



# Detector efficiency in the BM@N experiment in an argon run with a beam energy of 3.2 AGeV at the Nuclotron

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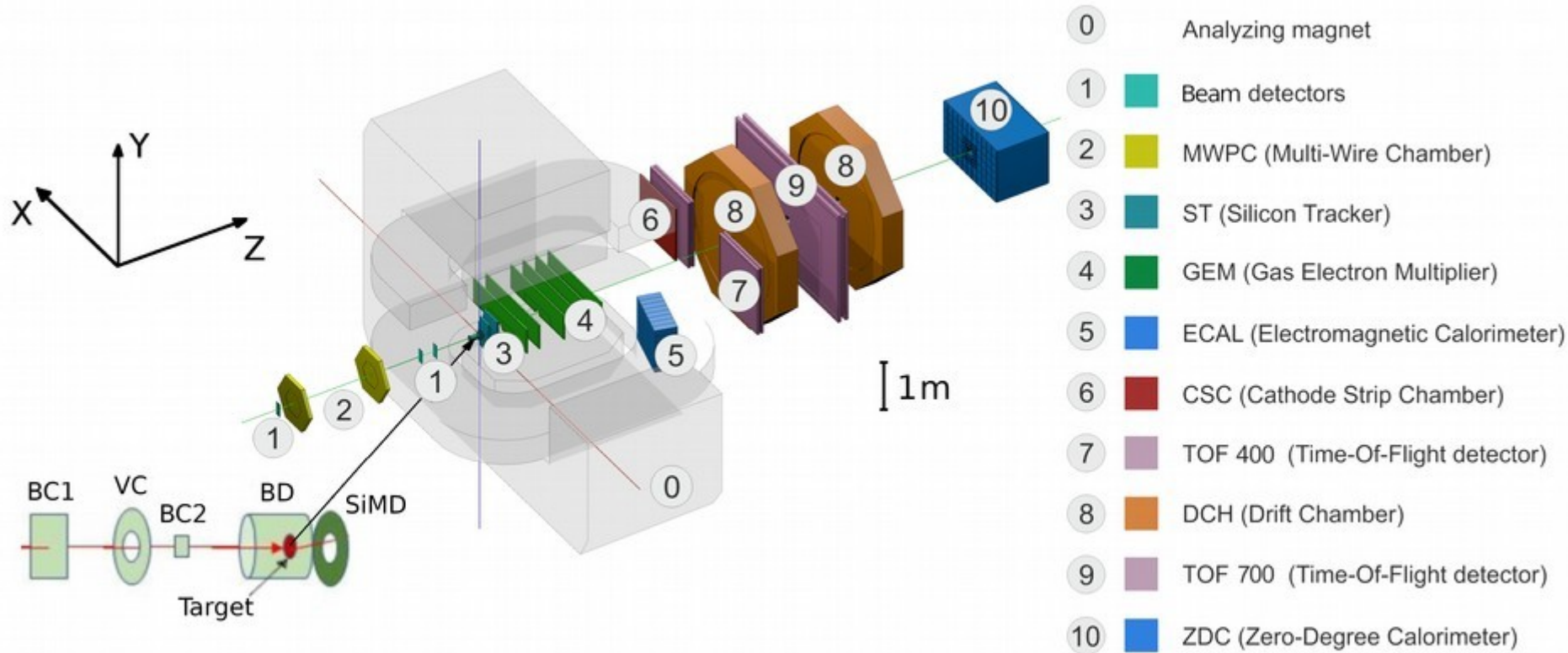
**Joint Institute for Nuclear  
Research**

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TOGETHER

VBLHEP Seminar  
June 2023

1. Run with argon beam (March 2018)
  - ✓ BM@N detector set-up
2. Detector efficiency
  - ✓ ST/GEM efficiency
  - ✓ CSC efficiency
  - ✓ ToF-400 efficiency
  - ✓ DCH efficiency
  - ✓ ToF-700 efficiency
  - ✓ Accounting efficiency for modeling
  - ✓ Comparison efficiency in MC and Data
3. Summary

# BM@N set-up in Ar run



Detectors used in the analysis: Beam detectors (1), Multiplicity Detectors, ST (3), GEM (4), CSC (6), ToF-400 (7), DCH (8), ToF-700 (9).

✓ Pseudorapidity range:  $1.6 \leq \eta \leq 4.4$

✓ Analysing magnet bending power:  $\sim 2.1 \text{ T}\cdot\text{m}$

✓ 1.05 m between poles

## ST

- ✓ Two-coordinate
- ✓ Pitch: 95/103  $\mu\text{m}$ ; angle: 2.5°

## GEM

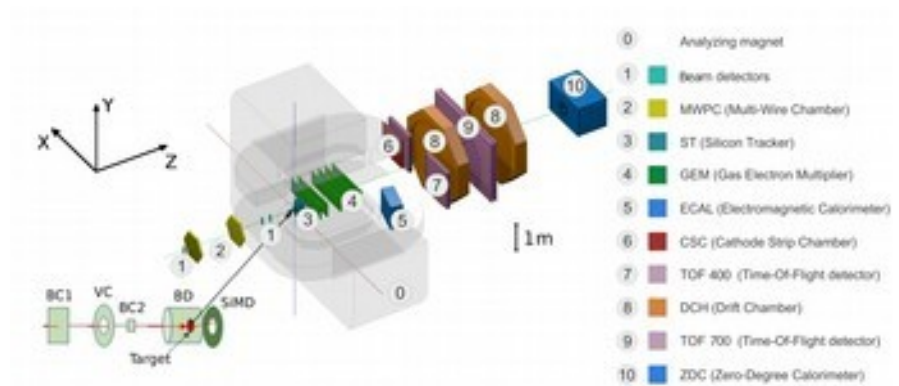
- ✓ Two-coordinate
- ✓ Hot and cold zones
- ✓ Pitch: 800  $\mu\text{m}$ ; angle: 15°

## CSC

- ✓ Two-coordinate
- ✓ Hot and cold zones
- ✓ Pitch: 2.5 mm; angle: 15°

## ToF-400

- ✓ Vertical strips
- ✓ Pitch: 1.25 mm; length: 30 cm



## DCH

- ✓ Pairs of wires at 0°, 45°, 90° and 135°
- ✓ Pitch: 10 mm

## ToF-700

- ✓ Horizontal strips
- ✓ Small chambers with pitch 10 mm and length 16 cm
- ✓ Big chambers with pitch 18 mm and length 56 cm

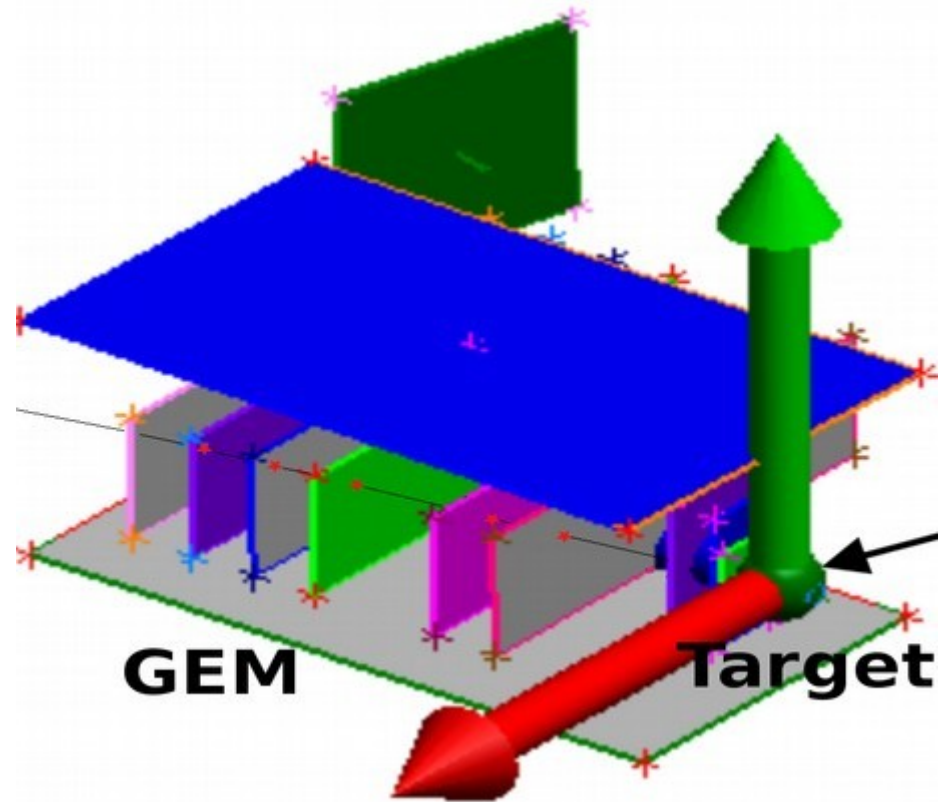
**Cells**  $1 \times 1 \text{ cm}^2$

## Event selection

- ✓ Reconstructed primary vertex (PV)
- ✓ PV in target region
- ✓ More than 2 tracks with  $>3$  hits (9 detectors in total)

