



Concrete **walls** are out of scale

At key area for RadCon on ceiling

Pb & W	**n**: 0.349±0.172 mrem/h γ: 0.078±0.005 mrem/h
Pb & no W	**n**: 0.614±0.246 mrem/h γ: 0.527±0.006 mrem/h
Pb & W-plu	**n**: 0.273±0.083 mrem/h γ: 0.065±0.002 mrem/h



W-plug
16 cm in diam
10 cm in length

- Increasing **plug diam** will increase **n** background.
- Increasing **plug length** will reduce **kaon** flux.

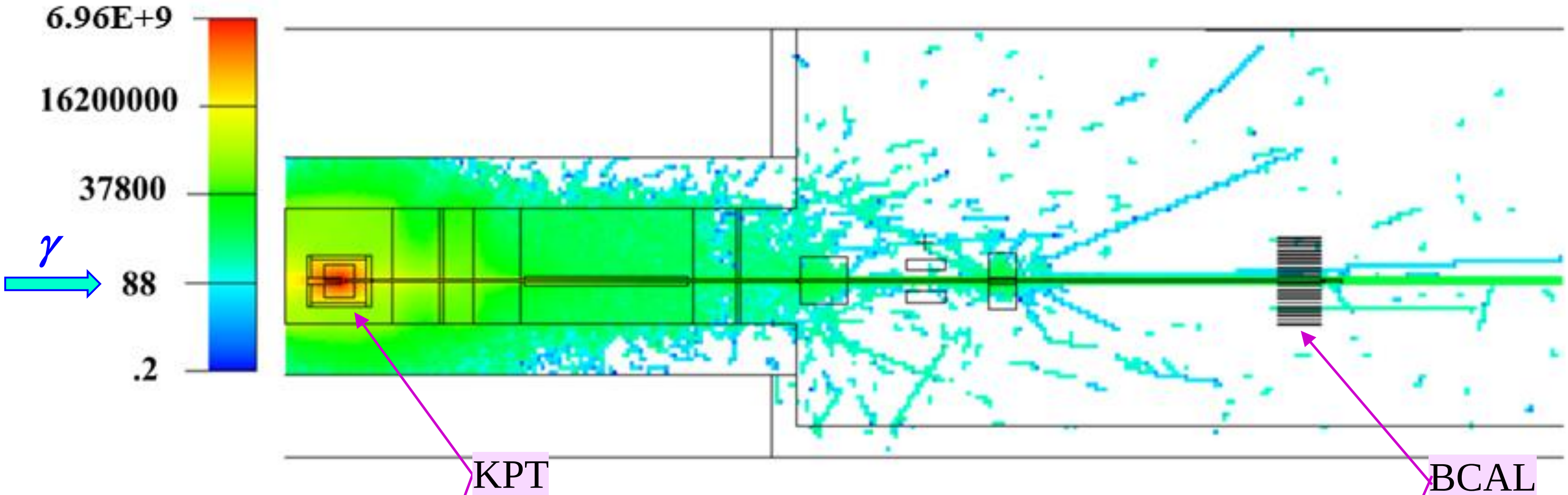
24 cm in diam:	**n**: 0.77 ± 0.33 mrem/h γ: 0.074±0.002 mrem/h
15 cm in length:	**n**: 0.16 ± 0.06 mrem/h γ: 0.003±0.001 mrem/h

