Status Summary: Estimation of Radiation Levels for the Pixel Insertion in (E)YETS 2016/17 and Residual Radiation Measurements: YETS 2015/16

S.Mallows on behalf of BRIL Rad Sim
Includes Results and contributions by H.Vincke & I.Bergstrom
(HSE/Radiation Protection Group)

Overview

- Review of status **at December** meeting of simulations of radiation levels for Pixel Insertion EYETS 2016/17
  - https://indico.cern.ch/event/468103/
- Summary follow-up work/simulations performed since December
- Recent Measurements of residual radiation (YETS 2015/16)
  - Gamma Ray Spectroscopy
    - N. Beni, Z. Szilasi, S.Mallows,
  - Ambient Dose Equivalent Rates: H*(10)

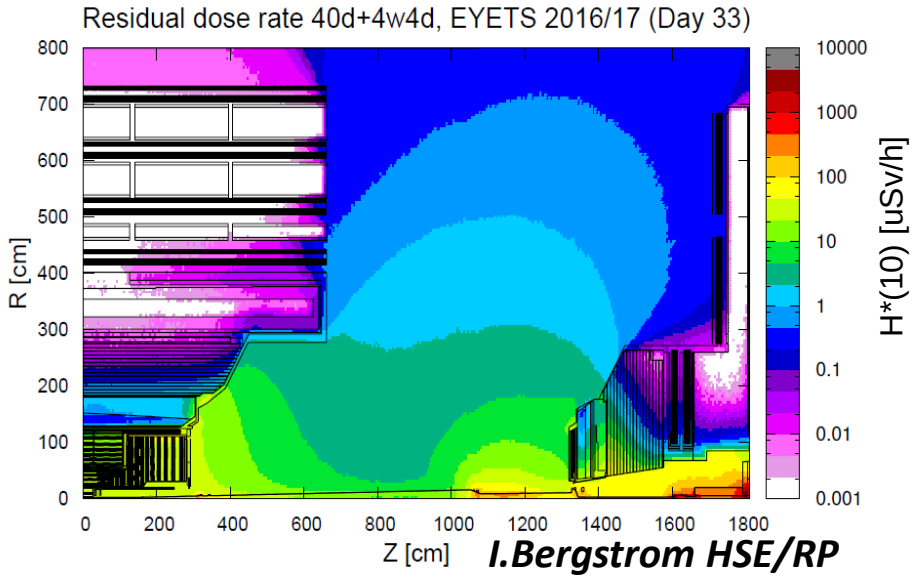
Dependencies: Residual Radiation Estimates

- **FLUKA Code itself**
  - In general very well benchmarked for activation with hadronic cascade
    - Some issues with isomer production
- **CMS Model for Prompt Field**
  - Correct modelling of total mass in regions
  - Correct hydrogen (moderating) content for thermalising neutrons
  - And, of course - All settings incl. the collision source (DPMJET-III)
- **CMS Model for Decay Radiation**
  - **Material compositions** (e.g. 1% impurity can be responsible for 99% of activity)
- **Normalization** & Luminosity Assumptions
  - Total luminosity *and* time distribution of luminosity. **In general**:
  - Long-lived nuclei - longer cooling times: depend on total luminosity
  - Short-lived nuclei - shorter cooling times: depends on instantaneous luminosity

Rad Level Estimates for Pixel Insertion EYETS 2016/17

Review of December Meeting

- Simulations with updated Tracker in CMS FLUKA model + SESAME Tool (for open configuration)
- Predicted Ambient Dose Eq. Rates, H*(10), higher than expected (considering measurements by S.Bally in LS1)



https://indico.cern.ch/event/468103/ for zooms and 1d plots

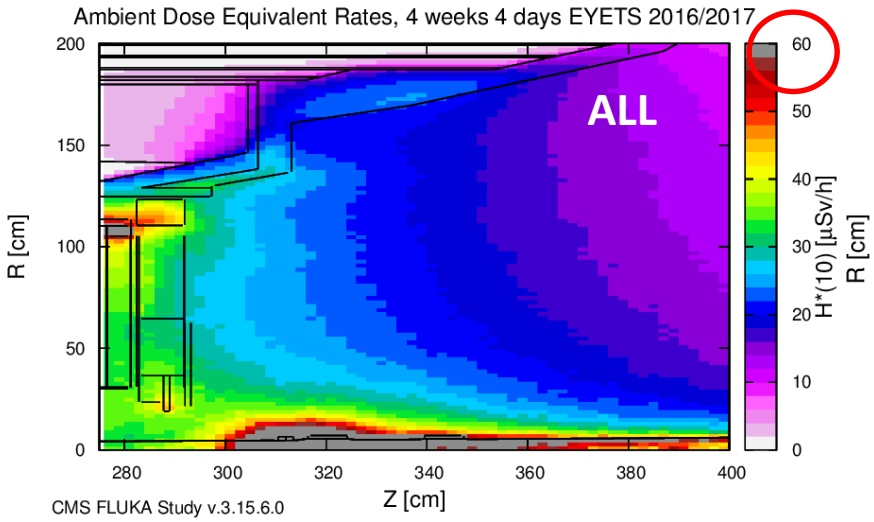
Heavy Ion Run is considered as cooling time. EYETS day 1 is 40 days since PP collisions in FLUKA simulations

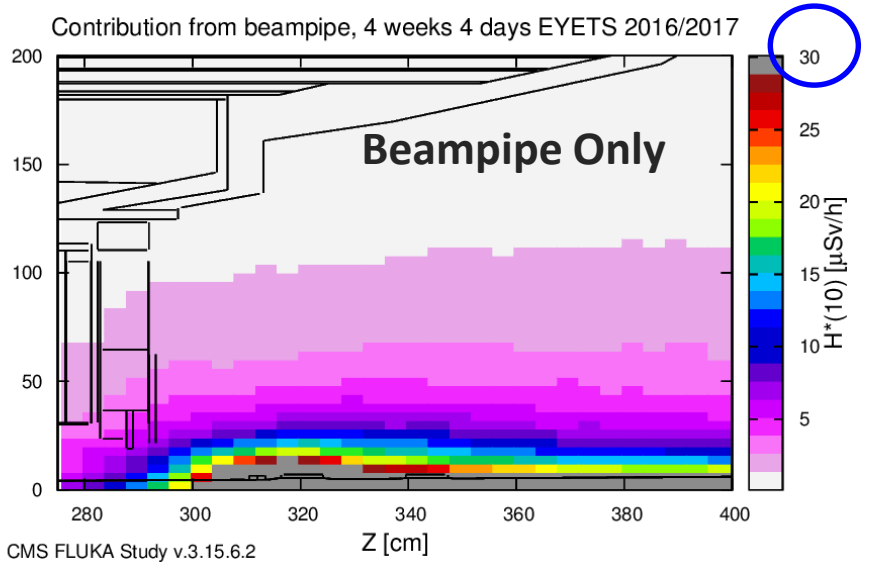
- LS1 simulation (identical model, but LS1 settings) & measurement comparison found here: https://indico.cern.ch/event/468103/ , I Bergtrom.
  - Good agreement near beampipe, not so good at larger radii

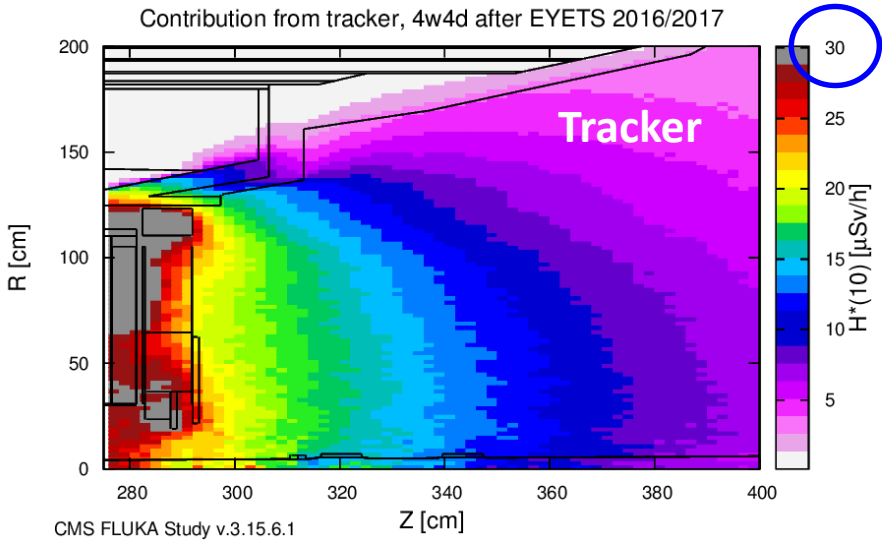
Contributions from Individual Components

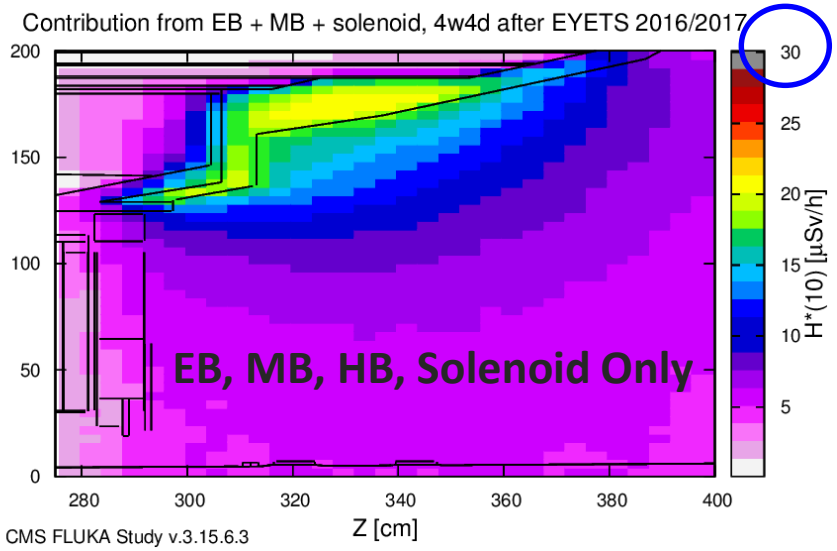
Review from December Meeting

T cool: EYETS 2016/17Day 33









Plots by L.Gloggler

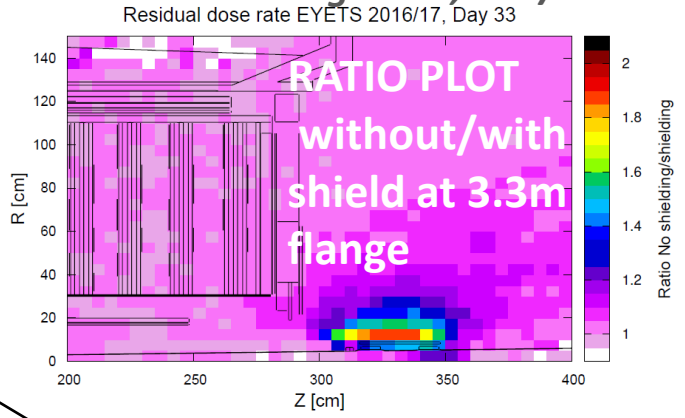
Main Contribution from Tracker and BH at ~ 30<R<120cm

