CMS Simulation Overview

S.Mallows on behalf of BRIL Radiation Simulation

Introduction

- **Radiation Simulation Team** part of CMS **BRIL project**
  - Beam Radiation Instrumentation and Luminosity
- Responsible for maintaining **framework** for radiation simulation
  - Perform simulations in global sense for phase 2 planning, shielding etc.
  - Maintain CMS FLUKA geometry and code for CMS FLUKA users
  - Perform 'multi-purpose' simulations and disseminate results
  - Perform specific simulations for sub-detectors on request
  - Hold regular meetings for CMS FLUKA users
- Support from CMS Technical Coordination
- Collaborate with CMS, Radiation Protection, Sub-detector and Upgrade Communities

Simulation Codes used by BRIL

FLUKA

- **Single events are generated**. 'Exclusive' code - all secondary particles are generated
- All particles are transported until they are destroyed or fall under a predefined cut-off
- **Typically not used for the purpose of recording single events or for studying the tracking of single particles**
- **The output is usually averaged over all simulated primary events** and normalized per primary event
- Has many user defined output formats, specific features for activation studies, and a more extensive (than MARS) low energy neutron group library

MARS

Similar to FLUKA, but:

- 'Inclusive' code - Fixed number of secondary particles are generated in one step, with weights according to averaged multiplicities of such particles. → MARS simulations are typically faster
- Not so many user defined outputs

→ We use MARS when fast turnaround jobs are required.

→ Furthermore **the CMS FLUKA model is a lot more detailed** (e.g. includes representation of all gaps/cracks in the Rotating Shielding) and necessary to use when such features are relevant.

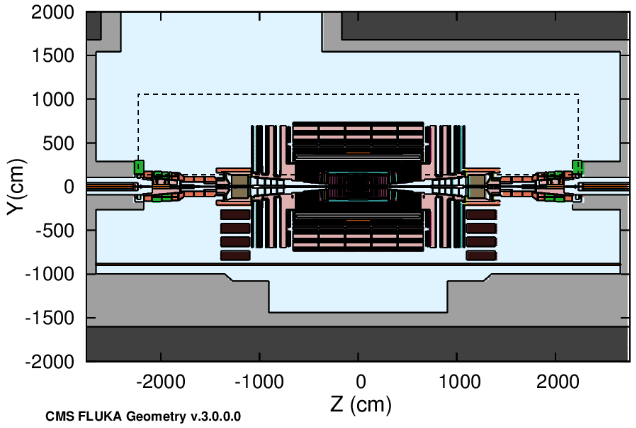
→ FLUKA is selected to produce more public flux and dose maps, and used for activation studies.

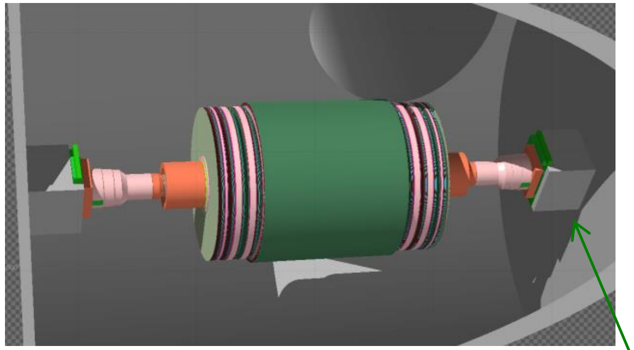
→ FLUKA model and simulation are focus of following slides

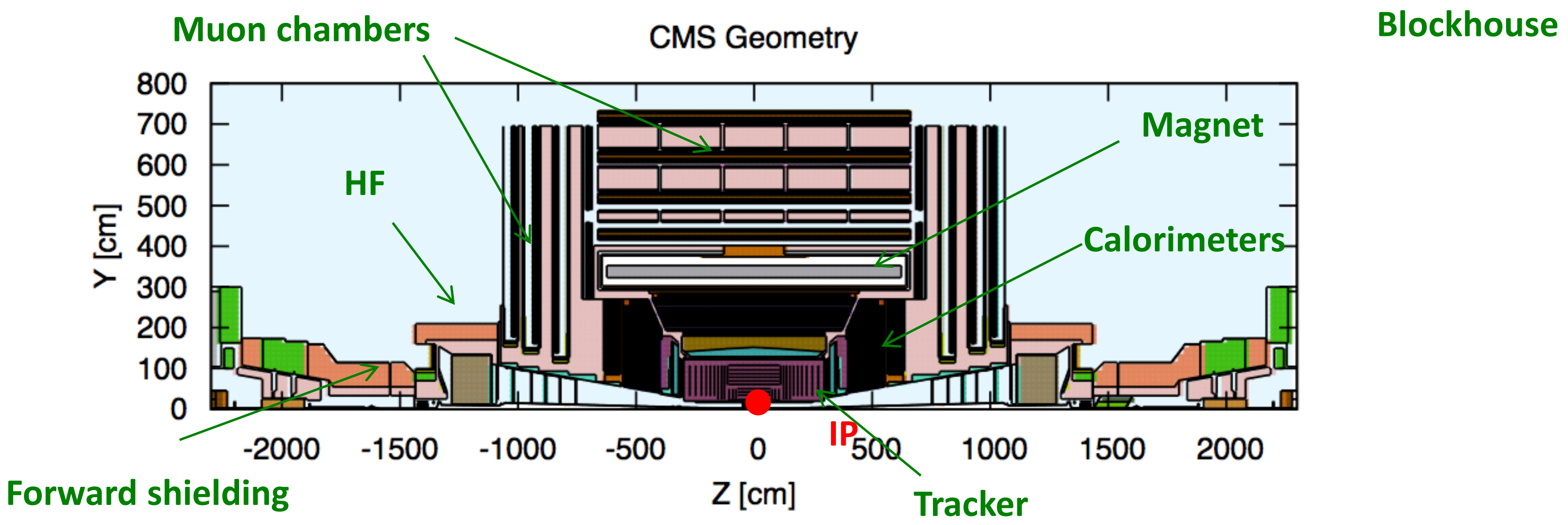
CMS FLUKA Geometry

- FLUKA - any compound material can be assigned to geometry volumes
- **Important to have correct total mass, density and material composition**
- **Trace elements** important for **activation simulations**
- Requirements for geometry resolution depends on the quantity estimated and detector region of interest
- **The CMS FLUKA Geometry is mostly cylindrical shapes - symmetric in Phi and Z**
  - **With exceptions – including rotating shielding and cavern elements**

