Measurement of Muon Flux at the LHC using the sRPC detector

LIP summer internship program 2025

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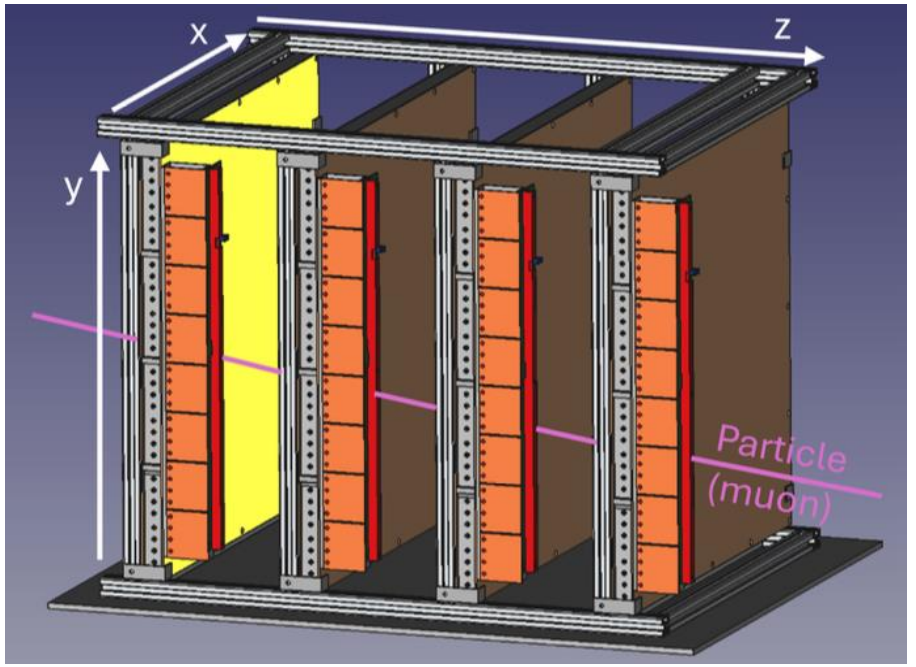
Introduction

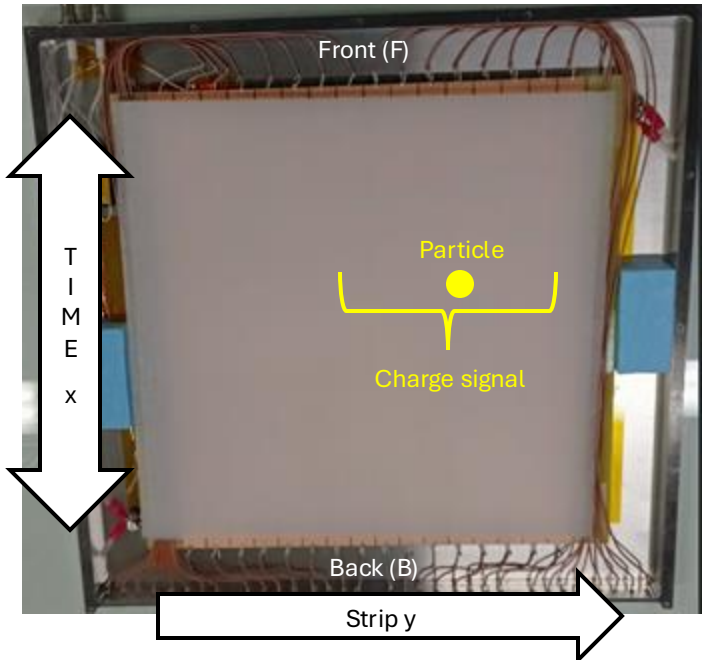
- Built in Lip Coimbra
- First data in 2023
- Located 480m from ATLAS
- In front of SND@LHC
- Goal: measure muon flux

Detector

- Measured quantities:
  - Charge induced on the back (QB) and front of the strip (QF):
  - Time of signal arrival at both ends of each strip, (TB and TF)
- Coordinates:
  - $x = \frac{TF - TB}{2} \cdot v$
  - $y = strip\ position\ (with\ the\ most\ charge)$
  - $z = plane\ position$

$^*v$ is the propagation velocity ≈ 165.5 mm/ns



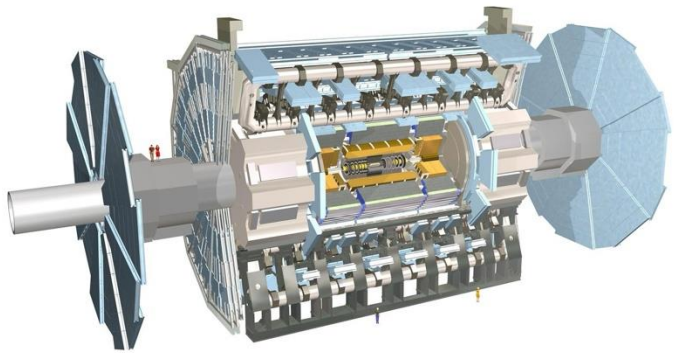


Monte Carlo Simulation

Muon Production

Proton-proton Collisions → Propagation to the SND@LHC Site → Propagation and interaction in the SND@LHC detector