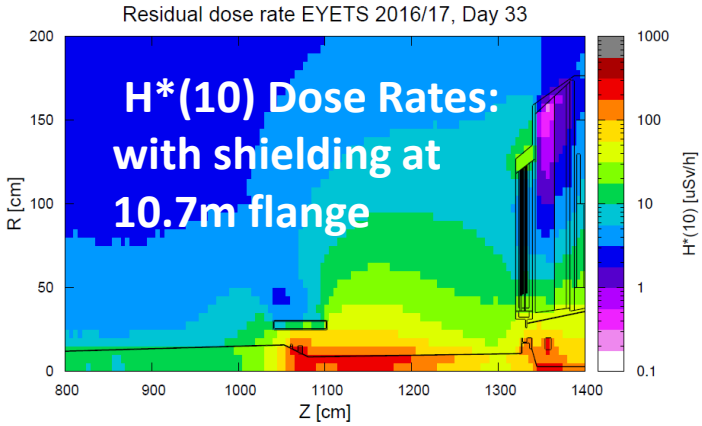
Conclusions & Follow-Up

Review from December Meeting

- FLUKA estimates beampipe activation okay
- **Beampipe shielding** (extended) required **at ~3.3 m**
- HF beam pipe contribution should be addressed (extend shielding/limit stay)
- Bulkhead shield study performed by L.Gloeggler (not feasible for use in EYETS 2016→ redo study for LS2)
- **Key Follow Up Points:**
- **Investigate further Bulkhead contribution to dose rate**
  - Material check and make further simulations for residual nuclei / Gamma Spectra - identify main contributing nuclides
- **Investigate cable hotspot region**
  - *Extensive* material check already in process I Kurochkin
- Profit from Benchmark Measurements in YETS 2015/16
  - Gamma ray spec and H*(10) detailed map near bulkhead
- Contribution from heavy ion run, in case of Pb-p collisions?
  - Simulations recently performed. Please contact Heinz Vincke/Ida Bergstrom for HSE/RP group results

I. Bergstrom, HSE/RP

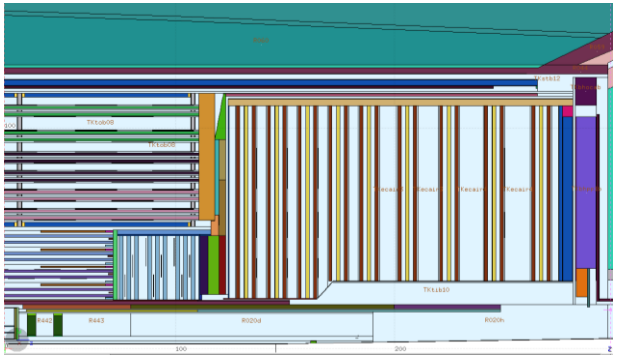


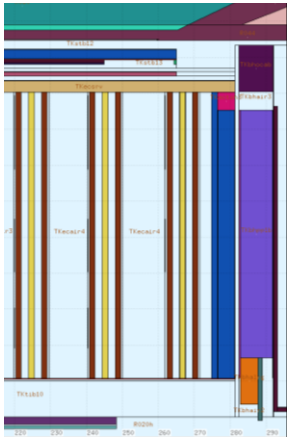


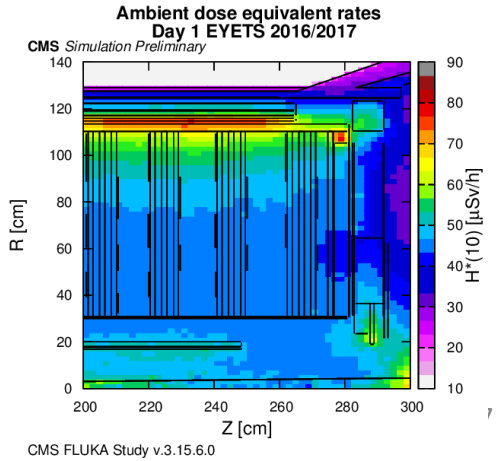
I. Bergstrom, HSE/RP

Tracker Model in FLUKA - Material Check

- **The current CMS FLUKA TK** model is based on material budget **for Phase I as in CMSSW**
  - Bulkhead Regions - material taken directly from GEANT 4 model.
- I.Kurochkin, N.Bacchetta, check: CMSSW material budget implemented to FLUKA – no faults
- **However** - GEANT 4 /TK model itself may not contain correct material description.
- Excess cobalt (2.8%) in “Inconel” used in GEANT4 models. There should be no cobalt (apart from *very* small trace amounts with nickel)
- ~200g of cobalt in the thermal screen region should be removed (&10g Cobalt in nose)
- & Add trace amounts where there is Nickel..?
- **Conclusion:** We can make minor improvements (as with any region) but this is unlikely cause of simulation/measurement difference



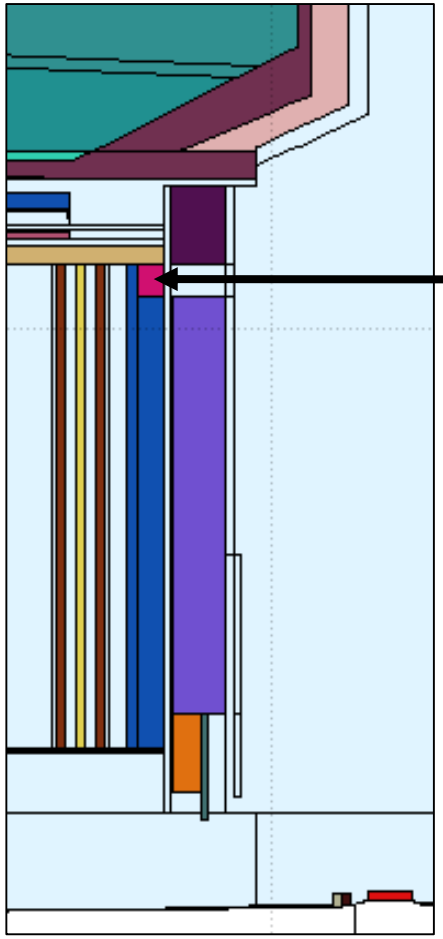




[Tracker Model by Igor Kurochkin:](https://espace.cern.ch/cms-project-bril/SitePages/v.3.9.0.0.aspx)
https://espace.cern.ch/cms-project-bril/SitePages/v.3.9.0.0.aspx
https://indico.cern.ch/event/386582/

Identification of contributing isotopes

Residual Nuclei (example hotspot region)

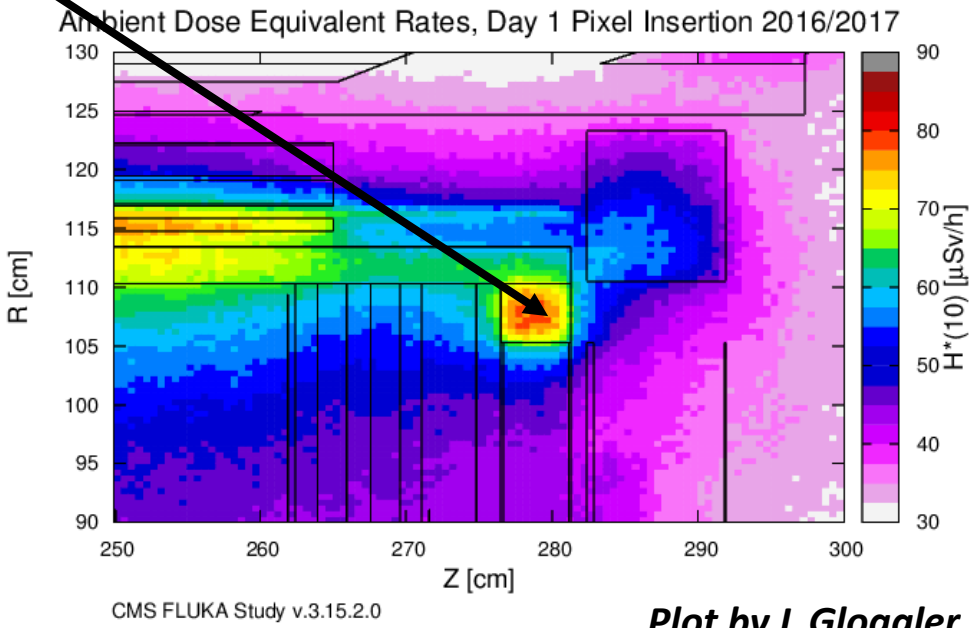


Hotspot: bulkhead outer cable region

material composition:

carbon	19.9%
copper	49.1%
oxygen	0.6%
hydrogen	2.8%
silicon	0.2%
iron	2.6%
aluminum	12.4%
silver	1.7%
fluorine	10.7%

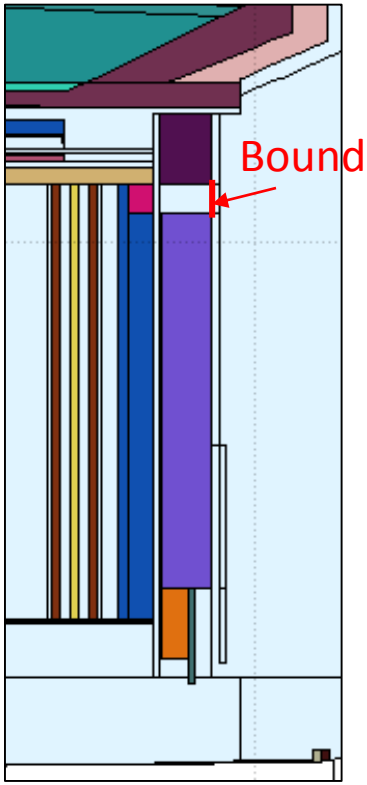
- Most active isotopes in material:
  - ^{110}Ag (incl. isomer)
  - ^{60}Co

