GMN ERR: Radiation Levels and Local shielding (Item 8 of ERR Charge)

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GMN experiment readiness review

June 16, 2017

Acknowledgements:

- The vast majority of the MC simulation work presented here was performed by UConn postdoc Eric Fuchey and UConn graduate student Freddy Obrecht
- Thanks to Pavel Degtiarenko for timely calculation of preliminary Radiation Budget
- Support from US Department of Energy, Award ID #DE-SC0014230

Outline

- Response to item 8 of the charge: "*Are the radiation levels expected to be generated in the hall acceptable? Is any local shielding required to minimize the effects of radiation in the hall equipment?*"
- Radiation Budget Form
- GEANT4 Monte Carlo simulation of GMN layout
  - Radiation dose rates in rad-sensitive detectors
  - Background rates in low-threshold detectors
  - Radiation levels in GEM electronics hut
- Status of beamline activation estimates
- Summary and conclusions

Hall: A

RADIATION BUDGET FORM

Exp. # GMn E12-09-016 **rev: 0** **run dates: 2019** **name of liaison: Eric Fuchey**

setup number			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
beam	energy	GeV	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	6.6	6.6	6.6	8.8	8.8	8.8	8.8	8.8
	current	uA(CW)	19.2	52.4	30.9	19.2	39.0	30.9	24.0	58.1	24.0	24.0	52.5	22.5	30.0	52.5	30.0	30.0	53.3
radiator	element																		
	thickness	mg/cm2																	
	dist. to pivot	m																	
	Z		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	A		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
exp't target	element		D	H	Al	D	H	Al	D	H	Al	D	H	Al	D	H	Al	D	H
	thickness	mg/cm2	2435	1062	935	2435	1062	935	2435	1062	935	2435	1062	935	2435	1062	935	2435	1062
	dist. to pivot	m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Z		1	1	13	1	1	13	1	1	13	1	1	13	1	1	13	1	1
	A		2	1	27	2	1	27	2	1	27	2	1	27	2	1	27	2	1
cryo tgt window	element		Al	Al		Al	Al		Al	Al		Al	Al		Al	Al		Al	Al
	thickness	mg/cm2	83	83		83	83		83	83		83	83		83	83		83	83
	dist. to pivot	m	0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0
	Z		13	13	0	13	13	0	13	13	0	13	13	0	13	13	0	13	13
	A		27	27	0	27	27	0	27	27	0	27	27	0	27	27	0	27	27
critical window	radius	cm	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8
	dist. to pivot	m	5.10	5.10	5.10	5.10	5.10	5.10	5.10	5.10	5.10	5.10	5.10	5.10	5.10	5.10	5.10	5.10	5.10
scattering weighting factor			0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
time	run time	hours	30	69	7	30	24	7	30	32	6	30	8	4	24	8	3	48	9
	(100% eff.)	days	1.3	2.9	0.3	1.3	1.0	0.3	1.3	1.3	0.3	1.3	0.3	0.2	1.0	0.3	0.1	2.0	0.4
	installation	hours																	
	time	days	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
dose rate at	method 1	urem/hr	0.97	0.53	1.35	0.97	0.39	1.35	1.21	0.59	1.05	1.37	0.53	1.10	1.87	0.55	1.58	1.87	0.56
the fence post	method 2	urem/hr																	
(run time)	conservative	urem/hr	0.97	0.53	1.35	0.97	0.39	1.35	1.21	0.59	1.05	1.37	0.53	1.10	1.87	0.55	1.58	1.87	0.56
dose per setup		urem	29	36	9	29	9	9	36	19	6	41	4	4	45	4	5	90	5
% of annual dose budget		%	0.3	0.4	0.1	0.3	0.1	0.1	0.4	0.2	0.1	0.4	0.0	0.0	0.4	0.0	0.0	0.9	0.1

date form issued: May 15, 2017 *authors:* P.Degtiarenko

Hall: A | # RADIATION BUDGET FORM |

Exp. # GMn E12-09-016 **rev: 0** **run dates: 2019** **name of liaison: Eric Fuchey**

setup number			18	19	20	21	22	23	24	25	26	27	
beam	energy	GeV	**8.8**	**11.0**	**11.0**	**11.0**	**4.4**	**4.4**	**4.4**	**4.4**	**4.4**	**4.4**	***totals:***
	current	uA(CW)	**30.0**	**30.0**	**55.4**	**30.0**	**20.0**	**20.0**	**60.0**	**20.0**	**20.0**	**60.0**	
radiator	element						**Cu**	**Cu**		**Cu**	**Cu**		
	thickness	mg/cm2					772	772		772	772		
	dist. to pivot	m					-0.15	-0.15		-0.15	-0.15		
	Z		0	0	0	0	29	29	0	29	29	0	
	A		0	0	0	0	64	64	0	64	64	0	
exp't target	element		**Al**	**D**	**H**	**Al**	**H**	**Al**	**H**	**H**	**Al**	**H**	
	thickness	mg/cm2	935	2435	1062	935	1062	935	1062	1062	935	1062	
	dist. to pivot	m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	Z		13	1	1	13	1	13	1	1	13	1	
	A		27	2	1	27	1	27	1	1	27	1	
cryo tgt window	element			**Al**	**Al**		**Al**		**Al**	**Al**		**Al**	
	thickness	mg/cm2		83	83		83		83	83		83	
	dist. to pivot	m		0.0	0.0		0.0		0.0	0.0		0.0	
	Z		0	13	13	0	13	0	13	13	0	13	
	A		0	27	27	0	27	0	27	27	0	27	
critical window	radius	cm	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	
	dist. to pivot	m	5.10	5.10	5.10	5.10	5.10	5.10	5.10	5.10	5.10	5.10	
scattering weighting factor			0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
time	run time (100% eff.)	hours	4	100	13	8	12	2	3	24	2	6	543
		days	0.2	4.2	0.5	0.3	0.5	0.1	0.1	1.0	0.1	0.3	22.6
	installation time	hours											0
		days	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
dose rate at the fence post (run time)	method 1	urem/hr	**1.58**	**1.94**	**0.59**	**1.65**	**1.57**	**2.53**	**0.61**	**1.57**	**2.53**	**0.61**	
	method 2	urem/hr											
	conservative	urem/hr	**1.58**	**1.94**	**0.59**	**1.65**	**1.57**	**2.53**	**0.61**	**1.57**	**2.53**	**0.61**	
dose per setup		urem	**6**	**194**	**8**	**13**	**19**	**5**	**2**	**38**	**5**	**4**	**676.46**
% of annual dose budget		%	**0.1**	**1.9**	**0.1**	**0.1**	**0.2**	**0.1**	**0.0**	**0.4**	**0.1**	**0.0**	**6.7646**
% of allowed dose for the total time													**109.13**
% of allowed dose for the run time only													**109.13**