DPMJet



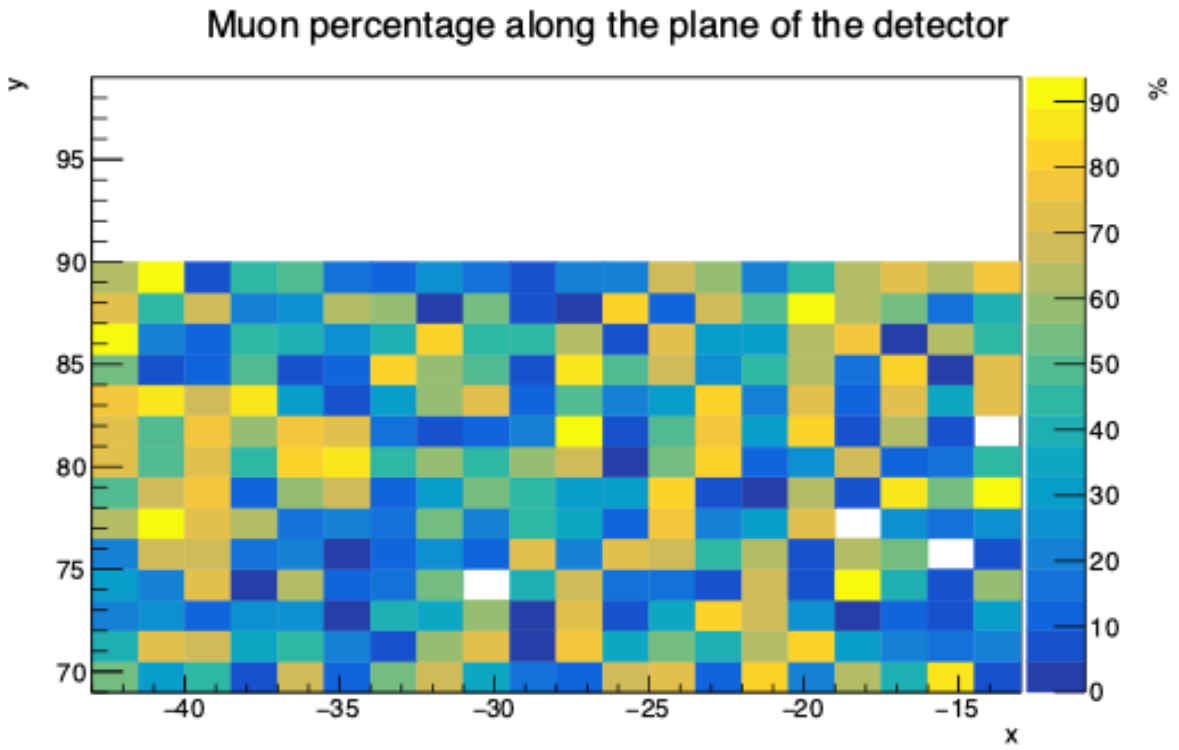
FLUKA

GEANT4

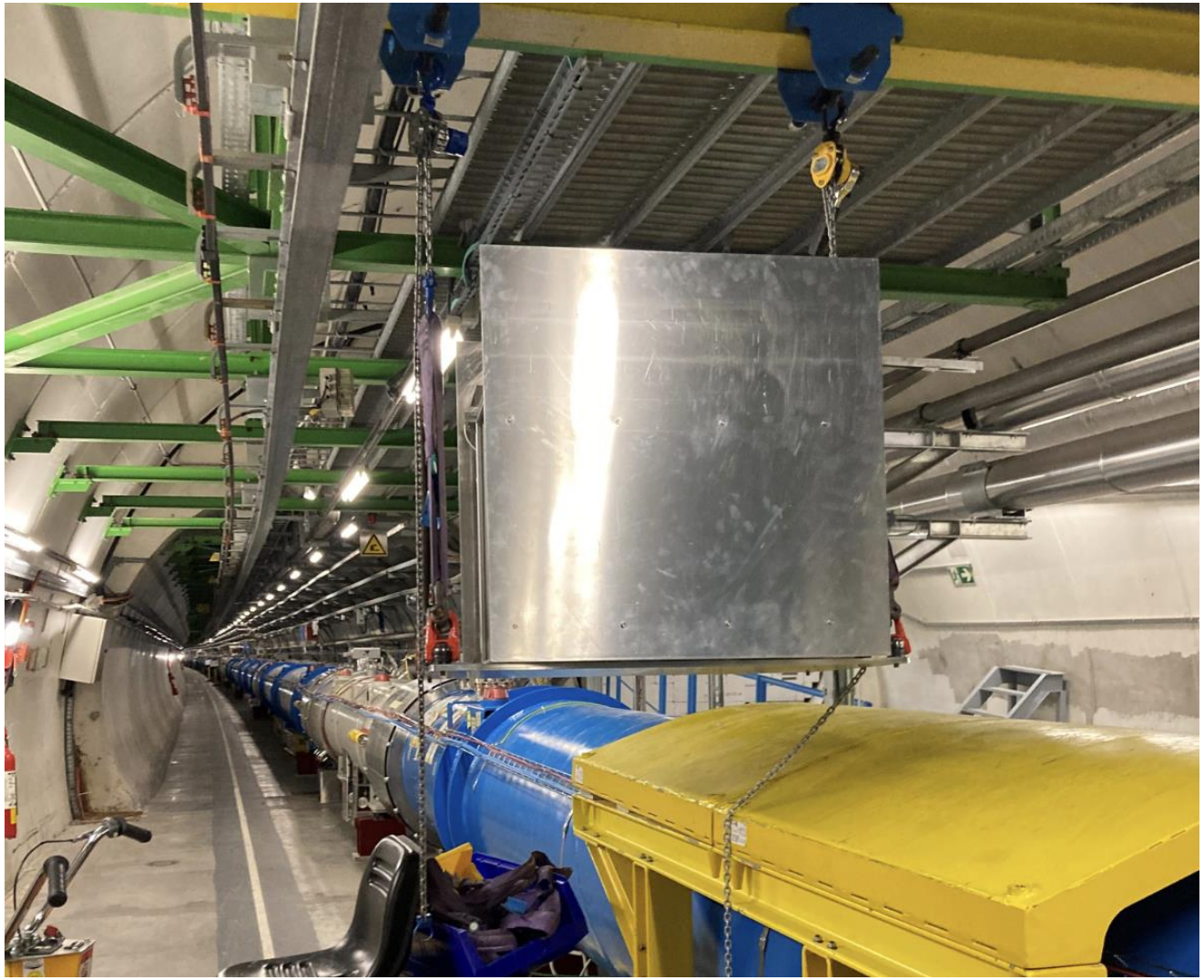
Received Data

Simulation Data Structure

- Root TTree;
- Total number of events = 205 446;
- Parameters:
  - Position (x, y, z);
  - Weight (w);
  - Particle identification (id);



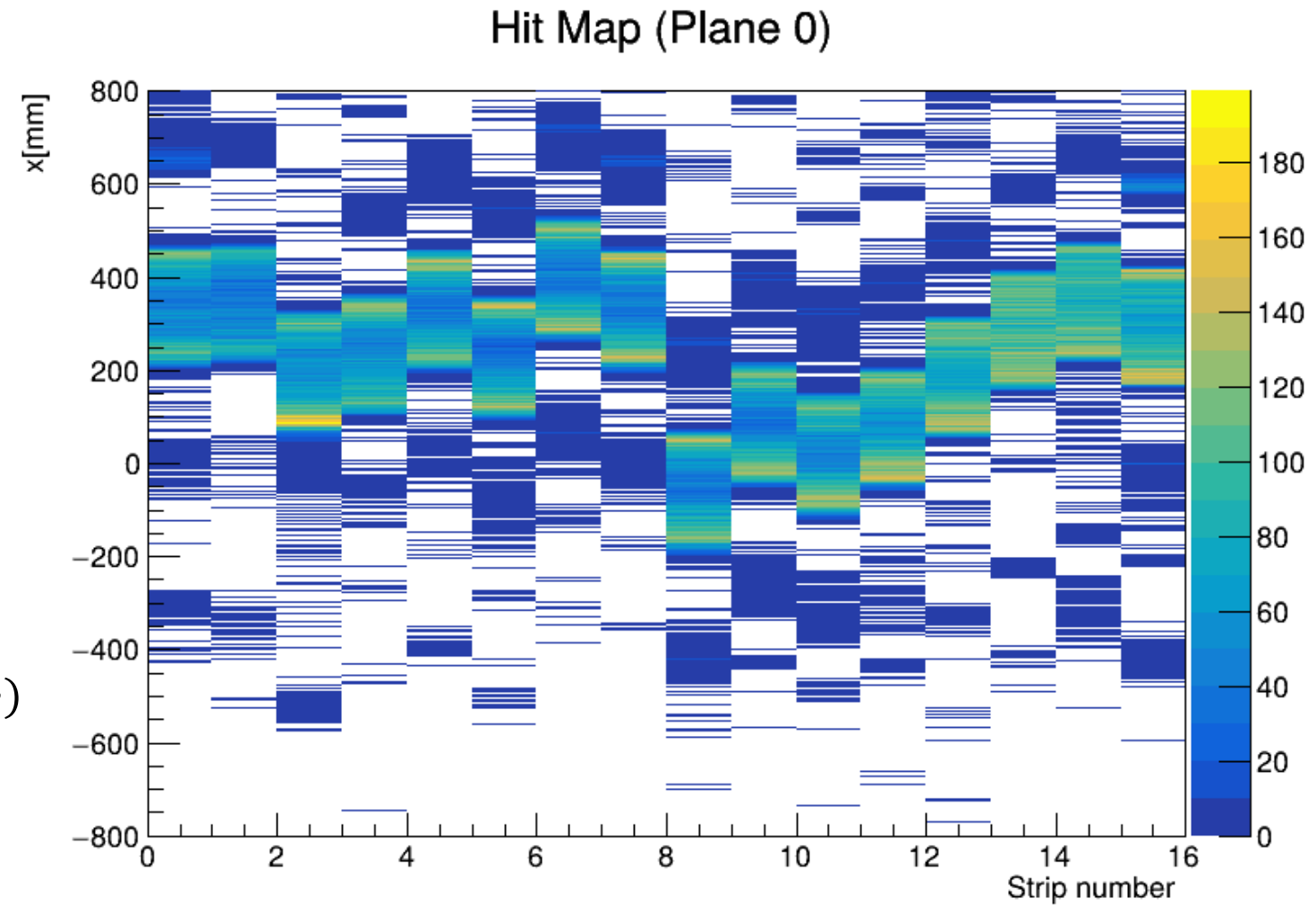
Detector Data Analysis



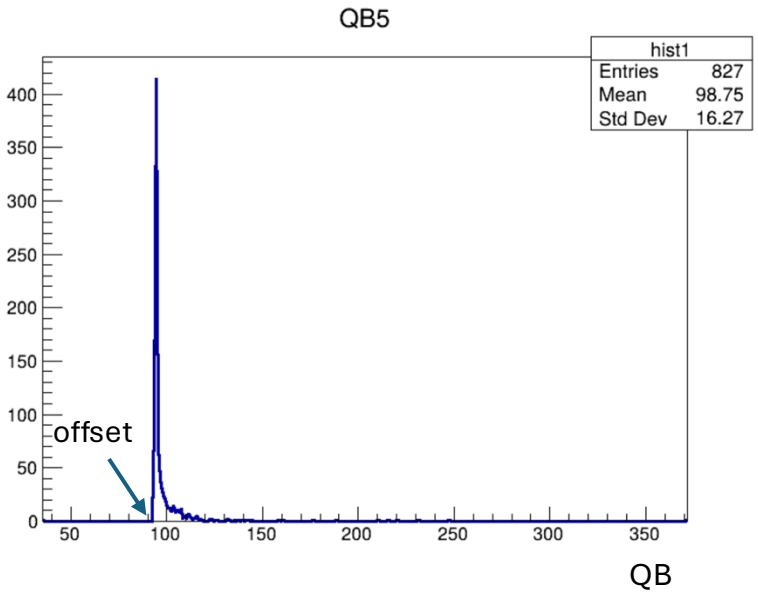
Hit map

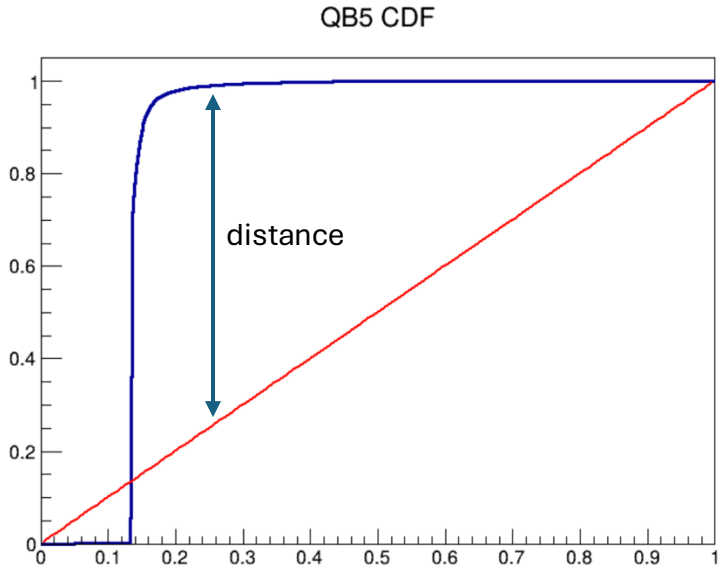
- Dispersed distribution;
- Calibration is necessary to correctly visualize data;