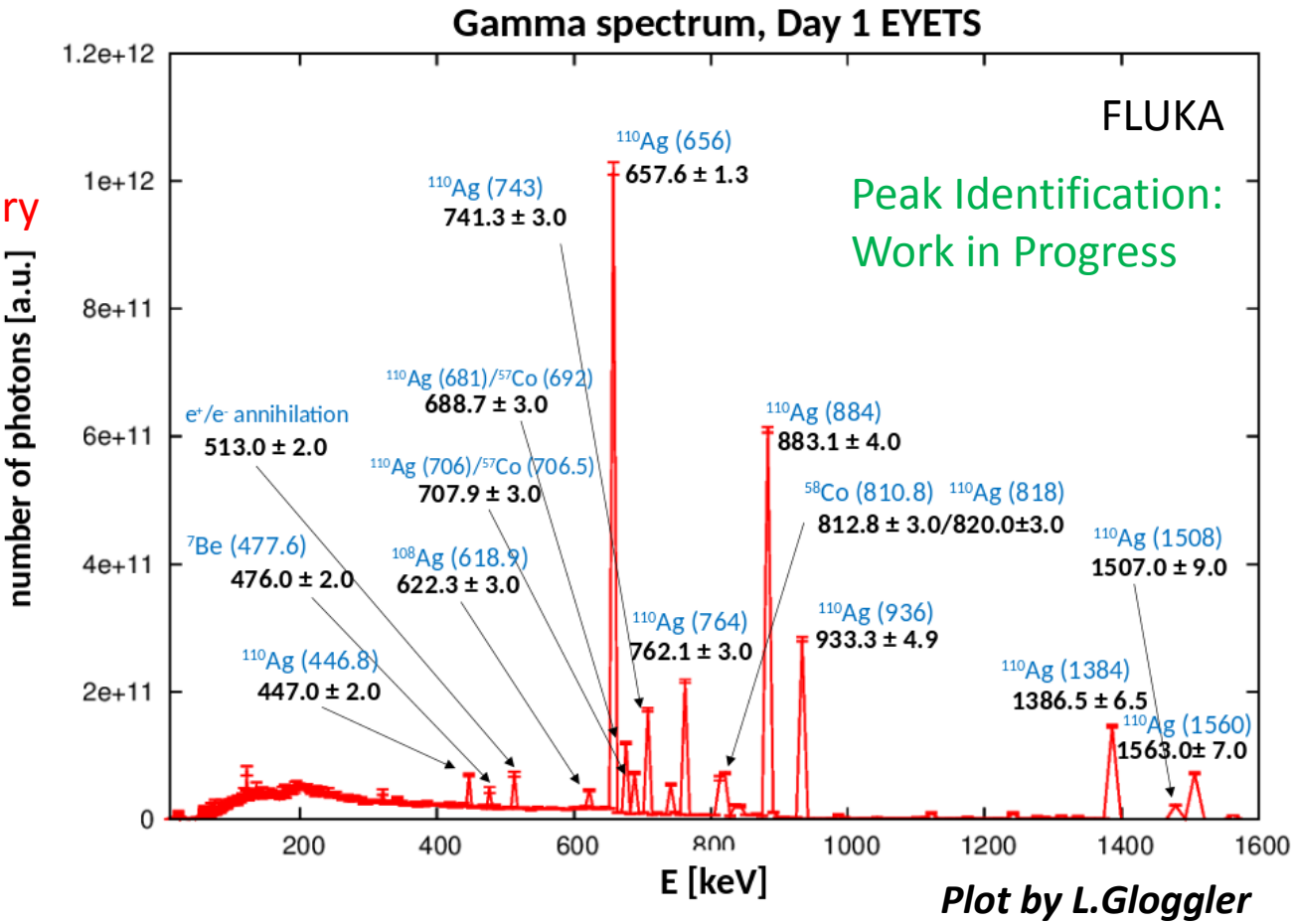


Plot by L.Gloggler

Identification of contributing isotopes

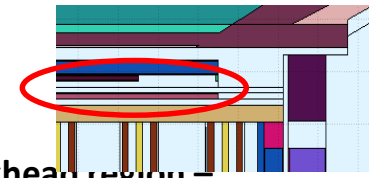
Gamma Spectrum (near example hotspot region)





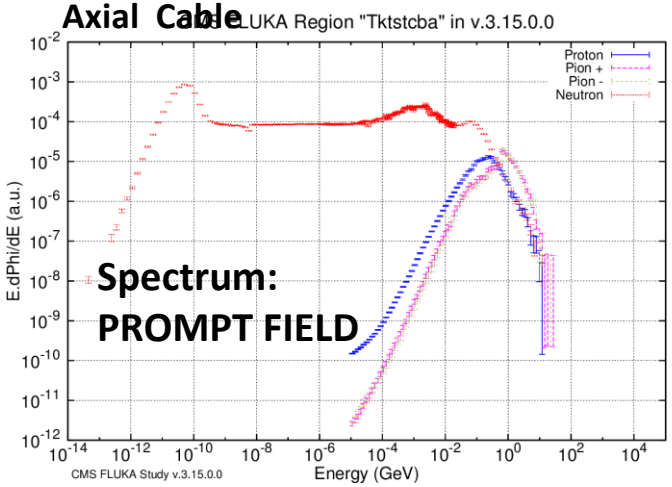
- Boundary crossing from air to air at Z=297.3cm and 102 cm < R < 123.3 cm
- Day 1 EYETS 2016/2017: Gamma energies consistent with Ag -110m decay

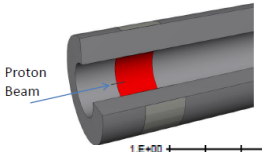
Identification of contributing isotopes
Actiwiz – RP tool (Ida Bergstrom RP)



- Advantage: provides info about **source**, i.e. identifies responsible element in material
- Input: prompt spectra, from database + exact material composition for region + irradiation period approximation
- **Actiwiz Results** example:
  - From Cable Axial region: **Silver Isomer Ag-110m** is top contributor (~95%) * or significant contributor*– Production 100% from silver.
  - From Pixel Cable Region: contributors* ^{58}Co, ^{56} Co, ^{54} Mn. Production of each nuclide from various elements (**e.g.** ^{54}Mn production from iron, copper & manganese etc.)
- The results & explanations from Ida/RP helped with understanding on *production* of various nuclides in hotspot region.
- Key Message Ag-110m seems to be main contributor from certain hotspot regions

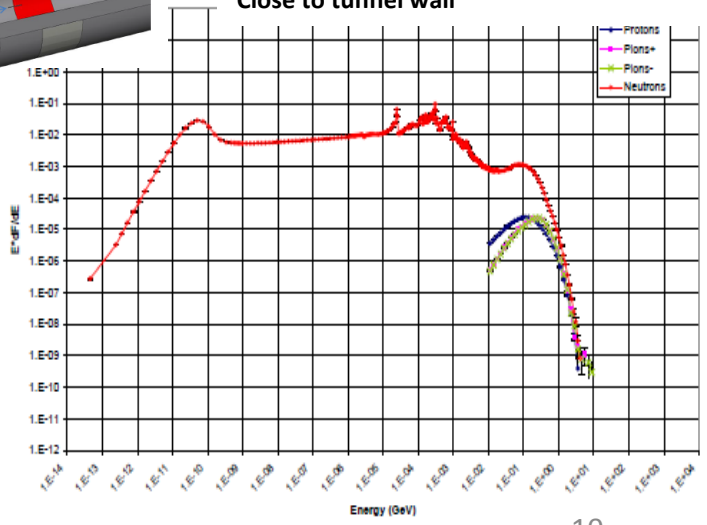
CMS FLUKA: Bulkhead region – Axial Cable





Actiwiz database example

Close to tunnel wall



***depends on which particular ActiWiz spectra.**
- ignoring self-absorption, geo effects

At the moment database is for accelerators only.
ActiWiz 3 will be adapted for CMS experiments

Silver 110m Isomer and FLUKA

- FLUKA (and ActiWiz 2) uses 1:1* branching ratio for **production** of isomeric states
- However in FLUKA **development version (and ActiWiz3),** amongst other changes
  - **New, more exact isomer production model for isomers created by <u>low energy neutrons</u> (<20MeV) based on JEFF activation**
- Silver half life info:
  - 110-Ag : 24.6 s
  - 110m-Ag : 249.9 days
- → Over production of silver isomer in simulations could lead to overestimates activity in cable regions at relevant cooling times
- Quick simulation (not SESAME set up) with Development versus Current FLUKA (v.2 011.2c.3) by I.Bergstrom:
  - Activation in outer tracker and cable regions reduced with devel. version:
  - Near bulkhead, day 1 EYETS: reduction in H*(10)by a factor of 2-3 at R~1m, no significant reduction close to beampipe.

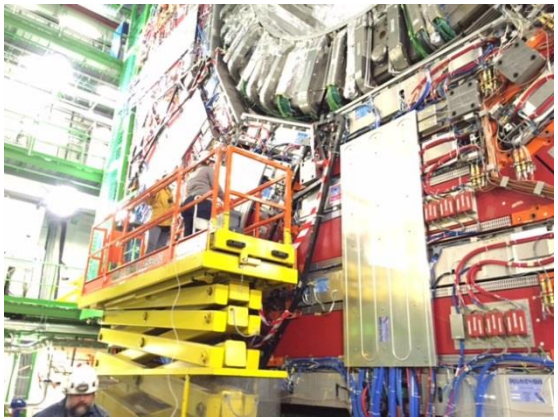
→ Full SESAME simulations will be performed with development FLUKA as soon as possible

(*) 1:1 for 1 isomeric state, 1:1:1 for 2 isomeric states, etc. etc.

YETS 15/16 Gamma Ray Spec Measurements

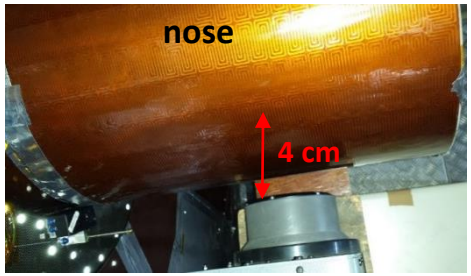
- Falcon 5000 - Germanium Detector
  - Requires cooling (5hrs minimum)
  - Good resolution: 1-2 keV up to 1 MeV
  - Portable, but heavy (~20 kg):
    - measurement/locations require planning
  - With additional collimator:
    - angular acceptance ~ 45 degrees (based on quick tests with source January).
  - Further more extensive characterization is planned in coming weeks
- Measurement Locations in Cavern
  - **18 separate measurements** at different locations, and with various shielding scenarios [S.Mallows, N.Beni, Z.Szilasi]
  - Locations include:
    - Tracker bulkhead
    - Beampipe bellows at ~3.3m
    - Cable regions on ES
  - 2 example spectra shown here

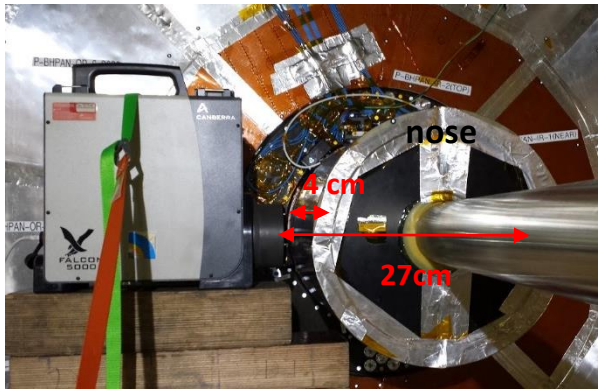
collimator



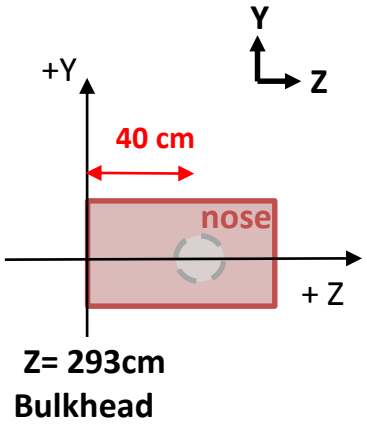
18 reference slides (as below) and corresponding spectra [plots and raw data] have been prepared and will be added to sharepoint:

