Backward Hadronic Calorimeter DSC report

Given at last ePIC Collaboration Meeting in Warsaw

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Ohio State University

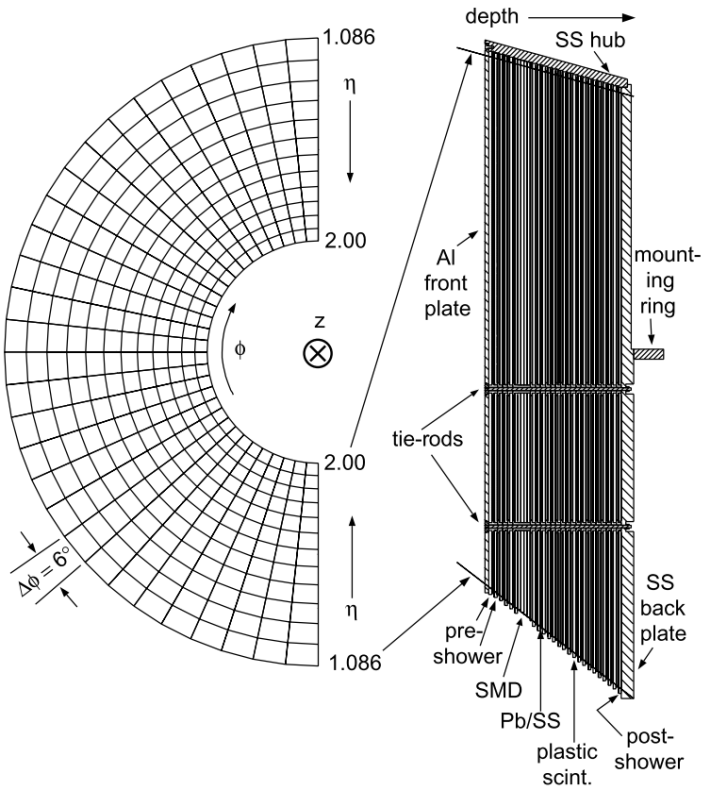
BNL group meeting, BNL 28.9.2023

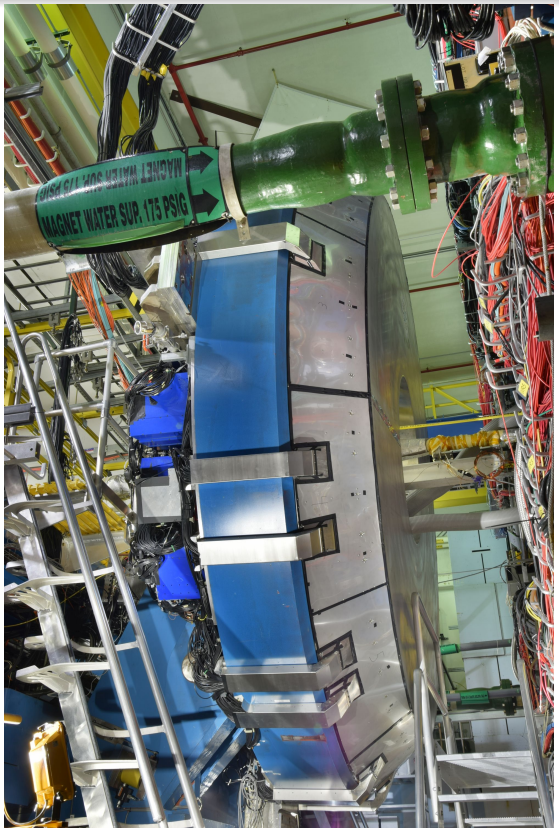
Outline

Introduction - backward HCal

Requirements: `https://eic.jlab.org/Requirements/`

A future backward HCal shall provide functionality of a tail catcher for the high resolution e/m calorimeter in electron identification, as well as for jet kinematics measurement at small Bjorken x

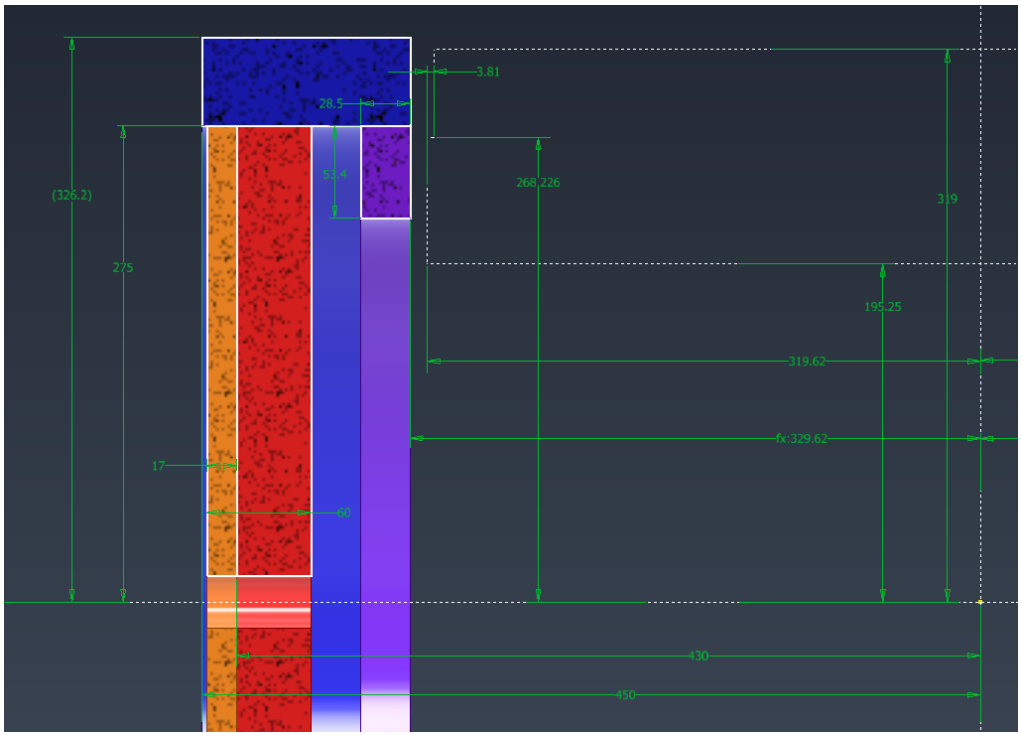




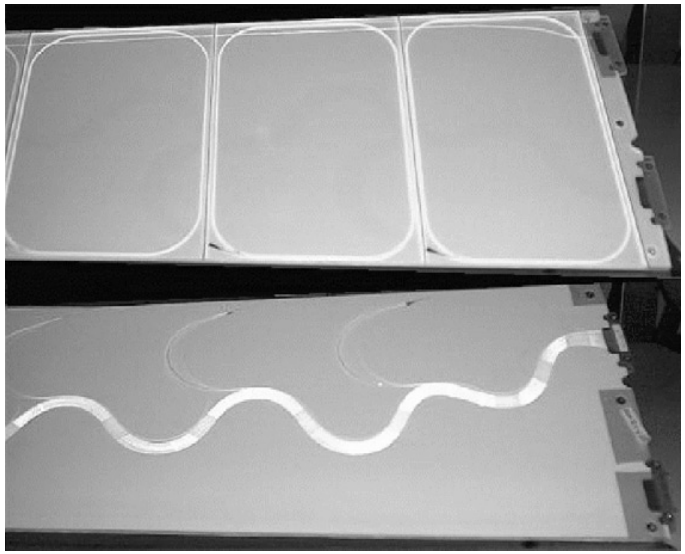
- Design considerations:
  - High efficiency for neutron detection
  - Good spatial resolution to distinguish neutral/charged hadrons
- Reuse STAR EEMC scintillator megatiles (expected to have lost only $\sim 5\%$ of light yield): `https://doi.org/10.1016/S0168-9002(02)01971-X`

Design

- Sampling calorimeter with 10 alternating layers, $2.4\lambda^0$ (red), similar to Belle-II KLM:
  - stainless steel 4 cm
  - plastic scintillator 4 mm Kuraray SCSN-81
- Scintillator light guided by 0.83 mm WLS (Kuraray Y11-doped 200 ppm fiber)
- Light collection by SiPM:
  - Candidate (to verify): S14160-1315PS `https://www.hamamatsu.com/eu/en/product/optical-sensors/mppc/mppc_mppc-array/S14160-1315PS.html`
- Electronics to follow solutions of other calorimetry systems (HGCROCv3 or EICROC)

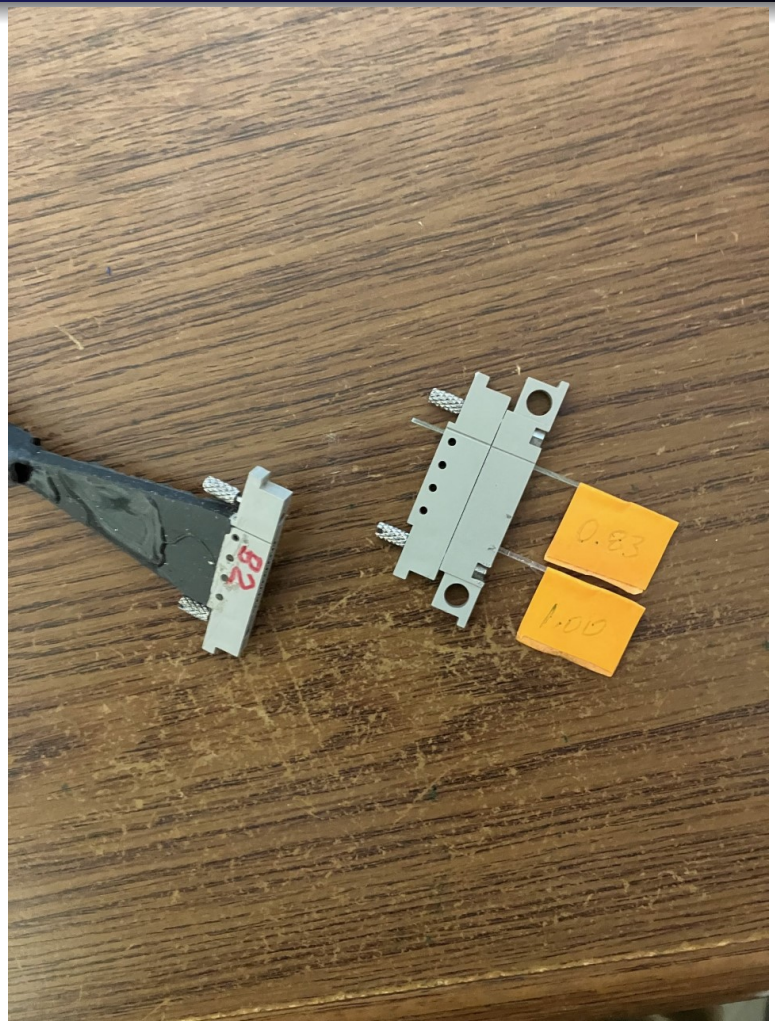


STAR EEMC 6° megatile - 12 tiles in η direction (radial) each



- nHCal decoupled from the magnetic steel $\Rightarrow$ more flexibility

STAR EEMC megatile and connectors



Pictures thanks to Will Jacobs

- 12° megatile shown (2 rows of 12 tiles in η)
- 0.83 mm diameter WLS fiber contained in σ-shaped grooves
- New, modified connectors need to be made, coupling light to an array of 12 SiPMs each (1 fiber/SiPM, but multiple fibers/SiPM to be considered)
- May need to remain wrapped after disassembly of STAR

Status of backward HCal DSC

Detector Subsystem Leader

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Czech Technical University in Prague

- Subhadip Pal (PhD student)
  - simulations, part time
- Alexandr Prozorov (fresh PhD)
  - geometry, clustering, part time