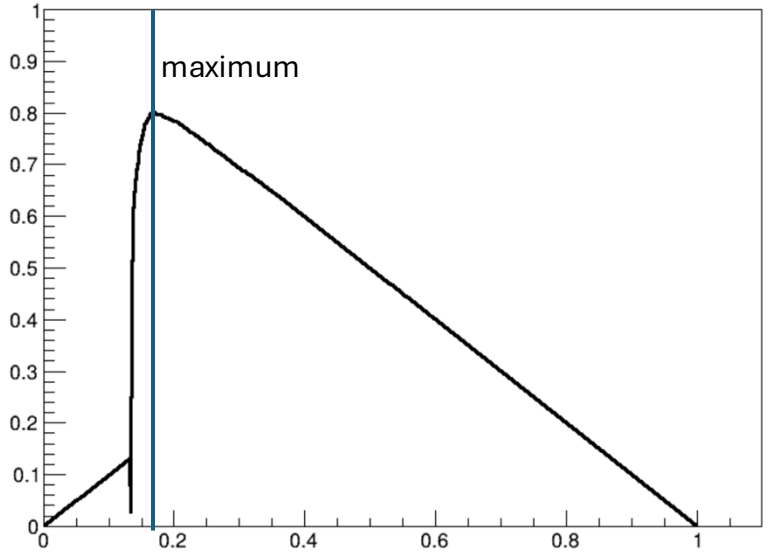
- Coordinates:
  - $x = \frac{TF - TB}{2} \cdot v$
  - $y =$ $strip\ number\ (with\ the\ most\ charge)$
  - $z = plane\ number$



Charge Calibration



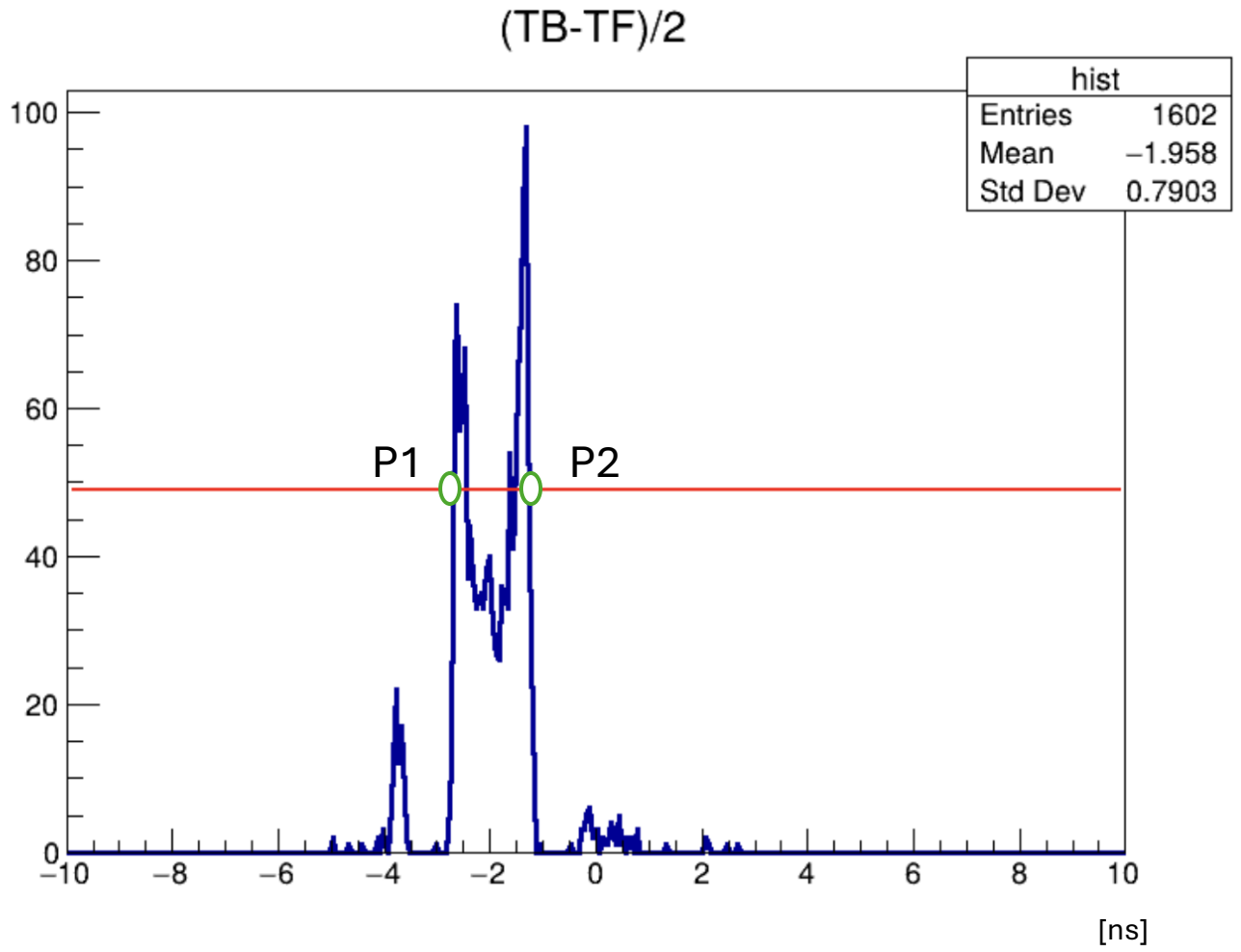




Histogram of QB or QF → Build the CDF → Draw linear function → Plot the diference → Find maximum

Time Calibration

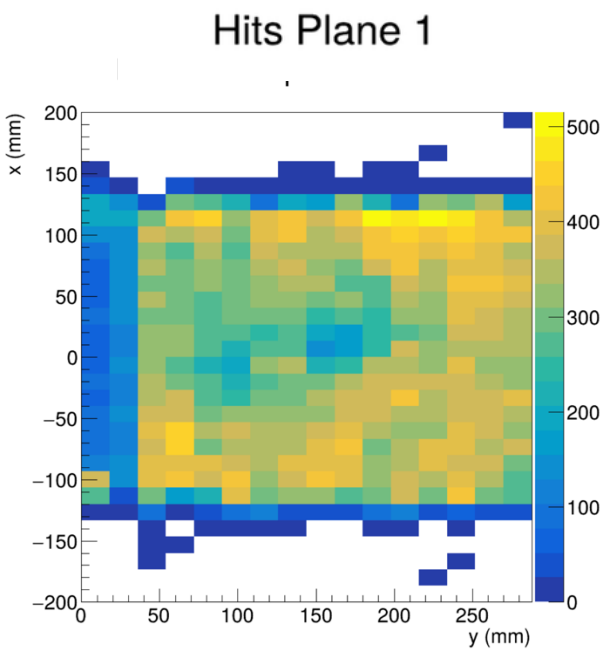
- Plot (TB – TF)/2
- Set a threshold (max*0.5)
- Find intersection points
- Compute offset:
  - $\frac{P1+P2}{2}$

