Charged particle identification using the Time–of–Flight method in the BM@N experiment

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FOR NUCLEAR RESEARCH

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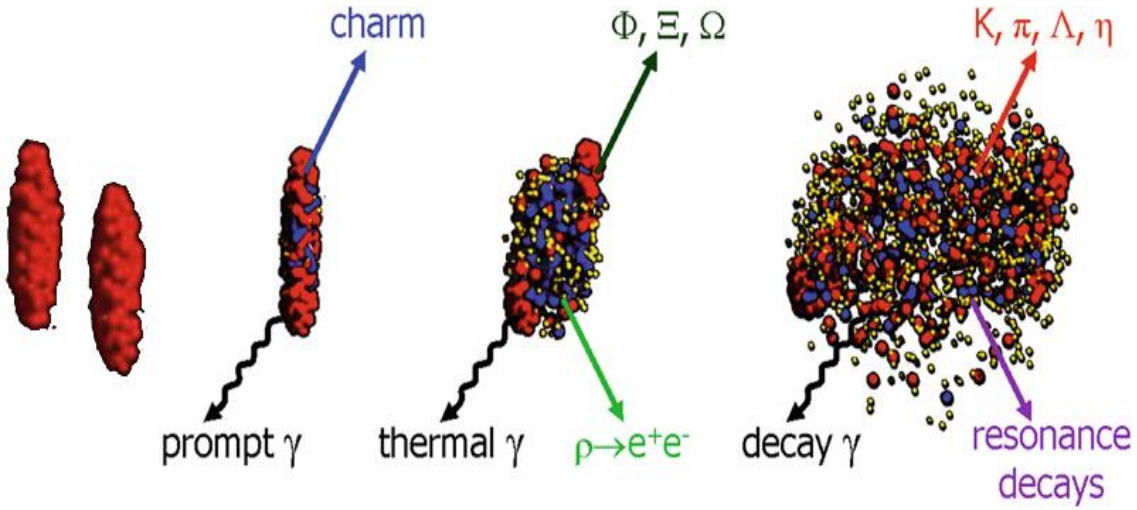
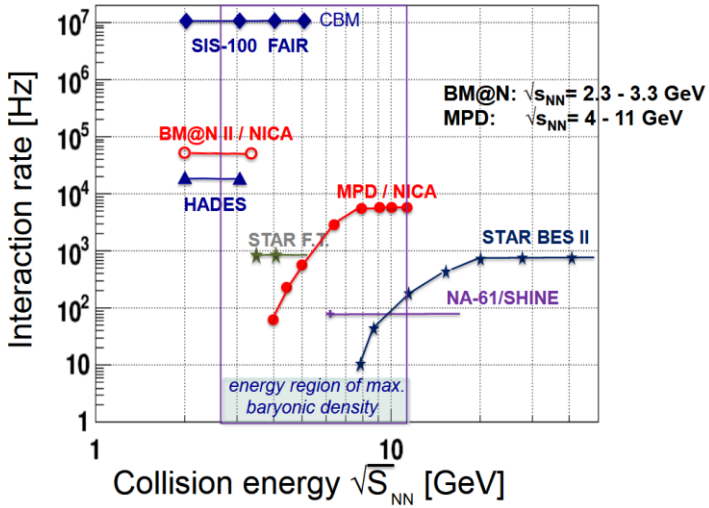
Outline

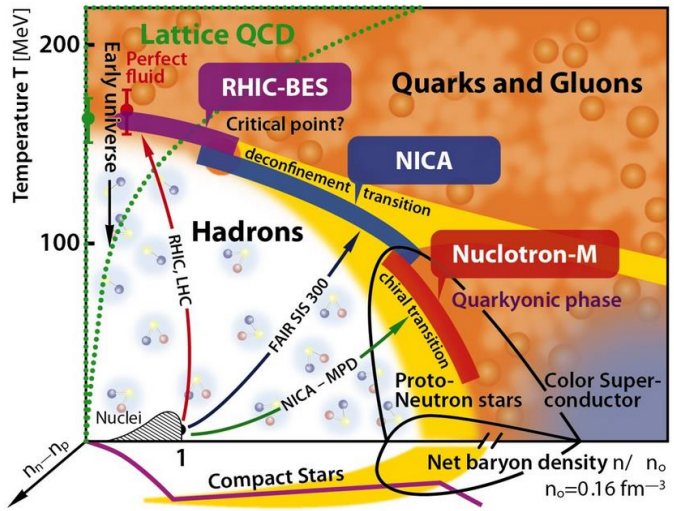
- **NICA project**
- **Development of BM@N (Baryonic Matter at Nuclotron)**
- **Argon - nucleus interaction**
- **CT to CSC track matching using detectors modelling**
- **Matching Central tracker – CSC - TOF**
- **Time - of - Flight method**
- **Data and MC Si/GEM/ CSC/ TOF efficiencies**
- **First results of identification**
- **Summary**

Heavy-Ion Collisions

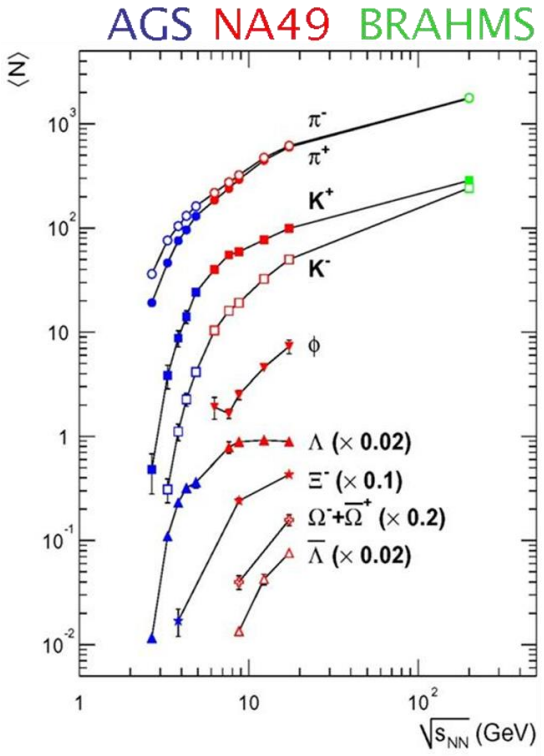


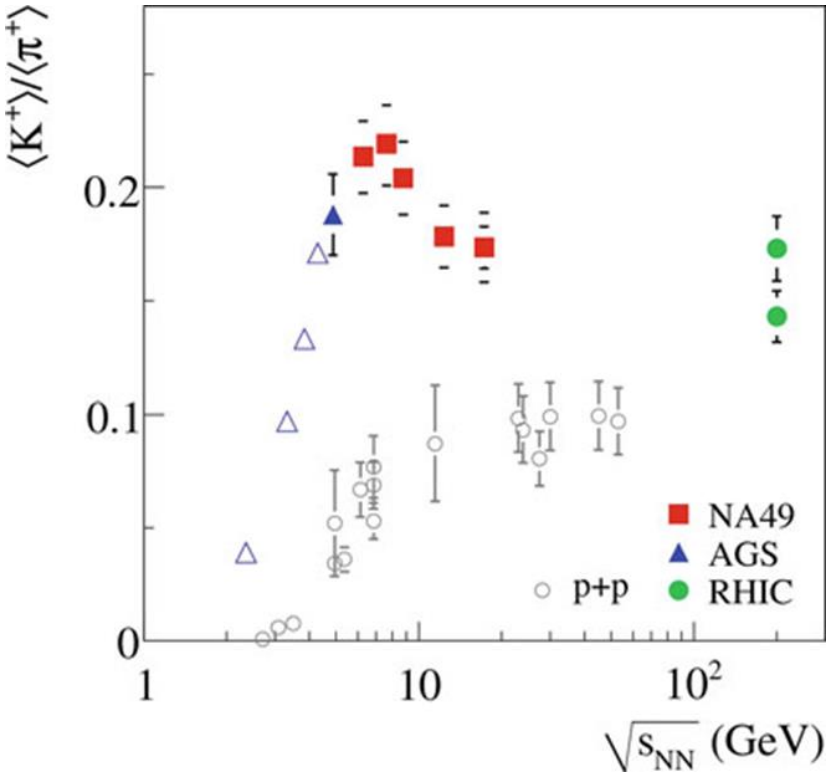


- At √s energies of 2 - 4.5 GeV, nucleon densities in a collision zone exceed the saturation density by the factor of 3-4.
- Hadrons with strangeness are early produced in the collision and not presented in the initial state of two colliding nuclei.
- Heavy-ion collisions are a rich source of strangeness, and the coalescence of kaons with lambdas or lambdas with nucleons will produce a vast variety of multi-strange hyperons or of light hypernuclei.