Corresponds to lost of 70% of kaons

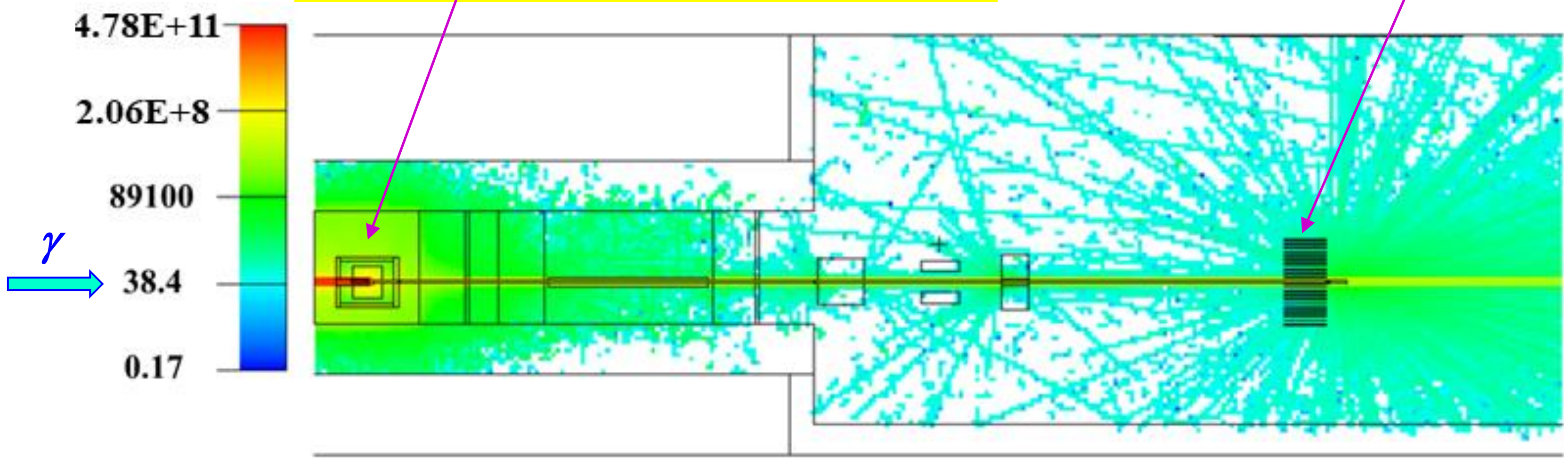
Prompt Dose Rate for Collimator Hall

Prompt Plots

- **Vertical** cross section of **neutron** flux calculated.



- **Vertical** cross section of **gamma** flux calculated.

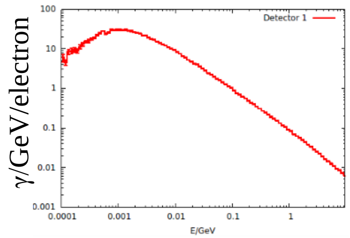


Soft **gammas** from elements of LH_2/LD_2

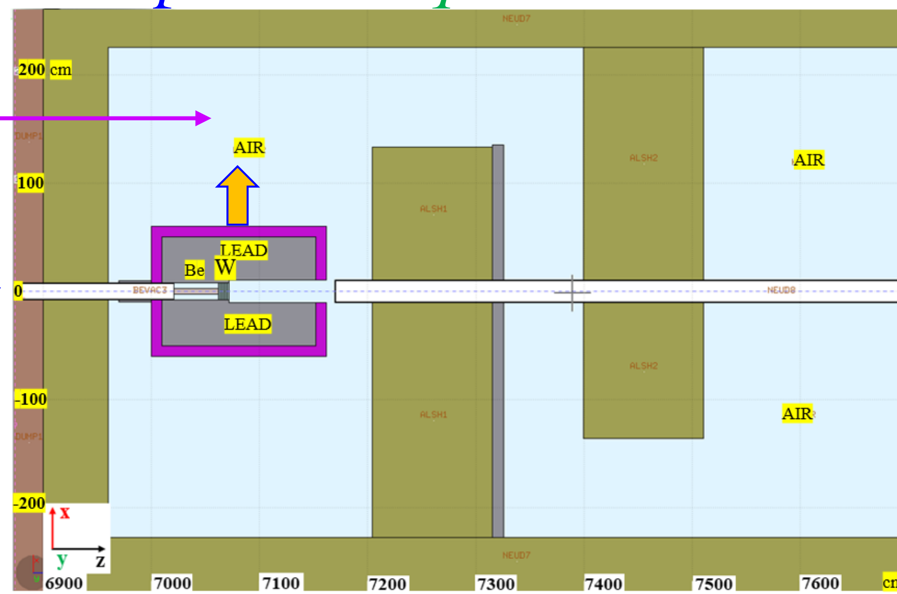
Prompt Dose Equivalent in Collimator Hall

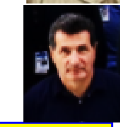
- Collimator Hall has enough space (**4.52** m width) for *KPT* to remain far enough from beamline.