Brookhaven National Laboratory

- Roland Wimmer, mechanical engineer
- other experts at BNL

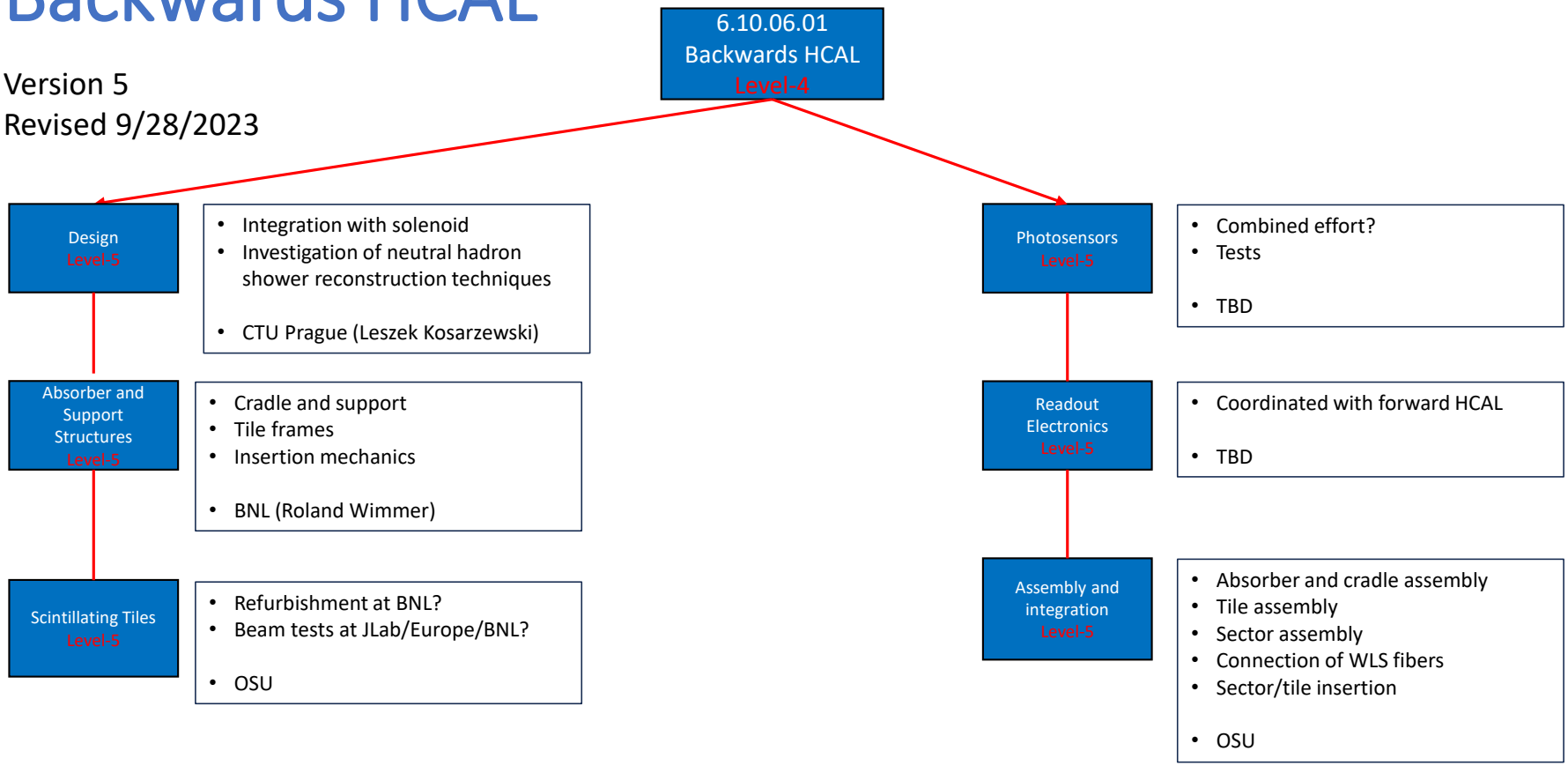
Ohio State University

- Details under discussion

- Looking now for institutions to join and more people to participate!
- Getting a lot of help from other people at BNL and CTU
- National Nuclear Research Center, Poland thinking about joining - SiPM tests

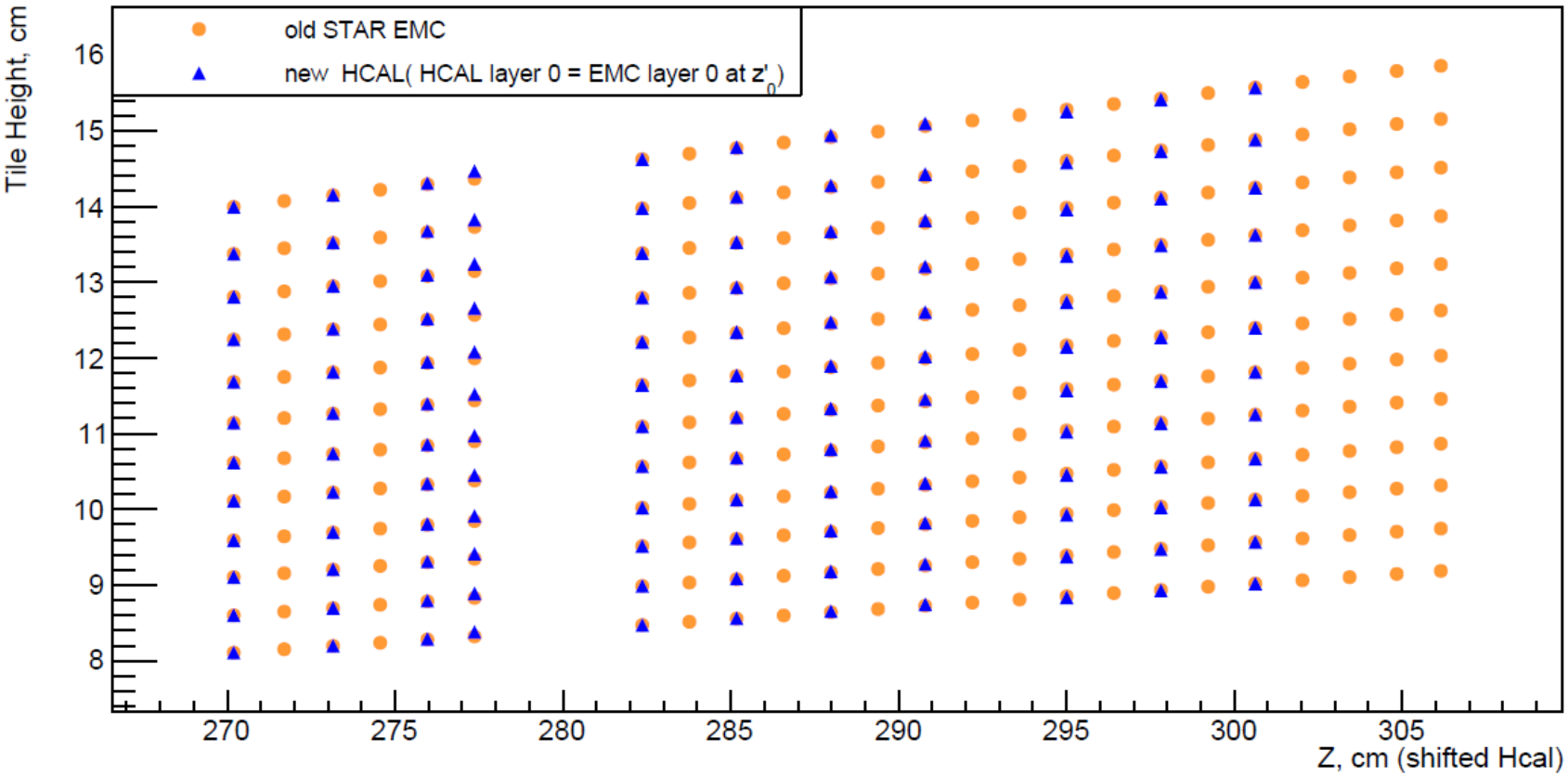
Backwards HCAL

Version 5
Revised 9/28/2023



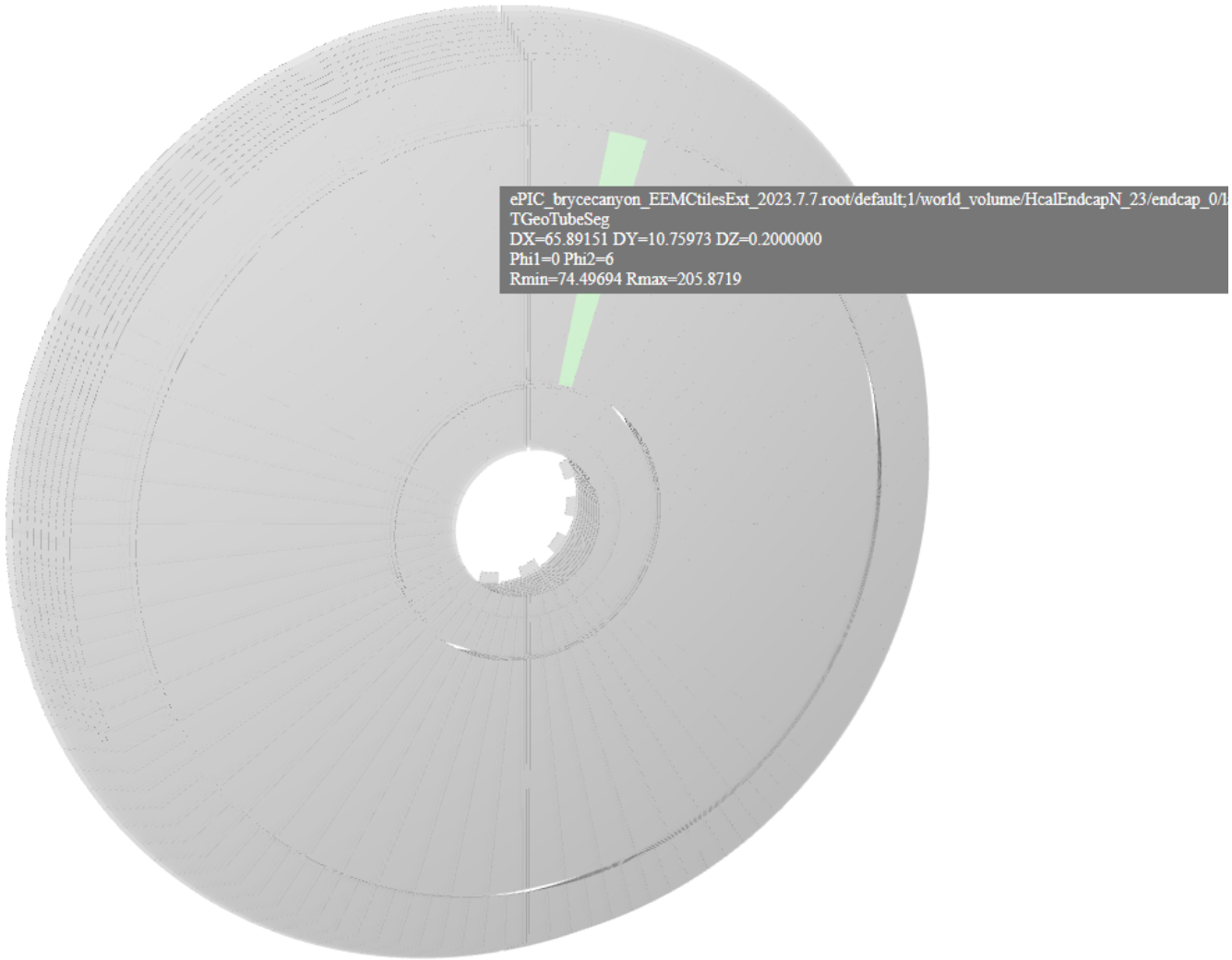
Choice of megatiles

- Megatile selection algorithm by Alexandr Prozorov
- Selects megatiles from a layer, which matches the η of the first, to maintain projective structure
- STAR EEMC tiles provide acceptance in $-2.39 < \eta < -2.195$



- Extrapolated tiles to cover the region close to beampipe and the outer region
  - extends acceptance to $-3.06 < \eta < -1.27$

