Shielding Optimization and New Ideas (Simplified and Baseline Scheme)

Nitin Yadav
IHEP

2020 EMuS & MOMENT General Meeting

CSNS

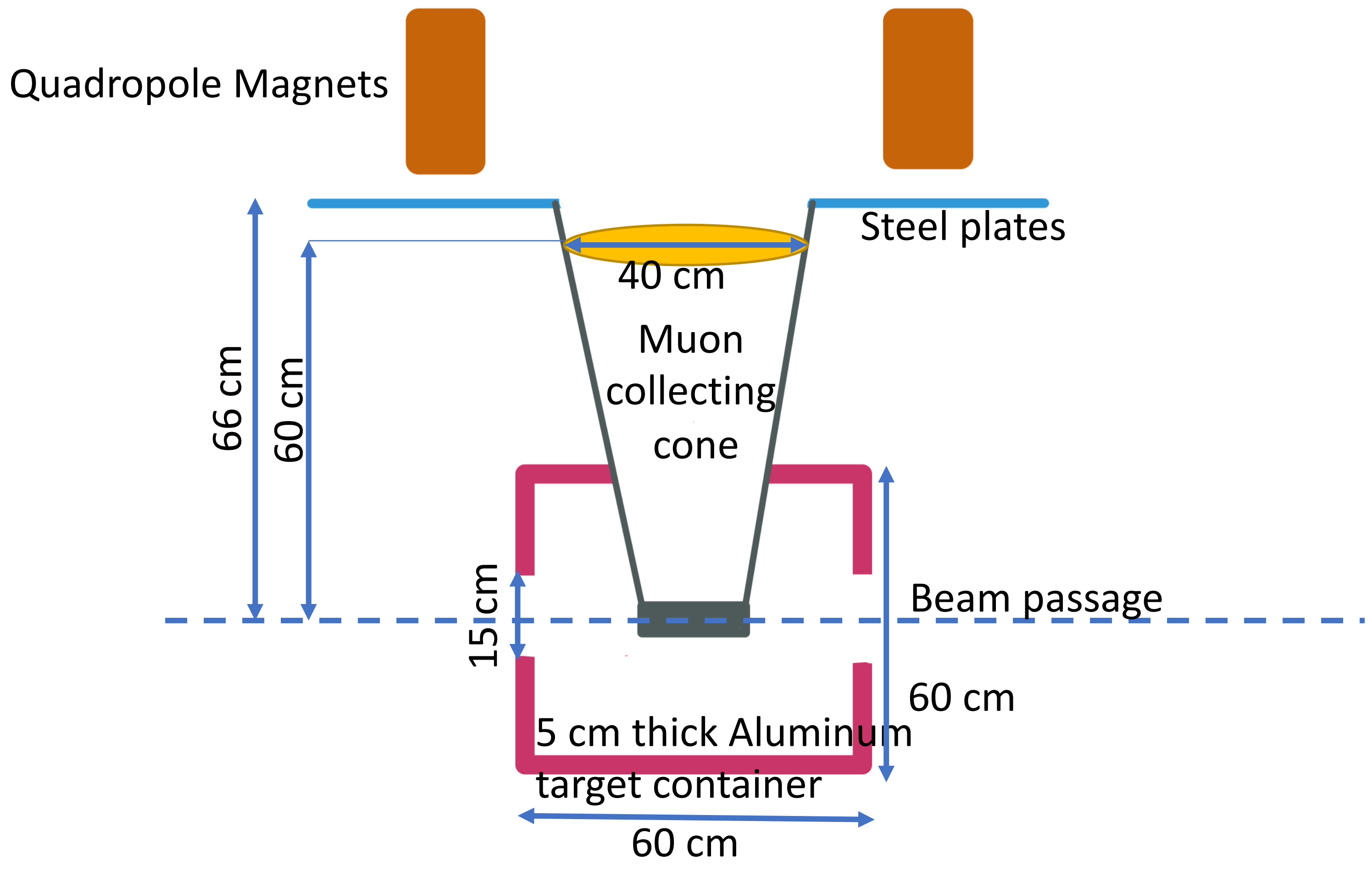
11 December 2020

Outline

- Simplified Scheme
- Baseline Scheme
- New shielding ideas and further prospects.

Simplified scheme as given:

- Aluminum container for target containment.
- The carbon target of dimension 3 cm x 4 cm x 8 cm
- A collecting cone centered behind the target as shown in figure.
- The steel plates and quadruple

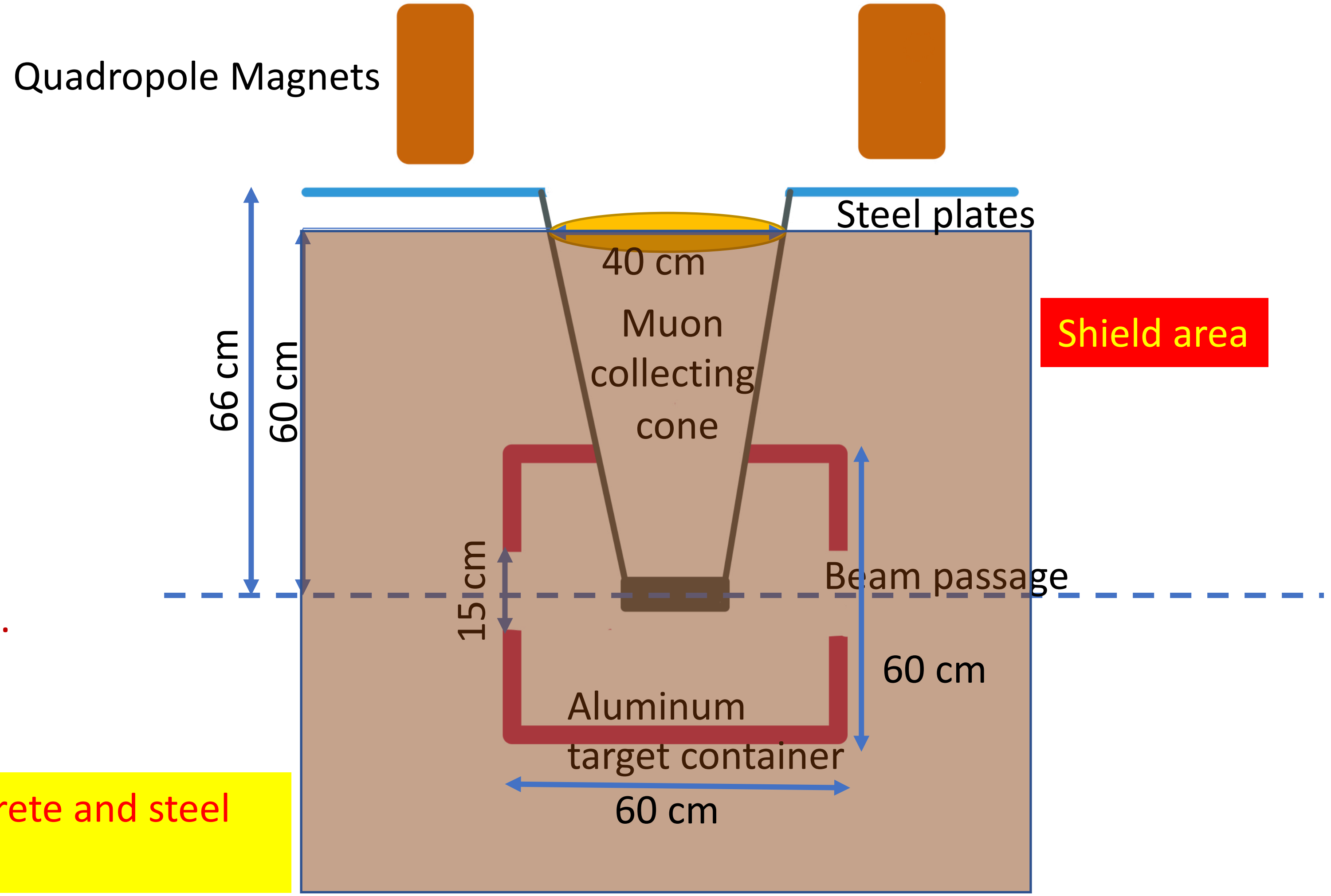


Simplified scheme shield to be designed:

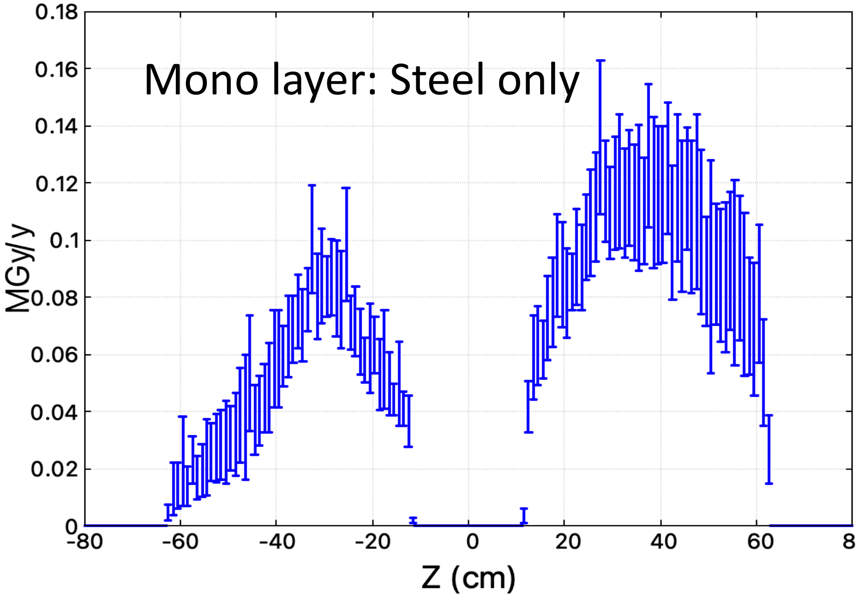
- Aluminum container for target containment.
- The carbon target of dimension 3 cm x 4 cm x 8 cm
- A collecting cone centered behind the target as shown in figure.
- The steel plates and quadruple
- A shielding (with cost effectiveness) has to be designed around it with above things considered as constant.

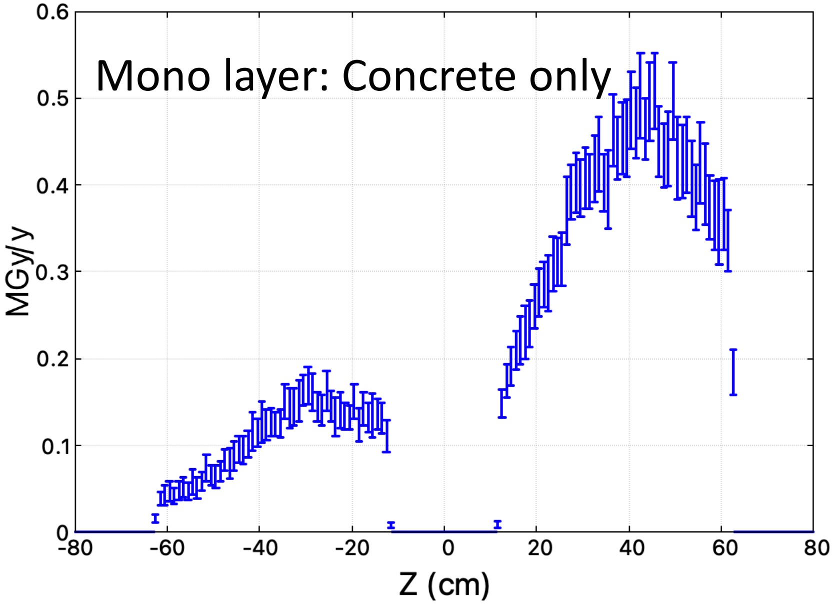
- The maximum dose limit has been consired intially a as 7MGy for 30 years of operation.
  - ~0.23 MGy/y
  - ~0.12 Mgy/y with a safery factor of 2.

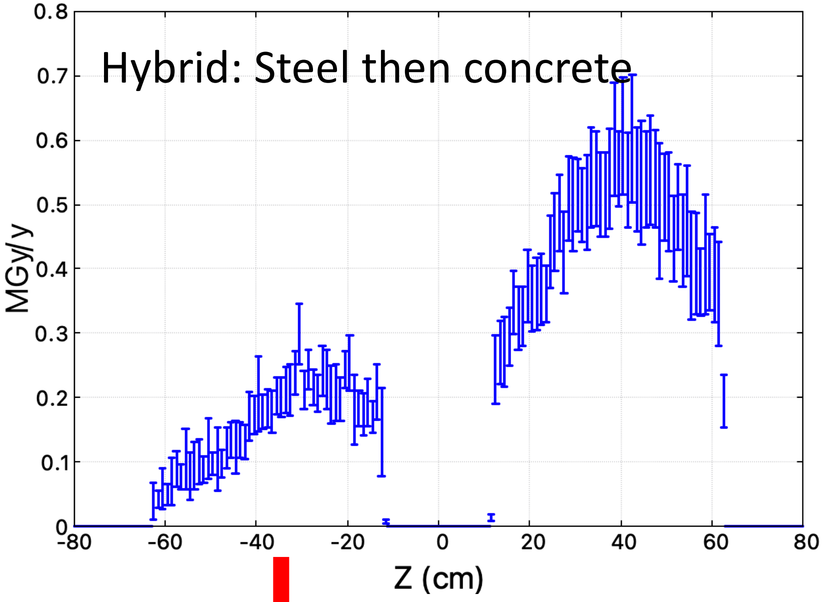
- Considering the cost effective ness, the concrete and steel has been considered for the shielding .



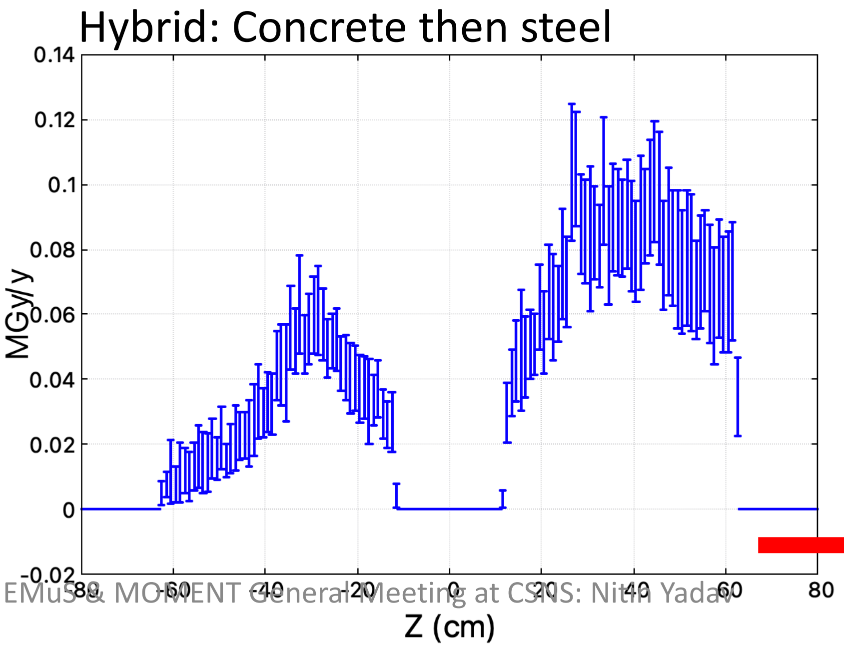
Mono material shielding Vs Hybrid material shielding

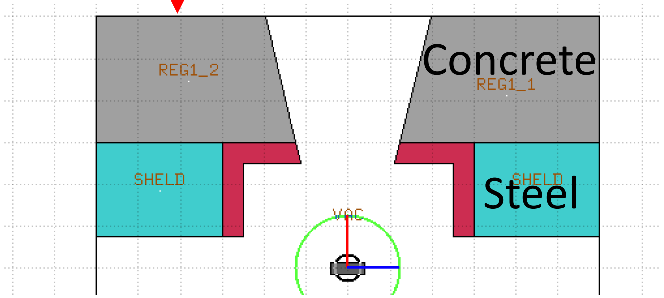


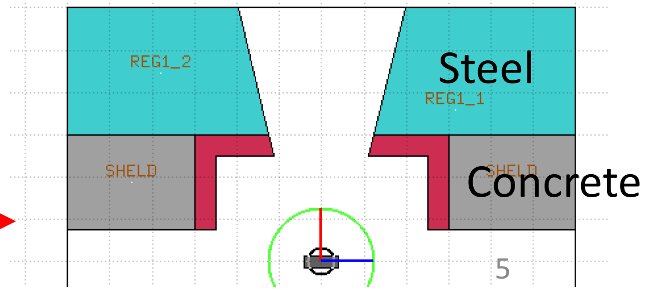




- ✓ With mono material like steel or only concrete the required limit (0.12 MGy/y) can not be achieved.
- ✓ With hybrid layers, the limit can be achieved.
- ✓ Usually low Z materials follows the high Z material in order to slow down the secondary neutrons. But here a low Z material first and then a high Z material later is found to be more effective in lowering the overall dose at coils.