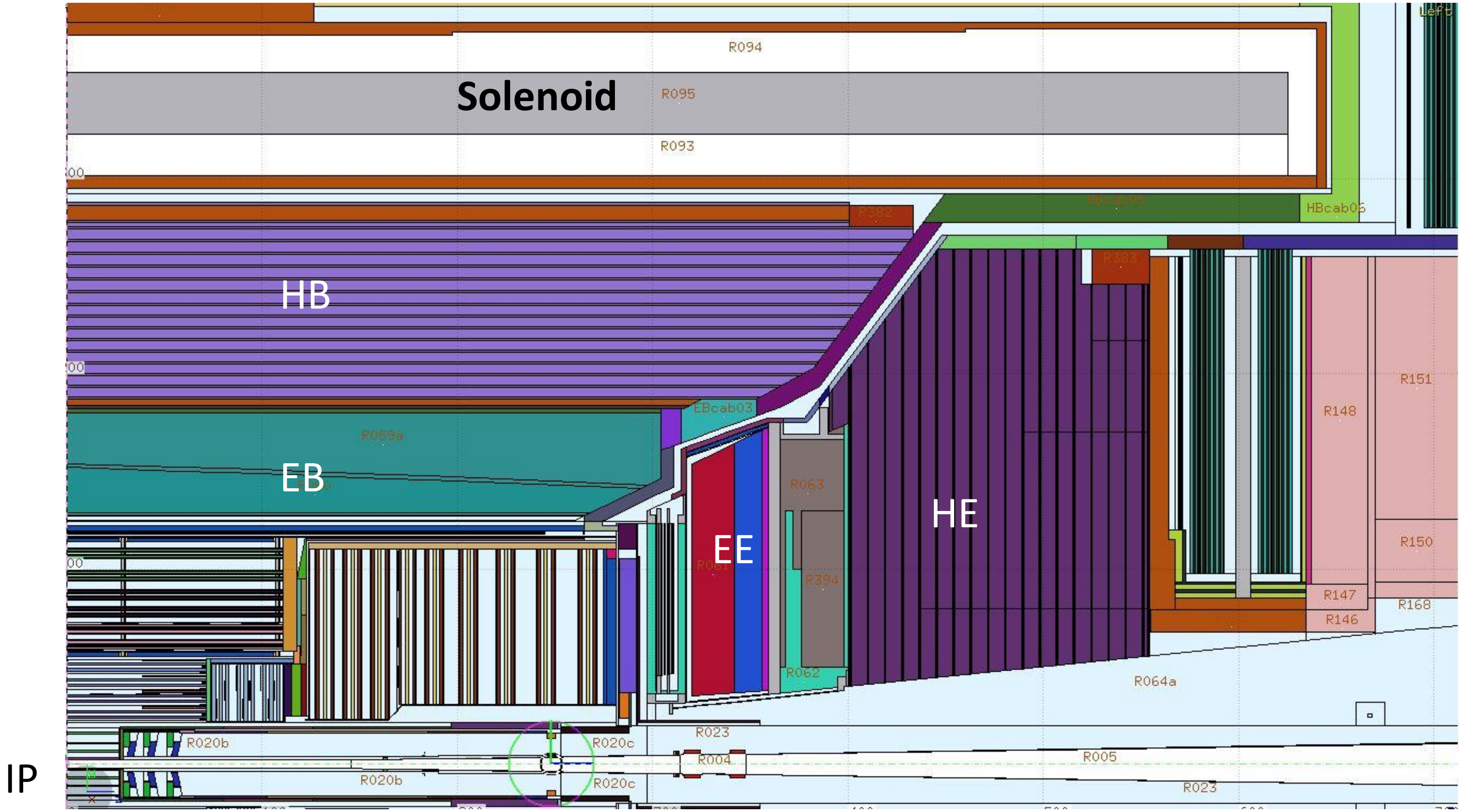
CMS FLUKA Model







FLUKA Geometry Model Central Detectors



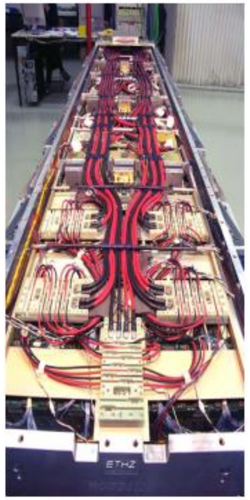
Maintaining CMS FLUKA geometry models

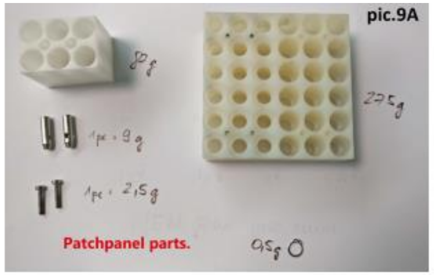
- Over past years BRIL has updated many aspects of geometry model:
  - Cavern elements
  - Rotating shielding: introduction of gaps, cracks etc.
  - Tracker – geometry resolution and material budget
  - Impurities in compositions for activation concerns
  - (cable compositions and ECAL Barrel electronics)
- The 'nominal' or **current** geometry model
  - Best available representation of **current detector configuration**
  - Continuously updated with **general improvements** and **actual upgrades**
- **Future geometry models** (Run 3 and Phase 2) are maintained for feasibility studies
- We aim to **maintain historic detector configuration** geometry models for benchmarking
  - i.e. Implement improvements but not the upgrades
  - although this is done much less frequently.

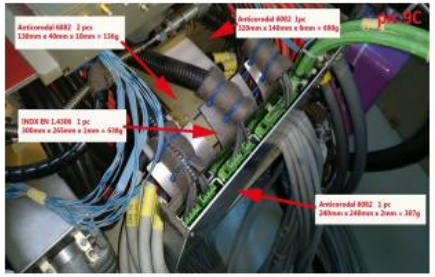
Maintaining the CMS FLUKA Geometry

BRIL Rad Sim team are heavily involved in collecting information and forming material descriptions. A strategy which we intend to change, particularly for phase 2

- Sub-detectors to provide information in FLUKA friendly format
- Or e.g. Tracker phase 2 investigating automatic generation of geometry description in FLUKA input format for every phase 2 TK-layout update







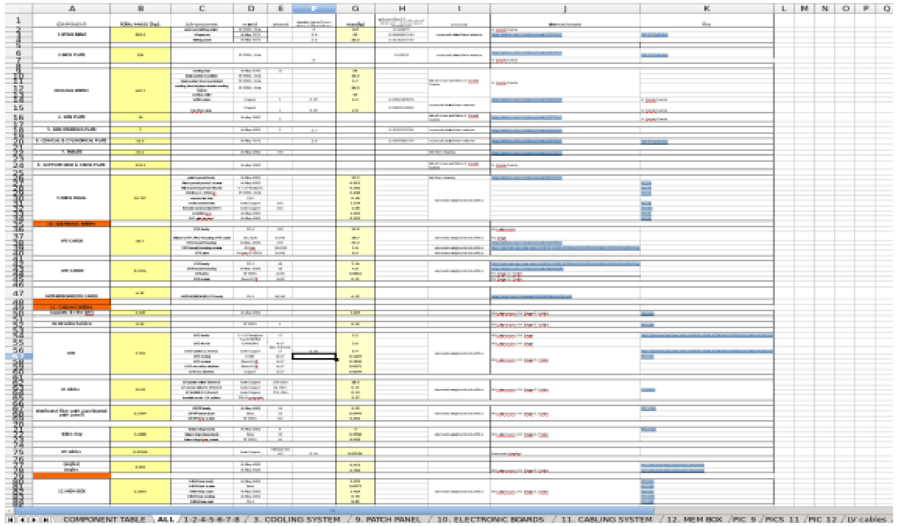


Illustration of information collection for ECAL Barrel electronics region

Simulations - Radiation Sources

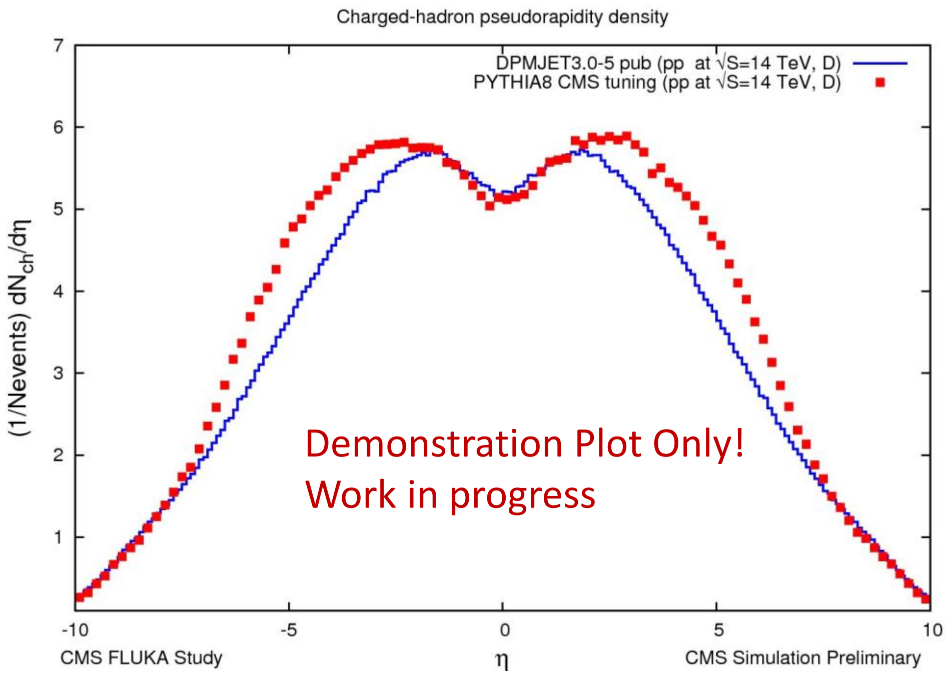
- Collision Induced Background
  - **PP collisions main source of radiation in cavern**
  - Background rates, detector damage

- Machine Induced Background
  - Pixel overflow events (PKAM), tracker damage scenarios, unwanted hits in any detector, BRIL detector development/calibration.