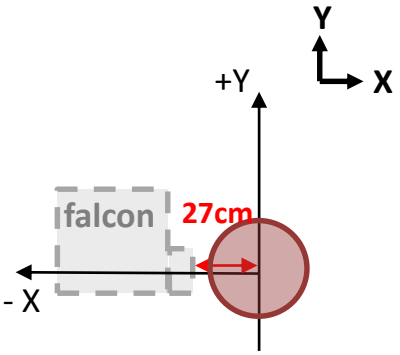
Beampipe, Z = 3.33m





- Date: 01/02/2016
- Original Filename (FALCON):
  - **UXC/20160201/BeamPipe_2**
- Text data File on SharePoint: /cern.ch/bril/SitePages/RadMeasurements.aspx
- Live Time:600s
- Dead Time:
- **CMS Scenario:**
  - ECAL Endcap Front face ES at 8.8m
  - No additional shielding
  - Nose in place
- **Location - Front face Falcon collimator in CMS FLUKA Coord System:**
  - **X: -27.0**
  - **Y: 0.0**
  - **Z: 333.0**
- **Orientation: Towards Near (+)**





YETS 15/16 Simulations

- Simulations with FLUKA/SESAME and the spectra analysis very much work in progress
  - The existing 'prompt step data' with fluka2011.2c (NB version with Isomer issues) has same settings as EYETS 16/7 pixel insertion simulations
  - → Use this to make some quick 'decay step' simulations performed for YETS 15/16
  - Need further characterization of Falcon to make better representation in decay step
  - 'Benchmark' irradiation profile formed for 2015
  - 2 examples given alongside meas. data in following slides
- Further simulations planned:
  - Gamma Spectrum at all locations
  - Better representation of Falcon
  - Exact cooling times
  - With and without FLUKA development version

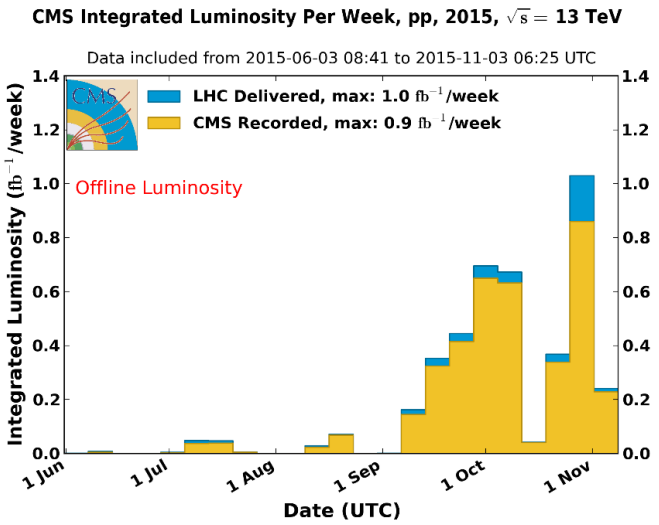
Simulations – Irradiation Profiles

- **Standard Irradiation Profile and Lumi** assumptions **finalised by HSE /RP Group**
- Implemented in FLUKA as continuous P-P collisions in the **end of each period,** assuming
- 75% expected peak lumi at
- 80 mb inelastic cross section 2015
- 75 mb inelastic cross section in 2010-2012

Year	Integrated lumi [fb^{-1}]	Instant. Lumi [$cm^{-2}s^{-1}$]
2010-2012	30	0.8 E 34
2015	4	0.63 E 34
2016	34	1.4 E 34

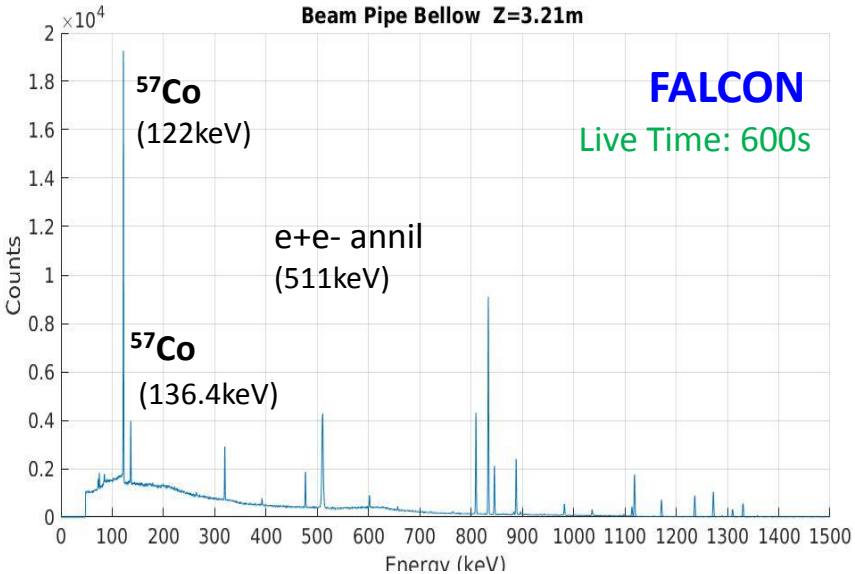
Lumi Assumptions for a 'standard' FLUKA irradiation profile for EYETS 2016/17
Remove 2016 for YETS 2015 simulations

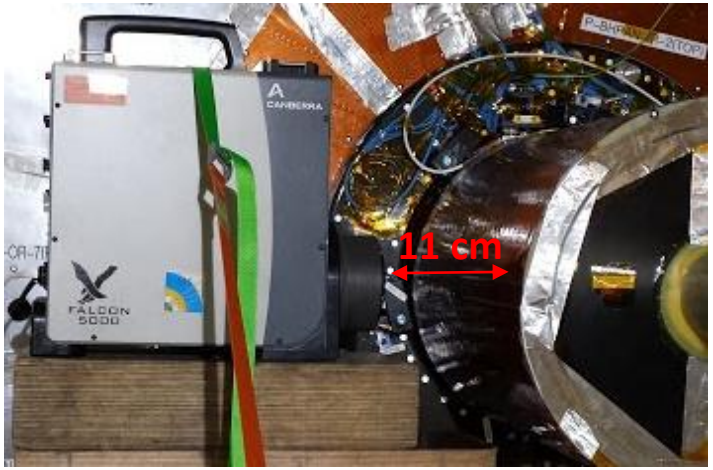
- **Benchmark Profile for 2015 (tag 'BM2')**
  - S.Mallows
- **Extract Lumi data – "Normtag1 "**
- Relevant Cooling times ~12 weeks
- Integrated delivered LHC lumi **per week** – convert to FLUKA as continuous P-P collision rate for each week
- Total lumi 4.22 fb^{-1}
- Assuming 80 mb inelastic cross section 2015

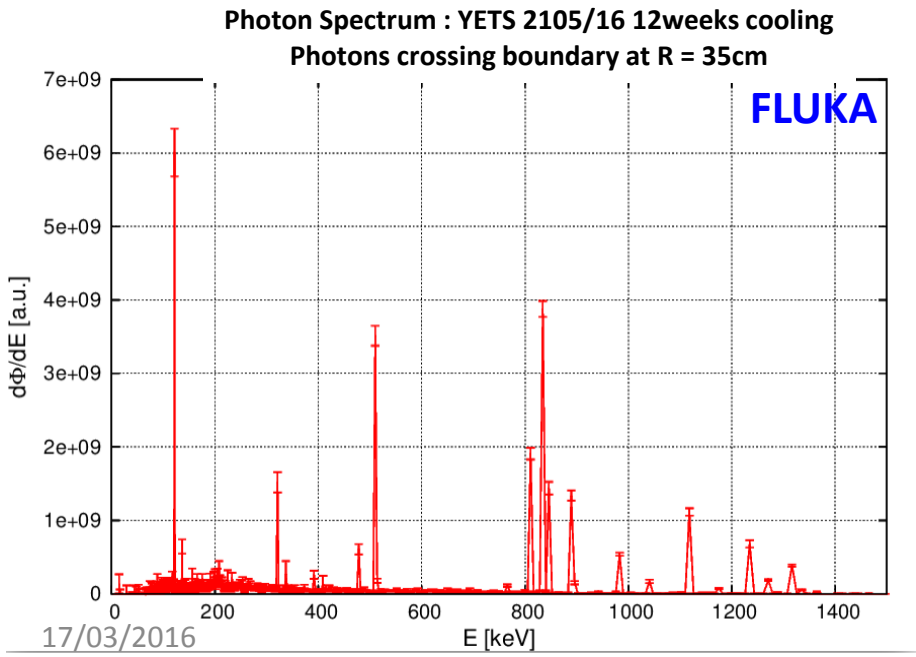


!!! Work in Progress

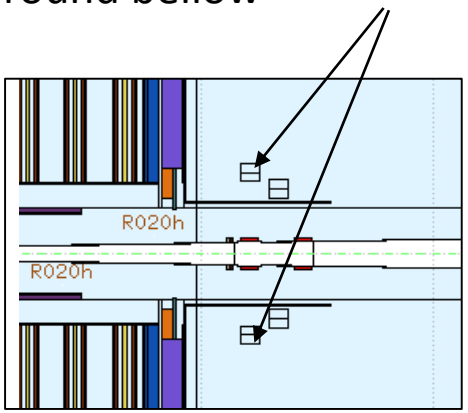
Spectra BeamPipe, Z= 3.21m





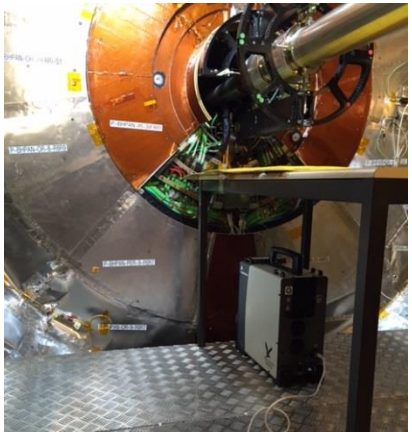


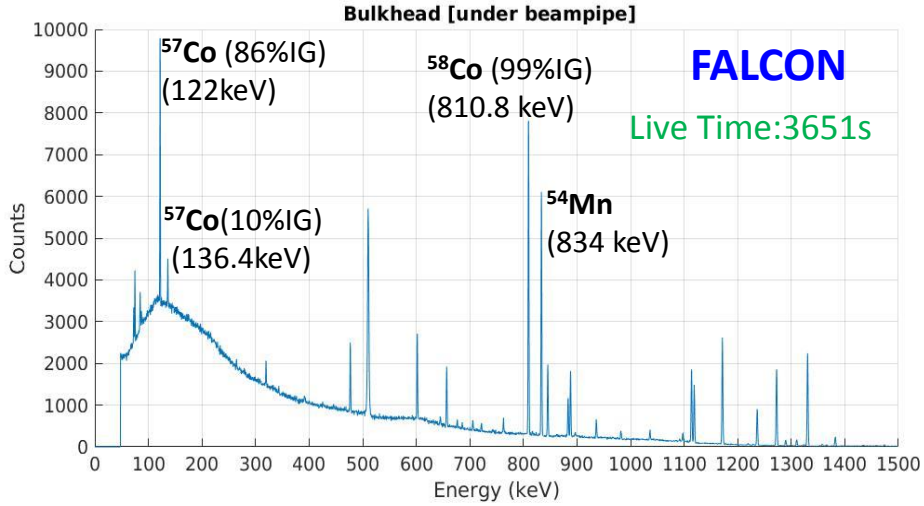
- 'Benchmark' irradiation profile 2015
- 12 weeks cooling
- Angular acceptance not modelled
- But only activation from beampipe components considered– bulkhead etc. switched off as 'source' of radiation
- Photons crossing boundary which is 360 deg around bellow

