Beam Induced Background at $\sqrt{s} = 3\ TeV$

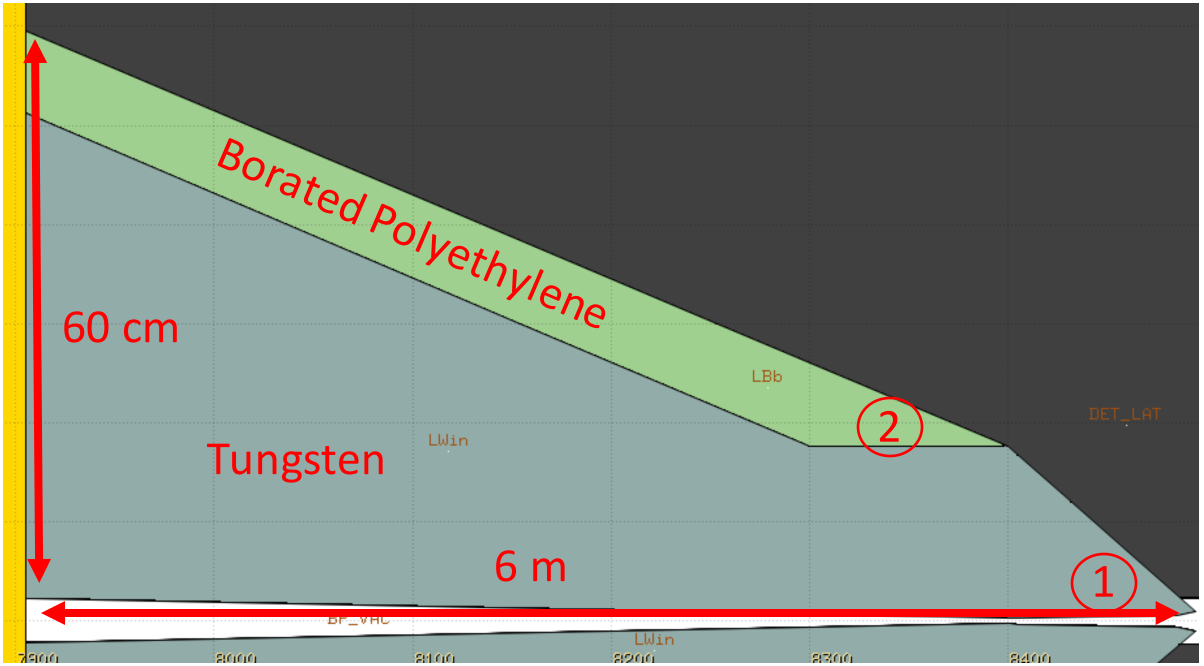
L. Castelli, D. Lucchesi, D. Calzolari, F. Collamati

Outline

- **3 TeV MDI**
  - MAP design
  - FLUKA simulation
- **Forward Muon Study**
  - Goals
  - Simulation and results
- **Machine Learning for Nozzle Optimization**
  - Low statistics approach
  - Results
- **New Nozzles designs**
  - Geometries descriptions
  - Impact on Beam Induced Background

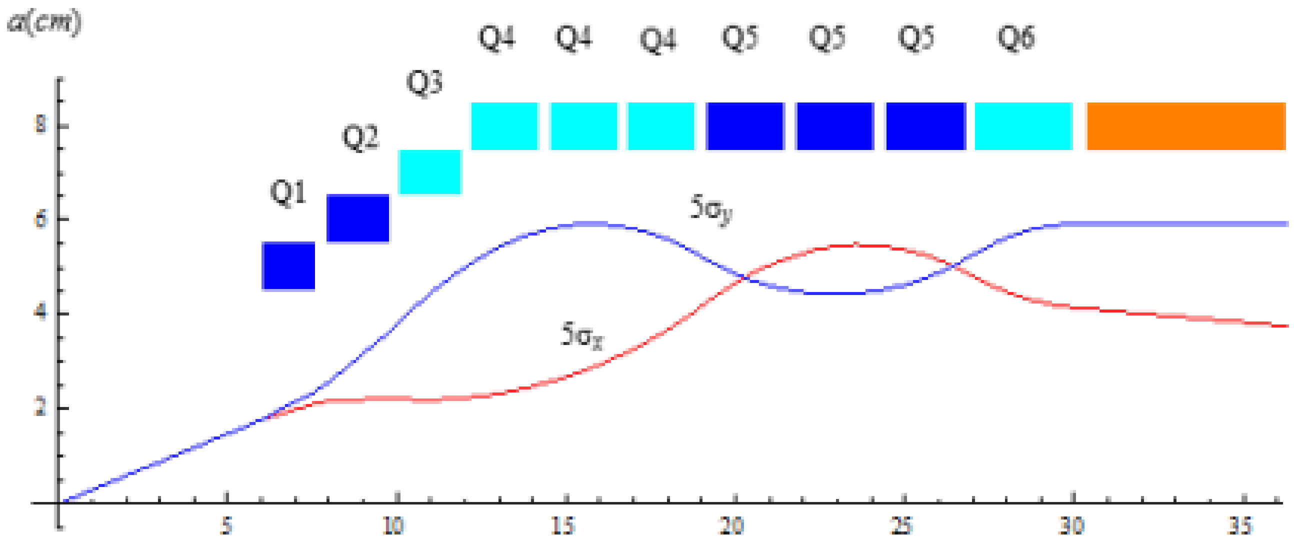
3 TeV MDI

- MAP nozzle design:
  1) 10° closest to the IP
  2) 5° starting from $z = 100\ cm$



IP

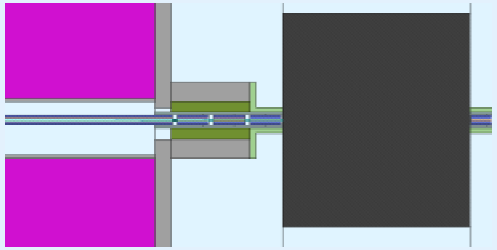
- MAP design[1] with mixed function FF quadrupoles (Cyan)



BIB simulation with FLUKA

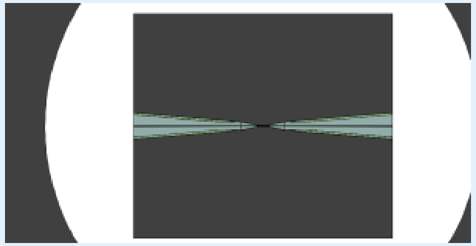
1. From muon decay to nozzle area

Machine dependent



2. Nozzle area to detectors

Nozzle dependend

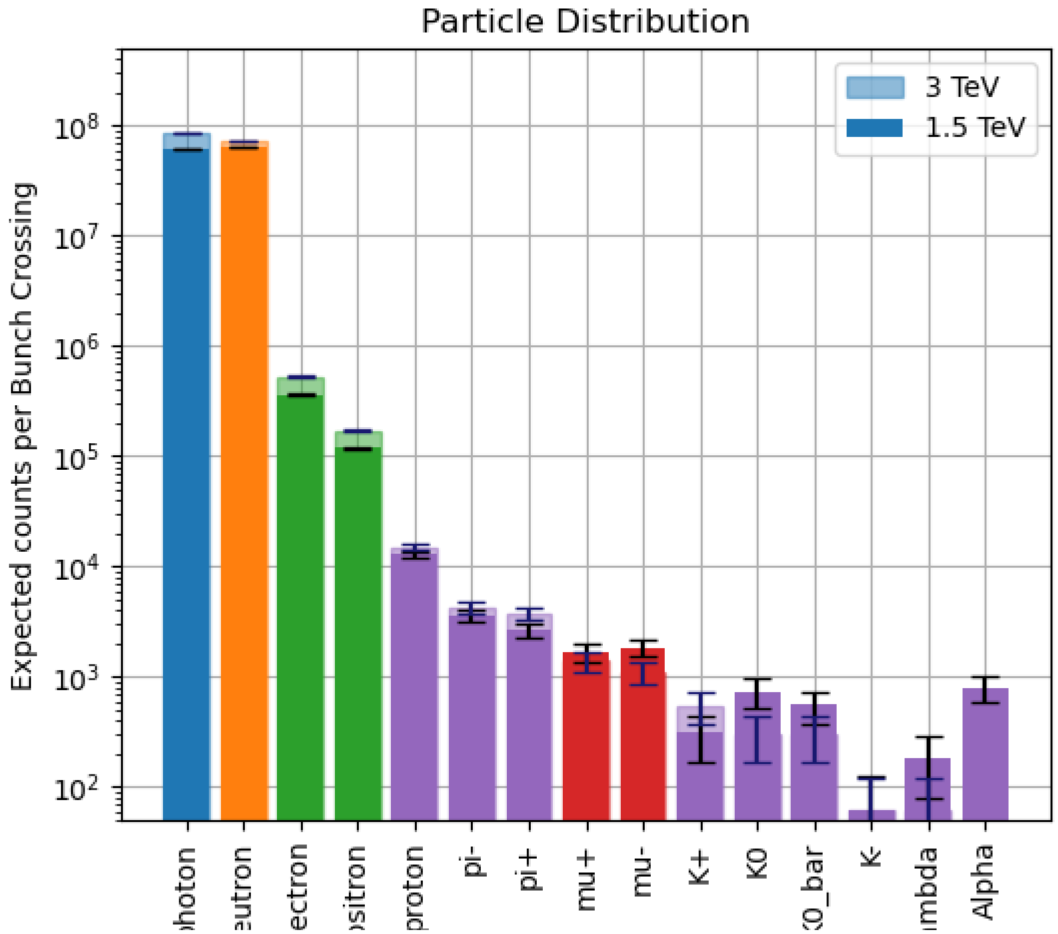


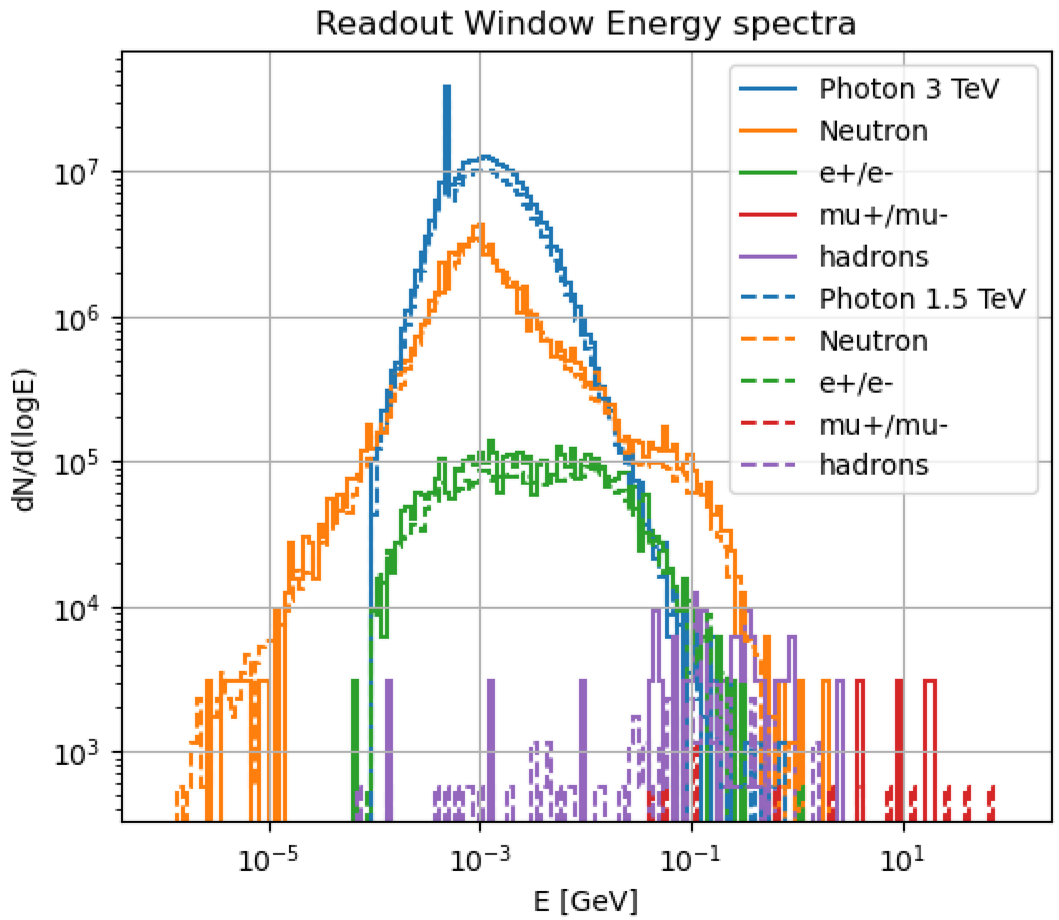
Pictures from D. Calzolari

- Generated one beam of μ^+ decays within $\mathbf{55}\ \boldsymbol{m}$ from the Interaction Point
- **Energy threshold** for particles production fixed at $\mathbf{100}\ \boldsymbol{keV}$
- Particles which arrives to the nozzles are scored

- Propagation through the Nozzles
- Particles who exit the nozzle and enters the detector area are scored
- $\sim 1.6\%$ of one BIB event (i.e. bunch crossing) considering only 1 beam $\rightarrow$ $\mathbf{4}\ \boldsymbol{days}$ **per simulation**

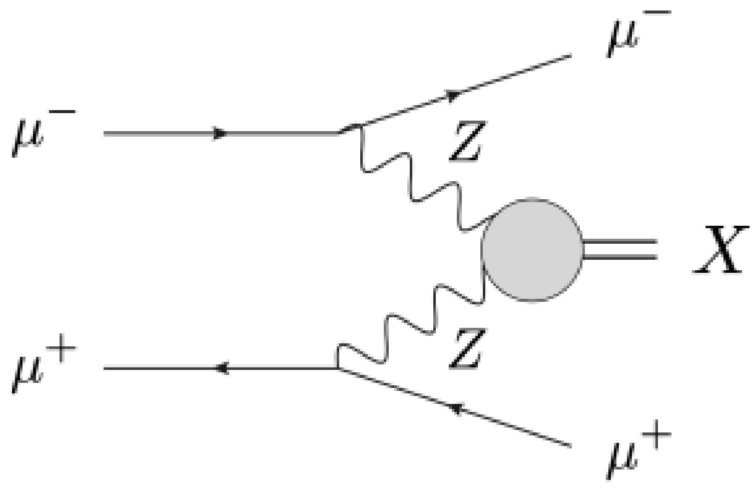
BIB simulation with FLUKA





Forward Muons

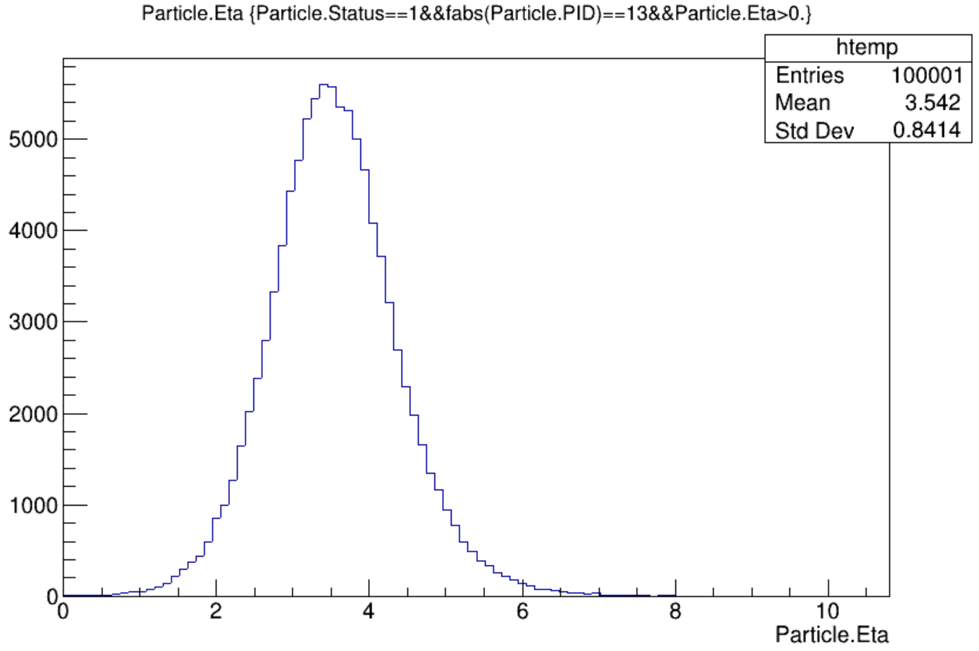
- **Why are we interested in forward muons?**
  - Allows to distinguish process from Z/W boson fusion
  - Allows precise measure of Higgs boson Width [2, 6]
  - New physics might have forward muons in the final state [3]