- Activation
  - Possible contribution background rates, **work planning for shutdowns**
  - Simulations performed in collaboration with the HSE/RP group

PP Collisions – Event Generation

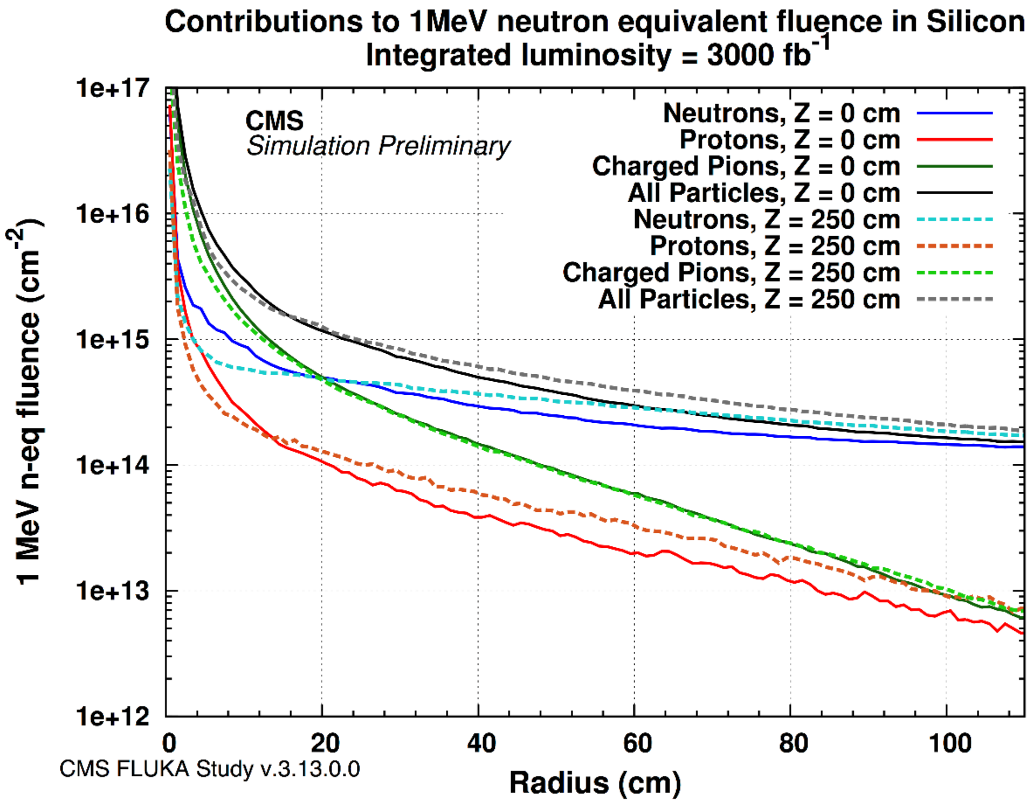
- We use DPMJET III “built in” to FLUKA
  - Ease of use; consistency with Radiation Protection Group
  - Different event generators under investigation
  - Transport through CMS geometry with new release DPMJET III and Pythia 8 in progress



***Comparison:** pp collision at $\sqrt{S_{NN}}$ = 14 TeV*
Pythia 8 and DPMJET 3.0-5

Simulations – PP Collisions

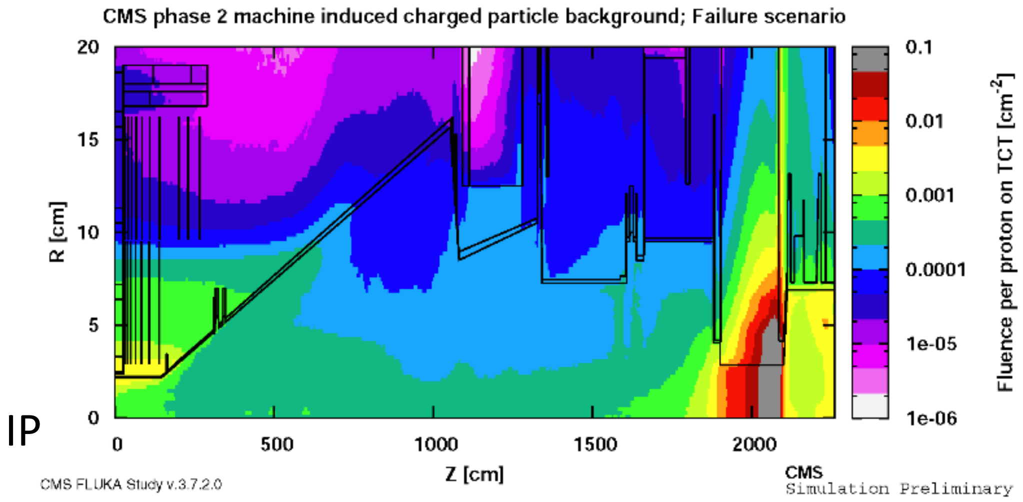
- Simulation Settings
  - Magnetic field map included extracted from CMSSW (latest update to be implemented in FLUKA)
  - Energy cut-offs for particle transport:
    - Hadrons + muons 1 keV, neutrons 0.01 meV, photons 3 keV, electrons 30 keV
    - Photons and electrons have significantly higher cut-offs in some regions (collimators, forward shielding)



- General Estimates made in independent R-phi-Z grid over full CMS detector and cavern include
  - Fluence-like 'scorings', e.g. Neutrons, charged hadrons, hadrons greater than 20MeV, high energy hadron equivalent fluence, ambient dose equivalent, etc.
  - Energy Deposition-like 'scorings', e.g. absorbed dose, NIEL
  - Results on WebBased Plotting RSP tool
- Special estimators can be provided on request, e.g. energy spectra, timing information, particle filters etc.

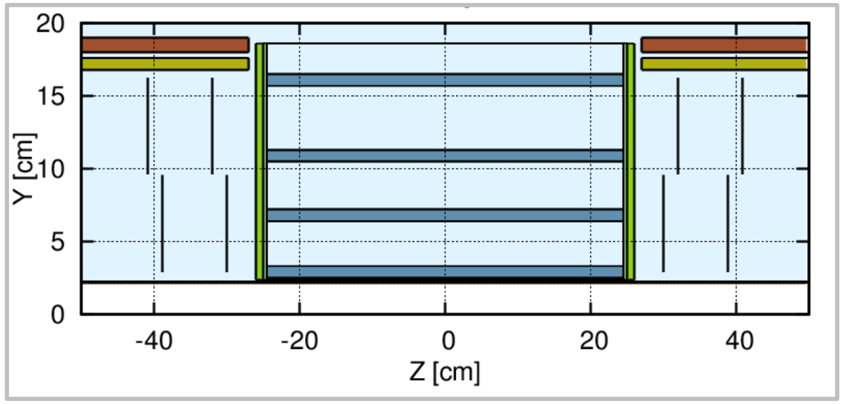
Simulations Machine Induced Background

- MIB: background particles entering the CMS cavern from the LHC tunnel
- Two strategies:
  - FLUKA:
    - SIXTRACK simulation of the Beam Halo scenarios (or similar for gas and failure scenario)
    - FLUKA simulation of particle showers in the straight section performed by EN/STI group
    - Store hit distributions at the entrance of the cavern
    - BRIL use as input for FLUKA simulation of particle showers in the experiment
  - MARS: Independent geometry development for CMS and Long Straight Section