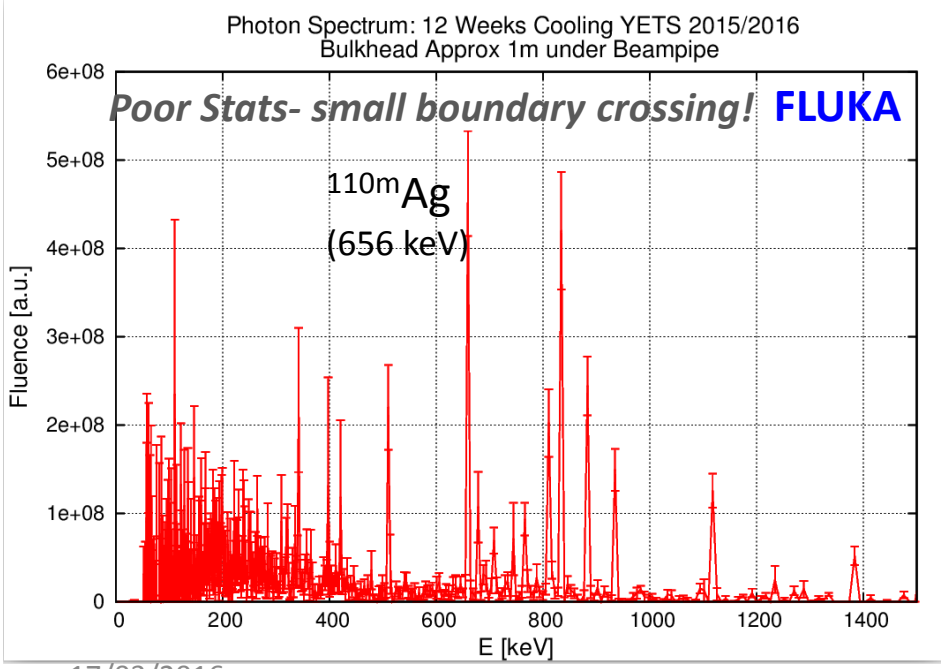


Spectra Bulkhead

!!! Work in Progress







- 'Benchmark' irradiation profile 2015
- 12 weeks cooling
- Angular acceptance not modelled
- & Activation from all elements simulated
- Photons crossing boundary at bulkhead

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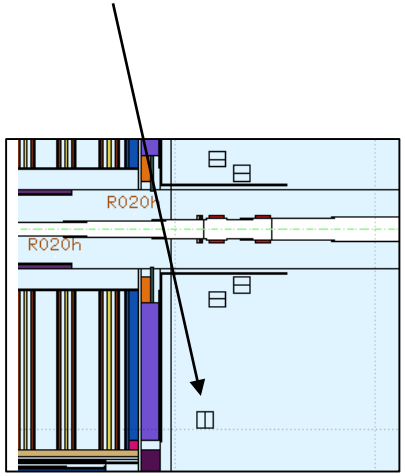
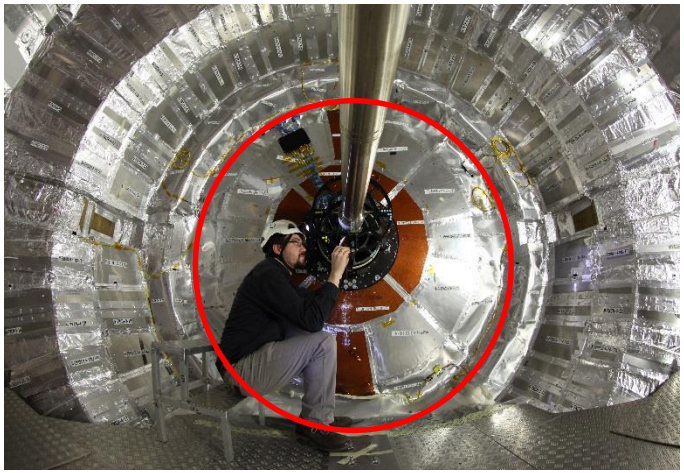
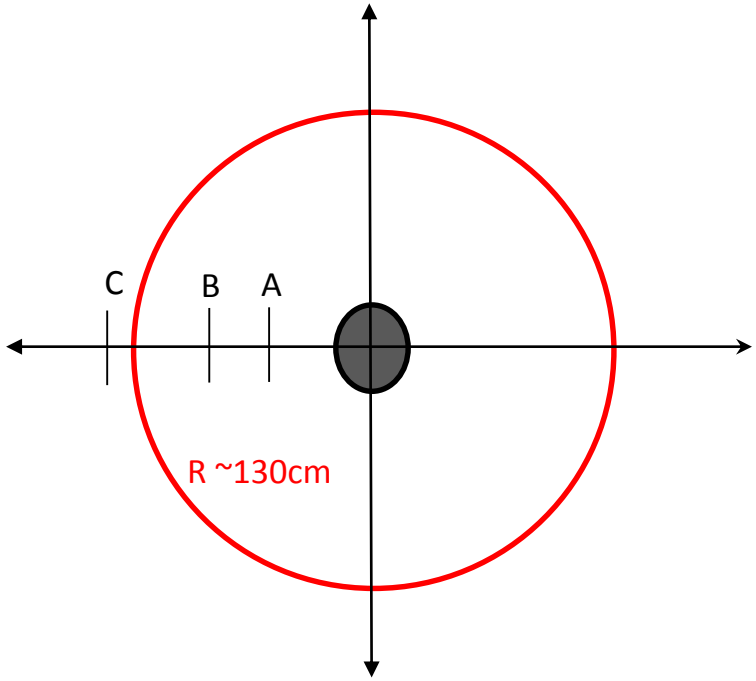


Measurements: Ambient Dose Eq Rates

- Taken at: 40 + locations with AD6 device within vac tank
  - Example measurement/simulations near (1cm from bulkhead): FLUKA (2011.2c.0) over predicts



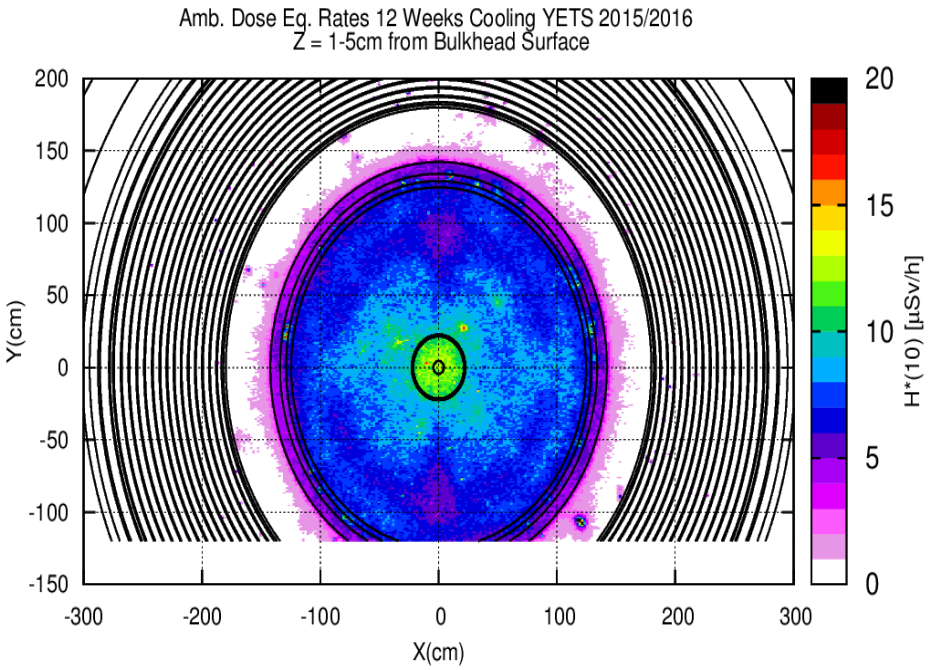


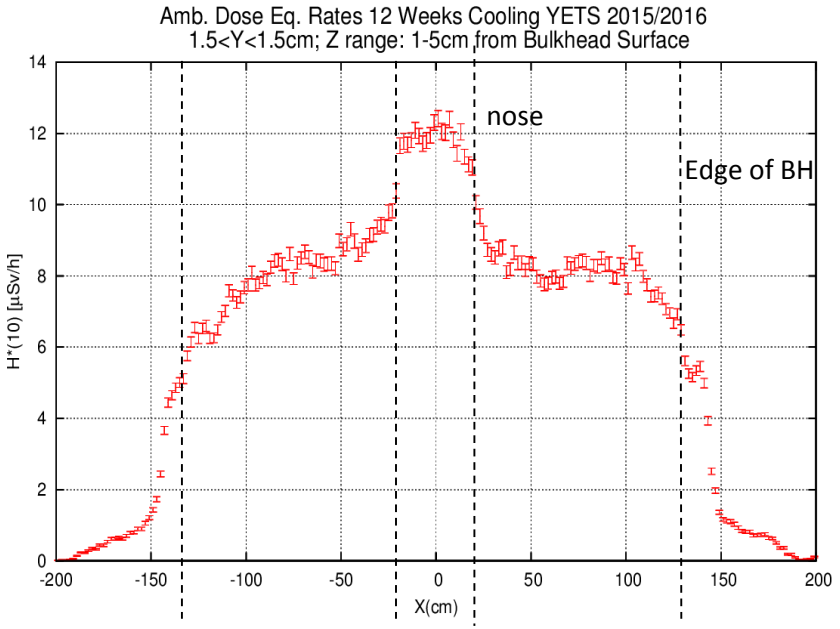
Location	Distance (R)	MEAS	FLUKA (v2011.2c.3)
A	73cm	1.3 µSv/hr	8 µSv/hr
B	123cm	0.79 µSv/hr	6.4 µSv/hr
C	153cm	0.53 µSv/hr	