5 μA e^{-} of **12** GeV



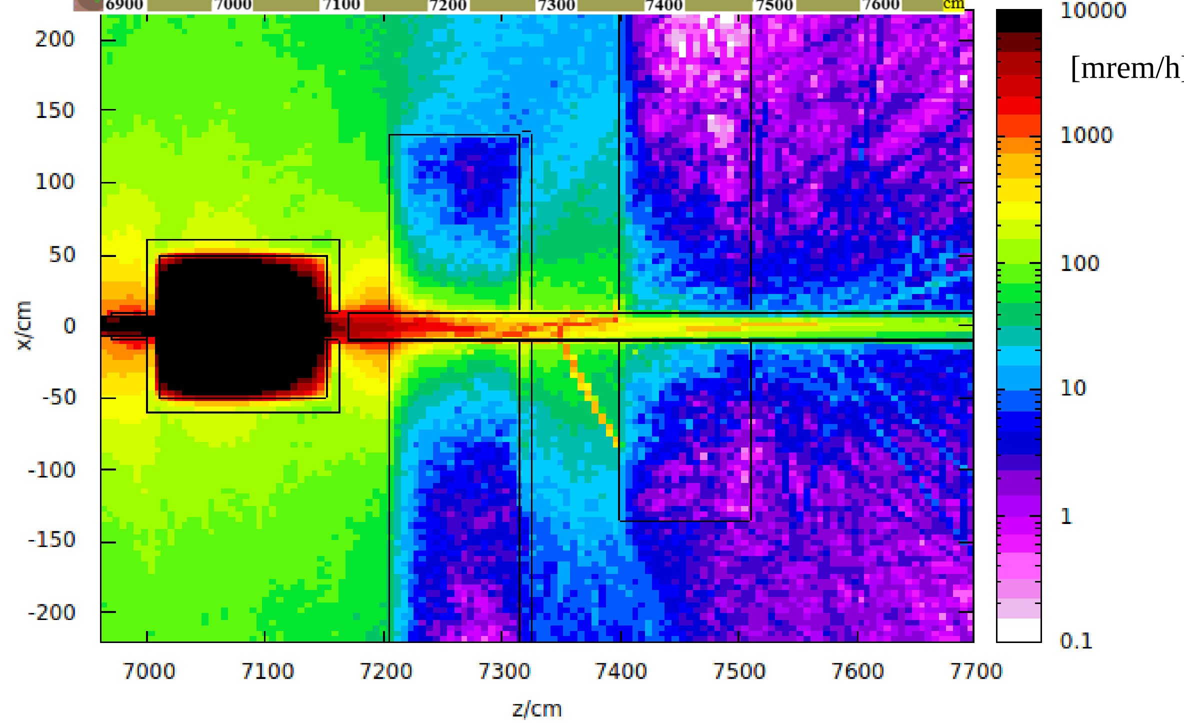
γ





Experimental Hall

γ

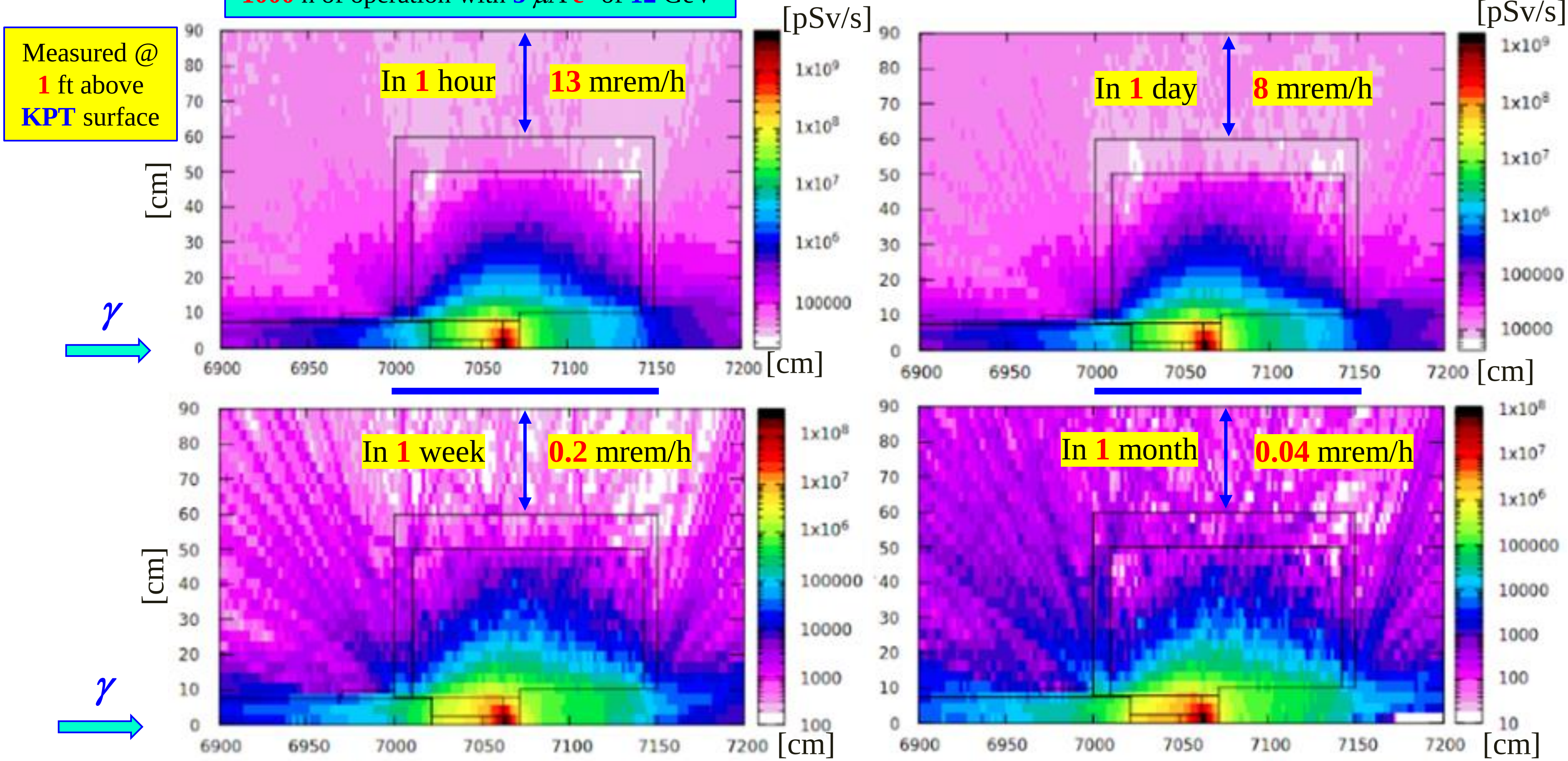


Activation Dose Rate for Collimator Hall

Activation Dose @ KPT

RadCon limit = 1 mrem/h

1000 h of operation with 5 μA e^- of 12 GeV