Machine Induced Background – thresholds

- Working on HL-LHC conditions: "nominal" MIB levels and failure scenarios
- Define to LHC maximum hits on TCT before damage. Method :
  - **Assume damage threshold** of e.g. 10^9 MIPs/cm and dE/dx = 3.9 MeV/cm/MIP*
  - **Calculate peak energy density** in layer **Pixel barrel Layer 1 from MIB source** (Scaling for effective energy dep in Silicon as Pixel Layer 1 in FLUKA is represented with 'average material')

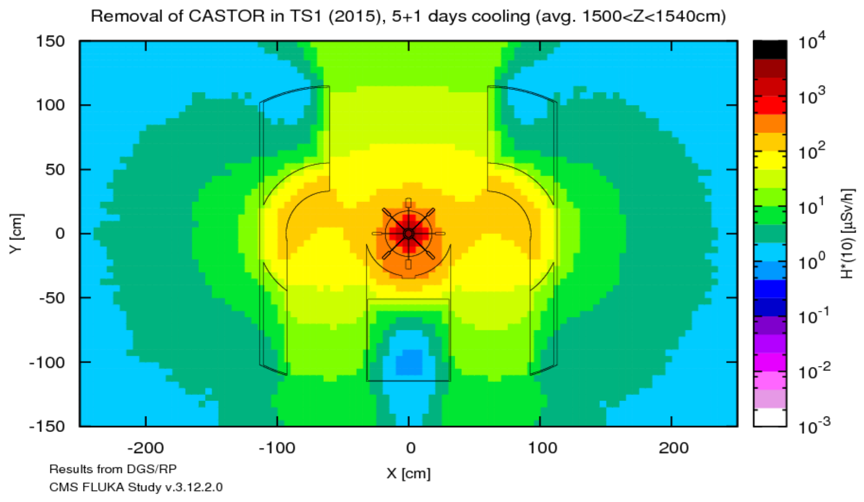


*for current pixel

Phase 2 damage thresholds required

SESAME Tool for Activation Studies

- FLUKA features very good for activation studies
  - But not allow not allow complete separation of prompt and decay geometries – not adequate for all CMS open configurations in shutdowns
- **SESAME** is a BRIL developed by tool for FLUKA that enables the complete separation of the prompt and decay simulation steps, and the transformation of the geometry model in between. This includes the ability to rotate, translate, add and remove components
- Maintained by HSE/RP for use in all CERN experiments



Activation Studies without FLUKA

Activation Tools available to CERN users when full Monte Carlo simulation not needed or to complement existing MC results

Actiwiz

- Developed by the HSE/RP group
- Light version gives relative hazards between material choices for various experimental locations
- Quick to use and cross sections for isomer production superior to current release FLUKA
- Extended version provides information (unlike FLUKA) about production channels (useful for refining impurities)
- Not for use when self shielding effects and complicated geometry assumptions are a consideration

Nucleonica

- Very comprehensive software
- Includes decay engines, easy access to several nuclear databases, gui for quick shielding calculations, assistance with gamma ray spectroscopy analysis, etc
- 2 day training course at CERN

To use “extended” Actiwiz version and Nucleonica, still need understanding of activation processes and radiation protection issues. If in doubt still contact RP

BRIL RS Results & Dissemination

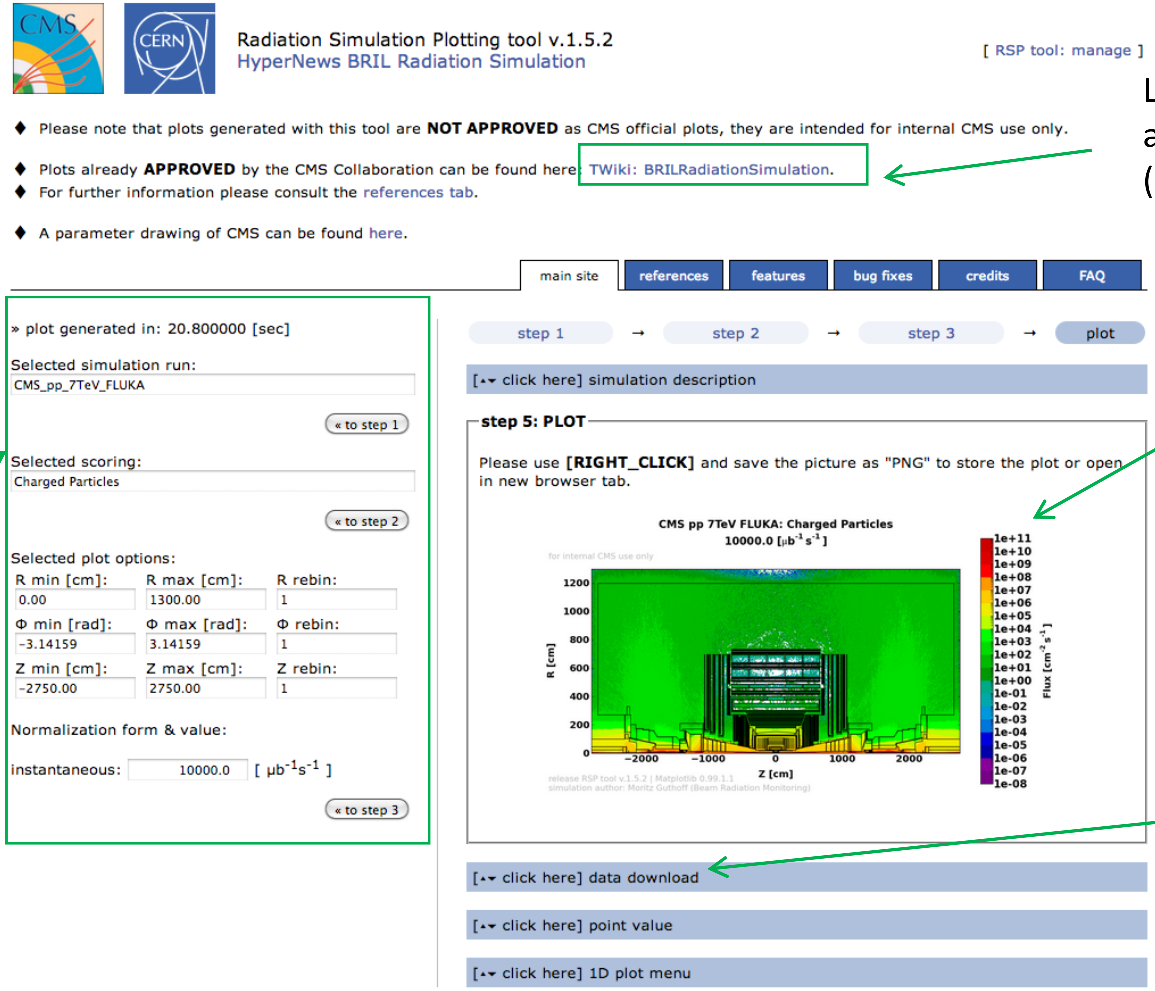
- Plots already Approved for Public can be found here:
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/BRILRadiationSimulation
- Create independent plot via Rad Simulation ‘plotting tool’
  - www.cern.ch/cms-fluxmap
- FOCUS tool for non-experienced CMS FLUKA users
  - www.cern.ch/bril/SitePages/Radiation%20Simulation.aspx
- Provision of CMS FLUKA input, and tools for simulation for experienced CMS FLUKA users
  - Stored in GIT repository

Approval for public must go first through BRIL Detector Performance Group, and then CMS Run Coordination.

