

Be-Target Assembly Conceptual Design: Progress & Plans

Igor Strakovsky

The George Washington University
(for KLF Collaboration)



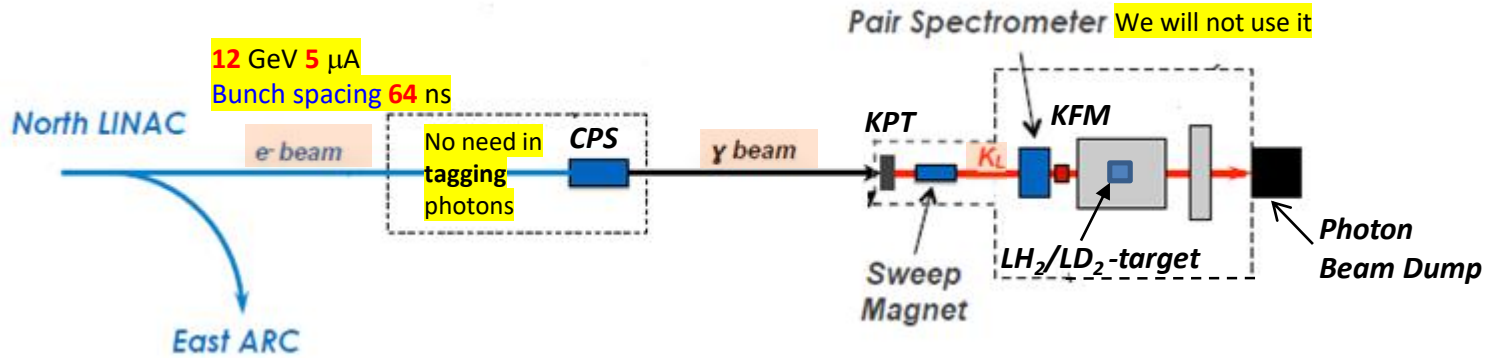
- Hall D beam line for .
- Hall D setting.
-  radiation transport code.
- KPT & Plug materials.
- Be-target assembly.
- Biological dose rate for n & γ .
- Muon background.
- Where we are now & where to go.





Hall D Beam Line for K-long

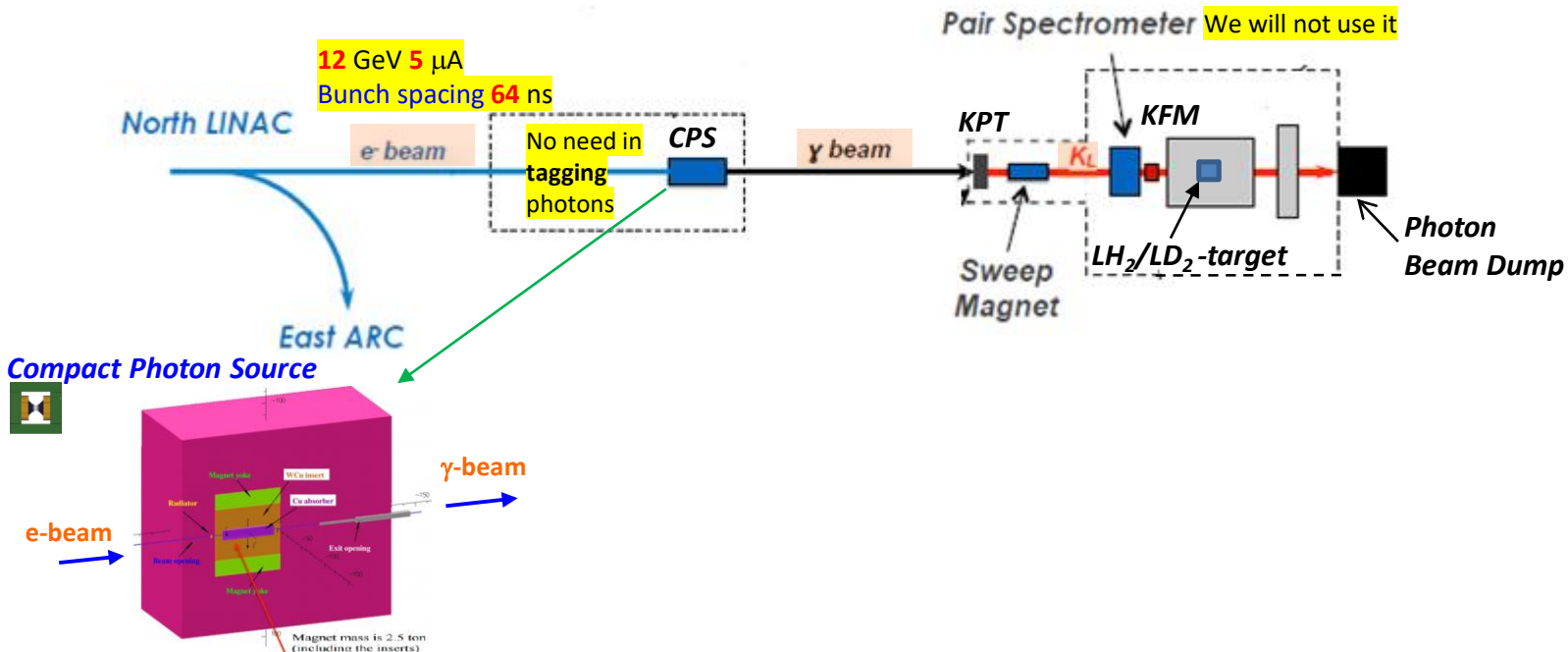
- Electrons (3.1×10^{13} e/sec) are hitting Cu-radiator @ CPS located in Tagger alcove.



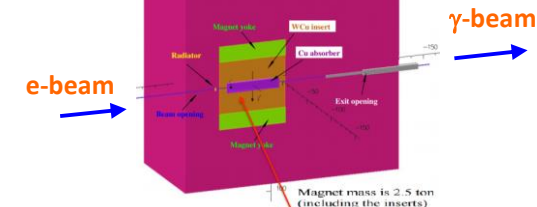


Hall D Beam Line for K -long

- Electrons (3.1×10^{13} e/sec) are hitting Cu-radiator @ CPS located in Tagger alcove.
- Photons (4.7×10^{12} γ /sec @ $E > 1.5$ GeV) are hitting Be-target located in collimator alcove.

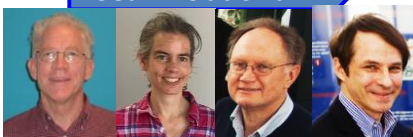


Compact Photon Source



D. Day et al, Nucl Ins Meth, A 957, 163429 (2020)

Sean Dobb's Talk



2/10/2020

KLF-2020, Newport News, Virginia, February 2020

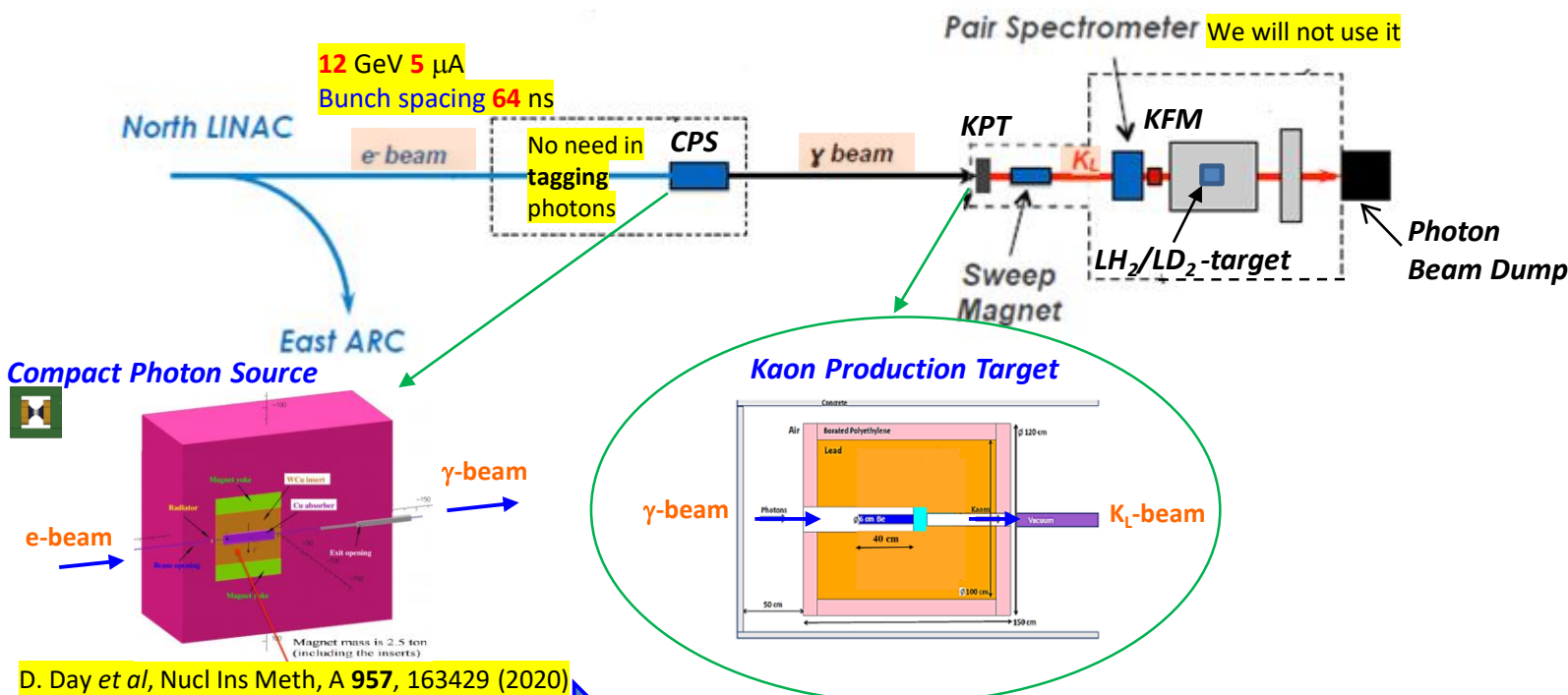
Igor Strakovsky 3





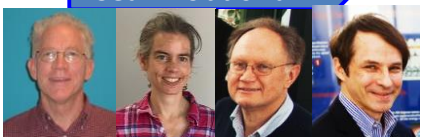
Hall D Beam Line for K-long

- Electrons (3.1×10^{13} e/sec) are hitting Cu-radiator @ CPS located in Tagger alcove.
- Photons (4.7×10^{12} γ /sec @ $E > 1.5$ GeV) are hitting Be-target located in collimator alcove.
- K_L s (1×10^4 K_L /sec) are hitting LH_2/LD_2 target within GLueX setting.



D. Day et al, Nucl Ins Meth, A 957, 163429 (2020)

Sean Dobb's Talk



2/10/2020

KLF-2020, Newport News, Virginia, February 2020

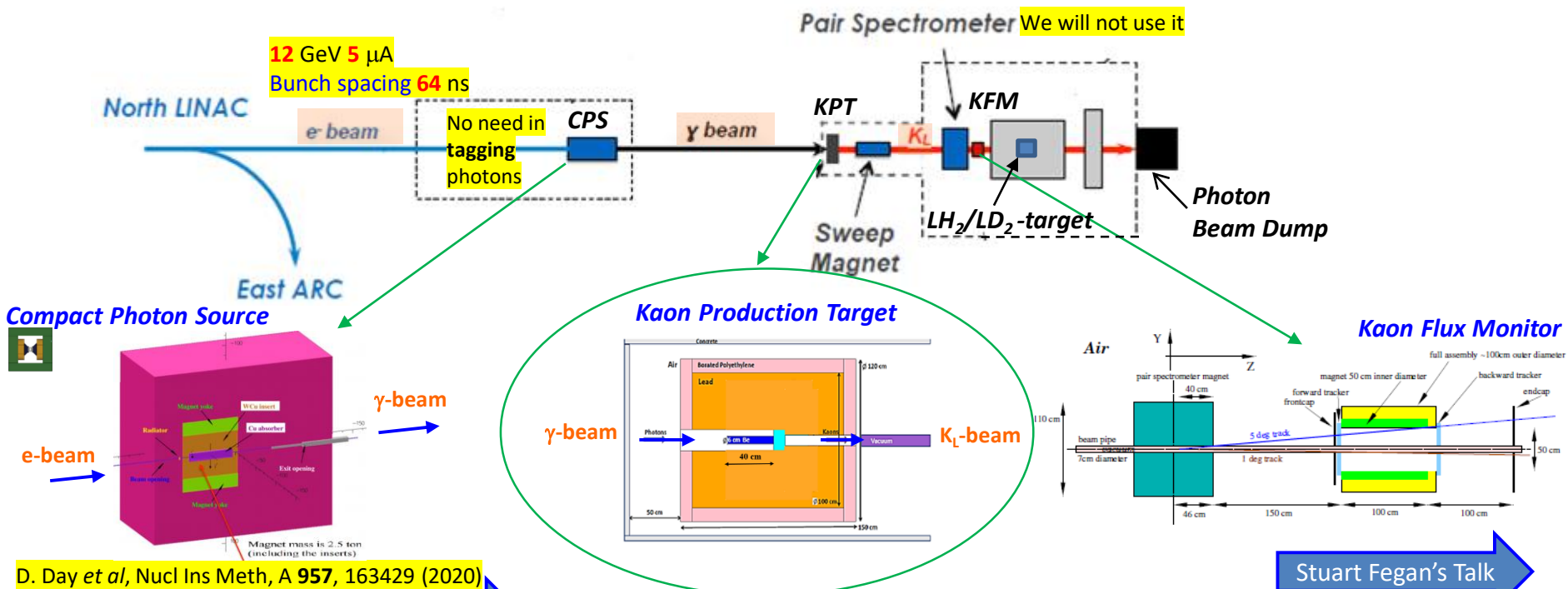
Igor Strakovsky 4





Hall D Beam Line for K-long

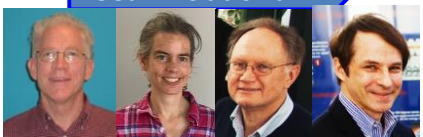
- Electrons (3.1×10^{13} e/sec) are hitting Cu-radiator @ CPS located in Tagger alcove.
- Photons (4.7×10^{12} γ /sec @ $E > 1.5$ GeV) are hitting Be-target located in collimator alcove.
- K_L s (1×10^4 K_L /sec) are hitting LH_2/LD_2 target within GLueX setting.