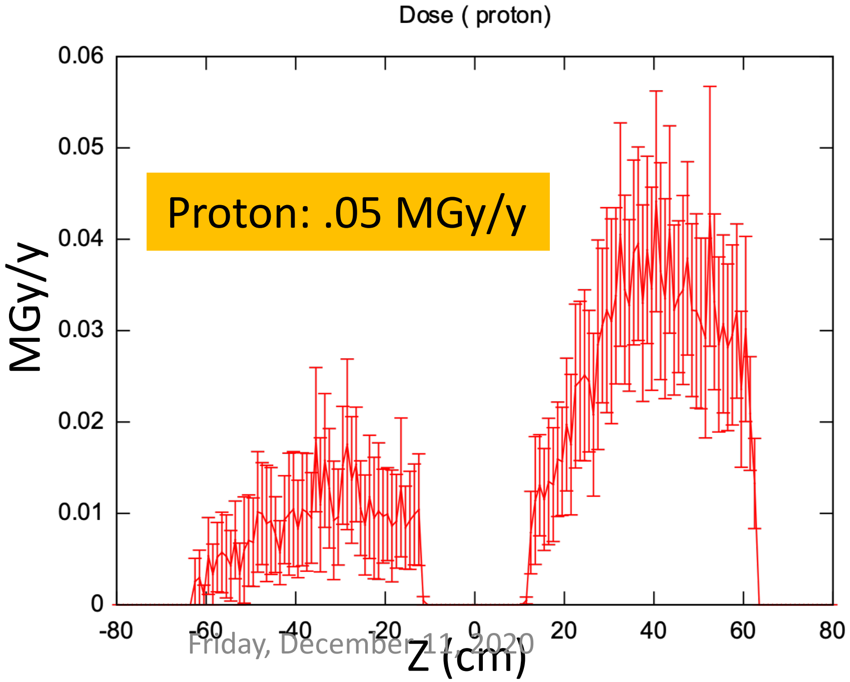


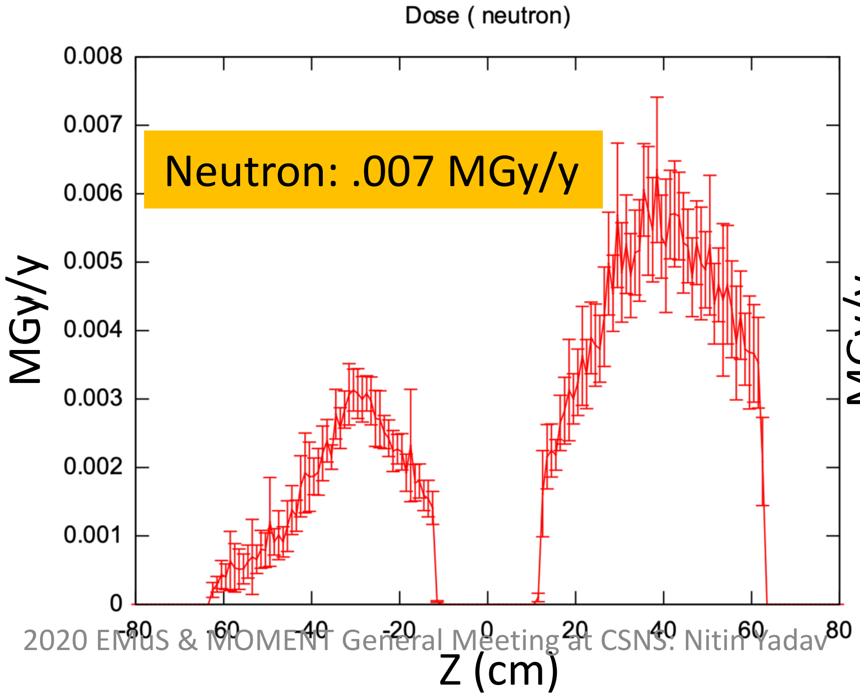


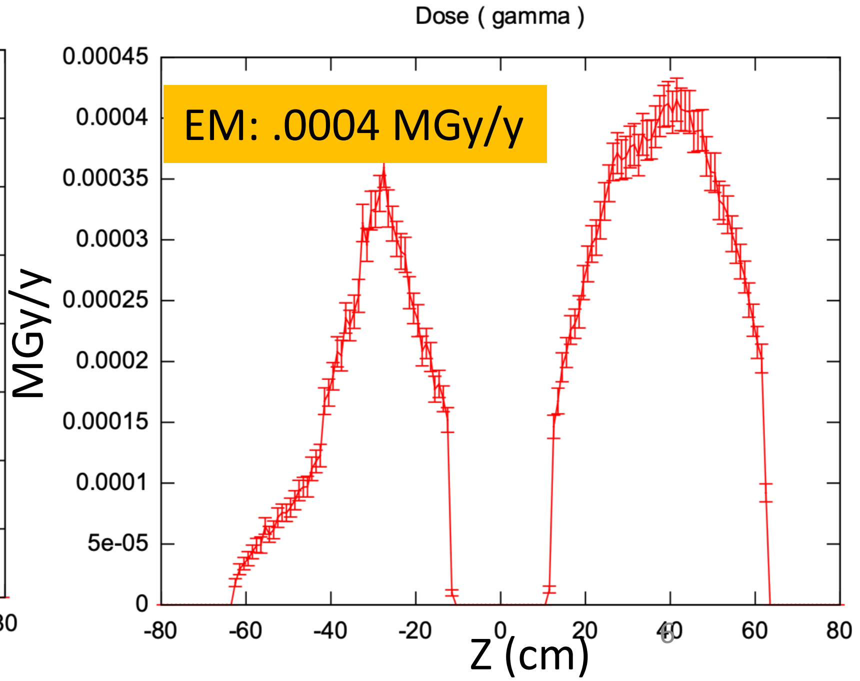


Proton shares the highest contribution to the dose. Dose due to proton is almost ~7-8 times more than that of neutron

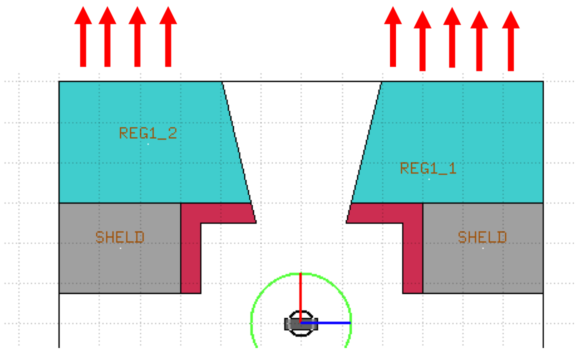
Individual dose: Proton > Neutron > Gamma







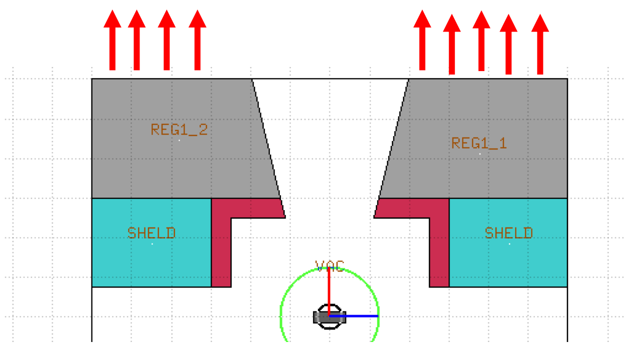
Particle emanating here



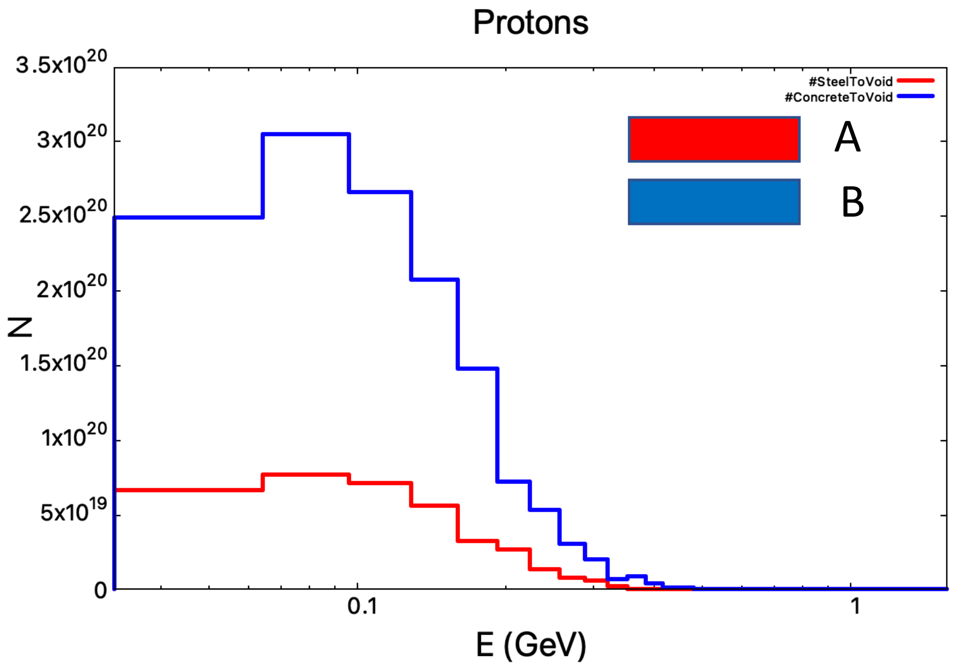
A: Concrete then steel

Vs

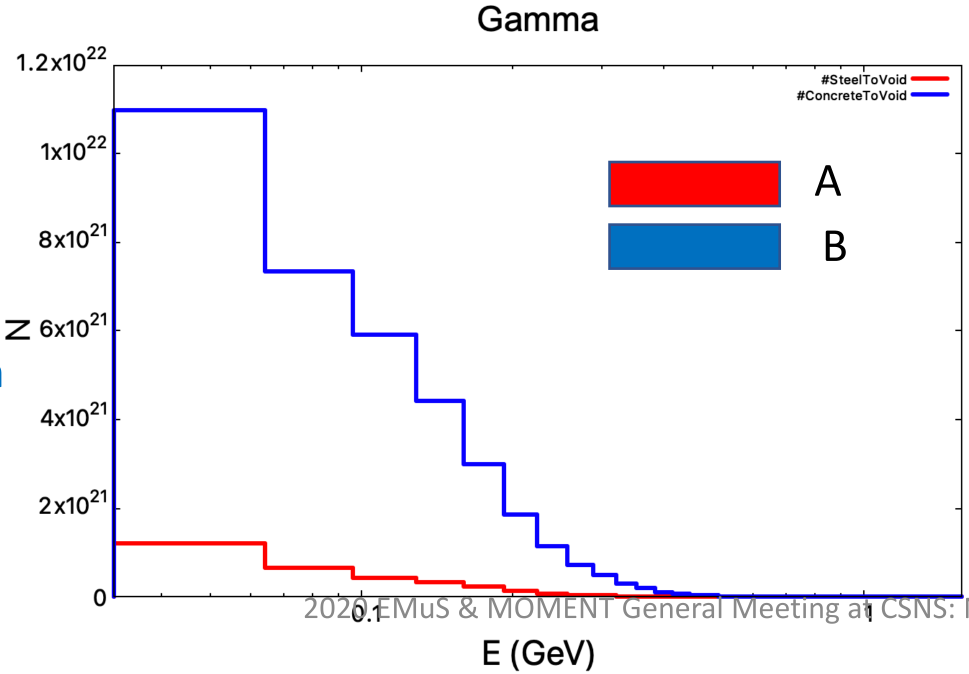
Particle emanating here

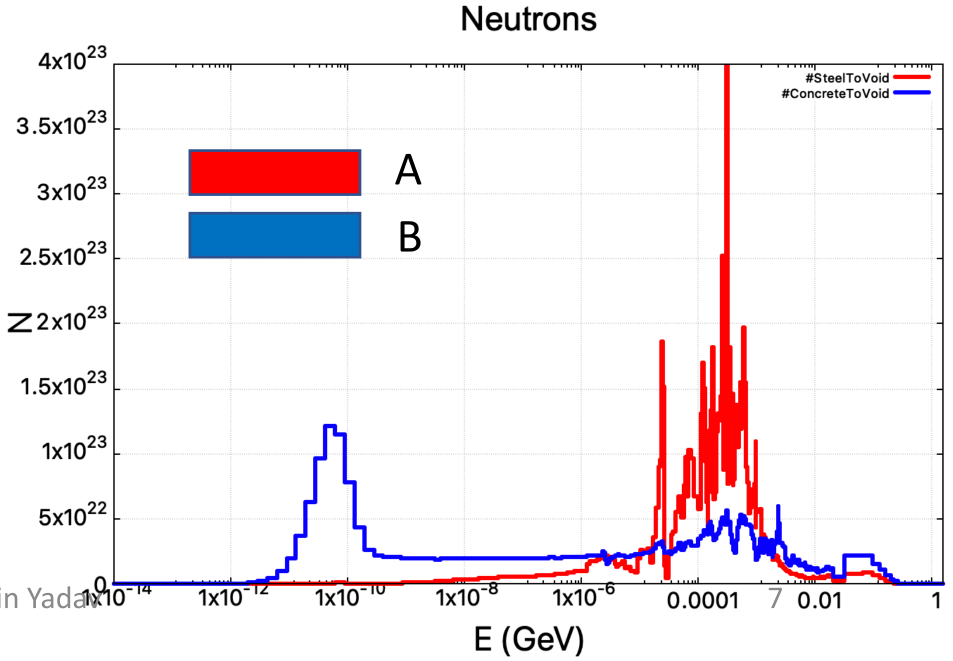


B: Steel then concrete



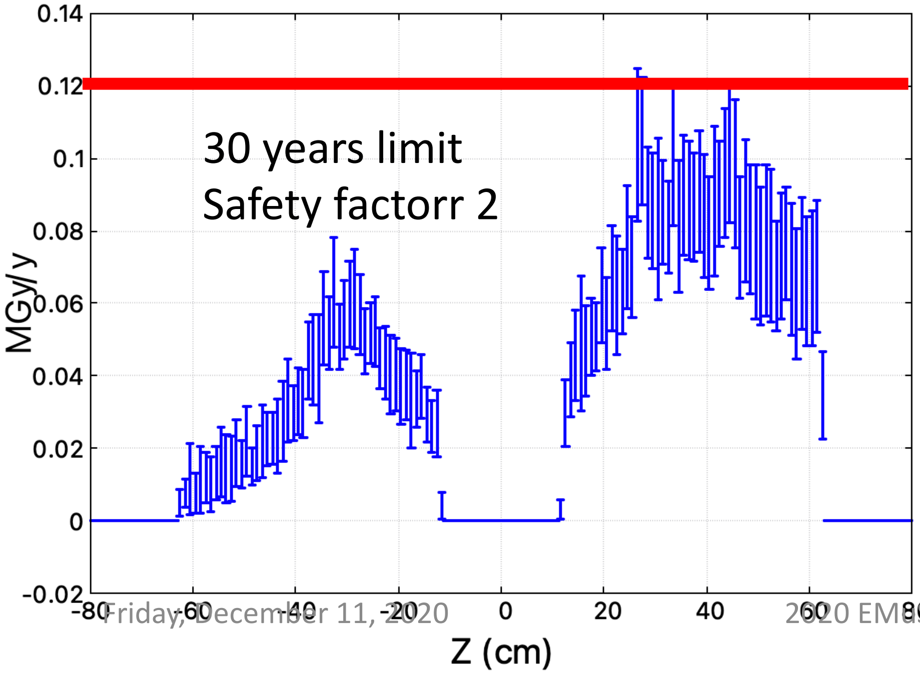
- We can see that protons/gamma are highly suppressed by a the combination choice of concrete followed up by steel. So we choose A.
- Neutrons are suppressed comparatively more in lower energy region than that at higher energies.