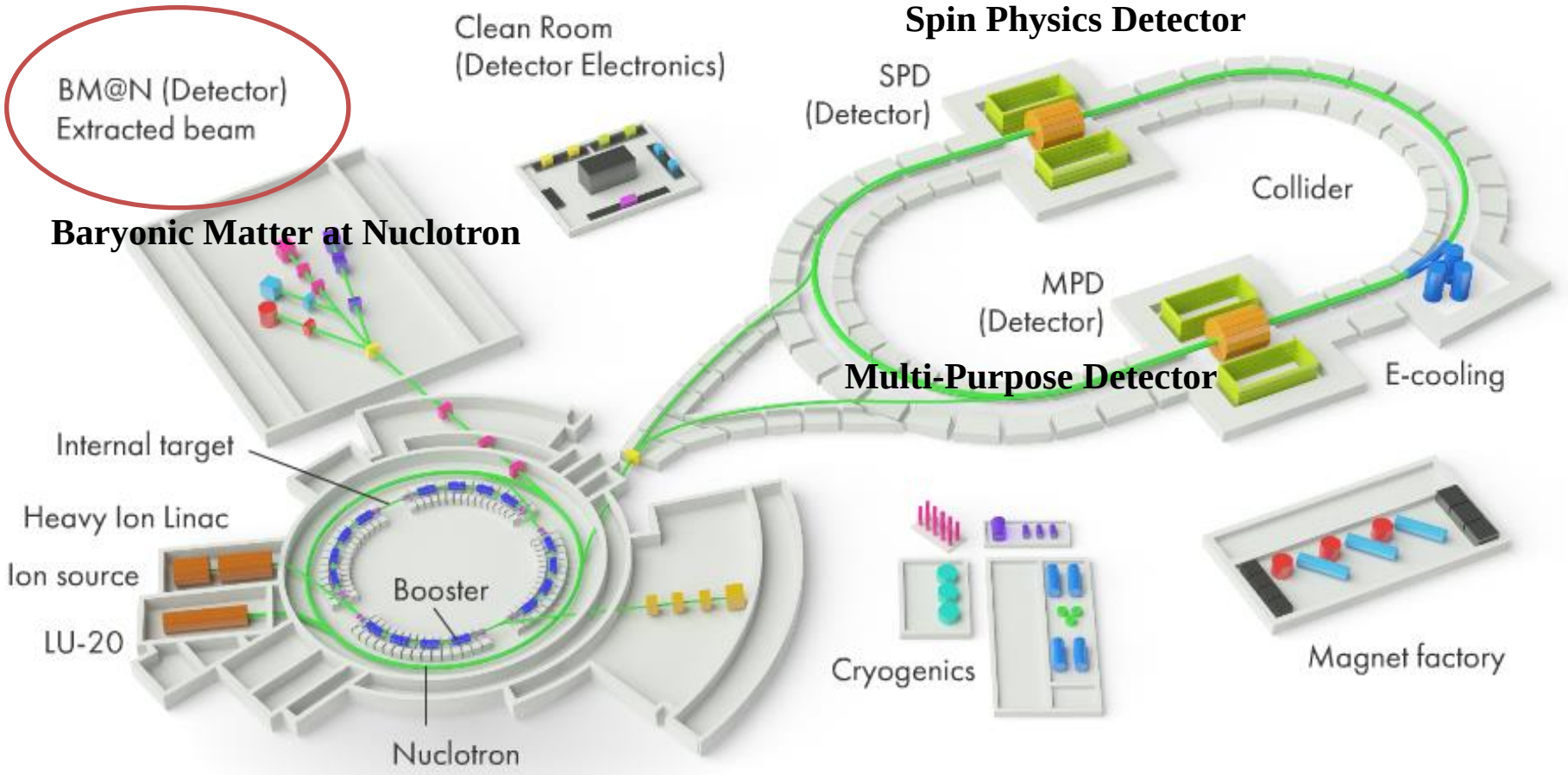
K^+/π^+ ratio





- **The K^+/π^+ ratio shows a rapid rise at energy increasing with a maximum ("horn") at incident √s energy of ~8 GeV and a saturation at SPS (Super Proton Synchrotron) energies.**
- **The "horn" has been interpreted as a possible indication for the observation of deconfinement in the fireball.**
- **Confirmation of peak-like structure in the K^+/π^+ ratio by an independent experiment would certainly stir up the debate on a possible signature for the deconfinement phase transition.**

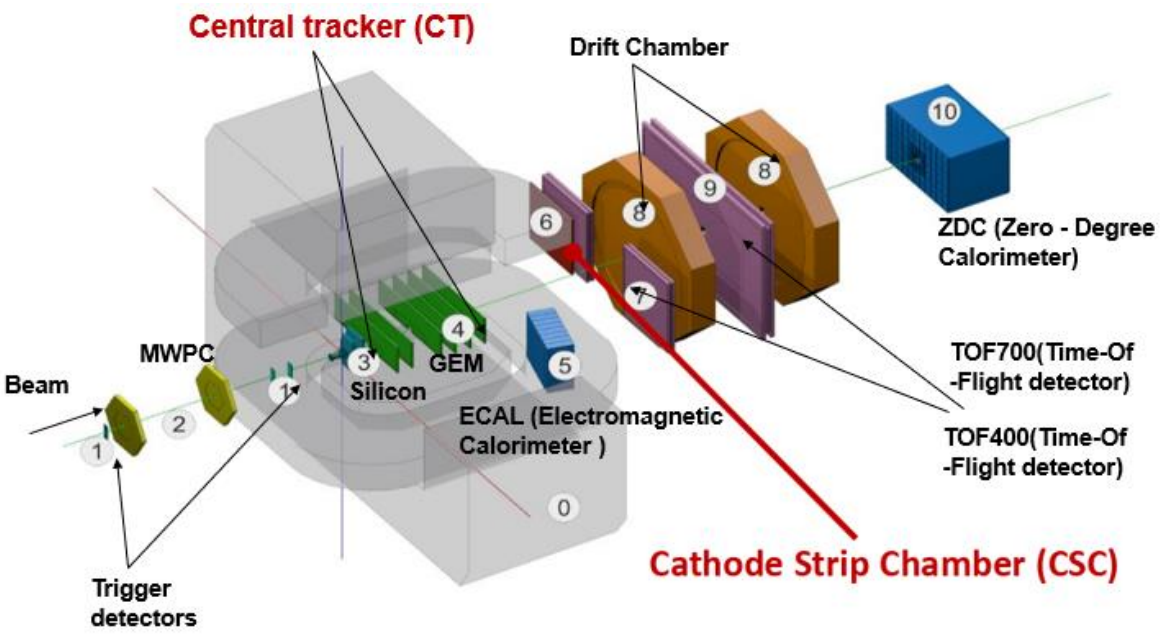
NICA project



$\sqrt{s_{NN}}$ = 11 GeV (for +79 Au, in the nucleon-nucleon center of mass system) luminosity of L = 10^{27} $cm^{-2}s^{-1}$,which allows to study nuclear matter at maximum baryonic density

Baryonic Matter at Nuclotron

Setup of BM@N for RUN-7 in spring 2018



- BM@N is the first experiment with a fixed target at the NICA.
- It is designed to study nuclear-nuclear collisions at high densities.
- The Nuclotron provides heavy ion beams with energies ranging from 2.3 to 4.5 GeV

November 2017
Technical work before the 7th run

Beam parameters and setup at different stages of BM@N experiment

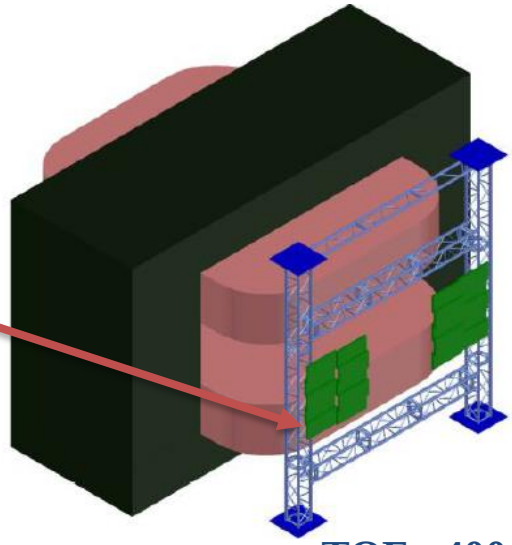
	Run 5	Run 6	Run 7	Run 8	
Year	2016	2017 spring	2018 spring	fall 2021	2022
Beam	d(↑)	C	Ar,Kr, C(SRC)	Kr,Xe	up to Au
Max.intensity, Hz	0.5M	0.5M	0.5M	0.5M	0.5M
Trigger rate, Hz	5k	5k	10k	10k	10k
Central tracker status	6 GEM half planes	6 GEM half planes	6 GEM half planes + 3 forward Si planes	7 GEM full planes + forward Si planes	7 GEM full planes + forward Si + 2 large STS planes
Experimental status	technical run	technical run	technical run+physics	physics run	stage1 physics

Argon - nucleus interaction

Run 7:

Inelastic reactions Ar (Kr) + target→ X on targets C, Al, Cu, Sn, Pb

- **Hyperon production measured in central tracker (Si + GEM)**
- **Charged particles and nuclear fragments identified with ToF**