Equivalent dose:
10^5 pSv/s = 36 mrem/h

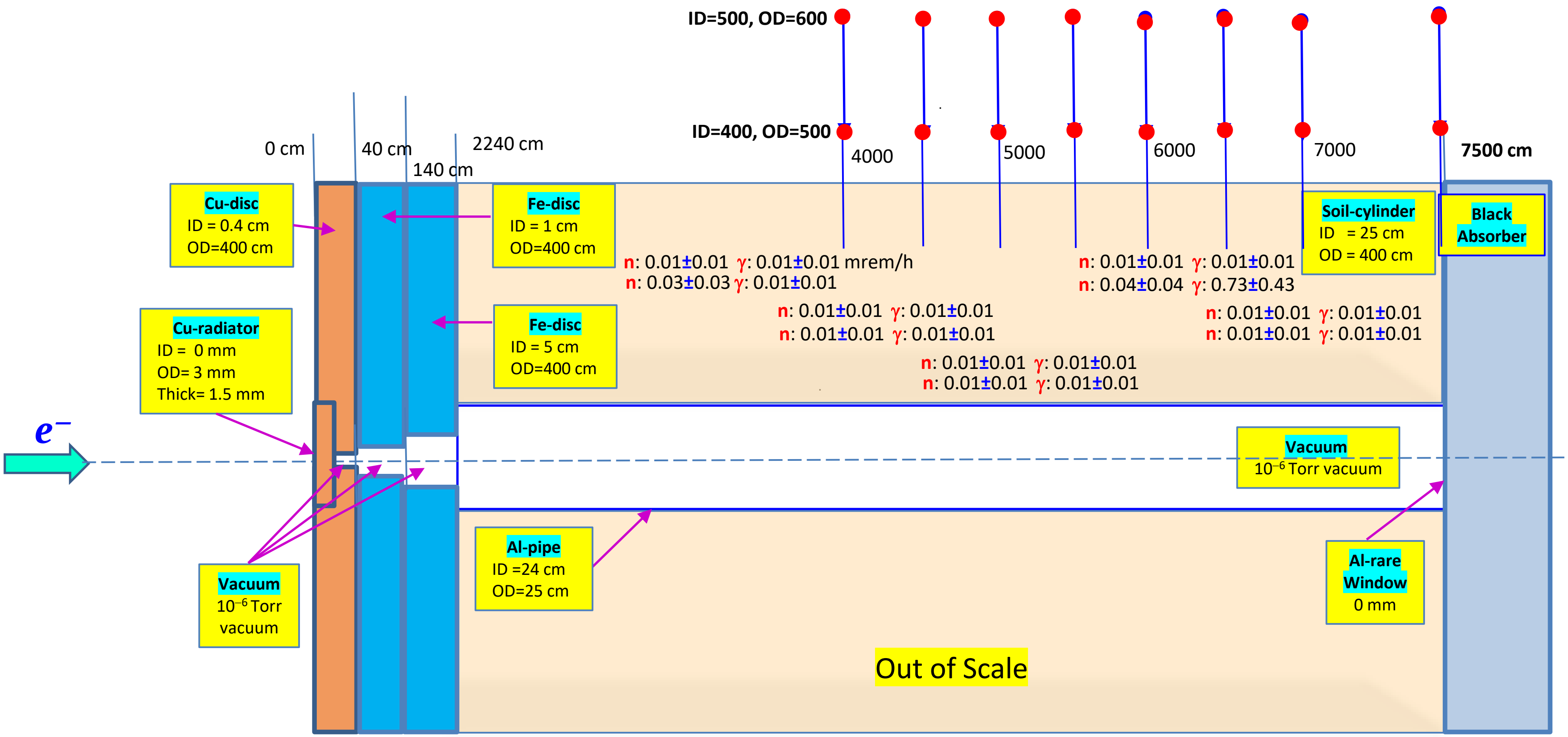
- *Collimator Hall's decommission* requires 1-2 months.
- KPT is kept in *Cave* & moved sideways.
- All other modifications in *Cave* are restored to GlueX.