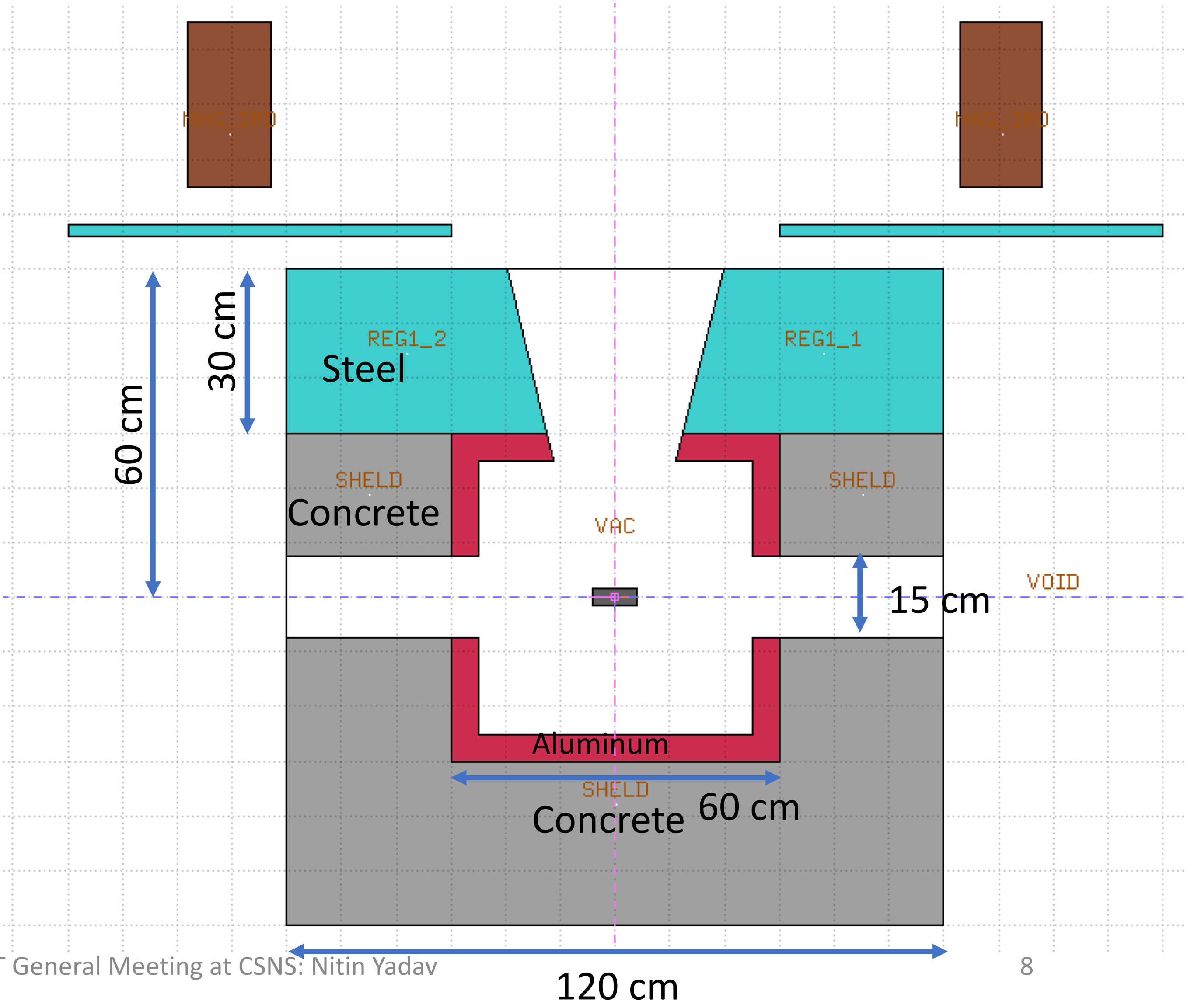




Final Simplified Scheme Shielding:

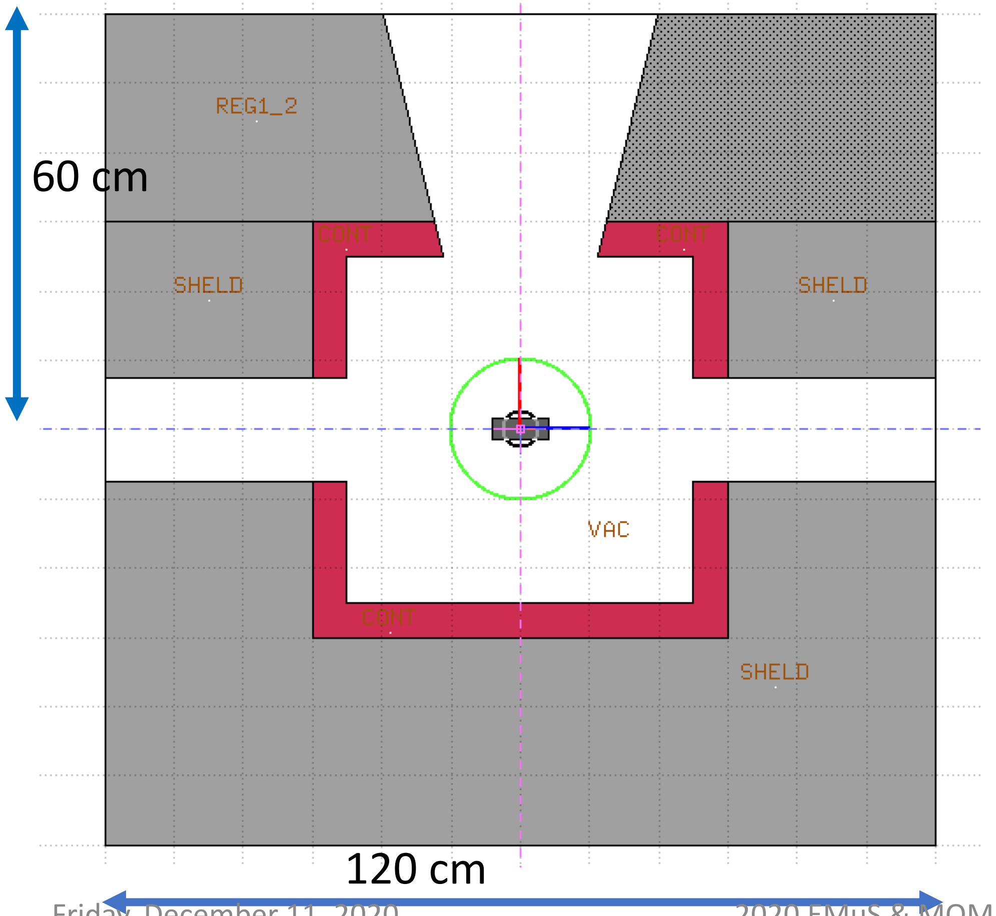
- ✓ A hybrid solution (dual layer) of steel after concrete has been found to be more effective in lowering the dose at coils than just single layer of steel or concrete.
- ✓ The steel width is optimized.
- ✓ Dose limit with a safety factor of 1 i.e., 0.12 Mgy/y i achievable.

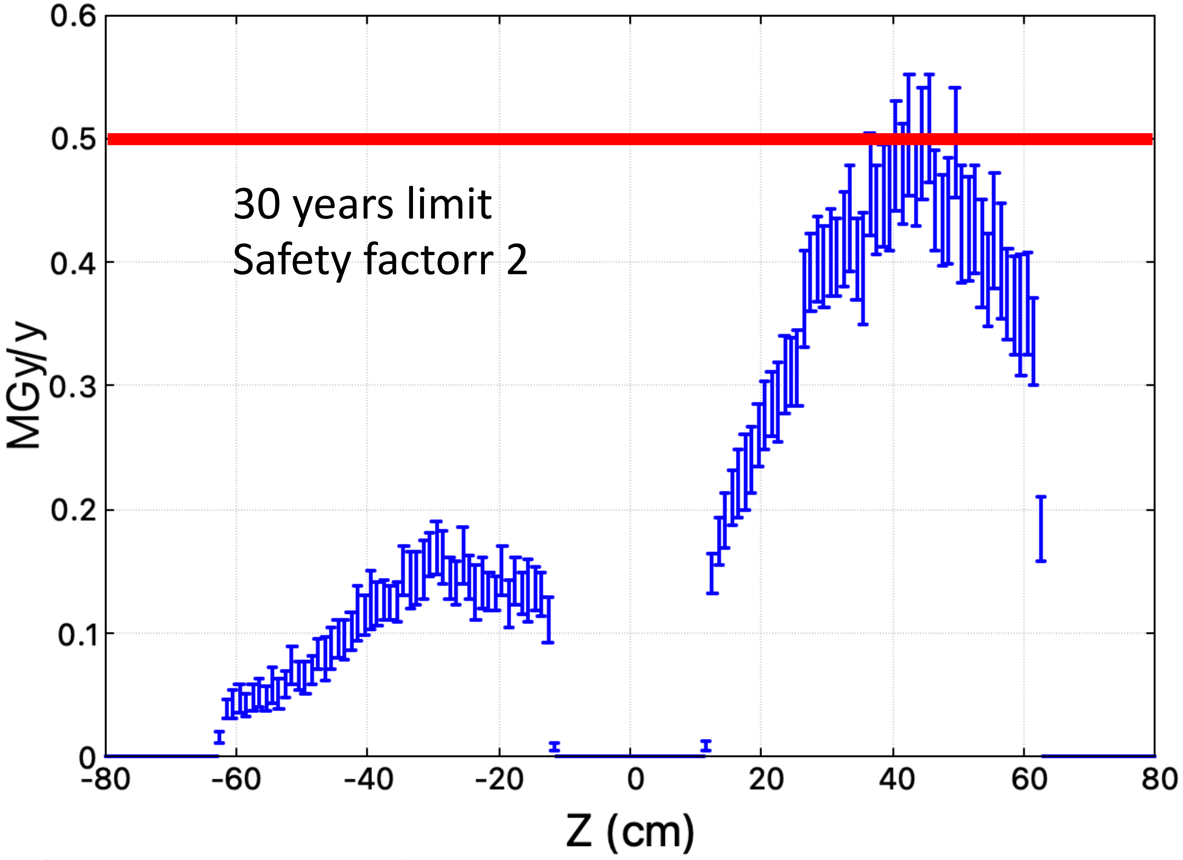




❖ However, with time, the dose limit has been increased from 7 MGy to 30 MGy for 30 year operation lifetime.
❖ With new limit (and same safety factor of 2), the new maximum dose limit is 0.5 MGy/y.

So we can either decrease the size of use the more economic concrete single layer solutuion as follows:
(remember target size is here 3 cm x 4 cm x 8 cm)