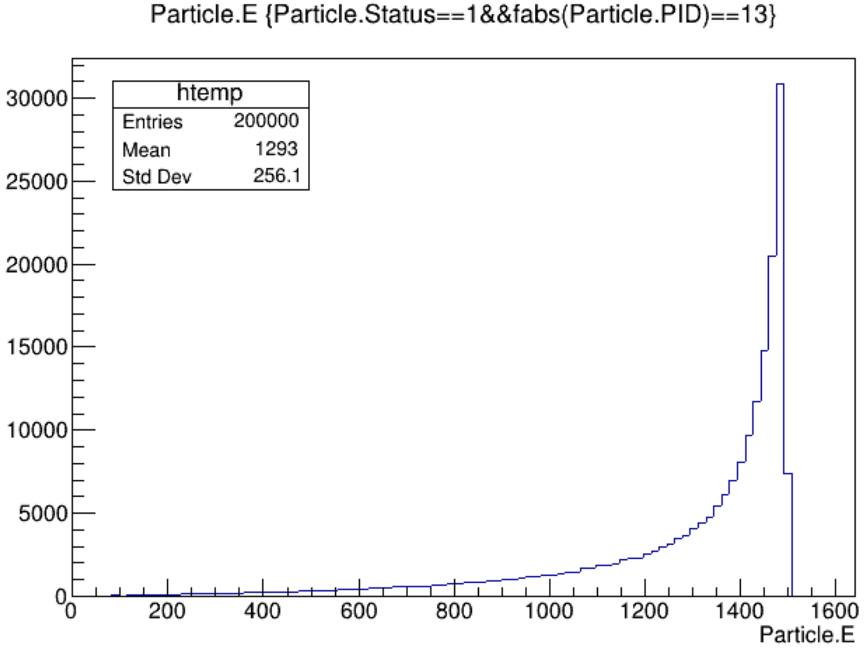


Z Boson fusion with forward muon production[3]

Forward Muons simulation

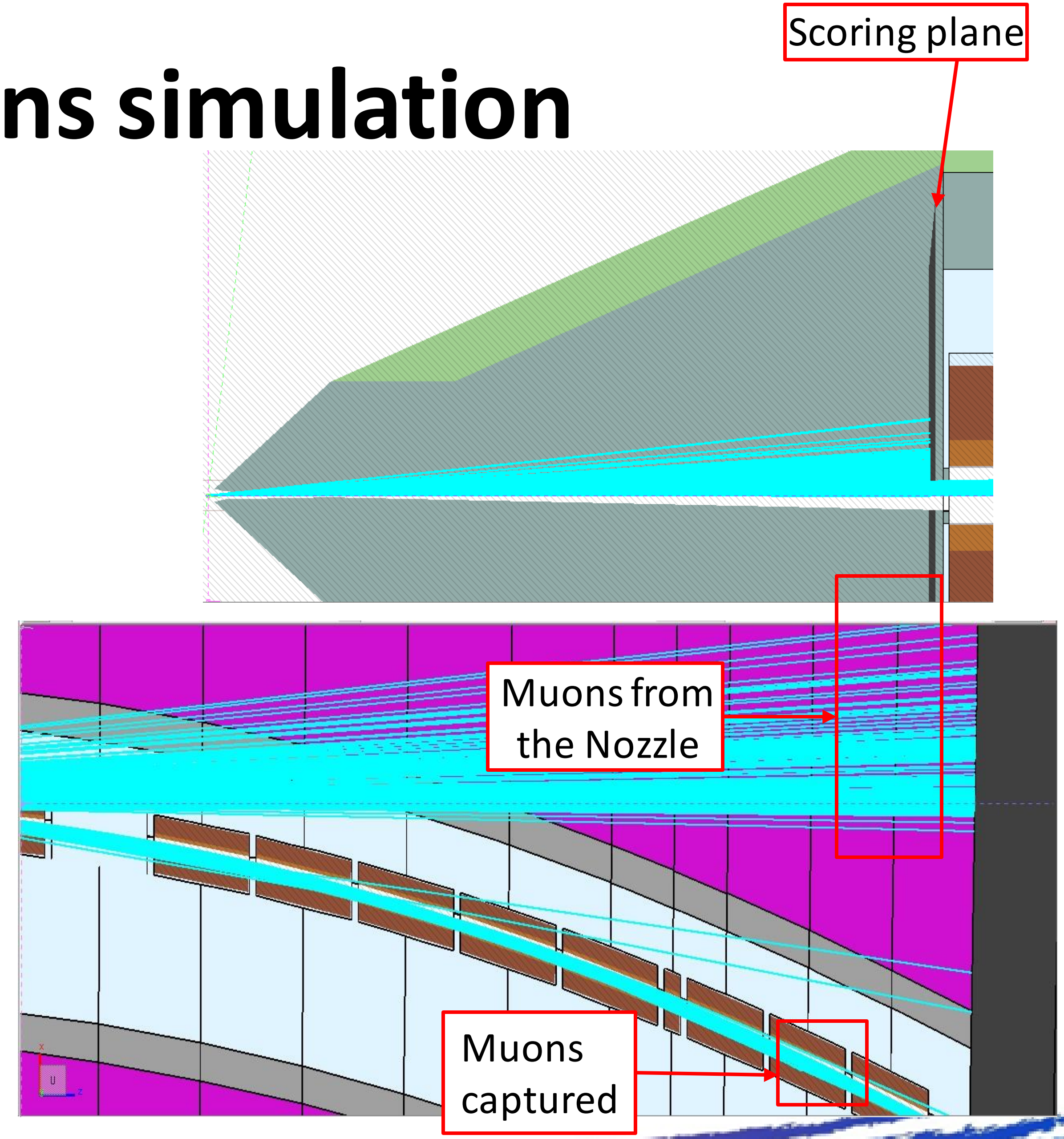
- Considering forward muons from $\mu^+\mu^- \to ZZ + \boldsymbol{\mu}^+\boldsymbol{\mu}^- \to \mathrm{H} + \boldsymbol{\mu}^+\boldsymbol{\mu}^- \to Invisible + \boldsymbol{\mu}^+\boldsymbol{\mu}^-$
- 5000 samples simulated according their η and E distributions, which were assumed independent





Forward Muons simulation

- Muon shot from Interaction Point
- Tagging plane at the end of the Nozzle
- Muon which goes into the beam pipe are **not** tagged
- Fraction of muon tagged: $\mathbf{44\%}$

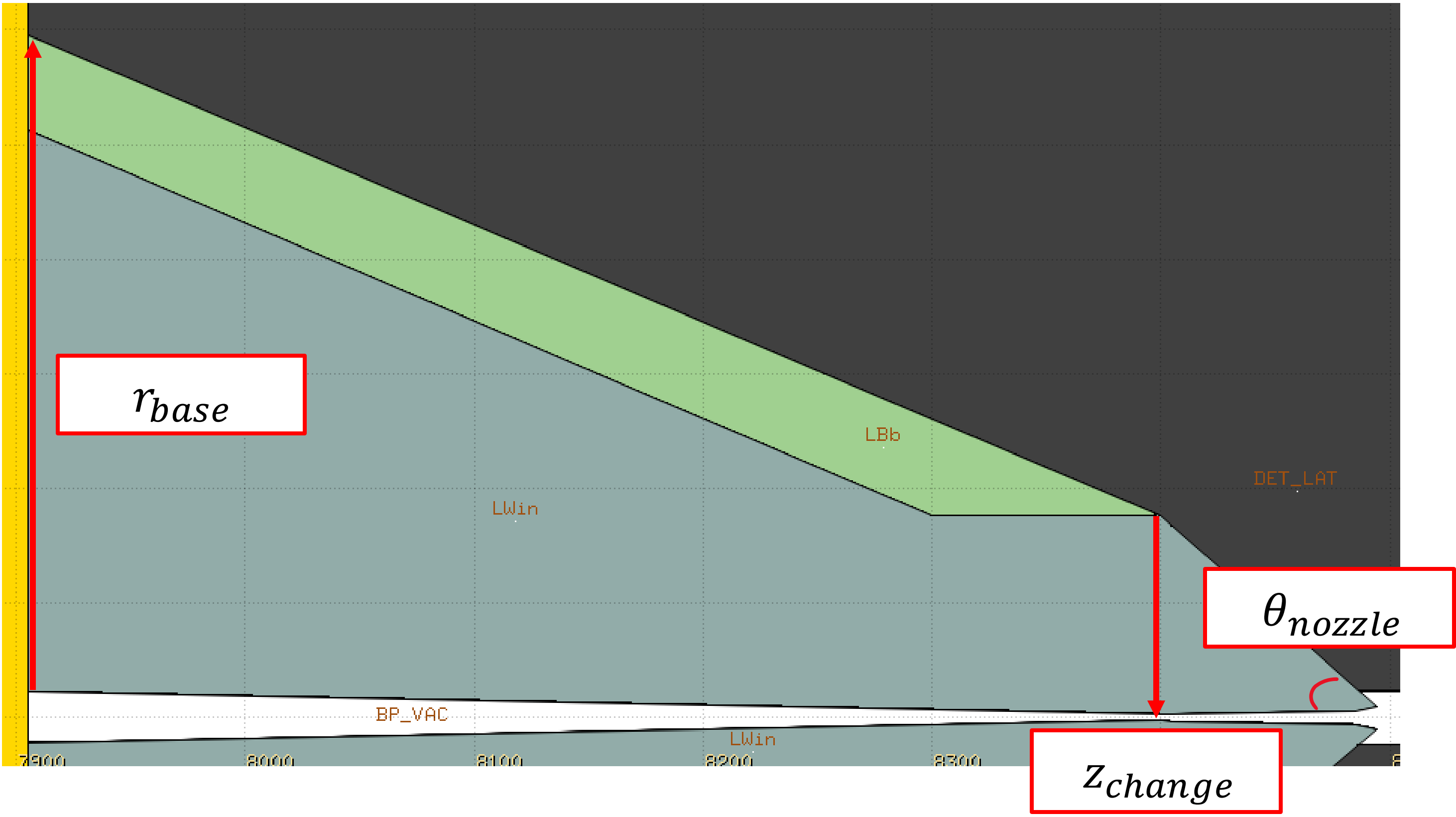


Machine Learning approach

- Parametrize the nozzle response as function of geometrical parameters
- Nozzle response could intend:
  - Beam Induced Background total flux in the detector (easy to achieve)
  - Hit occupancy in the vertex detector (needs detector reconstruction)
  - Photons energy deposit in the ECAL (needs detector reconstruction)
- Several simulation needed, unfeasible with 1.6% of BIB

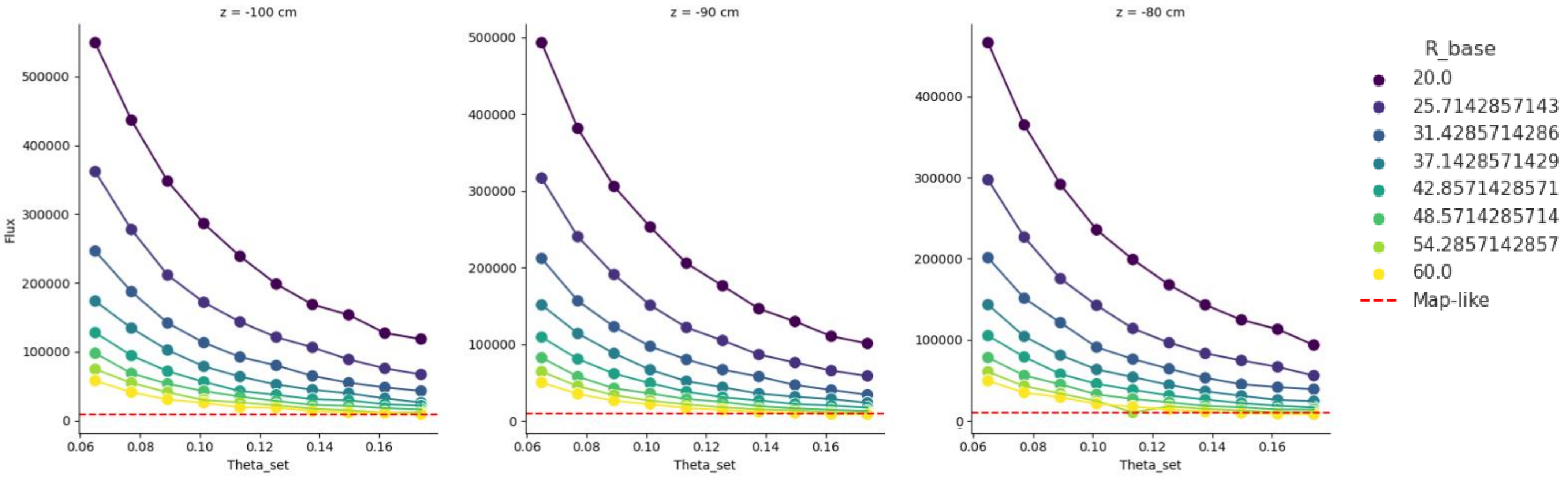
Towards ML Optimization

- 1200 simulation performed
- 3 geometrical parameters:
  - $\theta_{tip} \in [3.8; 10]° \rightarrow 10$ values
  - $|z_{change}| \in [50; 200]$ cm $\rightarrow 15$ values
  - $r_{base} \in [20; 60]$ cm $\rightarrow 8$ values
- 0.02% of 1 bunch crossing simulated
- Due to input settings, the real nozzle aperture is →
  - $$\theta_{nozzle} = tan^{-1}\left[\frac{(94 \cdot \tan\theta_{tip}) \cdot r_{base}/60}{|z_{change}| - 2}\right] \in [0.7; 18]°$$