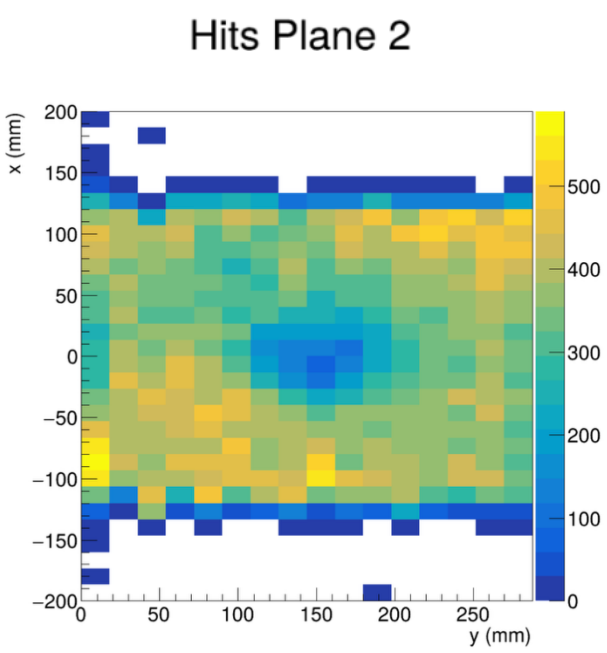


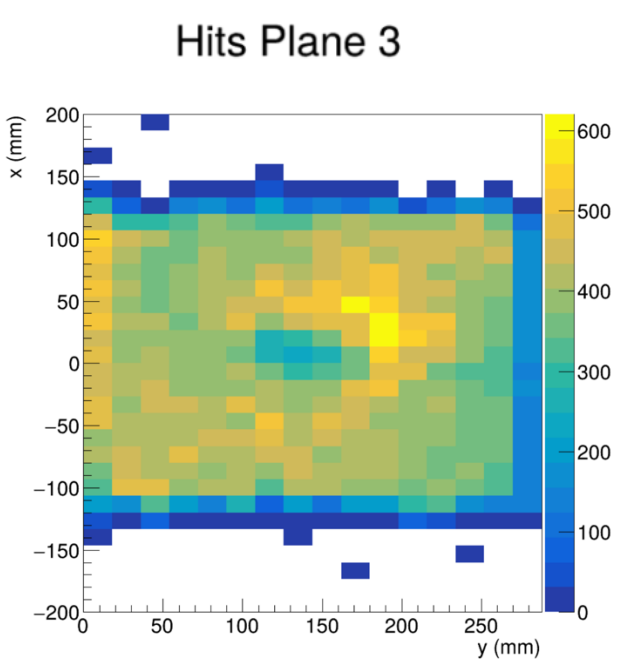
General Calibration

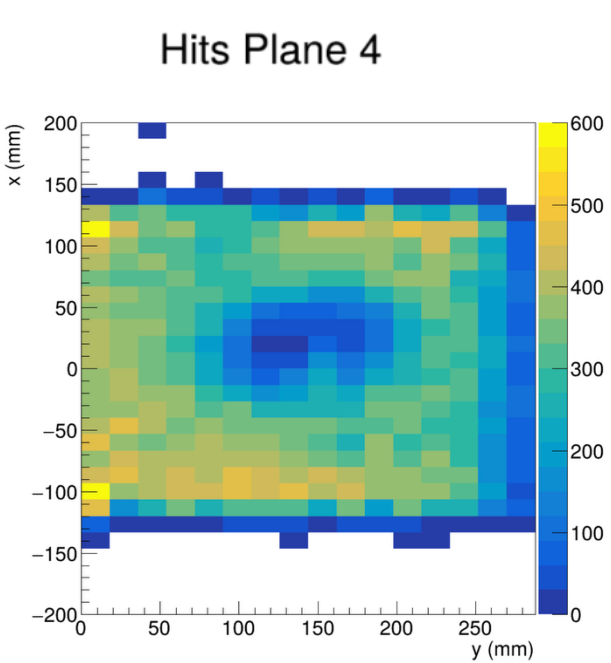
- $Q_{\boldsymbol{calibrated},i,p} = Q_{\boldsymbol{measured},i,p} - Q_{\boldsymbol{offset},i,p}$
- $T_{\boldsymbol{calibrated},i,p} = \frac{TF_{\boldsymbol{measured},i,p} - TB_{\boldsymbol{measured},i,p}}{2} - T_{\boldsymbol{offset},i,p}$

Hit map (calibrated)