Radiation Simulation Plotting Tool

- Developed and maintained by BRIL
- Visualization tool to access existing data from BRIL simulations
- Allows CMS users to create their own flux map for:
  - Particular region of interest
  - A selection of ‘generalized particle types’
    - e.g. muons, charged hadrons, absorbed dose
  - User Specified Normalization:
    - Instantaneous Luminosity
    - Integrated Luminosity
    - For Activation: Selected cooling time in a shutdown period
  - Download of data is also possible

Radiation Simulation Plotting Tool



Link to plots already approved for public use (CMS RC Approved)

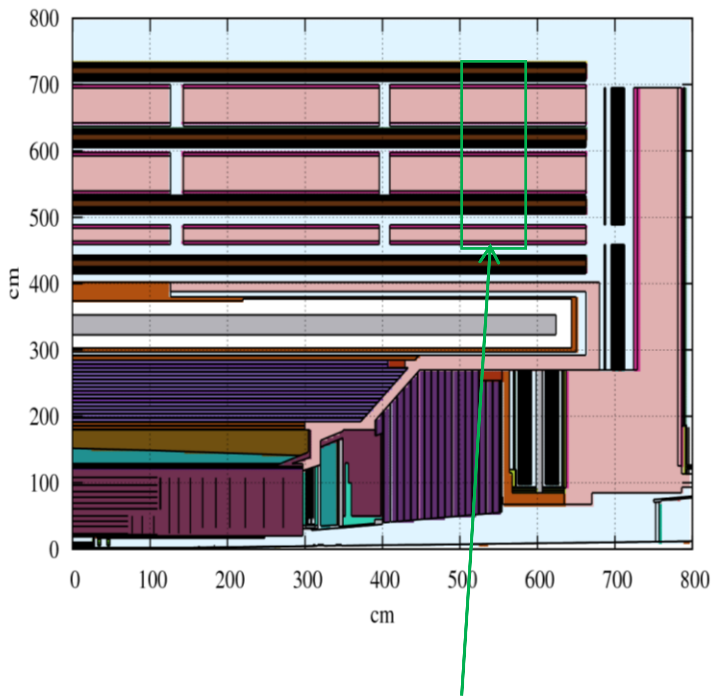
Wait several seconds…. and the plot will appear

Useful reminder of previous steps

Option to download data and make independent plot

FOCUS

- **F**luka f**O**r **C**ms User**S**
  - Developed by BRIL (uses adaption of FLUKA mgdraw.f routine)
- A user with **no FLUKA expertise** can perform FLUKA **CMS pp collision simulations**
- User simply defines boundary of interest
- Output File: Information of each particle crossing boundary, including particle
  - Location (x,y,z, coordinate)
  - Direction (cosine to each geometry axis)
  - Momentum
  - Time since collision
- Output can be used for 1st step e.g. 4 detector response simulation
- Whilst it is for non FLUKA users. Handling the output and data normalization does take experience



User defined boundary:
R_{min}, R_{max}, Z_{min}, Z_{max}

Other Simulation Handling Aspects

- Version Tagging
  - We tag a simulation run rather than just the geometry.
  - **Any change that influences a result** (geometry; energy; cut-off) invokes a new tag
  - Extremely important to use alongside plots containing FLUKA results
- CPU
  - Main issues with lxbatch: jobs launch at varying times and there is insufficient space
  - →Formed scripts to split and launch jobs on lxbatch and to **zip** and **combine** standard FLUKA outputs and use CMS priority computing account
  - Lxbatch now very convenient. BRIL can easily run several thousand primary collision events overnight
  - Otherwise we have 2 dedicated machines (only ~30 cpus) for local runs - sometimes necessary for tests and non standard outputs that cannot be zipped
- GIT
  - Useful for storage and tagging
  - Merges of FLUKA inputs have to be performed manually

Uncertainties

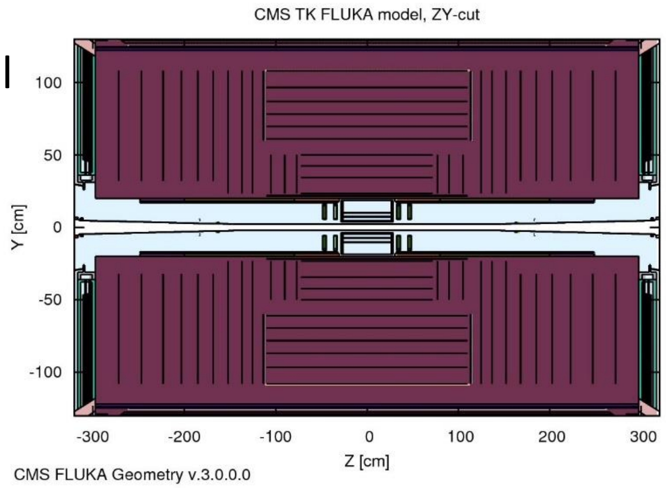
- Systematic uncertainties depend on the quantity of interest and location in the detector
- We can try to estimate on case by case basis
- Sources of Uncertainty
  - Material budget - often gives main uncertainty contribution to final result
  - Event Generators
  - Tracking particles due to imperfect algorithms (See FLUKA lectures)
  - Normalization Assumptions and Selected Binning also impact final result

- Goal over coming months to try to and establish the main uncertainties qualitatively and quantitatively
- See talk by I. Azghirey for benchmarking activities