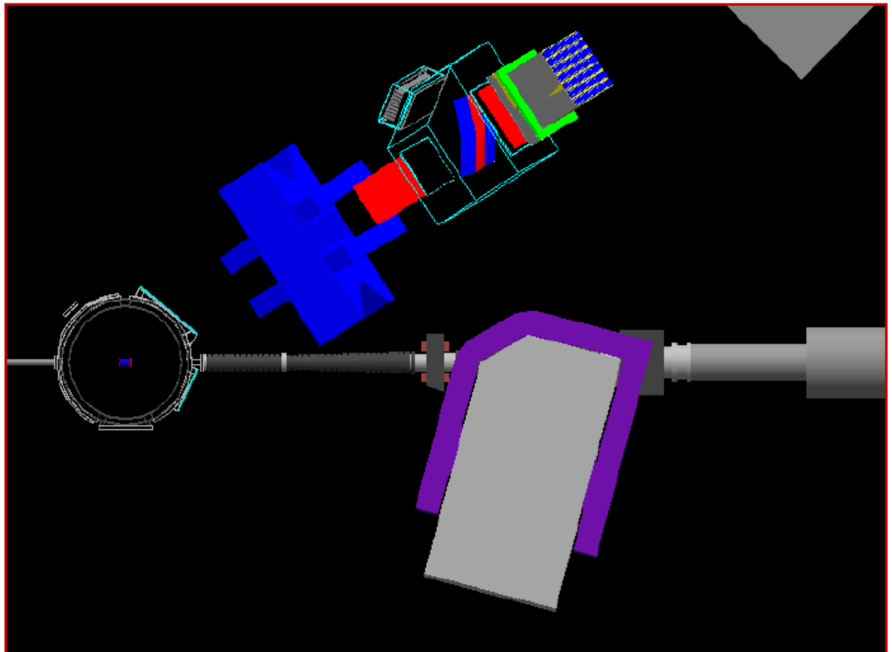
If > 200%, discuss result with Physics Research EH&S officer

date form issued: May 15, 2017 *authors:* P.Degtiarenko

GEANT4 Monte Carlo simulation of GMN layout

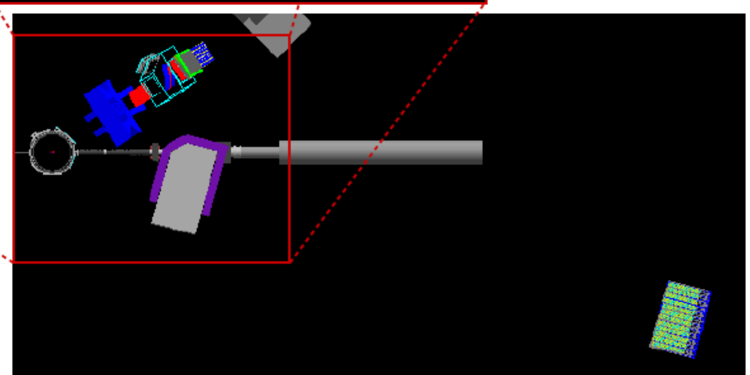
Reminder:
G_M^n setup update

Updated G_M^n beamline in g4sbs with the actual design:



- Conic vacuum line weldment;
- spool piece;
- inner and outer magnetic shieldings;
- beam corrector magnets;

Configuration of the two later items can be changed with a new command:
/g4sbs/beamlineconfig <int>
The integer being equal to the beamline configuration number convention used by the engineers:
1 for G_E^p, 2 for G_E^n,
3 for G_M^n (all Q2 but higher),
4 for G_M^n (higher Q2 + calibrations).

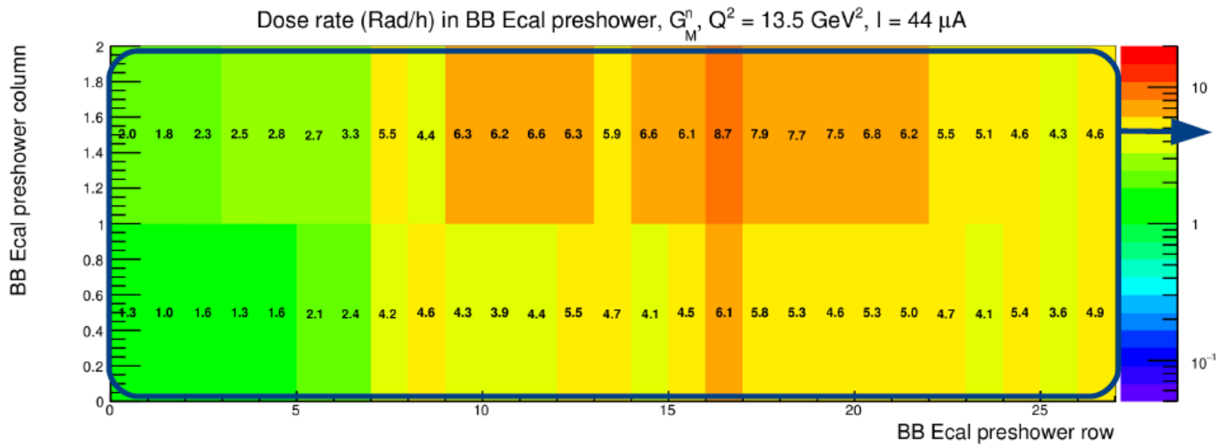


Detector Backgrounds: Baseline Scenario

- No additional shielding of downstream beamline nor local shielding of detectors
- TOSCA-generated realistic field maps for SBS and BigBite magnets
- Beam currents/kinematics/luminosities as shown in the table in Brian Quinn's overview talk
- $Q^2 = 13.5$ GeV^2 is worst-case scenario for radiation dose rates and detector background rates (also, nearly half the total production beam time is spent at this kinematic)
  - Unless otherwise noted, all simulation results shown here are for the $Q^2 = 13.5$ GeV^2 case

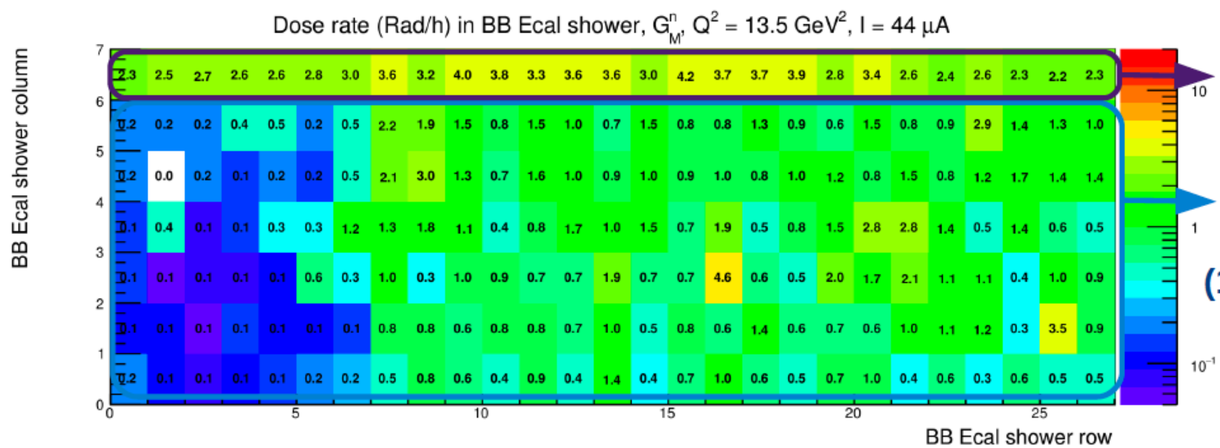
BB Ecal dose rate for G_M^n

Q^2 = 13.5 GeV^2, I_{beam} = 44μA, 10 cm LD_2, new setup, Tosca field map



4.6 Rad/h/block avg over PS

x100 h beam time: 460 Rad integrated *for this kinematic*. Max dose for a single block: ~900 Rad.