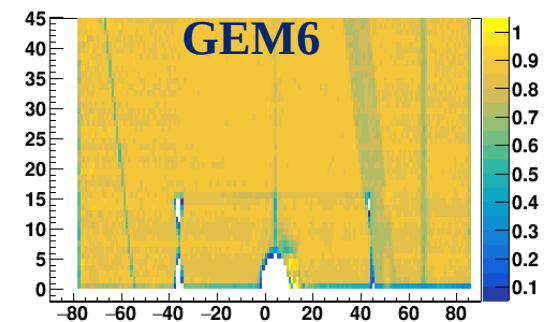
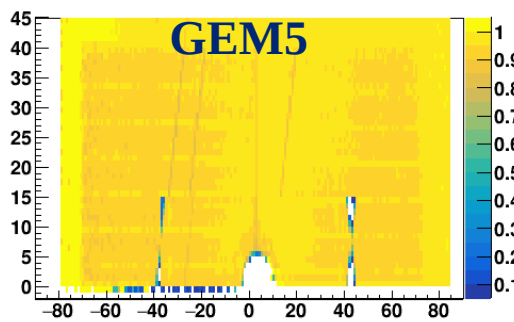
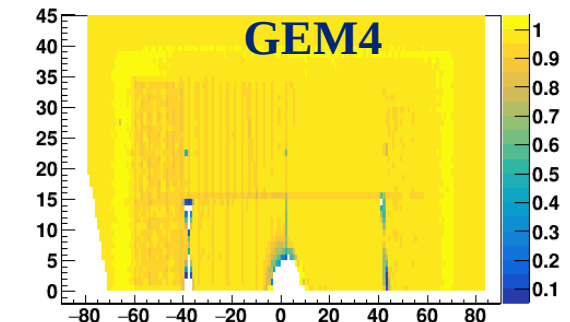
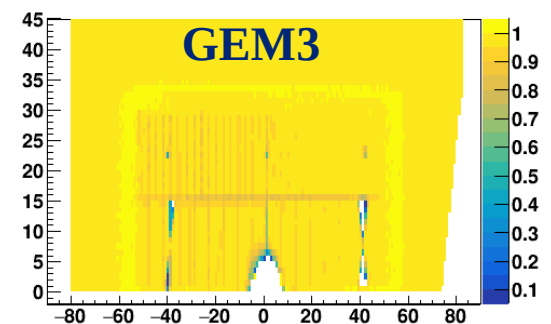
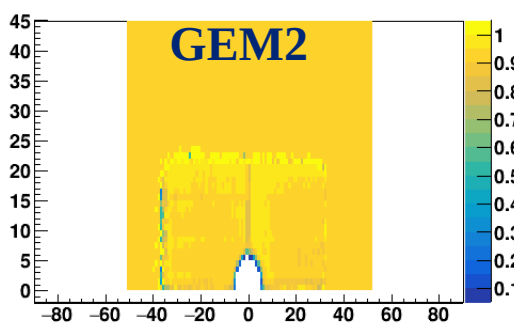
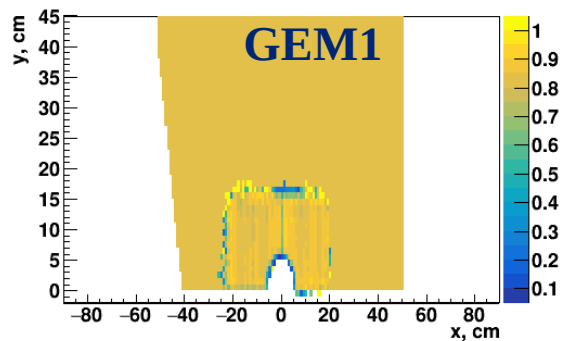
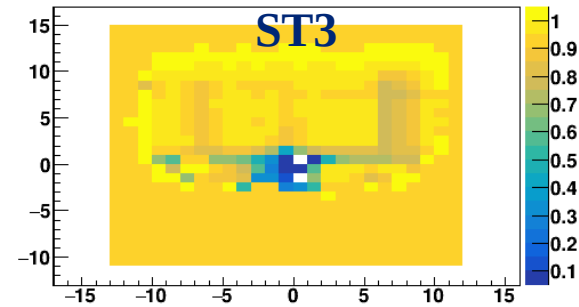
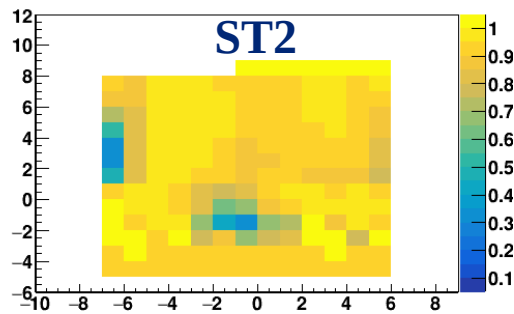
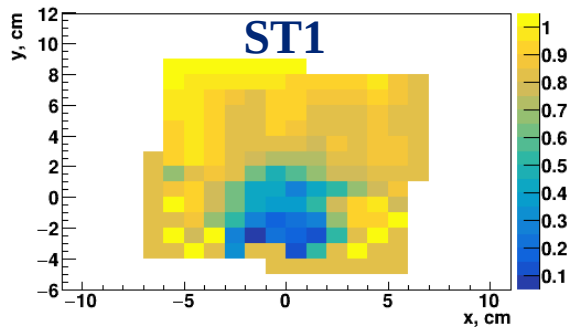
## Track selection

- ✓ Track from PV
- ✓ More than 3 hits (9 detectors in total)
- ✓ For ST (GEM) eff. 2 (4) hits (3 (6) stations in total)
- ✓ Track momentum in the range  $2 < p < 5 \text{ GeV}/c$



- ✓ Two global counters: **denominator** and **numerator**

# ST/GEM efficiency



$$\text{Eff}_{\text{SToutBeam}} = 80\%, \text{Eff}_{\text{GEM1,6}} = 80\%, \text{Eff}_{\text{GEM2-5}} = 90\%$$

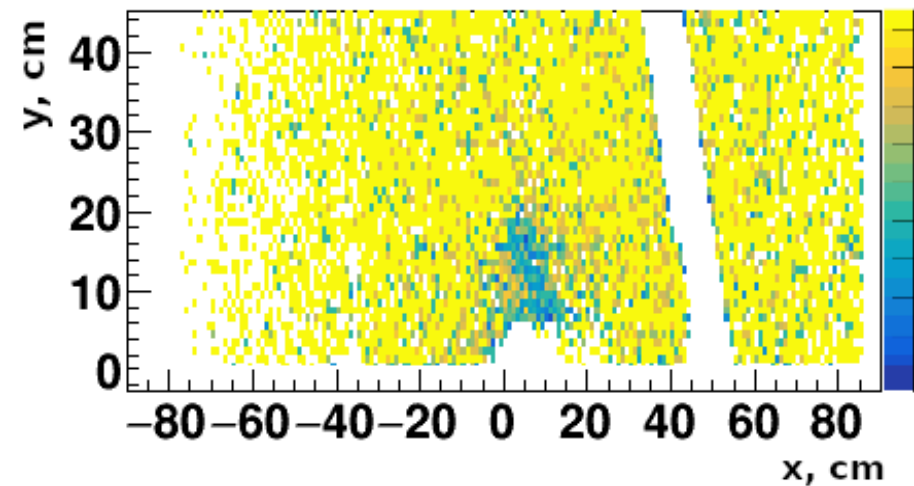
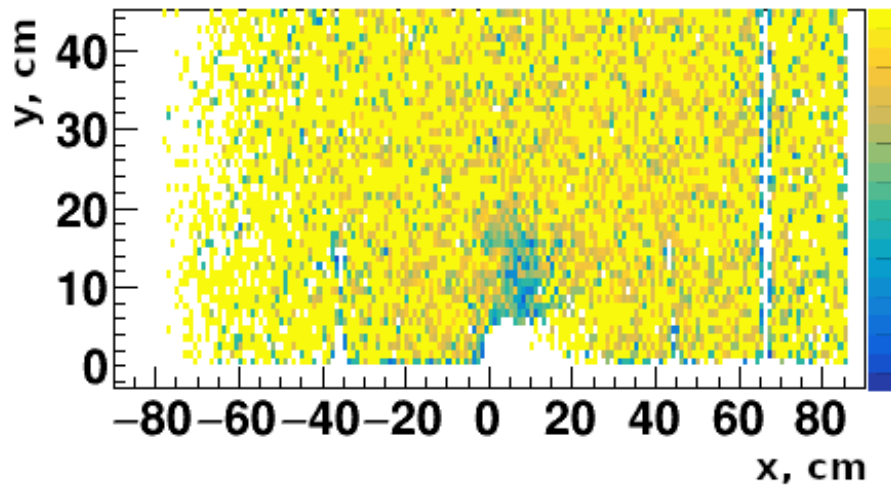