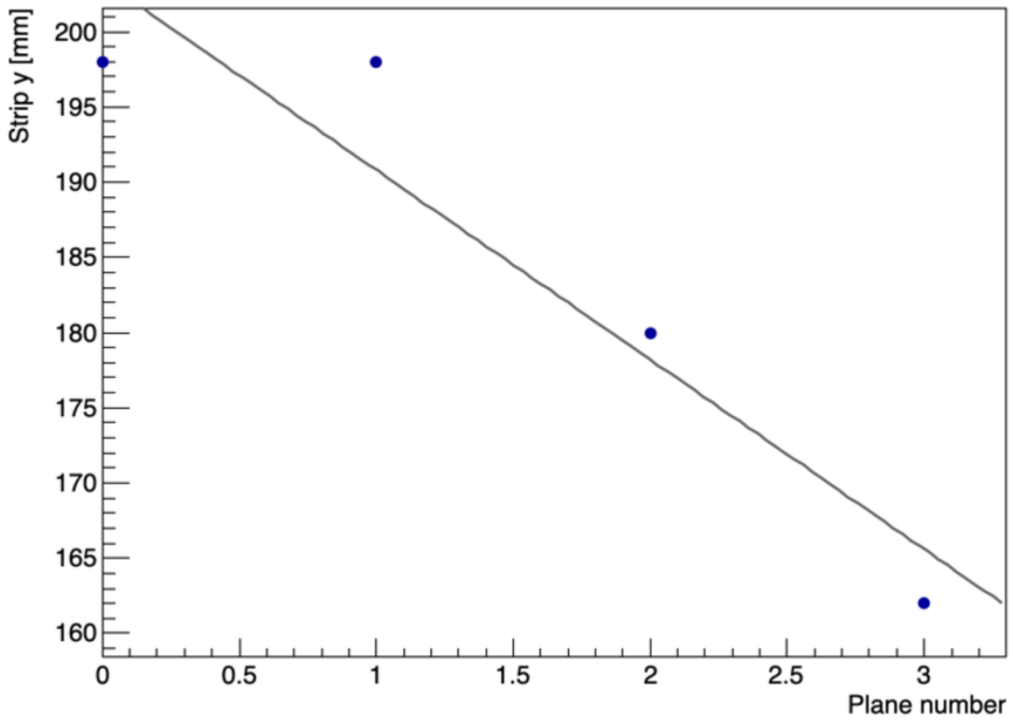


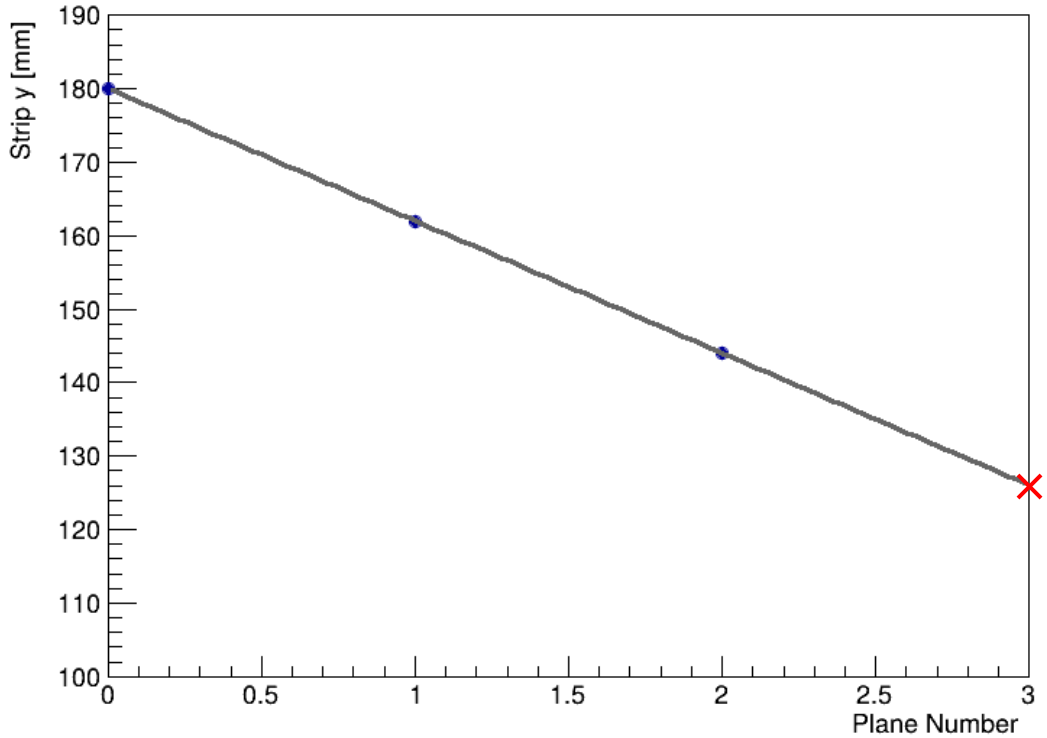




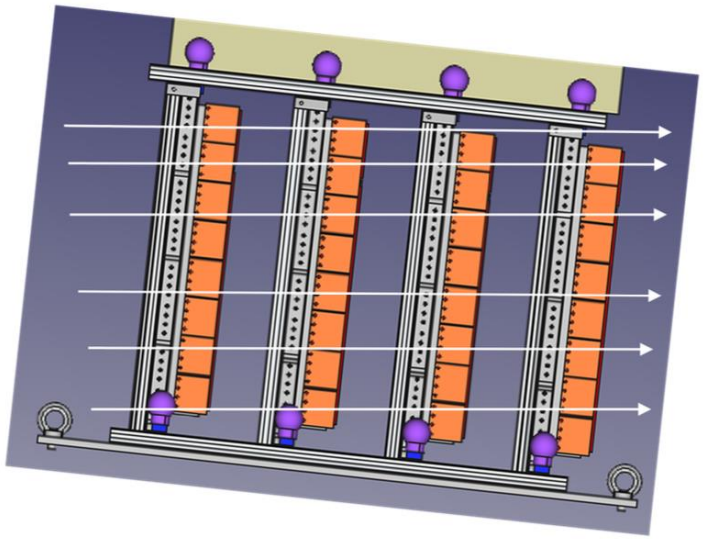


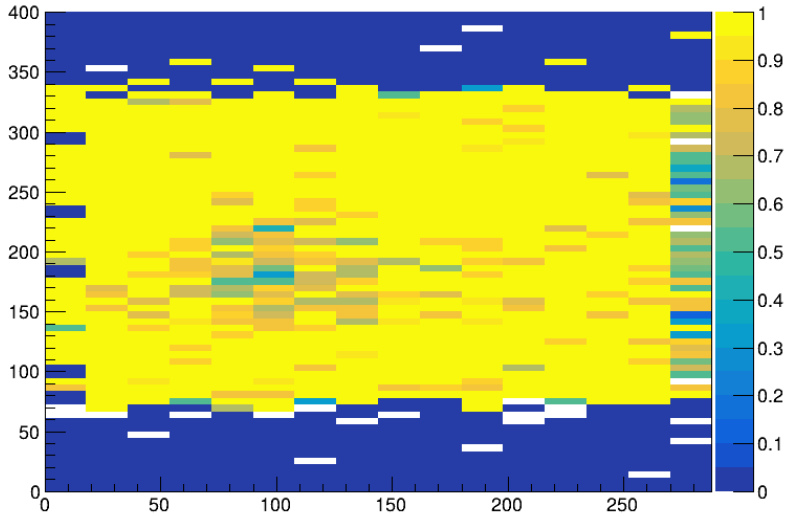
Trajectories



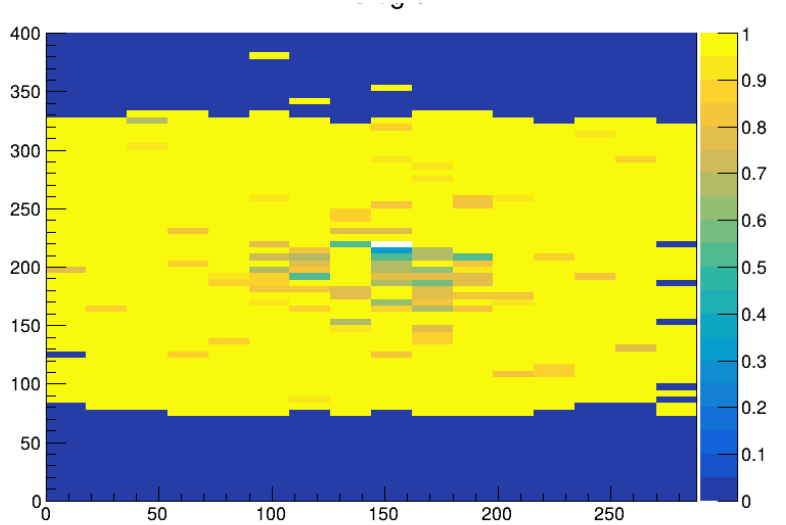


Efficiency

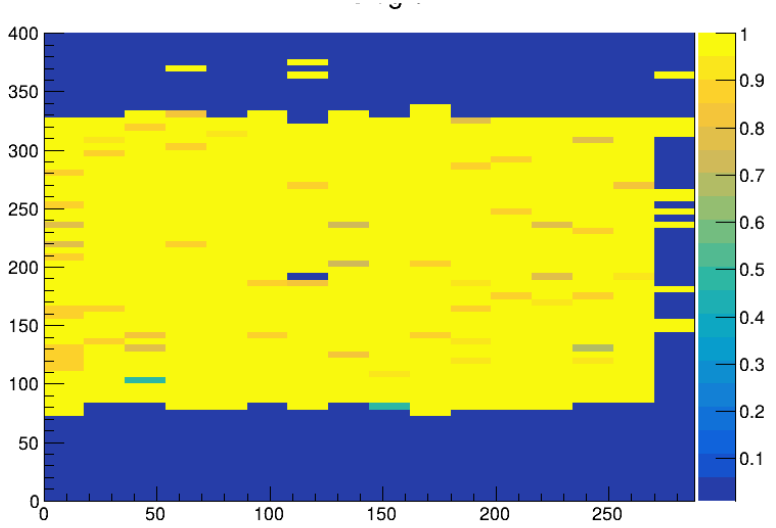




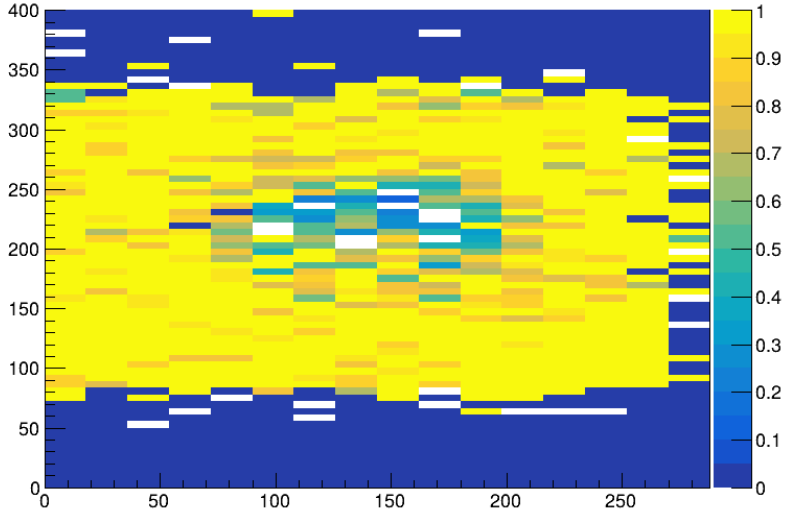
Plane 1



Plane 2



Plane 3

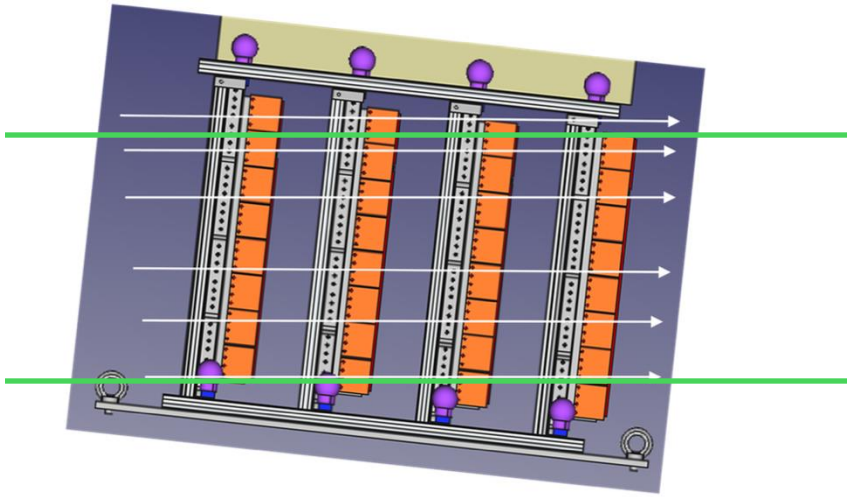


Plane 4

Efficiency

$$\varepsilon_{total} = \sum_{1 \le i < j < k \le 4} \varepsilon_i \times \varepsilon_j \times \varepsilon_k - 3 \prod_{i=1}^{4} \varepsilon_i$$

Plane	1	2	3	4	Total
Total Area	76.8 %	97.3%	98.2%	74.5%	92.0%
Reduced Area	71.3 %	92.2 %	95.5 %	61.7 %	83.3 %



Flux

Flux (fb/cm^2)	Total Area	Reduced Area
Real Data	6.39 x 10^4	

$$Flux = \frac{N}{\varepsilon \times L \times A}$$

- Total Area
  - ε = bbbb (Efficiency)
  - L = cccc (Luminosity)
  - A = 900 cm^2 (Area)

Flux

Flux (fb/cm^2)	Total Area	Reduced Area
Real Data	6.39×10^4	1.01×10^5

$$Flux = \frac{N}{\varepsilon \times L \times A}$$

58 % greater

- Reduced Area
  - ε = 83.3% (Efficiency)
  - L = 1.9×10^{-3} fb^{-1} (Luminosity)
  - A = 630 (Area)