D. Day et al, Nucl Ins Meth, A 957, 163429 (2020)

Sean Dobb's Talk

Stuart Fegan's Talk



2/10/2020

KLF-2020, Newport News, Virginia, February 2020

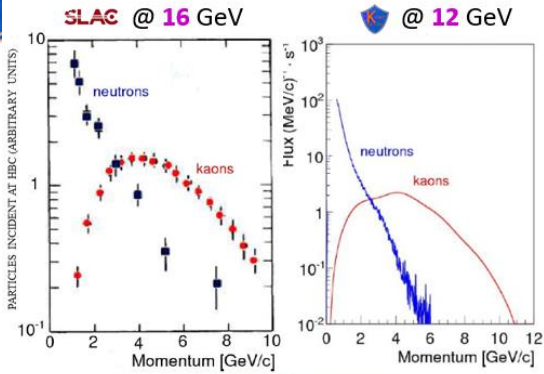
Igor Strakovsky 5





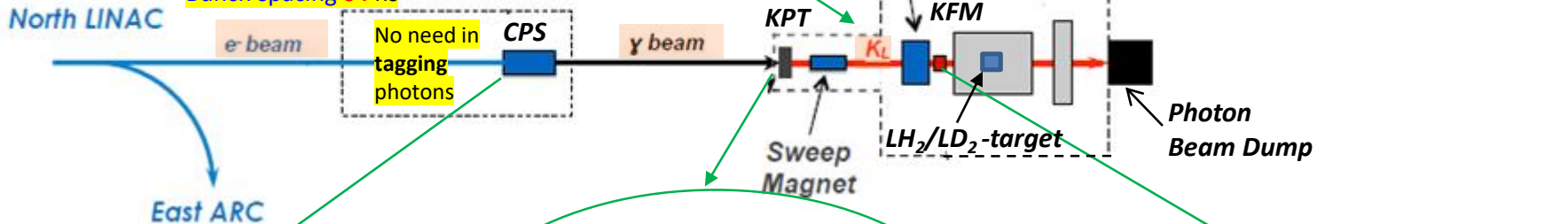
Hall D Beam Line for K-long

- Electrons (3.1×10^{13} e/sec) are hitting Cu-radiator @ CPS located in Tagger alcove.
- Photons (4.7×10^{12} γ /sec @ $E > 1.5$ GeV) are hitting Be-target located in collimator alcove.
- K_L^0 s (1×10^4 K_L^0 /sec) are hitting LH_2/LD_2 target within GLueX setting.

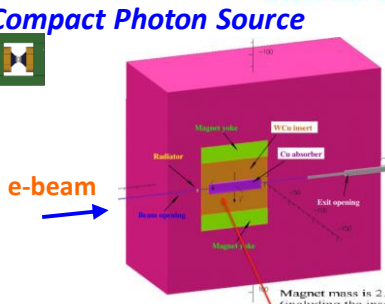
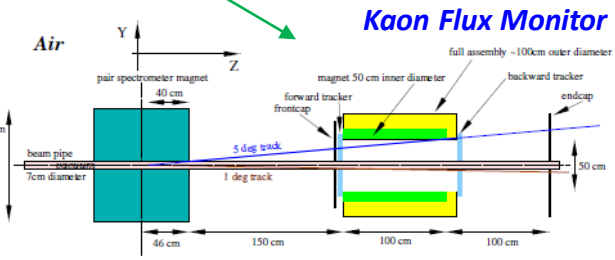
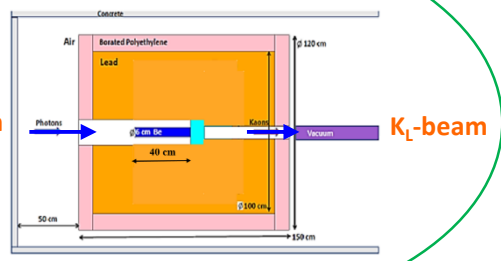


$$\frac{N(K_L^0)_{\text{Jefferson Lab}}}{N(K_L^0)_{\text{SLAC}}} \sim 10^3$$

12 GeV 5 μ A
Bunch spacing 64 ns



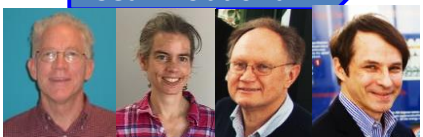
Kaon Production Target



D. Day et al, Nucl Ins Meth, A 957, 163429 (2020)

Sean Dobb's Talk

Stuart Fegan's Talk



2/10/2020

KLF-2020, Newport News, Virginia, February 2020

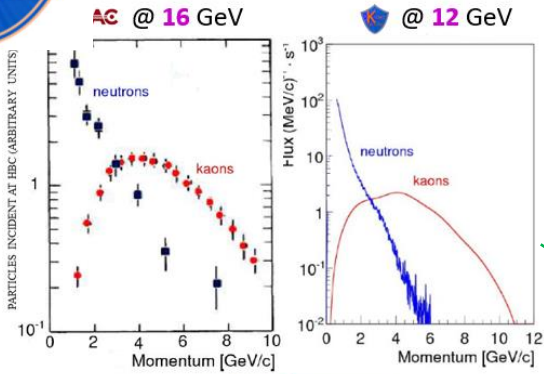
Igor Strakovsky 6





Hall D Beam Line for K-long

- Electrons (3.1×10^{13} e/sec) are hitting Cu-radiator @ CPS located in Tagger alcove.
- Photons (4.7×10^{12} γ /sec @ $E > 1.5$ GeV) are hitting Be-target located in collimator alcove.
- K_L^0 s (1×10^4 K_L^0 /sec) are hitting LH_2/LD_2 target within GLueX setting.



$$\frac{N(K_L^0)_{\text{Jefferson Lab}}}{N(K_L^0)_{\text{SLAC}}} \sim 10^3$$

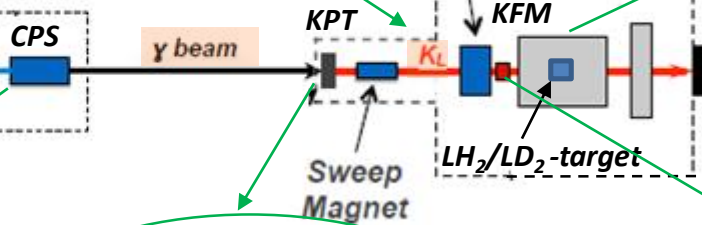
12 GeV 5 μ A
Bunch spacing 64 ns

North LINAC

East ARC

Compact Photon Source

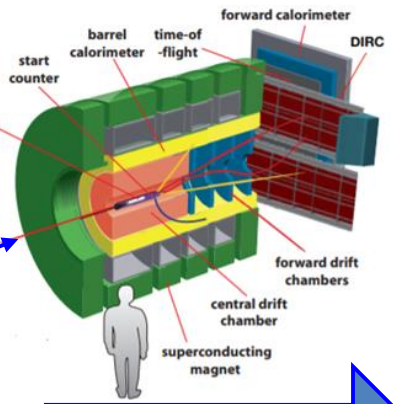
No need in tagging photons



GlueX Spectrometer



Chris Keith's Talk



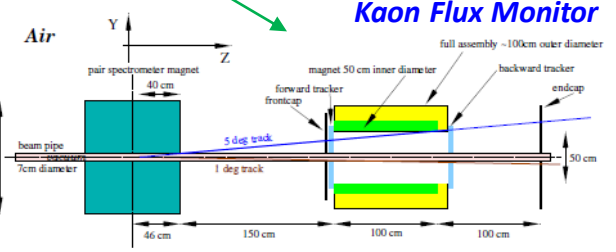
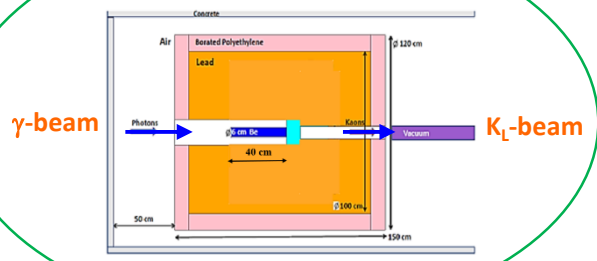
K_L^0 -beam

Pair Spectrometer We will not use it

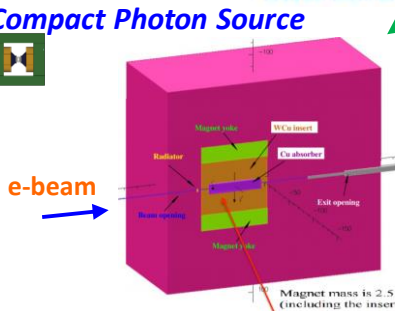
Sergey Furletov's Talk
Sasha Somov's Talk