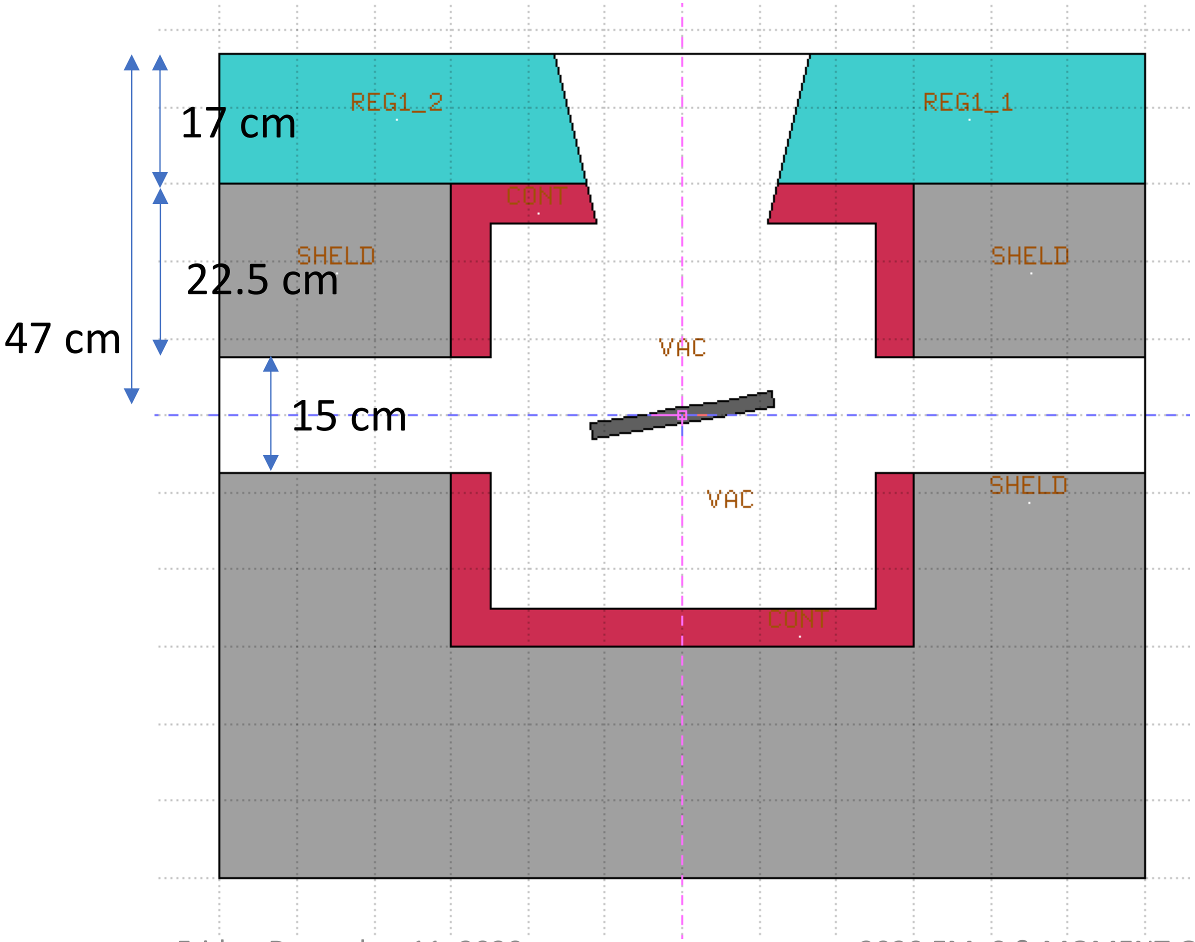


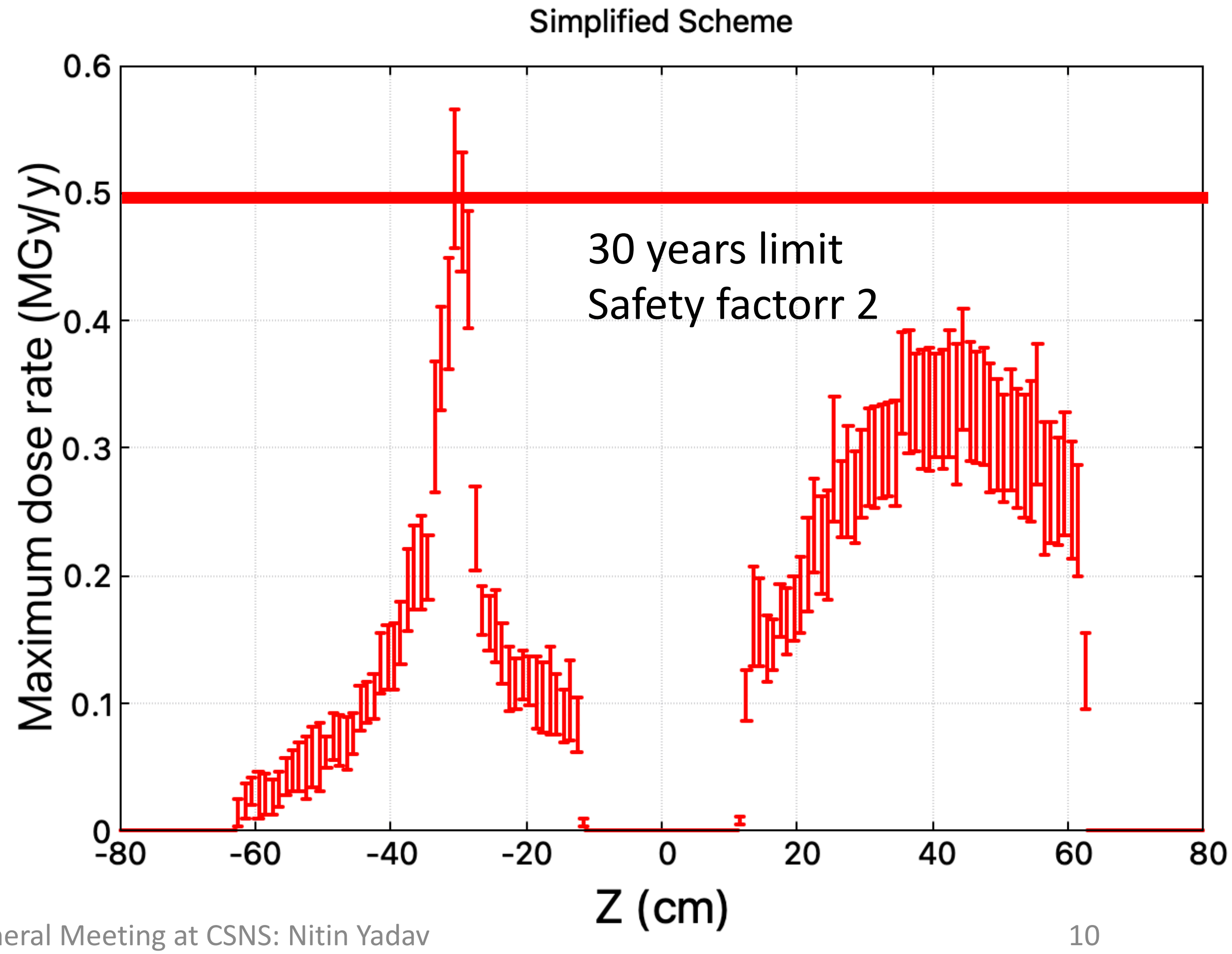
New target ： 2 cm x 12 cm x 24 cm.

The new rotated (10 degree w.r.t to beam direction) target with dimensions:
2 cm x 12 cm x 24 cm.

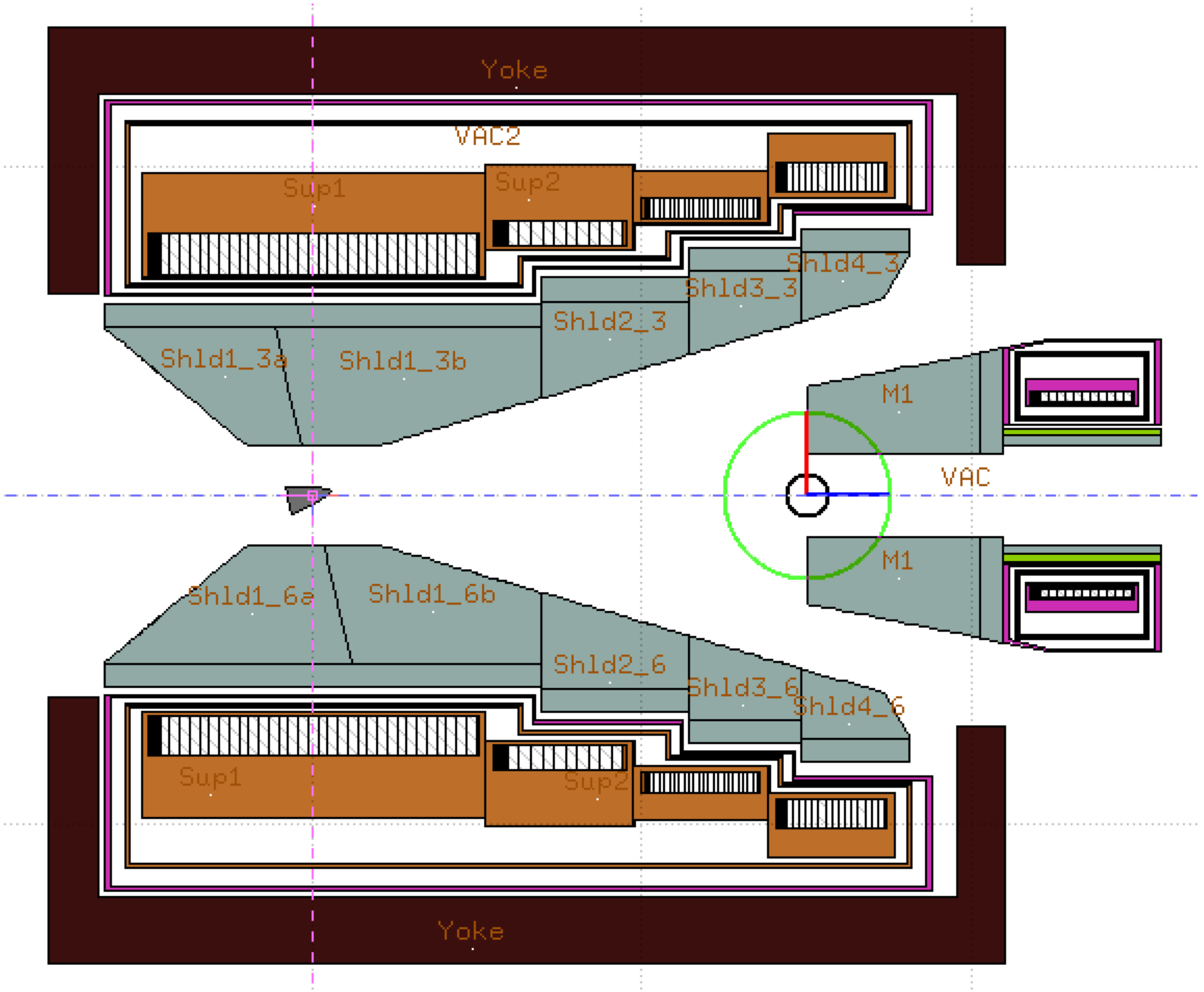
Full concrete (60 cm): 1.1 MGy/y
Full steel (60cm): 0.25 MGy/y

The hybrid shielding gives the best (and cost effective too) results.





Baseline Scheme

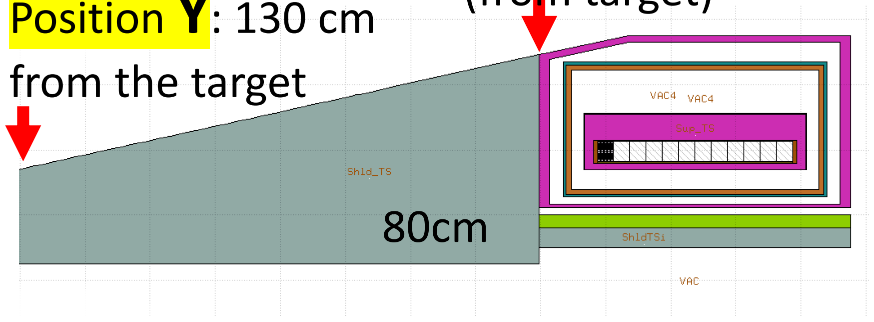


MS1 Shield (only W) length vs target size

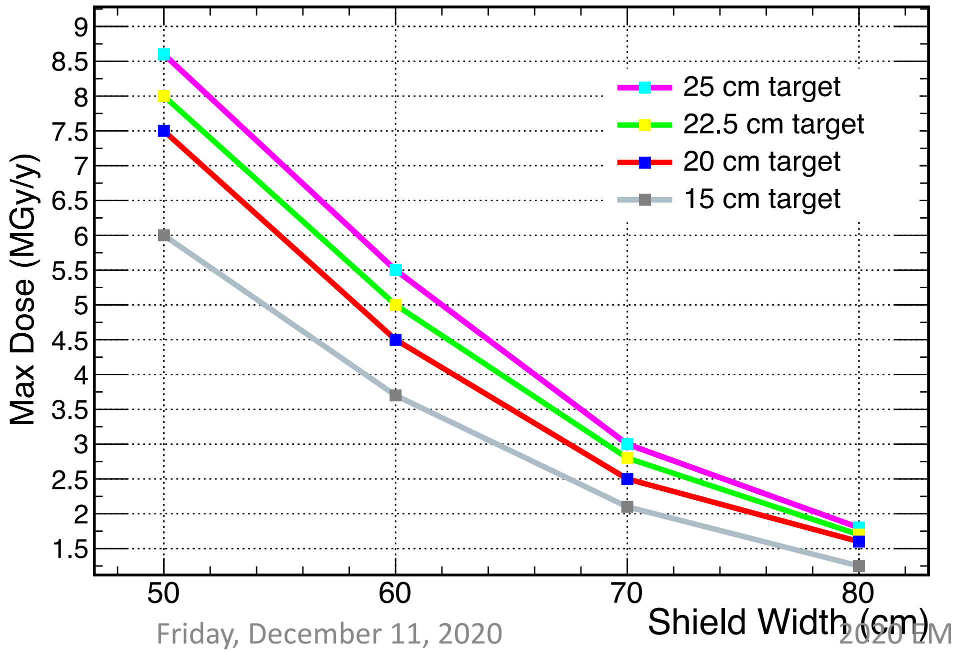
30 years limit : 1.0 MGy/y
20 years limit : 1.5 MGy/y
10 years limit : 3.0 MGy/y
5 years limit : 6.0 MGy/y

Position X: 210 cm (from target)