Simulation Data Analysis

```
*******************************************************************************
*Tree    :nt        : muon                                                    *
*Entries :   205446 : Total =        34620270 bytes  File  Size =   22272116 *
*        :          : Tree compression factor =   1.55                       *
*******************************************************************************
*Br    0 :run       : run/D                                                   *
*Entries :   205446 : Total  Size=    1648449 bytes  File Size  =      15580 *
*Baskets :       52 : Basket Size=      32000 bytes  Compression= 105.72     *
*.............................................................................*
*Br    1 :event     : event/D                                                 *
*Entries :   205446 : Total  Size=    1648561 bytes  File Size  =     539784 *
*Baskets :       52 : Basket Size=      32000 bytes  Compression=   3.05     *
*.............................................................................*
*Br    2 :id        : id/D                                                    *
*Entries :   205446 : Total  Size=    1648393 bytes  File Size  =      99479 *
*Baskets :       52 : Basket Size=      32000 bytes  Compression=  16.56     *
*.............................................................................*
*Br    3 :generation : generation/D                                           *
*Entries :   205446 : Total  Size=    1648841 bytes  File Size  =     159923 *
*Baskets :       52 : Basket Size=      32000 bytes  Compression=  10.30     *
*.............................................................................*
*Br    4 :E         : E/D                                                     *
*Entries :   205446 : Total  Size=    1648337 bytes  File Size  =    1564223 *
*Baskets :       52 : Basket Size=      32000 bytes  Compression=   1.05     *
*.............................................................................*
*Br    5 :w         : w/D                                                     *
*Entries :   205446 : Total  Size=    1648337 bytes  File Size  =     750251 *
*Baskets :       52 : Basket Size=      32000 bytes  Compression=   2.20     *
*.............................................................................*
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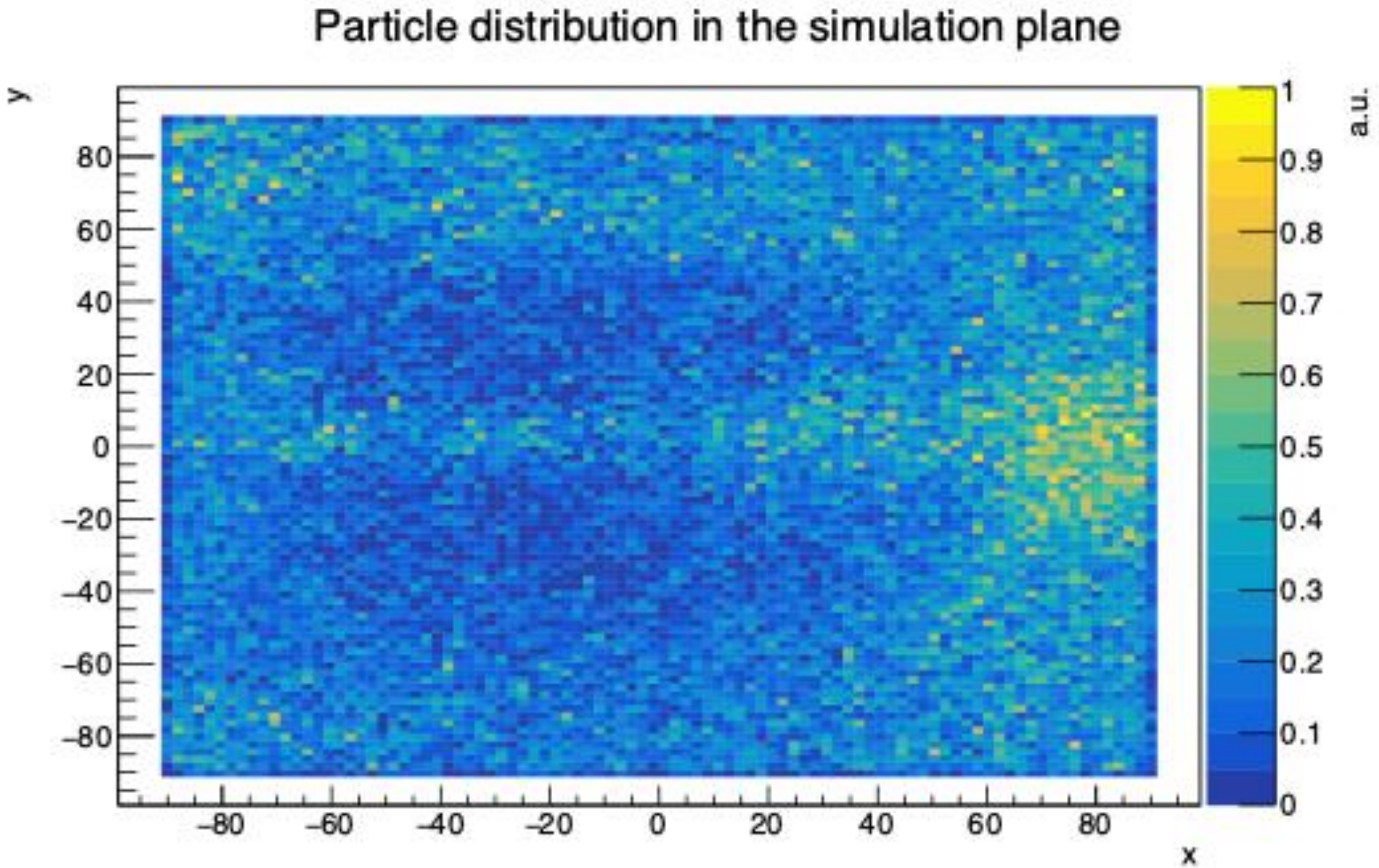
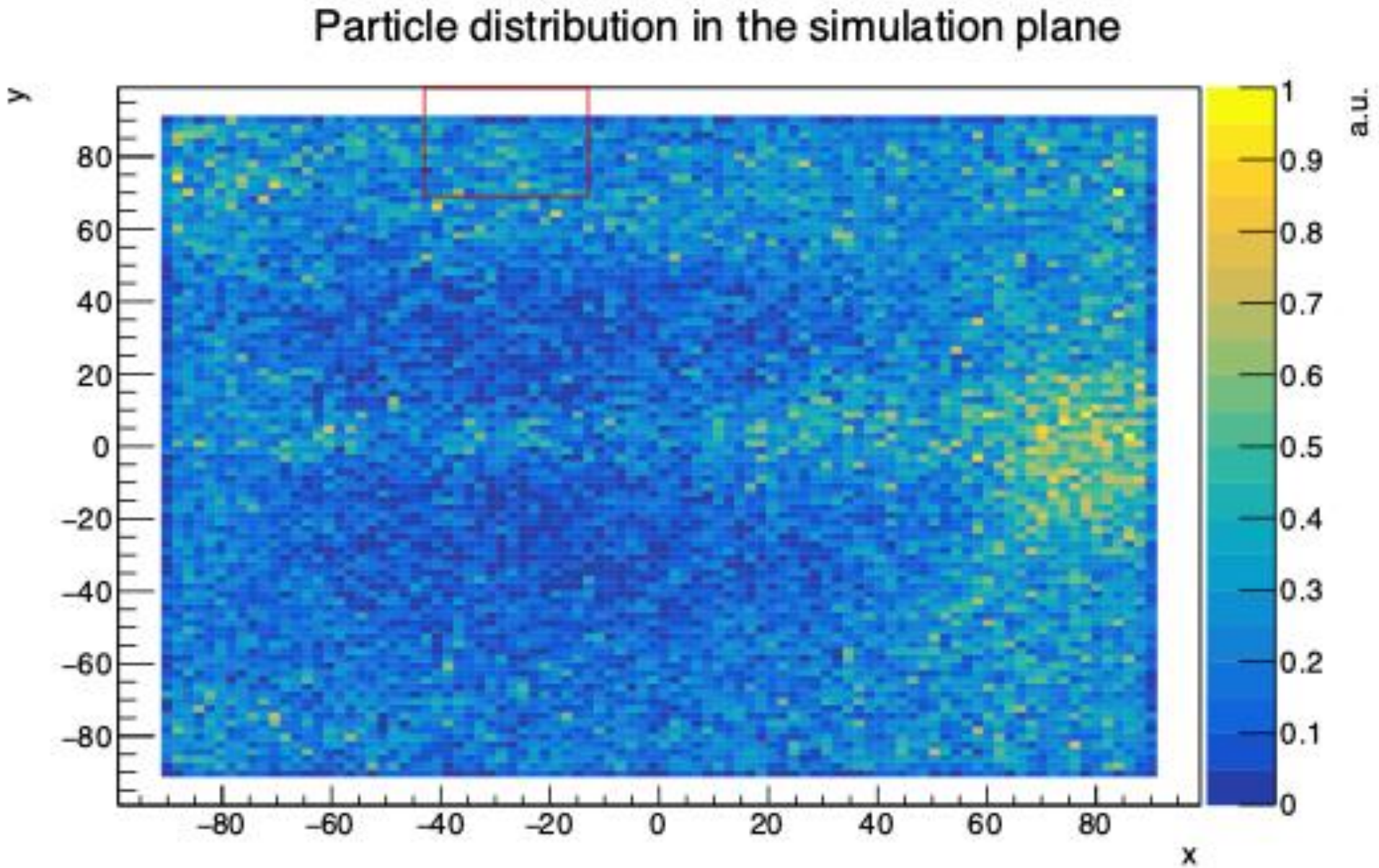
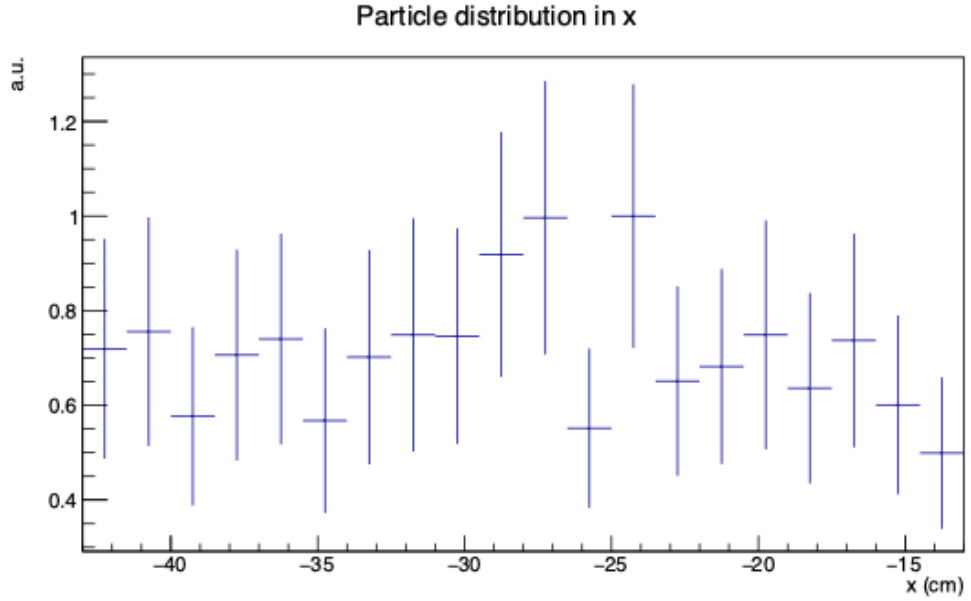
General Distribution

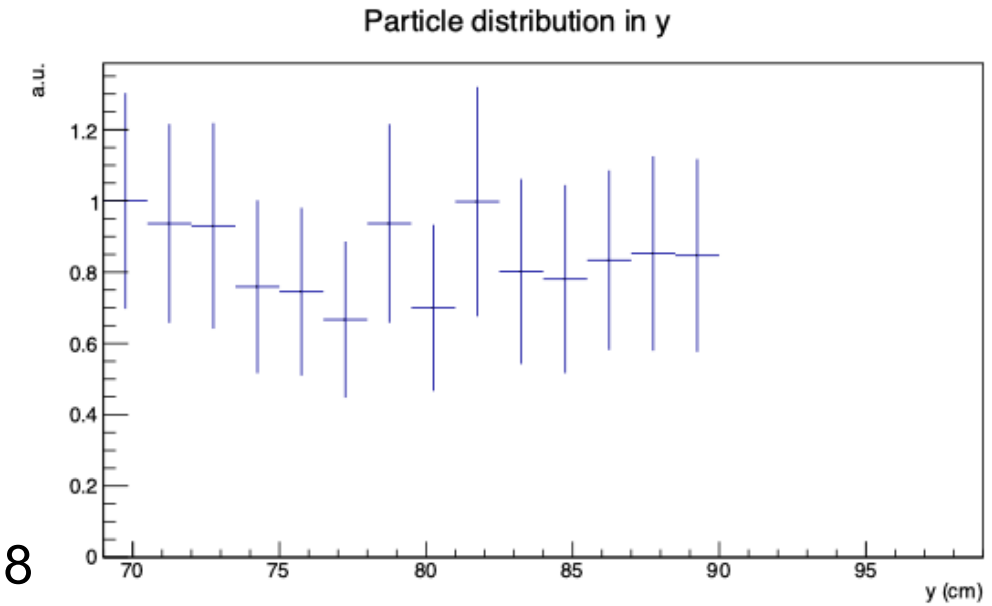


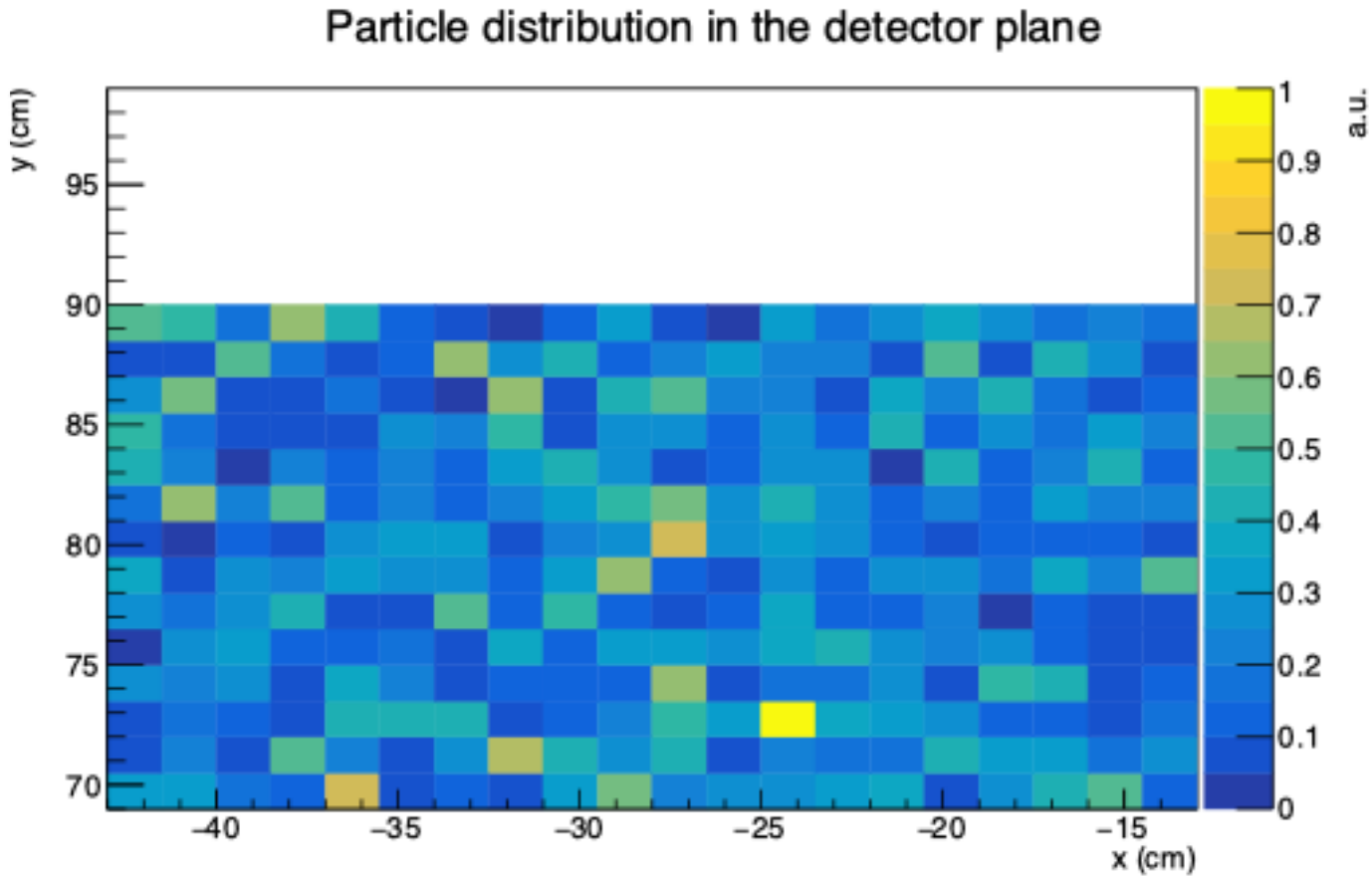
General Distribution



Distribution on the Detector







Luminosity

$$\text{Muon Flux} = \frac{N}{\varepsilon \times L \times A}$$

- $N_{pp} = L \times \sigma_{inel}$
- $\sigma_{inel} = 79.3 \pm 0.6$ mb
- $N_{pp} = 2 \times 10^{7}$

- $L = (2.52 \pm 0.02) \times 10^{-7}$ fb^{-1}

Muon Flux

$$\text{Muon Flux} = \frac{N}{\varepsilon \times L \times A}$$