3.1 Rad/h/block avg

0.9 Rad/h/block avg

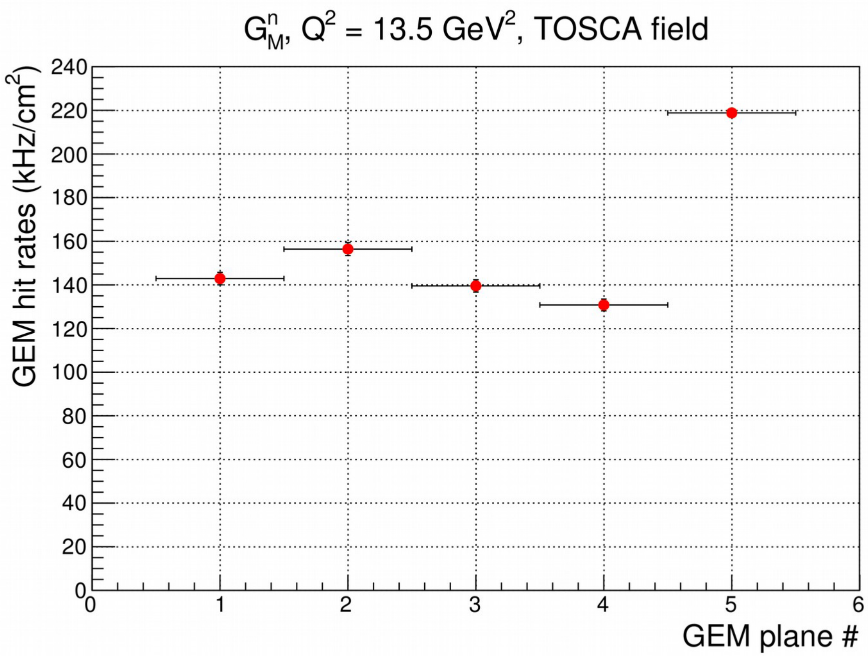
(1.2 Rad/h/block avg over SH)

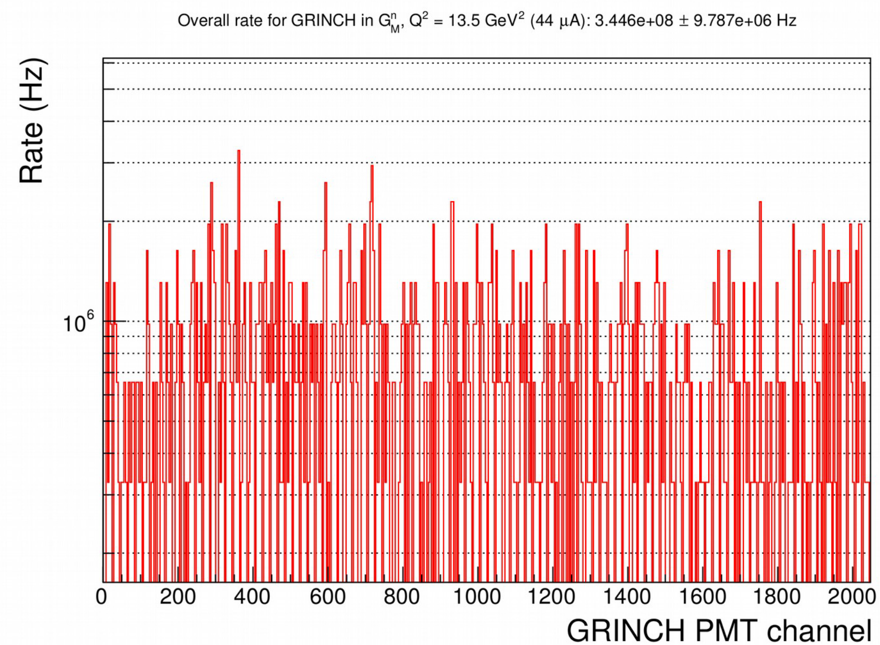
No additional shielding: Previous studies (SBS soft/simu meeting 2017/03/22) showed it could be shielded easily

Note: lead-glass starts to deteriorate for doses of order ~1 krad

Detector Background Rates for GMN @Q^2 = 13.5 GeV^2

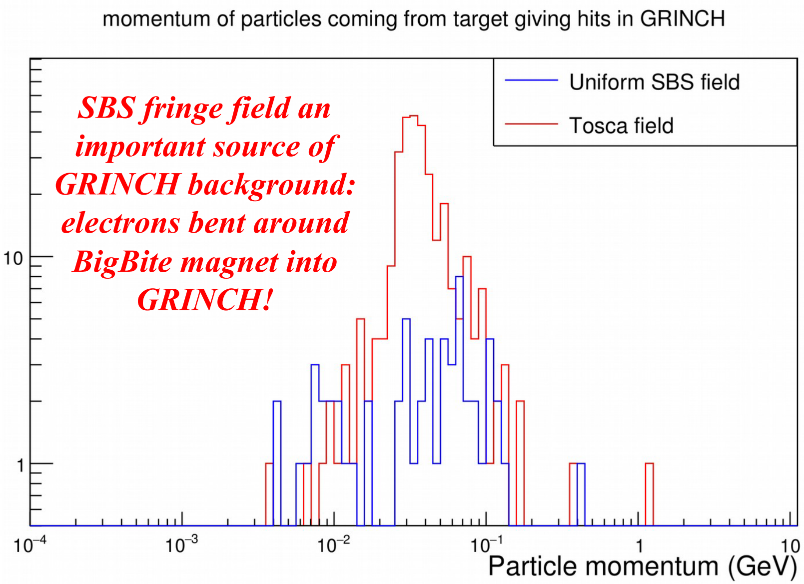
Baseline Scenario (TOSCA field map, NO SHIELDING)