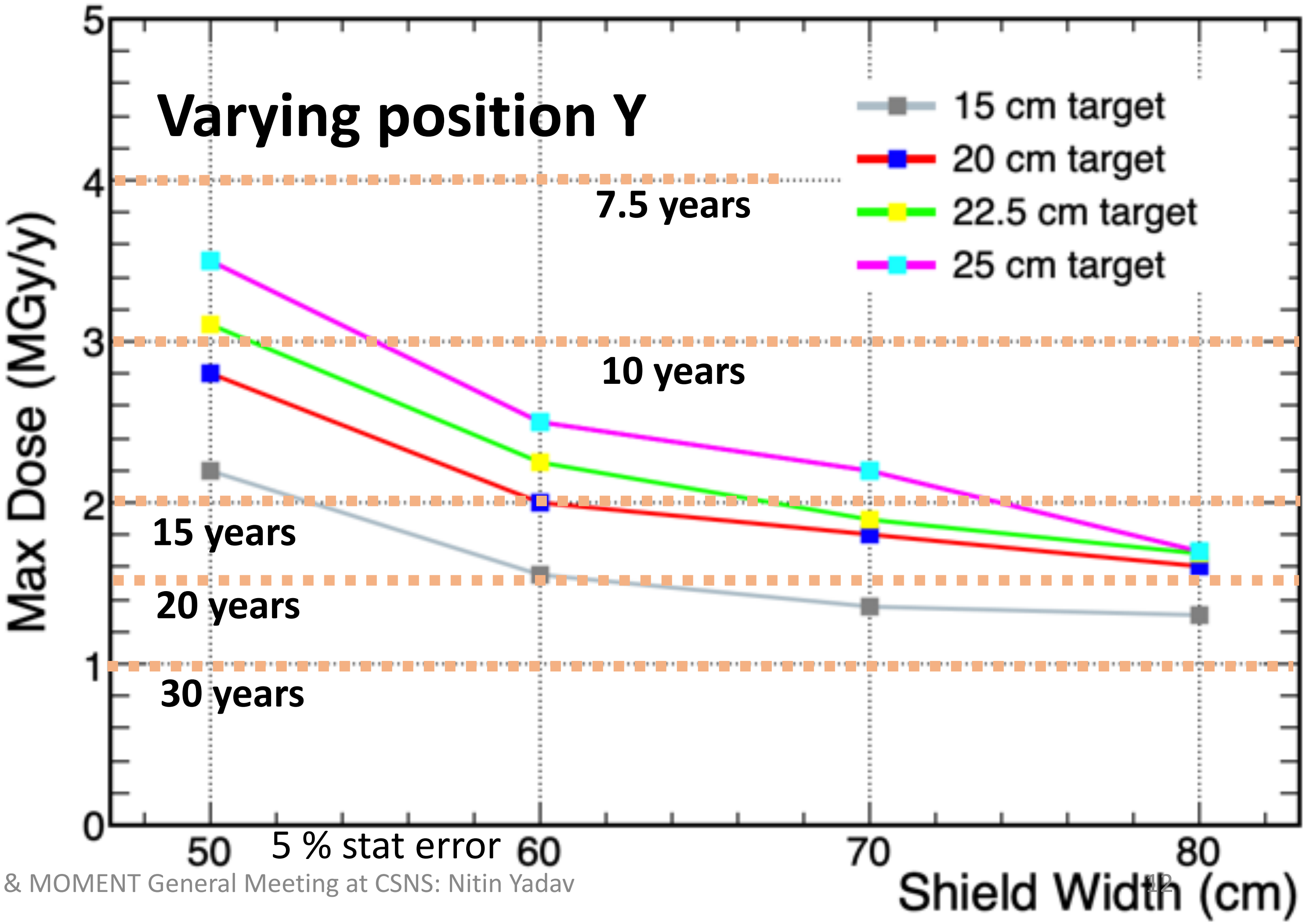
Position Y: 130 cm from the target



Varying position X



Dose on MS1 epoxy for 25 kW, TUNGSTEN shield



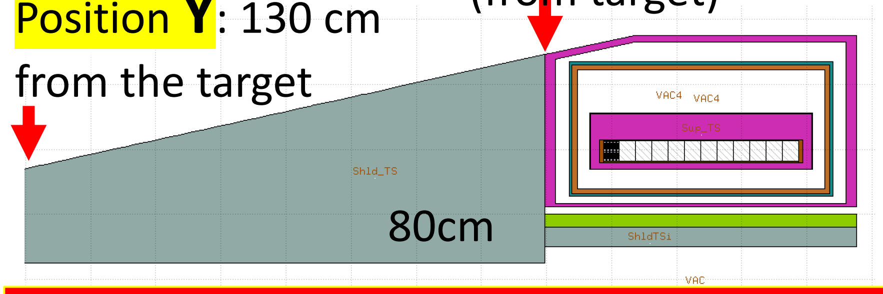
5 % stat error

MS1 Shield (only W) length vs target size

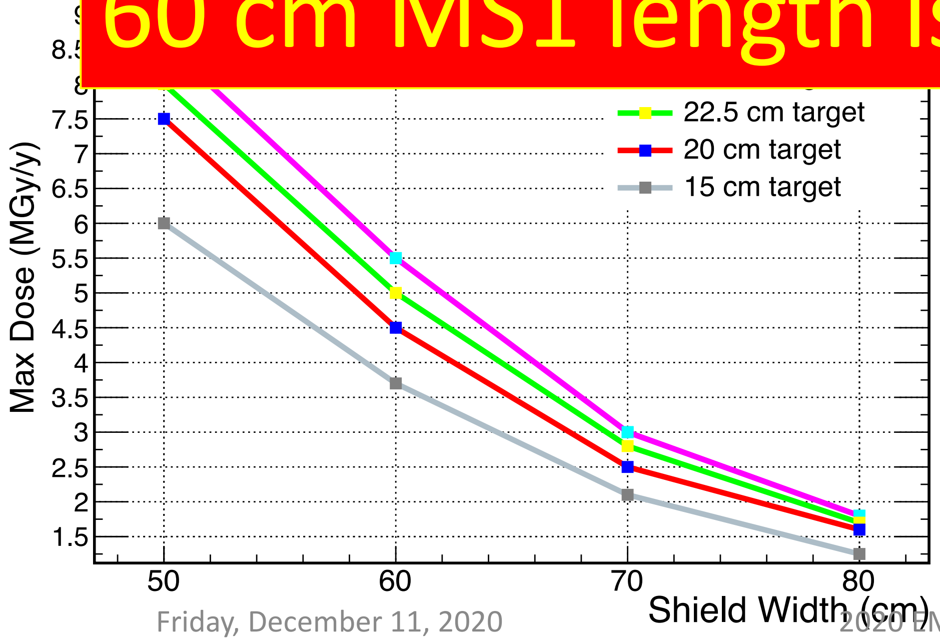
30 years limit : 1.0 MGy/y
20 years limit : 1.5 MGy/y
10 years limit : 3.0 MGy/y
5 years limit : 6.0 MGy/y

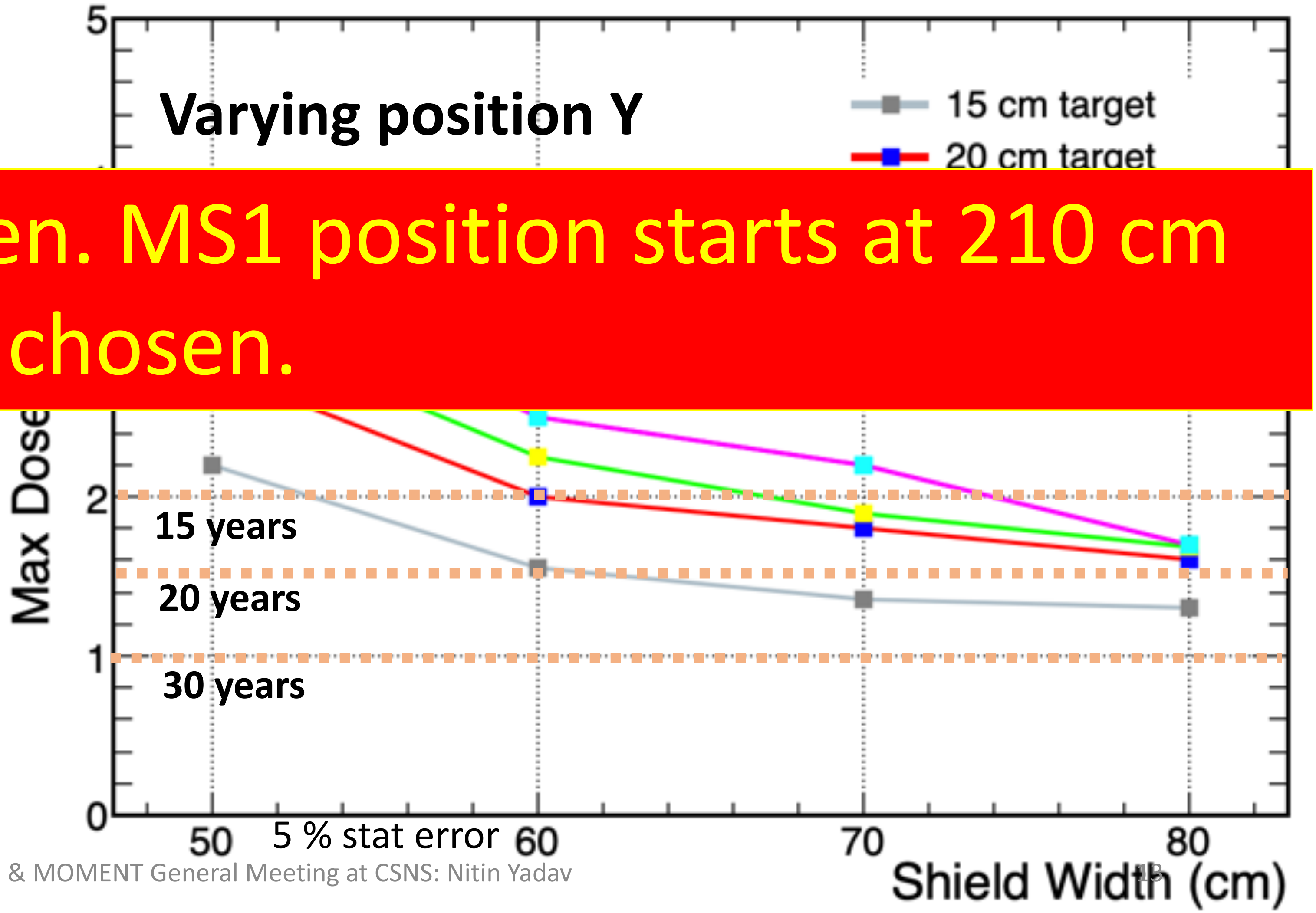
Position **Y**: 130 cm from the target

Position **X**: 210 cm (from target)



Dose on MS1 epoxy for 25 kW, TUNGSTEN shield



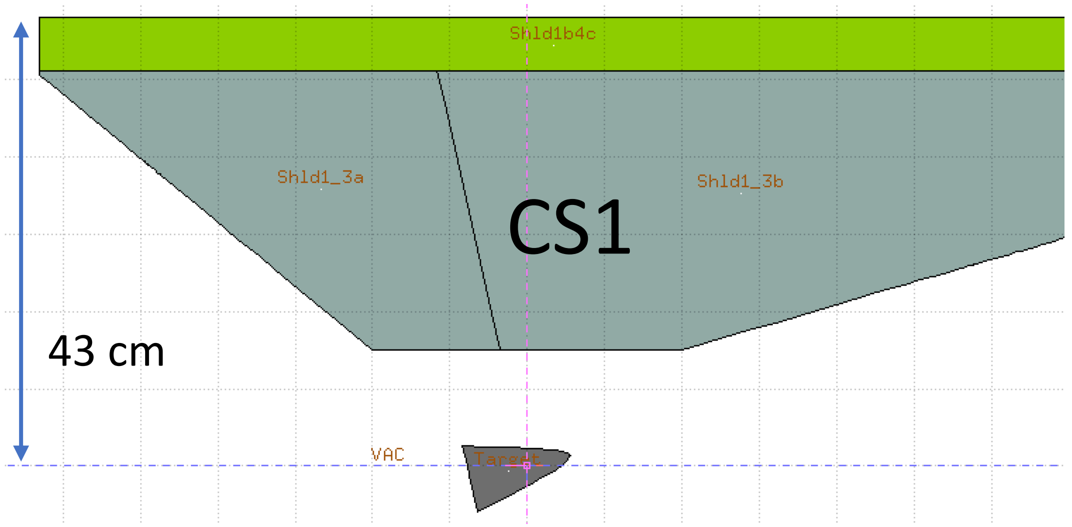


5 % stat error

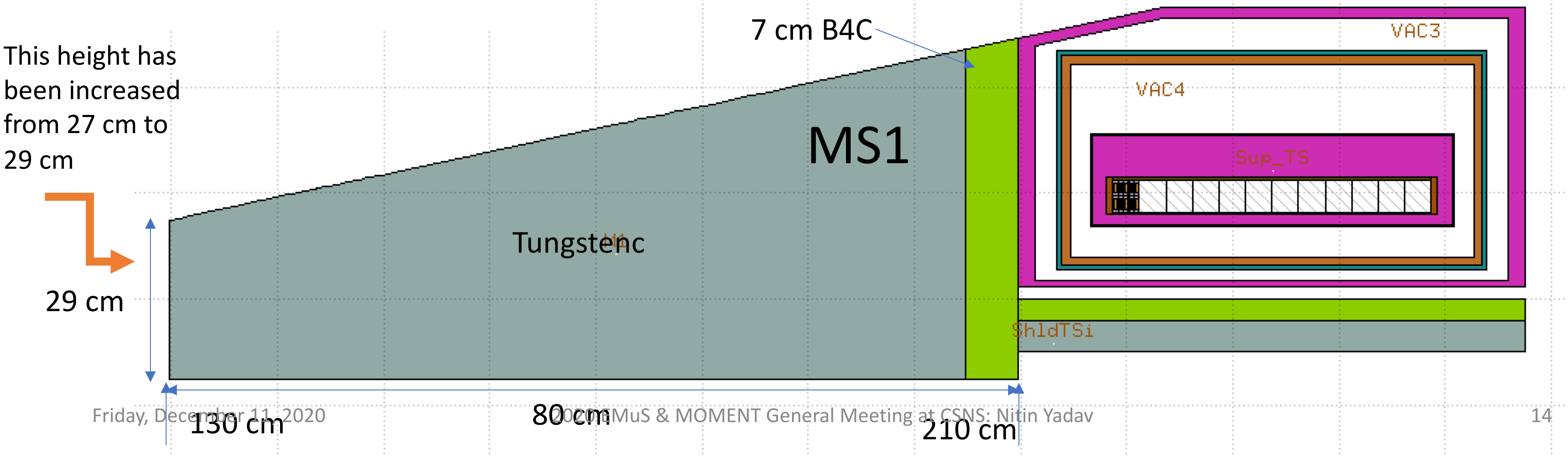
15 cm target is chosen. MS1 position starts at 210 cm

60 cm MS1 length is chosen.

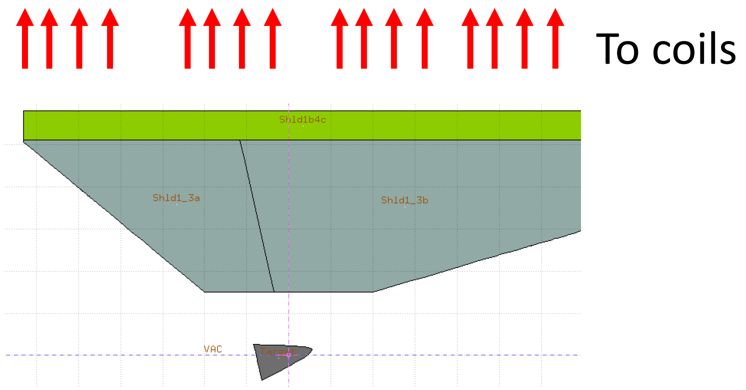
- With time we then move to hybrid (dual layer) solution of W + 7 cm B4C.
- With increased front dimensions from 27 cm to 29 cm.
- The overall drop gained from just tungsten to hybrid at MS1 is : 36 %.
- The drop of dose by adding B4C at CS1 is ~50 %.



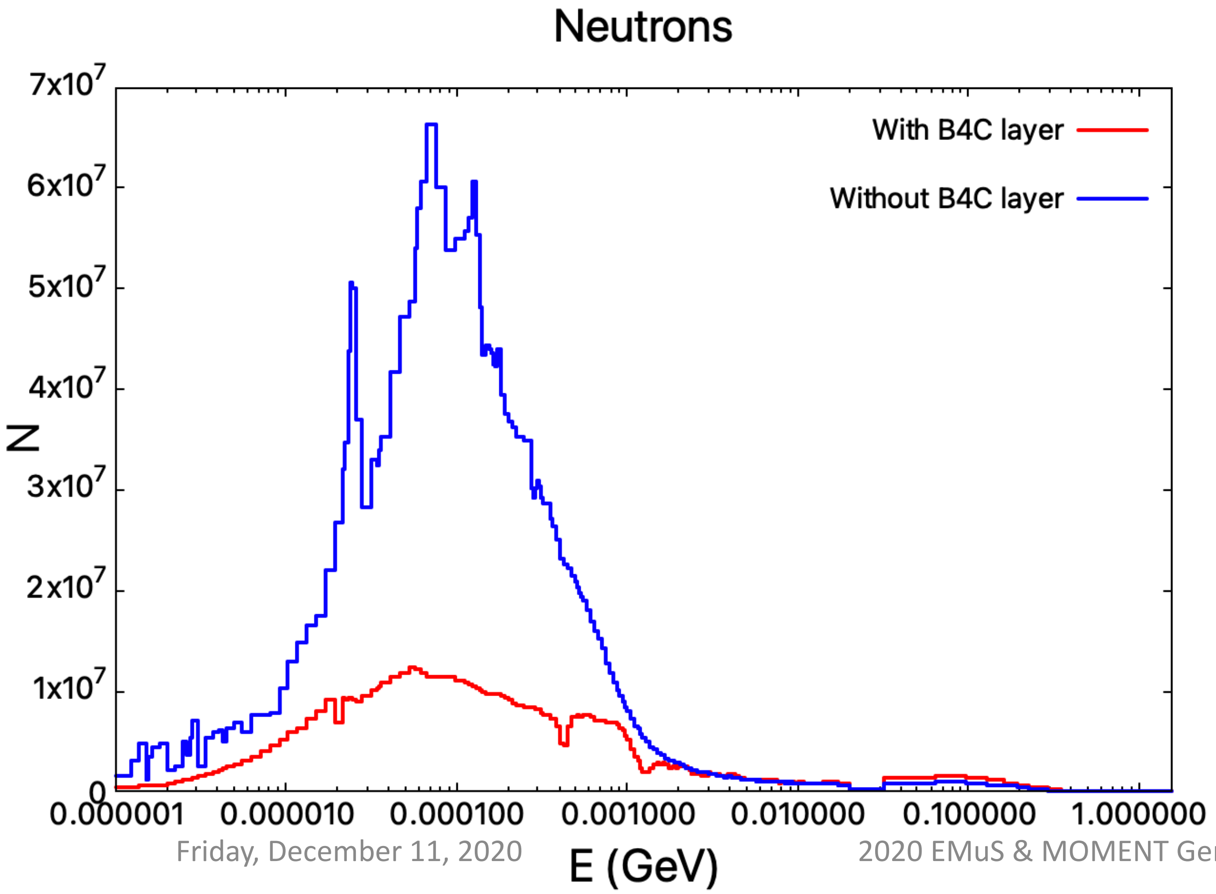
Target length is 15 cm, tilt angle 15 degree and density is 2 gm/cc.