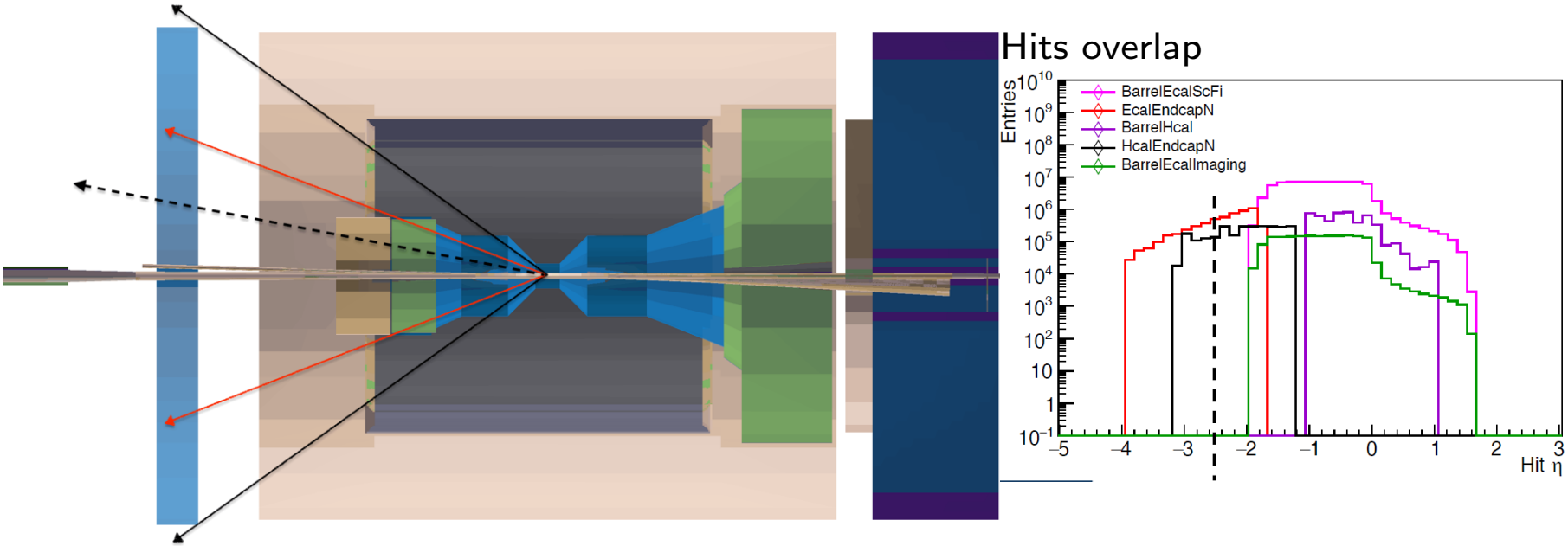
Geometry implementation in dd4hep



- Exact tile geometry implemented with absorber (no support structures)
- Added extrapolated inner and outer parts with a gap for connectors

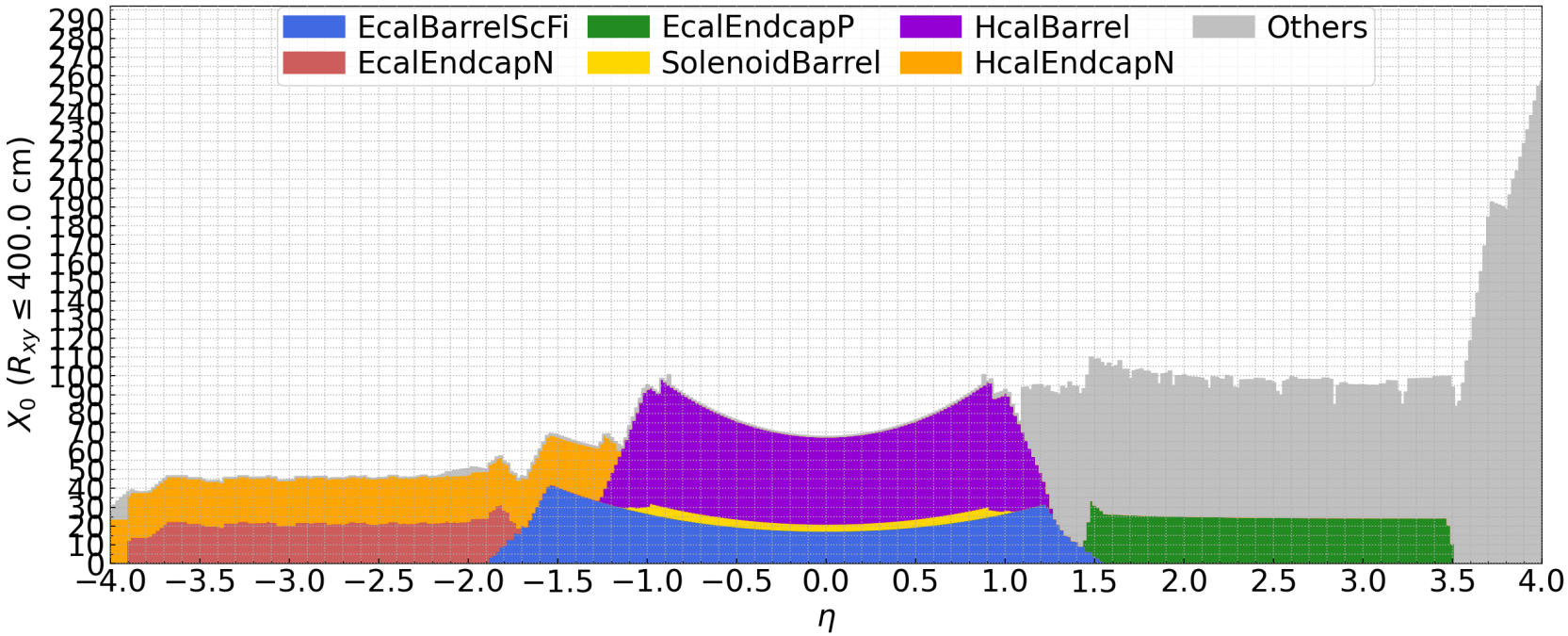
Overlap of calorimeters

Acceptance



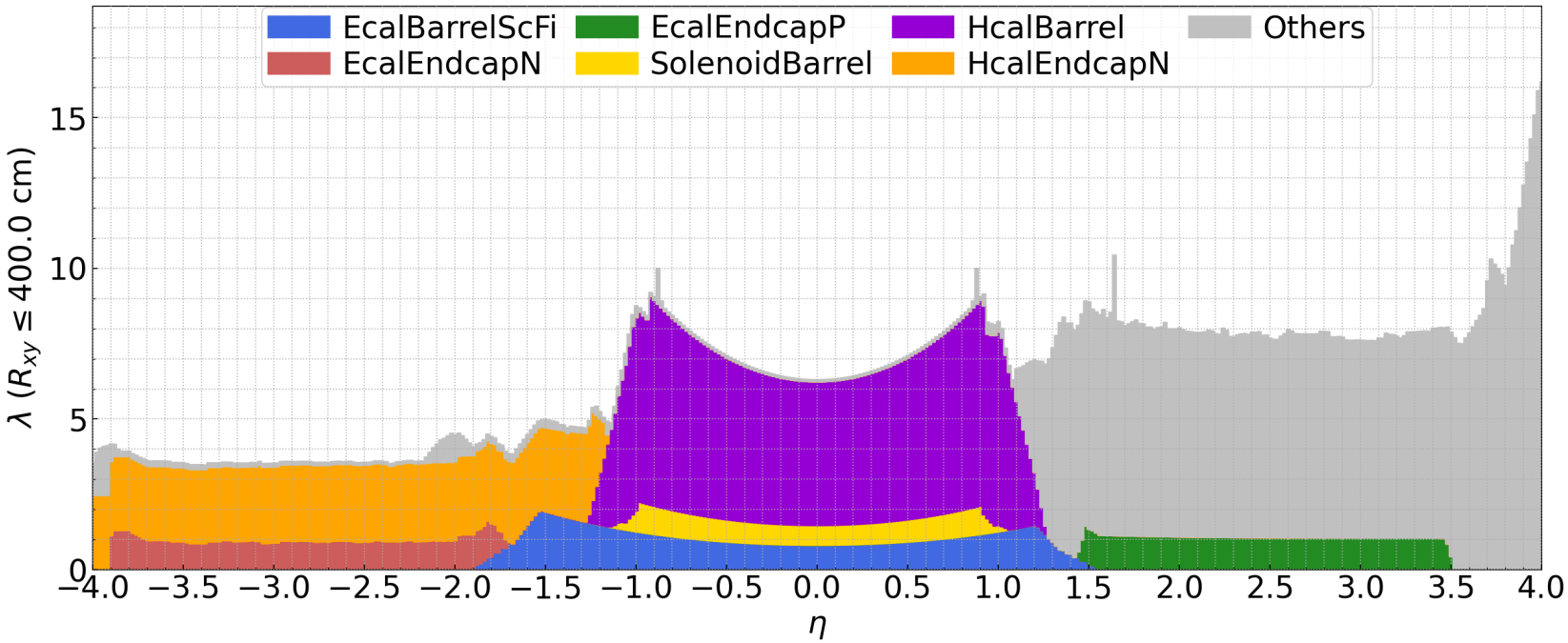
- Acceptance $-3.06 < \eta < -1.27$ - can still be extended to match the stainless steel absorber volume
- Overlaps with backward and barrel EMcals

Radiation length - brycecanyon geometry



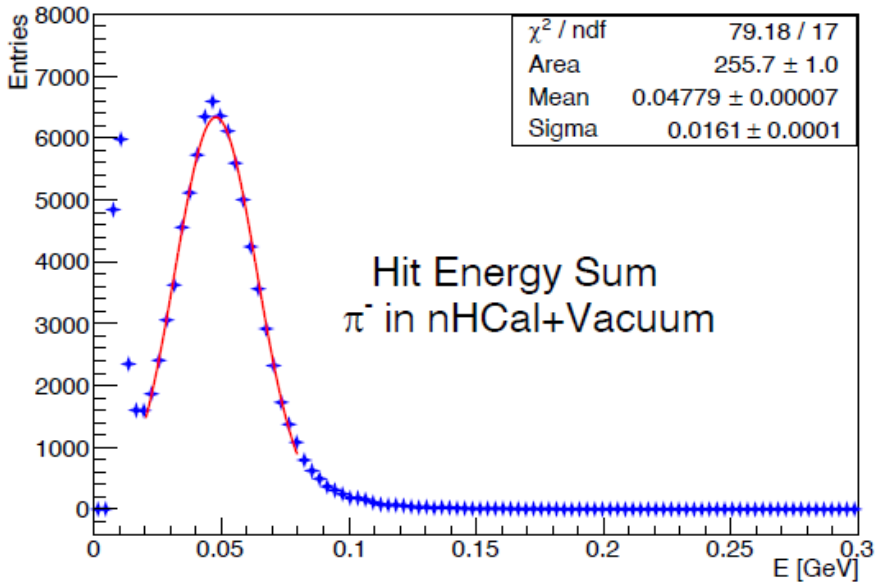
- $\sim 24 X_0$ for backward HCal
- Scintillator tiles do not cover the same volume as steel absorber yet

Interaction length - brycecanyon geometry



- $\sim 2.4\lambda_0$ for backward HCal
- Scintillator tiles do not cover the same volume as steel absorber yet