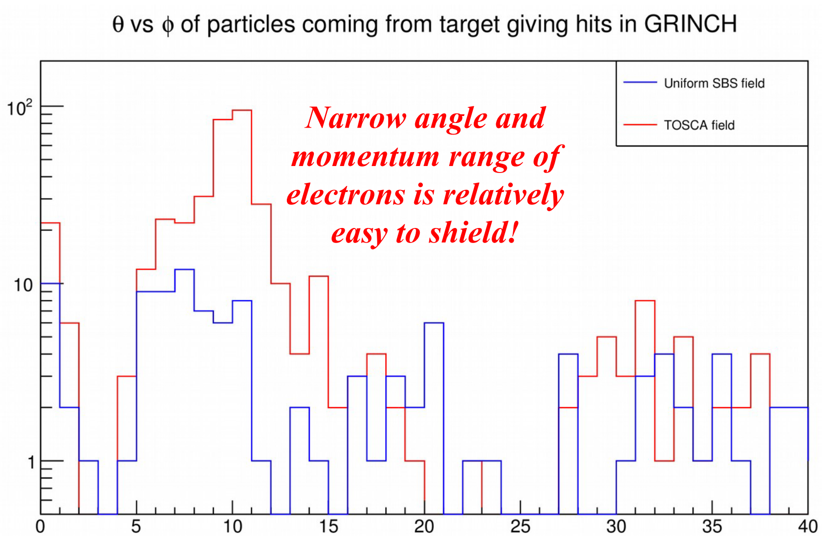


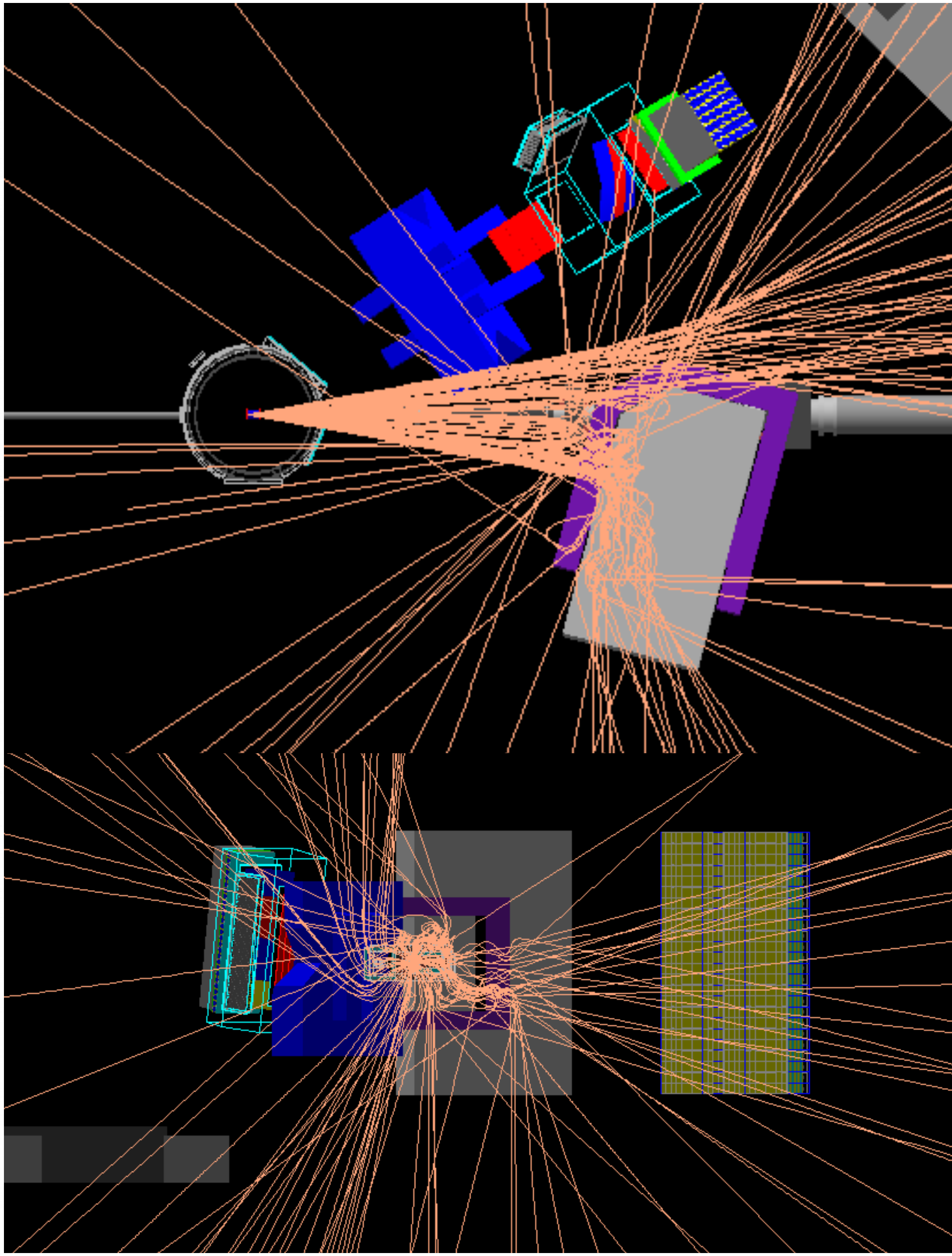


- For GEM layers 1-4 (5), located in front of (behind) the GRINCH, baseline scenario for GEM hit rate is ~140 (220) kHz/cm^2, of which:
  - ~70% is "direct" from target
  - The rest is from SBS magnet, downstream beamline, scattering chamber
- For the GRINCH, the baseline is 345 MHz total counting rate for the whole detector or ~680 kHz per PMT, of which:
  - ~60% "direct" from target
  - ~20% from downstream beam line
  - Rest from SBS magnet and scattering chamber