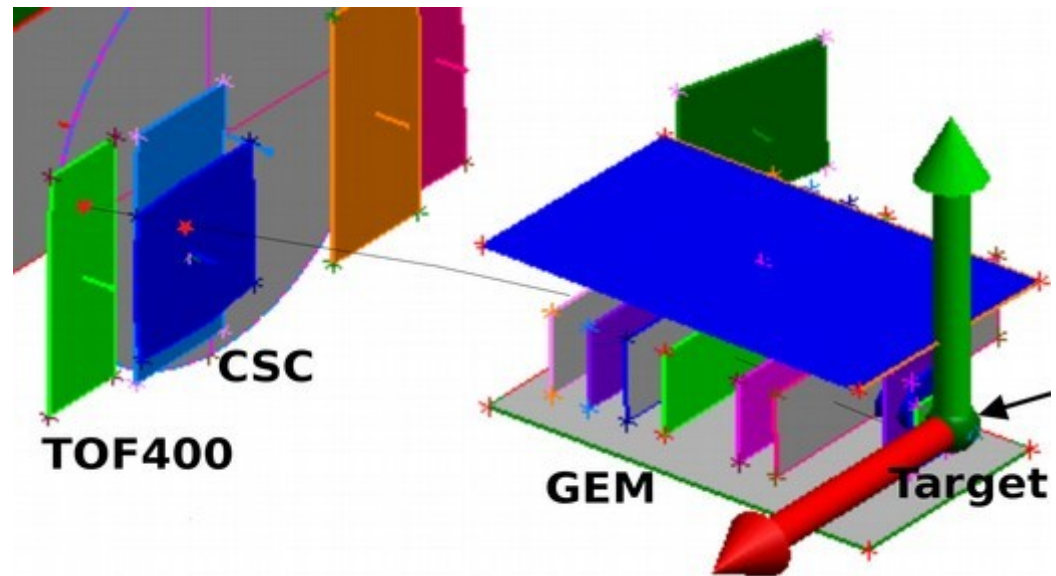
Illustration of strip blocks breaking and repairing in two different runs for GEM6

Short-term high-voltage trips due to the intensity instability of the beam ejection led to a decrease in the efficiency of the GEM detectors.

**Cells** 4.5x4.5 cm<sup>2</sup>

## Track selection

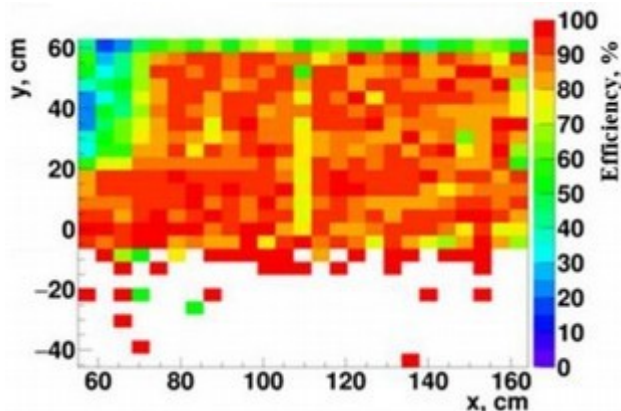
- ✓ Track from PV
- ✓ More than 3 GEM hits (6 detectors in total)
- ✓ More than 4 ST+GEM hits (9 detectors in total)
- ✓ Track momentum  $p > 1$  GeV/c
- ✓ Track has a hit in ToF-400



- ✓ Two global counters: **denominator** and **numerator**
- ✓  $\text{Track}_{\text{ST/GEM}} - \text{Hit}_{\text{CSC}}$  residual  $< 2.5\sigma(p)$

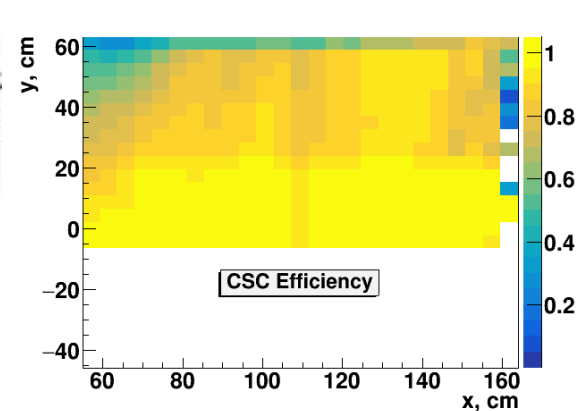


# CSC efficiency

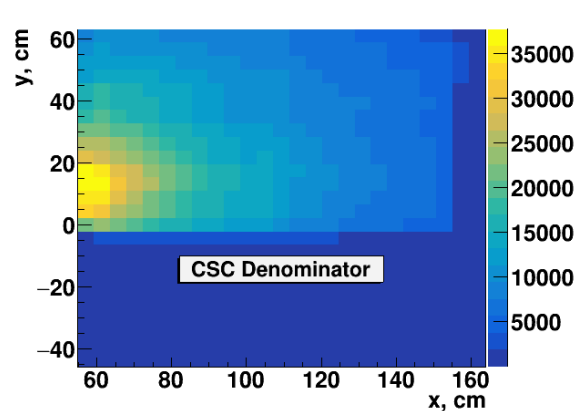


Several runs with broken front-end electronics in the topleft corner

- ✓ Only  $\text{Eff}_{\text{CSC}}$  for  $y > -5$  cm (due to GEM)
- ✓ Mechanical support at  $x = 110$  cm
- ✓ Lower  $\text{Eff}_{\text{CSC}}$  in the left part which close to the beam



All Ar runs with  $\text{Eff}_{\text{ColdCSC}} > 50\%$



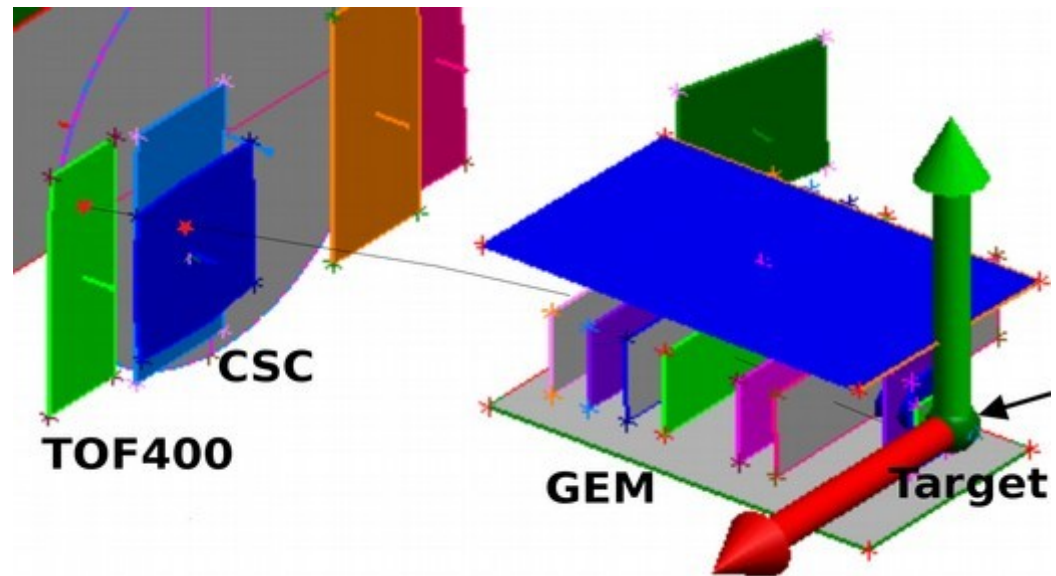
Global denominator for CSC

- ✓  $\text{Eff}_{\text{HotCSC}} > 90\%$
- ✓  $75 < \text{Eff}_{\text{ColdCSC}} < 80\%$