Kaon Production Target



Kaon Flux Monitor



γ -beam

D. Day et al, Nucl Ins Meth, A 957, 163429 (2020)

Sean Dobb's Talk



2/10/2020

KLF-2020, Newport News, Virginia, February 2020

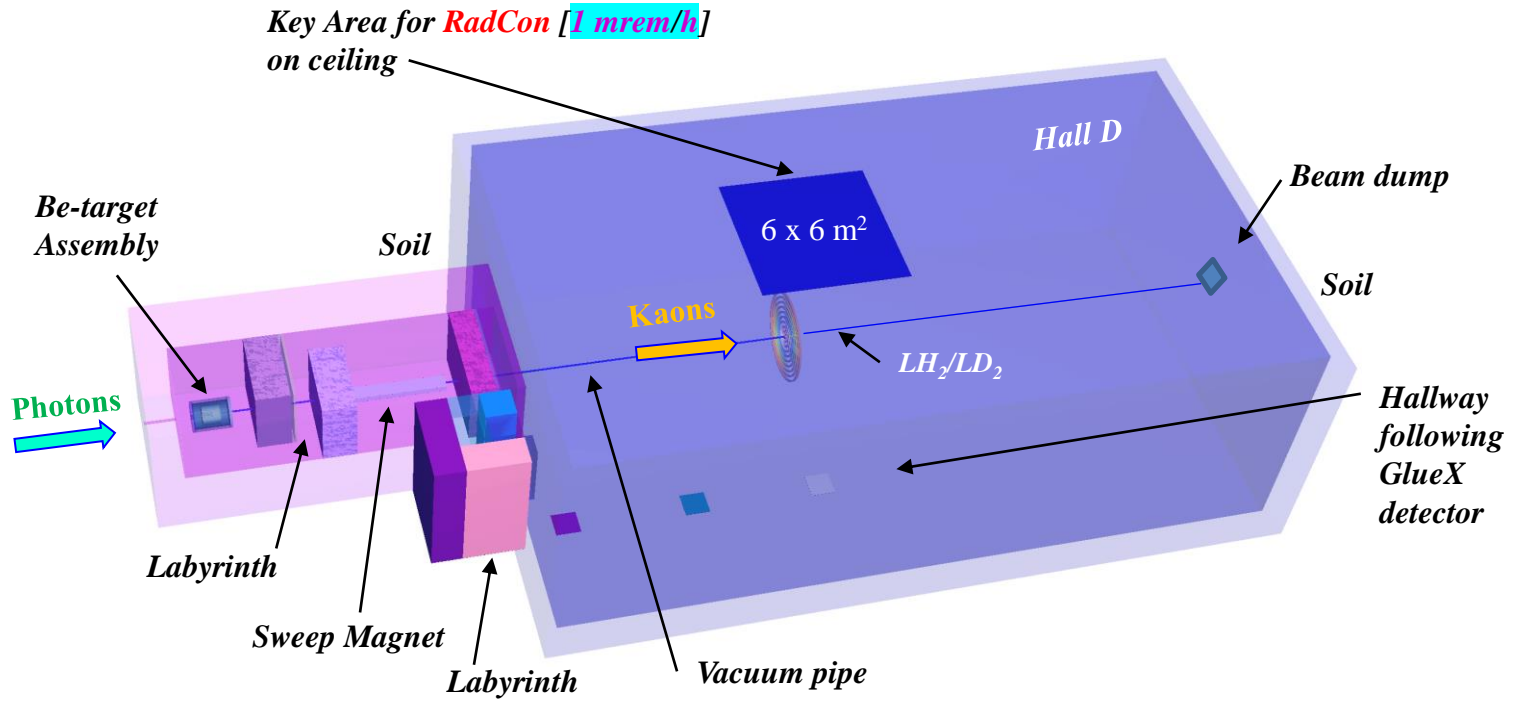
Stuart Fegan's Talk



Igor Strakovsky 7



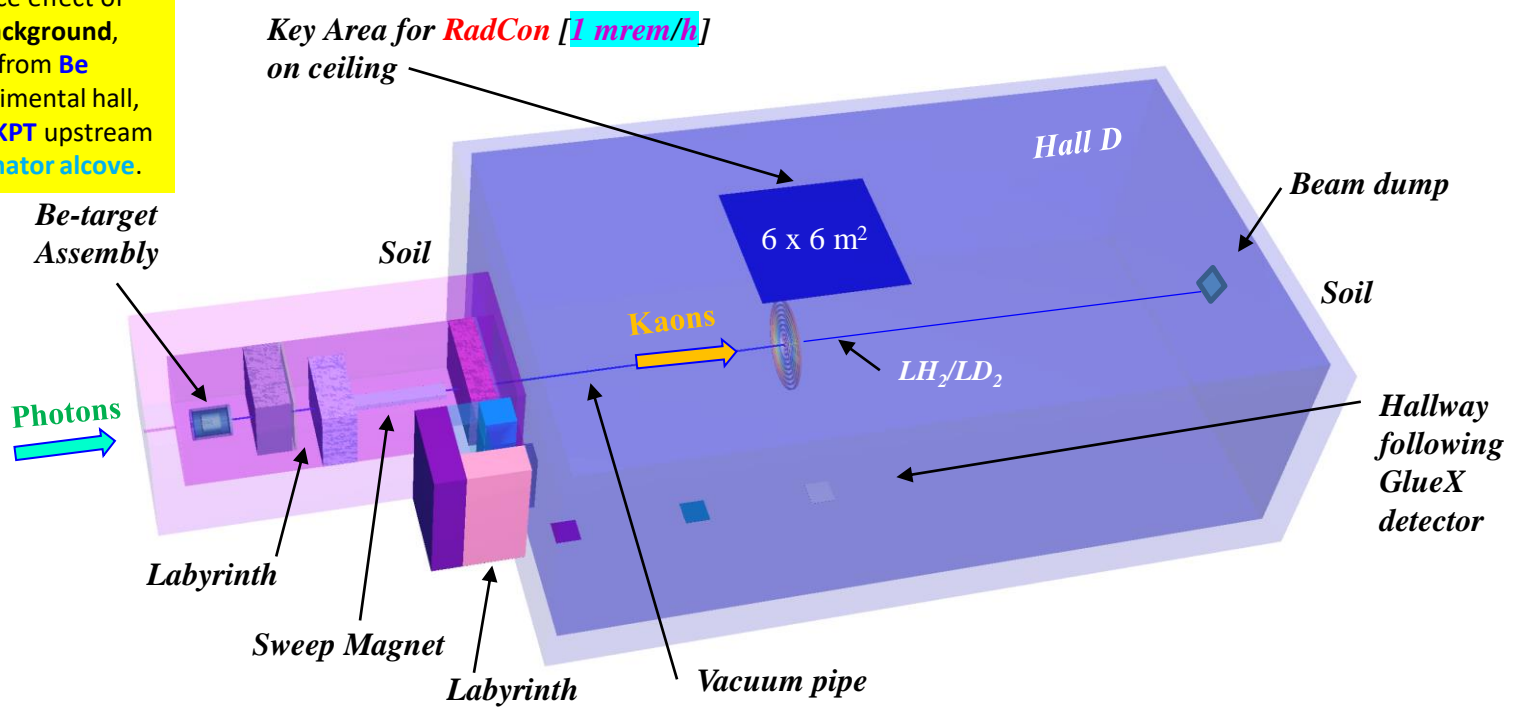
- For **neutron** & **gamma** calculations, we use **MCNP6** radiation transport code.



- Most important & unpleasant **background** for **K_L** comes from **neutrons**.

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

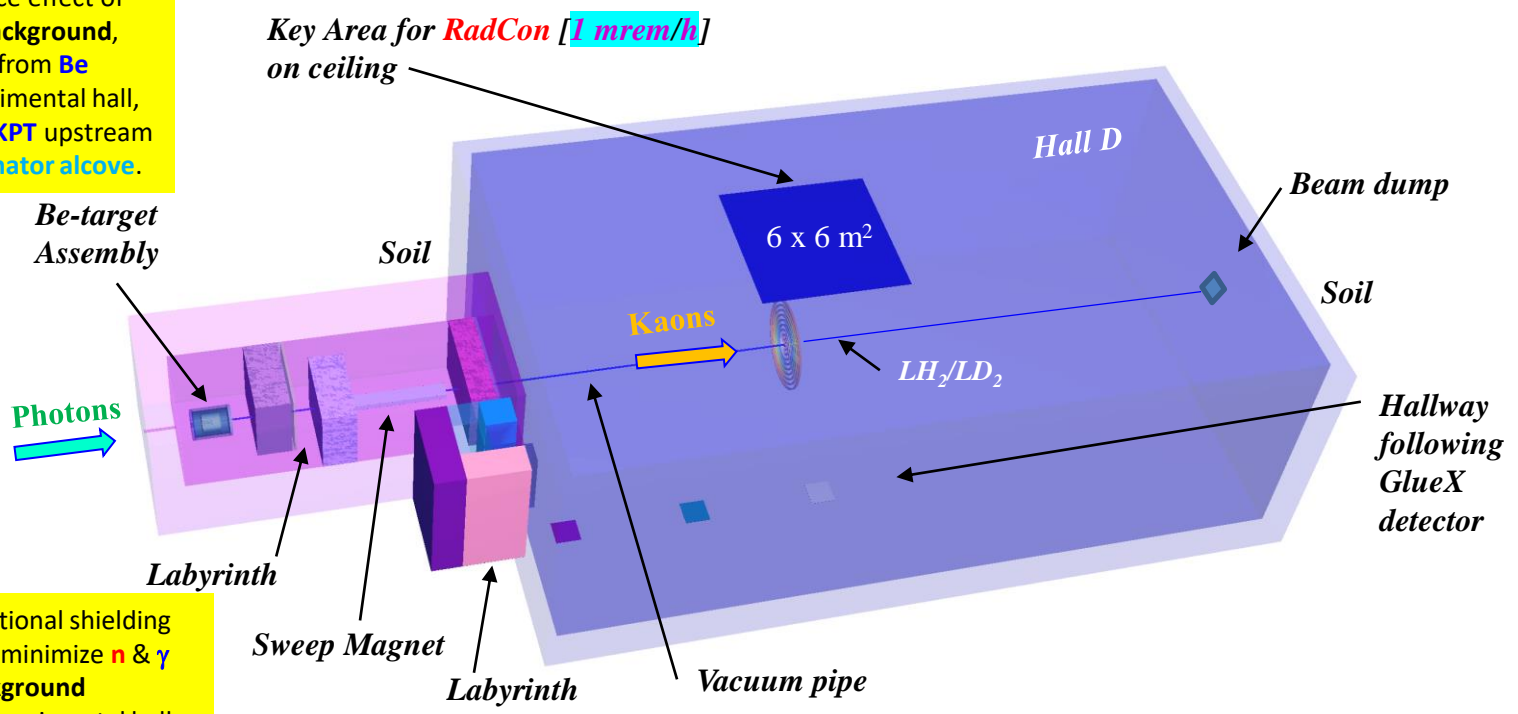
To reduce effect of **n** & **γ** background, coming from **Be** in experimental hall, we put **KPT** upstream in **collimator alcove**.



- Most important & unpleasant **background** for **K_L** comes from **neutrons**.

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

To reduce effect of **n** & **γ** background, coming from **Be** in experimental hall, we put **KPT** upstream in **collimator alcove**.



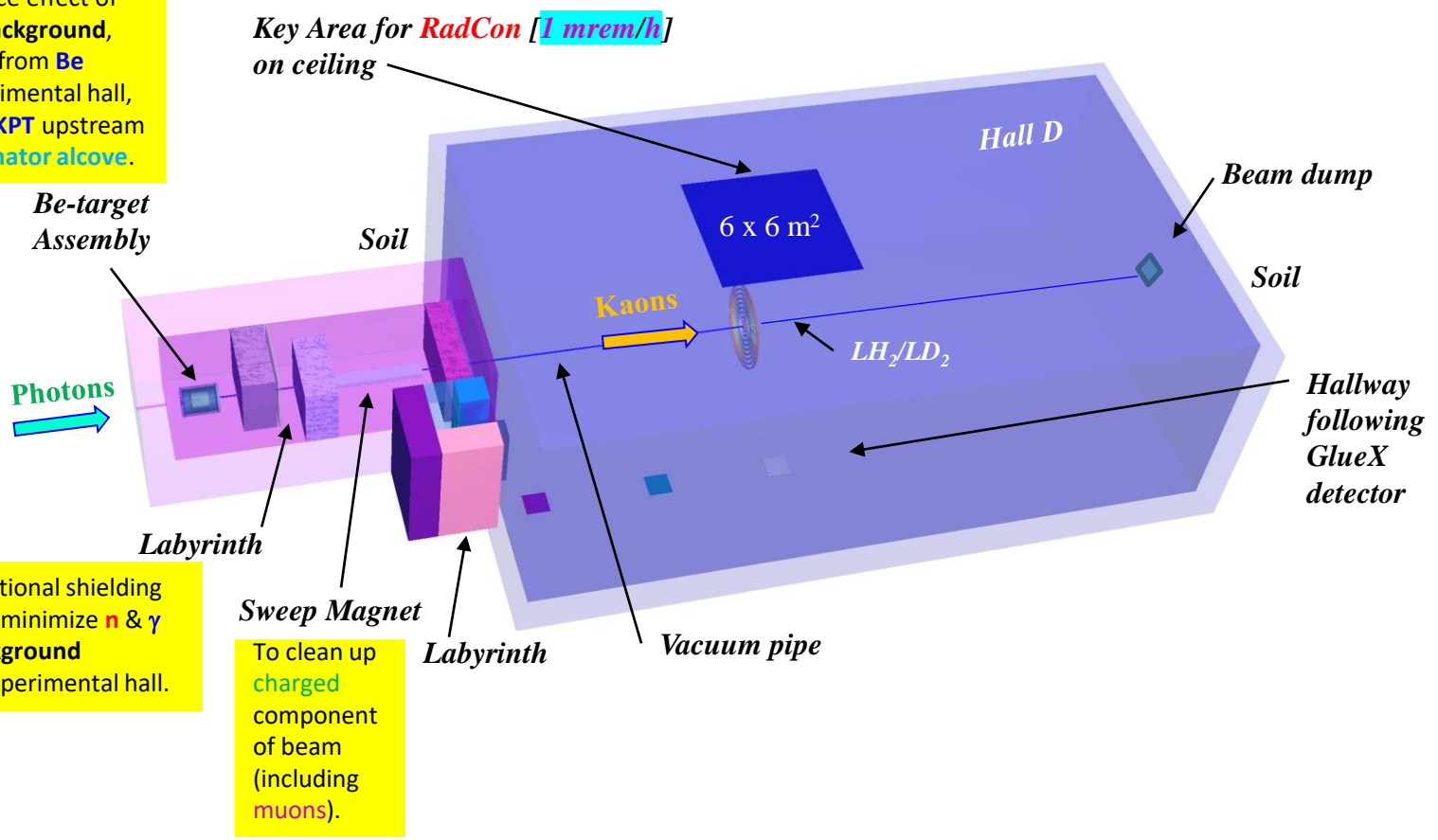
Additional shielding is to minimize **n** & **γ** background in experimental hall.

- Most important & unpleasant **background** for **K_L** comes from **neutrons**.



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

To reduce effect of **n** & **γ** background, coming from **Be** in experimental hall, we put **KPT** upstream in **collimator alcove**.



Additional shielding is to minimize **n** & **γ** background in experimental hall.