Source of large background rate in GRINCH



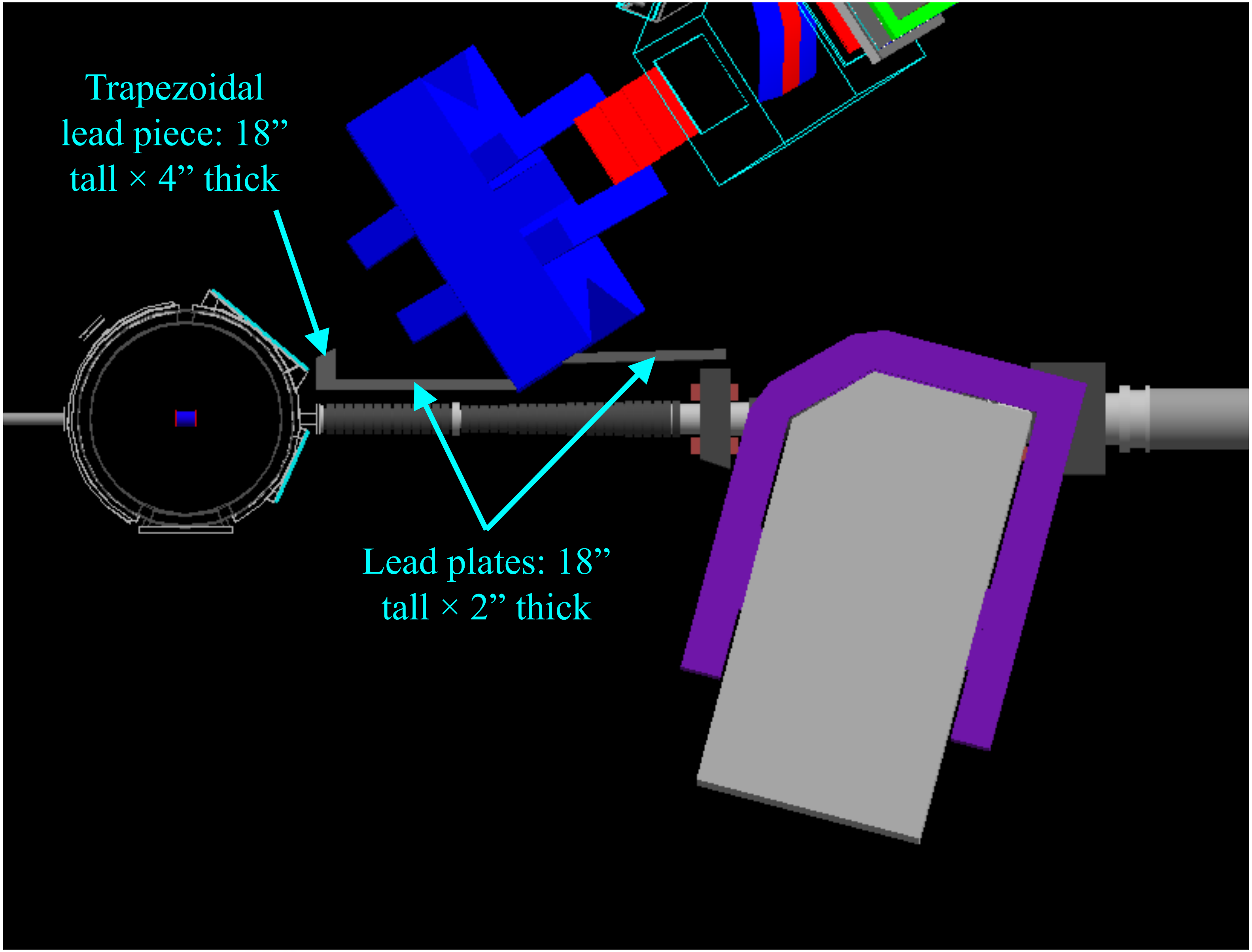




Summary of baseline scenario

- Without additional shielding of the BigBite detectors from backgrounds, the rates are high but manageable (in principle).
- GEM background hit rates (particularly in layers 1-4) are dominated by soft photon-induced backgrounds; i.e., Compton scattering, pair production in GEM materials and subsequent ionization
- GRINCH background rates experience a large contribution from electrons produced in a narrow angular and momentum range, bent around the BigBite magnet into the GRINCH
- As shown below, significant reductions are possible with modest volume of additional shielding with simple geometry, low-cost materials

“First” proposed shielding concept (`Iteration 2′′`)

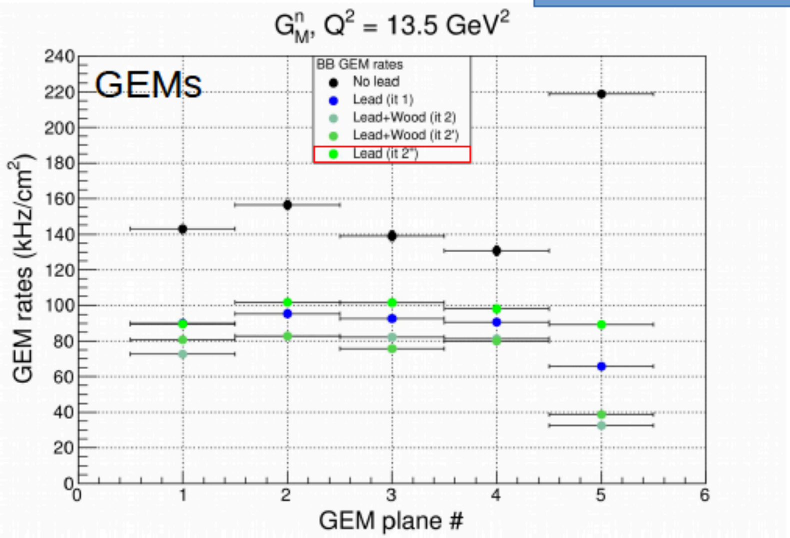


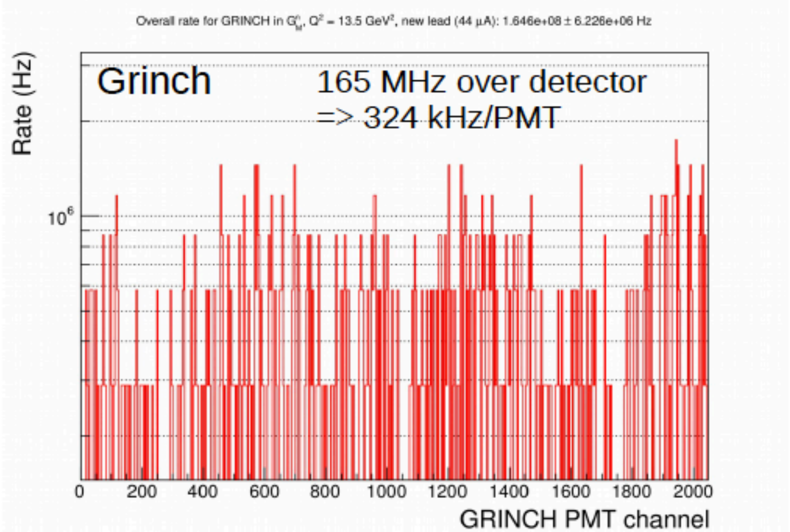
All detector rates for G_M^n

$Q^2 = 13.5$ GeV^2, $I_{beam} = 44\mu A$, 10 cm LD_2, new setup, Tosca field map

Beamline shielding + ECal shielding (1 cm steel + 5cm Al)

ITERATION 2"





64% from **target**,
6% from 48D48,
14% from BL,
6% from SC;

Rest (10%) ?

With lead shielding of the downstream beamline and scattering chamber ONLY, GEM hit rates reduced to 100 kHz/cm^2 or less. GRINCH rates down by a factor of 2 wrt baseline scenario.

146 kHz/PMT (45%) from **target**,
62 kHz/PMT (19%) from 48D48,
84 kHz/PMT (26%) from BL,
32 kHz/PMT (10%) from SC.

This shielding layout (`Iteration 2''`) is assumed in GEM occupancy/DAQ projections

(* wrt no lead shielding)

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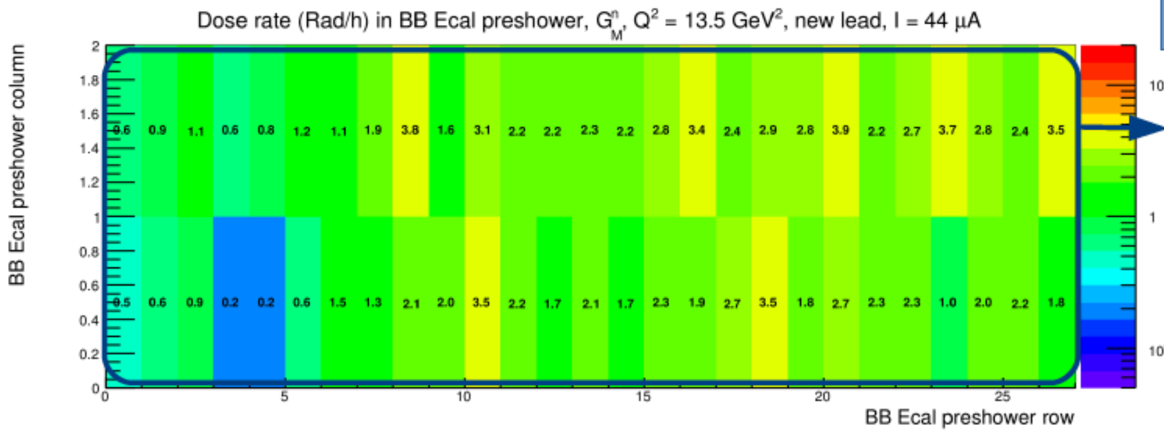
BB Ecal dose rate for G_M^n