Radiation Budget above Ground

Radiation Budget on Ground above Tagger Hall

RadCon limit =1 mrem/h

E_γ = **12** GeV I_e = **5** μA
OD_γ = **1** mm
No electrons beyond **Cu**-radiator



- Radiation *above ground from CPS to Cryo target* is under *allowed* limits.

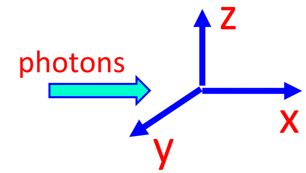

BACKUP

Expected Electron/Photon/Kaon Beam Conditions @ KLF Experiment

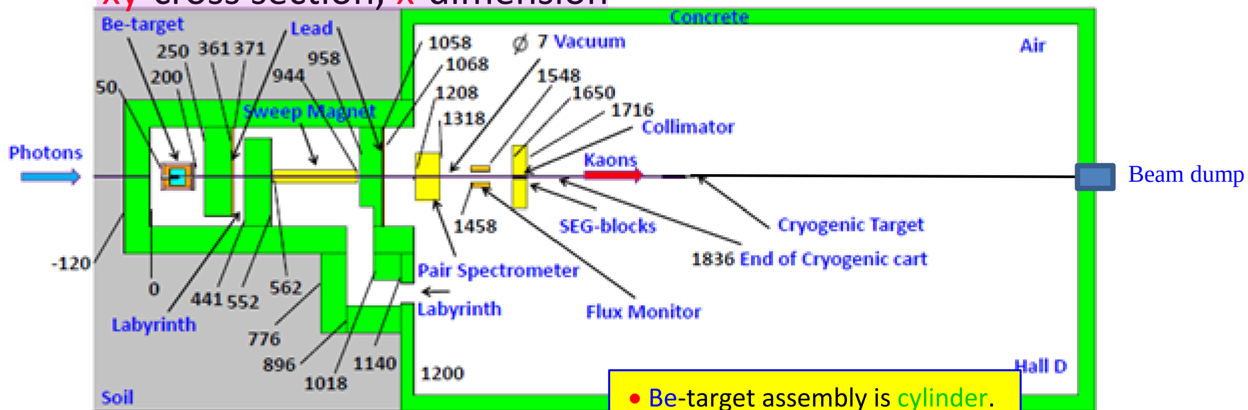
Property	Value
Electron beam current (μA)	5
Electron flux at CPS (s^{-1})	3.1×10^{13}
Photon flux at Be-target $E_\gamma > 1500$ MeV (s^{-1})	4.7×10^{12}
K_L beam flux at cryogenic target (s^{-1})	1×10^4
K_L beam σ_p/p @ 1 GeV/c (%)	$\sim$1.5
K_L beam σ_p/p @ 2 GeV/c (%)	$\sim$5
K_L beam nonuniformity (%)	< 2
K_L beam divergence (°)	< 0.15
$K^0/\overline{K^0}$ ratio at Be-target	2:1
Background neutron flux at cryogenic target (s^{-1})	6.6×10^5
Background γ flux at cryogenic target (s^{-1}), $E_\gamma > 100$ MeV	6.5×10^5