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

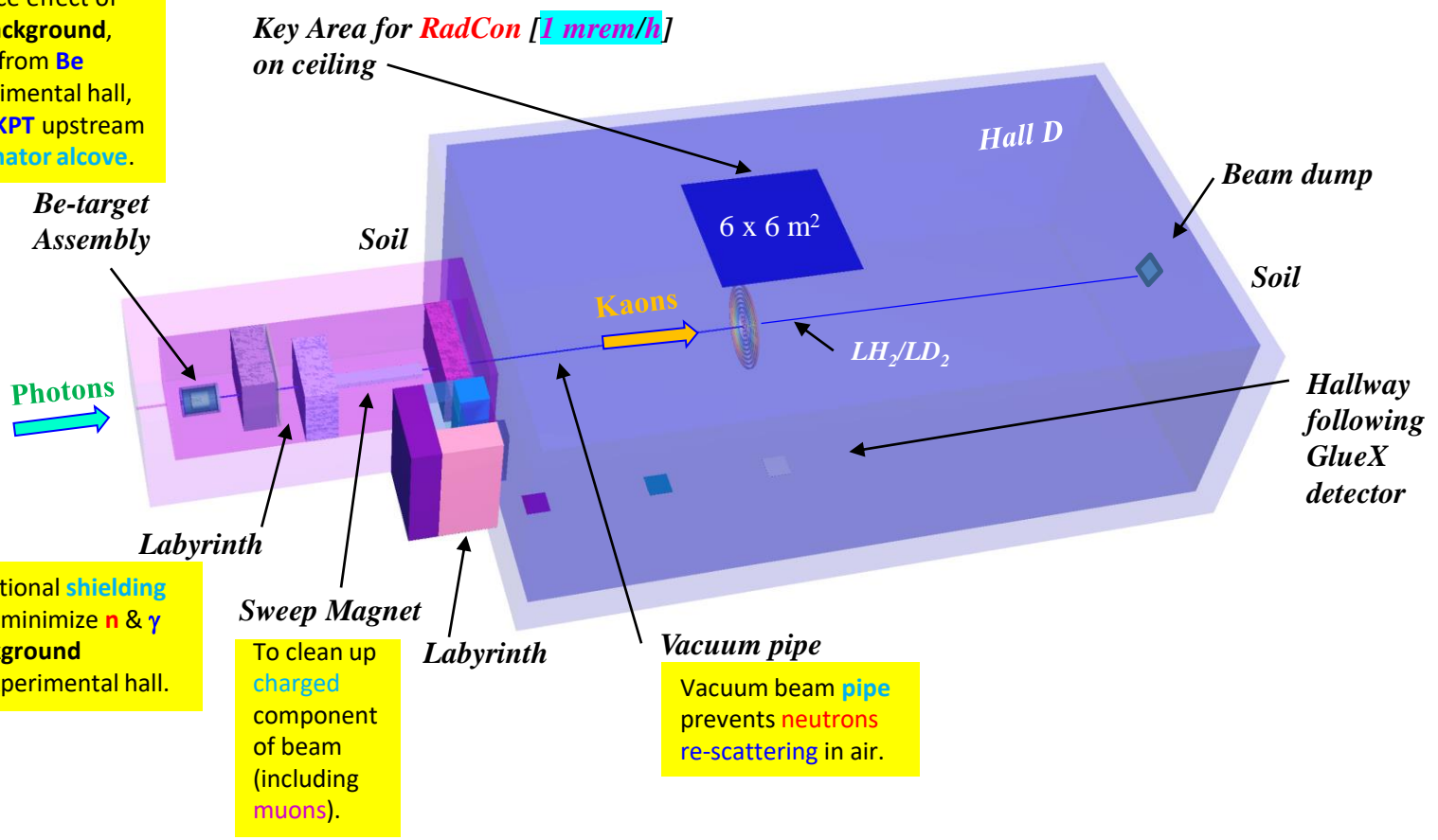
- Most important & unpleasant **background** for **K_L** comes from **neutrons**.





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

To reduce effect of **n** & **γ** background, coming from **Be** in experimental hall, we put **KPT** upstream in **collimator alcove**.



Additional **shielding** is 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.

- Most important & unpleasant **background** for **K_L** comes from **neutrons**.





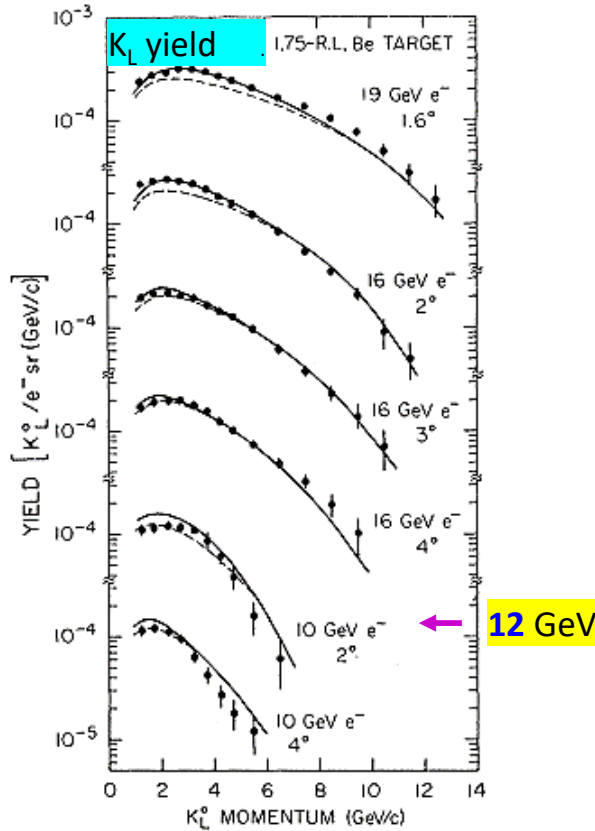
- Realism of  simulations is based on advanced nuclear cross section **libraries** created & maintained in **national laboratories** of  complex.
- Physical models, implemented in  code, take into account
 - *bremsstrahlung* photon production,
 - *photonuclear* reactions,
 - neutron & photon *multiple scattering* processes.
-  model simulates **12 GeV 5 μ A electron** beam hitting **Cu**-radiator inside **CPS**.
- **Electron** transport is traced in **Cu**-radiator, vacuum beam **pipe** for bremsstrahlung photons, **Be**.
- **Neutrons & gammas** is traced in all components of  model.
- **Media** outside concrete walls of collimator *alcove* & bremsstrahlung photon beam *pipe* were excluded from consideration to facilitate calculations. Additionally, we ignore **PS & KFM** magnets but took into account **5 iron**-blocks around beam pipe in front of **GlueX** spectrometer.
- For  calculations (in terms of **flux** [**part/s/cm²/ MeV**] & **biological dose rate** [**mrem/h**]), several **tallies** were placed along beam, collimator alcove, & experimental hall for **neutron & gamma** fluence estimation.





Why Be was Selected for KPT

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



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

- **PYTHIA** calculations show efficiency of **B** vs **C**.
Kaon yield $\sim X_0 * \rho$ & Ratio(Be/C) = (65/43) = **1.51**



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

At key area for RadCon on ceiling

Be: n: 0.27 ± 0.08 mrem/h **R(C/Be)=1.45**

γ : 0.065 ± 0.002 mrem/h

C: n: 0.40 ± 0.20 mrem/h

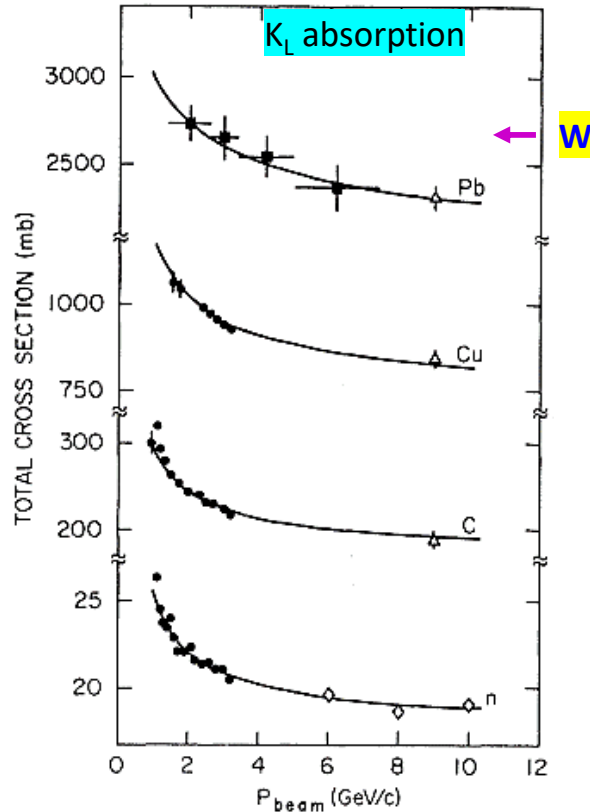
γ : 0.080 ± 0.002 mrem/h





Why W was Selected for Plug

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



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

Kaon: $W/Cu(20\%) = 1.16$ @ $P_k = 1.0$ GeV/c
 $= 1.36$ @ $P_k = 0.5$ GeV/c



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

At key area for RadCon on ceiling

W: $n: 0.27 \pm 0.08$ mrem/h $R(Pb/W)=2.25$ $R(Cu/W)=9.29$
 $\gamma: 0.065 \pm 0.002$ mrem/h

Pb: $n: 0.61 \pm 0.25$ mrem/h
 $\gamma: 0.527 \pm 0.006$ mrem/h

Cu: $n: 2.54 \pm 0.39$ mrem/h
 $\gamma: 4.34 \pm 0.02$ mrem/h

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

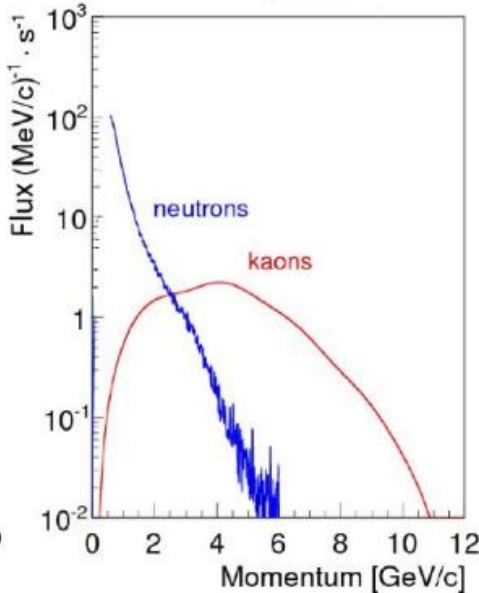
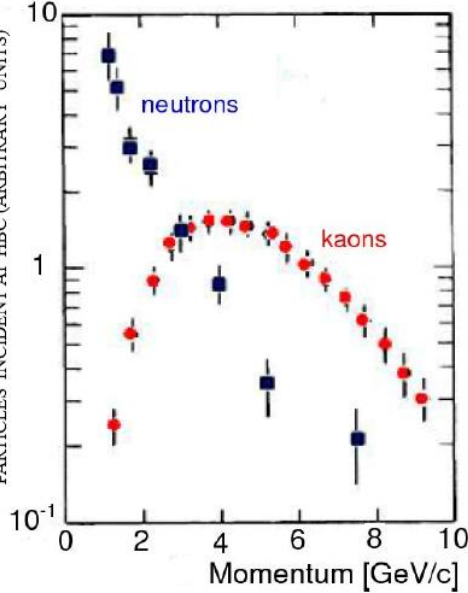




SLAC @ 16 GeV

@ 12 GeV

PARTICLES INCIDENT AT HBC (ARBITRARY UNITS)

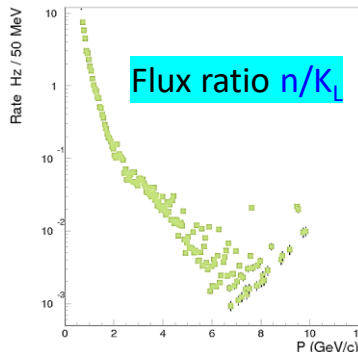


$$\frac{N(K_L)_{\text{Jefferson Lab}}}{N(K_L)_{\text{SLAC}}} \sim 10^3$$



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

- Flux of Kaons will be 1×10^4 K_L /sec on LH_2/LD_2 within GlueX detector, which has large acceptance with coverage of both *charged* & *neutral* particles.
- This flux will allow statistics in case of LH_2/LD_2 to exceed that of earlier SLAC experiments by almost *three orders* of magnitude.
- We simulated Kaon & neutron production from 12 GeV electrons for K^- by PYTHIA & MCNP6 & results are in reasonable agreement with results measured by SLAC @ 16 GeV.



- Delivered with 64 nsec bunch spacing avoids overlap between *neutrons* & *Kaons* in range of $p = 0.35 - 10.0$ GeV/c. *See recent talk by Todd Satogata*



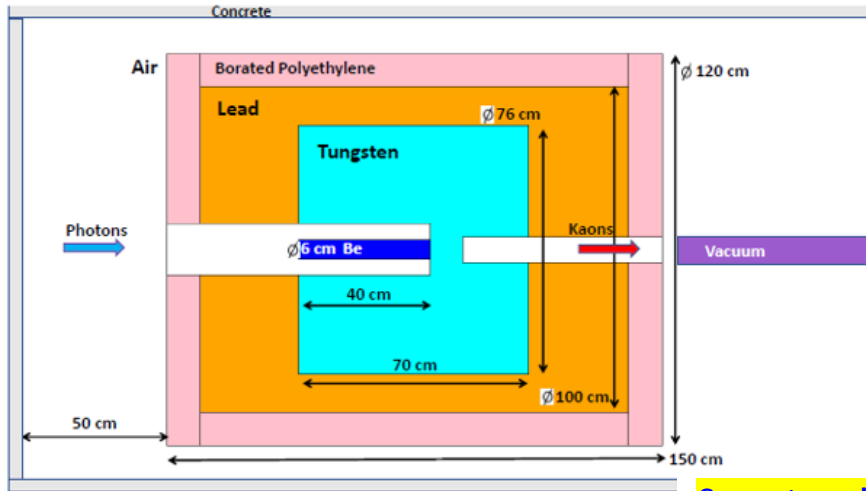
• With proton beam, ratio $n/K_L = 10^3 - 10^4$.