**Cells** 6x5 cm<sup>2</sup>

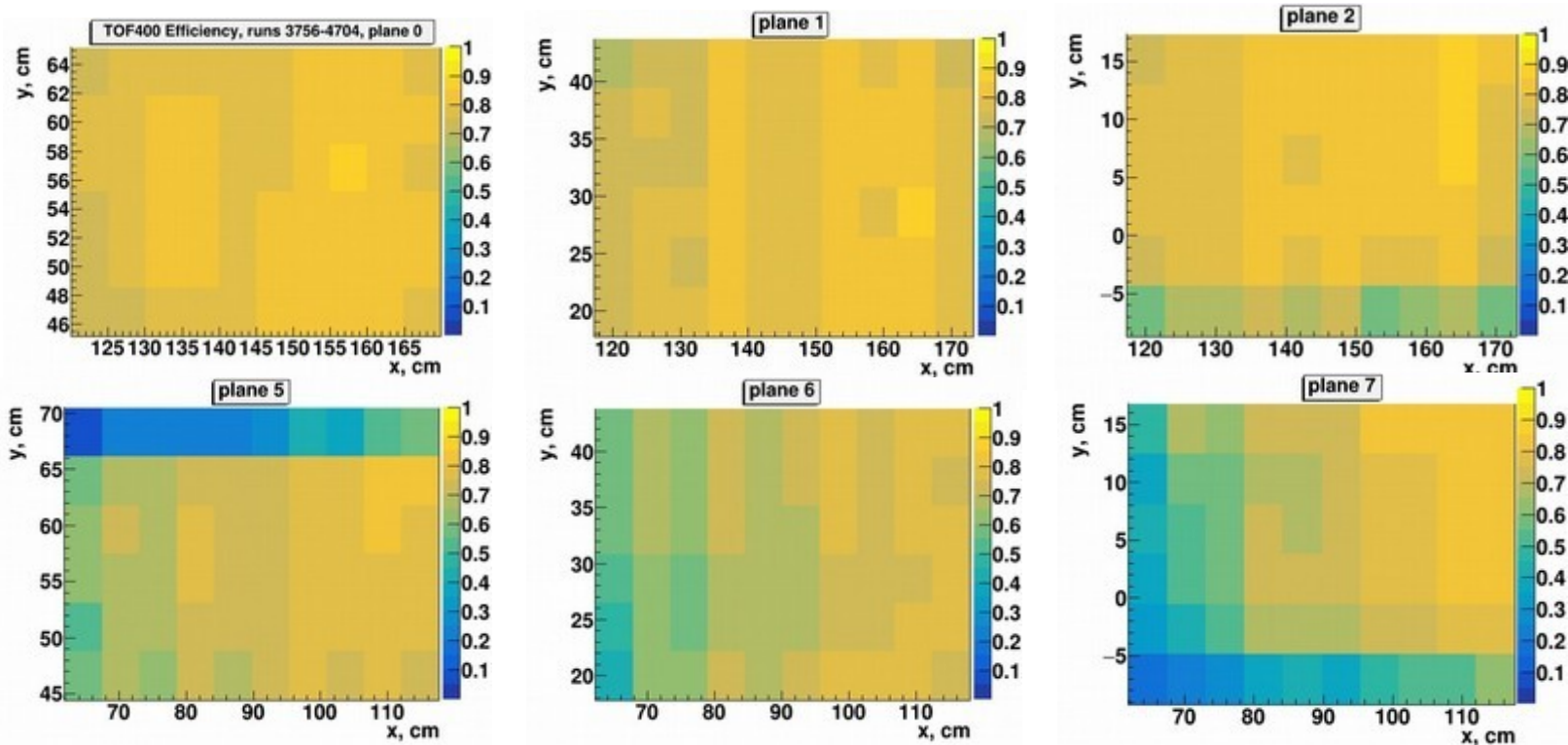
## Track selection

- ✓ Track from PV
- ✓ More than 3 GEM hits (6 detectors in total)
- ✓ More than 4 ST+GEM hits (9 detectors in total)
- ✓ Track momentum  $1 < p < 2.5$  GeV/c
- ✓ Track has a hit in CSC



- ✓ Two global counters: **denominator** and **numerator**
- ✓  $\text{Track}_{\text{ST/GEM}} - \text{Hit}_{\text{ToF-400}}$  residual  $< 2.5\sigma(p)$

# ToF-400 efficiency



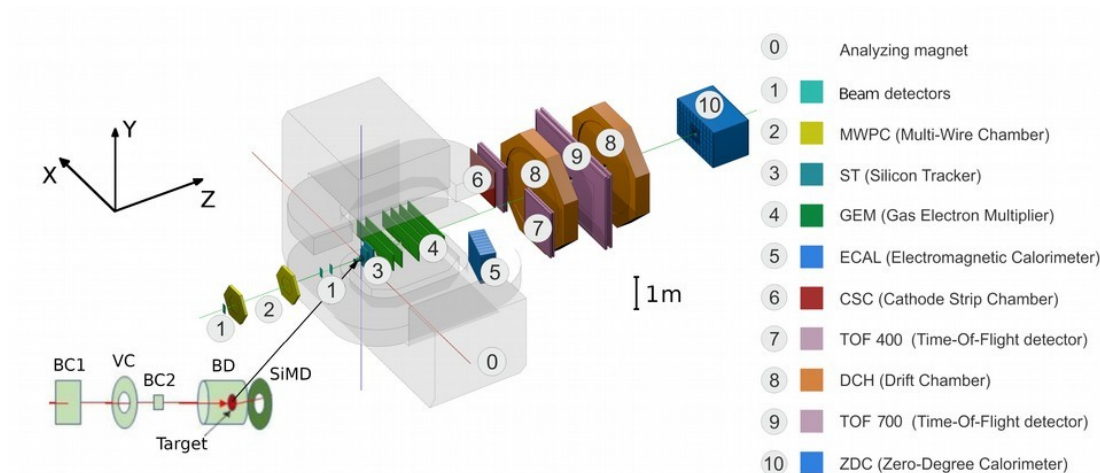
- ✓ Only  $\text{Eff}_{\text{ToF-400}}$  for  $x > 0$  cm,  $y > -10$  cm
- ✓ Lower  $\text{Eff}_{\text{ToF-400}}$  in the mRPC which close to the beam

- ✓  $\text{Eff}_{\text{pl0-2}} \sim 80\%$  (far from the beam)
- ✓  $\text{Eff}_{\text{pl5-7}} \sim 50\%$  (near the beam)

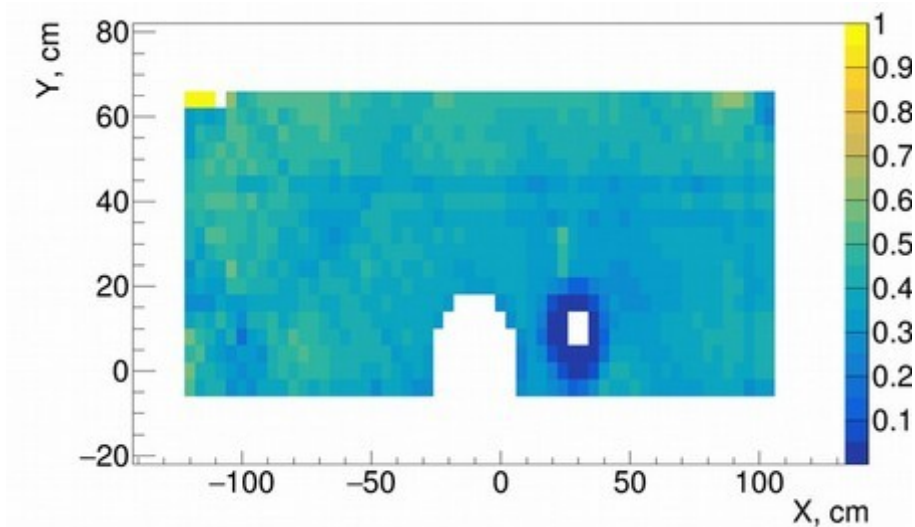
Cells  $4 \times 4 \text{ cm}^2$

## Track selection

- ✓ Same for CSC except the hit in ToF-400
- ✓ Track has a hit in ToF-700



- ✓ Two global counters: **denominator** and **numerator**
- ✓  $\text{Track}_{\text{ST/GEM}} - \text{Hit}_{\text{DCH}} \text{ residual} < 3\sigma(p)$



- ✓ Only  $\text{Eff}_{\text{DCH}}$  for  $y > -5$  cm (due to GEM)
- ✓ Lower  $\text{Eff}_{\text{DCH}}$  around  $x = 30$  cm,  $y = 15$  cm due to track restrictions near the beam