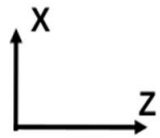


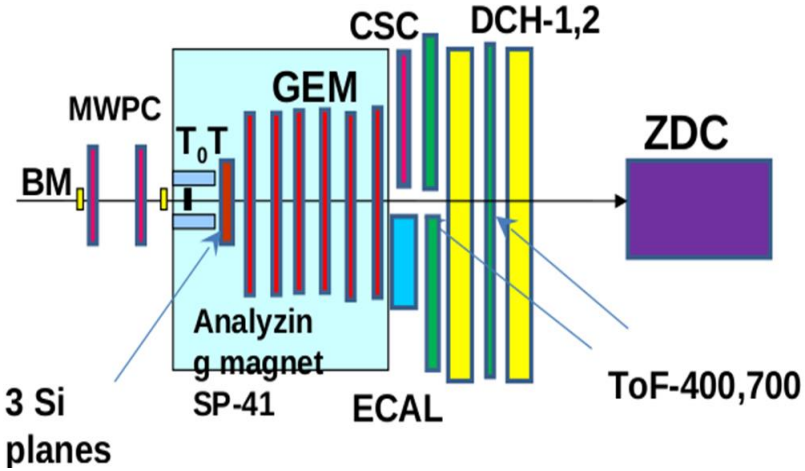
TOF - 400

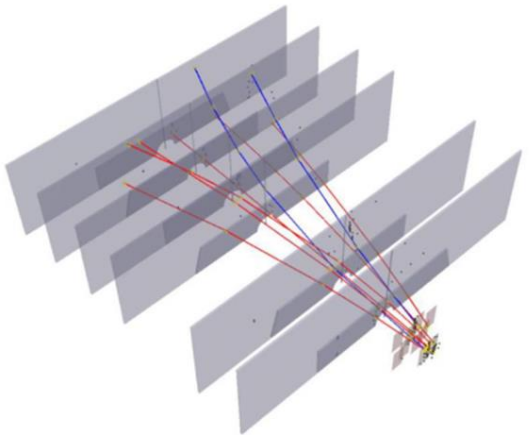
Detector setup for argon run

Ar beam, T_0= 3.2 GeV/n

Kr beam, T_0= 2.4 (2.9) GeV/n

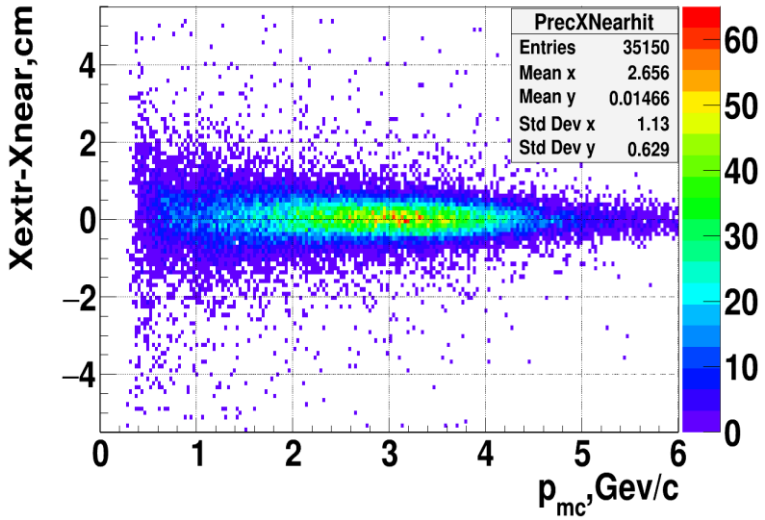


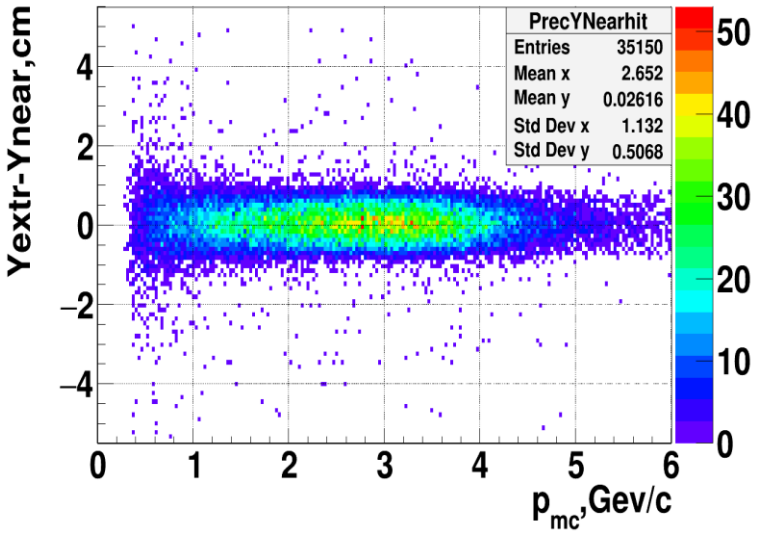




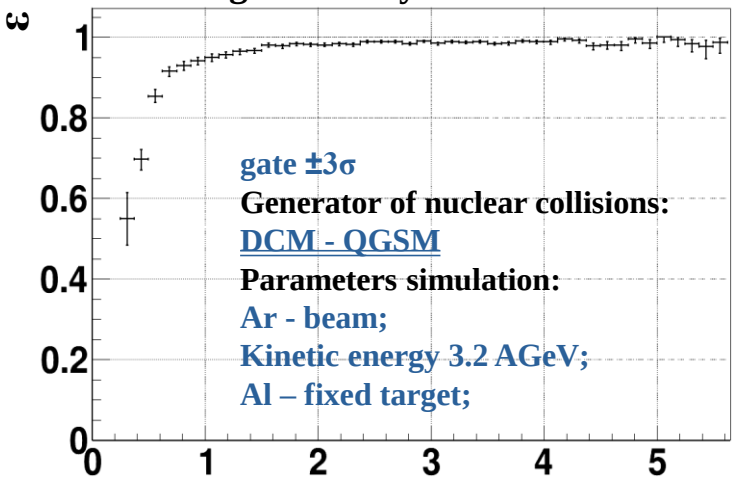
Central tracker in run 7

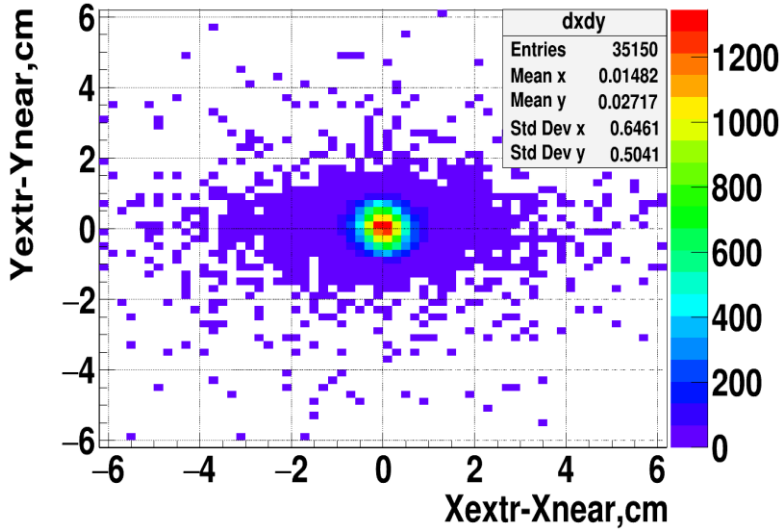
CT to CSC track matching using detectors modelling



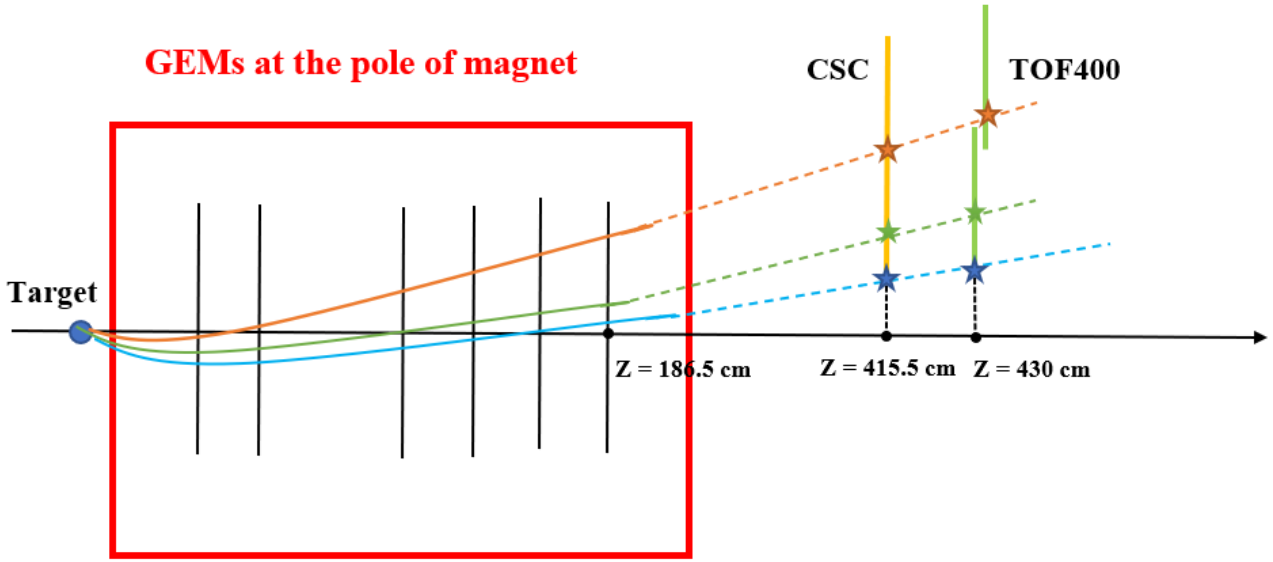


Matching efficiency CSC with CT





Matching CT- CSC-TOF400



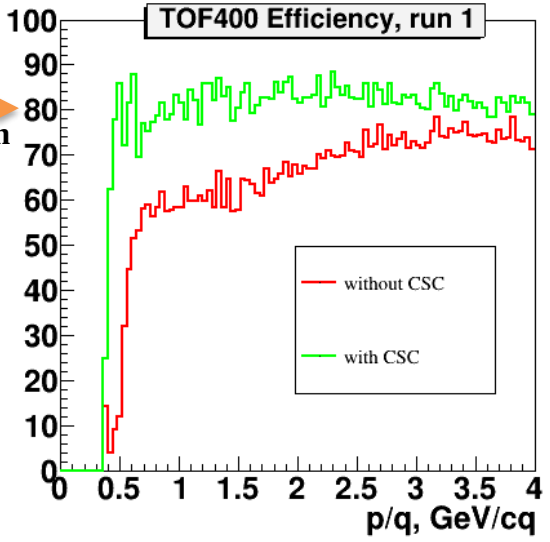
Real CSC det. In the BM@N setup.

Gas Electron Multiplier (GEM) system:
To measure momenta of a charged particle and reconstruct the interaction point.
Time - of - Flight (TOF400) system – time - of - flight of a charged particle.
Cathode Strip Chamber (CSC): filter fake tracks.

Matching procedure:

1. Extrapolate track from the central tracker to the Z of the CSC and TOF.
2. Tracks criteria:
2.1 Point from this track should be in CSC and TOF400;
2.2 Extrapolated track should be in acceptance of CSC and TOF;
2.3 Selected tracks with ≥ 5 hits;
3. Looking for nearest hit in the fixed gate.
4. Estimate efficiency.

MC simulation UrQMD



Time - of - Flight method

- Charged particle identification was performed using the Time - of - Flight method.

$$m = p\sqrt{\frac{1}{\beta^2} - 1}, \beta = \frac{L}{ct},$$

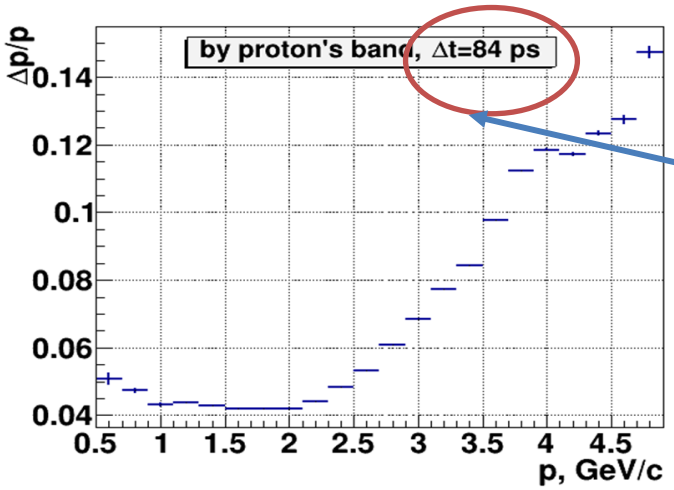
m – mass of the particle, p – momentum of the particle, L – length of particle track, c – speed of light, t – time - of - flight.

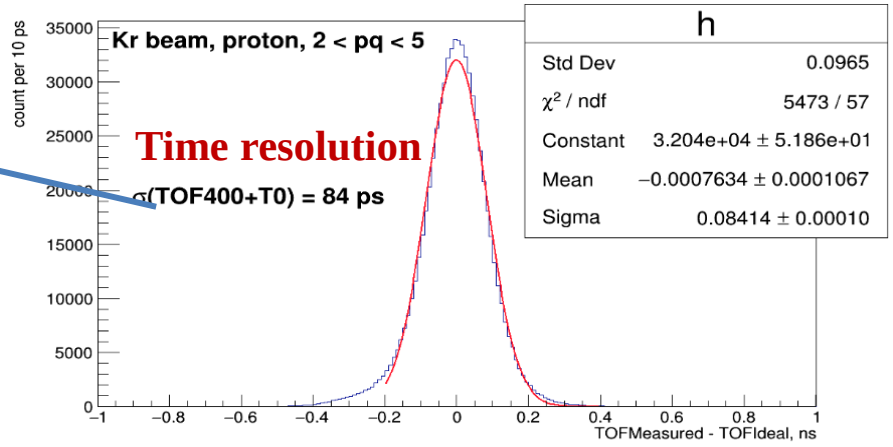
- We used m^2 vs p distribution to determine momentum resolution in our experiment.