Measurements at 1cm from bulkhead surface

FLUKA Results Ambient Dose Eq Rates

- Close to Bulkhead

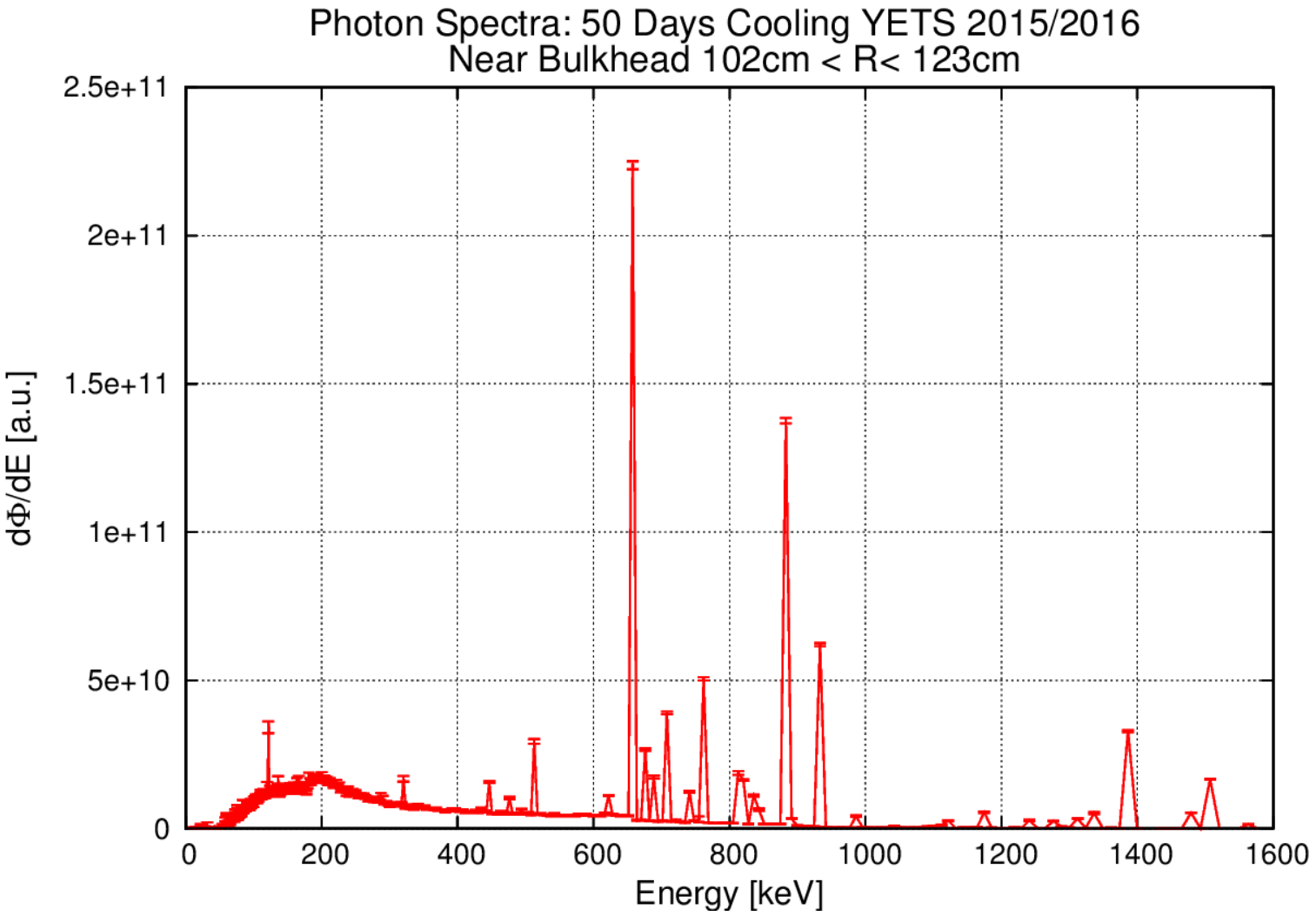




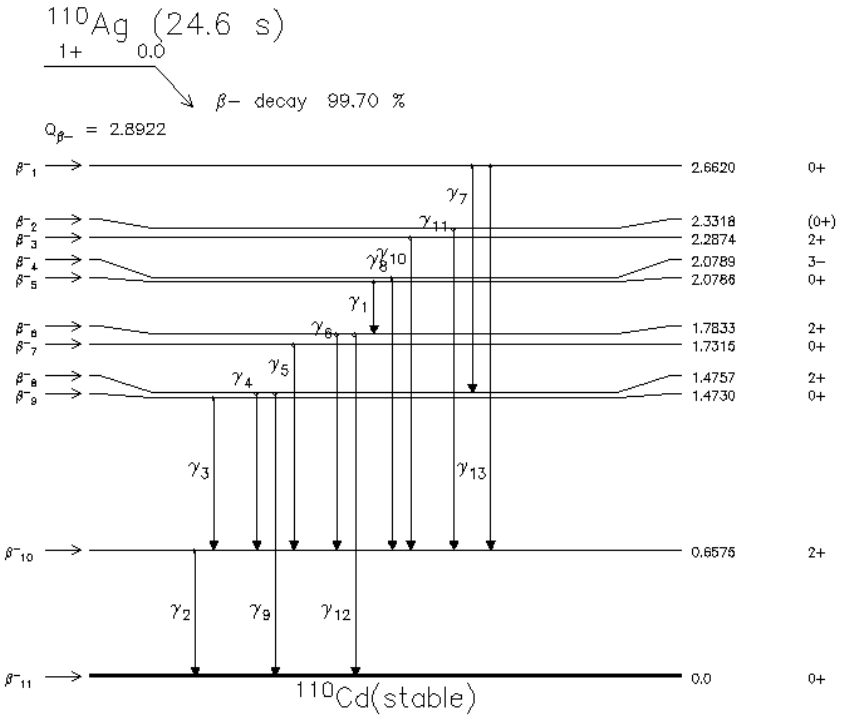
Summary

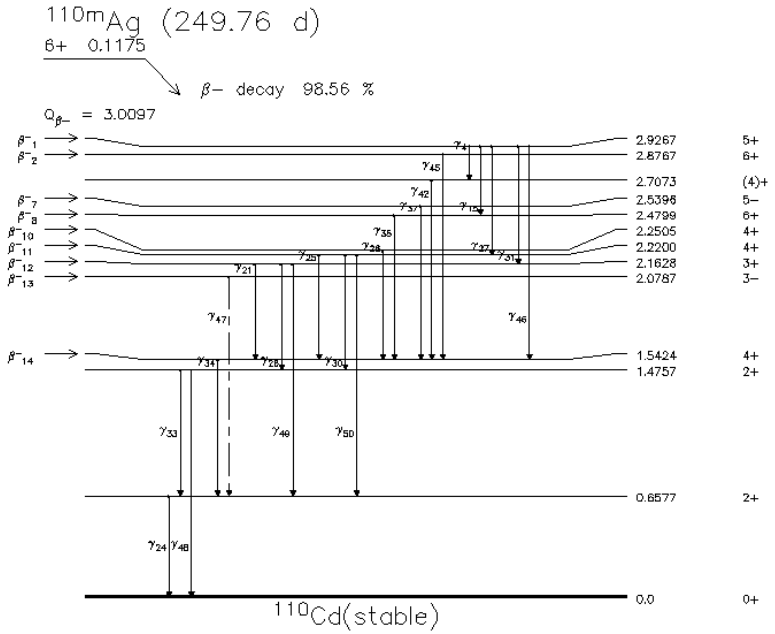
- Comparison measurements data (LS1 and YETS 15/16) suggests over prediction of residual amb dose eq. rates in certain regions
- BRIL CMS inputs / tools are okay
  - We can always continue with minor improvements.
- Simulation settings used/suggested by RP group okay
- Cause of over prediction seems to be a particular isomer production problem with FLUKA code (current 2011 vers
- YETS 2015 measurement campaign invaluable for verifying future CMS FLUKA simulations can be trusted
  - Comparisons to be made with development FLUKA asap.
- **Simulations for residual radiation in EYETS 2016/17 pixel insertion** with final beampipe shielding designs and FLUKA development version will be **performed by HSE/RP group**

Back-Up Slides


Photon Spectra: 50 Days Cooling YETS 2015/2016
Near Bulkhead 102cm < R< 123cm
dΦ/dE [a.u.]
2.5e+11
2e+11
1.5e+11
1e+11
5e+10
0
0
200
400
600
800
1000
1200
1400
1600
Energy [keV]