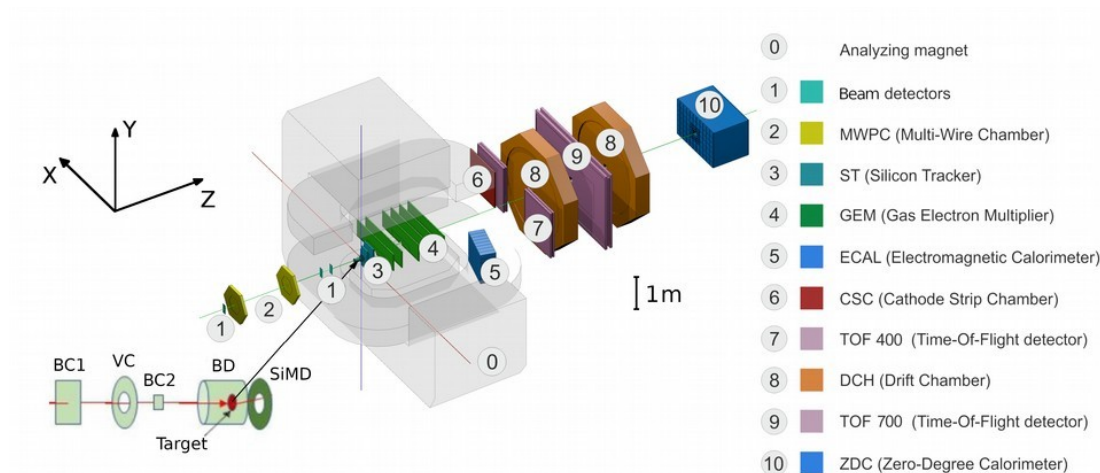
- ✓  $\text{Eff}_{\text{DCH}} \sim 40\%$
- ✓ Low  $\text{Eff}_{\text{DCH}}$  due to reduced voltage and periodical high voltage dropping in Ar beam

# ToF-700 efficiency

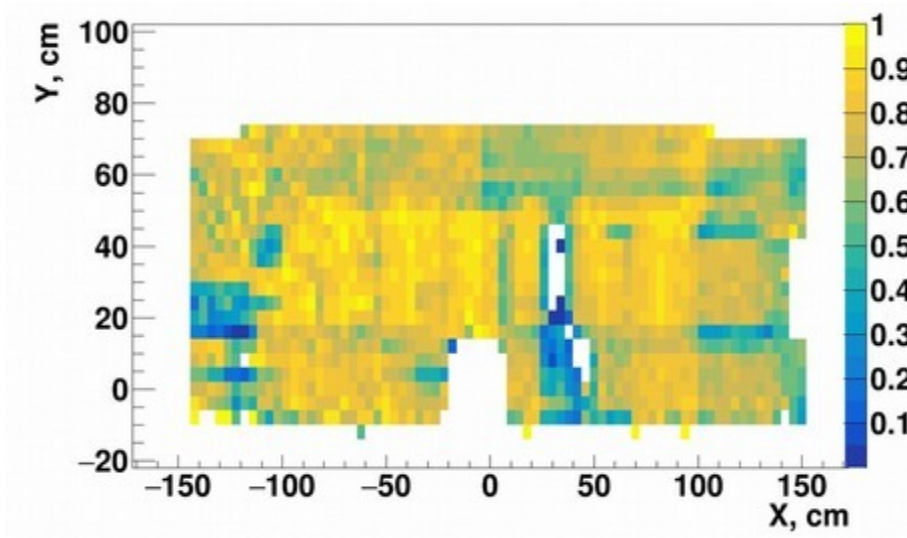
Cells  $4 \times 4 \text{ cm}^2$

## Track selection

- ✓ Same for CSC except the hit in ToF-400
- ✓ Track has a hit in DCH



- ✓ Two global counters: **denominator** and **numerator**
- ✓  $\text{Track}_{\text{ST/GEM}} - \text{Hit}_{\text{ToF-700}} \text{ residual} < 3\sigma(p)$



✓ Only  $\text{Eff}_{\text{ToF-700}}$  for  $y > -5$  cm (due to GEM)

✓  $\text{Eff}_{\text{ToF-700}} \sim 70\%$

✓ Lower  $\text{Eff}_{\text{ToF-700}}$  around  $x=40$  cm,  $y=15$  cm due to track restrictions near the beam

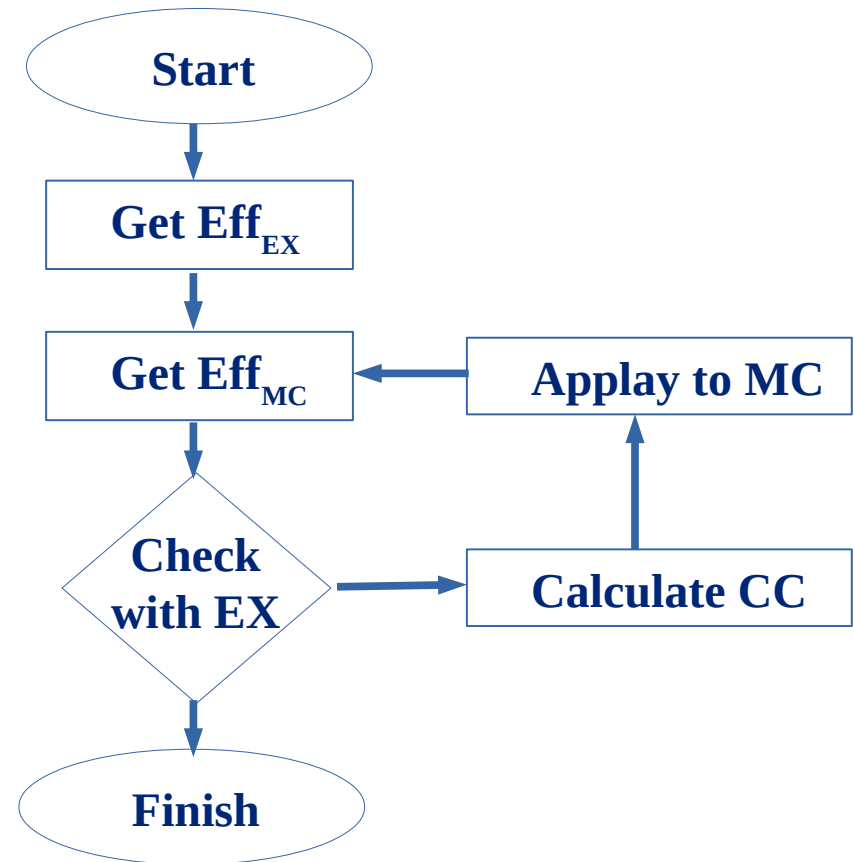
✓ Lower  $\text{Eff}_{\text{ToF-700}}$  around  $x=30$  cm,  $y=30$  cm due to an operation problem in one mRPC

✓ Lower  $\text{Eff}_{\text{ToF-700}}$  in edge strips due to edge effects of the calculation algorithm