Calibration - sampling fraction



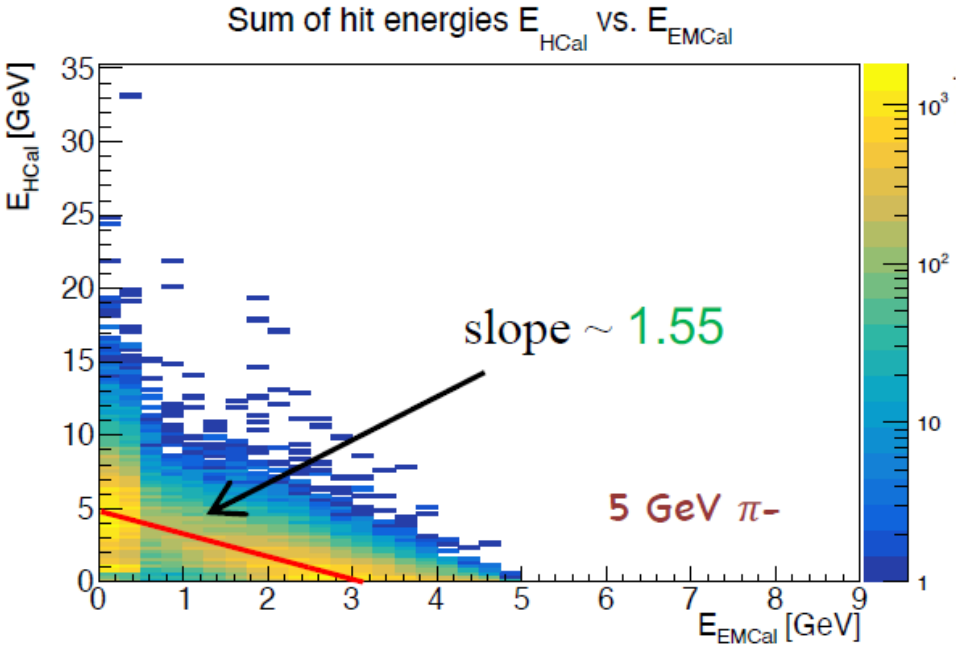
NAME	VALUE	ERROR
Area	255.7	1.0
Mean	0.04779	0.00007
Sigma	0.0161	0.0001

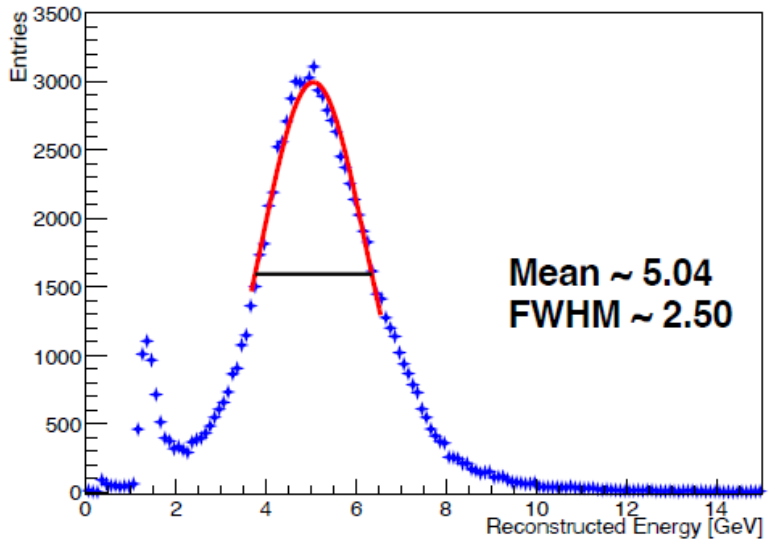
- nHCal is calibrated using π^-
- 1 π^- /event, 1mill events and p = 5 GeV
- $\theta = 170^\circ$ and $\varphi = 45^\circ$

Sampling Fraction (f)
= 0.04779/5.05
= 0.00946
~ 0.0095 +/- 1.4E-05

Study by Subhadip Pal

- Study energy sharing between backward HCal and EMCal





$E_{reco} = 1.55 * E_{EMCal} + E_{HCal}$

Fitted a linear function to E_{HCal} vs. E_{EMCal} histogram to extract the energy sharing parameters

* $E_{Hcal}/f \equiv E_{HCal}$

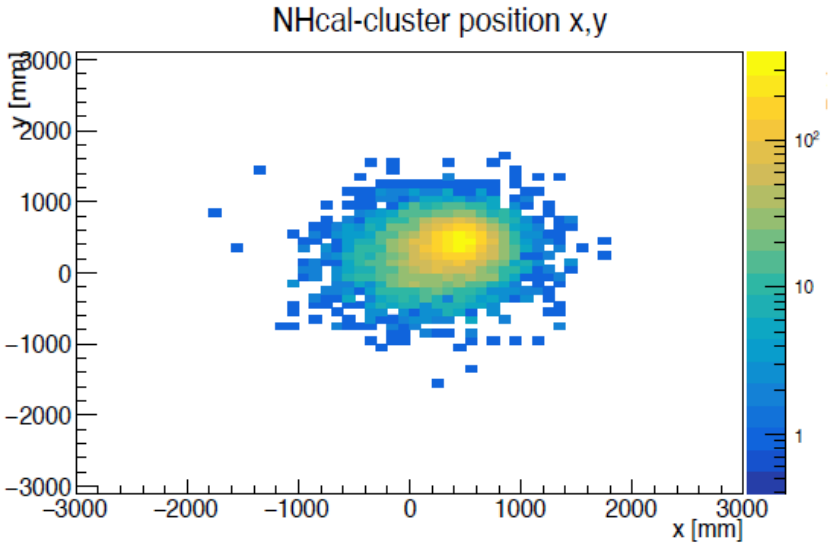
Study by Subhadip Pal

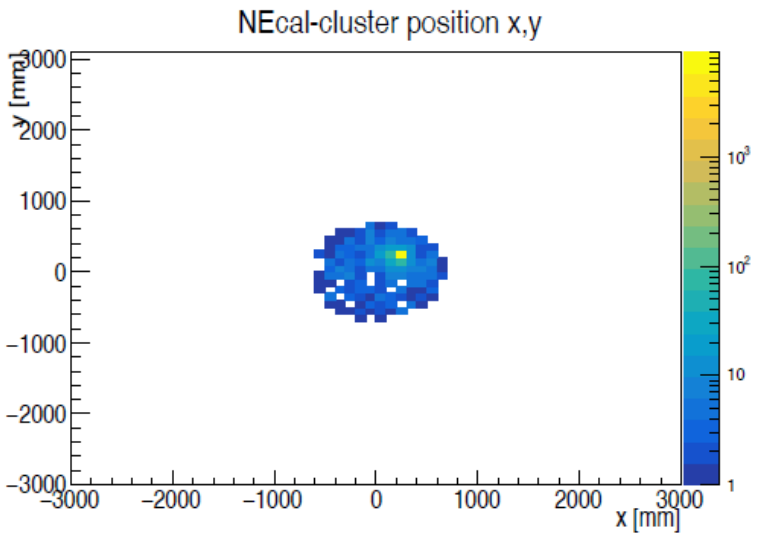
Position resolution study - algorithm

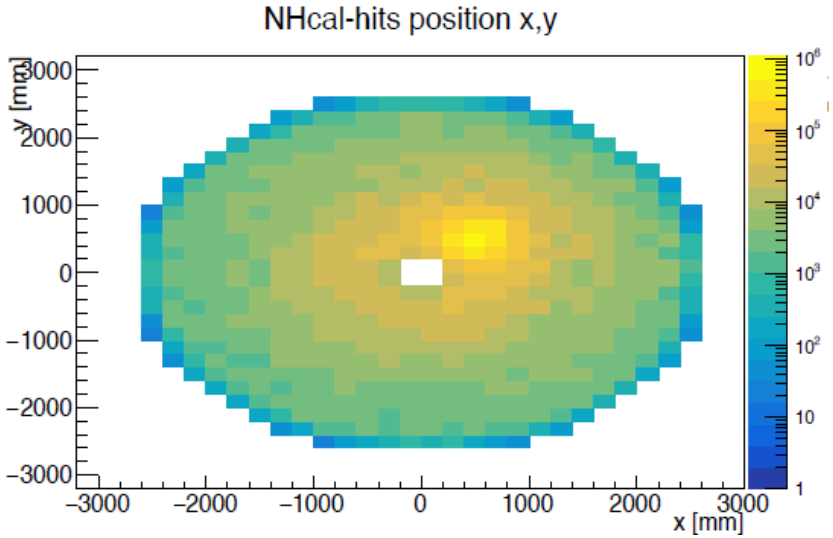
1. Simulated 1 neutron/event, $p = 5\,\mathrm{GeV/c}$
   - Angular direction:
     - $\theta = 170^\circ$ (2.967 rad)
     - $\phi = 45^\circ$ (0.785 rad)
2. Reconstructed clusters in both backward HCal and EMCal are combined with energy weights to have a combined angular position measurement

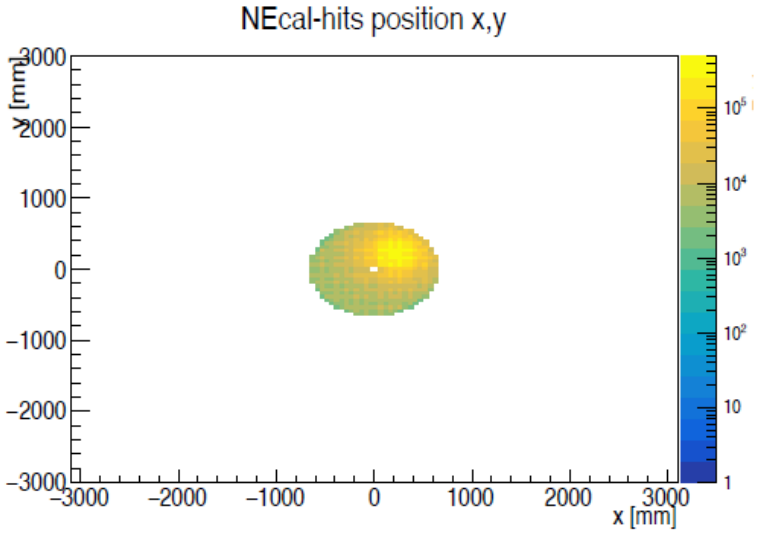
$$\theta_{RECO} = w_{EMCal}\theta_{EMCal} + w_{HCal}\theta_{HCal}$$
$$\phi_{RECO} = w_{EMCal}\phi_{EMCal} + w_{HCal}\phi_{HCal}$$
$$w_{EMCal} = \frac{1.55E_{EMCal}}{E_{RECO}}, w_{HCal} = \frac{E_{HCal}}{E_{RECO}}$$