Effects of Material Budget Modelling

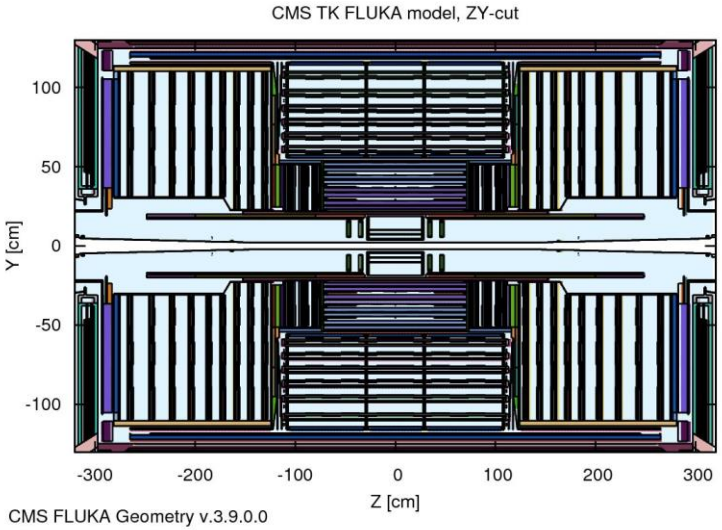
FORMER MODEL

“Average” material

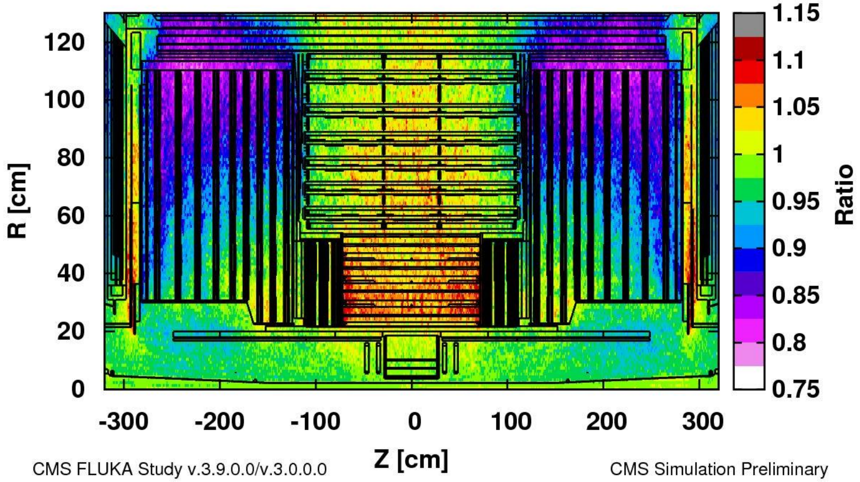


UPDATED MODEL

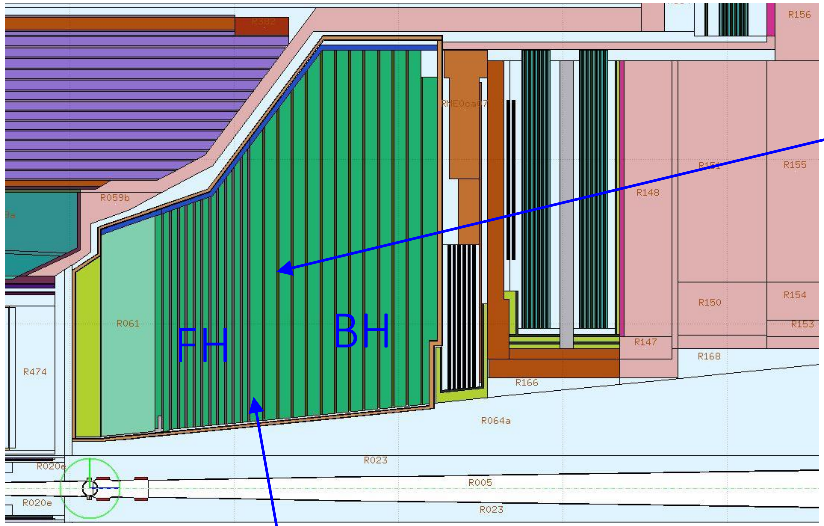
Layers, with bulkhead



RATIO OF 1 MeV neq Si
Updated / Former

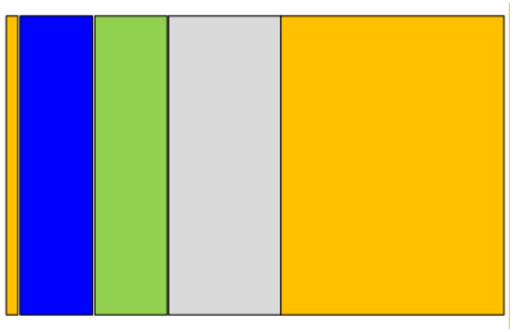


Effects of Material Budget Modelling



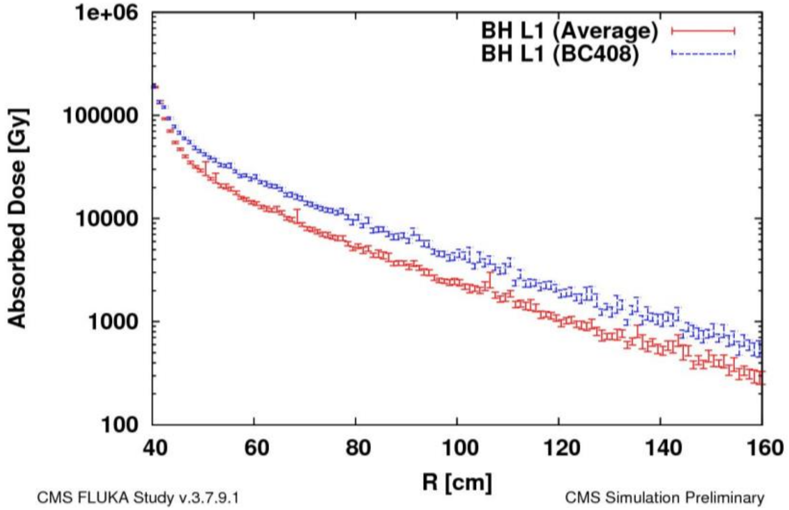
Stainless Steel Absorber (green)

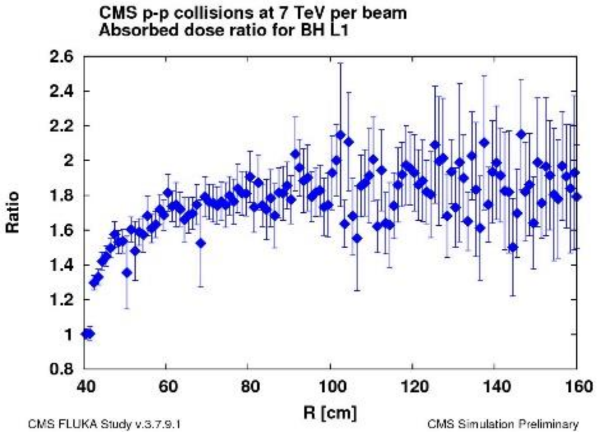
Thin layers composing:



Cu Air PCB **BC408** Cu

Absorbed DOSE in BH Layer 1 BC408 and over full layer





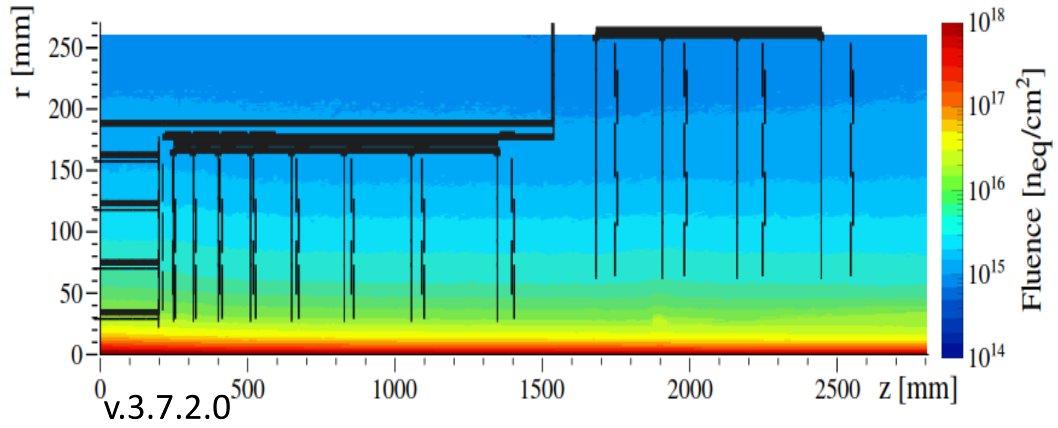
Summary / Outlook

- We have put a lot of effort into ‘nominal’ geometry improvements over past years
- We now hope to spend more time on benchmarking existing results (see next slides) and performing phase 2 simulations in lead up to EDRs
- Discussion of damage thresholds (in terms of FLUKA quantifiers) and models with upgrade communities
- We are interested in learning approach from other experiments

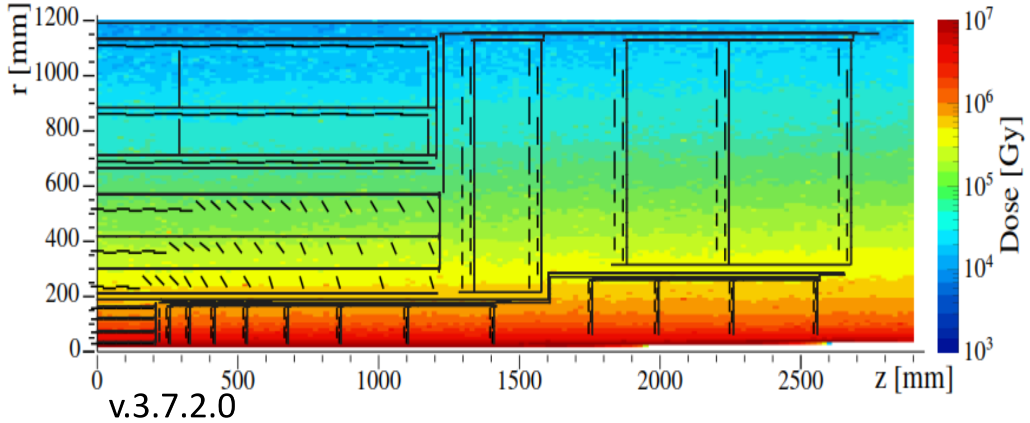
Thank you for your attention

Radiation Simulation Plotting Tool

- Use of downloaded data to make TDR plot 1 MeV neq Si in a phase 2 tracker model for a total integrated luminosity of 3000 fb^{-1}



1 MeV n eq. on Silicon



Absorbed dose (TID)

Approximate contribution of Uncertainties

- *Geometry & Materials Budget (from a few % up to more than 100 % due to model uncertainties and approaches, material composition uncertainties, design uncertainties, imperfection of some CMS subsystems during experimental runs)*
- *Cross-section data (about 10-15% ?)*
- *pp and hA –generators (up to 30-40 %)*
- *Transport of particles (up to 10-15 %)*
- *Scorings & Cut Offs (up to 100 %, f.e. due to Up-Down, L-R asymmetry)*
- *Normalization factors (up to 15% on base of the CMS and ATLAS inelastic cross-section measurements at* $\sqrt{S_{NN}}$ *= 13 TeV)*
- *Human factors (up to 100 %)*