$Q^2 = 13.5\ \mathrm{GeV}^2$, $I_{beam} = 44\mu A$, 10 cm LD_2, new setup, Tosca field map

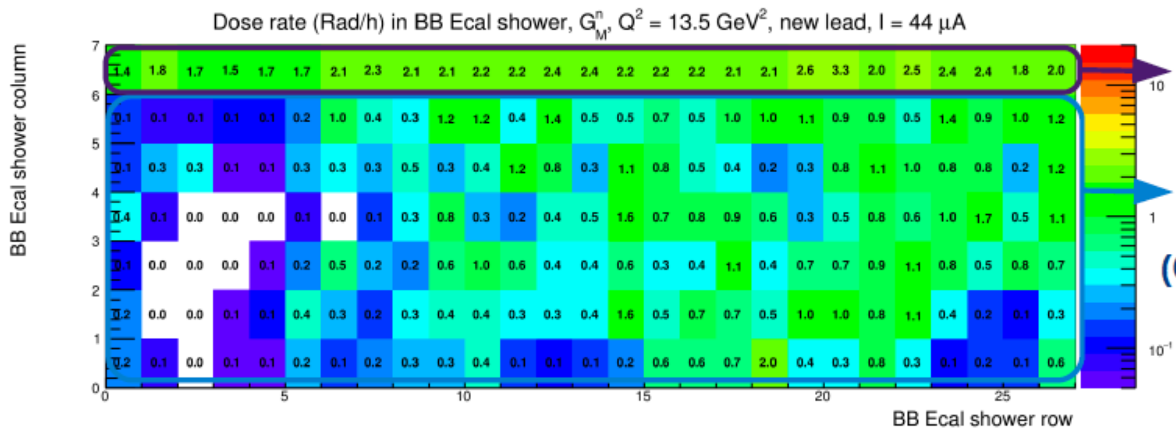
Beamline shielding + ECal shielding (1 cm steel + 5cm Al)

ITERATION 2"



2.01 Rad/h/block avg over PS

x100 h beam time: <200 Rad integrated *for this kinematic*. Max dose for a single block: ~300 Rad.



2.13 Rad/h/block avg

0.51 Rad/h/block avg

(0.74 Rad/h/block avg over SH)

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Shielding reduces cumulative radiation dose in BigBite lead-glass to a level well below the "threshold" for performance degradation

”Iteration 3” of shielding concept

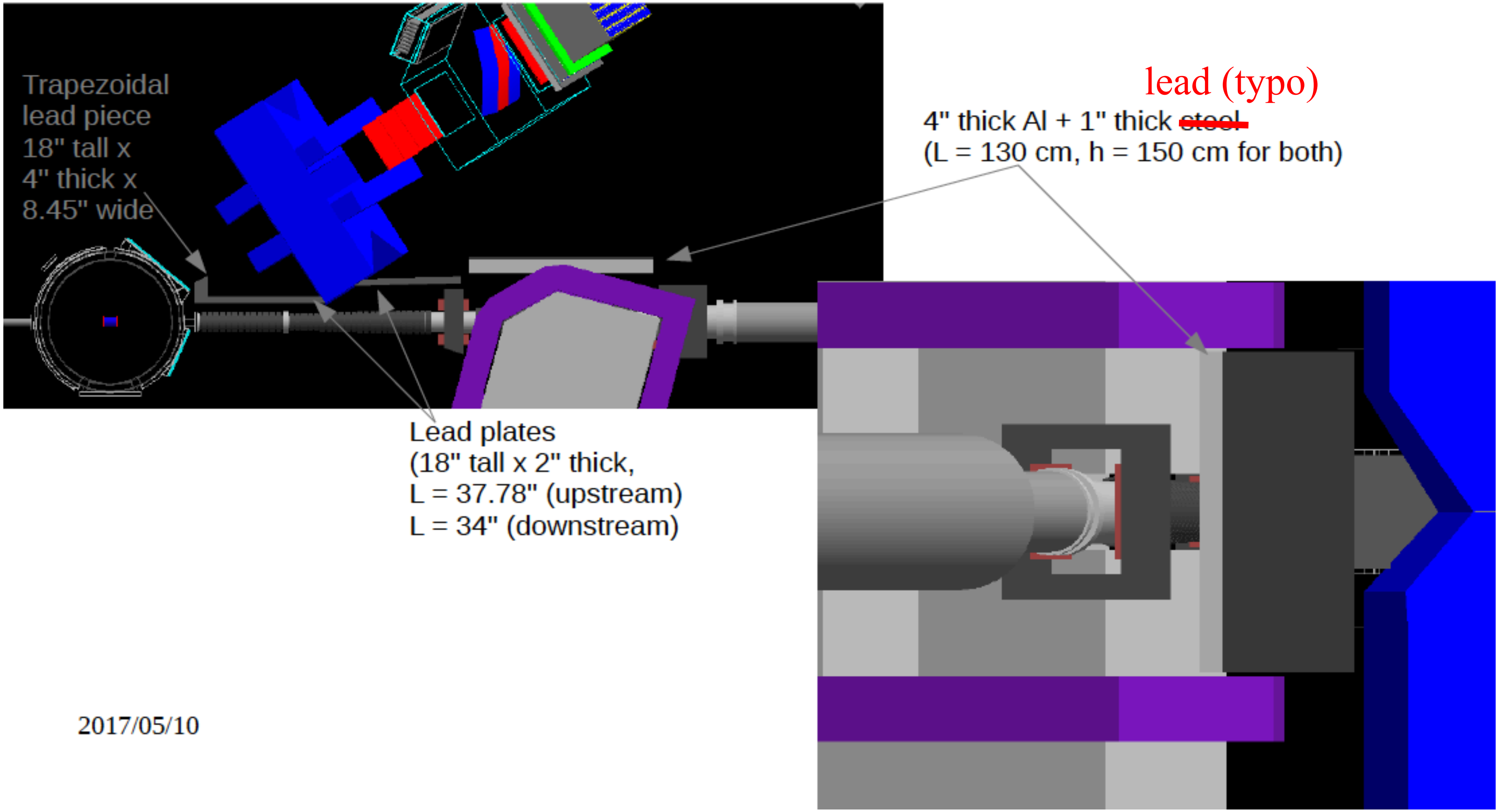
- Earlier studies (Iteration 2 and Iteration 2’) using unrealistic/impractical shielding geometries had indicated that further background suppression (especially for the GRINCH) would be possible by shielding the area of the downstream beamline between the two corrector magnets close to the SBS magnet
- In this region, the ideal shielding design is a ”hybrid” of low-Z material such as aluminum with sufficient thickness to stop low-energy (tens of MeV) electrons, followed by a small thickness of high-Z material (e.g. lead) to absorb soft photons

Beamline shielding for G_M^n

Q^2 = 13.5 GeV², I_{beam} = 44μA, 10 cm LD_2, new setup, Tosca field map

Preliminary design:

ITERATION 3



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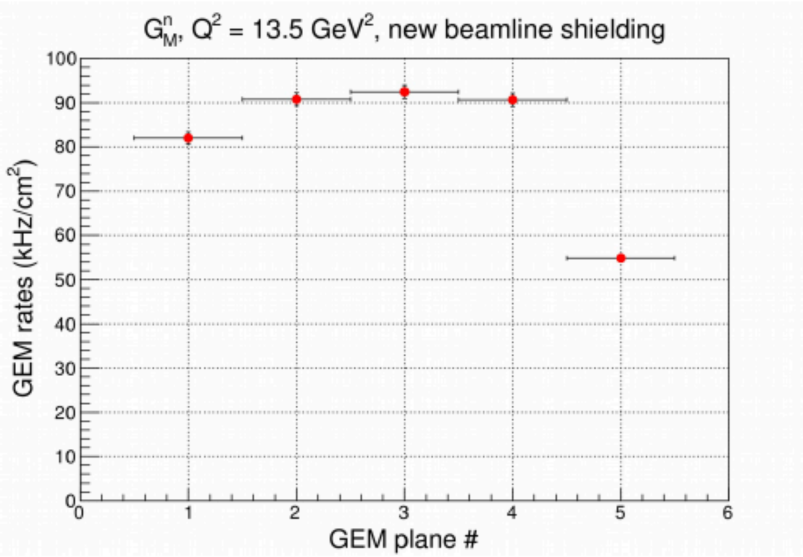
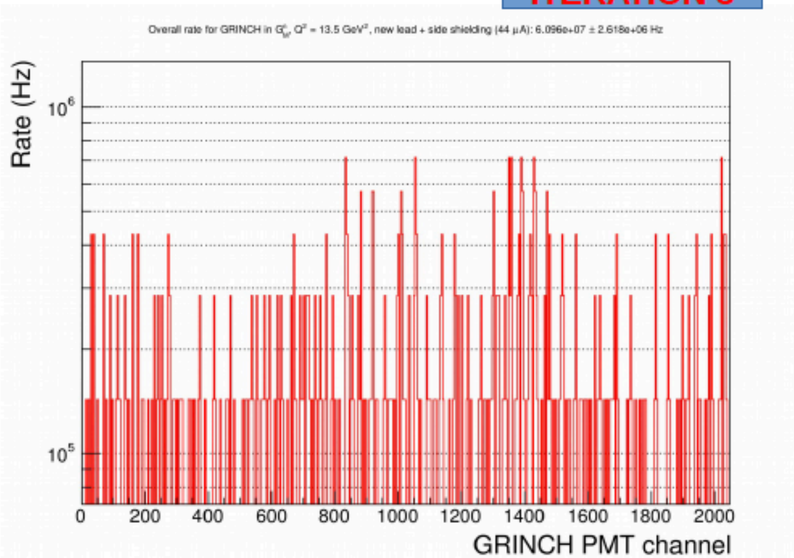
Reminder: GEM rates for G_M^n

Q^2 = 13.5 GeV^2, I_{beam} = 44µA, 10 cm LD_2, new setup, Tosca field map, SHIELDING

ITERATION 3





Rates < 100 kHz/cm2 for all planes:
~90 kHz/cm2 for INFN GEM (planes 1-4),
~55 kHz / cm2 for UVA GEM (plane 5)

~73 % from **target**,
~2% from 48D48,
~6% from BL,
~4% from SC;
Rest (15%) from shielding

61 MHz over detector
=> average rate per PMT: 120 kHz

~58% (~70 kHz/PMT) from **target**,
~13% (~16 kHz/PMT) from 48D48
~18% (~22 kHz/PMT) from BL,
~8% (~10 kHz/PMT) from SC
Rest (3%) from shielding

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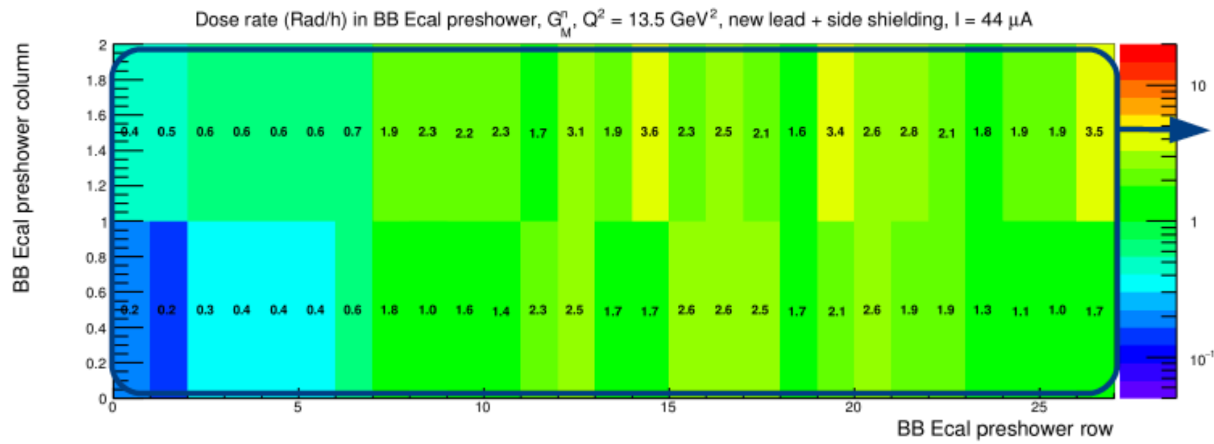
Reminder: BB Ecal dose rate for G_M^n

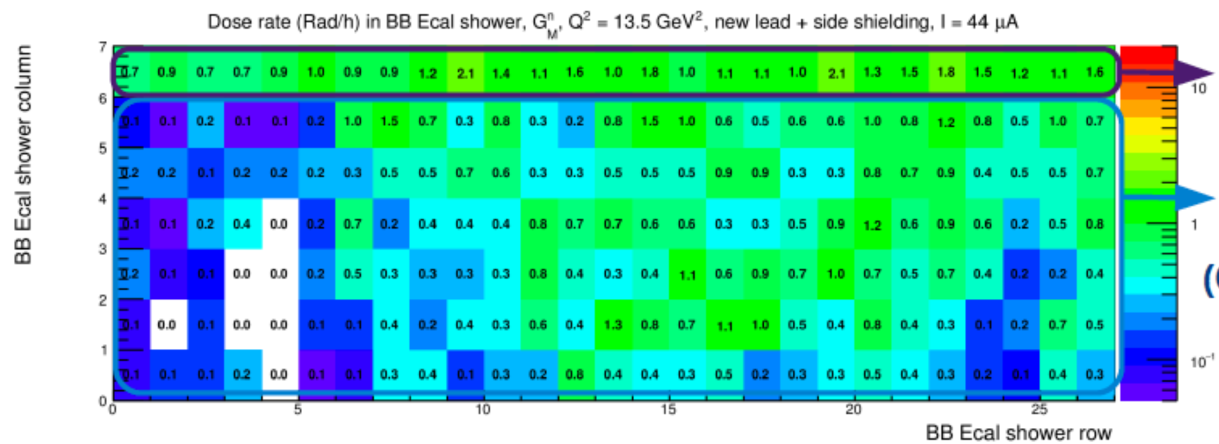
Q^2 = 13.5 GeV^2, I_{beam} = 44µA, 10 cm LD_2, new setup, Tosca field map, SHIELDING