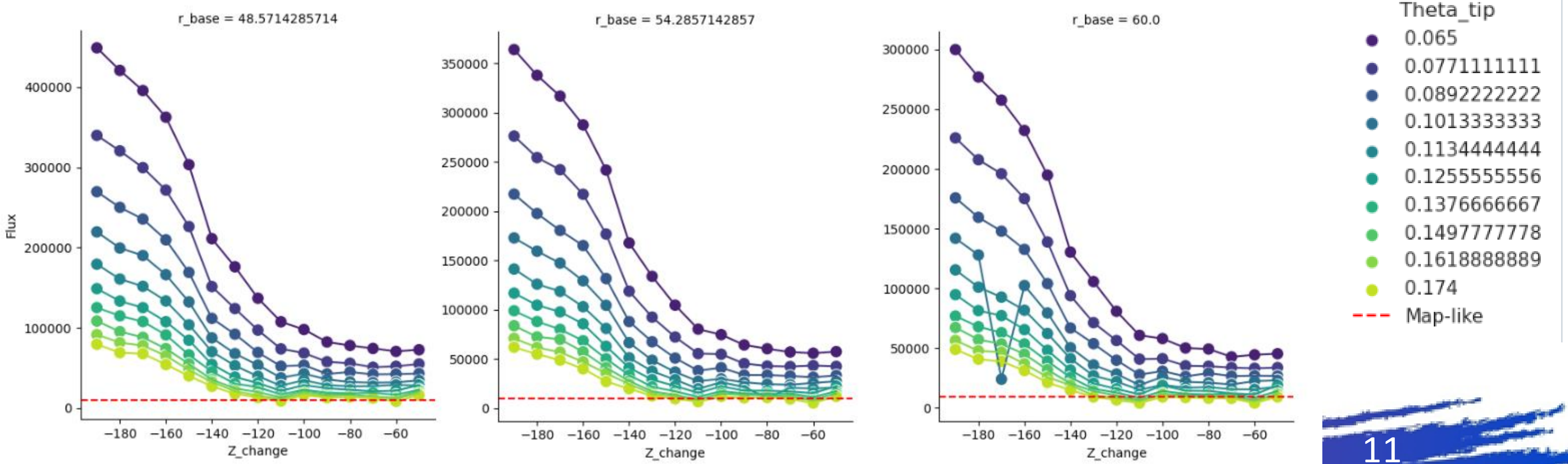


Flux*

As function of θ_{tip} at fixed r and z



As function of z at fixed r and theta

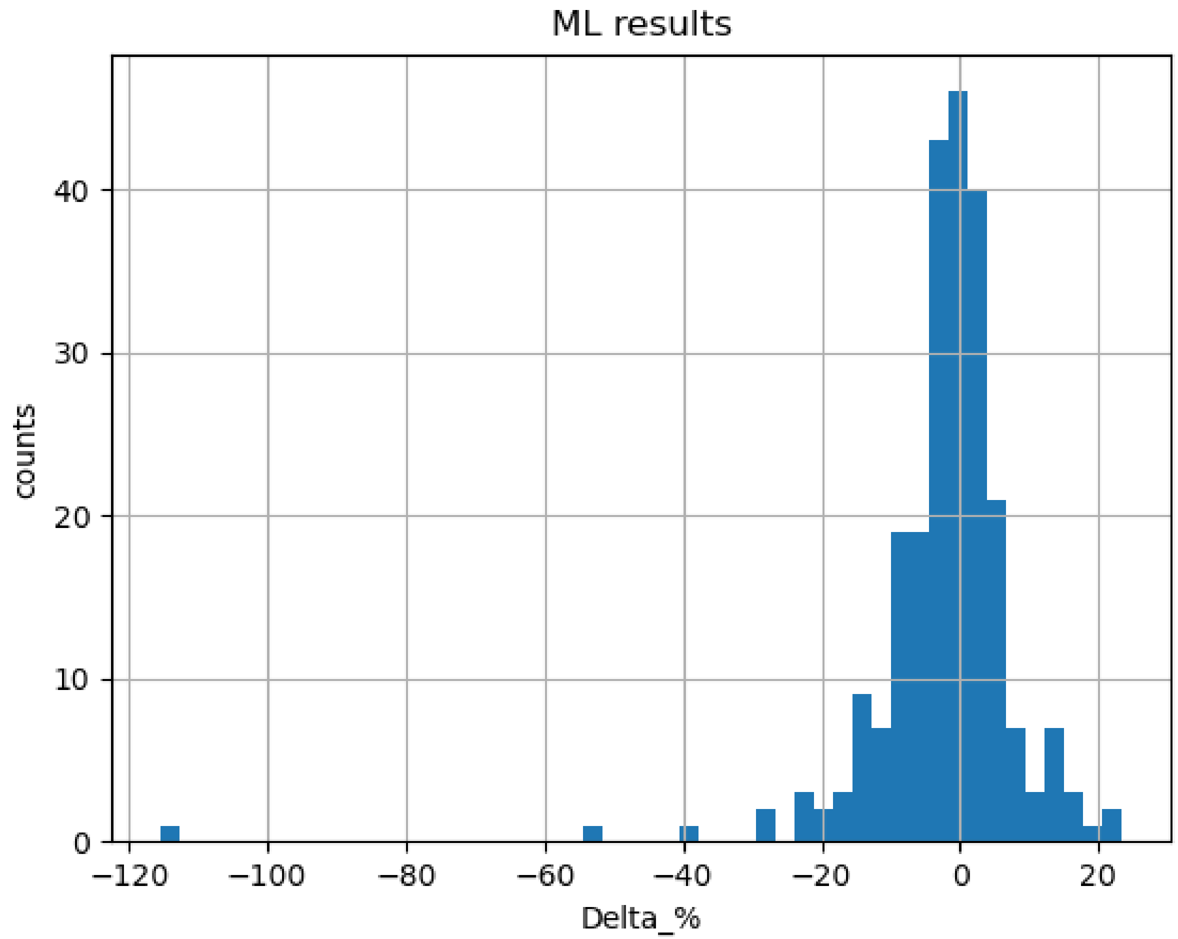


*σ_{flux} negligible

ML performance

- XGBoost regressor trained with 960 samples
- Test with 240 samples
- Evaluate the difference as:

$$\Delta = \frac{Flux_{true} - Flux_{predicted}}{Flux_{true}} * 100$$



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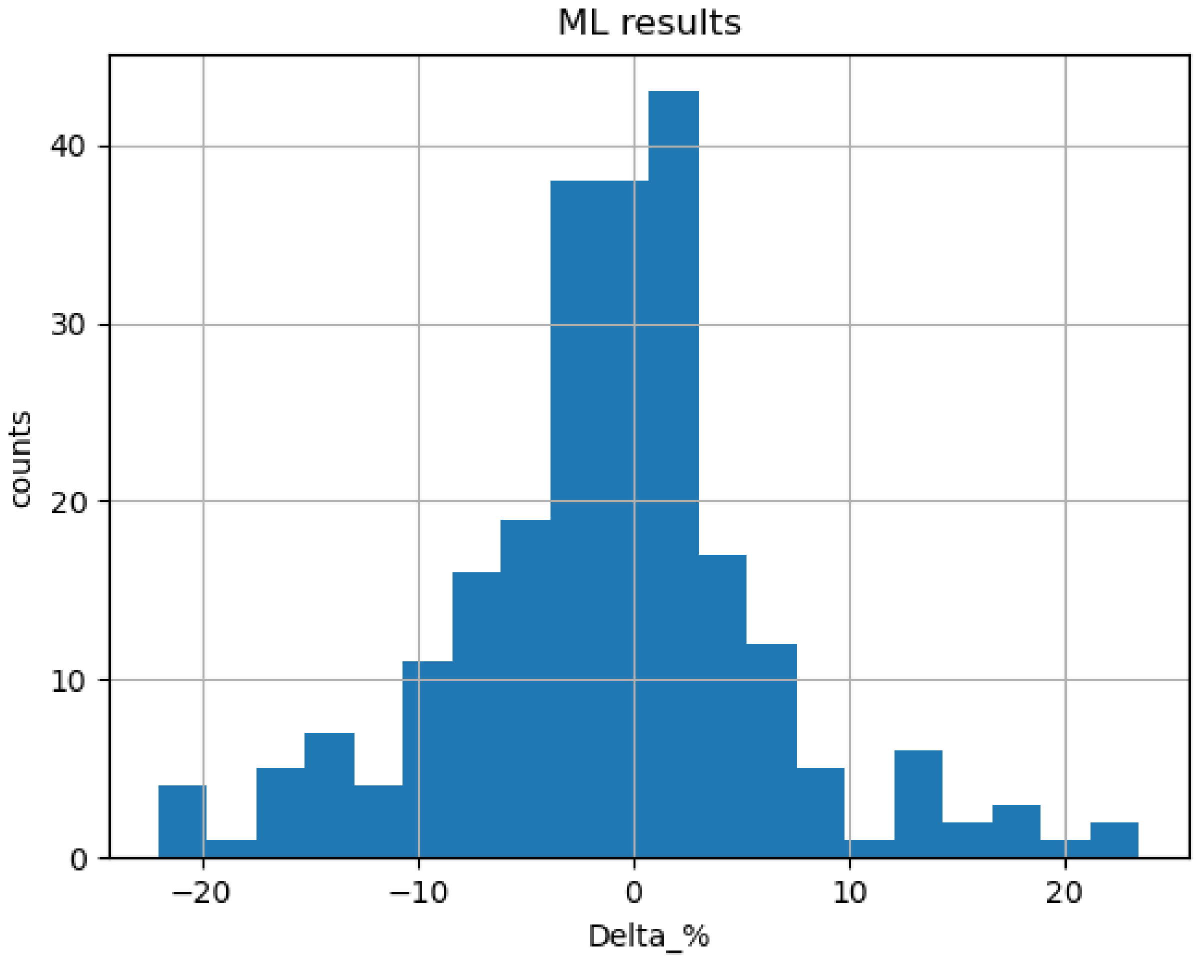
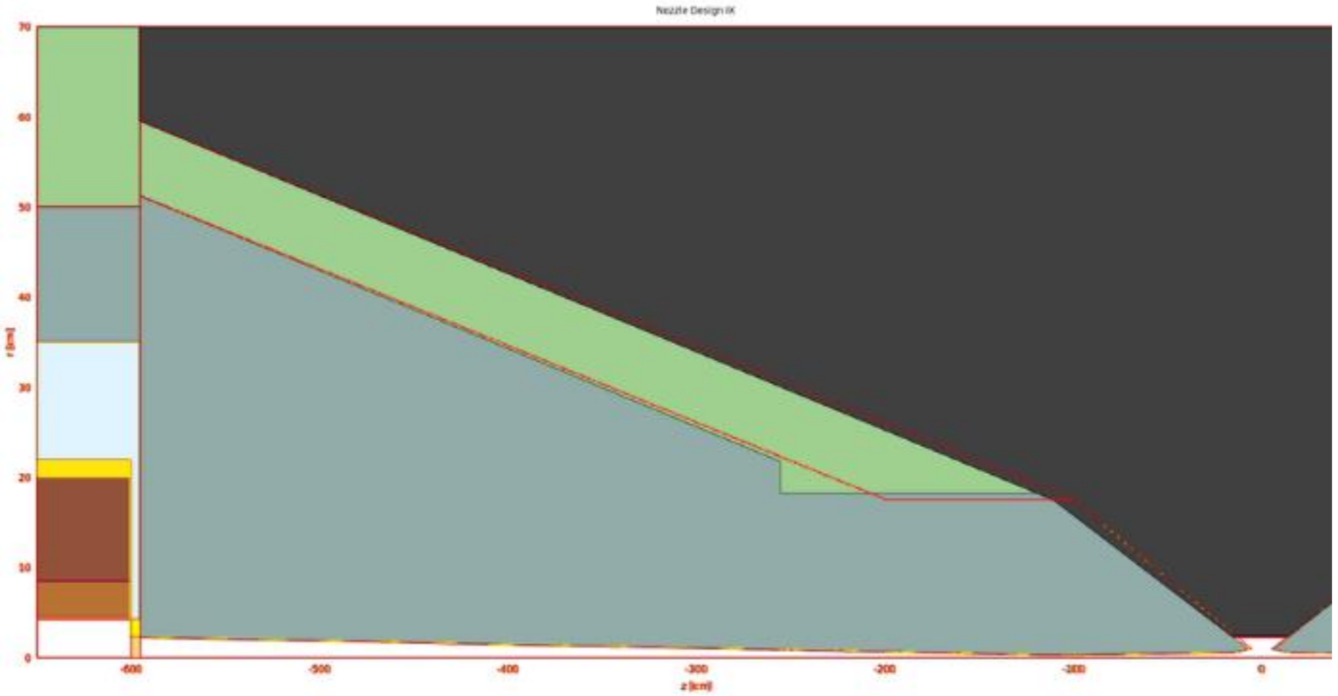


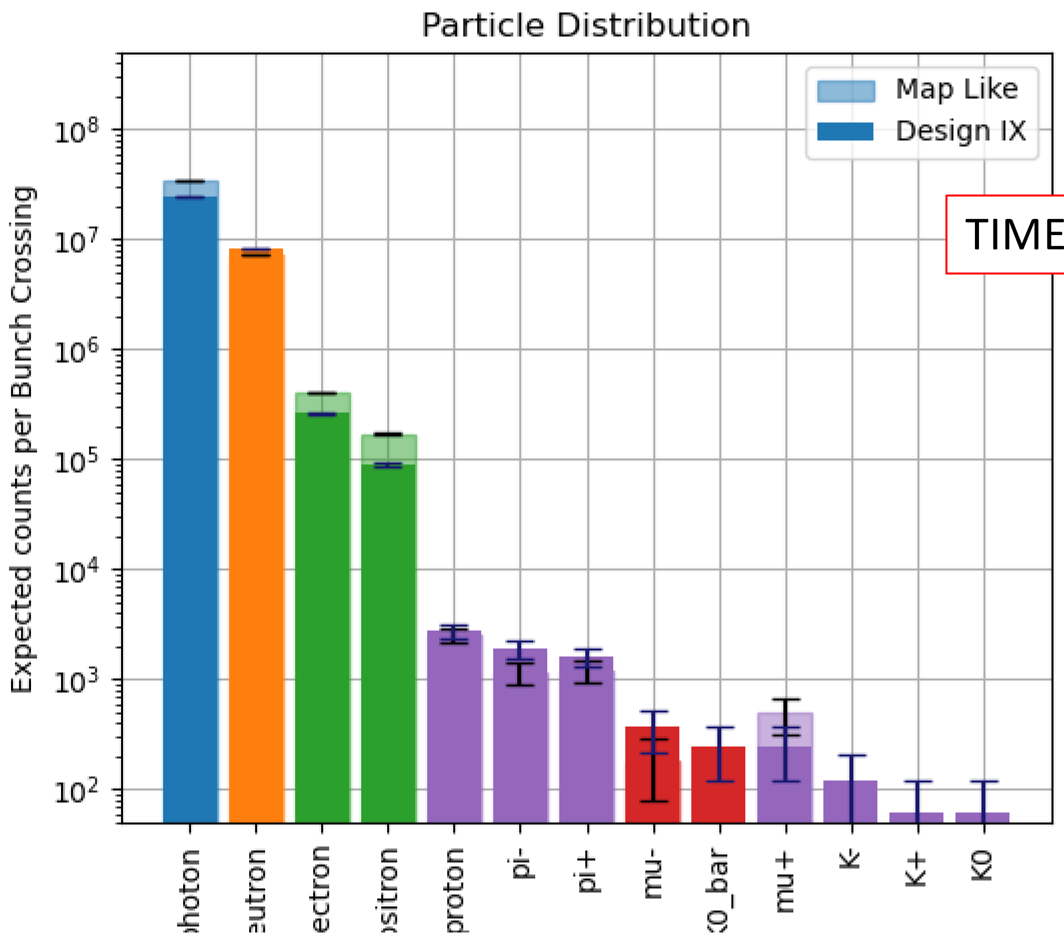
New Nozzle Design: IX

- Chose after studying the results with low stat. simulations
- Nozzle with
  - $\theta_{nozzle} = 9.2°$
  - $z_{change} = 110\ cm$
  - $r_{base} = 60\ cm$
- 2% of one beam simulated
- Compared with Map-Like design with same statistics

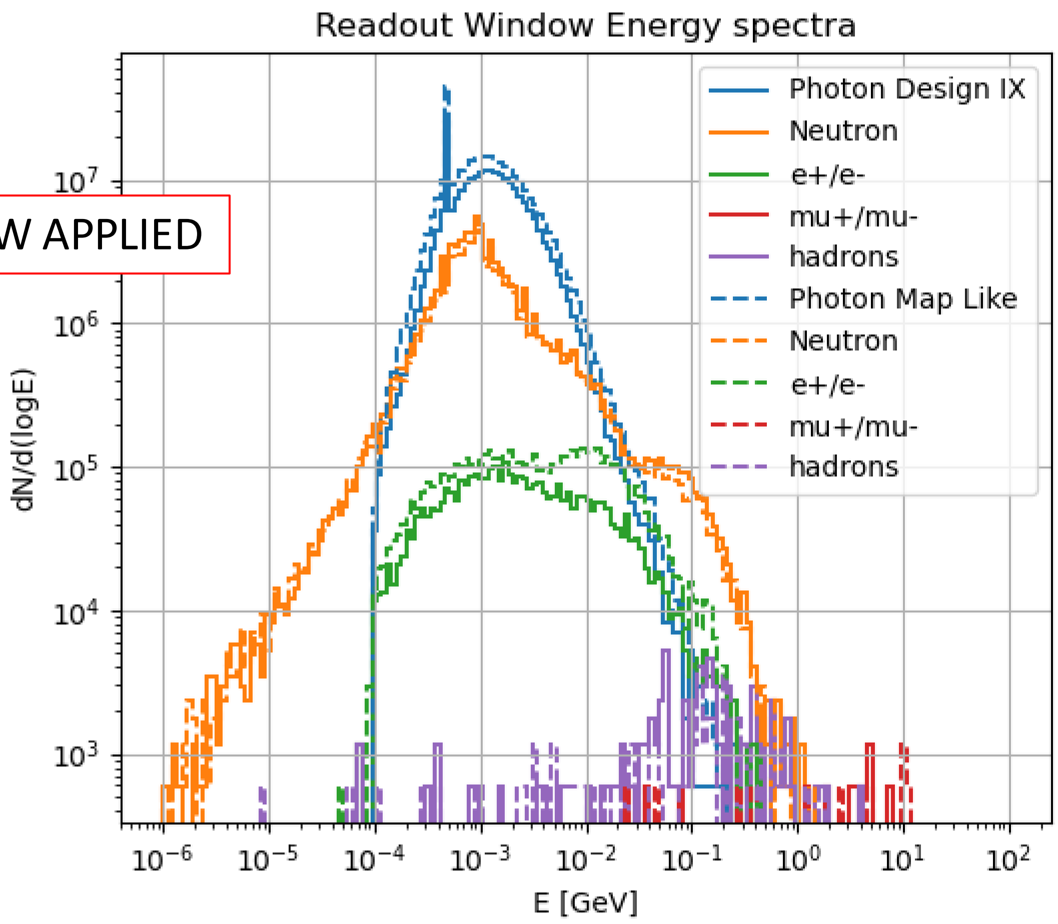


Nozzle geometry compared to the Map-Like design (red line). The Borated Polyethylene shape is due to redefinition of geometry in FLUKA for technical necessity