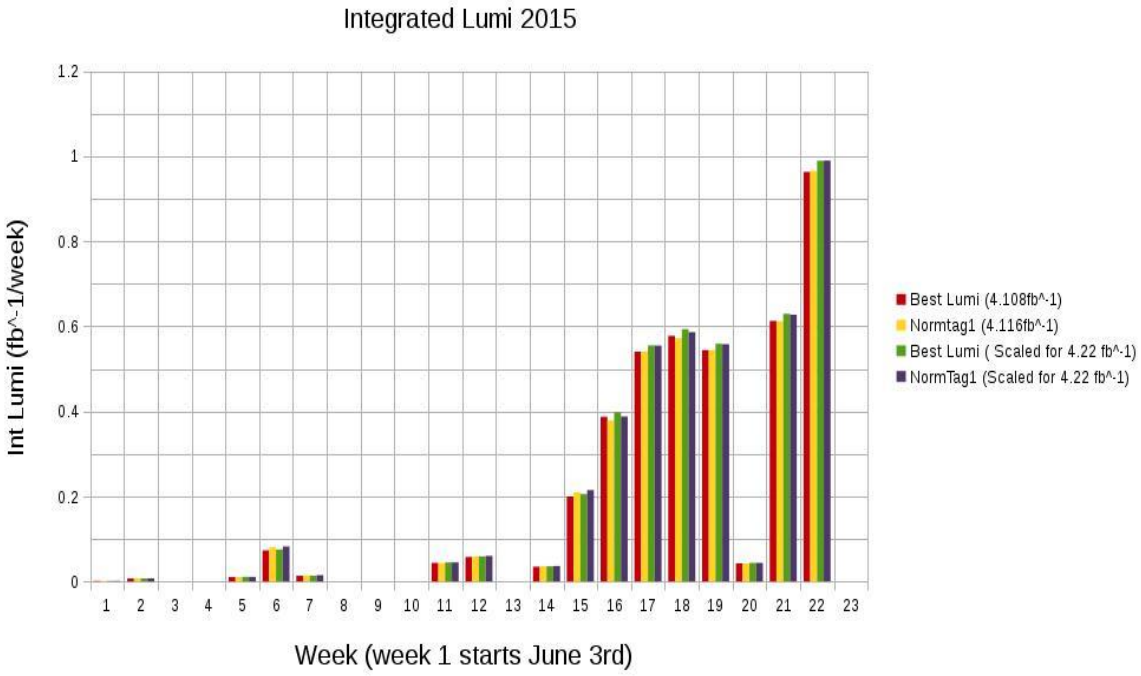
Ag-110 Ag-110m

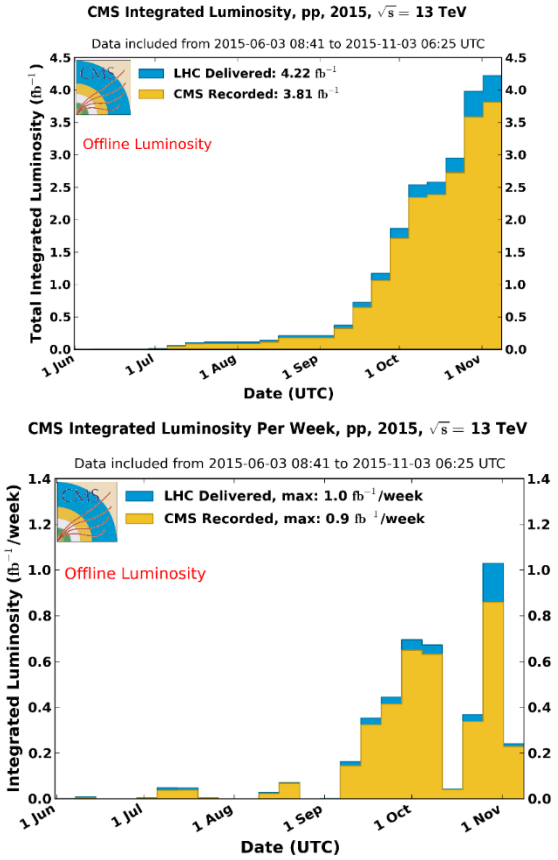




http://www.nucleide.org/DDEP_WG/Nuclides/Ag-110m_tables.pdf

Forming FLUKA PP collision profile





Cobalt 57 & 58

Gammas from ^{57}Co (271.79 d *9*)

Eg (keV)	**Ig (%)**	**Decay mode**
14.41300 *15*	9.16 *15*	e
122.0614 *4*	85.60 *17*	e
136.4743 *5*	10.68 *8*	e
230.29 *2*	0.0004 *4*	e
339.54 *18*	0.0139 *3*	e
352.36 *1*	0.0132 *3*	e
366.75 *1*	0.0013 *3*	e
569.92 *4*	0.017 *1*	e
692.03 *2*	0.157 *9*	e
706.40 *20*	0.0253 *5*	e

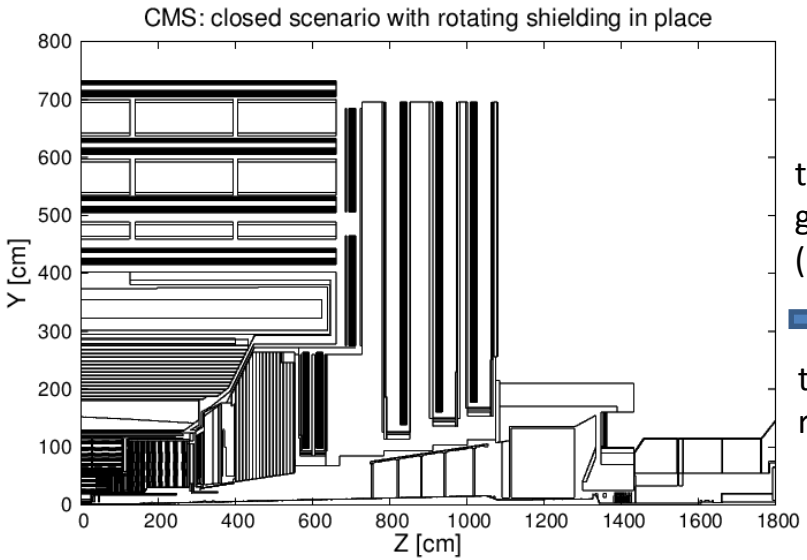
Gammas from ^{58}Co (70.86 d *7*)

Eγ (keV)	Iγ (%)	Decay mode
810.775 *9*	99	$\varepsilon+\beta^+$
863.959 *9*	0.683 *11*	$\varepsilon+\beta^+$
1674.730 *10*	0.518 *8*	$\varepsilon+\beta^+$

SESAME

- Developed by Tim Cooijmans (Technical student 2014/2015) and Moritz Guthoff
- A BRIL-developed tool for FLUKA activation simulations with CMS open scenarios
- Such scenarios can be approximated by simulating prompt radiation in the closed geometry and decay radiation in the open geometry
- Sesame provides the tools and workflow to separate the prompt and decay simulations and transform the model in between
- Download and manual:
  https://espace.cern.ch/cms-project-bril/SitePages/Sesame.aspx

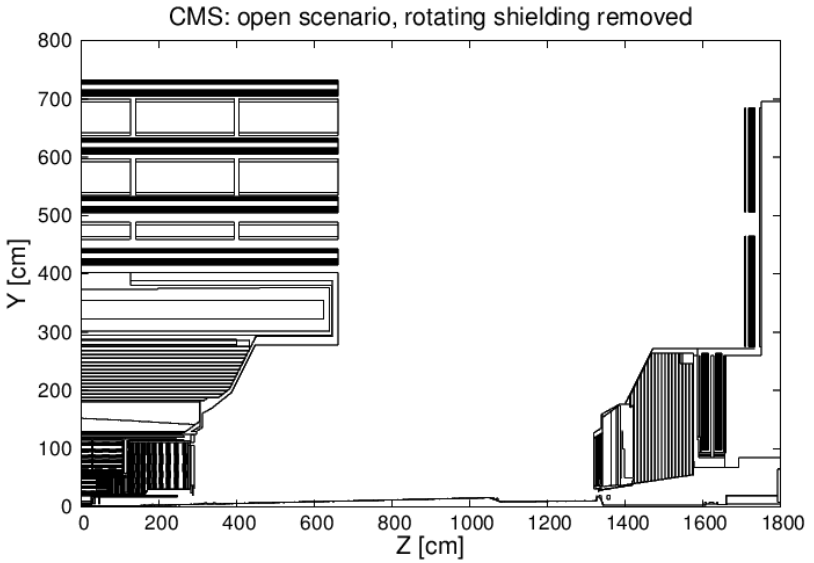
simulation of prompt radiation

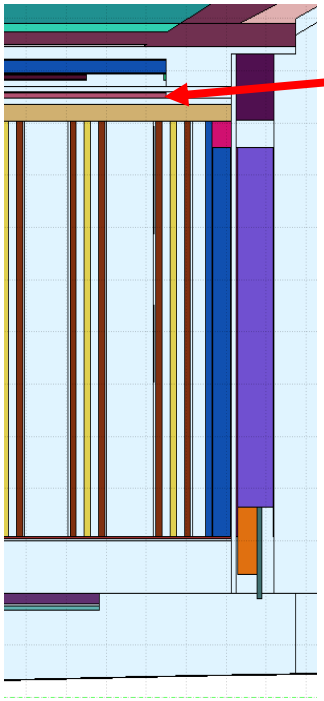


transformation of geometry model (including shielding)

transformation of residual nuclei

simulation of decay radiation





Region Represents: **Axial Cable**

FLUKA region name: **Tktstcba**

FLUKA Material name: **CAB-AXIA**

Information from GEANT 4 model in CMSSW, checked with CMS Internal Note 2007/000

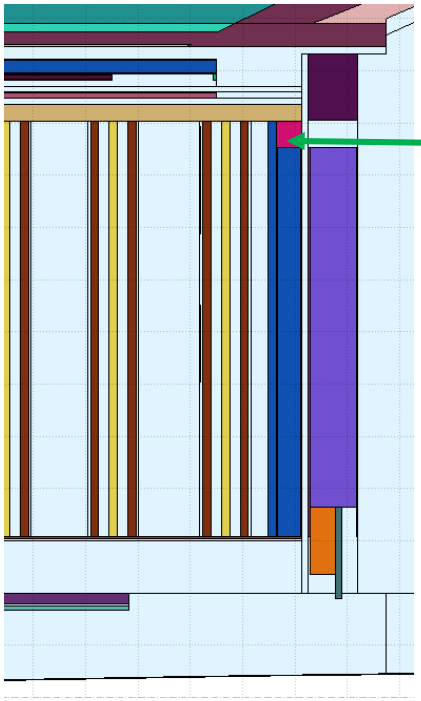
Volume: 113160 cm^3

Density: 0.89388 g/cm

Relative Mass Compositions (%) :

Carbon	17.1
Hydrogen *	2.4
Nitrogen	0.1
Oxygen	0.7
Fluorine	9.5
Aluminium	40.1
Silicon	0.1
Copper	28
Silver	2

* bound state



Region Represents: **Thermal Shield, Cooling Pipes**

FLUKA region name: **Tkectsh3**

FLUKA Material name: **EC-CIRCP**

Information from GEANT 4

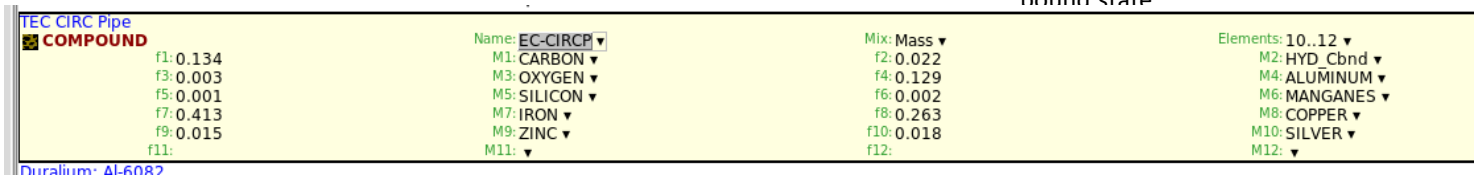
Volume: 16256 cm^3

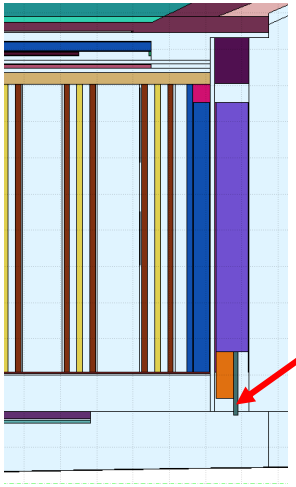
Density: 0.78 g/cm

Relative Mass Compositions (%) :

carbon	13.40
copper	26.30
oxygen	0.30
hydrogen *	2.20
silicon	0.10
iron	41.30
aluminum	12.90
silver	1.80
zinc	1.50
manganese	0.20