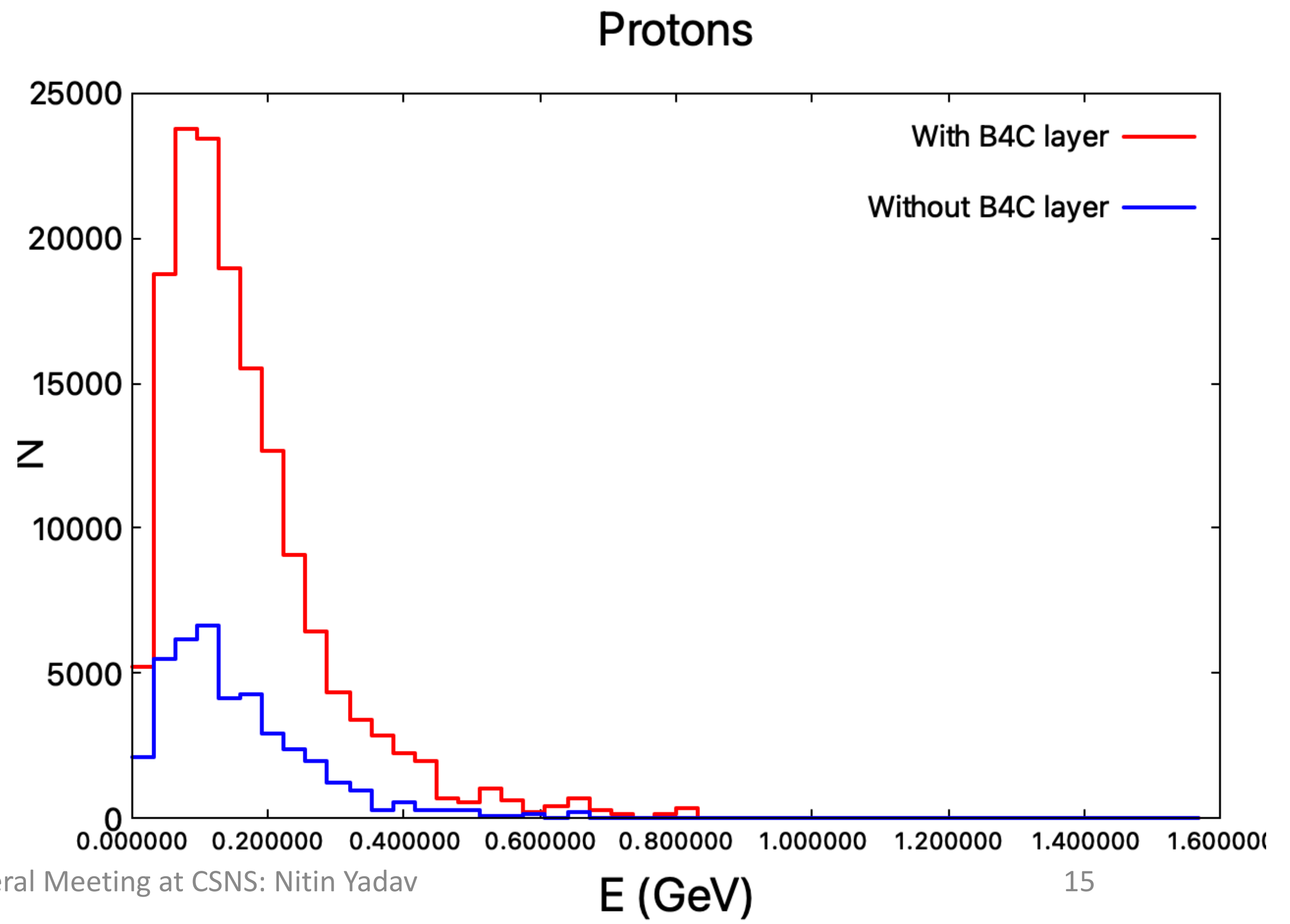


Particles emanating from shielding CS1



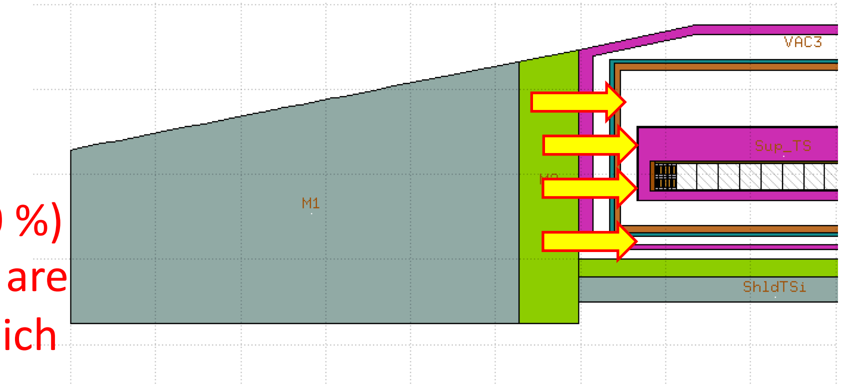
- The width has been optimised for CS1.
- Dual layer (W+ B4C) is found to be better than just a single layer of W.
- ~50 % drop in dose by protons on CS1.
- Dose by protons max : 0.45 MGy/y
- Dose by neutrons max : 0.04 MGy/y

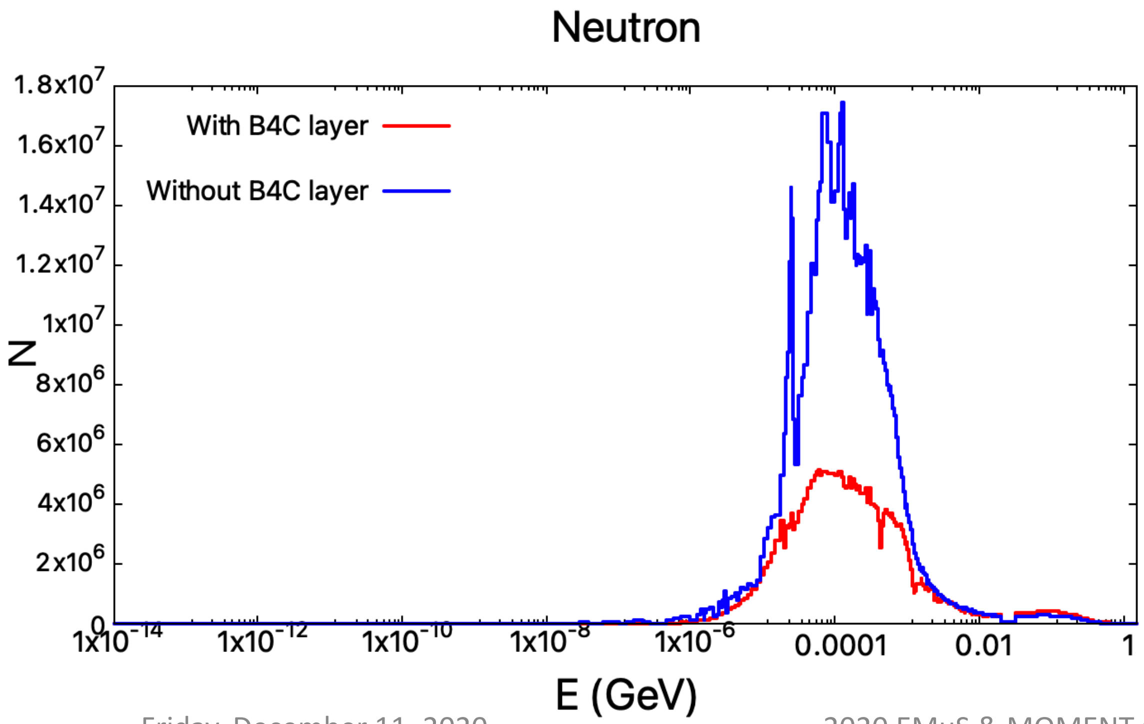


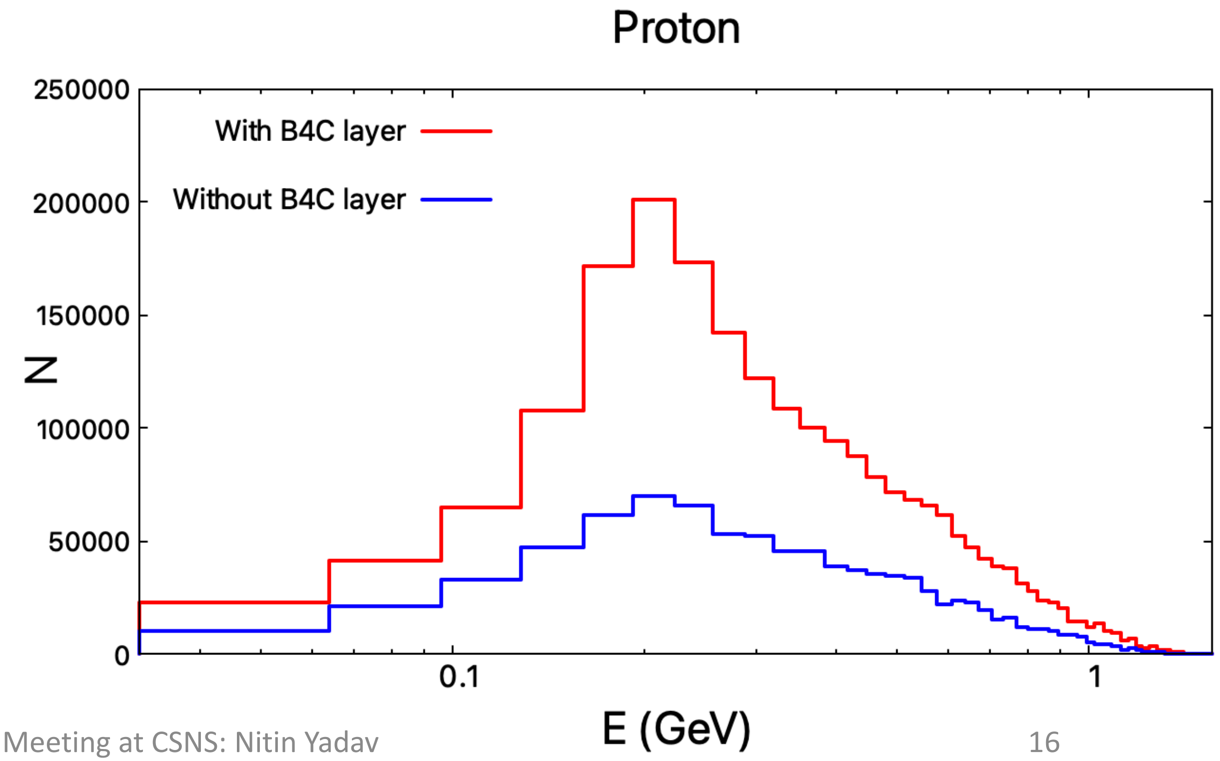


- The B4C width has been optimised for MS1.
  Dual layer (W+ B4C) is found to be better than just a single layer of W.
- ~20 % drop in dose by protons on MS1 after adding B4C.
- Dose by protons max : ~0.9 MGy/y
- Dose by neutrons max : ~0.05 MGy/y
- Protons are not suppressed much after addition of B4C. But there is decrement (20 %) in dose by protons. This is due to the fact that the huge number of neutron s (that are not suppressed in W only shield) may induce further production of protons and which may then increase its dose fraction.

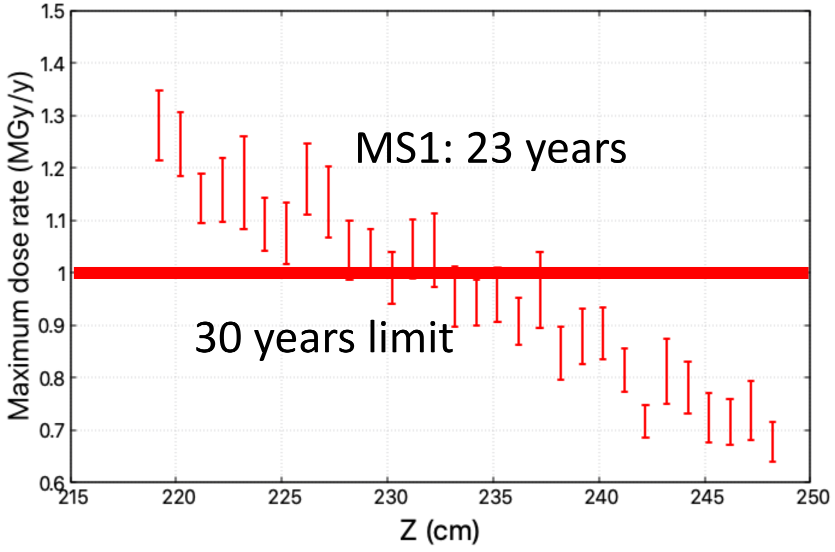
Particle emanating from shield towards coils