Be-Target Assembly

xy-cross section, x-dimension



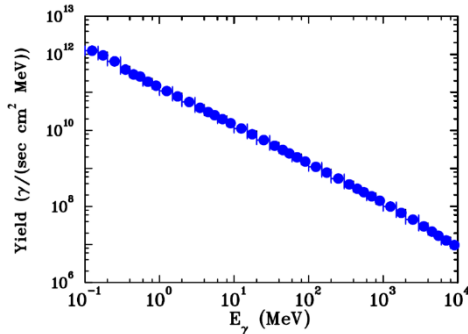
- Be-target assembly will weight **14.5 t**
- Be-target has estimated cost of **\$1.12M**

- **Changeover** from **photon** to **Kaon** beamline & vice versa is expected to take about **half year** or less, & thus should fit well into beam breaks of current CEBAF **schedule**.
- **Collimator alcove** has enough space (with **4.52 m** width) for **Be**-target assembly to remain far enough from beamline.
- **Water Cooling** is available in experimental hall, & is sufficient to dissipate **6 kW** of power delivered by photon beam to **Be**-target & **W**-plug.

$\rho(W) = 16.3 \text{ g/cm}^3$ – Rolf's value

Concrete walls are out of scale

MCNP6: gammas on face of Be-target



At key area for RadCon on ceiling

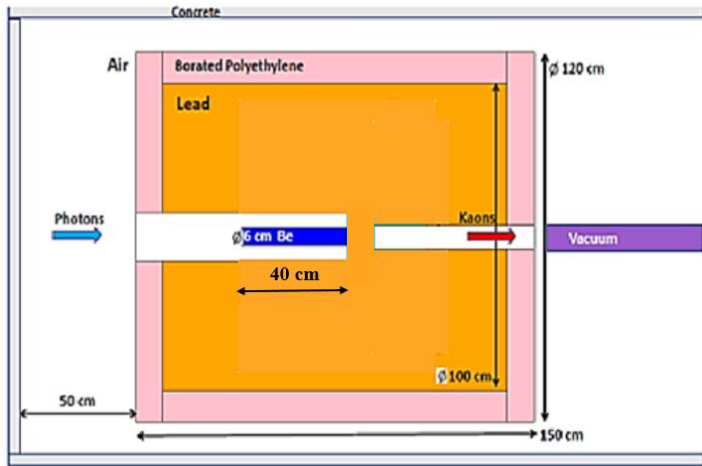
Pb & W n: $0.35 \pm 0.17 \text{ mrem/h}$
 γ: $0.078 \pm 0.005 \text{ mrem/h}$





Be-Target Assembly

xy-cross section, x-dimension



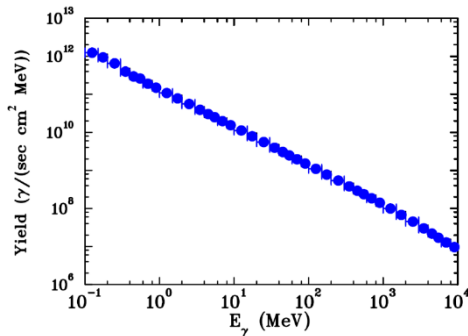
- Be-target assembly will weight **14.5 t**
- Be-target has estimated cost of **\$1.12M**

- Changeover from **photon** to **Kaon** beamline & vice versa is expected to take about **half year** or less, & thus should fit well into beam breaks of current CEBAF **schedule**.
- **Collimator alcove** has enough space (with **4.52 m** width) for **Be-target** assembly to remain far enough from beamline.
- **Water Cooling** is available in experimental hall, & is sufficient to dissipate **6 kW** of power delivered by photon beam to **Be-target** & **W-plug**.

$\rho(W) = 16.3 \text{ g/cm}^3$ – Rolf's value

Concrete walls are out of scale

MCNP6: gammas on face of Be-target



At key area for RadCon on ceiling

Pb & W n: 0.35 ± 0.17 mrem/h
 γ : 0.078 ± 0.005 mrem/h

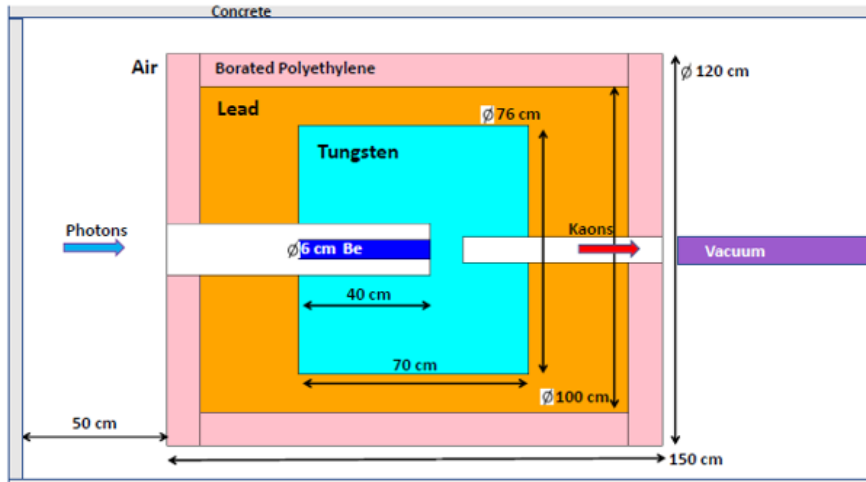
Pb & no W n: 0.61 ± 0.25 mrem/h
 γ : 0.527 ± 0.006 mrem/h





Be-Target Assembly

xy-cross section, x-dimension

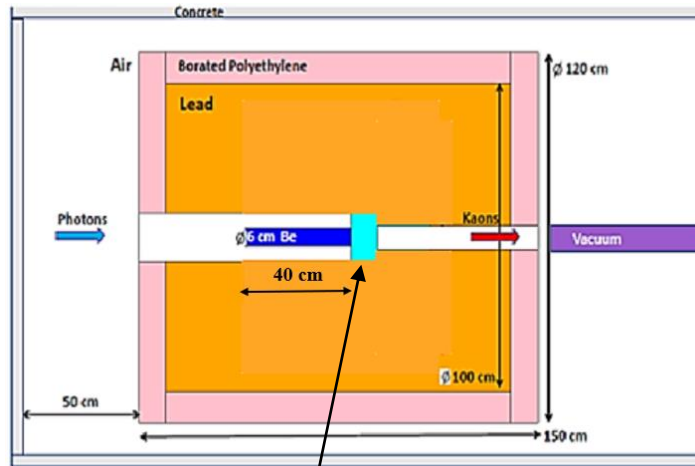


- Be-target assembly will weight **14.5 t**
- Be-target has estimated cost of **\$1.12M**

- Changeover from **photon** to **Kaon** beamline & vice versa is expected to take about **half year** or less, & thus should fit well into beam breaks of current CEBAF **schedule**.
- **Collimator alcove** has enough space (with **4.52 m** width) for **Be**-target assembly to remain far enough from beamline.
- **Water Cooling** is available in experimental hall, & is sufficient to dissipate **6 kW** of power delivered by photon beam to **Be**-target & **W**-plug.

$\rho(W) = 16.3 \text{ g/cm}^3$ – Rolf's value

Concrete walls are out of scale



W-plug
16 cm in diam
10 cm in length

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

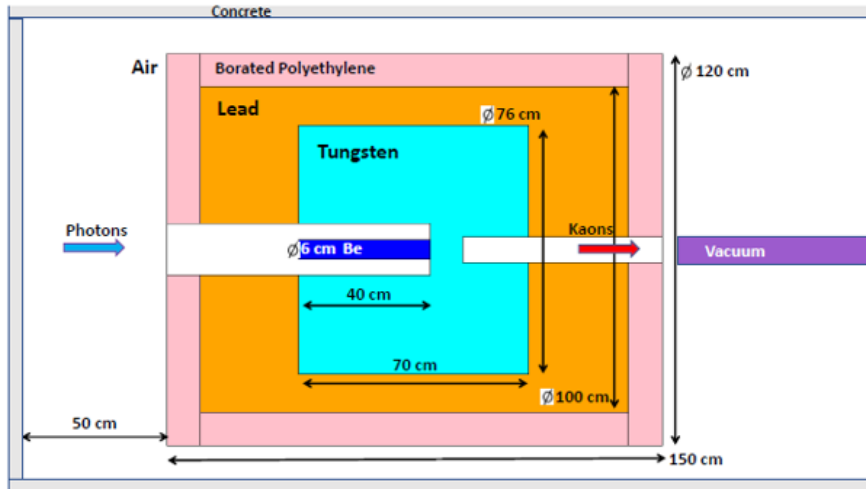
Pb & W-plug **n:** 0.27 ± 0.08 mrem/h
γ: 0.065±0.002 mrem/h





Be-Target Assembly

xy-cross section, x-dimension

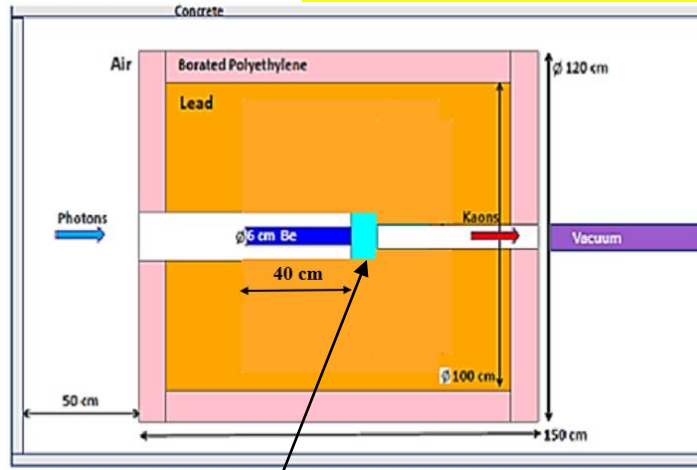


- Be-target assembly will weight **14.5 t** → **12 t**
- Be-target has estimated cost of **\$1.12M** → **\$0.134M**

- Changeover from **photon** to **Kaon** beamline & vice versa is expected to take about **half year** or less, & thus should fit well into beam breaks of current **CEBAF schedule**.
- **Collimator alcove** has enough space (with **4.52 m** width) for **Be-target** assembly to remain far enough from beamline.
- **Water Cooling** is available in experimental hall, & is sufficient to dissipate **6 kW** of power delivered by photon beam to **Be-target** & **W-plug**.