* bound state





Region Represents: **PIXEL CABLE**

FLUKA region name: **Tkbhpcab**

FLUKA Material name: **BHPIXCAB**

Information from GEANT 4 model in CMSSW

Volume: 1861.3 cm^3

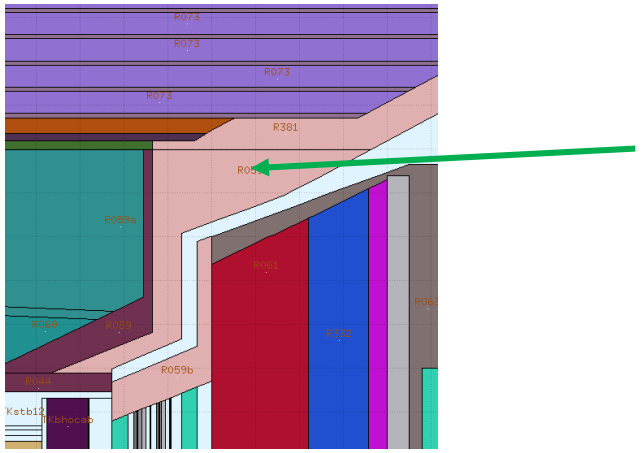
Density: 2.25064 g/cm

Relative Mass Compositions (%) :

carbon	26.30
iron	14.80
manganese	0.10
copper	47.50
fluorine	7.20
hydrogen *	4.10

* bound state

```
COMPOUND    Name: BHPIXCAB    Mix: Mass    Elements: 4..6
            f1: 0.263   M1: CARBON      f2: 0.041   M2: HYD_Cbnd
            f3: 0.072   M3: FLUORINE    f4: 0.148   M4: IRON
            f5: 0.475   M5: COPPER      f6: 0.001   M6: MANGANES
```



Region Represents: **Cable Tray and Cables**

FLUKA region name: R059b

FLUKA Material name: CABLE_AV

Information from Duccio's tables

Volume: ?

Density: 0.88 g/cm

Relative Mass Compositions (%) :

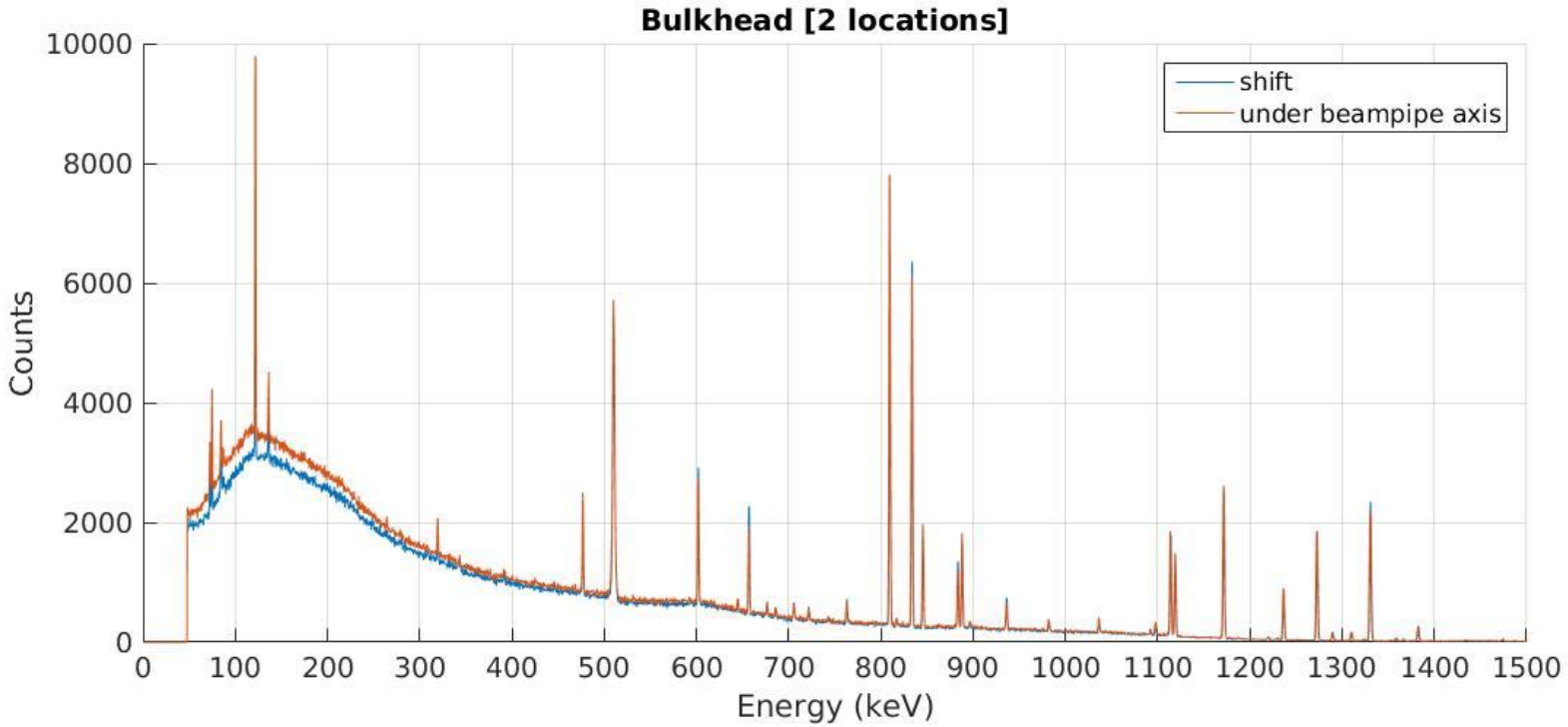
CABLE-AV:	
Copper	33.720
Silver	0.602
Aluminium	4.529
Iron	27.296
Nickel	6.185
Manganese	0.884
Chromium	8.174
Molybdenum	1.105
Phosphor	0.020
Sulfur	0.004
Cobalt	0.044
Carbon	9.689
Nitrogen	0.109
Hydrogen	1.293
Oxygen	0.435
Silicon	0.521
Fluorine	5.402

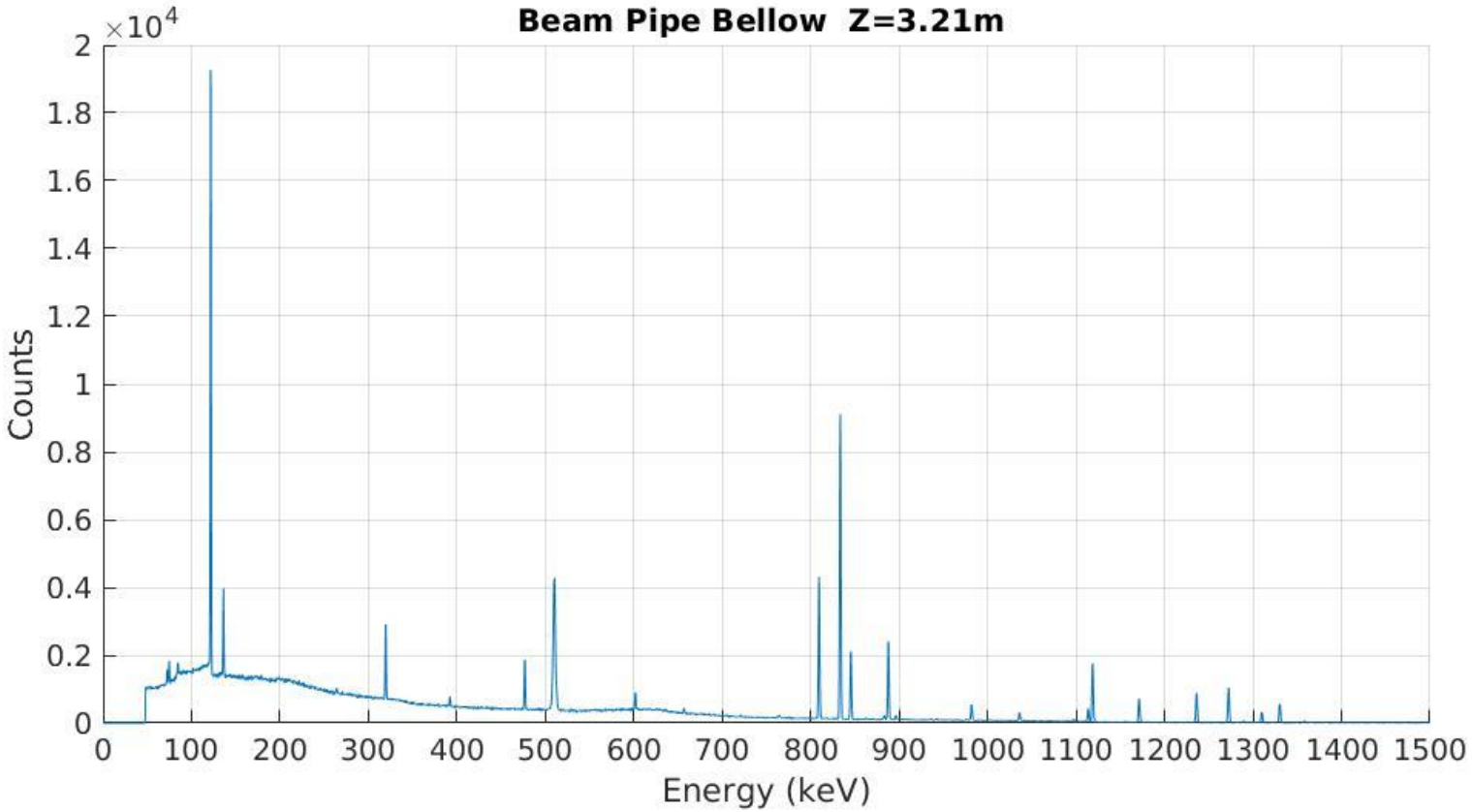
* bound state

EE/EB service channel, based on duccios numbers + st. steel for cable trays

COMPOUND

f1: 0.3372	Name: CABLE-AV	Mix: Mass	Elements: 10..12
f3: 0.00602	M1: COPPER	f2: 0.04529	M2: ALUMINUM
f5: 0.06864	M3: SILVER	f4: 0.00733	M4: KAPTON
f7: 0.0017	M5: C6F14	f6: 0.08357	M6: POLYETHE
f9: 0.00437	M7: SiO2	f8: 0.00401	M8: Plexigla
f11:	M9: RILSAN	f10: 0.44182	M10: ST.STEEL
	M11:	f12:	M12:


Bulkhead [2 locations]
shift
under beampipe axis
Counts
Energy (keV)
0
2000
4000
6000
8000
10000
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500


Beam Pipe Bellow Z=3.21m
×10^4
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Counts
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500
Energy (keV)