New Nozzle Design: IX

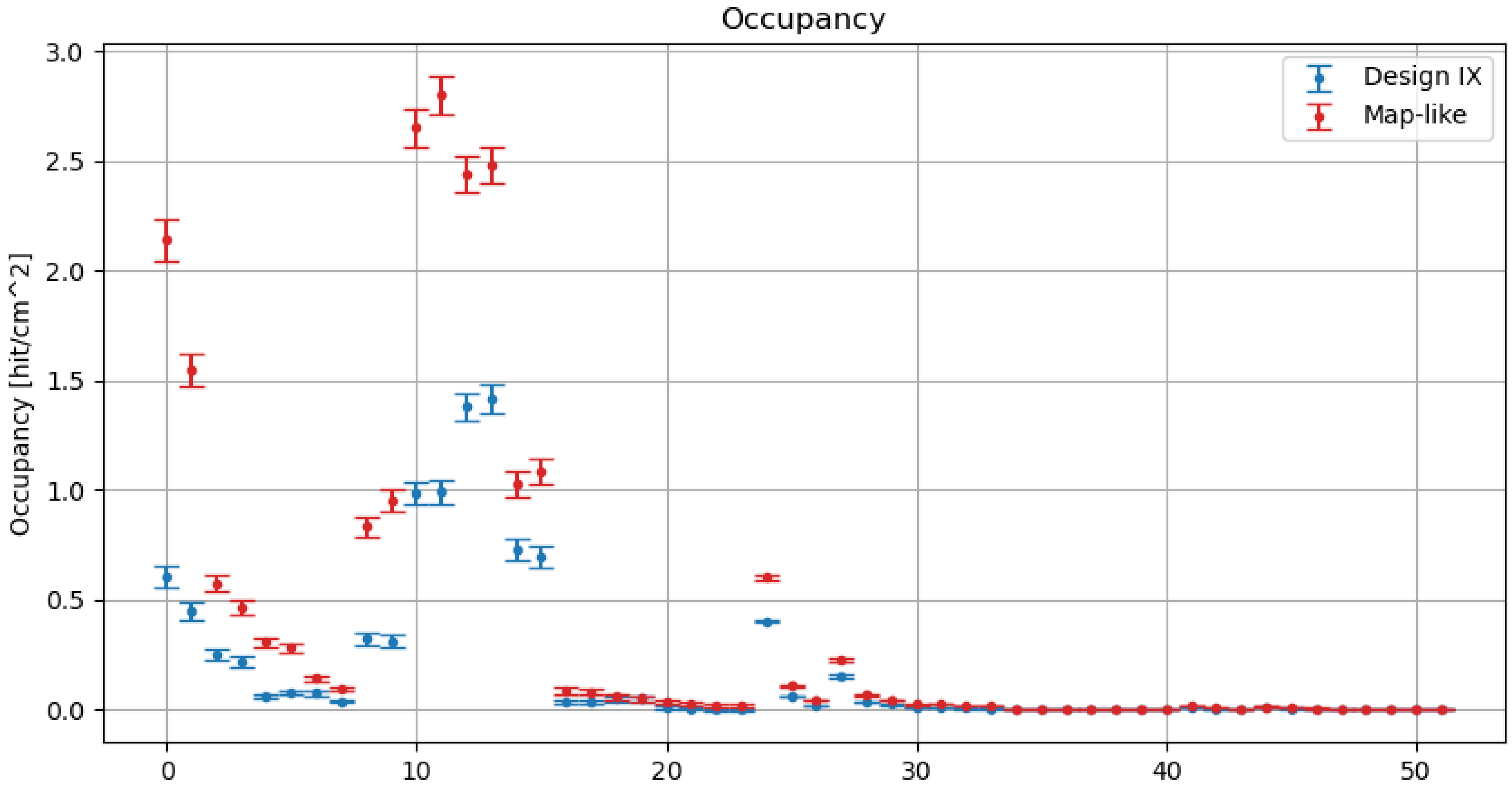


TIME WINDOW APPLIED



Design IX

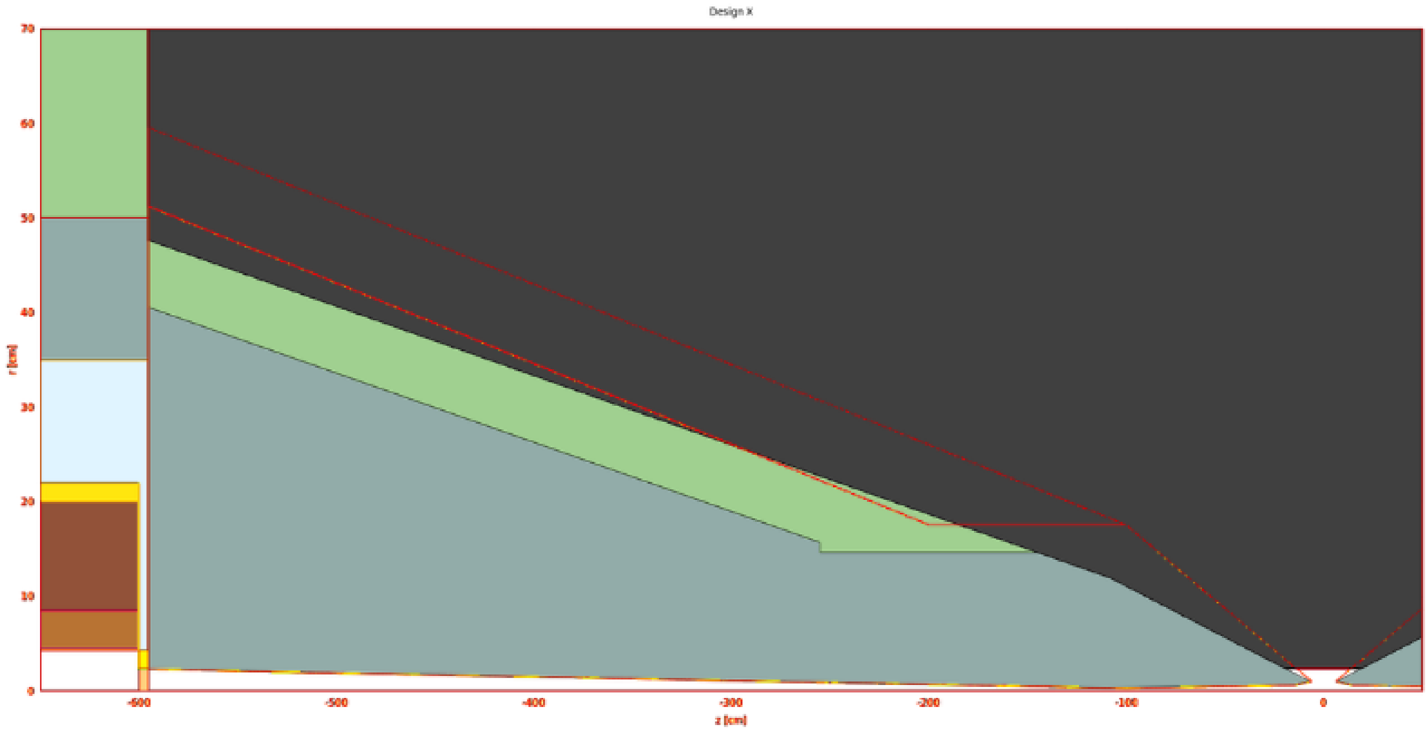
- Occupancy obtained from Simulated Hits in the detector **without any normalization**
- Considered Readout Window and Time Window in the subdetectors.
- With this design
  - Much Less occupancy



$$\sigma_{occupancy} = \frac{\sqrt{Hits}}{Layer\ Area},$$ assuming $Hits = Layer\ Area * Occupancy$

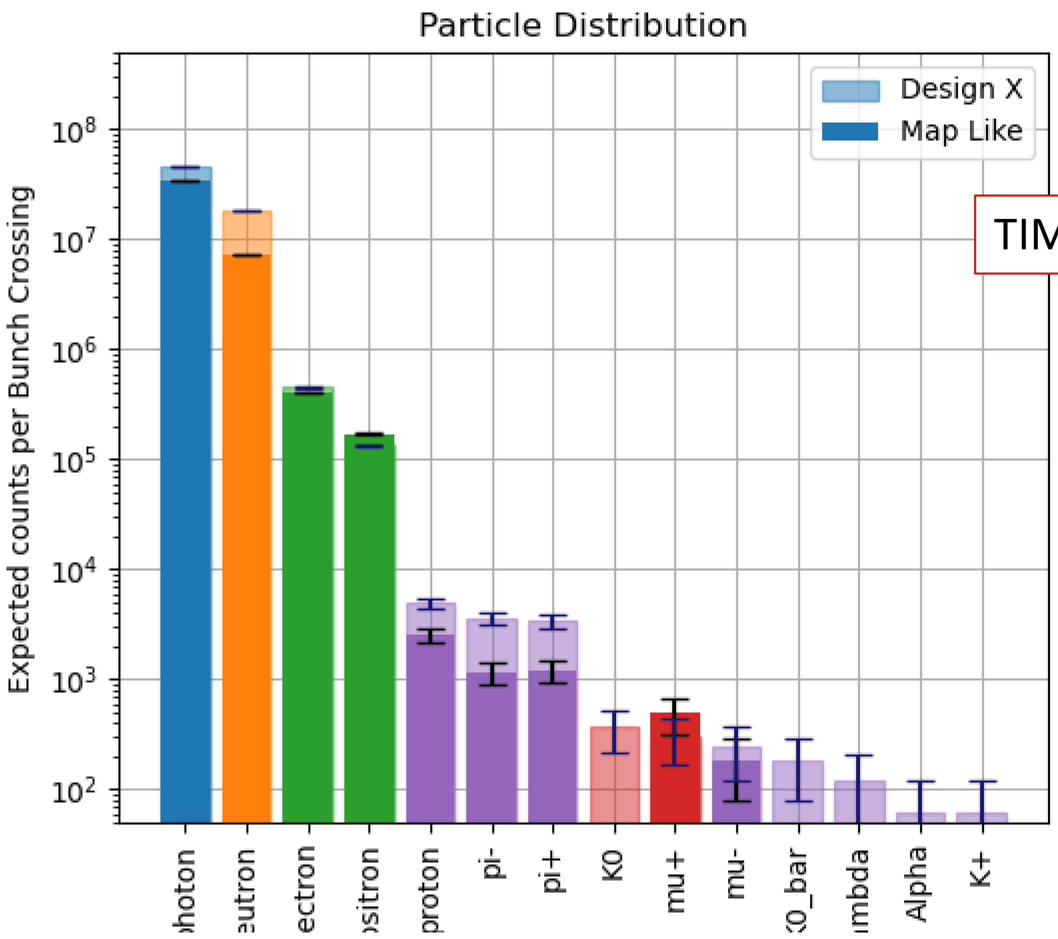
New Nozzle Design: X

- Chose after studying the results with low stat. simulations
- Nozzle with
  - $\theta_{nozzle} = 6.4°$
  - $z_{change} = 110\ cm$
  - $r_{base} = 48\ cm$
- 2% of one beam simulated
- Compared with Map-Like design with same statistics

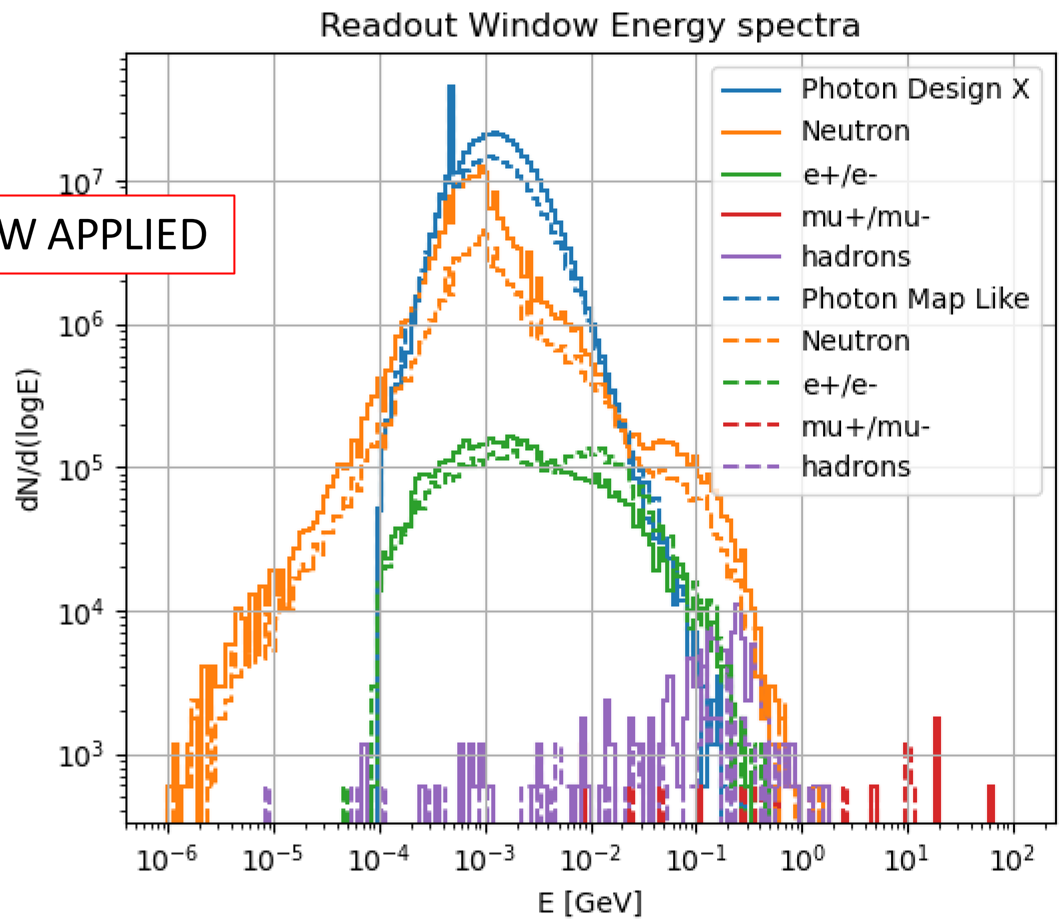


Nozzle geometry compared to the Map-Like design (red line). The Borated Polyethylene shape is due to redefinition of geometry in FLUKA for technical necessity