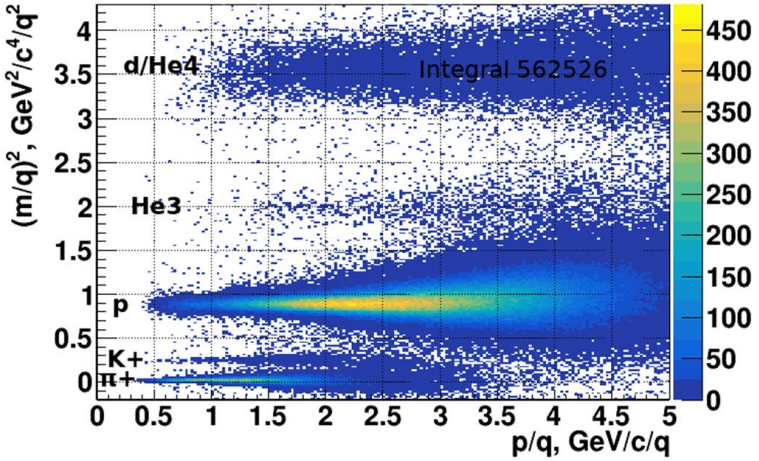
$$\frac{dm^2}{m^2} = \sqrt{\left(\frac{dp}{p}\right)^2 + \left(\frac{2}{1-\beta^2}\right)^2\left(\frac{dt}{t}\right)^2 + \left(\frac{2}{1-\beta^2}\right)^2\left(\frac{dL}{L}\right)^2}.$$

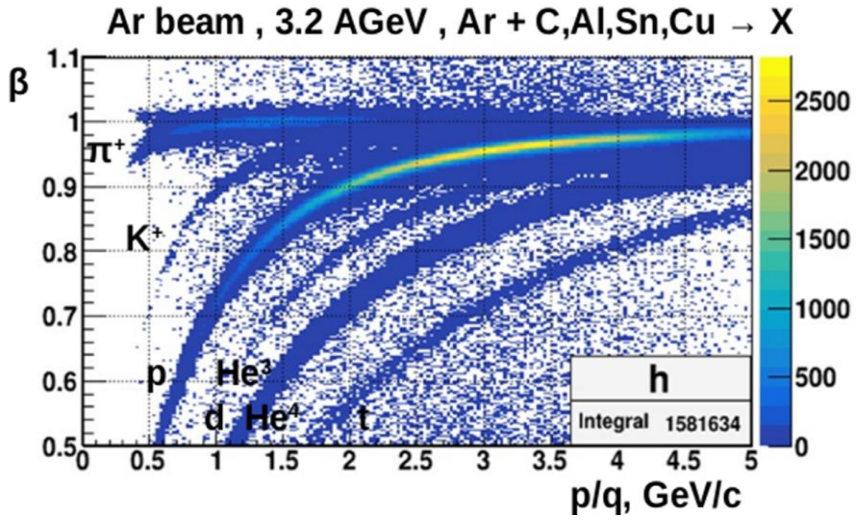
- For the low momentum, m^2 uncertainty is determined by the particle momentum uncertainty, and for the high momentum, it is determined by the time-of-flight due to Lorentz factor.

Time - of - Flight method





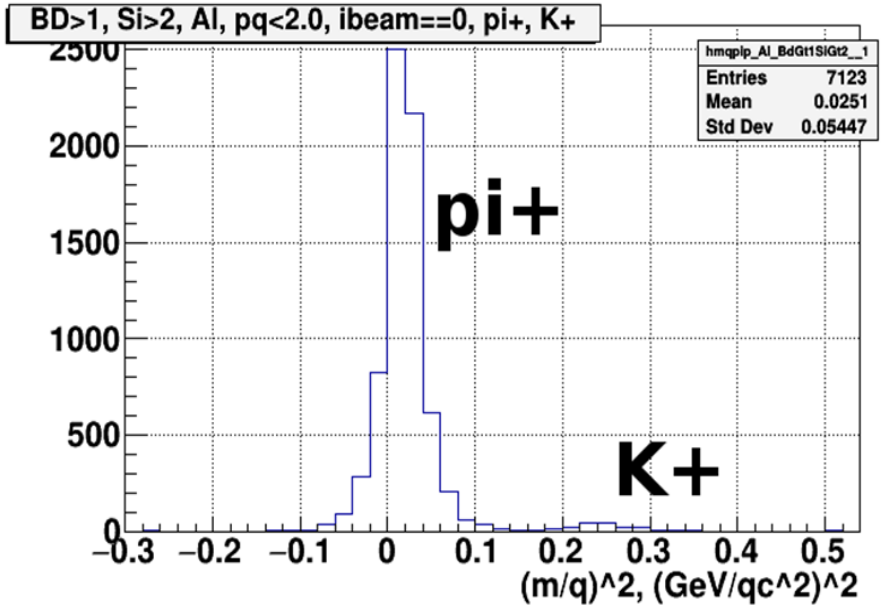


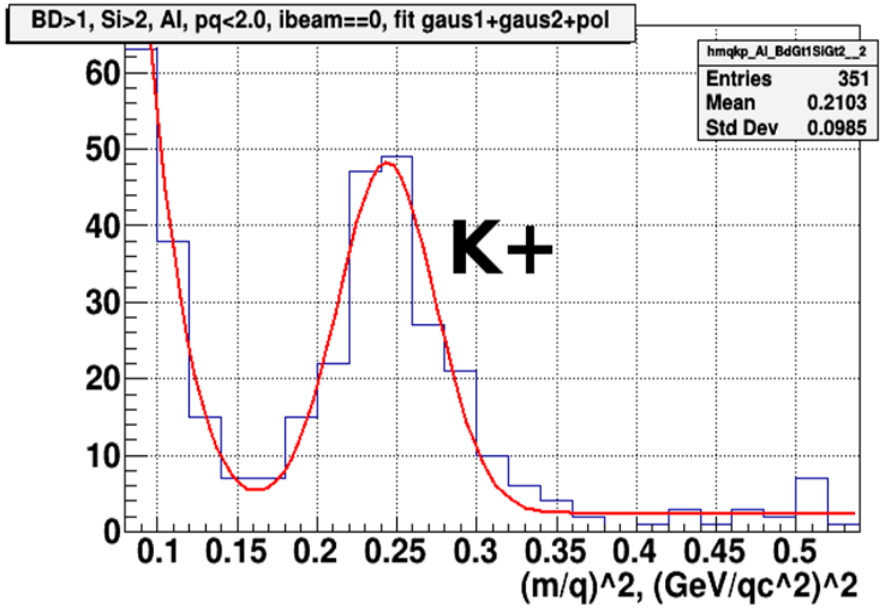


Ar data (March 2018), β vs p/q plot bands for π^+, K^+, p, He^3, d/He^4, t are clearly visible (TOF 400).

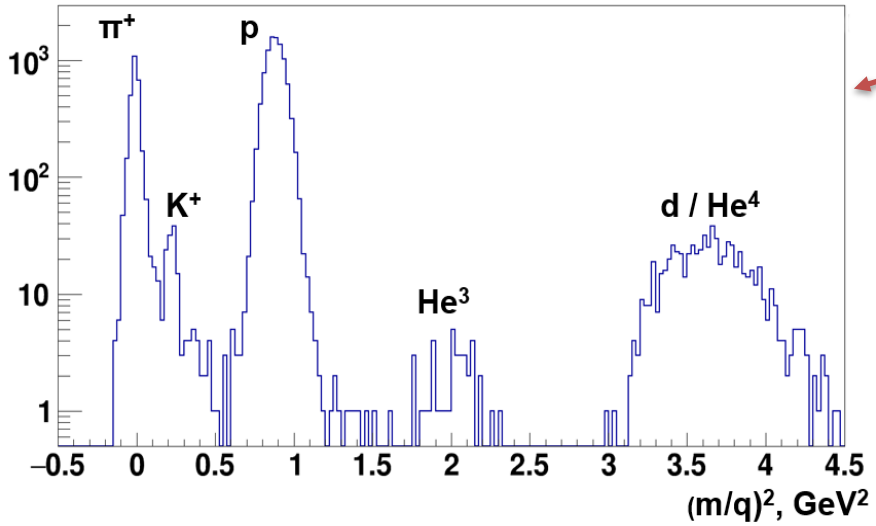
Time - of - Flight method

- m^2 distribution is used to extract the number of K^+ and π^+.
- Two sources of background are taken into account while extracting the number of K^+: from π^+ (Gaus fit) and from misidentified tracks (p0 fit).
- About $2 \cdot 10^3$ K^+ and 10^5 π^+ were identified in full Ar data.