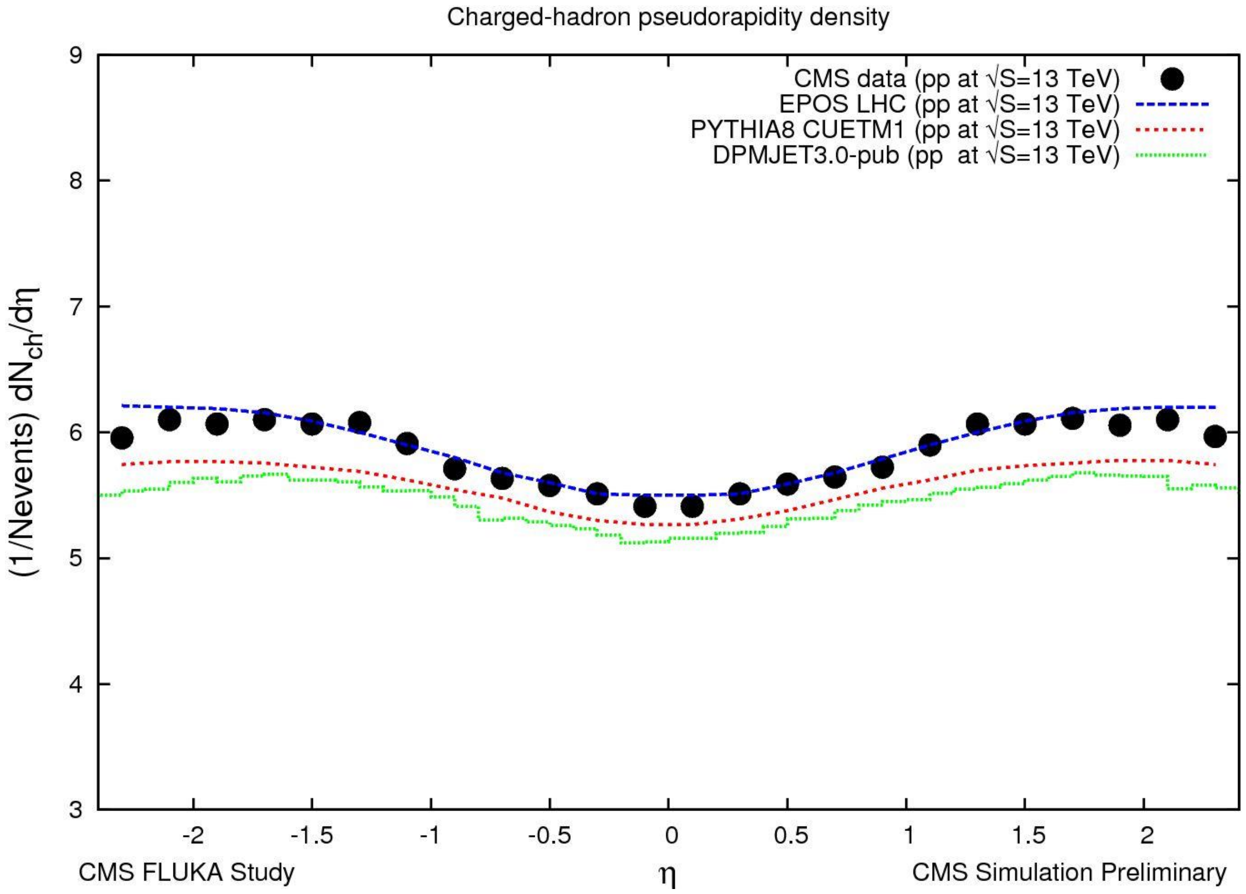
Comparisons: *Average multiplicity (Diffraction Included)*

Particles / pp at 14 TeV	DPMJET-3.0-5*	DPMJET-3.0-dev**	Pythia8'' D	RE=3.0.-dev/3.0-5	RE=P8/3.0-5	RE=P8/3.0-dev
p + pbar	4.0	4.6	5.02	1.15	1.26	1.09
n + nbar	3.4	4	4.61	1.17	1.36	1.15
pi+ + pi-	57.2	65.2	69.05	1.14	1.21	1.06
K+ +K-	6.9	8	8.75	1.16	1.27	1.09
photons	5.6	6.4	83.9	1.14	1.15	1.01
pi0	33.7	38.2	0	1.13		
other neutrals	8.1	9.7	10.28	1.19	1.27	1.06
other charged	1.4	1.5	1.18	1.10	0.84	0.79
total	120.3	137.5		1.14		

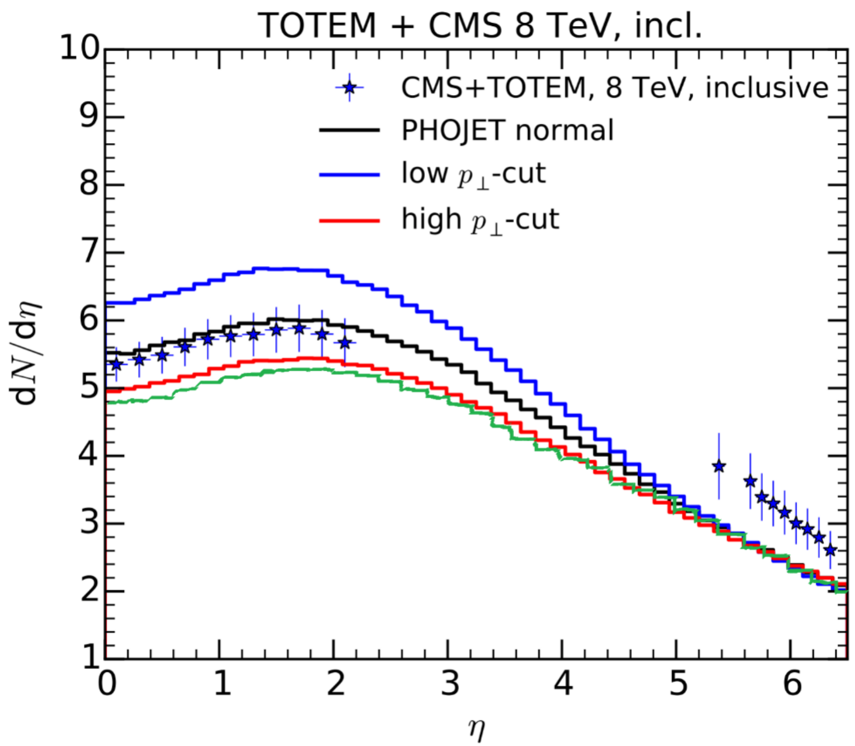
**Data by I. Kurochkin (DPMJET-3.0-5, version 2008)* ***Data by A. Fedynitch (2014)*

''Data by M. Kirsanov (2018) with CMS tuning (diffraction included)

Comparison: pp collision at $\sqrt{S_{NN}}$ = 13 TeV



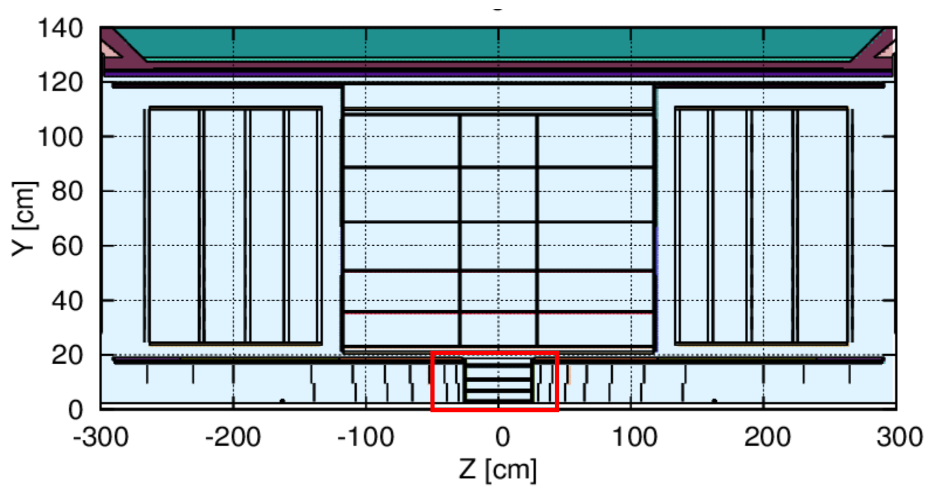
Comparison: pp collision at $\sqrt{S_{NN}}$ = 8 TeV



DPMJET III public version /data 2012 by S. Roesler/ for |η| < 2.3 from 10% to 16%; for 5.3< |η| < 6.4 from 20% to 30 %.