New Nozzle Design: X



TIME WINDOW APPLIED



Design X

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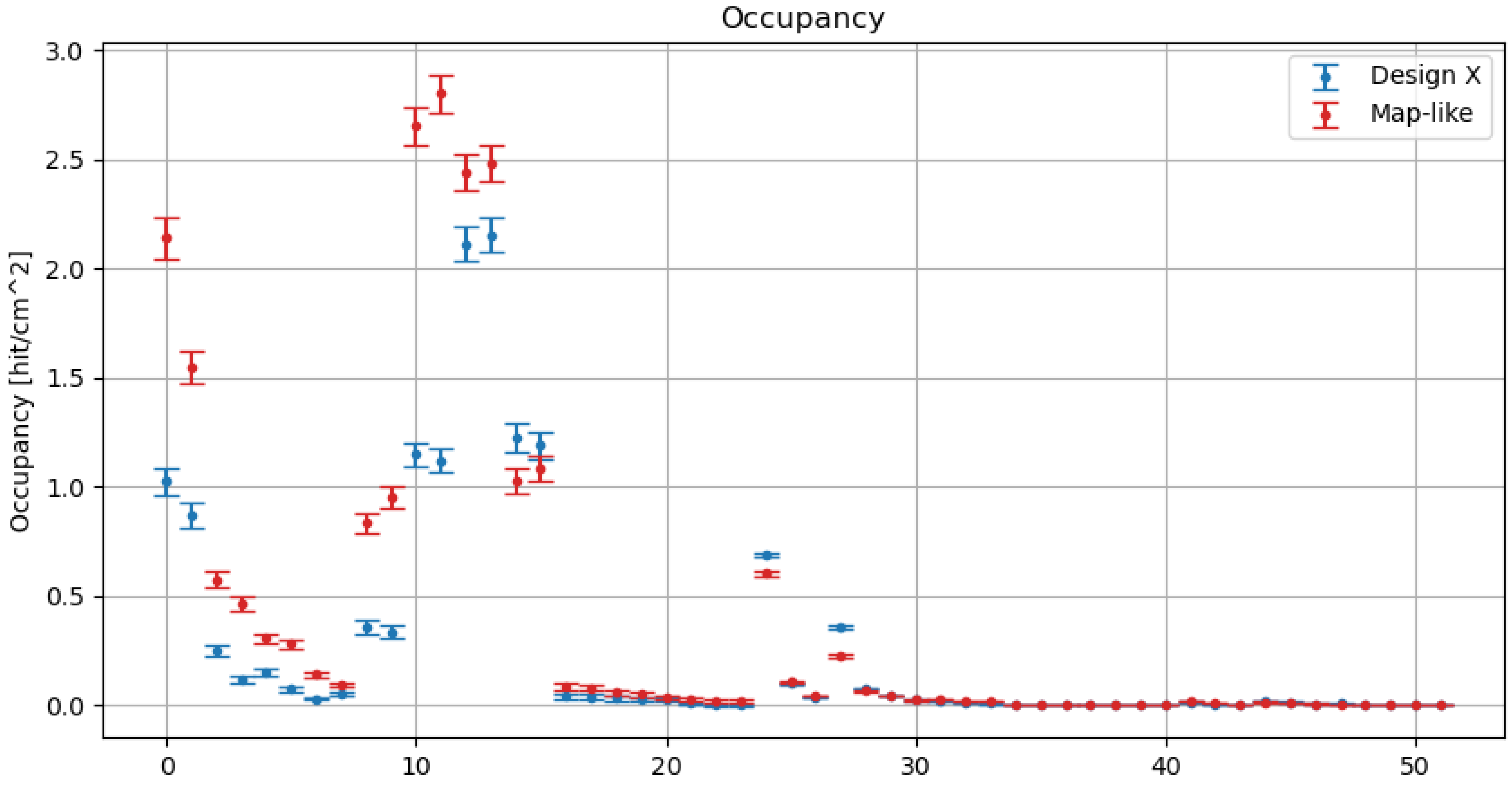


$\sigma_{occupancy} = \frac{\sqrt{Hits}}{Layer\ Area}$, assuming $Hits = Layer\ Area * Occupancy$

Conclusions

- **Machine Learning:**
  - Variation of the original geometry, no innovative design tested
  - Basic information obtained: $BIB\ flux = f(\theta_{tip}, z_{change}, r_{base})$
- **Nozzle design:**
  - Small changes in the geometry leads to significant variation in flux and occupancy
- **Next step:**
  - Collaboration with MODE [3] to apply advanced ML algorithm (ideally like SHIP optimization [4])
  - Correlating particles hitting and exiting the nozzle to understand its effect
  - Studying a proper region for a forward muons detector

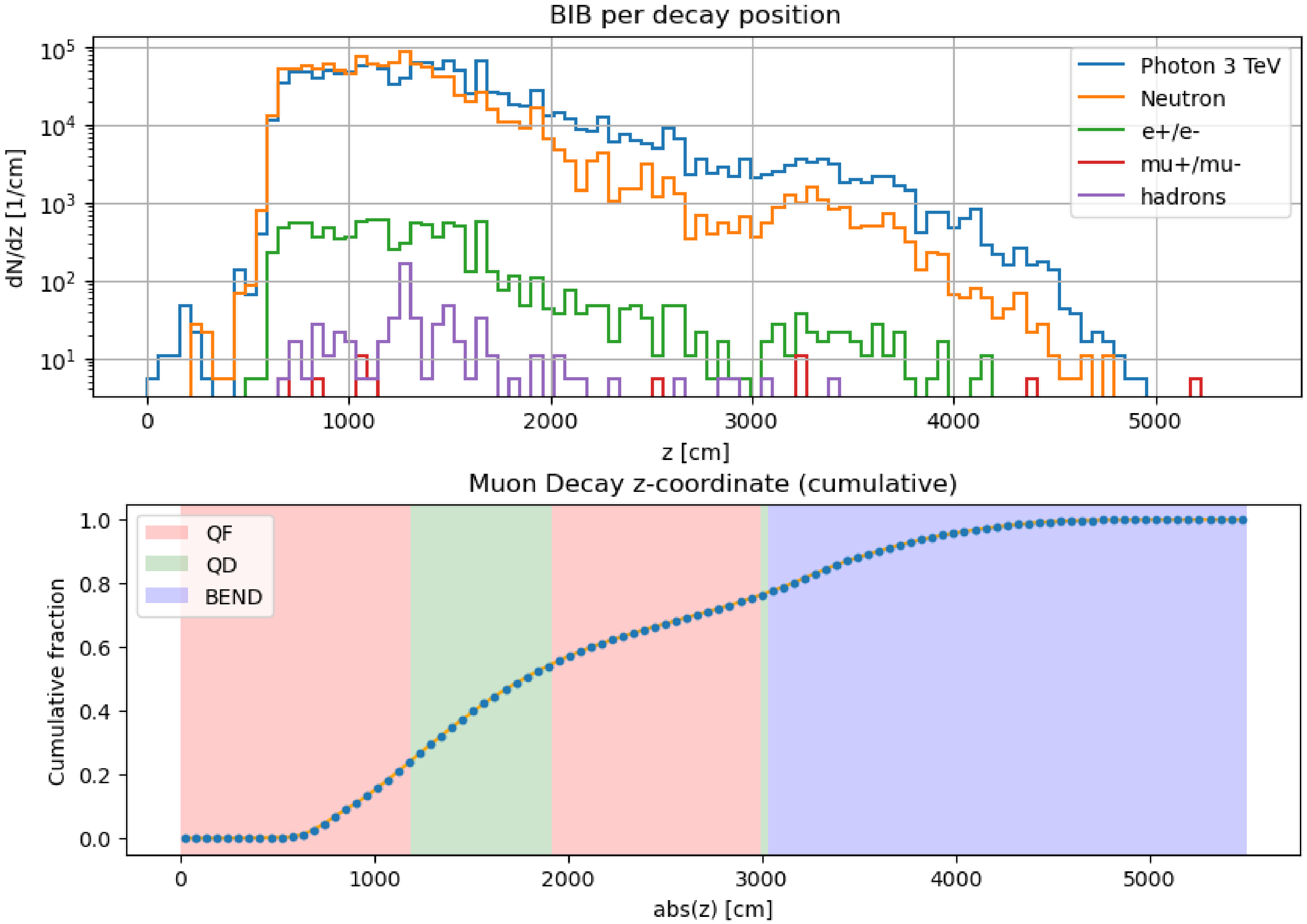
Thank you for the attention

References

- [1] Y. Alexahin, E. Gianfelice-Wendt, A 3-TeV MUON COLLIDER LATTICE DESIGN, Insiperhep.net
- [2] P. Li, Z. Liu, K. Lyu, HIGGS WIDTH AND COUPLINGS AT HIGH ENERGY MUON COLLIDERS WITH FORWARD MUON DETECTION, arxiv.org
- [3] M. Ruhdorfer, E. Salvioni, A. Wulzer, INVISIBLE HIGGS FROM FORWARD MUONS AT A MUON COLLIDER, arxiv.org
- [4] MODE Collaboration, mode.github
- [5] A. Baranov et al., OPTIMIZING THE ACTIVE MUON SHIELD FOR THE SHIP EXPERIMENT AT CERN, SHIP optimization
- [6] Z. Liu, HIGGS WIDTH AND COUPLINGS AT HIGH ENERGY MUON COLLIDERS WITH FORWARD MUON DETECTION, indico.cern

BACKUP

Muon decay position



Detector

hadronic calorimeter

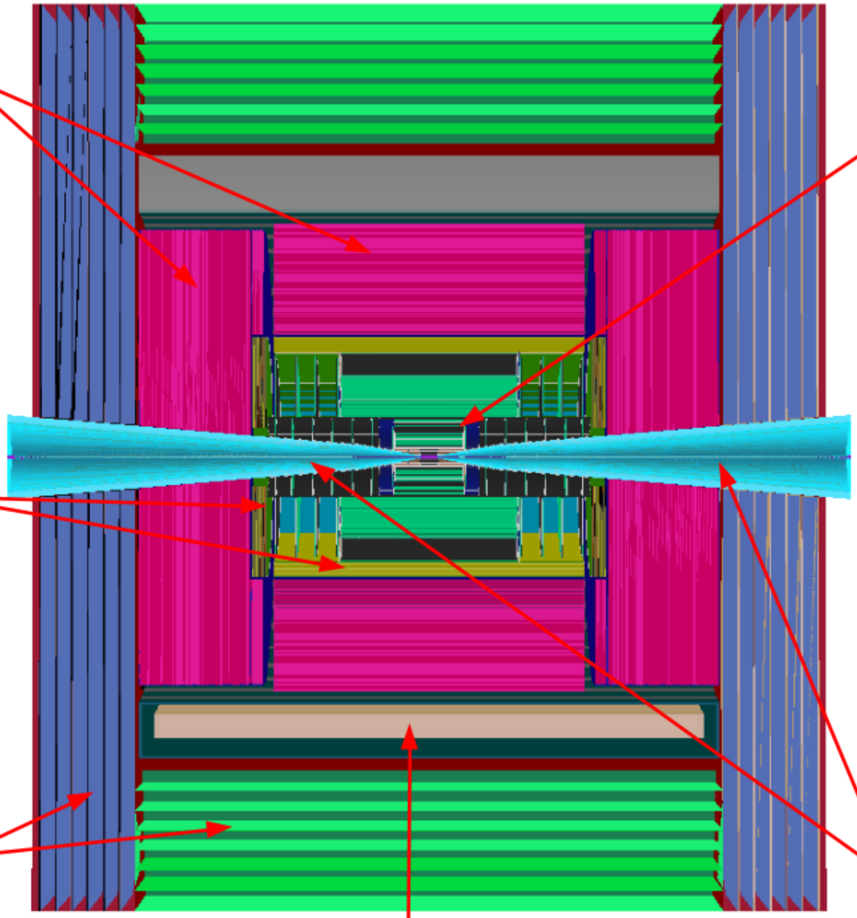
- 60 layers of 19-mm steel absorber + plastic scintillating tiles;
- 30x30 mm^2 cell size;
- 7.5 λ_I.

electromagnetic calorimeter

- 40 layers of 1.9-mm W absorber + silicon pad sensors;
- 5x5 mm^2 cell granularity;
- 22 X_0 + 1 λ_I.

muon detectors

- 7-barrel, 6-endcap RPC layers interleaved in the magnet's iron yoke;
- 30x30 mm^2 cell size.



superconducting solenoid (3.57T)

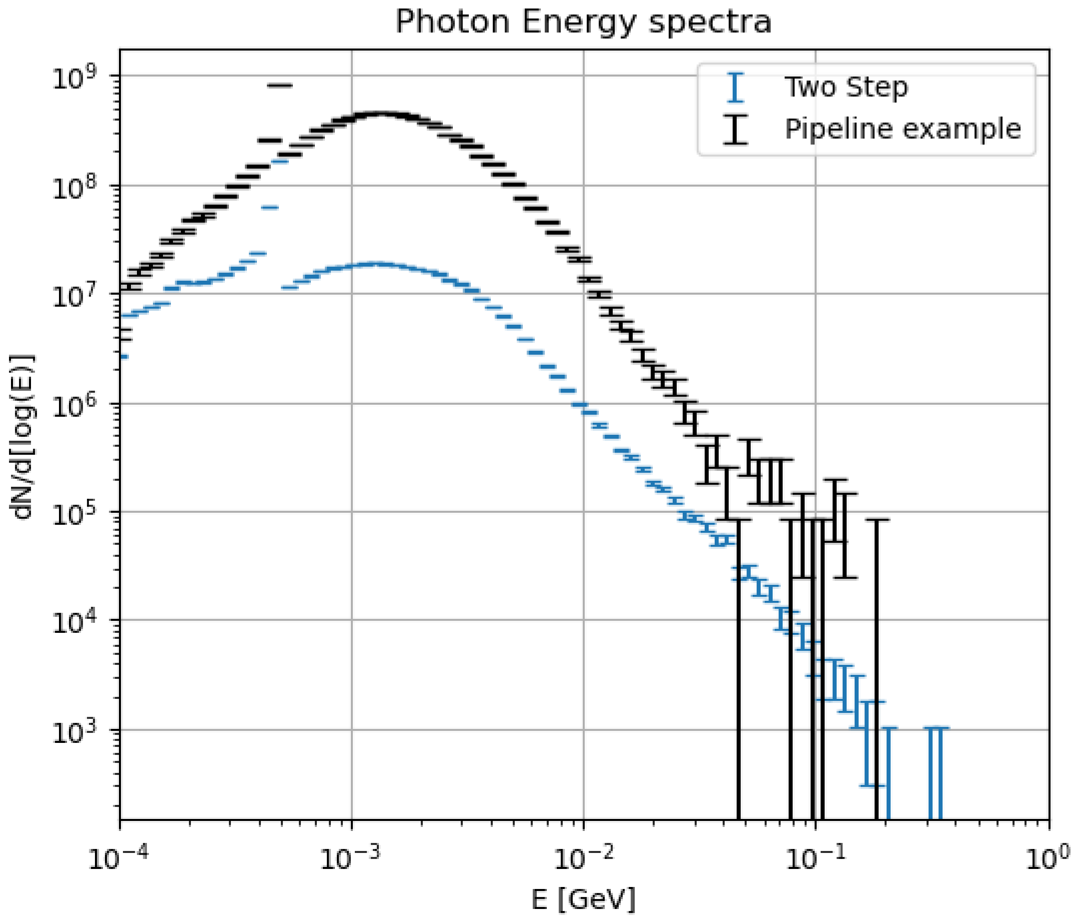
tracking system

- Vertex Detector:
  - double-sensor layers (4 barrel cylinders and 4+4 endcap disks);
  - 25x25 μm^2 pixel Si sensors.
- Inner Tracker:
  - 3 barrel layers and 7+7 endcap disks;
  - 50 µm x 1 mm macro-pixel Si sensors.
- Outer Tracker:
  - 3 barrel layers and 4+4 endcap disks;
  - 50 µm x 10 mm micro-strip Si sensors.

shielding nozzles

- Tungsten cones + borated polyethylene cladding.