Collimator & Experimental Halls

[29.5 m long x 17.2 m wide]

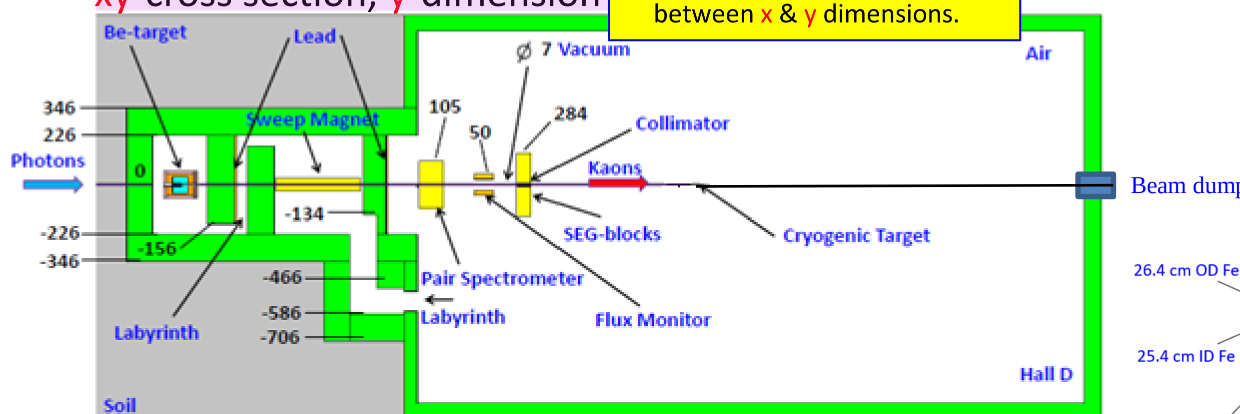


xy-cross section, x-dimension

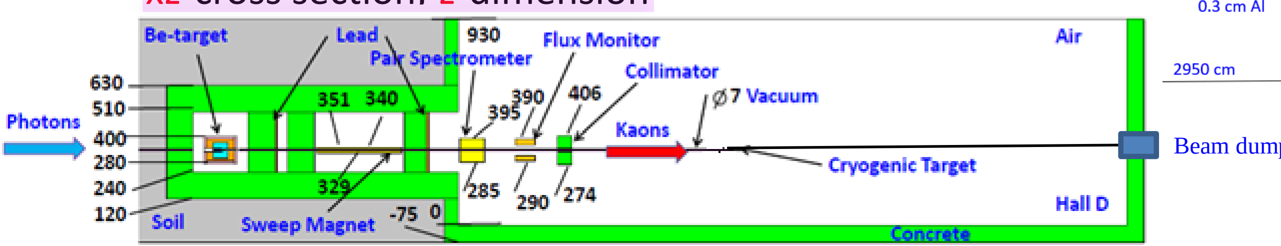


- Be-target assembly is cylinder. Then there is no difference between x & y dimensions.