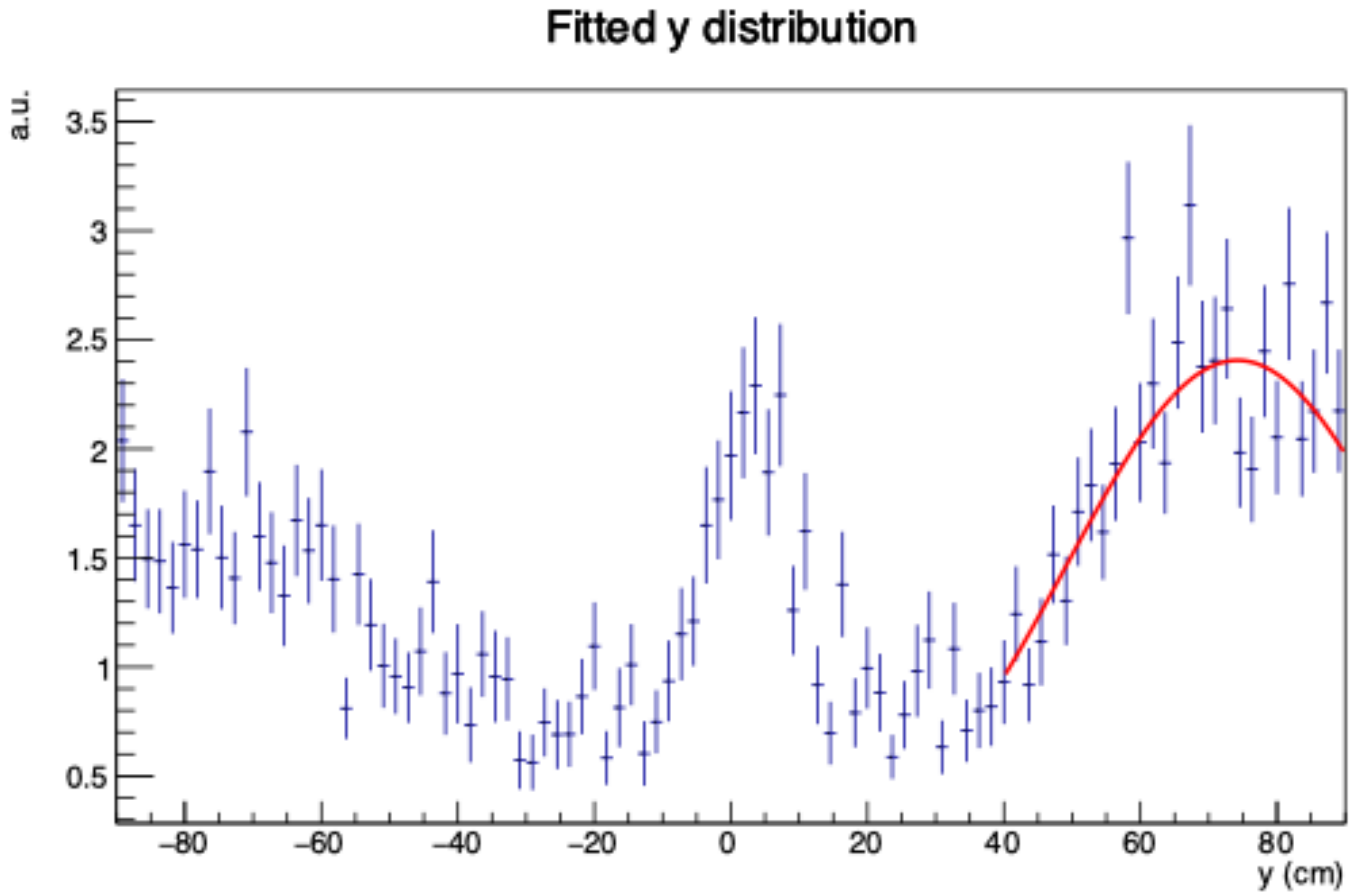
- $\varepsilon = 1$ (no interactions in the detector simulated)
- $N = 26.95 \pm 1.00$
- $L = (2.52 \pm 0.02) \times 10^{-7}\ fb^{-1}$
- $A = 21 \times 30 = 630\ cm^2$

- Muon flux = $(1.70 \pm 0.05) \times 10^{5}\ fb/cm^2$

Extrapolation

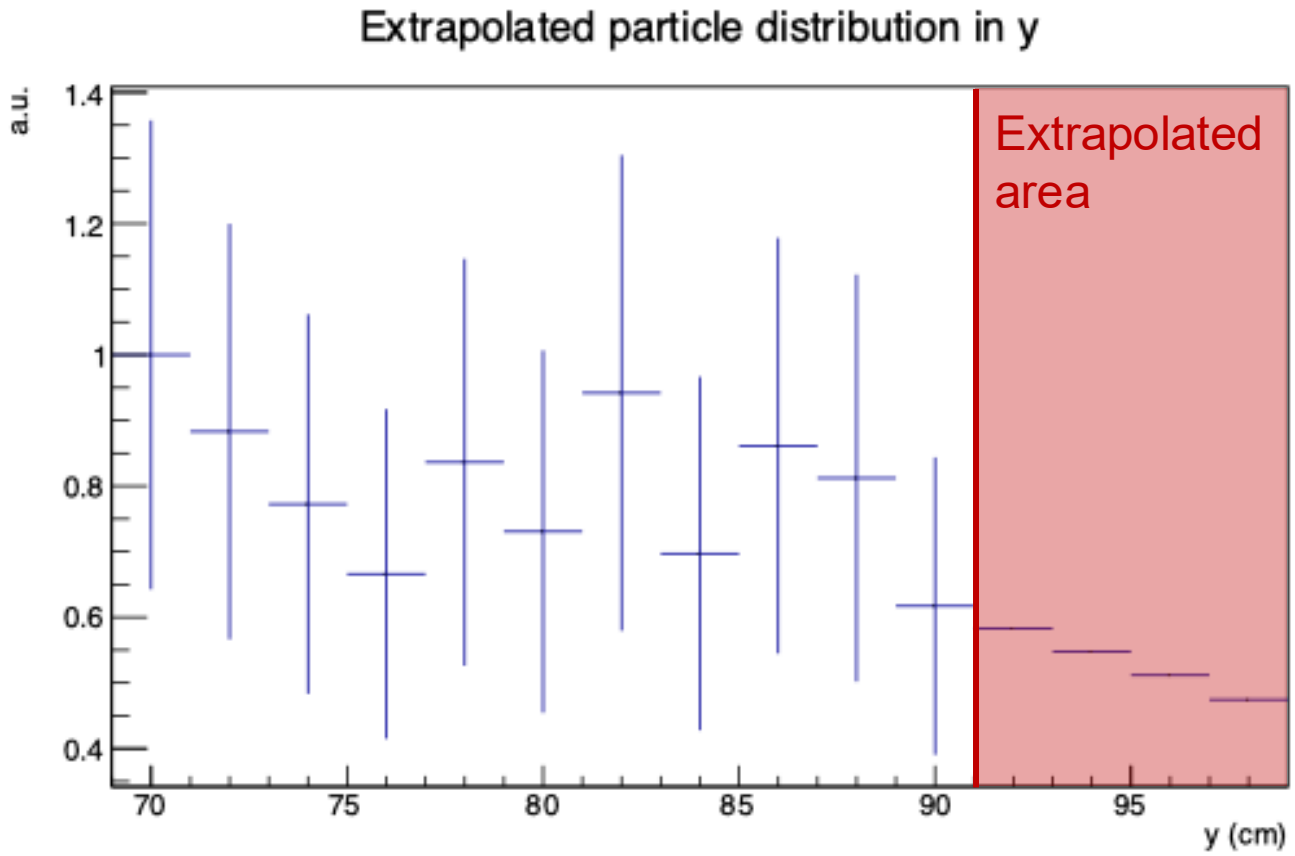
- Fitted structure at the right of the domain in y;

Gaussian: Norm = 2.41 ± 0.08; μ = 74.21 ± 2.07; σ = 25.17 ± 2.36



Extrapolation

- Filled remainder of domain according to fitted function



Extrapolation

- Calculated flux through the whole detector with and without extrapolated distribution;

- Regular flux = (1.70 ± 0.05) x 10^5 fb/cm^2
- Extrapolated flux = (1.51 ± 0.05) x 10^5 fb/cm^2

- Extrapolation decreases flux by 11,2% (0.19 x 10^5 fb/cm^2);

Conclusions

Flux Comparison

Flux (fb/cm^2)	**30x30**	**30x21**
Real Data	6.39 x 10^4	1.01x 10^5
Simulation	(1.51 ± 0.05) x 10^5	(1.70 ± 0.05) x 10^5

- The real data and simulation differ by 136% in the 30x30 area, and by 68% in the 30x21 area

In Summary

- Muon interactions at the sRPC detector were studied;
- A Monte Carlo simulation of the muon production and propagation towards this detector was also studied;
- Equivalent values for the muon flux were produced for both a restricted area and the full detector to compare the simulation and real data;
- Real muon flux was in the same order of magnitude as previous calculations for the SND@LHC
- Real and simulated flux differed by more than 100%