$\rho(W) = 16.3 \text{ g/cm}^3$ – Rolf's value

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-plug **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

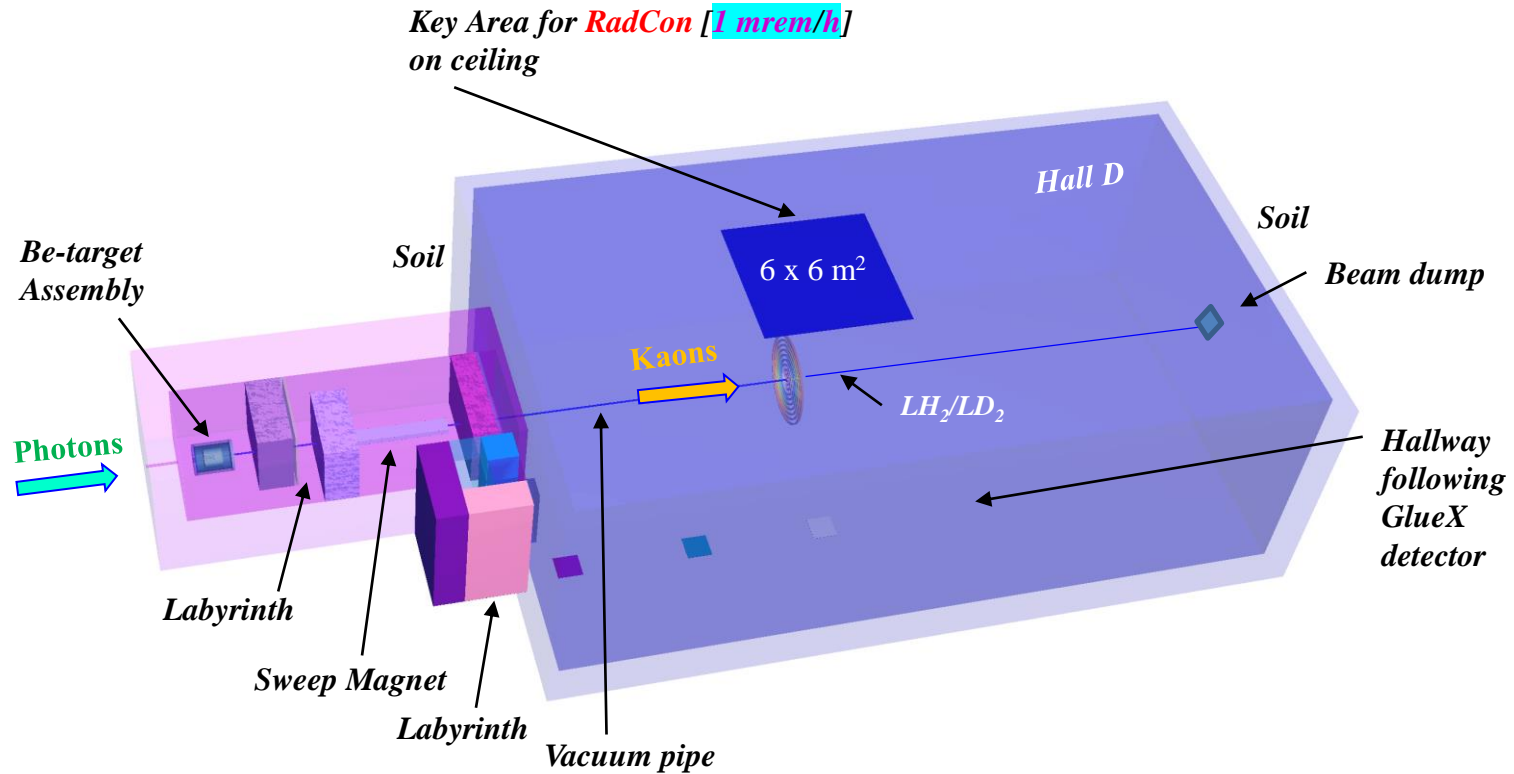
15 cm in length: **n:** 0.16 ± 0.06 mrem/h
γ: 0.003±0.001 mrem/h





Hall D Setting & Dose Rate

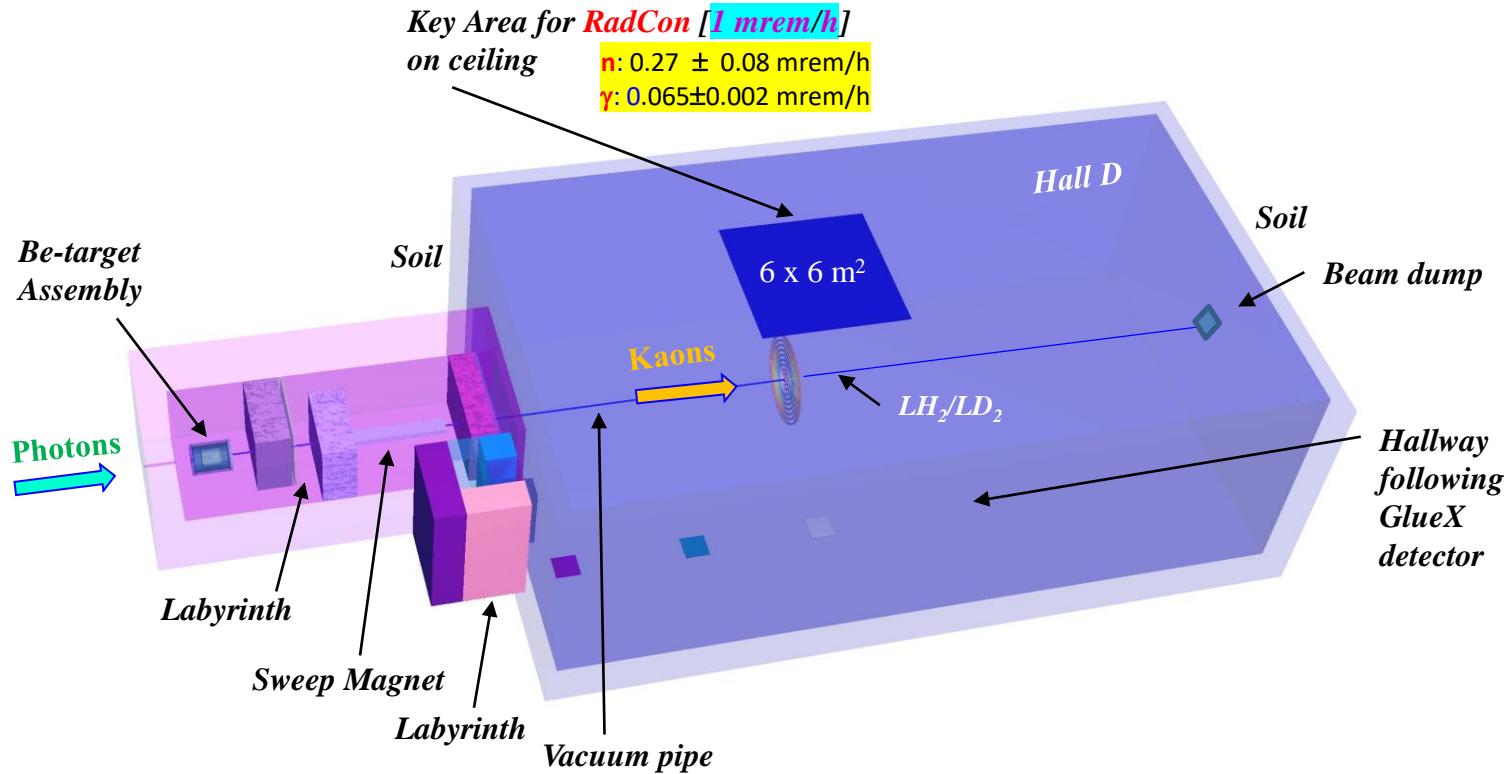
- For **neutron** & **gamma** calculations, we use **MCNP6** radiation transport code.





Hall D Setting & Dose Rate

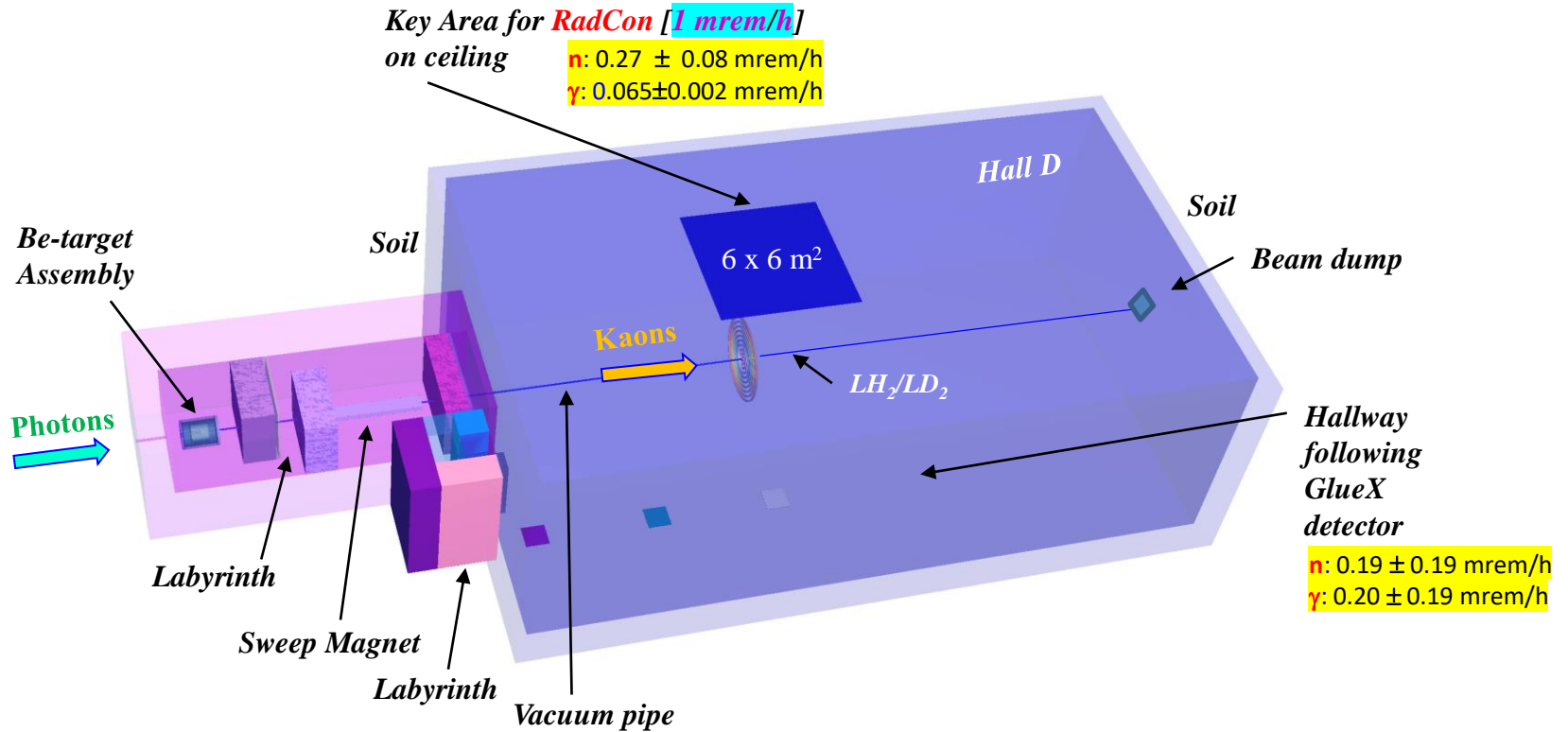
- For **neutron** & **gamma** calculations, we use **MCNP6** radiation transport code.





Hall D Setting & Dose Rate

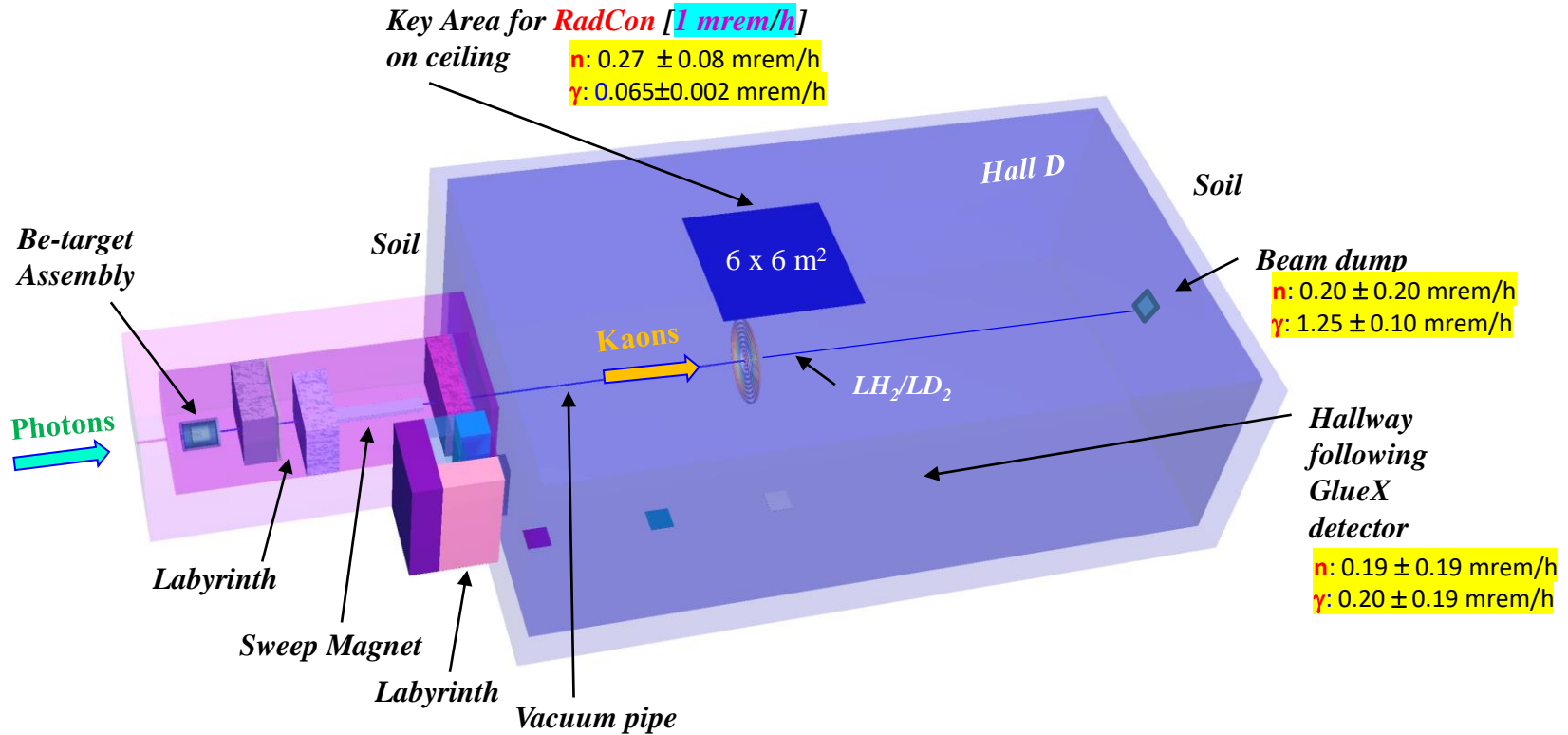
- For **neutron** & **gamma** calculations, we use **MCNP6** radiation transport code.