Position resolution study - hits



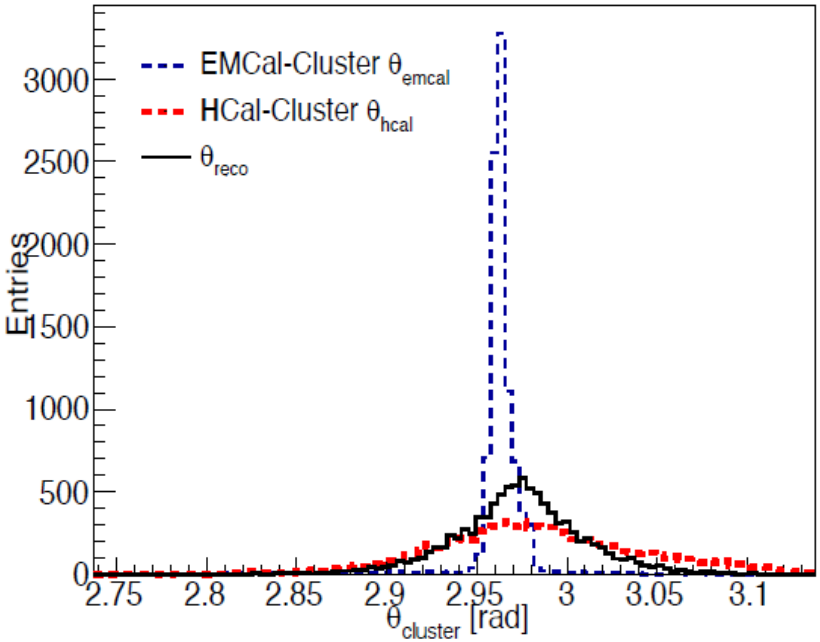


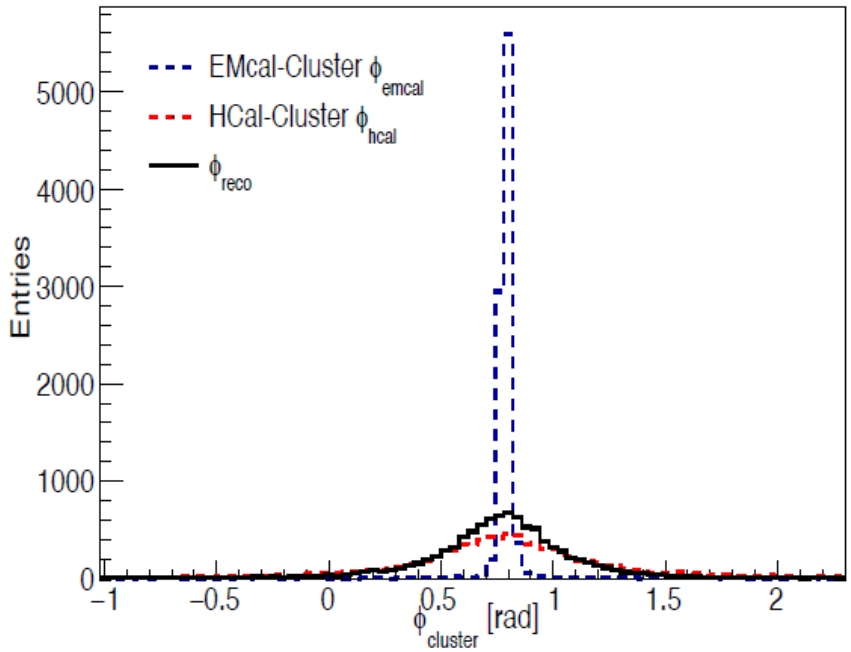




Study by Subhadip Pal

Angular resolution study

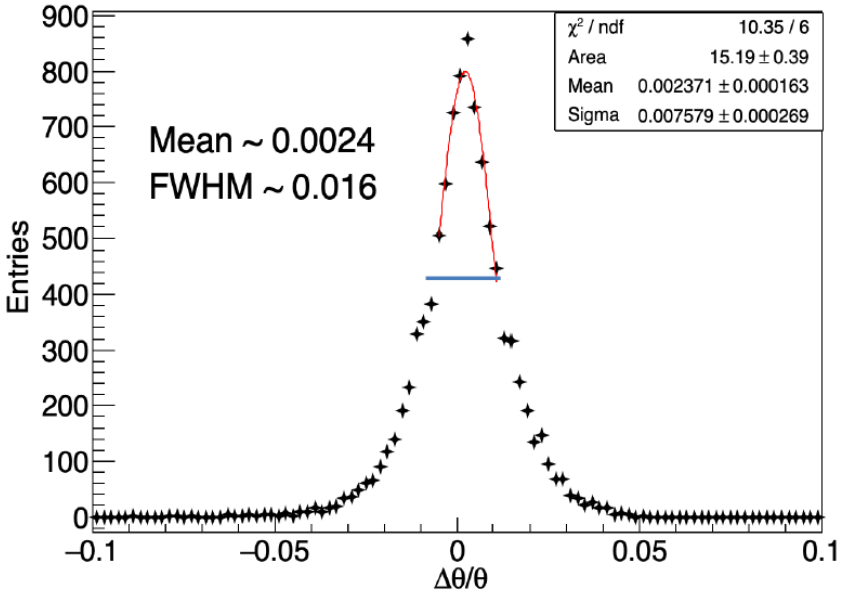


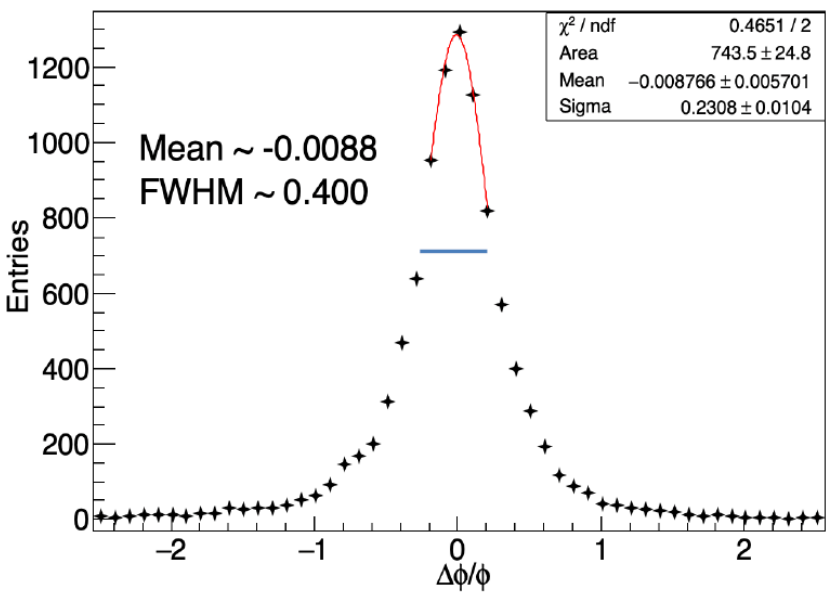


- Simulated 1 neutron/event, $p = 5\,\mathrm{GeV/c}$
- Angular direction:
  - $\theta = 170^\circ$ (2.967 rad)
  - $\phi = 45^\circ$ (0.785 rad)
- Much better resolution provided by backward EMCal
  - But HCal provides better response to hadrons

Study by Subhadip Pal

Angular resolution study

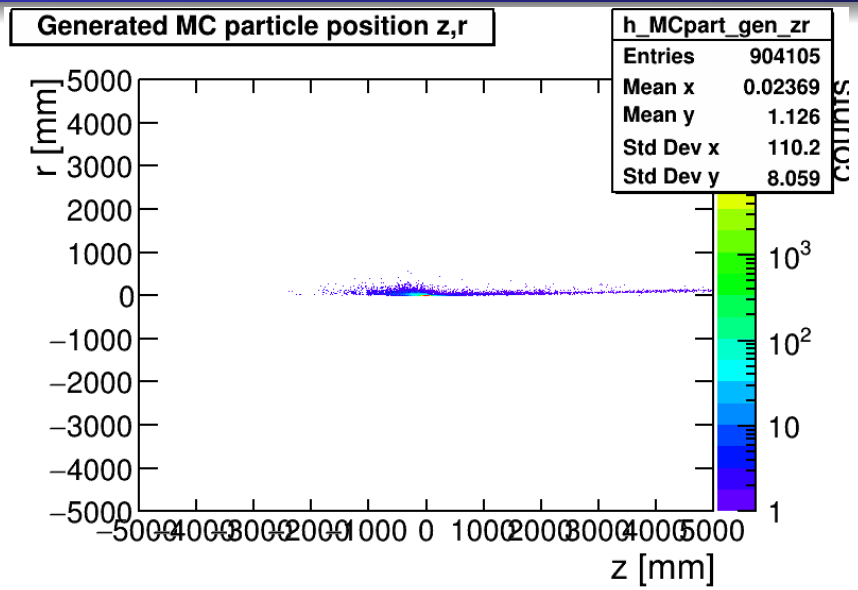


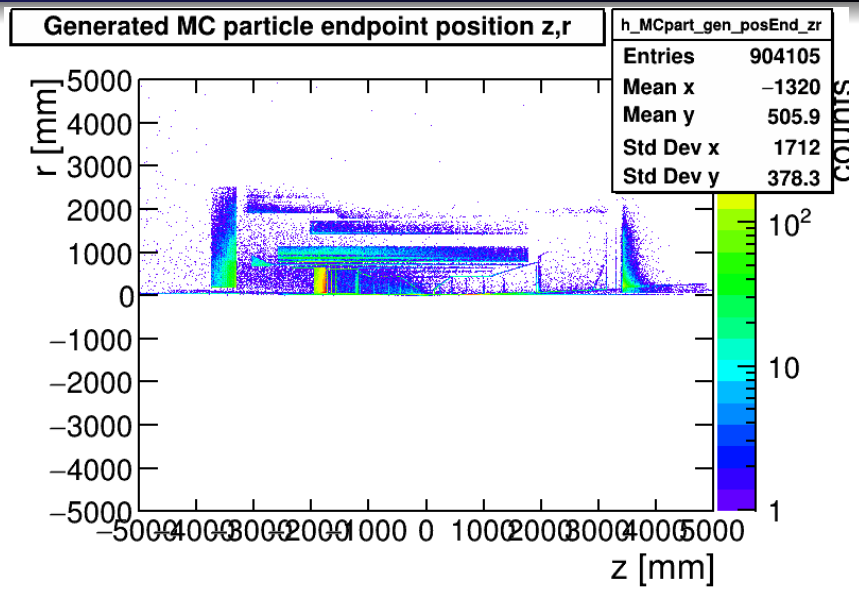


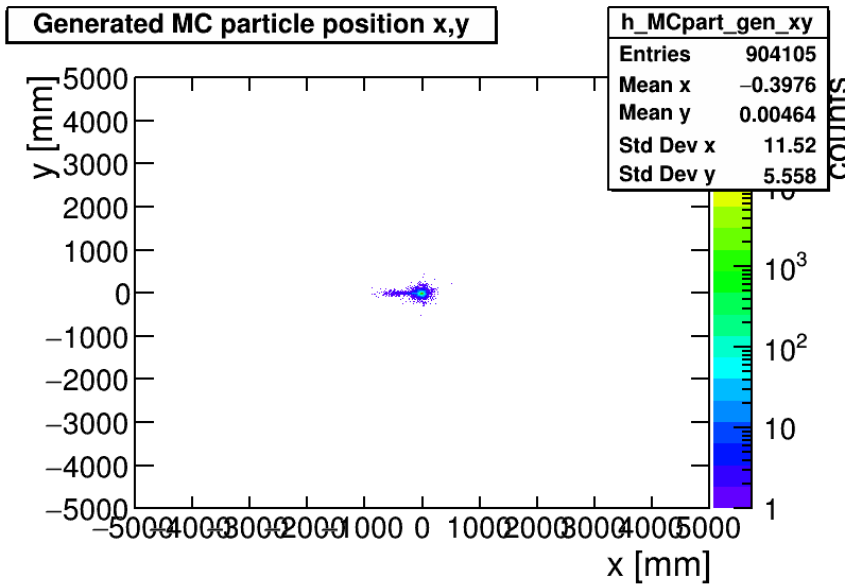
- Gaussian fits work only in a narrow range
- Much worse resolution in the ϕ direction
  - maybe due to proximity to beam