# Accounting efficiency for modeling

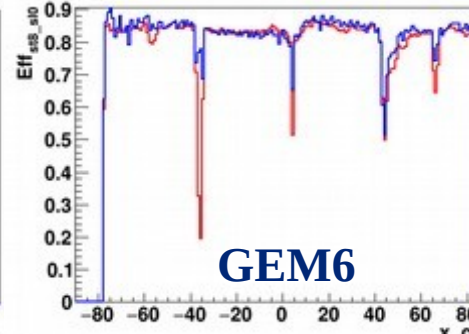
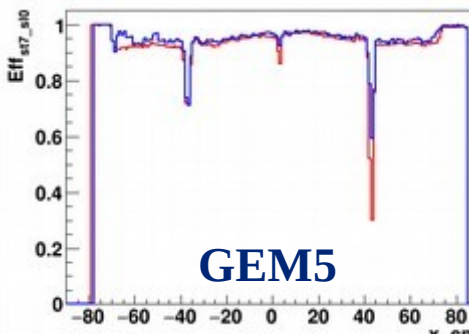
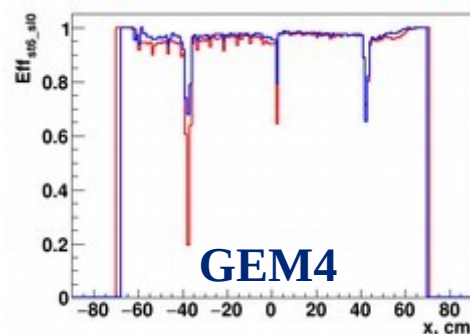
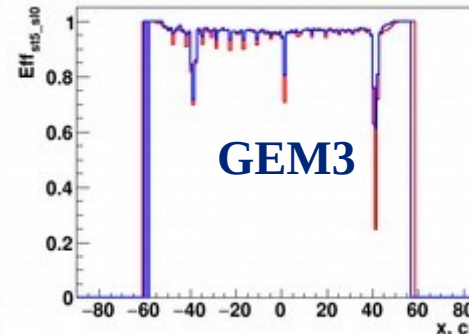
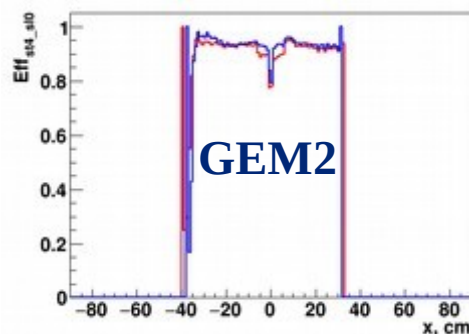
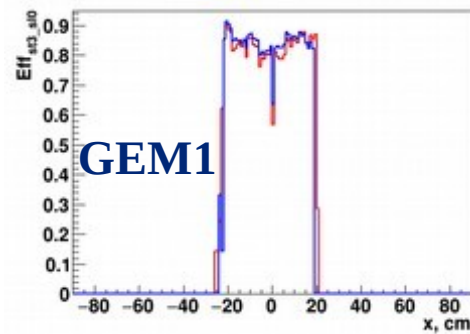
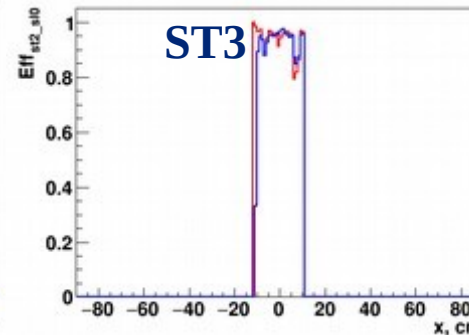
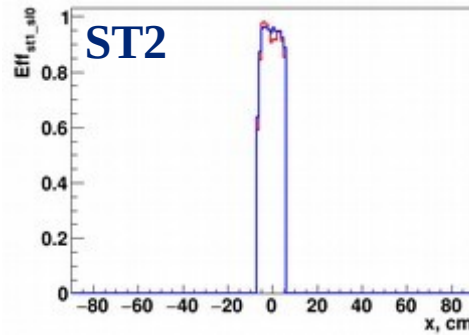
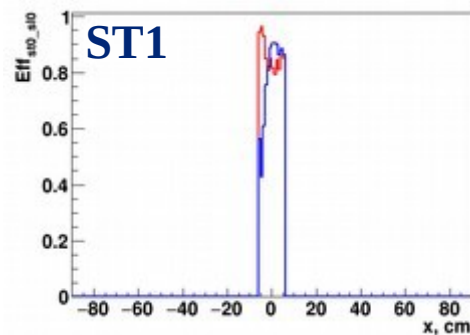


- ✓ The same reconstruction chain in modeling as for experimental data
- ✓ Random signal suppression in modeling
- ✓ Iterative approximation to experimental data using two types of correction coefficients (CC) ( $\text{Eff}_{\text{Data}}/\text{Eff}_{\text{MC}}$  and  $\text{Eff}_{\text{Data}} - \text{Eff}_{\text{MC}}$ )
- ✓ The best choice of CC depends on the detector or detector part
- ✓ Usually 2-3 iterations are enough
- ✓ The method was automatized and integrated to the analysis software system



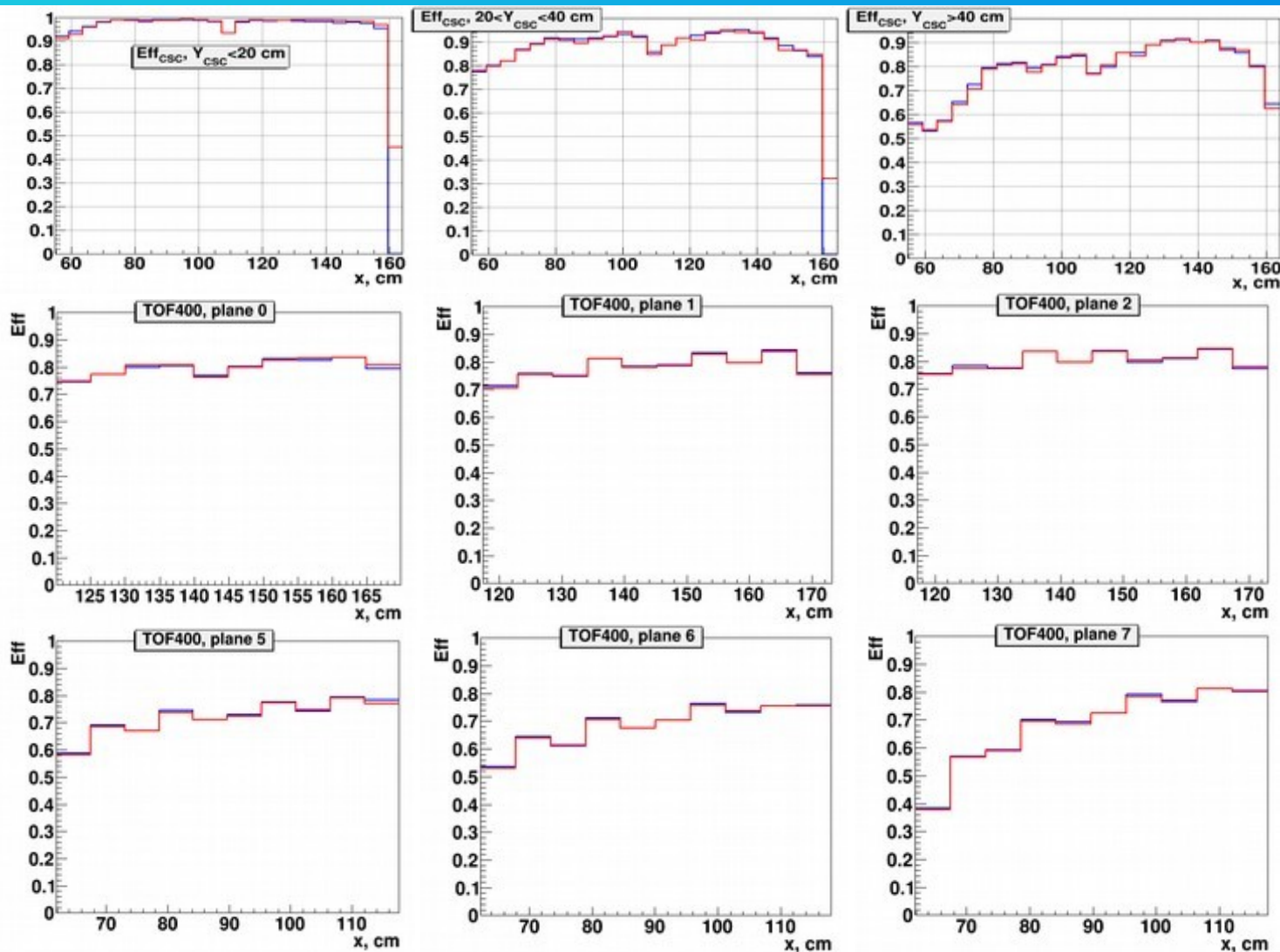


# Comparison efficiency in MC and Data



Systematic uncertainty  $\Delta \text{Eff}_{\text{ST/GEM}} = 3\%$

# Comparison efficiency in MC and Data

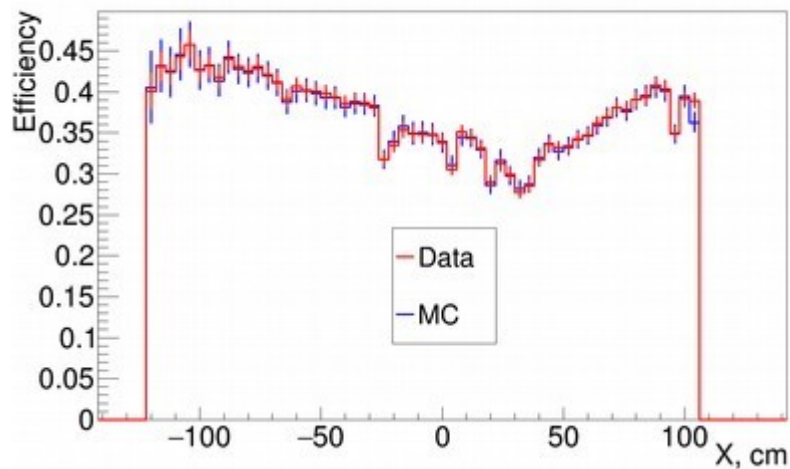


Systematic uncertainty  $\Delta\text{Eff}_{\text{CSC}} = \Delta\text{Eff}_{\text{TOF-400}} = 5\%$