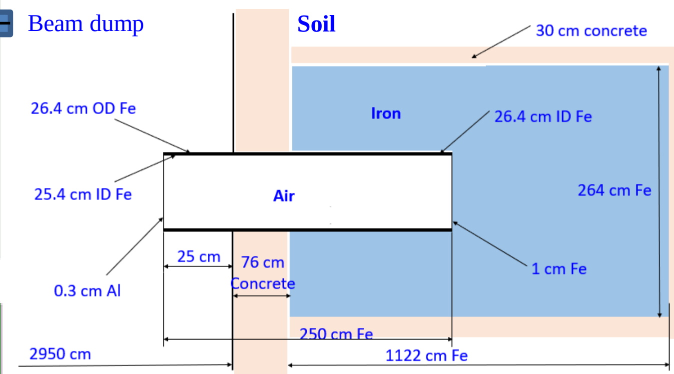
xy-cross section, y-dimension



xz-cross section. z-dimension



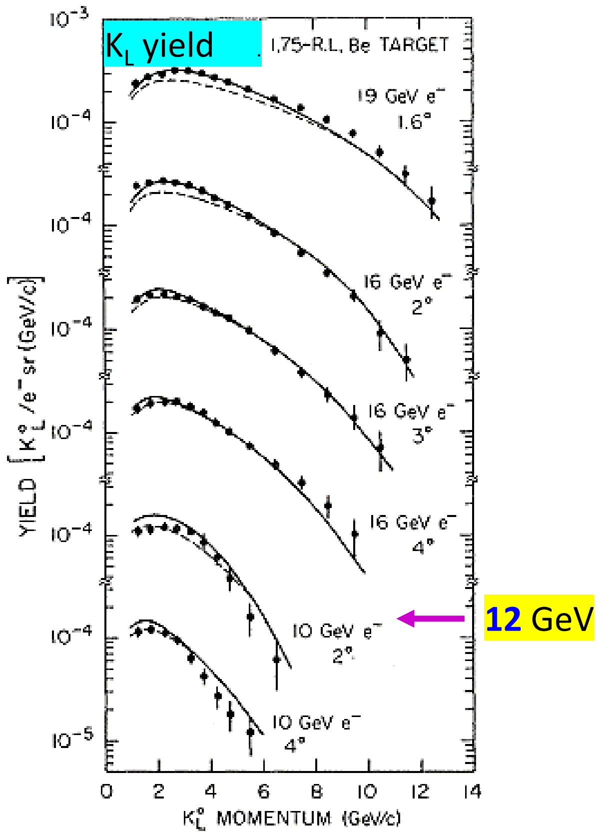
Beam dump



Why Be was Selected for KPT

RadCon limit = 1 mrem/h

- Previous SLAC studies shown that **Be** is optimal material for kaon photoproduction.



G.W. Brandenburg *et al*, Phys Rev D **7**, 708 (1973)

- GEANT4 calculations show efficiency of **Be** vs **C**.

Kaon yield ~ $X_0 * \rho$ & Ratio(C/Be) = (65/43) = **0.7**

- MCNP6 calculations show that **Be** reduces yield of **n**.

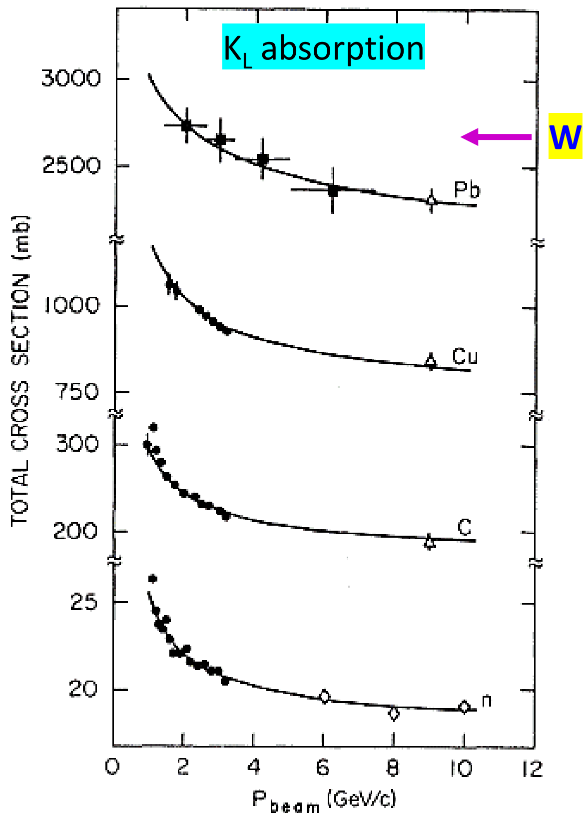
At key area for RadCon on ceiling
Be: n: 0.27 ± 0.08 mrem/h γ: 0.065±0.002 mrem/h
C: n: 0.40 ± 0.20 mrem/h γ: 0.080±0.002 mrem/h

R(C/Be)=1.5

Why W was Selected for Plug

RadCon limit =1 mrem/h

- Previous SLAC studies shown that **W** has low absorption factor for **K_L**.



G.W. Brandenburg *et al*, Phys Rev D **7**, 708 (**1973**)

- GEANT4 calculations show efficiency of **W** vs **Cu**.