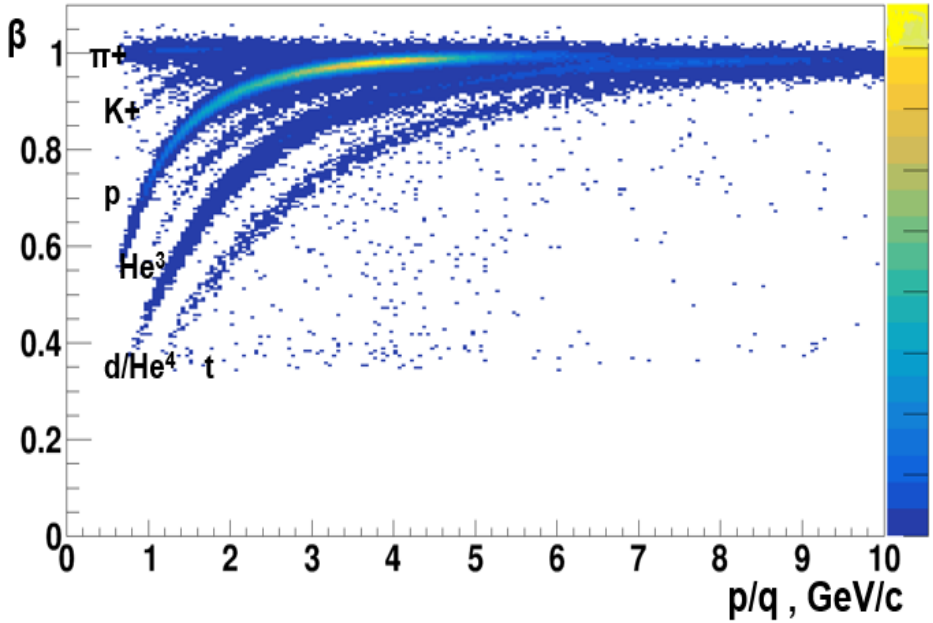


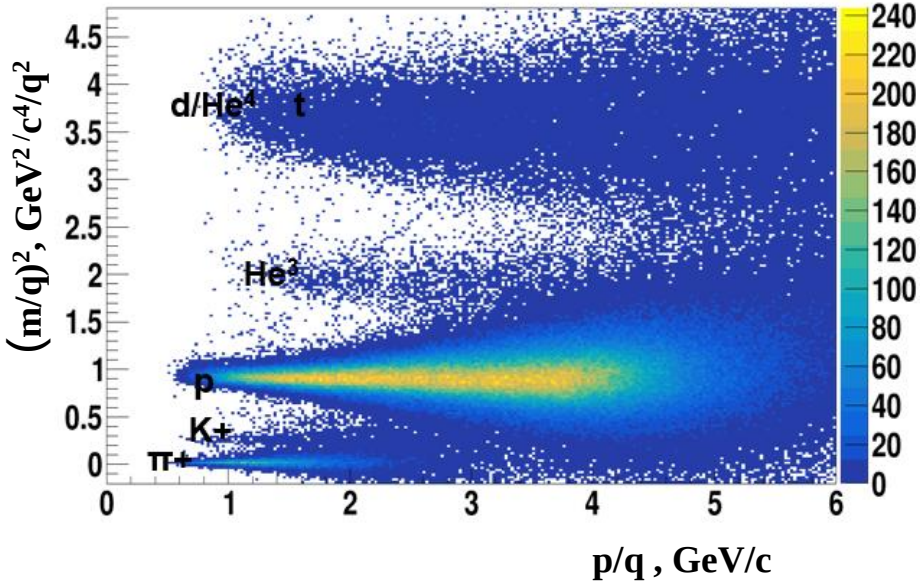


Time - of - Flight method



Results PID with using TOF 700

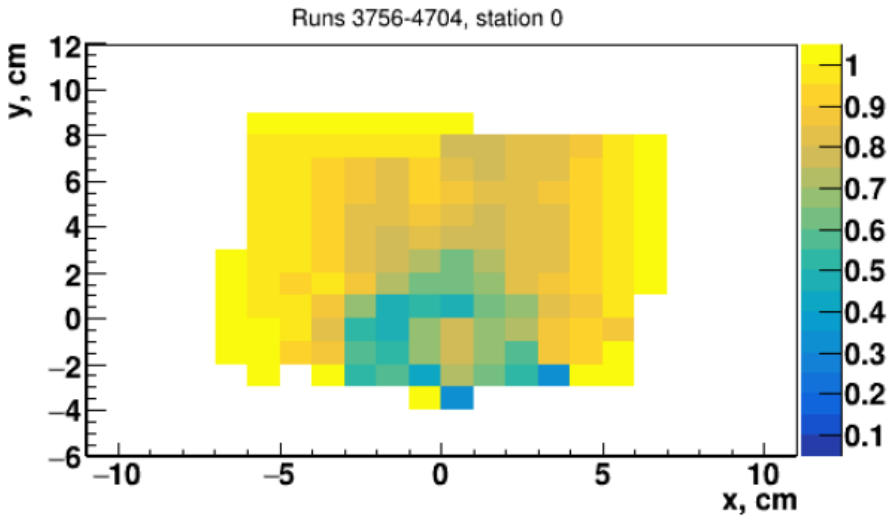




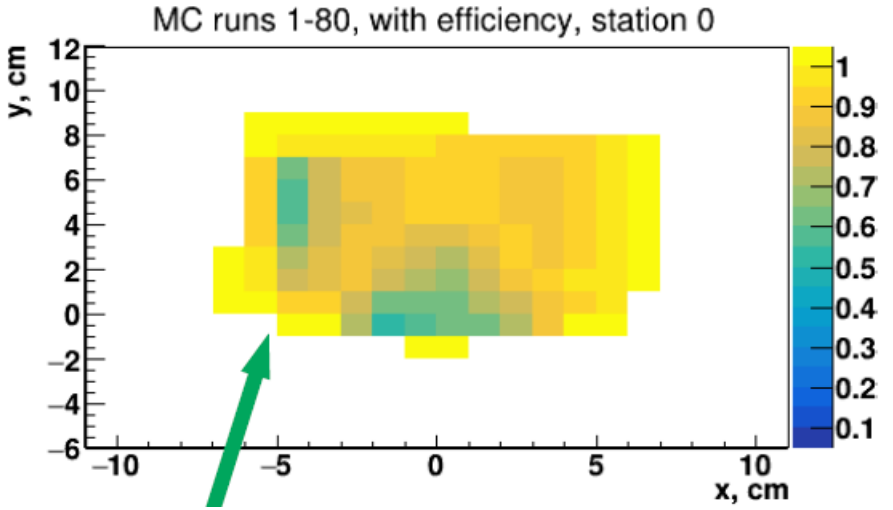
Ar data (March 2018)
for π^+, K^+, p, He^3, d/He^4.

Data and MC Si/GEM efficiencies

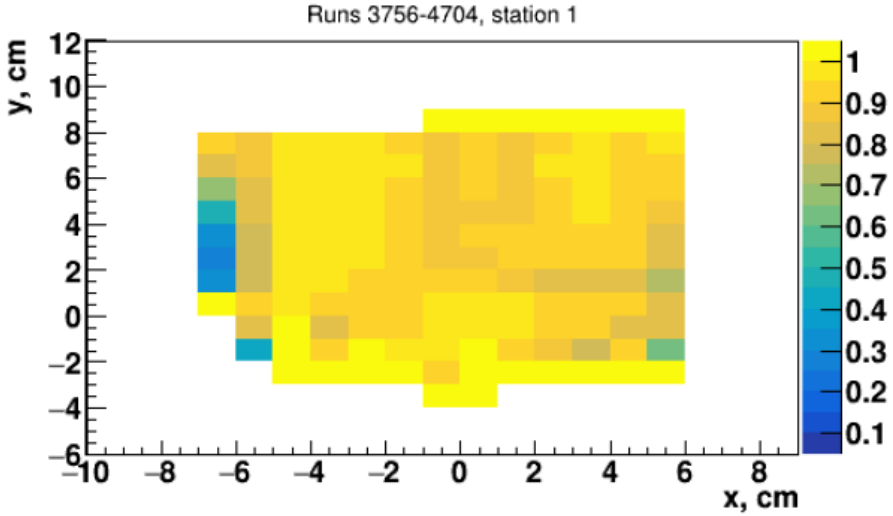
Argon Data

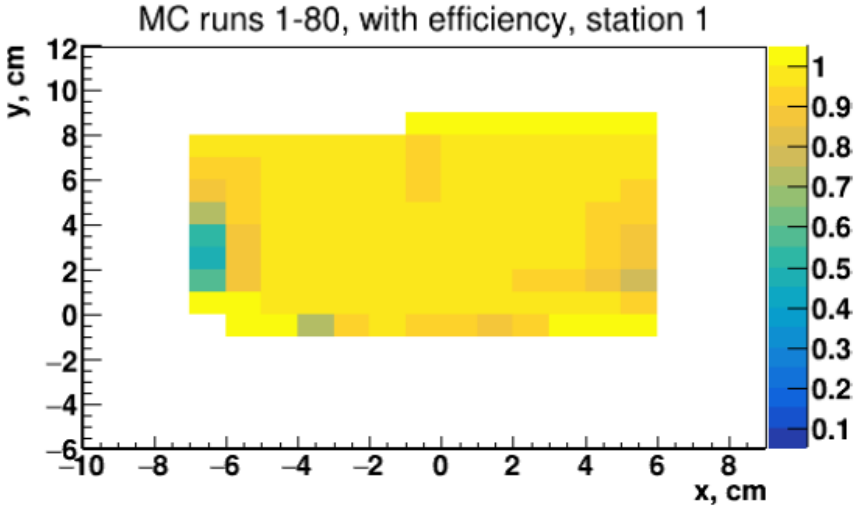


MC simulation



Low MC efficiency for Si1 at X~-5 cm





Data and MC Si/GEM efficiencies

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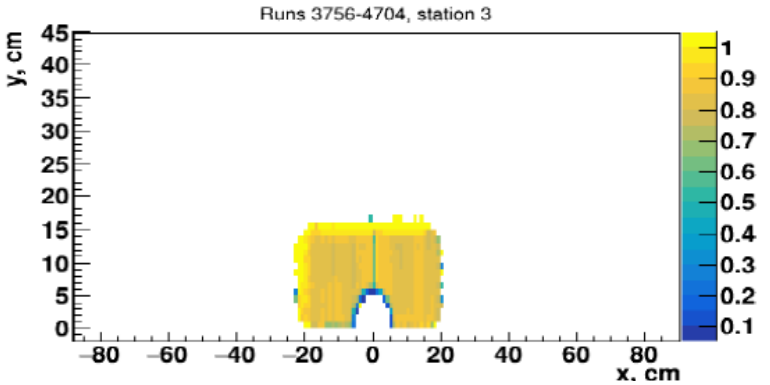
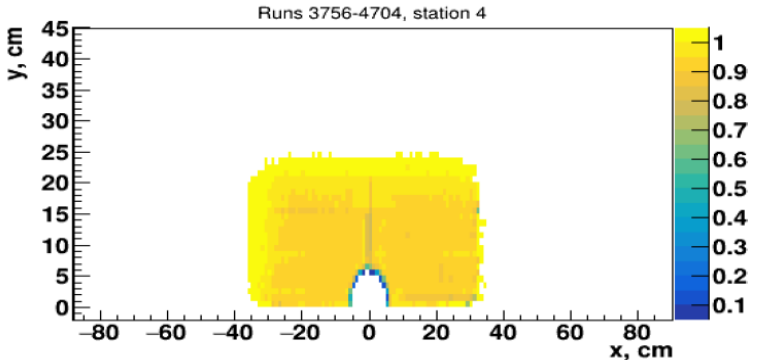
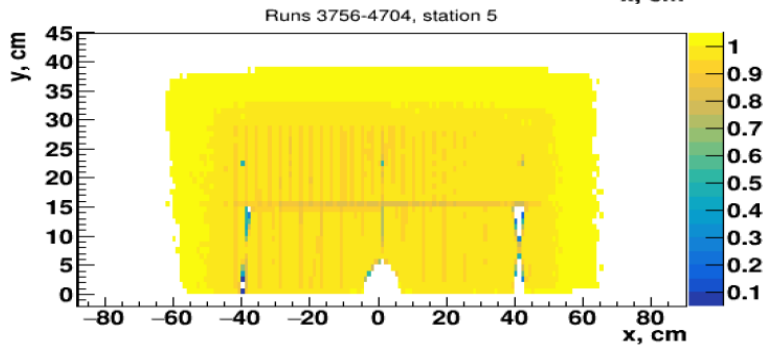
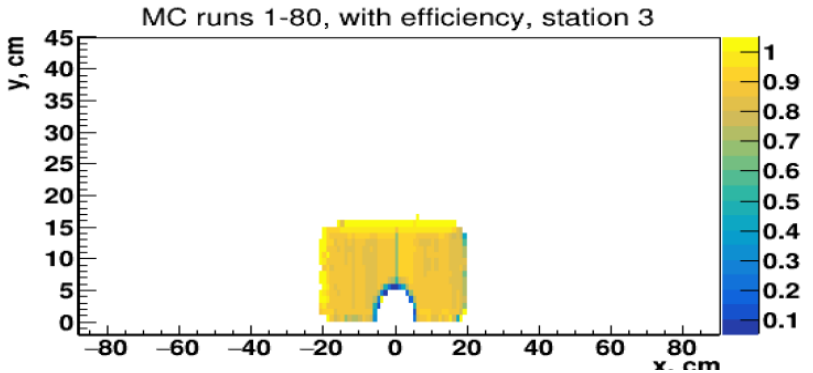
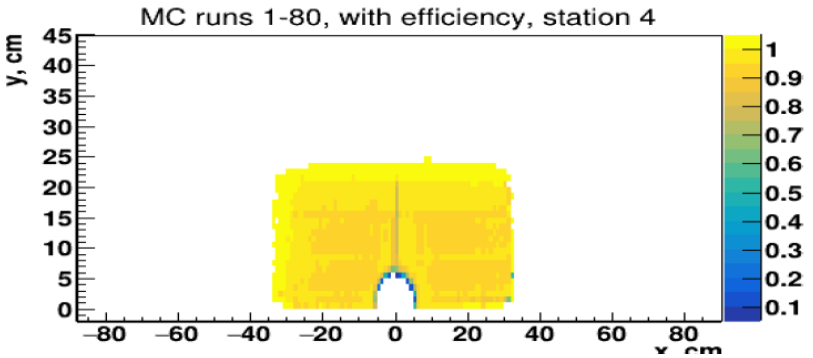