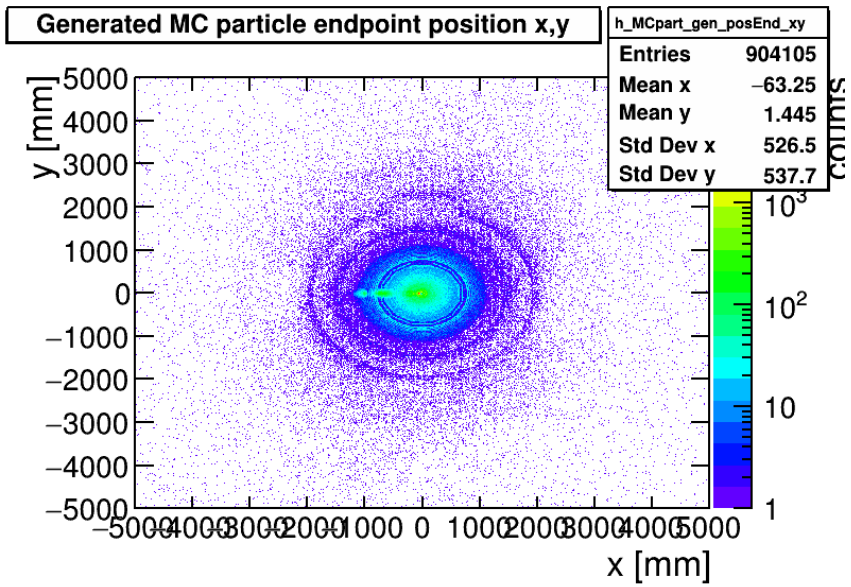
Study by Subhadip Pal

Primary particles(generated) - with nHCal hits



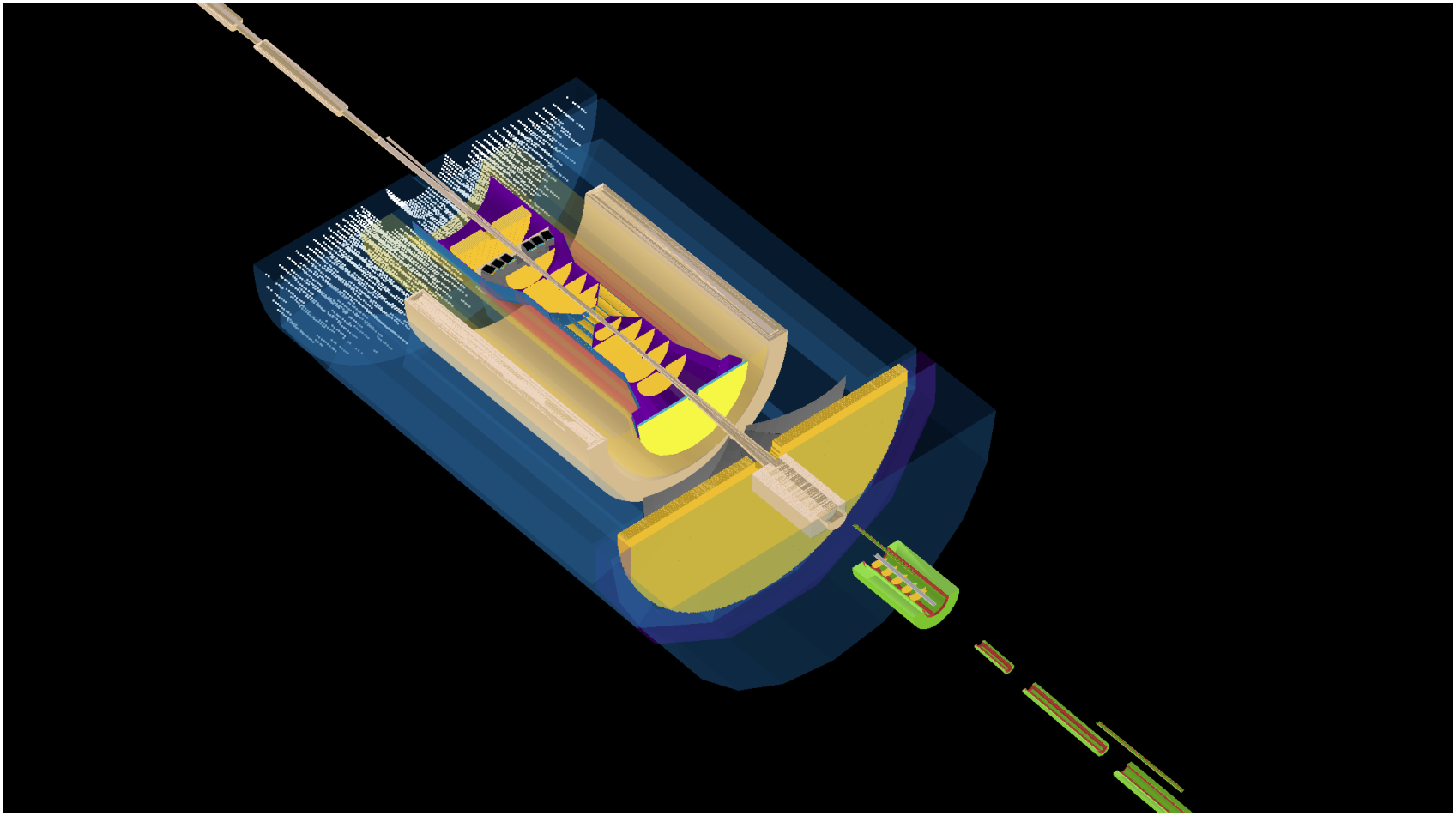






- Primary particles(generated, GenStat==1) with nHCal hits
- Investigating potential bugs and issues with basic particle distributions in full DIS/SIDIS events

Simple hit visualization



- Simple hit visualization
- May add MC particles or Reco tracks (need magnetic field map)
- More work needed

Summary

Conclusions

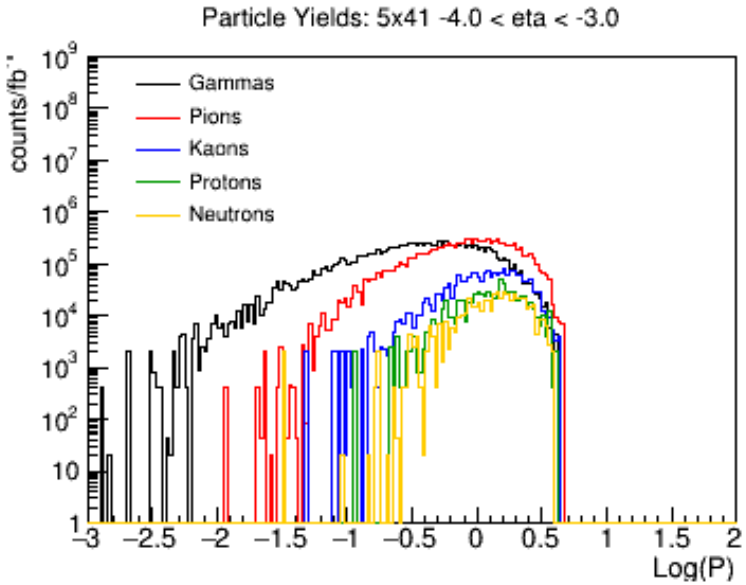
- Realistic geometry implemented in dd4hepp
- More flexibility in the design thanks to decoupling from flux return steel
- Response and calibration studied in simulations
- Position resolution tested with neutrons using backward HCal and EMcal as a combined system
- Tiles can be further extrapolated towards the beam

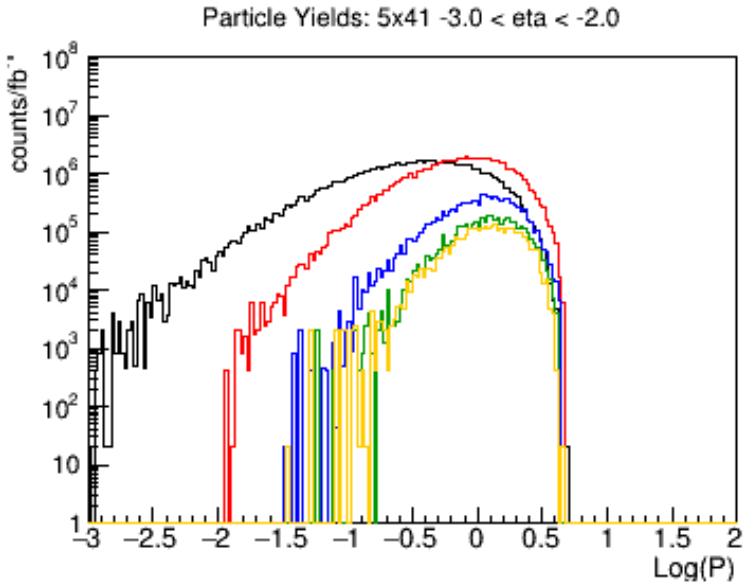
Next steps

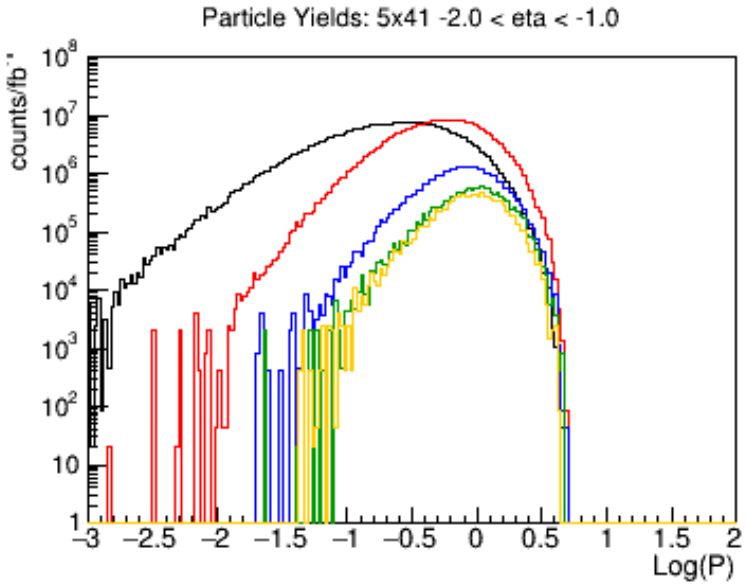
- Investigate potential bugs in hit-MC particle association
- Do a scan vs. η and ϕ for position resolution study
- Test clustering, track matching and neutral shower reconstruction in a realistic $e + p$ event
- Perform simulations of optical photon propagation
- Work with engineers to design support structures and FEE mounting