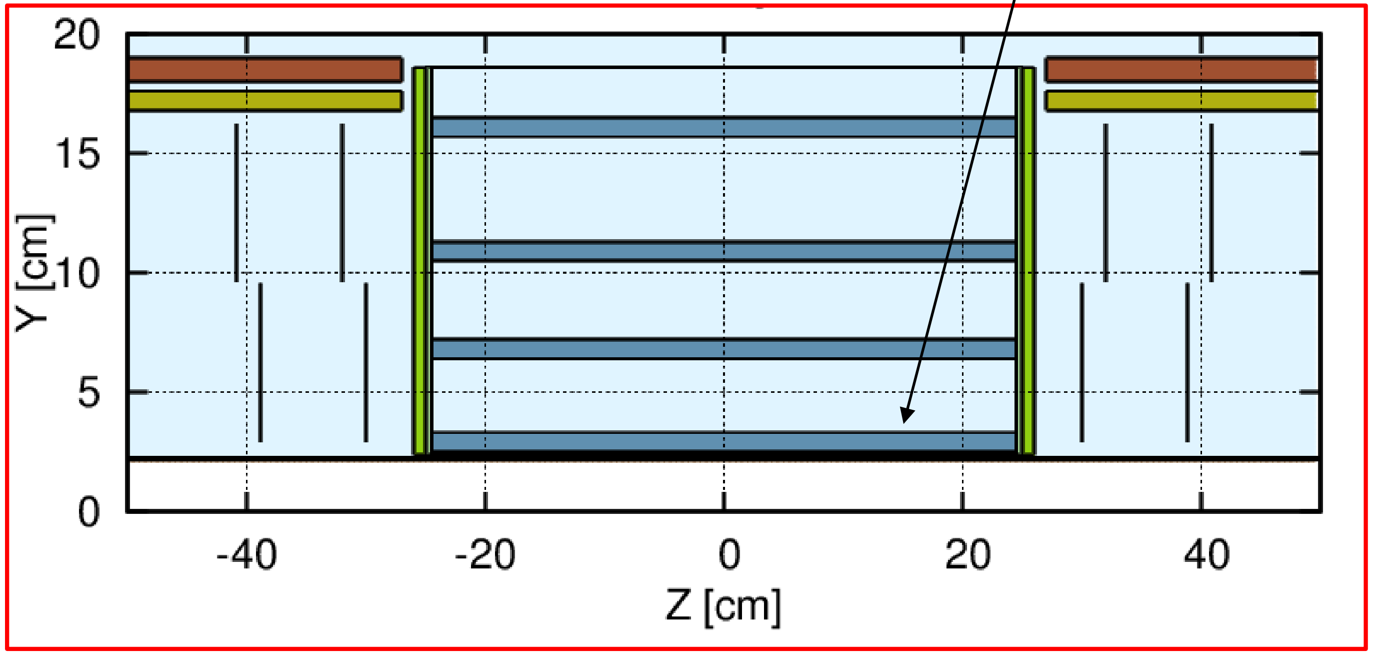
DPMJET III 2011 and DPMJET III 2016 give the same result on the tails of η-distributions

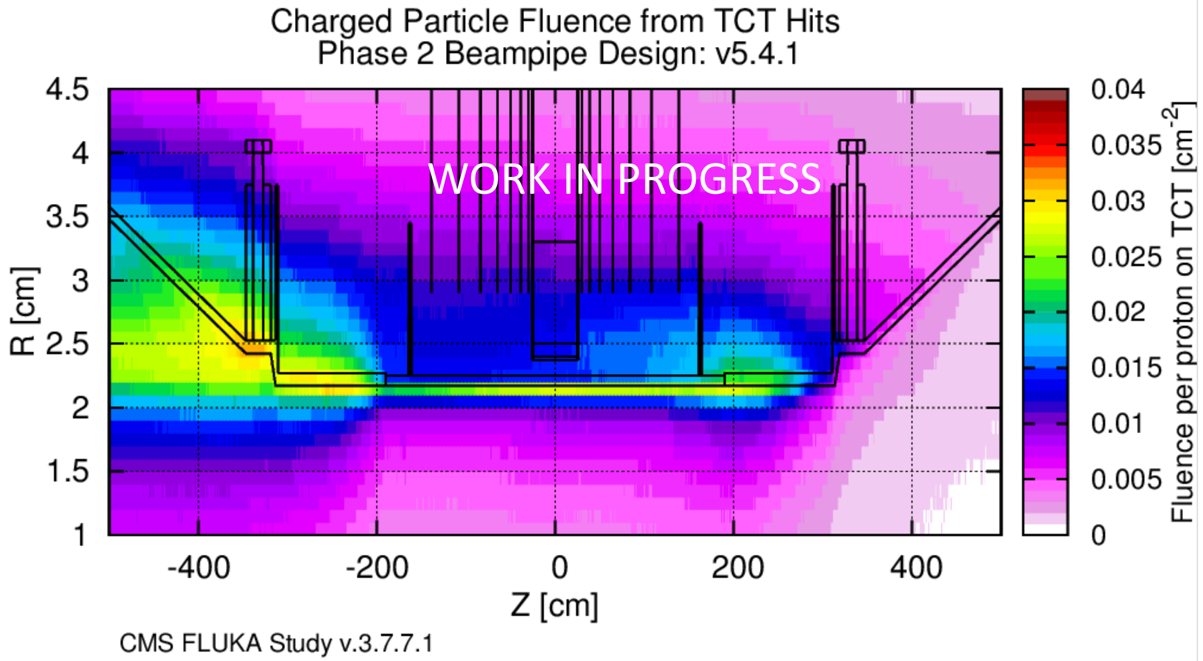
Tracker Region, Phase 2 FLUKA Geometry

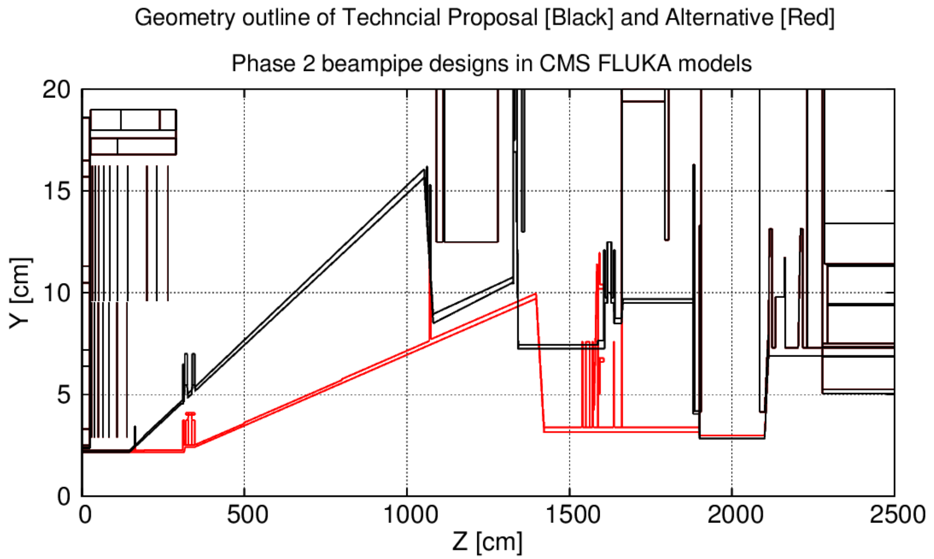


All simulations use phase 2 tracker layout as in TP FLUKA model (which has likely changed since then)

Pixel Layer 1 (average material to include silicon, services) 2.5cm <R <3.3cm







Likely contribution to increase also the extended cylindrical region in central BP