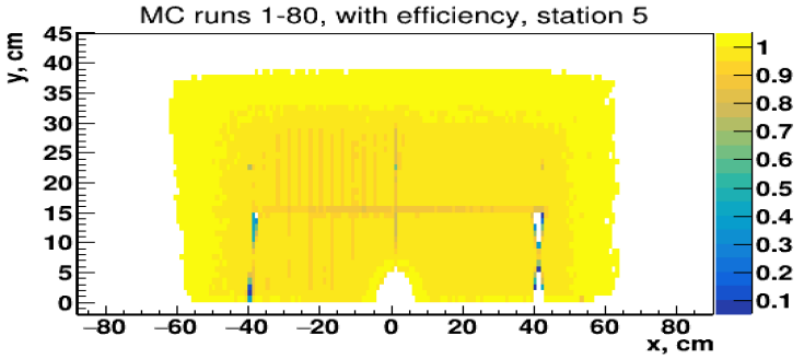




MC simulation

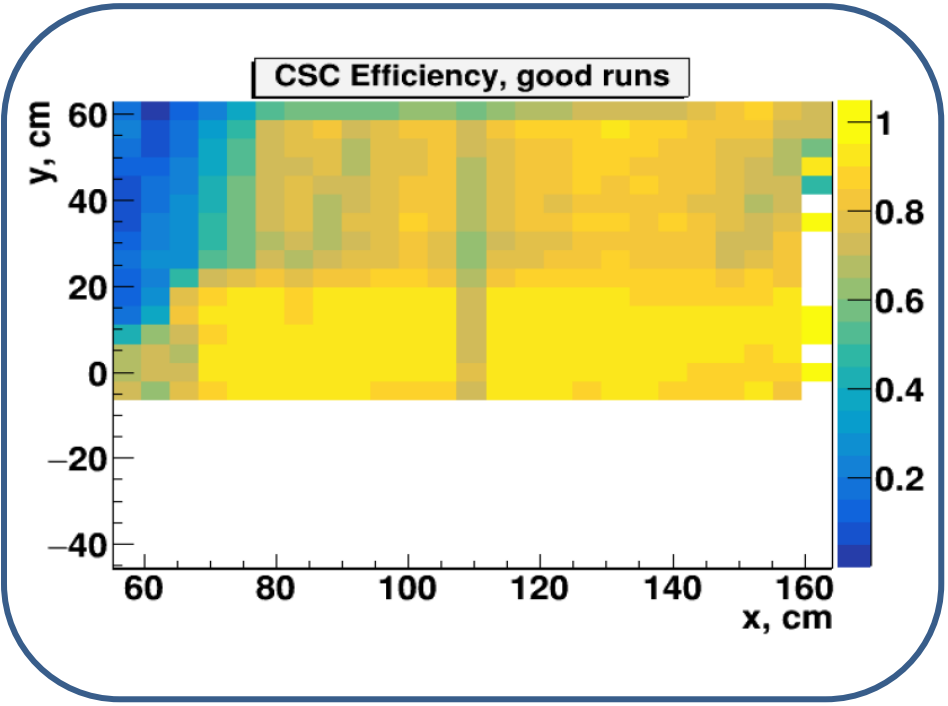




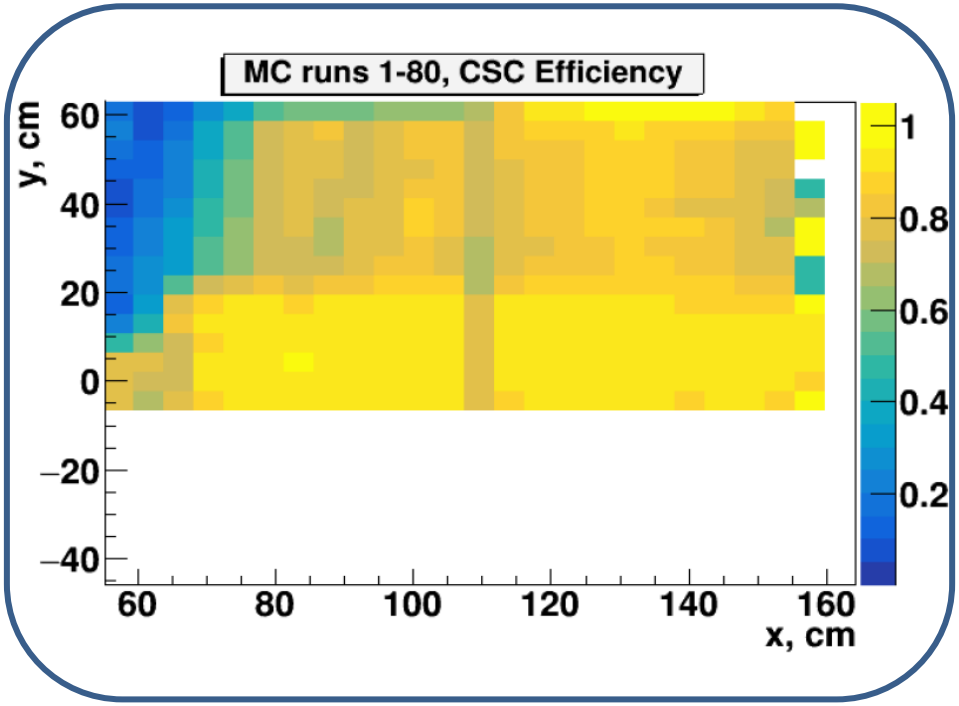


Data and MC CSC efficiencies

Argon Data



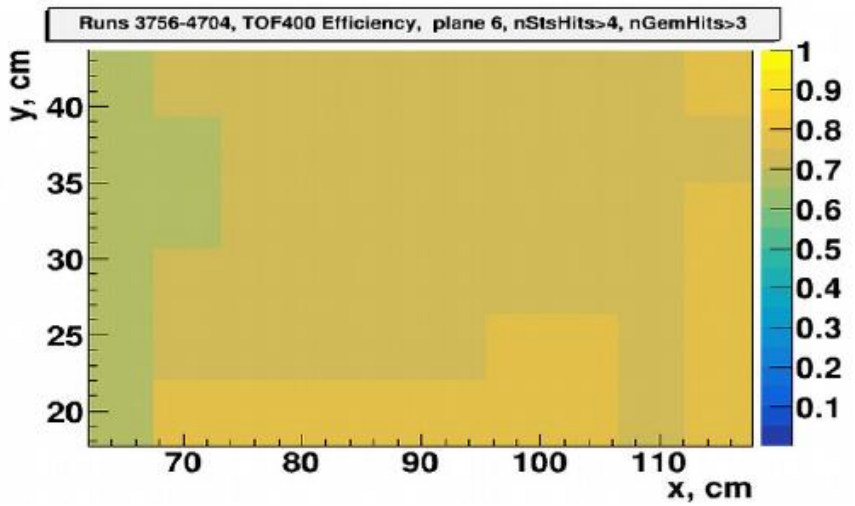
MC

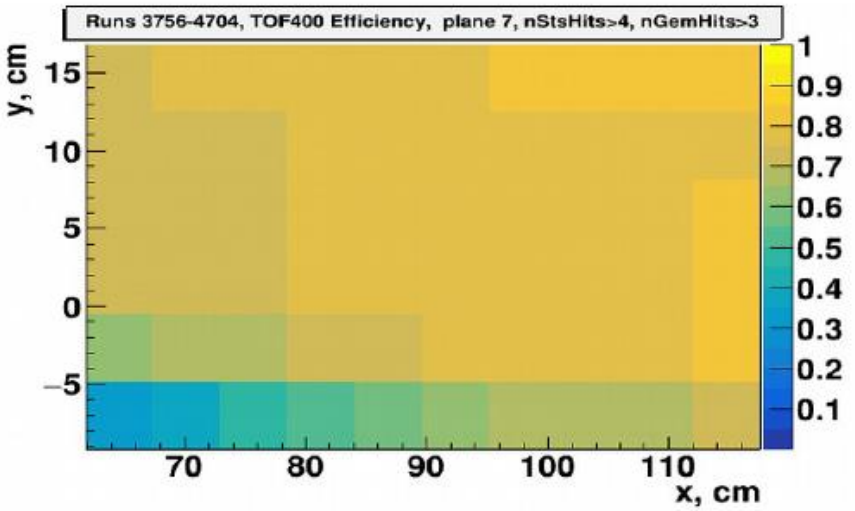


- Good runs - runs with Efficiency CSC > 40% in the Main zone
- MC and Data efficiencies are close to each other