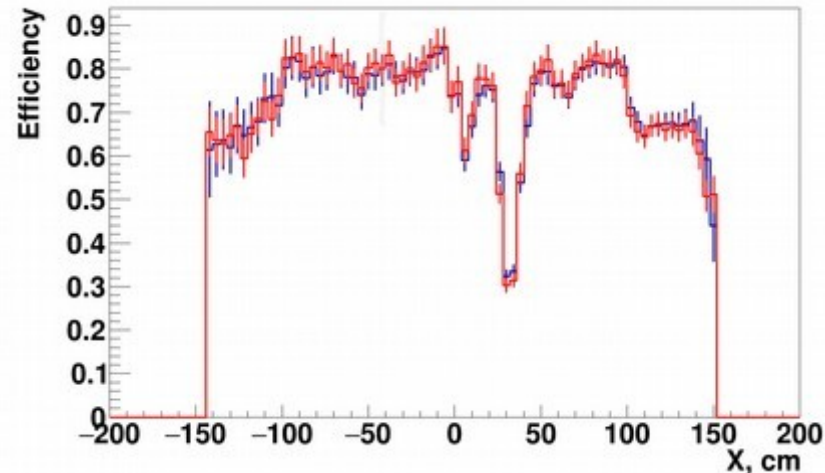
# Comparison efficiency in MC and Data



## DCH



## ToF-700



Systematic uncertainty  $\Delta\text{Eff}_{\text{DCH}} = \Delta\text{Eff}_{\text{ToF-700}} = 5\%$

- ✓ The method of detector efficiency (DE) calculation was developed
- ✓ DE estimated for experimental data
- ✓ The method of DE implementation into MC was worked out
- ✓ Methods for calculating and implementing DE were automated
- ✓ DE implemented into MC
- ✓ DE implemented into MC is compared with experimental DE, good agreement reached
- ✓ Systematic uncertainty was estimated:  $\Delta\text{Eff}_{\text{ST/GEM}} = 3\%$ ,  $\Delta\text{Eff}_{\text{CSC}} = \Delta\text{Eff}_{\text{ToF-400}} = \Delta\text{Eff}_{\text{DCH}} = \Delta\text{Eff}_{\text{ToF-700}} = 5\%$

Thank you for attention!

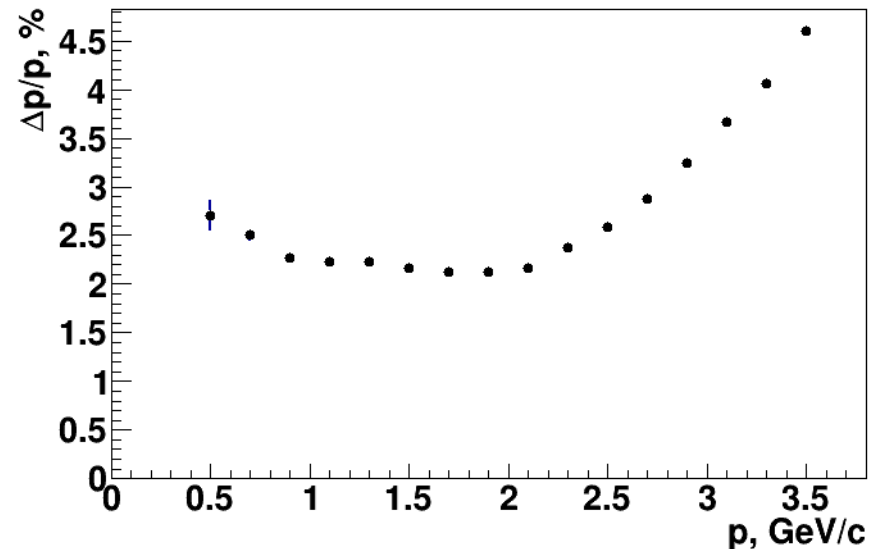
# Backup



# Technical characteristics of the Ar run

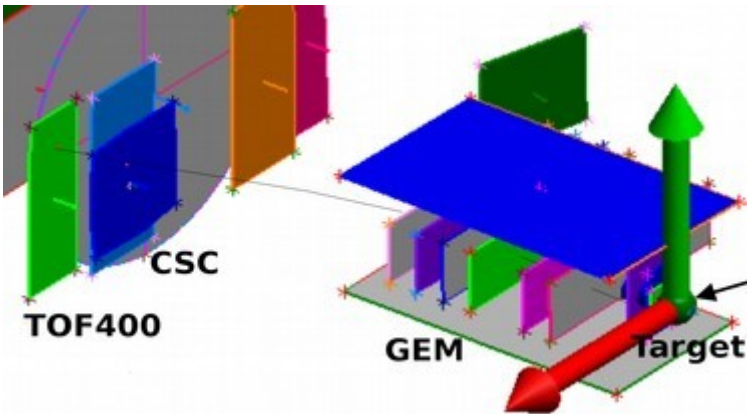


- ✓ Beam intensity: few  $10^5$  ions per spill
  - ✓ Spill duration: 2–2.5 s
  - ✓ Nuclear length of solid targets:  $\sim 3\%$
  - ✓ collision events:  $\sim 83\text{M}$
- 
- ✓ Pseudorapidity range:  $1.6 \leq \eta \leq 4.4$
- Analysing magnet bending power:  
 $\sim 2.1\text{T}\cdot\text{m}$
- ✓ Resolution of the distance from a track to PV in the X-Y plane: 2.4 mm
  - ✓ Time resolutions of the ToF-400 and ToF-700 systems: 84 ps and 115 ps



Relative momentum resolution as a function of the momentum

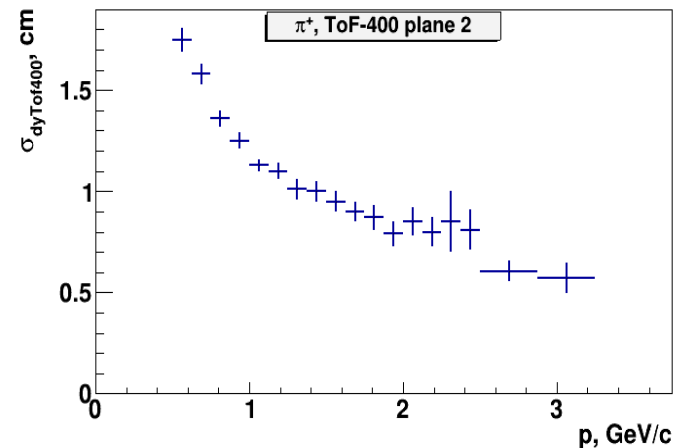
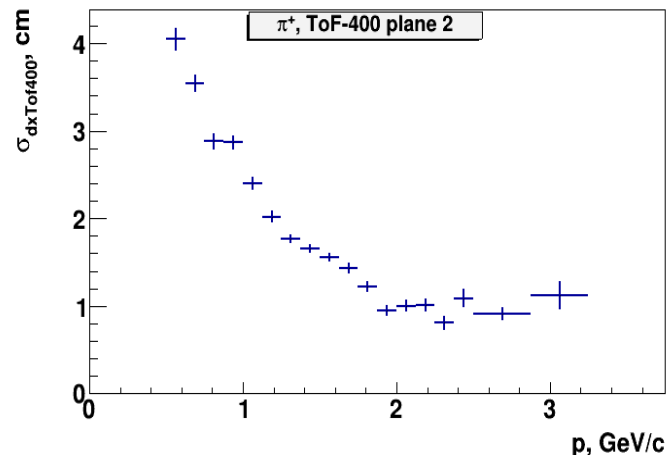
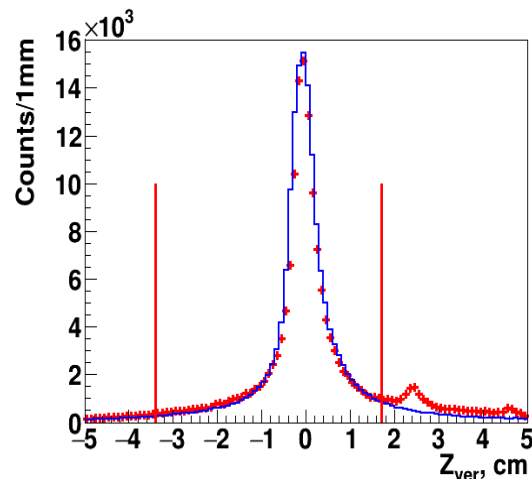
# $\pi^+$ and $K^+$ selection criteria