Hall D Setting & Dose Rate

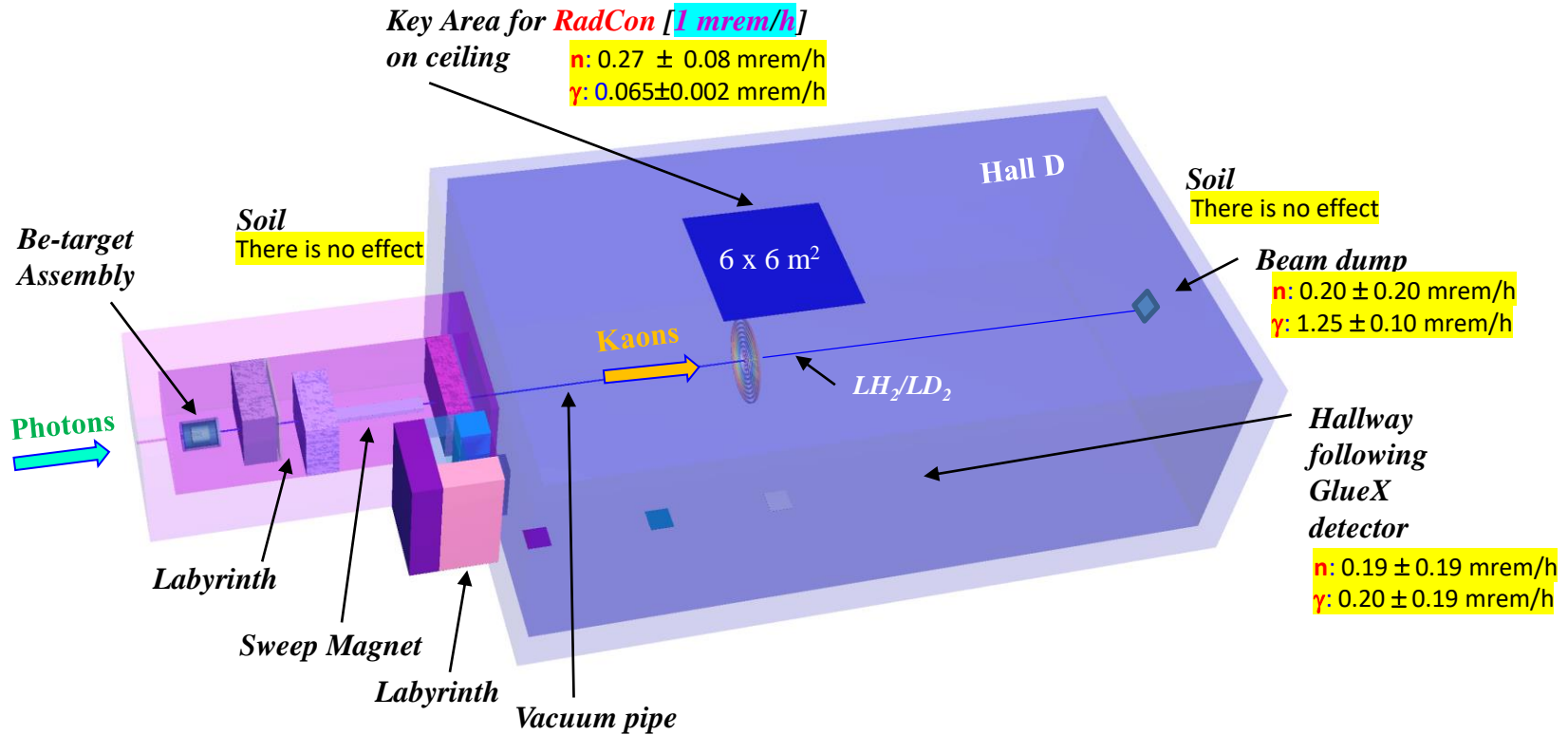
- For **neutron** & **gamma** calculations, we use **MCNP6** radiation transport code.





Hall D Setting & Dose Rate

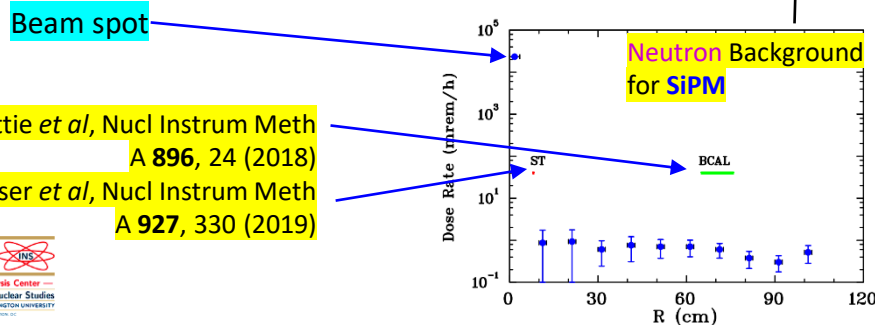
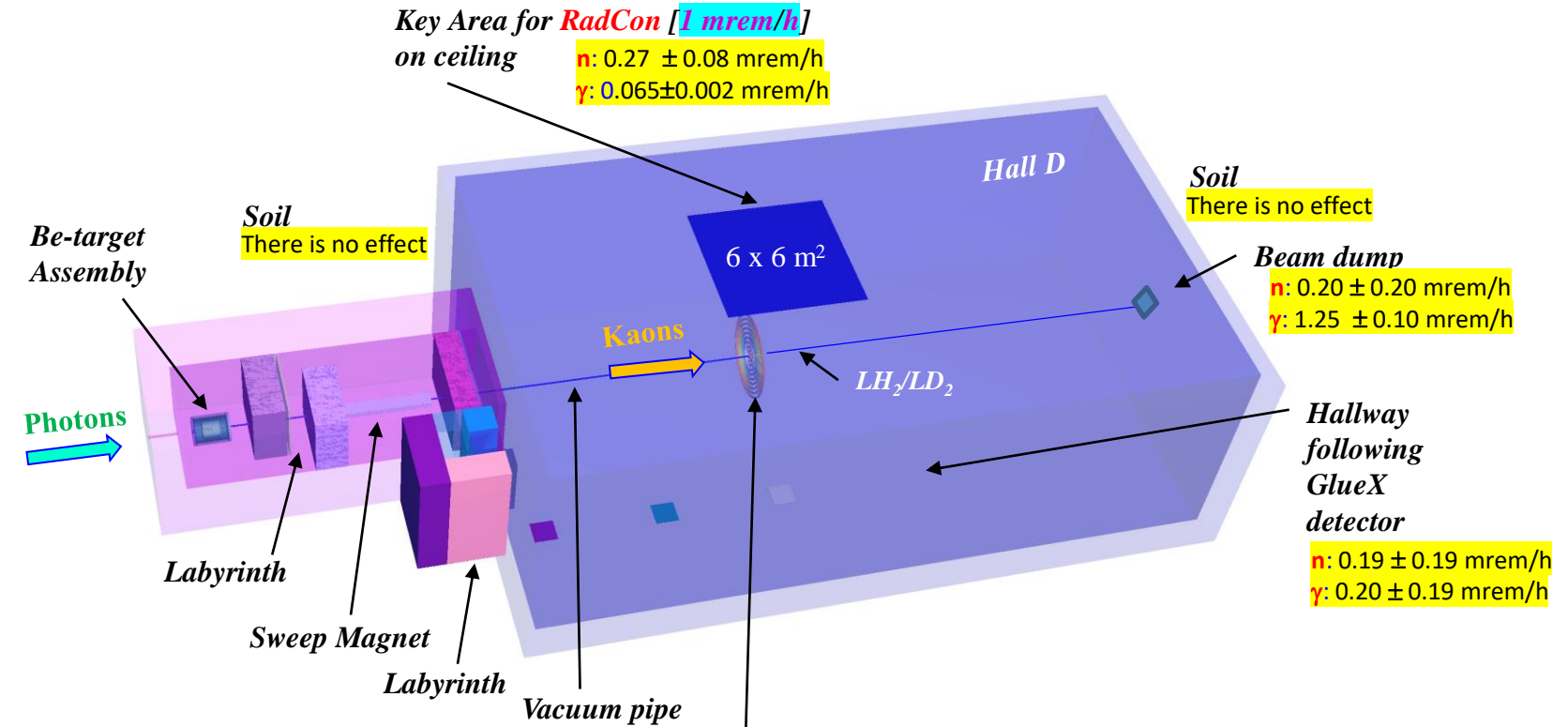
- For **neutron** & **gamma** calculations, we use **MCNP6** radiation transport code.





Hall D Setting & Dose Rate

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



BCAL: T.D. Beattie *et al*, Nucl Instrum Meth A 896, 24 (2018)

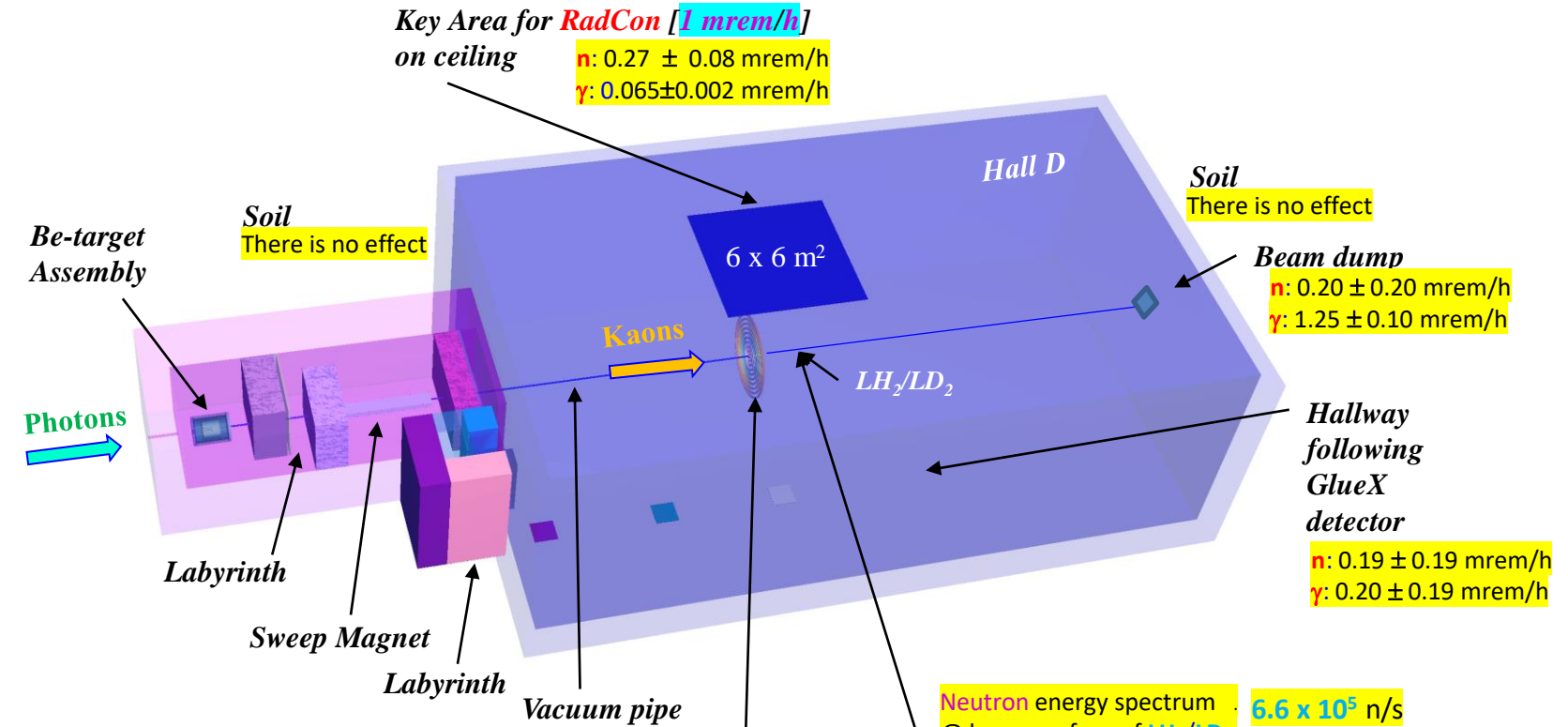
SC: E. Pooser *et al*, Nucl Instrum Meth A 927, 330 (2019)