BACKUP

Jet particle distributions

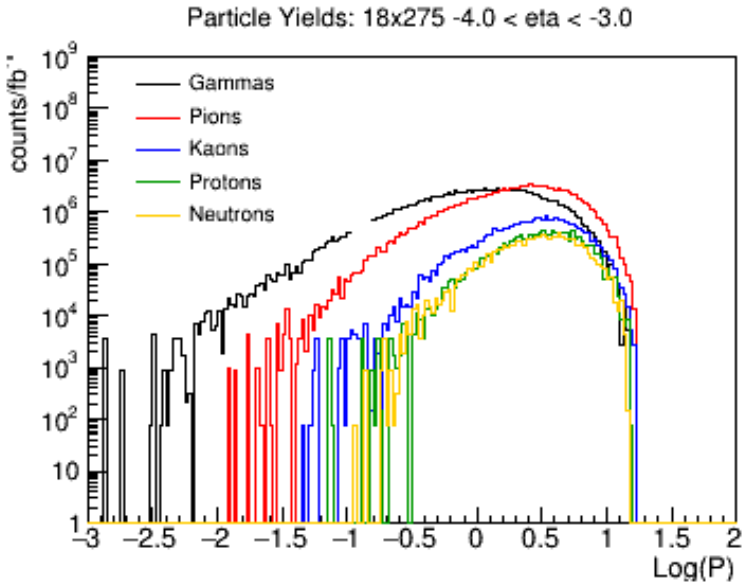


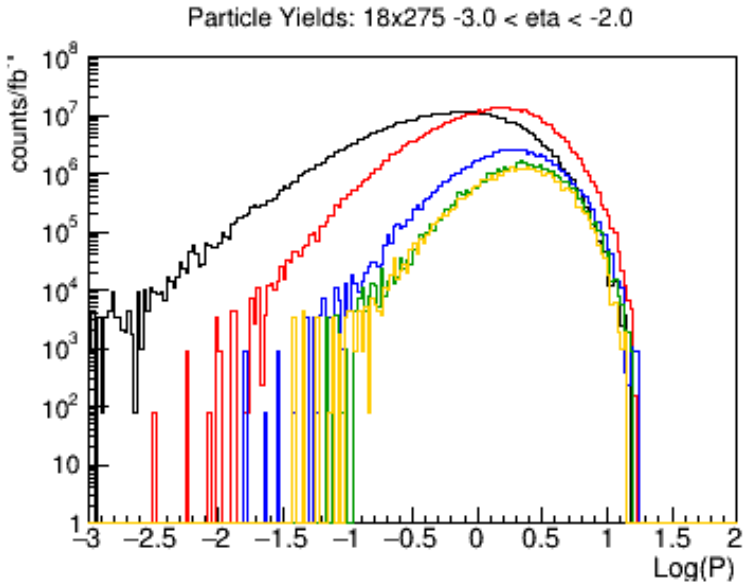


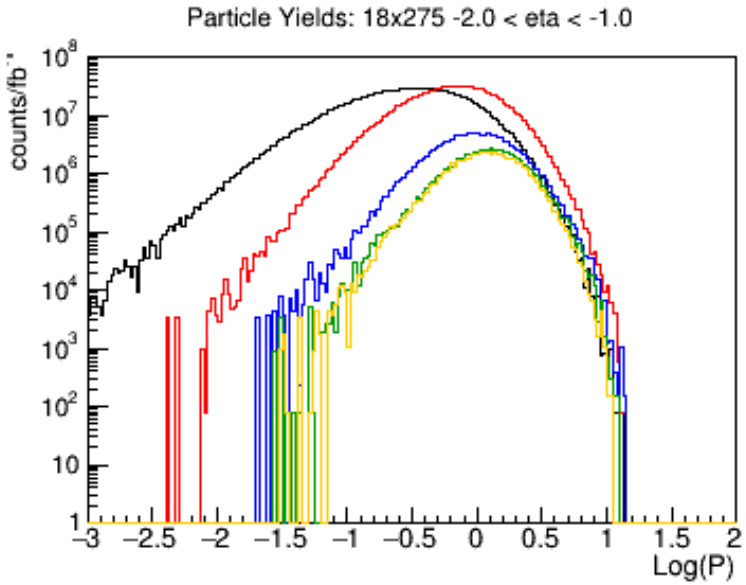


- Pythia simulation by Brian Page

Jet particle distributions

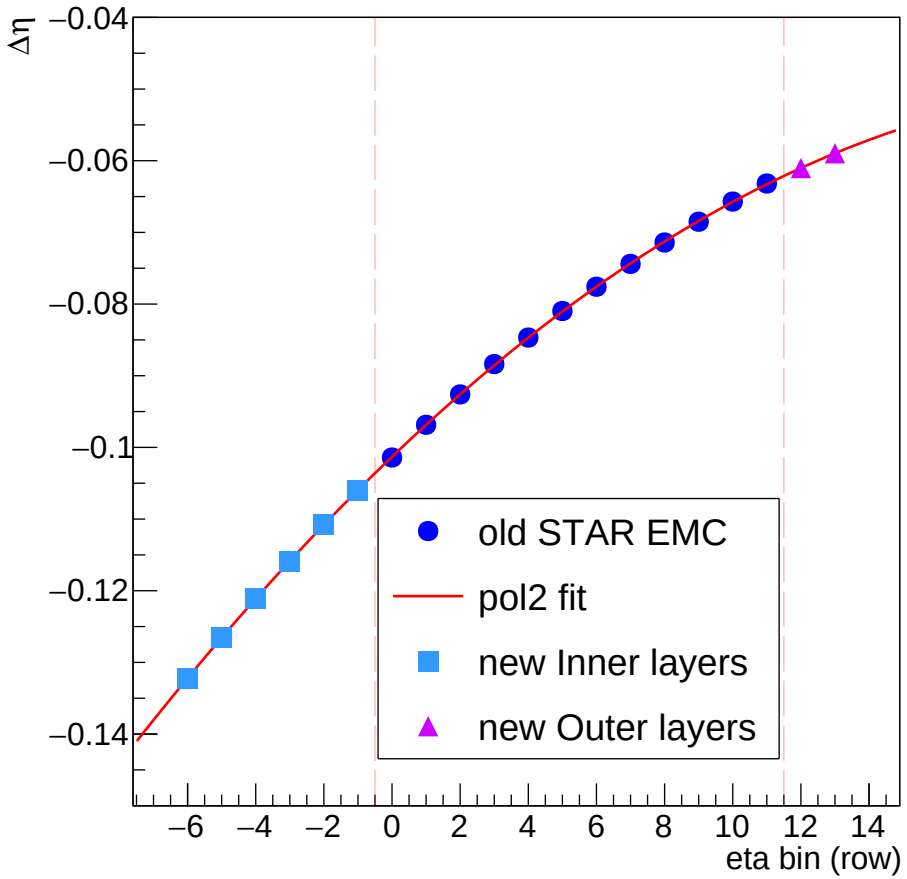




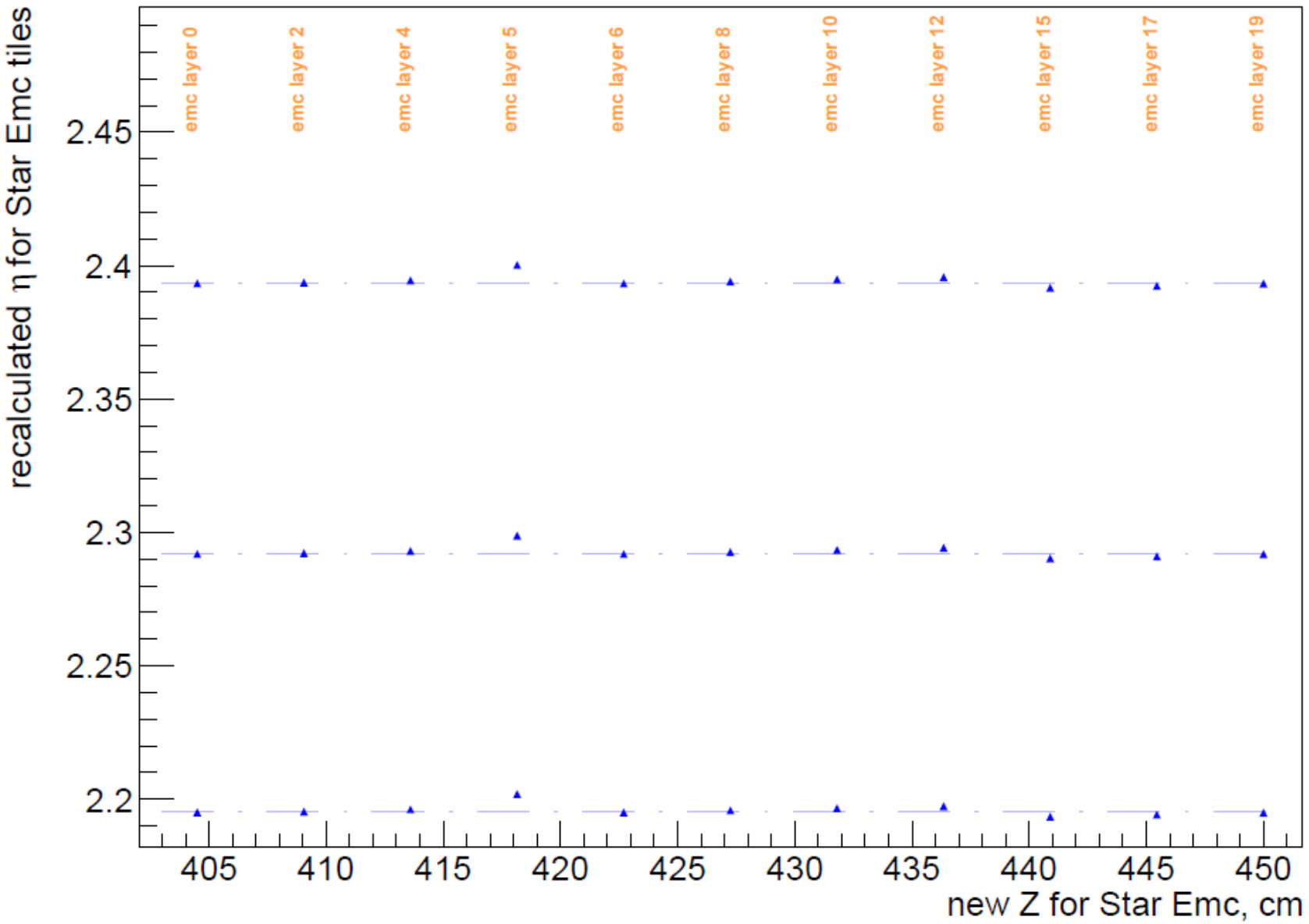


- Pythia simulation by Brian Page

η bins extrapolation



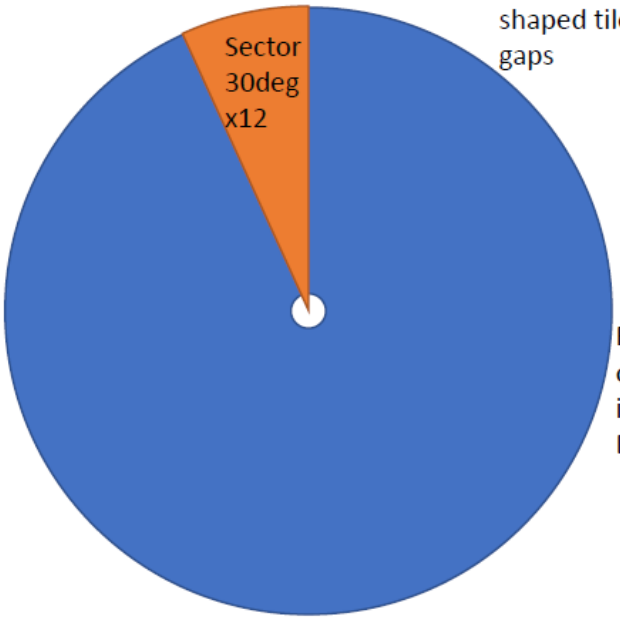
STAR EEMC tiles acceptance in η

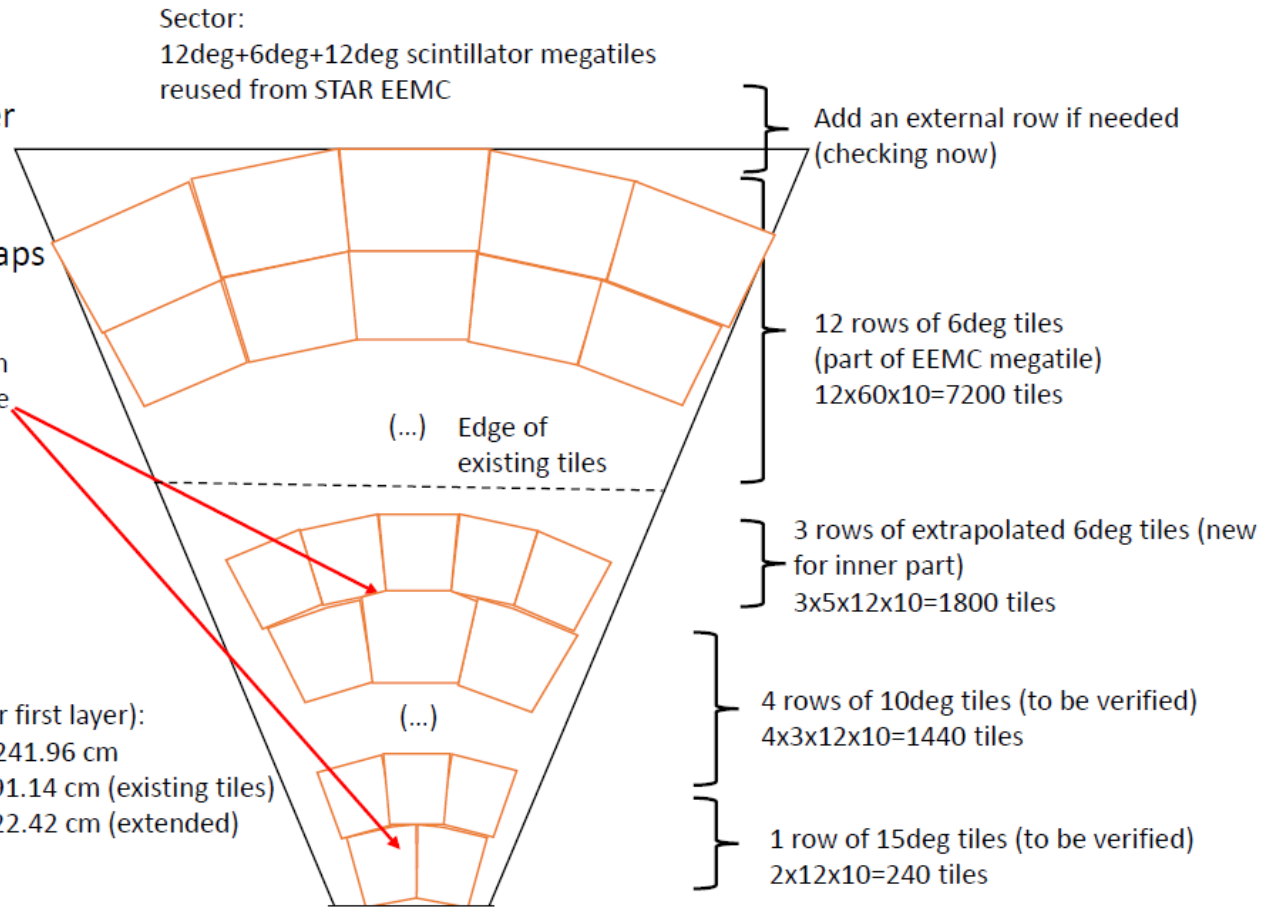


Layout version 4

Layout version 4 – full length sector with 12deg tiles

1. 12deg+6deg+12deg EEMC megatiles per outer sector
2. Inner part with tiles merged 5->3->2
3. Pentagon-shaped tiles used to fill the gaps