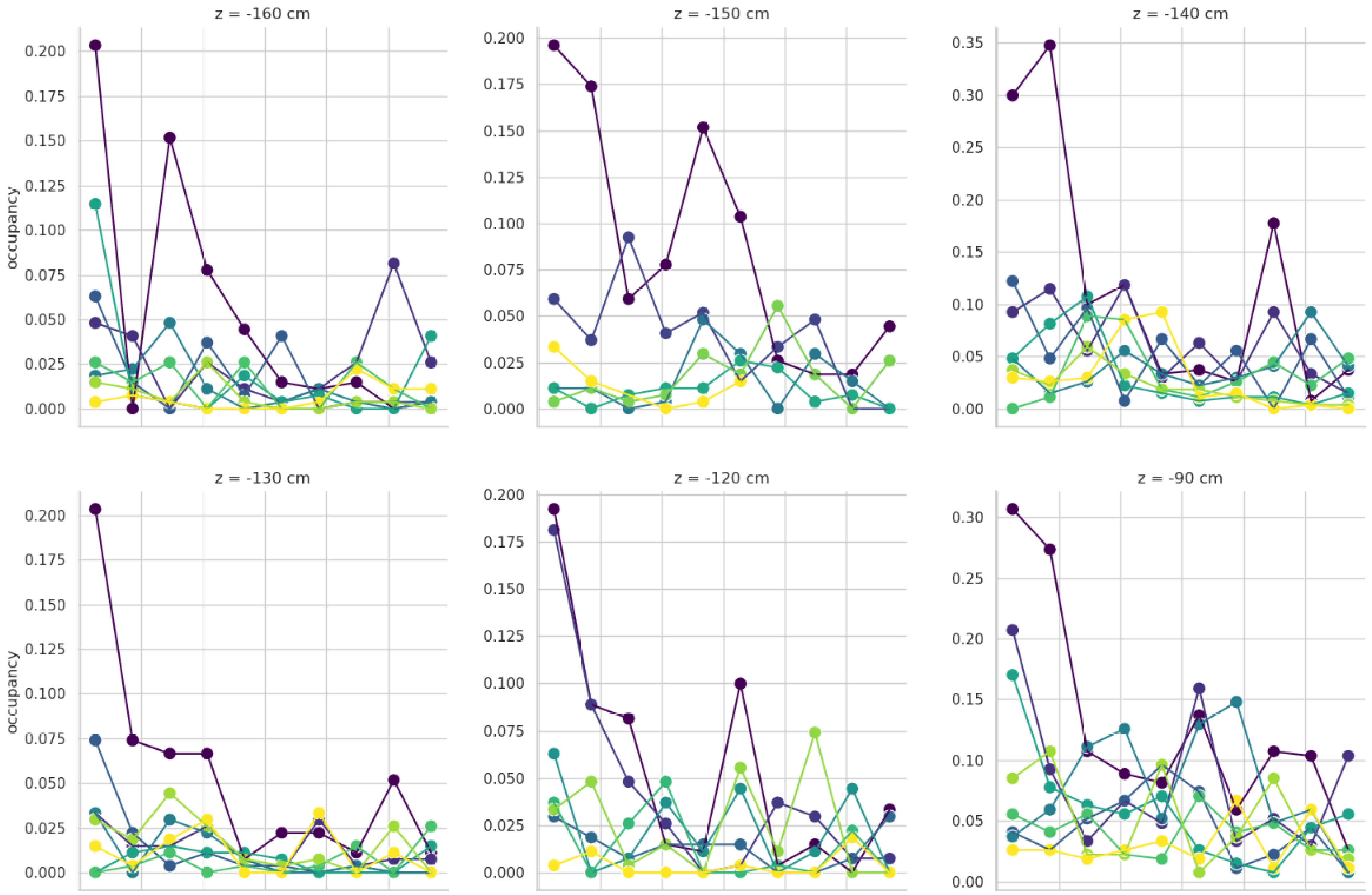
Low Statistic simulation



- Two step: 2% of one beam, one bunch crossing
- Pipeline: 0.025% of one beam, one bunch crossing
- **Pipeline nozzles smaller** than original (aperture = 20 cm)
- $\sigma = \sqrt{\#particles}$

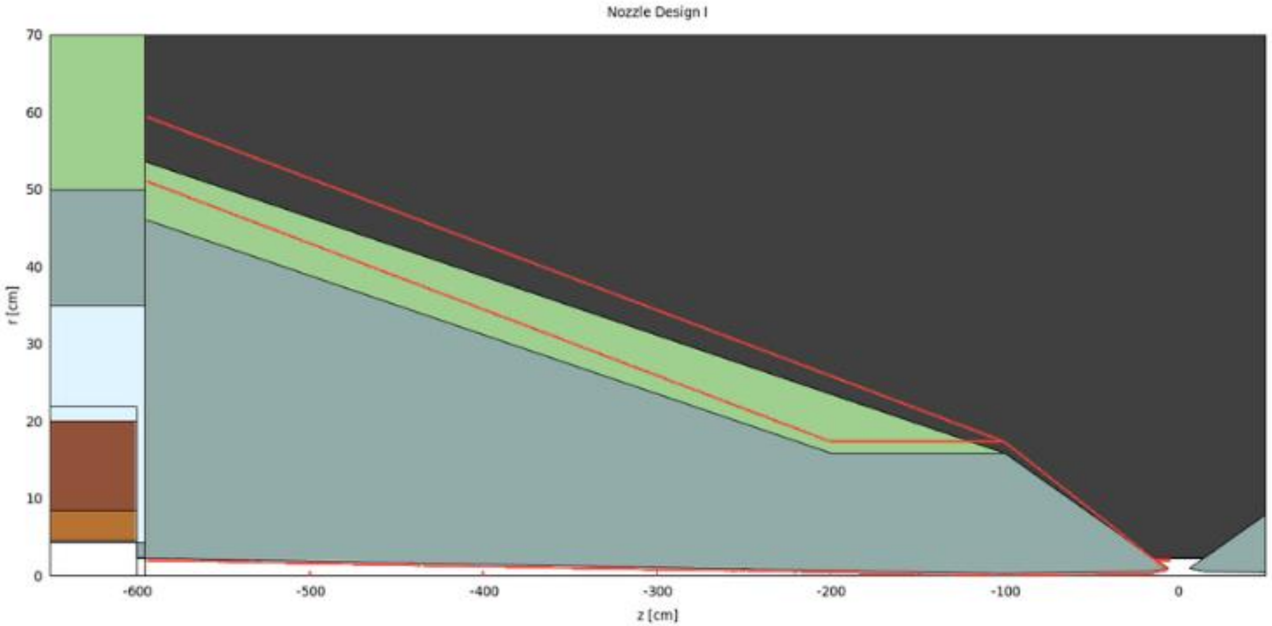
Other Observables

- Occupancy in the vertex detector is dominated by statistics
- Energy in the ECal not yet studied.



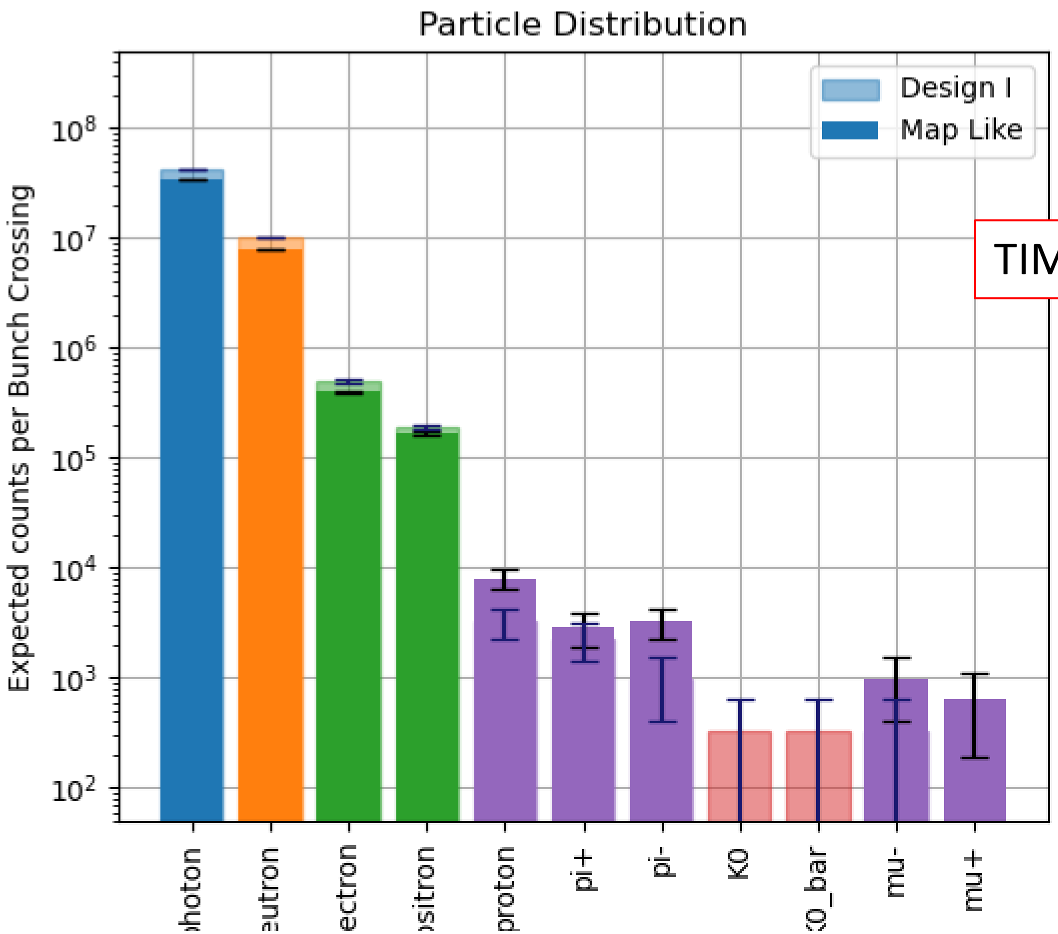
Design I

- Nozzle with
  - $\theta_{nozzle} = 9°$
  - $r_{base} = 54\ cm$
- 0.38% of one beam simulated
- Compared with Map-Like design with same statistics

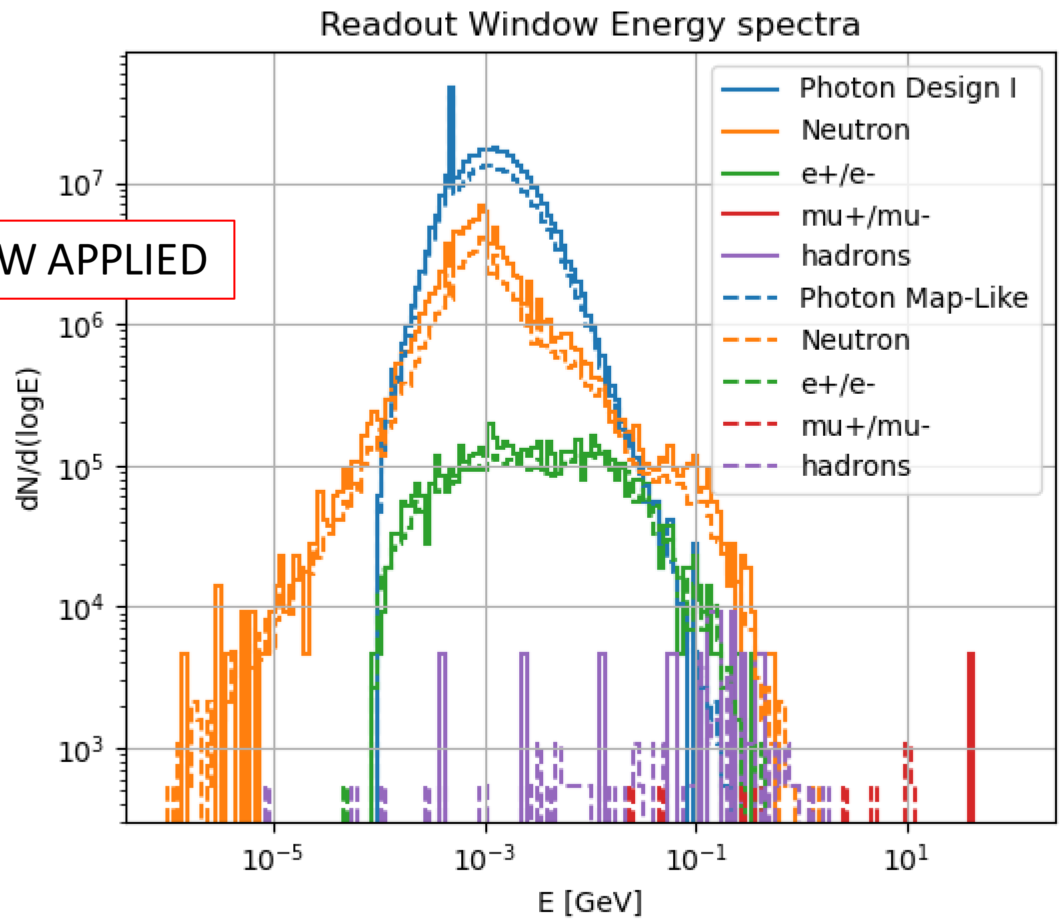


Nozzle geometry compared to the Map-Like design (red line)