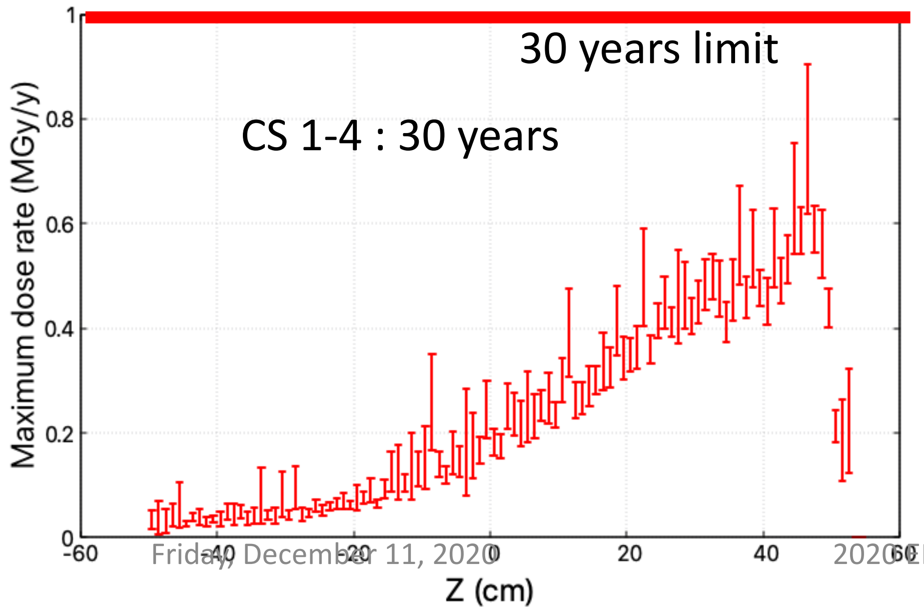


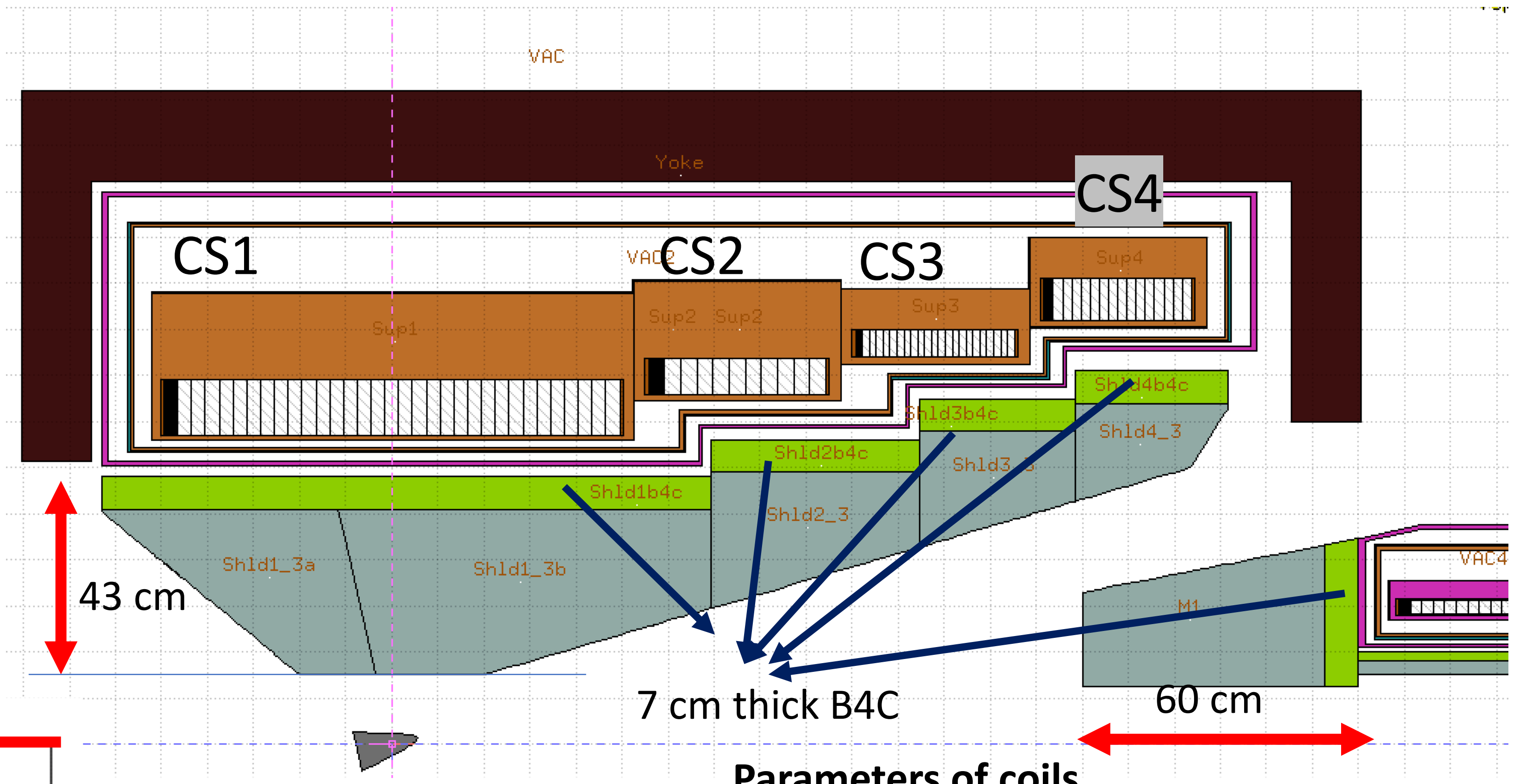




Final baseline shielding







Parameters of coils

coil	Rmin m	Rmax m	Zmin m	Zmax m	Layer	Je A/mm²	Length
CS1	0.67	0.7924	0	1.005	8	42.55	1.005
CS2	0.76	0.8518	1.069	1.435	6	42.55	0.366
CS3	0.84	0.9318	1.499	1.845	6	42.55	0.346
CS4	0.92	1.0118	1.909	2.228	6	42.55	0.319
MS1	0.28	0.3412	2.682	2.982	4	31	0.3
MS2	0.30	0.334	3.509	4.009	34	100	0.5

New shielding ideas and further prospects

Once the geometrical optimization, with available materials choices, exhausts the achievabe overall dose limit, the only way to go forward is innovation or invention. Considering this, our exploration of new material/design is naturally divided among following aspects:

- Invent a new alloy or material for shielding.
- Use hybrid shielding made up of different materials.

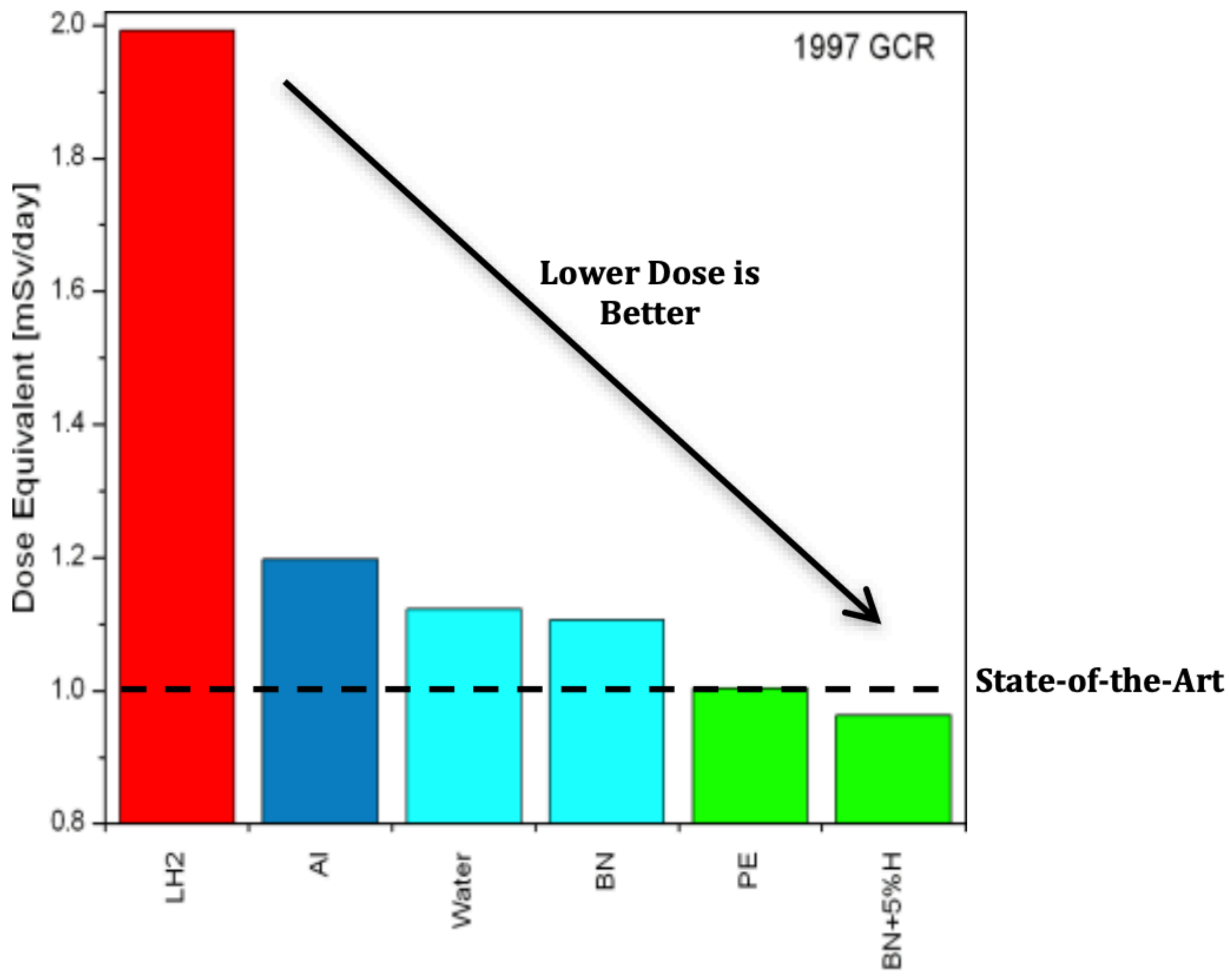
Molecular nano structures

https://www.nasa.gov/sites/default/files/atoms/files/niac_2011_phasei_thibeault_radiationshieldingmaterials_tagged.pdf

- Boron + Nitrogen + 5 % H is what they have used which is quite similar to our Alloy as well.

- So introducing hydrogen enhances the shielding.

- These are the boron nitrogen BNNT molecular nano tubes and boron nitride structure which can contain lot of hydrogen.



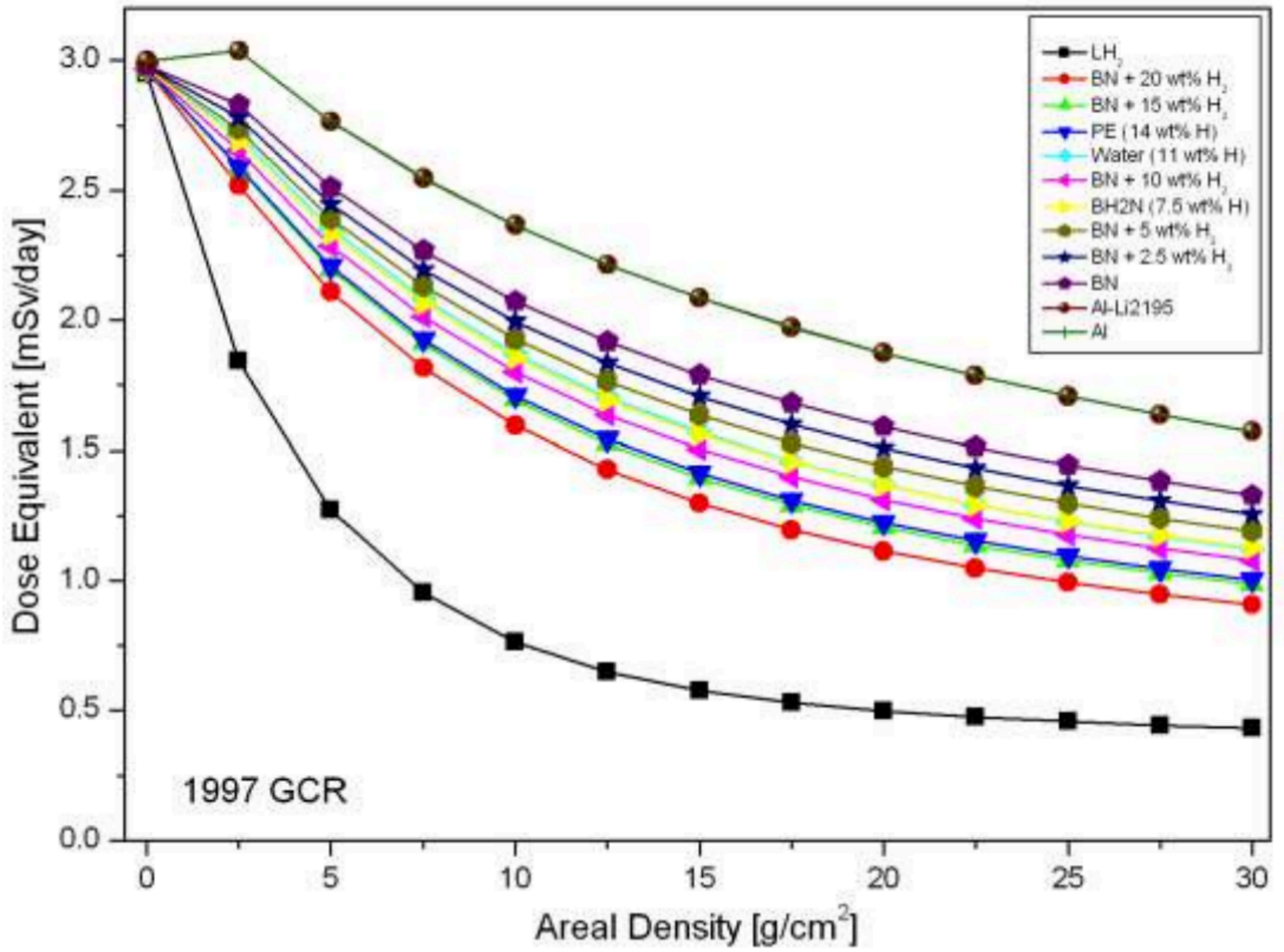
Molecular nano structures

https://www.nasa.gov/sites/default/files/atoms/files/niac_2011_phasei_thibeault_radiationshieldingmaterials_tagged.pdf

❖ As we increase the density the dose decreases.

❖ So in order to look for better shielding option, a combination of light materials including B + H + C or N etc expected to have better prospects.

(Because lower Z material has less spallation due to less number of hadrons, so good moderators)



➢ Invent a new alloy for shielding.

- The shielding materials for secondary neutrons are those which have low Z materials (preferably Hydrogen or hydrogenated materials).
- Also it has been found that higher is the density higher is the radiation stopping capability of the materials.

  - Considering above guidance we came up with an alloy, which is a amalgamation of 90 % tungsten and 10 % admixture of Boron, Carbon and Hydrogen.

    We can have alternate exotic MC solution based on Tungsten based on W-borocarbides alloys.
    We have three promising options (all better than W)-

    W + (B+C+H)

    W + (B+C+Li)

    W + (B+C+Bi)

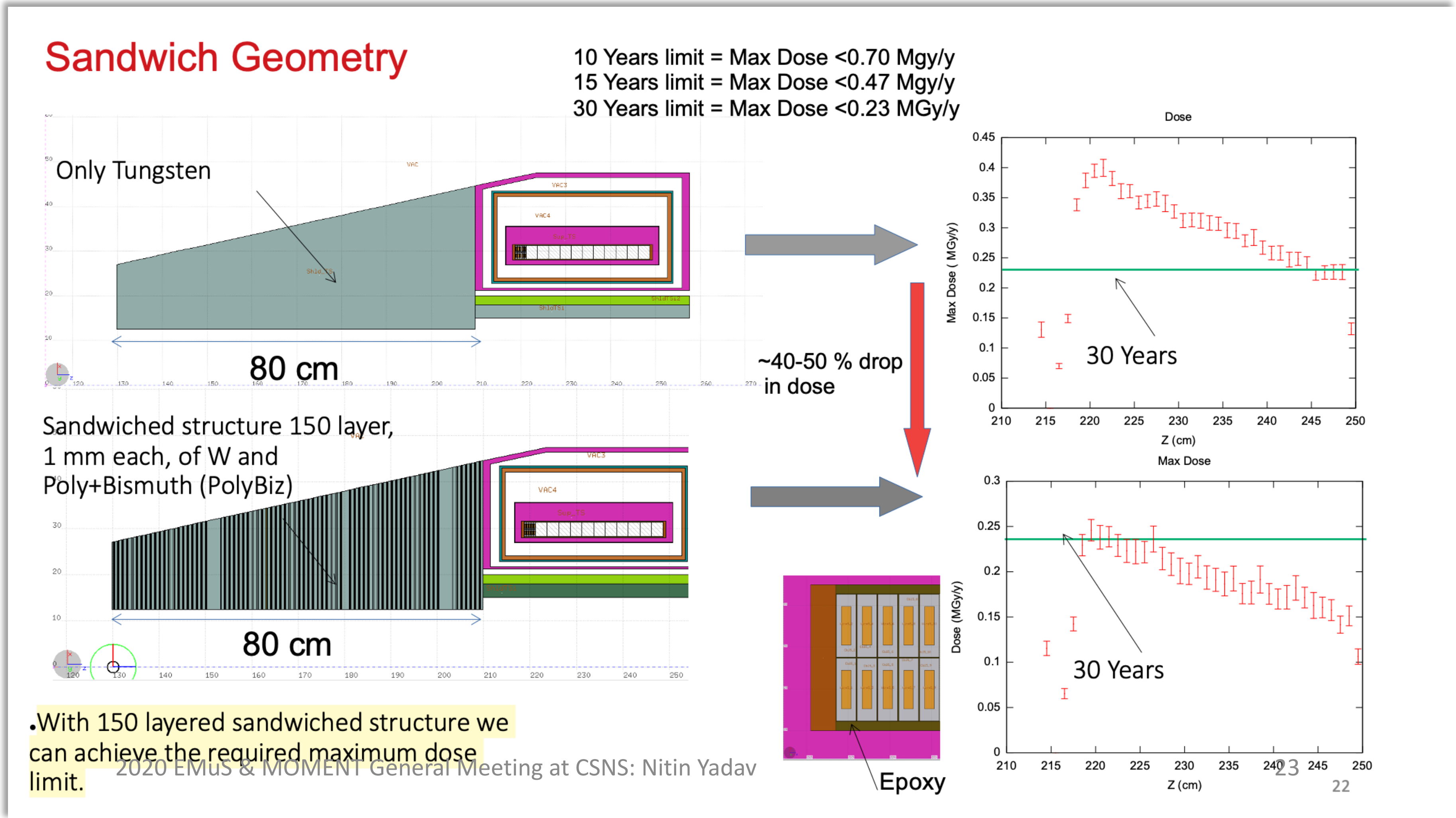
  - The simulated results are very promising.
  - 80 cm Alloy MS1 shield, 15 cm target : ~0.3 MGy/ : ~ 100 years operation.