ITERATION 3



1.7 Rad/h/block avg over PS

x100 h beam time:
< 200 Rad integrated *for this kinematic*. (20 % of maximal acceptable)



1.2 Rad/h/block avg

0.5 Rad/h/block avg

(0.6 Rad/h/block avg over SH)

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Shielding reduces cumulative radiation dose in BigBite lead-glass to a level well below the "threshold" for performance degradation

GEOMETRY

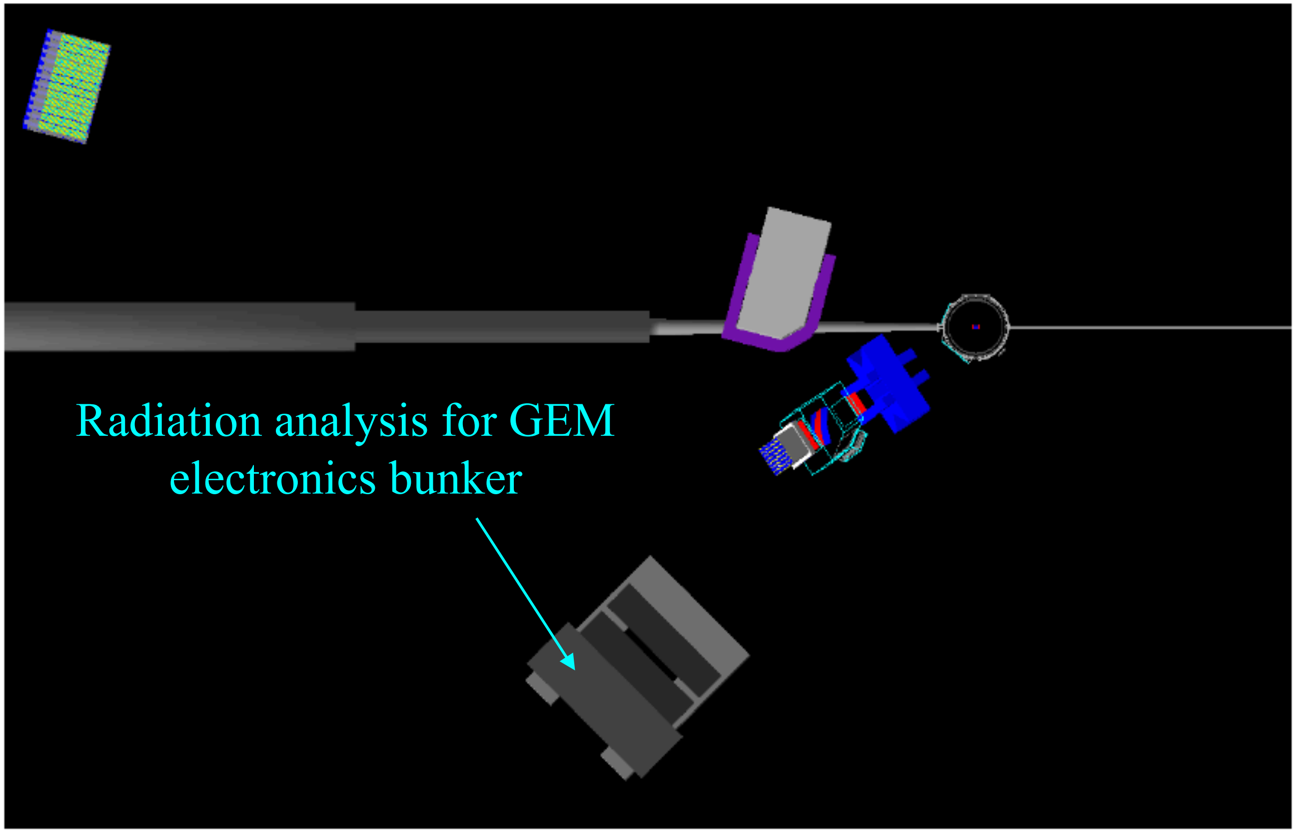

Figure: The hut face is located roughly 7.2 m from the target in the xz plane at a central angle of 45 degrees. All hut materials are steel.

G_M^n Electronics Hut

$Q^2(GeV^2)$	$\theta_{BB}(deg)$	$d_{BB}(m)$	$E_{beam}(GeV)$	$I_{beam}(\mu A)$
13.5	33.0	1.55	11.0	44.0

- Ran 15 $\times 10^9$ events with the beam generator
- Silicon sensitive region is 101.6 x 101.6 x 2.54 cm^3
- Density of Silicon used = 2.33 g/cm^3
- Total energy deposited = 910 MeV
- Results:

$$\boxed{\text{Dose rate} = 0.016\ \text{rad/hr}}$$

Note: This estimate was performed for the "baseline" scenario (no beamline shielding)

Status of beamline activation estimates

- Motivation: Need to confirm that the radiation exposure levels to personnel working near the beamline during config. changes will be acceptable, and determine whether or not a special RWP will be required for those changes
- A detailed, time-ordered run plan of beam times, targets, currents, energies and configuration changes of SBS during GMN has been provided by the GMN spokespeople and communicated to RadCon (V. Vylet and P. Degtiarenko)
- RadCon group has made contact with Hall A engineers; has requested necessary inputs for calculation.
- Current status:
  - Awaiting simplified engineering drawings and tables of parameters for the beamline geometry needed to specify the model and start the calculations
  - After this information is furnished, estimated time to completion of the model and execution of the simulation is 3-4 weeks.

Summary and Conclusions

- Standard LH_2/LD_2 targets at luminosities well within the range of luminosities routinely used during 6 GeV operations present no major challenges in terms of the annual radiation budget of Jefferson Lab.
  - Preliminary radiation budget estimate shows that the total rad. budget of the experiment is about 7% of the annual dose budget of the lab and approximately 109% of the "allowed" dose for the allocated beam time (the threshold of concern for this metric to trigger higher-level review is 200%).
- Exhaustively detailed GEANT4 Monte Carlo simulations of GMN in all configurations show acceptable radiation levels in rad-sensitive detectors and readout electronics
- Rates in low-threshold detectors (GRINCH and GEMs) are tolerable, *even in the absence of local shielding*
  - Simulations with realistic TOSCA map show importance of SBS fringe field for detector background rates (GRINCH in particular)
  - 30-50 MeV electrons in a narrow range of angles (9-11 degrees) bent by SBS fringe field are the dominant source of GRINCH background in the absence of shielding
  - Photon-induced backgrounds most important for GEMs
- Modest local shielding of the downstream beamline and/or BigBite detectors will reduce the background rate by ~1/3 (~4X) in GEM layers 1-4 (5) and ~6X in GRINCH PMTs.
  - Shielding also reduces rad. dose rate in BigBite lead-glass calorimeter by >2X, to a level well below the threshold for performance degradation
  - Since the data rate to disk/tape is dominated by the GEM hit rates, shielding that reduces the GEM hit rate leads to a roughly proportional reduction in the data volume of the experiment.