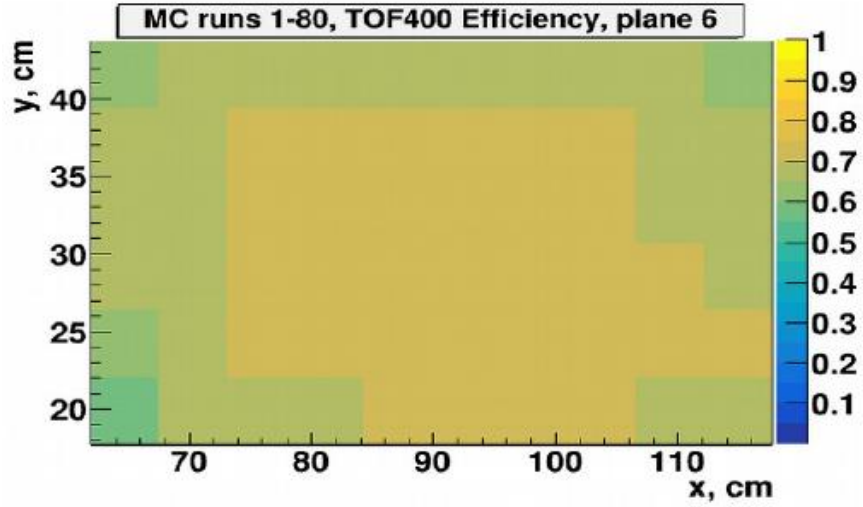
Data and MC TOF 400 efficiencies

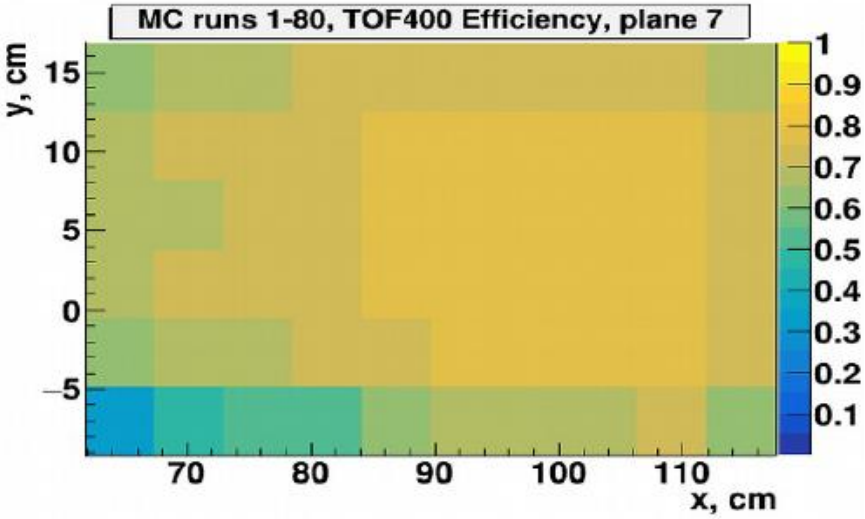
Argon Data





MC

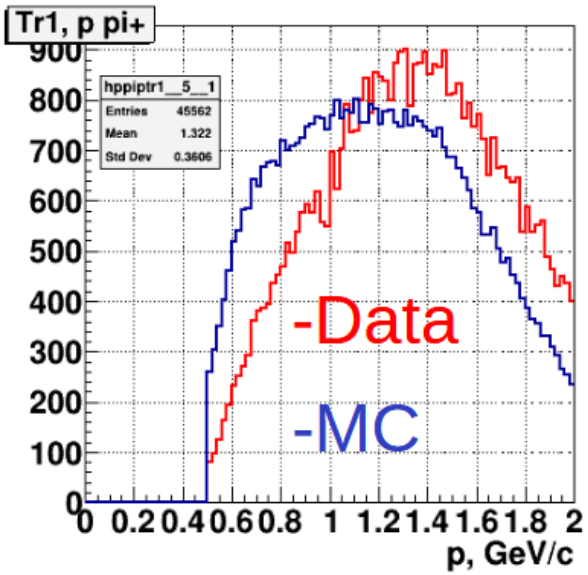


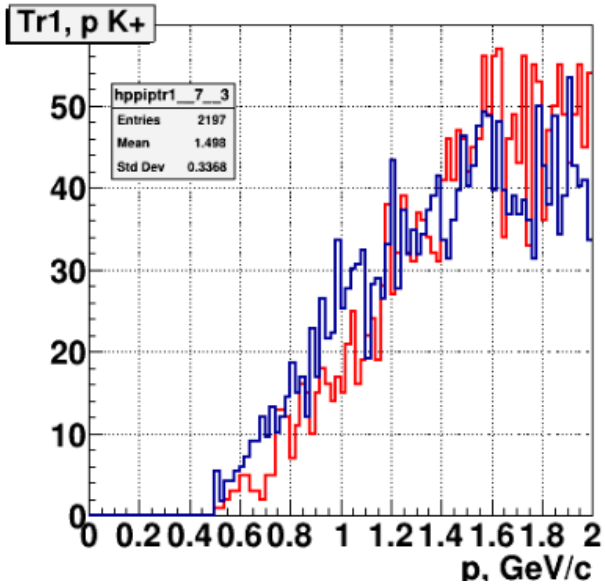


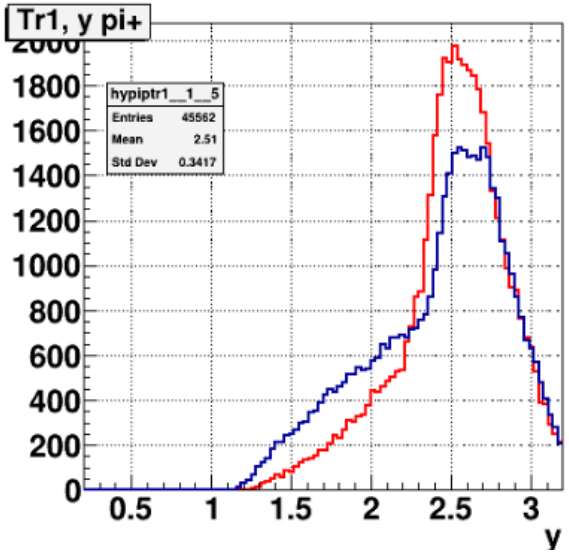
Status of identification

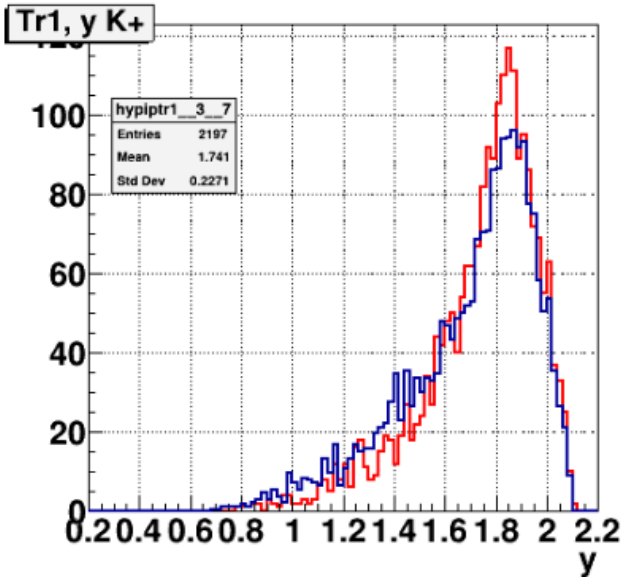
- We use UrQMD(Ultra-relativistic Quantum Molecular Dynamics) generator
- MC geometry for Si/GEM/CSC/TOF400 matches Data geometry by strips
- For MC we use the same Lorenz shifts in GEM as for Data
- MC signals for Si/GEM/CSC match Data signals
- MC Si/GEM residuals match Data residuals
- For Data and MC we use the same reconstruction chain
- MC efficiencies for Si/GEM/CSC/TOF400 close to the Data efficiencies
- We embeded MC π^+ to the Data to calculate Embedding Efficiency

Results of identification comparison for Data and MC with efficiencies

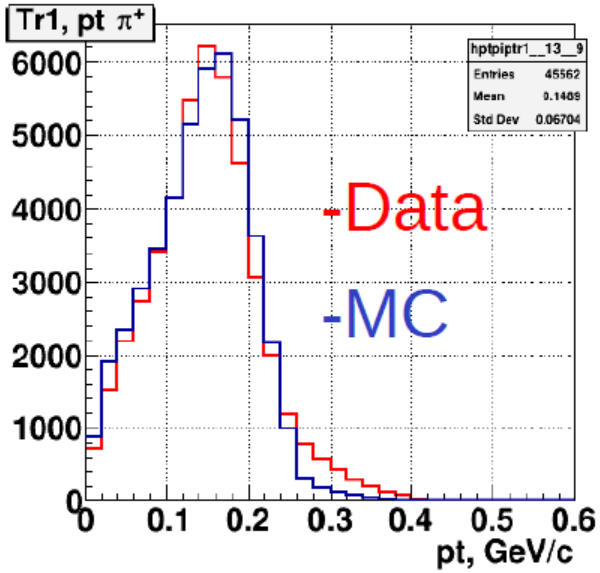


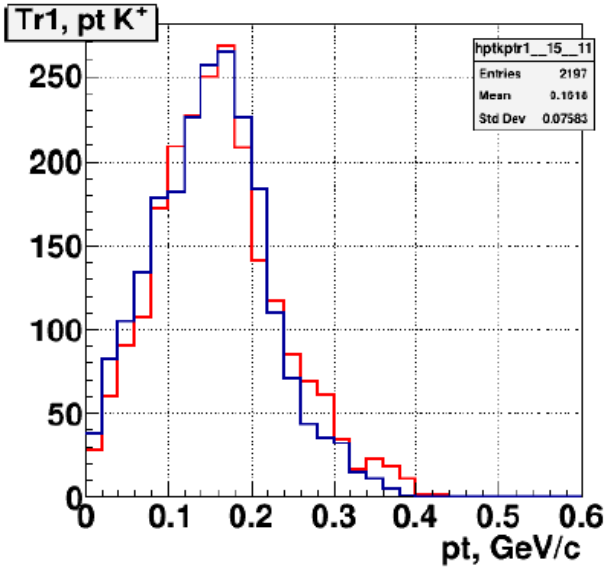


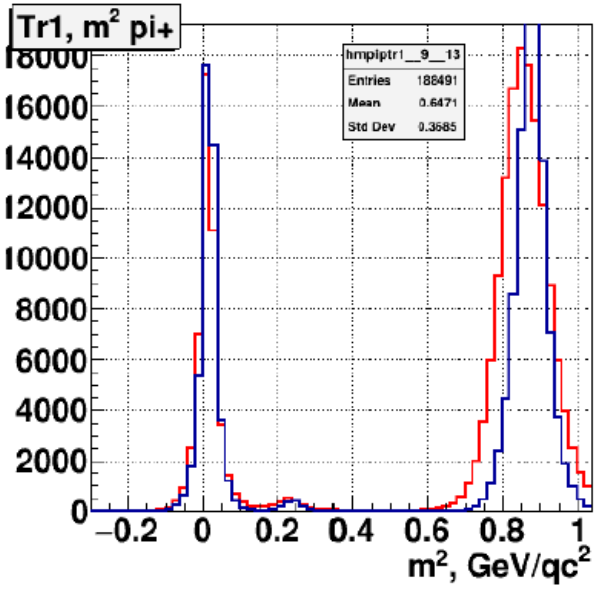


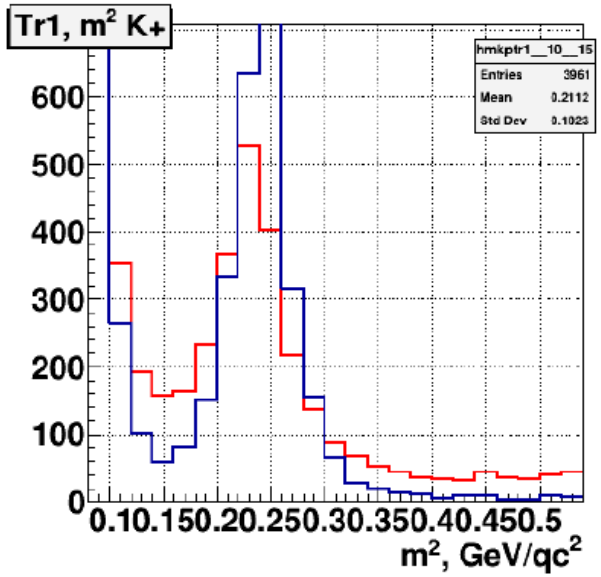


Results of identification comparison for Data and MC with efficiencies









Summary

On detector subsystems of BM@N:

- CSC test outer tracker plane shows its good usability. Technique of CSC assembly is set up. CSC detector description is implemented into the reconstruction chain of the BM@N experiment.
- Tracks from Central Tracker were refined using CSC and matched to the TOF hits.
- During the analysis process, the TOF400 calibration was improved and high time resolution ($\Delta t = 84$ ps) was achieved.
- Good performance of CSC motivate their extended usage in the next run.
- Matching of central tracker, DCH outer tracker and TOF700 was successfully performed.
- During the analysis process, good time resolution for TOF700 was achieved.