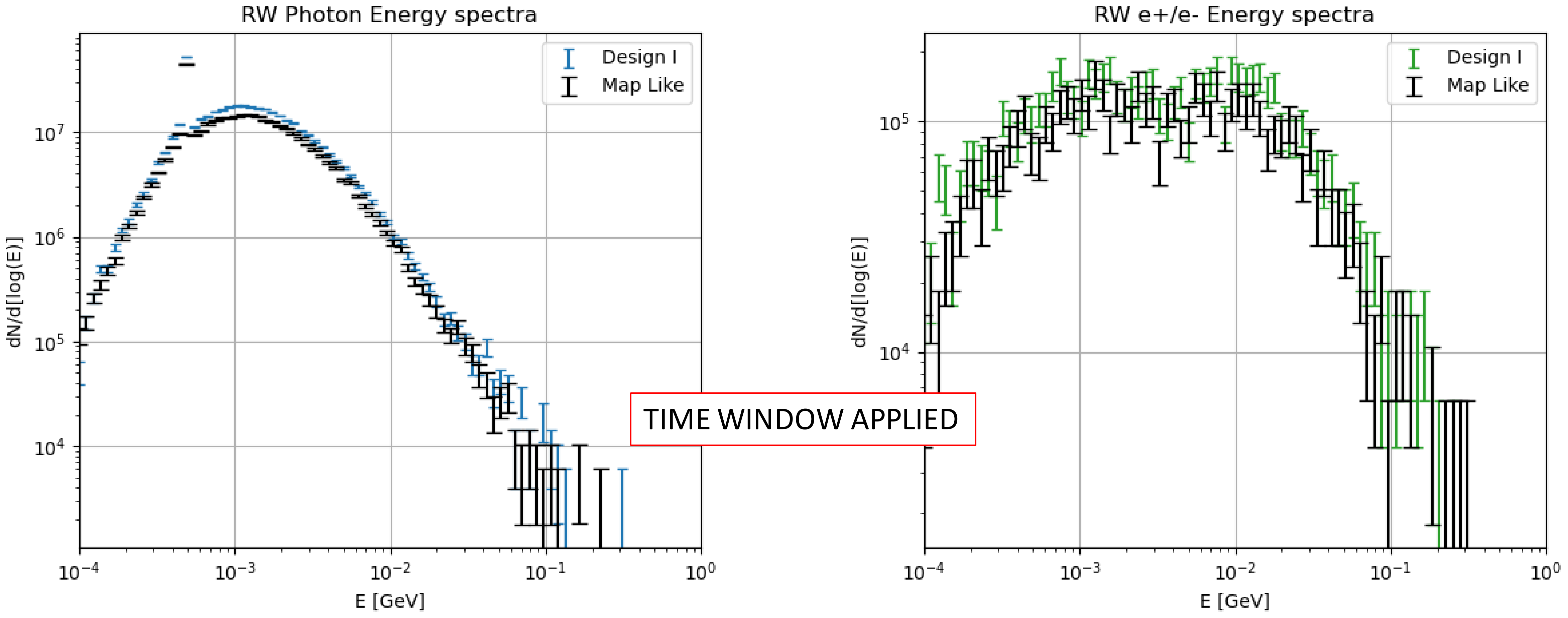
Design I



TIME WINDOW APPLIED

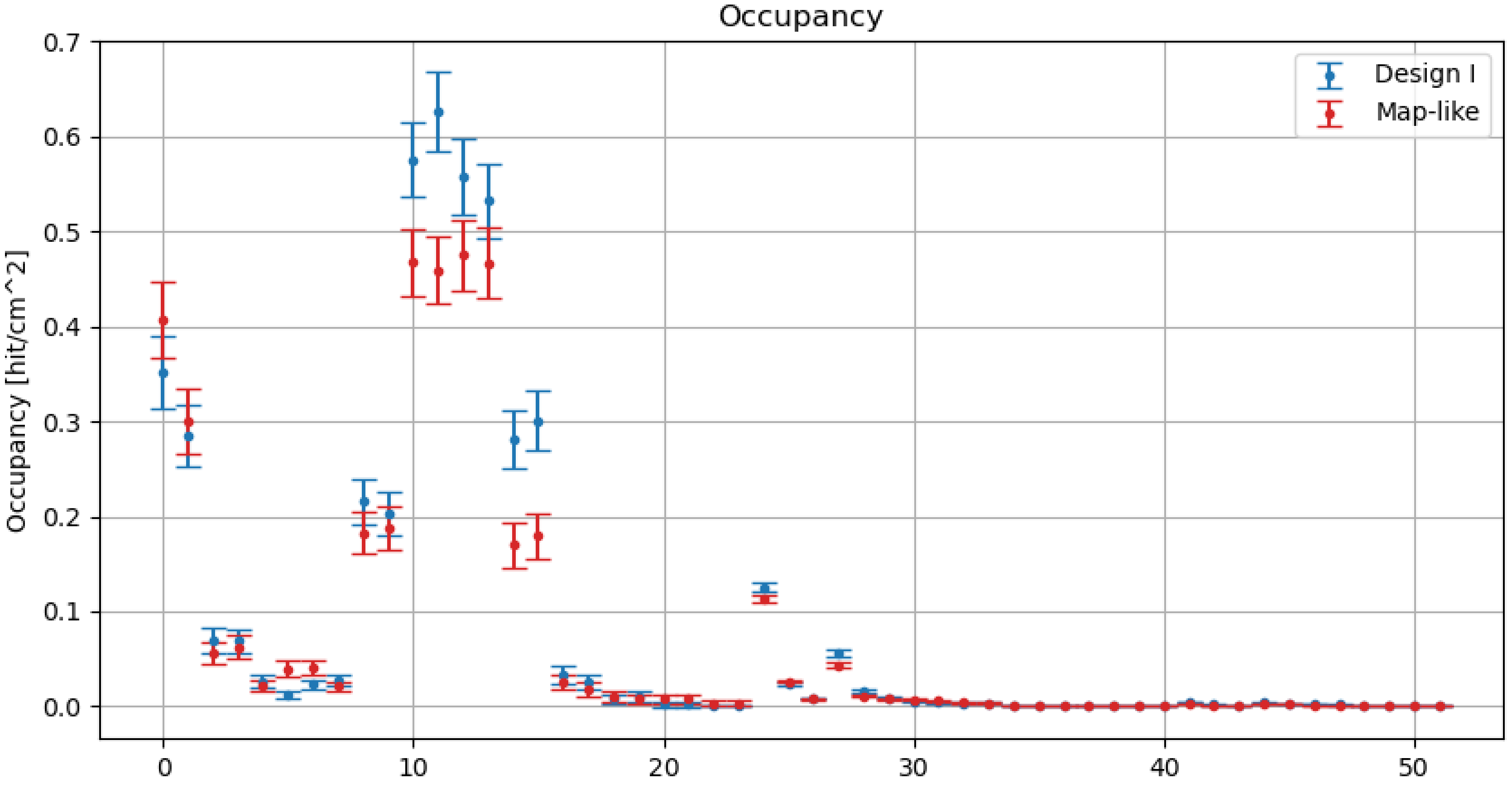


Design I


RW Photon Energy spectra
Design I
Map Like
dN/d[log(E)]
E [GeV]
RW e+/e- Energy spectra
Design I
Map Like
dN/d[log(E)]
E [GeV]
TIME WINDOW APPLIED

Design I

- Occupancy obtained from Simulated Hits in the detector **without any normalization**
- Considered Readout Window and Time Window in the subdetectors.
- With this design
  - Less occupancy in the vertex
  - More in the Tracker



$$\sigma_{occupancy} = \frac{\sqrt{Hits}}{Layer\ Area},\ \text{assuming}\ Hits = Layer\ Area * Occupancy$$

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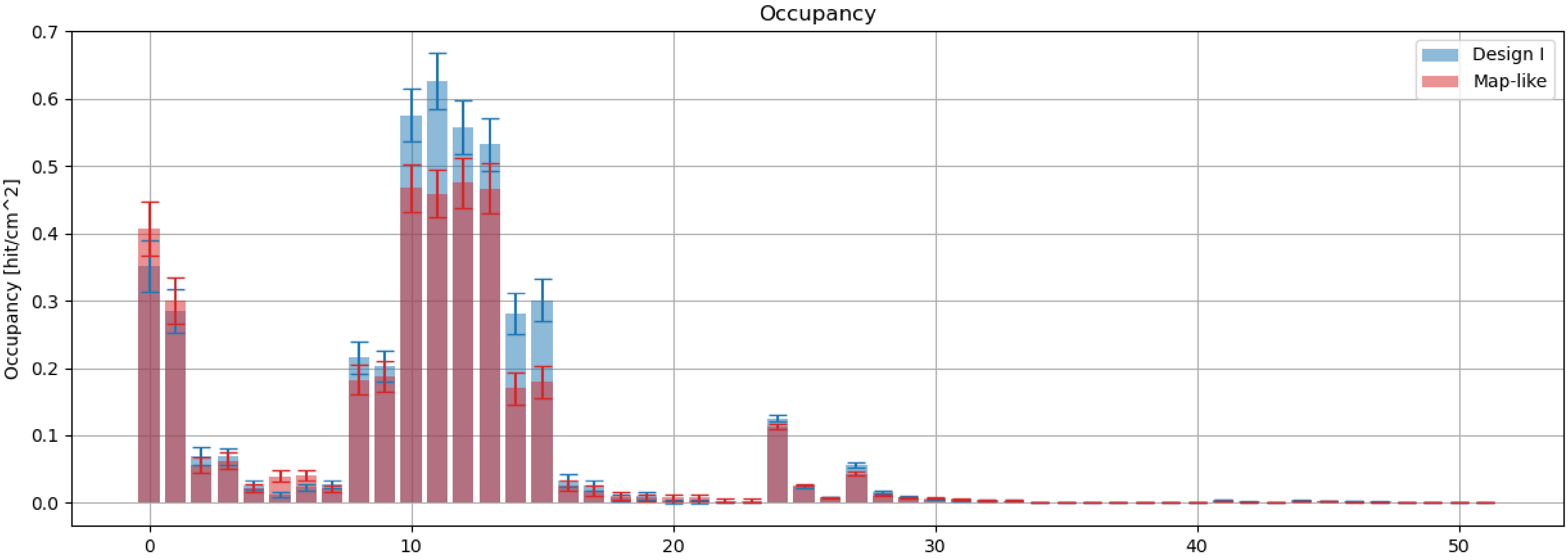
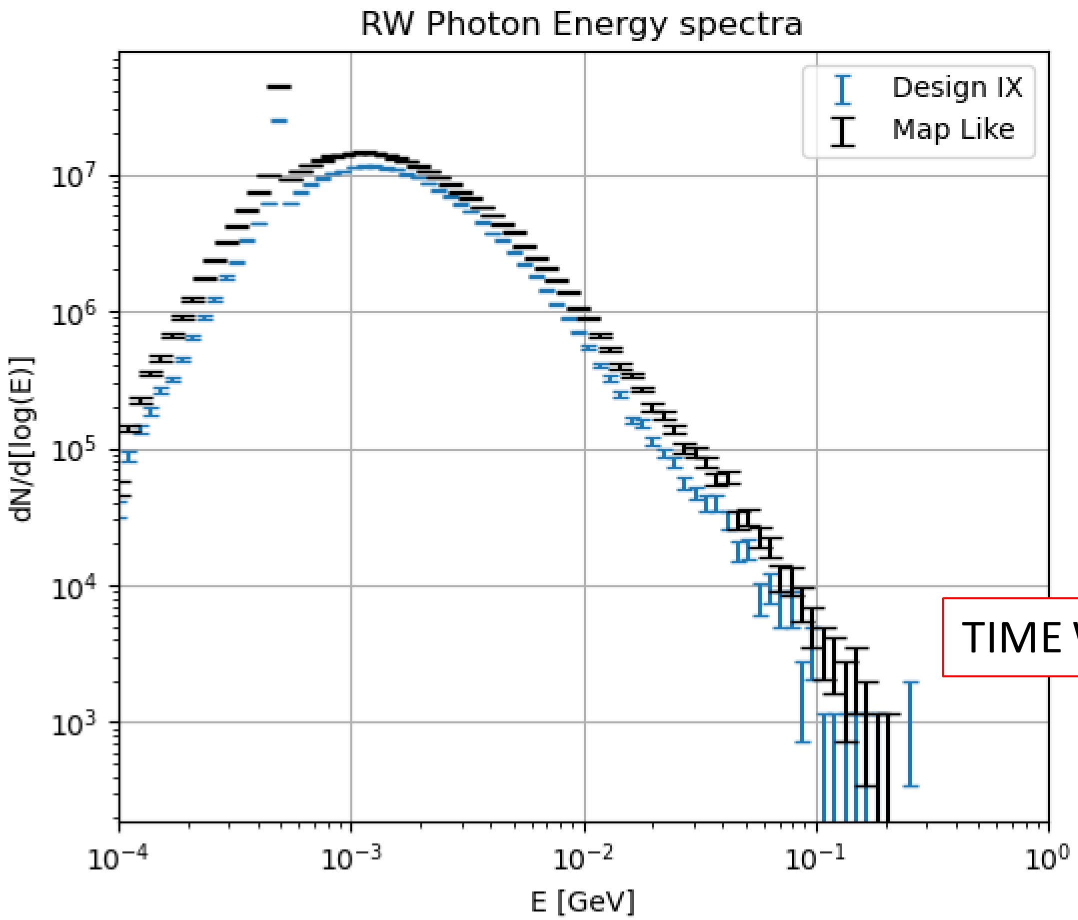


Occupancy
Occupancy [hit/cm^2]
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
Design I
Map-like

Design IX



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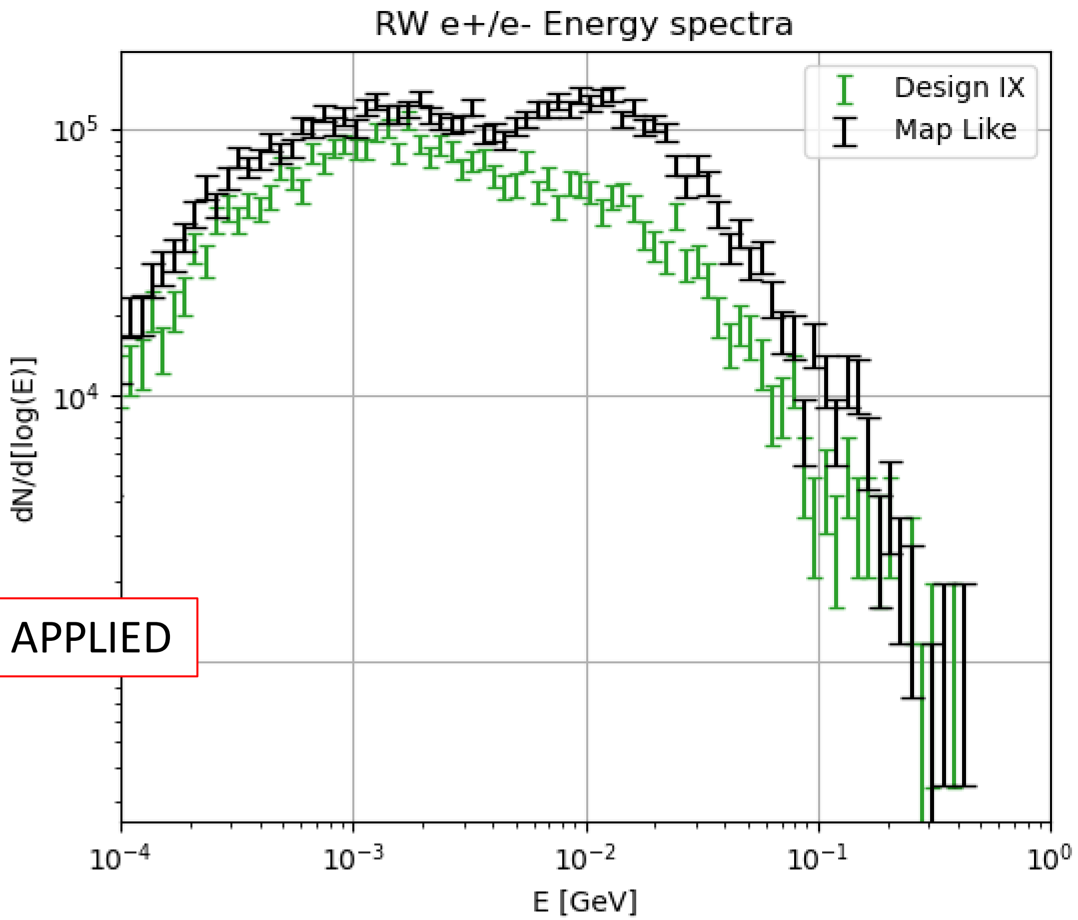
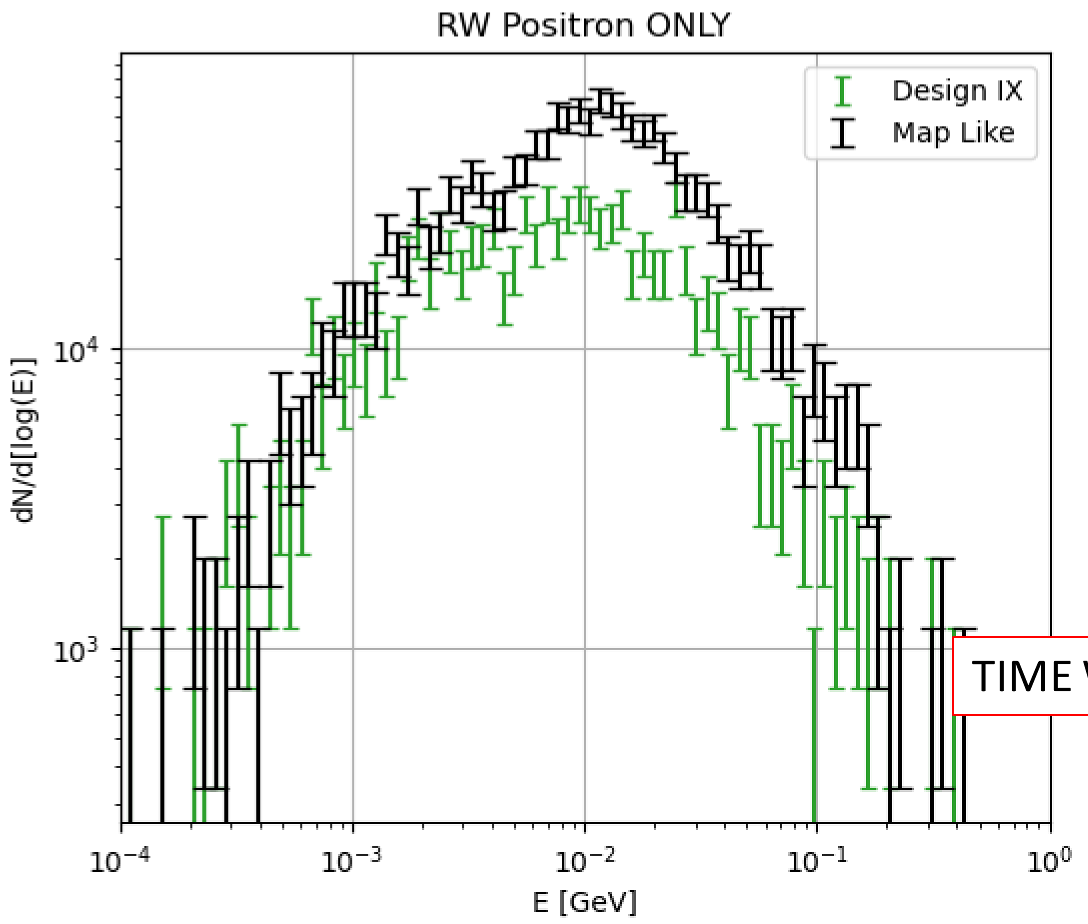
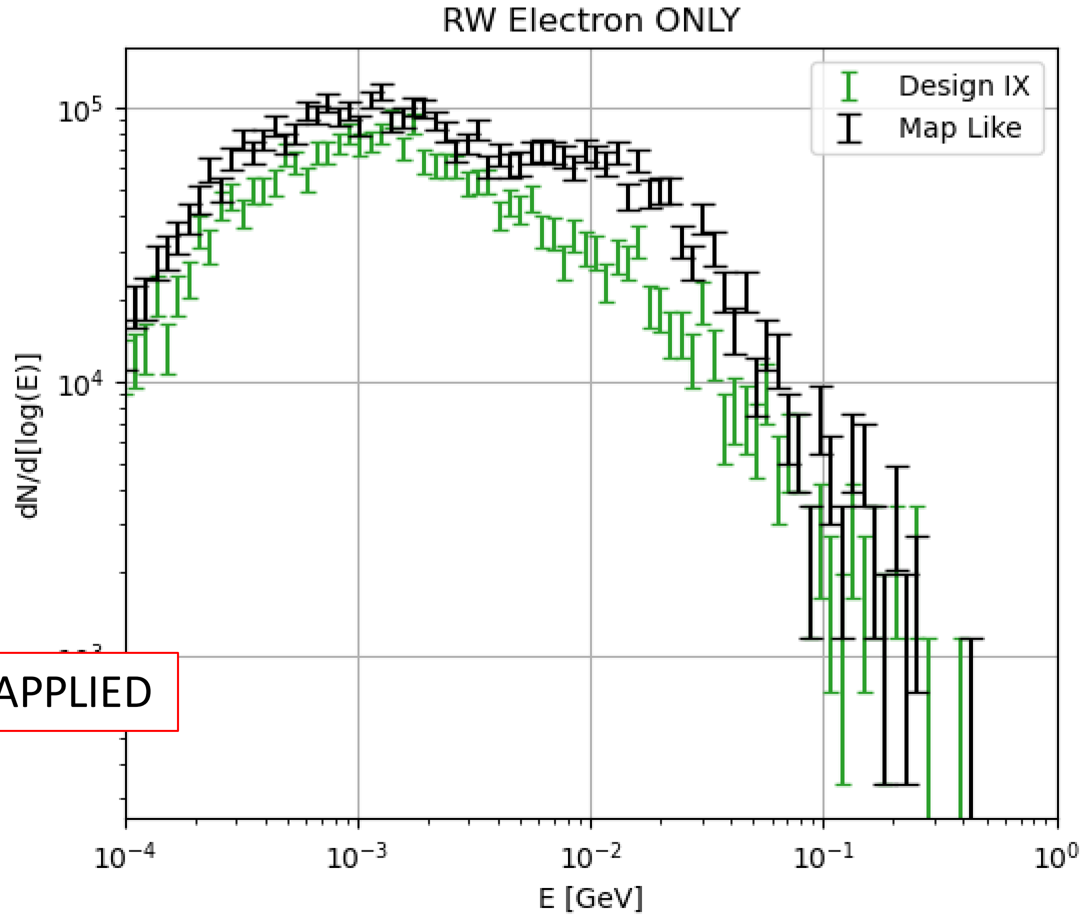