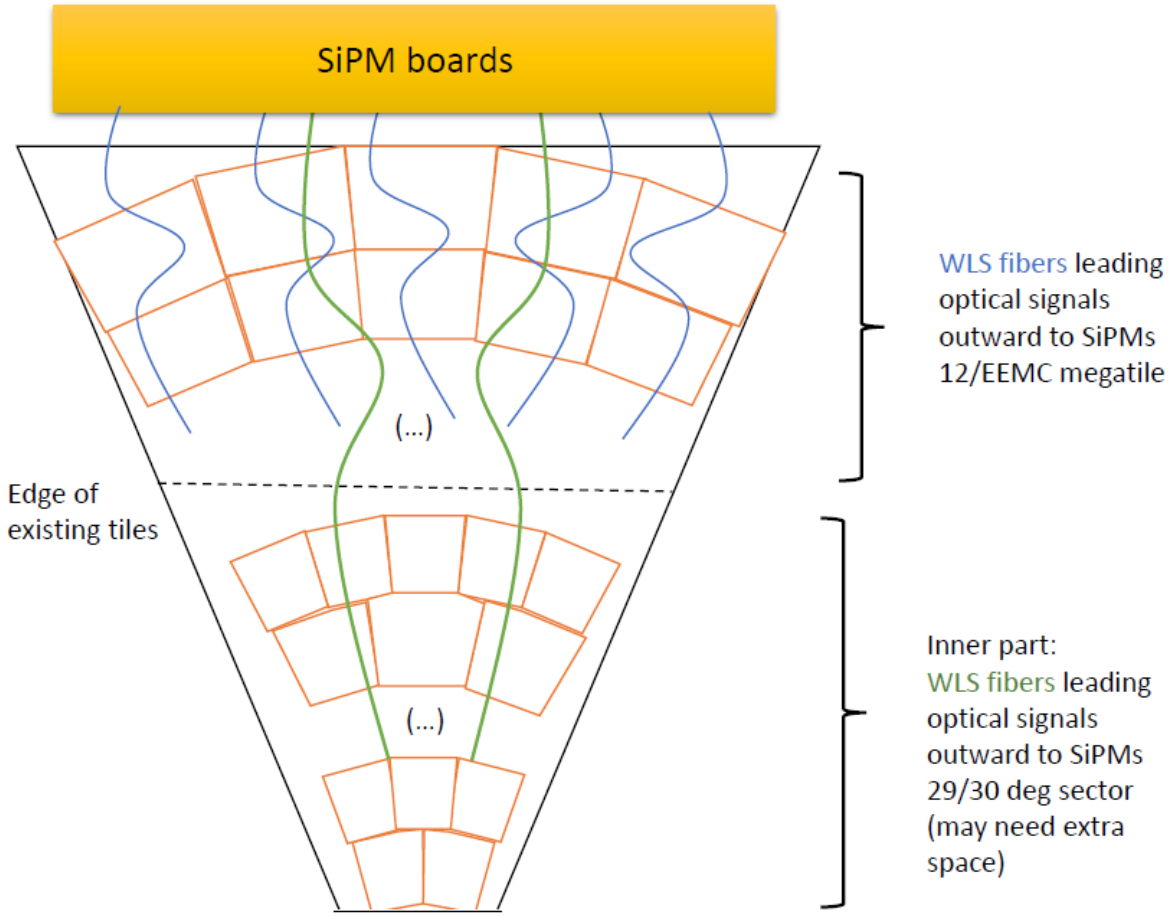
Radii (for first layer):
outer = 241.96 cm
inner = 91.14 cm (existing tiles)
Inner = 22.42 cm (extended)

Total tiles:
7200 existing ones + 3480 inner tiles = 10680 tiles
29 types x 10 layers = 290 different shapes of new tiles to be manufactured

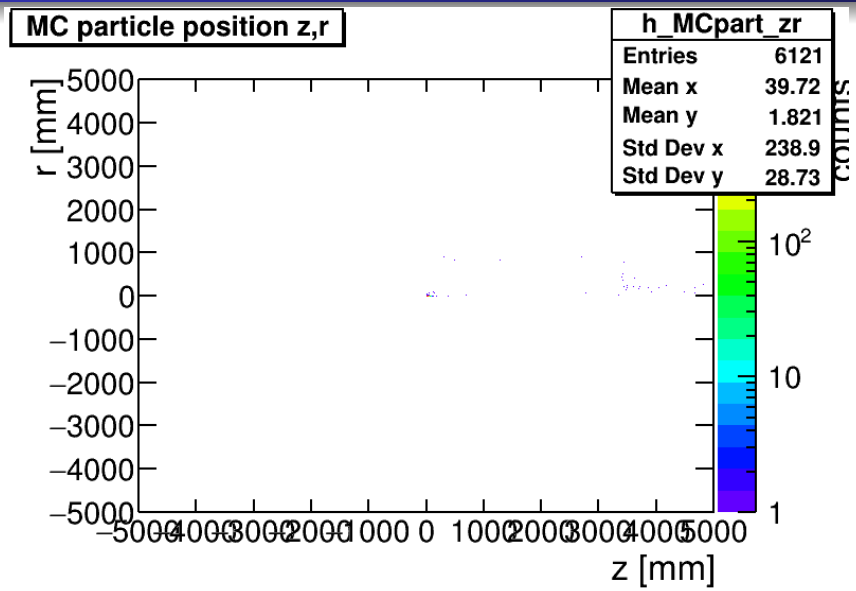
Readout – version 2

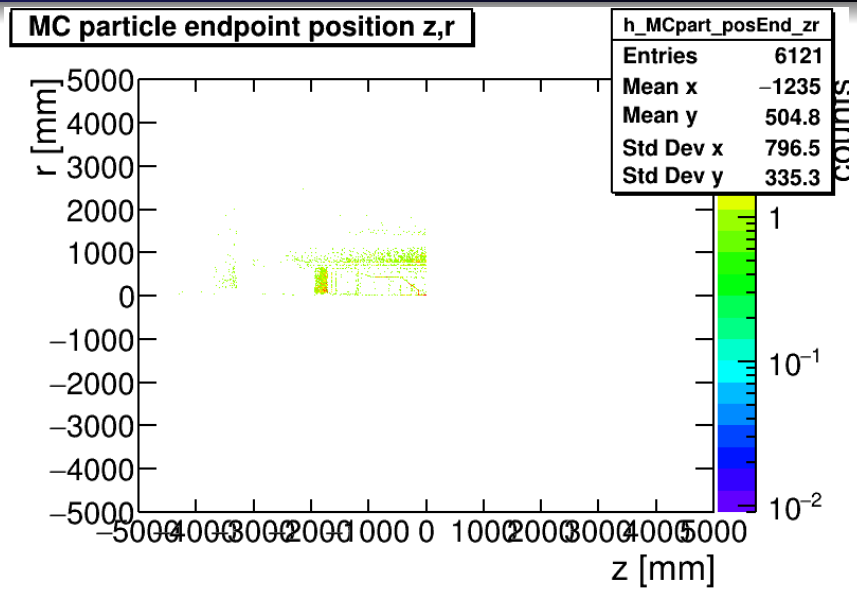
Extra space needed for the testing/calibration system to send light pulses to the tiles. 2 options

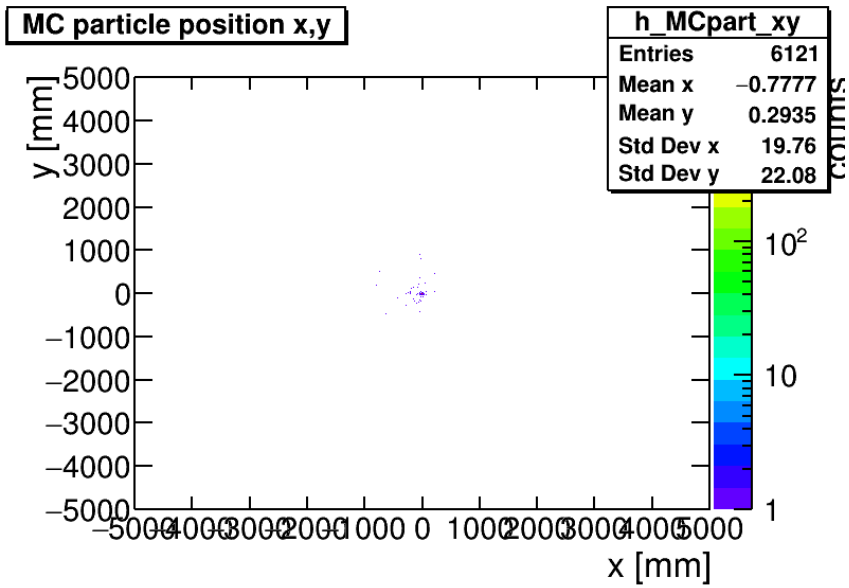
- Add fibers to guide signal from diode/laser mounted outside the detector
- Add small diodes to the tiles

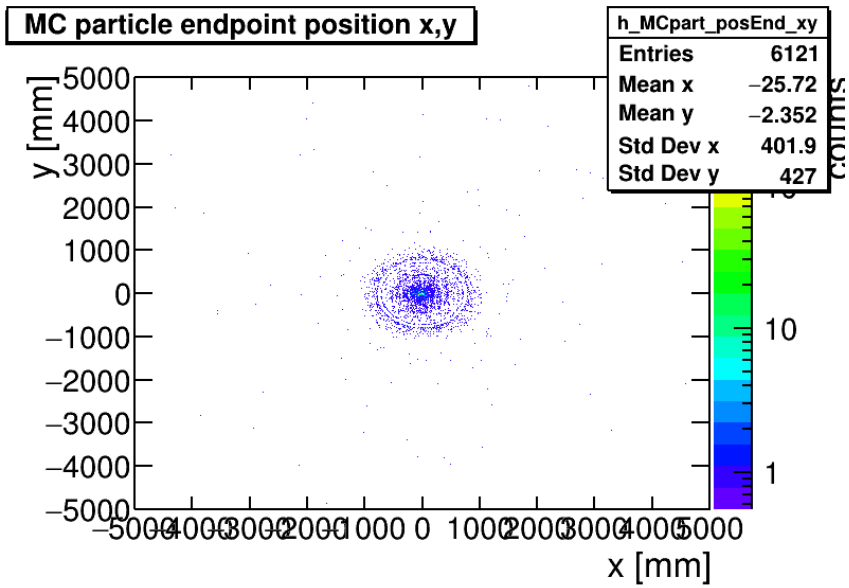


Particle distributions - with LFHCAL hits - start($z > 0$) and end points($z < 0$) (vertices)









- Particles with LFHCAL hits with start vertex $z > 0$ and stop vertex $z < 0$
- Still produce hits in LFHCAL! Backscatters? Non-trivial to debug, because not all