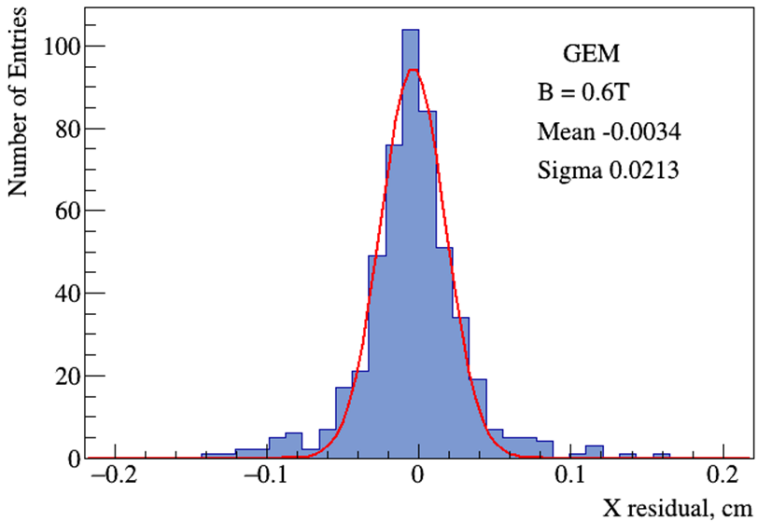
The first results on identification were obtained:

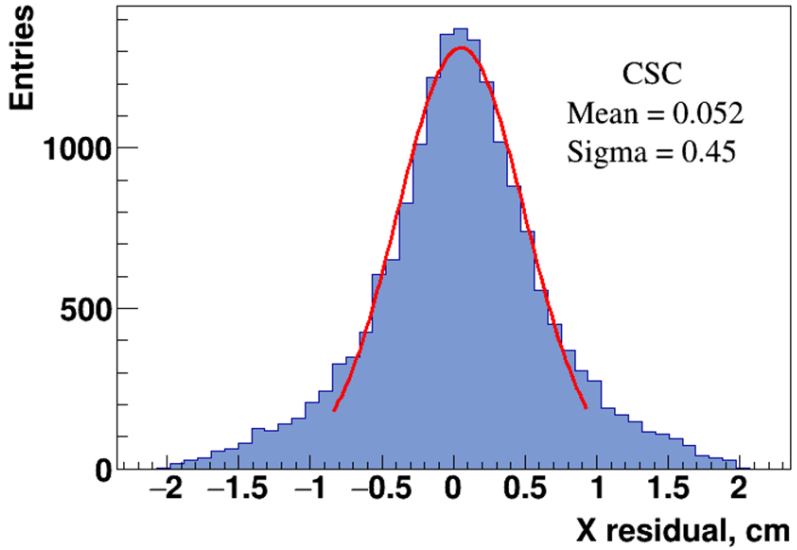
- Obtained m^2 distribution match for Data and MC in (π^+, K^+) region
- Pt spectra of π^+ and K^+ for Data and MC close to each other
- P and Y spectra of K^+ for Data and MC close to each other
- P and Y spectra of π+ for Data and MC significantly different

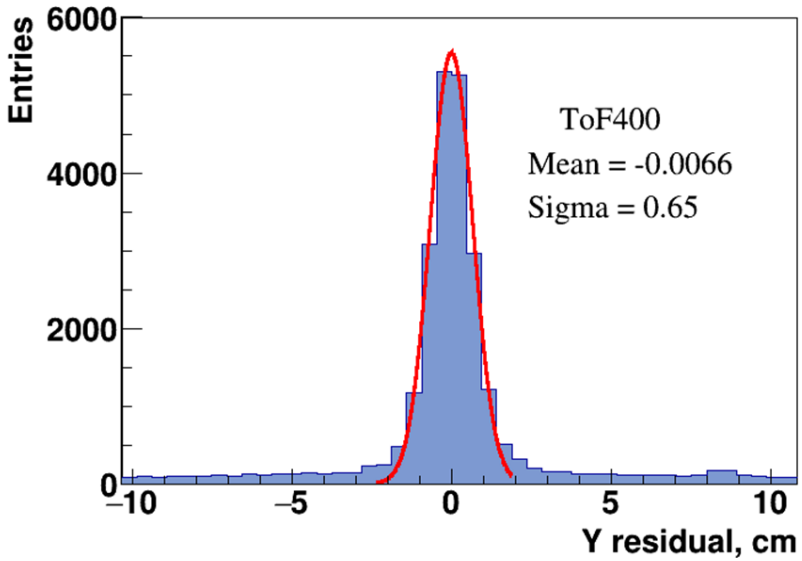
- As a result, good quality of charged particles identification was obtained and a tiny K^+ signal was separated from a large π^+ contribution

Thank you for attention!

Residual GEM+CSC+TOF400

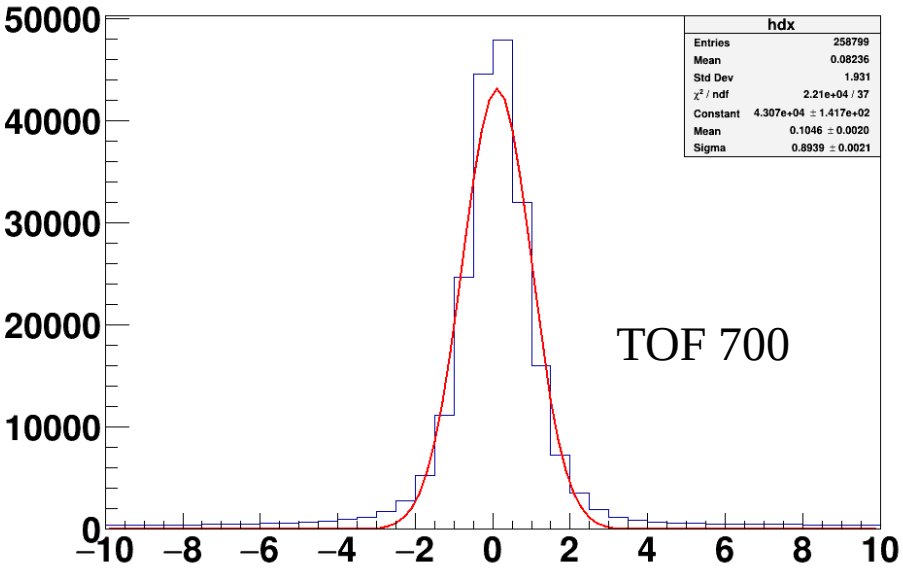




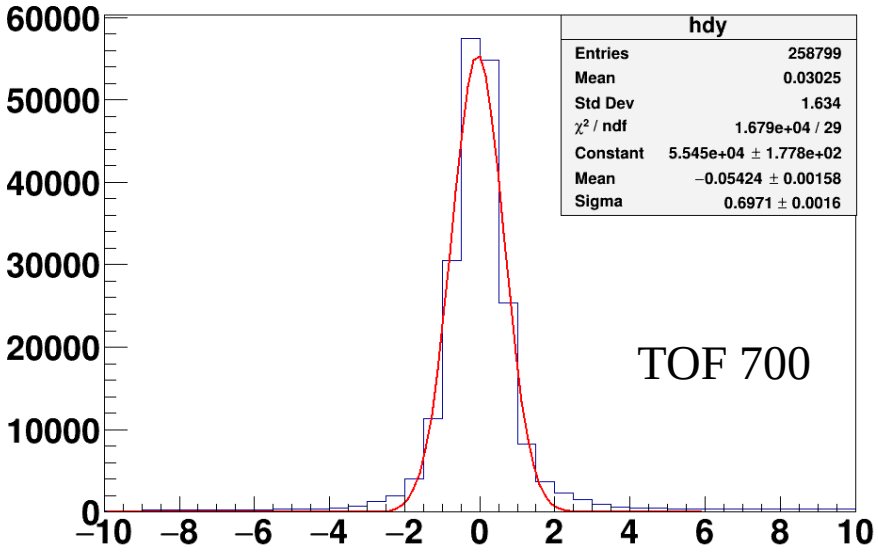


Backup

Residual GEM+CSC+TOF400+DCH+TOF700.

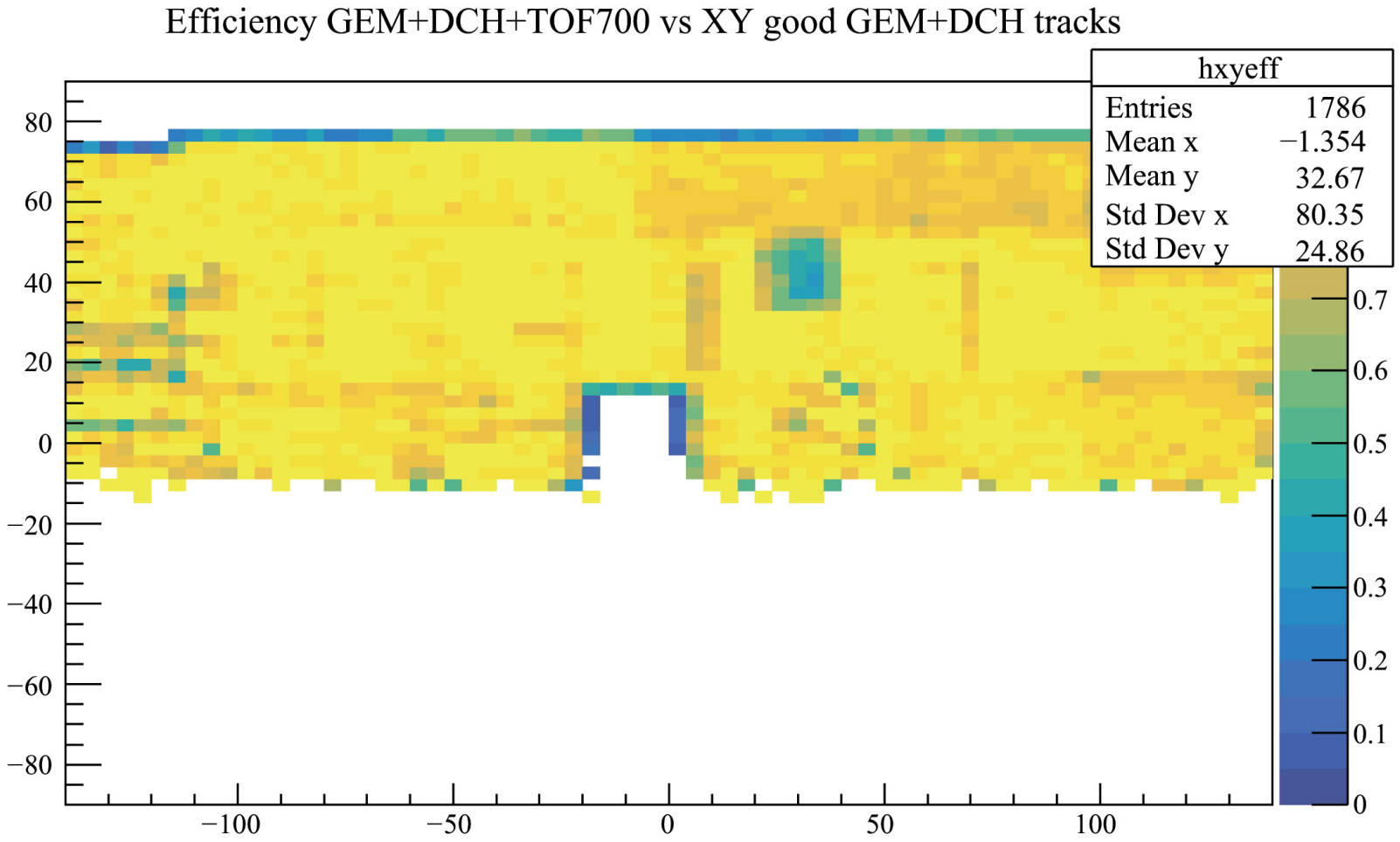


Residual X



Residual Y

Backup



Efficiency for a good track GEM + DCH ➡ matching with hit TOF700.
Small square dip in efficiency at XY in the region (30,40) connected by signal bounce in the chamber 5.1