Hall D Setting & Dose Rate

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



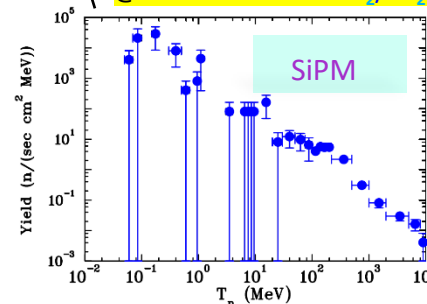
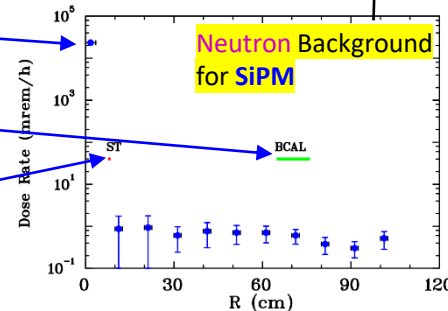
Beam spot

Neutron energy spectrum @ beam on face of LH₂/LD₂

6.6 x 10⁵ n/s

BCAL: T.D. Beattie *et al*, Nucl Instrum Meth A 896, 24 (2018)

SC: E. Pooser *et al*, Nucl Instrum Meth A 927, 330 (2019)



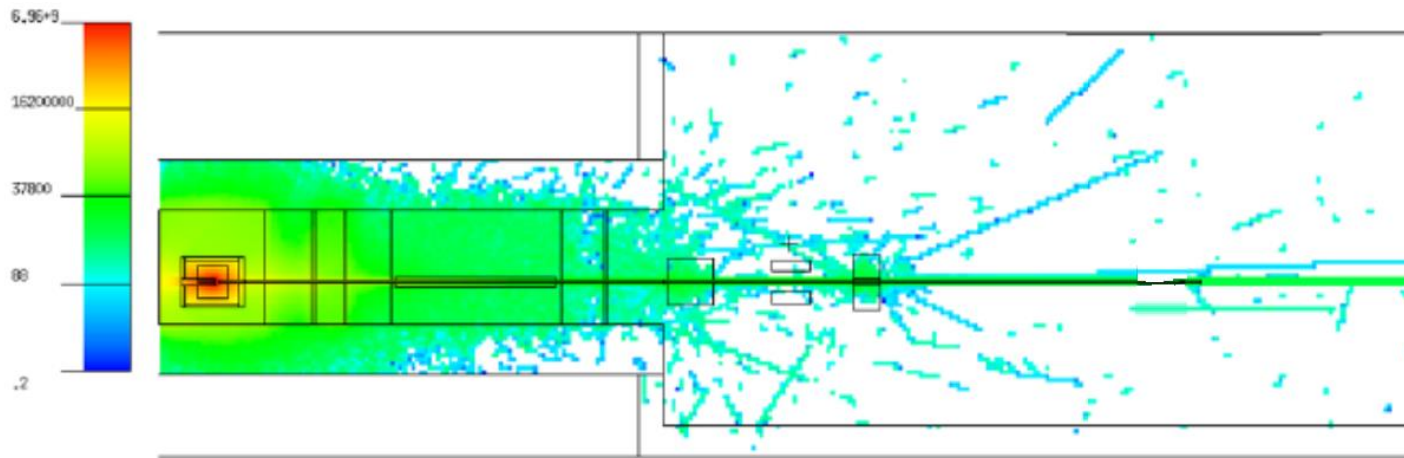
Previous studies stand that dose rate of 30 mreh/h increases dark current @ SiPM by factor of 5 after 75 days of running period.



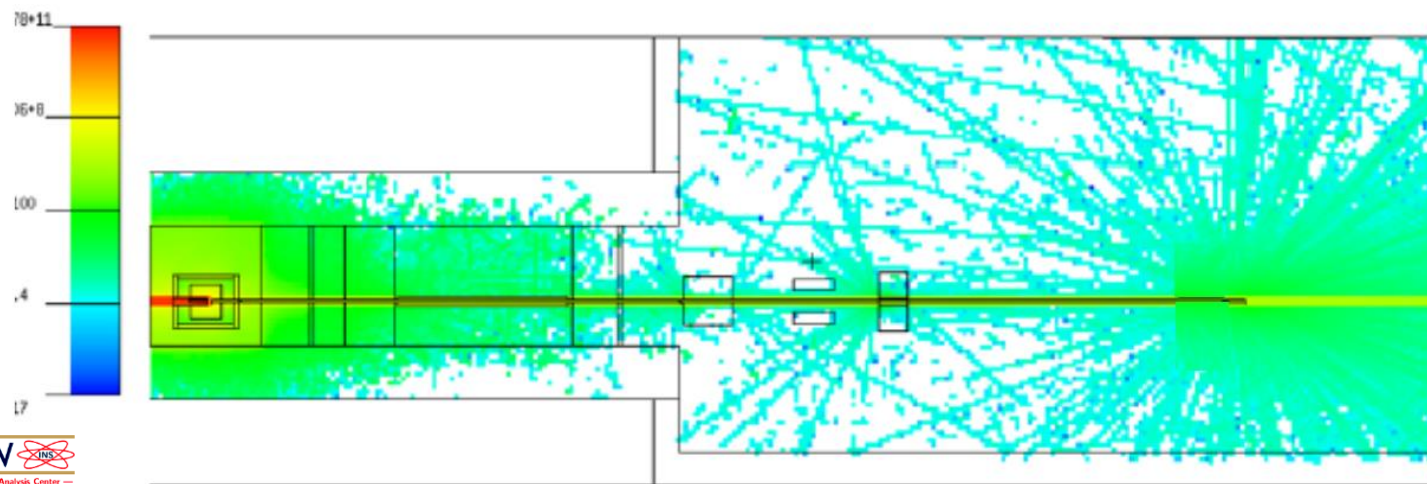


Prompt Plots

- Vertical cross section of **neutron** flux calculated using **MCNP6**.



- Vertical cross section of **gamma** flux calculated using **MCNP6**.

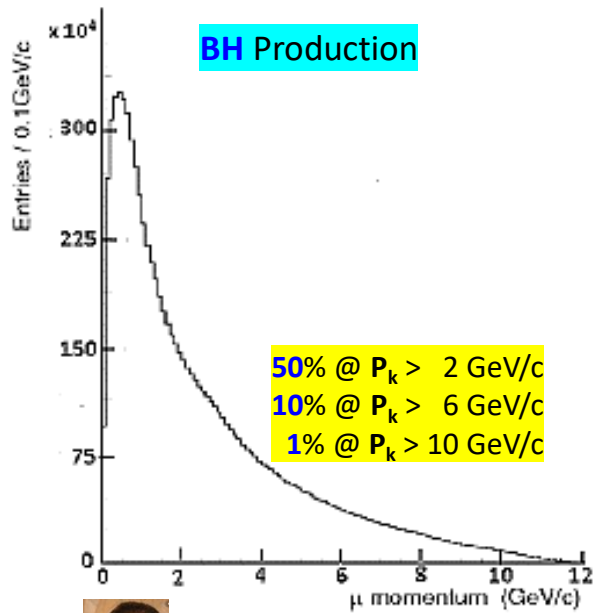


Soft gammas from elements of LH_2/LD_2

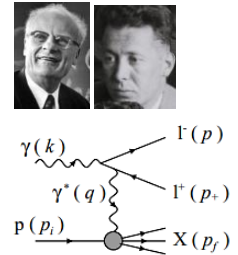




Muon Background



- Our simulations included **BH** muon background from **KPT** & photon dump @ **CPS**, both backgrounds into **GlueX** detector & **muon** dose rate outside **Hall D**.





- Number of produced **muon** in **KPT** & **W**-plug is about the same, but **muons** originating in **W** have much softer momenta.
- **Muon flux** is $< 10^7 \mu/\text{sec}$.
- Our calculations show that **muons** will be **swept** out of kaon beamline.

Overall, **Muon Flux** for experiment is tolerable.





Where We are Now & Where to Go

- Kaon flux @  will allow statistics in case of LH₂ target to exceed that of earlier SLAC experiments by almost three orders of magnitude.
- Calculations for KPT were performed for different shielding configurations to minimize neutron & gamma prompt radiation dose rate & reduce price of KPT.
- Neutron & gamma flux & dose rate for  is below JLab RadCon requirement establishing radiation dose rate limit in experimental hall. Materials & equipment: \$0.134M.
- Neutron flux & energy distribution on face of LH₂/LD₂ cryogenic target is important physical background in case of np or nd interactions in cryogenic target.
- SiPMs of SC & BCAL are expected to tolerate expected neutron background.
- Engineering design is in order ?

Mikhail Bashkanov's Talk



Any Questions ?

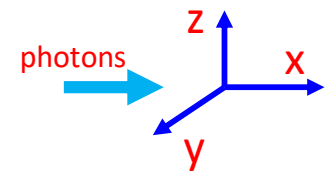
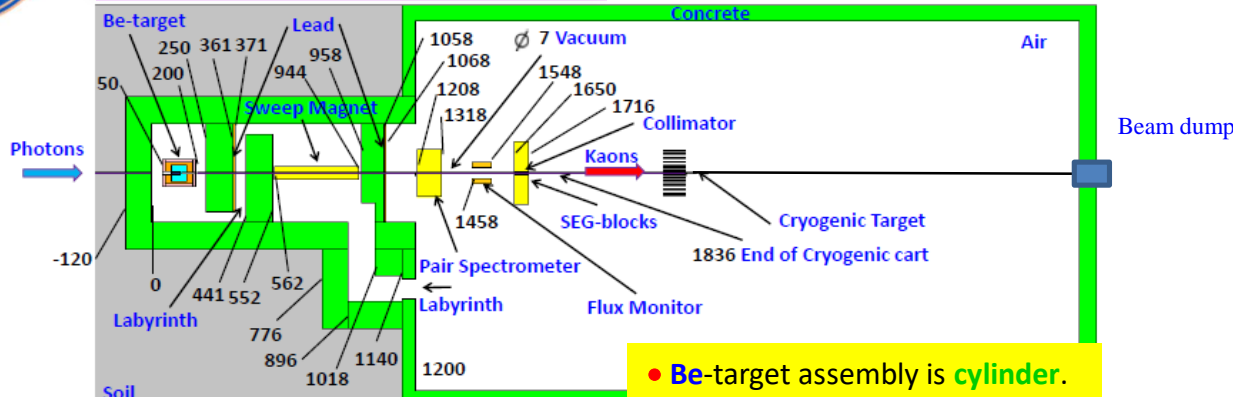




Collimator Alcove & Experimental Hall

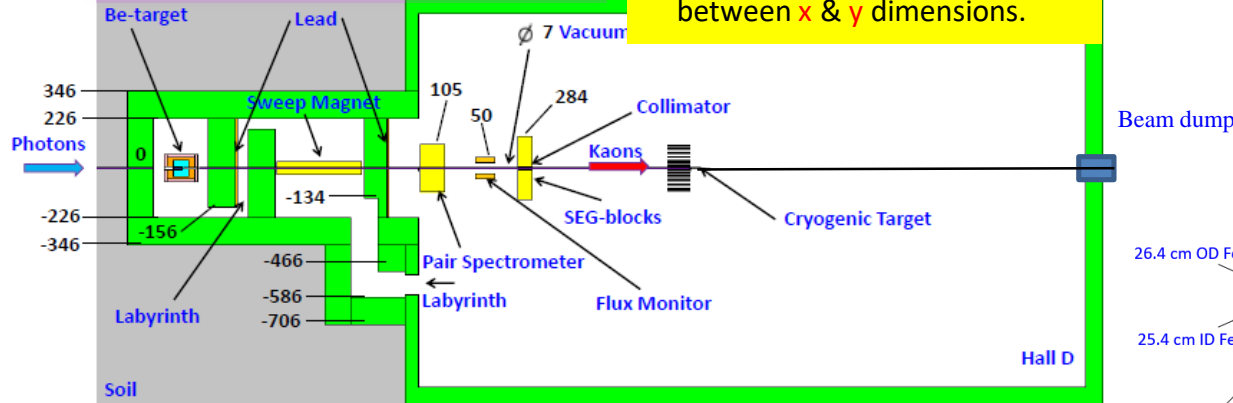
[29.5 m long x 17.2 m wide]

xy-cross section, x-dimension

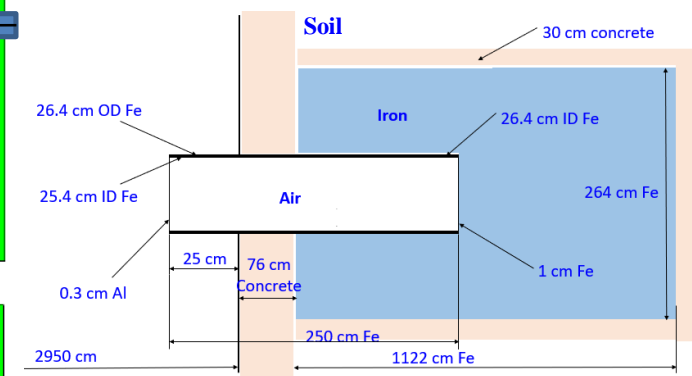


• Be-target assembly is cylinder.
Then there is no difference between x & y dimensions.

xy-cross section, y-dimension



Beam dump



xz-cross section, z-dimension