  - However, the alloy could not be made feasible due to its high density and technical problem of mixing hydrogen.

➢ Invent a new alloy for shielding.

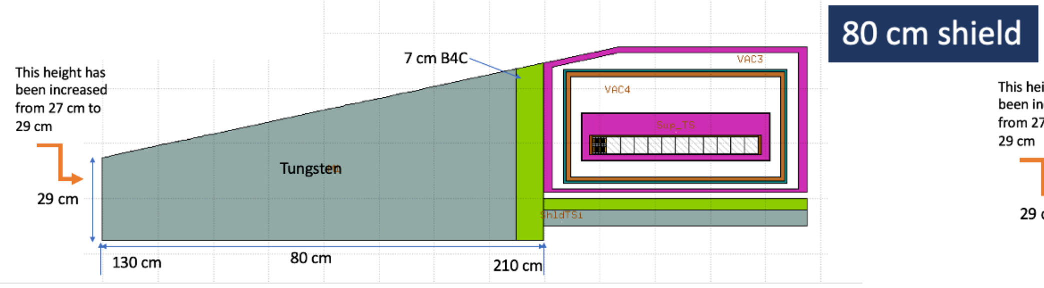
- ➢ Since alloy is mixed with fractional densities in simulation, we can make an alternate approximate feasible solution that can replace alloy.
  - ➢ The idea is to use sandwich structure with very thin layers of Tungsten and a material (which can mimic low Z character for BCH).

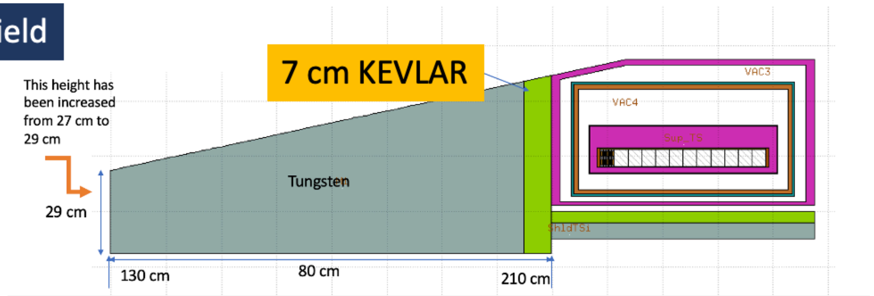
✓ 40 - 50 % drop in dose is possible in comparision with just W and sandwich structure made up of W and laternate polubiz layers.

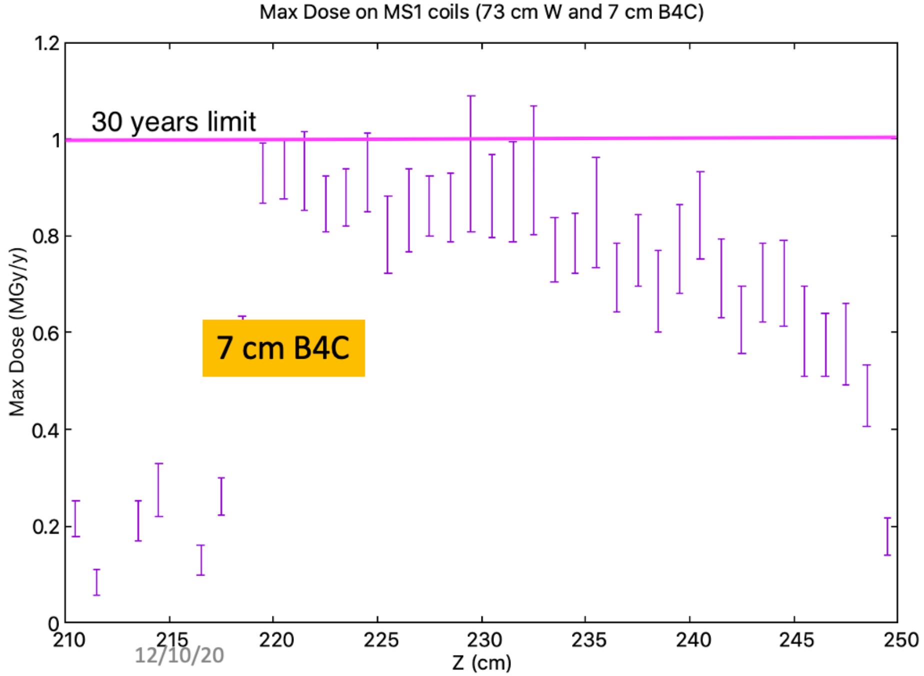


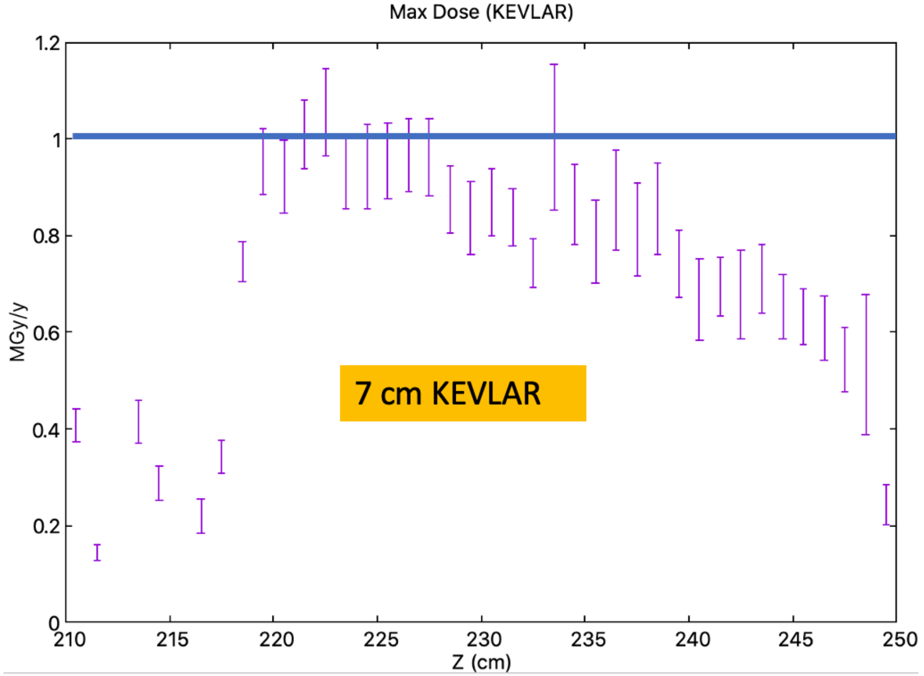
➢ Use hybrid shielding made up of different materials.

- ✓ Tungsten followed up by a low Z
- ✓ Material like B4C or KEVLAR found to be useful.
- ✓ W + B4C has been chosen for current shielding.
- ✓ KEVLAR is bullet proof material.
- ✓ Another material to be considered is Aluminium bromide.









Performances of Kevlar and Polyethylene as radiation shielding on-board the International Space Station in high latitude radiation environment - Scientific reports

https://doi.org/10.1038/s41598-017-01707-2

Several new materials/designed explored

More than or equal to 30 years operation

More than or equal to 15 years, but less than 30 years operation.

MS1 position at 210 cm, 15 cm target, 15 degree angle tilt

Shield L	As before (only W)	W + B4C	W + PolyBiz	Sandwich (not fully optimized)
80 cm	1.4 MGy/y (21.4 years)	1.0 MGy/y (30 years)	0.8 MGy/y (37.5 years)	0.8 MGy/y (37.5 years)
60 cm	1.7 MGy/y (17.6 years)	1.3 MGy/y (23 years)	1.0 MGy/y (30.0 years)	1.2 MGy/y (25.0 years)
50 cm	2.4 MGy/y (12.5 years)	2.0 MGy/y (15 years)	1.6 MGy/y (18.0 years)	1.8 MGy/y (16.7 years)
			80 cm Alloy shield, 15 cm target : ~0.3 MGy/. ~ 100 years operation.	

Upstream: MS1 position at 200 cm, 15 cm target, 15 degree angle tilt

	As before (only W)	W + B4C	W + PolyBiz	Sandwich (not fully optimized)
70 cm	2.4 MGy/y (12.5 years)	2.0 MGy/y (15 years)	~1.6 MGy/y (18.0 years)	~1.8 MGy/y (16.7 years)

In comparison to previous configuration dose rates the current configuration (increased radius and hybrid) with :

- B4C lowers the dose maximum upto ~30 % .
- PolyBiz lowers the dose maximum upto 43 % .
- Sandwich lowers the dose maximum upto 43 %.
- Alloy lowers the dose maximum upto ~ 80 %.

- We can move MS1 10 cm upstream for 15 years life operation.
- With two layers hybrid solution, PolyBiz works better than B4C.
- Since sandwich is not yet fully optimized, we can not say which one is better yet(two layer or sandwich).

Summary and outlook:

- ✓Simplified Scheme
  - ✓The shield has been designed made up of concrete and steel.

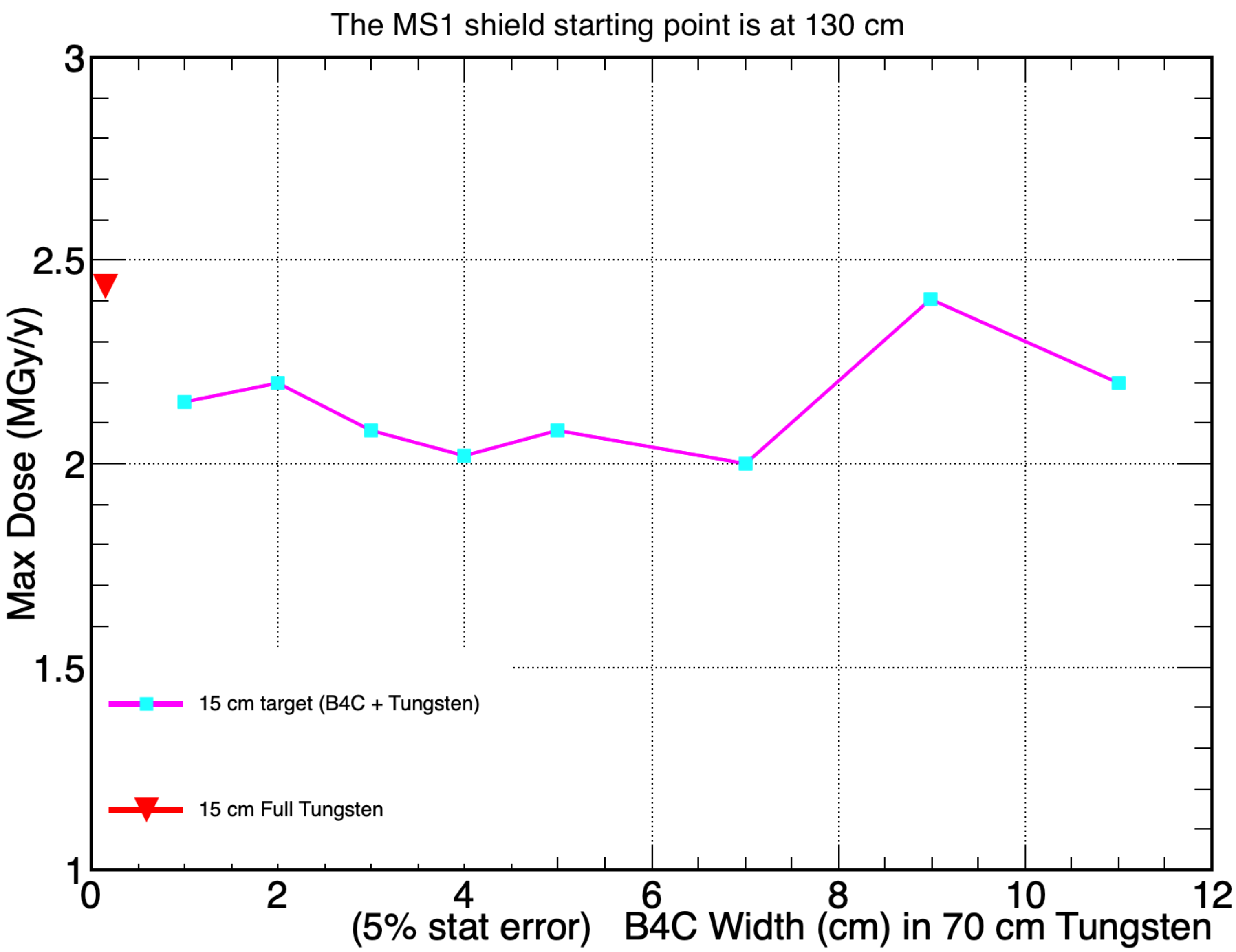
- ✓Baseline Scheme
  - ✓The shield has been designed with CS as 30 years operations and MS1 as 23 - 30 years operation (depending on MS1 length)

- ✓New shielding ideas and further prospects.
  - ✓Alloy, hybrid and sandwhich structures are studied. Currently a hybrid shielding (W + B4C) is chosen for baseline scheme.
  - ✓More ideas are being explored.

Thank you!

Backup and extras

B4C width optimization for upstream MS1 position.



Normalization factor
25 kW : 27e7

==>For 5 kW proton beam.

This is a non-normalises energy deposition. One need to normalise it.

B. How to do normalisation. (here normalisation is done for 200 days, beam energy is 1.6 GeV)
FLUKA gives scoring per primary (or per proton). To normalise it to certain beam power one needs to do :
- POT per sec= Power/Energy
- POT for time t= Power*t/ Energy

POT for 200 days: 5 *1000*(200*24*60*60)/(1.6*10E9 * 1.6*10E-19) = 3.375 *10E20 POT/200Days

1. Fluence unit in FLUKA: Particle/cm^2. So converting it to m^2 multiply it by 10^4.

So normalisation factor becomes- POT for 200 days * 10E4
----
2. Dose:
Normalization factor:
- POT= Power/Energy
- POT for time t= Power*t/ Energy
POT for 200 days: 5 *1000*(200*24*60*60)/(1.6*10E9 * 1.6*10E-19) = 3.375 *10E20 POT/200Days

1. Dose unit in FLUKA: GeV/g. To get it in Gy unit, multiply it with 1.6E-7. Then to convert it in MGy, multiply by 10E-6

So normalisation factor becomes- POT for 200 days * 1.6E-13 = 5.4E7
----

3. Power density (W/cm^3)

Normalization factor:
- POT= Power/Energy
- POT for time t= Power*t/ Energy

POT for 200 days: 5 *1000*(200*24*60*60)/(1.6*10E9 * 1.6*10E-19) = 3.375 *10E20 POT/200Days

1.Energy unit in FLUKA: GeV/cm^3. So to show the power density (Watt/cm^3). We need to multiply it with 1.6E-19 * 10E9 and divide by time (200 days).

So normalisation factor becomes- POT for 200 days * 1.6E-19 *10E9/ 200 days.=3125

==>For 25 kW. Just multiply the above numbers with 5.