Kaon: W/Cu(20%) = **1.2** @ **P_k** = **1.0** GeV/c
= **1.4** @ **P_k** = **0.5** GeV/c

- MCNP6 calculations show that **W**-plug reduces yield for **n** & **γ**.

At key area for RadCon on ceiling

W: **n**: 0.27 ± 0.08 mrem/h
γ: 0.065±0.002 mrem/h

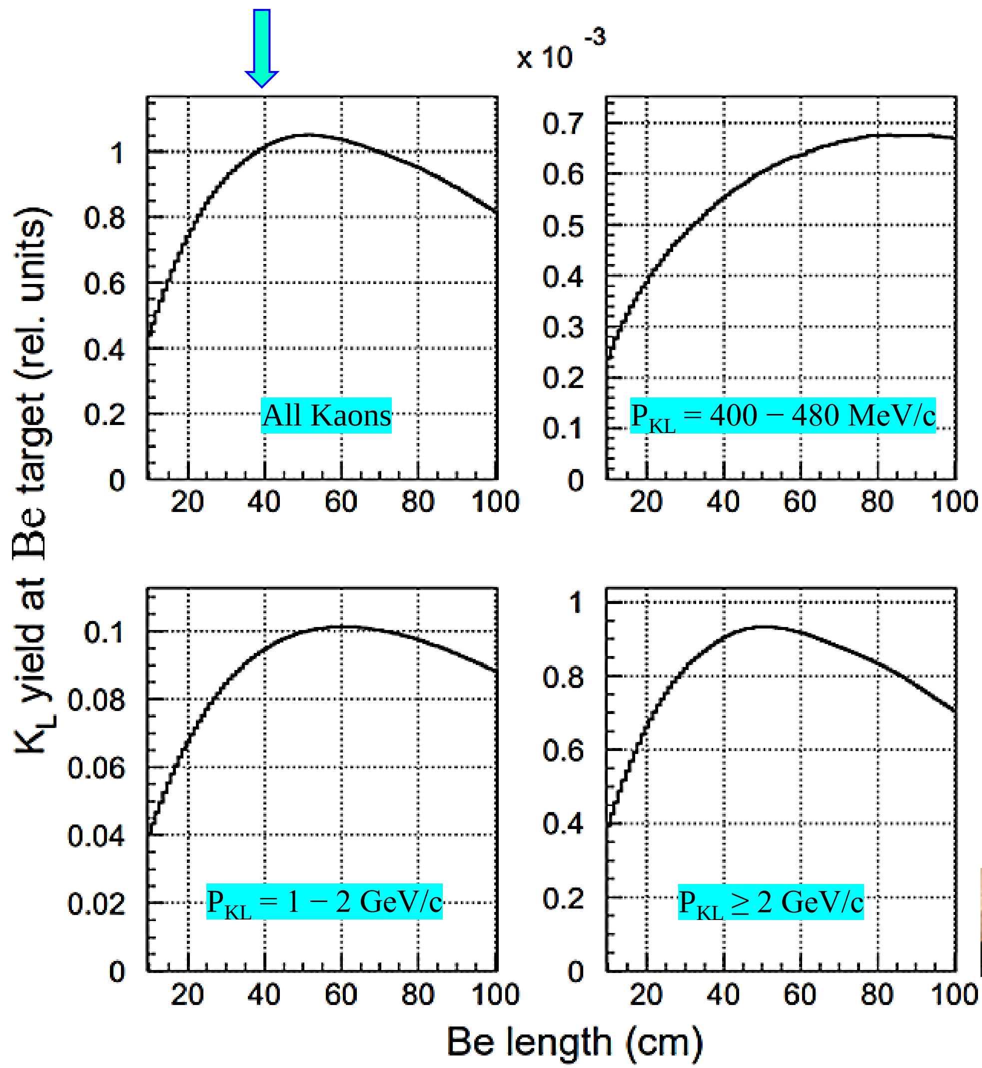
Pb: **n**: 0.61 ± 0.25 mrem/h
γ: 0.527±0.006 mrem/h

R(Pb/W)=2.3

Cu: **n**: 2.54 ± 0.39 mrem/h
γ: 4.34 ± 0.02 mrem/h

R(Cu/W)=9.4

Optimization of Be Target Length



- Yield of kaons from **W**-plug was estimated to be negligible, well below **1%** of kaons produced in **Be**-target.