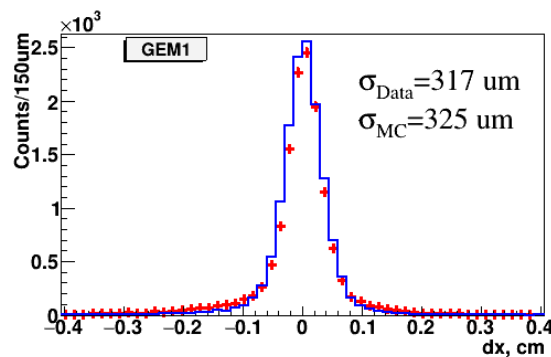
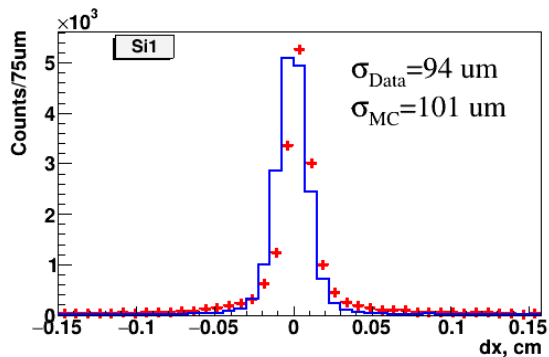
## Abbreviation:

- ✓ **PV** – primary vertex

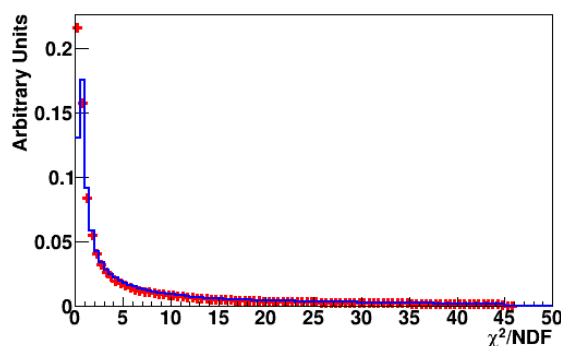
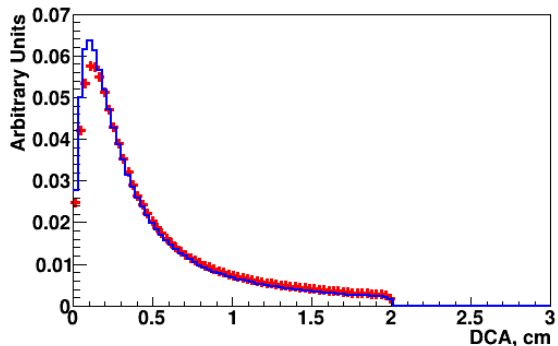
- ✓ Number of hits in 6 GEM per track  $> 3$
- ✓ Number of tracks in the PV  $> 1$
- ✓ Tracks from PV:  $-3.4 < Z_{PV} - Z_0 < 1.7$  cm
- ✓ Momentum range of tracks for ToF-400 (ToF-700):  $p > 0.5$  (0.7) GeV/c
- ✓ Distance from a track to PV in the X-Y plane:  $dca < 1$  cm
- ✓  $\chi^2/NDF$  for tracks from the PV  $< 3.5^2$
- ✓ Distance of extrapolated tracks to CSC (*DCH*) and ToF-400 (ToF-700):  $|\text{resid}_{X,Y}| < 2.5 \sigma$  of hit-track residual distribution



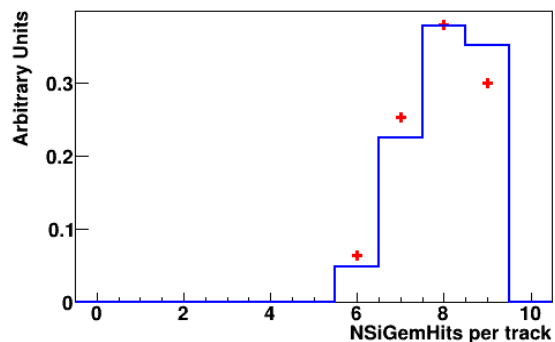
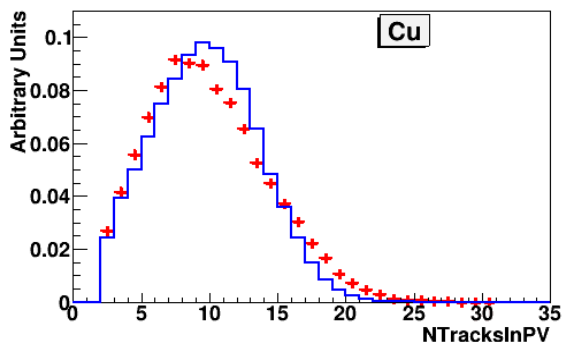
# Comparison of experimental data and MC



Residual distributions of hits in the X projection (magnet deflection plane) with respect to reconstructed tracks: (left) - in the first forward silicon plane, (right) - in the first GEM plane. Experimental data are shown as red crosses, and simulated data are shown as blue histograms.

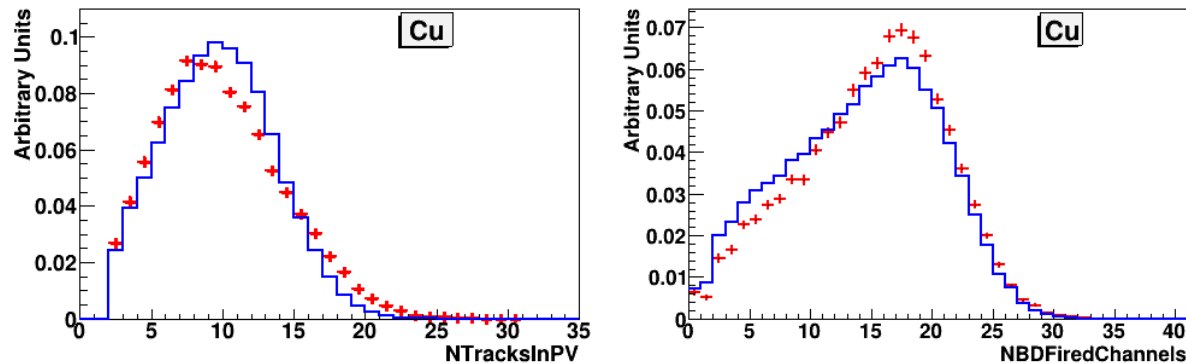


Comparison of the experimental distributions (red crosses) and reconstructed Monte Carlo GEANT distributions of events generated with the DCM-SMM model (blue lines): DCA;  $\chi^2/\text{NDF}$  of reconstructed tracks; number of tracks reconstructed in the primary vertex; number of hits per track reconstructed in 3 forward silicon and 6 GEM detectors.

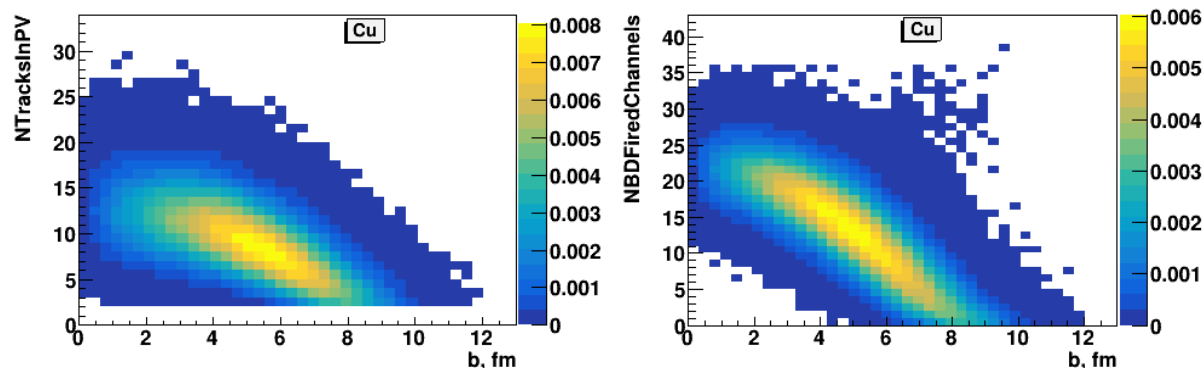




# Comparison of experimental data and MC



Comparison of the experimental distributions (red crosses) and reconstructed Monte Carlo GEANT distributions of events generated with the DCM-SMM model (blue lines): number of tracks reconstructed in the primary vertex; number of fired BD channels.



Correlation obtained from the DCM-SMM model of the number of tracks in the primary vertex (left) and the number of fired channels in the BD with impact parameter.