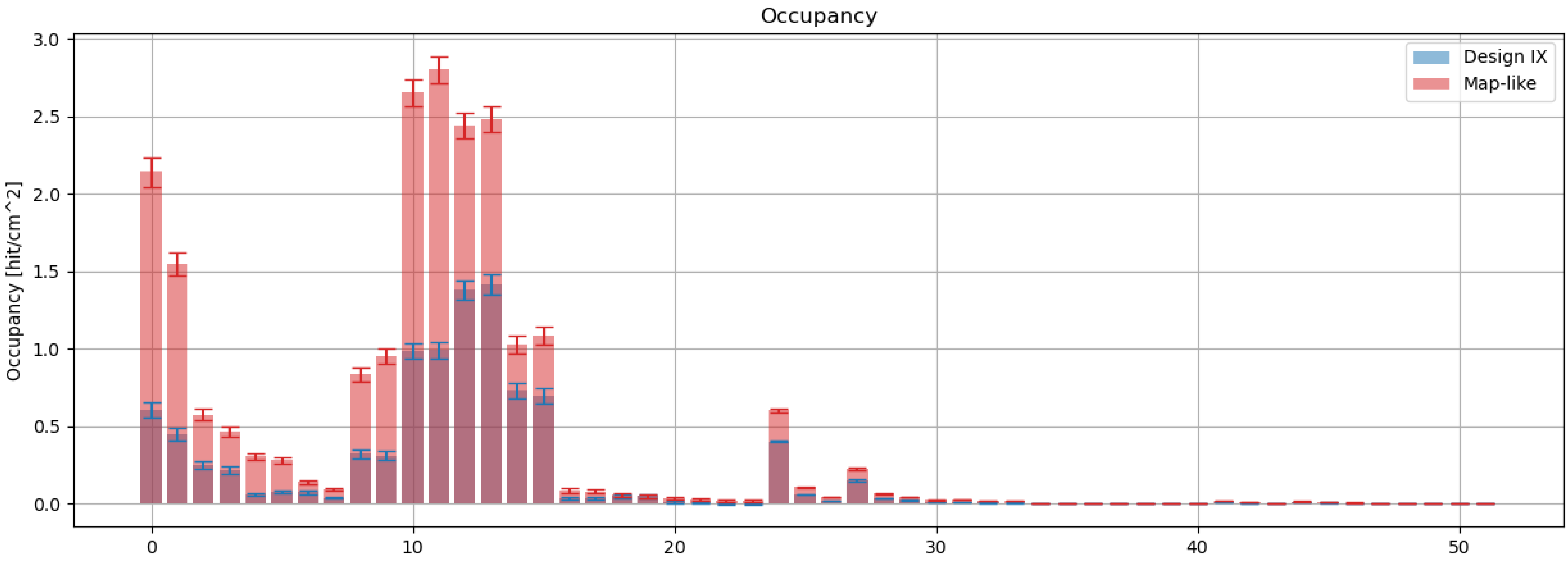
Design IX



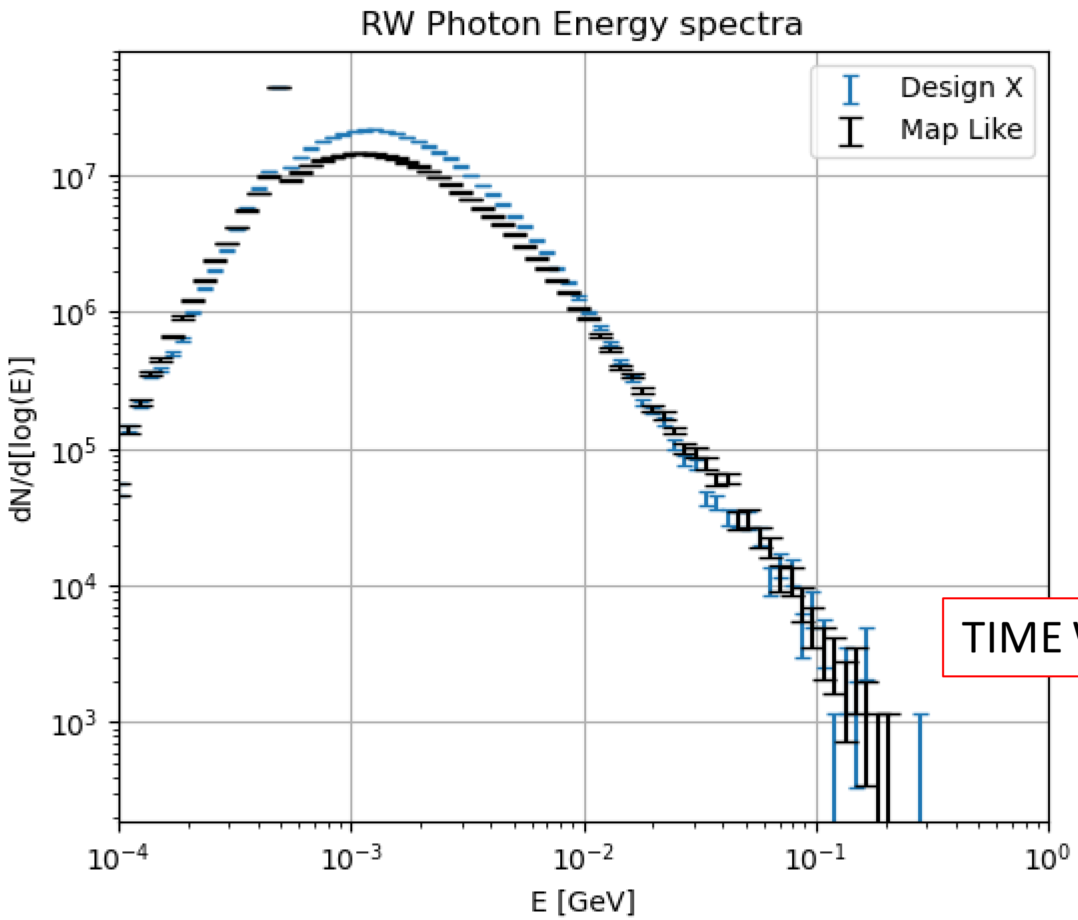


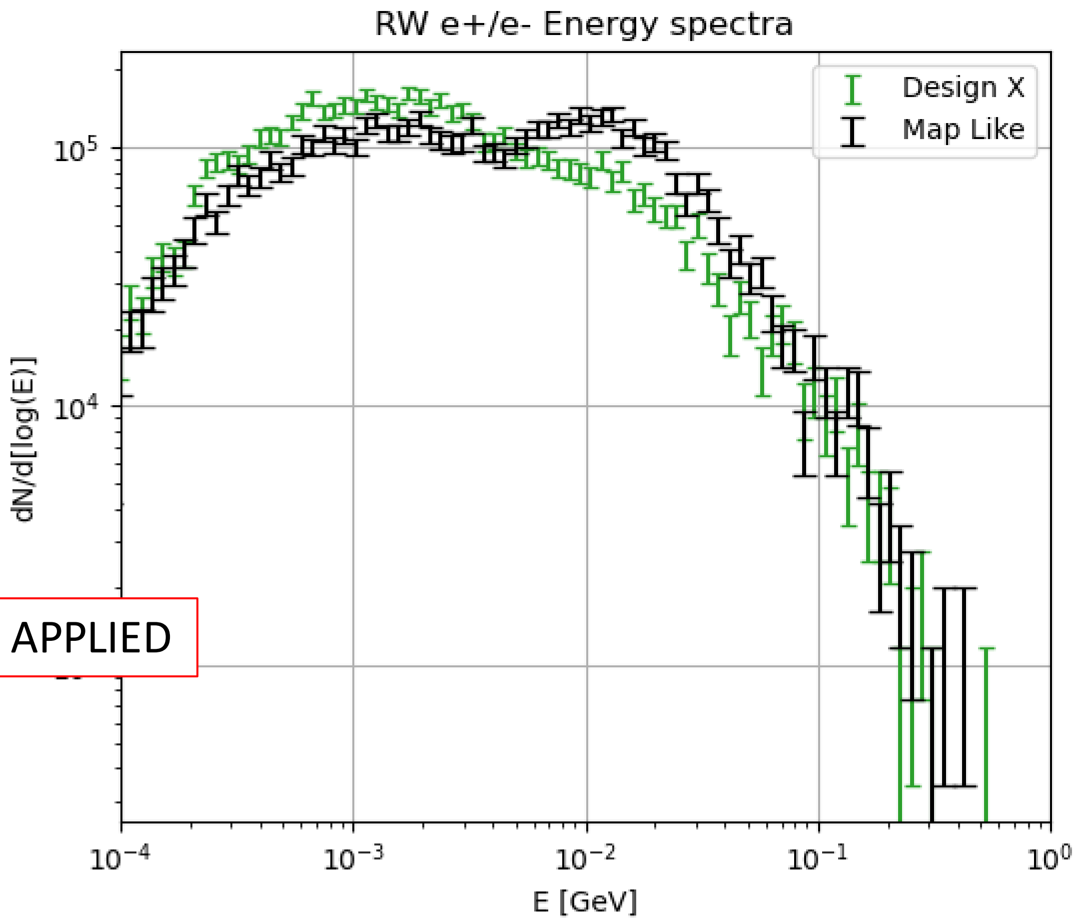
TIME WINDOW APPLIED

Design IX


Occupancy
Occupancy [hit/cm^2]
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
Design IX
Map-like

Design X





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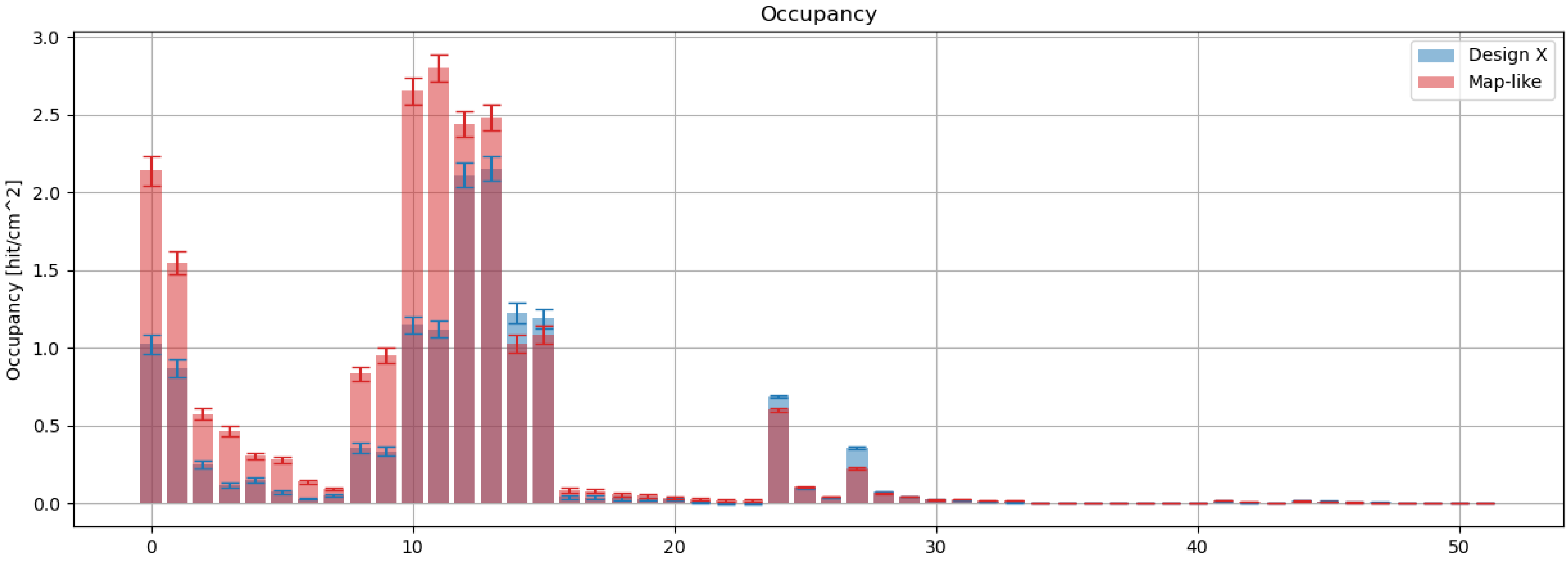

Occupancy
Occupancy [hit/cm^2]
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
Design X
Map-like